SPIRou status

René Doyon, Université de Montréal
Jean-François Donati, IRAP (Toulouse)
Xavier Delfosse, IPAG (Grenoble)
Etienne Artigau, Université de Montréal
Francesso Pepe, Observatoire de Genève

and the SPIRou team.

Outline

- Brief into on SPIRou
- SPIRou's status
  - Work done since PDR
  - Way forward
- Core science with SPIRou

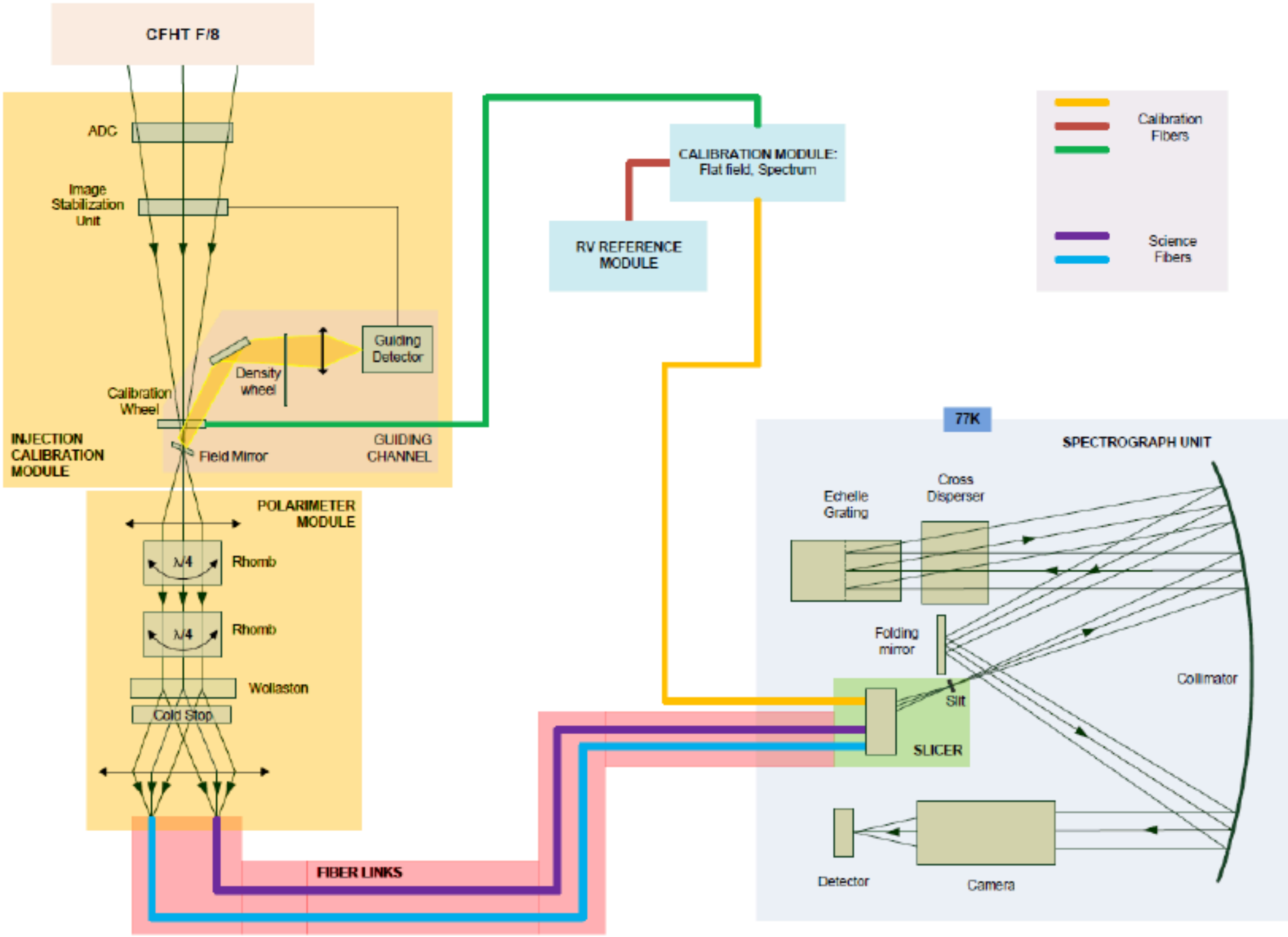
SPIRou in brief

An IR version of HARPS with spectro-polarimetry

- Simultaneous wavelength coverage: 0.98-2.35 μm
- Resolving power : 75 000
- **RV accuracy: 1 m/s**
  - **S/N~110, J=12**
- Sensitivity: H=14, 10 σ, 30 minutes.
- Achromatic polarimeter, <1% x-talk
  - Zeeman splitting scales as λ^2.

Wide λ coverage + polarimetry is key to mitigate/calibrate jitter noise.

An 8m-class instrument on a 4m class telescope



The SPIRou International Consortium

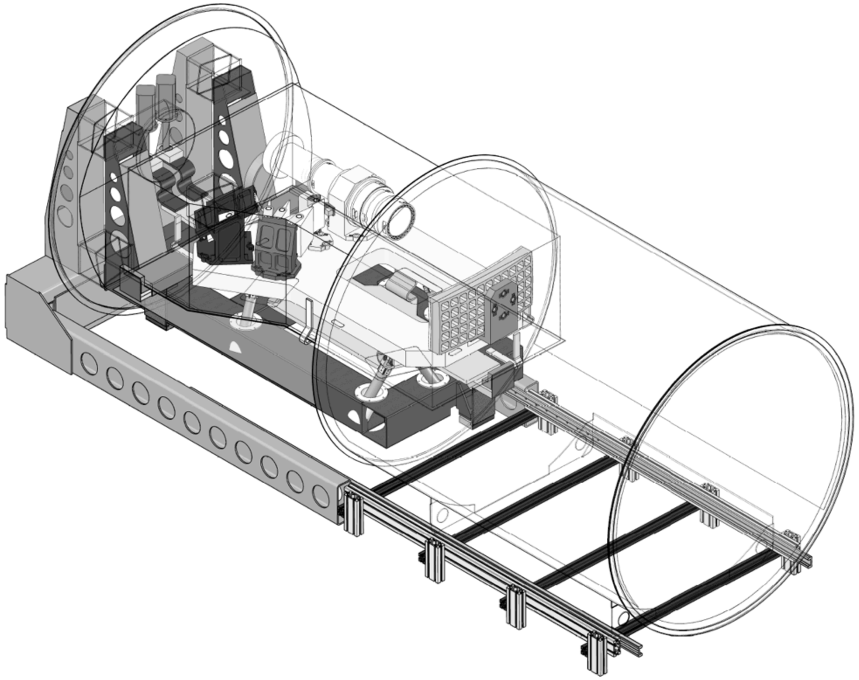
- IRAP (Toulouse)
  - Cassegrain unit, slicer, polarimeter, management, integration.
- IPAG (Grenoble)
  - Spectrograph optics.
- ASIAA (Taiwan)
  - Guiding camera
- Geneva (Switzerland)
  - Velocity reference module
- Université de Montréal/Laval (Canada)
  - Spectrograph camera, data simulation & reduction, optical design.
- HIA (Canada)
  - Cryogenic spectrograph, integration
- CFHT (Hawaii)
  - Instrument control, detector
- LAM/OHP (France)
  - Data reduction, calibration module

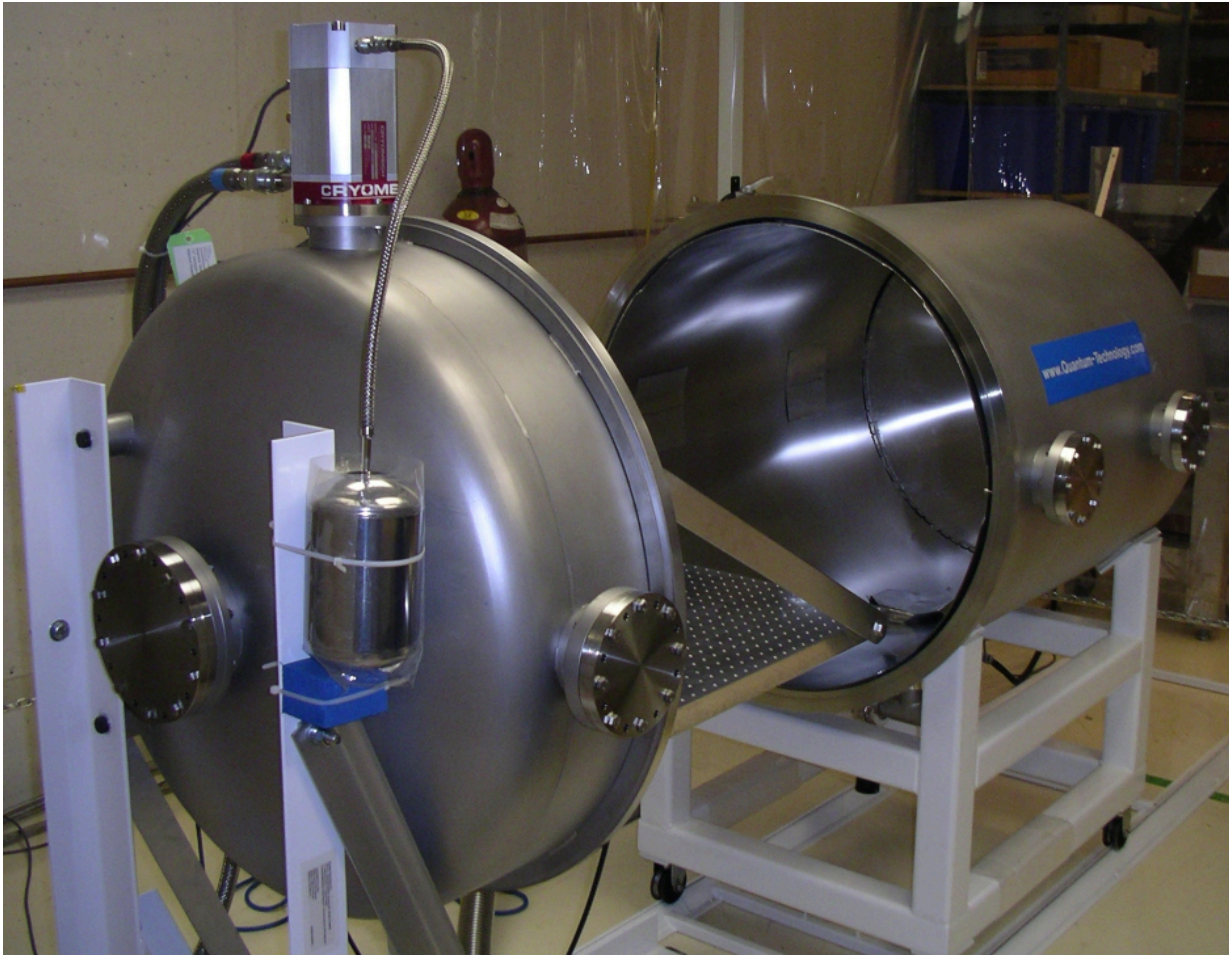
The SPIRou core team

- **PIs**: Jean-François Donati (France), René Doyon (Canada)
- **Project scientists**: Xavier Delfosse (France), Étienne Artigau (Canada)
- **System engineer**: Sébastien Baratchar
- **Projet manager**: Driss Kouach (IRAP) + local PMs at lead institutions
- **Science team**
  - Core of 13 + 80 (and growing) supporters in France, Canada, USA, Taiwan, Brazil, Switzerland, Italy, UK, & Sweden.

Spectrograph

- Cryogenic (80 K) spectrograph stabilized to a few mK
- Two cryocoolers
- Total mass: 1500 kg (490 cold)
- Dimension: a few meters across
- No moving part under science operation for increased RV stability (single mode of observations). Design very much inspired by HARPS.
- Third floor at CFHT (40 m)




CRYOME
www.Quantum-Technology.com

SPIRou's status

Sequence of events

- Mid-October 2012: PDR review in Waimea

Reviewers:
Chair - John Rayner (University of Hawaii, Honolulu)
David Harrington (University of Hawaii, Honolulu)
Gaspere Lo Curto (ESO, Garching)
Jim Thomas (CFHT, Waimea)
Doug Toomey (Mauna Kea Infrared, Hilo)
Gordon Walker (University of British Columbia, Vancouver)

- Nov. 2nd 2012. PDR detailed panel report.
- Nov. 14th 2012. SPIRou team response.
- Nov. 19-20th 2012. SAC meeting.

Main technical issue identified at PDR

- Echelle grating procurement/choice (R2 vs R4)
  - The baseline R2 design has low-risk (off-the-shelf) but sampling is not « optimal » and requires a (pupil) slicer.
    - Analysis and tests were presented at PDR to show that this baseline design *should* be fine.
  - The R4 has more sampling margin, no slicer, better compatibility with a Gemini link but it does not exist.
  - SPIRou team initiated a R4 prototyping activity to assess feasibility. Prototype result was not available at PDR. Prototype was received mid-March.

R4 prototype performance

Current status

- Work activities have slowed down on several fronts but the project *is not* stalled.
- Project runs on (limited) internal funds.
- R2 now identified as the baseline echelle grating.
- H4RG procurement risk has lowered since PDR TIS has firm orders of 4 H4RG-15 for delivery in 2014.
- Moving on to detailed FDR design.
- Several funding proposals prepared and submitted on the French side.
  - Goal is to secure 75% of the funding, the rest to be requested through CFHT's call for proposals.
- Most of the SPIRou sub-systems expected to be at FDR level near the end of this year.

SPIRou's key science questions

- What is the prevalence of habitable planets around low-mass stars?
  - Determine $\eta_{\oplus}$ for M dwarfs.
  - Characterize new super-Earths found through transit searches (e.g. TESS)
  - Identify suitable/credible targets for transit spectroscopy follow-up with JWST/ELT

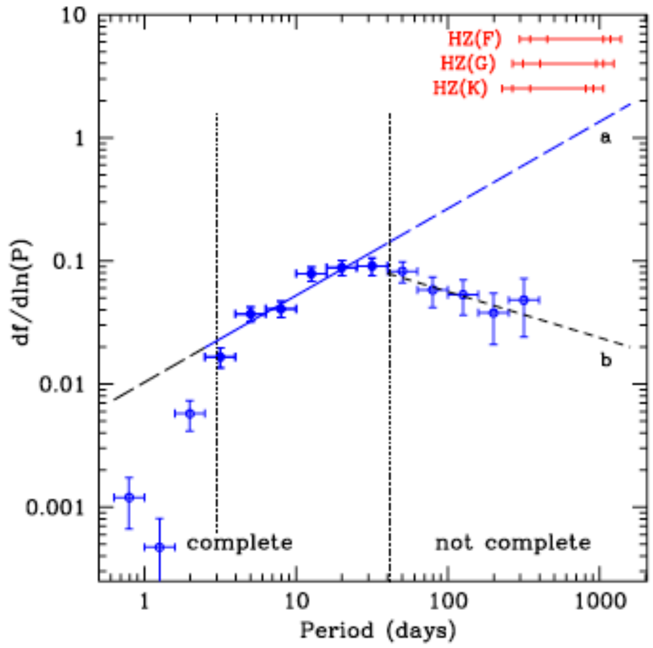
- How do stars/planets form and evolve ?
  - What is the role of magnetic field, especially in young embedded stars?
- And much much more !

$$\eta_{\oplus}$$

Fraction of stars with a terrestrial planet within the habitable zone?

Exoplanet frequency – Kepler data

- Relevant sample: FGK stars
- From extrapolation of the short period transiting population.



$$\eta_{\oplus} \simeq 0.34 \pm 0.14$$

$$\eta_{\oplus} \simeq (1-3)\%$$

Traub 2012

Exoplanet frequency – RV data

- HARPS survey of 100 M stars (Bonfils et al, 2011)
- 10 nights/yr over 6 yrs: 14 detections.

$$\eta_\oplus \simeq 0.41^{+0.54}_{-0.13}$$

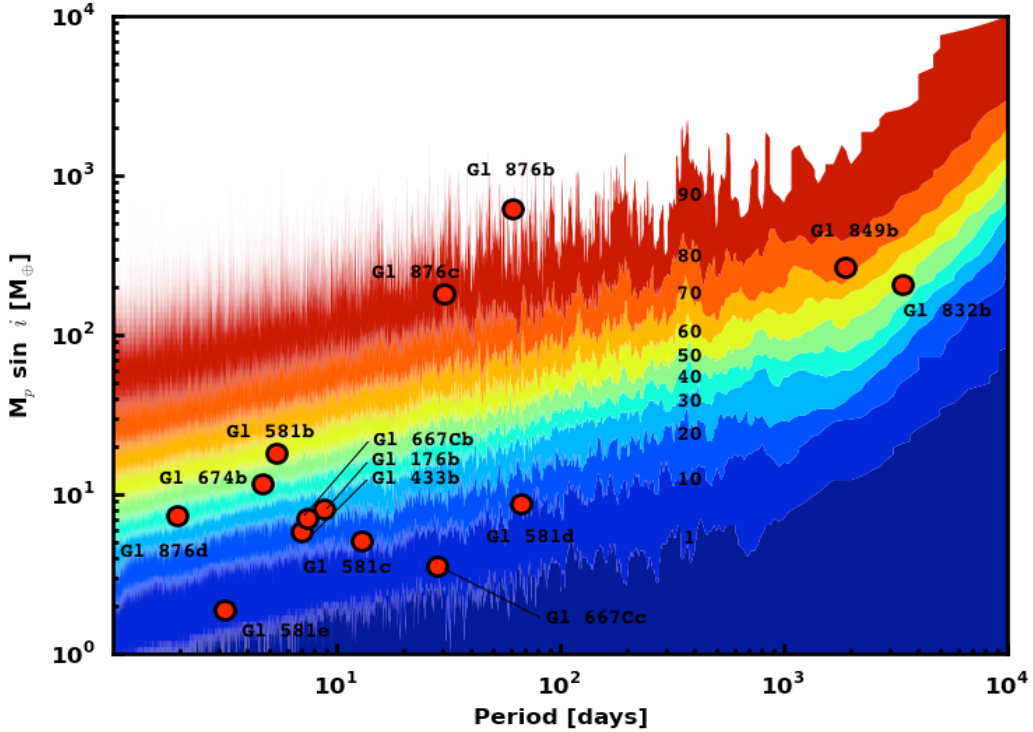
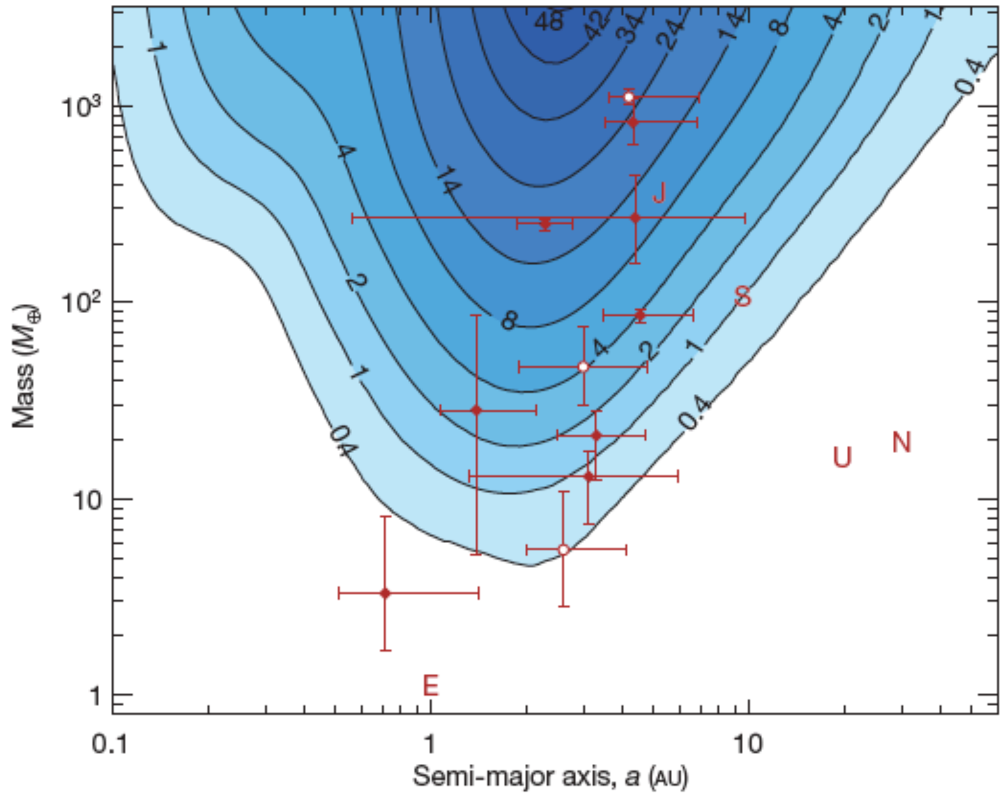


Fig. 15. Survey sensitivity derived from the combined phase-averaged detection limits on individual stars. Iso-contours are shown for 1, 10, 20, 30, 40, 50, 60, 70, 80 and 90 stars. Planet detected or confirmed by our survey are reported by red circles and labeled by their names.

Exoplanet frequency – lensing

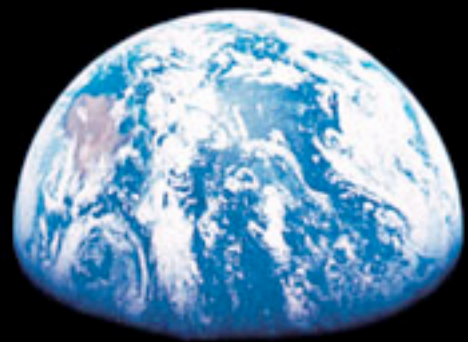


Cassan et al, 2011.

- Super-Earth frequency betwen 0.5 and 10 AUs: $f \simeq 0.62^{+0.35}_{-0.37}$
- On average every star has $1.6^{+0.72}_{-0.89}$ planets.

There are lots of planets, especially small ones.

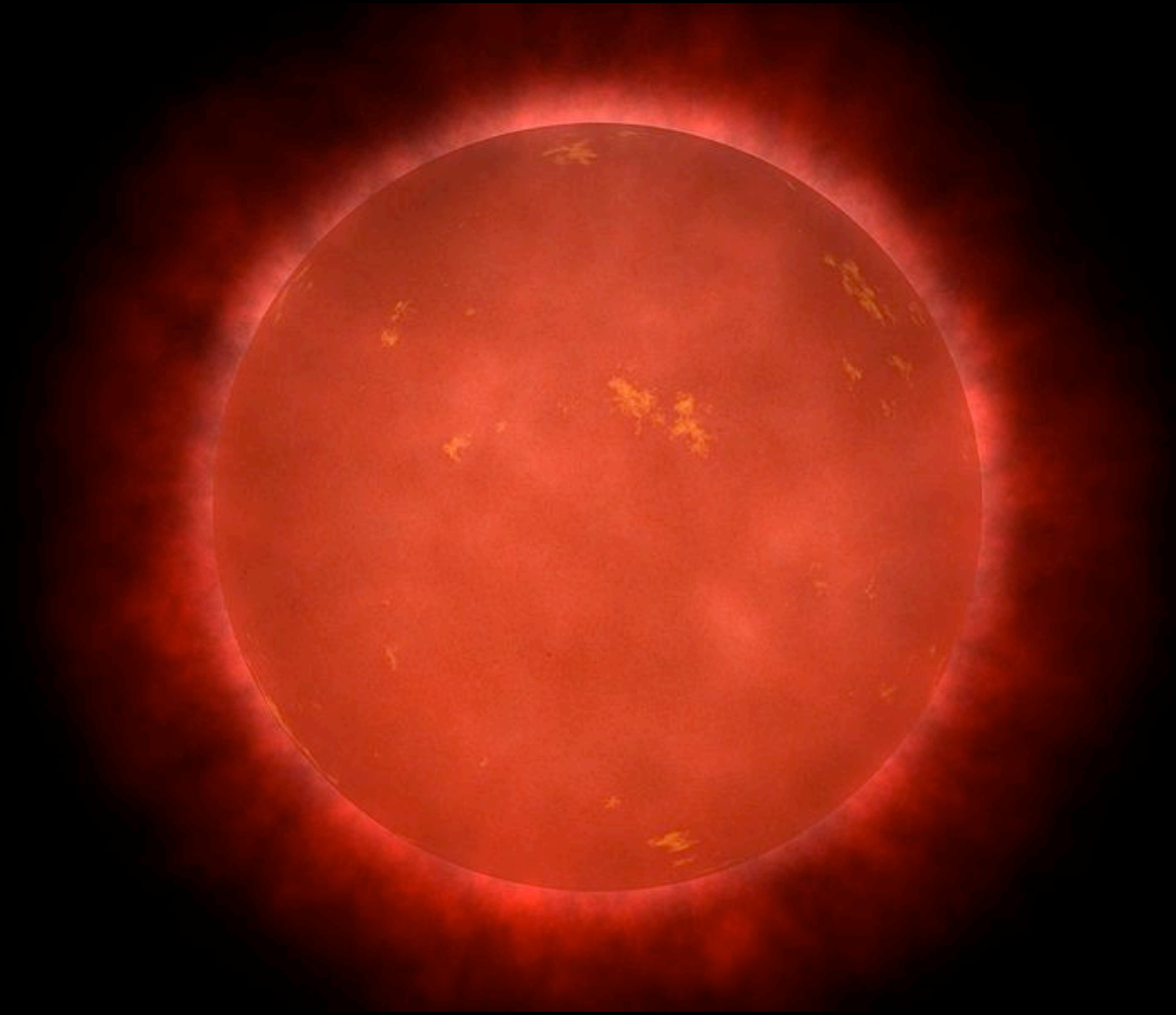
The ultimate quest



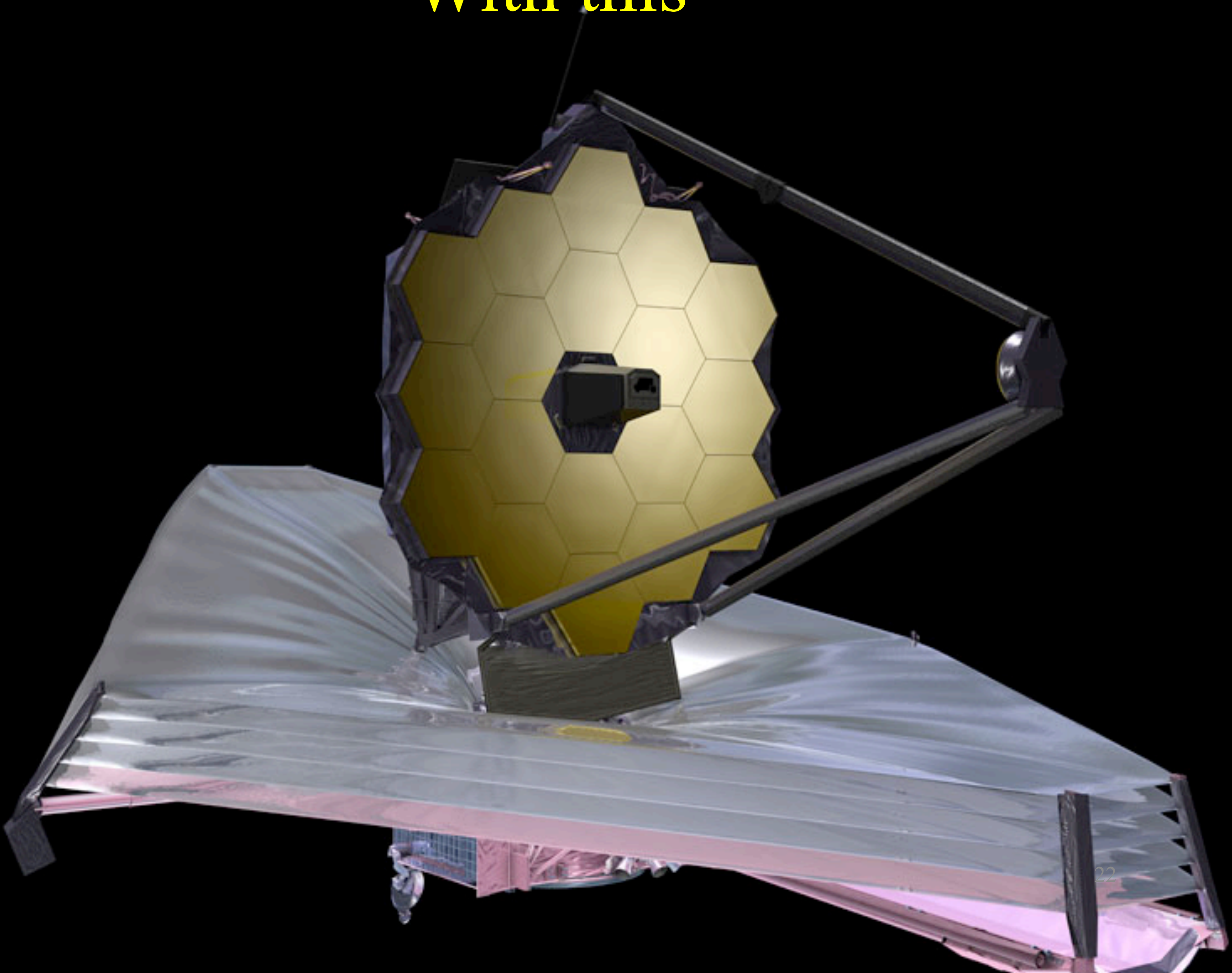
Roadmap to life

- Detect an Earth-like planet in the habitable zone
- Measure its mass (RV) and radius (transit)
- Probe its atmosphere for water and bio-markers

Our best shot: M dwarfs

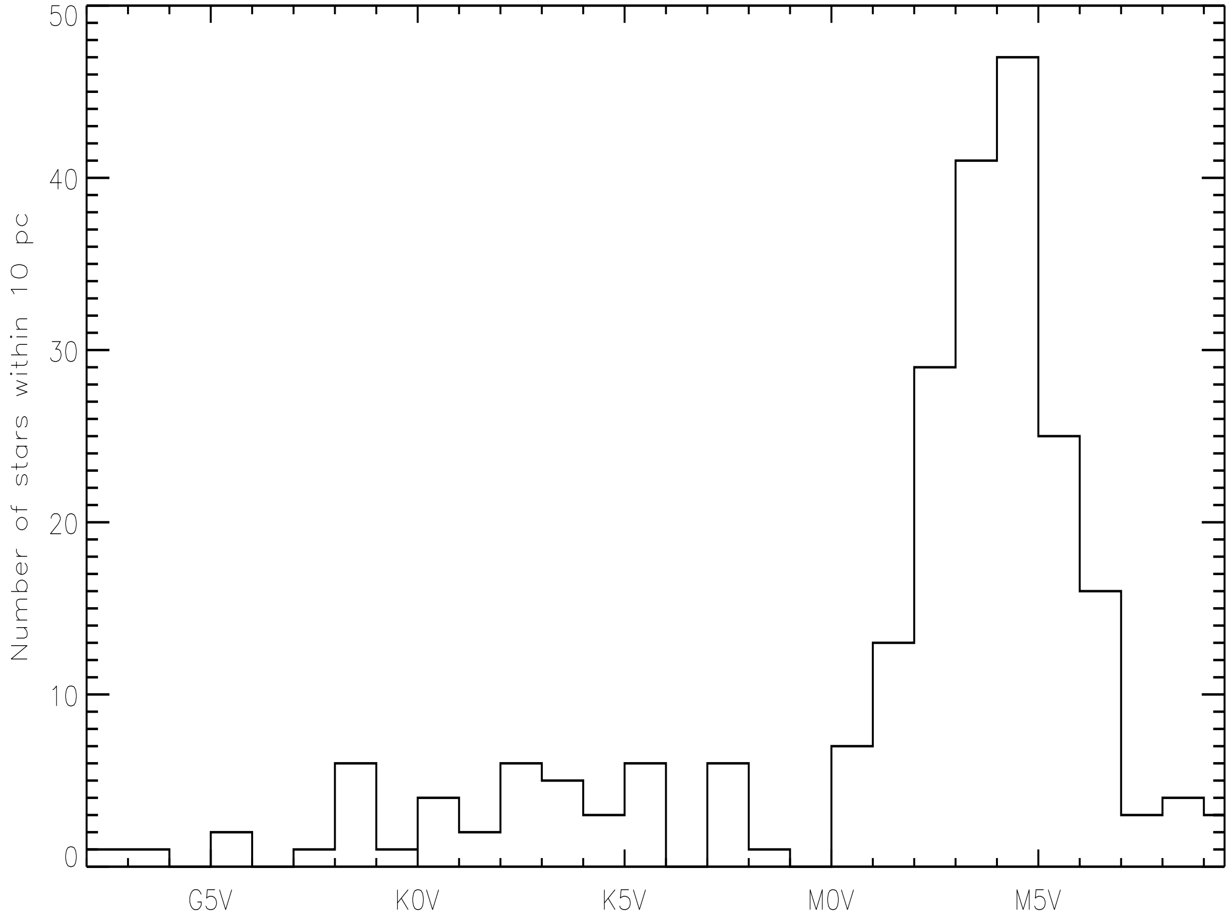


With this

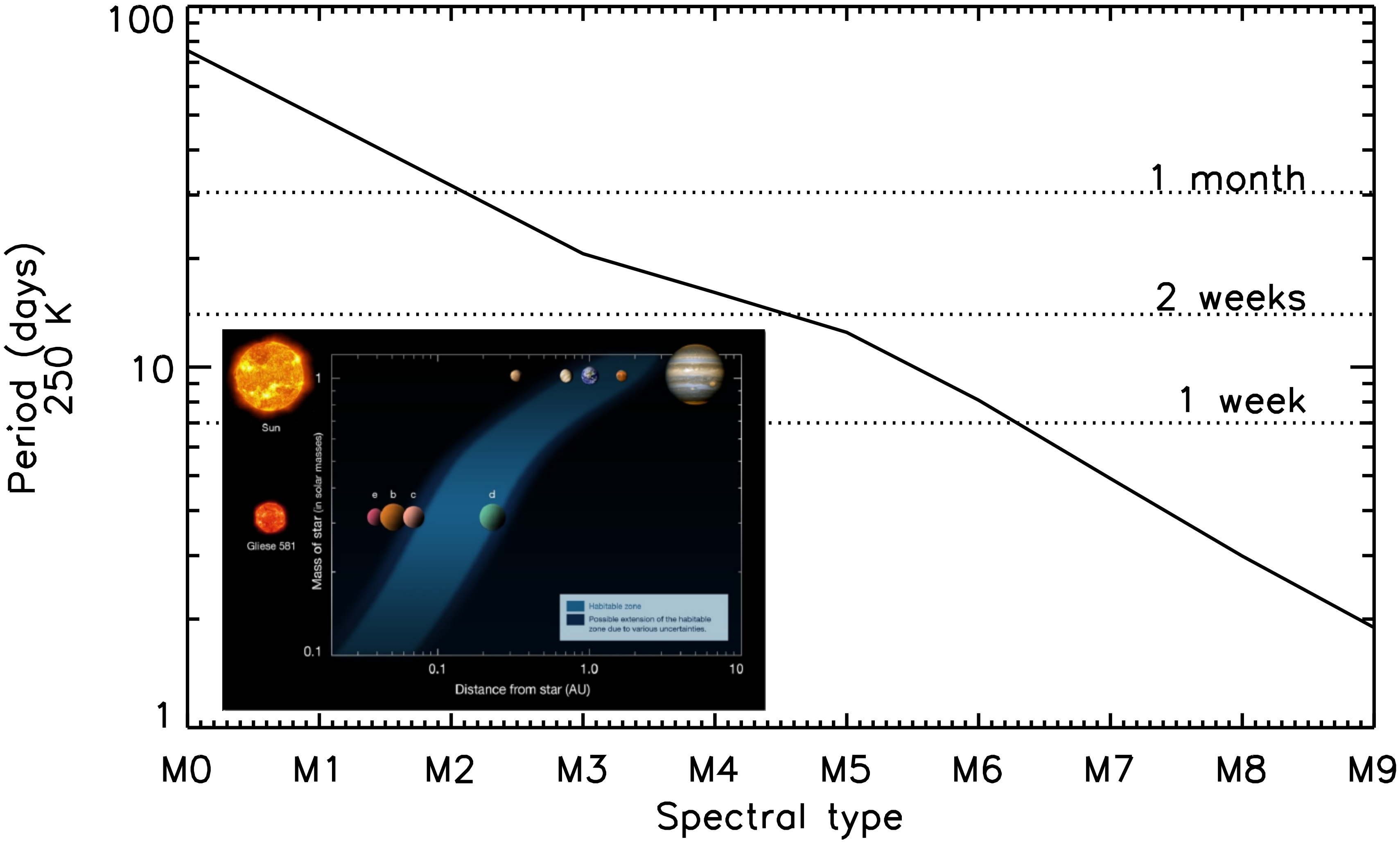


There are lots of them!

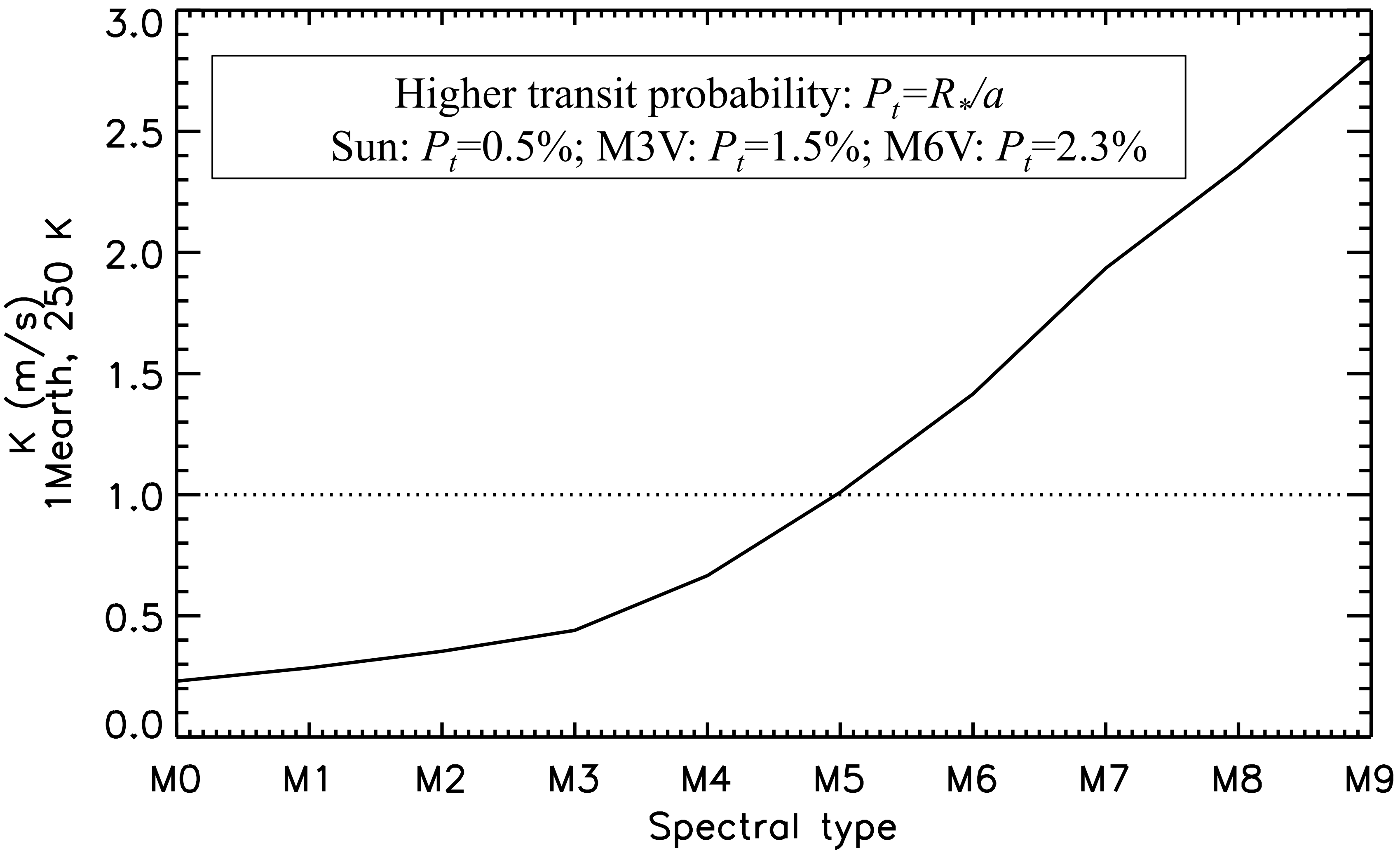
The most typical star in the Galaxy is a M3V (M~0.3 $M_\odot$)



Orbital periods in the HZ measured in weeks, not years



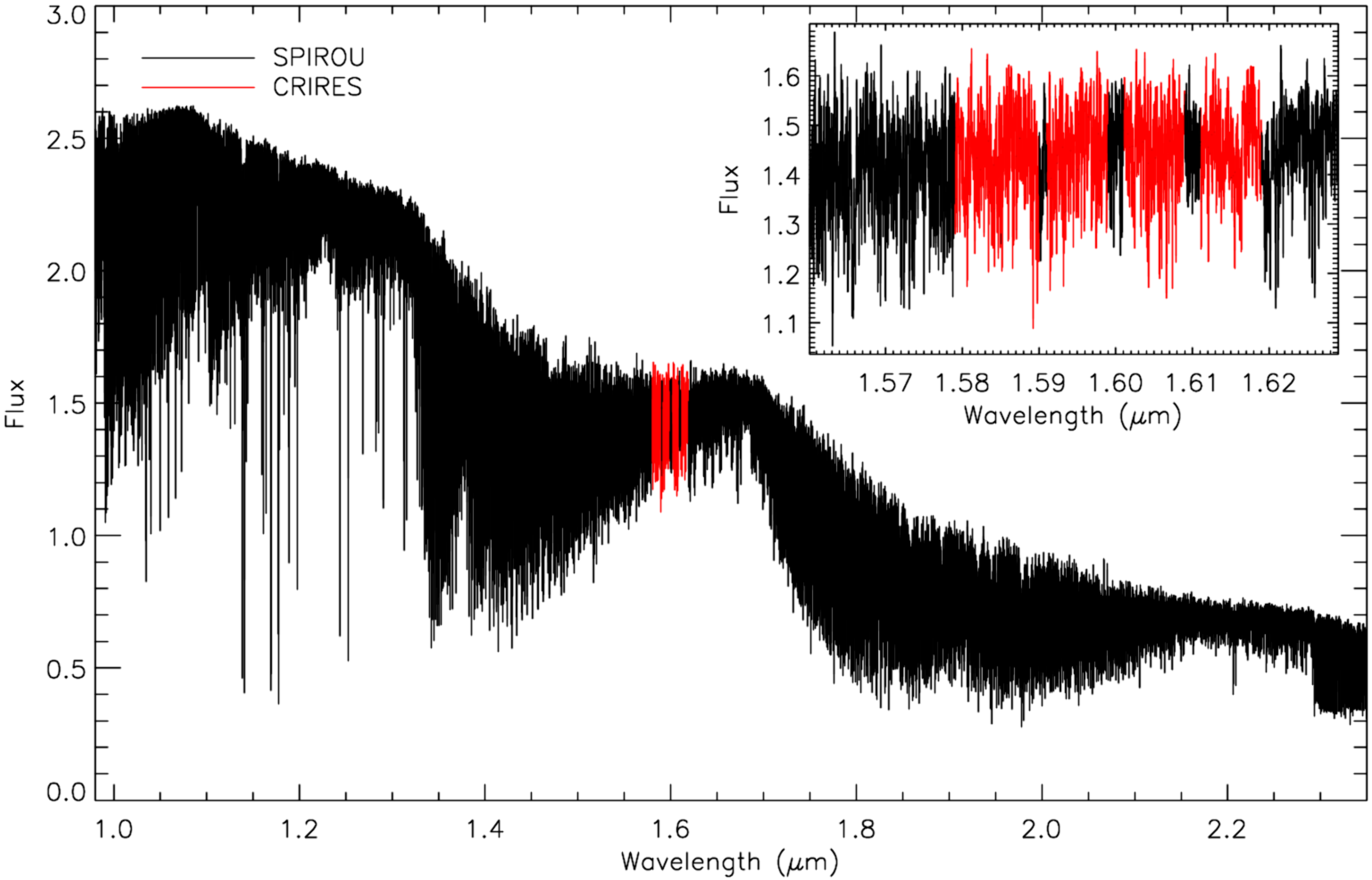
The RV signal is relatively strong



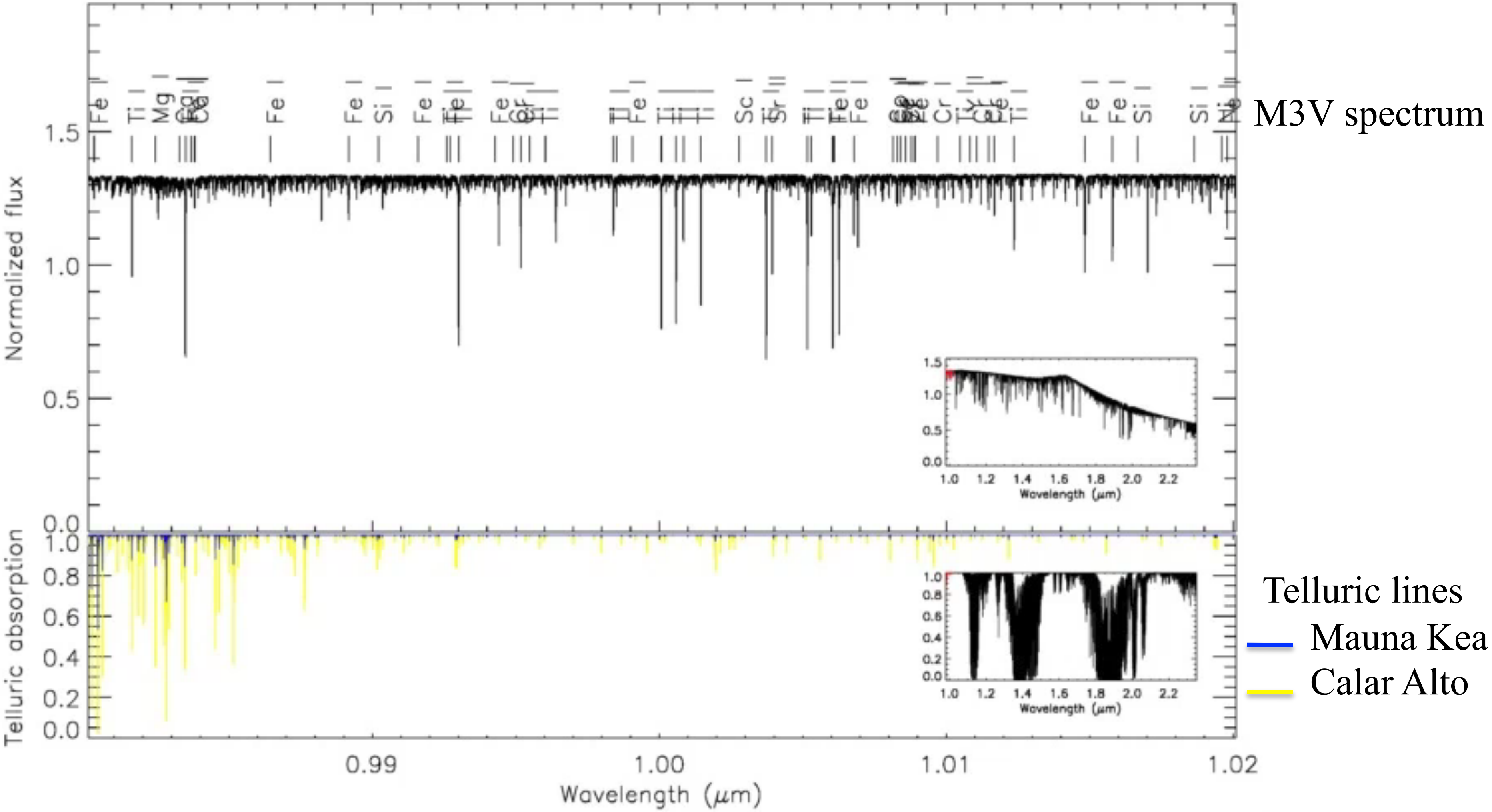
But...

- M dwarfs are faint.
  - Observations in the IR absolutely required especially for late Ms.
- M dwarfs are active. They are fully convective and show significant magnetic activity (stellar spots)
  - Source of jitter noise for the RV signal. Jitter noise is 4-5 smaller in the IR compared to the visible.
- RV at IR wavelengths is more complicated
  - Lots of telluric lines to deal with.
  - Instrumentation is more complex (cryogenic) i.e. expensive.

SPIROU *vs* CRIRES (VLT)

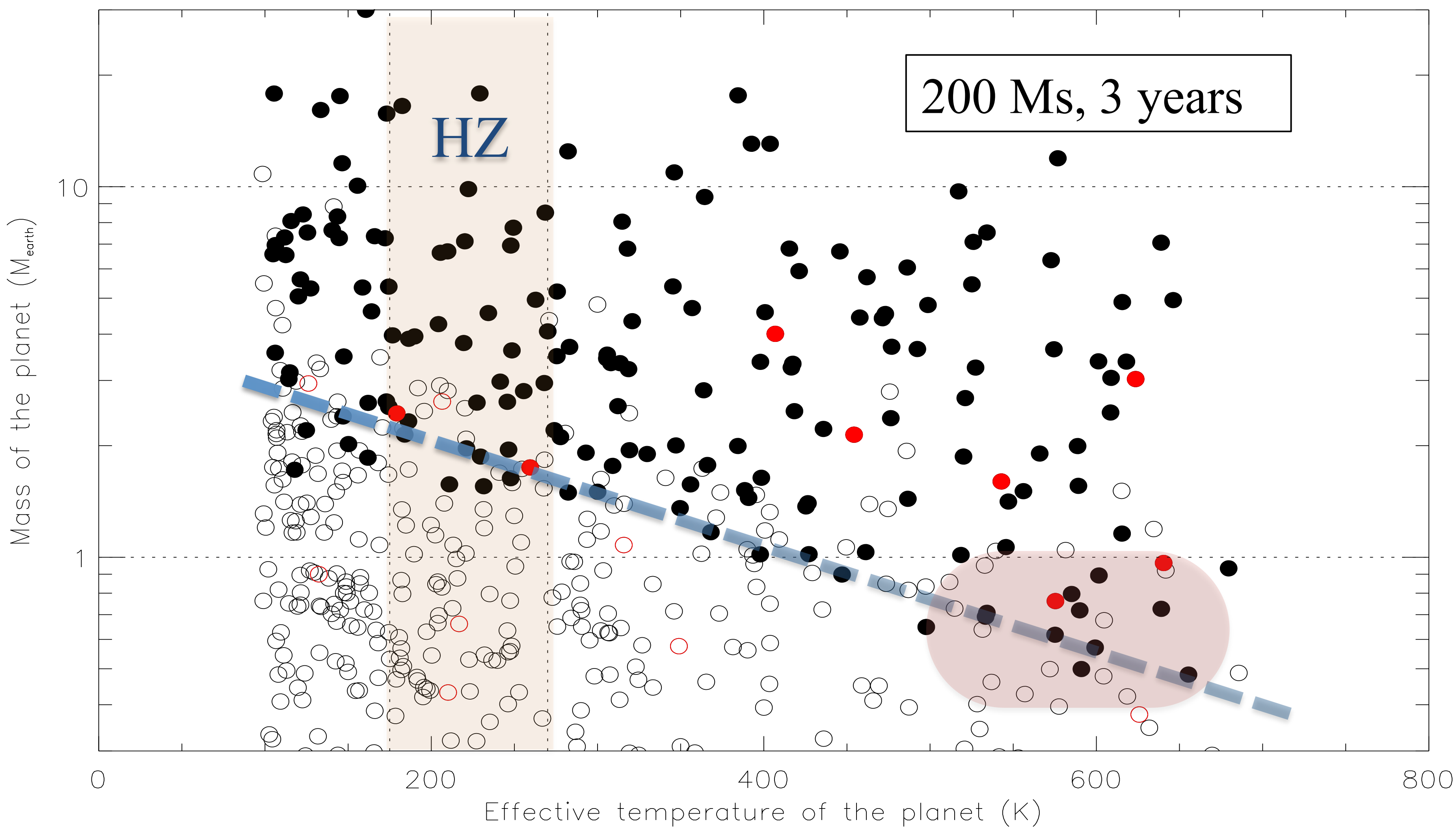


A spectrum is worth a thousand pictures!



A Strawman Exoplanet Legacy Survey

- Monte-Carlo simulation with the following assumptions
  - 308 nights over 3 years (217 clear nights)
  - Sample: 200 M3V to M7V (real sample)
  - Average number of visits per star: ~60
    - Based on experience.
  - Planet frequency drawn from early results by HARPS team (Bonfils et al, 2011)
    - Log flat distribution in period
    - Log-normal distribution in mass to match observations.
      - Large number of sub-Earth mass planets



- ~59 visits per star
- 180 planets detected
- Sample of >500K, sub-Earths

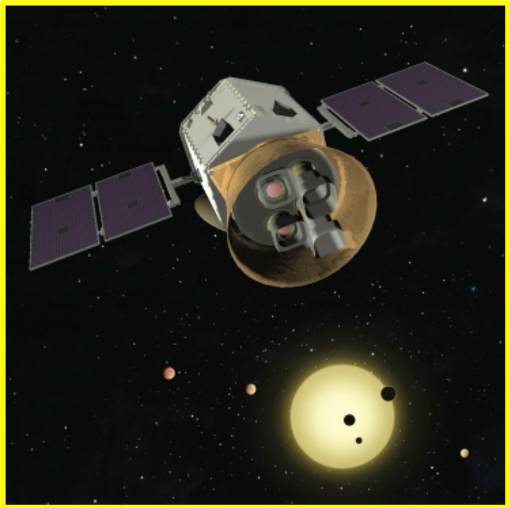
- Transiting planets: ~7
- <5 $M_\oplus$ transiting planets: ~6
- HZ transiting planets: ~0.5

Many more science programs with SPIRou

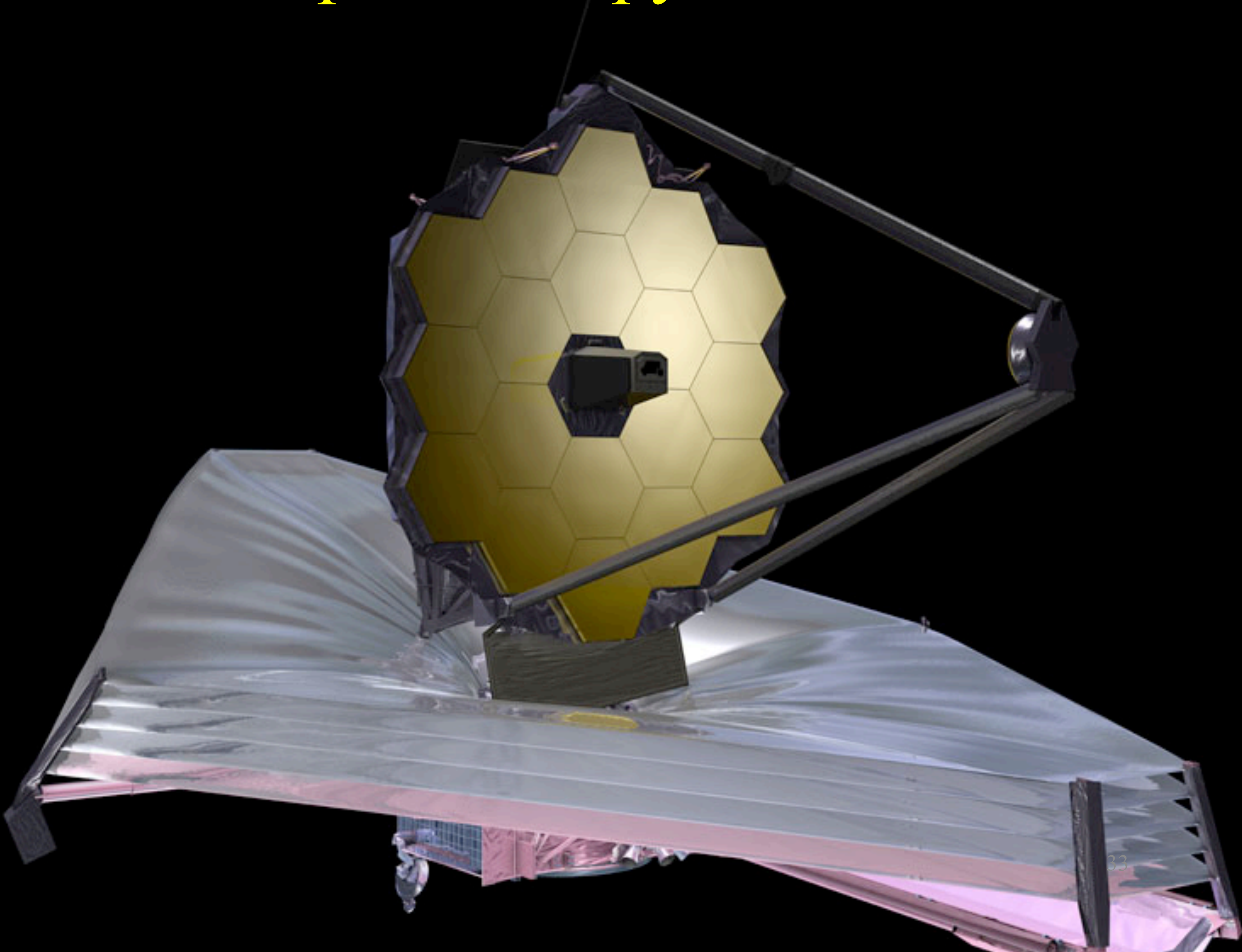
- Magnetic field of protostars and accretion disks
  - Second main SPIRou science programs
- Chemistry, kinematics & geometry of circumstellar environments
- Dynamo process in red and brown dwarfs
- Weather pattern in brown dwarfs
  - Through Doppler imaging
- Properties of stellar star spots
- Ultra-cool spectroscopic binaries
- Solar system planets
  - Airglow and aurorae
  - Chemistry & atmospheric wind
- Follow-up of transit candidates from other surveys
- Exoplanet atmosphere
  - Close-in exoplanets
  - Free-floating exoplanets
- Kinematics of young stars and brown dwarfs
- ….

New key development : TESS (NASA)

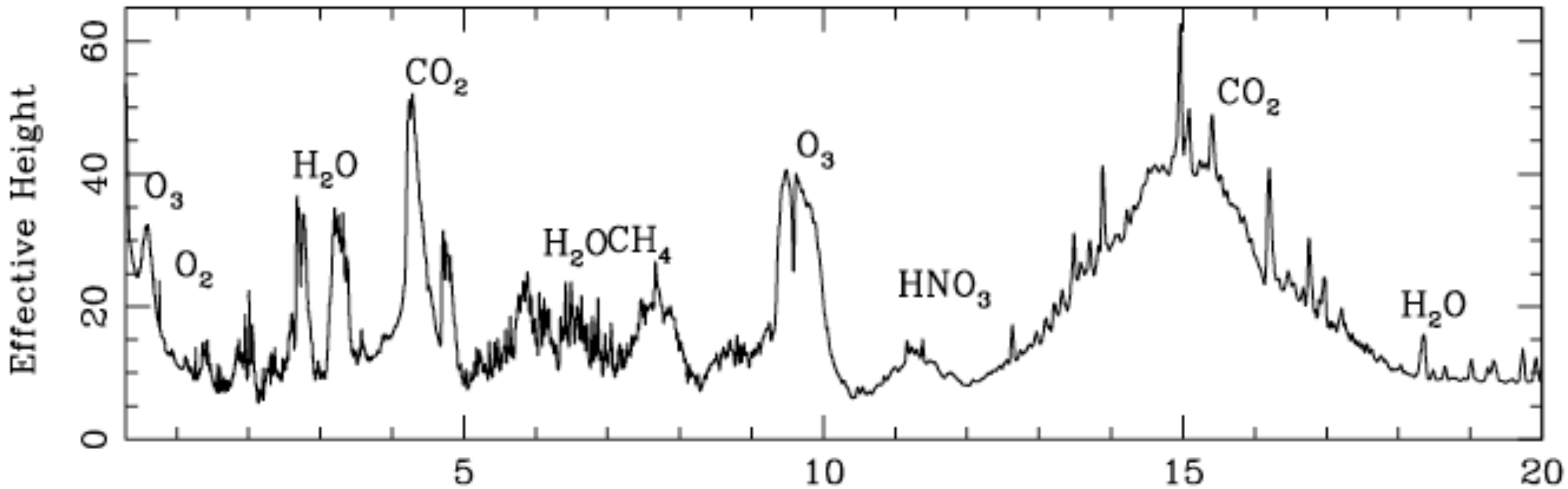
- All sky transit survey of nearby bright stars
  - P < ~72 days (HZ later than ~ M0V)
- Two-year mission
- Launch: 2017
- Will find ~300 super-Earths within 35 pc
  - Only ~90 could be followed-up with HARPS



Transit spectroscopy with JWST

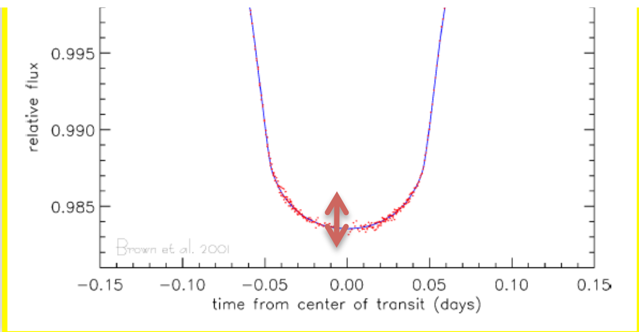


Probing exoplanet atmospheres through transit spectroscopy



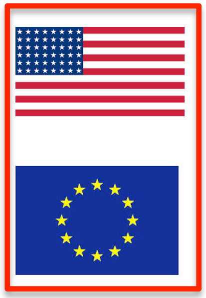
$$\left(\frac{\Delta f}{f}\right)_{atmo} \approx 10\frac{R_p H(\lambda)}{R_\star^2}$$

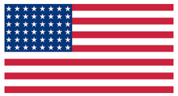
$$H = kT/\mu g$$

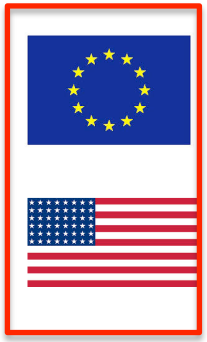


A powerful machine for transit spectroscopy

Instrument	Mode	Resolving power	Wavelength range (μm)
NIRISS	Grism, cross-dispersed, slit-less	700	0.6 - 2.5
NIRSpec	Prism, wide slit (1.6”)	100	1.0 - 5.0
	Grating, wide slit (1.6”)	1000 or 2700	1.0 - 1.8 1.7 - 3.0 2.9 - 5.0
NIRCam	Grism, slit-less	2000	2.4 - 5.0
MIRI	Prism, 0.6” slit or slit-less	100	5.0 - 11.0
	IFU (0.2” - 0.27”/pixel)	2400 - 3600	5.0 - 7.7 7.7 - 11.9 11.9- 18.3 18.3 - 28.3

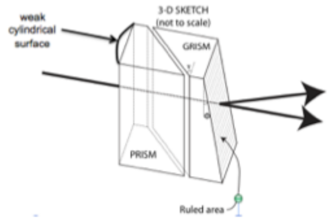






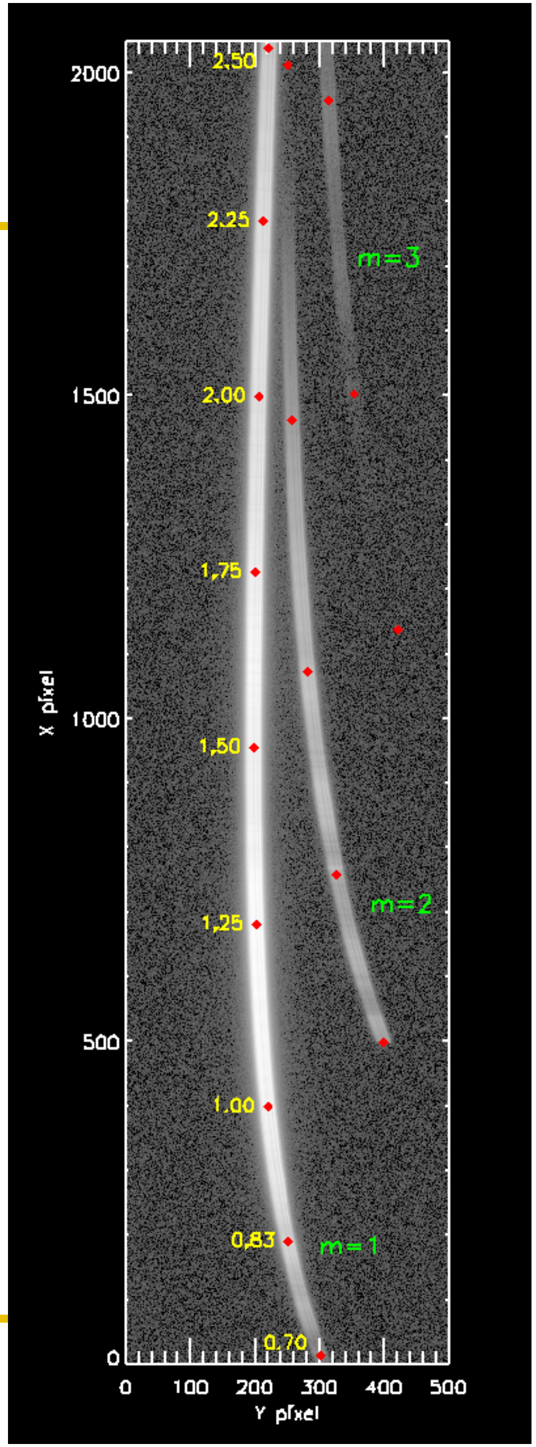
NIRISS grism spectroscopy

- Slit-less → less systematics (no slit effects)
- Cross-dispersed → both good resolution and wide spectral coverage



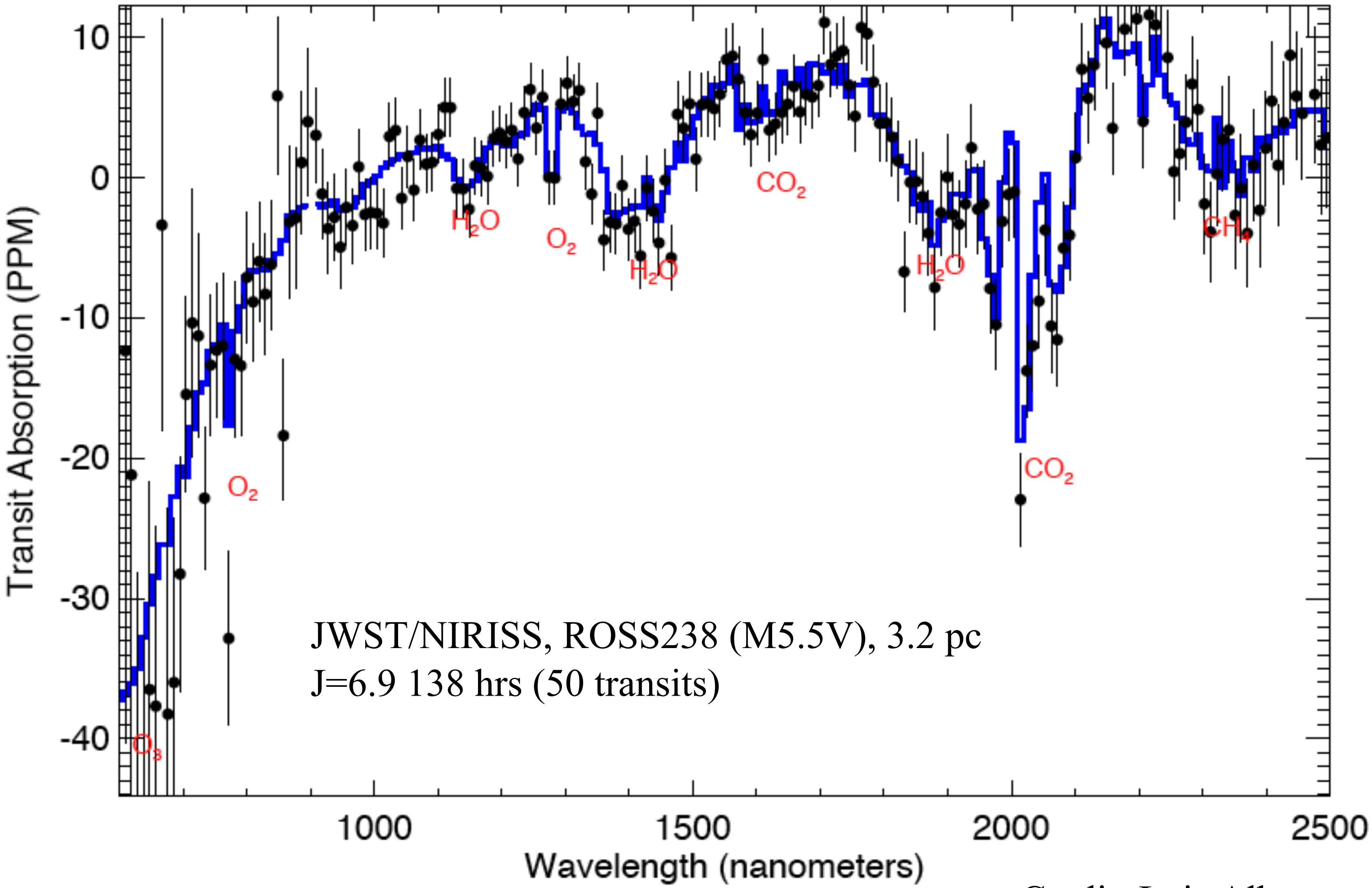
- Cylindrical surface on prism imparts a 25-pixel defocus in spatial direction only
  - Brighter saturation limit (J=6) → best photon noise limits
  - Signal spread over more pixels → less systematic errors

- Detector pixel response and stability (will be) characterized → less systematic errors



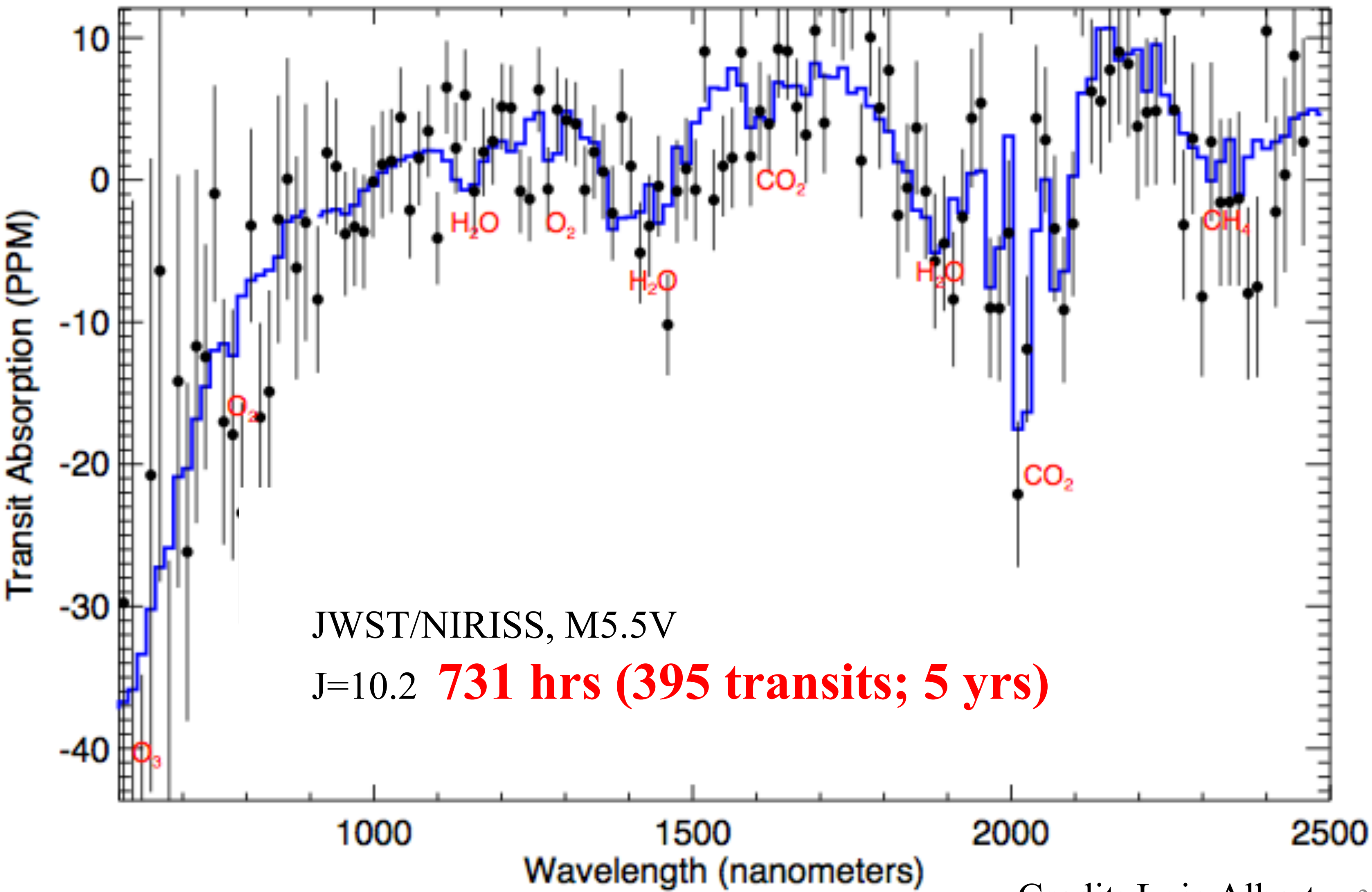
Will Webb find bio-markers?

An Earth analog around an M Dwarf

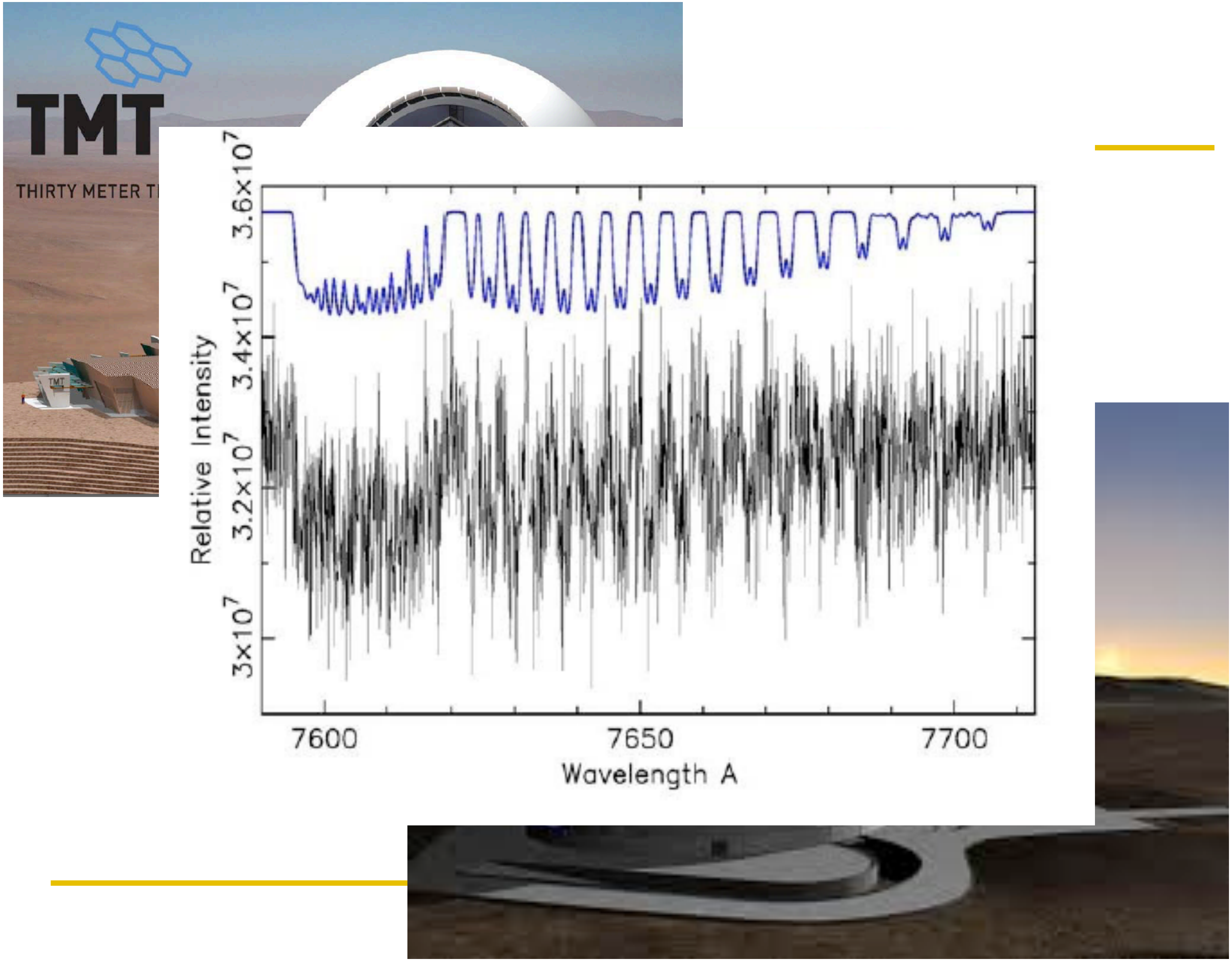


Credit: Loic Albert

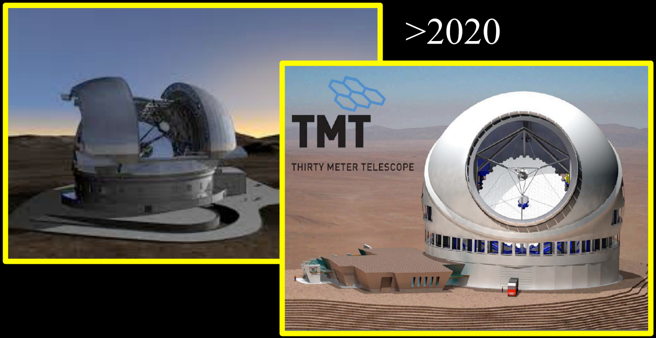
A more realistic case (M5V @ 15 pc) - Pushing Webb to its limit



Credit: Loic Albert

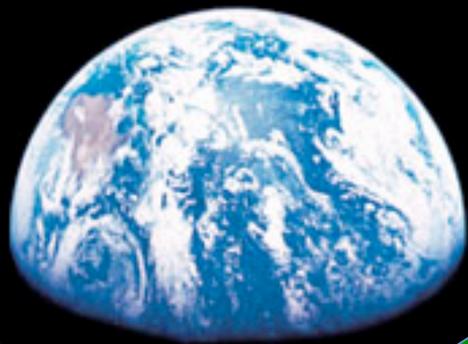

TMT
Relative Intensity
3×10^7
3.2×10^7
3.4×10^7
3.6×10^7
7600
7650
7700
Wavelength A

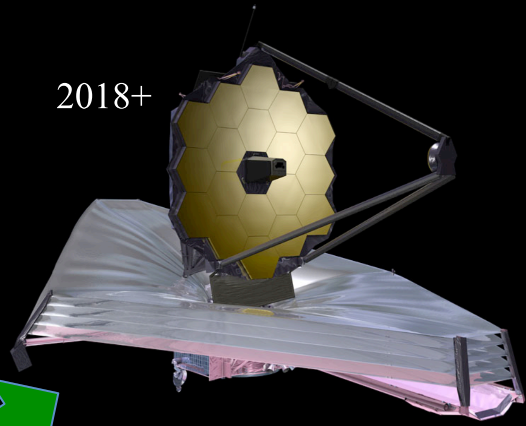
SPIRou and the Big (Science) Picture



>2020

Transit spectroscopy follow-up

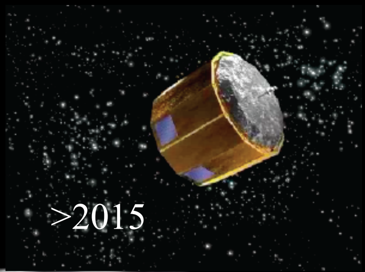




2018+

Transit spectroscopy follow-up

The GAIA Tsunami



2017

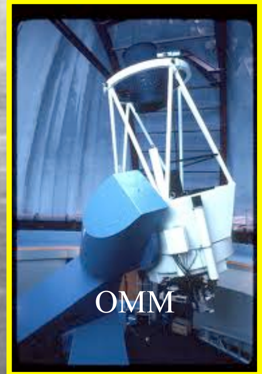
SPIRou

~0.3-1 planet/night

Transit confirmation follow-up
on 1m class telescopes

All-sky transit survey

Transit follow-up



TRAPPIST

Many

Arctic telescope ?

4. Are we alone?

For millennia people have speculated that we are not alone in the Universe. More than 2,500 years ago, the Greek philosophers Thales and Anaximander postulated that intelligent beings inhabit planets around other stars, and Giordano Bruno was burned at the stake only four centuries ago, in part for holding such beliefs.

What would the discovery of intelligent life elsewhere in the Universe mean for humans? Such a discovery has the potential to revolutionize society. The detection of life elsewhere in the Universe is a far-reaching goal of modern science, involving all of the natural sciences – from biology to astrophysics. The detection of extraterrestrial life would lead to an understanding of how life originated on Earth, and under what conditions it could evolve on other planets.

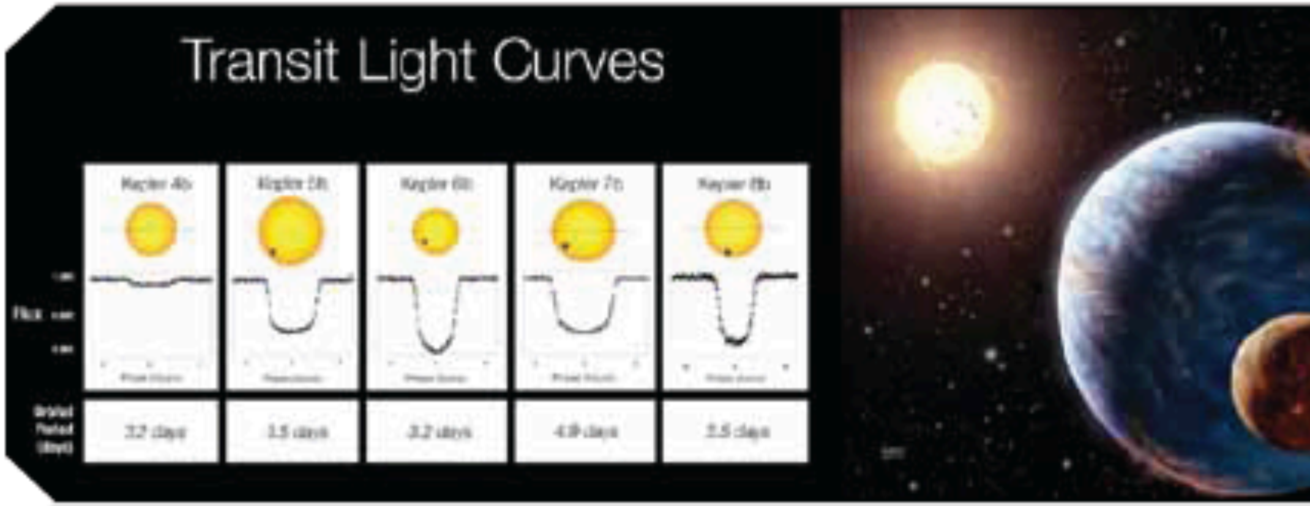


Figure 2-7. (Left) Planetary transits observed by the Kepler satellite [NASA/Kepler]. (Right) Artist's conception of an extra-solar planetary system. [NASA/Tim Pyle]

The first step in the quest for life in the Universe is the discovery of planets, and, in particular, Earth-like planets in the so-called "habitable zone" around other stars. Just twenty years ago, *no* planets were known outside the solar system. Using techniques developed by Canadians with the Canada-France-Hawaii Telescope (and prototyped with the NRC-HIA

radio signal searches with large ra
telescopes such as the SKA pathfi
and with SKA itself in the next de

The search for signatures of life th
makes a major contribution to wh
increasingly one of the most impo
questions, and explorations, in all
science – not just astronomy.


Merci