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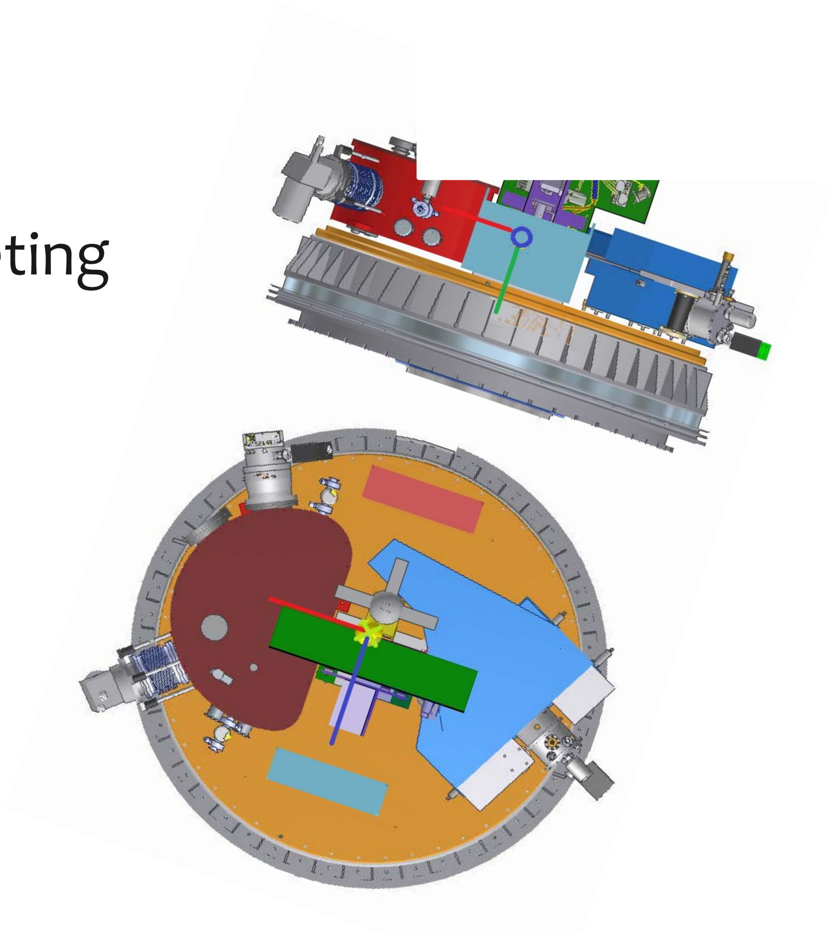
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

SOXS Consortium Science Meeting

24 - 26 Nov 2020



WG2: Exoplanets

Coordinator: Isabella Pagano, INAF – OACT

Team:

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Legend: INAF structures contributing to SOXS instrument; Other INAF structures, Weizmann

Exoplanet contest

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- **Thousands of exoplanets discovered over the past decade**
  - Including discoveries of potentially habitable planets around nearby low-mass stars.
  - Huge diversity of planets and planetary systems
  - Efforts going on to reckon theories for formation and evolution with observables
- **The field is rapidly progressing**
  - detailed spectroscopic observations to characterize the atmospheres of these planets.
- Various surveys from space and the ground are detecting and are expected to detect numerous more exoplanets orbiting nearby stars
  - Good targets for atmospheric characterization, studying star-planet interactions and environments, habitability, biomarkers.

SOXS and Exoplanets

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TOPIC	OBSERVATIONS	REQ TIME
Star-Planet Interaction	ToO	18 hr/yr
Planetary Atmospheres (VIS&NIR spectroscopy)	TC	40 hr/yr
Planets of dMe stars: flare irradiation of planetary atmospheres	TC	25 hr/yr
Spectro Astrometry	NTC	28 hr/yr
BD Monitoring	NTC	20 hr/yr
BD Characterization	F	20 hr/yr
Characterisation of ARIEL Targets	F	40 hr/yr

I will discuss for today only programs with Time Critical Observations.

ToO: Target of Opportunity; TC: Time Critical; NTC: Not Time Critical; F: Fillers

Star Planet Interaction (SPI)

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Gravitational interaction

⇒ Planet deformation, internal heating, orbit circularization, spin axis alignment

MHD Interactions

⇒ Magnetic activity phenomena, accretion and transfer of angular momentum

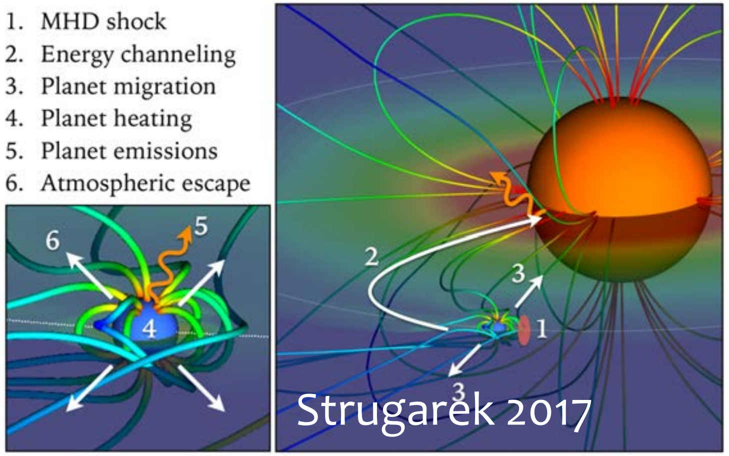
Wind-magnetosphere SPI

⇒ Magnetic storms and space-weather effects

⇒ Outflows/inflows

Irradiation

⇒ Ionosphere generation, heating and evaporation of planetary atmospheres



SPI model predictions

- Magnetic SPI expected within one day from periastron
- Energy release predicted in the range $10^{27} - 10^{28}$ erg/s (Lanza 2013)
- Expected increase of Lx by a factor 2–10

SPI observations

- Increased chromospheric emission, at periastron, e.g. Ca II H & K line core, coherent with brightening in X-rays (e.g., Maggio et al. 2015)

SOXS challenge for SPI studies

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- SPIs have been observationally difficult so far
  - ⇒ Opt/UV/X-ray monitoring programs of selected objects require coordinating ground-based Opt/NIR spectrographs and UV/X-ray space-borne instrumentation
- Search focused where we do expect major effects
  - ⇒ Hot Jupiters around young/active stars, especially those in highly eccentric orbits
  - ⇒ Search for phase-related variability of chromospheric lines
- Observation strategy
  - ⇒ Time-critical observations (periastron passages) of selected stars, relatively bright (V 8–10)
  - ⇒ Sequences of 10–30 m exposures at specific orbital phases, and about 10 epochs per object

Overall request:

less than about 100 hr spread over the whole SOXS GTO.

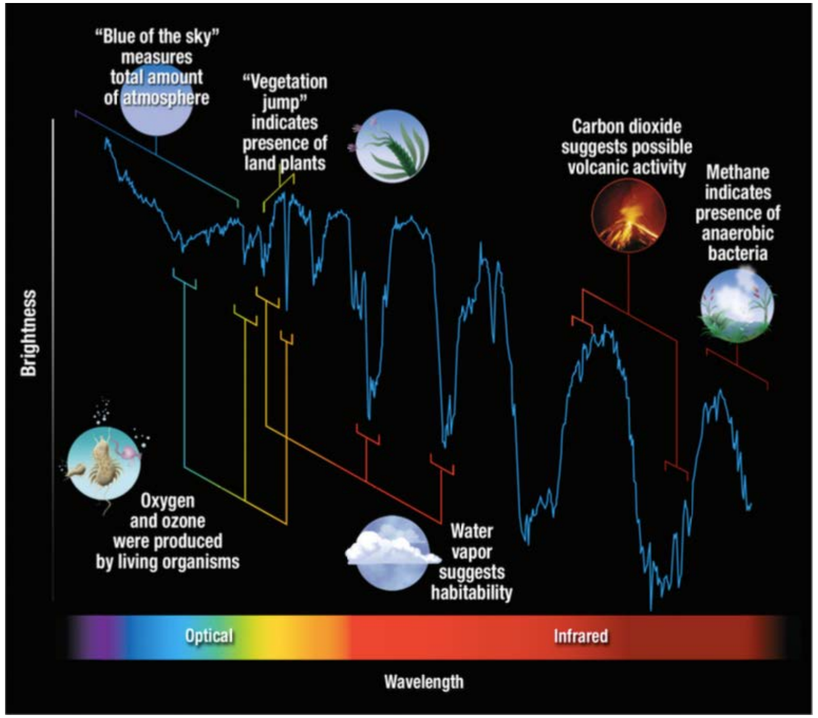
SOXS & exo-atmospheres

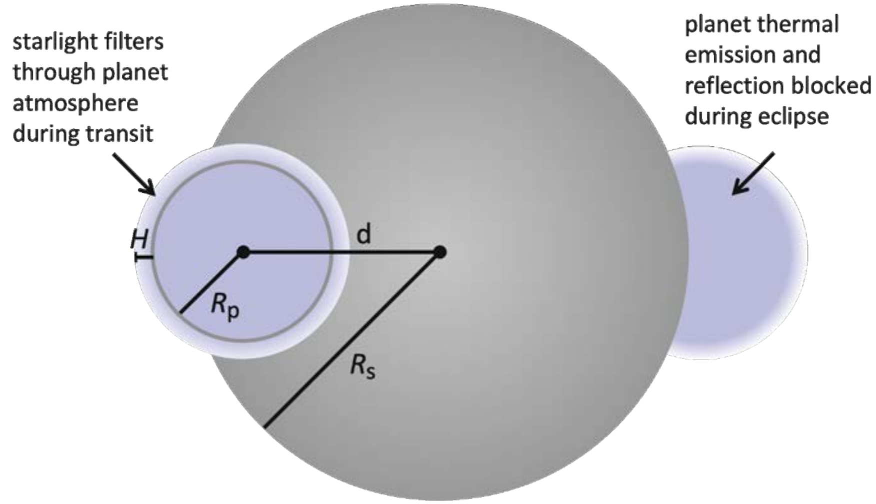
What exo-atmospheres tell us

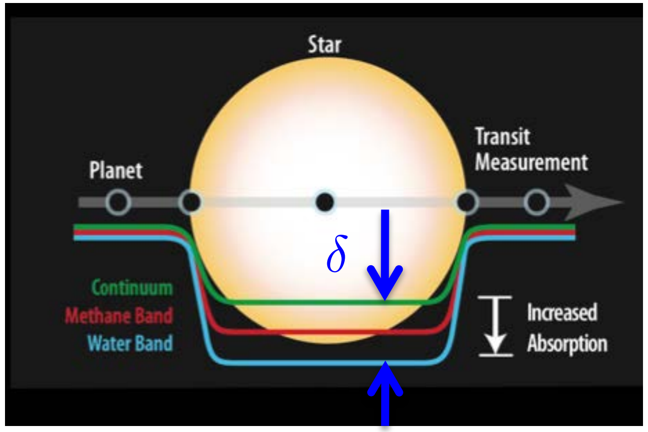
- Elemental abundances of exoplanetary atmospheres place important constraints on exoplanetary formation and migration histories.
- Recent studies reveal **a rich diversity of chemical compositions** and atmospheric processes hitherto unseen in the Solar System.

How to study exo-atmospheres

- Transmission and emission spectroscopy of transiting planets







Exo-atmospheres with SOXS-VIS&NIS

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Transmission spectroscopy of Hot Jupiter-type planets (HJs).

1) **Alkali metals**: NaI doublet at 589 nm and KI line at 770 nm. These lines mainly probe the thermosphere of the planet (huge cross section) and can be exploited as tracers of escape processes (Sing+ 2016)

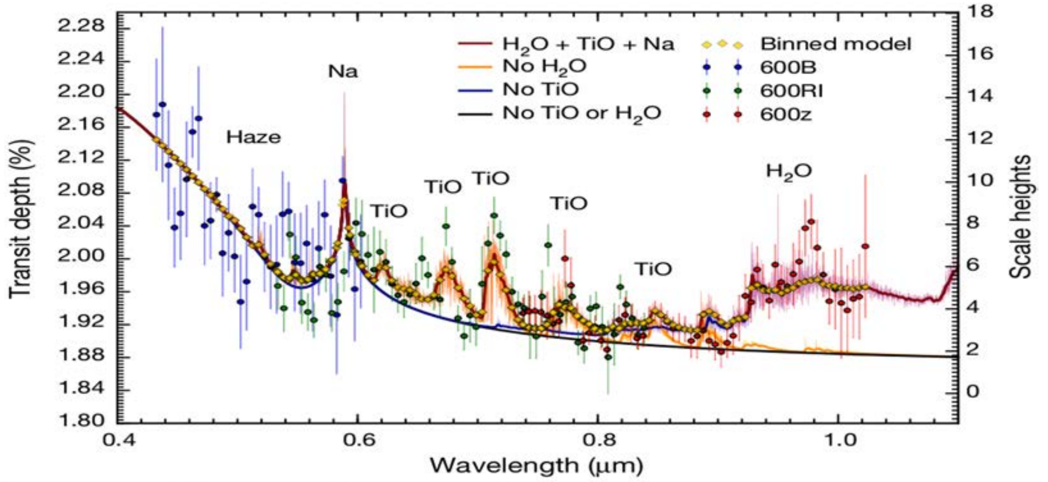
2) **Balmer series**, esp. H-α at 636 nm: hydrogen can be present as a tail in the evaporating planet (Cauley+ 2017)

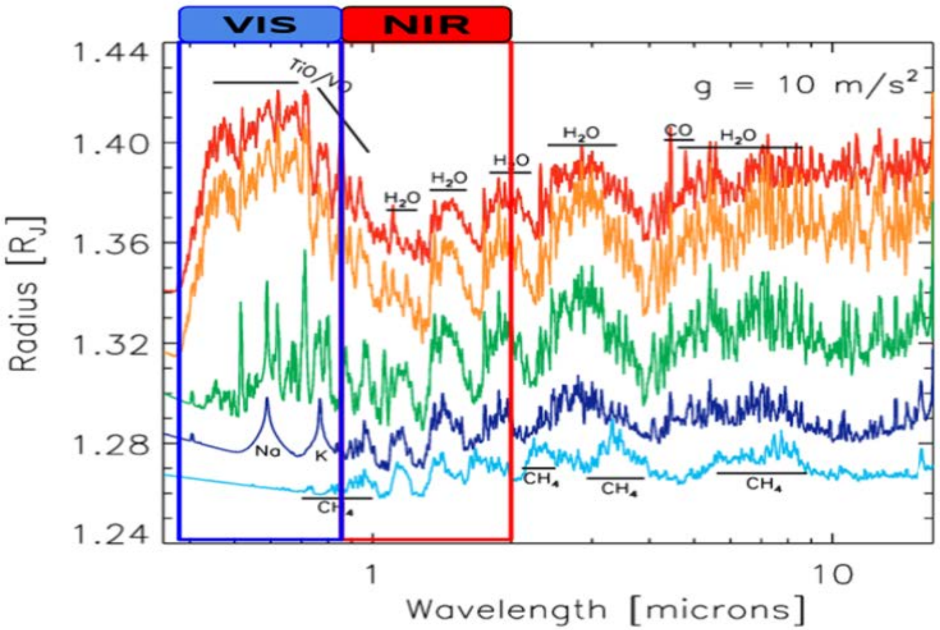
3) **Titanium Oxide (TiO) bands** in the 500-700 nm: thought to be the main optical absorber for very Hot Jupiters (>2000 K), hence fundamental to the thermal equilibrium of the planet (Sedaghati+ 2017)

4) **Other less investigated species**, such as MgI at 510 nm and other metals (Astudillo+ 2013, Cauley+ 2018)

5) The **metastable He absorption line at a wavelength of 1083.3 nm** is a diagnostic to probe the escaping atmospheres of exoplanets (Seager + 2000 and Okplopčić & Hirata, 2018).

- Robust analysis: **simultaneous study of the H-α line** in the visible band at 636 nm (Jensen + 2012); as in the case of the high resolution spectroscopy with the GIARPS observing mode at the Telescopio Nazionale Galileo (TNG).





Spectrophotometry of transits

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Exoplanetary low-resolution transmission spectrum

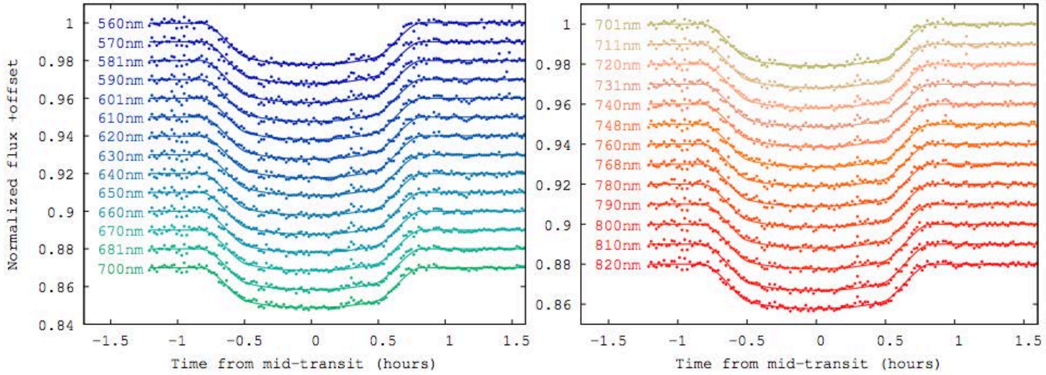
Planetary radius vs. wavelength, adapting “bandwidth” depending on S/N

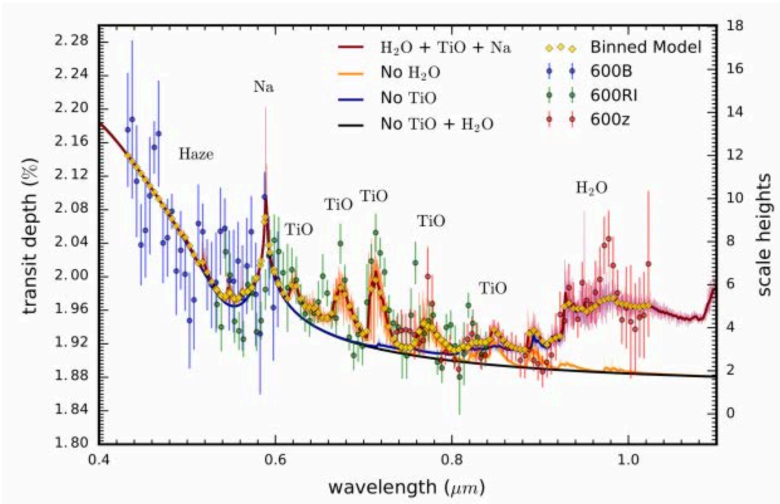
VIS Simultaneously! **NIR**

Clouds, hazes, particle size, Na, K, TiO, temperature…

H_2O, CO, CH_4, He…

Limited to targets with a closeby similar reference star (need for both target+reference centered in the slit)





e.g., Sedaghati+17, Nature, 549, 238

Overall request:

20 (nr. of targets) x 5hr (duration of transit) x 2 (mean number of transits per target) = 200 hr in 5 yr

Exo-atmospheres with SOXS Possible Issues

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- **Telluric contamination** can be a killer even in the VIS range (microtellurics). The relatively low spectral resolution does not allow to resolve the individual telluric lines, making "empirical" approaches mostly ineffective. Atmospheric models such as Molecfit (Smette+ 2015) could be more suited. To be tested on real data (X-SHOOTER perhaps? Kausch+ 2015)
- **Instrumental stability on the time scale of ~a few hours**, both in the line profile and on wavelength calibration is essential to detect signals on the order of ~10^{-4} w.r.t the stellar signal, at best. Again, analysis of X-SHOOTER archival data could provide some reference
- Schedule: **transit observation are strictly time-critical and require ~a few hours of uninterrupted data**

Pino+ 2018

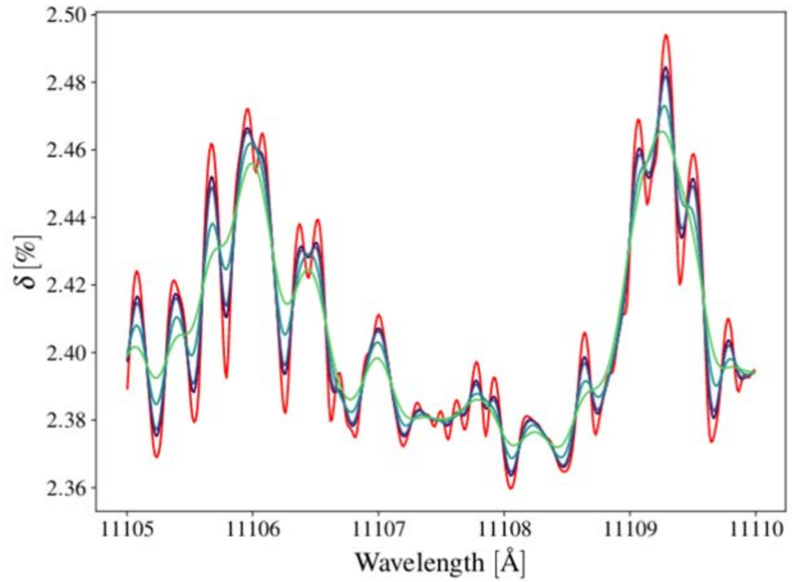

Fig. 2. Effect of finite resolving power on water lines. The red curve corresponds to a line-by-line model (with a resolution of $R \sim 10^6$). From the light green curve to the purple curve, we show the same spectrum convolved with Gaussian LSF corresponding to the following resolving powers: at $R = 50\,000$ (GIANO), at $R = 75\,000$ (similar to CARMENES), at $R = 115\,000$ (HARPS/-N), and at $R = 134\,000$ (ESPRESSO). At the lowest resolving power, the individual molecular lines are not entirely resolved.

Planets of dMe stars: flare irradiation of planetary atmospheres

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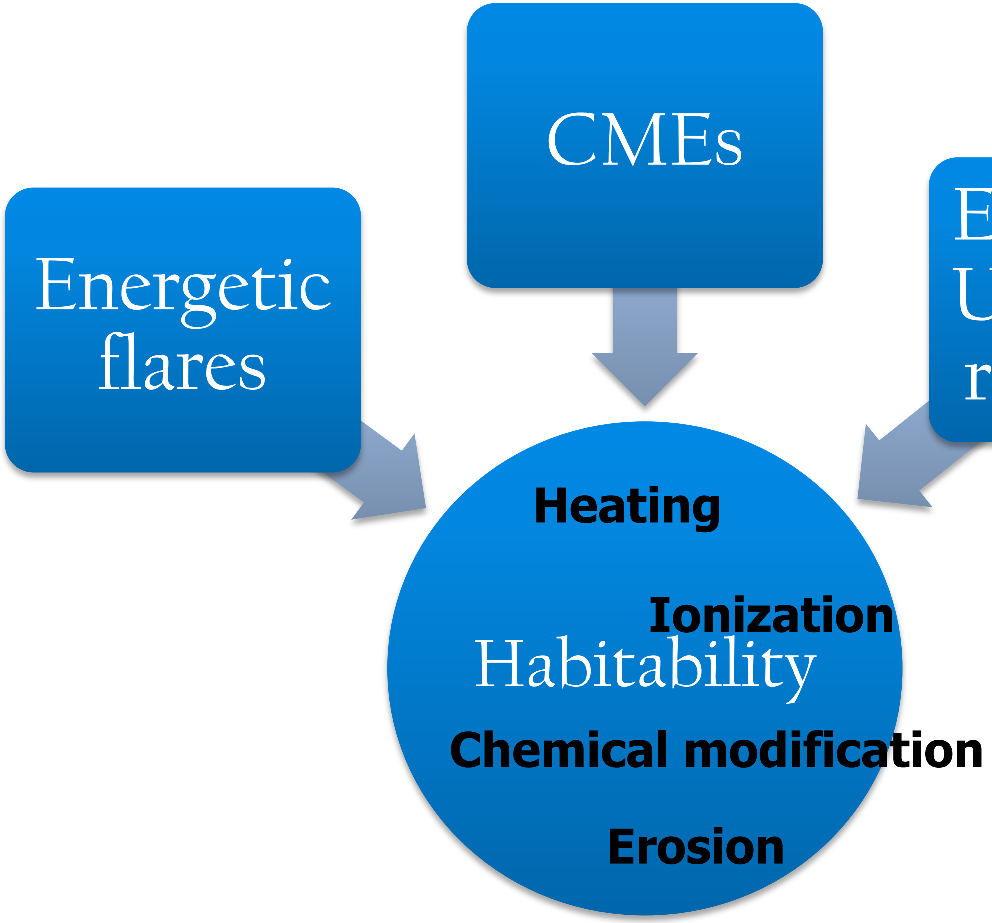

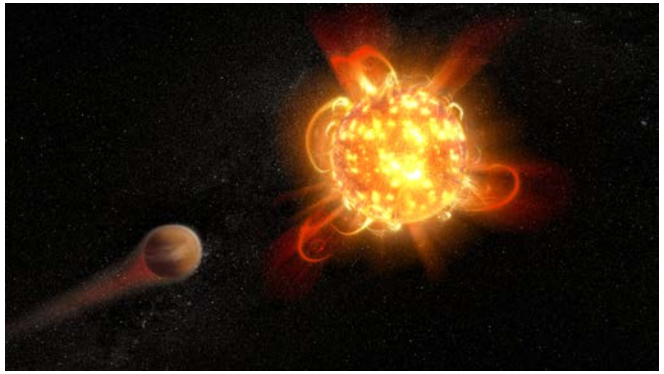

- M dwarfs are the main targets to search for rocky, low-mass planets with the potential capability of hosting life (e.g. Dressing & Charbonneau 2013; Sozzetti et al. 2013).

Activity Diagnostics for SOXS

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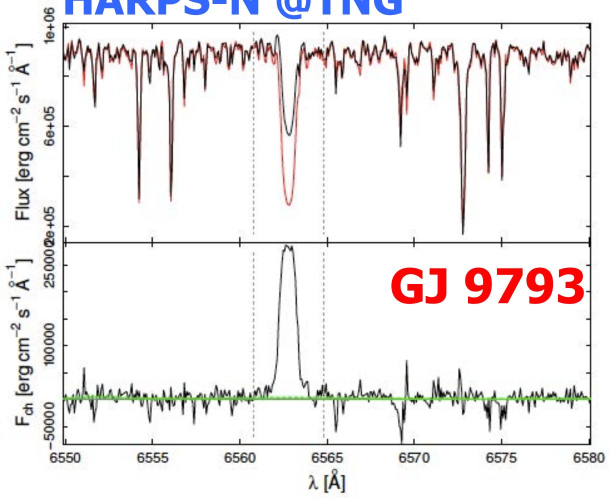
- Ca II H&K (396.85 and 393.37 nm)
- Ca IR triplet (849.8, 854.2 and 866.2 nm)
- The He I 1083.0 nm
  - This is controlled by EUV and soft X-ray radiation field, making it a proxy for coronal emission
- The ratio betweeen He I D3 line at 587.6 nm and the He I at 1083.0 nm.
  - It provides information on the filling factor of active regions (Andretta et al. 2017)
- Na D1, D2 doublet
- Mg I b triplet
- Balmer lines, e.g., Hα line at 656.3 nm

Moderately active M dwarf

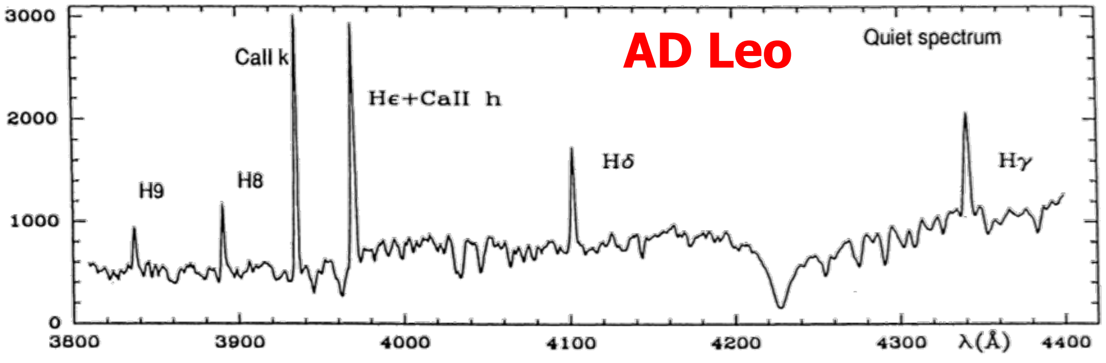
HARPS-N @TNG



Scandariato et al., 2017, A&A 598, A28

Very active M dwarf (dMe)

R= 2400; 3.6 m @ESO



Houdebine et al., 1993, A&A 274, 245

Flares from dMe

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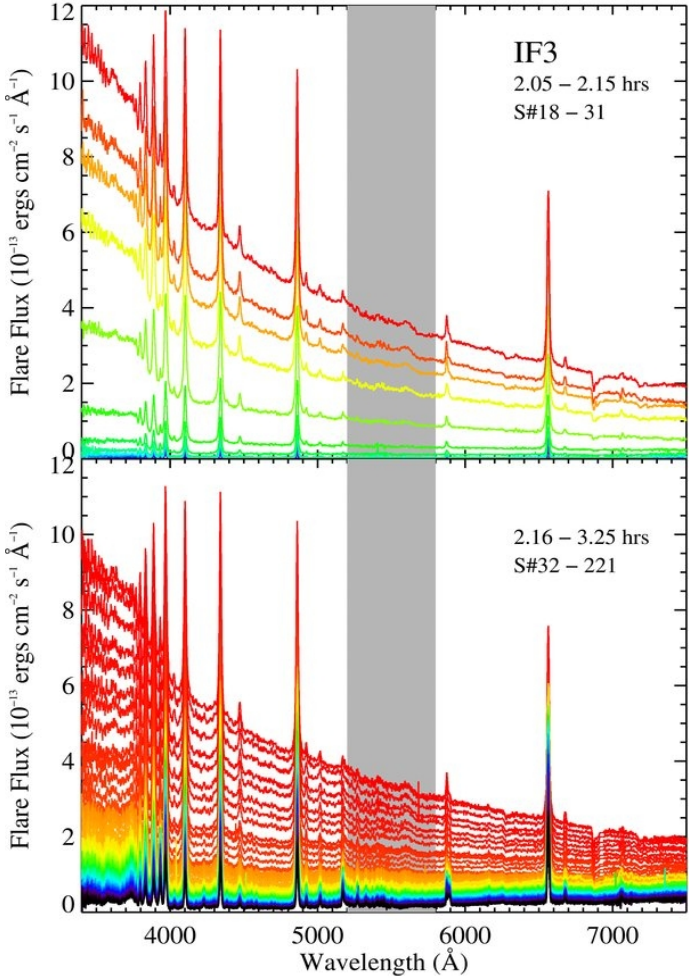
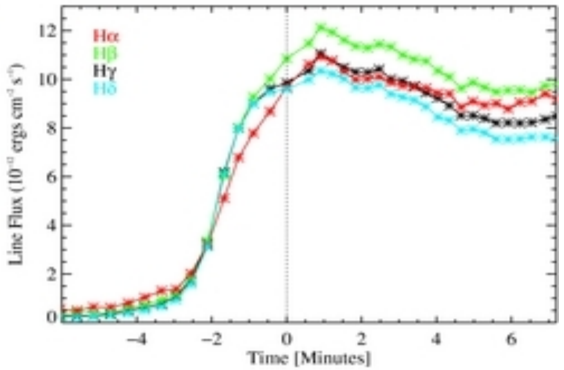
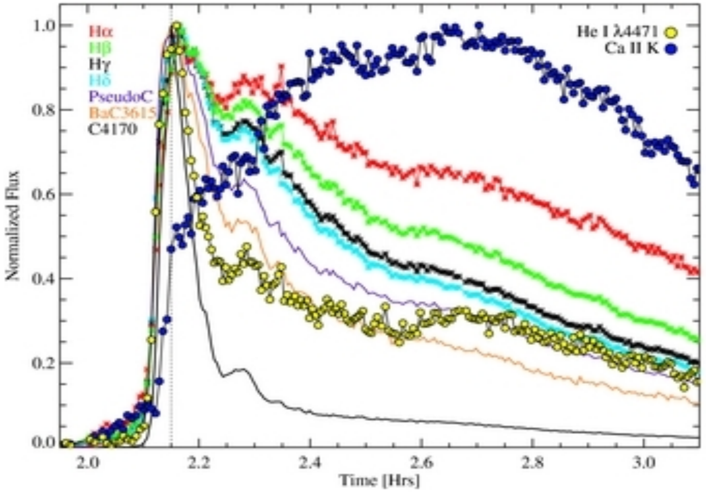
YZ CMi

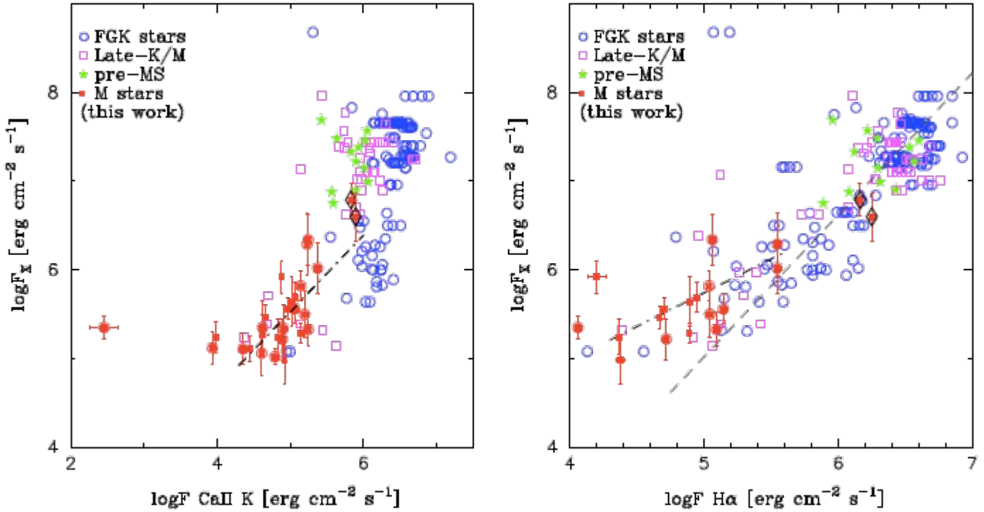


ΔU~4.7 mag; E=2 10^{33} erg





Opt line fluxes as proxy for high energy fluxes



Maldonado et al 2017, A&A 598, id.A27

$$\chi_{\mathrm{flare,peak}} \approx 0.020(\pm 0.002)\mathrm{H}\gamma/\mathrm{C4170} + 1.28(\pm 0.05).$$

from Time-resolved Properties and Global Trends in dMe Flares from Simultaneous Photometry and Spectra
Adam F. Kowalski et al. 2013 ApJS 207 15 doi:10.1088/0067-0049/207/1/15

CMEs and planetary atmospheres

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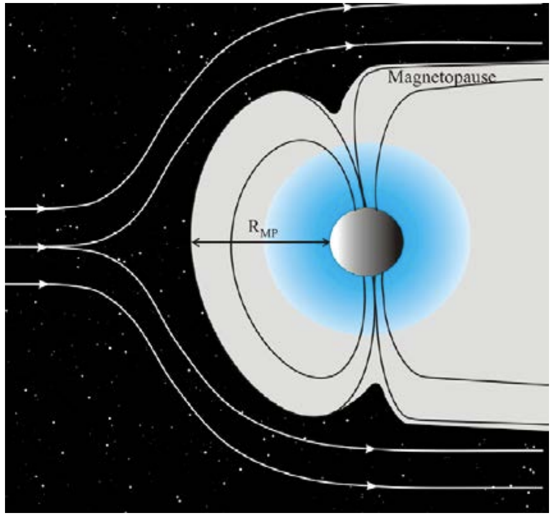
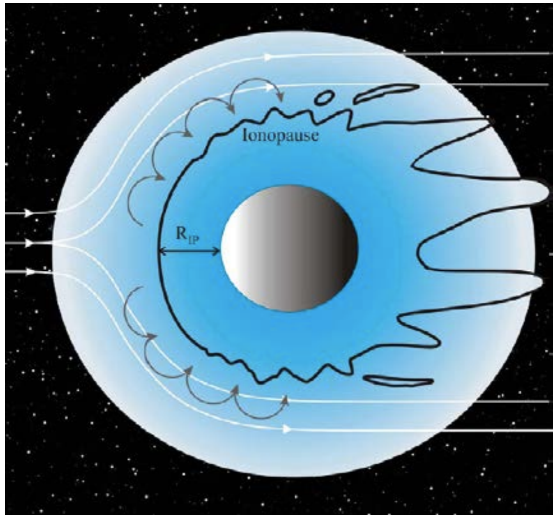
Earth-like



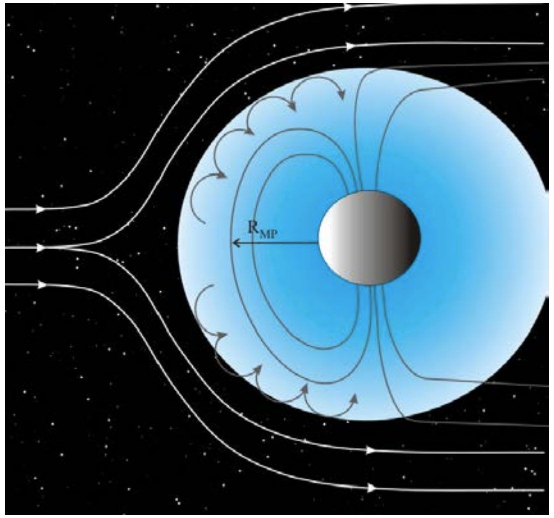
Strongly magnetized planet (the Earth-like). Here the atmosphere is protected against dense stellar/solar winds and the CME plasma interaction. R_{MP} distance for Earth is at about 10 Earth radii.

Venus or Martian-like



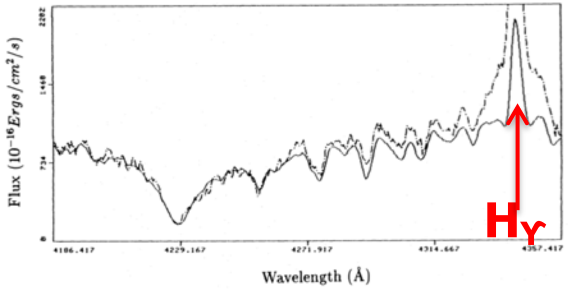
"Venus-like" or "Martian-like" non- or weakly magnetized exoplanet. The neutral atmosphere above the ionopause can be eroded by the stellar/solar wind and CME plasma flux.

Rocky planets in the HZ of M dwarfs



Compressed magnetized exoplanet and an extended thermosphere-exosphere environment. The exospheric gas above the magnetopause distance can be eroded by stellar wind and CME plasma flows.

Lammer et al, 2007, Astrobiology 7(1):167-84



- FWHM of the H_γ broad component of 21 Å, i.e, average turbulence speed ~880 km s^{-1}.
- Ejecta are estimated with speed up to 5800 km s^{-1} in the first minute from the flare onset, slowing down to 3700 km s^{-1} after 3 min.

Houdebine et al. 1990, A&A 238, 249

Targets for SOXS & time requested

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- **A small selected sample of bright dMe flaring stars hosting transiting planets**
- Observations should be linked to **time of transits and/or secondary eclipses (TC)**.
- **Goals**
  - studying how activity affects transit/eclipse profile and depth with the purpose to disentangle activity induced spectral line variability from planetary atmosphere signatures;
  - assessing the statistics of low-amplitude flares, studying the contribution from the lines formed at different temperatures in the stellar atmosphere;
  - studying the dynamics for major flares, from the modification of line profiles during the events, and estimating the energy carried out by mass ejecta and photons.
    - contribute input to understanding how flares and Coronal Mass Ejections (CMEs) impact the planetary environment affecting habitability.

Overall request:

- **120 hrs of observations in 5 yrs** (about 5 transits per year)
- Considering typical flare frequencies (e.g., *Kowalski et al. 2013 ApJS 207 15*), we should be able to detect tens of "low energy" flares ($E_U \sim 10^{30}$ erg), half a dozen of "moderate energy" flares ($E_U \sim 10^{31}$ erg), and a couple of "high energy" flares ($E_U \sim 10^{32}$ erg) with possibly CMEs.