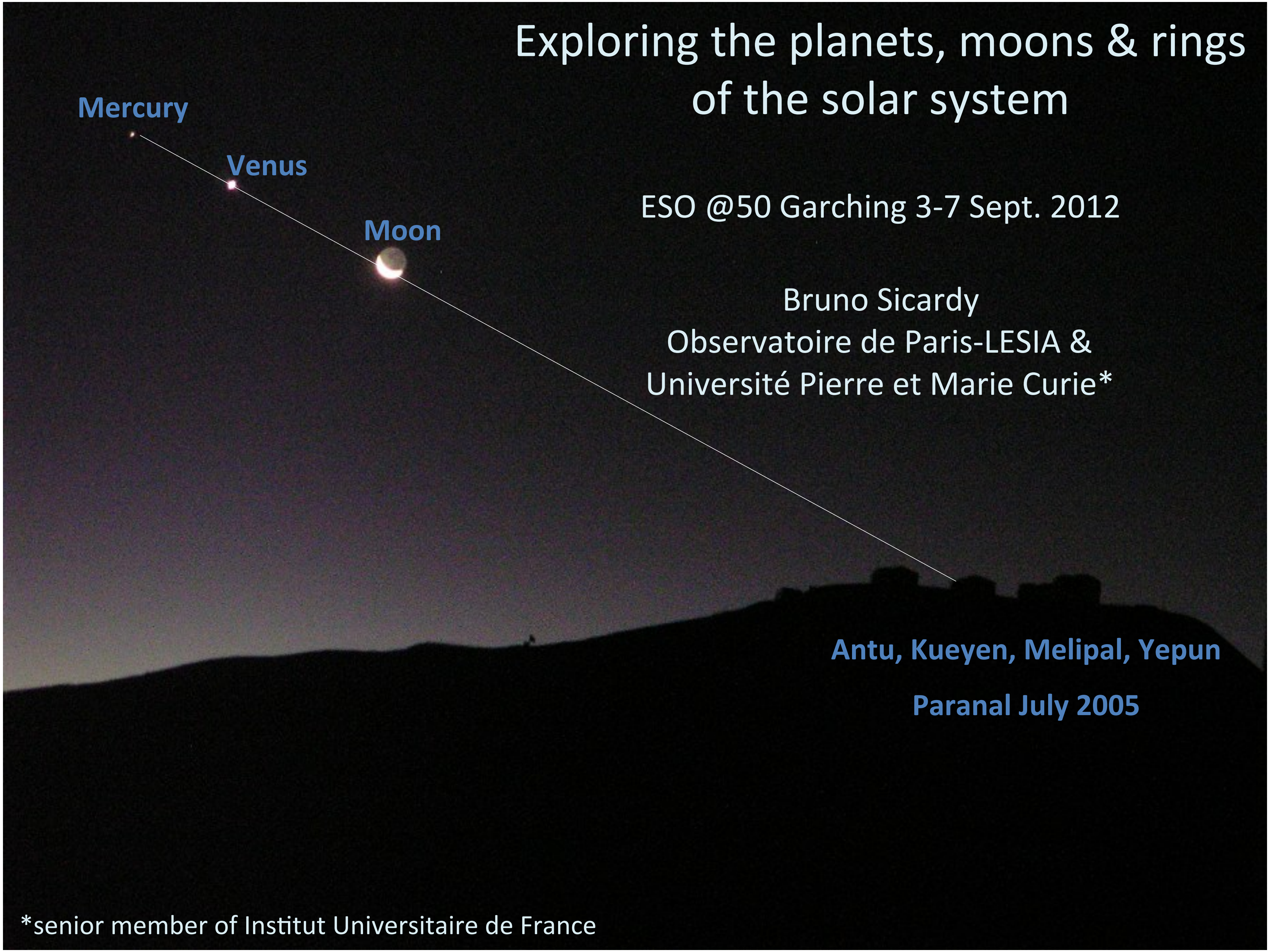
Exploring the planets, moons & rings of the solar system

ESO @50 Garching 3-7 Sept. 2012

Bruno Sicardy
Observatoire de Paris-LESIA &
Université Pierre et Marie Curie*



*senior member of Institut Universitaire de France

special thanks to:
B. Carry
A. Coustenis
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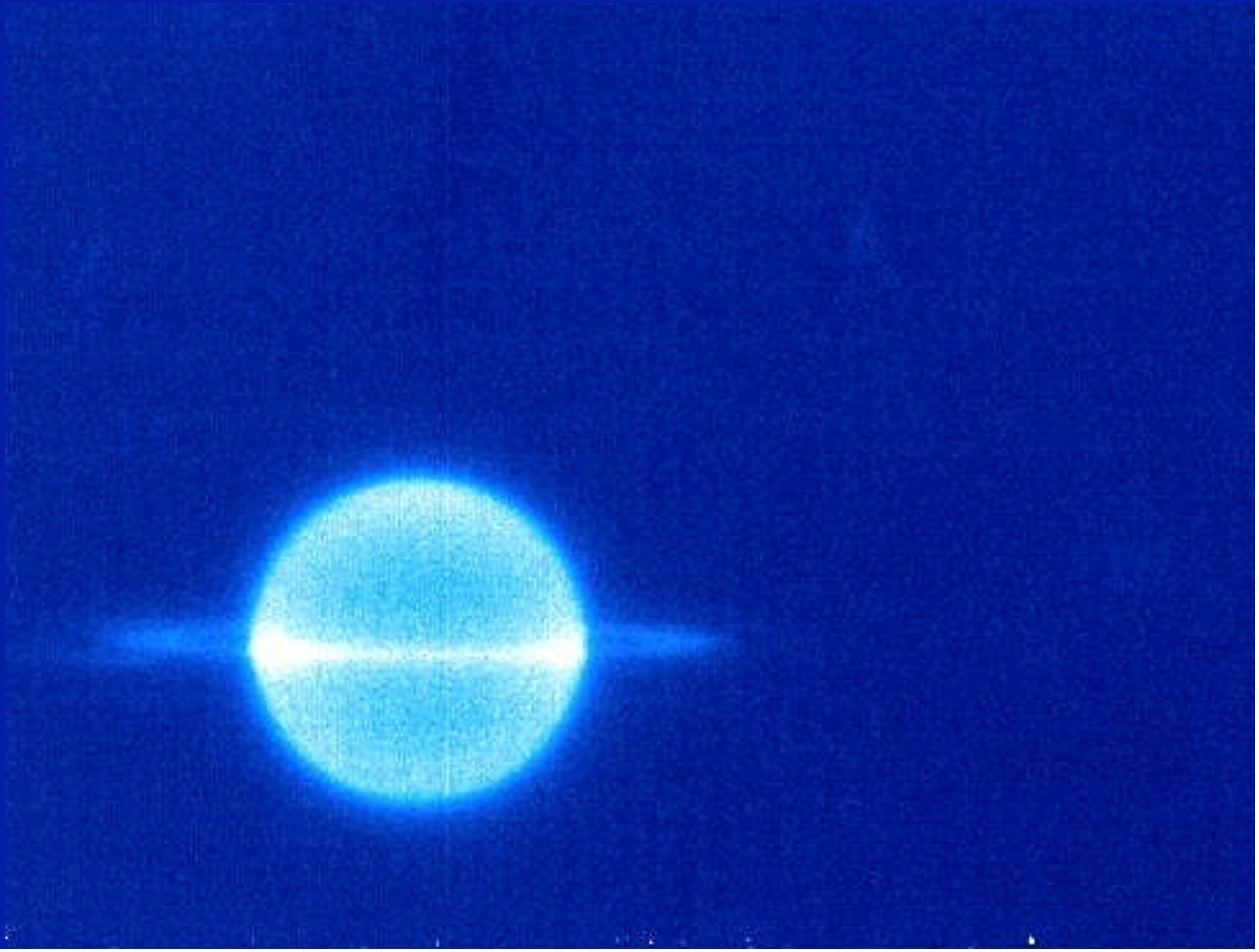
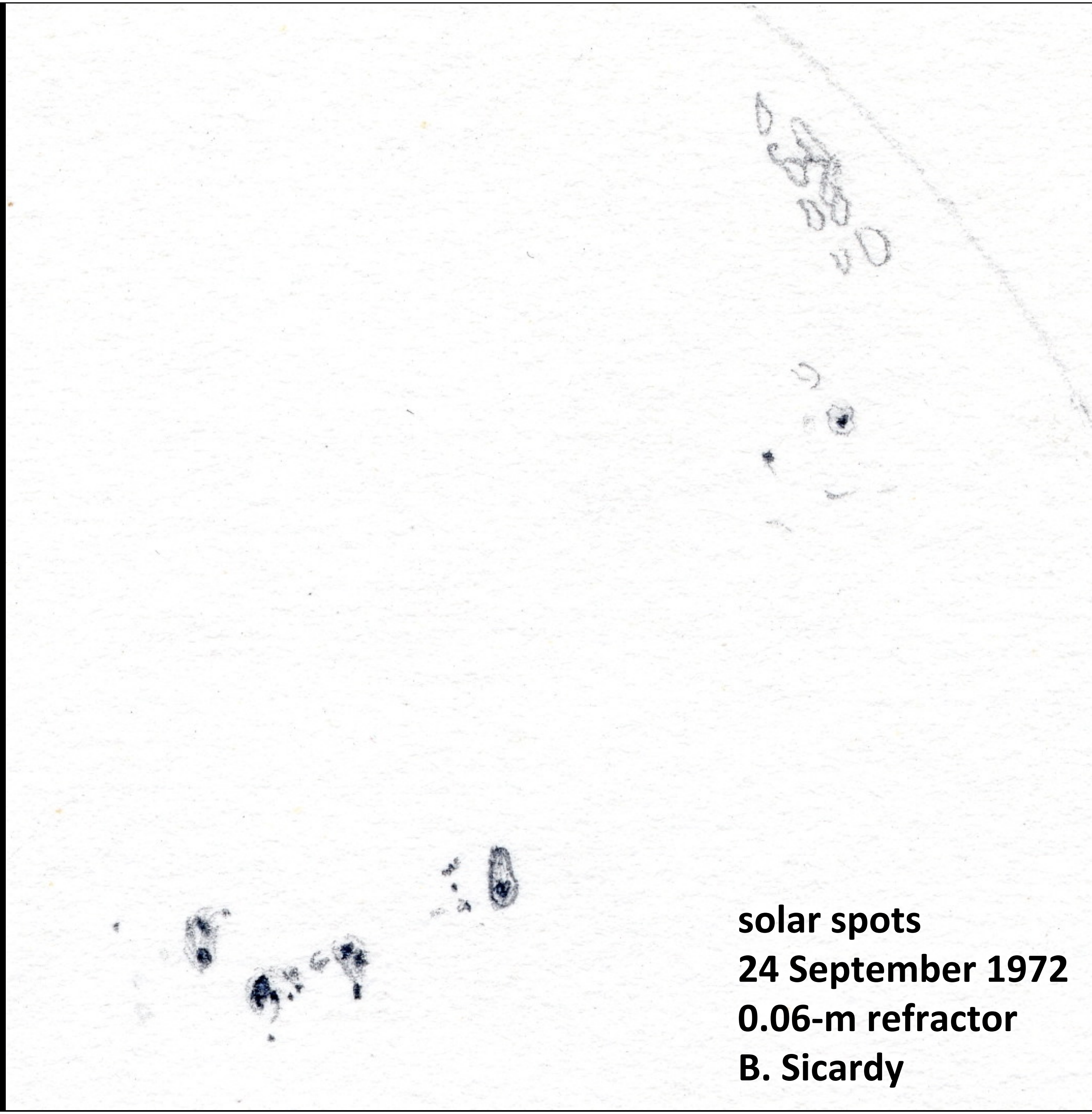
S. Erard
E. Lellouch
D. Luz
F. Marchis
F. Roques
T. Widemann



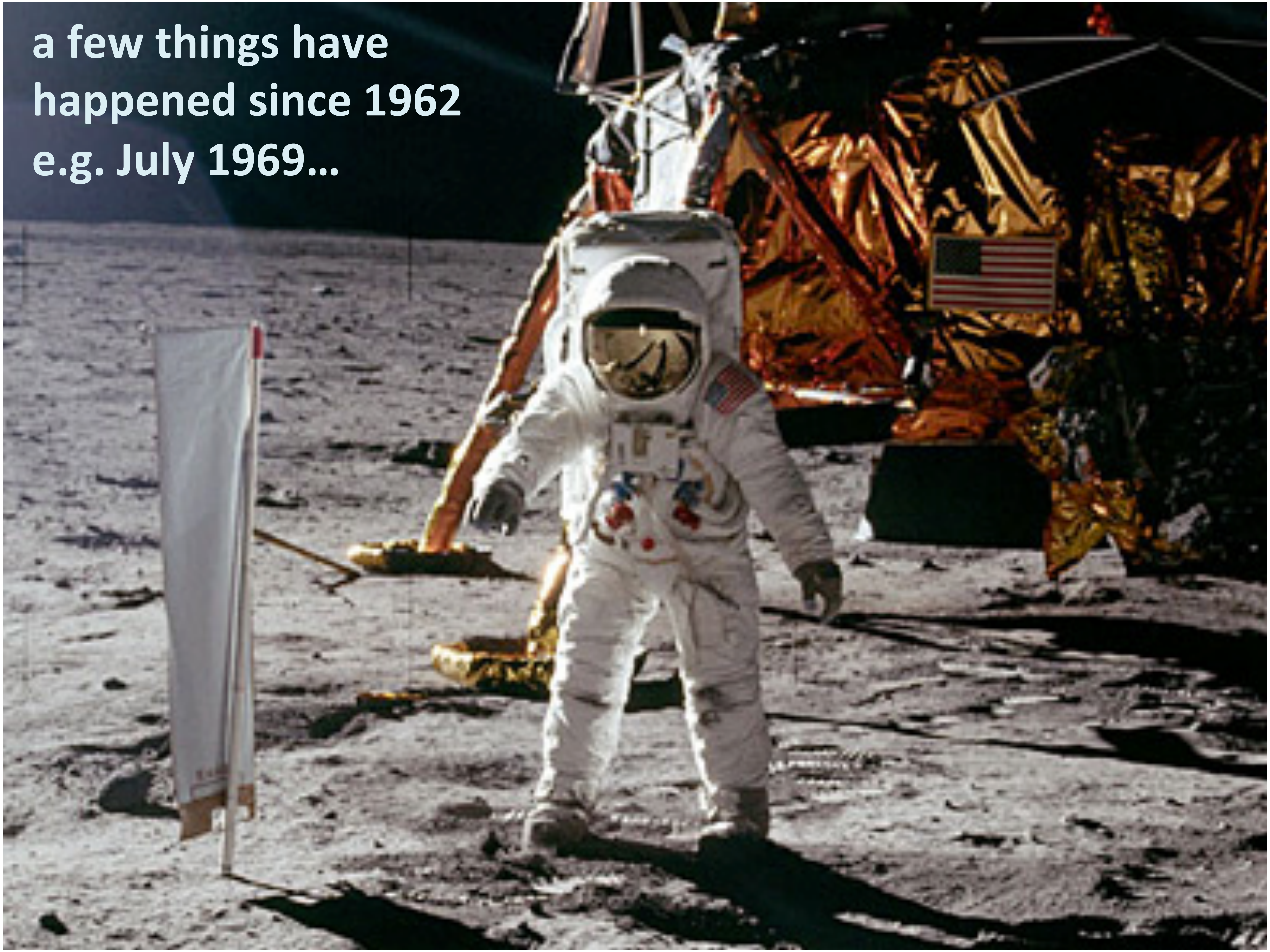
the big view

a (personal) list

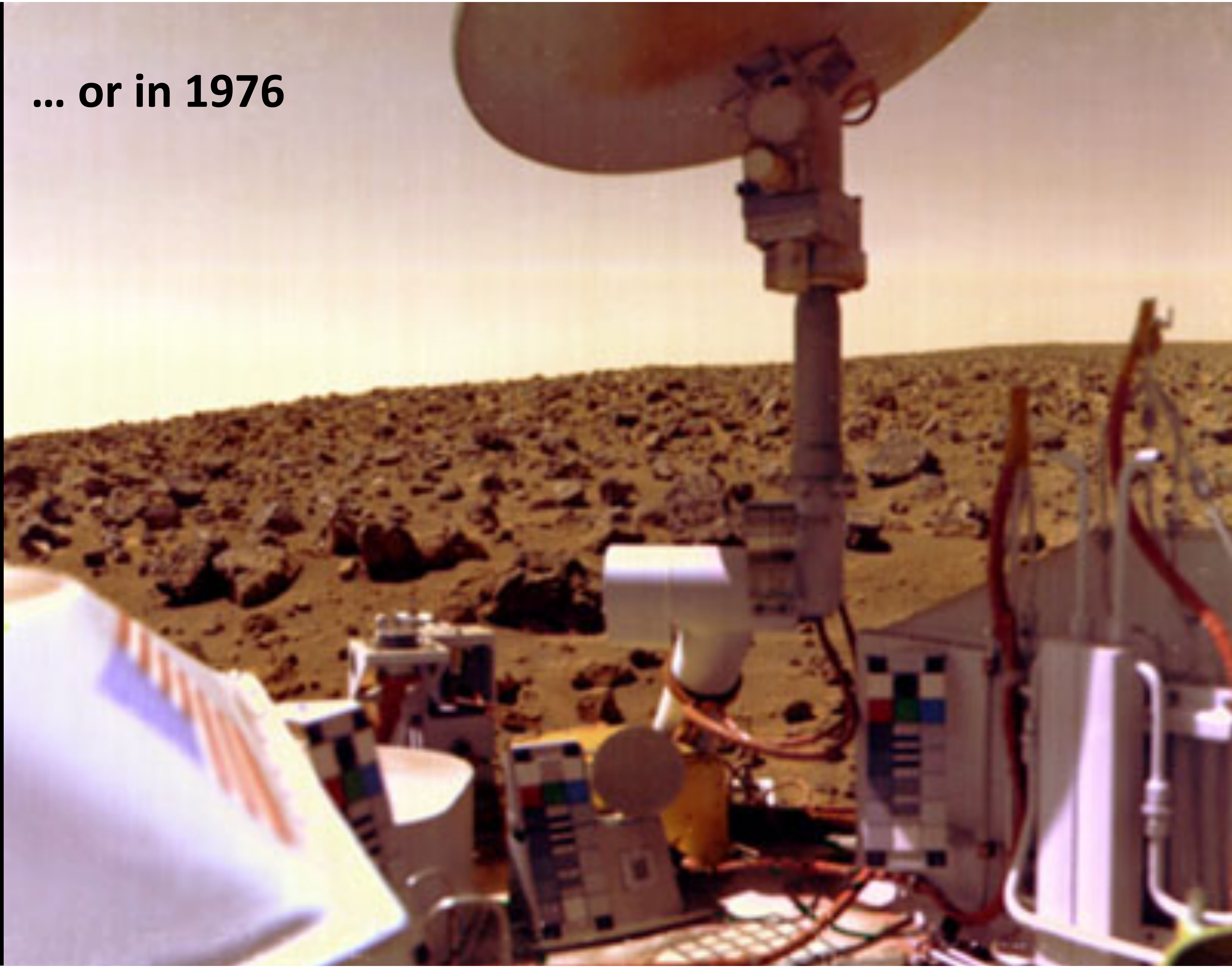
- ✔ the solar system is 4.6 billion years old
- ✔ planets turned from points to new worlds, huge variety, we saw rocks on Moon, Venus, Mars & Titan
- ✔ the solar system is chaotic (marginally stable)
- ✔ There are more 1000 objects observed beyond Neptune
- ✔ there are ~800 exoplanets detected in ~600 systems



solar spots
24 September 1972
0.06-m refractor
B. Sicardy

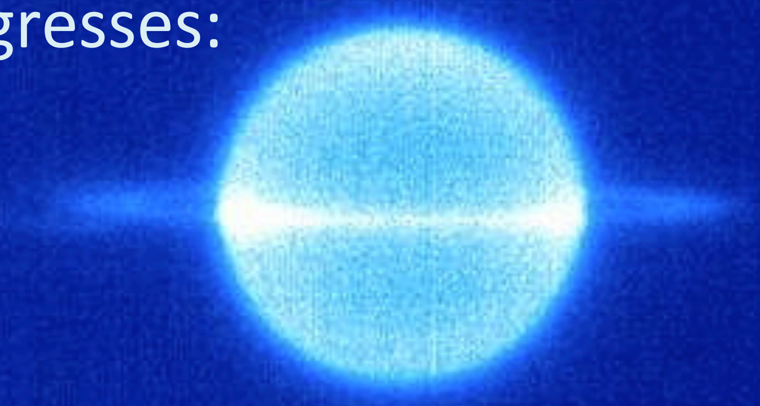

a few things have
happened since 1962
e.g. July 1969…

… or in 1976



importance of ground-based observations vs. space exploration

- ✔ complement space missions @ much lower cost
- ✔ entire body visible from Earth → day/night contrasts, atmospheric general circulation, etc…
- ✔ long-term campaigns: variability, seasons,… huge number of bodies: impossible to explore them all
- ✔ take advantage of technical progresses: new λ's, better sensitivity, spatial & spectral resolution,…



early ages…

1970's: rapid developments of near IR instrumentation for probing planetary atmospheres:

✓ chemical composition of giant planetary atmospheres CH_4,…,CO, NH_3, PH_3, H_20,…

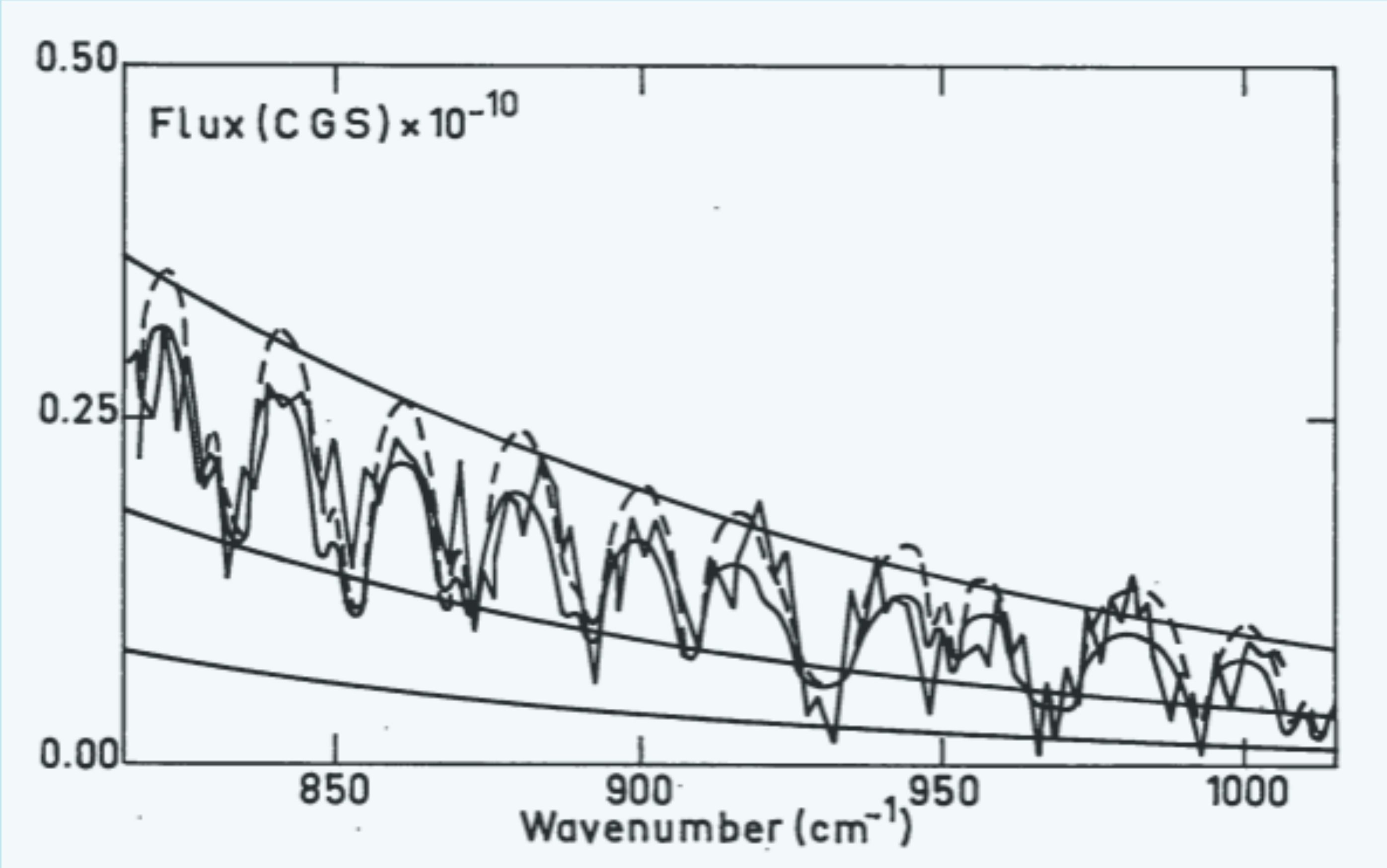
✓ vertical thermal profiles using various λ's

✓ isotopic ratios: D/H, $^{12}C/^{13}C$… for origin

NB. NASA/Voyager 1 & 2 spacecraft did not reveal new molecules in Jupiter & Saturn during the 1980's flyby's

Examples of early works on giant planets atmospheres in the 1970's: Michelson interferometer @152-cm ESO telescope

Combes *et al* (1976) → detection of NH_3 in Jupiter's atmosphere



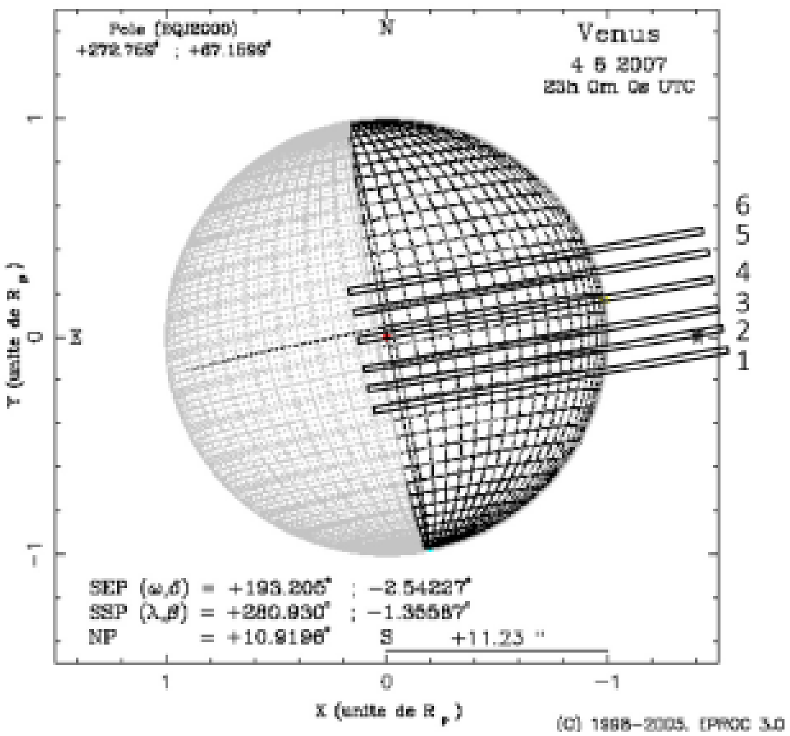
(thermal ~ 11 µm)

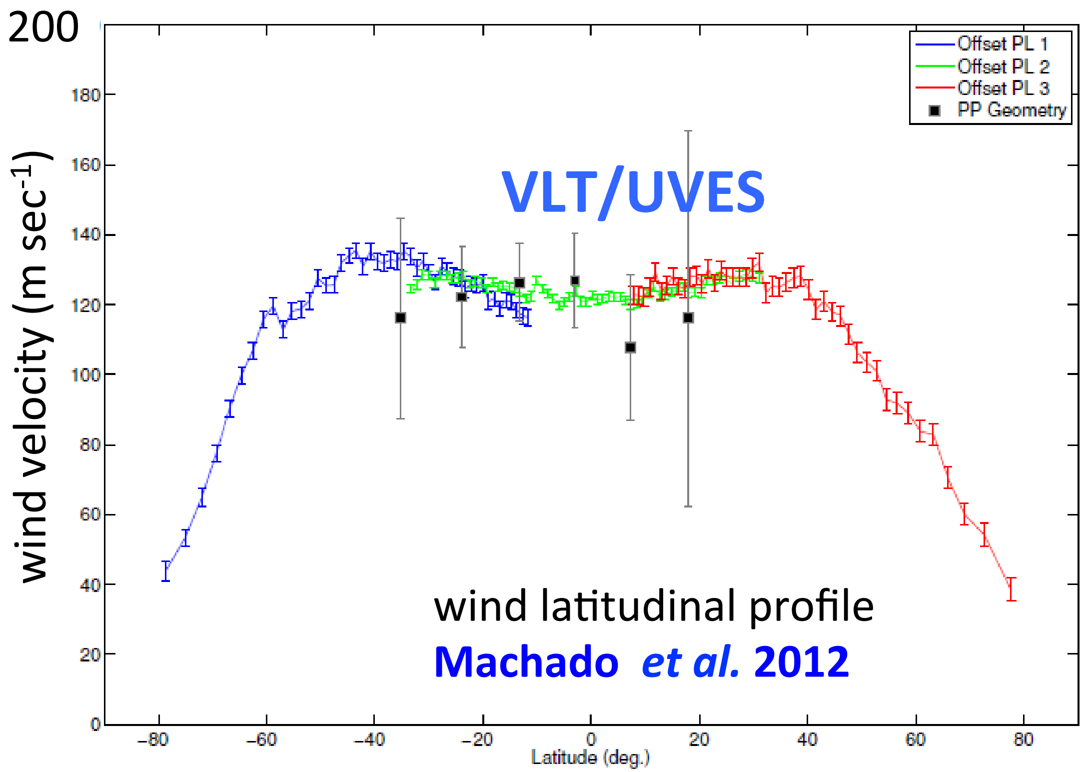

Venus: difficult to observe..
…then long period without hi-res spectroscopy →
VLT opened new era (CRIRES, VISIR, UVES, etc…)

Absolute wind measurements in Venus' atmosphere

✓ Winds are routinely monitored in Venus's atmosphere from cloud-tracking (e.g. from Venus Express), but method affected meteorological phenomena such as fronts.

✓ Doppler velocimetry (solar lines reflected off Venus clouds) provides *true* instantaneous gas velocity

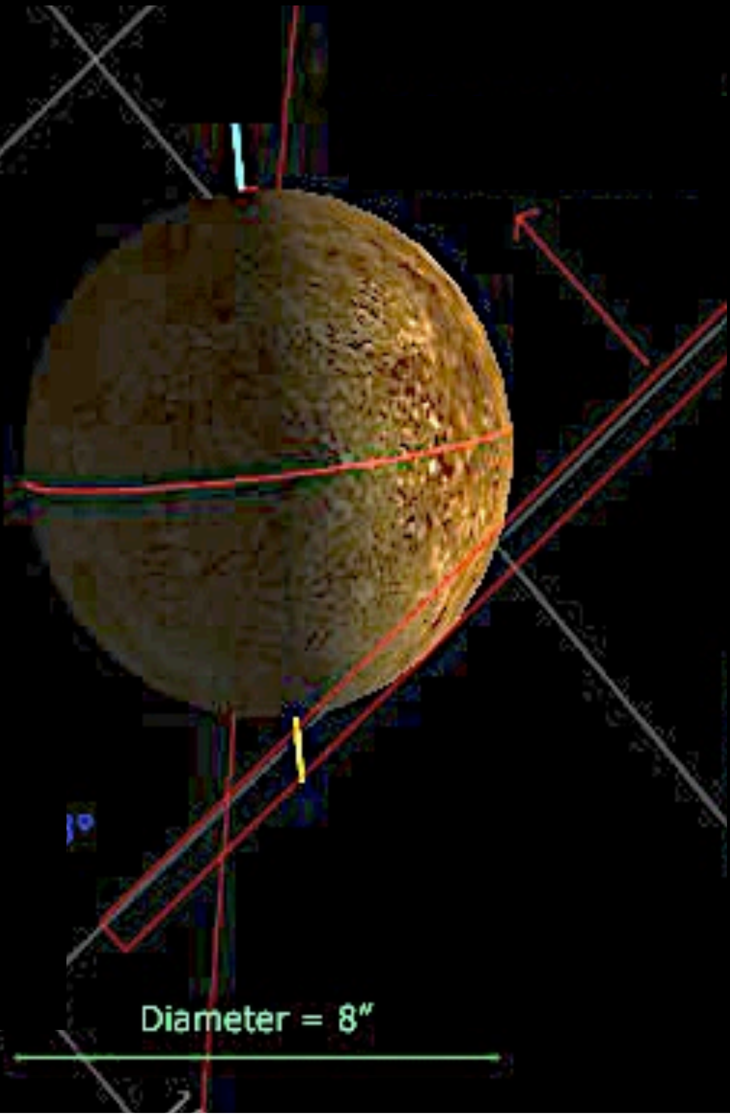





Mercury: difficult to observe too

Mercury: NTT/SOFI

June 2006 : minimum elevation, 13°, max. E elongation



Objectives:

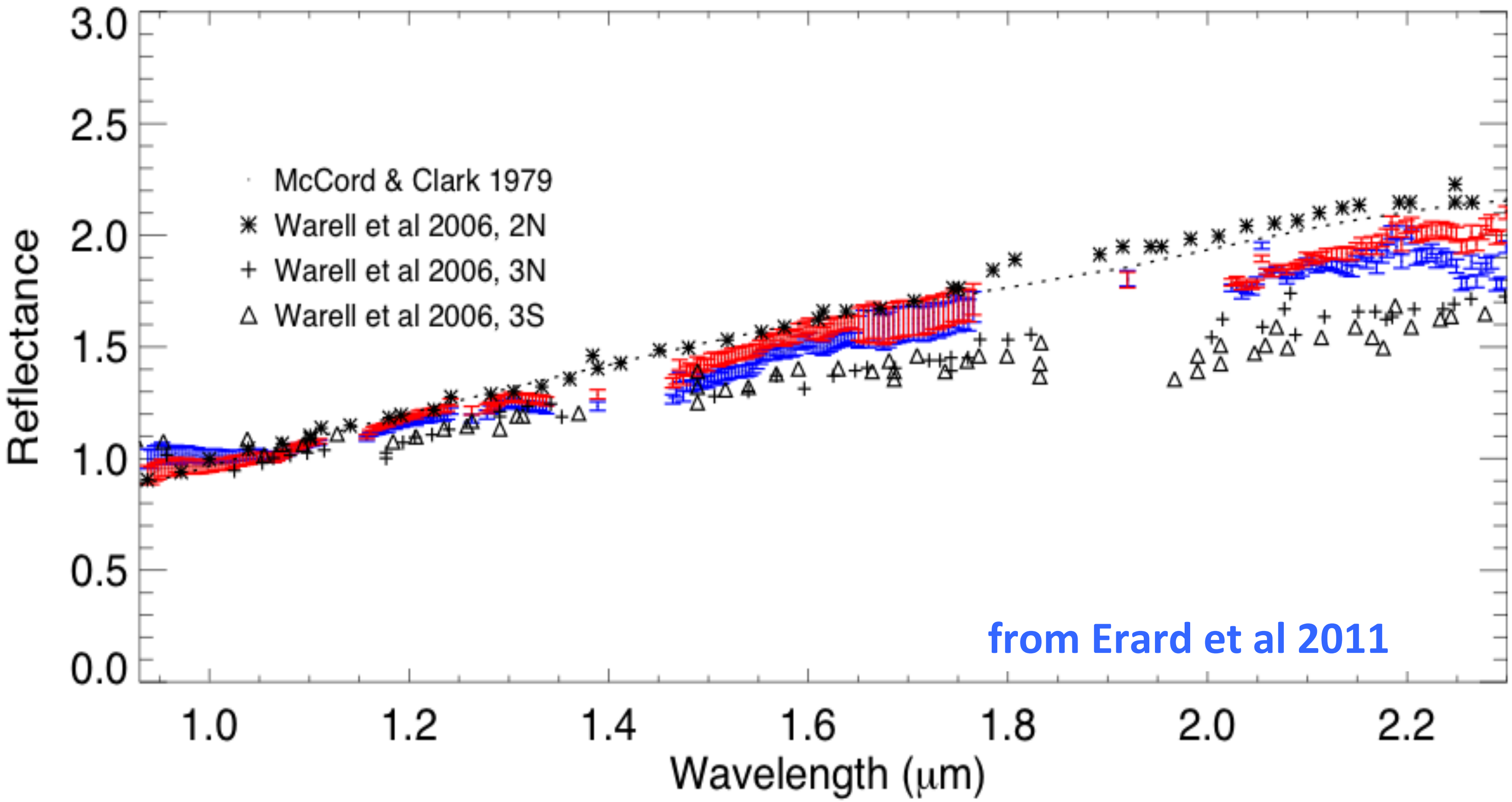
- Study pyroxene absorption
- Study spatial variations

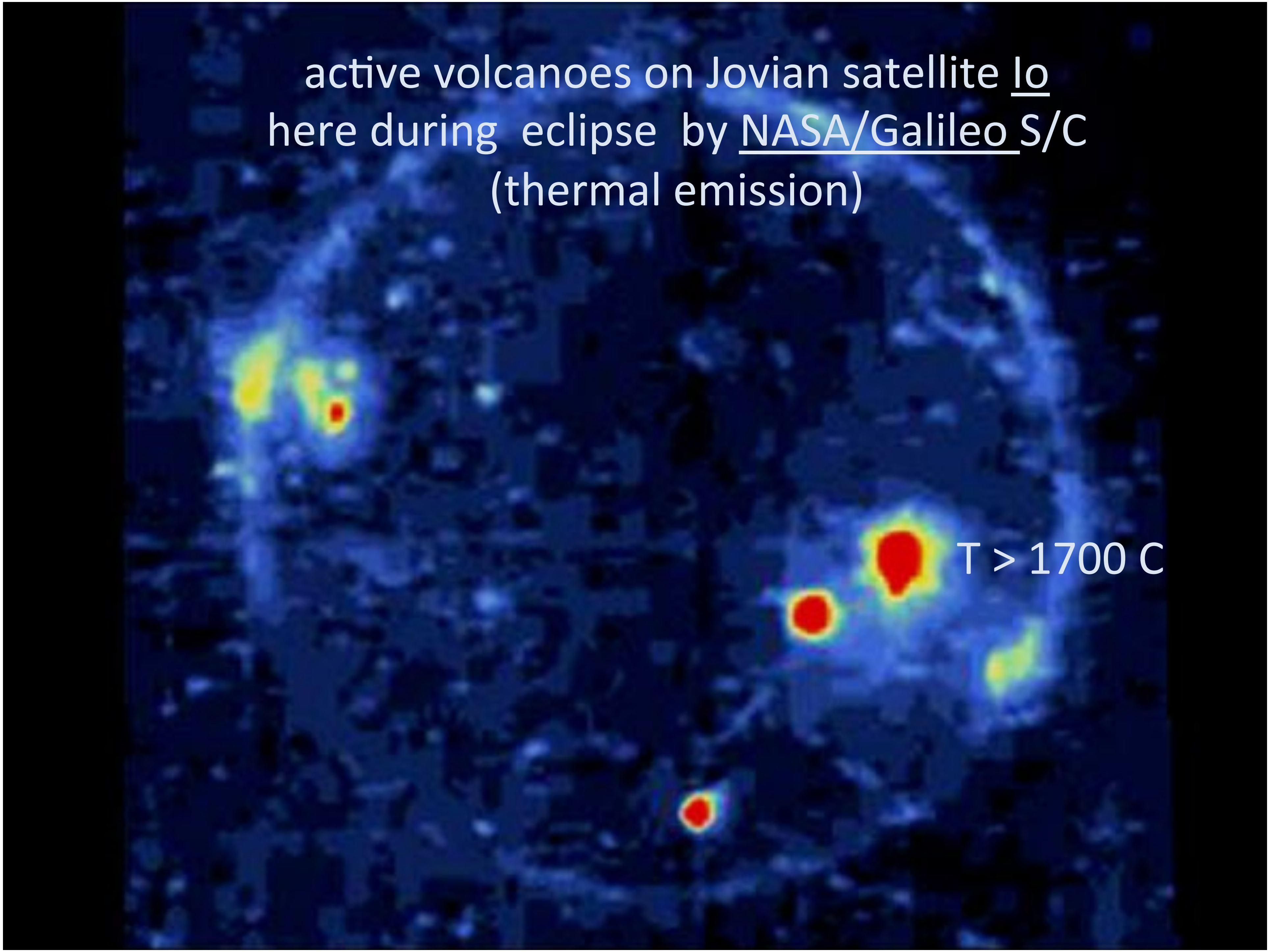
SofI composite reflectance spectra of Mercury

In contrast with previous observations:

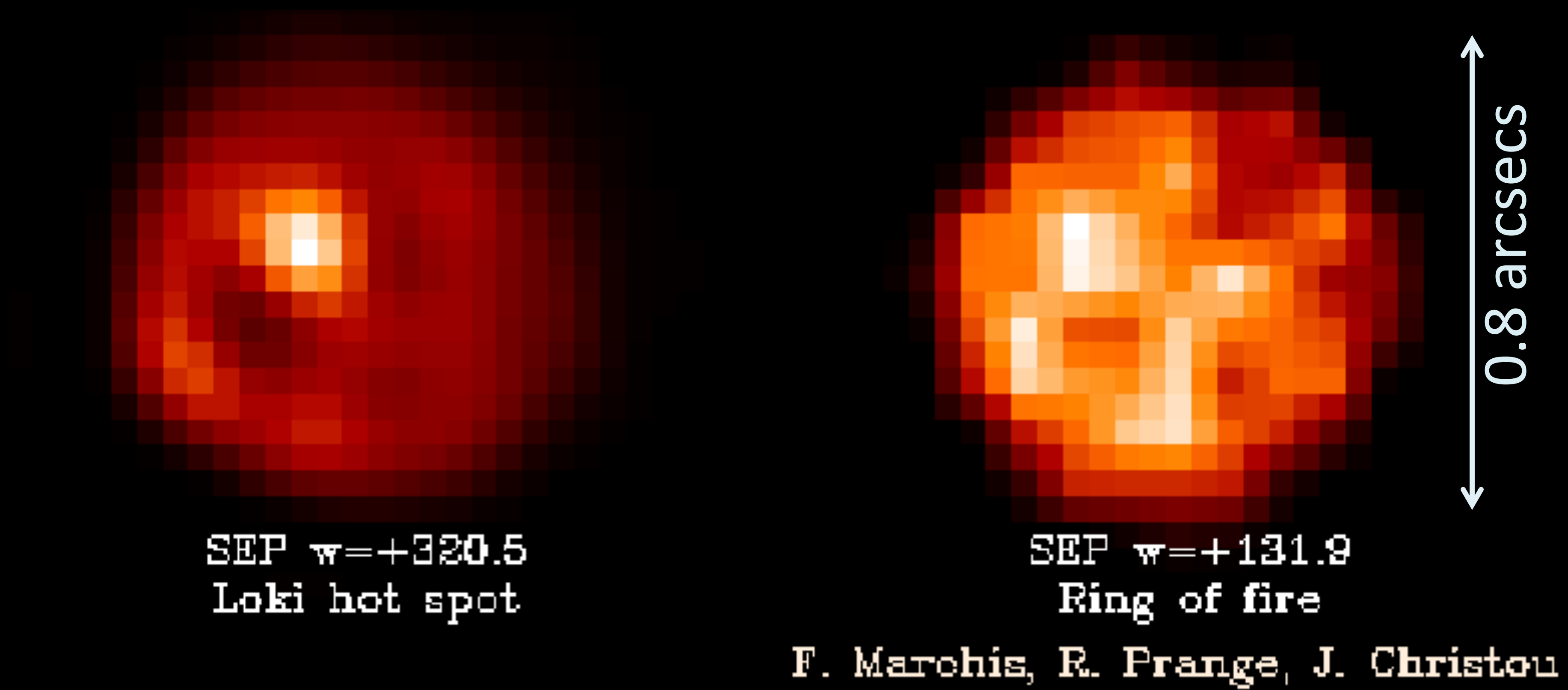
NO detectable 1 or 2 μm absorption detected ($\ll$ 1% enstatite, or $\ll$ 0.6% FeO in silicates)

NASA/Messenger mission will **NOT** do better…




active volcanoes on Jovian satellite <u>Io</u>
here during eclipse by <u>NASA/Galileo</u> S/C
(thermal emission)
T > 1700 C

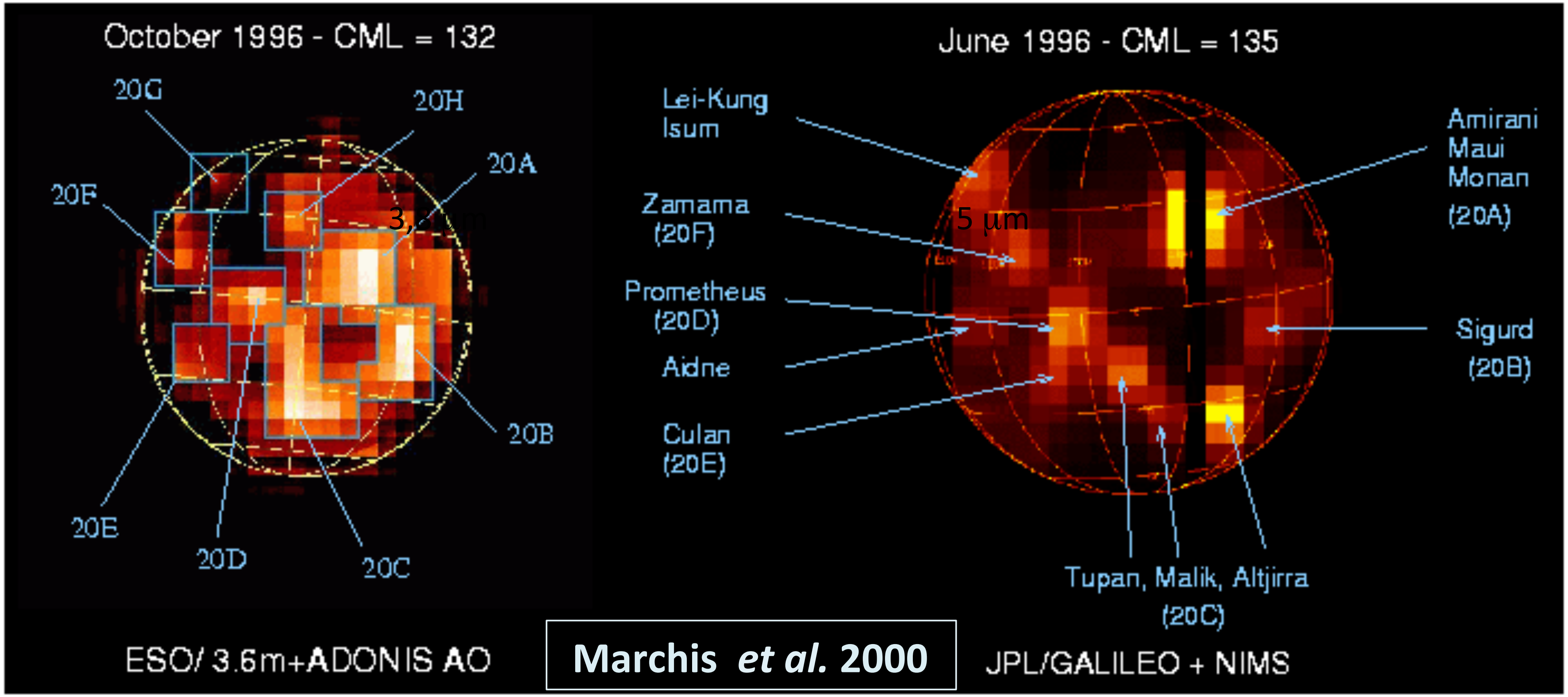
Io in L' band (3-4 µm)
ESO 3.6m/ADONIS AO images – Oct. 1996



http://astro.berkeley.edu/~fmarchis/Science/Io_OA/Io_OA.html

Marchis *et al.* 2000

Comparaison with GALILEO/NIMS (1-5 μm)



ADONIS Resolution: 0,15", or 570 km

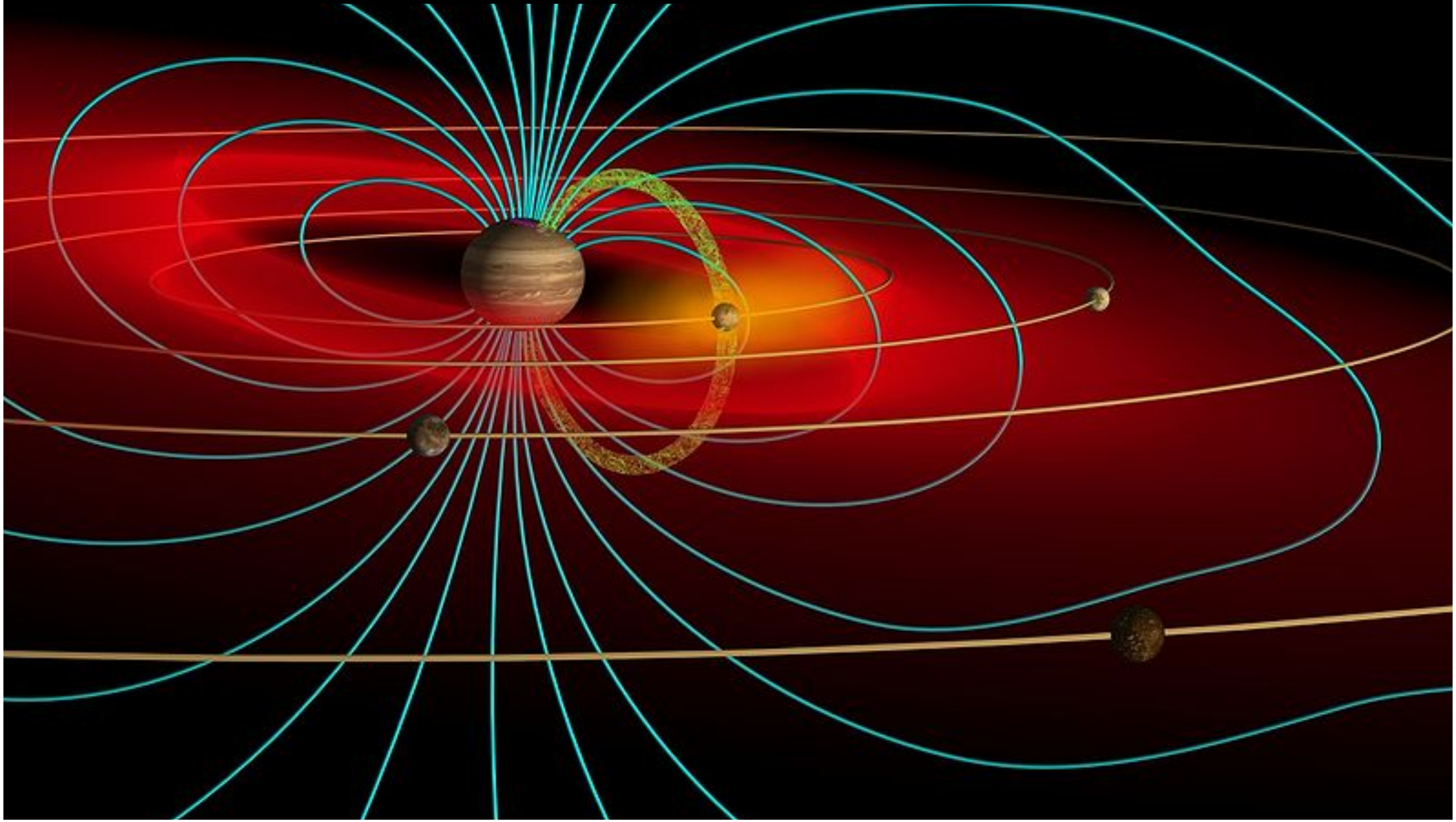
NIMS resolution: ~ 200 km

confirmation of nature of hot spots at comparable spatial resolution

$\Rightarrow$ *surveillance of Io volcanic activity from Earth: energy output, plasma input into Jupiter magnetosphere…*

first detection of [OIII] λ5007 from the Io plasma torus with the 3.6-m ESO telescope (CASPEC) →

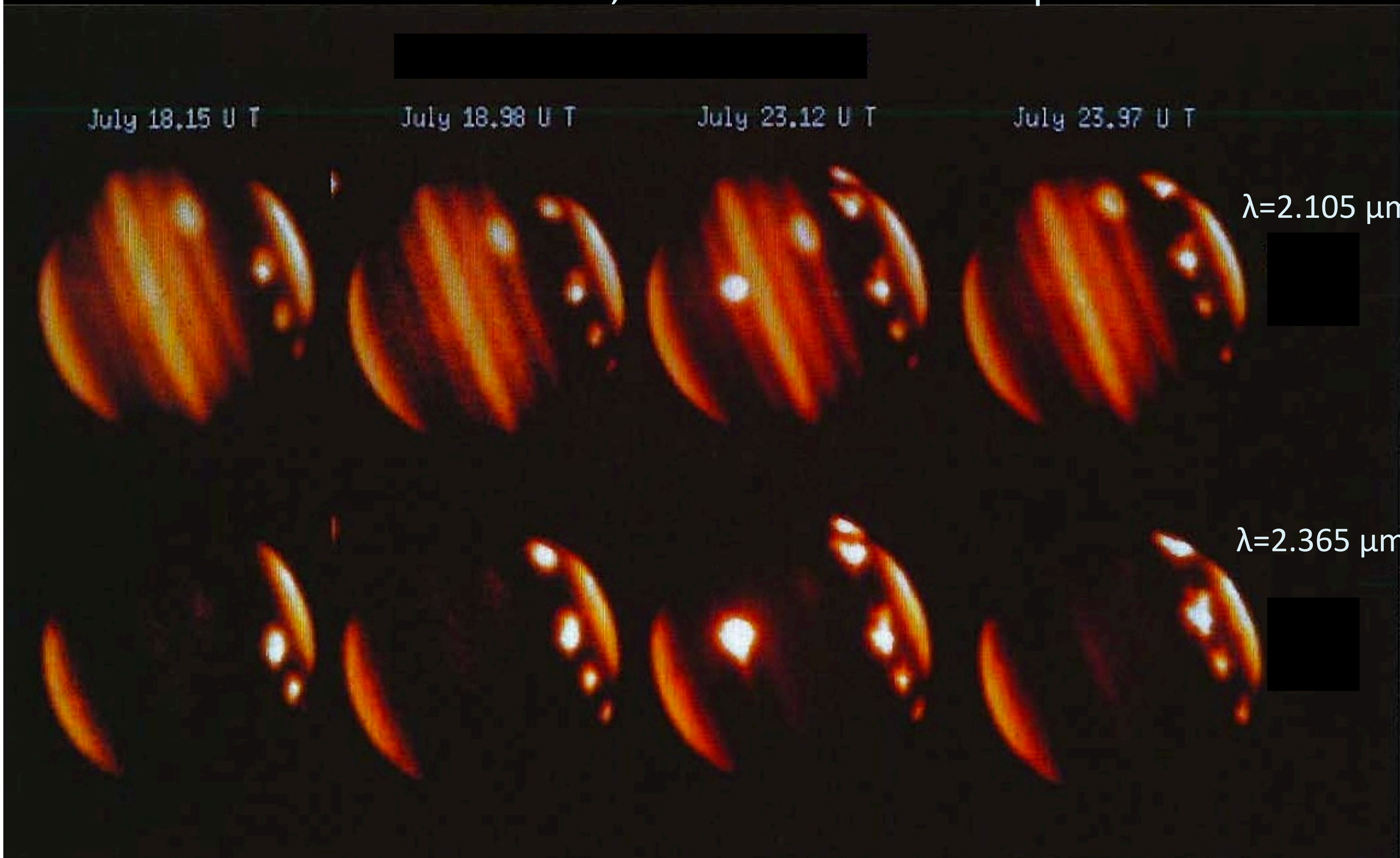
evidence for time variability of the torus (Thomas, 1993)



ESO watches
Shoemaker-Levy 9
impacts on Jupiter
July 1996

… more than 6
instruments involved
at La Silla

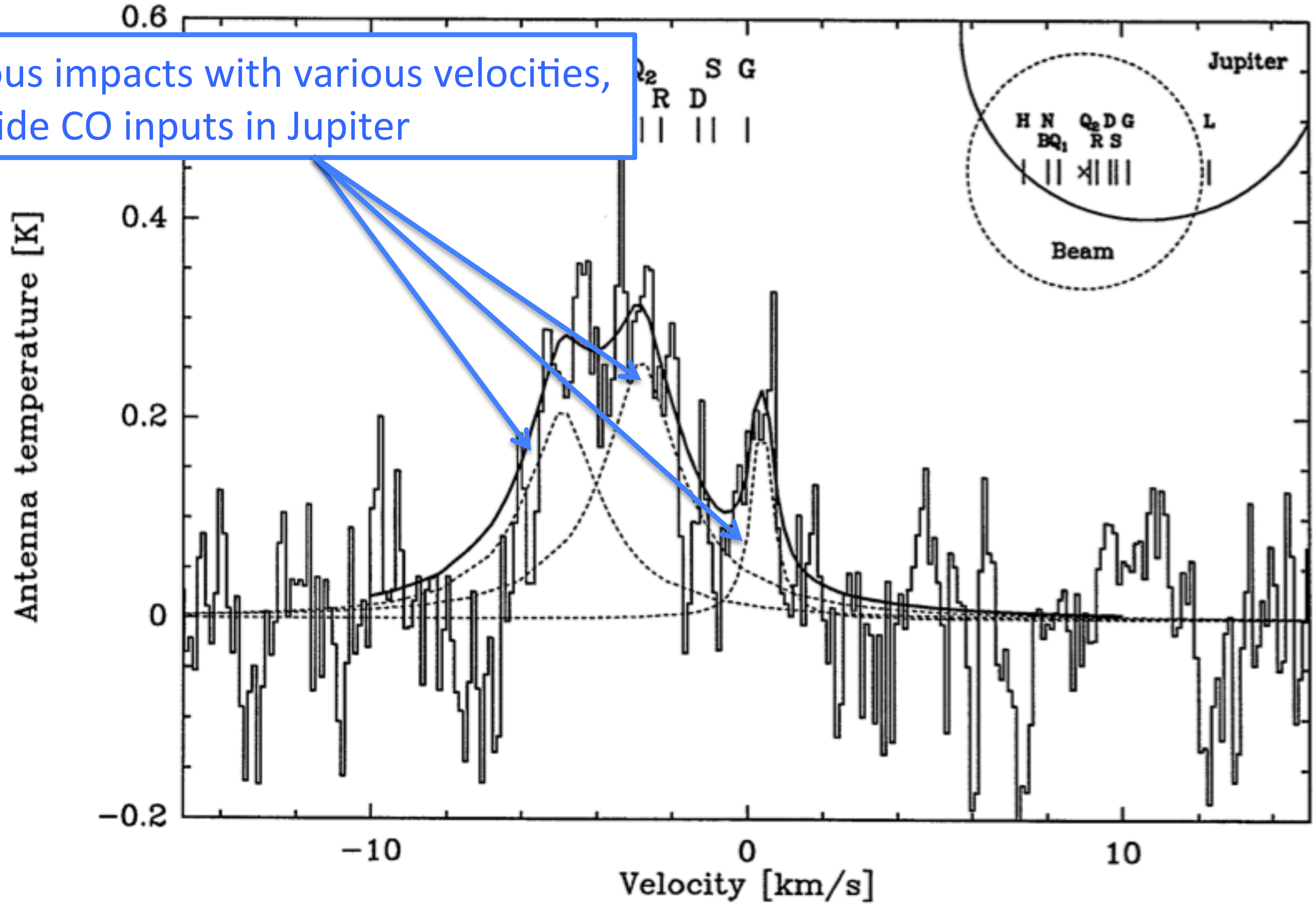
IRAC camera, La Silla 2.2-m telescope



Messenger Sept.1994

SEST mm observations of CO during SL9 impacts

various impacts with various velocities, provide CO inputs in Jupiter



Bockelee-Morvan et al. 1995

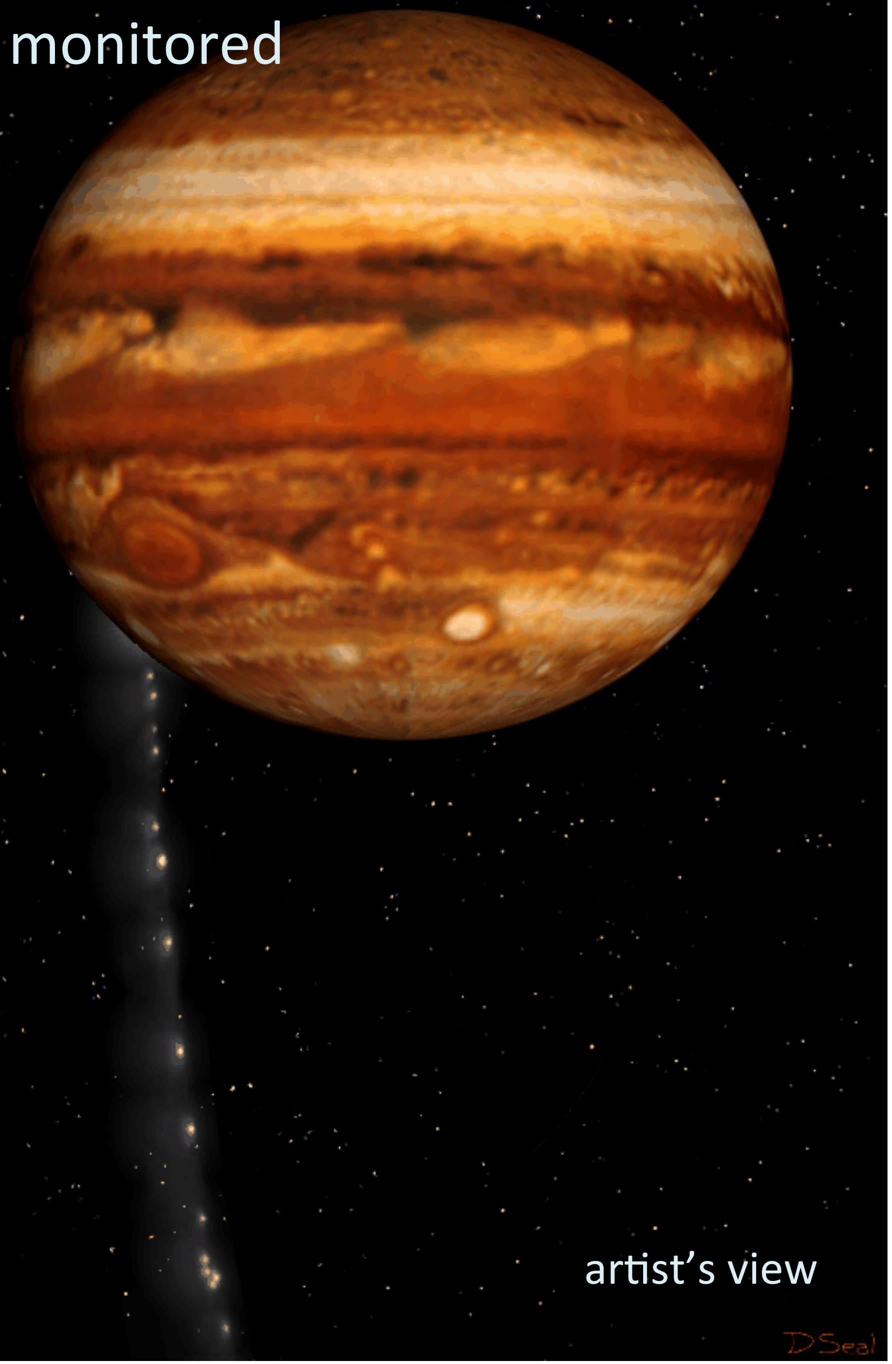
First cometary impact on a planet ever monitored

a few results:

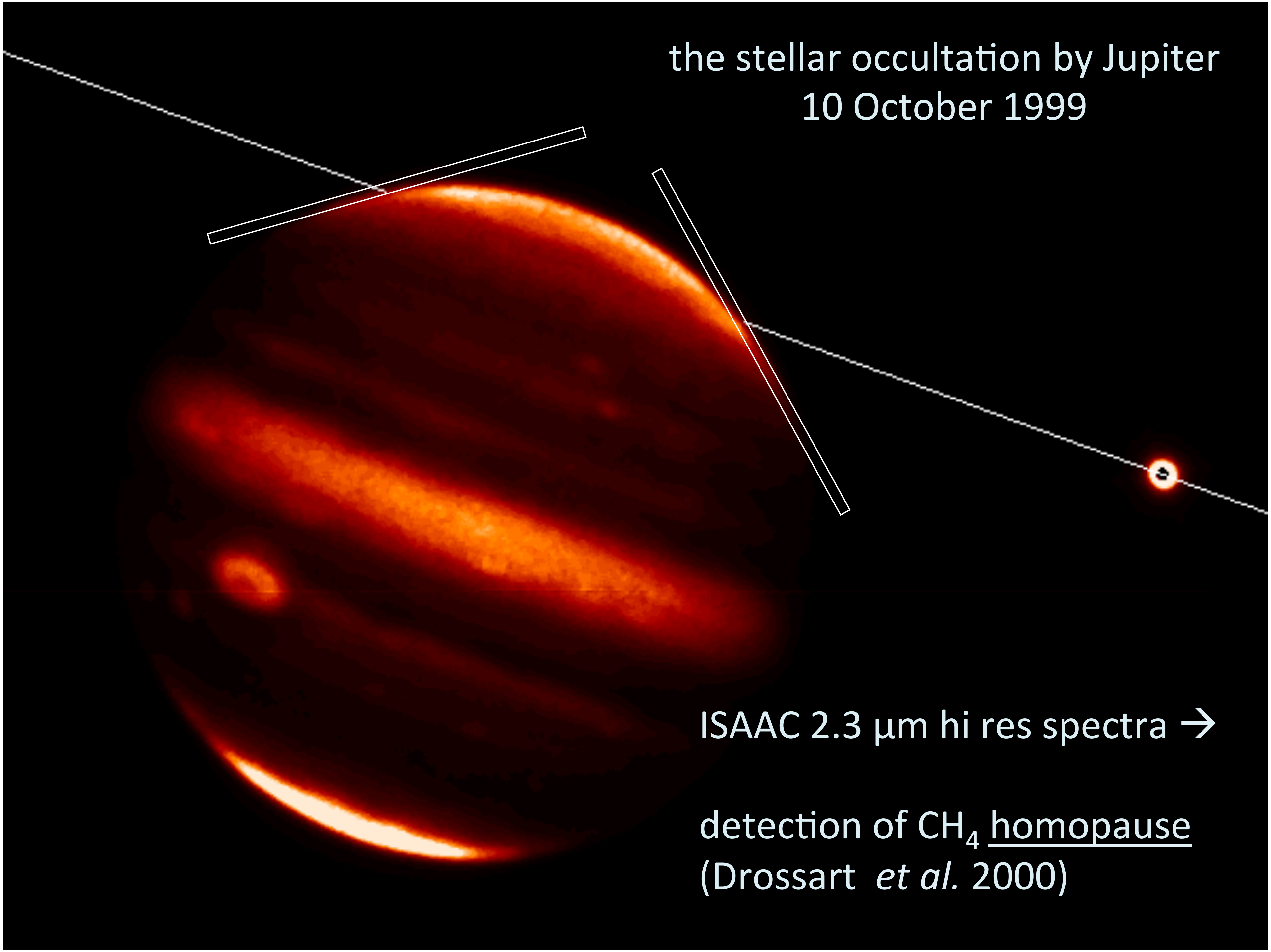
✓ comets are important sources of volatiles for planets

✓ rich « shock-chemistry », able to synthesize new molecules (e.g. CS, HCN)

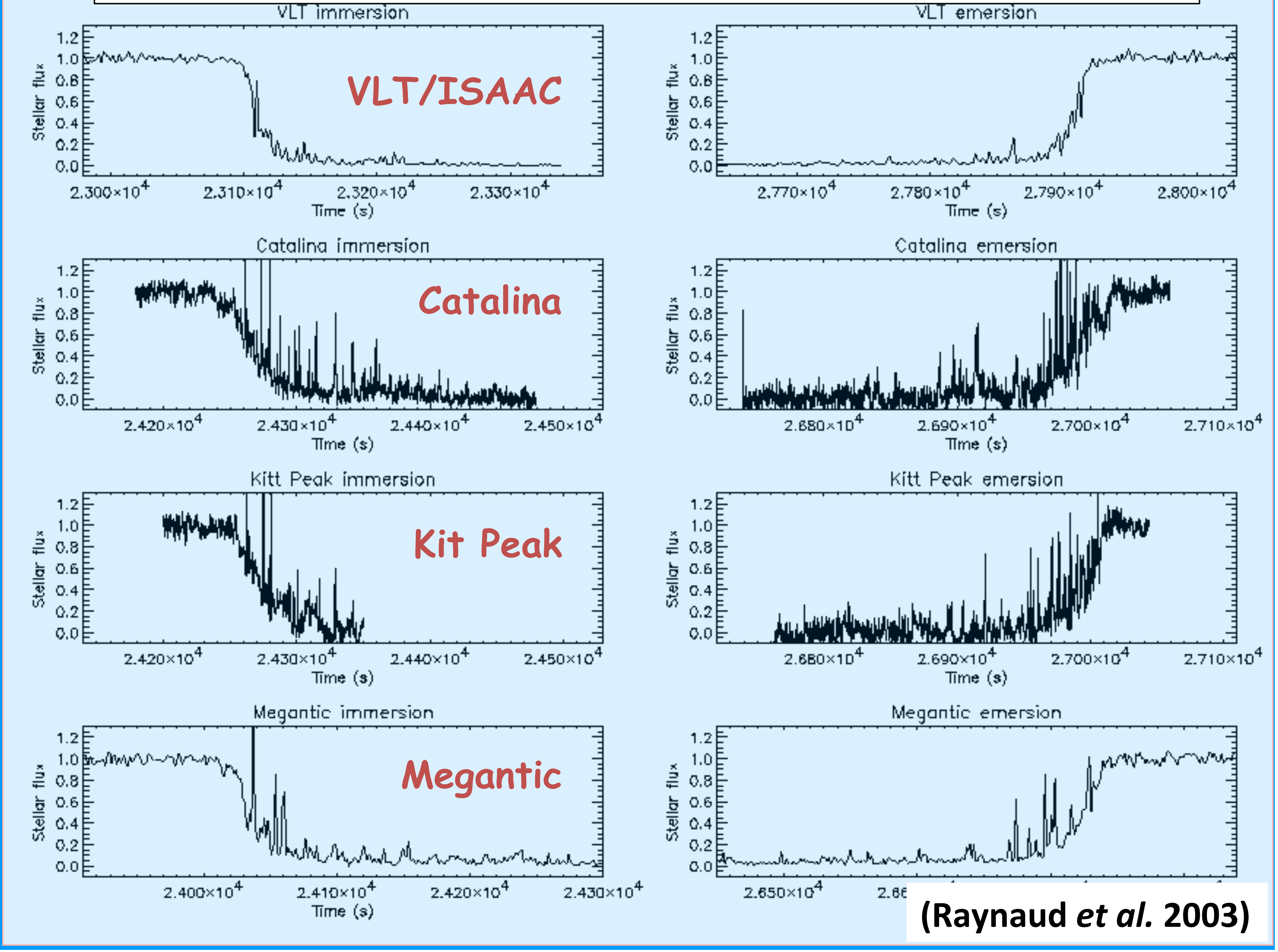
✓ species take a long time to diffuse (e.g. HCN, CO_2)



artist's view


the stellar occultation by Jupiter
10 October 1999
ISAAC 2.3 µm hi res spectra →
detection of CH_4 homopause
(Drossart *et al.* 2000)

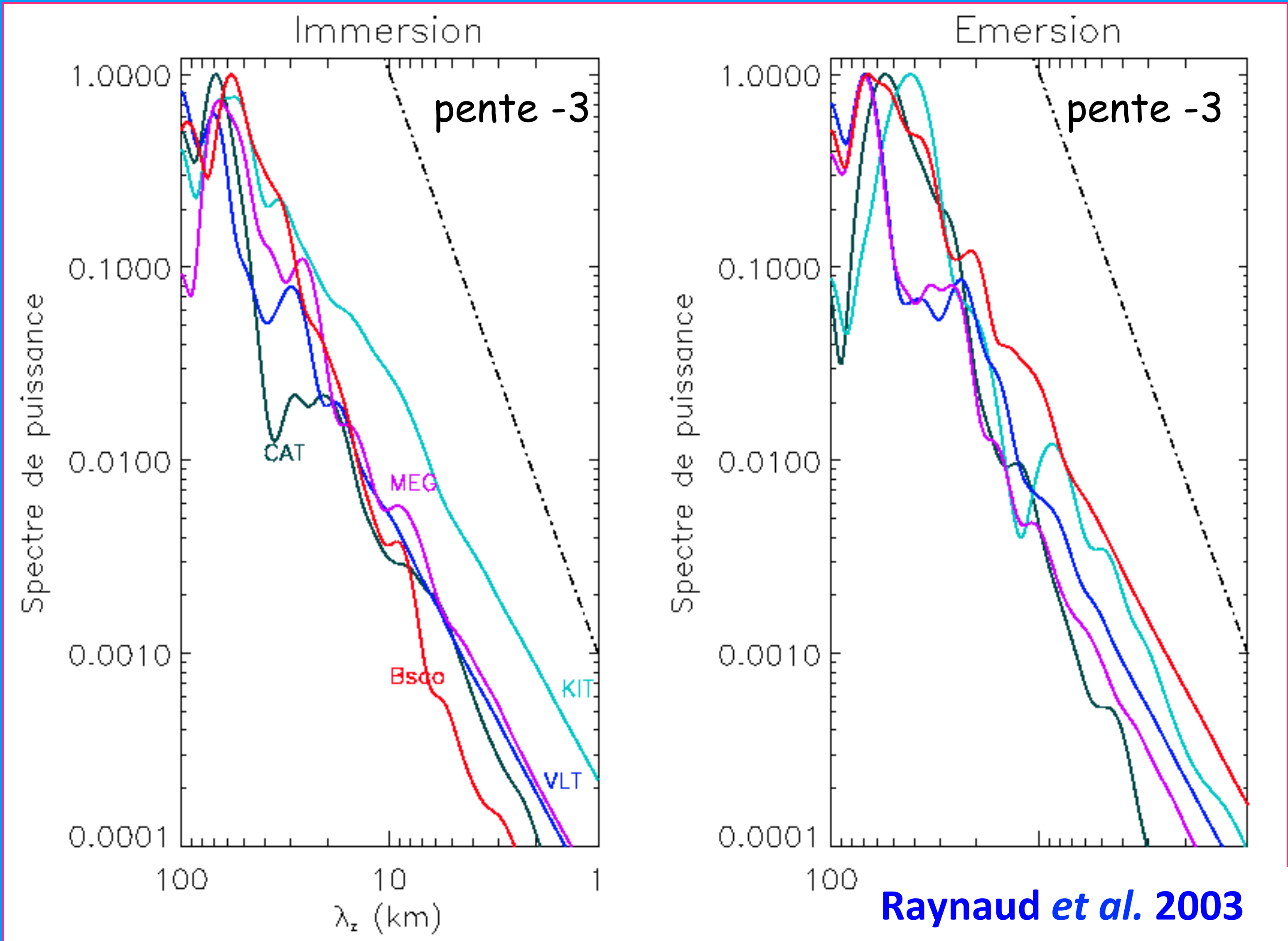
The stellar occultation by Jupiter, 10 October 1999



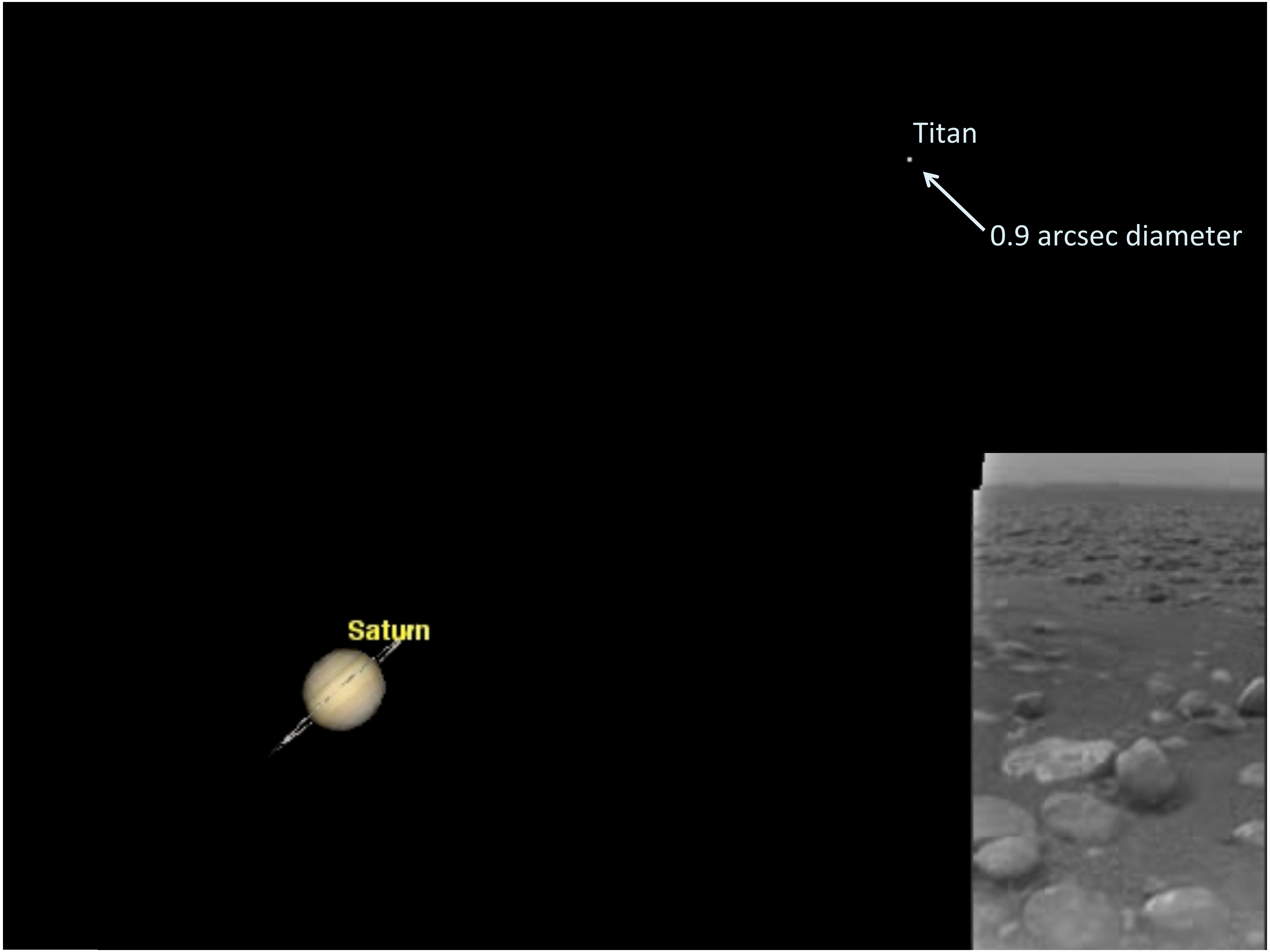
(Raynaud *et al.* 2003)

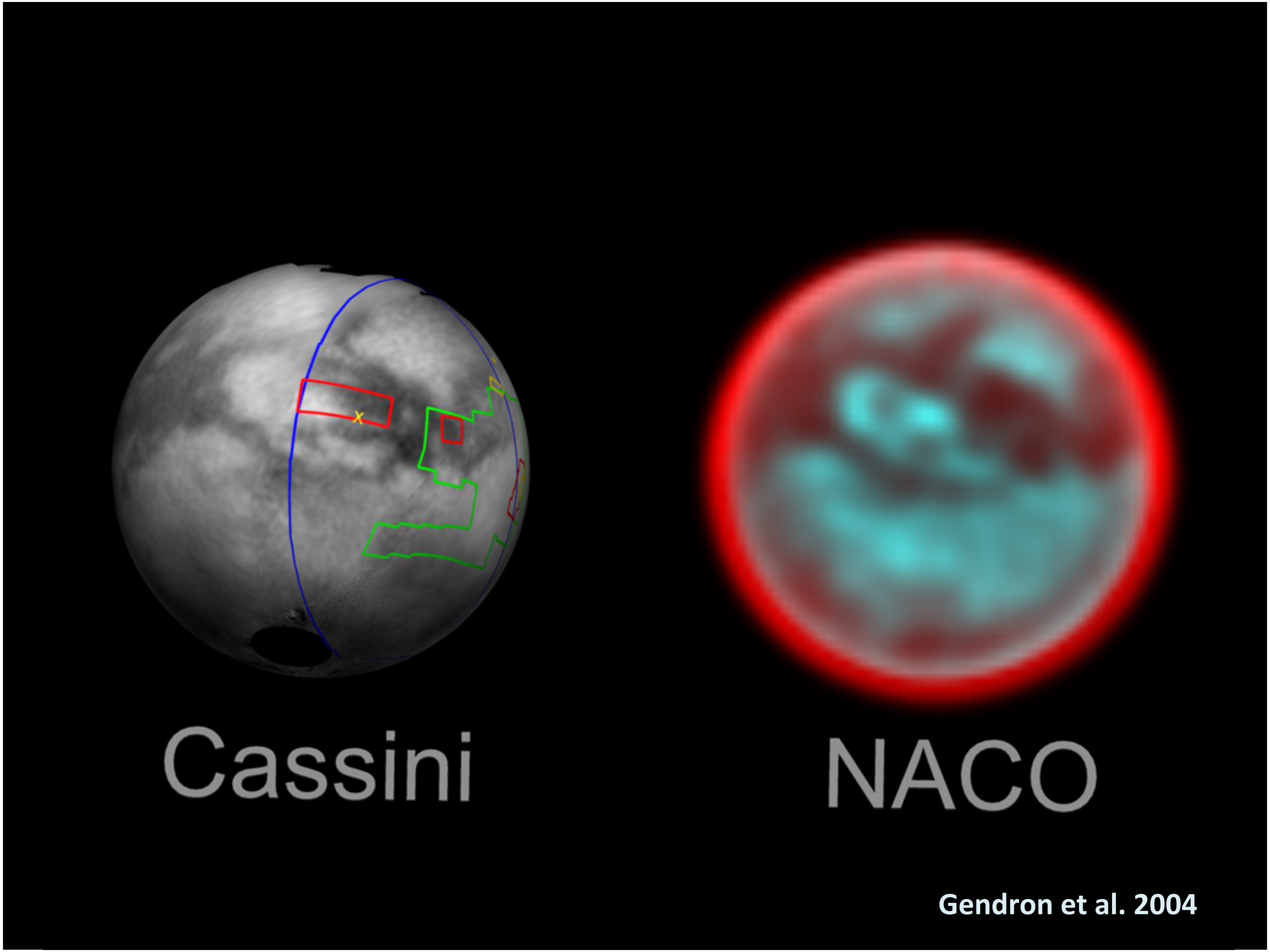
Results: spectral signatures of gravity waves

"Universal Spectrum" (Smith *et al* 1987): power ~$(1/\lambda_z)^{-3}$ [Earth, Titan, Neptune…]



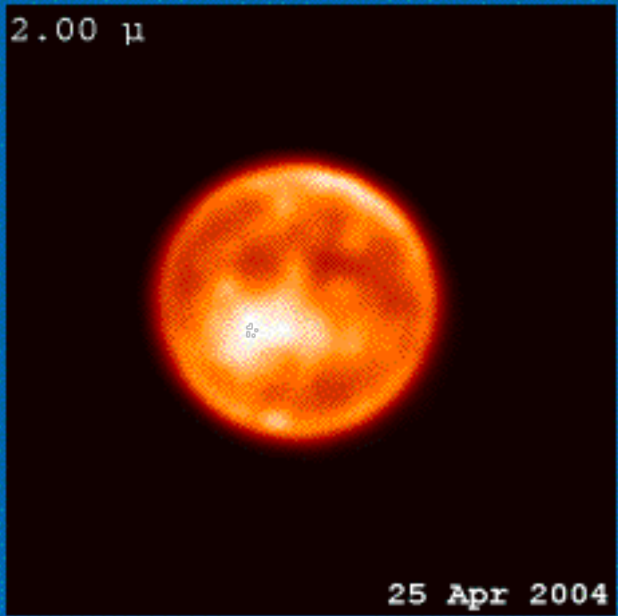
Raynaud *et al.* 2003

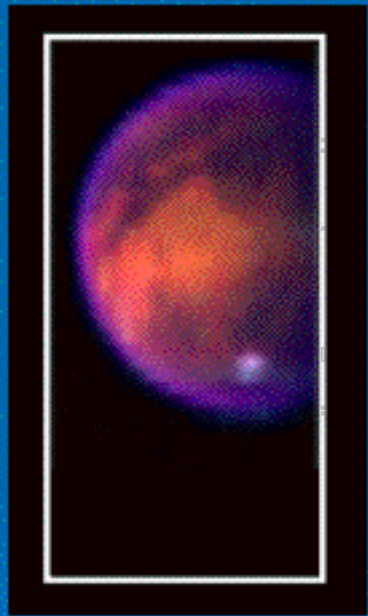

Titan
0.9 arcsec diameter
Saturn


Cassini
NACO
Gendron et al. 2004

Vues de Titan prises au sol et de l'espace

VLT
NACO





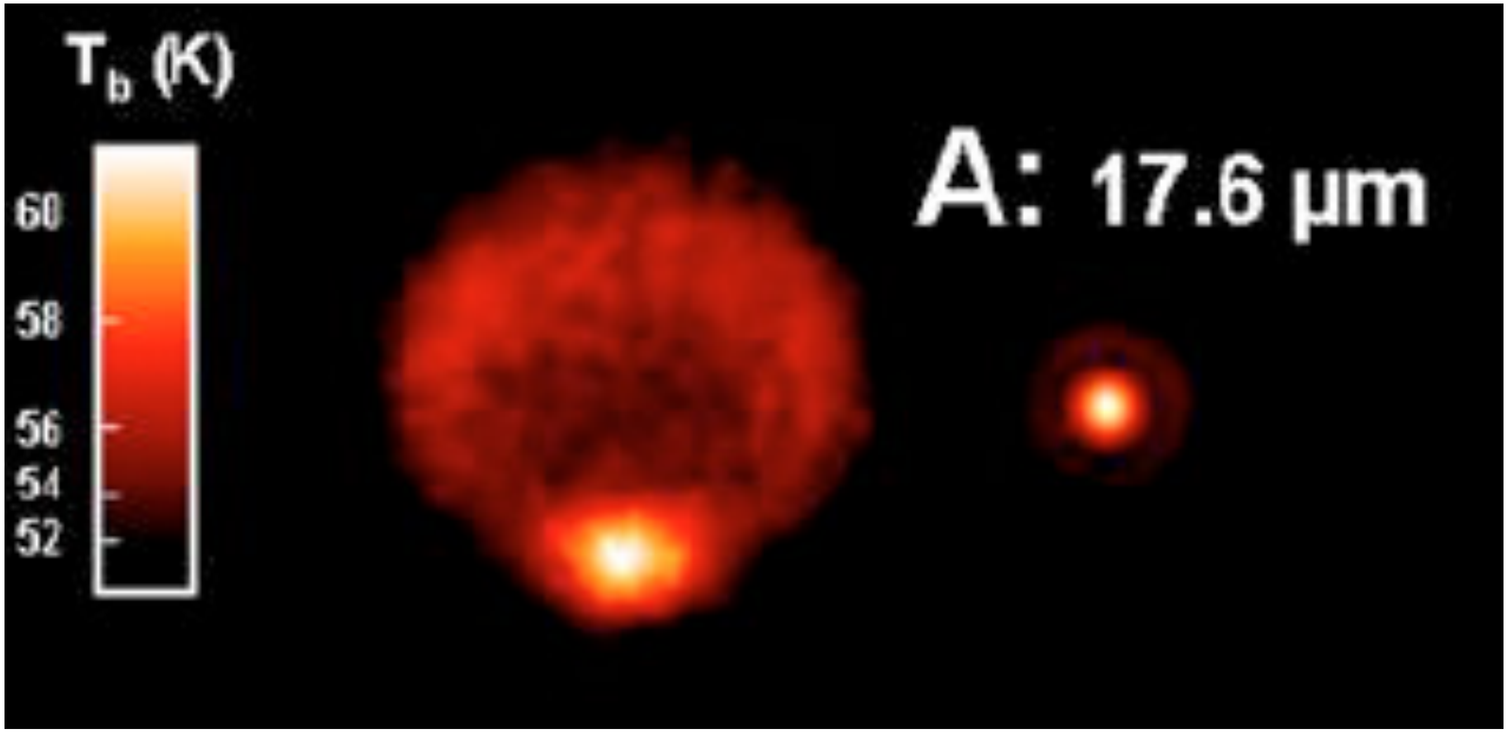
Cassini
VIMS

<u>long term</u> monitoring of Titan's seasons (clouds, circulation…)

Courtesy A. Coustenis

Discovery of "hot" pole on Neptune (VLT/VISIR)

✓ Neptune's south pole much (~6 K) warmer at tropopause (~100 mbar) than low latitude regions
✓ allows gaseous methane from troposphere to "leak" out to higher altitudes → enrich the stratosphere in CH_4 planetwide
✓ confirmed by Herschel telescope

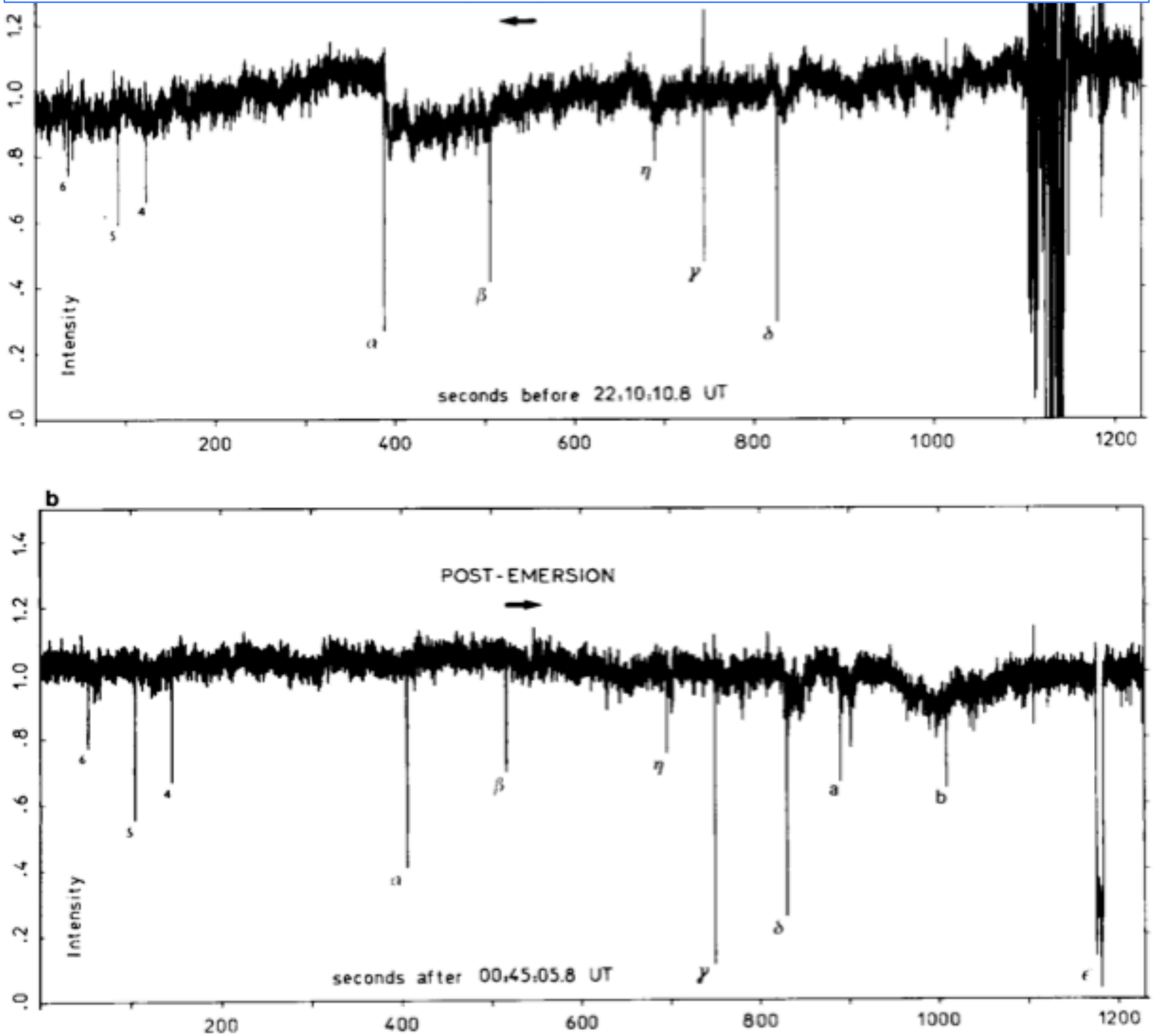


VLT/VISIR

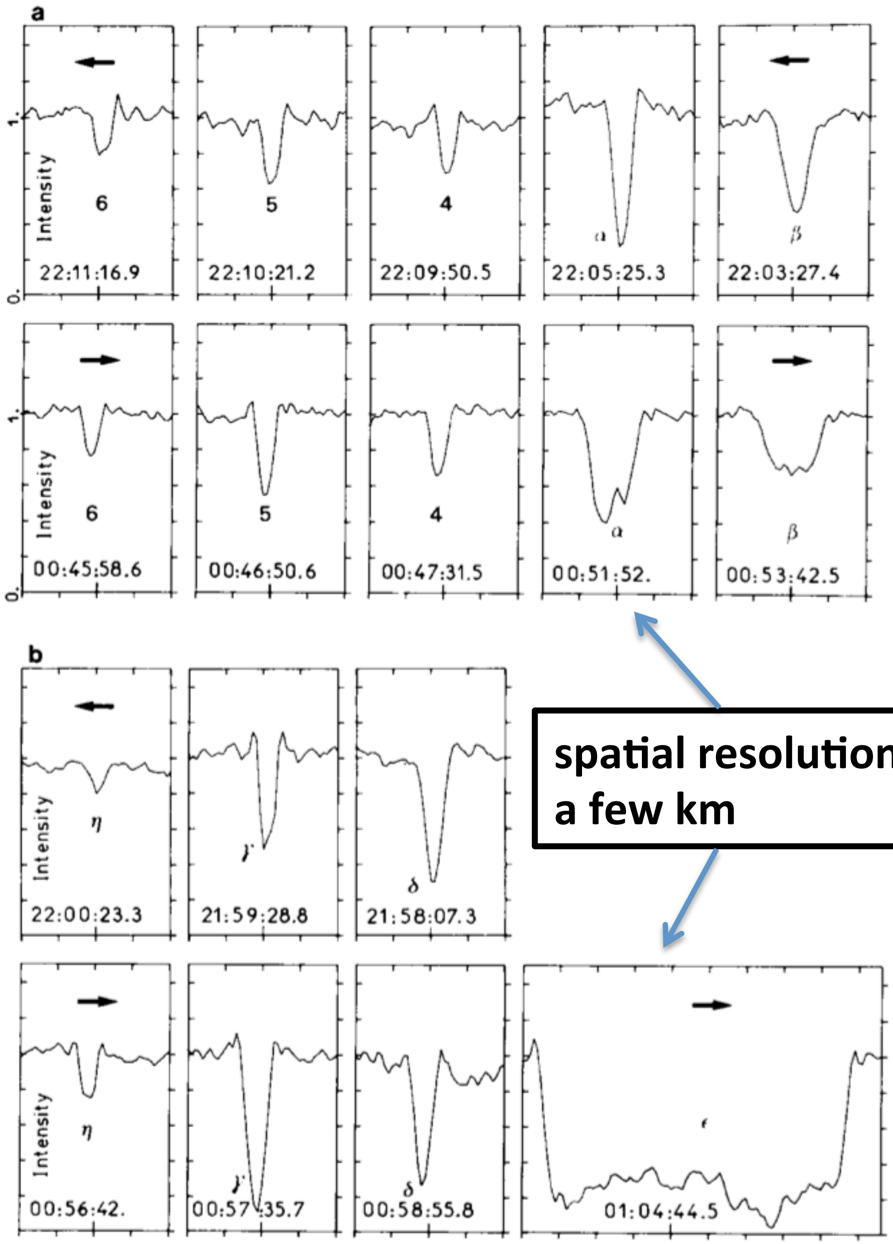
Orton et al. 2007


ringed planets
Uranus’s rings
ISAAC K band
VLT ANTU telescope
19 November 2003

The 15 August 1980 stellar occultation by Uranus and its rings
3.6-m IR aperture photometer

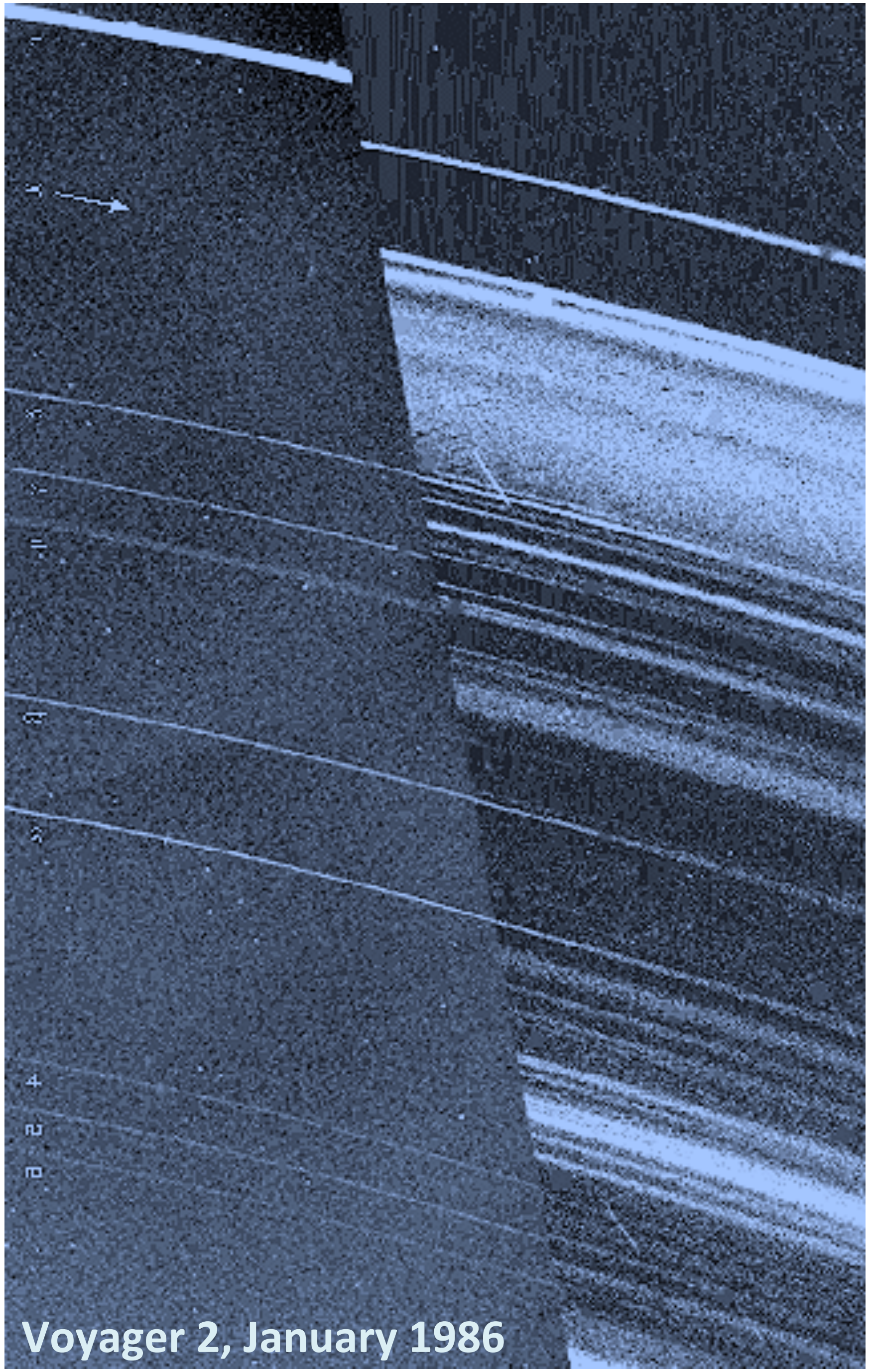


Sicardy et al. 1982

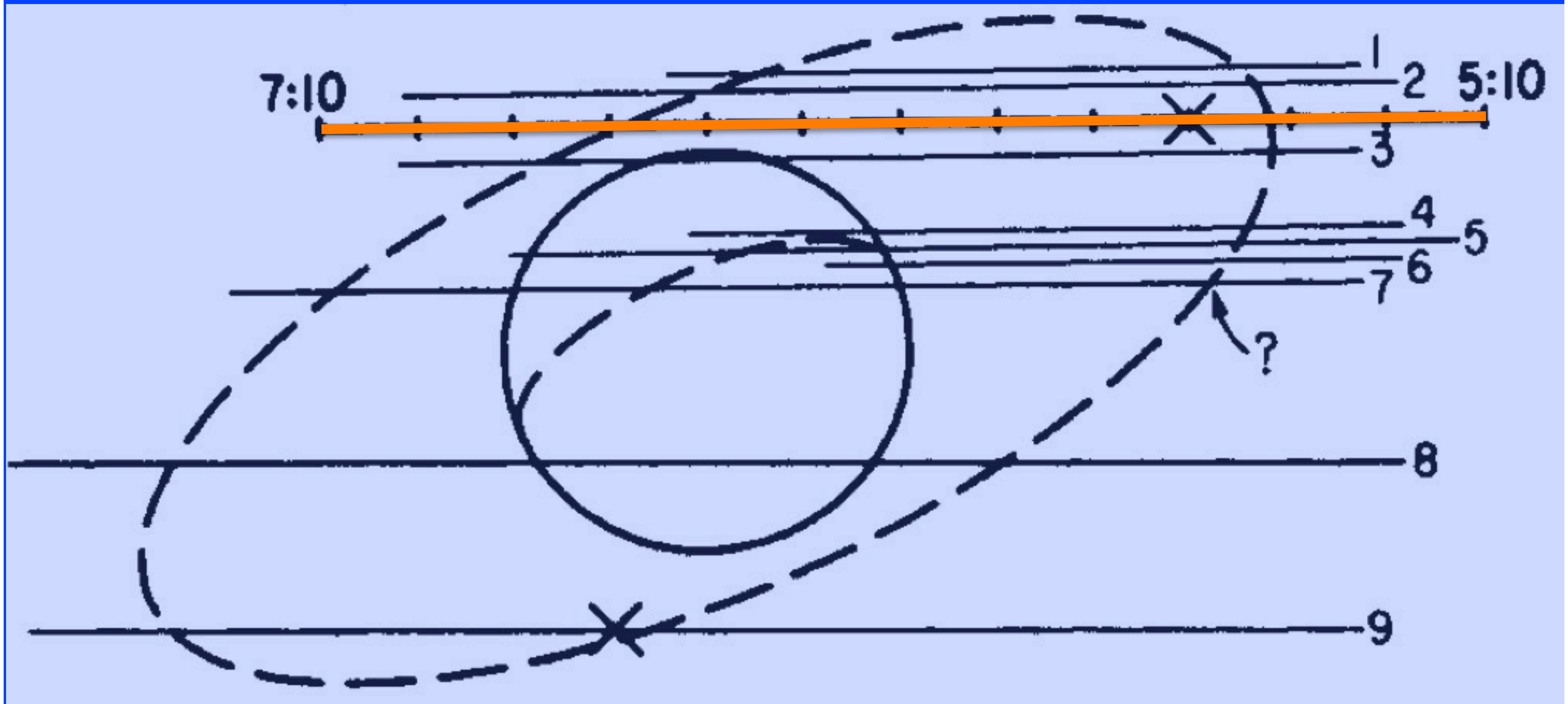


spatial resolution a few km

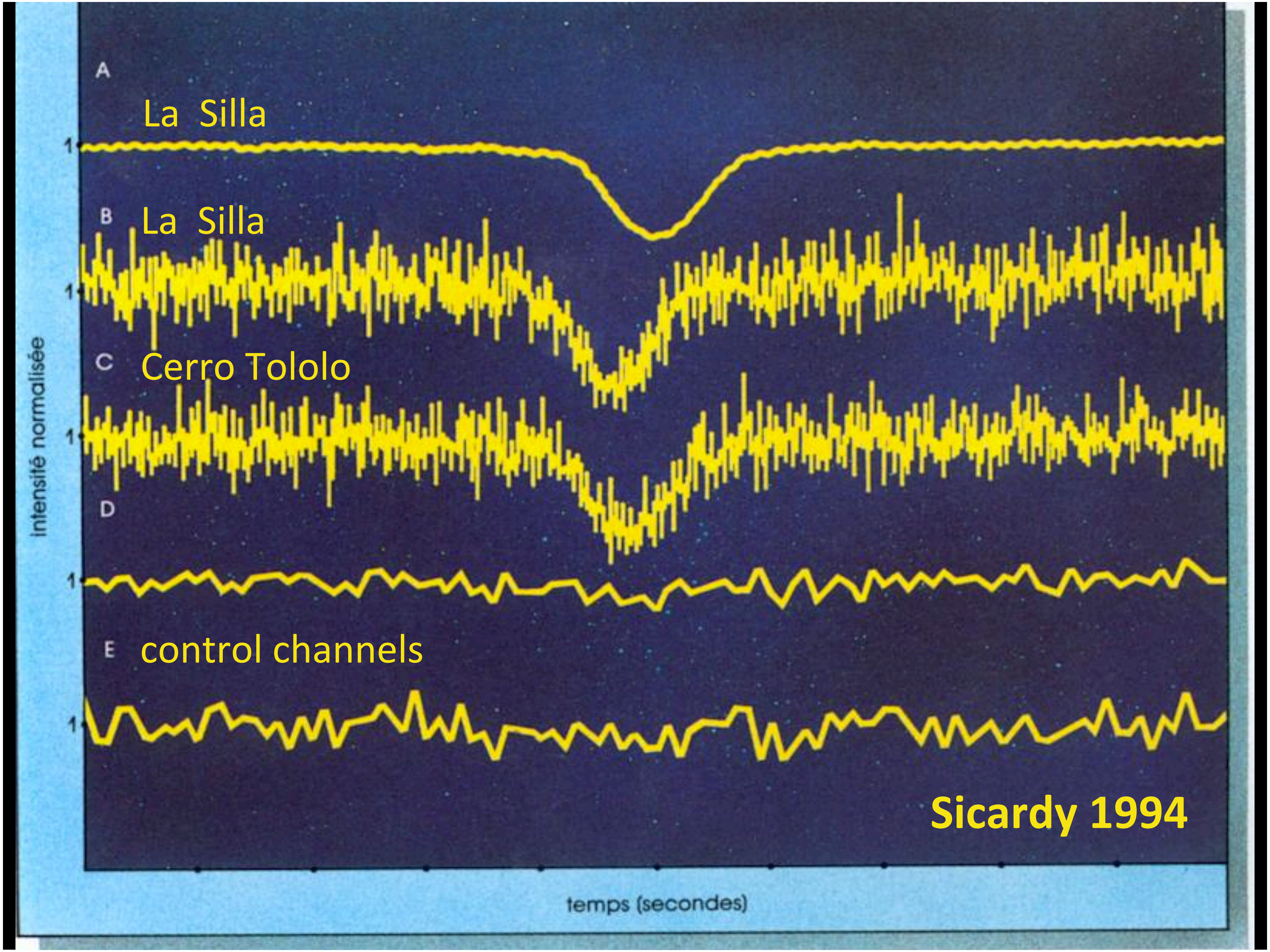
3.6-m telescope, 15 August 1980
Sicardy *et al.* 1982

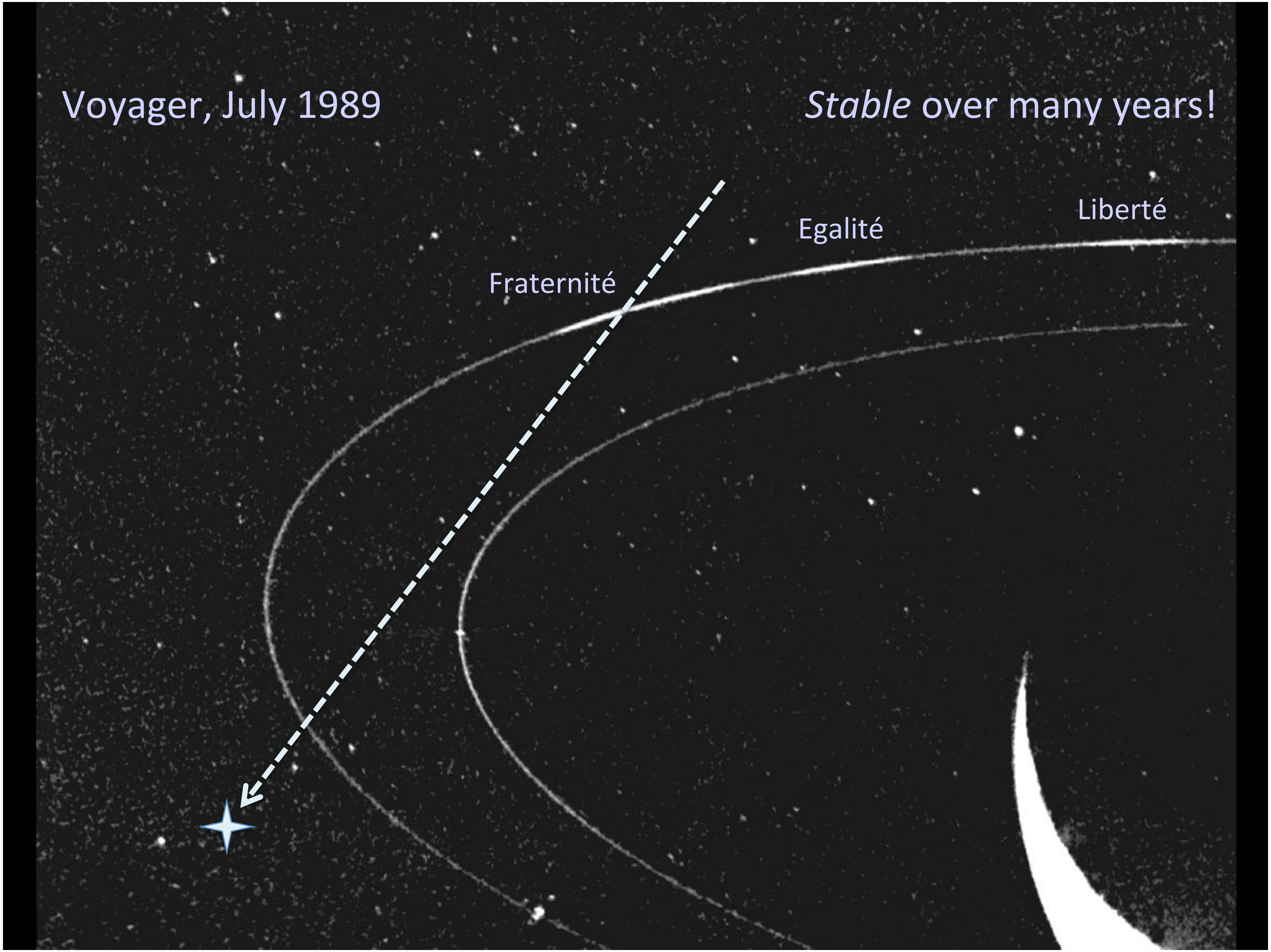


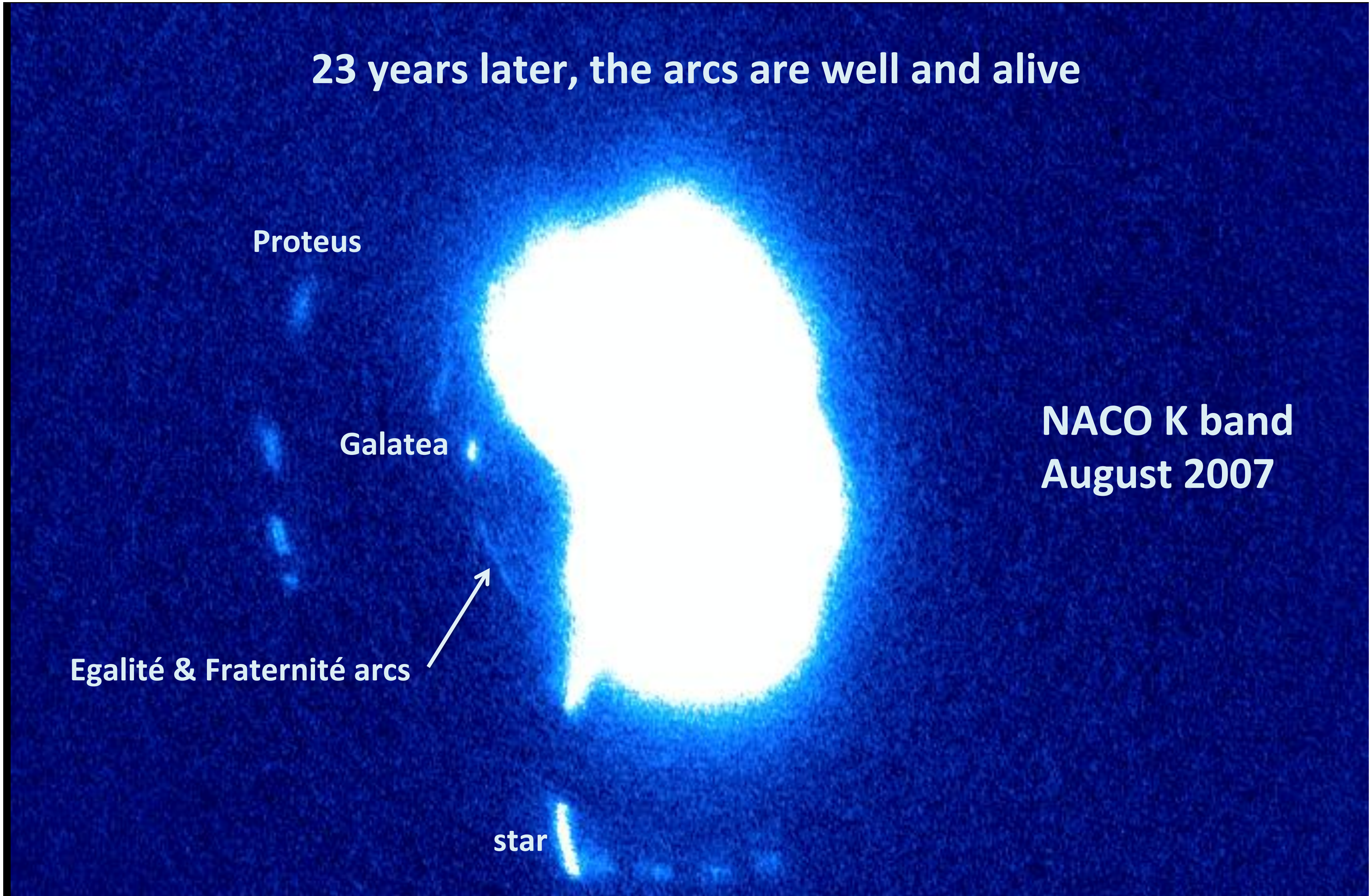
22 July 1984: discovery of ring-arcs of Neptune with a stellar occultation at ESO and CTIO



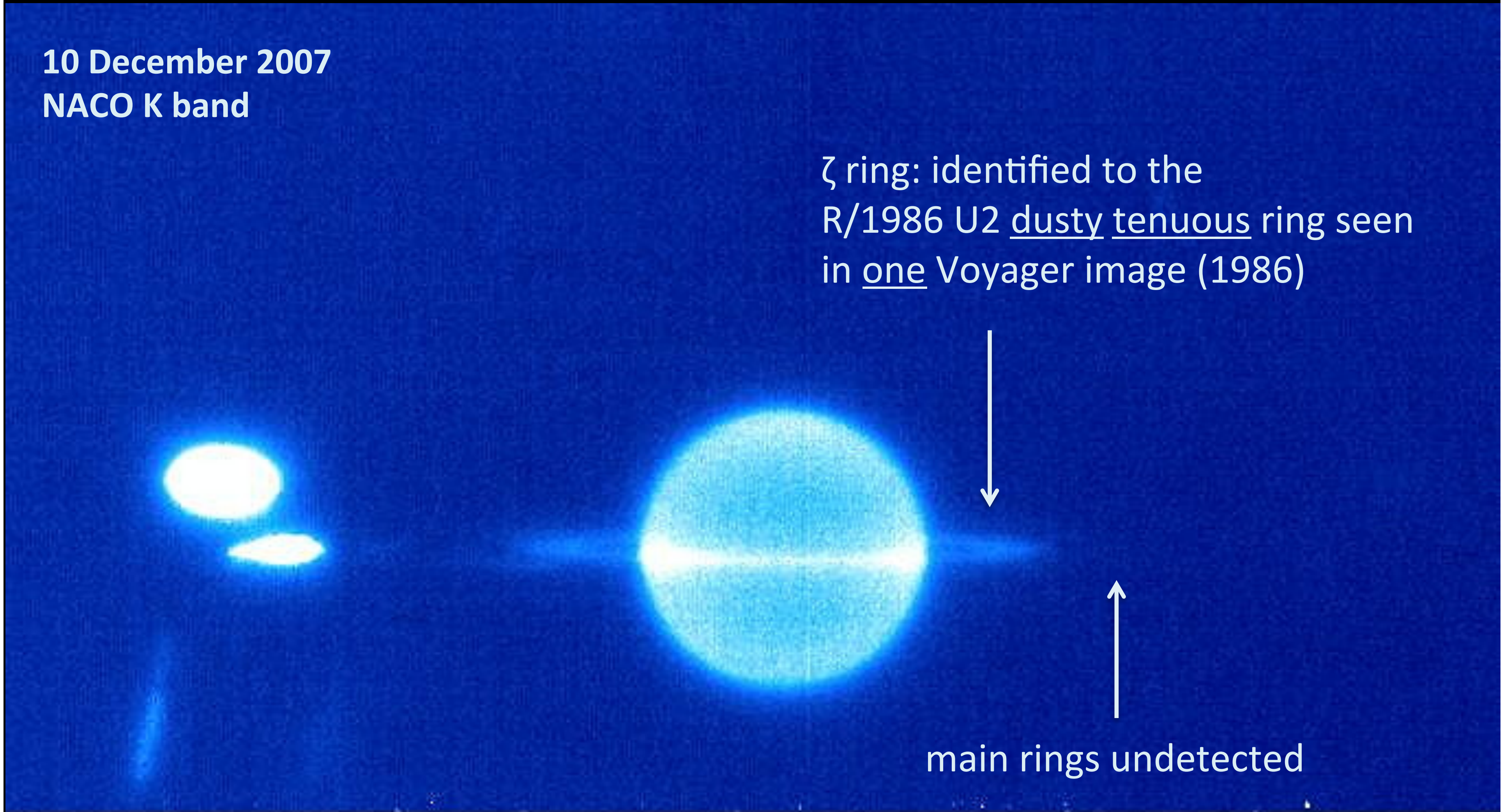
from Hubbard *et al., Nature, 1986*


A
La Silla
B
La Silla
C
Cerro Tololo
D
E
control channels
1
1
1
1
1
intensité normalisée
temps (secondes)
Sicardy 1994


Voyager, July 1989
Stable over many years!
Liberté
Egalité
Fraternité



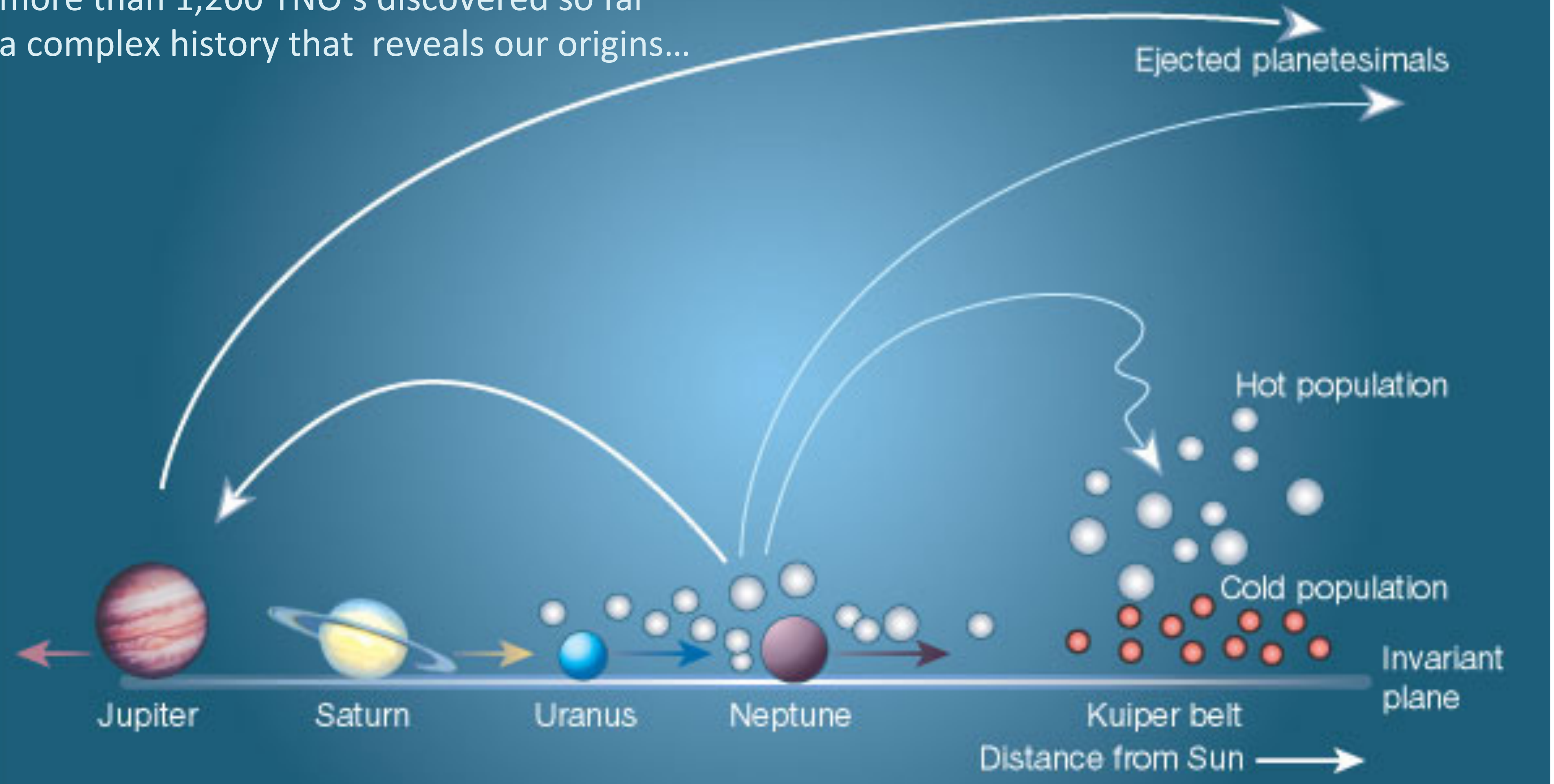
Renner et al. 2011



Uranus: Sun ring plane crossing, once every 43 years…
NACO/VLT K band
Sfair *et al.*, in preparation

exploring the solar system beyond Neptune

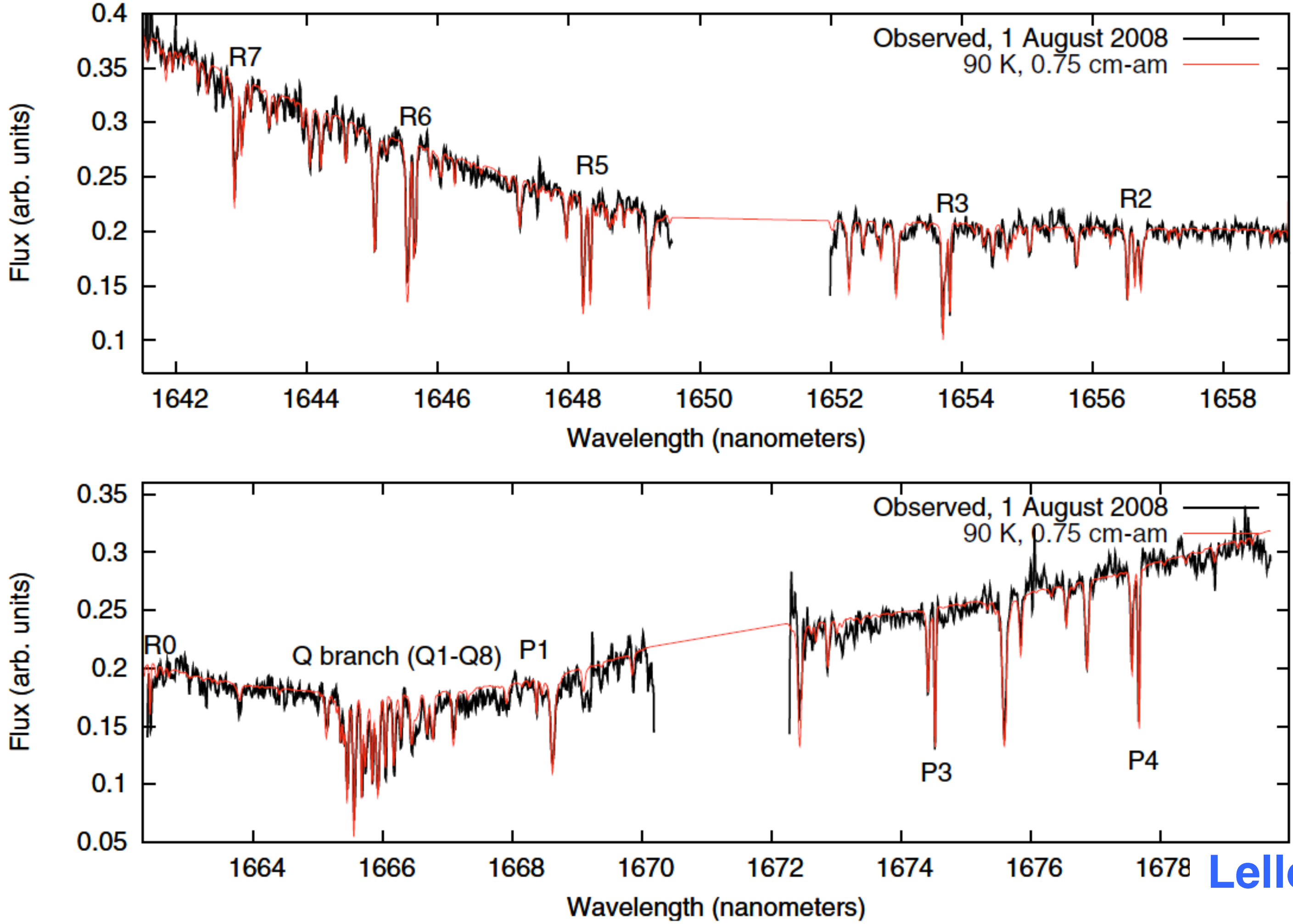
more than 1,200 TNO's discovered so far
a complex history that reveals our origins…



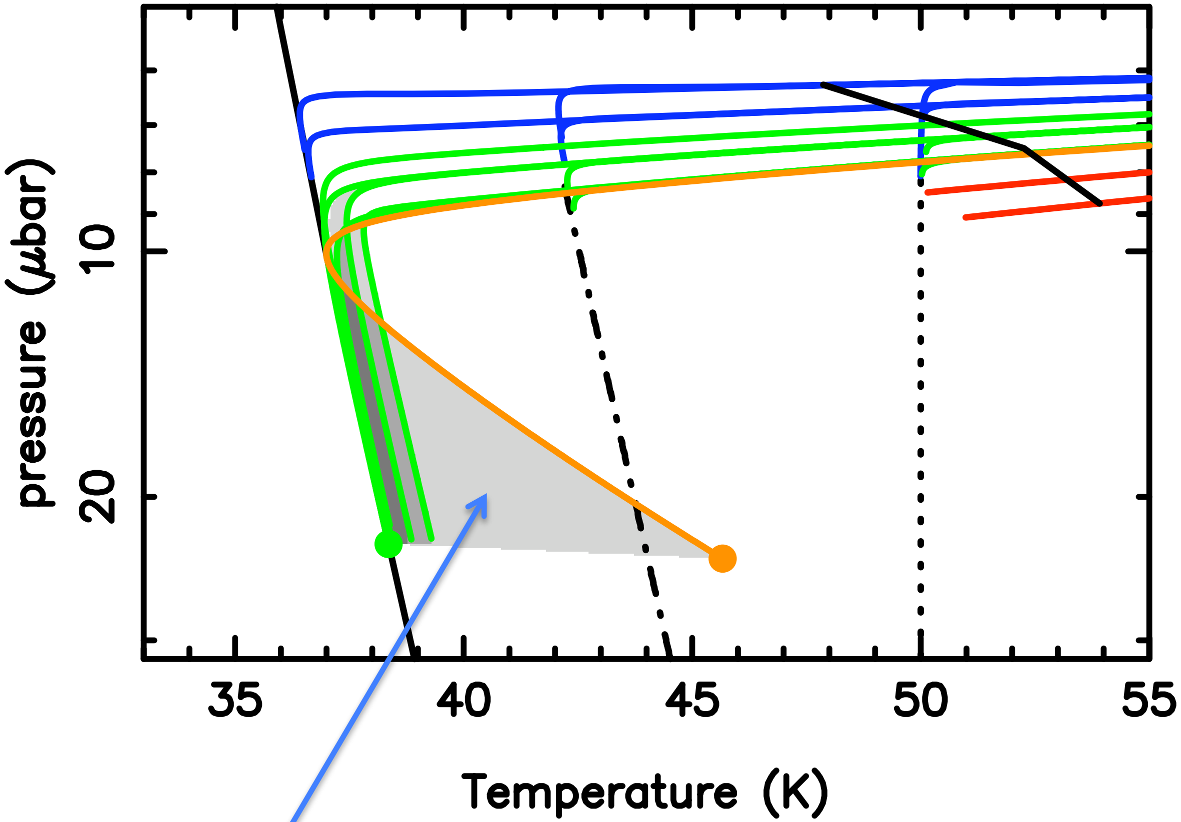
Morbidelli & Levison, Nature 2003

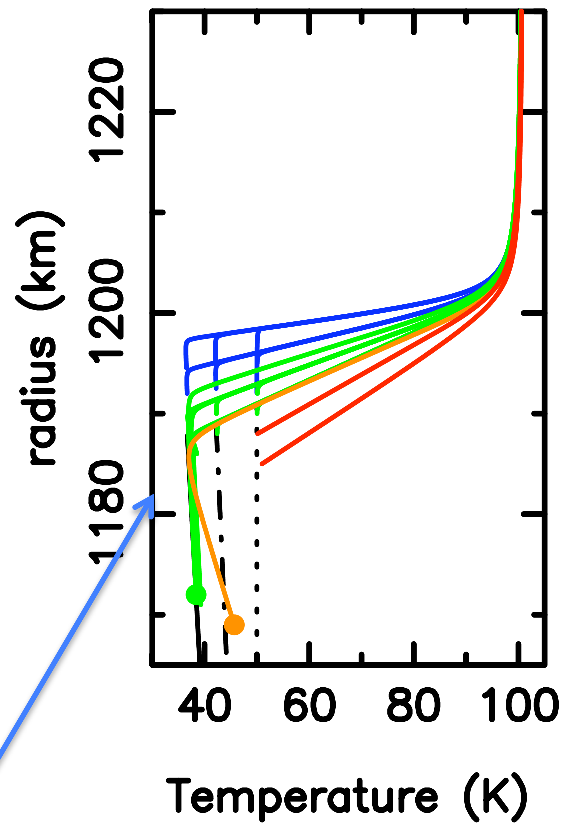
High-resolution spectroscopy of Pluto and Triton (VLT/CRIRES)

✓ Detailed observation of CH_4 in Pluto's atmosphere and combination with stellar occultations → characterization of Pluto's lower atmosphere: **~99.5% N_2, ~0.5±0.1 % CH_4**



Lellouch *et al.* 2009





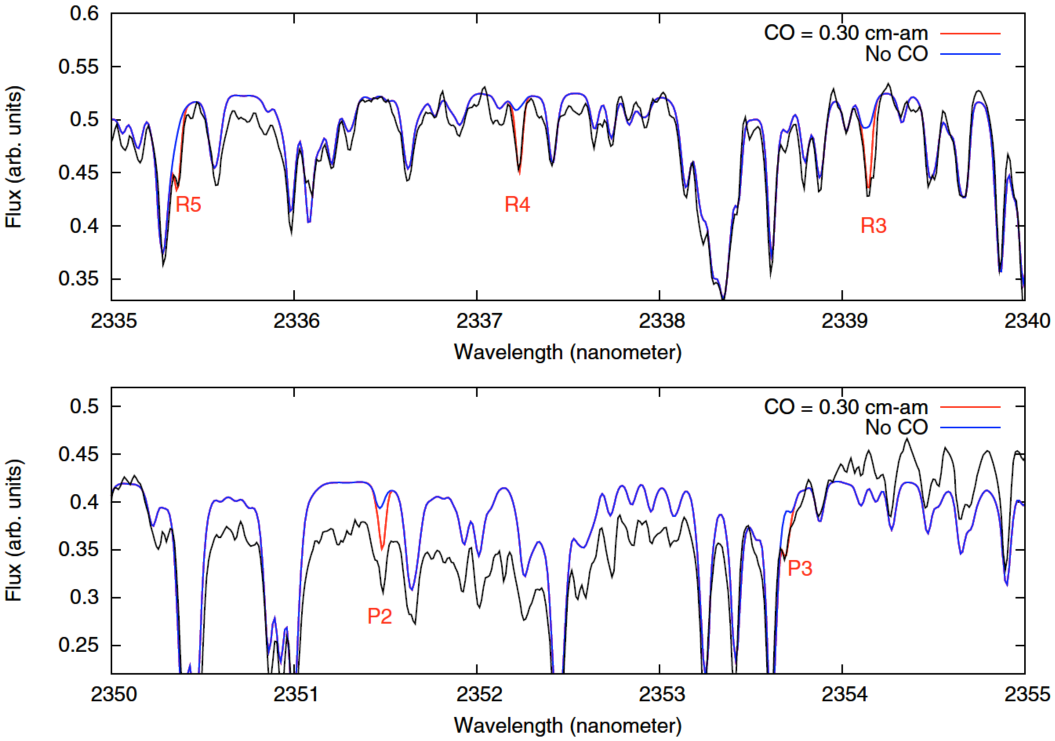
limits for Pluto's troposphere

limits for Pluto's radius

Lellouch *et al.* 2009

High-resolution spectroscopy of Pluto and Triton (VLT/CRIRES)

✓ detection of CO in Triton's and Pluto's atmospheres (~5×10^{-4})
✓ characterization of surface-atmosphere interactions



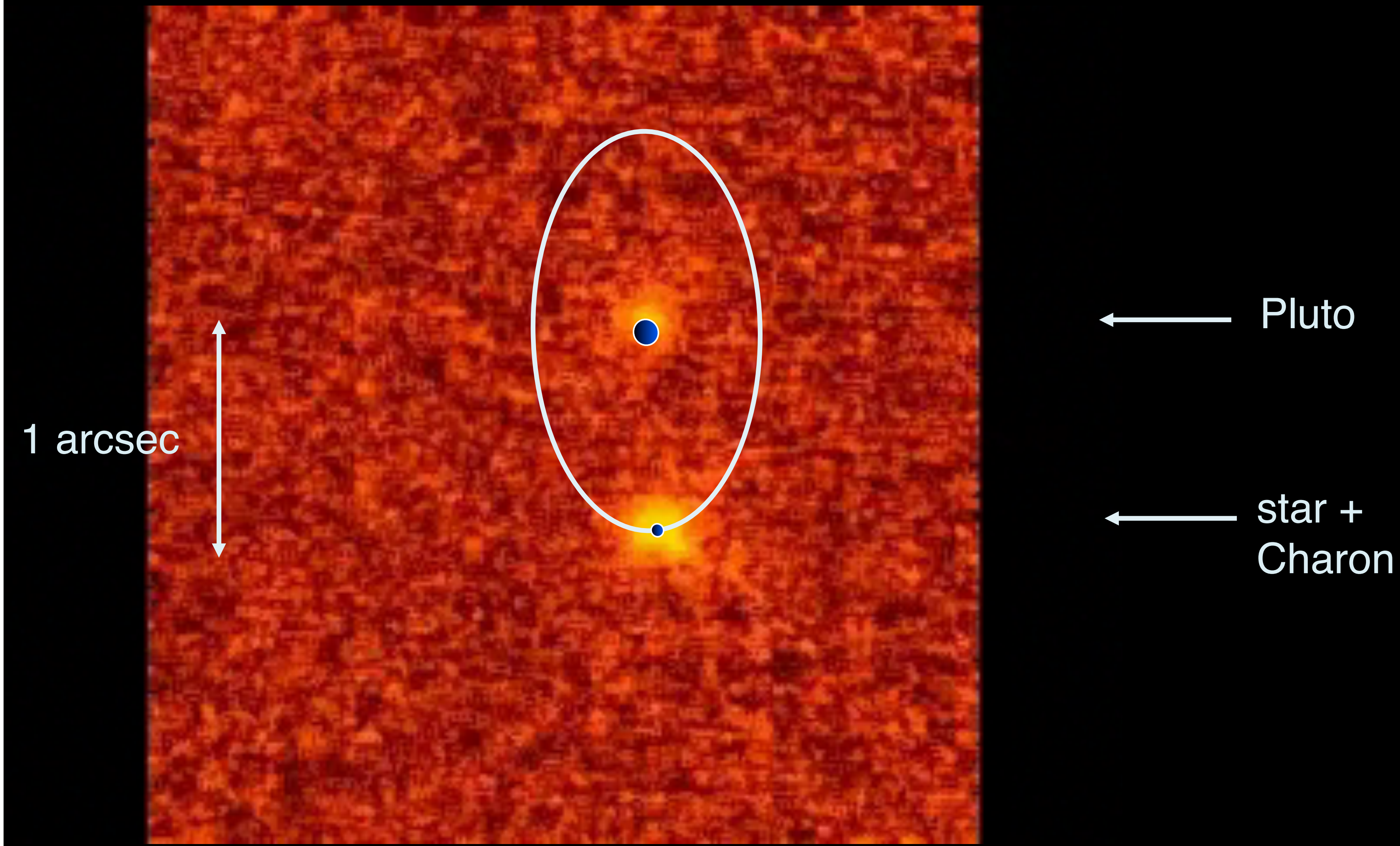
evidence for a thin CO-enriched surface veneer, enriching the atmosphere

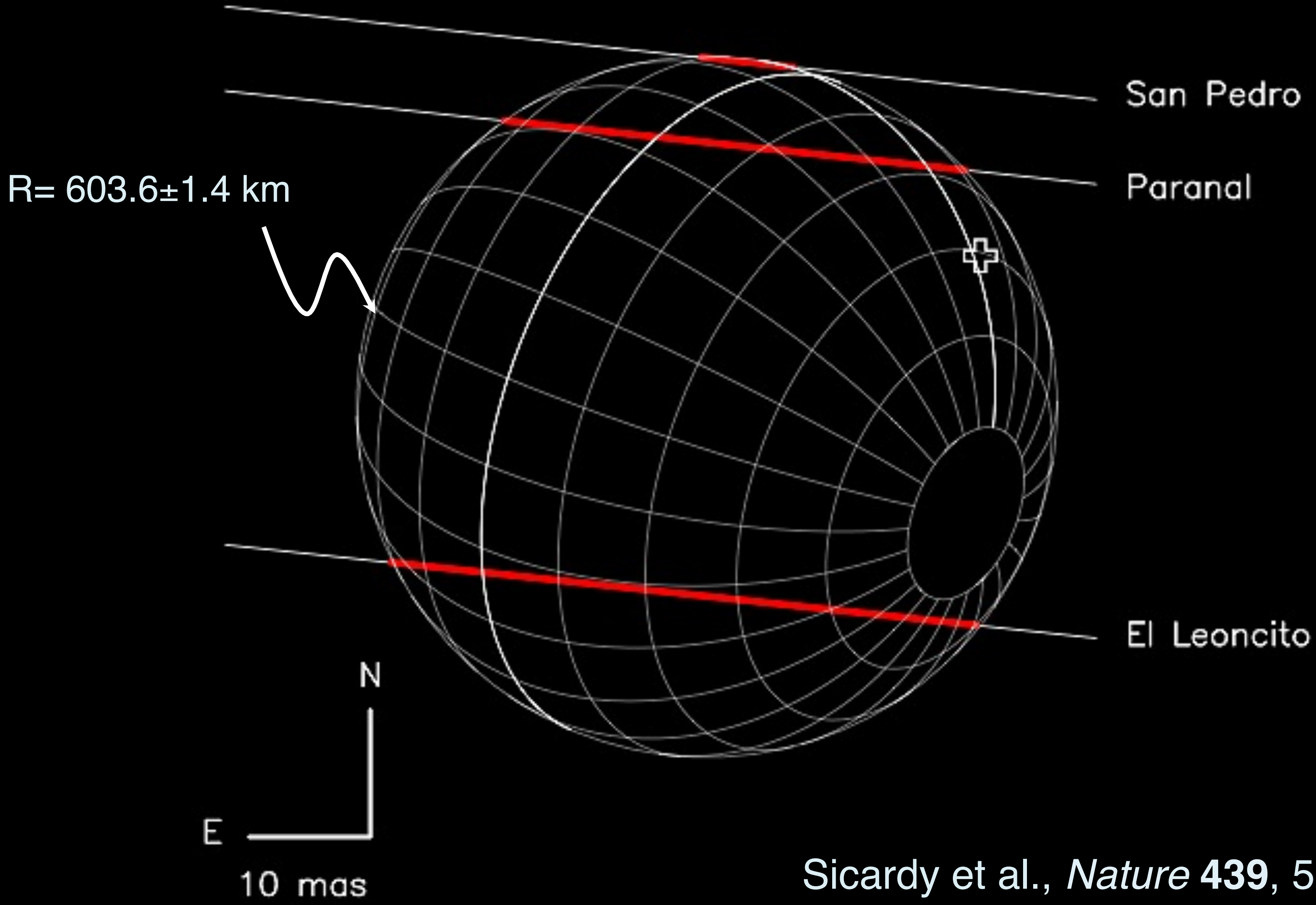
evidence that the atmospheric abundance is controlled by pure CH_4 ice patches

VLT/CRIRES: detection of CO on Triton

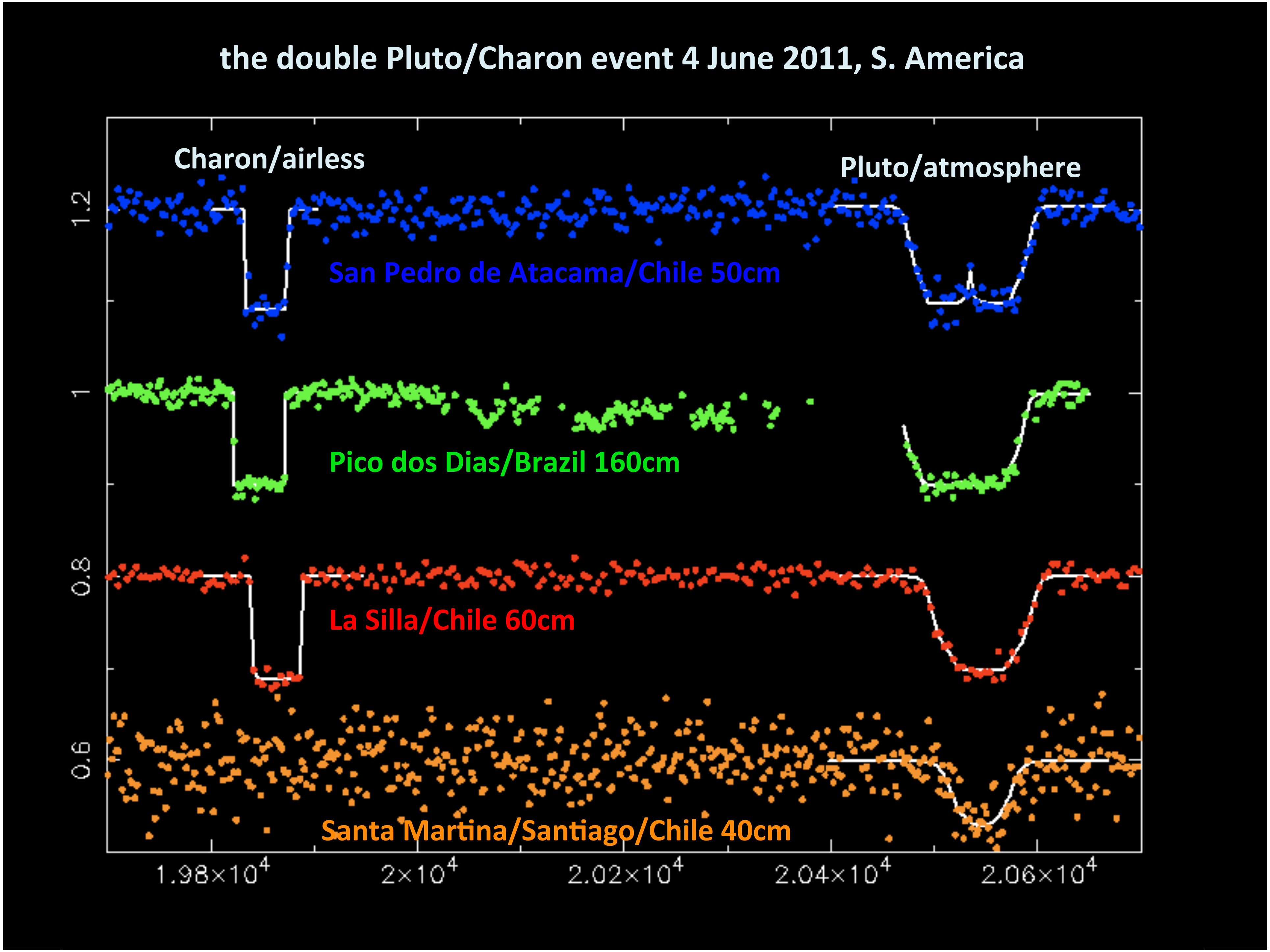
Lellouch et al. 2010

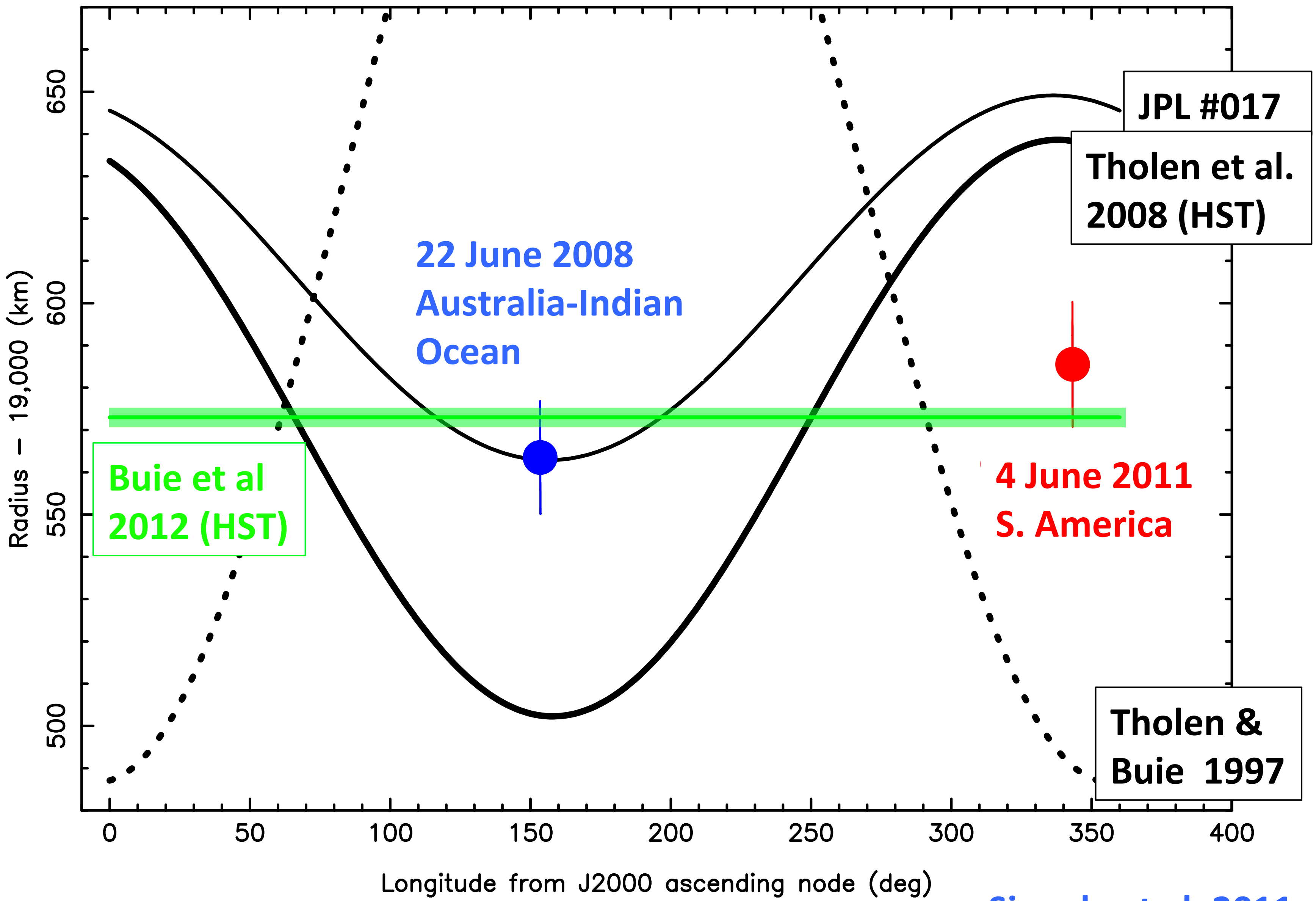
VLT/NACO K band, Charon occultation 11 July 2005





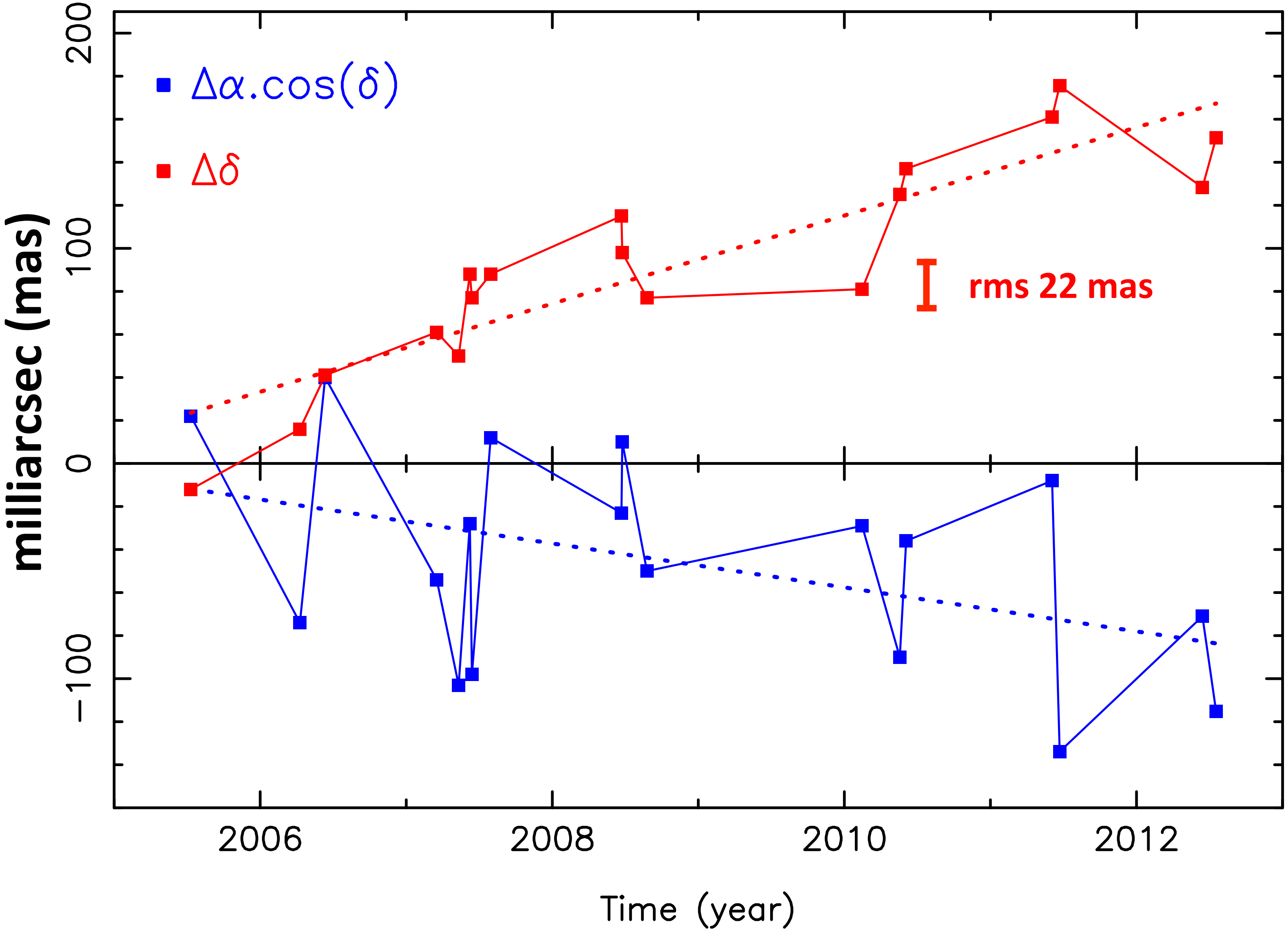
Sicardy et al., *Nature* **439**, 52, 2006
« Charon’s size and an upper limit on its atmosphere from a stellar occultation »


the double Pluto/Charon event 4 June 2011, S. America
Charon/airless
Pluto/atmosphere
San Pedro de Atacama/Chile 50cm
Pico dos Dias/Brazil 160cm
La Silla/Chile 60cm
Santa Martina/Santiago/Chile 40cm
1.2
1
0.8
0.6
1.98×10^4
2×10^4
2.02×10^4
2.04×10^4
2.06×10^4



Sicardy et al. 2011

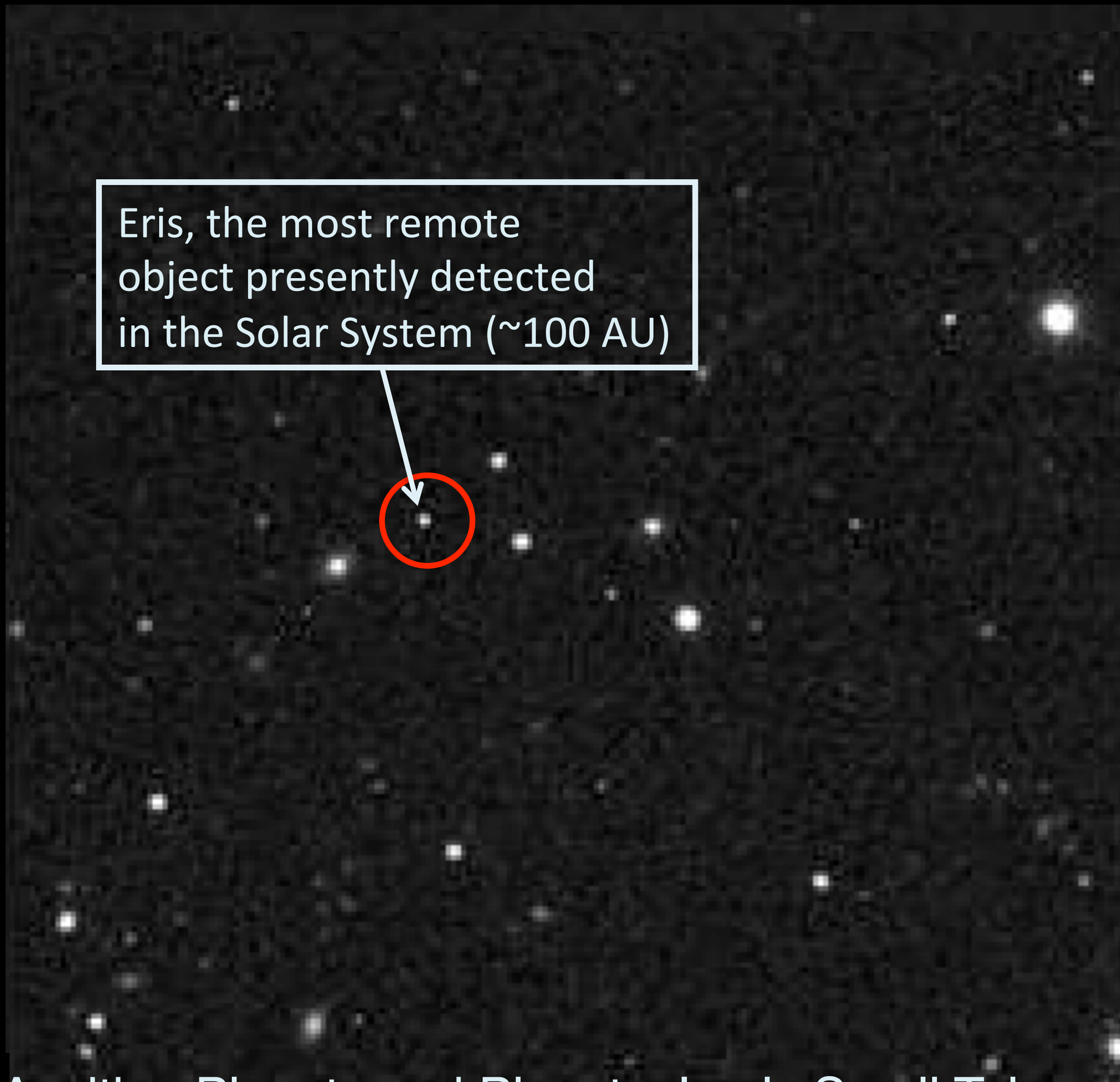
improvement of Pluto ephemeris (DE413)
using ESO 2.2m WFI camera & Pico dos Dias Obs. (Brazil)



adapted from Assafin *et al.* 2011

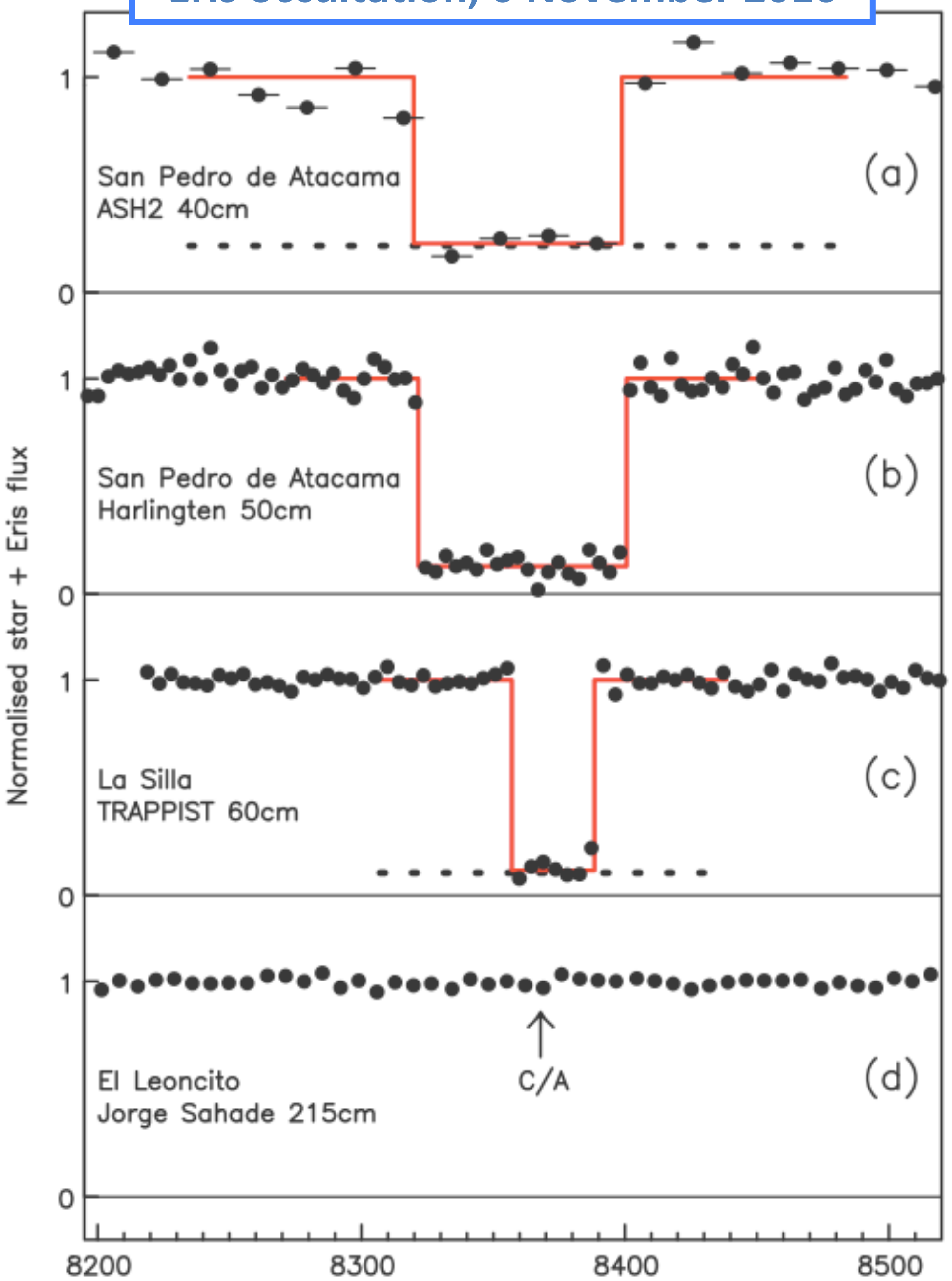
when Eris meets a star

TRAnsiting Planets and PlanetesImals Small Telescope
(60cm TRAPPIST) La Silla, Chile



TRAnsiting Planets and PlanetesImals Small Telescope
(60cm TRAPPIST) La Silla, Chile

Eris occultation, 6 November 2010



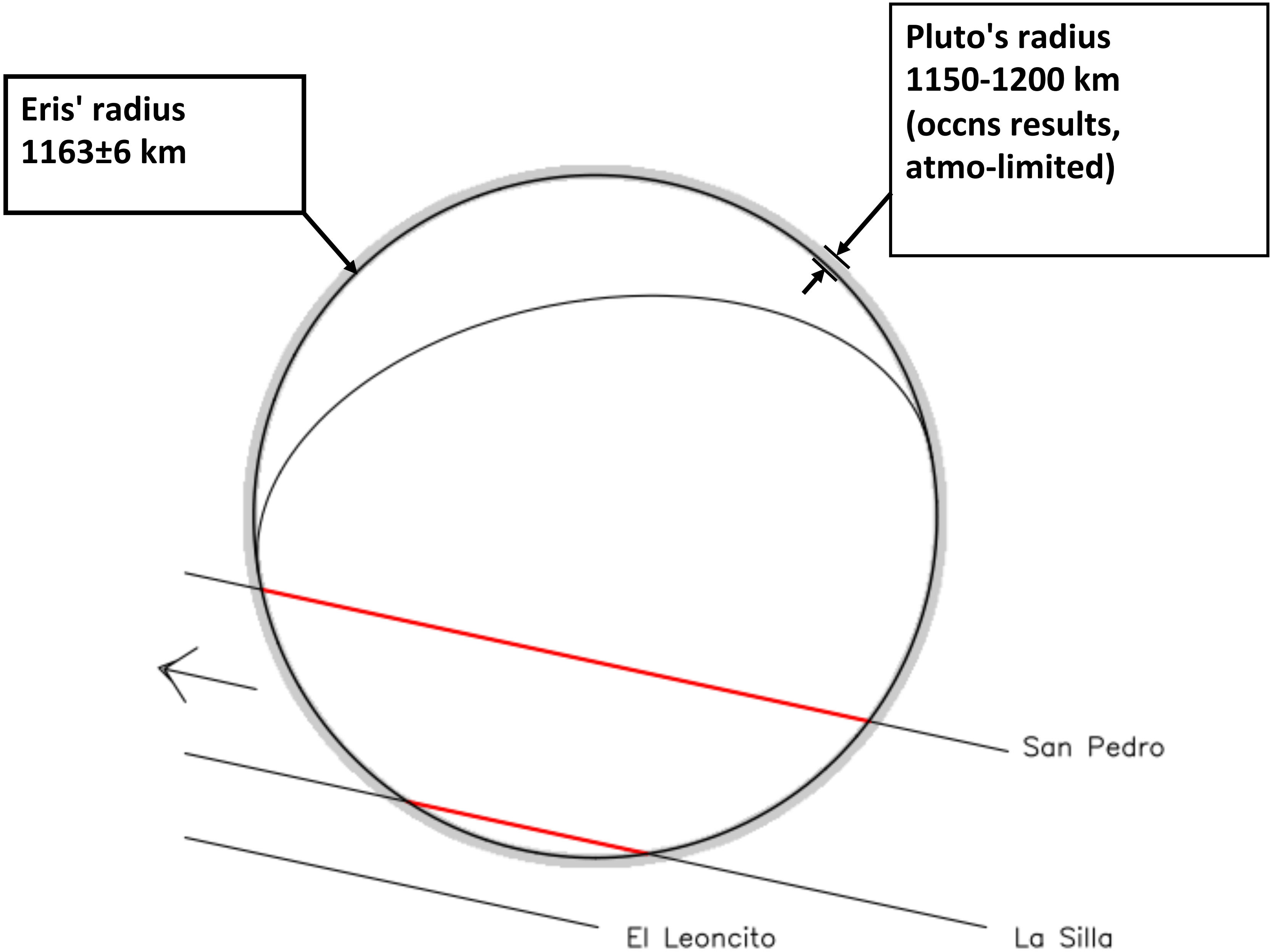
San Pedro

San Pedro

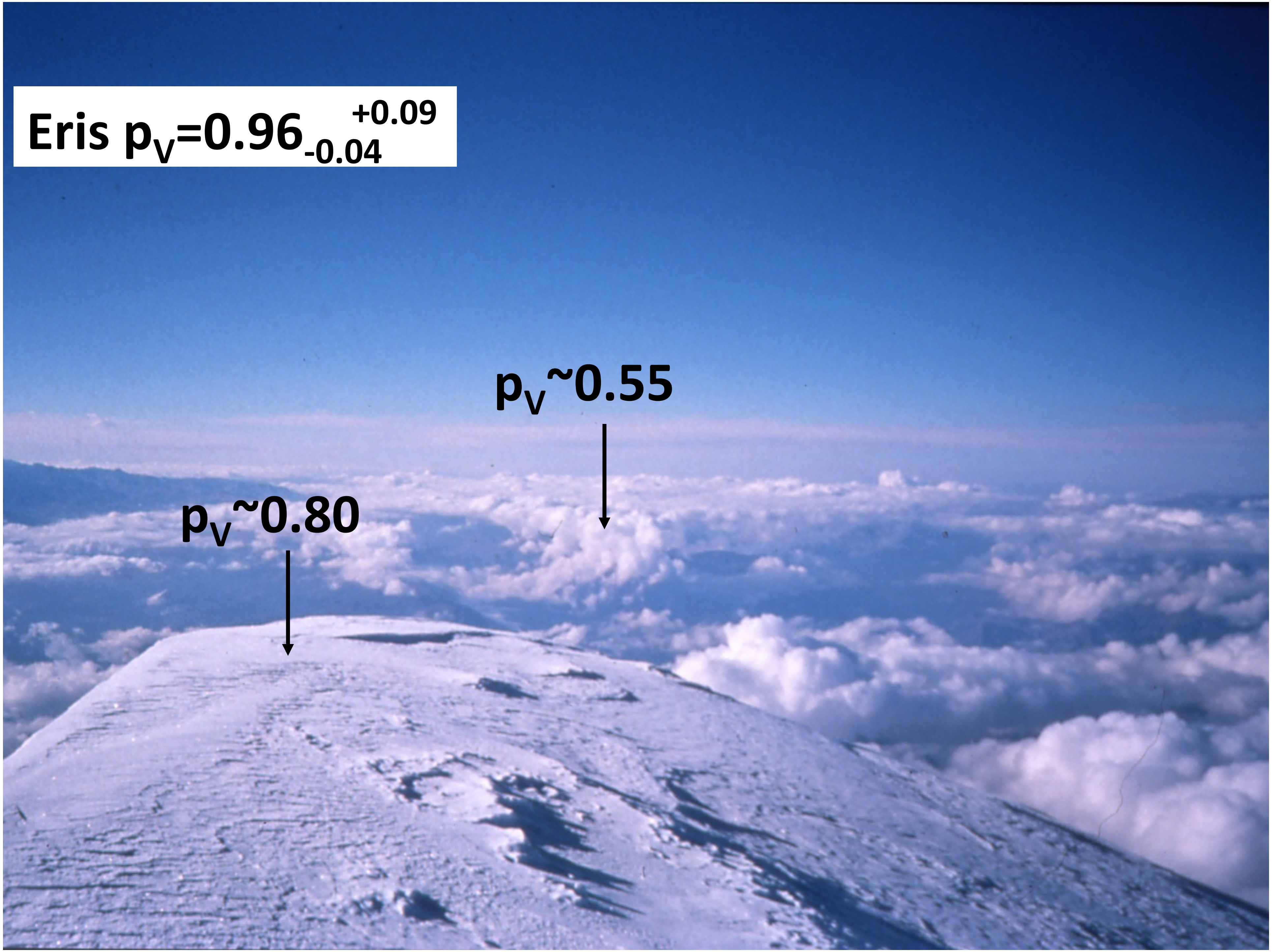
La Silla

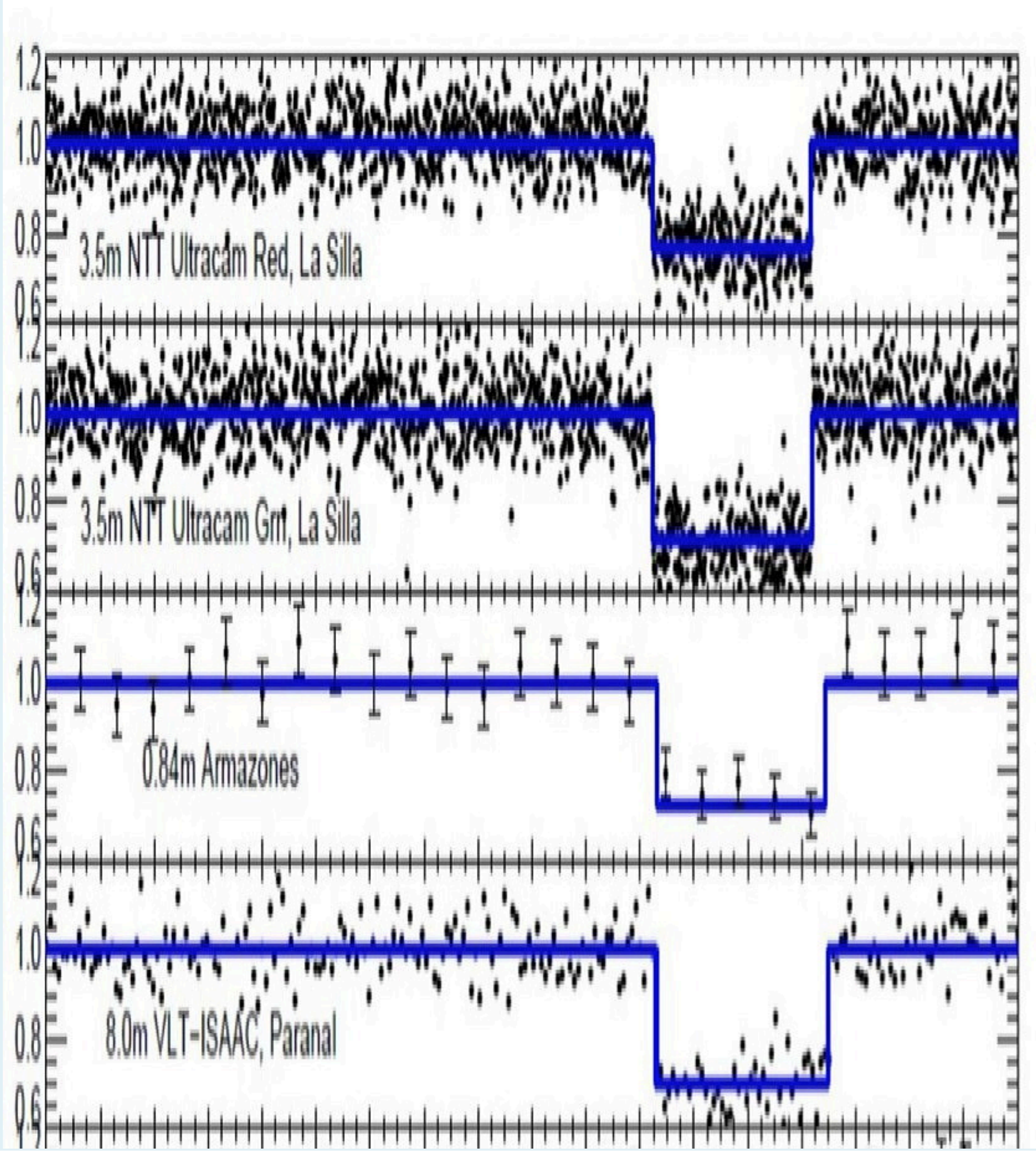
El Leoncito

Sicardy et al. Nature 2011



Eris' radius
1163±6 km
Pluto's radius
1150-1200 km
(occns results,
atmo-limited)
San Pedro
El Leoncito
La Silla


Eris p_V=$0.96_{-0.04}^{+0.09}$
p_V~0.55
p_V~0.80



NTT/Ultracam red

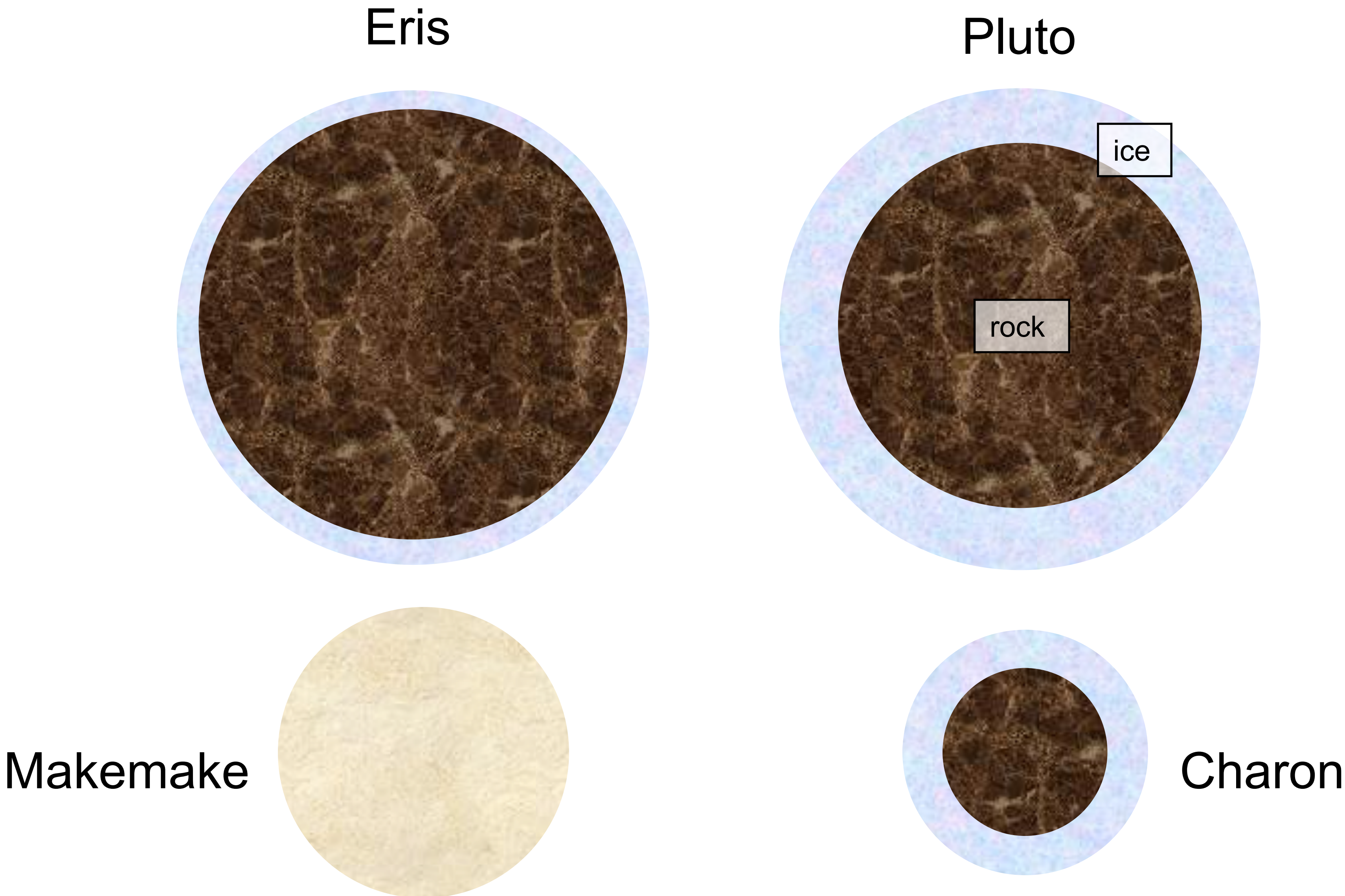
NTT/Ultracam green

Armazones clear

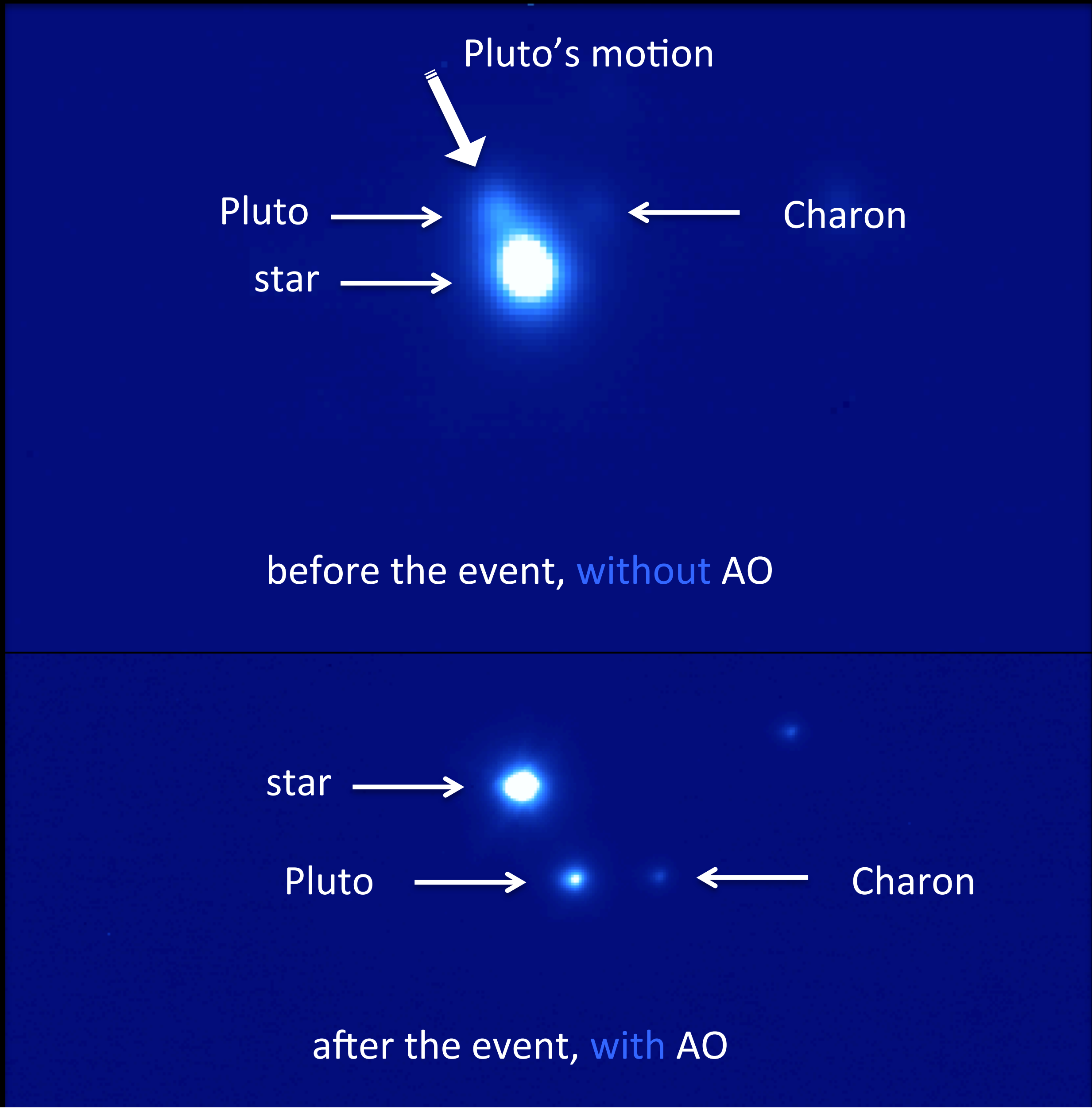
VLT/ISAAC J-band

Ortiz *et al.* 2012
Nature, submitted

four Trans-Neptunian Objects accurately measured/studied from ESO



Pluto stellar occultation, 18 july 2012
ESO Very Large Telescope, NACO, H band



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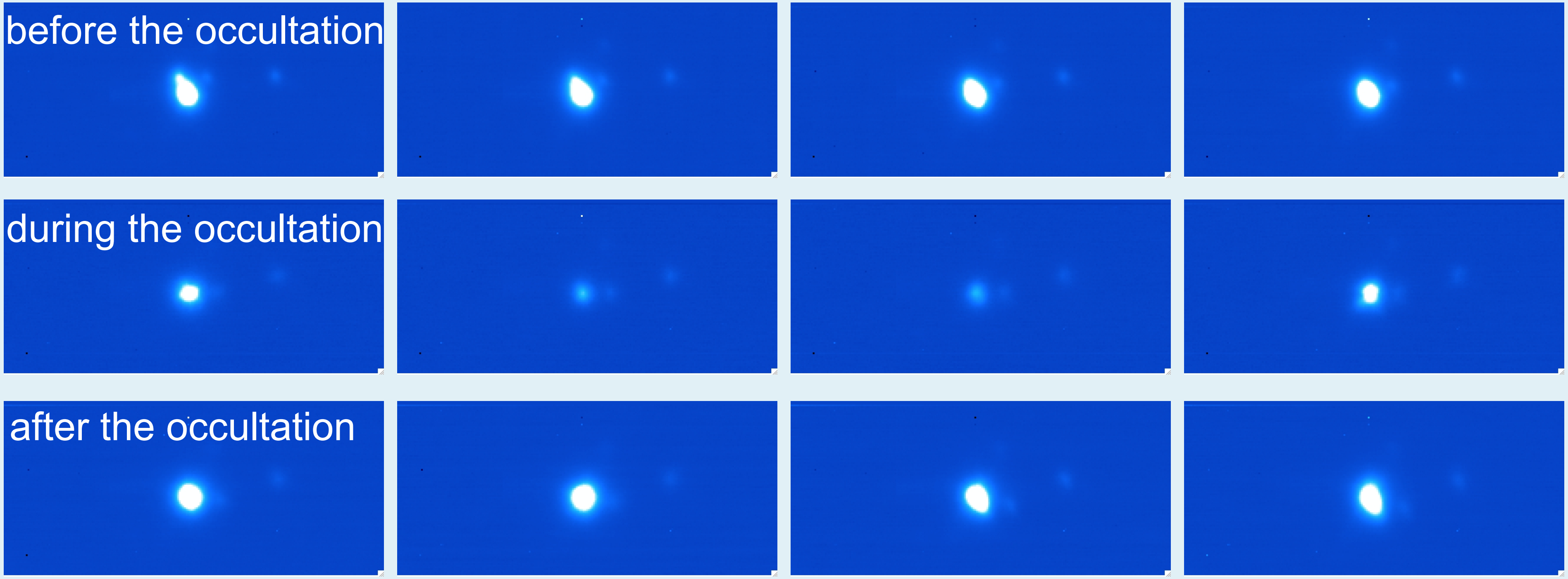
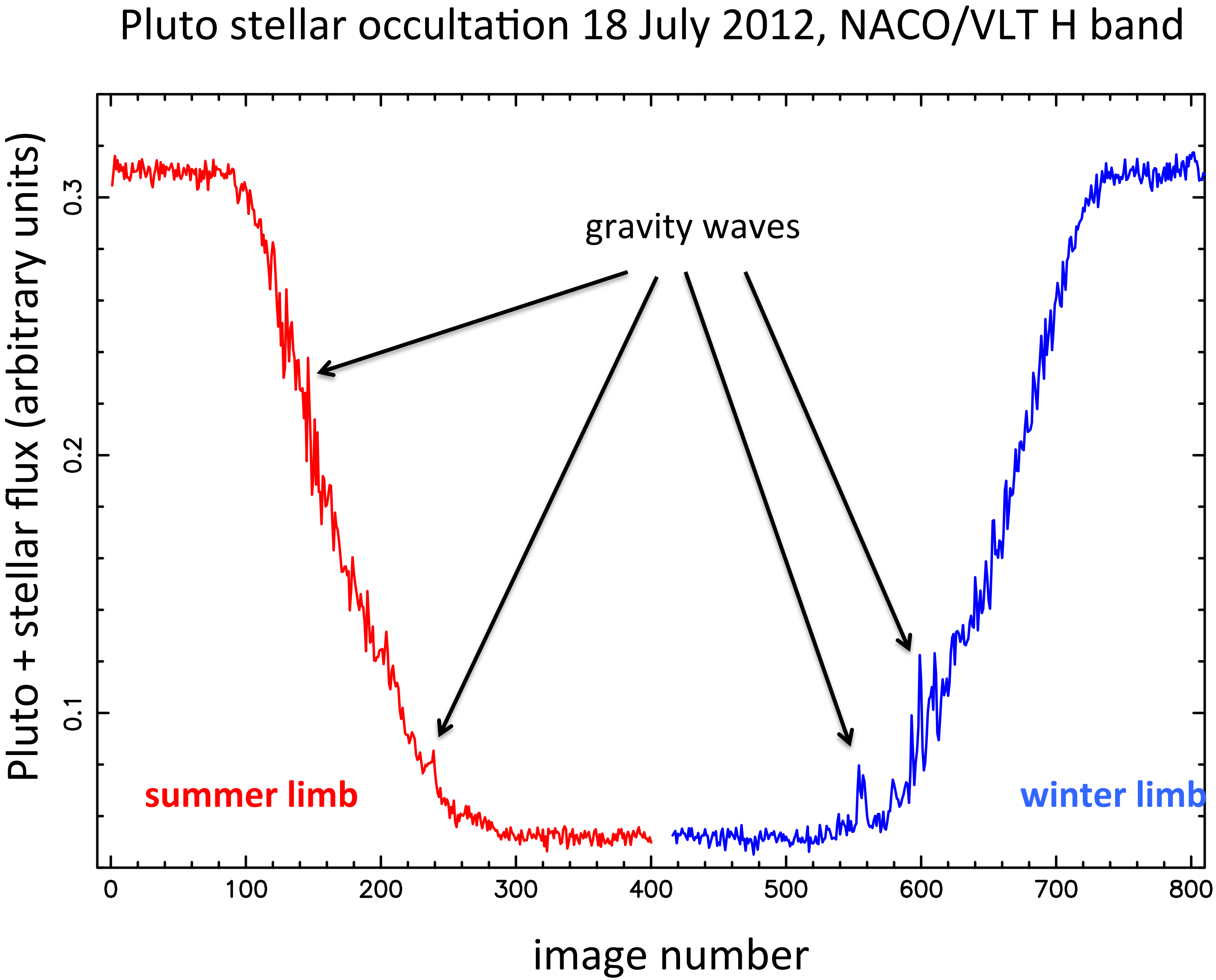
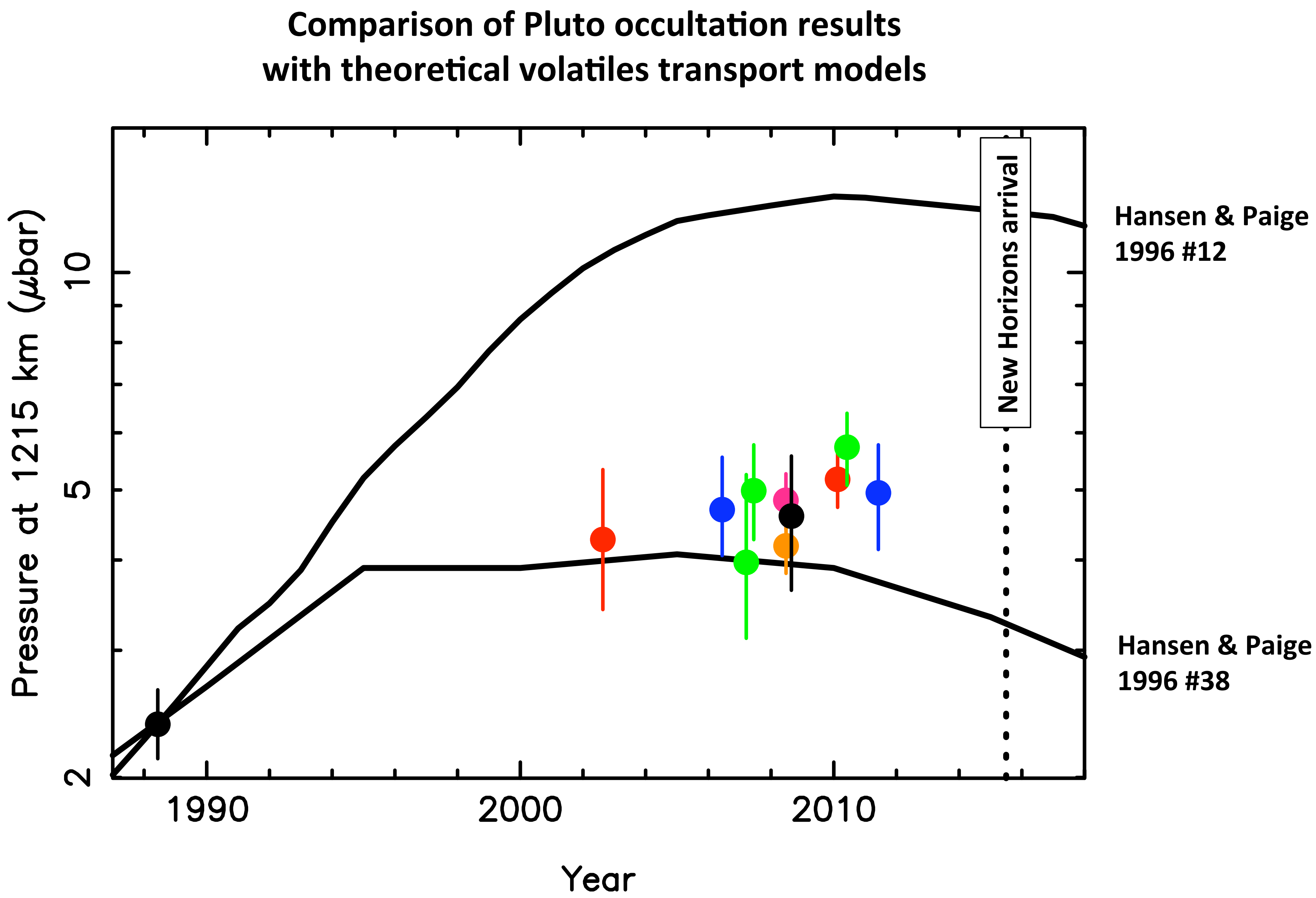
ESO Very Large Telescope, NACO, H band





Pluto stellar occultation 18 July 2012, NACO/VLT H band
Pluto + stellar flux (arbitrary units)
0.1
0.2
0.3
gravity waves
summer limb
winter limb
0
100
200
300
400
500
600
700
800
image number

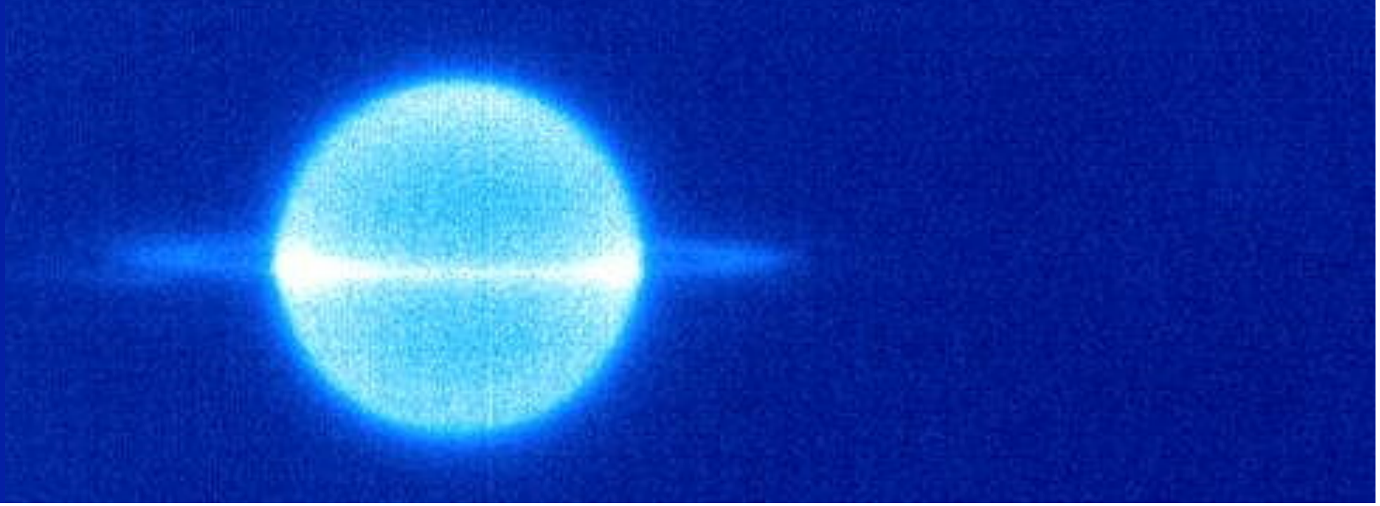


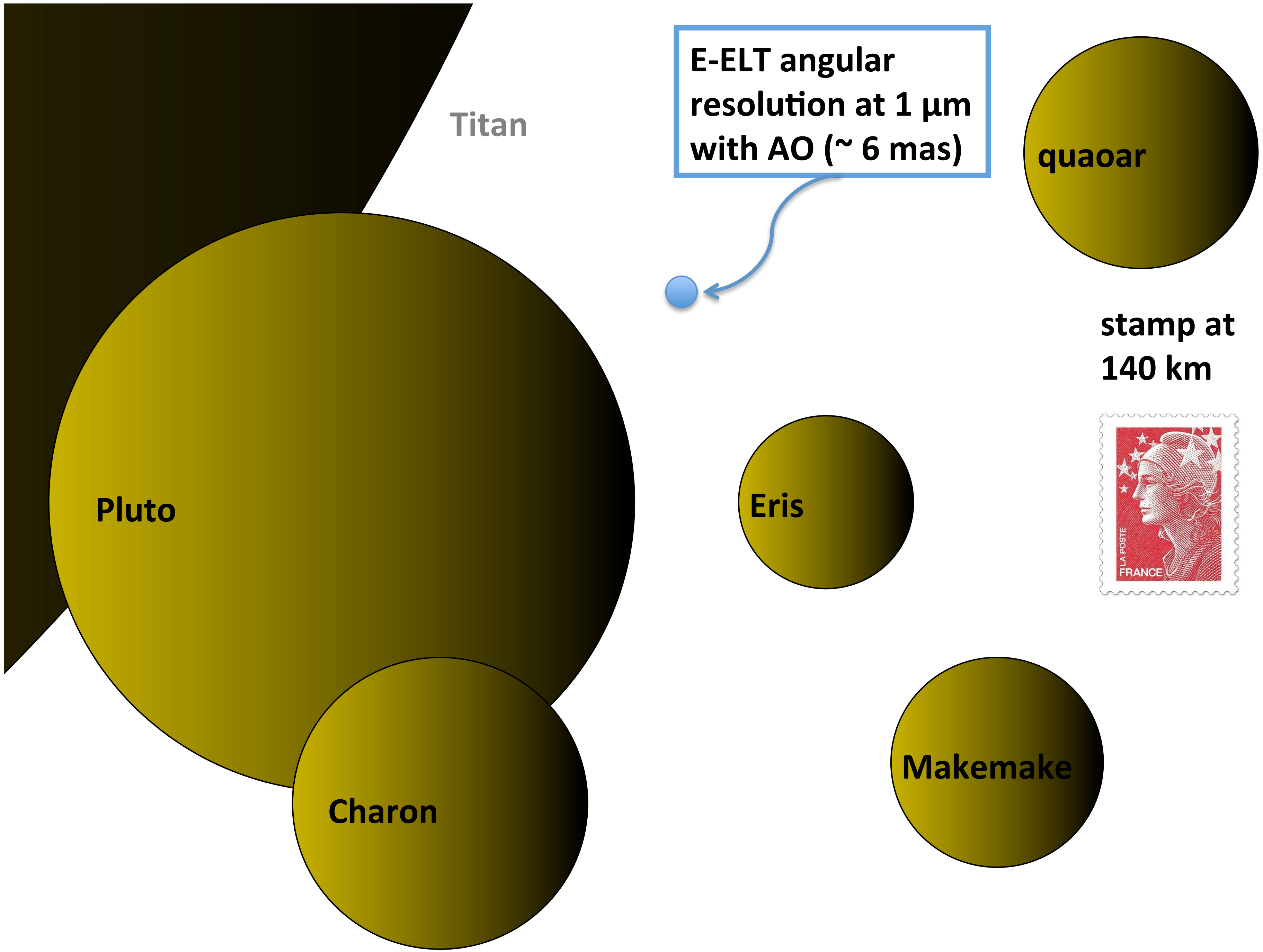
Comparison of Pluto occultation results
with theoretical volatiles transport models
Pressure at 1215 km (μbar)
10
5
2
1990
2000
2010
Year
New Horizons arrival
Hansen & Paige
1996 #12
Hansen & Paige
1996 #38

prospectives: E-ELT…

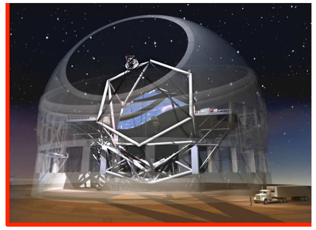
after Gaia, Alma & JWST 1st rounds:

- ✓ high spatial resolution for outer solar system objects and extra-solar planets
- ✓ high spectral resolution, atmospheres of x-solar planets
- ✓ hi-speed, hi-quality photometry for transient events

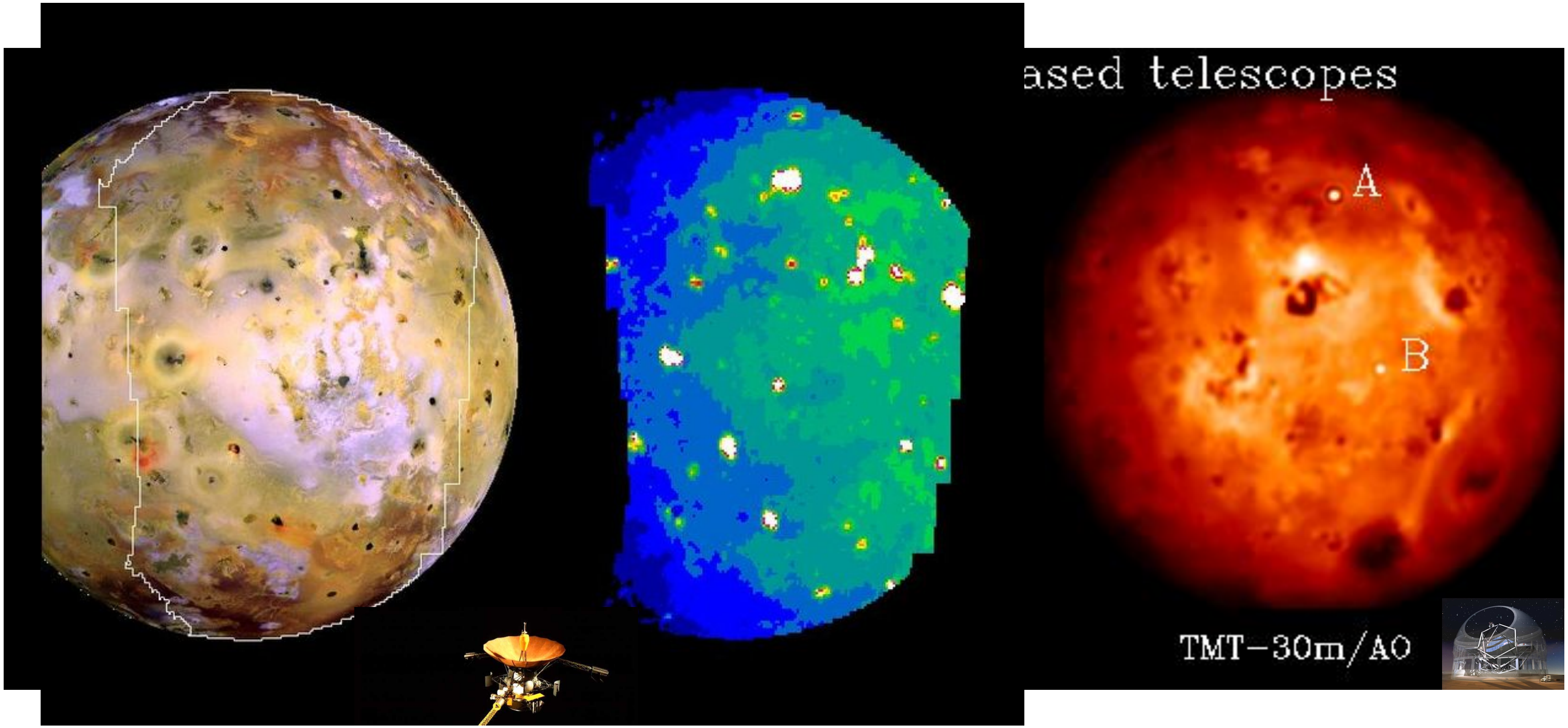



Titan
E-ELT angular resolution at 1 µm with AO (~ 6 mas)
quaoar
stamp at 140 km
LA POSTE
FRANCE
Pluto
Eris
Charon
Makemake

Potential of the ELTs

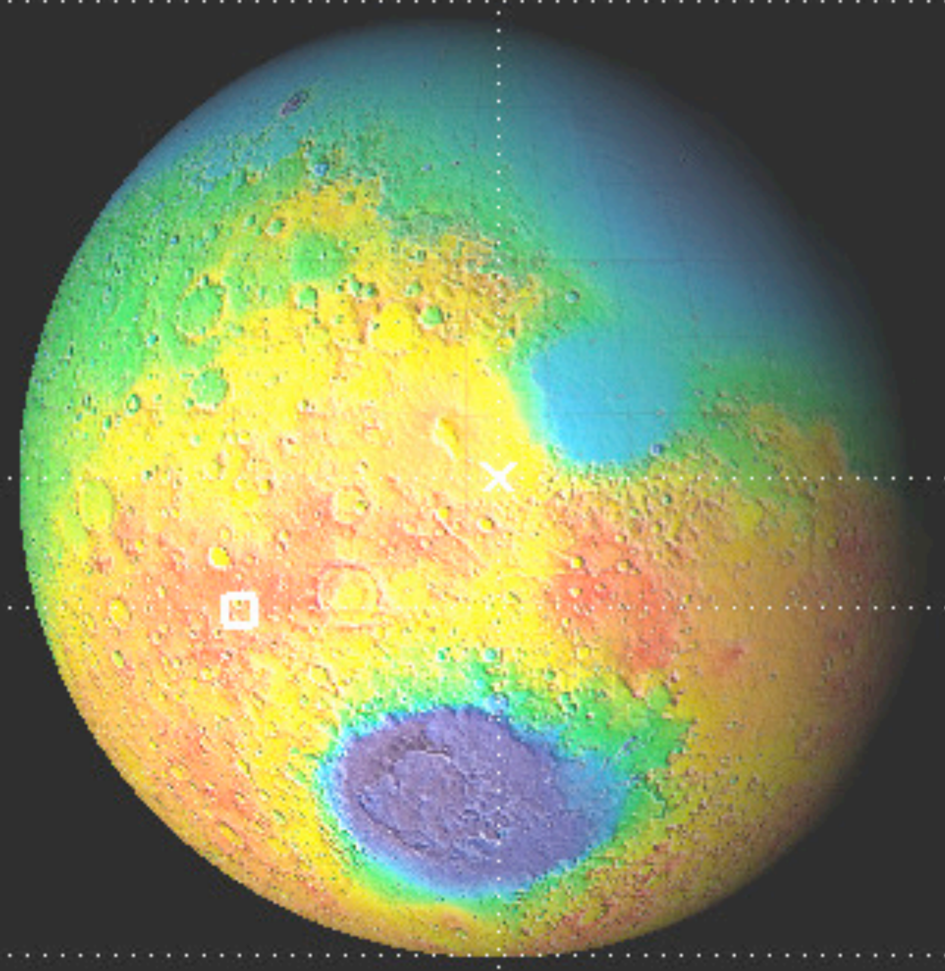


- The TMT/IRIS (0.8-2.5 um) will provide images with an angular resolution up to 7 mas at 1 um
- Spatial resolution of 20 km on Io



Mars:

Search for $CH4$ and other minor species
with CRIRES @ VLT
also a program for E-ELT METIS instrument

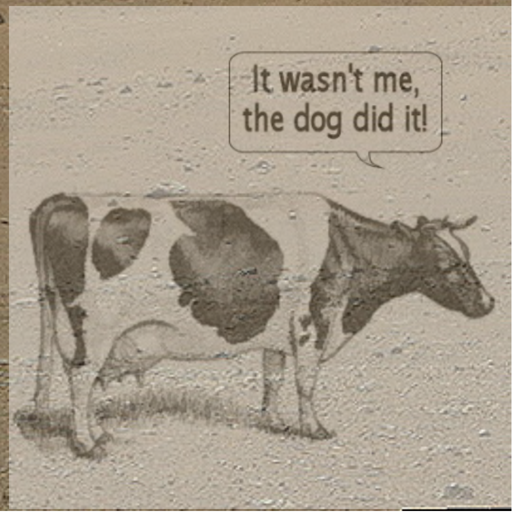


transient methane plumes on Mars with production comparable to Earth swamps??? (Mumma *et al.*, 2009, IRTF)

… surprising in highly oxidizing atmosphere,

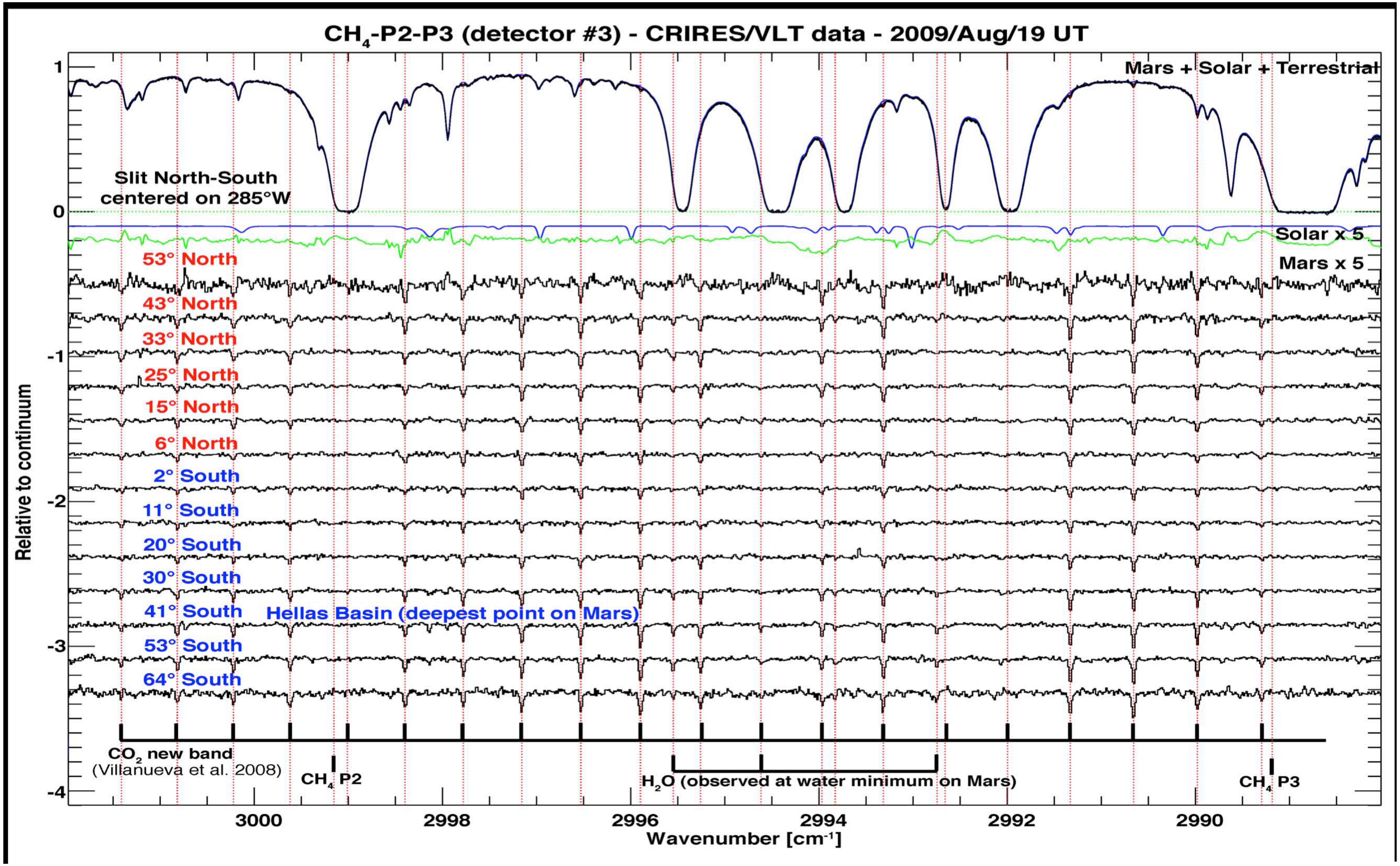
… also, spatial variations imply very short lifetime → requires unidentified loss processes

… active geology? biological origin?



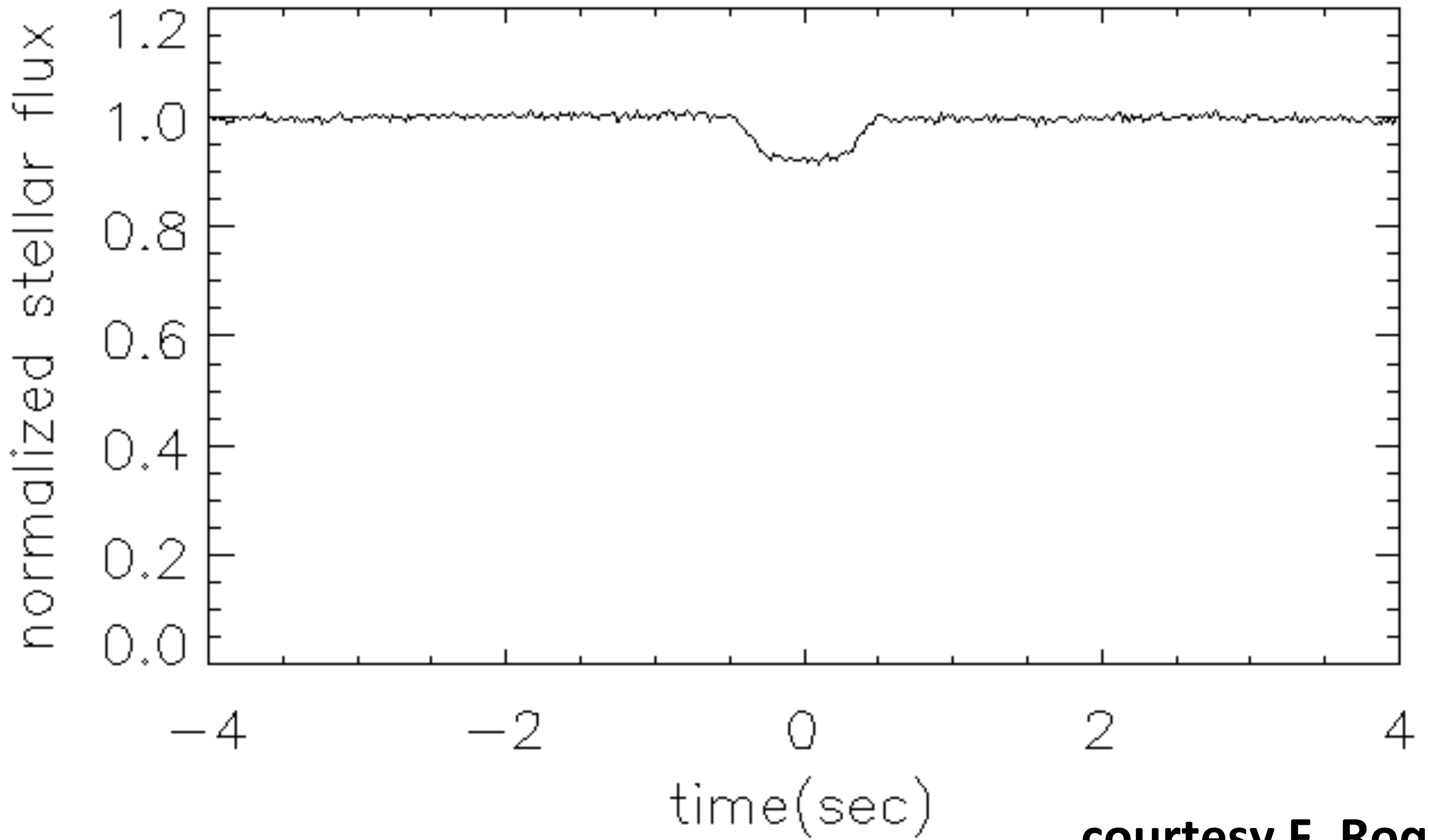
Curiosity landing site, 8 August 2012

… CRIRES hi resolution spectra bring strong further constraints…



Villanueva, 2009, METIS Science Analysis Report & B. Brandl et al. 2009

expected occultation of a V=12.4 star by a 2-km comet at 5000 AU (Oort cloud), using the VLT and fast fiber camera



courtesy F. Roques


back to Earth, near Paranal