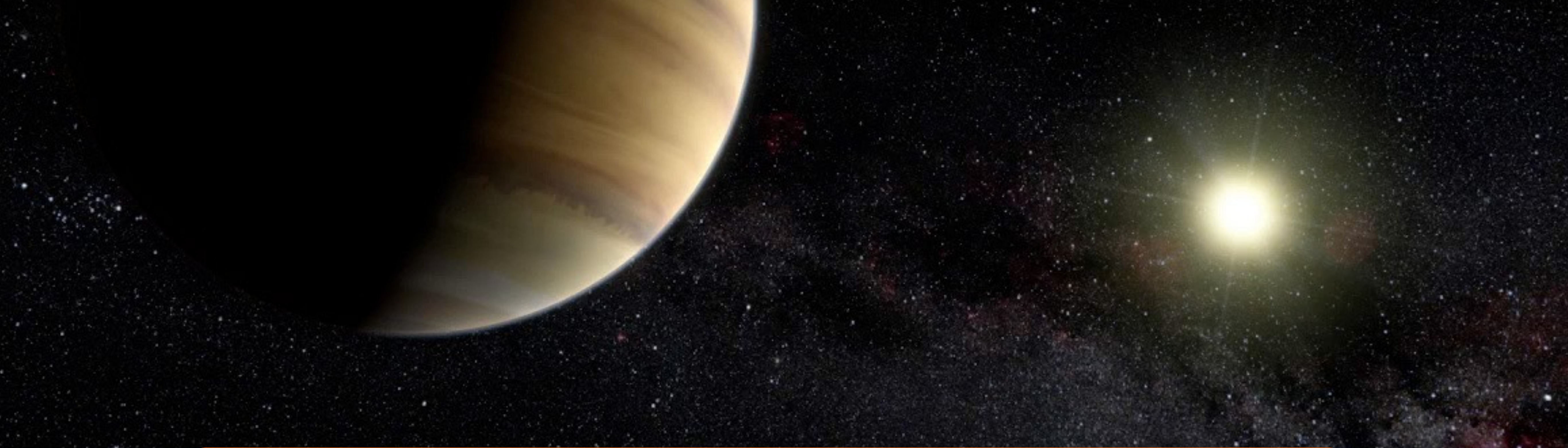
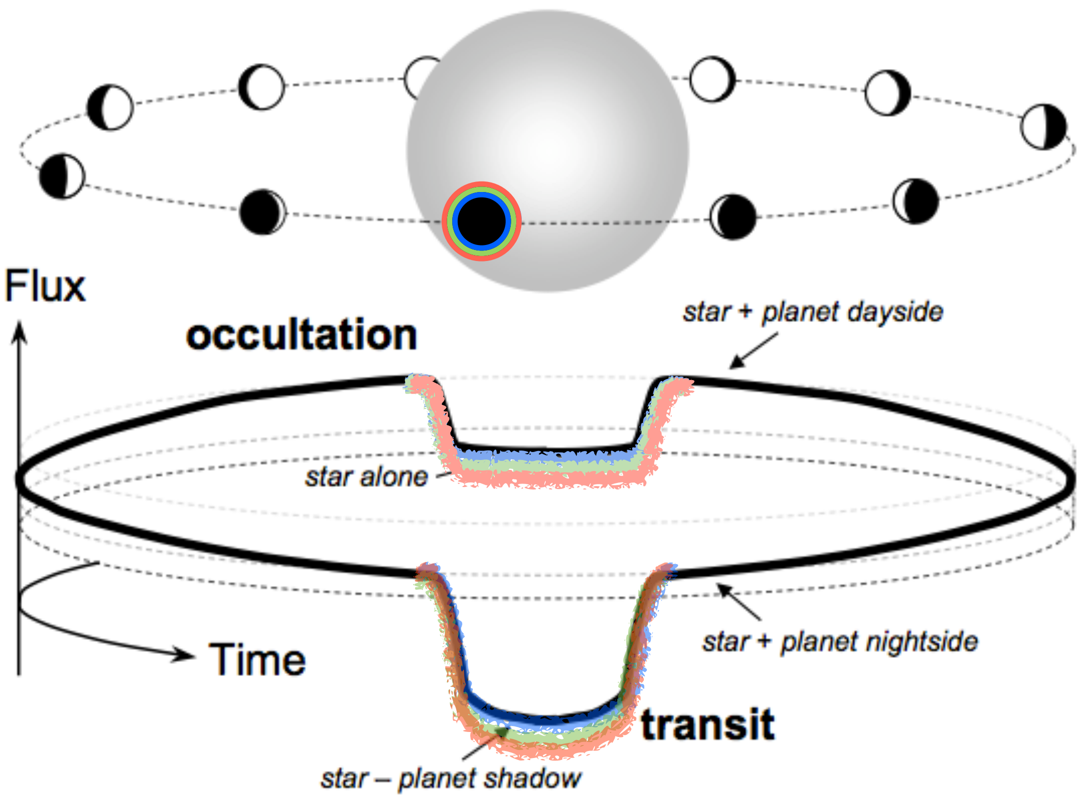


# ELT HIRES

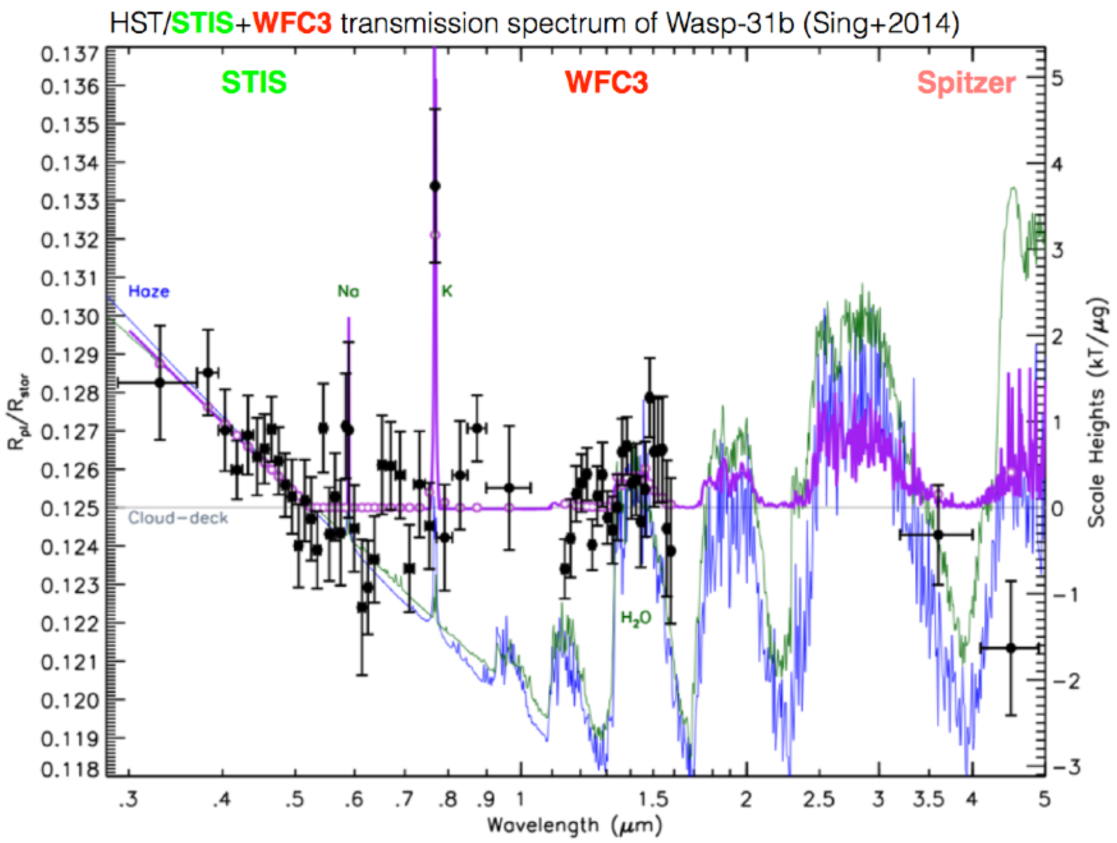
## The science case for exoplanets and disks

# Exoplanets w/ transmission spectroscopy




after Winn (2010)

**Visible**+**NIR** transit spectroscopy



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# Exoplanets w/ transmission spectroscopy

**Birkby arix:1806.04617**

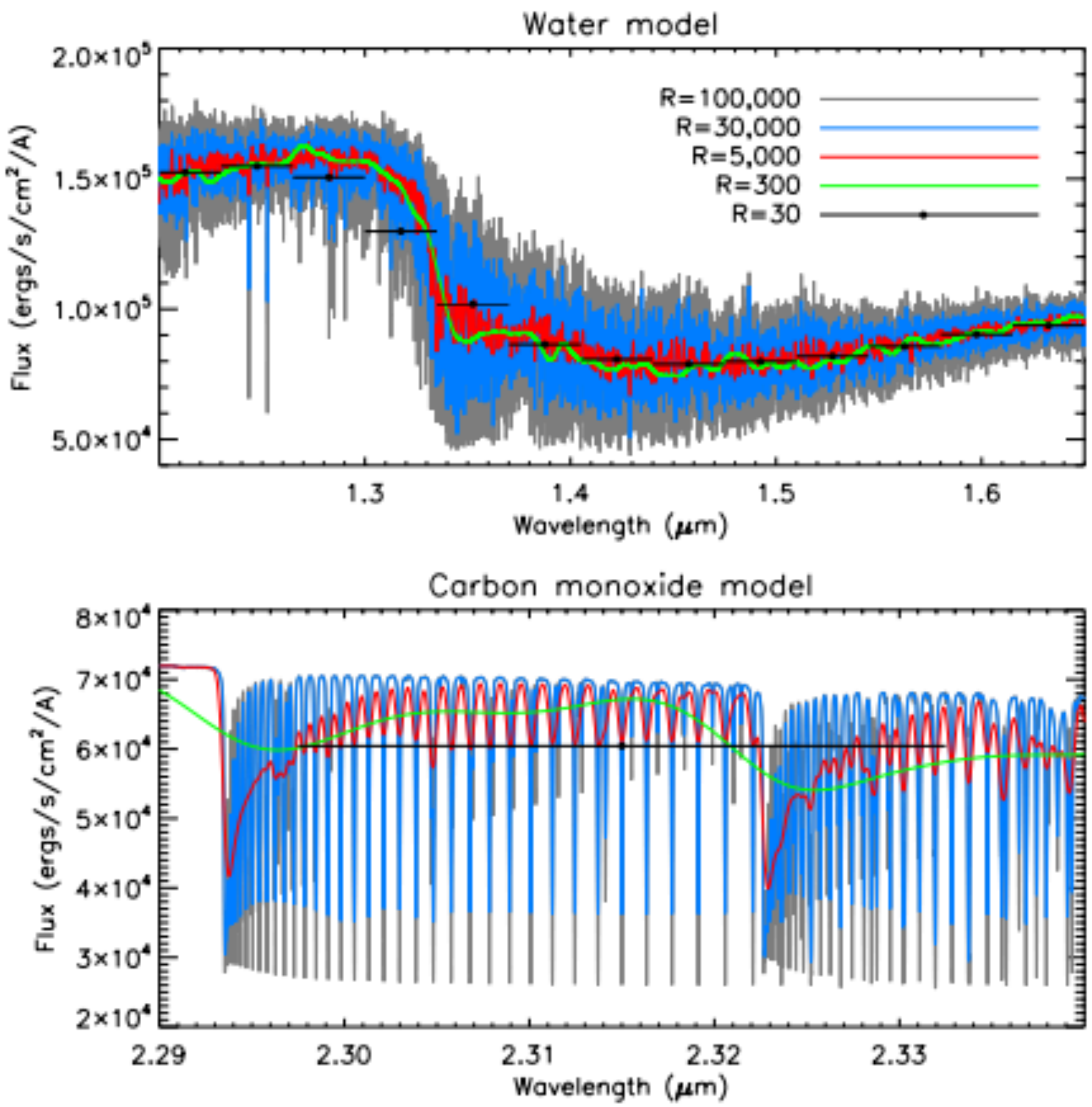
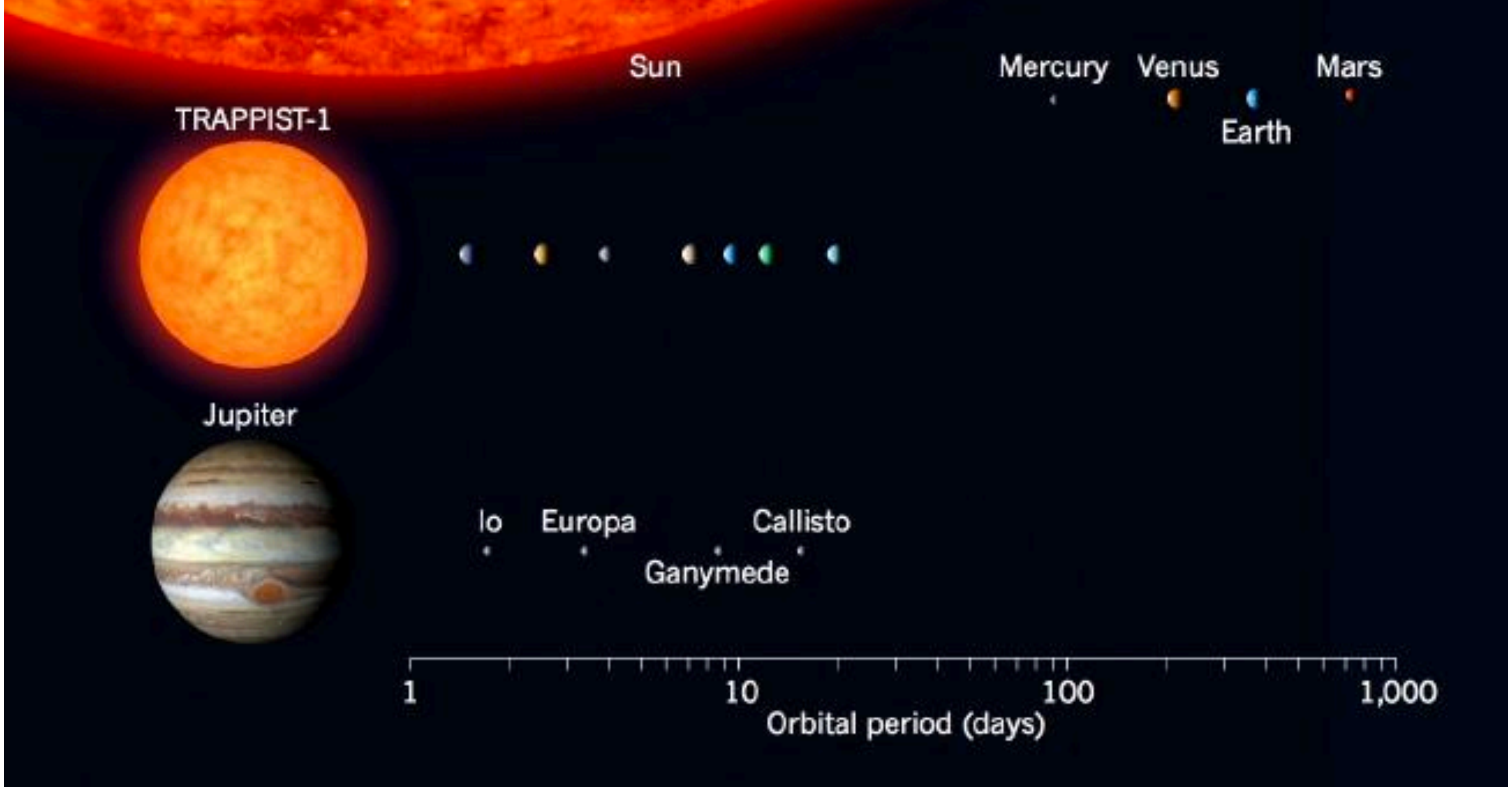
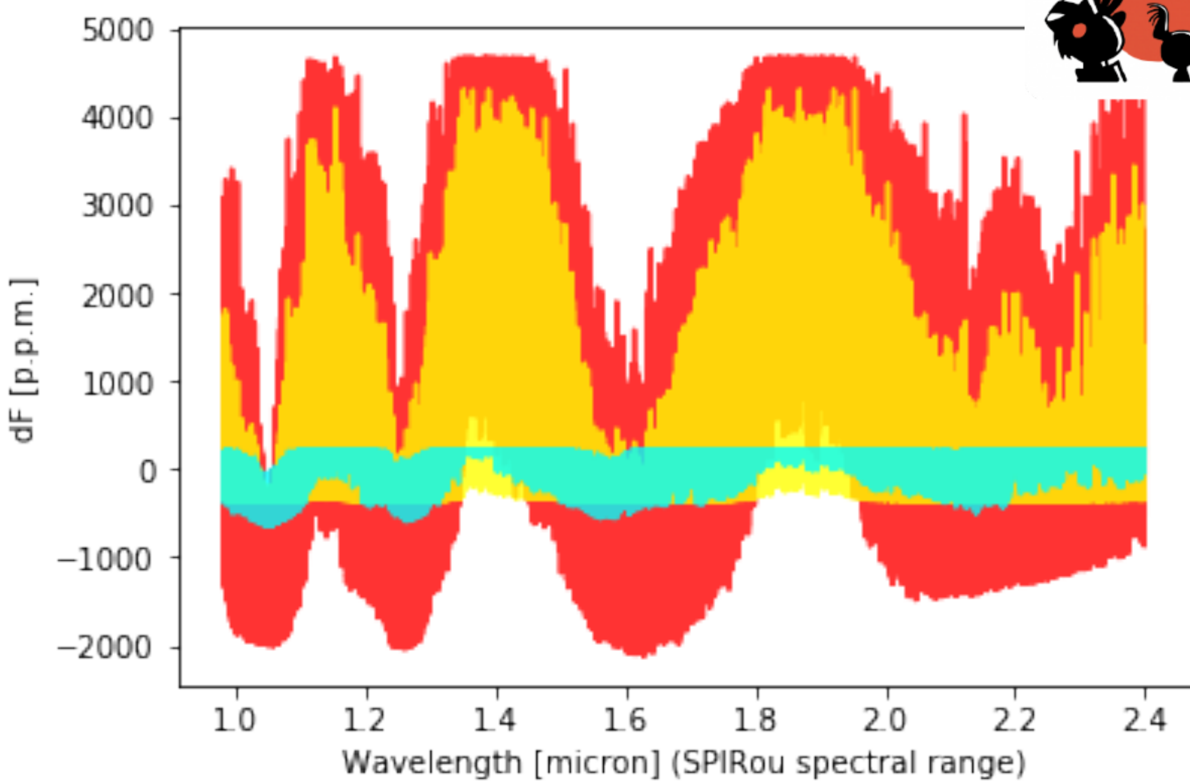


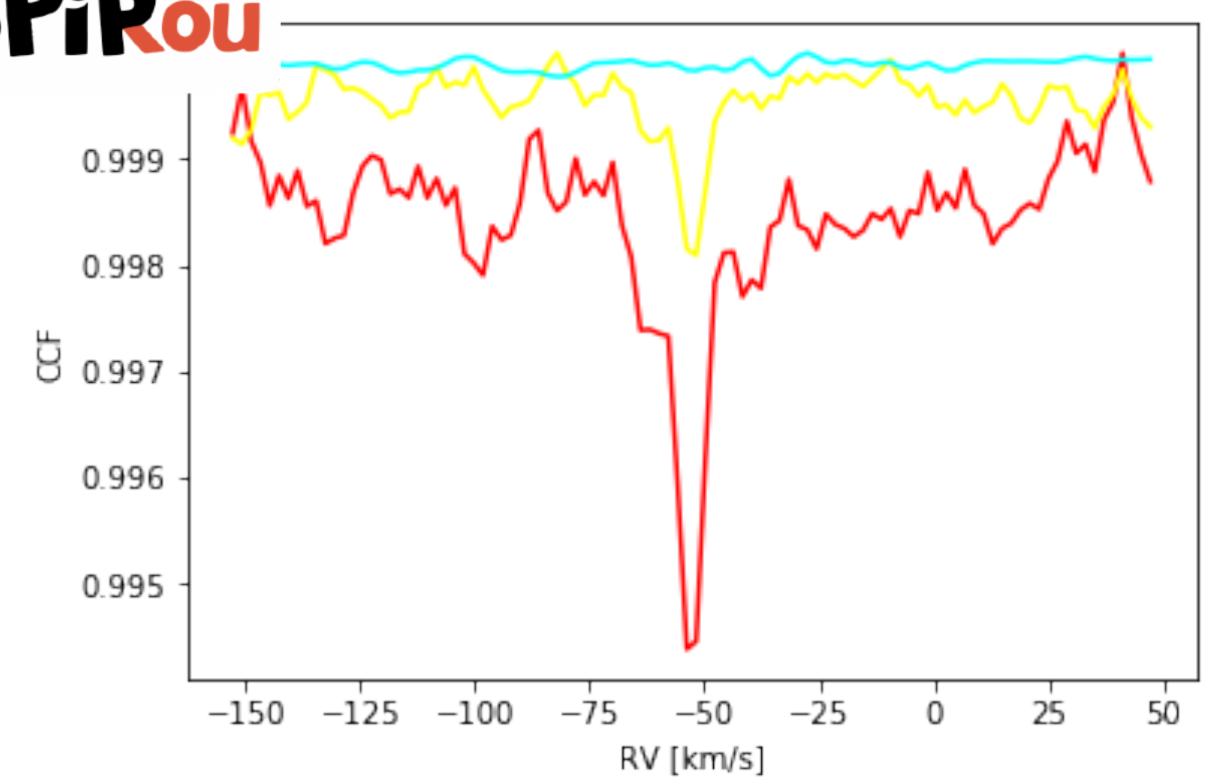

**Fig. 2** The effect of decreasing spectral resolution. The two panels show different wavelength regions of a model hot Jupiter atmosphere containing water and carbon monoxide. Note the difference in the x-axis scale. The model has been convolved to different spectral resolutions. The overplotted points represent the typical resolution resulting from current space-based observations and trace out only broad molecular features. Note how many individual CO lines are lost between a resolution of R=100,000 and R=300. The shallower lines disappear more quickly, but some of the stronger CO lines remain even at R=5,000, albeit much reduced in line depth. Each line that is detected with the high-resolution technique increases the total planet signal-to-noise by a factor of $\sqrt{(N_{lines})}$.

- S/N ~ sqrt(Resolution)

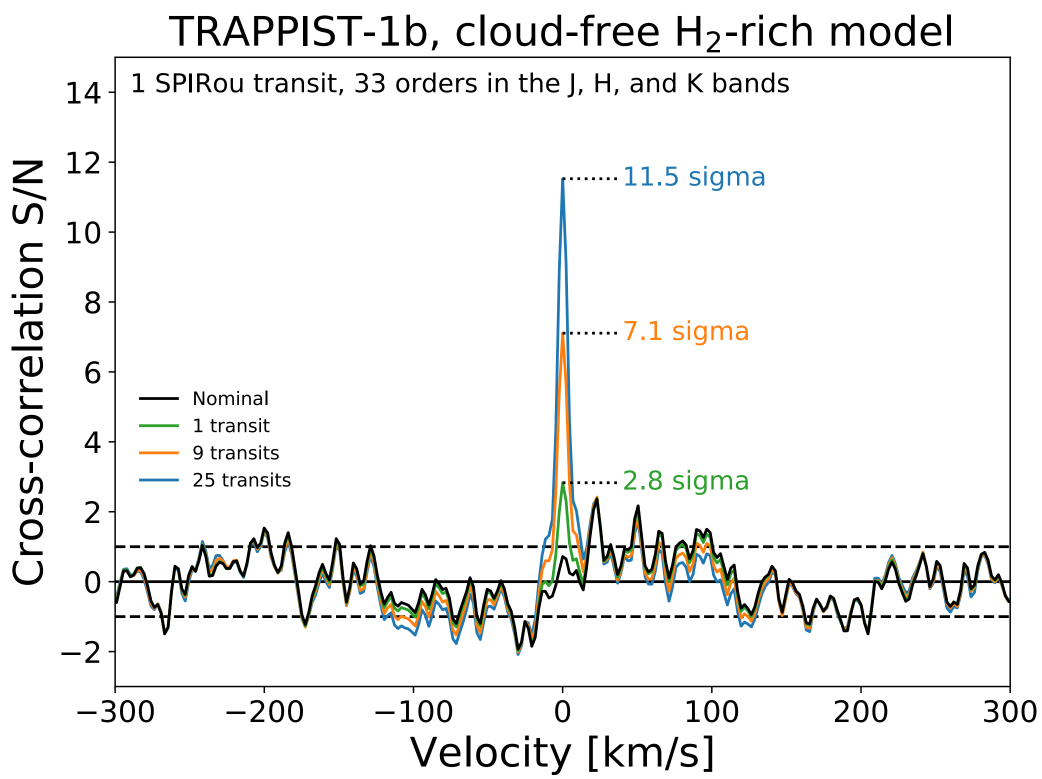



Sun
Mercury
Venus
Earth
Mars
TRAPPIST-1
Jupiter
Io
Europa
Ganymede
Callisto
1
10
100
1,000
Orbital period (days)

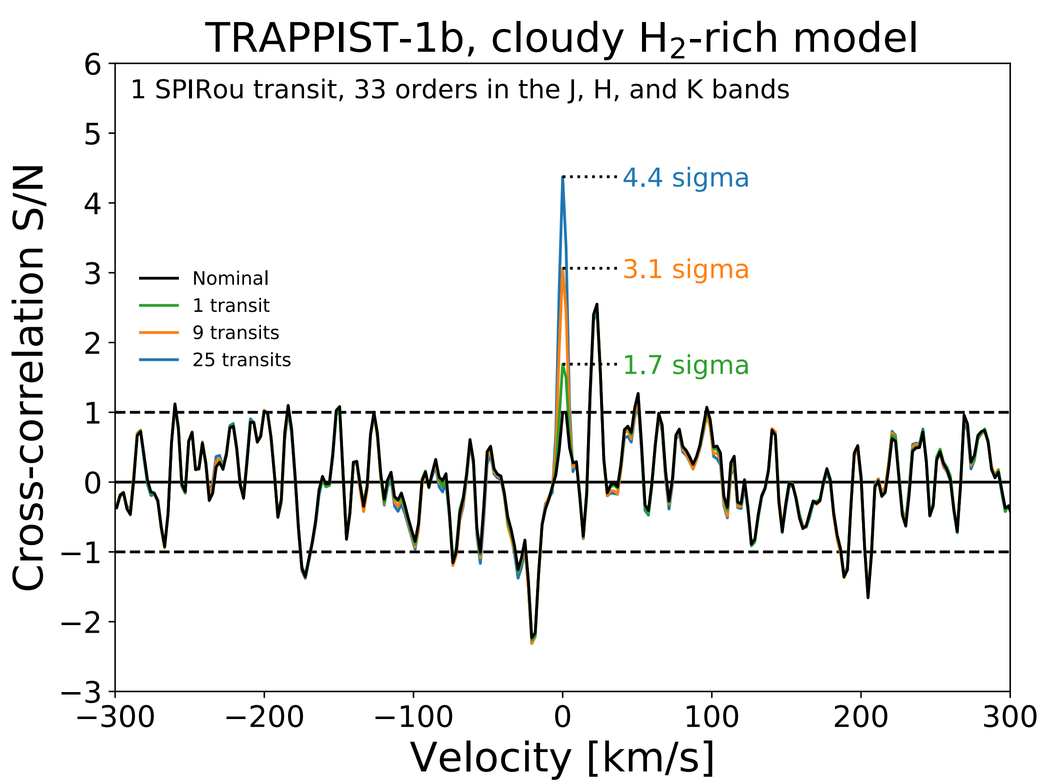

5000
4000
3000
2000
1000
0
−1000
−2000
dF [p.p.m.]
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Wavelength [micron] (SPIRou spectral range)

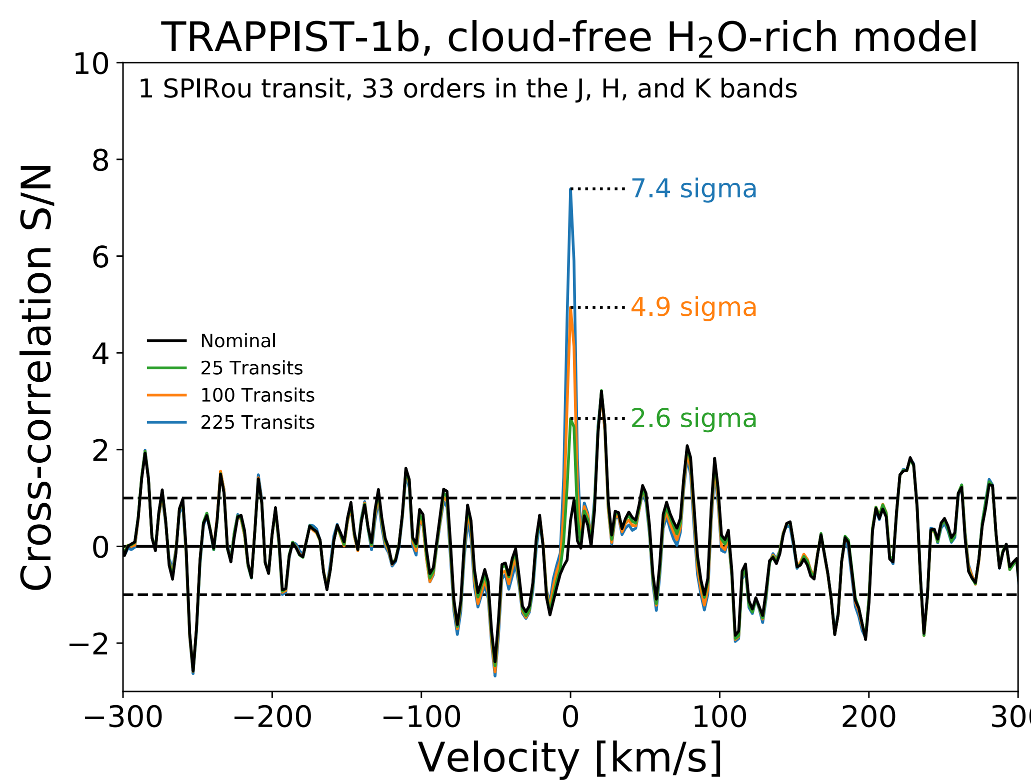

0.999
0.998
0.997
0.996
0.995
CCF
−150
−125
−100
−75
−50
−25
0
25
50
RV [km/s]

# Atmospheric characterization: TRAPPIST-1



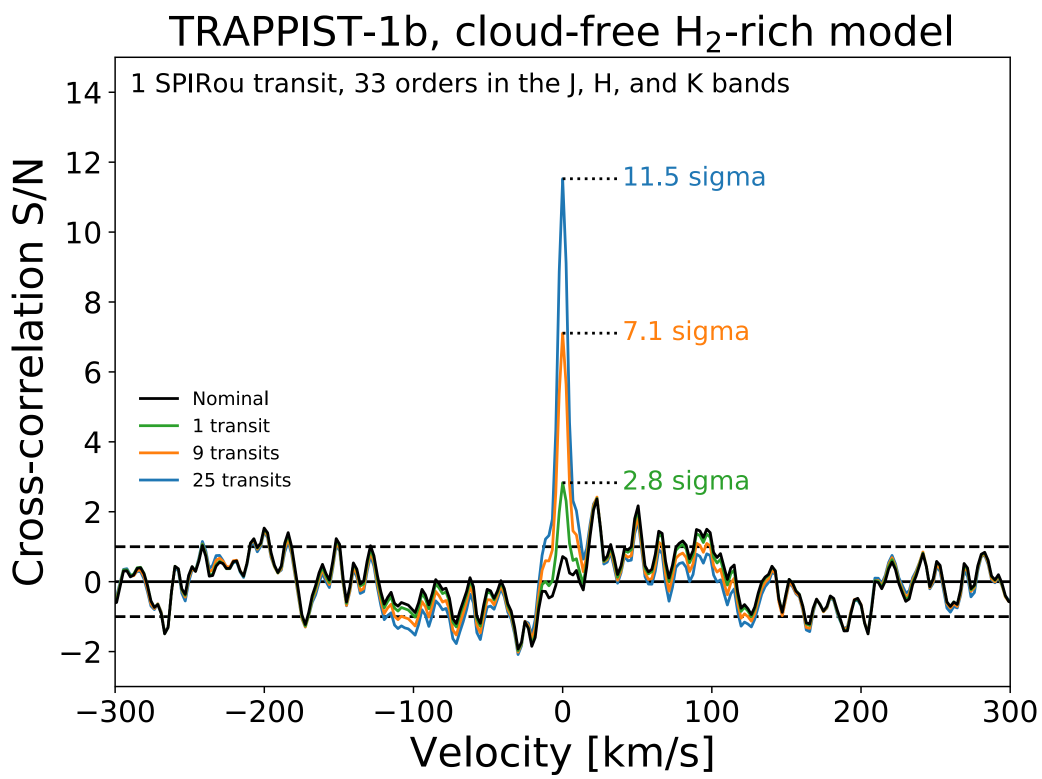

- We are near the expected S/N
- The implementation of several improvements should divide the number of required transits by 2



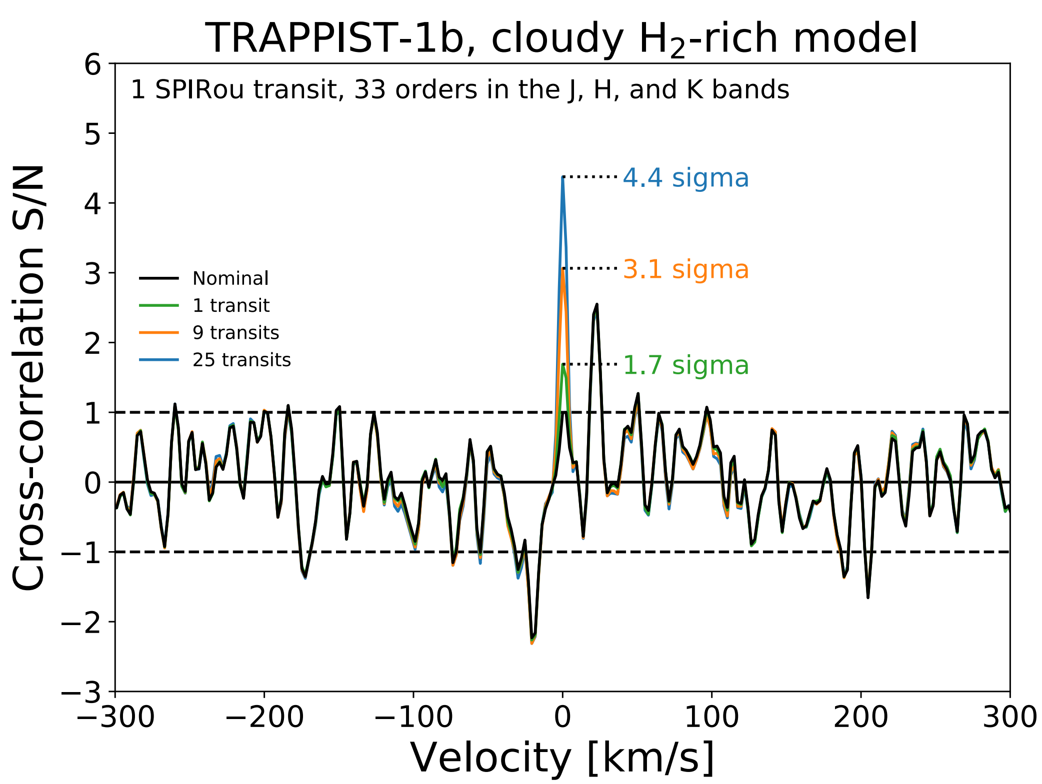



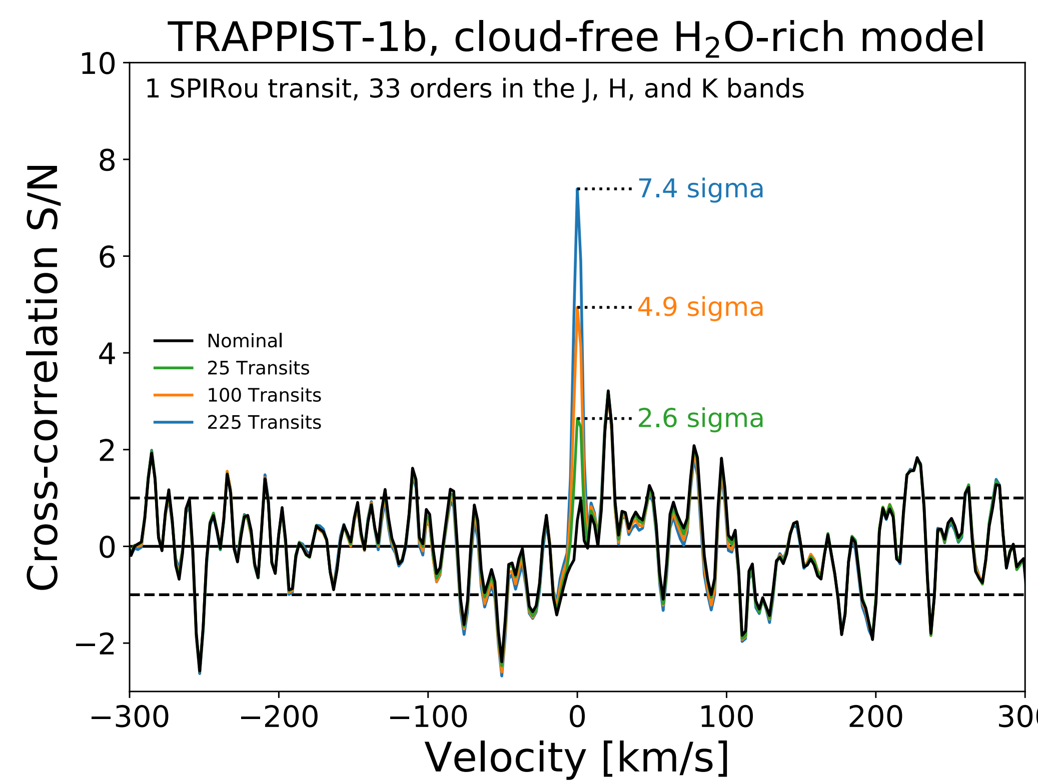

Aurélien Wyttenbach

# Atmospheric characterization: TRAPPIST-1

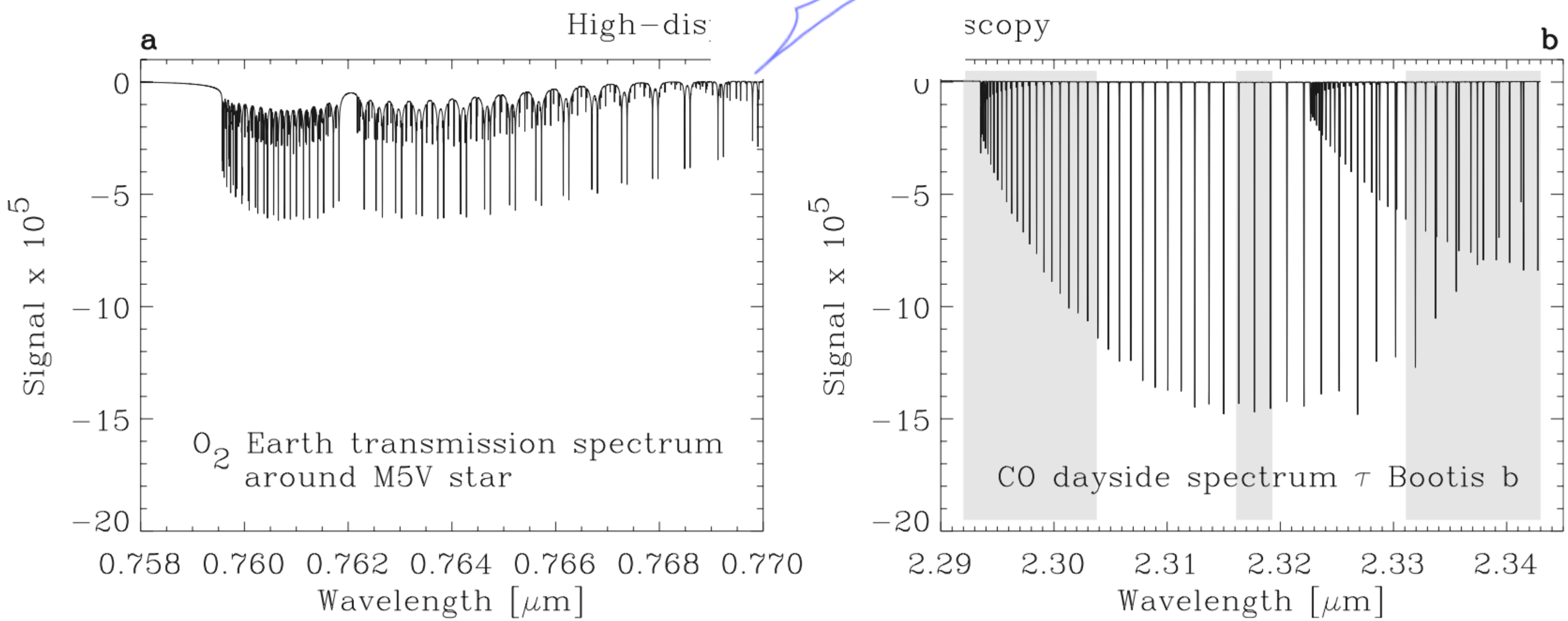



- We are near the expected S/N
- The implementation of several improvements should divide the number of required transits by 2
- Collecting power of ELT is ~ 120x that of CFHT…




Aurélien Wyttenbach




- HIRES will enable to target O2
- O2 is —depending on the context— the most robust bio-signature
- The sample of transiting planets is large (thousands being detected by TESS)

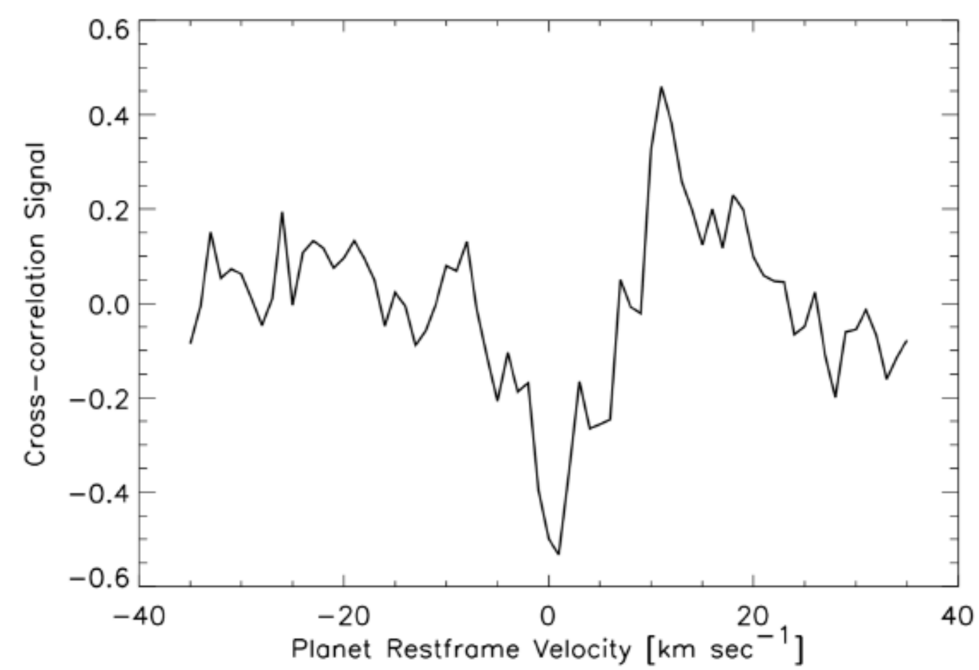
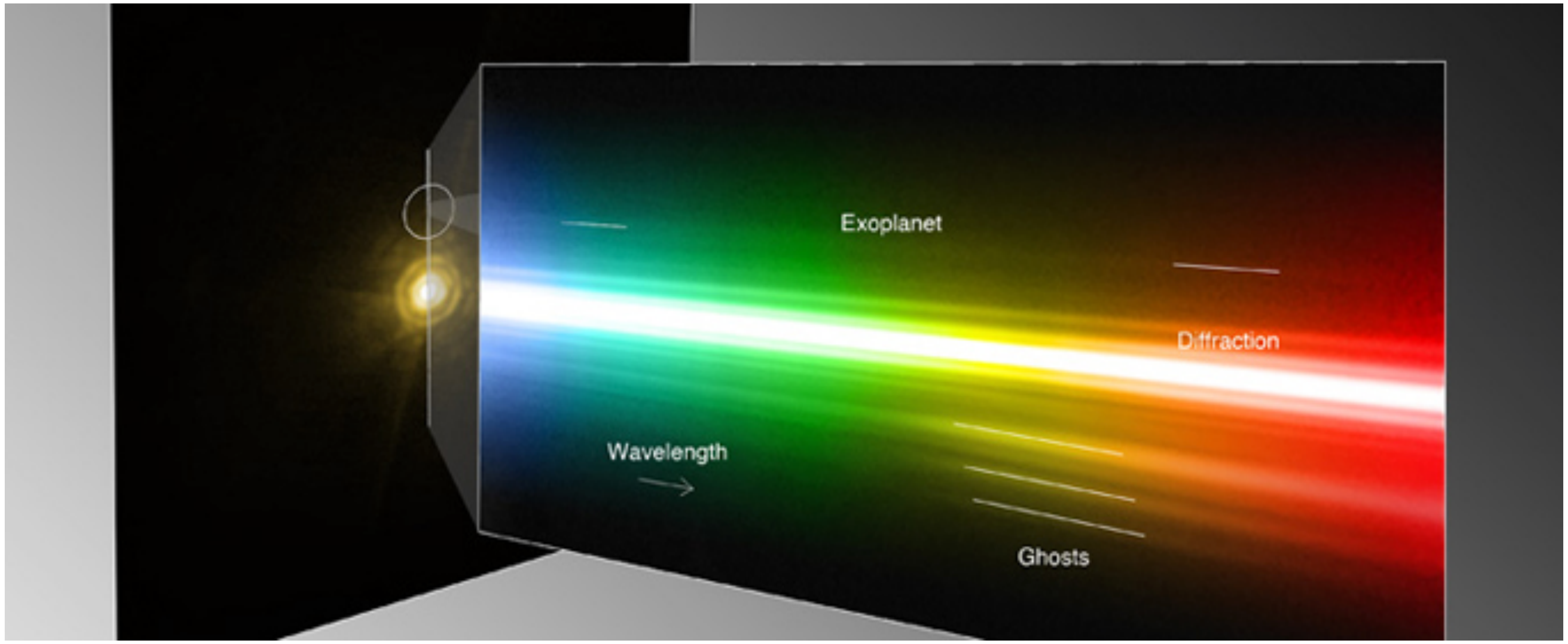



**Figure.4.1.2** *Simulated cross-correlation values of the detection of the $O_2$ molecule in a simulated Earth-like atmosphere orbiting an M5V (I=11mag) star, combining 30 transits with HIRES (from Snellen et al. 2015, A&A 576, 59).*

# Exoplanets w/ direct light detection




- combines high-contrast imaging w/ high-res spectroscopy to achieve planet-to-star contrast of 10^-6 - 10^-8
- probes deeper the atmosphere (atm. composition at the surface)
- can access non transiting planets too

  only 1/200th Earth orbiting a G star undergoes transit, and only 1/50th for M-star exo-Earth
- 39-m aperture => angular resolution Lbda/D ~ 8 mas in J band



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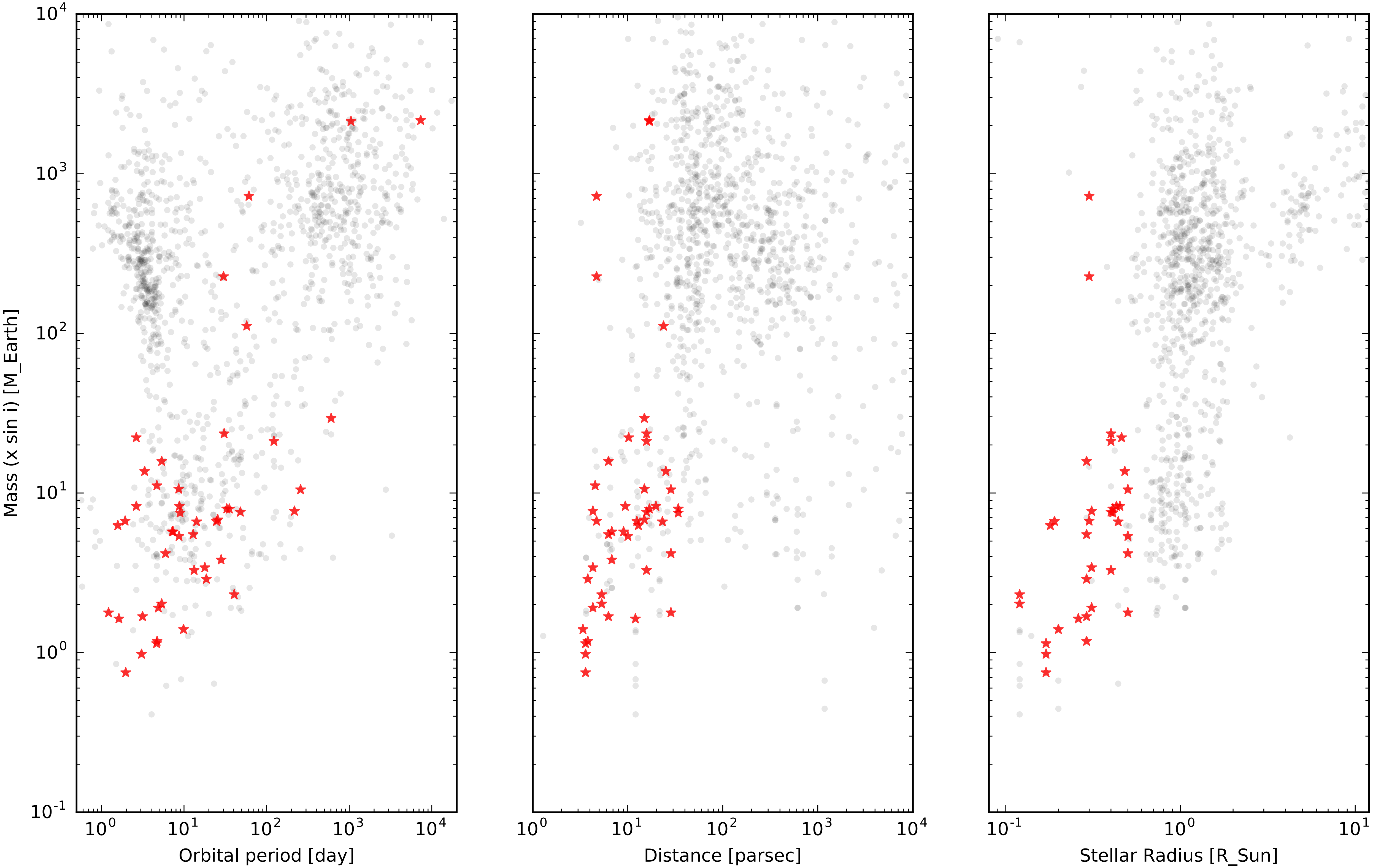
• most planets amenable to characterization come from our programs



# A temperate exo-Earth around a quiet M dwarf at 3.4 parsecs*

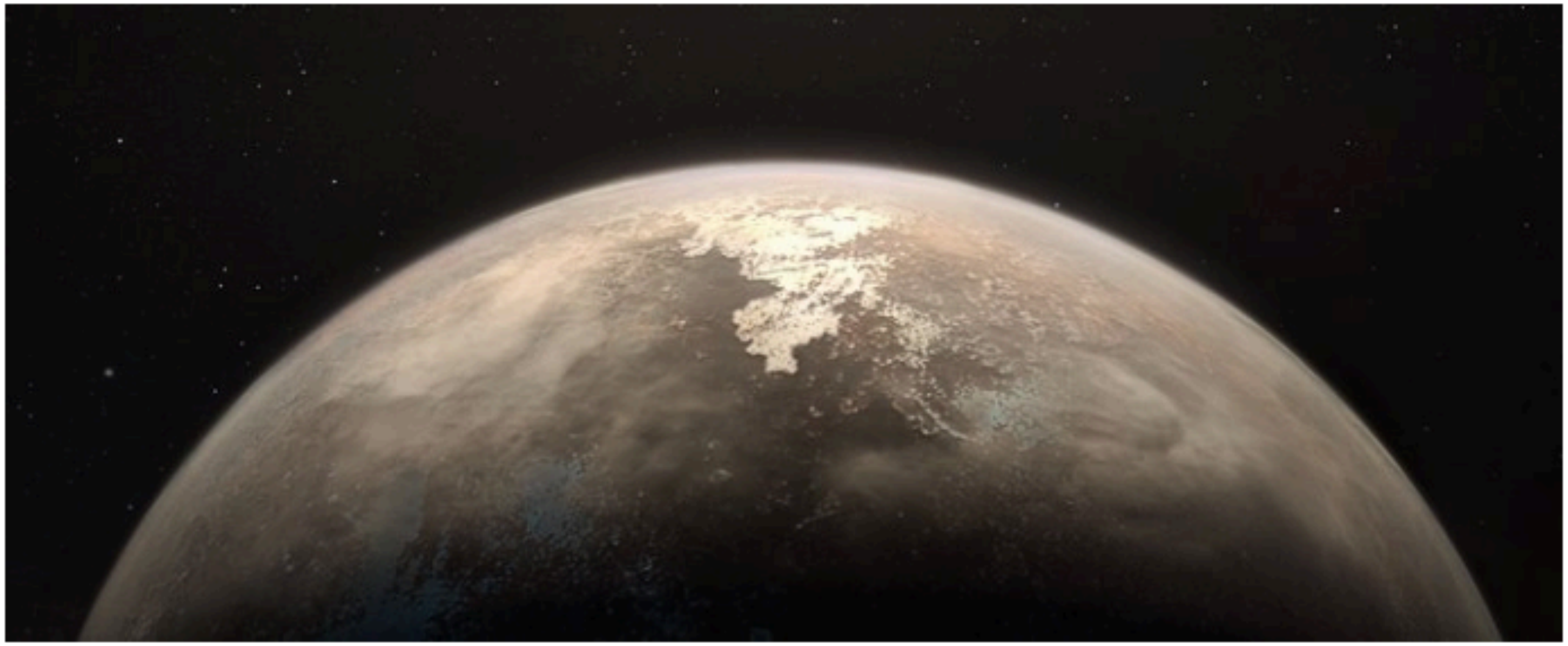
X. Bonfils[1], N. Astudillo-Defru[2], R. Díaz[3,4], J.-M. Almenara[2], T. Forveille[1], F. Bouchy[2], X. Delfosse[1], C. Lovis[2], M. Mayor[2], F. Murgas[5,6], F. Pepe[2], N. C. Santos[7,8], D. Ségransan[2], S. Udry[2], and A. Wünsche[1]

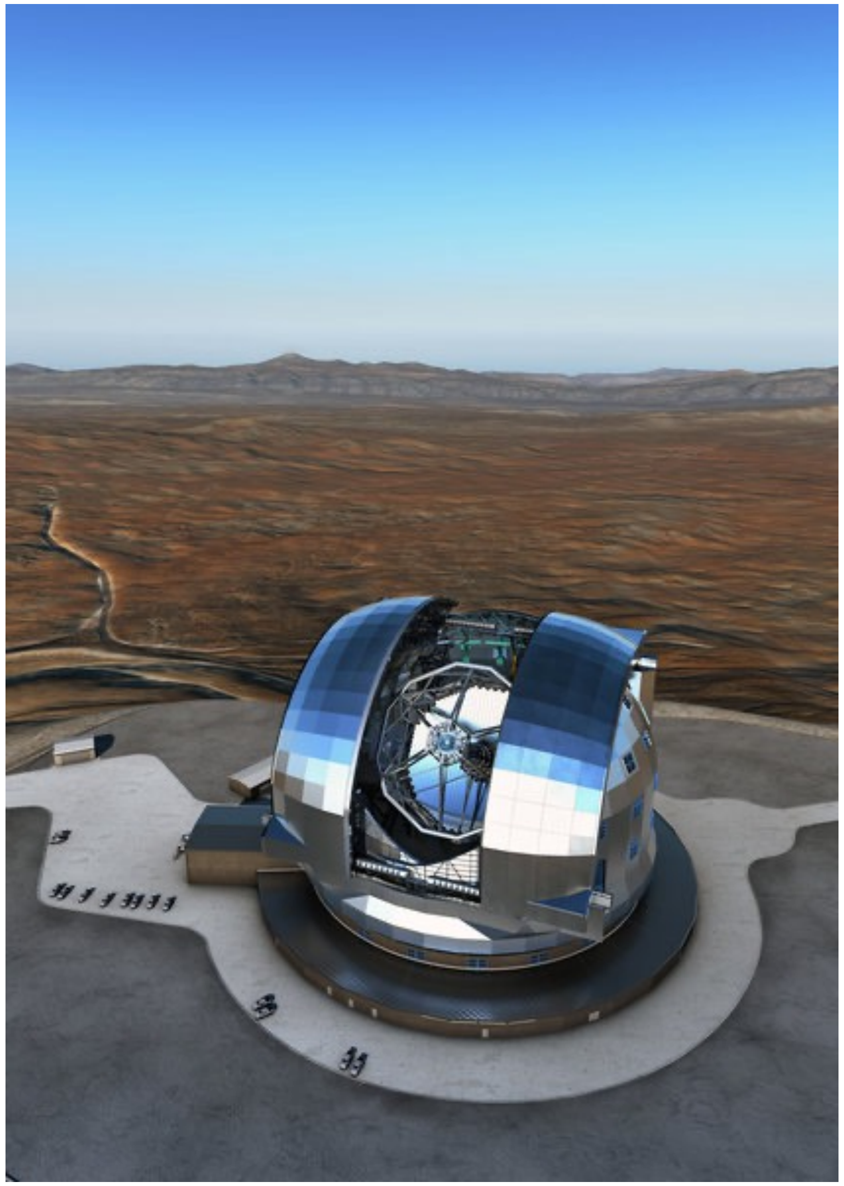
eso1736 — Science Release

# Closest Temperate World Orbiting Quiet Star Discovered

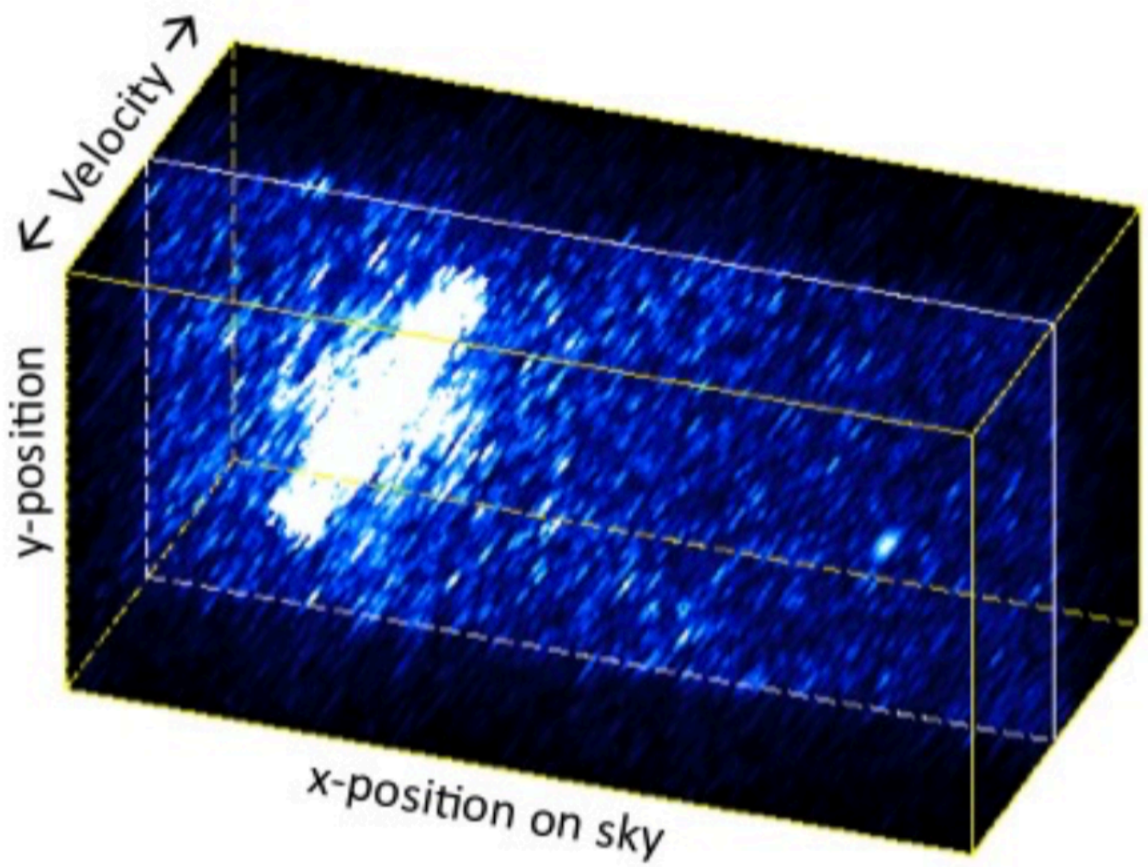
## ESO's HARPS instrument finds Earth-mass exoplanet around Ross 128

15 November 2017





A temperate Earth-sized planet has been discovered only 11 light-years from the Solar System by a team using ESO's unique planet-hunting HARPS instrument. The new world has the designation Ross 128 b and is now the second-closest temperate planet to be detected after Proxima b. It is also the closest planet to be discovered orbiting an inactive red dwarf star, which may increase the likelihood that this planet could potentially sustain life. Ross 128 b will be a prime target for ESO's Extremely Large Telescope, which will be able to search for biomarkers in the planet's atmosphere.




Snellen+15; see also Lovis+17

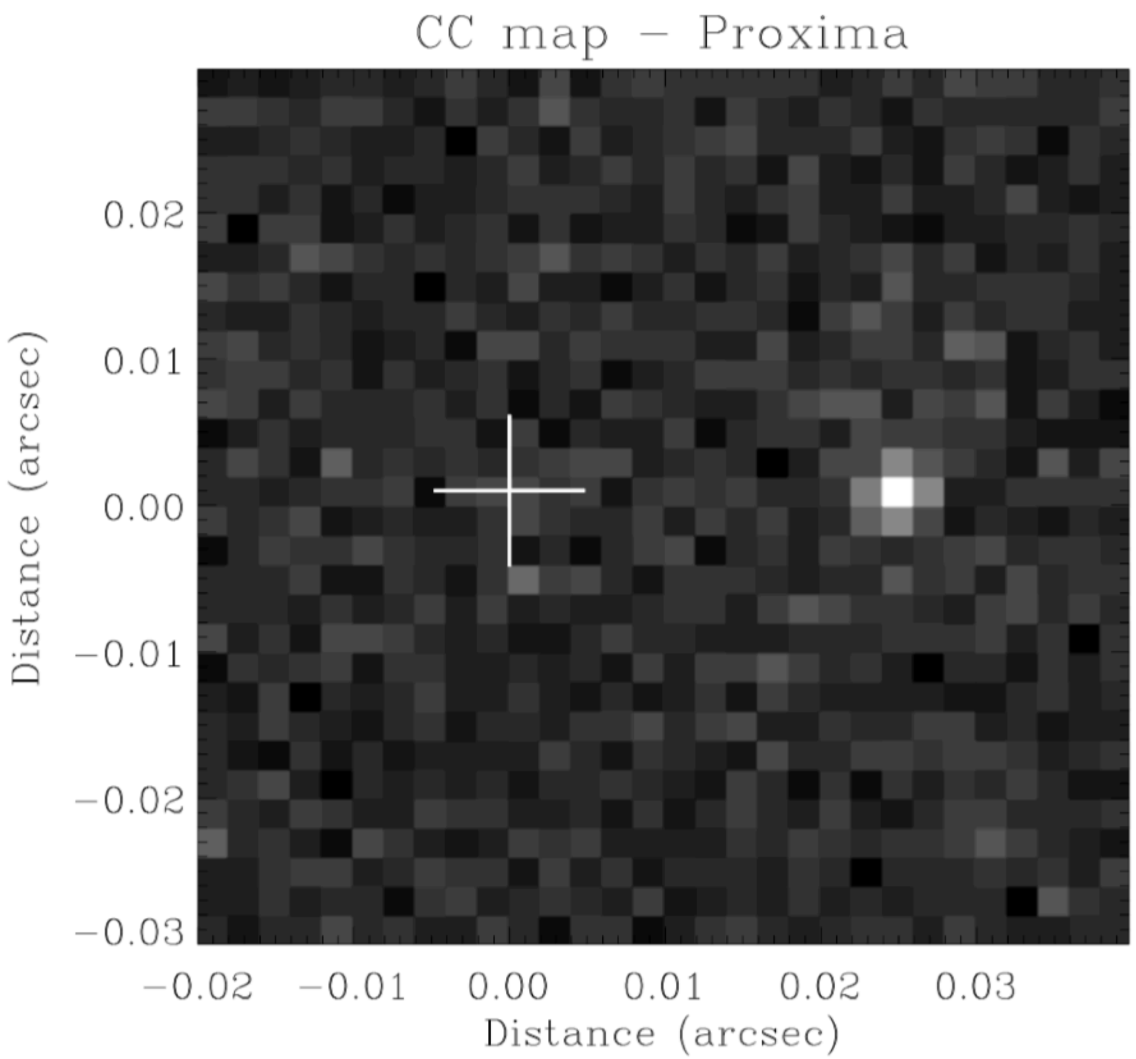



**Fig. 6.** HDS+HCI cross-correlation map of 10 hours of optical observations with the E-ELT using a R=100,000 IFS and an adaptive optics system producing a Strehl ratio of 0.3. The hypothetical planet with a radius of R=1.5 $R_{Earth}$, albedo of 0.3, and $T_{eq}$=280 K such that it is at an orbital radius of 0.032 AU, 25 milliarcseconds from the star. The starlight reflected off the planet is detected at an S/N of ~10.

- like Proxima b, detection of O2 is possible for Ross 128 b
- require ELT, HIRES w/ SCAO, a few nights

# Exoplanets w/ direct light detection

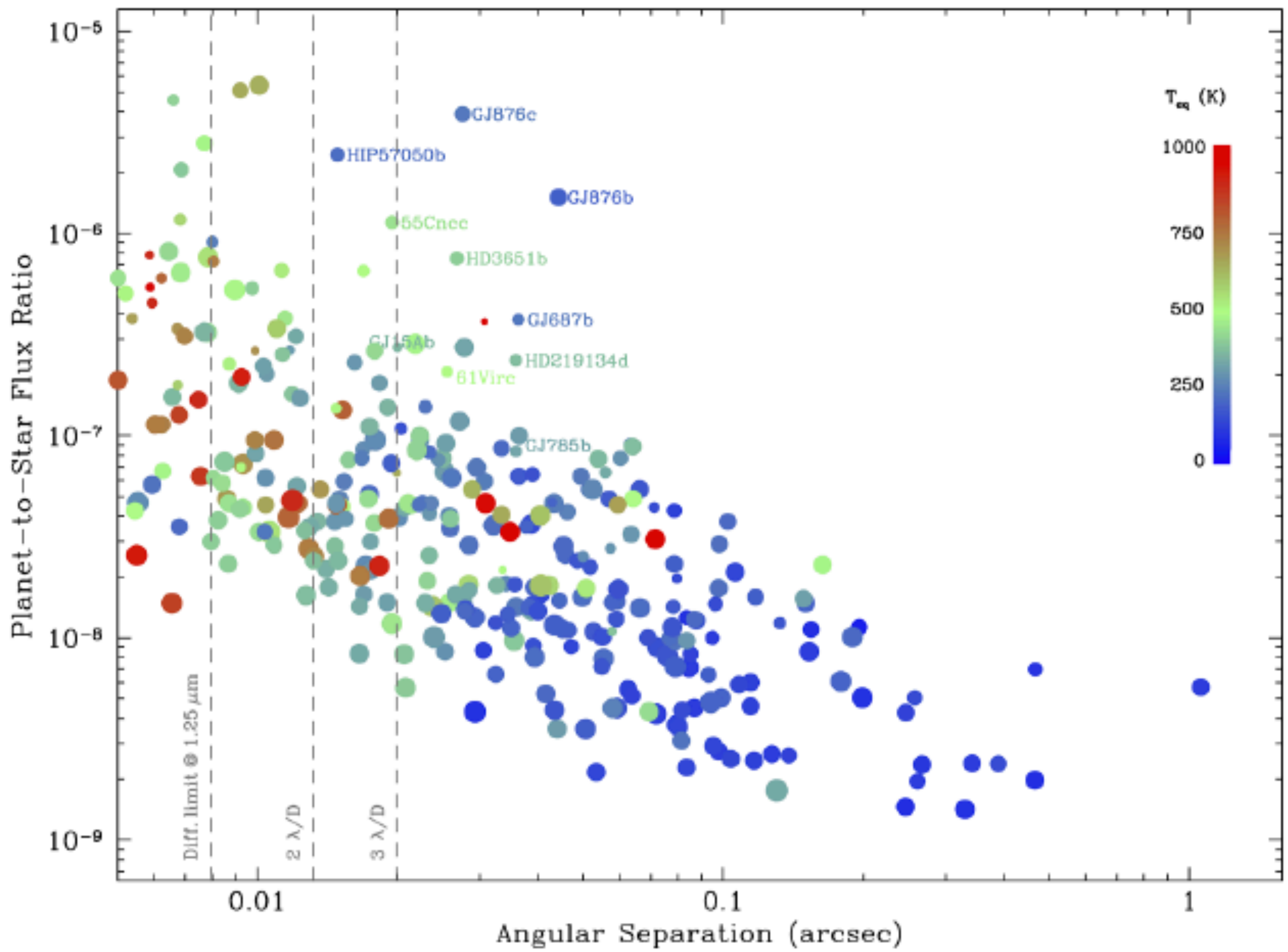



**Figure.4.1.4** *Planet-star contrast ratio for the know planets plotted against angular separation from the host star. The color code represents the effective temperature of the planet.*



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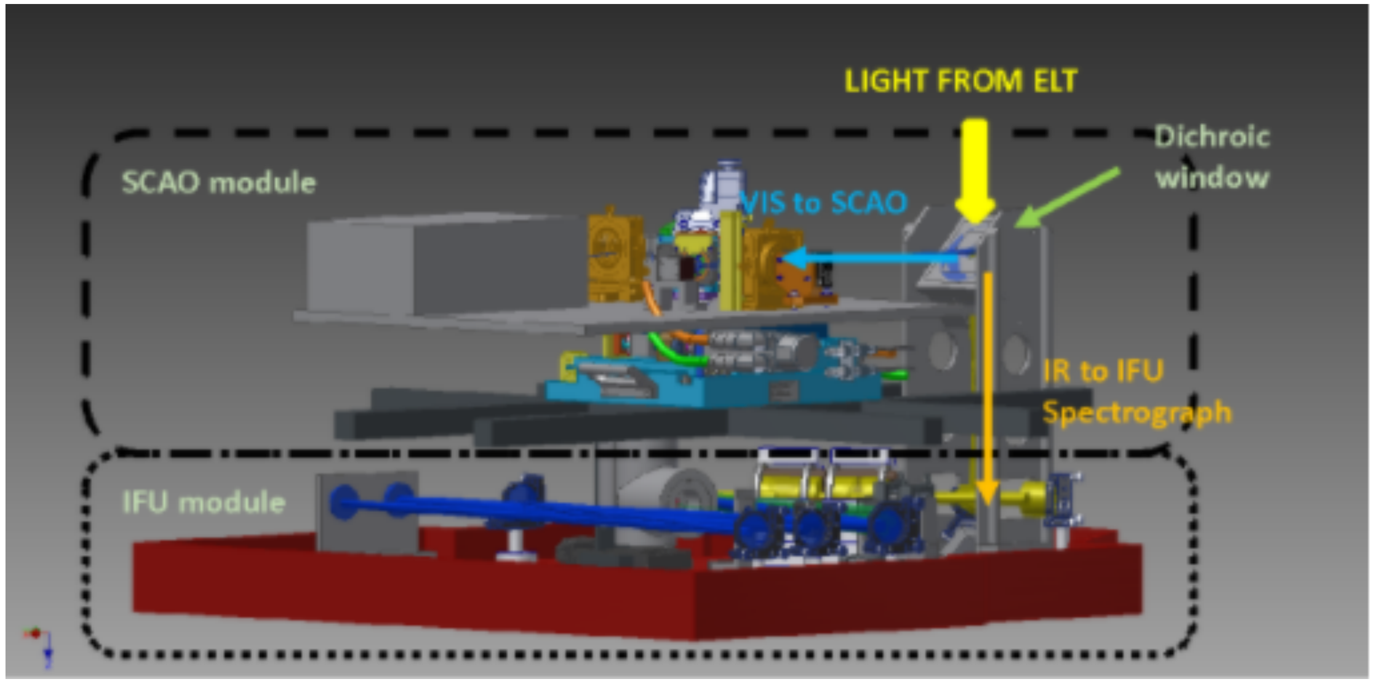
# High Contrast mode ?

- Phase A design includes a SCAO
- Is it enough ? How does it compare w/ the High-Contrast module of HARMONY ? Should we implement a similar HC module on HIRES ?
- Reflexion in progress with HARMONY team (N'Diaye+)



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# Need for K-band ?

- Phase A design does not include K band
- But leaves room for it
- K-band with seeing limited capability is hugely expensive
- However, behind an AO, there might be room for a single-mode, “cheap” spectrograph covering the K band
- Multiple interests :
    - Thermal emissions of hot planets
    - Strong features of $CO$, $CH_4$, $CO_2$ and $NH_3$
    - $CO_2$+$CH_4$+$CO$ is considered a bio-signature
    - K-band can lift cloud-metallicity degeneracy in transm.
    - Cloud opacity drops in K



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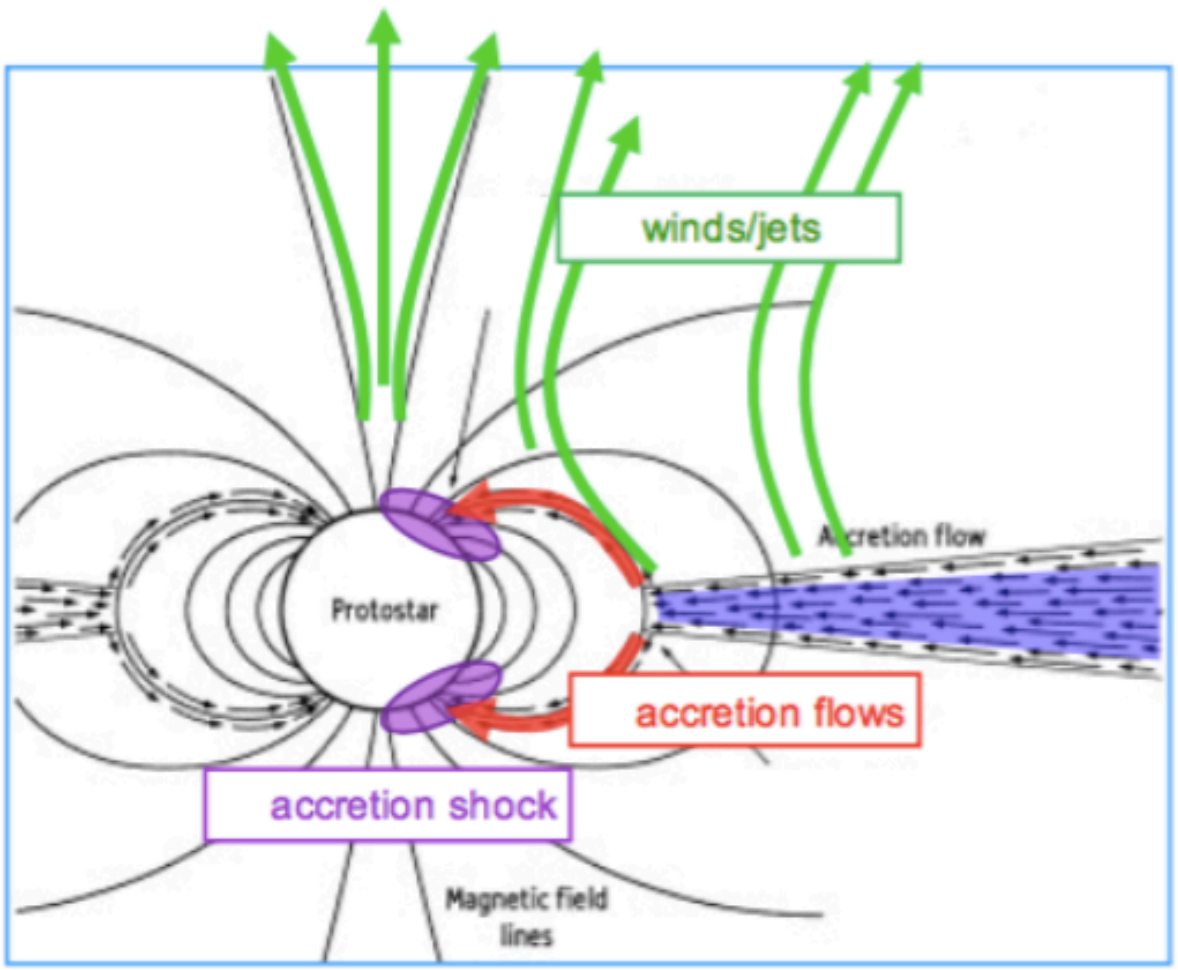
# Protoplanetary disks




- constraints on star-mass accretion, angular momentum removal, and initial condition for planet formation

- Properties of the gas in the inner star-disk region. What mechanisms are at play ? Magnetospheric accretion, jets, photo-evaporated and magnetically-driven disk winds

- Requires spatial (~10 mas) and spectral (R~100'000) resolutions
- Wish for K band (ro-vibrational transitions of H2)



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# Protoplanetary disks

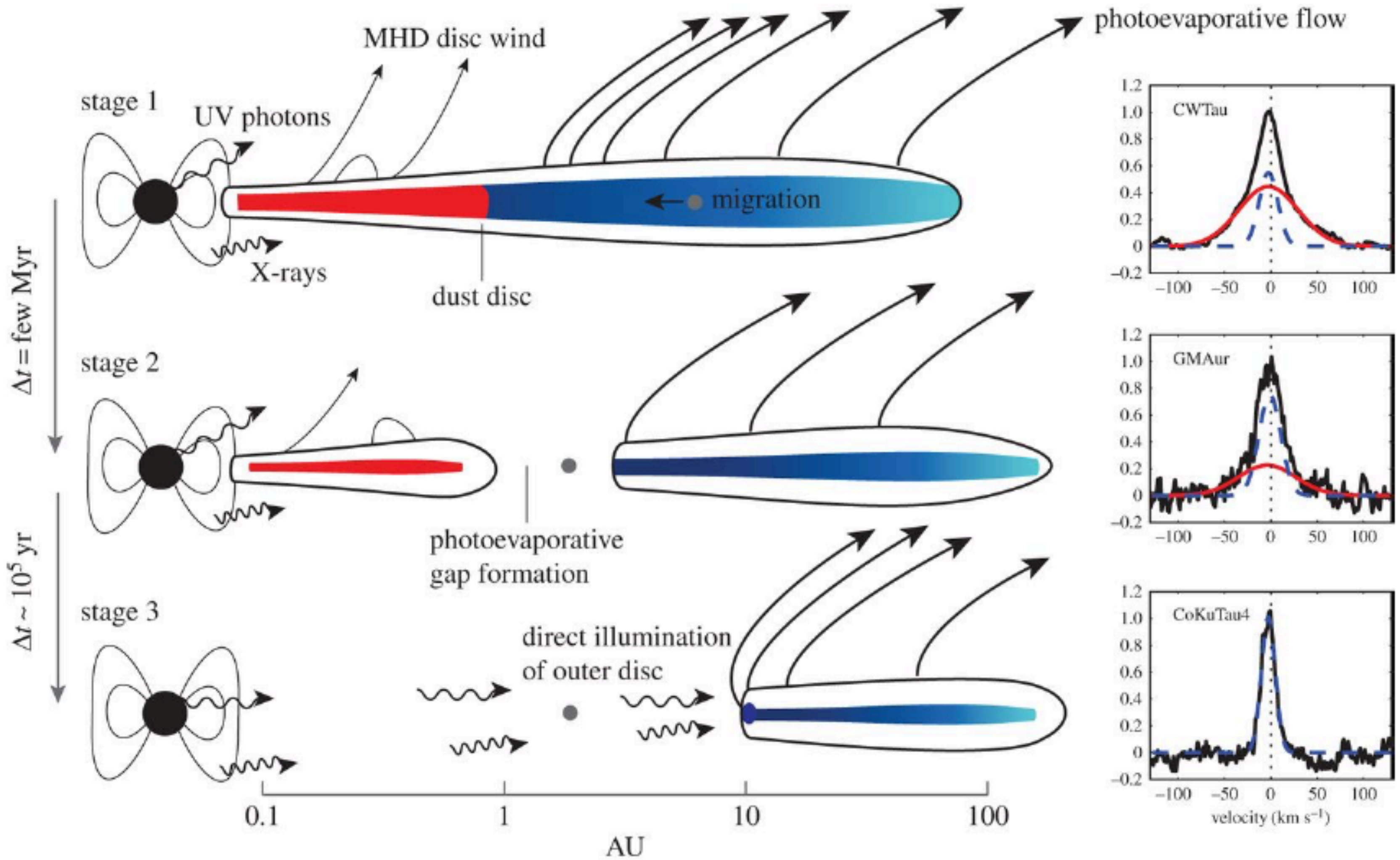


**Figure.4.1.6** *The three main stages of disc evolution and dispersal (Alexander et al. 2014, Protostars and Planets VI, 914, 475). The right panels show examples of [OI] 6300 Å emission whose composite profile traces the disk gas dispersal in the corresponding stages (Simon et al. 2016,ApJ 831, 169 ).*

- Modeling the various components of forbidden lines



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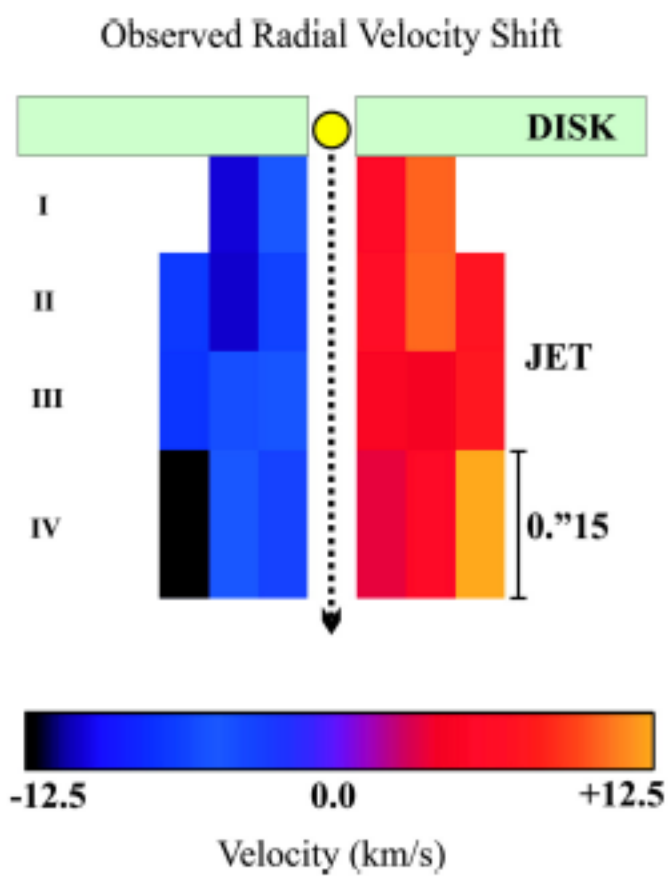
# Protoplanetary disks




**The physics of jets**

- Resolve different jet scenarios
- Rotation of the star-disk
- Important to understand the transfer of angular momentum

- Requires IFU fov ~100 mas and spectral (R~100’000) resolutions

# Planet formation

**Observing planet formation as it happens**

- Accreting protoplanets
  - shocks traced by Halpha, Paschen beta & Bracket gamma
  - SED + spectra => evolutionary sequence of forming planets
  - Halpha line with offset velocity as a way to detect unresolved plane
  - A way to discriminate hot vs. cold start scenarii

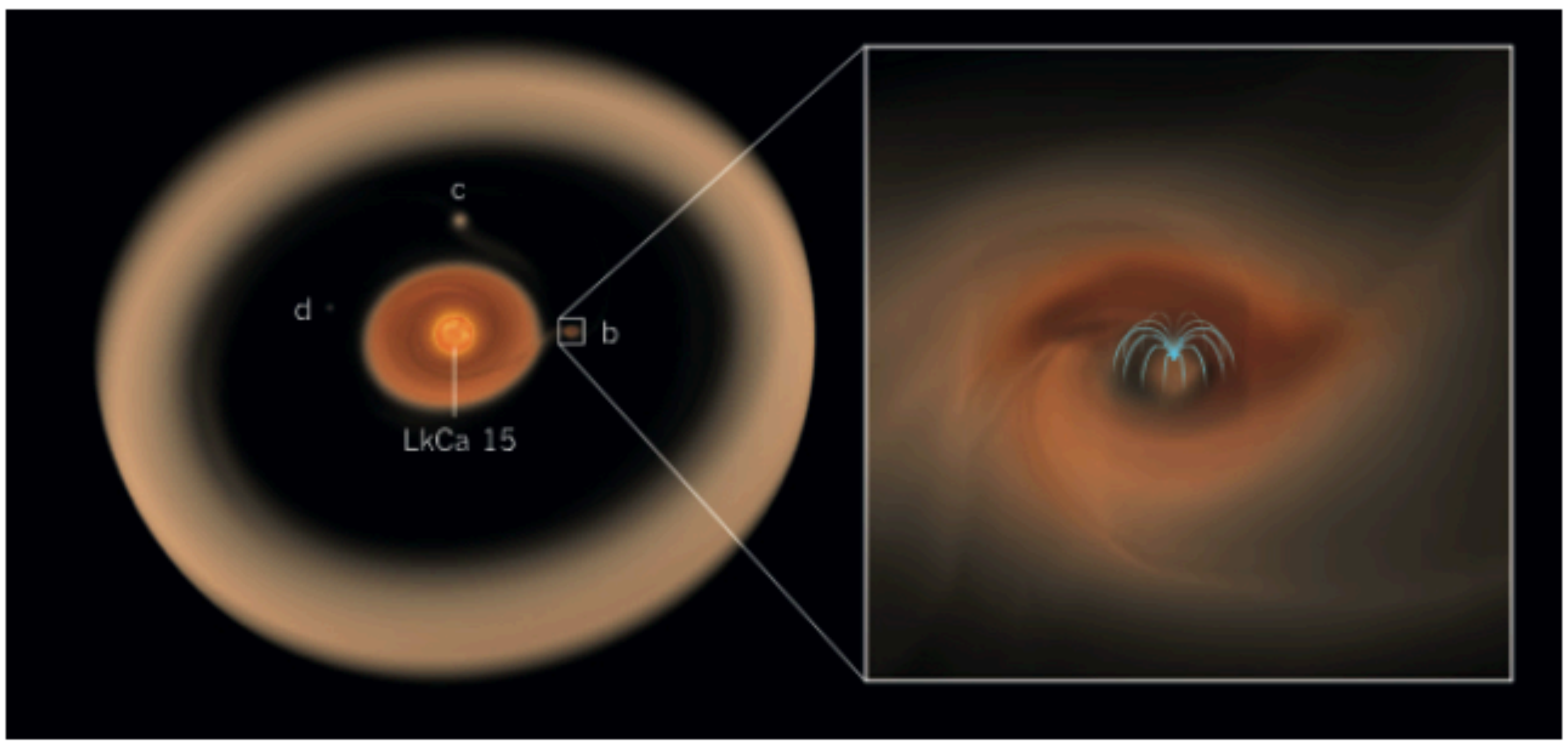



**Figure.4.1.8** *Schematic representation of the young star LkCa15 which is surrounded by a protoplanetary disk with a gap. Sallum et al. (2015, Nature, 527, 310) have found a young protoplanet (LkCa 15 b) growing in this gap, emitting Hα. The growing protoplanet*

# Planet formation

**Observing planet formation as it happens**

- Accreting protoplanets
    - shocks traced by Halpha, Paschen beta & Bracket gamma
    - SED + spectra => evolutionary sequence of forming planets
    - Halpha line with offset velocity as a way to detect unresolved plane
    - A way to discriminate hot vs. cold start scenarii
- Impact of protoplanets on the protoplanetary disks (pl. radiate and heat the disk locally)
- Chain accretion protoplanetary disk->cirum-planetary disk-> planet lead to velocity structures that could be resolved at high spectral dispersion
- Planet magnetic fields
- Planets are predicted to be larger when younger. Can be verified by measuring log g in exoplanet spectra as a function of age
- Search for hot-collision afterglow resulting from impacts



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# More…

- Mass of Earth analogs (w/ ~10% precision)
- RV search for Mars-mass planets, or around cooler M dwarfs
- Stellar spin—orbit obliquity with Rossiter-McLaughlin measurements. An Earth transiting a G dwarf induces an anomaly of just 20 m/s… once every year (and precision on short time scale imposes to have more photons)

# Conclusions

- HIRES shall address the most important questions raised in exoplanet and protplanetary disk science
- With transmission and occultation spectroscopy, HIRES did set the goal to find biomarkers

- Logical step forward w/ respect to current projects in France

- Note the ongoing reflexion around HC and K-band



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