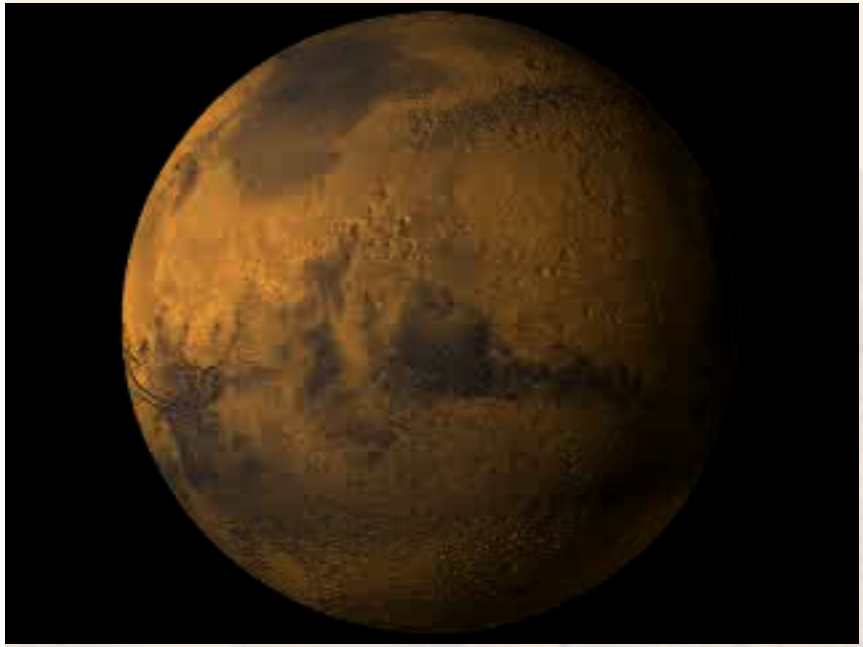


Milankovitch on Mars:
observing and modeling astronomically-induced climate change

Peter L Read

Atmospheric, Oceanic & Planetary Physics, University of Oxford

Oxford Physics

Unprecedented Ice Age Cave Art Discovered in U.K.

<< Back to Page 1

British First

Pettitt and his archaeologist colleagues Sergio Ripoli, of the Universidad Nacional de Educación a Distancia in Madrid, and Paul Bahn, an independent expert on cave art, first discovered a small number of the carvings in April 2003 in caves known to have been inhabited before the end of the Ice Age.

The researchers described their initial find in the June 2003 issue of the archaeological journal *Antiquity*.

Other archaeological artifacts, such as figures and needles carved from bone, had previously been found at Creswell Crags. The objects, which dated to 12,000 to 13,000 years old, prompted Pettitt and his colleagues to scour the site for cave art.

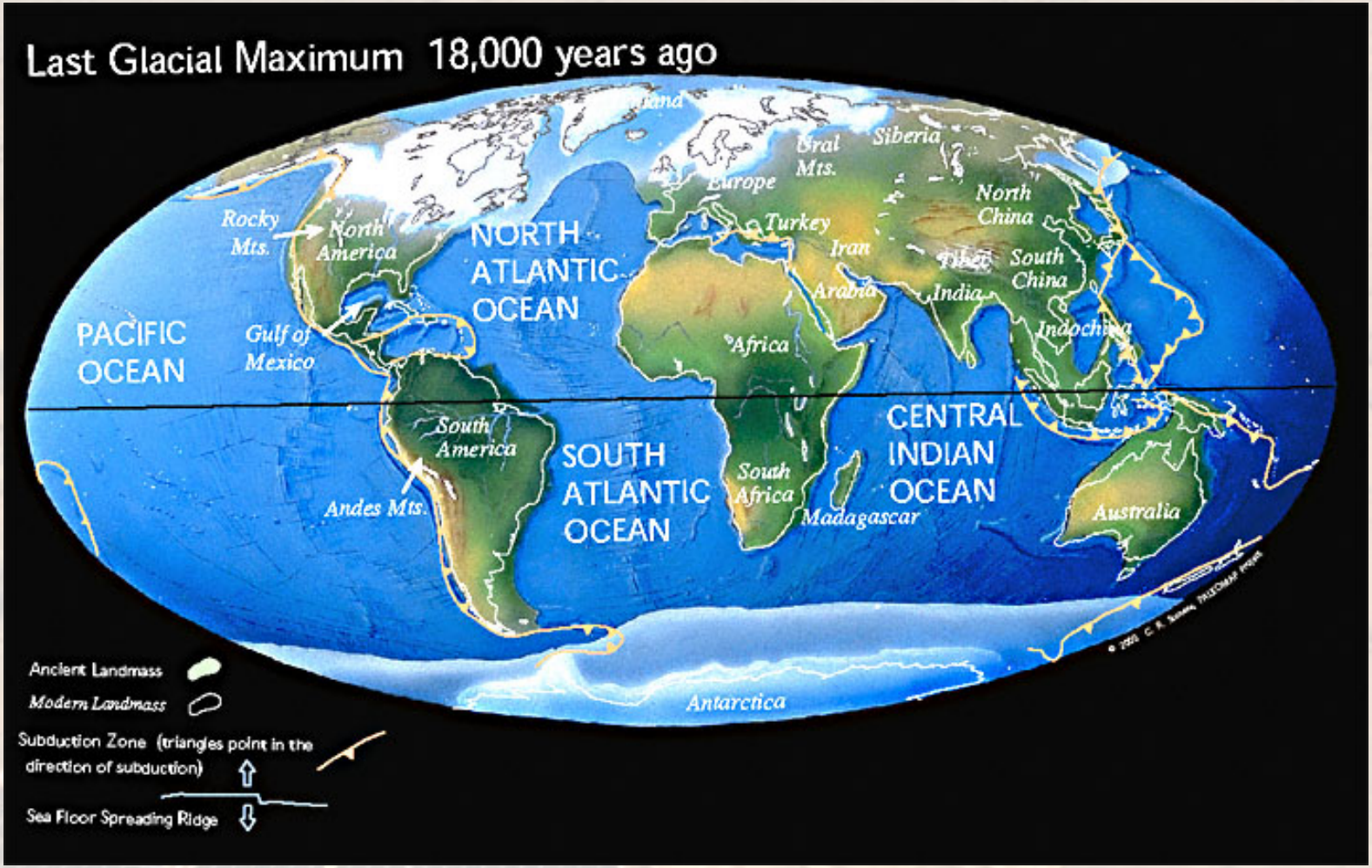
The team's discovery of the carvings was widely reported in the media last year as the only Paleolithic cave art ever known from the U.K. Most other ancient British rock art is 8,000 years more recent than the art at Creswell Crags and is found on open rock faces.

Pettitt said his team used "stylistic comparison" with continental cave art and carbon dating of artifacts found at Creswell Crags to set a rough date for the art last year.

Photo: stag panel with animal image outlined for clarity. Courtesy of UNED

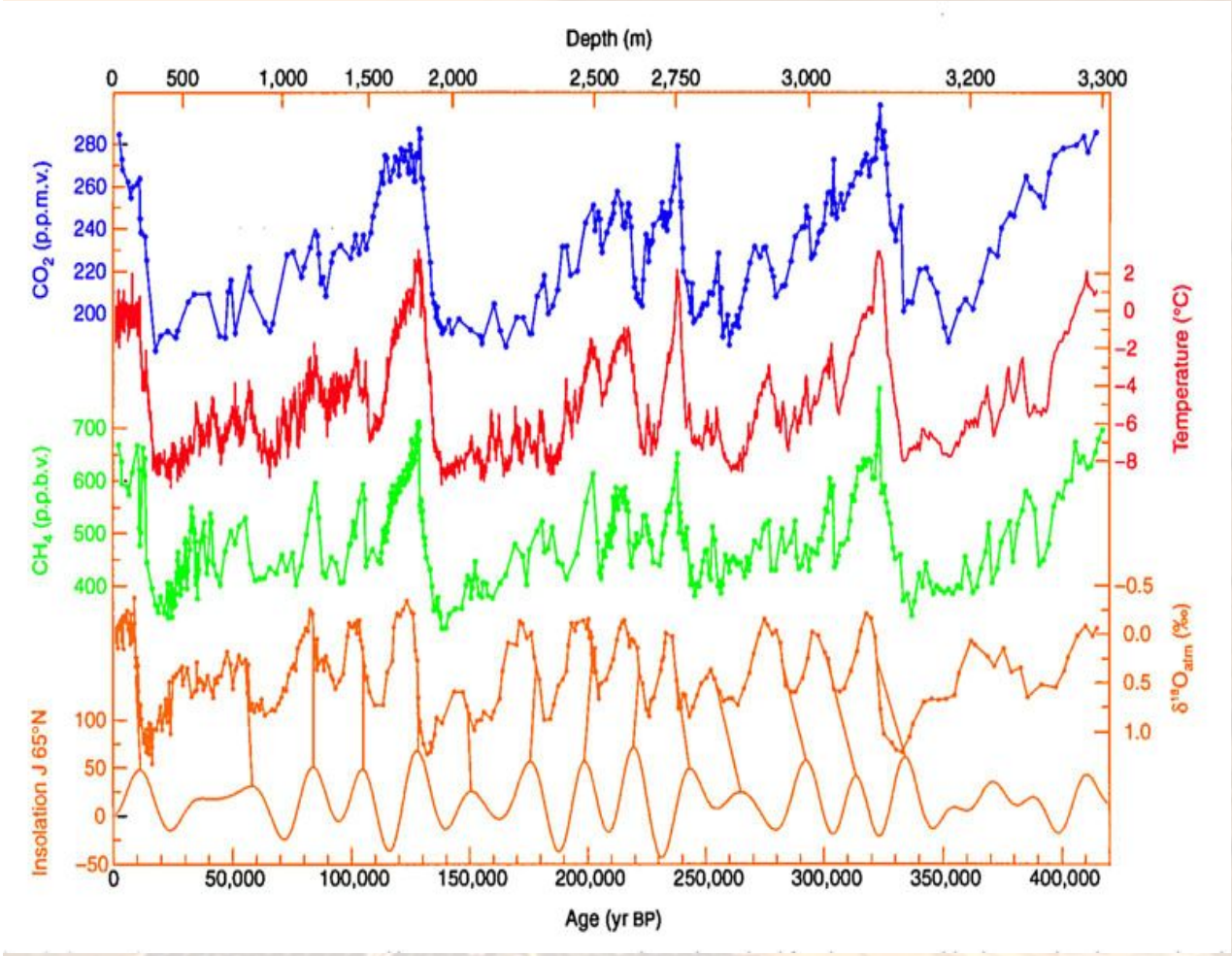
"Church Hole cave is really the Sistene Chapel of the Ice Age. The discoveries will provide increased impetus to the future development plans for a new museum and education centre, which will be able to showcase these finds.

Earth at the last Glacial Maximum



[Credit: Christopher Scotese]

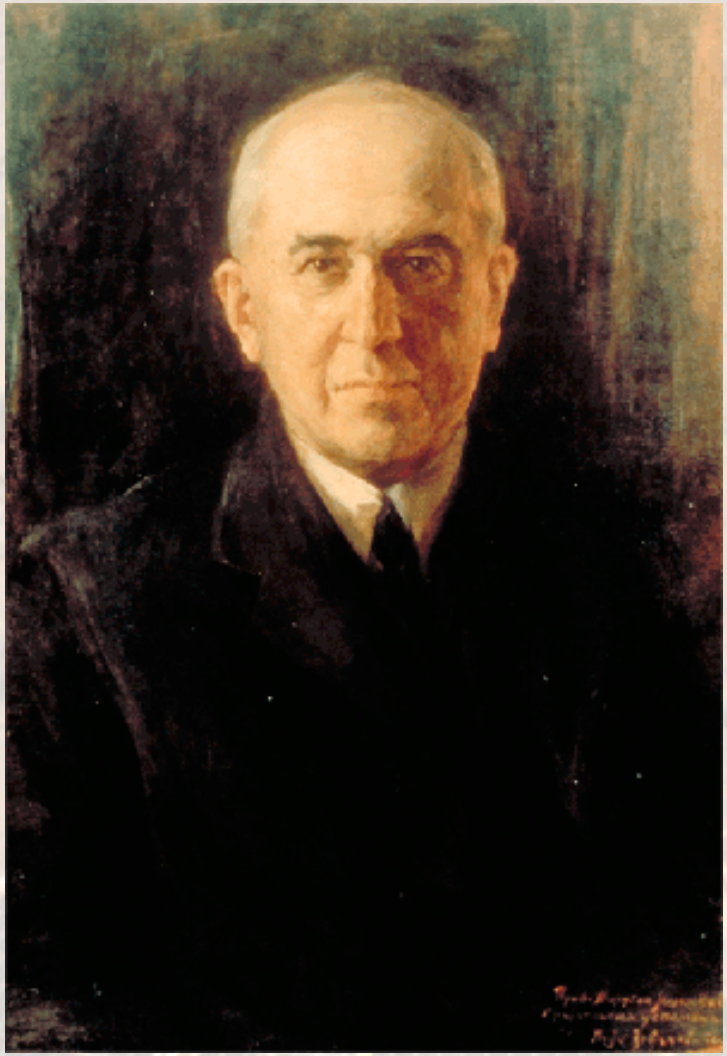
Glaciation Cycles on Earth



Measurements from Vostok ice cores
[credit: Wikipedia.org]

- Ice core measurements show cyclic fluctuations of
  - CO_2 (blue) and
  - CH_4 (green)
- Linked to 100kyr fluctuations in
  - temperature ($\delta^{18}O$?)
- Connection to variations in sunlight at high latitudes?

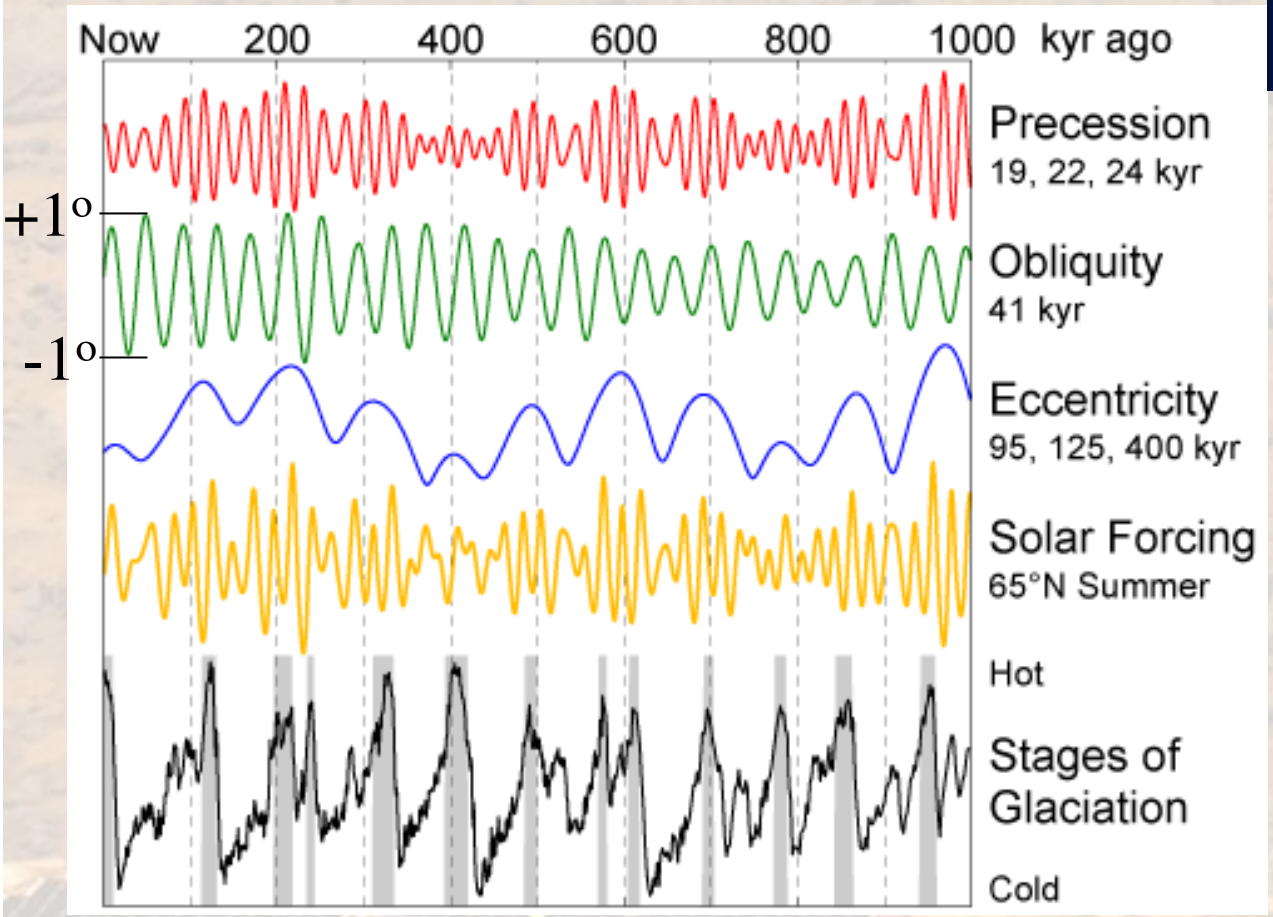
Milutin Milankovitch



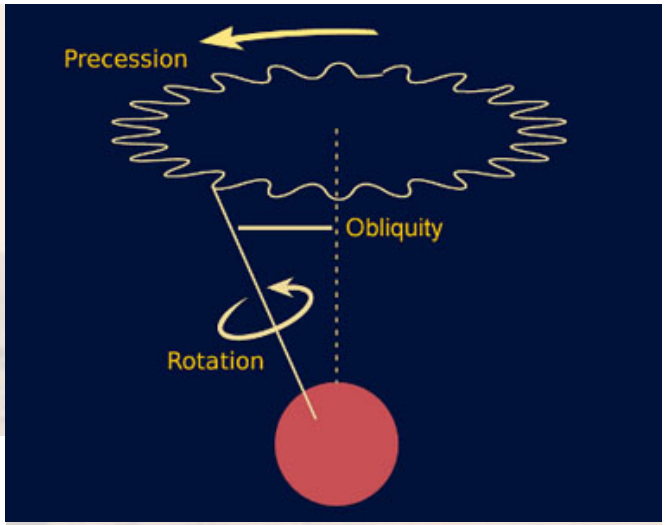
- 20th Century Serbian engineer/scientist (1879-1958)
- Best known for theory linking astronomical cycles and ice ages on Earth
- Also deduced mean surface temperature on Mars….(in 1916!)

Glaciation Cycles on Earth

['Milankovitch cycles']

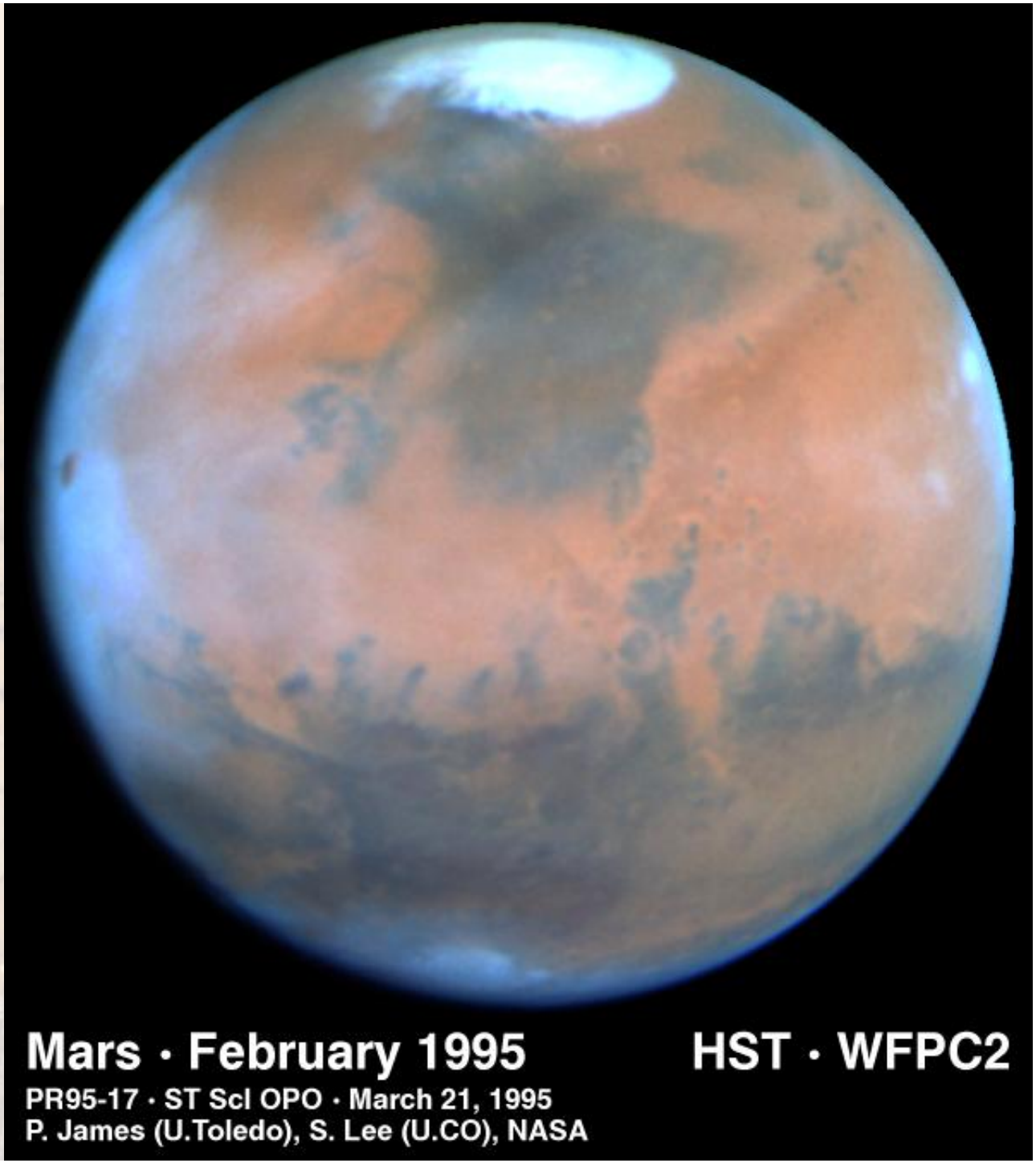


[credit: Wikipedia.org]



- Cyclic variations in orbit and rotation of the Earth
- Linked to 100kyr fluctuations in temperature
- Effects larger than their causes…??
  - 100kyr period not the strongest in insolation???

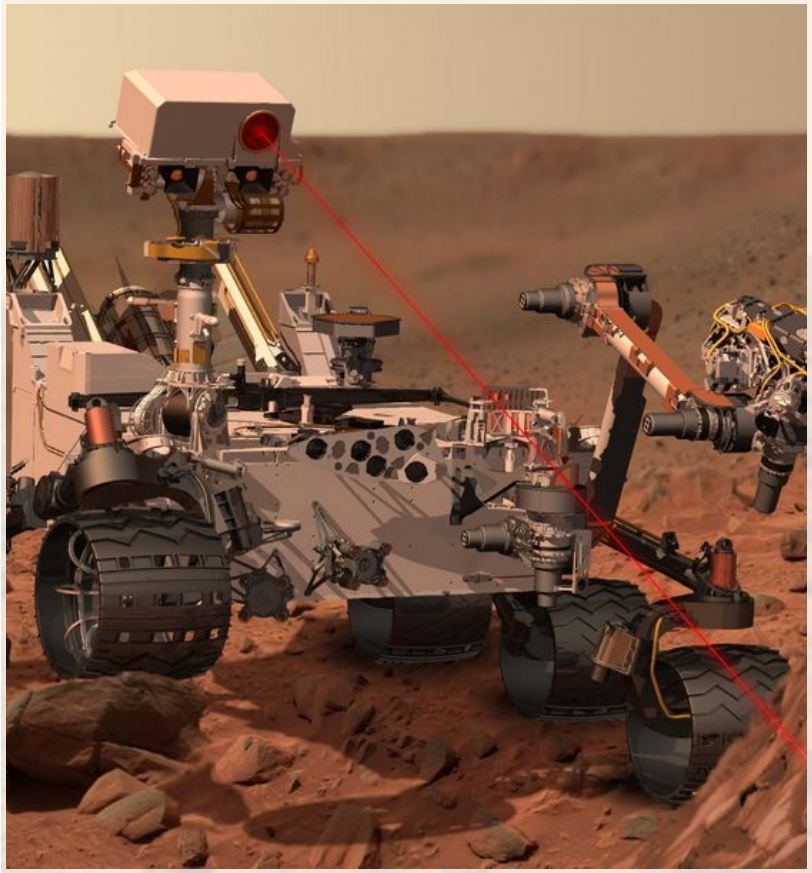
Mars from Hubble Space Telescope



Earth & Mars: facts & figures

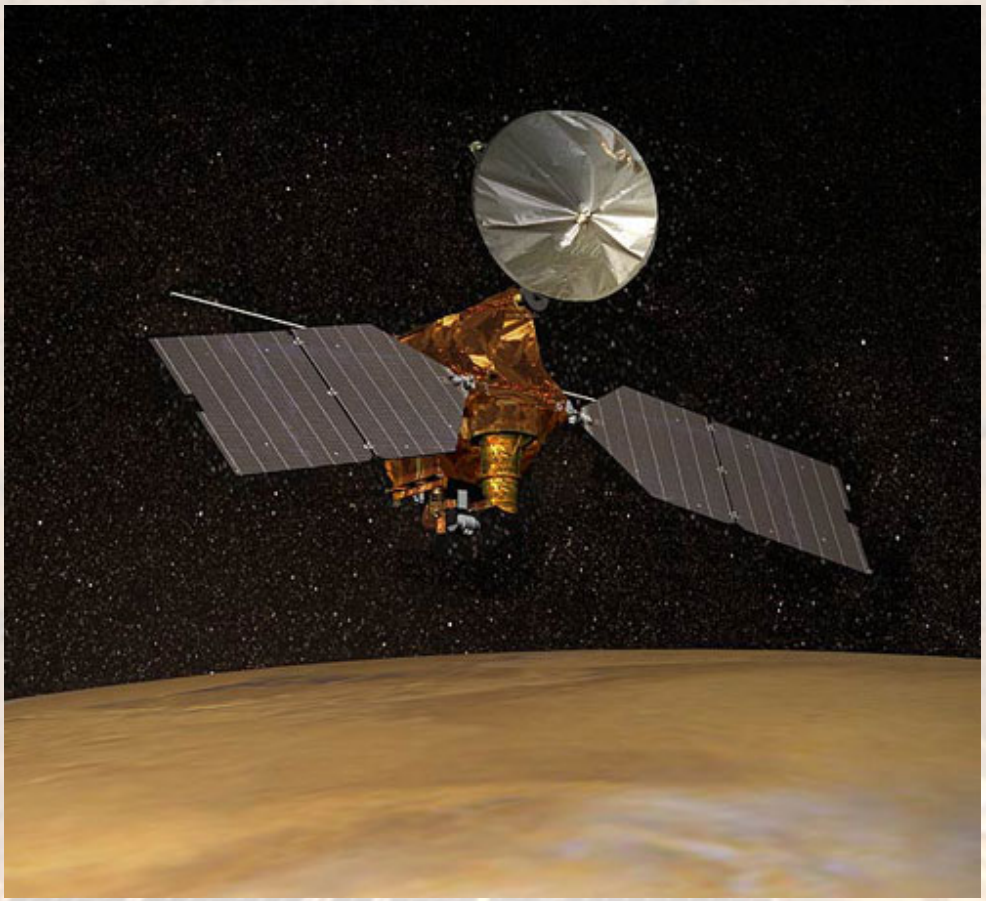
	Mars	Earth
• Equatorial radius (km)	3390	6380
• Rotation period (hrs)	24.62	23.93
• Obliquity (degs)	25.2	23.5
• Orbital period (sols)	668.6	365.24
• Distance from Sun (AU)	1.38-1.67	0.98-1.02
• Atmospheric composition	CO_2 (95%) N_2 (2.7%)	N_2 (78%) O_2 (21%)
• Surface pressure (hPa)	6-10	1013
• Surface temperature (K)	140-290	
230-315		

NASA's Curiosity Rover

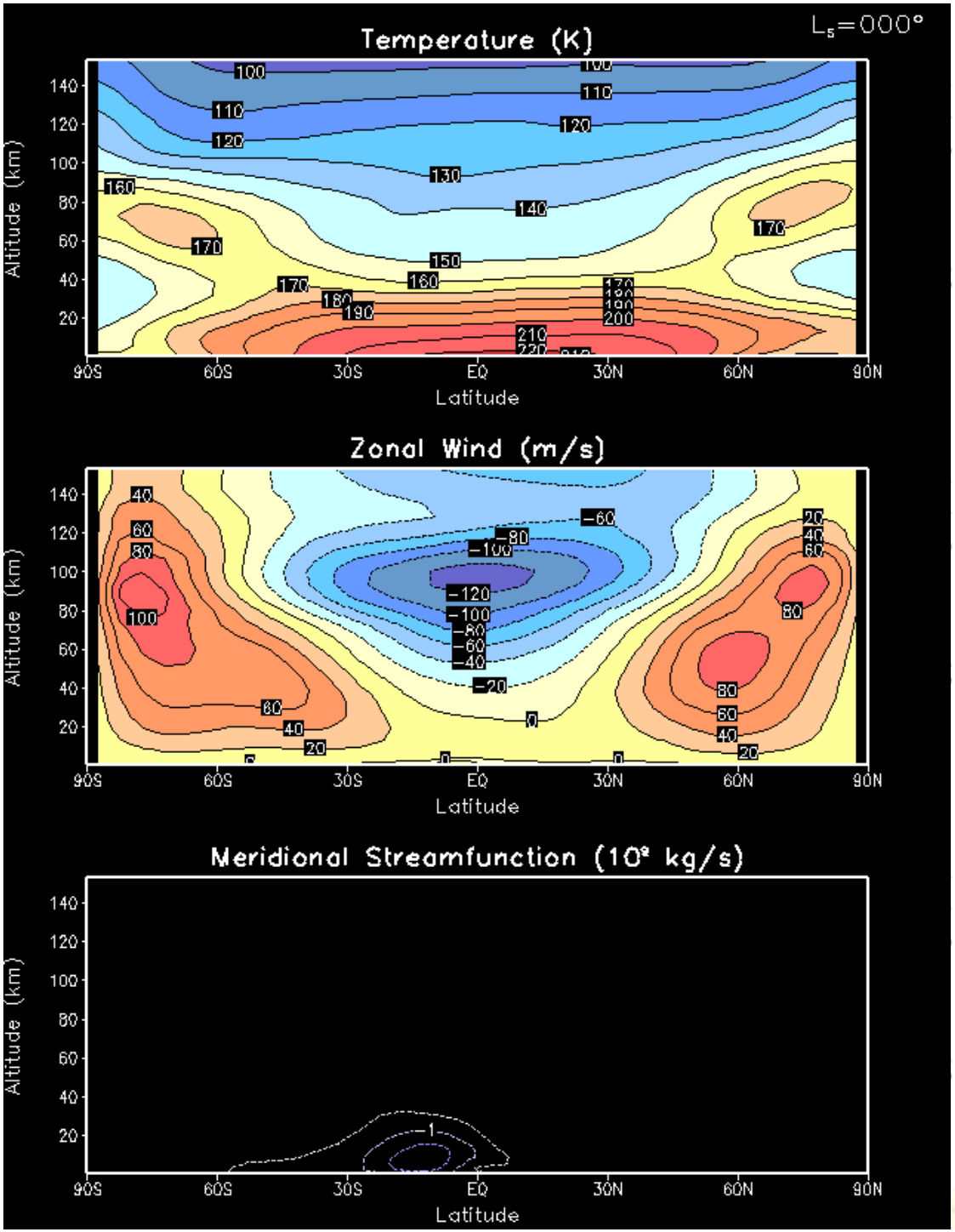


- Landed August 2012
- Gale Crater
  - Fossil lakes?
  - Layered sedimentary deposits
  - Action of water…..?

Mars Reconnaissance Orbiter (NASA: 2005)



- High resolution stereo imaging HiRISE
- CRISM surface IR spectrometer
- Colour weather imager (MARCI)
- Infrared atmospheric sounder (MCS)
- Subsurface radar (SHARAD)
- Radio occultation
- Gravity field…

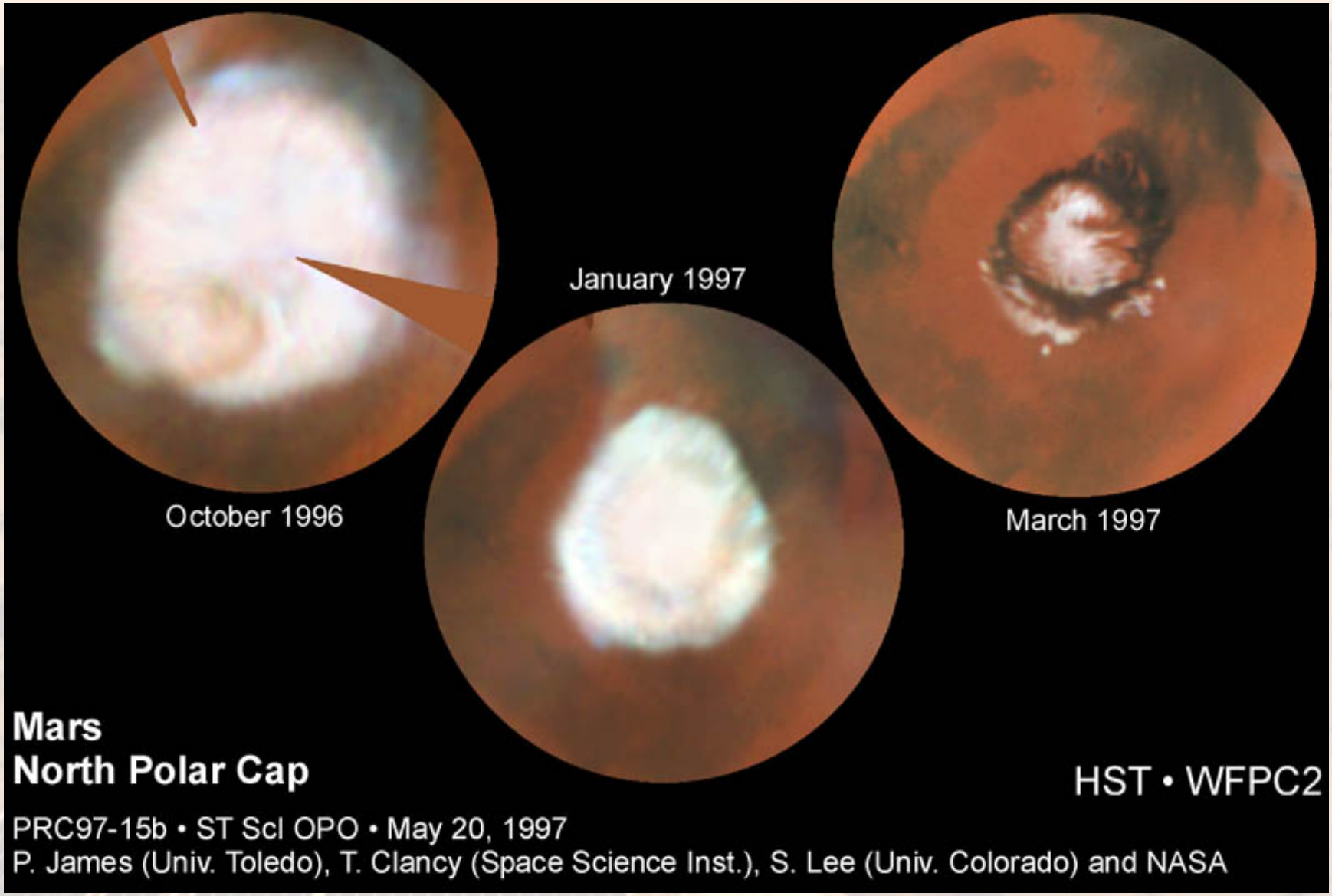


European Mars Climate model

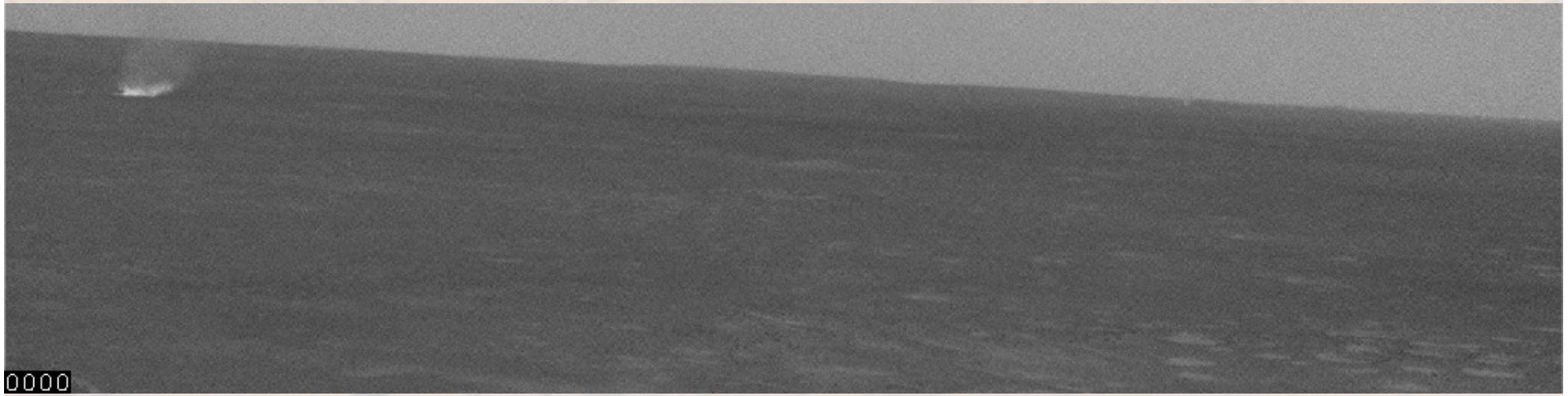
[Oxford+Open Univ+LMD/ Paris+IAA/Granada]

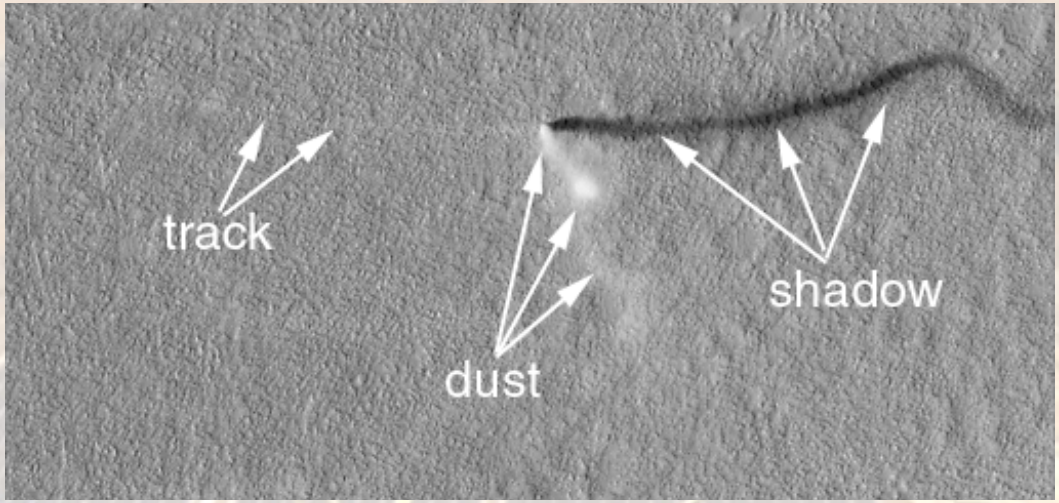
- Global numerical model of Martian atmospheric circulation (cf Met Office/Hadley Centre)
- High resolution fluid dynamics (in 3D)
  - Typically T31 (3.75° x 3.75°) x 32 levels (surface - 120km alt.)
- Surface topography & thermal properties
- Radiative transfer (solar heating and IR cooling)
- Seasonal and diurnal cycles
- CO_2, dust and H_2O transport
- Boundary layer turbulence and mixing

Mars north polar caps (HST)



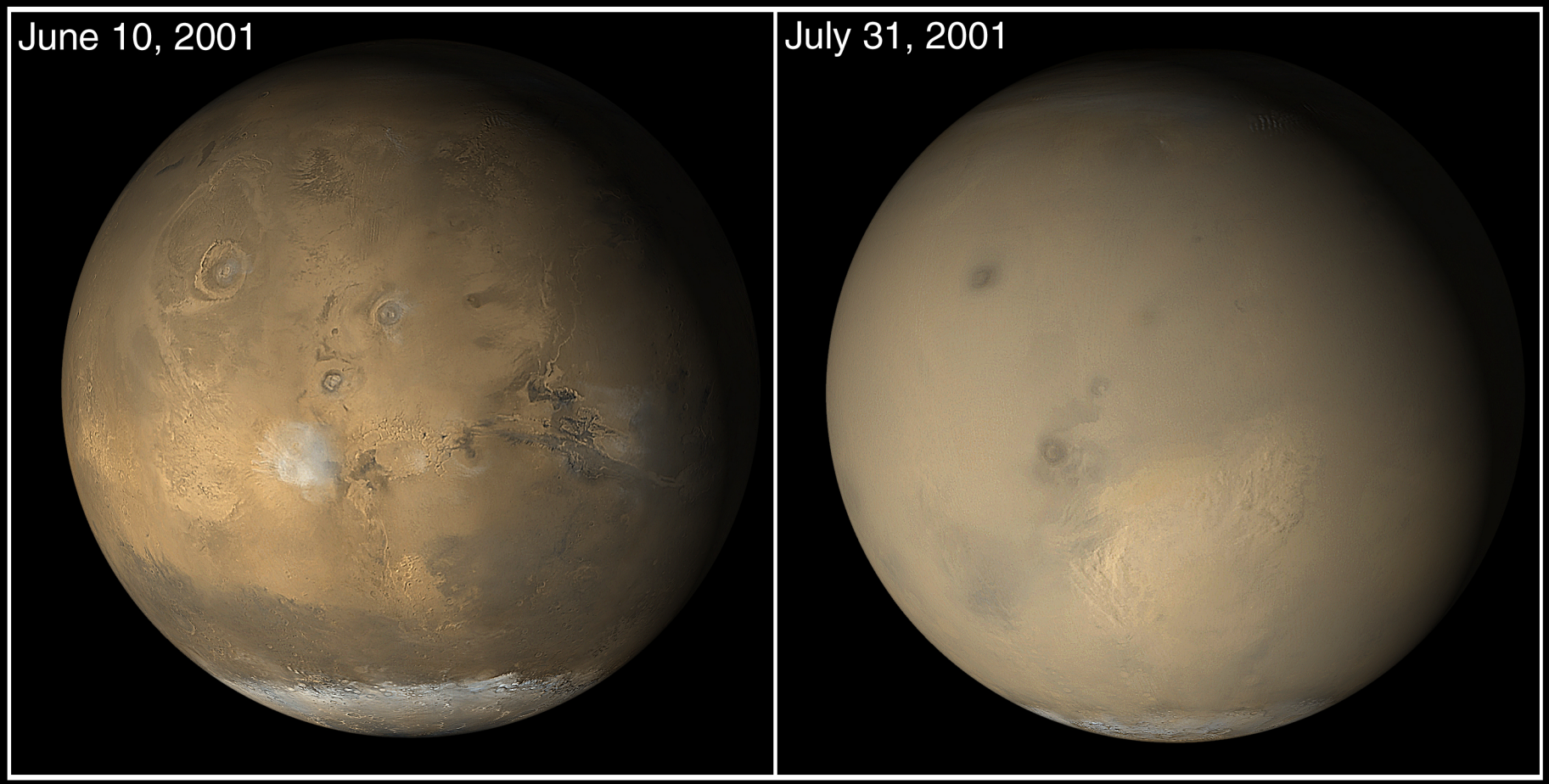
Dust Devils seen from Spirit Rover



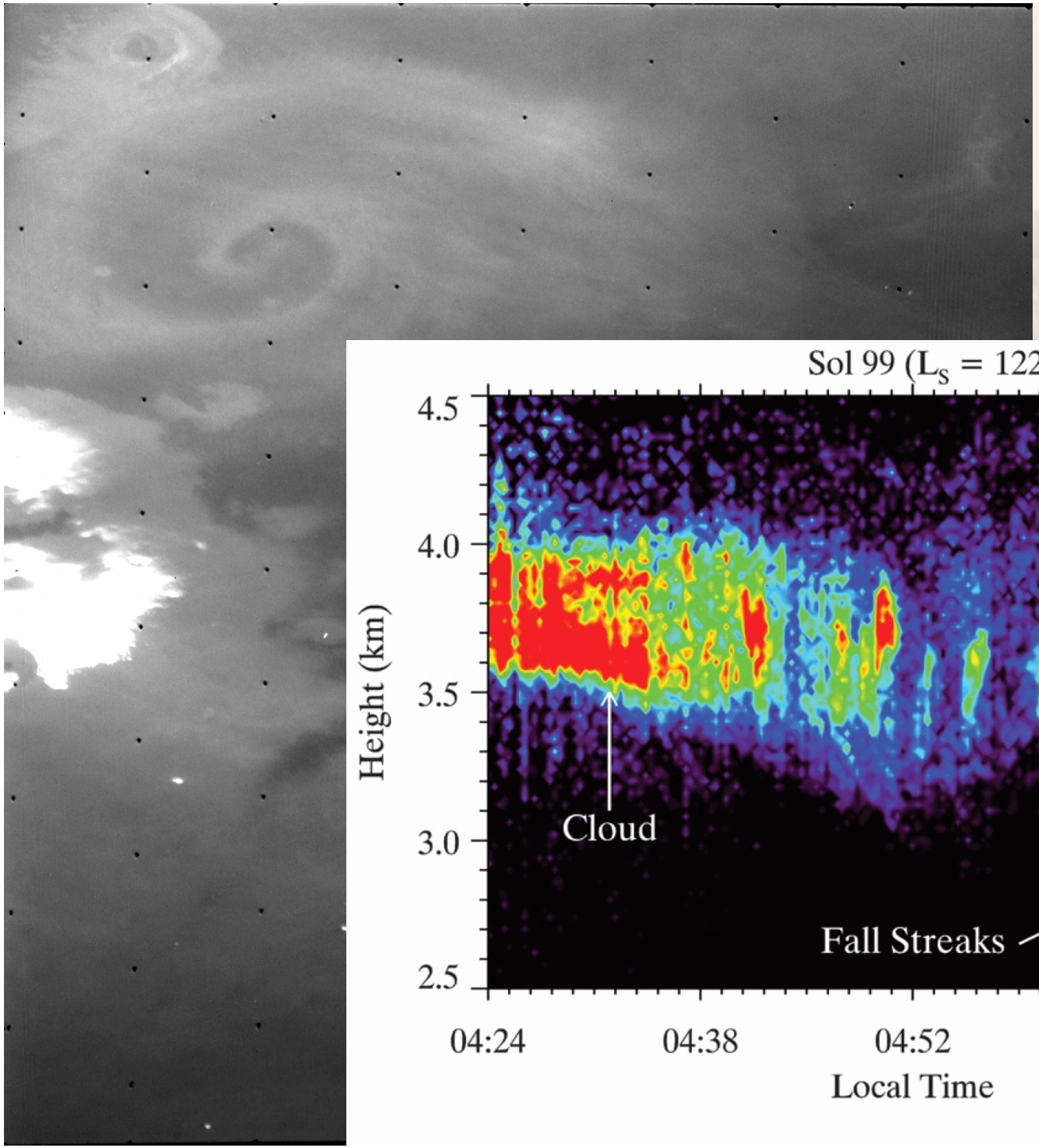


And Mars Global Surveyor

Global Dust Storm (MGS/MOC)

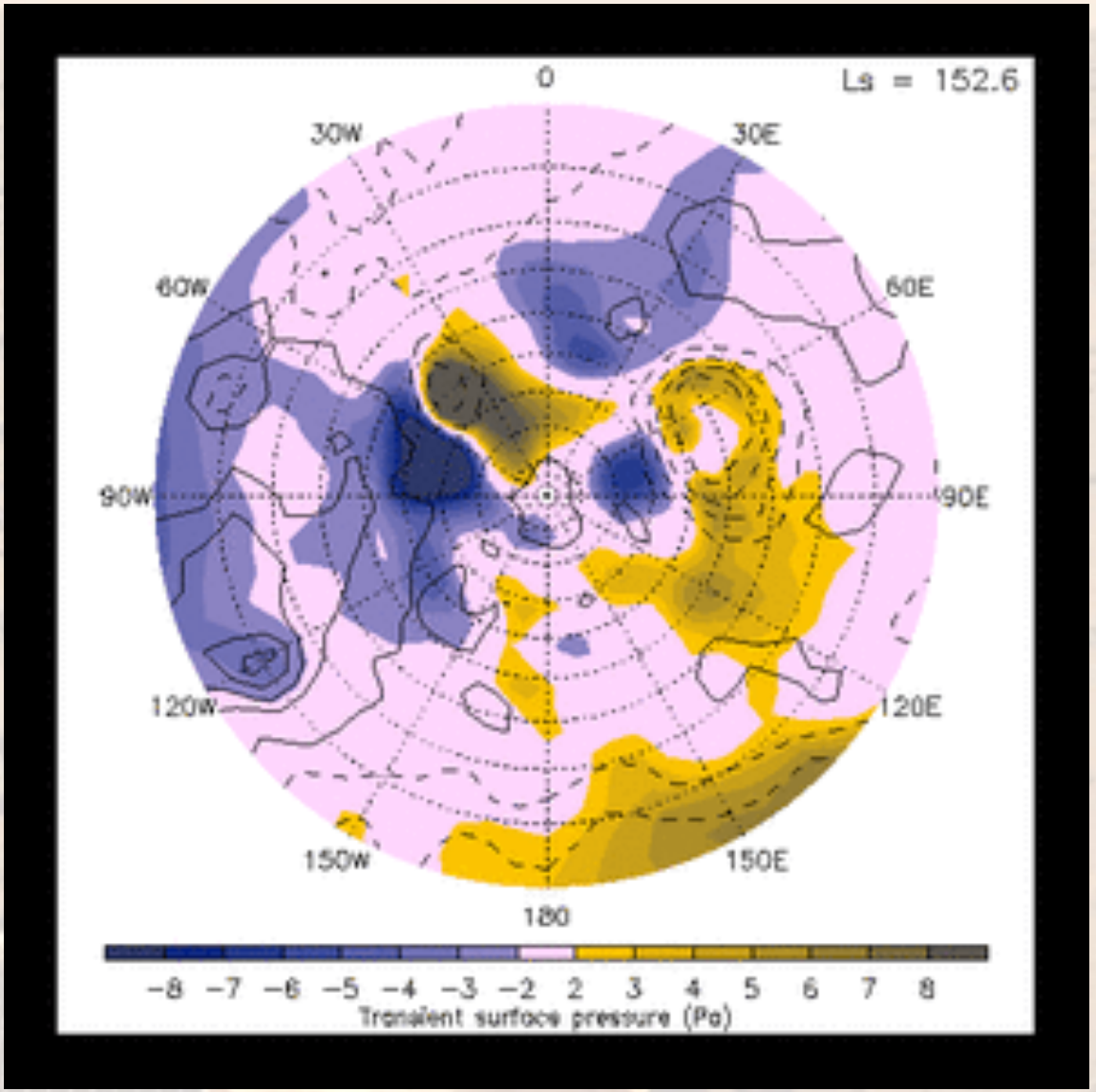


Cyclones: clouds,

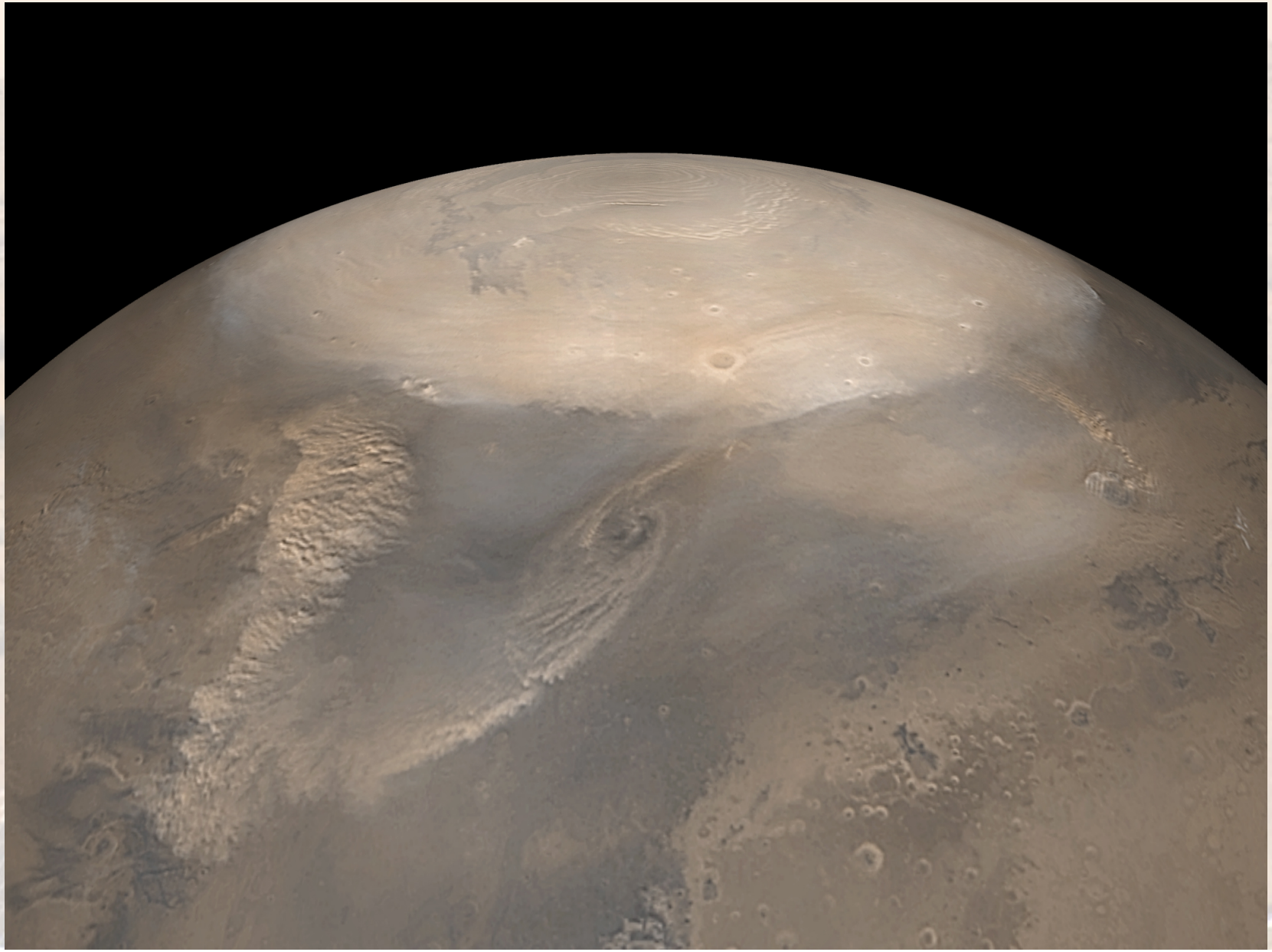


Mars Weather systems from MGS/TES

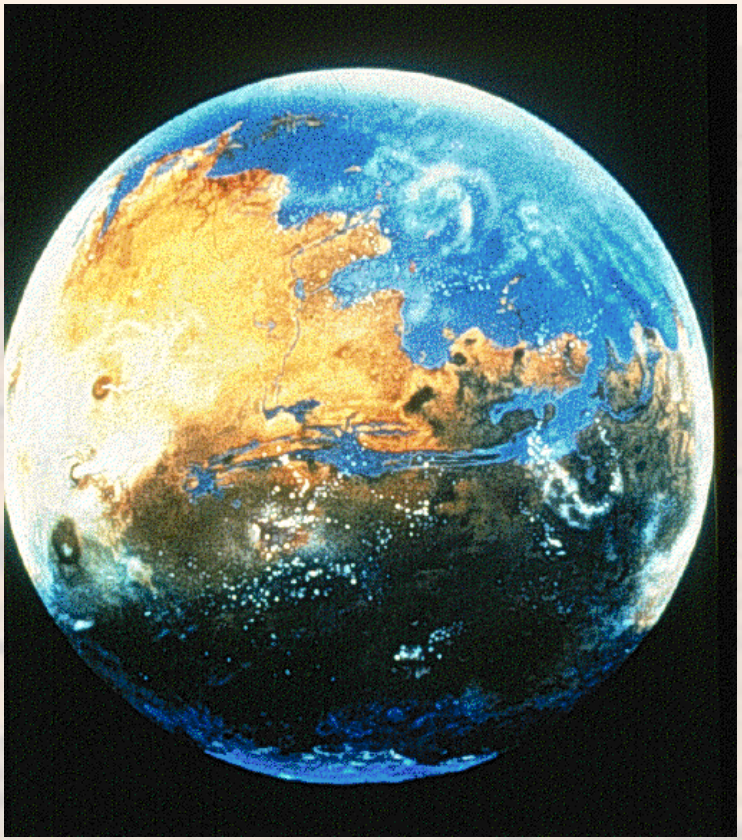
Assimilated transient surface pressure in Mars' southern hemisphere during Mars year 25, just before the onset of the planet-encircling dust storm.

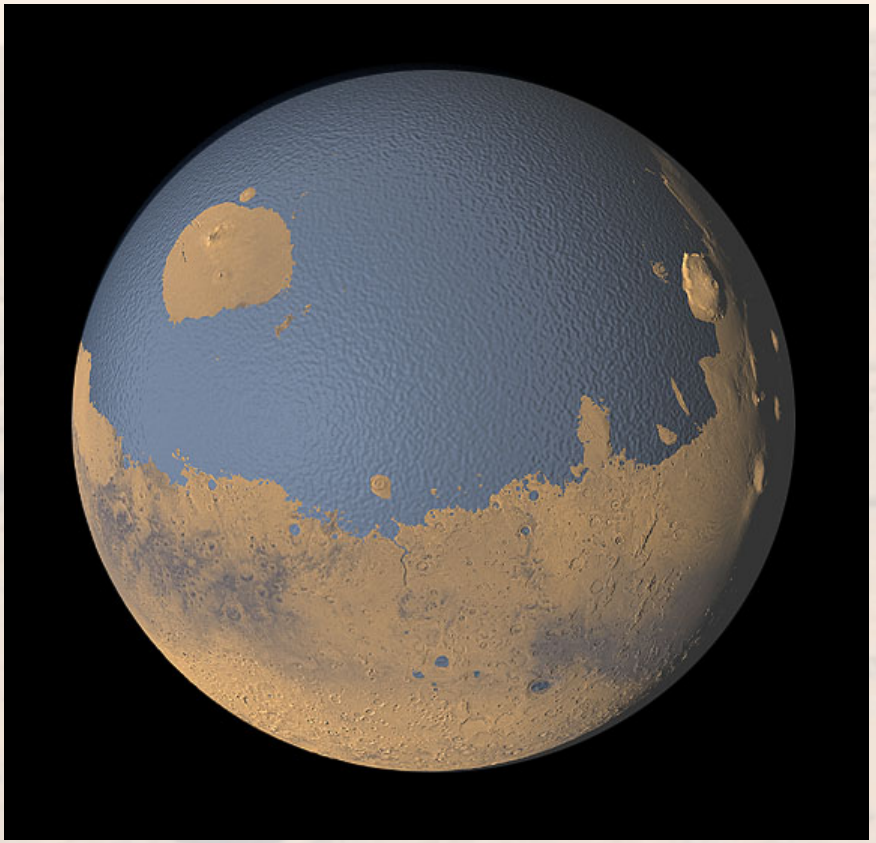


North polar storms



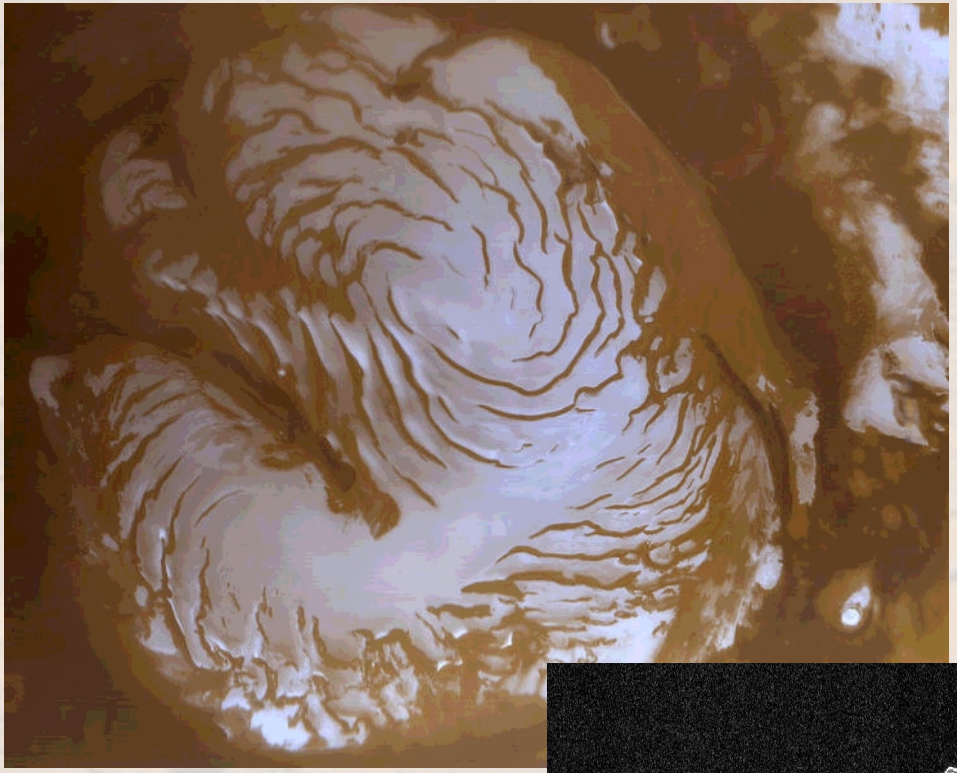
Water on Mars?



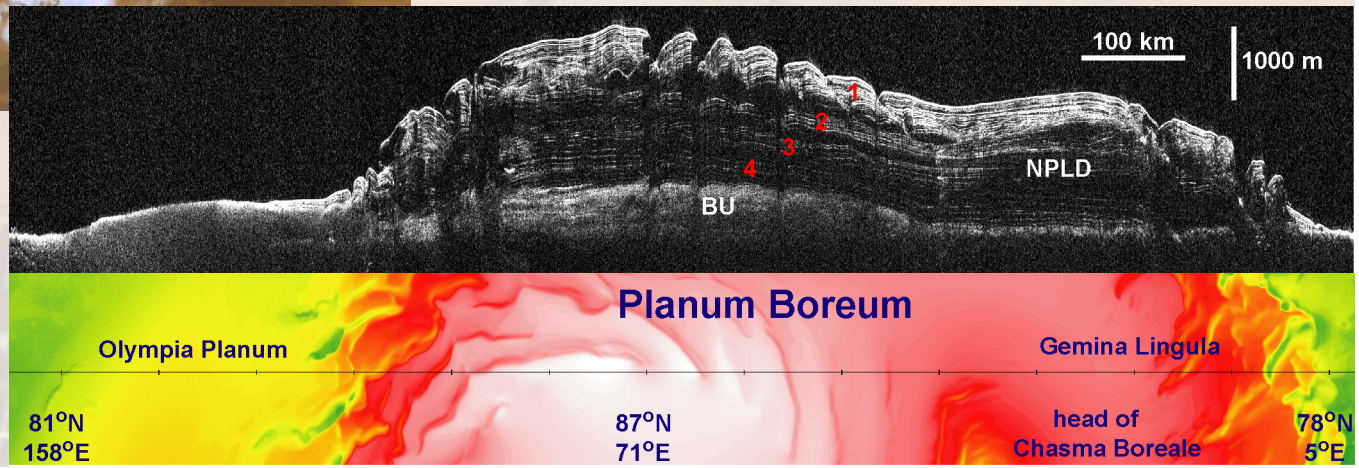


- Abundant on Early Mars - **[NB >3.5 Gyrs ago]?**
- Depth up to 500m
- Mainly in low-lying N Hemisphere
- WHERE IS THE WATER NOW….?

Water on present-day Mars - North Polar ice cap



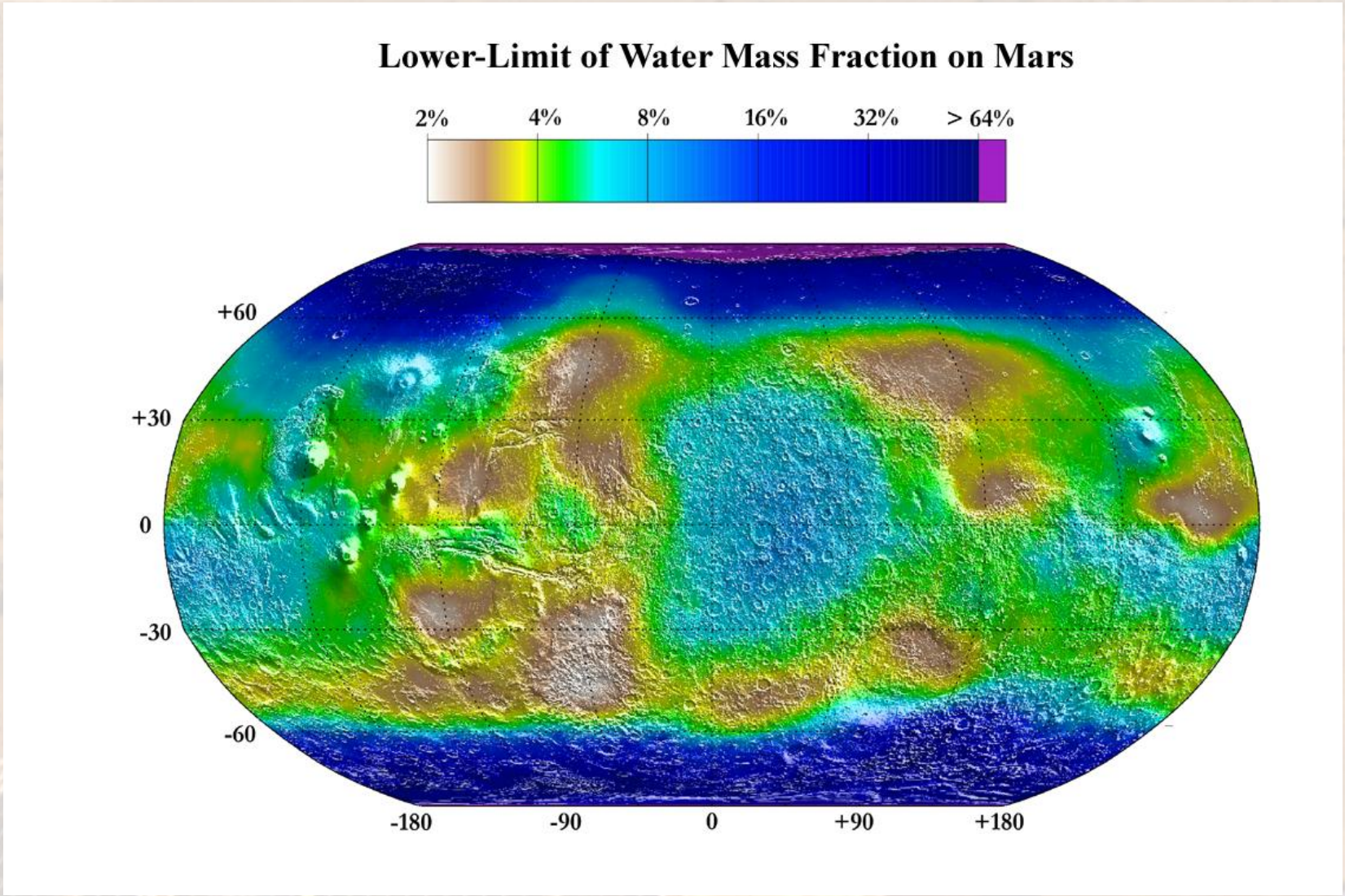
- Massive permanent ice deposits
- Up to 2.5 km thick
- Total ice volume comparable to Greenland ice sheet
- Evidence of layers in radar sections…..?



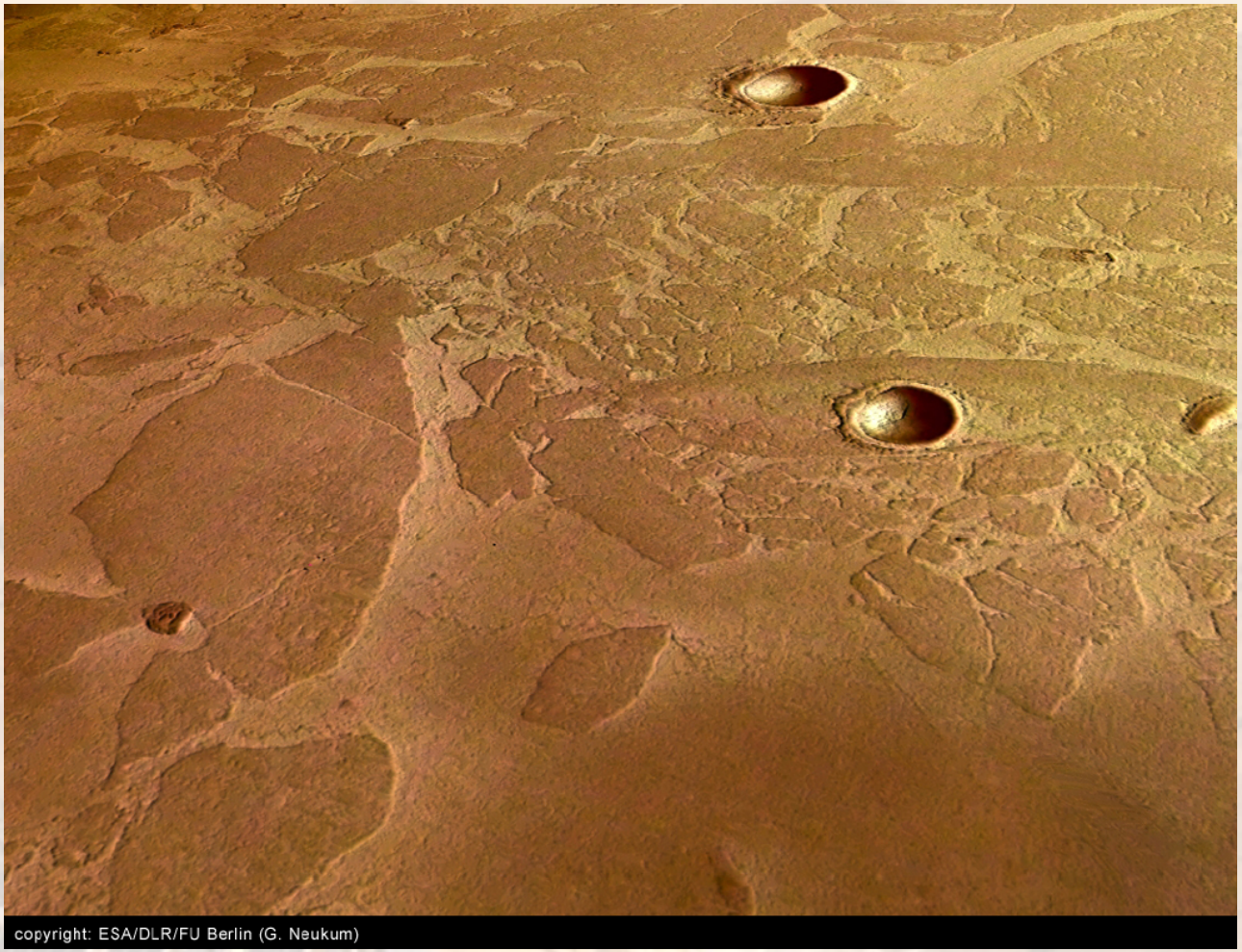
Section from ground-penetrating radar on MRO (Phillips et al. 2008)

Sub-surface Water Ice

(Mars Odyssey: gamma-ray spectrometer)



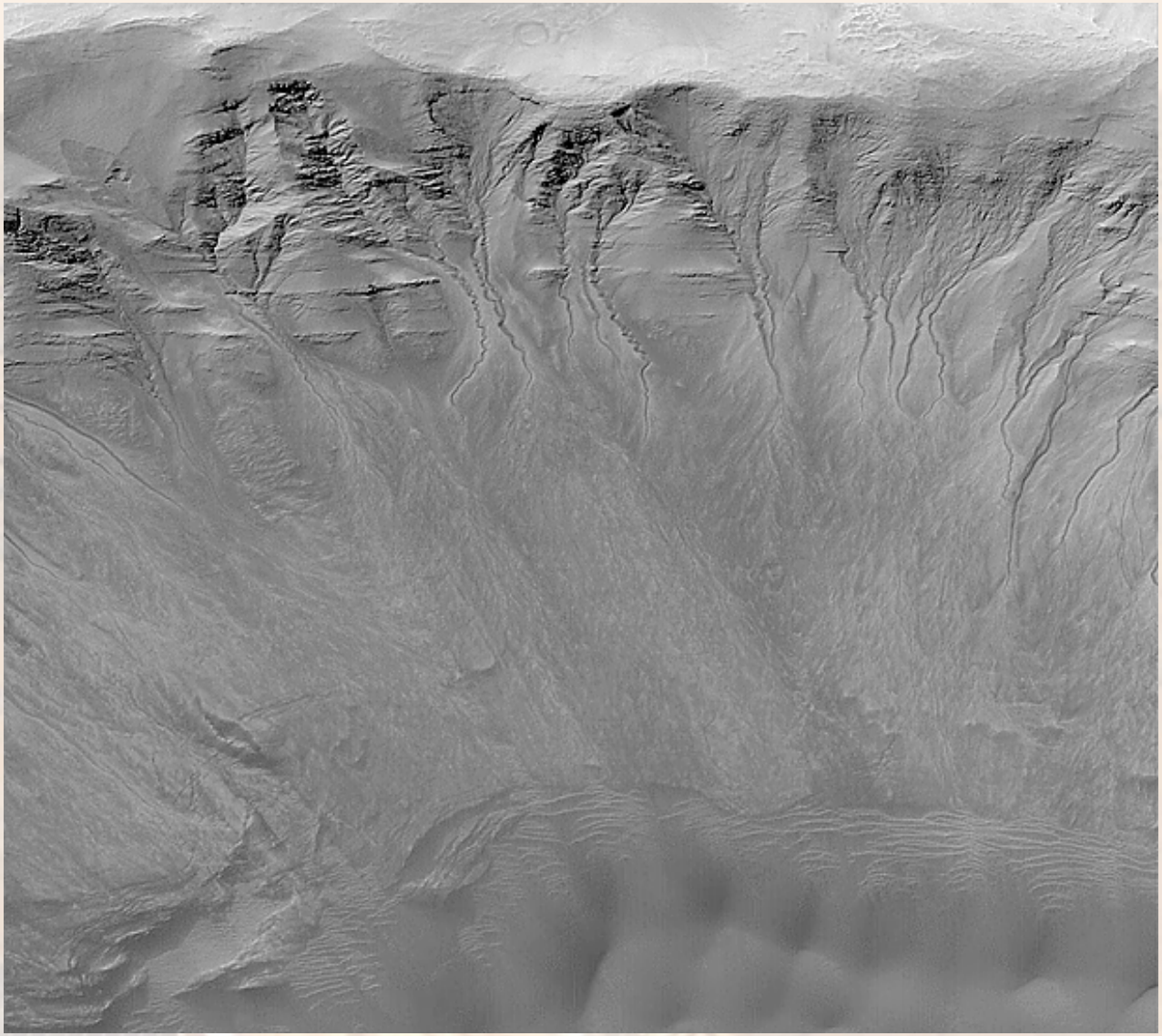
Changing climate on Mars



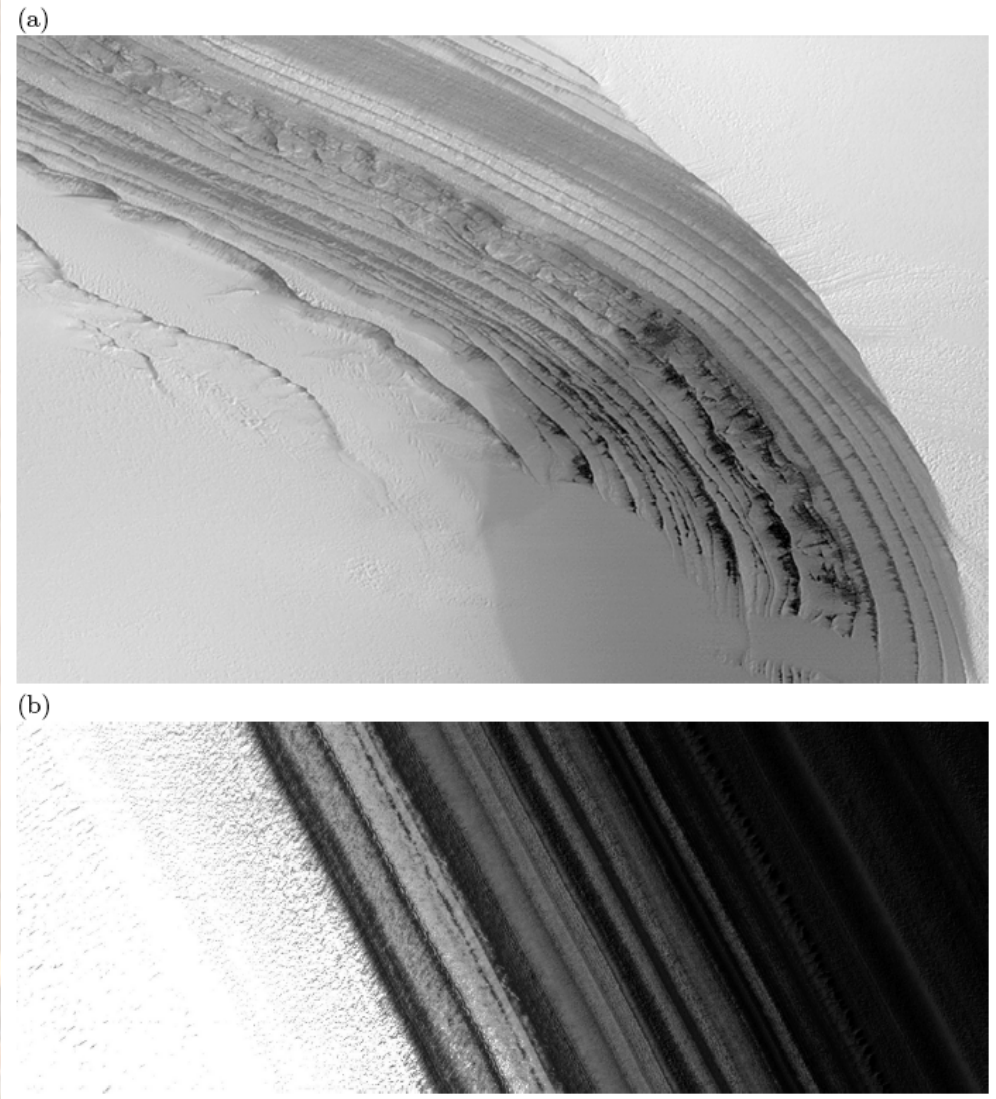
- Dust-covered frozen sea….?
- NB - at 5°N latitude! - so is almost certainly **UNSTABLE?**

Martian Gullies

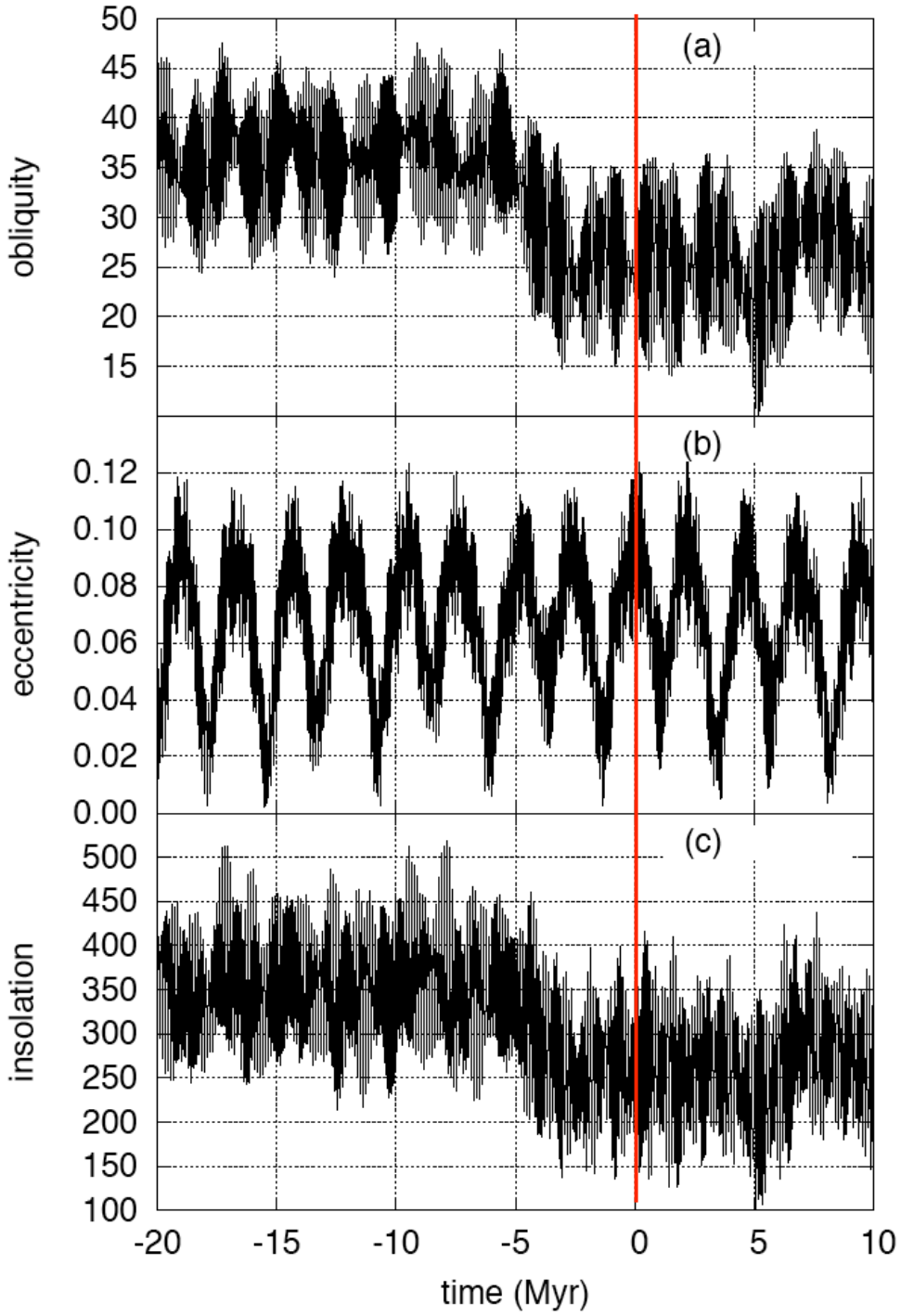
- recent (<10Myr BP) water erosion?



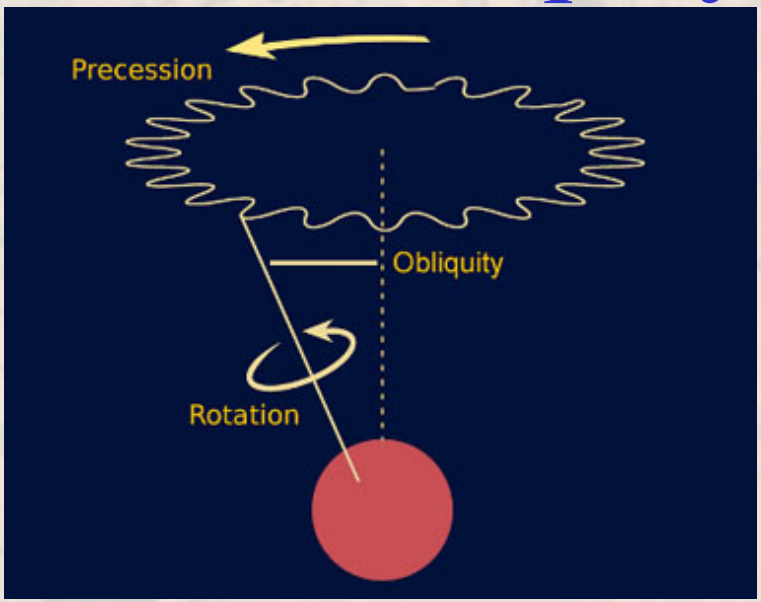
Recent climate change: polar layered terrains



- Layered deposits of water ice and dust
- Extensive terrains equatorward of polar caps
- Evidence of cyclic climate change…?



Cyclic (chaotic!) variations in Mars' obliquity

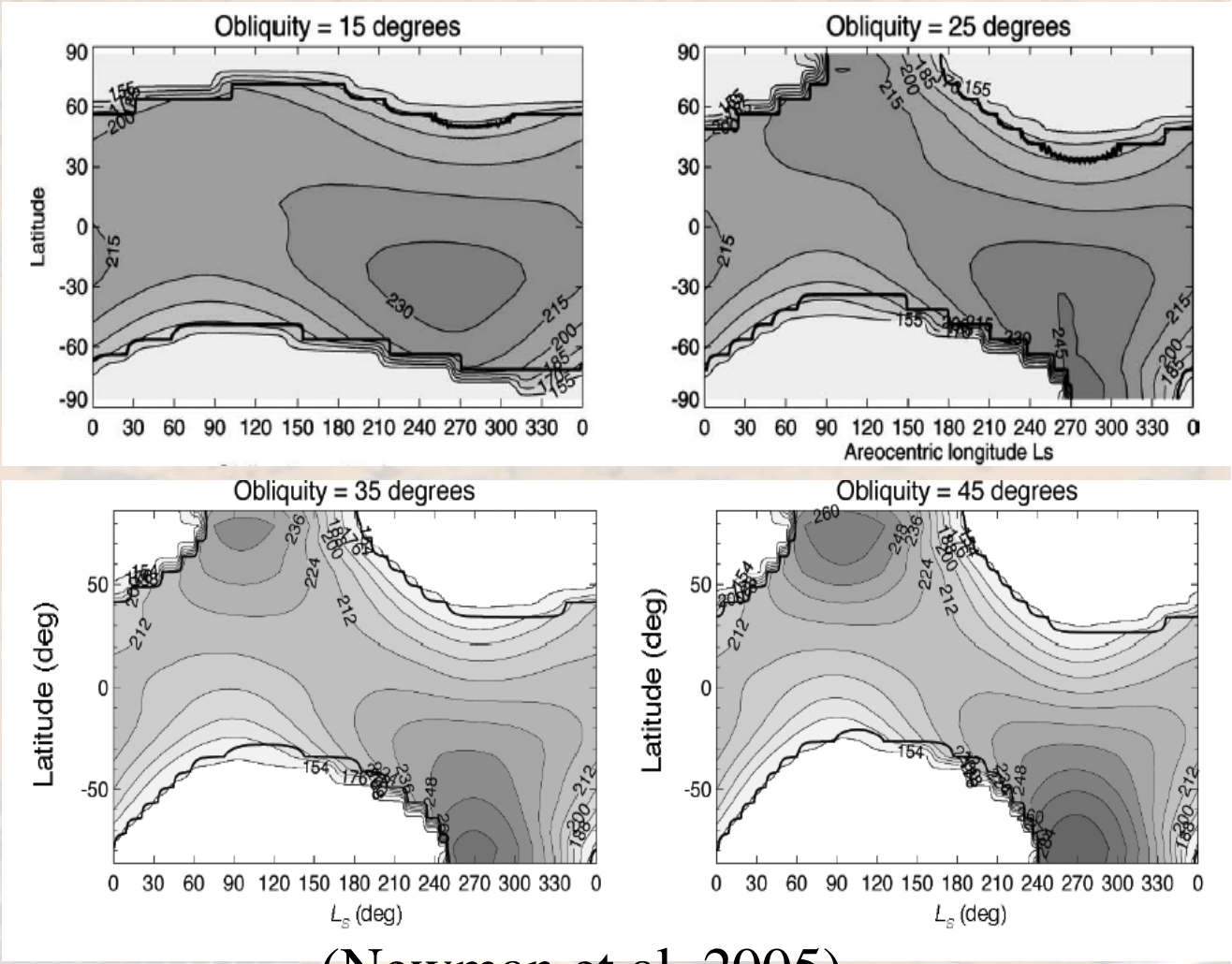


- Perturbations to Mars' orbit and rotation due to other planets

[From Laskar et al. 2004]

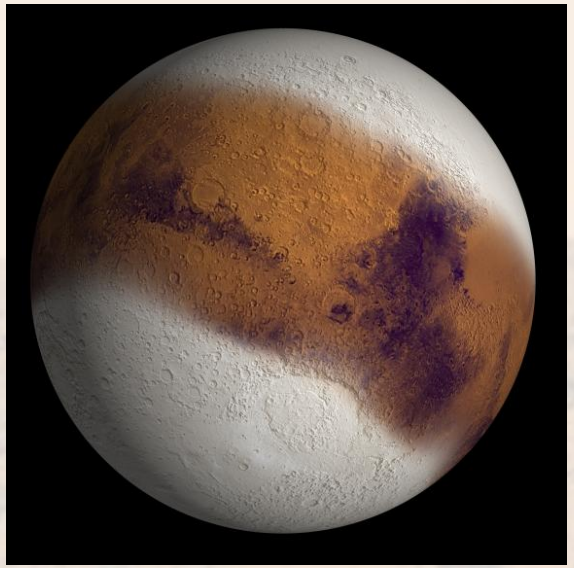
Climate modelling for other epochs…?

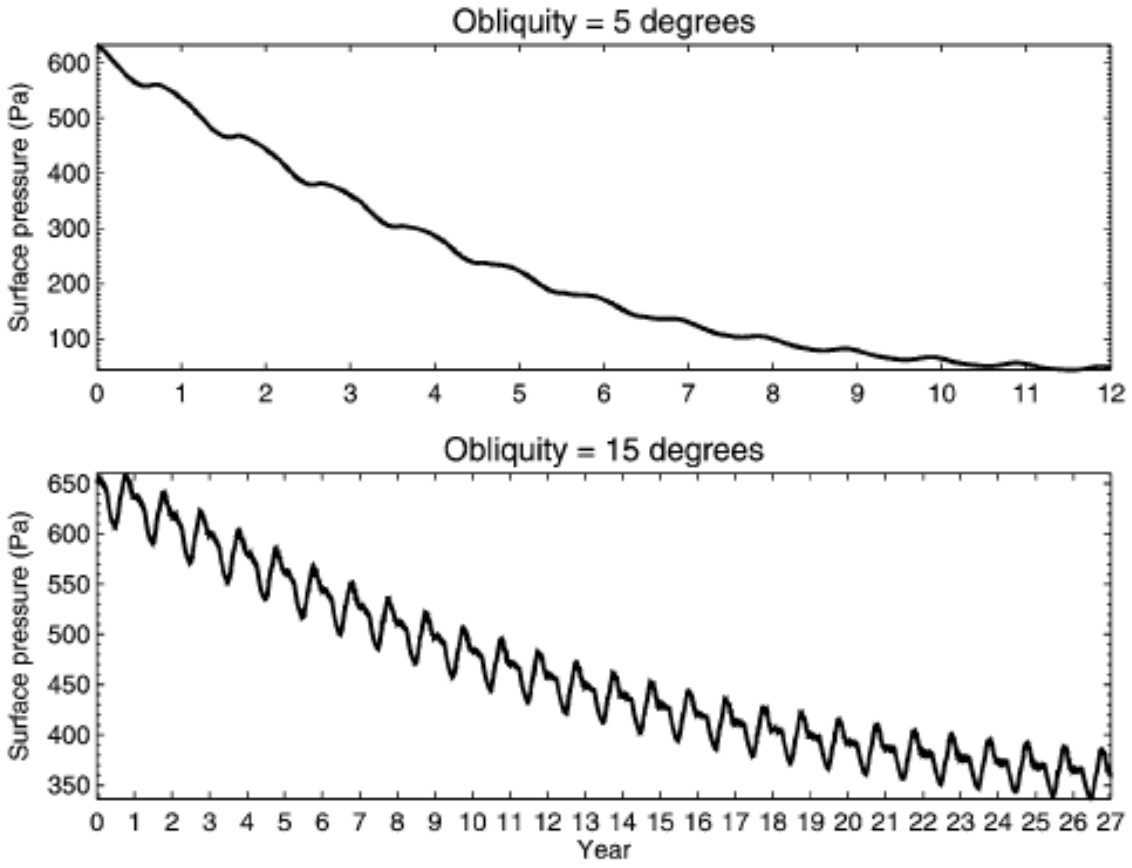
- Mars GCM/climate models can be adapted to run with orbital/rotation parameters for other epochs
- Vary obliquity/ eccentricity/ longitude of perihelion….
- Run model for intervals up to 20 Mars years to reach statistical equilibrium



(Newman et al. 2005)

Low obliquity climate states



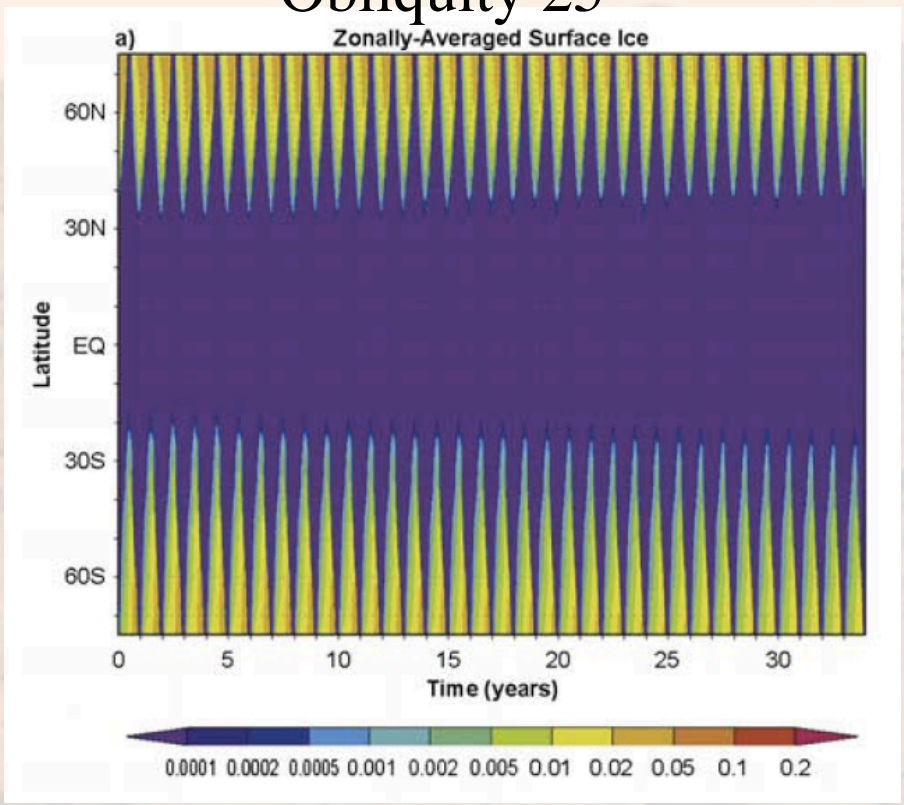


(Newman et al. 2005)

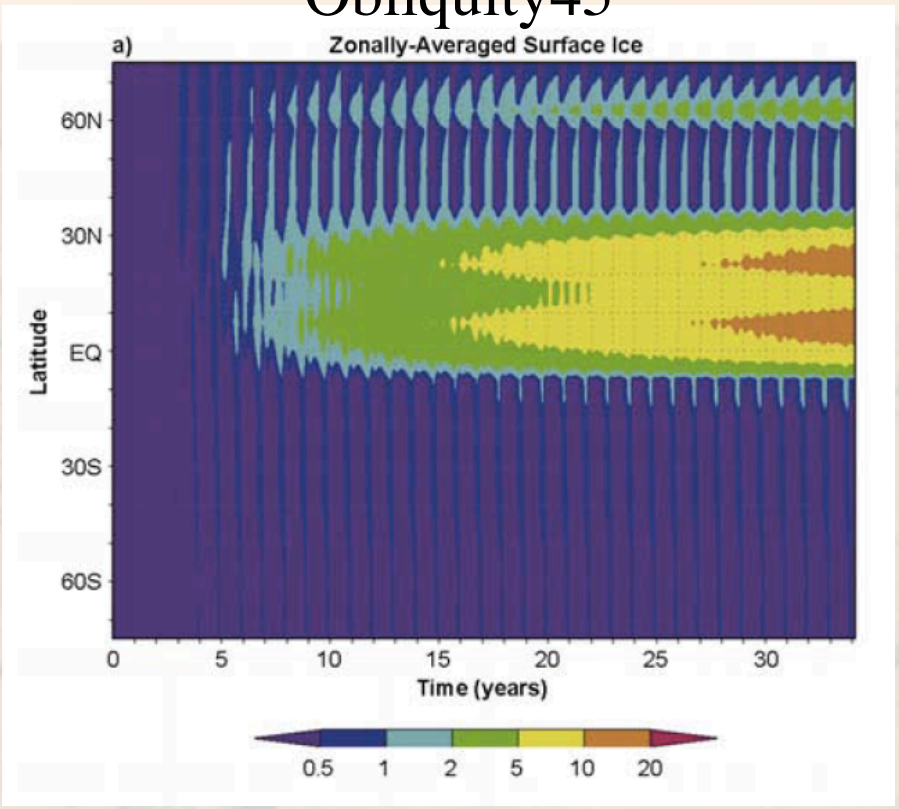
- Growth of permanent CO_2 ice caps
- Decrease of mean surface pressure
- Less dust lifting
- Clear and cold conditions

High obliquity climate states

Obliquity 25°



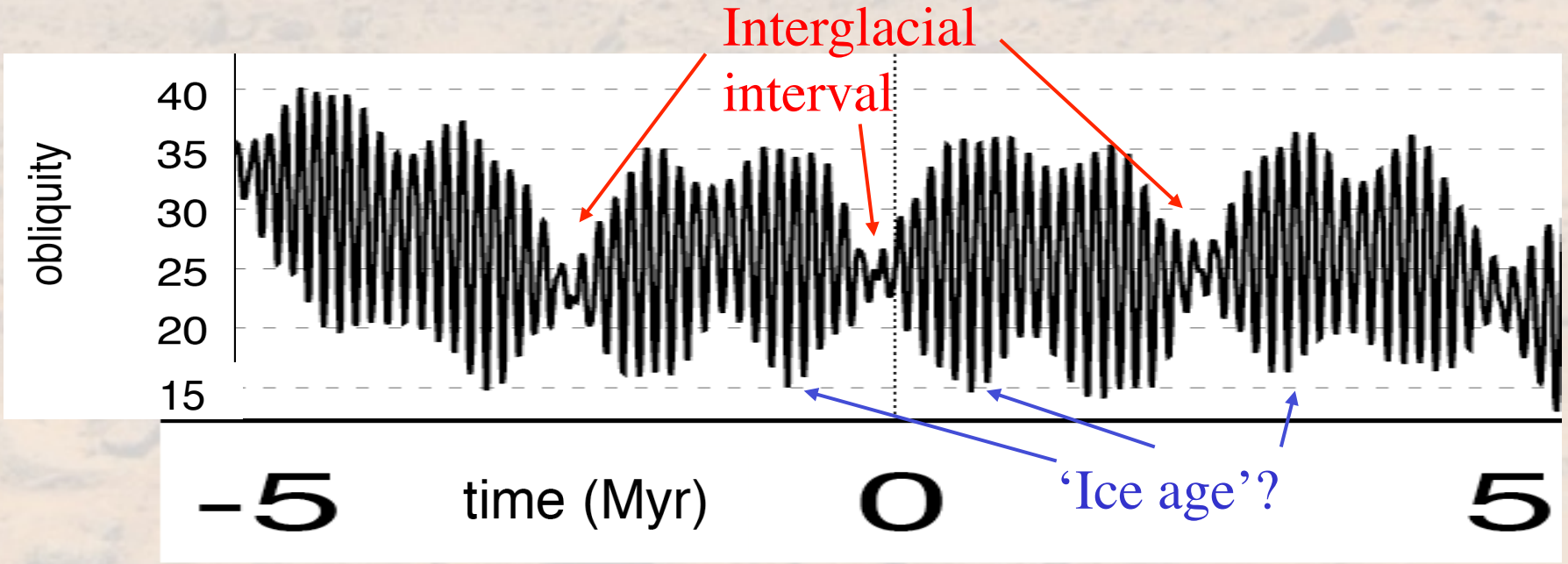
Obliquity45°



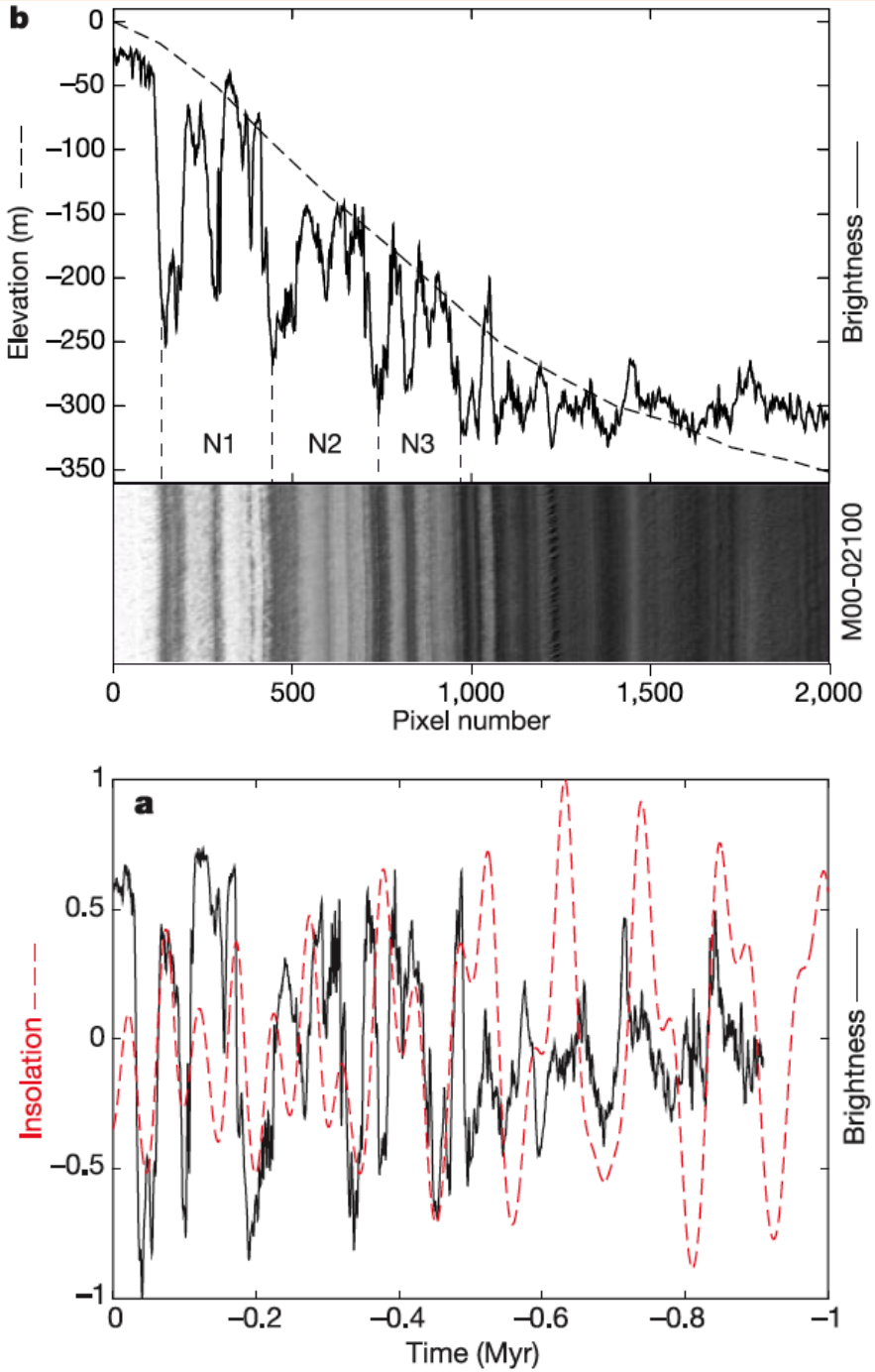
- Melting of permanent H_2O polar ice caps & migration to low latitudes
- Increase of mean surface pressure and humidity
- More dust lifting

(Mischna et al. 2003)

Glaciation cycles controlled by obliquity?



- Modulation of *amplitude* of obliquity cycle ->
  - Glaciation cycles when amplitude is **strong - > polar layers?**
  - Interglacial periods when amplitude is weak (as now)….?
  - Cf Head et al. (2003)…

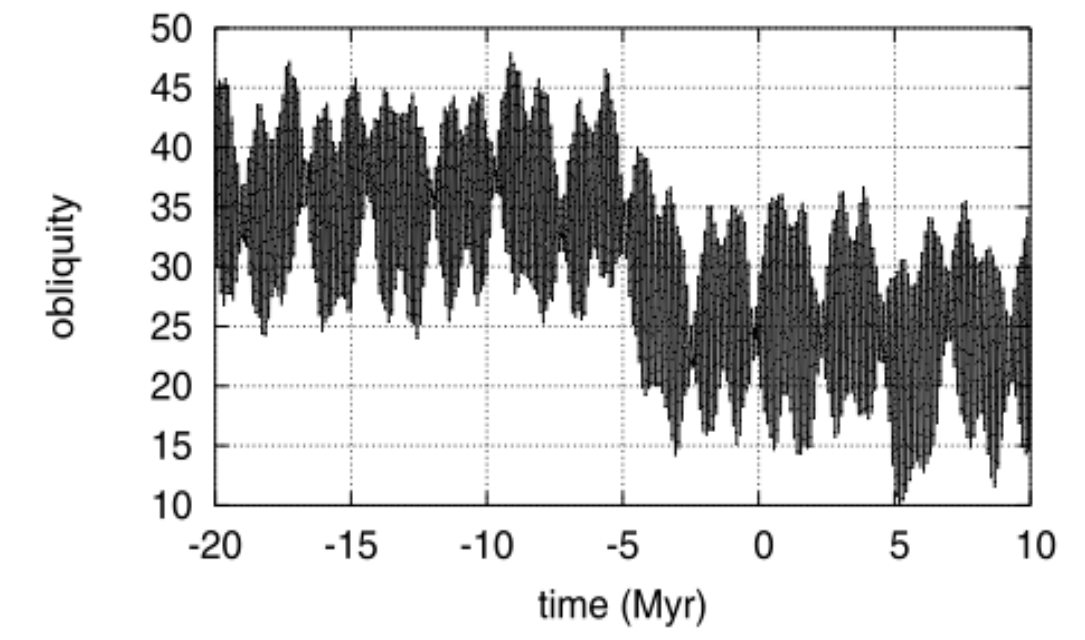


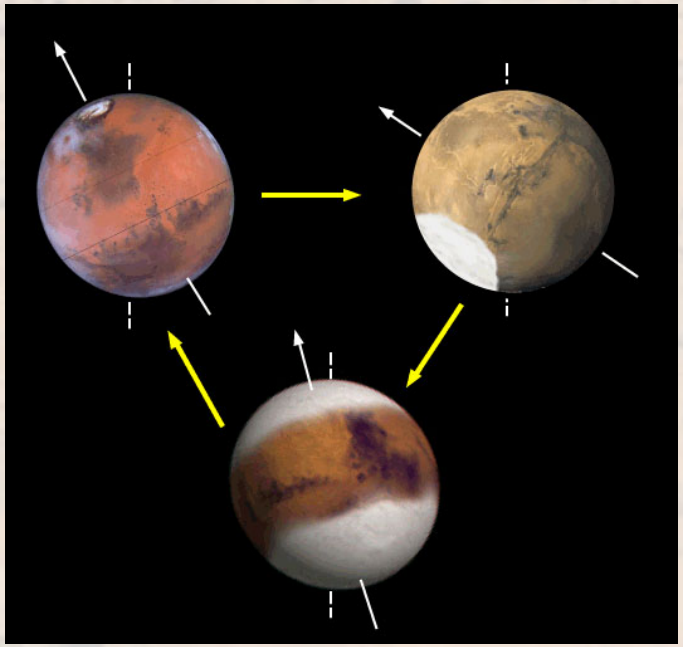
Cyclic variations in solar heating and Mars' polar layered terrains

- Measured brightness profiles across polar layers
- Best-fit correlation with solar heating at the poles

From Laskar et al. (2002; *Nature*)

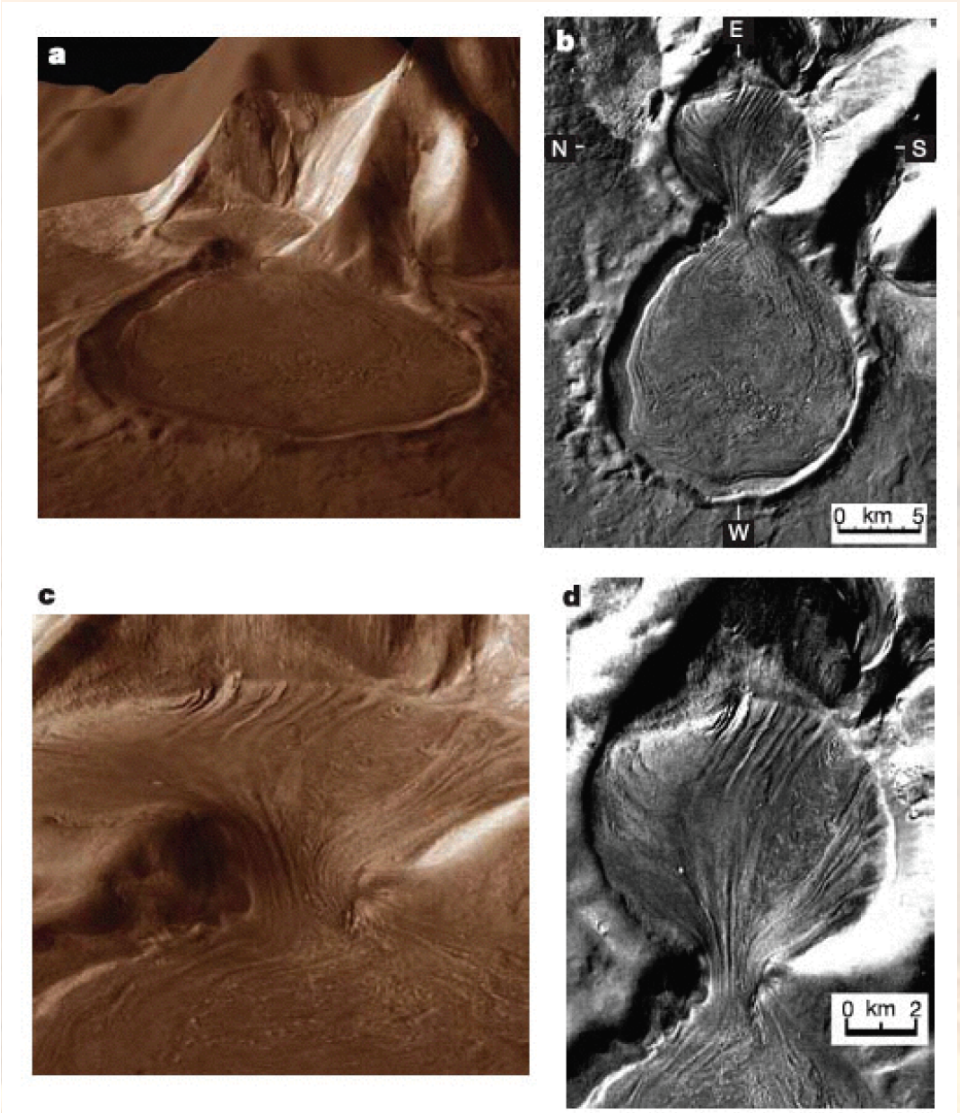
Glaciation cycles controlled by obliquity?





- Slow drift of mean obliquity ->
  - Polar ice probably not stable more than 5Myr ago ($\phi \sim 35^{o}$-45^{o})
  - High obliquity probably favoured accumulation of ice at LOW latitudes…..but now migrated/migrating towards poles?

~(100°E, 40°S)

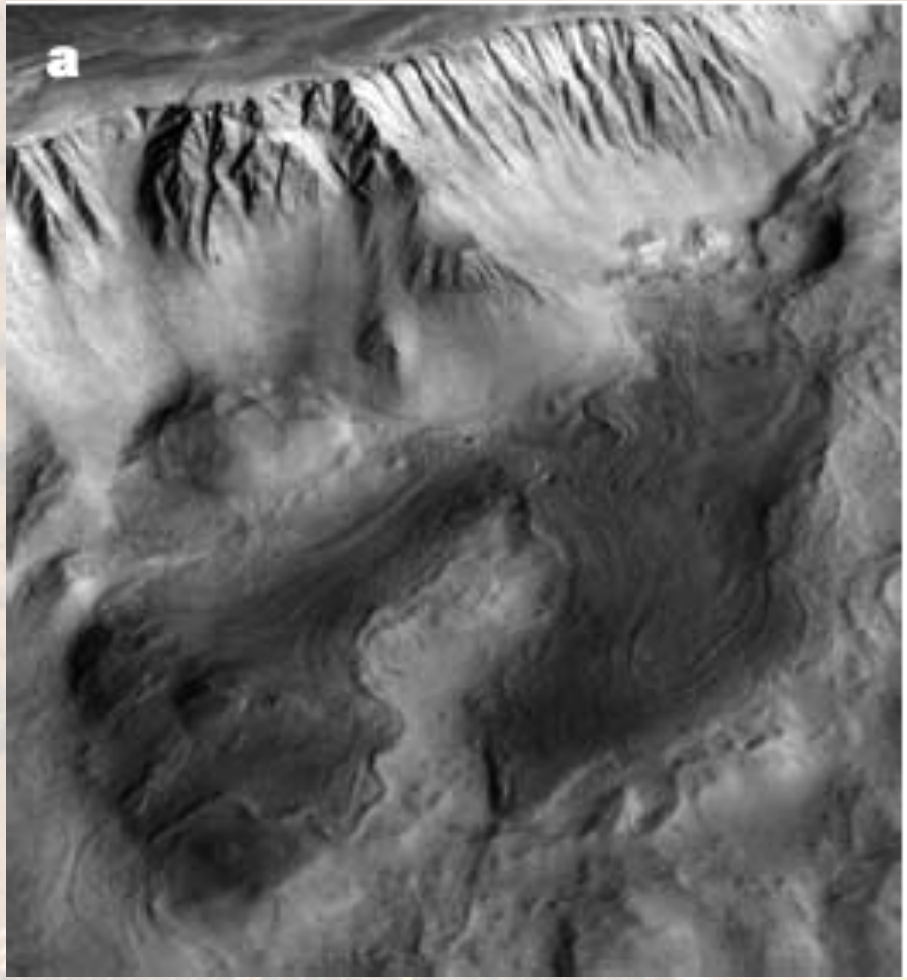


Low/mid-latitude water-ice glaciers on Mars

- Ice-filled craters
- Evidence of ice-flow down slopes and between depressions
- Origin of water ice?
  - Precipitation….?

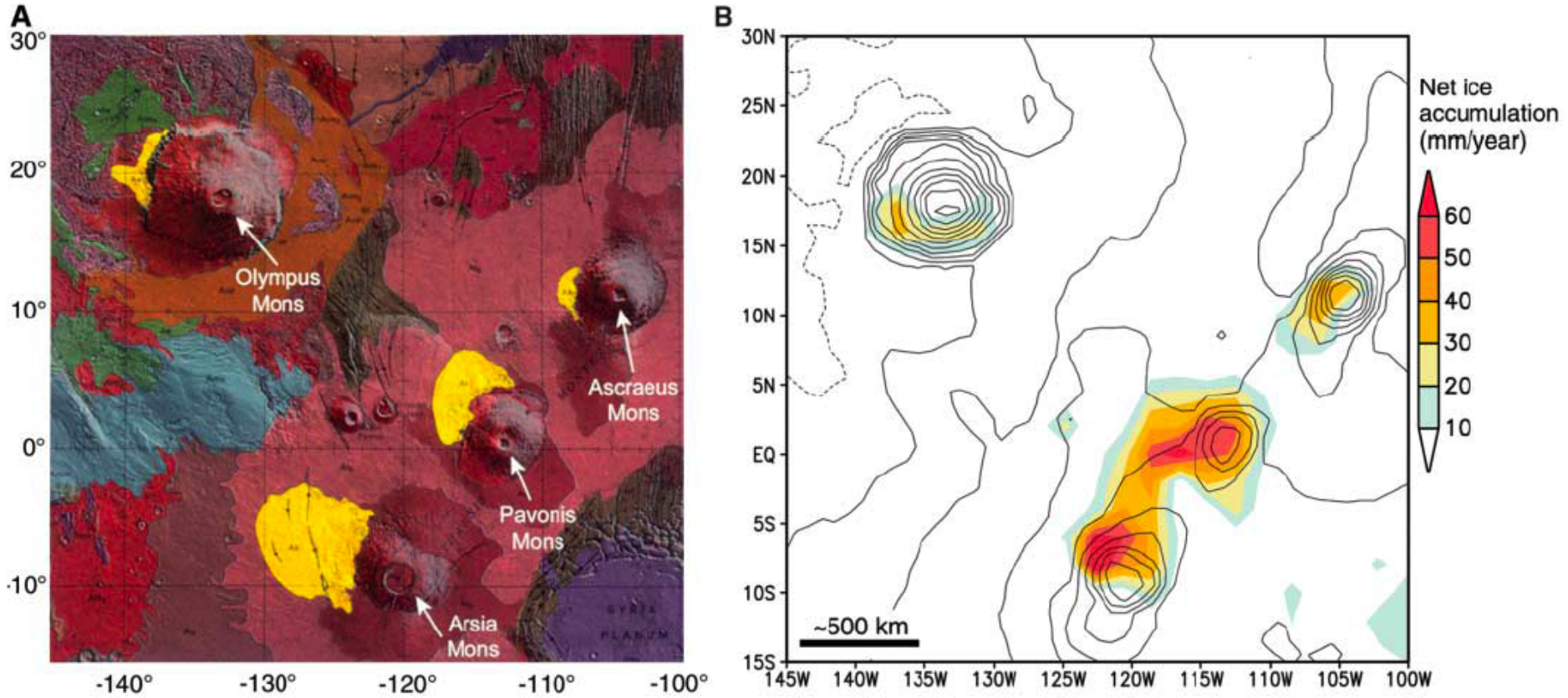
Credit: Mex HRSC - Head et al. 2005)

Rock glaciers on Mars and Earth



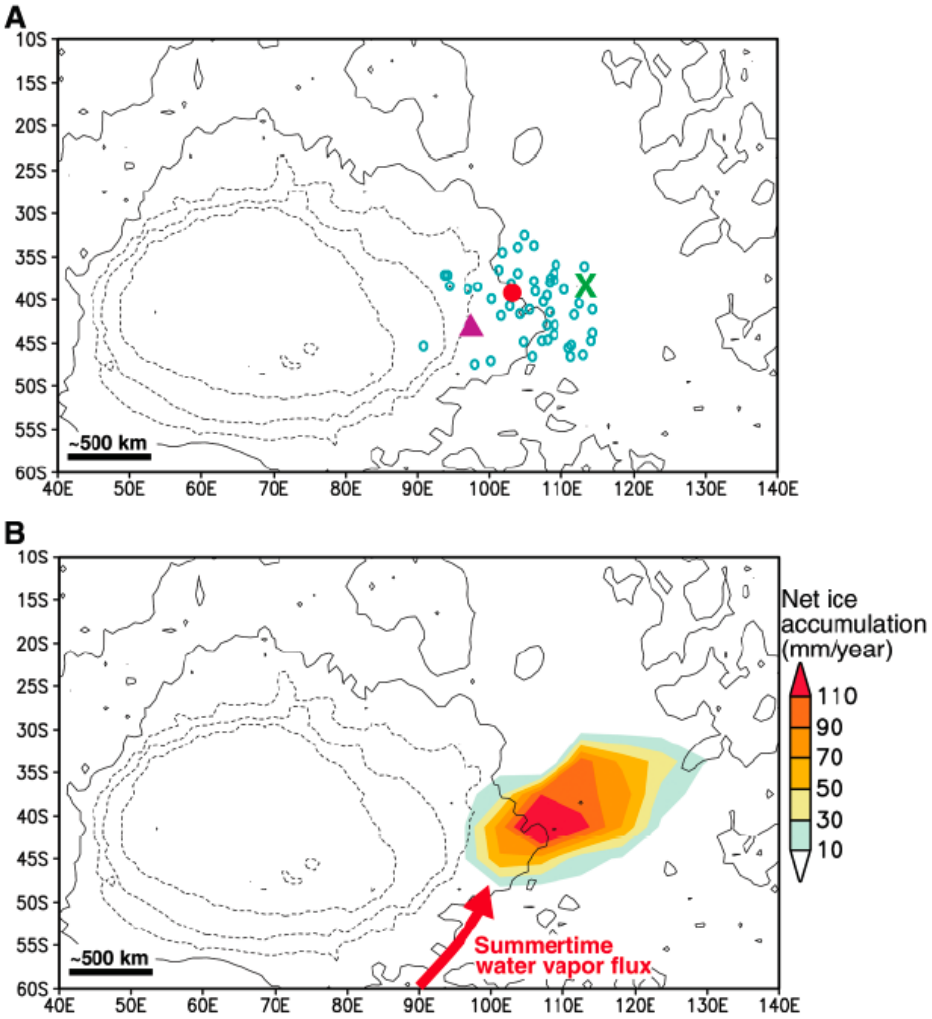
Olympus Mons (Mars @18°N) Antarctic Dry Valleys (Mullins)

Snowfall on Tharsis at high obliquity *($\phi > 35^o$)?*



From Forget et al. *Science* (2006) - LMD GCM at ϕ=45°

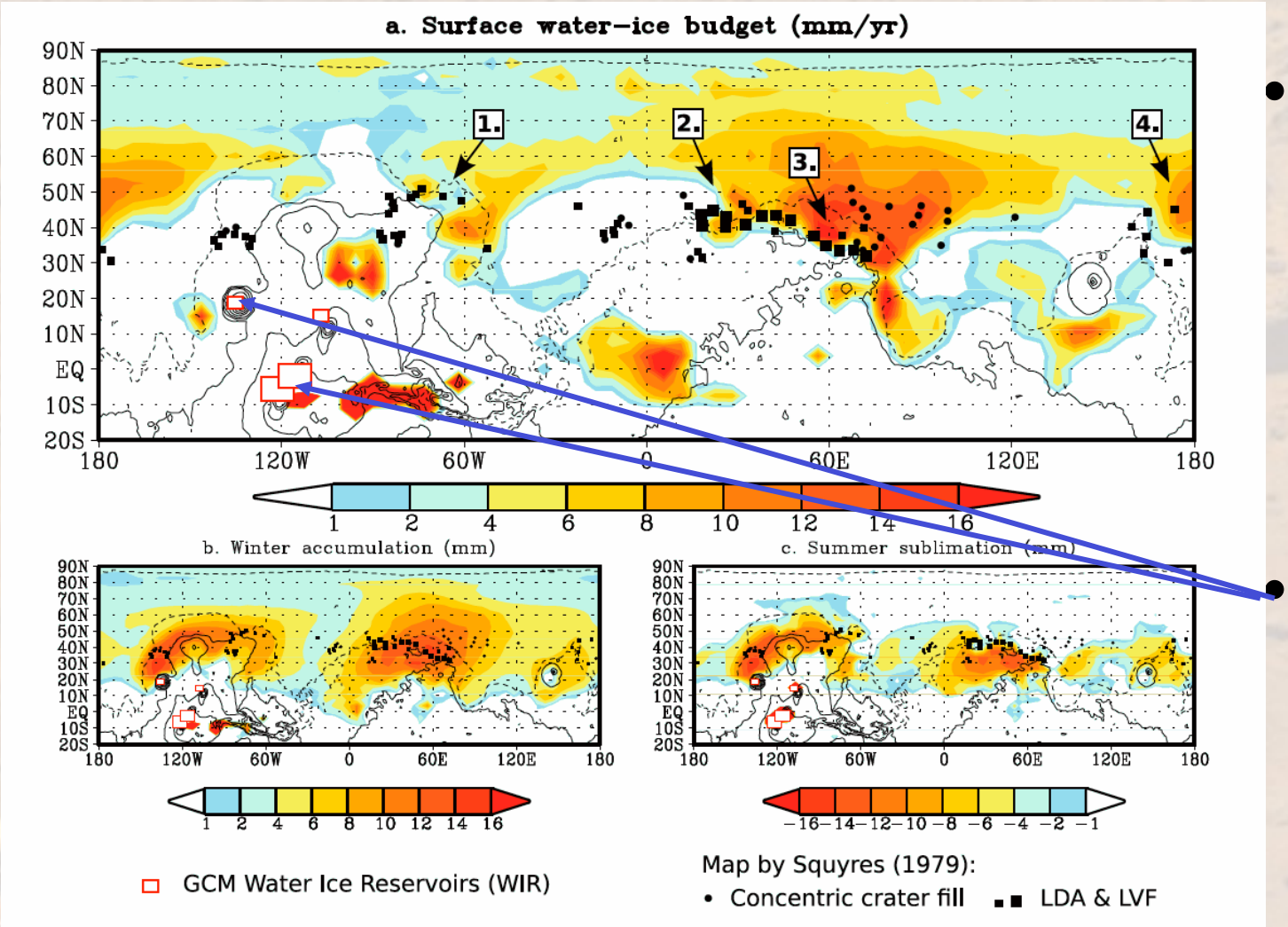
Snowfall at high obliquity in Southern Hemisphere



- Most glacial deposits and debris aprons in SH found East of Hellas Basin
- Preferred location of persistent snowfall at high obliquity
  - NB needs a massive water-ice cap at South Pole….?
  - Forget et al. (2006)

Snowfall at moderate/high obliquity?

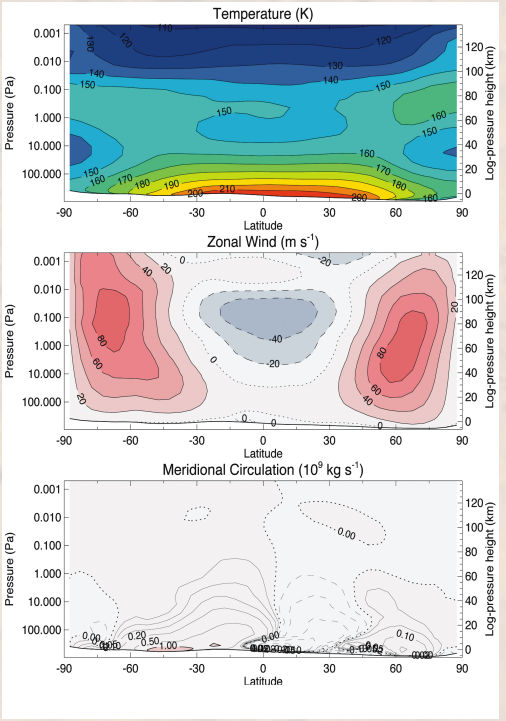
(25° < ϕ < 35°)

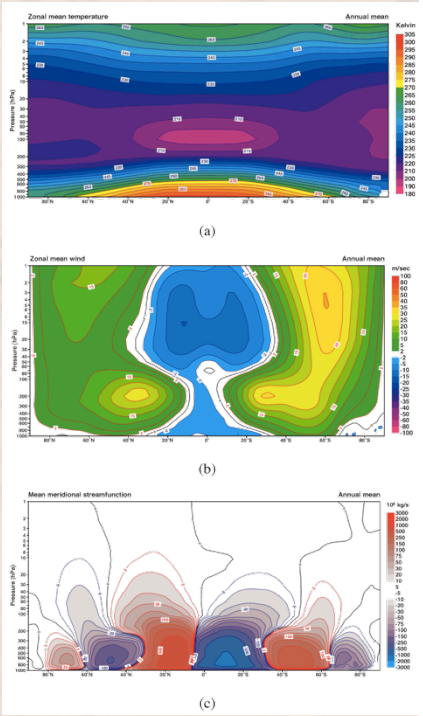


- Glacial deposits at mid-latitudes
  - Madeleine et al. (2009)
- Fed from glaciers on flanks of Tharsis??

Dynamic Climate Change on Mars

- Present atmospheric circulation and meteorology quite ‘Earth-like’
- Present climate is akin to terrestrial polar deserts (e.g. Antarctic ‘dry valleys’)
- Dominated by effects of:
  - CO_2 ice
  - Dust
  - Water (surface & sub-surface ice, atmospheric vapour & clouds - but no precipitation reaches the ground in present climate!)

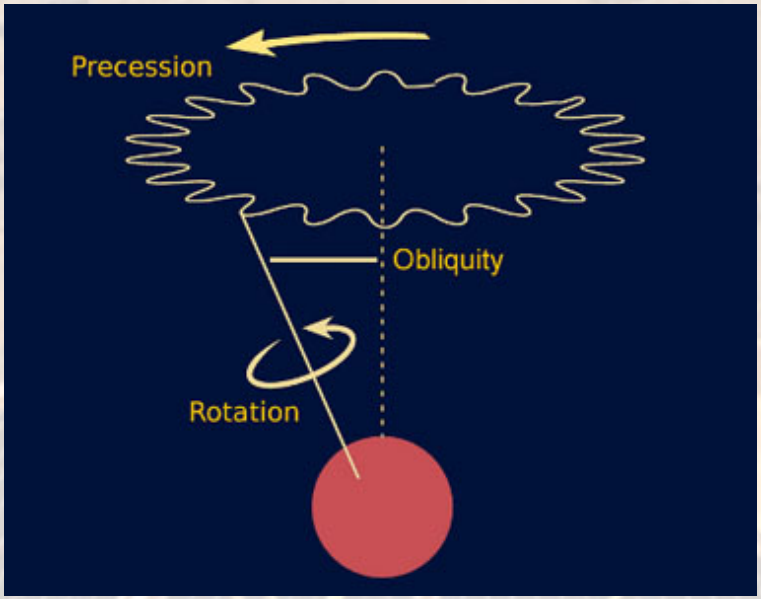


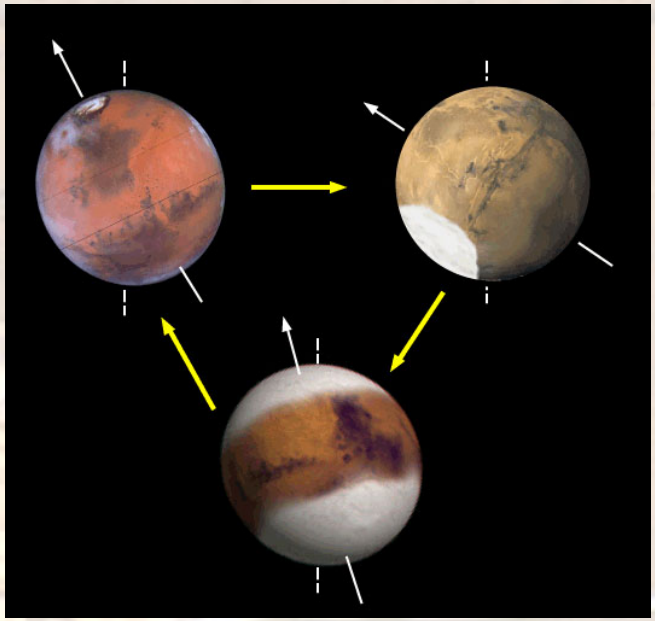


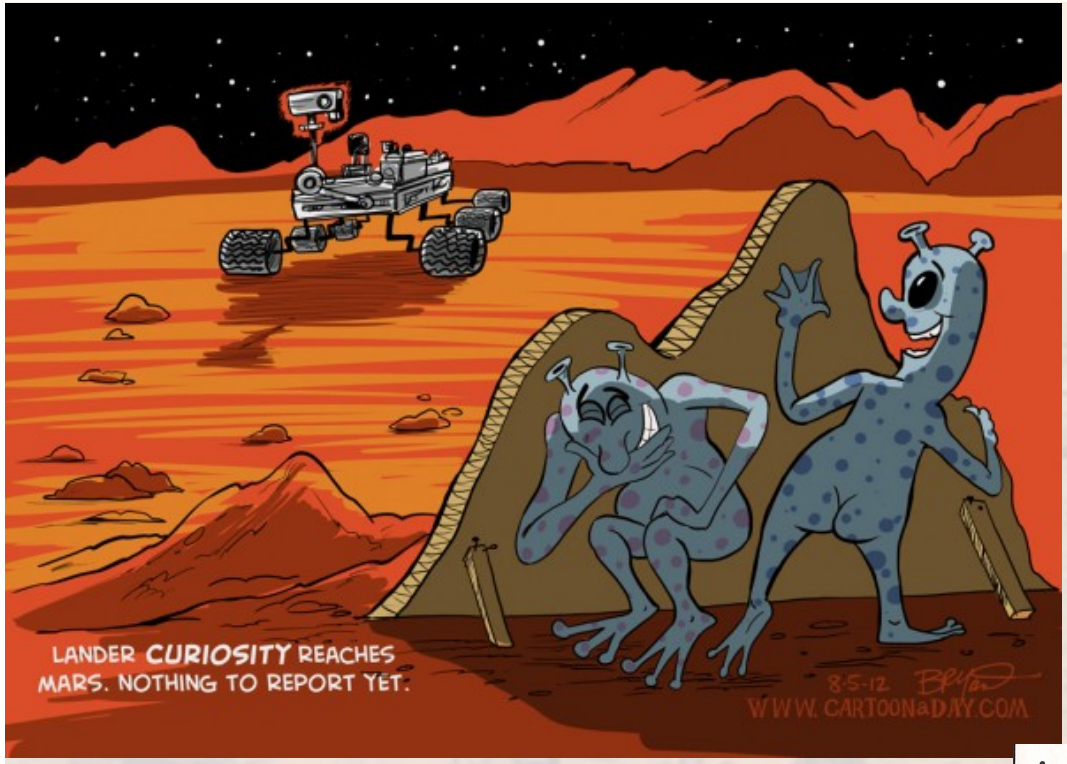
Mars Earth

Dynamic Climate Change on Mars

- The climate of both planets is strongly affected by fluctuations in their orbit and planetary rotation
  - A la Milankovitch's theory!
  - Though details are different on each planet….
- Astronomically-induced climate variability is part of the 'normal' behaviour of many planetary atmospheres - on timescales >10,000 yrs







Thanks for listening!

Oxford Physics