The ALFA Laser-Guidestar System
A User's Guide

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Introduction

ALFA is the adaptive optics(AO) system with sodium laser guide star(LGS) for the 3.5 m telescope on Calar Alto. ALFA has been developed jointly by the Max-Planck-Institute for Astronomy (MPIA, Heidelberg), responsible for the AO, and the Max-Planck-Institute for Extraterrestrial Physics (MPE, Garching), providing the LGS system. TBC: The LGS/AO system is capable of producing nearly diffraction-limited images in the NIR (typical Strehl number about 25 % in K) under medium seeing conditions (1.0- 1.5 arcsec) for nearly any point on the sky (zenith distance < 60 degrees).

This document starts with an introduction in sodium LGSs and an coarse overview on the ALFA LGS system and its limitations. In the next chapter a detailed technical description of the LGS system is presented, which is the basis for the last chapter, in which the regular operation of the LGS/AO system is described.

1.1 LGSs

It is well known in astronomy that the main problem of adaptive optics(AO) with natural guidestars (NGSs) is the frequent lack of a suitable natural reference source. To correct for the atmospheric induced wave-front distortion one need a sufficiently bright reference source to overcome the read noise of the detector of the wavefront-sensor(WFS), and this source must be within the isoplanatic patch around the scientific object, such that the wavefront distortions of the reference source and the target object are strongly correlated. These constraints define a sky coverage or percentage of the sky where an efficient correction with NGSs can be achieved. For a 4m-class telescope the sky coverage or the probability to find a suitable natural reference star is less than 1% if the correction should give a Strehl ratio better than 0.2 in the K-band.

A possibiliy to overcome this problem is the use of artificial laser guide stars(LGSs). To create a laser guide star a laser beam is transmitted into the atmosphere, pointed to the object of interest, and the returned backscattered light from a column of a specific length, diameter and altitude is then observed as the artificial star. Because atmospheric turbulence occurs at altitudes ranging from ground level up to heights of about 25 km, a LGS must be created at altitudes at least as high. To be useful for an AO system with a Shack-Hartmann WFS the LGS must be compact as well as bright, since one must measure the centroid of the artificial star in each subaperture as accurately as possible. To first order, the accuracy of wavefornt sensing depends only on the peak surface brightness of the artificial star not on its total luminosity, hence the desire to make the LGS spot as small as possible.

There exist two inherent problems associated with the use of LGSs: First, the LGS is generated at a finite height in the atmosphere. Thus the cone-shaped volume swept out by the rays from the LGS provide not the same information about the atmospheric turbulence distortionsas the column through which the light of the astronomical object passes. Therfore the turbulence is sampled uncompletely. This error in wavefront-sampling due to the finite height of the LGS is called focus anisoplanatism and it obviuosly increases with the telescope diameter and decreases with the beacon altitude.

Secondly, the apparent position of the LGS is not a good reference for overall tip-tilt or image motion compensation, because the absolute angular position of the beacon against the sky is not fixed with respect to the astronomical object. On the upward propagation through the atmosphere the beam wanders randomly and the unknown final offset from the aim point at the beacons altitude leads to an unknown overall-tilt to the returned wavefront. So only the differential tip/tilt between the transmitting and receiving apertures can be measured.

Therefore, to correct for image motion, a nearby, i.e. within the isoplanatic angle for overall tilt, and bright enough natural tip-tilt reference star is necessary to drive a seperate tracking system. Since the entire aperture of the telescope can be used for tip/tilt sensing this star can be much fainter than the star needed for correction of the higher-order wavefront aberrations.

For a 4m-class telescope the tip/tilt reference star has to brighter than 17th magnitude. Within the isoplanatic angle for overall tip/tilt , which is in the order of 20 arcsec for such telescopes, the probability of finding a 17th magnitude star is about 50 % for the galactic plane and about 10 % at the galactic pole.

The ALFA LGS is produced by focusing a laser beam into the mesospheric sodium layer which is at a mean altitude of about 92 km. The narrowband laser is tuned to the sodium D_2 line at 589.2 nm, so that the sodium atoms in the layer produce resonance fluorescence at this wavelength when excited by the laser light. Since the sodium layer has a total thickness of about 10 km at its mean height, the LGS as seen from the ground is the fluorescence light from a column about that value long (the exact value depends on the zenith distance the laser is pointing).

The sodium layer was choosen for generating the LGS for mainly two reasons: first, for a 4m-class telescope, a single sodium LGS is high enough, that focal anisoplanatism is neglegible, even when observing in the visible. Secondly, when using the sodium atoms in the mesospheric layer the product of particle column density and absorption cross section is maximized, given today's laser technology for induced fluorescence.

The mesopheric sodium layer is believed to be created by meteoric ablation, and depleted at its lower boundary by chemical processes. The latter are affected by mesopause-temperature changes which therefore causes diaurnal and seasonal variations in the column density of the sodium atoms which ranges from 2 to 9×10^{13} atoms/m^2 .

The natural occuring atomic sodium is composed of virtually 100 % one isotope with nuclear-spin-angular-momentum quantum number $I = 3/2$. Fig. 1.1 shows the energy level diagram for the ground state and first excited state of atomic sodium.

The ground state level with total-angular-momentum quantum numbers $F = 3/2 \pm 1/2 =1$ and 2 are separated by an energy equivalent of 1.772 GHz due to hyperfine-interaction between the nuclear magnetic dipole moment and the magnetic field from the valence-electron at the nuclear place.

The first excited state shows a dublett fine structure due to the interaction between the electron-spin magnetic moment and the magnetic field caused from the electron orbit. The excitation wavelength of the upper state ($J = 3/2$) is 589.2 nm, the well known D_2 transition and the excitation wavelength of the lower state is 589.6 nm, the D_1 transition.

Both dublett states split again into 2 and 4 hyperfine states, respectively. The radiative lifetime due to spantenous emission of an atom in either of the first excited states is 16 ns, which yields a natural homogenous linewidth of 10 MHz. Fig. 1.2 shows the absorption profile of the D_2 hyperfine transitions of a single sodium atom. The peak absorption of the D_2 transitions corresponds to the 3S F=2 to 3P F=3 transition.

The temperature at the layer is about 215 K, which leads to a Doppler broadening of each hyperfine transition of about 1 GHz, which results in a double-humped absorption profile for the layer atoms as shown in fig. 1.2 . Thus the 1.77 GHz separation of the sodium ground state is still well resolved and one might think of the sodium D_2 absorption line at the layer as the superposition of 1 GHz / 10 MHz or 100 different velocity groups in each hump. The average time between collisions of the sodium atoms with the background gas is about 100 μs, so pressure broadening is neglectible.

The total D_2 scattering cross section in the case of neglectible saturation, can be calculated by convolution of the Doppler-broadened sodium D_2 absorption profile with the given laser-line profile used for excitation. The peak cross section for continuous-wave (cw) natural linewidth excitation of

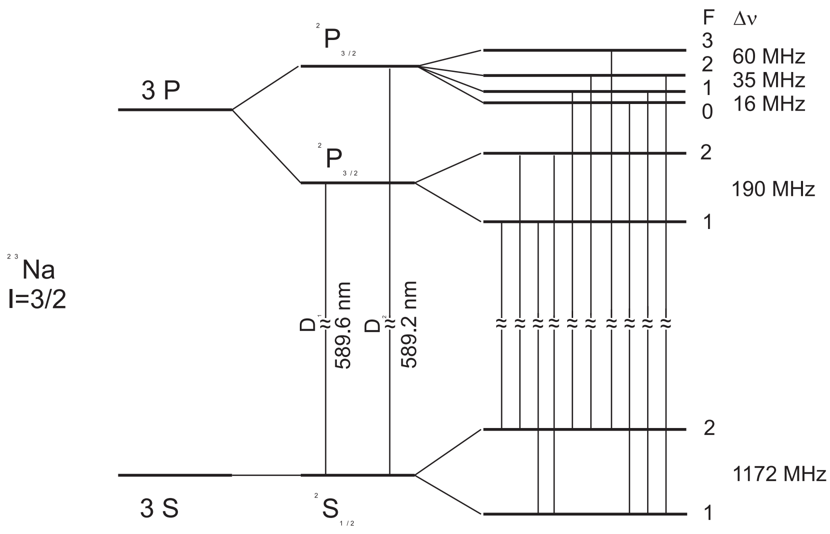

Figure 1.1: Energy-level diagram for atomic sodium.

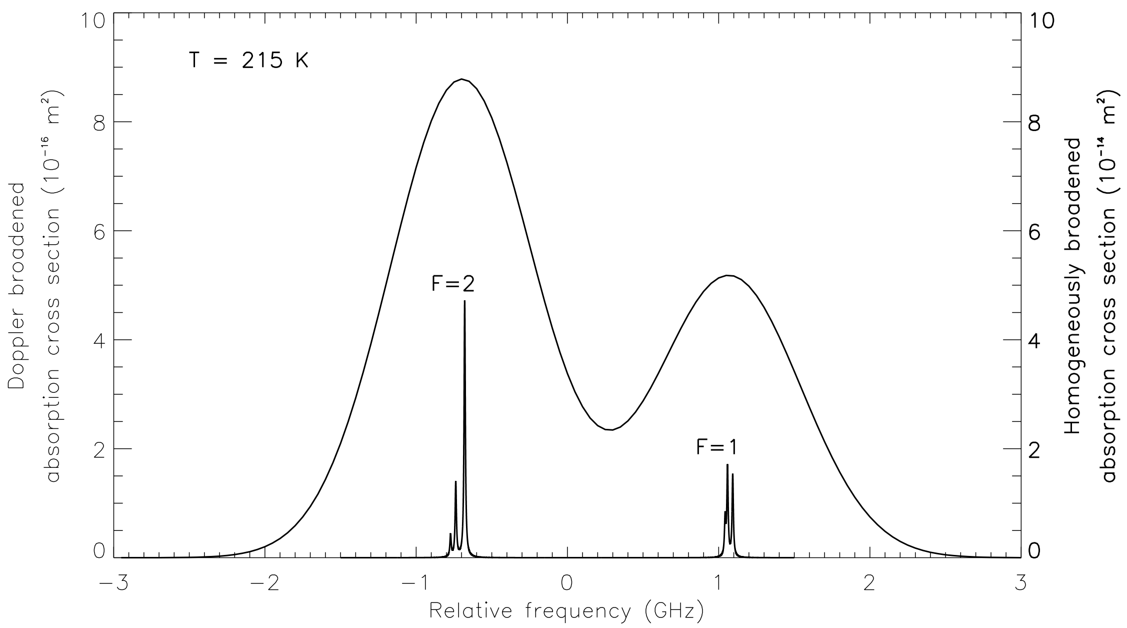

Figure 1.2: Homogenously and inhomogenously broadened absorption profile of the sodium D_2 line. The zero-point of the relative frequency corresponds to 509.20103 THz or 589.1583 nm.

the mesospheric D_2 transition is about 9×10^{-16} m^2. The D_2 resonance scattering is non-isotropic: it is peaked by an factor of 1.5 in the backward and forward direction.

The saturation intensity for a laser beam with a bandwith greater or equal the homogenous linewidth, incident upon the inhomogenously broadened D_2 transition in the mesosphere is about 6×10^{-6} W/m^2/Hz. So for single-mode radiation the saturation intensity is only 60 W/m^2. For accurate wavefront sensing and for a most efficient use of a given laser power it is desirable to make the LGS as small as possible and therfore care is needed not to saturate the transition which would mean that precious laser power is wasted. Another reason why saturation has to be avoided is that the wings of the LGS profile would be enhanced with respect to the core, leading to an angular broadening of the spot.

1.2 Overview on the ALFA LGS System and its Limitations

The ALFA laser for exciting the sodium D_2 line is a high power cw jet streamed dye ring laser in Rhodamine 6G(Rh6G). Depending on the solvent the dye Rh6G is tunable from 560 to 650 nm, which makes R6G to the best choice for a sodium dye laser. The dye laser is optically pumped by an argon-ion laser with 25 W multiline output power. The typical output power of the dye laser is 4 W single-mode in the TEM $_{00}$-mode. This power corresponds to an equivalent V-band LGS-brightness of 9 to 12 mag depending on zenith distance and sodium column density as can be seen from fig. 1.3.

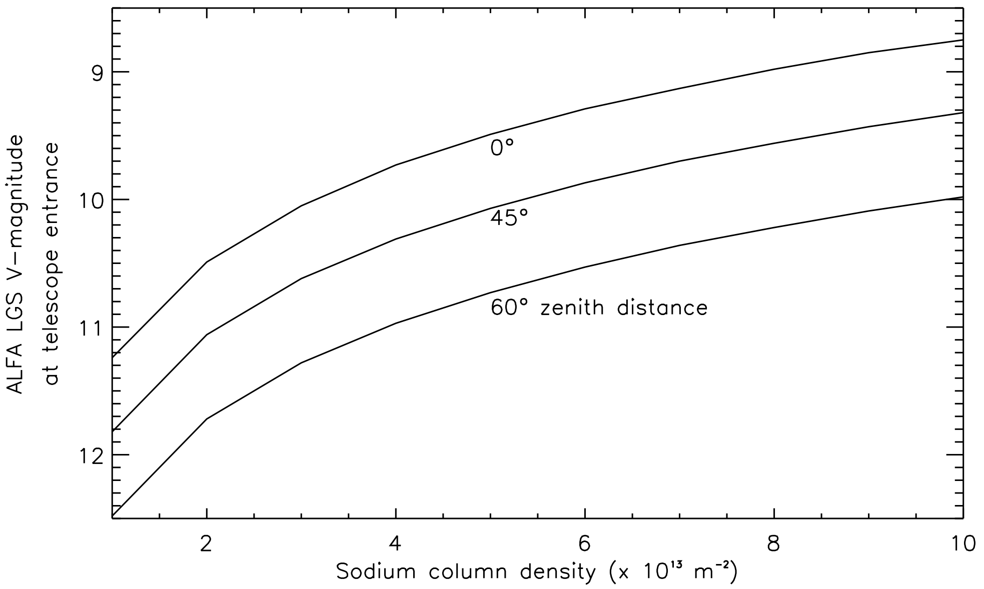

Figure 1.3: Predicted ALFA LGS brightness (equivalent V-magnitude). A total maximum transmission (including atmosphere) for excitation of 50 % is assumed.

In fig. 1.4 an schematic overview of the ALFA LGS system installed at the 3.5 m telescope is displayed. Important elements of the beam relay system are labeled (see the following chapter).

Both laser are installed on an optical bench in a separate room in the coude-lab. From there the laser beam is fed into the coude-train of the 3.5 m telescope. Near the 3.5 m primary the beam is picked off by a folding mirror, which directs the beam with the help of additional steering mirrors to the entrance of a 0.5 m launch telescope, which points and focuses the beam to the mesospheric sodium layer. Since the launch telescope is mounted at the side of the 3.5m mirror the Rayleigh backscatter produced by the laser beam in the lower atmosphere (up to altitudes of about 25 km) can be simply rejected from entering the WFS by limiting the field-of-view of the WFS to 10 arcsec, which is about twice the angular separation of the LGS from the end of the Rayleigh backscatter cone

From the start of the Coude train until the exit of the launch telescope the beam is baffled for turbulence and safety reasons. Behind the secondary of the 3.5 m a video-camera is watching the sky for airplane. If an aircraft is going to fly into the laser beam, the laser shutter will be automatically closed.

All important components of the LGS system are fully remotely controllable and several control loops serve to stabilize laser frequency, beam feeding into the launch telescope and optimum appearance of the LGS on the WFS. The control software of the LGS system has been implemented on three distributed VMEBus computers and an UNIX workstation in order to provide reliability, usability and maintainability of the whole system. The interprocess-communication uses variuos mechanisms, including EPICS, a distributed real-time database and shared memory concepts for local high-speed data transfer.

The use of the LGS system for the AO system is limited by the amount of laser light that can be transported into the mesospheric sodium layer and the amount of processed laser light entering the telescope. Thus thin clouds, e.g. cirrus, toghether with a low sodium column density can prevent a sucessful operation of the LGS/AO system.

Figure 1.4: Schematic representation of the ALFA LGS system at the 3.5 m telescope.

Chapter 2

Technical Description

In the following sections the individual parts of the LGS-System are desribed in detail. Important components are indicated in bold letters.

2.1 The ALFA Laser Facility

The main component of the ALFA LGS-system is based on a *Coherent Modell 899* dye ring laser. The dye laser and the pump laser(*Coherent Innova 420*), together with optics for beam forming and diagnostics (output beam position and quality, laser frequency) are mounted on a floated optical bench placed in a separate room in the coude-lab. The optical bench is shielded with removeable covers and above the dye laser a laminar flow box is installed to prevent the sensitive resonator components from contamination. The laser room is equipped with an air conditioning system to stabilize the air temperature to ? ± ? deg C independent from the environmental conditons. For safety reasons the heat-exchanger for water cooling of the pump laser and the chiller for the dye solution is installed in an adjacent cabin to the laser lab, as it is for the main power of the pump laser. The optic and supply schematic of the laser facility is shown in fig. 2.1.

The basic design of any cw dye laser is naturally constrained in fundamental ways by the photophysics and chemistry of the dissolved organic dye molecules, which represent the active laser medium. The important things to notice here are that the absorption and emission spectra of dissolved dye molecules are broadband features without sharp lines. The band structure results form that the fact, that in a dye-solution the narrowlying rotation-vibration levels are so strong collision broadened, that they overlap. The absorption band at lower frequency is nearly the mirror image of the emission band and the exact peak position of the absorption and fluorescence band depend on the solvent and dye concentration. The broadening of the gain of organic dyes is both a blessing and a curse. It is a blessing in the sense that in the case of homogenous broadening all of the gain medium can contribute power to the oscillating laser mode and because the broad emission spectrum provides the laser's tunability. It is a curse because the broad spectral width means that the excited-state lifetime is short and hence intense pump powers are required in order to achieve sufficient population inversion for the laser oscillation.

For exciting Rh6G strong blue light is neccesary. Today only cw ion lasers can produce high enough power in that wavelength regime in a good single-spatial mode. The quality of the pump laser (power stability, mode structure) is important because the dye laser output replicates the output of the pump laser. The multiline output of the ALFA pump laser consists of eight 8 lines from 457.9 to 514.5 nm which lase simultaneuosly with their relative linestrength well matched to the absorption band of Rh6G. The strongest line with nearly 50 % of the total power is at 514.5 nm.

The cavity of the pump laser consists of a low pressure plasma tube with ionized argon gas as the active medium positioned between one flat **high reflector** and one curved **output coupler**. The adjustable high reflector is sealed onto the plasma tube. Between the front **Brewster window** and the output coupler there is an **intracavity aperture**, a **manual shutter** and a **beamsplitter** for power monitoring. The intracavity aperture is adjusted for the largest aperture diameter that provides the highest output power (for a given tube current) with a gaussian TEM_{00} mode.

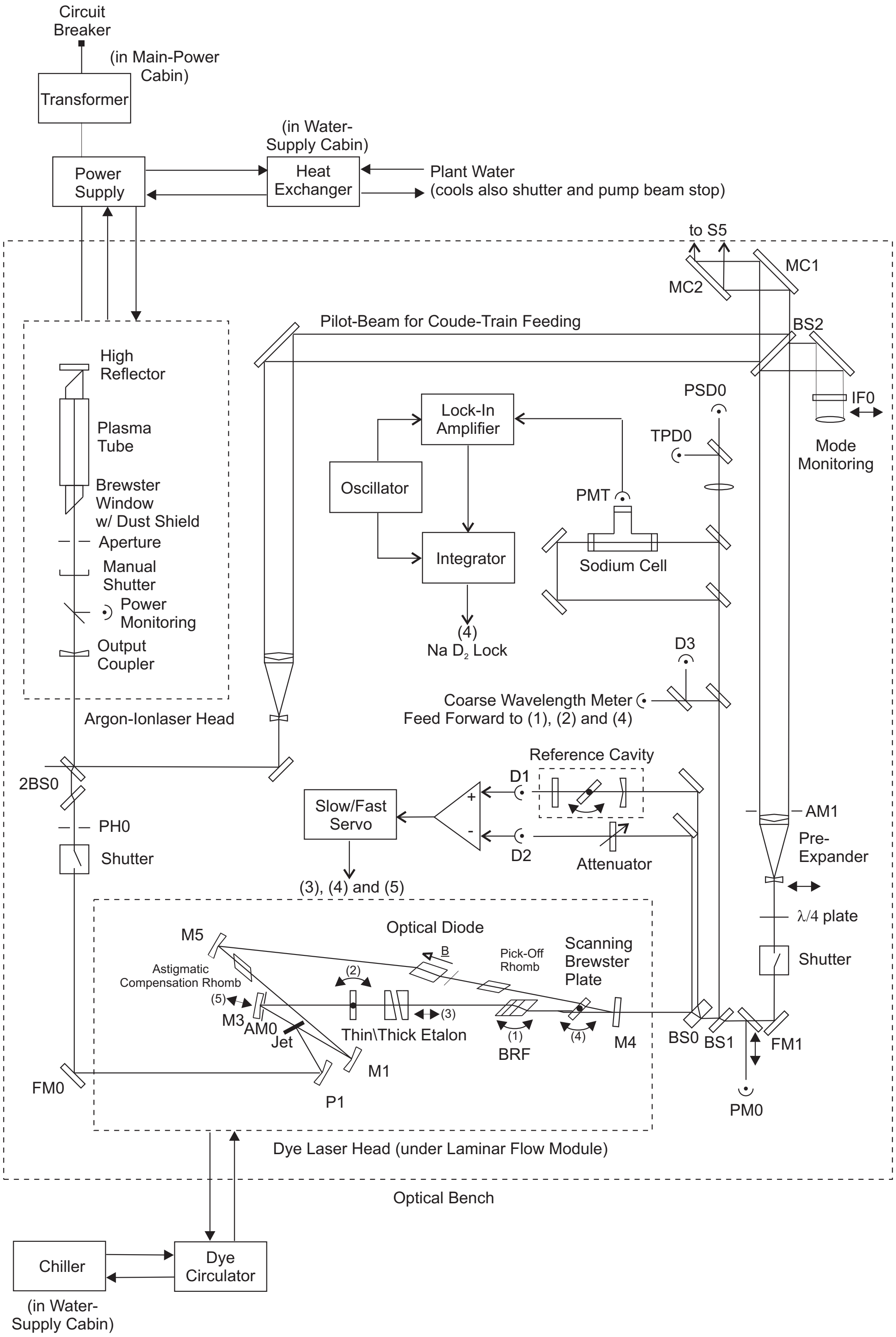

Figure 2.1: Optic and supply schematic of the ALFA laser facility in the coude-lab.The size of the optical bench is 1.2 x 2.4 m.

The plasma tube is cooled in a closed loop water cooling system (water flow rate about 25 liters / minute), with the **heat exchanger** installed in the water supply cabin. The **circuit breaker** together with a 480/380 V transformer for the pump laser power supply is installed in the main power cabin. The microprocessor controled **power supply** of the pump laser (in the laser room) provides the DC current for the tube and its axial electro-magnet. The power supply also monitors safety interlocks (covers, water flow) and diagnoses system faults. The communication with the power supply can be either done via a serial link or with a remote control modul.

At the output of the pump laser part of the pump light (7 %) is coupled out with the beam sampler **2BS0** to provide a pilot-laser beam with sufficient power for position control of the dye laser beam (see 2.2). The pinhole **PH0** blocks ghost reflections from 2BS0.

The **pump laser shutter** is automatically closed in case of a failure of the dye circulation system.

The flat folding mirror **FM0** directs the 2 mm diameter pump beam into the dye laser head.

In the following list the major elements of the ring dye laser are described:

- The basic resonator is a figure-8-shaped ring, formed with 3 spherical mirrors(**M1**, **M3**≡ M2 and **M5**) and one flat output coupler(**M4**) with 10 % transmission. All components are adjustable mounted to a solid Invar rod for thermal and mechanical stability. There are two beam waists: one is optically pumped at the dye jet; the other is at the place of an astigmatic compensation Brewster element.

- A curved mirror(**P1**) focuses the pump light into the free flowing dye **jet** stream, which is the active medium of the dye laser. P1 has a distance of 50 cm from the pump laser output. M1 and M2 match the beam diameter of the dye laser-cavity mode to the focused pump spot, which has a typical diameter of 30 microns. The dye jet is a nearly rectangular ribbon with a thickness of about 0.3 mm and it is oriented at the Brewster angle relatively to the laser cavity mode and near Brewster's angle to the pump beam, in order to minimize reflection loss and to prevent unwanted polarization effects. The optical quality of the jet plate is better then $\lambda/200$ peak-to-valley in the visible at the pumping region (an appropriate flow velocity and dye solution provided).

  Because of the heat produced in the dye (distorts the transverse mode) by the focused pump light which is not reradiated as fluorescence and because of triplet-state trapping, it is necessary to have the dye molecules traverse the pump spot very rapidly. Beside Singlet states, Triplet-states are other possible states of excited dye molecules into which they can decay, but due to the much longer lifetime of the triplett-states, these act as a trap for the excited dye molecules, which are then no more available for the lasing process. Therefore the flow velocity at the output of the jet-forming **nozzle** of the dye laser is such, that the dye molecules stay only in the order of the triplett-lifetime in the pump spot. Beside this step, triplett-state trapping can further quenched chemically by adding some amount of cyclooctatetraene (COT) to the dye solution.

  The **dye circulator** (see fig. 2.2) cools, filters and pump the dye solution. To dampen vibrations of the dye solution, which increase the effective laser linewidth, the pump and motor are magnetically coupled. The dye solution is kept at a constant temperature with a **chiller** installed in the water supply cabin. The materials coming in contact with the dye in the circulation system (stainless steel, teflon) are choosen such that they do not influence the lifetime of Rh6G, which is therefore subject to degradation only due to pump-laser heating and laser-induced photochemistry. The lifetime of Rh 6G is limited to about 2000 pump Watt hours. It is measured when the power has degraded to 75 % of the power available with fresh dye.

  The transmitted fraction of the pump light (several Watts) falls onto a water-cooled beam-stop in the dye laser head.

  The aperture mask **AM0** supports a more easy generating of the desired TEM_{00} dye laser mode.

- A fused silica **rhomb** mounted near the auxiliary waist at Brewster's angle compensates for astigmatism caused by off-axis reflection from the three spherical mirrors. Beside mode

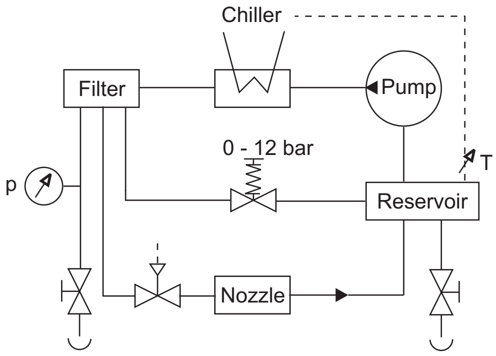

Figure 2.2: Schematic of the dye circulator.

quality this also improves the laser's spectral properties (i.e. the effective linewidth). Another rhomb near M4 is used for picking off the beam in the cavity.

- To ensure that the laser oscillates as a travelling wave, propagating in only one direction around the ring, an **optical diode** is used. This device works by rotating the polarization of the propagating laser mode for only one of the two possible propagation directions. This happens by combining the Faraday effect in a glass rhomb, which is kept in a strong magnetic field, together with the normal optical activity in a thin quartz plate. The Faraday rotation in the glass rhomb makes the polarization rotation non-reciprocal, since here the direction of polarization rotation is independent of the propagation direction of the light through the material.
  Unidirectional ring lasers with traveling wave fields have advantages over bidirectional or standing-wave dye lasers because of more efficient use of the available gain in the active medium and better spectral characteristics. In the active medium of linear dye lasers there are regions of unsaturated gain at the nodes of the standing wave. Such 'holes' limit the pump power and therfore output power to relatively small values, before secondary cavity modes appear. Suppression of such effects in standing-wave dye lasers requires increasing the finesse of the etalons used for the frequency selection. But this produces more insertion loss and less conversion efficiency. In ring dye laser, however, the travelling wave fills up the active medium uniformly (no nodes, no holes), increasing the conversion efficiency.

- The laser's oscillation frequency is controlled by providing frequency-selective loss inside the cavity which come from polarization-sensitive elements and from interferometry (see fig. 2.3). The hierachy of oscillation frequency selection in the laser start on the least selective end with a three-plate **birefringent filter**(BRF), which has a half power bandwith of about 1700 GHz. The wavelength-tuning with the BRF is done manually by rotating it about the normal to the plates, which can be done with a wavelength resolution of about 0.01 nm and a wavelength repeatability of about 0.1 nm, which corresponds to frequencies of 8 and 80 GHz at 590 nm, respectively.

  The BRF is followed by an electronically controlled intracavity etalon assembly(**ICA**) consisting of two etalons with progessively higher resolution. The **thin etalon** (0.5 mm thick) has a free spectral range(FSR) of 225 GHz (130 GHz bandpass FWHM) and a reflectance finesse of 2, the **thick etalon** (10 mm thick) has a FSR of 10 GHz (5 GHz bandpass FWHM) and also a finesse of 2. The role of these elements can be seen in fig. 2.3, which shows the transmission functions of these elements overlaid with the laser longitudinal mode structure. The resolving powers of the three frequency-selective elements are chosen so that the BRF has enough resolution to select a specific thin-etalon mode, the thin-etalon mode selects a specific thick-etalon mode, and the thick etalon has enough resolution to select a specific longitudinal mode.

  Thus the BRF alone (without the ICA) delivers a net spectral laser width of about 2 GHz

(broadband operation). The overlap of the transmittance peaks of the BRF and the thin etalon reduces the laser bandwith further to about 300 MHz (RMS) which is sufficient to enforce single mode operation (given 180 MHz mode spacing, see below). The additional use of the thick etalon permits the longitudinal mode to be scanned.
The thick etalon is constructed from two Brewster-cut Littrow-prism mounted on piezos. This allows the etalon to be elctronically tuned while still maintaining the advantages of an optically solid etalon, e.g. no AR-coated surfaces, low walk-off losses (i.e. when slightly tilted from normal incidence), together with the advantage of tunability of an airspaced etalon. The thin etalon in the ICA is galvo-controlled for electronic angle tuning.

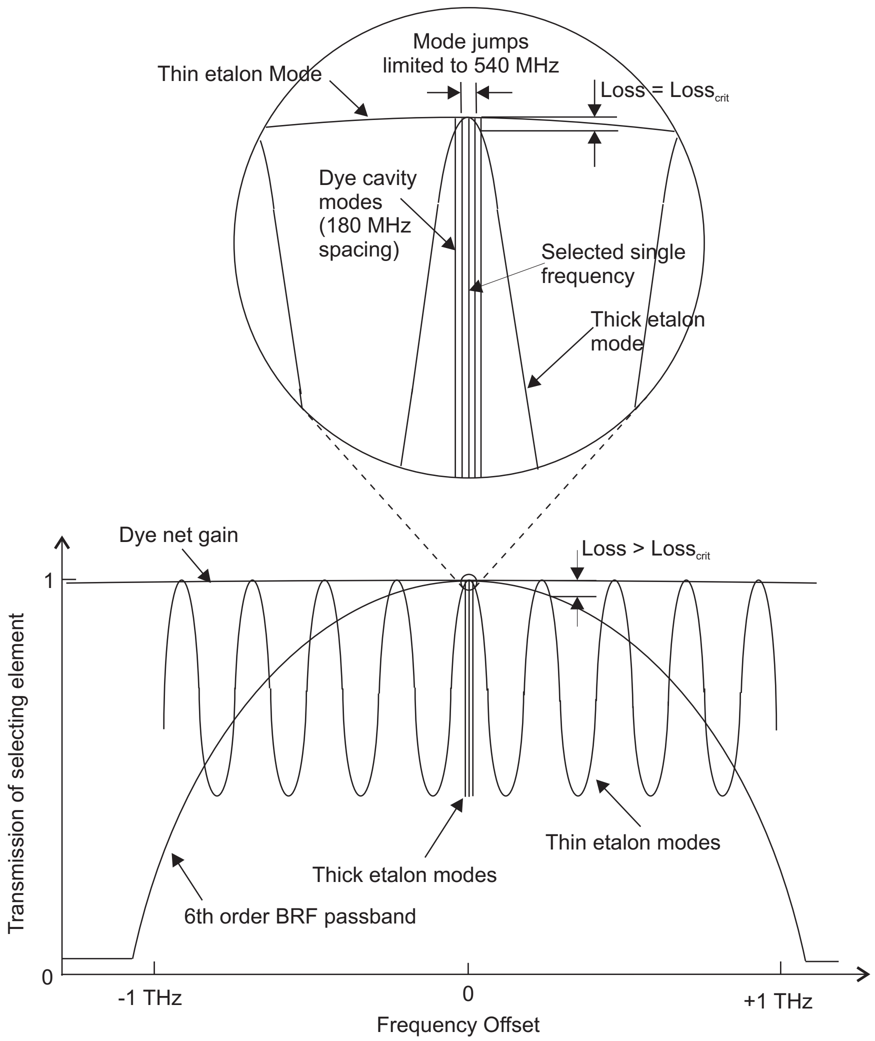

Figure 2.3: Schematic transmission functions of the three frequency-selective elements in the dye laser cavity. A net gain reduction of $Loss_{crit} \approx 0.5$ % is sufficient to suppress other modes from lasing.

- The resonator itself permits oscillation only at those wavelengths that correspond to stable modes of the resonator. Stables modes occur at frequencies that are separated from each other by $\Delta f = c/(2L)$ ($2L$ = optical round trip length) or $\Delta f \approx 180$ MHz ($2L \approx 160$ cm). If the resonator length is kept fixed then, no matter how the frequency-selective elements in the cavity are adjusted, the actual operating frequency will vary stepwise as it oscillates only at the frequencies defined by the modes of the resonator. To achieve tunability within the mode separation, the cavity length can be continously changed by rotating a single galvo-driven **Brewster plate** mounted at the vertex of the ring. This position minimizes output power modulation and beam movement during a frequency scan. The full scanning range of the Brewster plate is 30 GHz.

- The instanteneous linewidth of a single longitudinal resonator mode is in the order of Hertz. The effective linewidth, however, is the jitter of that mode caused by mechanical and acoustic disturbances, such as vibration, air turbulence etc., all of which produce variations in the cavity length. Since all optical resonator components are mounted on a single Invar rod the effective linewidth is typically ± 20 MHz.

  To reduce the laser-linewidth further (to 1 MHz rms) the dye laser is able to actively stabilize its cavity length, with a frequency error signal sent to the galvo-driven Brewster-plate and to the lower folding mirror M3. The large-scale and low frequency jitter corrections at drive frequencies up to 100 Hz are corrected with the Brewster plate. It is therefore the equivalent of a hi-fi '**woofer**'. For fast cavity length adjustments (faster than 100 Hz) the folding mirror M3 is mounted to a piezoelectric translator to keep frequency jitter below 1 MHz. This mirror is the equivavent to a hi-fi '**tweeter**'. It has a full scanning range of 1 GHz. The error signal for controlling the woofer and the tweeter is provided from the external **reference cavitiy**. The reference cavity is a temperature- and pressure-stabilized, scanning, confocal Fabry-Perot interferometer (FSR 1 GHz, finesse 3). Via the output coupler **BS0** a portion of the output beam (1.4 % of light power) is passed through the reference cavity, generating composite frequency and amplitude information at detector **D1**, which is compared to a signal containing only amplitude information (measured with detector **D2**). A deviation in laser optical frequency causes a change in the transmission signal detected by D1. The error signal is the difference between this signal and the photocurrent of the laser power measured in the reference channel by detector D2. With a variable attenuator in the reference channel the light levels are adjusted so that above difference is zero when the the laser frequency is tuned to a frequency where the transmission of the reference cavity is half the maximum transmission (at a cavity fringe's peak). This provides a smoothly varying monotonic frequency discriminator for laser frequency excursions less then one-half of the width of the reference cavity transmissions fringes, which have a FWHM of about 0.5 GHz. The reference signal generated by the laser power cancels laser-amplitude fluctuations that would otherwise cause an error in the frequency lock signal.

  Because of the limited linear motion of the tweeter-piezo there is also a galvo-mounted Brewster plate in the reference cavity to provide the laser frequency following the scanning lock point for scan ranges larger than 1 GHz.

- The dye laser **control box** contains the electronics for frequency stabilization and scanning. Beside the active stabilization with the oscillating mode servo locked to the reference cavity (control box operating mode LOCK) there is also the possibilty for passive stabilization for alignment and maintenance procedures. The passive stabilization (control box operating mode FREE RUN) prevents the dye cavity from mode hopping. This is achieved by a servo loop which lock the peak of the thick-etalon transmission band to the laser output frequency. Although this has no effect on system jitter or drift, it does prevent sudden frequency discontinuities (mode hops), particulary during scans.

With the use of the beam sampler **BS1** 1.5 % of the dye laser output is sent to further elements for frequency determination and stabilization and beam position measurement:

- For absolute wavelength tuning and long-term frequency stabilization the reference cavity is locked to the central peak of the saturated absorption signal in a **sodium cell**. The sodium cell is an evacuated and temperature-stabilized T-shaped cell with some amount of pure metallic sodium placed in it. It has two entrance windows and one window perpendicular to the former for monitoring the laser induced fluorescence signal in the cell with a **photomultiplier tube**(PMT). A portion of the dye laser output beam (coupled out with BS1) is split into a saturating beam and a weaker probe beam which are sent antiparallel through the heated sodium cell. The saturation signal of the stronger beam burns a hole in the velocity distribution of the excitable atoms (i.e. saturate the atoms) at the velocity group centered about the corresponding resonance velocity. If the laser frequency is unequal to one of the sodium D_2 hyperfine transition frequencies the weak probe beam will interact primarily with an opposite travelling group of atoms. This opposite velocity group will be very little saturated by the weak probe signal. Hence the absorption saturation produced by the saturating beam will have negligible effect on the measured fluorescence of the probe signal. If the laser frequency is exactly tuned to one of the sodium hyperfine transitions both the saturation signal and the probe signal are in resonance with the same group of atoms, namely, the zero-velocity group, which means that the attenuation through the cell (or the fluorescence signal) is particullary reduced. The burned hole at the zero-velocity group will thus appear right at the hyperfine line center, independent of any Doppler shifts and with a linewidth equal the natural linewidth of 10 MHz. Due to the hyperfine sodium ground state splitting there are two possible 'line centers' where the sharp fluorerscence attenuation appear (see fig. 2.4).

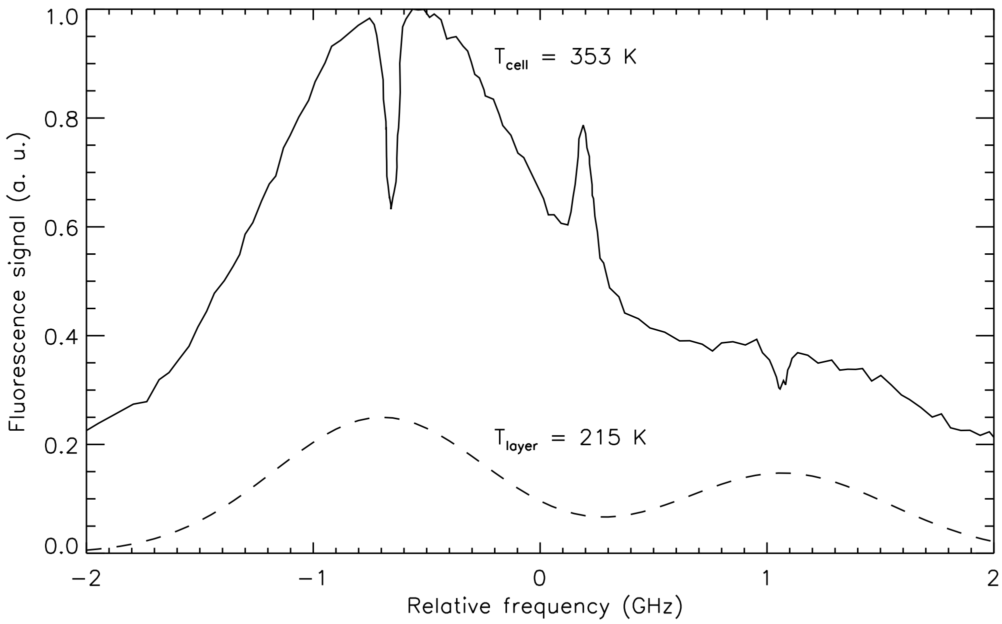

Figure 2.4: Saturated Na D_2 fluorescence spectrum from the sodium cell compared with the typical spectrum of the return signal from the sodium layer under narrowband resonant excitation.

- The laser frequency giving the maximum fluorescence signal in the sodium layer corresponds to the position of the fluorescence dip in the sodium cell at the lower frequency (Brewster-plate plate tilted clockwise).
- With a **wavelength meter** based on the photocurrent of a colour sensor the dye laser frequency can be determined coarsly with a resolution of 0.1 nm and an accuracy of ± 0.5 nm.
- The signal of the photodetector **D3** is used for power monitoring and signal normalization in the D_2 lock mode.
- Beam position of the dye laser is measured with the detectors **PSD0** and **TPD0**. Their signal support the aligning procedure of the dye laser and can be used to correct for excessive laser beam jitter.

Table 2.1 summarizes the performance specifications of the dye laser its pump laser and table 2.2 summarizes important geometrical values for the laser system.

CW Jet Streamed Dye Ring Laser	
Power	4.5 W single-mode
Efficiency	16 % (25 W argon-ion laser pump)
Linewidth	20 MHz passively stabilized 0.5 MHz actively stabilized
Beam diameter	0.7 mm (TEM_{00})
Beam divergence	1.3 mrad (full angle)
Polarization	100:1, vertical
Beam pointing stability	± 10 μrad
Beam centering stability	$\pm 10 \mu$m
Long-term power stability	± 4 %
Optical noise	0.5 % rms (10 Hz to 1 MHz)
Jet thickness	0.3 mm
Dye	Rhodamine 6G
Solvent	Ethylene Glycol, 21 °C
Additve	COT
Lifetime	2000 Watt-hours
Frequency Stabilization	Passive cavity side lock
Wavelength Reference	Doppler-free saturated flourescence in a sodium cell
Argon-Ionlaser	
Power	27 W multiline visible
Beam diameter	1.9 mm (TEM_{00})
Beam divergence	0.4 mrad (full angle)
Beam polarization	100:1, vertical
Beam pointing stability	< 10 μrad / ΔT (°C)
Beam centering stability	< 10 μm / ΔT (°C)
Long-term power stability	± 0.5 %
Optical noise	0.3 % rms (10 Hz to 1 MHz)

Table 2.1: Performance specifications of the ALFA laser.

Distances	
OC Pump Laser - P1	500 mm
M3 - Jet	50 mm
M1 - Jet	82 mm
M1 - M5	220 mm
M3 - M4	570 mm
Radii	
P1	125 mm
M1	100 mm
M3	100 mm
M4	∞
M5	150
Angles	
Jet Surface, M3 - M4	26°
Brewster	50°

Table 2.2: Important geometrical values for the laser system.

In the transmitted dye laser beam after the beamsplitter BS1 the following optical elements on the laser bench are:

- An electronically controlled and water cooled **shutter** is connected with the telescope control and the aircraft safety system. The shutter is normally closed.
- With a **quarter wave plate** the linearly polarized dye laser output is circulary polarized to make use of optical pumping of the sodium atoms in the mesospheric layer.

  Optical pumping is a nonlinear effect which must be considered for laser illumination times that are long compared to the radiative lifetime (i.e. in the case of a cw laser). It can cause reduced backscattering as well as increased backscattering, both depending on the polarisation of the laser light. If linear polarized laser light with a linewidth smaller than the 1.77 Ghz separation of the sodium ground states is tuned to the 3S F = 2 to 3P F = 1, 2, 3 transitions, the atoms will only be excited out of the F = 2 hyperfine ground state. But in general the atoms can decay back to either hyperfine ground level F = 1 or F = 2. Consequently, after several excitation/decay cycles all of the sodium atoms will reside in the unpumped F = 1 level. The pumping is never enough to make the layer completely optically transparent but a significant loss of atoms which are able to be excited will occur in a time scale of about 10 ms. The case of real tranparency is excluded because the atoms will be replenished by the atmosphere high altitude winds, which will blow new atoms into the laser beam in time scales of order 10 ms. However, if the incident radiation is circulary polarized, then the atoms will, on average, absorb angular momentum during the absorption-emission cycle. After several cycles, most of the atoms will be pumped to states with the highest total angular momentum (F = 2), which cannot decay to the ground state with the lowest total angular momentum. The result is a increased backscattering because the pumping has moved the population into the state with the largest backscatter cross section. Although the spin-polarization of the sodium atoms due to optical pumping with circular polarized light is degraded by several spin-depolarization mechanism in the atmosphere(e.g. Larmor precession of the atomic moment in the earth's magnetic field thus allowing optical transitions that would otherwise be forbidden, spin-exchange collisions or diffusion out of the beam) one can expect an enhancement of the fluorescence signal of several tens of percent when circulary polarized light instead of linear polarized is used.
- The **beam pre-expander** of refractive galilean telescope type, mounted at a distance of 40 cm from the dye laser output, expands and collimates the dye laser output beam to diameters which can range from 15 to 25 mm (Magnification can be changed by replacing the entrance lens). This is the input beam for the launch telescope (see 2.2). The aperture mask **AM1** cleans the beam from ghost reflections.
- The beamsplitter **BS2** couples the argon-ionlaser pilot-beam for beam position control (see below) onto the axis of the expanded dye laser beam. The reflected dye laser light is used for monitoring the mode structure. With interfernce filters (**IF0**) one can change between the pump and dye laser light. BS2 also acts as the a window between the warmer laser room and the telescope dome to reduce beam seeing.
- Two 3 inch flat steering mirrors **MC1** and **MC2** for beam centration and pointing fed the pre-expanded dye laser beam and the argon-ionlaser pilot-beam onto the axis of the coude-train .

2.2 The Laser Beam Relay and the Launch Telescope

For transmitting the laser light into the atmosphere a separate 0.5 m **launch telescope** is used, which expands the laser beam and provides focusing and beam steering capabiltiies. The dye laser beam is expanded before it is send into the atmosphere, because a previously expanded beam can be focused to a smaller spot at the layer. The focusing capability is necessary because the distance to the layer varies with the zenith angle. Beam steering capabilty is necessary to compensate for atmospheric induced jitter in the upgoing beam.

The launch telescope is a Cassegrain-type afocal galilean beam expander consisting of two paraboloids. It expands the collimated input beam by a factor of 16. Beam Steering and focusing is done with the secondary mirror mounted on a piezo tip/tilt platform and a motorized translation stage. In Table the specifications of the launch telescope can be found.

The diameter of the output-beam at the exit of the launch telescope is controlled by the diameter of the collimated input beam. The latter can be adjusted with the laser beam pre-expander on the laser bench, which allows magnifications from 15 to 25. This allows one to match the transmitted beam diameter to the current atmospheric seeing conditions. This is necessary since the optimum diameter is determined by two opposing factors. The most efficient use of a given laser power is made by focusing it into the sharpest spot on the layer. So larger apertures with smaller diffraction limit are preferred, but for beam diameters beyond $\approx$2 times the coherence length of the atmospheric turbulence, the atmosphere distort the upgoing beam such that the produced spot will be broken into a random speckle pattern of a width equal the seeing limit, which enlarges the spot as seen from the ground.

The launch telescope is mounted on a tilt platform on the upper north-east corner of the 3.5 m mirror main structure with its optical axis aligned with respect to the optical axis of the main telescope. Both axis are separated by a distance of 2.9 m, leading to an angular separation of the end of the light cone produced by Rayleigh backscatter of the laser beam in the lower atmosphere (which occurs up to heights of $\approx$ 25 km) and the sodium LGS of about 10 arcsec. Thus the light from the Rayleigh-backscatter can be rejected from the LGS spot by restricting the field of view of the wave-front sensor to about that value.

The slight elongation of the LGS in one direction due to the finite sodium layer thickness and the off-axis configuration of the launch telescope can be calibrated out to first order on point sources.

Since the laser beam traverses not exactly the same path through the atmosphere as the received backscattered sodium fluorescence, the centroid of the LGS image would wander around slighlty in the field of view of the telescope. To keep the LGS centroid centered on the detector of the WFS, the pointing of the beam is controlled by the signal provided from the average motion of the Hartmann spots on the detector. Once this image motion is removed the LGS provides a pseudostationary source for measuring the higher order wavefront aberrations. Nevertheless there is an uncorrelated motion of the astronomical object beeing observed relative to the pseudostaionary LGS which prevents the LGS from beeing used for overall tip/tilt correction. This is due to the fact, that on the upward propagation through the atmosphere the beam wanders randomnly and the unknown final offset from the aim point at the mesospheric layer leads to an unknown overall tilt to the returned wavefront. To correct for image motion ALFA therefore uses a separate natural tip/tilt reference star within the isoplanatic angle for overall tilt to drive a separate tracking system. Since the whole telescope aperture can be used for tracking and because the isoplanatic angle for overall tilt is larger than that for higher order distortions, the probabilty of finding a suitable tip/tilt reference star ist nearly 100 %.

The optics that relay the pre-expanded beam from the laser room to the entrance of the launch telescope is consiting of 8 flat folding mirrors (see fig. 2.5).

Starting in the laser room these are in direction to the launch telescope: **MC1** and **MC2/ESD** for beam centering and pointing, respectively, to fed the laser beams into the coude train, **S5**, the coude-train two-axis tracking mirror, **S4** on the telescope's declination axis, **MT1** the declination-axis pick-off mirror, then **MT2**, and finally **MT3** and **MT4** for centering and pointing the beam onto the optical axis of the launch telescope, respectively.

With the exception of the mirrors MC1, S4 and MT2 all steering mirrors are part of two electronic control loops that relay the dye laser beam onto the axis of the launch telescope independent of the main telecope postion. One control loop (lower beam position loop) drives the mirrors MC2 and MT1 and together with the telescope-controlled S5 this loop compensates for telescope motion, telescope deflection in the coude-train section, and irregularities in feeding the laser into the coude-train. The mirrors MT3 and MT4 for feeding the beam into the launch telescope are driven by the second, upper beam position control loop.

The beam position is measured with alltogether three position sensitive devices (PSDs) and one triple-prisma sensor. Two PSDs, **PSD1** and **PSD2**, installed in the reflection path of the beam sampler **BS3** positioned before MT1. They are measuring beam centration and pointing at the

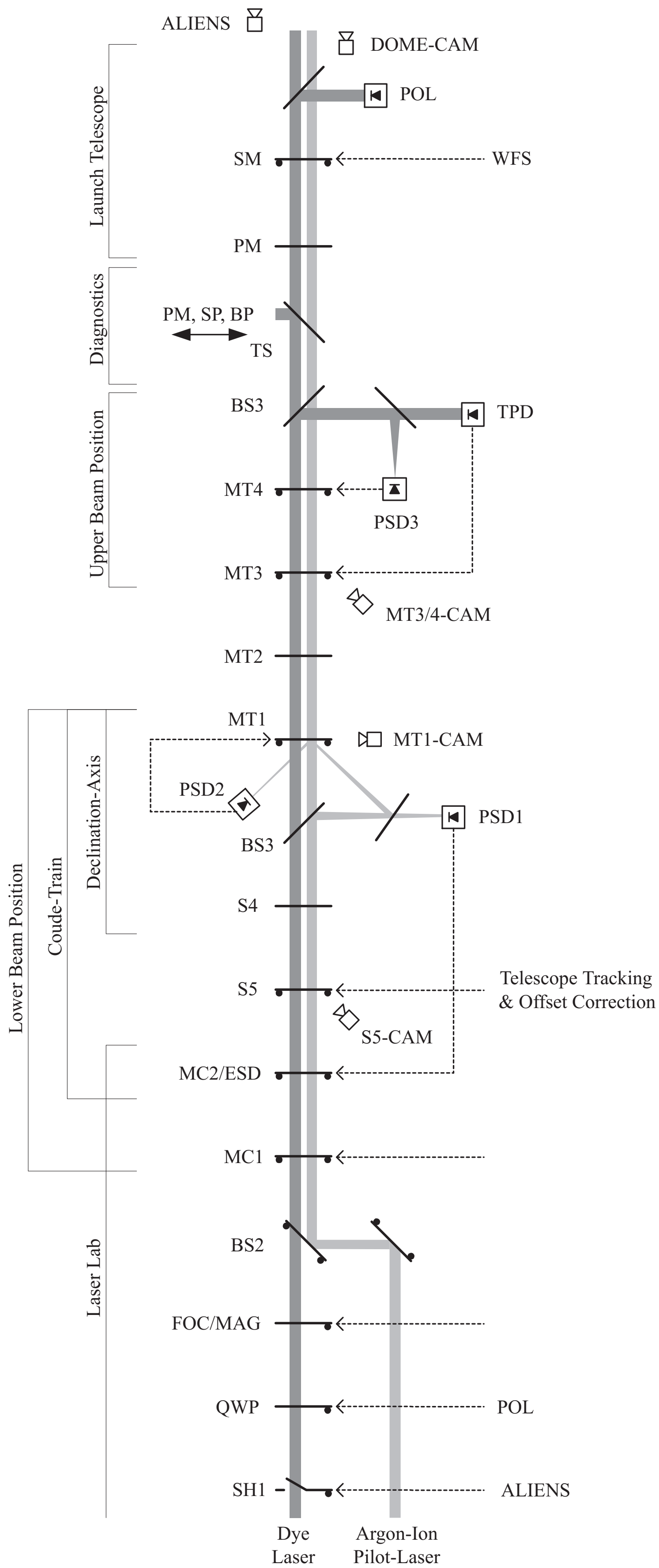

Figure 2.5: Schematics of the laser beam relay.

end of the used coude-train with the help of the argon-ion pilot-laser beam which is focused on both PSDs.

PSDs have the advantage over quadrant detectors that light can be focused on them to a smaller spot in order to reduce the influence of air turbulence and interference patterns on the signal-to-noise ratio since there are no gaps on the two-dimensional detector in between the laser spot can disappear.

PSD2 is both in the reflection path of a beamsplitter installed after BS3 and of MT1 which is driven by the PSD2 signal. In the control algorithm this signal is first regulated to the nominal zero point. Since the PSD1 signal is decoupled from the MT1 motion, PSD1 solely drives MC2/ESD. Because the dye laser beam and the argon-ion pilot-laserbeam are on-axis, both above PSDs are equipped with interference filters centered at 514 nm.

Beam centration in front of the launch telescope is measured with outcoupled dye laser light which is focused onto a **triple position detector unit** consisting of three photodiodes symmetrically arranged in the path of a reflective triple prisma used in reverse order. Their error signal drives MT3 in the upper beam relay control loop. Part of the outcoupled dye laser light at the diagnostics breadboard is also focused on **PSD3** which measures the beam pointing at the launch telescope entrance and provides the error signal for MT4.

Several video cameras (**S5-Cam**, **MT1-Cam**, **MT3-Cam** and **Dome-Cam**) are installed for doing convenient coarse alignment of the laser beams.

On the breadboard at the entrance of the launch telescope several diagnostic tools are installed. With a translation stage (**TS**) several optics can be moved into the dye laser beam path in order to measure laser power (**PM**), the beam profile (**BP**) and the wavefront curvature (**SP**). For internal aligning the red light of a laser diode can also be directed with the help of TS onto the upper beam position measurement devices.

At the exit of the launch telescope a small polarization measurement device (**POL**) is installed which drives the quarter-wave plate at the dye laser exit in order to generate the LGS with circulary polarized light.

With the exception of the primary mirror of the launch telescope, which has a protected silver coating, all mirrors of the beam relay system are dielectric broadband coated, and all transmissive beam forming and relay elements have an antireflection coating optimized for the dye laser. The substrate of all mirrors is a glass-ceramic. The total beam projection throughput from the exit of the dye laser to the exit of the launch telescope is about 75 % for freshly cleaned optics. It can degrade to about 60% with the optics uncleaned over 12 months.

Table 2.3 summarizes the specifications of the overall beam projection system consisting of the launch telescope and the beam relay system belonging to it. Table 2.4 summarizes important geometrical values of the relay system.

2.3 Laser Safety and ALIENS

Since the the ALFA laser is of the highest laser class IV every operator of the LGS system should be familiar with the according laser safety regulations (see ...).

The laser lab and the control room are equipped with **laser safety glasses** for each laser. Positions along the laser beam paths where hazardous radiation exposures can occure are labeled with **warning signs**. With the main power circuit breaker closed a **warning lamp** outside the laserlab indicates possible laser action.

Several safety interlocks are realized to maximize optical and electrical safety. In case of a cooling water leakage or failure the pump laser power supply automatically shuts down. In case of irregularities with the dye circulation system the dye pump is automatically switched off and the pump laser shutter is closed. The dye laser shutter is automatically closed in case of any detected pump or dye laser operation irregularity. It is also automatically closed in case of large telescope sweeps. This interlock has its origin in the positioning delay of the S5 mirror every time the telescope is not moving in the tracking mode. The pump and dye laser shutter can also be closed manually.

In case of an general emergency there are two **emergency switches** for the pump laser main power installed inside and outside the laser room next to the door in each case. The pump laser

Beam Relay to Launch Telescope	
Pre-Expanded Dye Laser Beam	15 - 30 mm diam.
Pilot Beam	Outcoupled argon-ionlaser light
Control Loop Components	5 flat steering mirrors (1 Coelostat and further 4 tip/tilt controlled) 2 PSD's for lower control loop, 1 PSD + 1 triple position detector for upper control loop EPICS based distributed real-time software on 3 VMEBus and 1 Unix machine(s)
Alignment Tools	1 PSD (launch telescope secondary mirror) 4 CCD cameras
Off-Axis Mounted Launch Telescope	
Type	Afocal on-axis Gallilean-type beam expander
Primary Mirror	f/5 concave paraboloid 508 mm diam.
Secondary Mirror	f/3 convex paraboloid 50 mm diam. mounted at zero-coma point for steering and focusing
Magnification	16
Exit-Beam Diameter	240 - 490 mm
Pointing Offset	9 arcsec
LGS-Elongation	1:1.2
Field-of-View for Beam Steering	50 arcsec
LGS Positioning Resolution	0.05 arcsec
Maximum Steering Frequency	30 Hz
Resolution in Focus Position	0.5 km
Diagnostics at Launch Telescope	
Translation Stage at Entrance	Power meter Beam profiler 2 Shear-Plates for wavefront-analysis 1 PSD + 1 laser diode for internal aligning
Exit	Polarization measurement device
System	
Total Throughput	60 - 75 %
Wave-Front Distortion at Focus	$\lambda/2$
Polarization	Circular
Aircraft Avoidance	
CCD-camera behind RC secondary, 20 deg F.O.V, 0.5 s on-chip integration, SGI Indy/AOA control system and software	

Table 2.3: Performance specifications of the ALFA laser beam projection system.

Optical heights above bench	
Dye Laser Output	185 mm
MC2/ESD	250 mm
Distances	
Dye Laser Output - S5	7500 mm
S5 - S4	14500 mm
S4 - MT1	2000 mm
MT1 - MT2	1500 mm
MT2 - MT3	500 mm
MT3 - MT4	2800 mm
MT4 - PM	2000 mm
Angles	
MT2 - S5, S5 - S4	54°at zenith
S5 - S4, S4 - MT1	73°

Table 2.4: Important geometrical values for the relay system.

can also be switched off remotely from any X11 based display (see ...). A foam extinguisher can be found beside the laser cabin entrance door.

The aircraft avoidance system is called **ALIENS**.This subsystem is decribed in detail in a separate document.

2.4 Electronics and Cabling

The complexity of several interacting realtime control loops and the large area over which the components are spreaded requires multiple control systems. Fig. 2.6 and 2.7 are showing the distribution of the control and data aquisition devices of the LGS system. There are four subsystems, each controlled by a computer which itself are communicating over ethernet:

1. The VME computer in the laser lab controls and monitors the pump and dye laser. It also controls parts of the lower beam relay.
2. For safety reasons ALIENS runs on a separate SGI Indy workstation (hostname: **aliens**) installed in the laser lab.
3. The VME computer installed in the rack mounted behind the horseshoe of the 3.5m telscope mounting controls the lower and upper beam relay and also distributes the video camera signals.
4. The VME computer installed the rack beside the launch telescope controls the lower and upper laser beam position measurement including cameras, the diagnostics tools and the launch telescope.

The specifications of the installed cables can be found in a separate document.

2.5 Software

The LGS control software is installed on a SUN SPARC4 workstation (hostname: **alfa-1**) located in the laser lab.

Most parts of the control software is written in C. Communiction between the subsystems is based on EPICS database records(db). Some device driver software is written in EPICS sequencer code (state notation language). Also parts of the graphical user interface(GUI) are written in EPICS display list(dl) code.

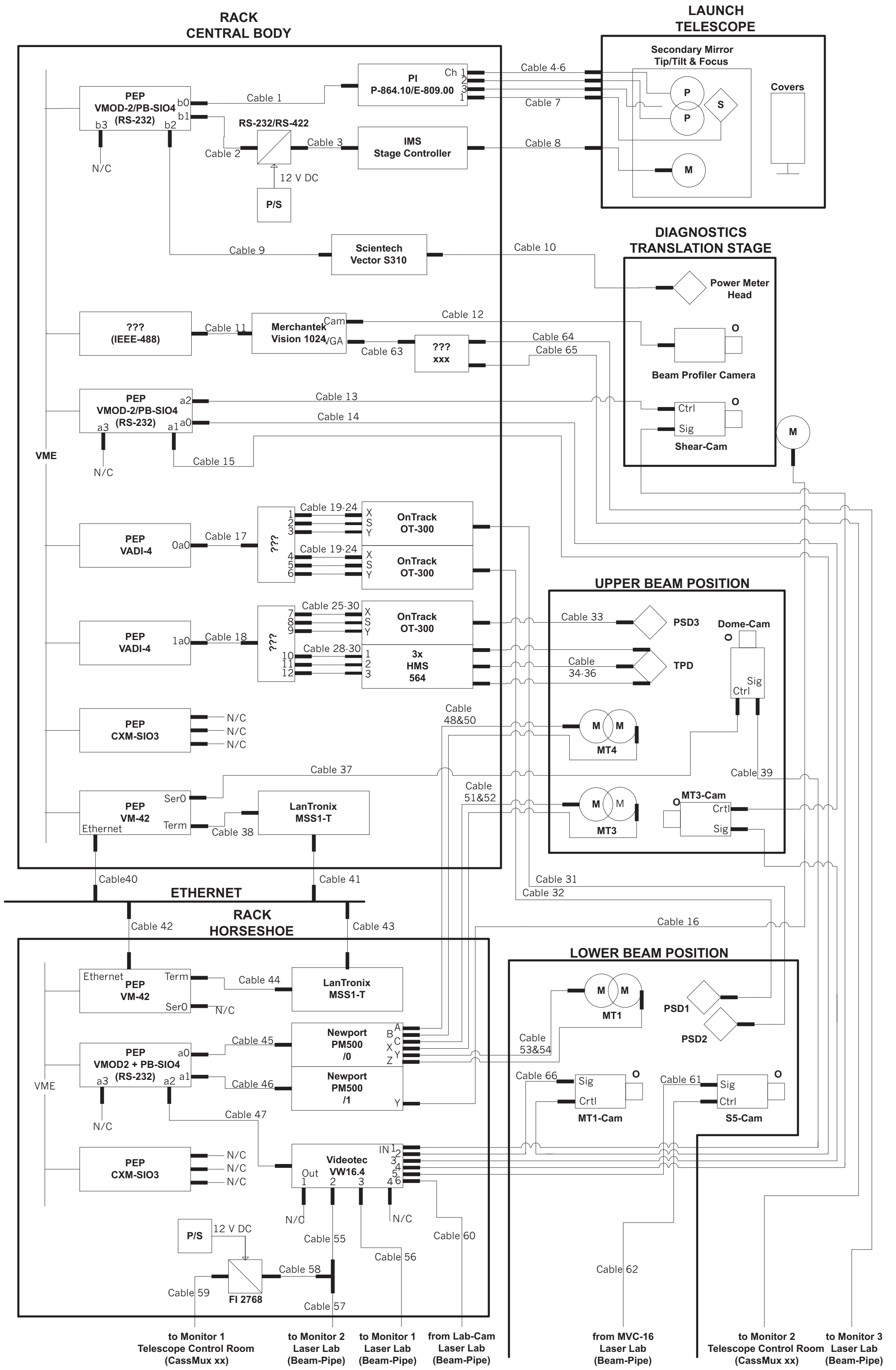

Figure 2.6: Electrical system block diagram for the on telescope components(except ALIENS).

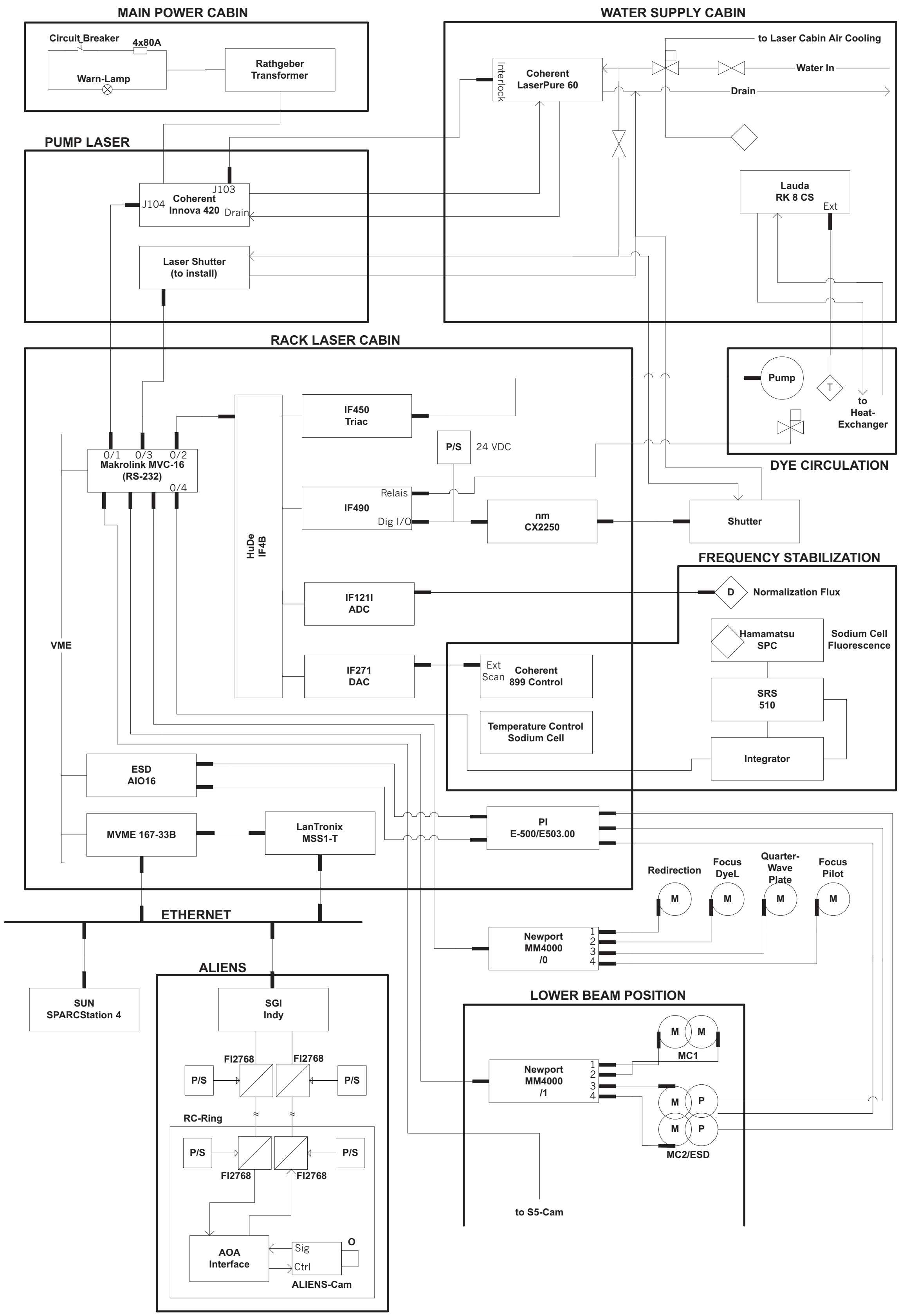

Figure 2.7: Electrical and supply system block diagram for the laser facility in the coude-lab and ALIENS.

The main GUI for normal LGS operation and test is based on the QT library. The individal GUI panels are explained in detail in the next chapter.

...

Chapter 3

Operating the LGS-System

Capital letters are indicating devices and device labels, respectively.

3.1 At the Beginning of an Observing Run

3.1.1 Preparations at the Telescope

- ...
- Switch on all components in both electronic racks.
- Verify that the position angle of the Cassegrain flange is 0.00 degrees.
  This ensures that the point at the sky where the launch telescope is aiming with the mirrors in their nominal positions coincidines with the center of the WFS field -of-view.
- Activate the S5 tracking mirror in the following order:

  1. Switch on the encoder lamps for S5 HOEHE(lower) and AZIMUT(middle) at the DB5-rack(3rd floor).
  2. Switch on STEUERUNG and LEISTUNG at the ES5-rack(2nd floor).
  3. With the main telescope in the OPERATOR mode enter at a TECS-terminal *RUN ALFA* and switch the ALFA-MODE *ON.*

  Note: The S5 drive (not the S5 tracking) is already switched on with the main telescope in the OPERATOR mode. So the telescope's HAUPTANTRIEBE might be switched off if a defined S5 position only corresponding to the zenith postion of the telescope is needed.
  Important: Currently a telescope interlock is active, which deactivates the S5 drives if the platform under the telescope is activated.
- Install the pipe section(laser baffle) between S5 and S4.
  Important: With the pipe section installed, the marked safety barrier near the platform has to be removed.
- ...

3.1.2 Preparations in the Coude-Lab and the Observer Room

- ...
- Switch on the coude-lab air cooling system in the 3.5m control room
  Important: With the airconditioning system switched off also the plant water in valve for the pump laser cooling closes.

- Switch on **alfa-1**, **aliens** and all rack components in the laser lab.
- ...
- Open the water in valve of the plant cooling water in the cooling water cabin.
- Check if there is enough water in the bath of the chiller for cooling the dye solution.
- Switch the laminar flow module above the dye laser head to TAG BETRIEB.
- With the help of the time counter ... check whether the dye solution has to be renewed.
- ...

3.2 Booting

Login to **aliens** as user
...

3.3 At the Beginning of an Observing Night

The startup of the laser system for the nightly routine operation requires about 45 minutes, stable environmental conditions provided.

3.3.1 Starting the Pump Laser

Before the dye laser can be started the pump laser has to be activated. A sufficiently stable pump laser operation requires about 30 minutes warm-up time.

- Close the circuit breaker in the main power cabin.
- Switch on the closed-loop heat exchanger.
- Open the water in valve for the dye laser shutter cooling.
- Switch on the power supply in the laser room.
- Place the beam stop in front of the pump laser output.
- Start the pump laser with the GUI ... or with the remote control modul and set the following operating parameters:
  27.0 W output power (i.e. pumping the dye laser with 25 W),
  MLVS (only multiline visible possible),
  58 A tube current (necessary for above output power),
  POWERTRACK ON.
  Current Regulation Mode, i.e. LIGHT REG (LED) off.

  With the pump laser in the POWERTRACK mode the alignment of the position of the output coupler is servo-controlled to give the maximum output power corresponding to a given tube current.
- Choose intracavity aperture size = 12 (i.e. 3.1 mm diameter) and open the manual shutter.
- Check whether the pump laser is operating in a gaussian TEM_{00} mode. The easist way to proove this is to observe the beam perpendicular to its direction.
- Check if all surfaces of the 2BS0 beamsampler are not contaminated and clean them if necessary according to the directions in section 'Cleaning the Laser Optics'.
- Check the alignment in the TUNE mode of the pump laser about 20 minutes after it has started and optimize the output power with the help of the cavity's high reflector.
- If the desired output power, assuming a given tube current and intracavity aperture, is not achieved, clean the Brewster window, the beamsplitter and the output coupler in the laser head, following the instructions in section 'Cleaning the Laser Optics'.
- Check the temperature of the cooling water. Typical values when running the laser with maximum tube current:
  Plant water in: 10 ^{o} C (raises during operation by about 2^o C)
  To pump laser: 25 ^{o} C,
  From pump laser: 45 ^{o} C,
  Plant water drain: 35^o C.

3.3.2 Starting the Dye Laser

When the pump laser is working stable at the desired parameters and with the dye solution sufficiently fresh, the dye laser can be started:

Preparations

- Switch on the chiller for the dye solution.

  Note: The chiller also cools the pump beam stop in the dye laser (for the transmitted pump light of the jet) and the electrical shutter.

- Switch on the dye laser control box and set
  OPERATING MODE = Zero Servo(i.e. all frequency servo-loops open),
  SCAN CONTROL = Manual.

- Switch on the heater for the sodium cell with the nominal temperature set to 100^o Celsius.

- Check that the switched-on dye laser shutter is closed.

- Remove the dye laser head cover and place it at a clean spot.

- Put the syringe protection above the jet house.

- Start the pump of the dye circulator.

- Open the valve to the jet nozzle and adjust the pressure to 11 bar.

  Important: Always open the valve to the nozzle after the pump as been switched on.

- Remove the syringe protection from the jet house and shove the beam stop out the pump laser beam.

  The dye laser should starting to lase now. If not, follow the instructions given in the section 'Troubleshooting'. Otherwise continue with the procedures decribed below.

Optimization of the Output Power

- Maximize the dye laser output by adjusting the following components in the dye laser head:

  - Pump mirror P1 (tip/tilt).
  - Ouput coupler M4 (tip/tilt).
  - BRF (rotation).
  - THIN ETALON tip (control box OFFSET knob).
  - Upper folding mirror M5 (tip/tilt).
  - Lower folding mirror M3 (tip/tilt).
  - Thick etalon (tip/tilt).
  - Thick etalon horizontal control.

  Repeat this sequence, until no further improvement in the output power can be achieved (2 - 4 iterations).

  Note: With the laser in LOCK operation mode, above alignments can be done most sensitivly.

- Adjust the focus position of P1. Make sure, that the pump focus in the jet always lies on the near side to P1, i.e. start the search for the best focus position with P1 first pulled back as far as possible.

  Note: This is important because when going through the focus the focused pump beam changes rapidly from a slight horizontal oriented oval shape to one that is slightly vertical oriented. If the pump focus is at the far side of jet (measured from P1) the beam is horizontaly elongated at the near side, causing excessive heating of the jet, possibly distorting the gaussian mode and making the laser highly unstable.

  After every adjustment of the P1 focus position it is recommended to align first the tip/tilt before the other components are adjusted again for optimum power.

- Adjust subsequently also the foci of M5 and M3. Whenever a new focus postion has been found, always adjust the tip/tilt position of the previously focused optics before that of the remaining components. This helps to converge faster in the power optimization process.

  Note: When adjusting the foci accept a lower output power in favour of a better mode quality (this power loss as compared to the maximum achievable output power can be as high as 20 %). This is especialy important for the focus position of P1 (see below).

- Check the alignment of the dye jet. For this remove both the jet cover with the neutral density glass and the magnet of the Faraday rotator (be cautious when laying it aside). The spots reflected from the both parallel jet surfaces over the open laid rhomb of the Faraday rotator should overlap to a stable interference pattern with parallel stripes.

  In the case of two seperated spots or of an inhomogenously interference pattern adjust the jet direction with the two hex head screws at the nozzle holder.

  To minimize the brightness of the interference pattern, rotate the nozzle slightly if necessary, until the jet is oriented at Brewster's angle relative to the cavity mode.

  Note: Since the jet is a polarizing element, this is also important in order to avoid an unwanted elliptical polarization of the cavity mode (with the pump beam verticaly linearly polarized the output of the dye laser should show the same polarization).

  After reinsertion of the removed parts optimize the output power as described before.

  Note: Die Lage der Farbstoffstrahlplatte relativ zum Pumplicht ist in Abb.? dargestellt. Breite des Jet (abzueglich Randwuelste) am Ort des Pumpfleckes 3 mm, d.h Abstand der Duesenstirnflaeche vom Pumpfleck etwa 6 mm. Abstand M1 - Pumpfleck = 82 mm.

- If the expected output power is not achieved yet, check with the help of the intensity of the straylight from every optical surface in the resonator their cleaness. At least at the beginning of an observing run a cleaning of the cavity optics and the beamsampler BS0 and BS1 might be necessary. For cleaning follow the instructions in section 'Cleaning the Laser Optics'.

  Note: If the Brewster plate was removed for easier cleaning then it might be necessary after reinsertion to slide it up or down in its holder to optimize the output power.

- The rms noise in the output power of the optimum aligned dye laser (regarding power, mode quality and linewidth) should be less than 3 % assuming a rms noise in pump power of less than 0.5 % (both measured with a bandwith between 10 Hz to 1 MHz). The peak-to-peak variations in output power (normaly an overall power drop) during an observing night is typicaly less than 5 % (if the peak-to-peak pump intensity noise is less than 1 %, which should be the case after a 30 minute warm up of the pump laser).

Optimization of the Cavity Mode

- The mode structure of the dye laser should be optimized to a gaussian TEM_{00} mode first after the output power has been optimized. If the laser is not operating near the maximum power this means in general that the laser is oscillating in a higher mode. To watch the mode structure the reflected light either from the astigmatic compensation rhomb on the clean box filter (for this the rhomb cover has to be removed) or from the beamsampler BS2 can be used.

- A deviation from the desired gaussian mode profile can have several reasons:

  - The pump laser is not working in the TEM_{00} mode.
  - The folding mirror FM0 is contaminated.
  - The cavity optics of the dye laser is contaminated.
  - The foci of the mirrors P1, M3 and M5 are not aligned correctly.

  Use the following directives to find the optimum resonator foci:

- After adjusting one focus optimize first the output power by adjusting tip and tilt of the same optic.
- If the mode has only one intensity peak, but is asymmetric in one direction, then P1 is too close to the jet.
- Moving P1 away from the jet elongates the mode verticaly.
- If the mode has only one intensity peak but a starlike shape then M3 or M5 is too far away from the jet.
- Moving the foci of M3 and M5 in direction of the jet(away from the jet) horizontaly(verticaly) elongates the mode, with the beam waist likewise increasing in the vertical(horizontal) direction.
- The waist of the output beam (or the beam diameter closely to the laser head output) should be about 0.7 mm (measured between the $1/e^2$ intensity points at the output coupler) with a full angle divergence of about 1.3 mrad.

Frequency Stabilization

In case of good alignment of the resonator optics, the reference cavity and of the BRF and the etalons the following steps should be sufficient to lock on the sodium line
In OPERATING MODE = Zero Servo flash the thin etalon (see below).
In OPERATING MODE = Free Run search for the fluorescence signal of the sodium D_2 line from the sodium cell with the help of the THIN ETALON OFFSET.
Set OPERATING MODE = Lock.
Maximize the flourescence signal with SCAN CONTROL.
Minimize the reference cavity error signal displayed at oscilloscope ♯ 1 with the BRF and the THIN ETALON OFFSET.
With SCAN CONTROL tune to the middle the most left (lowest frequency) lamb dip signal (see fig. 2.4) and close the long-term, absolute frequency stabilization control loop by setting LOCK = On on the D2 device.

Note: Due to a malfunction of the RING LASER CONTROL BOX motherboard TP1 (SIG) on the differential amplifier board 1A9 and TP9 (GND) on the low voltage regulation board 1A2 are connected with the oscilloscope ♯ 1 in order to display the reference cavity signal.

On oscilloscope ♯ 2 the error signal fed to the thick etalon is displayed.

In the following all steps for closing the frequency control loops are described in detail:

- Verify at the rear side of the RING LASER CONTROL BOX that the thick etalon control is switched on.
- Checking the adjustment of the thin etalon for the feed forward:

  Set the control box to
  OPERATING MODE = Zero Servo,
  THIN ETALON OFFSET = 0 (i.e. knob completely counterclockwise),
  SCAN CONTROL = Manual.

  Check, if the thin etalon position is at flash (see below). If not, adjust the thin etalon horizontal and vertical control by watching the position of the walk-off spots (see below).
- Coarse frequency tuning to the sodium line:

  Set the control box to
  OPERATING MODE = Free Run
  THIN ETALON OFFSET knob in mid-position (i.e. 1 turn away from flash position).

Check whether the micrometer-setting of the BRF is 0.4795 inch. The corresponding angle tunes the laser coarsly to the Na D_2 line at 589.2 nm. The wavelength-meter should display 589.2 ± 0.5 nm.

Maximize in an iteration the fluorescence signal in the sodium cell by adjusting the THIN ETALON OFFSET and the position of the brewster-plate with SCAN CONTROL. It might be necessary during this process to change the angle of the BRF by small amounts from the starting point.
Note: A change of the micrometer setting by 0.001 inch corresponds to a change in wavelength of 0.2 nm (or 200 GHz at 590 nm).
The precise BRF position can change with the resonator alignment. To check whether the desired sodium line has been found, remove both etalons in order to operate broadband and verify that the BRF setting for the two possible sodium cell signals is that for the lower wavelength signal.
If the D_2 line has been found, adjust the horizontal control of the thin etalon such that as little light as possible is reflected off the BRF and optimize the output power as described above.
If no fluorescence of the D_2 line can be detected a new coarse tuning of the BRF is necessary. For this set the control box to
OPERATING MODE = Zero Servo,
SCAN = Manual, CONTROL = mid-position,
THIN ETALON OFFSET = 0.
Now adjust the thick and thin etalon with the horizontal and vertical controls to the flash positions (see below) such that the BRF become the only frequency selective element with the laser operating broadband. This means that when tuning the BRF no periodic power modulations should appear.
Note: With the BRF tuned in single-mode operation, the tuning of the frequency will not be continuous, since both etalons and the brewster plate are not tracking the BRF-adjustment. Therefore frequency (and power) hops appear as new etalon modes come under the transmission maxima of the rotated BRF.
Now look for the sodium D_1 and D_2 fluorescence in the cell and maximize the D_2 emission with the BRF. After that turn the THIN ETALON OFFSET knob in mid-position and adjust the vertical control of the thin etalon such that as little light as possible is reflected off the BRF to the ceiling. Now walk-off the thick etalon (see below). Optimize the output power as described above.
Is it necessary to remove the ICA from the cavity for broadband searching of the respective BRF position for both sodium lines, the etalons may need a new fine alignment after reinsertion:

- Select Operating Mode ZERO SERVO.
- Adjust the horzontal and vertical control of the thick etalon such that both faint light spots, reflected off the BRF onto the ceiling (the so called walk-off spots) overlap exactly with the bright cavity reflections off the BRF on the ceiling. When this is the case, the thick etalon is perpendicular to the cavity mode (it is at 'flash') and due to the backreflection from the etalon surfaces a standing wave is building up in the resonator, i.e the laser is oscillating bidrectionaly and the output power should drop by a factor of 2. On the ceiling the etalon reflections should appear greenish.
- Center the ICA while maintaining the flash of the thick etalon. The ICA should be postioned relatively squared to the collimated beam.
- Maximize subsequently the output power by adjusting M3, M4 and M5. The output power should still be in the order of half the undirectional output.
- Now adjust the horizontal control of the thick etalon to maximize the output power (walk-off of the thick etalon). The tilt off normal incidence cause the multiply-reflected beams within the etalon to walk off tranversely. The thick etalon now acts in transmission as a frequency filter, supressing oscillation due to reflection from the etalon surfaces and output power should approximately double in value. The walk-off spots should then be approximately 3 cavity reflection diameters away from these reflections.

  - Rotate the THIN ETLON OFFSET knob completely counterclockwise and align the thin etalon position to flash, i.e. overlap the thin etalon walk-off spots (those which move when the THIN ETALON OFFSET is changed) with the bright cavity reflections by adjusting the horizontal and vertical control of the thin etalon. The output power should again be half.
  - Maximize subsequently the output power by adjusting M3, M4 and M5. The output power should still be in the order of half the undirectional output.
  - Turn the THIN ETLON OFFSET knob in mid-position and do a walk off for the thin etalon, i.e. adjust the thin etalon horizontal control such that as little light as possible is reflected off the BRF and maximize the output power as described above.

- Checking and adjusting the reference cavity, respectively:

  Connect the oscilloscope ♯1 with the control box according to
  channel 1 = HORIZ DISPLAY OUT,
  channel 2 = VERT DISPLAY OUT.
  Set the control box to
  DISPLAY = Reference Cavity
  OPERATING MODE = Zero Servo
  SCAN = INTERNAL(i.e. scan over 5 GHz), SPEED = 0.25 s.

  Set the oscilloscope ♯1 to
  X/Y,
  channel 1 = DC, 1 V / div.,
  channel 2 = GND, in the middle of the display.

  If the scan runs not from -5 V to +5 V calibrate this with the potentiometer above the HORIZ DISPLAY OUT connector at the control box.

  Set the oscilloscope ♯1 to
  X/Y,
  channel 1 = DC, 1 V / div.,
  channel 2 = DC, 2 V / div.

  The maxima and minima of the transmissivity ot the reference cavity should now be seen in form of 5 smooth bell-like curves with a FWHM of $\approx$ 1 div. (corresponding to 0.5 GHz) and a spacing of exactly 2 div. (or 1 GHz). The peaks of the cavity fringes should be of the same height and of constant amplitude (see fig. 3.1)

  Optimize the appereance of the fringes(number and spacing) by adjusting the thin etalon offset and potentiometer R7 on control box board **1A3**.

  If higher modes than the TEM_{00} mode are excited in the reference cavity, i.e. if there are side-maxima in the transmissivity, minimize them by adjusting the four hex-head screws supporting the reference cavity. When this is achieved, the reference cavity is exactly on-axis to the information beam. But this would be an unstable condition, manifesting itself in variations of the transmissivity, i.e. of the cavity fringe amplitudes, which has to be prevented by a slightly detuning of the reference cavity. Therefore: If the amplitude of the 5 cavity fringes is variing, adjust the small folding mirror at the entrance of the reference cavity in order to detune the reference cavity slightly until the fringes are showing a constant amplitude.

  Block the information beam to the reference cavity to measure the signal of the other information beam at the normalizing detector D2. The oscilloscope should display -5 V (the zero level of the frequency servo loop with the reference cavity). If not, check the adjustment of the normalizing information beam as desribed below. If both information beams are blocked the oscilloscope should display +2 V.

  Check whether the maxima of the transmission peaks are at +5 V, i.e. at the same distance from the lock point (i.e. ground level) as the zero level for the servo loop. If not, adjust the LEVEL SET potentiometer until this is the case. If the range of the potentiometer is not sufficient, turn the poti in its mid-position, change the attenuation of D2 and repeat the procedure.

Check whether the separation between two fringe peaks is equal to 2 div. (corresponding to 1 GHz spacing). If not, achieve this by adjusting the SCAN CAL potentiometer.

Fig. 3.1 summarizes the corresponding displays of the oscilloscope when scanning the reference cavity.

If above adjustments cannot be done the reference cavity and the information beams have to be newly coarsly aligned. For this change the control box setting to SCAN CONTROL = Manual.

Remove the detector block with D1 and D2. Check with the help of the mirror at the screen if an interference pattern can be seen in the cavity information beam projected onto the wall at a distance of some meters. If so, minimize the number interference stripes Are there instead 2 sharp spots with different brightness (i.e the transmitted cavity information beam and one backreflection from the etalon surface, adjust the support screws of the reference cavity until both spots overlap and minimize the number of interference stripes.

Are no spots visible, remove the reference cavity (for this the control box has to be switched off and the reference has to be disconnected from the cables) and adjust the cavity information beam as follows: Put a screen behind the entrance aperture plate for the reference cavity and hold a tissue into the beam in front of the small folding mirror. Center the beam with BS0 relative to the image of the entrance aperture. Now hold the tissue right after the entrance aperture plate of the cavity and watch the screen at 30 cm distance to the exit aperture plate. Adjust the small folding mirror such that the beam is centered relative to the image of the exit aperture. Repeat both steps, until the cavity information beam is centered on both the entrance and exit aperture. Do this procedure in an analogue way also for the information beam to detector D2. To make sure, that the tube baffle to this detector is not hit, check whether the spot at the screen is moving when the tube is rotated. Reinstall the detector block and start from the beginning of this subsection.

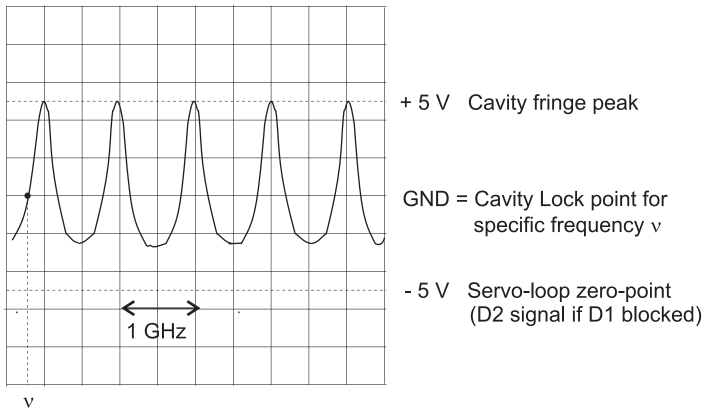

Figure 3.1: Display of oscilloscope #1 when scanning the reference cavity.

- Checking and adjusting the feed forward signal for the Brewster plate, respectively:

  Set the oscilloscope ♯1 to
  X/Y
  channel 1 = HORIZ DISPLAY OUT, DC, 1 V / div.,
  channel 2 = VERT DISPLAY OUT, DC, 2 V / div.
  Set the control box to:
  DISPLAY = Reference Cavity,

OPERATING MODE = Free Run,
SCAN = Internal, WIDTH = 29.99 GHz.

The displayed error signal should be a smooth flat or slightly curved line with spikes only at the start or the end of the scan.

If there are more spikes, minimize the number of zero crossings by adjusting the potentiometer on board **1A4**.

Note: If this is not possible, repeat the above check (and in an analog way the following checks) first for a reduced scan width and increase it in an iteration.

- Checking the feed forward with the thin etalon:

  Set the control box to:
  DISPLAY = Reference Cavity,
  OPERATING MODE = Lock,
  SCAN = Internal, WIDTH = 29.99 GHz.
  Set the oscilloscope ♯1 to
  X/Y,
  channel 1 = HORIZ DISPLAY OUT, 1 V / div., DC,
  channel 2 = VERT DISPLAY OUT, 2 V / div., DC.

  The displayed error signal should be a smooth flat line at 0 V. If not, adjust the THIN ETALON OFFSET to achieve this. If this is not sufficient, adjust the the potentiometer on board **1A5**, to flatten the error signal. If this is not possible, set the OPERATING MODE = Zero Servo and let all galvos relax. Now go back to OPERATING MODE = Lock and adjust again the potentiometer on board 1A5.

  When tipping the thin etalon there must be 3 - 5 'stable' THIN ETALON OFFSET positions (i.e with a flat error signal achievable. Use the 'stable' THIN ETALON OFFSET knob position which is nearest to the complete counterclockwise position.

  Note: In case of trouble when adjusting the electronics let the galvos first relax by switching to OPERATING MODE = ZERO SERVO for a few seconds before continouing.

- Adjusting the feed forward signal for the thick etalon:

  Set the control box to
  DISPLAY = Thick Etalon,
  OPERATING MODE = Lock,
  SCAN = Internal, WIDTH = 29.99 GHz.
  Set the oscilloscope ♯1 to
  X/Y,
  channel 1 = HORIZ DISPLAY OUT, 1 V / div., DC,
  channel 2 = VERT DISPLAY OUT, 2 V / div., DC.

  The displayed error signal should be a flat line, maybe slightly oval, but with the endpoints at the same level.

  If not, adjust the potentiometer R107 (foremost poti in this row) on board **1A1** and optimize the thick etalon walk-off.

  Note: The thick etalon error signal (for detecting mode hops) is always displayed at oscilloscope ♯2.

- Checking the power stability when scanning:

  Set the oscilloscope ♯1 to
  DC coupled, 1 ms / div., external trigger,
  channel 1 = HORIZ DISPLAY OUT, 1 V / div.,
  channel 2 = VERT DISPLAY OUT, 100 mV / div.
  Set the control box to
  DISPLAY = Laser Power or Reference Cavity,
  OPERATING MODE = Lock,
  SCAN = Internal, WIDTH = 29.99 GHz.

If there is a power modulation fine adjust the position of the thin etalon with the potentiometer R56 on board **1A5** to minimize them. Or rotate the ICA axialy, to achieve the best match of the polarization.

- Measure the peak-to-peak free run frequency jitter:

  Set the oscilloscope ♯1 to
  DC coupled, 5 ms / div.
  channel 1 = HORIZ DISPLAY OUT, 1 V / div.
  channel 2 = VERT DISPLAY OUT, 1 V / div.
  Set the control box to
  DISPLAY = Reference Cavity,
  OPERATING MODE = Free Run,
  SCAN = Manual.

  The jitter = peak-to-peak signal(V) x 32.7 MHz / V should have a value less than 20 MHz.

  See below how above value for the slope of the frequency sensitivity of the reference cavity in MHZ / V can be determined.

- Measure the rms lock jitter:

  Set the oscilloscope ♯1 to
  AC coupled, 5 ms / div.,
  channel 1 = HORIZ DISPLAY OUT, 1 V / div.,
  channel 2 = VERT DISPLAY OUT, 50 mV / div.
  Set the control box to
  DISPLAY = Reference Cavity,
  OPERATING MODE = Lock,
  SCAN = Manual.

  The jitter = peak-to-peak signal(V) / 2 x 0.707 x 32.7 MHz / V should have a value less than 1 MHz.

- Put the laser frequency with SCAN CONTROL on the of the both fluorescence dips in the sodium cell, which is at the lower frequency. Adjust the lock point in the middle of the dip.

  Note: If the flourescense signal in the cell becomes dimmer or even disappears when switching in single-mode operation from manual SCAN CONTROL to external, maximize the flourescence by adjusting the THIN ETALON OFFSET and the tip/tilt of the thick etalon.

- If during the the operation the displayed error signal at oscilloscope starts to fluctuate, first adjust the BRF, then the thin etalon.

3.3.3 Aligning the Beam Relay

- ...

- Check the illumination of the beam pre-expander (i.e. of the positive lens). The illumination should be only adjusted with the horizontal and vertical translation controls.

  Note: With the tip/tilt control of the beam pre-expander the exit beam position can be adjusted. With this one can compensate for small differences in the dye laser beam position due to temperature changes, different resonator alignment, etc.

- Check the collimation position of the negative lens corresponding to the choosen magnification of the pre-expander.

  Note: If the micrometer setting seems doubtfull check the collimation by putting an at least 2 inch flat mirror at the output of the pre-expander. Align the retro-reflected light such that it is passing through the shutter and minimize the size(s) of the projected spot(s) reflected off BS1 onto the wall with the micrometer.

- Move all mirrors into their nominal positions (see B.5).

- Finealign the collimated dye laser beam with MC1 and ESD onto the S5 and MT1 targets. For this use the marks on the monitor images of S5Cam and MT1Cam.
- Finealign the collimated dye laser beam onto the axis of the launch telescope with the help of MT3 and MT4 together with the signals from PSD3 and TPD. (see B.5).
- Check the illumination of the launch telescope at the dome.
- ...

3.4 Locking the AO System on the LGS

....

3.5 At the End of an Observing Night

The shutdown of the laser system at the end of an observing night last about 15 minutes.

- ...
- Place the beamstop in front of the pump laser output.
- Switch off the pump laser plasma tube and the power supply.
- Lower the pressure of the pumped dye solution by about 2 bar and close the valve to the nozzle.

  Important: Closing the valve must happen before switching off the pump. This ensures that the nozzle will always be filled with solution so that no dye can dry up in the nozzle channel.
- Switch off the dye circulation pump
- Switch off the heater of the sodium cell.
- With the dye laser not operating over longer periods (i.e. for more than several days), leave the control box on with the OPERATING MODE = Zero Servo.
- Switch off the chiller for the dye solution.
- Let the heat exchanger for the pump laser cooling water running for about 10 minutes after the laser has been switched off. This prevents excessive thermal stress to the plasma tube.
- Close the water-in valve for the dye laser shutter cooling.
- Open the circuit breaker in the main power cabin.
- ...
- Close the covers of the launch telescope.
- ...

3.6 At the End of an Observing Run

3.6.1 At the Telescope

- ...
- Switch off all components of both electronic racks.
- Deactivate the S5 to spare the encoder lamps (in opposite order to the activation procedure).
- Remove the pipe section (laser baffle) between S5 and S4 and reinstall the safety barrier.
- Put the dust caps on S5 and the window to the laser lab.
- ...

3.6.2 In the Coude-Lab

- ...
- Close the water-in valve of the plant water cooling.
- Switch the laminar flow module to NACHT BETRIEB.

  Note: The pre-filter of the clean-box has to be exchanged every 6 - 9 months, the main filter every 18 - 21 months.
- ...

3.7 Renewal of the Dye Solution

About every 1500 Watt hours (pump power times operating time of the dye laser) a complete renewal of the dye solution is necessary to prevent a significant output power drop or strong instabiltities in power and frequency. The procedure takes about one hour.

3.7.1 Preparations

- Start the pump laser.
- Switch on the cooling for the dye solution.
- Put the syringe protection over the dy jet house.
- For safety reasons put on rubber gloves and a coat and wear protection glasses.
- Presolve 0.90 g Rhodamin 6G in 40 ml reagent grade methanol with the help of the ultrasonic bath in the chemistry-room(coude-floor).

Keep further the following parts ready:

- A large tub for the old solution, a tub for depositing and a waste cub.
- Absorbant paper and a trash can.
- A Waste-canister with a funnel.
- A Filter-cartridge.
- 5,5 – 7,5 l water-free ethylene-glycole(EG) and a 3 l cup for filling.
- 100 ml reagent grade methanol.
- A stainless steel or glass rod for stirring.

3.7.2 Draining of the Old Solution

- Place the large tub under both drain taps of the dye circulator.
- Open both drain valves.
- Open the filter housing with a 30 mm wrench; use the 3 l waste cup as deposition for the cover of the filter-housing.
- Remove the filter pressing piece with the help of two M4 screws and deposit it together with the filter cartridge (dripping it off!) in the smaller tab.

  Check the filter.

3.7.3 Rinsing

First Rinsing

- Replace the old filter cartridge after every 3 – 4 dye changes.
- Close the complete filter housing and both drain valves.
- Fill the reservoir with 1.5 l EG.
  Note: Maximum input for the reservoir at one time is 1.5 l.
- Cover the input funnel of the reservoir and switch on the pump. Set the pressure to 11 bar.

- If a new filter cartridge has been inserted, let the pump circuit run for about 5 minutes with the nozzle valve closed and with varying pressure (4 – 11 bar) so that the filter can suck and air in the circuit can escape.
  Note: Avoid to let the pump running dry over a longer period (several minutes).
- Open the nozzle valve and raise the pressure again to 11 bar. Let the system run for about 5 minutes.
- Flush the content of the large tub into the waste canister.

Anew Rinsing

- Lower the pressure by 1 bar and close the valve to the nozzle.
- Switch off the pump.
- Open both drain valves and the filter housing, and drain the solution completely. Remove the filter pressing piece and lift the cartridge so that the solution can flow off faster. Clean the parts of the filter pressing piece, the seal grooves of the cap and the large o-ring. Moisten the o-ring with EG before re-inserting it.
- Close the complete filter housing and both drain valves.
- Fill the reservoir with 100 ml methanol and 1.5 l EG.
- Switch on the pump and set the pressure to 11 bar. After that momentary lower the pressure to 4 bar.
- Open the valve to the nozzle and raise the pressure again to 11 bar. Let the system run for about 5 minutes.
- Flush the content of the large tub into the waste canister.
- Depending on the clearness of the at last drained solution (check at nozzle input hose) a further rinsing might be necessary.

3.7.4 Filling In the New Dye Solution

- Close the valve to the nozzle (before lower the pressure by about 1 bar).
- Switch off the pump.
- Open both drain valves and the filter housing and drain off the whole solution.
- Close the complete filter housing and both drain taps.
- Refill the reservoir with 1.0 l EG.
- Switch on the pump, and raise the pressure to 11 bar. Subsequently lower the pressure temporary to 4 bar.
- Open the valve to the nozzle and raise the pressure again to 11 bar.
- Fill the 60 ml of the presolved Rh6G into the reservoir and stir it thorougly with the rod (for this lift the cap of the reservoir a few centimeters). Mix the fresh dye residue which remained in the cup with a few ml of methanol and fill it into the reservoir. Rinse the funnel with a few ml methanol the funnel of the reservoir and stir the reservoir again.
- Add 20 ml COT to the dye solution and stir the reservoir.
- Add the remaining 0.5 l EG to the reservoir in order to dissolve part of the dye that might have been remained sticking on the reservoir wall.

- Lower the pressure and close the valve to the nozzle.
- Remove with dust-free absorbant paper (and/or q-tips) dye residue from the nozzle housing and its cover and the abutting face of the nozzle. Place the syringe protection above the jet housing.
- Without optical pumping let the new dye solution circulate for about 20 minutes so that the solution can mix sufficiently.

3.7.5 Measuring the Absorption

- Above dye concentration (0.90 g Rh6G in 1.5 l EG) absorbs about 75 % of the pump light (optimum value); the pump light tranmitted is blocked by the water-cooled beam stop in the dye laser head.
- To check the absorption, place the calorimeter-type power probe between the jet housing and the pump beam stop in the resonator such that it touches no surface. Zero the display of the power meter and reset the stop watch.
- Open the pump laser beam and notice the displayed power value after 20 seconds measure time. Be careful that the pump beam entering the dye laser head does not hit the power probe on the back side.
- The variable (1 - measured transmitted pump power (W) / pump power (W) should have the value 0.25.

After finishing the dye change notice the number of working hours of the pump laser after the dye change to have a clue for the pump-age of the dye solution later.

3.8 Optics Cleaning

3.8.1 Resonator Optics

General

To clean optic elements in the laser resonator without removing it, use dust-free tissue, moisted with detergent and brought to the optic surface with the help of a crooked hemostat. Use reagent grade methanol as detergent, since then no impairment of the quality of the cleaning due to non-evaporating residues is to fear as it might be the case when using acetone as cleanser.
To protect both the optics and skin wear rubber gloves and proceed as follows:

- Fold a sheet of tissue in the height to a rectangular shape about 1 cm broad. Fold this stripe at a time twice in length and clamp and hold it with a curved hemostat beneath the fold line.
- Rip both overcoming ends of the tissue.
- Put some drops of methanol onto the fold spot.
- Wipe once across the optical surface with light pressure. Repeat this if necessary with a new tissue.
- Let the optic dry for a few seconds before exposing it to laser radiation.

Dye Laser Specials

- Be careful to clean only the central part of the BRF so that no detergent can come in contact with the cement between the three quartz plates.
- Wipe across the very thin quartz-plate in the optical diode with a significant lower pressure as in the case of other resonator optics.

Cleaning the Brewster Window of the Pump Laser

Only wipe from top to bottom, i.e in direction of the output coupler. Otherwise glass pieces can brake away from the sharp lower edge of the Brewster window, possibly scratching the window surface when wiping across it in the wrong direction.

If the dirt can not be removed with methanol the Brewster window has to be cleaned with ammonium-bifluoride (ABF).

This might be also an indication that the dust shield also has to be replaced.

Important: Direct skin contact with ABF can cause permanent damage to the bones and tooths.

Cleaning procedure with ABF:

- Put only some drops of ABF onto a 100 % cotton swab.
- Hold the cotton swab parallel to the opical table and clean the contaminated area of the window by moving the cotton swab with slight pressure in a circular manner.
  Important:
  - Do not bring the ABF in contact with the epoxy of the window.
  - Do not apply the ABF longer than about 30 s on the window; otherwise cristallization of the ABF can cause scratches on the optical surface with the consequence that the plasma tube has to be replaced.
- Remove the ABF with distilled water.
- Clean the window with methanol in the usual manner.

3.8.2 Beam Relay Optics

Beside the same procedure as described above the following method can be applied, especially when the optics to be cleaned has been removed:

- Remove dirt particles from the optical surface with the help of filtered cleaning gas.
- Moisten an (unfolded) tissue with some drops of methanol.
- Place the wet part of the tissue onto the optical surface and pull the tissue across the optic in one direction.

3.8.3 Futher Recommendations

- For large-size optics cotton swabs can be used instead of tissue. Use only 100 % natural cotton, since synthetic cotton can cause scratches on the surface or dissolve in alcoholes. Wipe across the optical surface gently in a figure-8 motion.
- Oil residues require a more extensive cleaning procedure, since trying to remove them with alcohole alone generally will only smear them on the optical surface. To avoid this lift the contamination first with a neutral soap (about 1 % in distilled water) from the surface. Subsequently rinse the prepared optical surface with distilled water. Finaly remove the water with methanol or isopropyl alcohol.
- MgF_2 antireflection-coated lenses are sensitive against soaps and acetone.
- Excessive cleaning shortens the lifetime of any optics.

3.9 Troubleshooting

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Appendix A

Basic Laser Alignment

A.1 The Pump Laser

For the internal aligning of the argon-ionlaser see *The Coherent Innova-400 Sealed Mirror Ion Laser Operator's Manual*.

A.2 The Dye Laser

The following procedures (see also *The Coherent 899-21 Dye Ring Laser Operator's Manual*) serve as a guide for troubleshooting if the dye laser fails to oscillate, if the nozzle has been removed or if the pump laser tube has been replaced.

A.2.1 Coarse Alignment of the Pump Beam and the Dye Jet Stream

1. Switch on the dye circulation system with a properly prepared dye solution as desribed in 3.3.2 and set the dye pump pressure to its nominal value. Align the jet with the two Allen screws of the jet pointing plate such that it enters the catcher tube horizontally in the middle and vertically in the upper third of the hose. This ensures that the pump beam will hit the flat surface area of the jet stream plate (see fig. A.1).
2. Switch on the pump laser as described in 3.3.1 and set the pump power to 50 mW. The pump beam has to be aligned such that it enters the dye resonator without any obstruction. Use tissue paper to center the pump light through the pump beam tube of the dye resonator. The position of the pump beam on P1 should be like it is shown in fig. A.1. This ensures maximum overlap of the pump focal area and the dye cavity mode at the place of the pumped jet stream.
3. Rotate the water-cooled pump beam stop away from the M3 aperture plate. Adjust the tip/tilt of P1 such that the pump beam hits the M3 aperture plate horizontally aligned with respect to M3 and vertically one pump spot diameter above M3 (see fig. A.1). Ensure that the pump beam is still centered on the dye jet stream as shown in fig. A.1.
4. Set the pump laser power to its nominal value. Pull the P1 focus as far away as possible from the dye jet. Move the P1 focus back into the direction of the jet until the transmitted pump spot on the M3 aperture plate starts to distort. Rotate the pump beam stop back in place.

A.2.2 Establishing Initial Oscillation

1. Hold a piece of paper in front of M5. Align the tip/tilt of M1 such that the flourescent spot from this mirror is centered horizontally and slightly above center vertically on M5 as it is shown in fig. A.1. This reflection from M1 will have a bite its upper part.

2. Place a piece of paper between the BRF and the optical diode and locate the fluorescent spots from M5 and M3. The spot from M5 is the larger one of the two. Adjust the M5 focus, so the spot from M5 is approximately 4 mm in diameter. Adjust also the M3 focus, so the spot from M3 is approximately 3 mm in diameter. As the paper is moved toward the dye jet the fluorescent spot should not change its diameter significantly to ensure a collimated beam.

3. Hold a piece of paper in front of M4. Adjust the tip/tilt of M5 and M3 such that the fluorescent spots from these mirrors are horizontally centered on the lower third vertically of M4 as it is shown in fig. A.1.

4. Hold a piece of paper in front of M5. Rock M4 vertically and look for a moving spot on M5. This reflection should have a diameter of less than 2 mm. If not, then P1 or M3 is improperly focused. Bring this spot with the tip/tilt adjustments of M4 into a vertical line just above the spot from M1.

5. If the laser flashes when rocking M4 vertically, adjust the M4 tip to achieve continuous operation and optimize the output power as described in 3.3.2.

6. If the laser fails to oscillate view the moving flourescent spots on the ceiling (reflected spots from the BRF at the right side of clean box filter) when rocking M4 vertically. The spot that moves with M4 should pass through the stationary right cavity reflection. If not, adjust the M4 tilt to achieve this. If the laser then flashes while rocking M4 vertically, adjust the M4 tip to achieve continuous operation and optimize the output power as described in 3.3.2.

7. If the laser still fails to oscillate watch for the appearance of a third dimmer spot as the flourescent spot from M4 passes through the staionary spot on the ceiling when rocking M4 vertically. Align the stationary spot, the second moving spot and the third dimmer spot with the help of M5 tip, M4 tip and P1 tip into one line. Rock M4 vertically and scan M5 tip until the laser flashes. Adjust the M4 tip to achieve continuous operation and optimize the output power as described in 3.3.2.

8. If the laser does not start oscillating, recheck the foci of M5 and M3

A.2.3 Fine Dye Jet Stream Alignment

- With the laser oscillating, remove the jet cover with the neutral density glass , the magnet of the Faraday rotator (be cautious when laying it aside) and the cover of the compensation rhomb. The spots reflected from the parallel jet surfaces over the open laid rhomb of the Faraday rotator should overlap to a stable interference pattern with parallel stripes.
- In the case of two seperated spots or of an inhomogenously interference pattern adjust the jet direction with the two Allen screws of the nozzle holder.
- To minimize the brightness of the interference pattern, rotate the nozzle slightly until the jet is oriented at Brewster's angle relative to the cavity mode.

Note: Since the jet is a polarizing element, this Brewster orientation is also important in order to avoid an unwanted elliptical polarization of the cavity mode (with the pump beam verticaly linearly polarized the output of the dye laser should show the same polarization).

- After reinsertion of the removed parts optimize the output power as described in 3.3.2

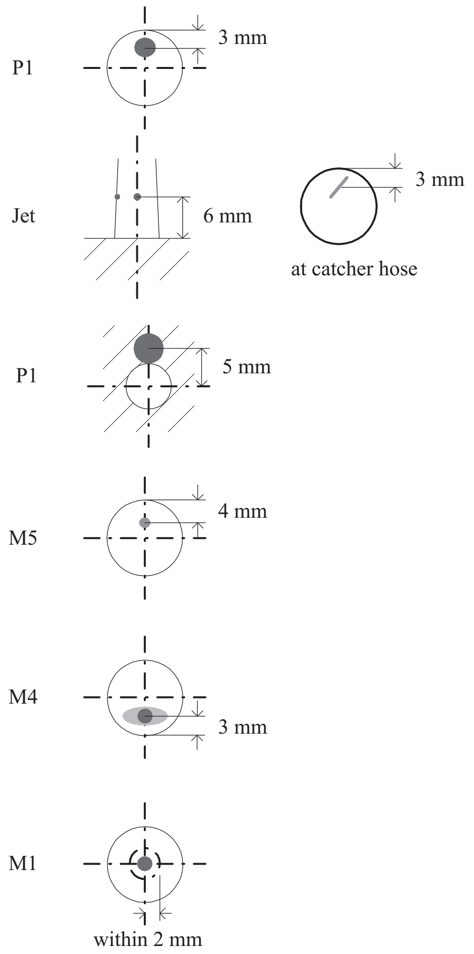

Figure A.1: Laser and fluorescent spots in the dye laser cavity.

Appendix B

Basic Alignment of the Beam Relay System and the Launch Telescope

Das Laserstrahltransportsystem hat die Aufgabe das Farbstofflaserlicht in jeder Teleskopposition auf der Achse des Projektionsteleskops zu halten. Das System basiert auf zwei geschlossenen Regelkreisen: einem, das den Laserstrahl der Teleskopbewegung nachfuehrt, und aus einem weiteren, das diesen Laserstrahl auf die Achse des Projektionsteleskopes legt.

Fuer den ersten Regelkreis werden Teleskopeinrichtungen verwendet, die urspruenglich fuer den Betrieb des Teleskops in der Coude-Konfiguration vorgesehen waren. In Coude-Konfiguration verfuegt das Teleskop ueber einen ortsfesten Fokus. Dieser wird beim CA 3.5m Teleskop dadurch erzeugt, das das Licht nach der Reflexion von Haupt(S1)- und Sekundaerspiegel(S2) mittels eines zusaetzlichen, auf der Deklinationsachse sitzenden Planspiegels(S3) auf dieselbe gelenkt wird. Von dort wird es ueber einen weiteren Planspiegel(S4) zu einem, vom eigentlichen Teleskop getrennt aufgestellten Planspiegel S5 geschickt. Dieser Spiegel sitzt in Verlaengerung der Stundenachse und wird der Teleskopbewegung nachgefuehrt, so dass dessen reflektiertes Licht auf einem ortsfesten Punkt im Coude-Labor faellt. Fuer das LLS-Sytem wird dieser Strahlengang in umgekehrter Richtung genutzt, wobei die Spiegel S5 (und dessen Regelung durch die Teleskopsteuerung) und S4 weiterhin verwendet werden.

B.1 Determination of the Coude-axis

Mit Coudestrahlengang ist in diesem Zusammenhang der Weg vom ML2 ueber den S5 und S4 zum MT1 gemeint. Die Achse S4 - MT1 ist dabei mit der Deklinationsachse der Teleskopmontierung identisch.

B.1.1 Definition of the axis S4 – MT1

Durch Schwenken des Teleskopes um die Deklinationsachse koennen mittels eines Hilfslasers die Durchstosspunkte der Achse auf den Spiegeln S4 und MT1 bestimmt werden.

- Montiere den Hilfslaser bei MT1 in der Naehe der Deklinationsachse, und richte in auf den S4.
- Schwenke das Teleskop um etwa 120 um die Deklinationsachse und notiere alle 20 Grad die Lage des Laserstrahls auf dem S4 (am Monitor einer auf den S4 gerichteten Kamera).
- Der Schwerpunkt der im Idealfall auf einer Kreisbahn verlaufenden Bewegung des Laserstrahls auf dem S4 markiert den einen Punkt der Deklinationsachse. Richtet man den Hilfslaser beim

MT1 auf diesen Punkt, so duerfte im Idealfall (d.h. keine Durchbiegungseffekte, kein Lagerspiel) beim Bewegen des Teleskops um die Deklinationsachse kein Wandern des Laserstrals auf dem S4 feststellbar sein.

- Bestimme analog wie oben den zweiten Punkt auf der Deklinationsachse beim MT1 und markiere ihn.

  Note: Als vorhandene Marken beim S4 gibt es sowohl einen gekennzeichneten 3 Zoll Gold-Spiegel, der mit einer Unterlegplatte und einem Reduzierring in die ebenfalls gekennzeichnete S4-Fassung eingebaut werden kann, als auch eine markierte Plexiglasplatte, die ohne Austausch der Spiegel auf den S4 gesteckt werden kann. Beim MT1 gibt es eine markierte Plexiglasplatte, die unmittelbar vor dem MT1 (d.h. in Richtung S4) an das Breadboard geschraubt werden kann.

B.1.2 Definition of the axis S4 – S5

Diese Achse liegt auf einem Kegelmantel um die Stundenachse, mit dessen Spitze auf dem S5 und einem Oeffnungswinkel gegeben durch den Abstand des S4 von der Stundenachse. Analog wie bei 1. wird die Lage der Spitze des Kegelmantels auf dem S5 bestimmt, d.h.

- Montiere den Hilfslaser zwischen S5 und S4 in der Naehe des S4, und richte ihn durch das Strahlrohr auf den S5.
- Schwenke das Teleskop um etwa 10 Winkelstunden um die Stundenachse und markiere alle 2 Winkelstunden die Lage des Laserstrahls auf dem S5.
- Der Schwerpunkt der im Idealfall auf einer Kreisbahn verlaufenden Bewegung des Laserstrahls auf dem S5 markiert die gesuchte Kegelspitze. Richtet man den Hilfslaser beim S4 auf diesen Punkt, so duerfte im Idealfall beim Bewegen des Teleskops um die Stundenachse kein Wandern des Laserstrals auf dem S5 feststellbar sein.

  Bem.: Als vorhandene Marken beim S5 gibt es sowohl einen gekennzeichneten 3 Zoll Gold-Spiegel, der mit einer Unterlegplatte und einem Reduzierring in die ebenfalls gekennzeichnete S5-Fassung eingebaut werden kann, als auch eine markierte Plexiglasplatte, die ohne Austausch der Spiegel auf den S5 gesteckt werden kann.

B.1.3 Pointing Model for the S5

Durch Fehler in der Bestimmung der Coude-Achse, etwa durch Durchbiegungen des Teleskops beim Schwenken verursacht, ist ein Strahlwandern eines auf die Coude-Achse ausgerichteten Laserstrahls am Ende des Coude-Strahlengangs nicht zu vermeiden, wenn bei der Nachfuehrung des S5 nur die Himmelsdrehung und keine Korrekturglieder hoeherer Ordnung fuer die Positionierung beruecksichtigt werden. Um ein (hysteresefreies) Strahlwandern auf der Coude-Achse zu minimieren, muss deshalb ein Pointing-Modell fuer den S5 auf folgende Weise erstellt werden:

- Aktiviere den S5 und setze alle Korrekturglieder des S5-Pointing hoeher als 1. Ordnung auf Null.
- Fokussiere einen Laserstrahl auf der Coude-Achse auf eine Flaeche unmittelbar vor dem MT1.
- Richte eine Kamera, die am Zentralkoerper befestigt ist, auf den MT1; d.h. diese Kamera darf sich beim Schwenken des Teleskopes um die Deklinationsachse nicht relativ zur Zielflaeche am MT1 bewegen.
- Markiere die zur Parkposition des Teleskops gehoerende Position des Laserflecks am MT1 auf dem zugehoerigen Kamera-Monitor.
- Fahre nun etwa 100 verschiedene Teleskoppositionen an, die moeglichst gleichmaessig ueber den gesamten Schwenkbereich des Teleskops verteilt sein sollten.

- Veraendere fuer jede von der Parkposition abweichende Teleskopstellung mit Hilfe des TECS-Programms SP5MOD den Nullpunkt der S5-Stellung derart, dass der Laserfleck immer auf die zur Parkposition gehoerenden Marke am MT1 trifft.
- Aus diesen, zu einer bestimmten Teleskopposition gehoerenden, S5 Offset-Korrekturen in Hoehe und Azimut lassen sich die Werte fuer die neuen Korrekturglieder der S5-Nachfuehrung folgendermassen bestimmen:
- /afs/mpa-garching.mpg.de/home/hacki/data/CALAR ALTO/S5

B.2 Alignment of the Optical Axis of the Launch Telescope with Respect to the Optical Axis of the Main Telescope

- The platform on which the launch telescope is mounted can be adjusted in two orthognal axis with the help of push and pull screws such that the LGS is in the field of view of the WFS. For this a coarse alignment of the beam fed into the launch telescope is sufficien: simply check the illumination of the launch telescope with the dye laser beam projected onto the dome.
- Use the TVG-Overlay ...
- ...

With the launch telescope platform aligned, the correct beam feeding into the launch telscope can now be adjusted.

B.3 Calibration of PSD3, PSD4 and PD1–3 at the Launch Telescope

- Replace the secondary mirror unit with a pinhole.
- Point the alignment laser on the diagnostics breadboard through an attached pinhole at the primary central mirror hole onto the pinhole mounted at the secondary mirror support struds. **Note:** The axis of the secondary mirror support is adjusted in the lab onto the optical axis of the primary mirror
- Replace the secondary pinhole with PSD4 and measure the beam position.
  Note: This measured position helps if the secondary mirror until has to be reinstalled.
- Also measure the beam position with PSD3 and PD1–3. Now the axis of the launch telescope is defined by these four values.

B.4 Alignment of the secondary mirror unit

This can be done either with the help of the argon-ion laser beam or with the alignment laser at the diagnostic board (preferred). Each laser has to be aligned onto the axis of the launch telescope before (either with the help of the pinholes or the adjusted alignment detectors, see above).

- Center the secondary mirror unit onto the alignment beam. For this use the marked mirror cap. Check the centration for the extreme secondary mirror focus positions.
- To adjust the tilt put a flat secondary mirror into autocollimation. This has to be done with zero voltage applied to the piezo platform. Check the tilt again for various focus positions.
- With the convex secondary mirror installed check for a symmetric projection of the launch telescope output on the dome.

Repeat above steps in an iteration, until the LGS is at the desired position in the field-of-view of the TV-guider with the laser beam on the axis of the launch telescope.

B.5 Alignment of the Beam Relay System

The beam relay system can be split into two subsystems ...

B.5.1 Calibration of MC1, MC2/ESD and S5

- Check the alignment of the dye laser beam pre-expander as described in .
- Align the collimated dye laser beam with the help of MC1, MC2/ESD and S5 onto the targets at S5 and MT1. The corresponding MC1, MC2, ESD and S5 positions are now the nominal positions of these mirrors.

B.5.2 Calibration of MT3 and MT4

- Align MT1 such, that the dye laser beam hit MT2 centered. Align MT2 such that MT3 is hit in its center. The corresponding MT1 position is now its nominal position.
- Align the collimated dye laser beam with MT3 and MT4 onto PSD3 and PD1–3 such that the signals are the same as taken with the alignment laser on the diagnostics breadboard.

B.5.3 Collinear Alignment of Argon-Ion Pilot Beam and the Dye Laser Beam

- Move all mirrors into their nominal positions.
- Do a coarse alignment of the argon-ion pilot laser beam by aligning it onto the S5 and MT1 targets. This has to be done with the pilot-laser-beam folding mirrors before BS2 and/or BS2.
- Find the best focus of the pilot-laser beam on PSD1 and PSD2 by minimizing the PSD noise.
- Fine align the argon-ion pilot laser beam with the mirrors before BS2 and/or BS2 onto PSD1 and PSD2.
- Check the illumination of the launch telescope with the pump laser.

Appendix C

Software Subsystem

C.1 Directory Structure

C.2 Configuration

C.3 Startup Scripts

Appendix D

Parts

In the following the manufacturers (first name is distributor) of main parts of the LGSS are listed with the parts grouped related to the individual system components.

For modified components not listed here or custom parts see technical drawings DSAZ xxx, MPE 502_0100_3 – 502_1099_3, 502_1100_4 and 502 ALFA Launch Telescope.

D.1 Laser

D.1.1 Pump Laser

- Coherent Innova 420

Electricity and Cooling

- Transformer:
  Rathgeber DFB612.5/IN
- Heat Exchanger:
  Coherent LaserPure 60

Optics, Opto-Mechanics and Opto-Electronics

- 2BS0:
  Laser Components BBAR/BBAR355-532/45 PW1025C (first, in direction of beam) Laser Components BBAR355-532/45 PW1025C
- FM0:
  Newport 10Z40DM.

D.1.2 Dye Laser

- Modified Coherent 899-21

Optics, Opto-Electronics, Opto-Mechanics and Electro-Mechanics

- P1:
  Laser Components HR488-515 PLCC-10.0/64.4C
- M4:
  Laser Components PR590/90/AR PW1006OC10

- BS0:
  Laser Components PW1025UV
- BS1:
  Melles Griot 08BSQ003/618
- NDF1:
  Melles Griot
- WM:
  Coherent: APE Wavelength Meter λ 500
- NDF2:
  Melles Griot
- NDF3:
  Melles Griot
- D3:
  Hamamatsu
- W0:
  Melles Griot
- PMT:
  Hamamatsu PMT Module HC135-01
- Cell Heating Wires:
  Roth C998.1
- Cell Temperature Controller:
  Modified Roth: Horst HT30
- Cell Isolation:
  Kager ACE-1210
- Galvatron P/S:
  F.u.G. MCN 140-1250 PM: Coherent LM-10 w/ Analog Ouput Module
- Lock-In Amplifier/Oscillator:
  SRS 510
- Preamplifier:
  HMS 564
- Photodiodes:
  Hamamatsu ...

Dye Circulation System

- Dye:
- Solvents:
- Additives:
- Pump head:
  Scherzinger 92503ZK
- Filter:
  Memtec Filterlite DFN 0.2-4A
- O-rings:

- Fittings:
- Hoses:
- Pneumatic Valve:
  Swagelock MS-INS-40-ACT
- Chiller:
  Lauda RK 8 CS

D.1.3 Environment

- Optical Bench
  Newport ...
- Table Frame:
  FMS MGE
- Laminar Flow Module:
  Froebel Labortechnik Modul Fed.Std 209b, Kl 100

D.2 Beam Relay

D.2.1 Optics, Opto-Electronics, Optomechanics and Electromechanics

- FM1:
  Newport 10Z40BD.1
- Shutter:
  Optilas: nmLaser Programmable Laser Shutter LS200F w/ Controller CX2250λ
- /4-Plate:
  Newport M-URM80ACCHL Spindler & Hoyer 033891/ARSD
  Newport Motion Controller/Driver MM4005
- Beam Pre-Expander:
  Melles Griot 01LLD003/078 (17x),
  Newport SBC010AR.14 (25x),
  Melles Griot 01LLD003/078 (31x),
  Newport KBC013AR.14 (40x),
  Melles Griot 01LLD001/078 (50x),
  Spindler & Hoyer 032558
- M1P, M2P:
  Melles Griot 02MFG015
- M3P, M4P:
  Melles Griot 02MFG021
- WP:
  Laser Components BBAR/BBAR 355-532/45 PW3050C
- Beam-Expander Pumplaser Pilot-Beam:
  Melles Griot 01LLK003/078
  Spindler & Hoyer 032558
- BS2:
  old: Laser Components BBAR400-700/45 PW4050C
  has to be installed: Laser Components BBAR400-700/45 PW4037C

- MC1:
  Modified Newport SL8ABM
  Newport 30Z40BD.1
  Newport Actuators 850F-HS
  Newport Motion Controller/Driver MM4005
- MC2:
  Modified Newport SL8ABM
  Newport 30Z40BD.1
  Newport Actuators 850F-HS
  Newport Motion Controller/Driver MM4005
  PI S-330.10
  PI E-500 w/ E503.00 LVPZT Amplifier Module
- S5 window backup (has to ordered):
  Laser Components BBAR/BBAR400-700/0 PW3037C
- S5 and S4:
  Newport 40Z20BD.1
- MT1:
  Modified Newport SL101.6BM
  Laser Components HR590/0-45 PS4050C (has to be replaced against Newport 40Z40BD.1)
  2 Newport Actuator PM500-1A.100
- MT3 and MT4:
  like MT1
- PM500 Driver:
  Newport PM500-C
- BS3:
  Modified Newport SL8ABM
  old: Laser Components BBAR400-700/45 PW4050C
  has to be installed: Laser Components BBAR400-700/45 PW4037C
- PSD1 – 3:
  Laser Components: SiTek Two Dimensional PSD 2L20SP w/o window
- Position Sensing Amplifier:
  Laser Components: On-Track OT-300
- Filter PSD1/2:
  Spindler & Hoyer 371117
- Filter PSD3/4:
  Schott RG610 Laser Diodes:
  Coherent: Applied Laser Systems MircoBlaze VMB 2-1L w/ Power Supply
- BS4:
  Laser Components ...

D.2.2 Video

- S5:
  Erdkreis Video: Sony B/W Video Camera SPT-M308CE 1/3"ITCCD w/ Computar Auto Iris Vari-Focal Lens TG2Z3514FCS F1.4/3.5-8.0mm
- MT1:
  DBS: CV-M10RS w/ Tevidon 2.8/70

- MT3:
  DBS: CV-M10RS w/ B2514D

- LaunchTel:
  DBS: CV-M10RS w/ H2Z4515CS 1.5/4.5-10mm C-mount

- Dome:
  DBS: Chugai Boykei Colour Video Camera CD-14

- Video Fiber Optic Links:
  FOIC: Force Incorporated model 2768

D.3 Launch Telescope and Diagnostics-Board

- PM Substrate:
  A.P.M. Ludes: Aries

- PM Ag Coating:
  POG Ag+S6B/mod

- SM Substrate:
  A.P.M. Ludes: Aries

- SM Dielectric Coating:
  Tafelmeier

- SM Focus Stage:
  Modified MICOS MP-40

- SM Focus Driver:
  Schenkel: Servo Control Tech.: IMS IM483IE

- SM T/T Stage :
  PI S-330.10

- SM T/T Controller:
  PI P846.10 + E809.00 + E-255.60 + E509.S3

- Translation Stage:
  Newport M-PM500-6L.100

- TPD/POL Preamplifier:
  Femto Messtechnik LCA-S
  HMS 564

- POL $\lambda/4$ Plate:
  Melles Griot 01F/WRQ003DH

- POL Polarizing Cube Beamsplitter:
  Melles Griot 03PBB009

- PM:
  Laser2000:Scientech Vector S310

- BP:
  Laser2000:Merchantek Vision 1024

- VGA Distributor:
  Buerklin 12M580

D.4 Computer, Data Aquisition and Remote Control Electronics

D.4.1 UNIX

- alfa-1:
  Sun Sparcstation 4 w/
  VigraPix SBus Video Digitizer
  Spectroscania

D.4.2 VME

- LaserLab:
  EBV: MVME 167-33B w/
  EBV: Transition Modul MVME 712M
  FPS: Makrolink 16-Line Asynchronous Communications Multiplexer MVC-16
  ESD AIO16
  EBV: XYCOM Fast Analog Input Module XVME-566
  AMD System Timing Controller Am9513A

- Horseshoe:
  PEP ASM3-VME w/ (68040, 2x RS232, Ethernet) VM42
  (Ethernet 10Base5) SI-10B5
  (2x RS232 fast, 1x RS422 fast) CXM-SIO3-4
  (12 Bit ADC, 16x $\pm$ 10V) VADI-4 w/ VADI-PB5
  (16 Bit ADC, 8x $\pm$ 10V) VADI-3 w/ PB-VOL

- LaunchTel:
  PEP (68040, 2x RS232, RTC, CXC) ASM3-VME w/
  (68040, 2x RS232, Ethernet) VM42
  (Ethernet 10Base5) SI-10B5
  (2x RS232 fast) CXM-SIO3-4
  (4x RS232, 4x R232) FP-SIO4 w/ VMOD-2 + PB-SIO4
  (10x Din, 10x Dout) VMOD-2D w/ PB-DIO
  (12 Bit ADC, 16x $\pm$ 10V) VADI-4 w/ VADI-PB5
  (16 Bit ADC, 8x $\pm$ 10V) VADI-3 w/ PB-VOL
  OR Industrial Computers IEC Bus Controller VIEC10, V2.x

D.4.3 Data Aquisition and Remote Control

- LaserLab:
  HuDe Interfacer IF4B w/
  16 Bit, 8 Ch. ADC IF121
  16 Bit, 2 Ch. DAC IF271
  Dig I/O, Relais IF490
  Triac IF450

- LaunchTel(Backup):
  HuDe Interfacer IF4Z w/
  12 Bit ADC IF110

D.4.4 Video

- Video Matrix LaserLab and Horseshoe:
  Erdkreis Video: Videotec SW16/4 OSM

- Monitor LaserLab and TelControlRoom:
  Erdkreis Video: Sony B/W Monitor SSM-930CE
- VGA Monitor LaserLab and TelControlRoom
  ...

D.4.5 Communication and Network

- OptoBridge:
  RS Components: Secomp 12.03.8507
- LaserLab Micro Serial Server:
  Lantronix MSS1-T
- LaunchTel Micro Serial Server:
  Lantronix MSS1-T
- Horseshoe Micro Serial Server:
  Lantronix MSS1
- Lantronix Mini 10Base-T Repeater LMR8TA

D.5 ALIENS

- Camera:
  Pulnix Progressive Scan TM-9701 w /Cosmicar/Pentax TV Lens 25 mm, 1:1.4
- Video Fiber Optic Links:
  FOIC: Force Incorporated model 2768
- Workstation:
  Silicon Graphics Indy R5000SC
- Fiber Converter:
  RS Components 19.2 Kbps Asynchronous Fibre Line Driver 837-363

D.6 Lab Utilities

D.6.1 Dye Preparation

- Precision Electronic Balance:
  Roth: Kern 4440
- Ultrasonic Bath:
  Roth: Elma T 310 H

D.6.2 Optics Cleaning

Appendix E

Logs

The following logsheets can be found in ... on ...

E.1 Laser

Date, Time
Ar+:
P (W)
I (A)
V (V)
t (h)
Ap. $\sharp$
Mode
DyeL:
Solv.
Add.
Abs.
Pumphours
$T(^oC)$
p (bar)
P(W)
Notes

E.2 LGSS

Date, Time
Filename
P_{out} (W)
$\Delta\nu$ (MHz)
Sys. Transm.
Pol.
Seiing
Tel. height
Tel. Focus
TVG Focus
TVG Gain
WFS:
RLM
FSM
Frame rate

Subarray
Pixelscale
Astrocam:
Focus
Pixelscale
Binning
Filter
t_{int}
Notes