Stellar Observations Network Group

F. Grundahl, H. Kjeldsen, S. Frandsen, J. Christensen-Dalsgaard et al.

Department of Physics and Astronomy, Aarhus University

Outline

- What is SONG?
- Scientific and technical motivation
- Design and performance
- Project status and outlook

What is SONG and what will it do?

SONG is an initiative to design and build a global network of small telescopes dedicated to two (complementary) science goals:

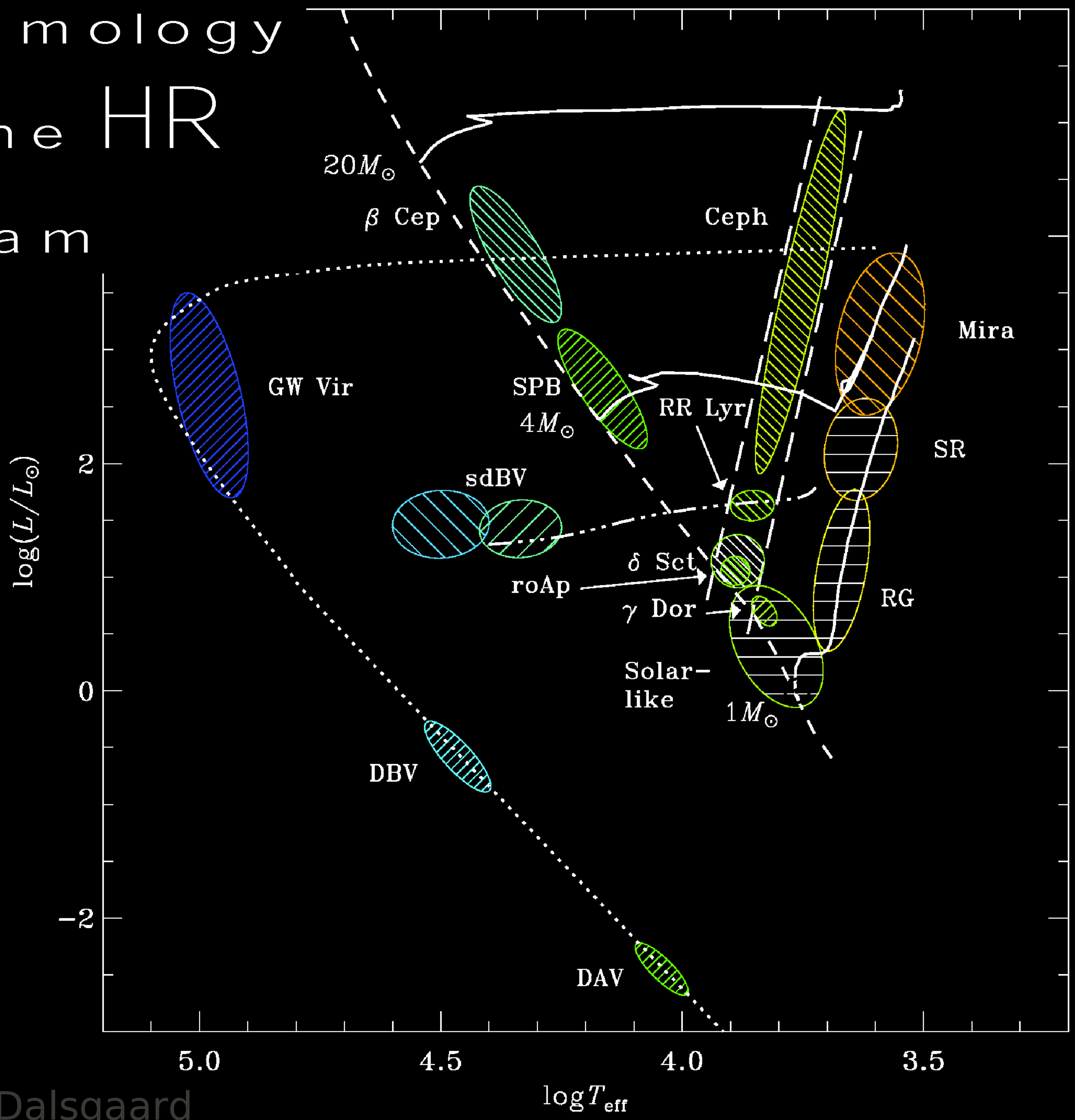
Asteroseismology:

- Ultra-precise radial velocity measurements
- Daytime solar observations

Extra-Solar Planets:

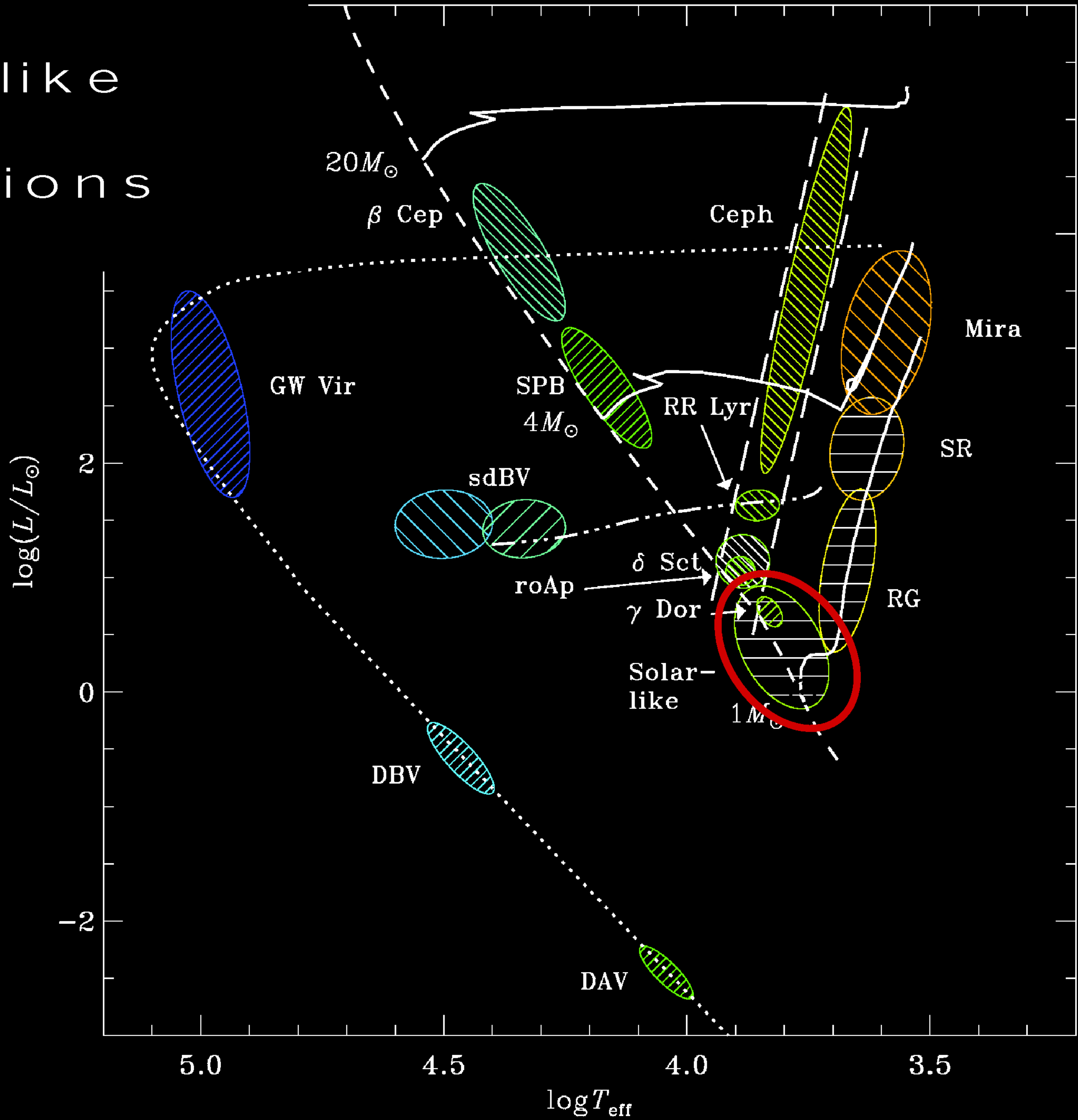
- Microlensing observations (photometry)
- Ultra-precise radial velocity measurements

Asteroseismology across the HR diagram

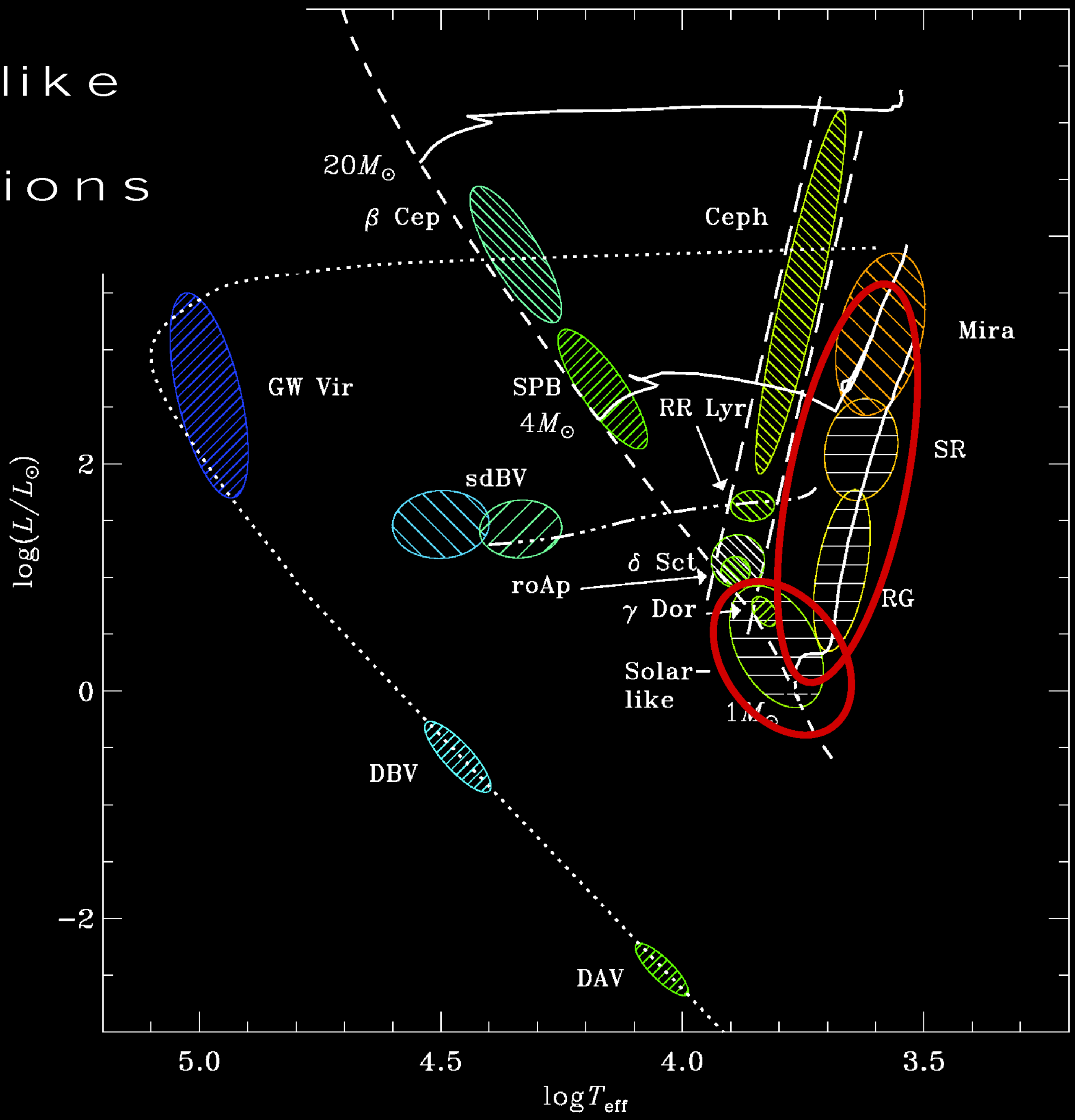


Courtesy: J. Christensen-Dalsgaard

Solar-like oscillations



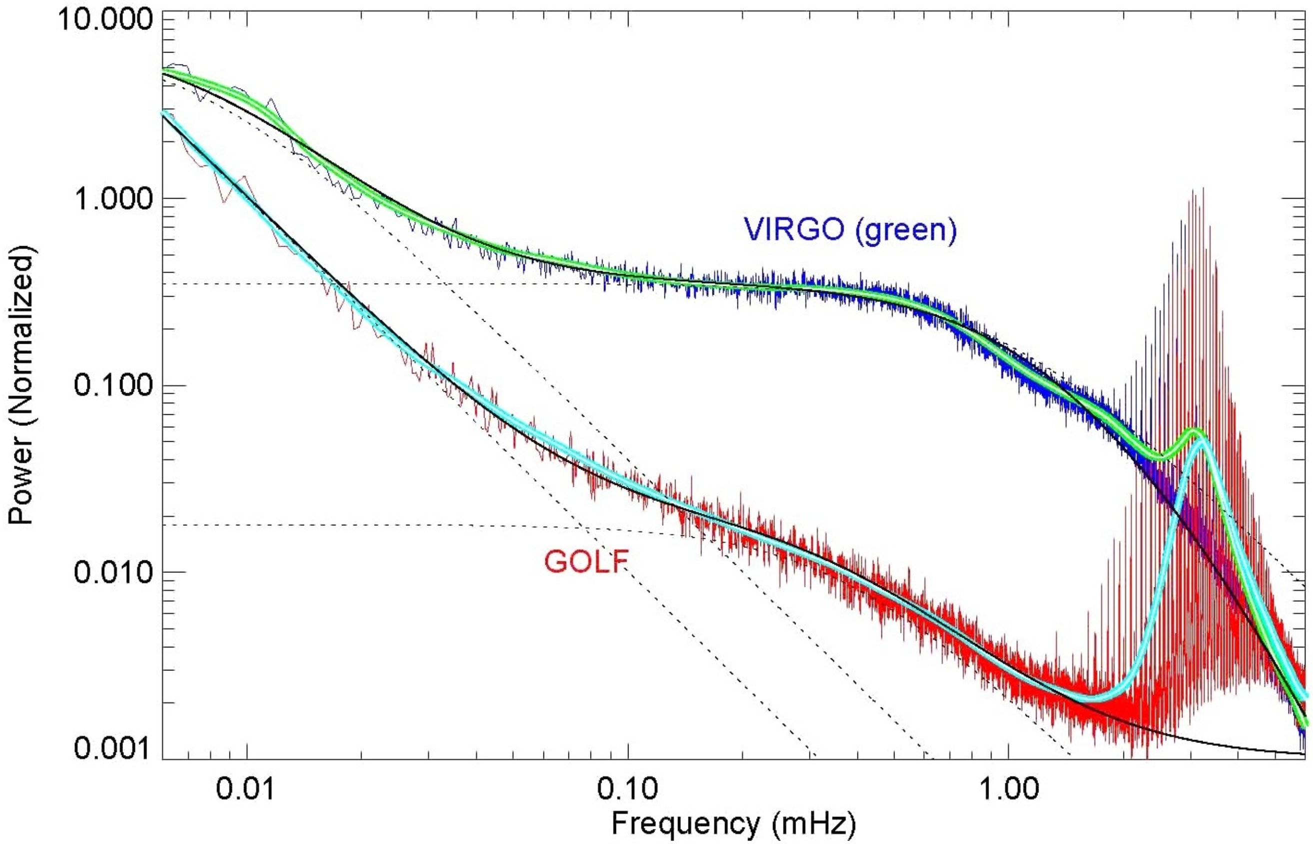
Solar-like oscillations



Asteroseismology

a tool to look inside the stars, providing many more constraints than normally available; mean density, envelope He content, rotation, age.....

Use radial velocities for solar-like oscillations - superior to photometry



Seismology targets: V < 6

Long, continuous periods

Bright, nearby targets, can get **R** from interferometry (also **L** and $\mathbf{T_{eff}}$)

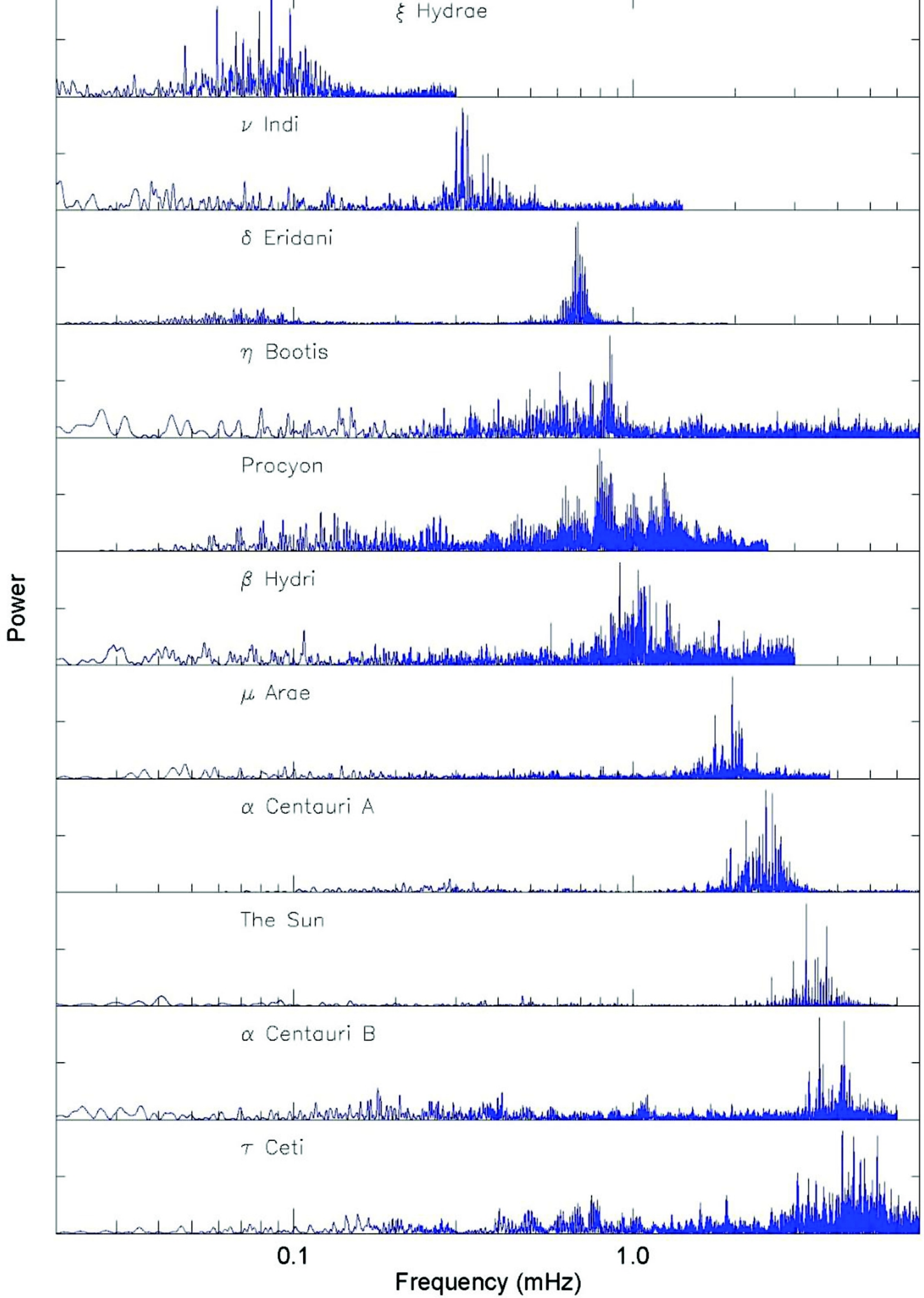
Relatively few but well studied targets.

Low degree modes; *l*=3

Observed oscillation spectra of
Well-known stars...

Luminosity

Stellar mean density



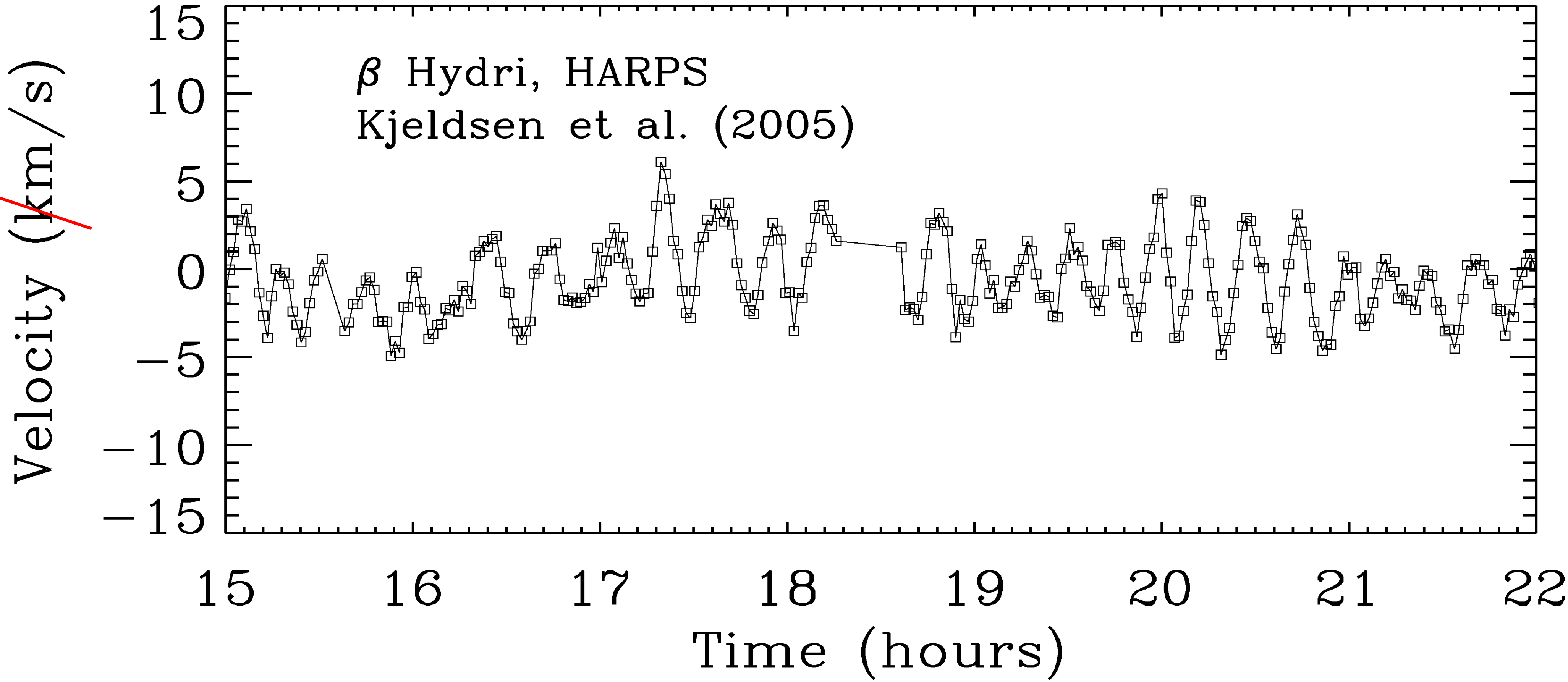
Observational limits

Why do we need a network?.... power spectra do exist, planets have been found....

- Window function
- Sampling/Cadence
- Length of observing period
- Long term stability
- Data homogeneity

We can measure solar-like oscillations directly
But the requirements are strict!

1.1 solar mass, slightly evolved



UVES, HARPS: Short-term precision better than 50cm/s

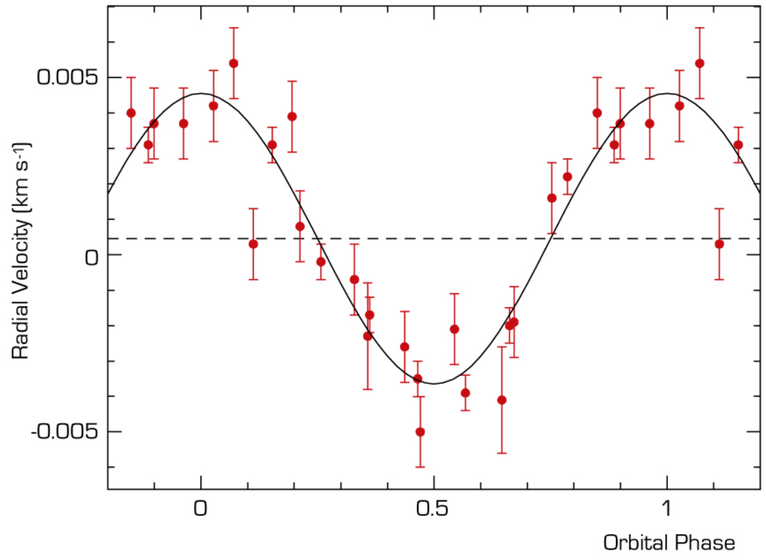
Planets then?

Stellar oscillations occur on timescales shorter than ~ few hours.
- Long term stability is not (very) critical.

Planetary orbital periods are longer than ~3 days
- Long term stability is critical
- This makes continuous observations important (network!).
- High time-sampling is also highly desirable

Quote from ESO Press Release 22/04 (low mass planet around μ Arae:

“This discovery has been made possible thanks to the large number of measurements obtained during the astero-seimology campaign.”



“Velocity Curve” of mu Arae

ESO PR Photo 25d/04 (25 August 2004)

© European Southern Observatory

Microlensing observations

Follow up of high-amplification events discovered by OGLE or MOA

Only a small field of view needed (but high crowding)

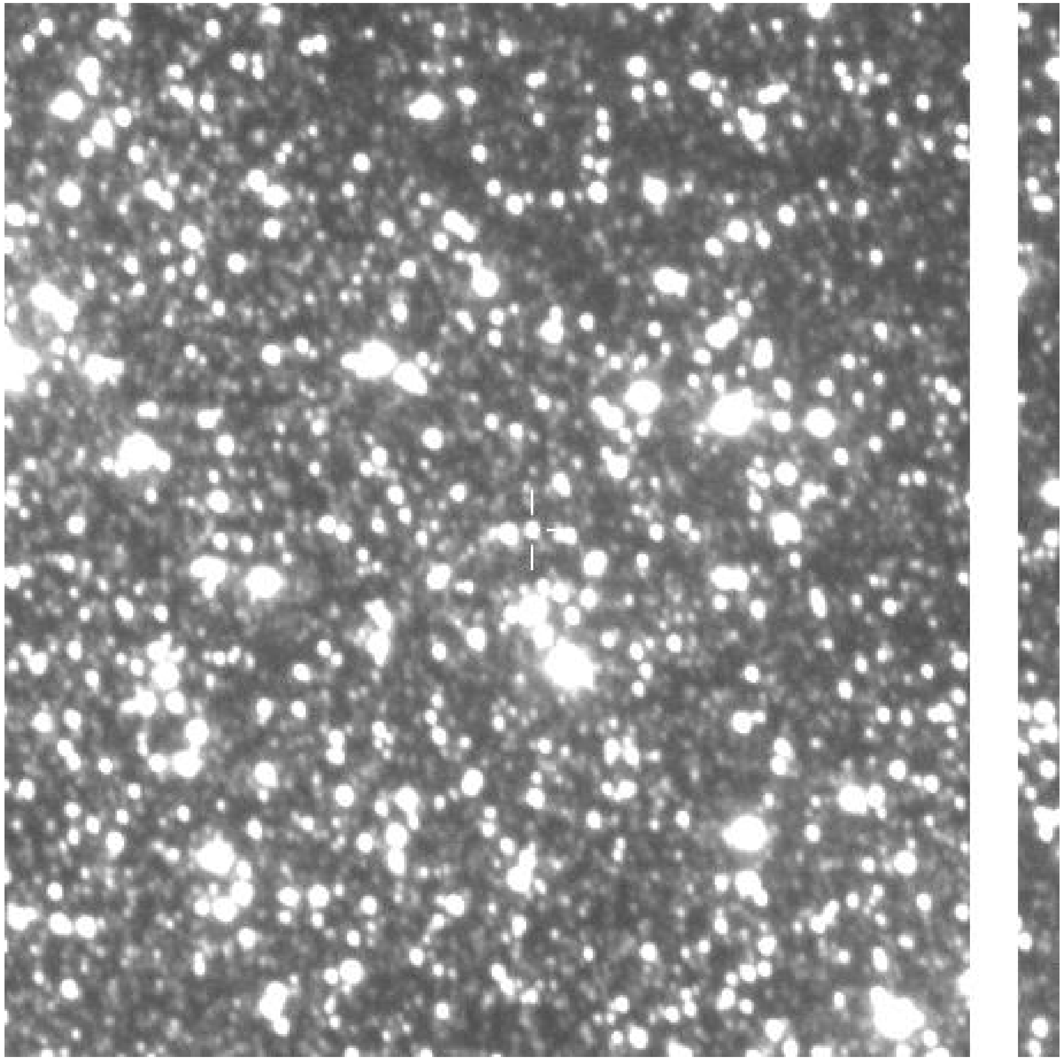
Planetary events have durations less than 24h

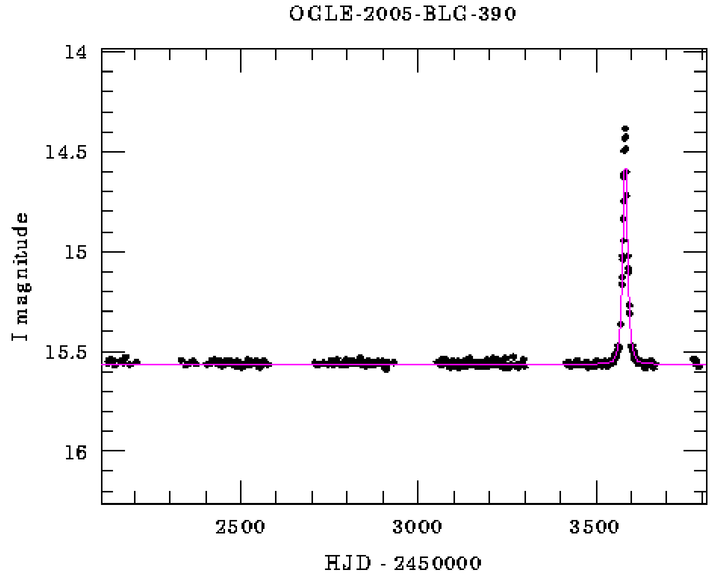
Continuous coverage for entire duration of event is desirable

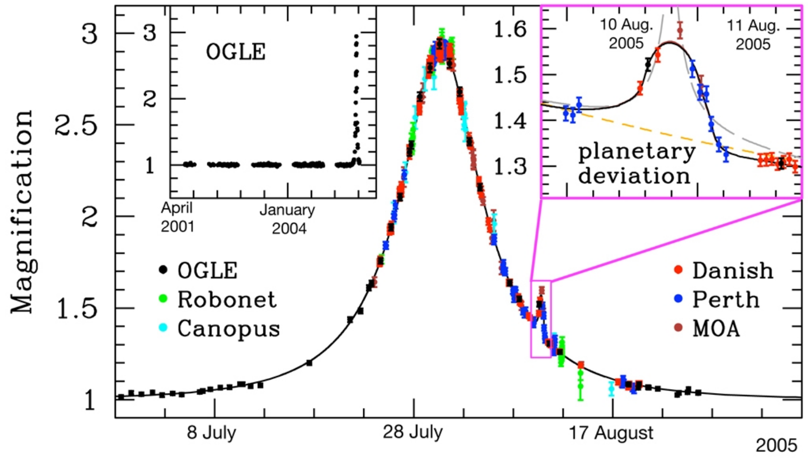
Microlensing has already produced several planet discoveries as well as limits on the occurrence of planetary systems.

However, more events with better coverage are desirable

FOV 2' x 2'







Light Curve of OGLE-2005-BLG-390

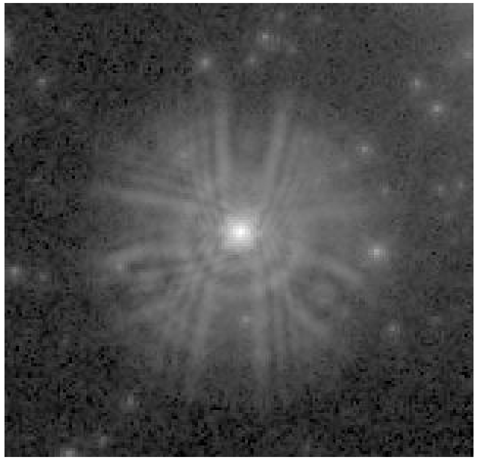
The field of the recent 5.5 Earth mass planet discovered by microlensing (Nature, 439, 437, 2006).

ESO PR Photo 03b/06 (January 25, 2006)

© ESO

NOT possible for this

summer school :-(

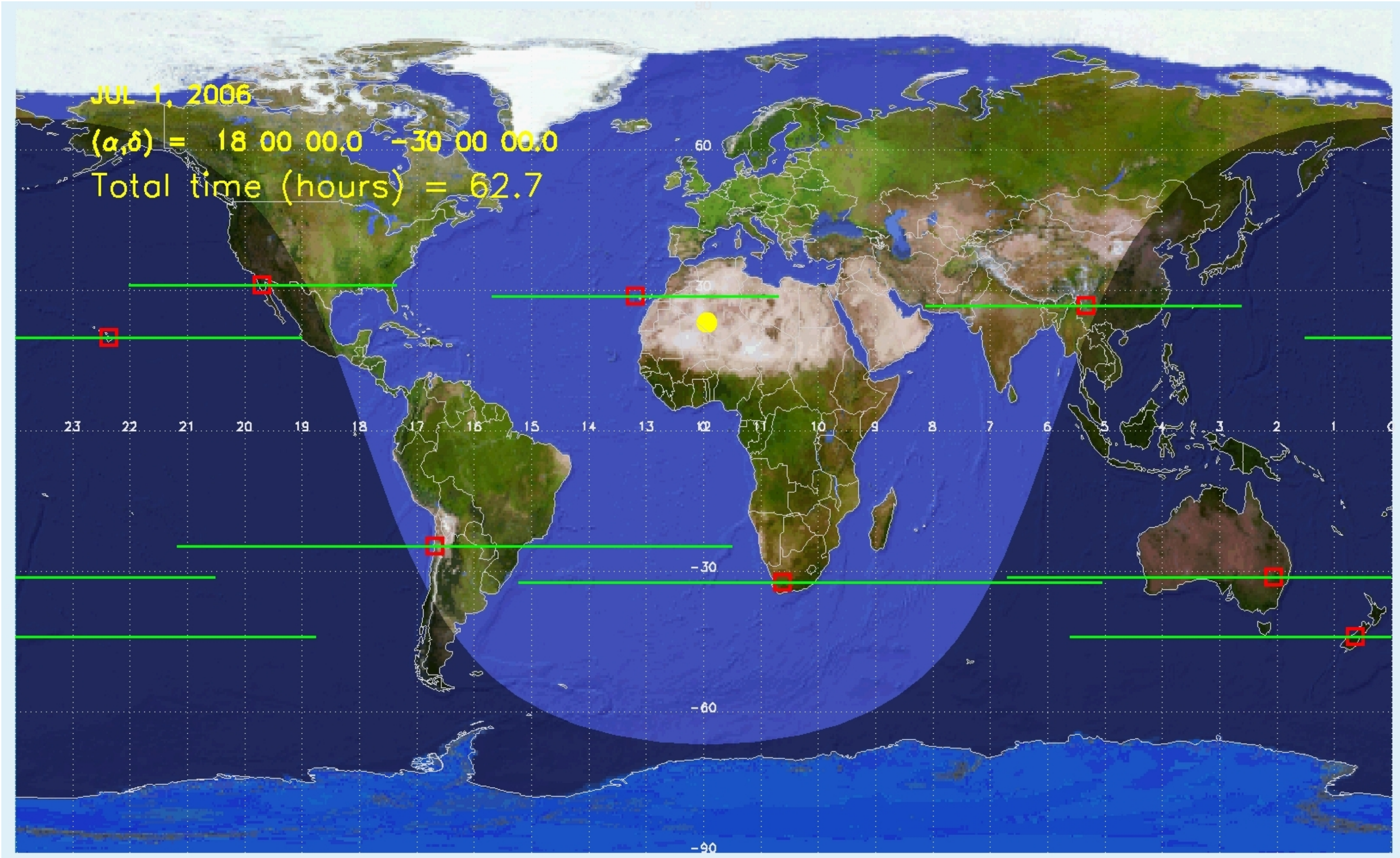


SONG BASELINE

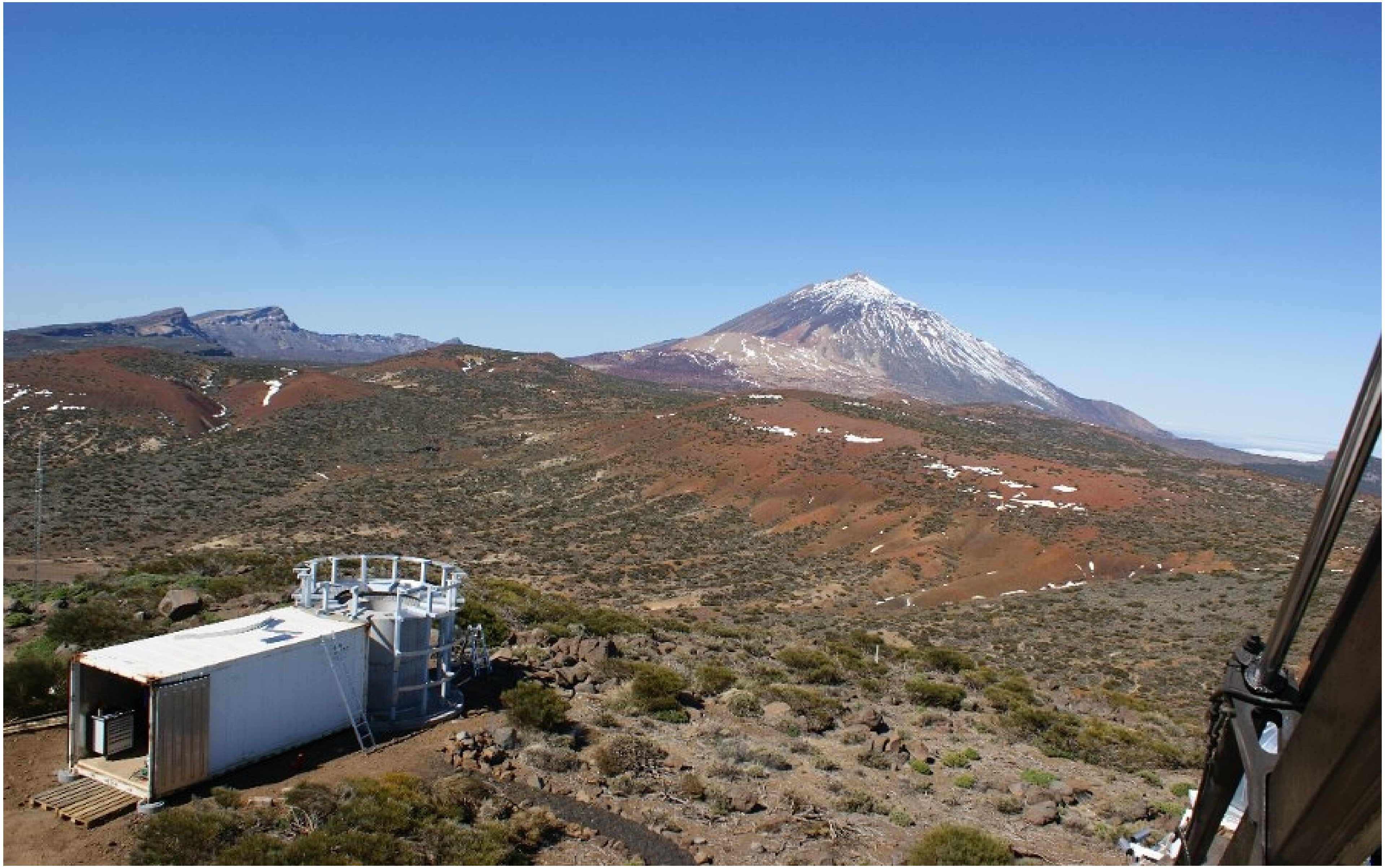
- 8 network nodes (4S / 4N) at already existing sites
- 1.0m telescopes at each node, Coudé focus.
- Dome, 5m diameter.
- Instruments: spectrograph + lucky imager
- Optimized for main science goals
- Automatic operations

The sites

Distributed to provide maximum temporal and sky coverage



First site – for the prototype: Tenerife



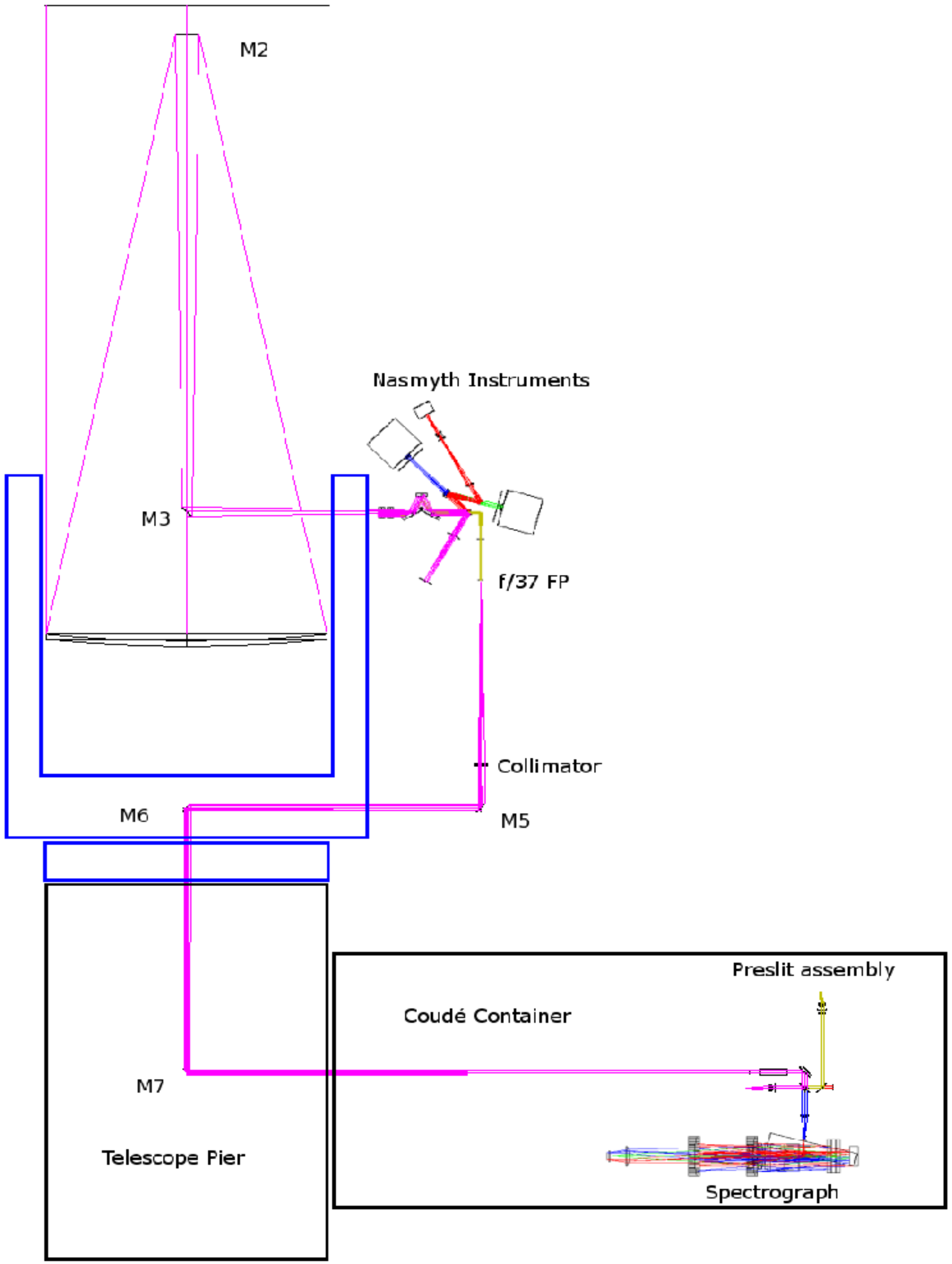

SONG webcam 1 11:11:58 2012/07/19

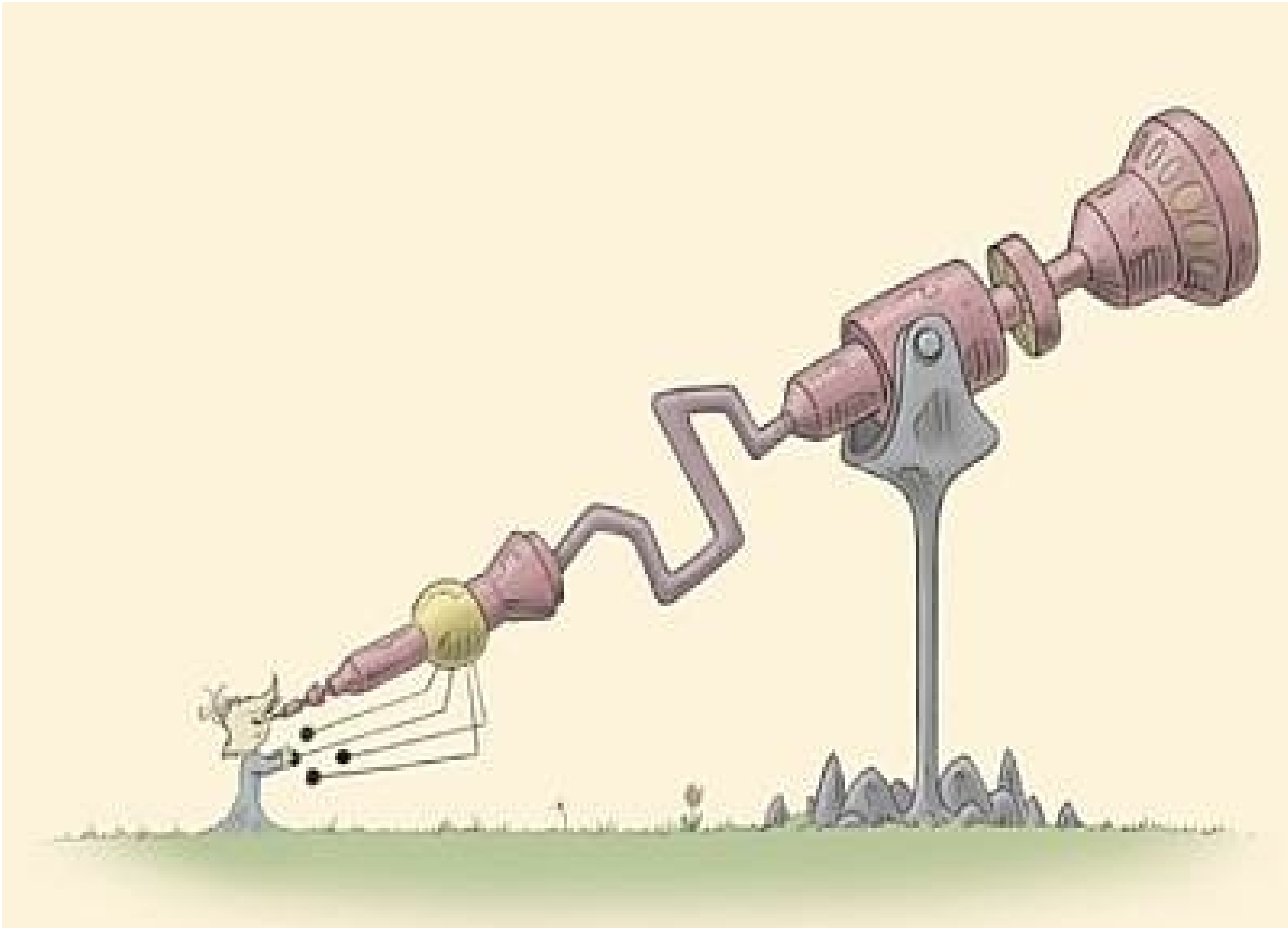
Use mirrors and lenses with optimized coatings over the spectrograph working wavelength range (off-the-shelf products!):

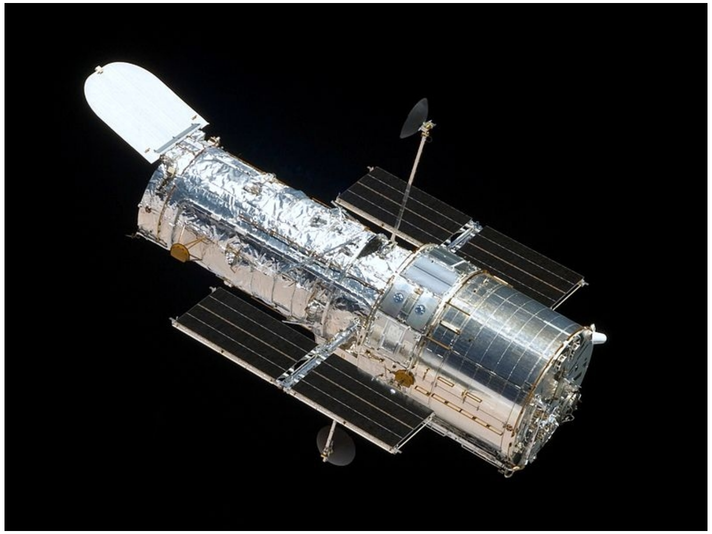
R > 99%

T > 99%

Coudé path in “vacuum” tubes @ 0.01 x atmospheric pressure, this reduces maintenance and prolong coating lifetime. Eliminates effect of thermal gradients in optical path.

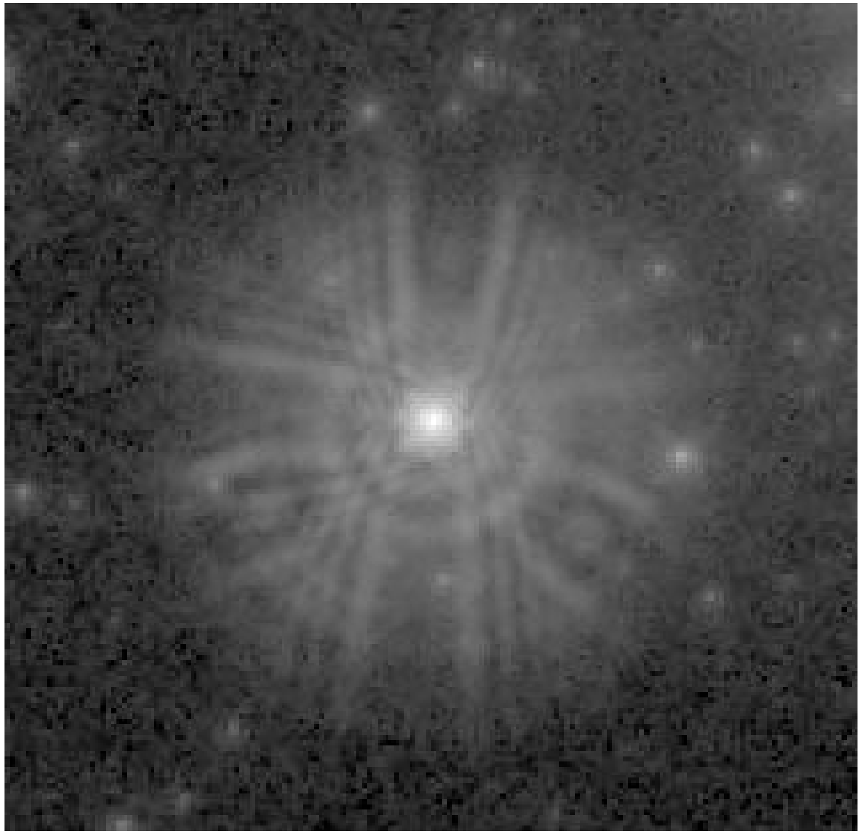






We have the 'Hubble Trouble' ....

Spherical Aberration :-(



Cause: The secondary mirror has an incorrect radius of curvature

- 1m telescope, alt-az mount
- 5” pointing precision and ZD < 80°
- Thin (5cm), controllable primary mirror w
  Shack-Hartmann WFS
- M2 on high-precision hexapod
- Rapid re-pointing (20deg/s)
- 2 Nasmyth foci (~60s switching)
- ADC (lucky imaging)
- Optical de-rotator
- 5m diameter dome w. sideports
- Wind-screen for dome
- Window to allow solar obs.

M2 and M3 dimensioned for ø15' field in the 2^{nd} Nasmyth port

Nasmyth Instrumentation

Functions:

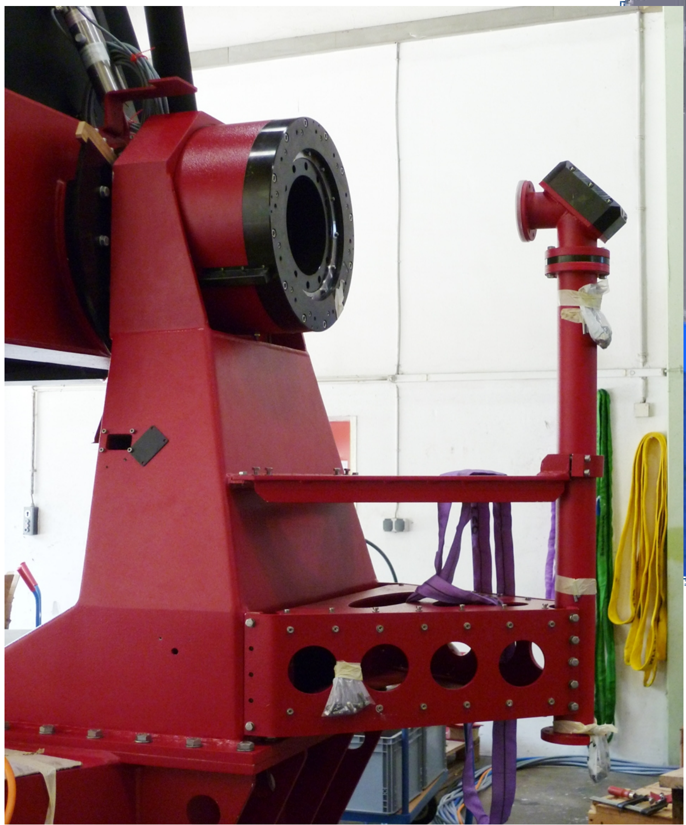
Dual-color lucky-imaging

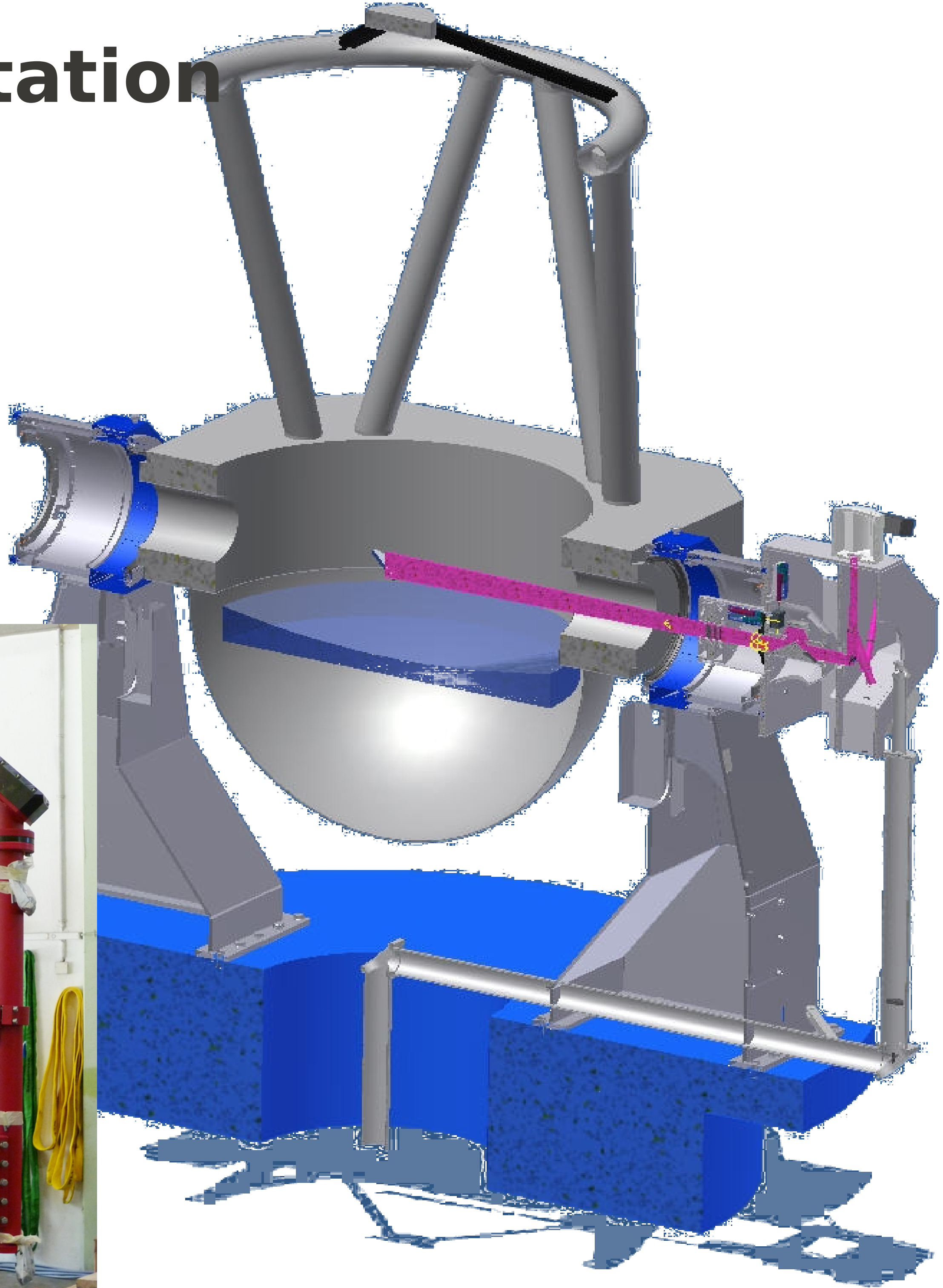
Telescope focus monitor

Filter wheel(s), 6 positions.

Entrance to Coude path

Aux. port





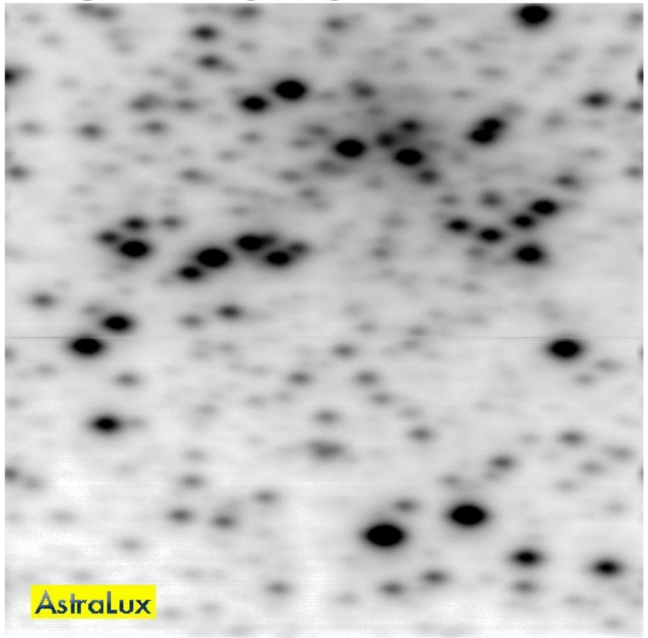
Nasmyth characteristics

Camera model	Andor, Ixon^{EM}+ DU897
Pixel size	16µm, 0."09 on sky
Detector size and Field-of-view	512 × 512 pixels (46" x 46" on sky).
QE @ 550nm	~95%
QE @ 800nm	~75%
Max. Readout speed	10 MHz
Max. Full-frame rate	34Hz
Read noise (e-, typical @ max. frame rate)	49e (rms.) in conventional mode
Read noise with L3 operation	< 1, but effective QE reduced by ~2
Wl. split between VIS/RED channel	650nm.

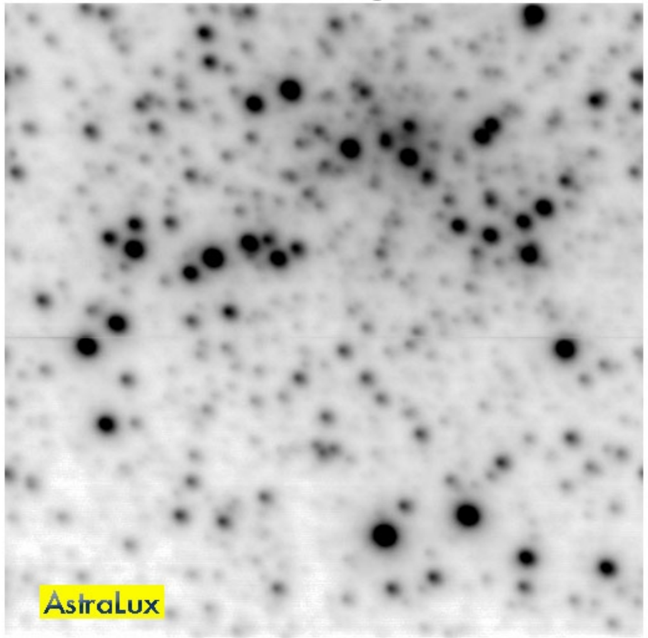
The imaging camera

- Use lucky-imaging at wavelengths longer than 680nm
- L3 CCD from E2V Technologies, 512 x 512, thinned, QE ~90% @ 550nm
- Only small field required
- Large isoplanatic angle
- In bulge fields (microlensing) “guide” stars will be available for most of the time.
- For 1m telescope the I-band diffraction limit is ~0”21
- ~30% of time expected to provide ~0”4 imaging.
- On-site data reduction, storage of raw data for limited periods.

Lucky Imaging at its best: The core of the globular cluster M15 imaged at 900nm

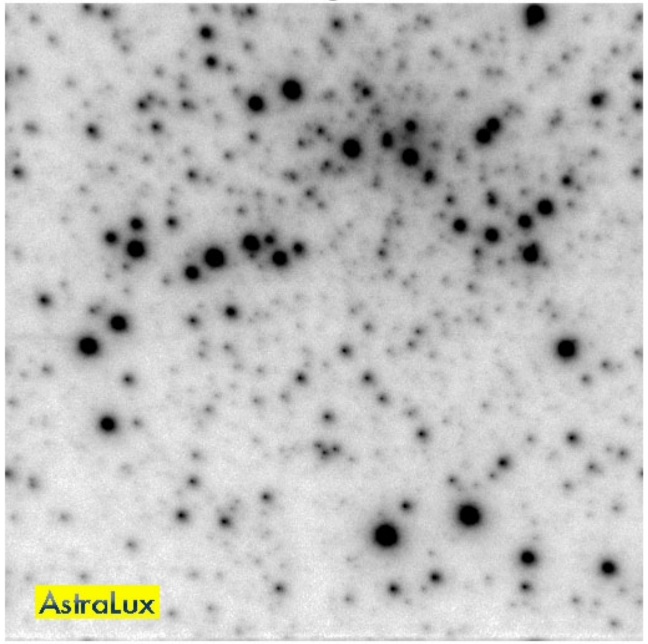


Conventional long-time exposure with an autoguider time constant of one second. The image was constructed using 5000 single frames with 60ms exposure time each, accounting for a total integration time of 300 seconds.
Due to a periodic error of the telescope tracking, the stellar PSFs appear elongated and have an FWHM of 730x430 mas, which indicates very good Seeing for the Calar Alto observatory.



Tip-tilt corrected image, constructed from all 5000 single frames.
This correction efficiently compensates the tracking error and atmospheric tip-tilt, leading to a stellar FWHM of 390 mas.

Field of view: 24 x 24 arcsec^2



Lucky Imaging result. Only the best 250 images of all 5000 were used for image reconstruction, resulting in a total exposure time of 15 seconds. The stellar FWHM is 110 mas on average.
Despite the much shorter exposure time, the signal-to-noise ratio of point sources is actually improved compared to the tip-tilt corrected image in the middle.

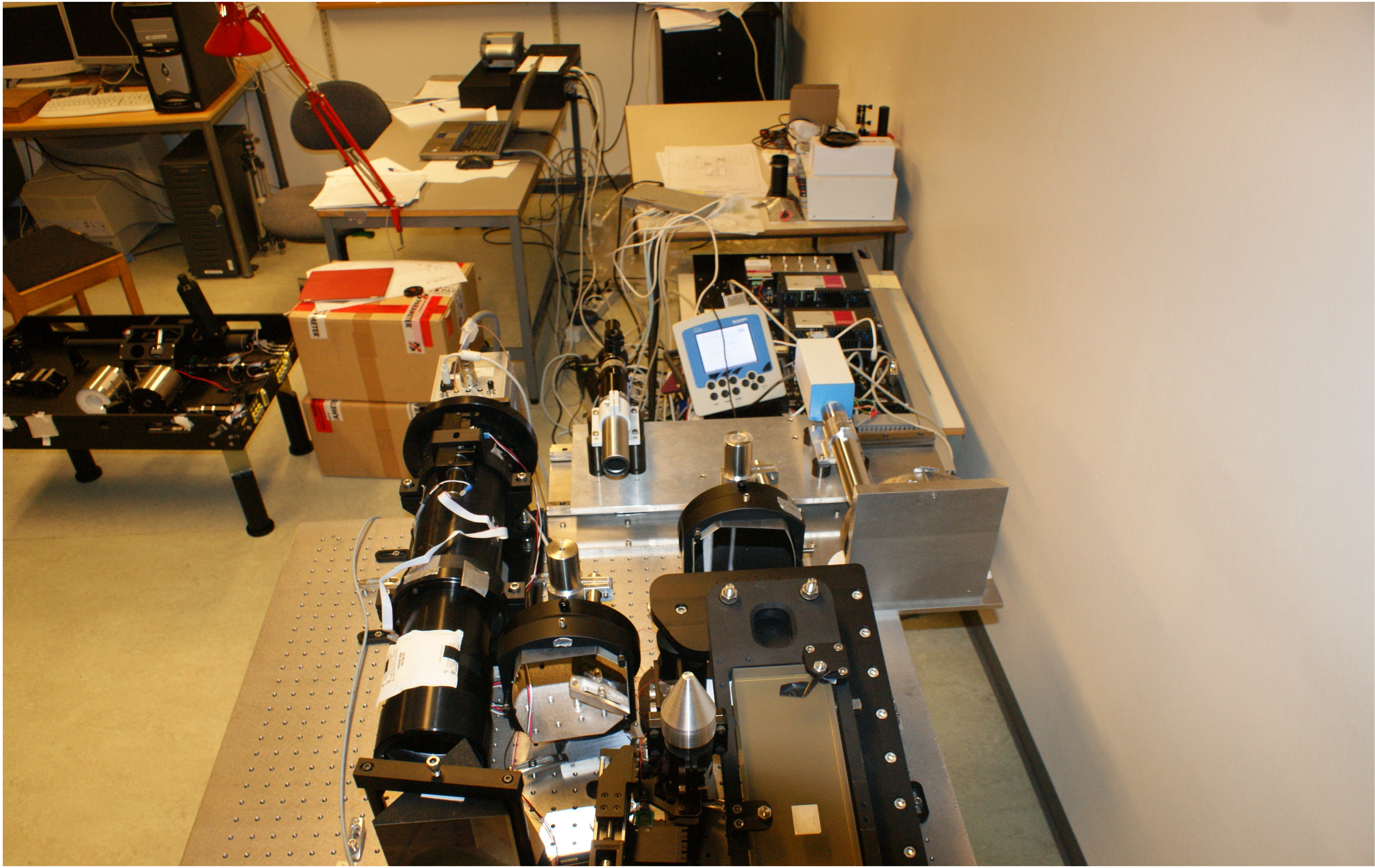
AstraLux First Light (CAHA 2.2m)
© Calar Alto Observatory July 2006

The spectrograph

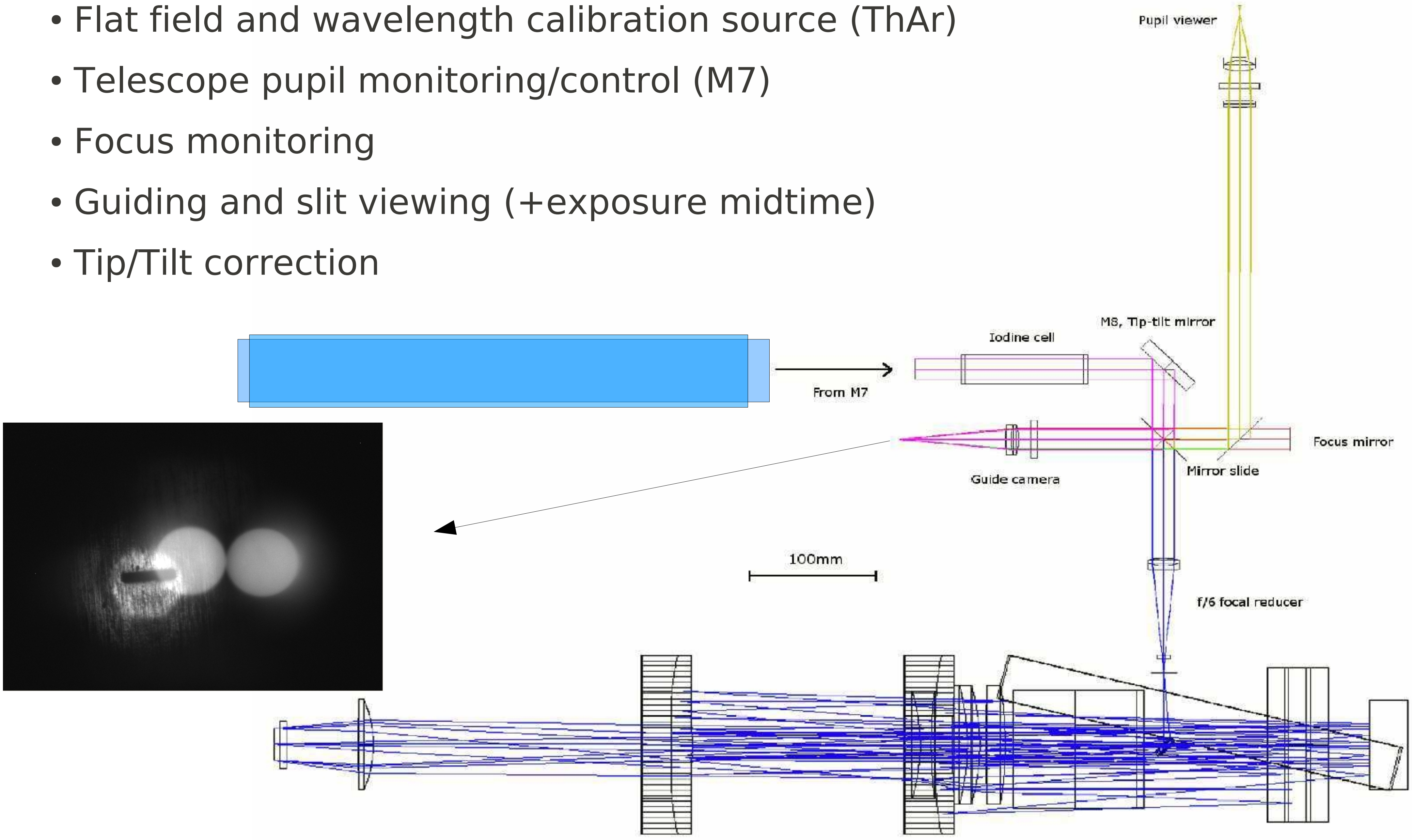
Main features:

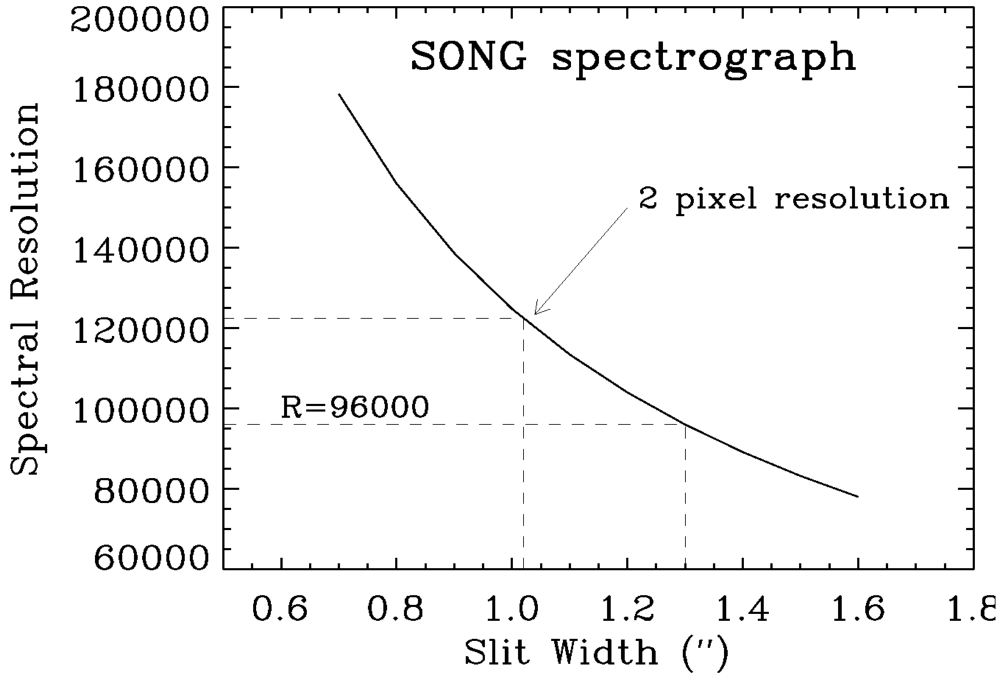
- UVES-like, white pupil design
- R4, 75mm x 300mm echelle, R < 120.000 (6 slits)
- 2K x 2K E2V chip (readout time <5s), QE ~90% @ 5500Å
- Iodine cell for velocity reference and instrumental profile
- Wavelength range: 440-670nm
- Well behaved Line Spread Function, nearly diffraction limited over chip area
- Small chromatic aberrations, minimal line-tilt.
- On-site pipeline data reduction to minimize internet traffic.

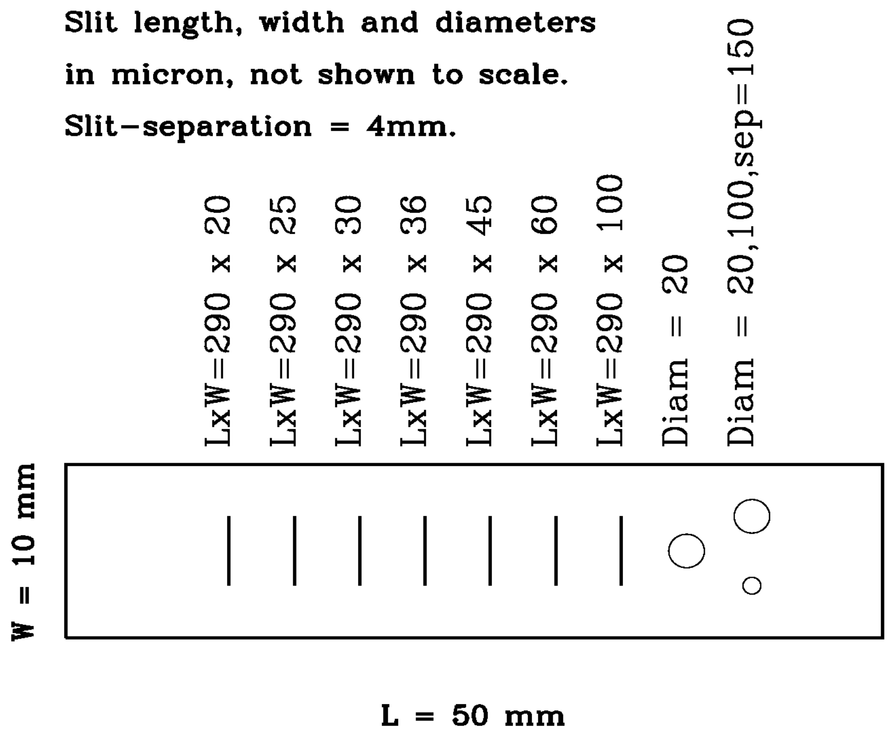
Why Iodine? Much lower demands on spectrograph stability than ThAr method.



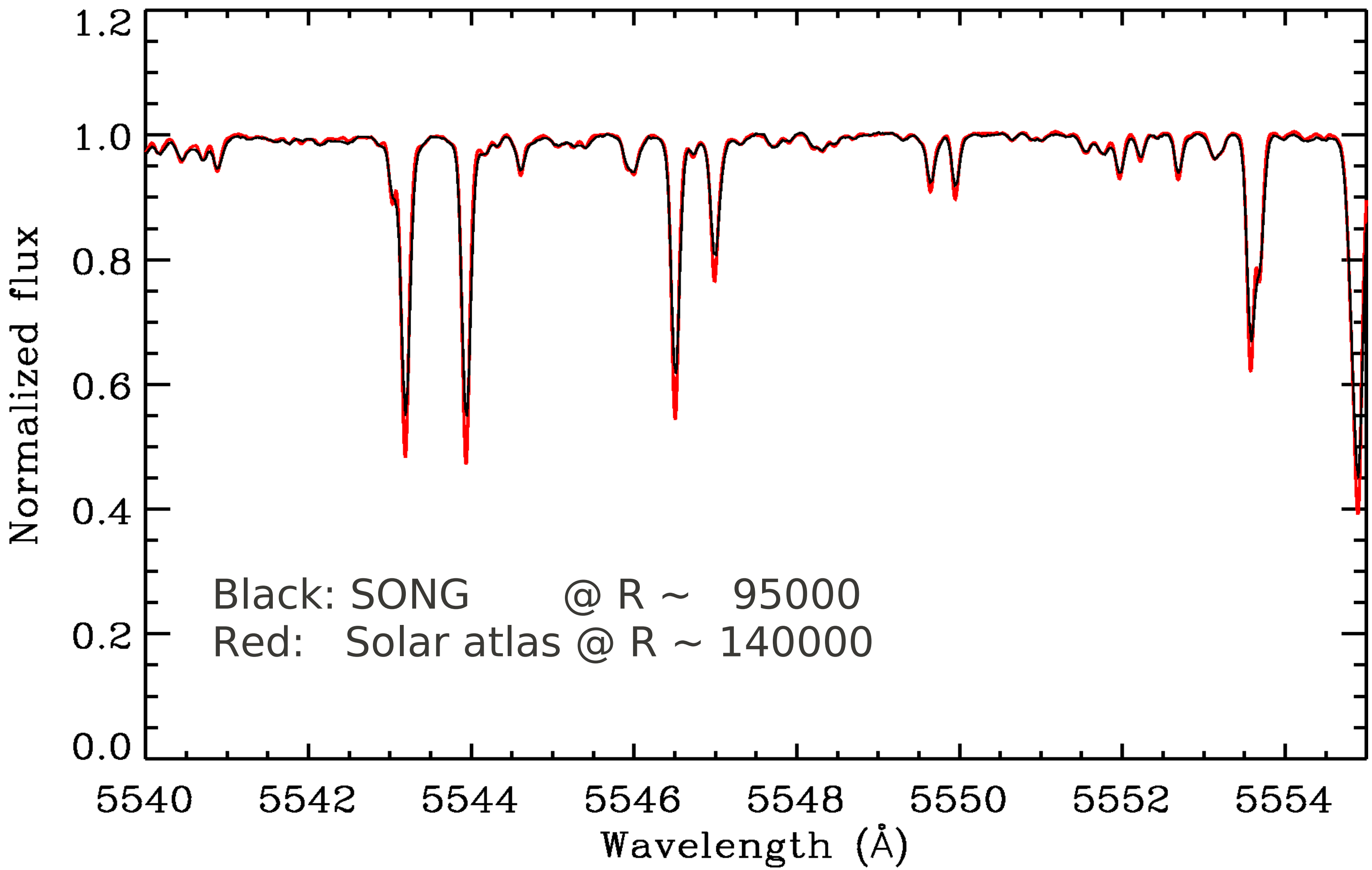
- Iodine Cell
- Flat field and wavelength calibration source (ThAr)
- Telescope pupil monitoring/control (M7)
- Focus monitoring
- Guiding and slit viewing (+exposure midtime)
- Tip/Tilt correction







Slit pos	Resolution (λ/δλ)	Width (″)	Width (µm)	Length (µm)	Sampling (pixels)
4	60504	2.06	60.00	290	4.05
5	80672	1.55	45.00	290	3.03
6	100841	1.24	36.00	290	2.43
7	121009	1.03	30.00	290	2.02
8	145211	0.86	25.00	290	1.69
6	181514	0.69	20.00	290	1.35
3	Wide slit	3.44	100	290	6.76
8	Pinhole		ø=20		
9	Alignment		ø=20,100		



Normalized flux
Wavelength (Å)
Black: SONG @ R ~ 95000
Red: Solar atlas @ R ~ 140000
1.2
1.0
0.8
0.6
0.4
0.2
0.0
5540
5542
5544
5546
5548
5550
5552
5554

To ensure long-term stability a gas cell with iodine is put in front of the spectrograph slit, allowing very high velocity precision to be achieved.

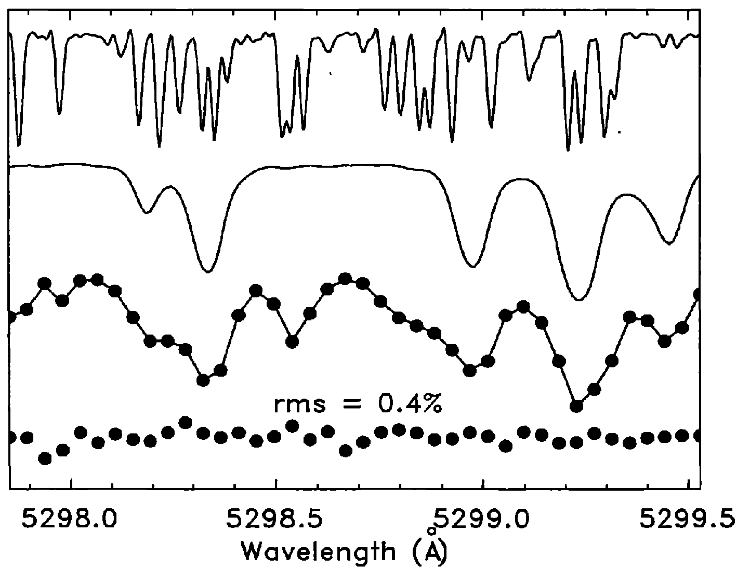
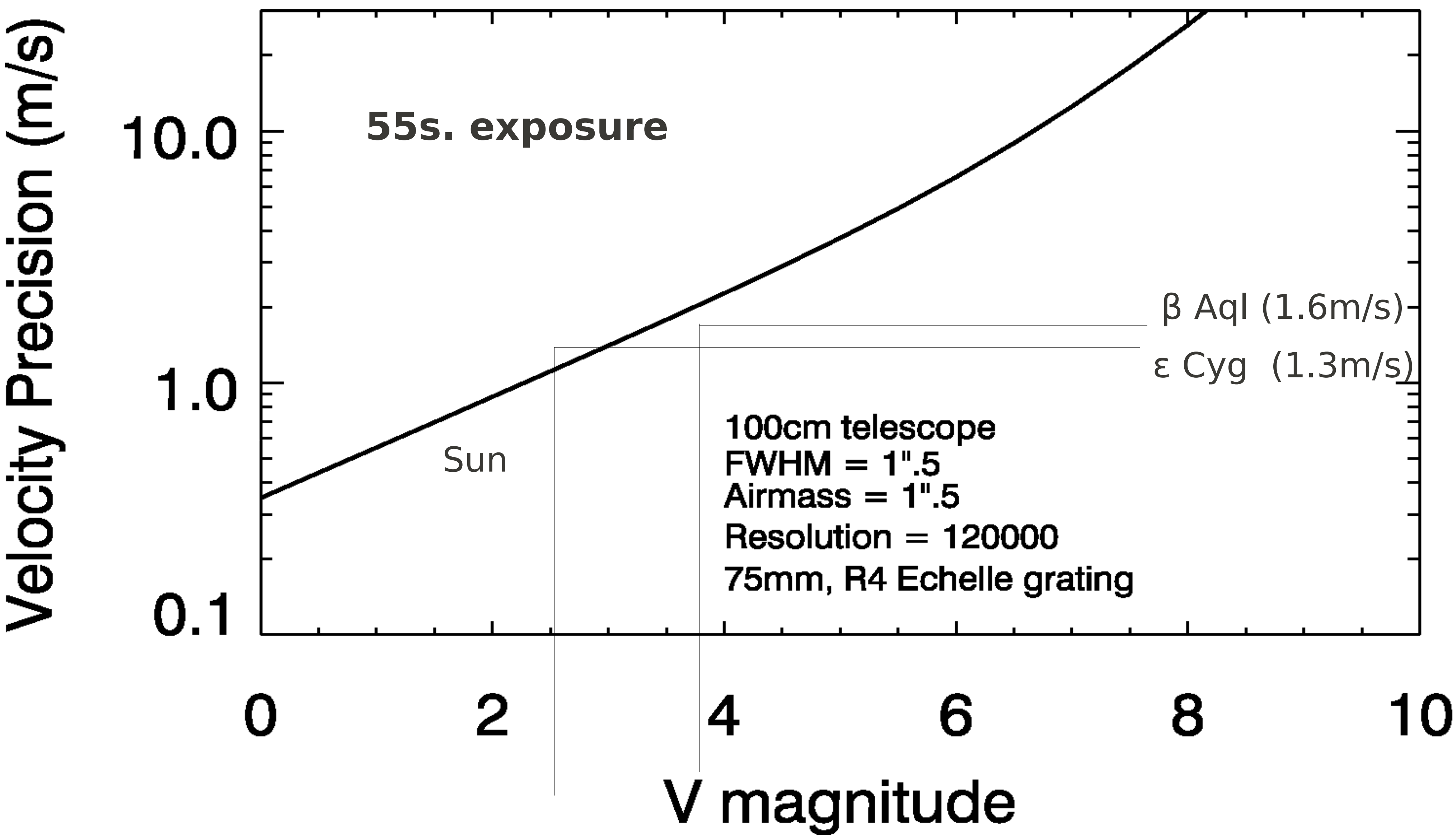
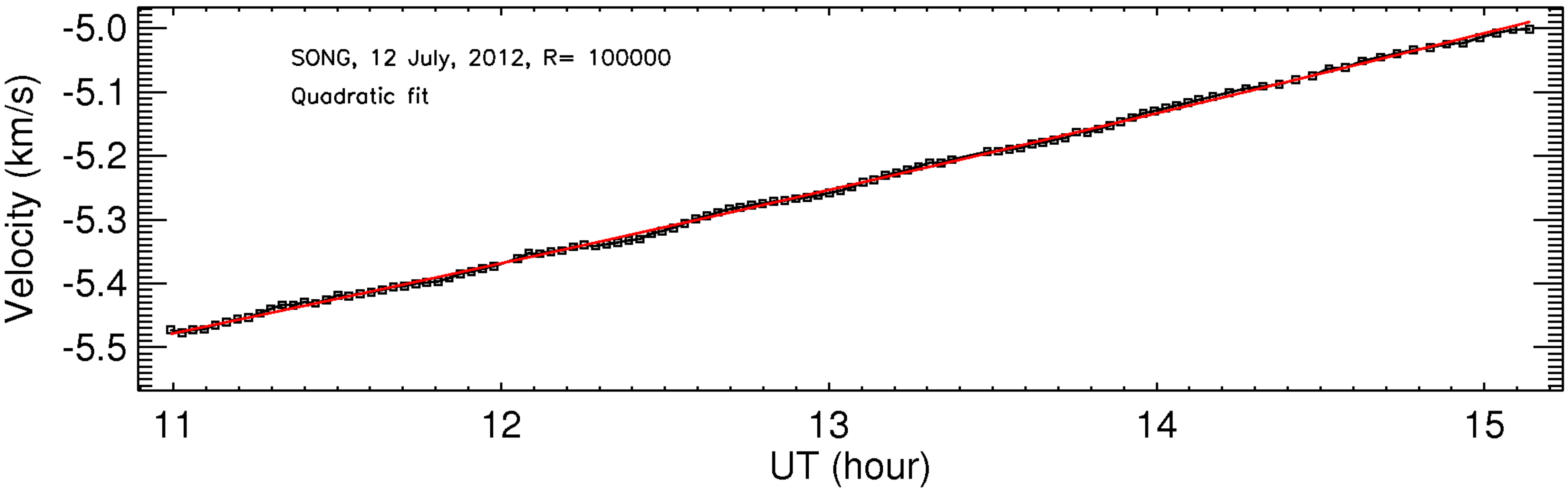
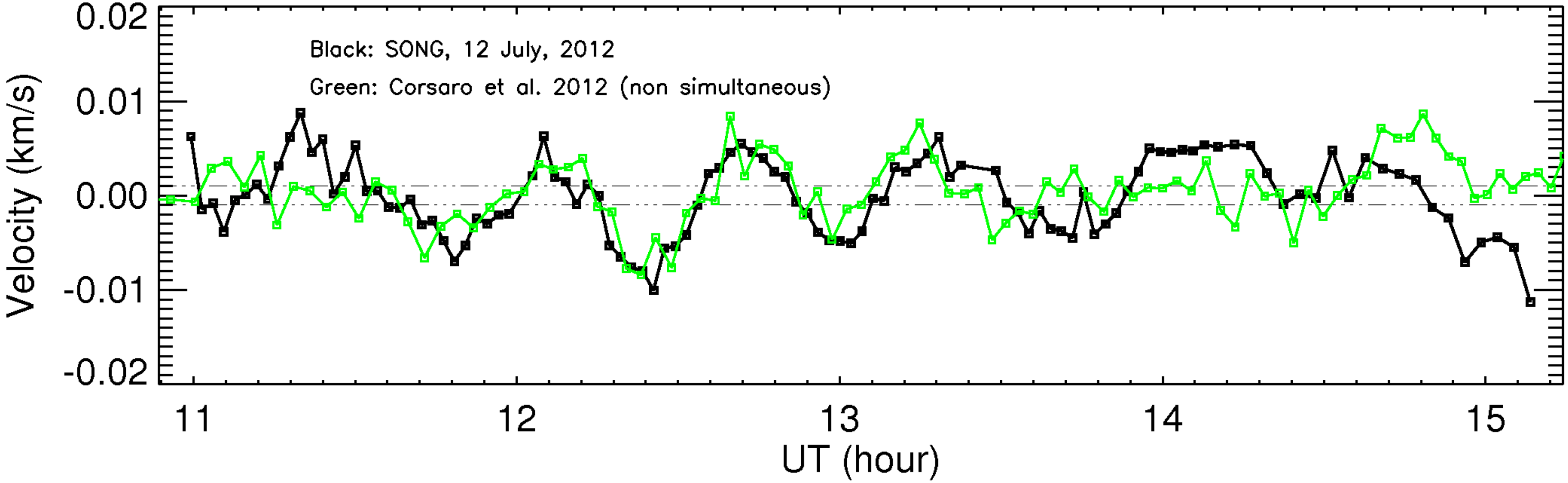


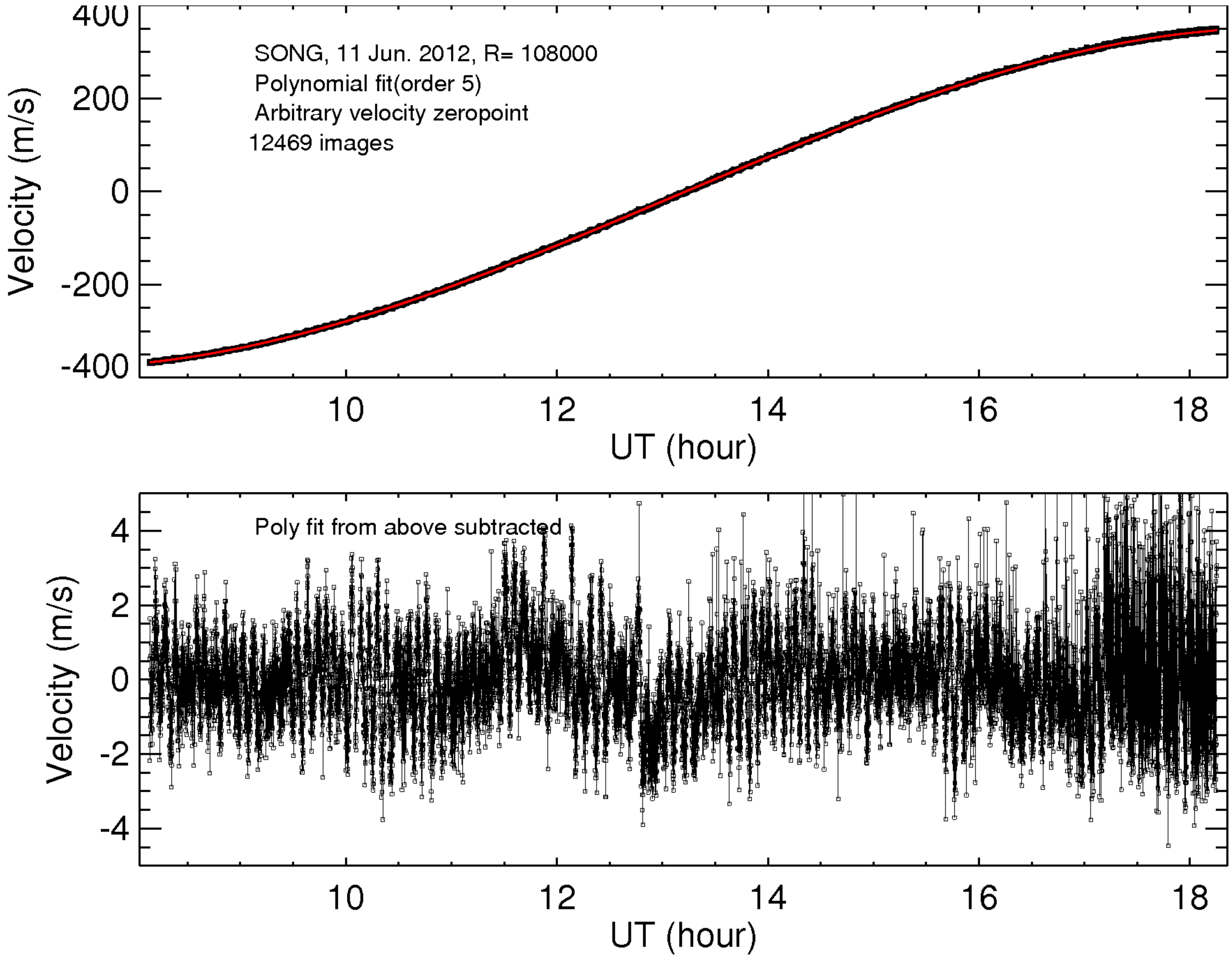
FIG. 1—The modeling process. Top: The template iodine cell spectrum. Second: The template stellar spectrum (τ Ceti, G8 V). Third: The points are an observation of τ Ceti made through the iodine absorption. The solid line is a model of the observation. The model is composed of the template iodine and stellar spectra. The free parameters consist of the spectrograph PSF and the Doppler shift of the template star relative to the template iodine. Bottom: 10 times the difference between the model and the observation. The model and observation differ by 0.4% rms.

Velocity precision of SONG spectrograph




SONG, 12 July, 2012, R= 100000
Quadratic fit
Velocity (km/s)
-5.0
-5.1
-5.2
-5.3
-5.4
-5.5
11
12
13
14
15
UT (hour)


Black: SONG, 12 July, 2012
Green: Corsaro et al. 2012 (non simultaneous)
Velocity (km/s)
0.02
0.01
0.00
-0.01
-0.02
11
12
13
14
15
UT (hour)


SONG, 11 Jun. 2012, R= 108000
Polynomial fit(order 5)
Arbitrary velocity zeropoint
12469 images
Velocity (m/s)
UT (hour)
Poly fit from above subtracted
Velocity (m/s)
UT (hour)

Where are we now ?

All components/instruments installed:

- New M2 needed (late August/September, 2012... I hope)
- Proper alignment of Coudé path
- Test of Nasmyth Unit (lucky imaging)
- Setup and verification of the active optics
- Establishing of proper (automatic) observing procedures

- Next installation trip: mid-late August...... 20112 :-)

SONG-node 2: NAOC is funding a Chinese node, to be ready in late 2013

SONG for this summer school:

- High-resolution spectroscopy of the sun and stars

- Daytime observations of the sun

- Night time observations of bright stars (V<4) for short (high cacdnce) guided exposures and maybe as faint as V=8 for long exoposures (blind tracking).

SONG install movie...

Web-pages..

Summary of capabilities

Telescope and dome

- 1m telescope, alt-az mount with <5” pointing precision and ZD < 80°
- Thin (5cm), controllable primary mirror with Shack-Hartman WFS
- M2 on high-precision hexapod
- Rapid re-pointing (20deg/s)
- 2 Nasmyth foci (< 60s switching)
- ADC and Optical de-rotator
- 5m diameter dome w. sideports
- Wind-screen for dome and window to allow daytime solar obs.
- M2 and M3 dimensioned for ø15' field in the 2nd Nasmyth port

Summary of capabilities

Spectrograph @ Coudè focus

- Ultimate RV. precision of 1m/s expected with iodine cell.
- Wavelength range 4500-6700Å.
- R = 60.000 – 120.000 (higher possible with undersampling).
- Uniform PSF over detector area.
- High throughput (~7% TOTAL expected).
- Tip-tilt correction.
- Pupil correction/control/monitoring.
- Focus control and monitoring.
- Photon-weighted midtime of exposure calculation.
- “Ordinary” operation is possible (no I_2 cell, ThAr calib.)

Summary of capabilities

Imaging @ Nasmyth focus

- Dual color lucky imaging – wavelength split at 650nm.
- FOV 46" × 46" with 0.09 pixels to sample diffraction limited imaging.
- Up to 6 filters possible for each channel (minus dark+grey filter).
- Continuous monitoring of the focus.
- Full frame-rate up to 34Hz.
- Near-diffraction limited performance during best weather conditions.
- Conventional CCD mode possible with low RON and ~1s readout.
- Extra port available to cover up to 75” field in third position.

Principal Investigator: Jørgen Christensen-Dalsgaard (IFA)

Project manager: Per Kjærgaard Rasmussen (NBI)

Project scientist: Frank Grundahl (IFA)

Project group: Uffe Gråe Jørgensen,

Hans Kjeldsen,

Søren Frandsen,

\+ many more

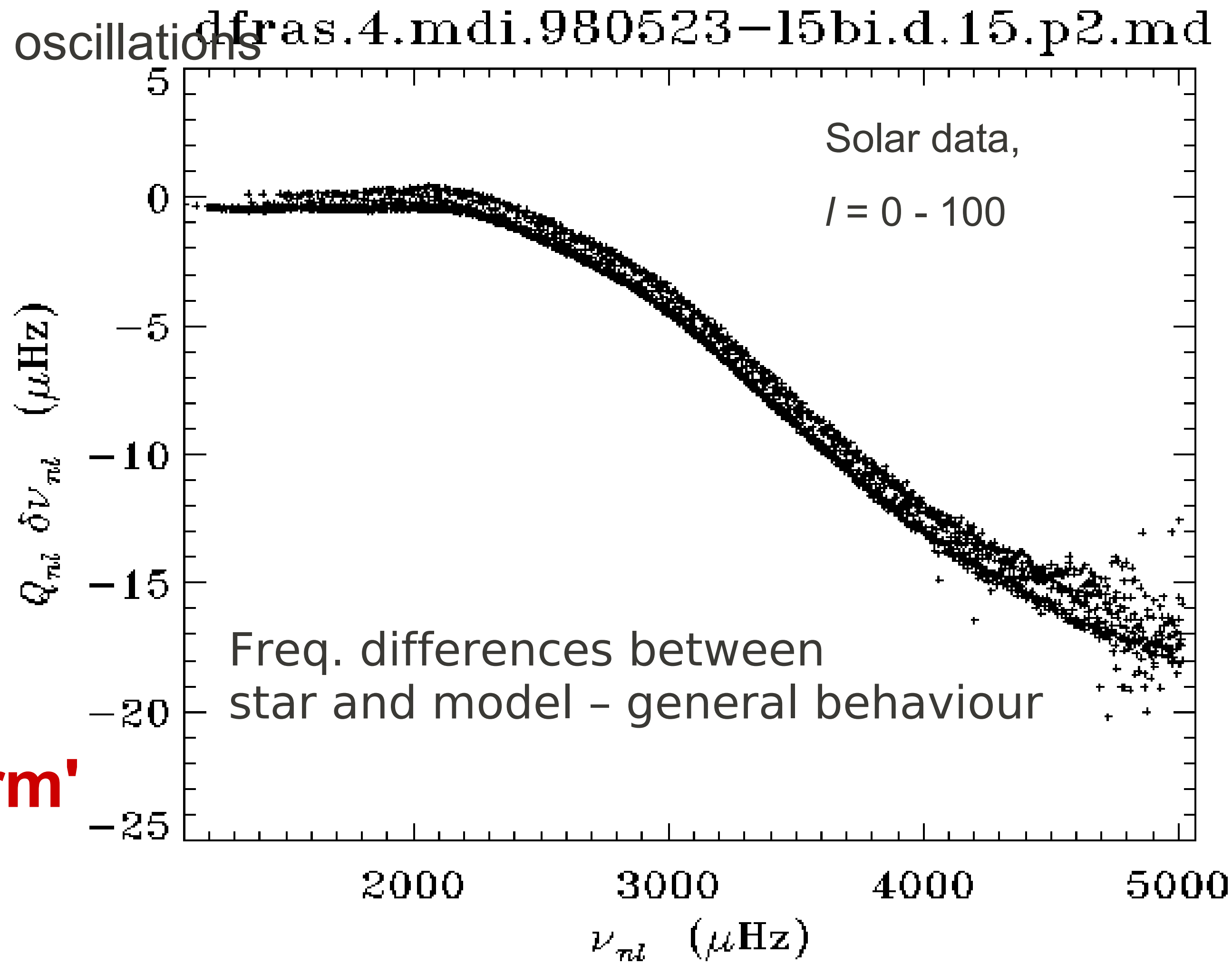
.... so we went ahead and obtained funding for ONE

Telescope to serve as a prototype for the network instruments...

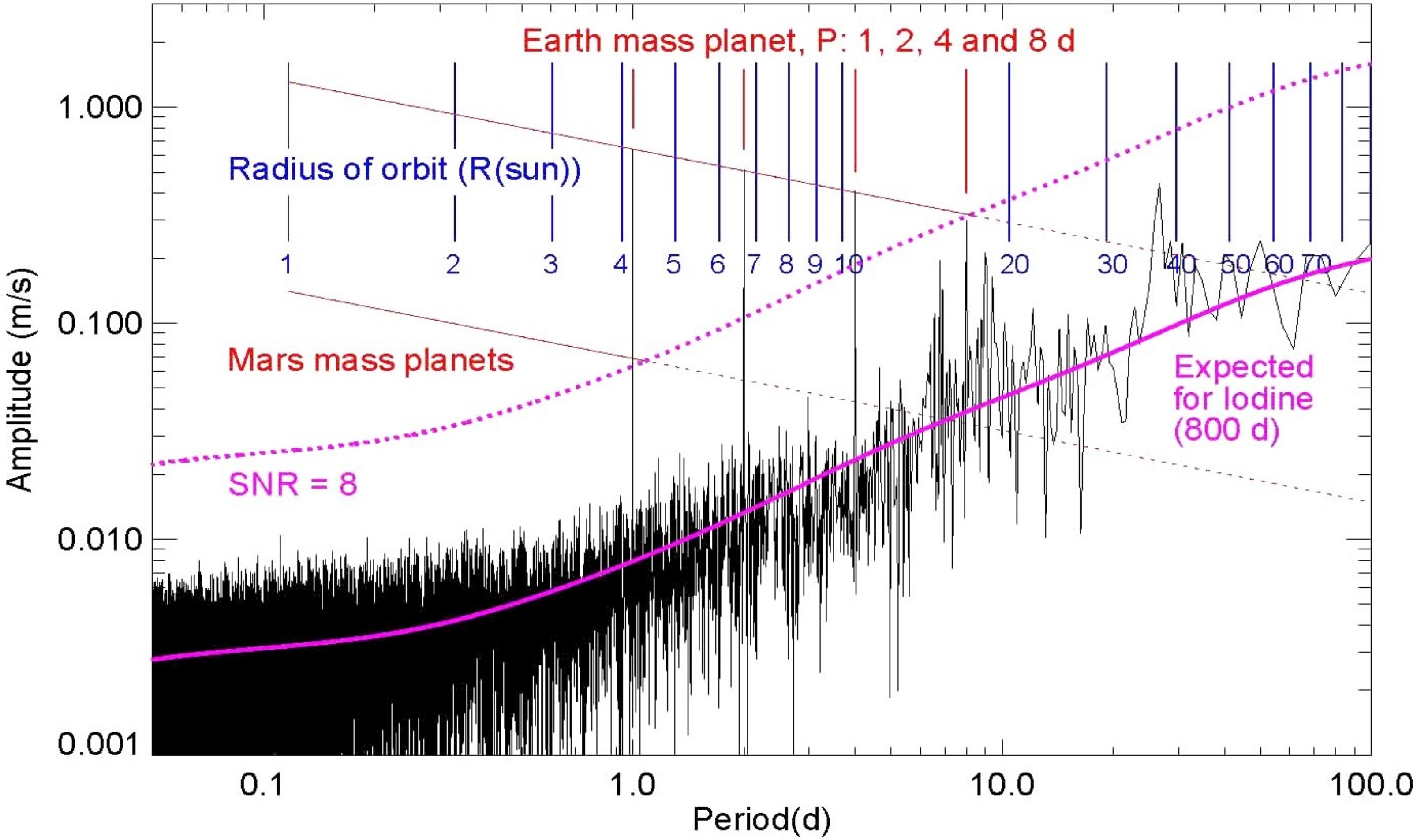
Near-surface frequency effects

Stellar structure and oscillation modelling deal inadequately with

- Treatment of convection in modelling (thermal structure, turbulent pressure)
- Mode damping excitation
- Dynamical effects of convection on oscillations
- Atmospheric structure



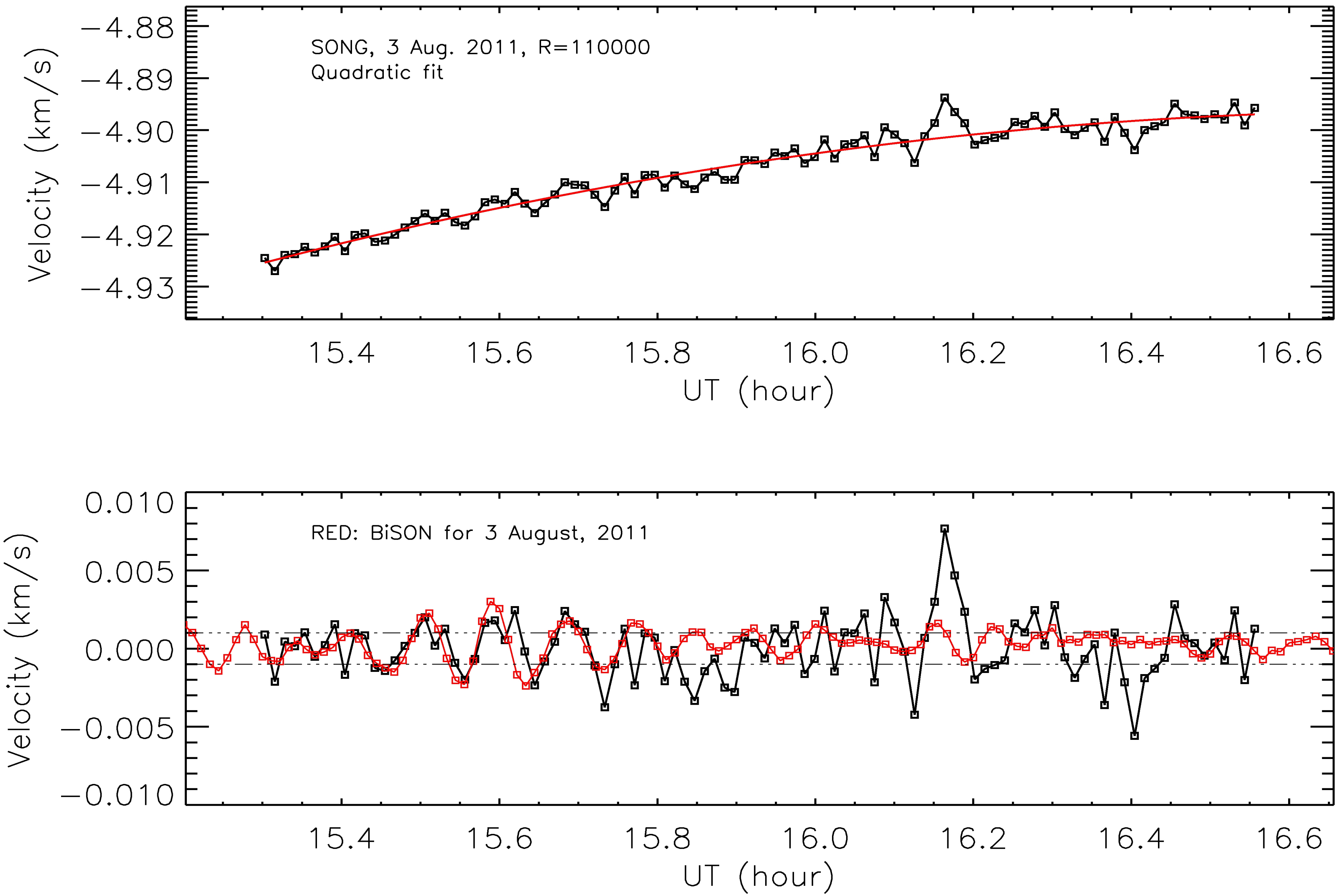
These effects are concentrated very near the surface (known as 'the surface term'

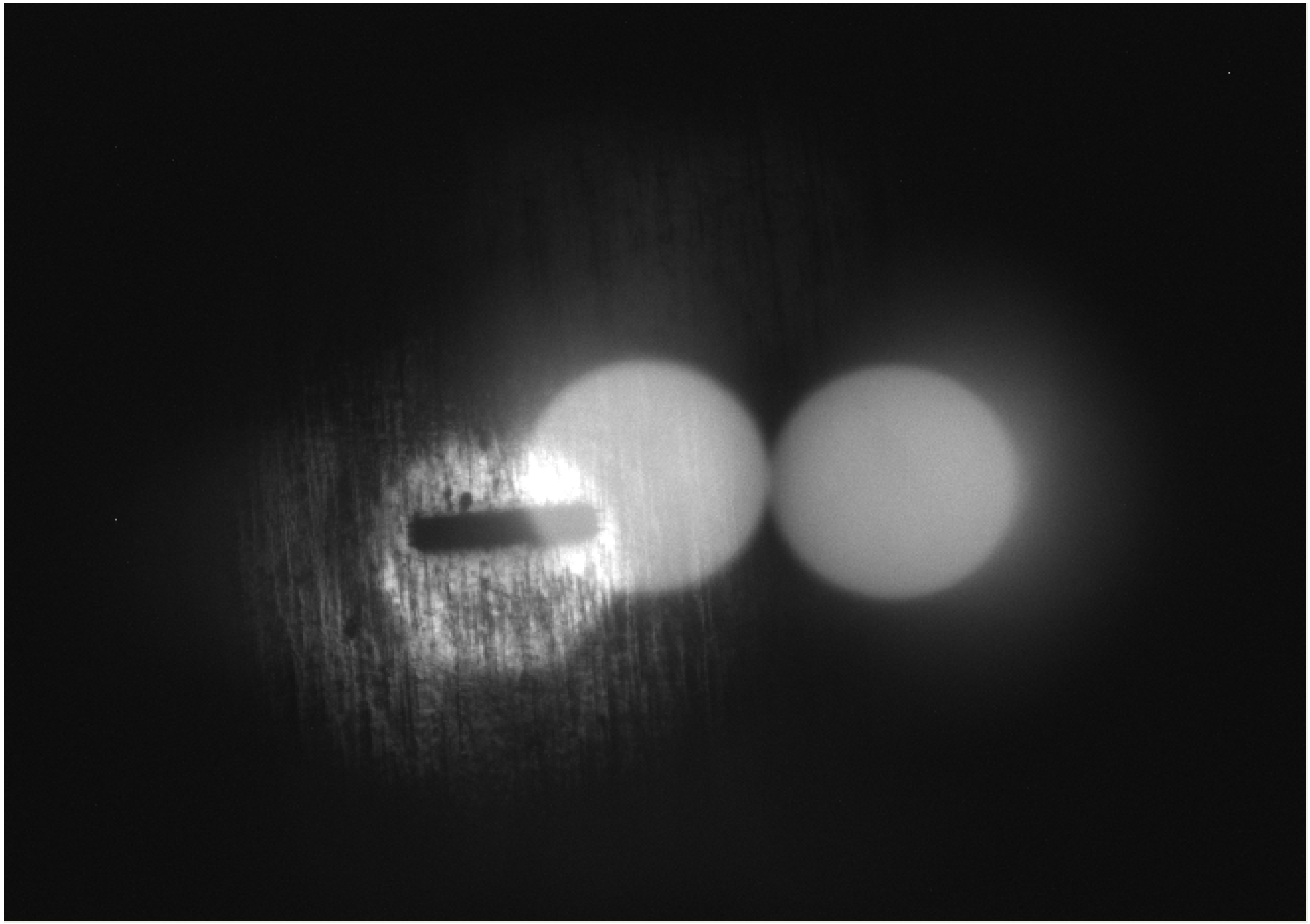


$$K = 6.4\,\mathrm{m/s}\ \times (M_{\mathbf{Planet}} / 10M_{\mathbf{Earth}}) \times P(d)^{\mathbf{-1/3}} \times (M_{\mathbf{Star}} / M_{\mathbf{Sun}})^{\mathbf{-2/3}}$$

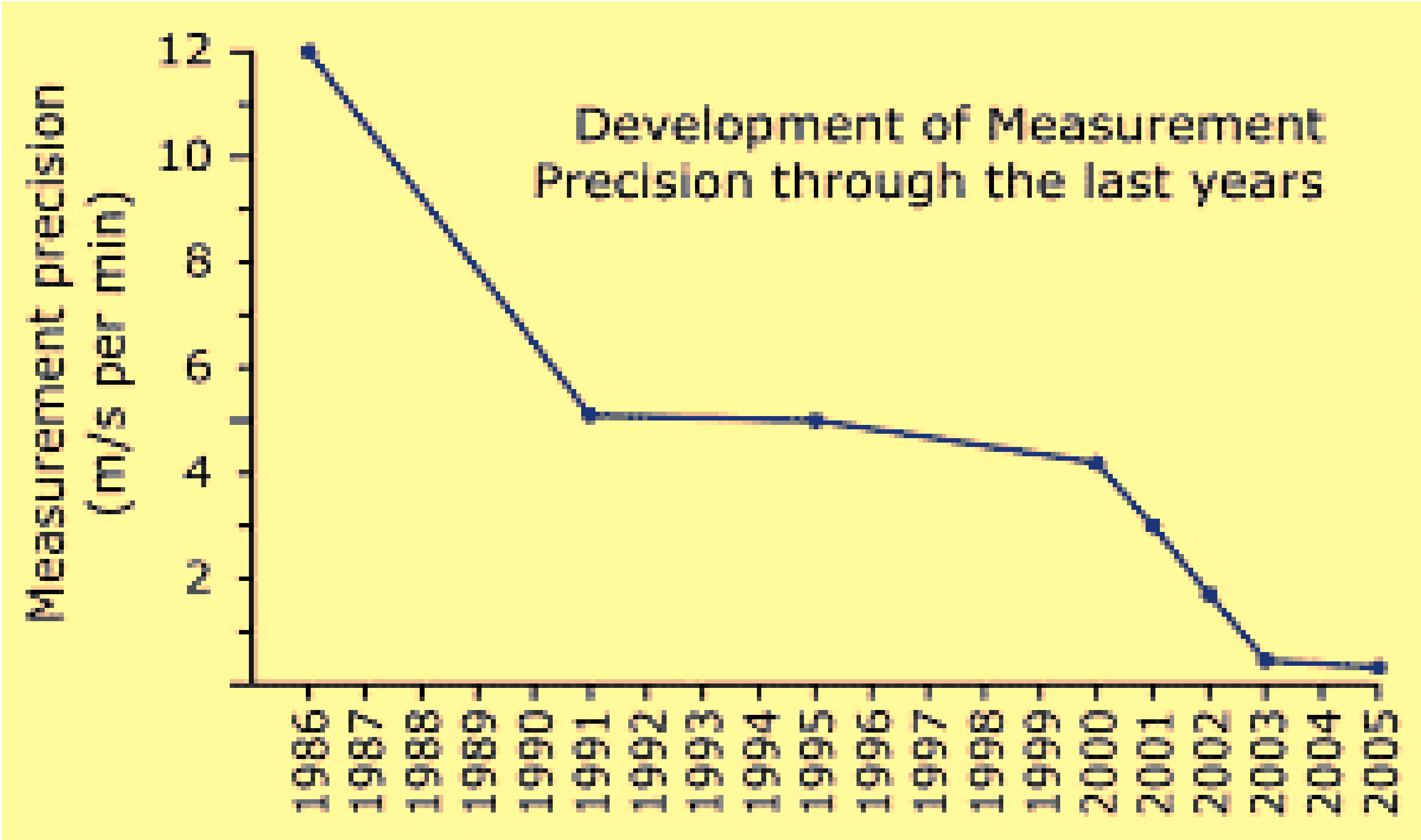
Main source of “noise” on long time scales: Activity and spots

Testing the velocity precision using observations of the Sun with through a fibre

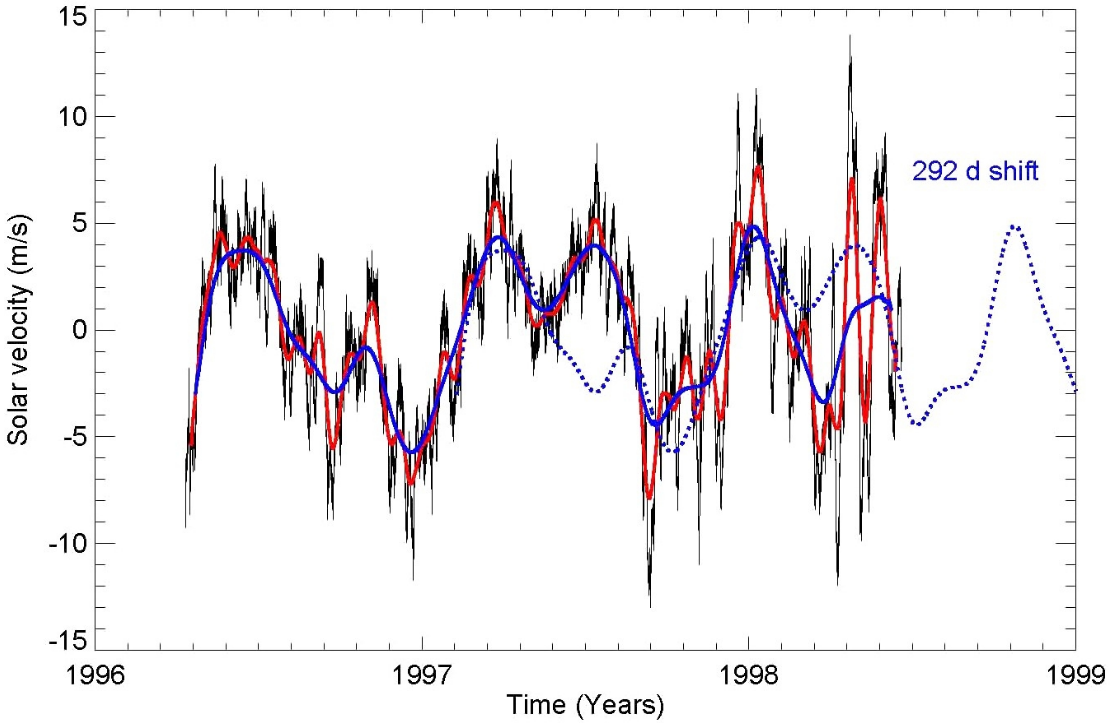


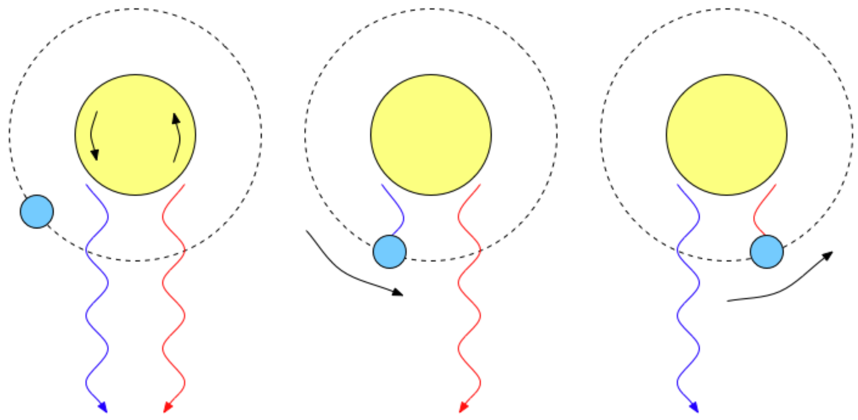


Limits to seismology and planet hunting

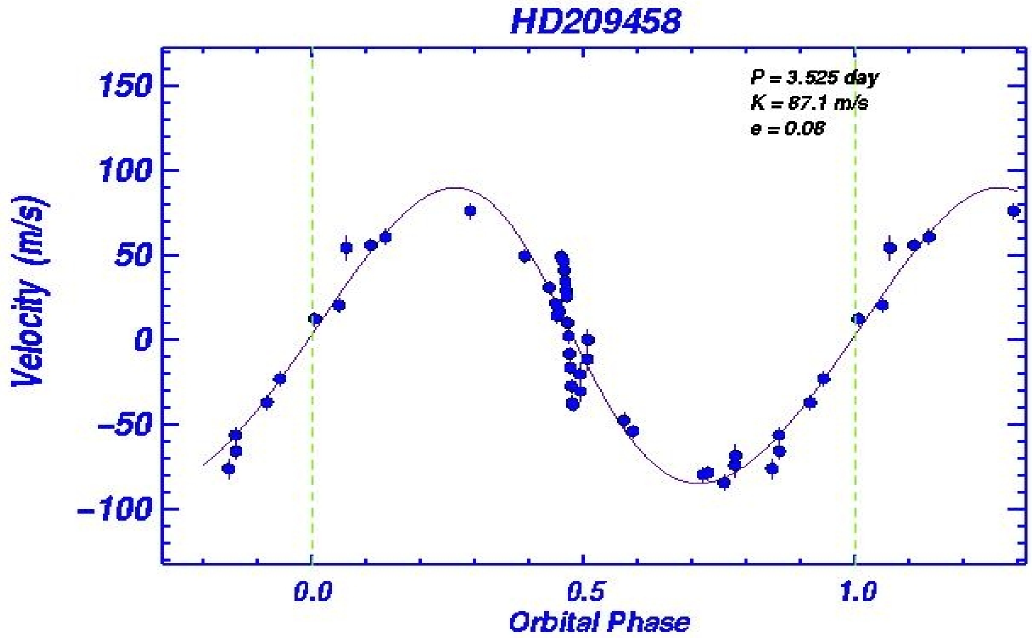


Activity and spots behave like the Rossiter effect, also known from eclipsing binaries and transitting extrasolar planets.





From http://exoplanets.org



- Oscillations
- Activity