Exoplanets in Ondřejov

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Czech Republic
AI SAV, 22 June, 2016

Akademie věd
České republiky

Outline

- Intro Astronomical institue Ondřejov
- Working plan for exoplanets
  - transmission spectroscopy
  - occultation photometry
  - VISIR
  - RV follow-up with Ondřejov 2-m
- Outlook

Team and collaborations

- **Astronomical Institute Ondřejov**

  P. Kabáth, T. Jeřábková, M. Blažek

- **DLR Berlin**

  H. Rauer, E. Sedaghati, M. Godolt, The BEST team

- **ESO**

  V. Ivanov, E. Sedaghati (DLR)

- **Universidad de Chile and Univ. Valparaiso**

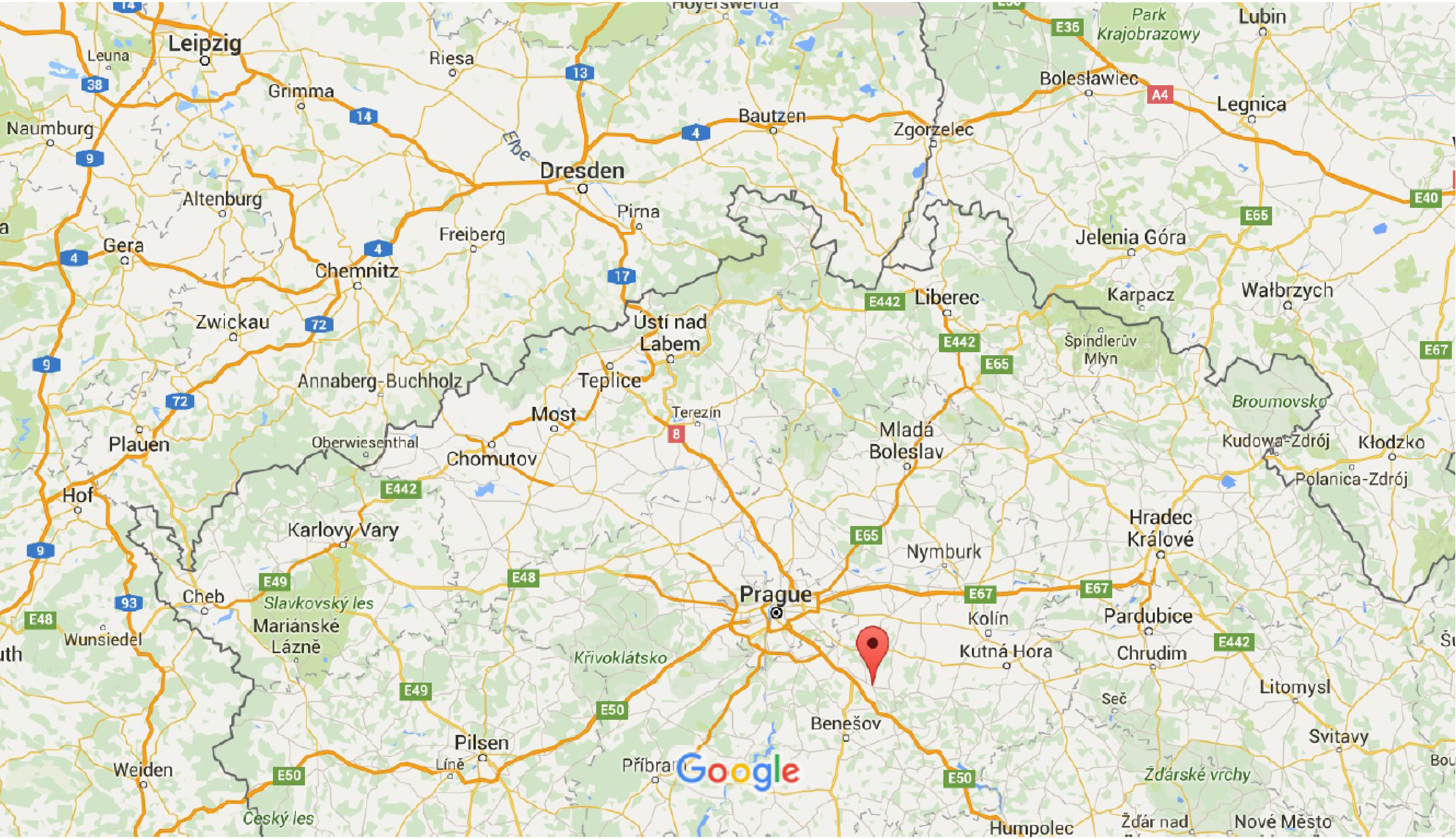
  P. Rojo, C. Caceres

- **IAC Tenerife**

  S. Hoyer

Astronomical Institute Ondřejov

- **Institute of Czech Academy of Sciences**
- **Largest astronomical institute in CZ**
- **Headquarters about 30 kms south of Prague**
- **A few departments located in Prague**
- **Operates 2-m twin telescope of Tautenburg**
- **About 120 science staff**
- **Variable stars, solar physics, galaxies, relativistic astrophysics**



Map data ©2015 GeoBasis-DE/BKG (©2009), Google 20 km

Central Bohemia region – Ladův kraj

Google Maps Ondřejov

Imagery ©2015 Google, Map data ©2015 Google 100 m

Google Maps Ondřejov

Imagery ©2015 Google, Map data ©2015 Google 50 m

Exoplanets at Ondřejov

Motivation for exoplanetary research

- Statistics of exoplanetary systems
- Evolution of exo-systems compared to our Solar systém
- Description of exo-systems
- LIFE

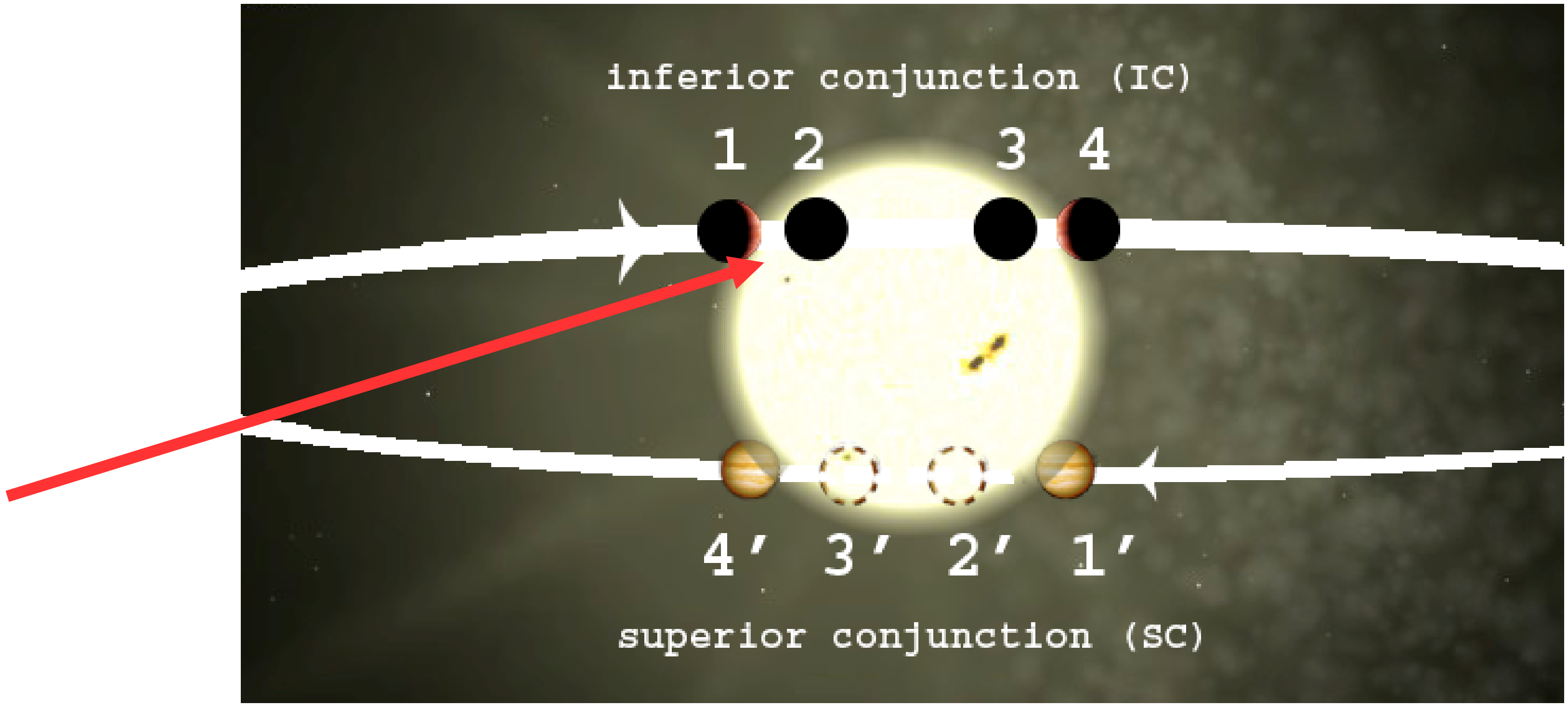
Description – Exo-atmospheres

- Probing exoatmospheres with transmission spectroscopy
- Variation of transit depth due to exo-atmosphere composition
- Accuracy of 10-4 and better needed
- Automatic pipeline and optimization process needed
- We would like to be ready for new planets from NGTS and TESS

Transmission spectroscopy

What to observe?

Eclipses!!!

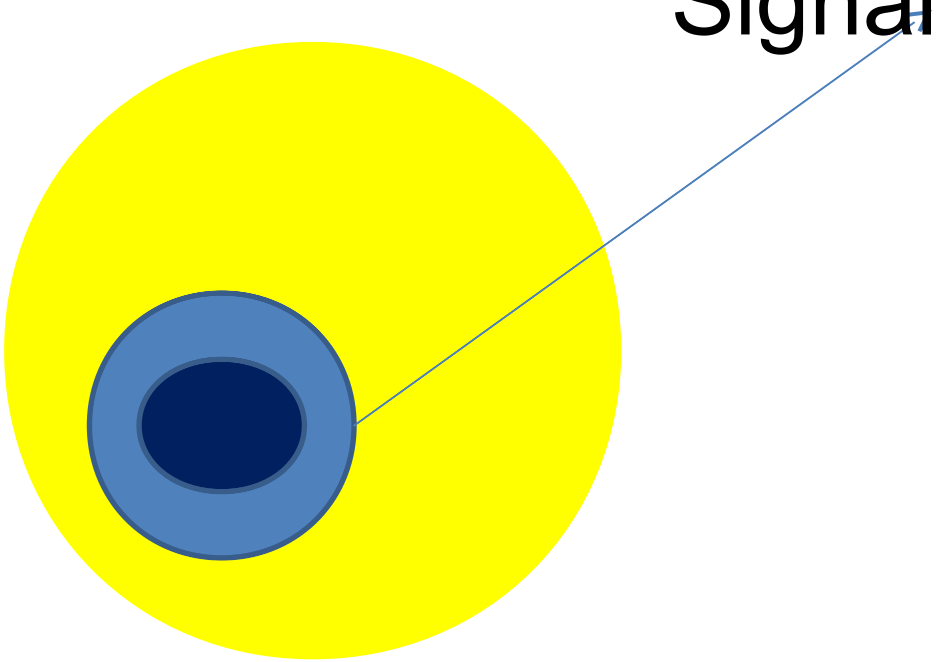


From Angerhausen et al. 2008

Transit spectroscopy

Transit spectroscopy = transmission spectroscopy

$$\text{Signal} = \text{Annulus}/R^2_{star}$$



Typical Signal of the planetary spectral lines < 10^{-4}

Smaller star & larger planet = better chance to see something

Transmission spectroscopy

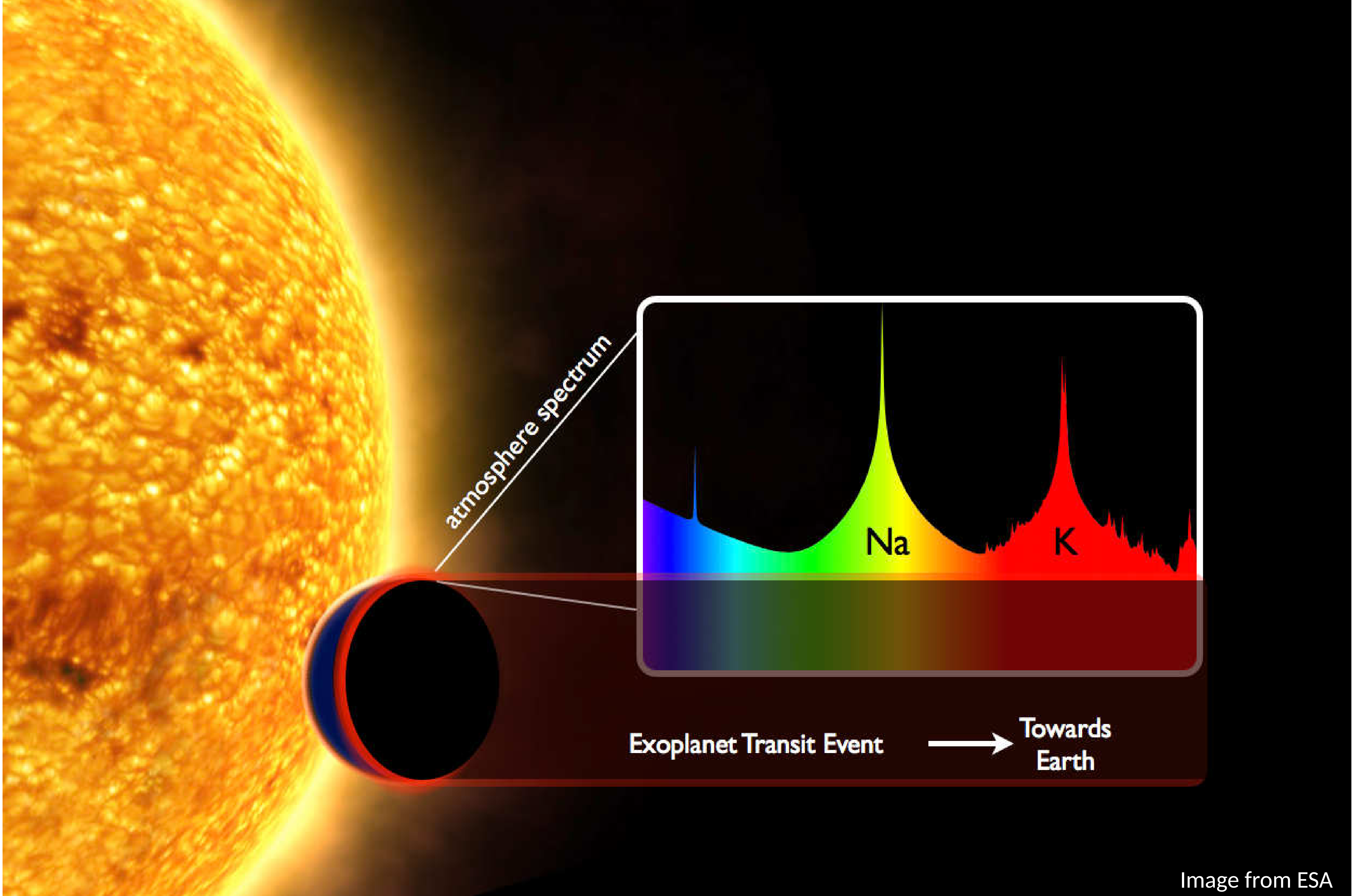
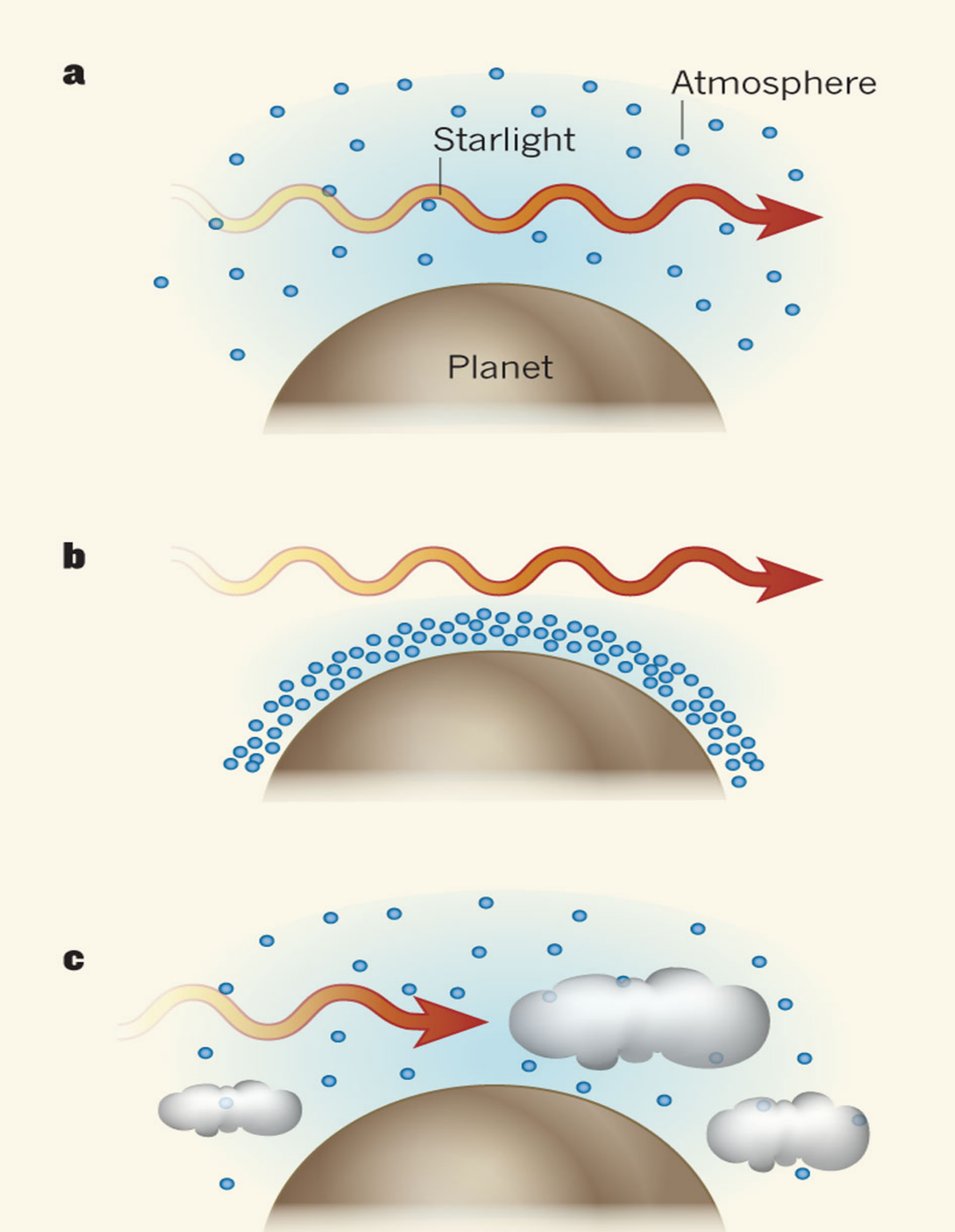
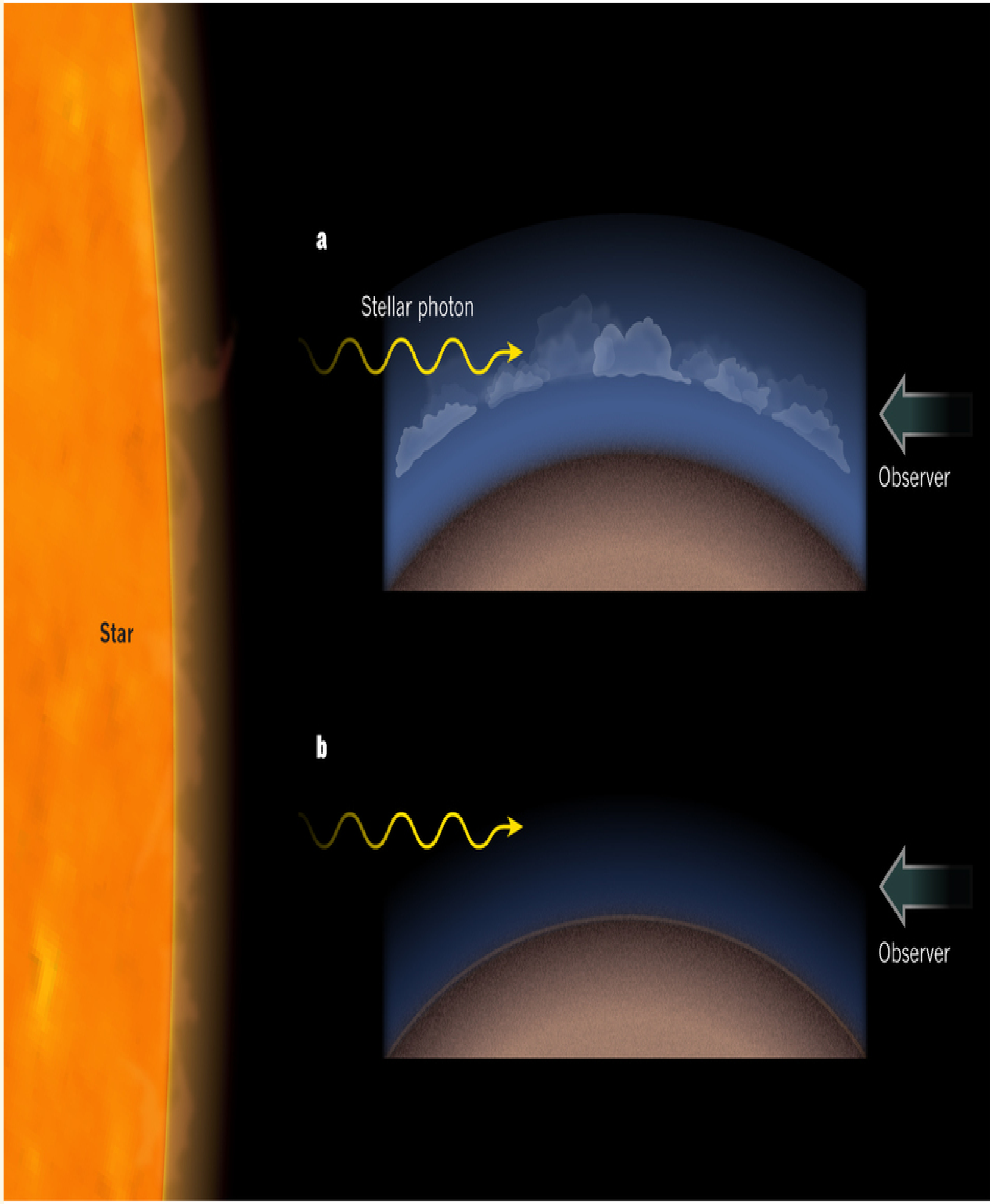


Image from ESA

Different types of atmospheres





Deming, Nature, 468, 636–637

Our universal pipeline and optimization

Our pipeline and optimization – in steps

- Basic spectroscopic data reduction – bias, darks, flats, arcs
- Optimal aperture extraction
- Optimal spectral bin selection
- Influence of atmosphere, instrument etc. determination
- Fitting of the transit LC and noise analysis
- Transmission spectrum

Results so far

- The first part is instrument specific, can be added as needed (Elyar now has FORS2 script, also Philipp worked within DAAD project on this part)
- The second part done by T. Jeřábková – selection of optimum bands and optimal aperture for extraction of spectra
- Demonstration on GJ3470b and on WASP-19b

Kabath et al. And Jerabkova et al. (in prep.)

- Optimized bands used also in WASP-17b by Sedaghati et al. (figure later)

TRANSMISSION SPECTROSCOPY OF EXTRASOLAR PLANETS
Reduction, data and noise analysis

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Institut für Planetenforschung, Deutsches Zentrum für Luft- und Raumfahrt,
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The main aim of the transmission spectroscopy is to investigate the composition of the atmosphere of extrasolar planets. During the transit of the planet across the stellar disk the radiation transfers also through the exoplanetary atmosphere. As a consequence, part of the light can be absorbed and therefore the observed light curves during transit are influenced differently at the particular wavelengths. This is demonstrated on Fig. 1.

This effect causes changes only in orders of hundredths in obtained relative flux as can bee seen on the lower part of Fig. 1. For that reason this method demands high-quality data and especially rigorous data analysis to extract only changes caused by atmosphere of extrasolar planet.

The main structure of this work in several points:
(The original main contributions are written in bold font and explained in more details later in text.)

1. Production of synthetic data
   The several scripts that allow to model and predict final light curves are developed. Based on several key parameters (planetary and stellar radius, period, limb darkening coefficients) we can put limits to proposed observations. Adding arbitrary white or red noise is also possible.

2. Detrending and noise analysis
   Detailed tests are performed on synthetic and real data. The `Python` code is developed with automatic transit detection, evaluation of the best model and **the estimation of the errors added to the light curve by detrending (I)**

3. Optimization of light curve production.
   We are using standard procedure, but with **new optimization method (II)**. For that purpose the `Python` scripts are developed.

4. The semi-autmatic pipeline for LIRIS instrument at WHT
   The `IRAF` and `Pyraf` pipeline for long slit mode with one comparison star is written. There is no publicly available pipeline for data reduction.

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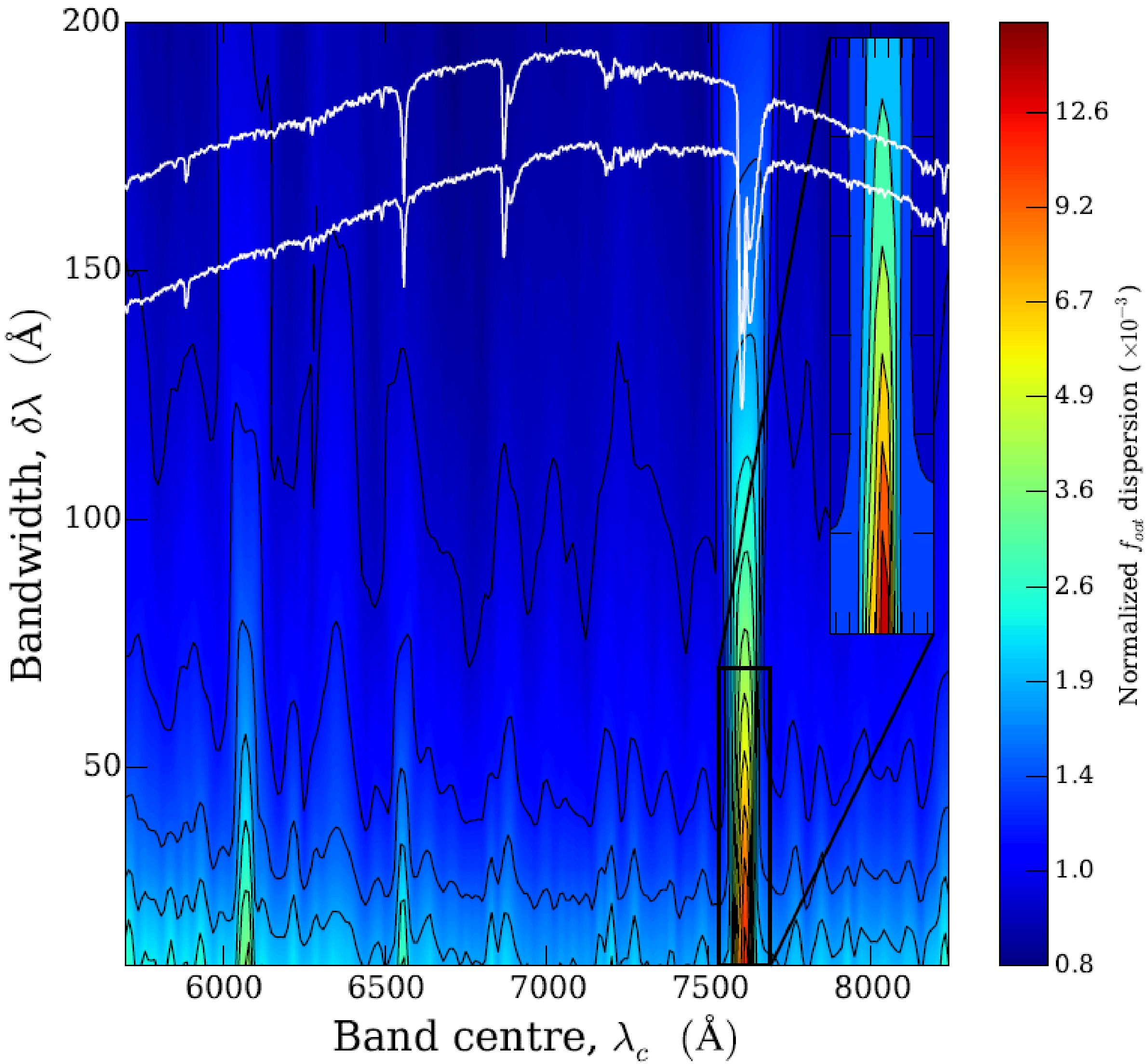
†juan.cabrera@dlr.de

Spectrum example (from Sedaghati et al. 2016)



GJ3470b and WASP-17b

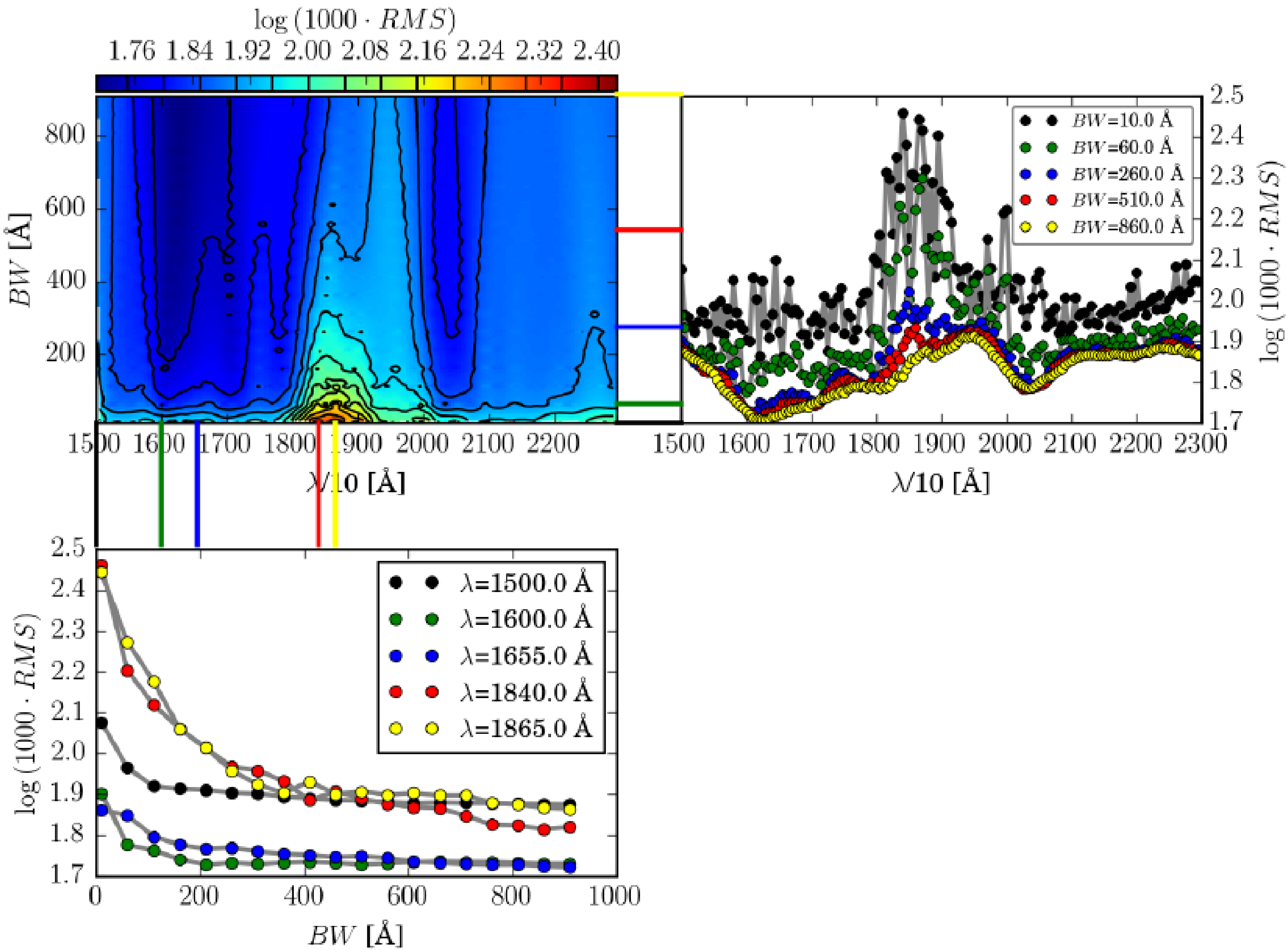
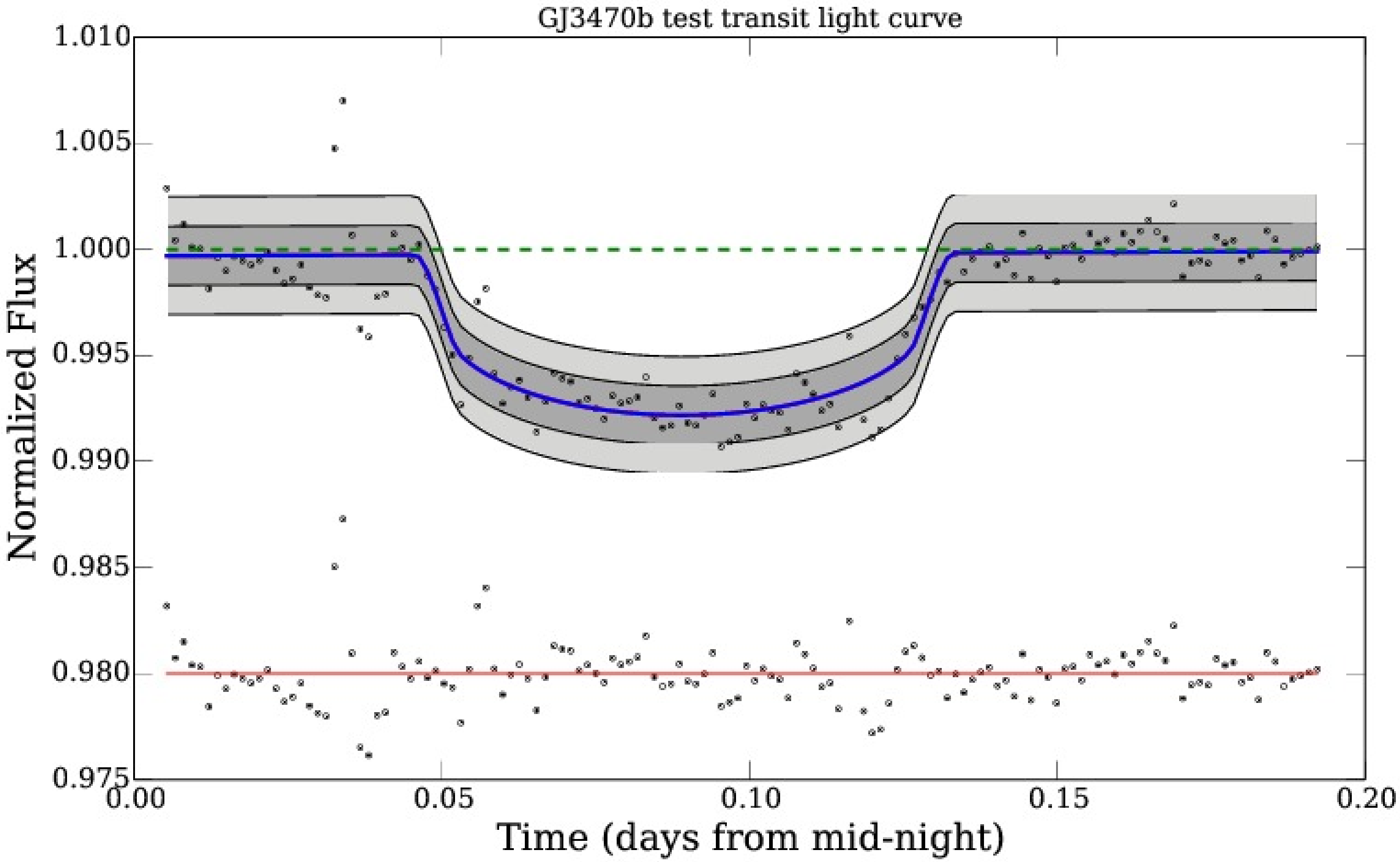


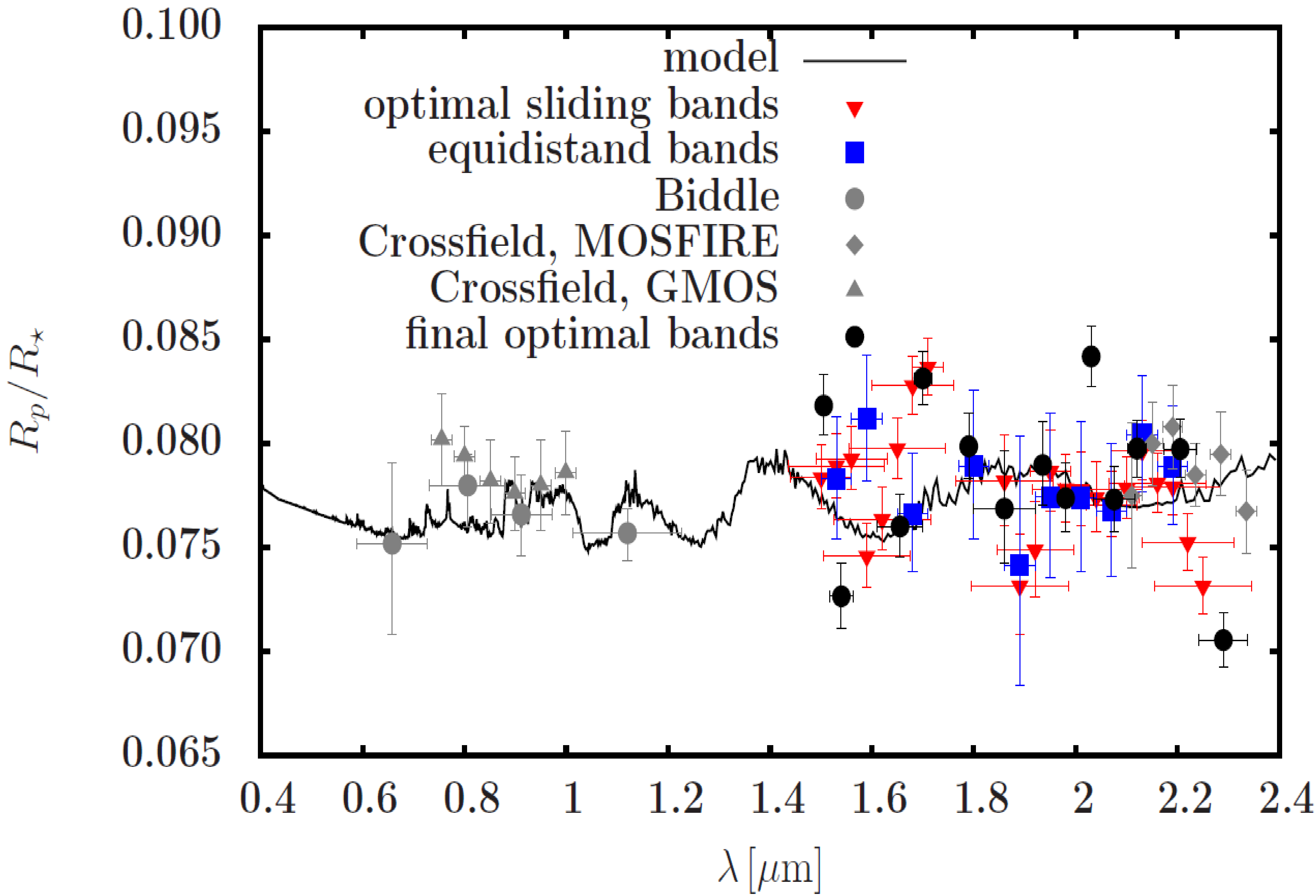
Figure 11: The global RMS analysis for WHT data of GJ 3470b

GJ3470b modeling

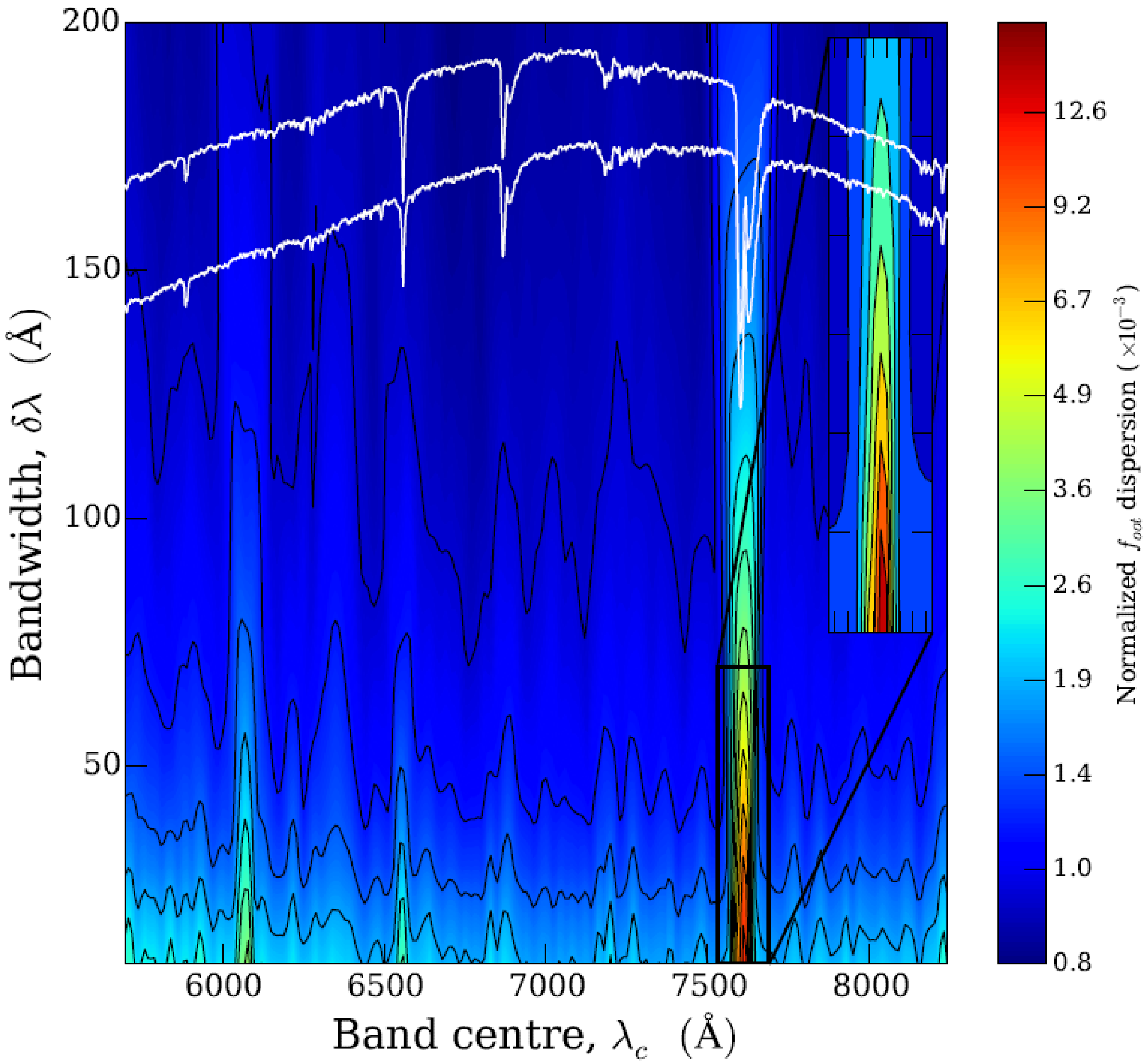
- Gaussian process models parameters of noise - N. Gibson et al. 2013



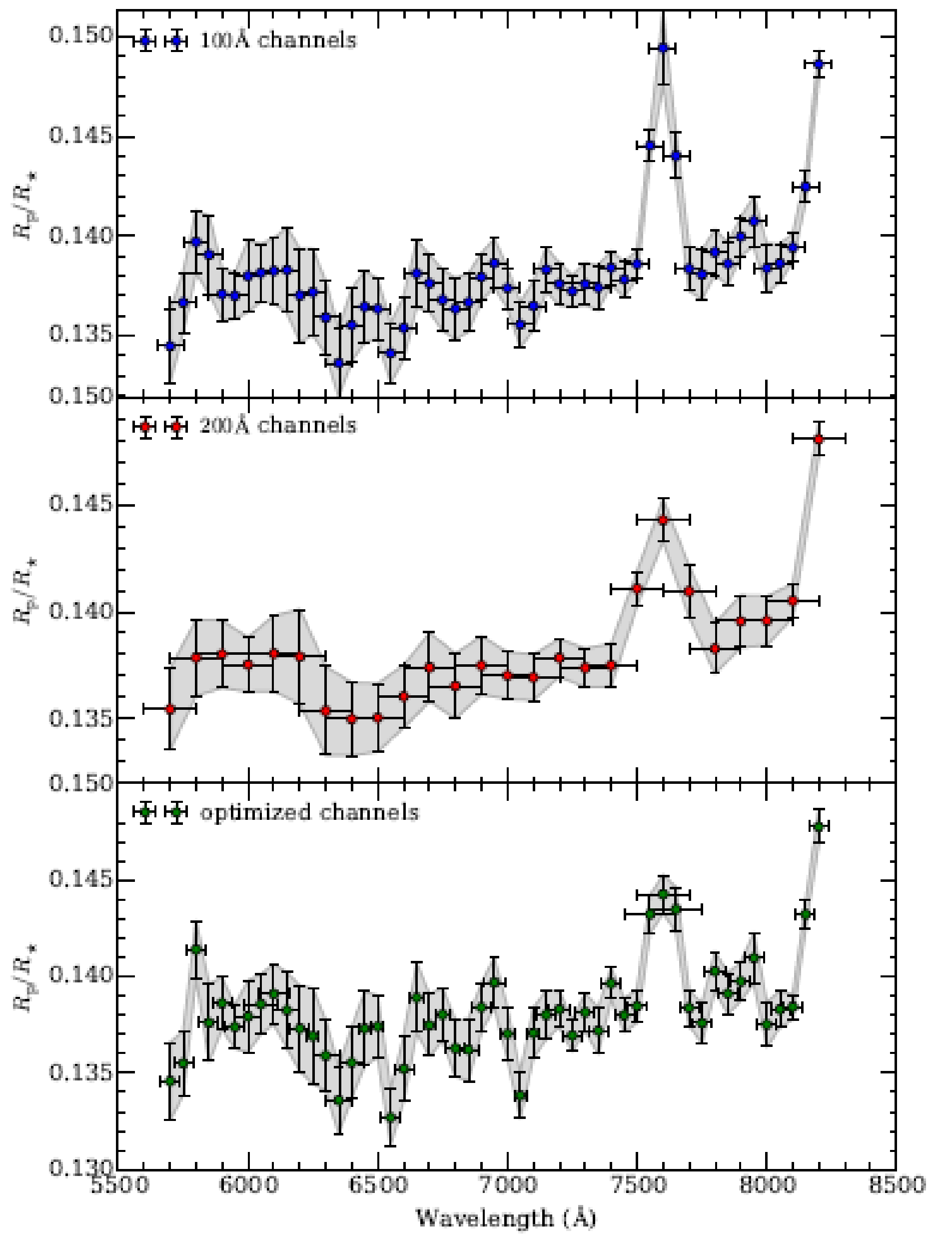
GJ3470b - example



Further example where our optimization works - from Sedaghati et al. (2016) - WASP-17b



And more from Sedaghati et al. 2016 – optimized/not optimized



Occultations of exoplanets

Occultations and exoatmospheres

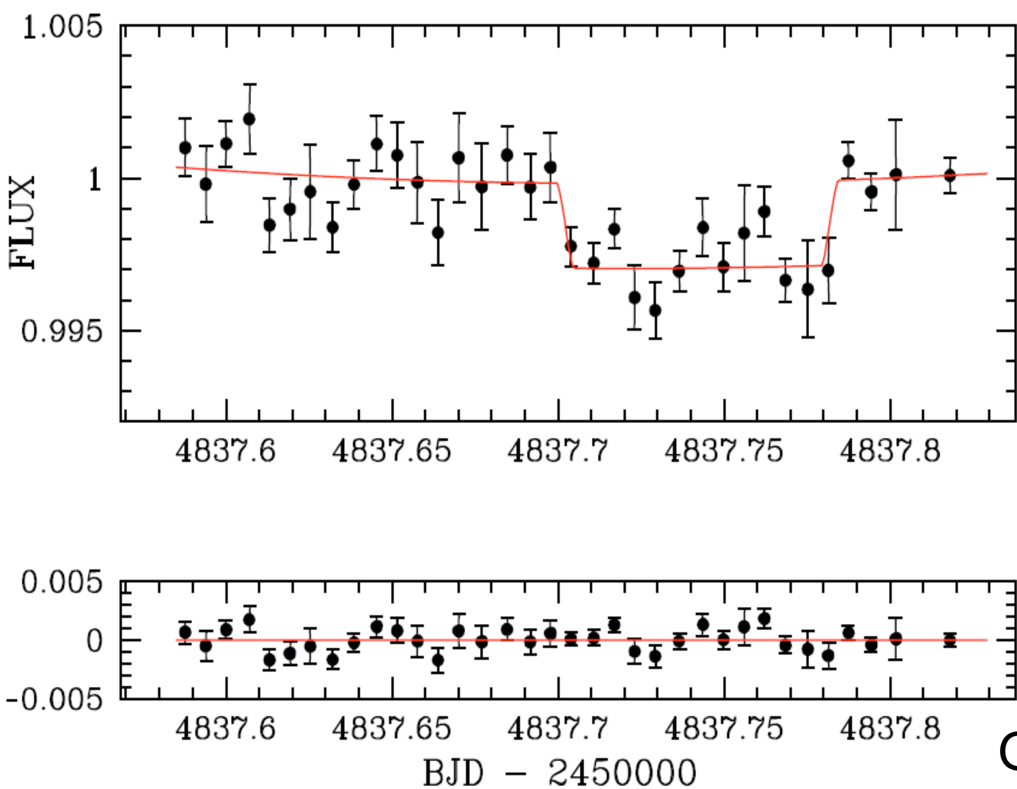
- First detection by Deming et al. 2005 from Space at 24 micron – HD209458b
- Occultation depth is a measure for the atmospheric parameters of exoplanets
- Due to peak of SED mostly observed in NIR
- Depths typically in order of mmags and less
- Delivers info about processes in the atmosphere (TiO no TiO atmospheres)

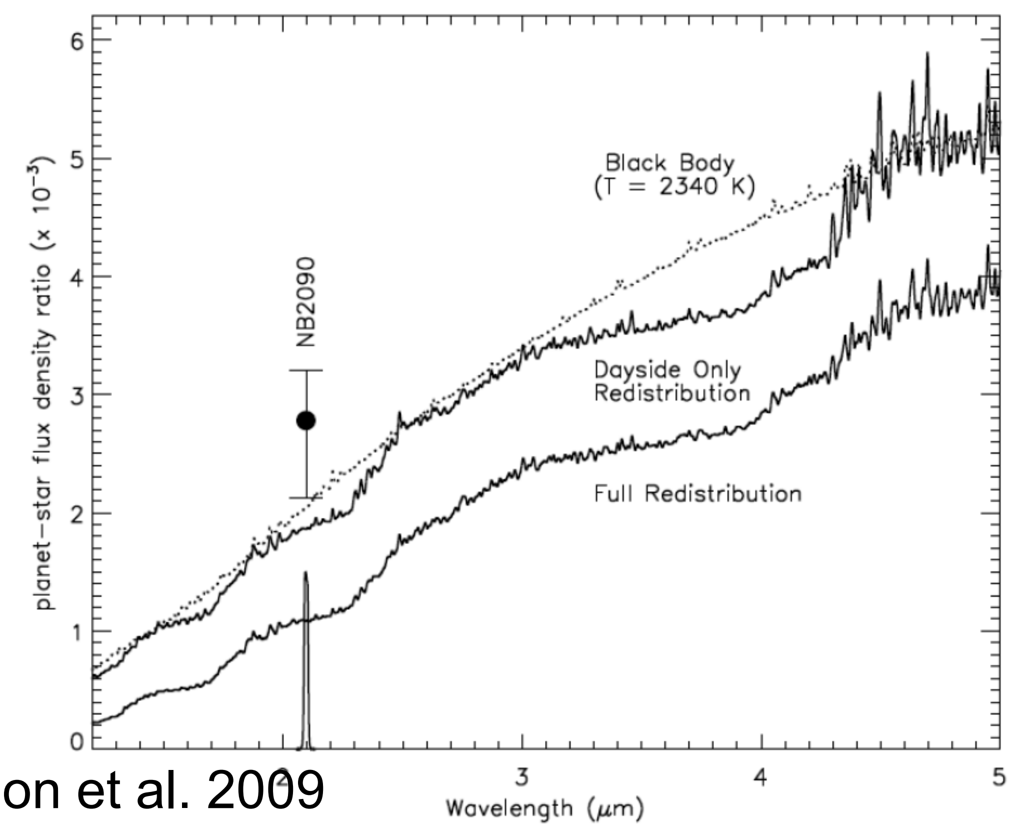
Secondary eclipse photometry

- Thermal radiation from the planet in IR

$$\text{Signal} = T_{planet}/T_{star}(R_{planet}/R_{star})^2$$

Typically few mmags for hot Jupiters

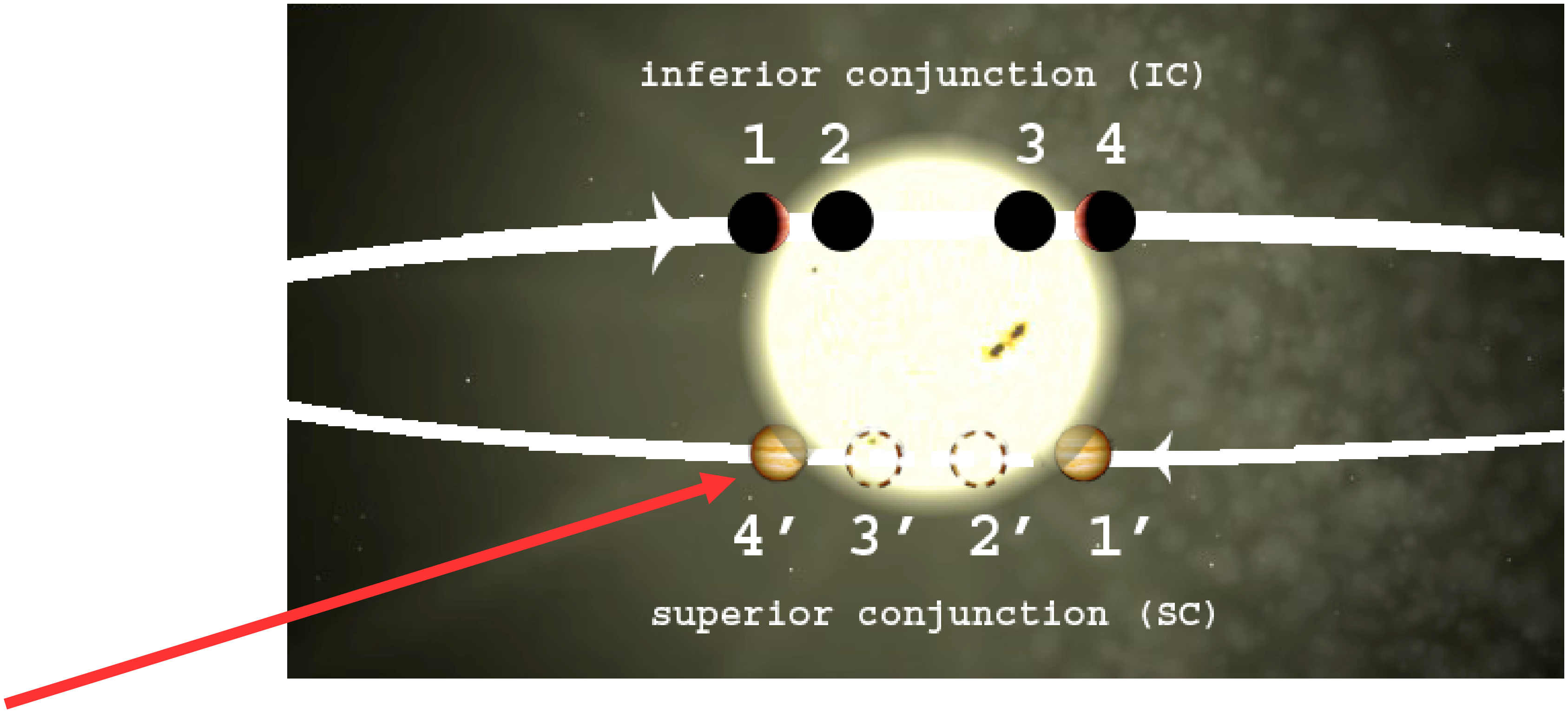




Gillon et al. 2009

What to observe?

Eclipses!!!

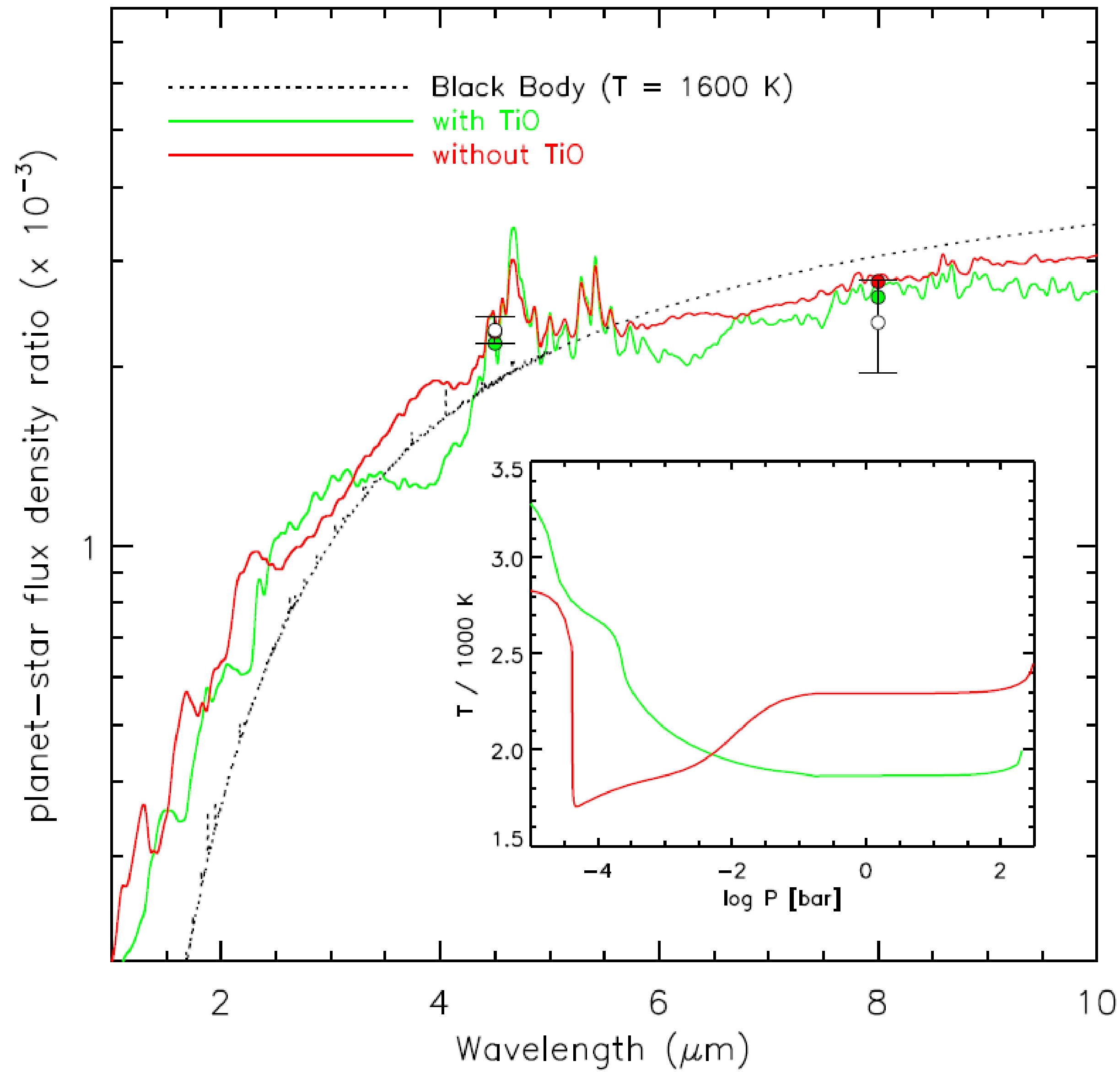


From Angerhausen et al. 2008

HAWKI photometry

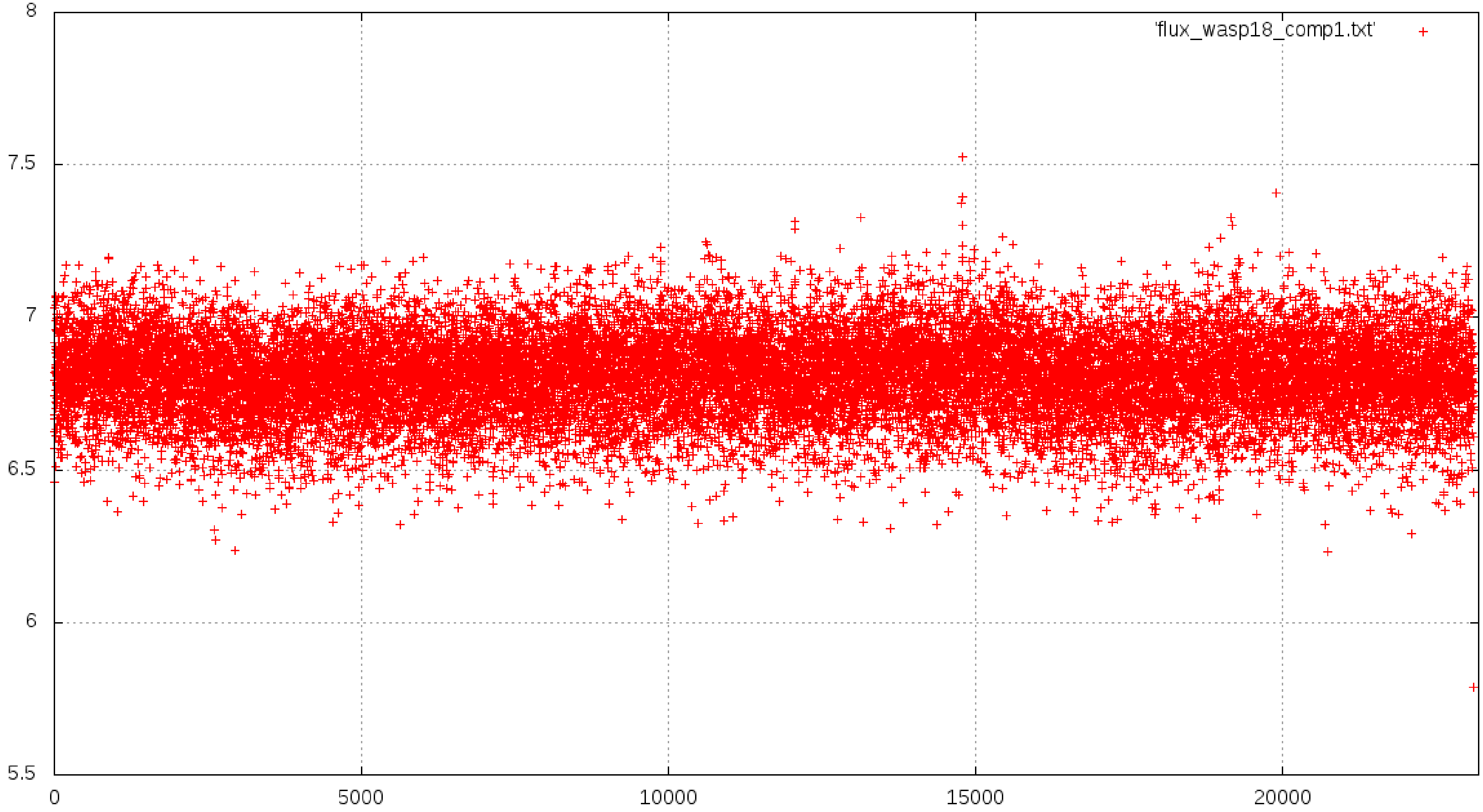
- Reduction of the WASP-17b data set from HAWKI fast phot mode by Msc. student Martin Blazek – NB2090 filter
- HAWKI fast phot allows for ms short exposures and has very fast readouts allowing for windowing
- FIRST LC obtained but now noise analysis etc. Needed – work ongoing

WASP-17b



From Anderson et al. 2011

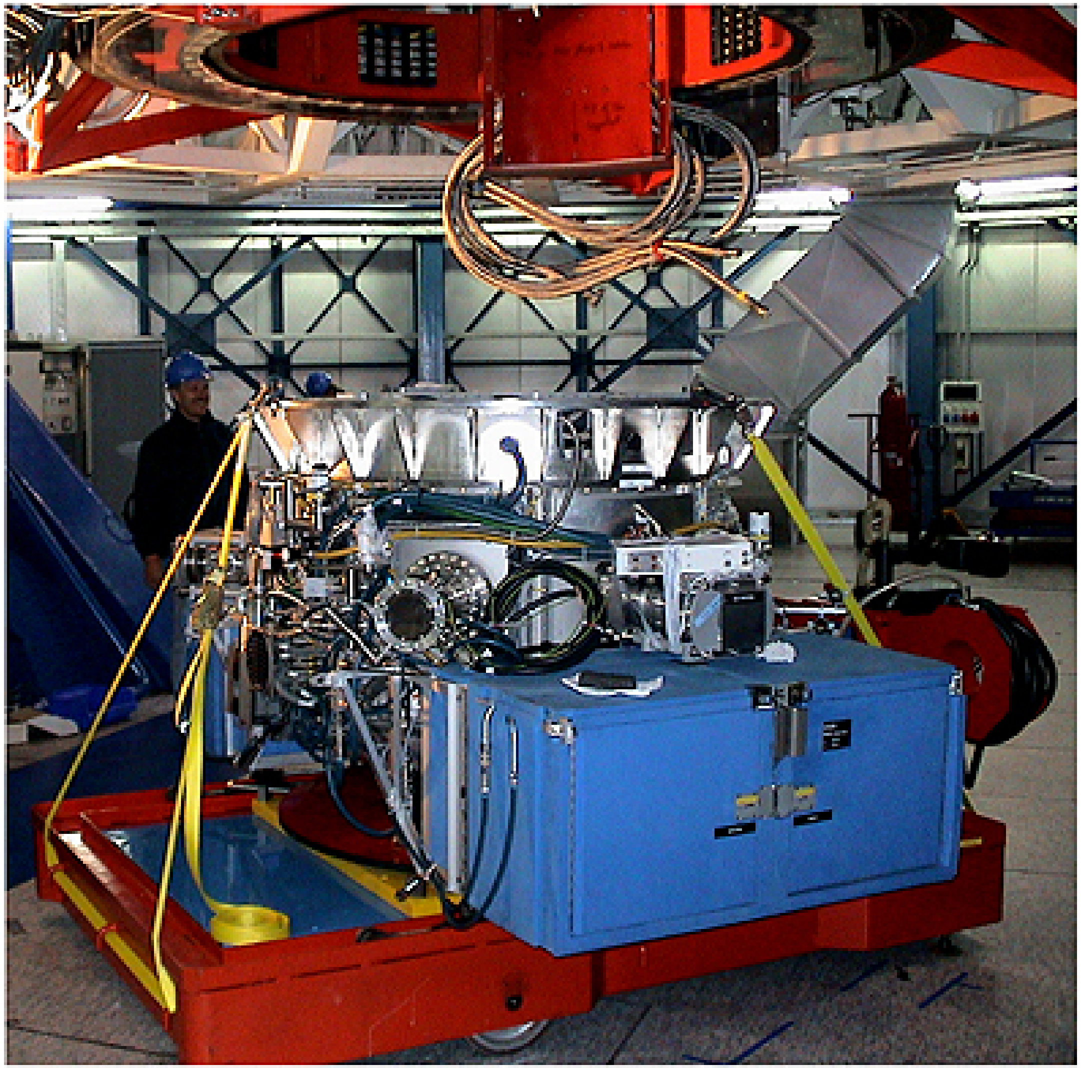
And the first LC



Using VISIR in the future?

- ESO Paranal VISIR instrument capable of NIR to MIR wavelengths up to about 25 micron
- Aquarius detector with FoV of about 38x38"
- What is the photometric accuracy in MIR?
- Occultation depth significantly deep in MIR?
- Our data will be a test of accuracy

ESO VISIR



VISIR under the Cassegrain Focus of the 8.2-m VLT Melipal Telescope

ESO PR Photo 16a/04 (12 May 2004)

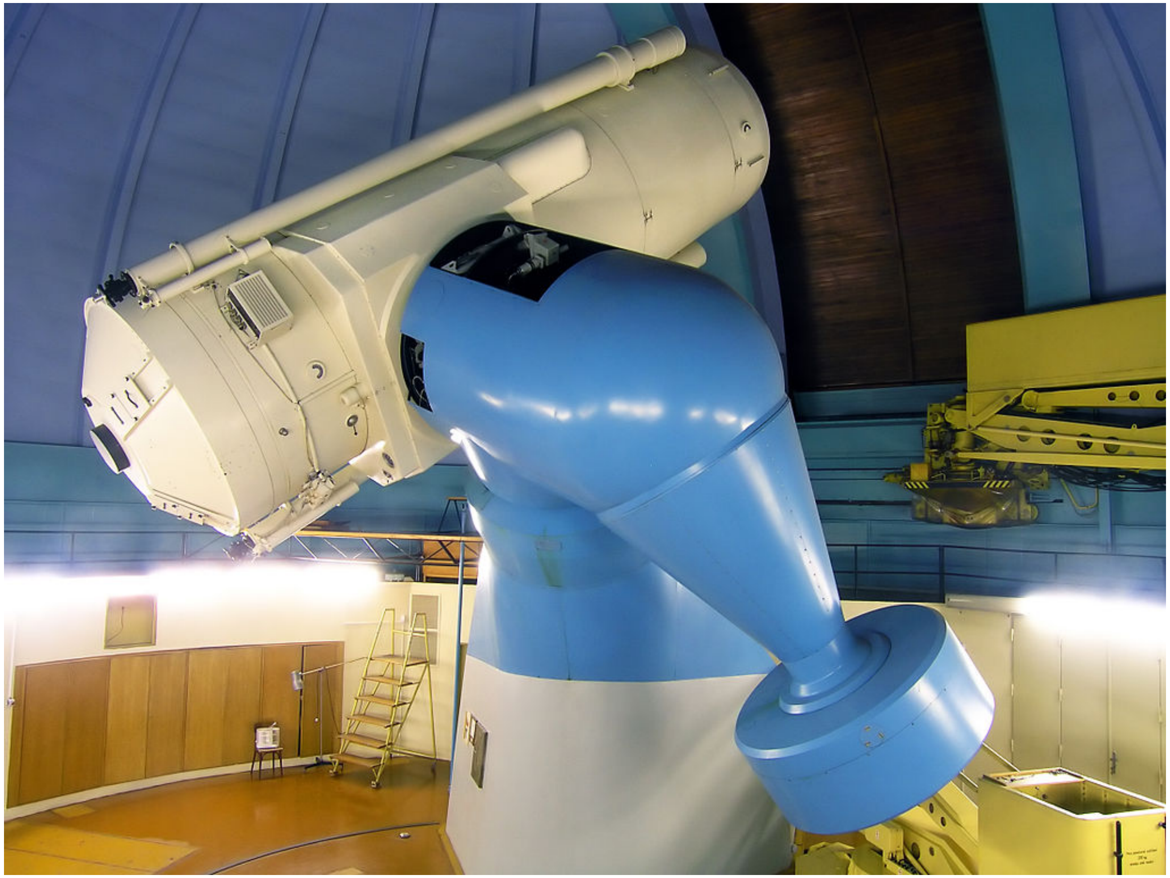
Wasp-8b

- Ideal object – brighter end, nearby star in FoV as comparison
- Two data sets taken, last on September 2015 – 8 hrs transit LC
- Observing band PAH 1 at 8.59 micron
- First 1.5 hrs. OOT sequence in June 2015
- Data being retrieved and analysed

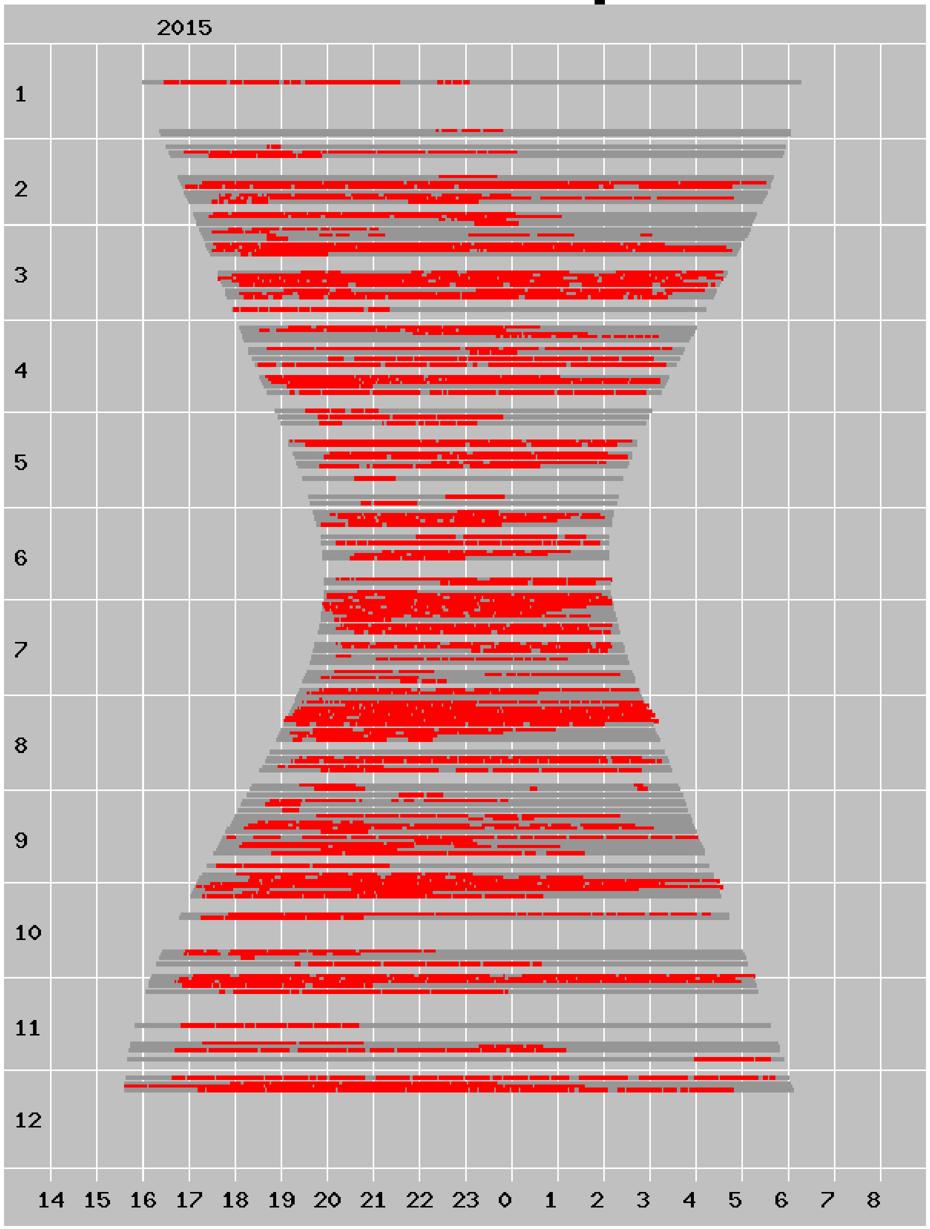
Radial velocities - 2m

Radial velocities at 2m telescope

- 2-m telescope – Zeiss built in 1967
- Twin of TLS 2-m
- Operates in Coude
- Equipped with slit spectrograph and with an Echelle spectrograph



Ondrejov observing stats 2015 around 60 percent



Echelle spectrograph

- Wavelength coverage – 400-900 approx.
- R=up to 44000
- RV accuracy can be now around 40 m/s (might be some optical problem, udner investigation)
- RV in near future – down to 5 m/s
- Limiting magnitude
- Iodine cell from Tautenburg

Program

- Cooperation with Tautenburg (TLS) – A. Hatzes, E. Guenther
- K2 giants planets – looking for planets around selected giant stars
- Interesting objects – RM effect? Known planets for testing RV
- Ideal for RV follow-up of bright stars with planets to confirm candidates – joint project for TESS and NGTS and K2 stars (with TLS)

Education of students in observing techniques and data reduction

- ESO/IAU/OPTICON Summer school organized in Brno in September – 2 weeks
- 39 students all around the world
- Talks about observatories, instrumentation and projects with real data
- Career session, observing proposal writing

Outlook

- PPP program with Dr. Vanko/Dr Budaj from SAV
- PPP program with prof. Rauer, DLR Berlin
- ERASMUS plus possibilities?
- Joint GACR/DFG grant Tautenburg w. dr. Guenther
- Further courses for students – summer 2016
- Data collection ongoing on exo-atmospheres
- Looking forward at NGTS, TESS and well PLATO planets – small planets

Summer school Ondřejov 2016

- Summer2016.asu.cas.cz
- Ondřejov, 11-18 September
- 15 students from 4 countries
- Project work accompanied by lectures
- Beginning of a tradition – next year a bigger event maybe joint with other contries?

Exo-meeting, Ondřejov

- September 19-21, 2016
- Meeting which shall exploit collaboration on exoplanets between central european institutes and various research groups
- Participants: SAV, DLR, TLS, ESO, Graz AS

- 2-m meeting Ondřejov 21/22 September 2016

 - discussion of science with 2m class telescopes in the era of VLT

Collaboration with SAV and TLS? (some ideas)

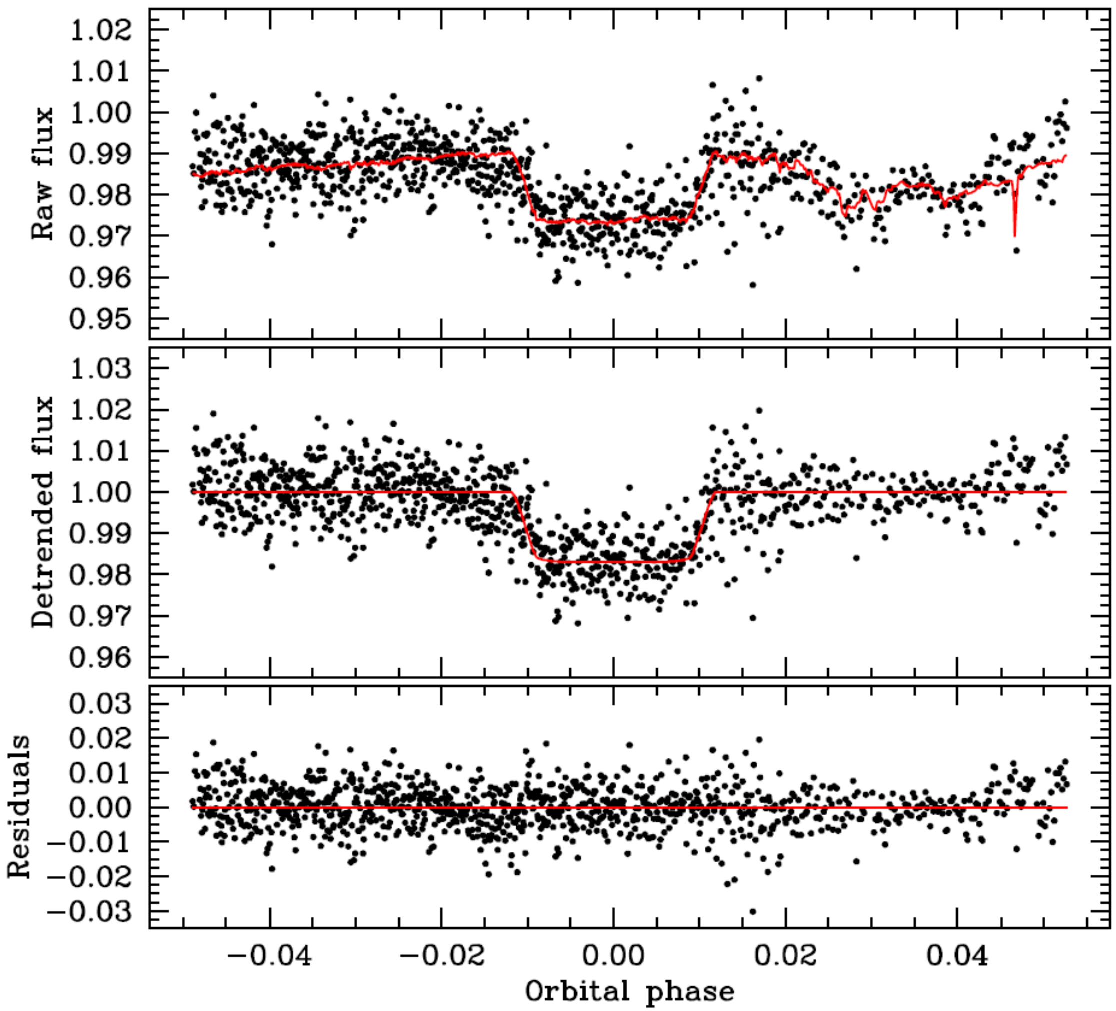
- Ideally to motivate students Msc., Phd
- Students like mobility and observing
- Scientific framework: exoplants/variable stars
- Observations at Ondřejov, SAV, TLS and ? (Canaries, ESO, ????)
- Depends on the funding sources and other factors…..

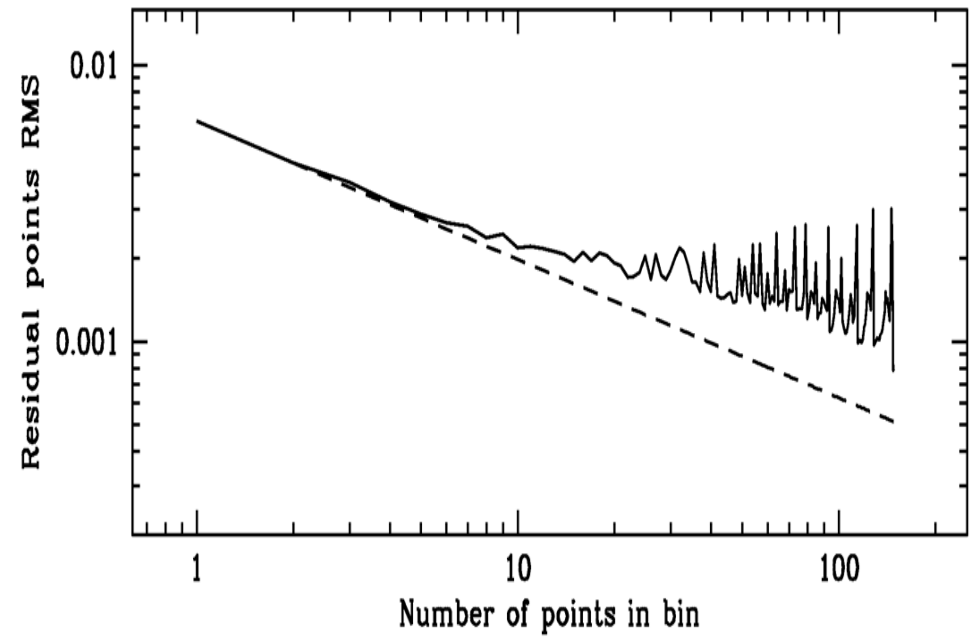
Thanks

- Especially to M. Vaňko for organizing everything
- And to J. Budaj for great tips where to go in beautiful Tatra mountains…
- Hopefully see you soon in Ondřejov

Thank you

Our measurements - OSIRIS



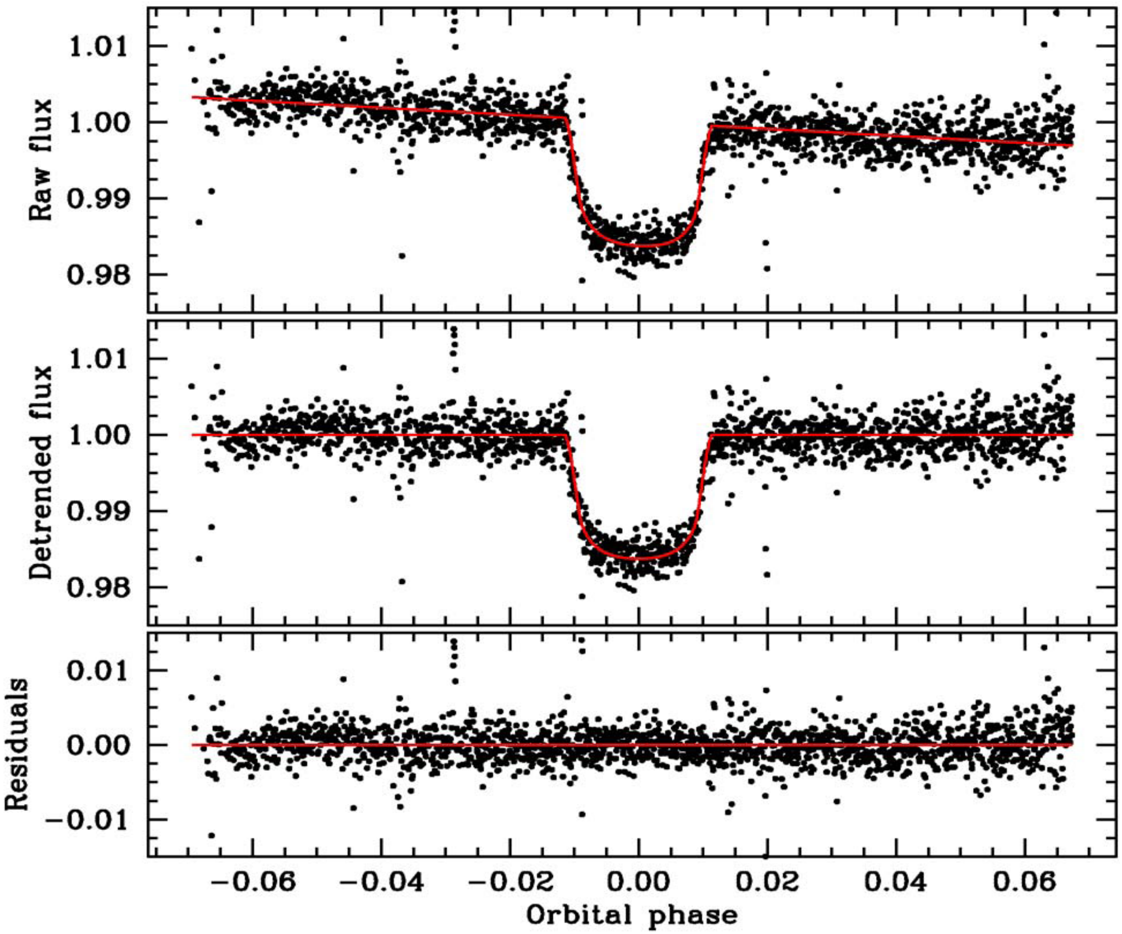


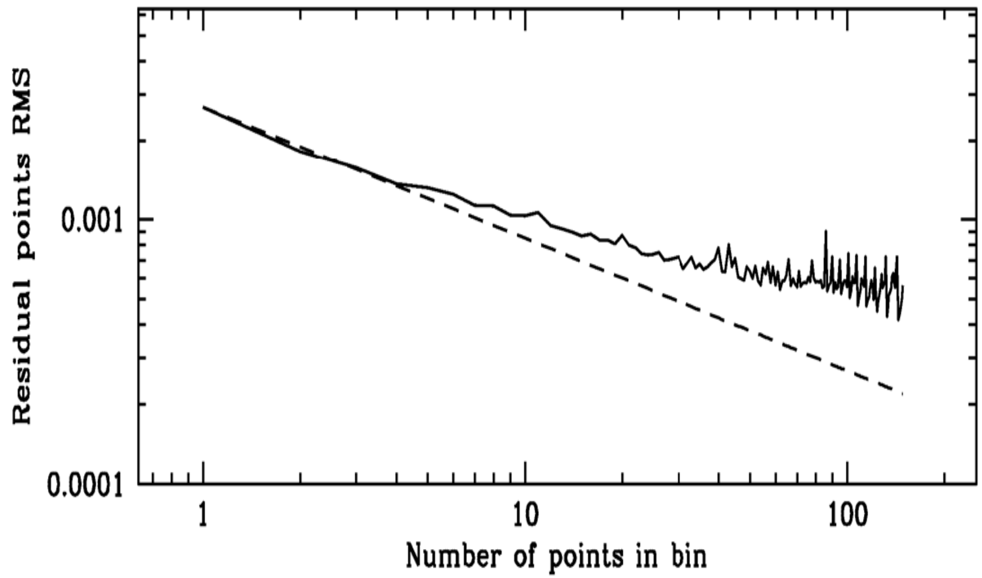
Rp/Rs = 0.118101 (-)0.002766(+)0.00256

Caceres et al. 2012, in prep.

MCMC code by M. Gillon and C. Caceres
(e.g. Gillon et al. 2012; Caceres et al. 2011)

Our measurements - SOI

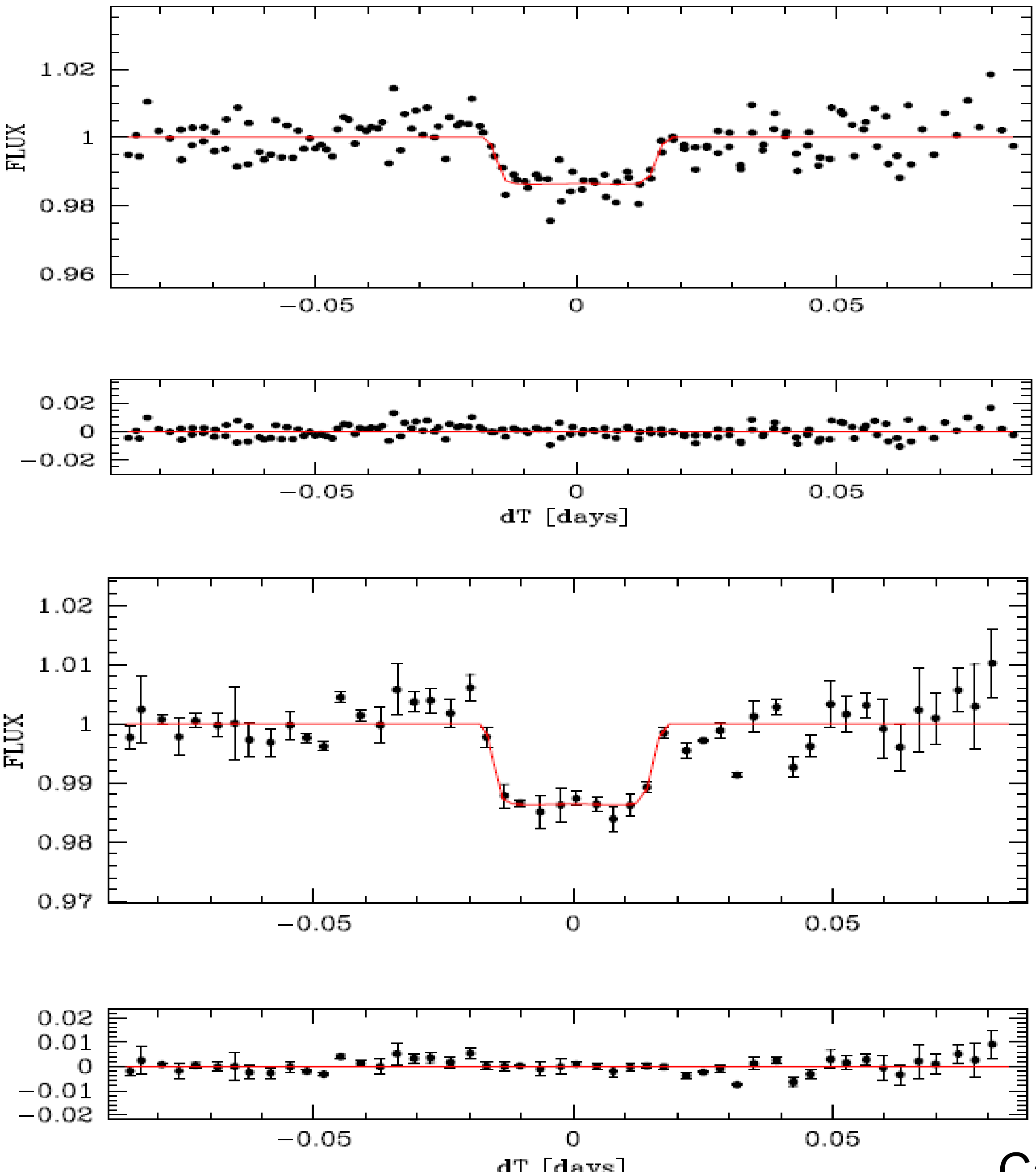




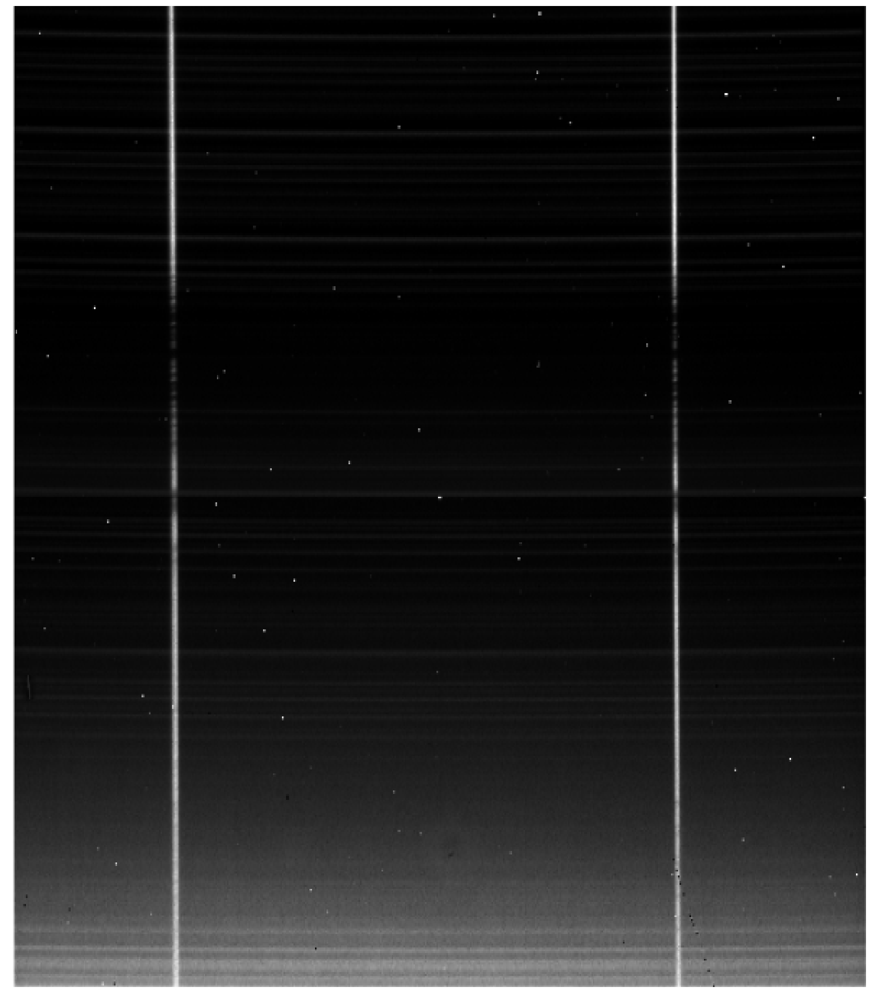
SOAR I-BESSEL:
Rp/Rs = 0.117151 (-)0.001173
(+)0.001182

Observations performed by S. Hoyer

SOFI NIR transmission spectroscopy

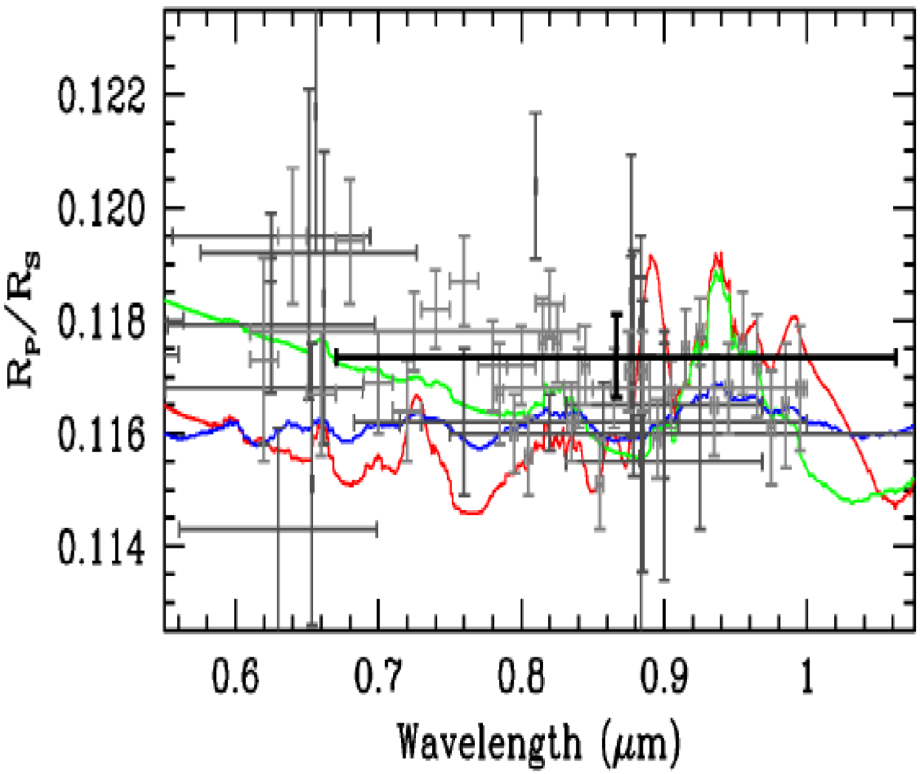


1.5 – 2.3 micron low res.
3 nights in 2011



Caceres, Kabath et al., 2014, A and A

Our results compared (photometry)



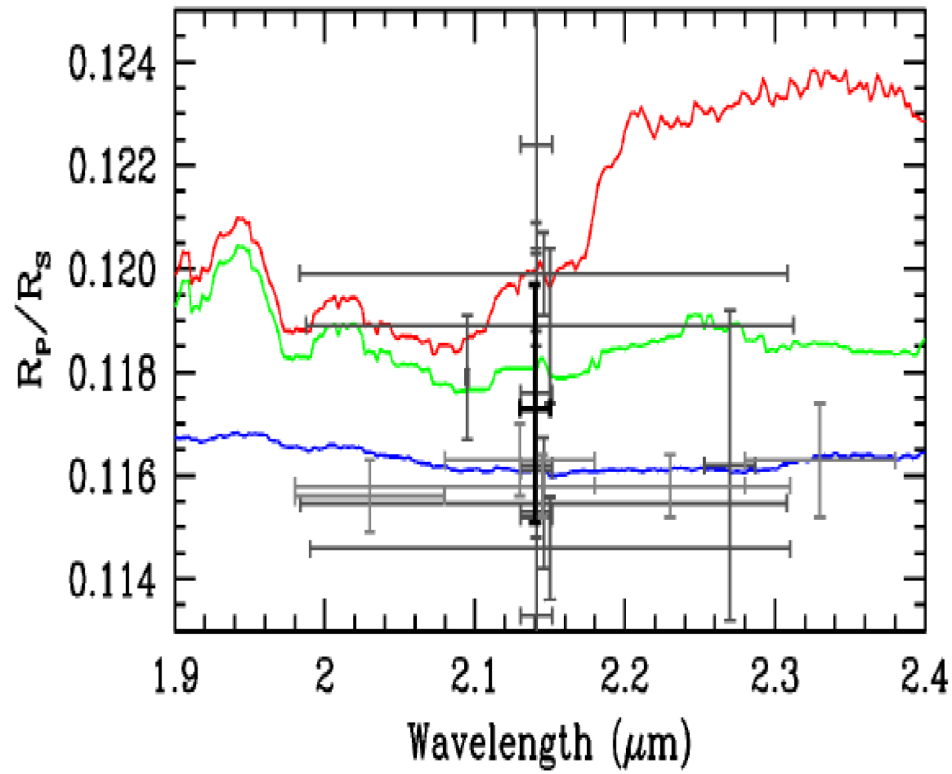


Fig. 11. *Left:* A zoom-in from Fig. 10 for the optical region around our *I*-Bessel measurements. *Right*: The *K*-band region of spectra around our 2.14 μm observation. Our measurement points are represented by dark circles, while gray points follow the description in Fig. 10. A color version of this plot can be found in the electronic version of the paper.

Caceres, Kabath et al., 2014, A&A

Another small planet - GJ3470b

- First reported – Bonfils et al. A&A, 546, A27

PARAMETERS

- Orbiting M1.5 dwarf star (V=12.27 mag, K=7.9) in 3.33 days
- M=0.04Mj
- R=0.37Rj
- Star of similar brightness nearby on the sky

(K=8.0)

LIRIS @ William Herschel Telescope – transmission spectroscopy

- LIRS long slit, 10arcsec slit, 4.2arcmin, HK, low spectral resolution, 2 nights in 2014
- Simultaneously observing nearby star of similar brightness very close
- Thanks to T. Jerabkova, very thorough optimization of extraction parameters and spectral bins

Why is GJ3470b interesting?

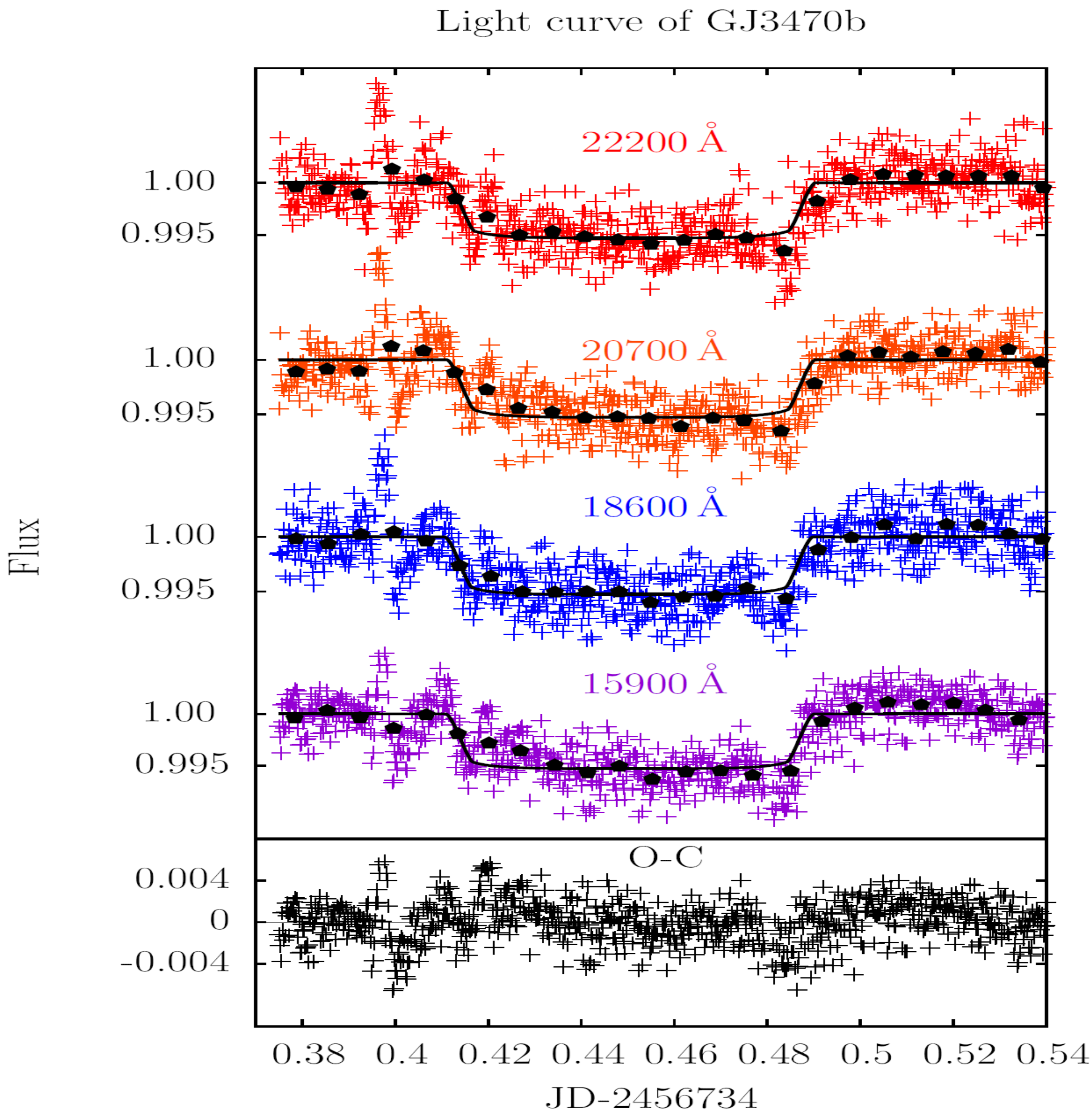
- Scattering?

- Nascimbeni et al. 2013, A&A, 559, 32A
- Fukui et al. 2013, ApJ, 770, 95

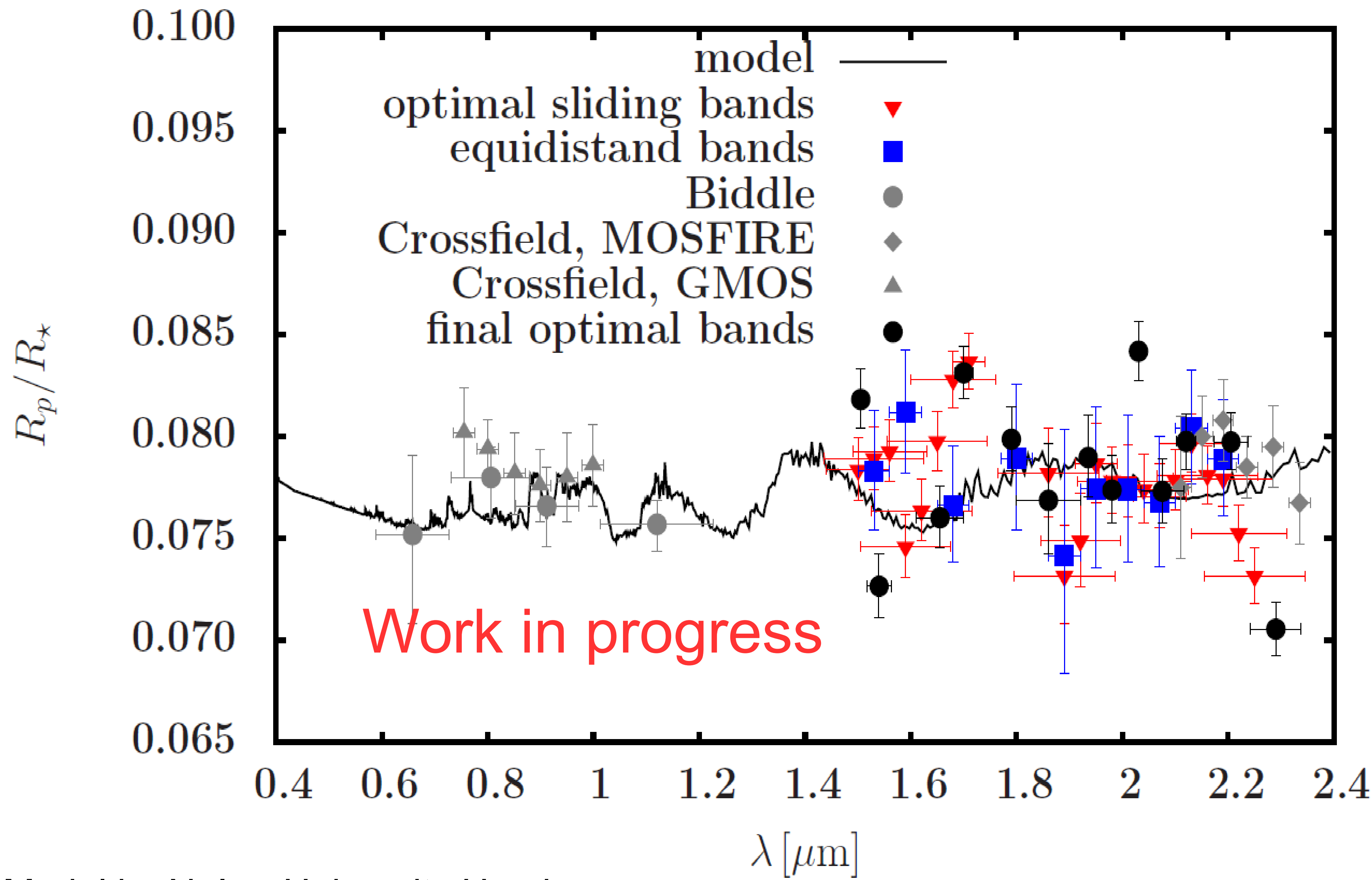
- NIR part of the spectrum flat?

- Crossfield, et al. 2013, A&A, 559A, 33C
- Demory et al. 2013, ApJ, 768, 154

LIRIS preliminary results



Preliminary results GJ3470b – Kabath et al. 2015, in prep.



Model by N. Iro, University Hamburg

Outlook- New hope

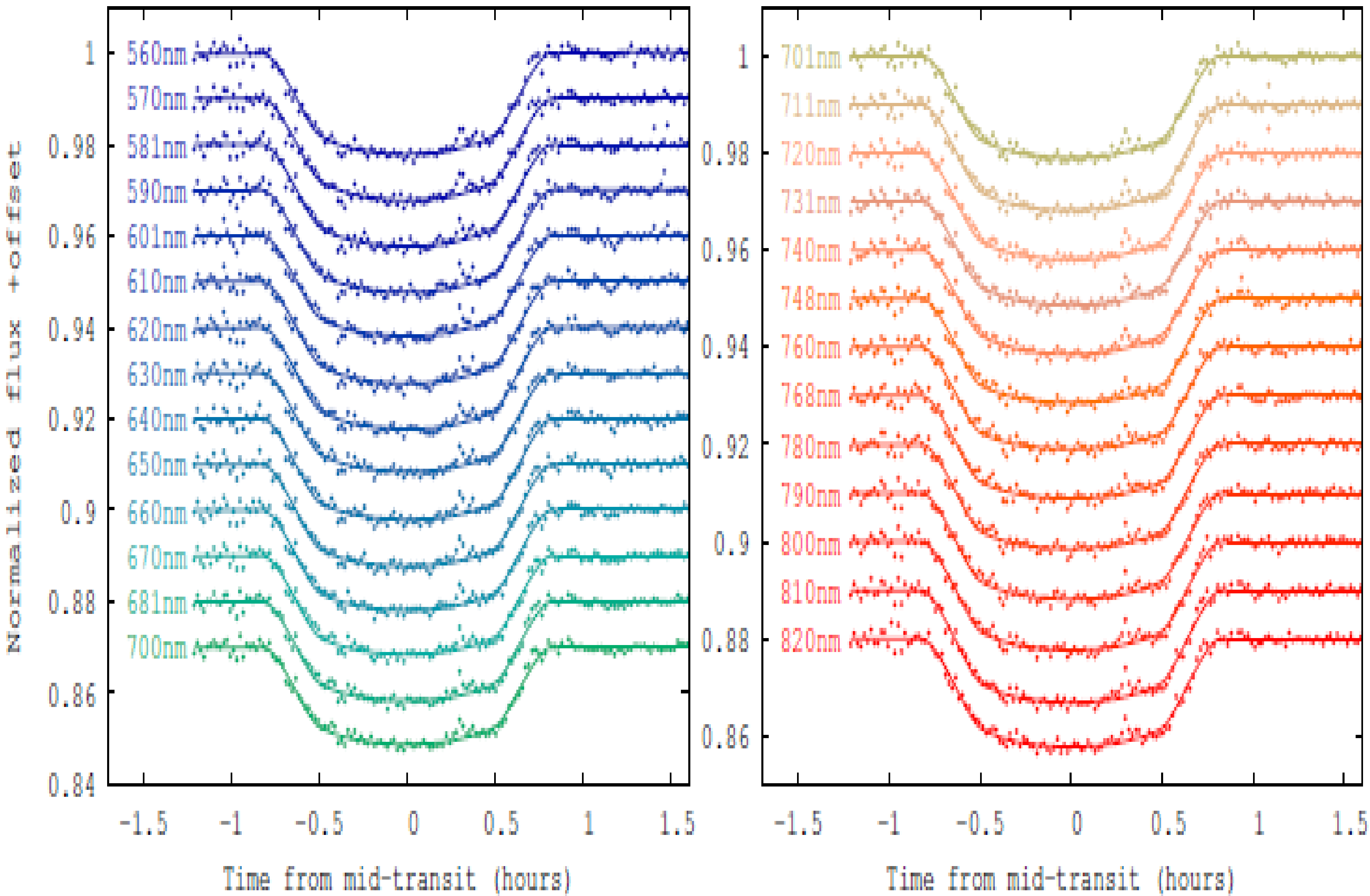
FORS2 LADC, image by ESO

FORS2 is back for exoplanets

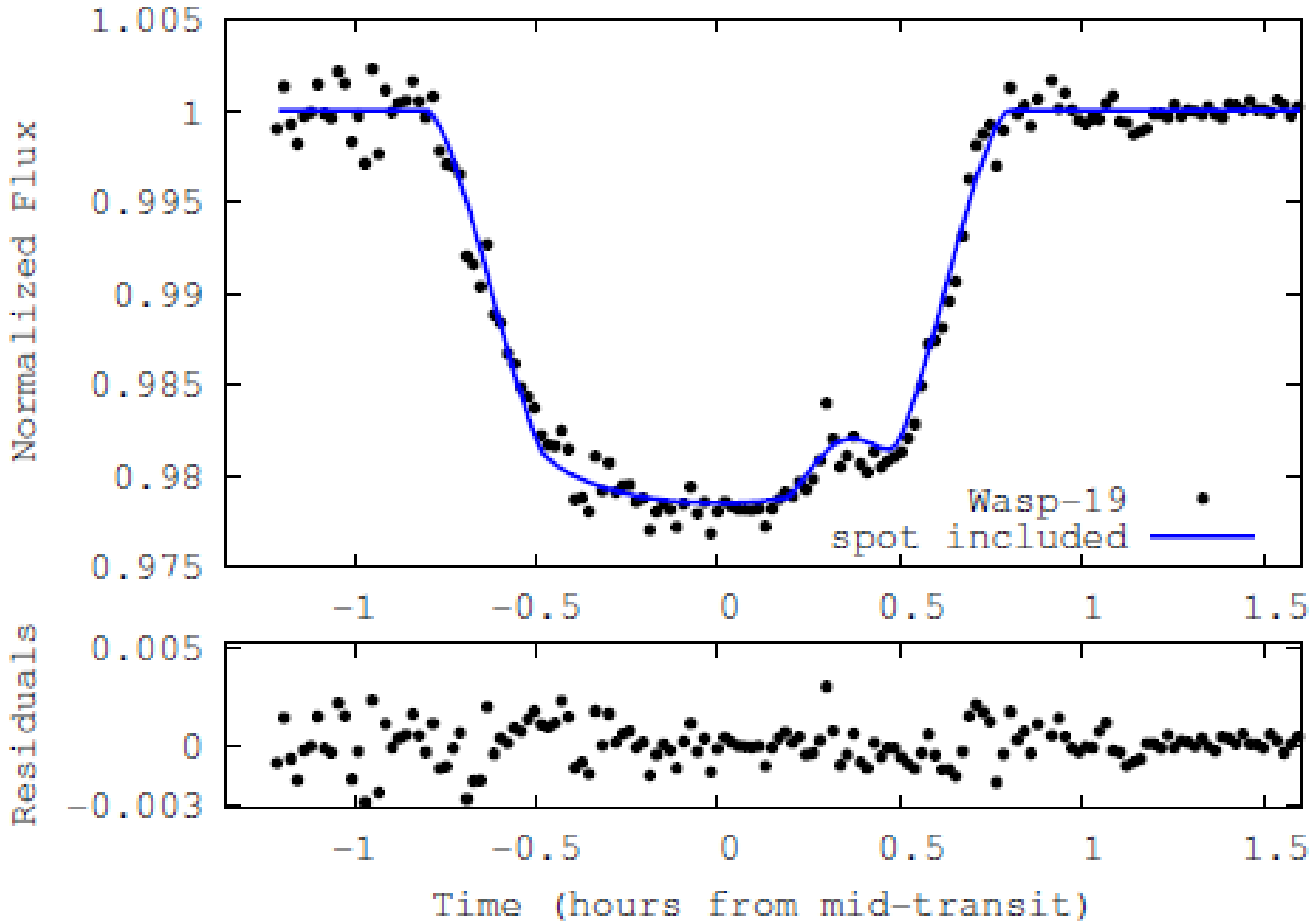
- Wasp-19b bserved in November with LADC
- Paper submitted by Sedaghati et al. 2015, A&A
- Now no coating of LADC
- FORS2 again usuable for detection of atmospheres (after problems since 2012)

WASP-19b

- Sedaghati et al. 2015, A&A, submitted



Sedaghati et al. 2015, A&A, submitted



HAWKI@VLT defocussing, fast phot

- HAWK-I has now a new defocussing mode implemented
- Officially offered from new period
- Able to defocuss the adapter but keep a good active optics correction
- Able to go 1-2 magnitudes brighter
- Might be combined with FastPhot mode (windowing and extremely short exposures)

Summary

- Even 4-m class telescopes might provide nice results, especially for bright targets
- FORS2 back in business
- HAWKI defocussing mode & fast phot

Summary

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