Saturn's Rings: the Large and Small

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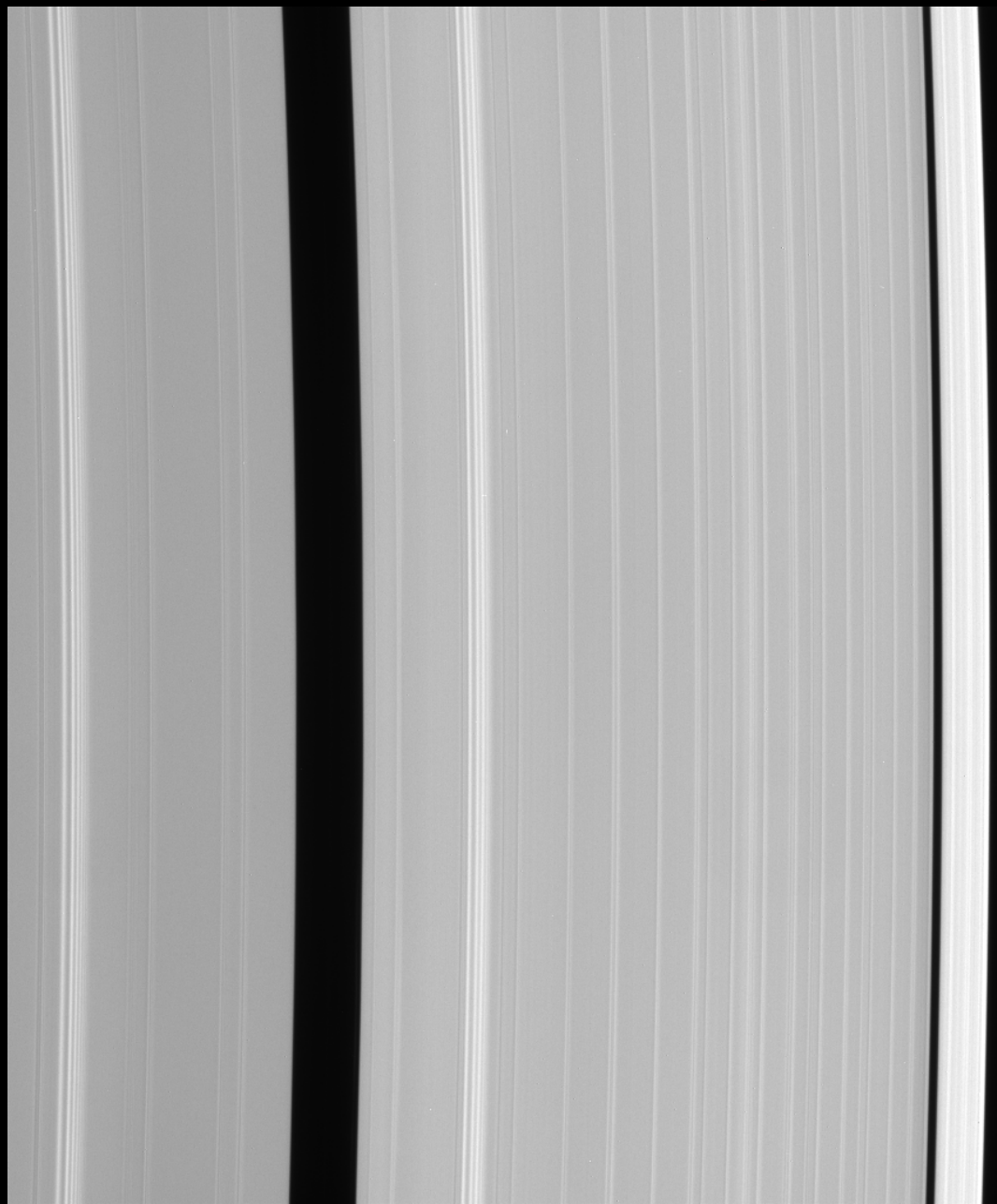
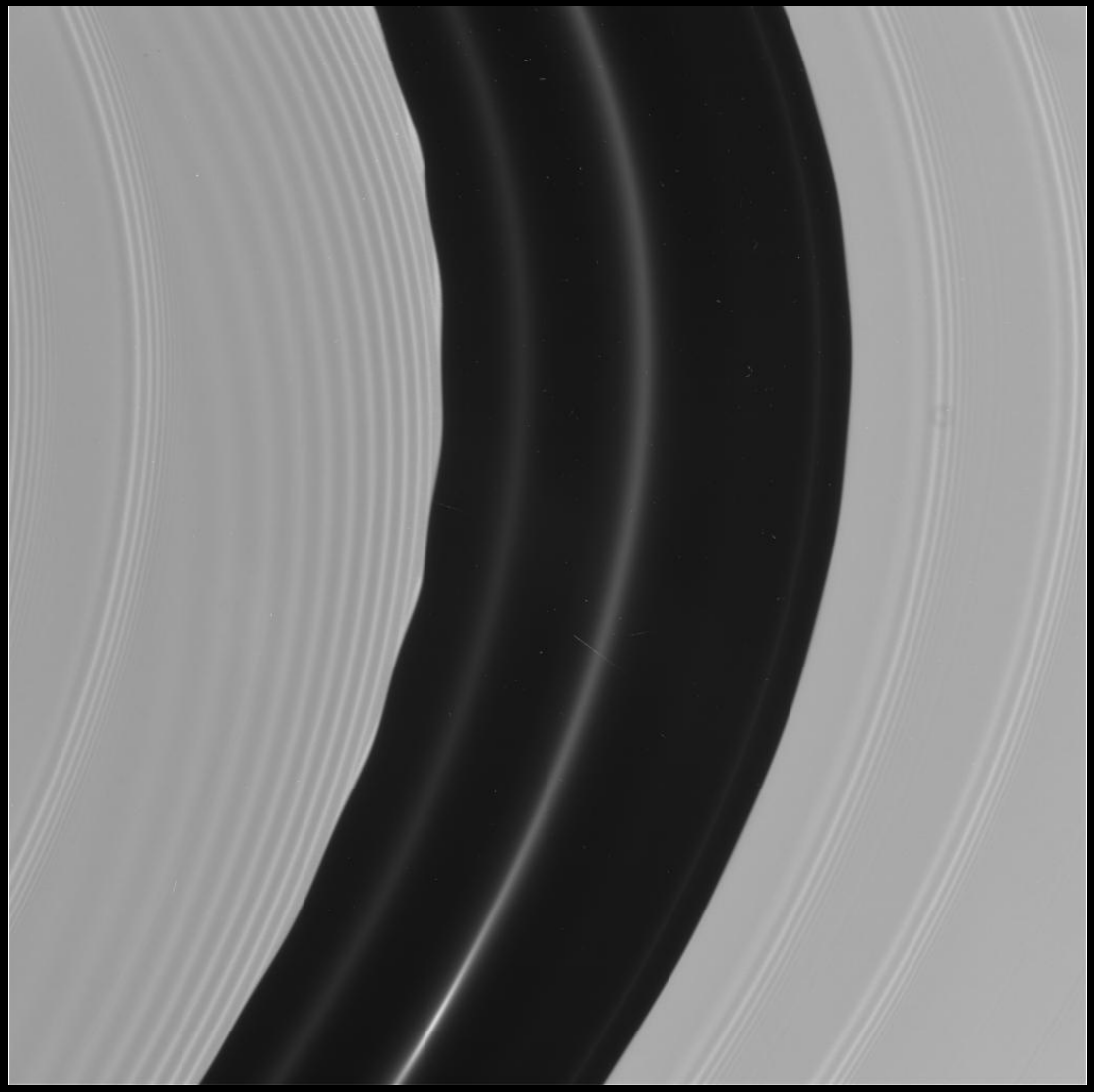
John Weiss
(Carolyn Porco)
31 July 2007

Those Tiny, Little Moons

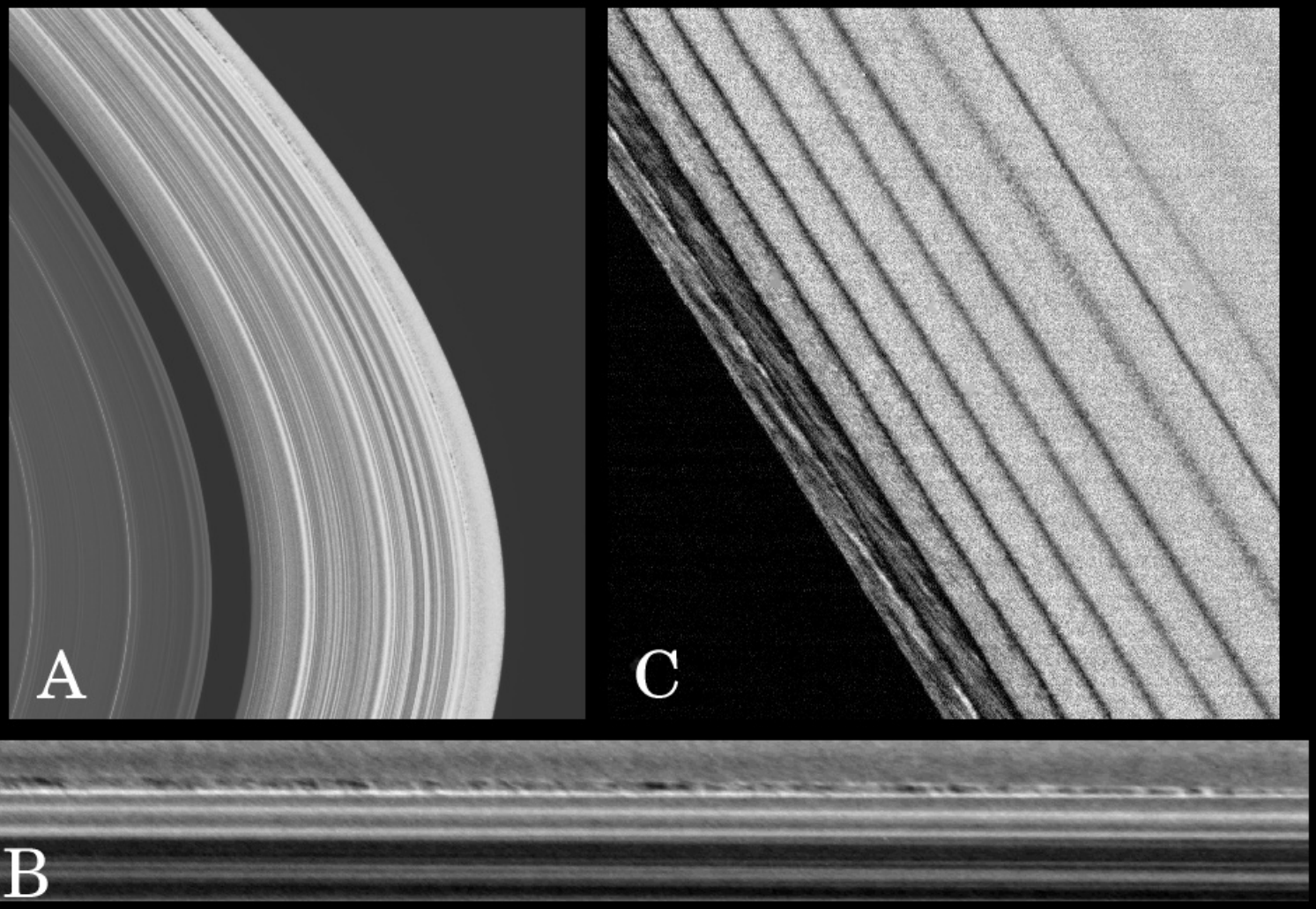
A Ring



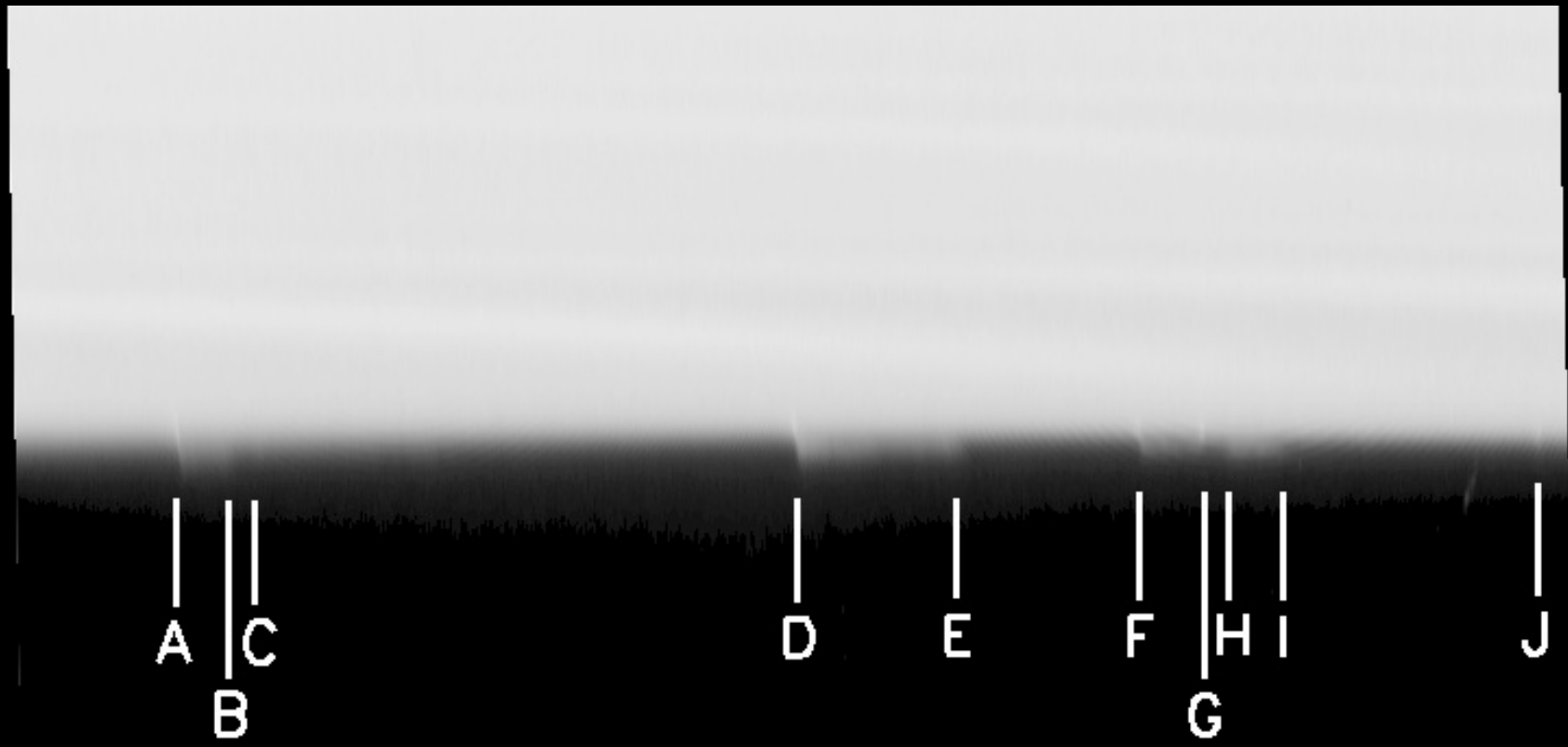
Encke Gap



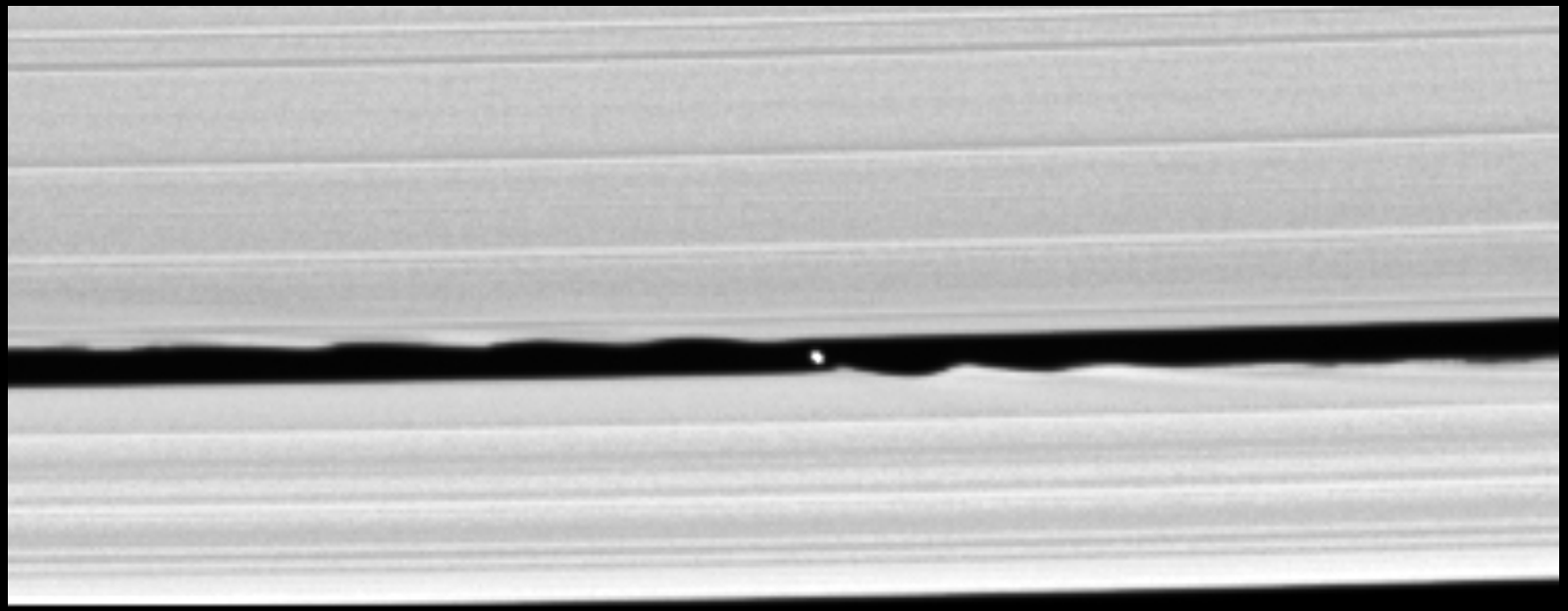
Edge of the Encke Gap



Keeler Gap



Keeler Gap with Daphnis



The Main Question:

- How to determine the mass of an embedded moon from the effects on the nearby ring edges?

Other Questions:

- Can the moonlet induce a time-variable structure?
- How does the eccentricity of the moon change these results? What about the particles' eccentricities?

Previous Work

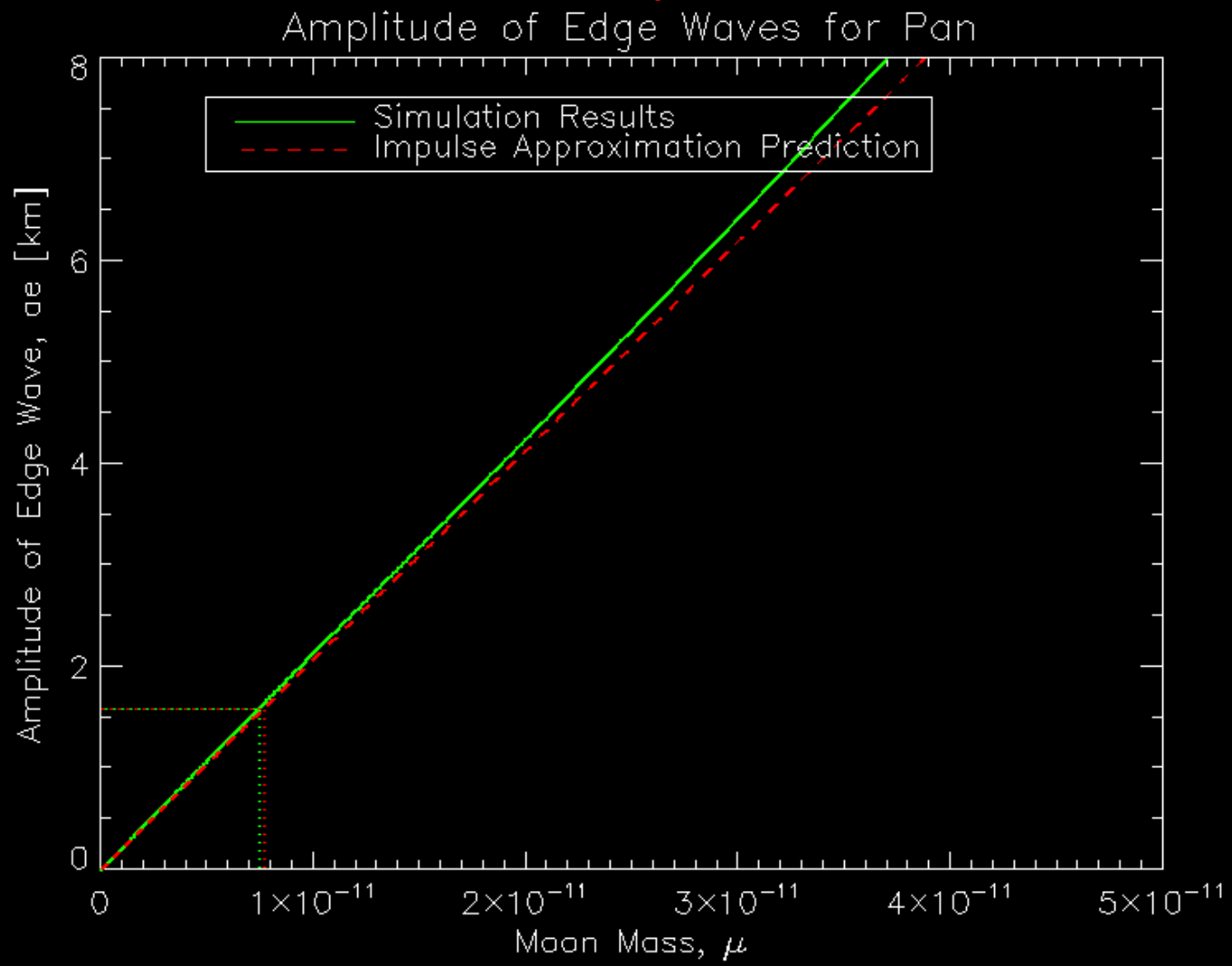
$$\mu = \frac{ae}{2.24}\left(\frac{\Delta a^2}{a^3}\right)$$

- Nice, analytic expression
- Uses an impulse approximation
- Assumes particle and moon are initially on circular orbits

Approach

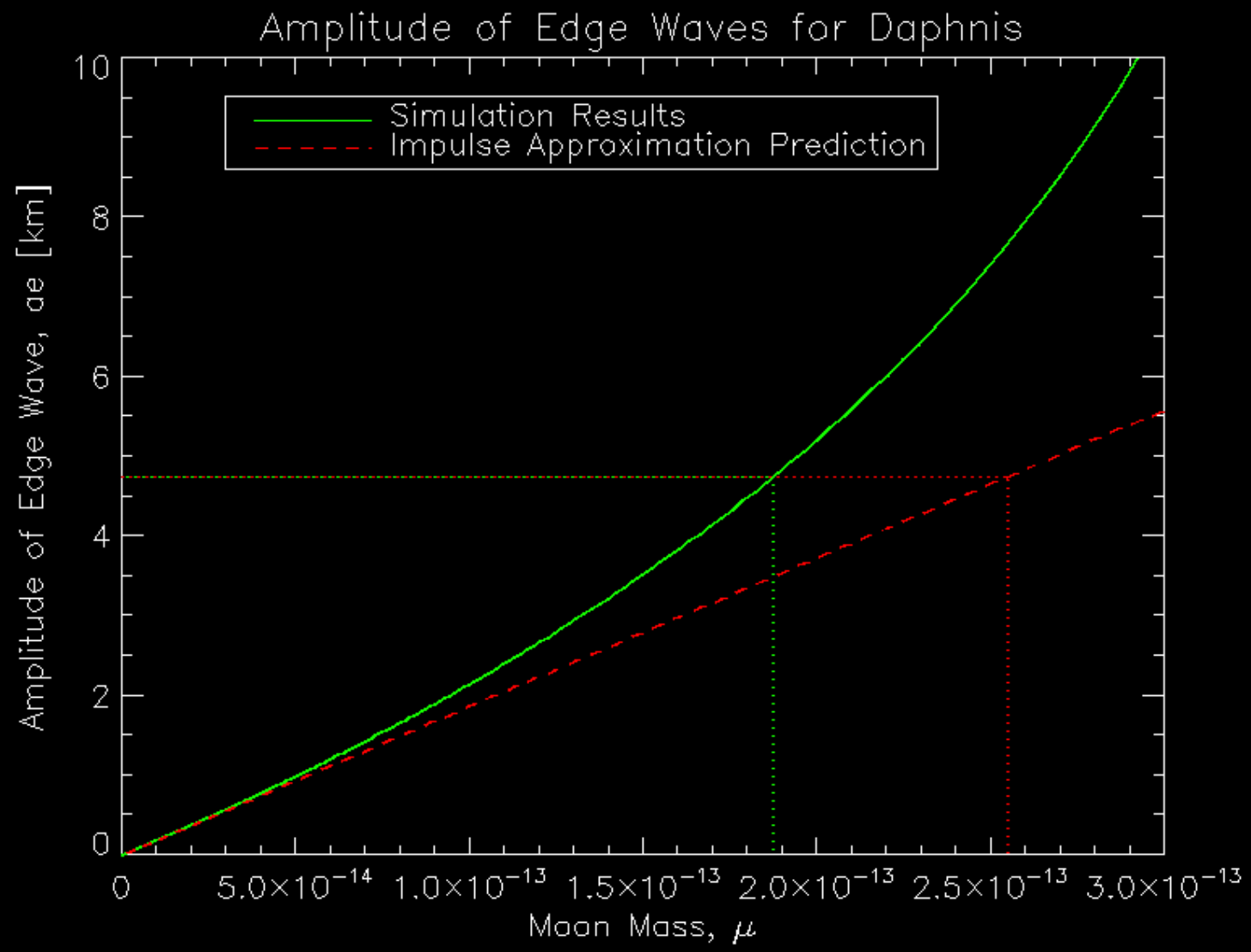
- Integrate orbits of particles passing near a moon.
- Particles and moons can have eccentric orbits and arbitrary phase.
- Particles do *not* interact with each other.

Mass of Pan



- Analytic theory agrees with integrations to about 3%

Mass of Daphnis

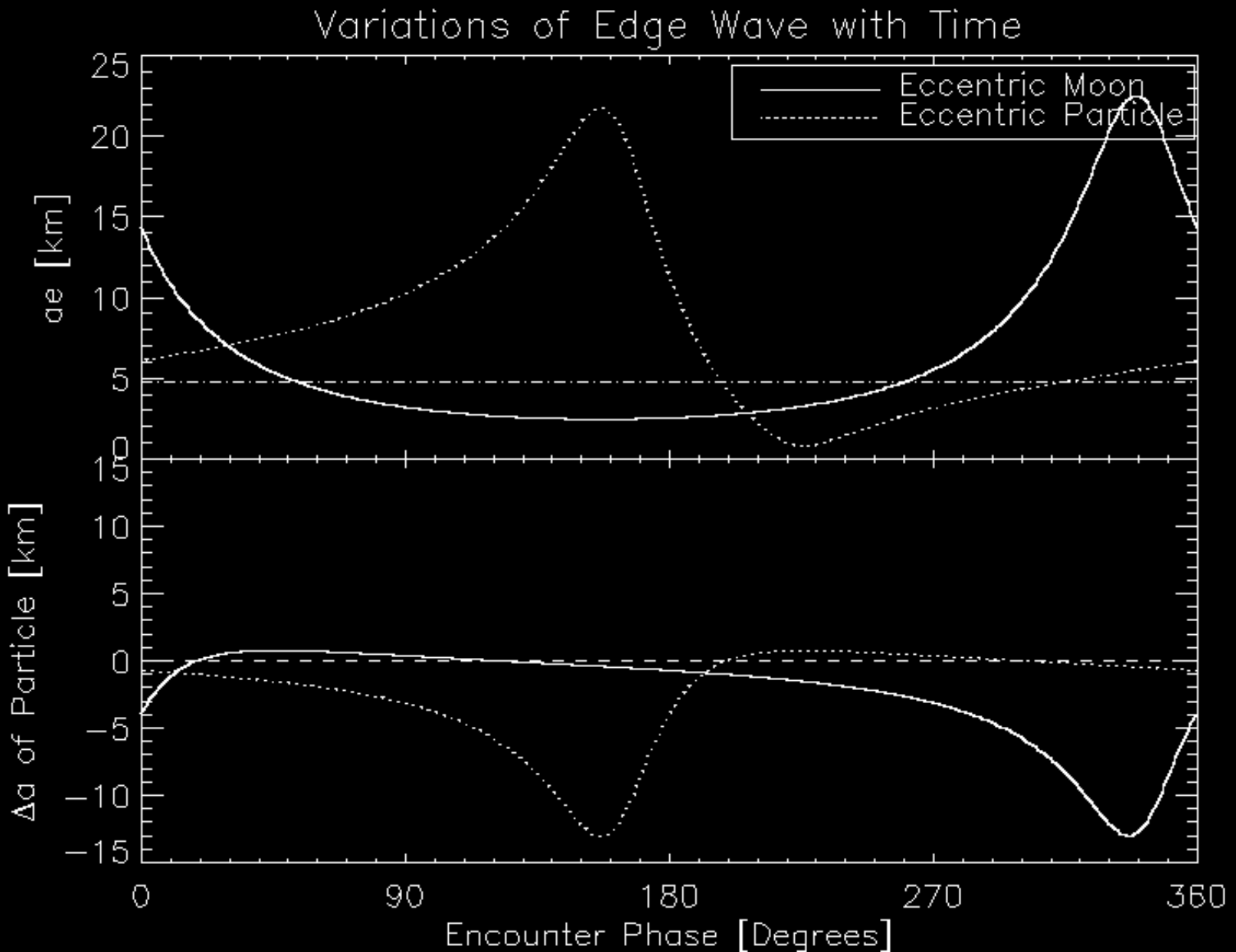


Analytic theory disagrees with integrations by 35%

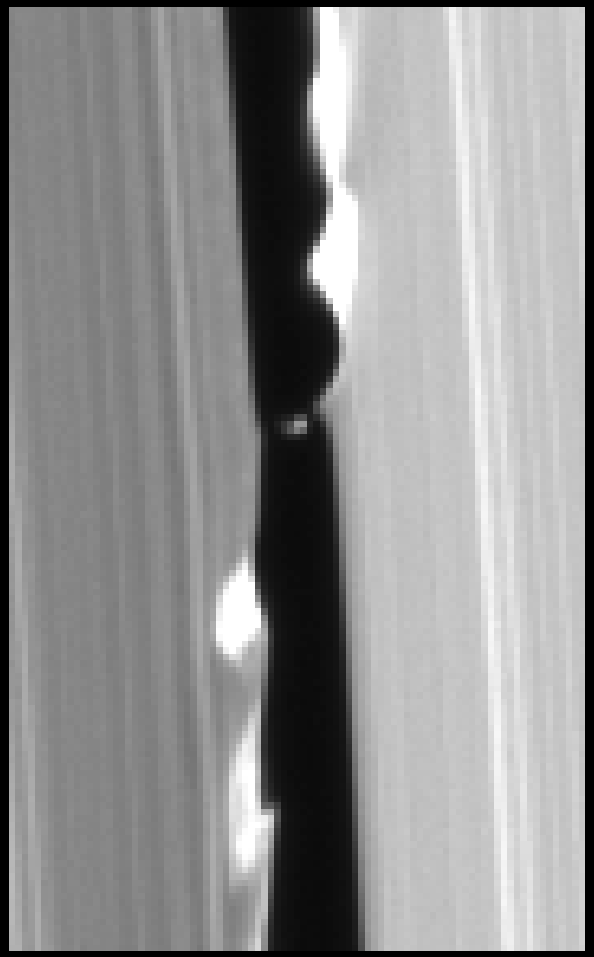
What Does Eccentricity Do

- Following runs give either moon OR the particle eccentricity
  - e is the same for both case, equal to what is measured for the moon
- Observe the variations in dX and ae for the particles
  - Note ae is not equal to the edge wave amplitude! (I'll show you what I mean later)

That Eccentric Daphnis



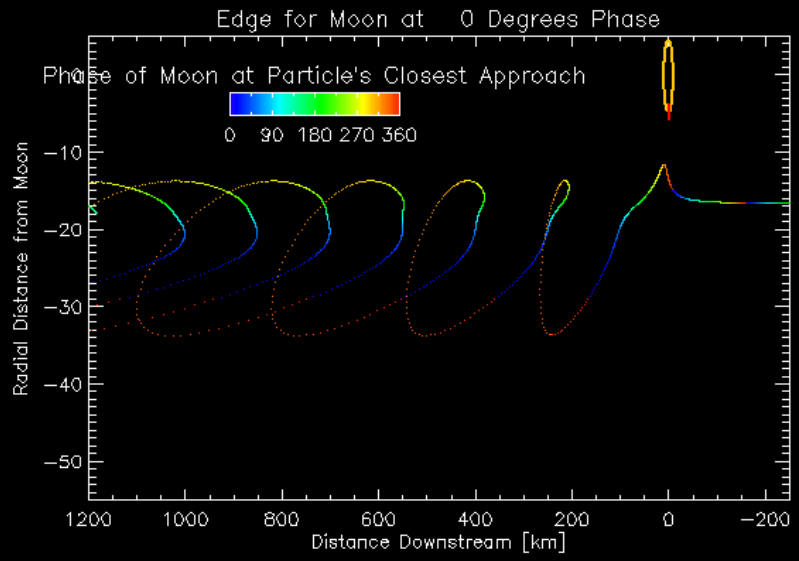
Daphnis Again

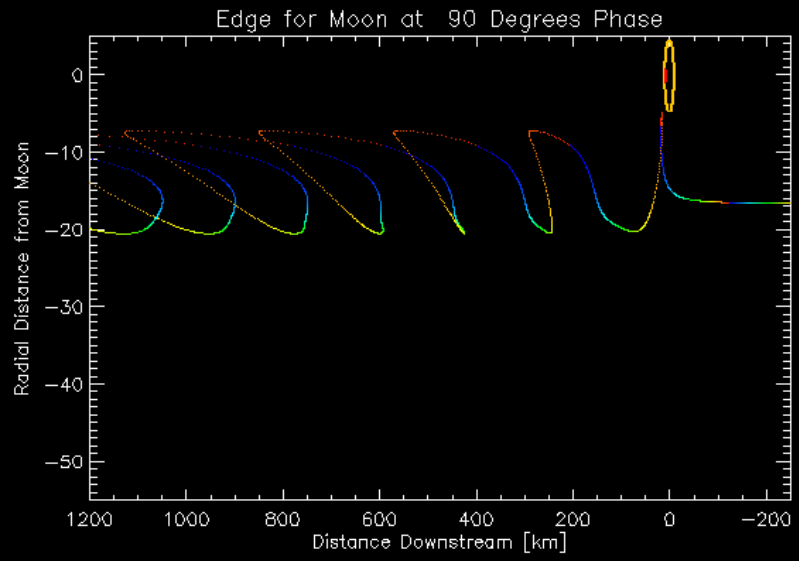


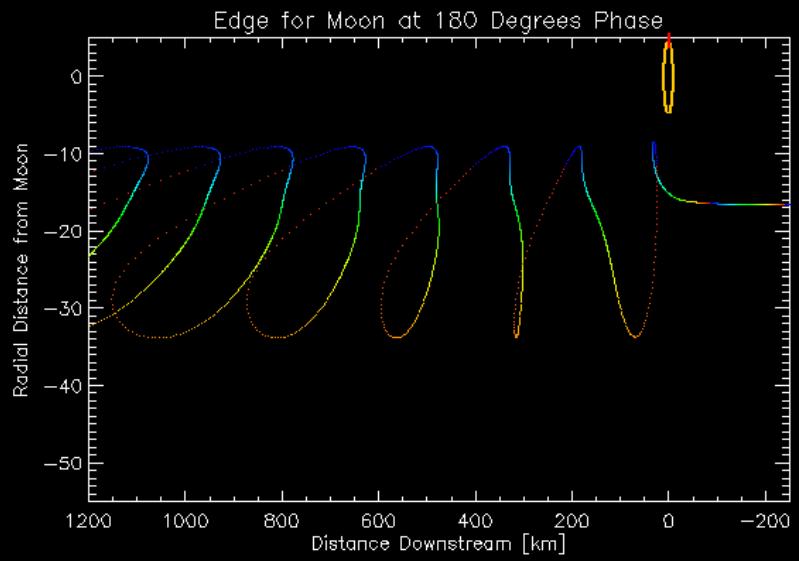
Why “ae” isn’t Amplitude

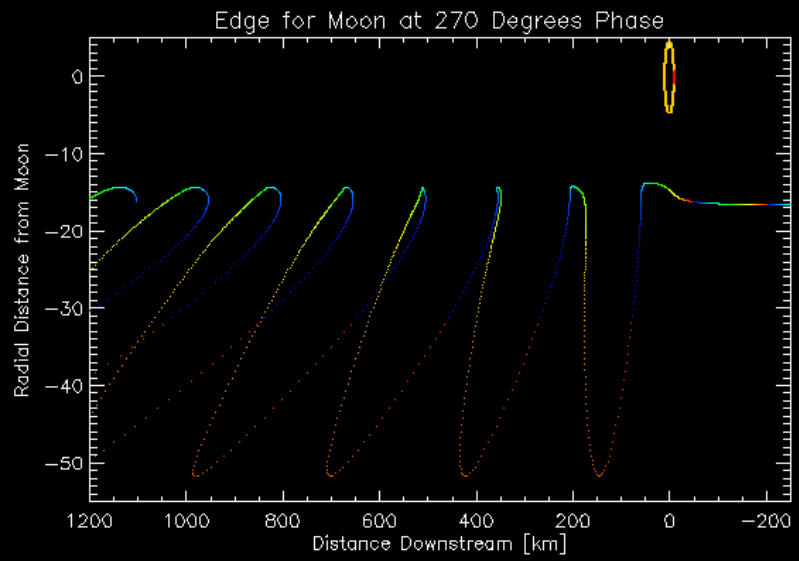
- Because you see particles at all different phases making up the edges.
- This complicates things *a lot!*

Graphically…

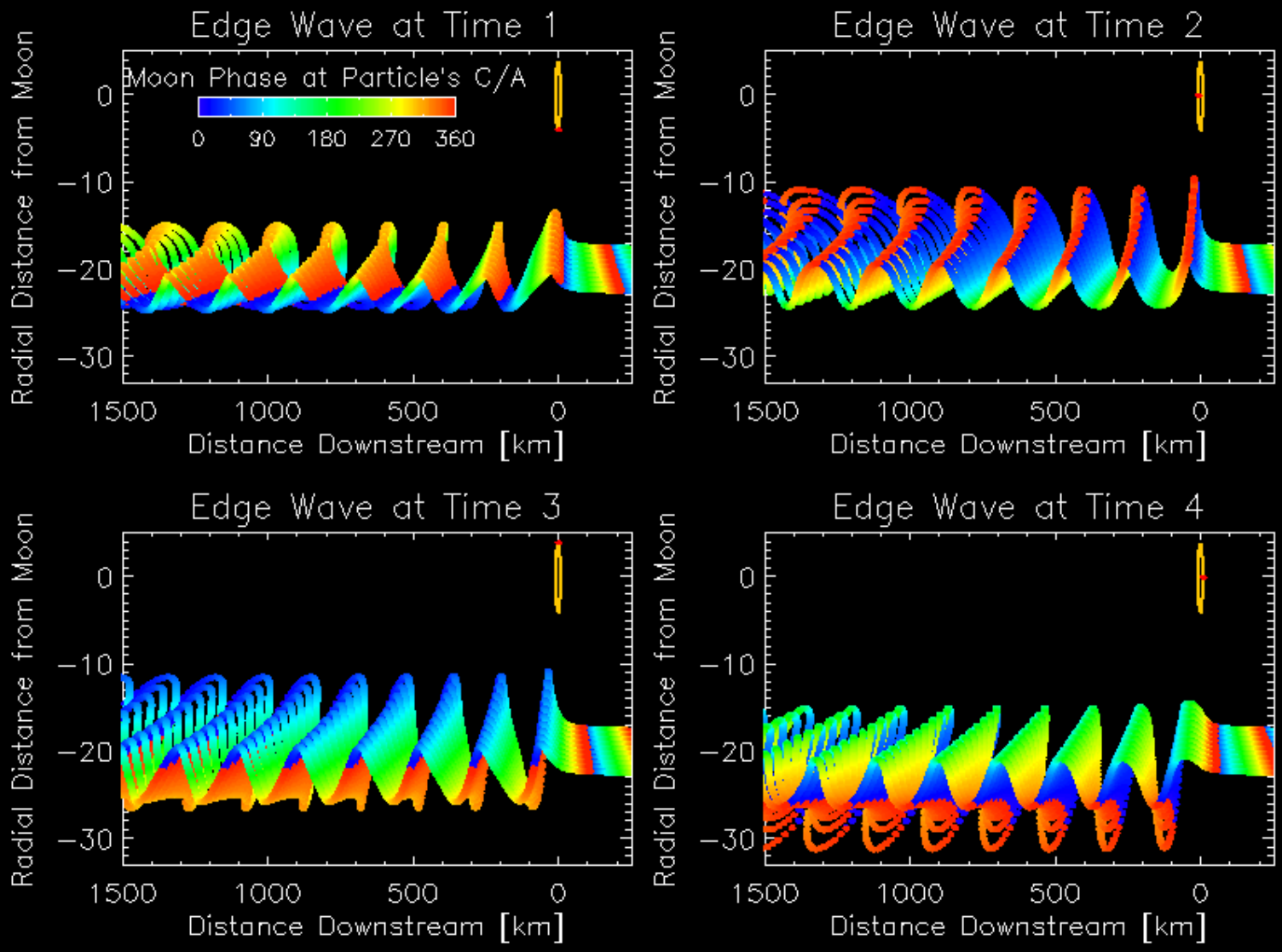




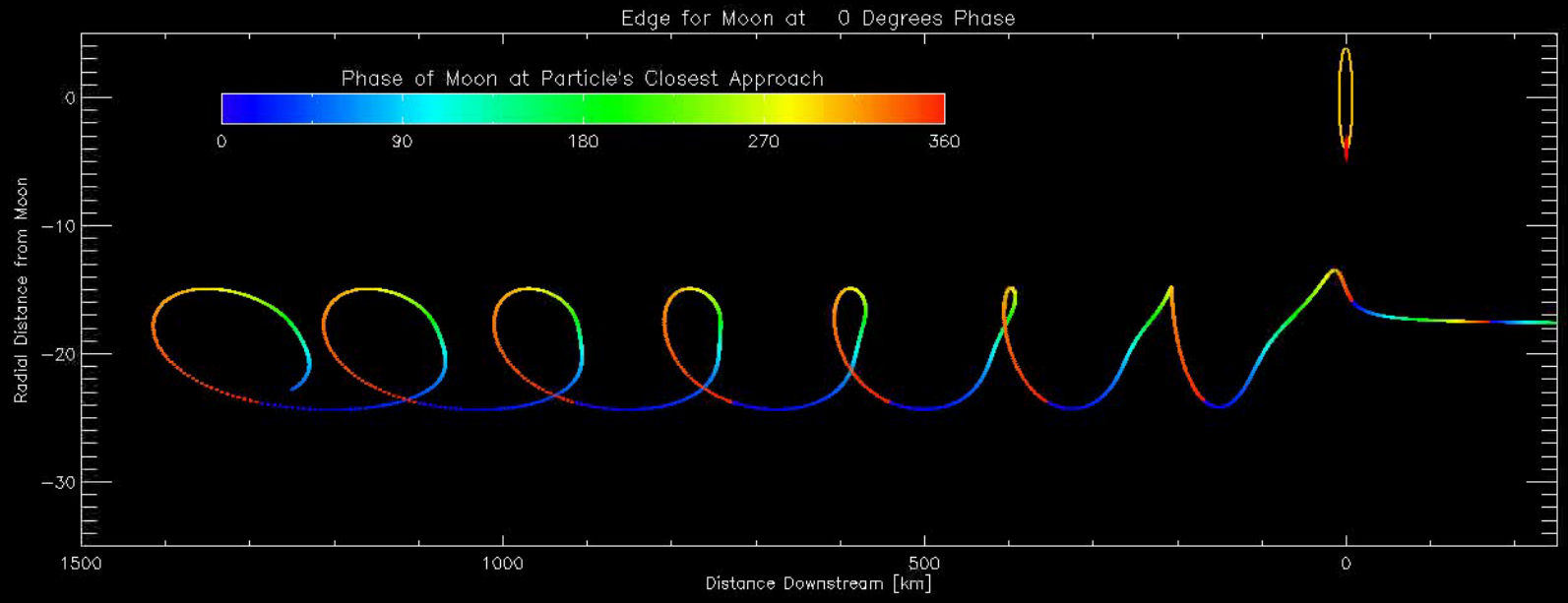




More Interesting Still



Movie


Edge for Moon at 0 Degrees Phase
Phase of Moon at Particle's Closest Approach
0
90
180
270
360
0
−10
−20
−30
Radial Distance from Moon
1500
1000
500
0
Distance Downstream [km]

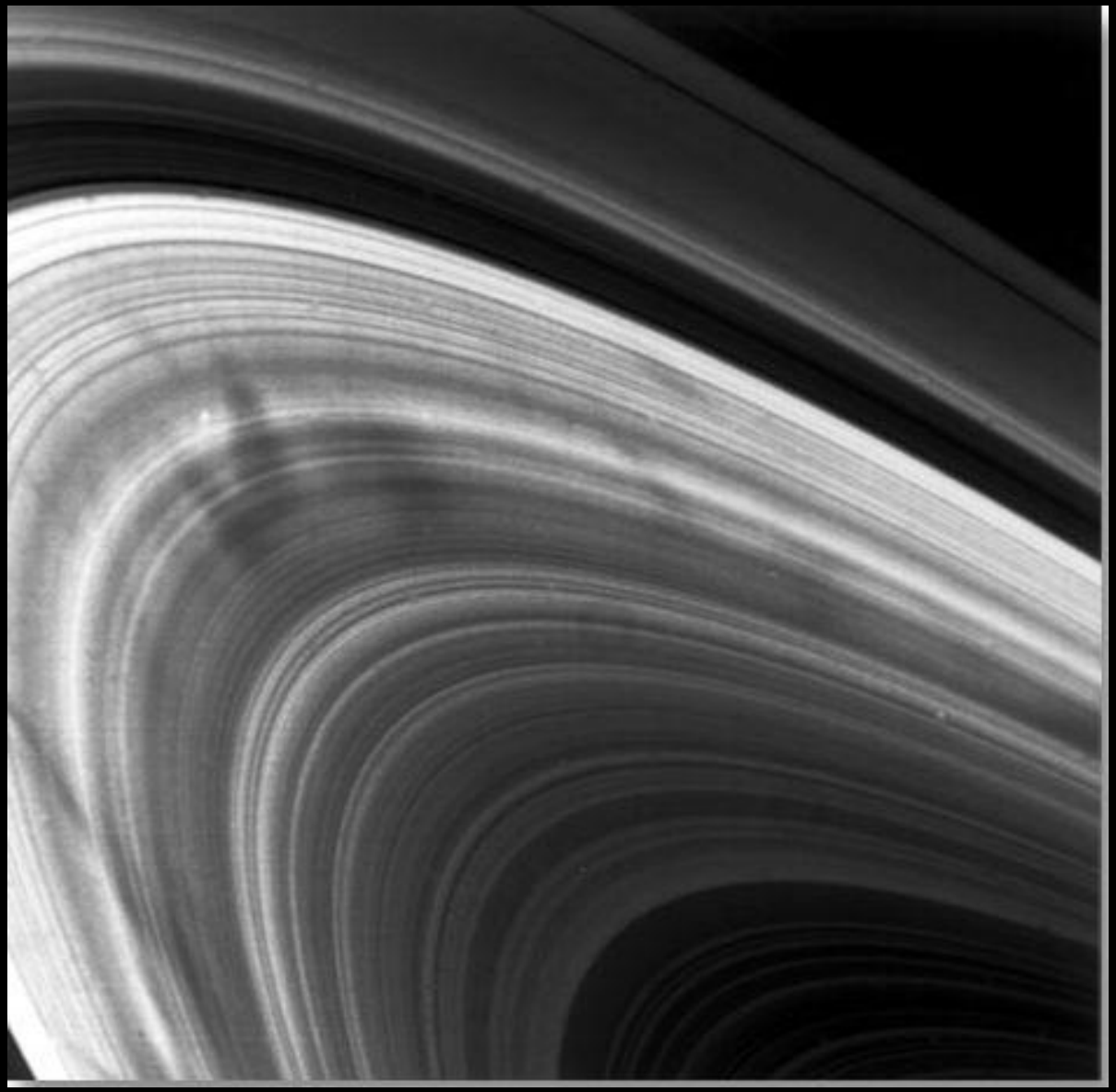
So What?

- The analytic formula works for distant moon-edge encounters, but not for nearby ones.
- Eccentric moons cause time-variable edges
- Need better simulations (*i.e.*, include particle collisions and gravity) to improve mass estimates

Who Cares?

- What all of this means is that small moons can have big effects on rings.
- This is a kind of "open hunting license" for Cassini to go hunting for moons which might have been too small to see yet.
- Knowing the masses of the moons can help us understand their origins... but that's a different part of the talk.

Spokes



Introduction

Spoke Observations:

- Voyager (1980 & 1981) : Discovery
- Hubble (1994-1998) : Faded out
- Cassini (2005-???) : Recovered

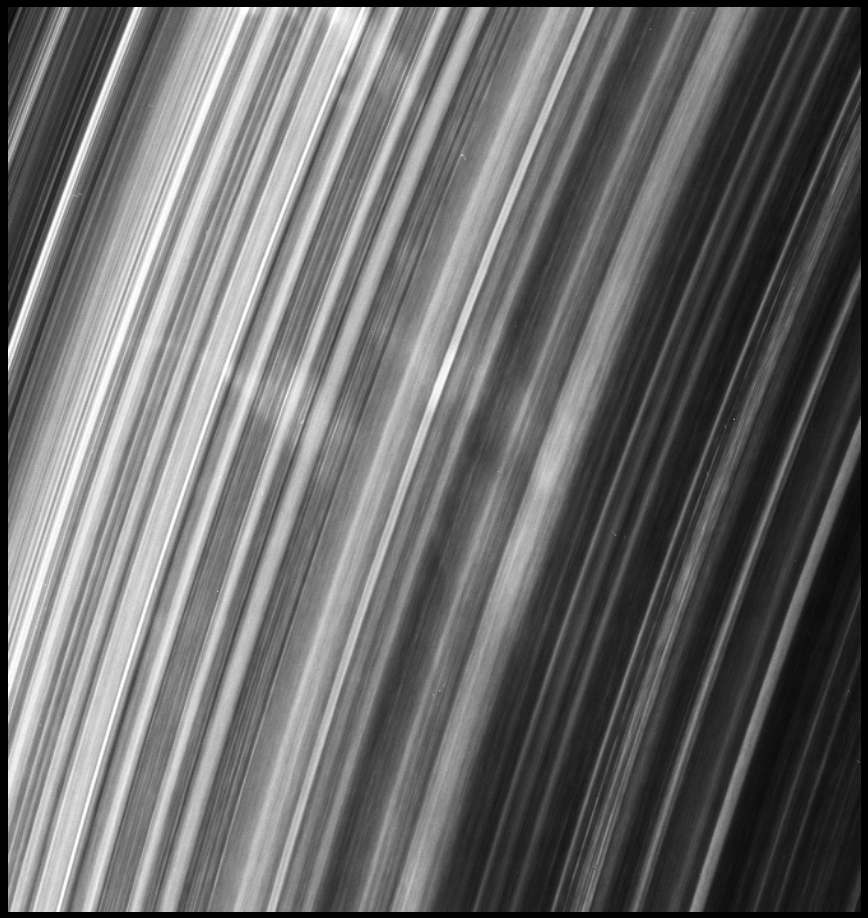
Composed of small, charged dust particles (~0.5μm)

Start off radially aligned

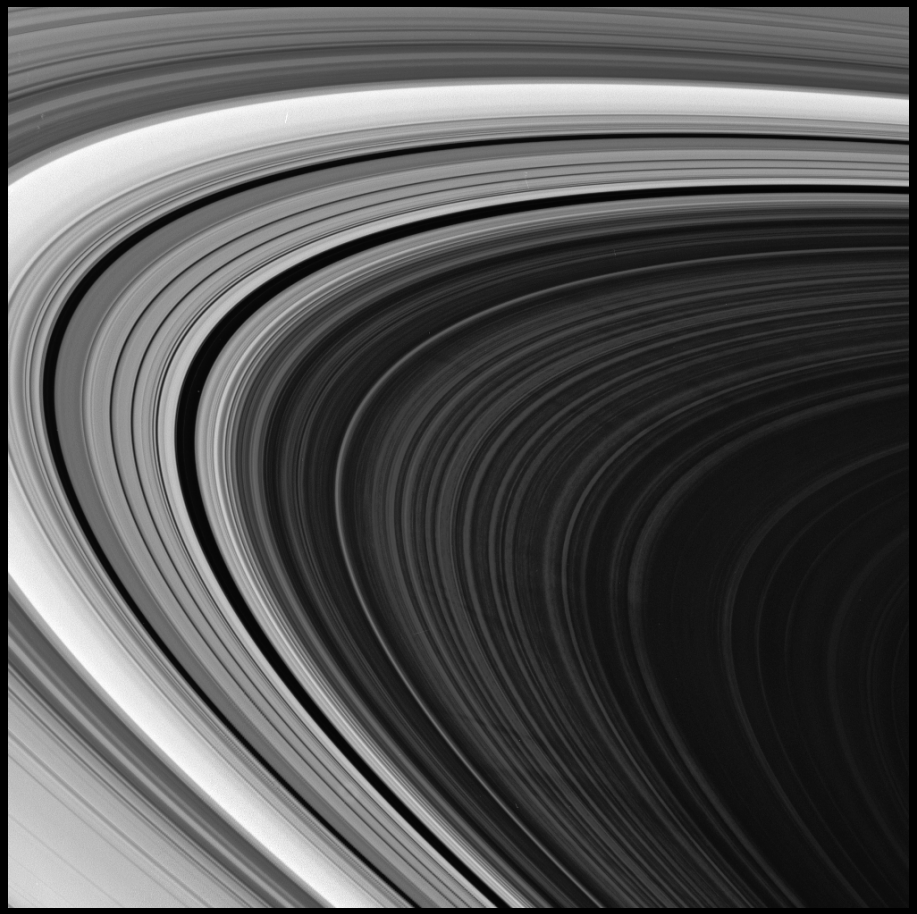
Most exhibit Kepler shear

Preferentially form at the SKR active region during a particular magnetic field orientation

Contrast Phase Dependence

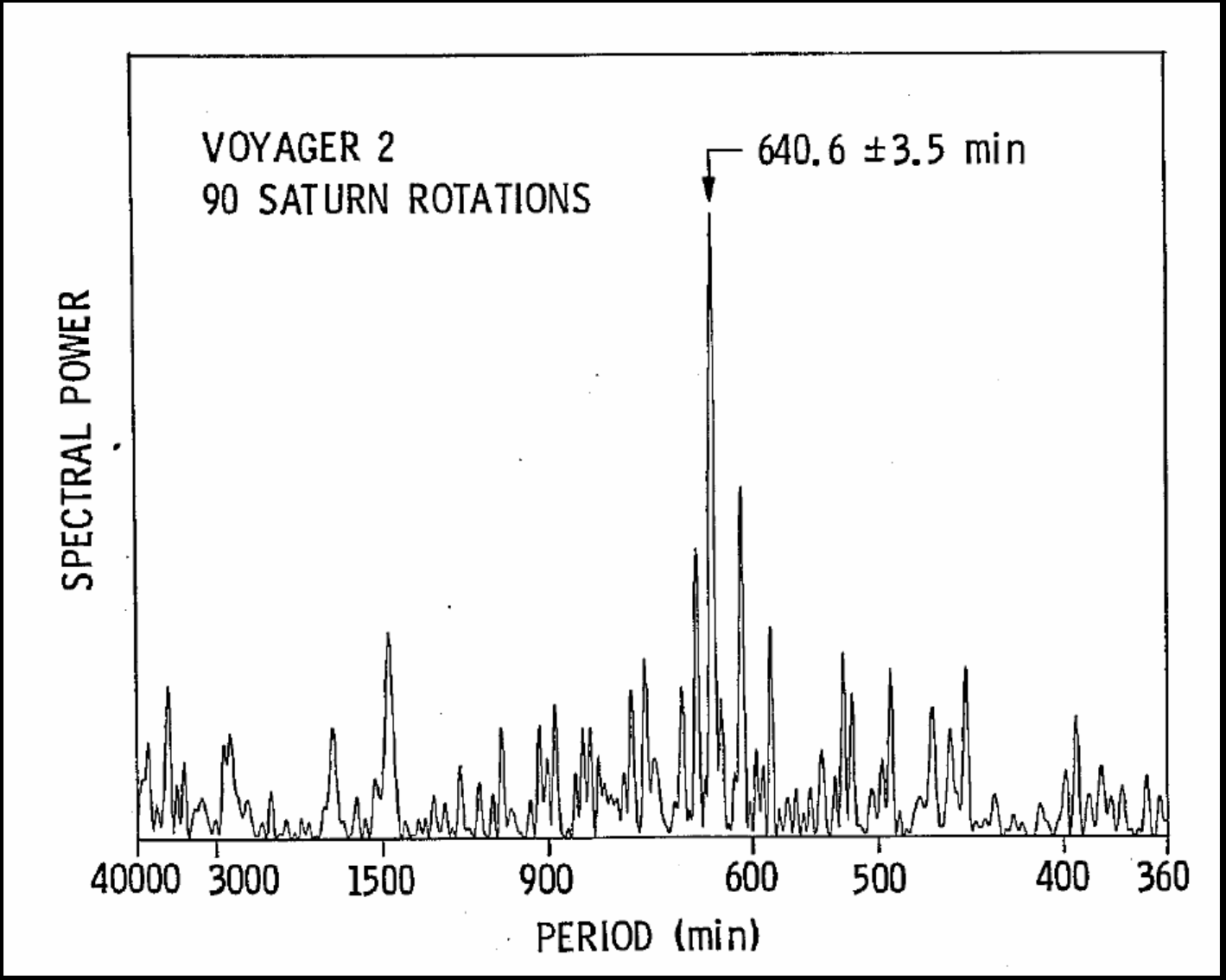


High Phase

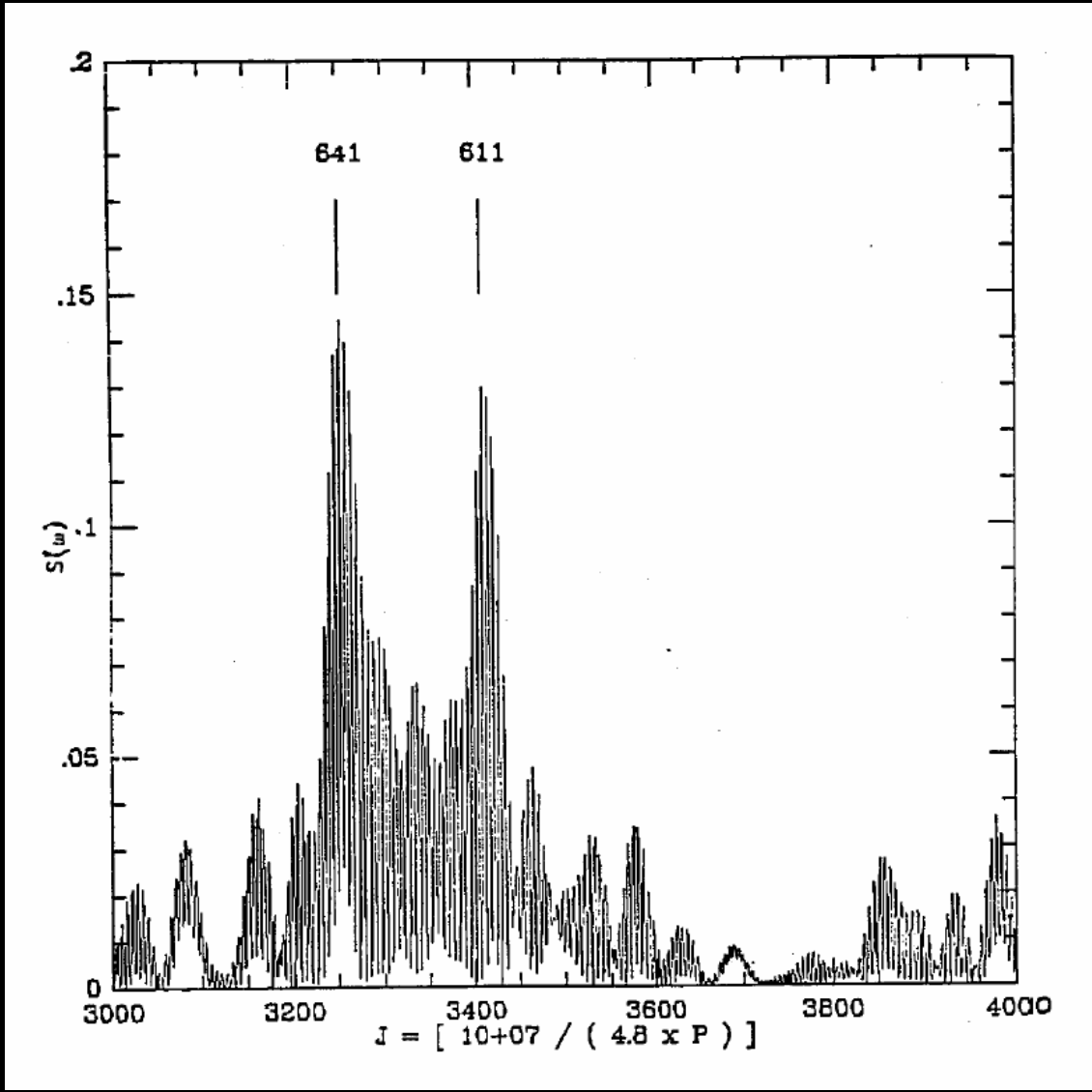


Low Phase

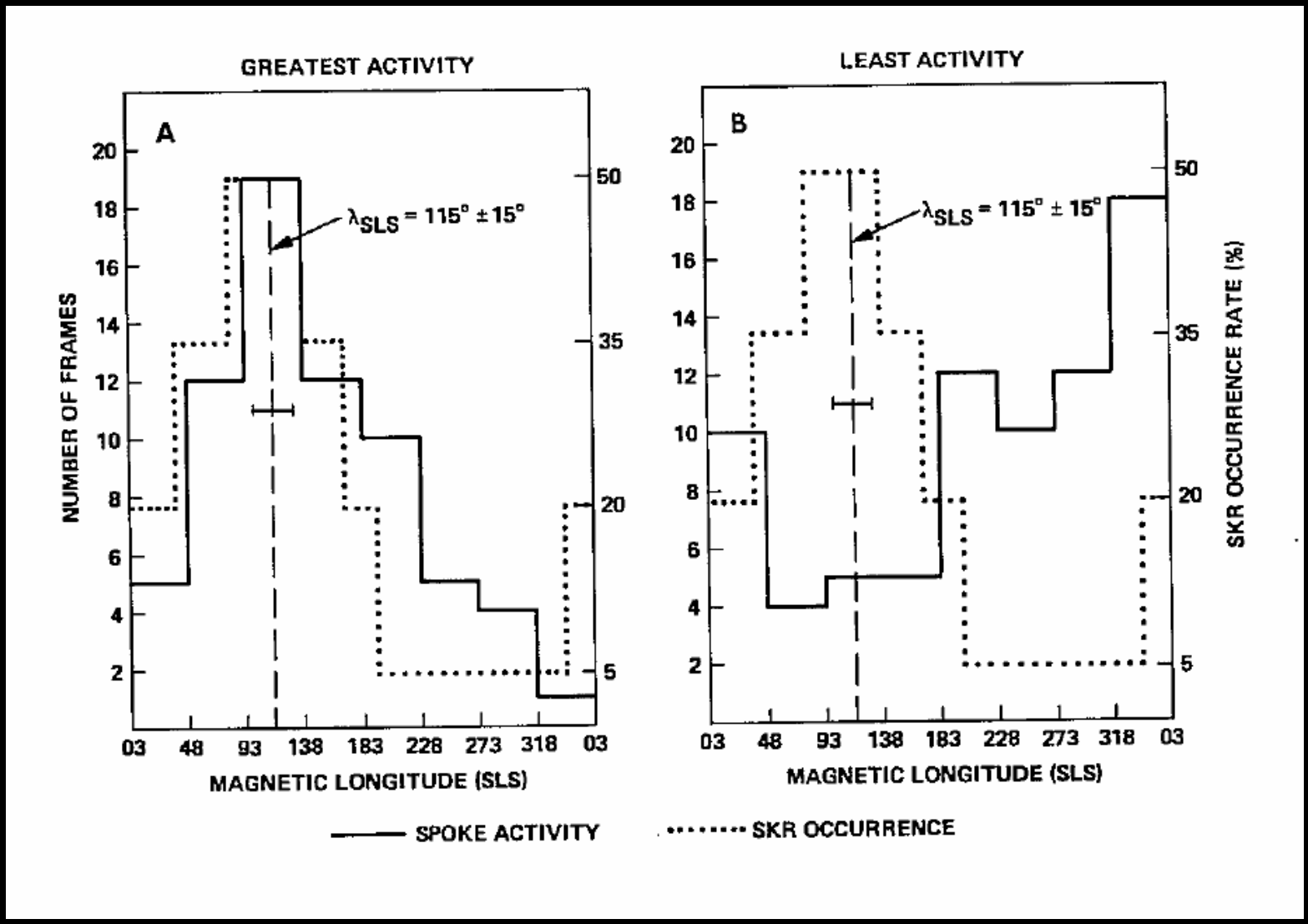
Spoke Periodicity



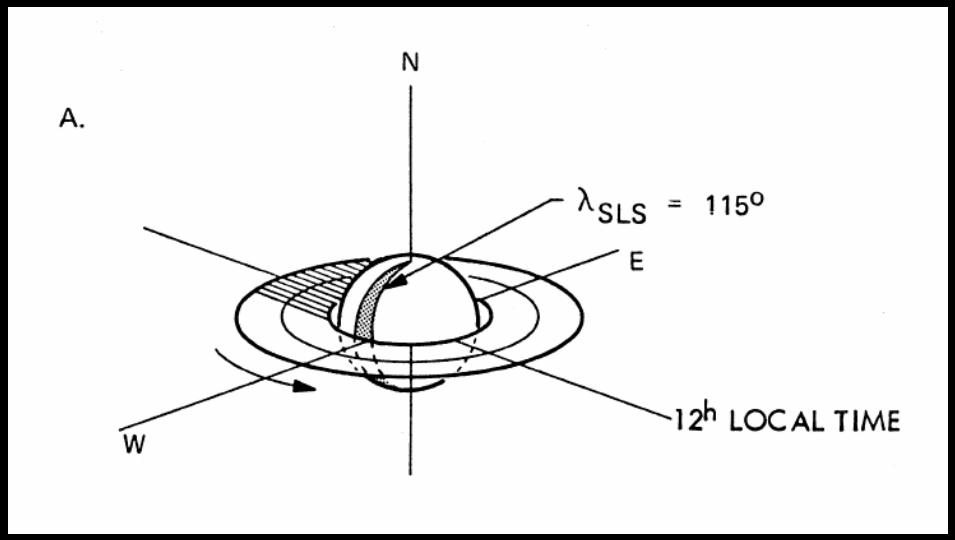
Spoke Periodicity



Spoke Periodicity

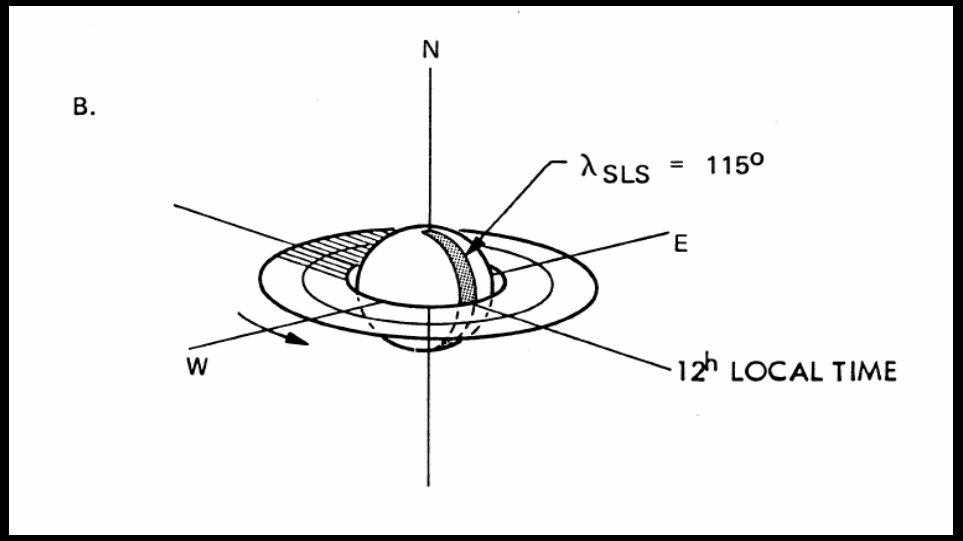


Preferred Geometry



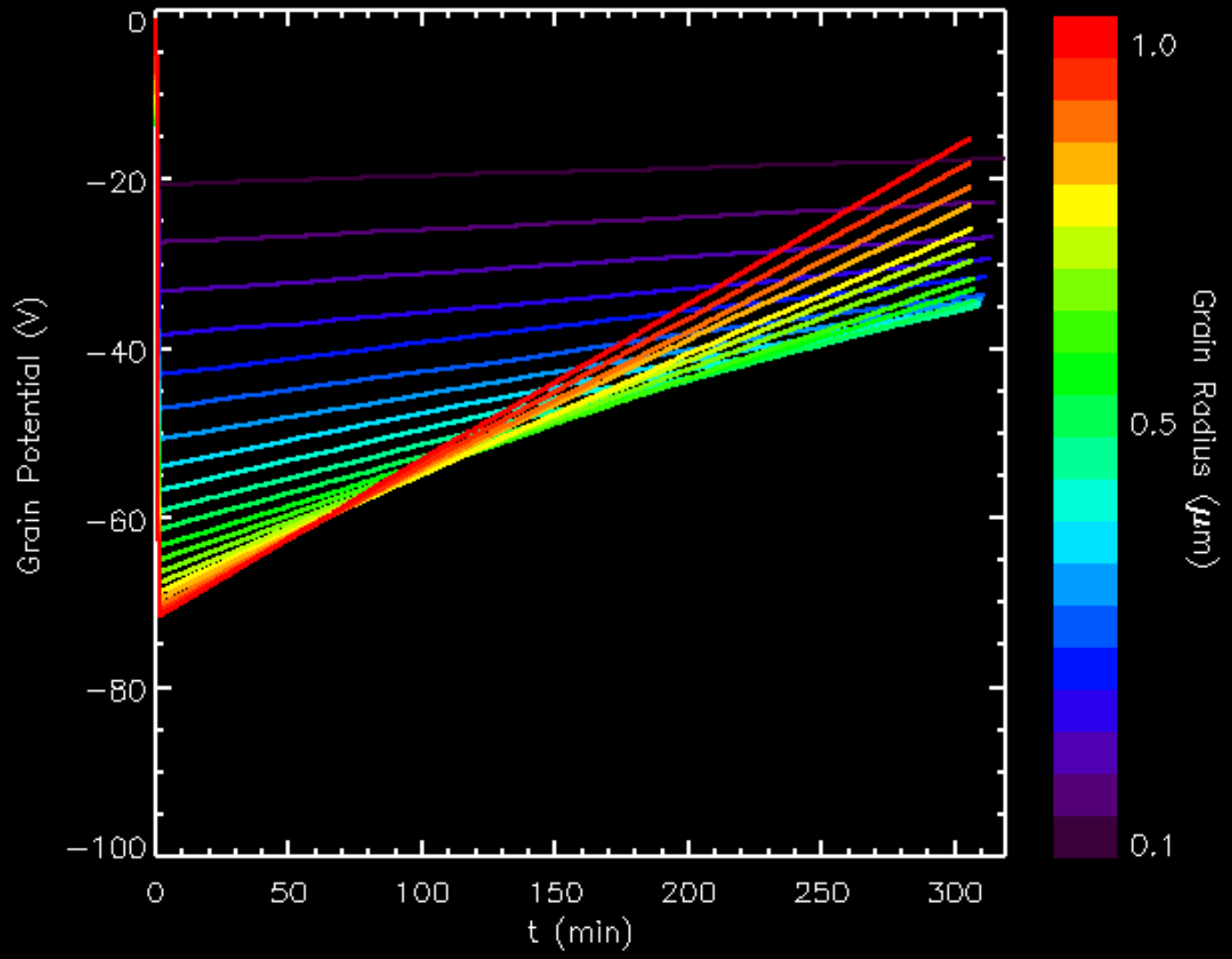
Preferential Geometry
for high Spoke Activity

Peak SKR Emission
Geometry

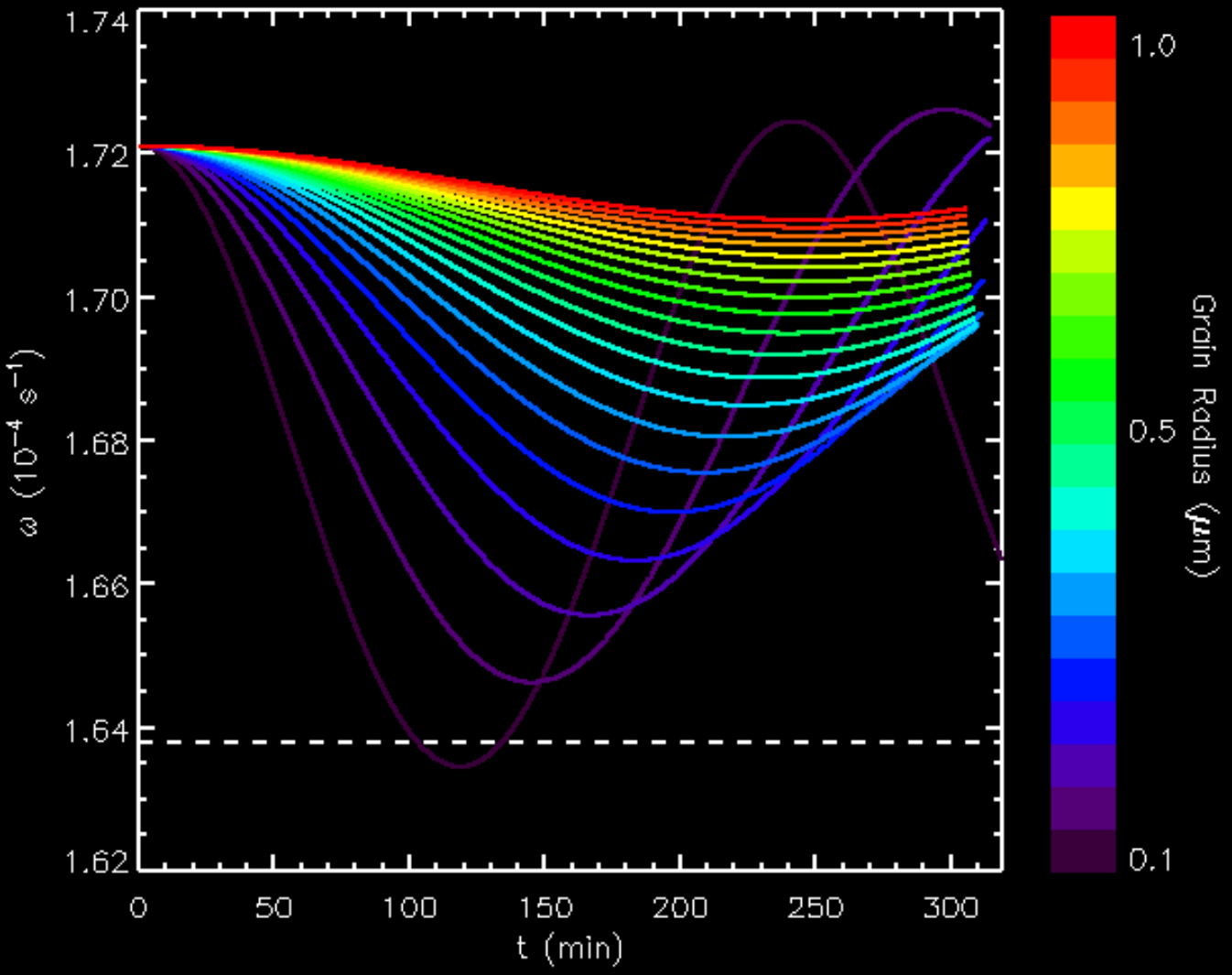


Porco and Danielson, 1982

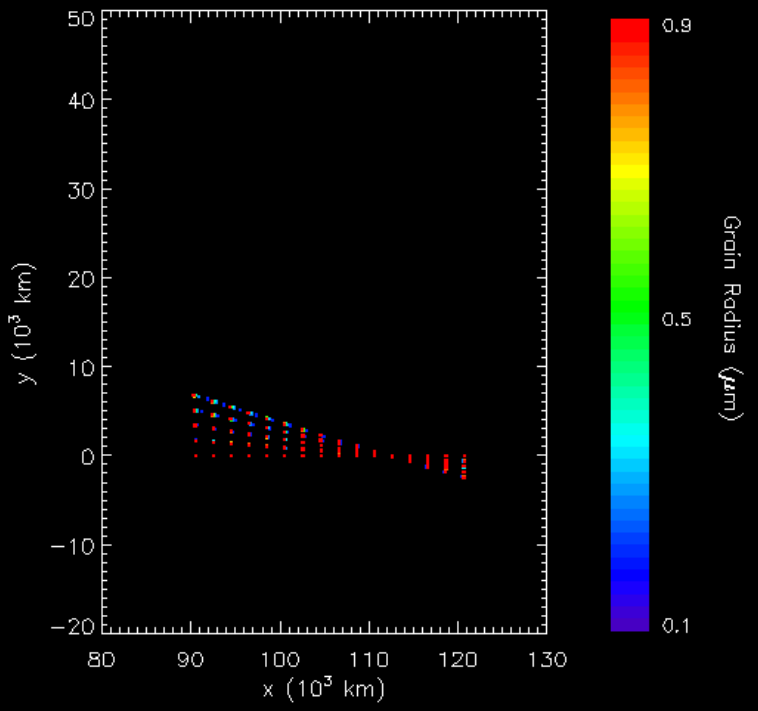
Dynamics


0
−20
−40
−60
−80
−100
Grain Potential (V)
0
50
100
150
200
250
300
t (min)
1.0
0.5
0.1
Grain Radius (μm)

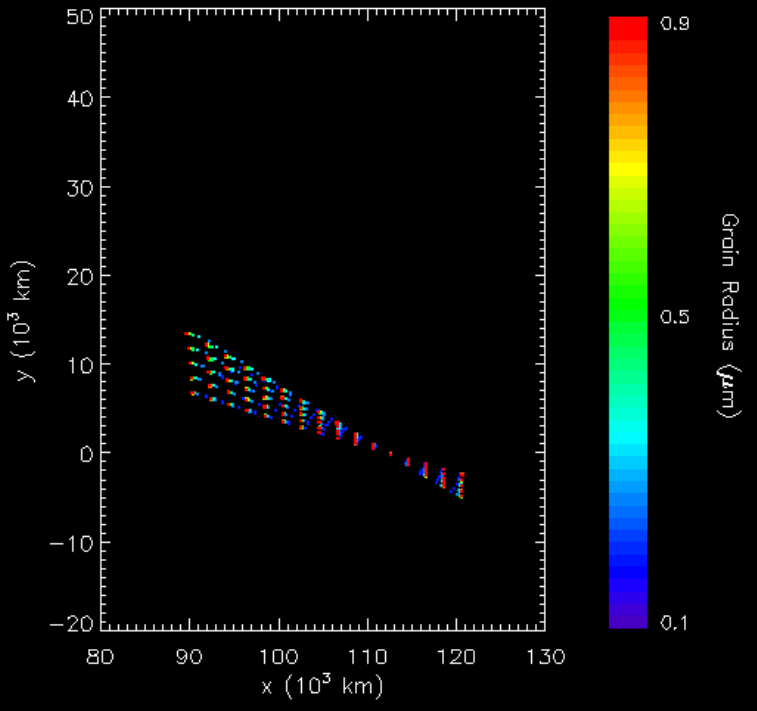
Dynamics


1.74
1.72
1.70
1.68
1.66
1.64
1.62
ω (10^-4 s^-1)
0
50
100
150
200
250
300
t (min)
1.0
0.5
0.1
Grain Radius (μm)

Dynamics

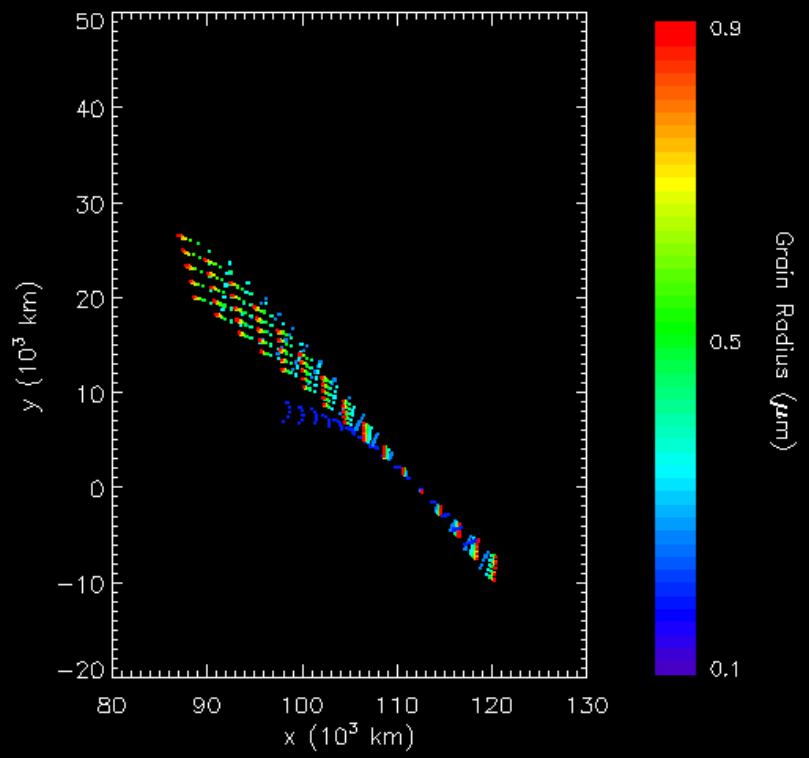


t=0

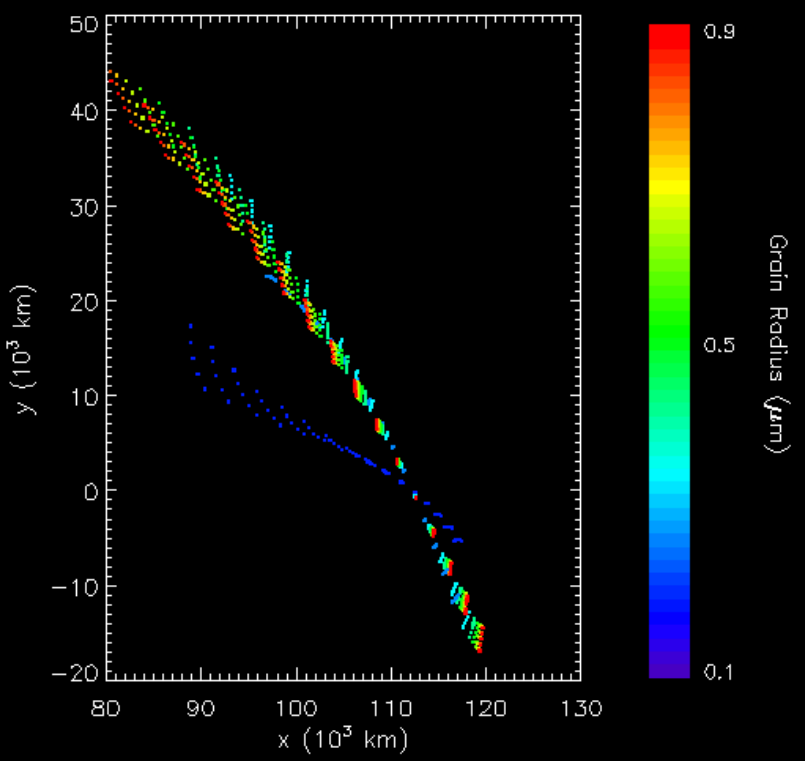


t=20 min

Dynamics



T = 1 hr



T = 2 hr

Formation Theories

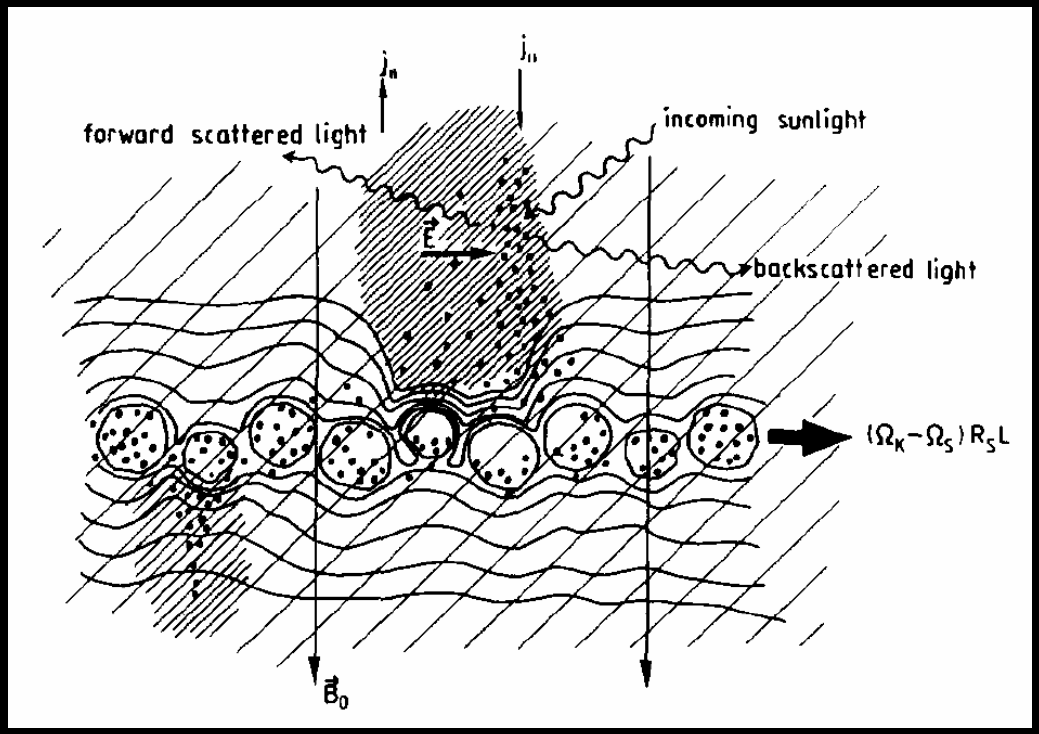
Need to explain:

- Charging and levitation of small grains
- Morphology (some long and narrow, others broad)
- Multiple spokes at nearly same location
- Periodicity with SKR and SED
- Rapid formation (perhaps < 5 mins)

Two possibilities:

- Impacts
- Lightning

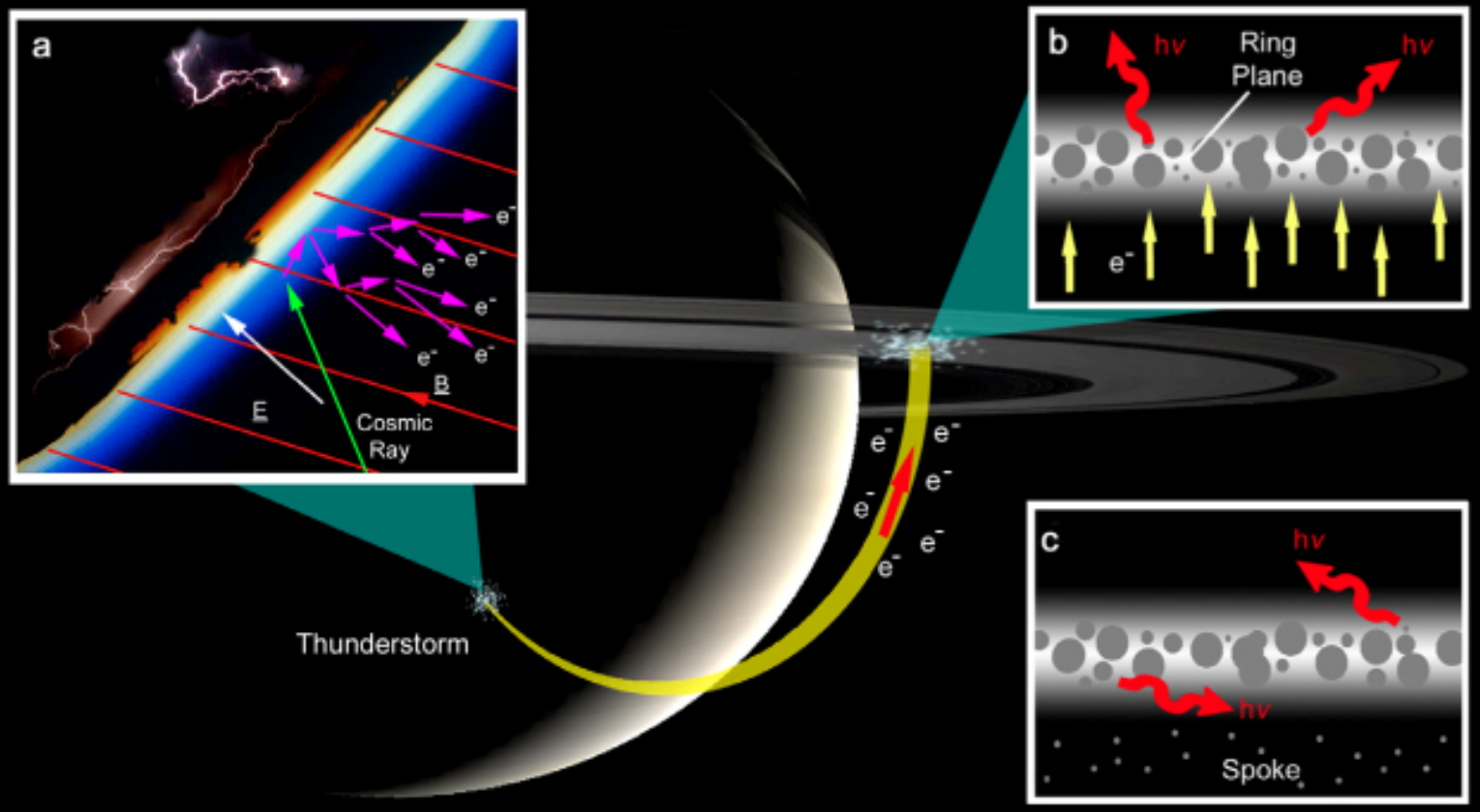
Impacts



Goertz and Morfill, 1983

- Impact produces plasma
- Plasma charges dust
- Dust levitates
- Electric field is produce as dust leaves plasma
- E x B drift pushes plasma radially

Lightning



Jones et al. 2006

Model Features

Impact:

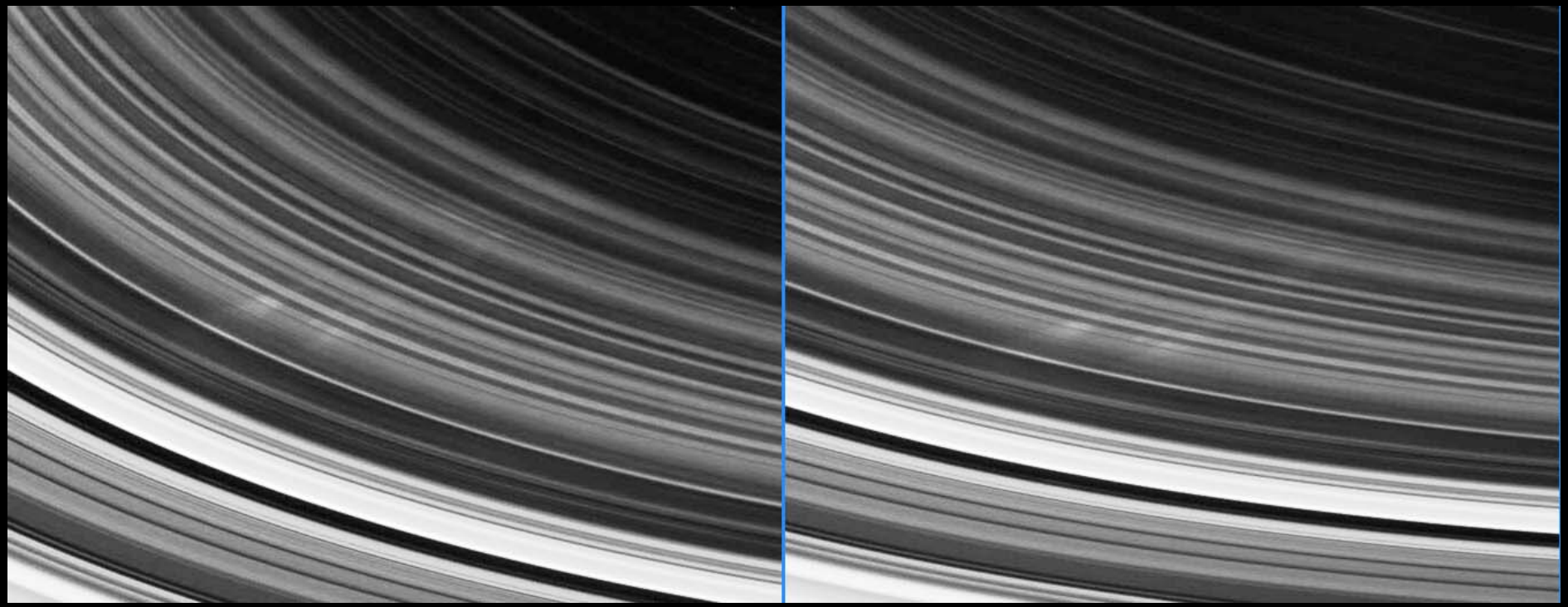
- Explains long narrow spokes well
- Clusters of spokes would imply multiple impactors
- Radial motion of plasma may not be as fast as once thought

Lightning:

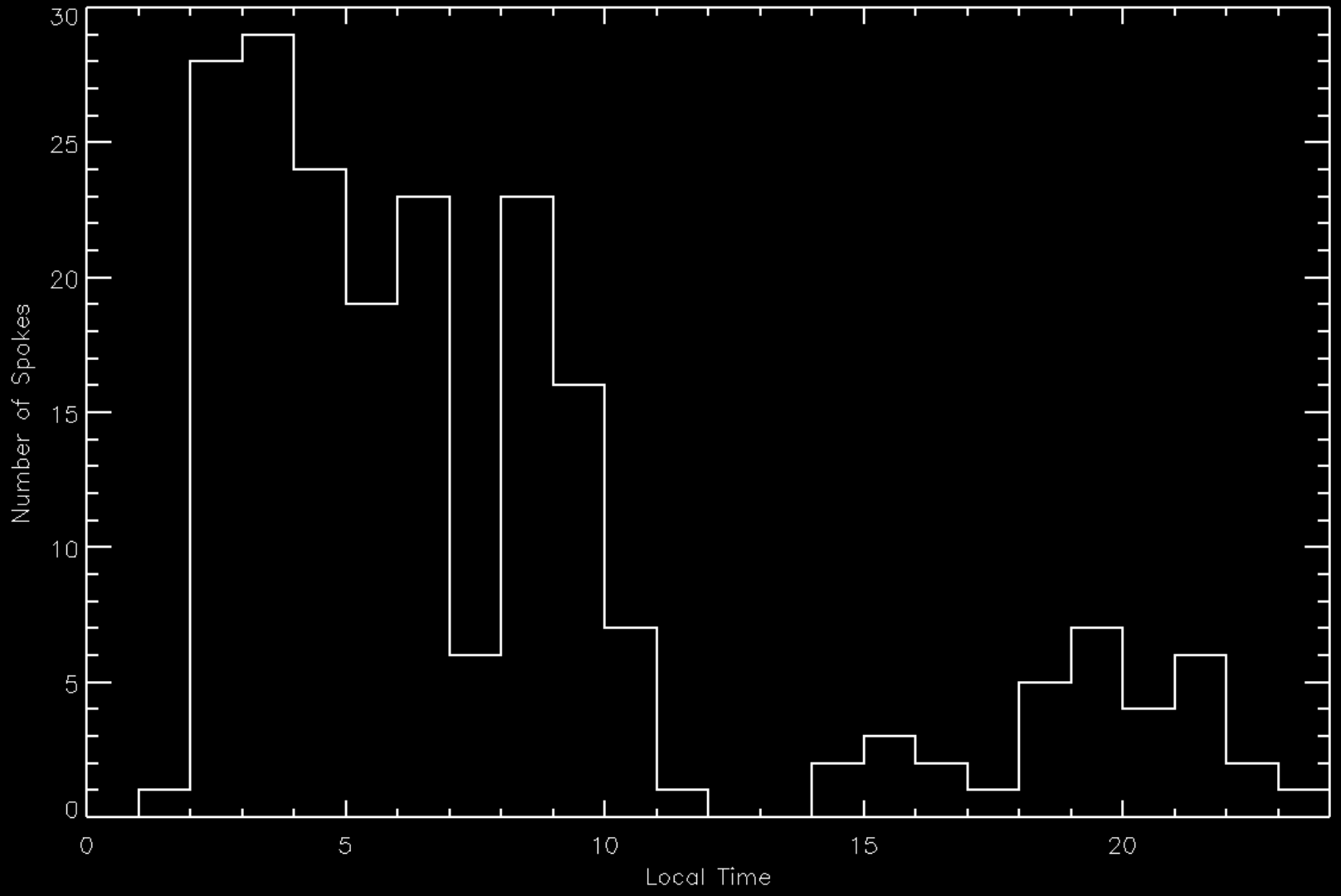
- Explains groups of spokes well
- Has difficulty with long narrow spokes

Cassini Results

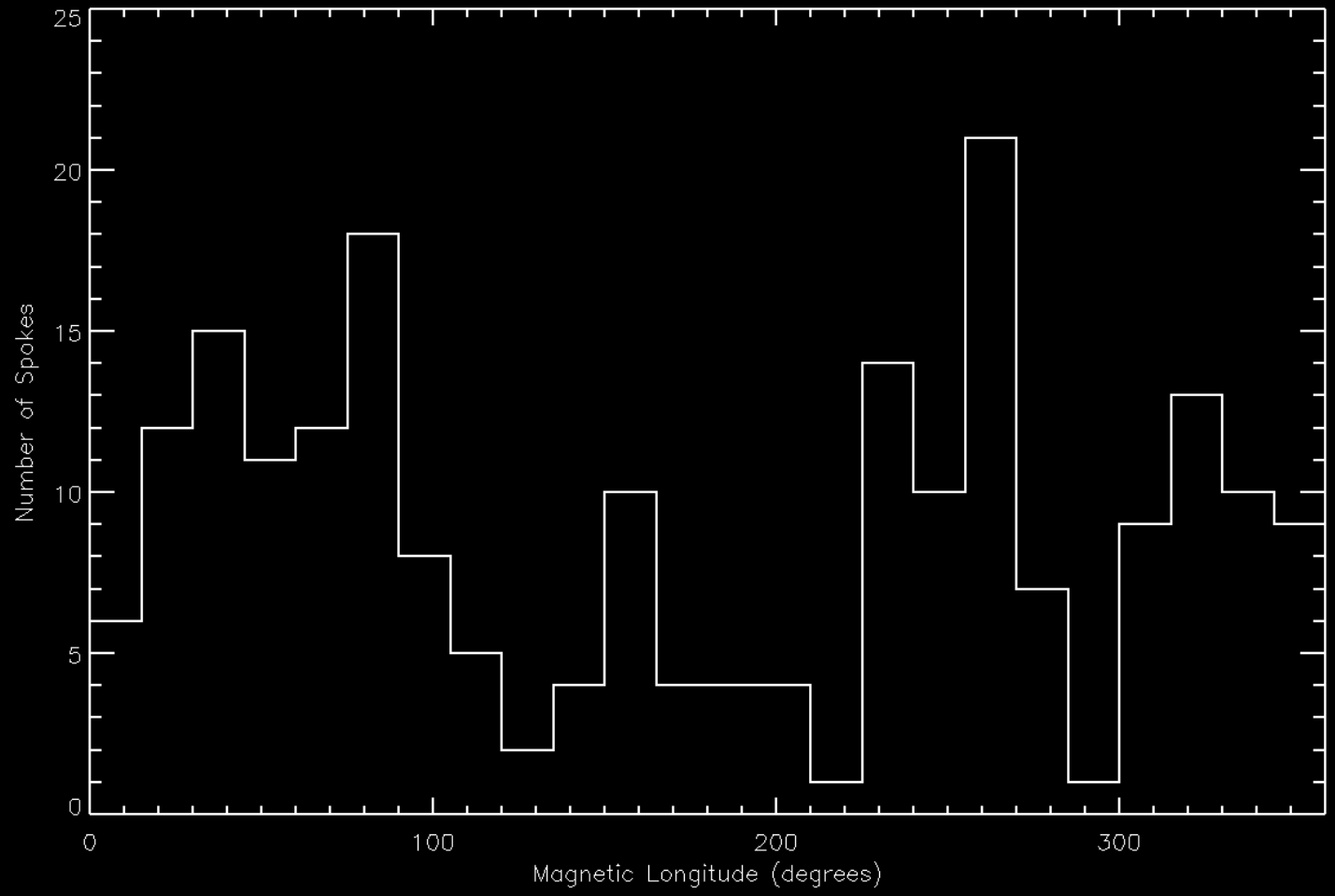
Didn’t see any spokes until Sept. ‘05



Local Time

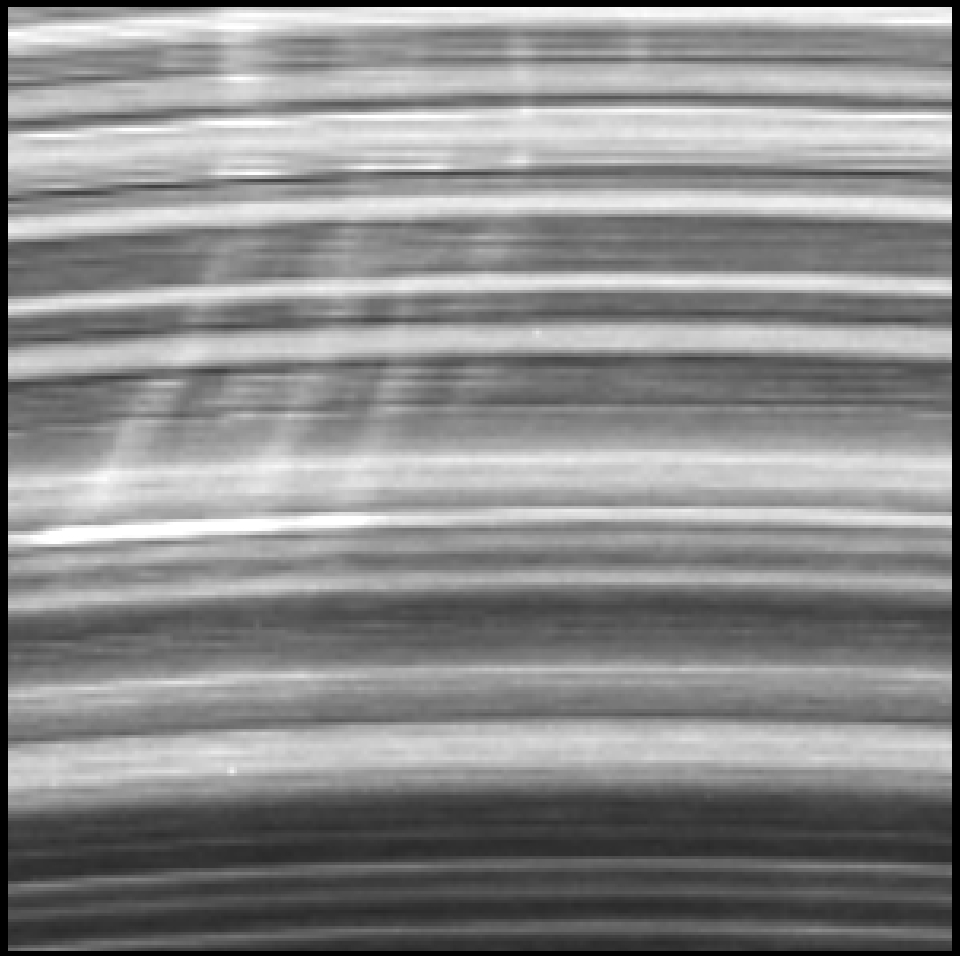


Magnetic Longitude



Mag. Coordinate system by Kurth et al. 2006

Morphology



Spoke Conclusions

The spokes have returned

They appear most abundant on the morning ansa, as expected from Voyager results

They have yet to display any significant dependence on the magnetic field sector

We have yet to see a spoke form

Much work to be done…

Growth of Ring Moons

Pan

(Not a lemon)

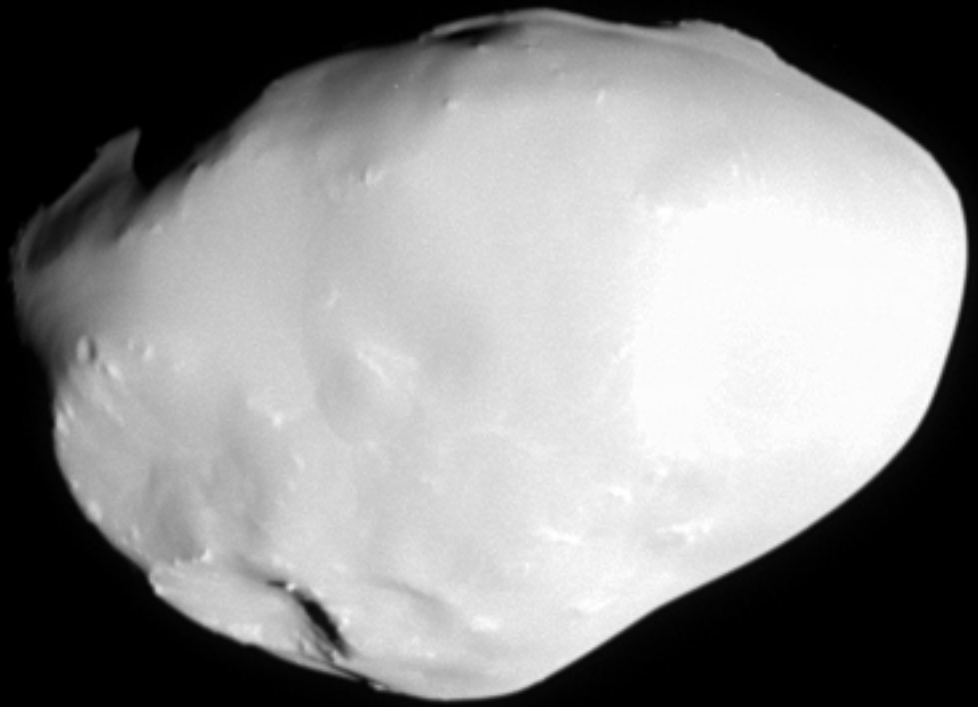
Atlas

(Not a flying saucer)

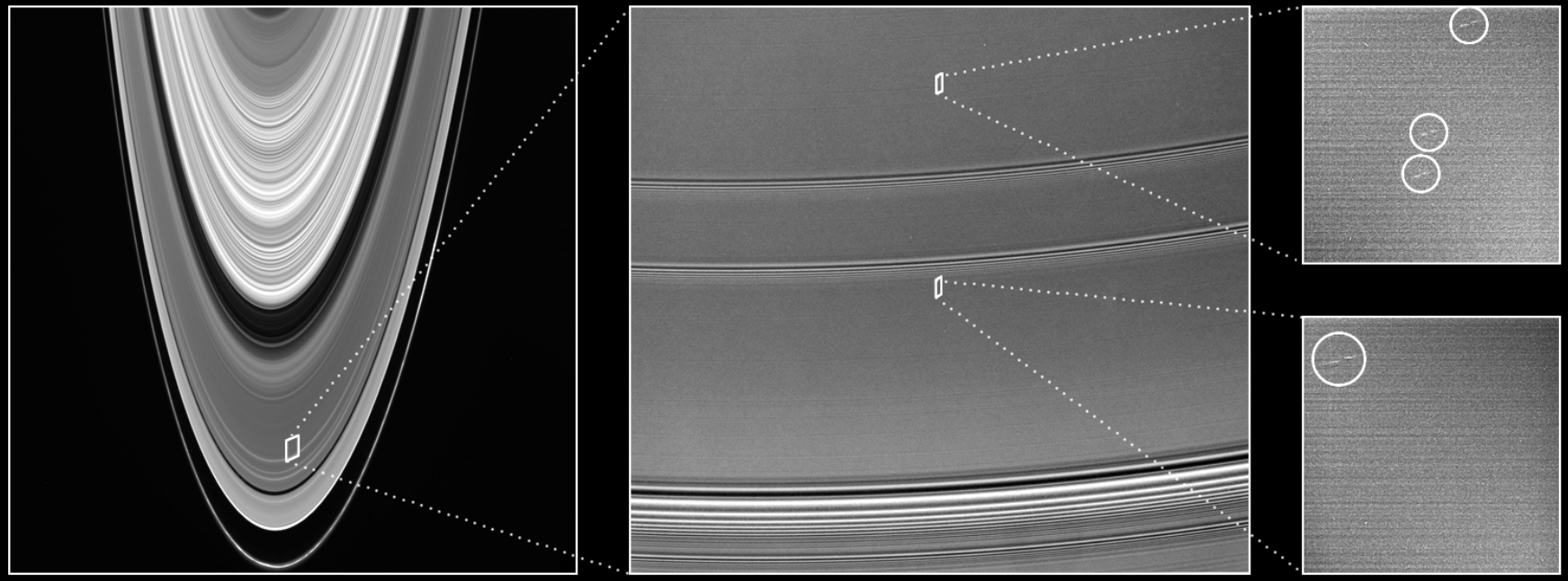
Prometheus

Pandora

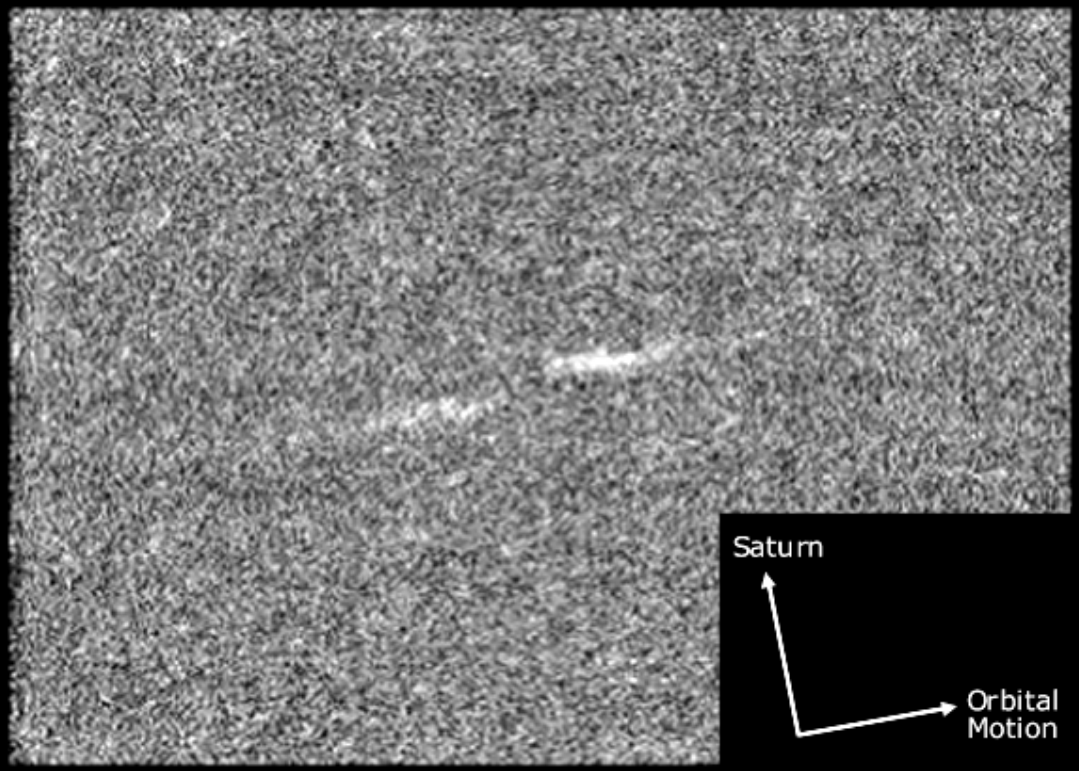
Telesto



Serendipity

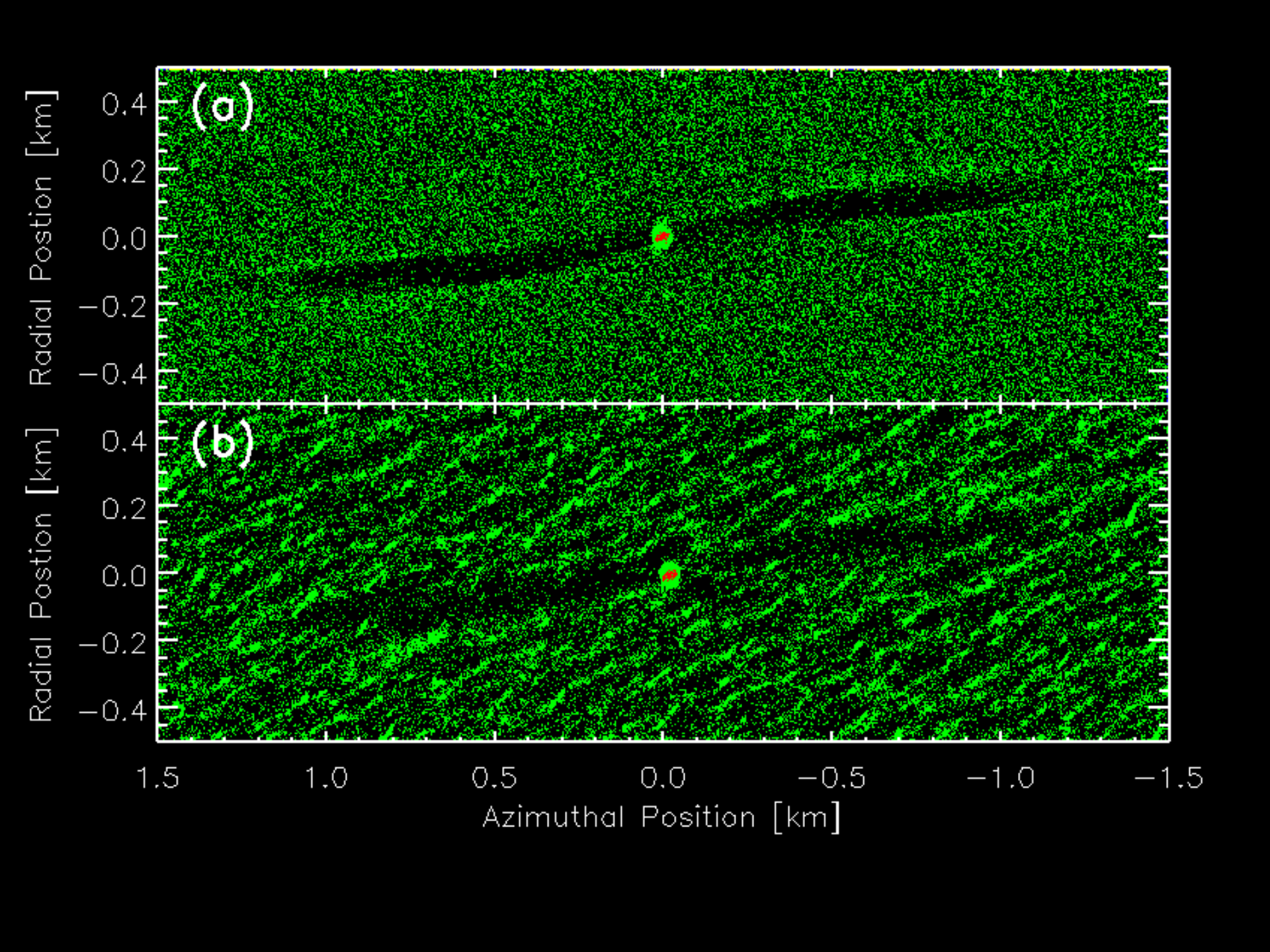


A Propeller in the Rings?

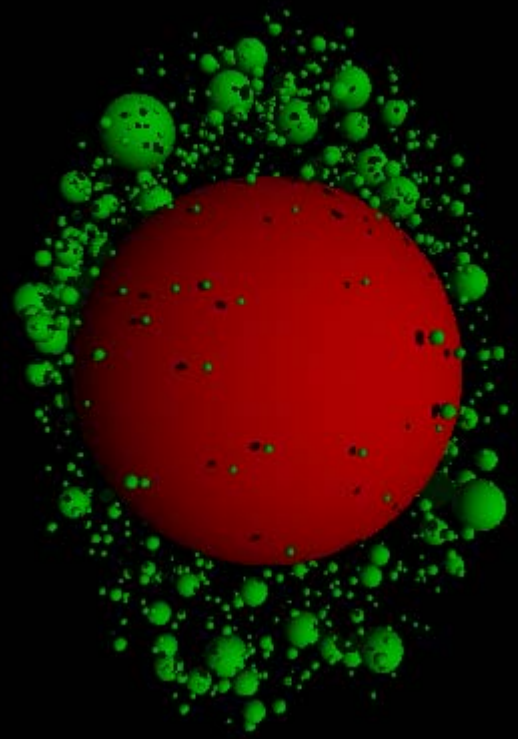


What Was That?

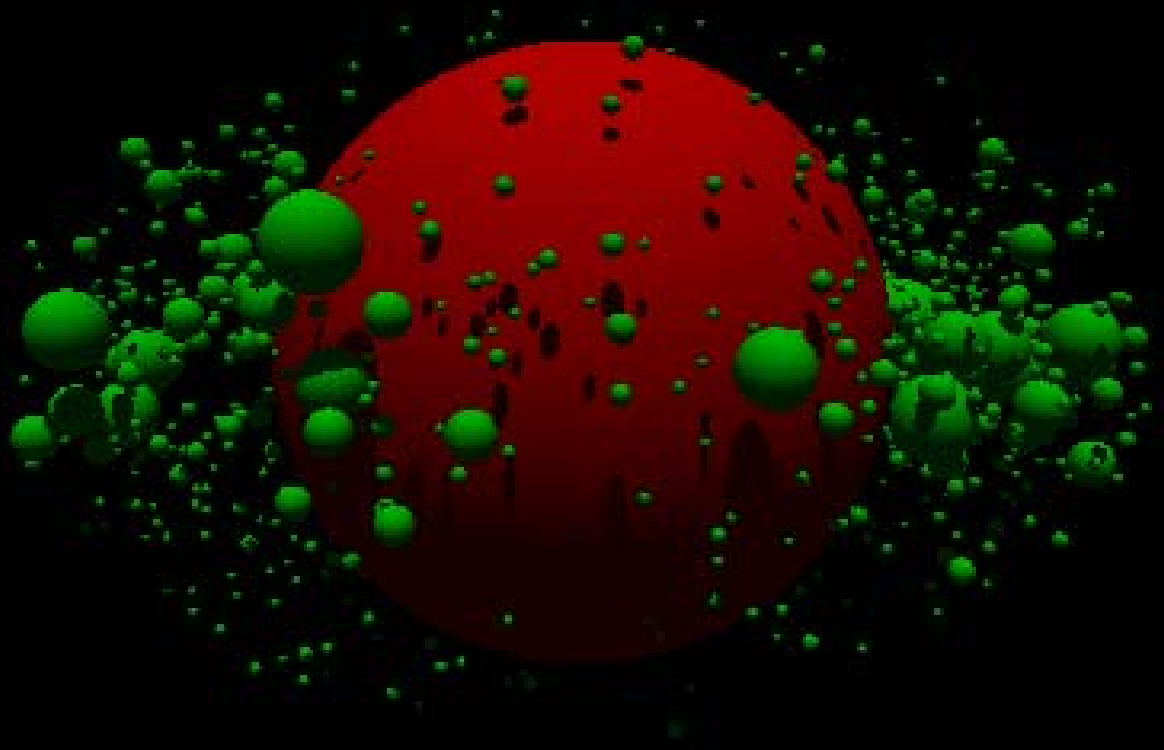
- Probably the signature of a moonlet (~50 m) embedded in the ring.
- What are we actually seeing? Only one way to find out!


(a)
(b)
0.4
0.2
0.0
−0.2
−0.4
Radial Postion [km]
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Azimuthal Position [km]

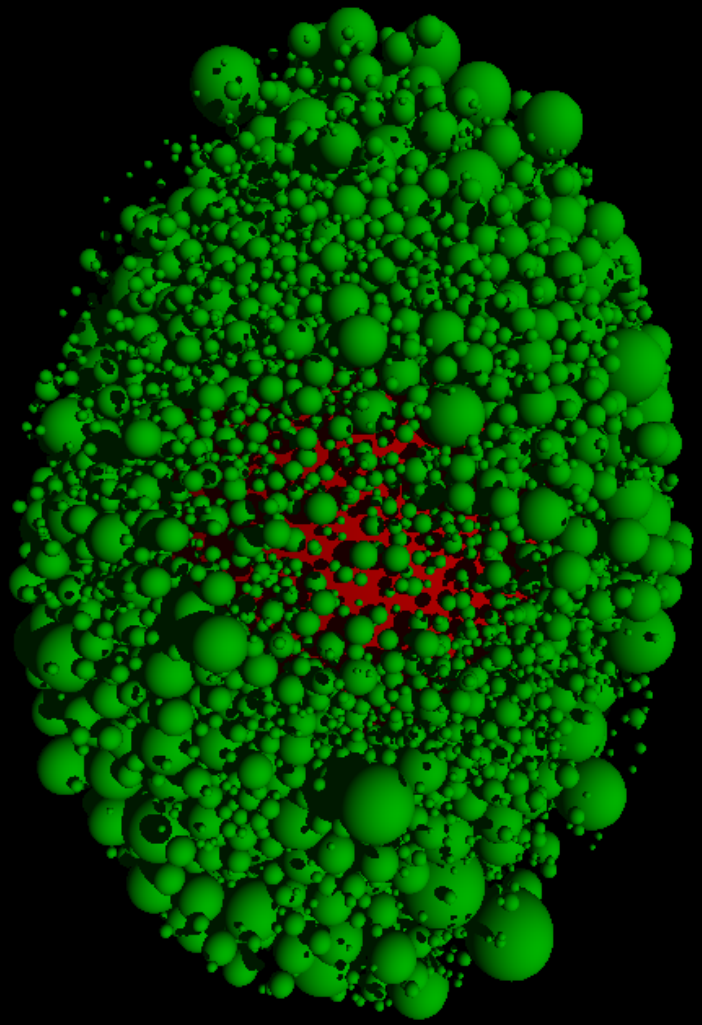
Start of Simulation



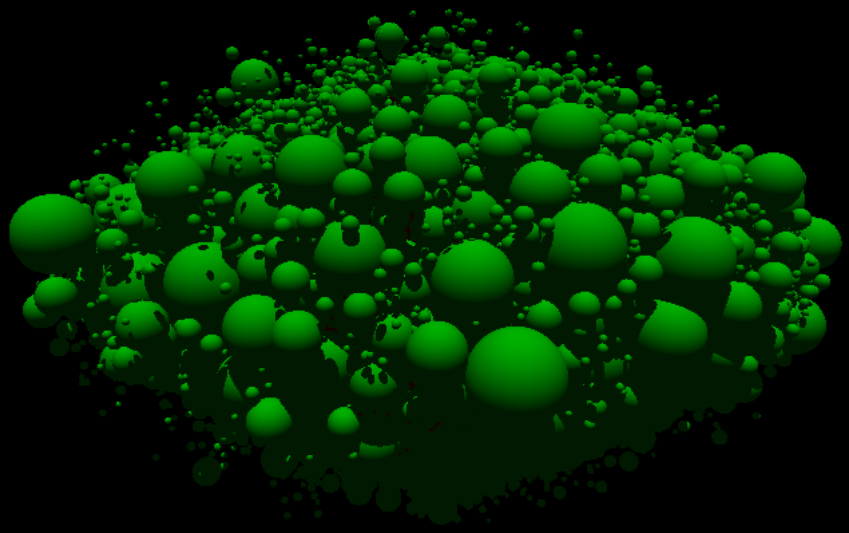
Side View

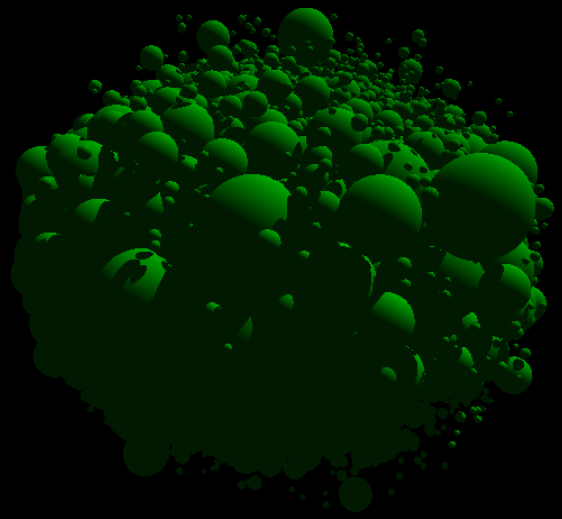


15 Orbits Later…



Side Views





- From along y-axis
- From along x-axis

Why Does Growth Stop?

- Roche Zone = Region around the moon where the moon's gravity dominates
- If one assumes a particular shape for the moonlet, we can work out the critical density at which the moonlet exactly fills its Roche zone: ~ 0.5 g cm^{-3}
- This density is independent of size of the moon

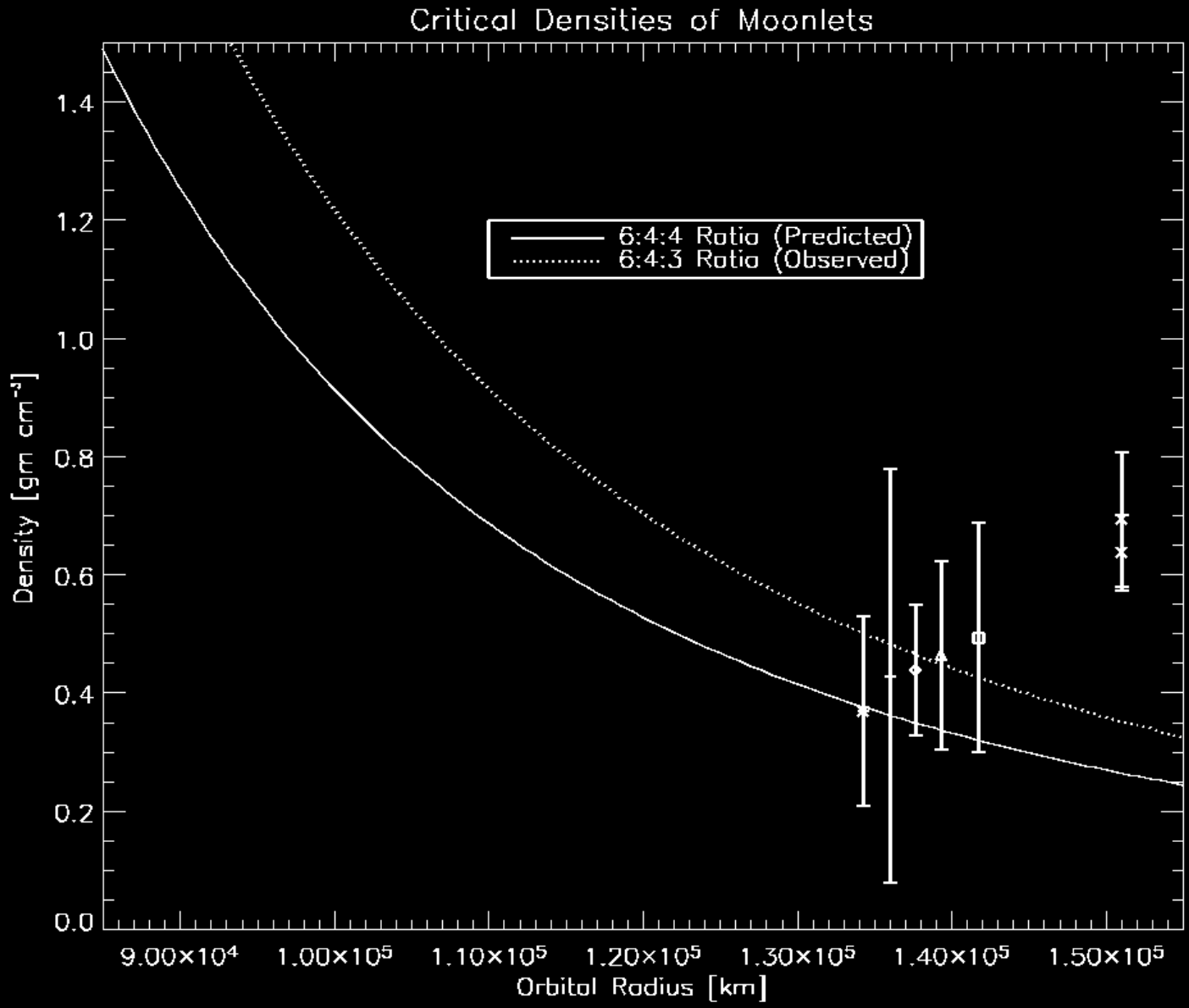
How Long Does it Take?

- Actually, just a few orbits to grow to the final size
- Particles don't always stick around, though
- Given lots of orbits into and out of sunlight, particles might "weld" themselves together, making a more solid moon

Does Growth Always Stop?

- No.
- It depends on how far you are from the planet and how dense the infalling material is
- This theory predicts that the planets, for example, can grow as large as they want. (Which is good, because we're not shaped like lemons!)

How Dense Are They?



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