Instrumentation projects of the Thüringer Landessternwarte Tautenburg

Frame-work, outline:

Research on extrasolar planets is not the only subject that is being done at the Thüringer Landessternwarte but this field of research sets a nice framework for all our instrumentation projects.

Two paths how to proceed in extrasolar-planet research:

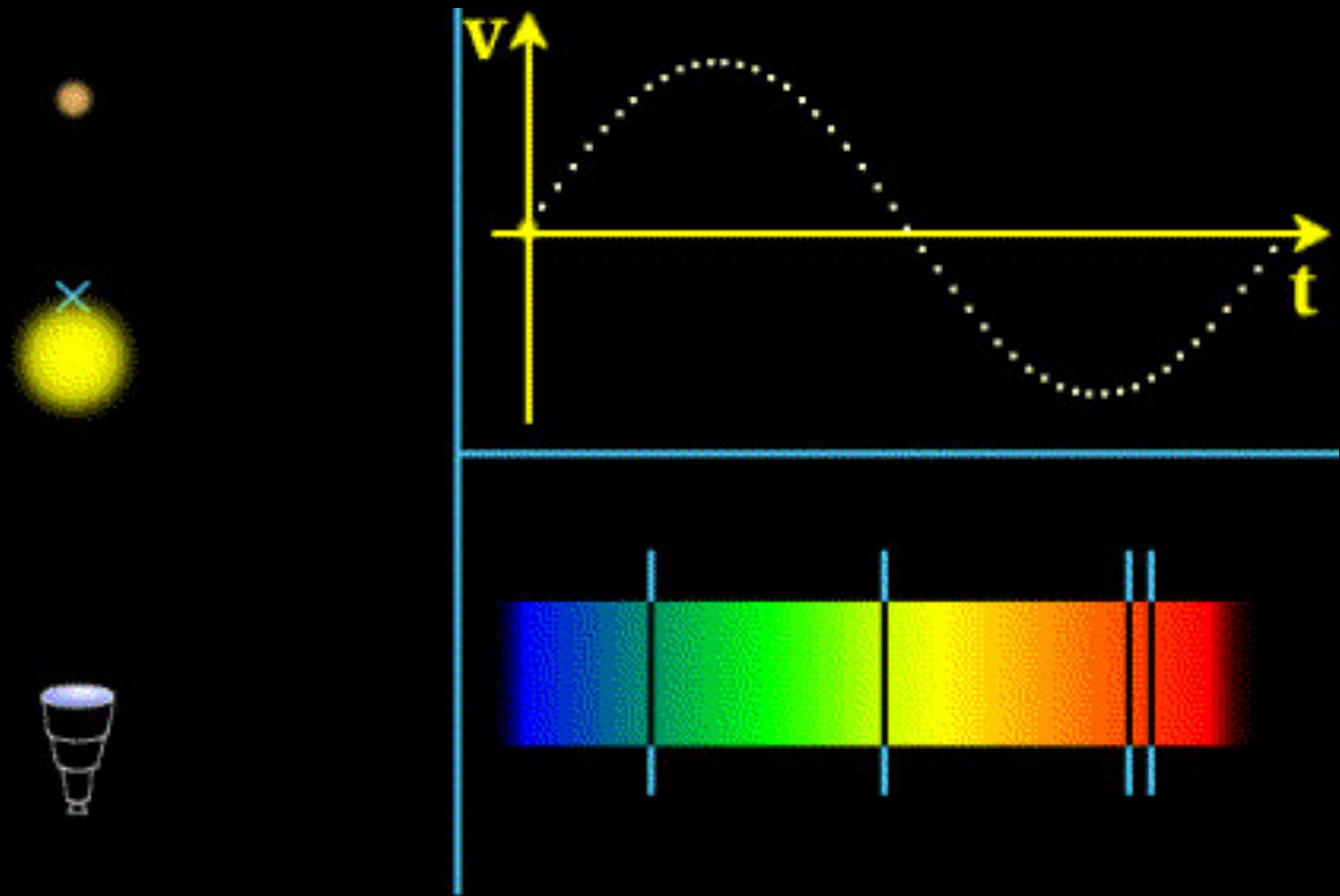
First Path:

i.) Discover planets of low-mass stars with RV-method
ii.) Find-out whether they are transiting (space mission: CHEOPS)
iii.) Study atmospheres with transmission spectroscopy
(CREIRS$^+$, E-ELT)

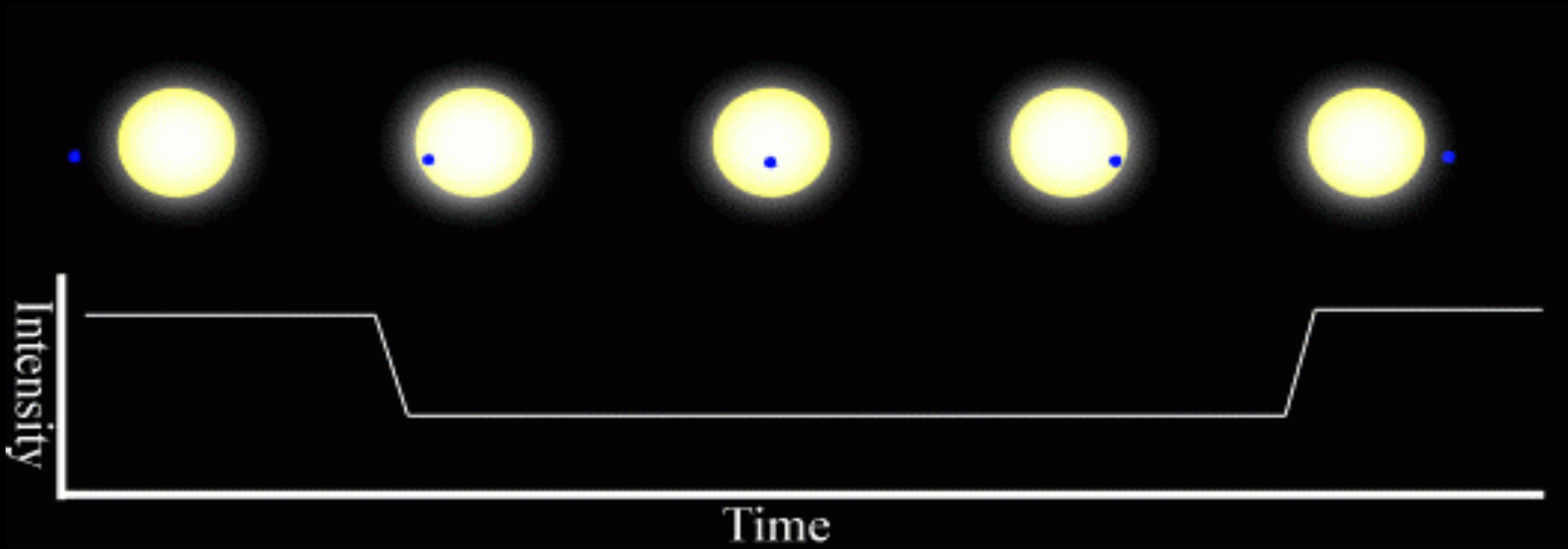
Second Path:

i.) Discovery transiting planets
(space missions: CoRoT, Kepler, TESS, PLATO)
ii.) --> Remove false-positives
iii.) Determine masses by high precision radial-velocity (RV)
measurements with high-resolution spectrograph
iv.) Study atmospheres (CREIRS$^+$, E-ELT)

RV-method: Detecting exoplanets and determining their mass (m sin i)



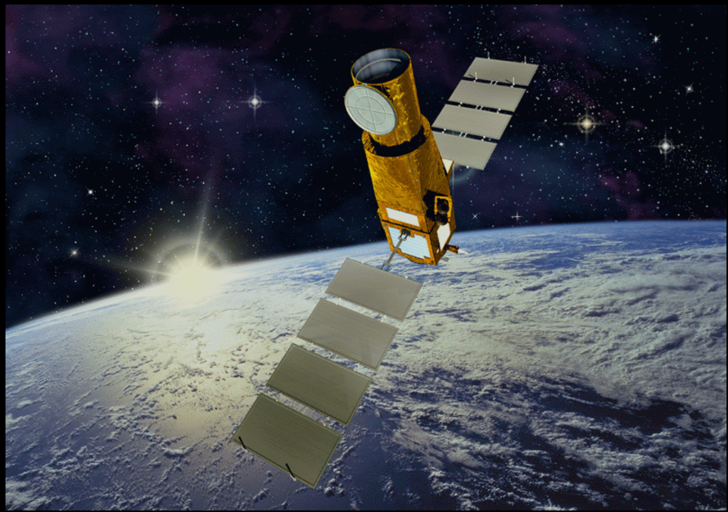
Transiting of planets

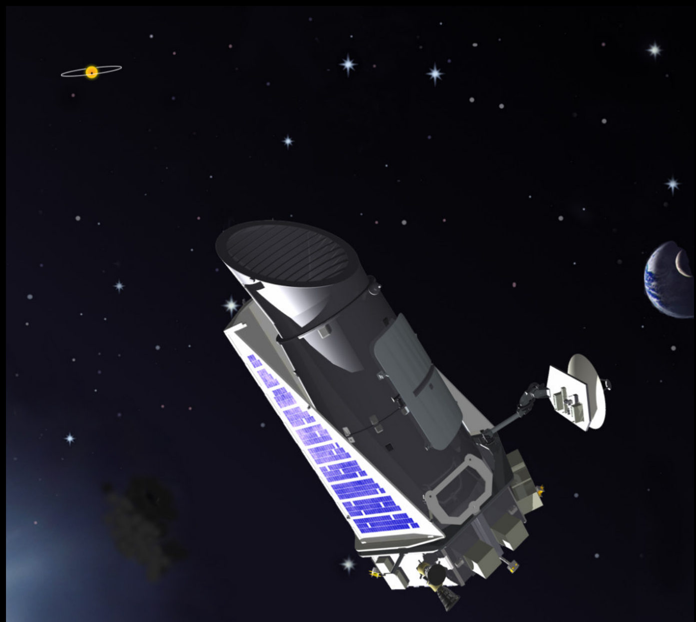


Transit gives us the size of the planet.

Combining the two gives us the density of the planets!

Space-Missions



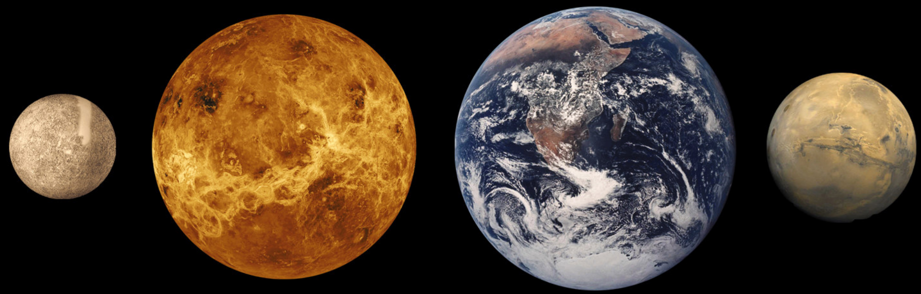


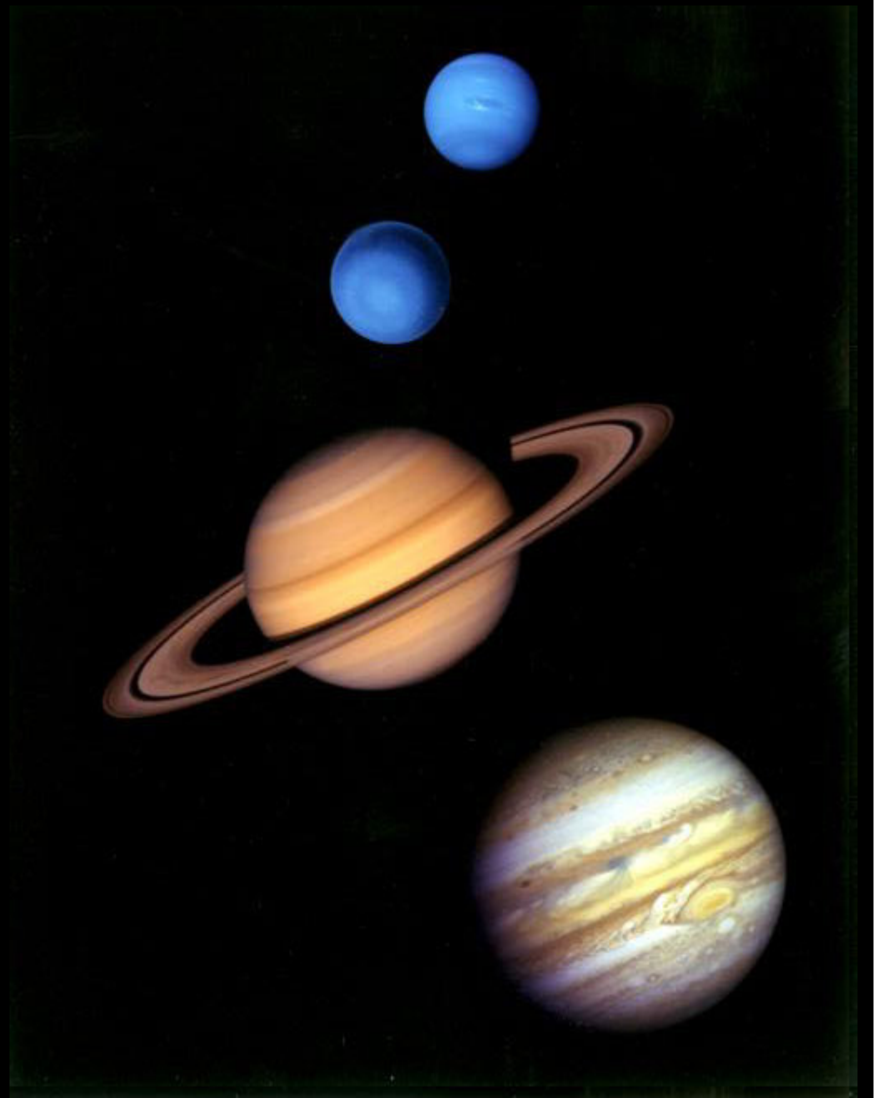
CoRoT: Dec 2006-Nov 2012
27 cm Telescope
4.5 Square degrees
--> First rock planet
--> First reflected light from planet
--> First transiting “temperate” gas- giant
--> First planet of young, active star
--> Transiting brown dwarfs with precisely determined parameters

Kepler: March 2009-May 2013
95cm telescope
100 Square degrees
--> Statistics of planets

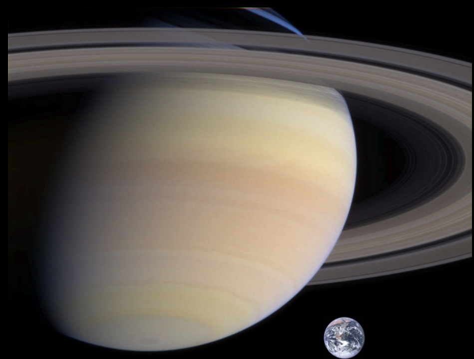
K2: continuation in CoRoT-like mode

Planets in the solar-system



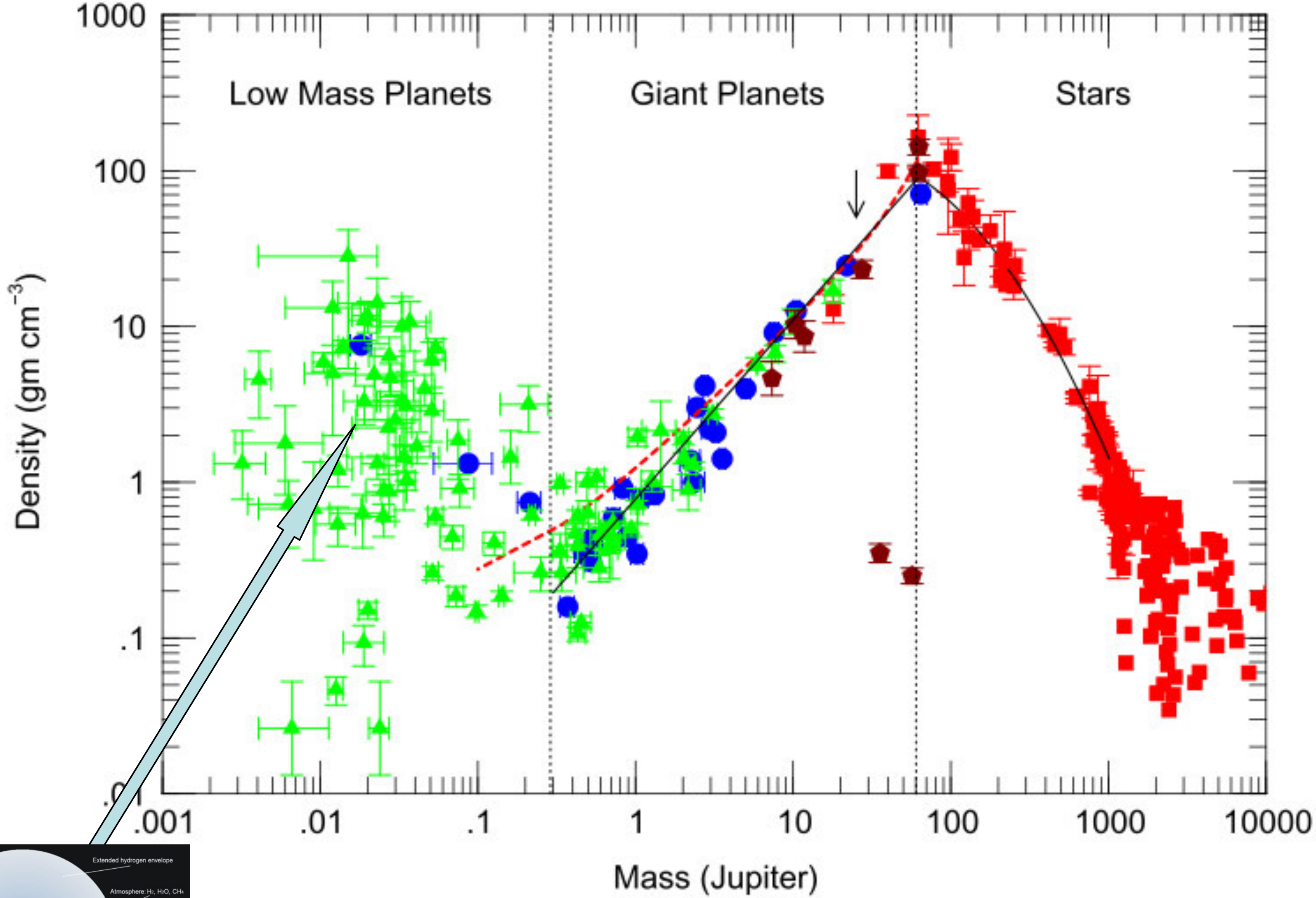


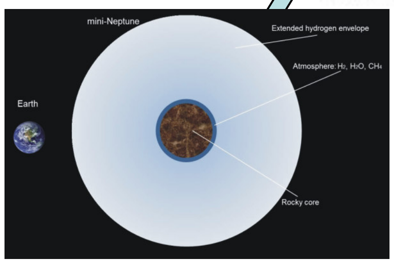
Gas(Ice-)giants (density 0.7-2.2 gcm^{-3}) and
Rocky planets (density 4-6 gcm^{-3}) .



The big surprise CoRoT und Kepler:

-“Super-Earth“, or „mini Neputnes“: M~10 M_{Earth}), Density 1-10 gcm^{-3}





No dsicontinuety at
BD/planet boundary

(Hatzes, Rauer 2015)

Up-coming Space-Missions

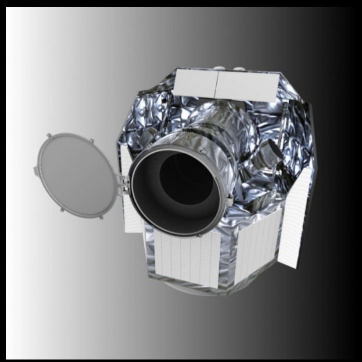
TESS: launch Dec 2017

4x10 cm telescopes (no overlap of the fields)

24x24 Square degrees

--> All sky survey for planets with orbital periods of typically less than 20 days.

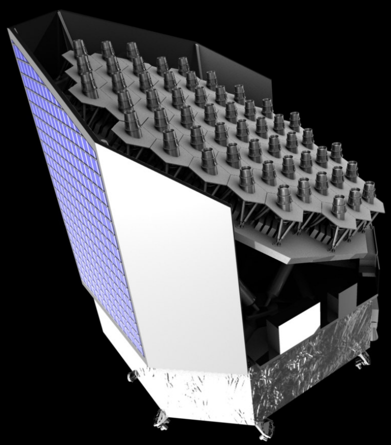
Focus on late-type stars.



CHEOPS: launch 2017/2018

32 cm telescope

--> Determination of precise diameters of known transiting planets, search for transits of known RV-planets.



PLATO: launch 2025

24x12cm Telescopes (overlapping fields)

2232 Square degrees

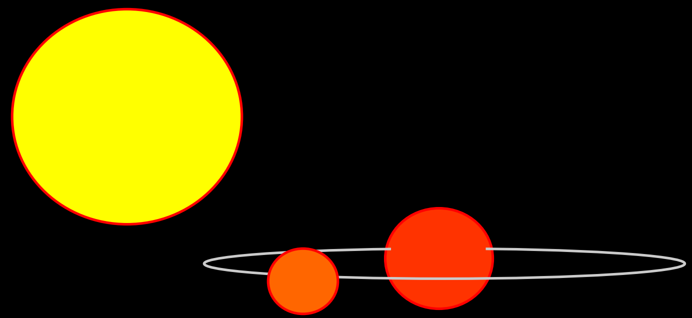
--> Transiting terrestrial planets in habitable zone of relatively bright solar-like stars. Precise stellar parameters, evolution of planets.

Problem of transit search programs: False-positives!

Class 1: Host star is giant
(Low-resolution spectrograph)

Class 2: Host is a (grazing) SB1-binary
(RV-measurements with high-resolution spectrograph)

Class 3: Eclipsing binary within the PSF
(Imaging and high-resolution NIR spectroscopy)



Instrumentation the Alfred-Jensch telescope

The Alfred Jensch telescope of the TLS

Schmidt:

aperture: 1.34 m

f.l.: 4m (f/3)

Nasmyth:

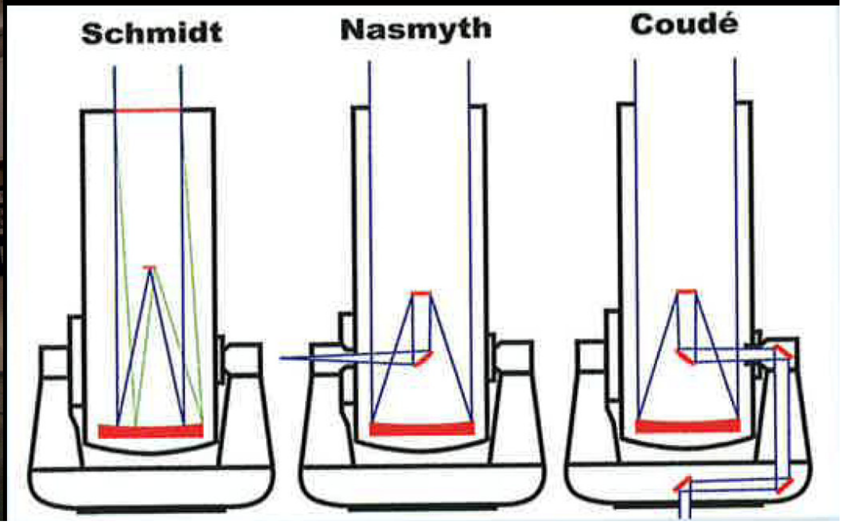
Aperture 2.0 m

f.l.: 21.8m (f/10.9)

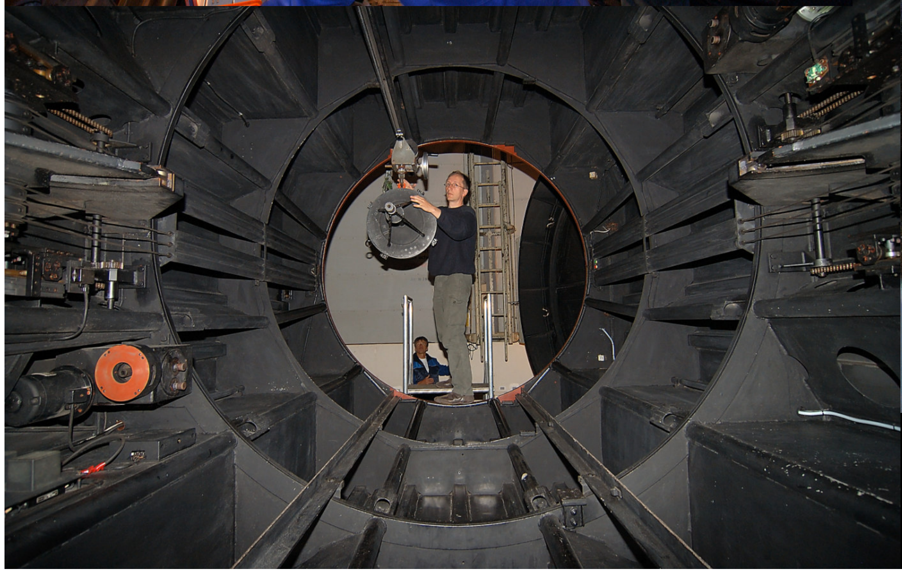
Coudé:

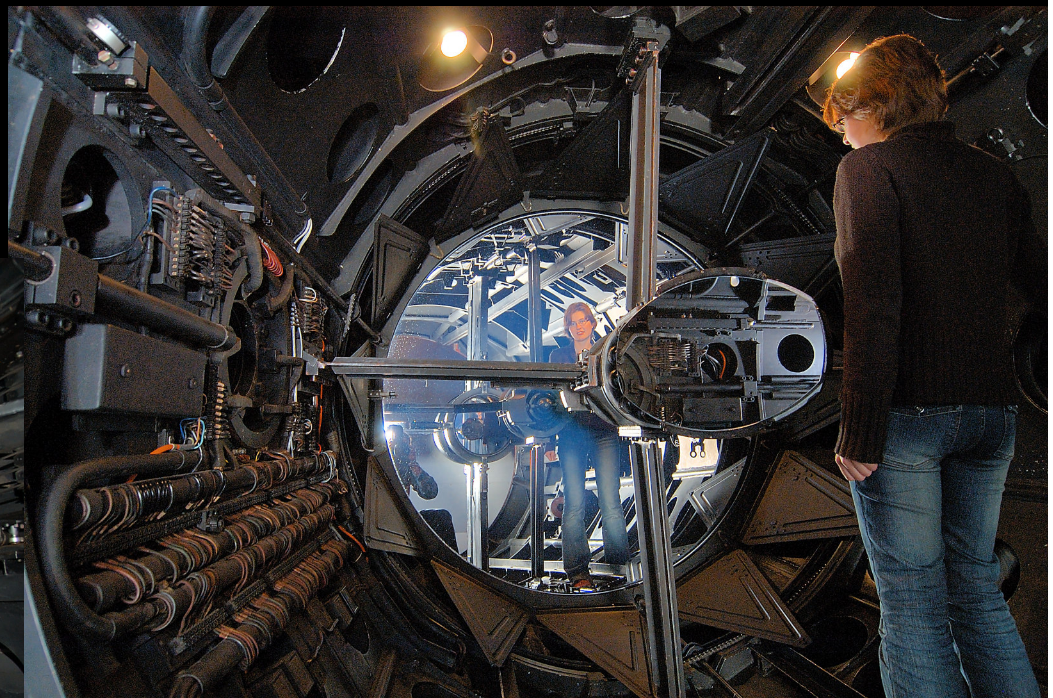
Aperture: 2.0m

f.l.: 92m (f/46)



Instrument change: typically twice a month: this is done manually (4-5 hours of work)



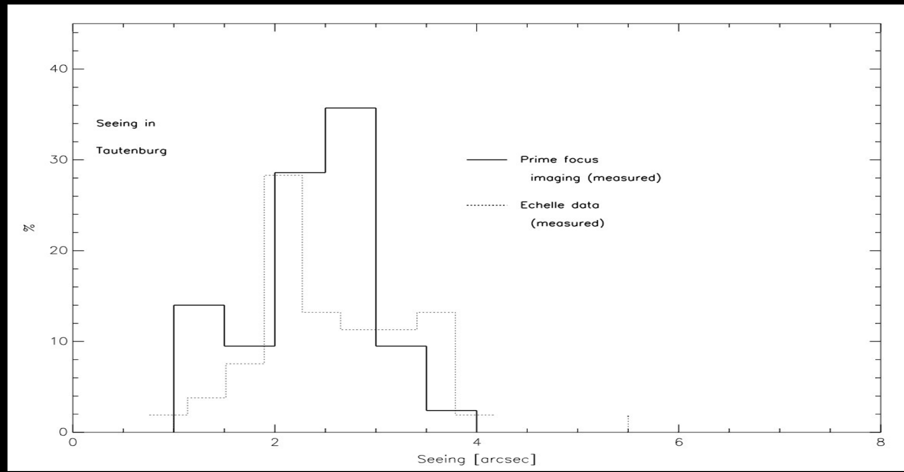


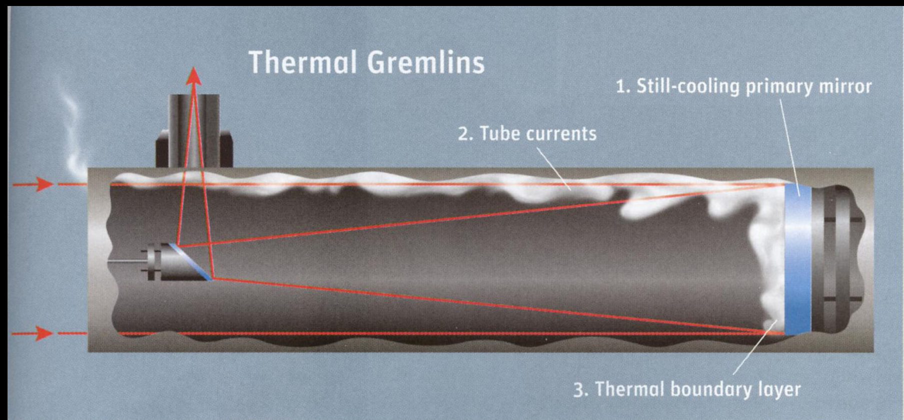
Site Quality

Number of useable hours:
1075+/-170

Sky- brightness (mag):
B (436.1 nm): 21.5 mag
V (544.8 nm): 20.5 mag
R (640.7 nm): 19.9 mag
I (798.0 nm): 18.3 mag

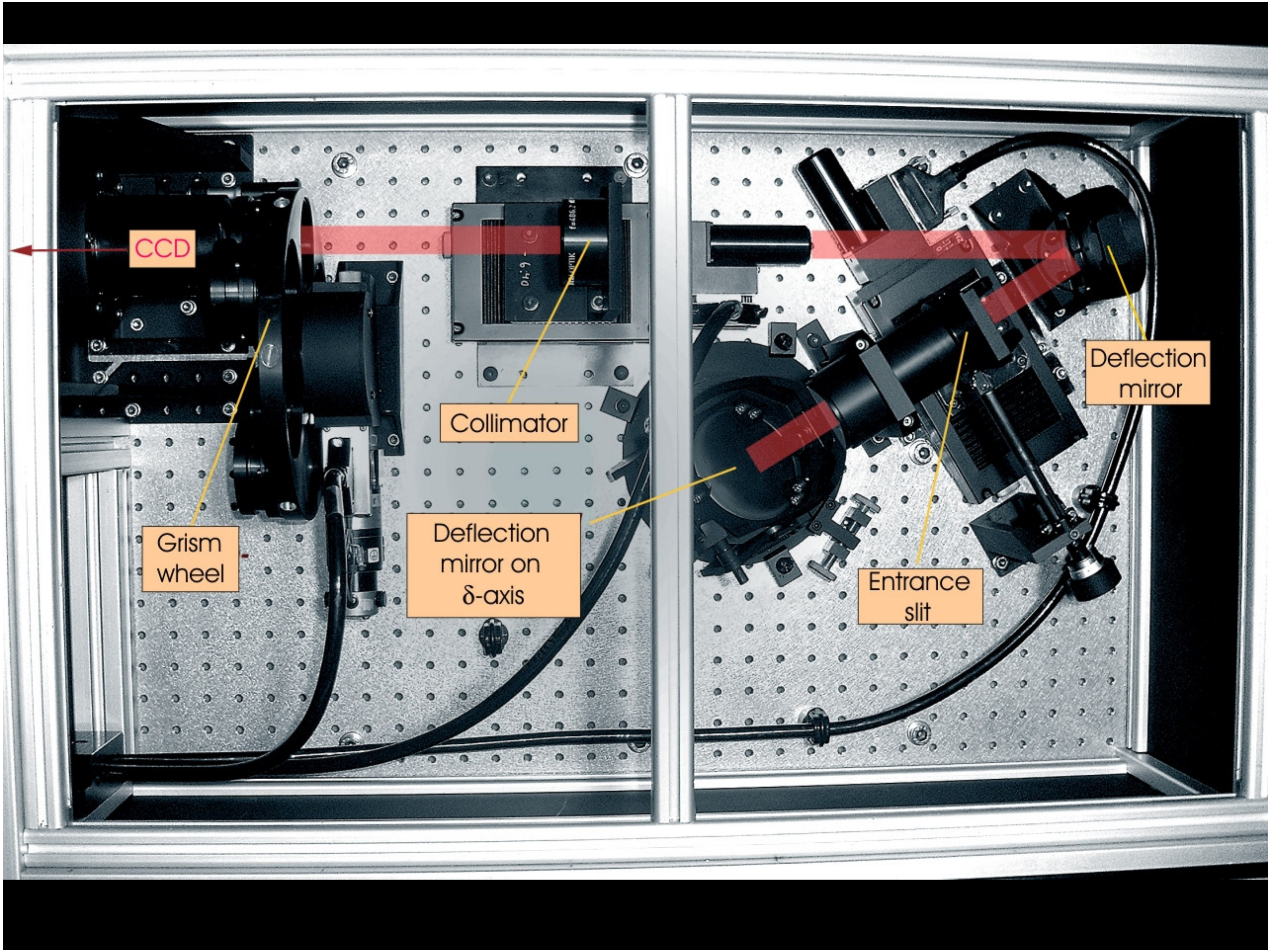
Seeing measurements
(18/19 Jun 2007):
Contribution:
→ 26% external (weather)
→ 23% dome
→ 51% telescope





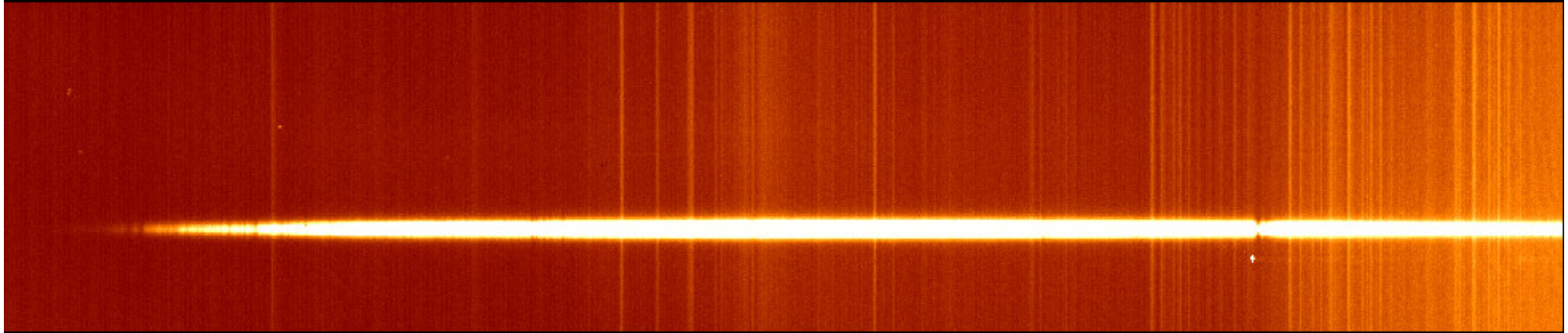
Using NASMYTH Spectrograph to remove class 1 false positives:

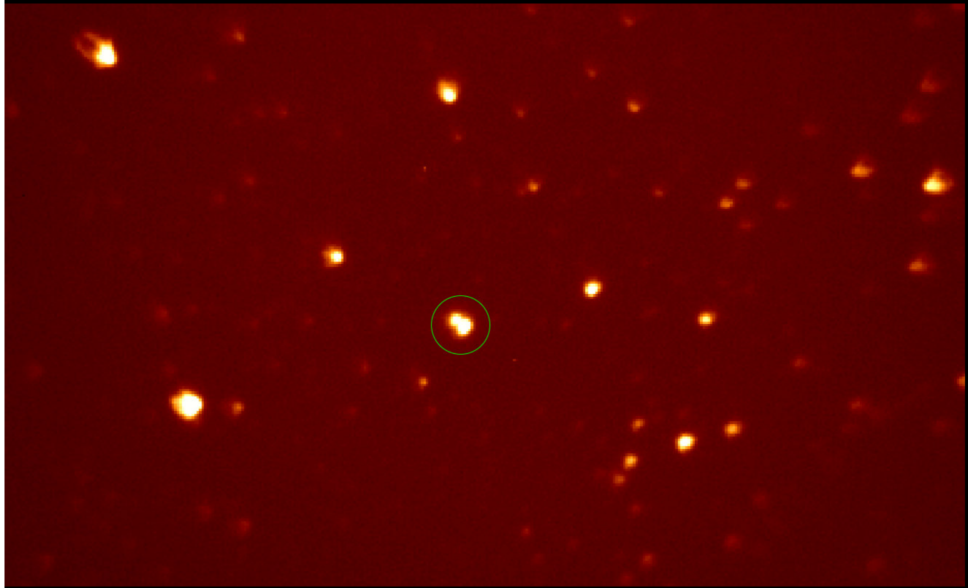
The NASMYTH spectrograph of the AJT is well suited to determine the spectral types of CoRoT (etc) target to ensure that the candidate is a planet of a dwarf star, and not a giant with a stellar companion.

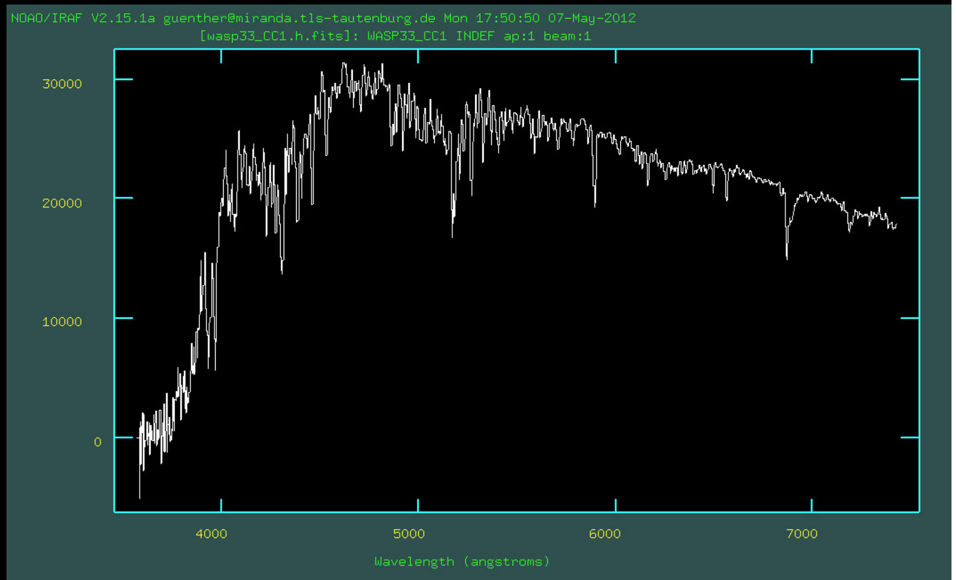


CCD
Collimator
Deflection mirror
Grism wheel
Deflection mirror on δ-axis
Entrance slit

Spectra (GRISM V200)







NASMYTH spectrograph

- F-ratio of Nasymth focus: 10.9
- Focal length of collimator: 482 mm
- Focal length of camera: 135 mm
- Pixel-size of CCD: 15 mum
- CCD: 800x2024 Pixel
- Scale on the slit: 1 arcsec = 103 mum
- Scale on CCD: 1 arcsec = 28.6 mum = 1.9 pixel
- FOV of CCD in imaging mode: 7 arcmin

  (about the same as the guide telescope)

Settings:

B200: 360-749 nm, R=580
V200: 360-935 nm, R=960
R200: 548-950 nm, R=1310
B100: 360-573 nm, R=1220
V100: 467-950 nm, R=2140

S/N-ratio that can be achieved:

	NASMYTH		FORS2 (300V-grism)
V	15min	60min	10 sec
11	160	> 200	315
12	100	200	198
13	60	130	125
14	40	80	80
15	-	50	50
16	-	30	30

Trick: Use ESO FORS2 ETC and 300V grism and simply multiply the exposure time by 360

Using Schmidt mode for removing class 2 false positives

(eclipsing binaries within the PSF)

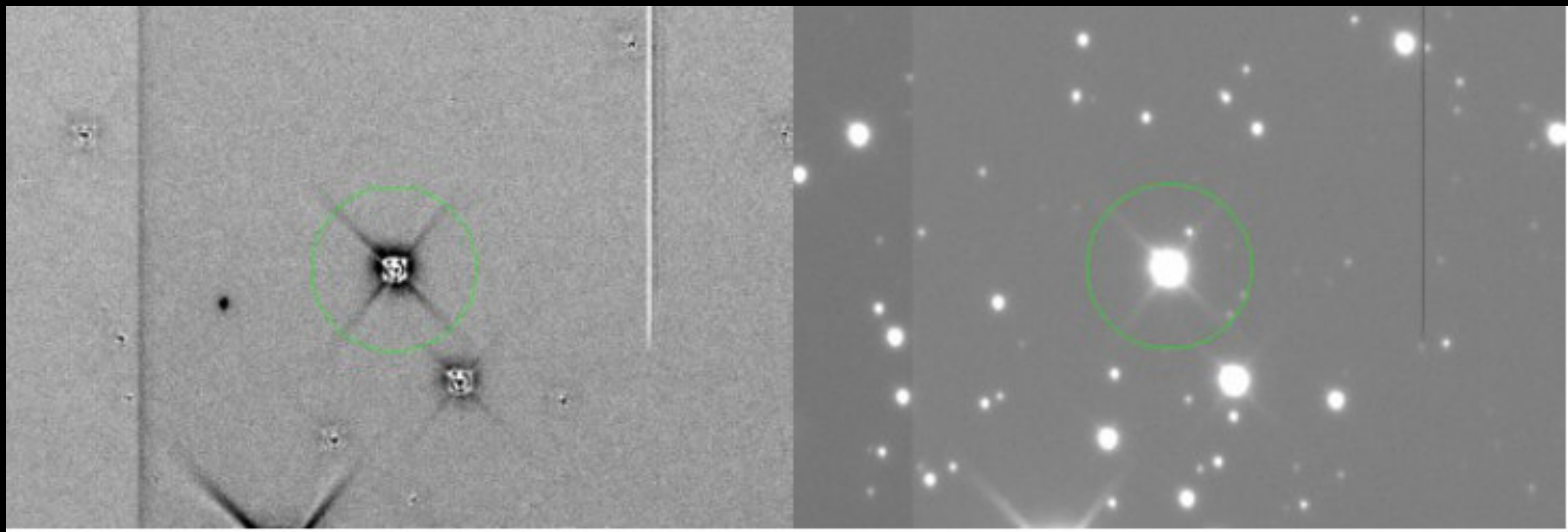
CoRoT experience I

Removing eclipsing binaries with separations of 2-30 arcsec from the target

CoRoT had a photometric mask with a size of (typically) 30x16 arcsec.

By taking one image during transit and one out of transit it was possible to find out whether any of the faint stars within the mask is a binary which is causing the transit.

Note: Many of such FPs can be identified using the centroid method during the LC analysis.

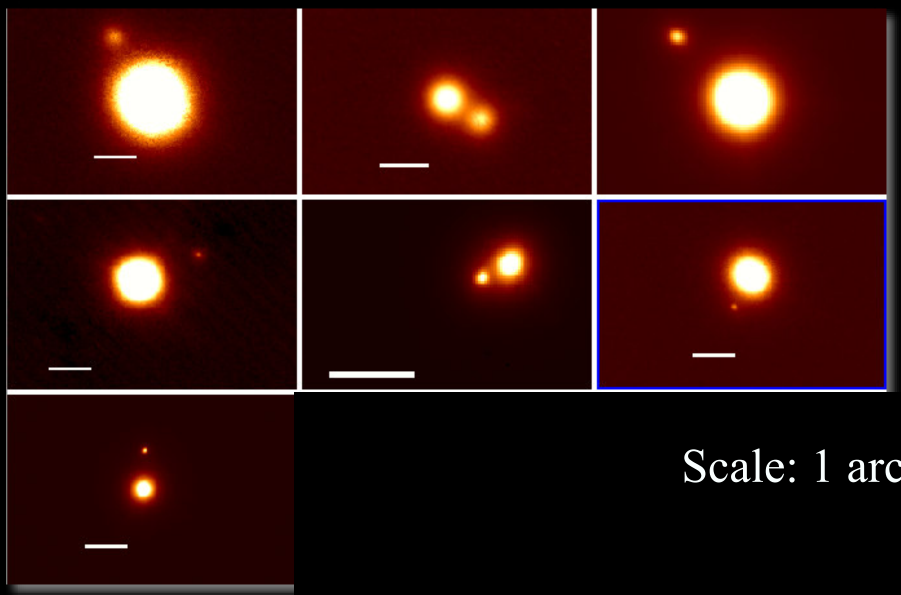


CoRoT experience II

Excluding eclipsing binaries with separations < 2 arcsec from the target (Guenther et al. 2013; Guenther & Tal-Or 2010).

Expectation: ~6% of the stars should have such companions.
CoRoT Result: 30-40% have one!

Santerne et al. (2012) found by Kepler a FP-rate 30% for giant planets.



Scale: 1 arcsec

Schmidt mode of Alfred-Jensch telescope

Currently 2k x 2k SITe chip of 24µm x 24µm pixel size (1.2 arcsec/pixel)

42' x 42' field of view.

6kx6k CCD being planed.

→S/N ≈ 3 of 22.8 mag star in R in an hour

→S/N ≈ 3 of 22.0 mag star in R in 8 minutes

The 7-hannel imager GROND

The TLS participated in building GROND
(optical design, NIR-detector, M3-mirror)
For the 2.2m ESO/MPE telescope in La Silla (science case GRBs):

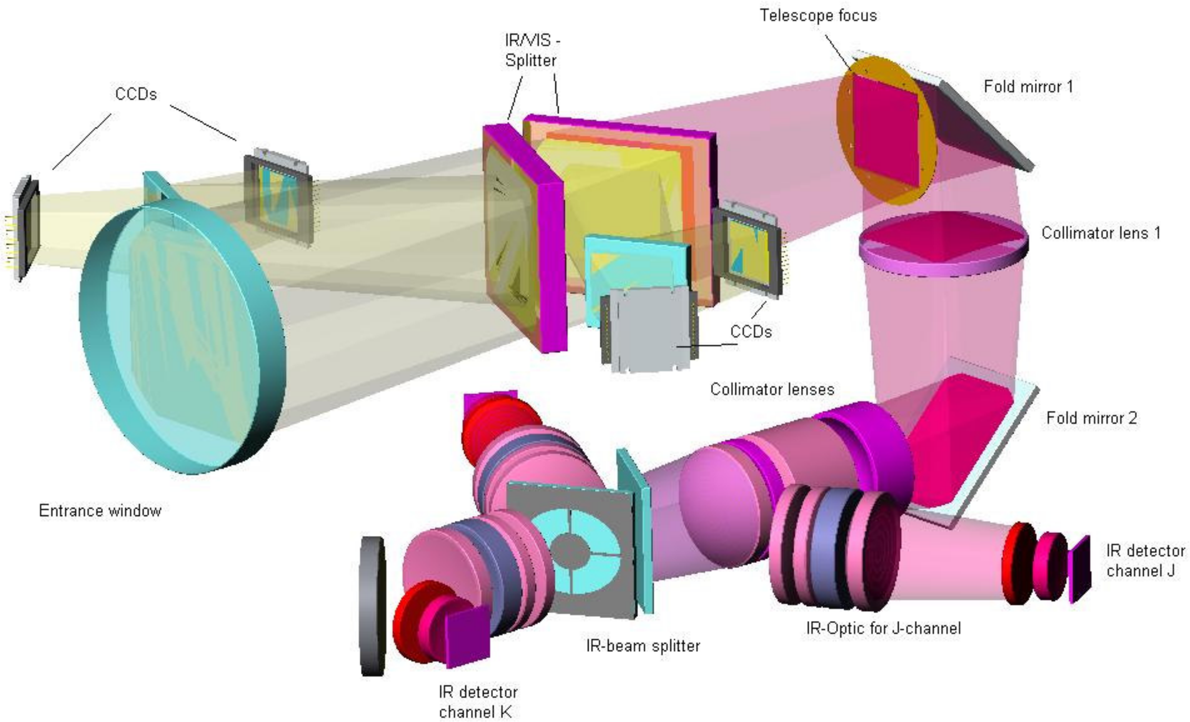
Visual channels: 5.4x5.4 arcmin field of view (2kx2k CCD):

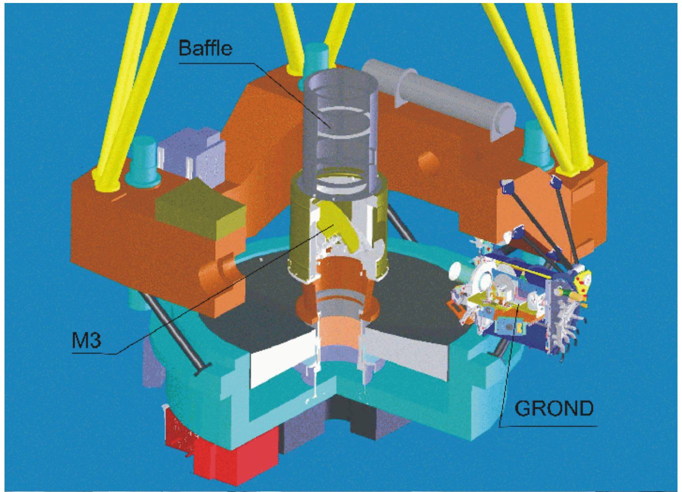
- g’ 8min: 24.2 mag
- r’ 8 min: 24.2 mag
- i’ 8 min: 23.7 mag
- z’ 8 min: 23.5

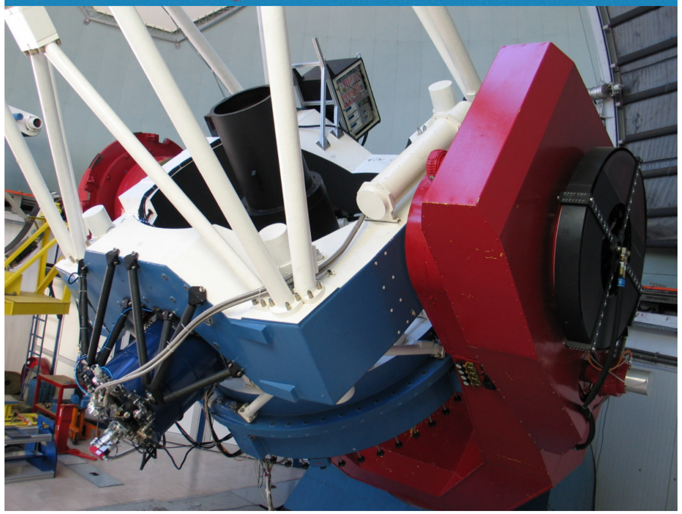
NIR channels: 10.2x10.2 arcmin field of view (1kx1k HAWAI detector):

- J 8 min: 21.4 mag
- H 8 min: 20.4 mag
- K 8 min: 19.0

GROND


Telescope focus
IR/VIS -
Splitter
CCDs
Fold mirror 1
Collimator lens 1
CCDs
Collimator lenses
Fold mirror 2
Entrance window
IR detector
channel J
IR-Optic for J-channel
IR-beam splitter
IR detector
channel K


Baffle
M3
GROND



New transit surveys

All new surveys are targeting bright stars, and have large, or even huge photometric apertures.

- **K2** (ongoing): 150 ppm for a V = 12 mag star in 1 hour integration time, number of observed stars in the K2 mission will be about 4 -5 times larger than the number of stars observed by CoRoT.

- **TESS** (2017+): 500000 stars in total, 200 ppm in one hour for I=10 mag star, main targets F5-M5 stars, mostly planets with periods < 20 days.

  --> PSF of TESS of 44x44 arcsec.

- **PLATO** (2024+): 500000 stars in total, 25 ppm for V=11 mag star in one hour; planets with periods < 1 years; stellar parameters from oscillations; 24 cameras with overlap.

  --> PSF of PLATO 45x45 arcsec

Requirements for Imager I

- Since the targets are V=10-12 we need to exclude binaries of

  V=15-17 for Jupiter-size planets,

  V=15-19 for Neptune-size planets,

  V=18-21 for planets of 1-2 R_{Earth} (note there are typically at least one such star per square-arcmin closer than 30° to the plane of the MW.)

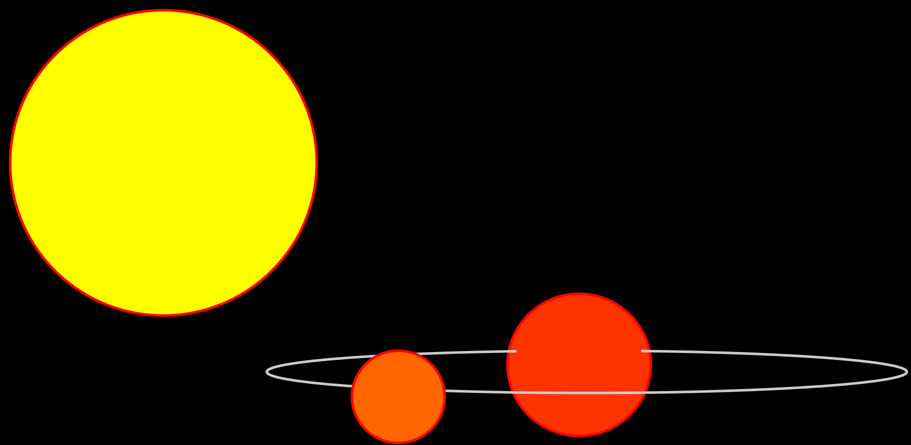
- FOV >10x10 arcmin to have enough comparison stars of roughly equal brightness as the target.

Requirements for Imager II

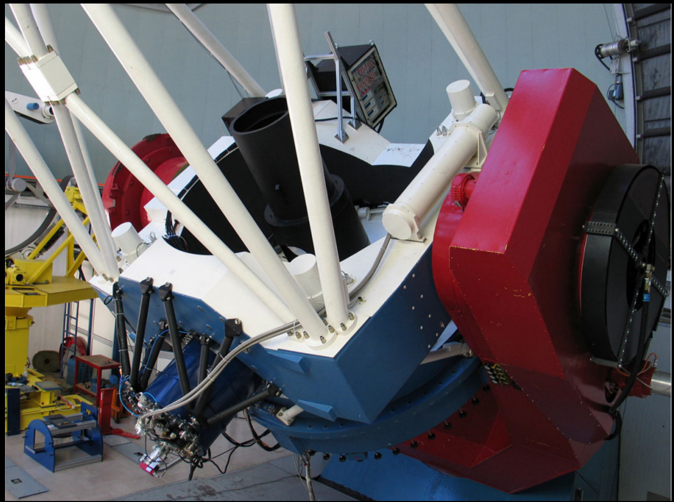
- If the eclipsing binaries were physical companions, the companions MUST have a much later spectral types (e.g. M-stars), and the transits MUST then be deeper in the red than in the blue.

- What is needed is an imager with just two channels were the S/N in both channel is about the same.

- Example: Triple star-system consisting of a G-star primary and two eclipsing M-stars which mimics a star with Jupiter-sized planet. Such a system would have transits that is 0.6% deep in B and 2.3% in R.



Existing multi-channel Imagers



Disadvantages:

-- FOV often small.

-- S/N very different in the different channels.

-- Too many channels!

-- Very limited amount of observing time available.

---> New instrument(s) needed for TESS and particularly for PLATO

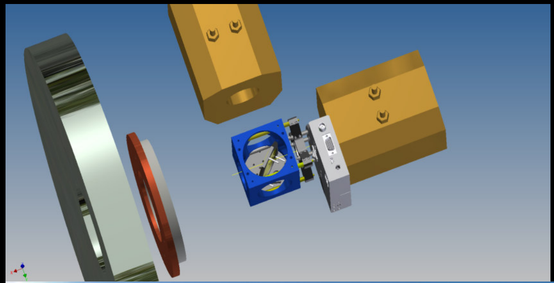
Instrument	Telescope	No. of Channels	Field of View [arcmin]
GTI	OSN 0.9	2	13.0 x 13.0
GROND	ESO/MPG 2.2	7	5.3 x 5.3
MAIA	Mercator 1.2	3	9.0 x 6.6
BUSCA	Calar Alto 2.2	4	12.0 x 12.0
ULTRACAM	WHT	3	5.0 x 5.0
	Danish 1.54	2	0.8 x 0.8

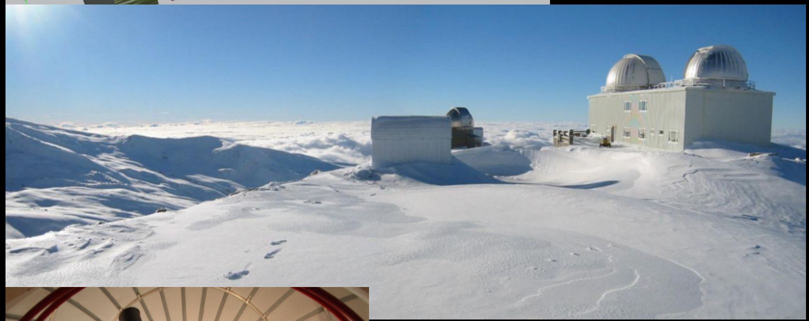
The Graz-Tautenburg Imager

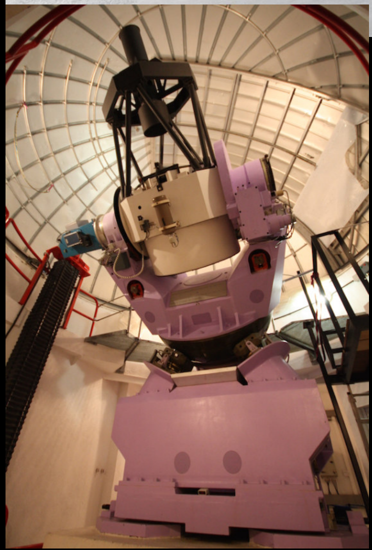
Table 1: Expected performance of GTI on the OSN 0.9 m telescope using 15 minute exposures. The first column gives the brightness, the second column the spectral type of the target. The last column lists the signal to noise ratio for the given wavelength range. The listed wavelength ranges can be measured with the specified dichroics.

V [mag]	SpecType	Dichroic	Arm	Wavelength [µm]	S/N
14	A5V	#1	Blue	380-550	2860
14	A5V	#1	Red	584-700	1860
14	G2V	#1	Blue	380-550	2320
14	G2V	#1	Red	584-700	2180
14	M3V	#1	Blue	384-550	1490
14	M3V	#1	Red	584-700	3040
21	G2V	#1	Blue	380-550	49
21	G2V	#1	Red	584-700	36
14	G2V	#2	Blue	380-490	1580
14	G2V	#2	Red	520-700	2630
14	G2V	#3	Blue	400-790	4550
14	G2V	#3	Red	830-950	1390
14	M3V	#3	Blue	400-790	4550
14	M3V	#3	Red	830-950	2850

Beamsplitters (Thorlabs, Inc.)	380 - 550 nm / 584 - 700 nm (#1)
	380 - 490 nm / 520 - 700 nm (#2)
	400 - 790 nm / 830 - 950 nm (#3)







Repetition:
Problem of transit search programs:
False-positives!

Class 1: Host star is giant
(NASYMTH)

Class 2: Host is a (grazing) SB1-binary
(high resolution optical spectroscopy)

Class 3: Eclipsing binary within the PSF
(Imaging, high-resolution NIR-spectroscopy)

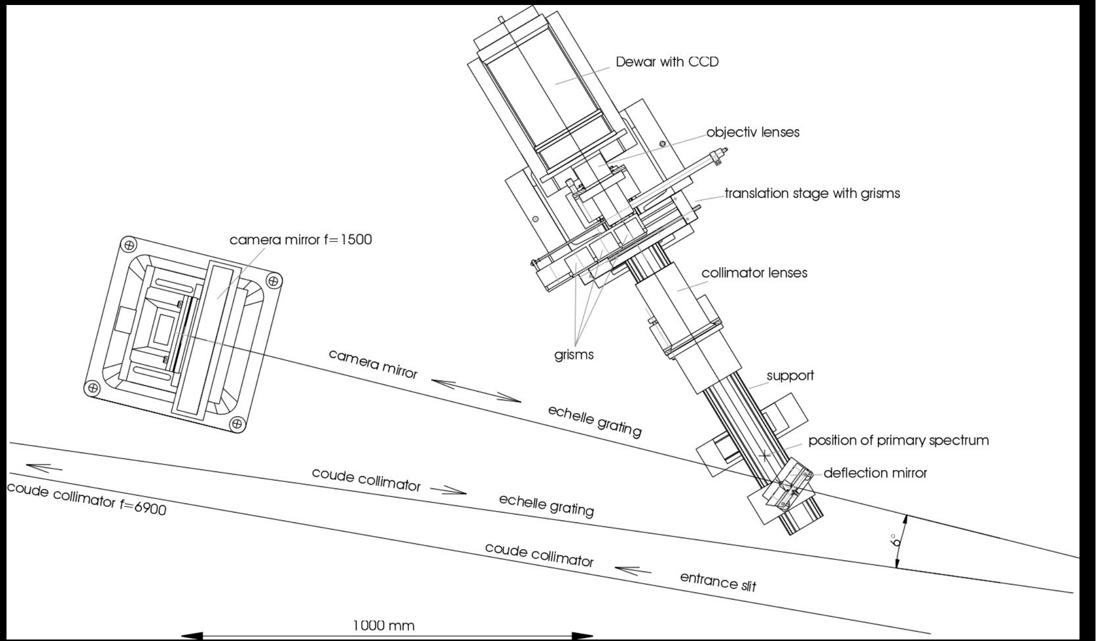
The high-resolution Echelle Spectrographs

TLS- Echelle spectrograph

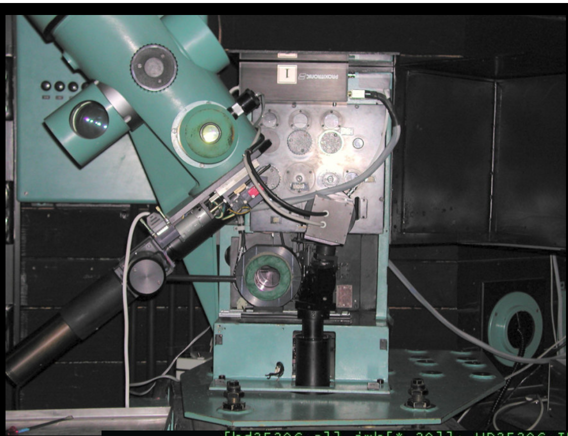
- UV grism: 3400 to 5500 Å
- VIS grism: 4700 to 7400 Å
- IR grism: 5380 to 9270 Å

- f-ratio at Coudé focus: 46
- f-ratio camera: 3
- Pixel-size of CCD: 13.5 mum
- CCD: 2kx2k

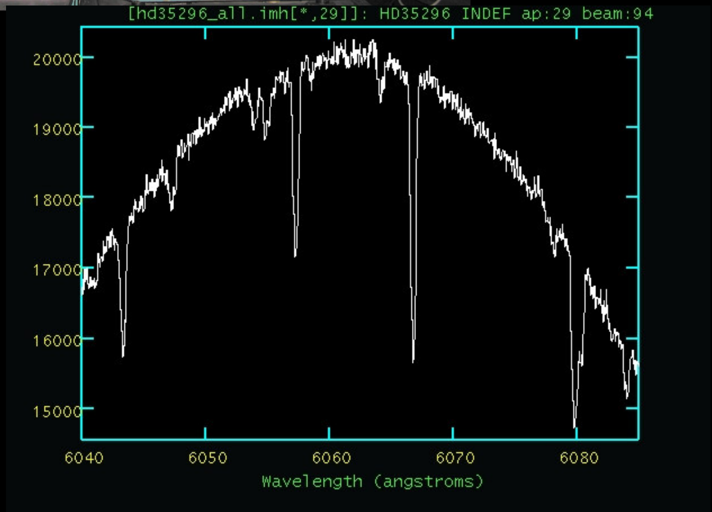
- Slit: 1.2 arcsec (0.57 mm): R=67000
  --> 900s 10mag star : S/N=20-36

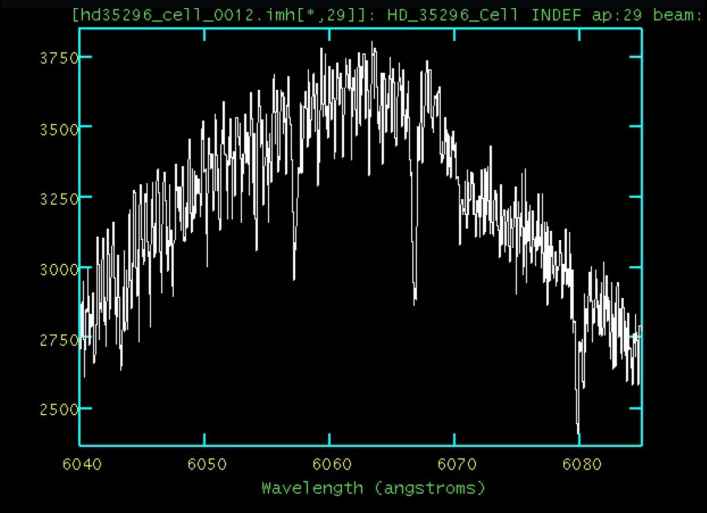


- Slit: 2.0 arcsec (1.0mm): R=30000
  --> 900s 10mag star : S/N=50
  (use Café exposure-time calculator with 0.0 mag extinction.)

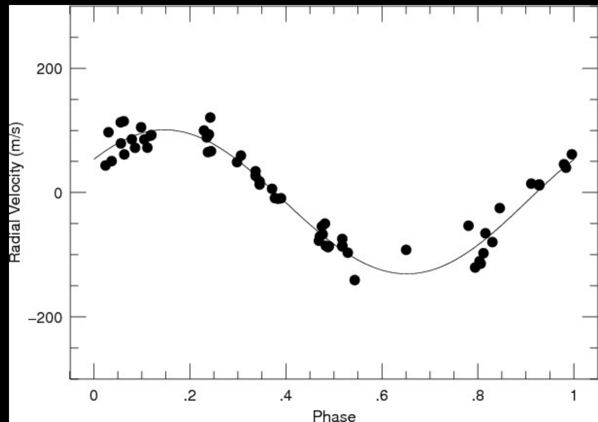


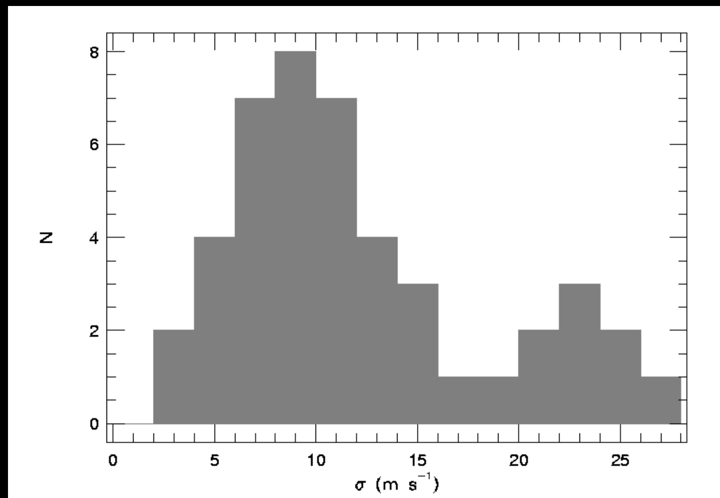
Iodine-cell measurement



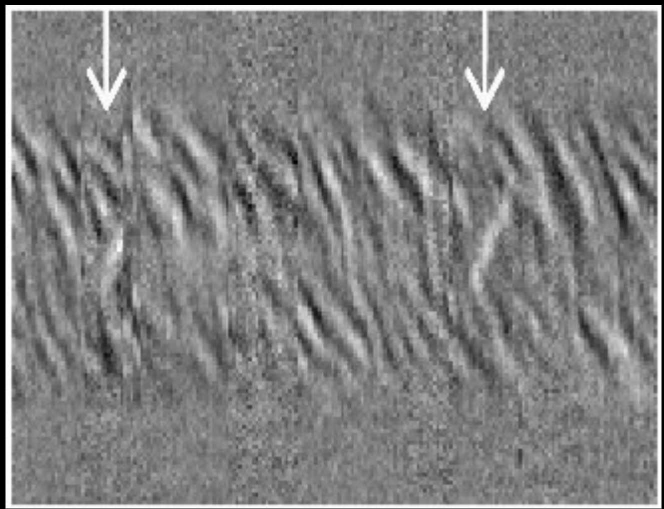


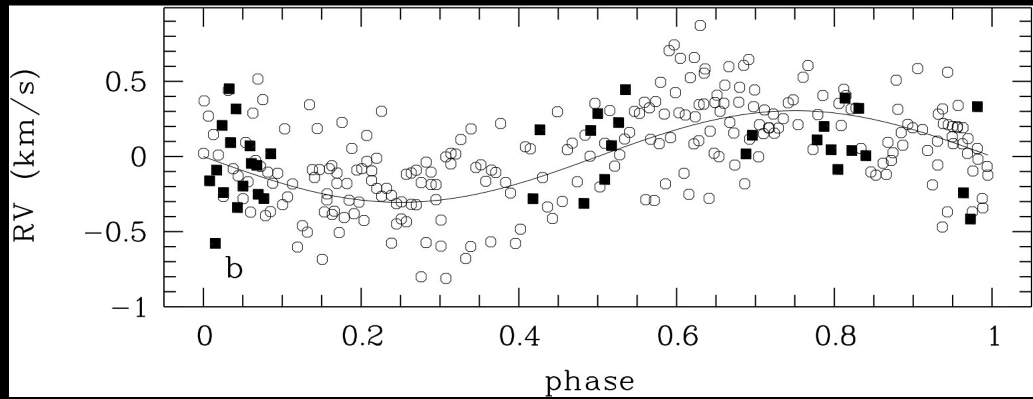
HD32518





HD15082b (WASP-33b)





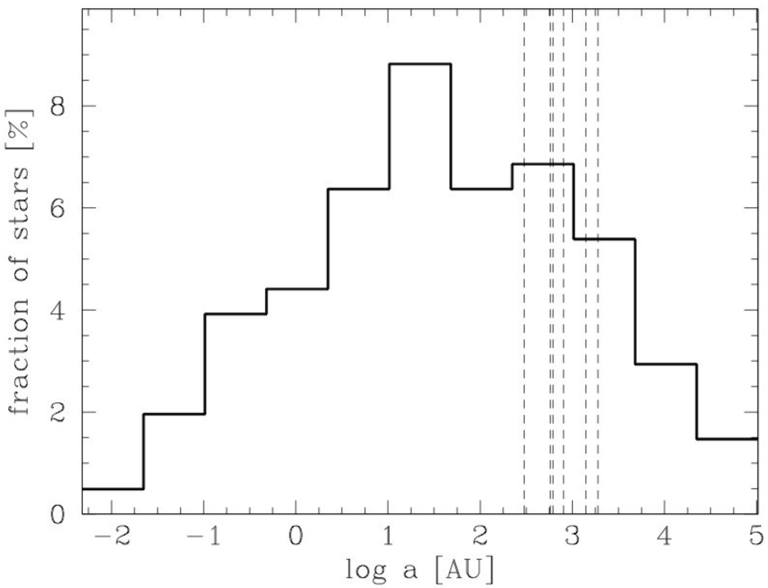
Discovery of the first close-in planet of an A-star (amazing that such a planet can exists!)

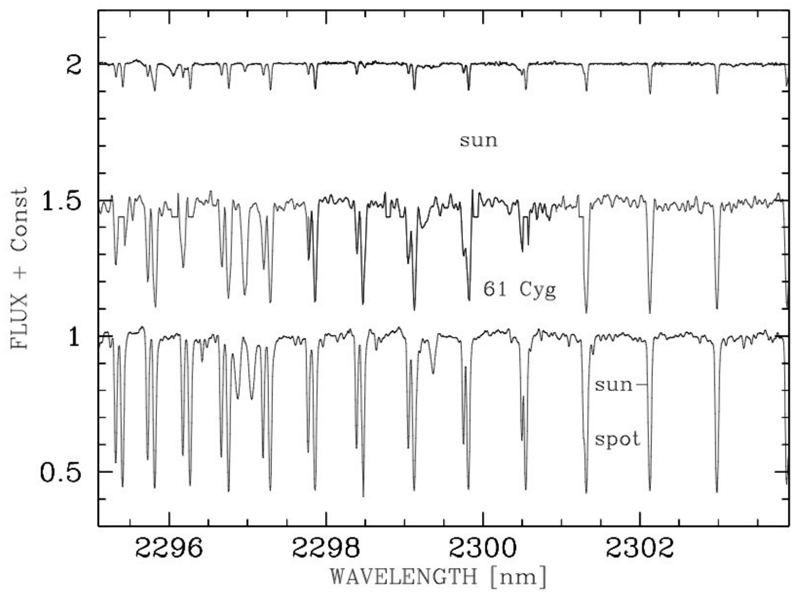
Planet mass 2.1+/-0.2 M_{jup},
Planet radius 1.497±0.045 R_{jup}
Planet density 0.6 gcm^{-3}
Orbital period 1.219 days
Orbit is retrograde (!): projected obliquity 250 deg

The upgrade from CRIRES to CRIRES$^+$

CoRoT experience

- Projected distances of companions found in AO-observations:
 300 and 1900 AU.
- Companions within separations of less than 300 AU can be excluded by means of high-resolution NIR-spectroscopy (brightness difference of M-star to G-star much smaller in NIR). For example: CARMENES & CRIRES+.





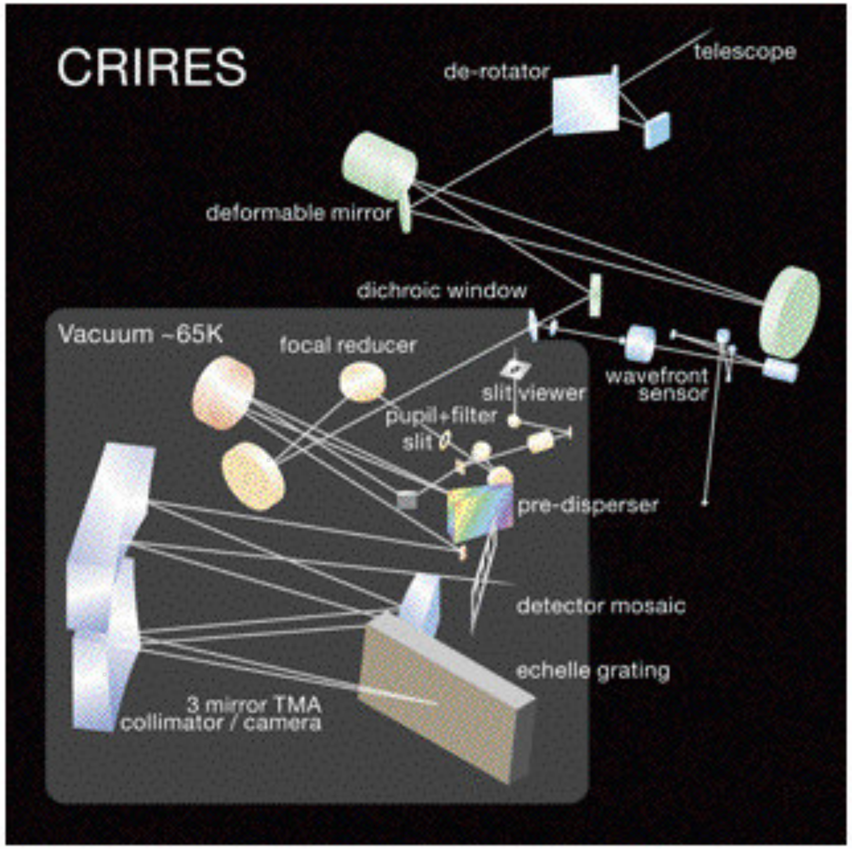
CRIRES (history)

CRIRES was located at the Nasmyth A focus of UT1 and removed in 2014 for the upgrade to CRIRES+.

Main characteristics of CRIRES were:

Wavelength range	0.95-5.2μm
Resolving power (2 pixels)	100,000
Slit width	0.2 and 0.4 arcsec
Slit length	40 arcsec

- ❑Adaptive optics 60 actuators curvature sensing system
- ❑Calibration system with integrating sphere + cont.+ line lamps + gas-cells
- ❑Slit viewer Aladdin array, J, H, K
- ❑Pre-disperser ZnSe prism
- ❑Echelle grating 40x20cm, 31.6 lines/mm, 63.5 deg. blaze
- ❑Detector array 4096x512 pixels using 4 Aladdin arrays, with inter-detector gaps of nominally 283 pixels



The setup was limited to a narrow, single-shot, spectral range of about 1/70 of the central wavelength (15 nm) , resulting in low observing efficiency => Upgrade

CRIRES$^+$ Consortium

5 Institutions:

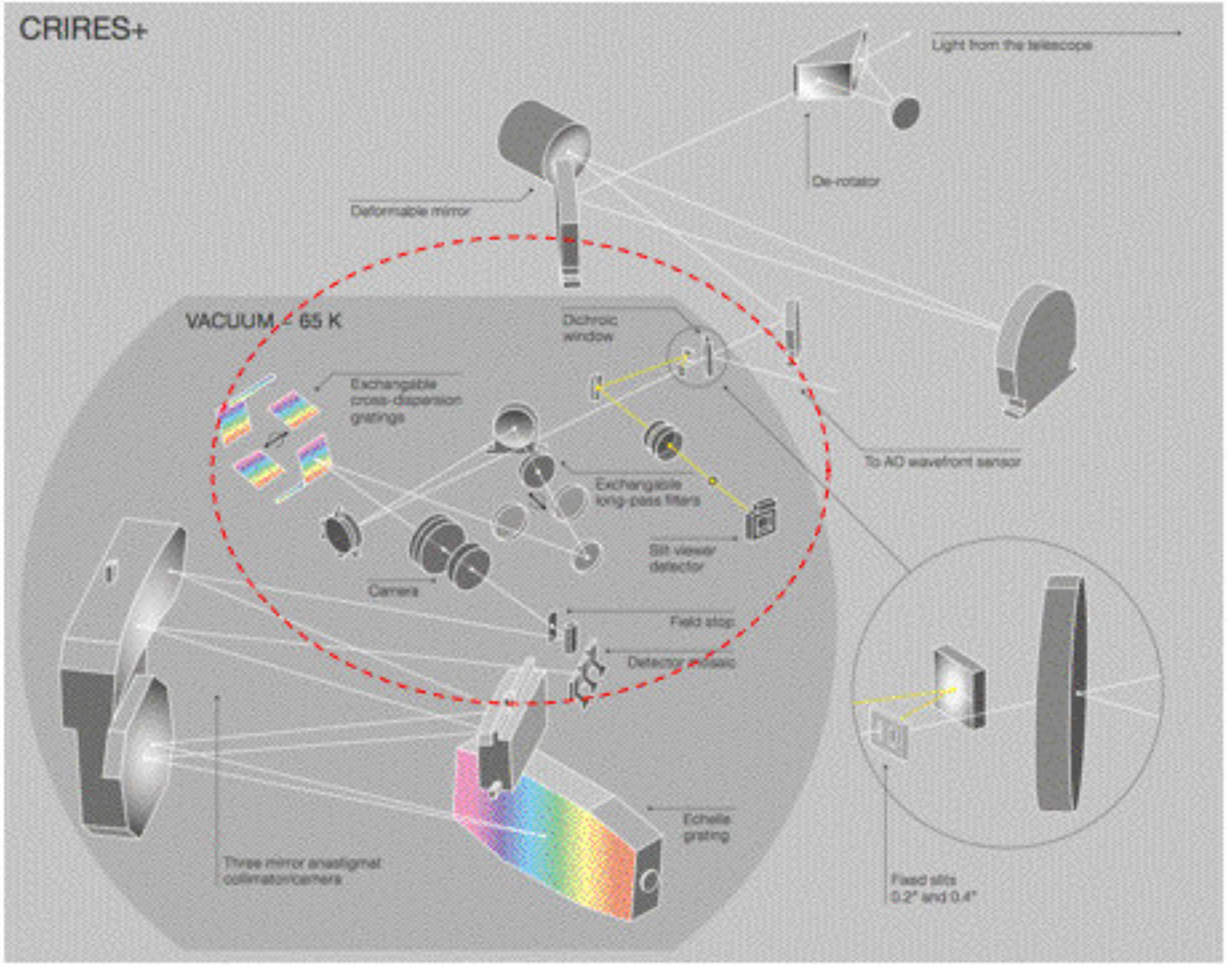
- Thüringer Landessternwarte, Germany (PI A. Hatzes)
- Institut für Astrophysik, Georg-August Universität Göttingen, Germany (Co-PI A. Reiners)
- Institute of Astronomy, Uppsala University, Sweden (Co-PI N. Piskunov)
- Osservatorio di Arcetri, INAF, Italy
- European Southern Observatory

CRIRES⁺: What is required

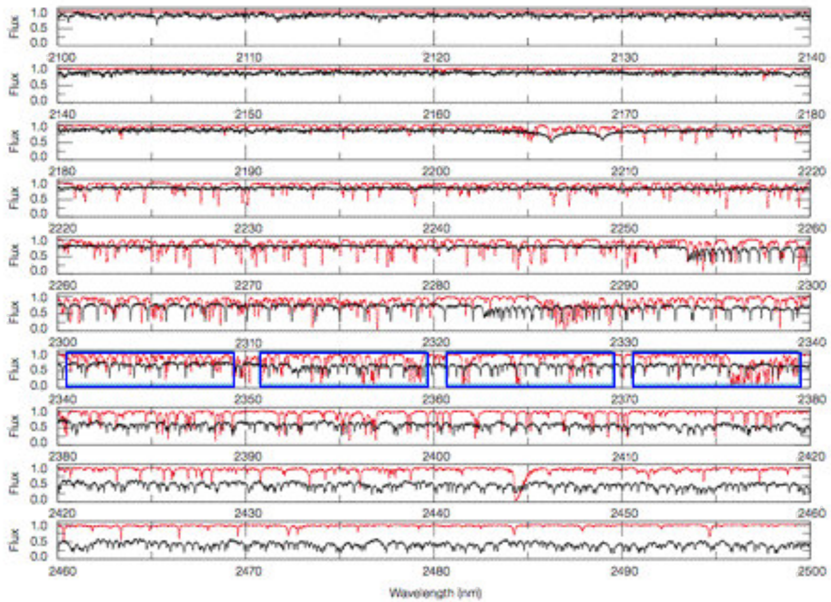
- Turn CRIRES into a cross-dispersed echelle spectrograph
- Upgrade scientific detectors to accommodate multiple orders
- Wavelength calibration from 1-5 µm (UNe lamp and etalon)
- High precision wavelength calibration for RV measurements (new gas cell)
- Add circular / linear polarimetry for magnetic fields
- Support the instrument with new data reduction software
- Refurbish subsystems as required to prolong life

CRIRES^{+}: A cross-dispersed echelle spectrograph

- ❑ Grating wheel with 6 gratings (YJHKLM)
- ❑ New CDU Camera 1-5 µm
- ❑ New slit assembly (0.2 and 0.4 arcsec) and slit viewer
- ❑ Upgrade metrology system
- ❑ New dichroic dewar window
- ❑ Filters and cold stop to reduce stray light
- o But: Don't touch main spectrograph unit



CRIRES$^+$: Cross dispersion and new detectors



The wavelength coverage of the current CRIRES (blue boxes correspond to the four Aladdin detectors currently installed) in the K-band compared to the expected coverage of a single exposure from CRIRES$^+$.

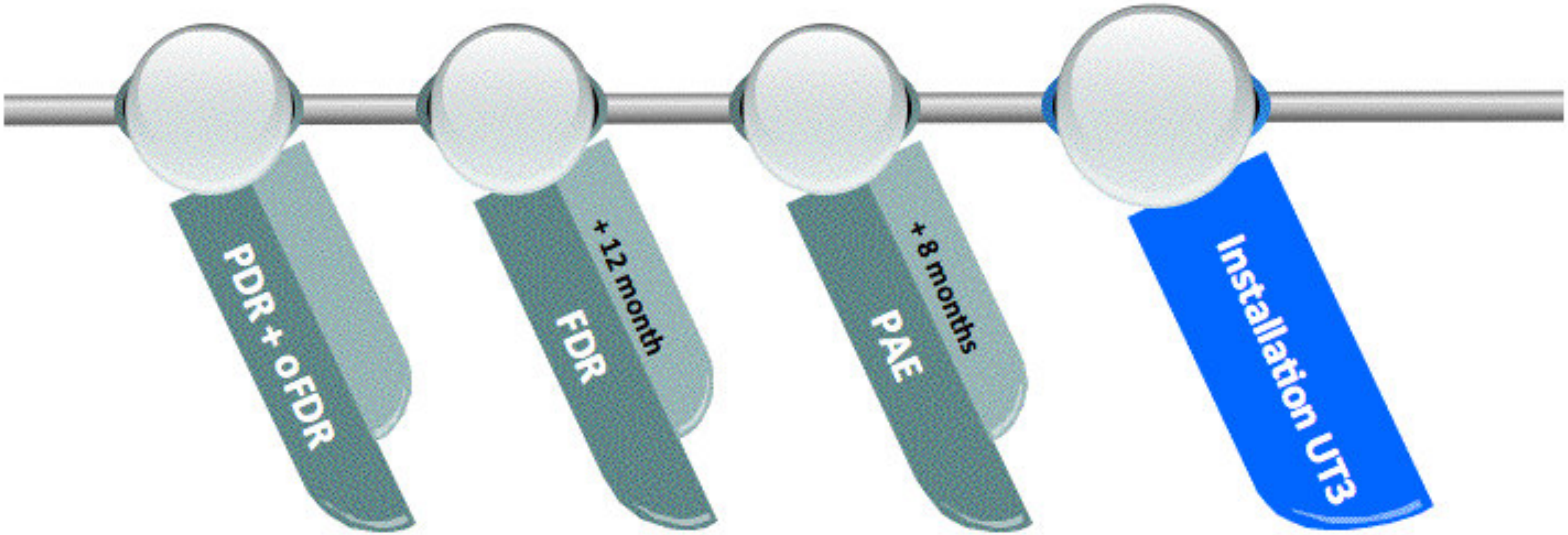
The black line: M4 dwarf star (~ 0.15 M_{Sun}).

Red line: Laboratory spectrum of the first gas cell prototype

Tradeoff: Slit length reduced from 40 arcsec to 10 arcsec

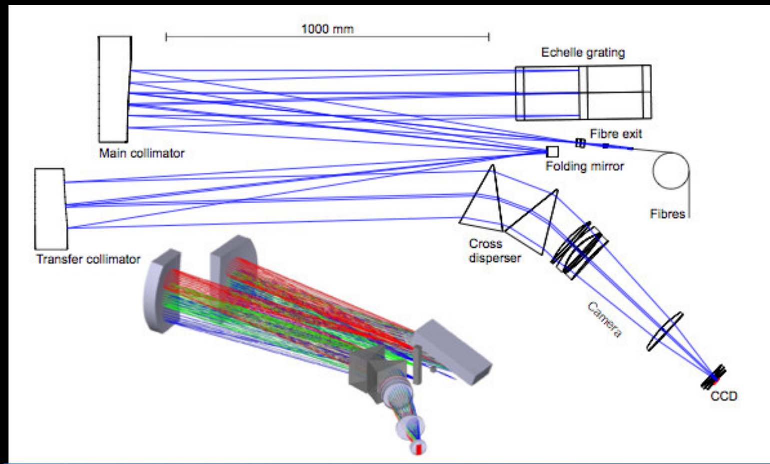
CRIRES⁺: Schedule

April 2015 → May 2016 → December 2017 → January 2018

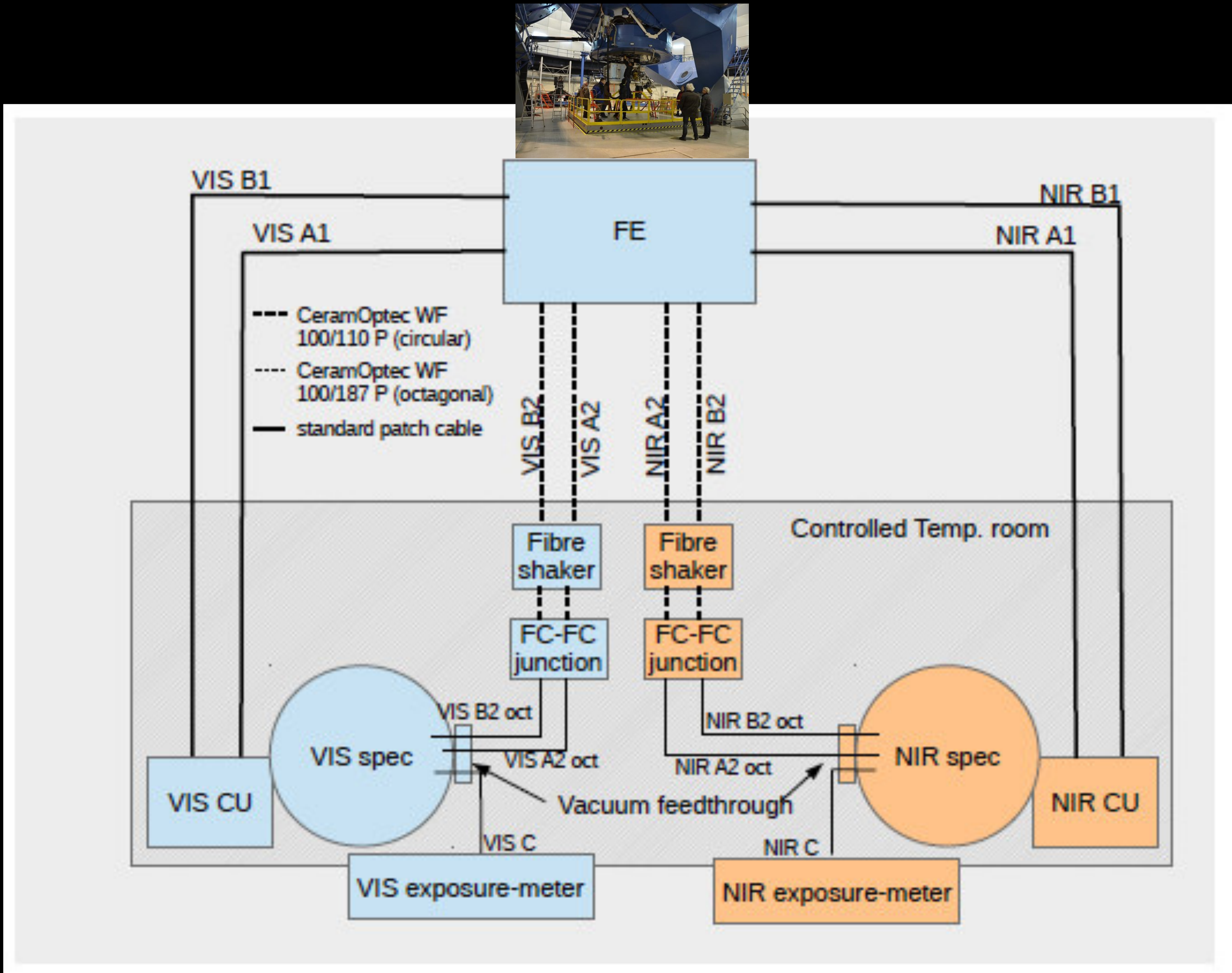


HERMES Echelle spectrograph

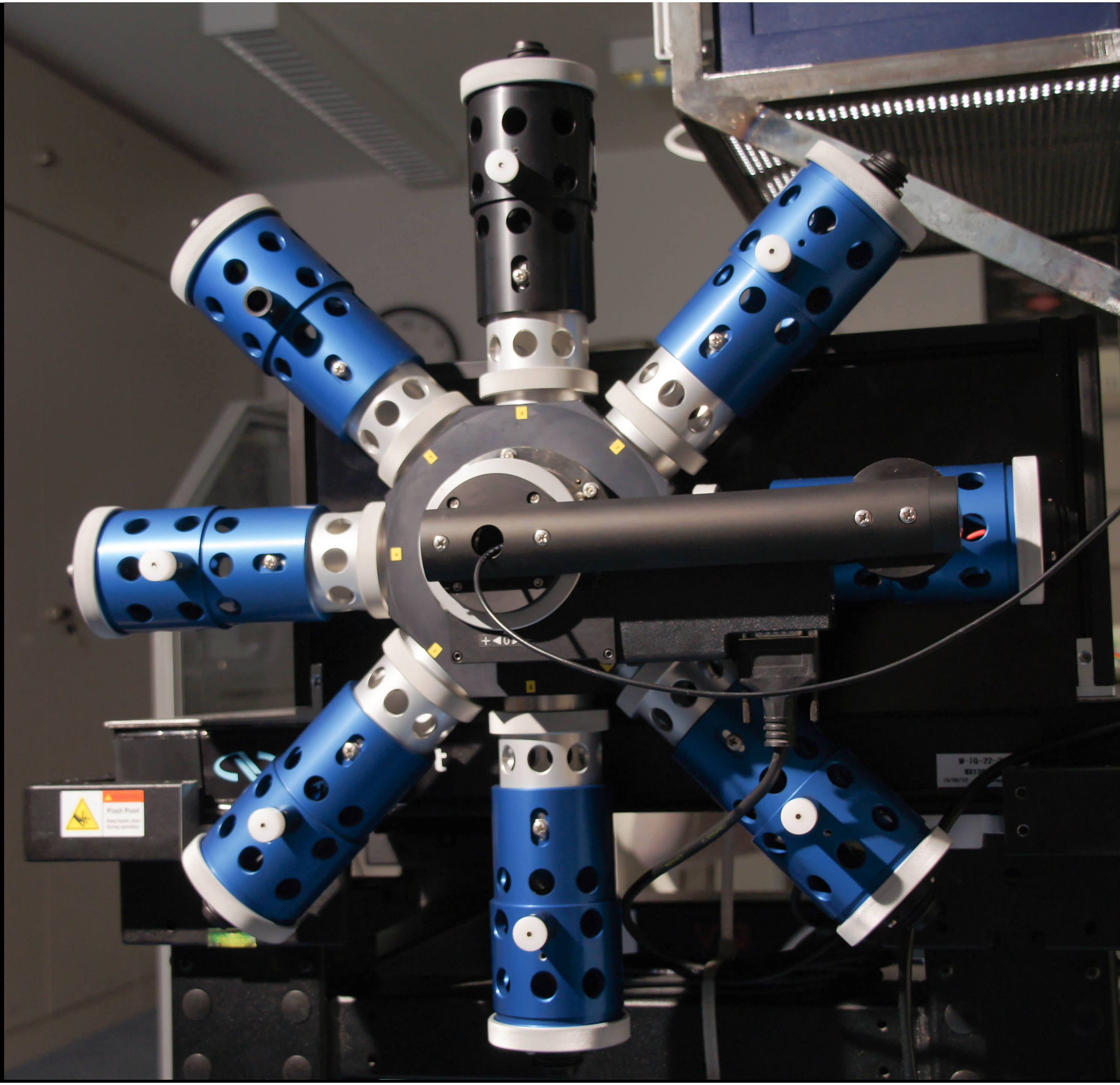
- 1.2-m Mercator telescope, La Palma
- e2V 2kx4.5k CCD
- Collimators f9.2
- Camera f.l. 475mm, f3.1
- High-resolution fibre (2.5 arcsec+image slicer): R=85000, 2.3 pixel sampling
- Low-resolution fibre (2.15 arcsec): R=63000, 3-3.8 pixel sampling
- S/N=100, one hour V=10 mag
- S/N=40, one hour 12 mag star

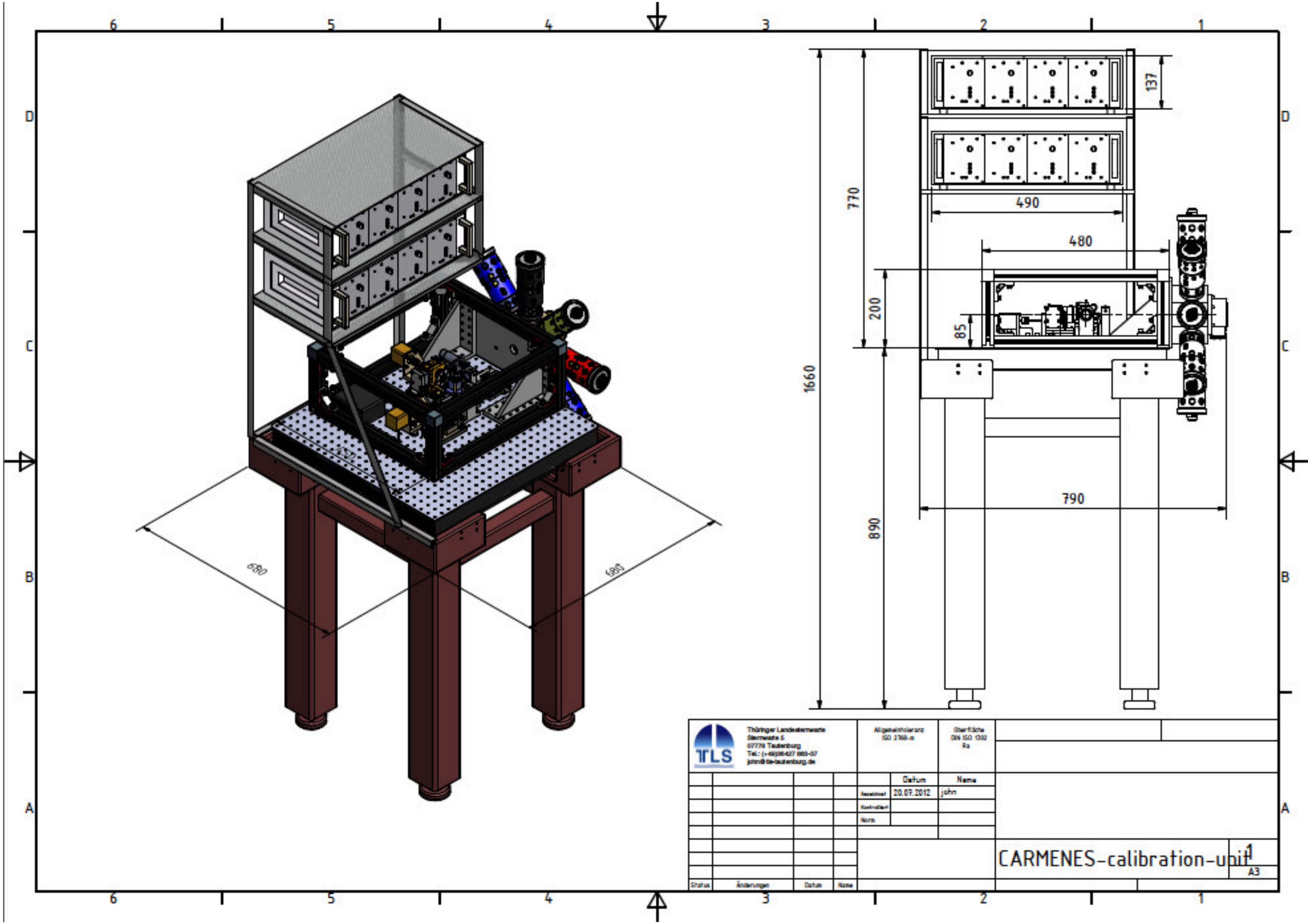


The calibration units of the CARMENES Echelle Spectrograph



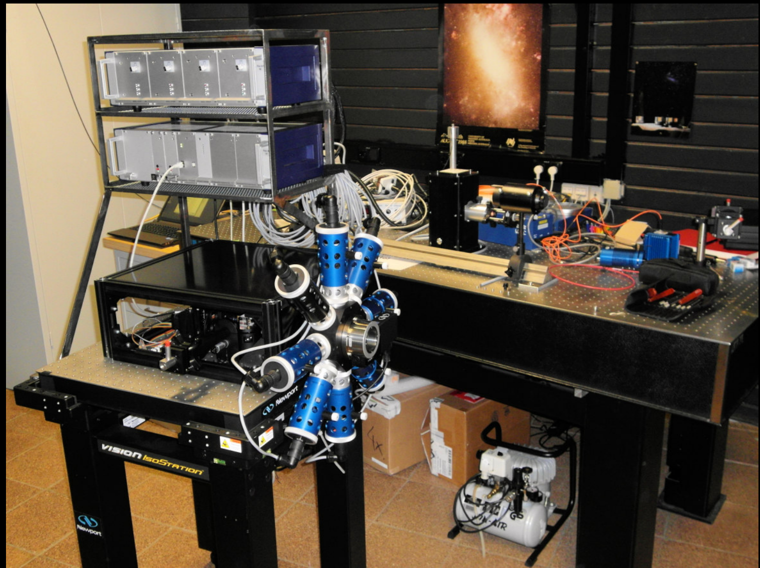
FE
VIS B1
VIS A1
NIR B1
NIR A1
CeramOptec WF 100/110 P (circular)
CeramOptec WF 100/187 P (octagonal)
standard patch cable
VIS B2
VIS A2
NIR A2
NIR B2
Controlled Temp. room
Fibre shaker
Fibre shaker
FC-FC junction
FC-FC junction
VIS B2 oct
VIS A2 oct
NIR B2 oct
NIR A2 oct
VIS spec
NIR spec
VIS CU
NIR CU
Vacuum feedthrough
VIS C
NIR C
VIS exposure-meter
NIR exposure-meter

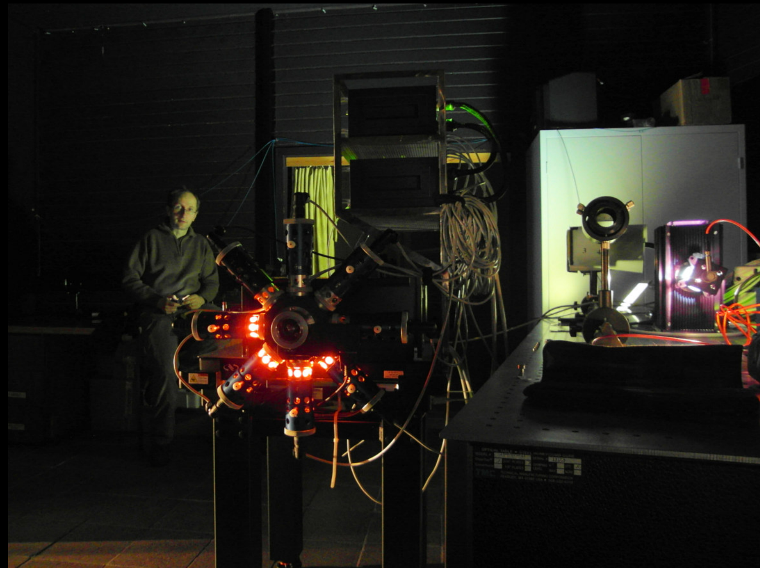


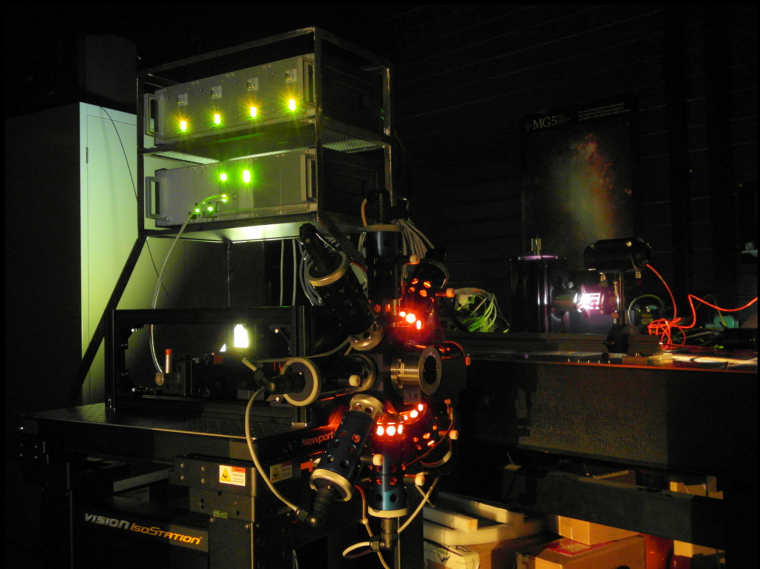


680
680
137
490
480
770
200
85
1660
790
890
Thüringer Landessternwarte
Sternwarte 5
07778 Tautenburg
Tel.: (+49)36427 863-07
john@tls-tautenburg.de
Allgemeintoleranz
ISO 2768-m
Oberfläche
DIN ISO 1302
Ra
Datum
Name
Gezeichnet
20.07.2012
john
Kontrolliert
Norm
Status
Änderungen
Datum
Name
CARMENES-calibration-unit
1
A3

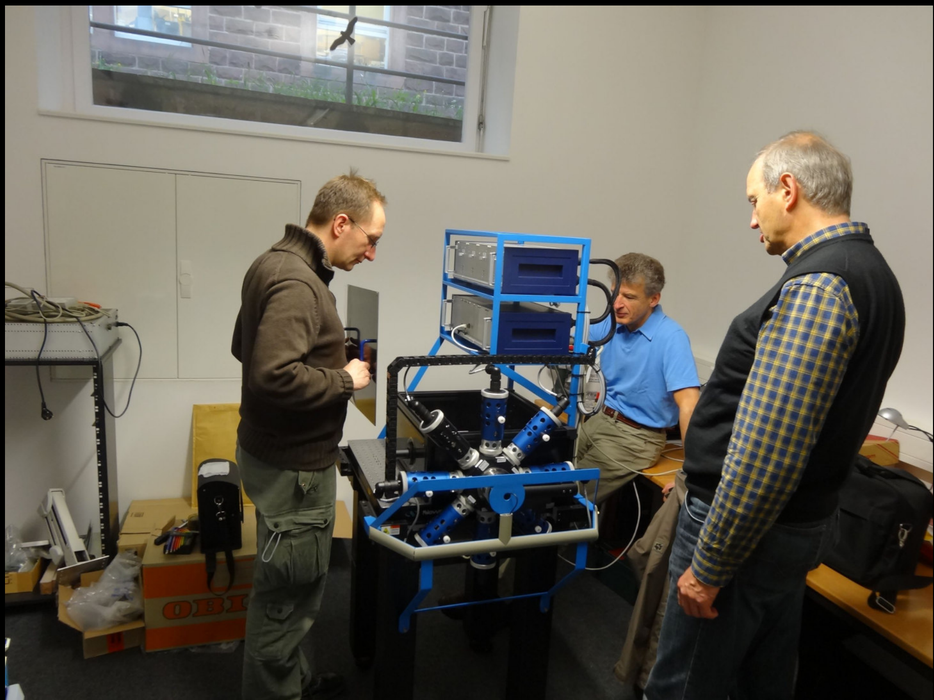
First light December 16, 2013





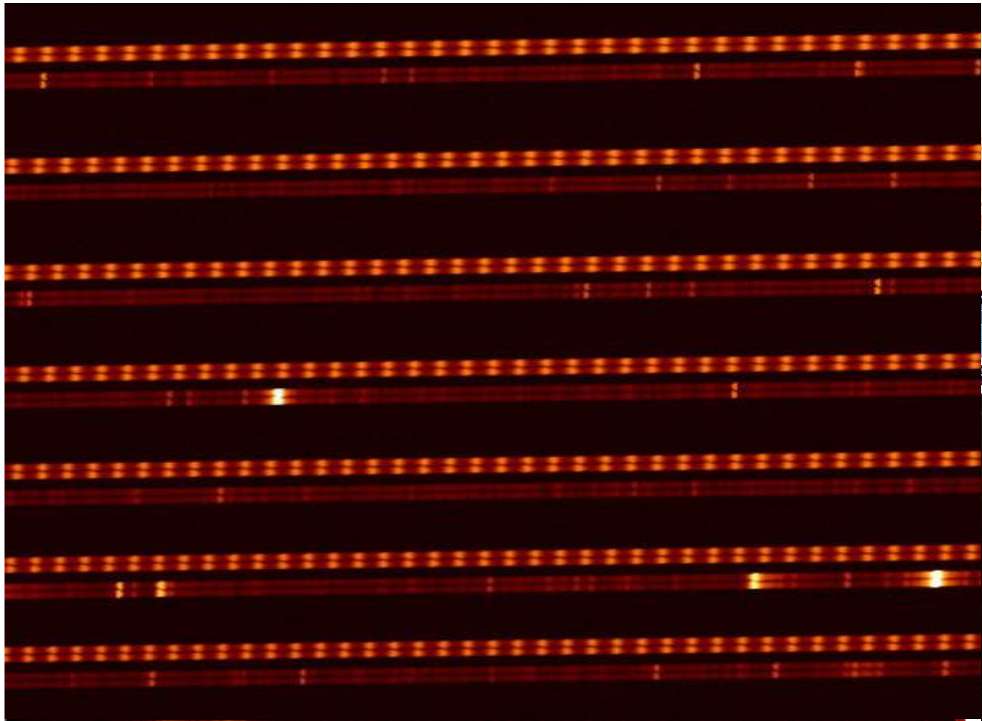


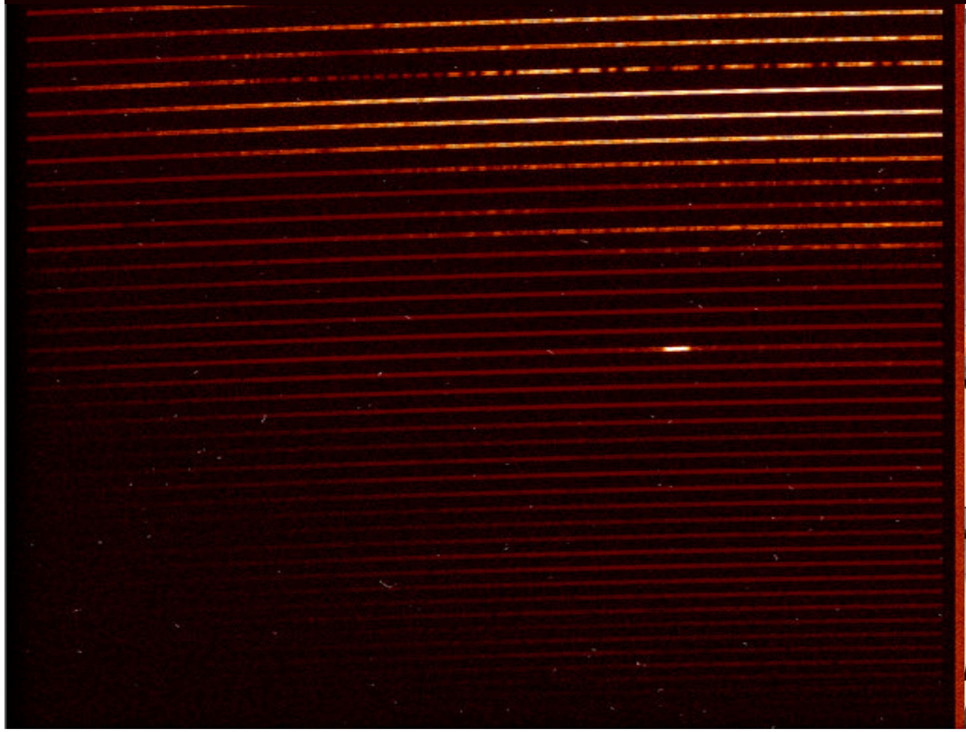
5-8 May 2014: delivery of CU "blaues Wunder” to LSW Heidelberg

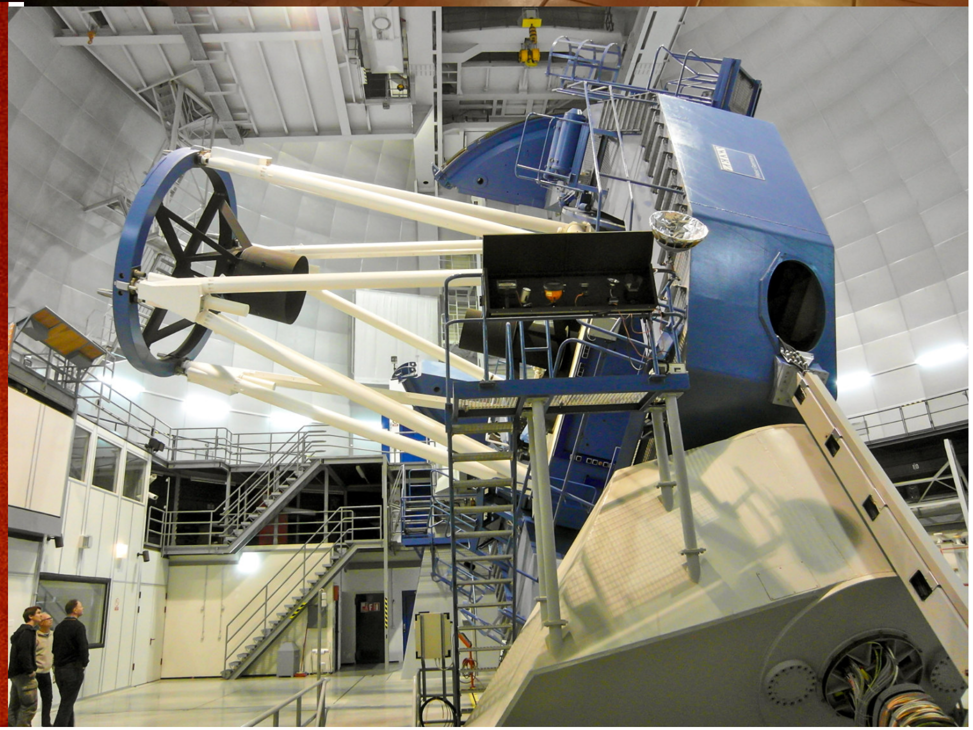


Sep 2014 delivery of CU "roter Drache" to IAA Granada

15-19 Sep 2014 delivery of NIR Calibration Unit "roter Drache" to IAA Granada and then to Calar Alto








Thanks