PHASES: Planet Hunting and AsteroSeismology Explorer Spectrophotometer

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The mission

MISSION CONCEPT

We propose to fly a spectrophotometer on a microsatellite to study a sample of active/ non-active stars with/without planets in order to characterize their physical properties from time series of absolute calibrated spectra

For host stars, characterize the properties of their planets with unprecedented detail

See more details in *del Burgo, Allende Prieto, Peacocke 2010, JInst, 5, 1006*

Background image courtesy of Rrakanishu

MAIN SCIENCE PROGRAMS

PAYLOAD: GENERAL CHARACTERISTICS

LEO orbit to avoid scintillation noise resulting from air turbulence in the Earth's atmosphere, day-night cycle, and variable weather conditions that hinder long-term observations

Targets brighter than V=10:

1 min → S/N = 35-140 per resolution element

Host stars, V=10: expected photometric precision in light curves (transit duration of 4 hours) is better than 10 ppm


PHASES E = 303.919° M = 303.919° v = 303.919°
a = 7201.01Km e = 0 ω = 28.667° i = 98.7° Ω = 180°
WINTER


PHASES E = 52.817° M = 52.817° v = 52.817°
a = 7201.01Km e = 0 ω = 125.201° i = 98.7° Ω = 270°
SPRING


PHASES E = 160.592° M = 160.592° v = 160.592°
a = 7201.01Km e = 0 ω = 221.736° i = 98.7° Ω = 360°
SUMMER


PHASES E = 269.565° M = 269.565° v = 269.565°
a = 7201.01Km e = 0 ω = 318.27° i = 98.7° Ω = 90°
AUTUMN

LIST OF PLANETS TRANSITING BRIGHT HOST STARS

PLANET	M. (MJUP)	RADIUS (RJUP)	PERIOD (days)	SEM-MAJ AXIS (AU)	ECC.	INCL. (deg)	ANG. DIST. (arcsec)	ALPHA	DELTA	MAG. V	DIST. (pc)	[Fe/H]	MASS (MSUN)	RADIUS (RSUN)
55 Cnc e	0.027	0.194	0.7365449	0.0156	0.057	81	0.001264	08 52 37	+28 20 02	5.95	12.34	0.31	0.905	0.943
HD 97658 b	0.02	0.262	94.957	0.0797	0.13	-	0.003777	11 14 33	+25 42 37	6.27	21.1	-0.23	0.85	0.73
HD 209458 b	0.714	1.38	352.474.859	0.04747	0.014	86.59	0.00101	22 03 10	+18 53 04	7.65	47	0.02	1.148	1.146
HD 189733 b	1.138	1.138	221.857.312	0.03142	0.0041	85.51	0.001628	20 00 43	+22 42 39	7.67	19.3	-0.03	0.8	0.788
HD 149026 b	0.356	0.718	28.758.916	0.04288	0	85.3	0.000543	16 30 29	+38 20 50	8.15	78.9	0.36	1.3	1.497
HD 17156 b	3.191	1.095	212.163.979	0.1623	0.6768	86.49	0.002074	02 49 44	+71 45 12	8.17	78.24	0.24	1.275	1.508
Kepler-21 b	< 0.033	0.1459	2.785.755	0.042507	0	82.58	0.000394	19 09 27	+38 42 50	8.27	108	-0.15	1.34	1.86
WASP-33 b	< 4.59	1.438	121.986.967	0.02558	0	87.67	0.000221	02 26 51	+37 33 02	8.3	116	0.1	1.495	1.444
HAT-P-2 b	8.74	0.951	56.334.729	0.0674	0.5171	90	0.000571	16 20 36	+41 02 53	8.71	116	0.14	1.36	1.64
HD 80606 b	3.94	0.921	11.143.637	0.449	0.93366	89.285	0.007688	09 22 37	+50 36 13	8.93	58.4	0.43	0.98	0.98
WASP-18 b	10.43	1.165	0.9414518	0.02047	0.0088	86	0.000205	01 37 25	-45 40 40	9.3	100	0	1.24	1.23
WASP-38 b	2.712	1.079	6.871.815	0.07551	0.0321	88.69	0.000686	16 15 50	+10 01 57	9.42	110	-0.12	1.216	1.365
WASP-7 b	0.96	1.33	49.546.416	0.0617	0	87.03	0.000441	20 44 10	-39 13 31	9.51	140	0	1.276	1.432
HAT-P-11 b	0.081	0.452	4.887.804	0.053	0.198	88.5	0.001395	19 50 50	+48 04 51	9.59	38	0.31	0.81	0.75
HAT-P-22 b	2.147	1.08	321.222	0.0414	0.016	86.9	0.000505	10 22 44	+50 07 42	9.73	82	0.24	0.916	1.04
WASP-14 b	7.341	1.281	22.437.661	0.036	0.087	84.79	0.000225	14 33 06	+21 53 41	9.75	160	0	1.211	1.306
XO-3 b	11.79	1.217	31.915.239	0.0454	0.26	84.2	0.000175	04 21 53	+57 49 01	9.8	260	-0.177	1.213	1.377
WASP-8 b	2.244	1.038	8.158.715	0.0801	0.31	88.55	0.000921	23 59 36	-35 01 53	9.9	87	0.17	1.033	0.953
HAT-P-14 b	2.2	1.2	4.627.657	0.0594	0.095	83.2	0.00029	17 20 28	+38 14 32	9.98	205	0.11	1.386	1.468
KOI-13 b	8.3	1.83	17.637	-	-	-	-	19 07 53	+46 52 06	10	-	-0.14	-	2.44

Source: data from exoplanet.eu

PHASES IN CONTEXT:

Currently only HST/STIS can obtain absolute calibrated fluxes

PHASES can perform long-term ultraprecise absolute spectrophotometry of bright stars ...

... making possible to observe stars (<6 mag) that will saturate GAIA (to be launched by 2013)

PHASES is designed to provide a higher power resolution (R~200-900) than GAIA (~50) in a wide wavelength range (370-960 nm)

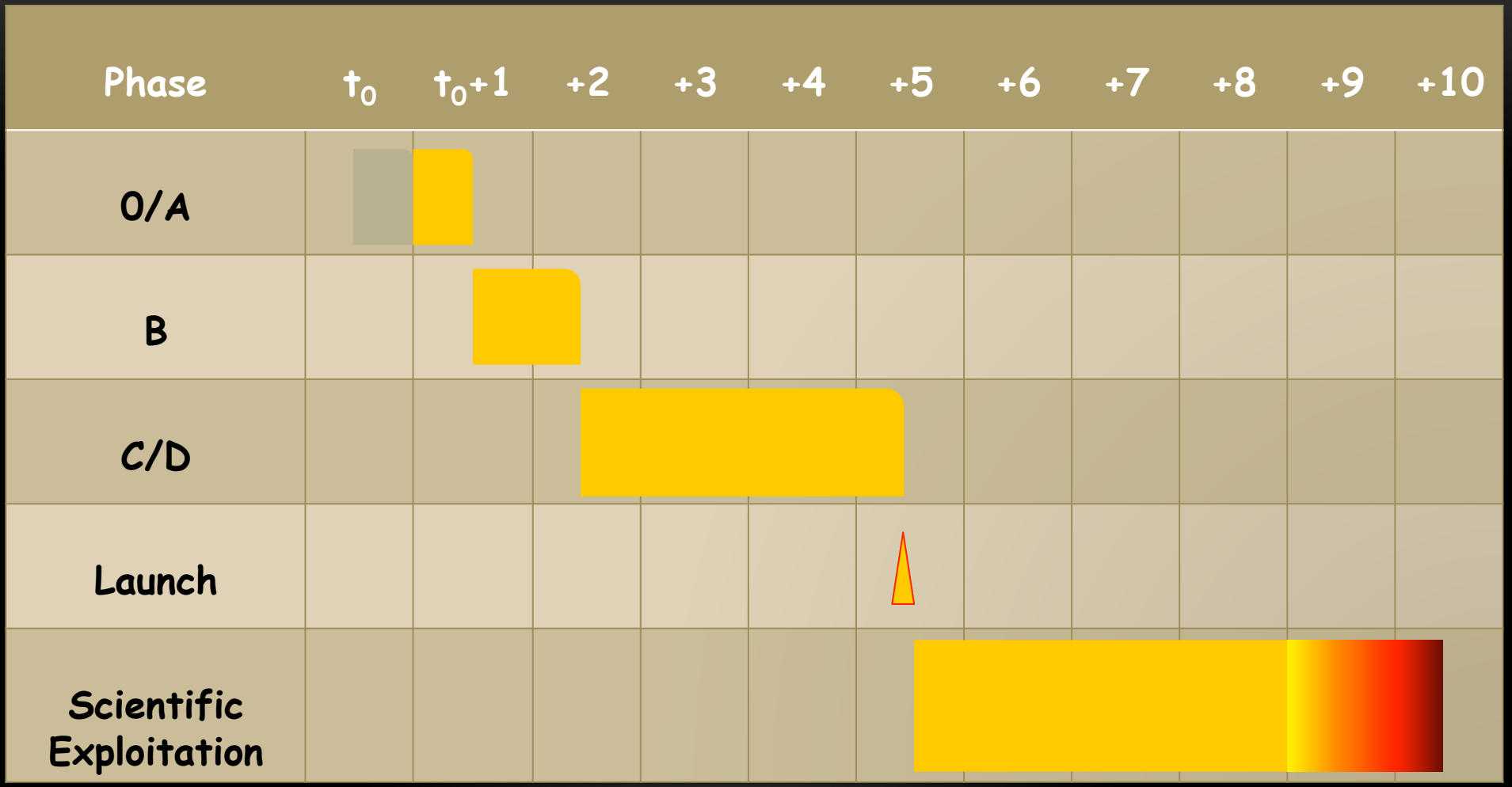
PHASES will make possible to study planetary atmospheres in a different fashion than ECHO (2022), to do **relative** spectrophotometry

MICROSATELLITES

Micro-satellites offer an extremely economical means to obtain the large quantity of space-based measurements that will be vital in the future if, e.g., we are to properly study the full range of transiting planet discoveries

This is in keeping with the general guide-lines of the ongoing ESA Cosmic Vision process and US National Science Foundation remits for low-cost missions

TIME SCHEDULE

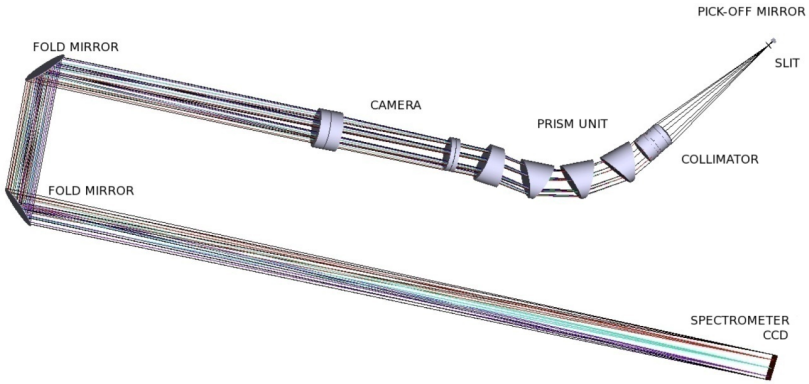


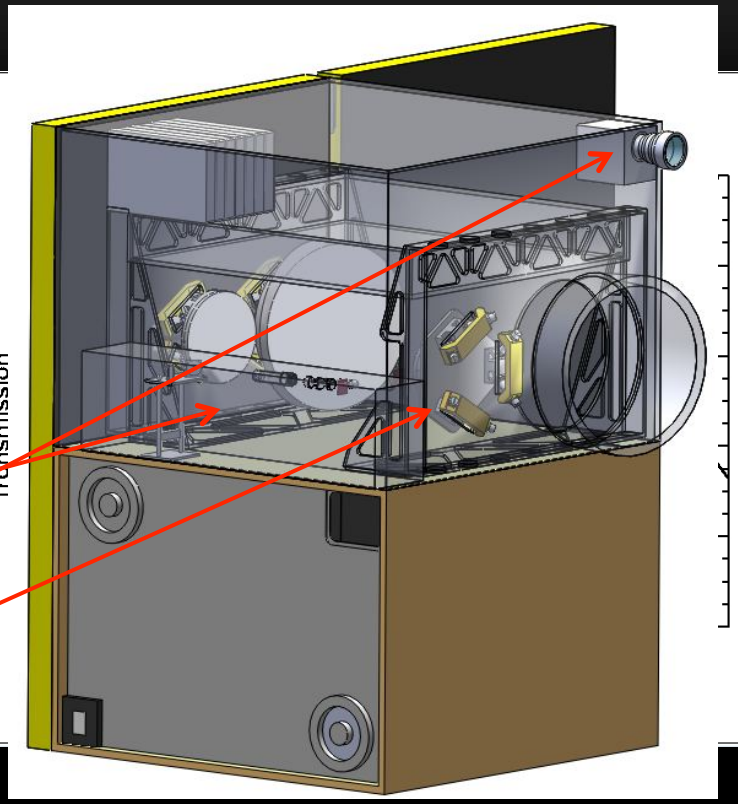
Opto-mechanical concept

THE RESEARCH DESIGN AND METHODS

- ESA Project Management Standards
- ESA Design Standards
- SolidWorks 2009 for mechanical design of components
- CosmosWorks 2009 and Algor for FEA
- CosmosWorks 2009 for thermal analysis

OPTICS





Stellar sensor

- Auxiliary star sensor: FOV of 20 deg
- Integrated star sensor: FOV of 1 deg
- Pointing stability of 0.2" (goal: 0.1")

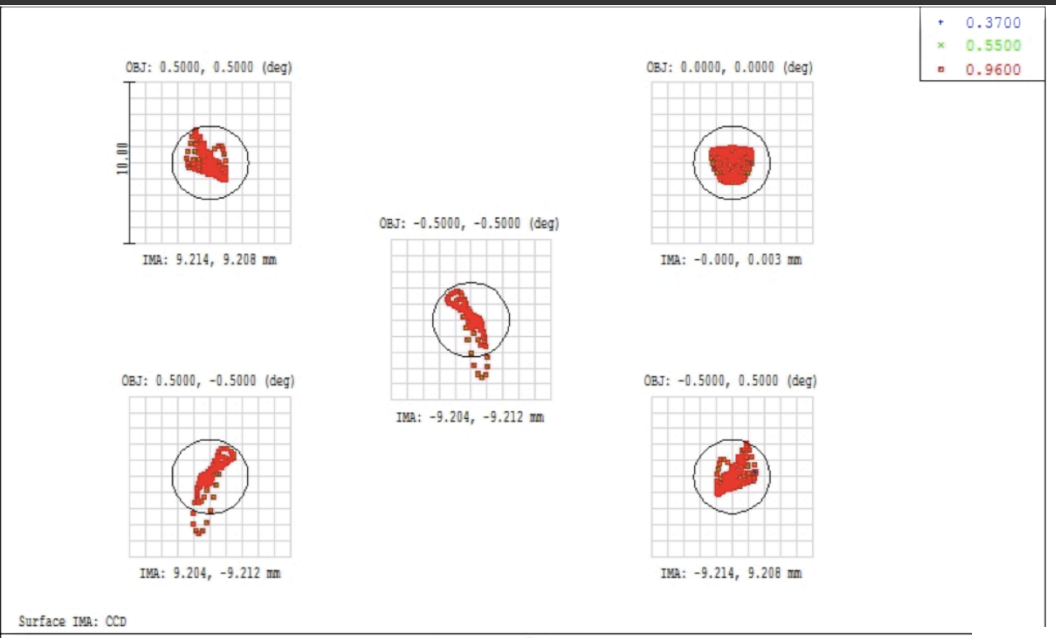
del Burgo et al. 2010

SPECTROSCOPIC MODE: TRANSITs

HD 209458 (V=7.65): t = 1 min → S/N = 70-225 per resolution element

Light curve: precision of 4 ppm for two transits (duration of 3.7 h each)

INTEGRATED STAR SENSOR: SPOT PATTERN



Spot Diagram

Baker type telescope for the PHASES satellite
10/12/2010 Units are µm. Airy Radius: 2.339 µm

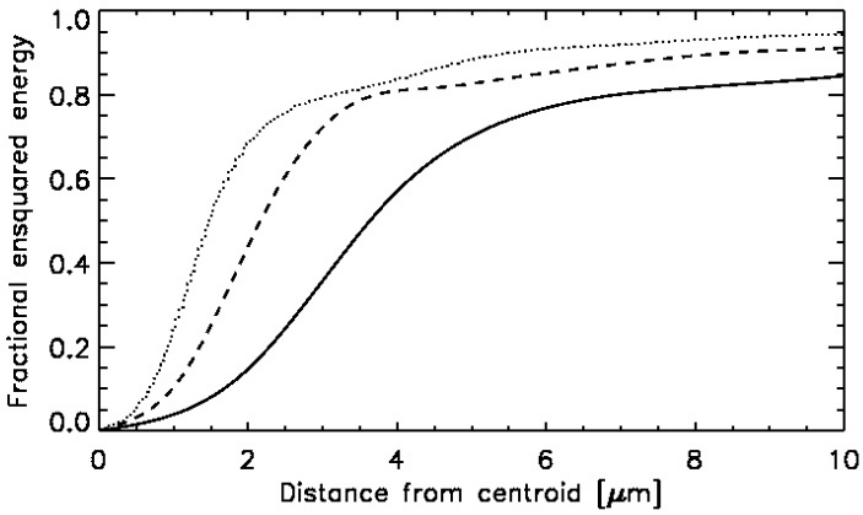
Field	1	2	3	4	5
RMS radius	1.041	0.928	1.146	1.146	1.041
GEO radius	2.283	1.411	3.628	3.628	2.283

Scale bar : 10 Reference : Centroid

Tully Peacocke
Experimental Phys
NUI Maynooth
Nano_Baker_v0.4
Configuration 1

Spot pattern

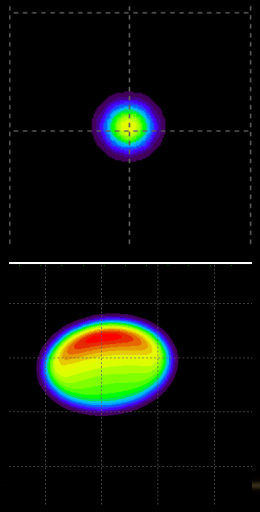
Diffraction ensquared energy across full 1 degree field of view



Computational Testing for Passive Compensating Design

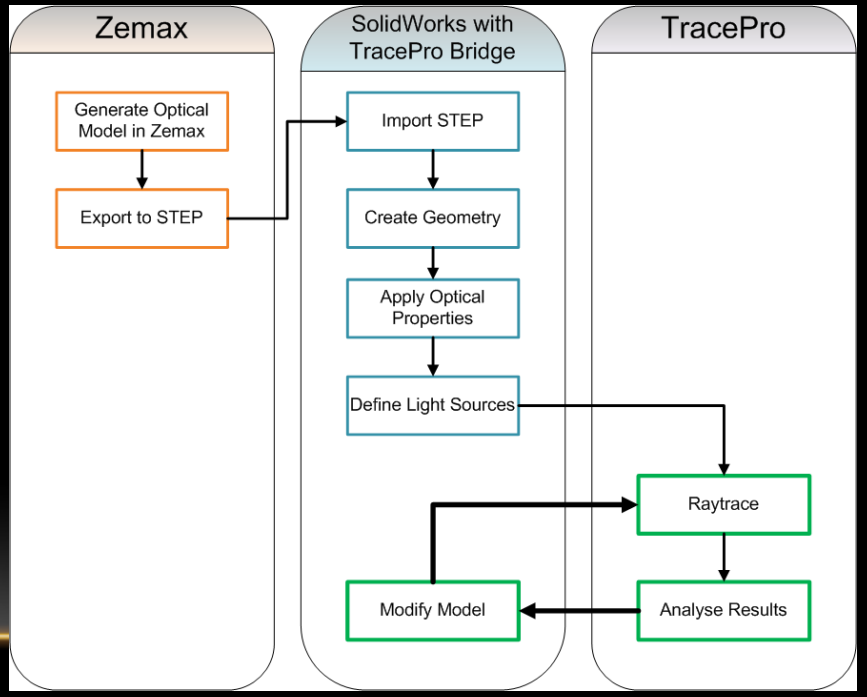
- For a given design mechanical constraints are defined in SolidWorks
- Thermal loads are then applied to the model using SolidWorks simulation
- The model is then taken into TracePro and the optical path of the model is traced
- An irradiance map of the detector is plotted and analysed. This tells us if the instrument is in focus and correctly aligned
- If the instrument is not in focus over the desired temperature range, changes are made to the mechanical model , based on the results, to optimise the instrument performance

Irradiance map of detector



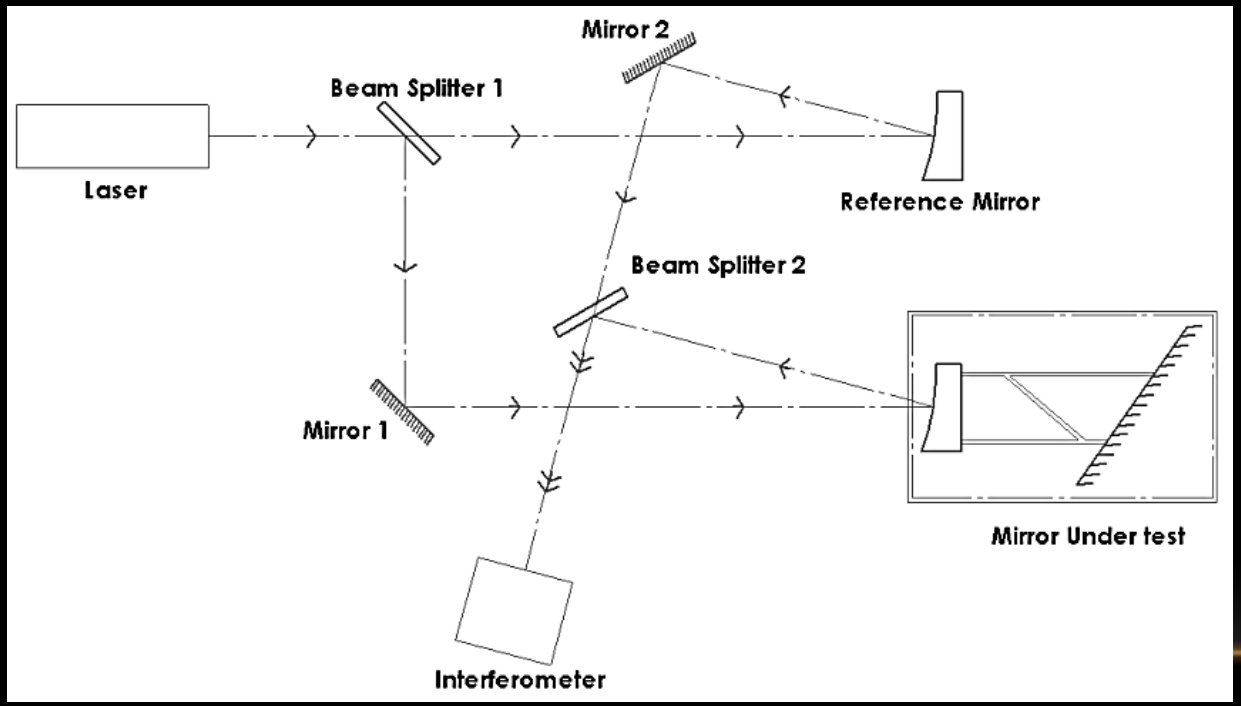
Instrument in Focus

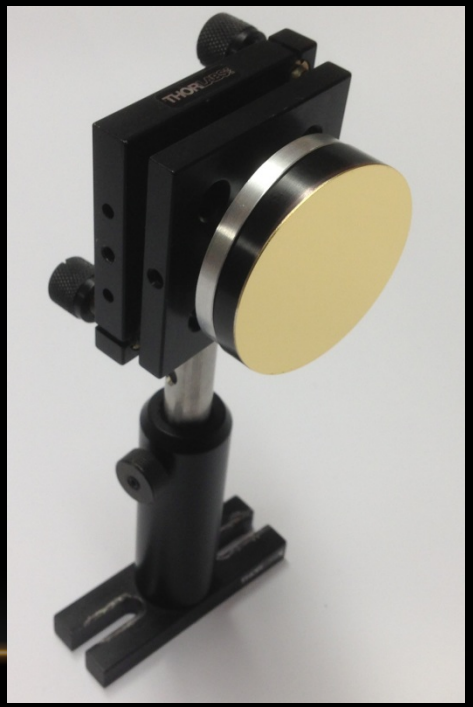
Instrument not in focus due to a change in mirror angle



MECHANICAL TESTING FOR PASSIVE COMPENSATING DESIGN

- To qualify final PHASES computational model, the opto-mechanical design of one mirror and its truss structure is tested
- Test mirror and supporting truss is subjected to a thermal change
- Interferometer used to detect changes in the test mirrors form and relative position
- Results compared to the computational model to validate the different truss designs



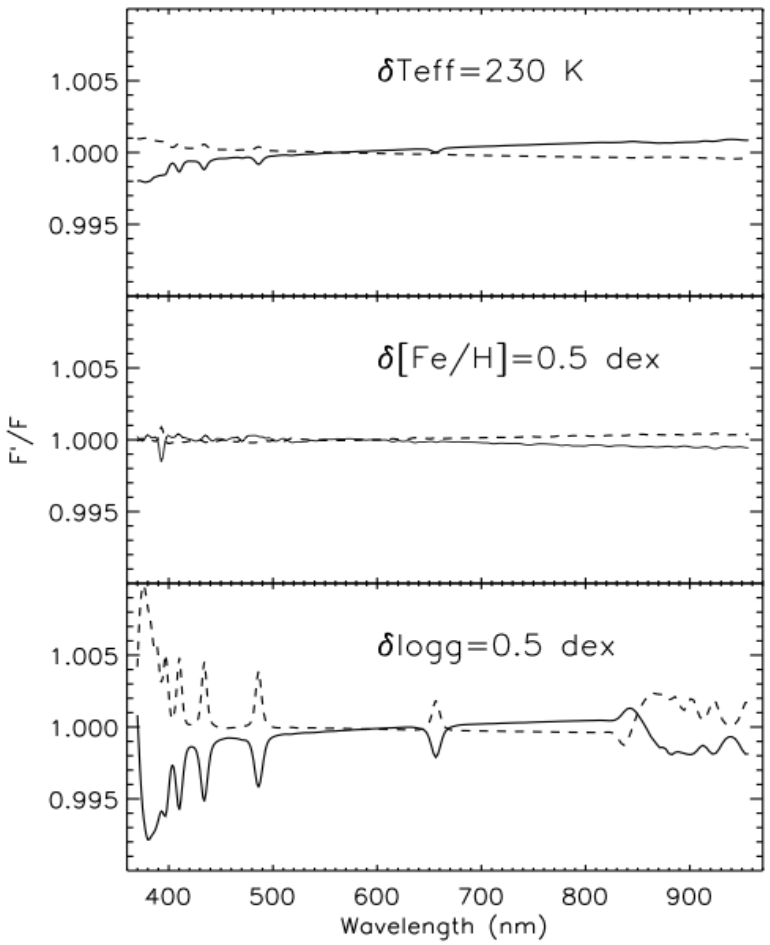


Absolute flux calibration

A-TYPE STARS AS FLUX CALIBRATORS

Vega example:

Strong continuum Response to T_{eff}, but weak response of the slope to T_{eff}, logg, and [Fe/H] between 450 and 1000 nm



Teff=10,000 K; logg=4; [Fe/H]=-0.7

A TEST WITH VEGA

HST/STIS spectrum of Vega + standard plane parallel model + Hipparcos parallax:

Our best fitting model:

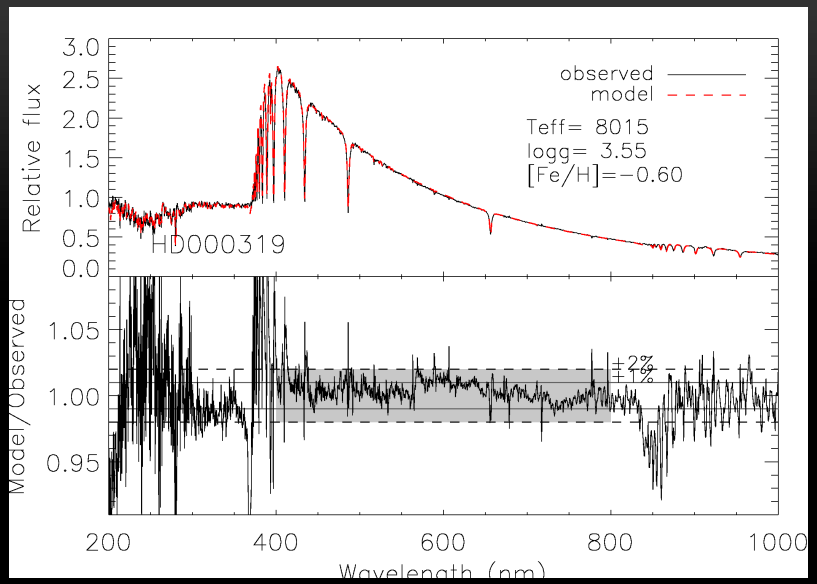
[Fe/H]= −0.7, imposed; Teff = 9506±23K; log g = 4.01±0.02 dex)

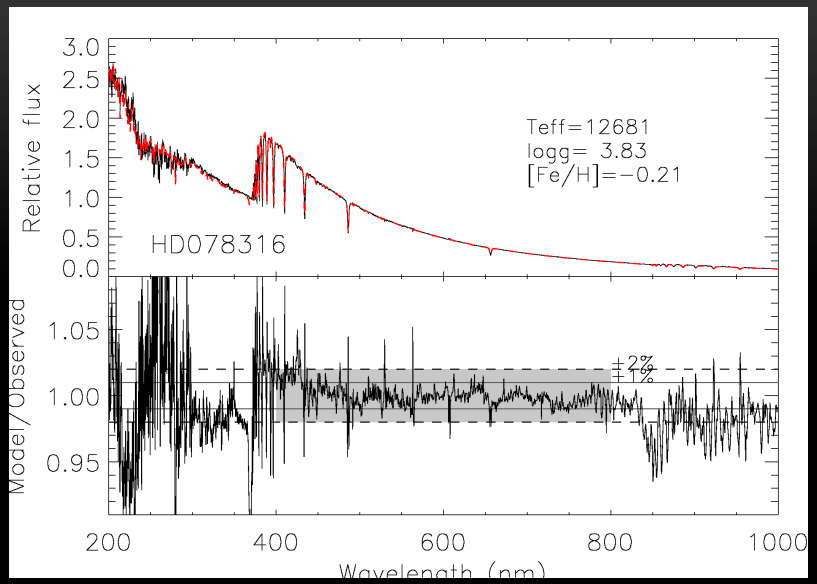
→ flux of 5.40×10^{7} erg s^{-1} cm^{-2} $Å^{-1}$ at 555 nm, or, scaled by the inferred angular diameter (3.31 mas), 3.48×10^{-9} erg s^{-1} cm^{-2} $Å^{-1}$ at 555 nm at Earth

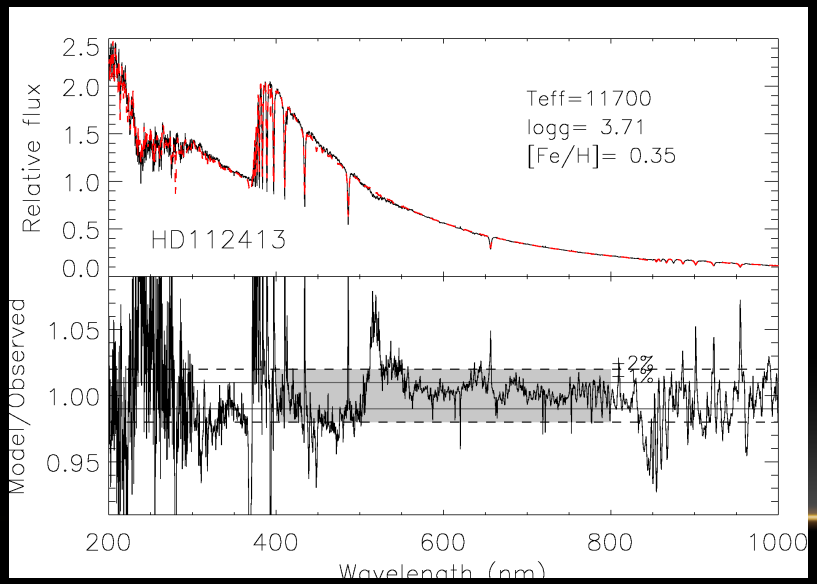
This is in excellent agreement with the result of Bohlin of 3.46×10^{-9} erg s^{-1} cm^{-2} $Å^{-1}$

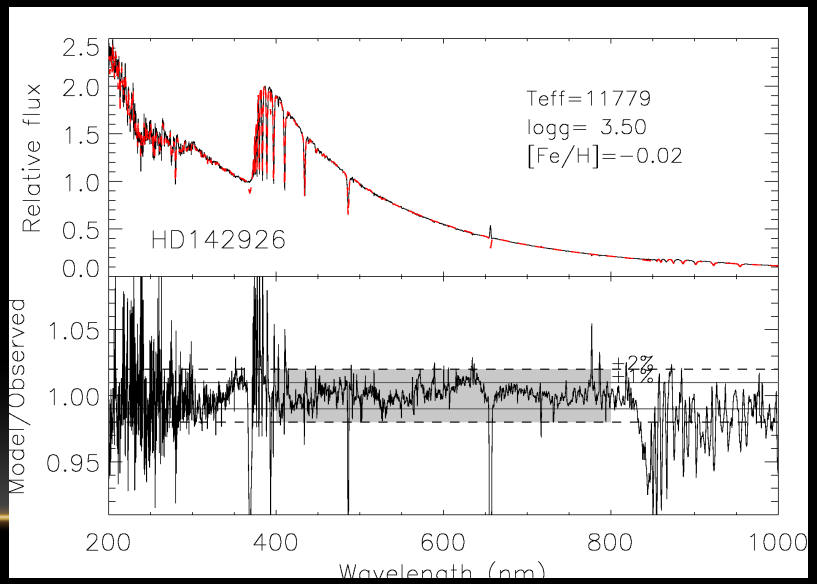
del Burgo et al. 2010

AND MANY OTHERS FROM THE NGSL









A-TYPE STARS AS FLUX CALIBRATORS

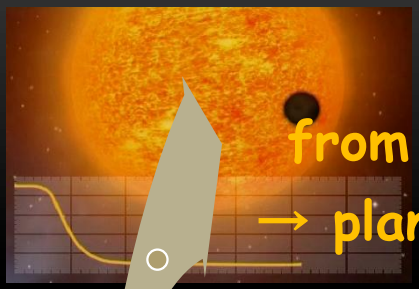
CCDs QE peaks in the red

A-type stars energy peaks in the UV-blue range, making them ideal for flux calibration throughout the optical range:

- λ = $2.8977685 \times 10^{6} \times T^{-1}$ nm (Wien's law)
- λ = 290 nm at T=10,000 K (A0V)
- λ = 402 nm at T= 7,200 K (A9V)

Characterization of extrasolar planets

DETERMINING THE PLANET RADIUS



from the LC's transit depth
→ planet to stellar radii ratio

Transits:

Time series of spectra: integrating in each spectrum → LC

→ star's radius

→ planet's radius

Absolute flux spectra

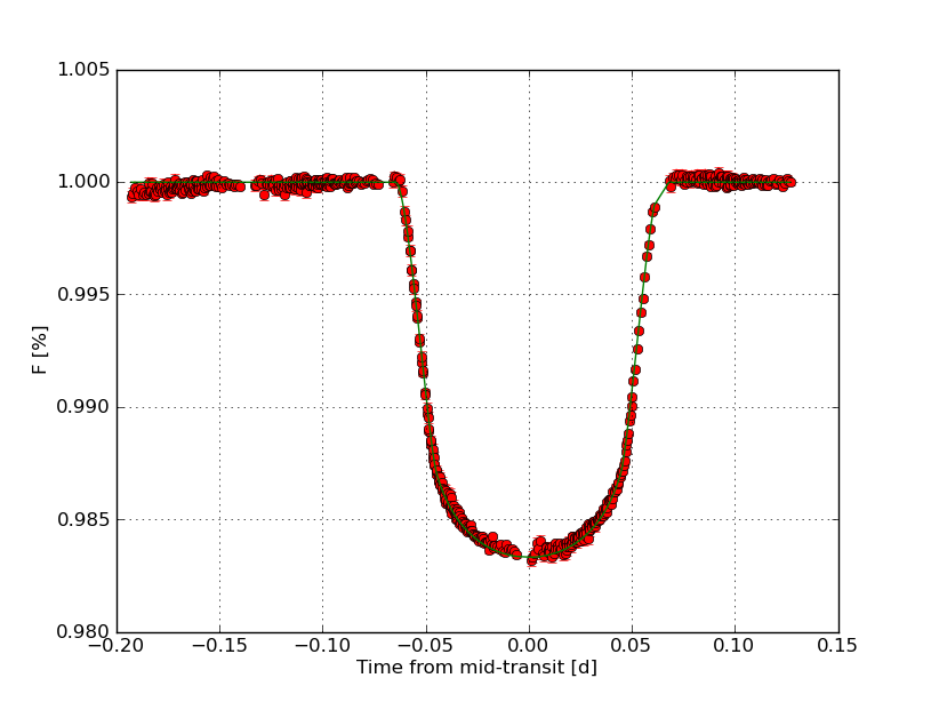
+

Hipparcos parallax (in the future GAIA)

TIME SERIES

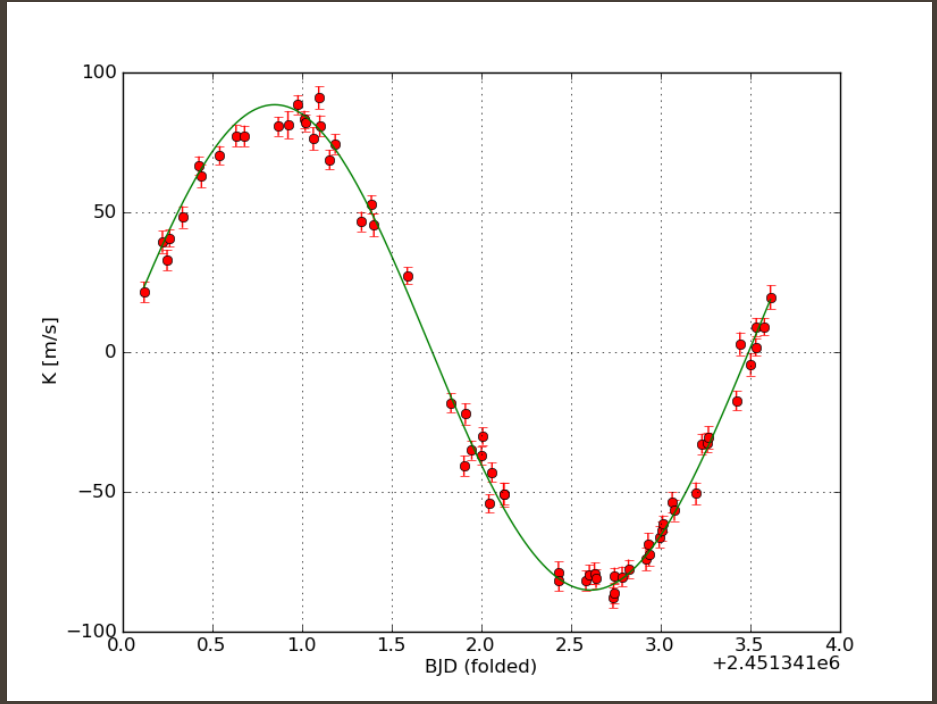
EXAMPLE: THE BRIGHT HD209458 AND ITS PLANET

Light Curve



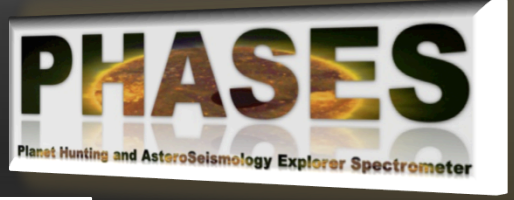
Source data: Brown et al. 2001

Radial Velocity Curve

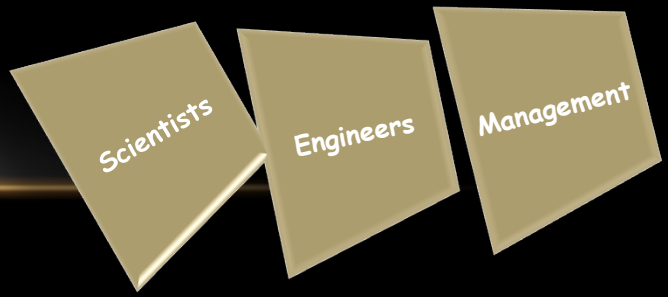


Source data: Butler et al. 2006

PHASES Development Team



PI	• C. del Burgo
Calibration	• C. Allende Prieto
Optics	• T. Peacocke
Mechanics	• D. Vather, N. Murphy
Laboratory	• T. Brennan, N. Devaney
Star tracker	• H. Silva
Orbit	• J. T. Vila
Electronics	• P. McGillion



SUMMARY

PHASES: absolute spectrophotometry from space

Precise determination of star's properties such as the radius

For host stars: precise determination of the planet properties

MORE INFORMATION ABOUT PHASES

- C. del Burgo, C. Allende Prieto, T. Peacocke, 2010, Jinst, 1, 1006: "PHASES: a concept for a satellite-borne ultra-precise spectrophotometer"

- C. del Burgo, D. Vather, C. Allende Prieto, N. Murphy, Proceedings of "New Quest in Stellar Astrophysics III, A Panchromatic View of Solar-Like Stars, With and Without Planets", Puerto Vallarta, Mexico, on March 12 - 16, 2012, APS, in press: "PHASES: a project to perform Absolute Spectrophotometry from Space"