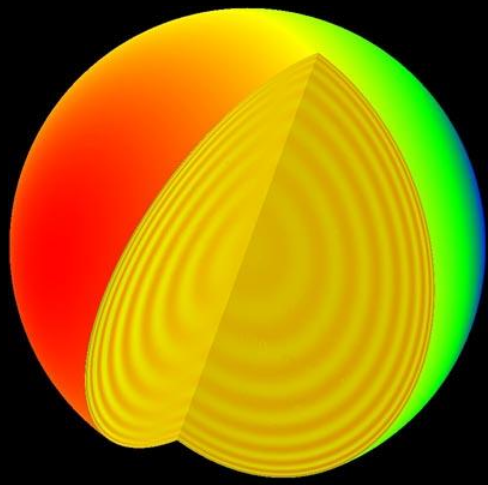
The SONG project: past and present (and a little future)

Jørgen Christensen-Dalsgaard



Danmarks Grundforskningsfond
Danish National Research Foundation

STELLAR ASTROPHYSICS CENTRE

The SONG concept

- Network of 8 telescopes with a global distribution
- Long, nearly continuous observations
- Ultra-precise Doppler-velocity measurements
- Precise photometry of faint stars in crowded fields

SONG is regarded as one scientific instrument

Rationale for SONG project

- Ultimate asteroseismic precision requires radial velocity observations
- Continuous extended observations require dedicated facility
- Optimized instrumentation can reach required sensitivity with 1m telescopes

A little history

- Early ideas: Spring 2005
  - With optimized instrumentation, spectroscopy with iodine reference, adequate sensitivity can be reach for bright stars with very modest telescopes
- Developed further during 2005
- Conceptual design phase through 2006
  - Funded by VKR, Carlsberg, …

Asteroseismology with an 8 m telescope

THE ASTROPHYSICAL JOURNAL, 635:1281–1290, 2005 December 20

SOLAR-LIKE OSCILLATIONS IN α CENTAURI B

HANS KJELDSEN,[1] TIMOTHY R. BEDDING,[2] R. PAUL BUTLER,[3] JØRGEN CHRISTENSEN-DALSGAARD,[1] LASZLO L. KISS,[2] CHRIS MCCARTHY,[3] GEOFFREY W. MARCY,[4] CHRISTOPHER G. TINNEY,[5] AND JASON T. WRIGHT[4]

Received 2005 April 7; accepted 2005 August 26

ABSTRACT

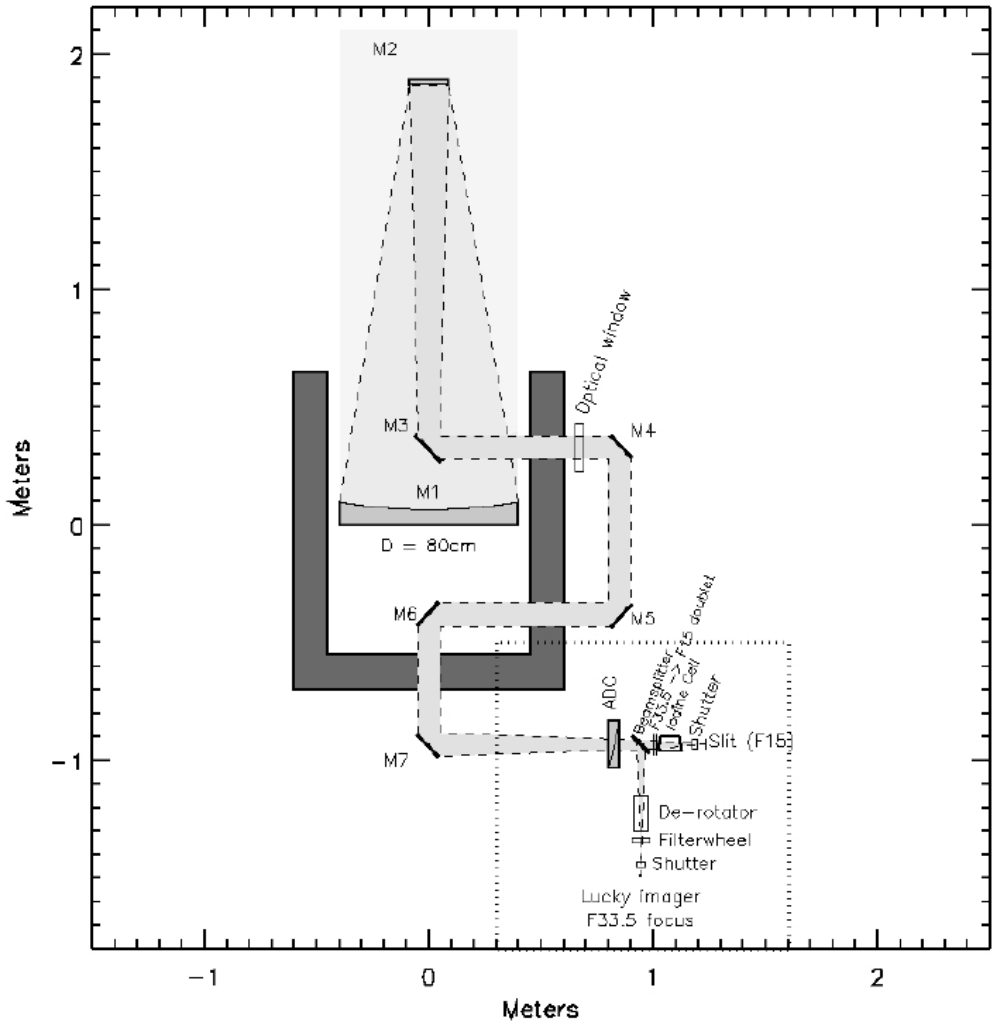
We have made velocity observations of the star α Centauri B from two sites, allowing us to identify 37 oscillation modes with $l = 0$–3. Fitting to these modes gives the large and small frequency separations as a function of frequency. The mode lifetime, as measured from the scatter of the oscillation frequencies about a smooth trend, is similar to that in the Sun. Limited observations of the star δ Pav show oscillations centered at 2.3 mHz, with peak amplitudes close to solar. We introduce a new method of measuring oscillation amplitudes from heavily smoothed power density spectra, from which we estimated amplitudes for α Cen α and B, β Hyi, δ Pav, and the Sun. We point out that the oscillation amplitudes may depend on which spectral lines are used for the velocity measurements.

Subject headings: stars: individual (α Centauri A, α Centauri B, β Hydri, δ Pavonis) — stars: oscillations — Sun: helioseismology

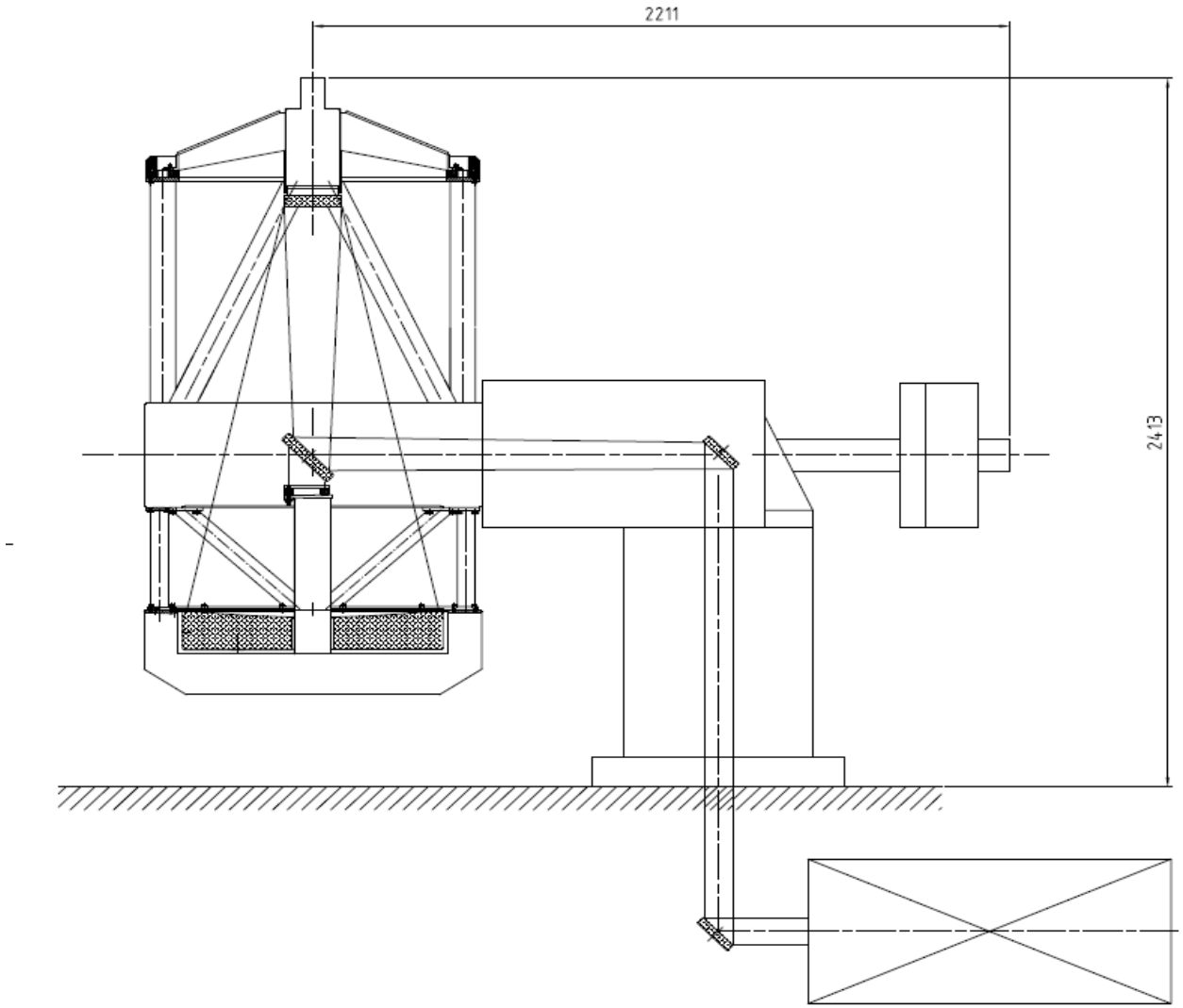
Using UVES on VLT and UCLES on AAT

Early concept (December 2005)

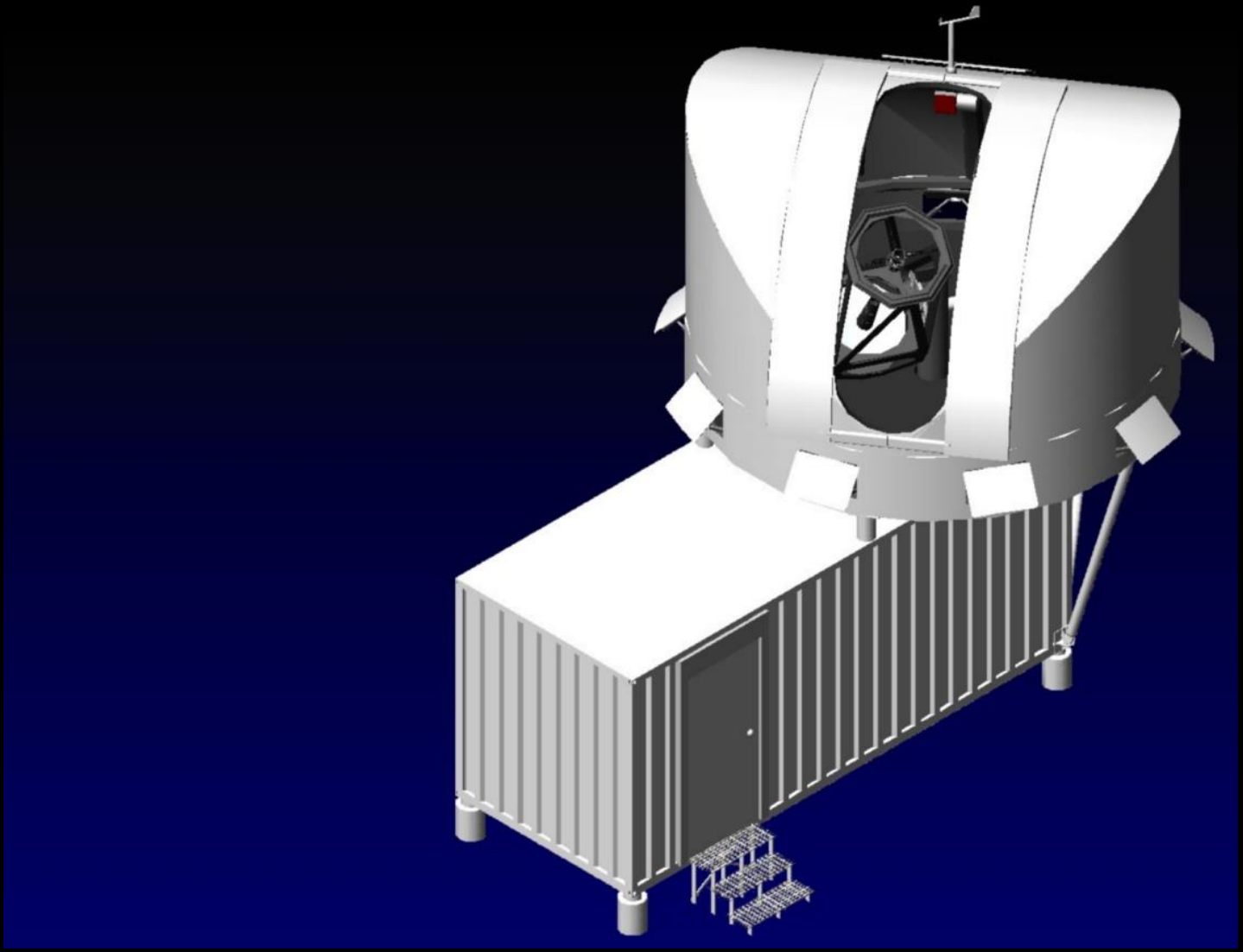
Revised design, mid-2006



ASTELCO sketch, early 2007



An early sketch for the design



Conceptual design review, 1 – 2 March 2007

- Team: Keith Horne, Thomas Augustein, Don Kurtz
- Conclusion: *We commend the SONG team for its remarkable progress in developing the SONG concept to its present level of definition. SONG's unique combination of instrumentation and continuous observing capabilities for time-domain observations will open a new era in asteroseismology and will have a major impact on the discovery and study of extrasolar planets*

Prototype funding

- Villum Fonden, 2007: General funding for prototype development
- Danish Natural Science Research Council, 2008: Funding of spectrograph
- Carlsberg Foundation, 2008: Partial funding of telescope
- Aarhus, Copenhagen Universities: In-kind contributions
- Instituto de Astrofísica de Canarias, Tenerife: Local infrastructure, local operations

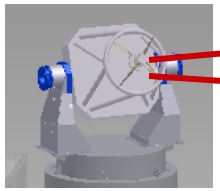
Scientific goals of SONG

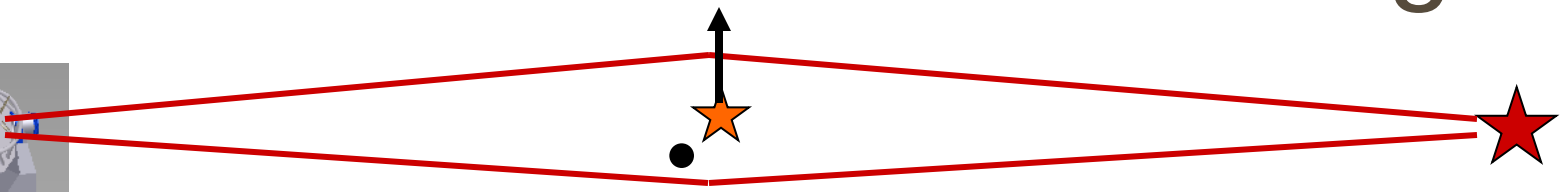
- Asteroseismology of unprecedented resolution and accuracy
  - Radial-velocity observations
- Characterization of extra-solar planetary systems
  - Radial-velocity observations
  - Gravitational microlensing
- Additional science

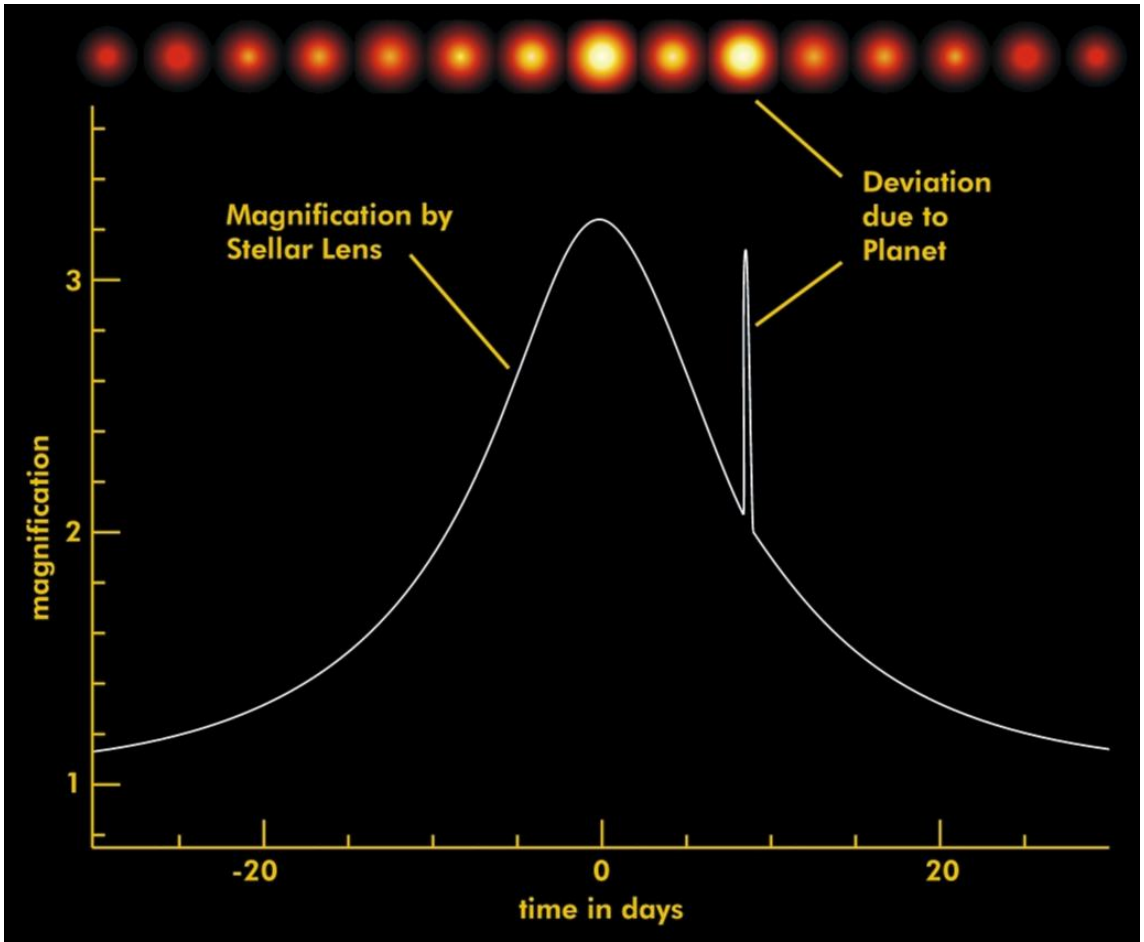
Studies of exo-planets

- Radial velocity
  - Low-mass planets in short-period orbits
- Gravitational micro-lensing
  - Characterization of statistics of planetary systems, including low-mass planets in long-period orbits

Gravitational micro-lensing







Asteroseismology

The study of stellar interiors from observations of stellar oscillations

- Oscillation frequencies can be determined with extremely high precision
- Frequencies are sensitive to internal structure and rotation
- Mode amplitudes and lifetimes are sensitive to near-surface physics, including convective dynamics

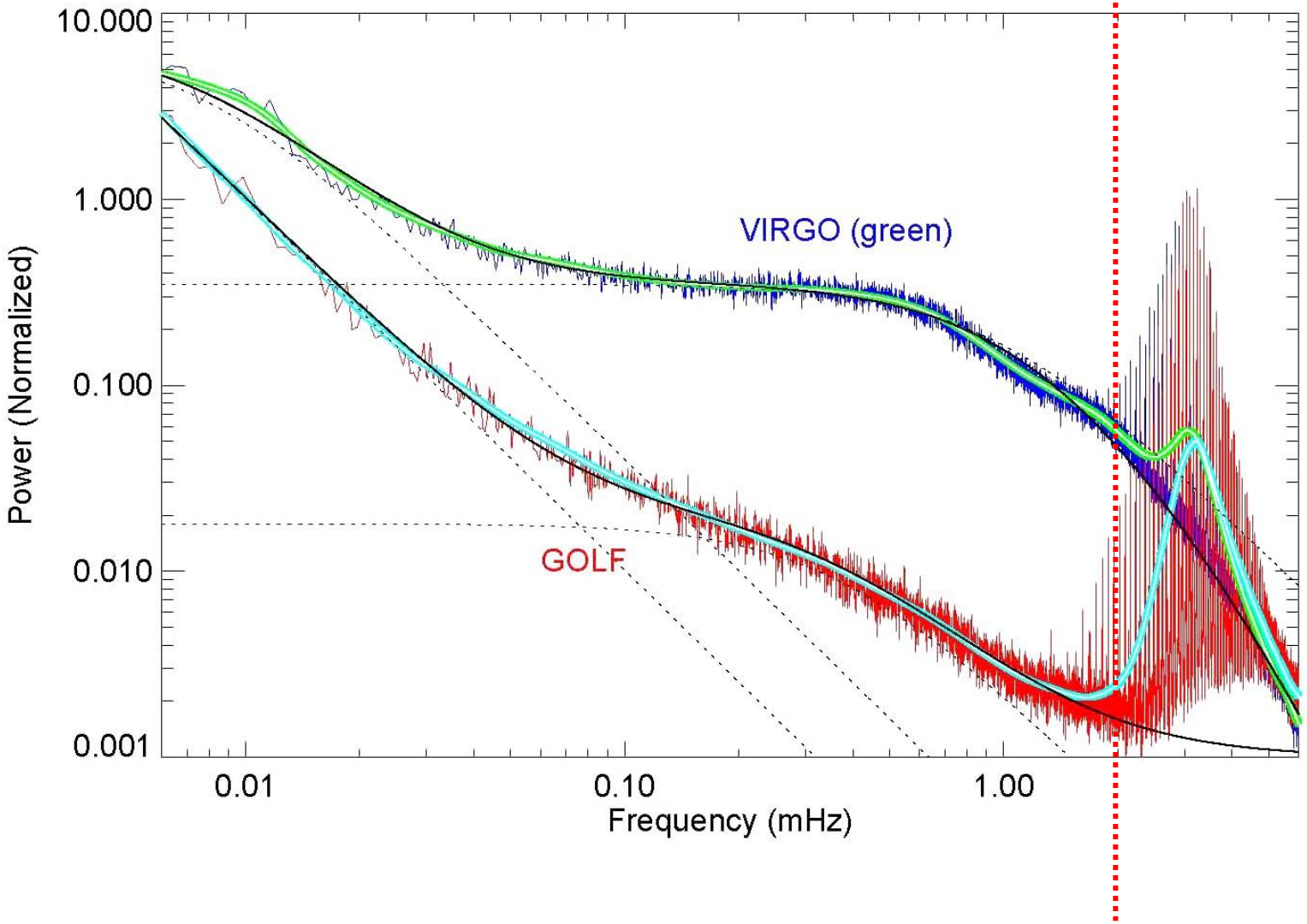
Observational requirements

- Extreme sensitivity
  - Amplitudes down to a few cm/s in velocity and a few parts per million in intensity
- Very long observation series (weeks or months)
  - Ensure sufficient frequency precision
- Nearly continuous data
  - Avoid complications in observed oscillation spectrum

SONG in the *Kepler* era

- *Kepler* provides very good data for hundreds (thousands) of stars
  - Ensemble asteroseismology (comparison of stellar properties)
  - Population studies
  - Characterization of pulsation properties for broad range of stars
- SONG will provide exquisite data for a limited number of stars
  - Detailed probing of stellar internal structure
  - Detailed investigations of physics of stellar interiors

Stellar noise vs. oscillations

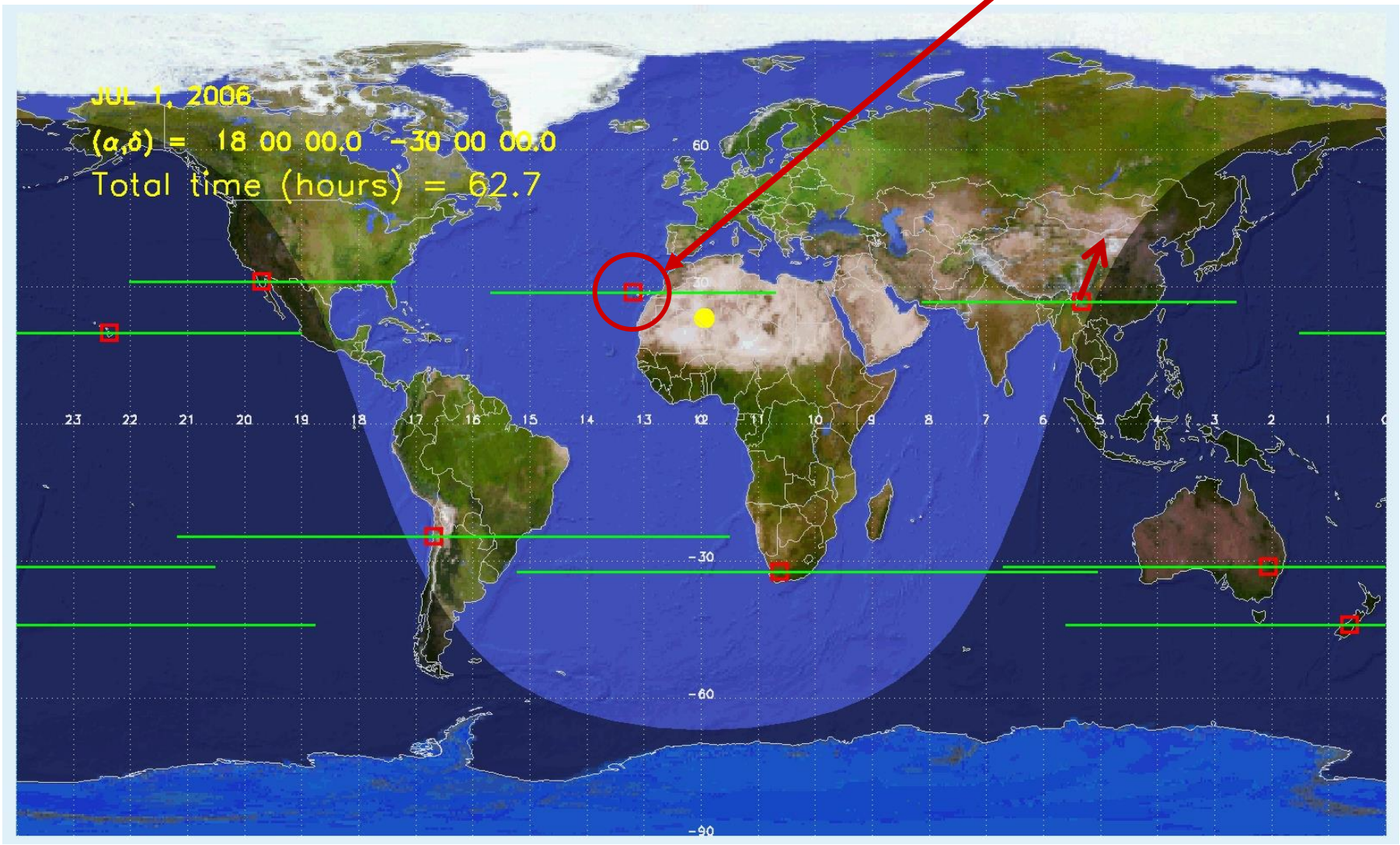


Overall design drivers for SONG instrumentation

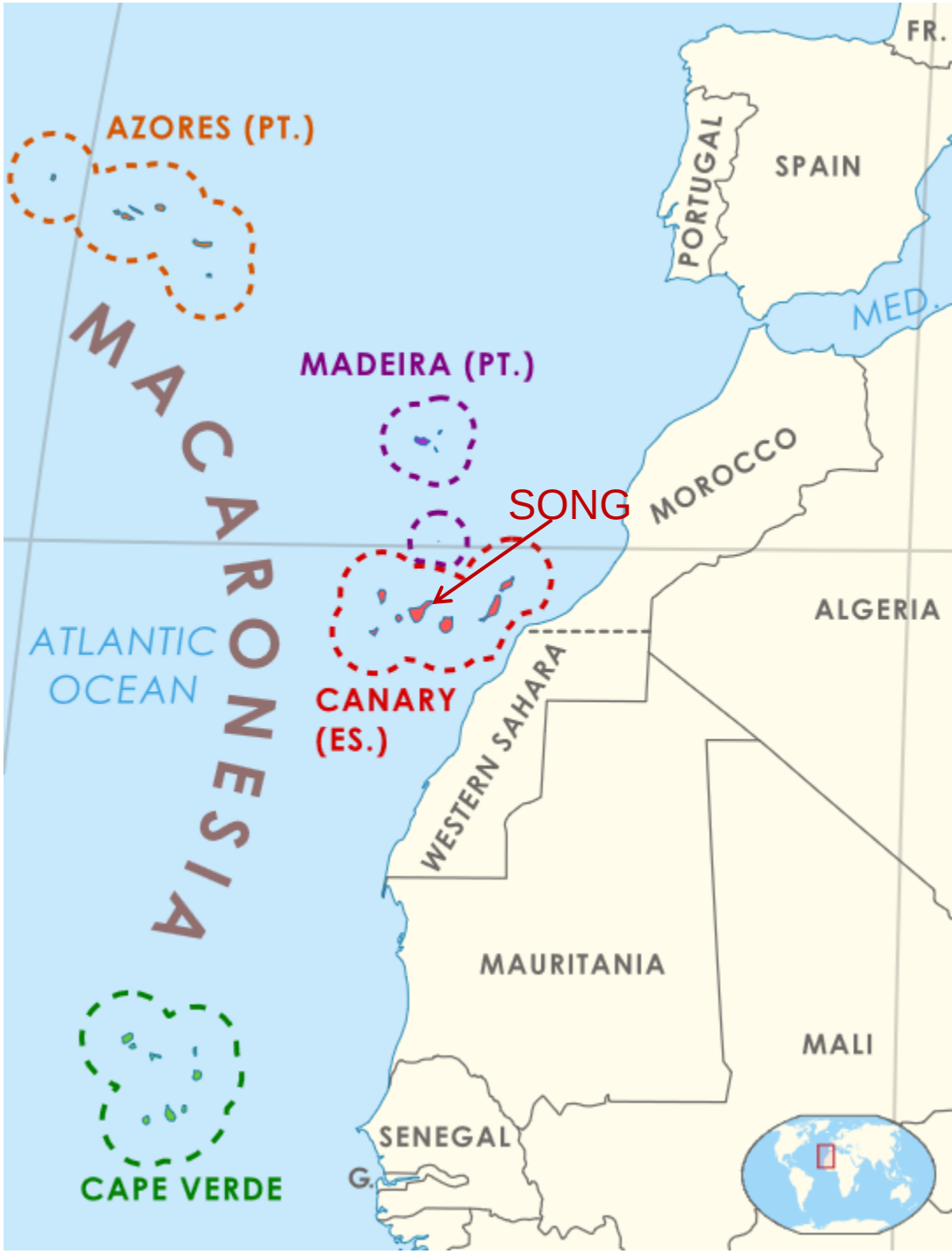
Optimize the design for the primary science purposes:

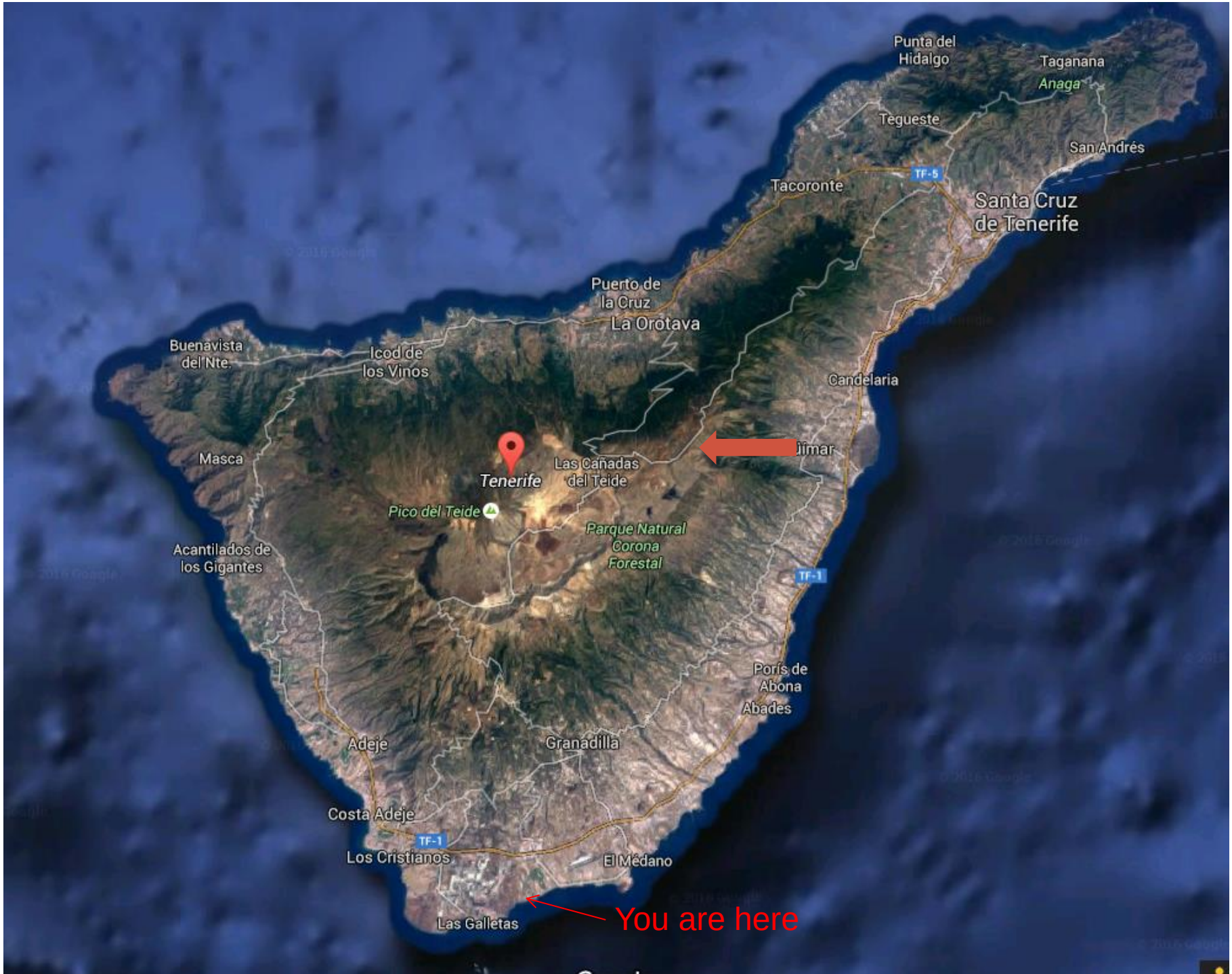
- Ultra-precise radial velocities
- Photometry in crowded fields
- High duty-cycle
- Long lifetime

Strawman sites



Macaronesia

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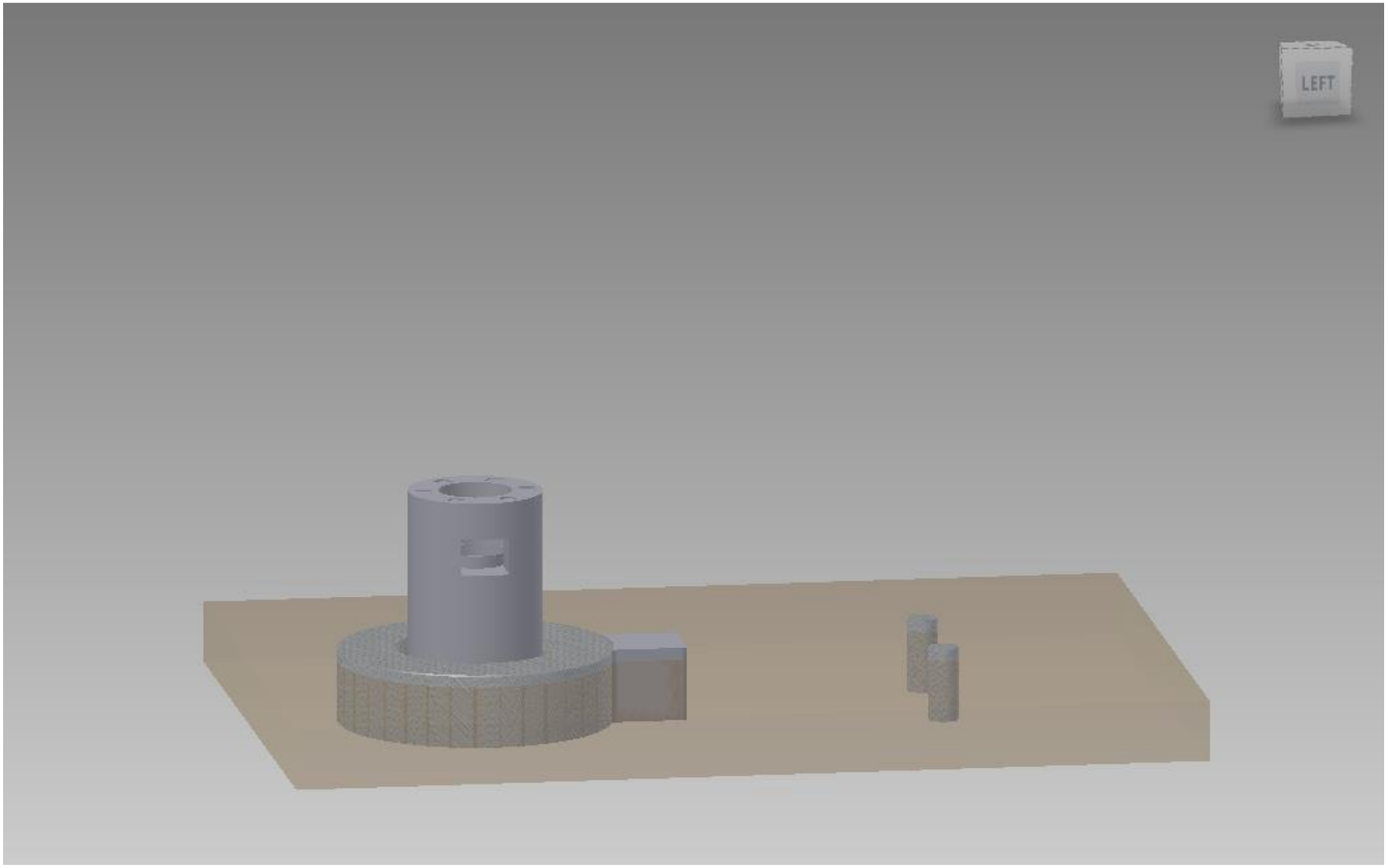
Taganana
Anaga
Tegueste
San Andrés
TF-5
Tacoronte
Santa Cruz de Tenerife
Puerto de la Cruz
La Orotava
Buenavista del Nte.
Icod de los Vinos
Candelaria
Masca
Tenerife
Las Cañadas del Teide
Pico del Teide
Parque Natural Corona Forestal
Acantilados de los Gigantes
TF-1
Porís de Abona
Abades
Adeje
Granadilla
Costa Adeje
TF-1
Los Cristianos
El Médano
Las Galletas
You are here


TF-24
Arafo
La Hidalga
TF-1
Güímar
TF-24
Samarines
Teide Observatory
Las Cañadas
del Teide
Puertito
de Güímar
TF-28
Lomo
de Mena
Punta Prieta
El Escobonal
Zoom

Telescope and dome

- 1 m telescope, alt-az mount
- High-resolution spectrograph
- Lucky Imaging camera for micro-lensing
- Telescope, dome delivered by Astelco Systems, GmBH
- Acceptance, Tenerife, Autumn 2012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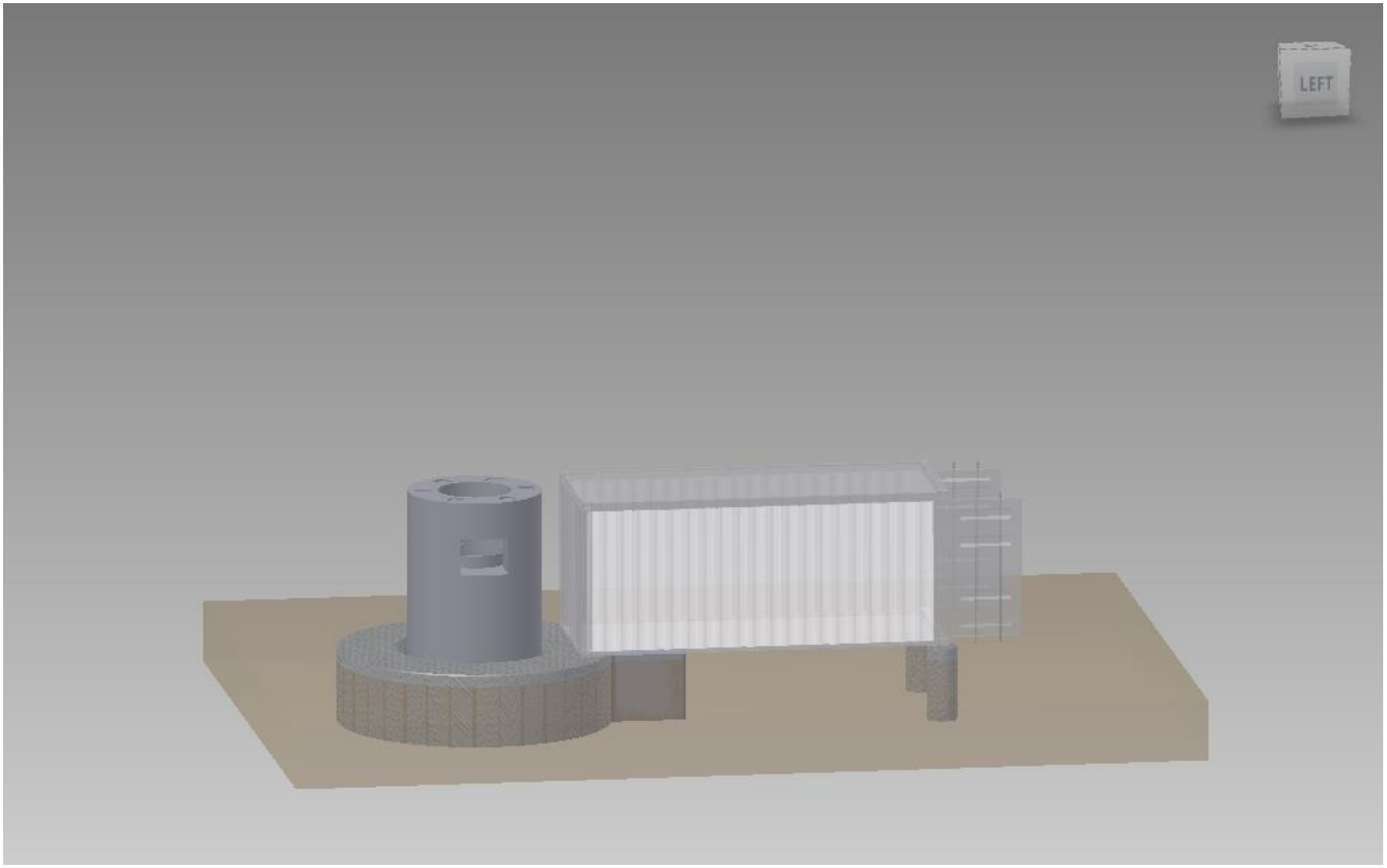
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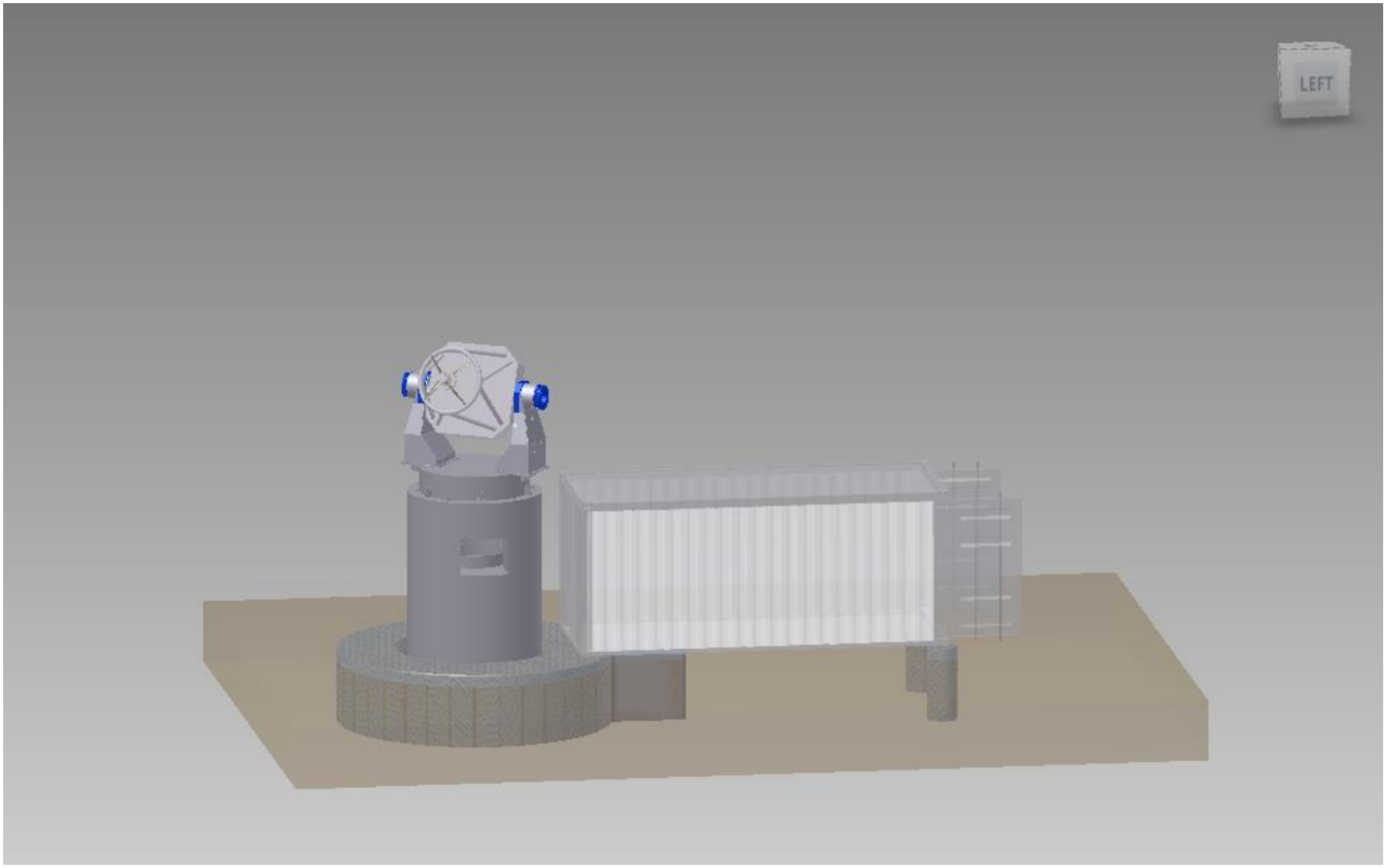
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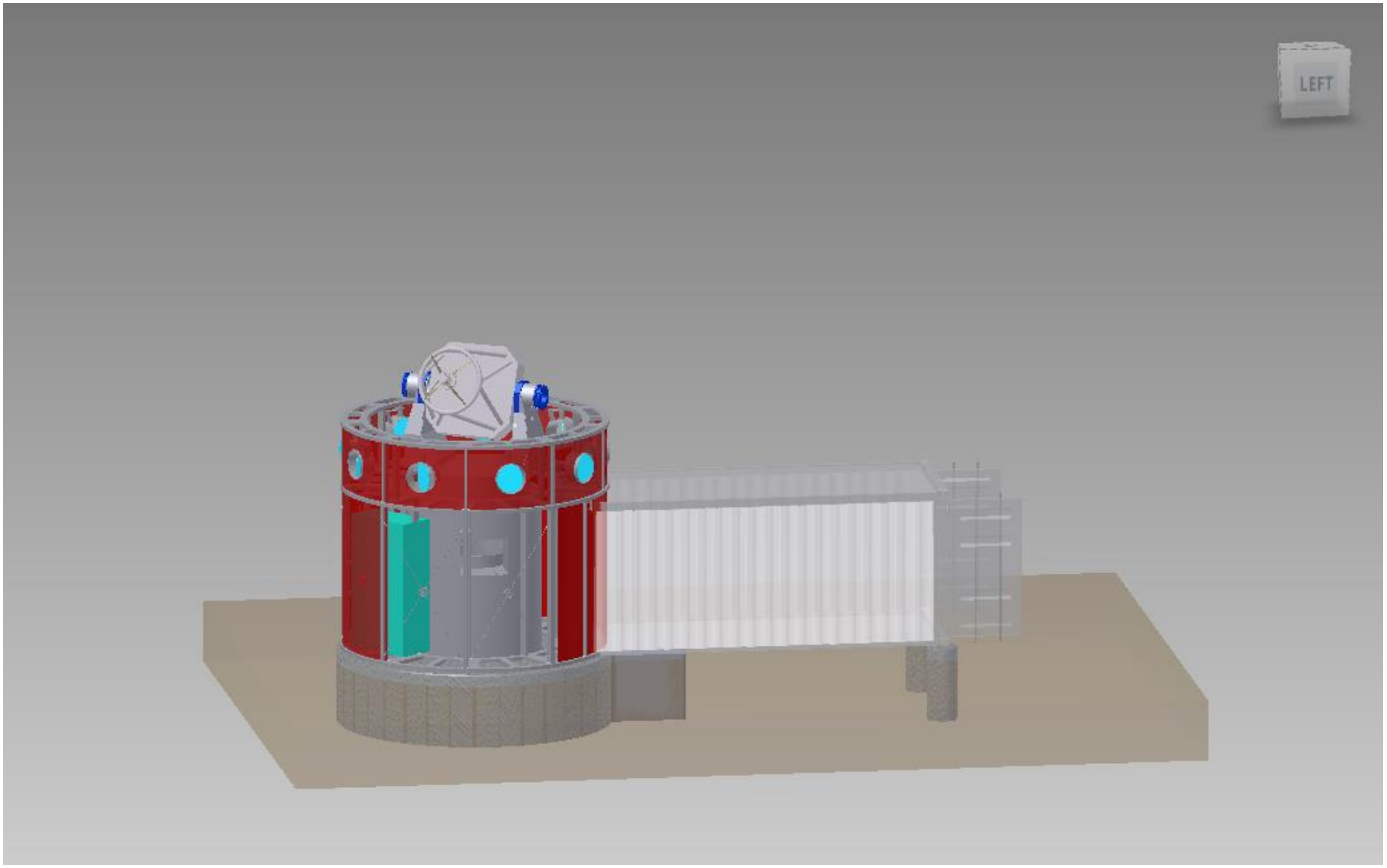
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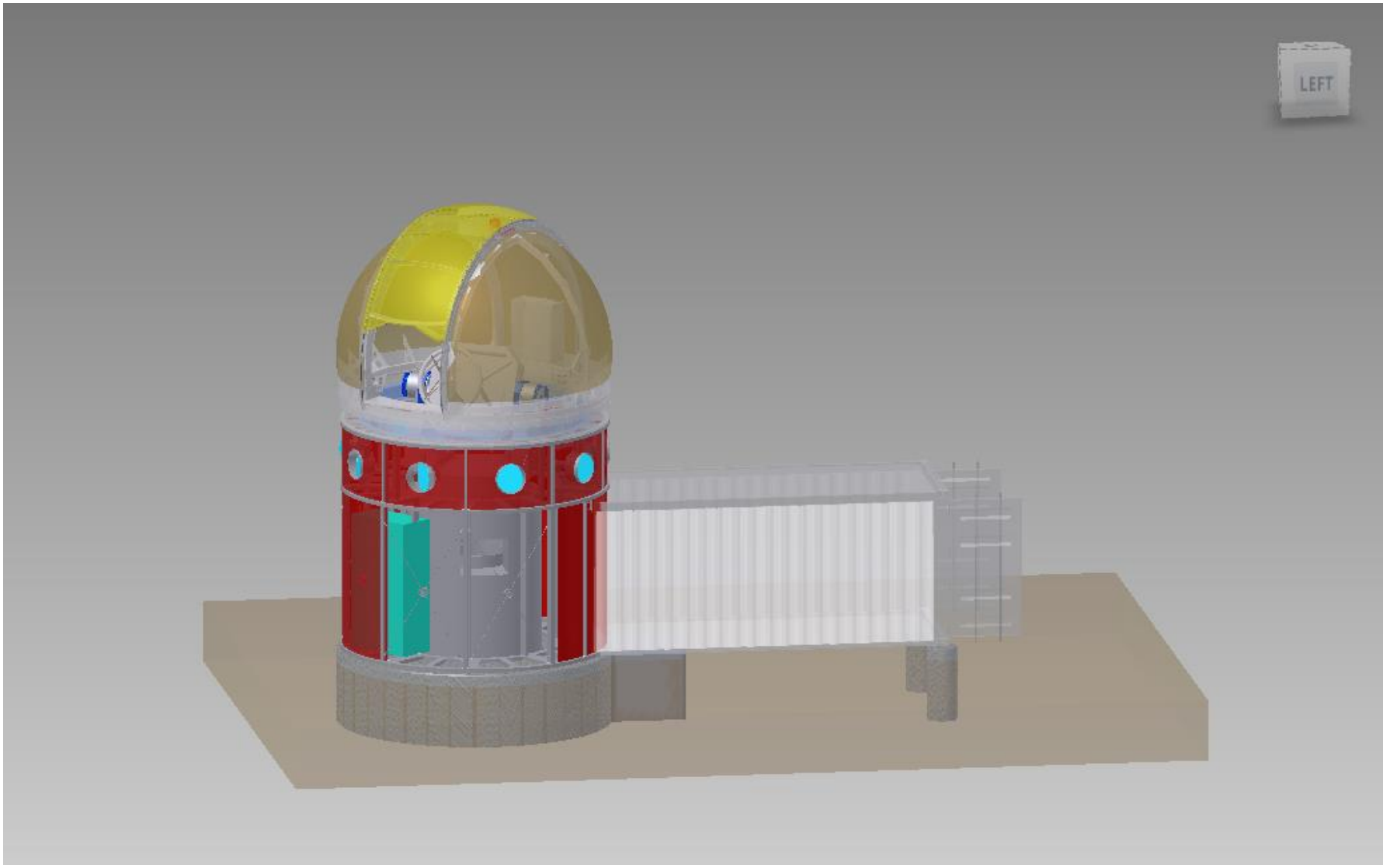
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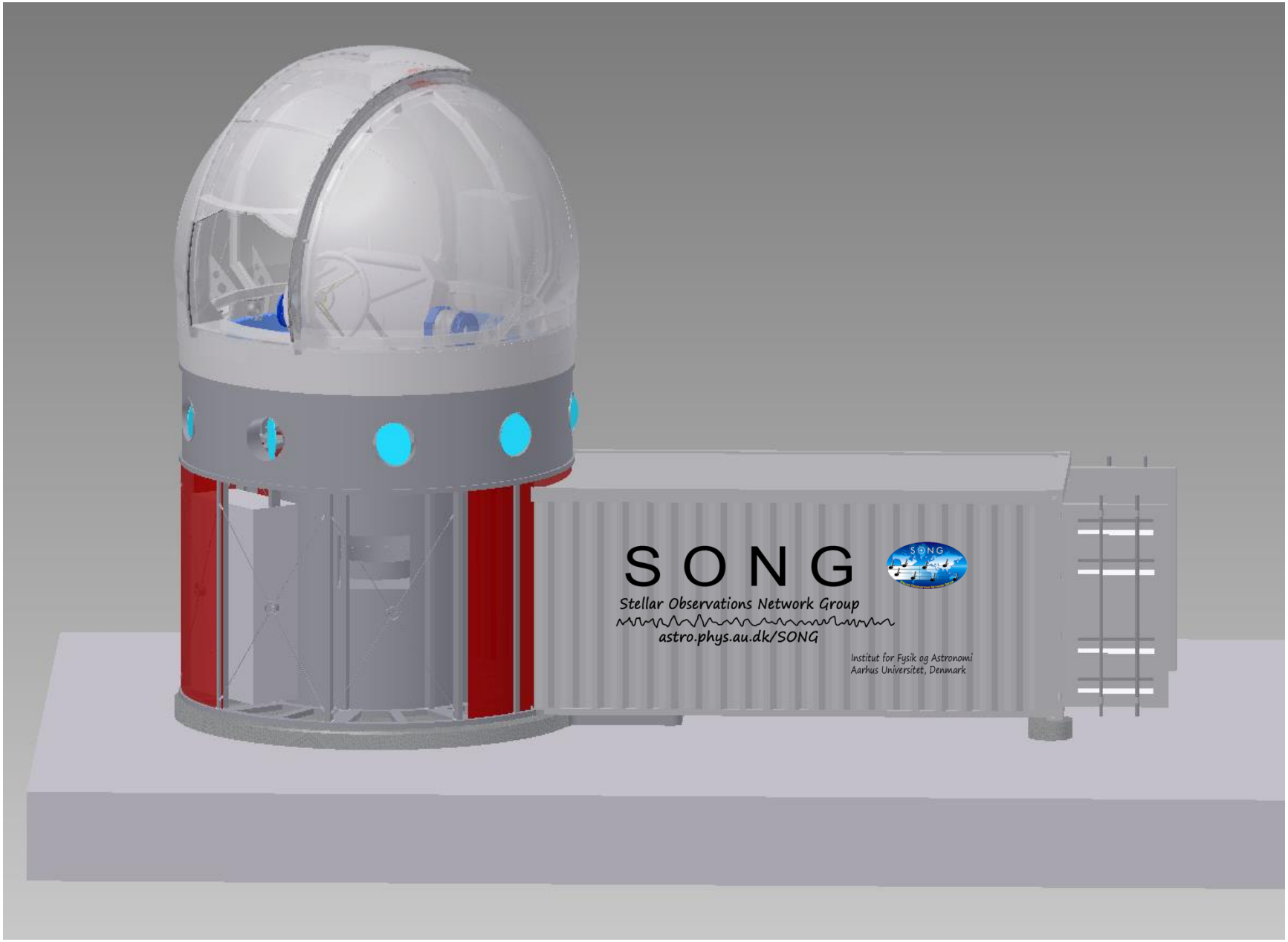
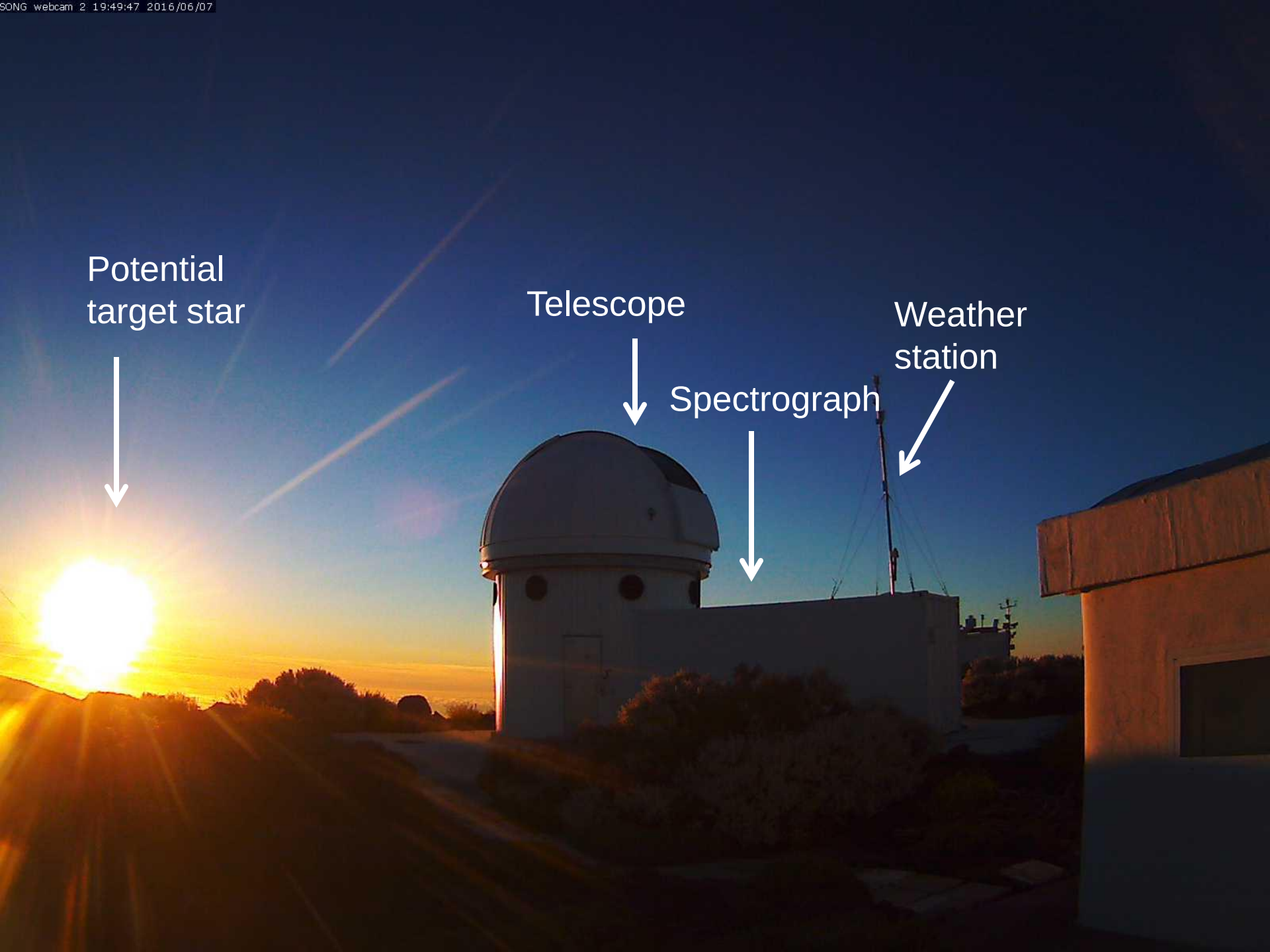
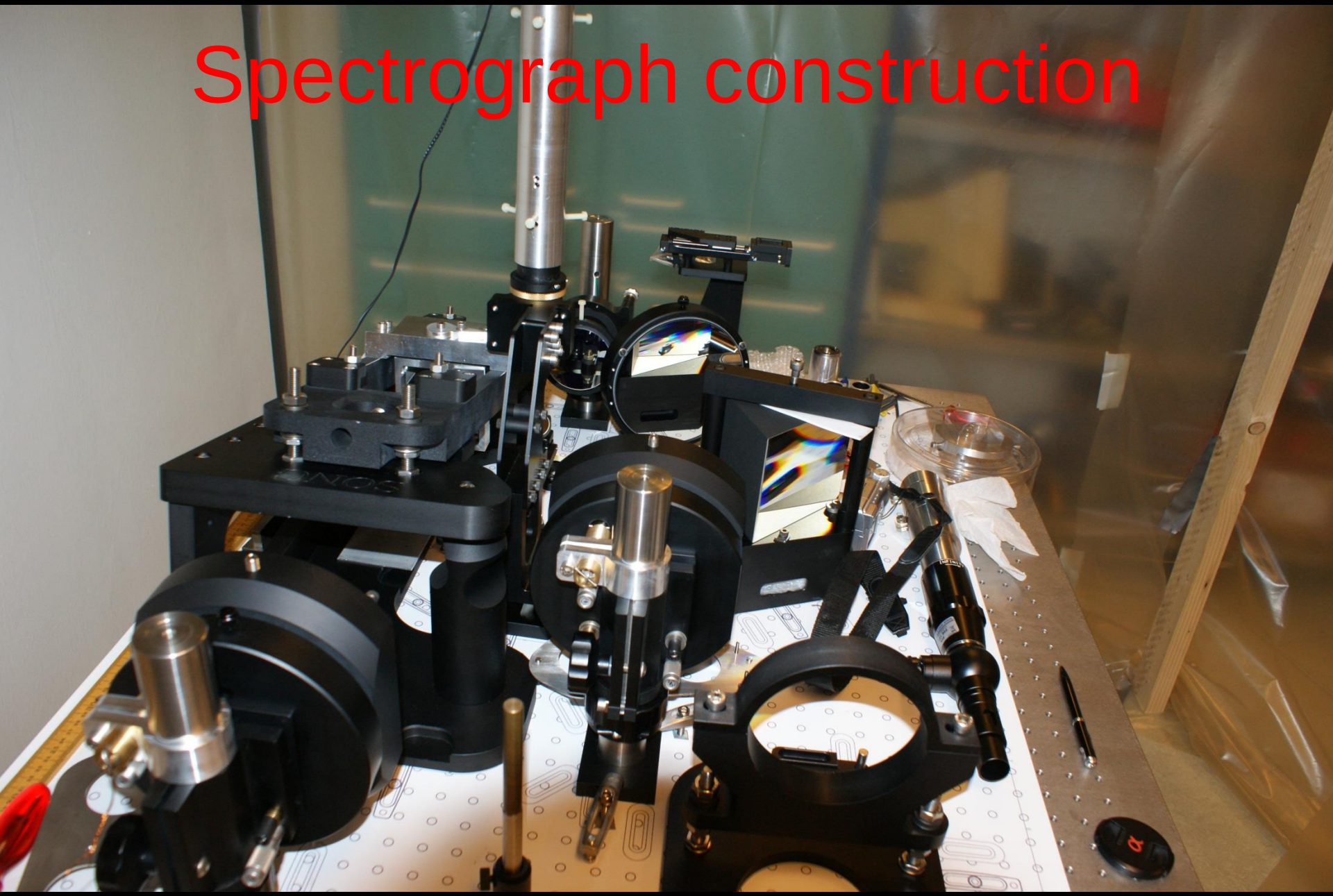

SONG
Stellar Observations Network Group
astro.phys.au.dk/SONG
Institut for Fysik og Astronomi
Aarhus Universitet, Denmark


SONG webcam 2 19:49:47 2016/06/07
Potential target star
Telescope
Spectrograph
Weather station

Radial-velocity measurements

- High-resolution spectrograph (R ~ 100,000)
- Spectrograph in moderately temperature-stabilized environment
- Iodine-cell reference
- Optimize instrumentation for iodine wavelength region
- Develop efficient software for analysis of iodine data

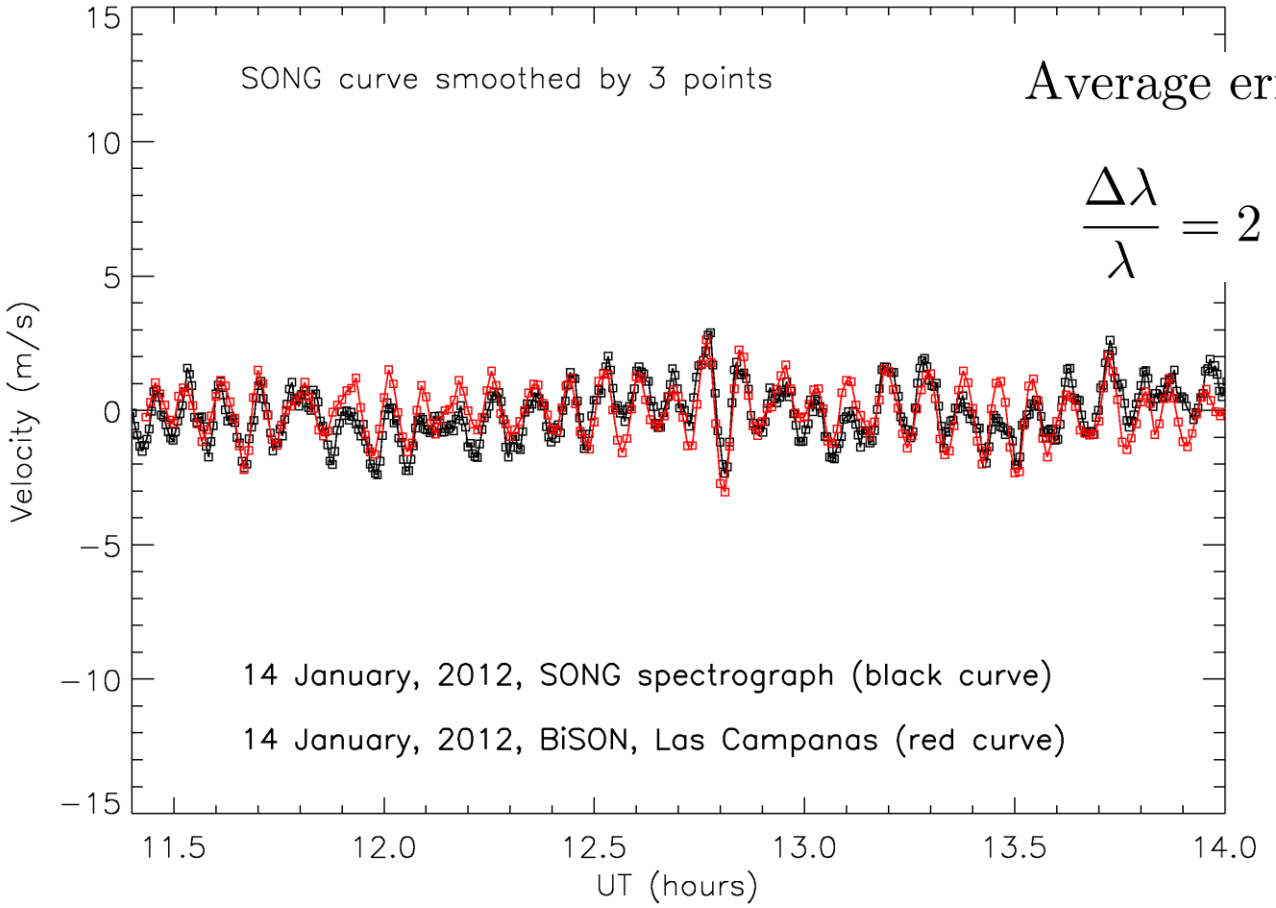
Spectrograph construction



The first iodine cells for SONG after heating to 80ºC in a kitchen oven.

Was scanned in 2010 with a FTS at Lund Observatory, Sweden.

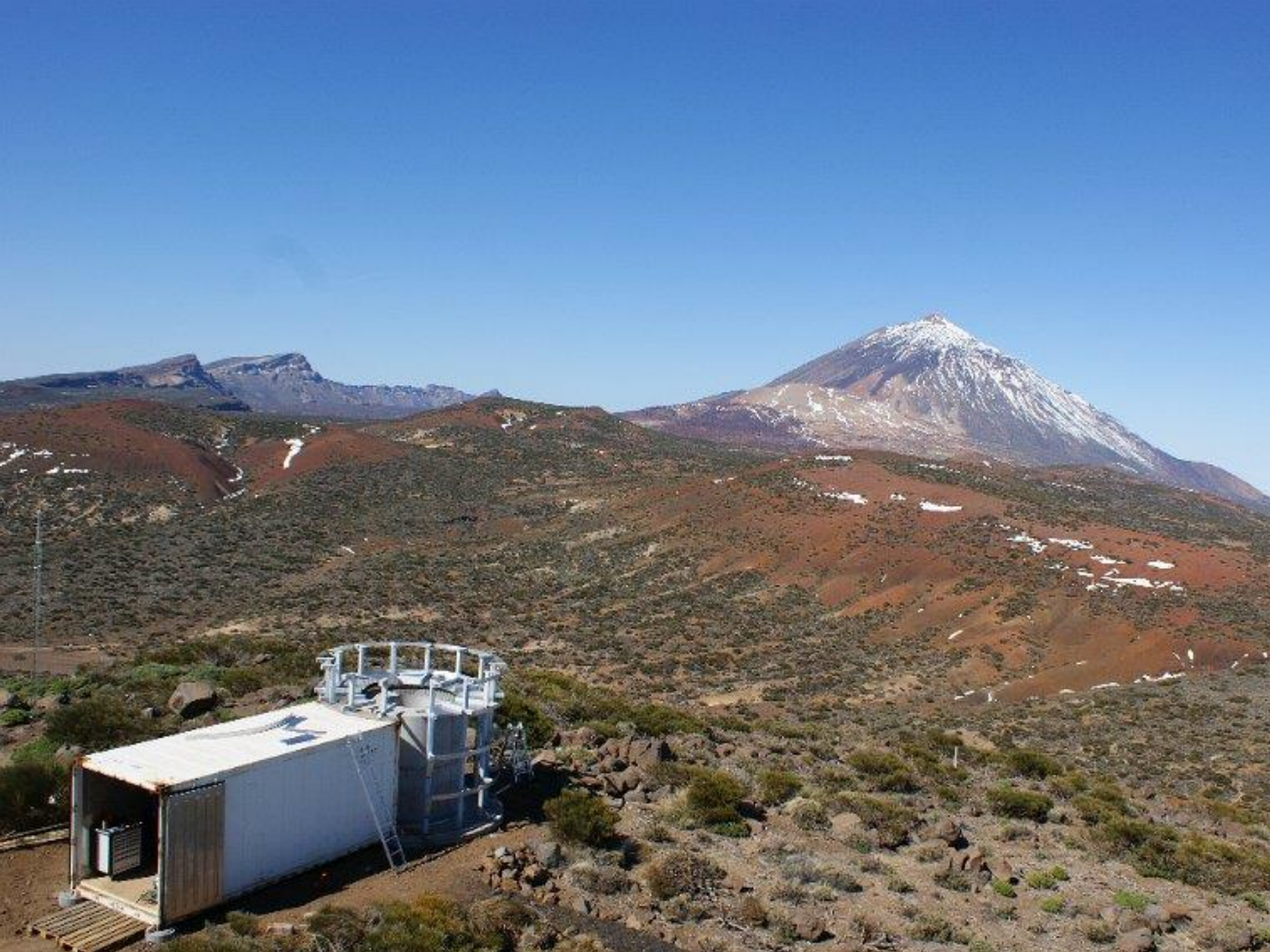
Solar observations from IFA parking lot



Average error: $0.7\,\mathrm{m\,s^{-1}}$ per point.

$$\frac{\Delta\lambda}{\lambda} = 2 \times 10^{-9}$$

November 2010



March 2012


JORGEN

23 April 2012


SONG webcam 1 15:43:43 2012/04/23

SONG Weather page - Windows Internet Explorer

http://demo.ss1n1.phys.au.dk/weatherpage/index.php?d=12

Google

Convert Select

Favorites E-mail Indbakke Google Maps Byvejr - Danmark Nyheder - seneste nyt - P...

SONG Weather page

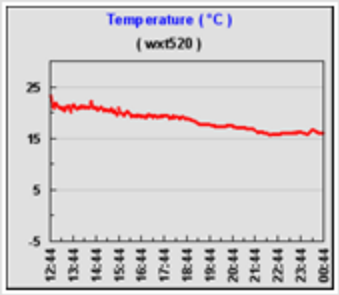
Page Safety Tools

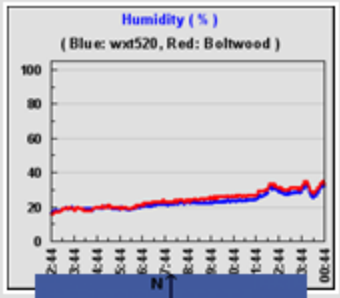
Site:	Tenerife
Latitude:	28:17:54
Longitude:	-16:30:34
Date:	2012-08-15
Local time:	01:44:08
Universal time:	00:44:08
Your local time:	2:44:09

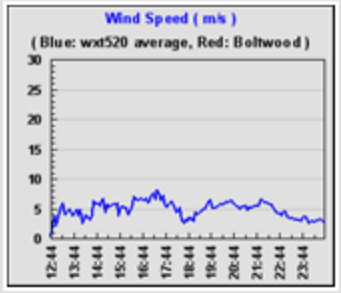
Temperature:	15.90 °C	✓
Humidity:	32.10 %	✓
Wind speed:	2.68 m/s	✓
Rain:	No	✓
Clouds:	Clear	✓
Dust:	0.0112	✗
Wind dir:	249.00 °N	
Dew point:	0.40 °C	
Pressure:	772 hPa	

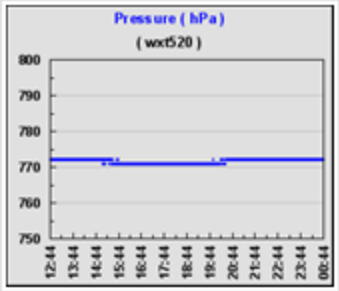
6H Data 12H Data 24H Data 3D Data 1W Data 1M Data 6M Data 1Y Data

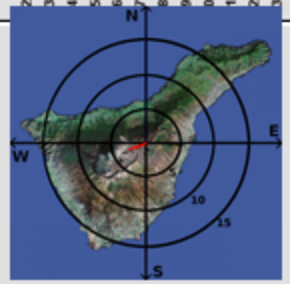
Time in days: Go



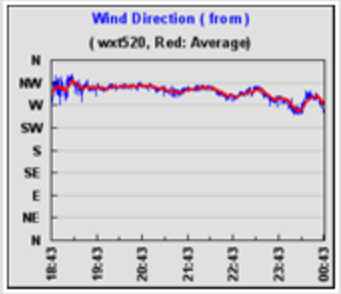


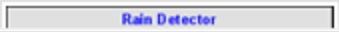






The red line indicates direction (from) and speed in m/s.





Done

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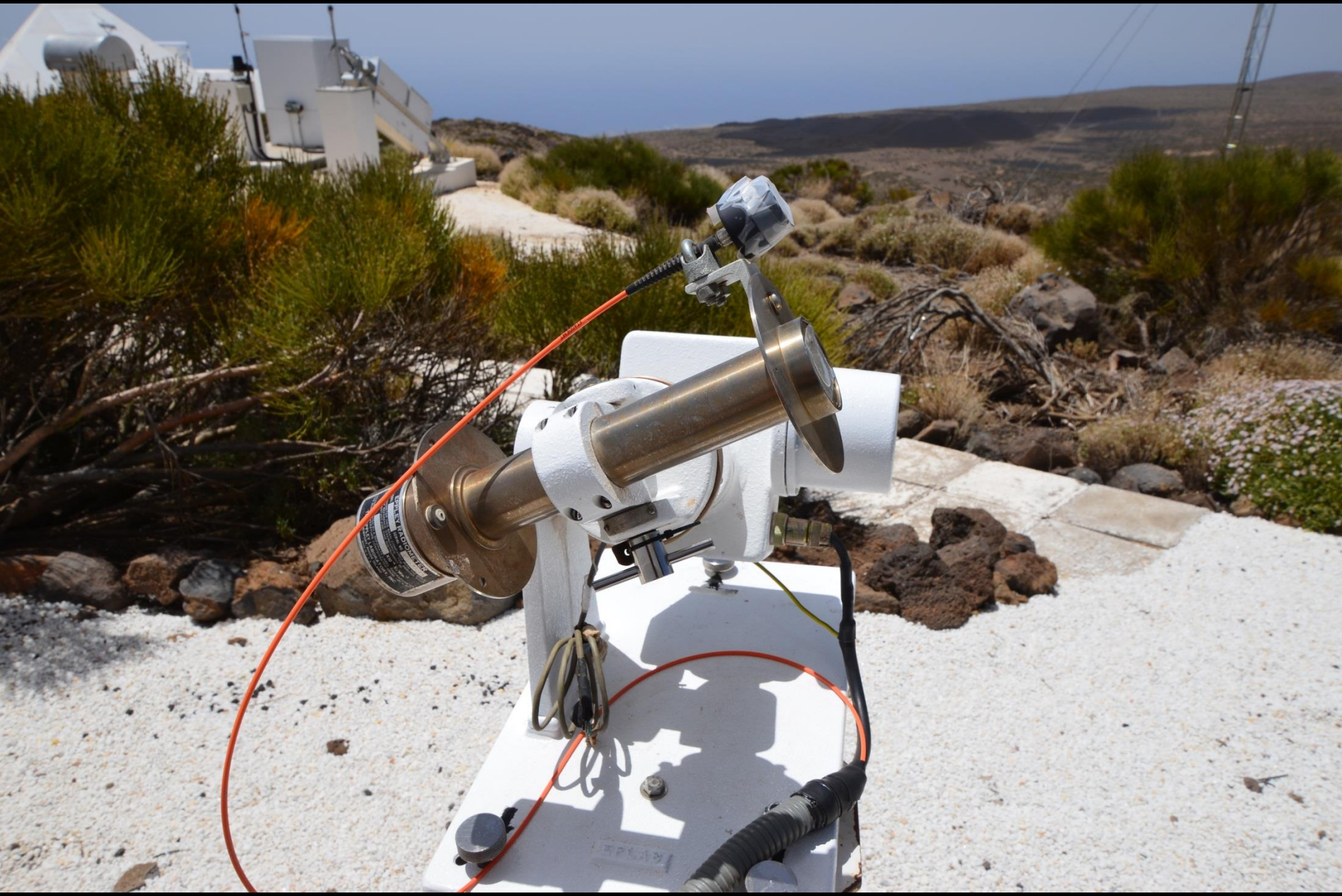
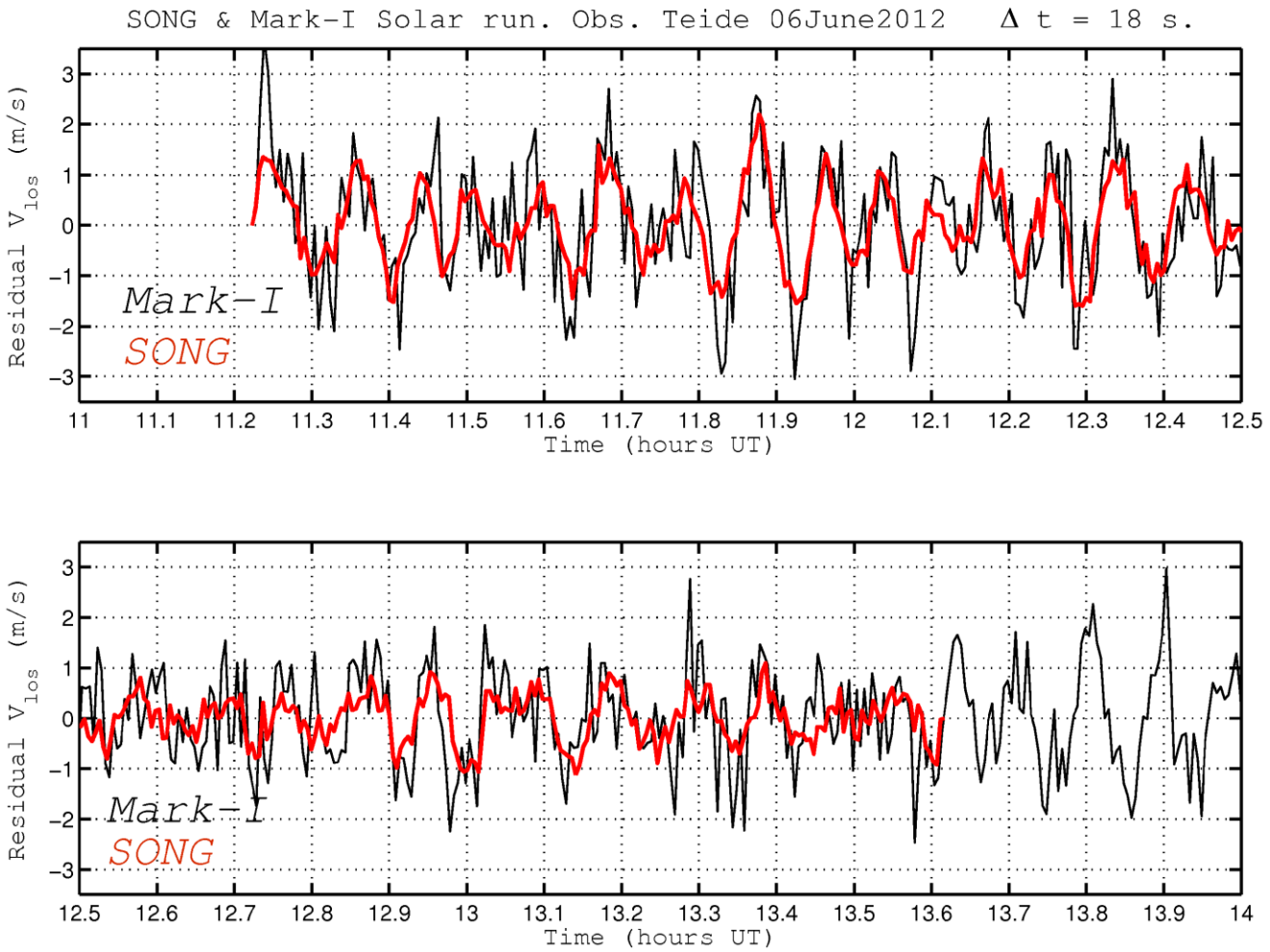
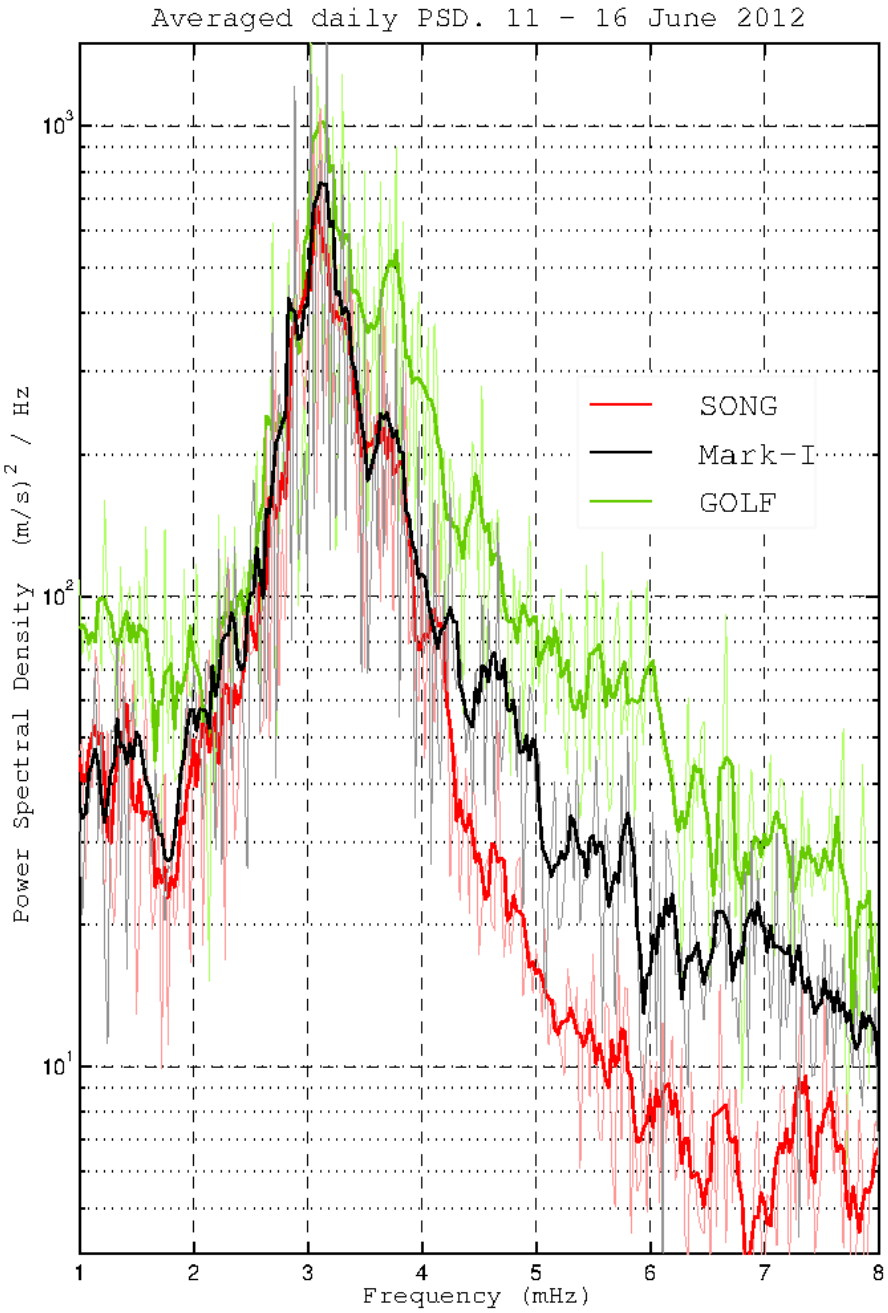
SONG webcam 1 15:43:43 2012/04/23
12



Solar observations from Tenerife



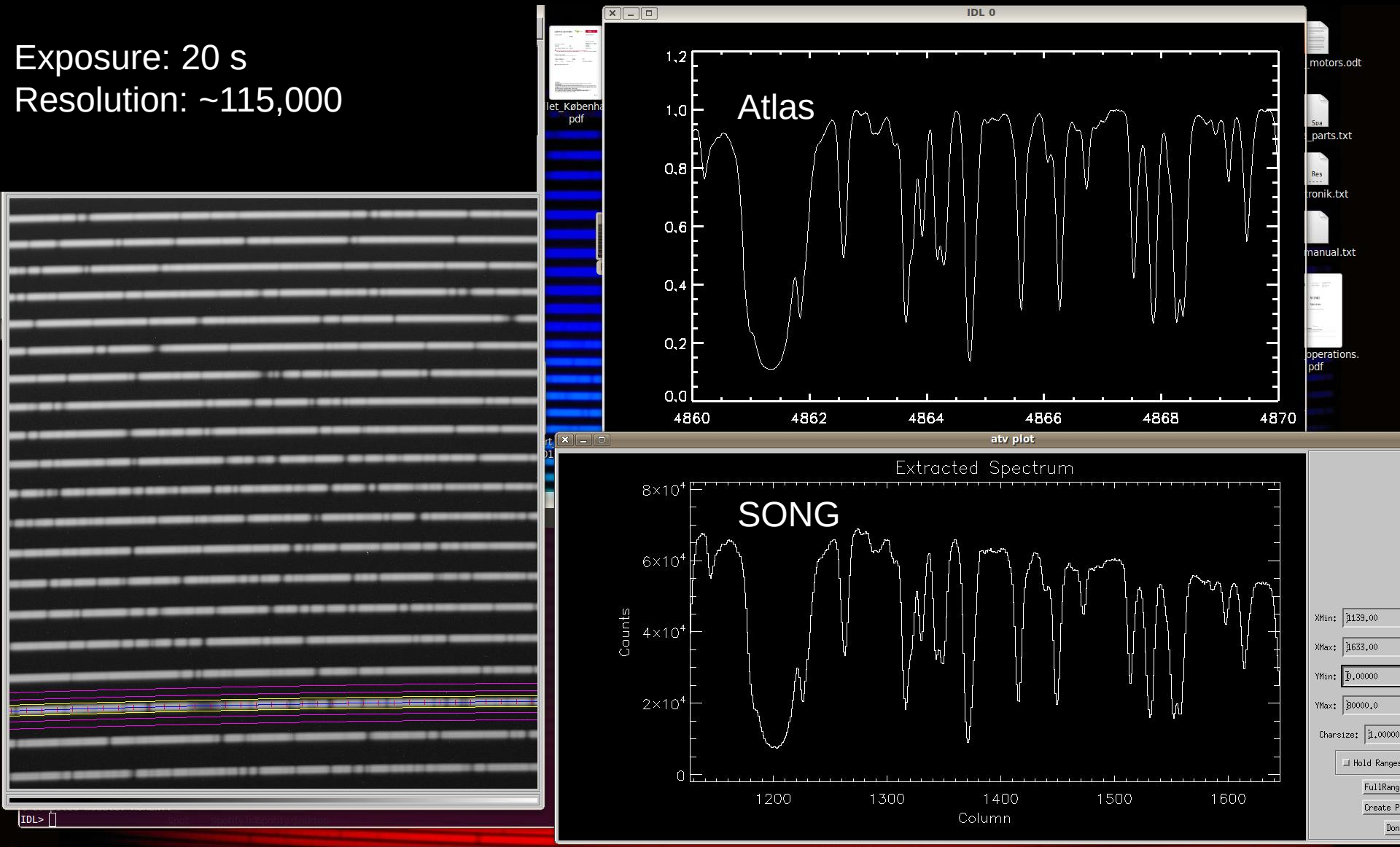


SONG solar observations will let us compare solar and stellar observations directly by observing using exactly the same method.

Data volume: ~15000 spectra / day = 120Gb.

SONG first light: Arcturus

Exposure: 20 s
Resolution: ~115,000

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File ColorMap Scaling Labels Blink Rotate/Zoom ImageInfo Help
Saturn
Min= 139.783
Max= 55518.0
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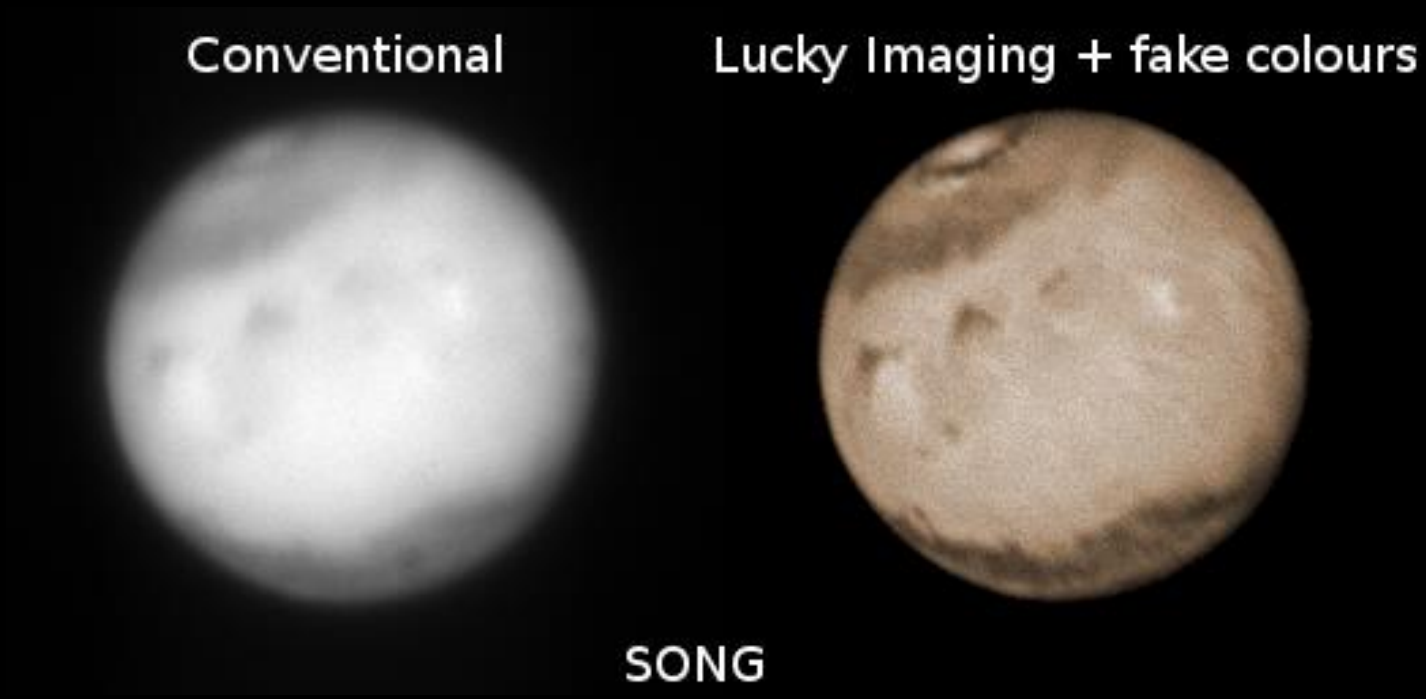
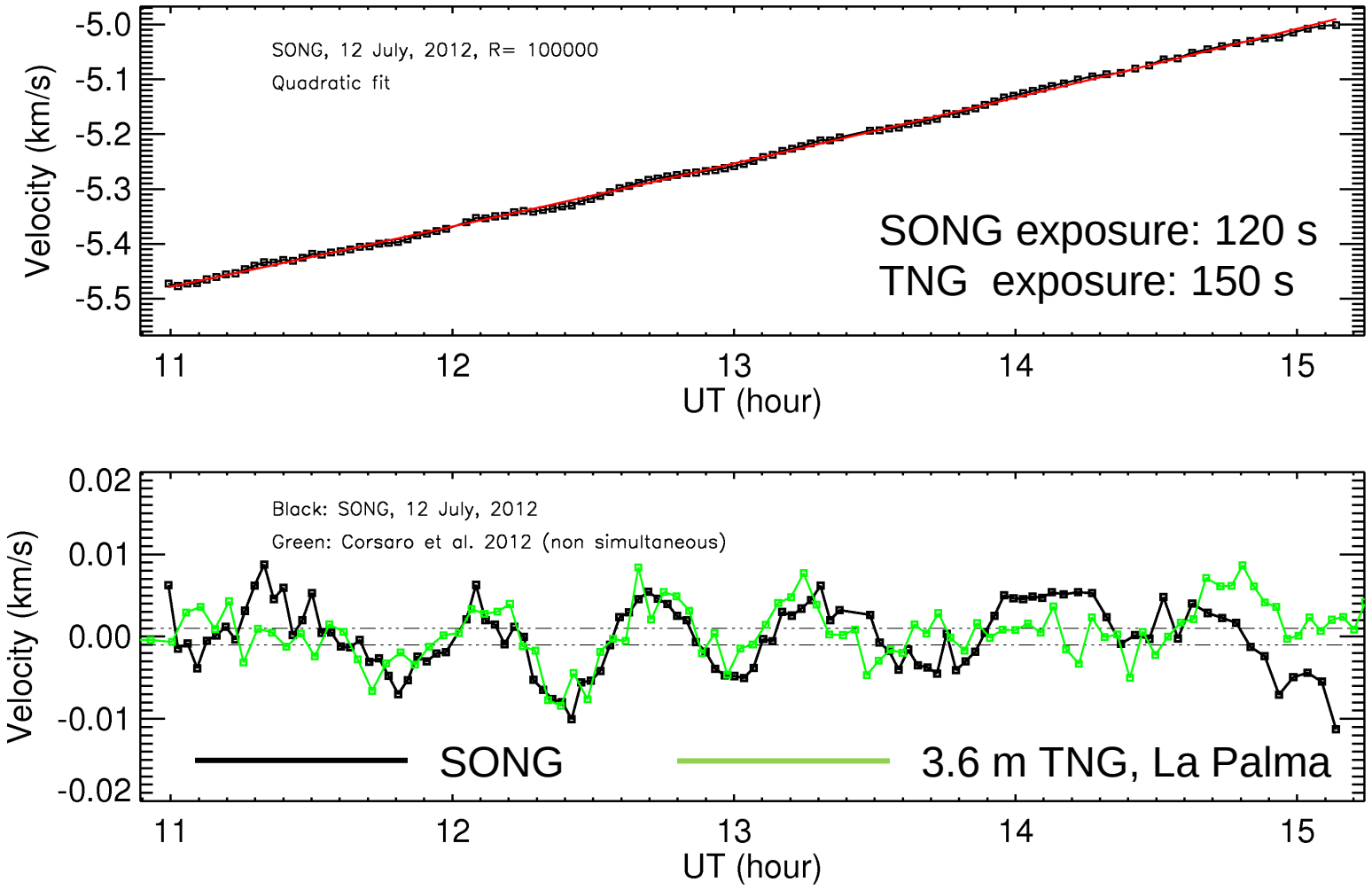
Invert Restretch AutoScale FullRange
ZoomIn ZoomOut Zoom1 FullView Center

A Lucky Image of Mars



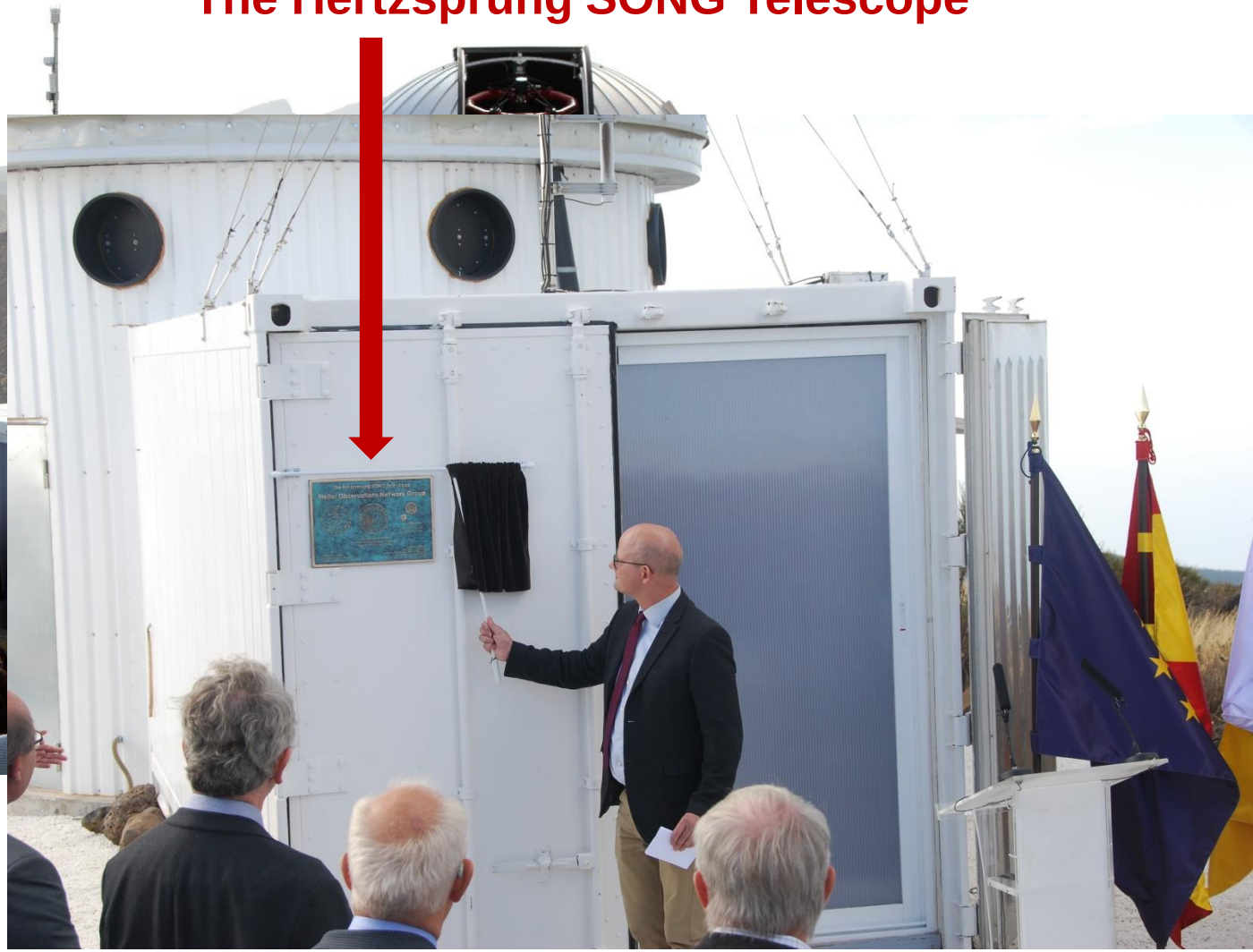
Beta Aquilae (V = 3.7, G9.5 IV)

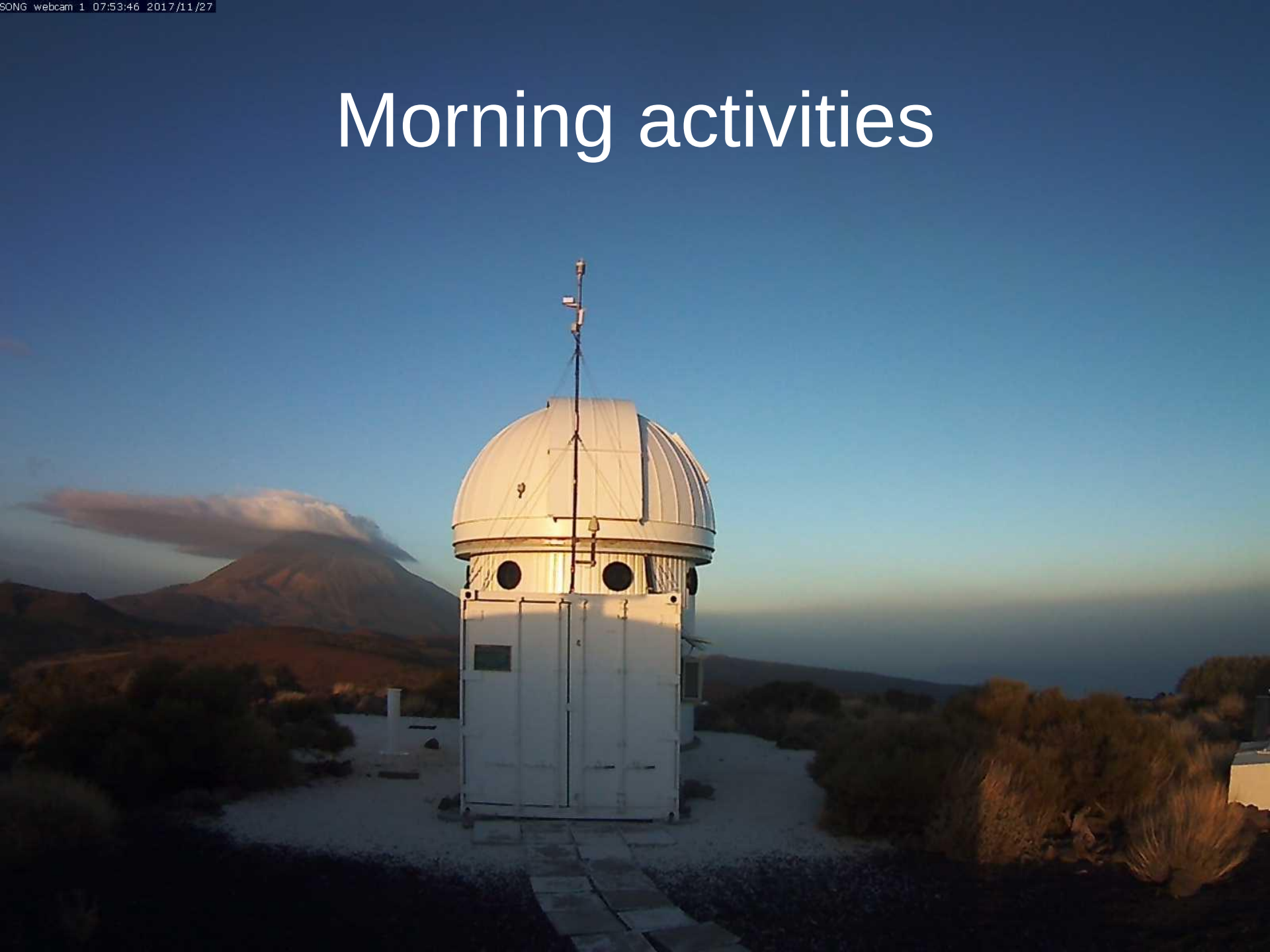


Inauguration, 25 October 2014

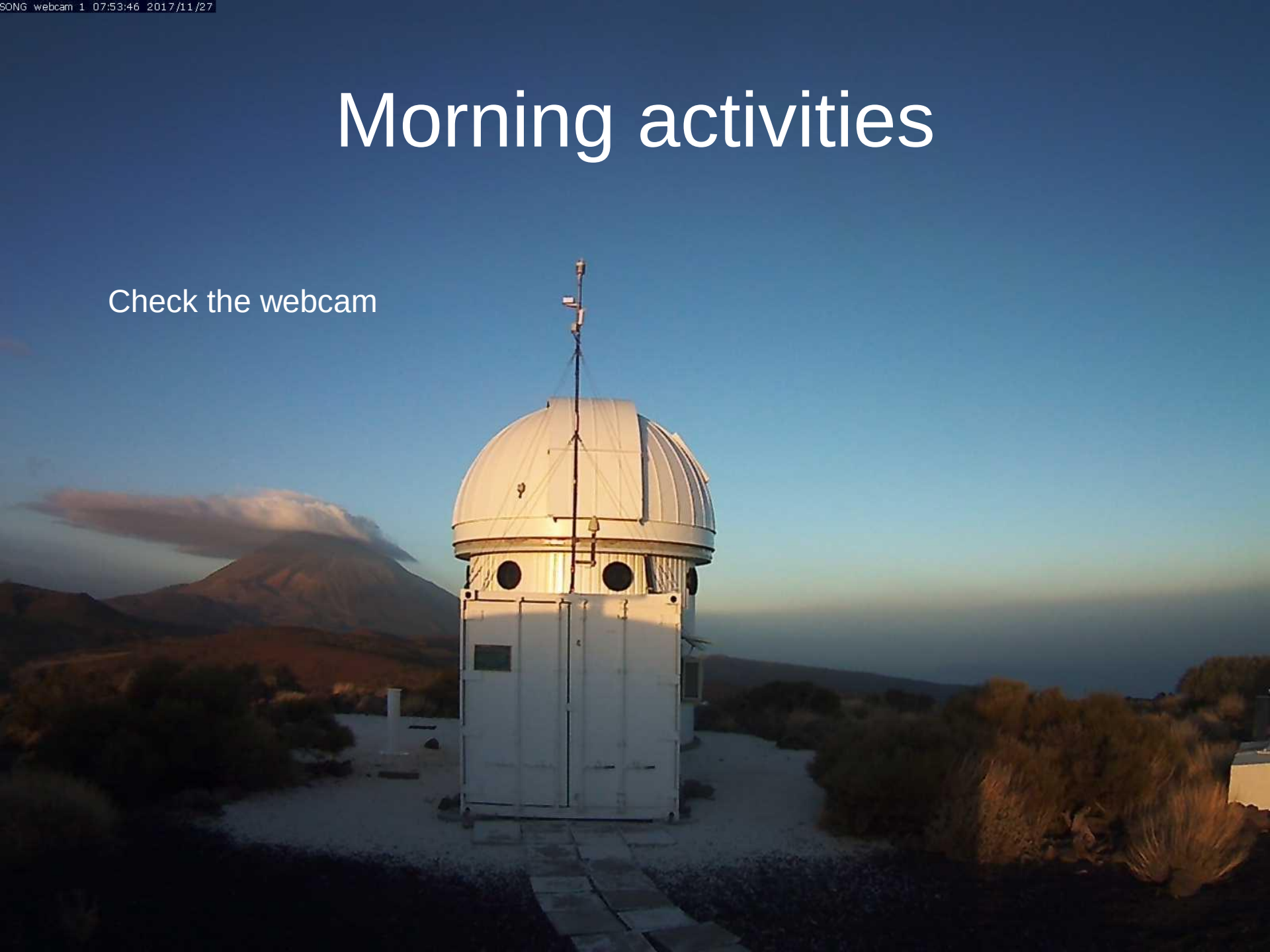
Inauguration, 25 October 2014

The Hertzsprung SONG Telescope





Morning activities



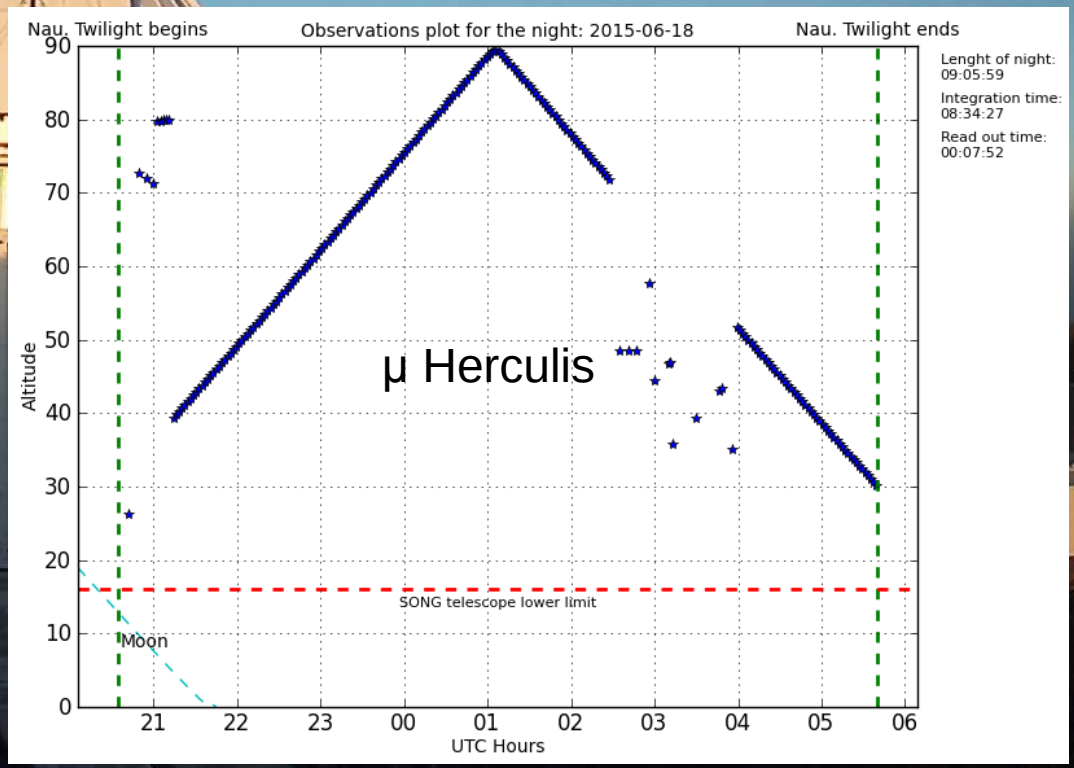
Morning activities

Check the webcam

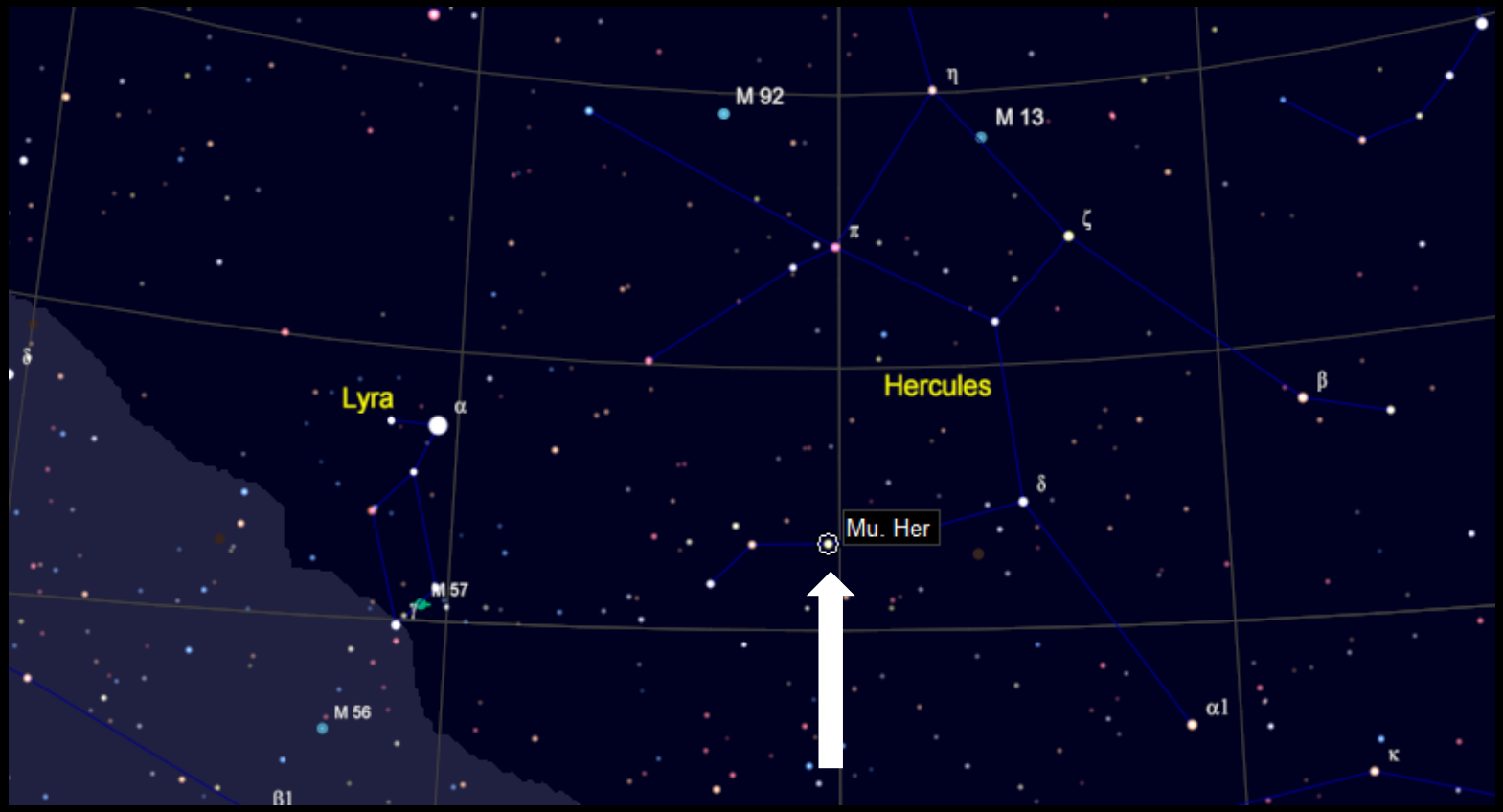
Morning activities

Check the webcam

Check the observing log



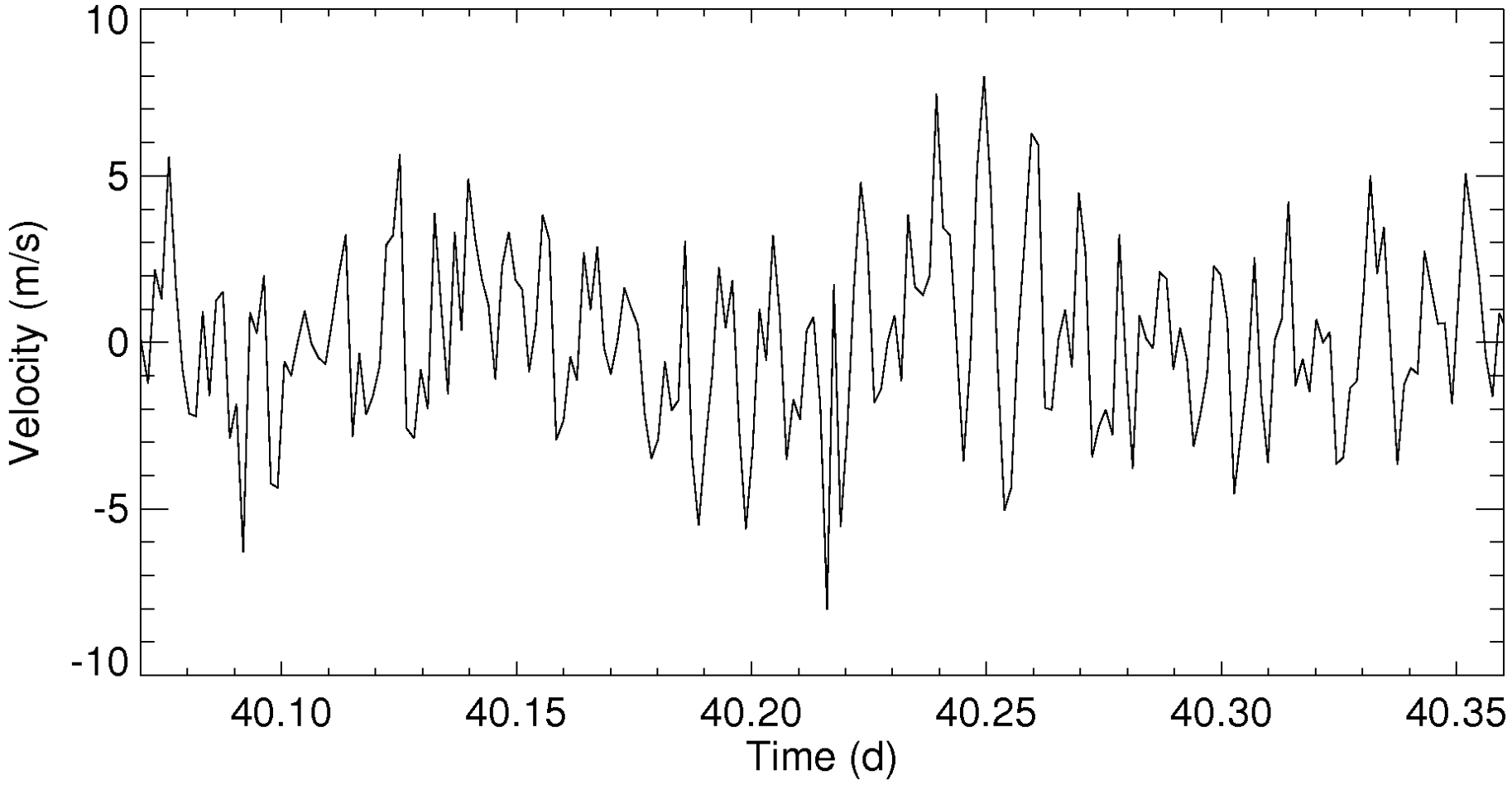
μ Herculis



V = 3.42

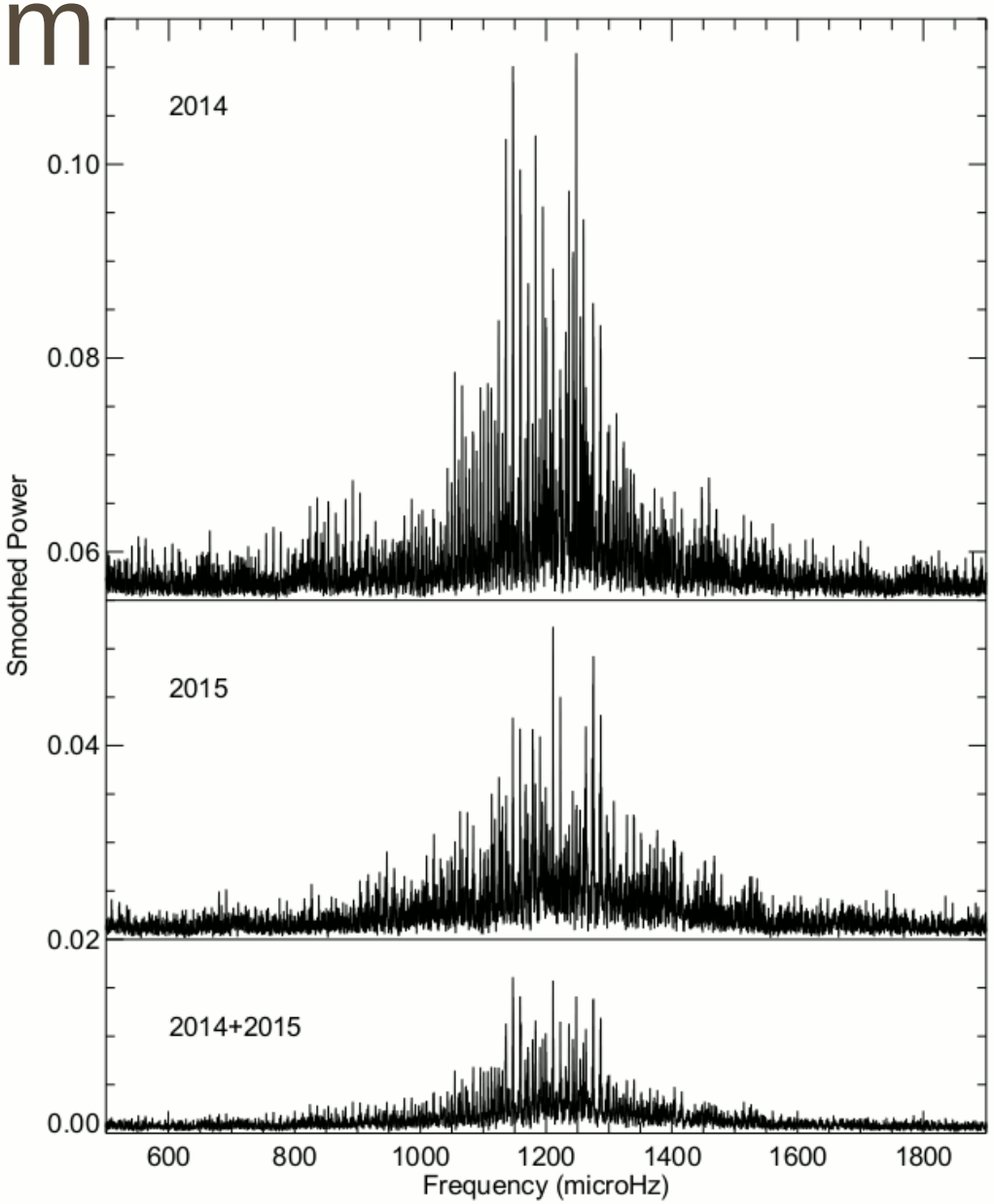
Binary binary

μ Herculis observations

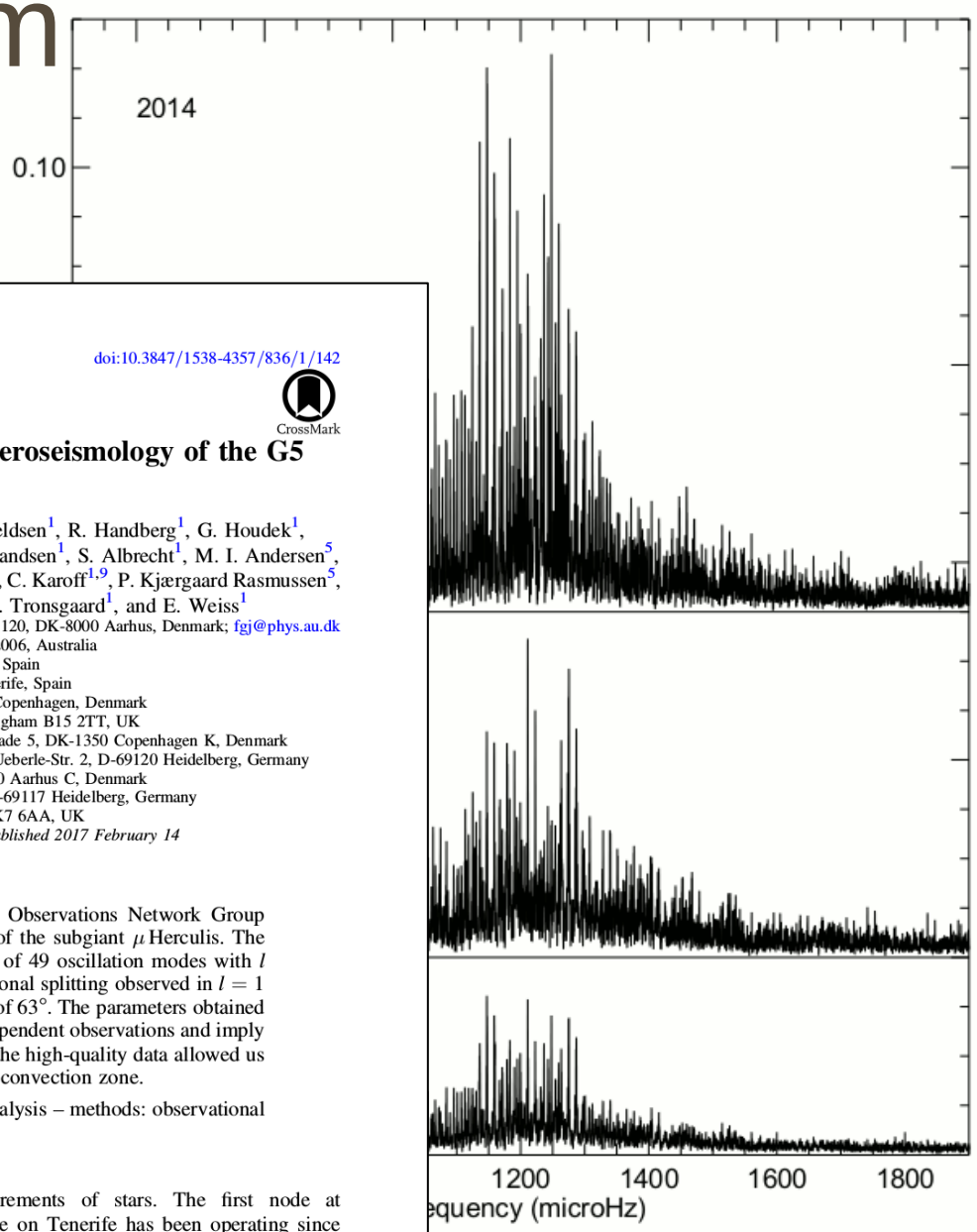


Power spectrum

$\Delta \nu$ = 64.0 μHz



Power spectrum



The Astrophysical Journal, 836:142 (12pp), 2017 February 10 doi:10.3847/1538-4357/836/1/142

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First Results from the Hertzsprung SONG Telescope: Asteroseismology of the G5 Subgiant Star μ Herculis*

F. Grundahl[1], M. Fredslund Andersen[1], J. Christensen-Dalsgaard[1], V. Antoci[1], H. Kjeldsen[1], R. Handberg[1], G. Houdek[1], T. R. Bedding[1,2], P. L. Pallé[3,4], J. Jessen-Hansen[1], V. Silva Aguirre[1], T. R. White[1], S. Frandsen[1], S. Albrecht[1], M. I. Andersen[5], T. Arentoft[1], K. Brogaard[1], W. J. Chaplin[1,6], K. Harpsøe[7], U. G. Jørgensen[7], I. Karovicova[8], C. Karoff[1,9], P. Kjærgaard Rasmussen[5], M. N. Lund[1,6], M. Sloth Lundkvist[1,10], J. Skottfelt[7,11], A. Norup Sørensen[5], R. Tronsgaard[1], and E. Weiss[1]

[1] Stellar Astrophysics Centre (SAC), Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus, Denmark; fgj@phys.au.dk
[2] Sydney Institute for Astronomy, School of Physics, University of Sydney 2006, Australia
[3] Instituto de Astrofísica de Canarias, E-38205 La Laguna, Tenerife, Spain
[4] Universidad de La Laguna, Dpto. Astrofsica, E-38206 La Laguna, Tenerife, Spain
[5] Niels Bohr Institute, University of Copenhagen, Juliane Maries vej 30, DK-2100 Copenhagen, Denmark
[6] School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
[7] Niels Bohr Institute and Centre for Star and Planet Formation, University of Copenhagen, Øster Voldgade 5, DK-1350 Copenhagen K, Denmark
[8] Zentrum für Astronomie der Universität Heidelberg (ZAH), Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, D-69120 Heidelberg, Germany
[9] Department of Geoscience, Aarhus University, Høegh-Guldbergs Gade 2, DK-8000 Aarhus C, Denmark
[10] Zentrum für Astronomie der Universität Heidelberg, Landessternwarte, Königstuhl 12, D-69117 Heidelberg, Germany
[11] Centre for Electronic Imaging, The Open University, Milton Keynes MK7 6AA, UK
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Abstract

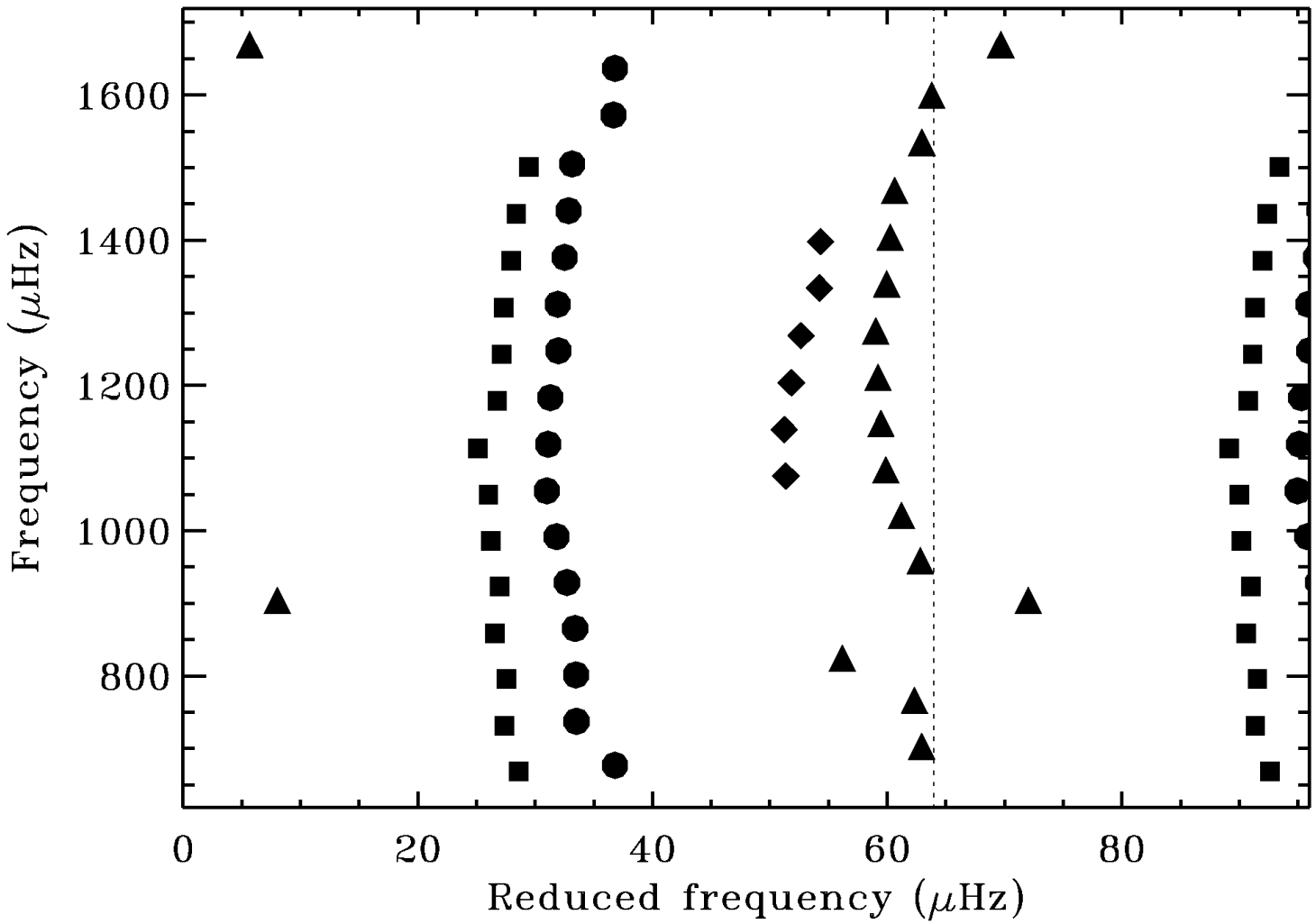
We report the first asteroseismic results obtained with the Hertzsprung Stellar Observations Network Group Telescope from an extensive high-precision radial-velocity observing campaign of the subgiant μ Herculis. The data set was collected during 215 nights in 2014 and 2015. We detected a total of 49 oscillation modes with l values from zero to three, including some $l = 1$ mixed modes. Based on the rotational splitting observed in $l = 1$ modes, we determine a rotational period of 52 days and a stellar inclination angle of 63°. The parameters obtained through modeling of the observed oscillation frequencies agree very well with independent observations and imply a stellar mass between 1.11 and 1.15 $M_{\odot}$ and an age of $7.8^{+0.3}_{-0.4}$ Gyr. Furthermore, the high-quality data allowed us to determine the acoustic depths of the He II ionization layer and the base of the convection zone.

Key words: asteroseismology – instrumentation: spectrographs – methods: data analysis – methods: observational – stars: individual (HD 161797) – stars: oscillations

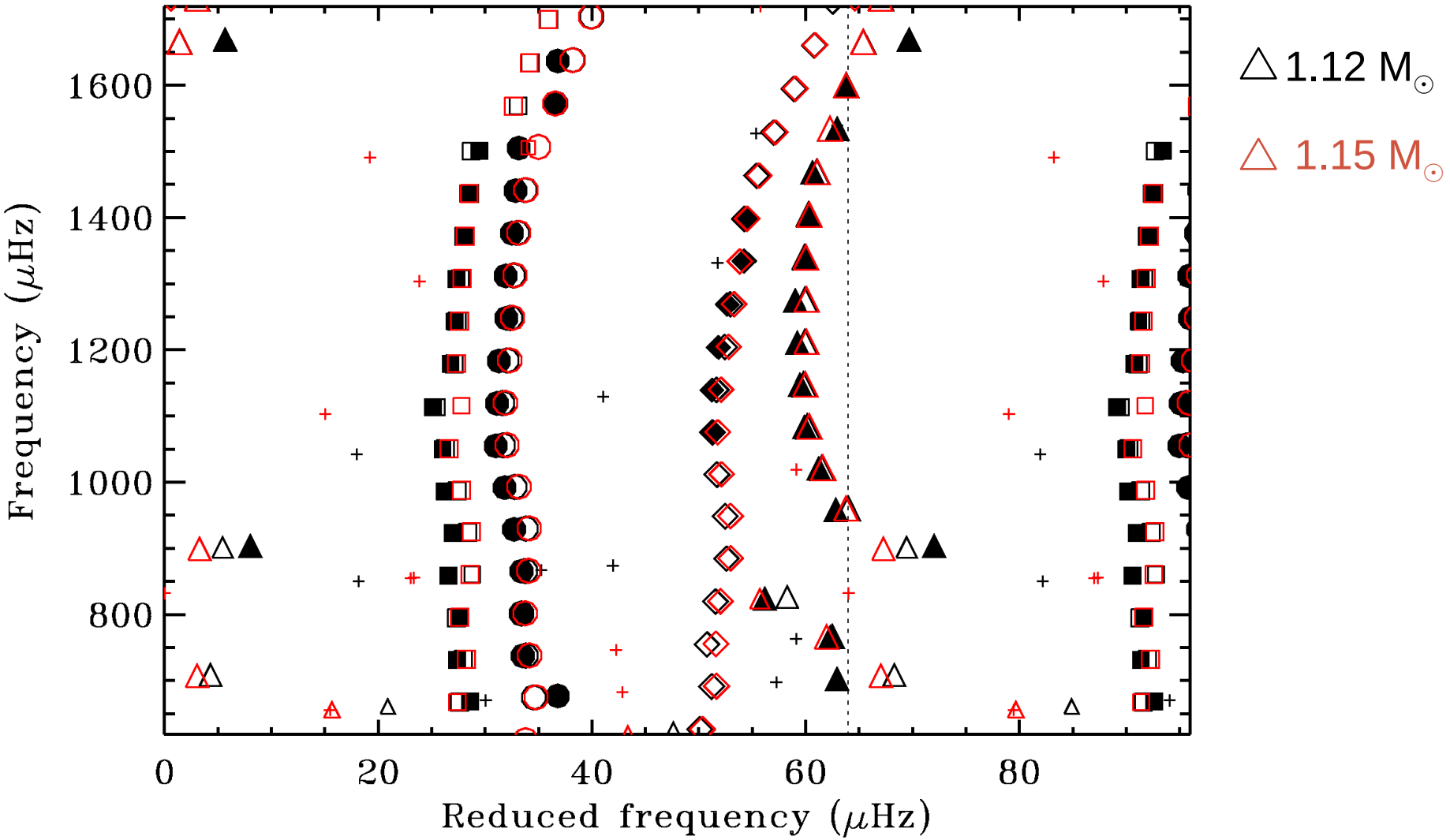
1. Introduction

Asteroseismology of solar-like oscillations has blossomed as an observational science in the past few years, thanks to the radial-velocity measurements of stars. The first node at Observatorio del Teide on Tenerife has been operating since 2014 and consists of the Hertzsprung SONG Telescope, which is equipped with a coudé échelle spectrograph with an iodine

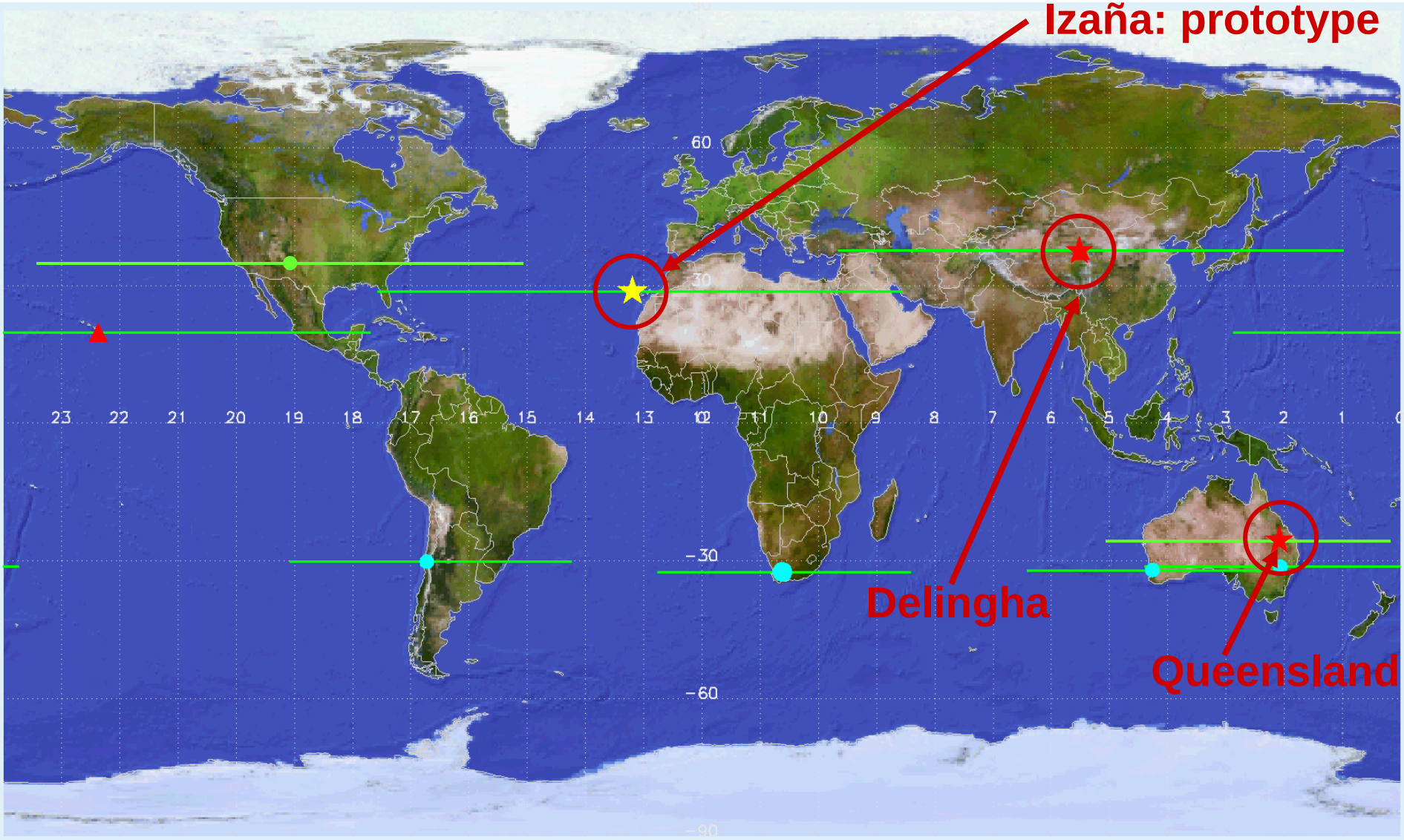
Observed échelle diagram



‘Well-fitting’ models



Possible and actual locations

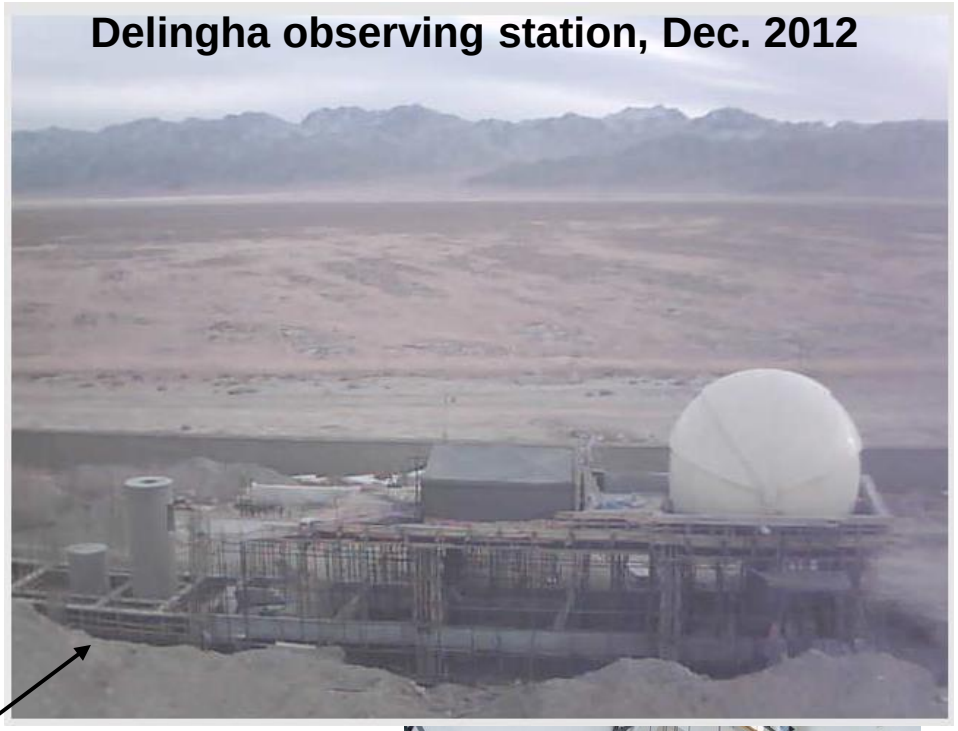


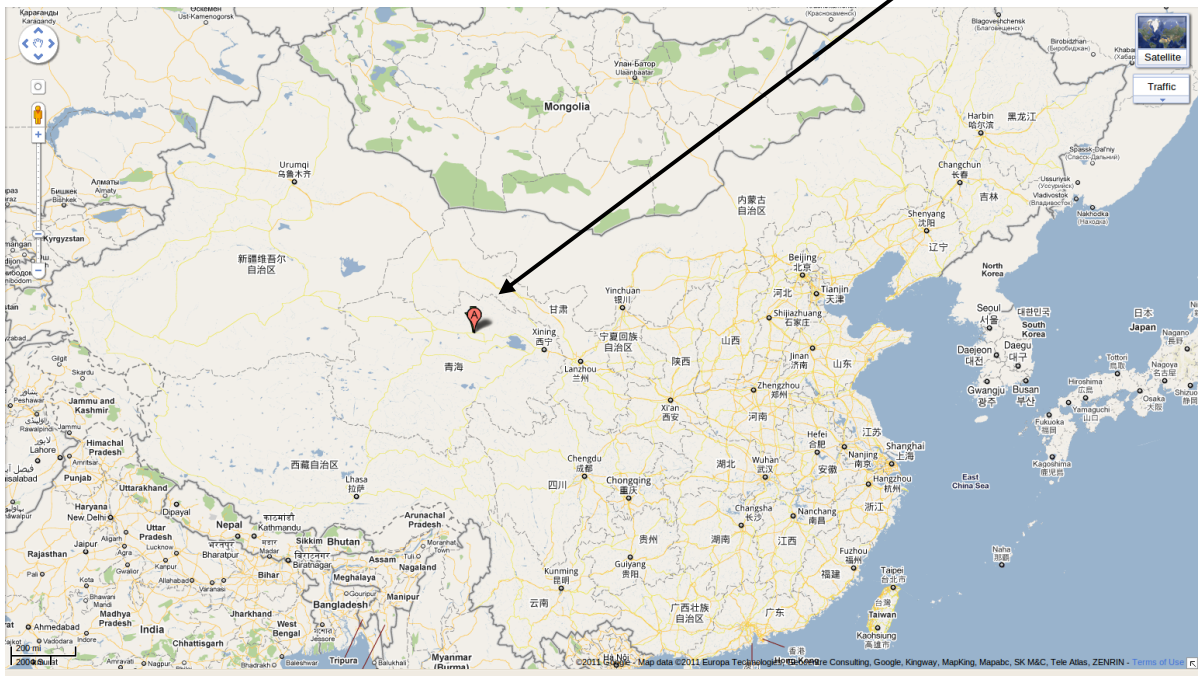

September 2009


Agreement

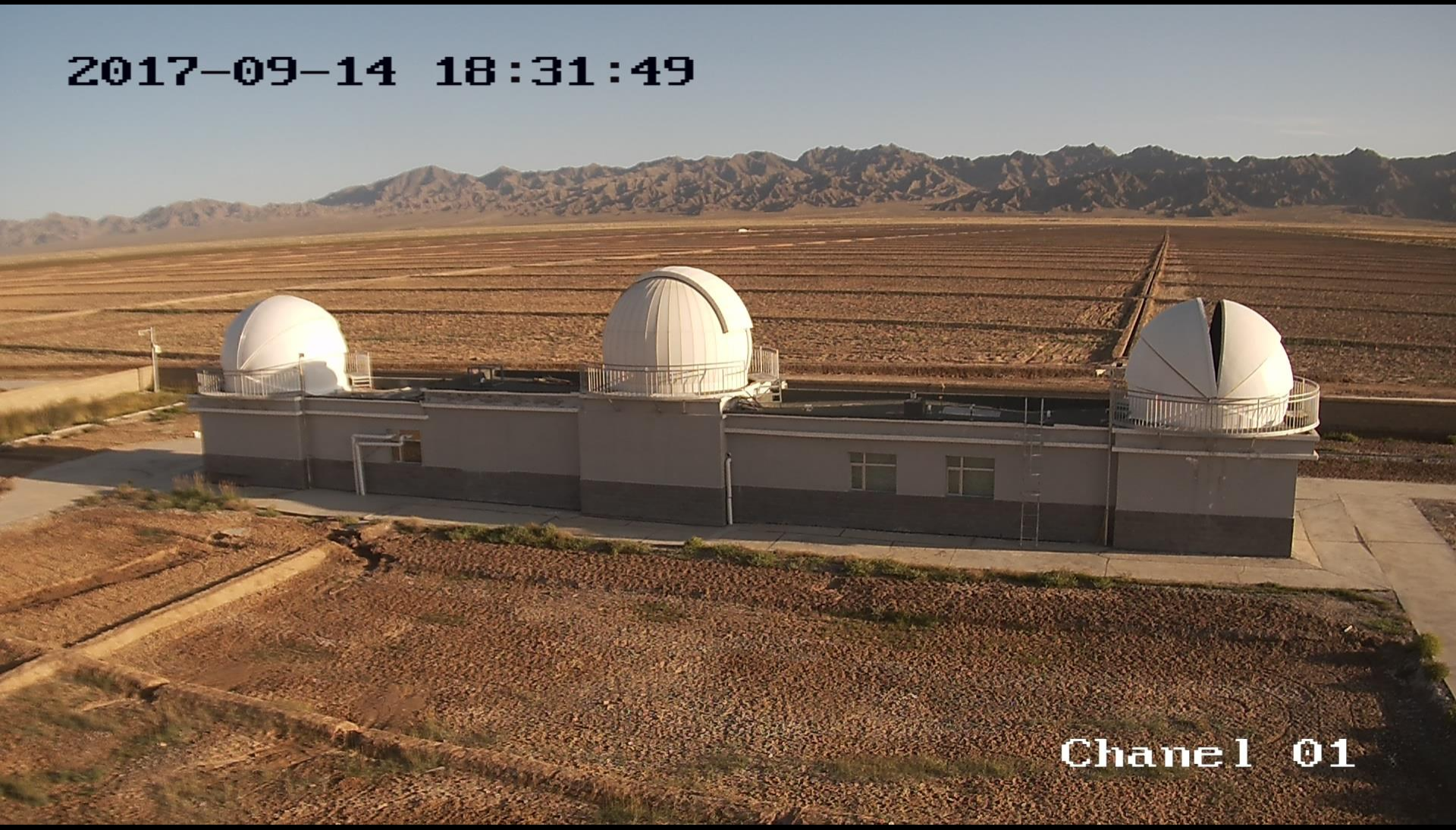

December 2009
非吸烟区
Non-Smoking Area
703
戒烟我能

SONG node #2 in China is underway





Delingha site



Mt Kent, Queensland
SONG node #3

Mt Kent Observatory

SONG site #n: Apache Point, NM?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