Diagnosing Circumstellar Debris Disks

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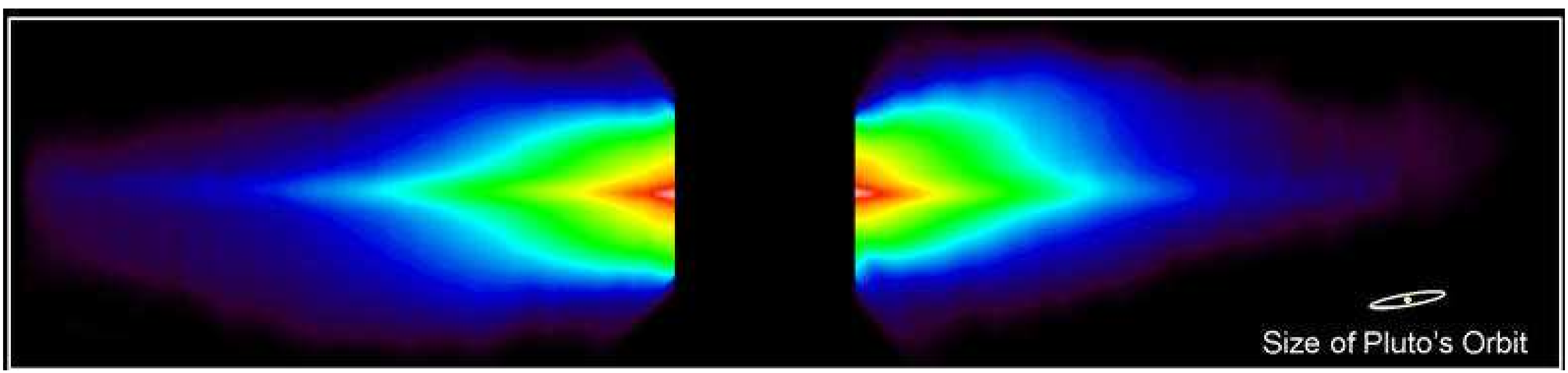
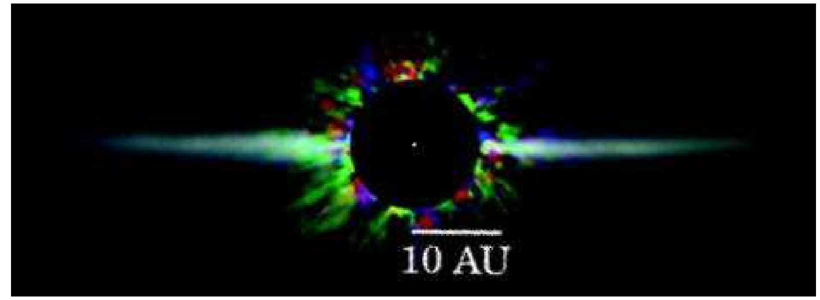


the edge-on debris disk orbiting β Pictoris, from Heap et al (2000)

The debris disk phenomenon (eg, Strubbe & Chiang 2006)

- unseen planetesimals in narrow ring or broad disk collide & generate dust
- radiation pressure or stellar wind lofts small micron-size dust out to $r \sim$ hundreds AU
- collisions among dust grains depletes disk



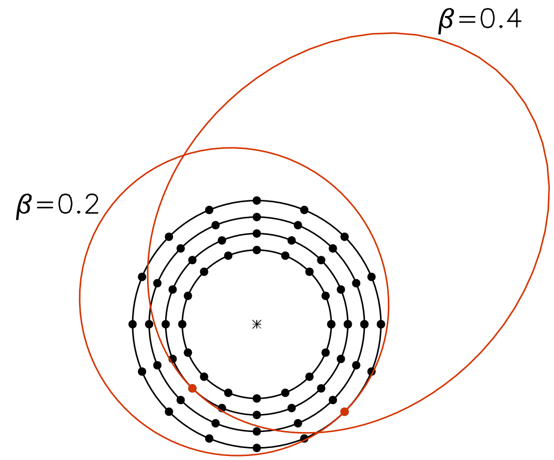
AU Mic, from Fitzgerald et al 2007

My interest here:
Are debris disks indicators of ongoing planet-formation?
Or are they regions of planetesimal destruction?

- planetesimals are seeds of planets, which suggests planet-formation
- but debris disks are resupplied by collisional erosion of planetesimals, which can inhibit planet formation
- could be argued either way...

The model:

- the planetesimal disk is composed of rings that produce dust at various sites in the disk
- dust production rate is a power-law in grain size, $P(R) \propto R^{-q}$



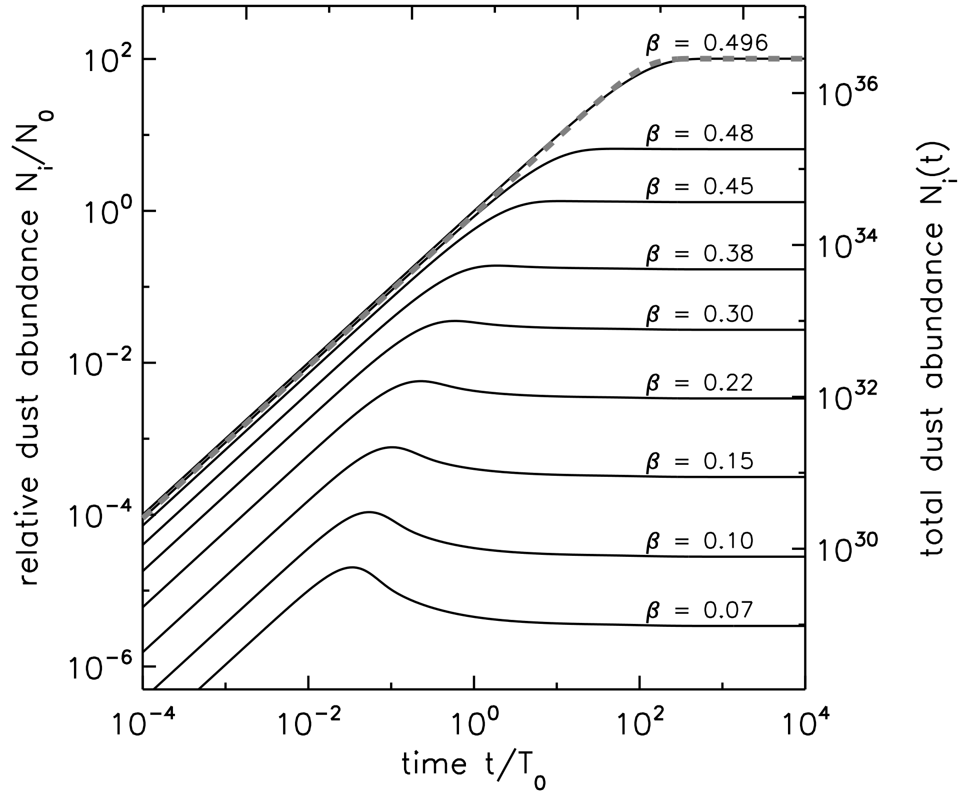
Dust orbits are simple functions of grain size parameter β:

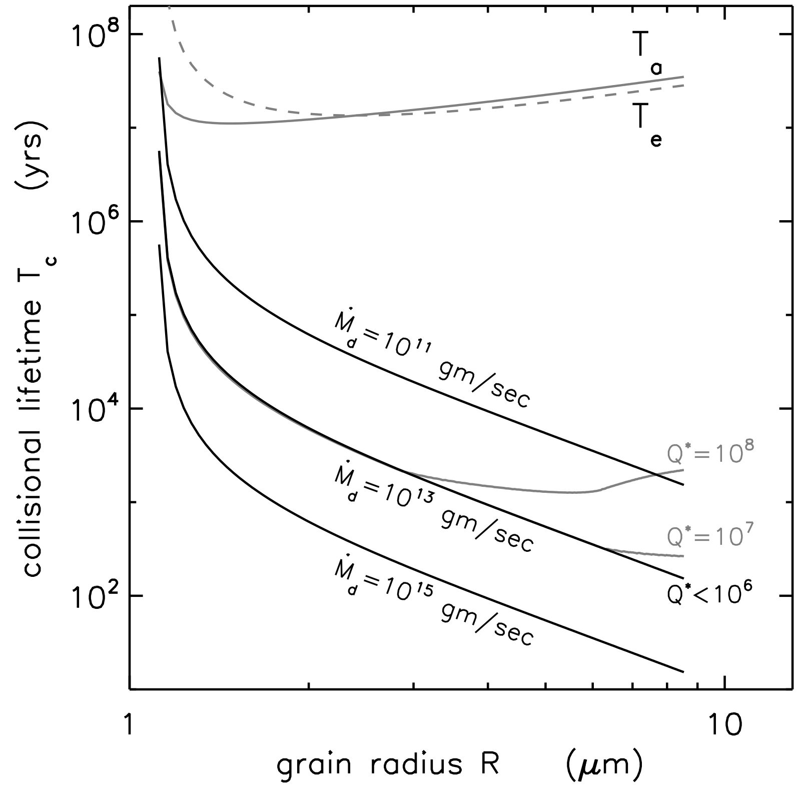
$$a(\beta) = \frac{1-\beta}{1-2\beta} r_p \quad \text{and} \quad e(\beta) = \frac{\beta}{1-\beta} \qquad \text{where} \quad \beta = \frac{\text{rad. prs.}}{\text{gravity}} \sim \frac{1}{R_{\text{microns}}}$$

Dust abundance $N_i(t) =$ number of grains of size R_i in orbit $a_i, e_i, \tilde{\omega}_i$ at time t obeys rate equation $dN_i/dt =$ dust production rate - collisional destruction rate,

$$\frac{dN_i}{dt} = P_i - \sum_j \alpha_{ij} N_i N_j$$

where collision probability rate $\alpha_{ij} =$ function(dust sizes, orbits, and strength $Q^\star$)
detailed are in Hahn (2010).



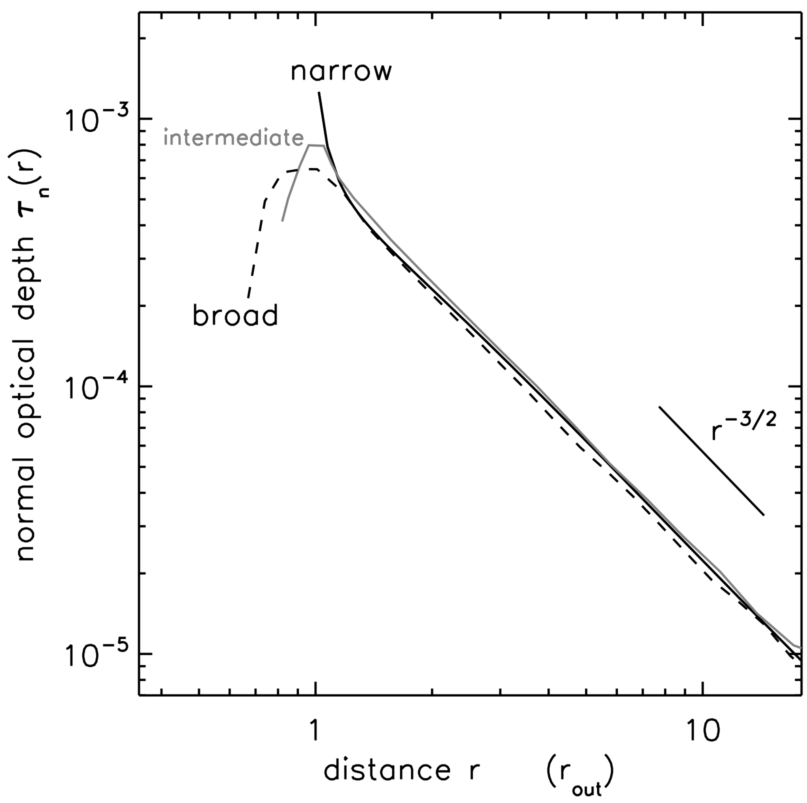


that coupled system of rate equations is solved numerically for abundances $N_i(t)$,

providing dust collisional lifetimes $T_c(R)$,

and dust optical depth $\tau(r)$ produced by narrow planetesimal ring or broad disk,

and disk surface brightness $B(r)$



Diagnosing the β Pictoris debris disk:

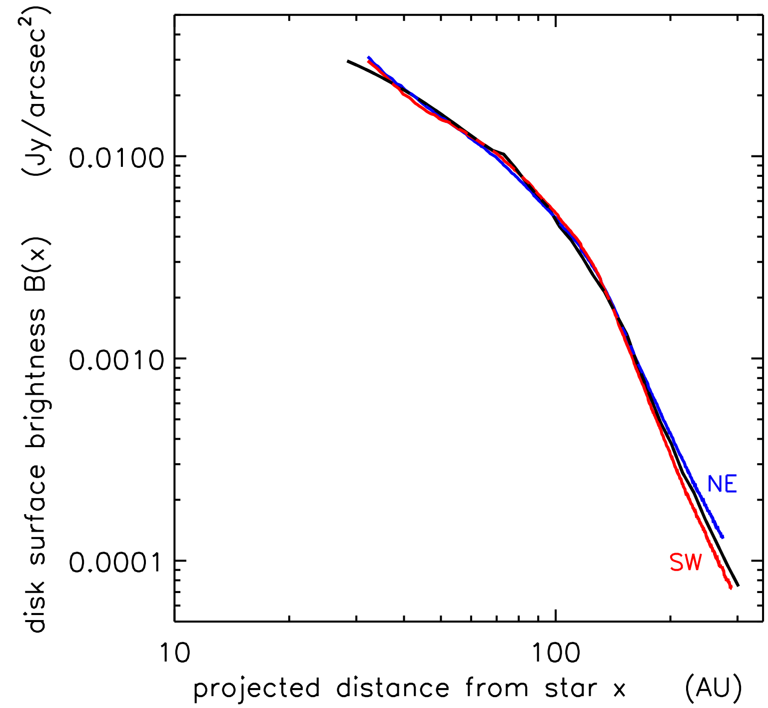
fitting model disk to optical HST observations (Golimowski et al 2006) requires:

- broad planetesimal disk, $75 \lesssim r_p \lesssim 150$ AU,
  comparable to what Wilner et al (2010) infer from mm observations

- heavy dust production, $\dot{M}_d \sim 10$ $M_\oplus$/Myr

- dust grains are probably icy & reflective
  I assumed $Q_s = 0.7$ (Saturn's icy rings),
  however darker $Q_s = 0.1$ dust
  would require $\dot{M}_d \uparrow \times 50$,
  because $B \propto Q_s \sqrt{\dot{M}_d}$

- a good fit also requires:
  $q = 2.5$ (shallower than Dohnanyi)
  strong dust, $Q^\star \sim 10^8$ ergs/gm,
  asymmetric light scatters, $|g| \simeq 0.7$.



red & blue curves are disk's
optical surface brightness,
black curve is best fitting model

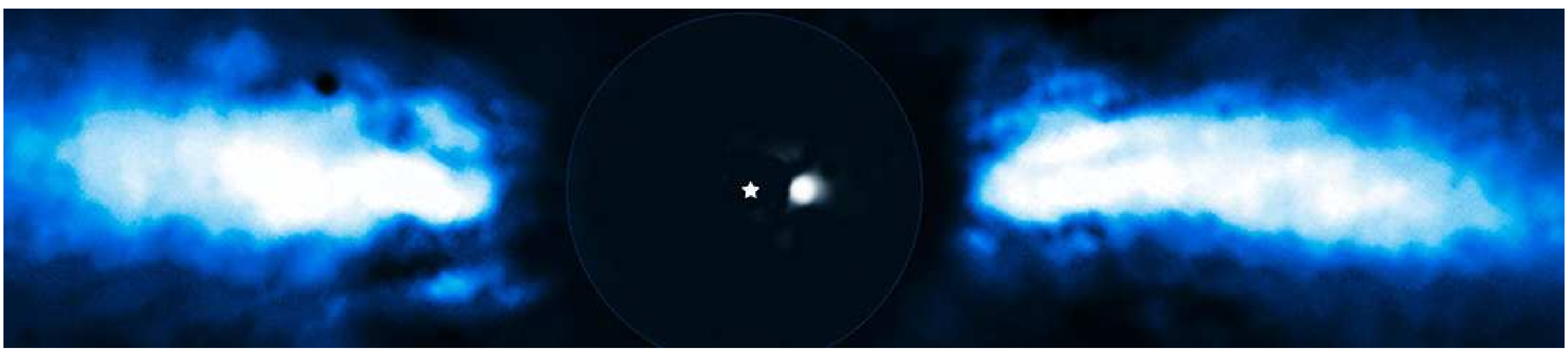
Conclusions, assuming albedo $Q_s = 0.7$:

- dust mass is $M_{\text{dust}} \sim \mathbf{10}$ lunar masses,
  similar to Holland et al (1998) from from sub-mm observations,
  total dust cross section is $A_{\text{dust}} \sim \mathbf{2 \times 10^{20}}$ km^2

- β Pic's age $t_\star \sim \mathbf{10}$ Mys implies a total planetesimal mass $\dot{M}_d t_\star \sim \mathbf{100}$ $M_\oplus$
  was lost due to collisional erosion, equivalent to 6 Neptunes!
  β Pic's planetesimal disk is (or was) very massive

- heavy planetesimal erosion in $r > \mathbf{75}$ AU zone
  may preclude any planet formation there

- however the recent recovery of β Pic b at $r \sim \mathbf{10}$ AU (Lagrange et al 2010)
  shows that the innermost part of this disk did successfully produce a planet



Lastly...

- model details and results are in Hahn (2010), reprint available
- debris-disk model is available online, written in IDL, google ‘SSI’ to find my homepage