SPIRou @ CFHT

Exploring New Worlds Beyond the Solar System

SPiRou

JF Donati + the SPIRou engineering & science teams

SPIRou

Main Science Goals

planetary systems around nearby M dwarfs

detect & characterize planetary systems & habitability
model & filter activity to optimize detection
synergy w/ TESS, JWST, PLATO, CHEOPS, ELT…

magnetized star & planet formation

magnetic topologies of young stars & discs
young close-in giant planets / hot Jupiters
synergy w/ ALMA, SPHERE, JWST

many more science programmes

eg brown dwarfs, Solar System, ISM, galactic archeology

SPIRou Legacy Survey

300 CFHT nights over 4 years on two main topics

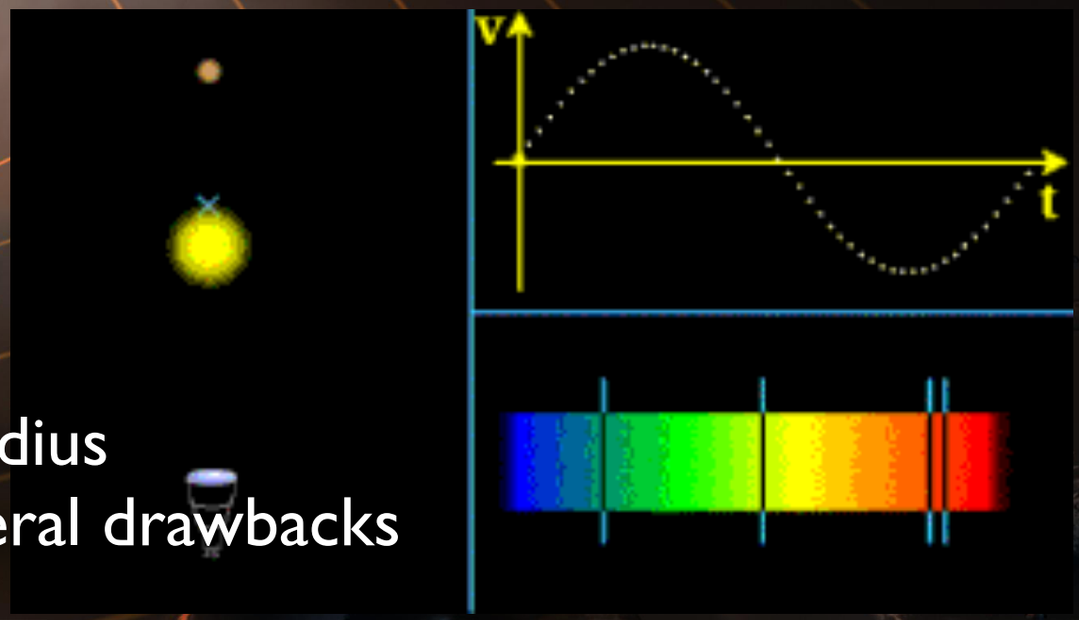
SPIRou

Detecting exoplanets

SPiRou

velocimetry

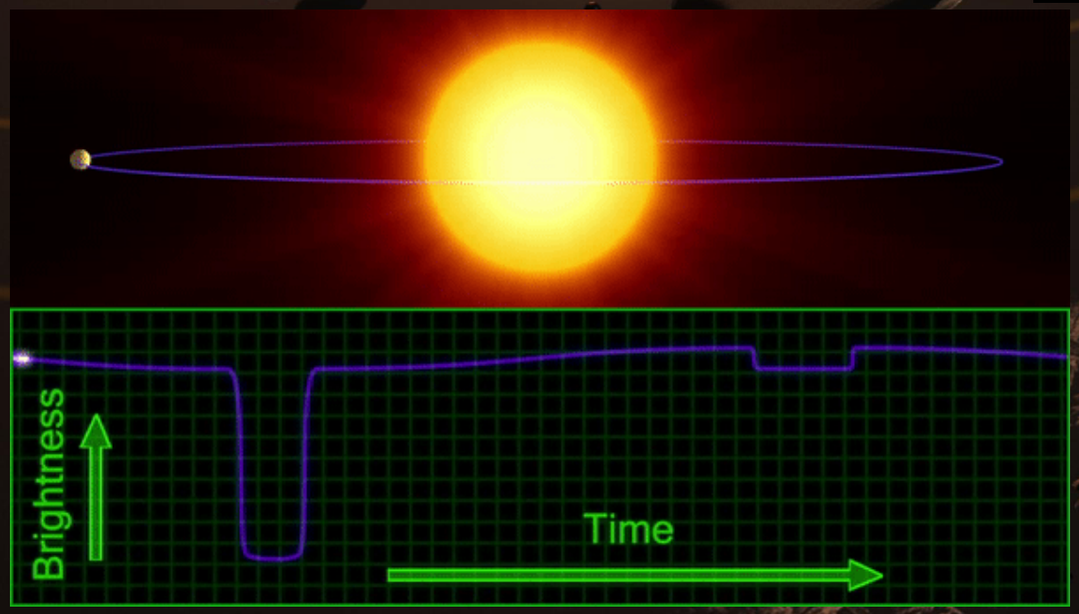
reflex motion > planet mass



photometry

planetary transits > planet radius

lots of detection despite several drawbacks



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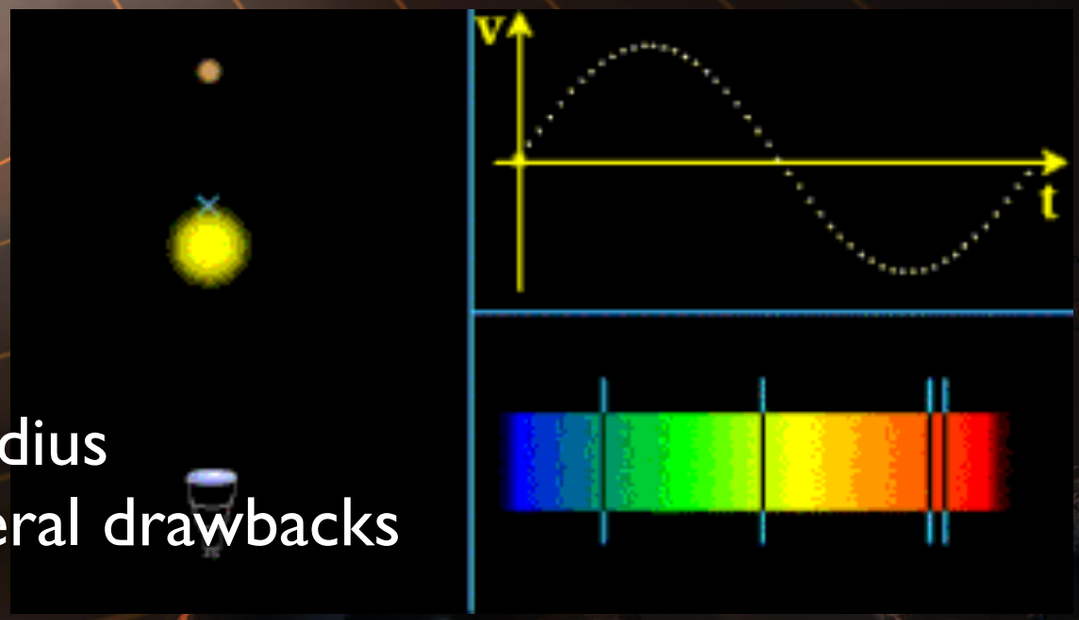
Detecting exoplanets

SPiRou

velocimetry

reflex motion > planet mass



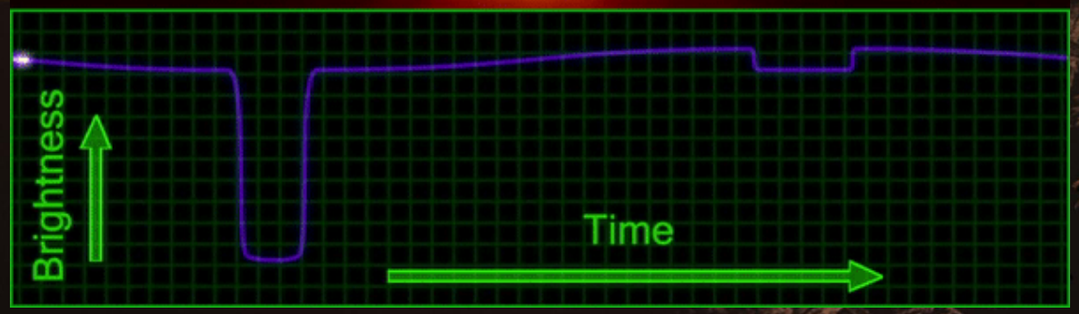
photometry

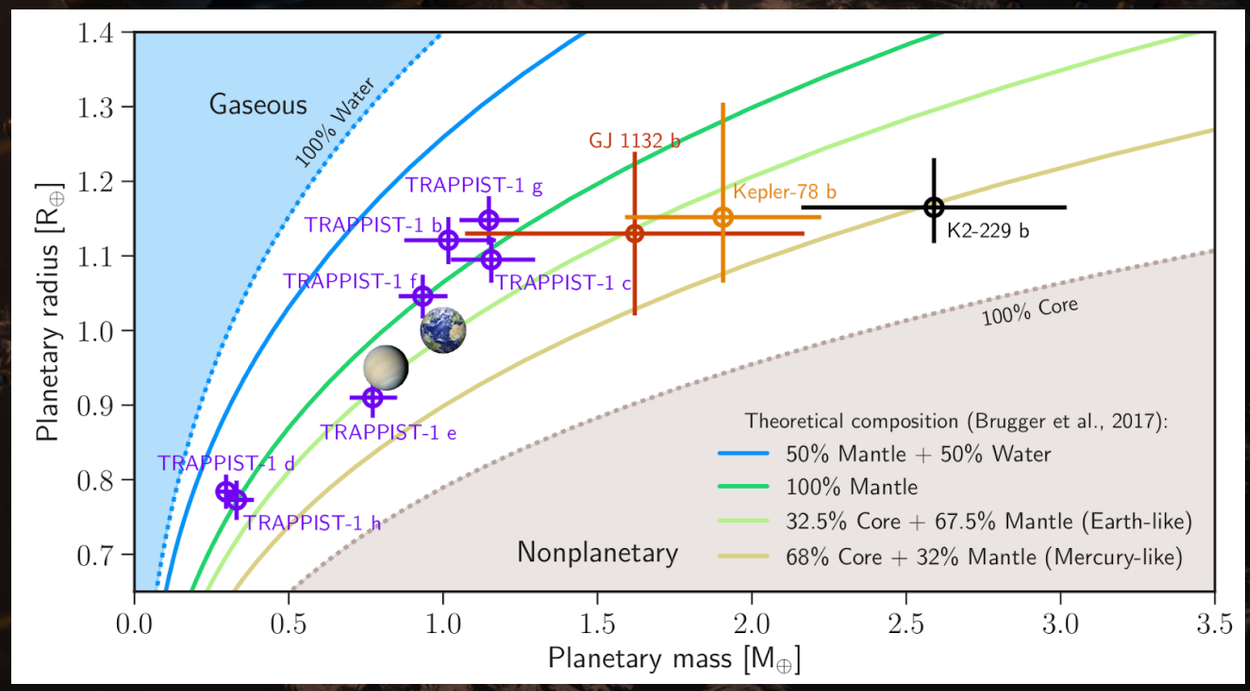
planetary transits > planet radius

lots of detection despite several drawbacks

both

planet density & structure

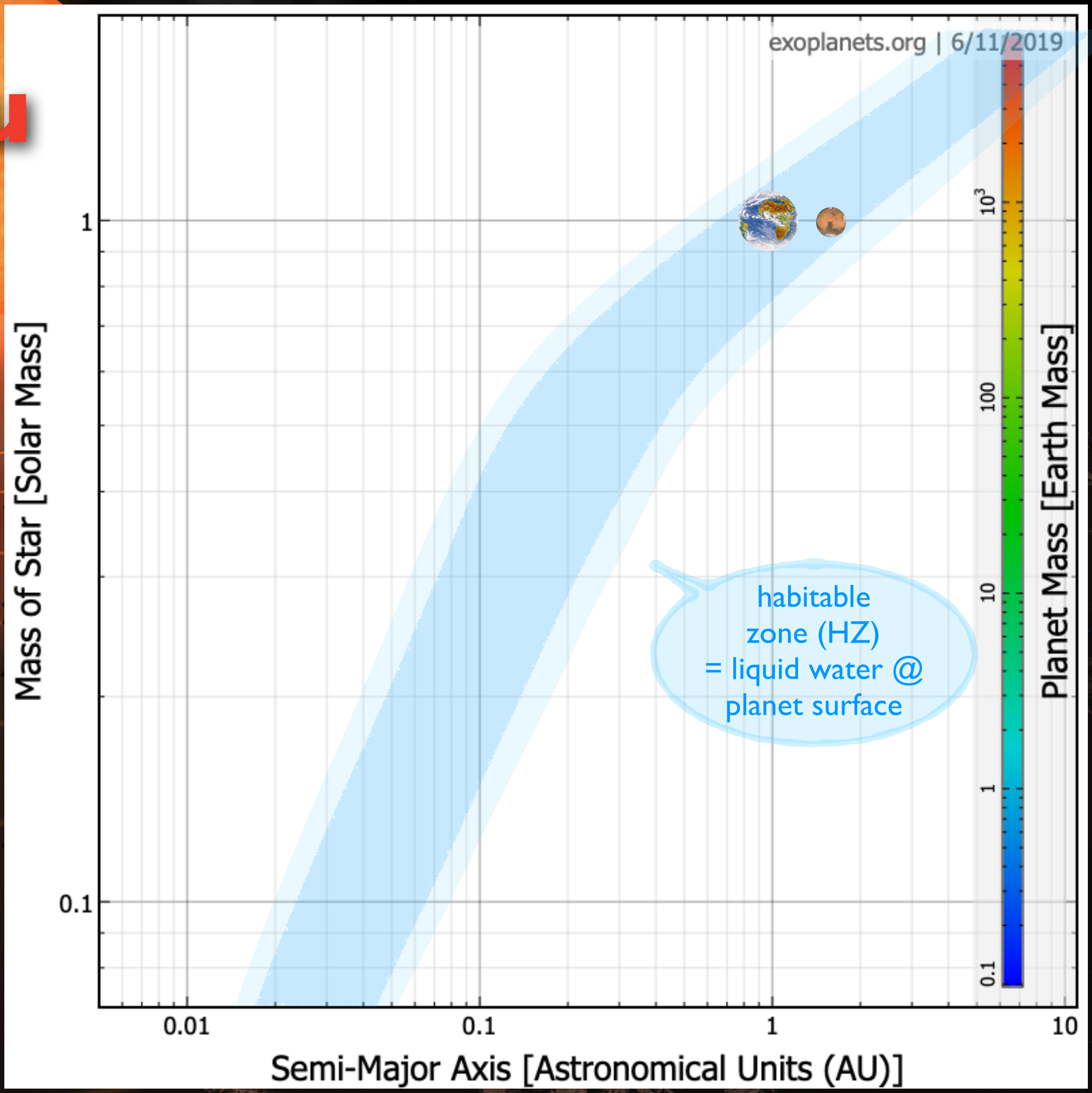




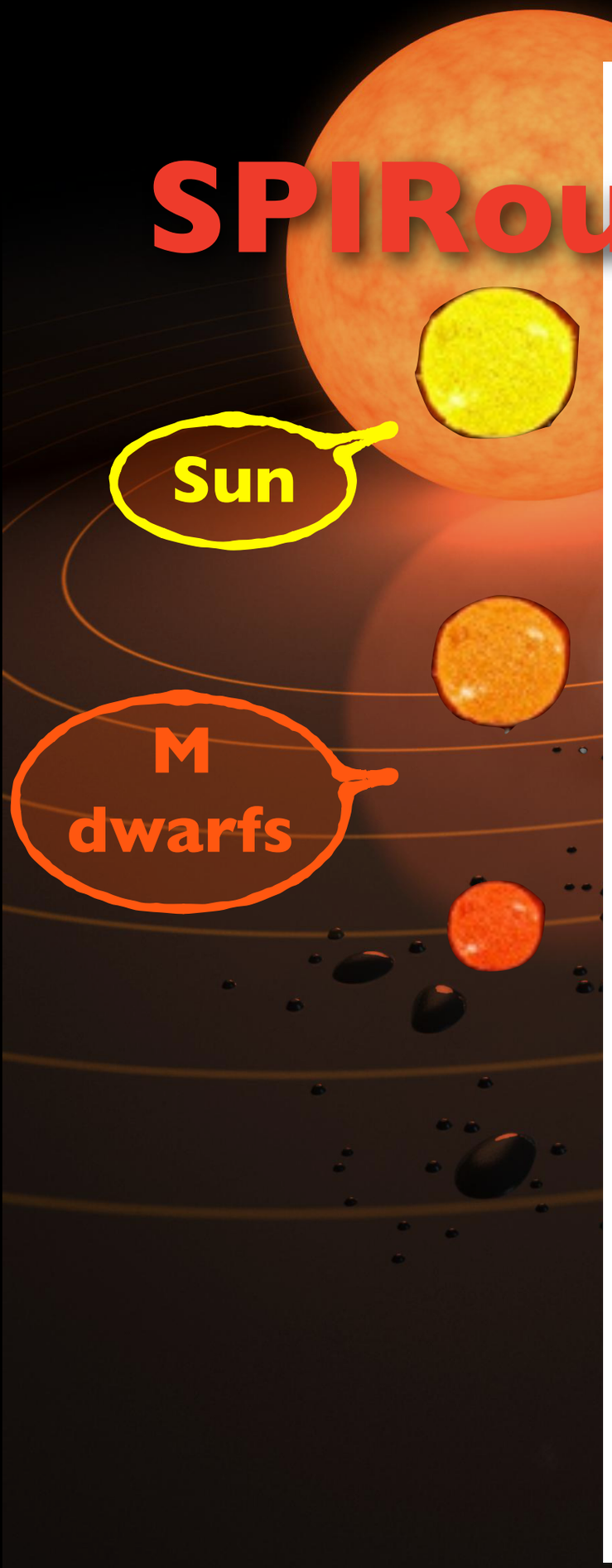
SPIRou

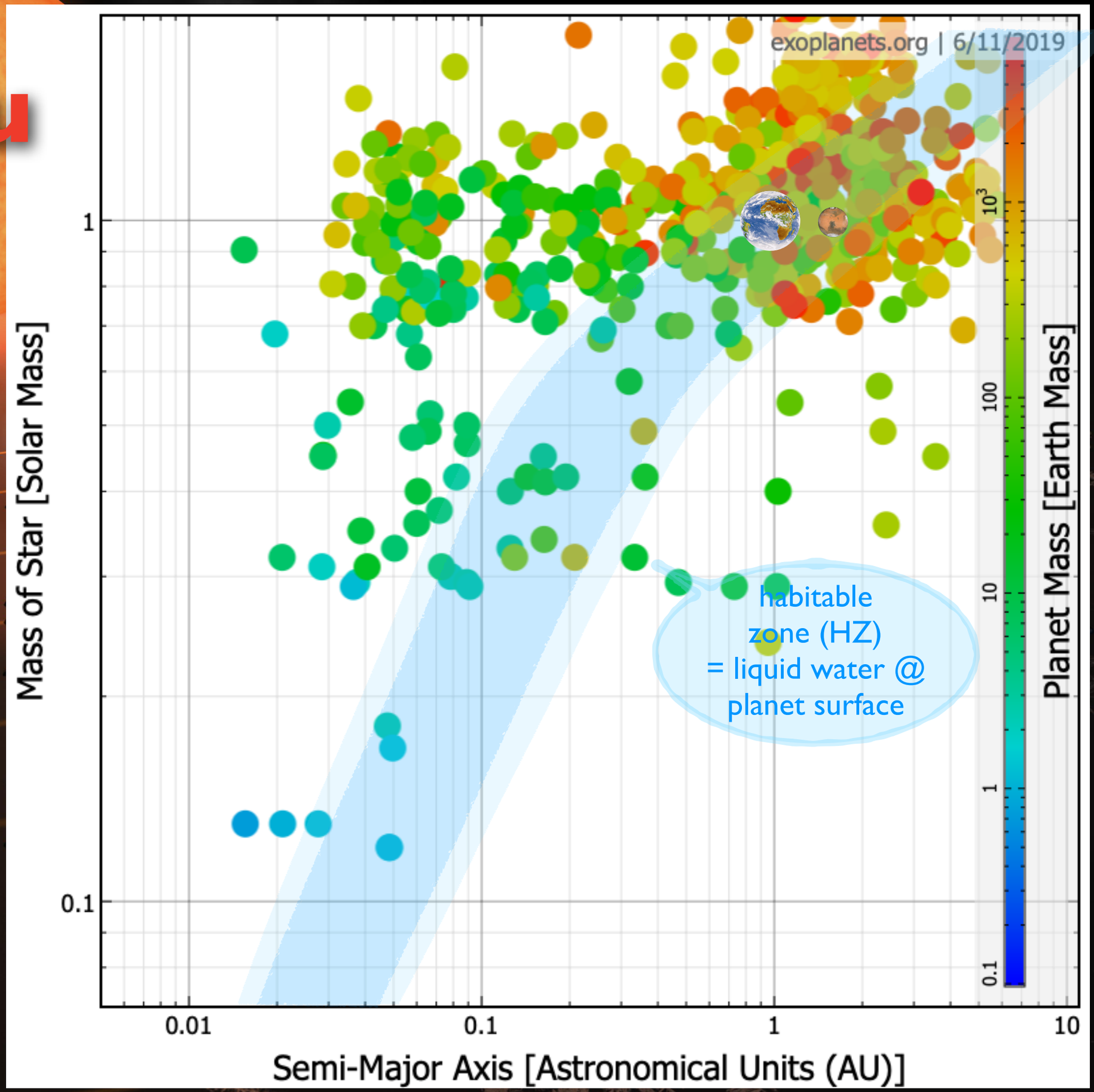
Sun

M dwarfs



SPIRou


Sun
M
dwarfs

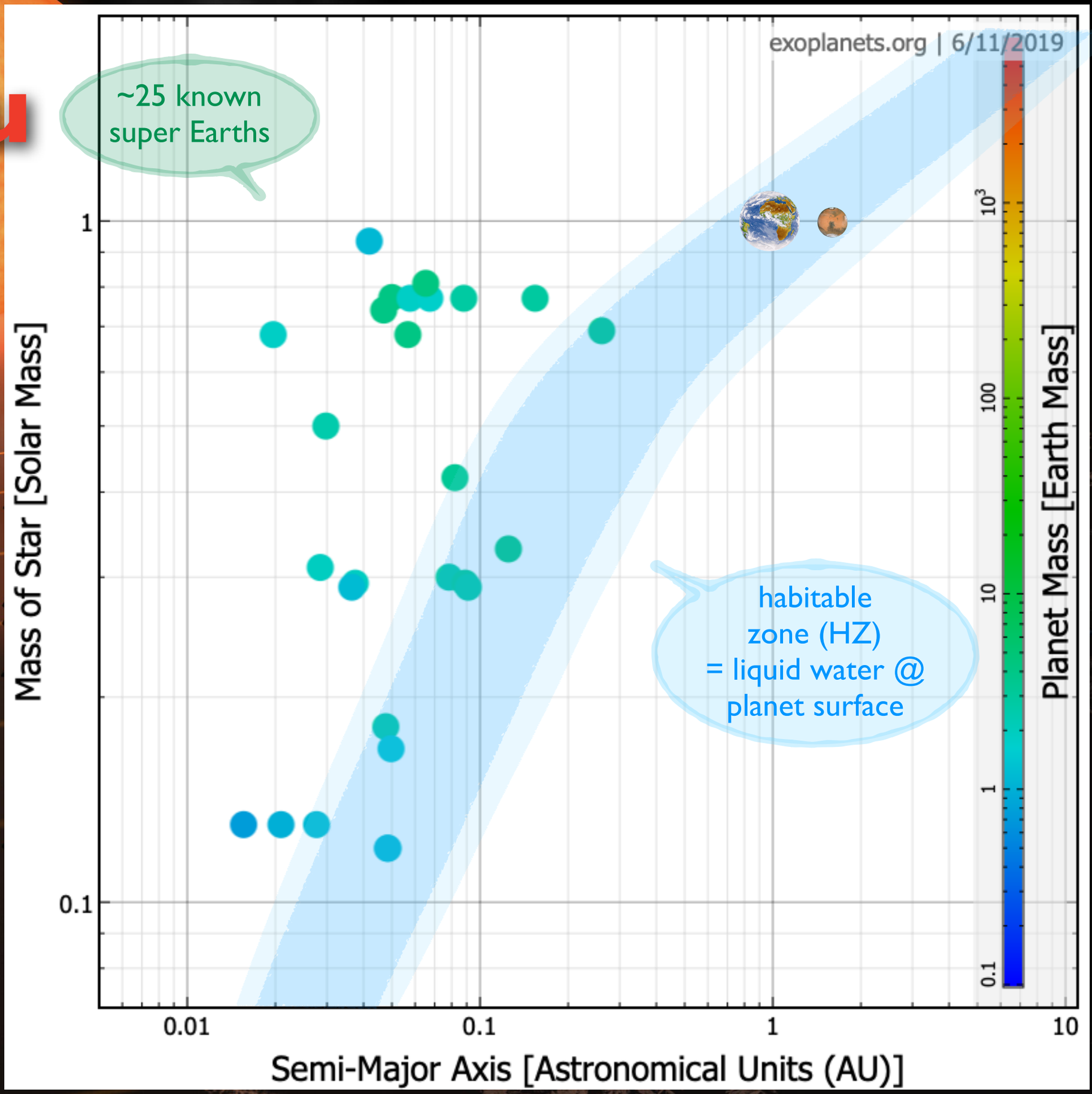

exoplanets.org | 6/11/2019
Mass of Star [Solar Mass]
Planet Mass [Earth Mass]
Semi-Major Axis [Astronomical Units (AU)]
habitable
zone (HZ)
= liquid water @
planet surface
1
0.1
0.01
0.1
1
10
100
10^3

SPIRou

Sun

M dwarfs

~25 known super Earths



SPIRou

Sun

M dwarfs

~25 known super Earths

exoplanets.org | 6/11/2019

habitable zone (HZ) = liquid water @ planet surface

Mass of Star [Solar Mass]

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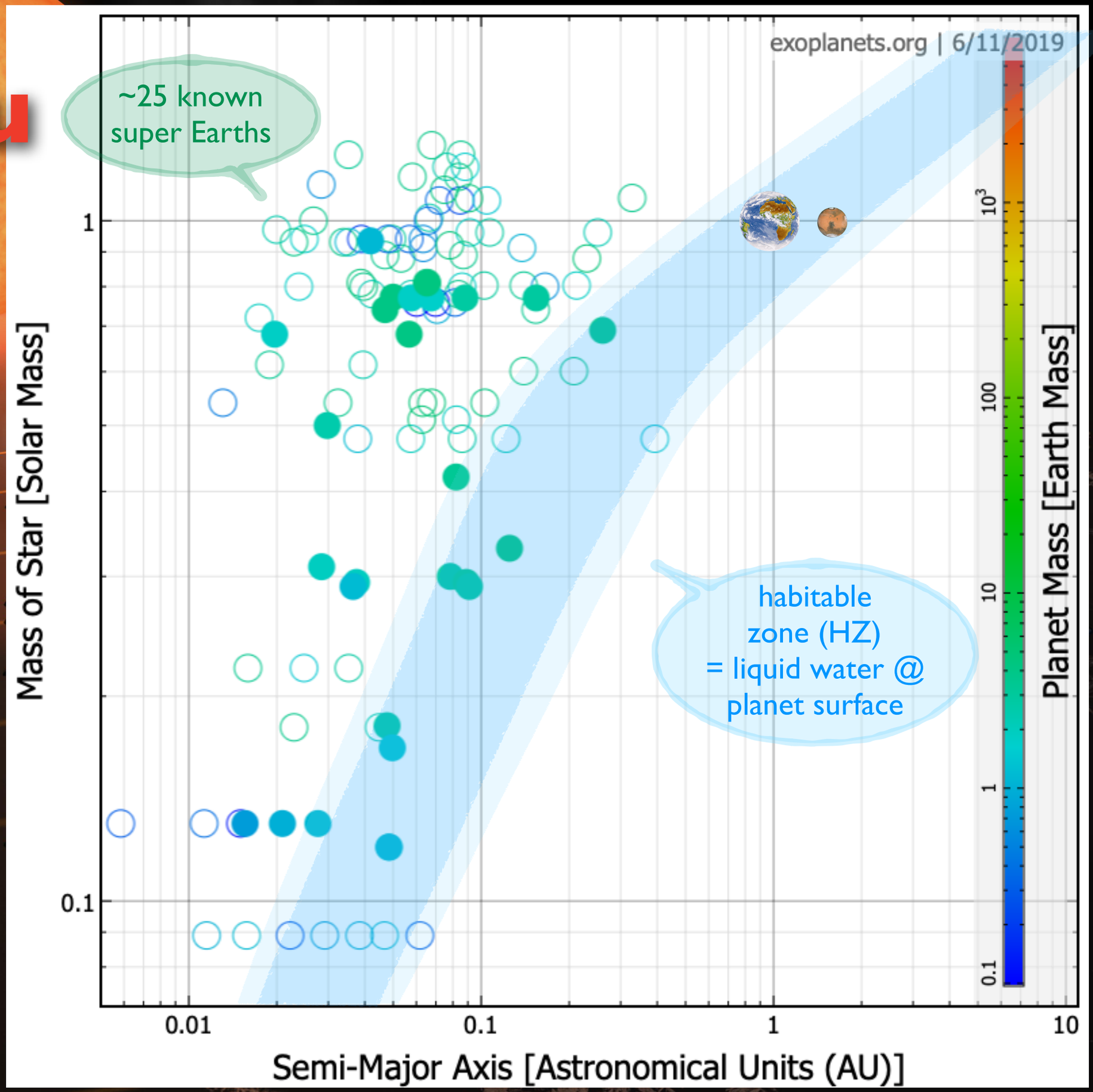
SPIRou

Sun

M dwarfs

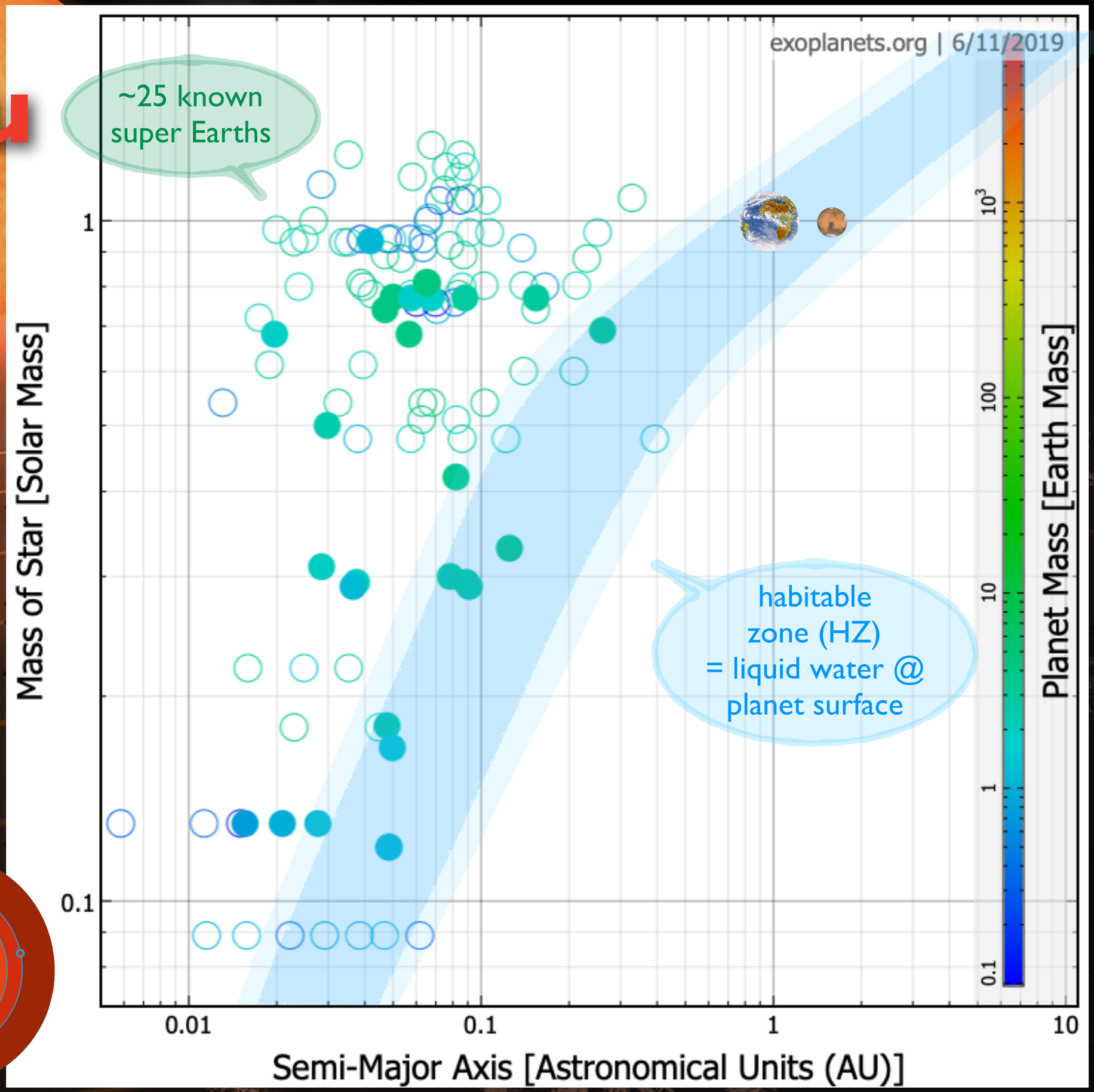


SPIRou

Sun

M dwarfs

Trappist I



SPIRou

Sun

M dwarfs

Trappist I

~25 known super Earths

habitable zone (HZ) = liquid water @ planet surface

~10% of nearby planets known to date

exoplanets.org | 6/11/2019

Mass of Star [Solar Mass]

Planet Mass [Earth Mass]

Semi-Major Axis [Astronomical Units (AU)]

1

0.1

0.01

0.1

1

10

10^3

100

10

1

0.1

SPIRou

Planetary Systems of nearby M Dwarfs

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why M dwarfs?

our nearest neighbors, eg Proxima Cen
host 2.2+ planets per star, of which 0.5+ in the Habitable Zone (HZ)
compact HZs ➾ HZ planets easier to detect
need nIR velocimeter to maximize efficiency ➾ SPIRou
magnetic activity & flares ➾ spectropolarimetry

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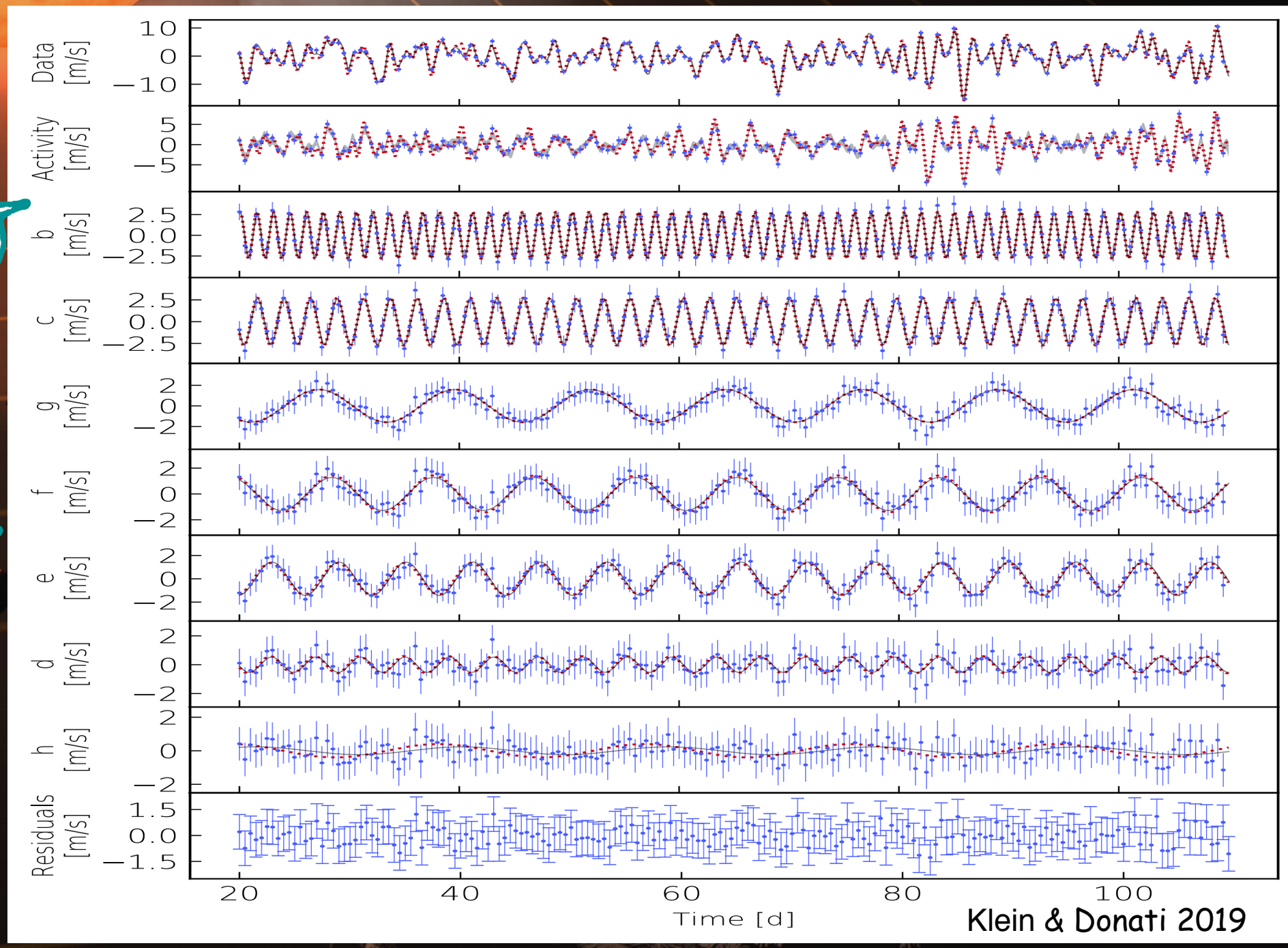
Planetary Systems of nearby M Dwarfs

SPiRou

Trappist-1

dominant activity

~5 planets revealed in filtered RVs



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Planetary Systems of nearby M Dwarfs

SPiRou

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compact HZs ➾ HZ planets easier to detect
need nIR velocimeter to maximize efficiency ➾ SPIRou
magnetic activity & flares ➾ spectropolarimetry

planet search / PS & transit follow-up / TF

PS: observe ~80 nearby M dwarfs w/ ~200 visits per star
➾ yield ~80 planets, ~25 Earth-mass ones, ~8 in HZ
TF: follow ~50 M dwarfs w/ transiting planets (eg TESS)
➾ determine mass & bulk density
➾ characterize atmospheres of close-in giants

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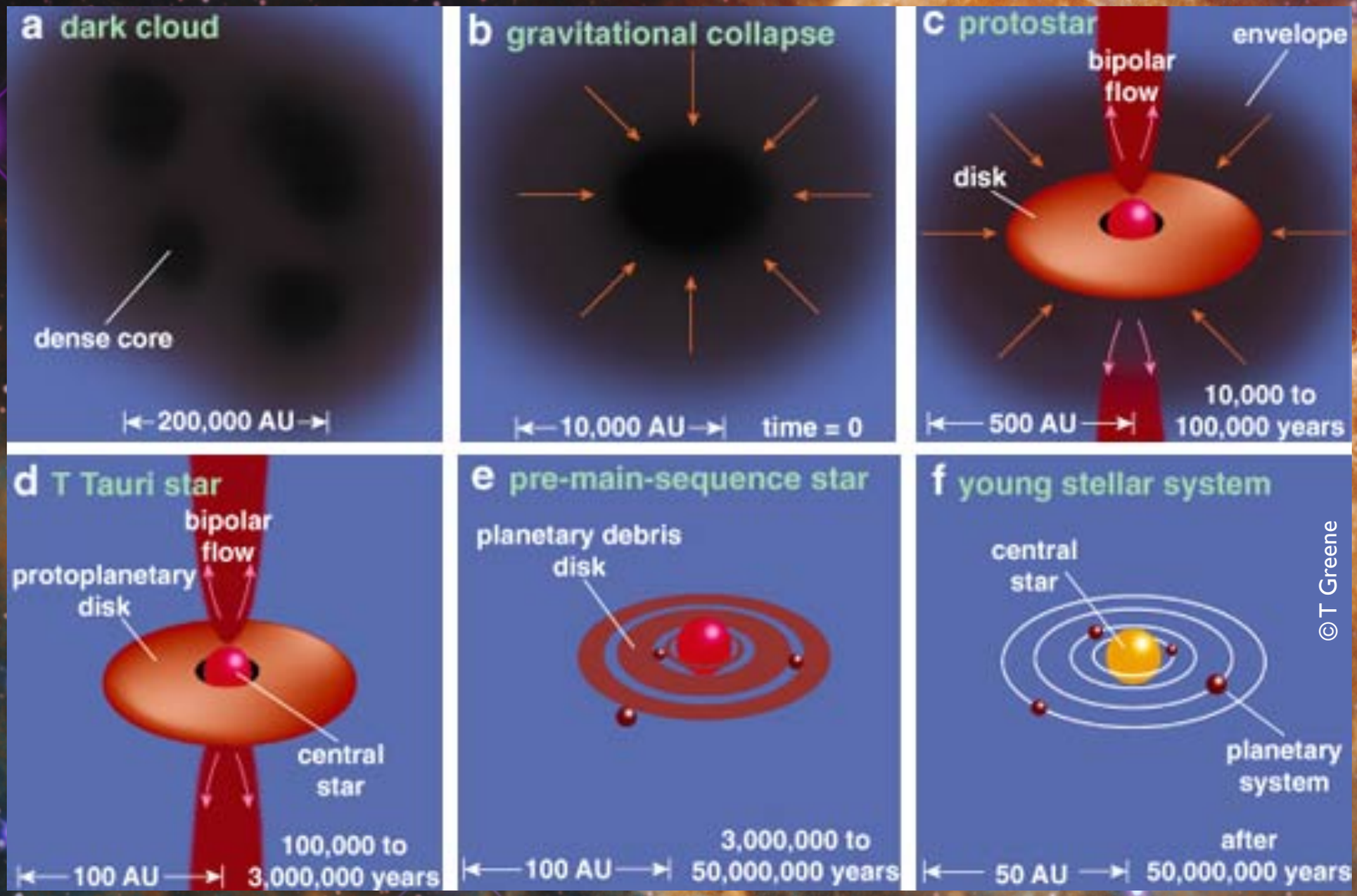
Star / Planet Formation

SPiRou



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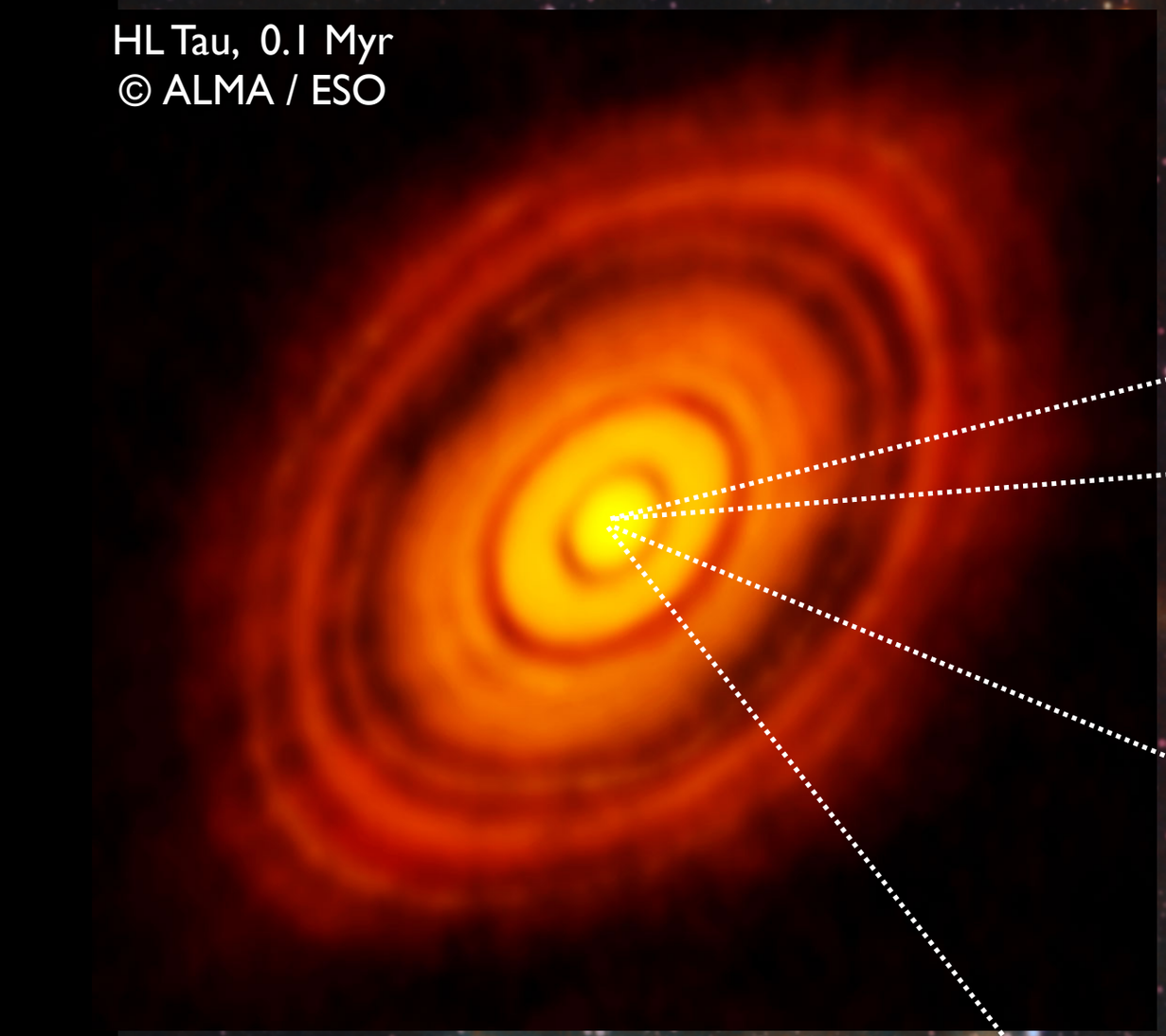
Magnetized Star / Planet Formation

SPiRou

HL Tau, 0.1 Myr
© ALMA / ESO



© M Romanova

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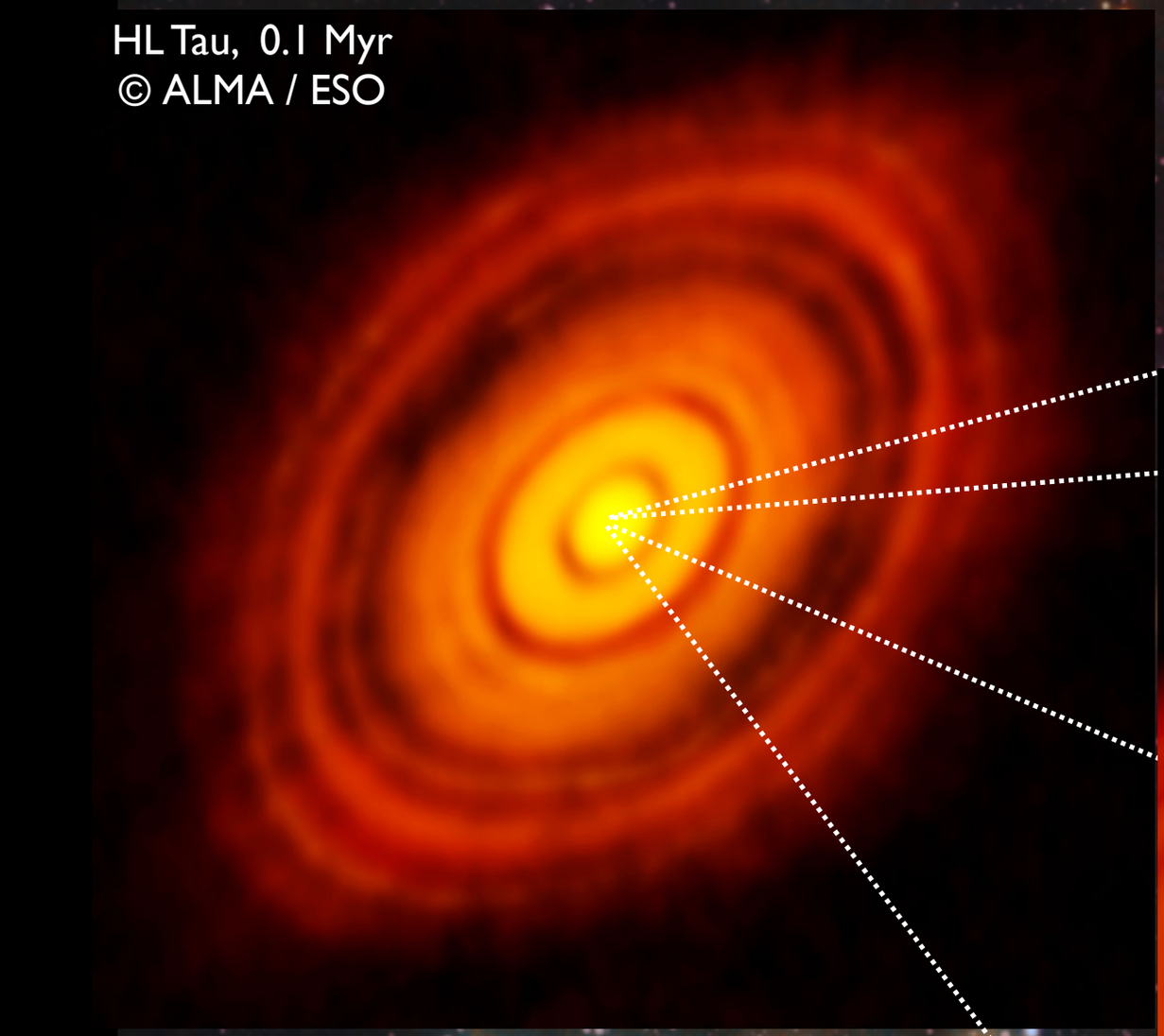
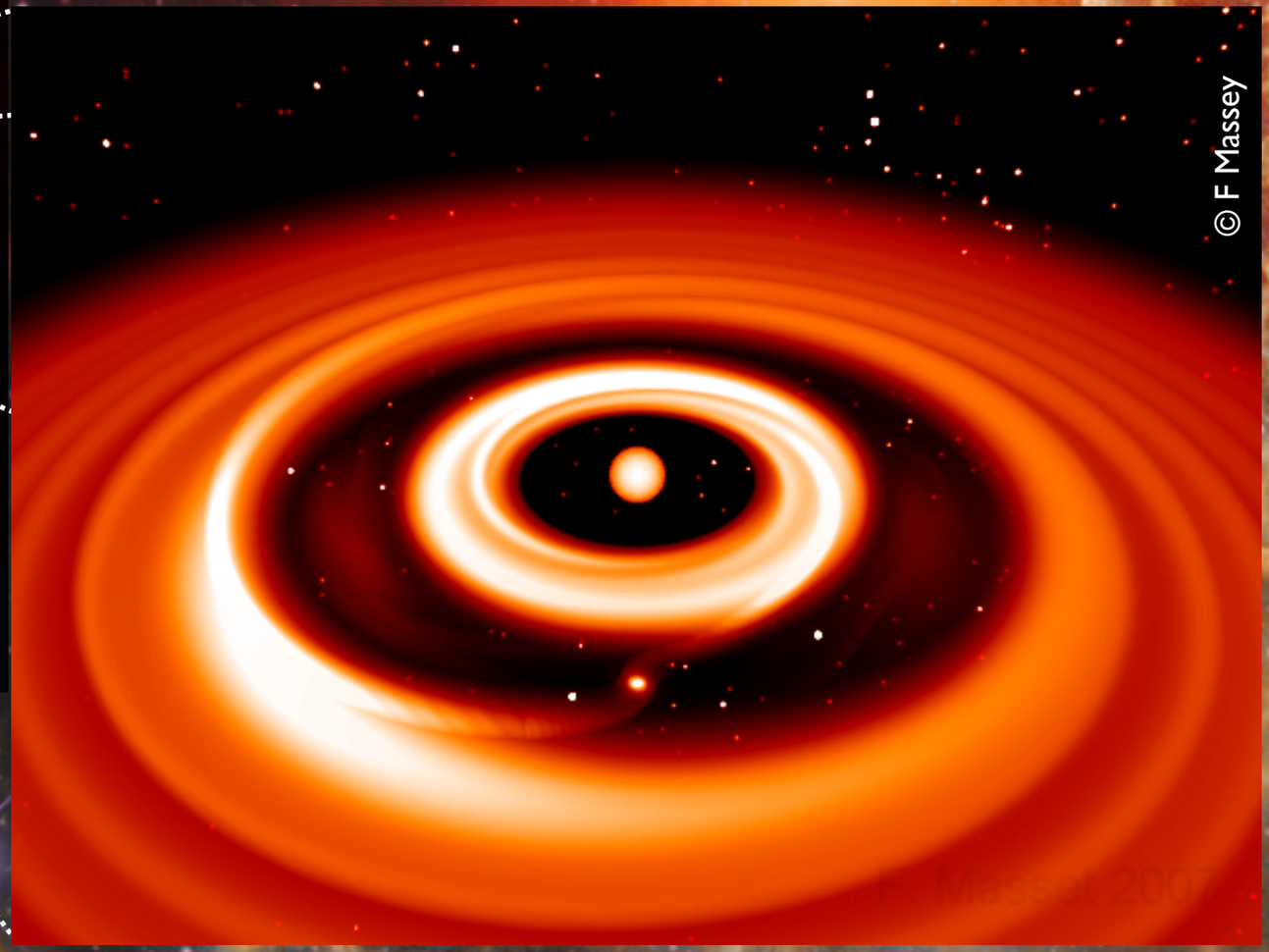
Magnetized Star / Planet Formation

SPiRou

HL Tau, 0.1 Myr
© ALMA / ESO





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SPIRou

Magnetized Star / Planet Formation

magnetic fields of newborn stars & discs

tomographic magnetic imaging of PMS stars

magnetized accretion patterns & star-disc interactions

↬ survey ~100 T Tauri stars & protostars

need nIR spectropolarimeter w/ K band

obvious synergy with ALMA

young close-in giant planets

formation / migration of hot Jupiters

early architecture of planetary systems

filter activity to unveil planet signals

↬ survey ~50 disc-less T Tauri stars

SPIRou

Main Science Requirements

high-resolution nIR spectroscopy

spectral domain 0.98-2.35 μm (YJHK)
spectral resolving power 70k
peak SNR~100 in 1 hr on M dwarf w/ H~11
thermal noise < stellar flux @ 2.33 μm for H<9.5

precision velocimetry

RV precision ~1 m/s rms

spectropolarimetry

circular & linear polarimetry
circular <> linear crosstalk <2%

SPIRou

Instrument Modules

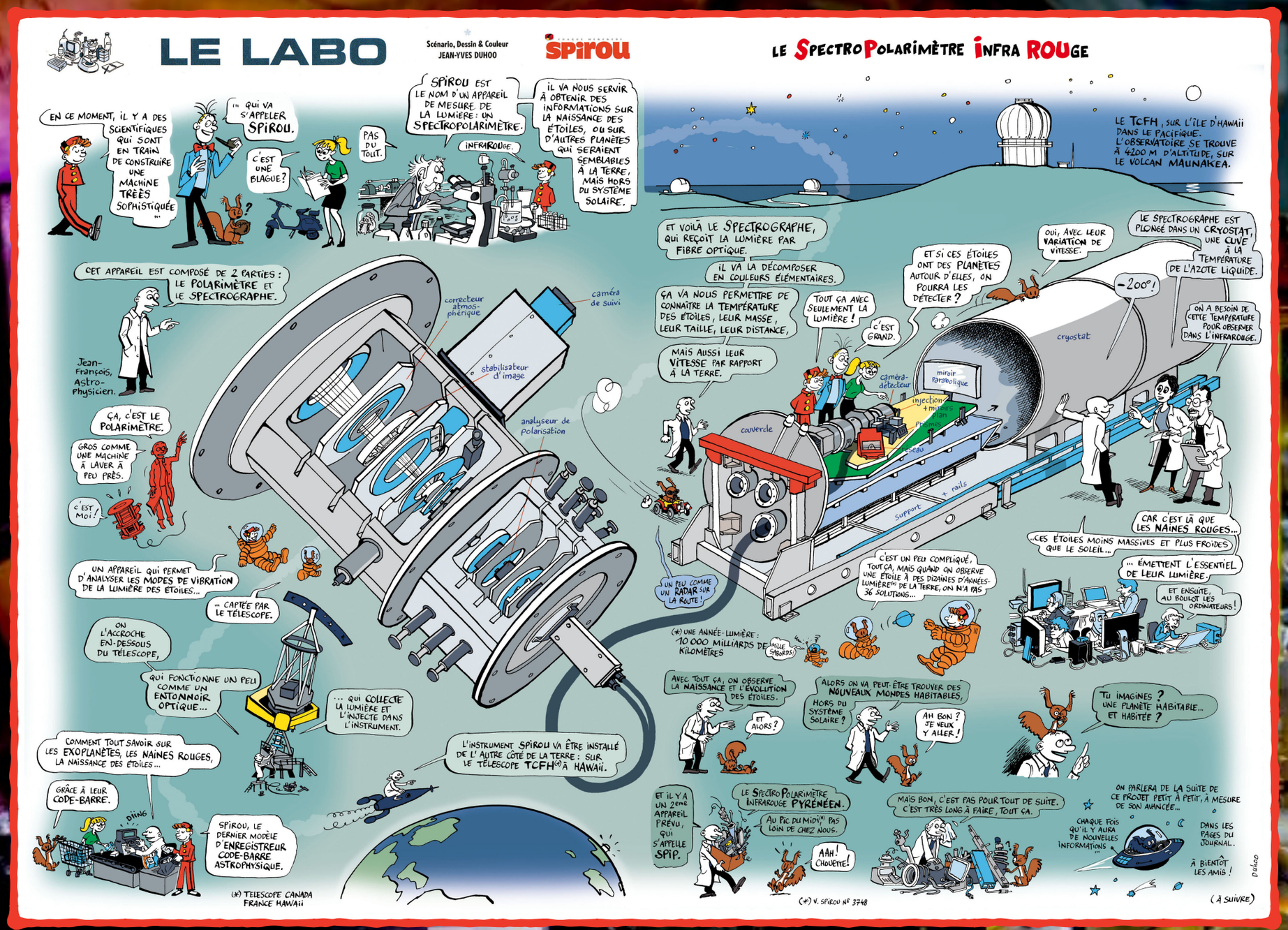
- **cryogenic high-resolution nIR spectrograph**
  cooled down at 75K & stabilized at better than 1mK
  échelle spectrograph with dual-pupil fully-dioptric design
  H4RG science grade detector

- **Cassegrain module & calibration unit**
  achromatic polarimeter w/ ZnSe 1/4-wave Fresnel rhombs,
  atmospheric disp corrector (ADC) & image stabilisation unit (ISU)
  calibration unit providing light from calibration lamps

- **fluoride (ZBLAN) fiber link**
  purified ZBLAN w/ attenuation <11dB/km
  octogonal fibers & pupil slicer to feed spectrograph

SPIRou

Instrument Modules



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SPIRou @ CFHT

- **installed @ CFHT in 2018 Feb**
  first cryogenic cycle in 2018 Feb
  H4RG detector installed in 2018 Apr
  Laser Frequency Comb (LFC) installed in 2018 Oct (tests ongoing)

- **lab tests @ CFHT throughout 2018**
  study velocimetric stability & polarimetric properties

- **tech commissioning (TC) & science verif (SV)**
  TC#0 for guiding only (1 night, 2018 Mar)
  TC#1-7 & SV for overall performances (~29 clear nights)
  ~3800 SPIRou spectra of ~100 stars

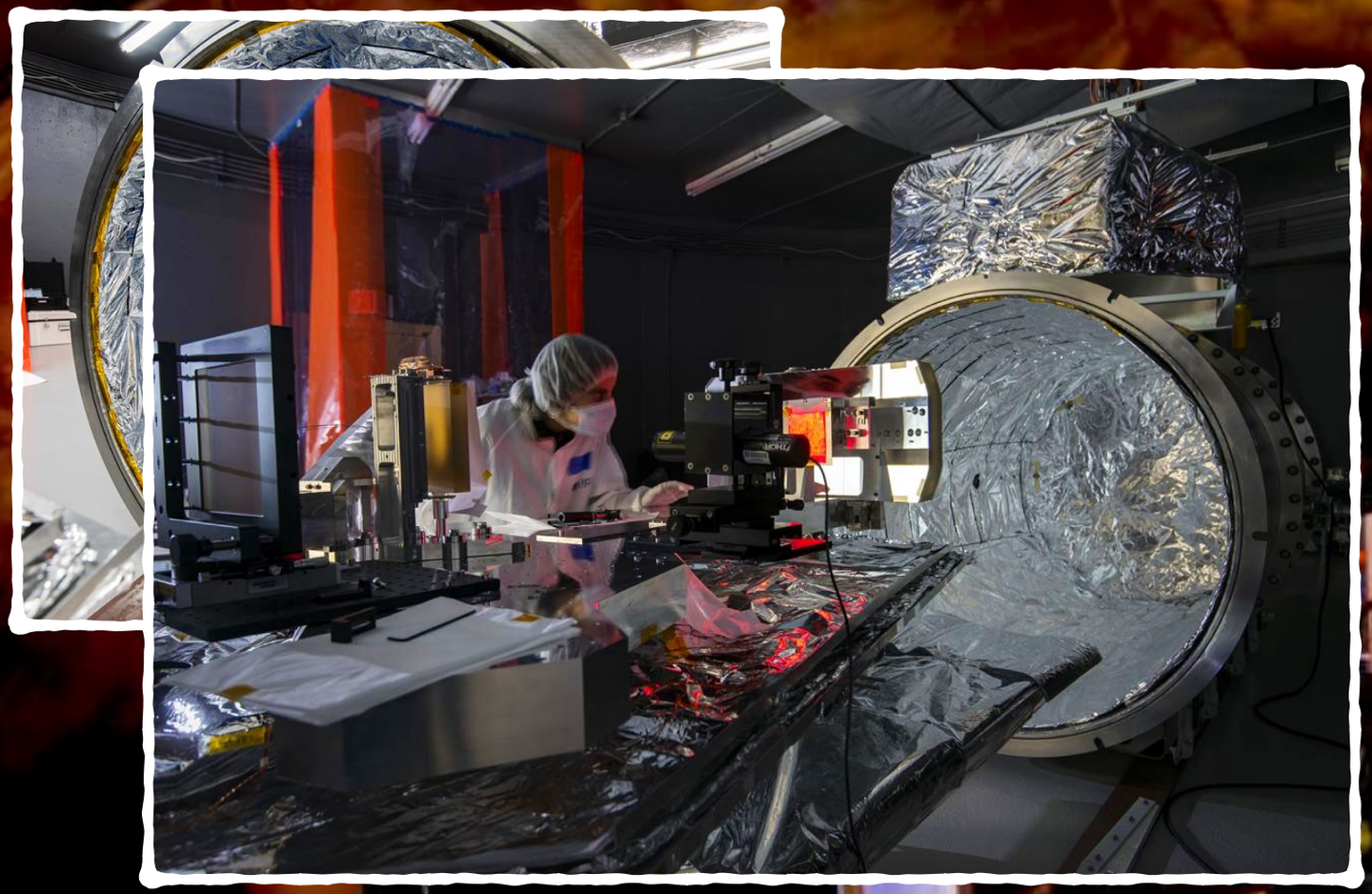
SPIRou

SPIRou @ CFHT

SPiRou

SPIRou

SPIRou @ CFHT



SPIRou

SPIRou @ CFHT

SPIRou

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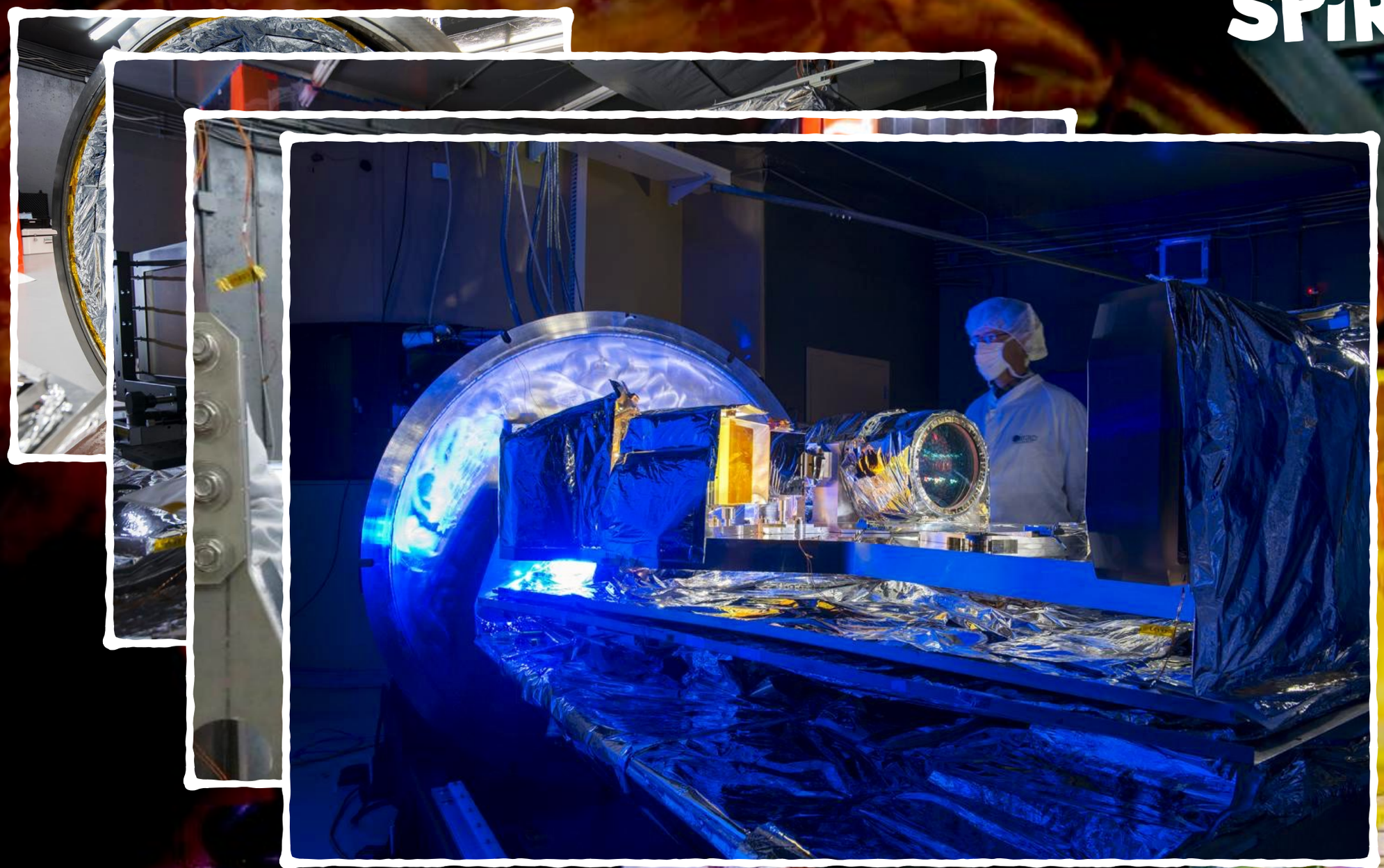

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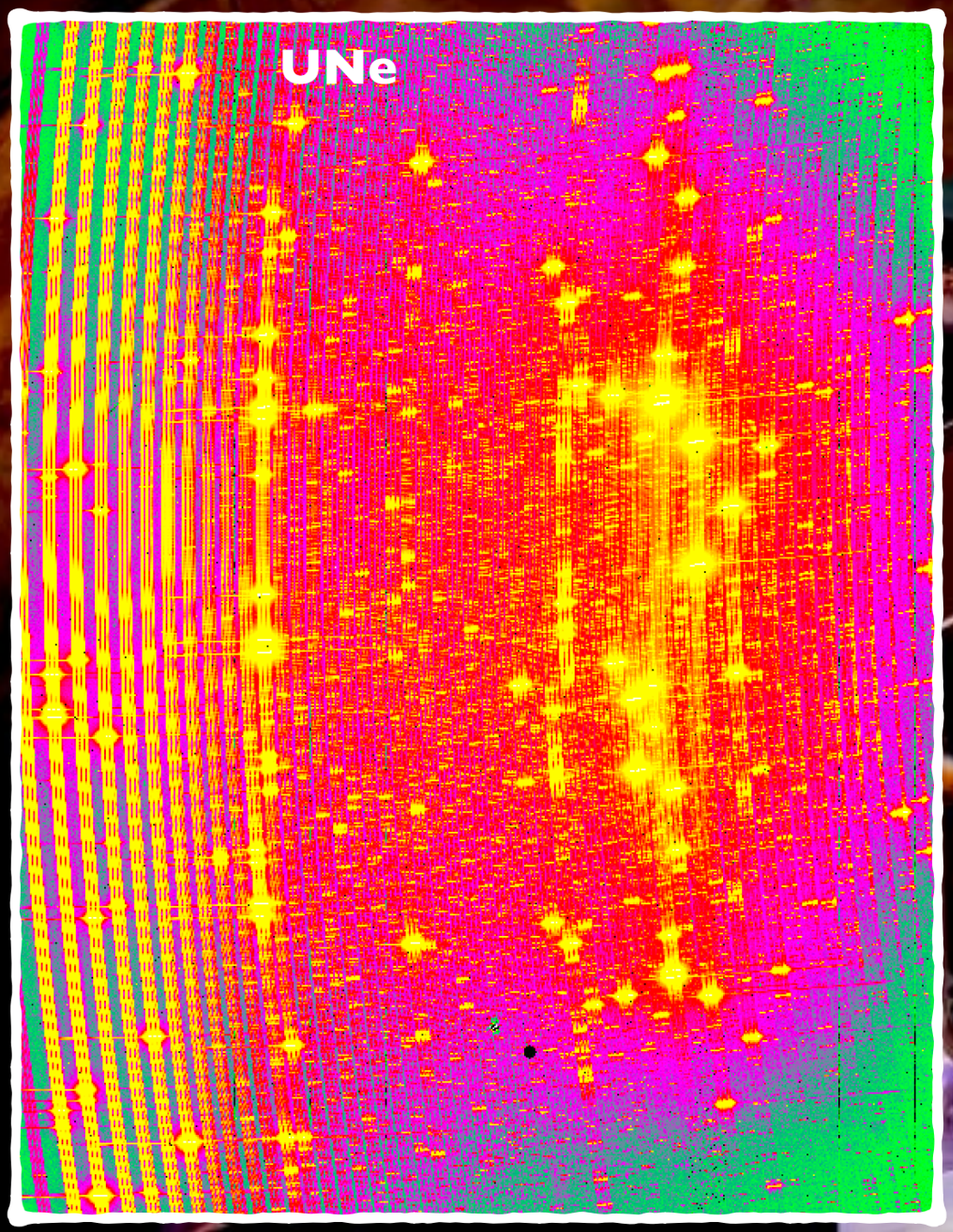
Example raw images



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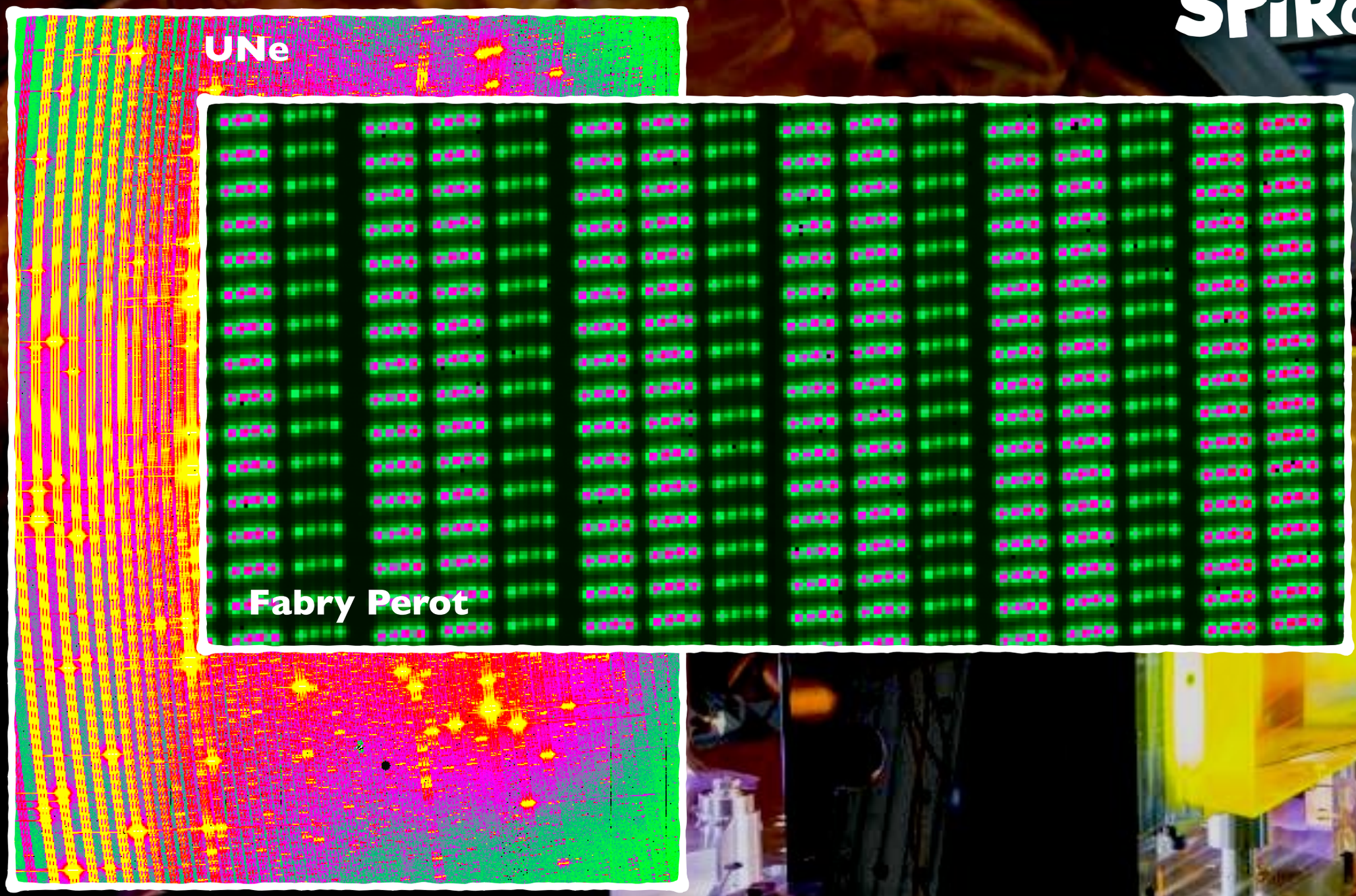

SPIRou

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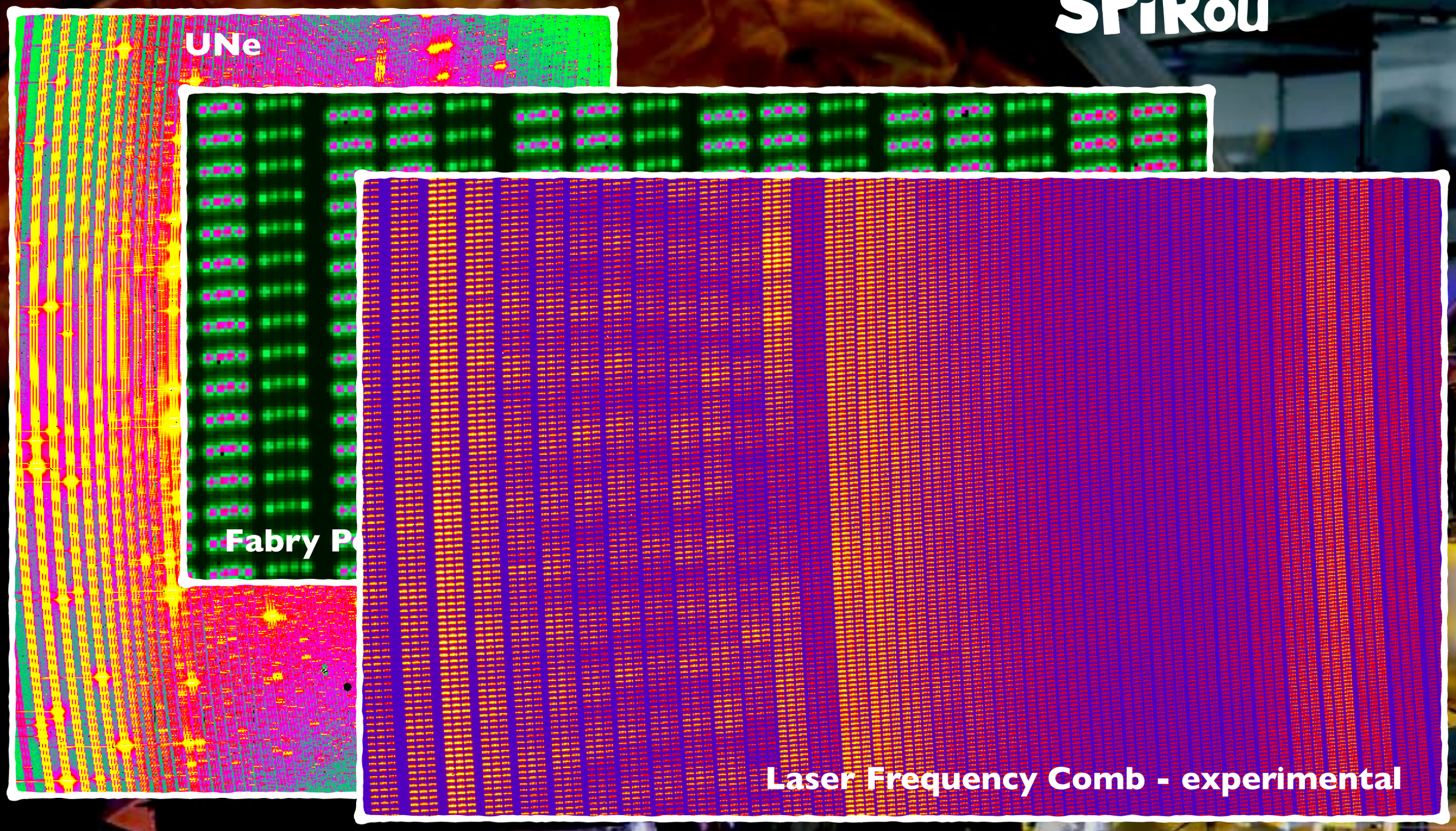


SPIRou

Performances: spectroscopy

conclusions wrt spectroscopy

spectral domain supernominal

spectral resolving power nominal (70k)

throughput nominal in HK, subnominal in YJ

- ZnSe transmission larger than assumed in design

thermal background subnominal: ~1.1mag too strong @ 2.33µm

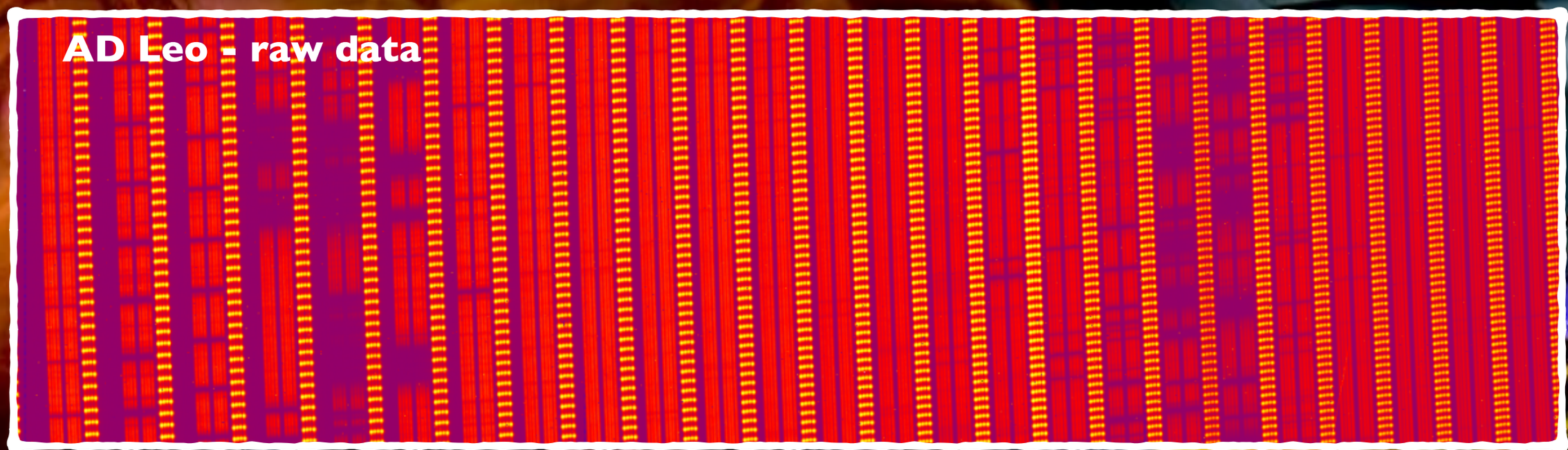
- from polarimeter & spectrograph feedthroughs

forthcoming upgrades

lower thermal background by cooling polarimeter & feedthroughs

SPIRou

Performances: spectroscopy



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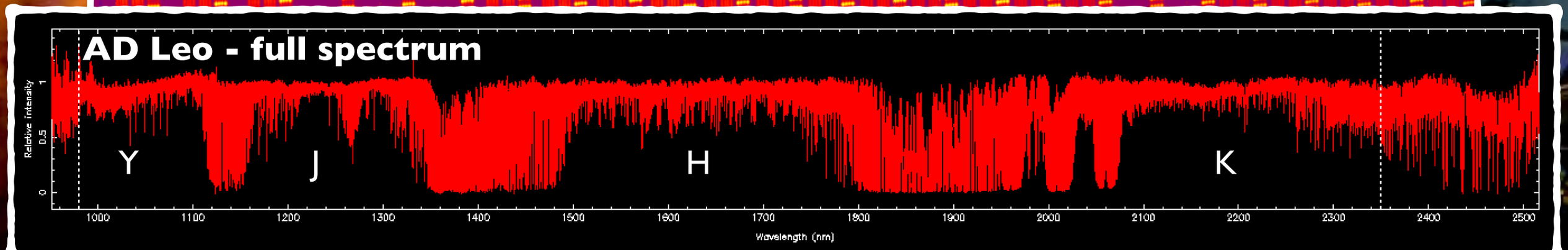
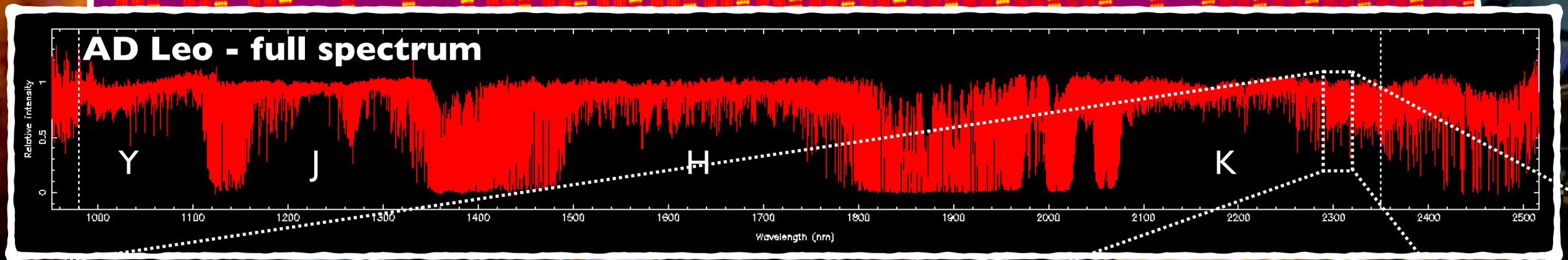
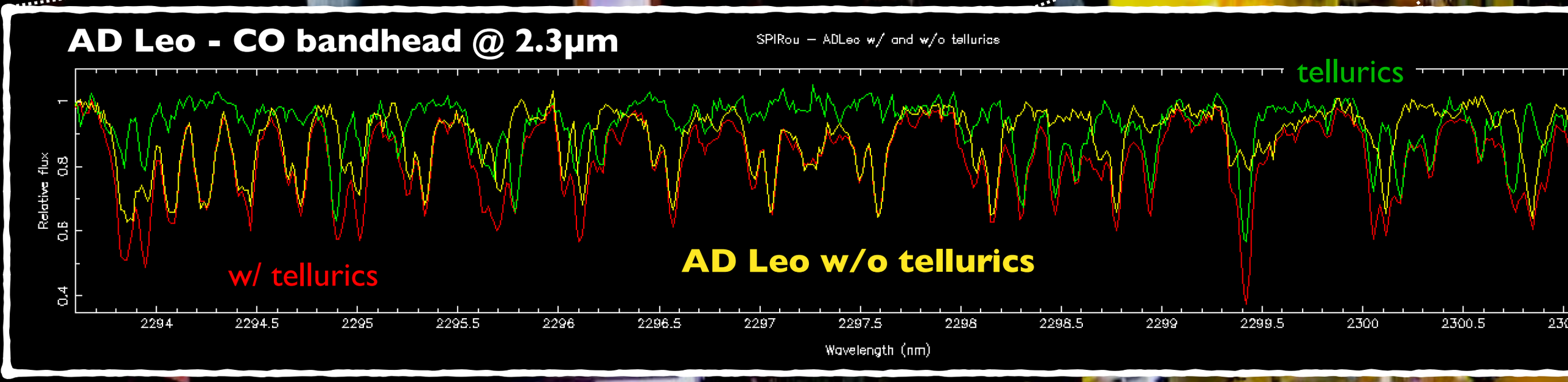
Performances: spectroscopy



SPIRou

Performances: spectroscopy





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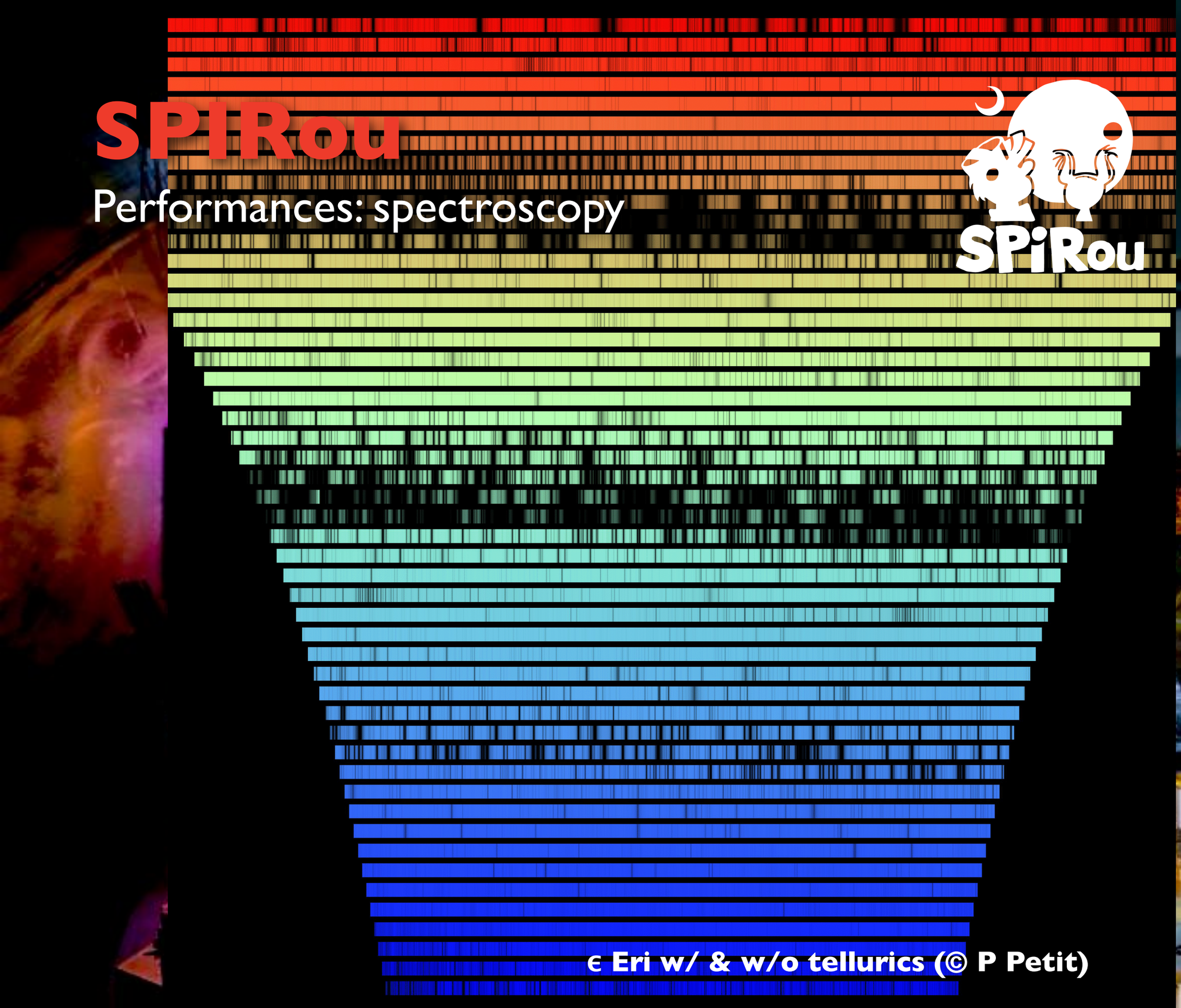


ϵ Eri w/ & w/o tellurics (© P Petit)

SPIRou

Performances: velocimetry

conclusions wrt velocimetry

RV precision better than 1m/s in the lab, ~2 m/s on the sky
main contributor: telluric correction & data reduction

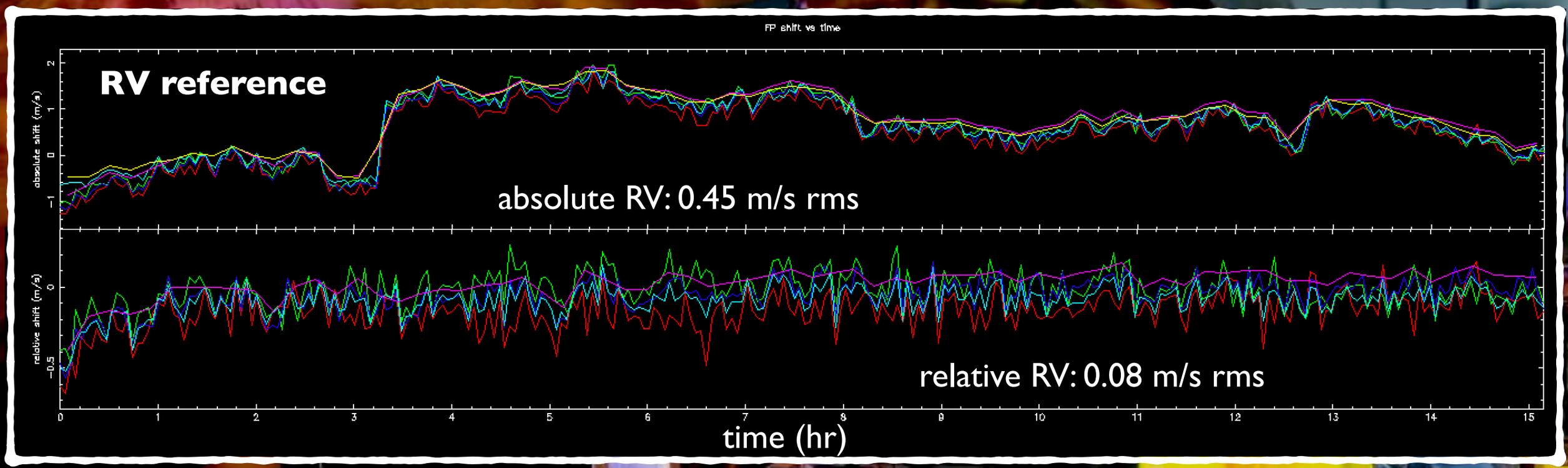
- upper limit on RV precision only, will improve w/ more data
- best nIR RV precision so far (eg Carmenes: 5-10m/s rms)

forthcoming upgrades

improved telluric correction & data reduction
fiber link upgrade

SPIRou

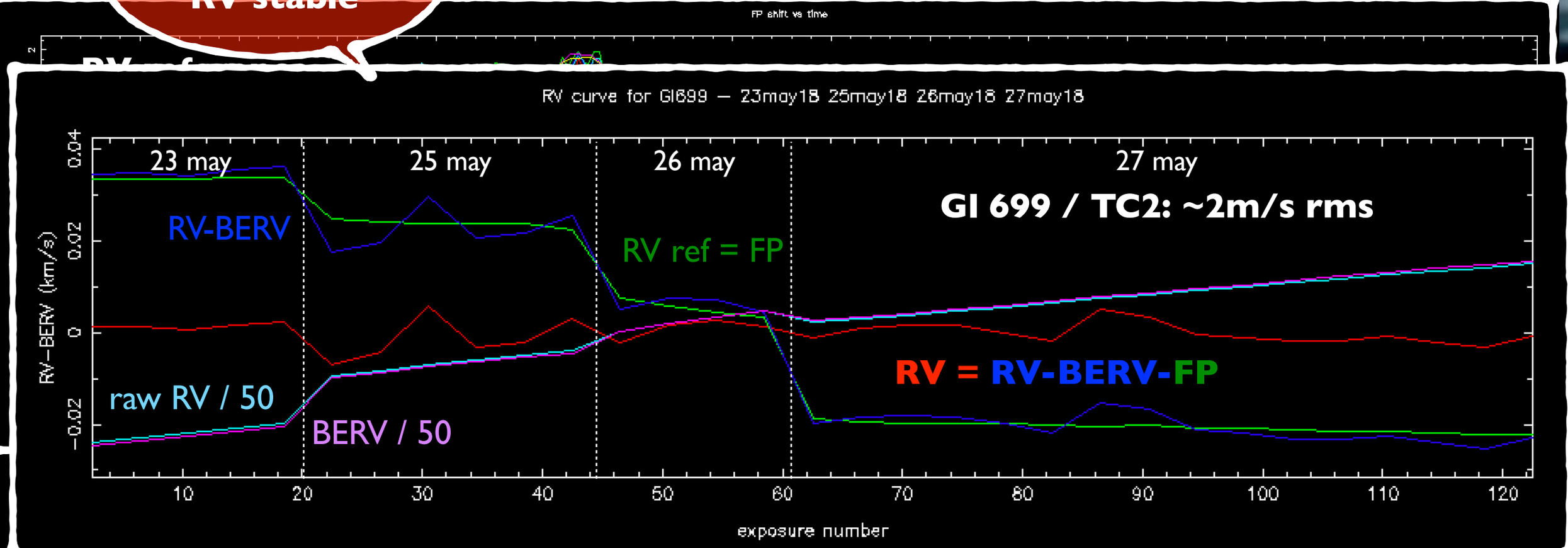
Performances: velocimetry



SPIRou

Performances: velocimetry

GI 699 (M4), RV stable



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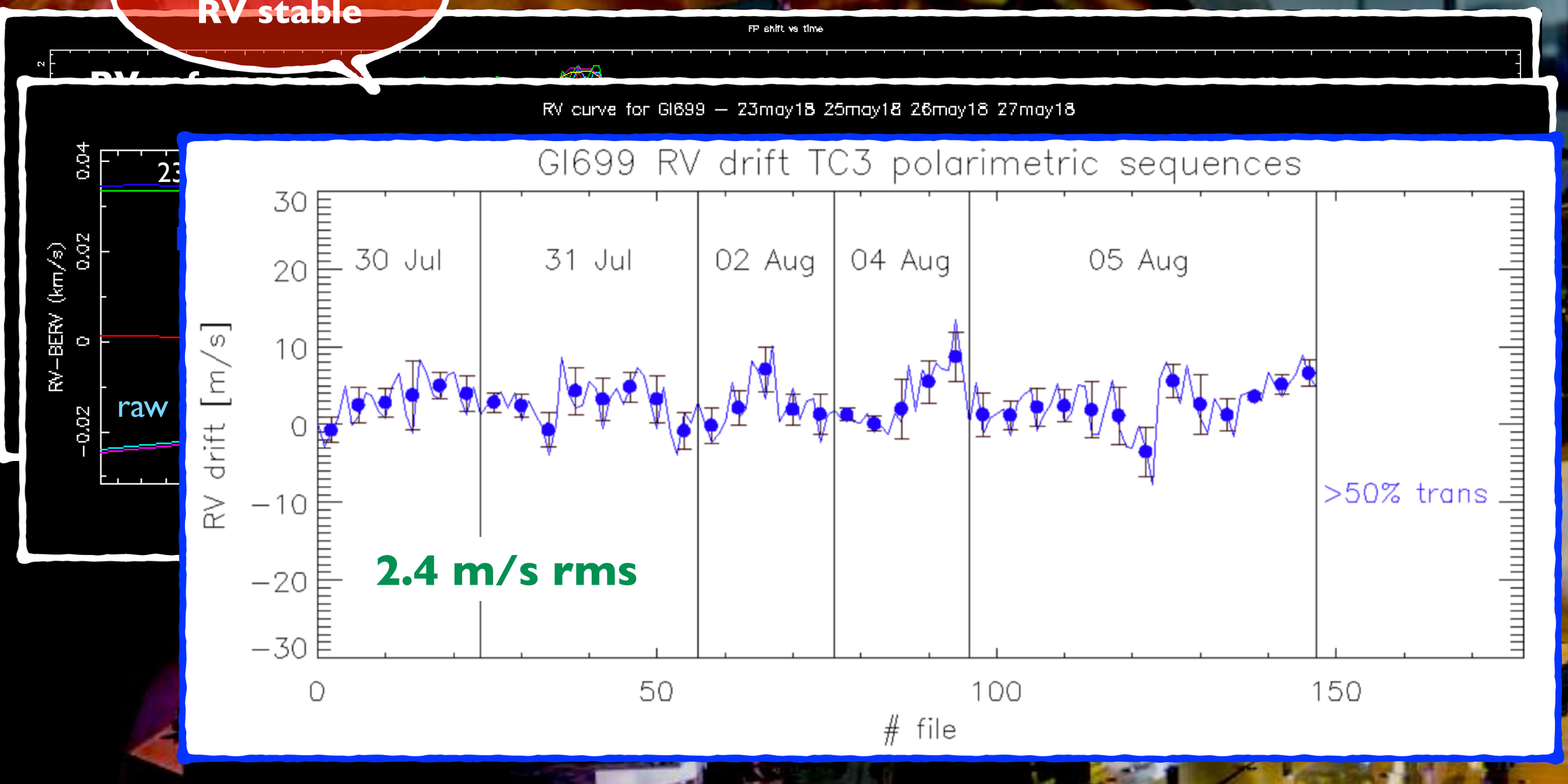


SPIRou

Performances: spectropolarimetry

conclusions wrt spectropolarimetry

durable ZnSe Fresnel rhombs tricky to construct
circular & linear polarimetry in line profiles functional
circular & linear polarized Zeeman signatures detected in stellar spectra
nominal polarimetric sensitivity & minimal polarization crosstalk

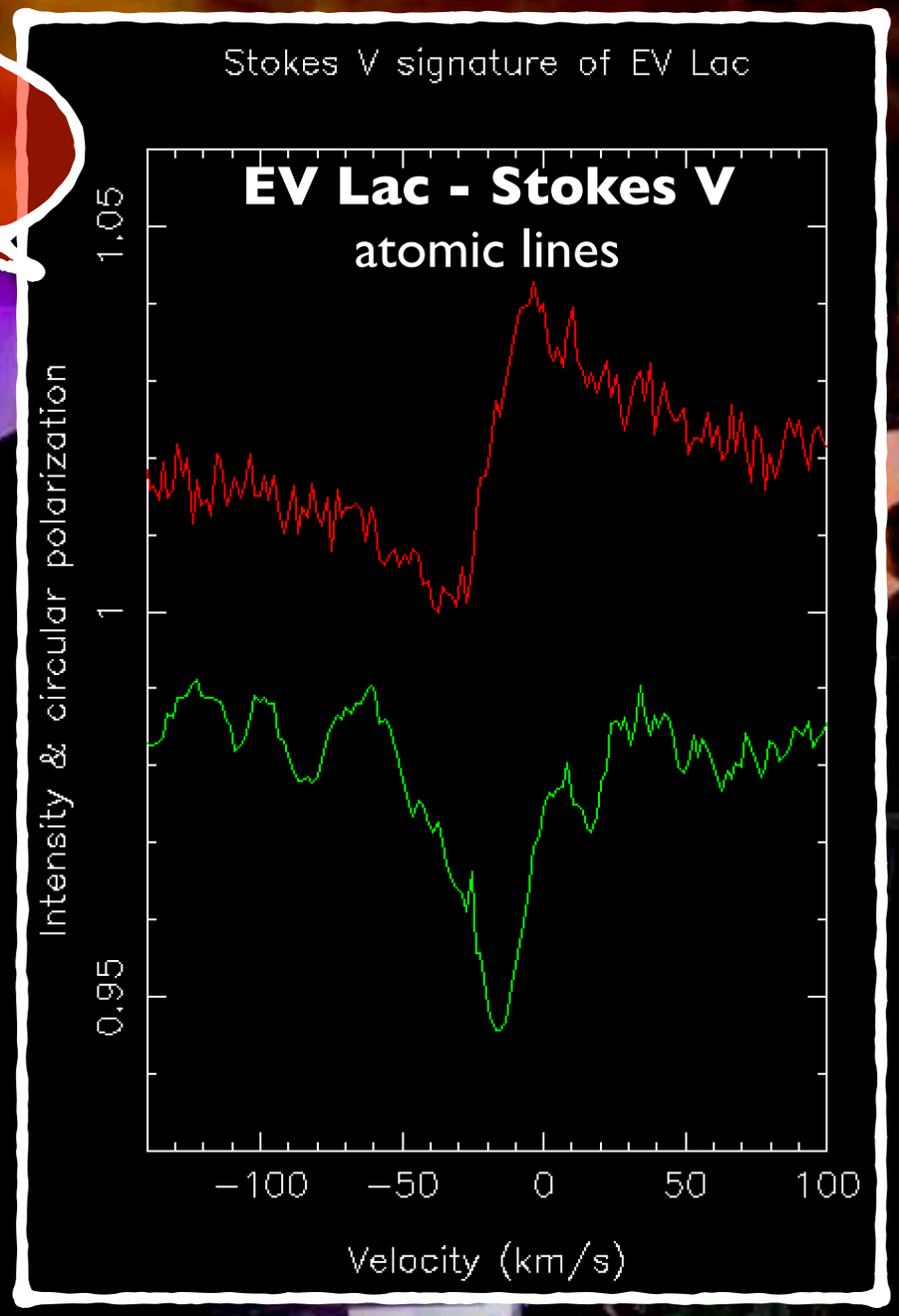
forthcoming upgrades

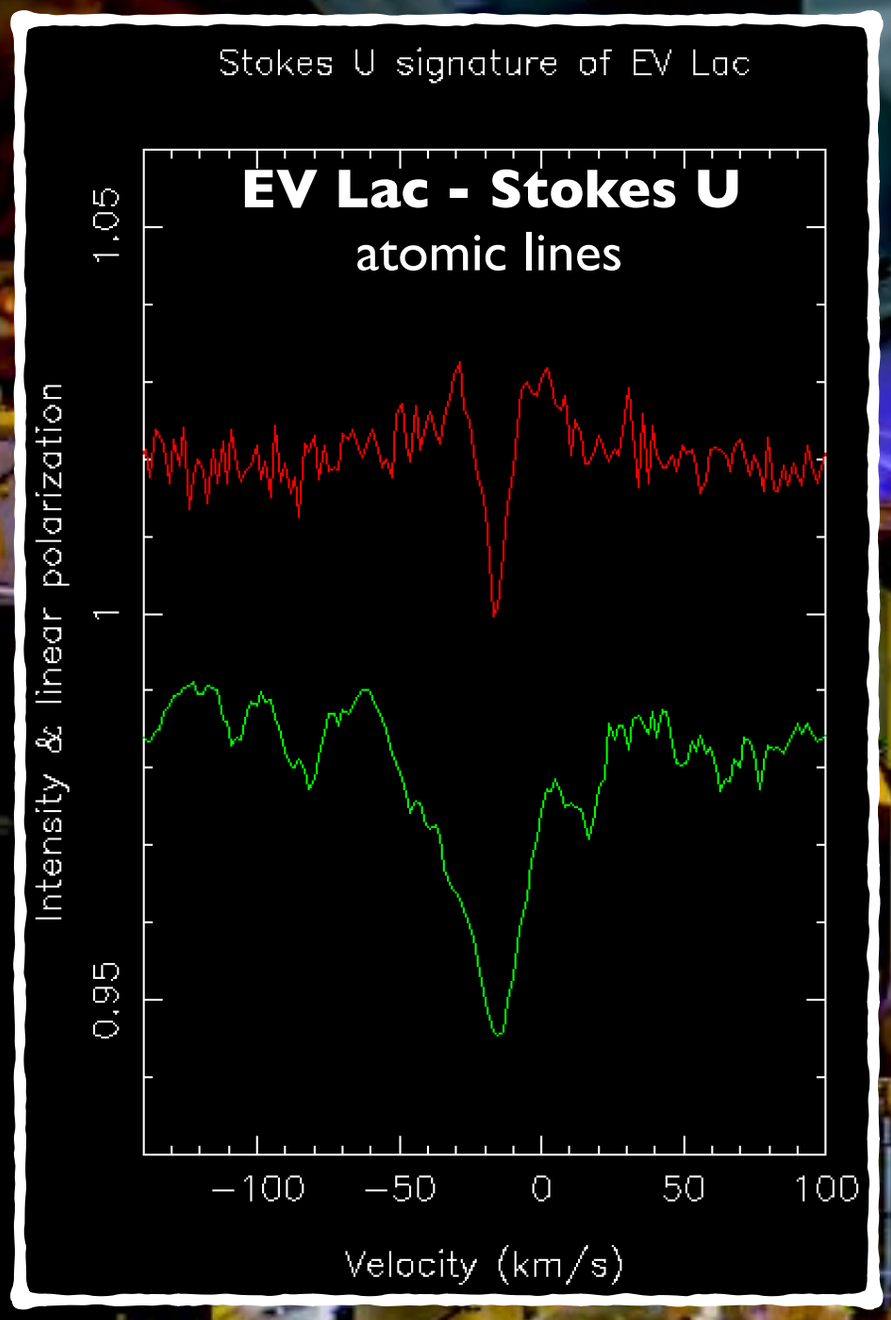
improved & long-lived Fresnel rhombs

SPIRou

Performances: spectropolarimetry

EV Lac (M3)
very active





SPIRou

First science results

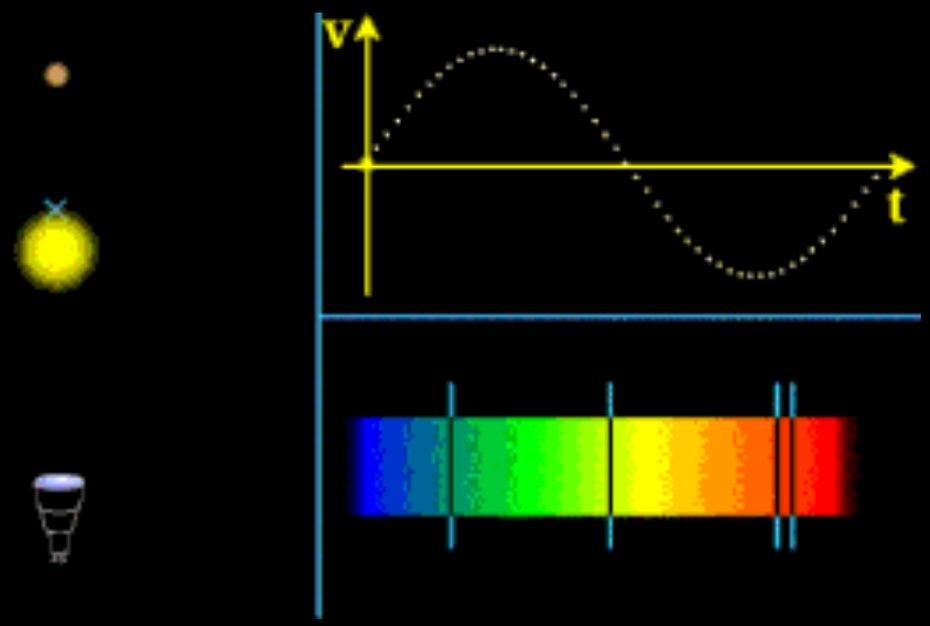
exoplanets & activity of M stars

a few tens of M dwarfs monitored so far, w/ up to ~30 visits

way too early for any firm result (aim : 150-200 visits per M dwarf)

clear magnetic activity in some of them (eg GI 388, GI 406)

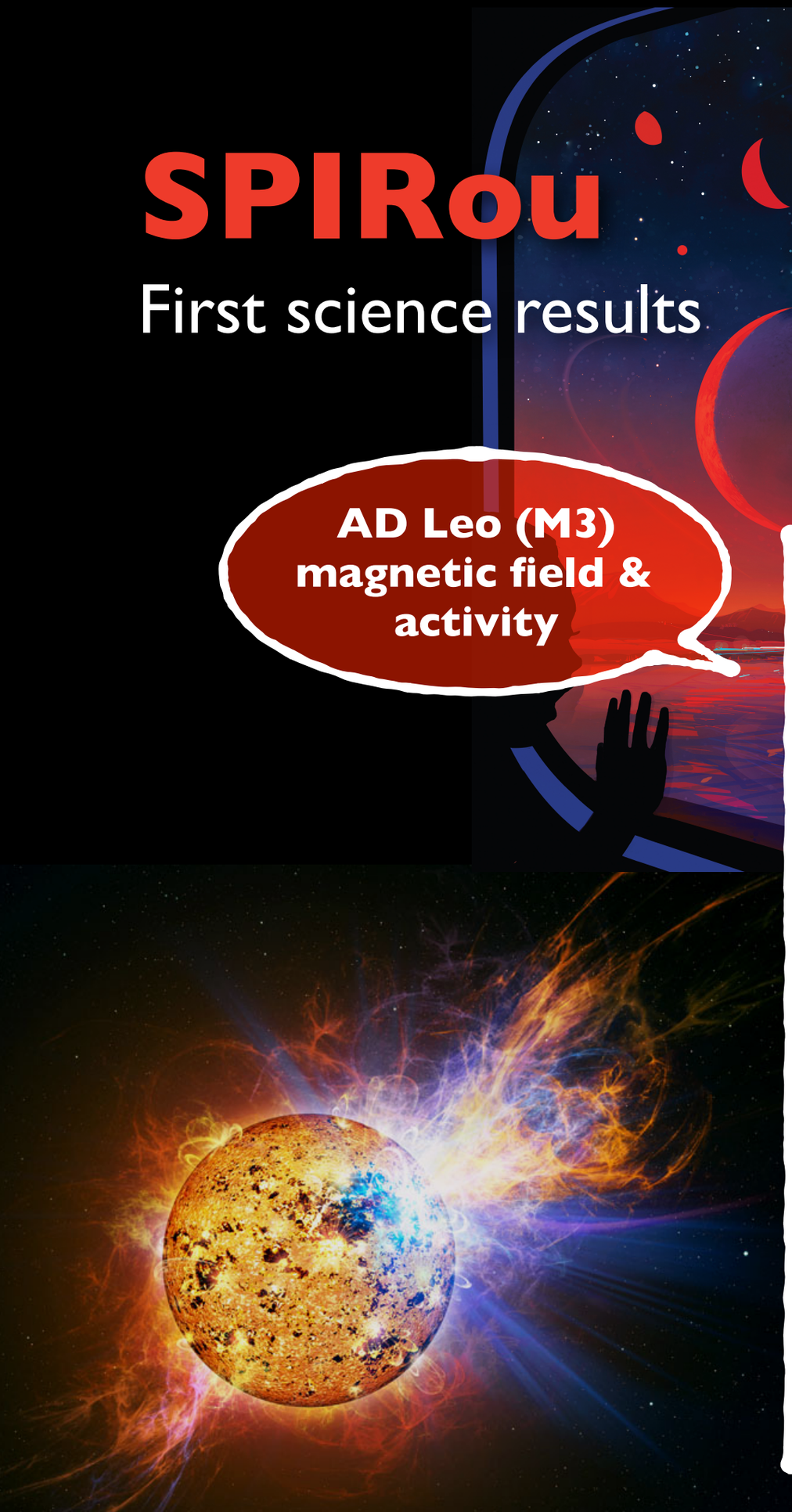
several planetary transits observed (hot Jupiters, Earth-like planets)

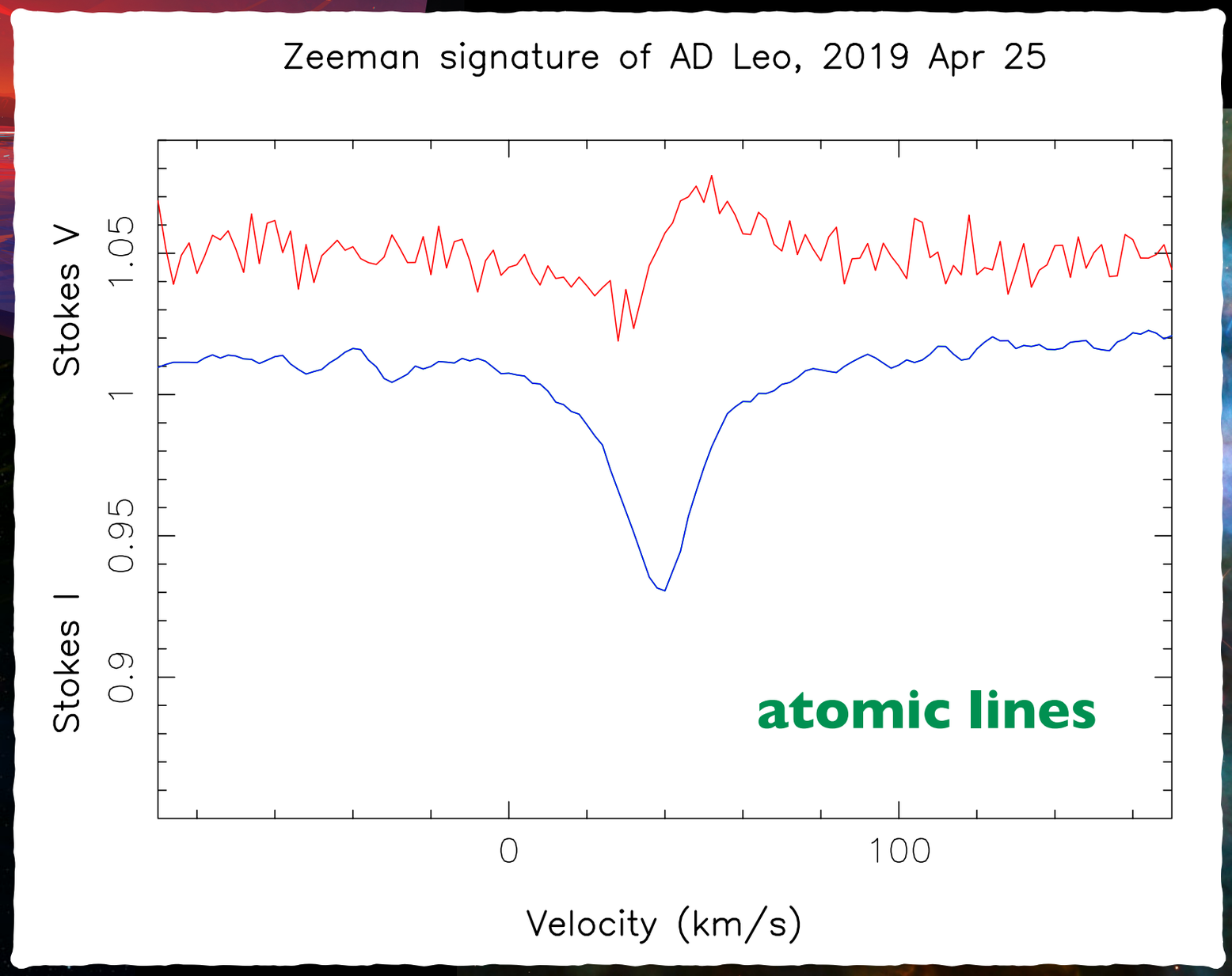


SPIRou

First science results

AD Leo (M3) magnetic field & activity





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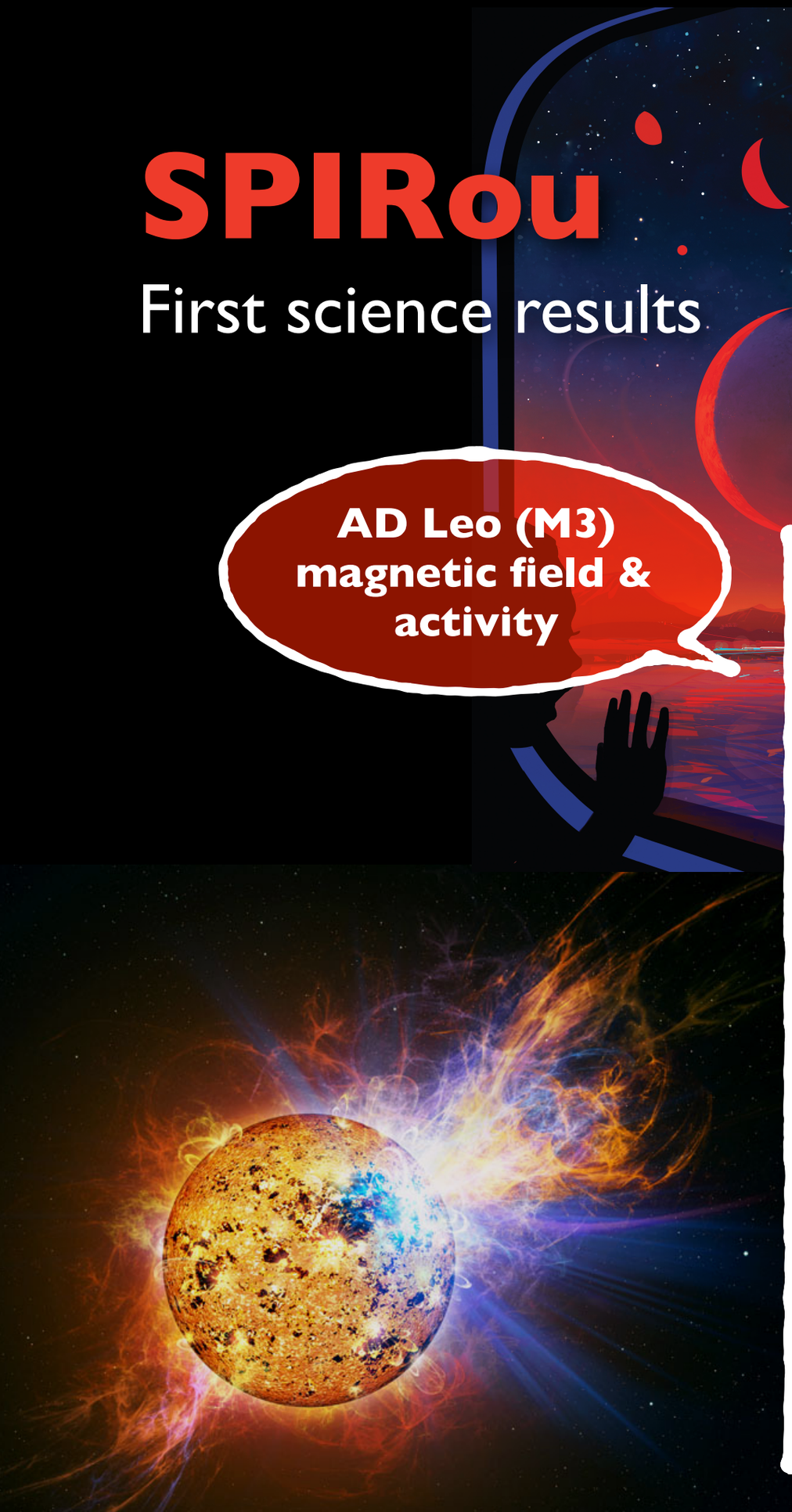

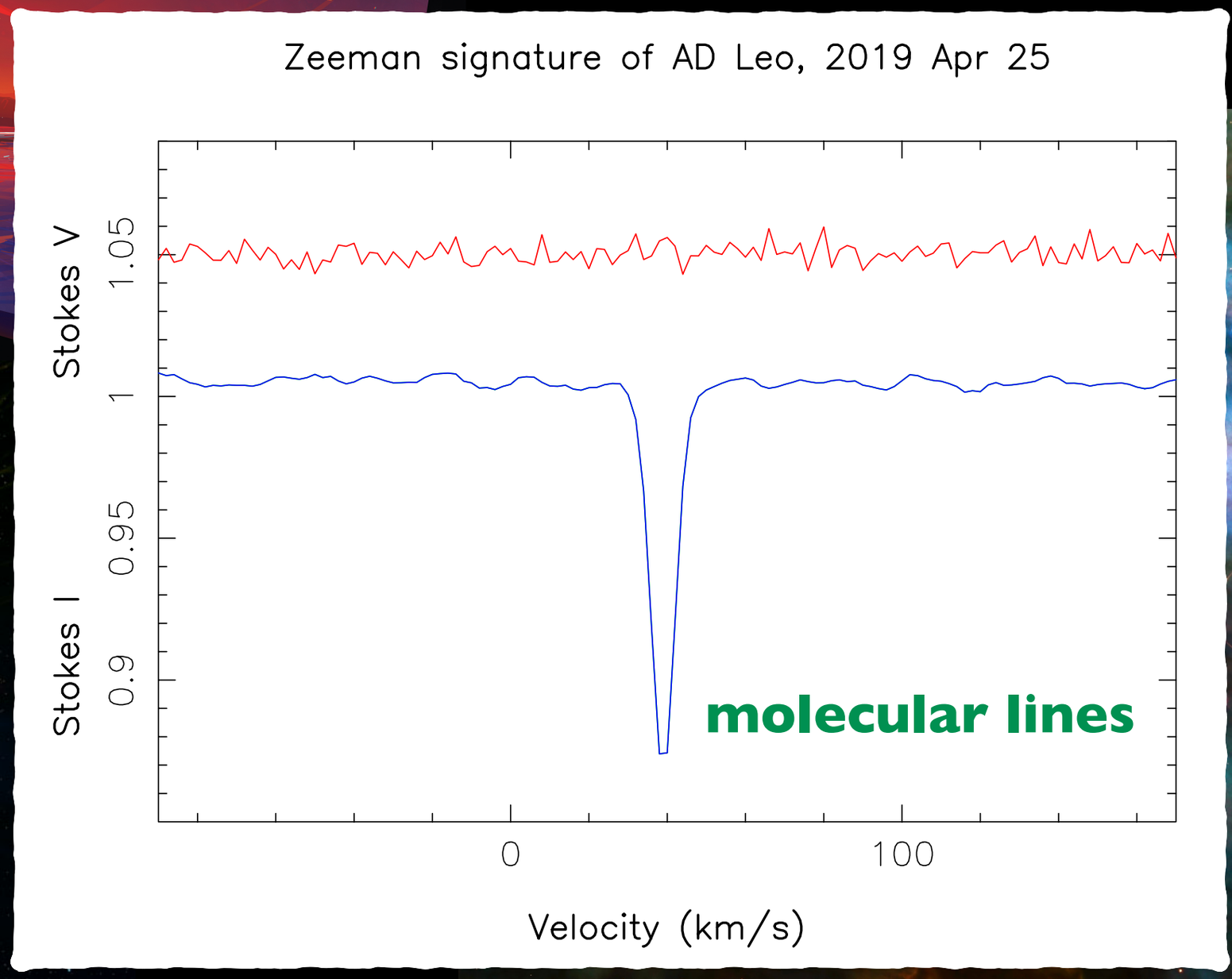

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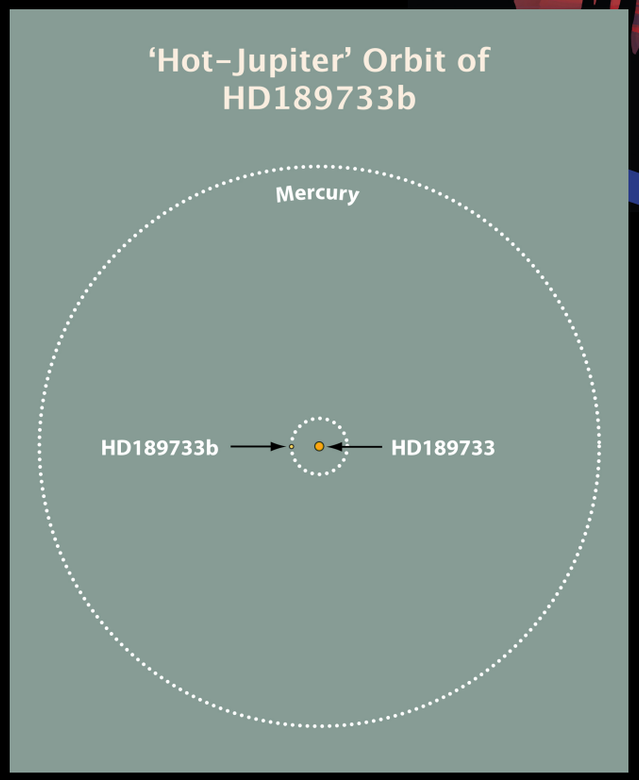
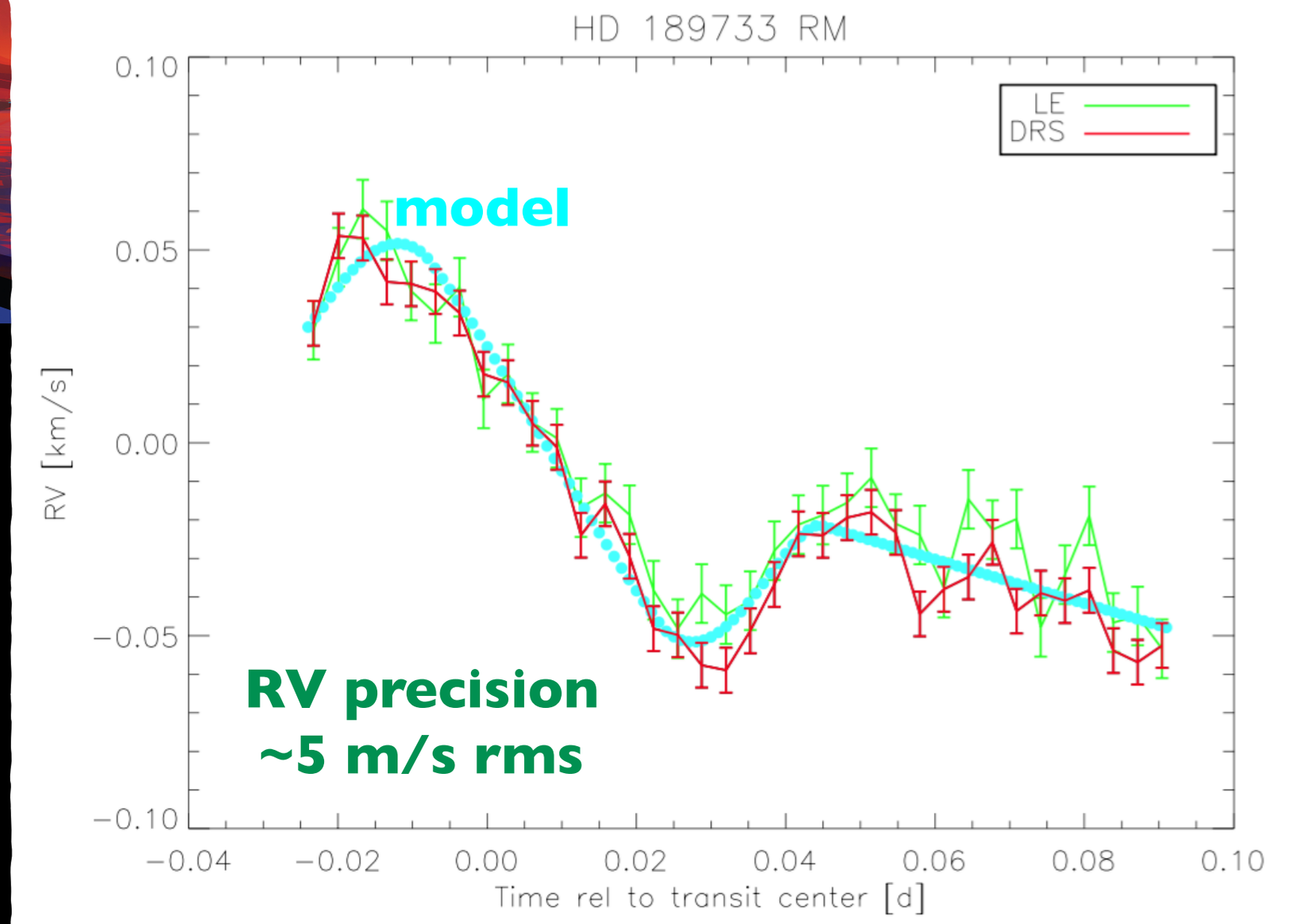
First science results

RM effect transit of HD 189733b (Moutou et al in prep)

SPiRou





SPIRou

First science results

SPiRou

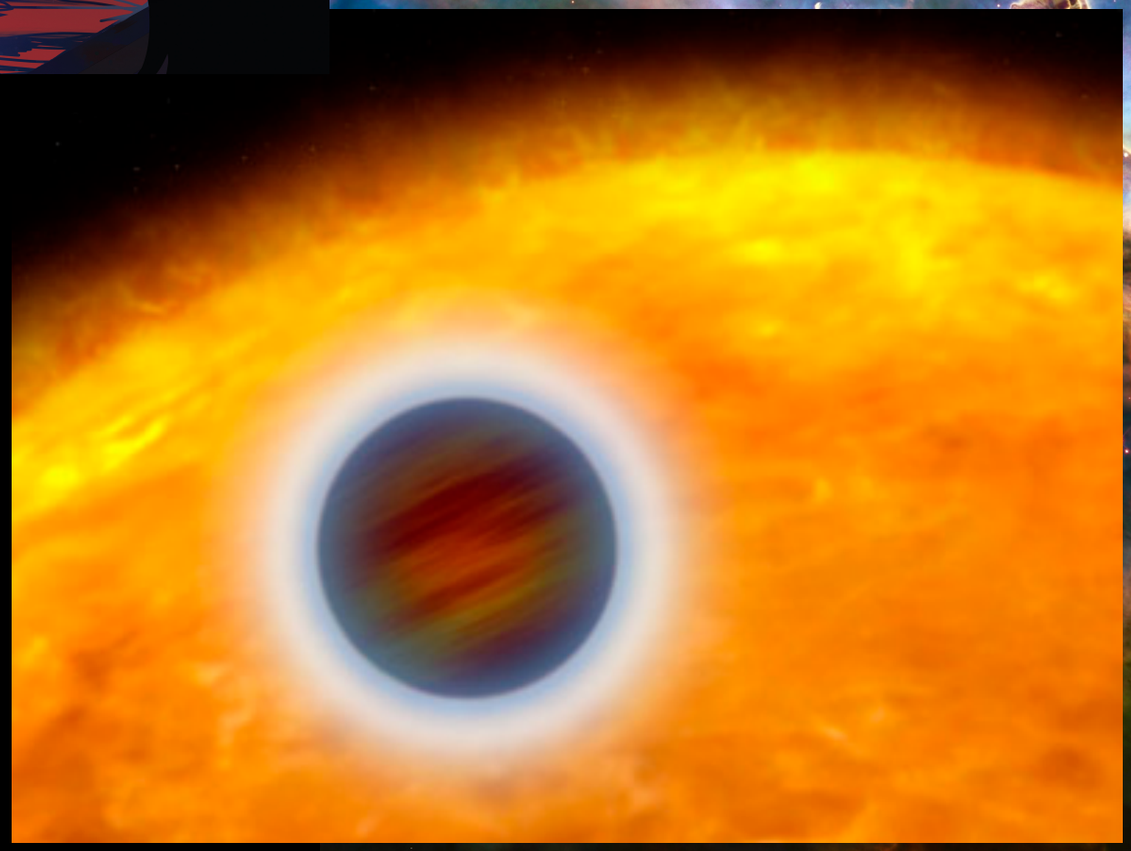
exoplanet atmospheres

detect atmospheric signatures of transiting planets

a few close-in planets observed w/ SPIRou during transits

hot Jupiters, eg HD 189733 b; hot Neptunes, eg AU Mic b

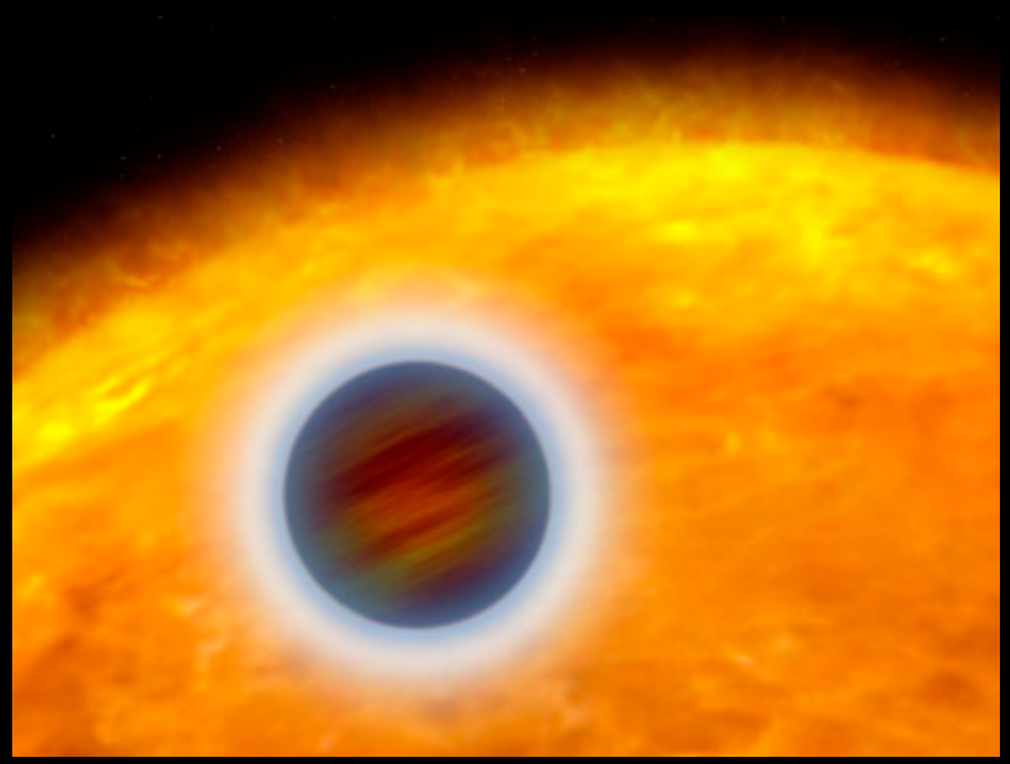
➽ He, H_2O, CO detected - O_2, CH_4 ?



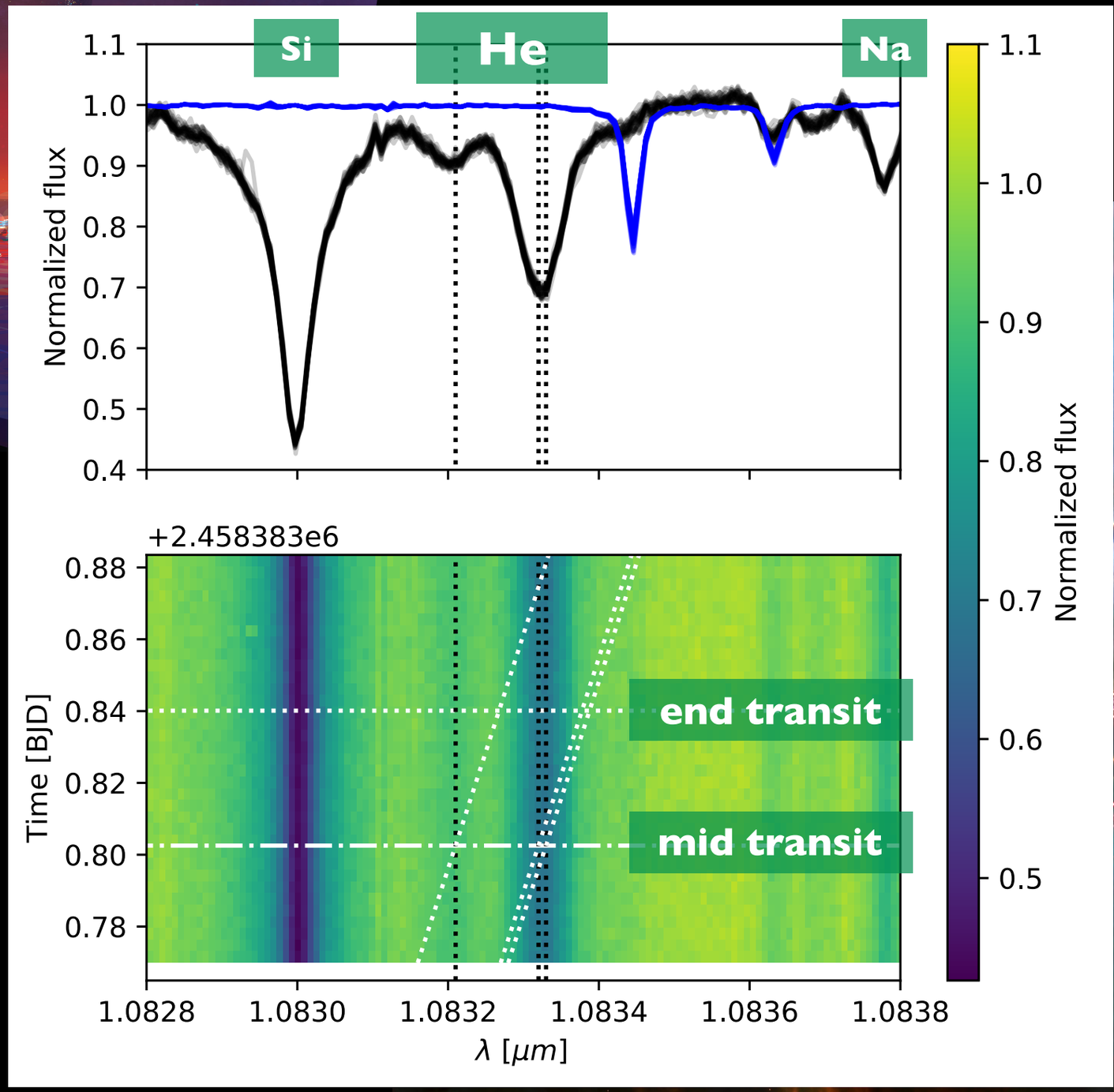
SPIRou

First science results

transit of HD 189733b, 1083 nm He I absorption (Darveau-Bernier et al in prep)

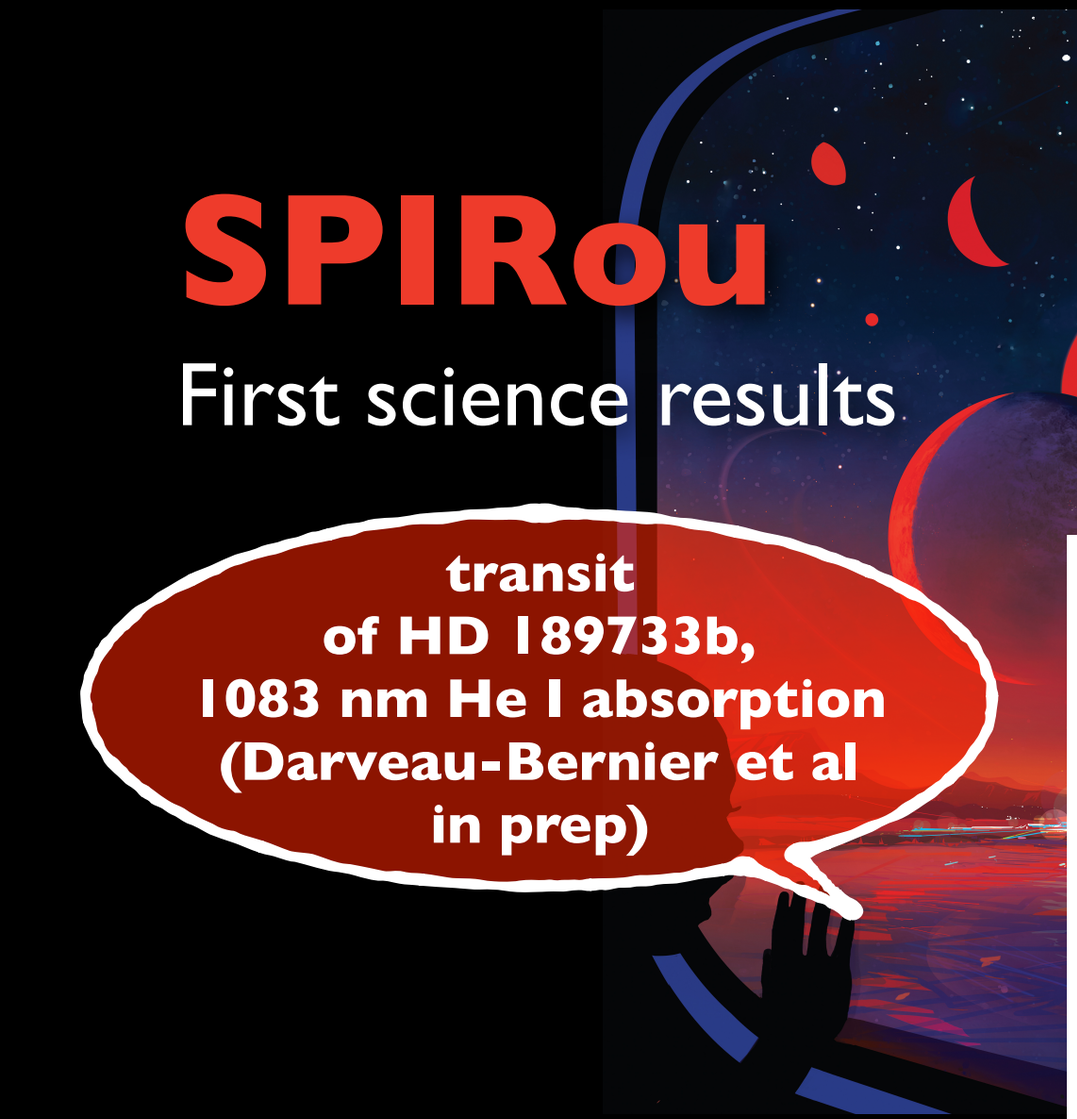


SPiRou

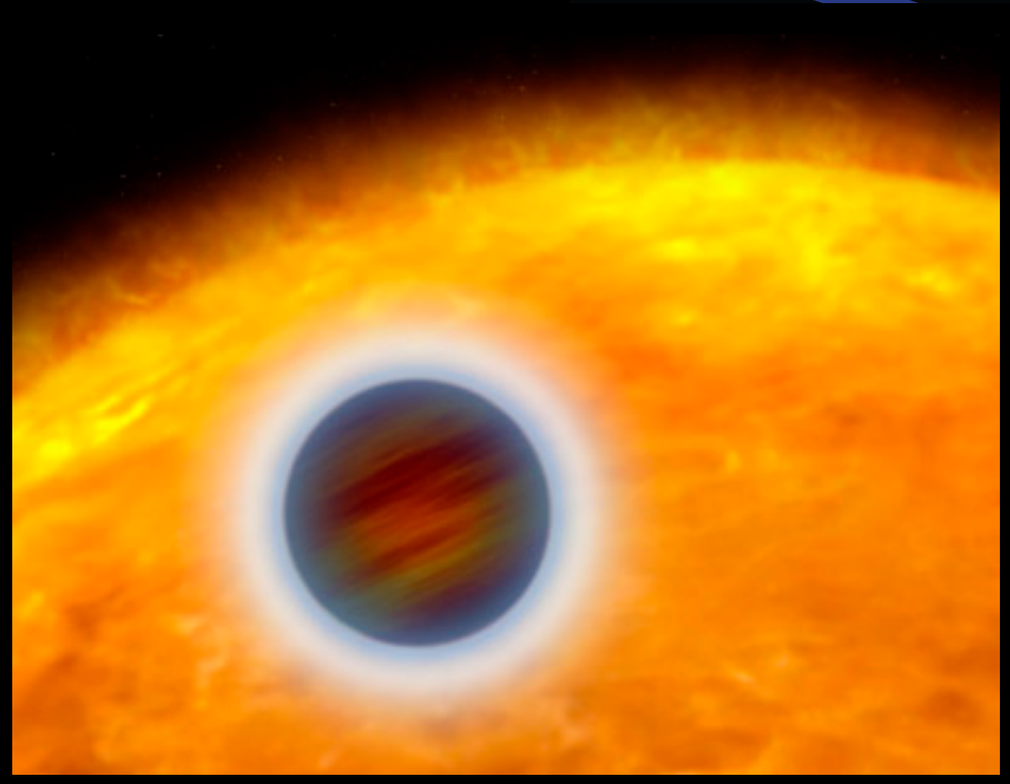


SPIRou

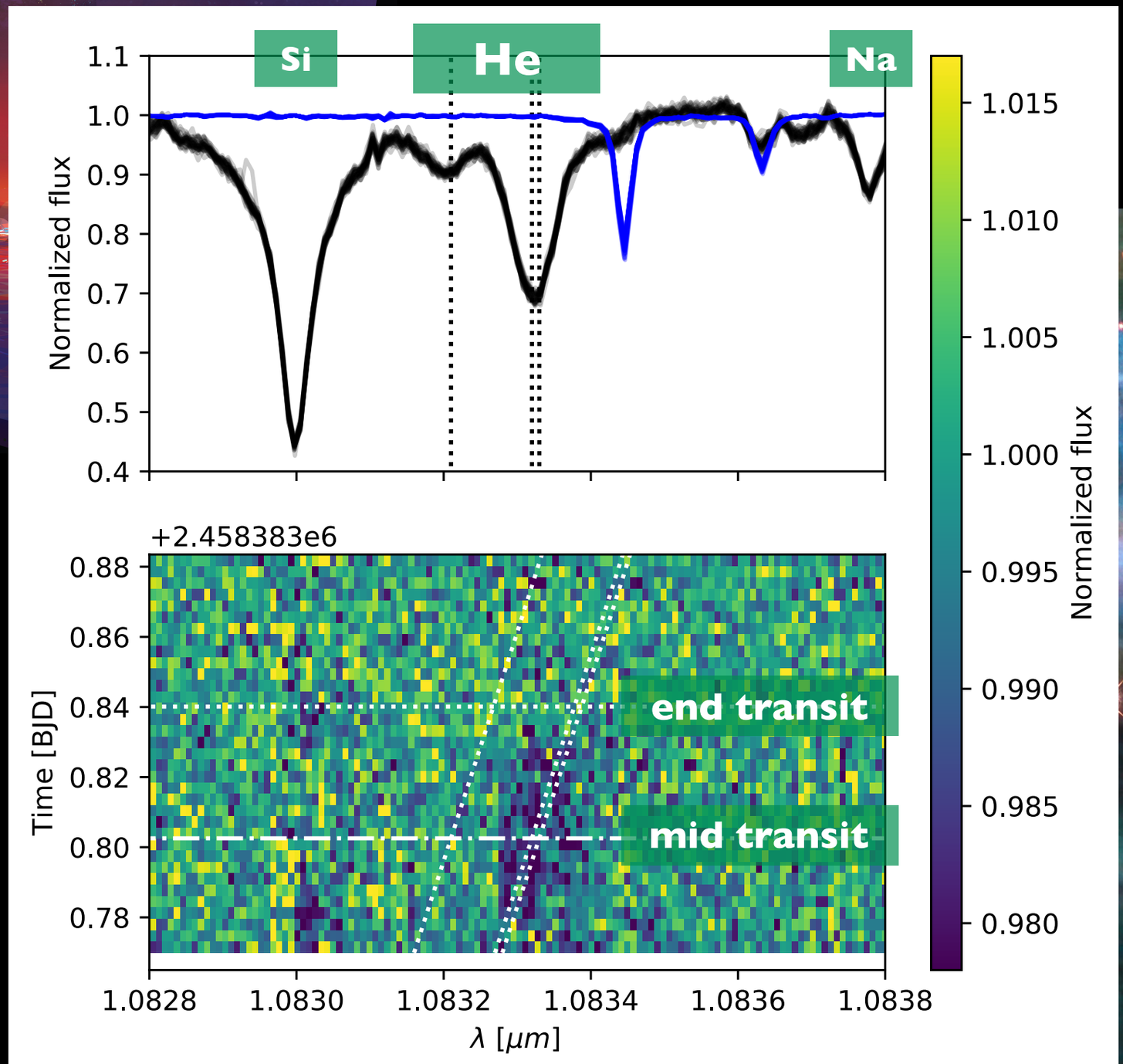
First science results



transit of HD 189733b, 1083 nm He I absorption (Darveau-Bernier et al in prep)



SPiRou

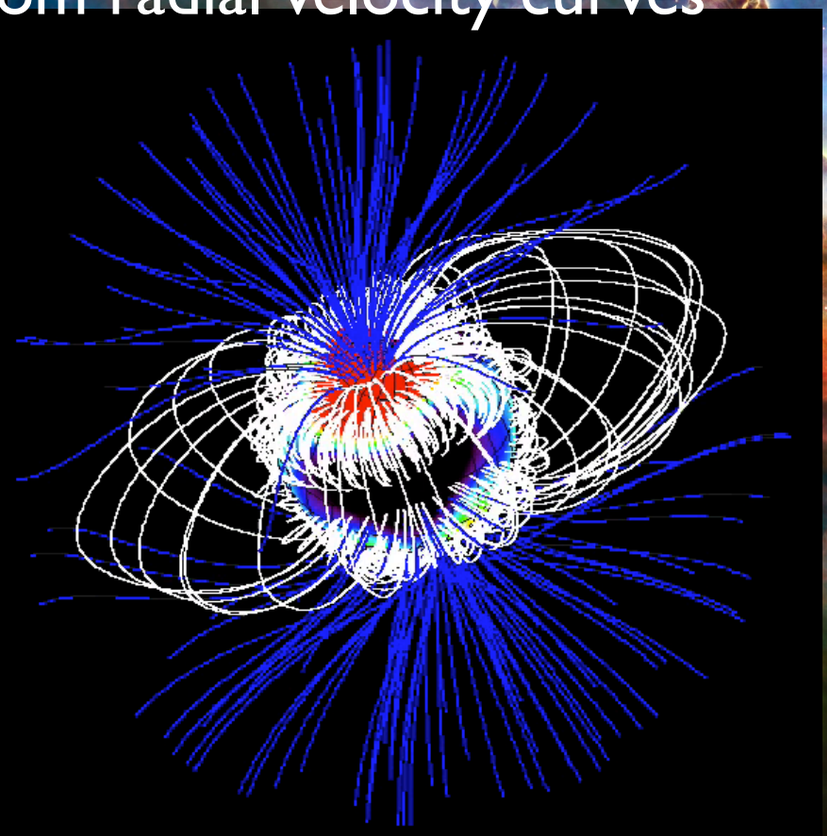


SPIRou

First science results

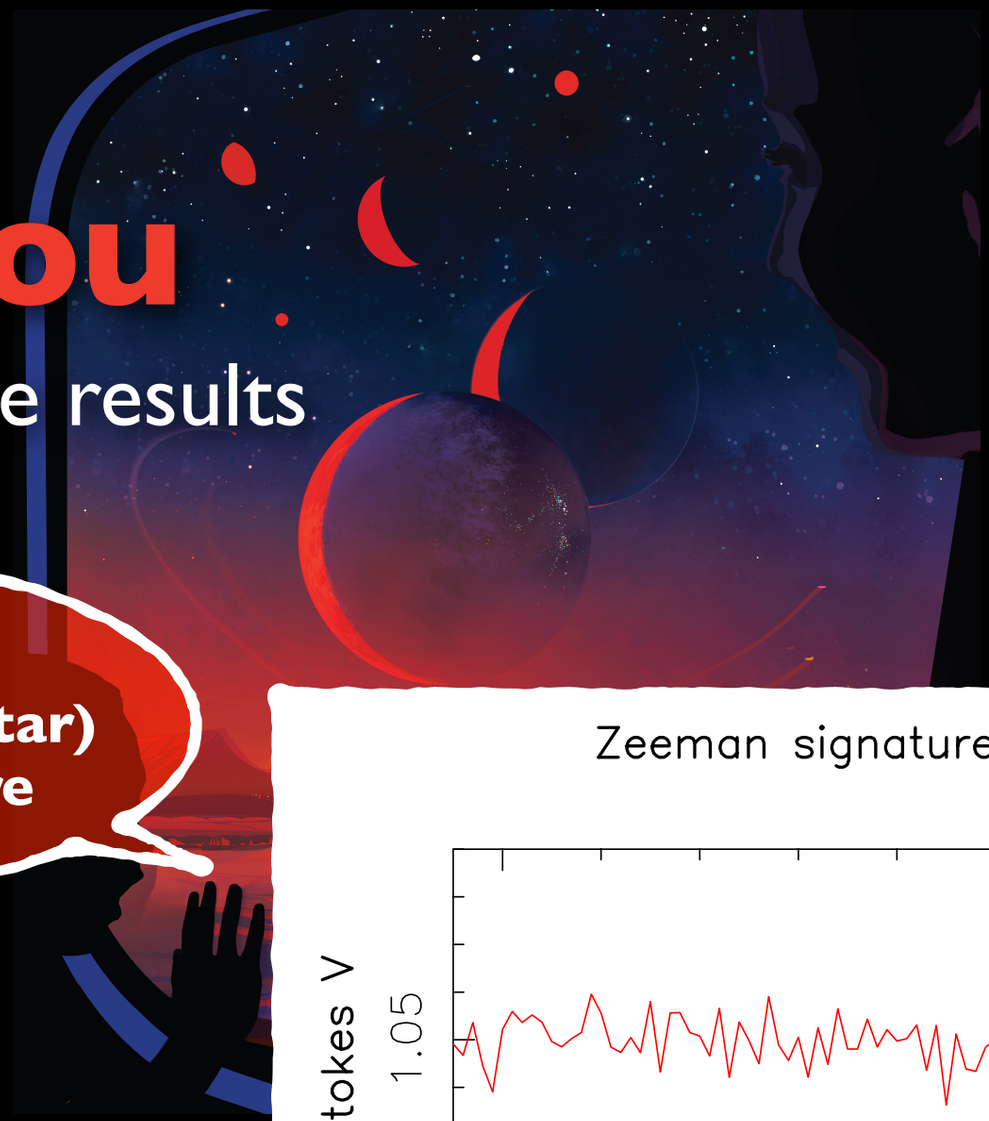
star / planet formation

detect Zeeman signatures in the spectral lines of the young star
collect times series of modulated line profiles & Zeeman signatures
recover spot patterns & magnetic topologies using tomographic imaging
investigate accretion from spectral proxies (eg HeI, Pa g, Pa ß, Br g)
look for close-in giants after filtering activity from radial velocity curves



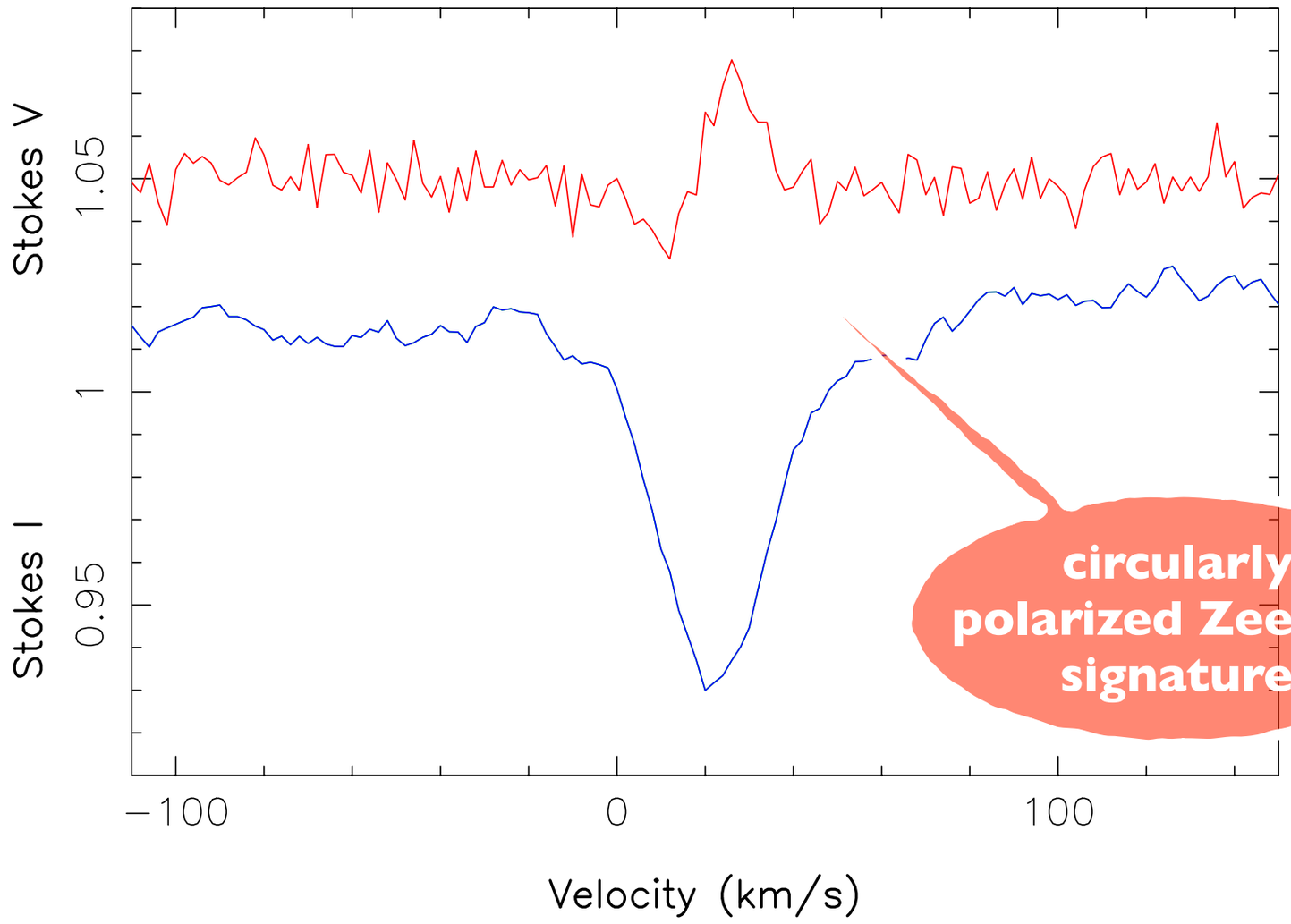
SPIRou

First science results



SPiRou

TWA 13A (disc-less T Tauri star) Zeeman signature

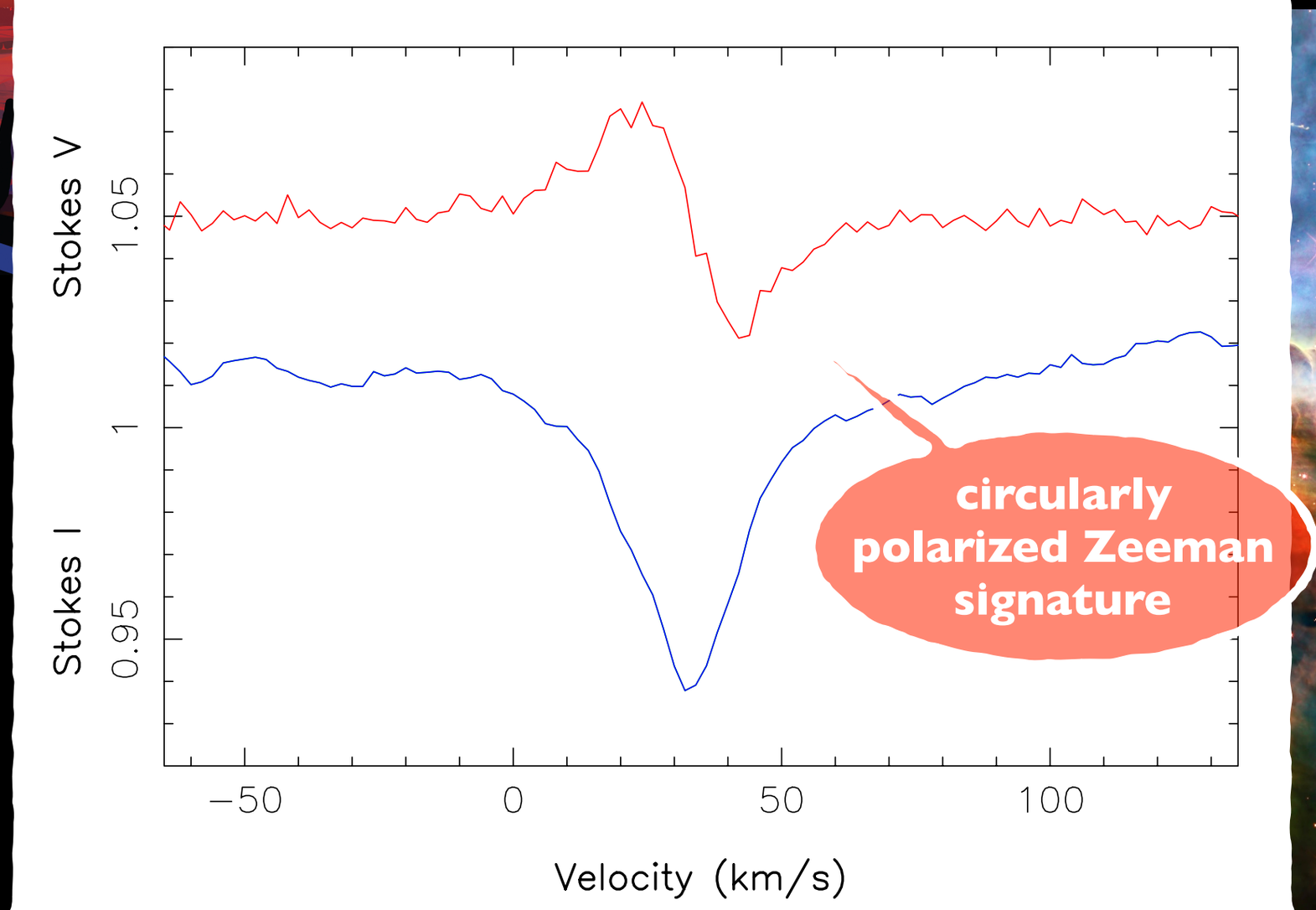


SPIRou

First science results

SPiRou

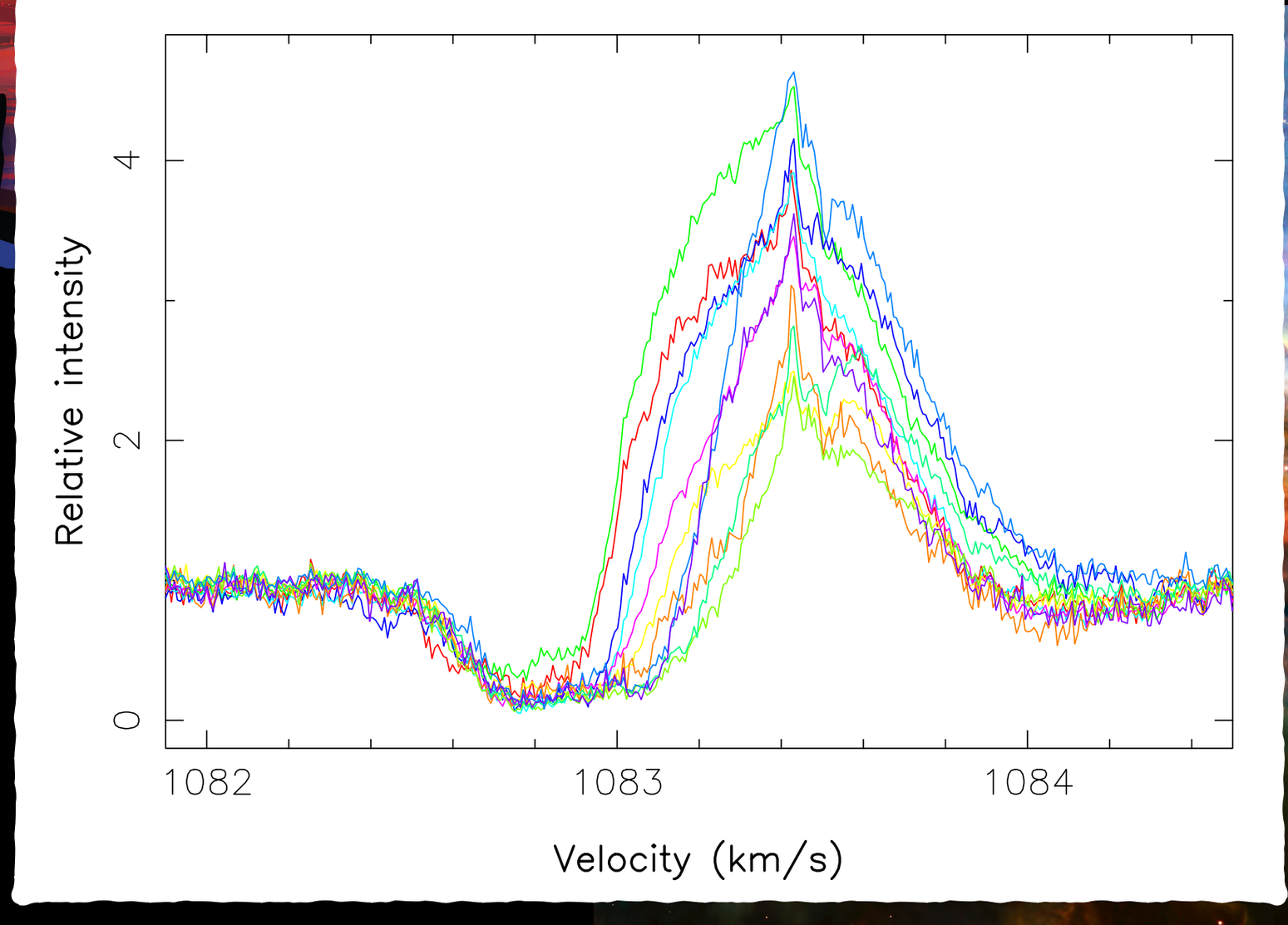
TW Hya (classical T Tauri star) Zeeman signature



SPIRou

First science results

TW Hya
(classical T Tauri star)
1083 nm He I accretion & wind proxy

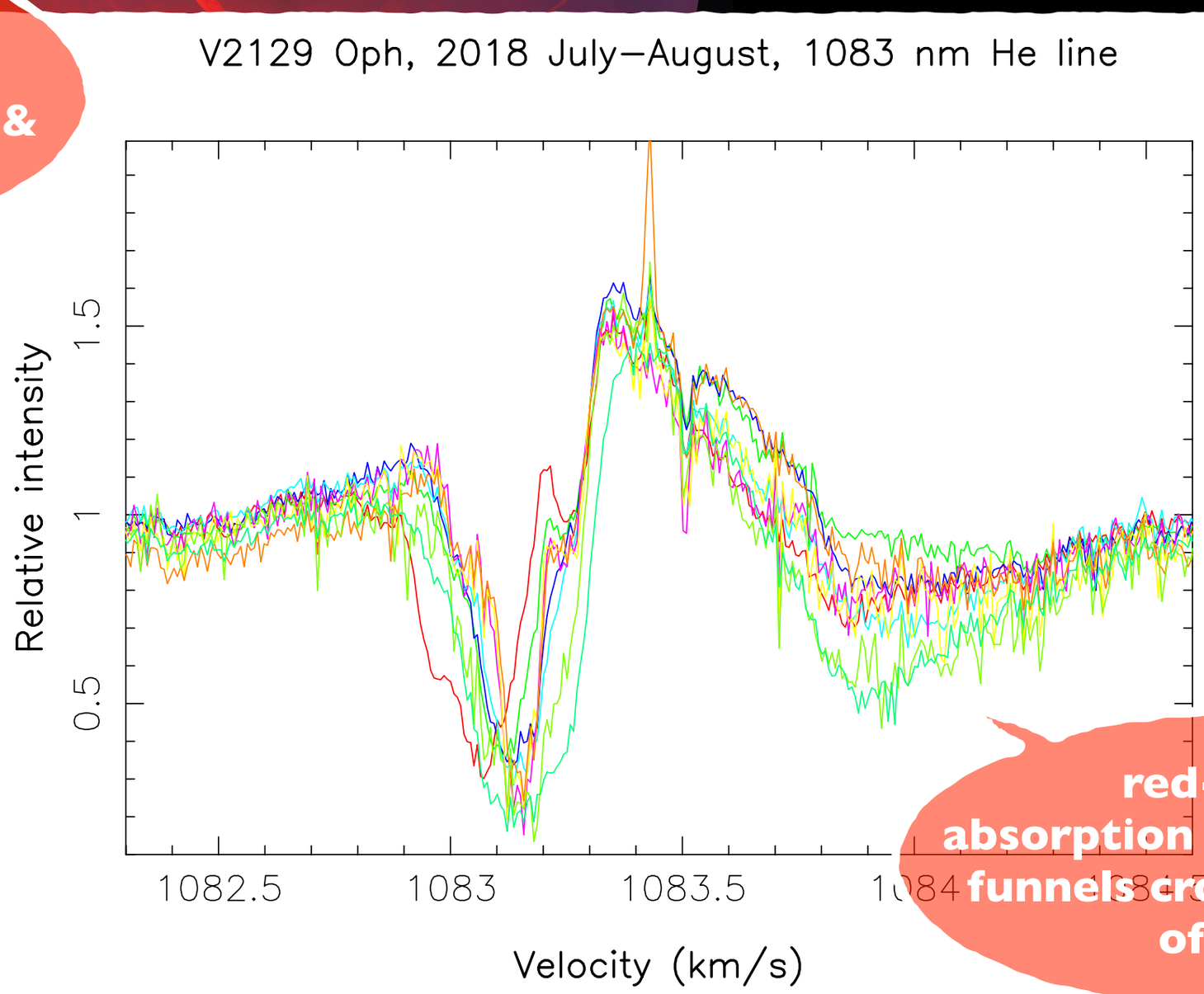


SPIRou

First science results

SPiRou

V2129 Oph (classical T Tauri star) 1083 nm He I accretion & wind proxy



red-shifted absorption from accretion funnels crossing the line of sight

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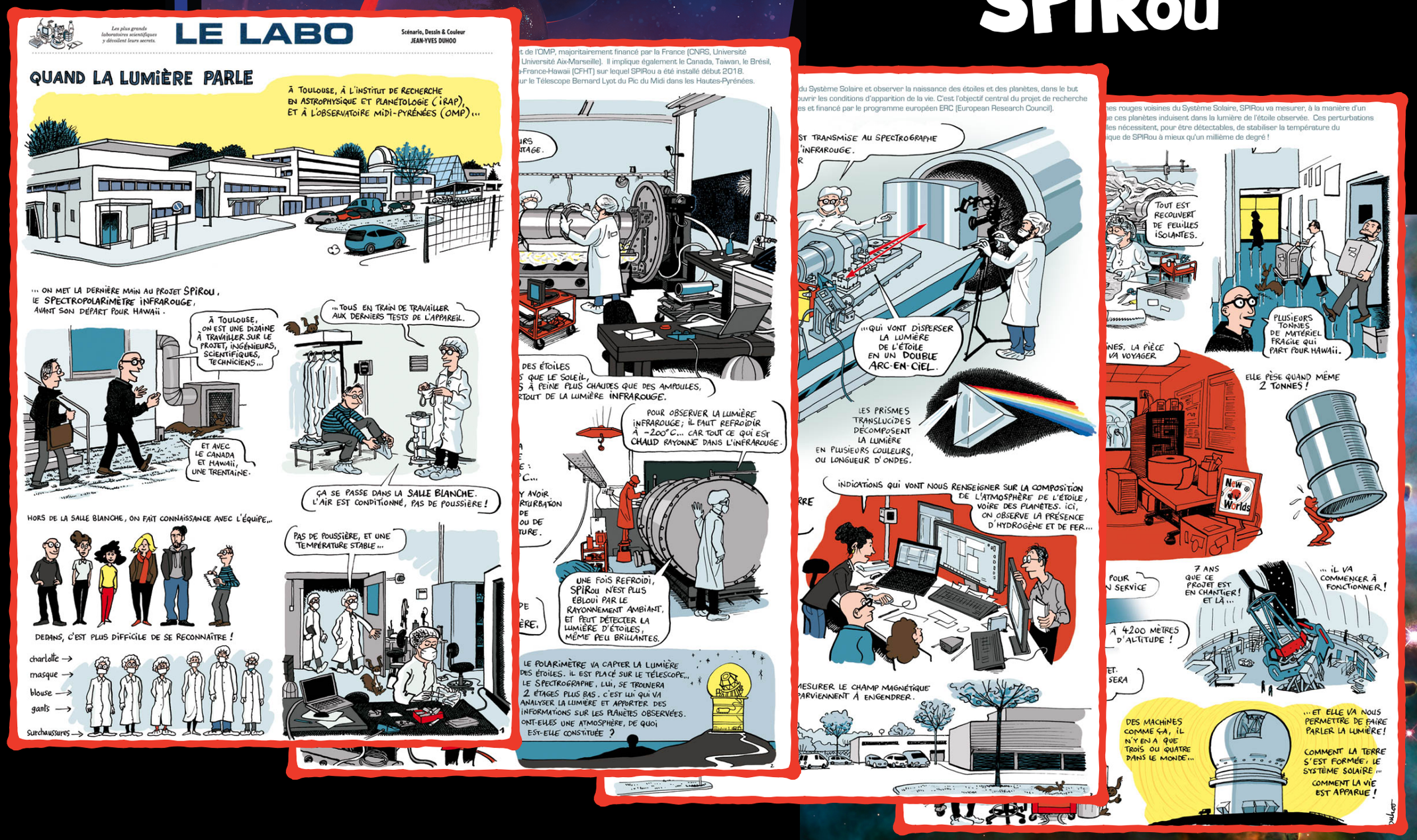
Outreach



SPIRou

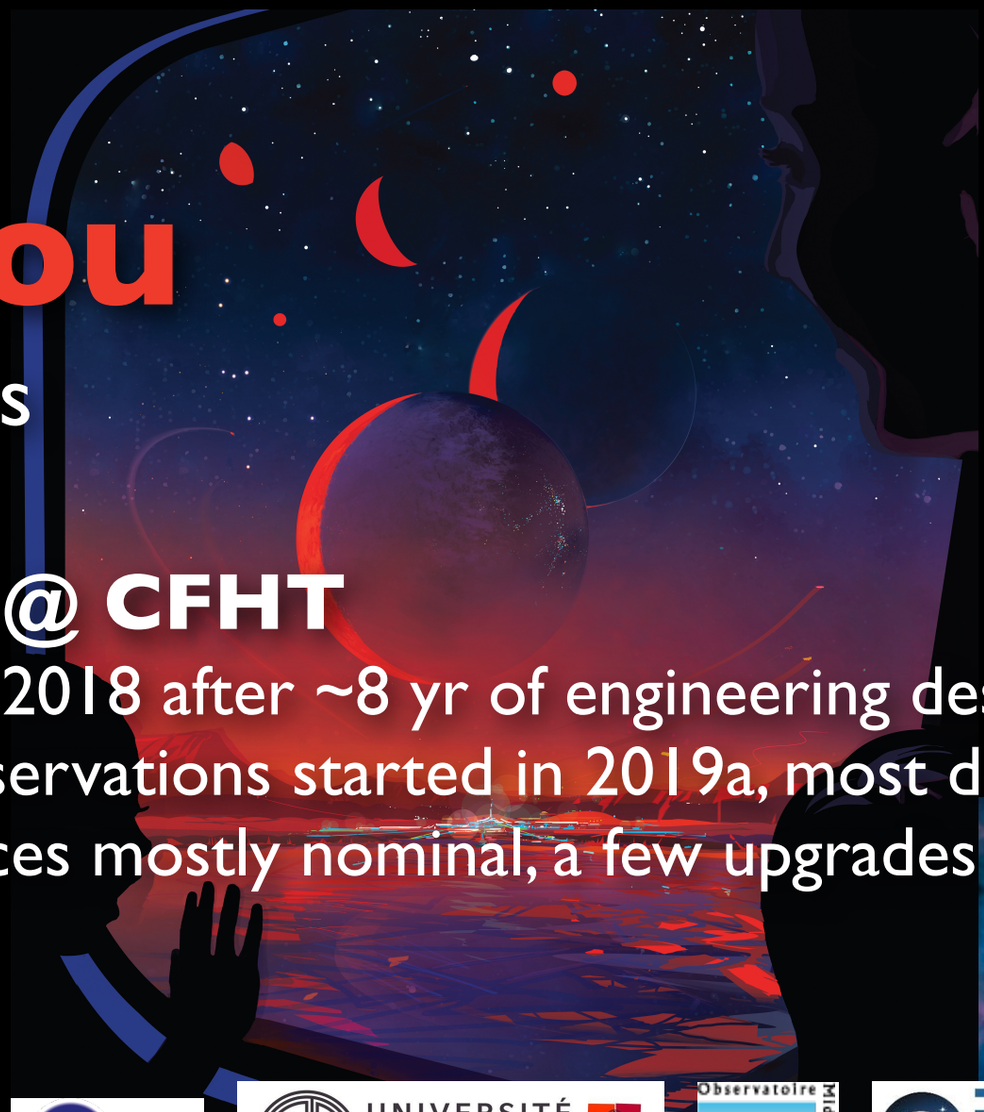
Conclusions

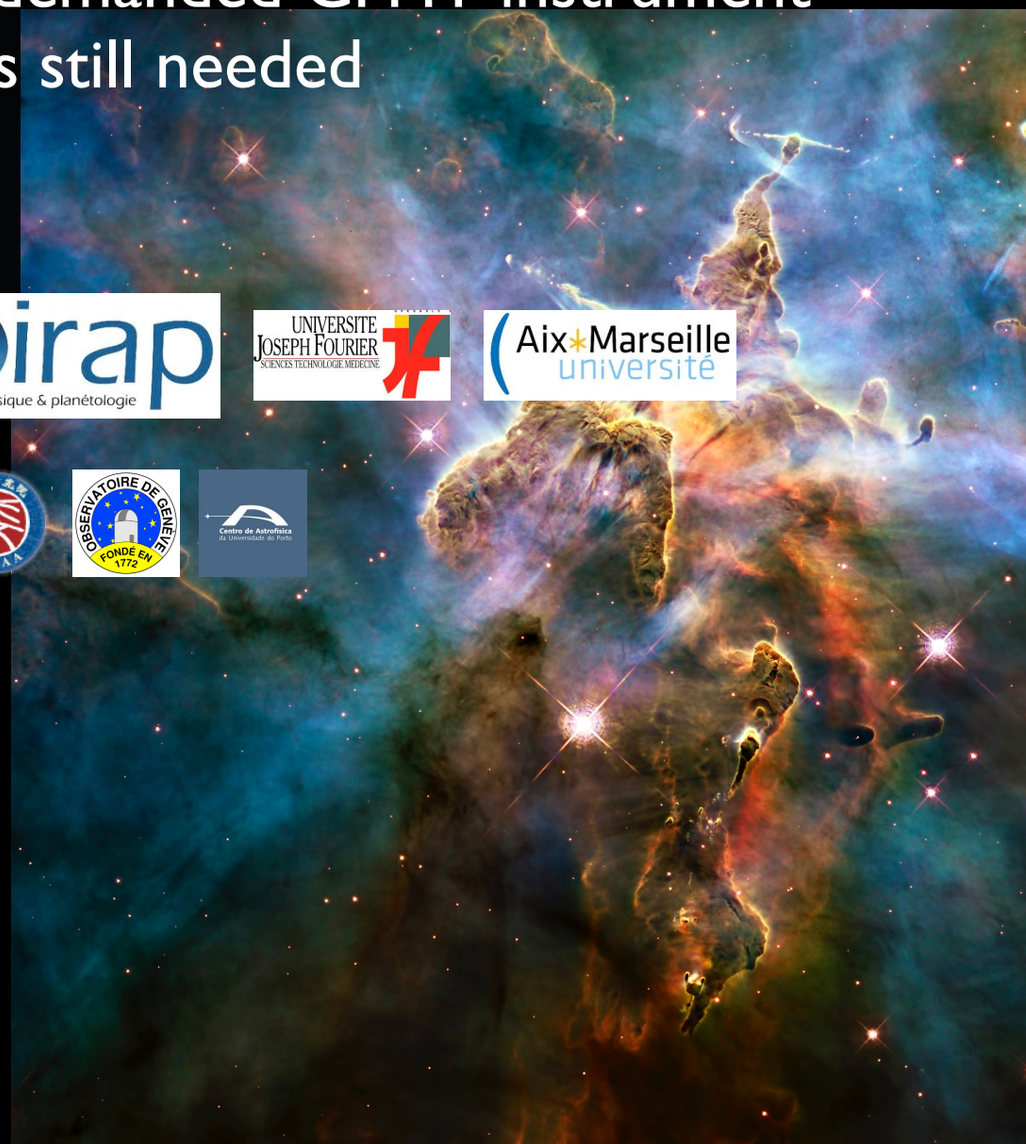
SPIRou @ CFHT

installed in 2018 after ~8 yr of engineering design, integration & tests

science observations started in 2019a, most demanded CFHT instrument

performances mostly nominal, a few upgrades still needed





SPIRou

Conclusions

SPIRou @ CFHT

installed in 2018 after ~8 yr of engineering design, integration & tests
science observations started in 2019a, most demanded CFHT instrument
performances mostly nominal, a few upgrades still needed

first results to come

velocimetric monitoring & planetary transits of M dwarfs
modeling magnetic activity & velocimetric jitter of M dwarfs
magnetic fields, accretion & hot Jupiters of young T Tauri stars
ERC-funded PhDs & postdocs

SPIP @ TBL

funded by Région Occitanie, to be installed at TBL in 2021
essential for dense phase coverage in dark time