

# Enriched Heavy Oxygen on Mars Depends on Time of Day



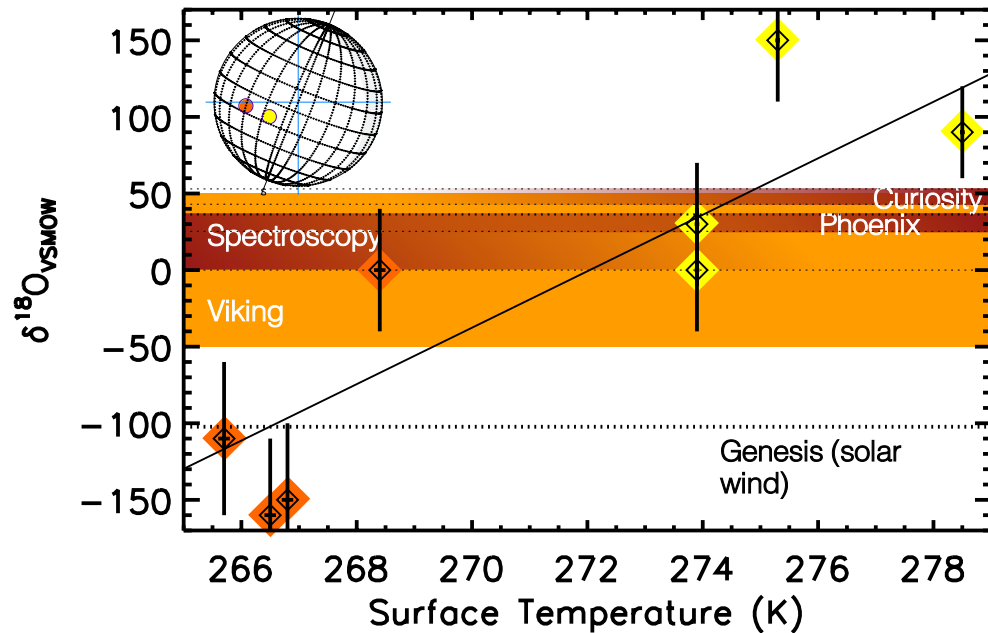
**What is the science question?** How much atmosphere did Mars once have?

**What were your findings?** We detected clear evidence for the loss of the majority of Mars' ancient carbon dioxide atmosphere, beyond previous measurements.

**What was the impact?** The primary clue to the loss of Mars atmosphere is enriched heavy isotopes in the atmosphere. We found a pattern of variation that could explain why past measurements all disagree with each other.

Livengood, T. A., T. Kostiuk, T. Hewagama, R. L. Smith, K. E. Fast, J. N. Annen, and J. D. Delgado (2020). Evidence for Diurnally Varying Enrichment of Heavy Oxygen in Mars Atmosphere. *Icarus* 335, id 113387, doi: 10.1016/j.icarus.2019.113387.

**Why does it matter to non-scientists?** Mars is the most Earthlike other planet we have to compare to ourselves, with signs it was once even more Earthlike. Understanding what it once was like and how it changed is essential to understanding the history of our own world, and can be a guide to understanding planets of other stars.



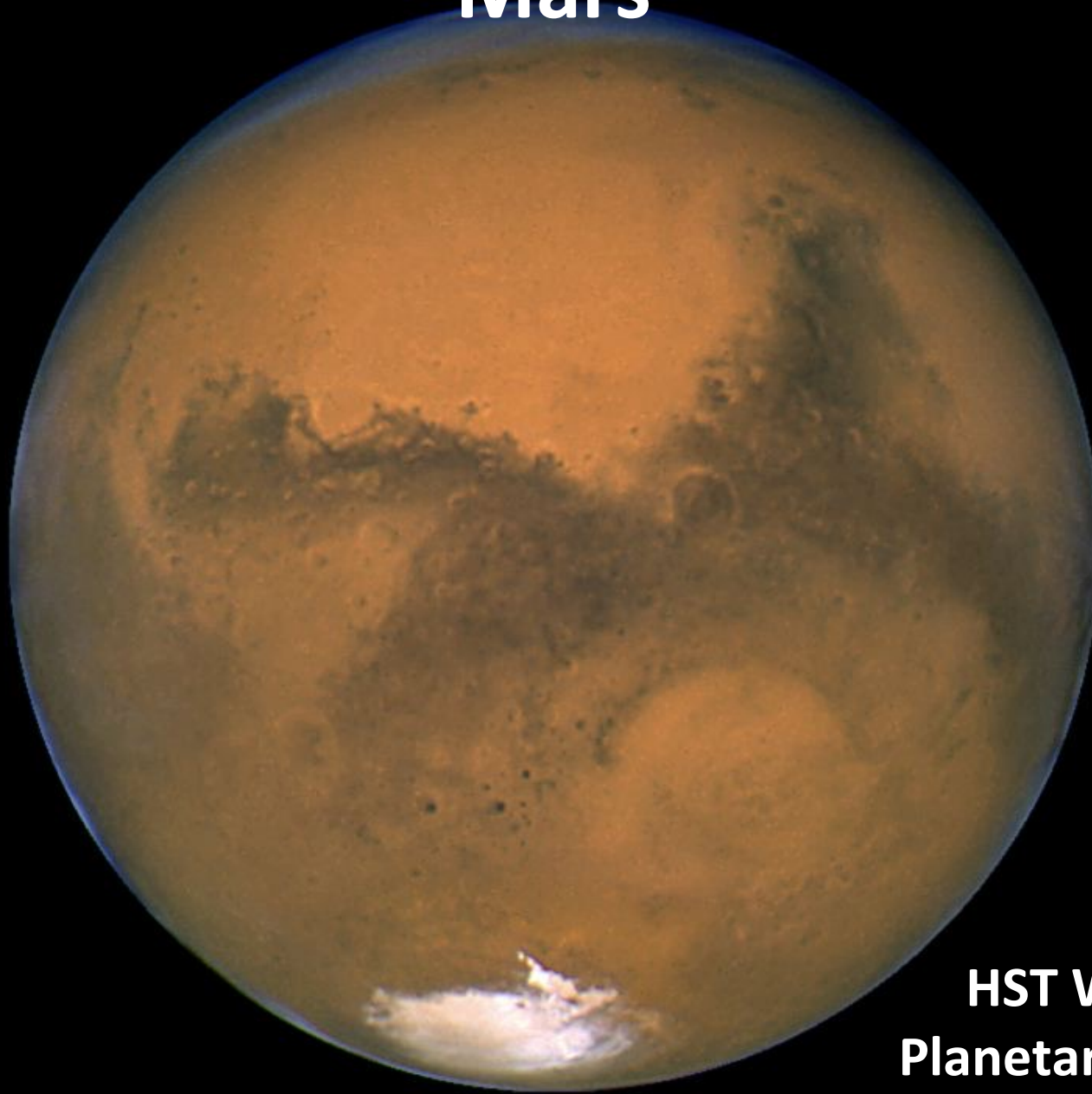
# Where Has All the Atmosphere Gone?



...long time passing...

Dr. Tim Livengood  
CRESST / University of Maryland / GSFC

# Mars



HST, 27 Aug 2003

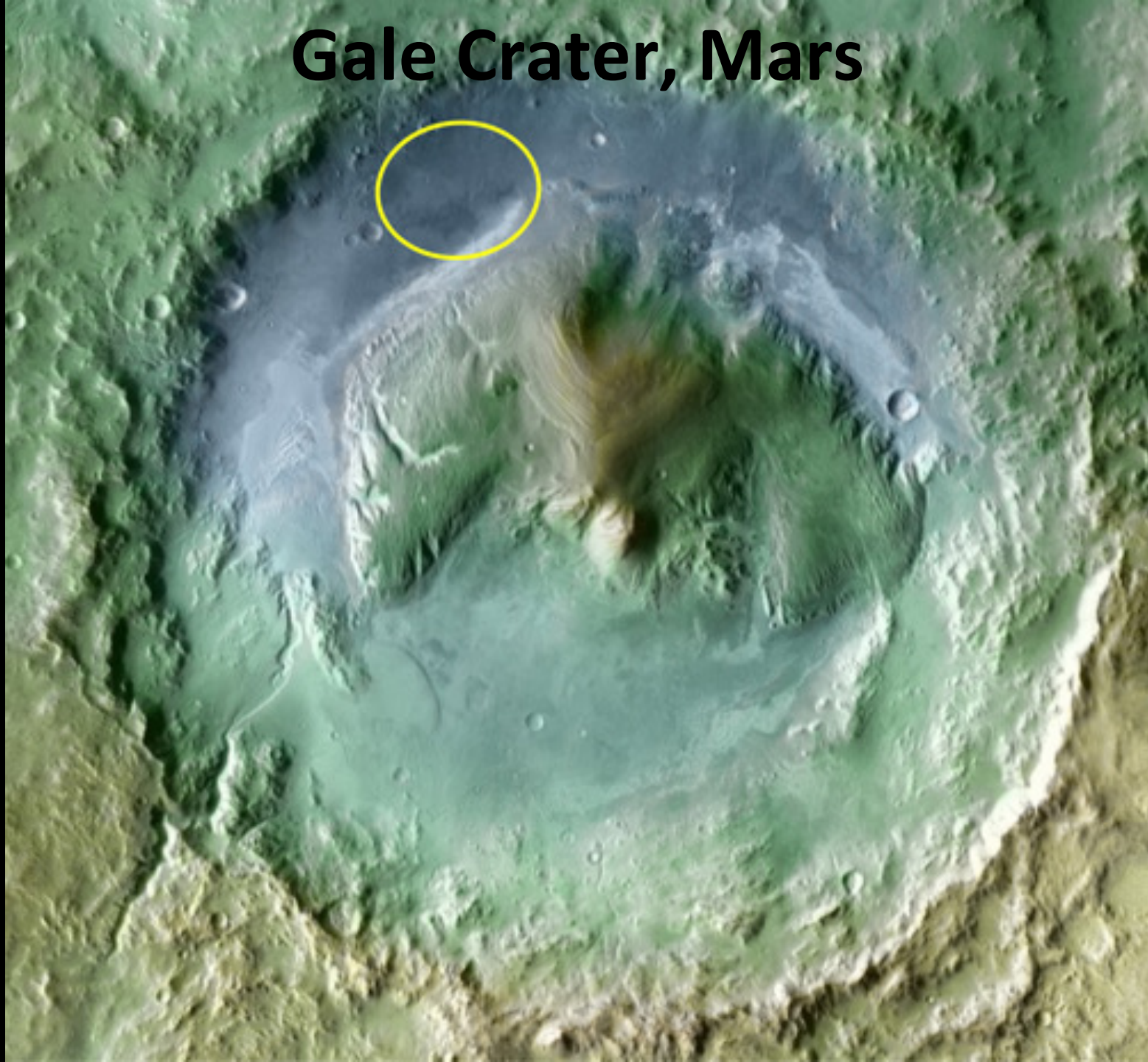
HST Wide-Field /  
Planetary Camera 2  
Bell *et al.*, Cornell U.

# Outflow Channels of Kasei Valles, Mars



NASA/JPL-Caltech/Arizona State University

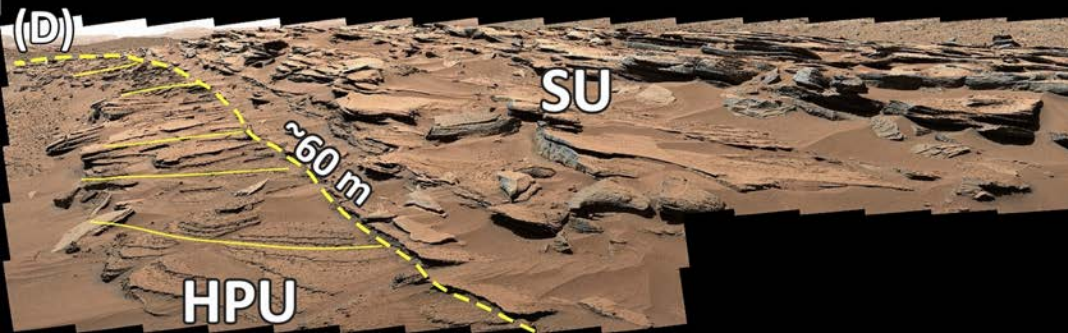
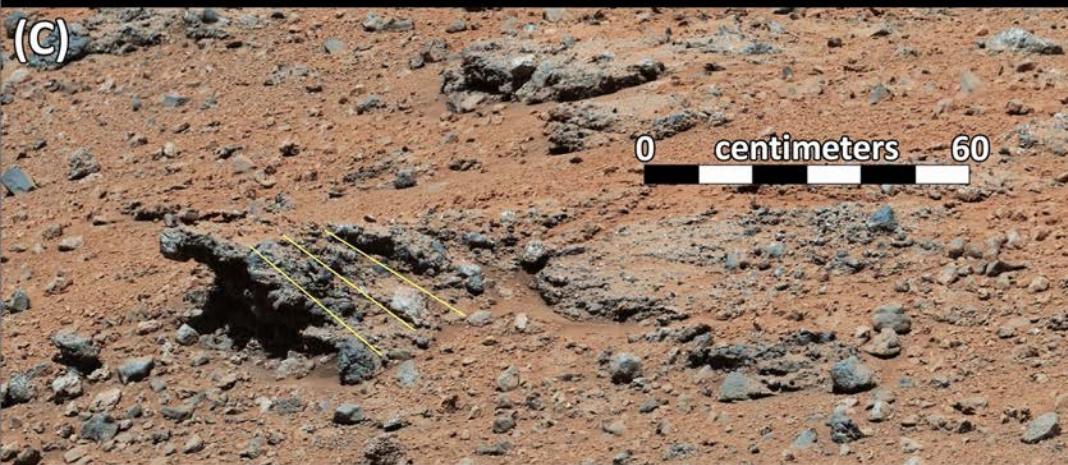
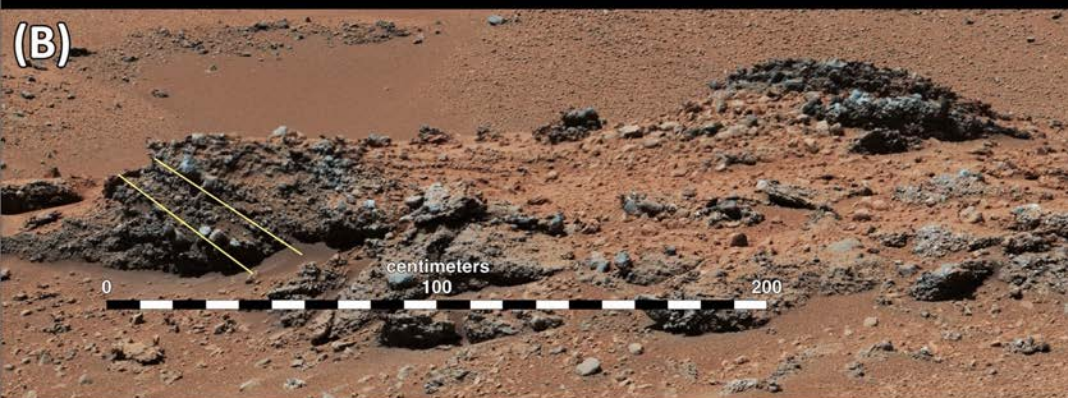
# Gale Crater, Mars



# Gale Crater, Mars

Deposits from giant floods in Gale crater and their implications for the climate of early Mars.

Heydari *et al.*, *Scientific Reports* **10**, #19099, 2020.



**“Old Soaker” → polygonal mud-cracks**



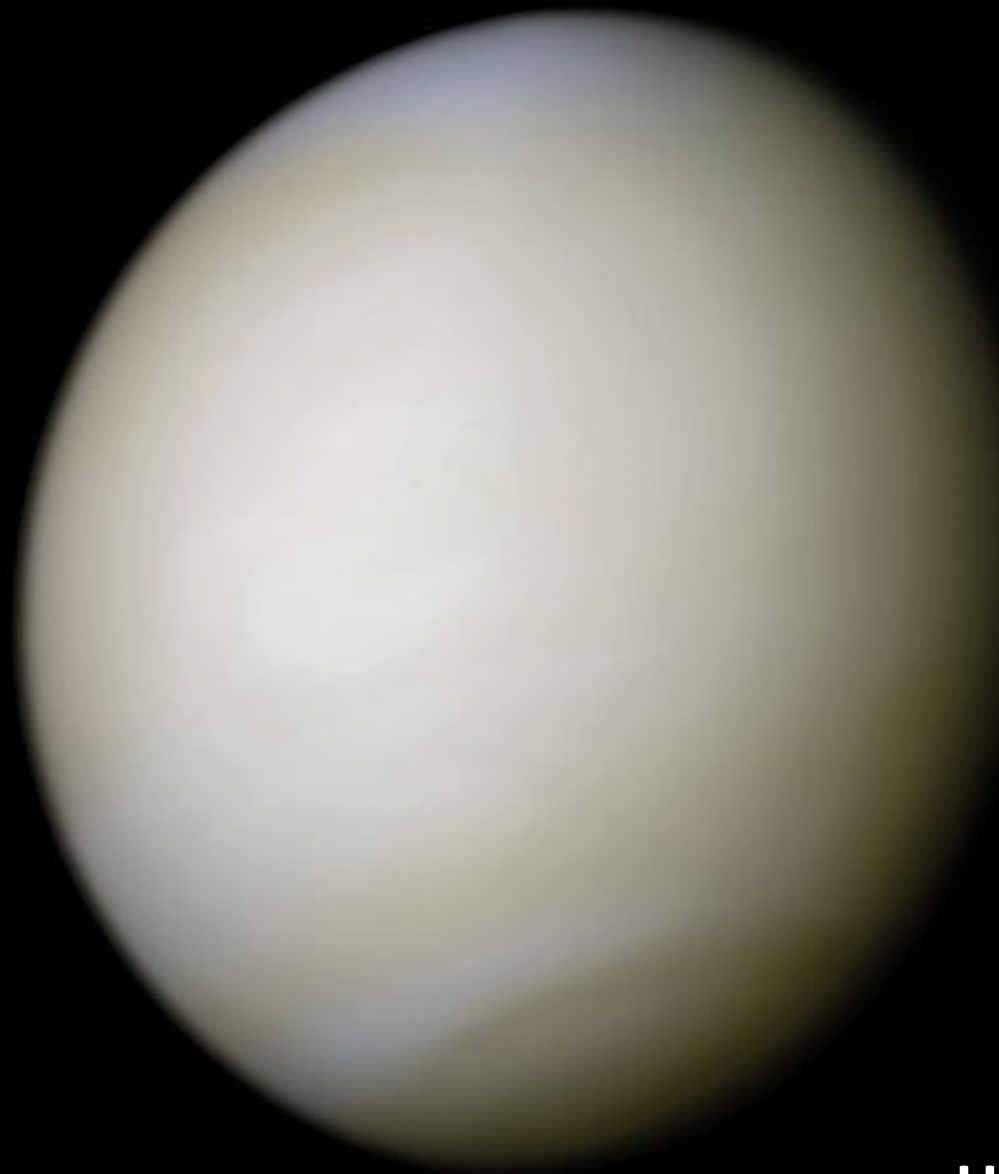
**Mars Science Laboratory Curiosity  
NASA/JPL-Caltech/MSSS**

# Earth (and the Moon)

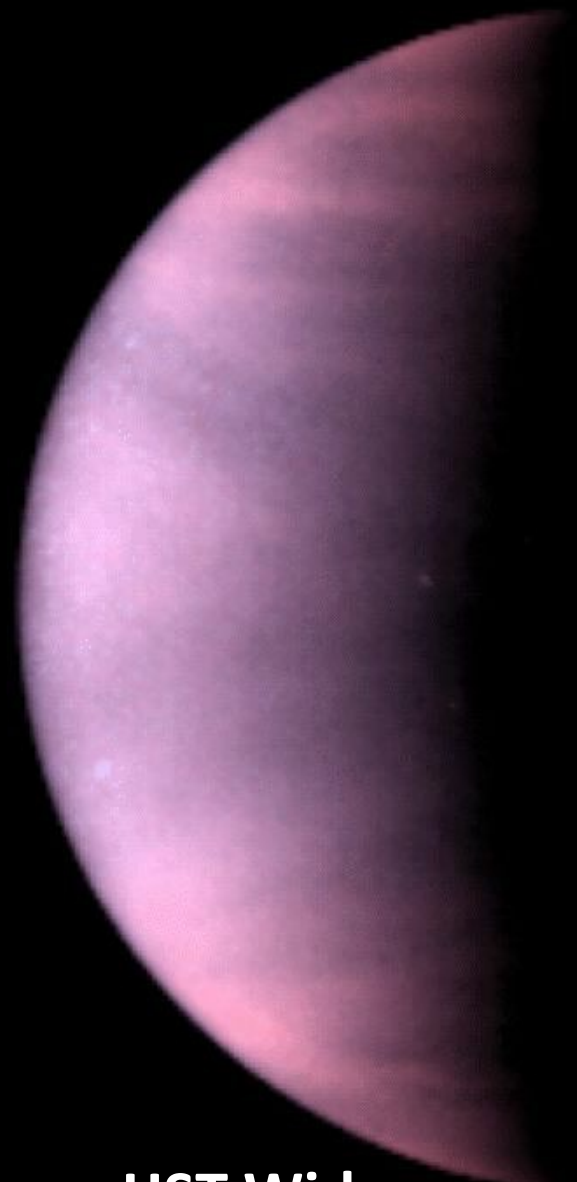




# Venus



**Mariner 10, 1974**



**UV image, HST Wide-Field/Planetary Camera 2, 1995**

# Comparing Air (%)

**Venus**

92 bar

**Earth**

1 bar

**Mars**

0.00636 bar

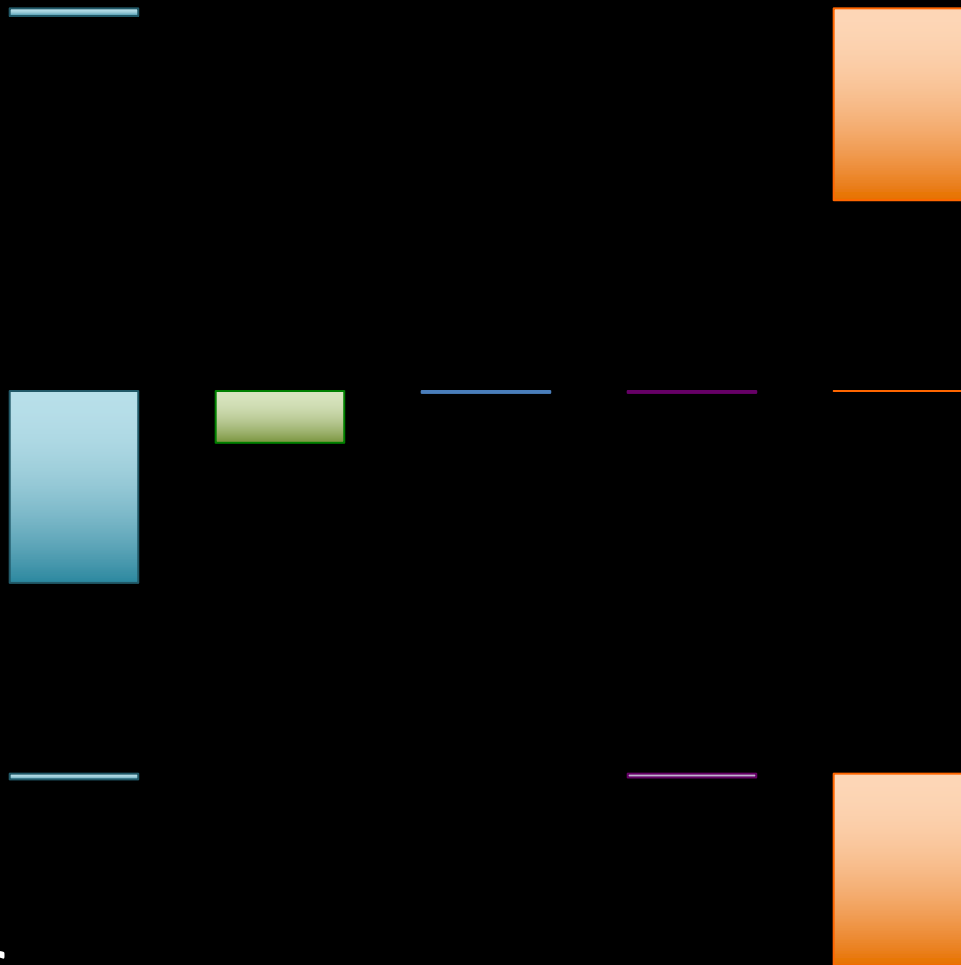
N<sub>2</sub>

O<sub>2</sub>

H<sub>2</sub>O

Ar

CO<sub>2</sub>



# Comparing Air (#mol rel. to Earth)

**Venus**

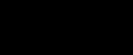
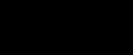
92 bar



157,000

**Earth**

1 bar



**Mars**

0.00636 bar

N<sub>2</sub>

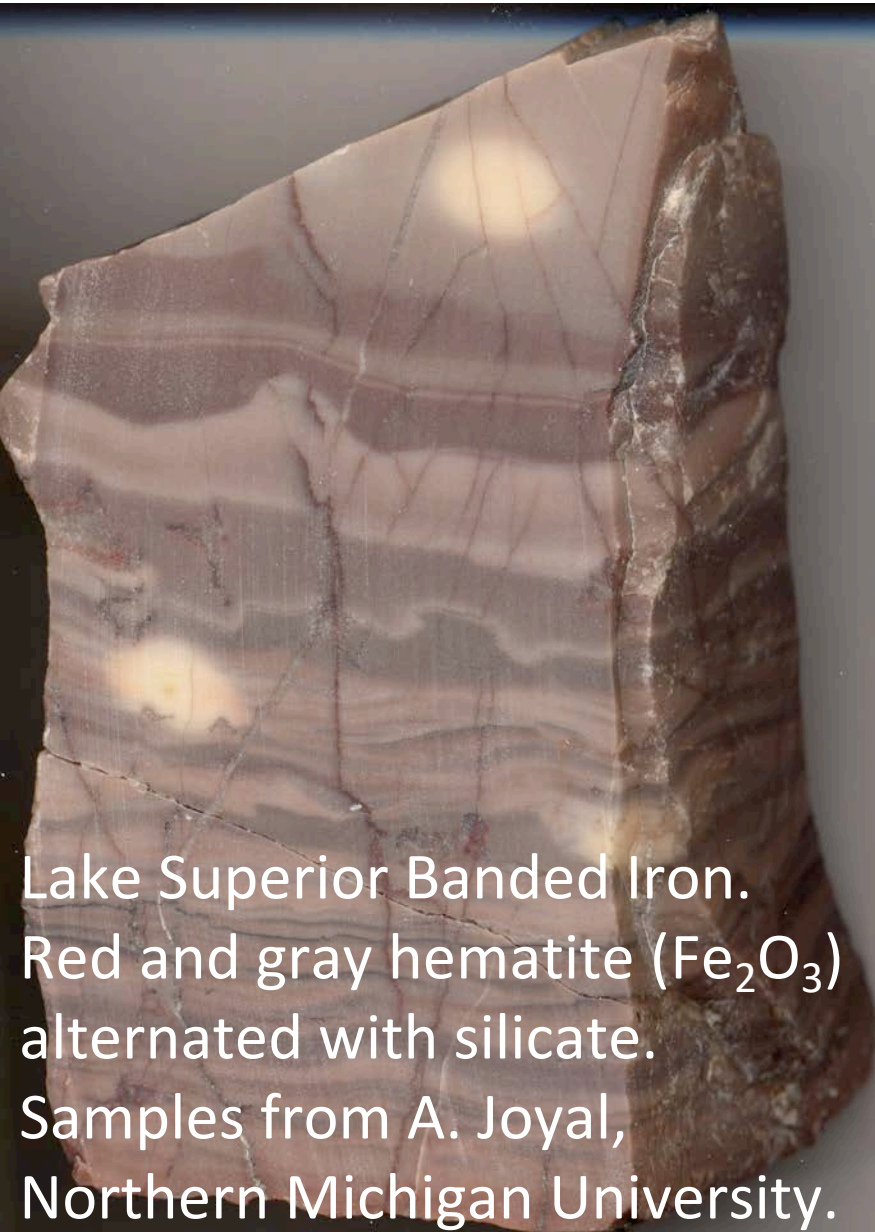
O<sub>2</sub>

H<sub>2</sub>O

Ar

CO<sub>2</sub>

# Earth – Banded Iron



# Earth – Carbonate Rocks

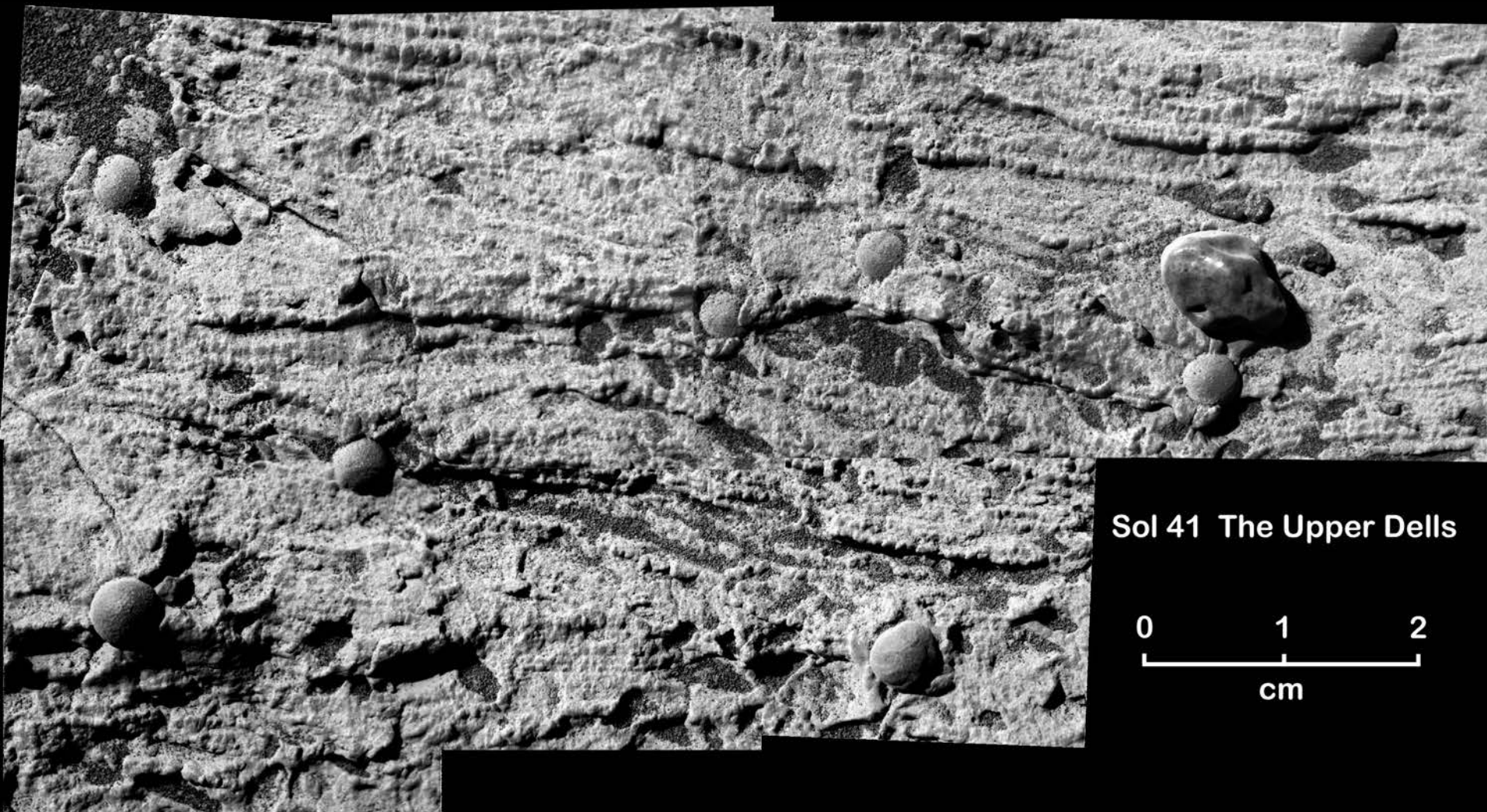
Carbon and oxygen



Hydrogen and oxygen



# "Upper Dells" Clues to Watery History

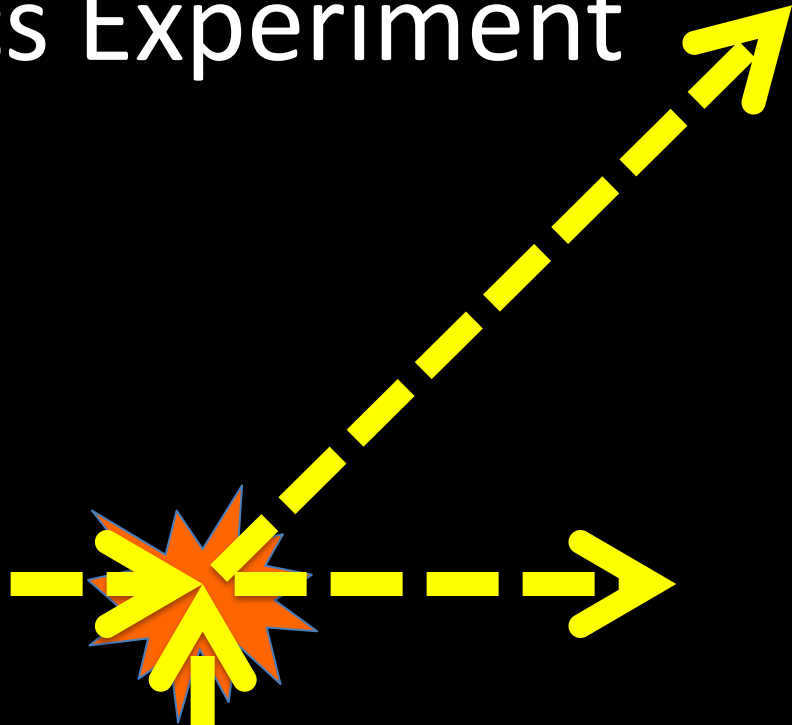


**Mars Exploration Rover Opportunity  
NASA/JPL/Cornell/USGS**

# A Physics Experiment

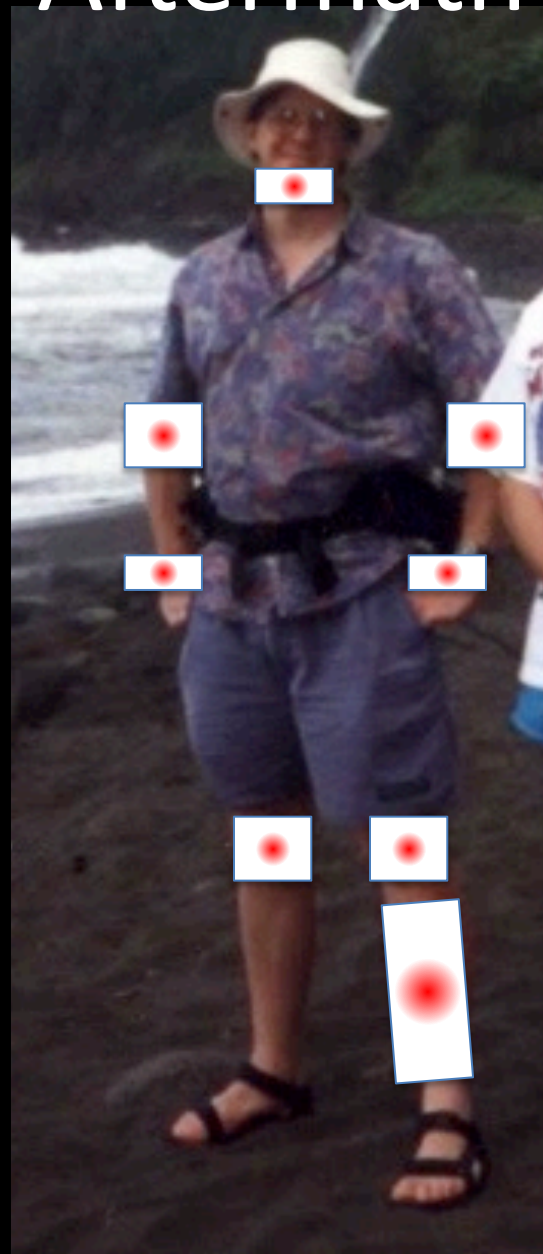


# A Physics Experiment

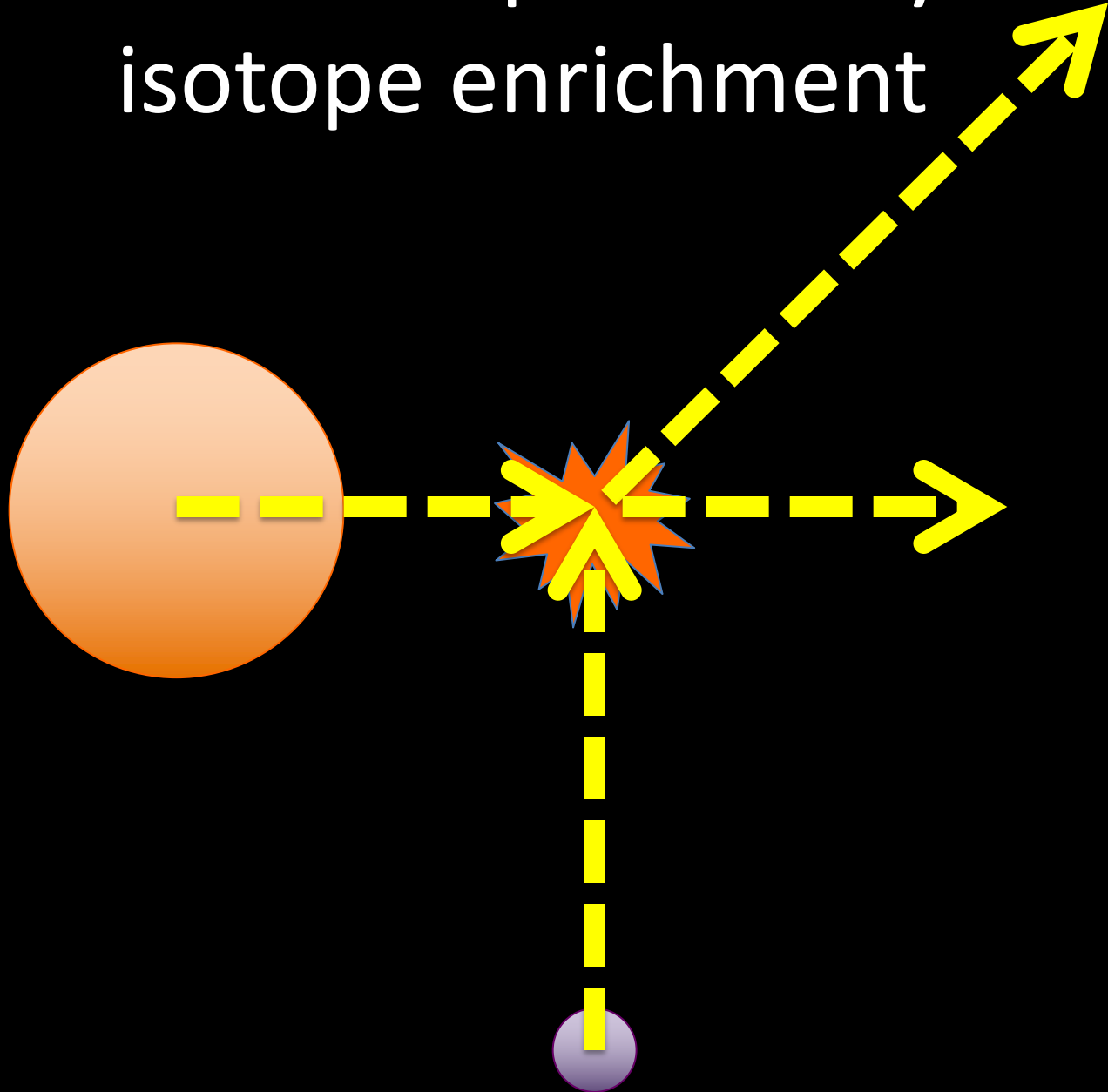




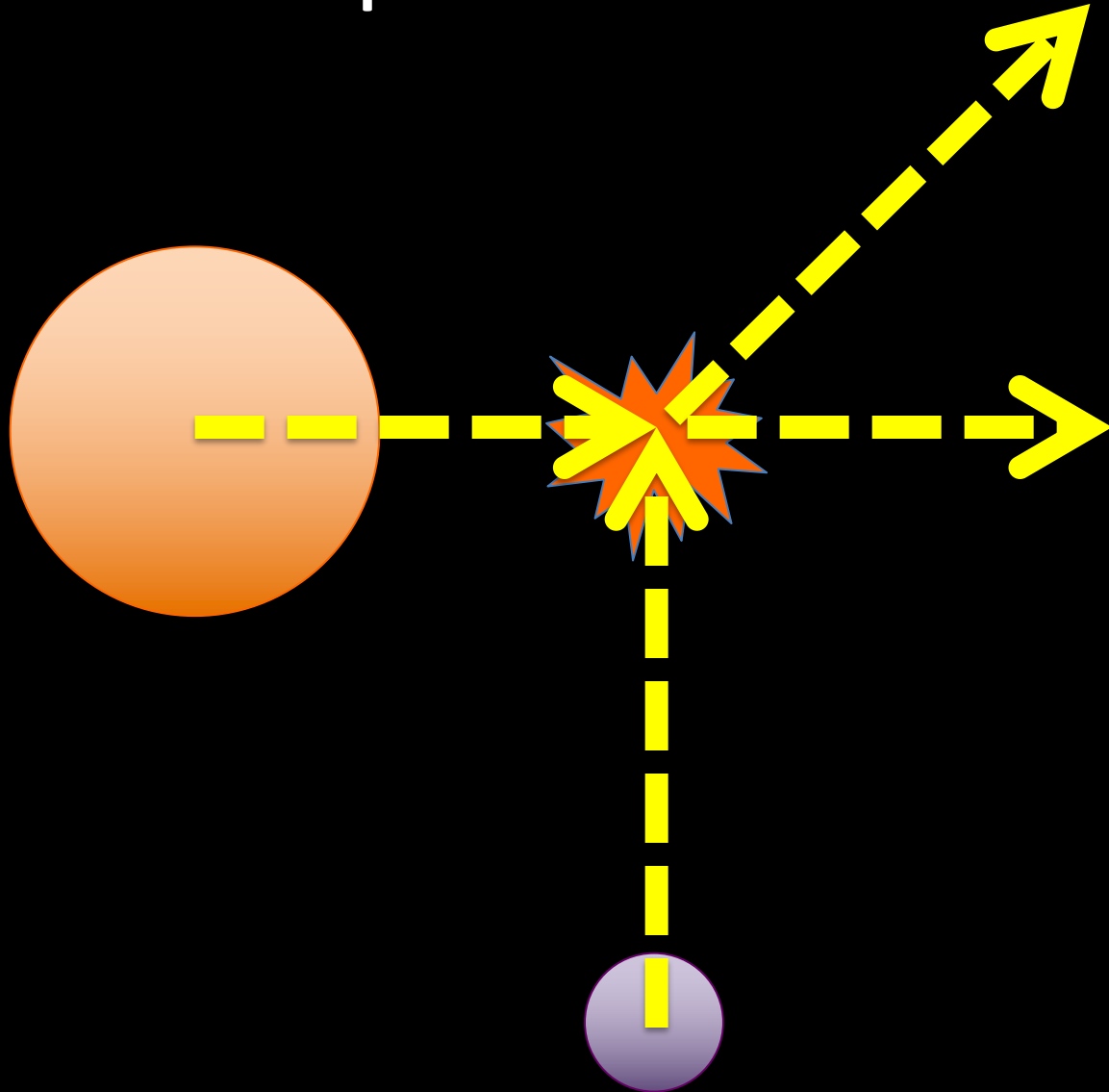
# Aftermath



# Jeans Escape – heavy- isotope enrichment



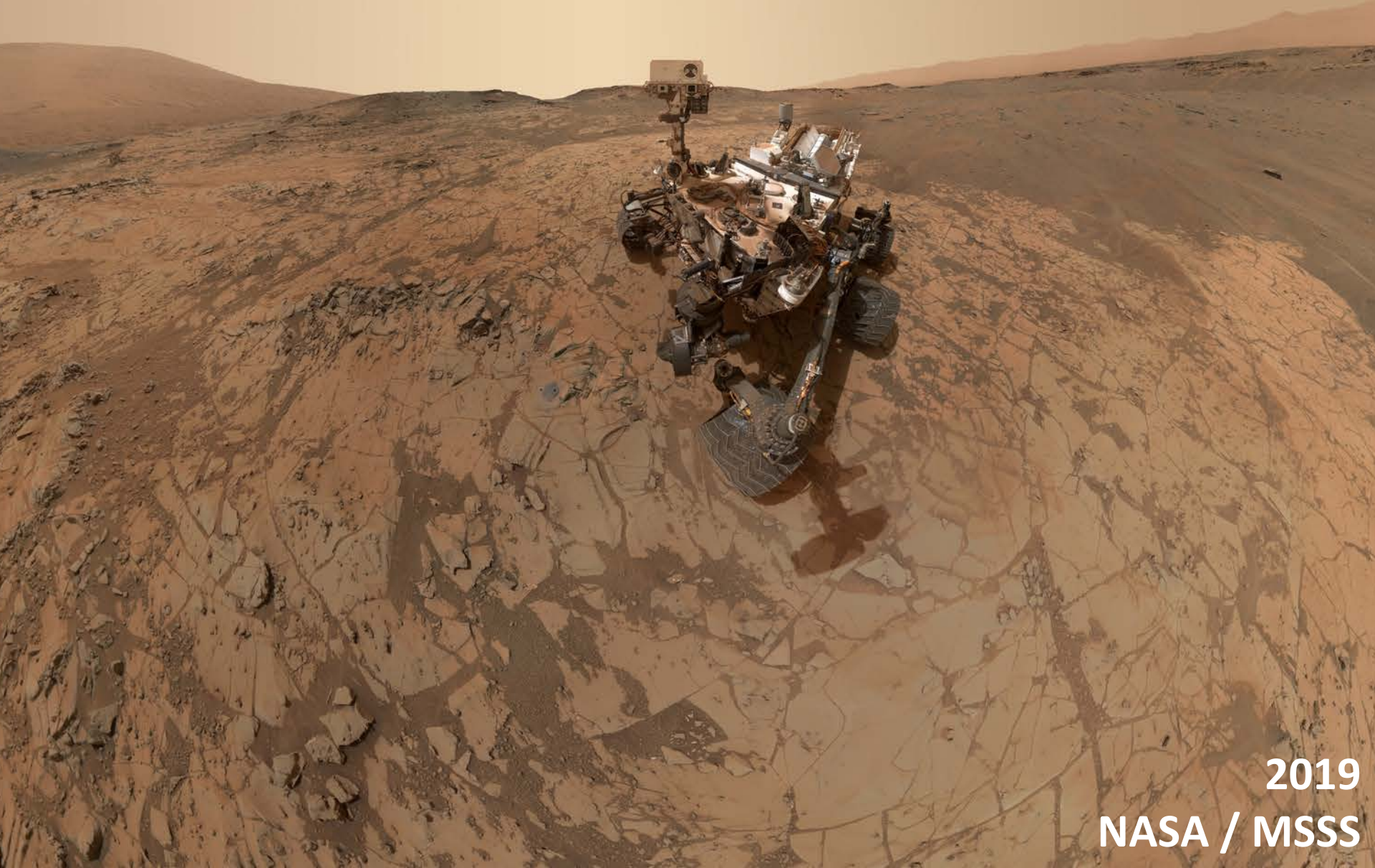
# Jeans Escape – heavy- isotope enrichment



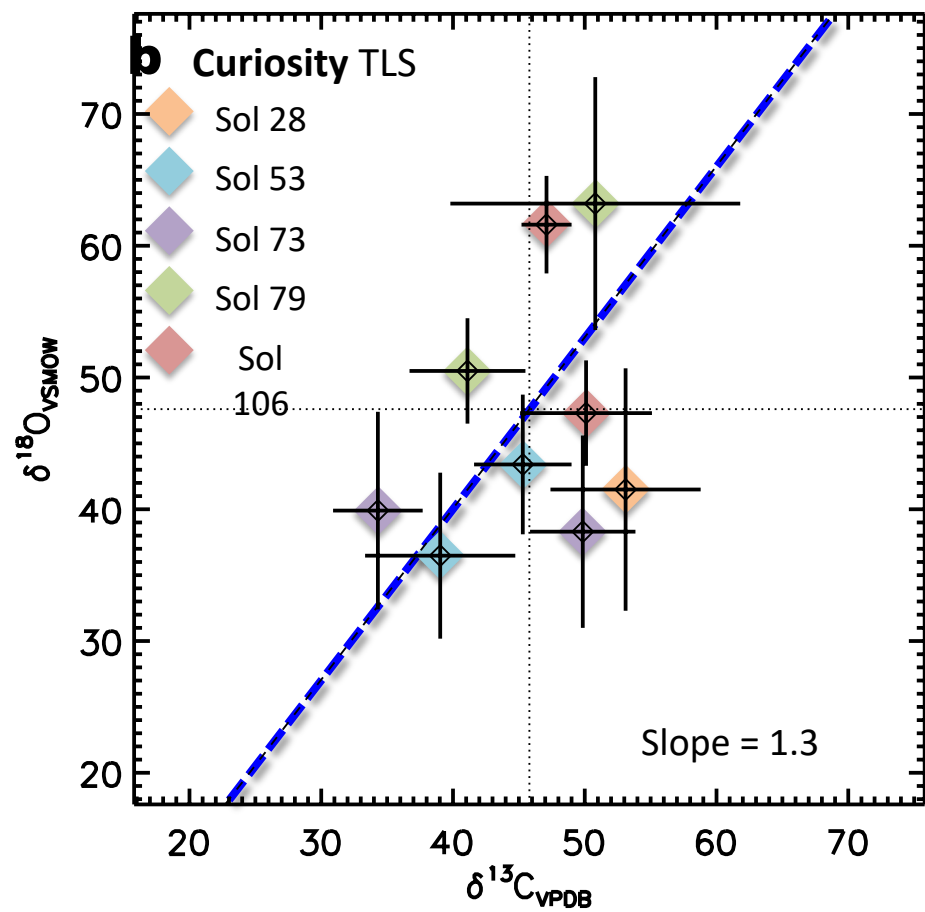
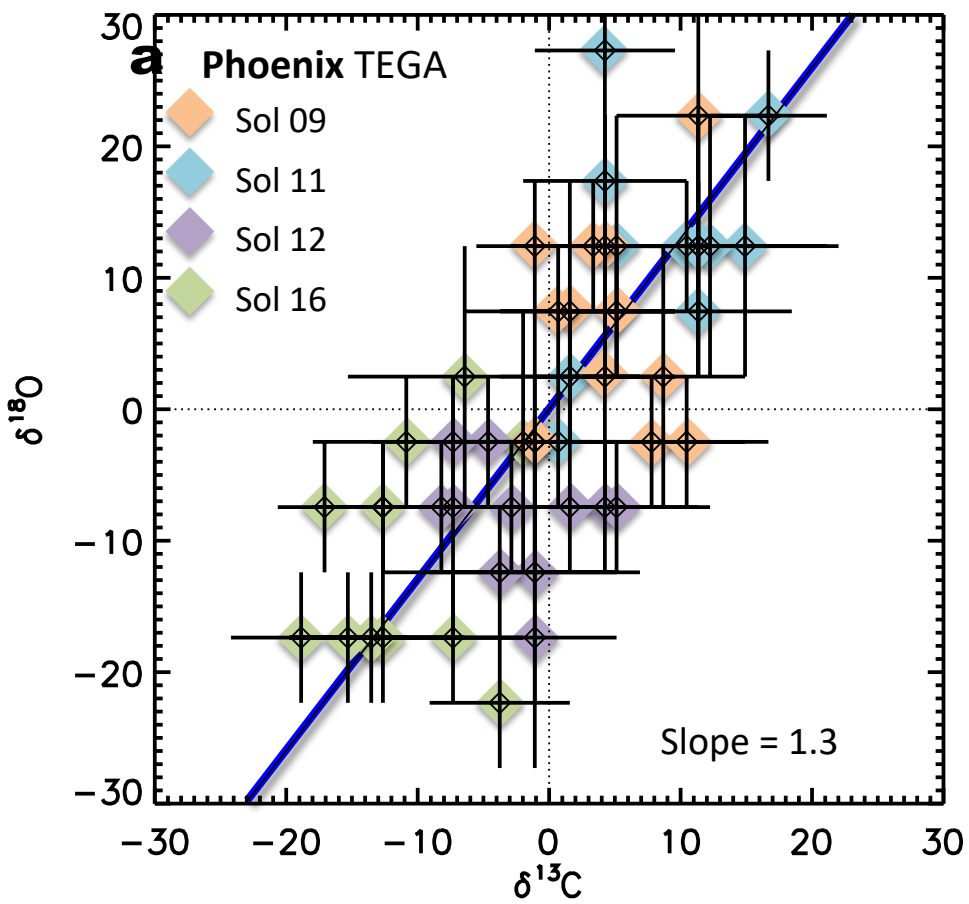
# Phoenix Lander, 2008

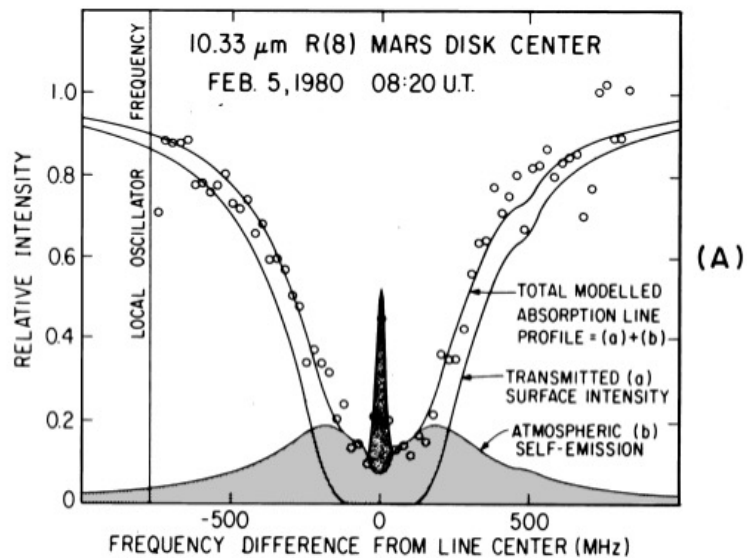


# MSL Curiosity, 2012–now

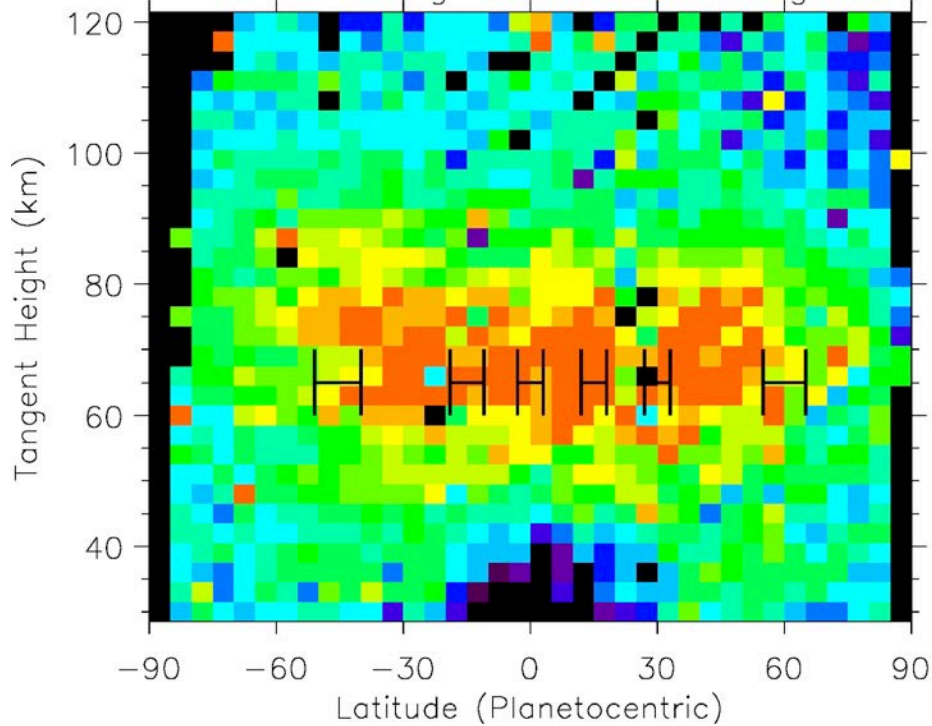


2019  
NASA / MSSS





HIPWAC Observed Regions vs. TES at  $L_S = 170-190$





# NASA Infrared Telescope Facility (IRTF)

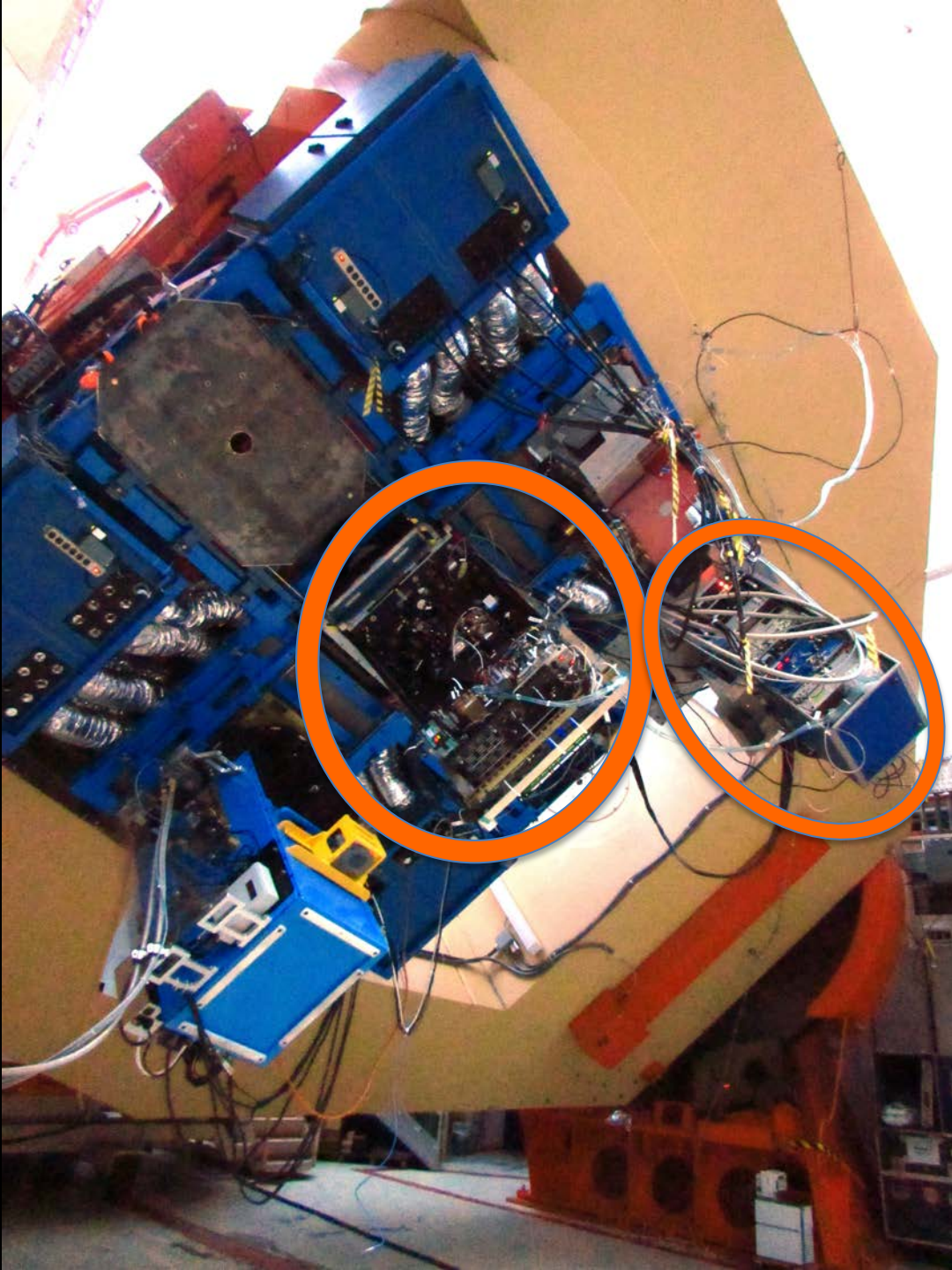






# NASA IRTF





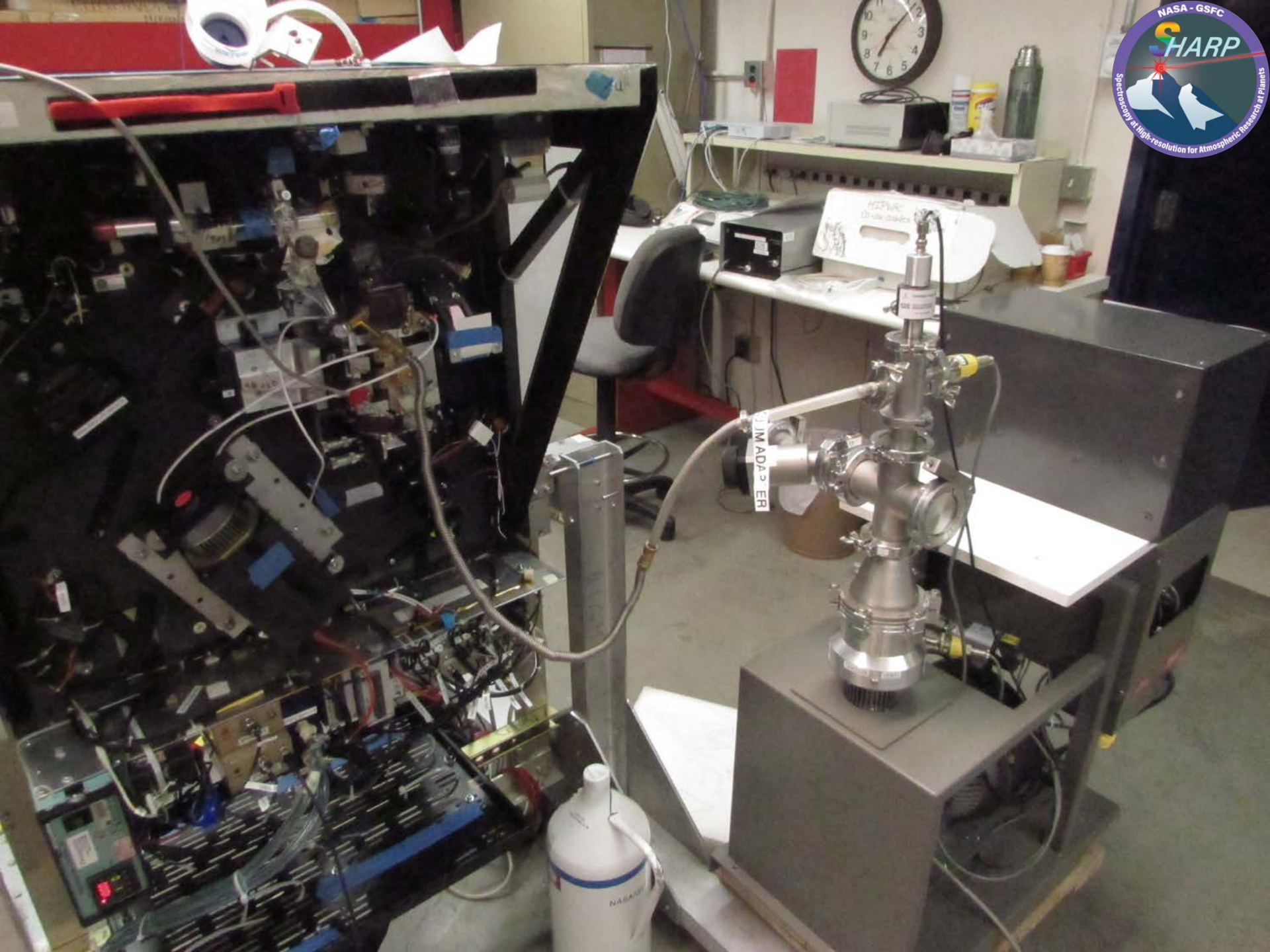
**HIPWAC:  
Heterodyne  
Instrument  
*for*  
Planetary  
Winds  
And  
Composition**











JIM ADA 2 ER

NABAU









# HIPWAC at IRTF





# Observatory next door (Keck)



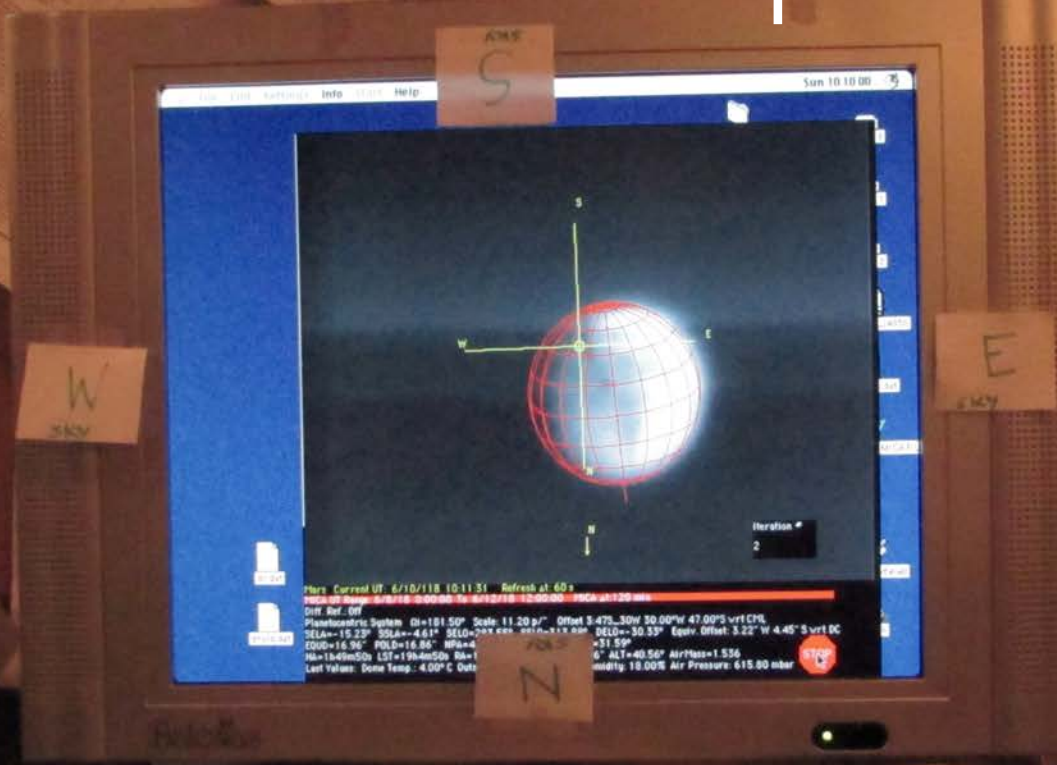


# Observatory next door (Keck)



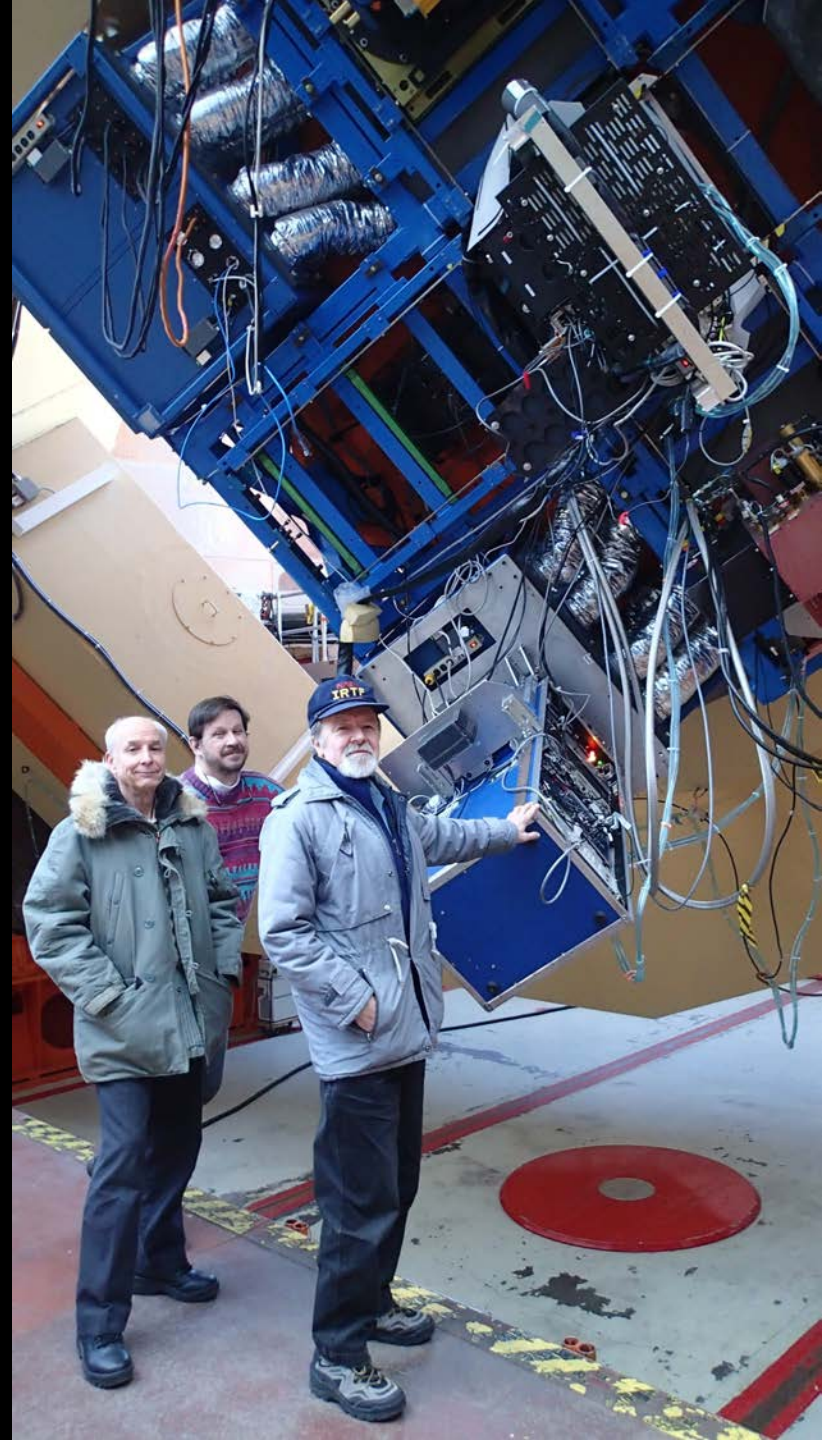


# HIPWAC : Heterodyne Instrument for Planetary Winds and Composition



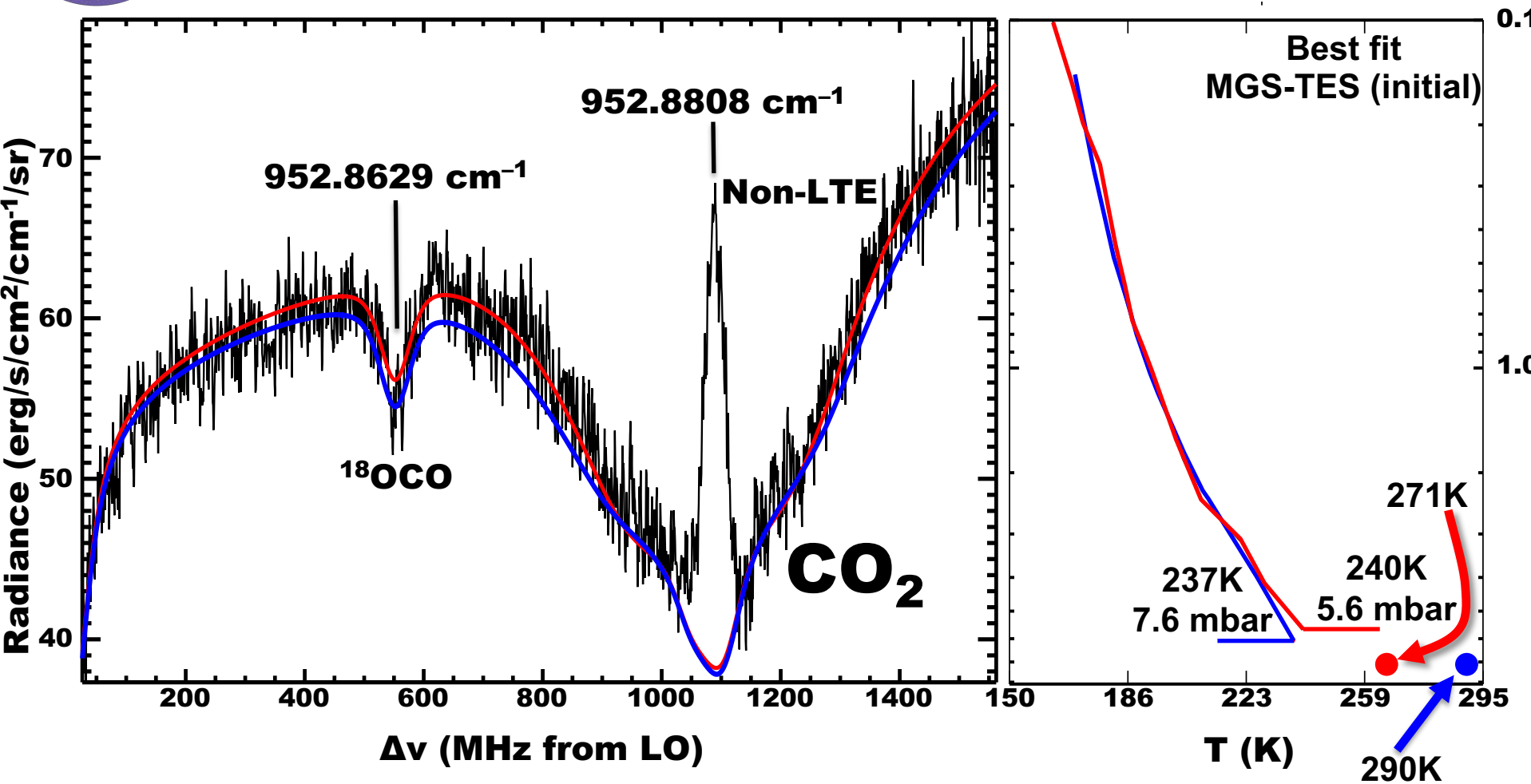
Planet: Current UT: 6/10/18 10:11:31 Refresh at 60s  
Planet: Name: 67P/Churyumov-Gerasimenko Epoch: 2018-06-10 00:00:00 UTC  
Diff. Ref. Off  
Planetocentric System: Cl=181.50° Scale: 11.20 px" Offset: 5.475\_30W 50.00°W 47.00°S wrt CPL  
SELA=-15.23° SELA=-4.61° SELC=70x xxx xxx=11.8 mm DELC= 50.33° Equiv. Offset: 3.22" W 4.45" S wrt DC  
COPD=-15.96° POLD=15.85° HRA=4.31 59°  
NA=1549mSDs LST=19h4mSDs NA=1.6" ALT=40.56° AirPass=1.536  
Lat Value: Dome Temp: 4.00° C Outd. Humidity: 18.00% Air Pressure: 615.00 mbar

CHECK FOCUS!



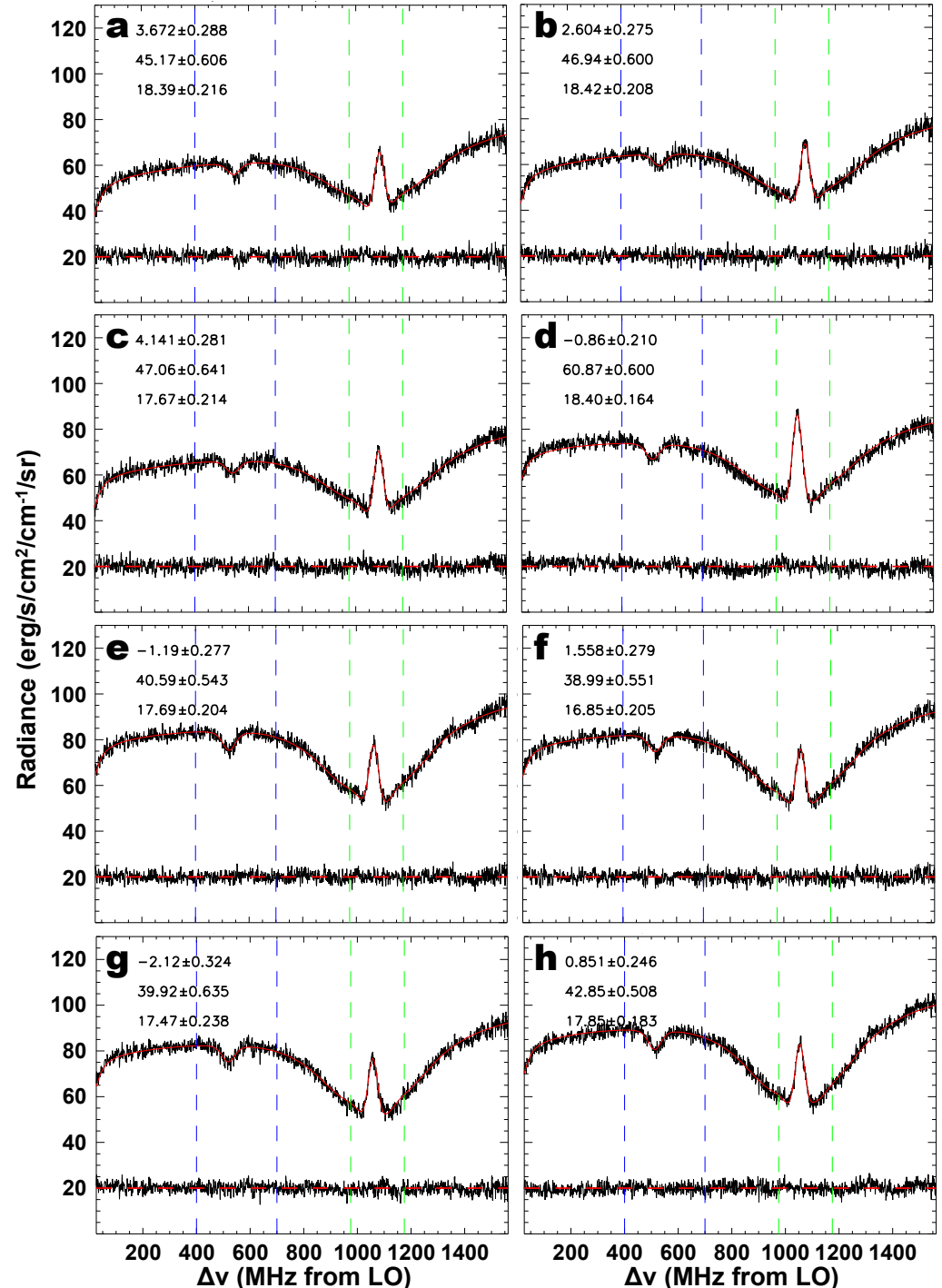


# Mars Isotopes, Temperatures, Non-LTE





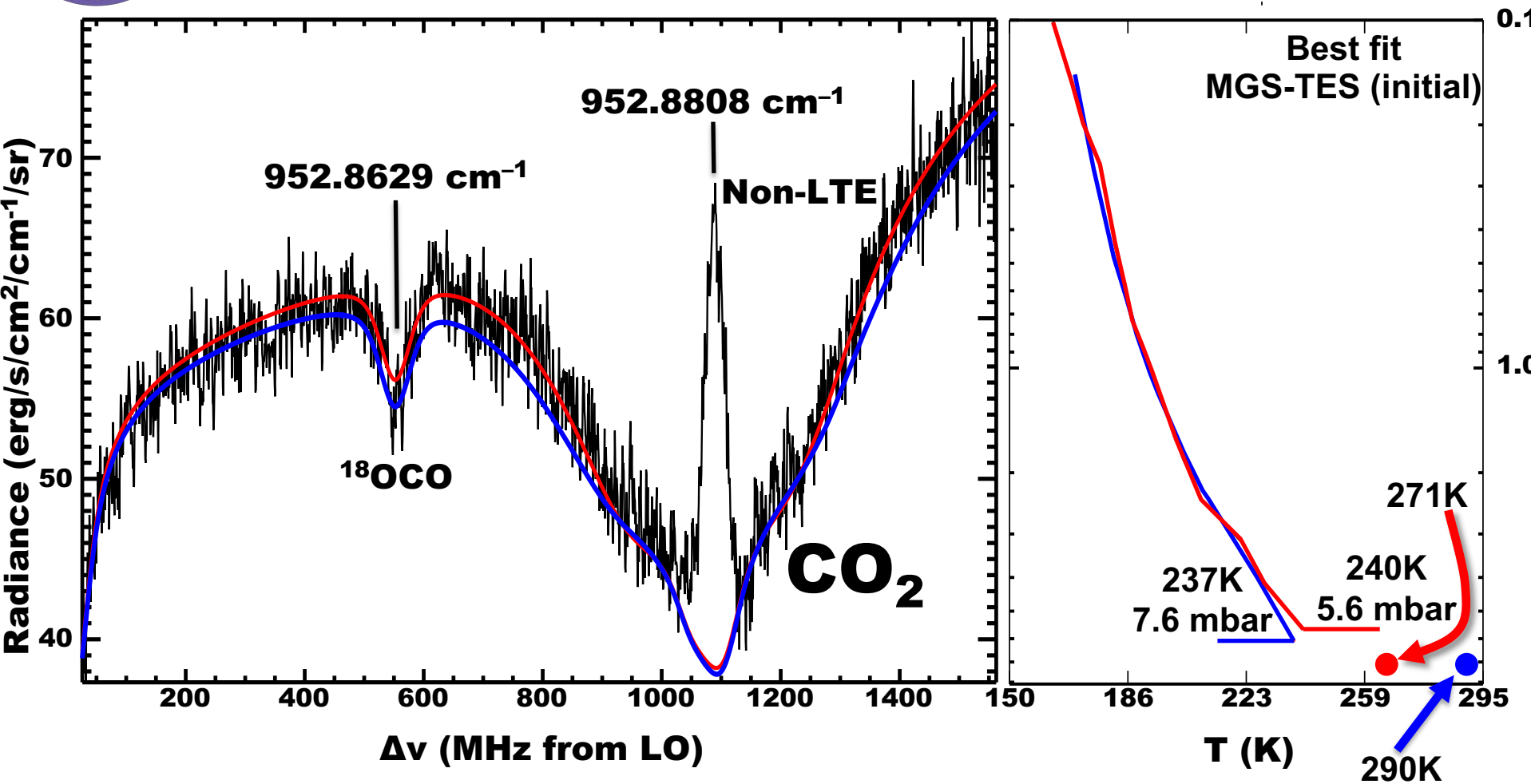
# Mars – Enriched Heavy Isotopes





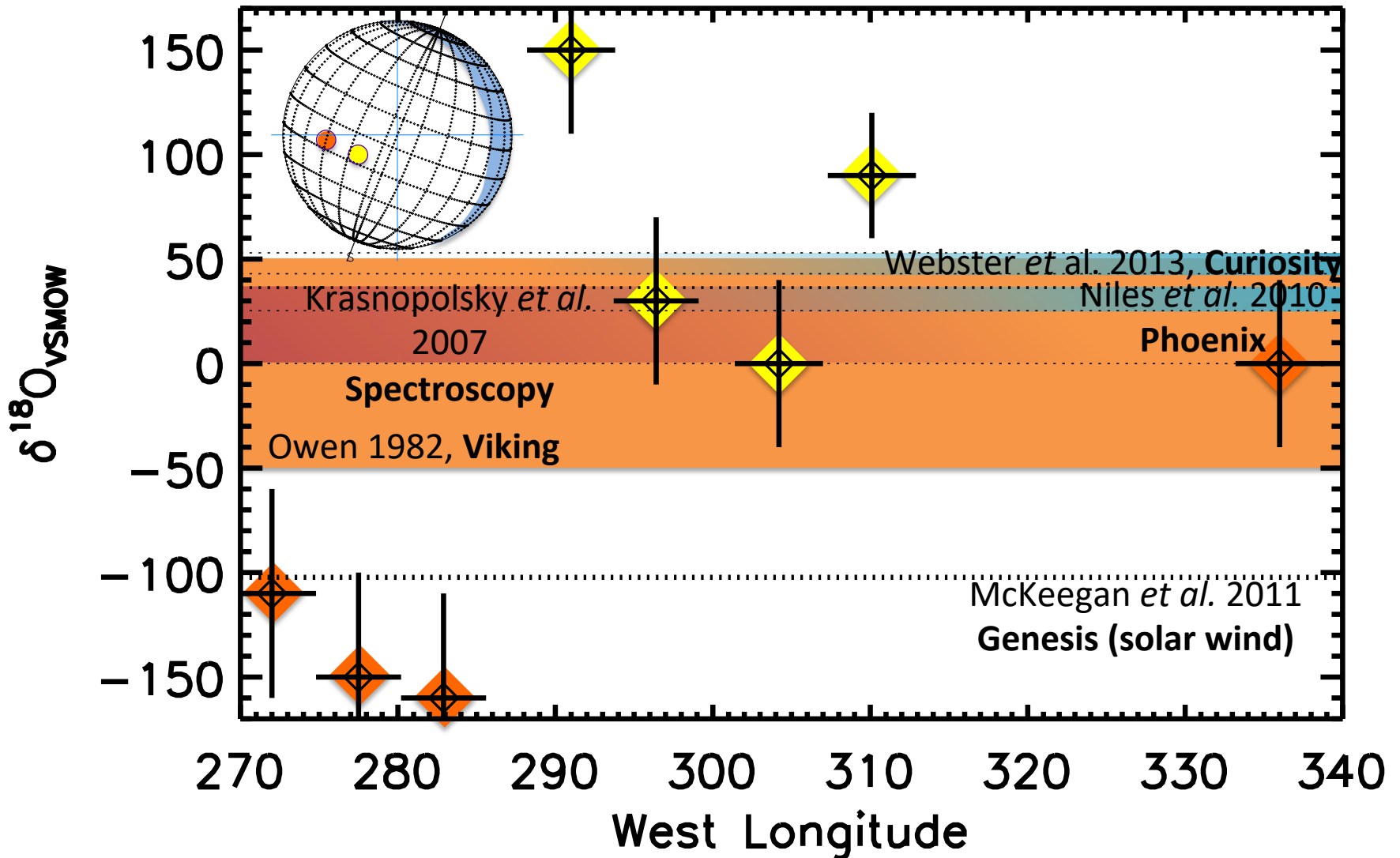


# Mars Isotopes, Temperatures, Non-LTE



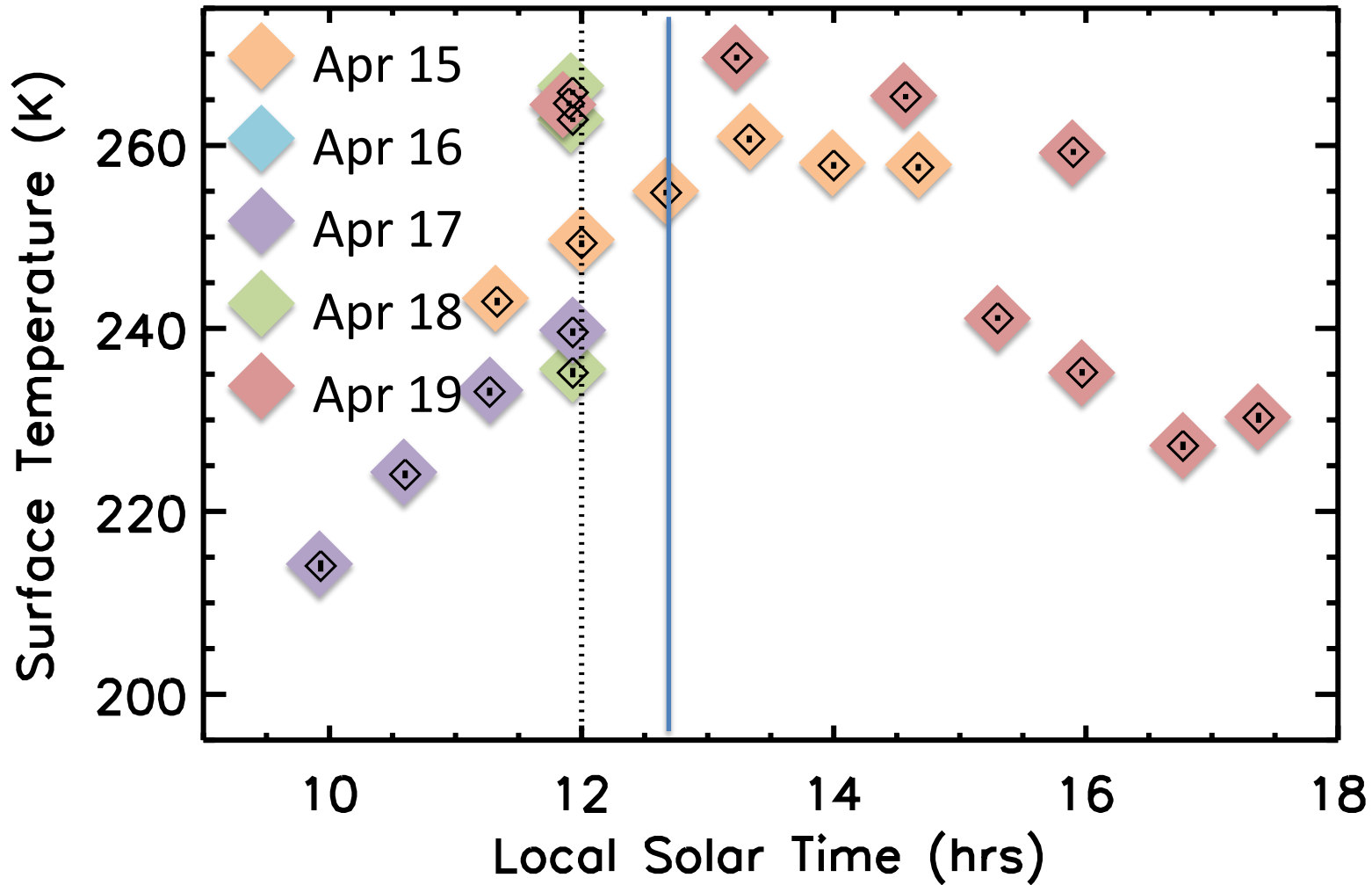


# Mars – Enriched Heavy Isotopes?



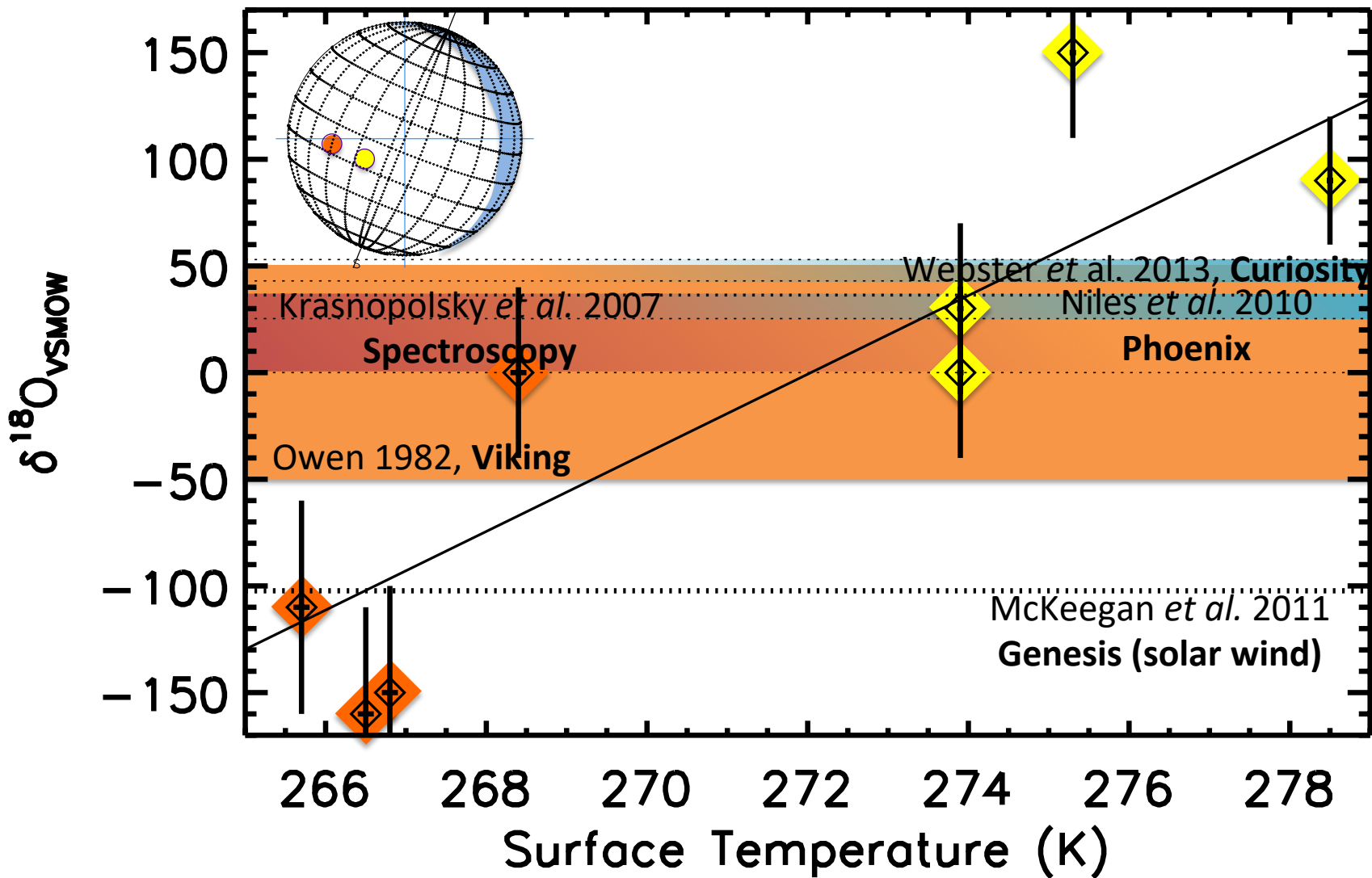


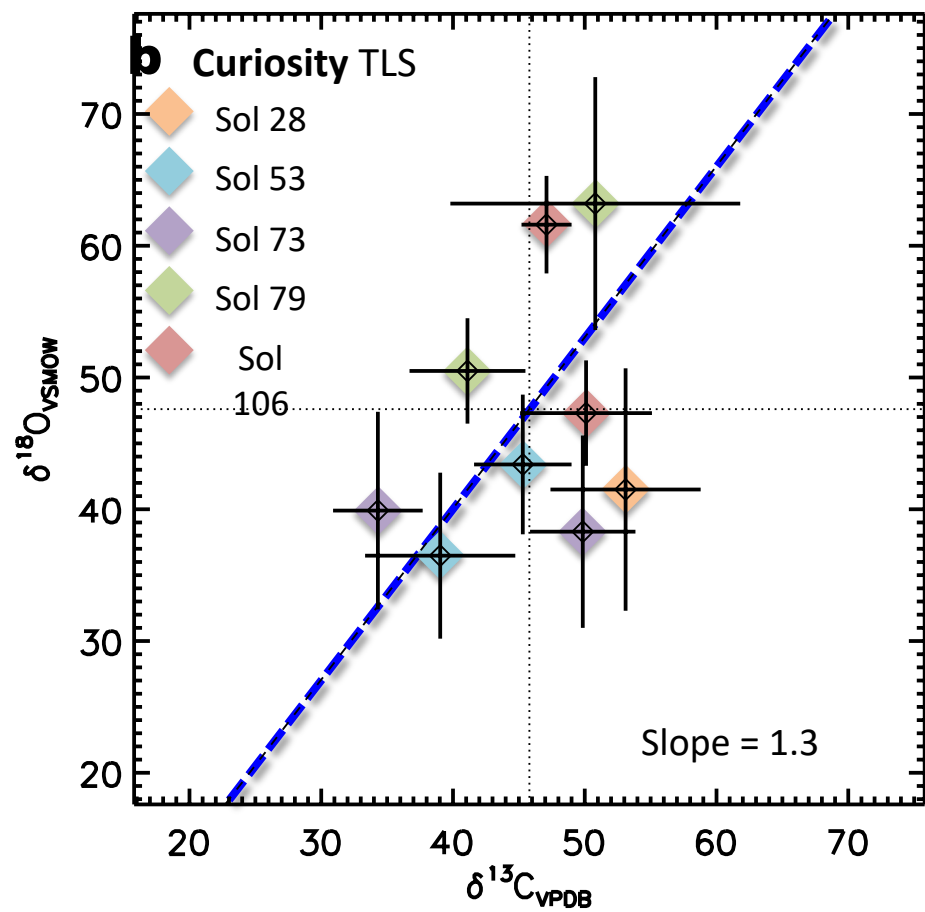
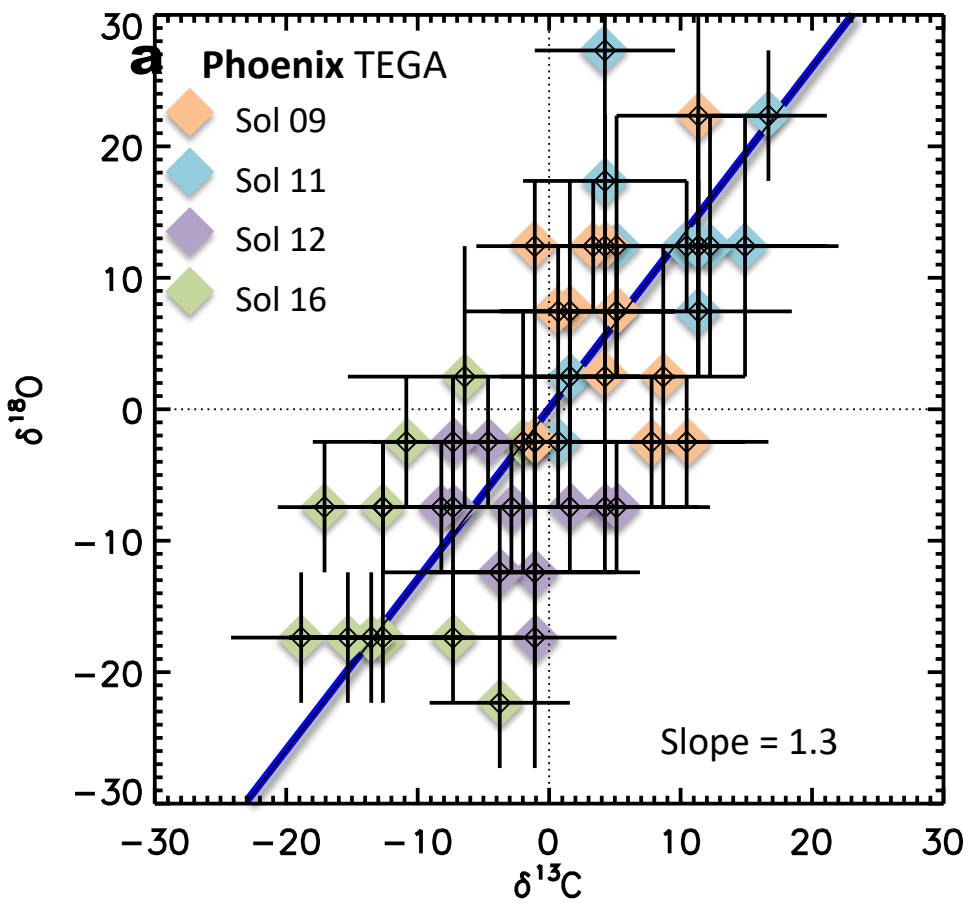
### Gale Crater Latitude





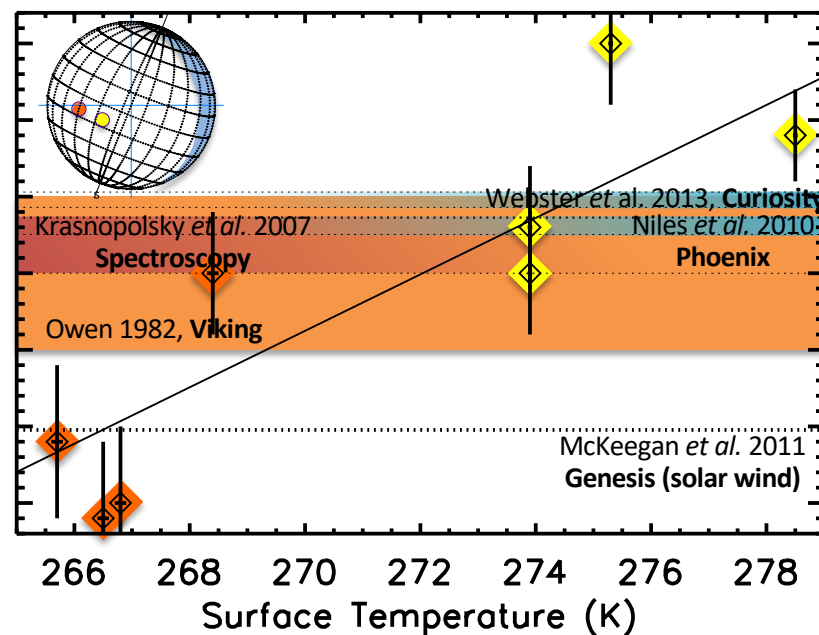
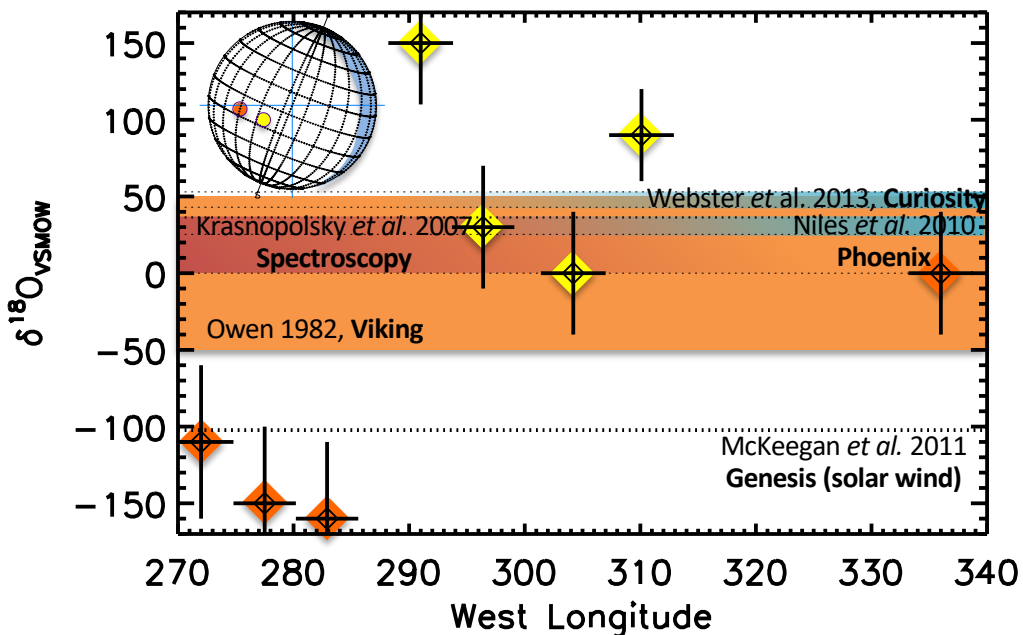
# Mars – Enriched Heavy Isotopes!

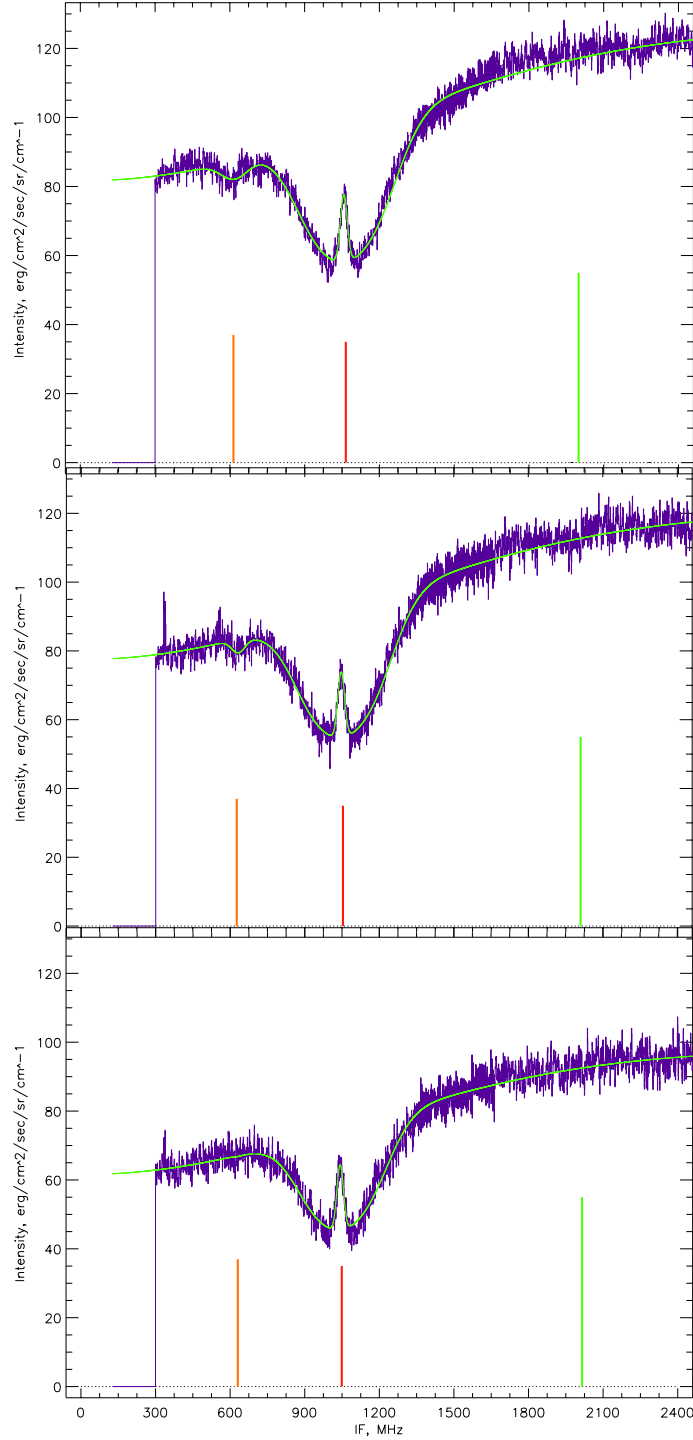






# Mars Oxygen Isotopes and Surface T





**+16°  
(subsolar)**

**-5.6°  
Gale Crater  
latitude**

**-16°**

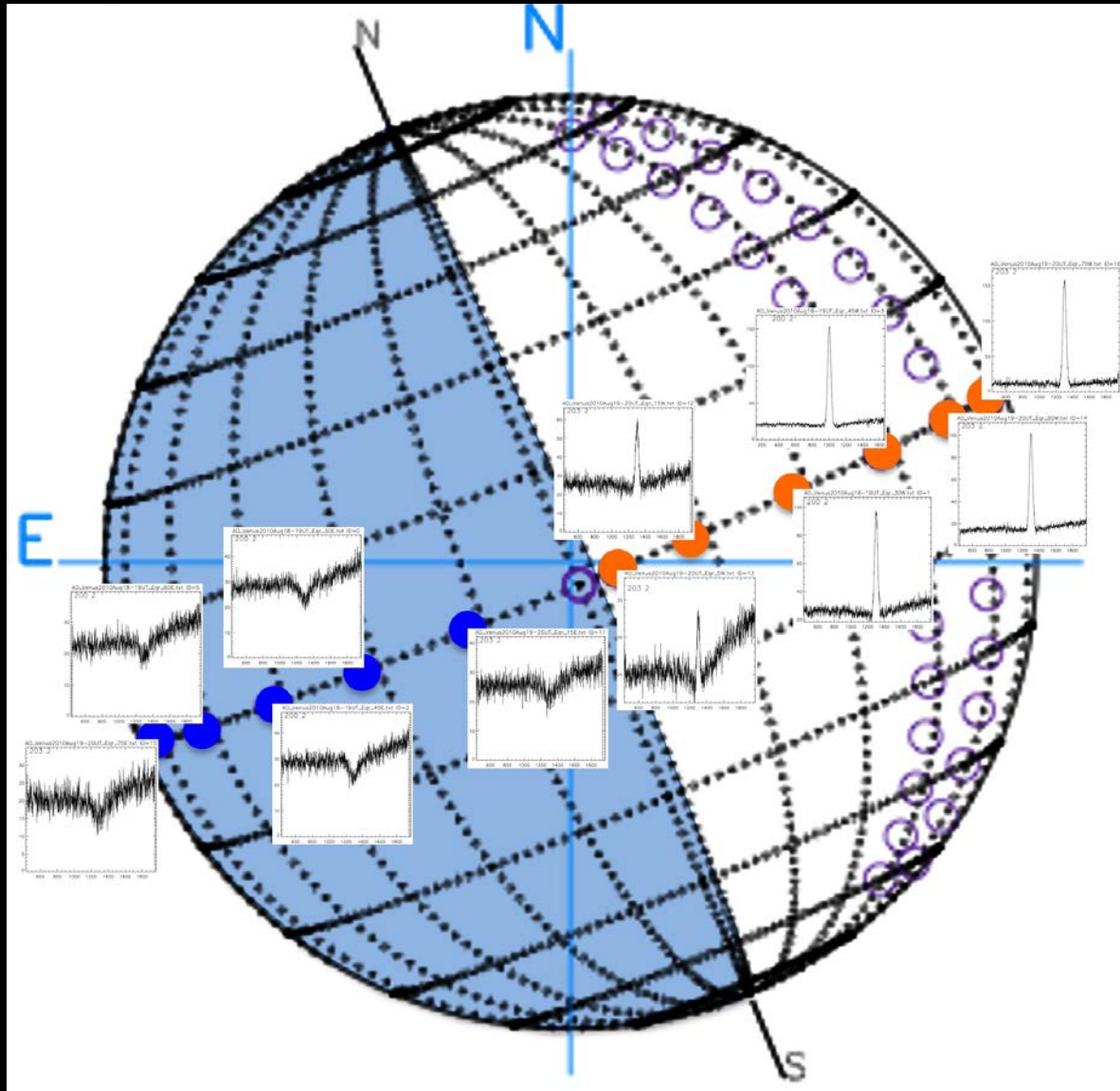
A large, textured, yellowish-orange sphere representing Venus, set against a black background. The sphere has a mottled, cloudy appearance with various shades of yellow, orange, and brown. The text "What about Venus?" is written in white at the top, and "We don't know!" is written in yellow in the center.

What about Venus?

*We don't know!*



# HIPWAC Spectra: Venus





# Remember this?



# Where did all the gases go?

Where did all the carbon go?

Long time escaping...

Where did all the carbon go?

Long time ago.

Where did all the carbon go,  
Gone to carbonates, most of it.

When will we ever learn?

When will we ever learn?

*Other verses: nitrogen, water, argon, ...*