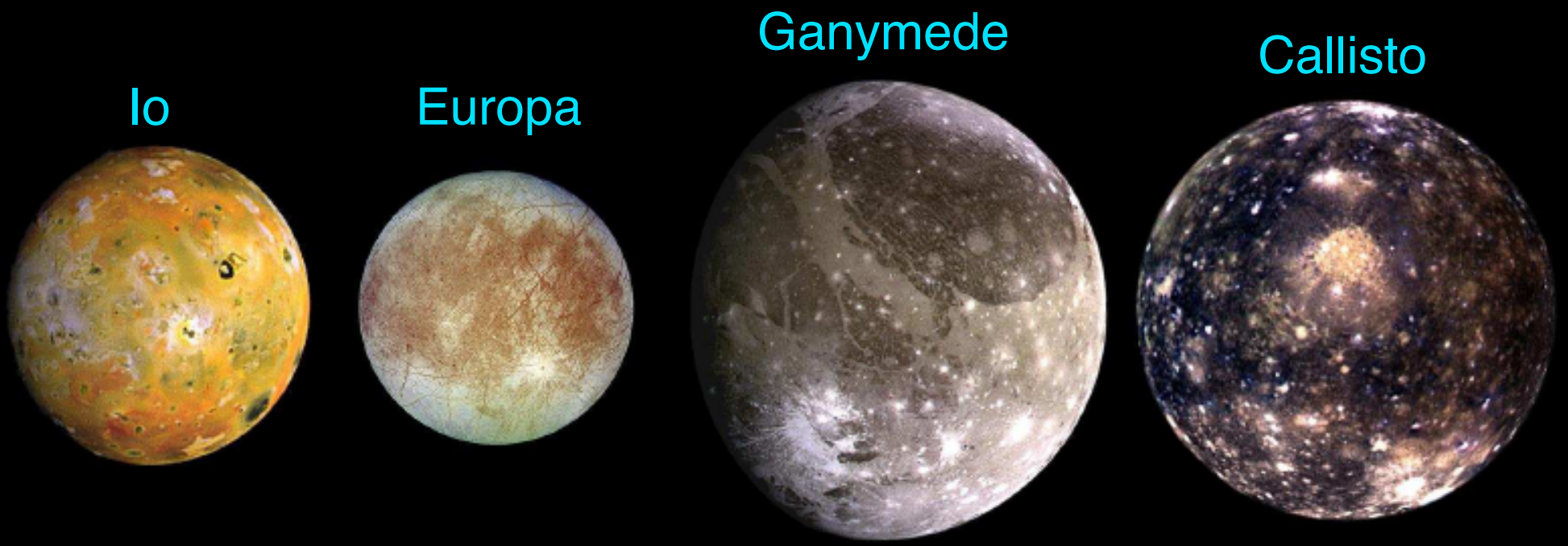
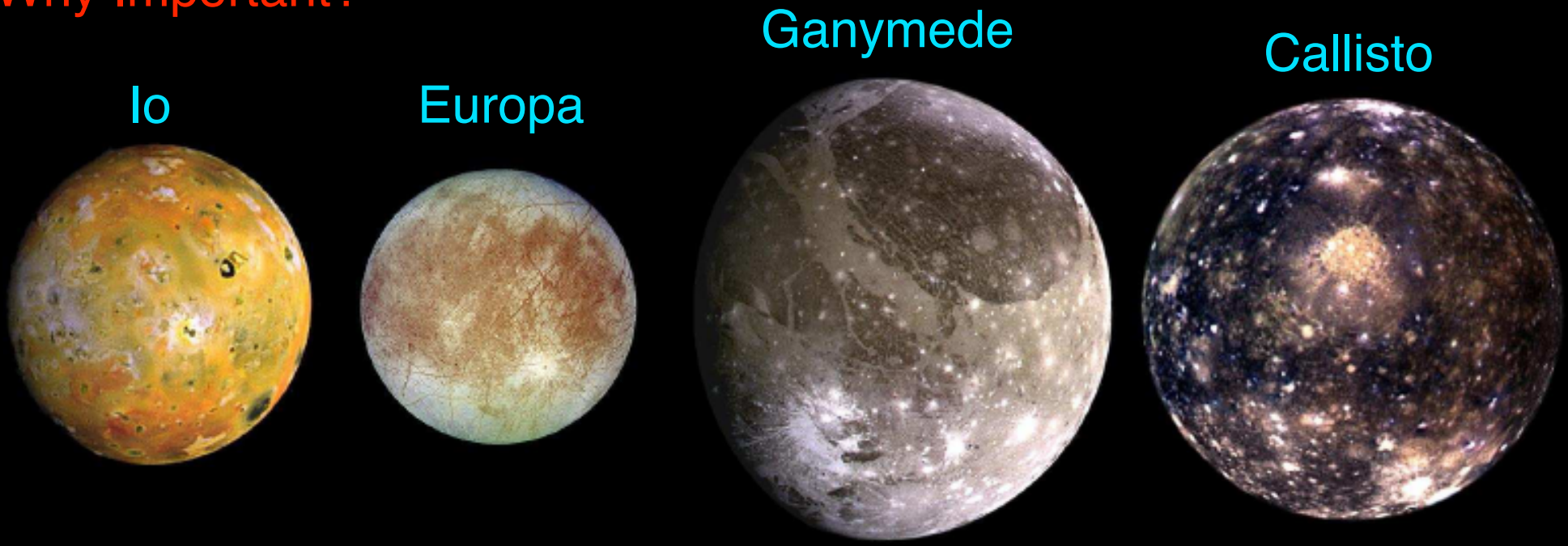
Formation of Satellite and Ring Systems



Research with Doug Hamilton

Where did the Galilean Satellites Form?

Why Important?



Where did the Galilean Satellites Form?

Why Important?

Geophysics

Has Io always had volcanoes?

How long has Europa had liquid water?

Why did rock separate from ice more fully at Ganymede than at Callisto?

Where did the Galilean Satellites Form?

Why Important?

Planetary Formation

Satellite Systems of the giant planets are local analogs to Planetary Systems

Four Things to Know About Satellite Dynamics

1. Tides move Satellites Radially Outward; damp eccentricities, but not inclinations

2. Diverging Orbits lead to Resonant Kicks; Converging Orbits lead to Resonant Trapping

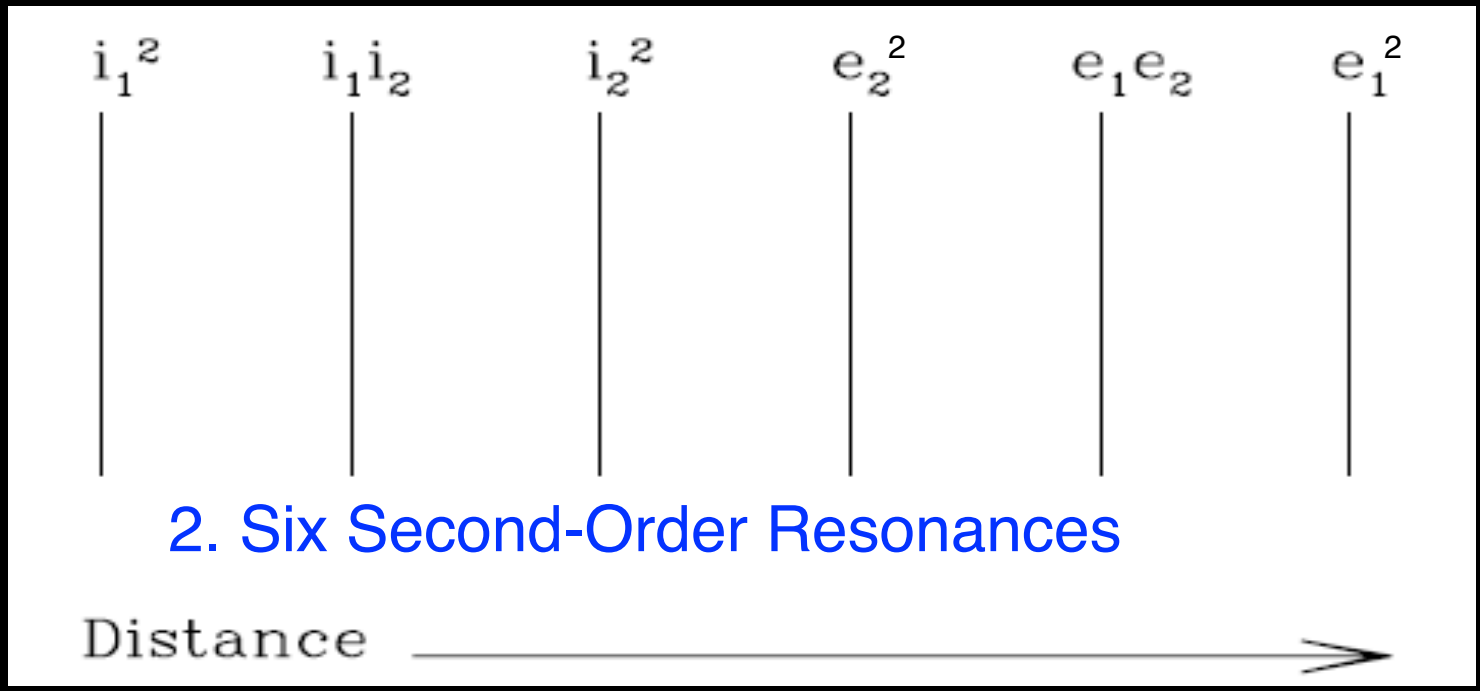
3. Resonant Strengths depend on e,i

4. Precession Splits Resonances

4. Precession Splits Resonances

Example: The 2:1 Resonance

1. Two First-Order Resonances: e_1, e_2 — strong



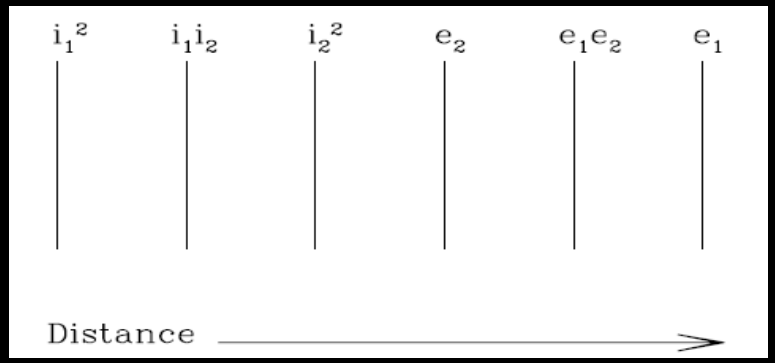
weaker

3. Many More Third-Order Resonances — weakest

Diverging Orbits: Io & Amalthea

Jupiter

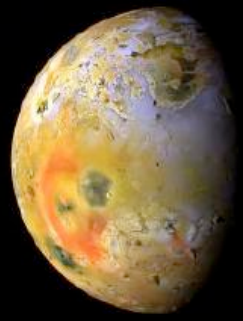
Io Resonances



moving with Io

Amalthea

Io

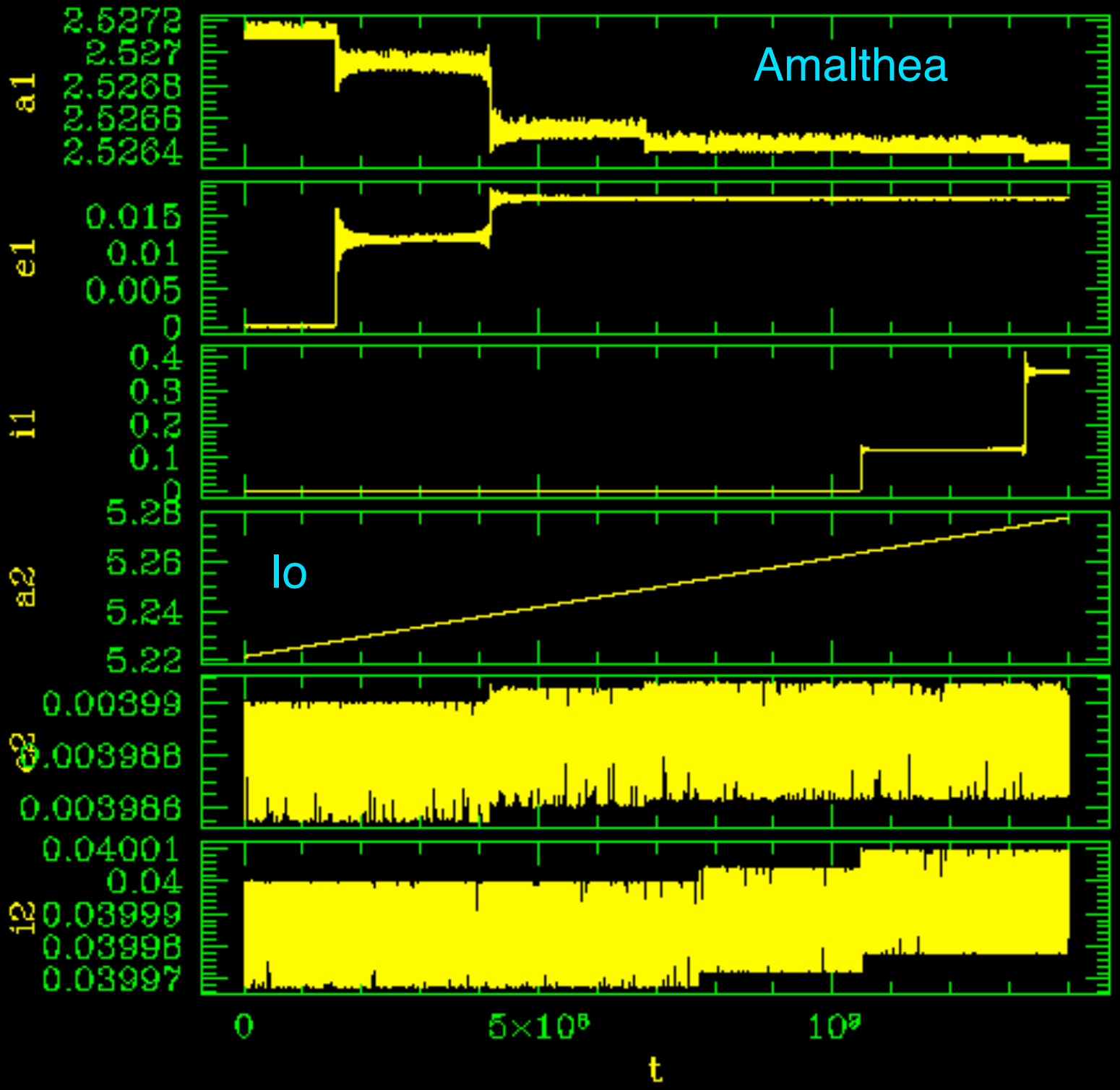


Tides push
Io outward

2 satellites

Numerical Simulations
with hnbody/hndrag

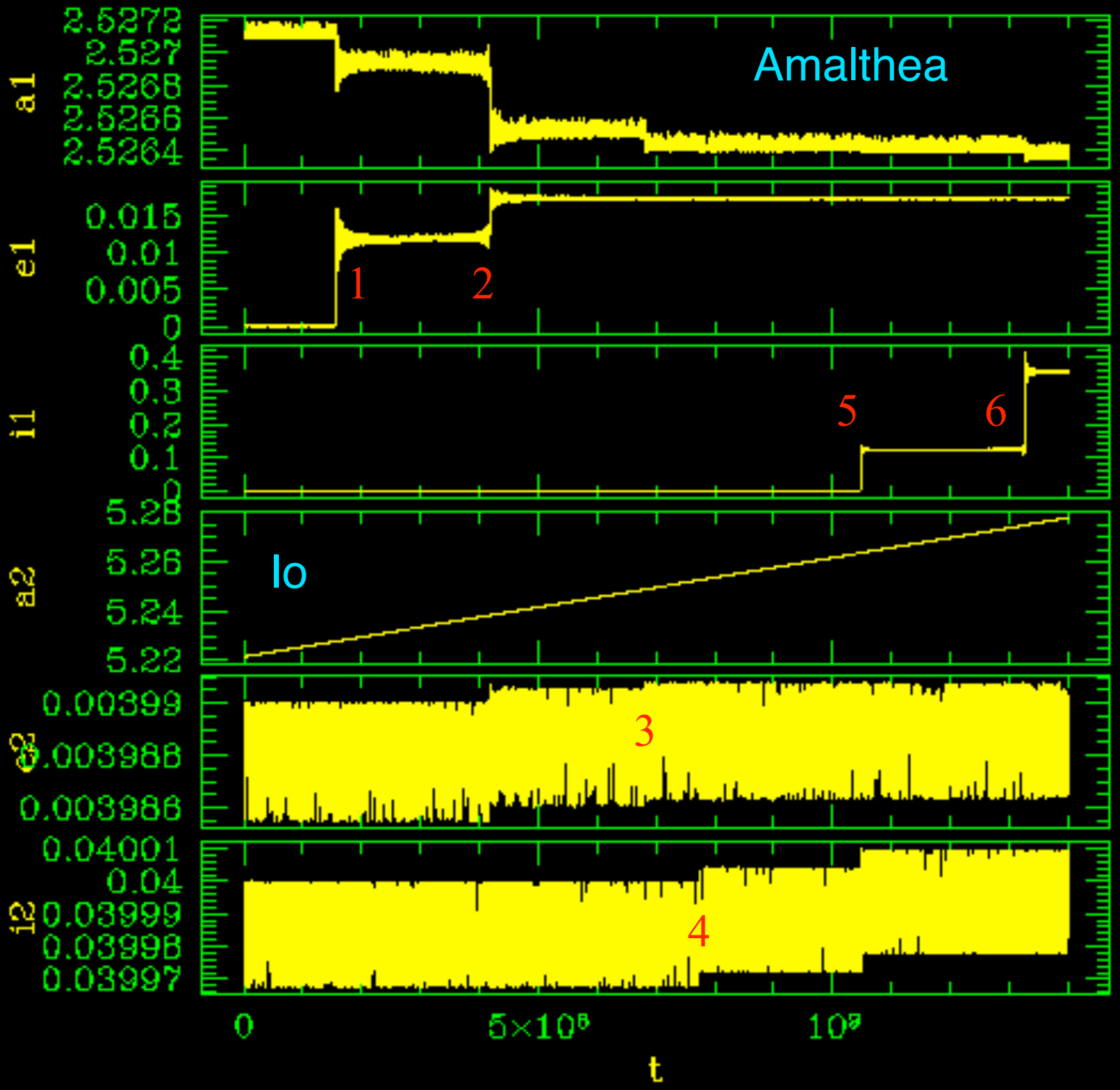
Io-Amalthea 3:1,
diverging



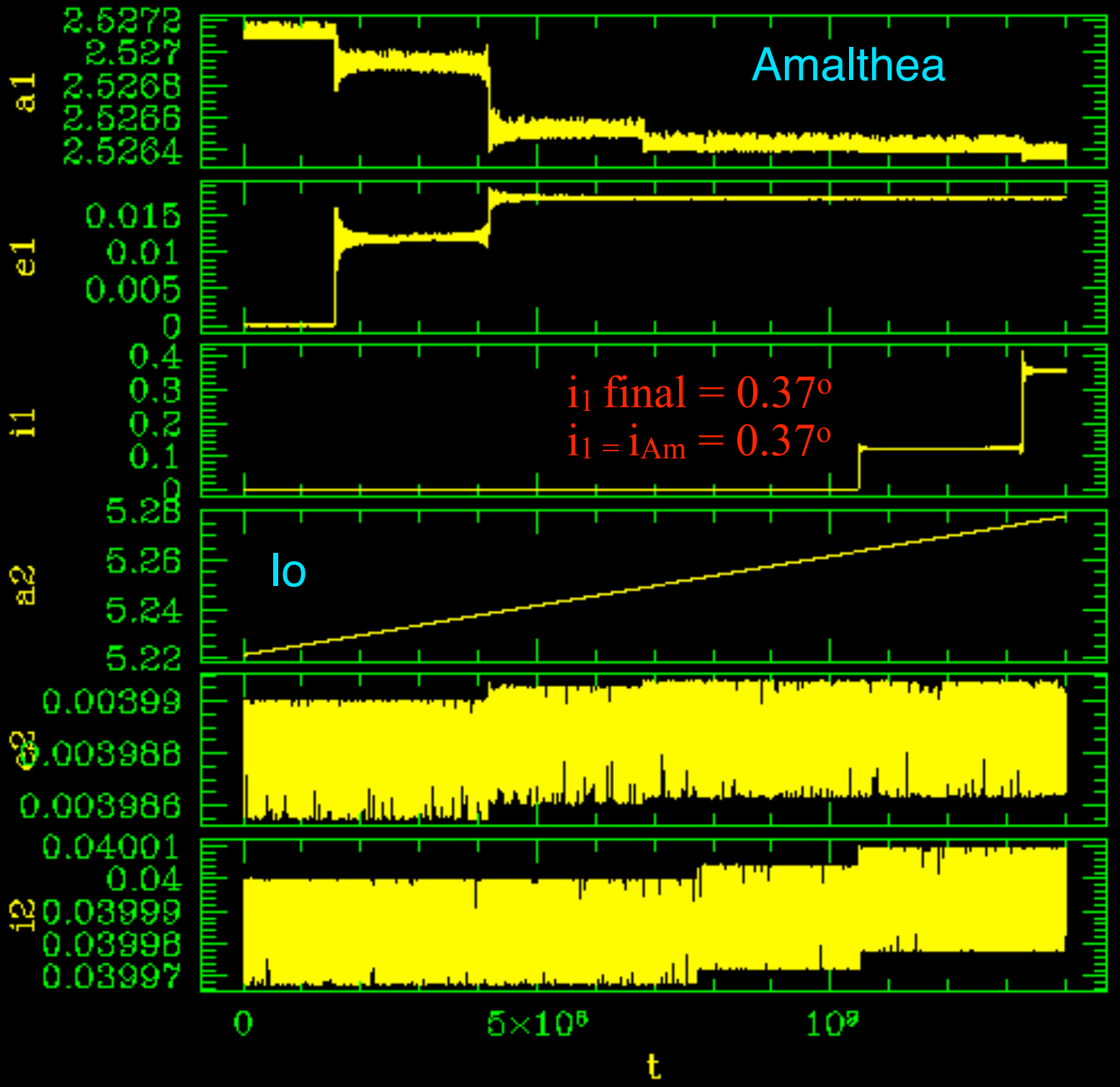
2 satellites

6 resonant kicks

Io-Amalthea 3:1, diverging

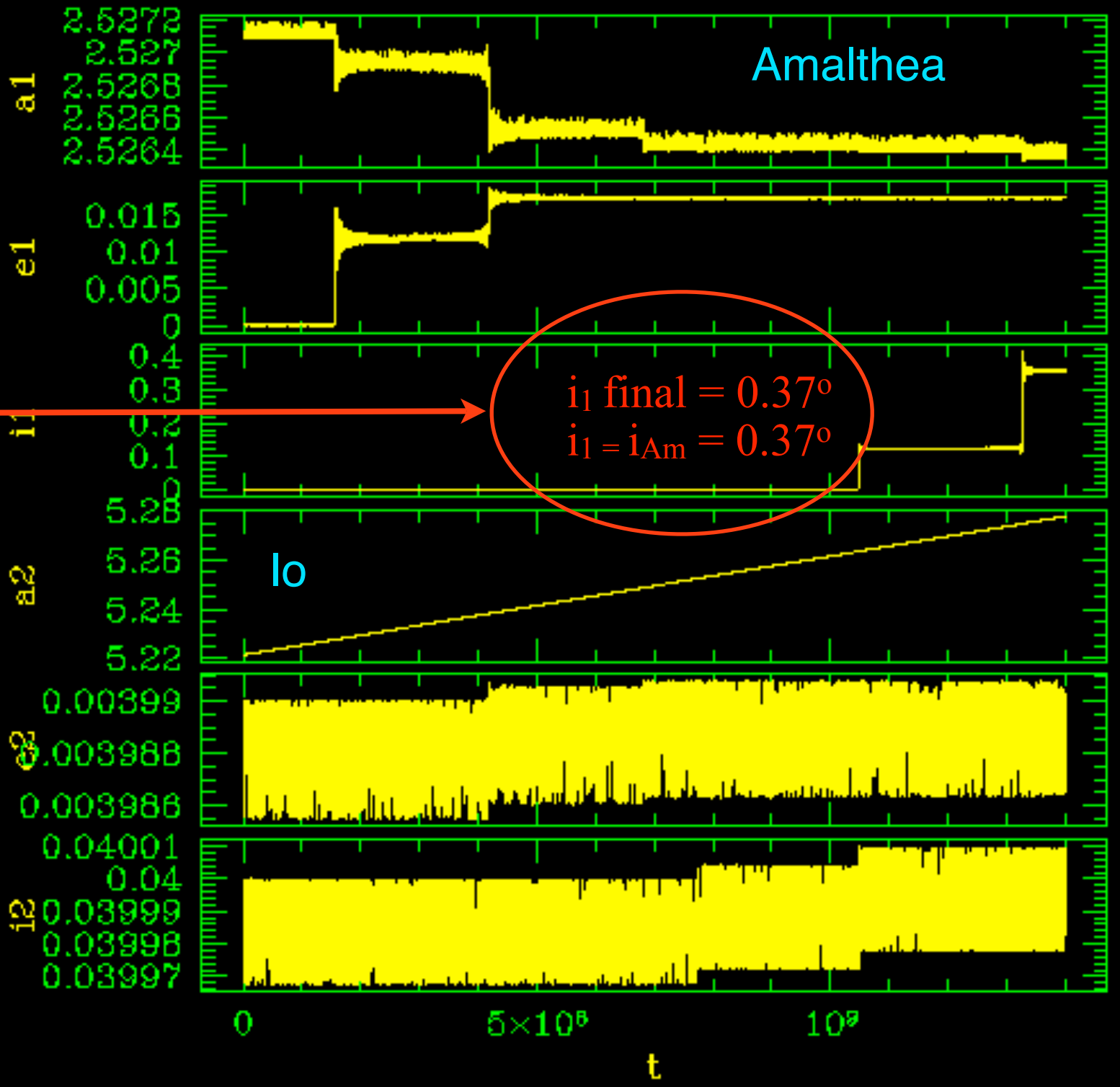


2 satellites



Io-Amalthea 3:1, diverging

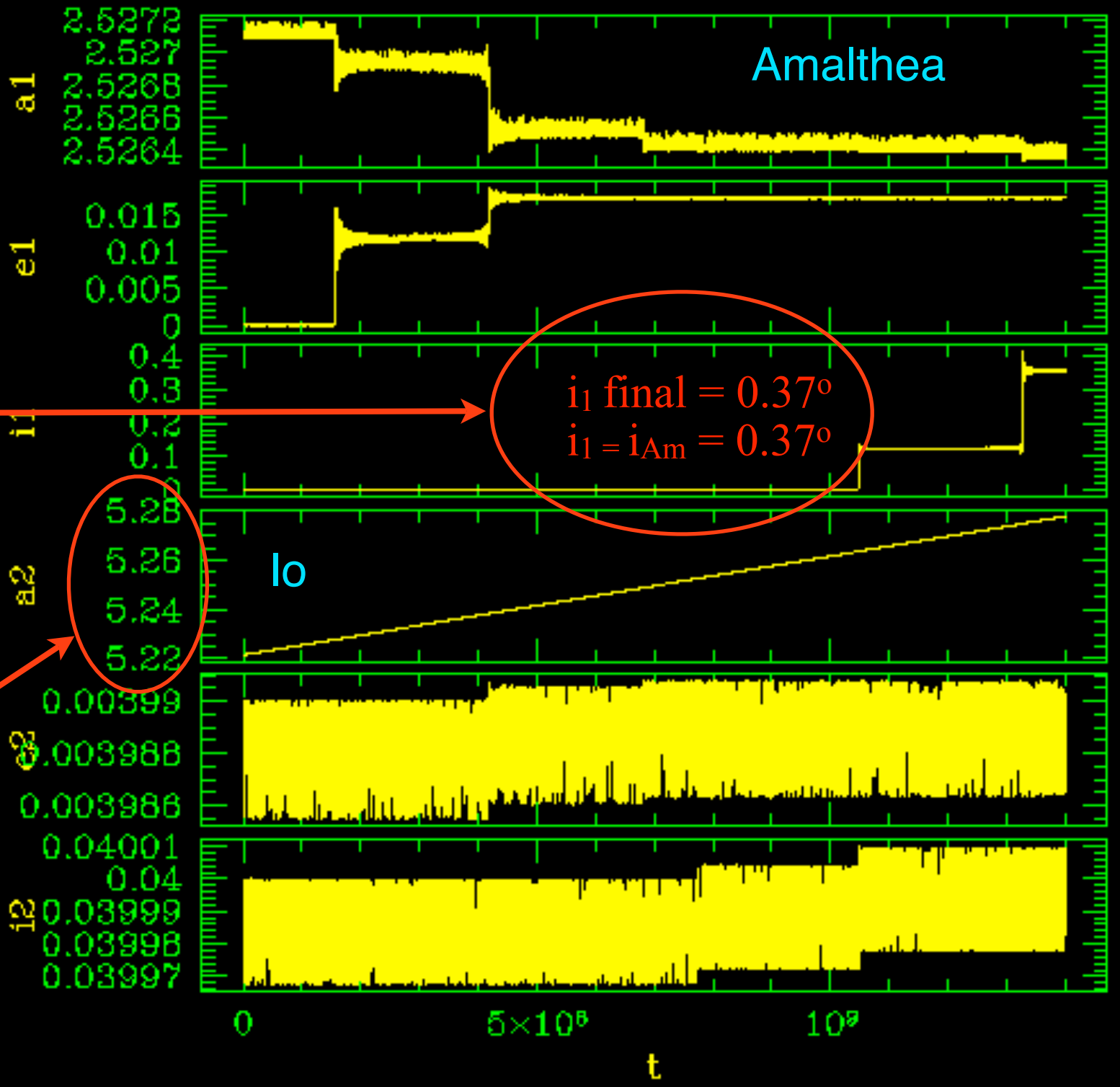
2 satellites



Io gives Amalthea the correct inclination!

Io-Amalthea 3:1, diverging

2 satellites



Io gives Amalthea the correct inclination!

i_1 final = 0.37°

$i_1 = i_{Am}$ = 0.37°

So Io must have once been here

Io-Amalthea 3:1, diverging

Constraints on Formation Distance

	close packing		today
Io	2.25	-	5.99
Europa	3.56	-	9.38
Ganymede	5.66	-	14.97

Old Constraint,
Peale + Yoder 1981

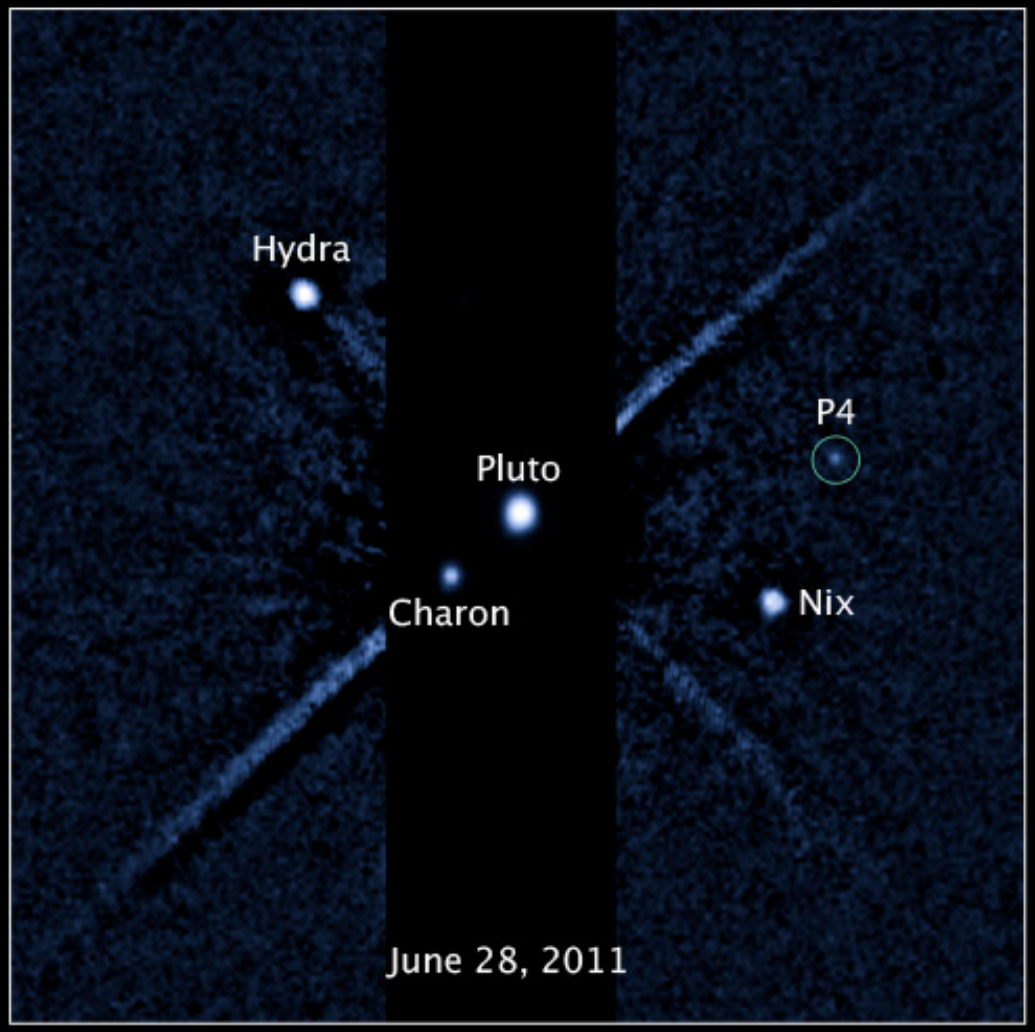
Adding Constraints from Amalthea (shown)
and another moon Thebe (not shown):

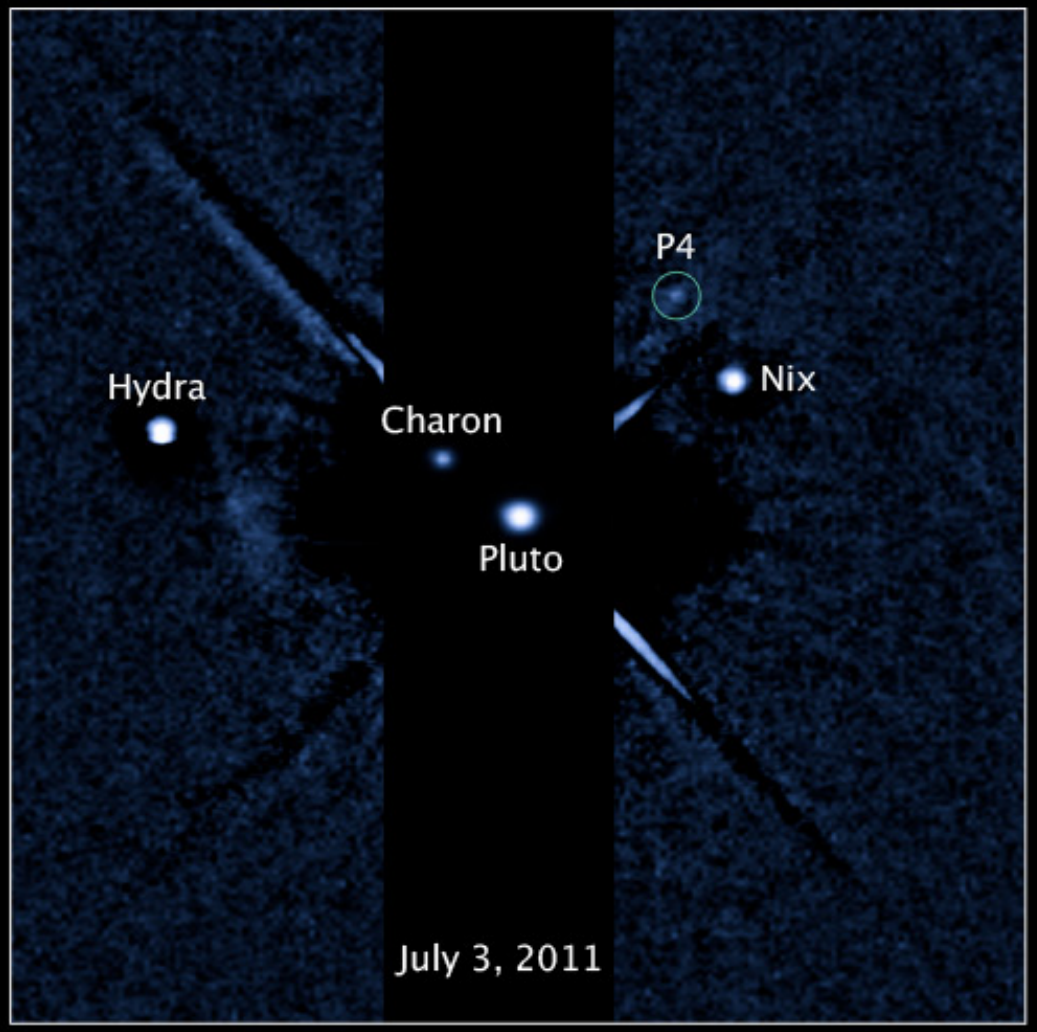
Io	$4.05 < a_I < 4.90$
Europa	$6.44 < a_E$
Ganymede	$10.24 < a_G$

New Moon Discovered Orbiting Pluto!

M.R. Showalter and D.P. Hamilton 2011

Pluto System ▪ *Hubble Space Telescope* ▪ WFC3/UVIS

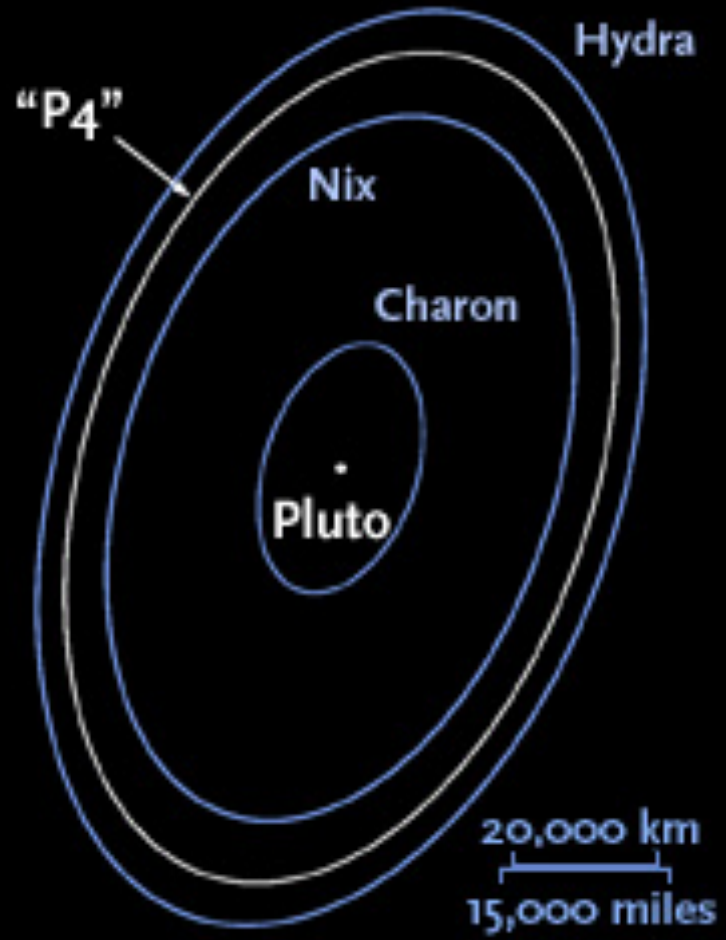




NASA, ESA, and M. Showalter (SETI Institute)

STScI-PRC11-23

P4 is between Nix and Hydra



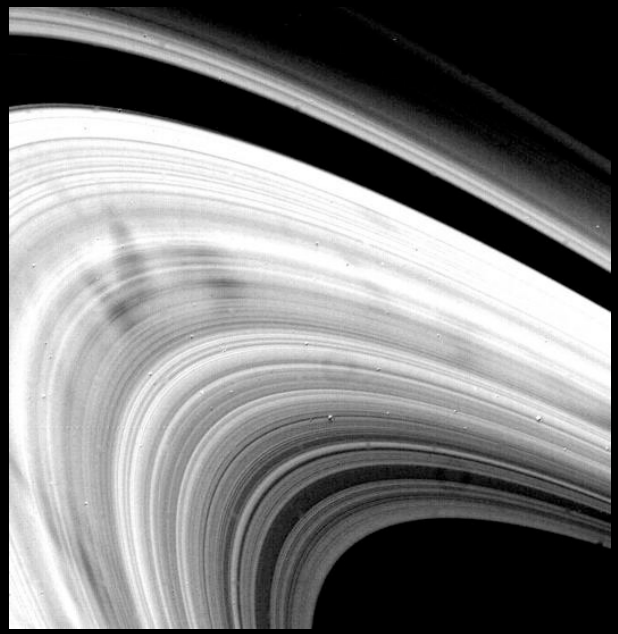
Nix is near Charon's 1:4 resonance
Hydra is near 1:6
P4 is near 1:5

These resonances hint at how the system formed.

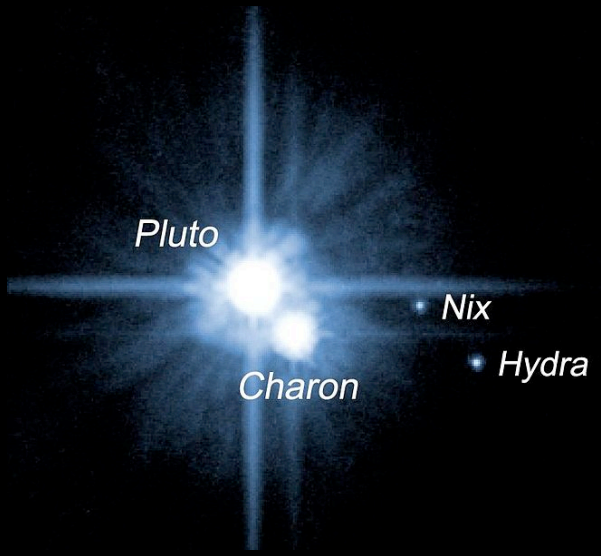
2nd-Year Projects

Galilean Satellites
(Katie Philpott)

Planetary Rings
(Daniel Jontof-Hutter)



Pluto
(Kate Krivjanik)



Uranian Satellites