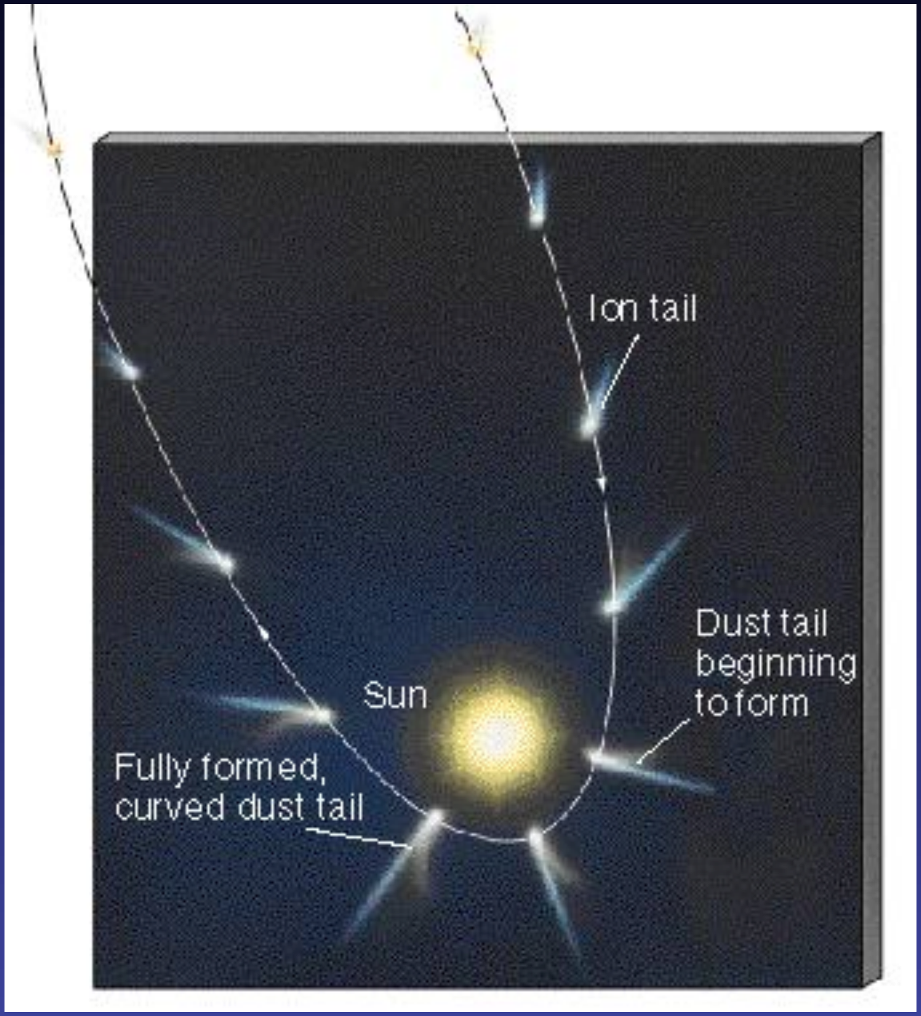
Astronomy 405
Solar System and ISM

Lecture 14
Comets

February 15, 2013

Dynamics of Comet Tails



Gas (ion) tails

- interact with the solar wind
- point away from the Sun.

Dust tails

- pushed by radiation pressure,
- lagging behind the radial direction

Radiation Pressure on Dust Grains

$$F_{\rm rad} = \frac{\langle S \rangle \sigma}{c} = \frac{L_\odot}{4\pi r^2}\frac{\pi R^2}{c}$$

F = dp/dt and
p = E/c for photons
p: momentum; E: energy
σ*: cross section*

R : grain radius
r : distance to Sun

$$F_g = \frac{G M_\odot m_{\rm grain}}{r^2} = \frac{4\pi G M_\odot \rho R^3}{3r^2}$$

$m = \rho\,(4\pi R^3/3)$

$$\frac{F_g}{F_{\rm rad}} = \frac{16\pi G M_\odot R \rho c}{3L_\odot}$$

Gravitational force balances the force due to radiation pressure.

$$R_{\rm crit} = \frac{3L_\odot}{16\pi G M_\odot \rho c}$$

R_{crit} : blow-out radius
Smaller grains will be blown out

For $\rho = 3$ g/cm^3,
R_{crit} = 191 nm = 0.19 μm

Small dust grains will be blown out of the solar system.

The situation is more complicated because…
R_{crit} is 191 nm.
The Sun's radiation peaks near 500 nm.
R_{crit} is comparable to the wavelength of sunlight, small Grains cannot absorb sunlight efficiently.
Dust scatters light depending on the dust composition and geometry, and the wavelength.

Large dust grains orbits around the Sun, but the Poynting-Robertson effect makes the large grains to spiral in toward the Sun:

$$t_{\text{Sun}} = \frac{4\pi\rho c^2}{3L_\odot} R r^2$$

The Poynting-Robertson Effect

- particles absorb sunlight but radiates preferentially in the forward direction

As a dust grain radiates, the photons carry an effective mass of E/c^2, so the angular momentum changes:

$$\frac{d\mathcal{L}}{dt} = -\frac{\sigma_g}{4\pi r^2}\frac{L_\odot}{mc^2}\mathcal{L},$$

$$t_{\mathrm{Sun}} = \frac{4\pi\rho c^2}{3L_\odot}Rr^2$$

$$v_x = \frac{v'_x + u}{1 + uv'_x/c^2} = u$$

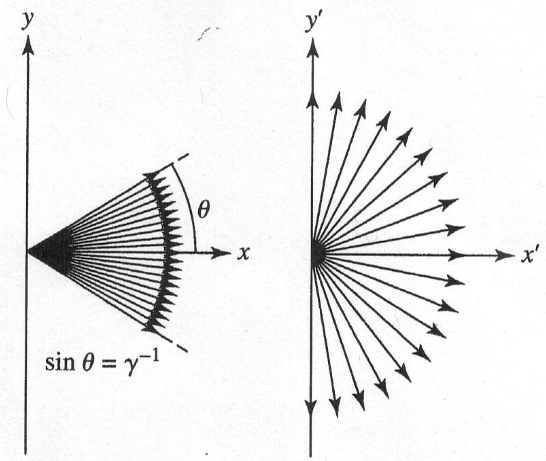
$$v_y = \frac{v'_y\sqrt{1-u^2/c^2}}{1 + uv'_x/c^2} = c\sqrt{1-u^2/c^2}$$

$$v_z = \frac{v'_z\sqrt{1-u^2/c^2}}{1 + uv'_x/c^2} = 0.$$

$$v = \sqrt{v_x^2 + v_y^2 + v_z^2} = c$$

is the speed of the light ray measured in frame S. Thus

$$\boxed{\sin\theta = \frac{v_y}{v} = \sqrt{1-u^2/c^2} = \gamma^{-1},}$$



(a) S (b) S'

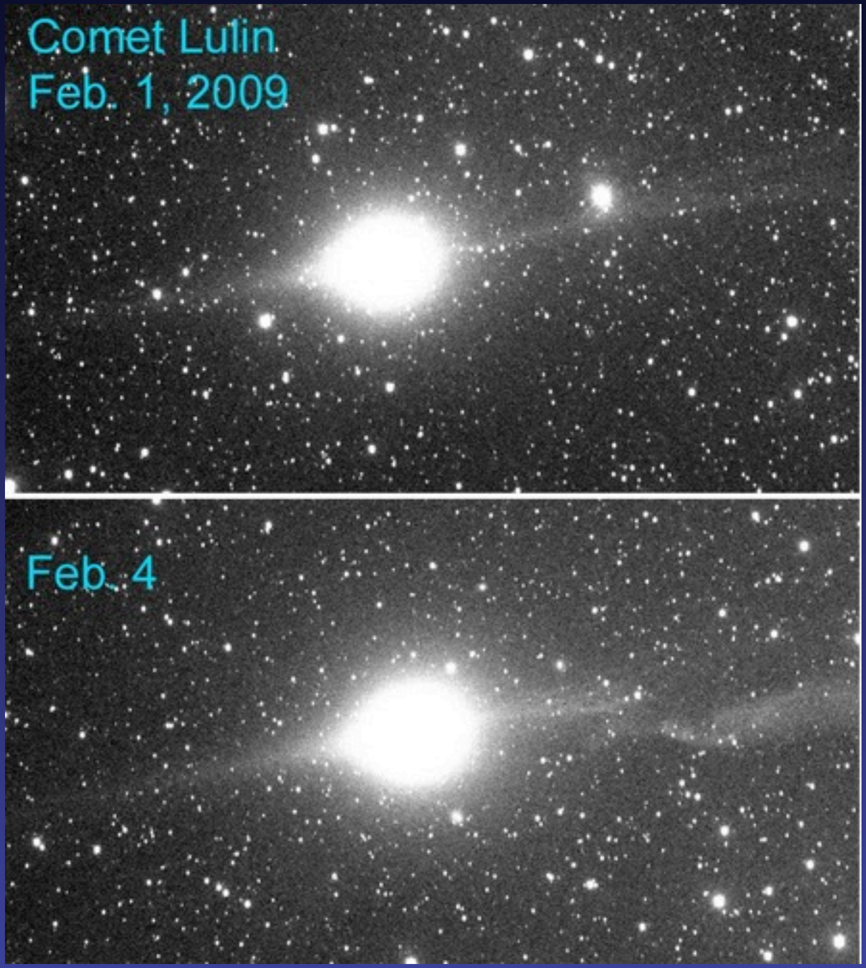
Compositions of comets

Dust tail scatters sunlight, appearing white/yellowish. Gas tail appear blue because CO+ ions absorb sunlight and radiates near 420 nm.

80%	H_2O
10%	CO
3.5%	CO_2
A few %	$(H_2CO)n$
1%	CH_3OH

Because of the abundant water in comets, it has been suggested that the water on Earth was brought by comets. But comets have higher D/H ratio than Earth ocean water. The issue is still unsettled…

Disconnection of Ion Tails



The Ion tail is affected by the solar wind and magnetic field.

The relative speed between solar wind and comet exceeds both the local sound speed and Alfven speed => bow shock

⇒ Ions pile up

⇒ load magnetic field down

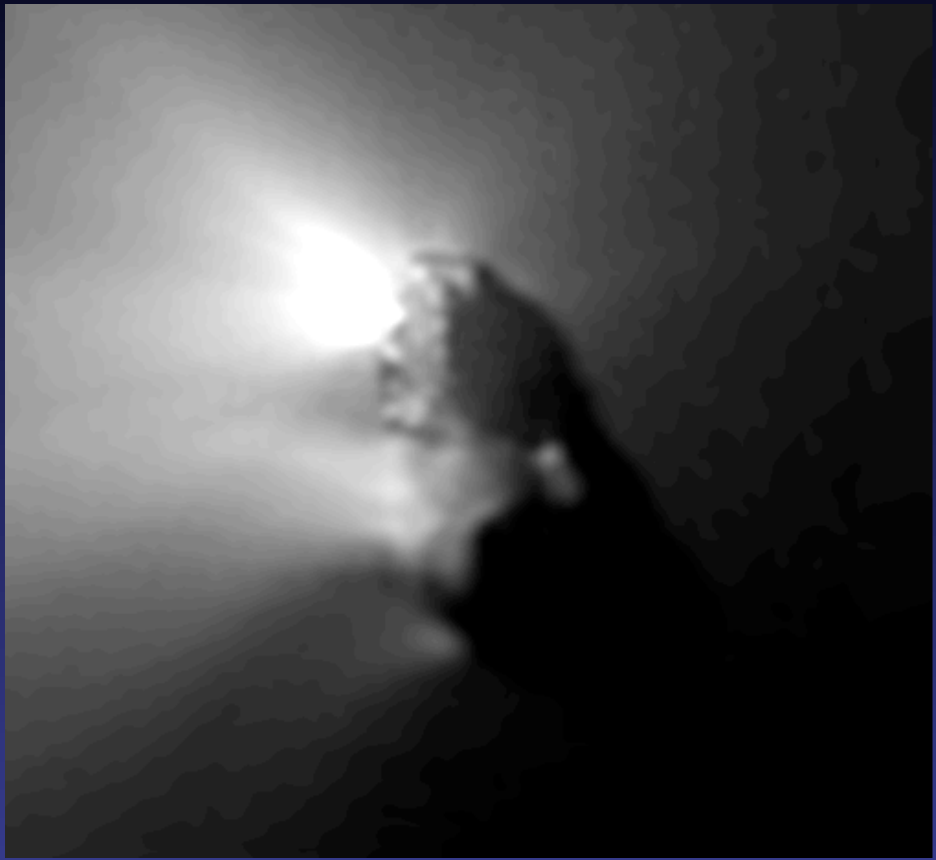
⇒ when a comet encounters a reversal in the solar magnetic field, a disconnection event occurs.

Robotic Missions to Comets

When Comet Halley came to perihelion in 1986,

Japan - Suisei, Sakigake
USSR - Vega 1, Vega 2
ESA - Giotto
USA - International
Cometary Explorer

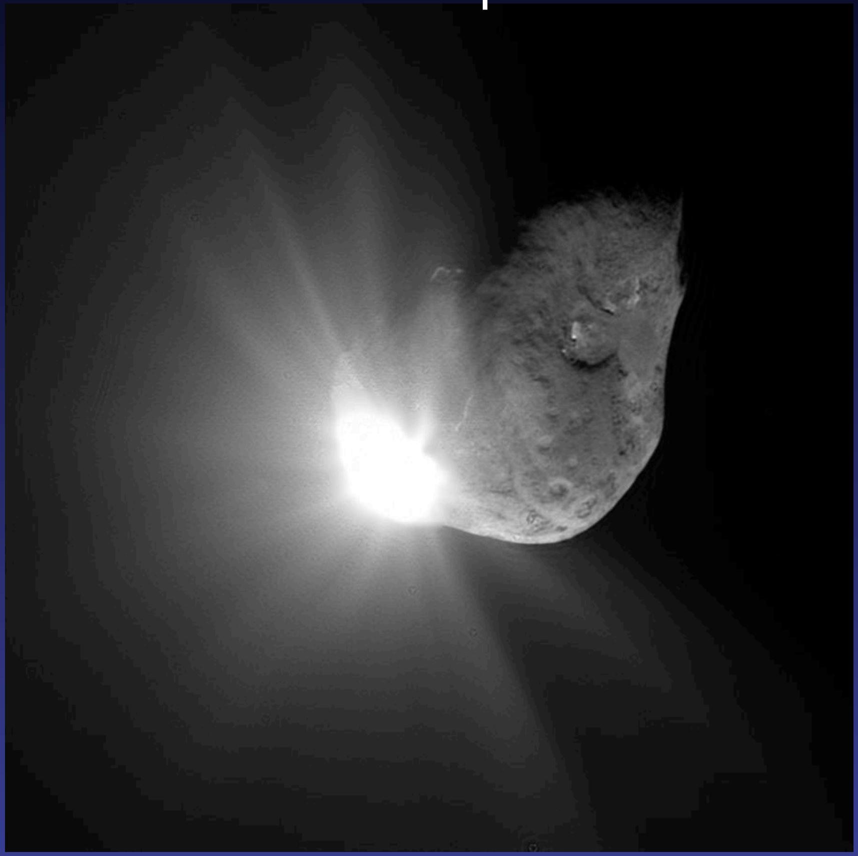
15 x 7.2 x 7.2 km^3
Average density ~ 1 g/cm^3
Albedo ~ 0.02-0.04
Discharges gas and dust at 2×10^4 and 5×10^3 kg/s.



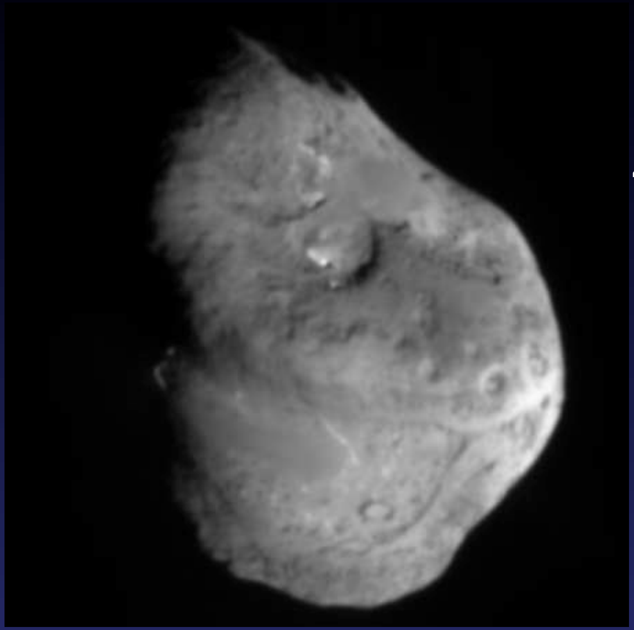
Halley Comet's nucleus
(*Giotto, ESA*)

Deep Impact
Comet Tempel 1

67 sec after the impact



5min before the impact



7.6 km
X
4.9 km

Landscape on Tempel 1

July 4, 2005 Deep Impact sent a 370-kg impactor into comet Tempel 1 at a speed of 10.2 km/s.

The impact created a crater for scientists to study its interior.

Water, CO_2, hydrogen cyanide, methyl cyanide, PAHs, and other organic molecules.

Fine sand with the consistency of talcum powder.

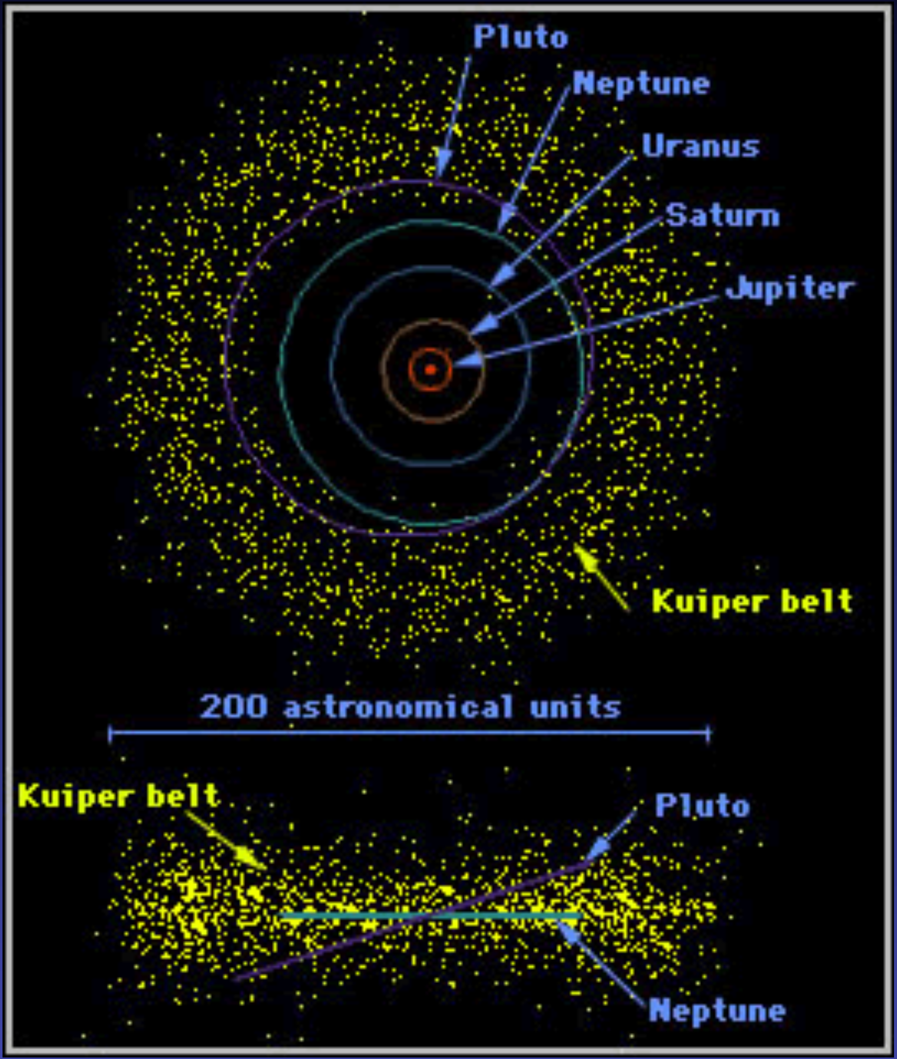
Density ~ density of powder snow

Mass 7.2×10^{13} kg, density of 600 kg/m^3
=> Very porous

Sun-grazing comets
http://sohowww.nascom.nasa.gov/gallery/Movies/comets.html

Two types of comets:

period < 200 yr	short-period	Kuiper Belt
period > 200 yr	long-period	Oort Cloud

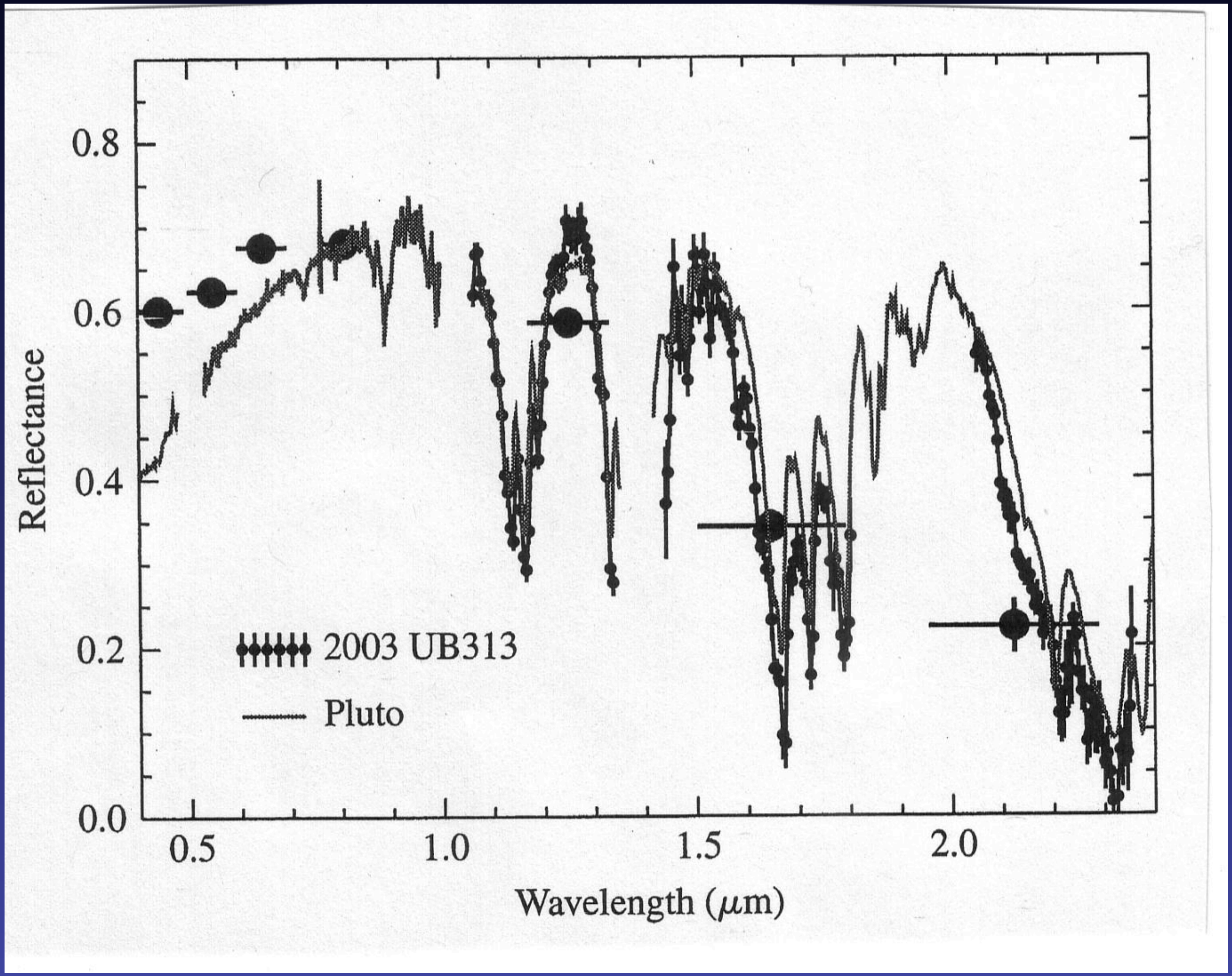


Kuiper Belt Objects (KBOs)

Trans-Neptunian Objects (TNOs)

30-1000 AU from the Sun

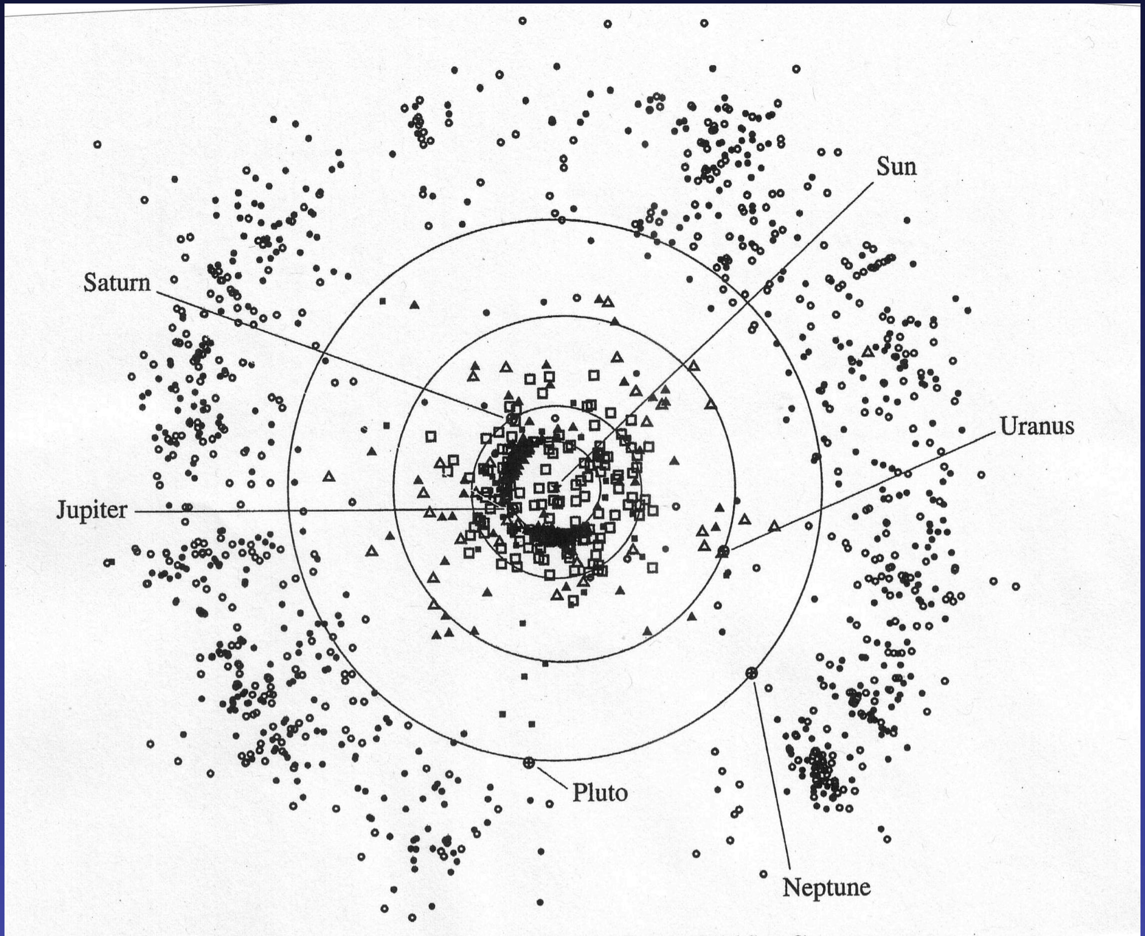
Spectrum of Zena (2003 UB313) is dominated by Methane absorption features.



Name	Diameter (km)	Period (yr)	a (AU)	e	i (deg)
2003 UB313	2400	559	67.89	0.4378	43.99
Pluto	2274	248	39.48	0.2488	17.16
Sedna*	1600	12,300	531.7	0.857	11.93
Orcus	1500	247	39.39	0.220	20.6
Charon	1270	248	39.48	0.2488	17.16
2005 FY9	1250	309	45.71	0.155	29.0
2003 EL61	1200	285	43.34	0.189	28.2
Quaoar	1200	287	43.55	0.035	8.0
Ixion	1070	249	39.62	0.241	19.6
Varuna	900	282	42.95	0.052	17.2
2002 AW197	890	326	47.37	0.131	24.4

* Sedna has an orbit that is much larger than the classical Kuiper belt.

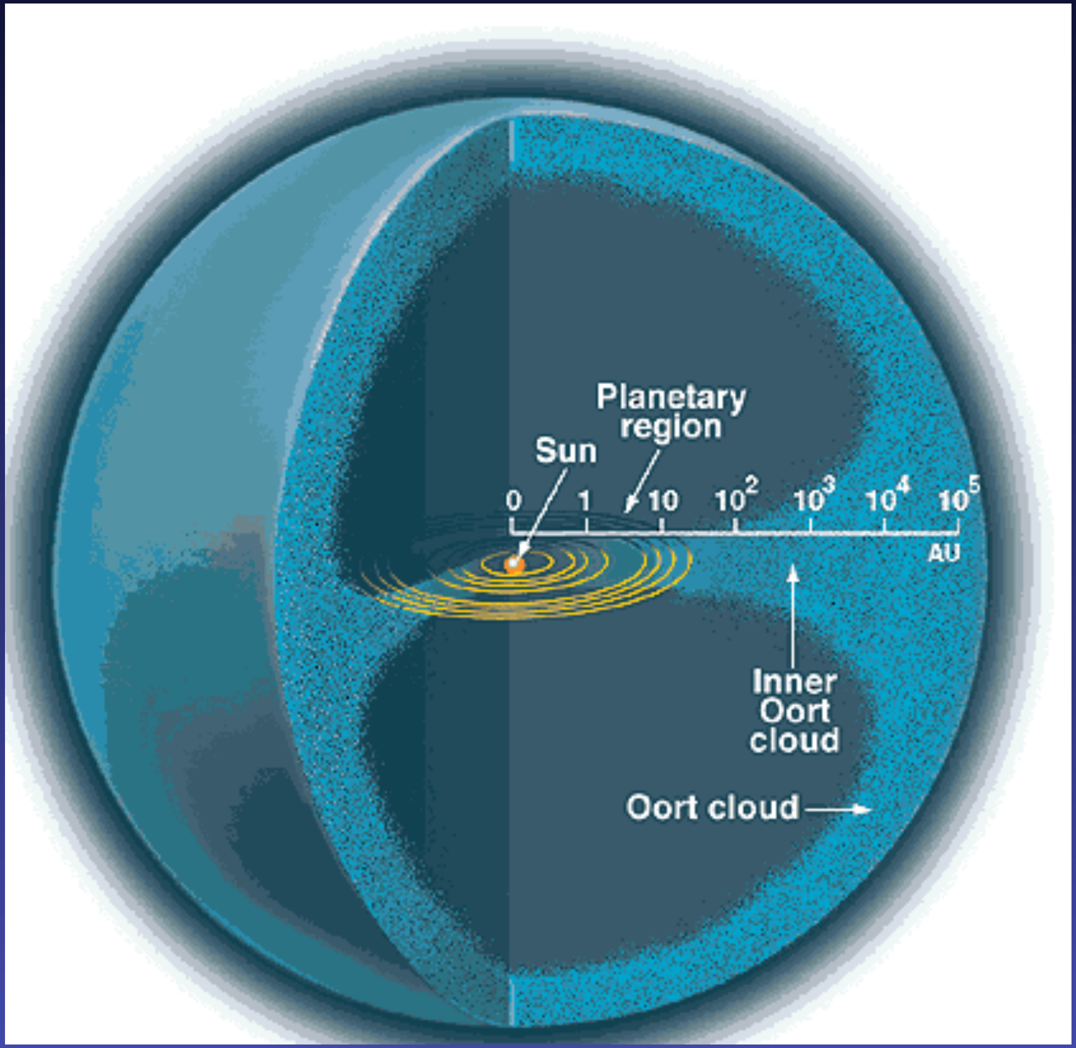
Classical KBOs - 30 to 50 AU from the Sun, i < 30 deg
Scattered KBOs - higher *e*; orbits perturbed by Neptune; Zena
Resonant KBOs - resonant with Neptune; Pluto 3:2; Plutinos
Centaurs - large icy bodies; cross Saturn's orbit; KBOs scattered; will become short-period comets



Plot prepared by the Minor Planet Center (2005 Sept 8).

Two types of comets:

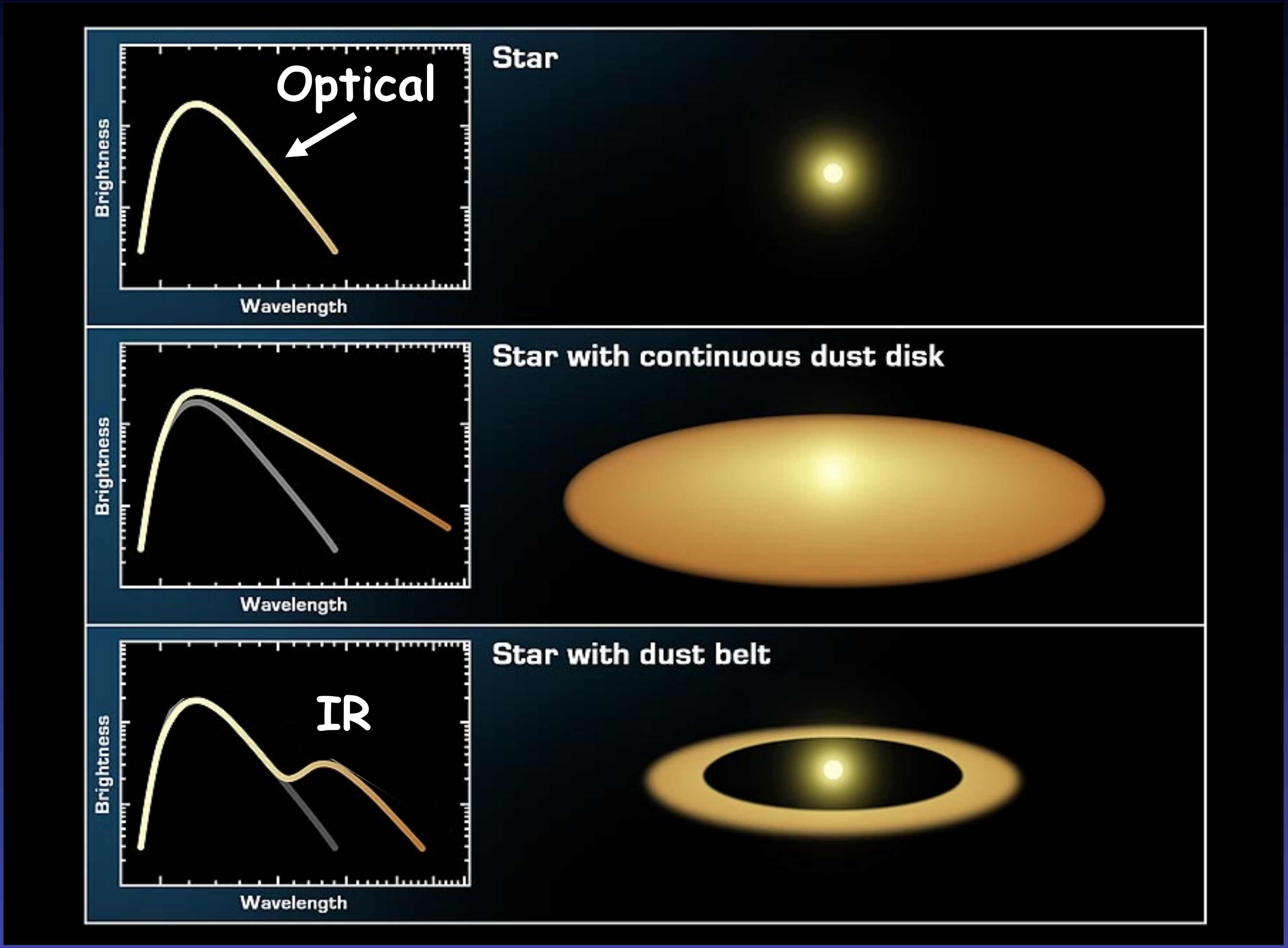
period < 200 yr	short-period	Kuiper Belt
period > 200 yr	long-period	Oort Cloud



Oort Cloud
- spherically symmetric
- 3000-100,000 AU
- none have been detected "at home" in the cloud
- detected as comets near perihelion

From here on, the material is taken from my research projects… The real deal…

How Do we Diagnose Dust Disks?



Debris Disks of MS & WDs

Dust in MS debris disks does not survive through stellar evolution.

- driven out by radiation pressure
- blown out by stellar wind
- spiral in due to angular momentum loss (Poynting-Robertson effect)

Dust disks around WDs must be new and may indicate the existence of asteroids or Kuiper Belt Objects…

Where do we expect to find dust around WDs?

1. Within the Roche Limit (< 0.01 AU)
2. Asteroid Belt at 3-5 AU
3. Kuiper Belt at 30-50 AU

Thermal equilibrium

Energy absorbed = Energy emitted

$$4\pi R_*^2 \ \sigma T_*^4 \ (\pi r_g^2 / 4\pi D^2) = 4\pi r_g^2 \ \sigma T_g^4$$

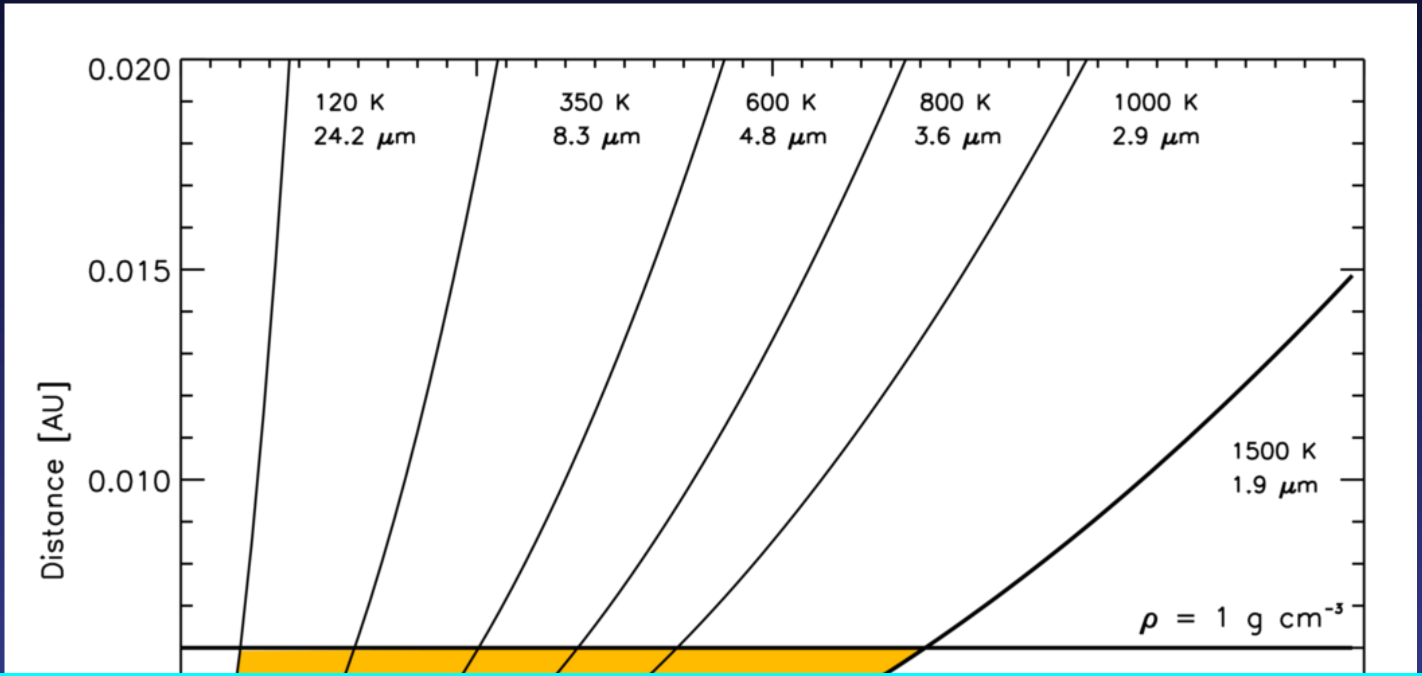
$$T_g = T_* (R_{\oplus} / 2D)^{0.5}$$

$$\lambda_{max} \sim 2900 \ \mu m / T_g$$

Sublimation temperature ~ 1500 K

Where do we expect to find dust around WDs?

1. Within the Roche Limit (< 0.01 AU)
2. Asteroid Belt at 3-5 AU
3. Kuiper Belt at 30-50 AU



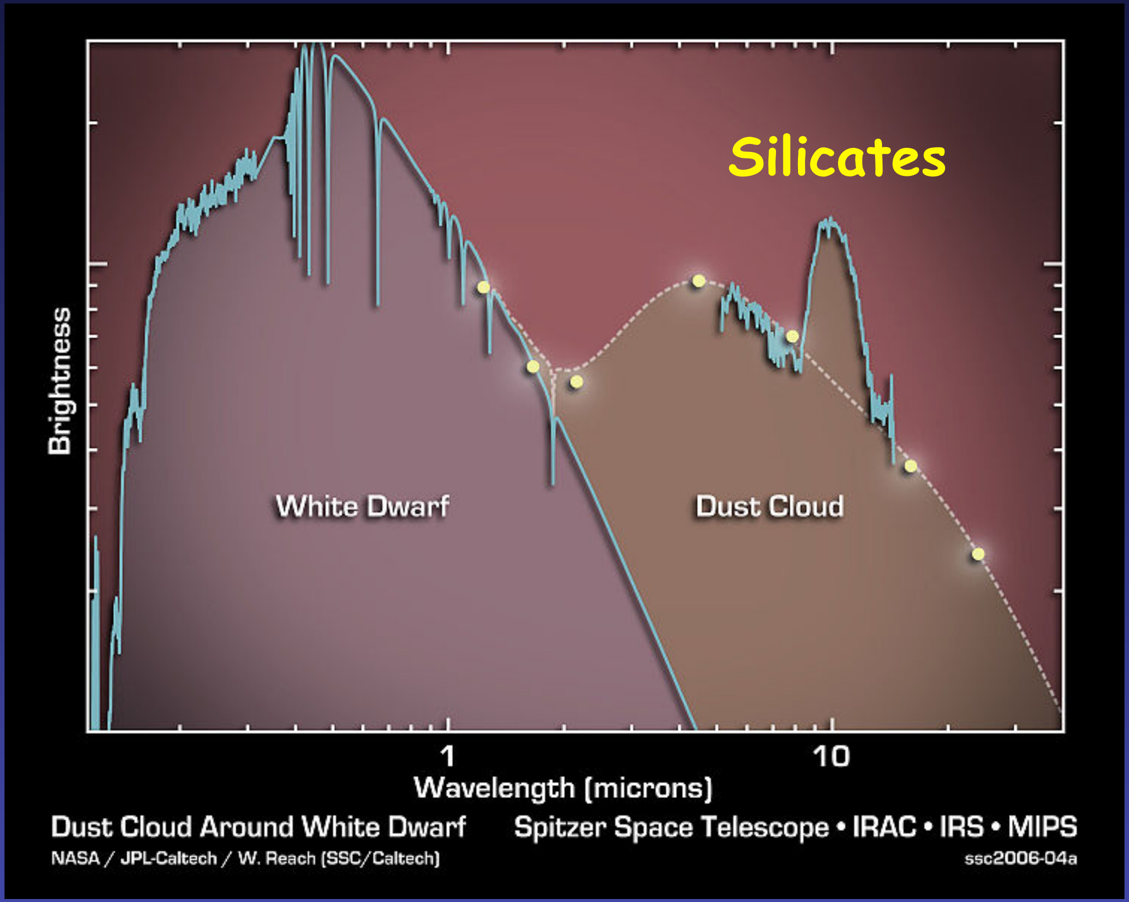
Spitzer IRAC can detect these around WDs <20,000 K

Dust Disk of WD G 29-38

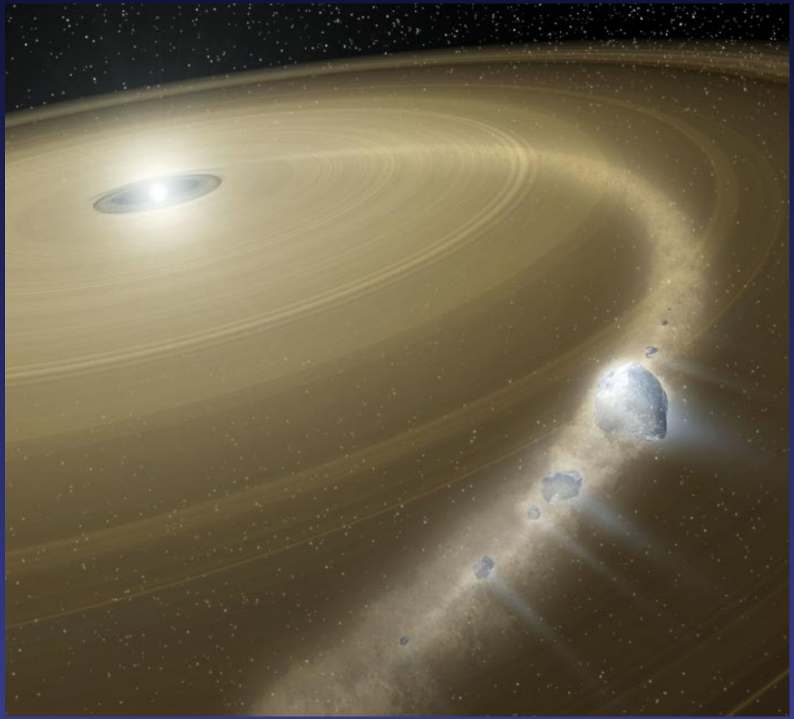
$T \sim 2900\ \mu m\ K / \lambda_{max} \sim 500\ K$

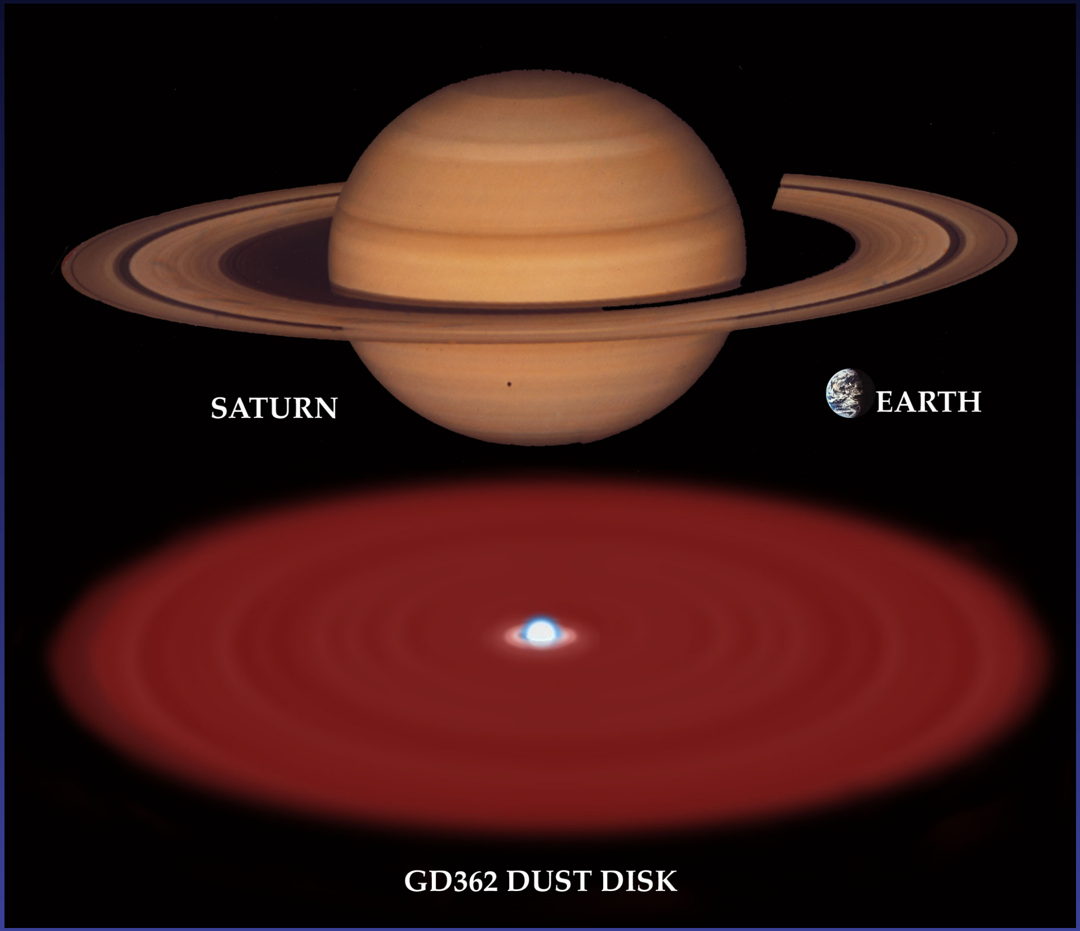
$D = (278 / T_g)^2 \ (L_* / L_\odot)^{0.5}$

$D < 0.005$ AU



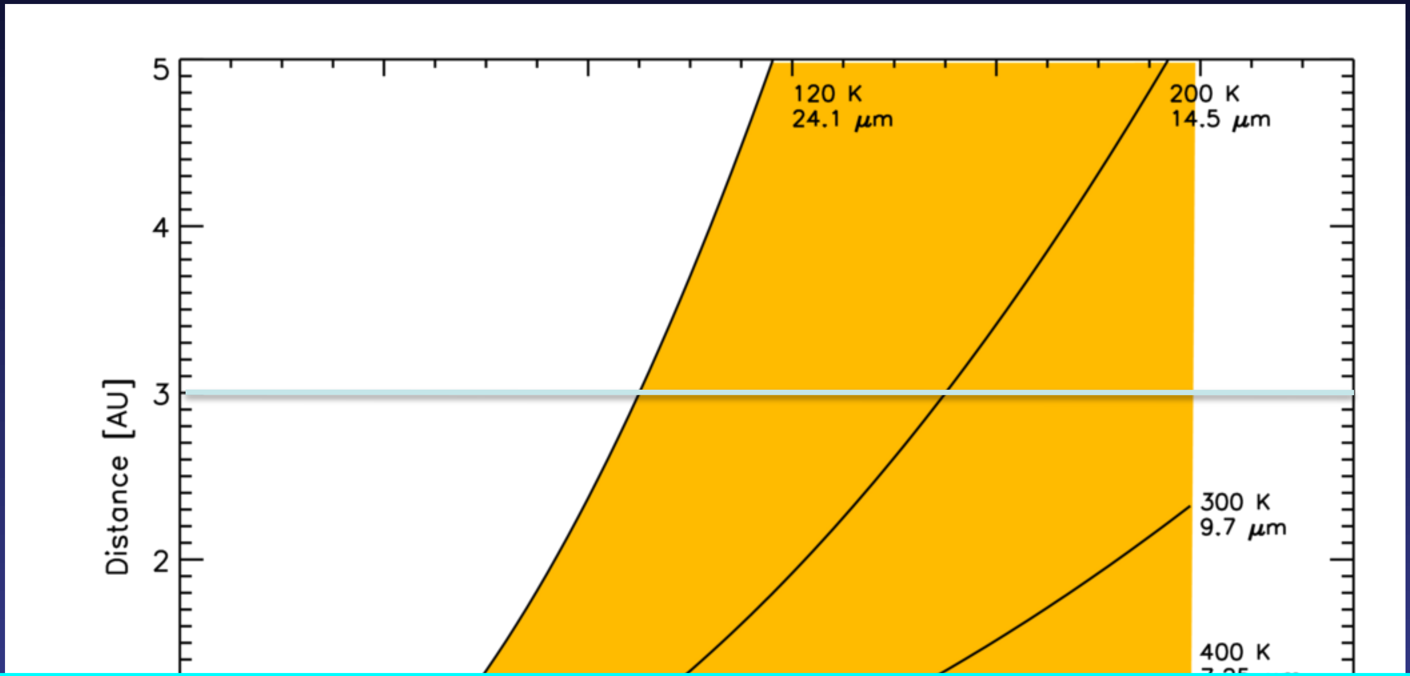
Dust Disk of WD GD 362





Where do we expect to find dust around WDs?

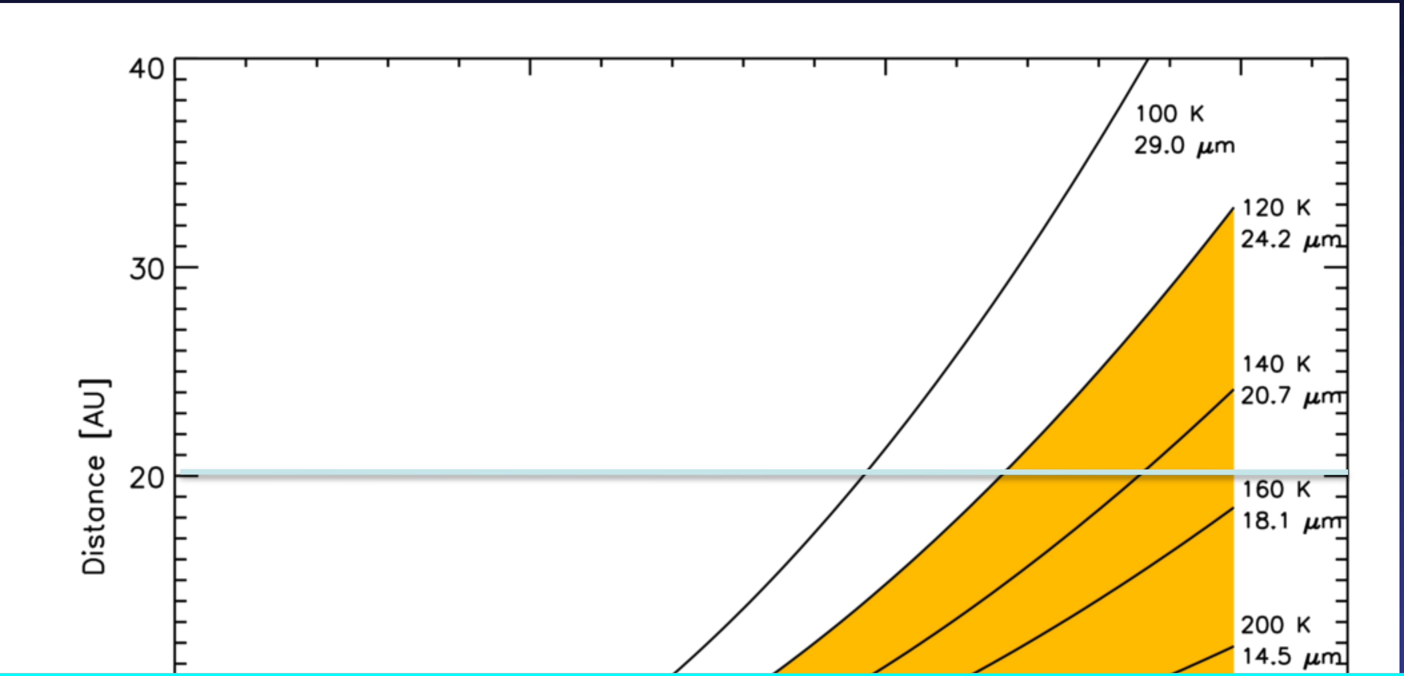
1. Within the Roche Limit (< 0.01 AU)
2. Asteroid Belt at 3-5 AU
3. Kuiper Belt at 30-50 AU



Spitzer MIPS can detect these around WDs ~50,000 K

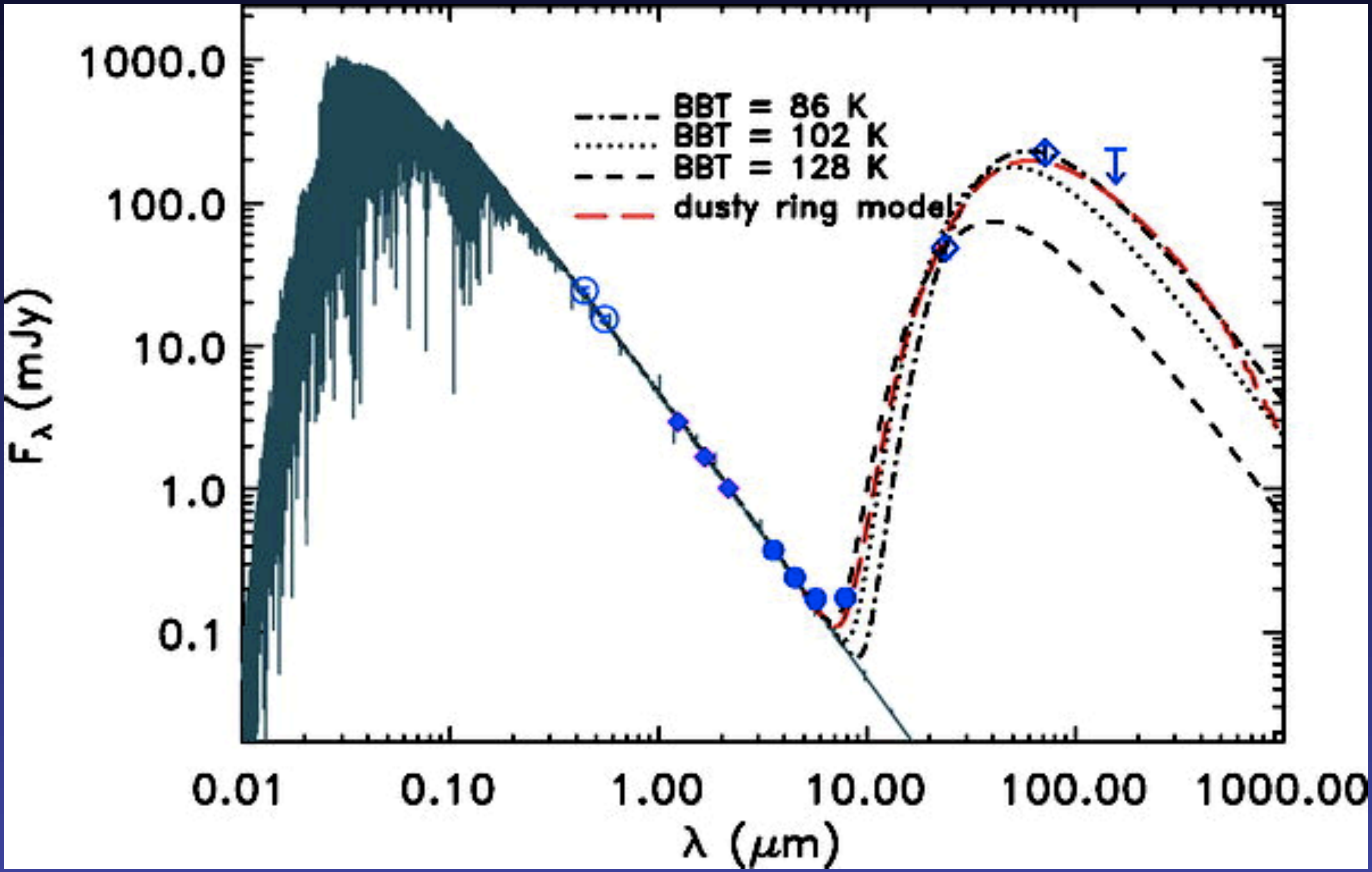
Where do we expect to find dust around WDs?

1. Within the Roche Limit (< 0.01 AU)
2. Asteroid Belt at 3-5 AU
3. Kuiper Belt at 30-50 AU



Spitzer MIPS can detect these around hot WDs ~ 100,000 K

The Central Source of the Helix Nebula Spectral Energy Distribution



Su, Chu, Rieke, et al. 2007