SURVEYOR*

Klaus Pontoppidan
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asd.gsfc.nasa.gov/firs

On behalf of the FIRS Science Definition and Technology Team
Asantha Cooray (Community Co-chair)
Margaret Meixner (Community Co-chair)
David Leisawitz (NASA Center Study Scientist)
Kartik Sheth (NASA HQ Program Scientist)
Dominic Benford (NASA HQ Program Scientist)

FAR-INFRARED SURVEYOR

14th ExoPAG meeting, June 12, 2016

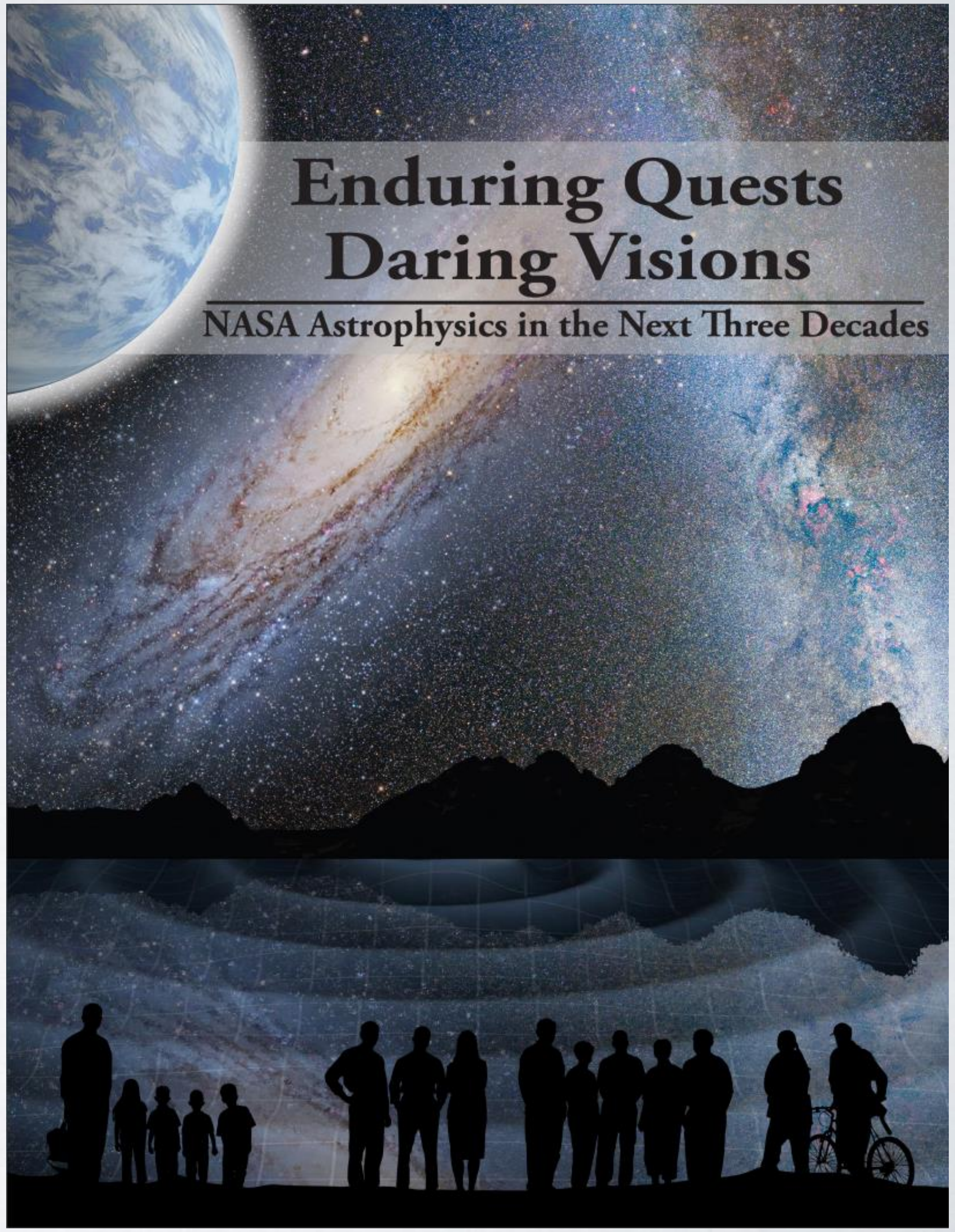
* Name may change to reflect inclusion of mid-infrared scienc

What is FIRS?

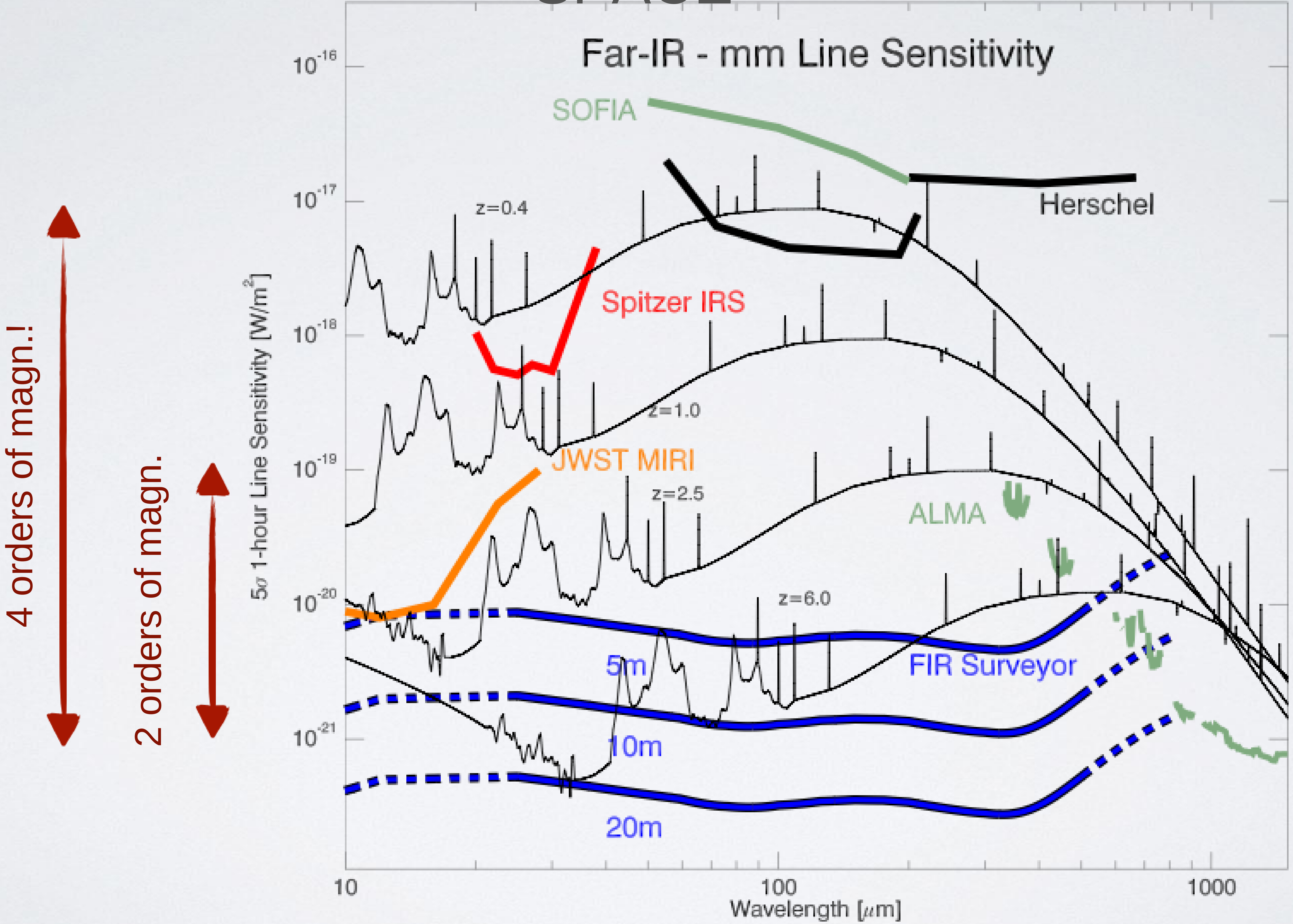
- Comes from the NASA Astrophysics Roadmap, Enduring Quests, Daring Visions
- Roadmap envisages enhanced measurement capabilities relative to those of the Herschel Space Observatory:
  - Very broad science case
  - large gain in sensitivity
  - angular resolution sufficient to overcome spatial confusion in deep cosmic surveys
  - new spectroscopic capabilities

ALMA, JWST, WFIRST, and new 25m-35m ground-based facilities will change the landscape by the time FIRS could fly.

Science goals and measurement requirements must be relevant for 2030+.



IN THE 2030S, THE 10-600 MICRON RANGE WILL CONTAIN THE LARGEST UNEXPLORED DISCOVERY SPACE



STDT STUDY TEAM

- Chairs:
  - Asantha Cooray, University of California, Irvine
  - Margaret Meixner, Space Telescope Science Institute
- NASA Center Study Scientist
  - David Leisawitz, NASA GSFC
- NASA Center Study Manager
  - Ruth Carter, NASA GSFC

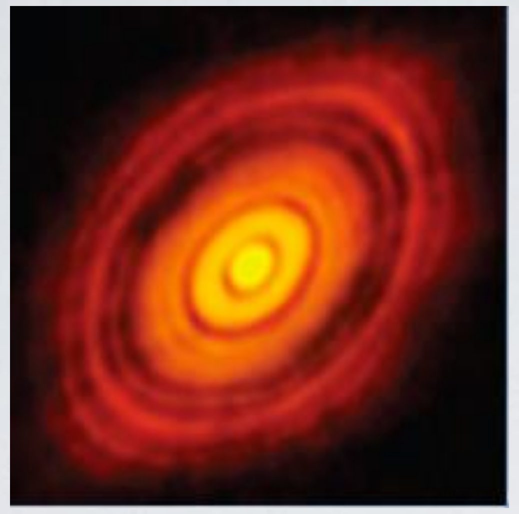
Ex officio non-voting representatives:

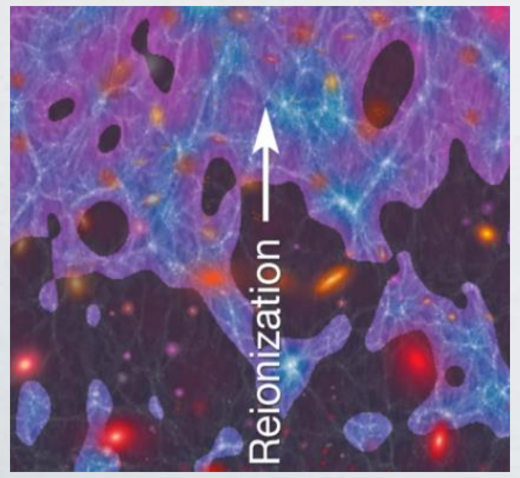
Susan Neff & Deborah Padgett, NASA Cosmic Origins Program Office

Susanne Alato, SNSB	Douglas Scott, CAS
Maryvonne Gerin, CNES	Itsuki Sakon, JAXA
Frank Helmich, SRON	Roland Vavrek, ESA
Karl Menten, DLR	Sean Carey, IPAC

STUDY TEAM (CONT'D)

Members appointed by NASA (> 90 applications):
Dr. Lee Armus, NASA Infrared Processing and Analysis Center
Dr. Cara Battersby, Harvard-Smithsonian Center for Astrophysics
Dr. Edwin Bergin, University of Michigan
Dr. Matthew Bradford, NASA Jet Propulsion Laboratory
Dr. Kim Ennico-Smith, NASA Ames Research Center
Dr. Gary Melnick, Harvard-Smithsonian Center for Astrophysics
Dr. Stefanie Milam, NASA Goddard Space Flight Center
Dr. Desika Narayanan, Haverford College
Dr. Klaus Pontopiddan, Space Telescope Science Institute
Dr. Alexandra Pope, University of Massachusetts
Dr. Thomas Roellig, NASA Ames Research Center
Dr. Karin Sandstrom, University of California, San Diego
Dr. Kate Y. L. Su, University of Arizona
Dr. Joaquin Vieira, University of Illinois, Urbana Champaign
Dr. Edward Wright, University of California, Los Angeles
Dr. Jonas Zmuidzinas, California Institute of Technology

STUDY PLAN

What's happening now:

- We have five science working groups. Membership open to the community (US and foreign).
- Teams already have started telecons and have action items to produce science questions in the post-JWST, post-WFIRST, 15 years of ALMA operations in an era of ELT, GMT, Athena, eLISA etc

Solar system: Stefanie Milam

Planet formation and exoplanets: Klaus Pontoppidan and Kate Su

Milky-Way, ISM and local volume of galaxies: Cara Battersby and Karin Sandstrom

Galaxy and blackhole evolution over cosmic time: Lee Armus and Alexandra Pope

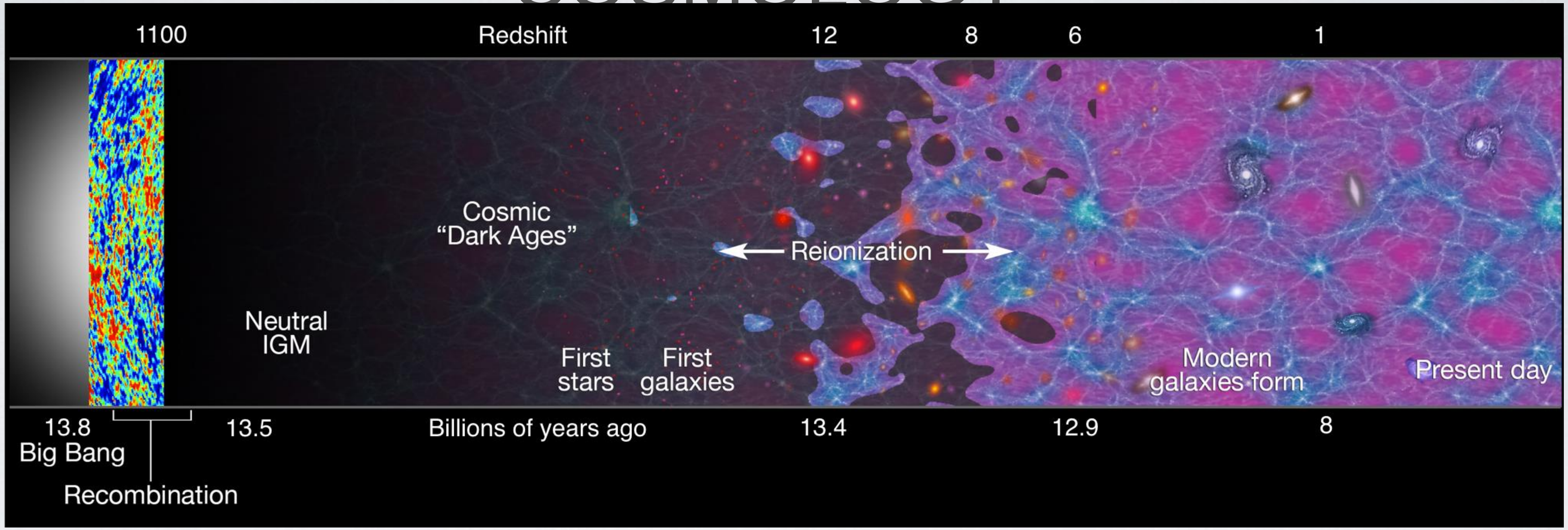
First Billion years: Joaquin Vieira, Matt Bradford

Please contact, if interested in contributing!

What is the cosmic history of the growth of elements and dust?

What is the chemical trail from molecular clouds to proto-planetary disks and exoplanets ?

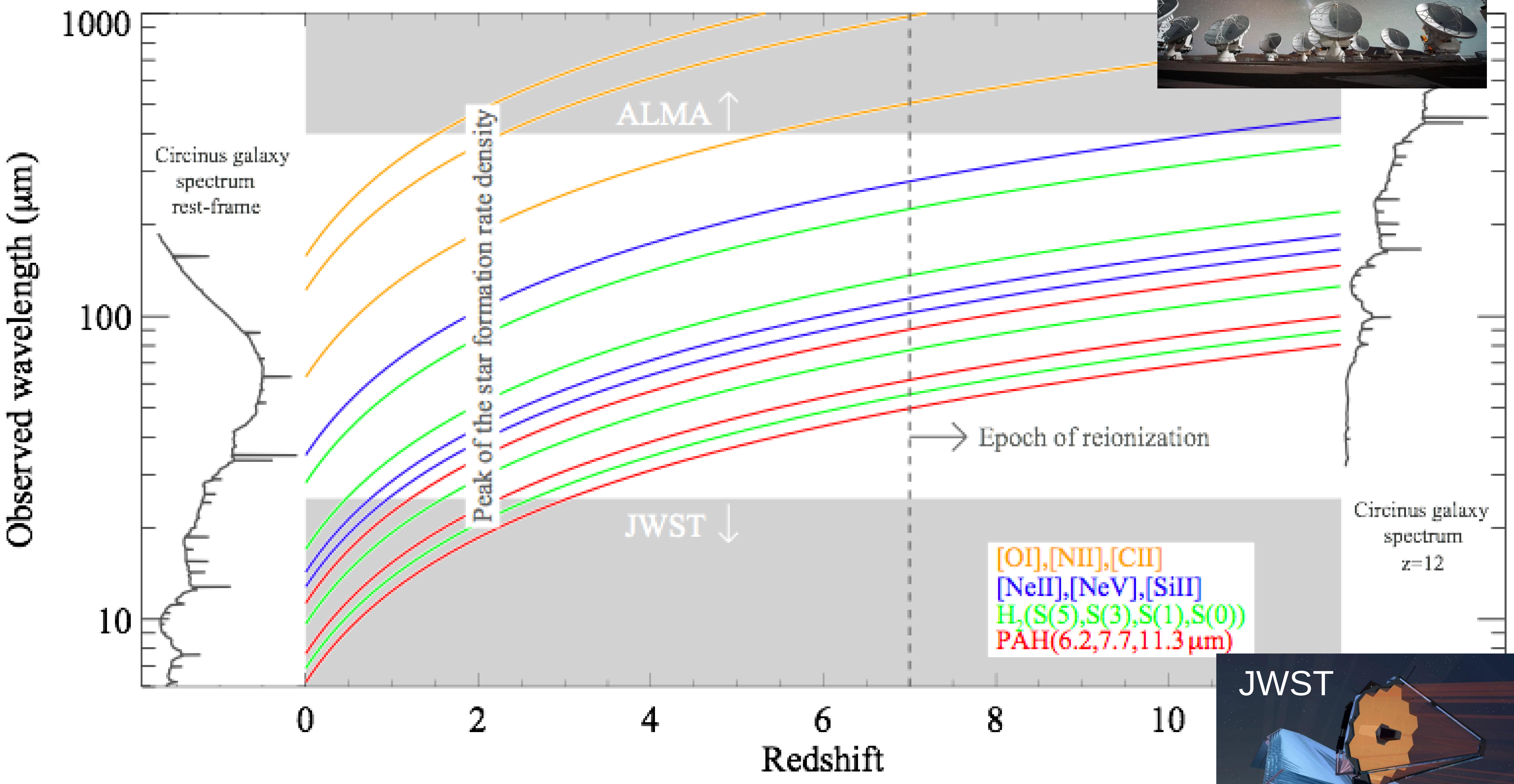
COSMIC DAWN - EARLY UNIVERSE - COSMOLOGY



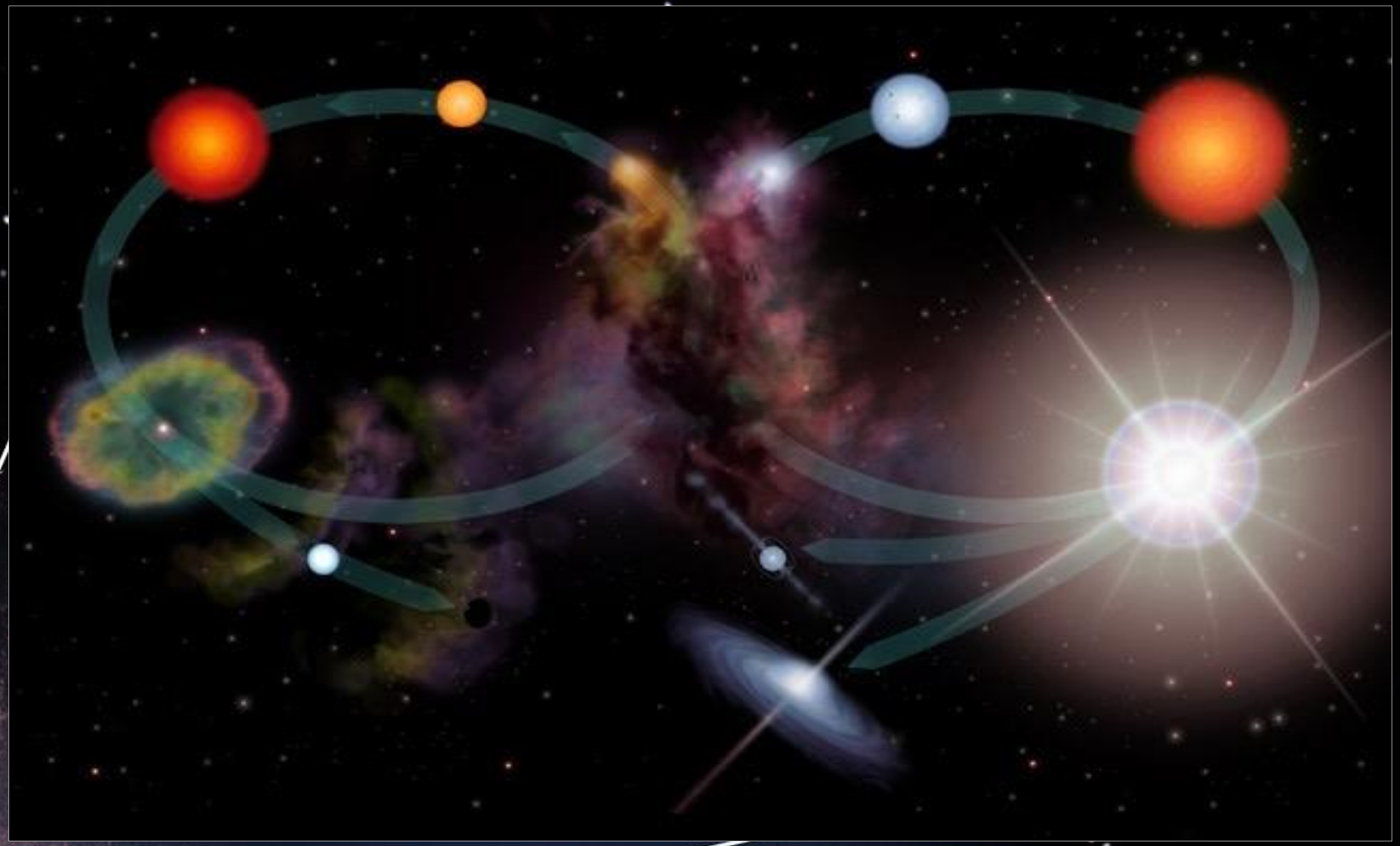
Big Picture topics already identified:

- Collapse to form first stars and proto-galaxies
    - Primordial cooling via H2 rotational lines
    - seeds of super massive black holes
- Cosmic chemical evolution of the Universe
    - First dust, rise of heavy elements and building blocks of life
- Properties of reionizing galaxies
    - 3D maps of the Universe
    - 3-D clustering revealing fine-structure line intensities -> metallicity, UV fields

Energy balance in the Universe and in the evolution of galaxies



How are star formation and feedback regulated in galaxies and how do they interact with the wider environment?

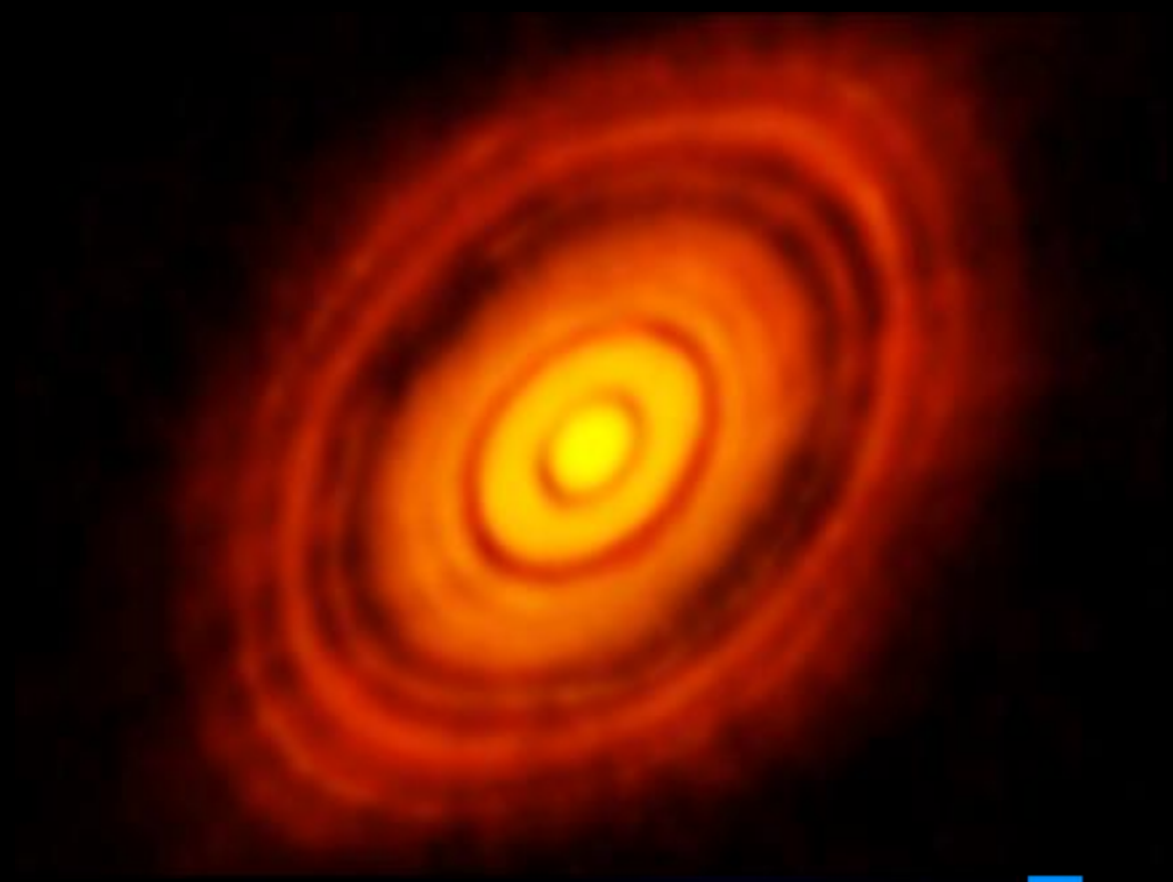


Credits: ESA/ATG Medialab

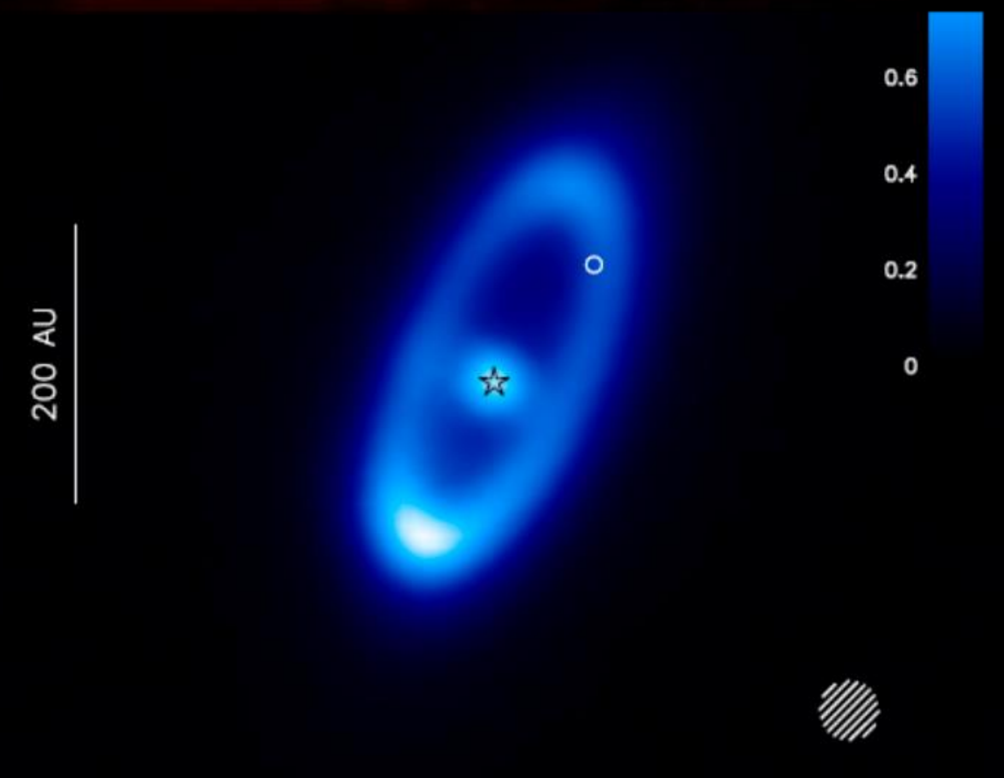
What is the interplay between supermassive black hole feeding and star formation?

How do star formation and feedback processes vary with environment?

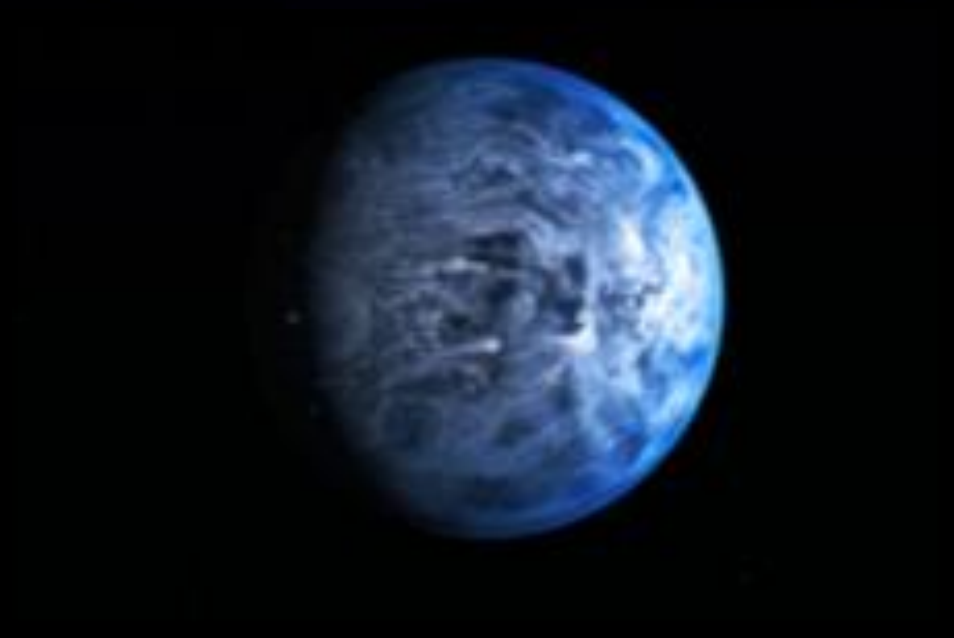
PLANET FORMATION AND EXOPLANET THEMES



Planet formation and protoplanetary disks



Planet evolution and debris disks

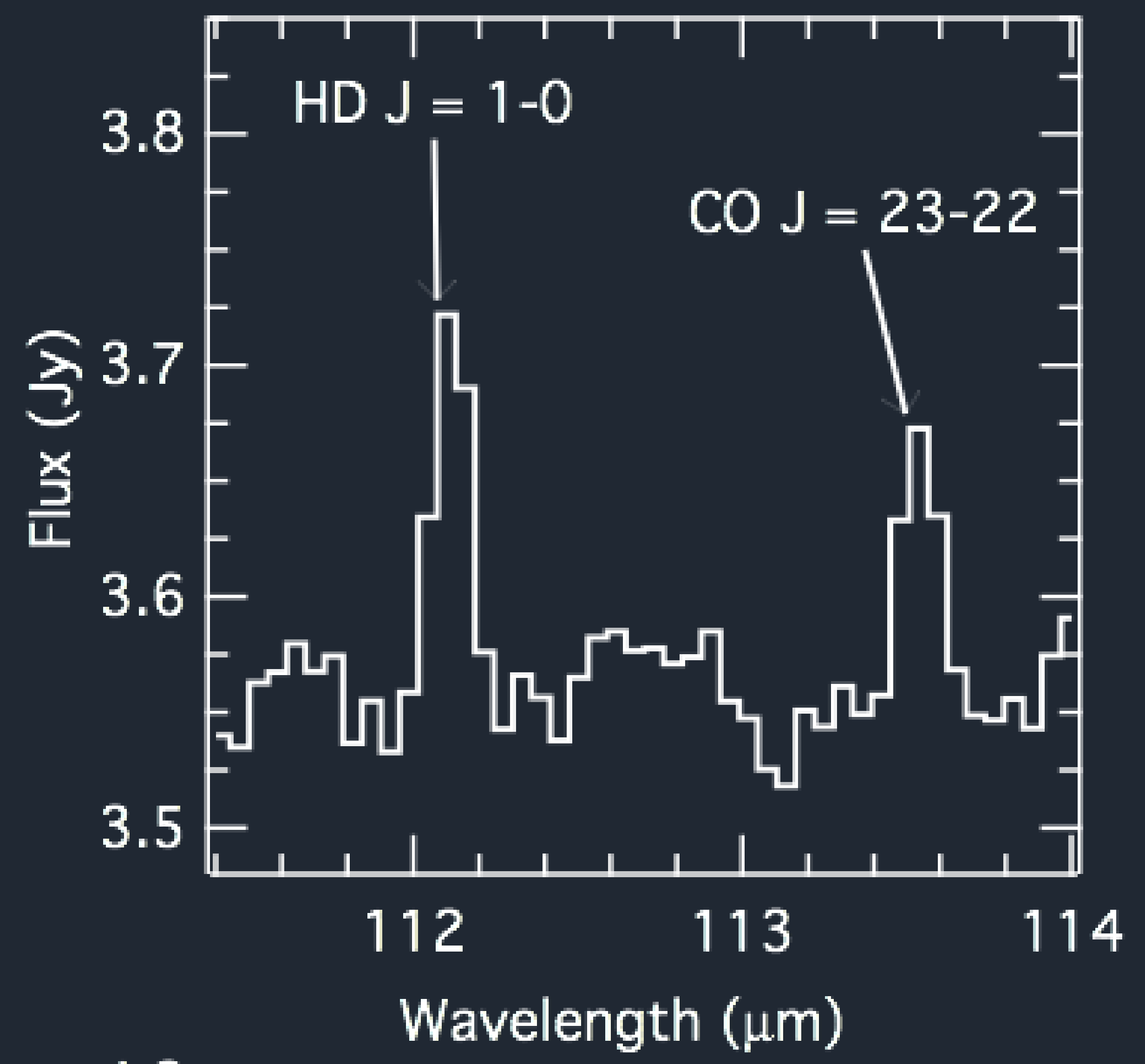


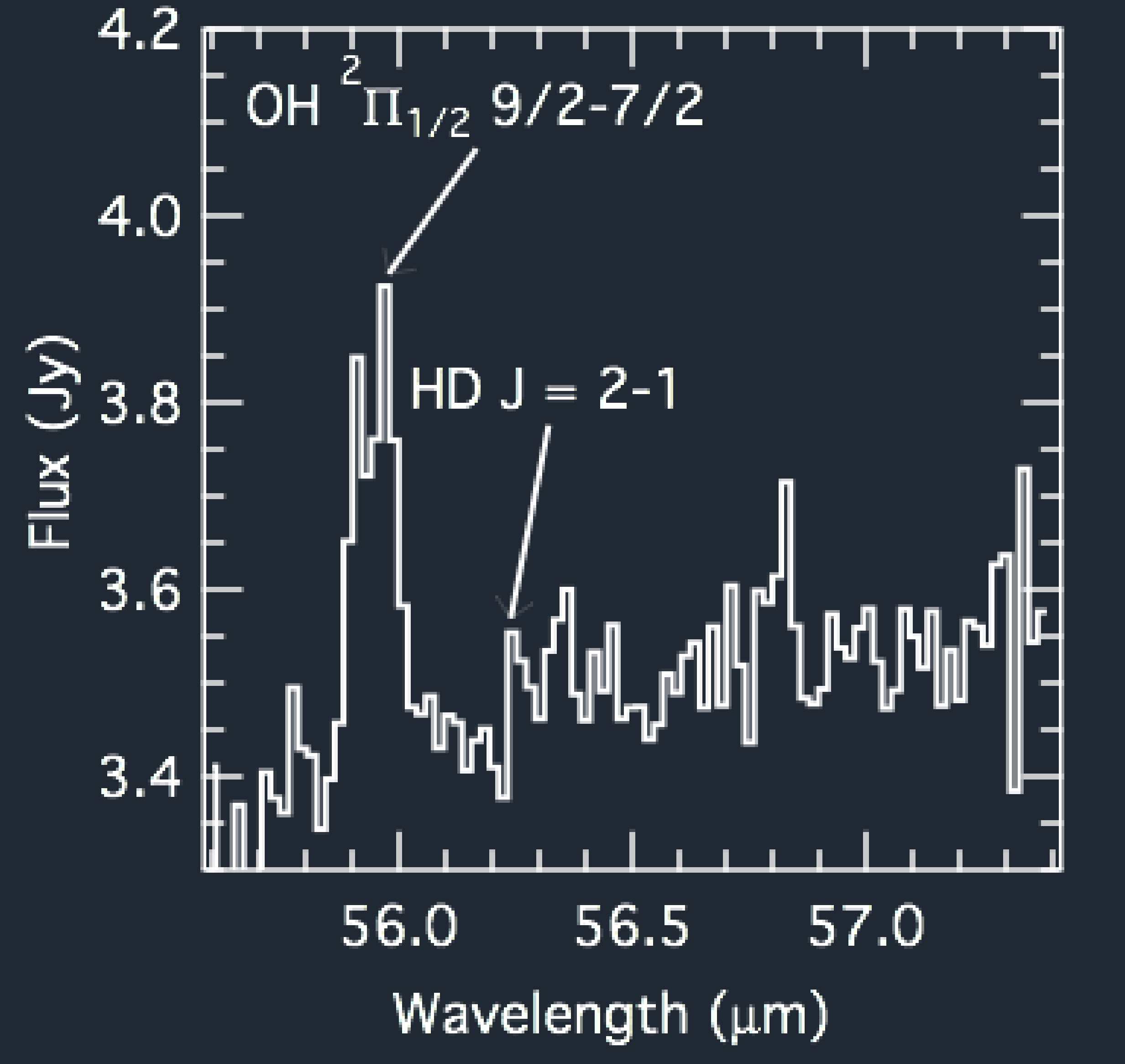
Exoplanet atmospheres and composition

MEASURING GAS MASSES OF PROTOPLANETARY DISKS

- ➞HD is a million times more emissive than H_2 at T ~ 20 K.
- ➞Atomic D/H ratio inside the local bubble is well characterized (~1.5×10^{-5})
- ➞HD will follow H_2 in the gas

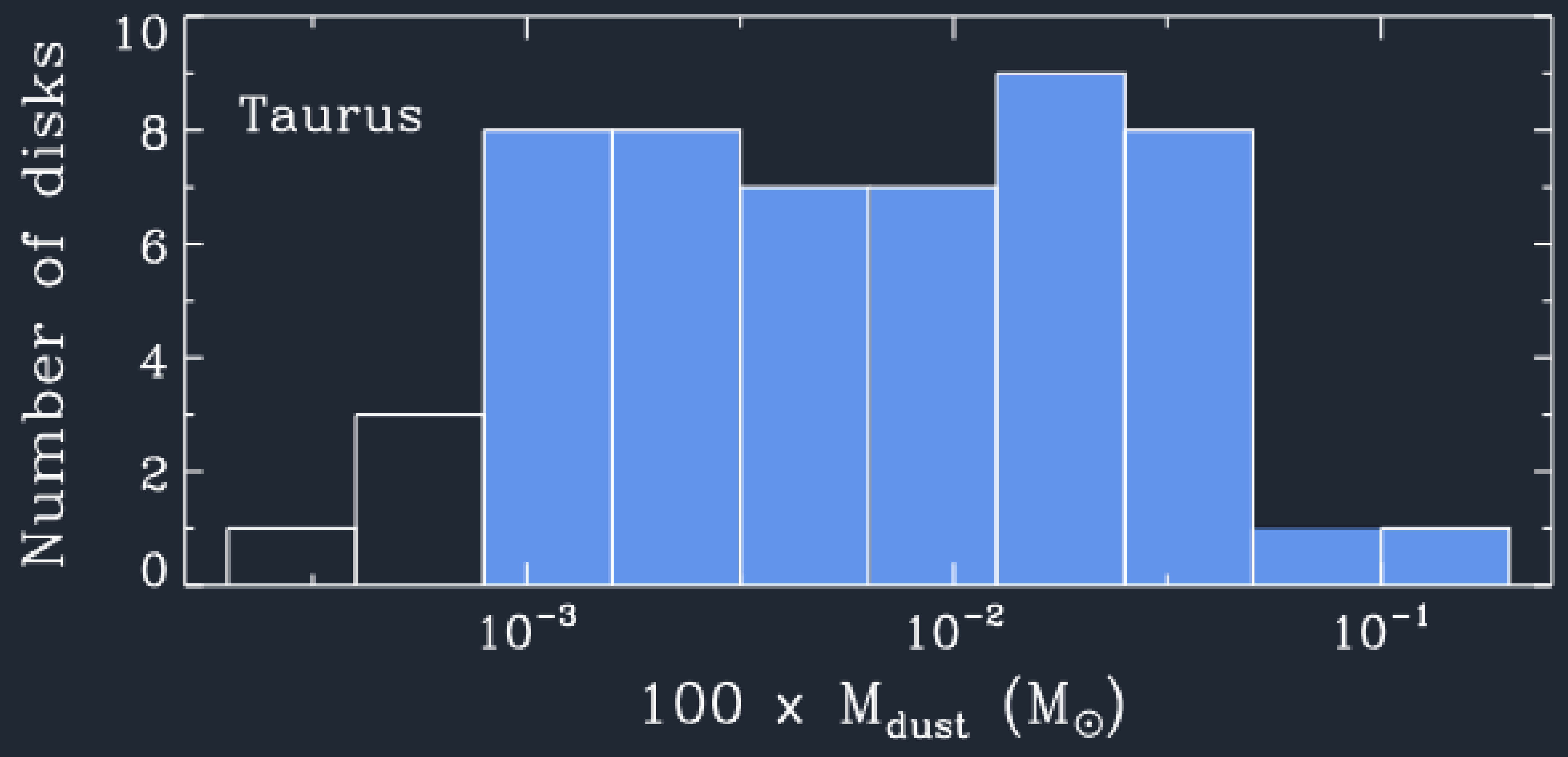
➞TW Hya disk mass $M_{disk} \sim 0.05\ M_\odot$



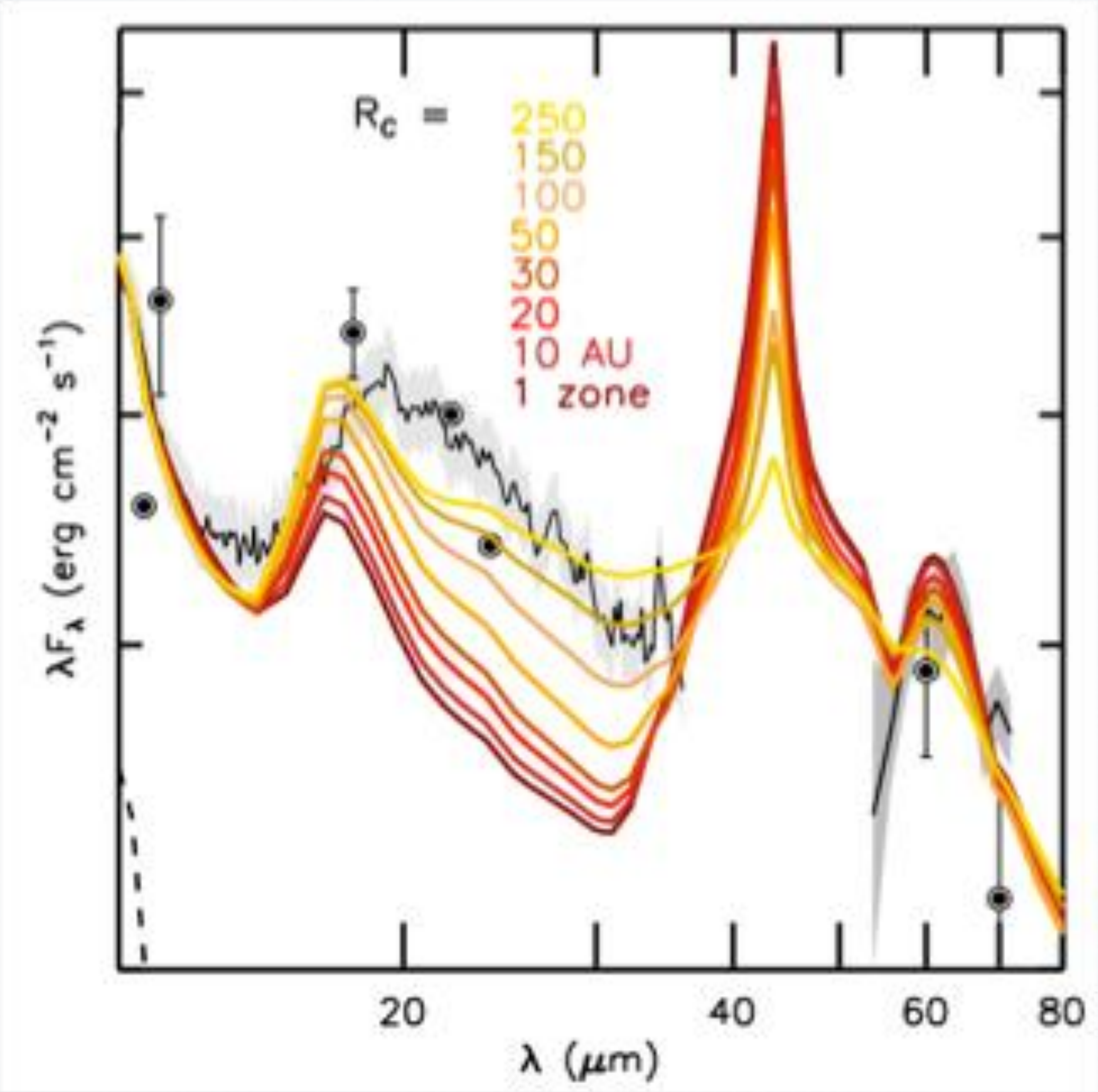


Bergin+ 2013

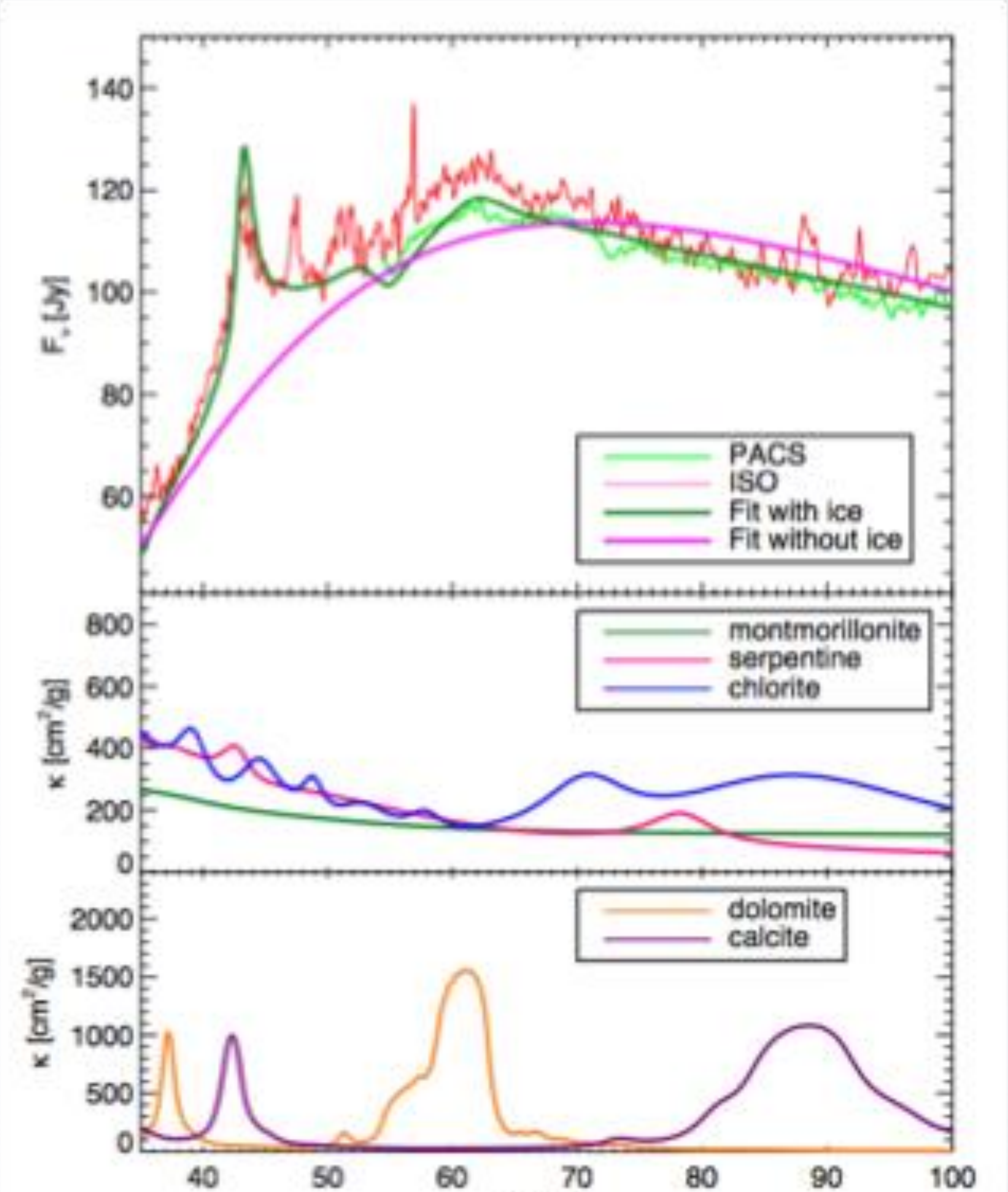
Williams and Cieza 2011



MASSES AND LOCATIONS OF DISK ICE RESERVOIRS

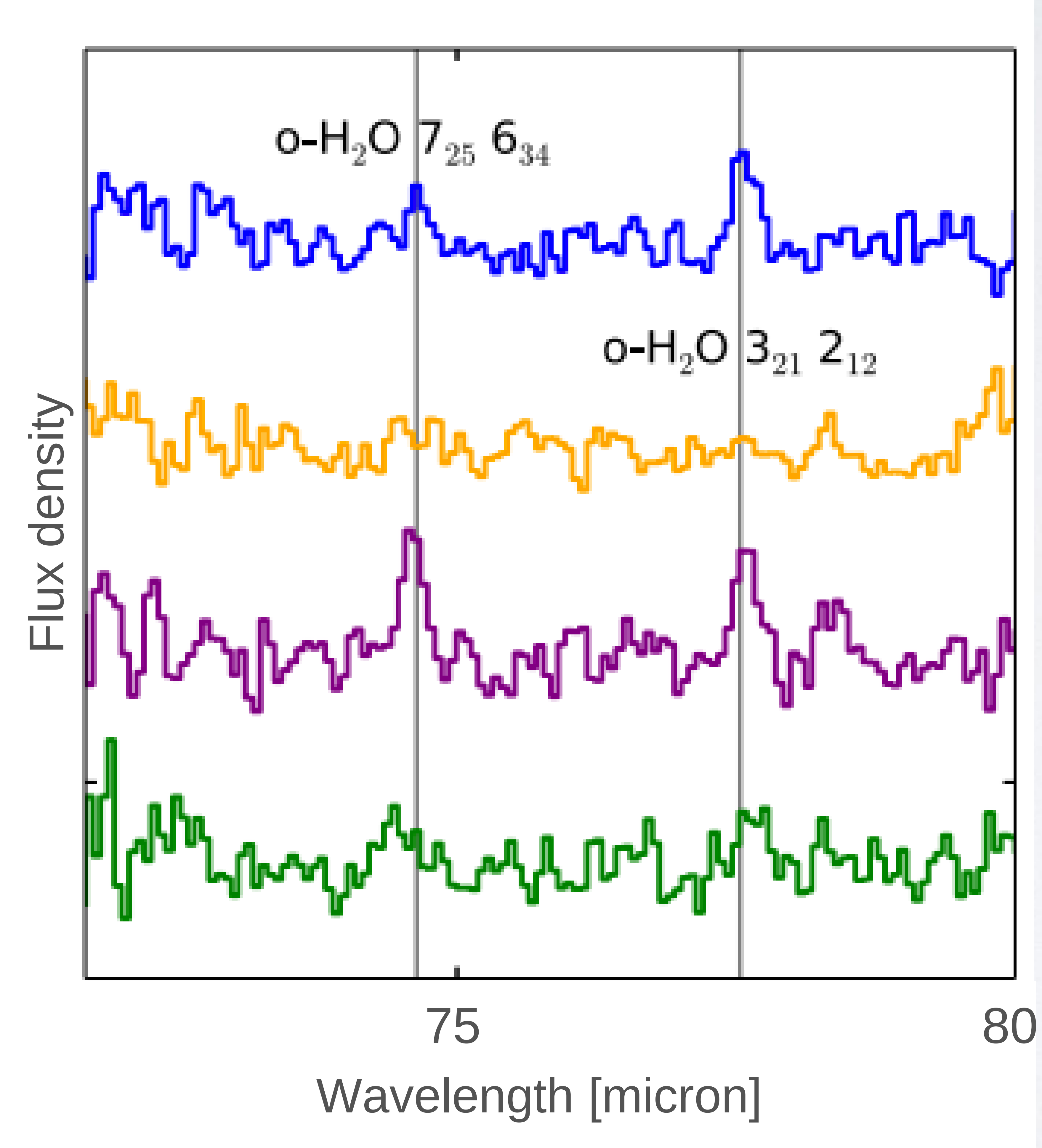


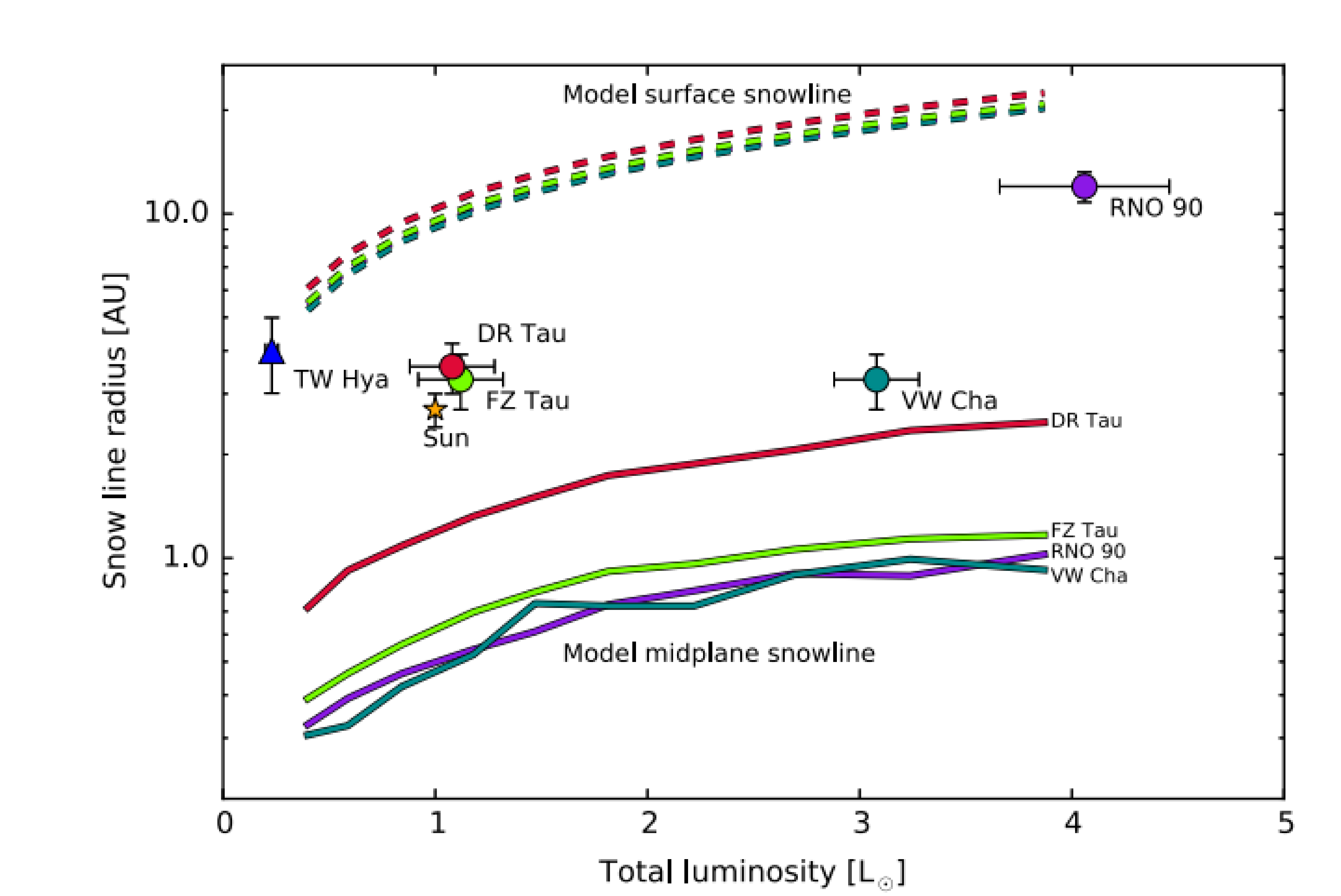
McClure+ 15



Min+ 16

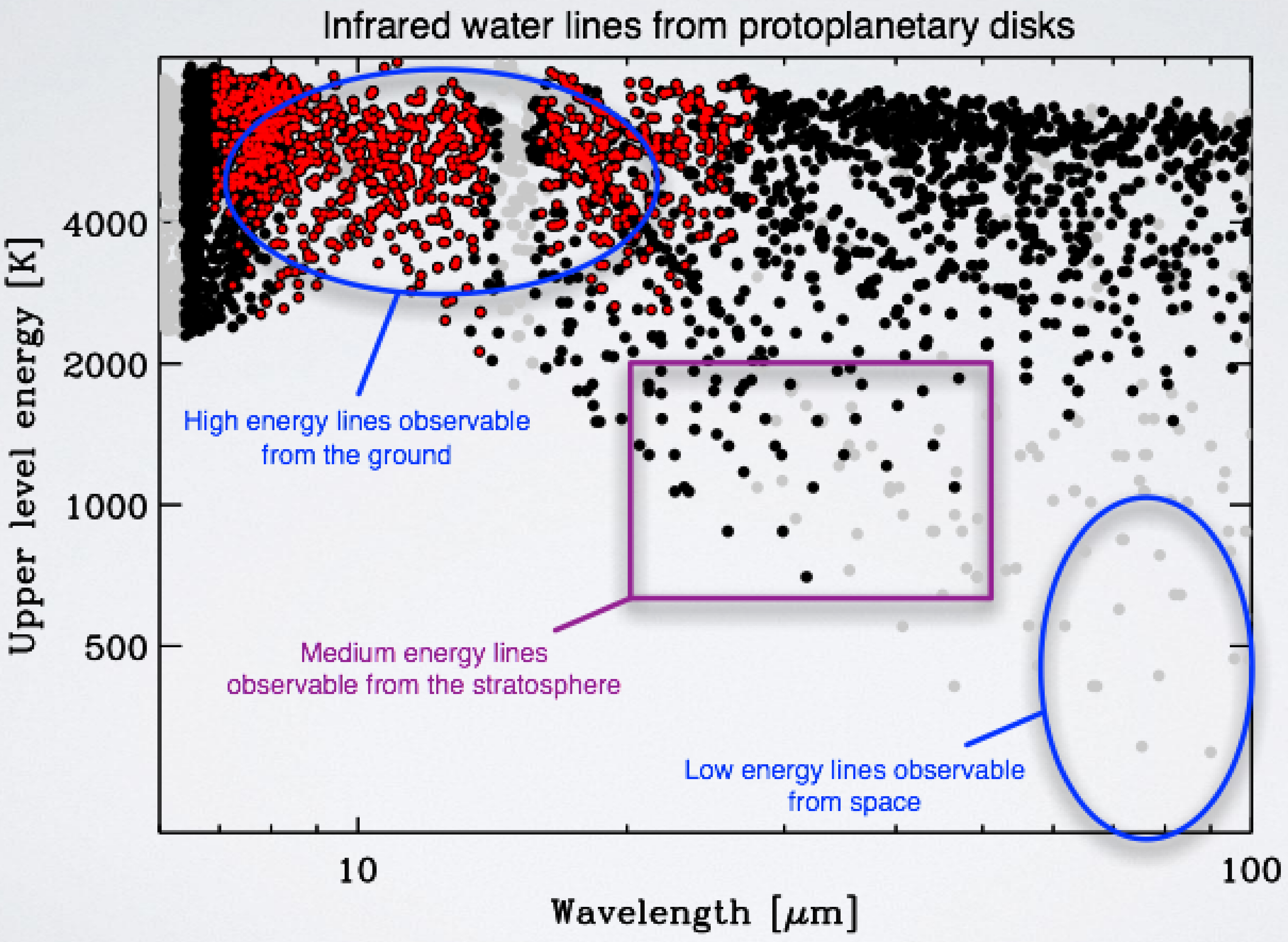
WHERE IS THE WATER SNOW LINE?





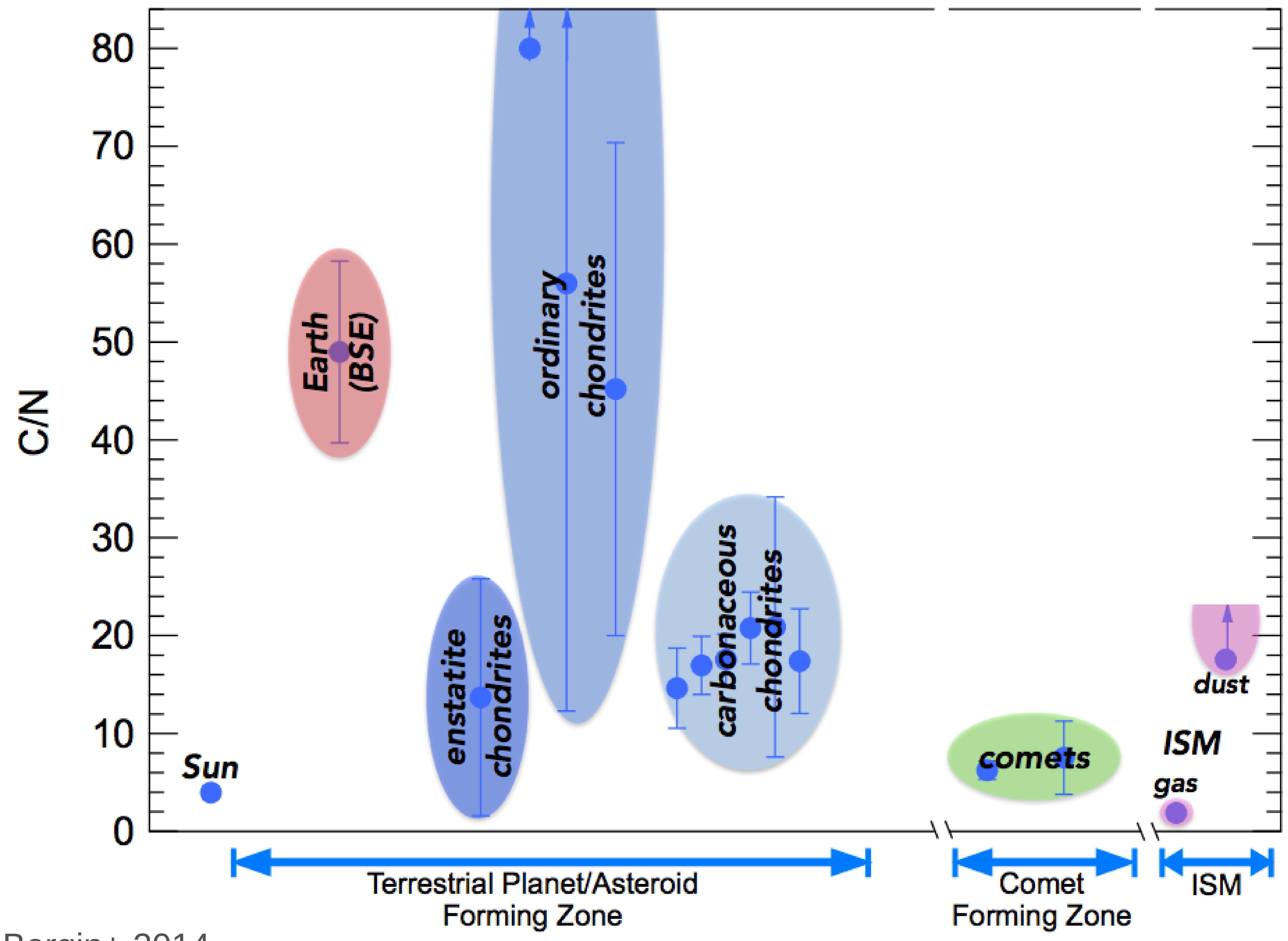
Blevins, Pontoppidan+ 2016

OBSERVABILITY OF WATER

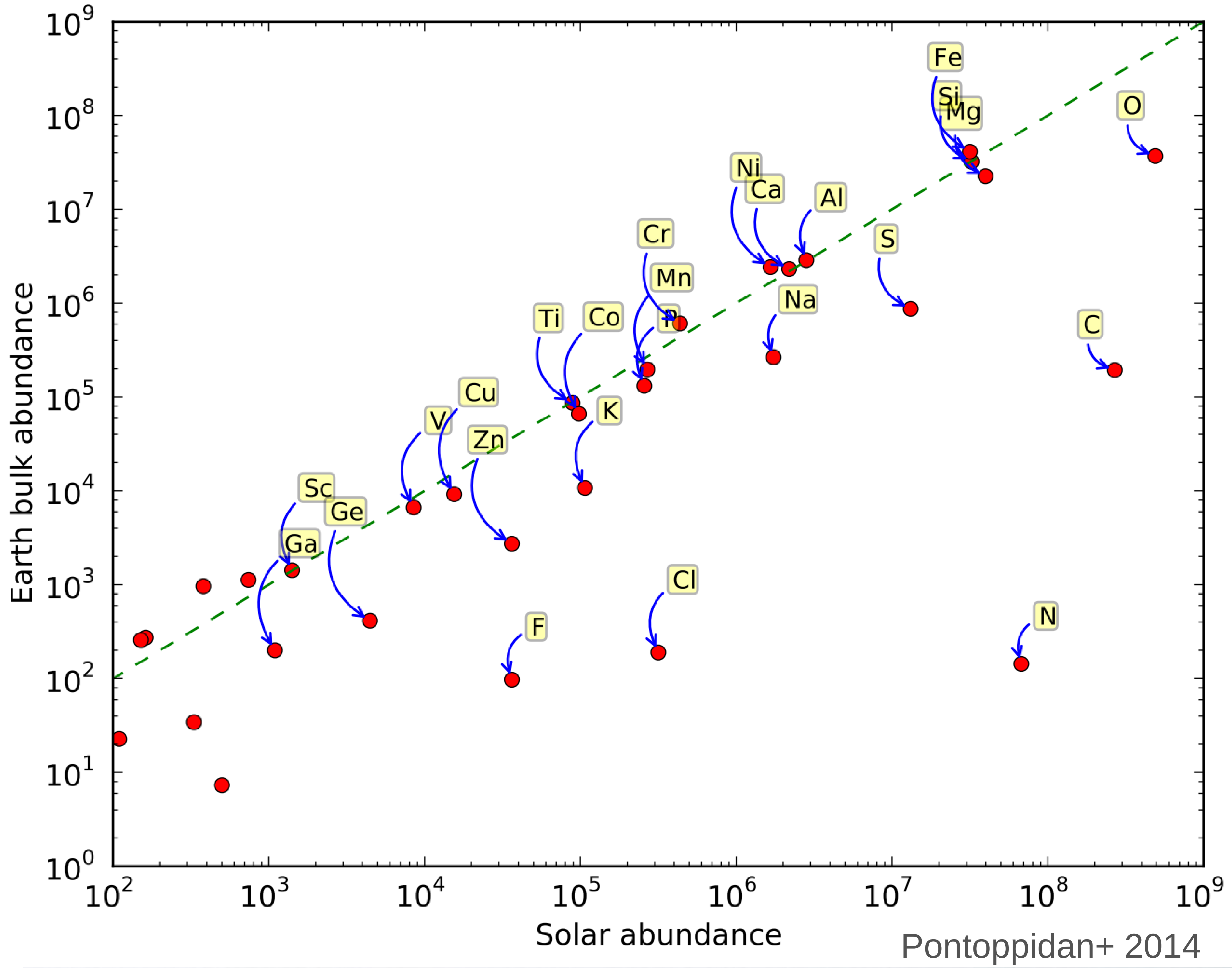


WHAT ARE THE VOLATILE RESERVOIRS OF DISKS?

WHERE IS THE OXYGEN, CARBON, NITROGEN, FLUORINE, SULFUR, …?



Bergin+ 2014



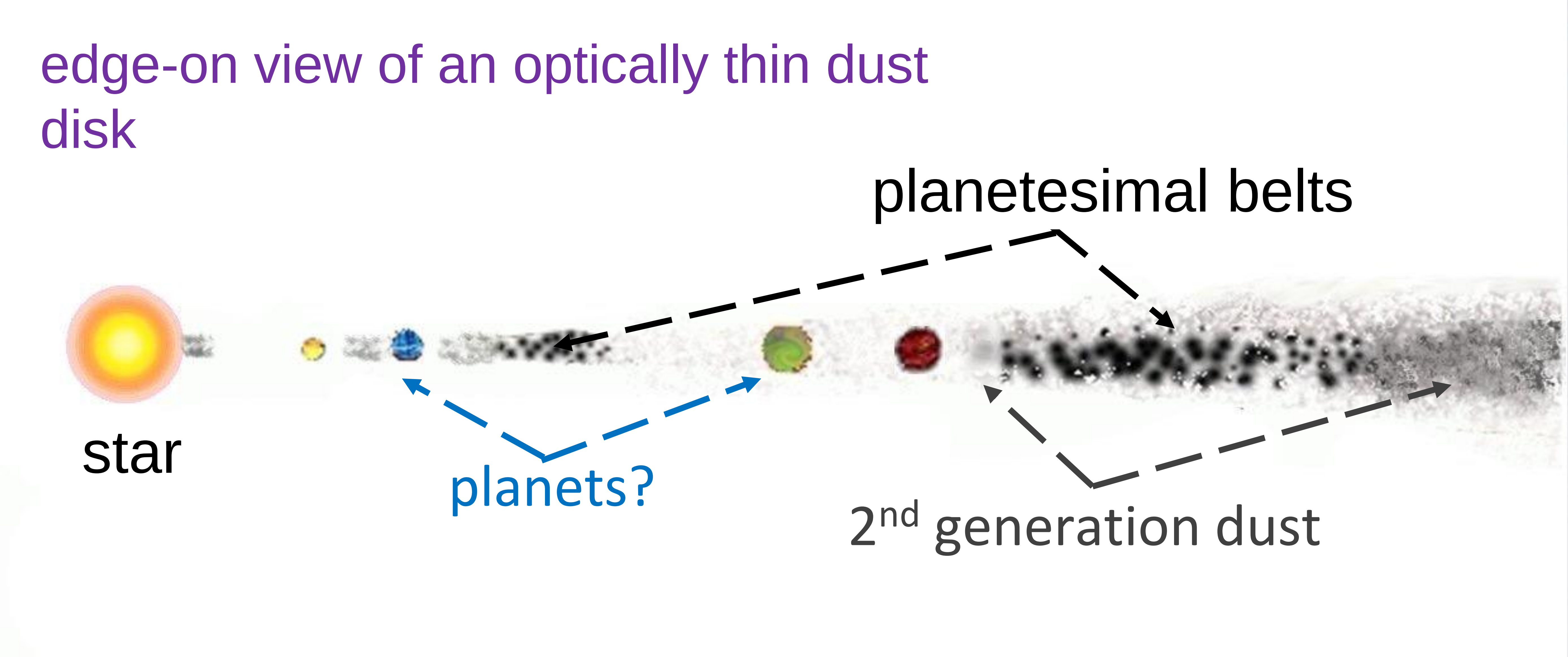
Pontoppidan+ 2014

Debris disks

- Planetary Architecture – Is our Solar System an Outlier?
  - Use debris disk structures to find and characterize the masses and orbits of outer exoplanets less massive than Jupiter (e.g., ice giants).
  - Use debris disk structures to constrain planet formation and migration history

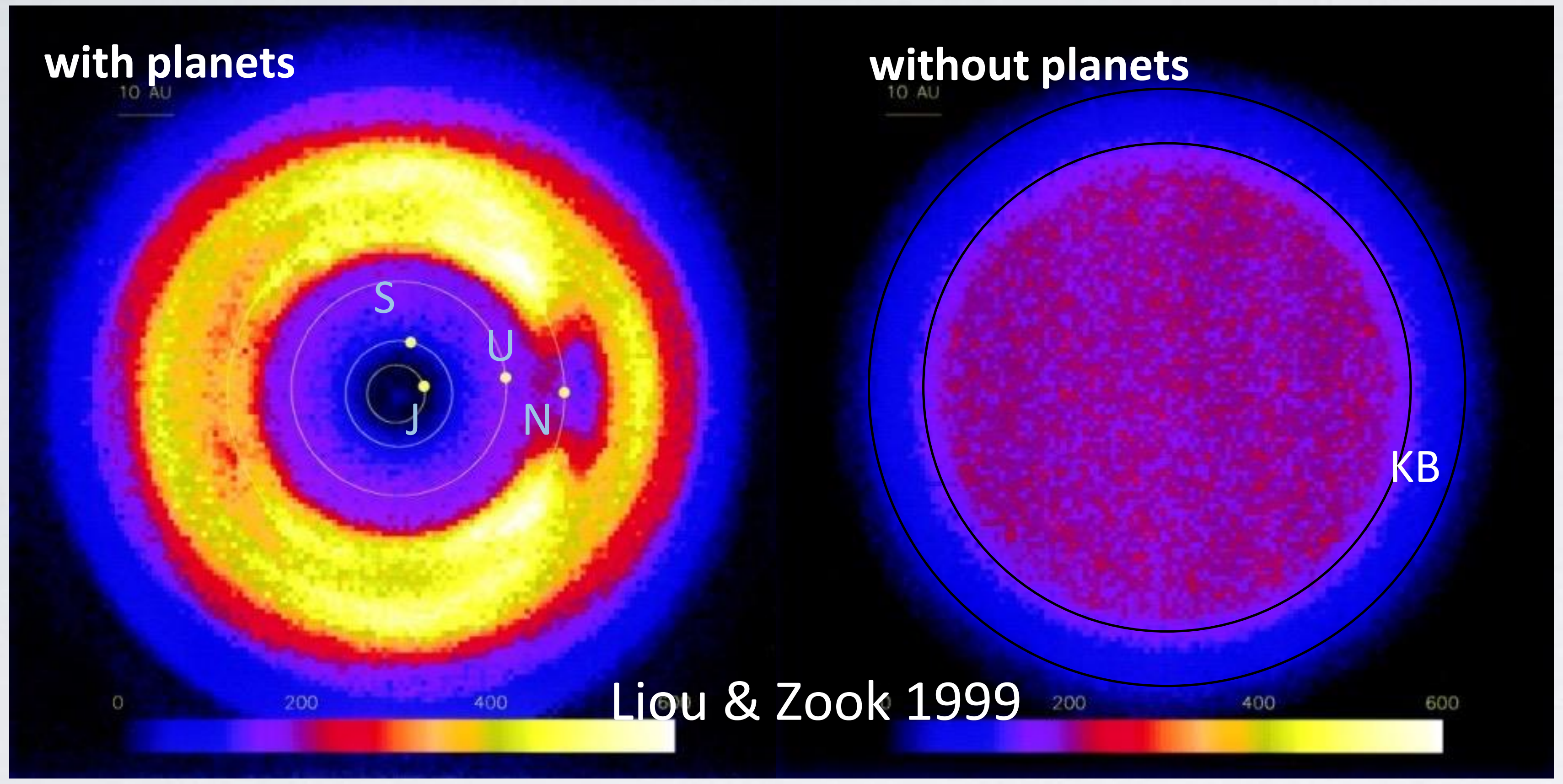
- Composition in Debris Disks -
  - Gas in debris disks – where does it come from? Composition?
  - Dust mineralogy and size – silicates, ices, and calcites…etc, hydro-material?

- Planetary Systems beyond Main

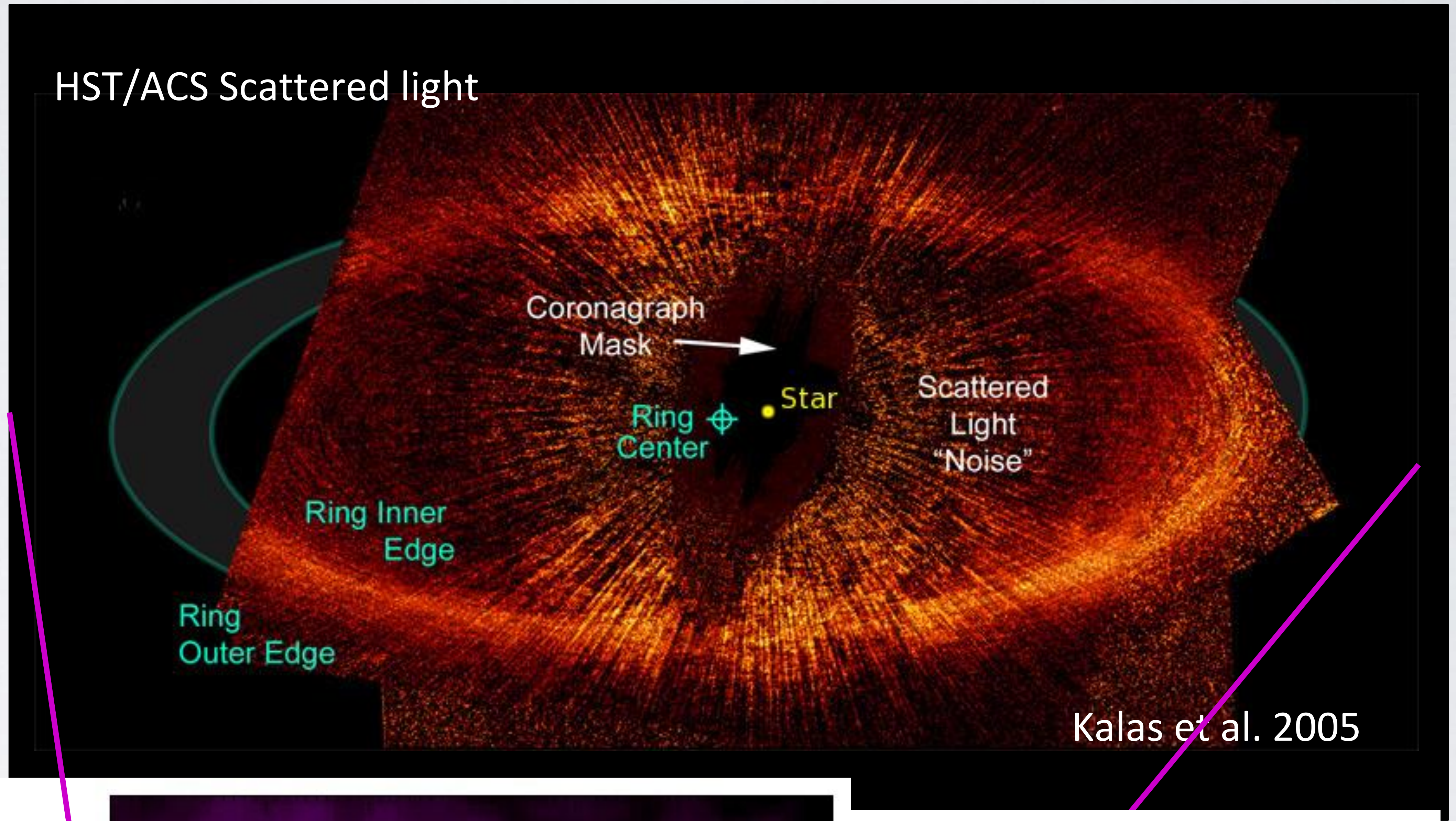


Planet-Disk Interaction - structures created by planet(s)

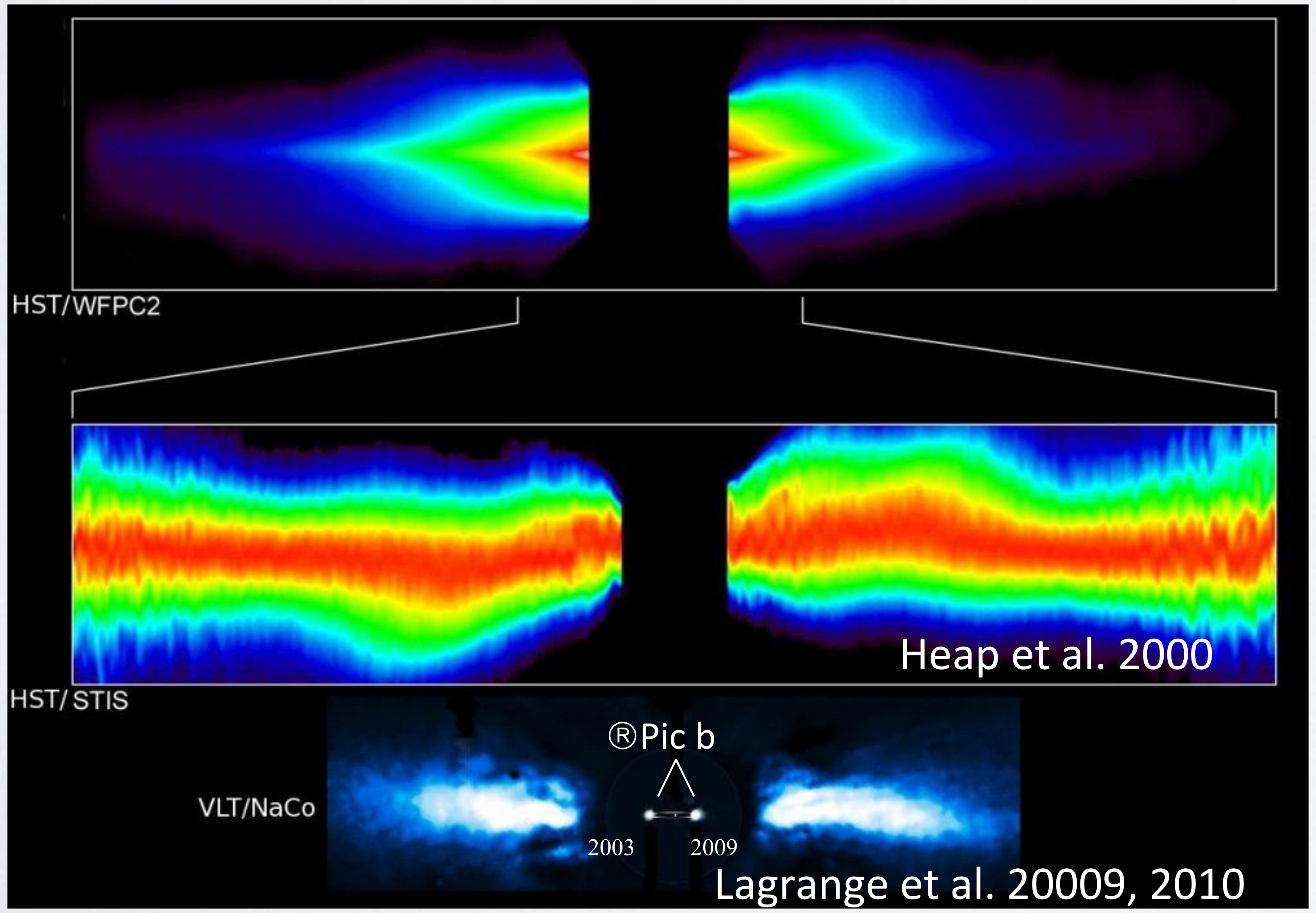
- Particle Distribution for Solar System

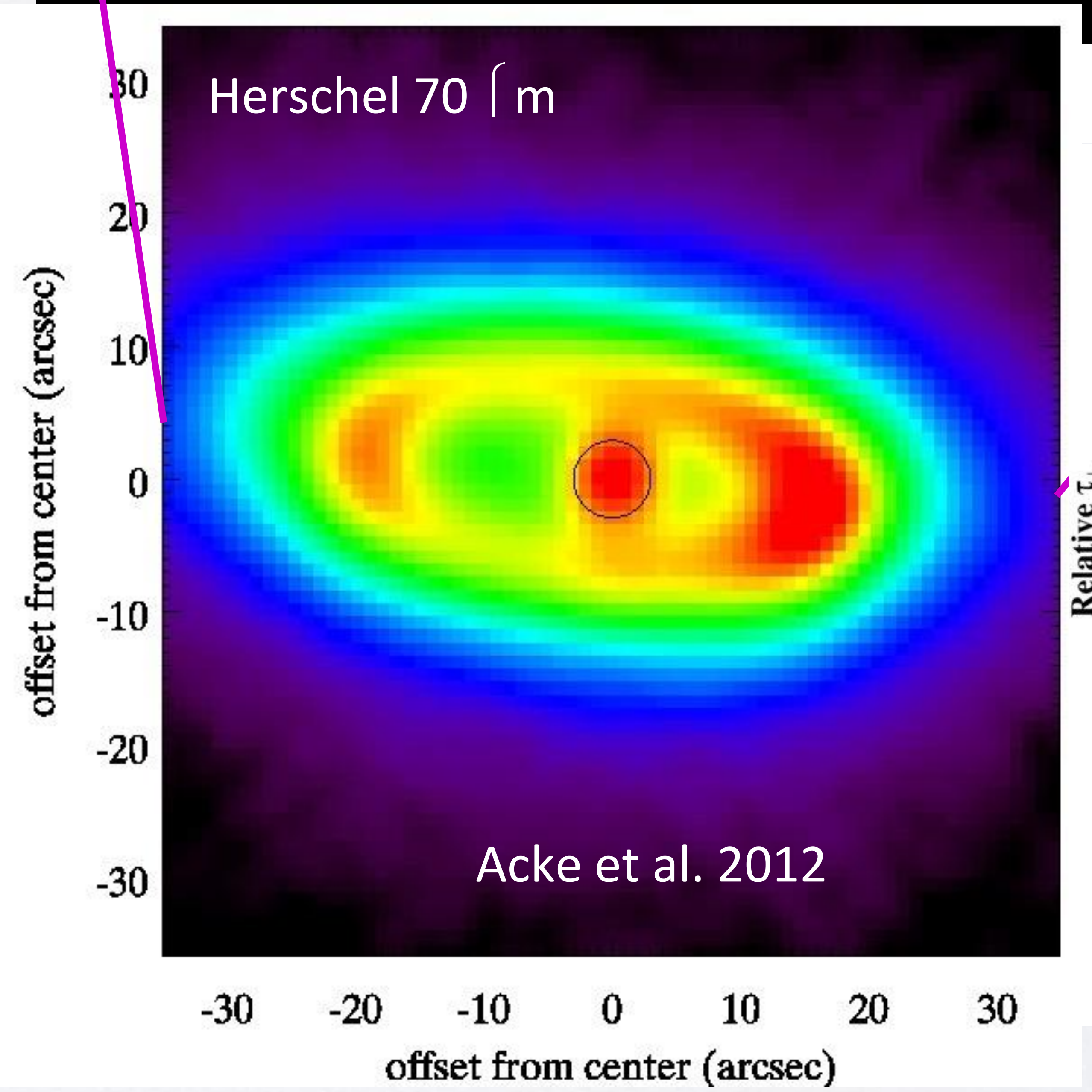


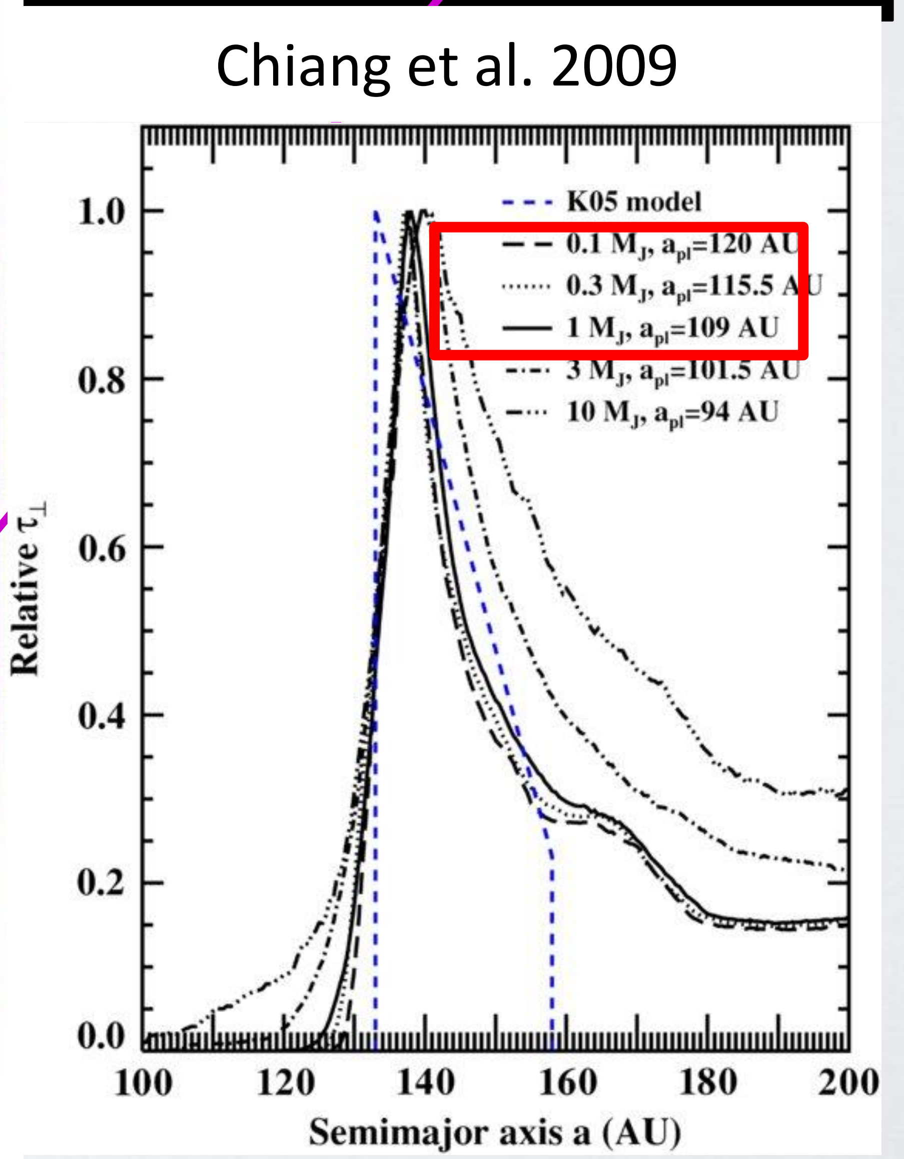
- Offset Narrow Ring – Fomalhaut



- Warp Disk – ®Pictoris



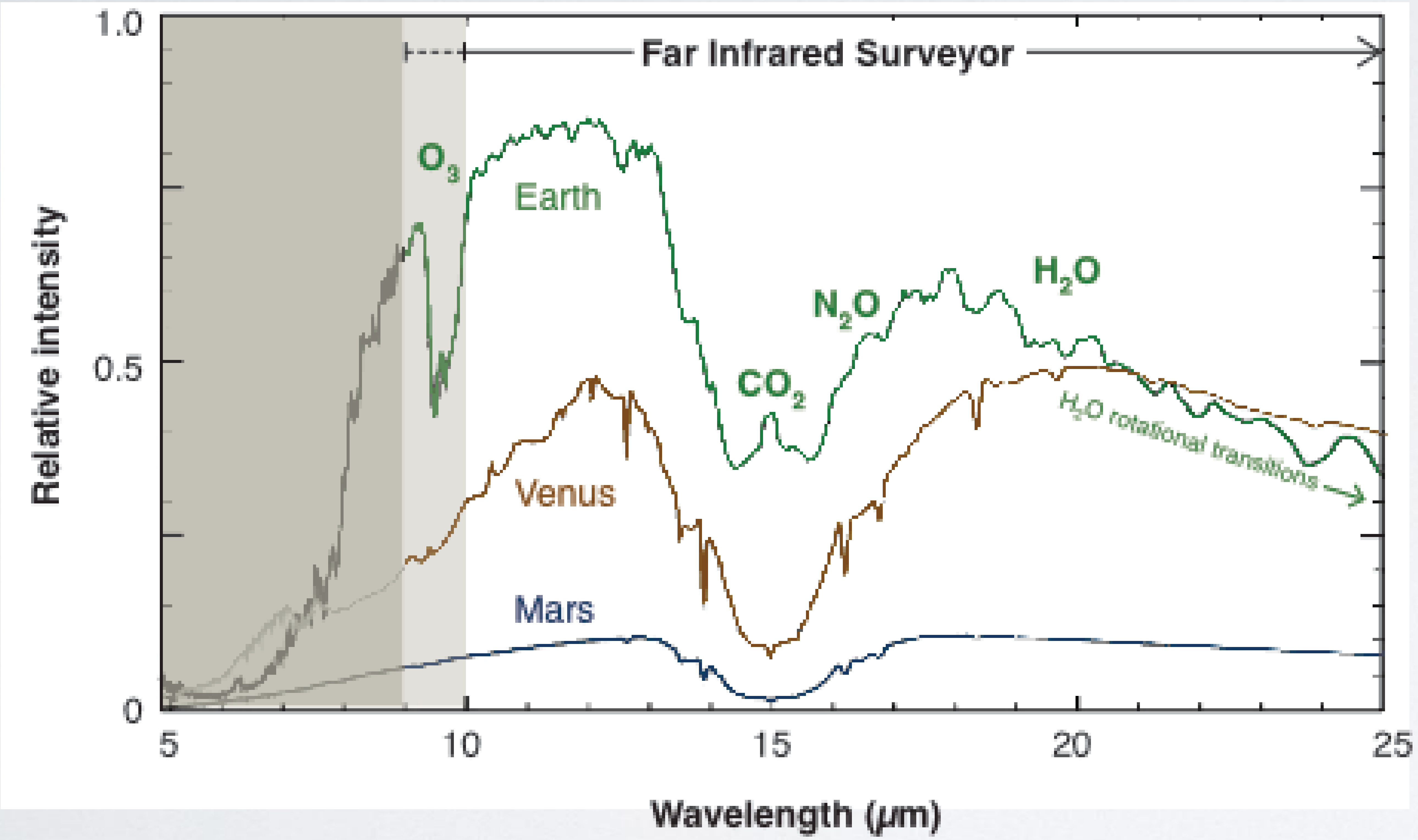




also see Boley et al. 2012

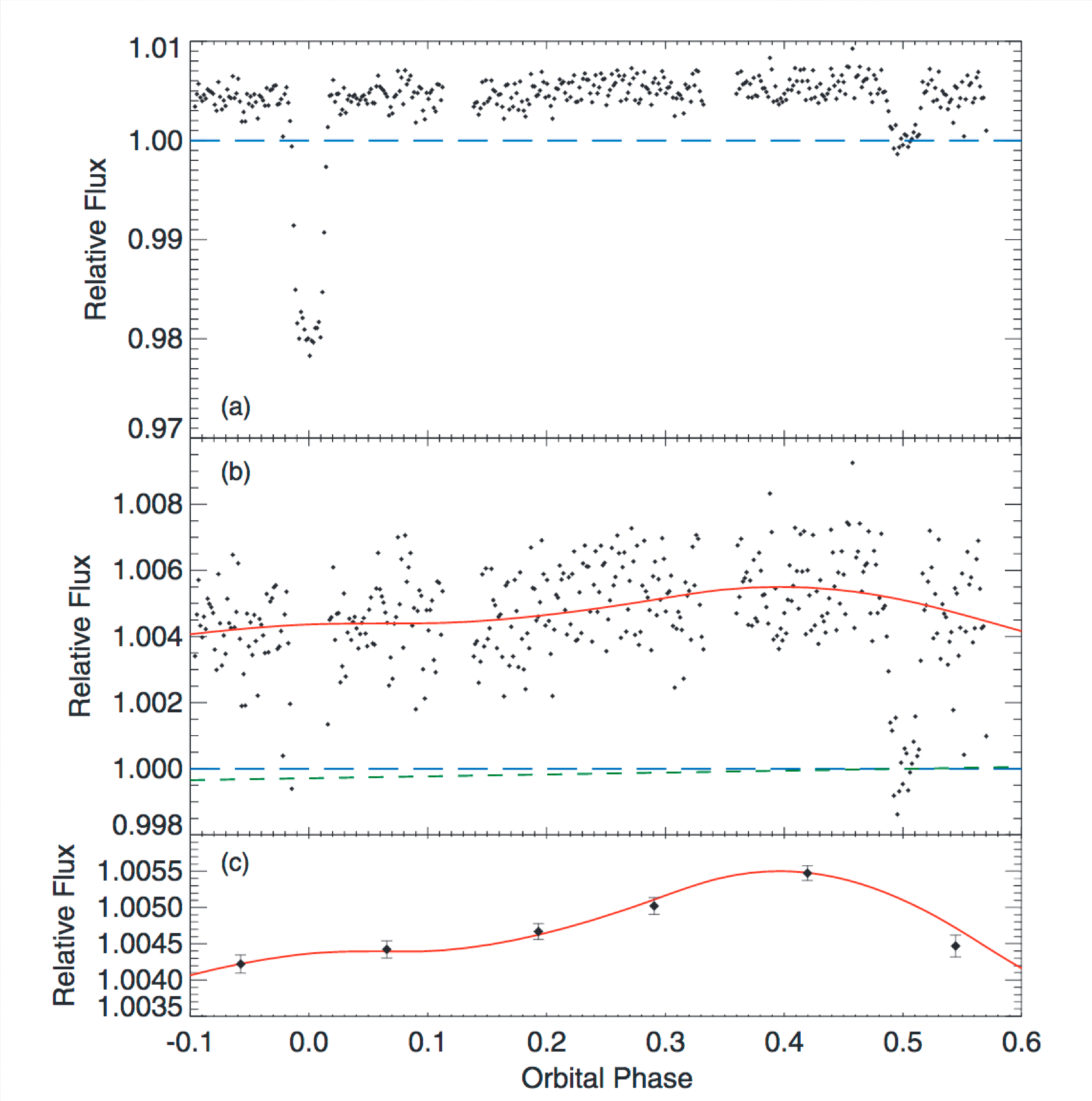
Weather and climate on exoplanets

POTENTIAL FOR TRANSITING HABITABLE SUPER-EARTHS AROUND M DWARFS?



Credit: J. Haqq-Misra

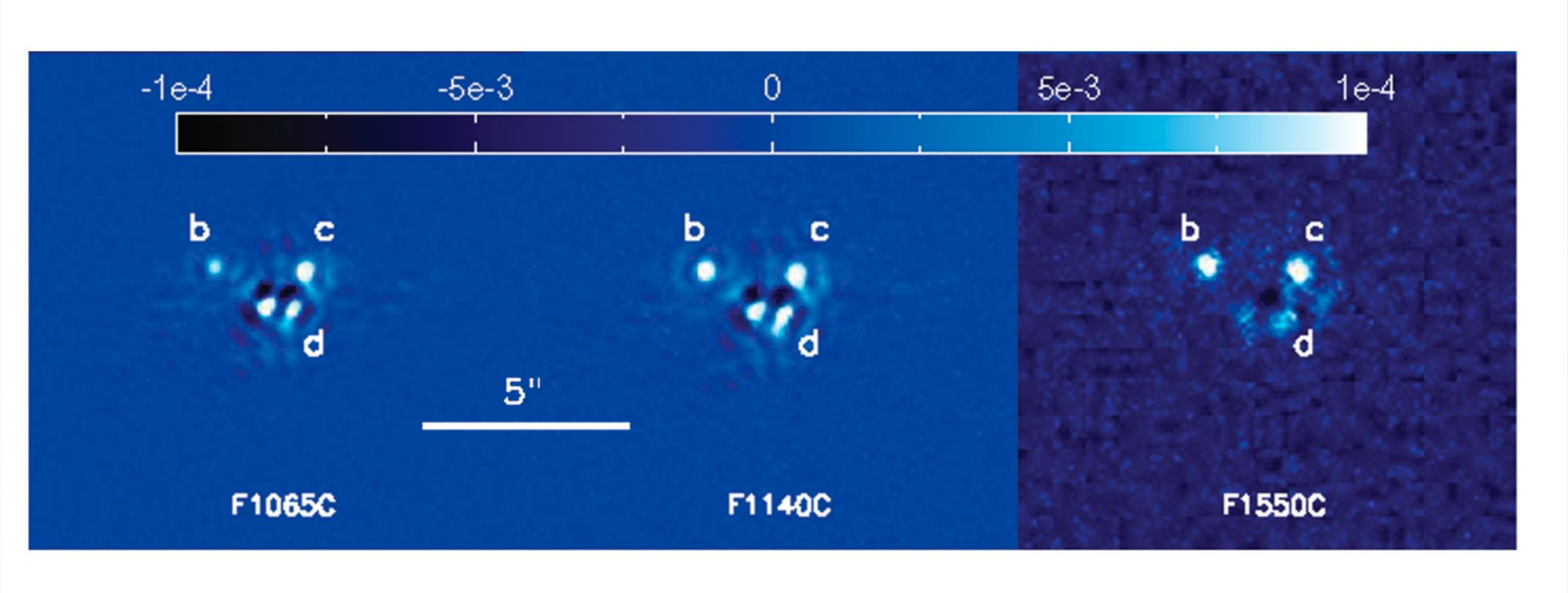
Spitzer 24 micron phase curve of HD 189733b



Knutson+ 2009

The atmospheric composition of Jupiter analogs and cool planets

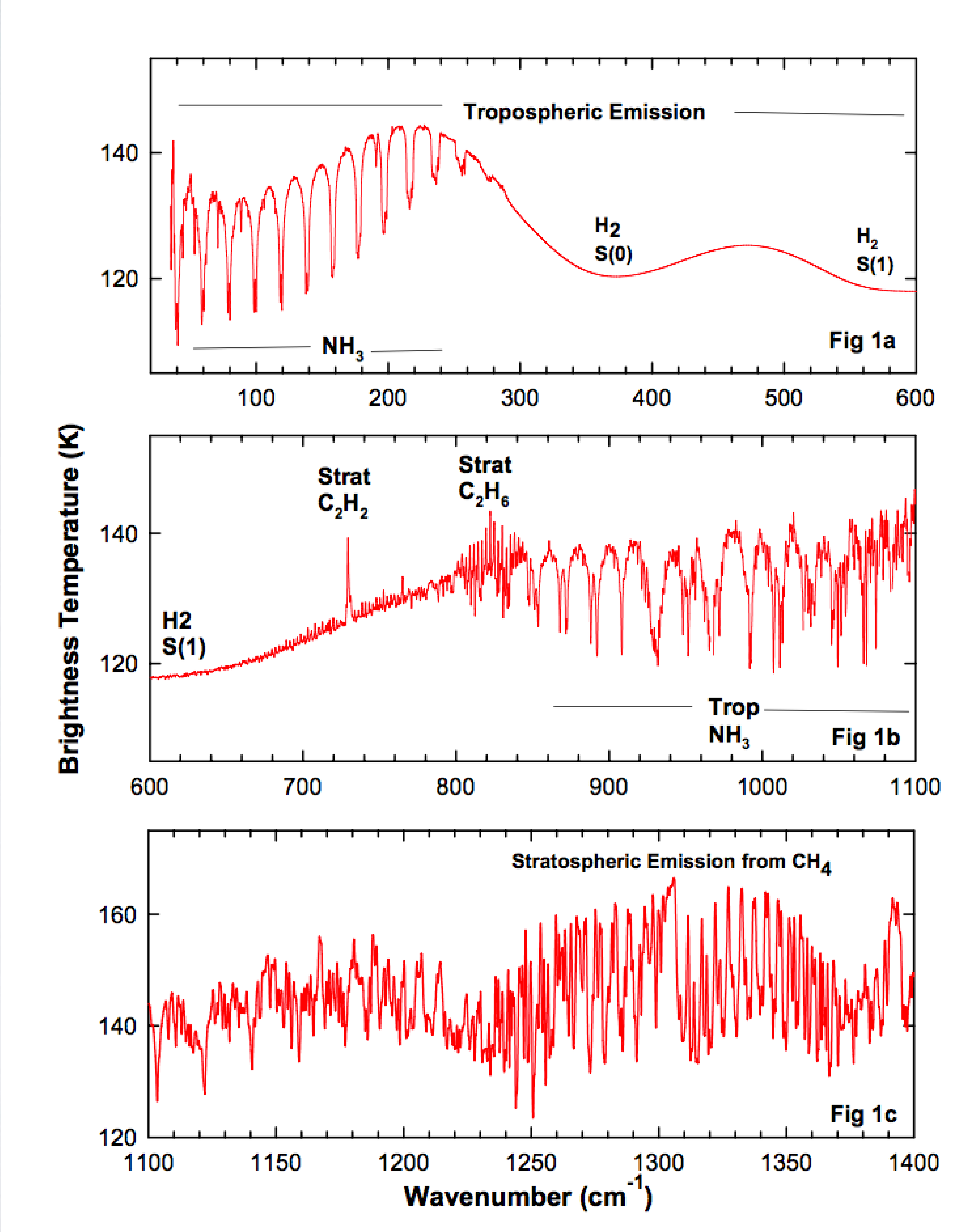
10.65 micron 11.40 micron 15.50 micron



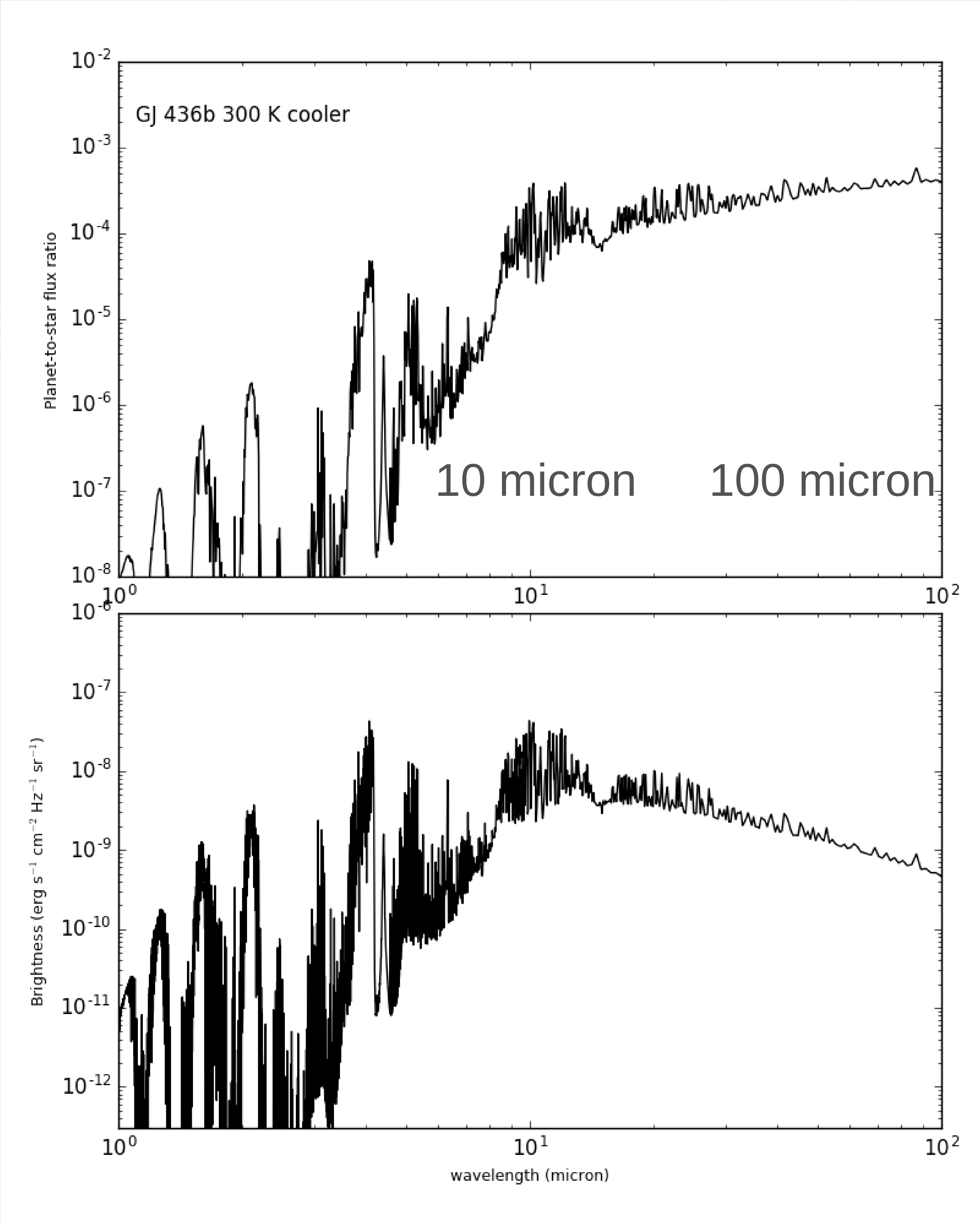
Boccaletti+ 2014 Simulated MIRI coronagraphy of HR 8799

The Far-IR Surveyor could improve resolution by a factor 2.5, sensitivity by factors of 10-300, and offer spectrally dispersed coronagraphy

Composition of Jupiter analogs



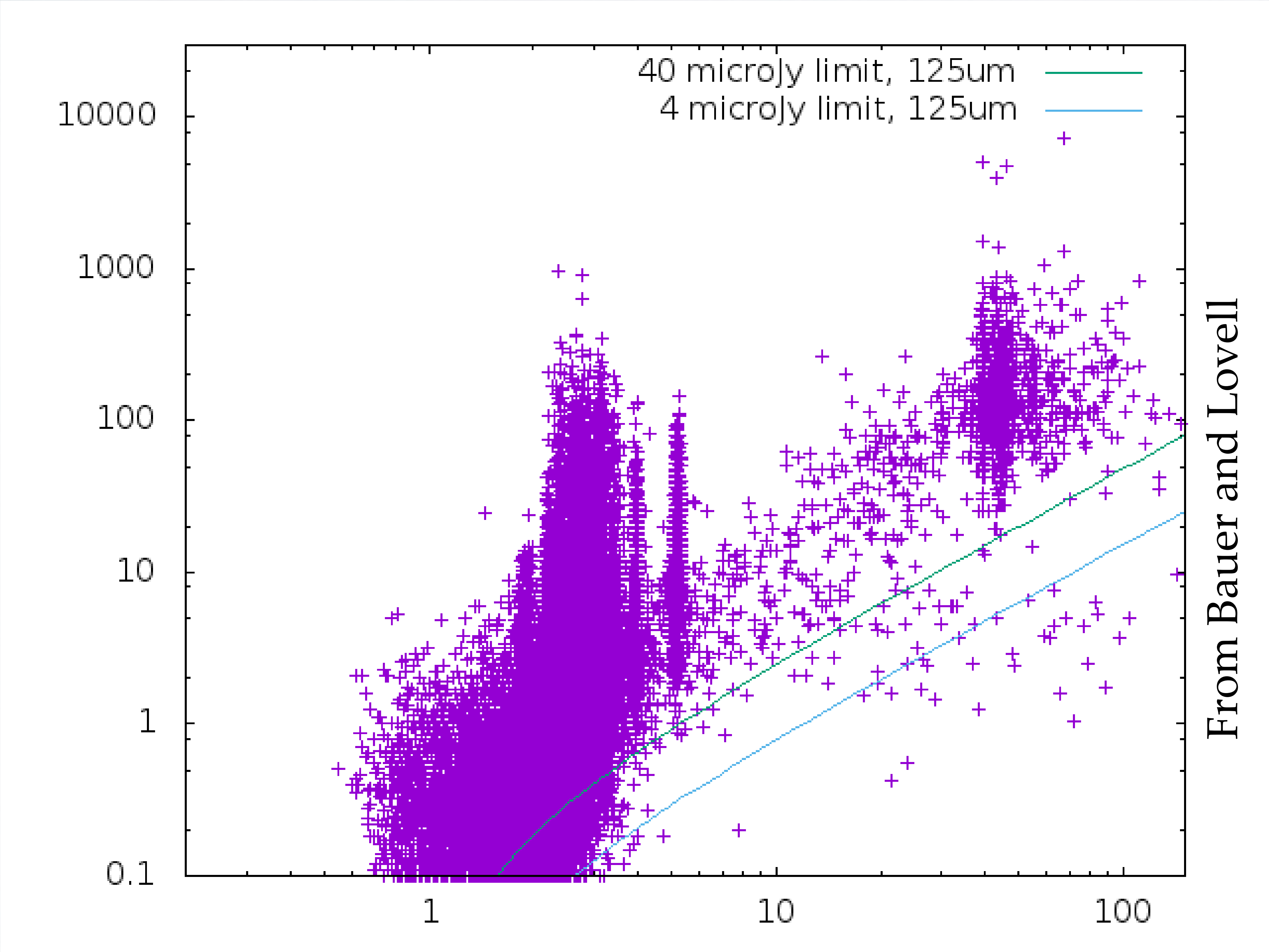
Credit: B. Bezard



Credit: M. Agundez

REVEALING THE SOLAR SYSTEM IN THE FAR-IR

History and Evolution of the Solar System:



Diameter (km)

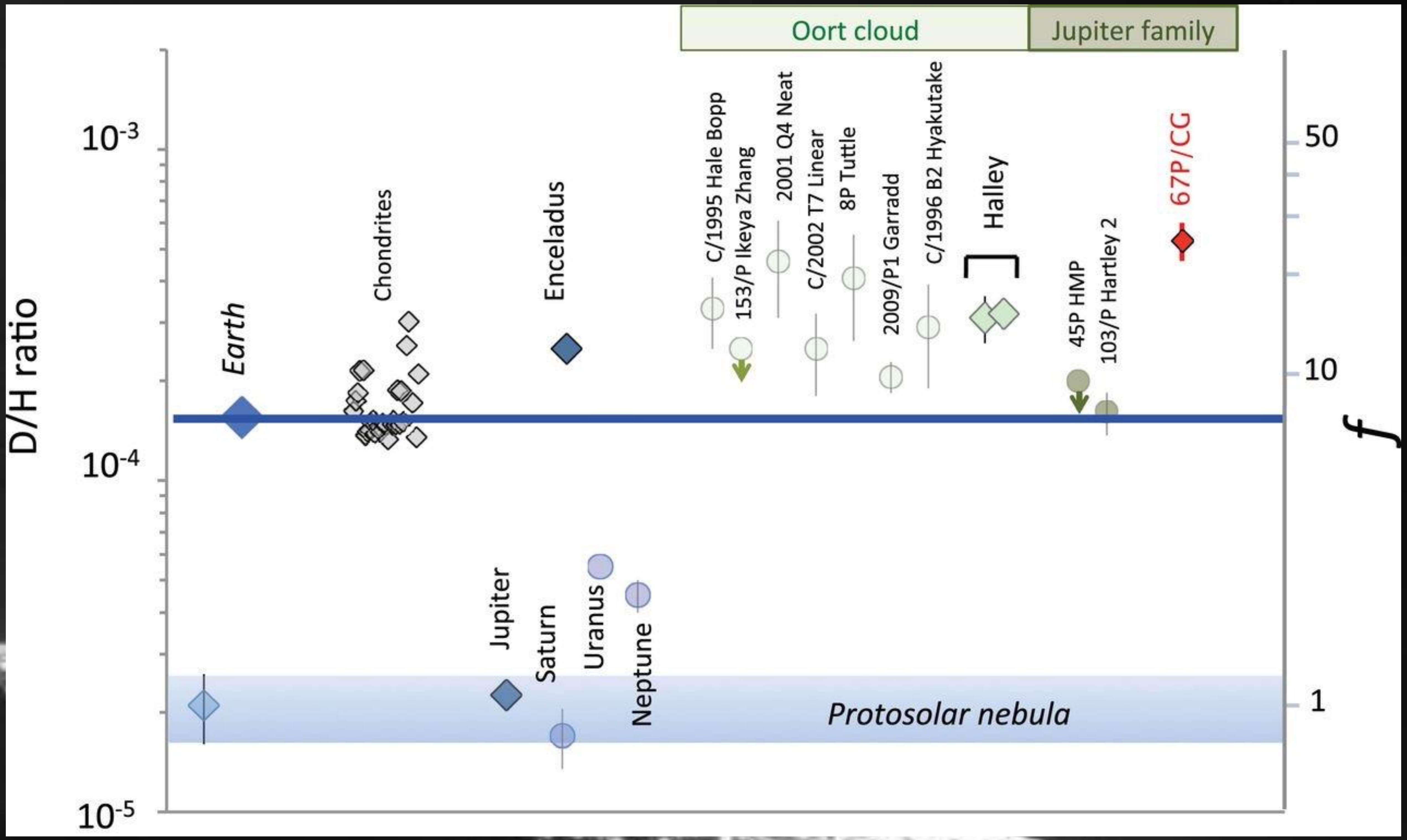
Heliocentric Distance (AU)

- Measure the thermal emission (via Far-IR imaging) of small bodies in outer SS – 1000's of targets
- Volatile isotope measurements (HCNO) across the SS
- Constrain the Thermal History/Evolution of the Solar System – He/H2 measurements.
- Not limited by confusion.

REVEALING THE SOLAR SYSTEM IN THE FAR-IR

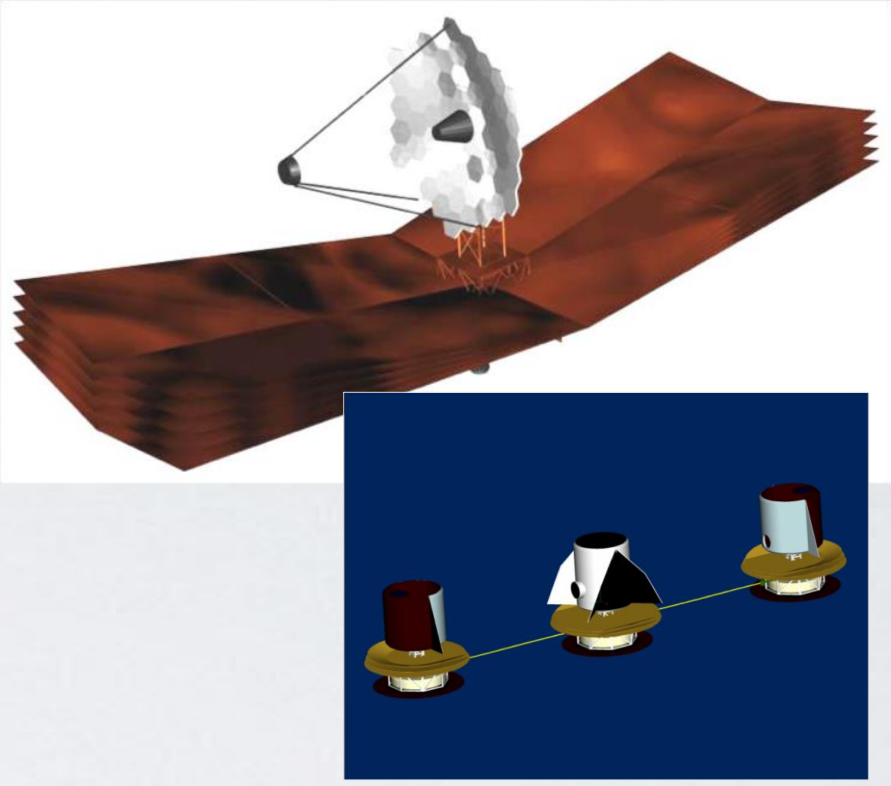
Studies of Isotopes across the solar system:

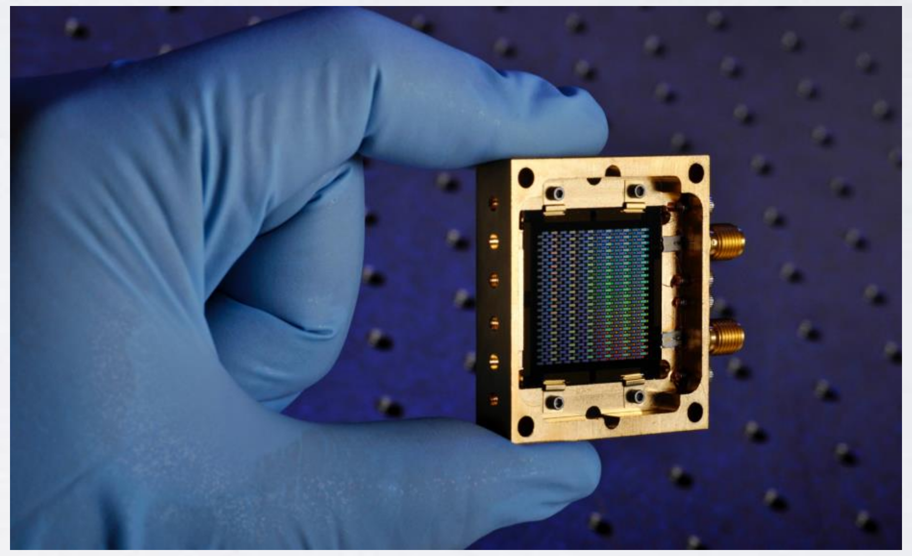
- How does presolar deuterium chemistry inform our understanding of D/H in the solar system and the development of Earth's oceans?
- Measure HDO in comets for an un-biased survey.

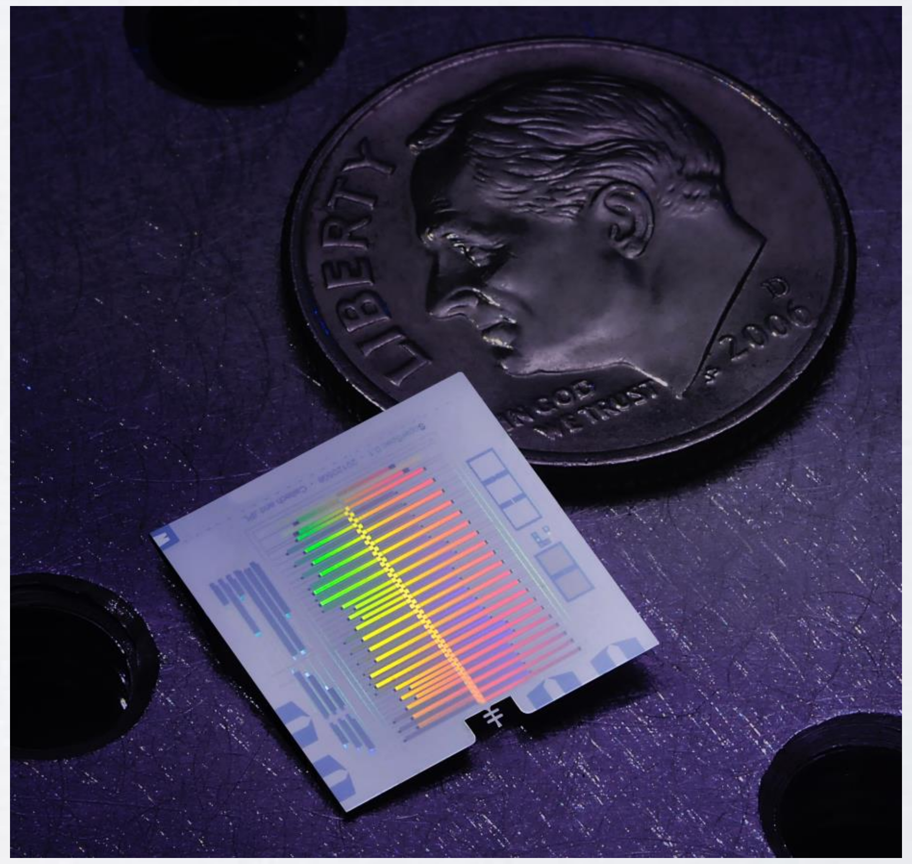


NEW TECHNOLOGIES

New Technology	New Capability
Space	Wavelength coverage JWST<—>ALMA
Cold Mirror	Huge sensitivity gains
Large Telescope	Spatial resolution and sensitivity
Large Detector Arrays	Wide field imaging
Integrated Spectrometers	3D mapping
Mid-IR Coronagraph	Exoplanet+Disk Characterization
Stable Mid-IR Detectors	Exoplanet transit/occultation spectroscopy







SCHEDULE

- 2016: Establish key/unique science goals and science requirements and a decision on the architecture.
- 2017-2018: mission concept development/engineering, independent costing, finalize concept, sciences.
- 2019: Present report to NRC 2020 Decadal Survey committee.
- Goal is an actual mission in the 2020 Decadal so some trade-offs to study in 2017-2018 on science requirements vs. tech readiness level.