New Spectrographs for precise RV

(An ESO-centric view)

Luca Pasquini

ESO

Outline

- Old but good:
  - HARPS + LFC
  - CRIRES Upgrade
- ESPRESSO
- E-ELT HIRES
- Another reason to go faint
  - Planets in Open clusters: the case of M67

HARPS: stability at 1 m/s

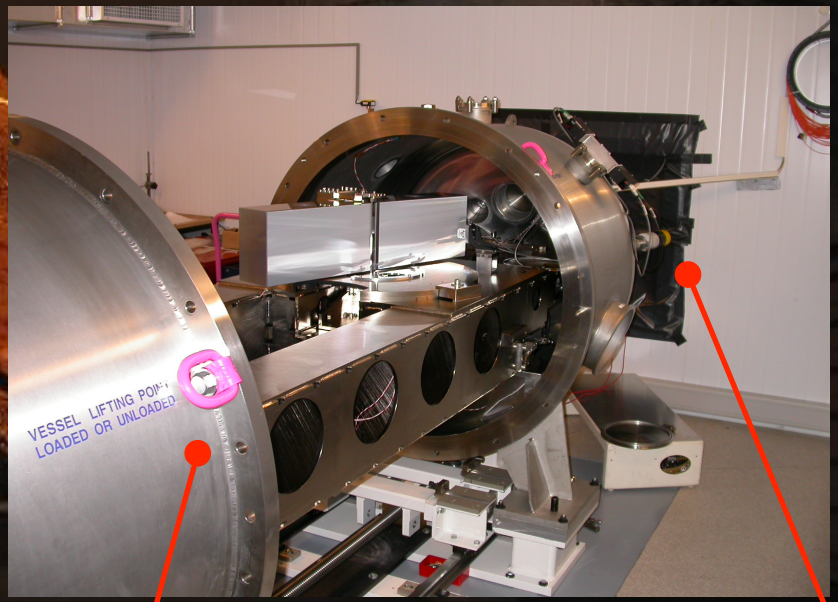
- Observatoire de Genève
- Physikalisches Institut, Bern
- Observatoire Haute-Provence
- Service d' Aéronomie, Paris
- ESO

ΔRV =1 m/s

Δλ=0.00001 A

15 nm

1/1000 pixel



thorium calibration

2-fiber fed

ΔRV =1 m/s

ΔT =0.01 K

Δp=0.01 mBar

Pressure controlled

Temperature controlled

HARPS ERRORS

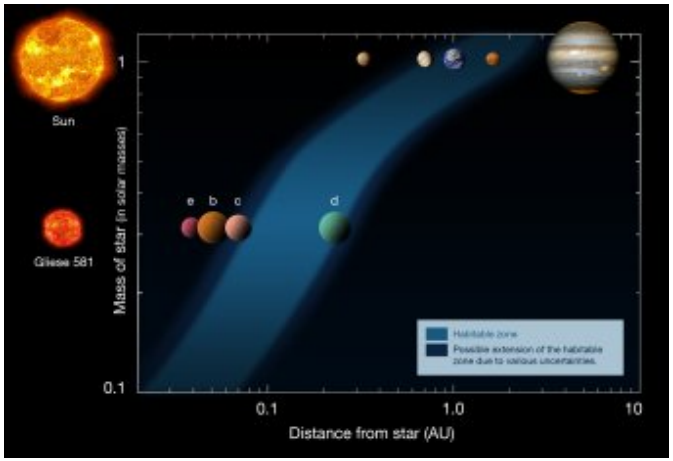
✧ Wavelength calibration ThAr:		30cm/s	<10cm/s
✧ Guiding	old *:	30cm/s	≤ 15cm/s
✧ Photon noise			
✧ Other sources (estimated)		≤ 15cm/s	≤ 15cm/s

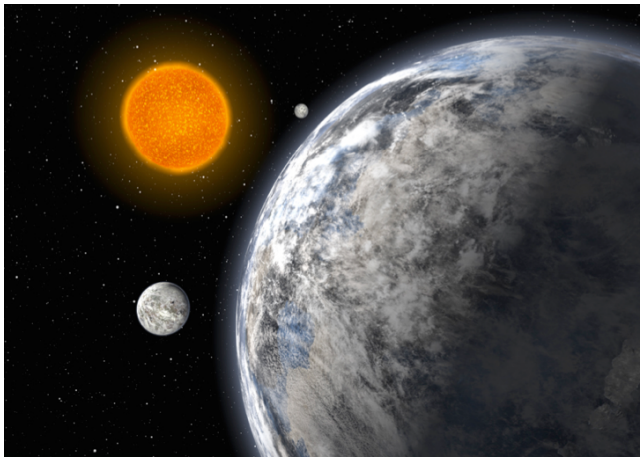
* Faster and more accurate guiding system implemented, contribution to the RV error budget estimated in ≤ 15cm/s **(TBC)**

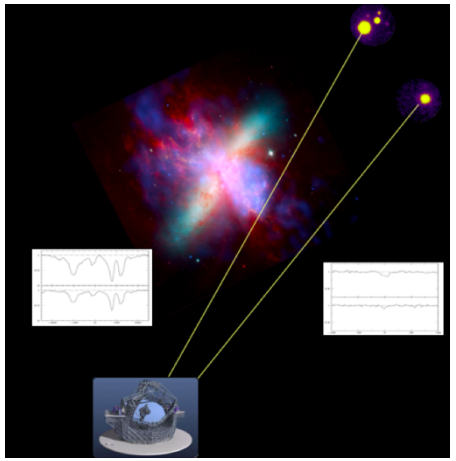
LFC as calibrator

Laser Frequency Combs is the ideal spectrograph calibrator:

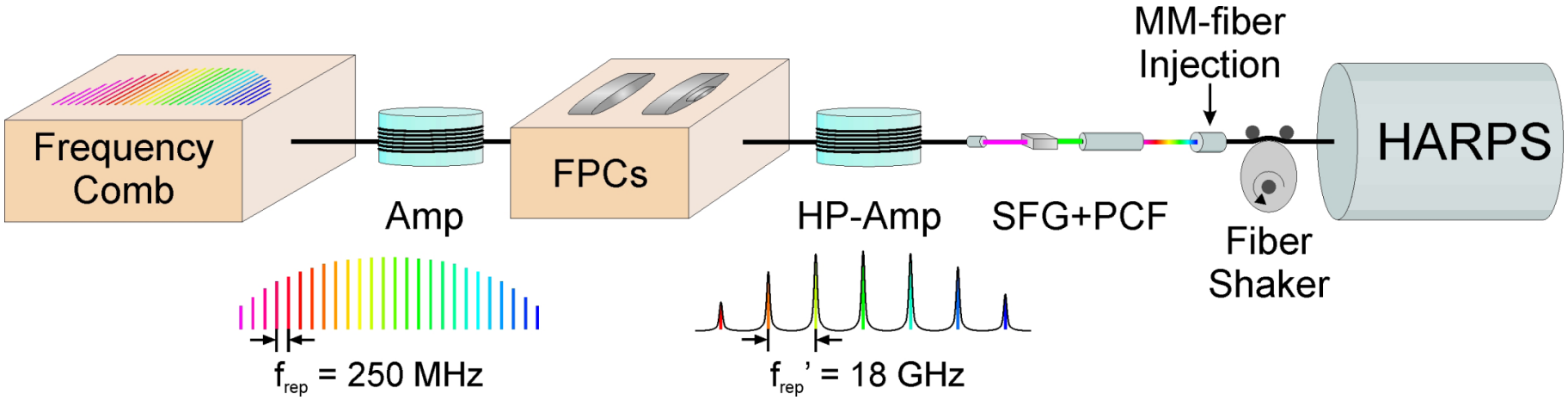
- Provides millions of perfectly equidistant lines (in frequency)
- Lines frequency is known a priori
- Covers a large wavelength domain
- Stabilized at the 10^{-11} to 10^{-16} level
- The absolute reference linked to an atomic clock

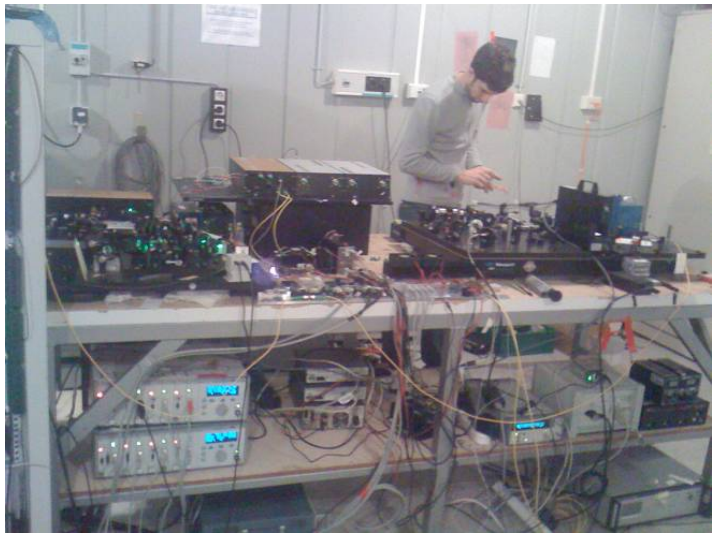


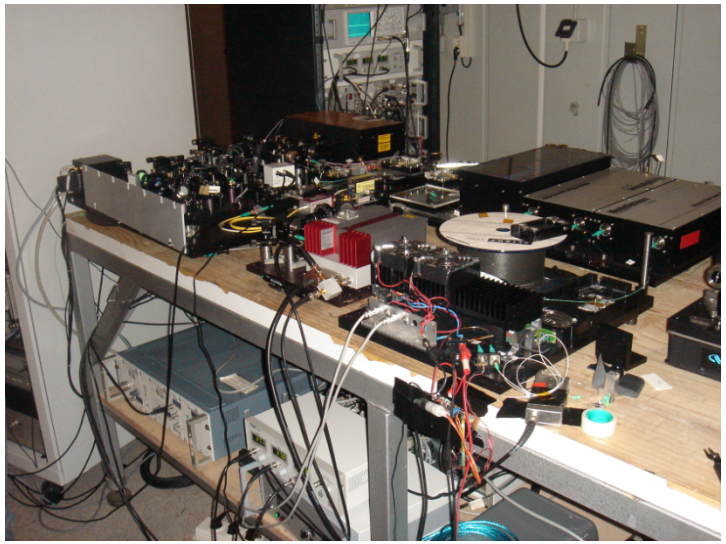




System design

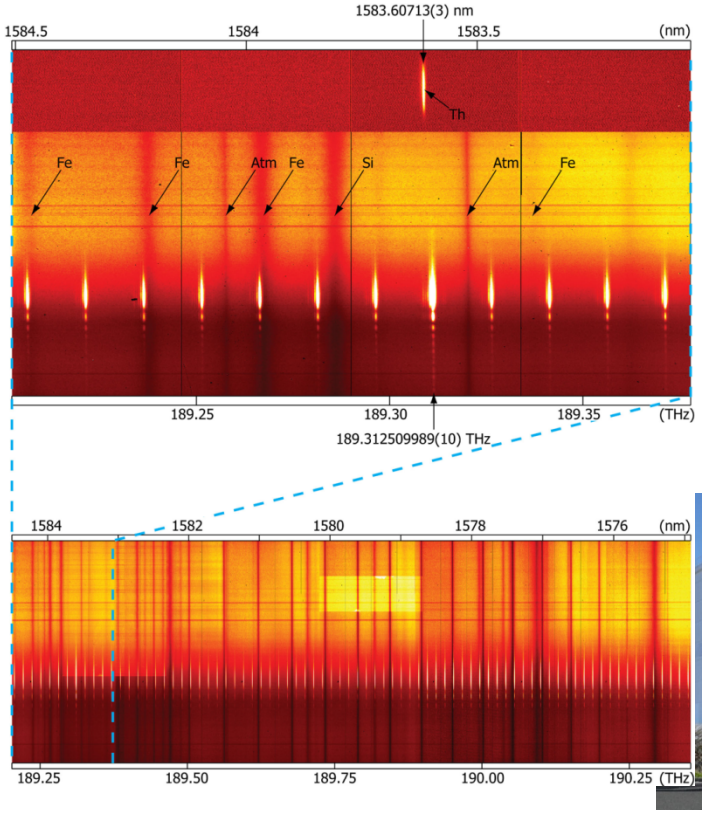


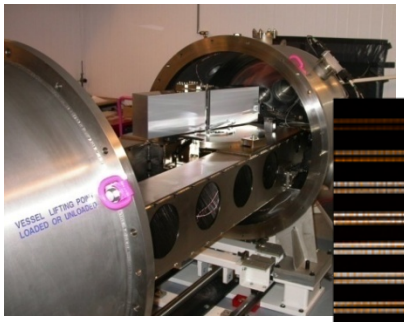


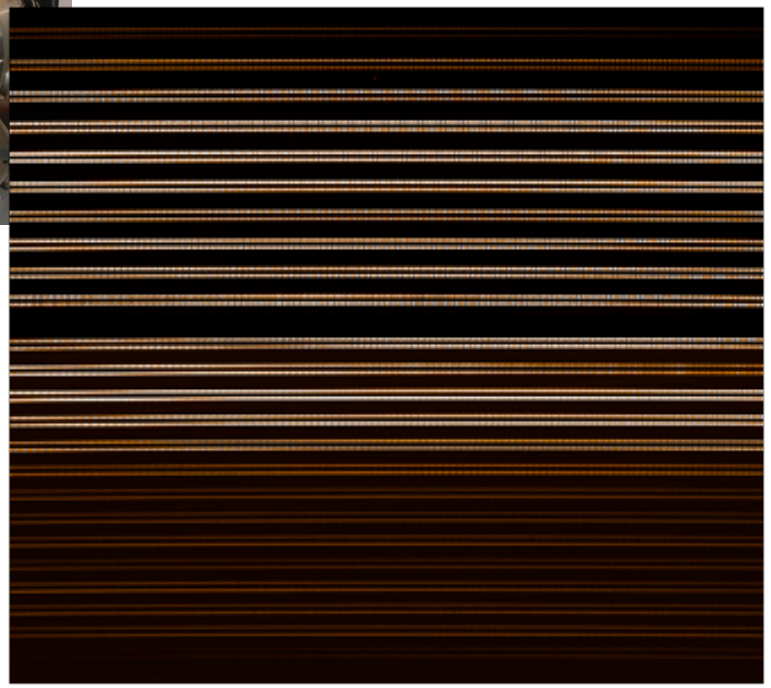


Telescope runs

- 1st run at the VTT in Tenerife on March 2008
  - IR grating, spectral resolution ~ 300 000 => Steinmetz et al. Science 321,1335-1337 (2008)
- 4 runs at the 3.6 m Telescope on La Silla using HARPS spectrograph
  - Visible range, spectral resolution ~ 115 000 => Wilken et al. MNRAS 405, L6-L20 (2010)
    Lo Curto et al. 2010SPIE.7735E..33L
    Wilken Ph.D. Thesis (2010)
    Wilken et al. Nature 485, 611 (2012)

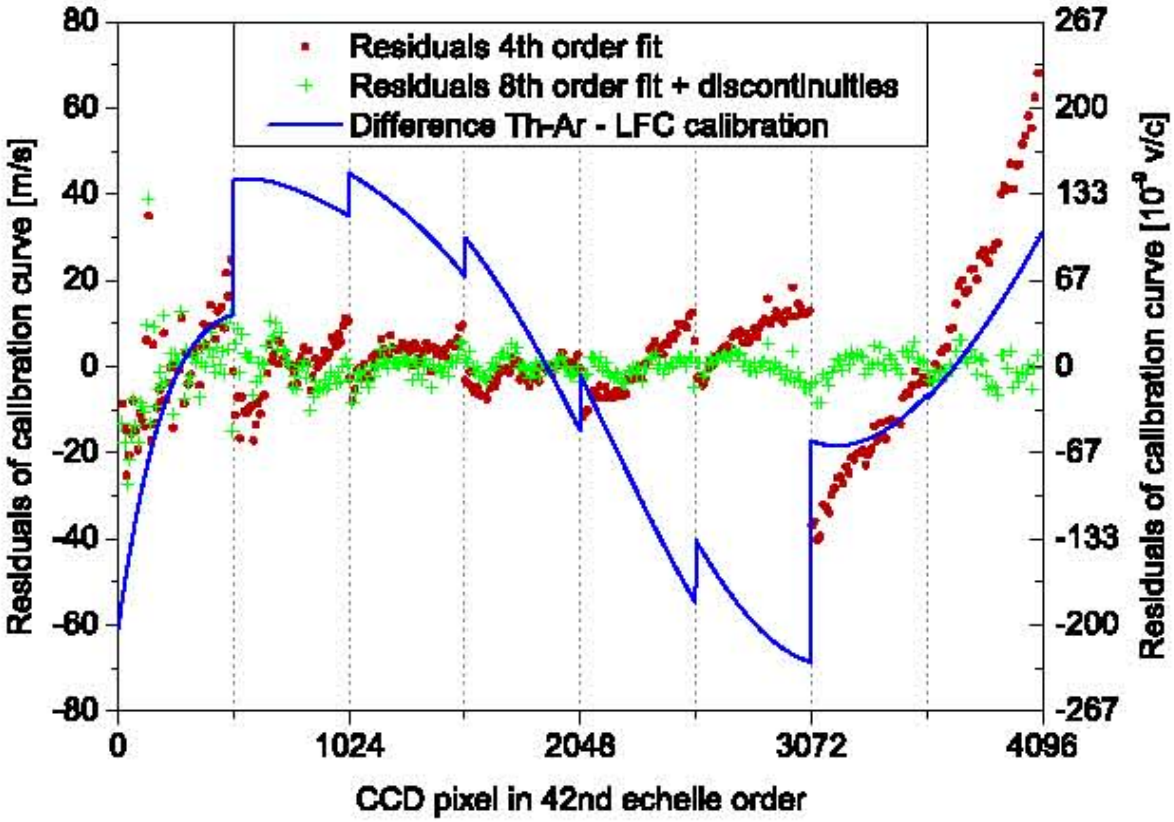






Wavelength calibration

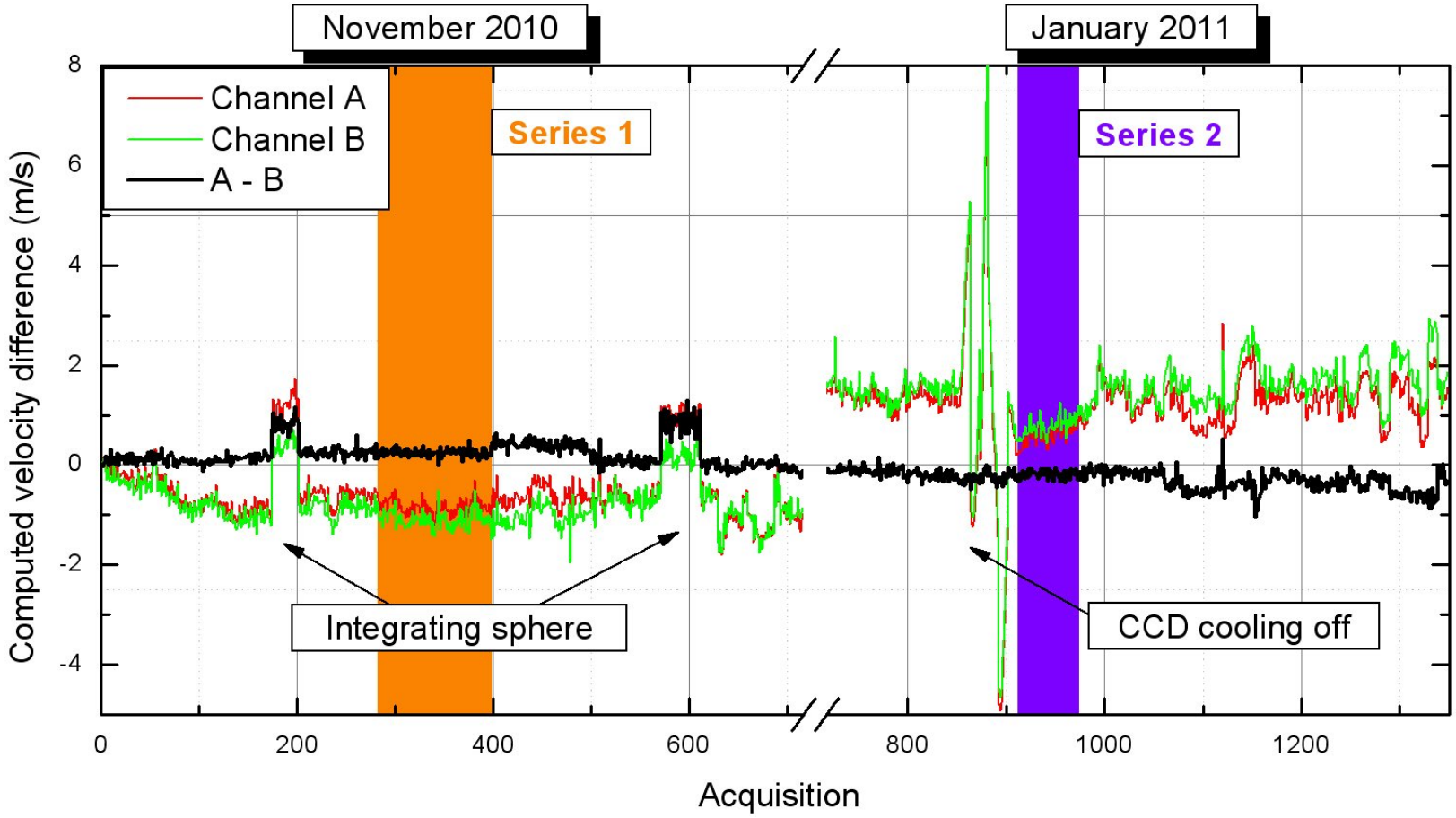
Detect the systematics introduced by the stitching pattern of the CCD



Wilken et al. MNRAS 405, L16–L20 (2010)

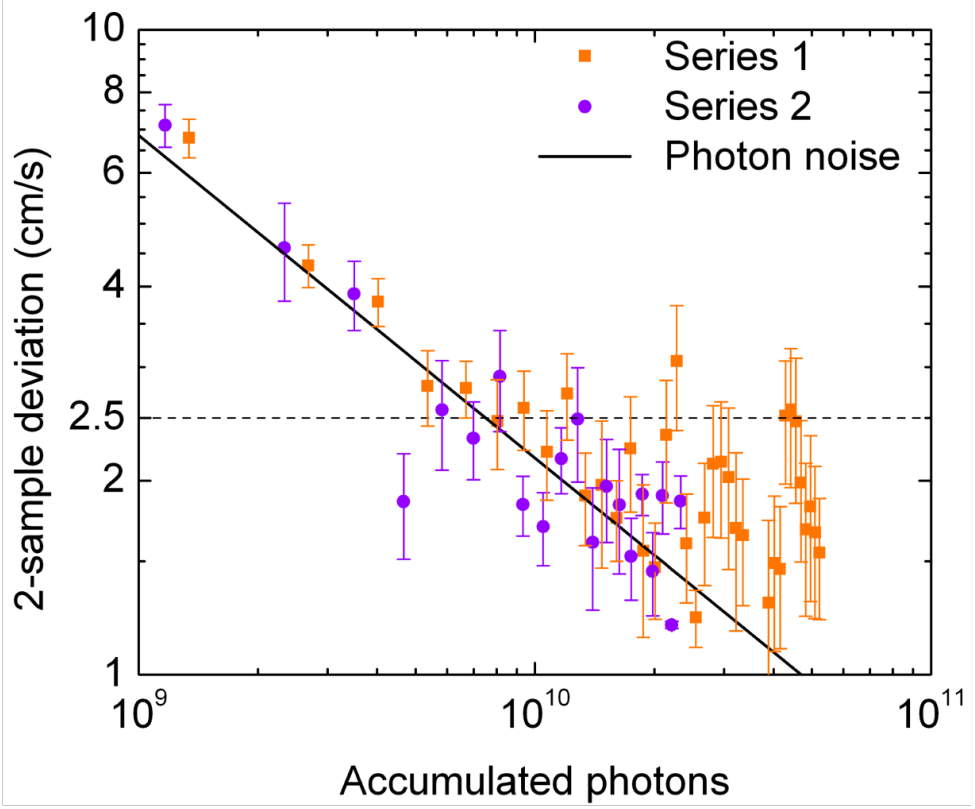
Precision

- 1400 spectra acquired during 45 days
- Major system overhaul after the first week of operations
- RMS(A-B) ~ 34cm/s over the full run (not binned)



Precision

Achieved photon noise limited repeatability down to 2.5cm/s



Turn-key system in development.

Expected delivery: end 2013

Wilken et al. 2012, Nature

CRIRES Upgrade

- **Consortium:** Thüringer Landessternwarte, University of Göttingen, INAF Arcetri & Bologna, University of Uppsala, ESO
- **scope of the upgrade:**
  - adding a cross-disperser to increase the spectral coverage
  - Long-range gas cell for high precision radial velocity searches
  - Polarization Optics
  - State-of-the-art detector array
- **Scientific potential:** ~10 larger wavelength coverage + increased RV precision. Solar system studies, RV-searches, systematic abundance studies in galactic bulge, LMC and SMC, planets' atmospheres
- **Status:** In phase A study, about 3 yrs development expected. Project largely funded by Consortium

ESPRESSO

Observatoire de Geneva and University of Bern, Switzerland
INAF-Trieste and Brera, Italy
Instituto de Astrofisca de Canarias, Spain
Universidade do Porto and Lisboa, Portugal
ESO

PI: F. Pepe (Geneve)

What is ESPRESSO?

- ESO asked for an instrument with specific science cases and clear characteristics

  - Rocky Planets
  - Variability of physical Constants
  - Chemical composition of stars in nearby galaxies

What is ESPRESSO?

- ESPRESSO is Unique in 2 aspects:

  a) Doppler Precision and Wavelength Calibration Accuracy (Super-HARPS)

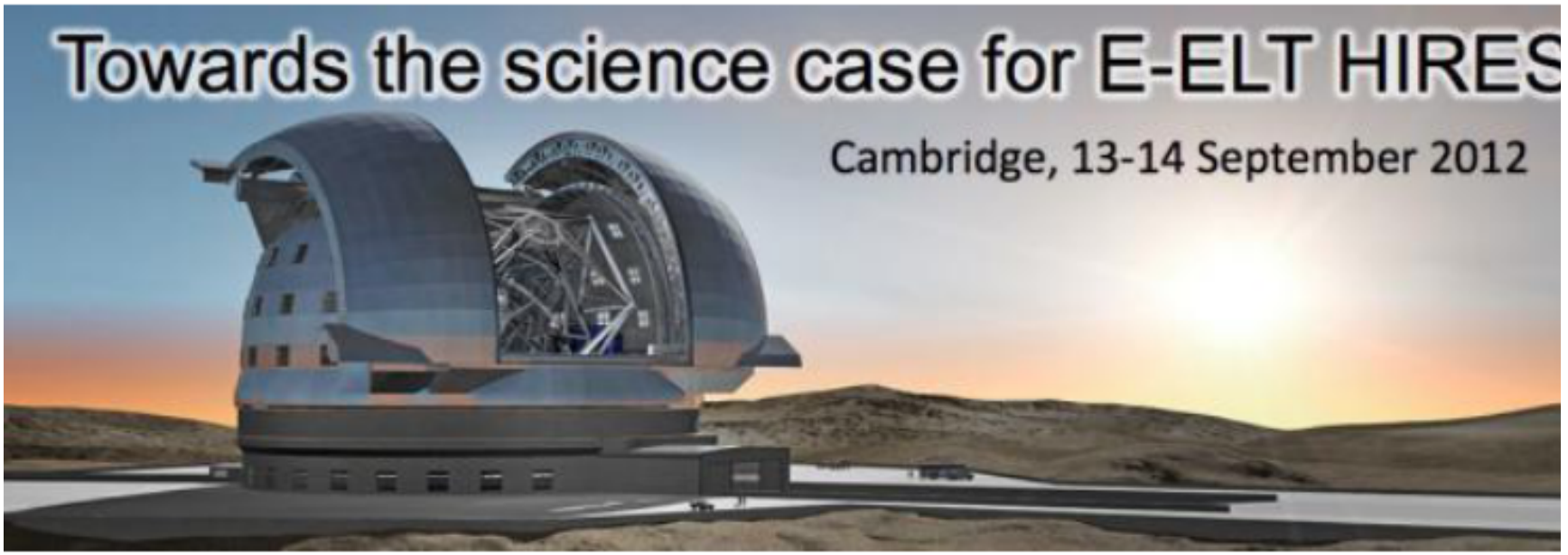
  b) Capability of reaching faint objects at high spectral resolution beyond existing instruments exploiting the 4-UT (Super-UVES)

Some Requirements

Requirement	Standard 1-UT	4-UT	Very-High Res 1-UT
Wavelength Range	380-686 nm	380-686 nm	380-686 nm
Resolving Power	120.000	30.000	220.000
Aperture on Sky	1.0 arcsec	4x1.0 arcsec	0.5 arcsec
Sampling (average)	3.3 pixels	4.0 pixels (binned x2)	2.1 pixels
Spatial Sampling	6.9 pixels	4.0 pixels (binned x2)	3.5 pixels
Simultaneous reference	Yes (no sky)	Yes (no sky)	Yes (no sky)
Sky subtraction	Yes (no sim. ref.)	Yes (no sim. ref.)	Yes (no sim. ref.)
Total Efficiency	>10% at peak	>10% at peak	> 7% at peak
Instrumental RV precision (requirement)	<10 cm/sec	<=5 m/sec	<=5 m/sec

ESPRESSO Development

E-ELT HIRES



Martin Haehnelt and Roberto Maiolino

E-ELT HIRES

Requirements:

- full spectral coverage from optical (4000A to near-IR, K-band)
- high resolution mode (R>~100,000)
- medium resolution mode (R~15,000) with moderate MOS capabilities
- Stability and accuracy ~10 cm/s (TBC)
- Seeing limited

Desiderata:

- small IFU with AO in the High Resolution mode

E-ELT-HIRES possible observing modes

Mode	R (x10³)	λ-sampl (pix)	D-Fib	# Fib	Extra infos
HR	100	4(O) 2.7(IR)	0.8"	2 +λ-cal	x6 slicing
MR MOS	14	33(O) 22(IR)	1.0"	10	no slicing
HR²IFU	100	2.7(IR)	0.005"	80	IFU 0.02" x 0.1"

E-ELT HIRES

HIRES Targets (Exo-Planets)

(1) None-transiting planets:

Host stars follow-up: Resolution and stability VIS and IR
Extend ESPRESSO for photon limited stars (late M)

(2) Transiting planets:

GOAL: get the highest SN as faster as possible.
... consider planet weather

Transit follow up (late stars): precision, VIS and IR
Rossiter: precision, VIS
Planet atmosphere: resolution, IR, "photometric" precision, stability, dynamics

courtesy of Didier Queloz

Some questions on planets

Non exhaustive list of open questions includes:

- Do planet host stars carry special chemical signatures ?
- Do evolved and main sequence host stars have a different [Fe/H] ?
- How does the planet formation depend on stellar mass ?
- Does the planet formation depend on environment ?

Go Faint: Open Clusters

A large sample of stars in Open Clusters of different age would immediately answer to the these questions:

➔ Differential abundances of P-H and non P-H stars !!

stars in cluster share same abundances (De Silva et al. 2007)

➔ Determine Mass-dependence of planet frequency directly

Stellar mass is well constrained in clusters

➔ Compare the Planet frequency in field and clusters

➔ Control systematic effects in the analysis

(e.g. Metallicity..)

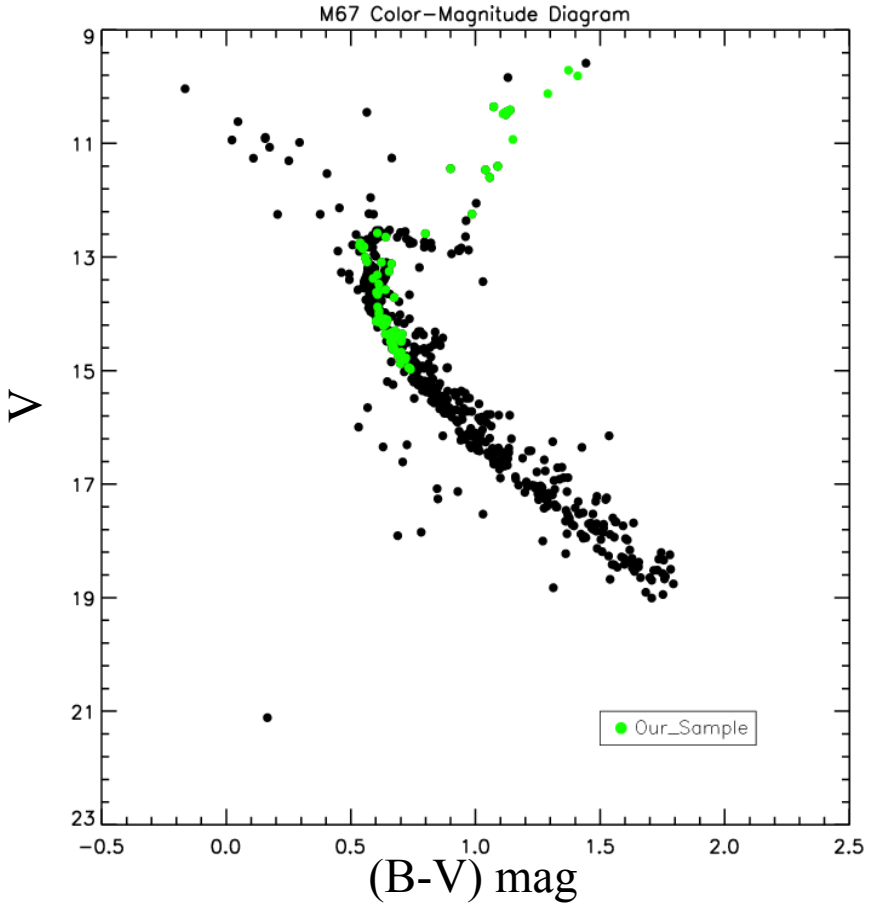
M67

- **M67 is one of the best studied open cluster for:**
  - astrometric membership (Sanders 1977, Yadav et al.2008)
  - precise photometry (Mongomery et al.1993, Sandquist, 2004)
  - precise RV and binary search (Mathieu et al.1986, Melo et al. 2011)
  - X-ray sources identified (Pasquini & Belloni, Van den Berg et al. 2004)

- **General characteristics:**
  - one of the few old open cluster
  - quite rich in stars and CMD well populated in MS, Subgiants, RGB.
  - chemical composition and age very close to solar values (Randich et al. 2006, Pace et al 2008, Onehag et al. 2010)
  - very good candidates for Solar Twins (Pasquini et al. 2008)
  - distance modulus: 9.63 (Pasquini et al 2008) and low reddening E(B-V)=0.041

Color-Magnitude Diagram

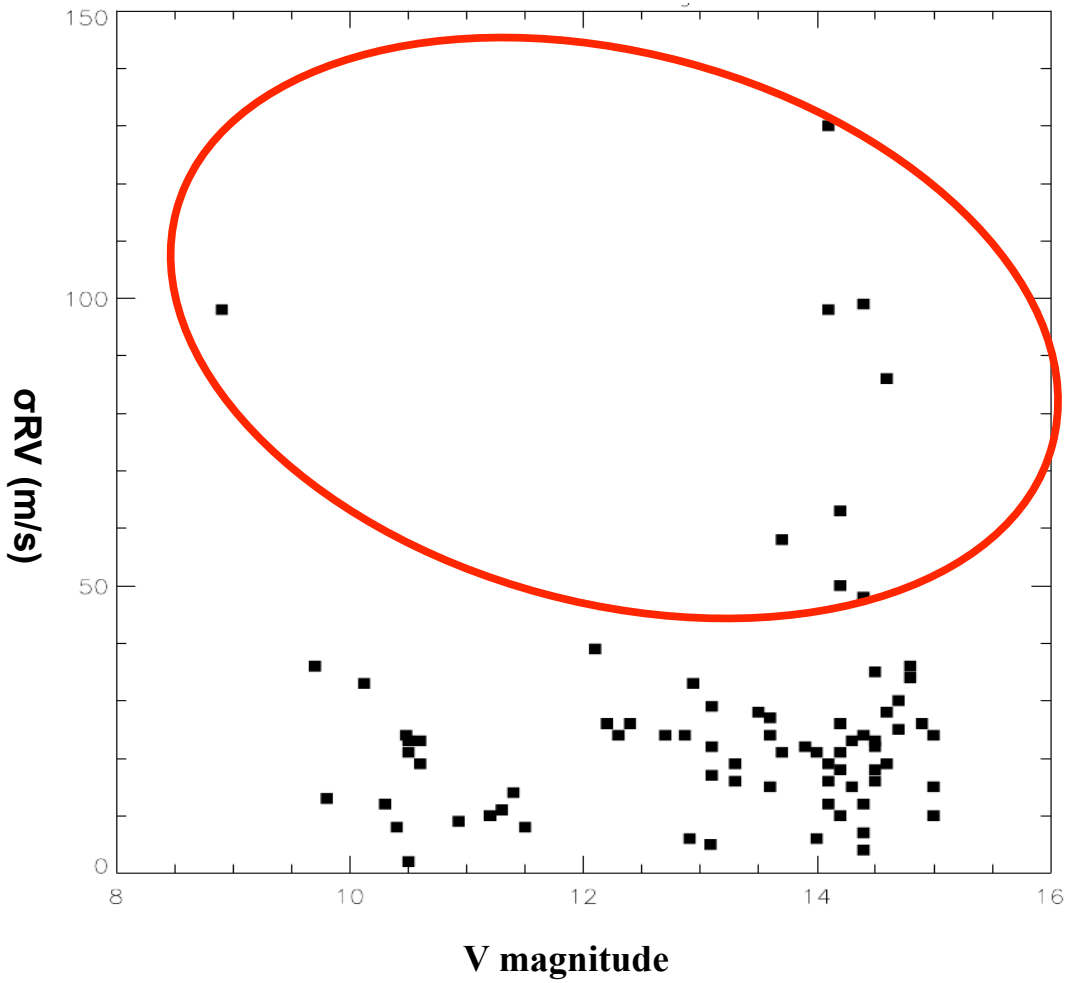
Aim: **Precise stellar radial velocities to search for massive (Jupiter or higher) Exo-planets around stars of M67**



Sample: 88 stars
cover the diagram CM diagram, including 10 solar analogs (Pasquini et al. 2008).

proper motion members:
P > 60% (Yadav et al. 2008)
8.9< Vmag< 15

The σRV – V Magnitude diagram



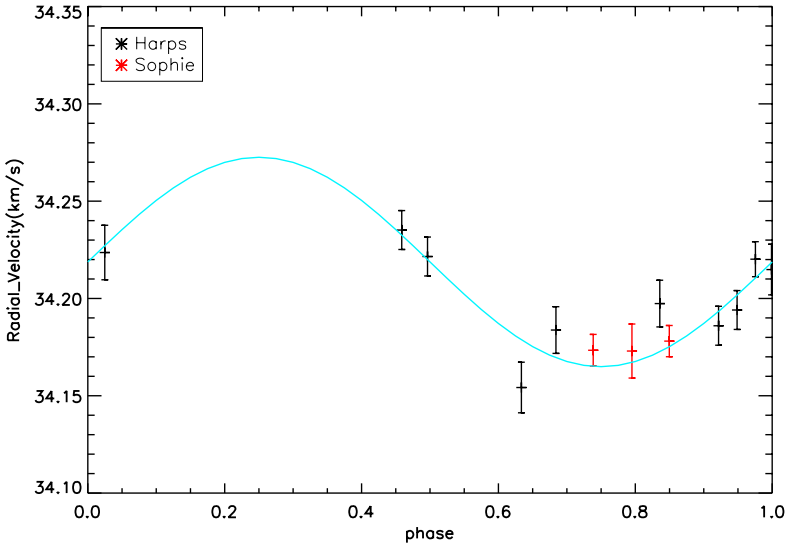
σRV = 20 ±10 m/s
Constant with magnitude

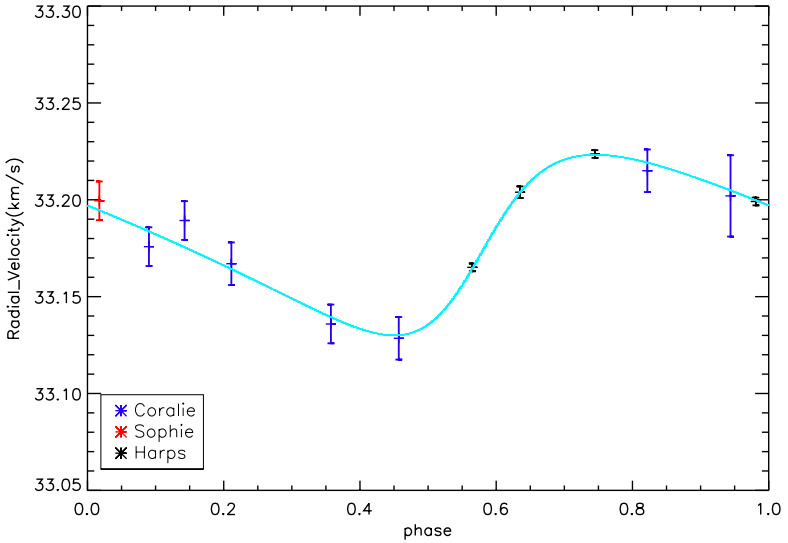
11 stars σRV>50 m/s
Long Period
Planets or Binaries?

Excess of σRV may indicate more candidates among lower variability stars

(Pasquini et al. 2012, A&A 545, 139)

Some results .. .





Brucalassi et al. 2013 (in preparation)

Conclusions

Study of planets in clusters are essential.
Previous results have shown a strong dependence of formation of giant planets from stellar mass and a high frequency of stars with long period planets

Evidence for new planets around M67 stars is growing and will open a new window .. For ESPRESSO and E-ELT HIRES

Use the spectra to search for possible chemical differences between stars w and w/o planets