The Smallest Free Particles in Saturn’s Rings

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- Philip Nicholson (Cornell), Matthew Hedman (University of Idaho) - Co-authors
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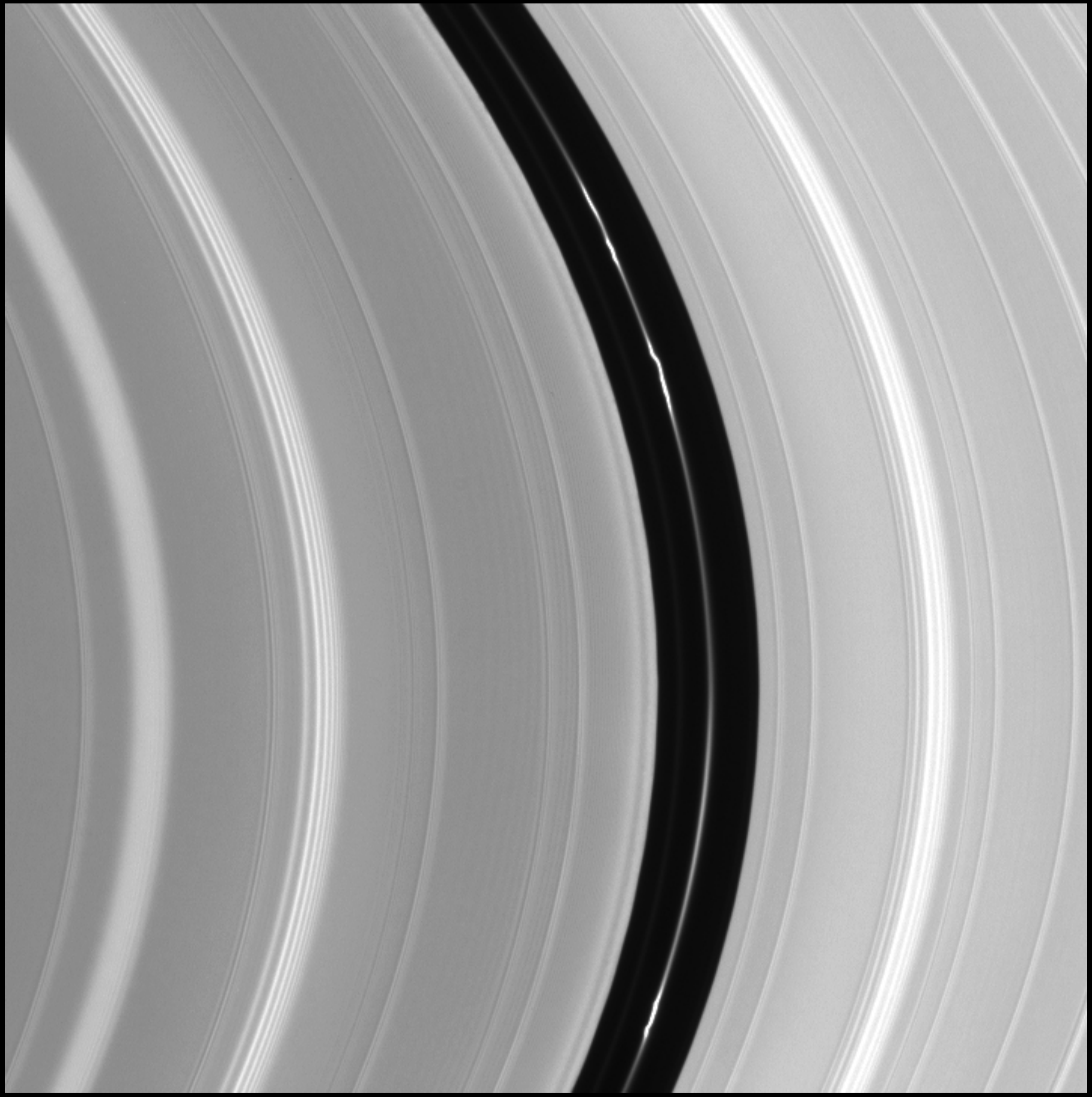
Outline

1. Introduction
   - Saturn’s Rings & Cassini
   - Occultations
   - Particle Size Distributions
2. Solar Occultations
   - Data Analysis
   - The C Ring
   - The A Ring (is more complicated)
3. Conclusions about Ring Particle Size Distribution

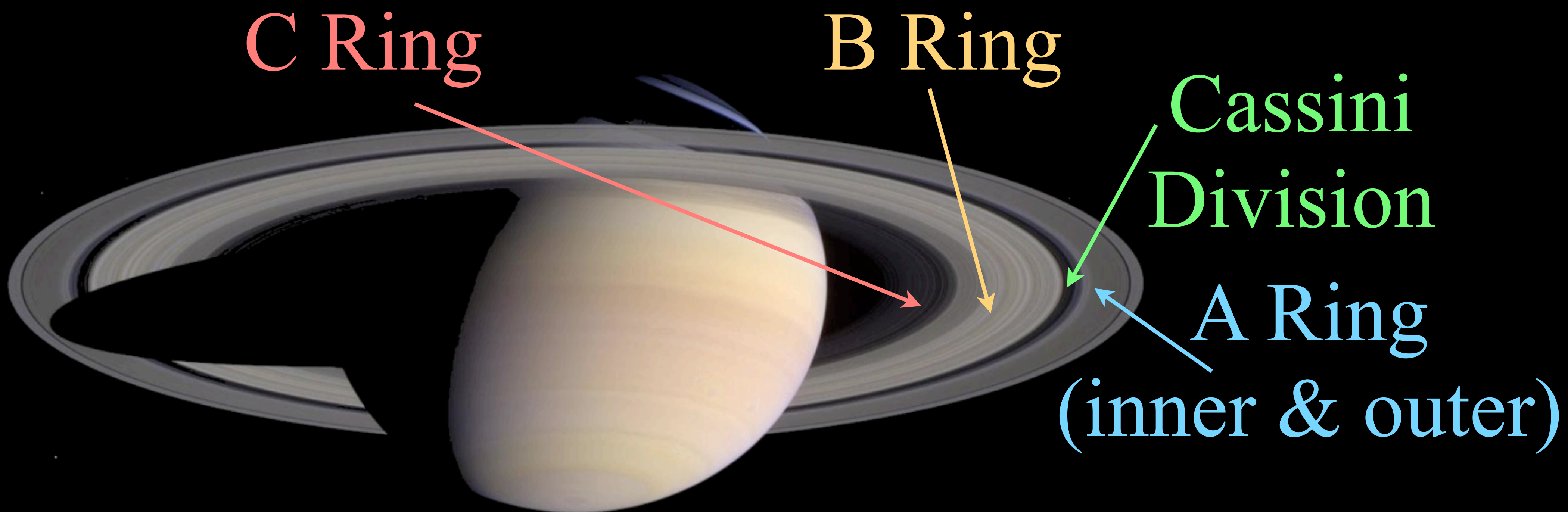
Motivation

Why do we care about what size Saturnian ring particles are?

- Better models of Saturn ring s dynamics.
- A better understanding of Saturn's rings and their possible origin and evolution.
- Rings are our local debris disks (common objects in the Universe).

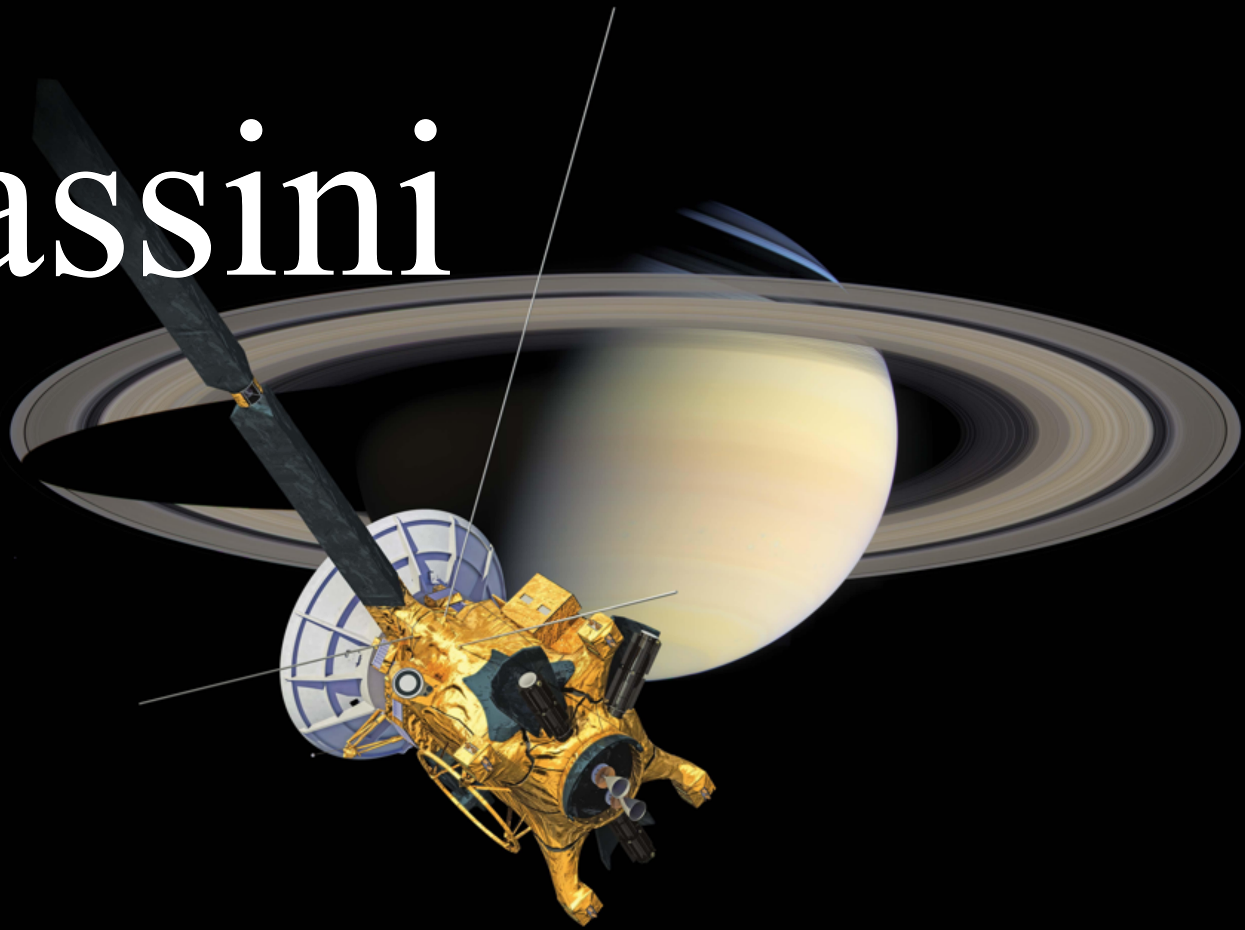


The Rings of Saturn

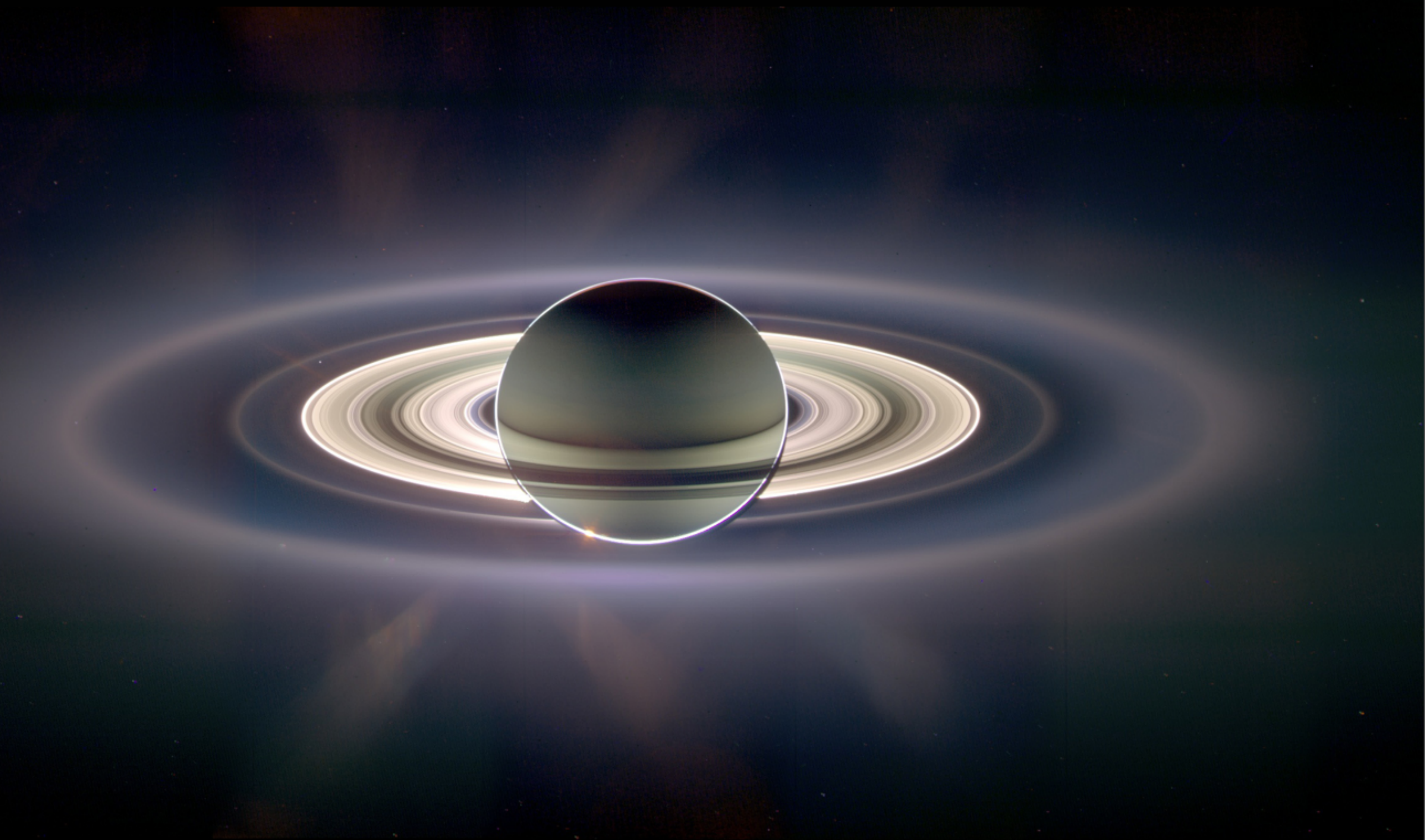


- The Main Rings are made of solid pieces of water ice + trace impurities.
- Rings exist because tides > self-gravity.
- The rings have distinct regions with different properties.

Cassini



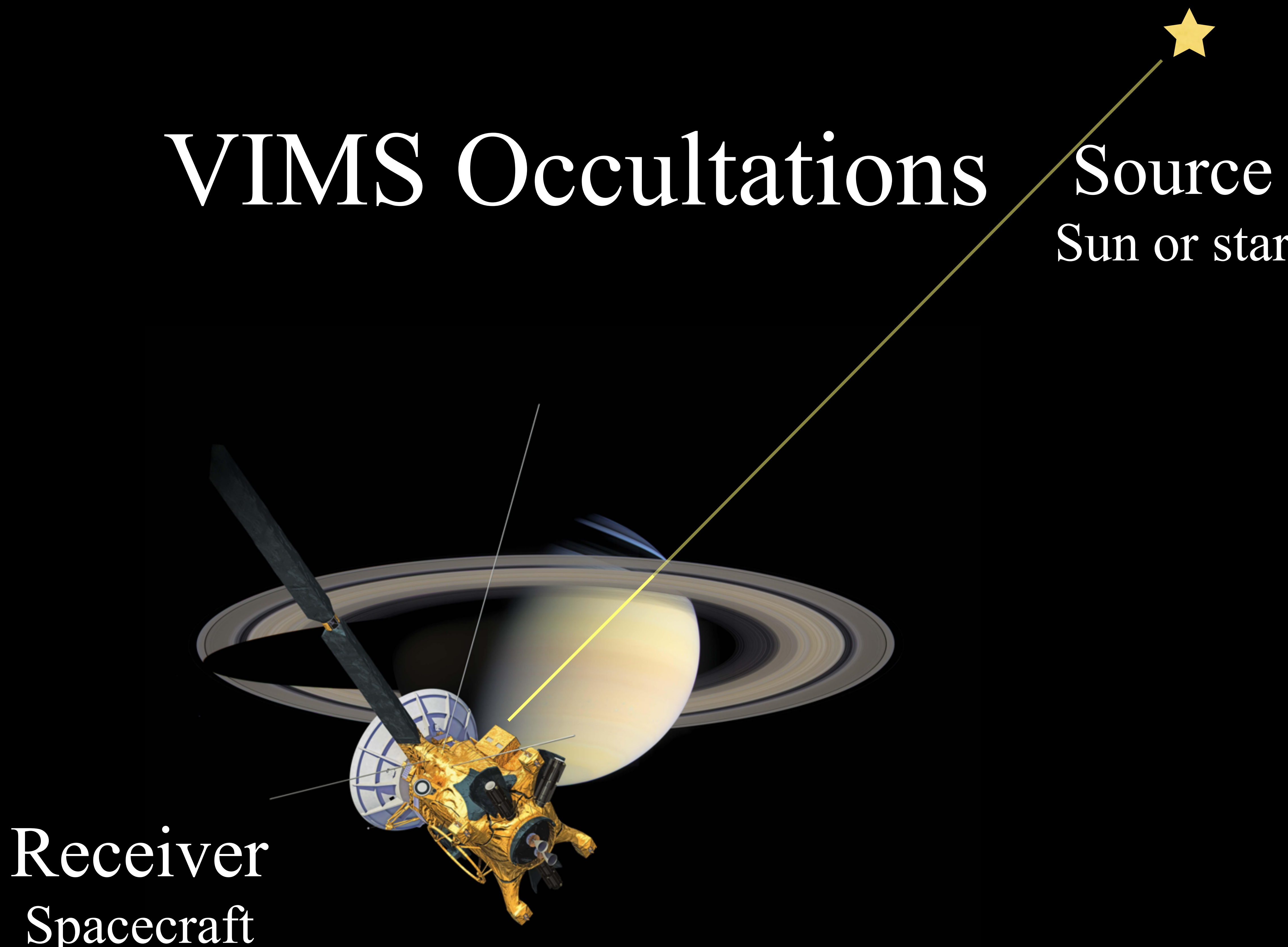
- Cassini entered orbit around Saturn in 2004.
- Constantly changing geometry as repeated close encounters with Titan alter the orbit.
- Able to achieve resolutions and geometries impossible from Earth



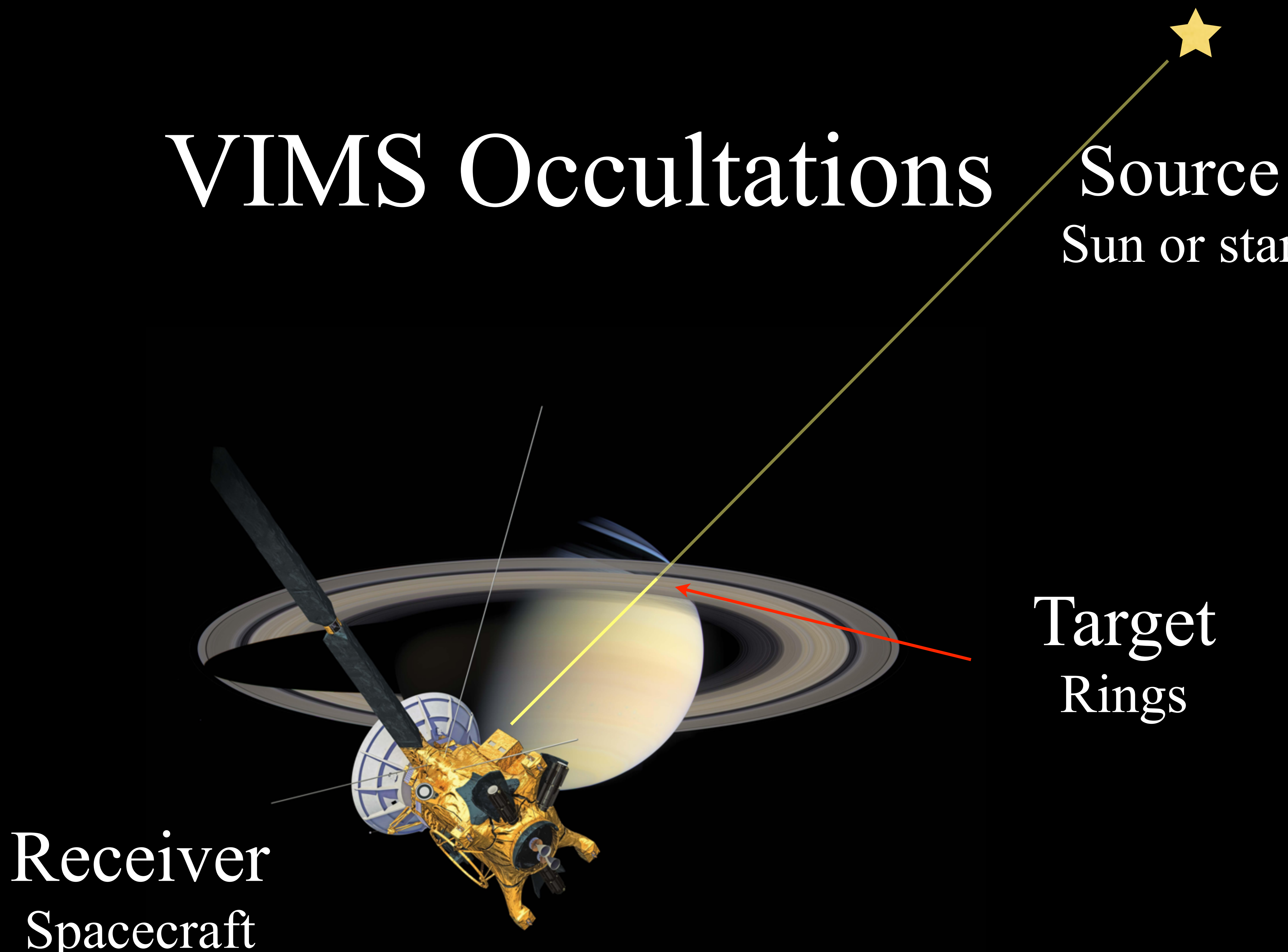
Visible-Infrared Mapping Spectrometer

- 256 infrared channels.
- Wavelength range from 0.9 to 5.2 μm in occultation mode.
- Pixel size 0.5 x 0.5 milliradians
- Boresight allows solar observations
- Capable of imaging pixel-by-pixel.

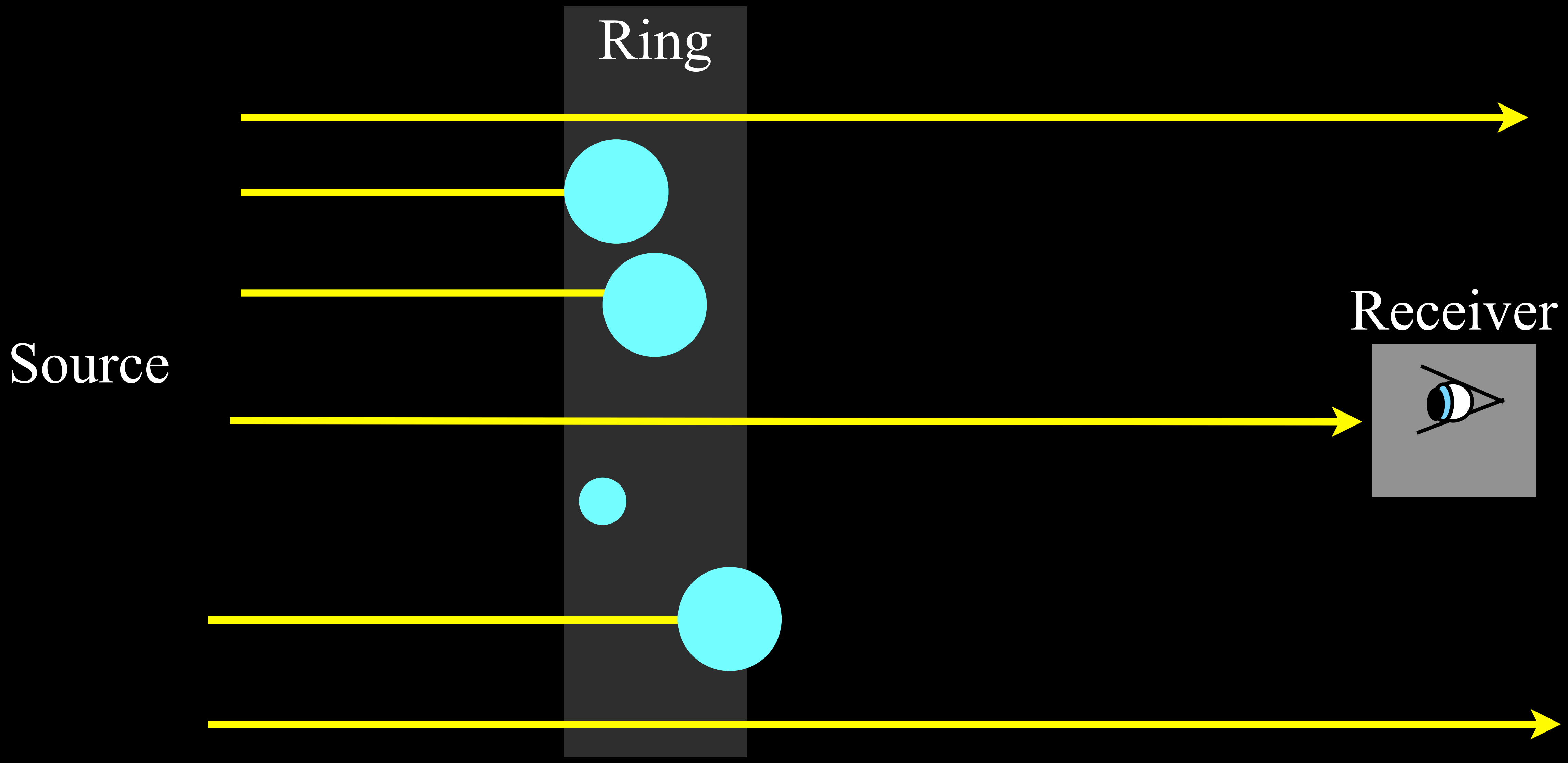
VIMS Occultations



VIMS Occultations

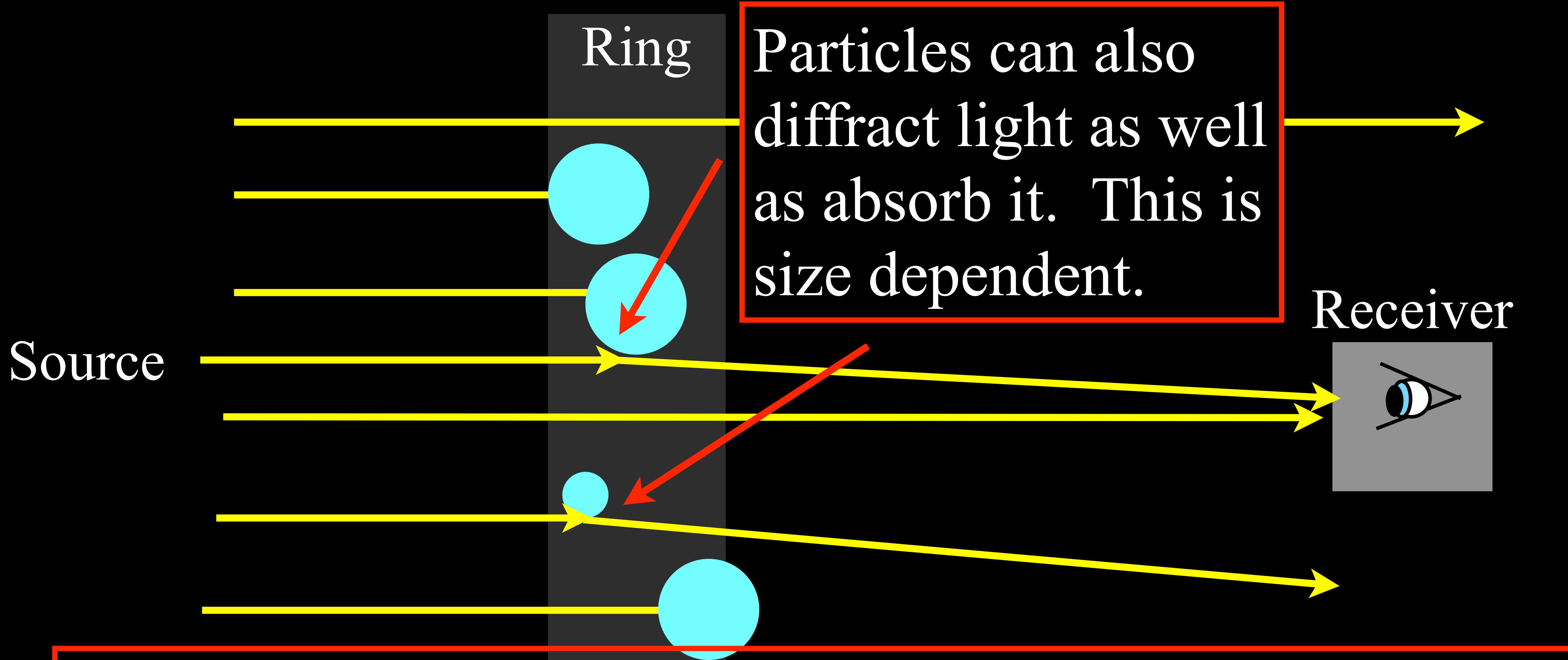


Occultations



Some light makes it through the ring,
Some light is absorbed /reflected by ring particles.

Occultations

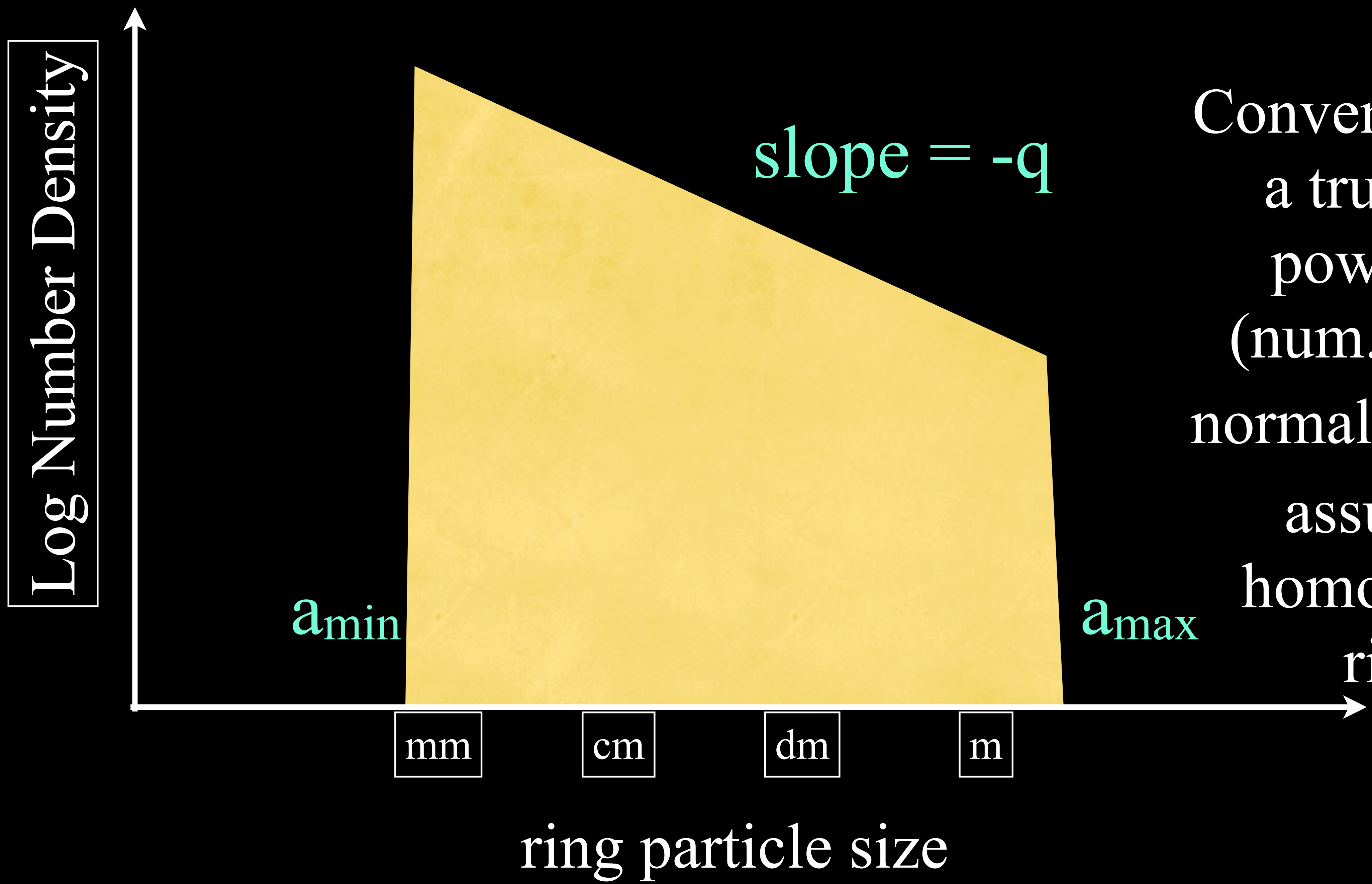


$$\theta \sim \lambda/a$$

0.5 mrad @ 2 μm —> mm-sized ring particles

Diffracted light would make an aureole around the source.

Modeling the Particle-Size Distribution

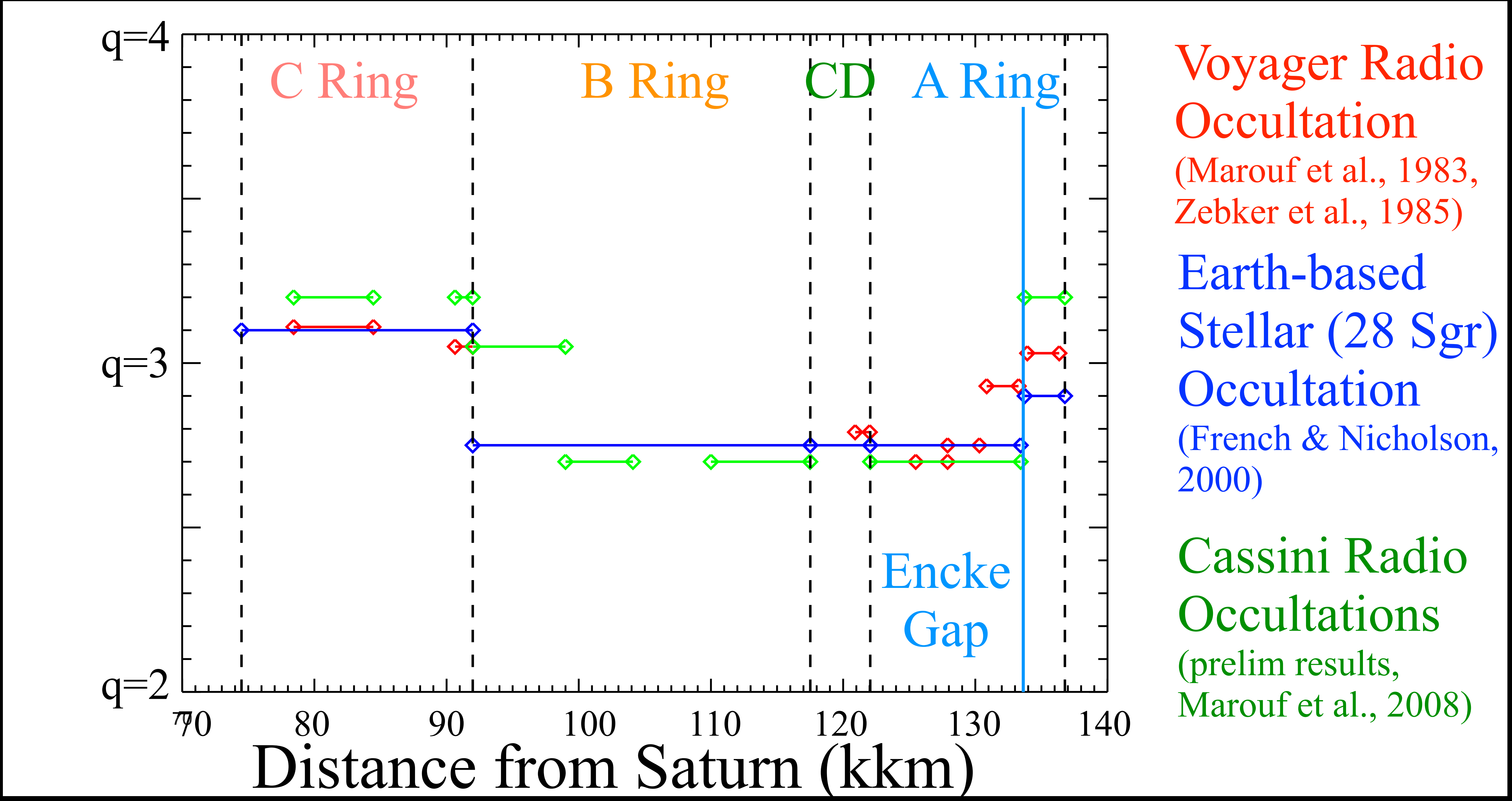


Convention uses a truncated power law (num. density normalized by τ, assuming homogenous ring)

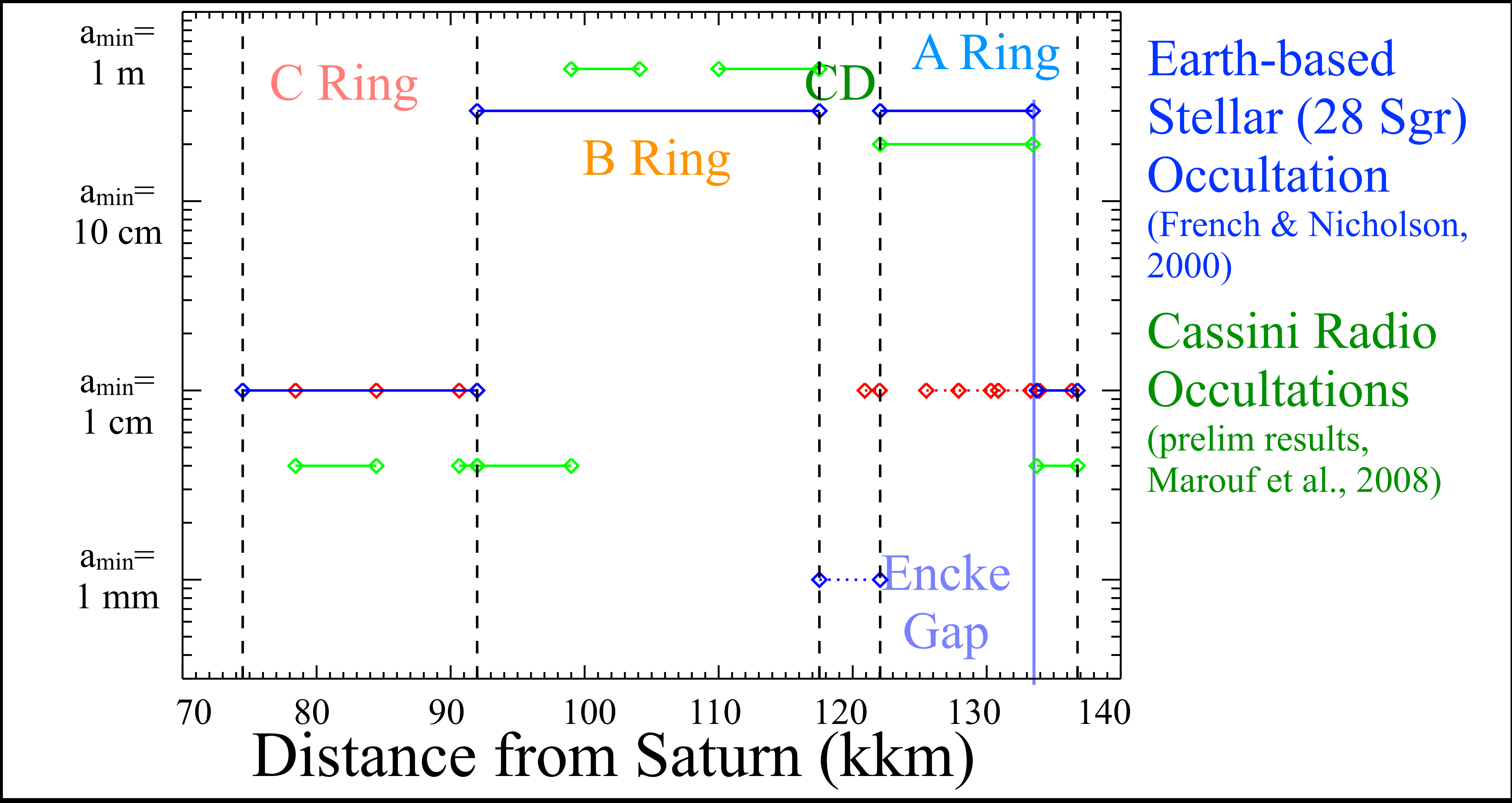
Previous Knowledge: General

- There is little free ring material smaller than millimeter-sized ring particles.
- Not much is known about the exact lowest cutoff size. (a_{min})
- The size-distribution steepens markedly at ~5-10 meters, acting like an upper cutoff (a_{max})
- The size distribution of the ring particles between centimeters and meters acts like a power law of $q \sim 3$.

Previous Knowledge: Ring Regions

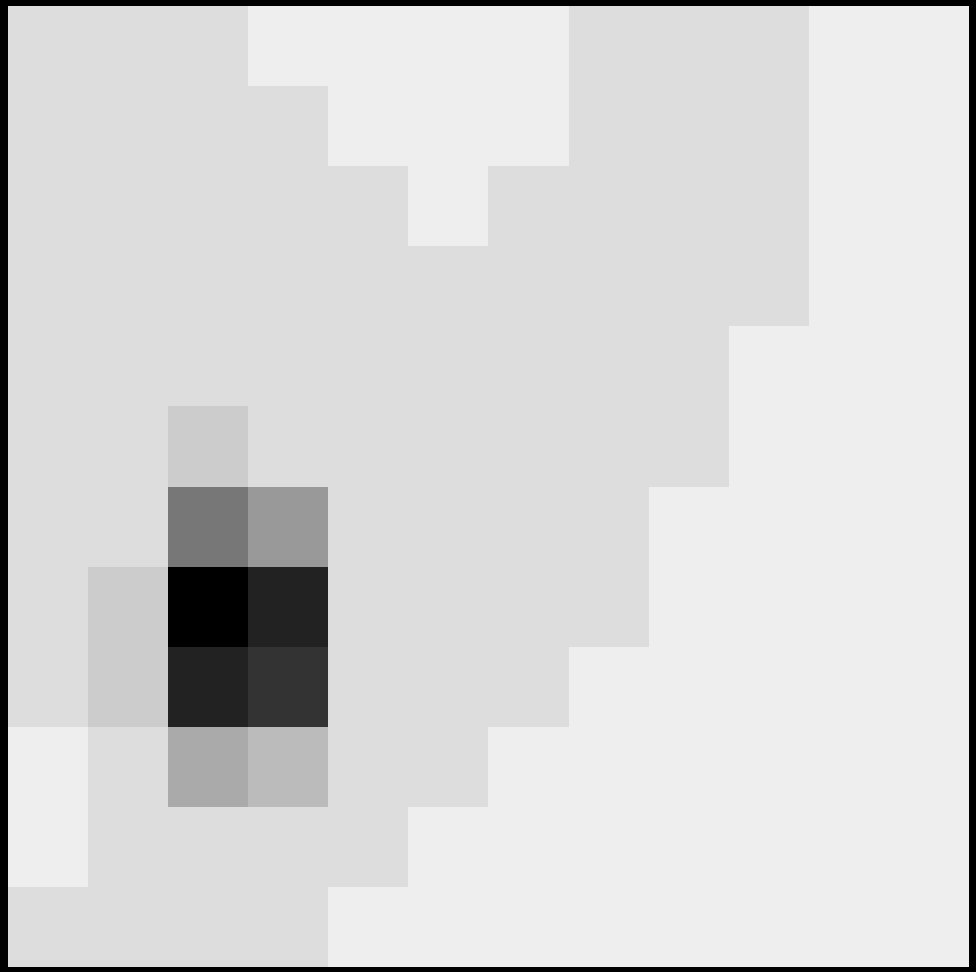


Previous Knowledge: Ring Regions



Solar Occultations

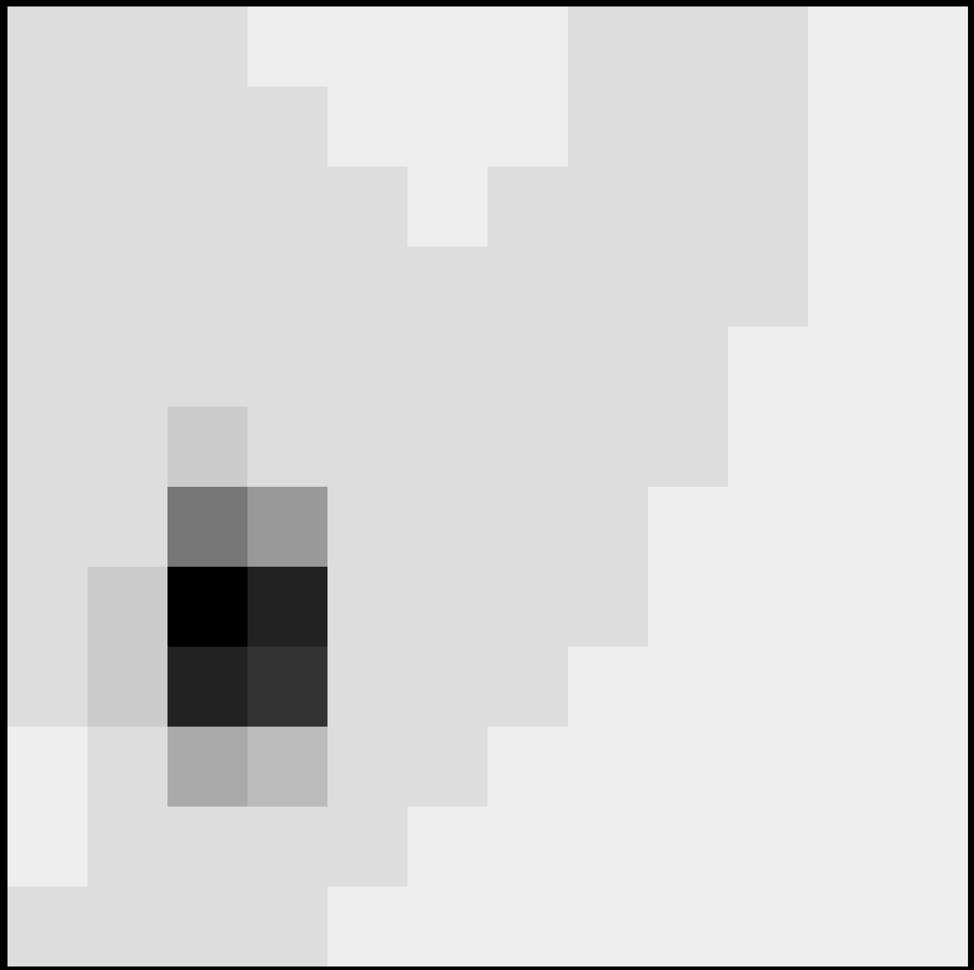
- Details in Harbison et al., 2013, in *Icarus*
- Taken as 12 x 12 pixel images.
- 6 occultations had sufficient S/N.



Reverse-contrast VIMS image of the Sun

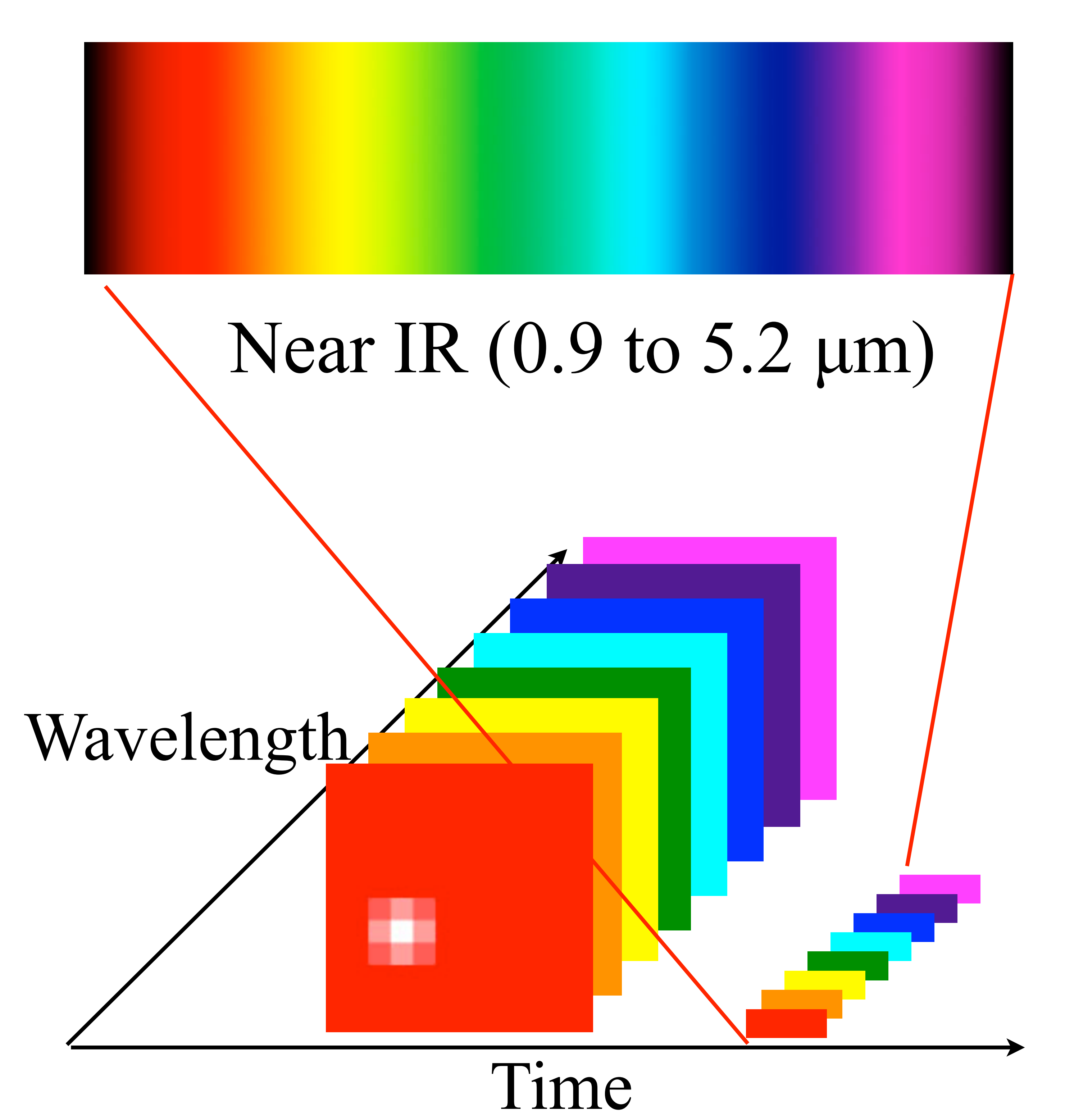
Instrumental Effects

- This is an image of the Sun outside the rings.
- Instrument-scattered light is stronger than the halo from ring particle diffraction.
- How to measure it?



Background is ~1/10 of peak solar signal

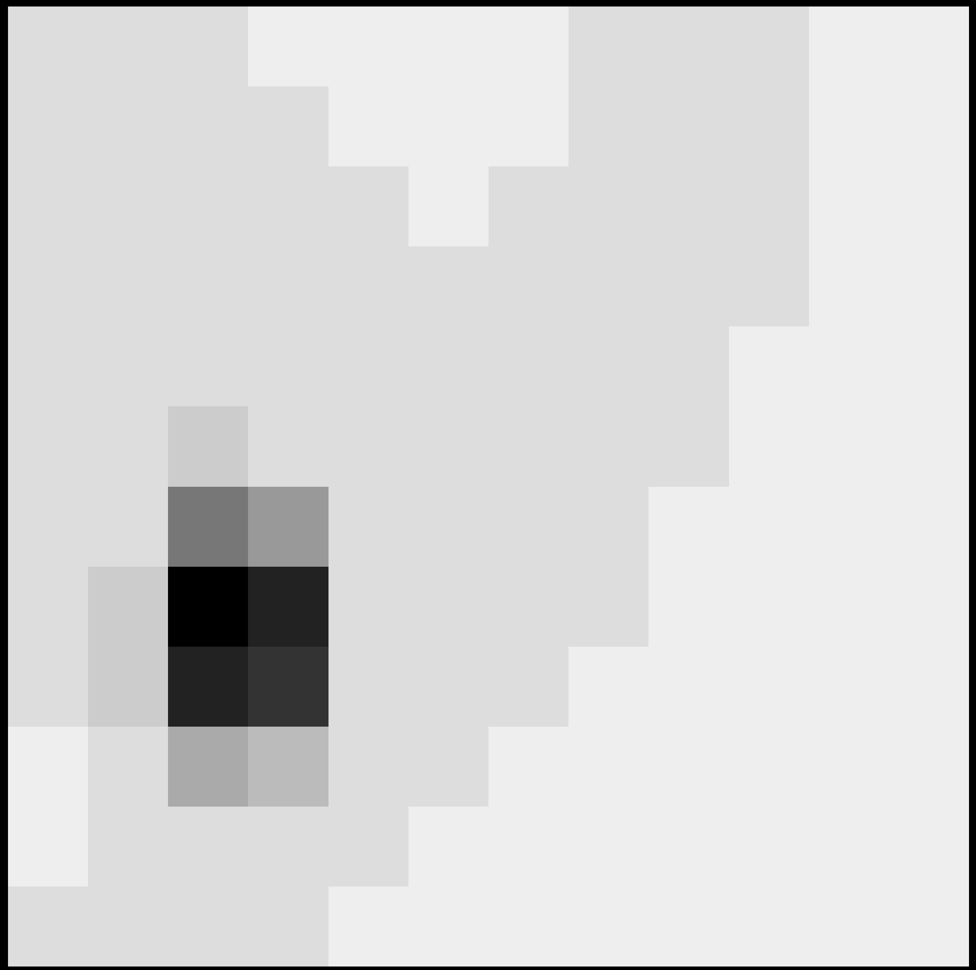
VIMS Imaging (Theory)



- Light enters the solar port and is attenuated.
- A small mirror directs part of the field of view into the spectrometer.
- This creates a spectrum of one pixel.
- The mirror tilts to direct the next pixel's light onto the spectrometer.

VIMS Imaging (Practice with Solar Port)

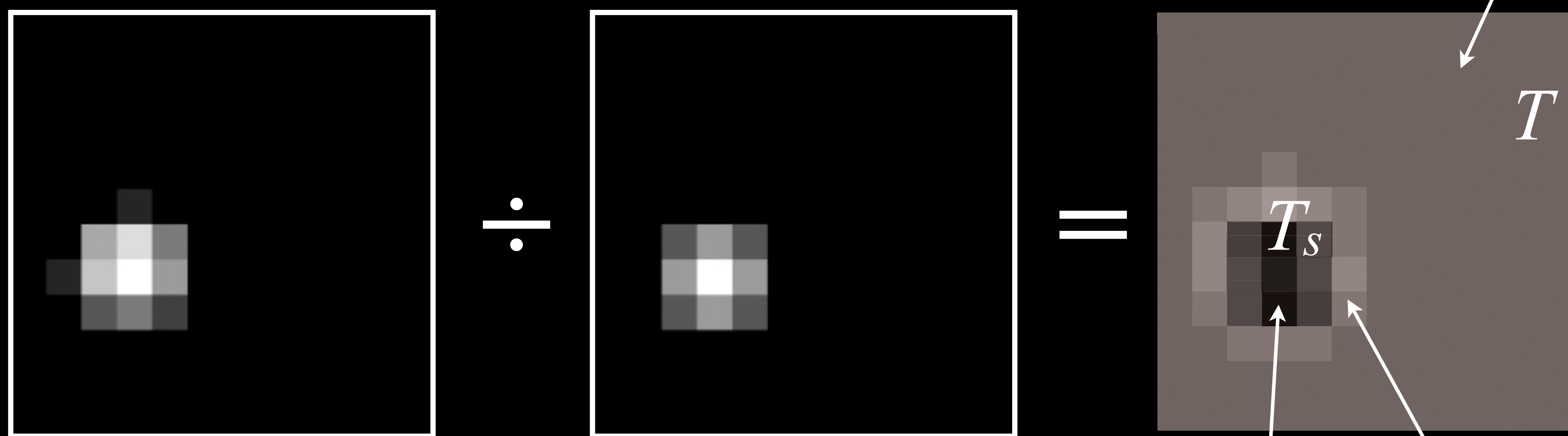
- Light enters the solar port and is attenuated and scattered.
- A small mirror directs part of the FOV into the spectrometer.
- Scattered light from the entire FOV also enters the spectrometer.
- The mirror tilts to direct the next pixel's light onto the spectrometer. The scattered light entering the spectrometer does not change (as much).



Measuring Diffraction

(Simulated images)

BG large enough to work as reference.



Ring Cube

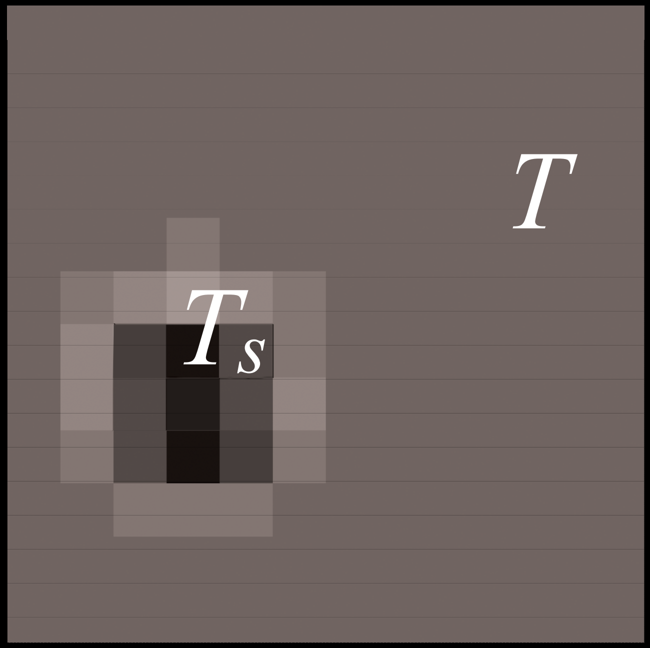
Mean of Empty Cubes

Sun's image is dimmer

Surrounding pixels are brighter.

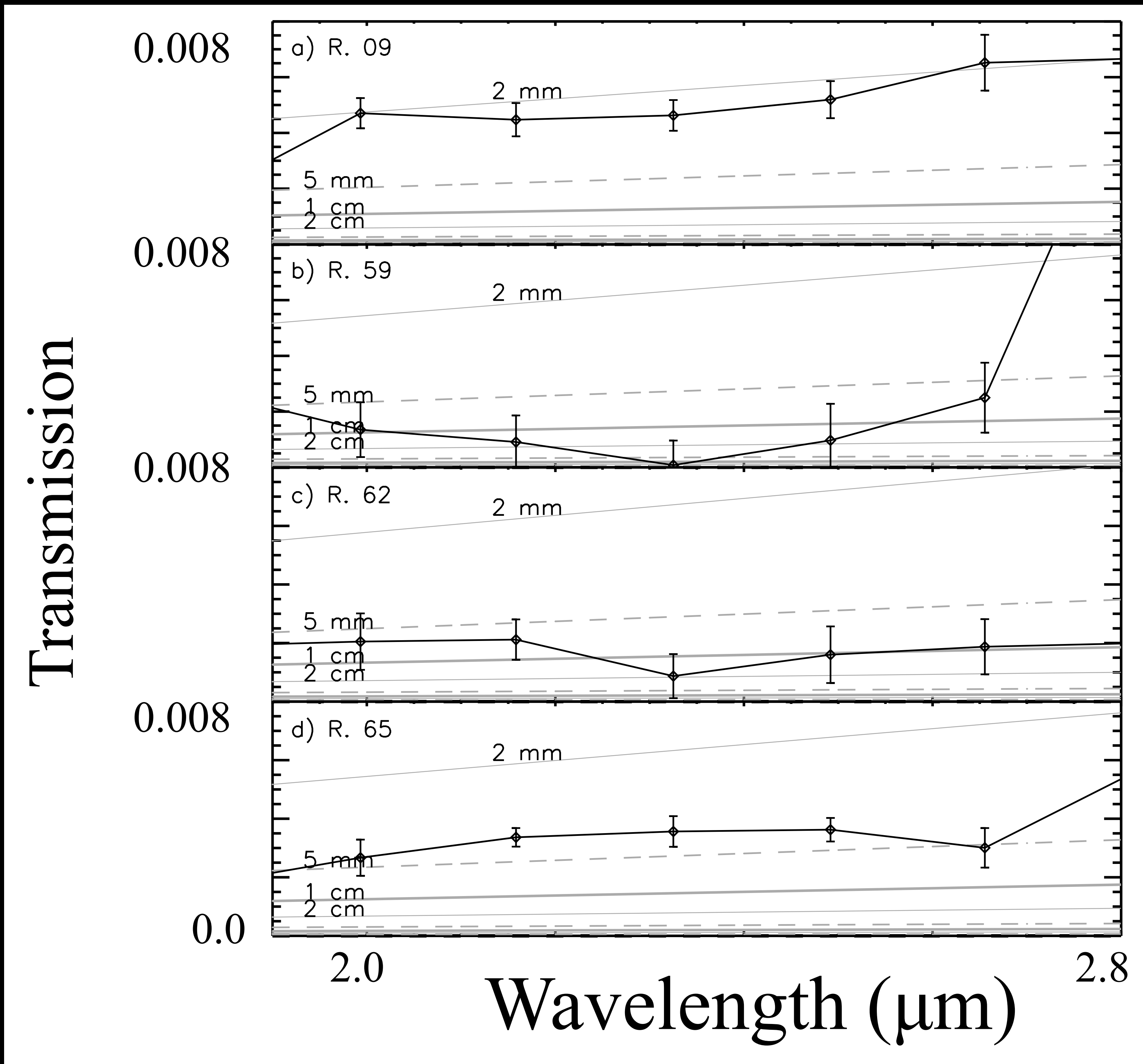
Measuring Diffraction

- Transmission found by fitting Gaussian function to sun + background.
- Difference in transmission => fraction of light diffracted to θ greater than 0.5 mrad => measure of particle properties.



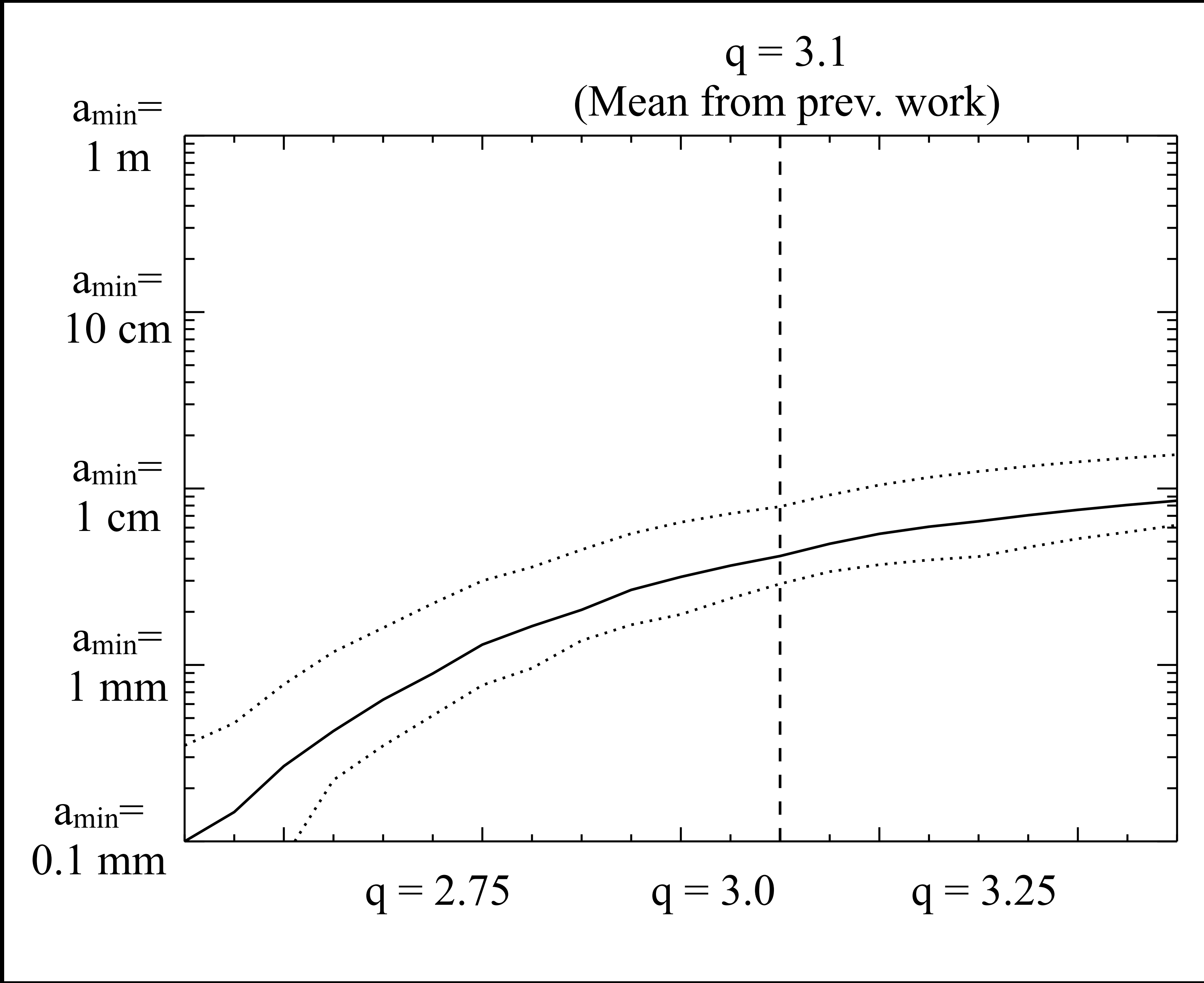
Results

The C Ring



Signal is an average over many cubes and binned in wavelength.
3 positive detections, 1 partial positive, 1 negative detection.

Minimum Particle Size in the C Ring

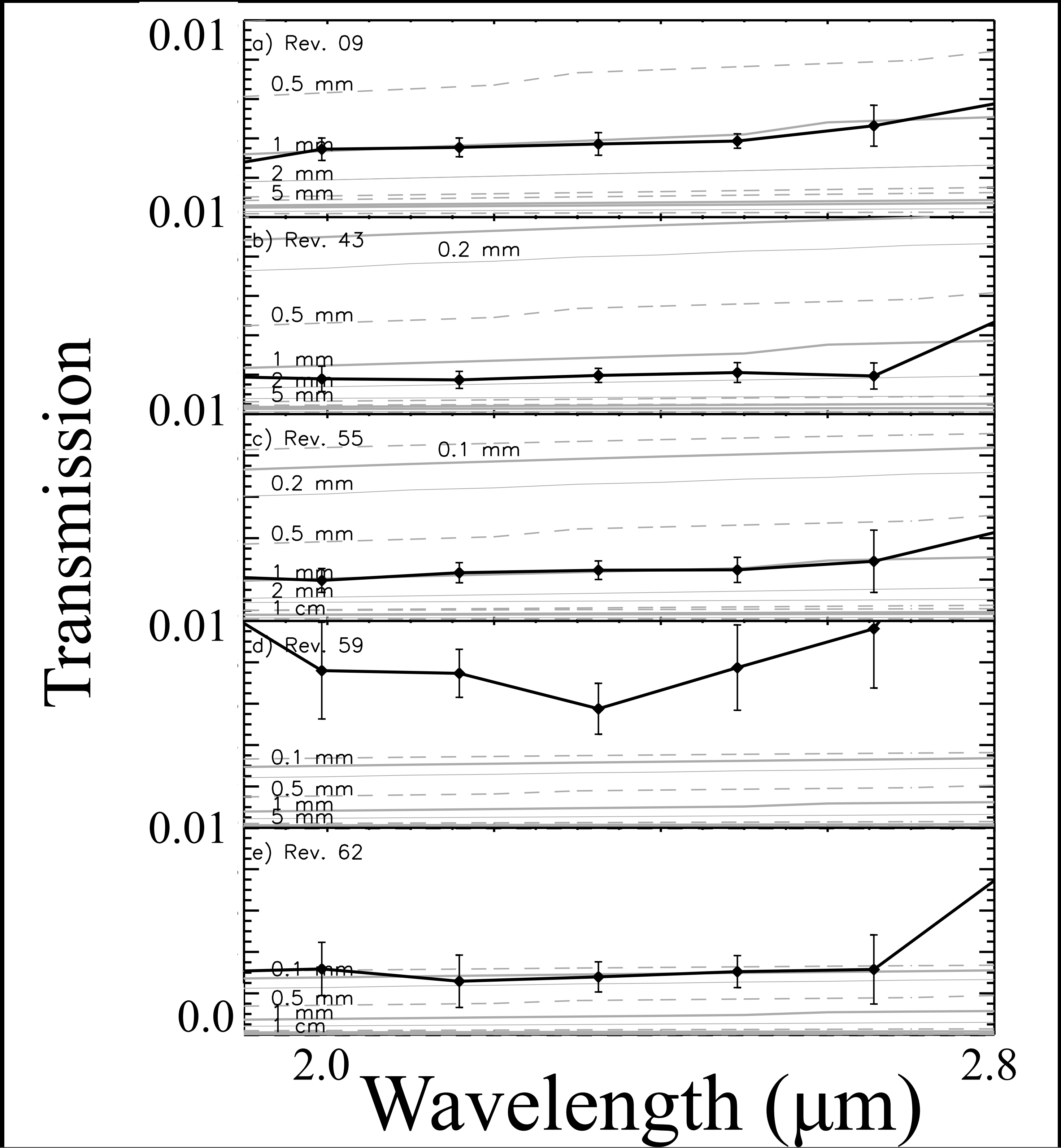


Using q = 3.1, this work finds a_{min} = $4.1^{+3.8}_{-1.3}$ mm

Comparison: C Ring

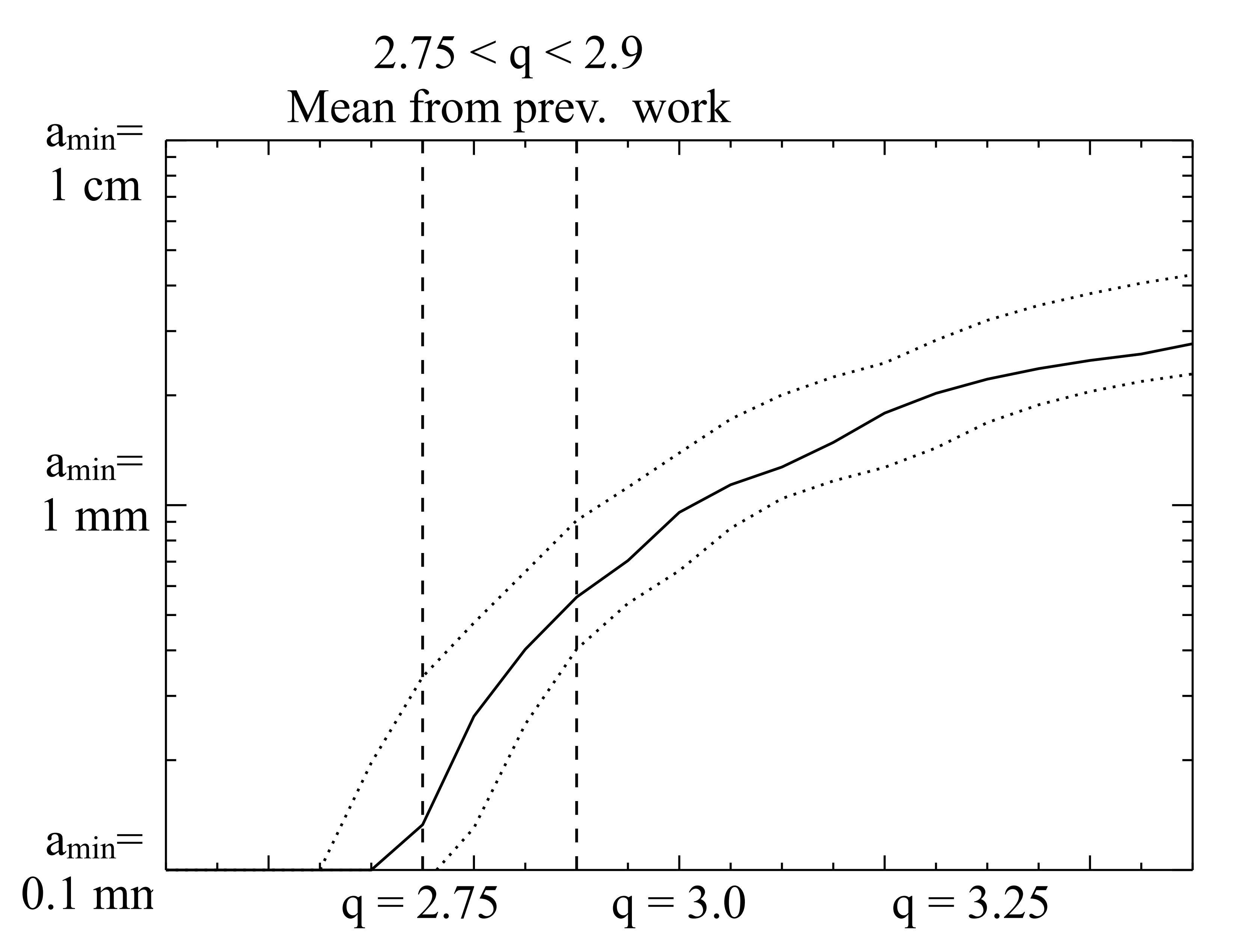
- 28 Sgr ~ 1 cm in C Ring (French & Nicholson, 2000)
- Cassini RSS = 4 mm in C Ring (Marouf, 2008)
- **This work = 4 mm in C Ring for q = 3.1**

The A Ring



Signal is an average over many cubes and binned in wavelength.
5 positive detections, 1 negative detection.

Minimum Particle Size in the A Ring



Using q = 2.9, this work finds a_{min} = $0.6^{+0.4}_{-0.2}$ mm

Using q = 2.75, this work finds a_{min} < 0.3 mm

Comparison with Previous Results

- 28 Sgr = 30 cm in inner-to-mid A Ring (French & Nicholson, 2000)
- Cassini RSS = 20 cm in inner-to-mid A Ring (Marouf, 2008)
- **This work = 0.6 mm (*or less!*) in inner-to-mid A Ring**
- However, previous work does not include self-gravity wakes.

Self-Gravity Wakes

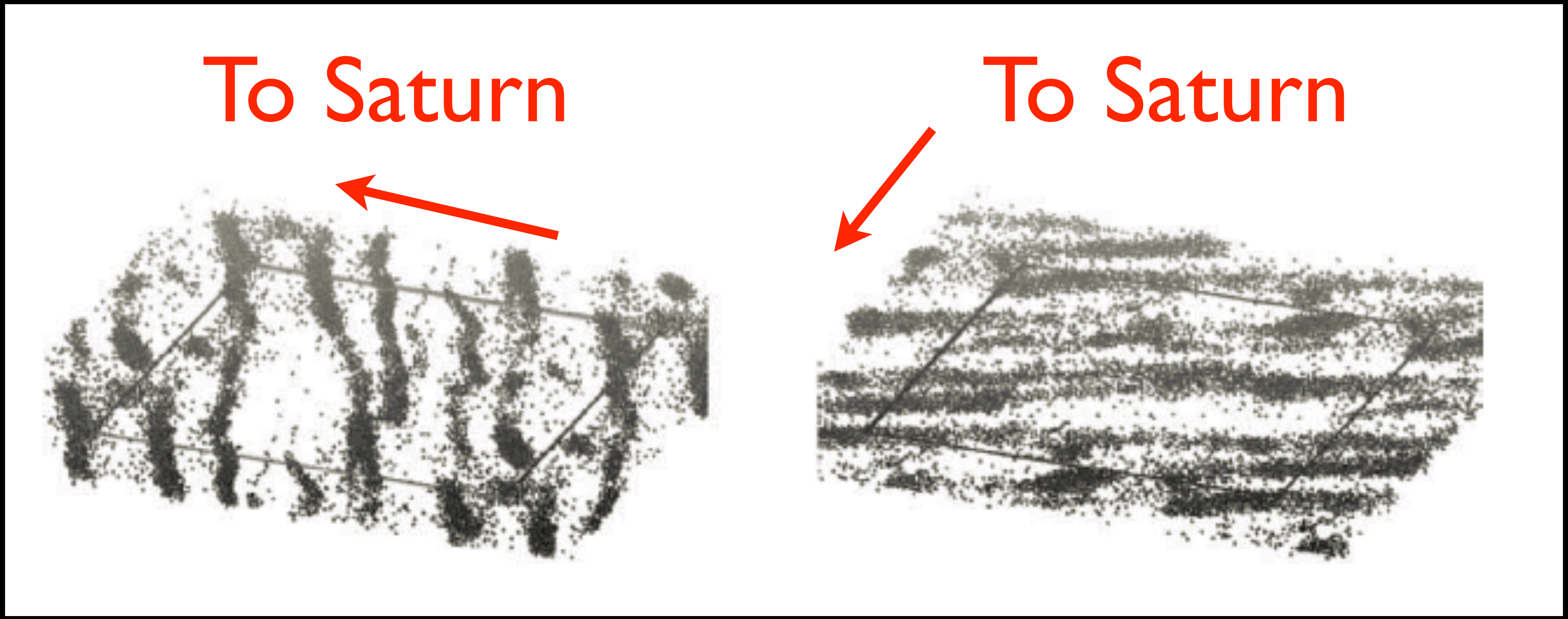


Figure from Salo et. al, 2004

- Seen seen in computational modeling of A Ring (in early 2000s).
- Explains azimuthal asymmetries seen in the A Ring pictures & occultations.

Self-Gravity Wakes

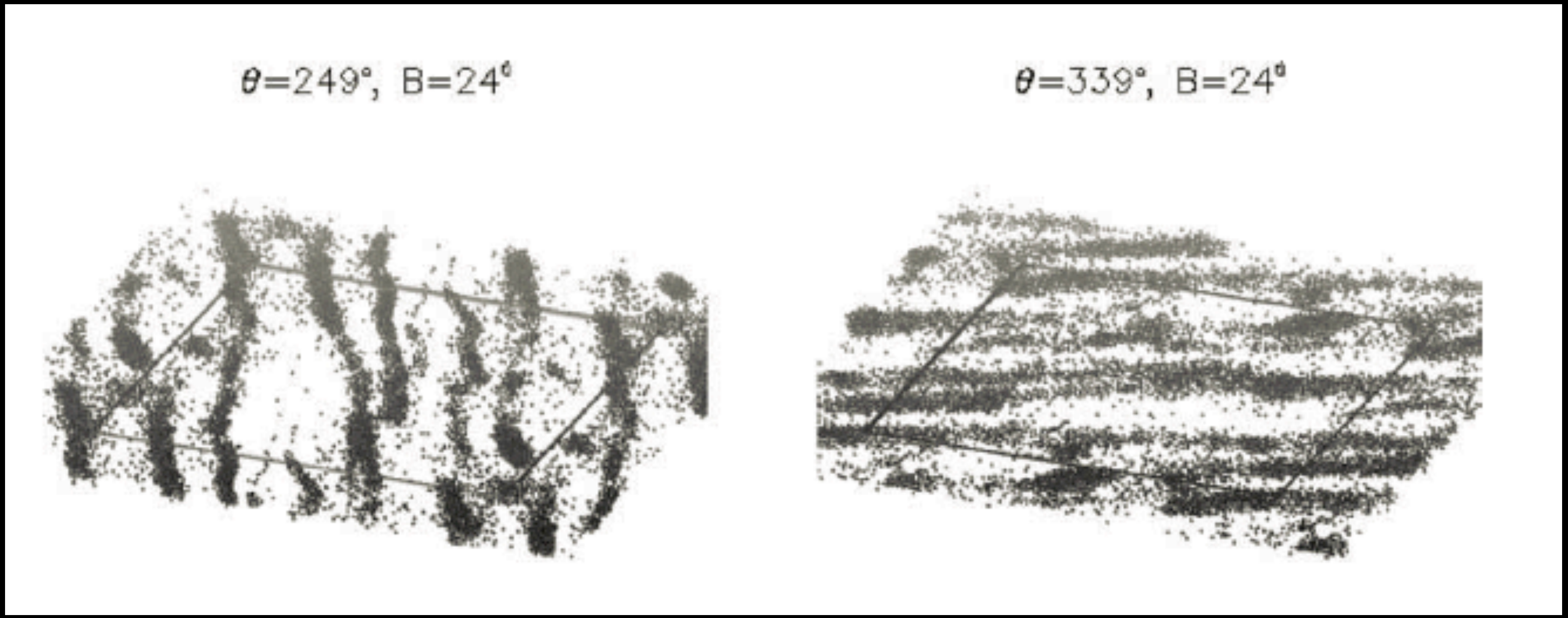


Figure from Salo et. al, 2004

Wakes are a balance between the ring's self-gravity and tides from Saturn.

Wakes are aggregates of ring particles. A wake is temporary, but the A ring *always* has self-gravity wakes

Self-Gravity Wakes

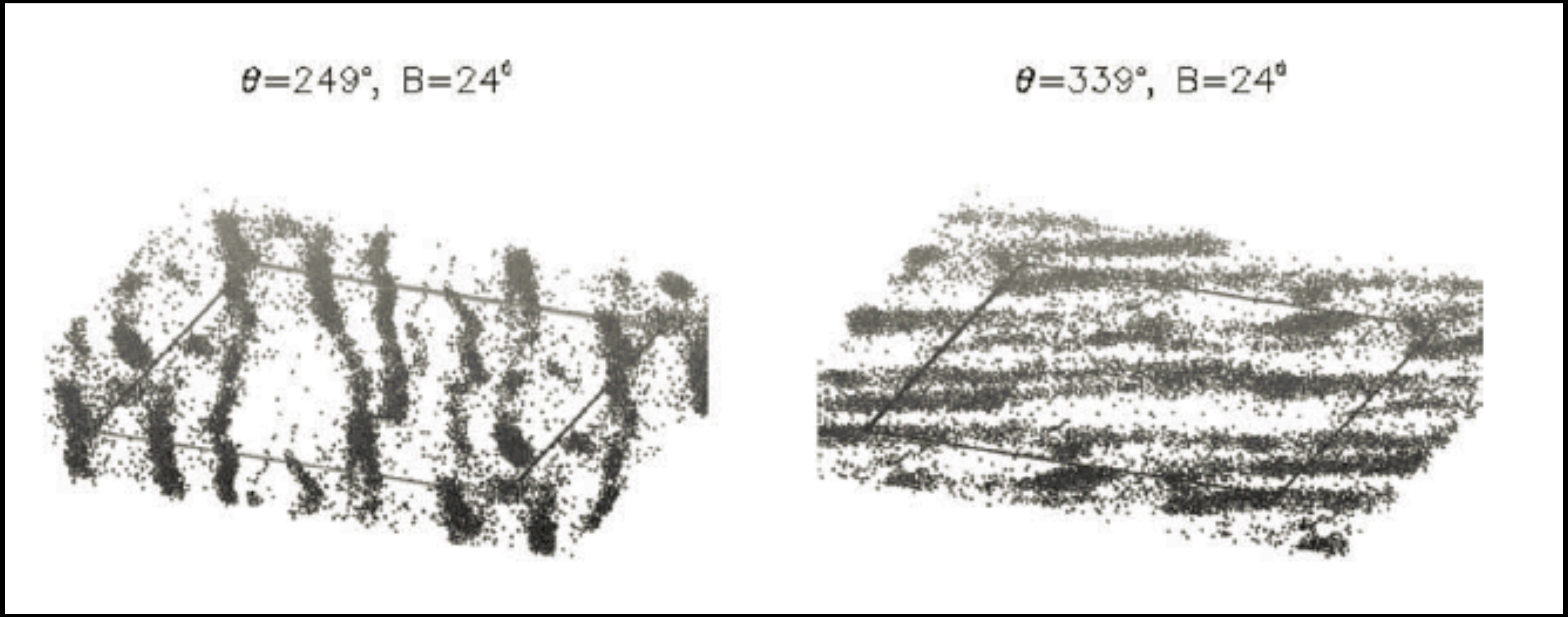


Figure from Salo et. al, 2004

- Wakes can violate a model assumption => that num. density comes from τ.
- However we know wake properties and can model them to get the correct num. density.

Ignoring Self-Gravity Wakes

- Wakes mean fewer particles *of all sizes* are free to interact with light for a given τ.
- A model with wakes would have less effect from (free) small particles than one without.
- But, in many cases no wakes and few small particles produce the same effect as wakes.
- Unlike previous experiments, I am insensitive to larger particles, so my results *cannot be explained* without mm-sized particles.

Conclusions: Particle Size Distribution

- We confirm minimum particle sizes of $a_{min} \sim 4$ mm in the C Ring.
- The inner-to-mid A Ring has minimum particle sizes of $a_{min} < 1$ mm, over two orders of magnitude less than previous results.
- Modeling the inner to mid A Ring *must* take the self-gravity wakes into account.