How known planets from the Solar System would be seen if they were exoplanets

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CONTEXT:
- ARIEL WG “Synergies with Solar System planets Atmosphere”
- Work in progress to test tools and provide science cases for ARIEL

OUTLINE:

PART 1 (G.Gilli)
Modeling: Transit of exo-Venus observed by ARIEL

PART 2 (P.Machado):
Observations: High resolution spectra of Solar System bodies
Part 1:
Transit of exo-Venus

work-in-progress in collaboration with E. Marcq
1. LATMOS, Paris, France

G.Gilli @ ARIEL Conf. 2020, ESA/ESTEC, The Netherland 15/01/2020
**MOTIVATION:**

- More and more close-in-orbit hot terrestrial planets detected: favorable targets for transmission spectroscopy
- VENUS: good natural laboratory for those targets
- Venus-like planets around M-stars: more favorable for detecting molecular features during a transit
- Trappist 1 exoplanet System: likely to host Venus-like planets
- Possible presence of clouds and aerosols: observational predictions more challenging

**APPROACH:**

1. Observed *variability of upper hazes* by Venus Express
2. State-of-the-art of Venus General Circulation Model (GCM) developed at LMD

("Realistic" templates of CO$_2$ and sulfur-bearing compound atmosphere)

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From stellar/solar occultation measurements by Venus Express

- Main cloud deck 48-75 km + tenuous hazes up to ~90 km

**Spatial & Temporal variability**

- Extinction coefficient lower at high latitudes than at low latitudes
- Haze extinction coefficients in the UV and near IR can vary by one order of magnitude
- Time scale variability ranging from several Earth days to several months

Wilquet et al 2009
Simulated transmission spectra of VENUS-like planets (previous works)

Venus transiting in front of the Sun
(as seen from the Earth)

- Lowest altitude possible to reach is set by the dominant diffusion regime: Rayleigh or Mie
- Absorption reaches $\sim 25$ ppm for CO$_2$ UV bands, $\sim 15$ ppm for CO$_2$ for most noticeable feature at 4.3 um

Transit of Trappist 1 planets (Venus-composition)

- “Flat” spectra in presence of clouds
- CO$_2$ feature dominated spectra, approaching 90 ppm
- Higher temperature and lower g $\rightarrow$ stronger features

\[ \frac{dF_a}{F} \approx \frac{2 R_p R_a}{R^2} \]
Venus-like “atmosphere templates” from IPSL/LMD-Venus GCM

Improved from Gilli+2017

Observational data-set from Venus Express

Luginin+2016

ASSUMPTIONS:
- Transit observed by ARIEL
- Trappist 1d is a Venus-analogue
- Clouds and hazes mainly composed of \( \text{H}_2\text{SO}_4 \)
- Tidally-locked planet
- Sub-stellar lat/lon are set to the center of the planet

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Transit depth of Exo-Venus observed by ARIEL (work-in-progress...)

- Transit altitude range included in the mesosphere (90-140 km)
- Main molecular features by CO$_2$, CO, SO$_2$ clearly identified
- Stronger slope in the visible for R< 0.05 um
- Variable haze radii and density → variable “floor” altitude
- The larger the haze abundances the “flatter” the spectra

\[ h(\lambda) = \int A(z, \lambda)dz = \sum A_i(\lambda) \Delta h_i \]
Take-home messages

- Trappist 1 system “too challenging” to detect with ARIEL: ~5000h transit needed! (L. Mugnai, private communication).
- Intrinsic variability of photochemical hazes would significantly affect any atmospheric retrievals.
- Address potential spatial and temporal variability of clouds & haze in exoplanetary atmospheres when interpreting ARIEL primary transit spectra.
- (Relatively) “flat” transit depth also help constrain radii, composition and density of upper hazes.

Future works

- Find another Venus-like analogue around other M-stars?
- Quantify the impact of the variation of upper haze on transit depth.
- Check the sensitivity of predicted observable with the orbital characteristics of the planets, and test other targets.

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How planets from the Solar System would be seen if they were exoplanets based on Solar System planets’ observations from high resolution ground-based instruments.
Venus at optical: HARPS-N /TNG, UVES /VLT, ESPaDOnS/ CFHT
Venus at infrared: iSHELL and SPECS / IRTF
In the 1960s, a huge dark cloud structure was first observed on Venus through ultraviolet images. This feature with the shape of a “Y” has been observed for many decades of spatial missions, be a **WAVE**.

**What is the Venus “Y” feature?**

- We have deduced a **new type of equatorial wave** that only appears in planets of slow rotation like Venus.
- This wave brings up an ultraviolet absorber commonly thought to exist below, and concentrates it at the cloud tops. This is why we see dark regions in UV images of the “Y”.
- After being created, the wave becomes gradually distorted by the winds and adopts the “Y” shape until it is finally dissipated,

*Peralta et al. 2015*
Venus brilliance temporal variability in the infrared
IRTF, MaunaKea
Jupiter as an exoplanet proxy

VLT – ESPRESSO
July 2019
CAHA – CARMENES
May 2019
Jupiter

14 frames – span of 24 jovian days (~10 Earth days)

Cassini ISS – NASA/ESA
Jupiter spectra
(ESPRESSO 22Jul2019)
Results - Jupiter

\[ \text{CH}_4 \] absorption at 2.6 microns

\[ \nu_3 \text{CH}_4 \] band emission at 3.3 microns
Results - Jupiter

\[ \text{H}_3^+ \text{ emission in the 3.5 to 3.9 microns region} \]

Results - Jupiter

\[ \text{NH}_3 \text{ lines in the 9 to 12 microns region} \]
Saturn: optical with UVES / VLT, infrared with CAHA / CARMENES
Results - Saturn

Saturn's 619 nm methane band

$C_4H_2$ emission at 15.92 $\mu m$
CARMENES – Calar Alto: Saturn and Jupiter
June 2019
Saturn - CARMENES / CAHA
Mars Global dust storm
VLT/UVES coordinated with Mars Express
DDT – ToO July 2018
Mars with UVES/VLT and CARMENES

Titan atmosphere with UVES/VLT
Prospects and future work

Transit of Venus 2012

Earth seen from Venus (VIRTIS – Venus EXPRESS)
Photometric profiles
Transmission spectroscopy on Venus’ transit

4. Aureole Spectrum

The scan starting at 16:19 MDT taken while Venus was crossing onto the solar limb had the brightest arc from which the spectrum could be extracted. The spectra in Figure 3 were produced by averaging over the arc positions in the limb-justified data cube (top panel), the average off-limb stray light spectrum was subtracted and the residual solar spectrum was divided (middle panel), and a line spectrum was made by averaging over the spatial extent of the arc (bottom panel). A synthetic spectrum given to us by Pascal Hedelt (Hedelt et al., 2011) of the Venus model atmosphere was resampled and convolved with the FIRS spectrograph profile determined from laser measurements (Jaeggli, 2011) to produce the model spectrum shown in violet.

Figure 3: The mean spectrum in the arc of Venus during the scan starting at 16:19 MDT.
Earth seen from Venus
Venus Express - VIRTIS
Save the date!

Towards Other Earths III
From Solar System to Exoplanets

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Lamego, Douro Valley, Portugal

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