Agrupació Astronòmica de Sabadell

The occultation of the bright star 45 Capricornii in 2009: Observations, scientific results, lessons learned and future prospects

Photo: Manos Kardassis

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ESOP XXXII
23-25 AUG 2013
BARCELONA, SPAIN

Collaborators/Co-observers

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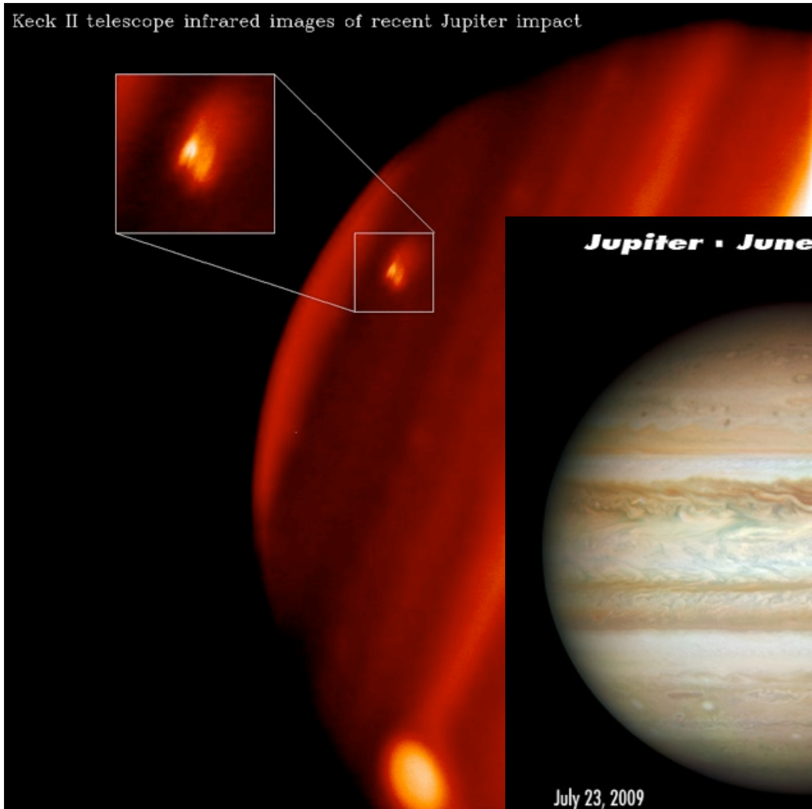
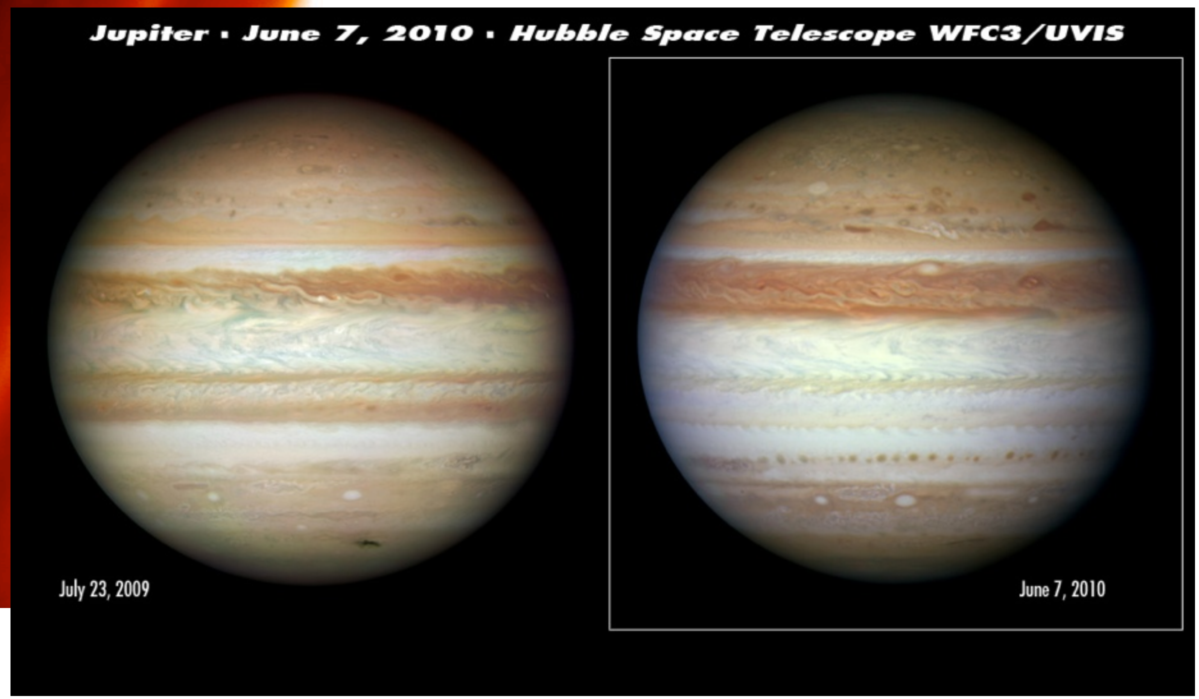
Structure of Talk

- rationale (why do it?)
- how does it work?
- observations
- results
- conclusions & future work

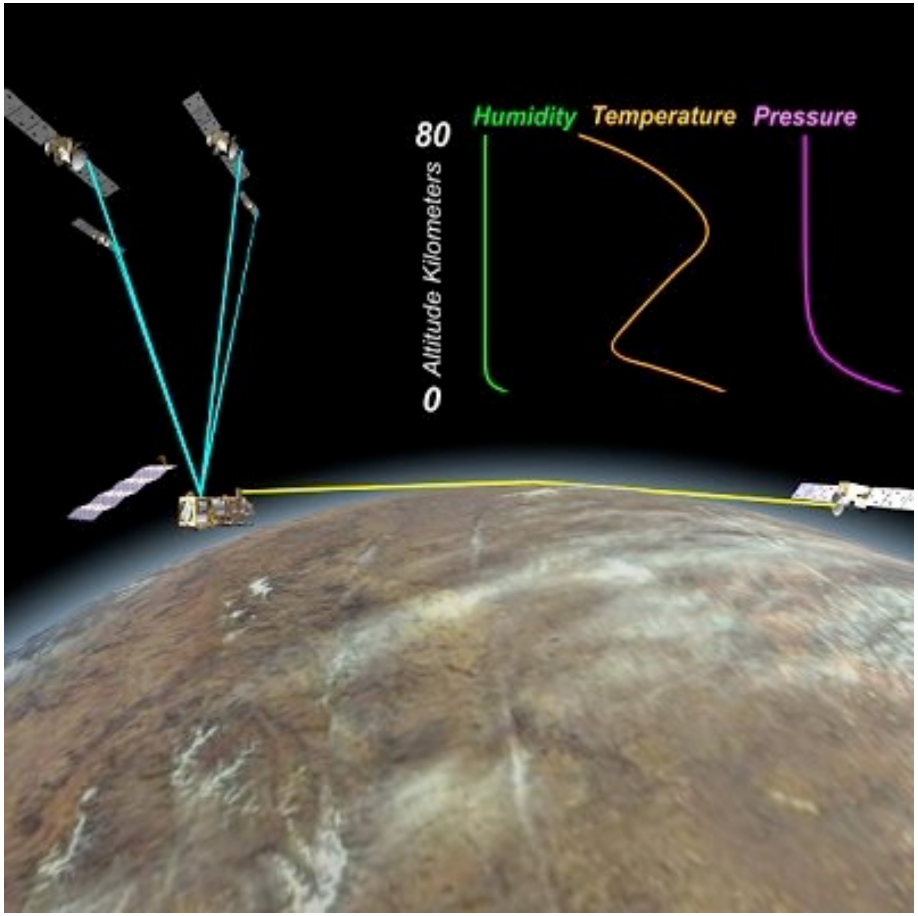
Rationale: Atmospheres are <u>dynamic..</u>





..so, to understand, you have to <u>monitor!</u>

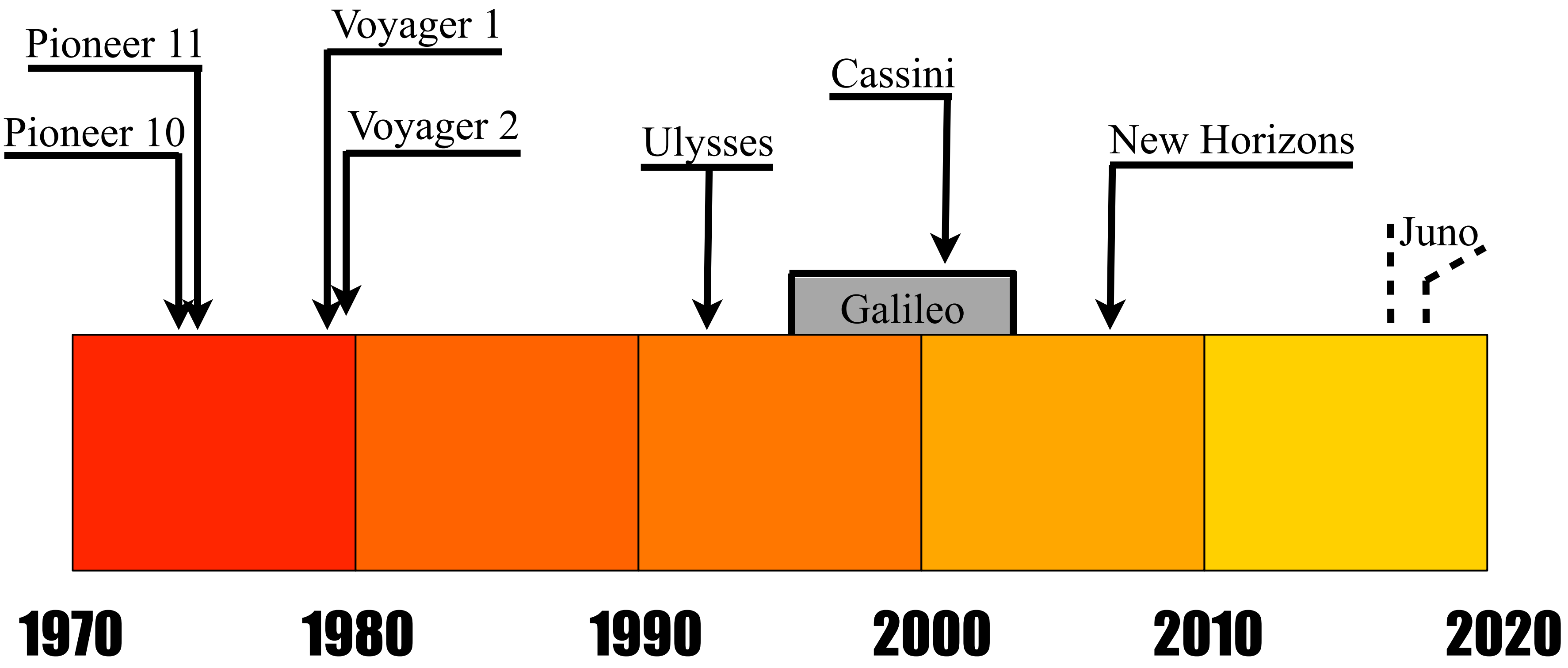
Occultations are used to probe the atmospheres of the Earth and other planets



Occultation techniques

- S & X - Band radio → •spacecraft
- Stellar visible-NIR → •ground-based
- UV → •spacecraft

Spacecraft visits to Jupiter



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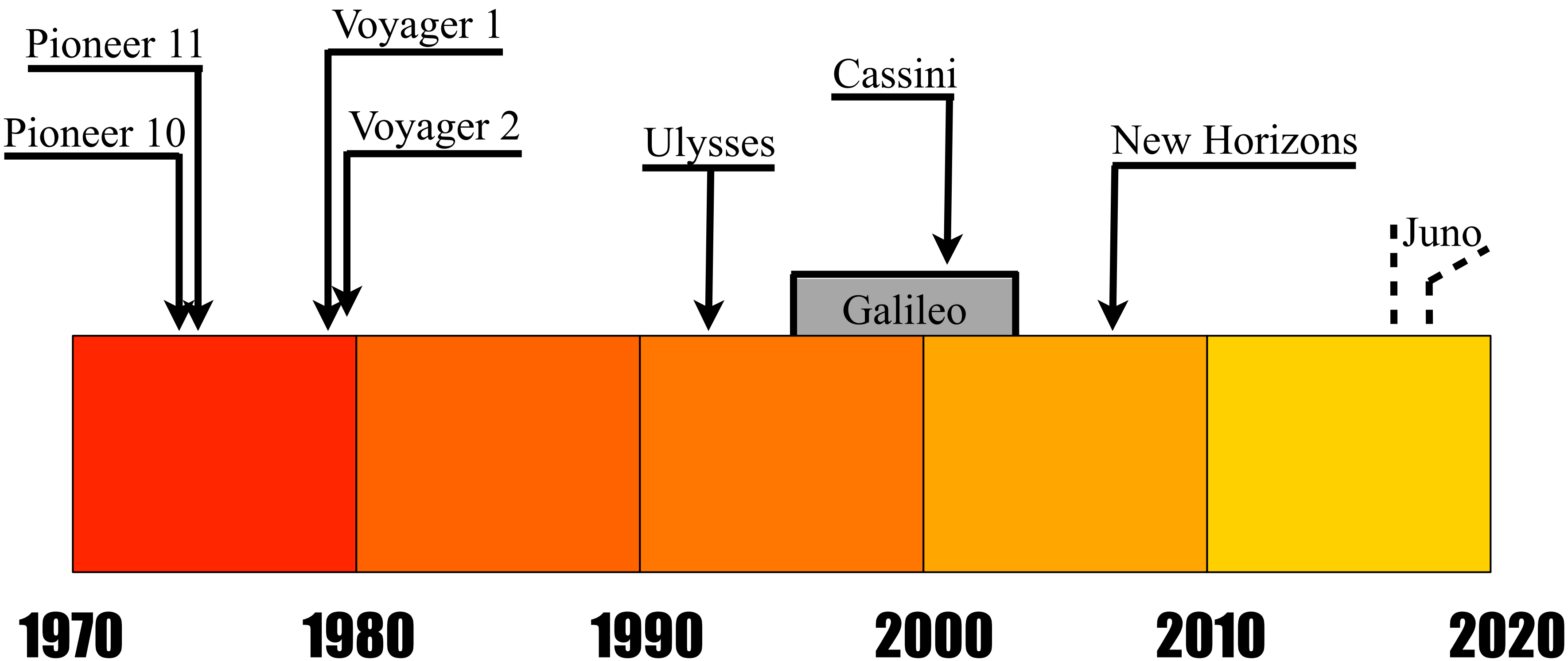
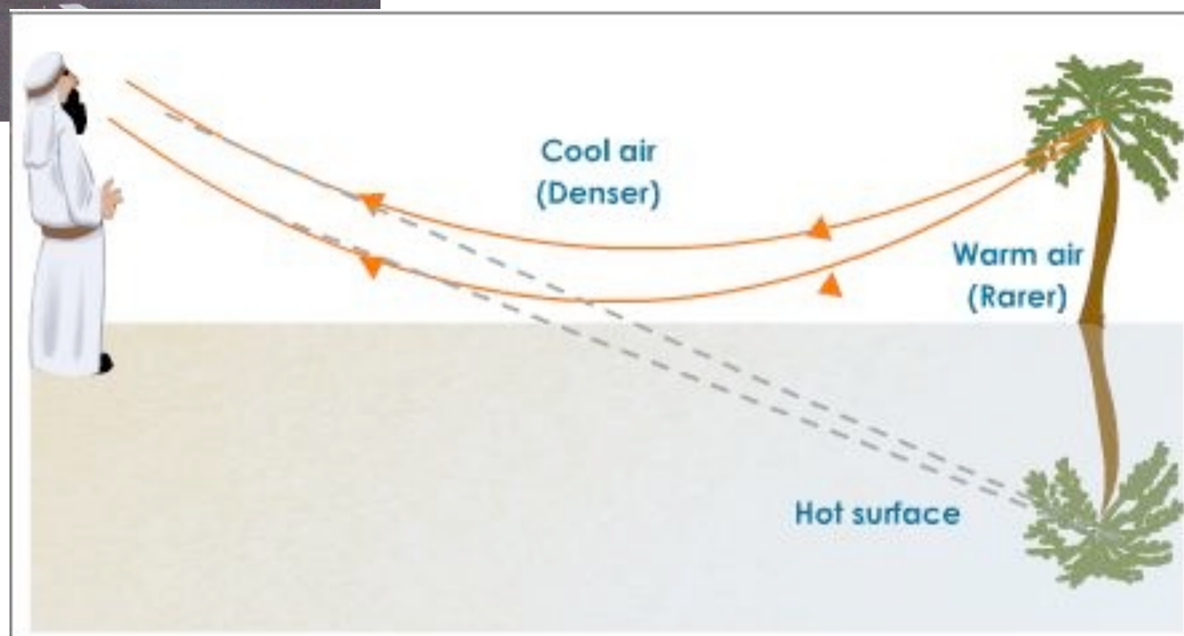


can pro-am occultation campaigns achieve useful (→ publishable) scientific results?

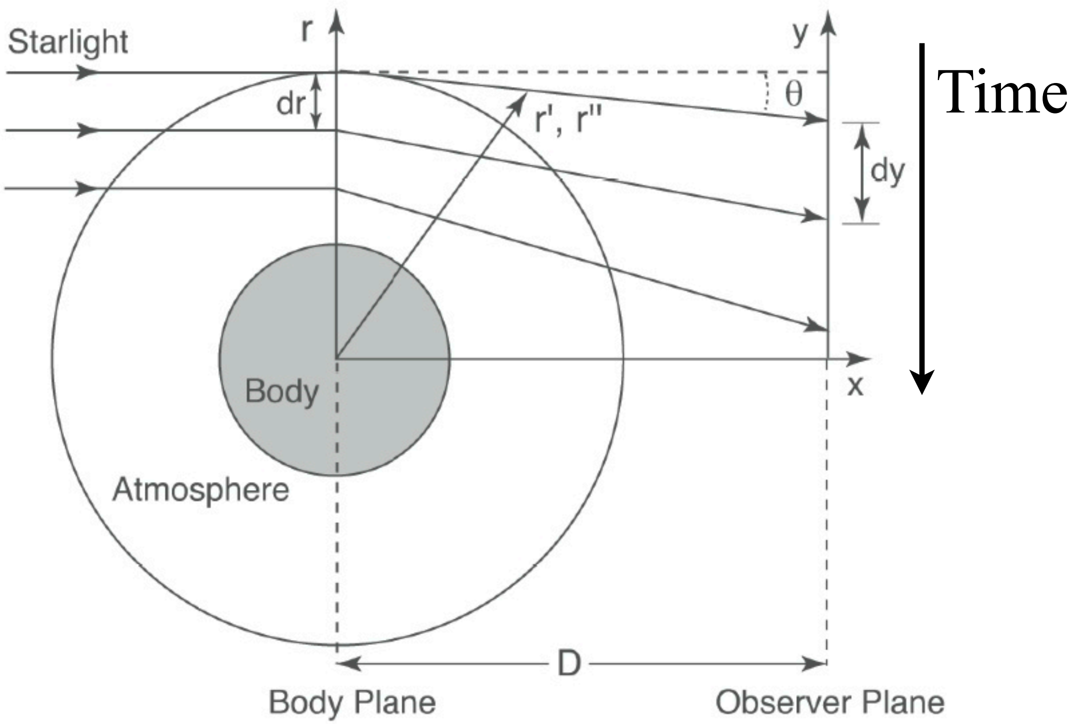
How do occultations work?

Temperature affects the <u>refractivity</u> of air

Text



The star fades and reappears due to differential refraction



Implicit assumption: absorption and scattering are negligible

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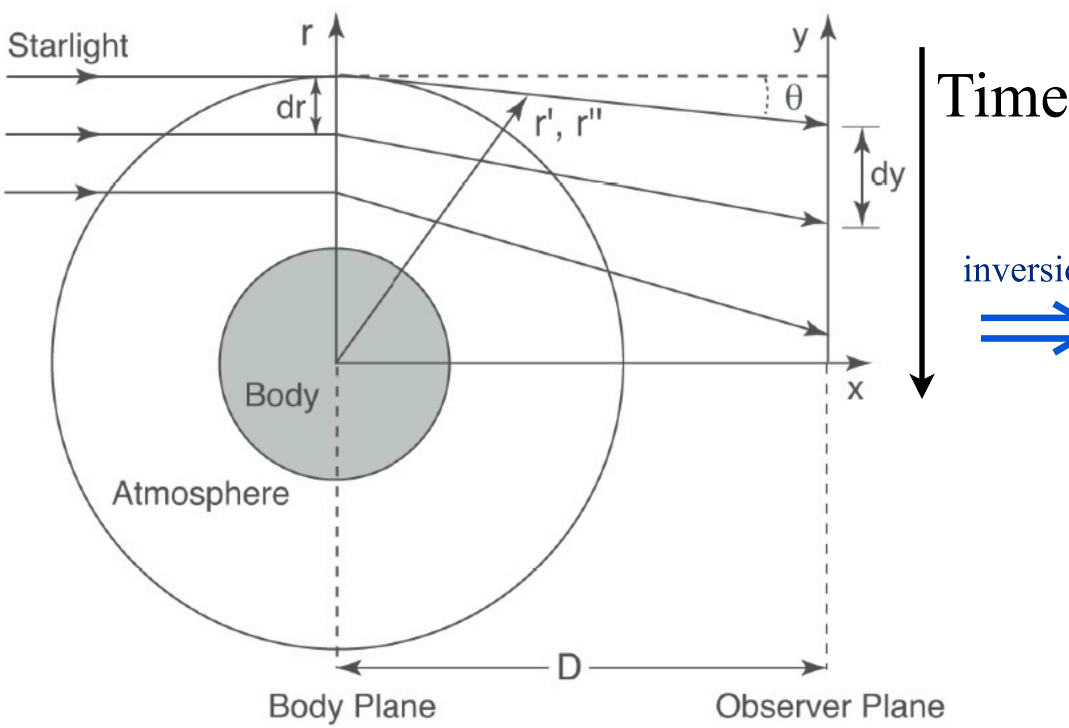


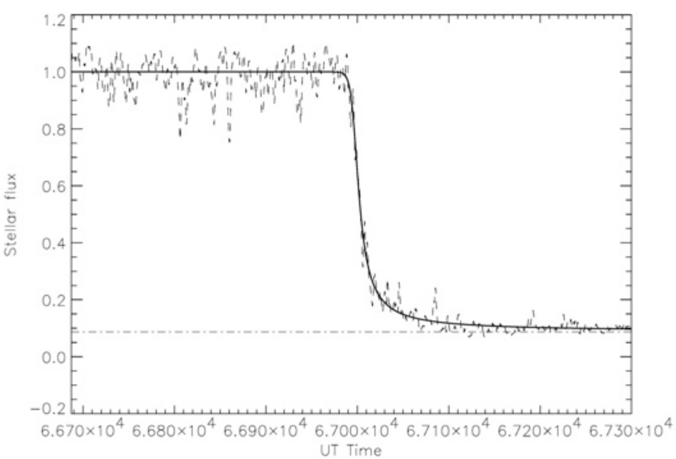
$$\xrightarrow{\text{inversion}} v, h \xrightarrow{\text{assumptions}} \rho, P, T$$

Implicit assumption: absorption and scattering are negligible

Isothermal (Baum-Code) fit

Assuming an isothermal atmosphere, Baum & Code (1953) give:

$$(\varphi^*/\varphi - 2) + \log(\varphi^*/\varphi - 1) = v(t-t_0)/H$$



Raynaud et al, Icarus, 2004, Fig 5

φ/φ^* : (relative) stellar intensity

t_0 : time at "half flux"

v : vertical velocity of star

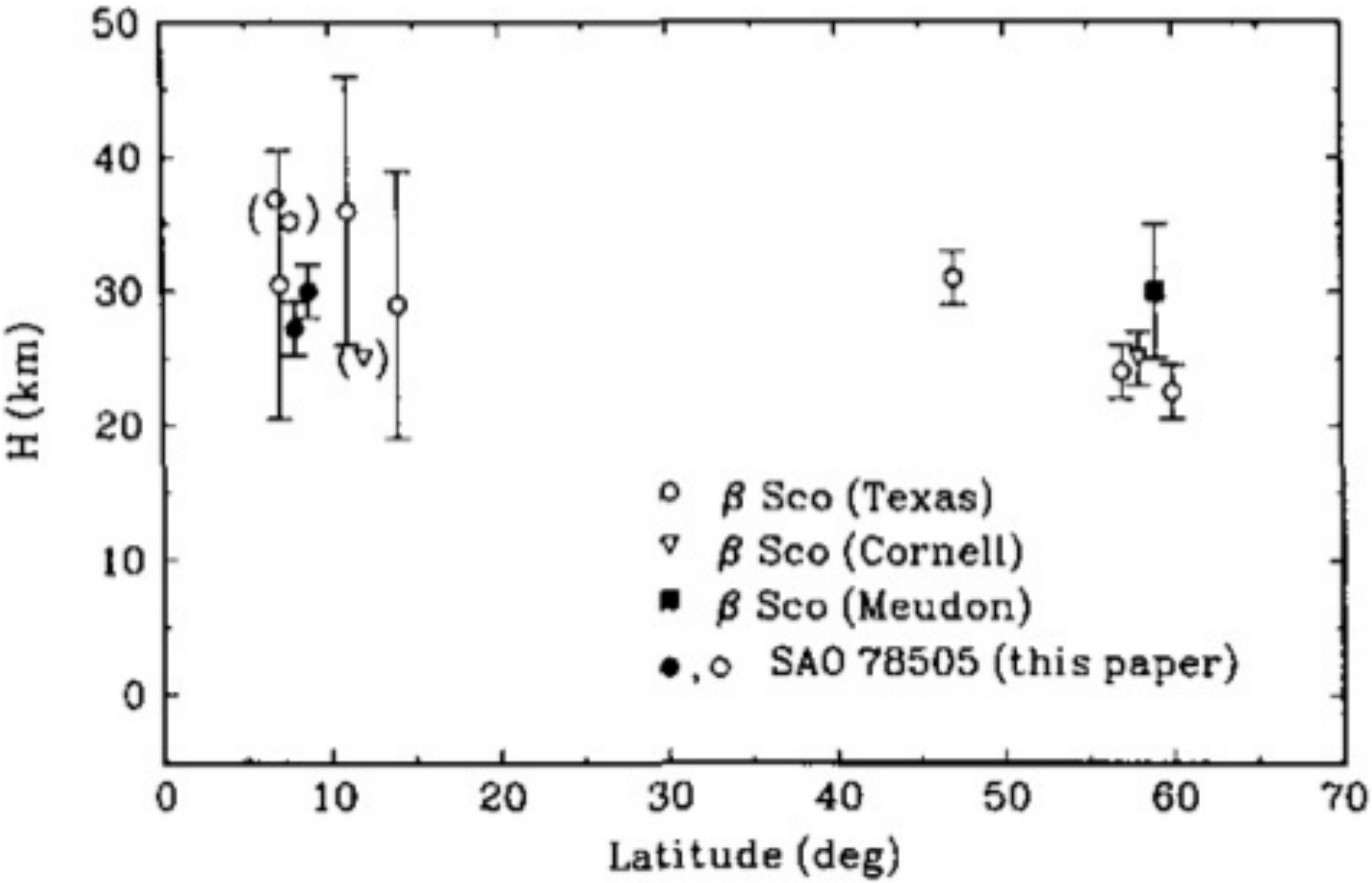
H : refractivity scale height

$$H = RT/\mu g$$

Past ground-based occultation campaigns

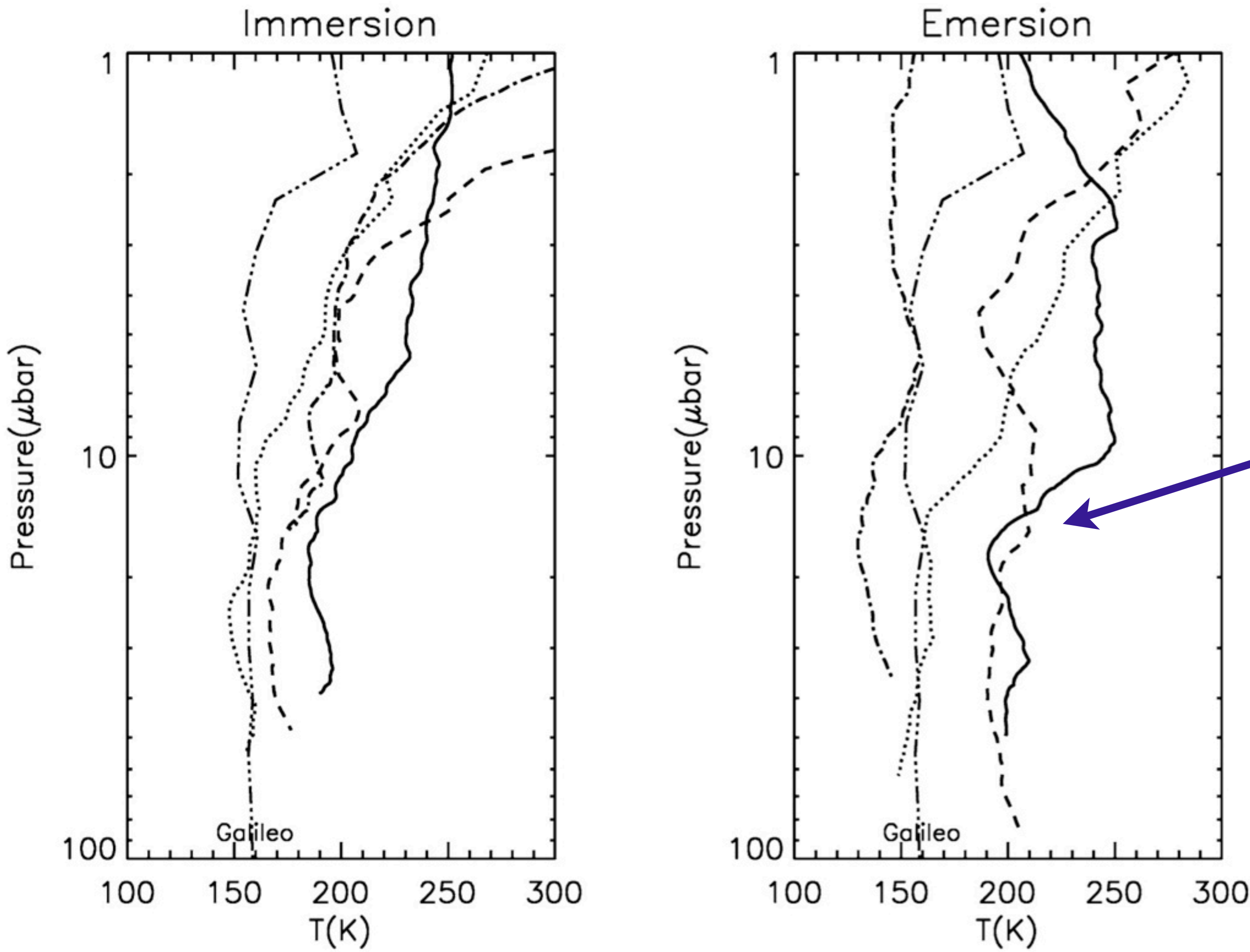
- β Scorpii (A: V=2.8, C: V=2.9, Sep: 13”) in 1971
- SAO 78505 (V=8.7, K=7) in 1989
- HIP 9369 (V=7.7, K=6.5) in 1999

Past Results: Scale Height



Hubbard et al, Icarus, 1995, Fig 4

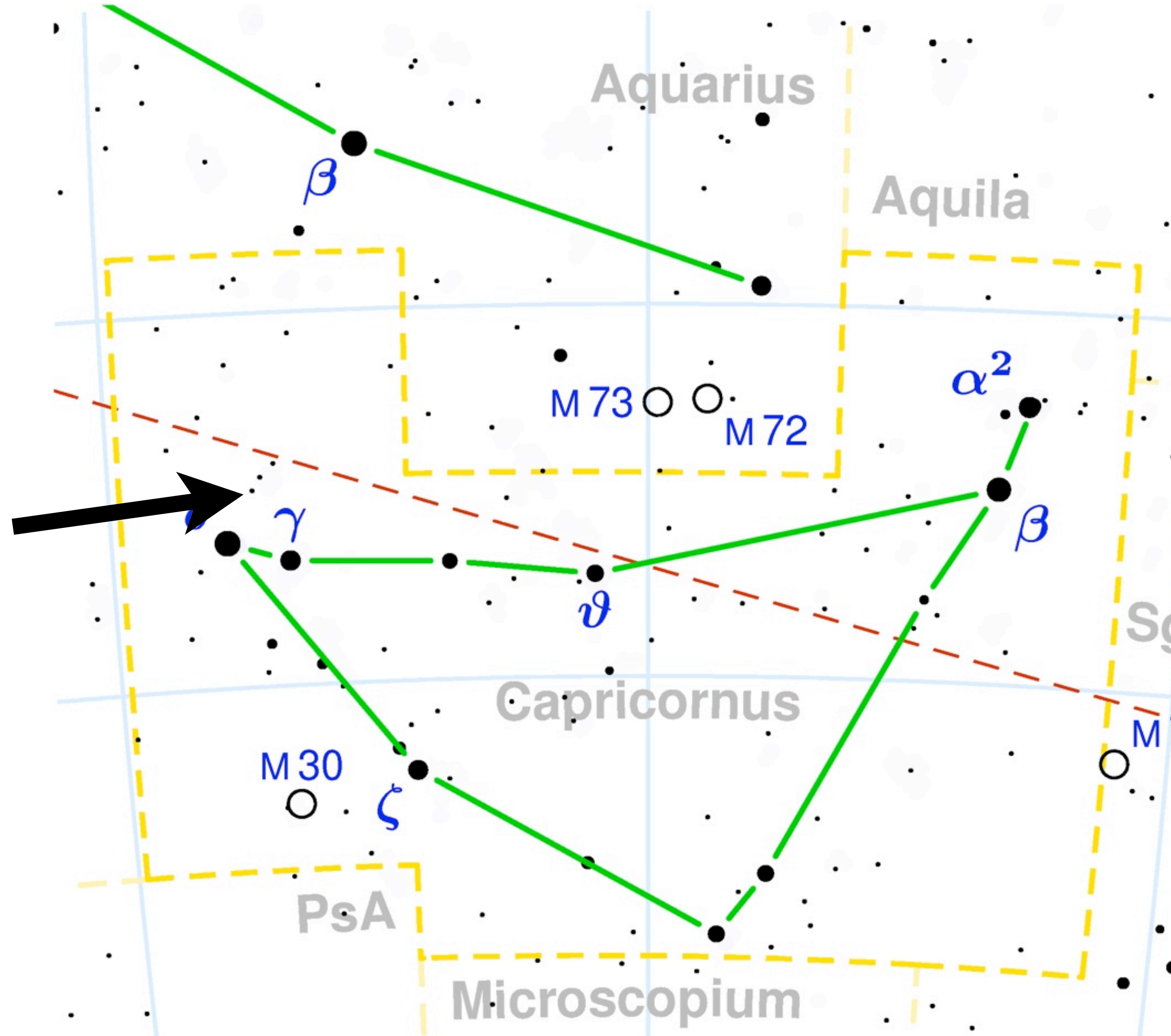
Past Results II



<u>High</u> latitudes warmer than <u>low</u> latitudes: **auroral heating?**

Raynaud et al, Icarus, 2003, Fig 5

HIP 107302: A7, V=5.96, K=5.4, aka **45 Capricornii**



An occultation by Jupiter was predicted for the night 3/4 August 2009 (D. Mink, 1995)

IOTA · ES

International Occultation Timing Association

European Section

Occultations by

Moon

Asteroid

Planet

Pluto, TNOs

Astrometry

Occultation of HIP 107302 by Jupiter on the 3rd of August 2009

The occultation has been observed from many stations and observatories around the world! The star could be seen up to 20 minutes in the Jovian atmosphere, the movement of its position relative to the Jovian disk and the tremendous flickering due to structures in the atmosphere of Jupiter could be recorded. At first you can find a list of stations contributing to our campaign. Read more...

Information about the possible impact on Jupiter (21st July 2009) concerning the occultation

Visible from Europe, Asia, Africa and the Americas!

The star HIP 107302 with **visual magnitude 6m0** is occulted by Jupiter on the 3rd of August. This is the brightest star, which will be occulted for the next more than 100 years visible from Europe. In the near future, there is only on more occultation with a similar bright star, but this is only visible from western southern America (Chile...). For the rest of us, no similar occultation will take place for generations!

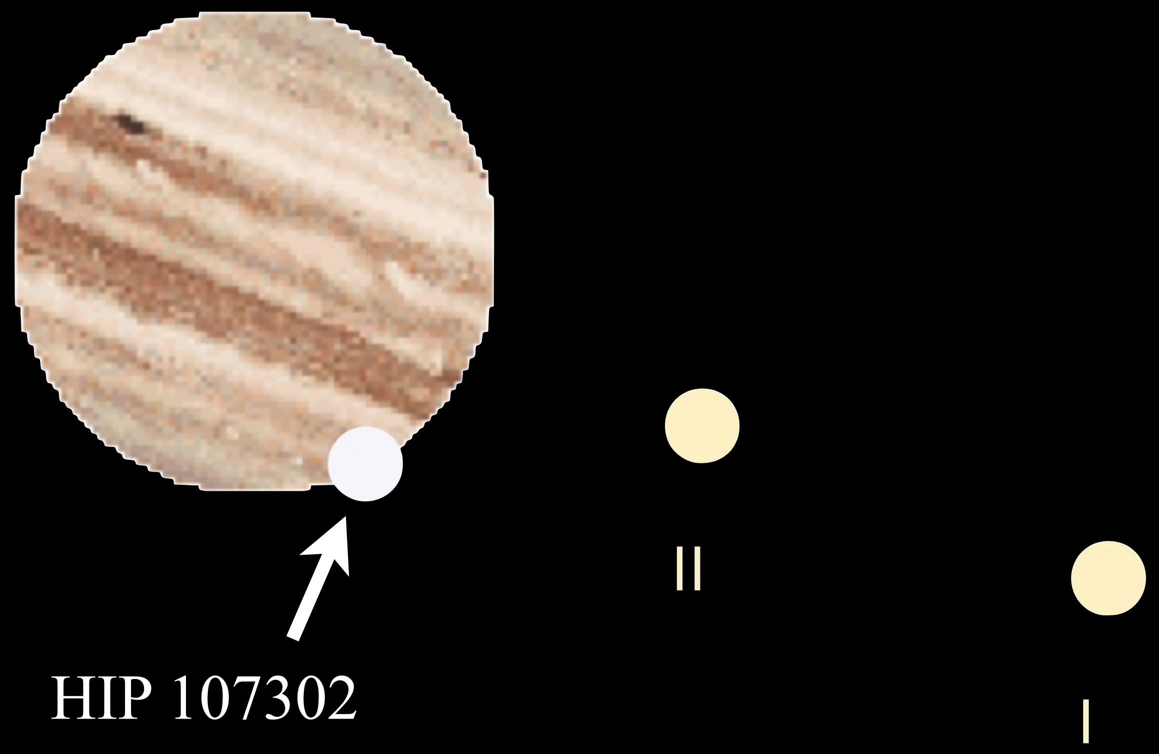
Therefore, its not only a spectacular show for the "Year of Astronomy 2009", but also a great opportunity to gain information about the Jovian atmosphere by earthbound astronomy.

But keep in mind, that even a 6th magnitude star is hard to see on Jovian's limb, when it disappears or reappears! You need an excellent air quality and a telescope perhaps larger than 10 inch in diameter.

IOTA-ES will maintain a special website http://jupiter2009.iota-es.de all over the year for this event, giving all necessary informations for a successful observation as well as

Using WINOCCULT, a prediction for this event has been generated in the following figure:

INGRESS (~ 23:00 UT, 3 AUG 2009)



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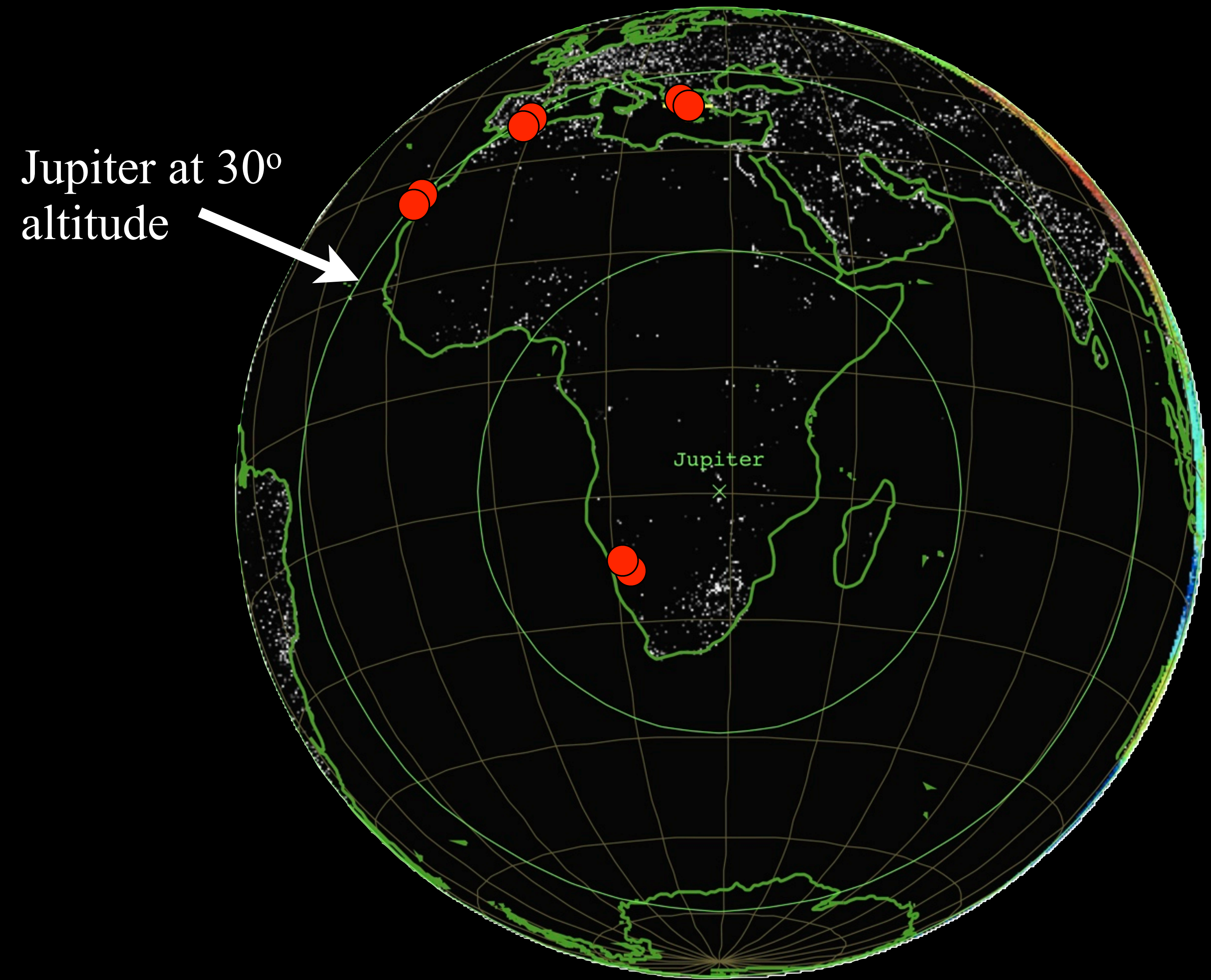
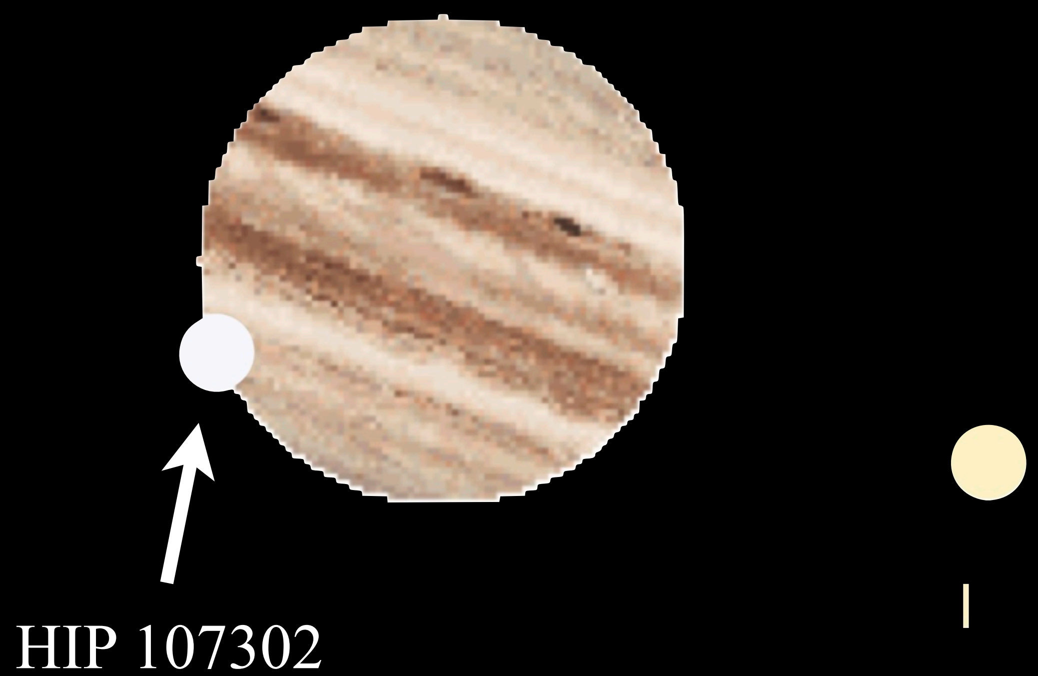
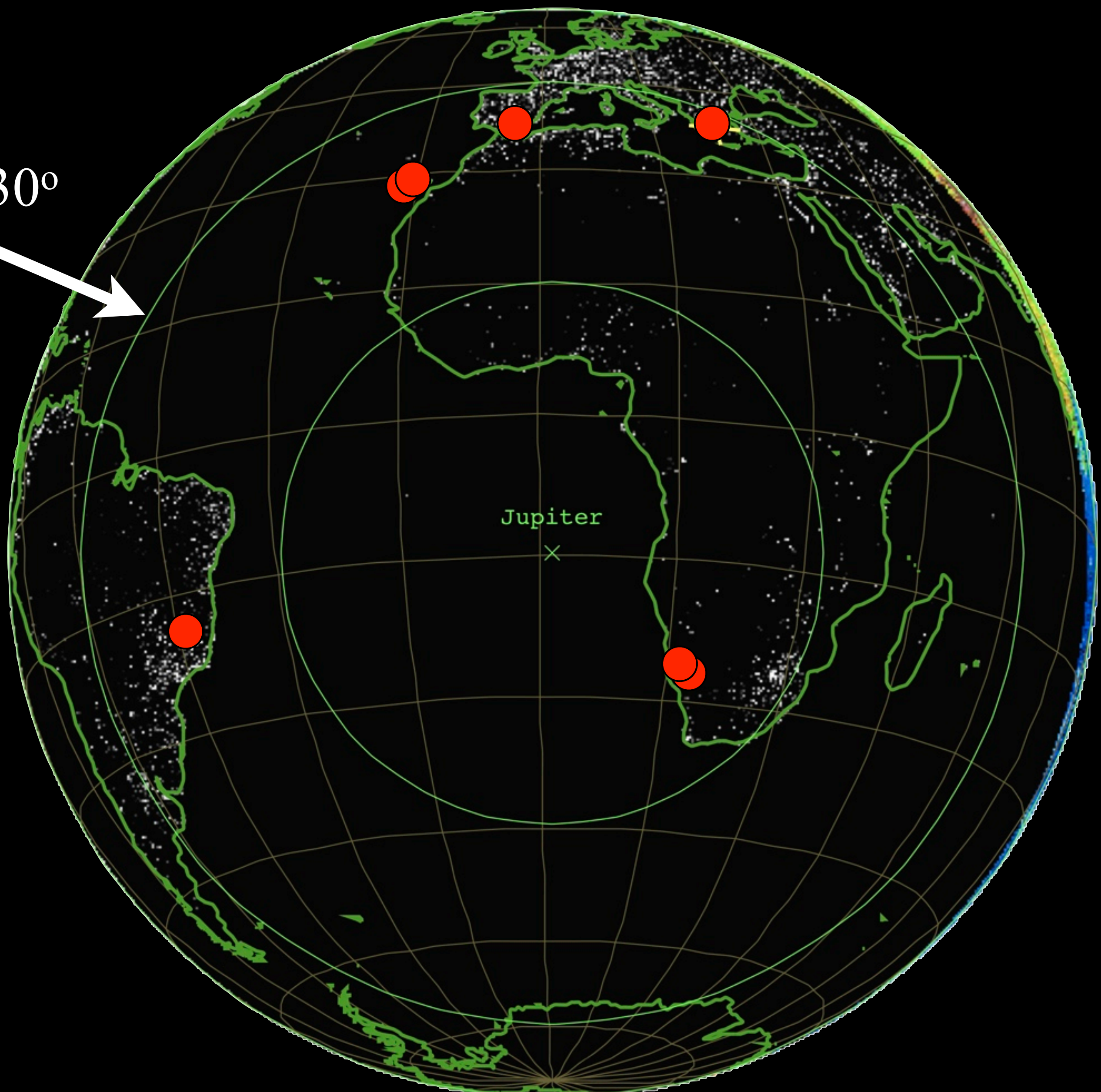


EGRESS (~ 00:50 UT, 4 AUG 2009)



EGRESS (~ 00:50 UT)

Jupiter at 30° altitude



Problem: Measuring the flux from a star next to a bright planet

Jupiter's surface brightness: ~5.5 mag/arcsec^2

Stellar brightness is: ~6 mag

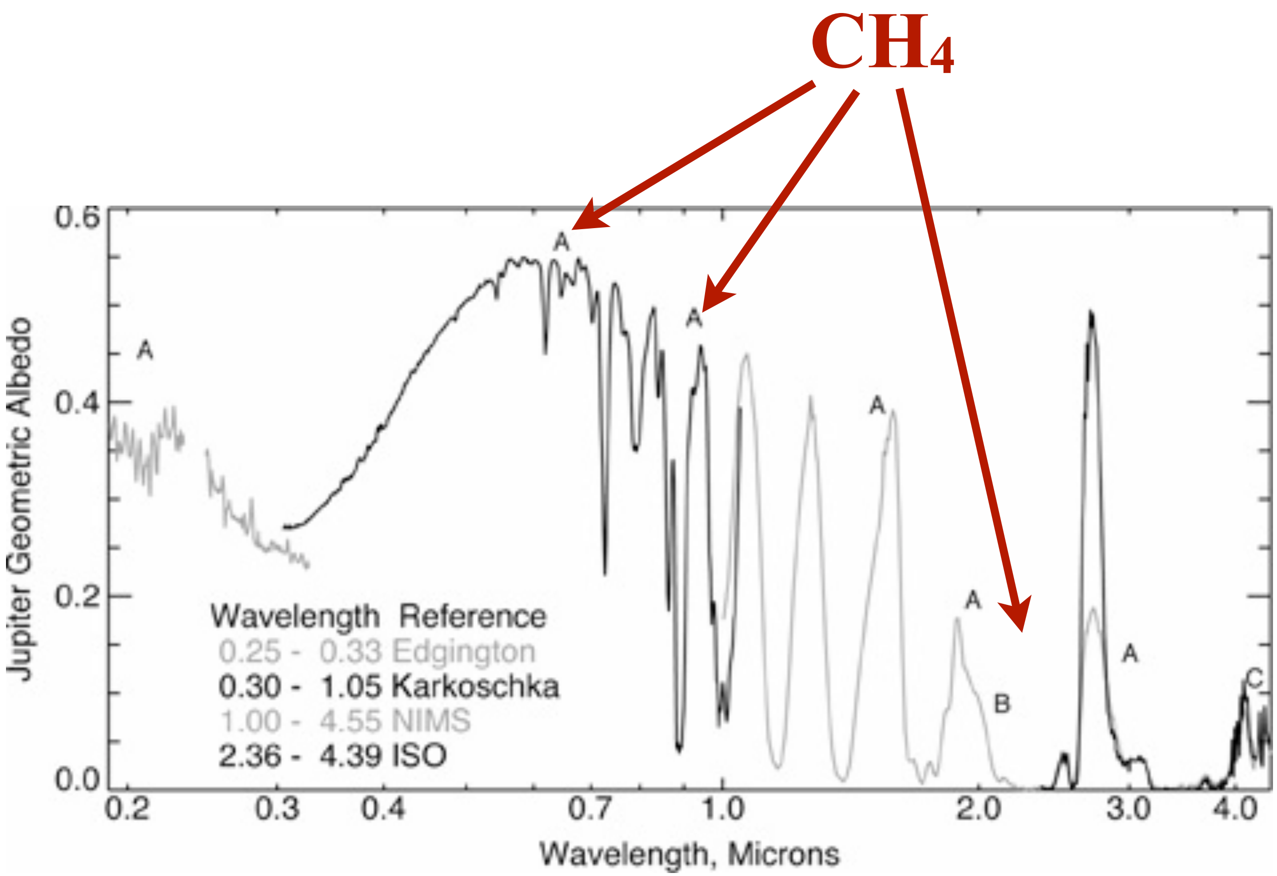
Problem: Measuring the flux from a star next to a <u>bright</u> planet

Jupiter's surface brightness: ~5.5 mag/arcsec^2

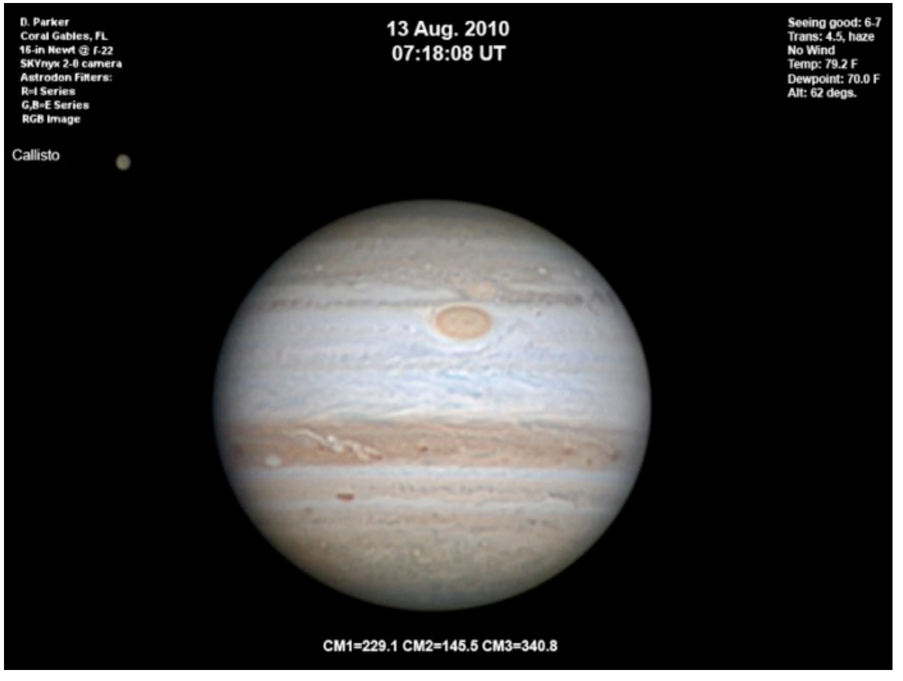
Stellar brightness is: ~6 mag

$\Longrightarrow$ reduce the flux from the planet

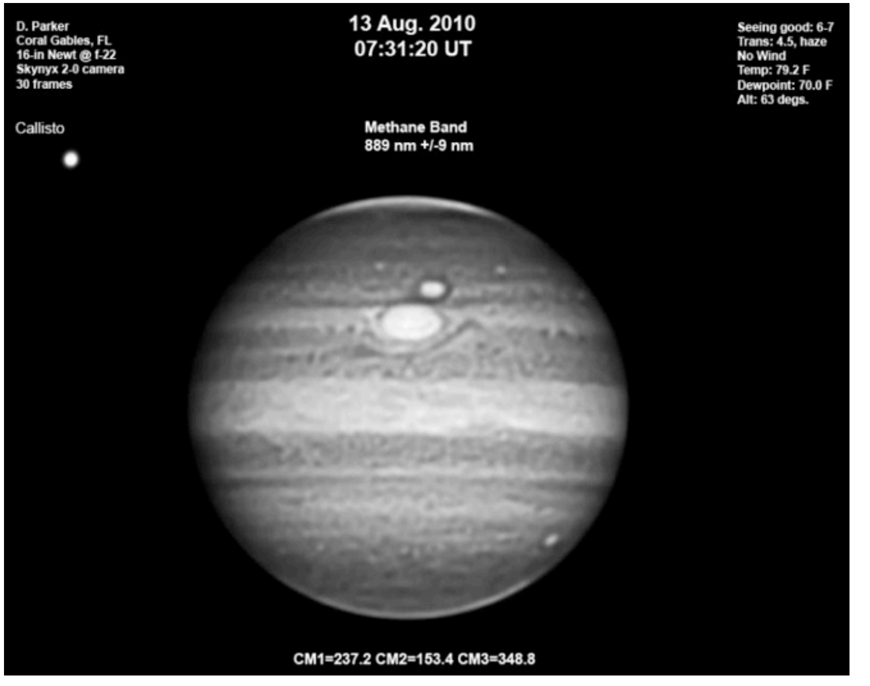
Utilising methane absorption filters to decrease the flux from Jupiter



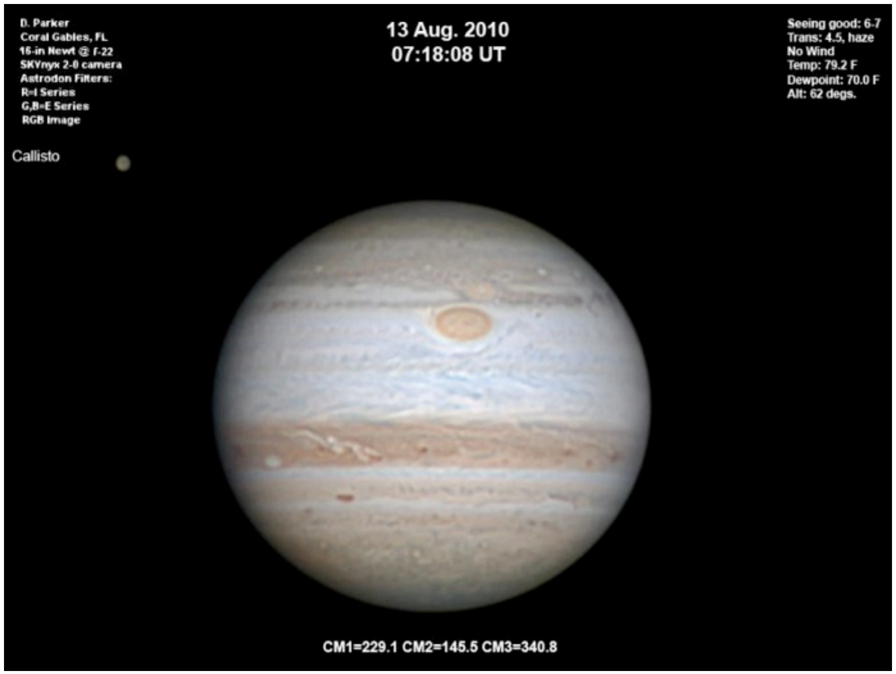
Utilising methane absorption filters to decrease the flux from Jupiter

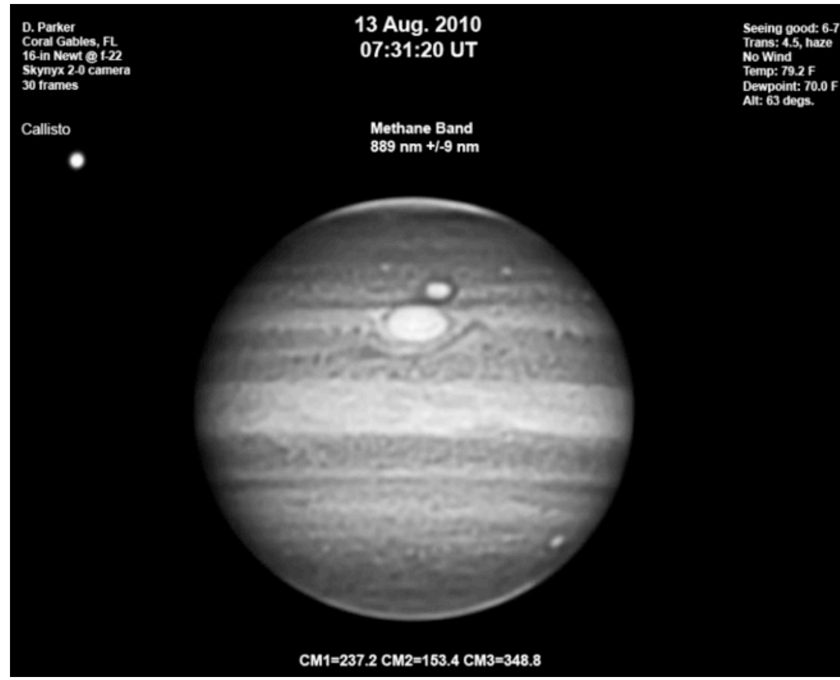


Jupiter “RGB”



Jupiter@0.89μm





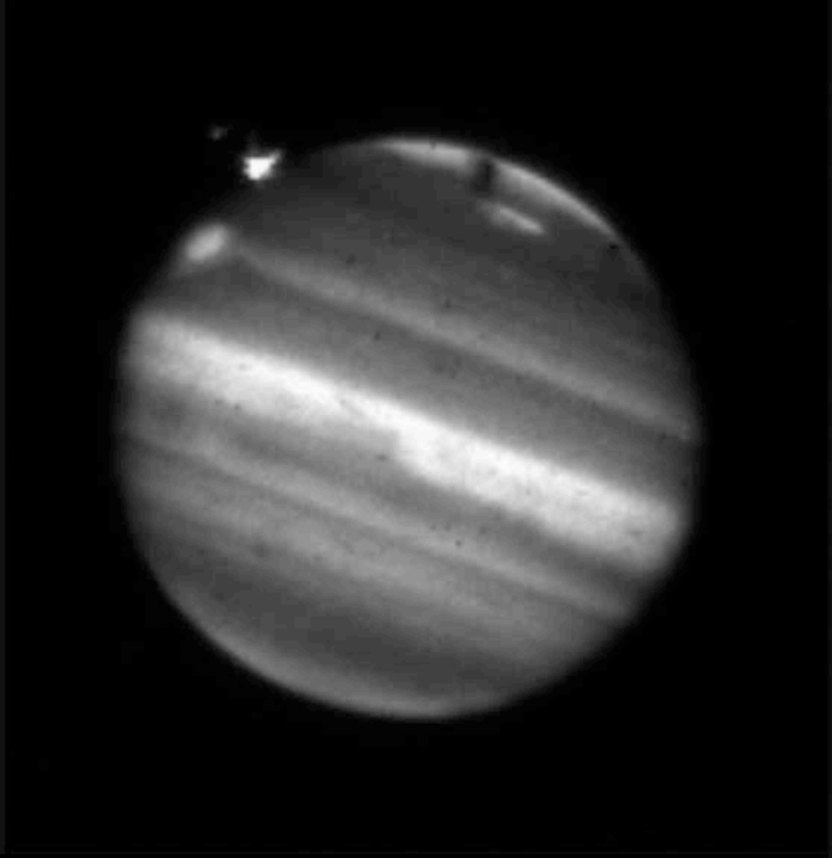
Jupiter "RGB"

Jupiter@0.89µm

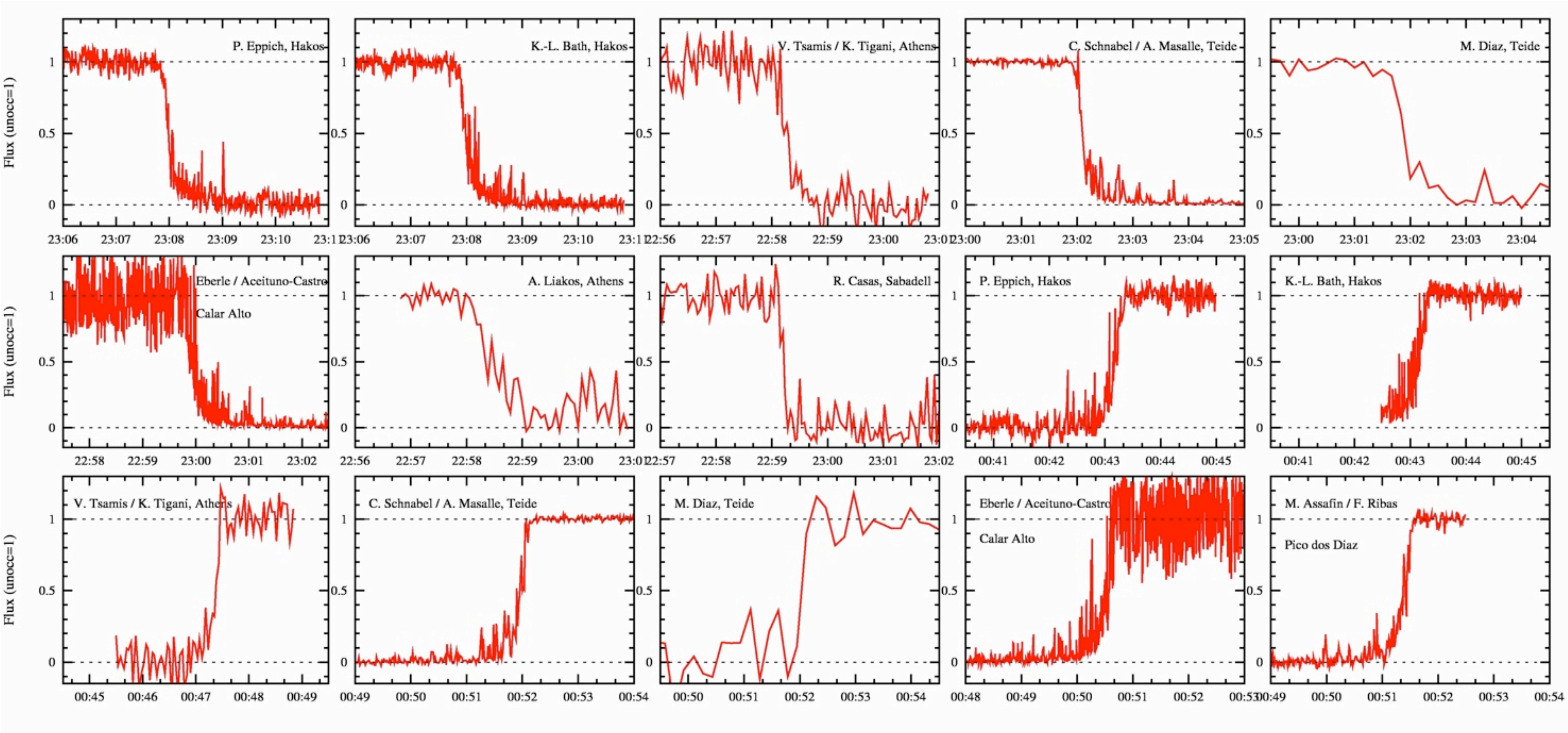
>>Cloud topography<<

Bright is high, faint is low

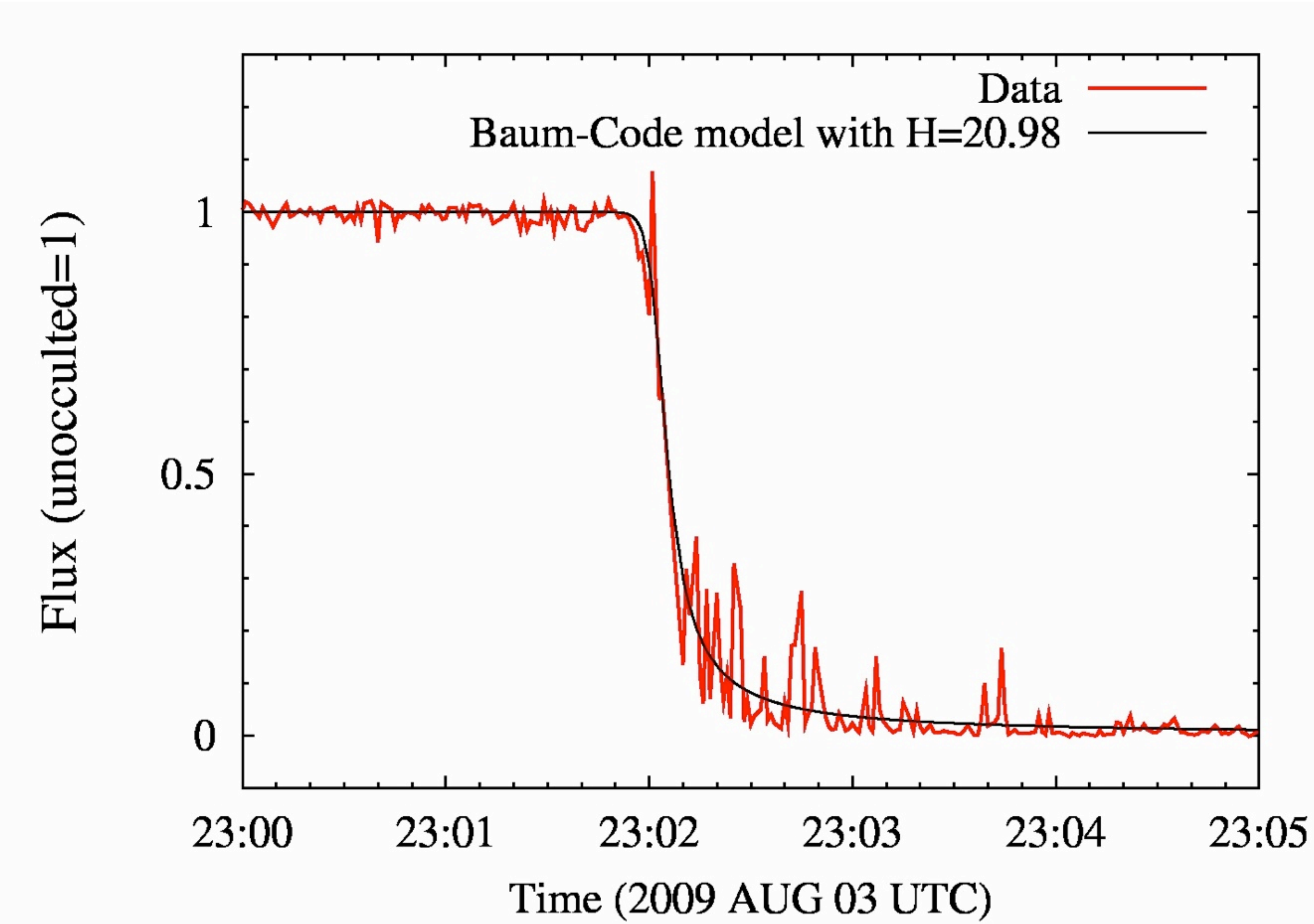
Observer	Location	Telescope	Camera	Filter	Cadence
P. Eppich	Hakos, Namibia	0.4m	QHY6	0.89 µm	0.7s
K.-L. Bath		0.5m	“	“	0.45s
V. Tsamis	Athens, Greece	0.4m, f/10	AtiK 16HR	0.89 µm	2.4s
A. Liakos		0.4m, f/10	SBIG ST-10	0.89 µm	4s
R. Casas, M. Malorino	Sabadell, Spain	0.5m, f/4	SBIG ST-8	0.89 µm	2.33s
Eberle/ Aceituno	Calar Alto, Spain	2.2m, f/		K-band	0.37s
M.C. Diaz	Teide, Canary Is	0.82m, f/11.83		U	10.0s
C. Schnabel, A. Massalle		1.52m, f/13.8	CAIN-3	K-band	1.0s
F. Ribas, M. Assafin	Pico dos Diaz, Brazil	1.6m		0.89 µm	0.78s



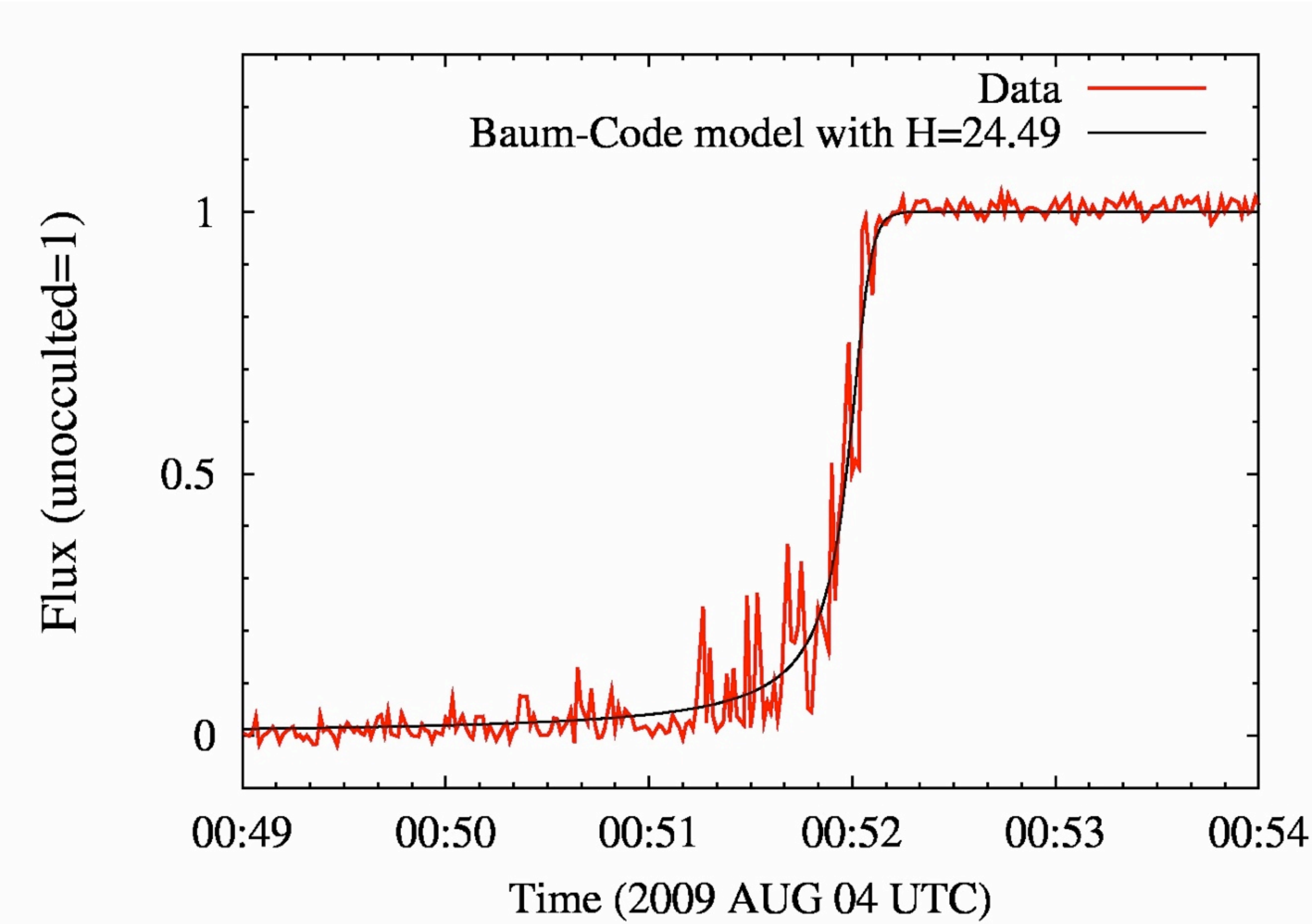

Lightcurves!



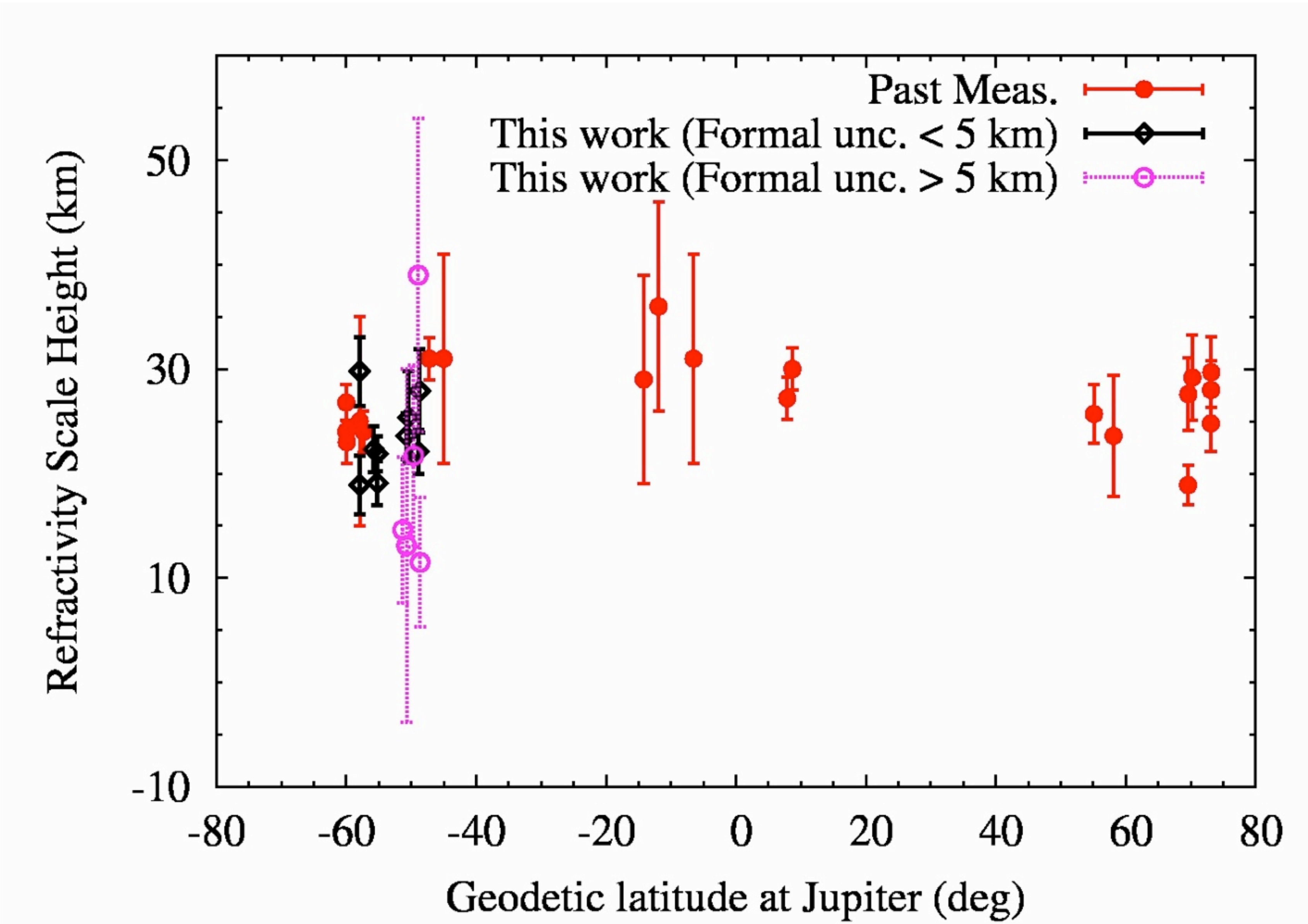
Baum-Code fit for Teide Obs (I)



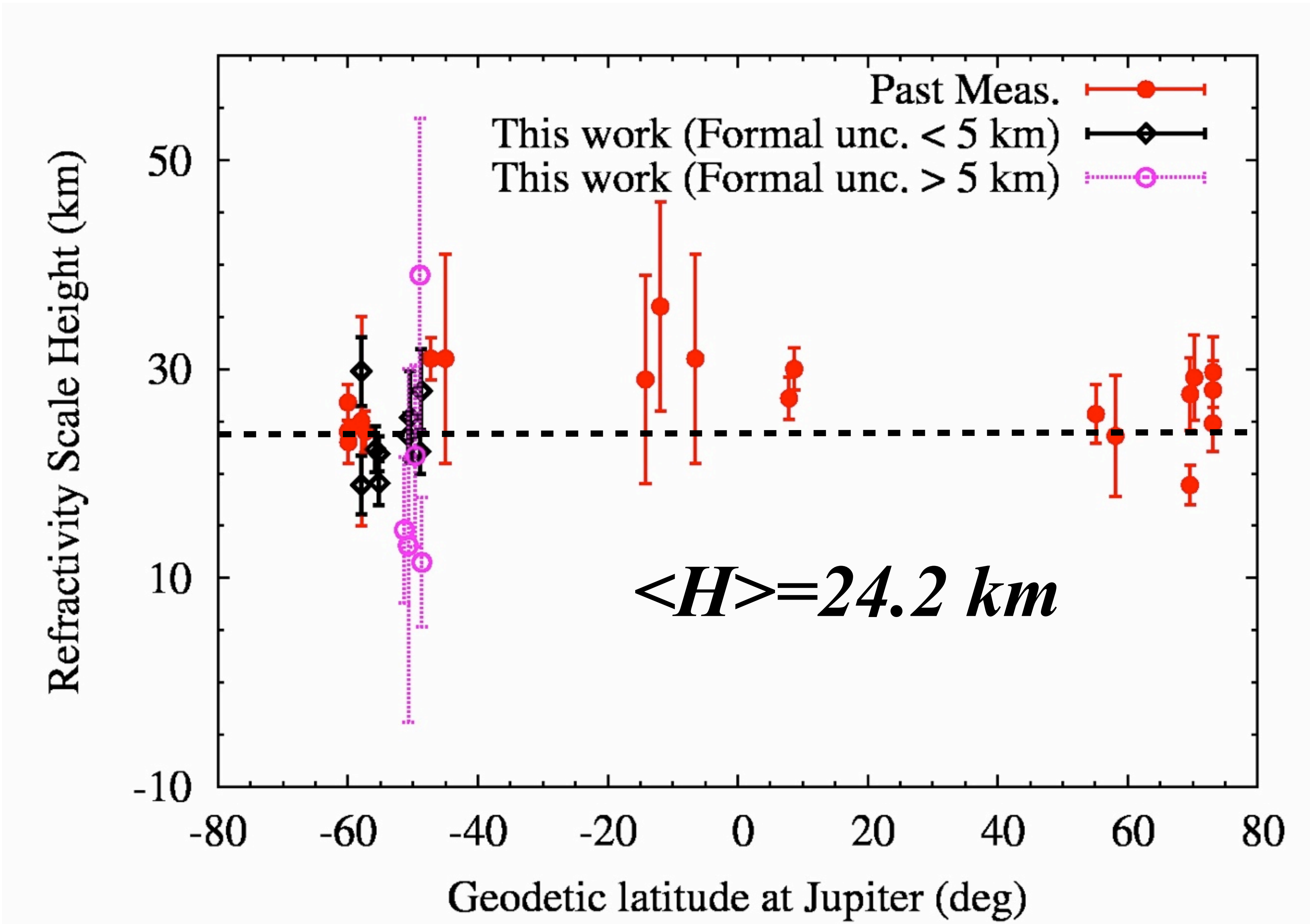
Baum-Code fit for Teide Obs (E)



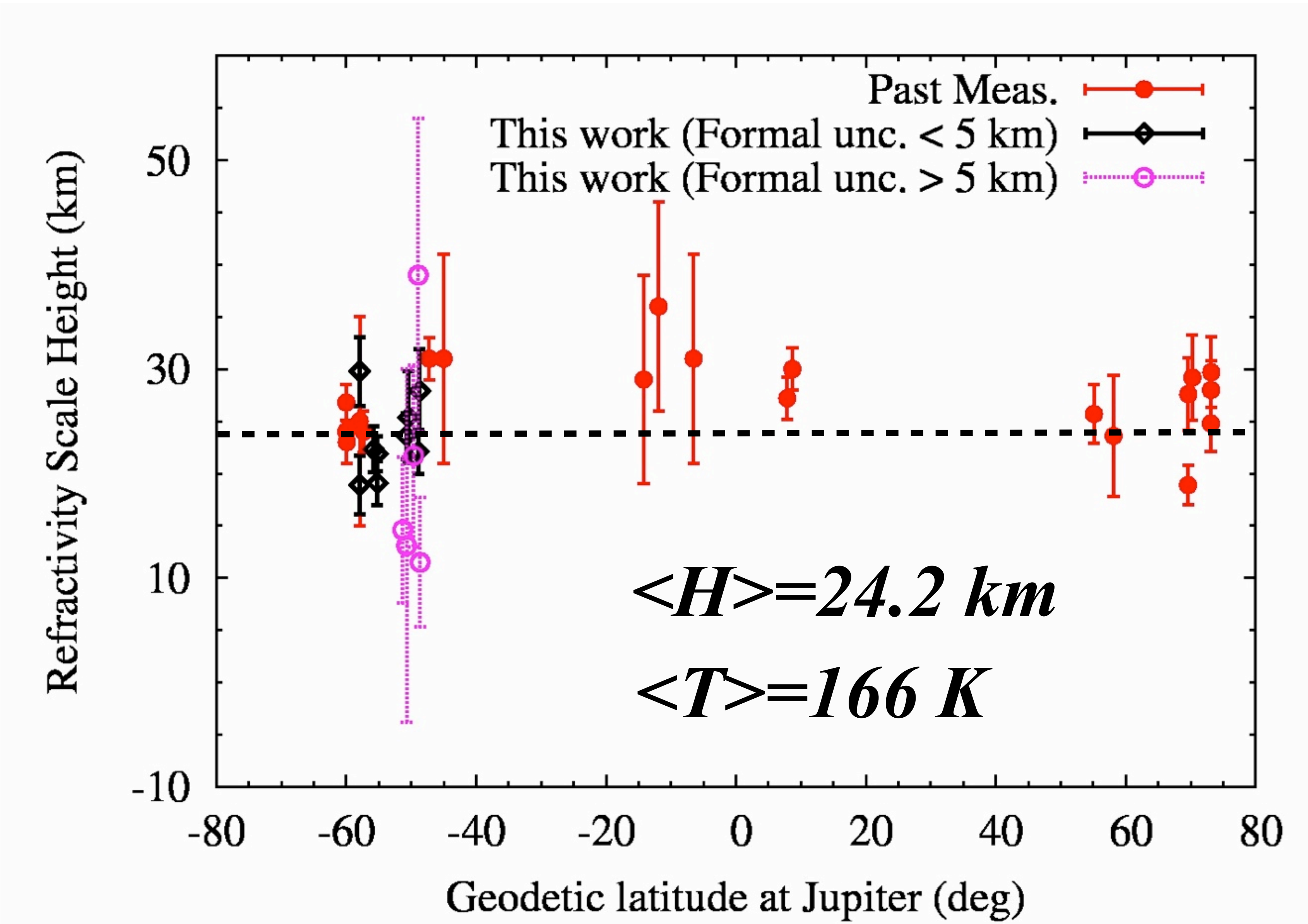
Past & present estimates of H



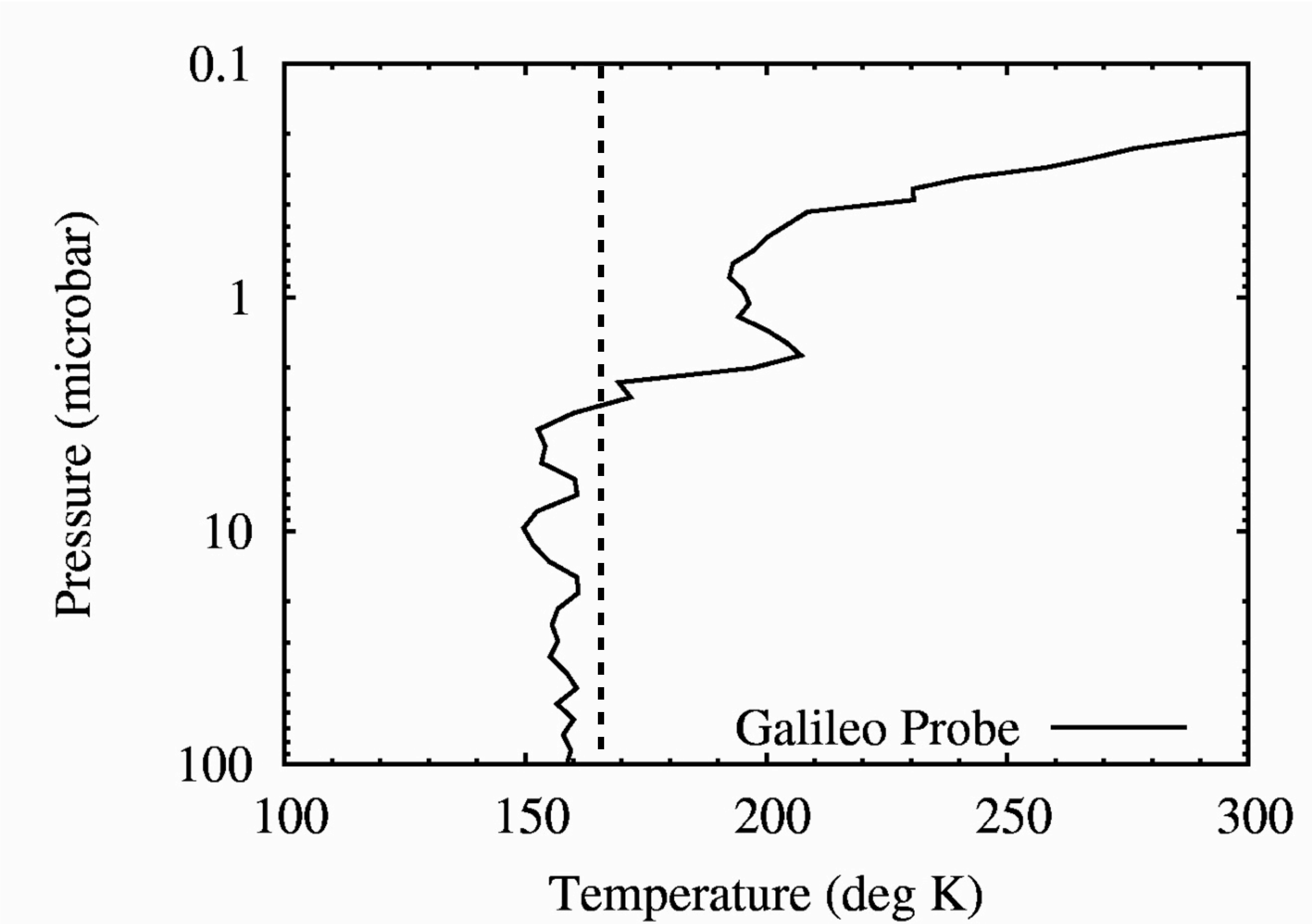
Past & present estimates of H



Past & present estimates of H



Pressure vs Temperature profiles



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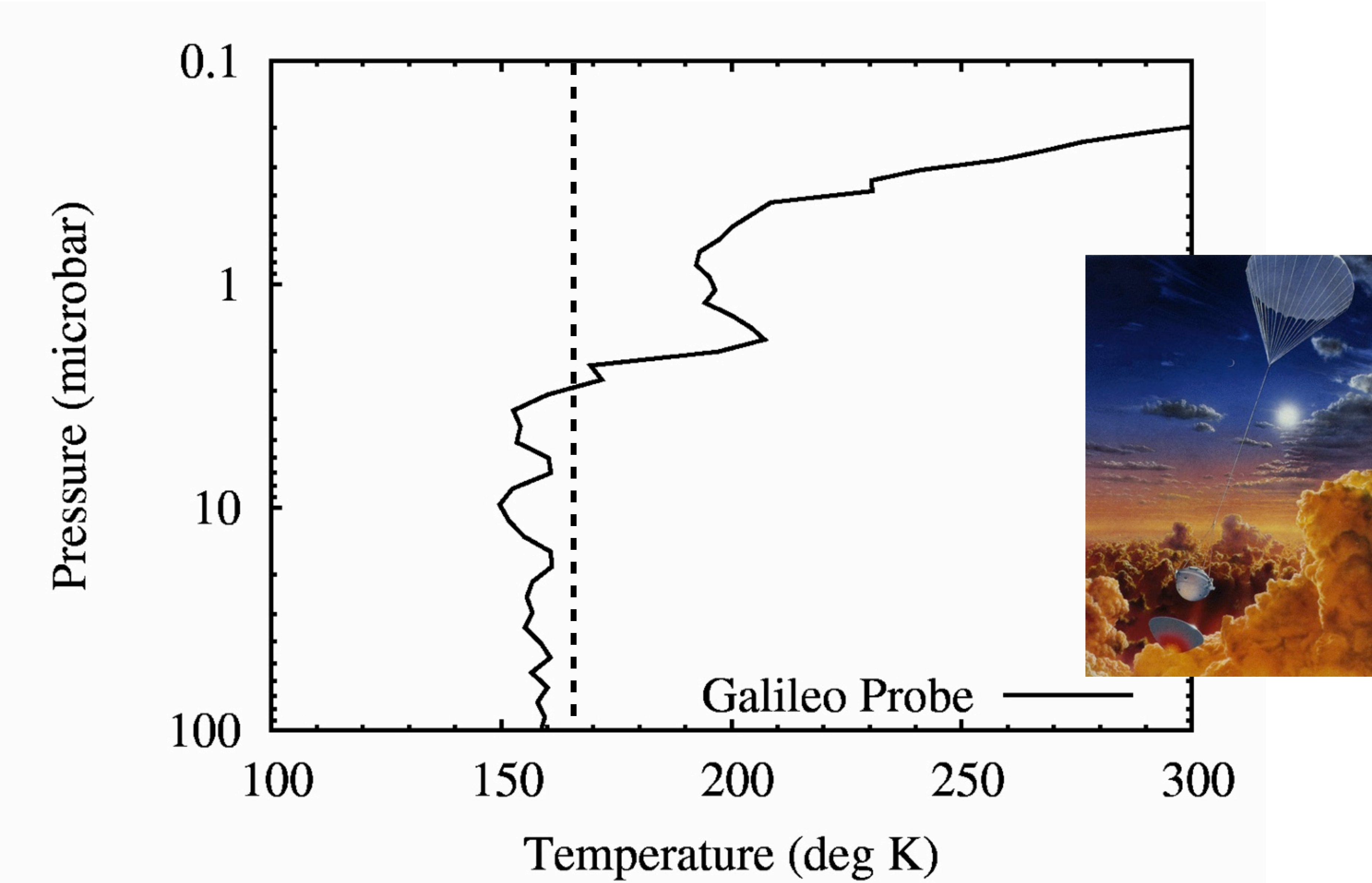

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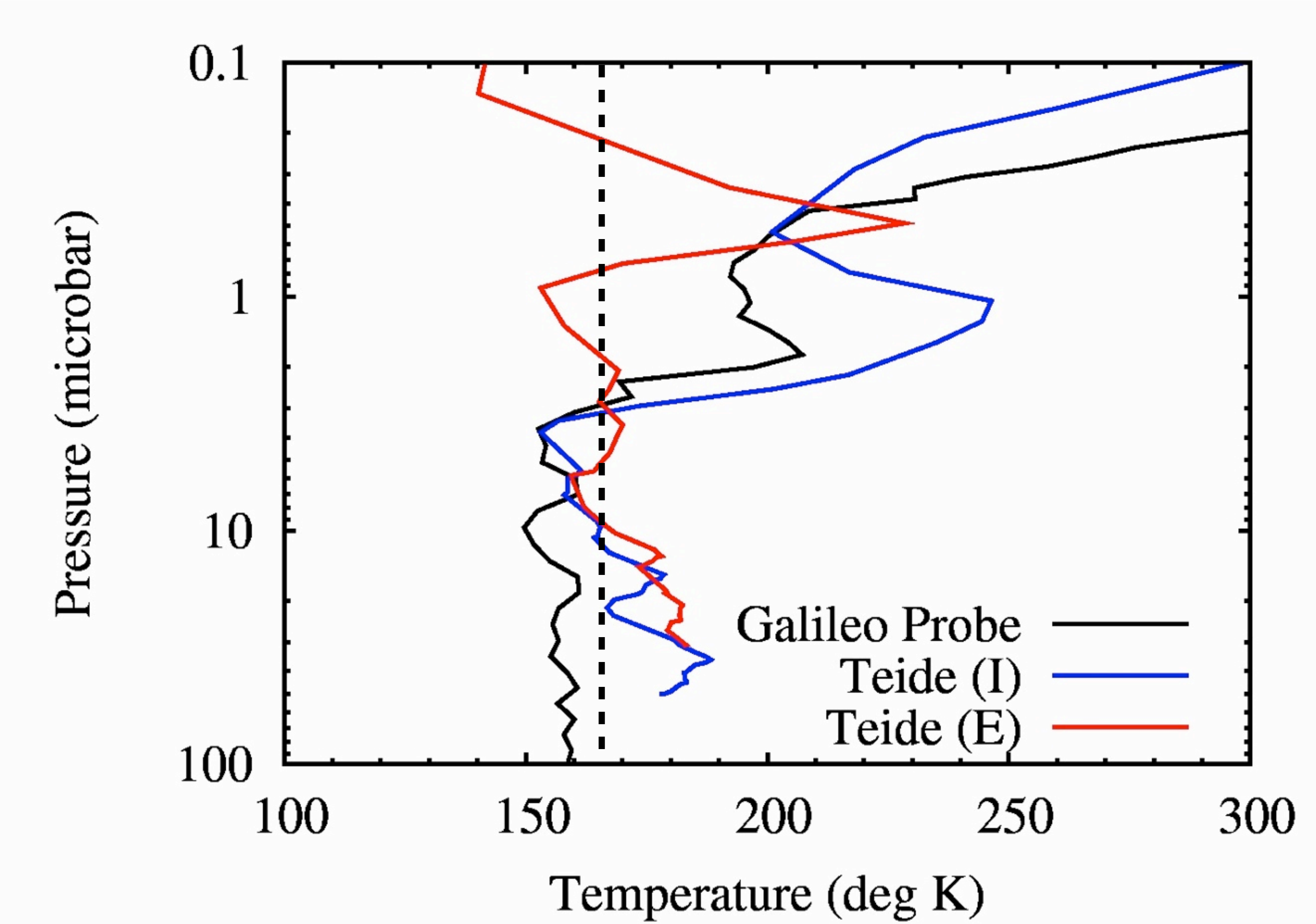

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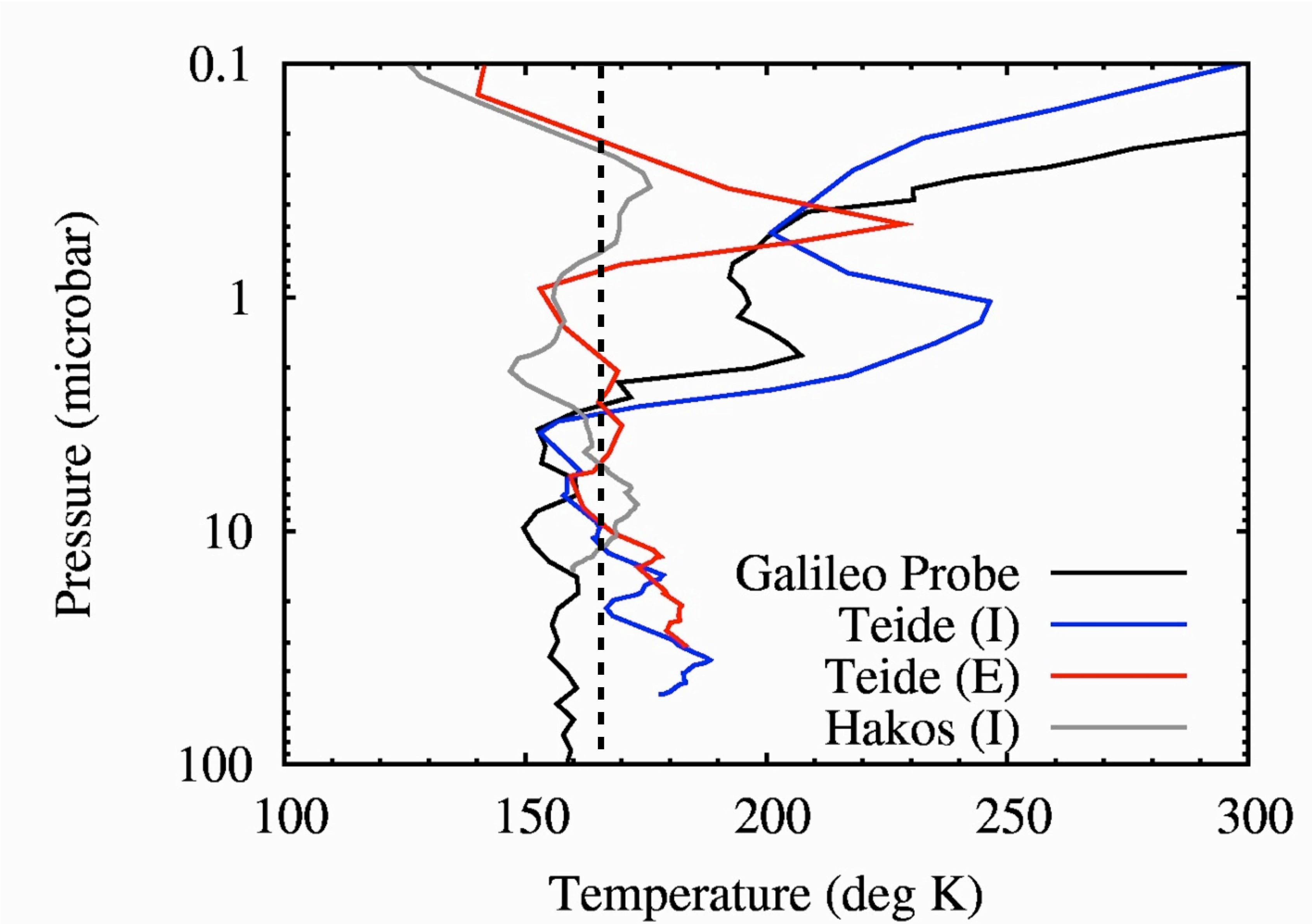

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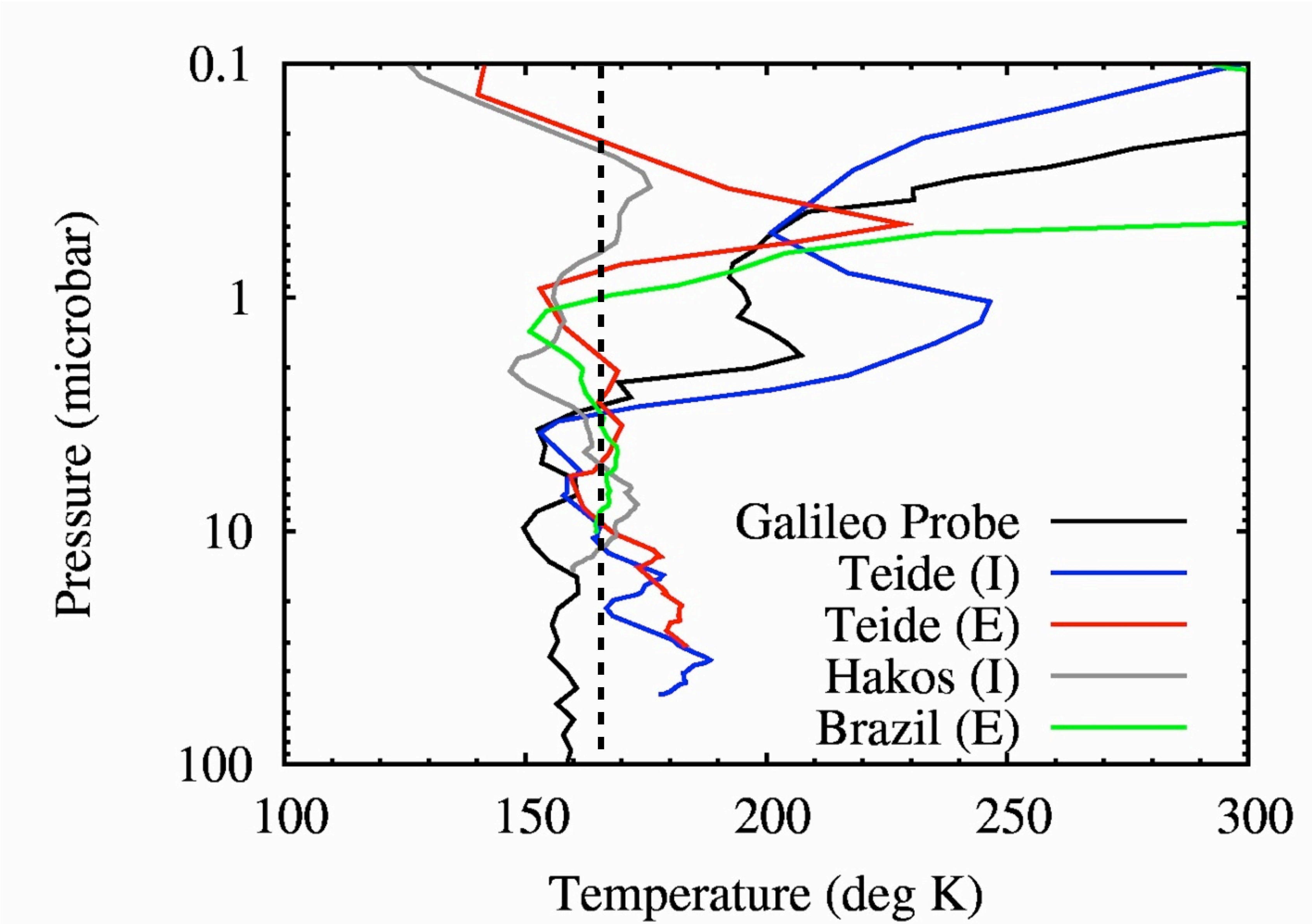

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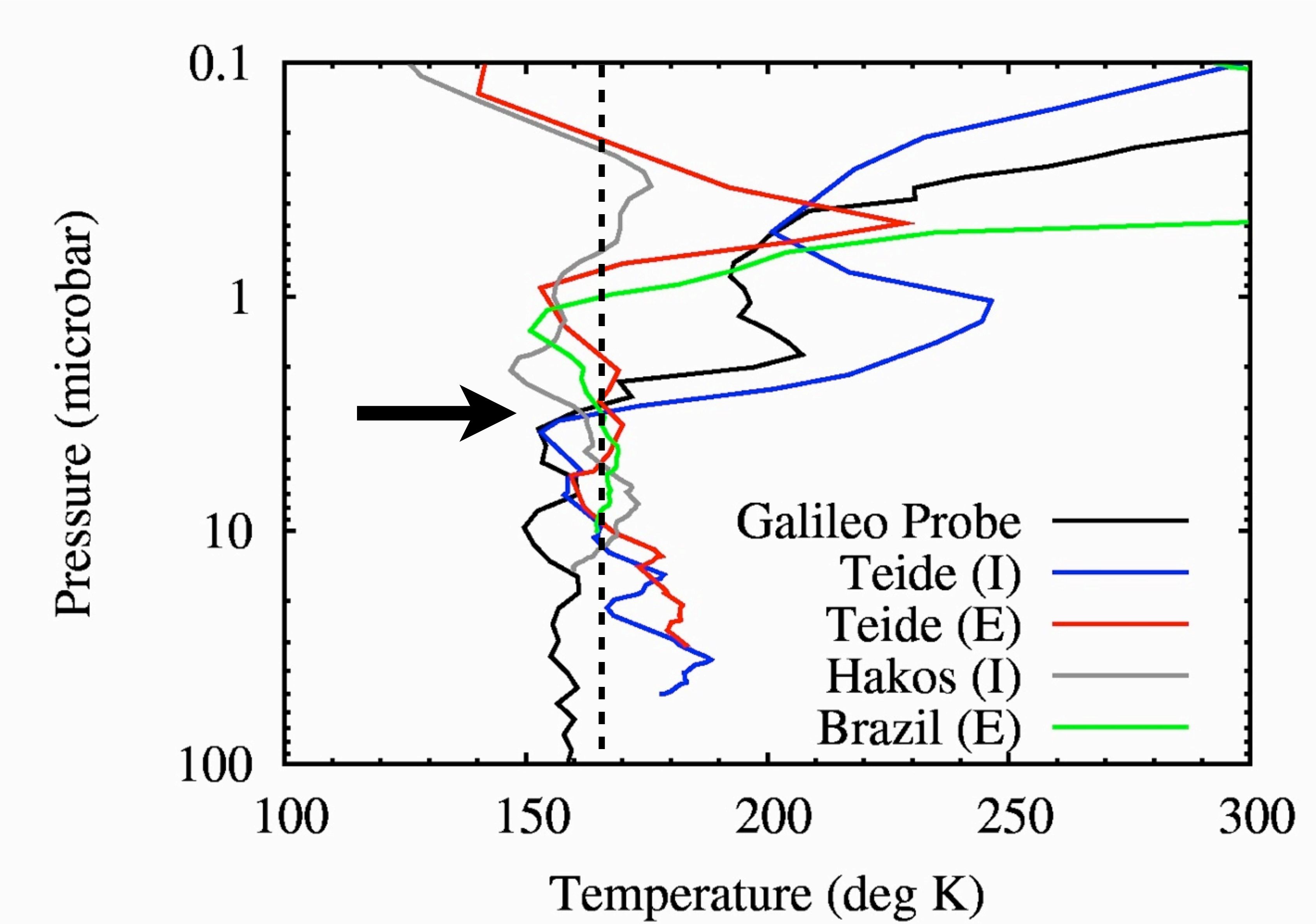
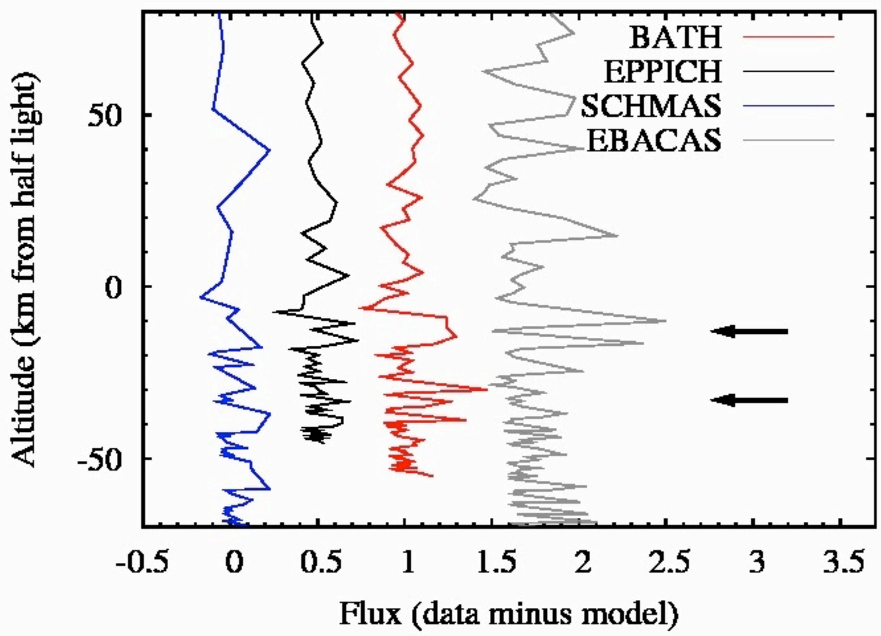
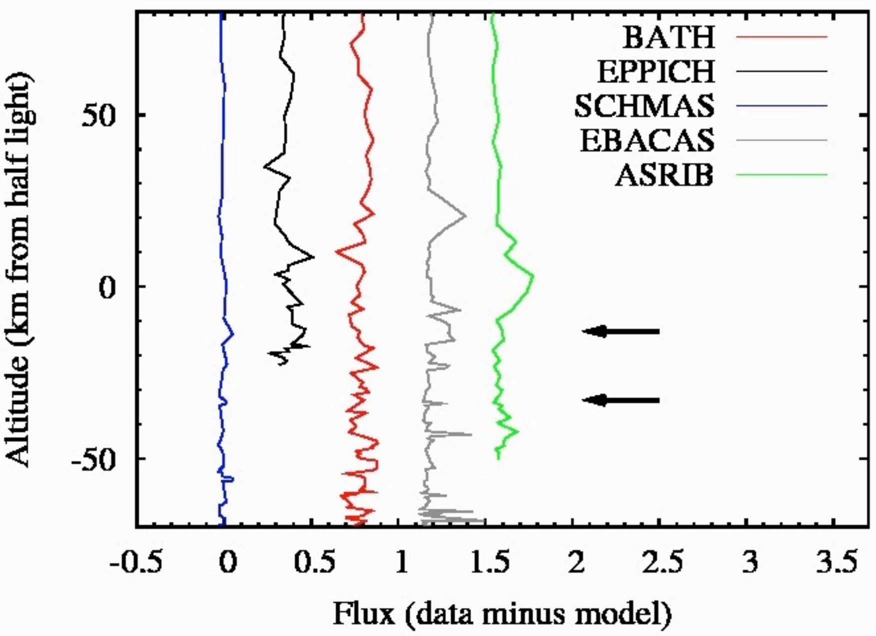


Non-isothermal Features >> "Spikes"





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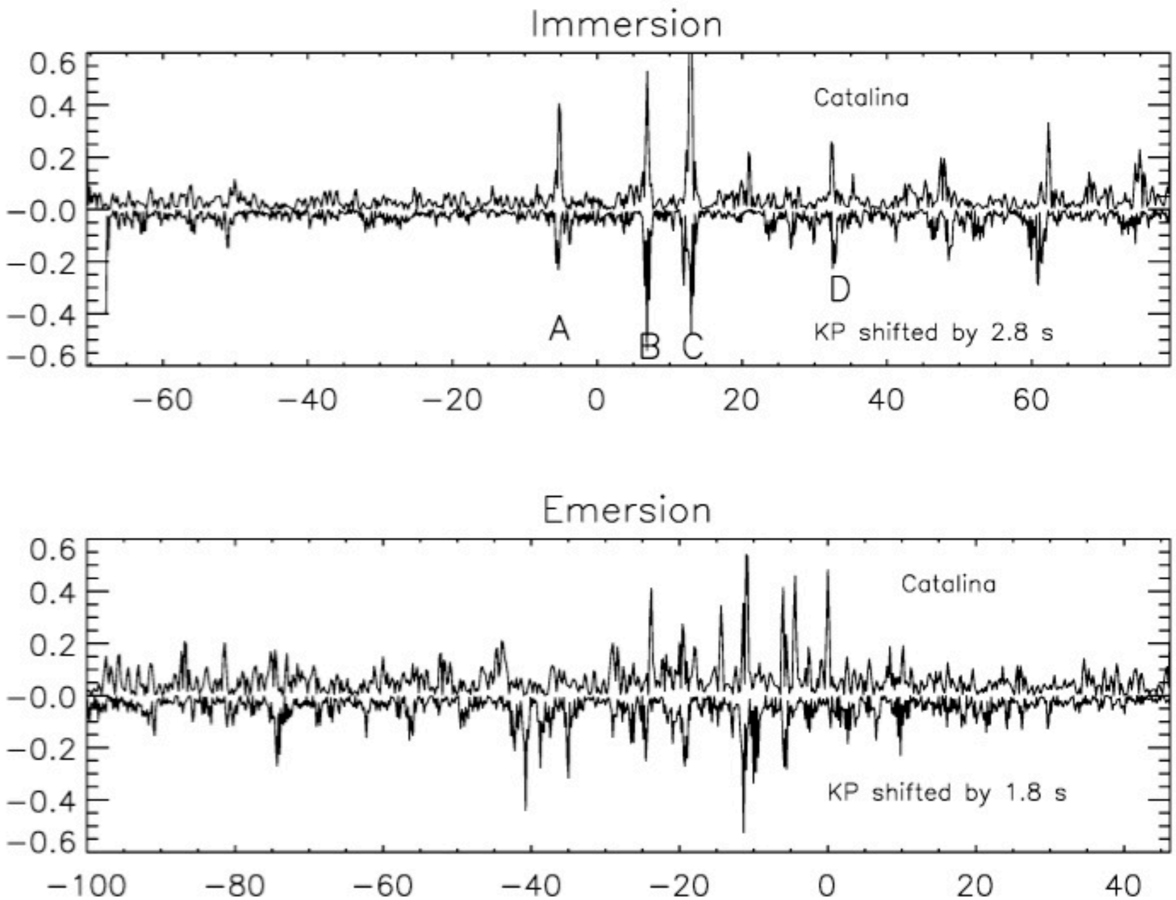
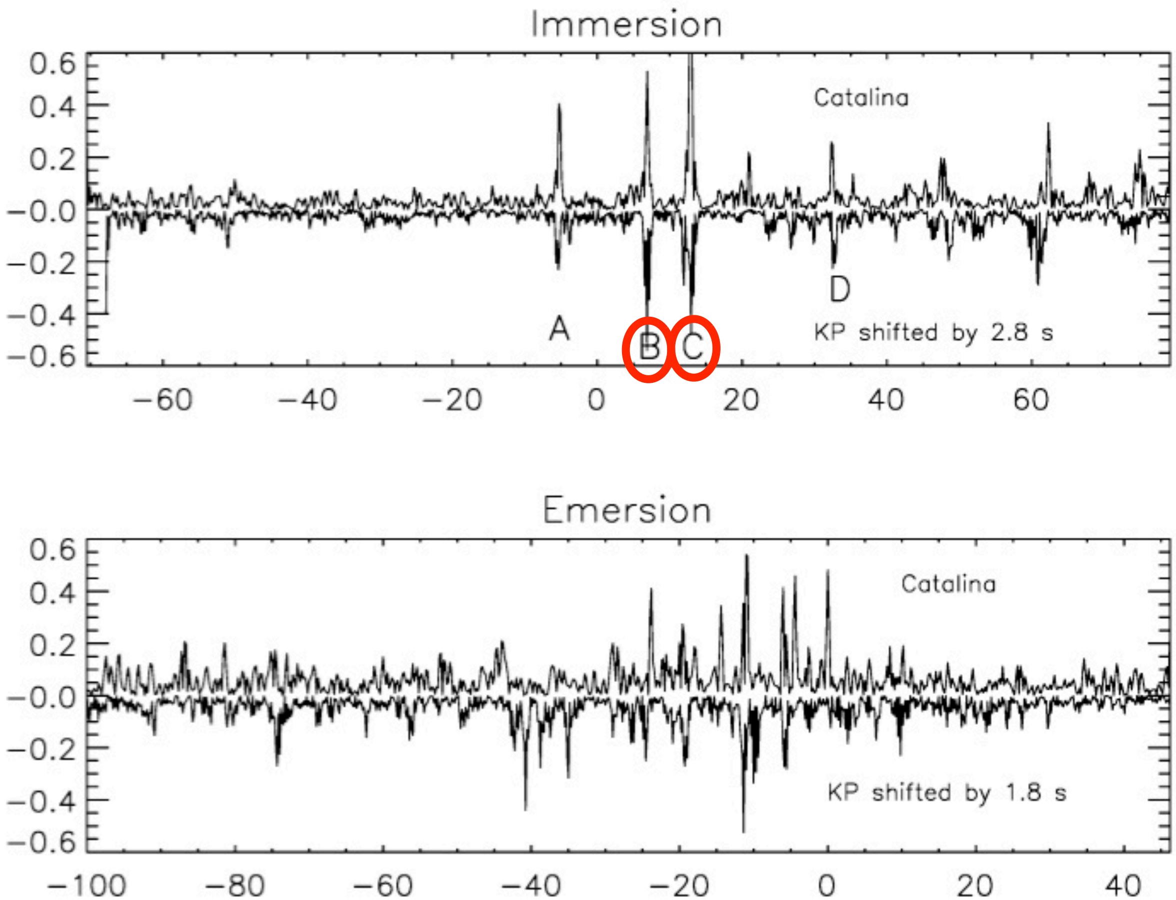


Fig. 9. Filtered lightcurves at highest frequency for Catalina and Kitt Peak. (Upper panel) For ingress, a shift of Δt = 2.8 s has been imposed on the Kitt Peak curve, represented upside down for better viewing. Peaks A, B, C, and D are shown on both signals (see text). (Lower panel) For egress, the Kitt Peak curve has been shifted by Δt = 1.8 s.

HIP 9369 occ., Raynaud et al, Icarus, 2003

Non-isothermal Features >> "Spikes"



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HIP 9369 occ., Raynaud et al, Icarus, 2003

Scientific Results

- 15 lightcurves from 9 groups
- Atmospheric H/T estimates from 9 lightcurves in very good agreement with previous work
- search for non-isothermal features (``spikes'') possible in the 9 lightcurves above
-features positively identified at ingress but not at egress; correlate with features recorded previously; spatial and/or temporal variability implied
- 4 lightcurves inverted to give Press-Temp profiles; these agree in the 3-10 μbar range and with Galileo Probe data
- No evidence of significant perturbations from July 2009 impact, consistent with atm. models

Lessons Learned

- What did we do right?
- What did we do wrong?
- how can we do better in the future?

Post-campaign:

DATA GATHERING + REDUCTION
DATA ANALYSIS - FITTING/
COMPARISON TO MODELS/PAST
WORK, SEARCH FOR NEW FEATURES
WRITING UP OF RESULTS!

Problems along the way..

No video results reduced - considered too time-consuming

Obs. with high f/ratio proved easier to reduce - increases contrast and separation from bright features on planet (eg GRS)

most of the analysis was done WYOC

Calar Alto lightcurves did not give a satisfactory P-T profile due to high (scintillation?) noise

some things were left undone (more rigorous comparison with β Sco results; re-reduction of Calar-Alto data)

A&A 556, A118 (2013)
DOI: 10.1051/0004-6361/201321811

Astronomy & Astrophysics

The occultation of HIP 107302 by Jupiter★

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[11] Astronomical Union of Sparta, 23100 Sparta, Greece
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Received 1 May 2013 / Accepted 21 June 2013

ABSTRACT

Aims. Occultations of bright stars by planets provide information on the state of their atmospheres. An occultation of the bright star 45 Capricornii (HIP 107302) by Jupiter occurred on the night of 3/4 August 2009.

Methods. The event was observed at multiple sites in Europe, Africa and South America and with instruments ranging in aperture from 0.4 m to 2.2 m. All observations, except one, were carried out in methane absorption bands centred at 0.89 μm and 2.2 μm to minimise the planetary contribution to the measured stellar flux. Following the application of special post-processing techniques, differential photometry was performed. Nearby bright satellites were used as reference sources.

Results. Fifteen lightcurves were obtained. The photometric time series for fourteen of these were fitted to a model atmosphere of constant scale height (H). Estimates of H for most lightcurves lie within the range 20−30 km with an inverse-variance weighted mean of 23.6 ± 0.4 km, in good agreement with previous works. A comparison between half-light times at ingress and at egress implies an astrometric offset of 10−15 mas in Jupiter's position relative to the star. Five lightcurves – two for ingress and three for egress – were numerically inverted into profiles of pressure versus temperature. Isothermal, mutually consistent behaviour is observed within the pressure range 3−10 μbar. The inferred temperature of 165 ± 5 K is consistent with, but slightly higher than, that measured by the *Galileo* Probe at 5° S latitude in 1995 at the same pressure level. Subtraction of isothermal models for nine cases show the presence of at least one, and possibly two, non-isothermal layers a few tens of km below the half-light datum. Their altitudes are similar to those of features previously reported during the occultation of HIP 9369 in 1999. Our temperature estimates are consistent with the expected small magnitude of the perturbation of the atmosphere following the impact event on Jupiter in July 2009.

Key words. planets and satellites: atmospheres – planets and satellites: individual: Jupiter – occultations – methods: observational – methods: data analysis

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Astronomy & Astrophysics

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9 Observatoire de Paris/LESIA, bâtiment 10, 92195 Meudon Cedex, France
10 IAS Observatory, 9000 Hakos, Namibia
11 Astronomical Union of Sparta, 23100 Sparta, Greece

➡We did do science!

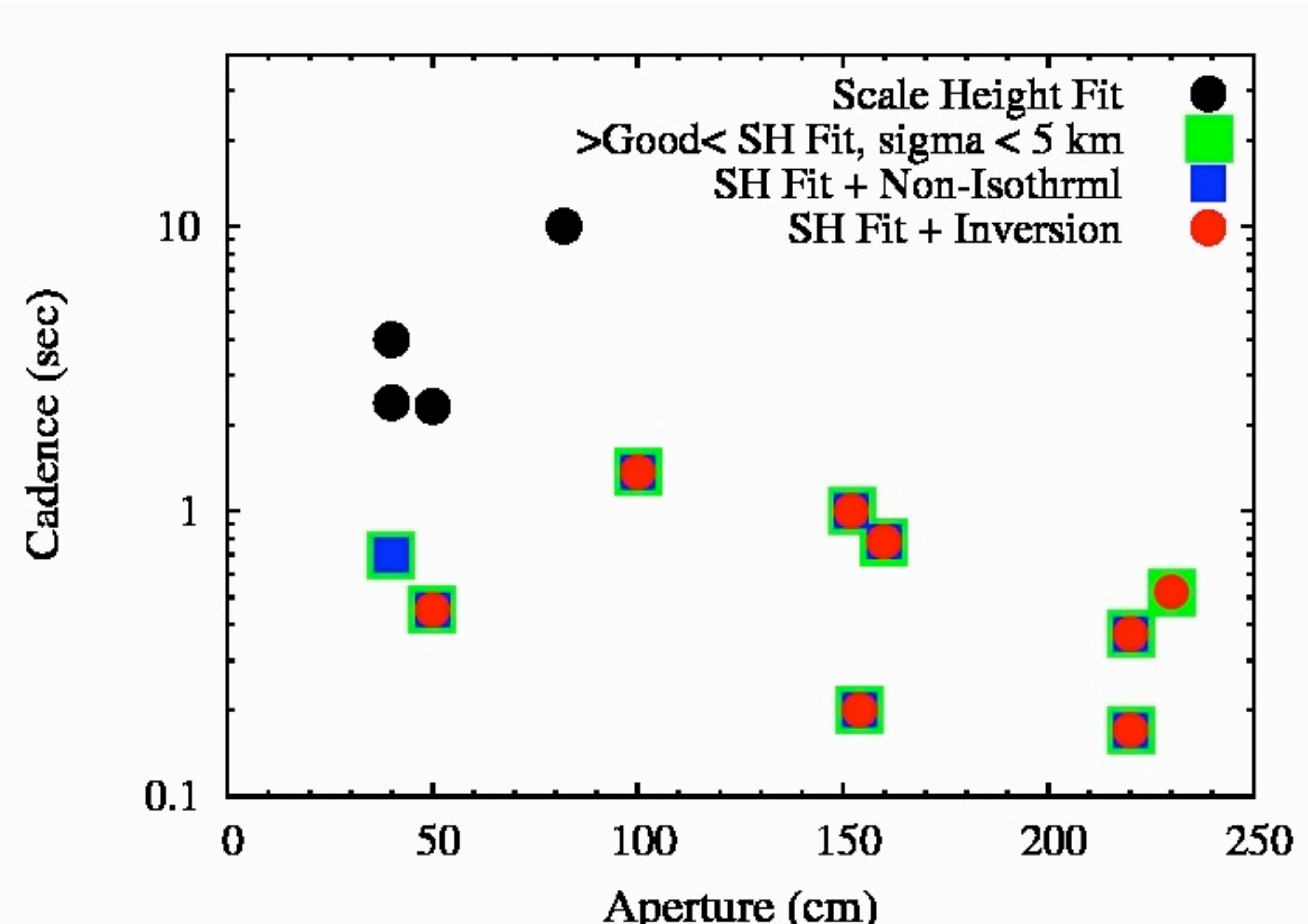
➡time from obs. to pub. was 4 yr, (not bad; β Sco: 1-3 yr, re-analysed in 2004; SAO 78505: 6 yr, HIP 9369: 4 yr)

ABSTRACT

Methods. The event was observed at multiple sites in Europe, Africa and South America and with instruments ranging in aperture from 0.4 m to 2.2 m. All observations, except one, were carried out in methane absorption bands centred at 0.89 μm and 2.2 μm to minimise the planetary contribution to the measured stellar flux. Following the application of special post-processing techniques,
of 23.6 ± 0.4 km, in good agreement with previous works. A comparison between half-light times at ingress and at egress implies an astrometric offset of 10–15 mas in Jupiter's position relative to the star. Five lightcurves – two for ingress and three for egress – were numerically inverted into profiles of pressure versus temperature. Isothermal, mutually consistent behaviour is observed within the pressure range 3–10 μbar. The inferred temperature of 165 ± 5 K is consistent with, but slightly higher than, that measured by the *Galileo* Probe at 5° S latitude in 1995 at the same pressure level. Subtraction of isothermal models for nine cases show the presence of at least one, and possibly two, non-isothermal layers a few tens of km below the half-light datum. Their altitudes are similar to those of features previously reported during the occultation of HIP 9369 in 1999. Our temperature estimates are consistent with the expected small magnitude of the perturbation of the atmosphere following the impact event on Jupiter in July 2009.

Key words. planets and satellites: atmospheres – planets and satellites: individual: Jupiter – occultations – methods: observational – methods: data analysis

How do aperture/cadence affect data quality?



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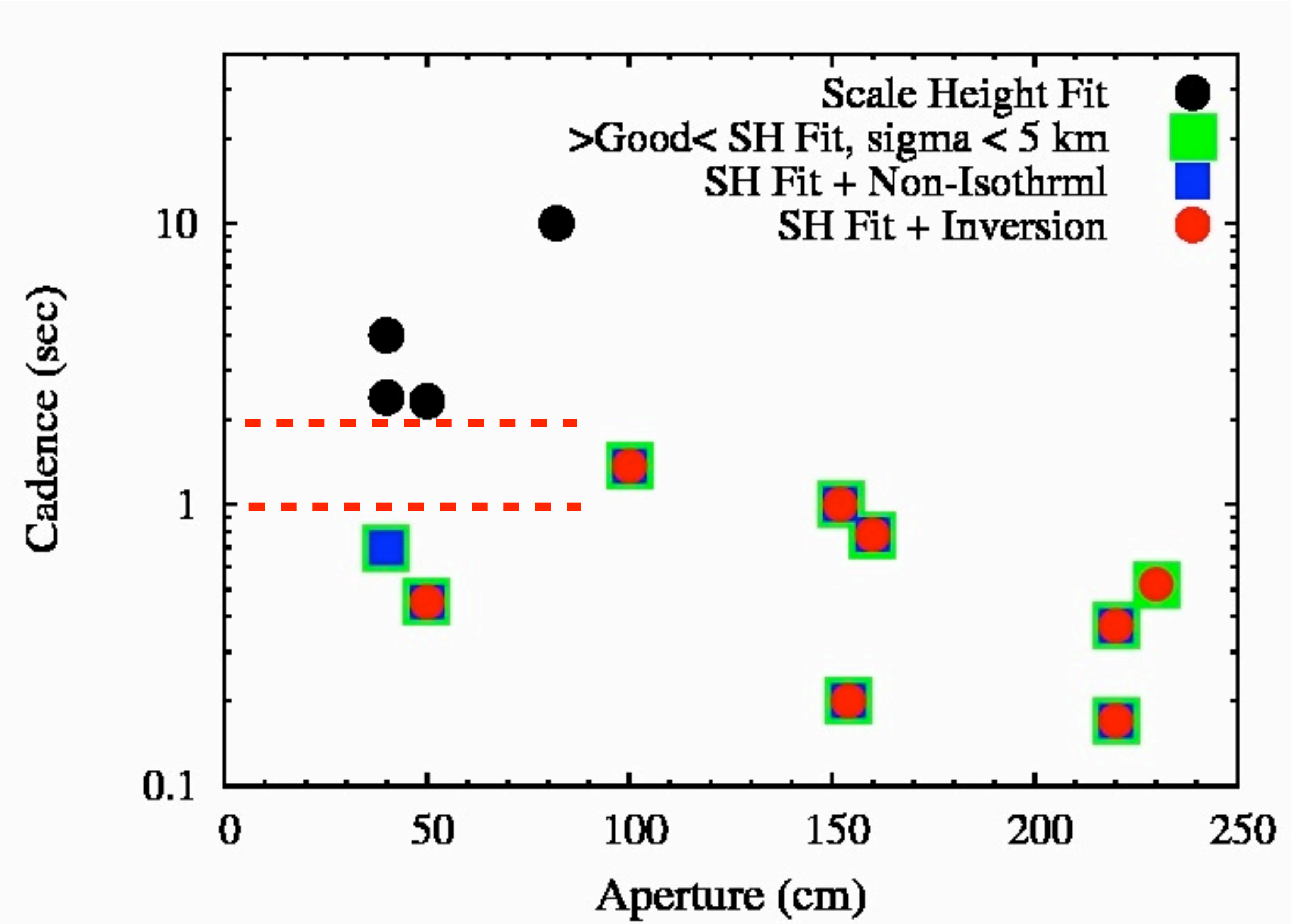


Next time:

- organise better pre-event: divide/assign responsibilities; invite experts to apply their state-of-the-art codes
- advise observers on how to maximise data quality: increase cadence, use CCD (or better CCD), increase f-ratio
- remember: technology only gets better/cheaper with time!

Future opportunities

HIP 54057

-K0, V=7.25, V-I = 1.02, K=4.9

-12 April 2016 (+ Ganymede occ. 13 April)

-visible from Asia, Oceania, E Africa & SE Europe

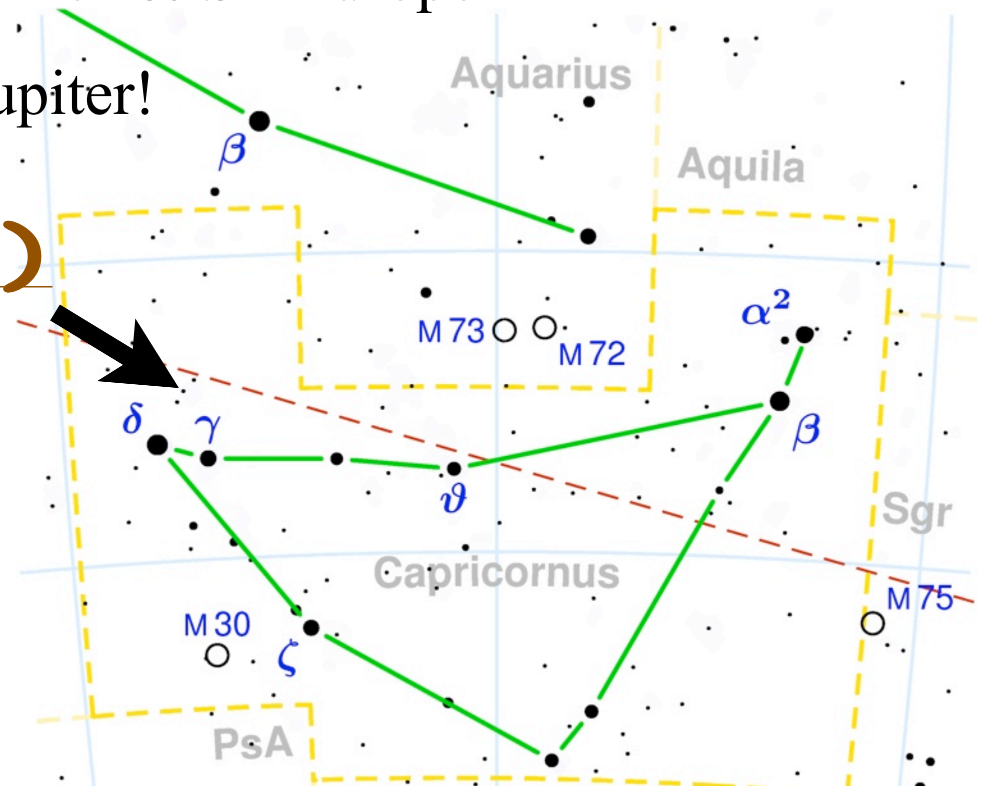
-coincides with Juno arrival at Jupiter!

44 Cap (HIP 107232)

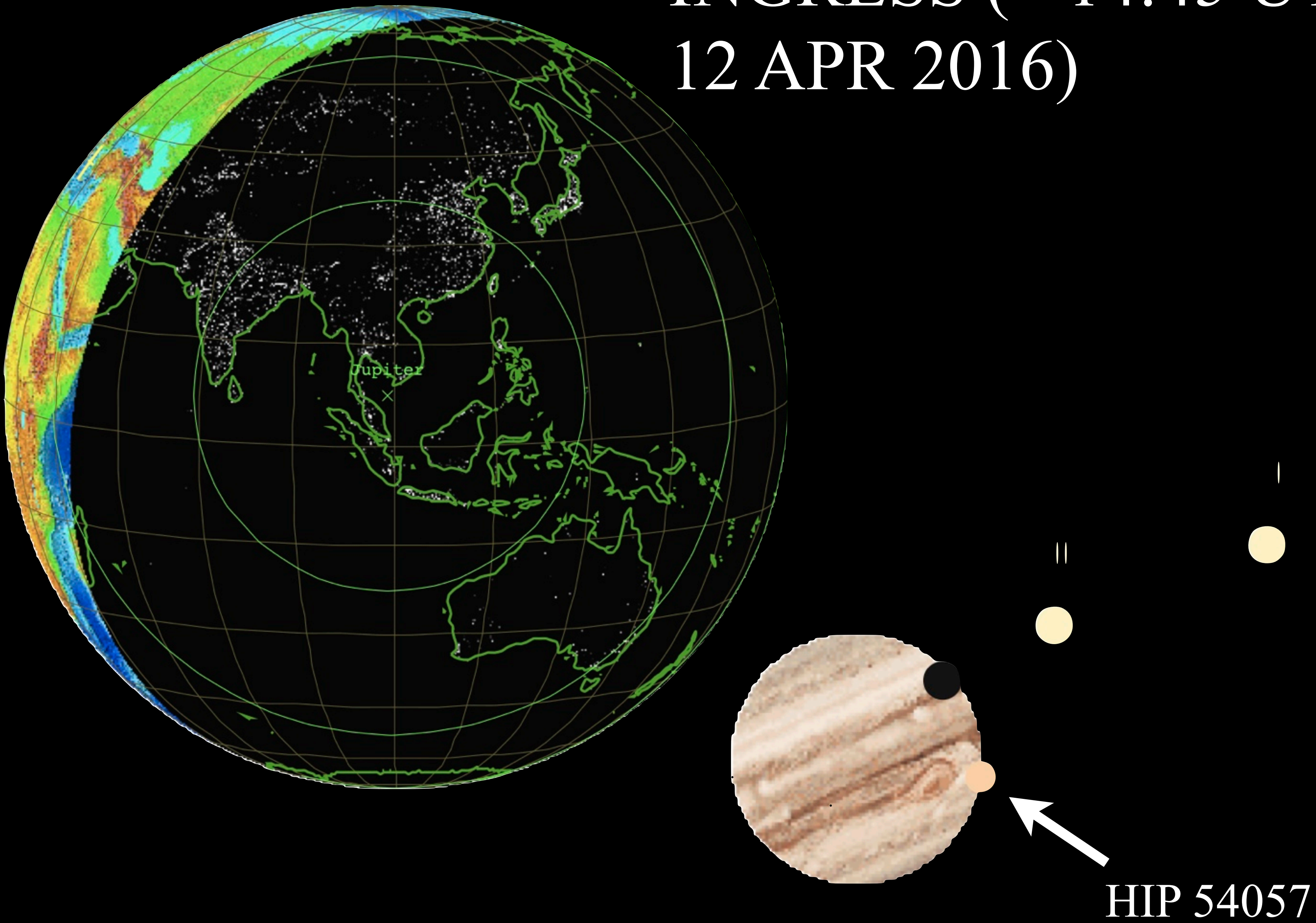
-A9/F0, V=5.9, K=5.2

-2 April 2021 (+ Io occ.)

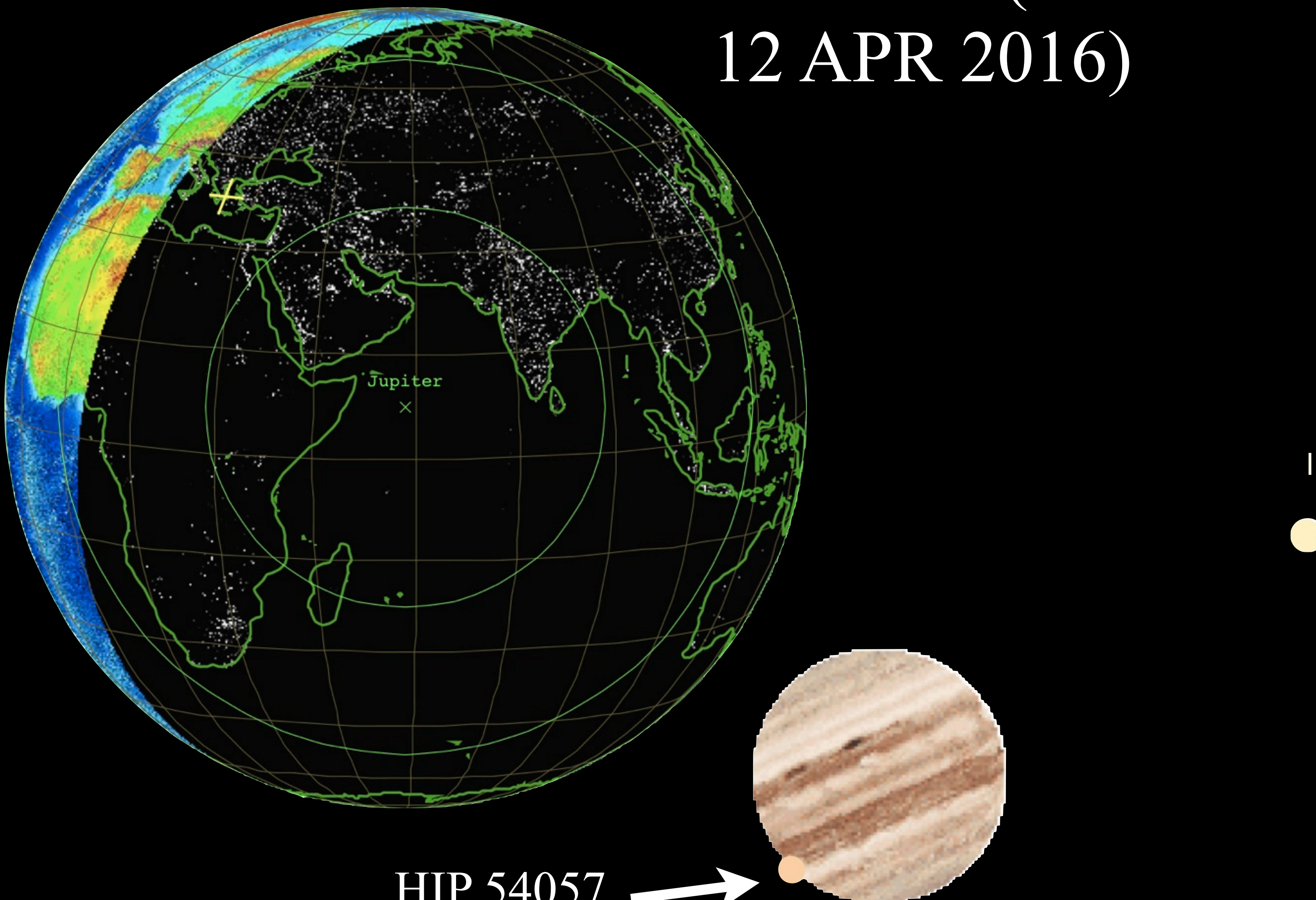
- visible from the Americas



INGRESS (~ 14:45 UT, 12 APR 2016)



EGRESS (~ 17:45 UT, 12 APR 2016)



Thank you for your attention!