SOFIA -- Planetary Science Vision

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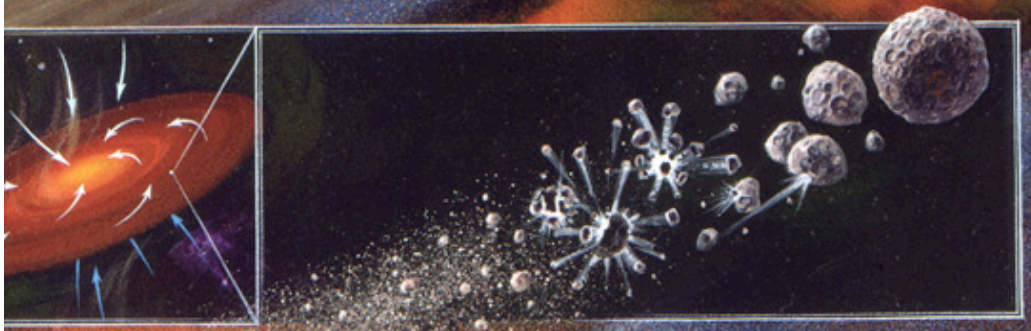
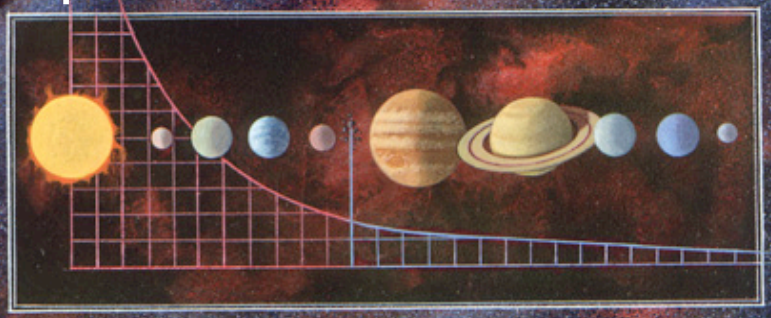
Main topics:

Primitive Bodies (esp. comets, Kuiper Belt objects)
Gas giant planets
Venus and Titan atmospheres





High-level themes and objectives of planetary science

2003 Solar System Decadal Study Themes:

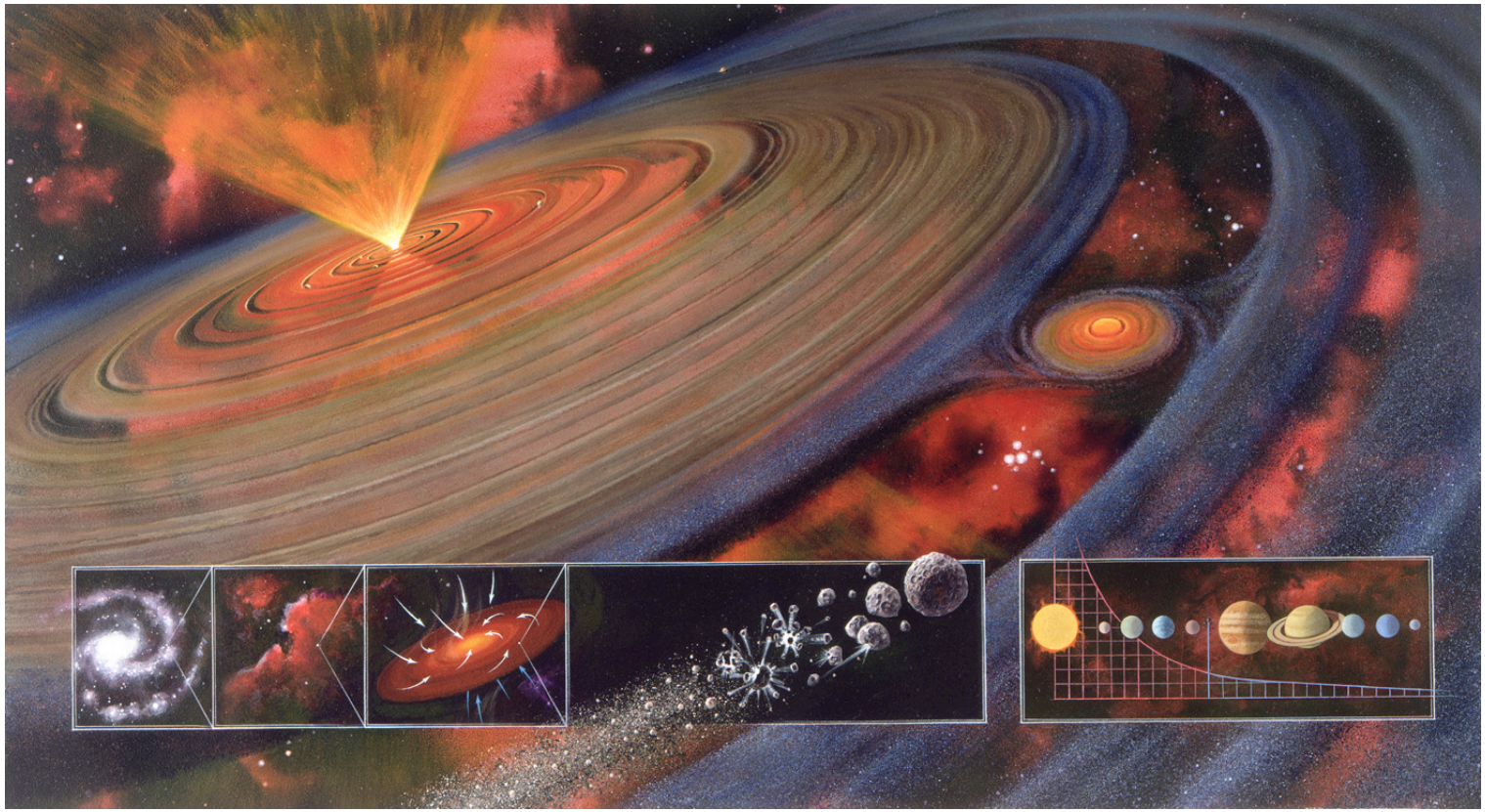
1) Formation and evolution of the planets and life on them
2) Evolution of volatile and organic material in the solar system
3) Origin and evolution of habitable worlds elsewhere in the galaxy
4) Fundamental processes of planetary evolution.

NASA Objectives:

A) How did the solar system form?
B) How do other planetary systems compare with ours?
C) What are the locations, characteristics, and histories of biogenic compounds in our solar system?

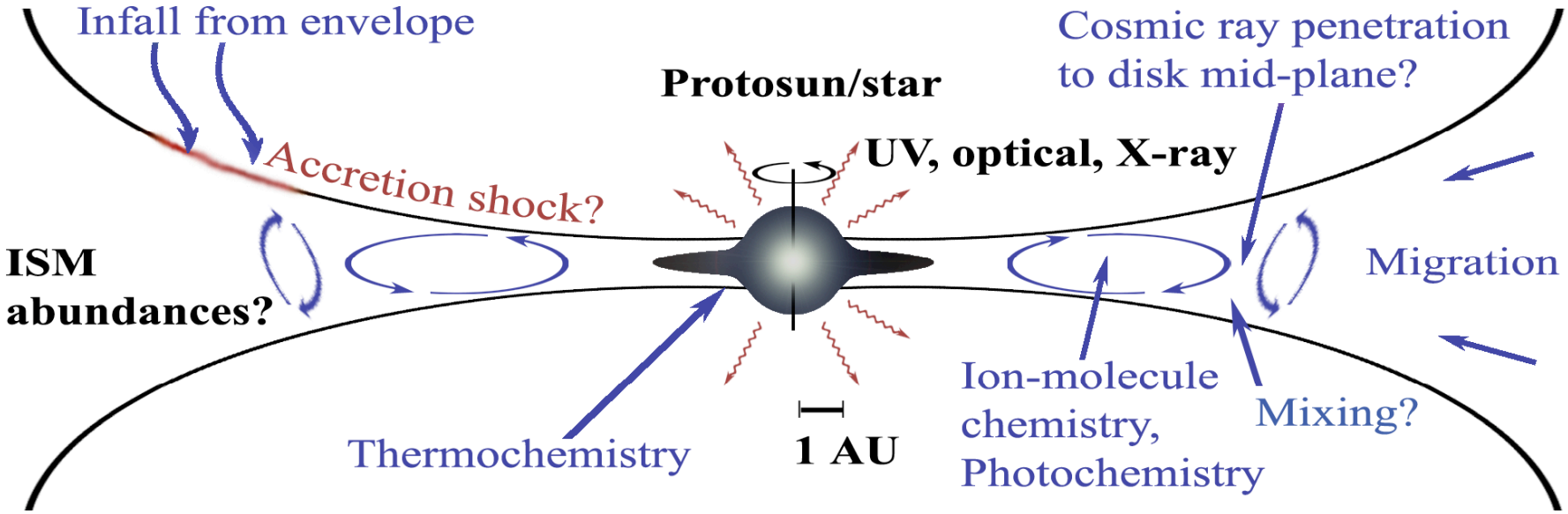
SOFIA: An astrophysics mission with important planetary science capabilities

- *Can observe at low solar elongation: objects closer to the Sun than Earth*
- *Can observe stellar occultations and other transient events from anywhere on Earth*
- *Can point at bright planets and their inner moons*
- *Can monitor seasonal changes over decades for slow-orbiting outer planets*



Solar System Rosetta Stones: Primitive Bodies

- *Comets, Asteroids, Centaurs, KBOs (Kuiper Belt Objects)*
- *Material condensed early in S.S. history, subsequently little- or un-altered*
- *Evidence from comet Wild 2 for substantial radial mixing in the solar nebula*
- *"Nice" model indicating primitive body dynamical families could be from mixed sources*



Primitive Bodies: Comets

• *SOFIA spectroscopy can address comet formation and evolution processes:*

- *Water abundance, isotopic composition, and formation temperature*
- *Grain mineralogy and crystallinity*
- *Organic content*
- *Individual comets' inhomogeneities*

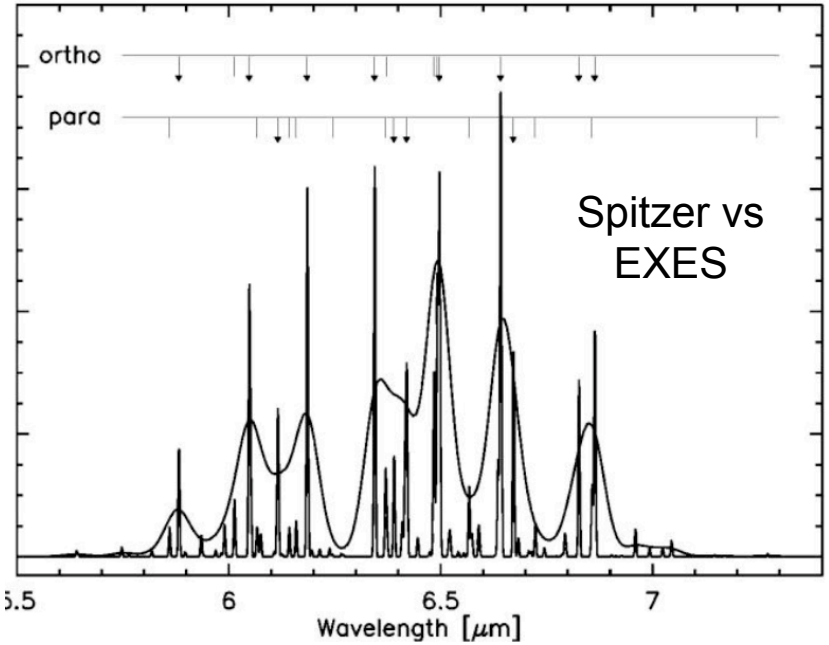
** SOFIA can observe est. 60 comets over its lifetime, including several visited by spacecraft.*

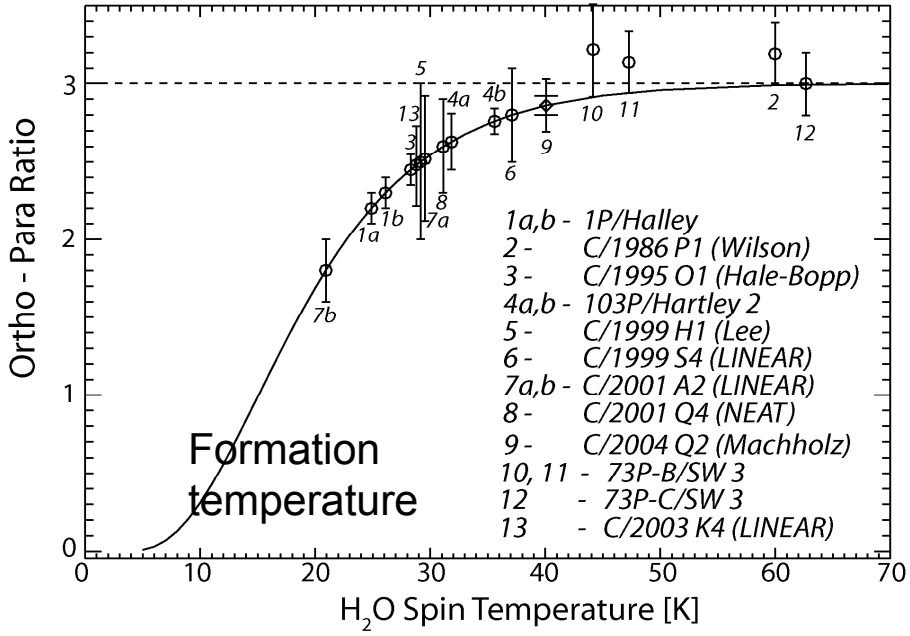
** SOFIA can go anywhere on Earth to obtain the most favorable geometry, and follow comets at their most active stages, close to the Sun.*

Comets: gas content

• Water is difficult to observe from the ground, but can be observed in a number of bands across SOFIA's spectral range from the near-IR into the sub-mm.
• $H_2{}^{18}O$ provides measurements of the total water mass being outgassed.
• Ortho-Para H_2 ratios in H_2O measure formation temperature (FLITECAM)
- line structure is far narrower than Spitzer resolution (see below, left)
• HDO abundance is another indicator of formation temperature/region.

BOTTOM LINE: test theories of early solar system evolution and dynamical mixing
BOTTOM LINE: information re. provenance of Earth's water and organics

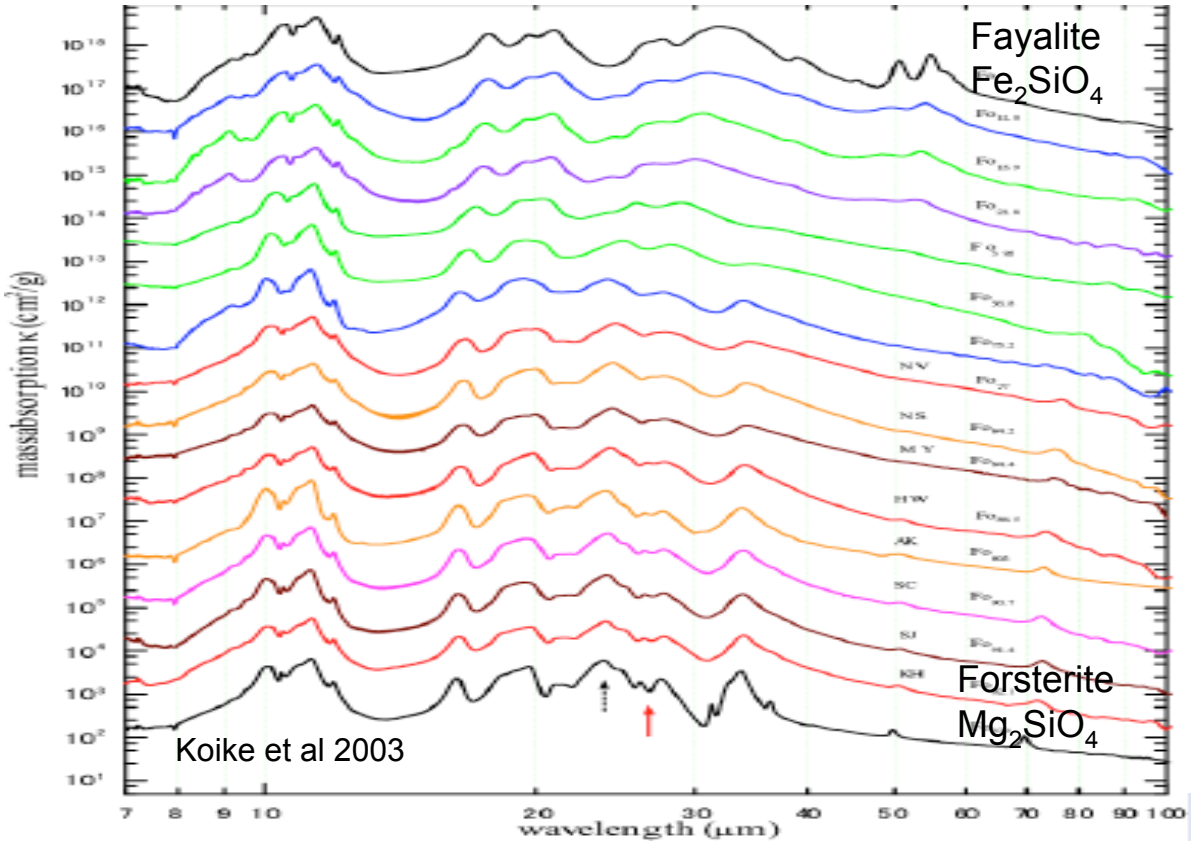




Comets: solids

- High abundance of crystalline and refractory silicates in comets (STARDUST)
- Wide range of Fe/Mg ratios seen, indicating range in grain formation temperatures
- Those data can be correlated with volatile formation temperatures (from OPR, previous slide) and dynamical class of the comet (Oort Cloud, Kuiper Belt, etc.)
- Broad FORCAST spectral range is key to comet mineralogy.

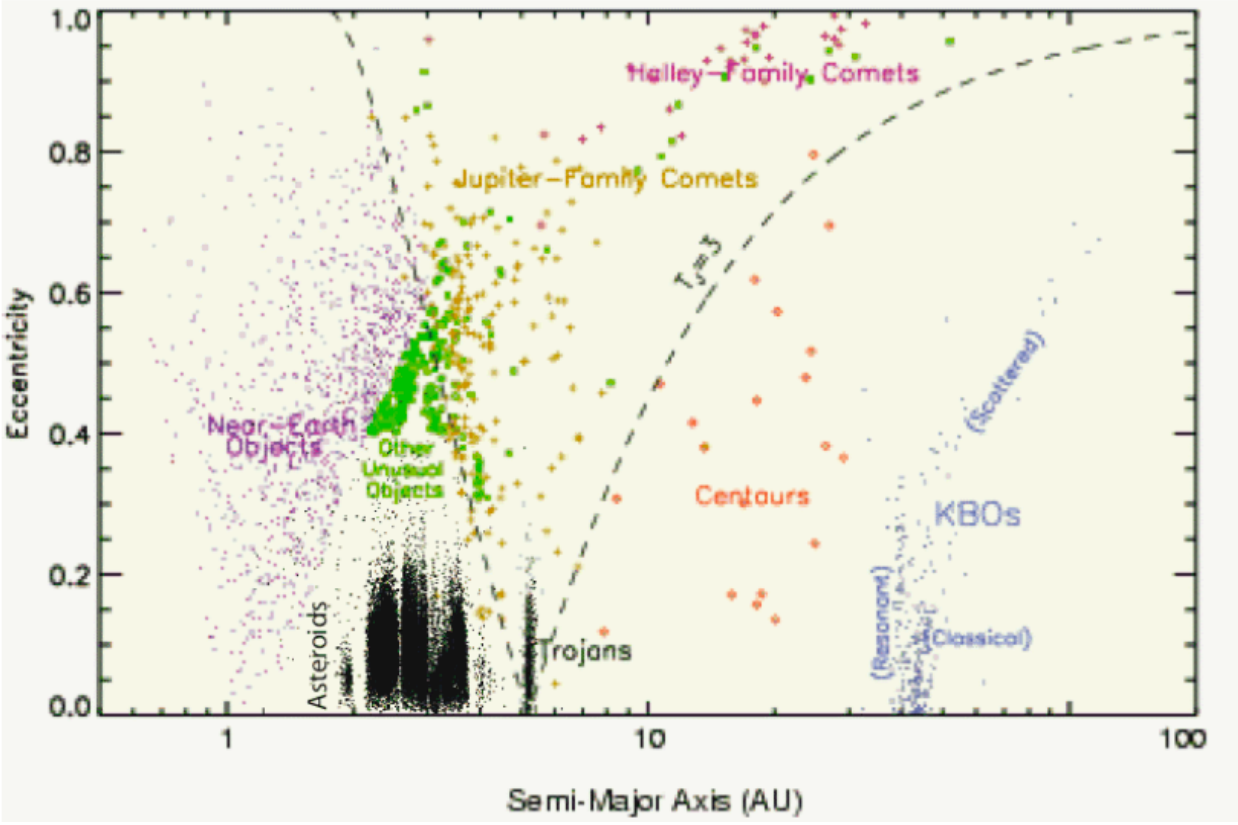
BOTTOM LINE: test theories of early solar system evolution and dynamical mixing



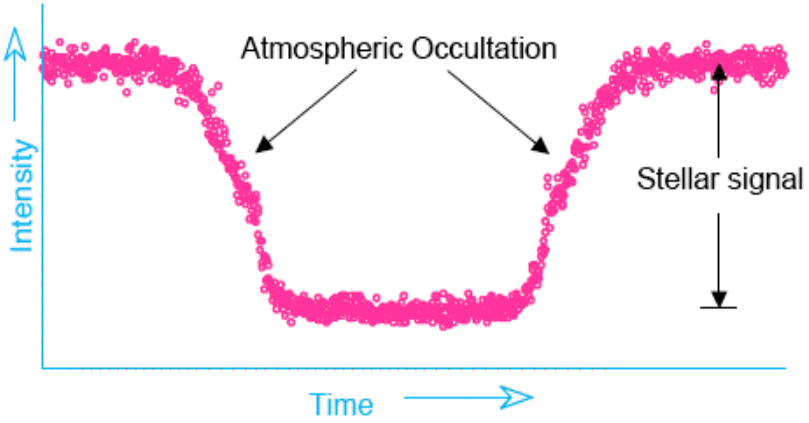
Other Rosetta Stones: Asteroids, Centaurs, KBOs

- *Occultation studies can trace atmospheric density profiles.*
- *Occultation studies can constrain diameters and detect multiplicity.*
- *Just as for comets, SOFIA can measure mineralogy, water content, and organic composition in significant sample sizes.*

BOTTOM LINE: test theories of early solar system evolution and dynamical mixing
BOTTOM LINE: information re. provenance of Earth's water and organics



Occultations: Atmospheres and Sizes



Pluto atmosphere, KAO, 1988

- How many other KBOs have atmospheres?
- Actual sizes and albedos are only guesses
- Many KBOs are binaries. From their sizes and masses we can infer densities. Are they rubble piles?
- BOTTOM LINE: Clues to history of outer s.s.

For small s.s. objects, SOFIA is 30X more effective at capturing occultations than either large ground-based facilities or small portable telescopes.

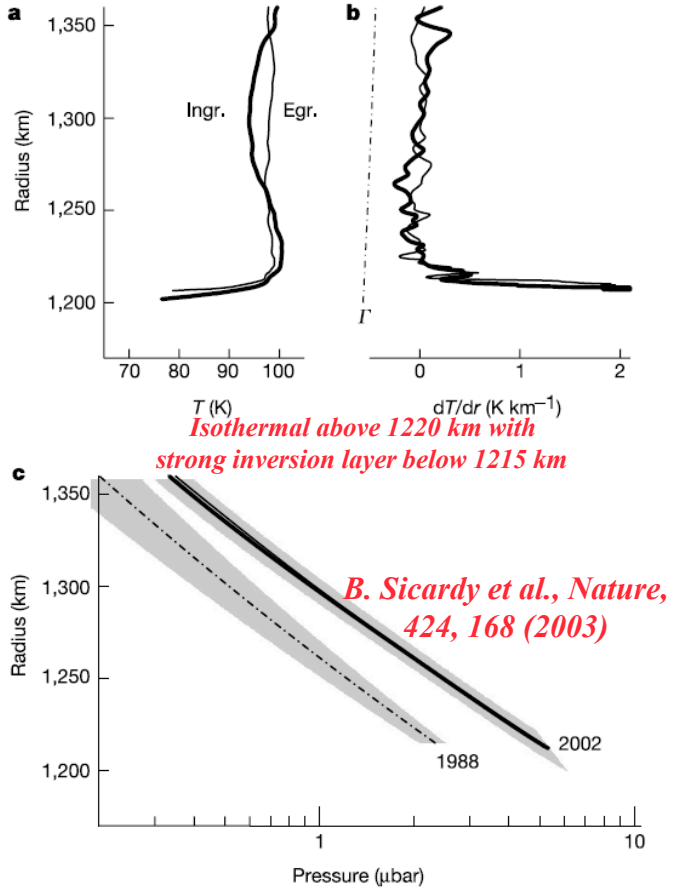


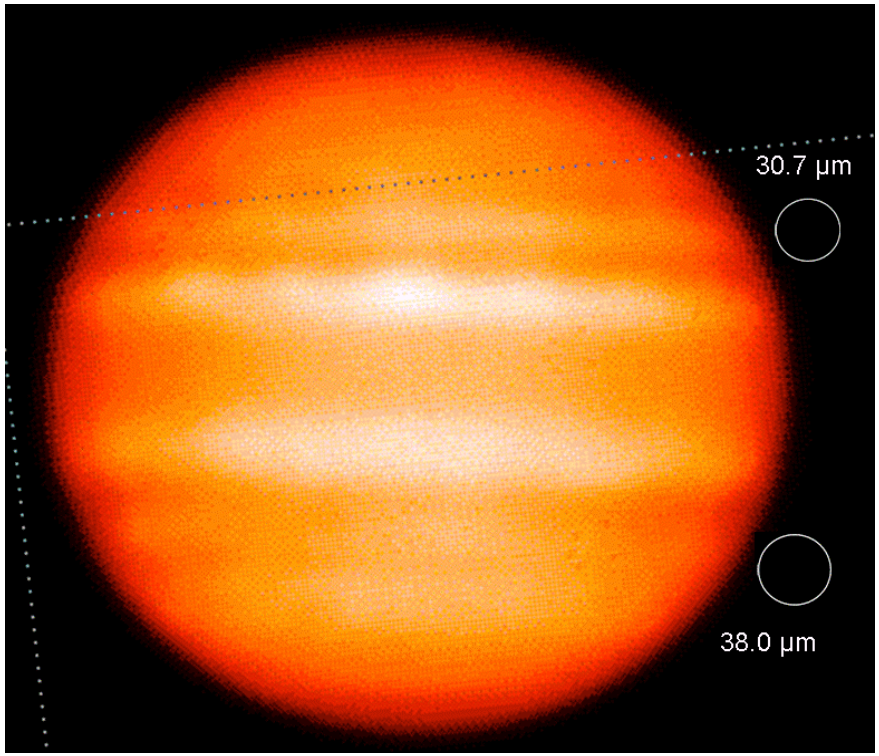
Figure 2 Temperature and pressure profiles of Pluto's atmosphere derived from the inversion of the P131.1 light curve. This inversion[17] assumes a spherically symmetric and transparent atmosphere. It first provides the atmospheric refractivity profile, then the density profile for a given gas composition, and finally the temperature profile, assuming an ideal gas in hydrostatic equilibrium. We assume for Pluto a pure molecular nitrogen[6] atmosphere,

Gas Giant Planets

SOFIA can observe all four gas giants across their full bolometric spectrum, with spatial resolution, studying atmospheric structure and composition:

- ***opacity, temperature, bulk composition, vertical upwelling***
- ***changes over seasonal cycles***
- ***spatial variation of trace molecules***

BOTTOM LINE: giant planet formation, solar system formation
BOTTOM LINE: local comparison for analysis of extrasolar giant planets



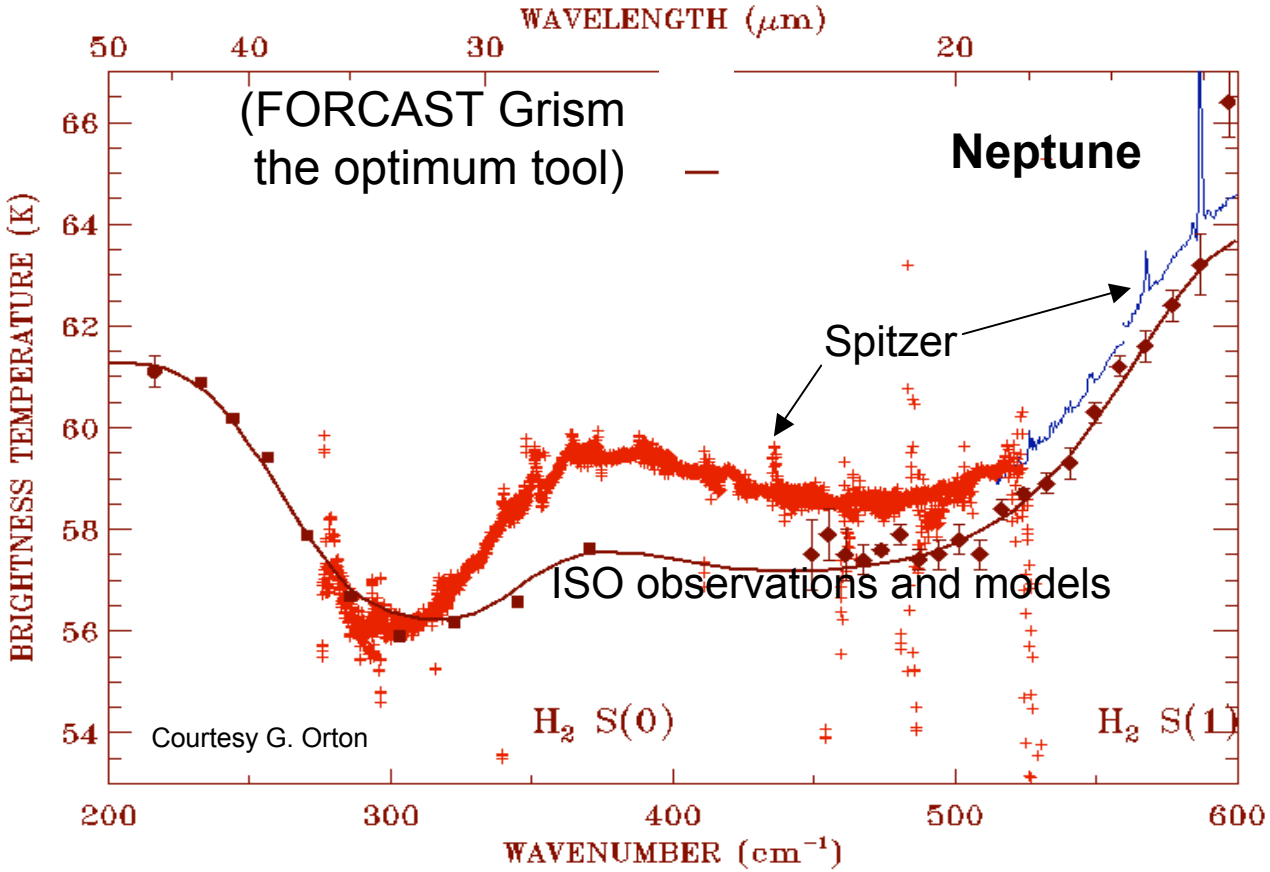
FORCAST beam sizes, Jupiter

Gas Giant Planets, continued

• He/H, D/H, and global atomic inventory still poorly known except for Jupiter

• Spitzer data only for Neptune, and problematic (figure below)

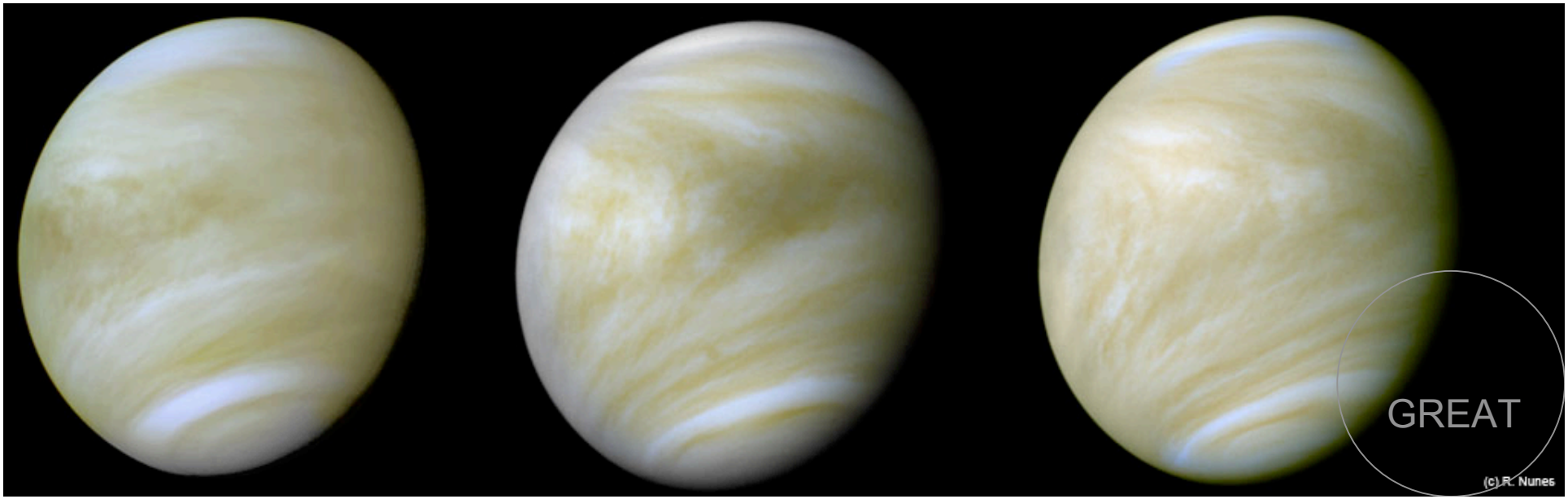
• SOFIA brings unique EXES 6 μm and 14-30 μm spectroscopy (difficult or impossible to do from Earth) to bear on H_2O and hydrocarbon spatial, vertical, and temporal variations.



Venus: Why and how did its history diverge from Earth's?

- ***By circumstance, Venus has not been thoroughly explored with broadband, high resolution spectroscopy***
  - ***-- Venus off-limits to Herschel; 6 μm water band inaccessible from Earth***
- ***D/H ratio indicates Venus lost an ocean; missing piece of evidence: where's the O?***
  - ***-- Basic atmospheric chemical network not understood.***
- ***Observations of atmospheric composition variability (esp. SO_2, SO) can constrain possibility of ongoing intermittent volcanic(?) activity***
- ***Stratospheric super-rotation not understood***

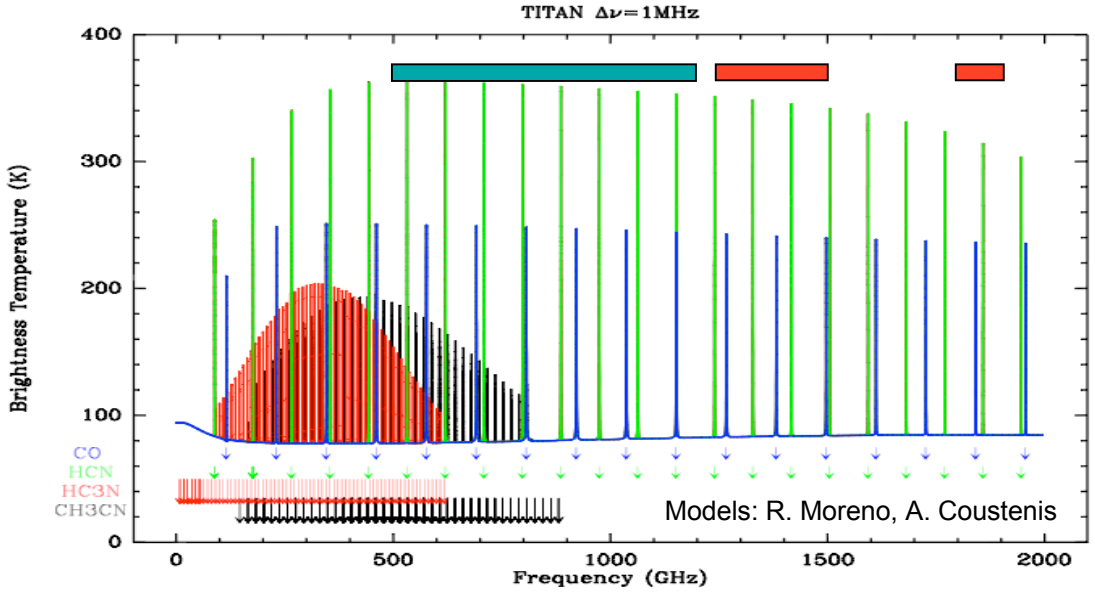
BOTTOM LINE: Venus and Earth, comparative atmospheres [and lithospheres]
BOTTOM LINE: Information about runaway greenhouse on an Earth-like planet
BOTTOM LINE: Constraints on width of Continuously Habitable Zone around G star

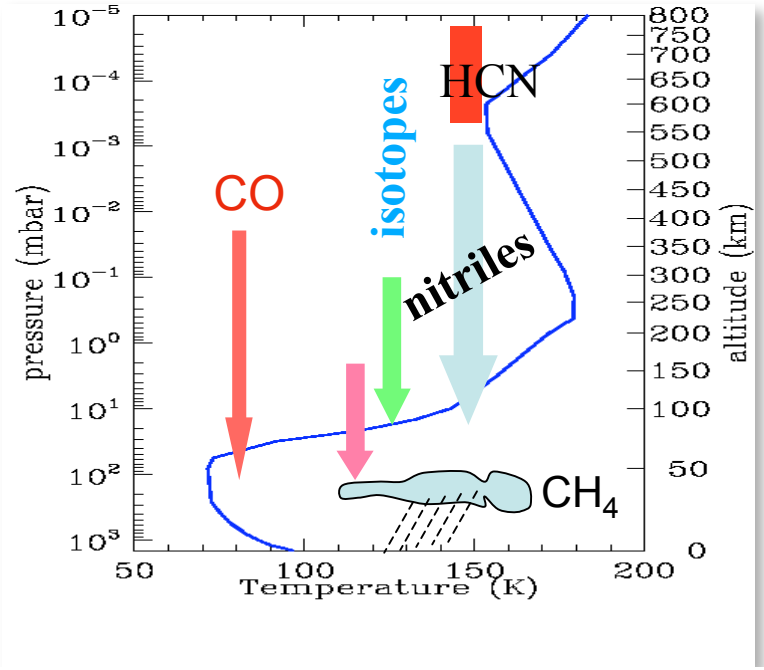


Titan - an exobiological laboratory

- ***Heavy hydrocarbons and nitriles (EXES, CASIMIR) only hinted at by Cassini (or seen only in the laboratory) may be observed directly, vertical distribution inferred.***
- ***SOFIA can monitor temporal variations in major atmospheric constituents such as CH_4 (87 μm, 260 μm), CO and HCN (below). The methane "monsoon" cycle can be studied for a full season.***
- ***SOFIA can greatly extend and enhance limited ISO and Cassini observations of Titan and build a bridge to future spacecraft exploration of the Saturnian system.***

BOTTOM LINE: Comprehensive investigation of atmospheric chemistry and dynamics in a low-temperature analog to pre-biological Earth





Summary: SOFIA enables "discovery-level" observations in planetary science

* Observations of …

  - Primitive bodies,
  - Gas giant planets,
  - Venus and Titan,

… address NAS and NASA highest-priority goals regarding:

  - Planetary formation and evolution in our system and elsewhere
  - Conditions leading to the origin of life (distribution, redistribution, and evolution of water and organics).

* Focus on Venus provides a unique spacecraft-like contribution regarding how the atmosphere of our sister planet has diverged from our own.

* SOFIA mission duration can span the long gap between outer planet missions, tracking short-term and seasonal variability.