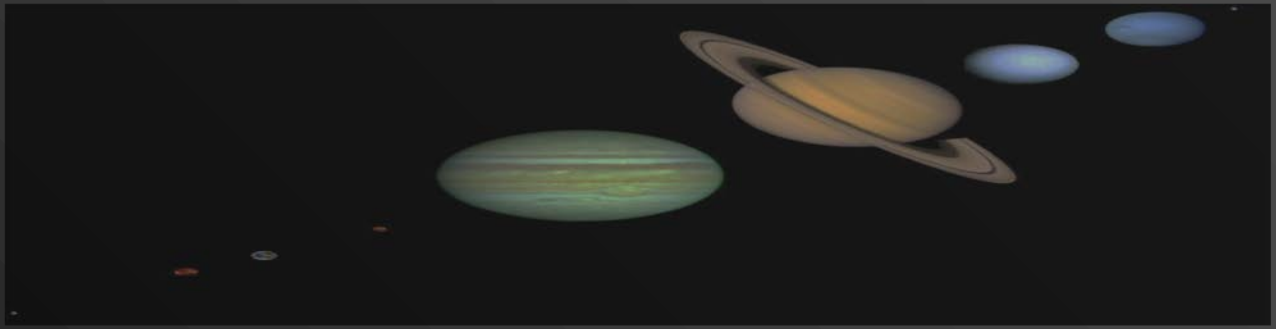


How known planets from the Solar System would be seen if they were exoplanets

G. Gilli[1], P. Machado[1]

(1) Instituto de Astrofisica e Ciências do Espaço (IA), Portugal

Acknowledgment: European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 796923"

instituto de astrofísica
e ciências do espaço

ARIEL Conference 2020,ESTEC, Noordwijk, 15/01/2020

FCiências^ID
ASSOCIAÇÃO PARA A INVESTIGAÇÃO E DESENVOLVIMENTO DE CIÊNCIAS

CONTEXT:

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

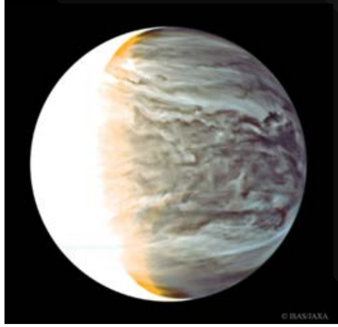
OUTLINE:

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]
1. LATMOS, Paris, France



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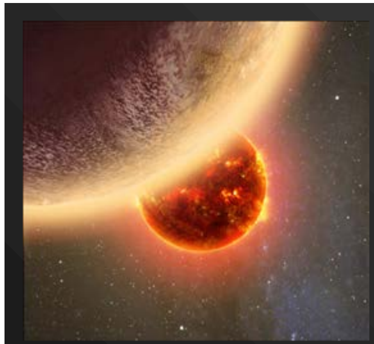
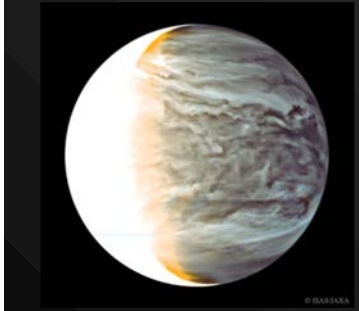
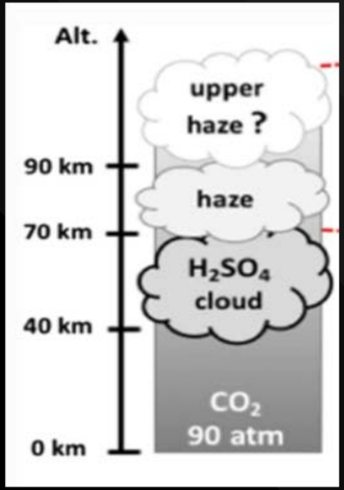
G.Gilli @ ARIEL Conf. 2020, ESA/ESTEC, The Netherland 15/01/2020







Credits: Takagi+2019

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

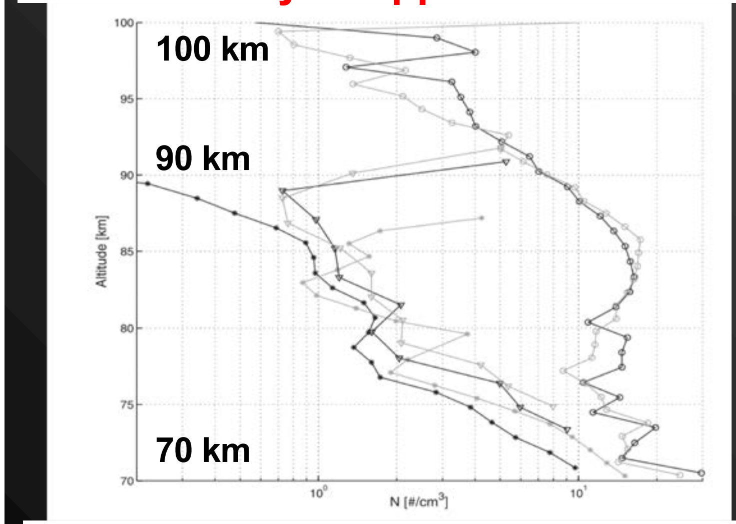
APPROACH:

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

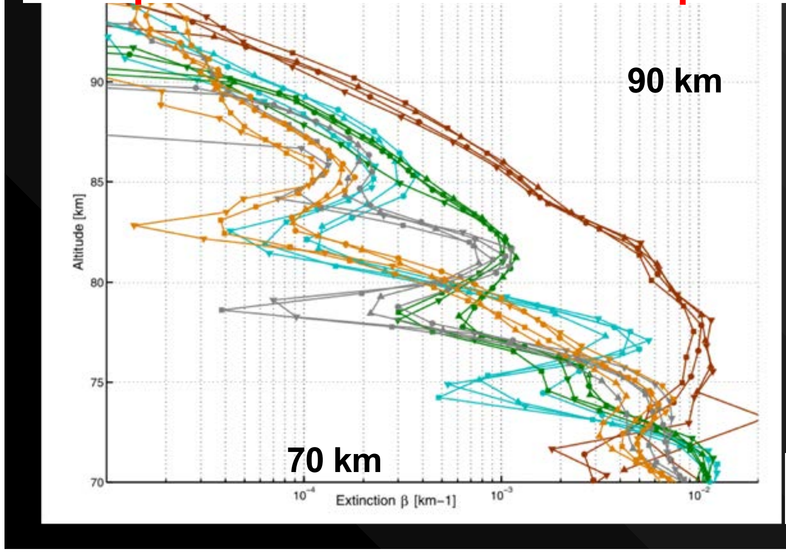
("Realistic" templates of CO_2 and sulfur-bearing compound atmosphere)

From stellar/solar occultation measurements by Venus Express

Total density of upper haze aerosols



Temporal variation of extintion profile



Wilquet et al 2009

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

  Spatial & Temporal variability

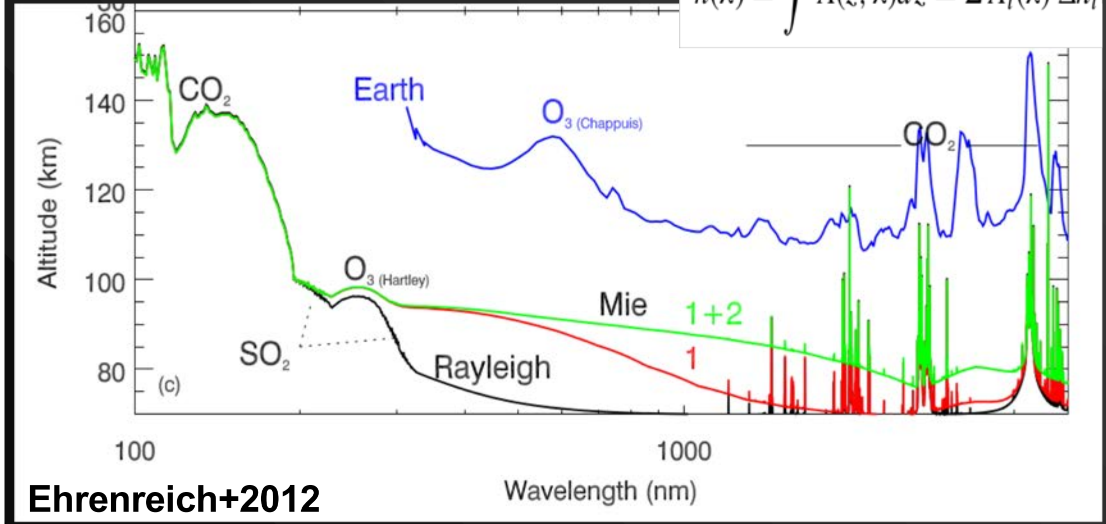
- Extinction coefficient lower at high latitudes than at low latitudes
- Haze extinction coefficients in the UV and near IR can vary by one order of magnitude
- Time scale variability ranging from several Earth days to several months

Simulated transmission spectra of VENUS-like planets (previous works)

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

Effective height of absorption [km] =>

$$h(\lambda) = \int A(z,\lambda)dz = \Sigma A_i(\lambda)\,\Delta h_i$$

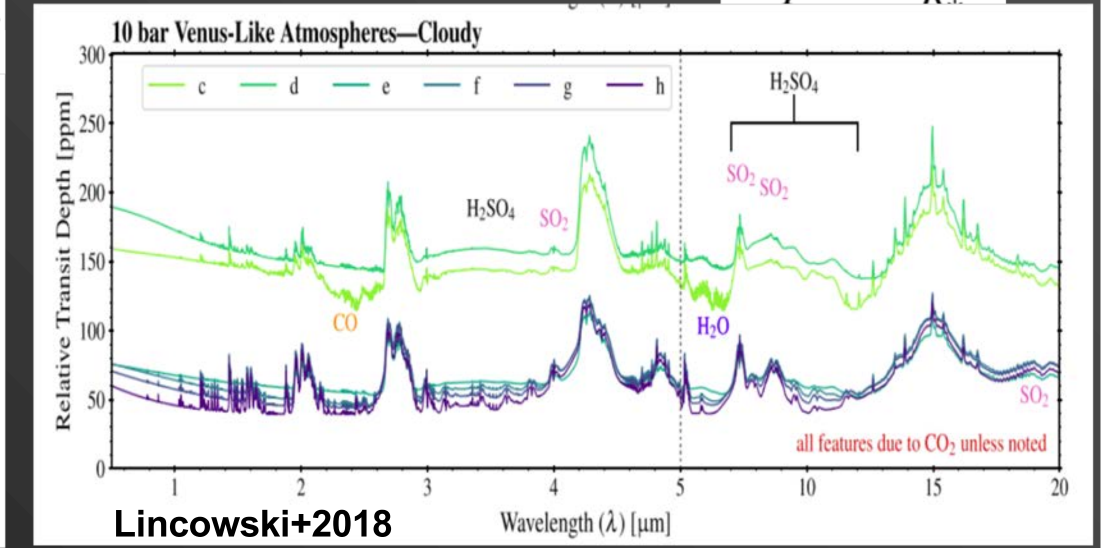


Ehrenreich+2012

Transit of Trappist 1 planets (Venus-composition)

Relative transit depth (ppm)

$$\frac{dF_a}{F} \approx \frac{2R_pR_a}{R_*^2}$$

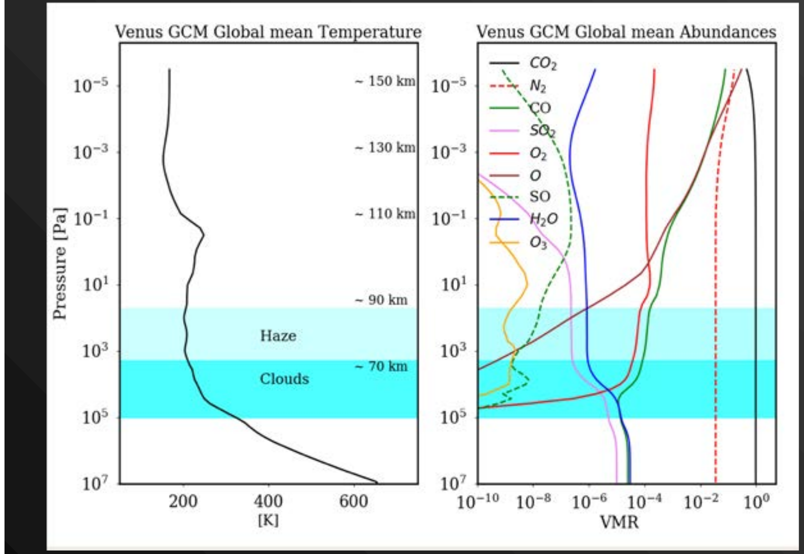


Lincowski+2018

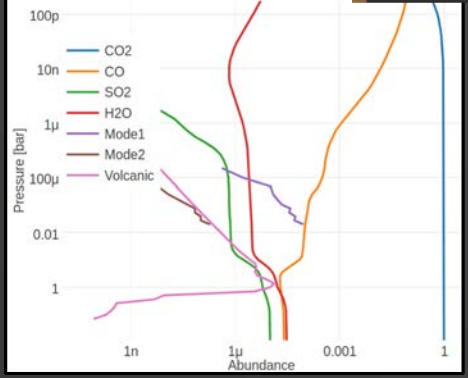
- Lowest altitude possible to reach is set by the dominant diffusion regime: Rayleigh or Mie
- Absorption reaches ~ 25 ppm for CO_2 UV bands, ~15 ppm for CO_2 for most noticeable feature at 4.3 um

- “Flat” spectra in presence of clouds
- CO_2 feature dominated spectra, approaching 90 ppm
- Higher temperature and lower g → stronger features

Venus-like “atmosphere templates” from IPSL/LMD-Venus GCM

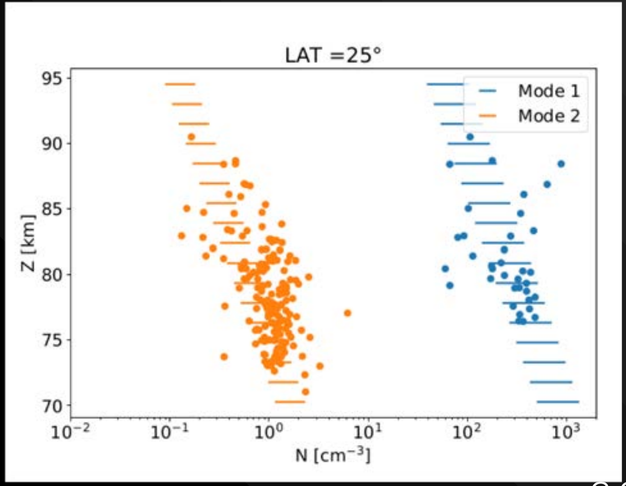


Improved from
Gilli+2017



Inputs for Planetary Spectra Generator (Villanova et al. 2018)

+



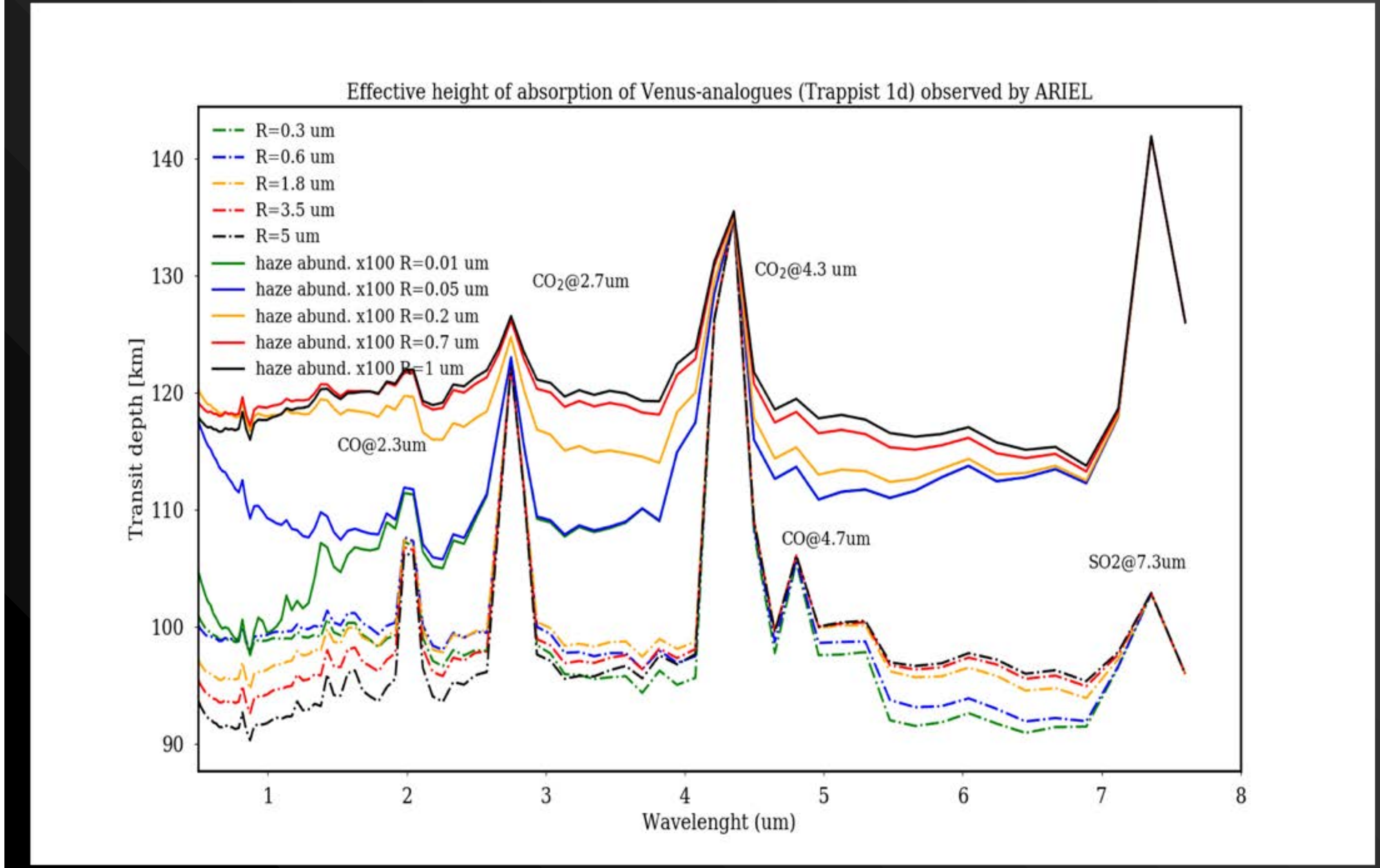
Luginin+2016

Observational data-set from Venus Express

ASSUMPTIONS:

- Transit observed by ARIEL
- Trappist 1d is a Venus-analogue
- Clouds and hazes mainly composed of H_2SO_4
- Tidally-locked planet
- Sub-stellar lat/lon are set to the center of the planet

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


Effective height of absorption of Venus-analogues (Trappist 1d) observed by ARIEL

$$h(\lambda) = \int A(z,\lambda)dz = \Sigma A_i(\lambda)\,\Delta h_i$$

- 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

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*

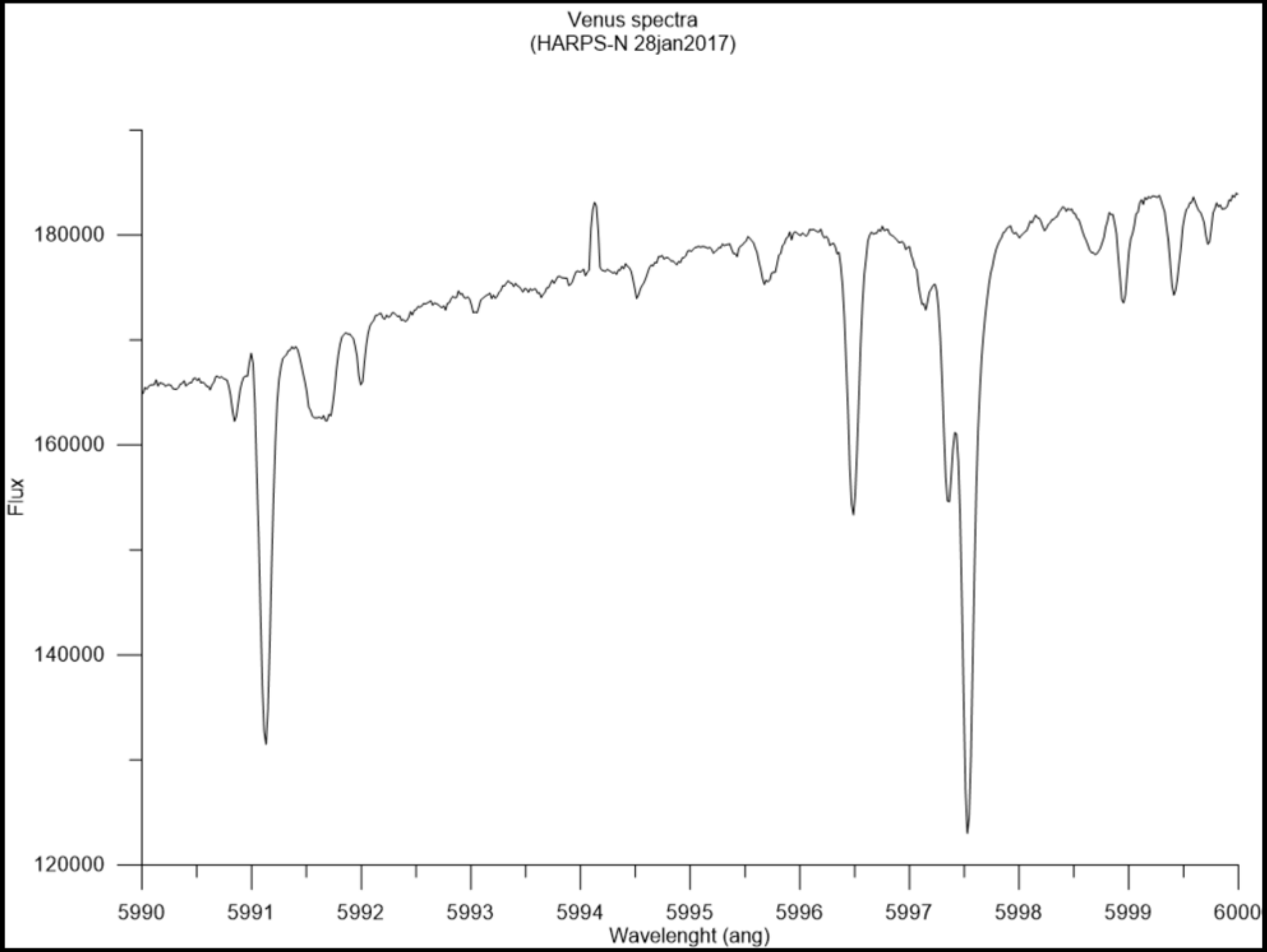
Future works

- *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*

Part 2

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



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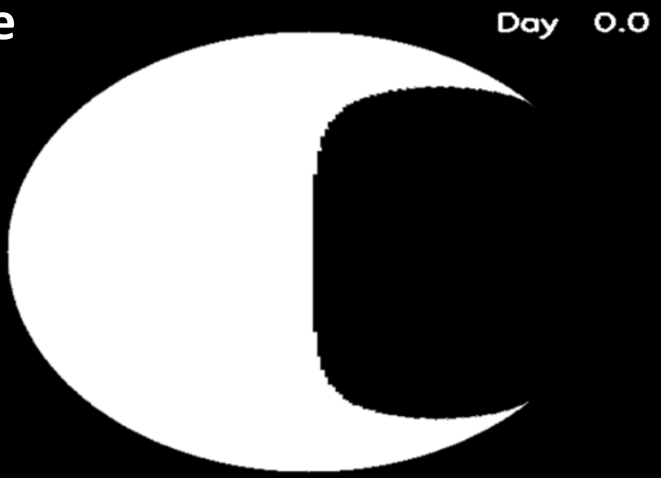
Venus's Y feature as a wind distorted wave

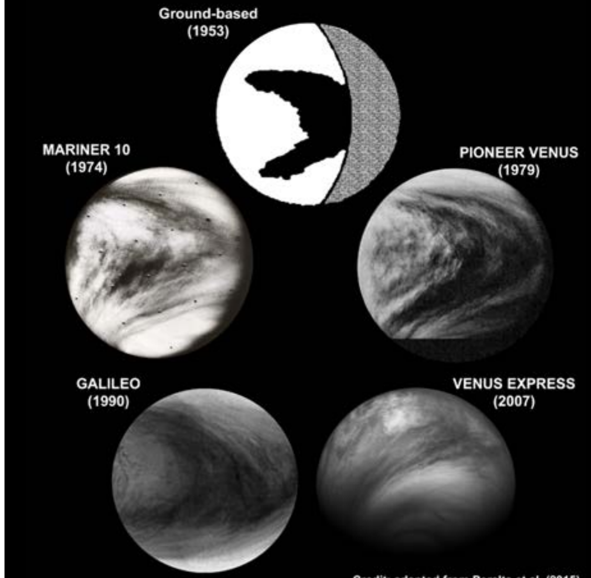


What is the Venus "Y" feature?

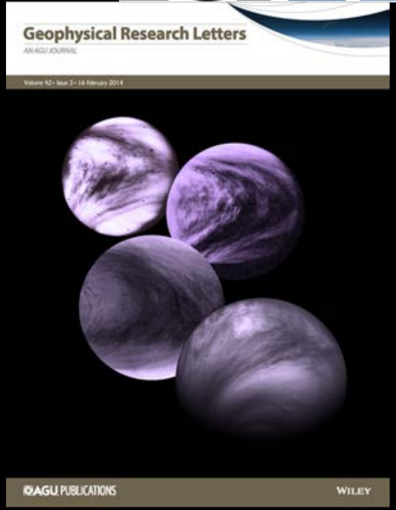
In the 1960s, a huge dark cloud structure was first observed on Venus through ultraviolet images.

This feature with the shape of a "Y" has been observed for many decades of spatial missions,

be a **WAVE.**



Credit: adapted from Peralta et al. (2015)

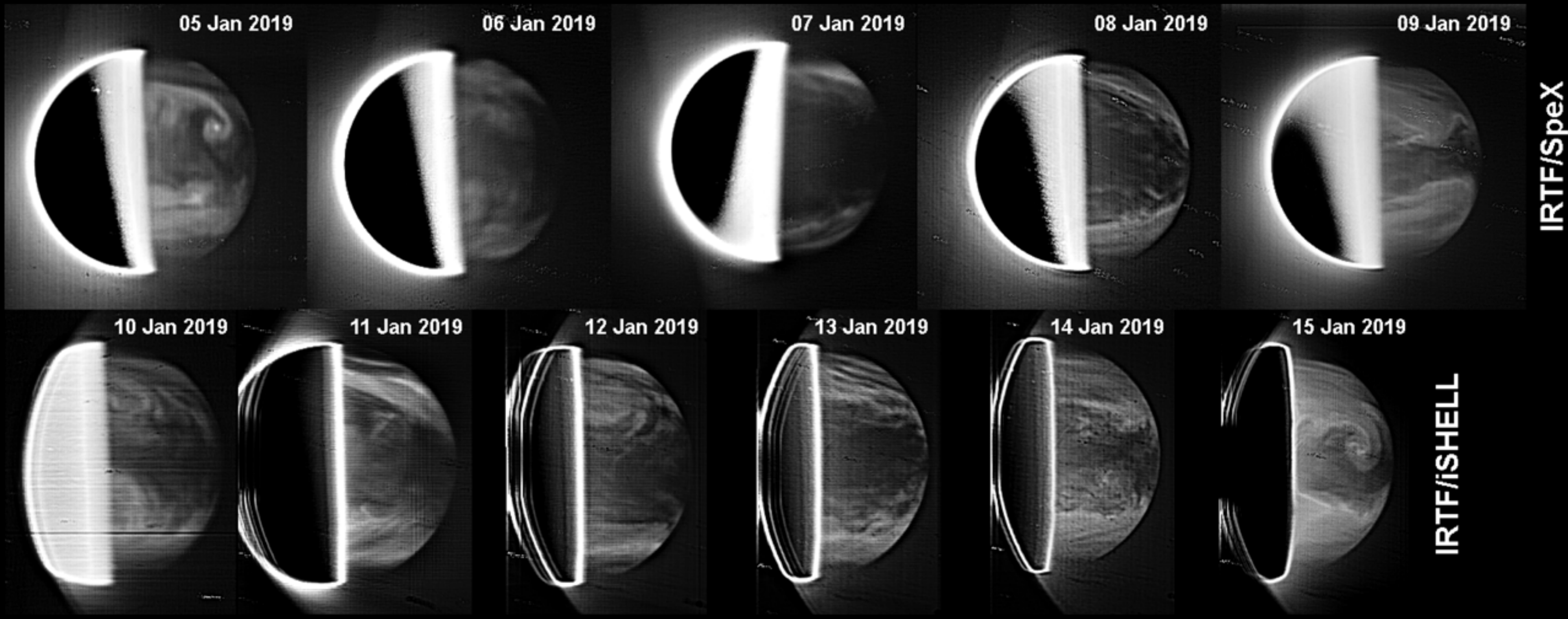


A new type of wave distorted by Venus winds

- 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,

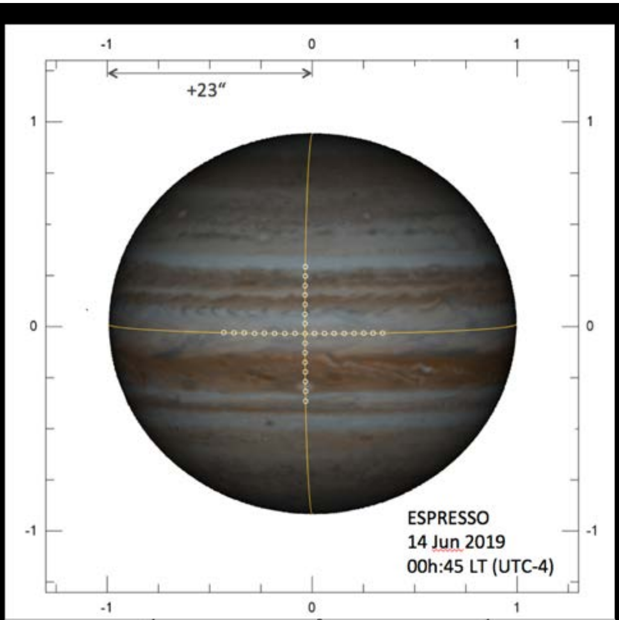
Peralta et al. 2015

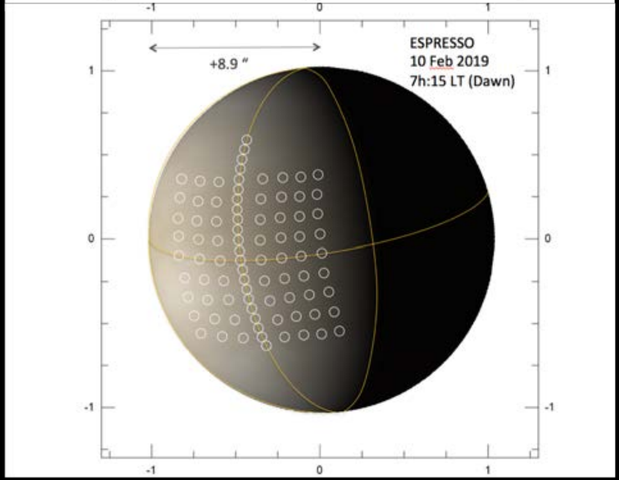
Venus brilliance temporal variability in the infrared
IRTF, MaunaKea



Jupiter as an exoplanet proxy

VLT – ESPRESSO
July 2019
CAHA – CARMENES
May 2019





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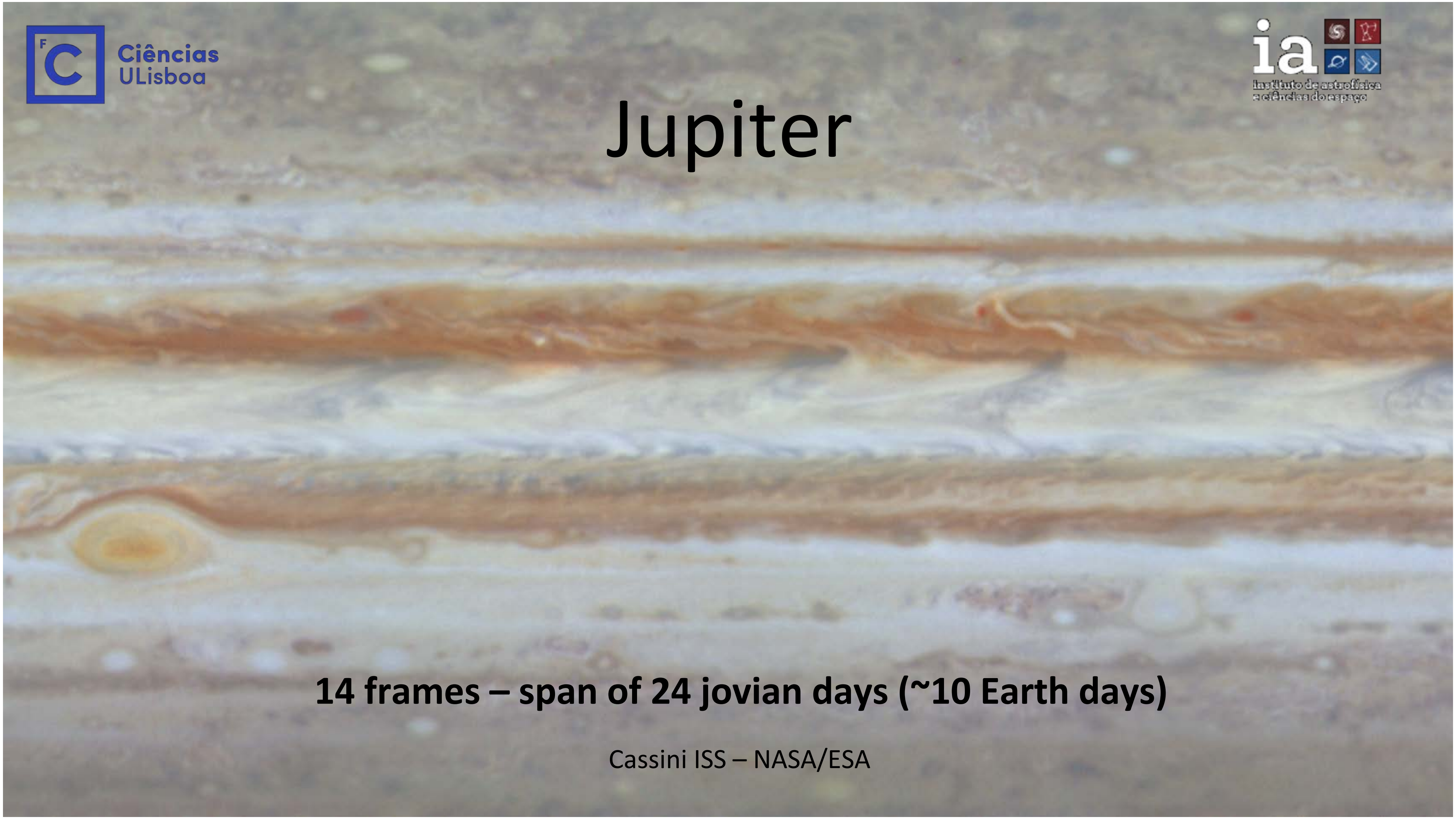
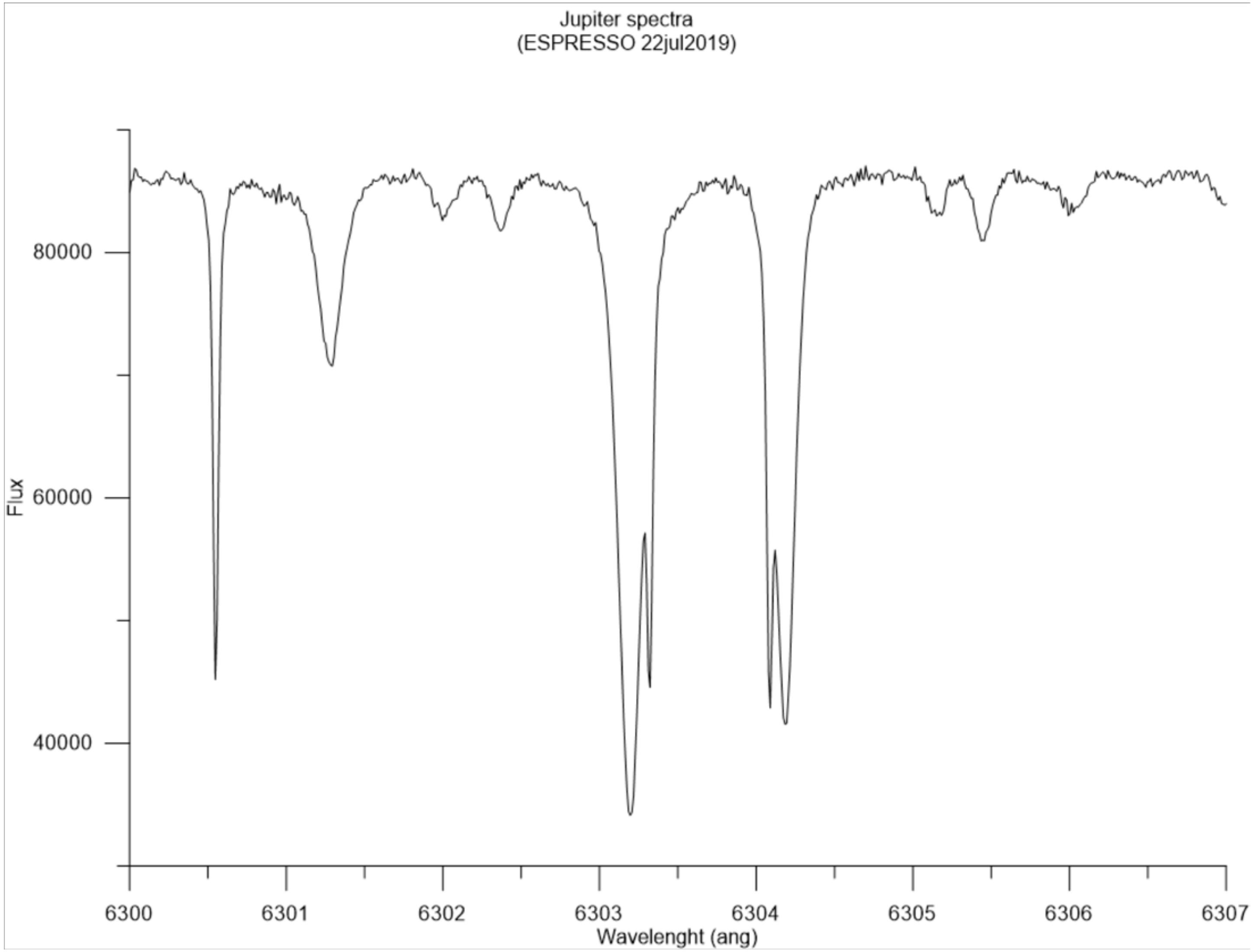
Jupiter



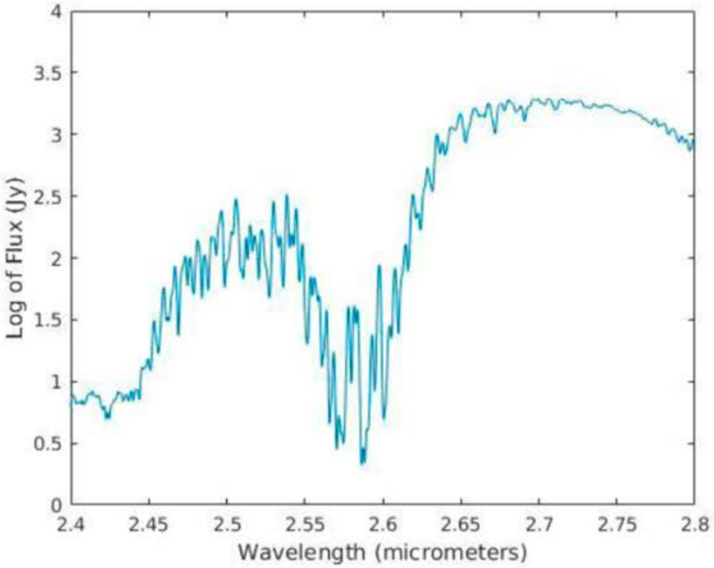
14 frames – span of 24 jovian days (~10 Earth days)

Cassini ISS – NASA/ESA

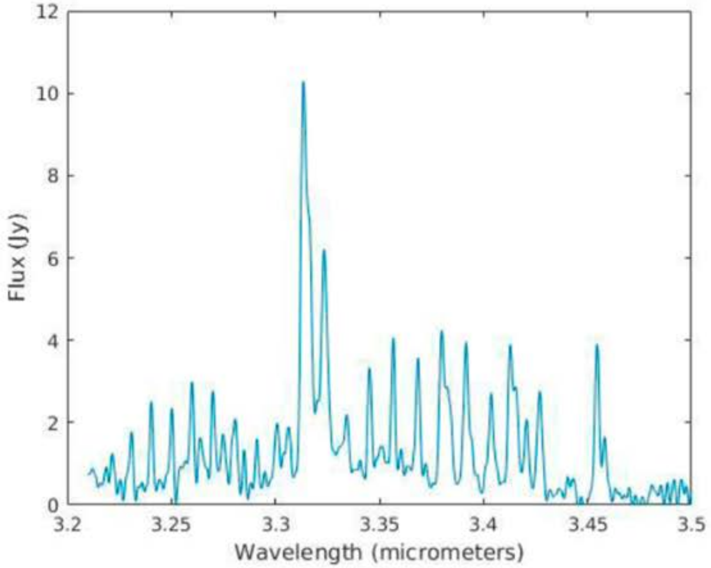
ESPRESSO / VLT , July 2019



Results - Jupiter

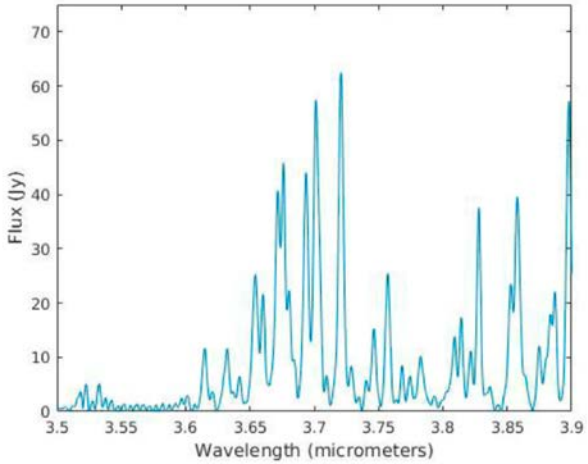


CH_4 absorption at 2.6 microns



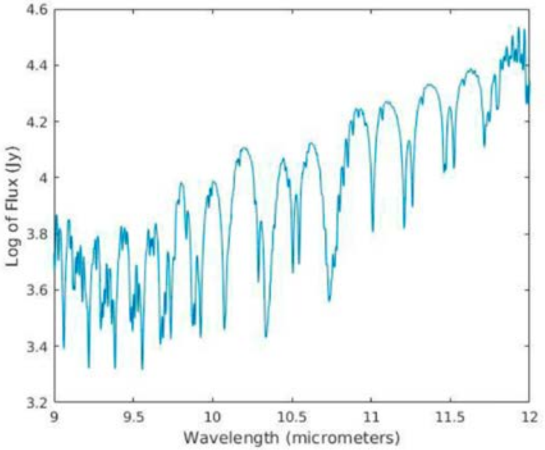
ν_3 CH_4 band emission at 3.3 microns

Results - Jupiter



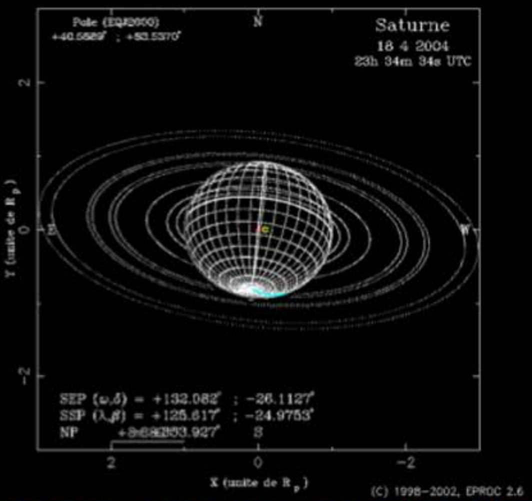
H_3^+ emission in the 3.5 to 3.9 microns region

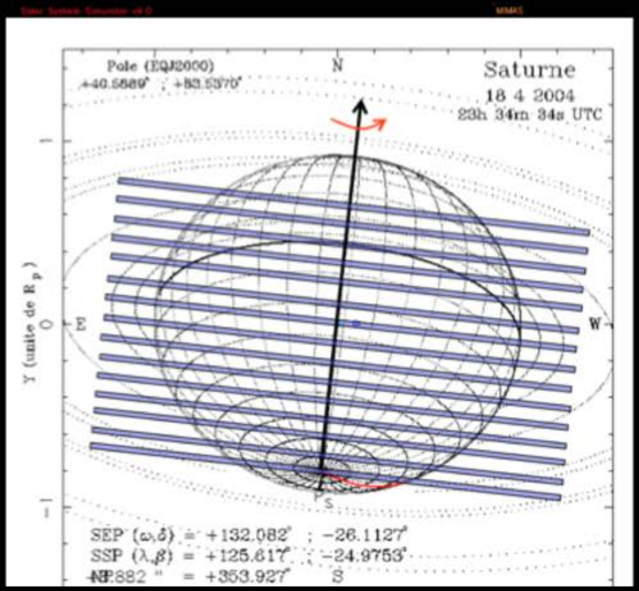
Results - Jupiter

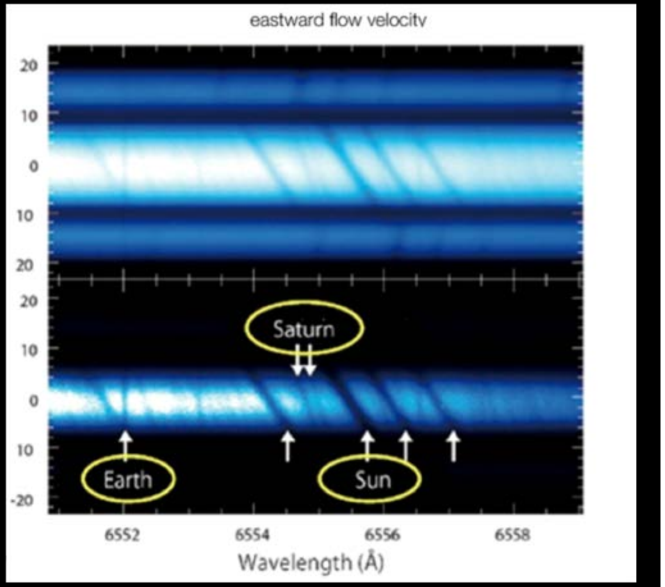


NH_3 lines in the 9 to 12 microns region

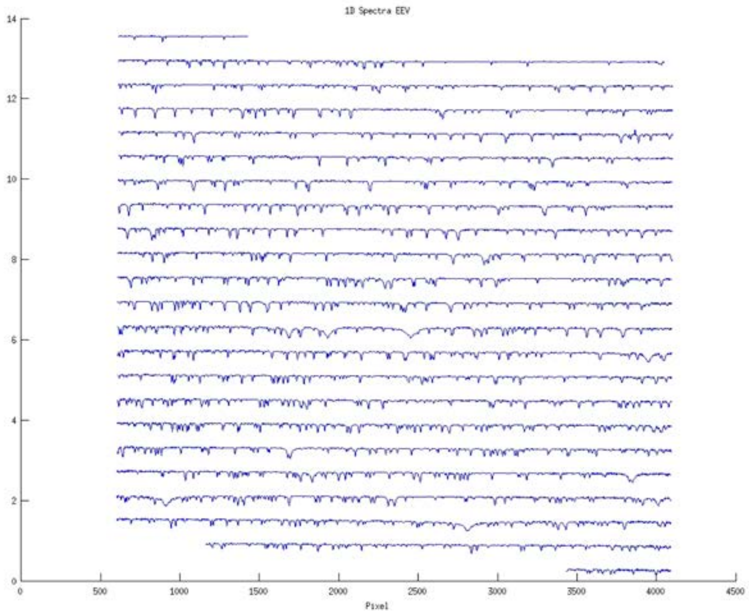
Saturn: optical with UVES / VLT, infrared with CAHA / CARMENES

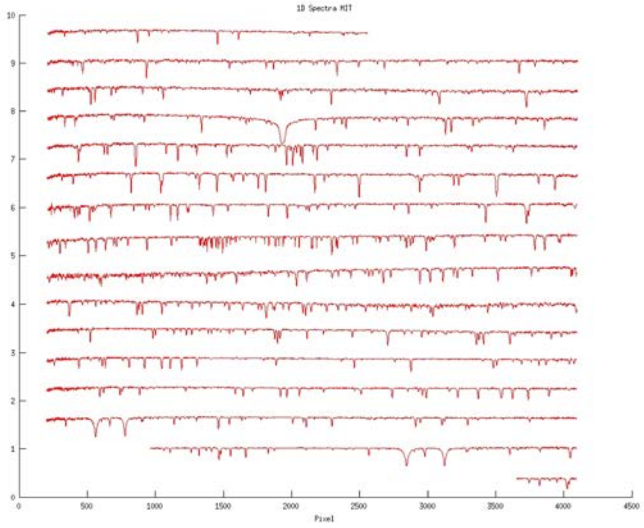


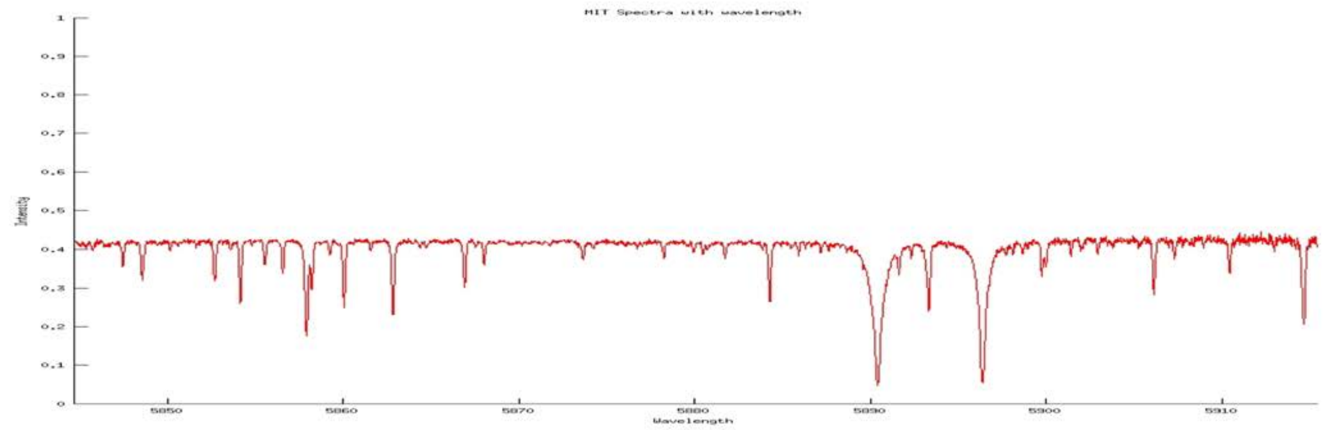




P.Machado@ ARIEL Conf. 2020, ESA/ESTEC, The Netherland 15/01/2020


1D Spectra EEV
14
12
10
8
6
4
2
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Pixel


1D Spectra MIT
10
9
8
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Pixel


MIT Spectra with wavelength
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Intensity
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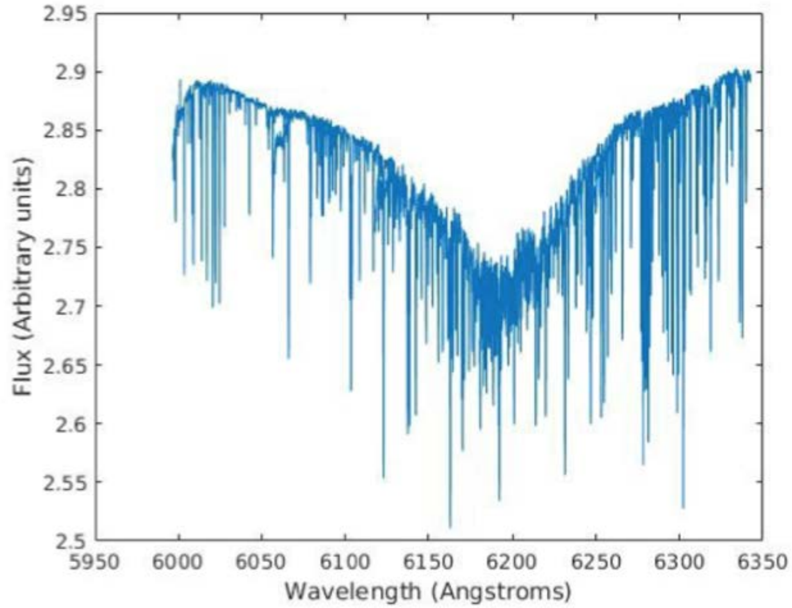
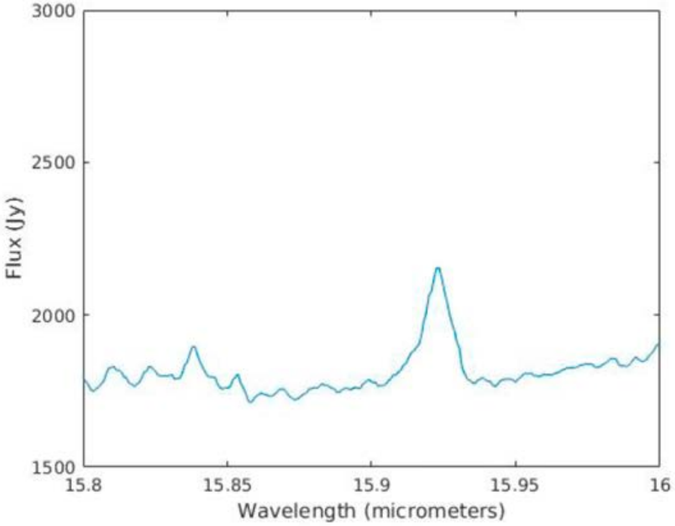
5860
5870
5880
5890
5900
5910
Wavelength

Results - Saturn

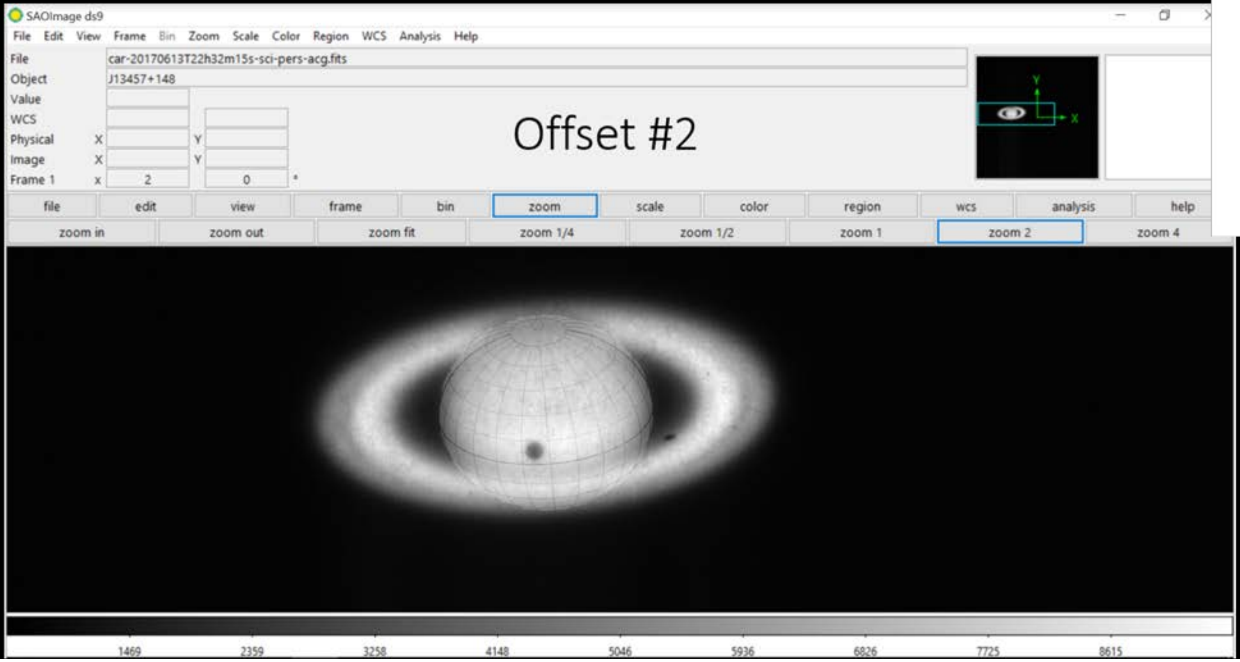


Saturn’s 619 nm methane band



C_4H_2 emission at 15.92 μm

CARMENES – Calar Alto: Saturn and Jupiter June 2019



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Object J13457+148

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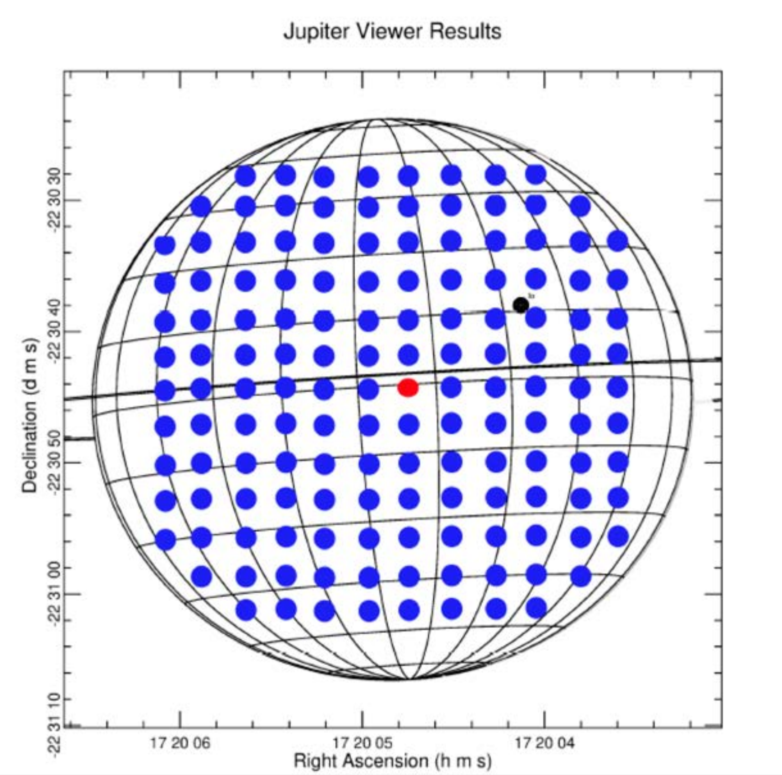
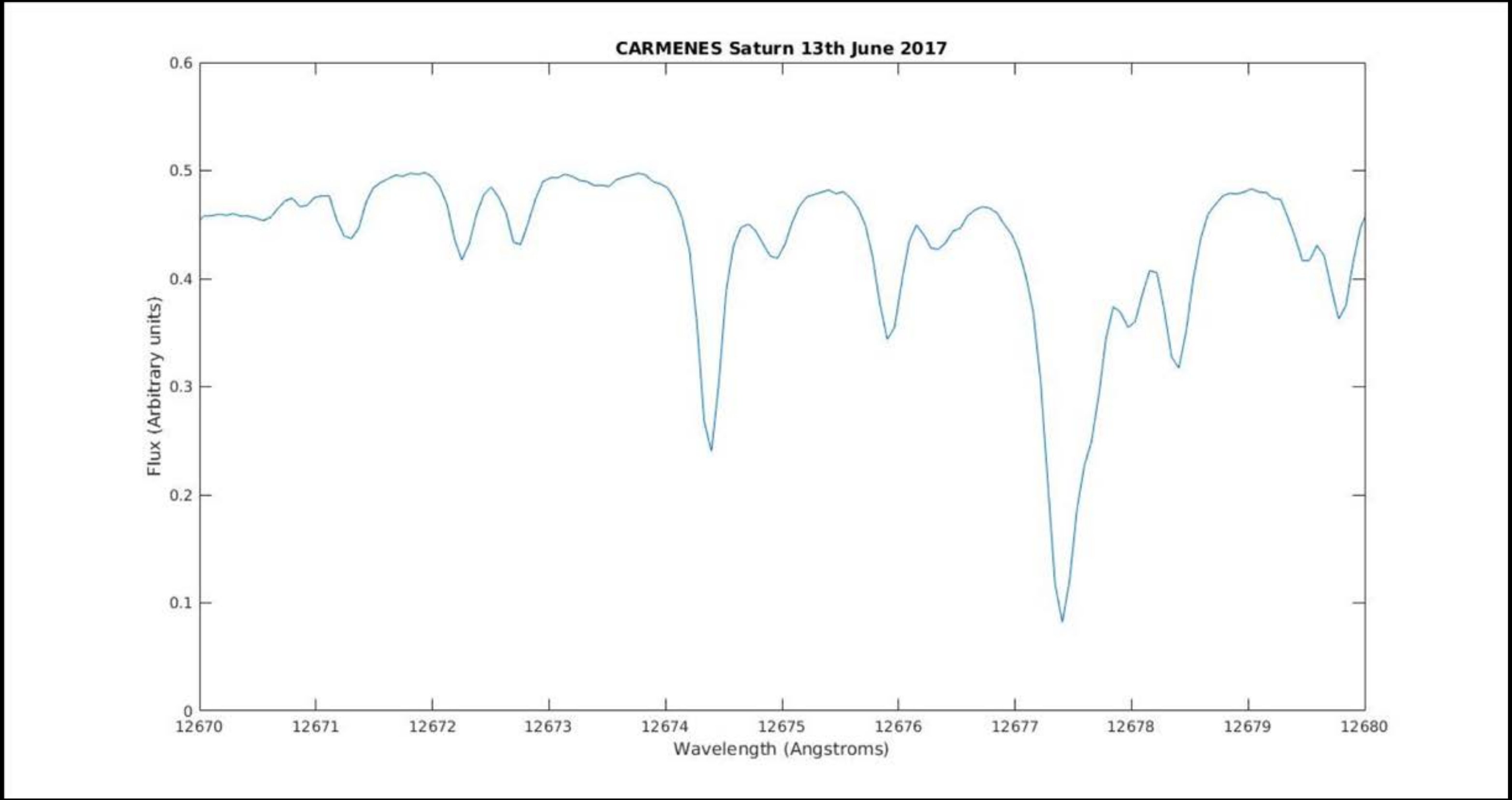
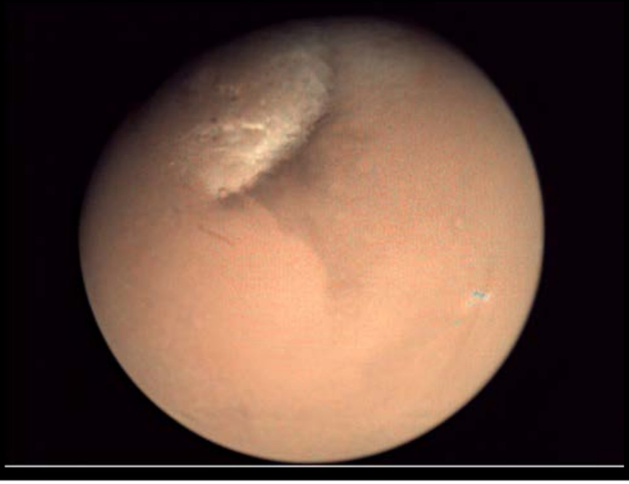
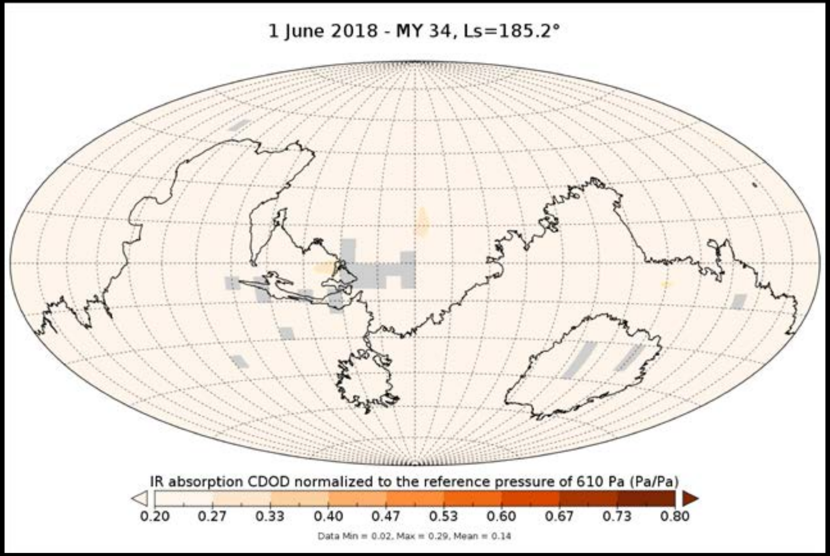
Offset #2

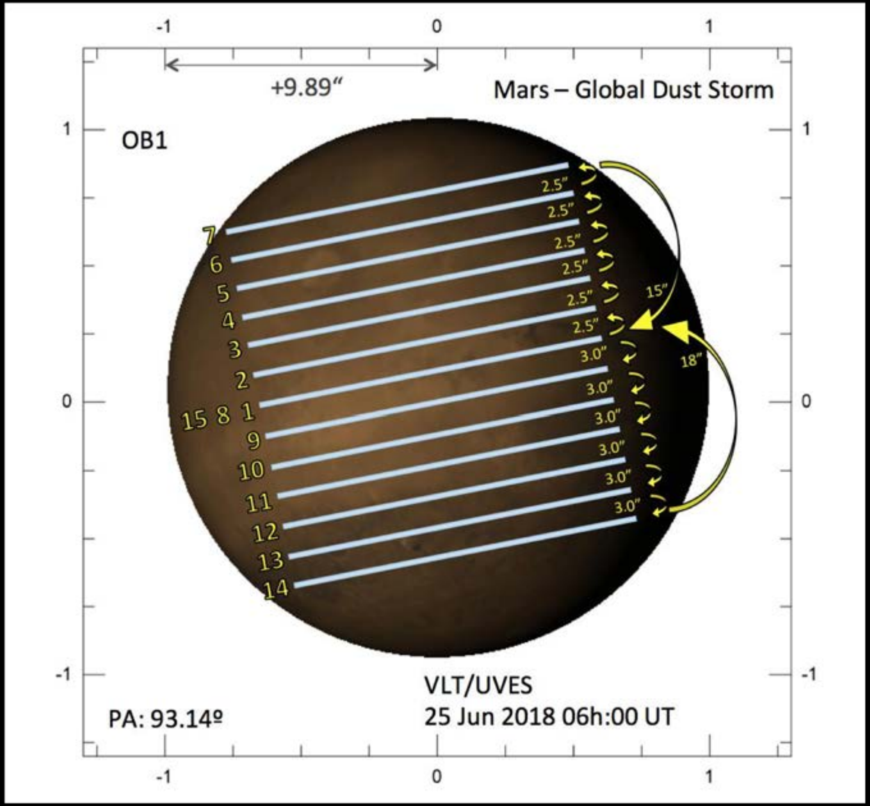


Saturn - CARMENES / CAHA





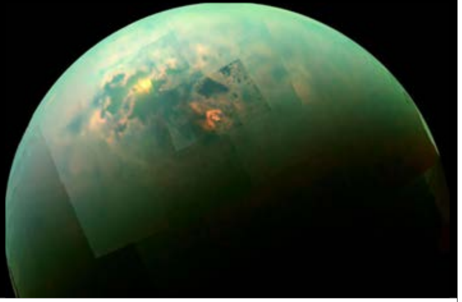


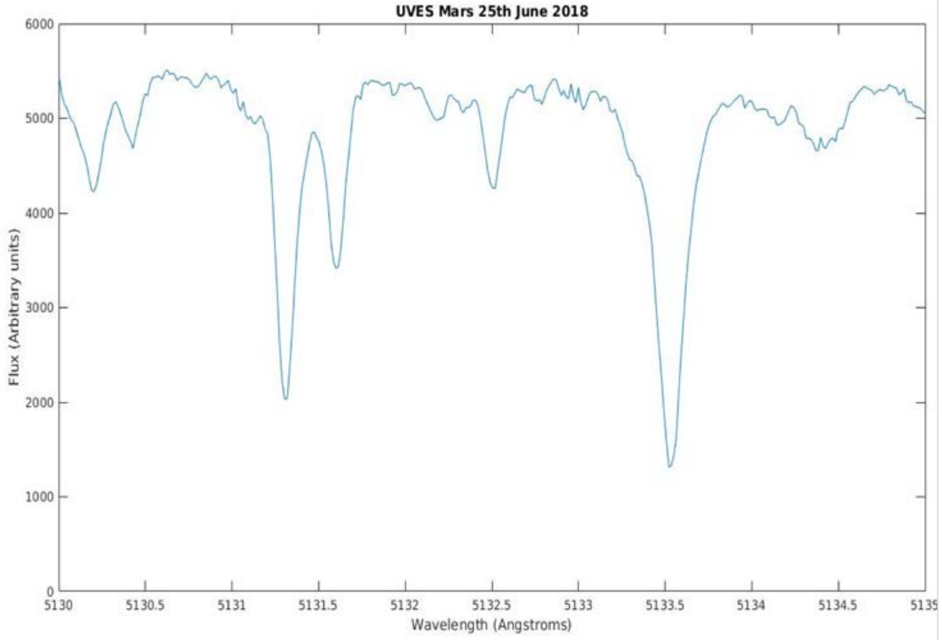


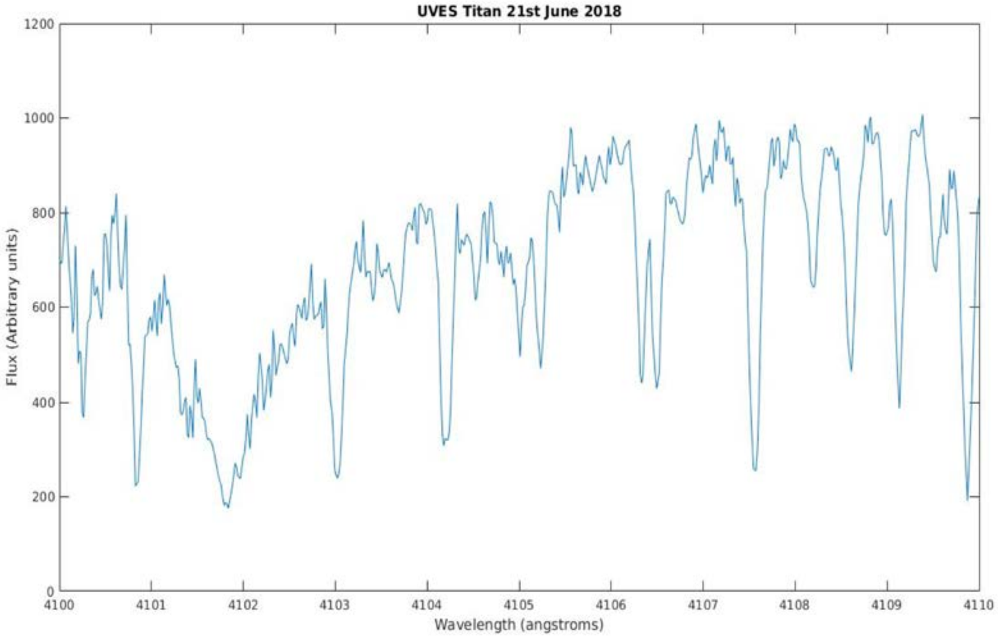
Mars Global dust storm
VLT/UVES coordinated with
Mars Express
DDT – ToO July 2018

Mars with UVES/VLT and CARMENES

Titan atmosphere with UVES/VLT

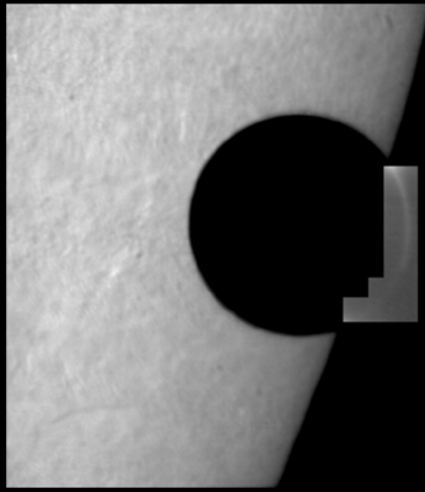




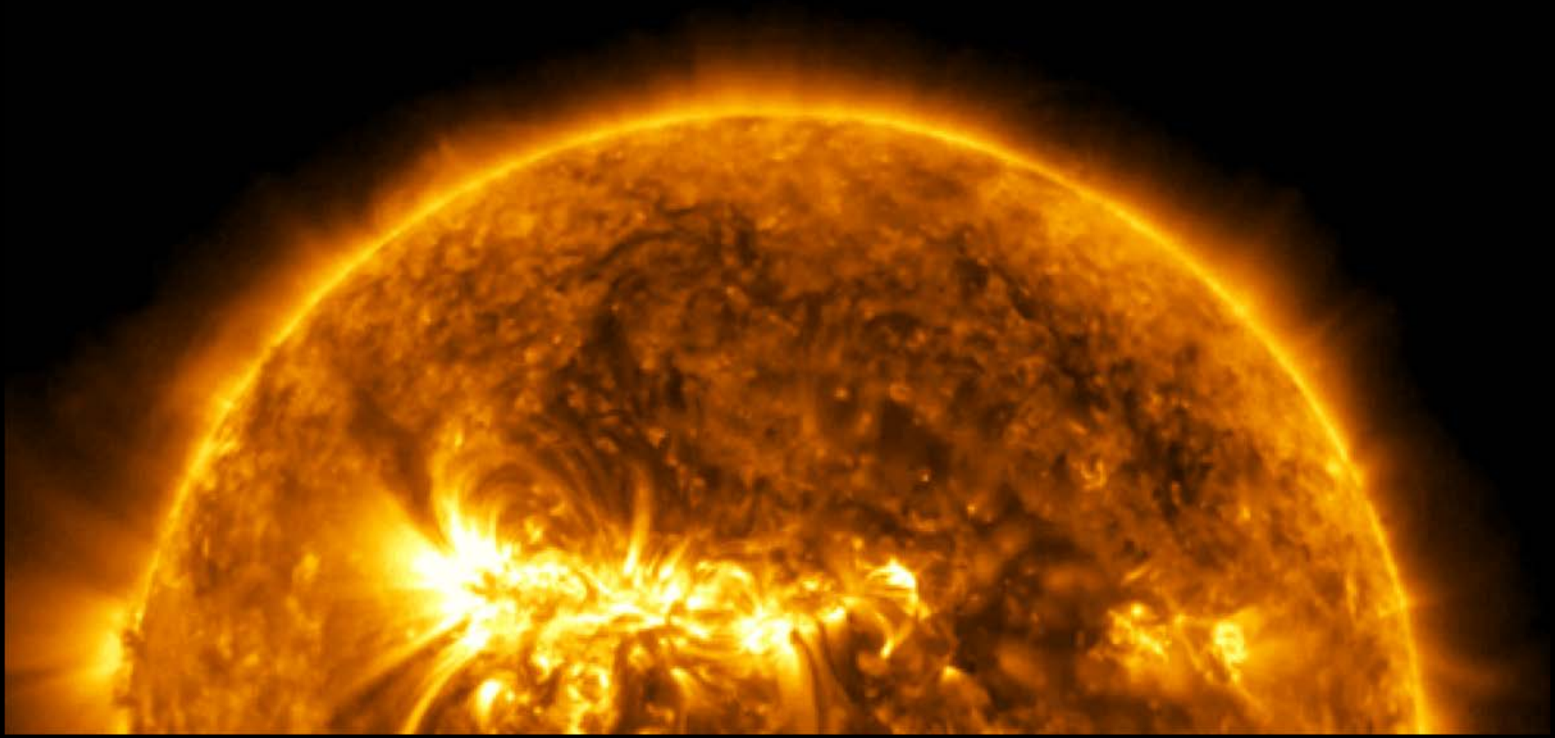


Prospects and future work

Transit of Venus 2012

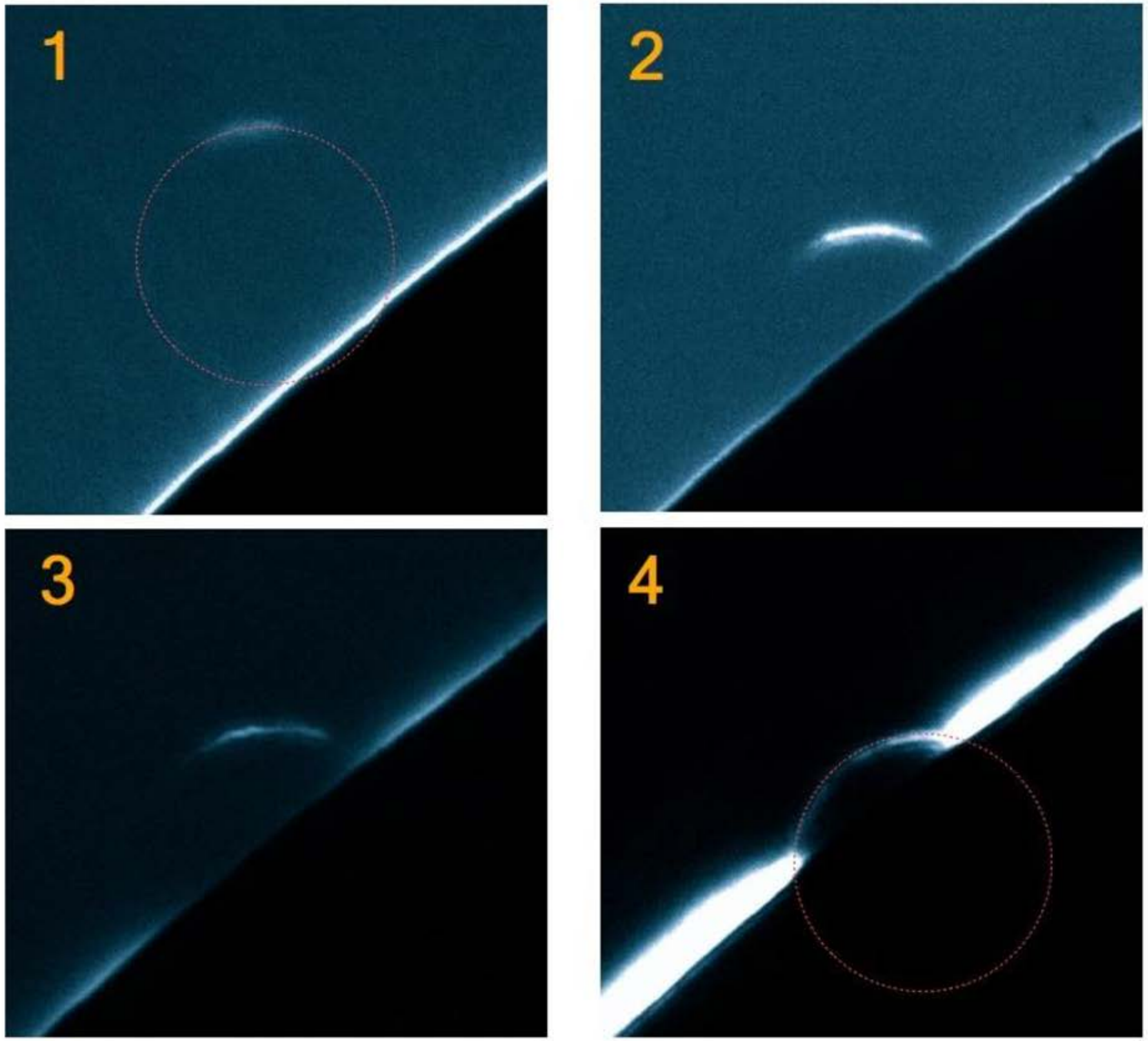


Earth seen from Venus (VIRTIS – Venus EXPRESS)



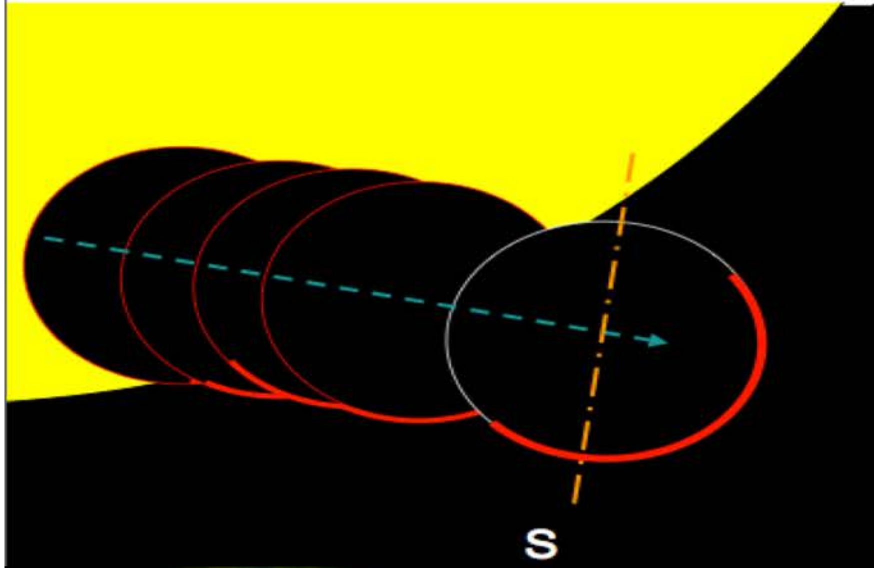
Venus Twilight Experiment

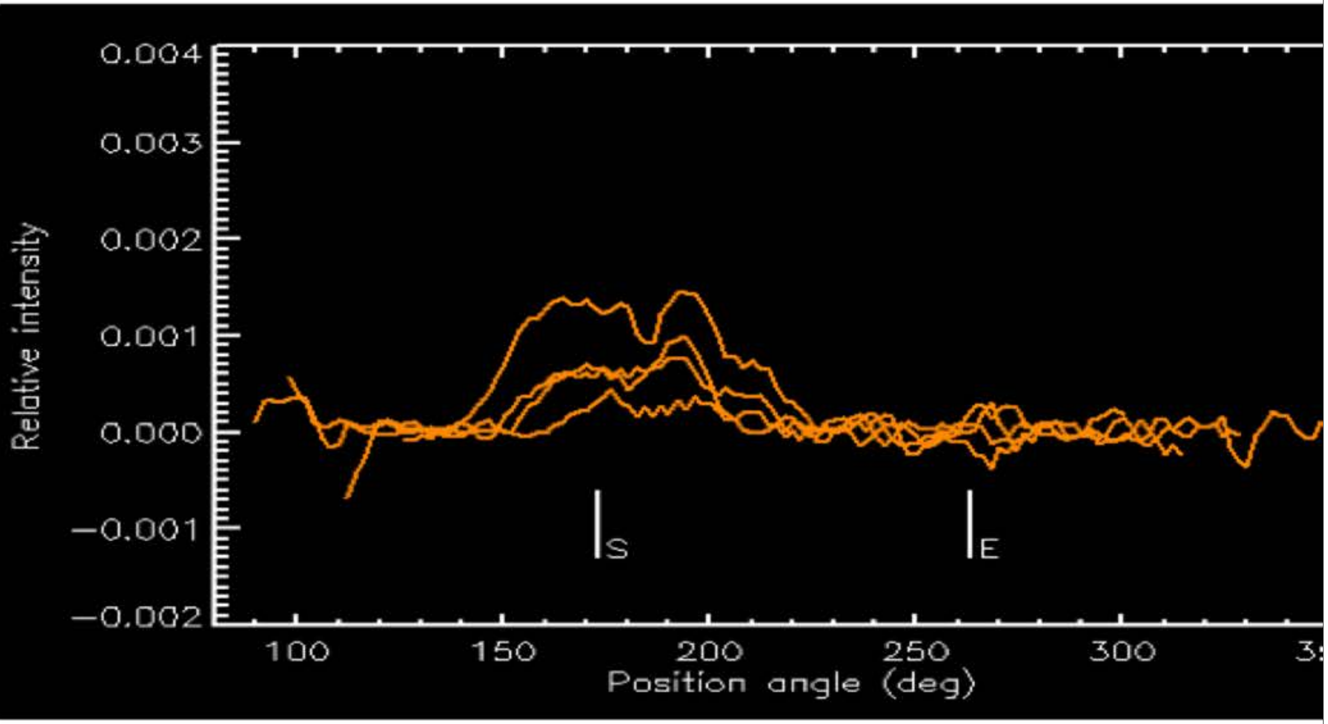
Aureole at ingress, on June 5, 2012

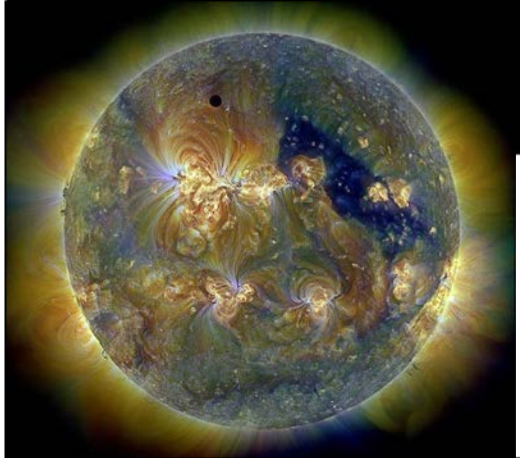


anga, Laboratoire Lagrange, Obs. de la Côte d'Azur; Th. Widemann, LESIA, Obs. de Paris - Venus Twilight Experiment

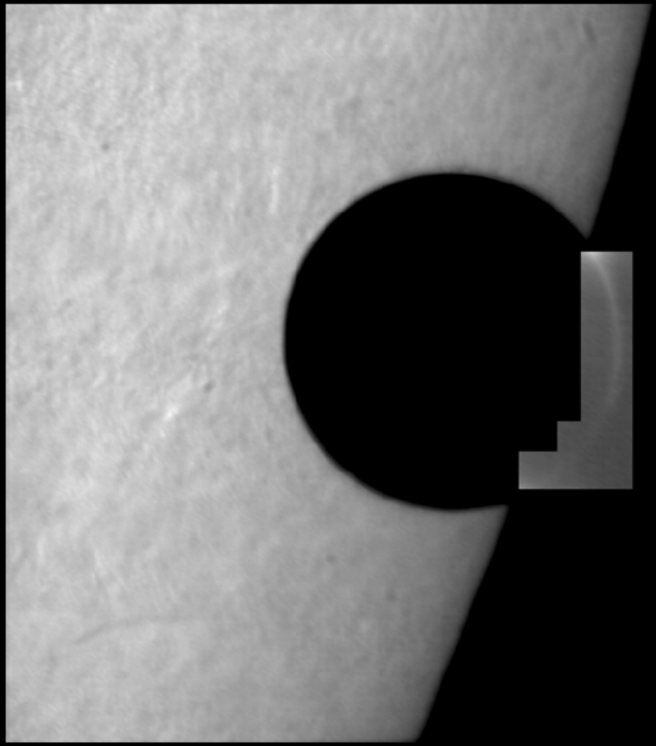
Photometric profiles

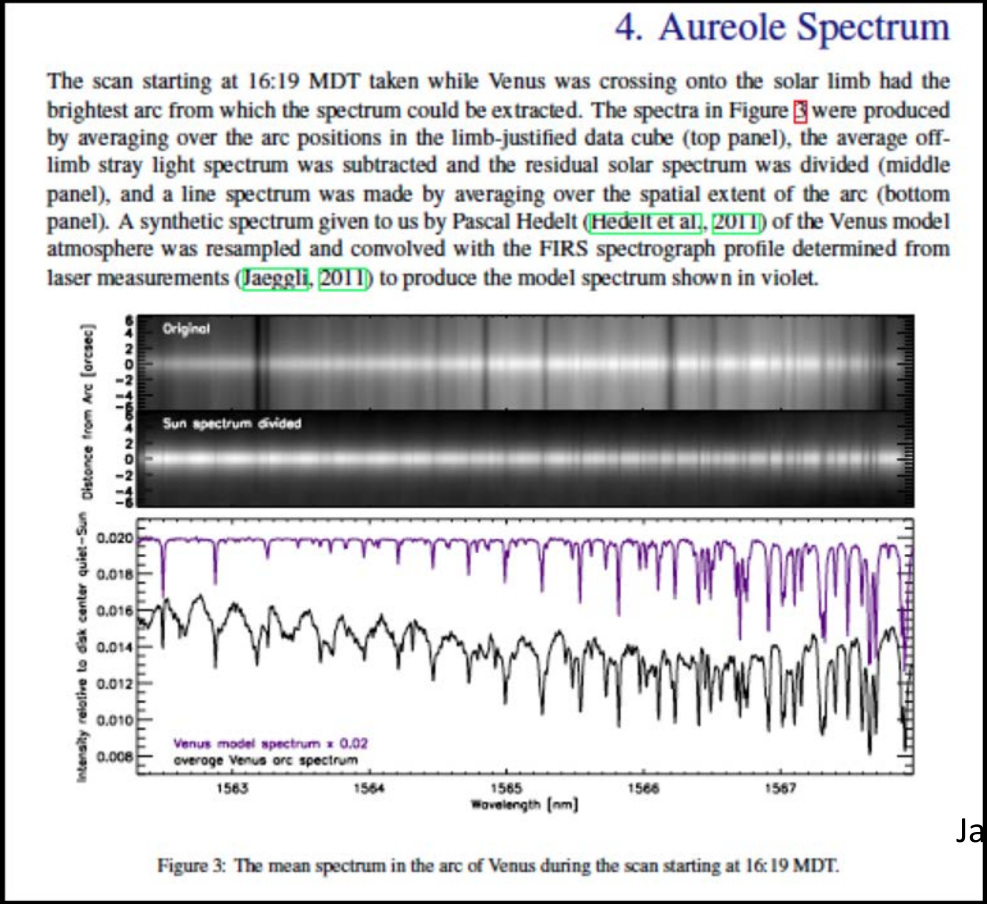






Transmission spectroscopy on Venus' transit



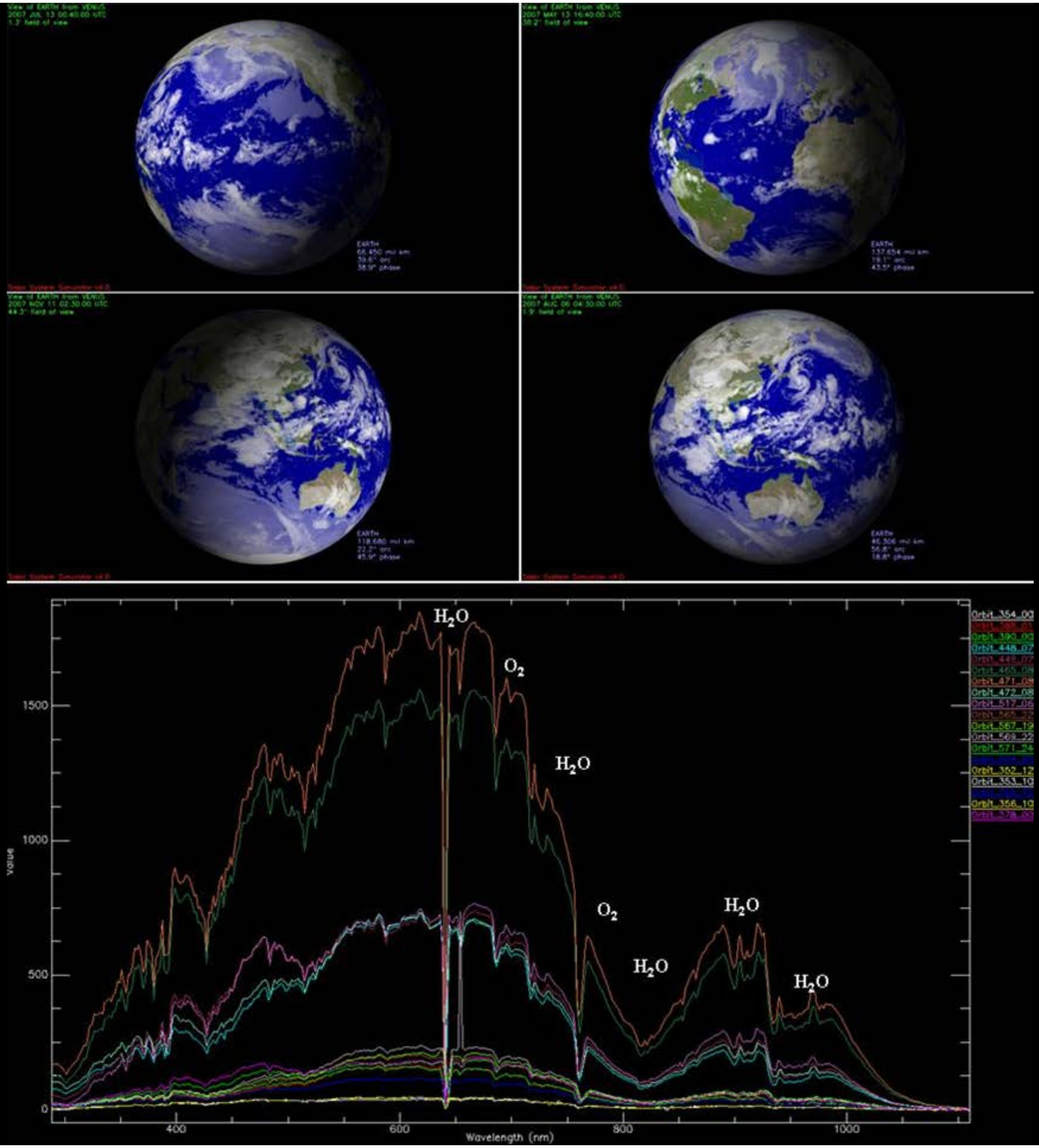


4. Aureole Spectrum

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.

Ja



Earth seen from Venus
Venus Express - VIRTIS

- *Atmospheres*
- *Formation and evolution*
- *Structure and composition*

TOWARDS OTHER EARTHS III

From Solar System to Exoplanets

01–05 June, 2020

Lamego, Douro Valley, Portugal

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