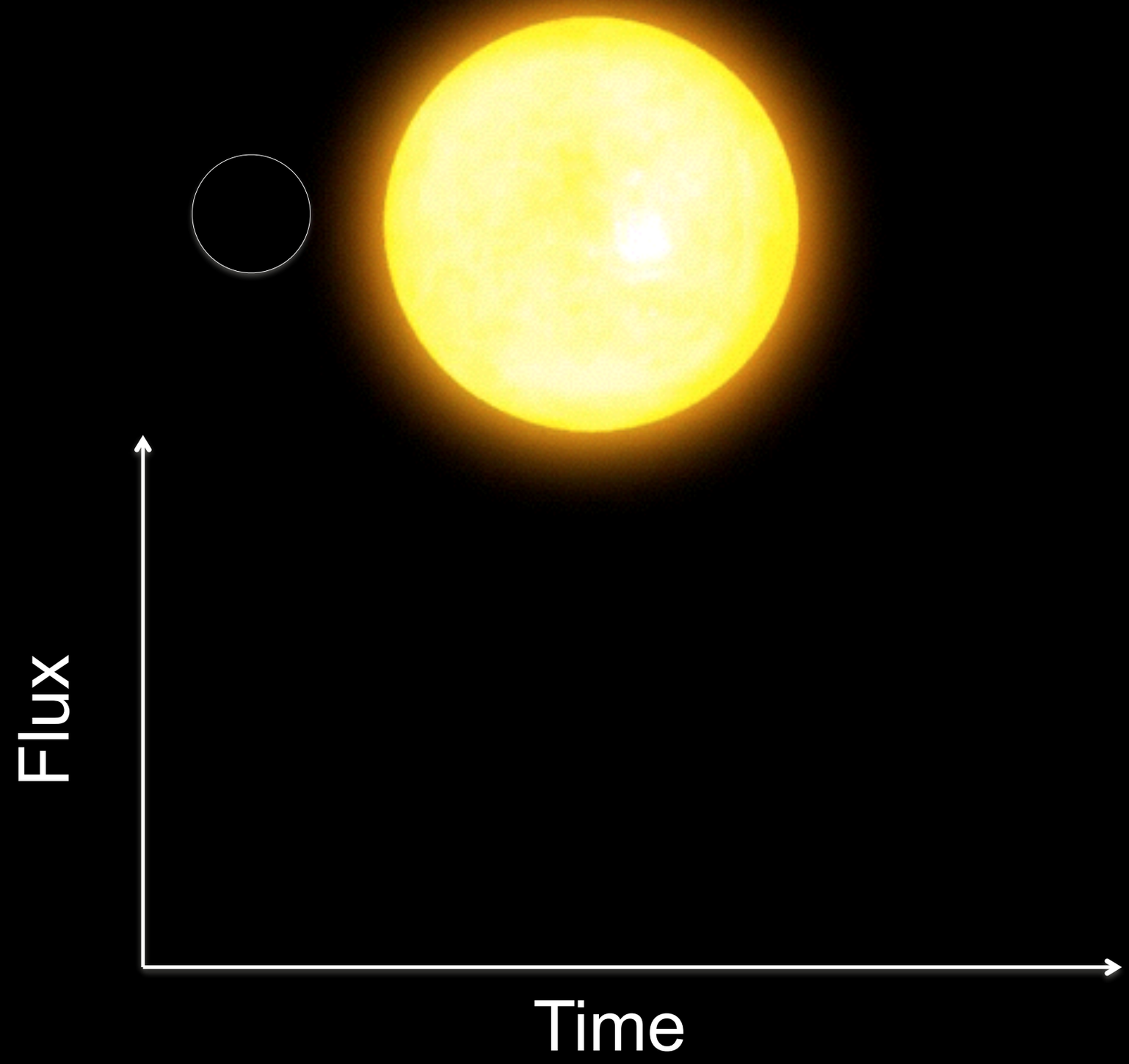
Developing the science case for future space missions that characterise the atmosphere of extrasolar planets

Camilla DANIELSKI,

in collaboration with
M. OLLIVIER (IAS) AND P-O. LAGAGE (SAp/CEA)

Transiting exoplanets



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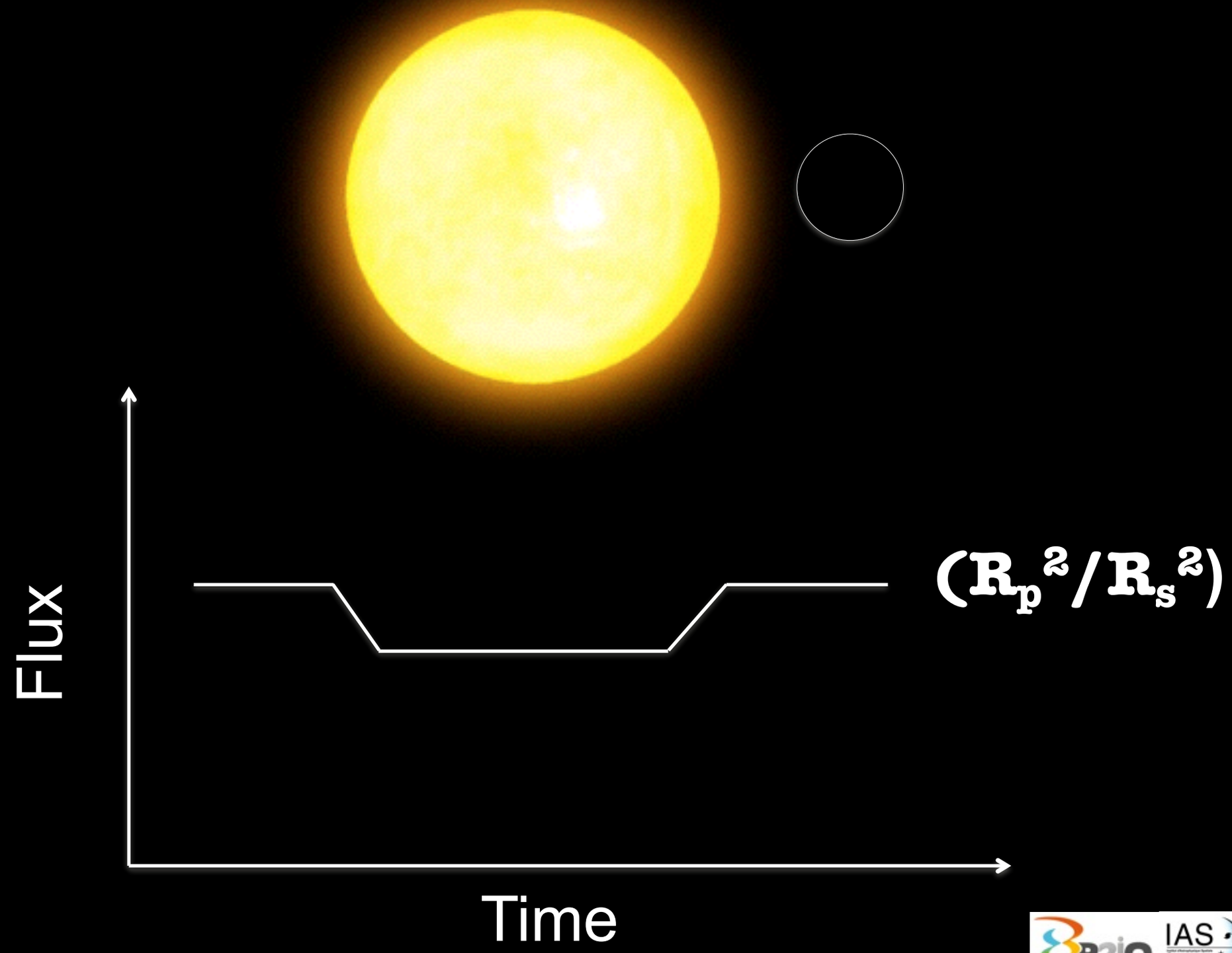

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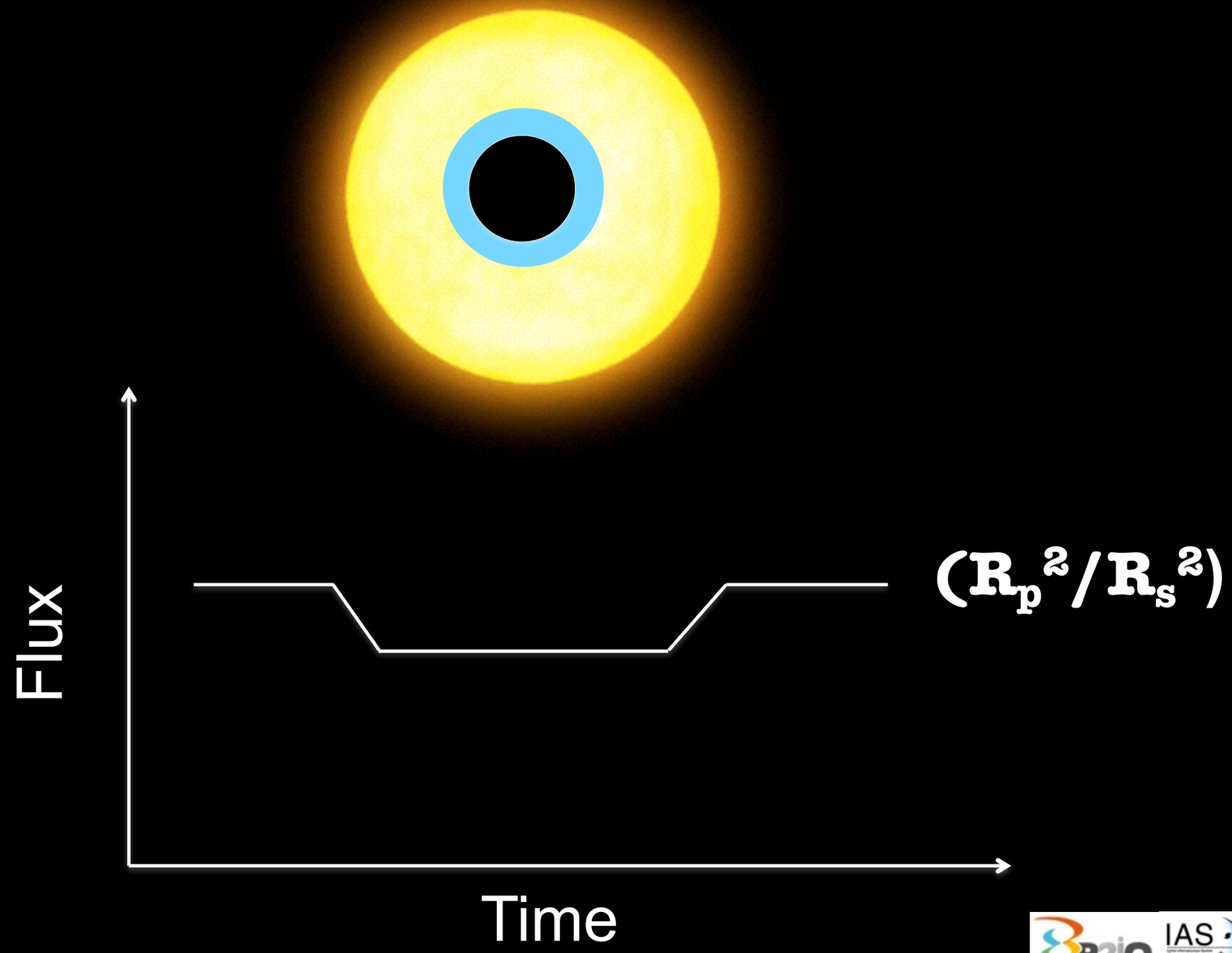

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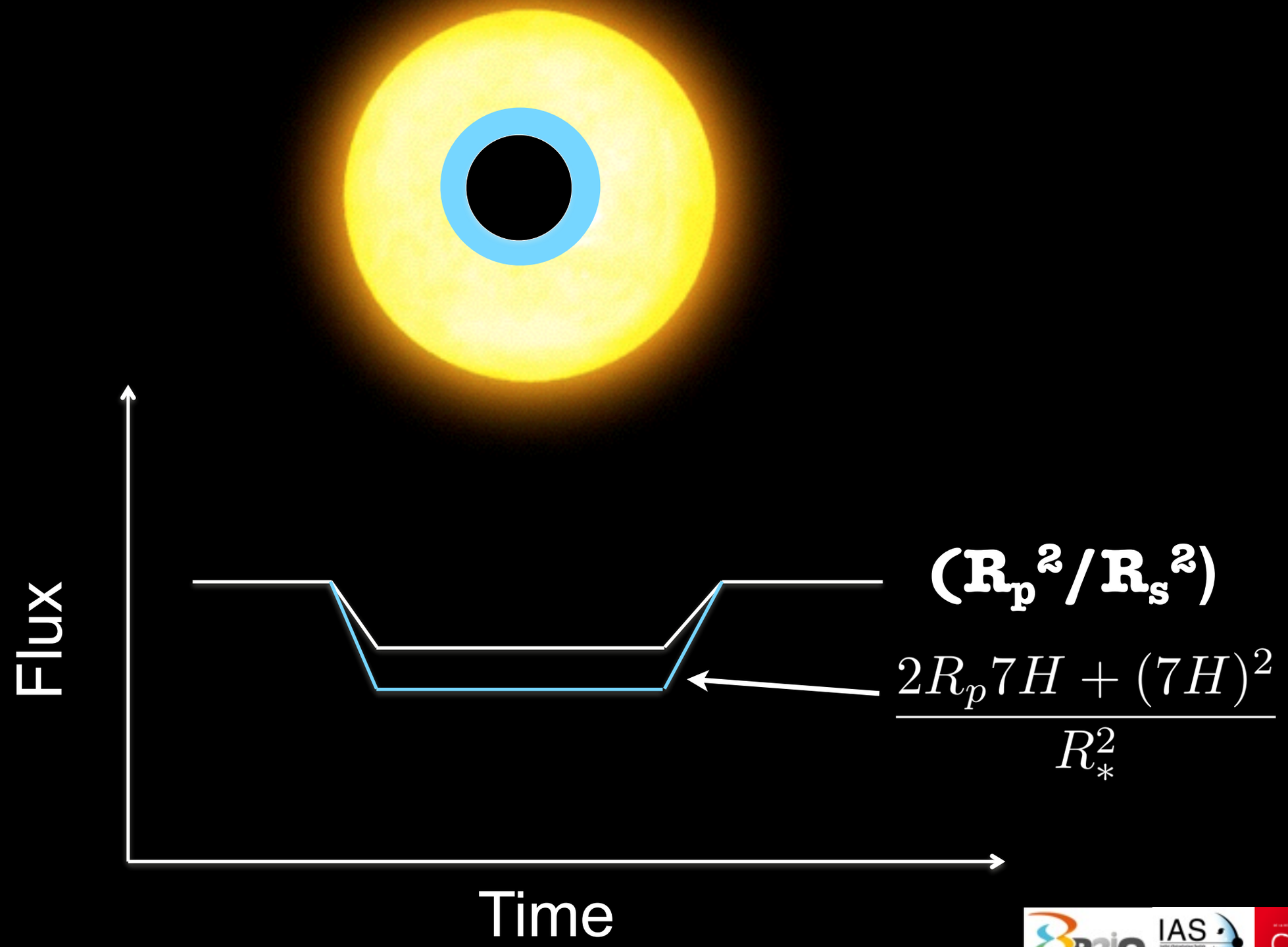
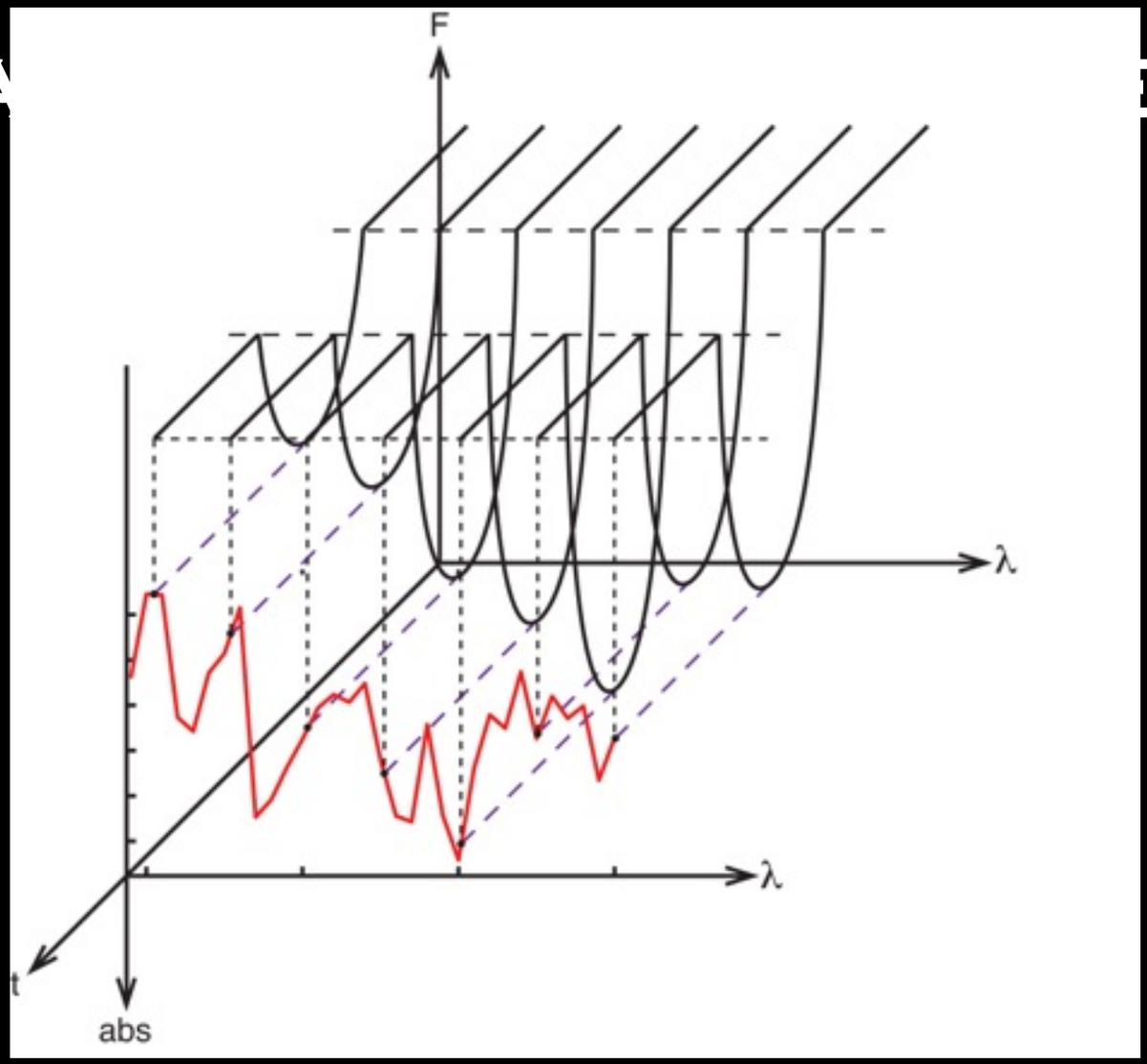
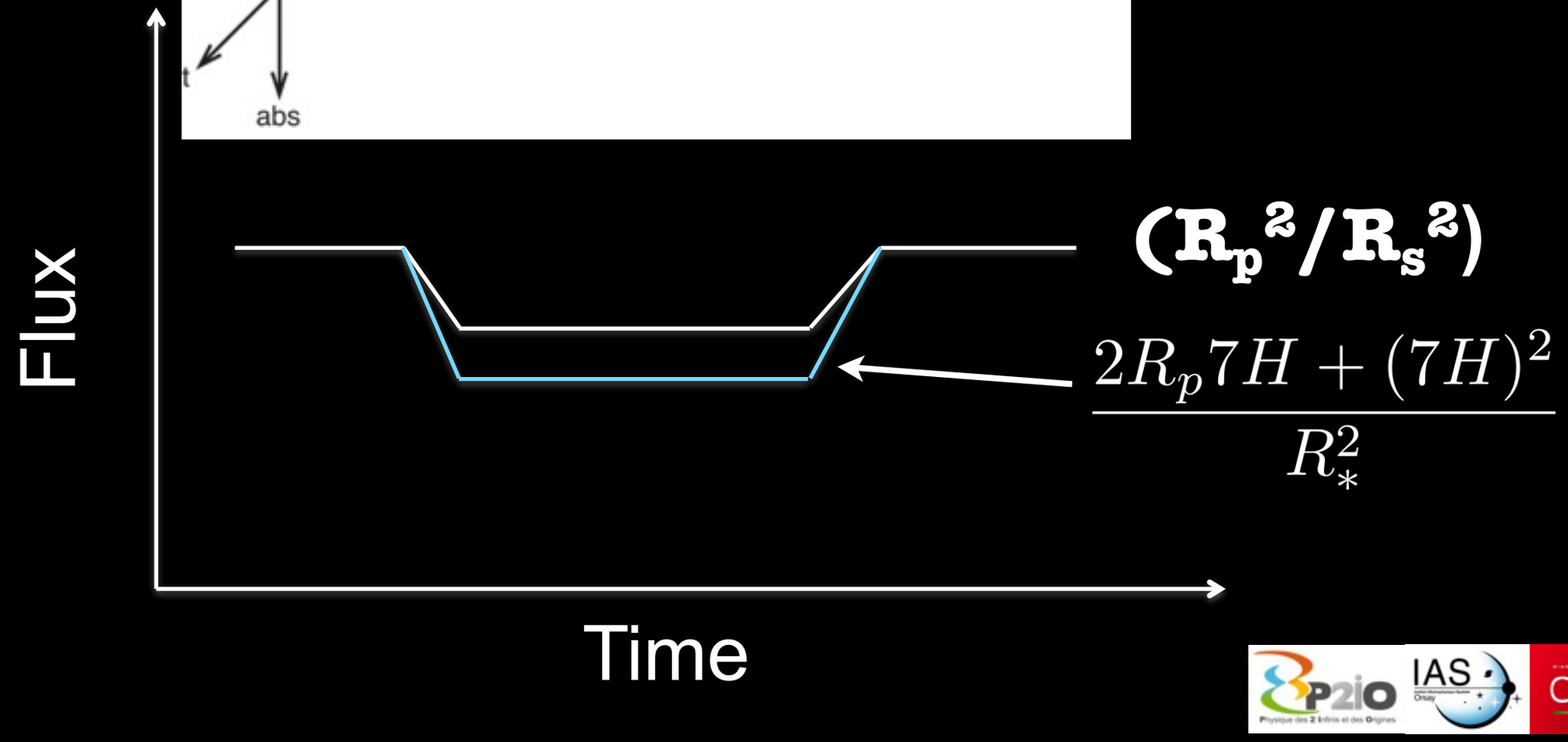


Tra ets





$$\left(R_p^2/R_s^2\right)$$

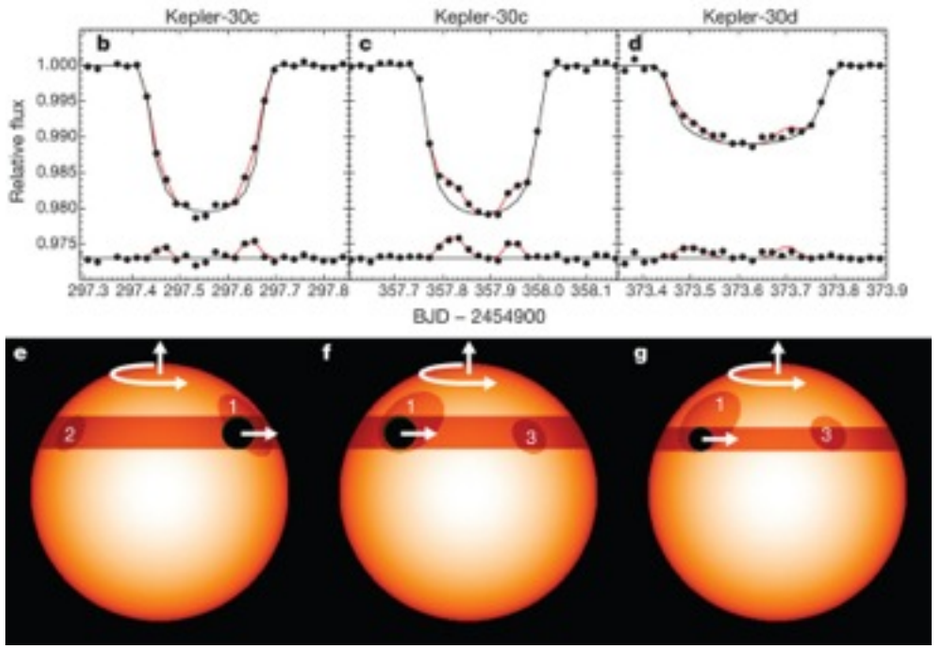
$$\frac{2R_p 7H + (7H)^2}{R_*^2}$$

Stellar noise is a problem !

10^-5

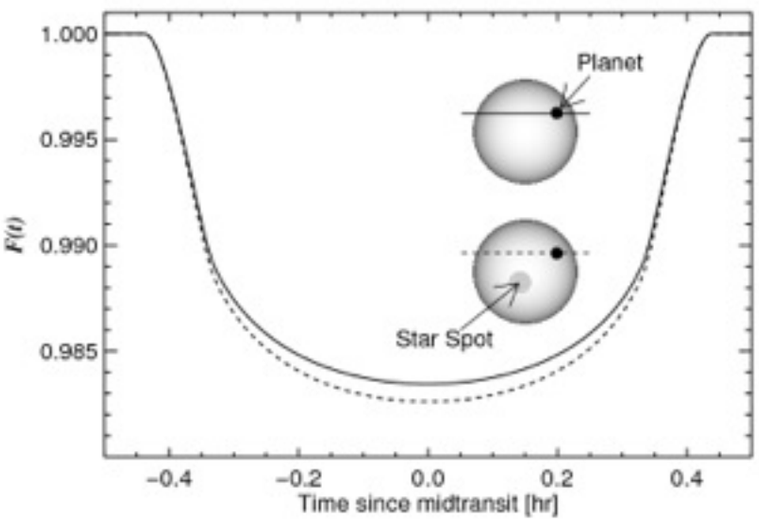
Photometric variability

Transited spot



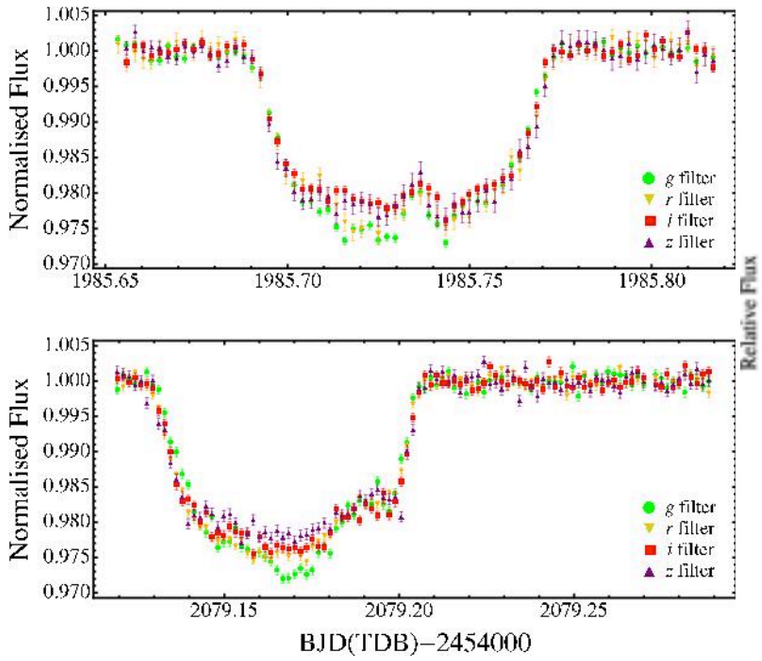
Sanchis-Ojeda et al. 2012

Non transited spot

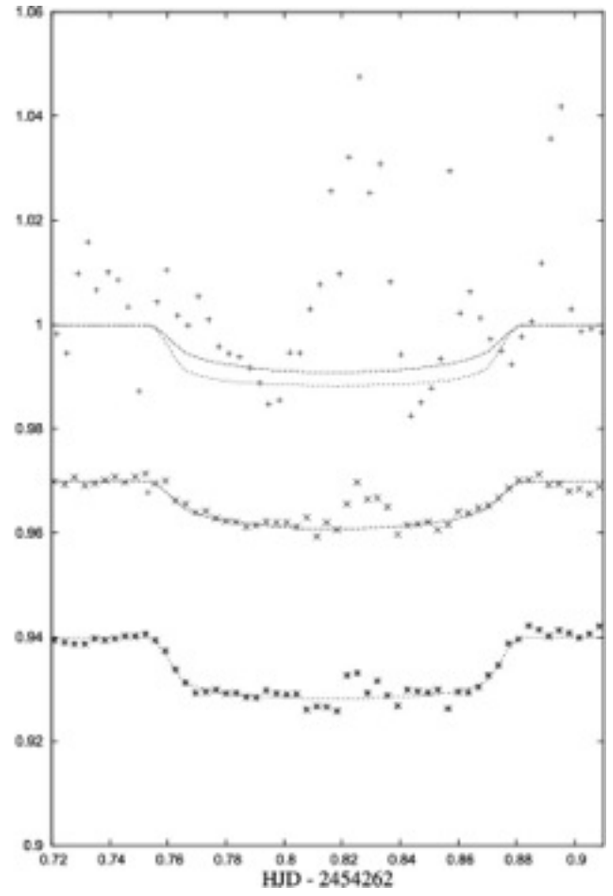


Carter et al. 2011

Multi-wavelength variability

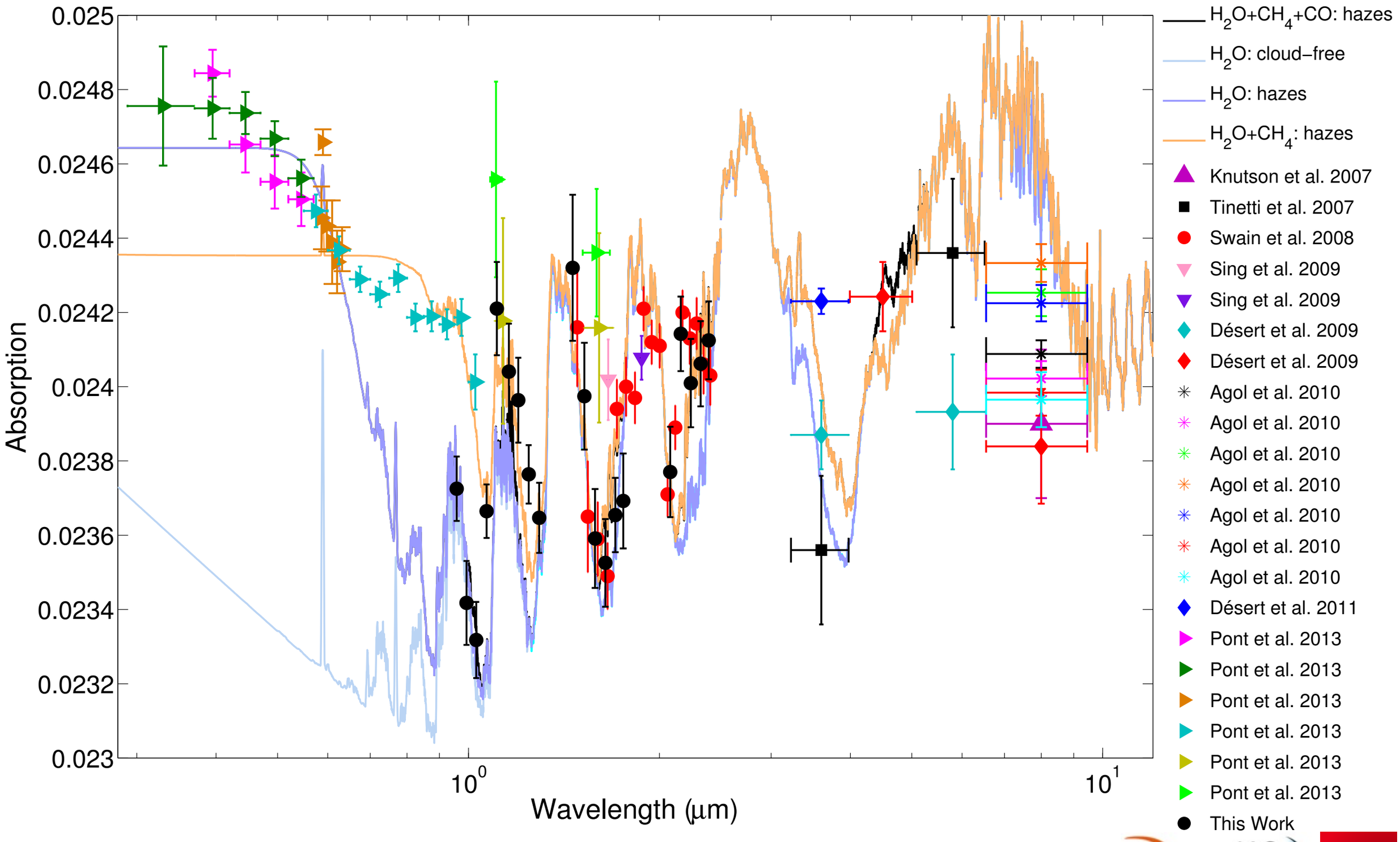


Mohler-Fischer et al. 2013



Bentley et al. 2009

Transmission spectrum of HD-189733b



Danielski et al. 2014

IS THERE ANY CORRELATION BETWEEN SIGNALS AT DIFFERENT WAVELENGTHS?

IF SO, CAN WE USE THE VISIBLE INFORMATION TO CORRECT FOR STELLAR ACTIVITY IN THE INFRARED?

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SIMULTANEOUS DATA IN MULTIPLE BANDS ARE NEEDED

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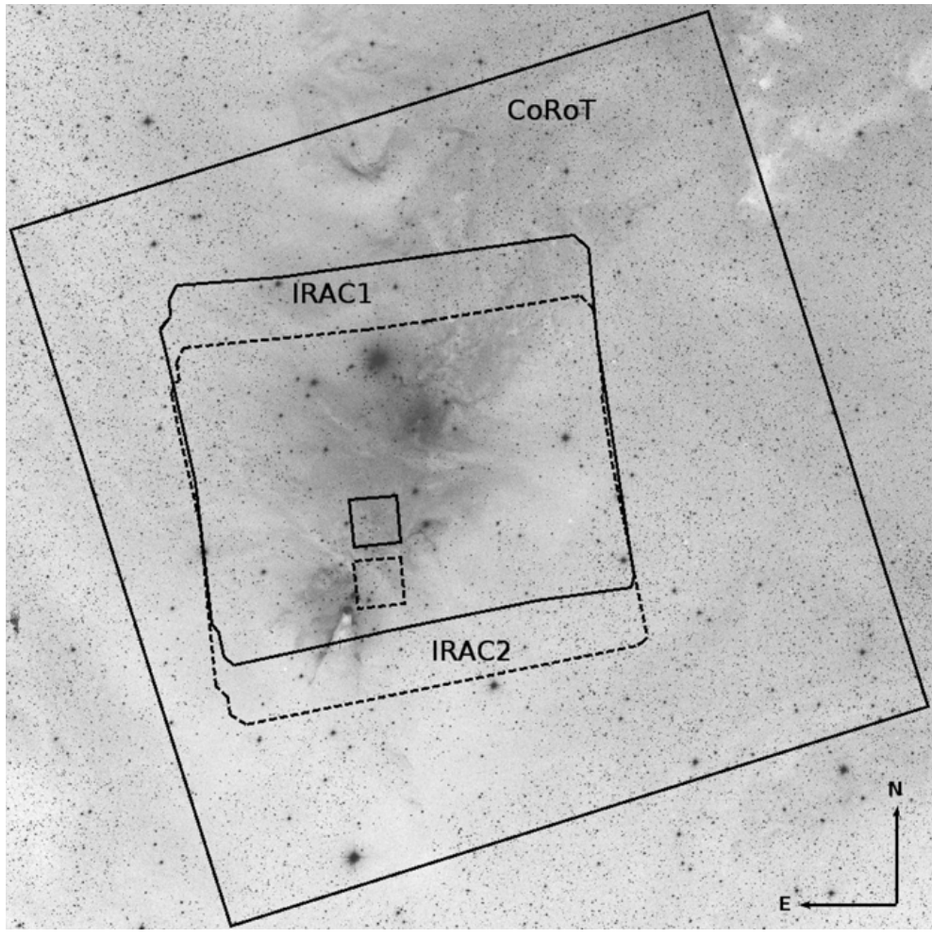
SIMULTANEOUS DATA IN MULTIPLE BANDS ARE NEEDED

Coordinate Synoptic Investigation 2264 Campaign

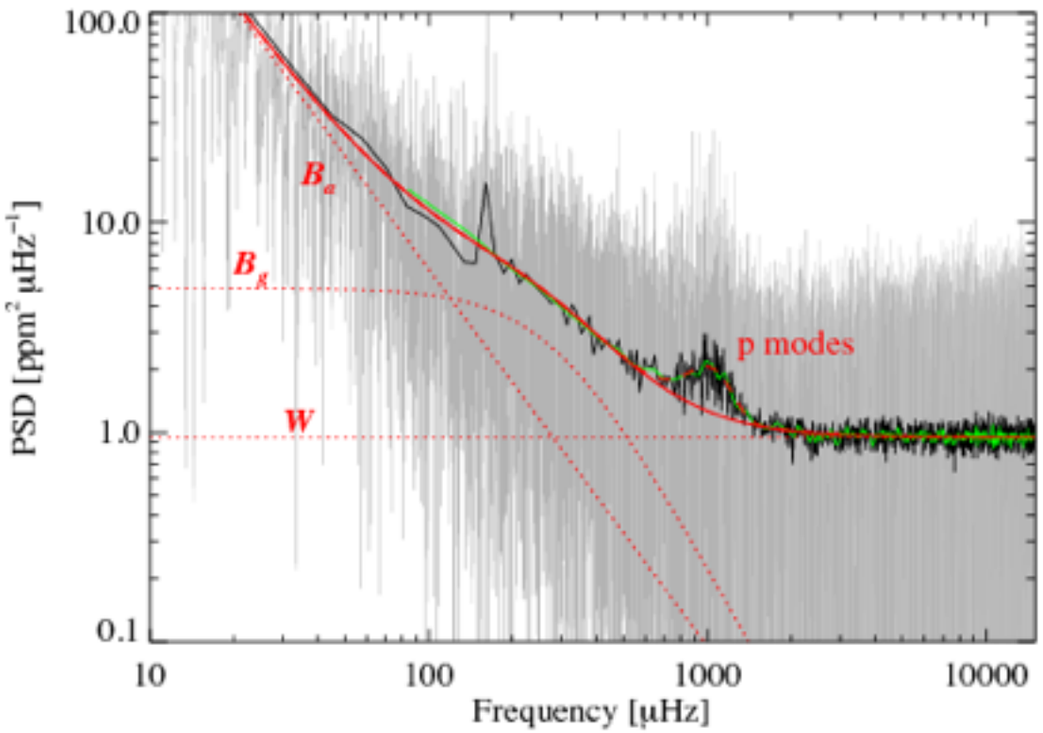


Cody et al. 2014

- Non members of NGC 2264
- N = 195 stars in total
- 103 with observations in all the channels (R band, 3.6 μm, 4.5 μm)
- V < 15
- few stars with V < 10, although the available ones have very few data points

HOW DO WE DETECT CORRELATION?

SPECTRAL ANALYSIS: STELLAR BACKGROUND AND TIME-SERIES X-CORRELATION



Mathur S. et al. 2013

PSD of HD~169392 data (grey) modeled using the usual three components:

white noise (W),
granulation noise (Bg) and
stellar activity and/or large scales of convection (Ba).

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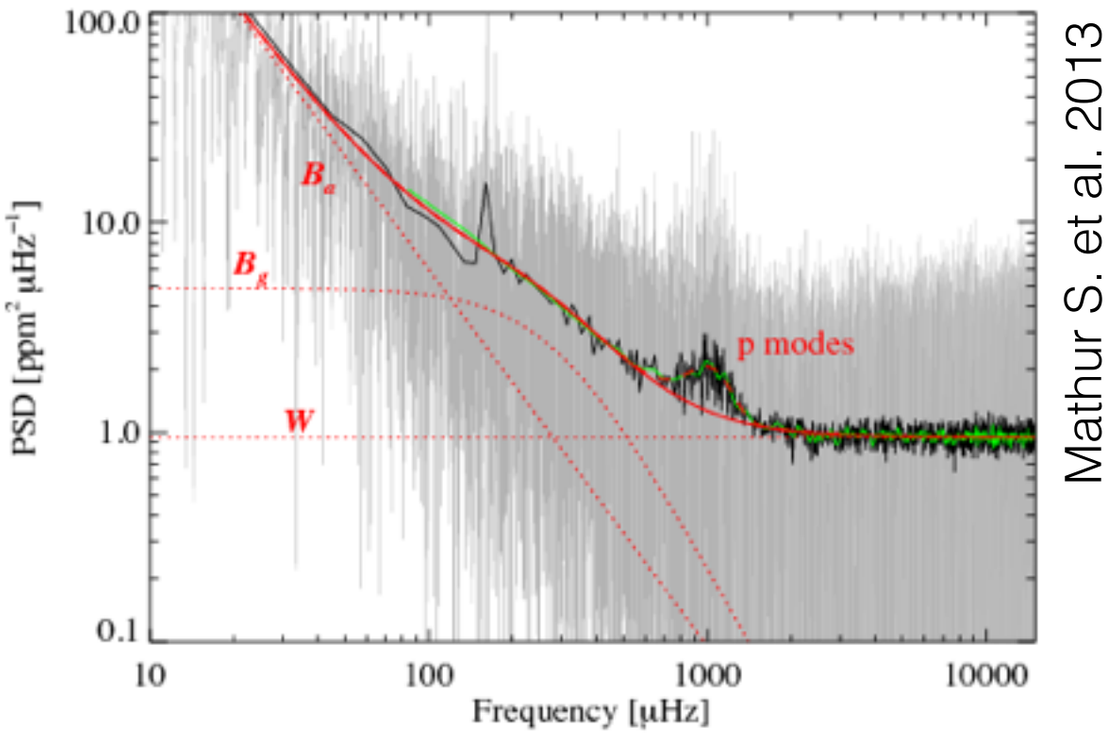

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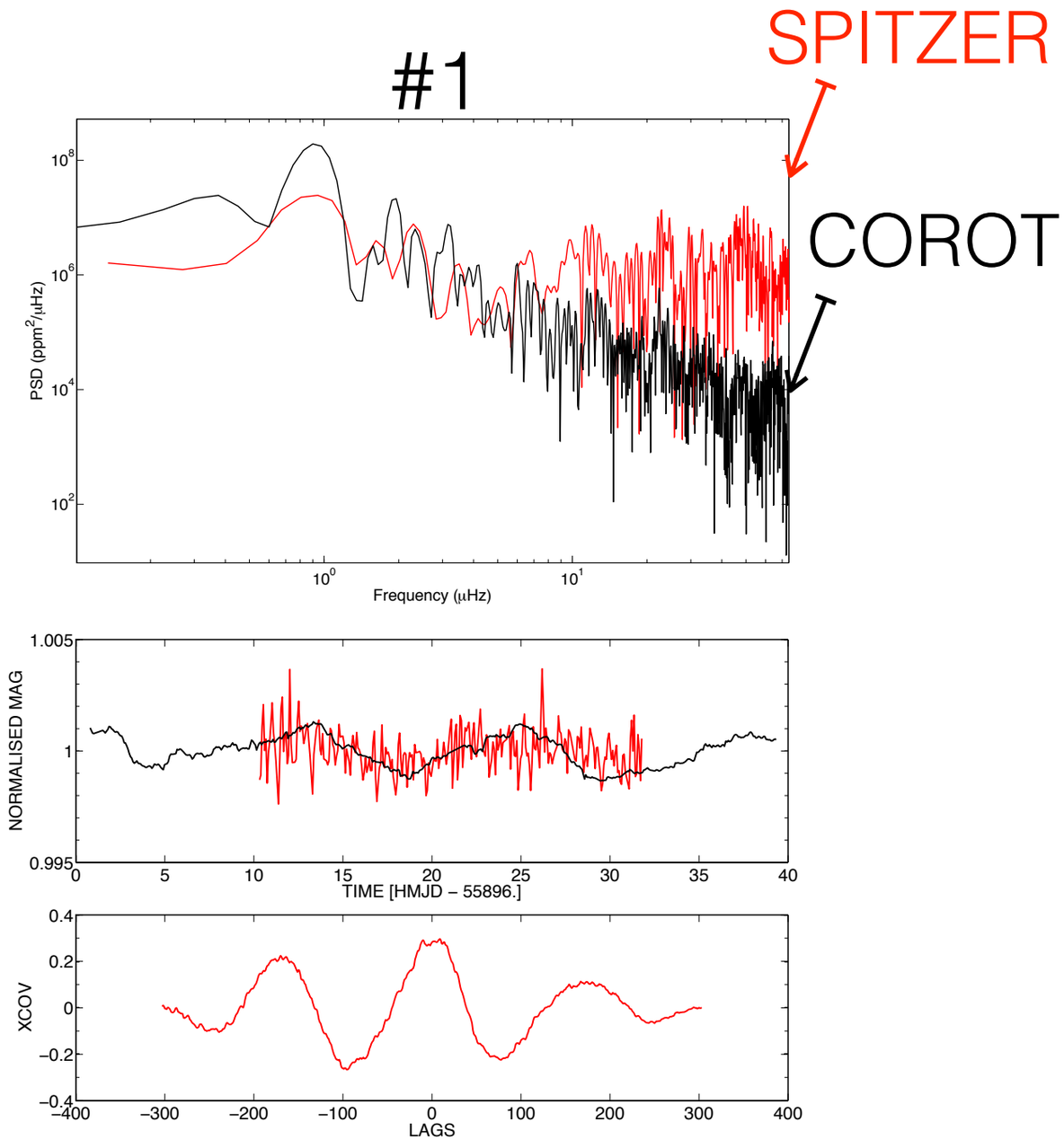

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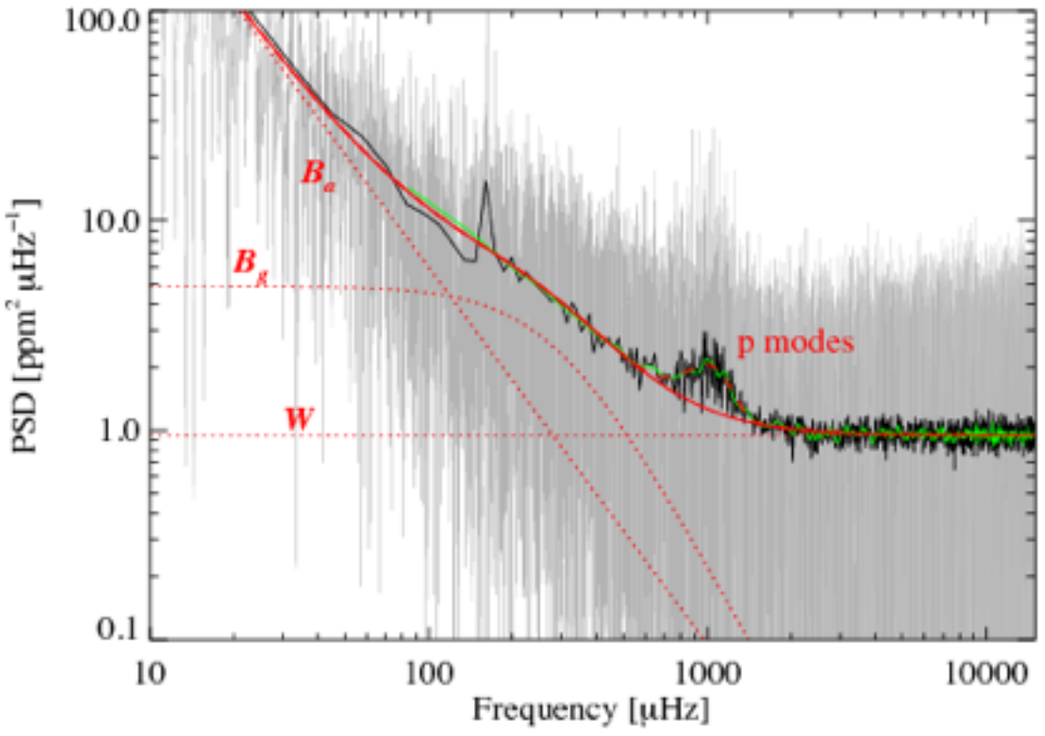

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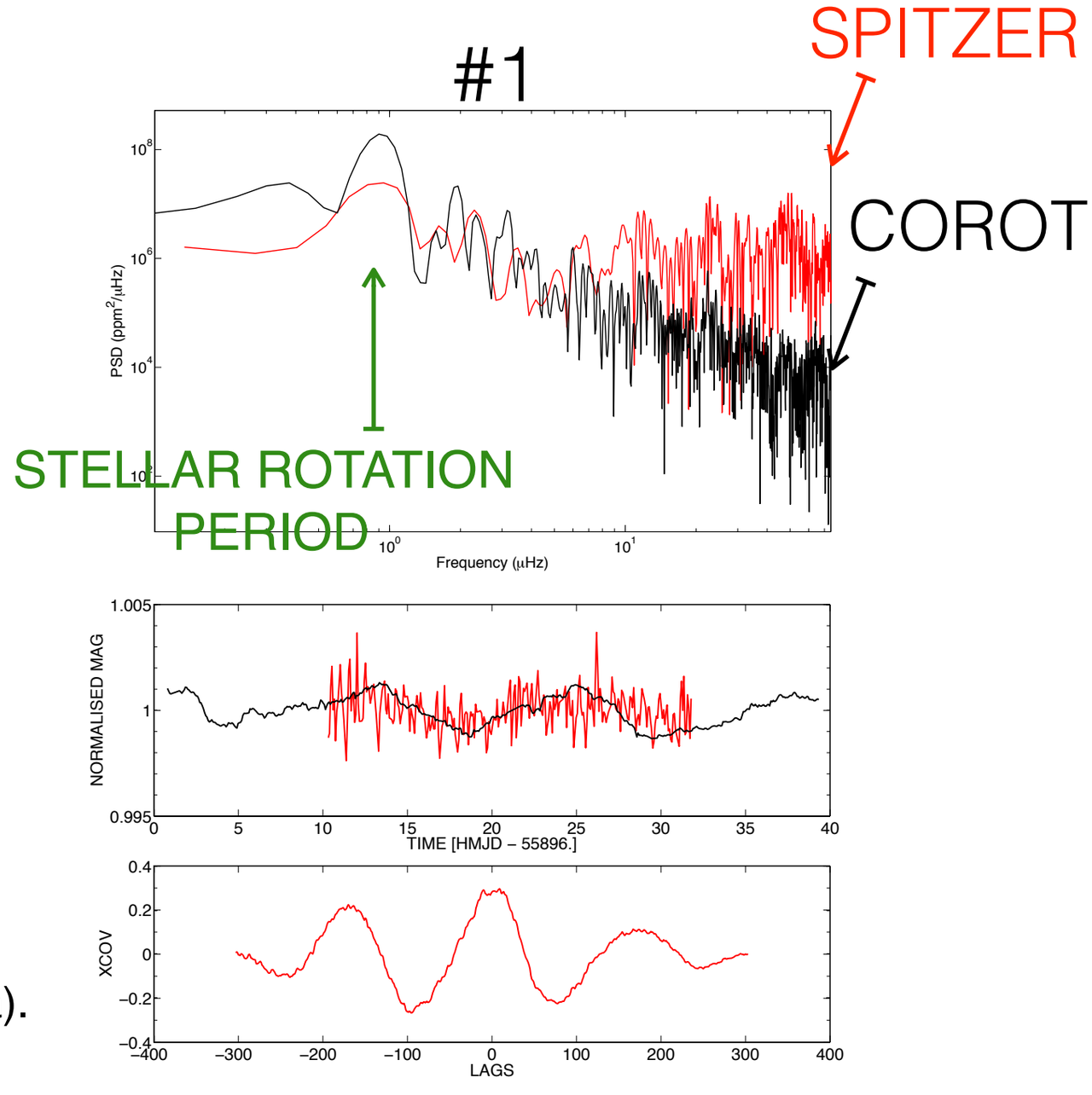
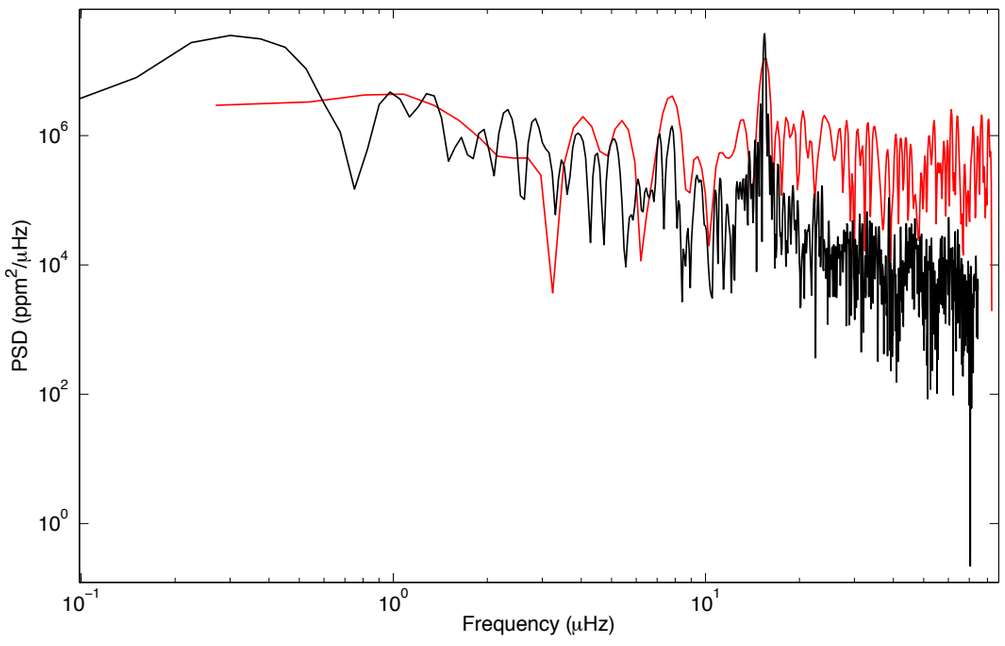
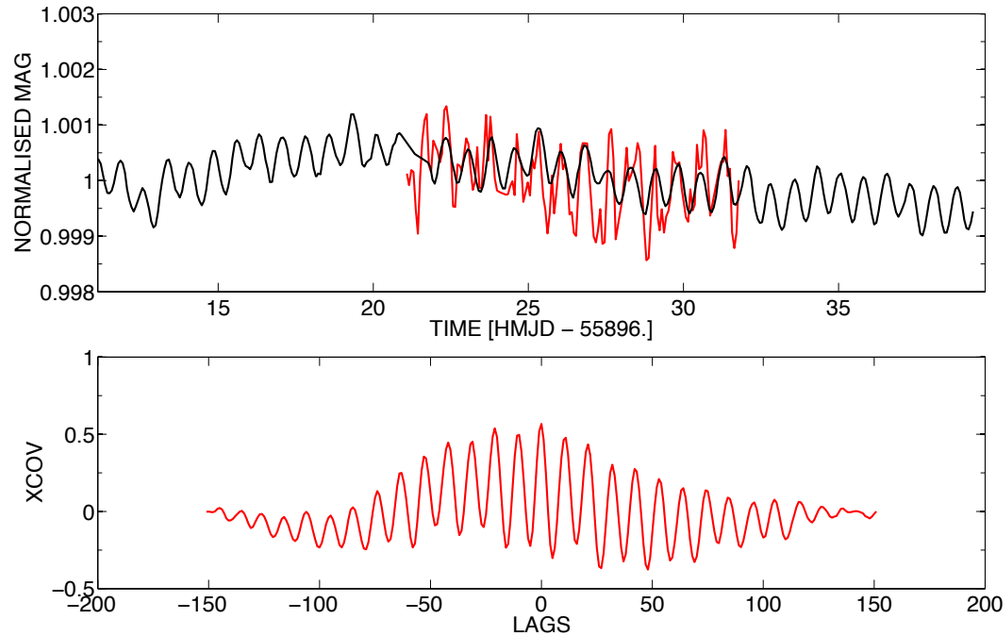
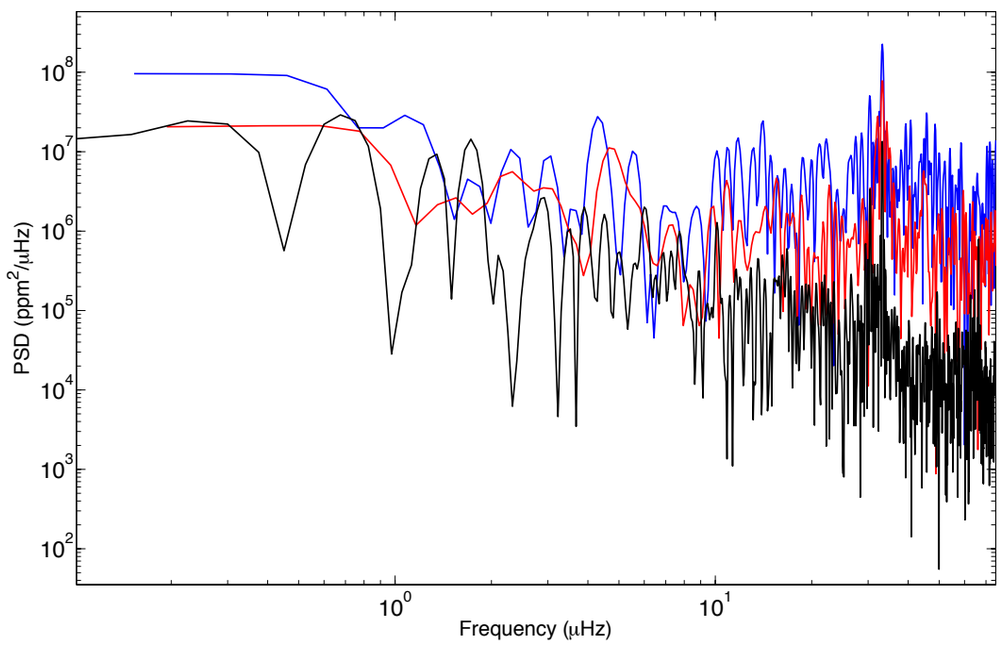


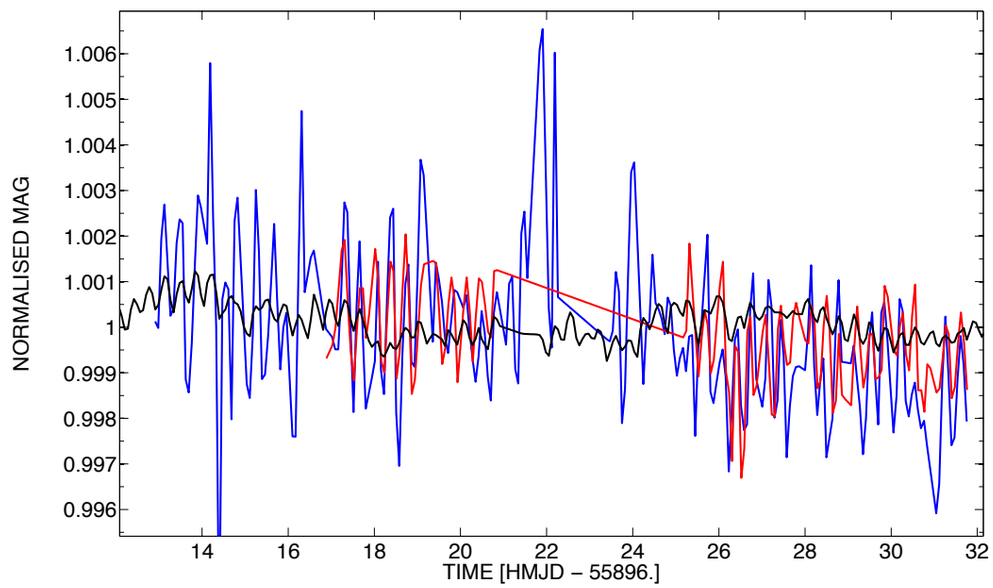
#2


PSD (ppm²/μHz)
Frequency (μHz)


NORMALISED MAG
TIME [HMJD – 55896.]
XCOV
LAGS

#3


PSD (ppm²/μHz)
Frequency (μHz)


NORMALISED MAG
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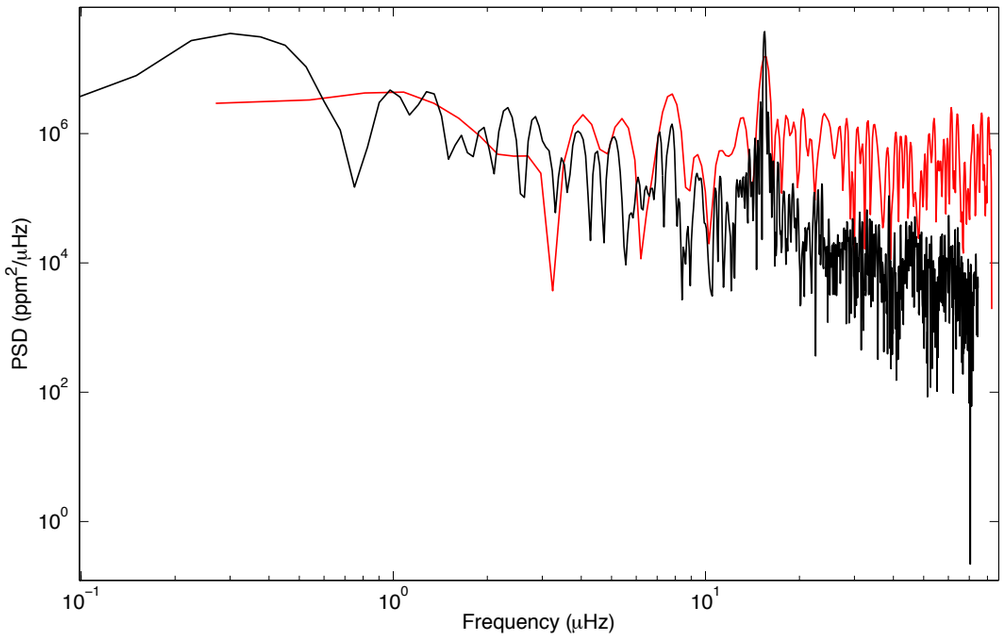

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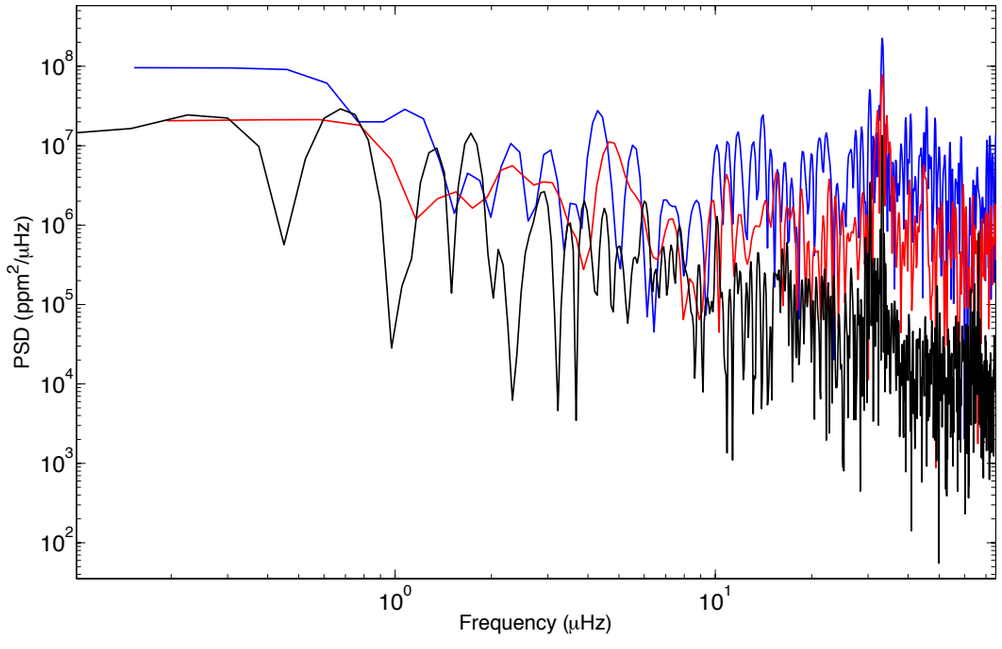
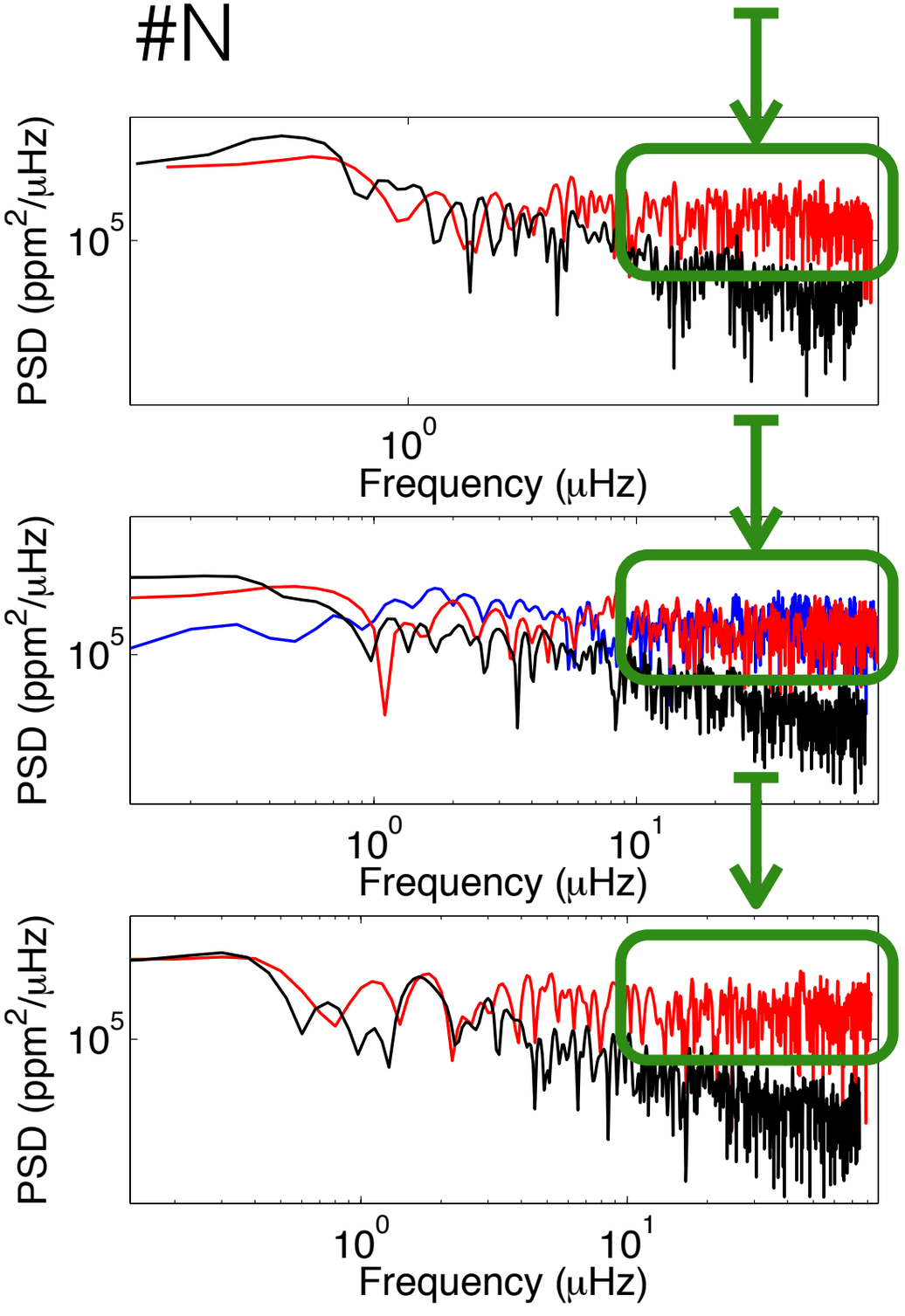


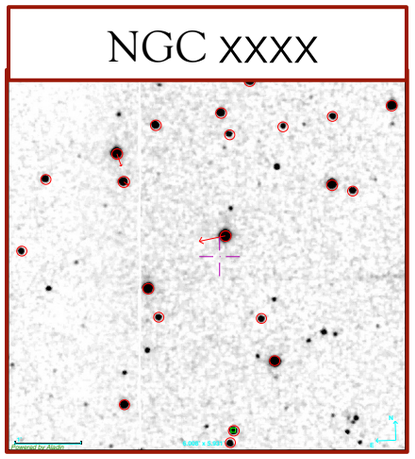
ALIASING PROBLEM

#N



- Frequency > 20 μHz (i.e.13.88 hours)

TIME-SCALE OF A TRANSIT (~ 10hours)



Observational Proposal
@Liverpool Télescope
(visible and IR)

ALIASING PROBLEM

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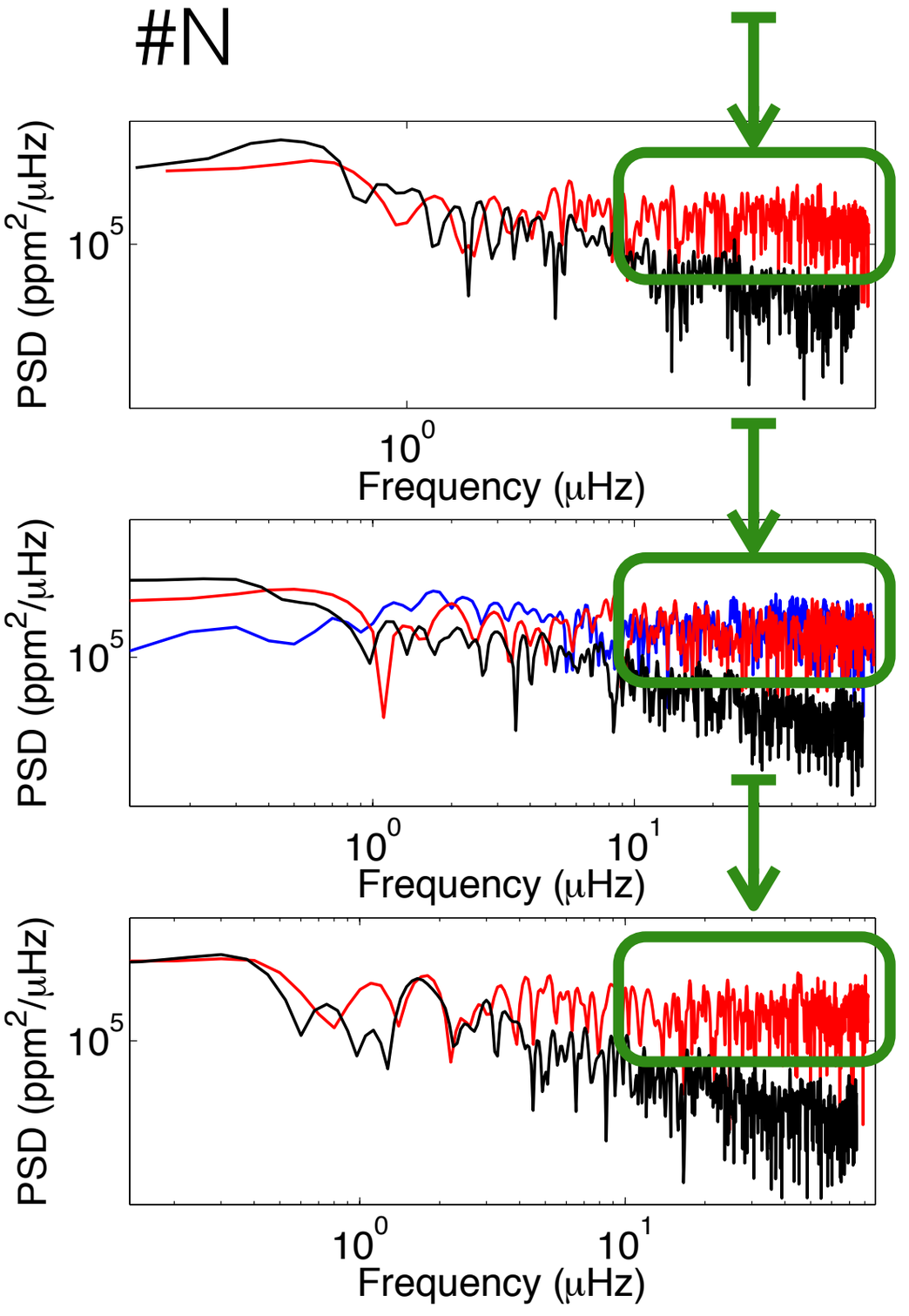

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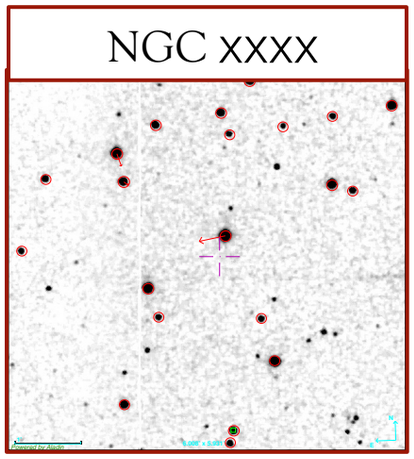

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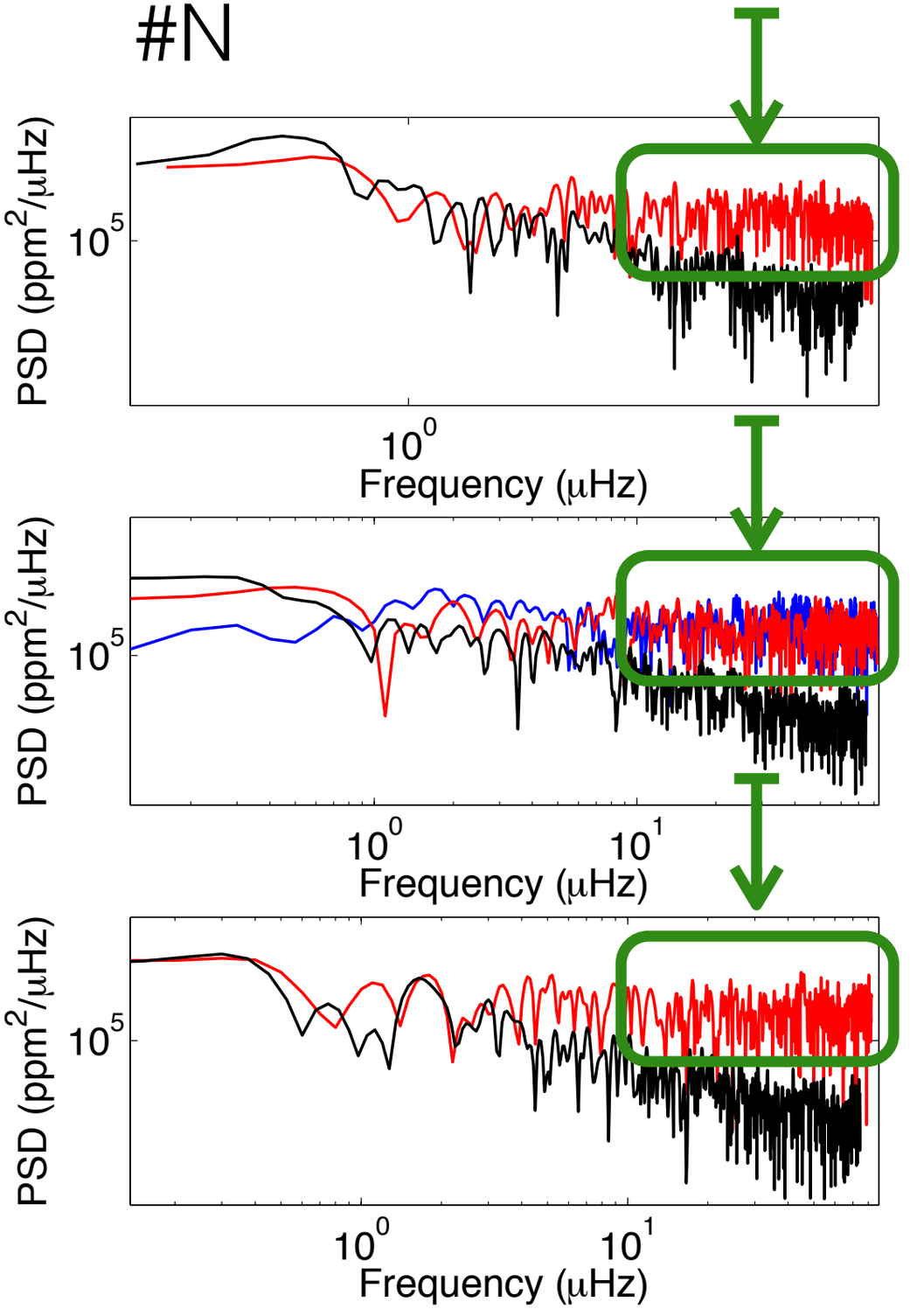
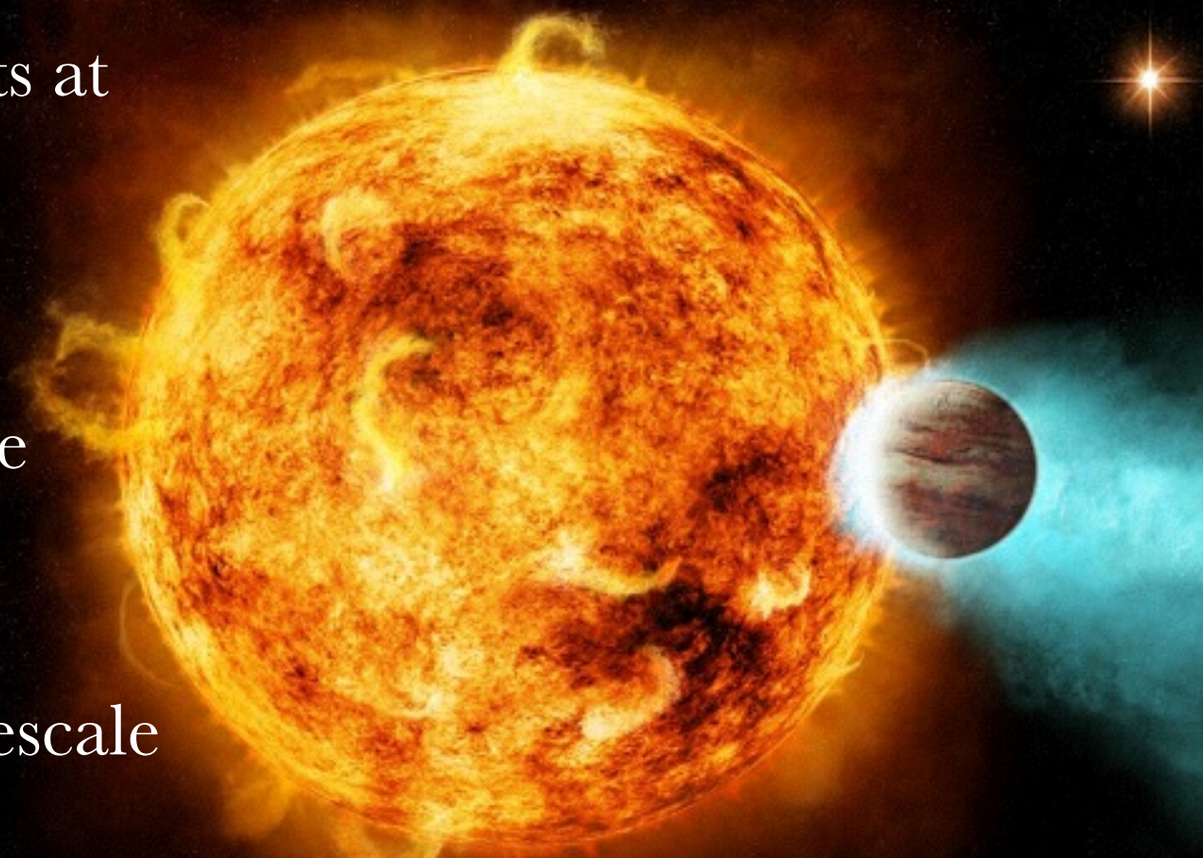
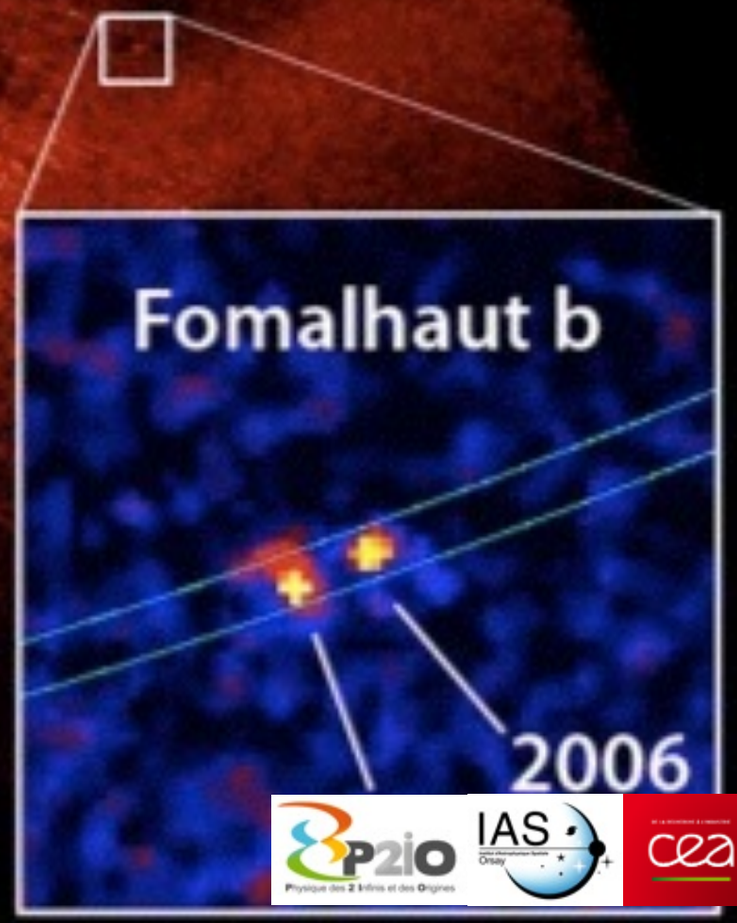


Summary part 1

- Important study for JWST, EChO(ESA / M3), ARIEL (ESA / M4)
- Correlations are detected in some targets at both low and high frequencies.
- However, it is not possible to generalise a level of correlation as a function of the stellar spectral class or the magnitude.
- Simultaneous observations over the timescale $t < 10$ hours are needed.
- The presence of correlations at low frequencies (i.e. $t > 1$ day) means that, when we observe the infrared phase curve of the planet, we need to be extremely careful and take into account the stellar variation.

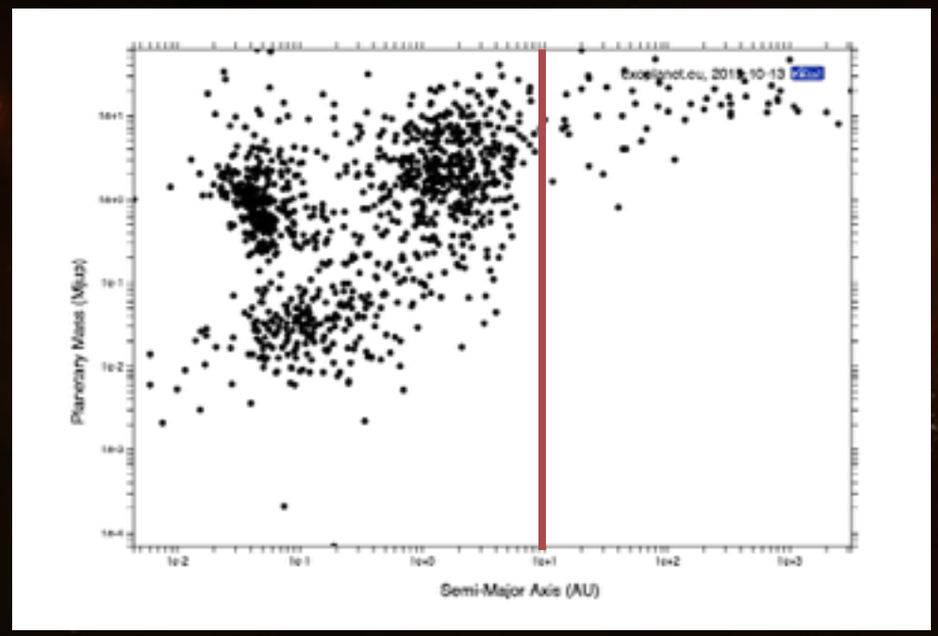


DIRECTLY IMAGED EXO-PLANETS



GIANT PLANETS: 10-100 Myr

have just formed, they had not time to cool down to their final equilibrium temperature.



Theoretical Models for early cooling and contraction are poorly constrained

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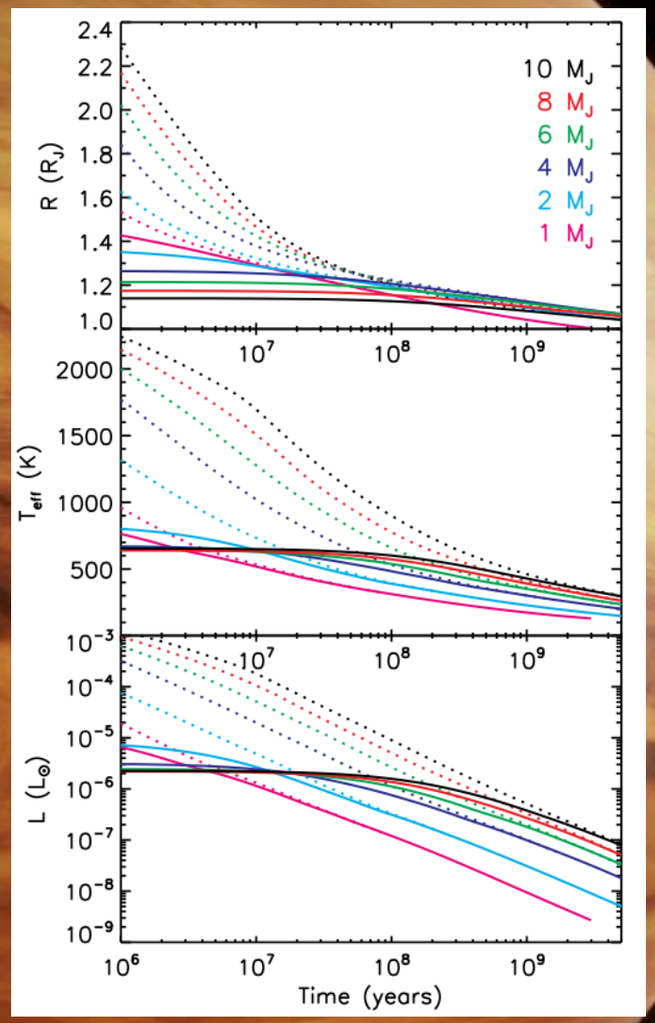

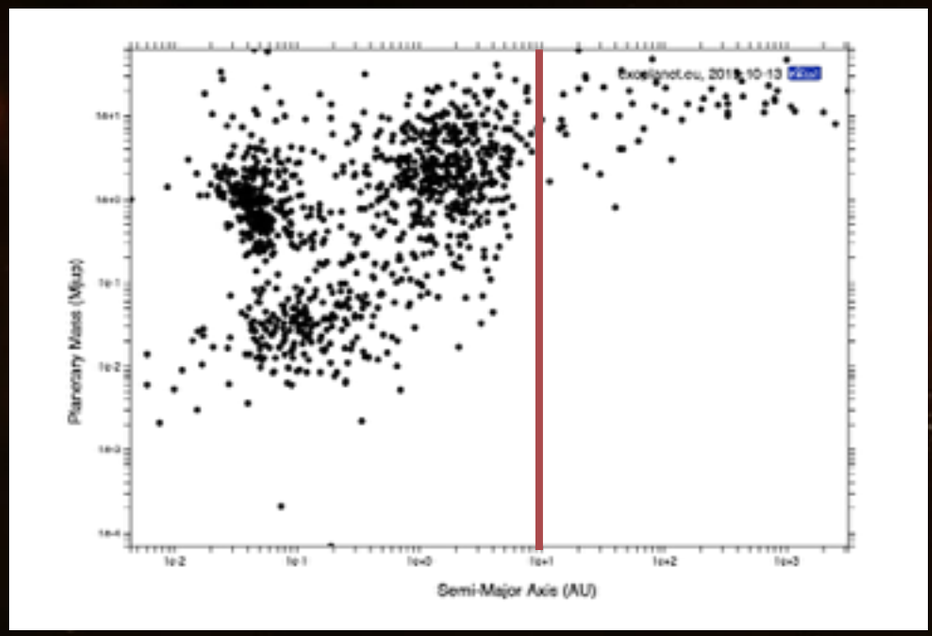

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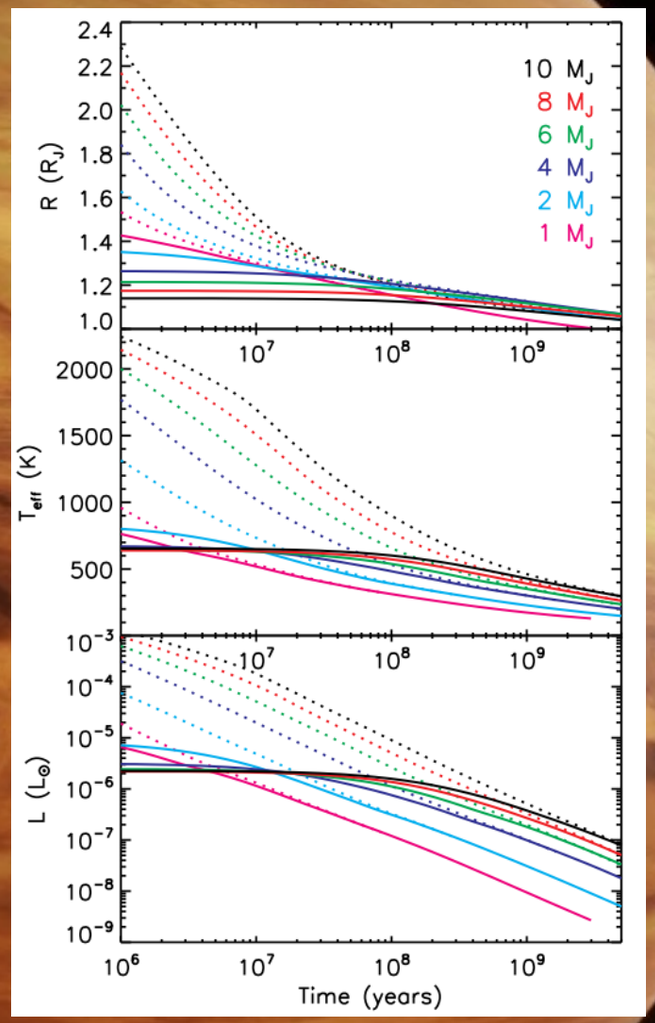
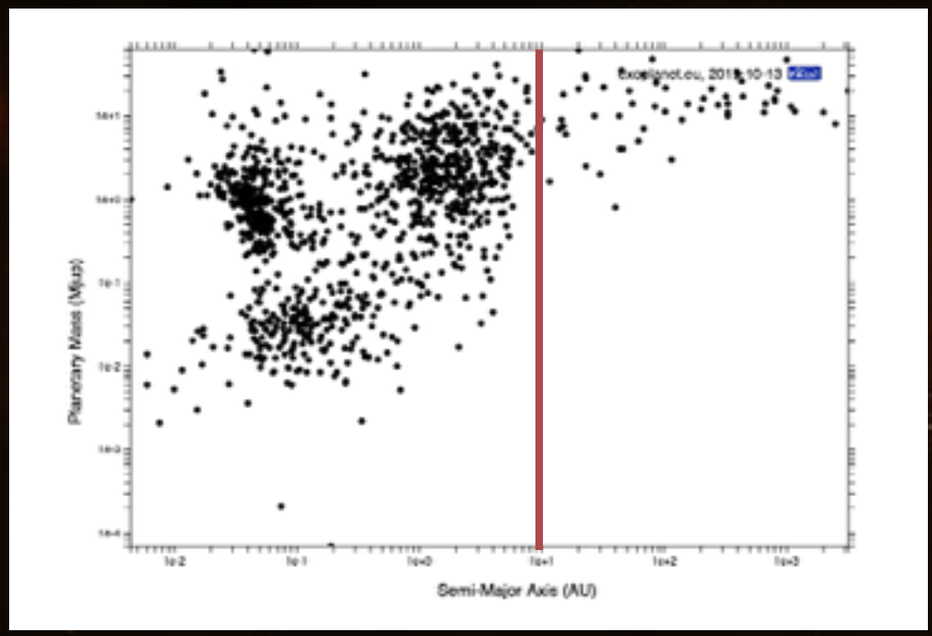




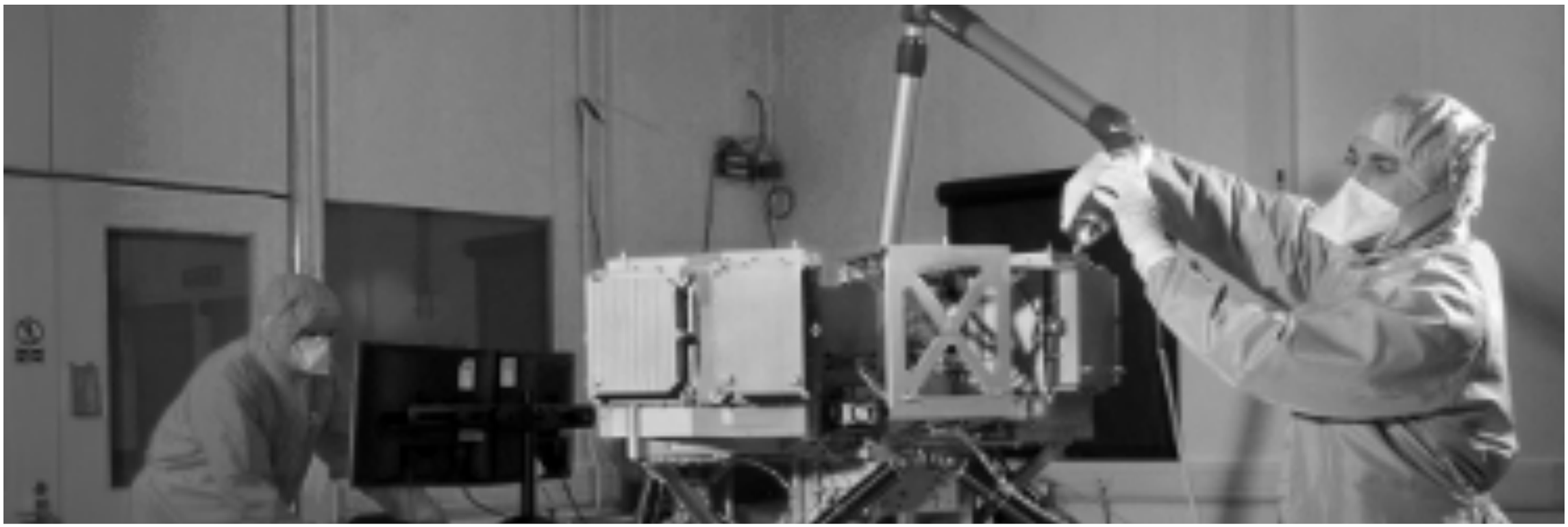
Theoretical Models for early cooling and contraction are poorly constrained

<u>NO observations MIRI wavelength range</u>

We apply a planetary model to see what MIRI can bring to the atmospheric characterisation.

JWST/MIRI

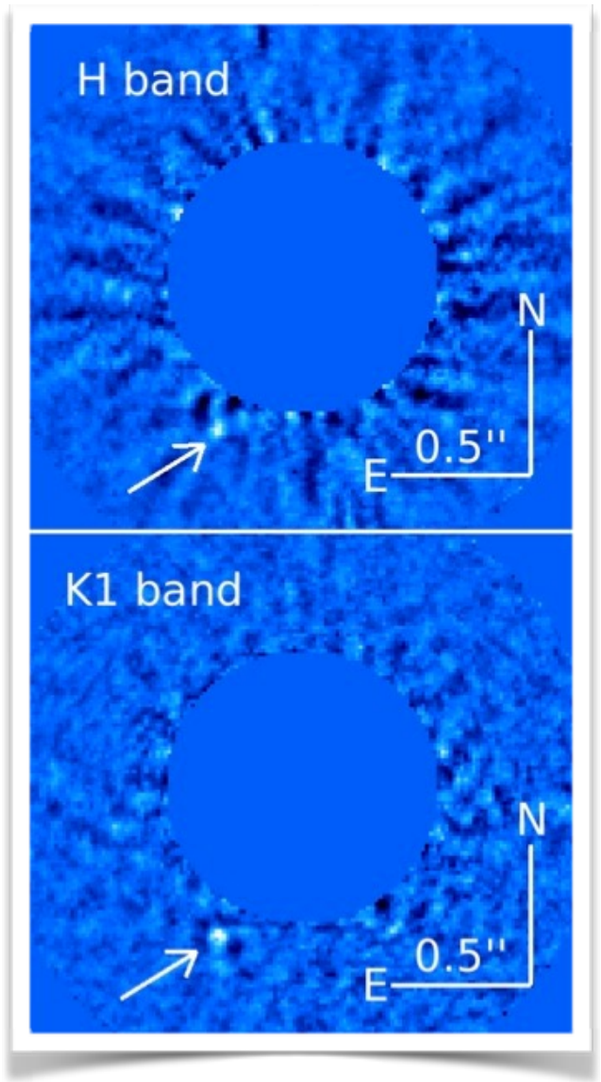
(5-28 MICRONS)



name	FOV	Wavelength Range (μm)	Spectral Properties
Diffraction-limited Imaging	$74'' \times 113''$	5.6 - 25.5	9 bands
Low Res. Spectroscopy	$0.''51 \times 4.''7$ slit	5 - 12	$\lambda/\Delta\lambda \sim 100$
Slitless Spectroscopy	$7.''9$ wide	5 - 12	$\lambda/\Delta\lambda \sim 100$
Phase Mask Coronagraphy	$24'' \times 24''$	10.65 - 15.5	3 bands
Lyot Coronagraphy	$30'' \times 30''$	23	one band
Medium Res. Spectroscopy	$3.''44 \times 3.''64$ IFU[a]	4.9 - 28.8	$\lambda/\Delta\lambda \sim 1500$ - 3500

HD 95086b

Near- IR



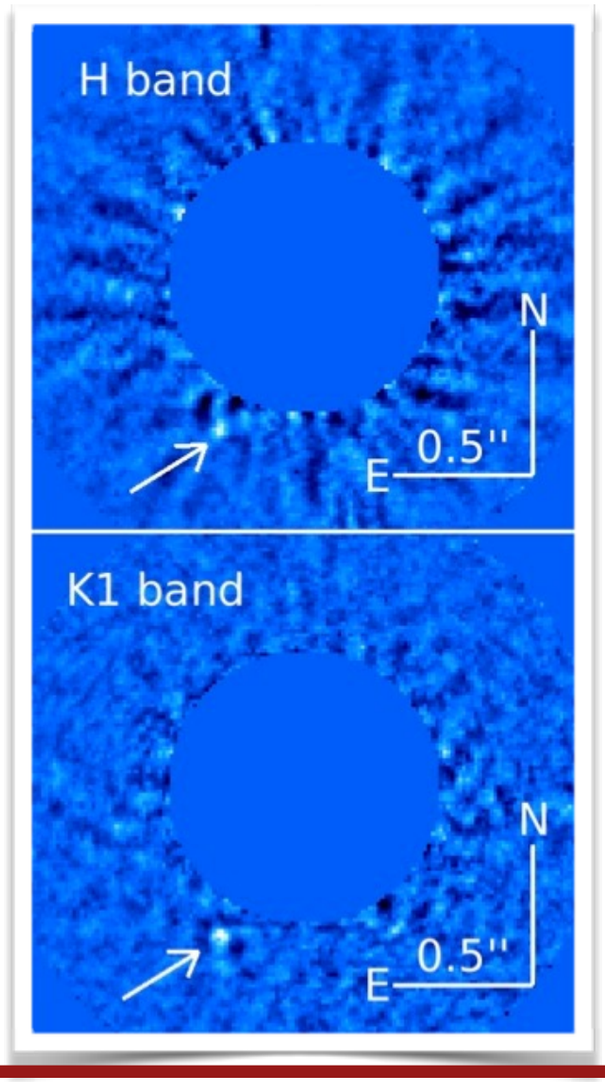
Galicher et al., 2014, GPI

600K ≤ Teff ≤ 1500K

2.1dex ≤ log(g) ≤ 4.5dex.

HD 95086b

Near- IR



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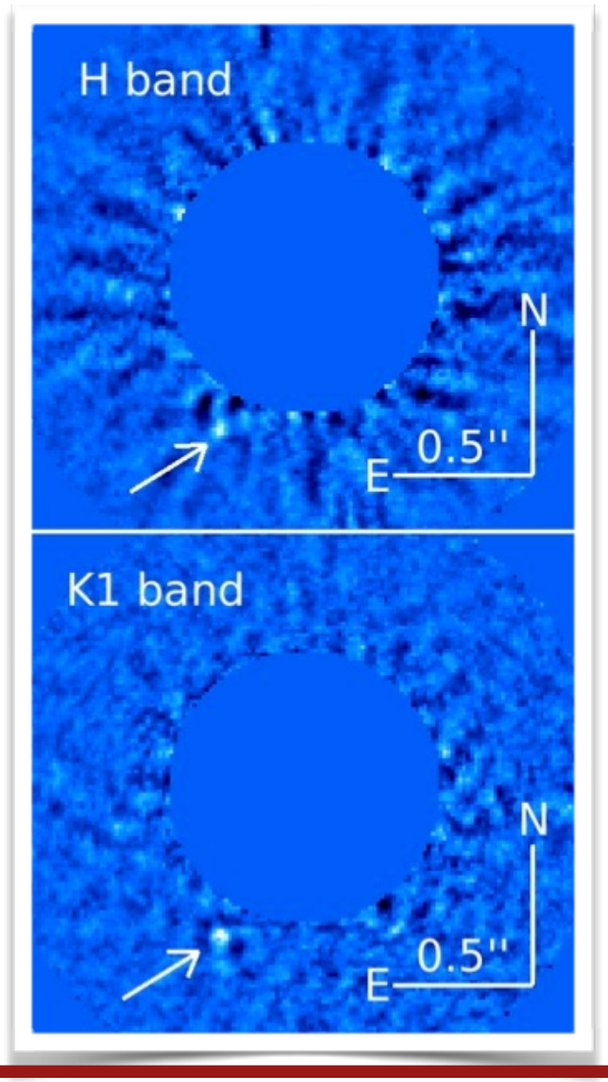

Galicher et al., 2014, GPI

What can we achieve with MIRI?

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HD 95086b

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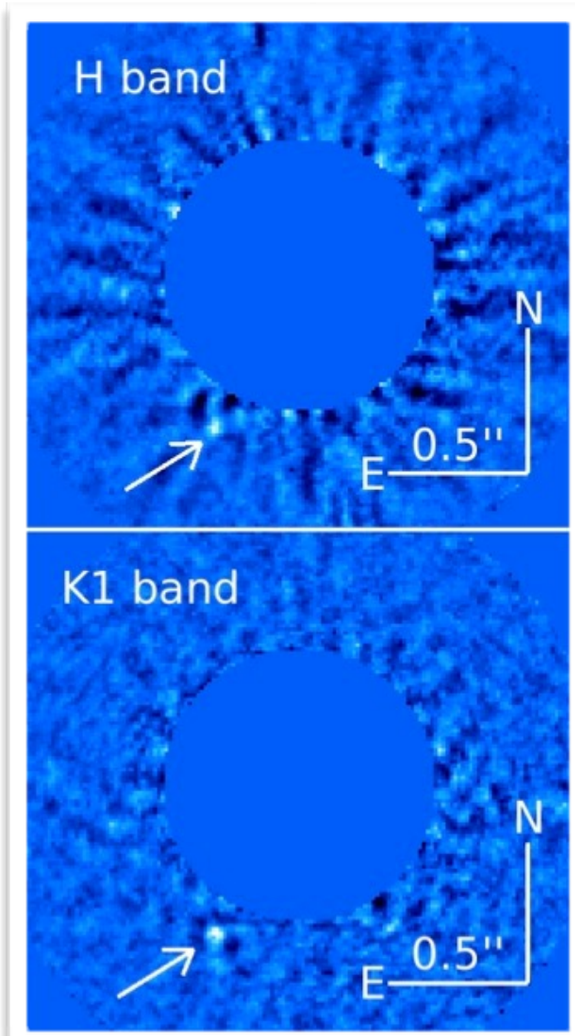

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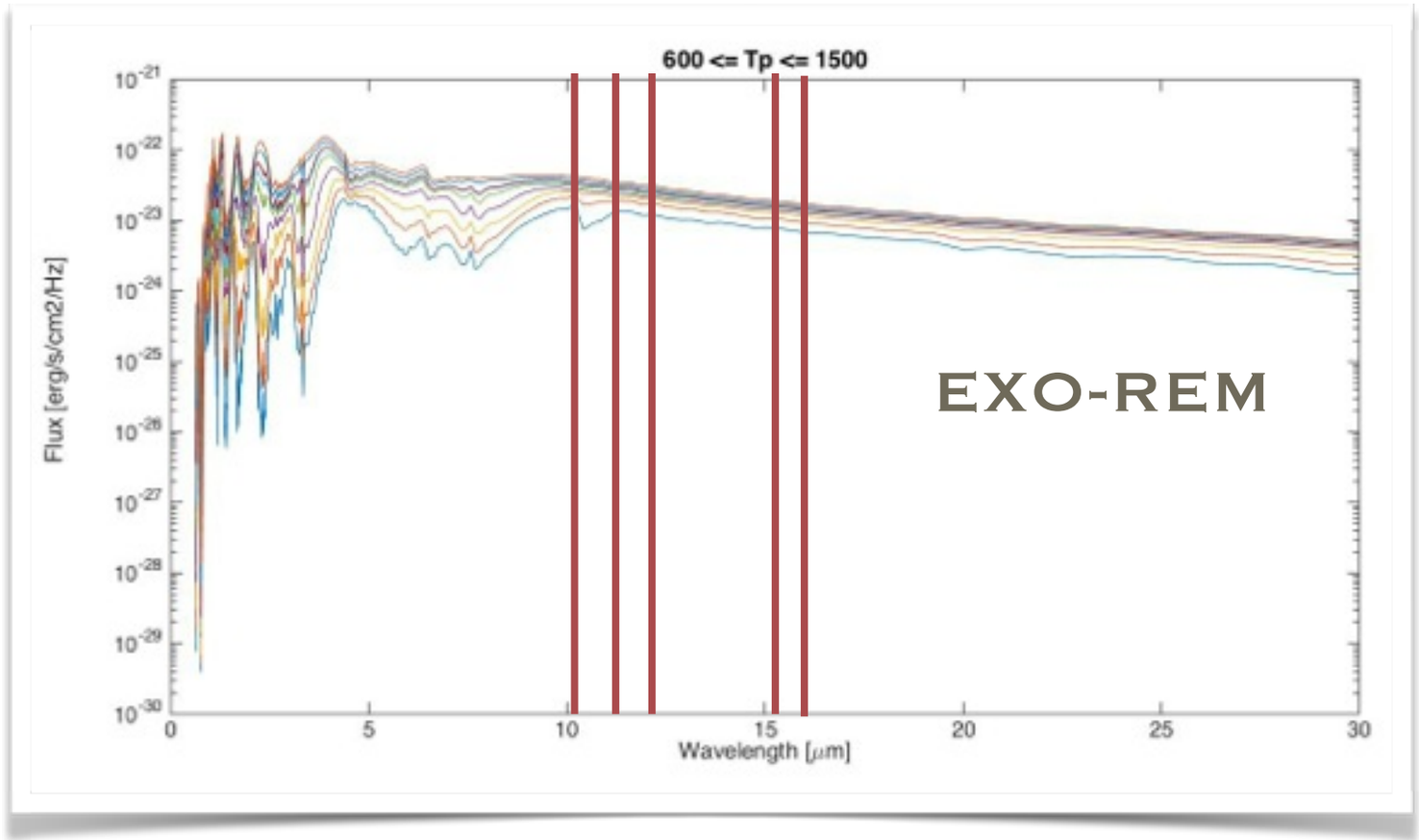
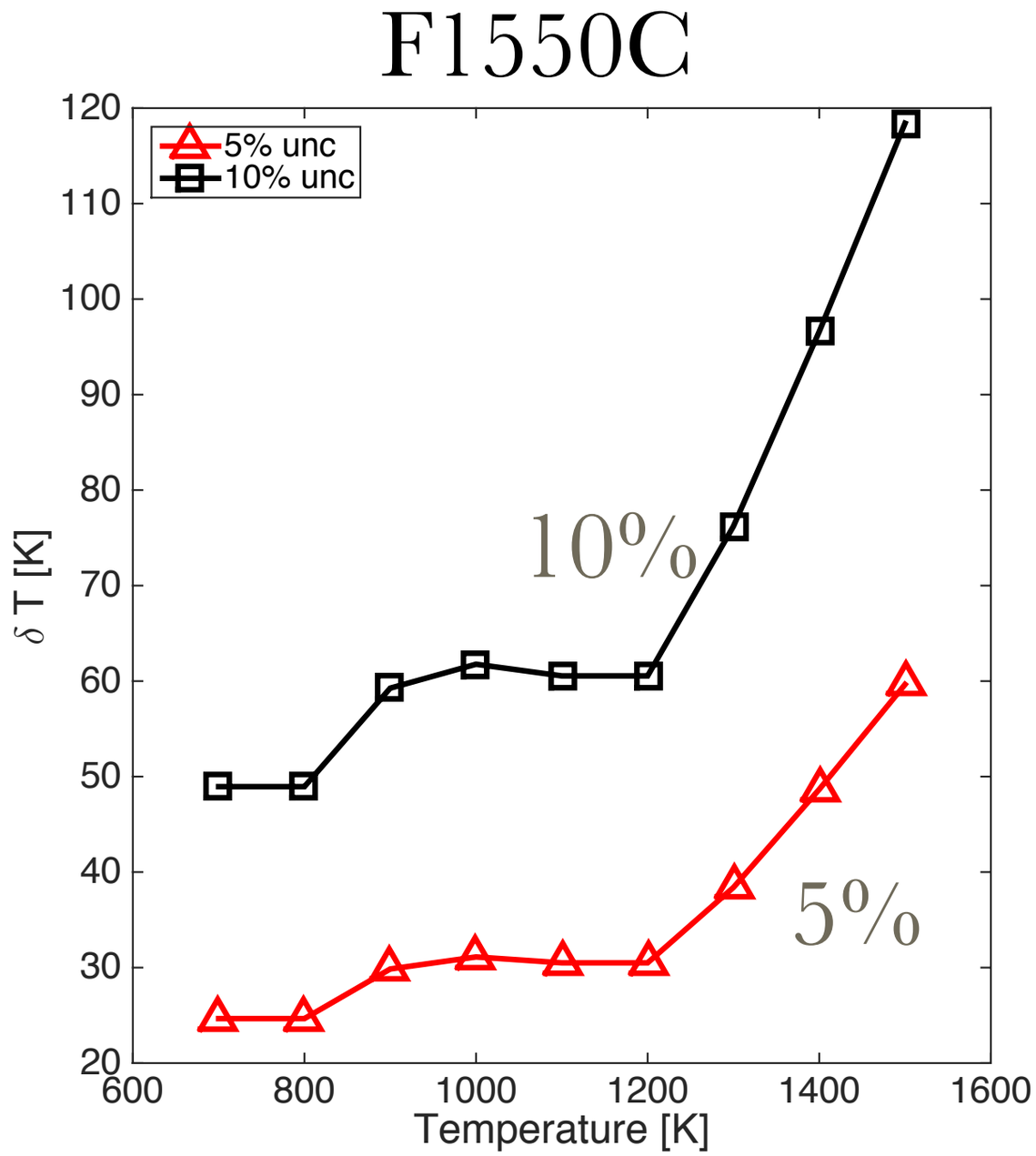


Filter	Corono	stop	bandwidth (μm)
F1065C	4QPM_1	62%	0.53
F1140C	4QPM_2	62%	0.57
F1550C	4QPM_3	62%	0.78

600K ≤ Teff ≤ 1500K

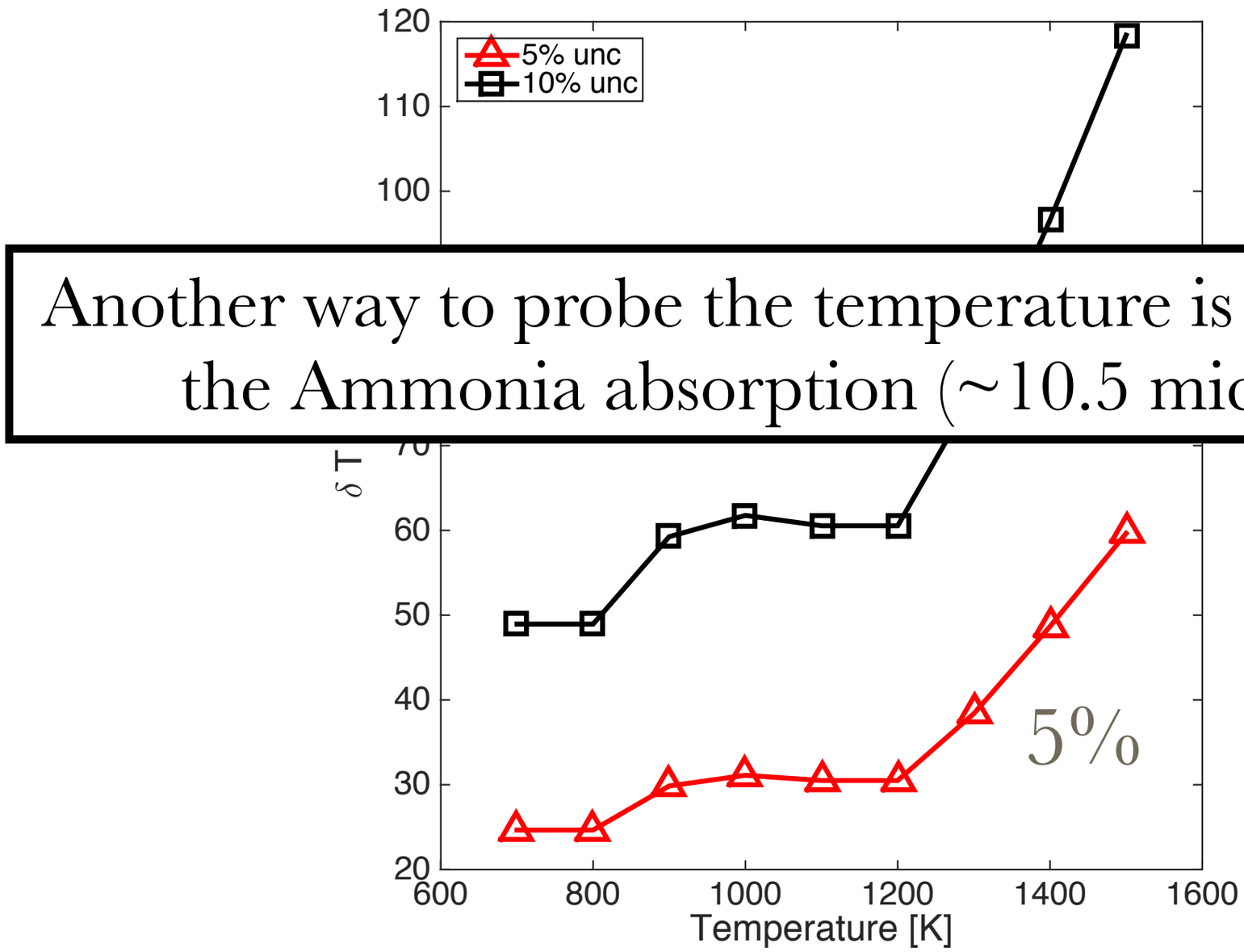
2.1dex ≤ log(g) ≤ 4.5dex.

HD 95086b TEMPERATURE Accuracy with NIR+MIRI observations



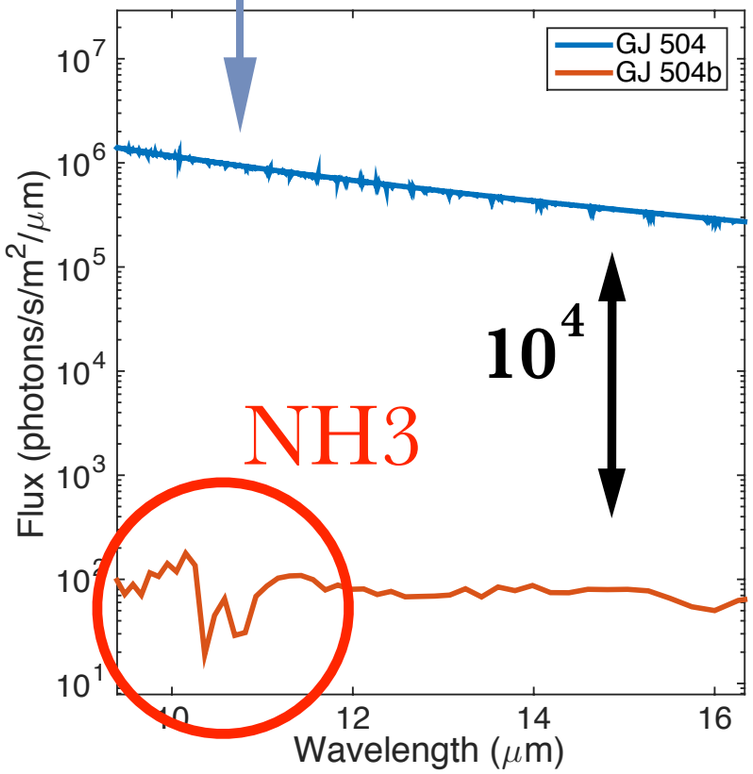
HD 95086b TEMPERATURE ACCURACY WITH NIR+MIRI OBSERVATIONS

F1550C

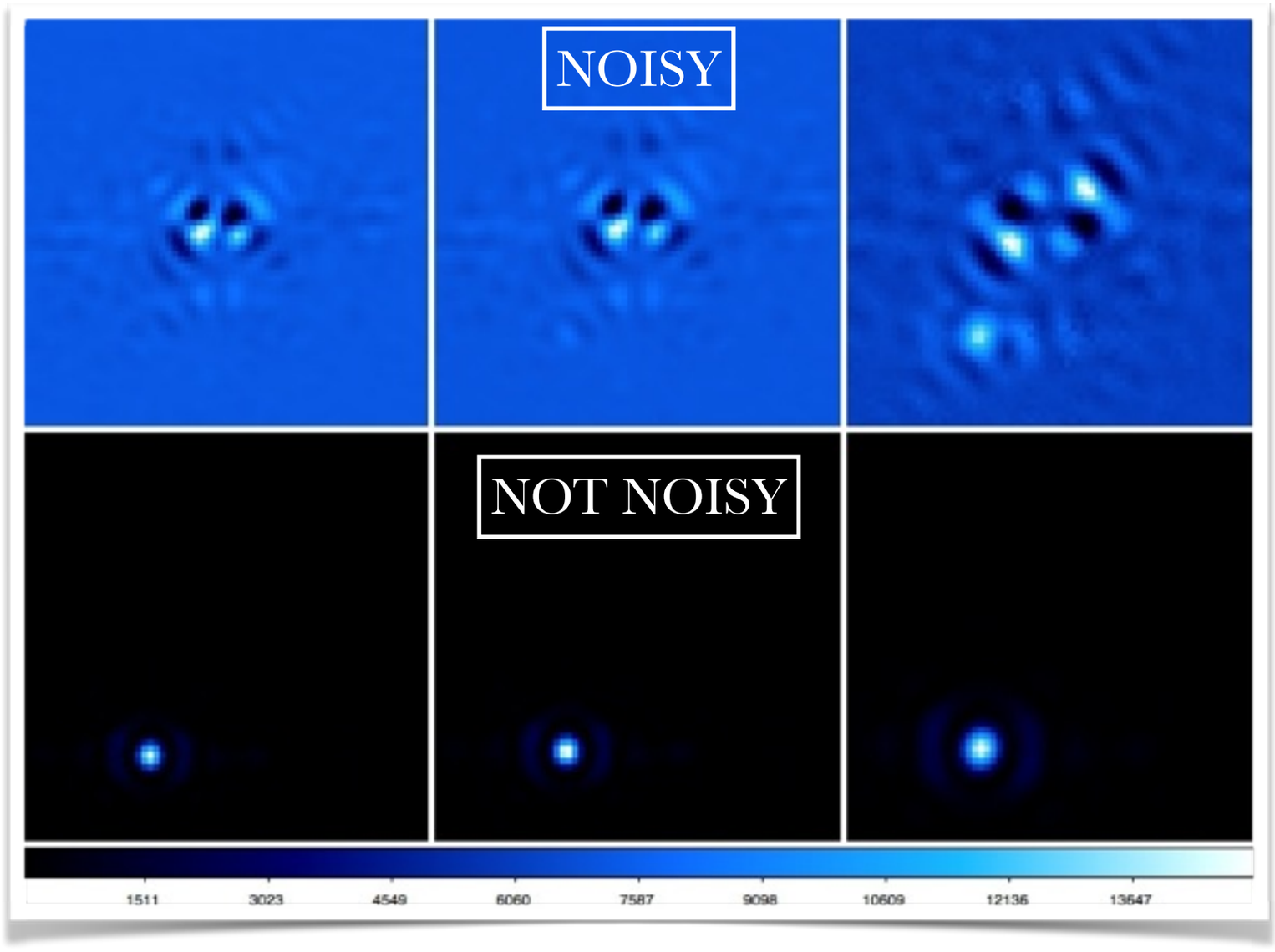


Another way to probe the temperature is measuring the Ammonia absorption (~10.5 microns).

PHOENIX
stellar model

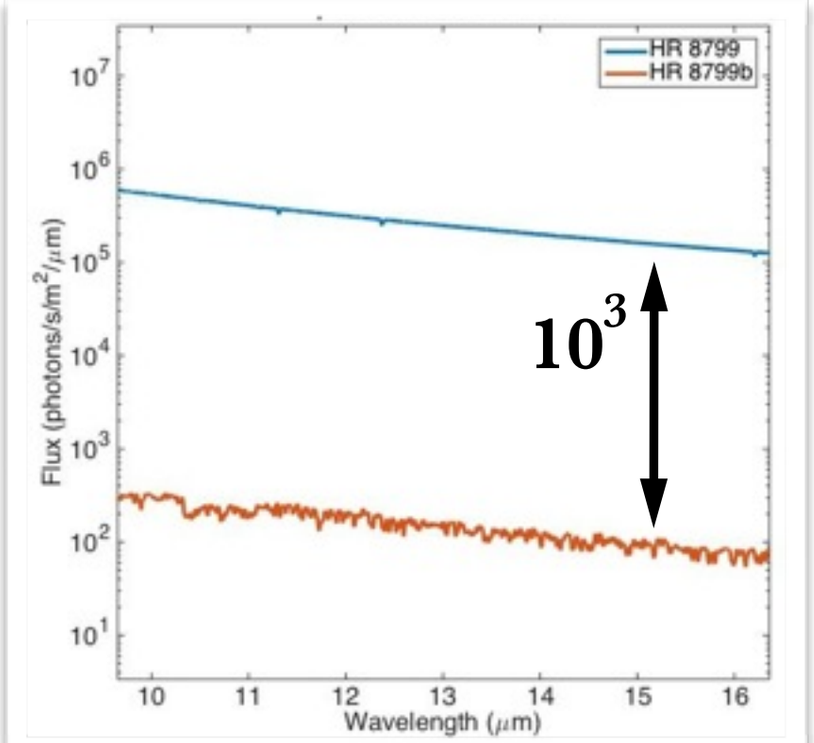


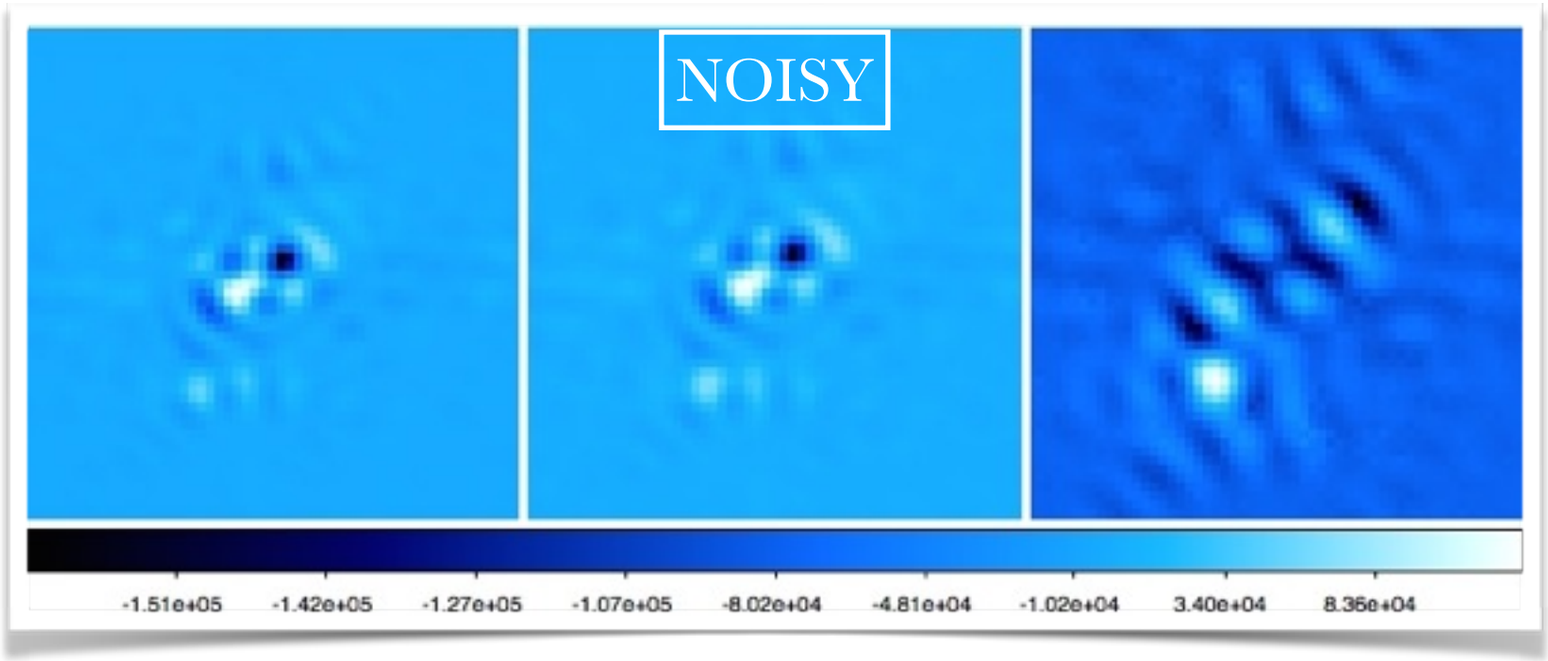
GJ 504b



$M_P = 4\ M_J$
$R_P = NA$
$T_P = 500\ K$
$T_S = 6234\ K$
$M_K = 4.033$
d = 2”.48

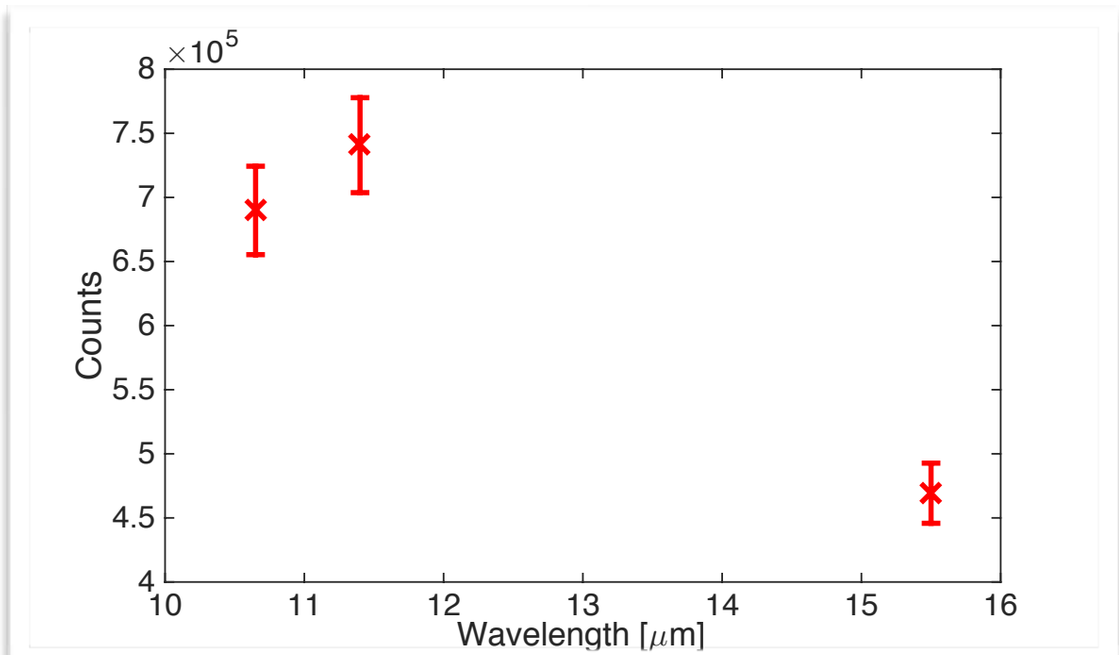
HR 8799b



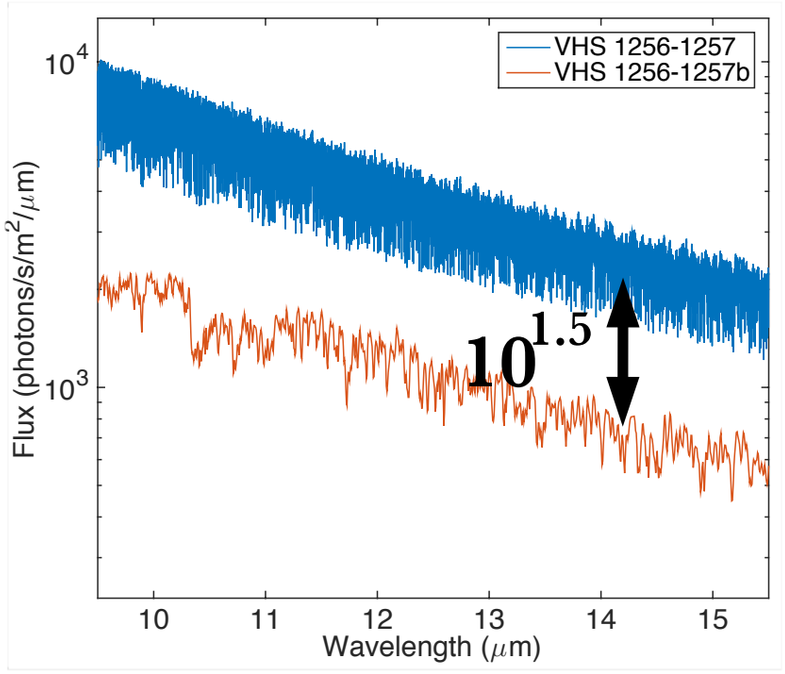


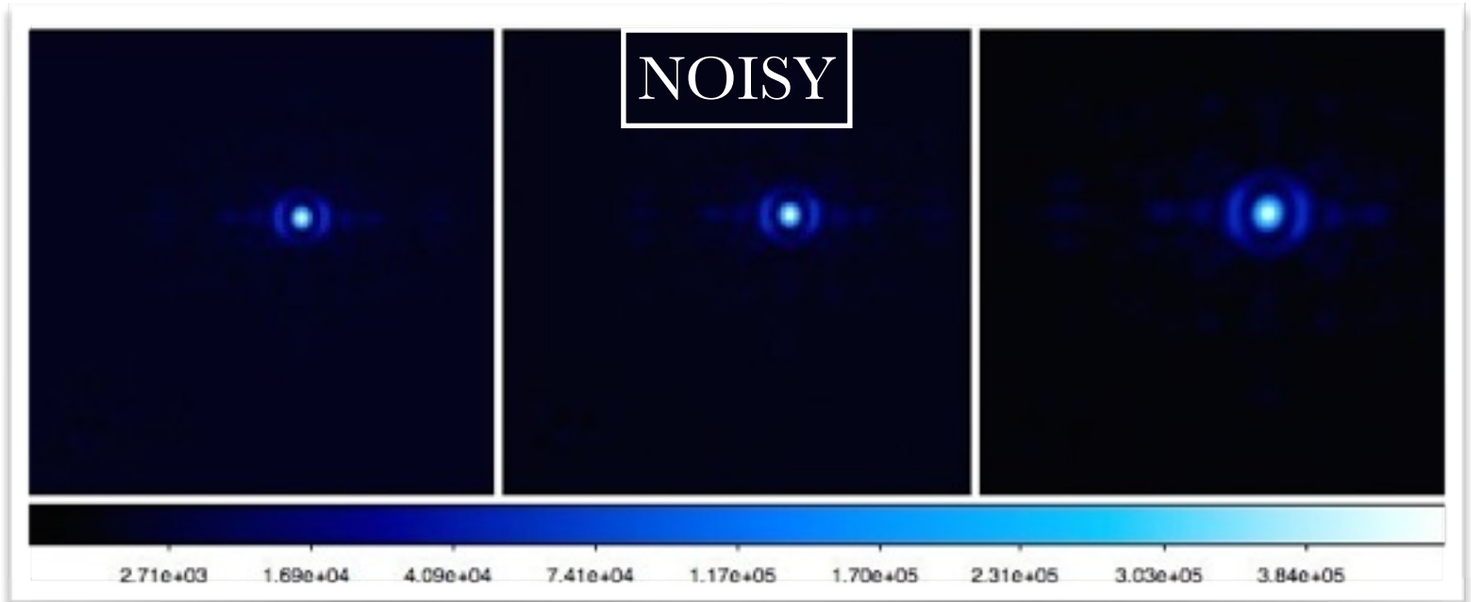
$M_P = 7\ M_J$
$R_P = 1.2\ RJ$
$T_P = 900\ K$
$T_S = 7430\ K$
$M_K = 5.24$
d = 1”.72

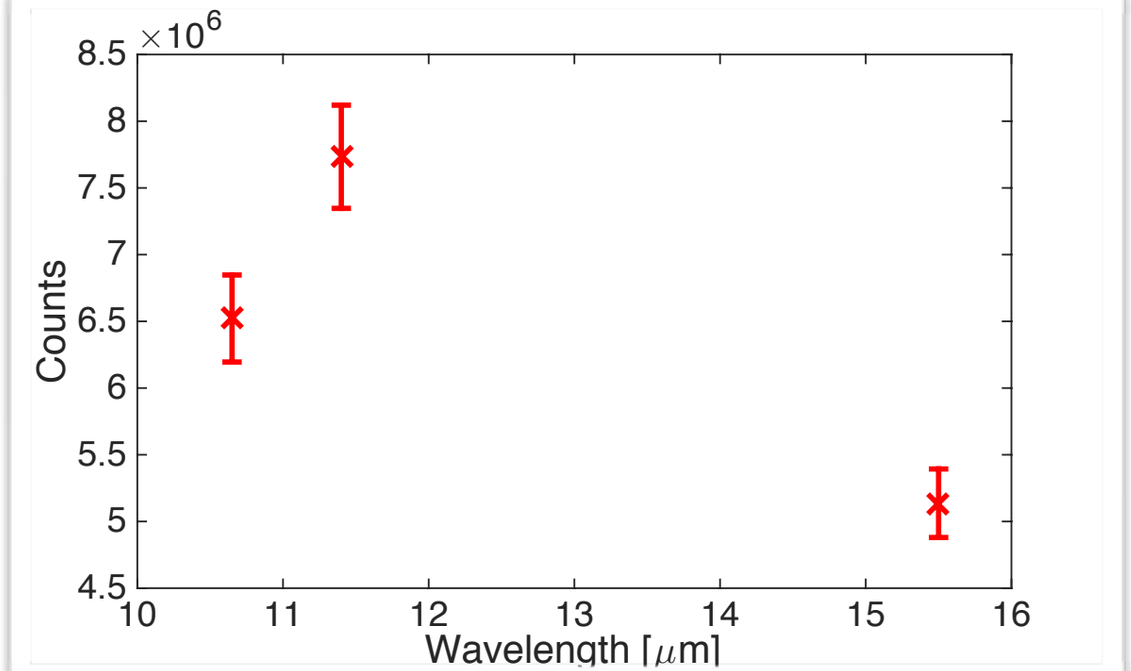
APERTURE PHOTOMETRY



VHS 1256b







$M_P = 11.2\ M_J$

$R_P = NA$

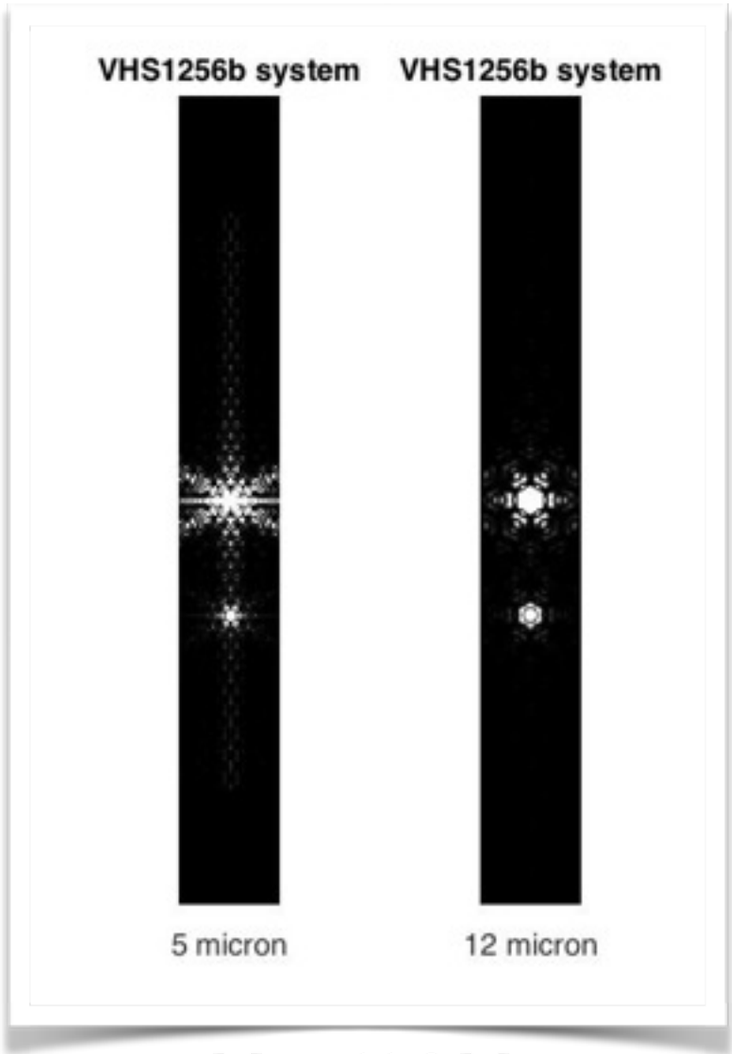
$T_P = 880\ K$

$T_S = 2620\ K$

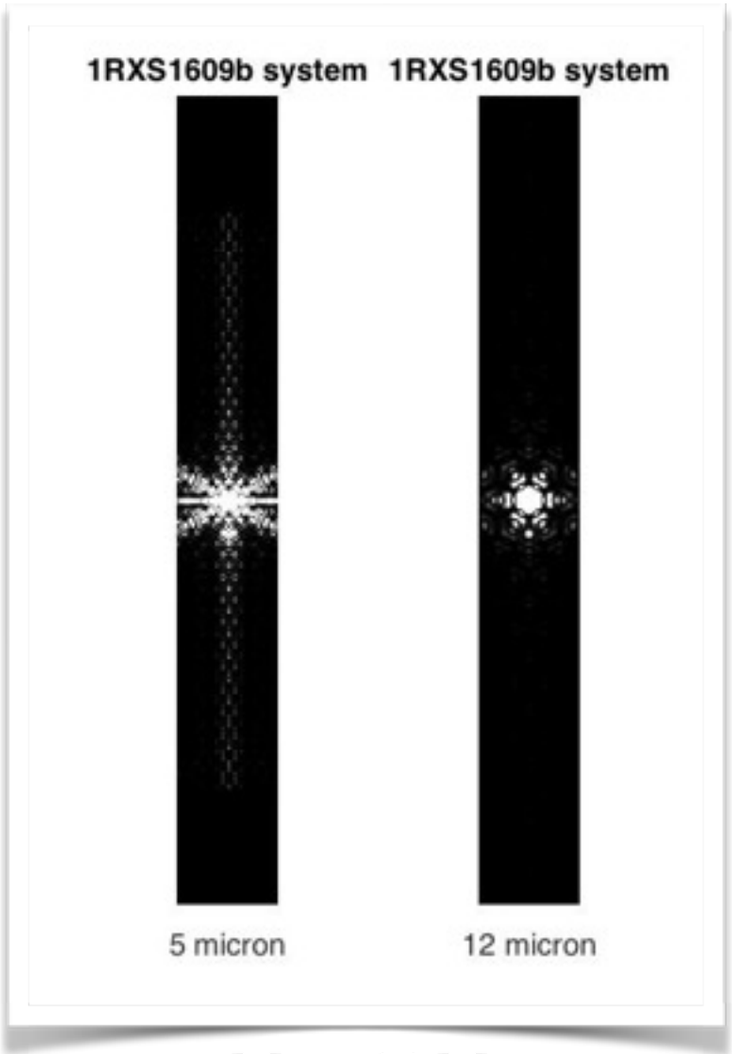
$M_K = 10.044$

d = 8”.06

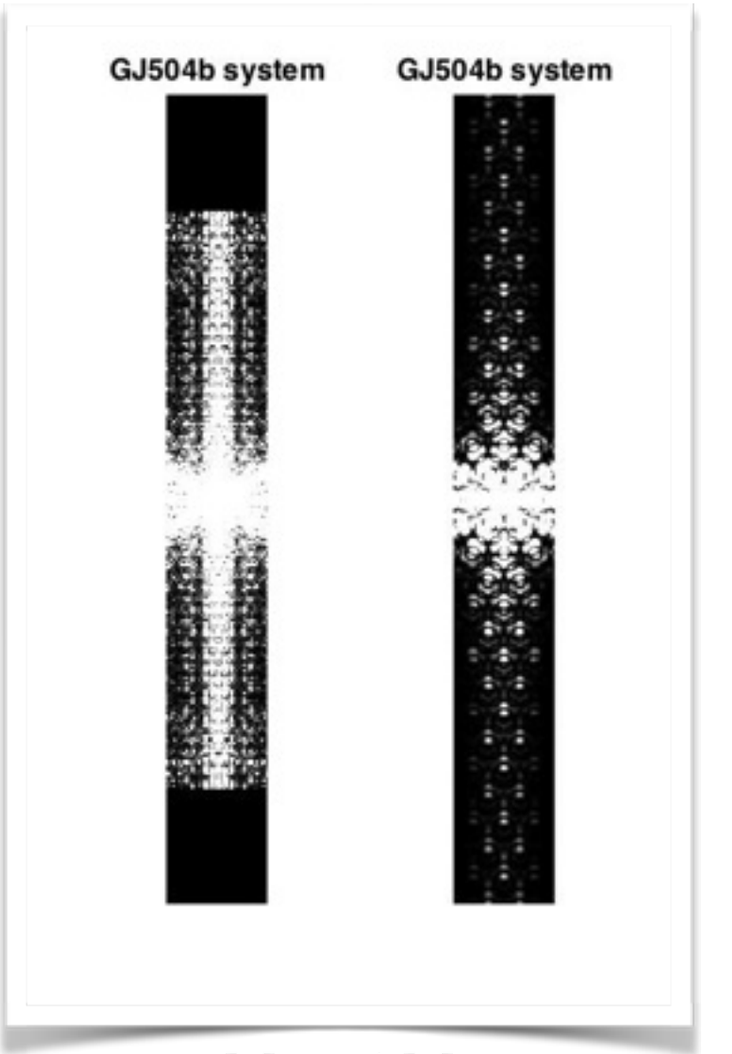
PSF



$M_P = 11.2\ M_J$
$R_P = NA$
$T_P = 880$ K
$T_S = 2620$ K
$M_K = 10.044$
d = 8”.06



$M_P = 14\ M_J$
$R_P = 1.7\ R_J$
$T_P = 1800$ K
$T_S = 4060$ K
$M_K = 8.92$
d = 2”.27



$M_P = 4\ M_J$
$R_P = NA$
$T_P = 500$ K
$T_S = 6234$ K
$M_K = 4.033$
d = 2”.48

Summary part 2

- MIRI combined with NIR measurements, can constrain the planetary temperature down to 20K.
  > Better constrain the theoretical models
- We are using statistical procedures on the post process of the coronographic images, in order to get a better planetary signal to noise ratio.
- With MIRI we finally have the opportunity to probe NH3 in a planetary atmosphere (and we already know where to look for it!)
  In the process of measuring the significance of the NH3 detection for diverse planetary systems.
- Constraints for the planetary formation theories!

"A scientist naturally and inevitably (…) mulls over the data and guesses at a solution. He proceeds to testing of the guess by new data—predicting the consequences of the guess and then dispassionately inquiring whether or not the predictions are verified"

- Edwin Powell Hubble