Planetary Rings

- A Little History
  - 1610 \( \rightarrow \) Galileo discovered rings; they disappeared in 1612
  - 1659 \( \rightarrow \) Christian Huygens discovered disk-like nature
  - 1977 \( \rightarrow \) Uranus’ rings discovered during occultation
  - 1979 \( \rightarrow \) Voyager 1 discovered Jupiter’s rings
  - 1980s \( \rightarrow \) Neptune’s arc-like rings discovered via occultation
Cassini-Huygens Science - Rings

- Study configuration of the rings and dynamic processes responsible for ring structure
- Map the composition and size distribution of ring material
- Investigate the interrelation of Saturn’s rings and moons, including imbedded moons
- Determine the distribution of dust and meteoroid distribution in the vicinity of the rings
- Study the interactions between the rings and Saturn’s magnetosphere, ionosphere, and atmosphere

Basic Properties

- Solid disk vs particles
  - Too big to rotate as solid body
  - Maxwell $\rightarrow$ rings are particles
- 100m thick vs $10^5$ km wide (Saturn)
- Just one ring? No
- All reside within Roche limit of planet
Ring Comparison

- **Jupiter**
  - Main ring – bigger particles, more scattering
  - Halo – interior component, orbits scattered by interaction with Jupiter's magnetic field
  - Gossamer – very low density, farther out → more inclined orbit so its fatter

- **Uranus**
  - 6 identified rings
  - Thickness ~10 km, width ~250000 km
  - Very close to being in circular orbit
Rings: Uranus & Neptune

Uranus' rings

Neptune rings
Particle Size Distribution

- Power law $n(r) = n_0 r^{-3} \rightarrow$ number of 10 m particles is $10^{-9}$ times less than # of 1 cm particles
- Total mass distribution is uniform across all bins
- Collisions
  - Net loss of energy $\rightarrow$ flatten ring
  - Fracture particles $\rightarrow$ power law distribution of particle size
  - But, ring should actually be thinner and radially distribution should gradually taper off, not have sharp edges
Measuring Composition

- Water ice plus impurities
- Color variation = variation in abundance of impurities
- What could they be?
Ring Composition

Red slope arises from complex carbon compounds

Variation in grain size included in model → 90% water ice overall

Comparative Spectroscopy

olivine

Ring particle
Ring Dynamics

- Rings are all inside Roche Zone
  - $a_s/R_p = 1.44(\rho_s/\rho_p)$
  - Something with $D < 100$ km is ok
- Inner particles overtake outer particles $\Rightarrow$ gravitational interaction

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Ring Dynamics

- Inner particles overtake outer particles $\Rightarrow$ gravitational interaction
  - Inner particle loses energy, moves closer to planet
  - Outer particle gains energy, moves farther from planet
  - Net effect is spreading of the ring

- Spreading timescale = diffusion timescale
Ring Dynamics

- Spreading stops when there are no more collisions
- Ignores radiation/magnetic effects that are linearly proportional to the size
- Exact distribution affected by
  - Differential rotation
  - Presence of moons and resonances with those moons

Saturn’s Rings

- D ring: 66900-74510
- C ring: 74568-92000
  - Titan ringlet 77871
  - Maxwell Gap: 87491
- B ring: 92000-117580
- Cassini division
- A ring: 122170-136775
- F ring: 140180 (center)
- G ring: 170000-175000
- E ring: 181000-483000
Structure in the Rings

- Let's look at some pictures and see what there is to see....
- Gaps
- Ripples
- Abrupt edges to the rings
- Presence of small moons
Moons and Rings

- Perturb orbits of ring particles
  - Confine Uranus’ rings, create arcs around Neptune
- Shepherding – two moons on either side of ring
  - Outer one has lower velocity $\rightarrow$ slows ring particle, particle loses energy
  - Inner one has higher velocity $\rightarrow$ accelerates ring particle, particle gains energy
- Saturn’s F ring is confined between Prometheus and Pandora

Shepherds in Uranus’ ring system
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- Resonances
  - Similar to Kirkwood Gap in asteroid belt → 2:1 resonance with Mimas

Resonances

- ALMOST ALL STRUCTURE IN RINGS IS PROBABLY DUE TO DYNAMICAL INTERACTIONS WITH MOONS

- Orbits of the ring particles have:
  - Orbital frequency
  - Radial frequency
  - Vertical frequency
- Pattern speed of the perturbing potential vs. orbital frequency of the particles → when they match we get corotation
- Pattern speed vs radial frequency → Lindblad resonances
“Perturbing Potential”? 

- **Gravitational potential**
  - Orbit about main planet $\rightarrow$ ring particles are in orbit
  - Potential due to moon that varies with same period as that of the moon $\rightarrow$ rotating reference frame

- **Net effect $\rightarrow$ spiral density wave**
  - Exists between inner and outer Lindblad resonances
  - Fluctuations in potential $\rightarrow$ fluctuations in the surface density $\rightarrow$ azimuthal variation, tightly wound, shows up looking like an old-fashioned LP
Vertical resonances – vertical structure

Moonlets?
Pan – density waves

Origin of Saturn’s Main Ring System

- Impact generated debris from current moons – works for Saturn’s “e” ring, but not generally
- A satellite originally in the Roche Zone was destroyed by a passing comet
  - When? How large?
  - There are big chunks (50m-100m size) in the rings (Tiscareno et al. 2006, 2008)
- A massive comet was tidally disrupted during a close encounter with Saturn
  - Shouldn’t all giant planets have prominent rings?
- The rings are the remnants of Saturn’s disk
  - Composition of the rings is “more pure” than composition of Saturn’s moons (few silicates)
Origin of Saturn’s Main Ring
(Charnoz et al. 2009 Icarus 199 413)

- Destruction of large satellite during late heavy bombardment
  - LHB $\rightarrow$ resulting from migration of giant planets during formation $\rightarrow$ how many planetesimals need to be scattered?
  - Formation and destruction of moons around giant planets until local debris disk is cleared
  - Survival of satellite within the Roche Zone $\rightarrow$ depends on strength of material out of which satellite is made; can be done
- Question for you: how do you go about estimating the likelihood of this taking place?

Enceladus
Enceladus occultation

Enceladus