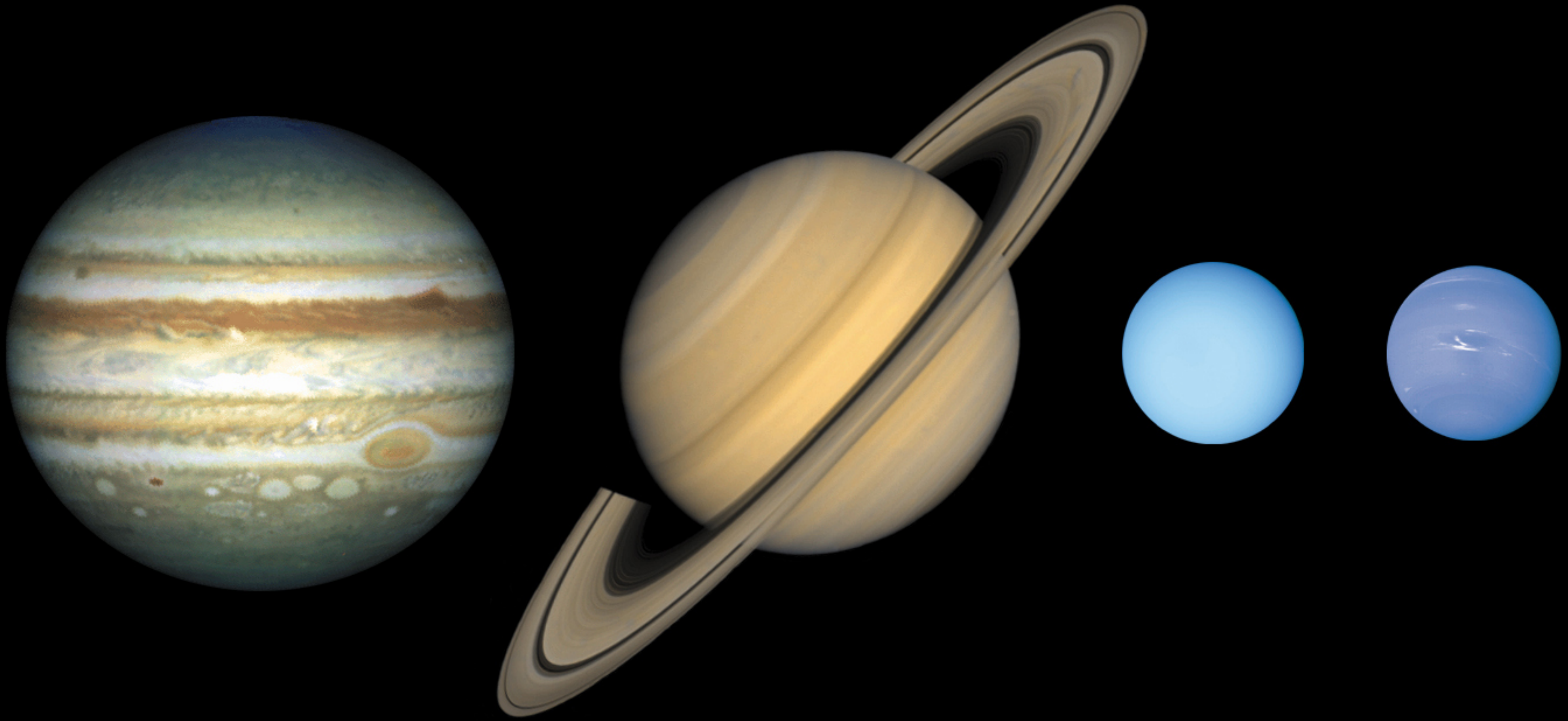
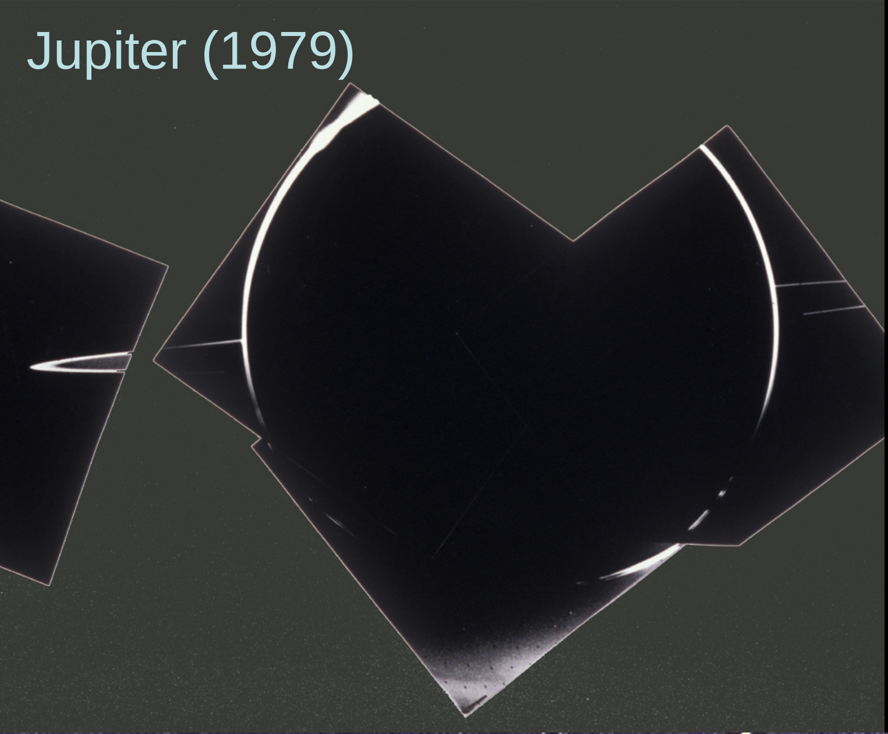
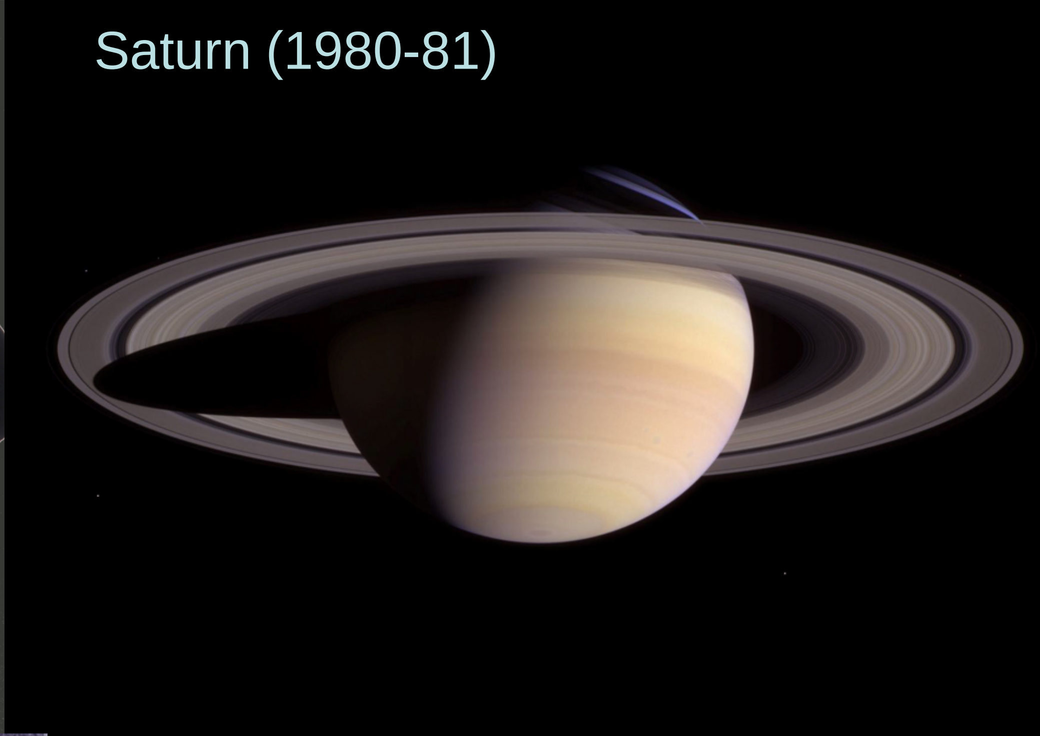
Musings on outer planet exploration

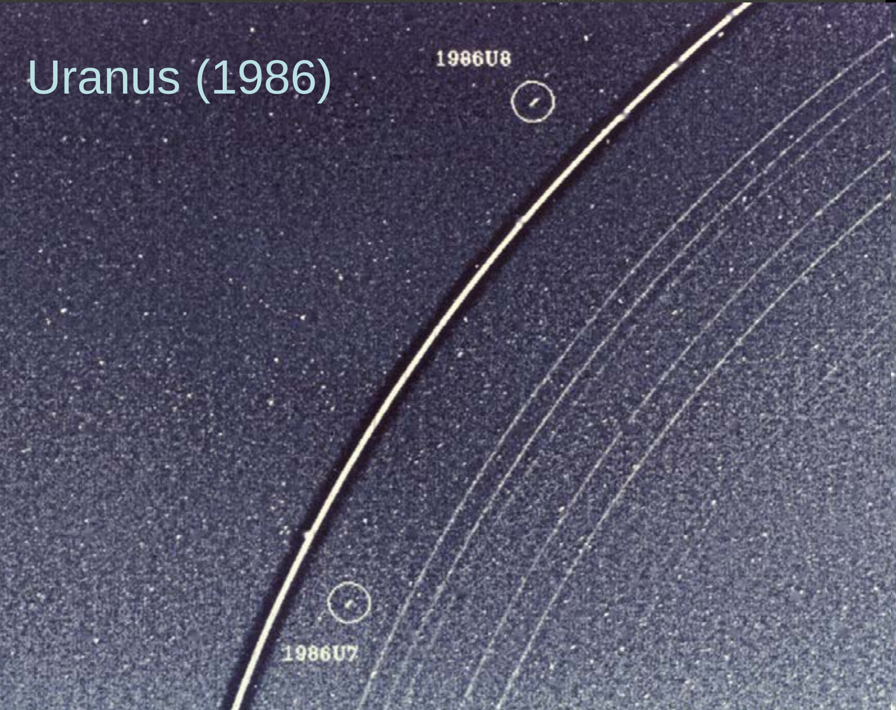
Jeff Cuzzi; OPAG 2/19/15

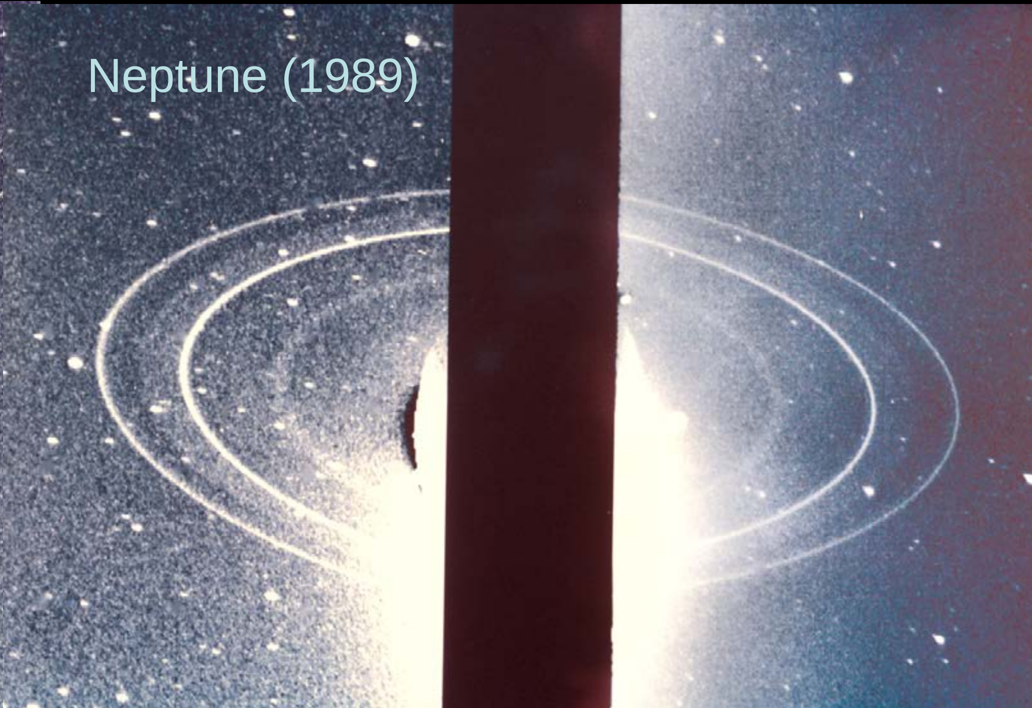


Thanks to P. Agrawal, S. Atreya, K. Baines, P. Estrada, M. Hofstadter, M. Marley, M. Munk, N. Murphy, M. Tiscareno, E. Venkatapathy, K. Zahnle

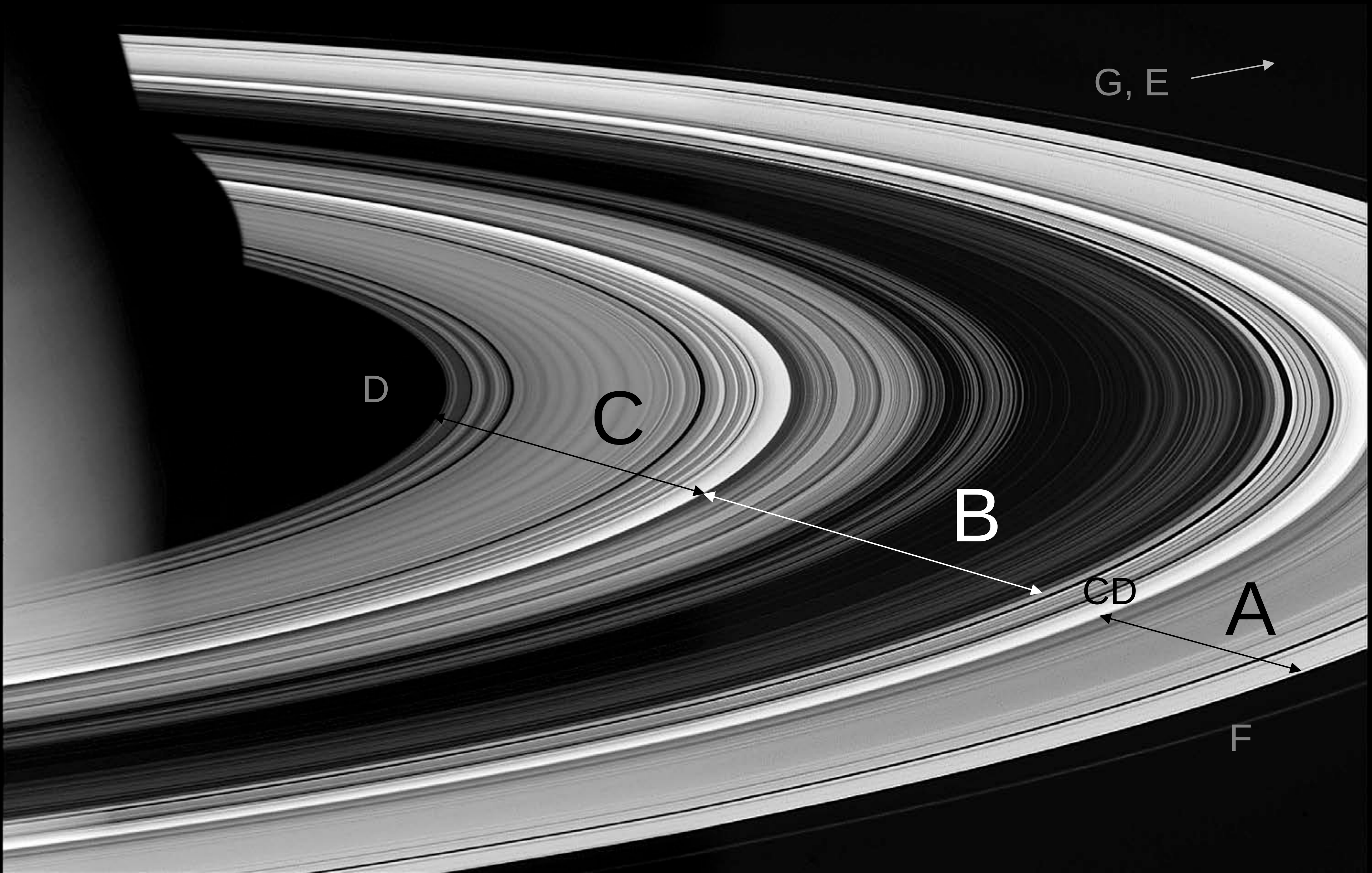

Jupiter (1979)


Saturn (1980-81)


Uranus (1986)


Neptune (1989)

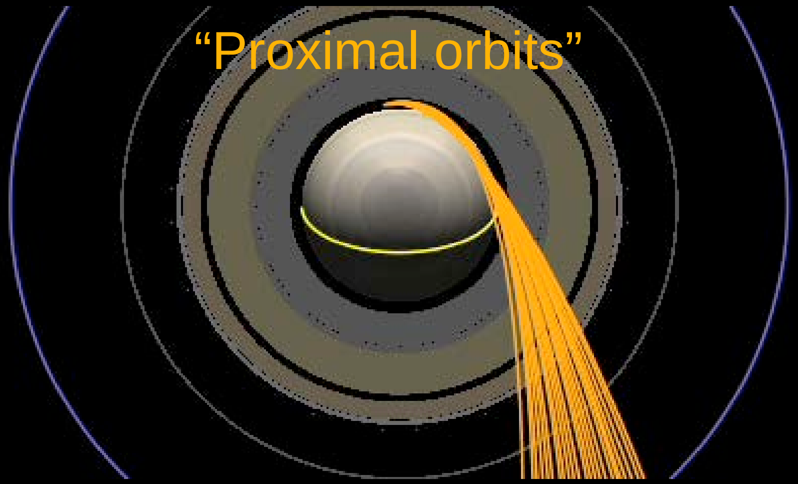
The Dark Side



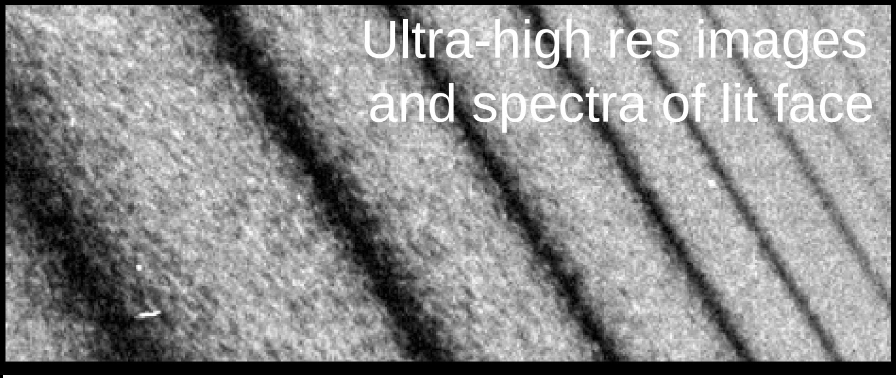
Rings: completely new science in Cassini “Grand Finale”

Extended time baseline and wide open rings for studies of variable structure and the dense mid-B Ring

Measure ring mass directly with 5% (1♦) accuracy. Supermassive rings can be easily detected or ruled out this way.

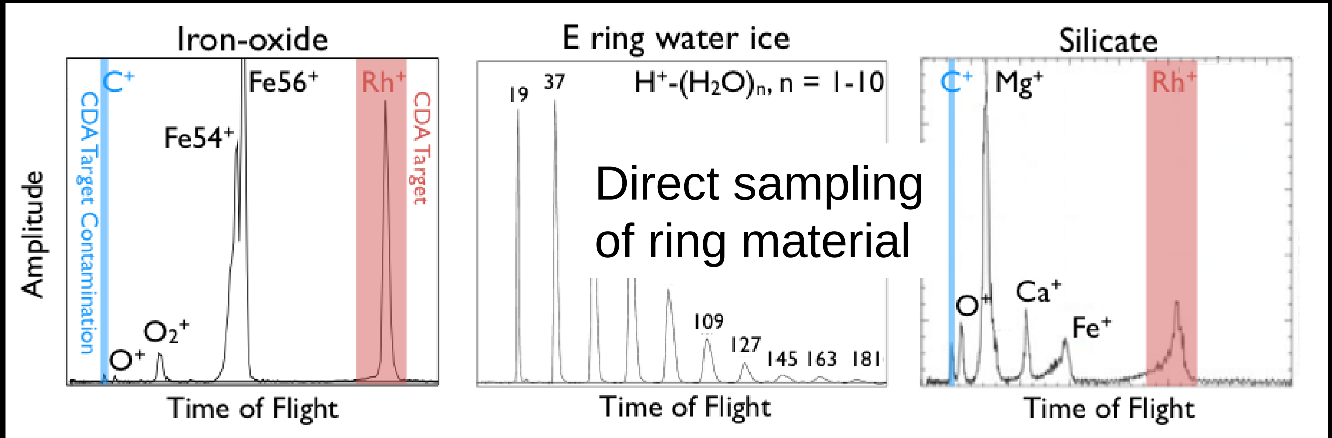


“Proximal orbits”

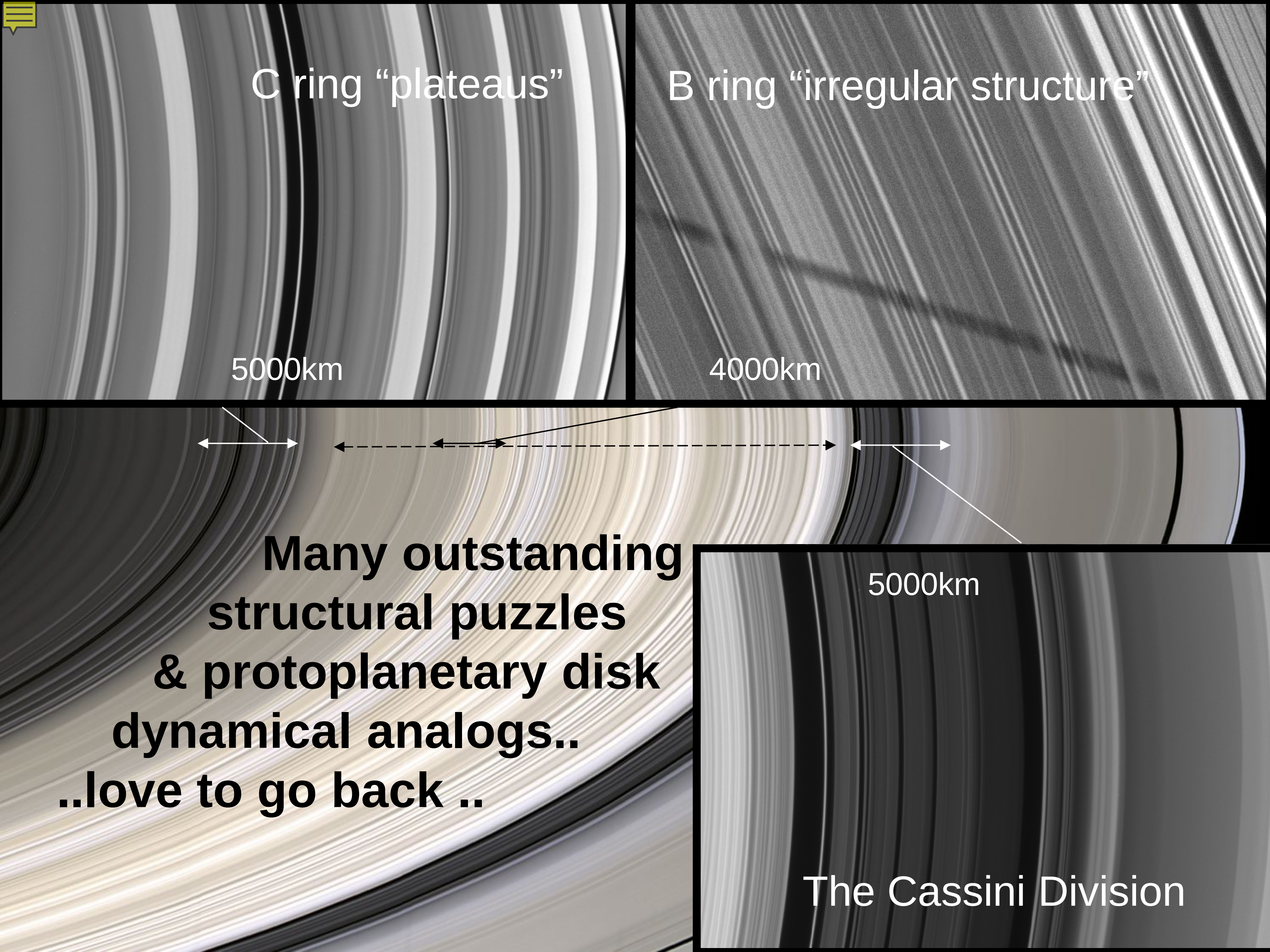


Ultra-high res images and spectra of lit face

Cassini RADAR maps of the rings



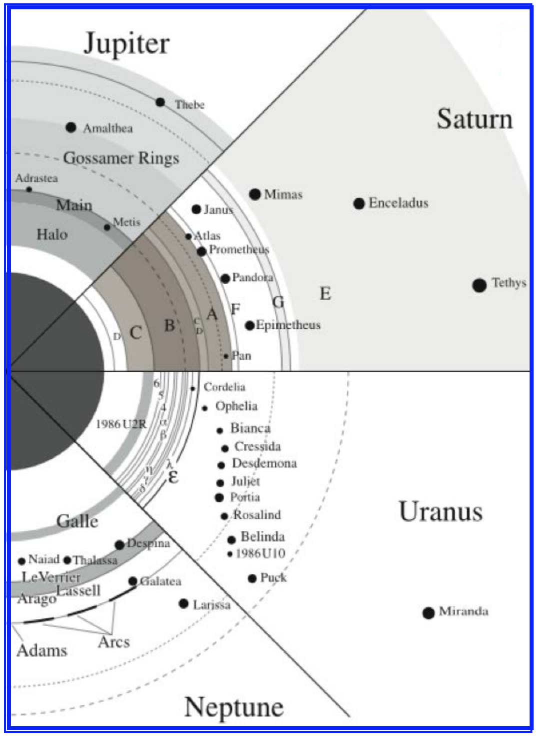
Direct sampling of ring material



Many outstanding structural puzzles & protoplanetary disk dynamical analogs..

..love to go back ..

CONTEXT:

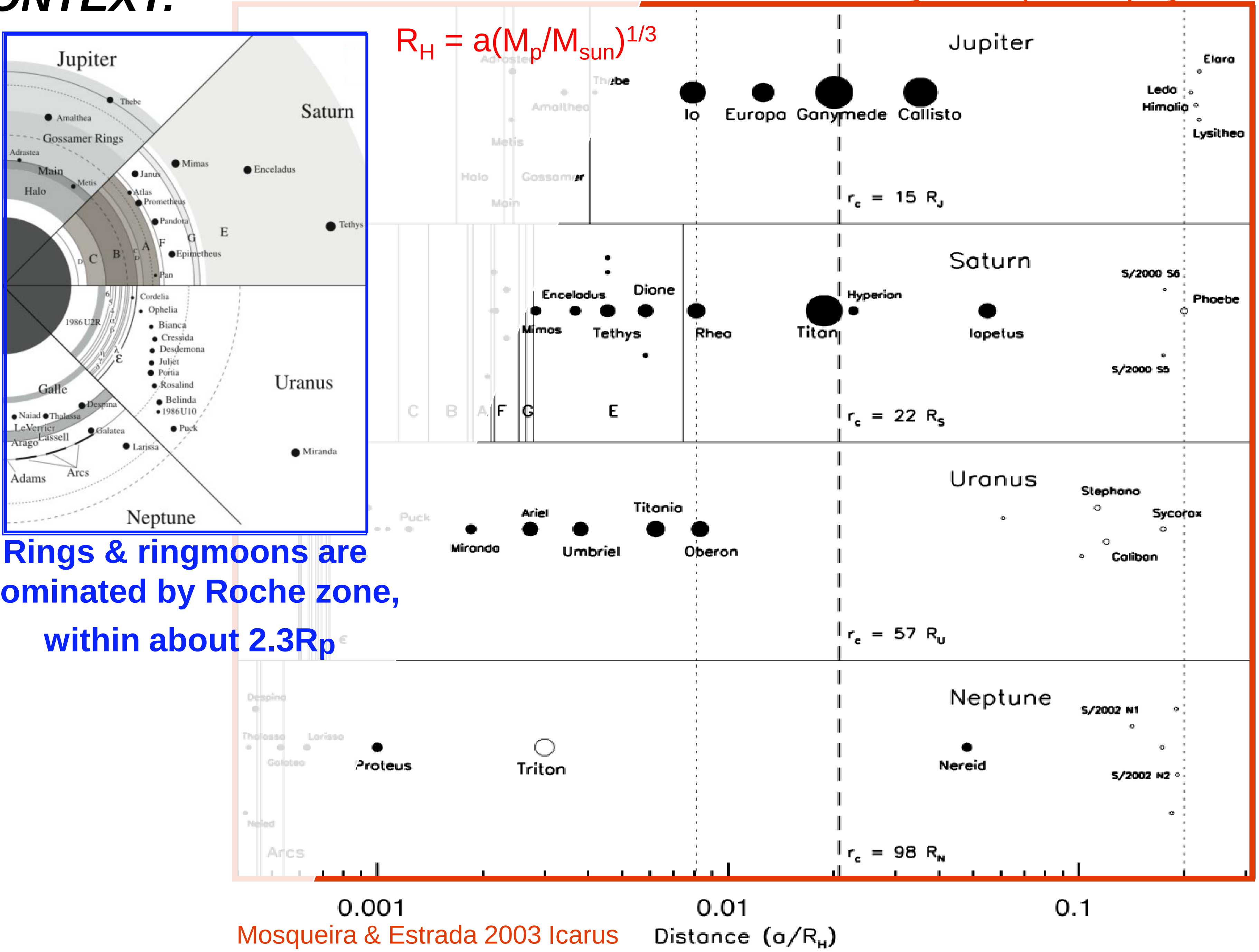


Rings & ringmoons are dominated by Roche zone, within about $2.3R_p$

CONTEXT:

Satellite systems as a whole dominated by Hill-sphere physics

$R_H = a(M_p/M_{sun})^{1/3}$



Rings & ringmoons are dominated by Roche zone, within about 2.3R_p

Mosqueira & Estrada 2003 Icarus

CONTEXT:

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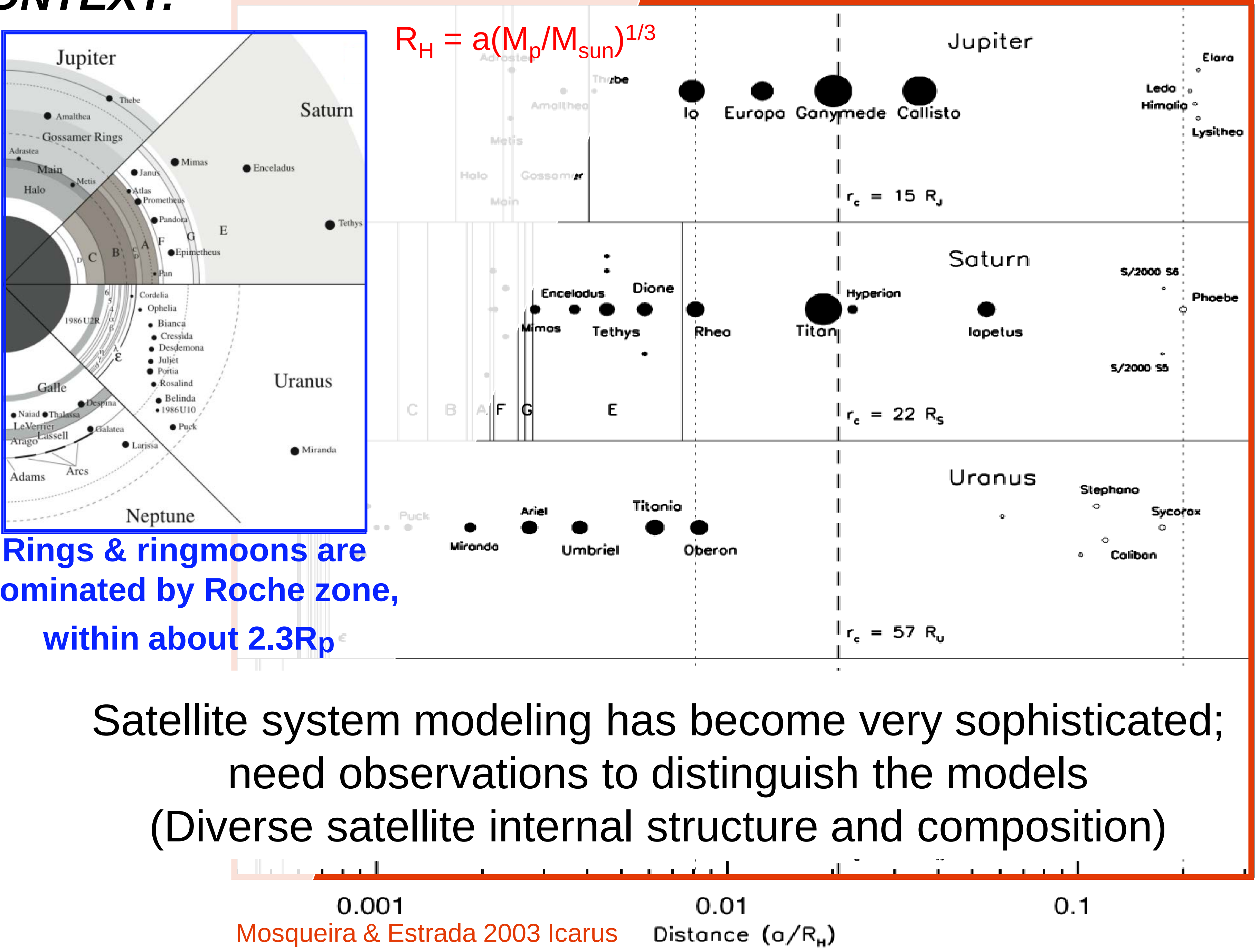
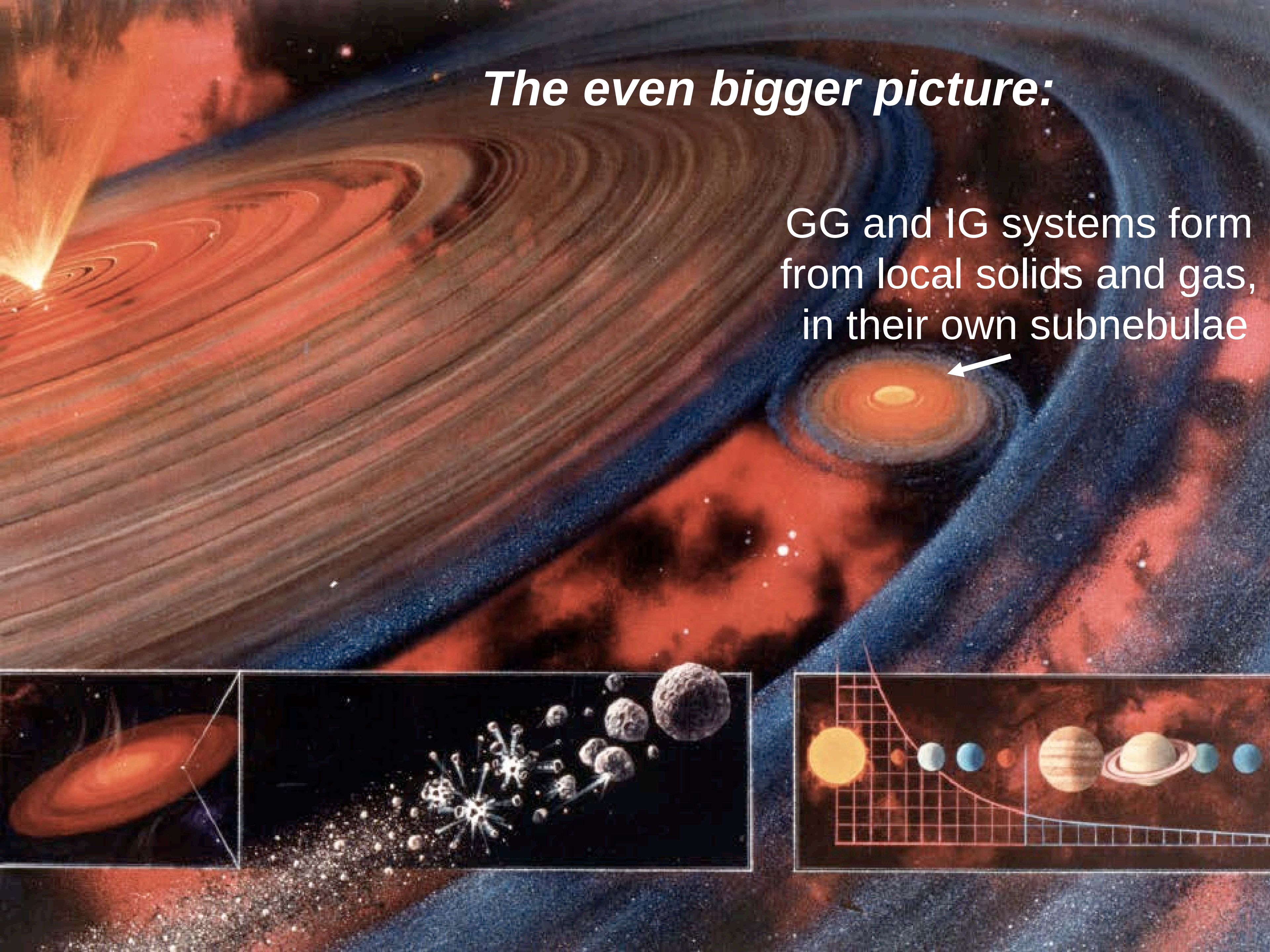


Rings & ringmoons are dominated by Roche zone, within about 2.3Rp

Satellite system modeling has become very sophisticated; need observations to distinguish the models (Diverse satellite internal structure and composition)

Mosqueira & Estrada 2003 Icarus

The even bigger picture:



GG and IG systems form from local solids and gas, in their own subnebulae

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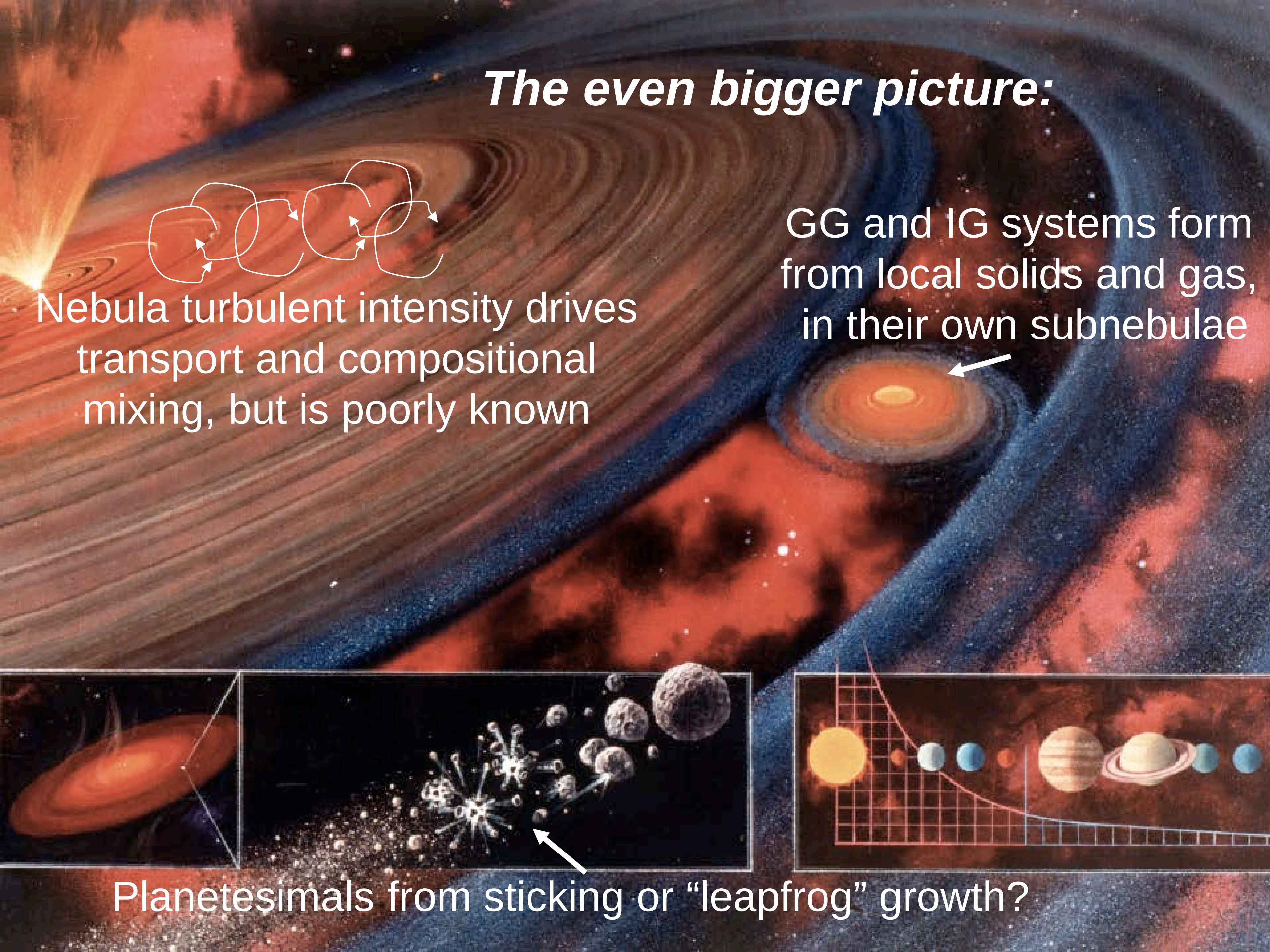

Nebula turbulent intensity drives transport and compositional mixing, but is poorly known

GG and IG systems form from local solids and gas, in their own subnebulae

Planetesimals from sticking or “leapfrog” growth?

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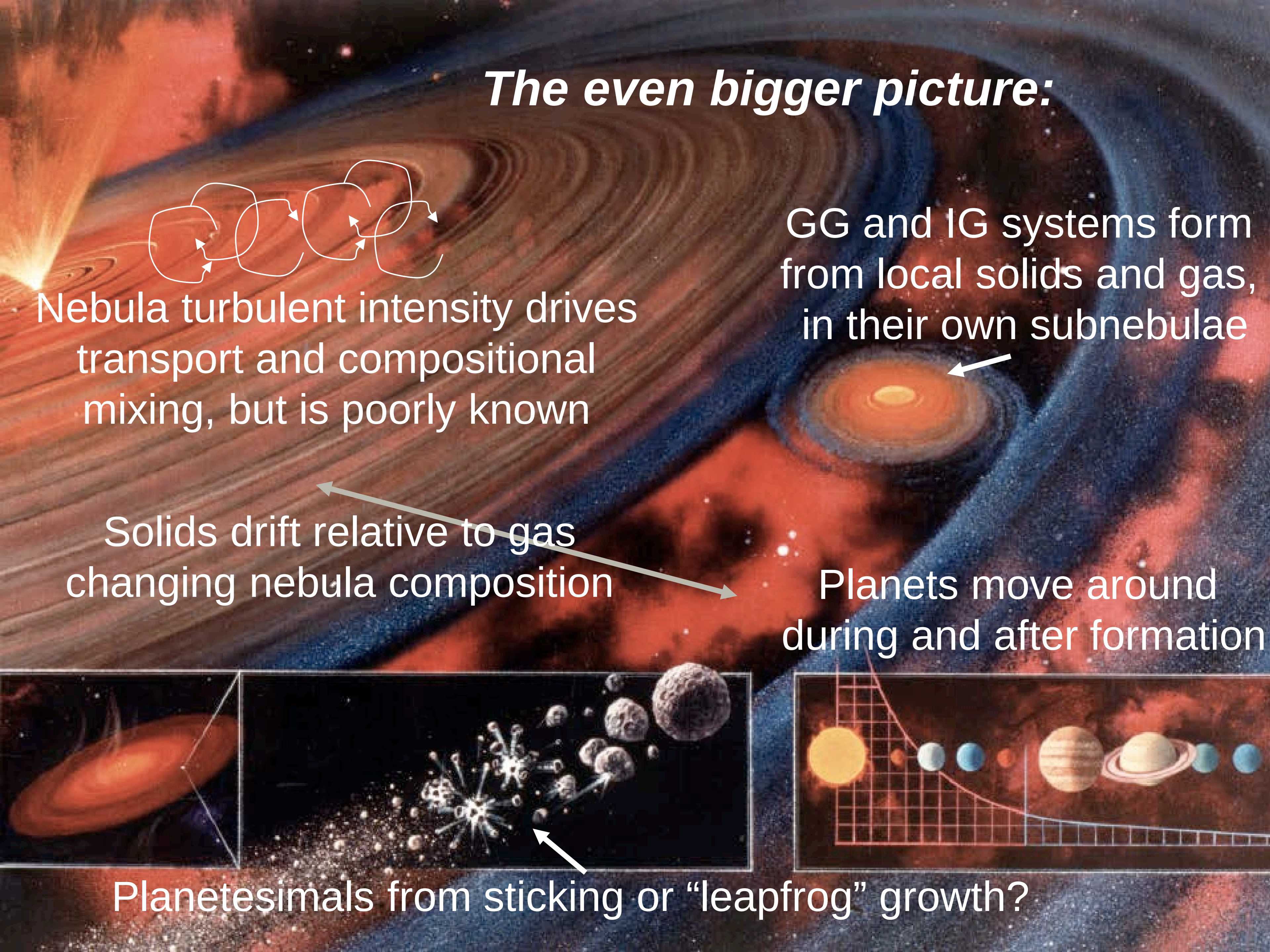


Nebula turbulent intensity drives transport and compositional mixing, but is poorly known

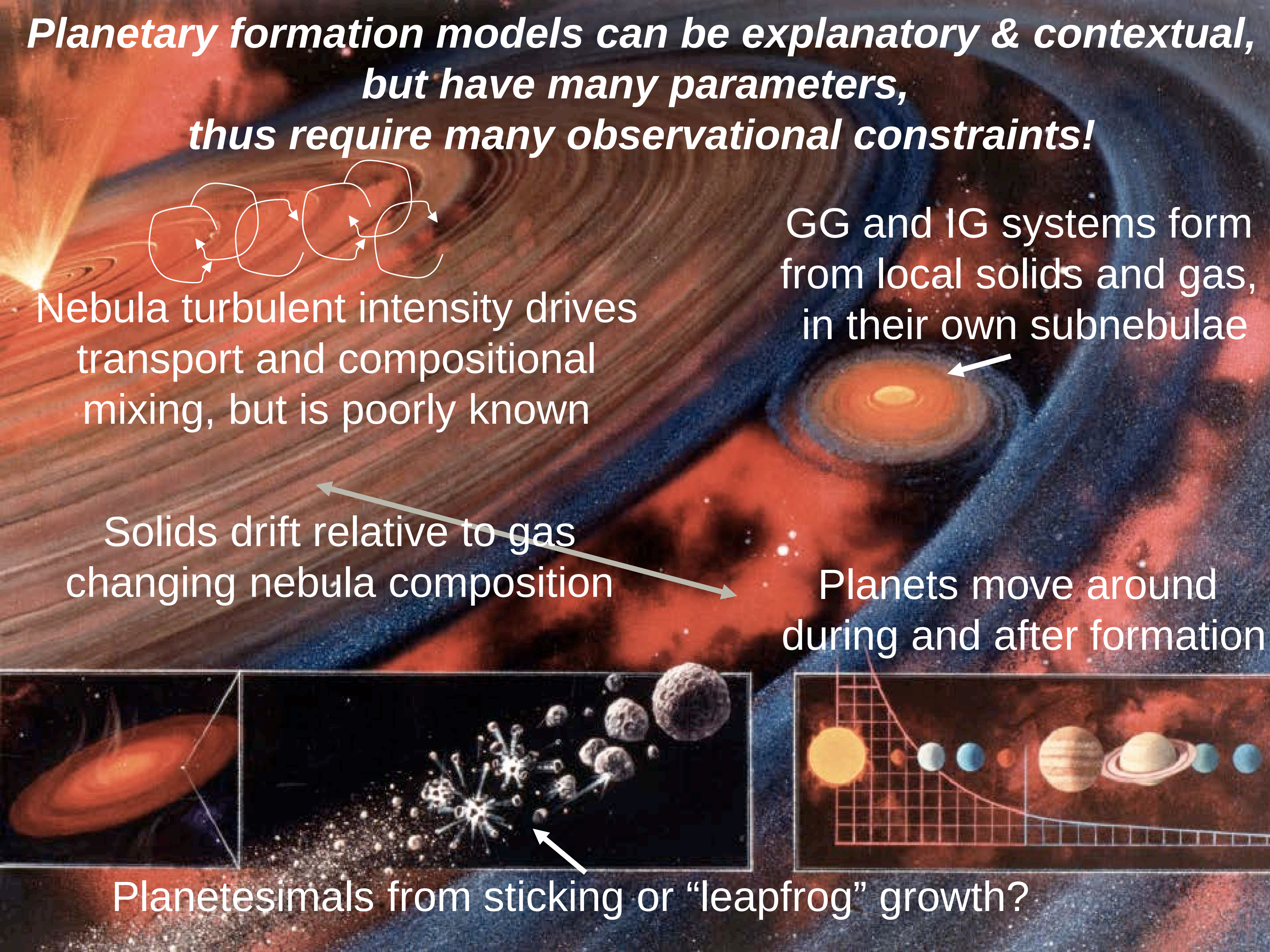
GG and IG systems form from local solids and gas, in their own subnebulae

Solids drift relative to gas changing nebula composition

Planets move around during and after formation

Planetesimals from sticking or “leapfrog” growth?

Planetary formation models can be explanatory & contextual, but have many parameters, thus require many observational constraints!



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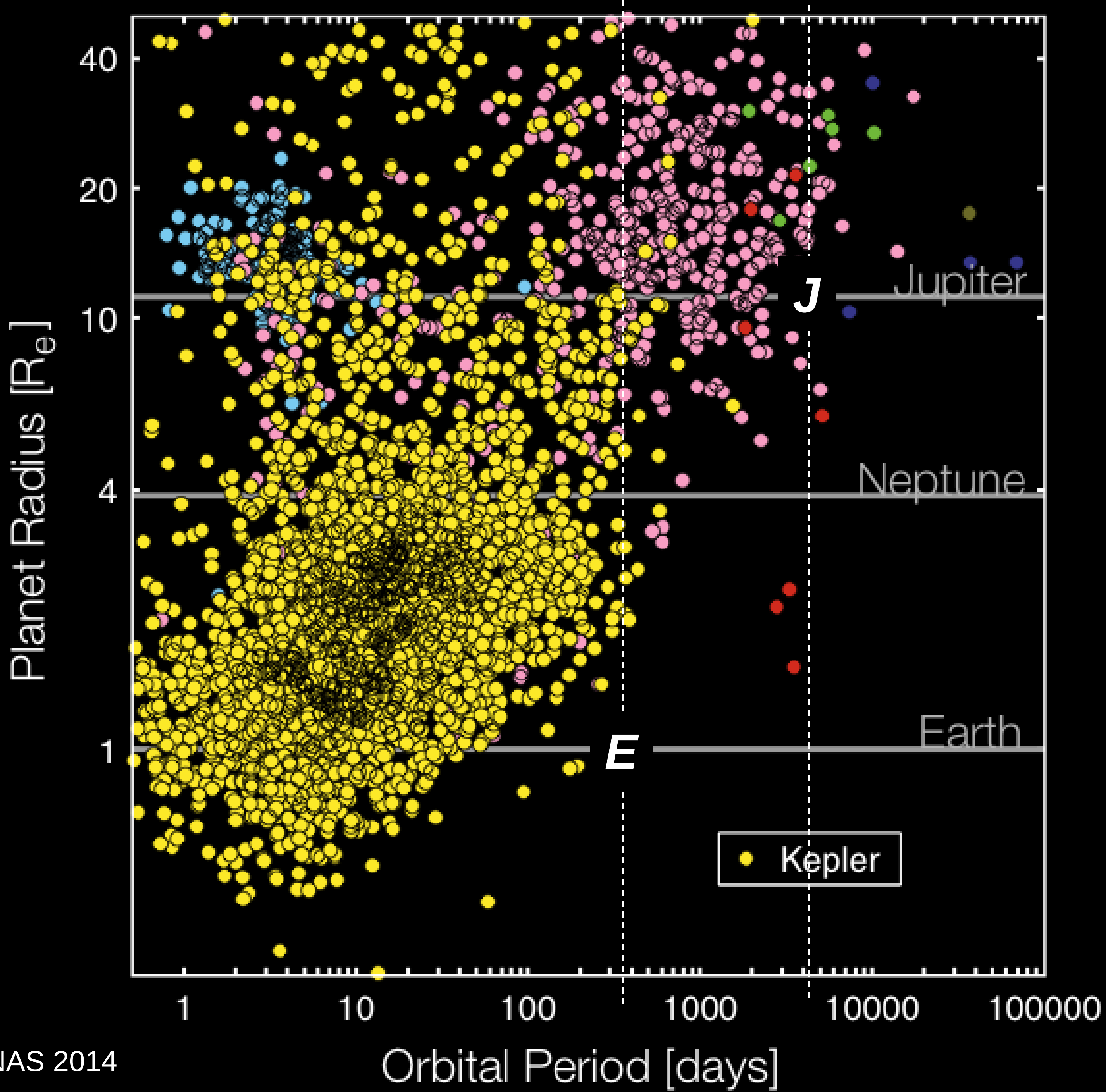
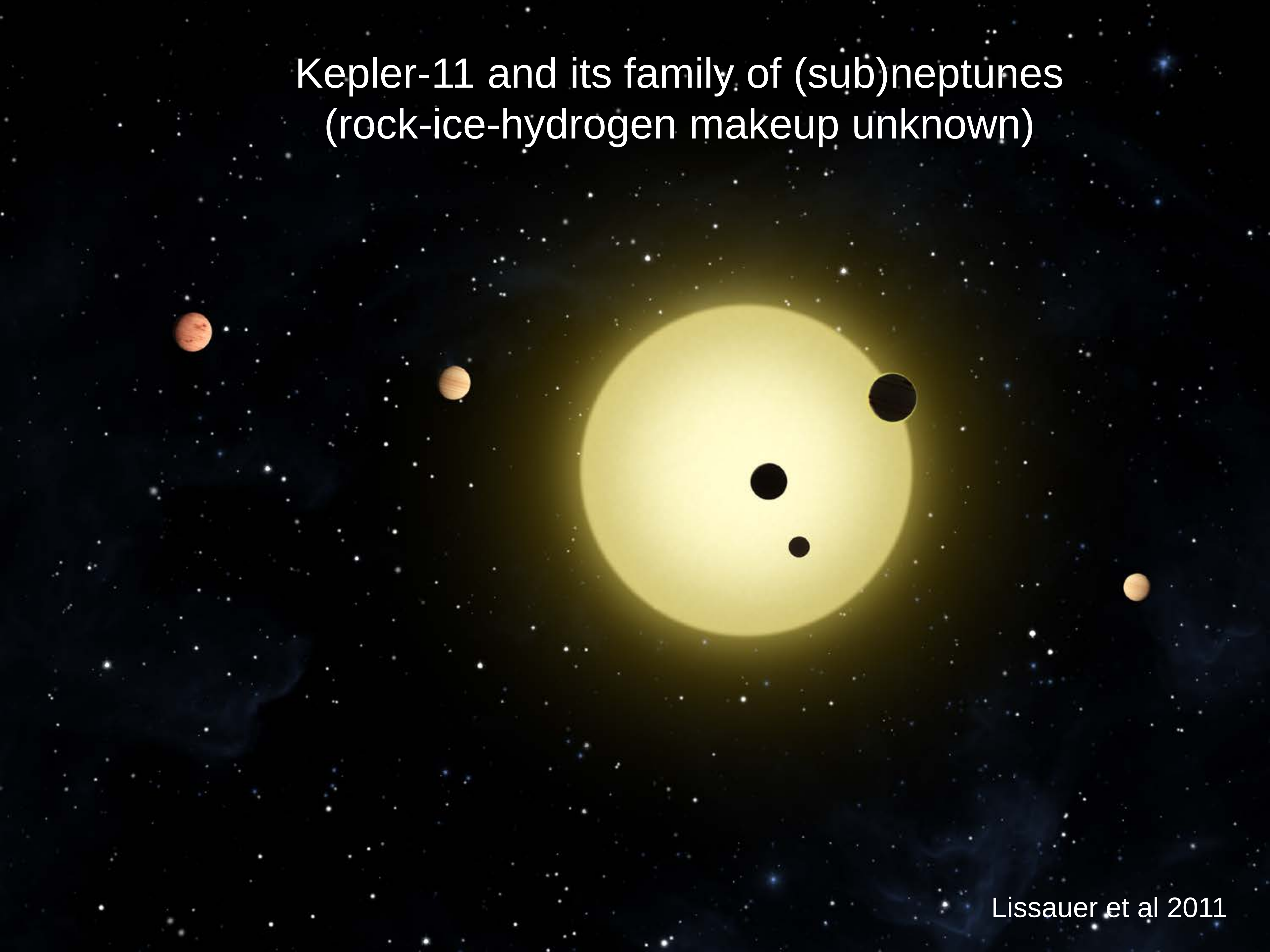
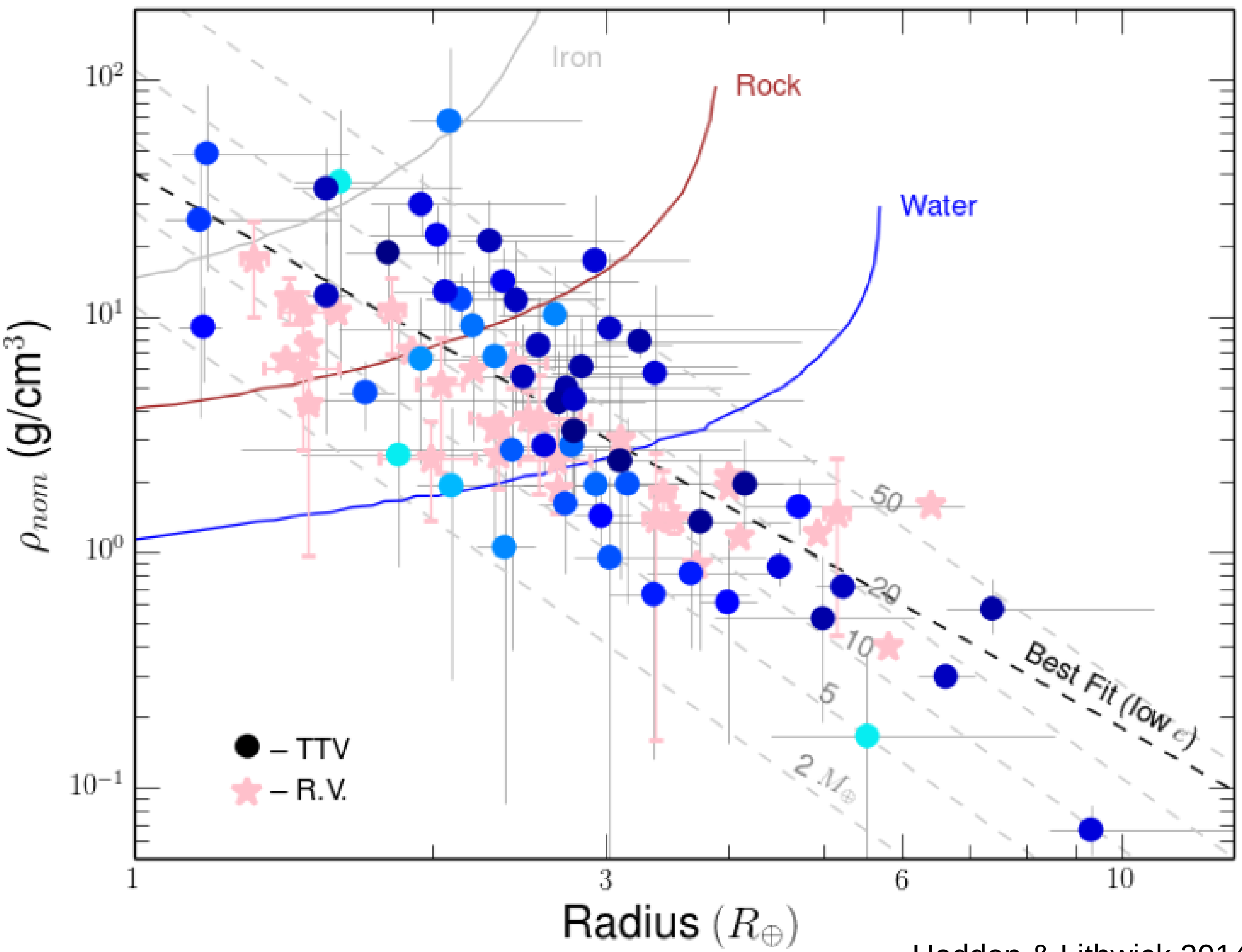


N. Batalha PNAS 2014

Kepler-11 and its family of (sub)neptunes (rock-ice-hydrogen makeup unknown)

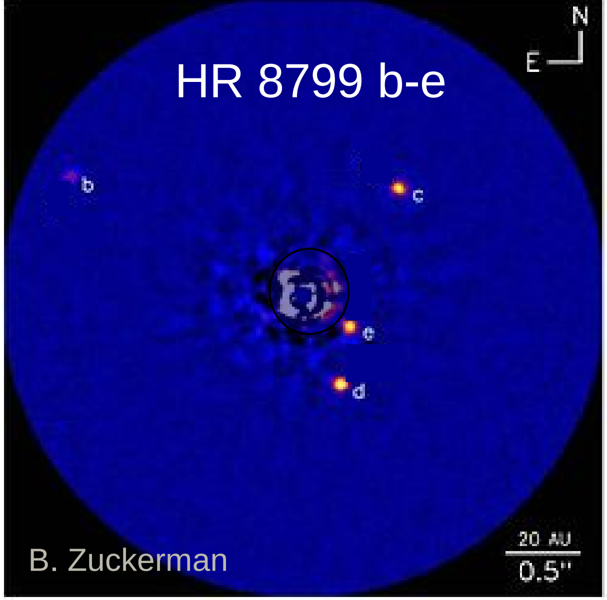


Lissauer et al 2011

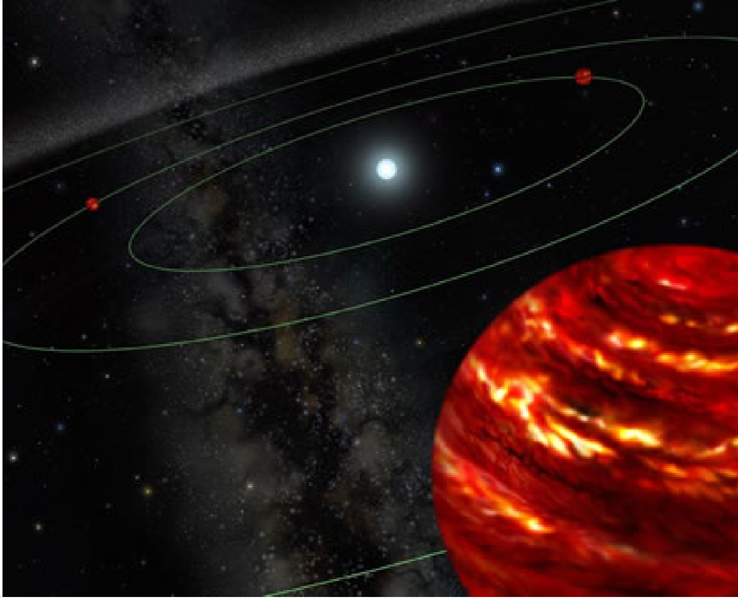


Hadden & Lithwick 2014 ApJ

Directly Imaged Exoplanets



B. Zuckerman

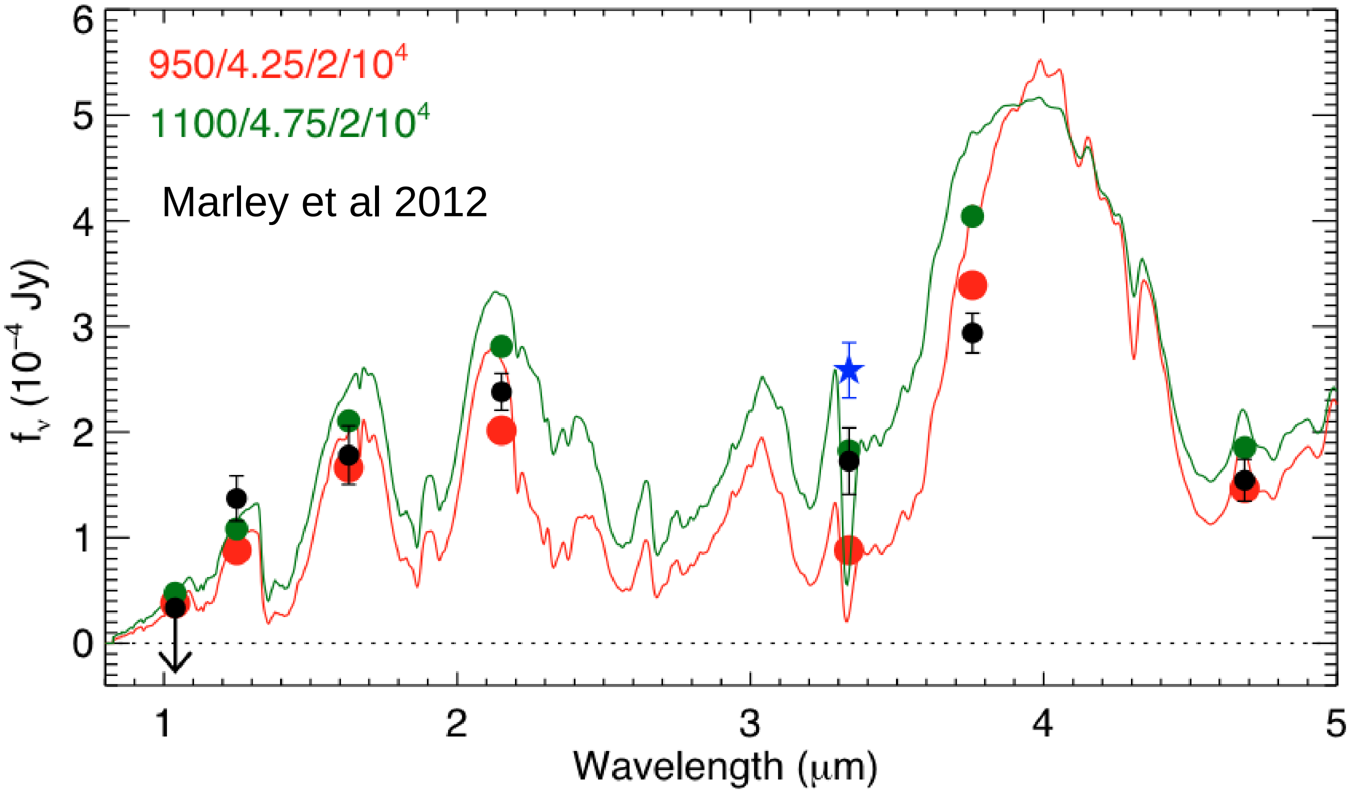


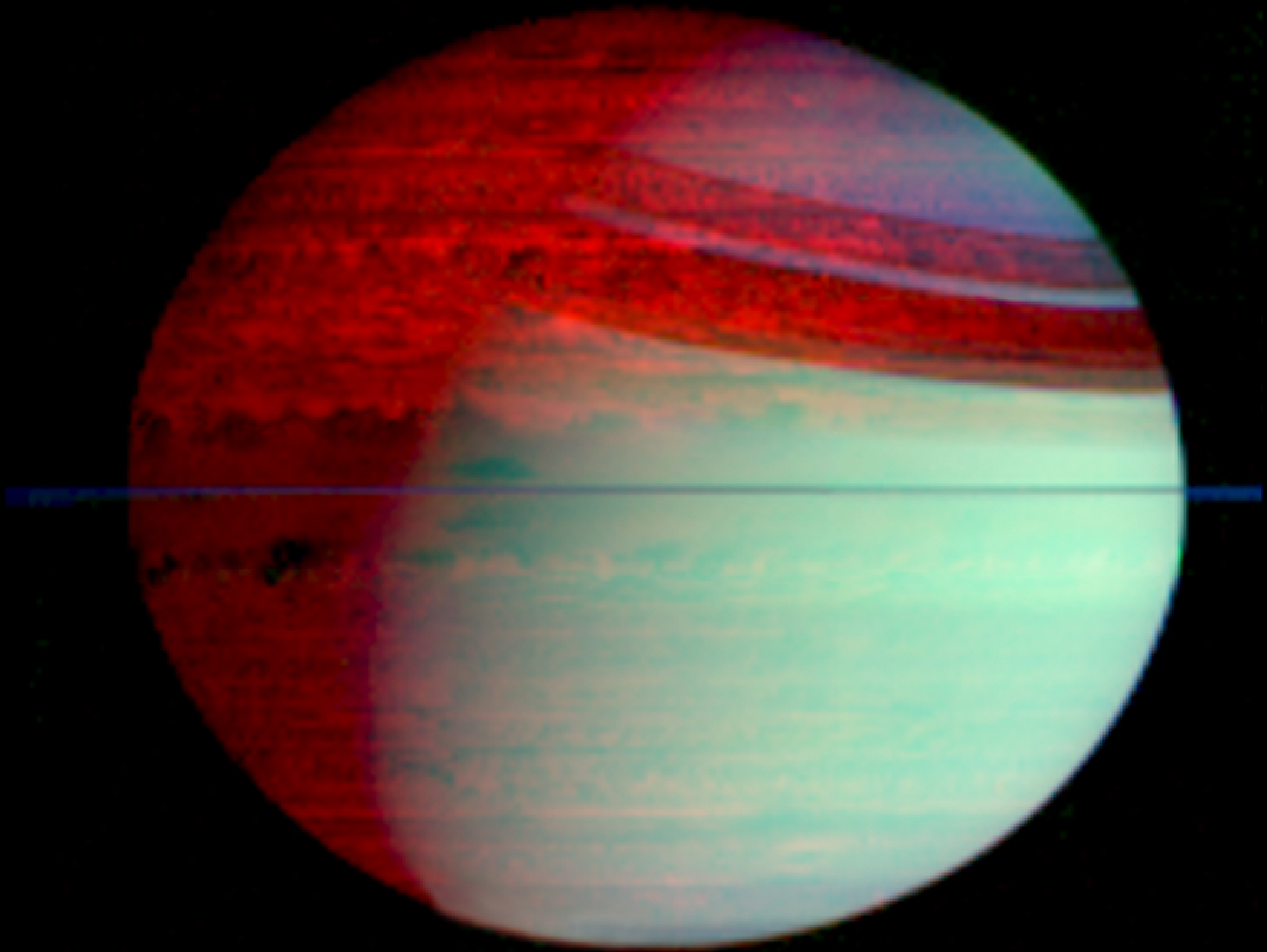
Crude spectra, like planetary spectra of a generation ago …

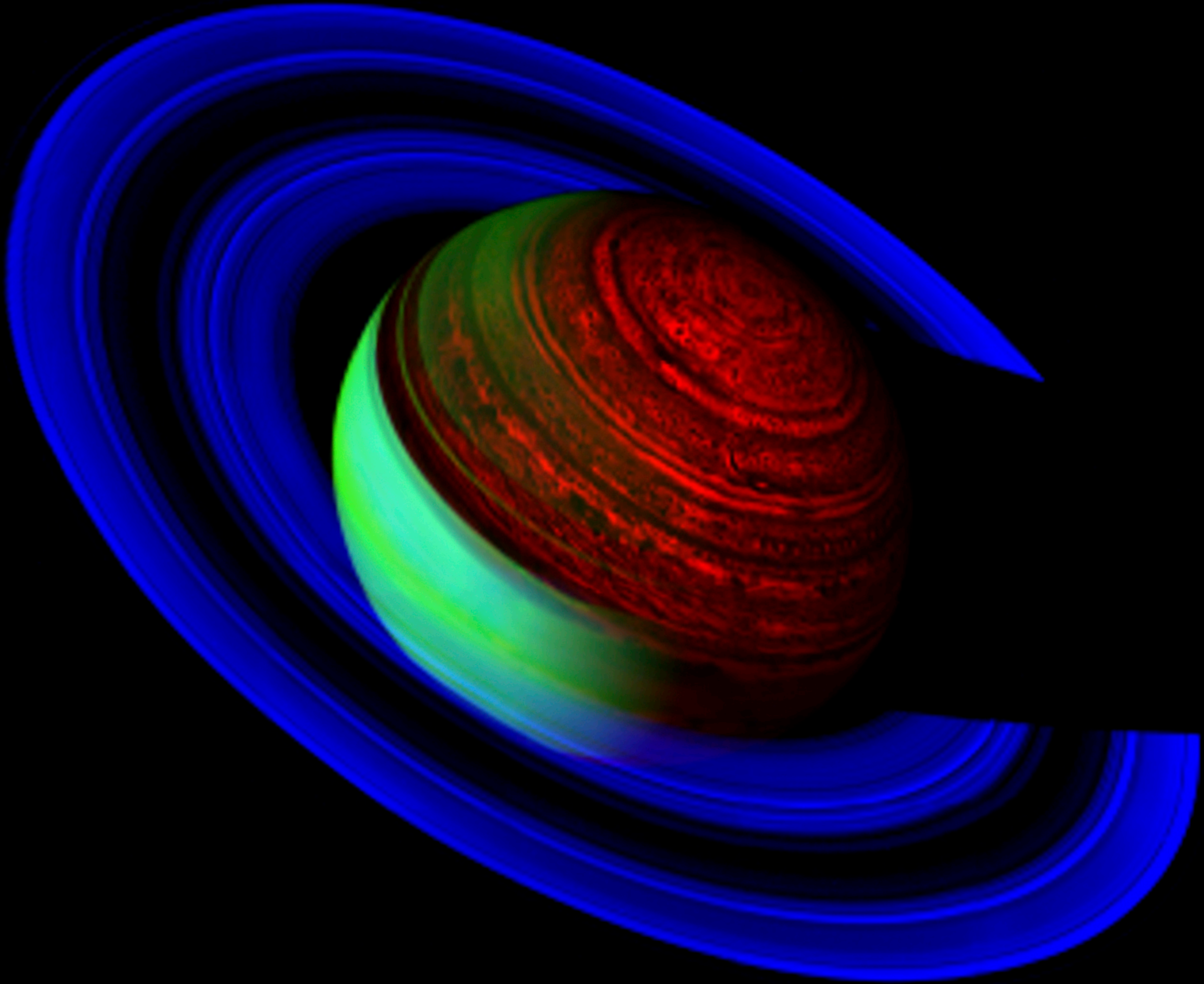
Quality and number rapidly growing with AO coronographs (GPI, Exo-C, WFIRST)

Important conclusions can be drawn about C/O/H ratio, etc.

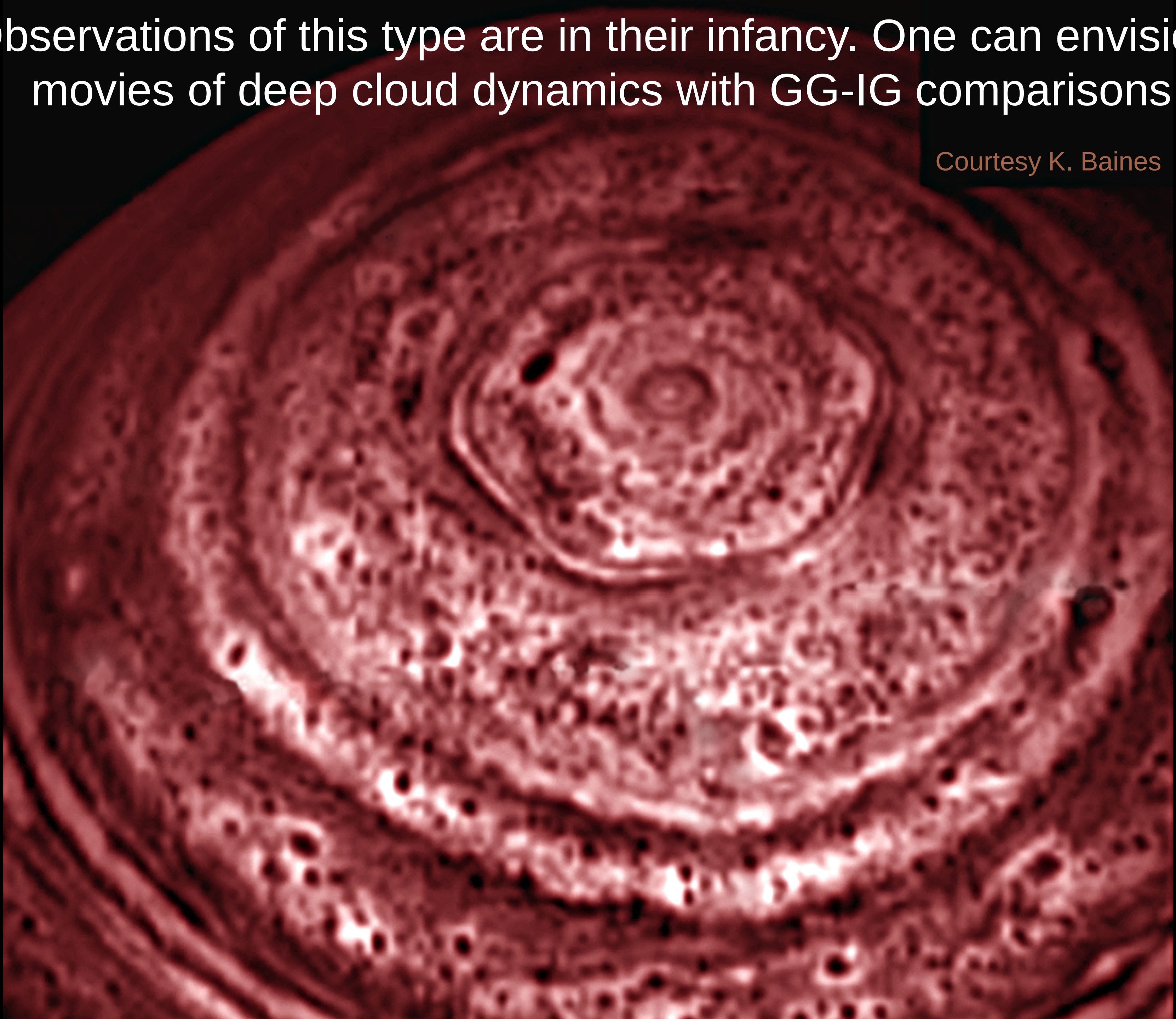
Time and phase angle variability, clouds, even basic thermal structure essentially unexplored.





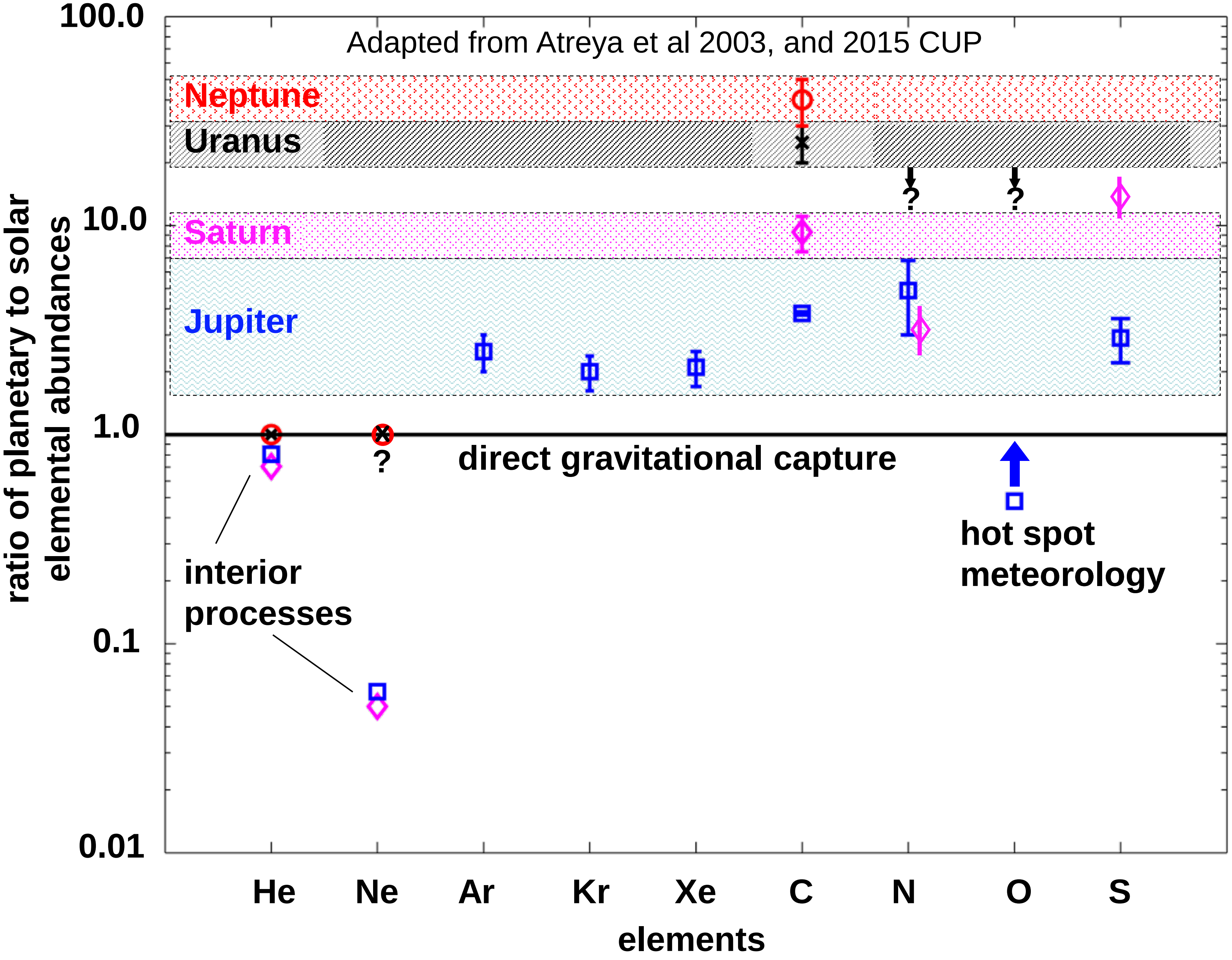


Observations of this type are in their infancy. One can envision movies of deep cloud dynamics with GG-IG comparisons



Courtesy K. Baines

“Heavy element (and isotope)” abundances



Adapted from Atreya et al 2003, and 2015 CUP

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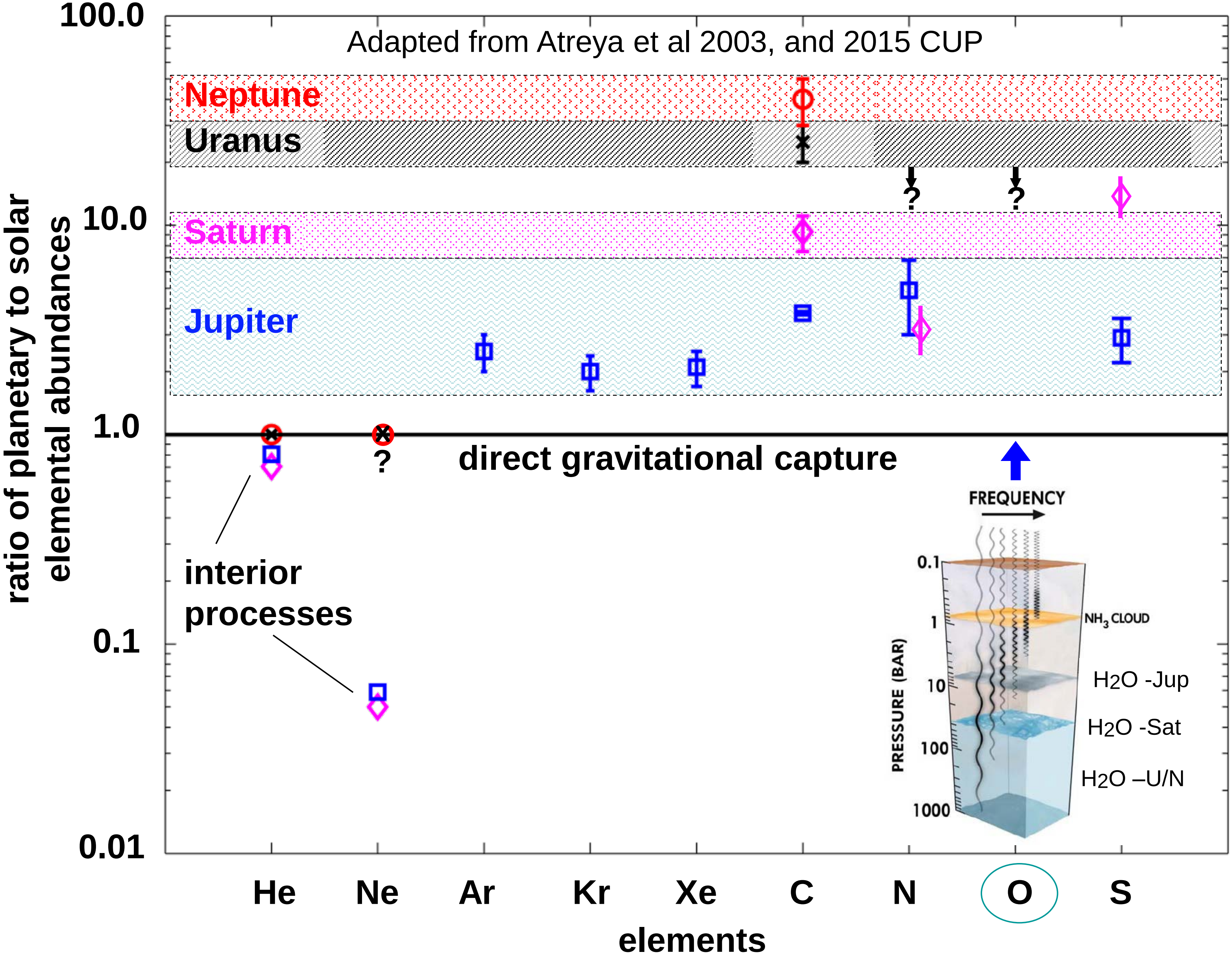
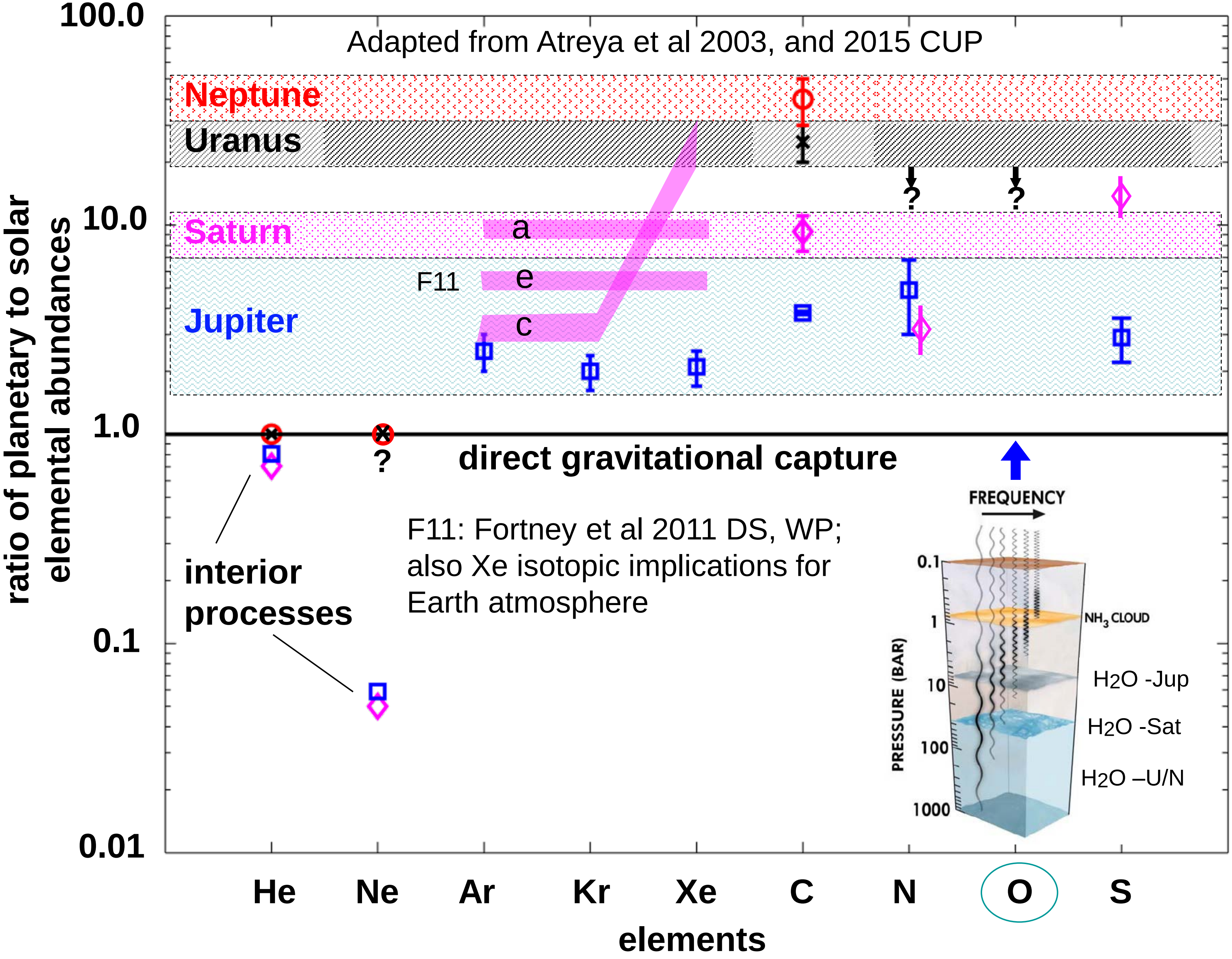

Adapted from Atreya et al 2003, and 2015 CUP

“Heavy element (and isotope)” abundances



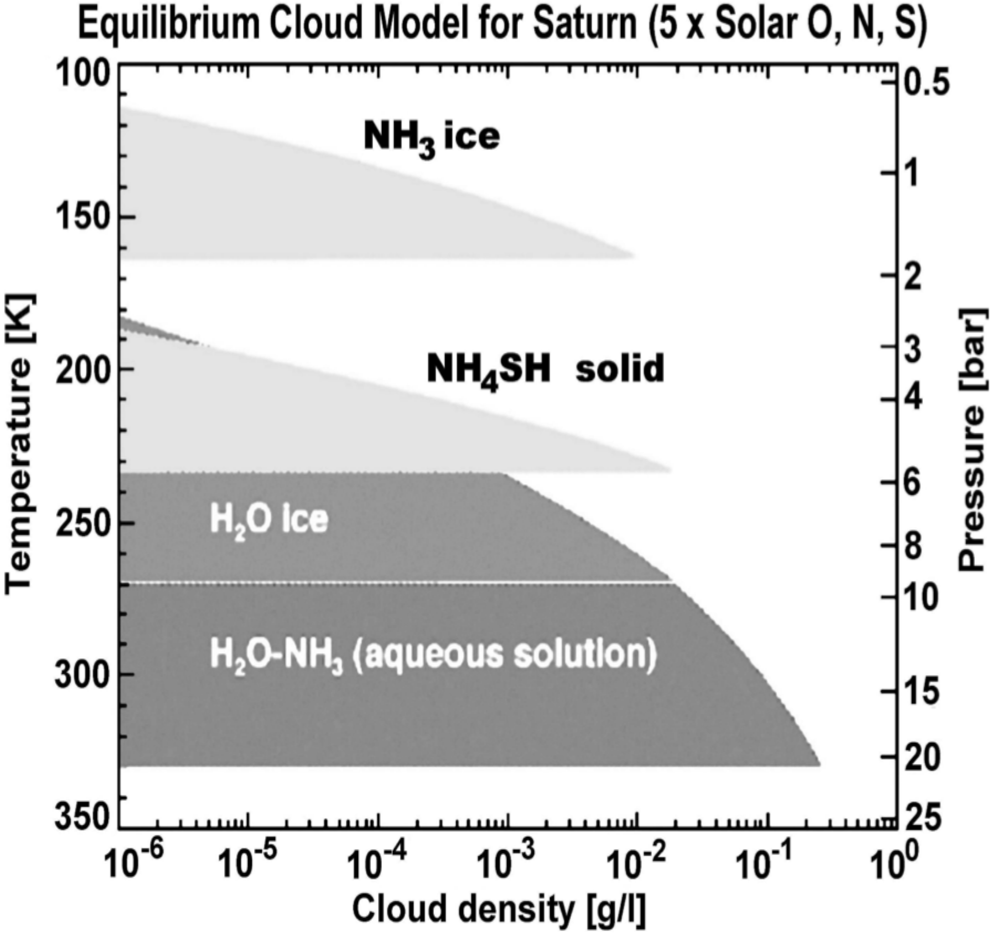
Adapted from Atreya et al 2003, and 2015 CUP

direct gravitational capture

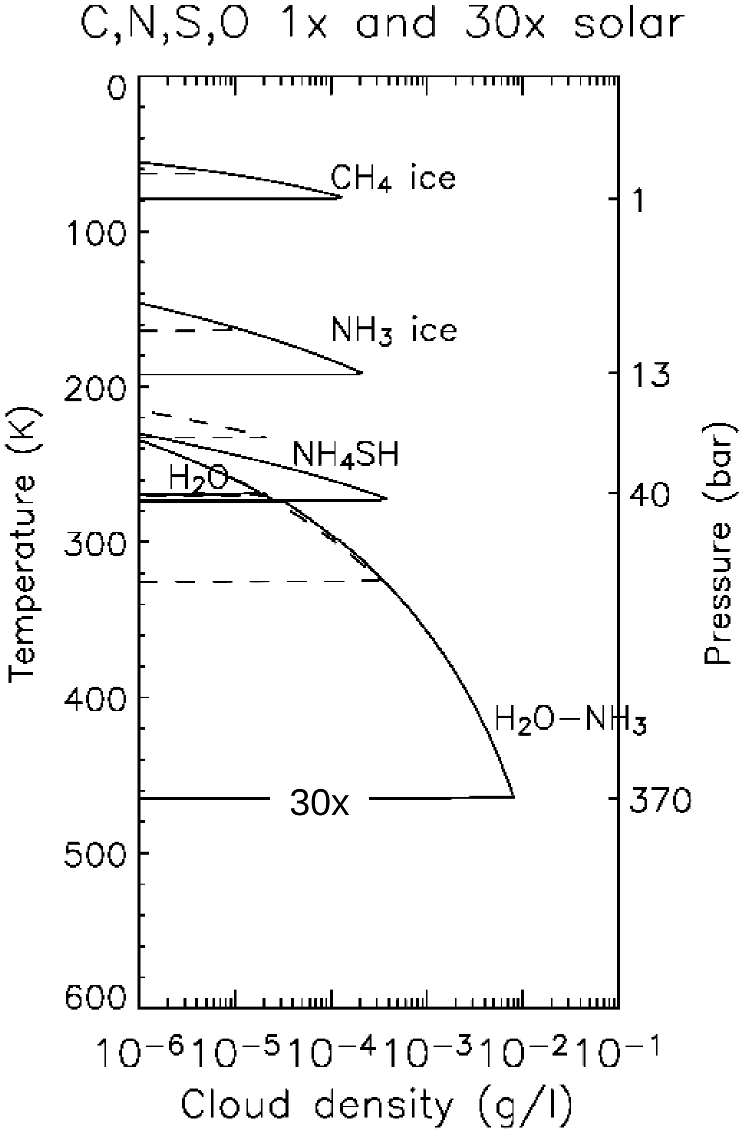
interior processes

F11: Fortney et al 2011 DS, WP; also Xe isotopic implications for Earth atmosphere

Ice Giants: even the S-clouds are deep!

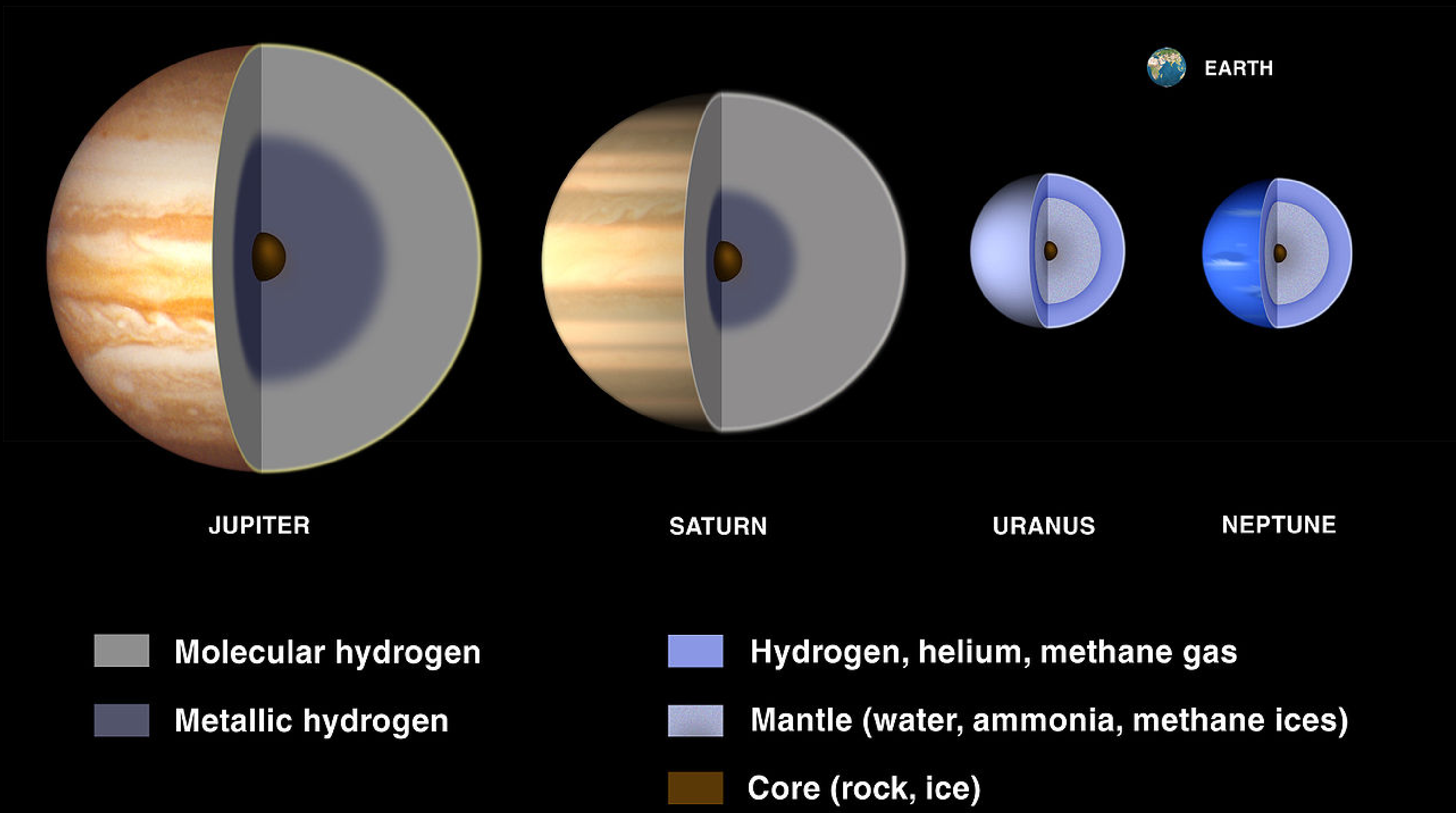

Equilibrium Cloud Model for Saturn (5 x Solar O, N, S)

ECCM of Saturn, assuming a five-fold enrichment of the condensible volatiles.

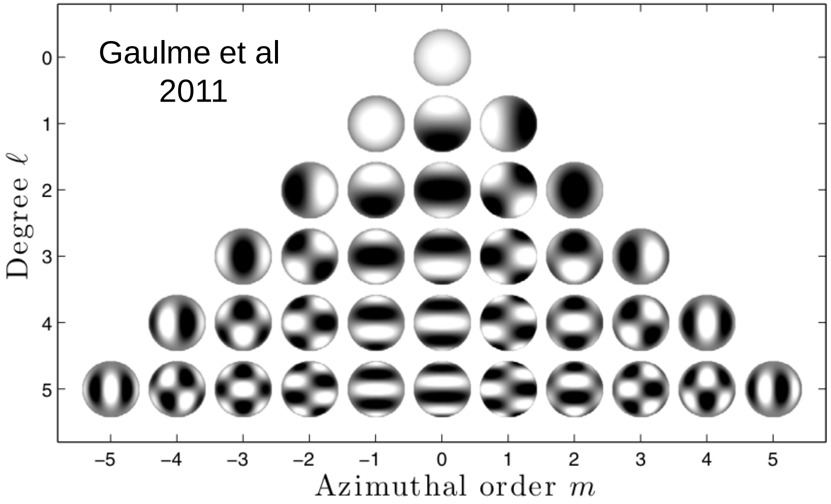

C,N,S,O 1x and 30x solar

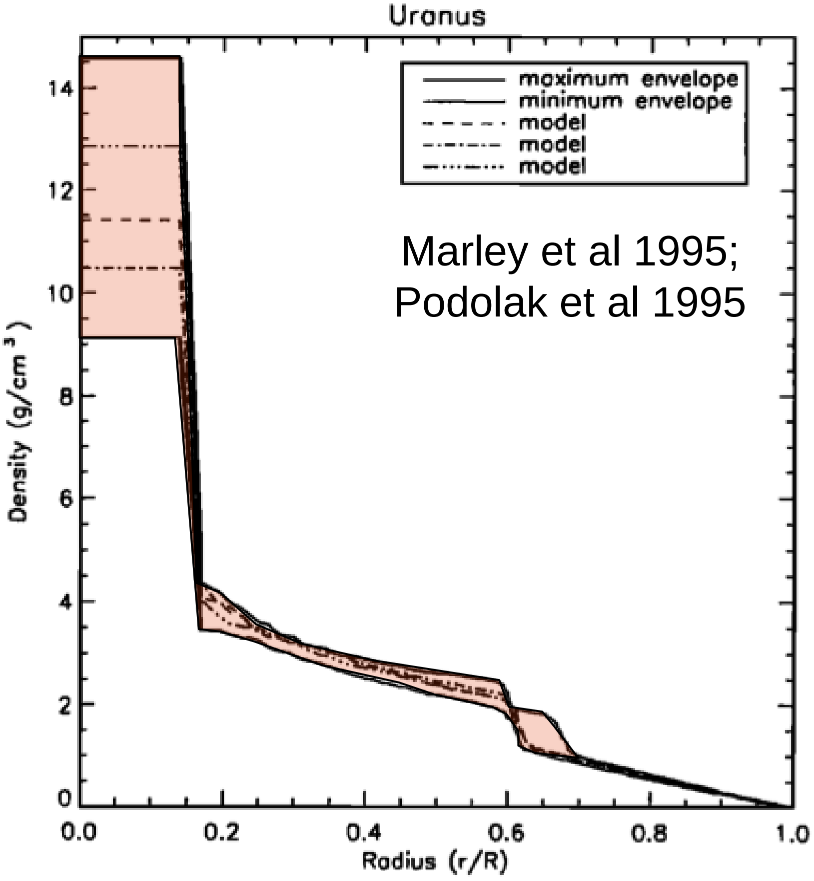
Both models from Atreya and Wong 2005 SSR

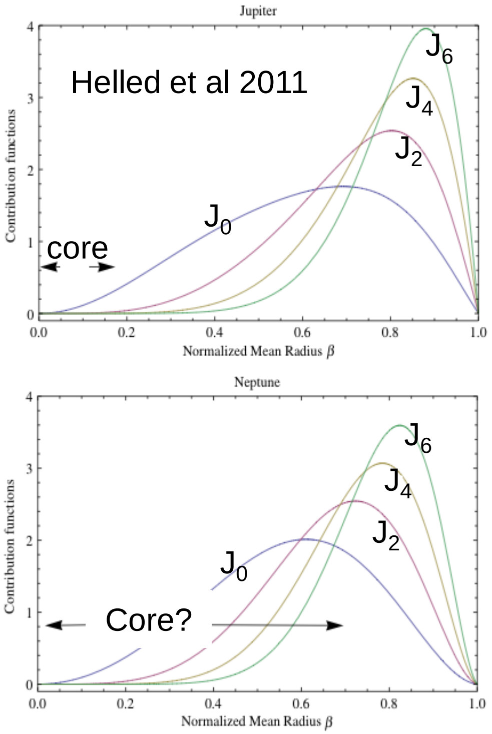
Deep internal structure

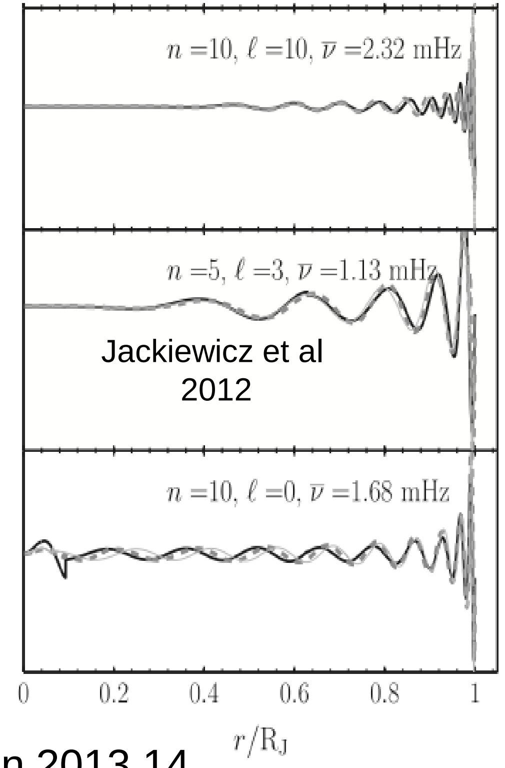


The Deep Interior:
Doppler Imaging (DI) of seismic modes complements gravity mapping


Gaulme et al 2011


Marley et al 1995; Podolak et al 1995


Helled et al 2011


Jackiewicz et al 2012

Saturn modes already observed, perturbing the rings: Hedman & Nicholson 2013,14

Origins of gas and ice giant planets and exoplanets*:

Fundamental chemical and isotopic properties

Entry Probes to below NH_4SH clouds

Photochemical haze/cloud *properties*; upper atm *structure*

C, N, S: arrived as *clathrates, ices, adsorbed, or vapor*?

Noble Gases (He, Ne, Ar, Kr, Xe *& their isotopes*)

P, As, Ge..; CO, HCN (chemistry/“eddy diffusion”)?

D/H; Ortho/para-H; $^{15}N/^{14}N$; C and O(?) isotopes

Deep microwave mapping to get O/S-abundance globally?

Possible on flyby?? ..

Fundamental physical properties

Envelope/core structure with gravity & Doppler Imaging;

“planetesimals” *vs* “pebbles”? “core dredging”? *etc*

Benchmarks and ground truth for exoplanets

NIR spectra as functions of phase/time/clouds

Deep or shallow atmospheric dynamics? (GG and IG)

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*The opinions expressed here are my own and do not represent any official or unofficial position of NASA, the US government, or any of the people who shared their expertise with me.

Mission strategy implications*

International collaboration seems both obvious and necessary
Witness success of Cassini/Huygens
NASA and ESA have *both* done studies and advocacy
for Probe//Flyby missions to Saturn, Uranus, *and* Neptune

Preference for IG mission vs Saturn mission (DS11; but see below)?
Ignorance level; heavy elements & isotopes; Kepler population

- or ?? -

Spectral/dynamical mapping: preference for GGs, closer to D.I.P.'s?

Single Orbiter/Probe mission is always attractive (extended mapping in NIR/μwave, gravity, rings/moons; maybe deep probe?

- or ?? -

Saturn-to-Uranus probes/flybys (Hof13) with DI on extended approach with microwave mapping at encounter to get O/S?

New mission technology needing more study
(Agrawal et al 2014; also subm. GCD & EDL)
Aerocapture/braking
Lower-mass thermal protection and components
Onboard "smart" algorithms for entry/braking (*eg.* Cassini)?

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CONCEPT STUDIES FOR URANUS ENTRY

POC: Parul Agrawal, parul.agrawal-1@nasa.gov

MOTIVATION

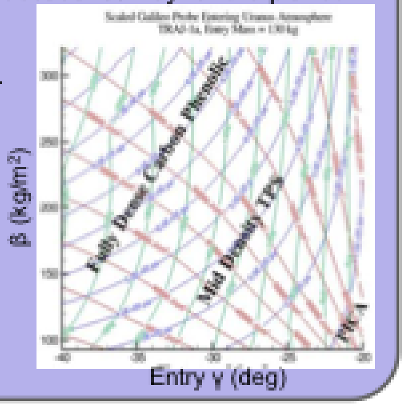
A Flagship mission to Uranus, including an atmospheric entry probe, has been called out in the current Decadal Survey as one of the highest priority missions for the period 2013-2022.

This proposed study will provide critical ground work in the preparation for a mid-term update to the Decadal Survey and be useful in determining the viability of a Uranus mission for future New Frontiers call

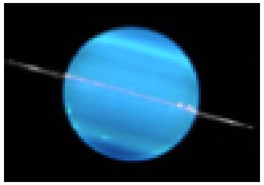
ACHIEVEMENT

EVT project funded concept studies to understand the trade space for atmospheric entry in Uranus and to provide in-depth analysis of the mission concept outlined in the 2013-23 decadal survey for the planet

- New Uranus atmospheric model created
- Trades for entry space was performed for 2029 and 2043 arrival windows
- *It was shown that trajectory and mission concepts outlined in the Decadal survey were not a viable option*
- Various existing TPS options were examined for the entry space.
- Case study with aerocapture performed



RESOURCES



Leverage expertise from various NASA centers including

ARC, LaRC, and JPL

Proposed FY 15 funding

0.5 FTE and $250K

PROBLEM STATEMENT

Several constraints posed by the planet include: 84 year orbital period, wide ring system, significant axial tilt, poorly understood atmosphere

The decadal survey study and ISPT/EVT funded studies do not provide a viable mission design

A study that combines science requirement with a comprehensive trajectory analysis, TPS and other entry system technologies as well as communications is needed

PROPOSED STUDY GOALS

In partnership with NASA ARC, NASA LaRC, JPL and planetary science community, we will perform trade studies to answer specific questions related to Uranus missions by executing the following tasks

1. Detailed trajectory analysis and mission design concepts that would avoid the rings, provide shallow entry based on available TPS technologies, and address the data communications
2. Address the broad science objectives by investigating larger probe options with lower ballistic coefficients
3. Infusion of new enabling TPS: woven and conformal
4. Examine sensitivity to atmospheric models for entry technologies

QUANTITATIVE IMPACT

Viable Mission Design

This study will address open questions from past studies with a focus on trade studies, concept viability, identifying high risk elements, and demonstrating ways to mitigate them

Enabling Science

As part of trades we will study larger probes with lower ballistic coefficients

The proposed concept studies will fullfill the current knowledge gap and provide a technology platform that will enable future Flagship, New Frontier and lower cost mission to Uranus

Low to Mid Density Ablators for Outer Planets

TAL: Entered by Project
SUBMITTER: Parul Agrawal
(parul.agrawal-1@nasa.gov)

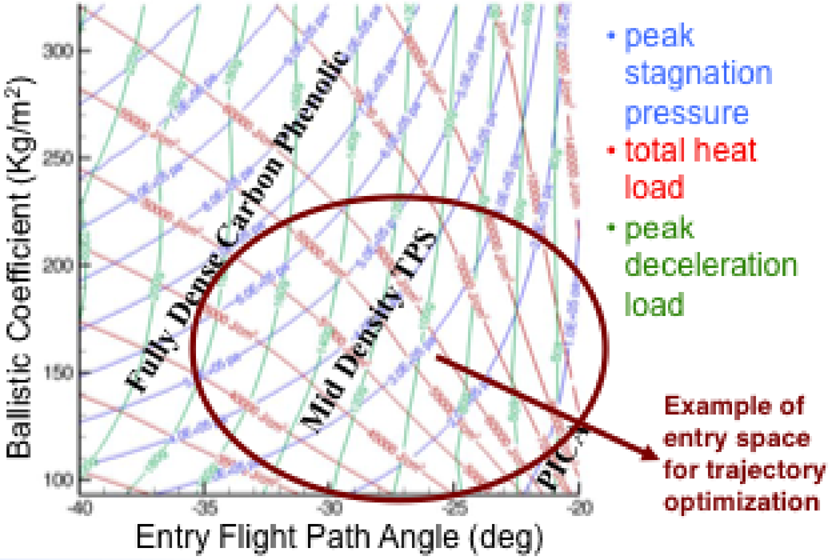
Objective

- Develop viable mission design solutions to outer planets (Saturn and Uranus) with low to mid density ablators that include PICA variants and HEEET

Significance/Impact

- Previous Ice Giant entry concepts only considered heritage carbon-phenolic (C-P)
  - Carbon-phenolic has a host of well documented issues including cost, weight, and the inability to produce C-P heritage material due to missing heritage constituents. It is also not suitable for shallow entries.
- PICA variants and HEEET would address the TPS gap by providing a mass effective solution over a large trade space for planetary entry missions

Entry trades for Uranus for 130 kg probe



Key Milestones:

- Leverage existing R&D efforts on HEEET and PICA variants to establish performance envelope and limits.
- Investigate mission trade space (entry flight path angle, deceleration loads, peak pressure, etc) for these ablators.
- Detailed trajectory analysis and mission design concepts incorporating constraints such as ring avoidance, data communications, and shallow entries using PICA and HEEET technologies

Partners:

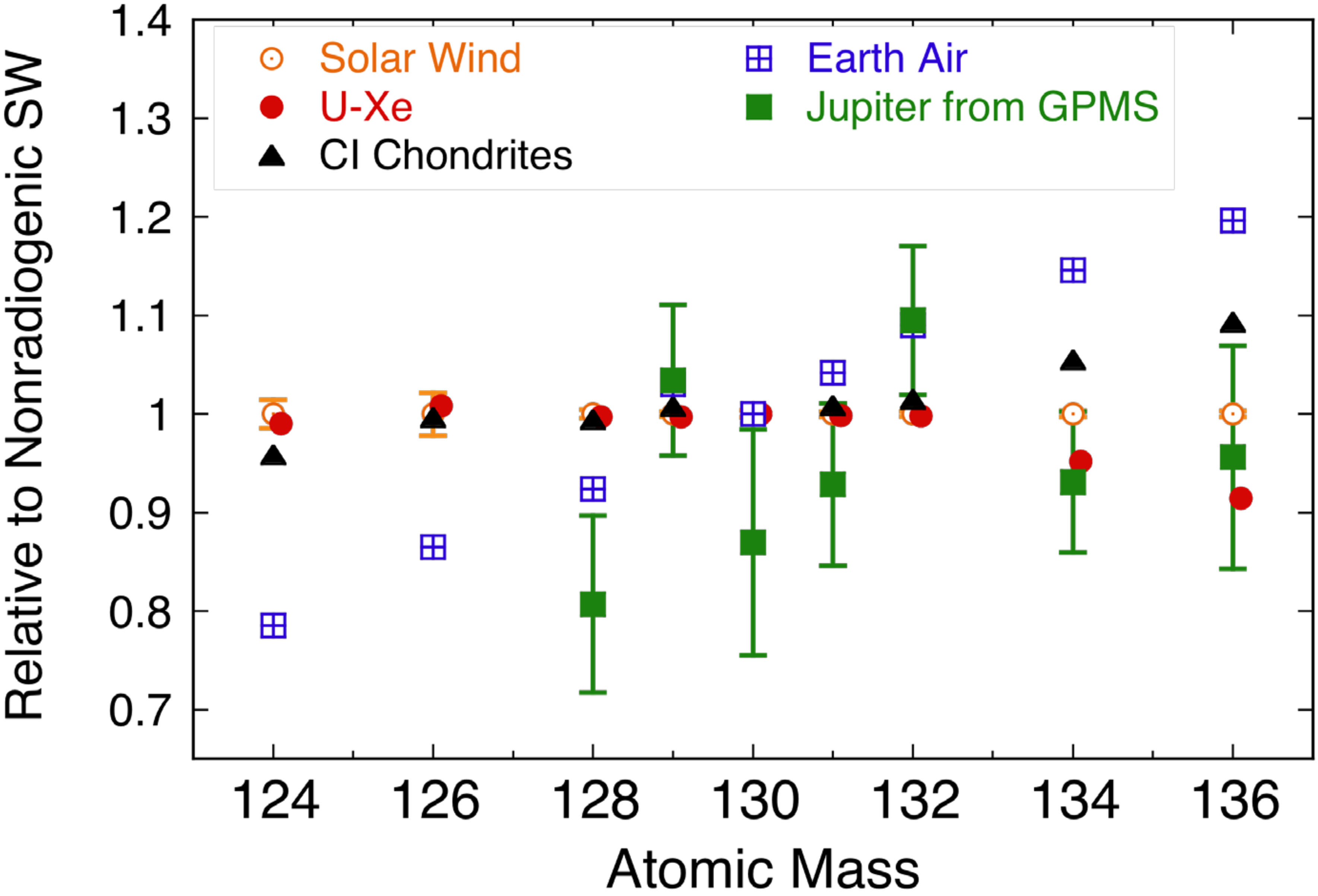
- JPL, NASA LaRC, SMD and Planetary Science community

Mission Infusion Potential:

- The proposed concept studies will fulfill the current knowledge gap and provide a technology platform that will enable future Flagship, New Frontiers class mission to Saturn and Uranus

Funding Information:

All $K	FY16	FY17	Total
ARC			
FTE #	1.0	1.0	2.0
WYE #	1.0	1.0	2.0
Travel, $K	15	15	30
JPL			
WYE #	0.5	0.5	1.0
LaRC			
FTE #	0.5	0.5	1.0
Travel, $K	5	5	10



Courtesy K. Zahnle

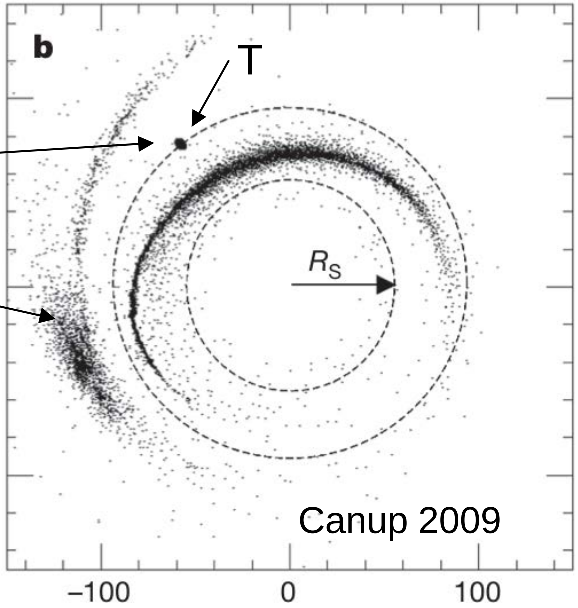
Current thinking on Ring origin

The low current meteoroid mass flux no longer requires and may preclude a young ring age. Much larger fluxes are expected during LHB and primordial era, so primordial ring would need to be much more massive than current ring.

Present locations of “ringmoons” are still a puzzle but resonant interactions, collisions, reaccretion might frustrate their outward torque-based evolution.

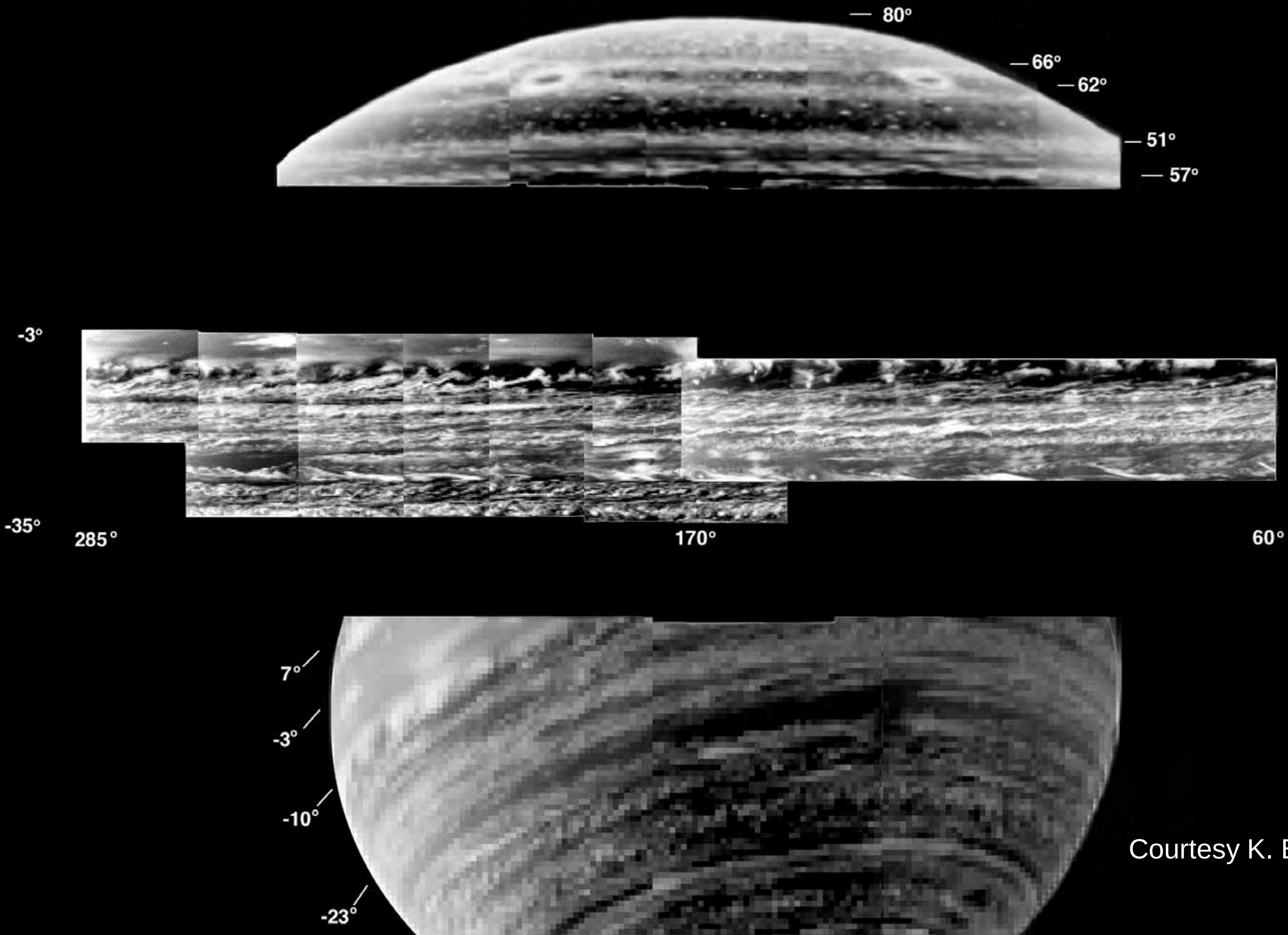
At least the A and B Ring parent(s) must be nearly pure ice. Saturn system has other examples of large, nearly pure ice bodies (Iapetus, Tethys). Disruption of a differentiated body and loss of the core have long been advocated to explain this. C Ring might be younger/derivative. BUT there is some widespread non-icy UV absorber (PAH/organic or Fe/hematite related).

Recent scenarios involve tidal migration and disruption of Titan-sized ring “grandparent” to *create* a Rhea-sized ring “parent”, which evolves in *later* and is *again* disrupted. Mosqueira/Estrada scenarios grow the Rhea-sized parent *in situ* directly. Formation of satellite systems is an active area of study.



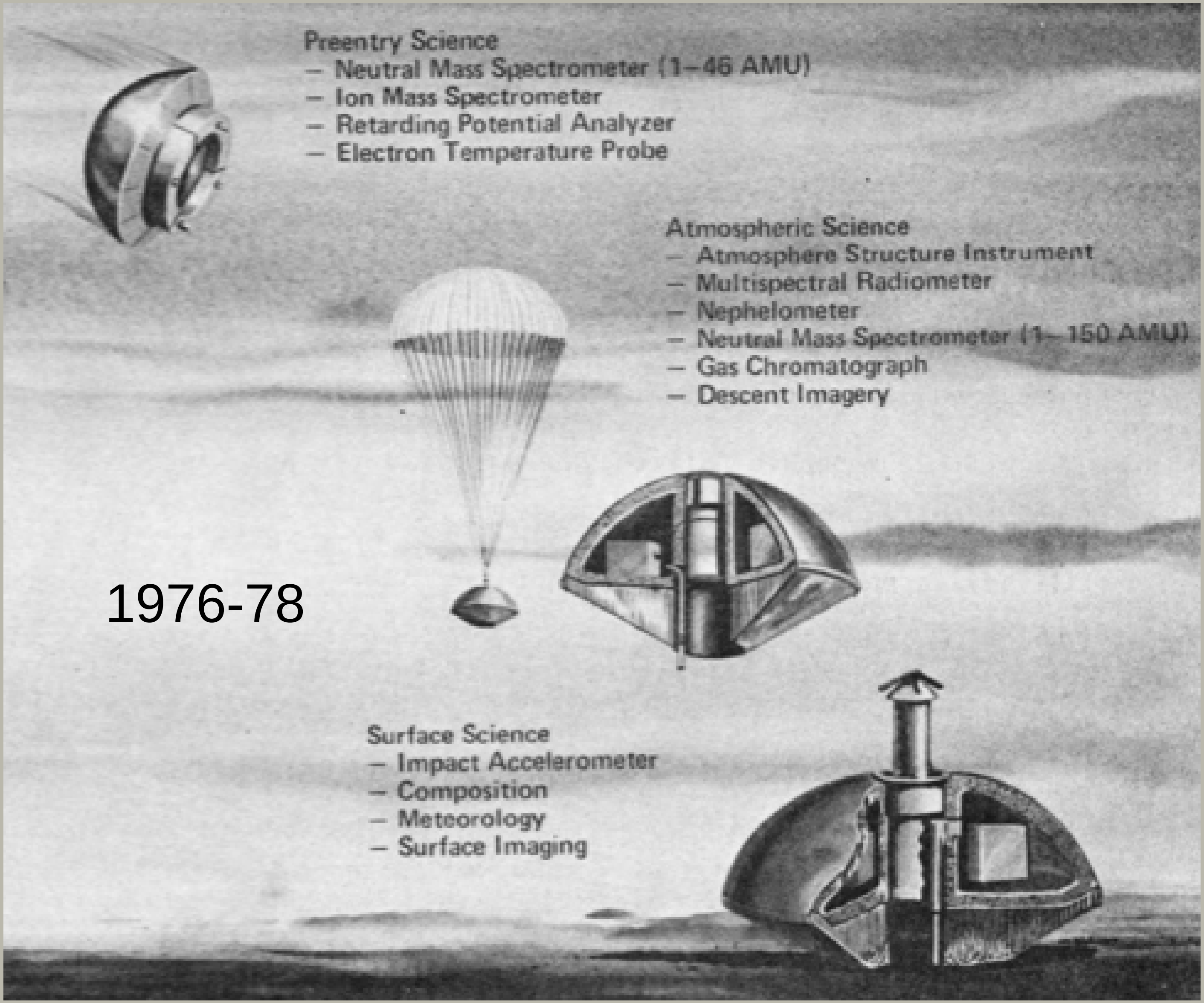
Canup 2009

Observed in the 5 μm window, Saturn shows complex cloud and dynamical band structure; this work is in its infancy



Courtesy K. Baines

Patience is a virtue!



Preentry Science
- Neutral Mass Spectrometer (1–46 AMU)
- Ion Mass Spectrometer
- Retarding Potential Analyzer
- Electron Temperature Probe

Atmospheric Science
- Atmosphere Structure Instrument
- Multispectral Radiometer
- Nephelometer
- Neutral Mass Spectrometer (1–150 AMU)
- Gas Chromatograph
- Descent Imagery

Surface Science
- Impact Accelerometer
- Composition
- Meteorology
- Surface Imaging

1976-78