

Planetesimal Disks as Tracers

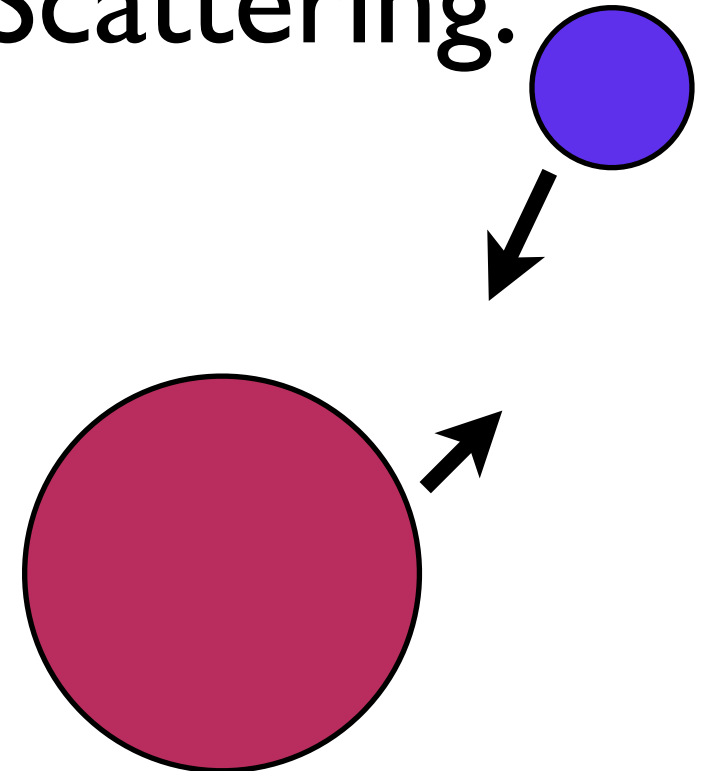
of Planet-Planet Scattering:

At Home and Abroad

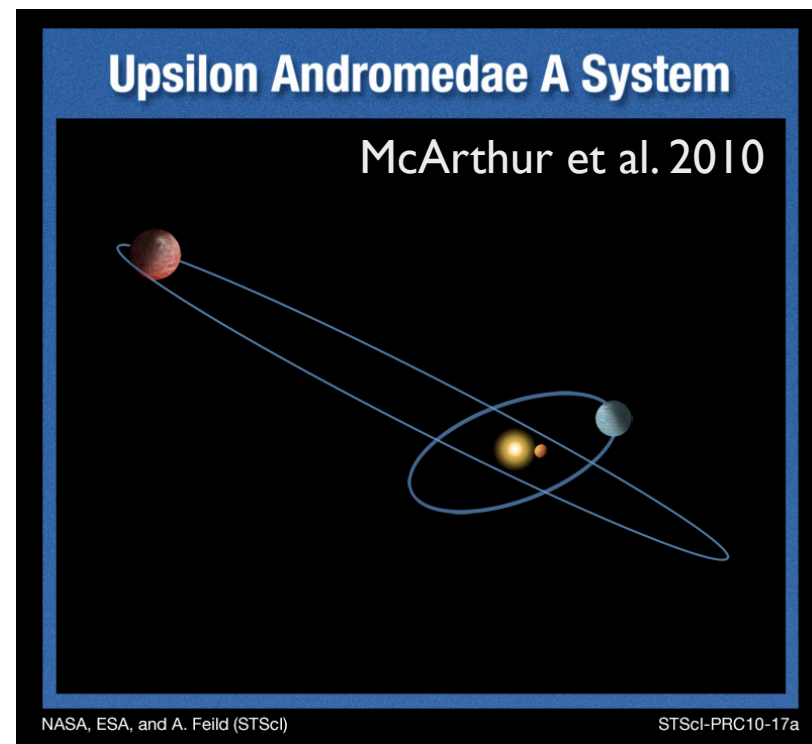
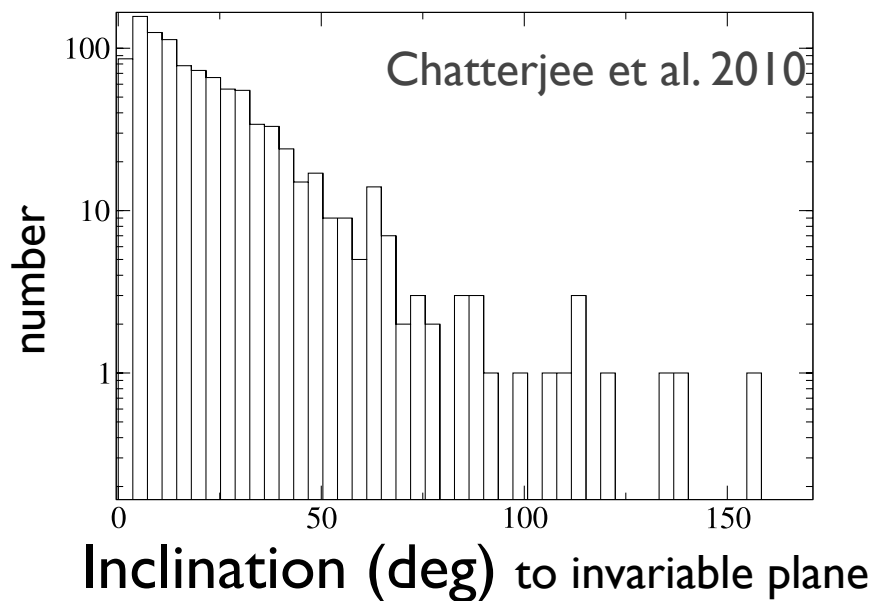
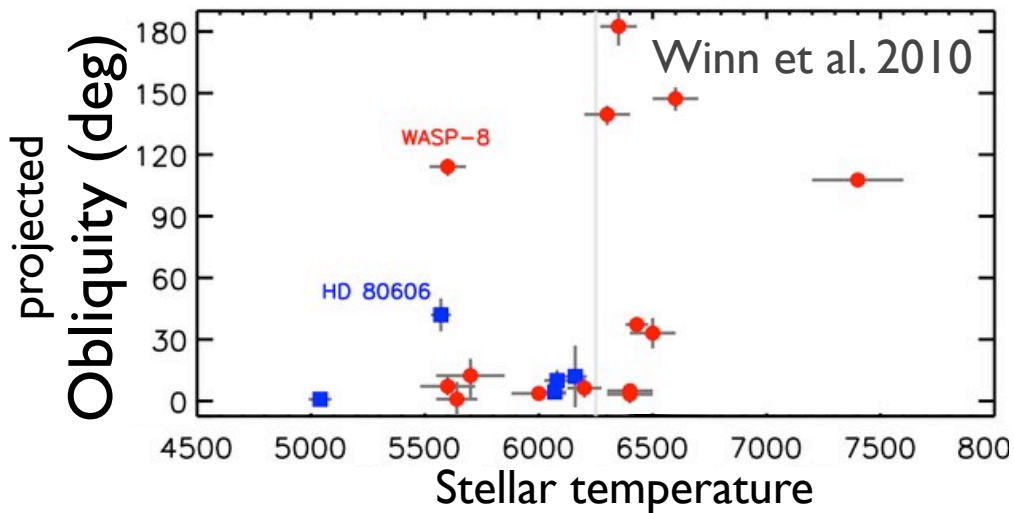
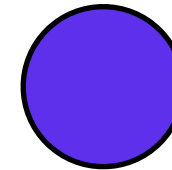
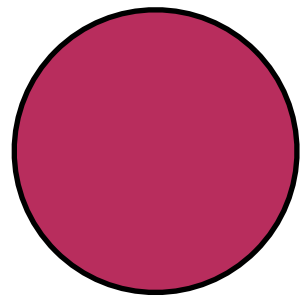
Bekki Dawson

Ruth Murray-Clay

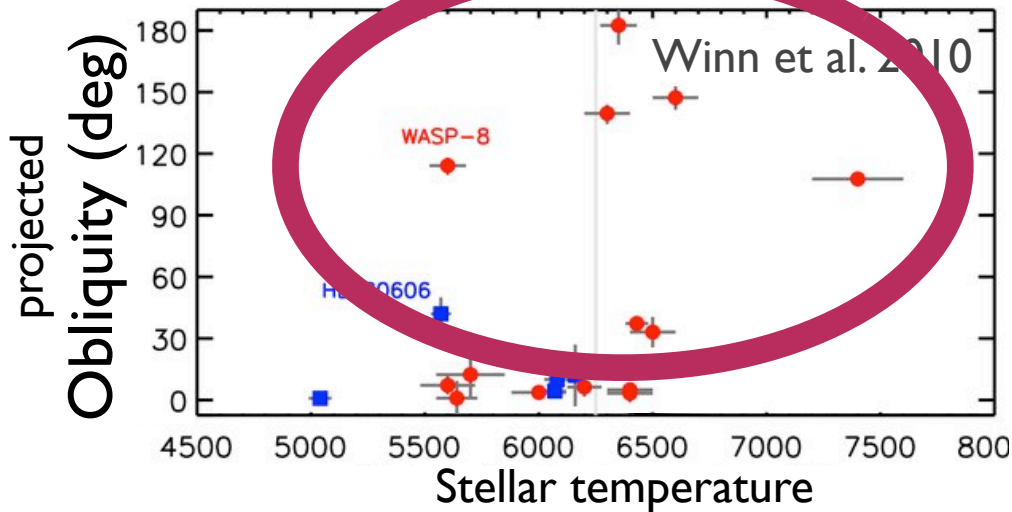
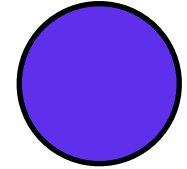
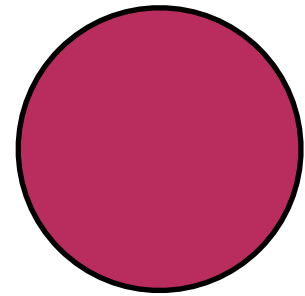
Harvard-Smithsonian CfA



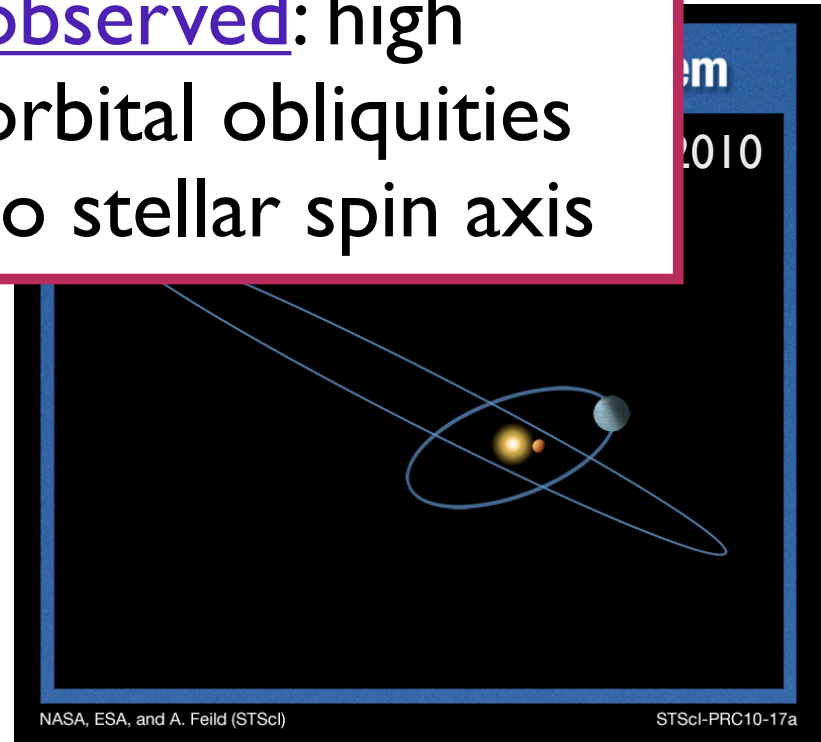
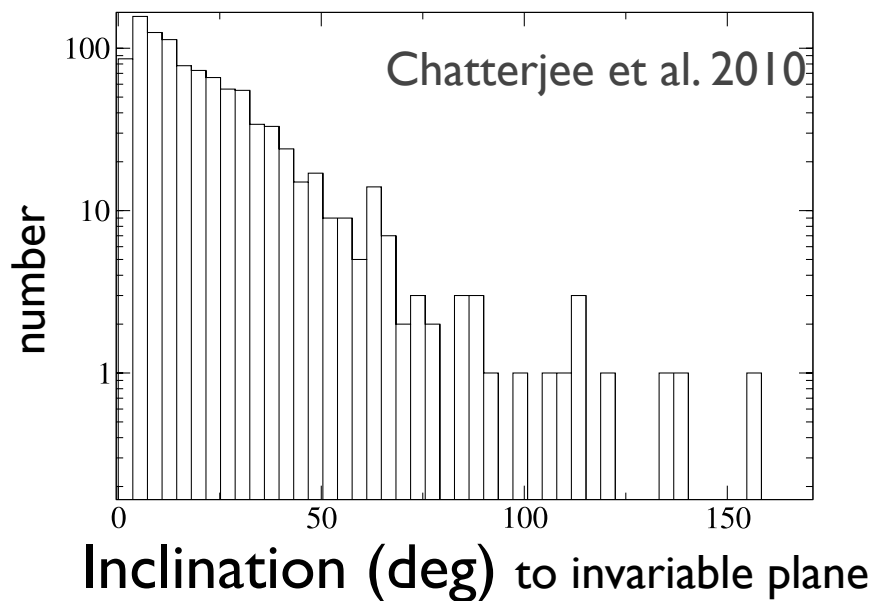
Planet-Planet Scattering: It could happen to you



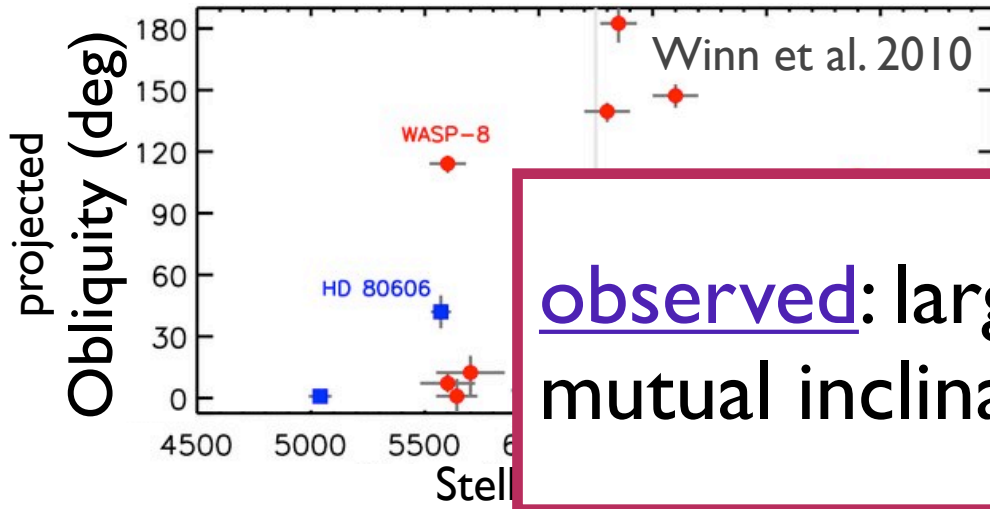
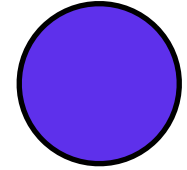
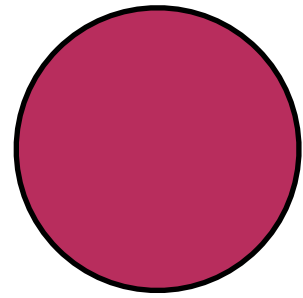
Planet-Planet Scattering: It could happen to you



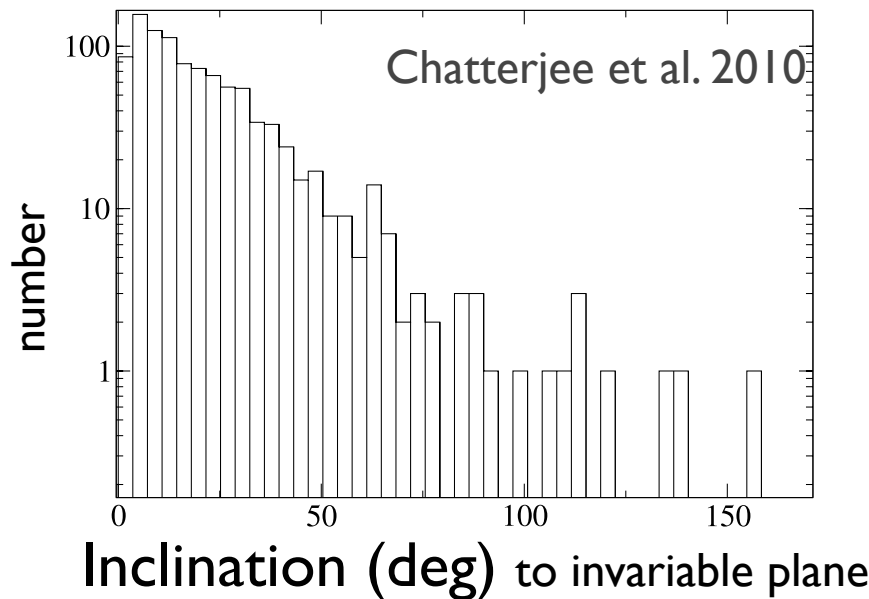
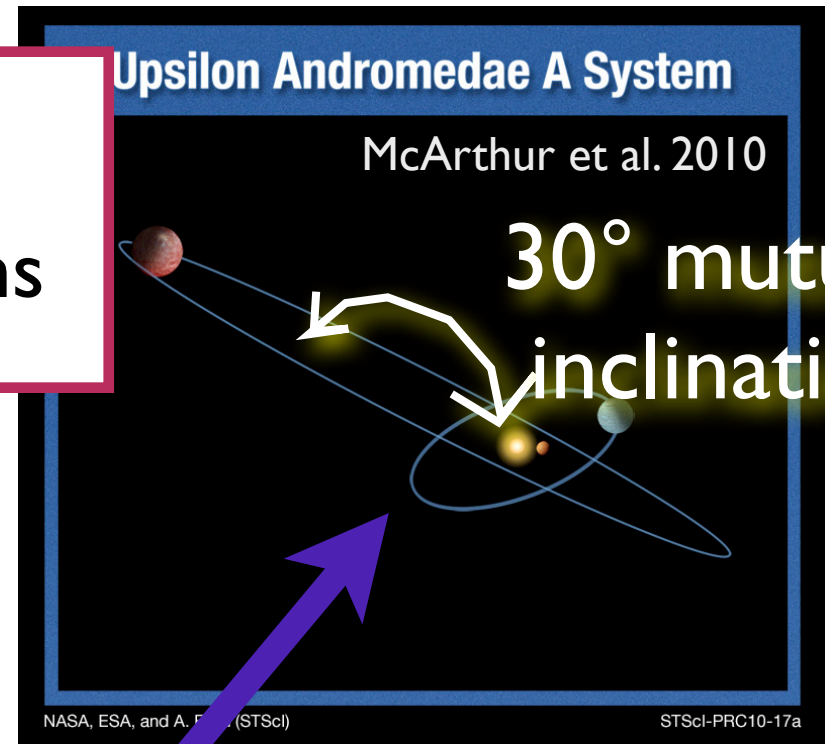
observed: high
orbital obliquities
to stellar spin axis



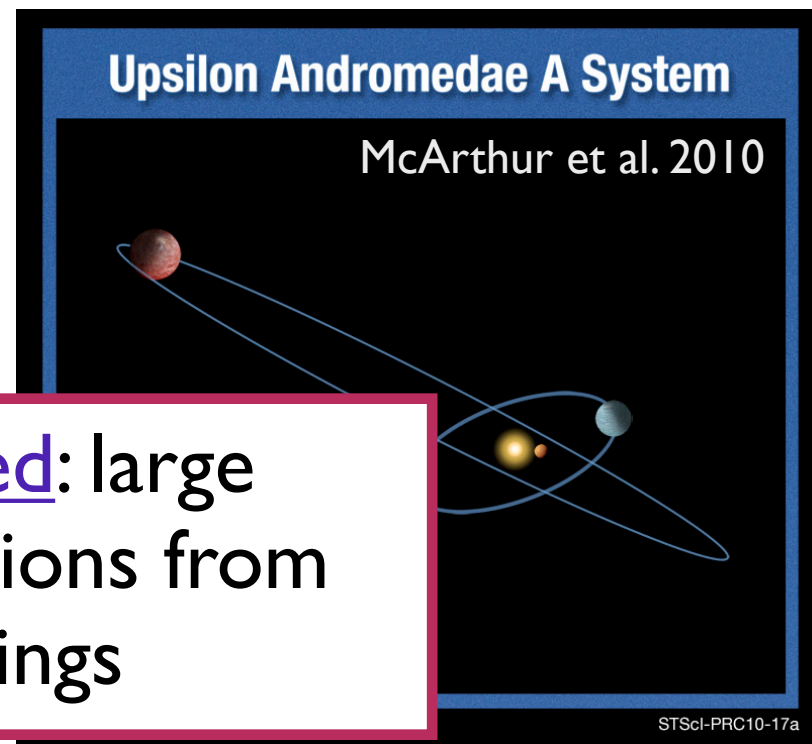
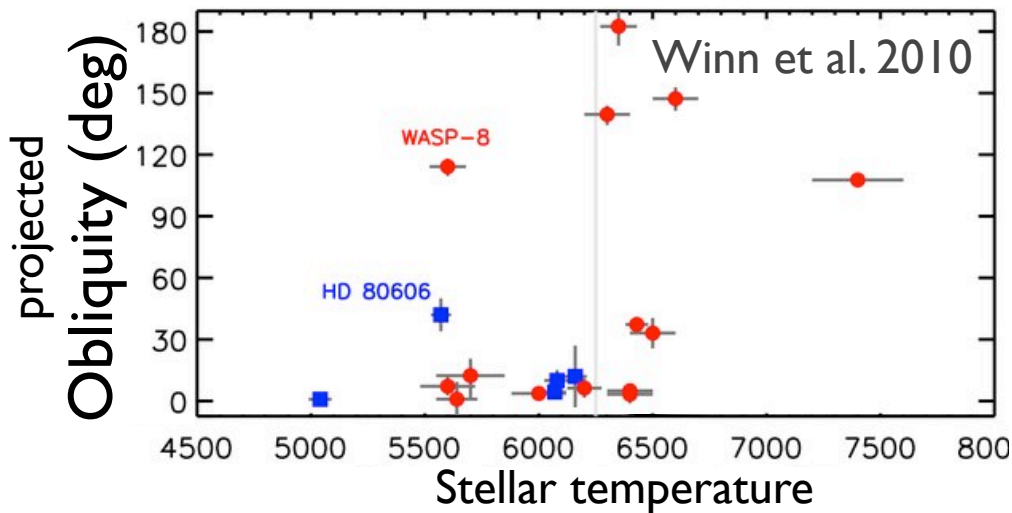
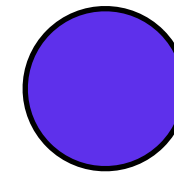
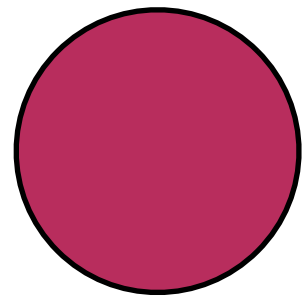
Planet-Planet Scattering: It could happen to you



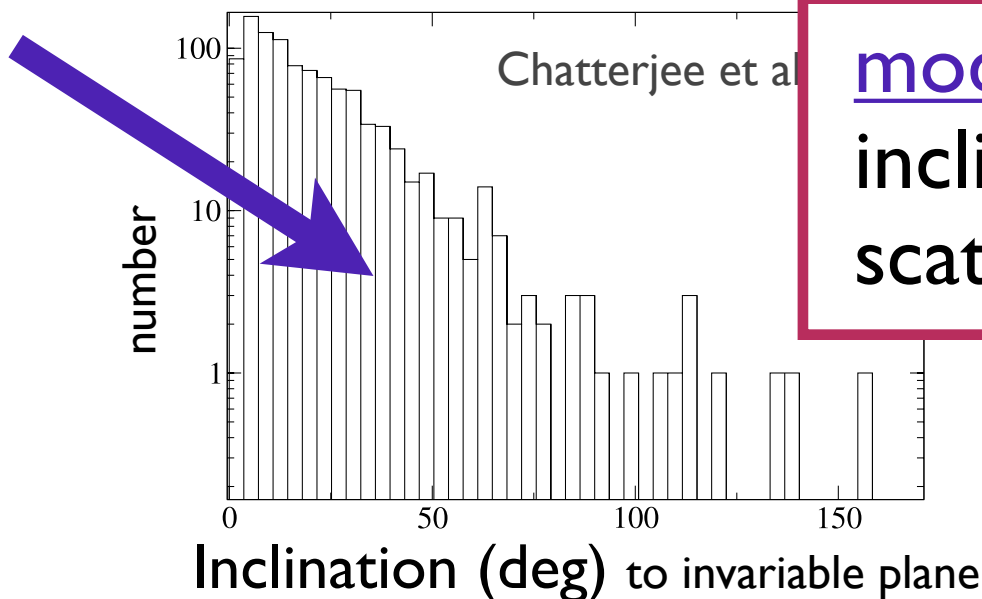
observed: large mutual inclinations



Planet-Planet Scattering: It could happen to you

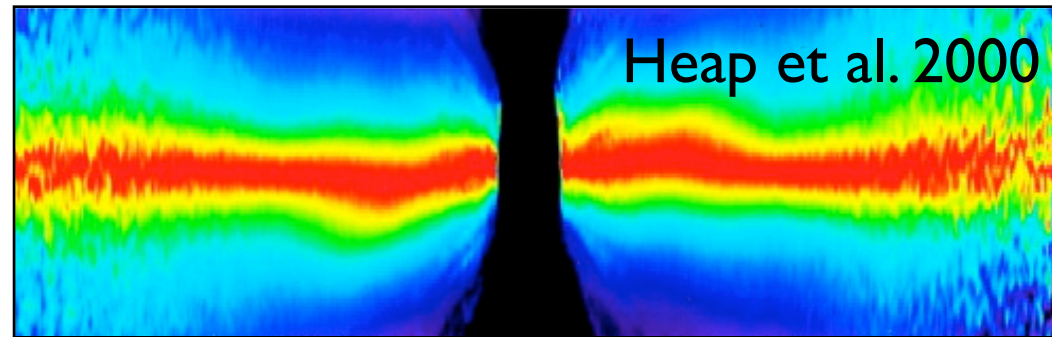


modeled: large inclinations from scatterings

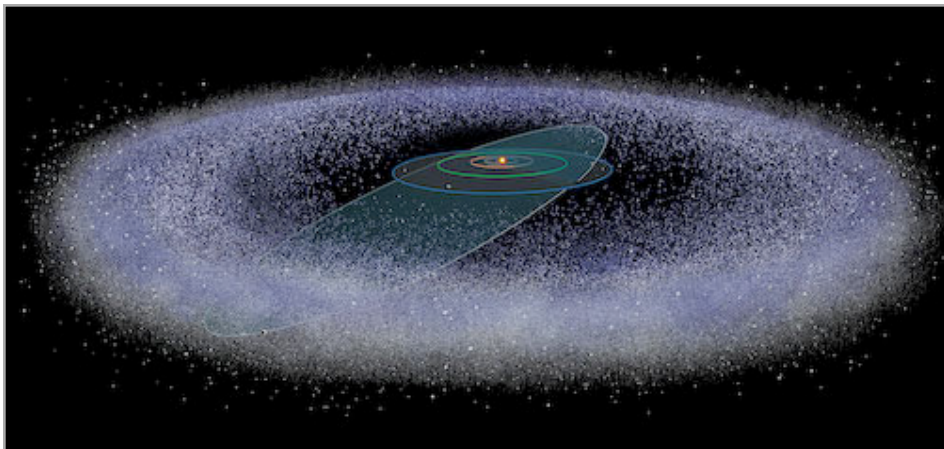


Sculpted Planetesimal Disks: At Home and Abroad

Beta Pictoris



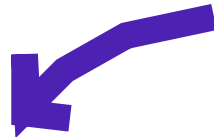
The Kuiper Belt



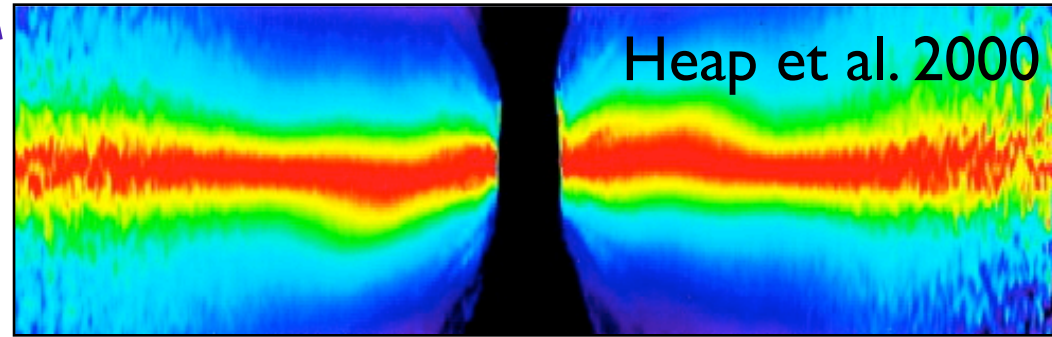
Sculpted Planetesimal Disks: At Home and Abroad

Warping by
inclined planet
previously
modeled by:
Mouillet et al.
(1997), Augereau
et al. (2001).

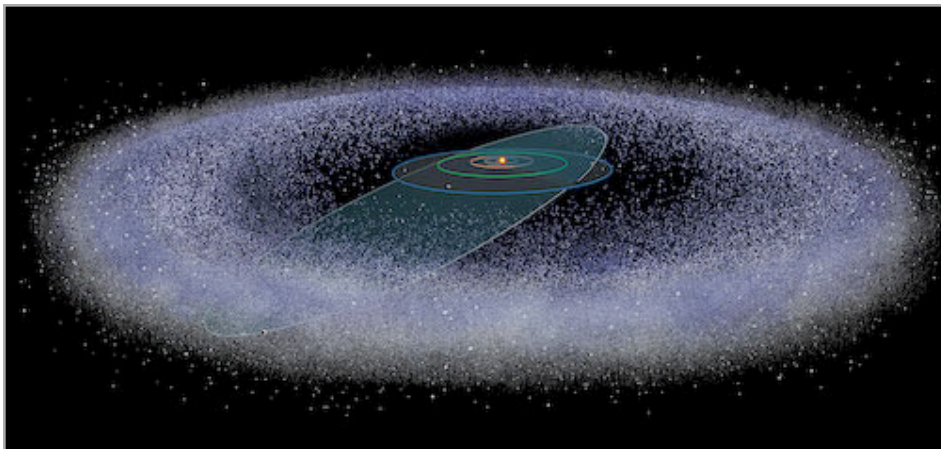
Beta Pictoris b (or c?)



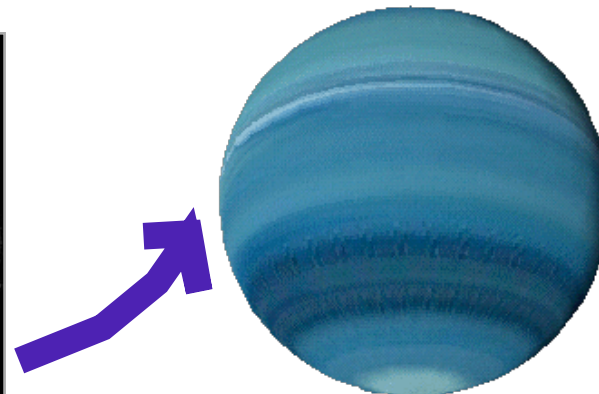
Beta Pictoris



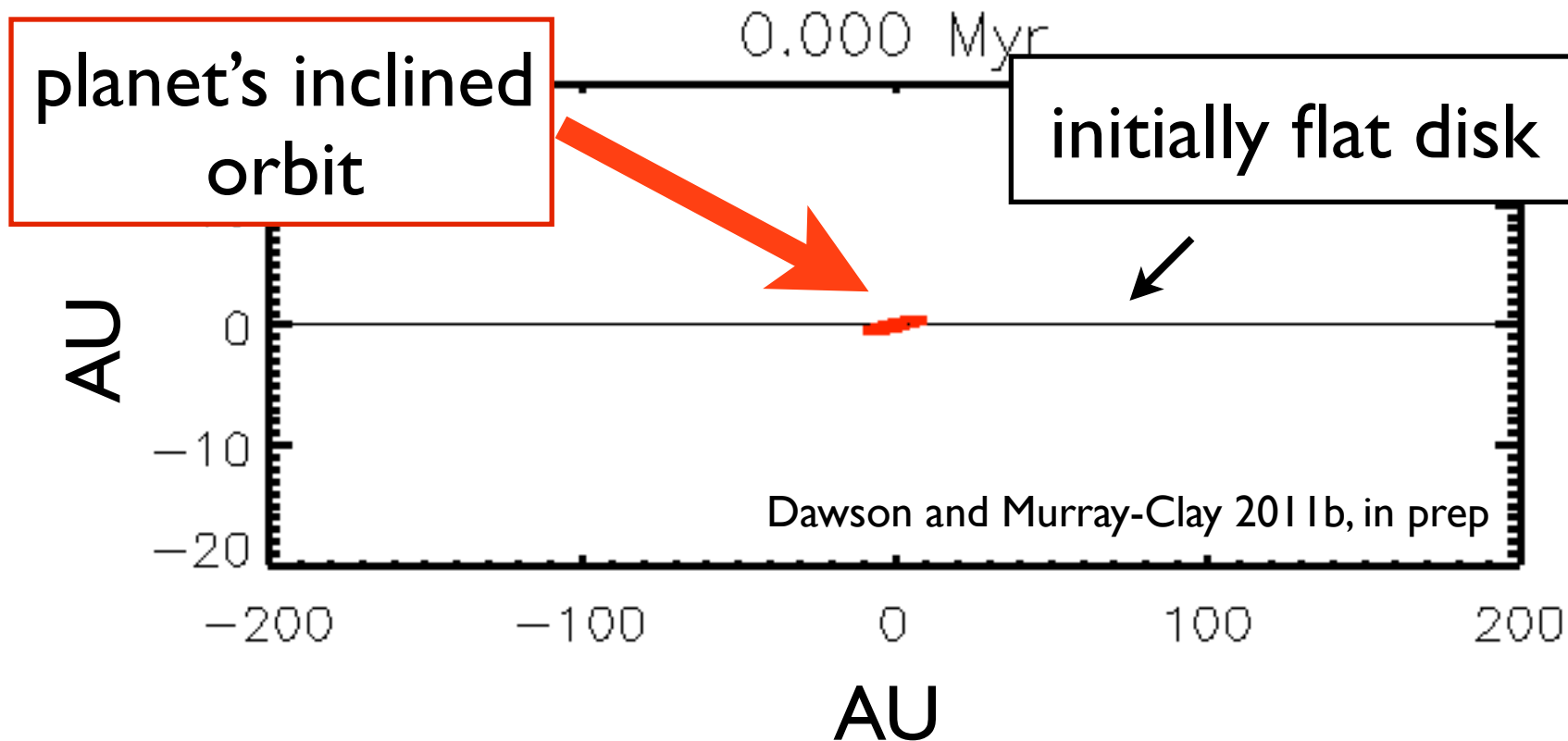
The Kuiper Belt



Neptune



Planetesimal Disks as Tracers



Edge-on view from N-body simulation

Planetesimal Disks as Tracers

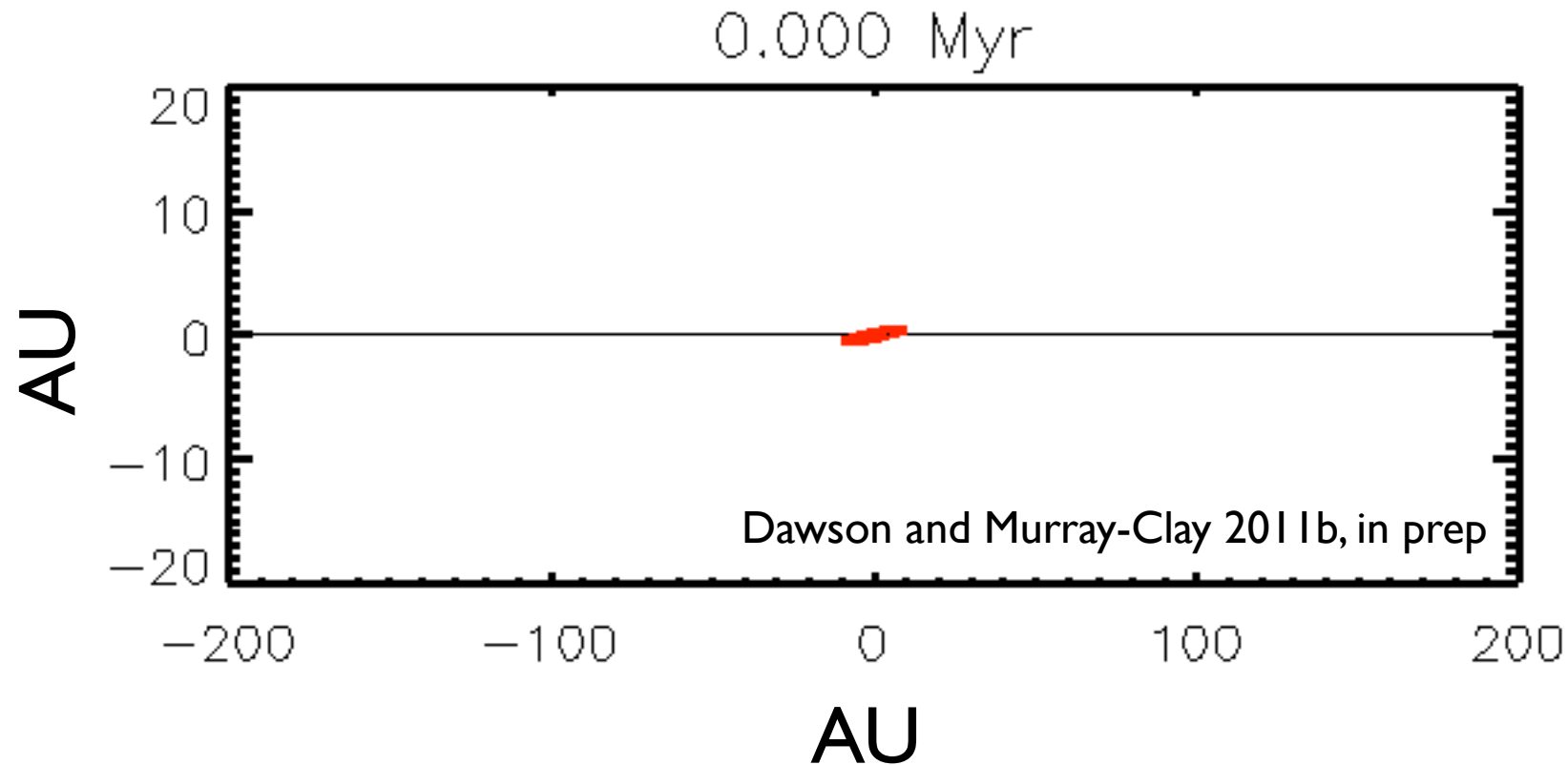
AU

Dawson and Murray-Clay 2011b, in prep

AU

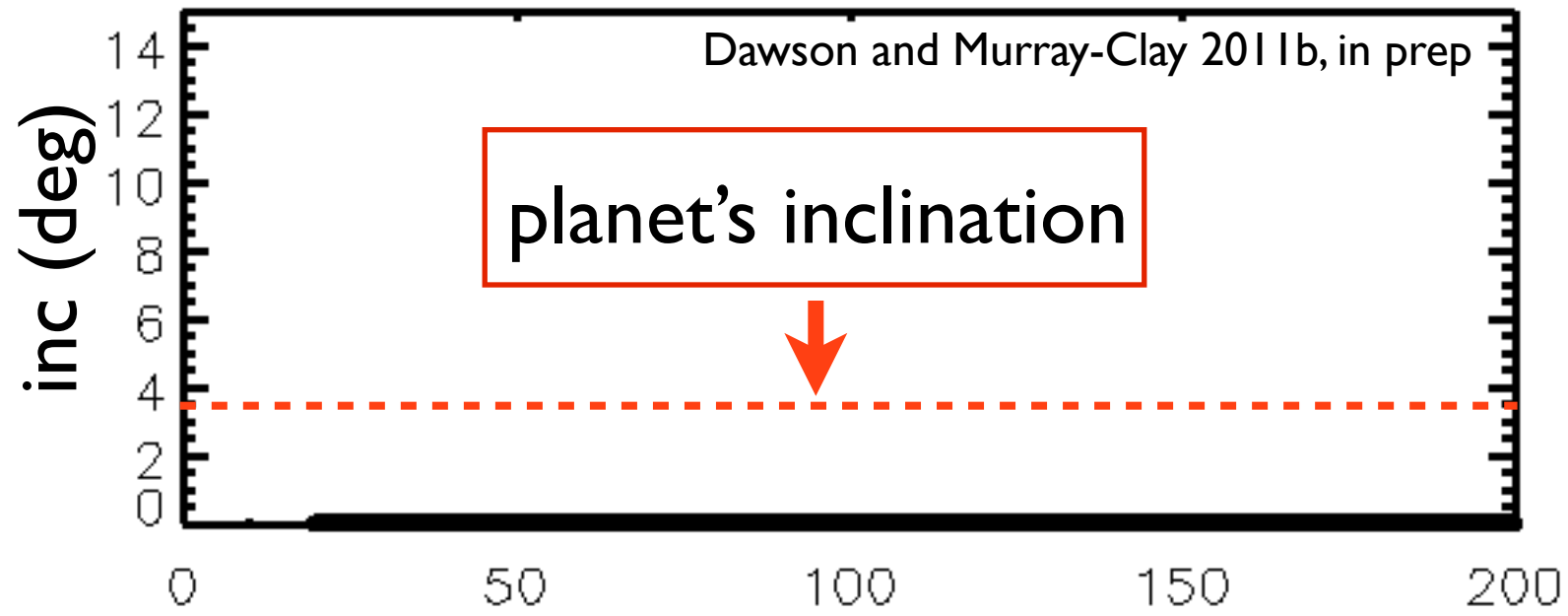
Edge-on view from N-body simulation

Planetesimal Disks as Tracers



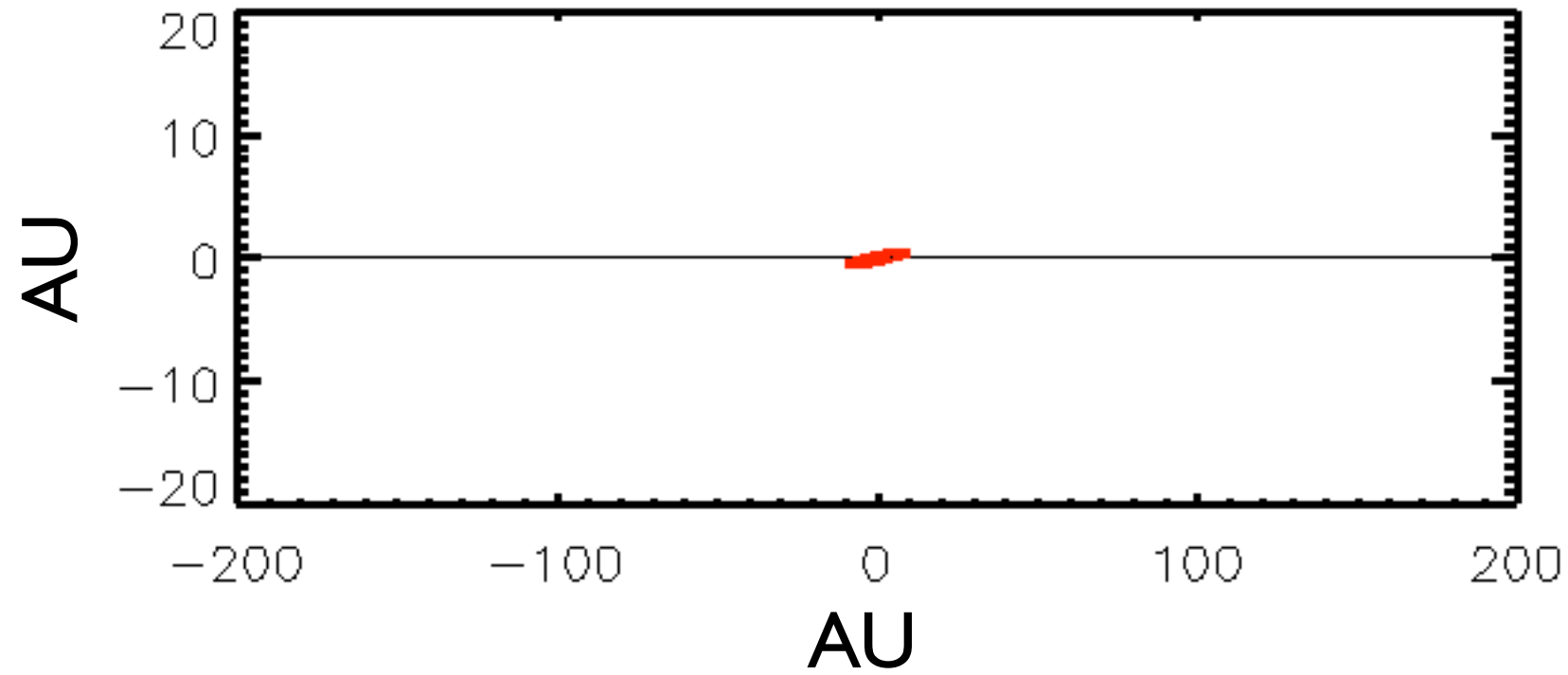
Edge-on view from N-body simulation

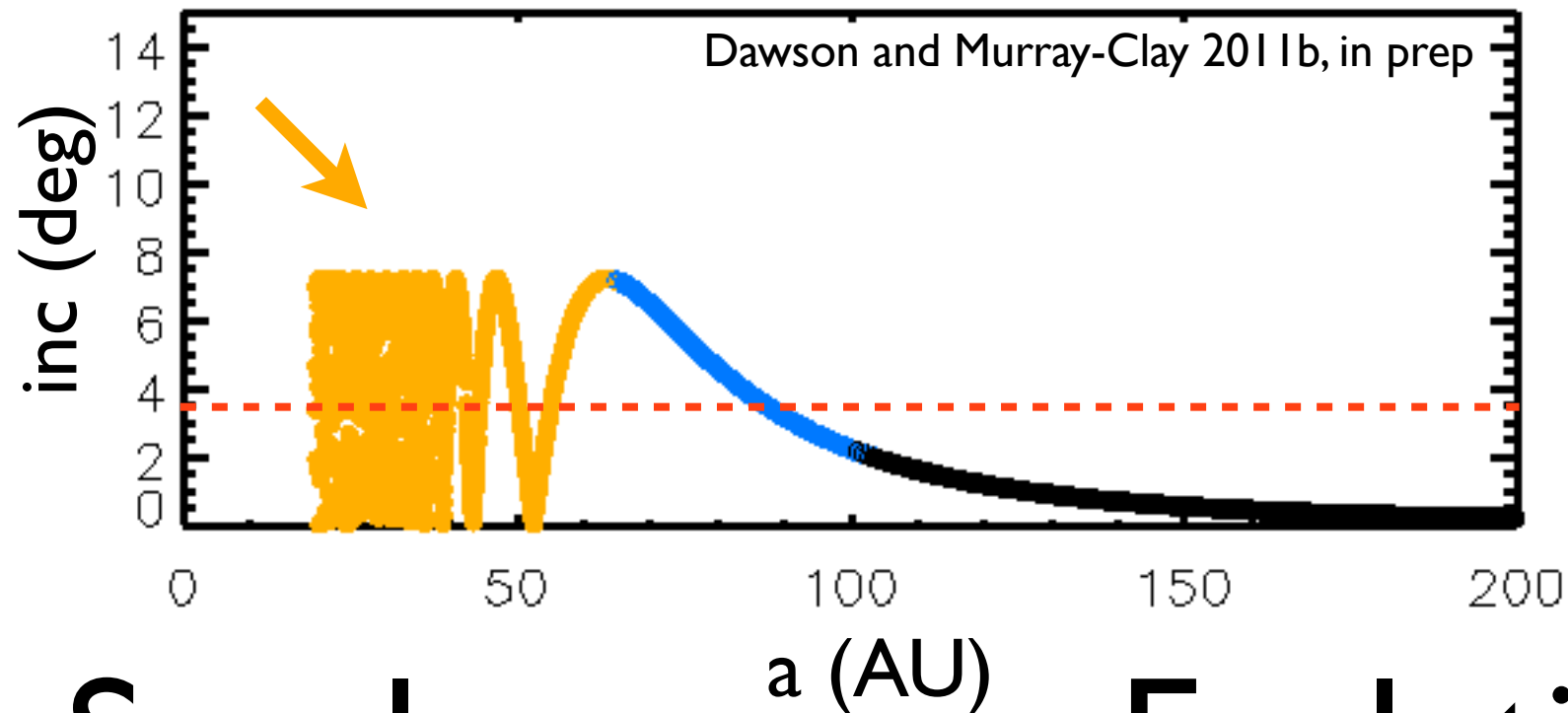
Dawson and Murray-Clay 2011b, in prep



Secular Evolution

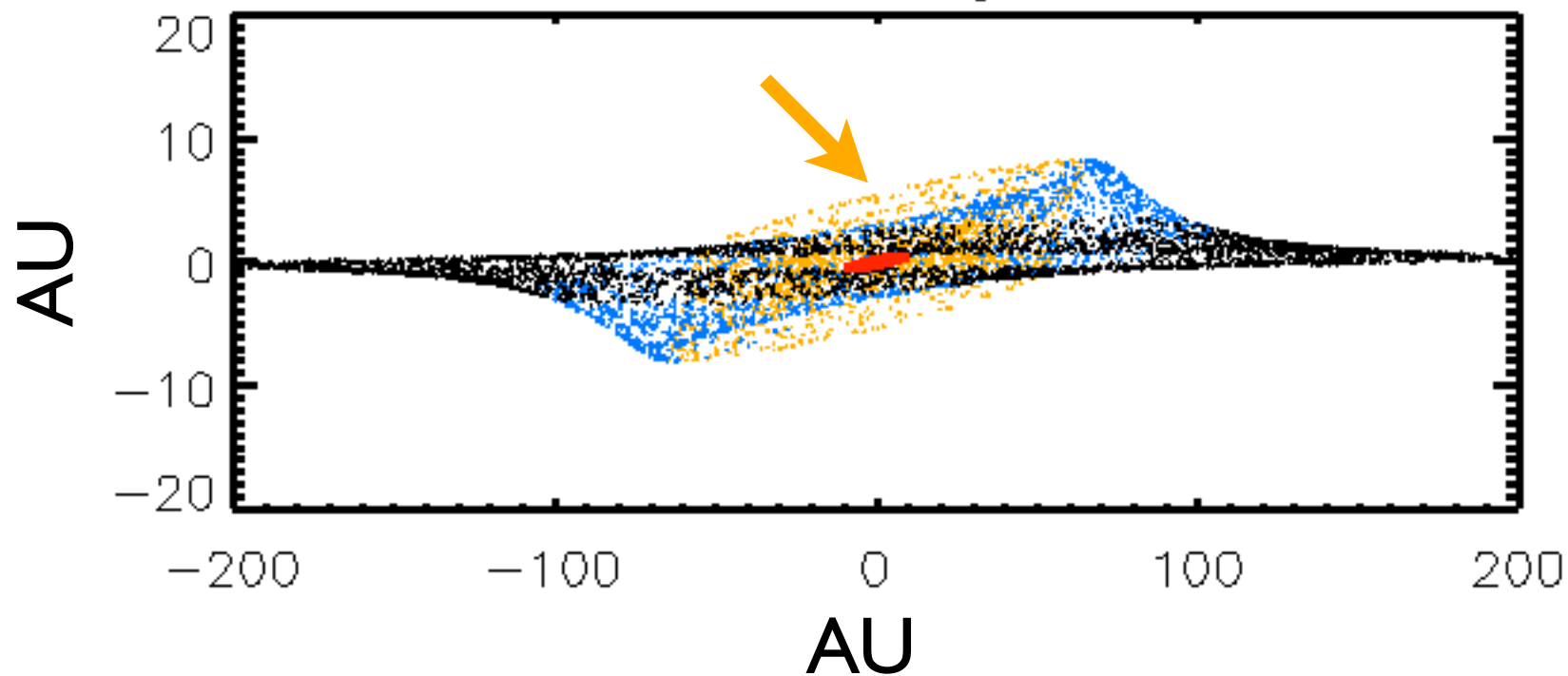
0.000 Myr

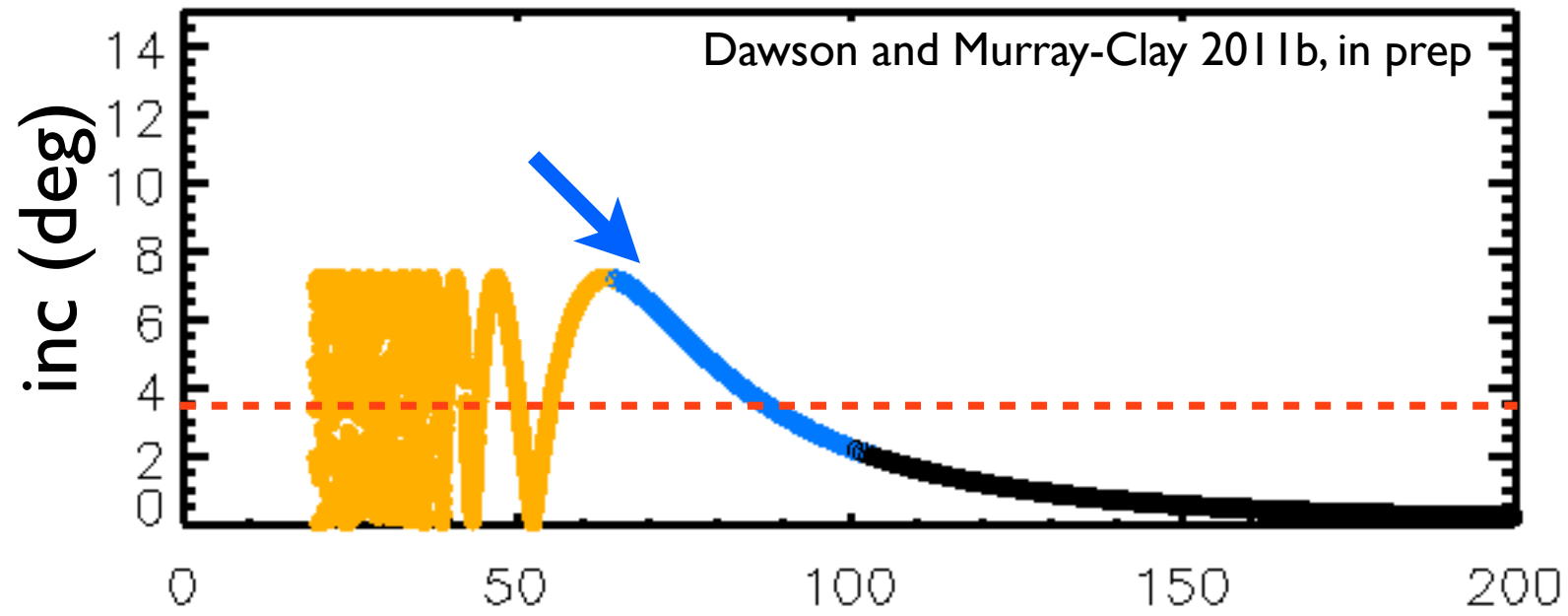




Secular Evolution

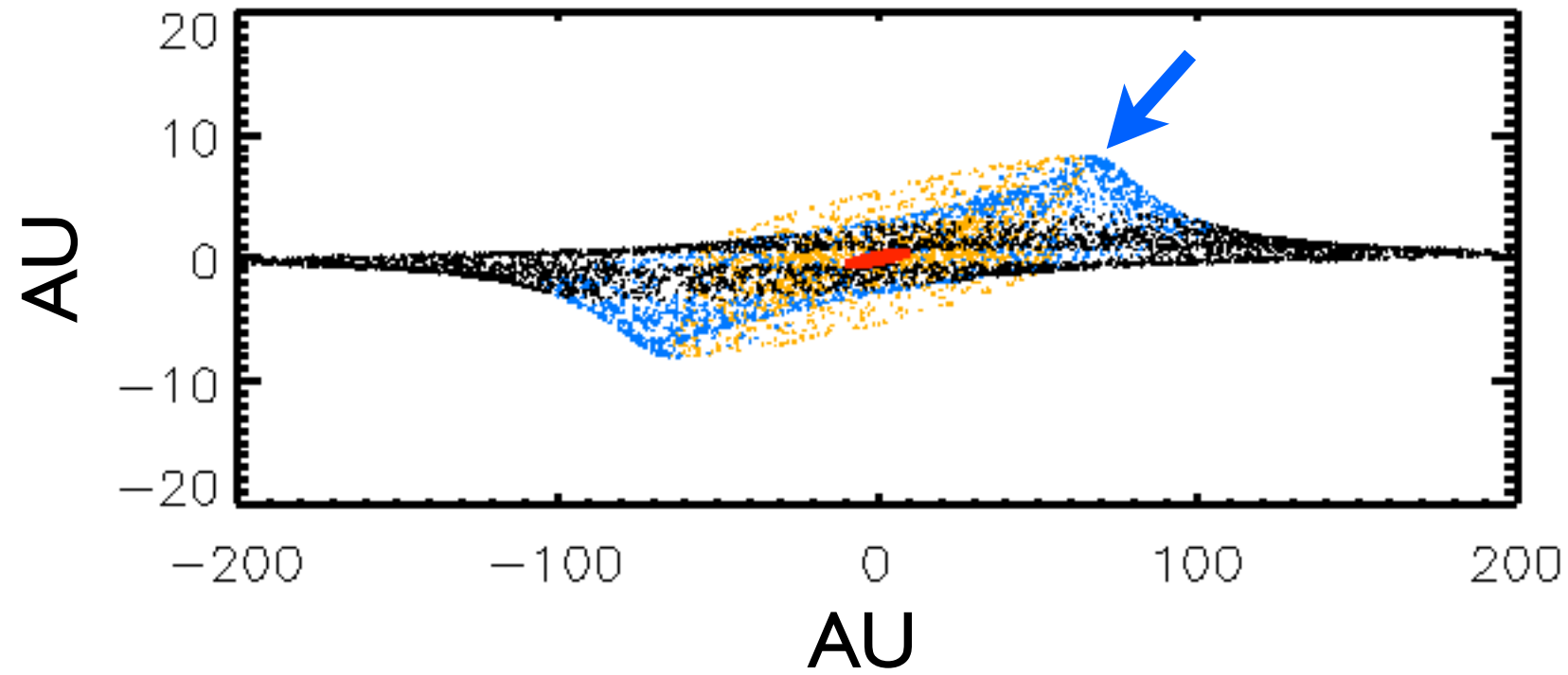
5.913 Myr

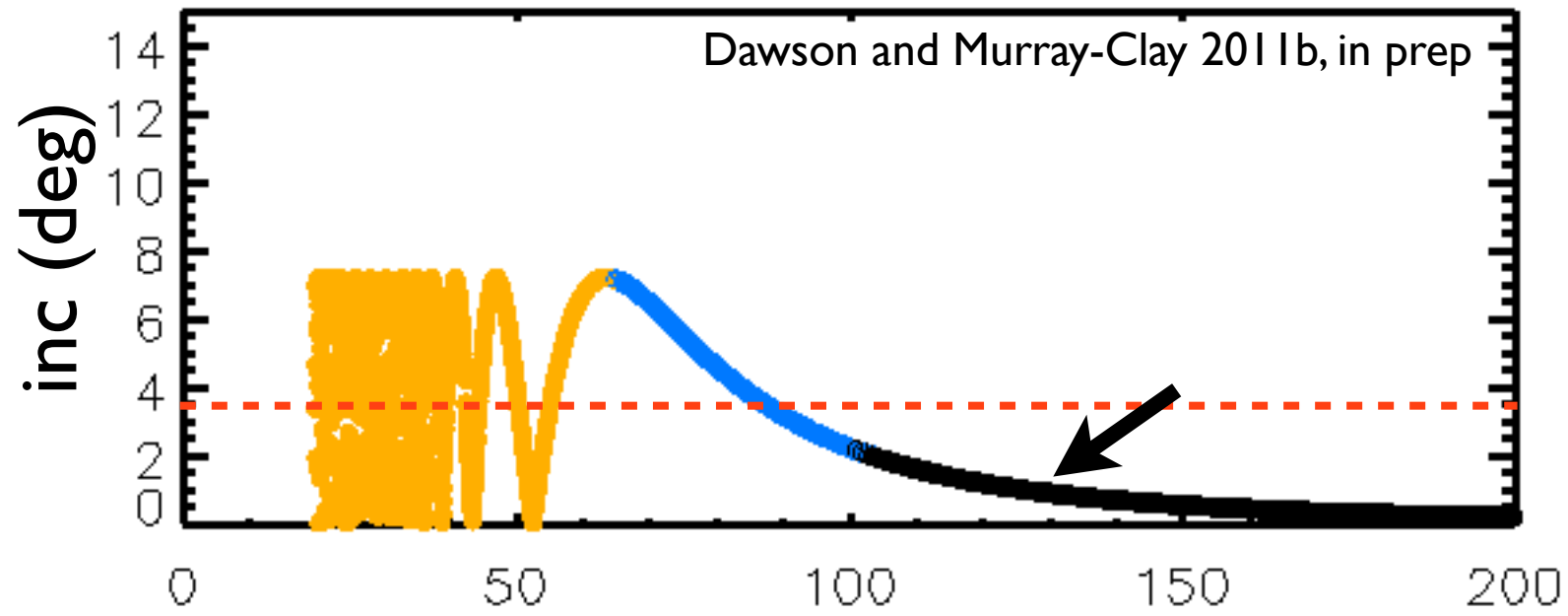




Secular Evolution

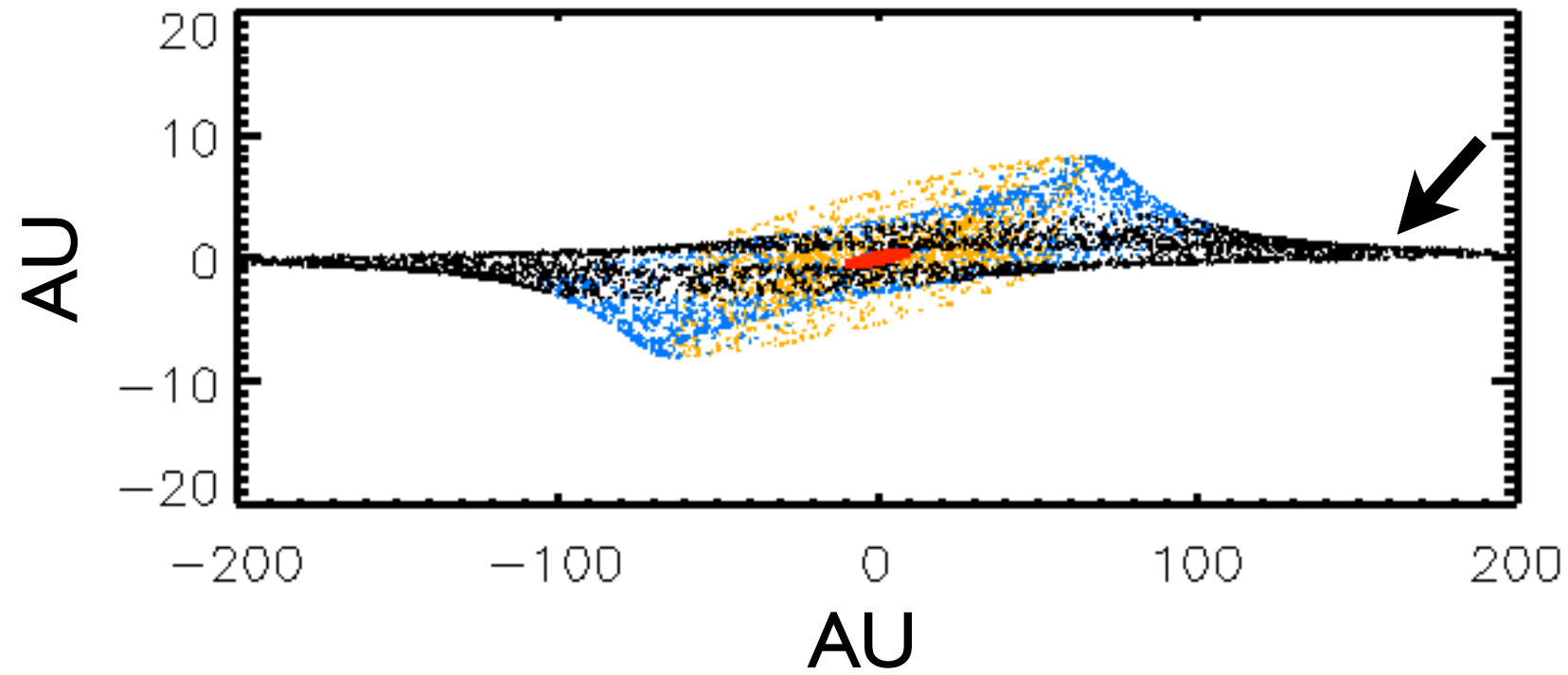
5.913 Myr





Secular Evolution

5.913 Myr



inc (deg)



Secular

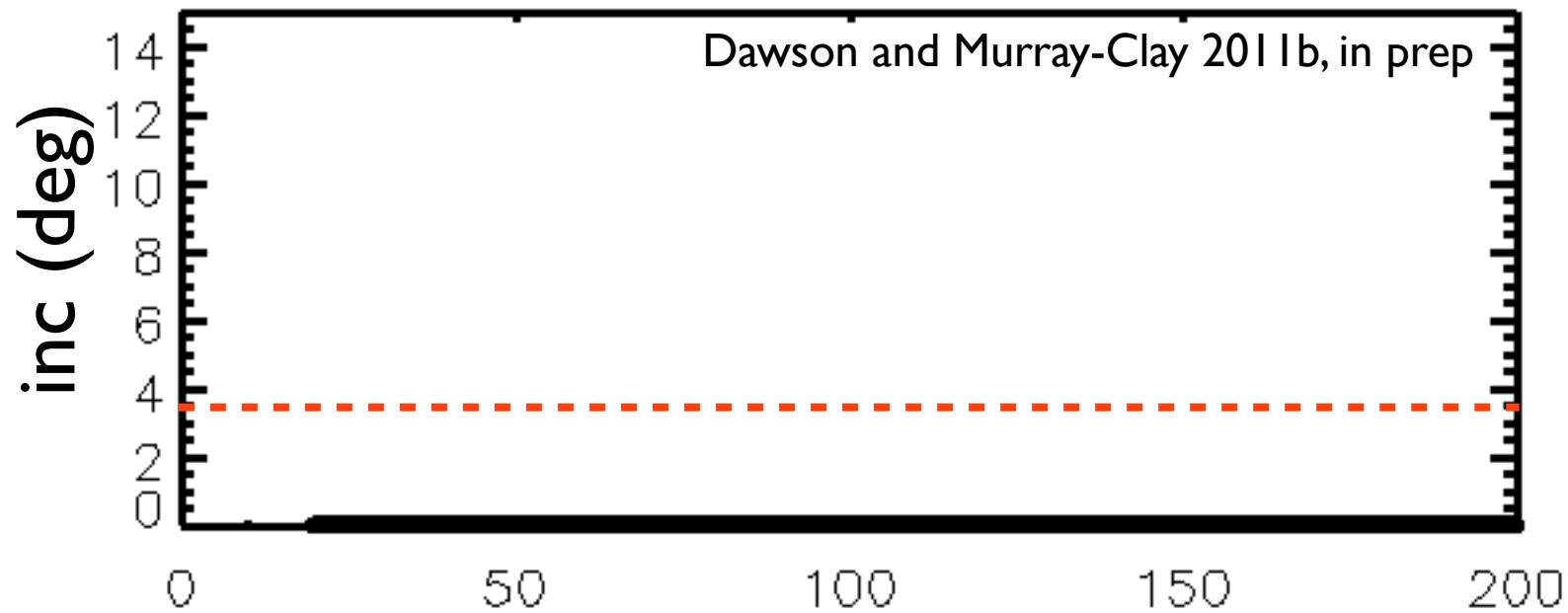
a (AU)

Evolution

AU

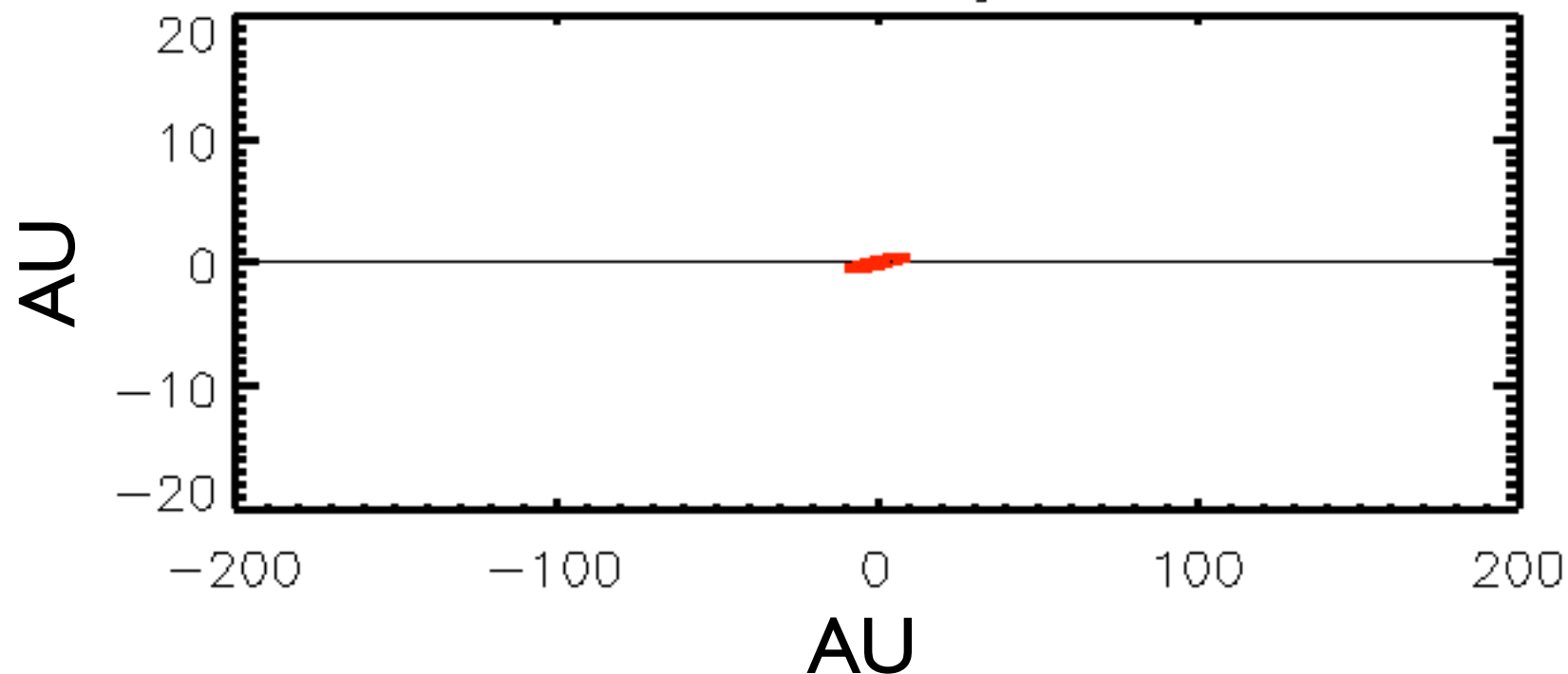
AU

Dawson and Murray-Clay 2011b, in prep

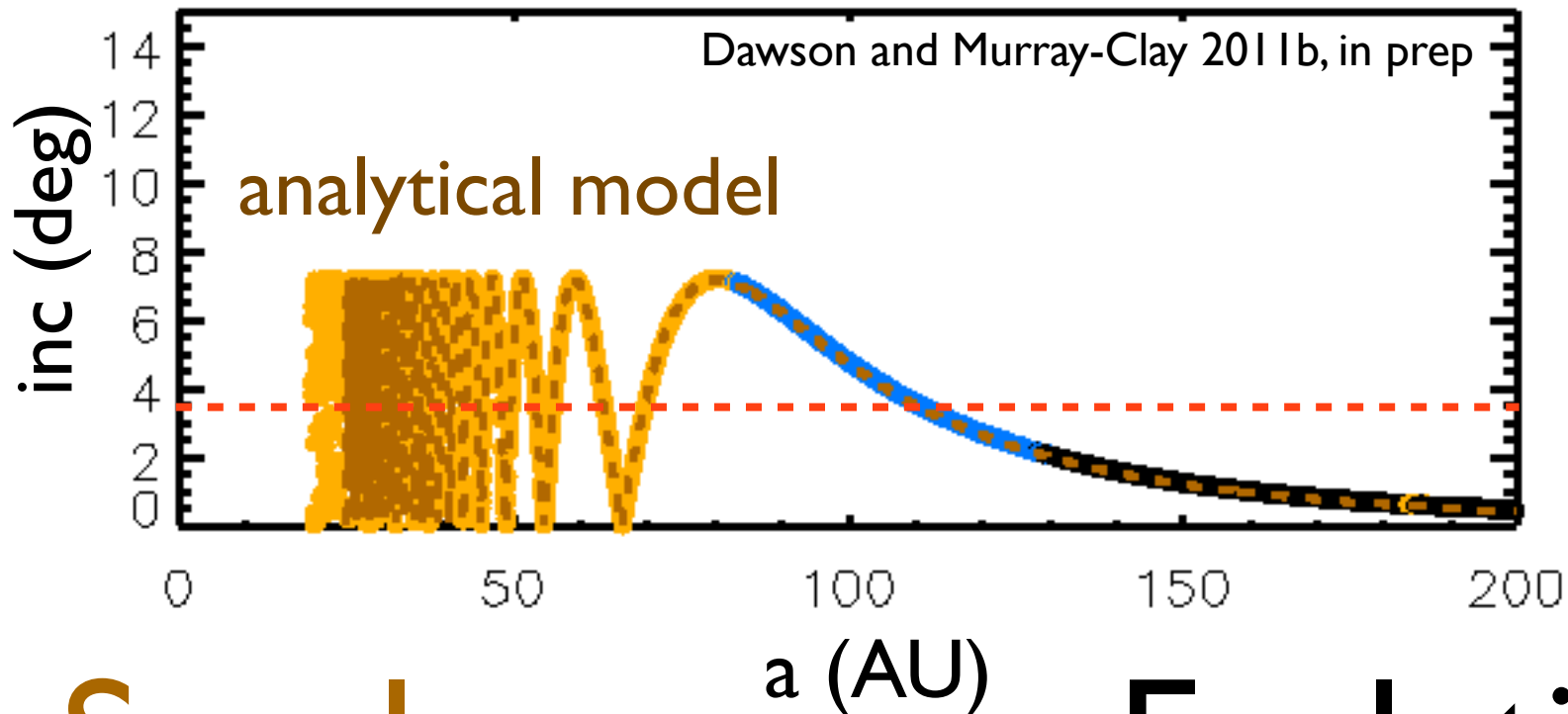


Secular Evolution

0.000 Myr

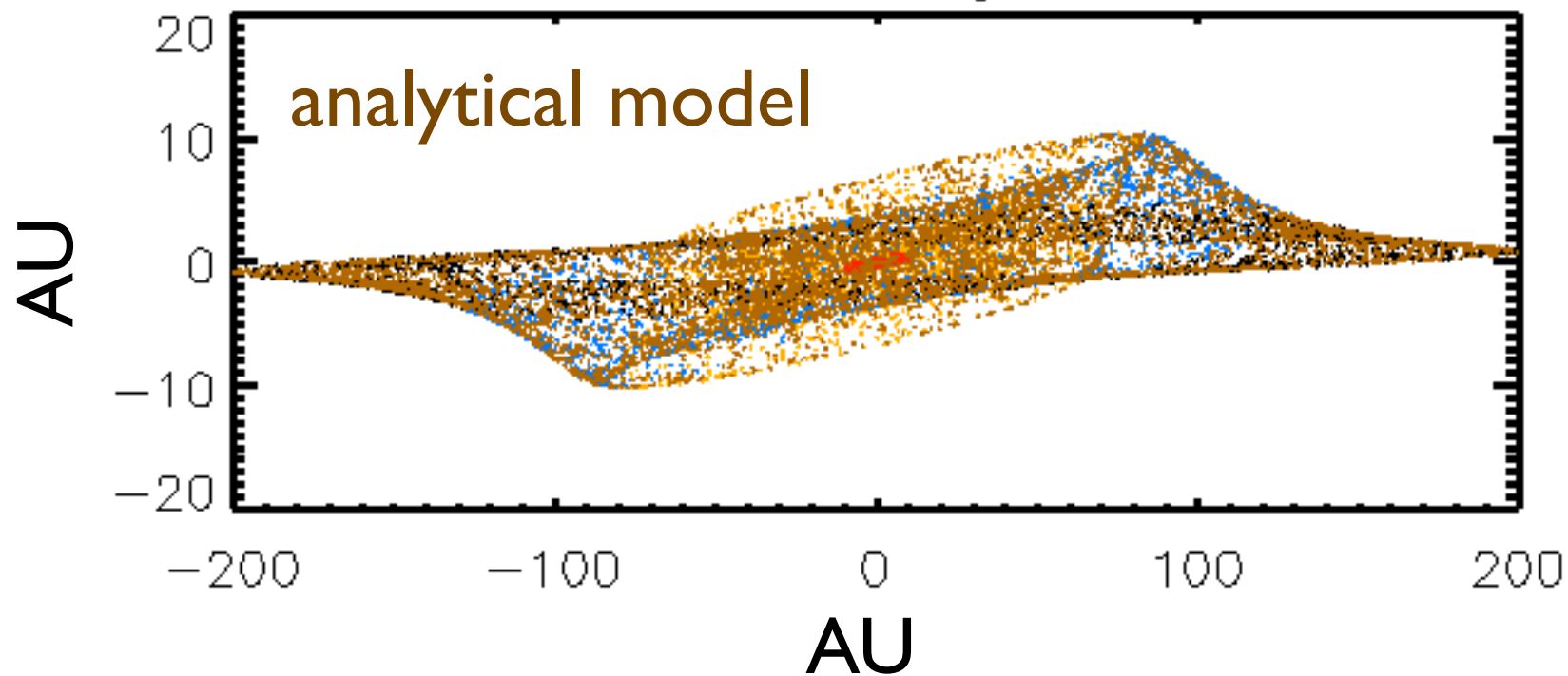


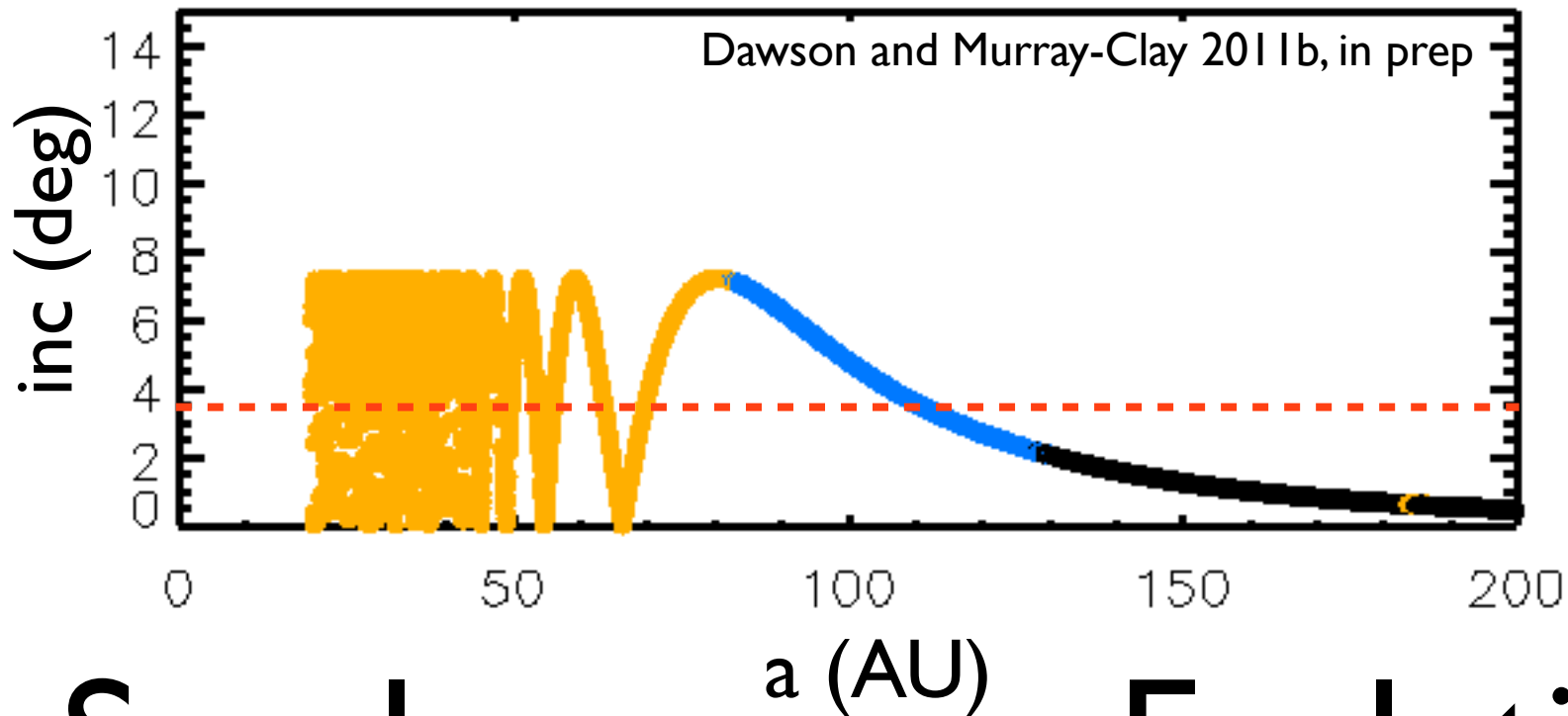
Dawson and Murray-Clay 2011b, in prep



Secular Evolution

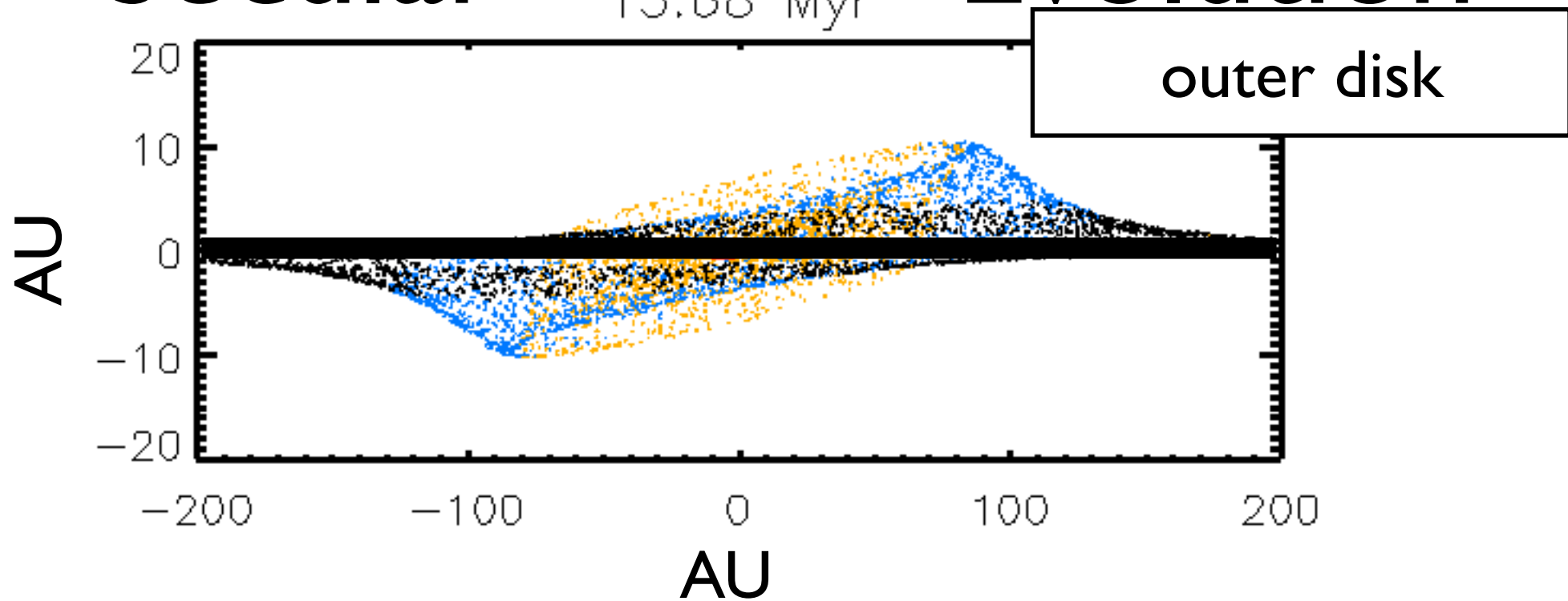
13.68 Myr

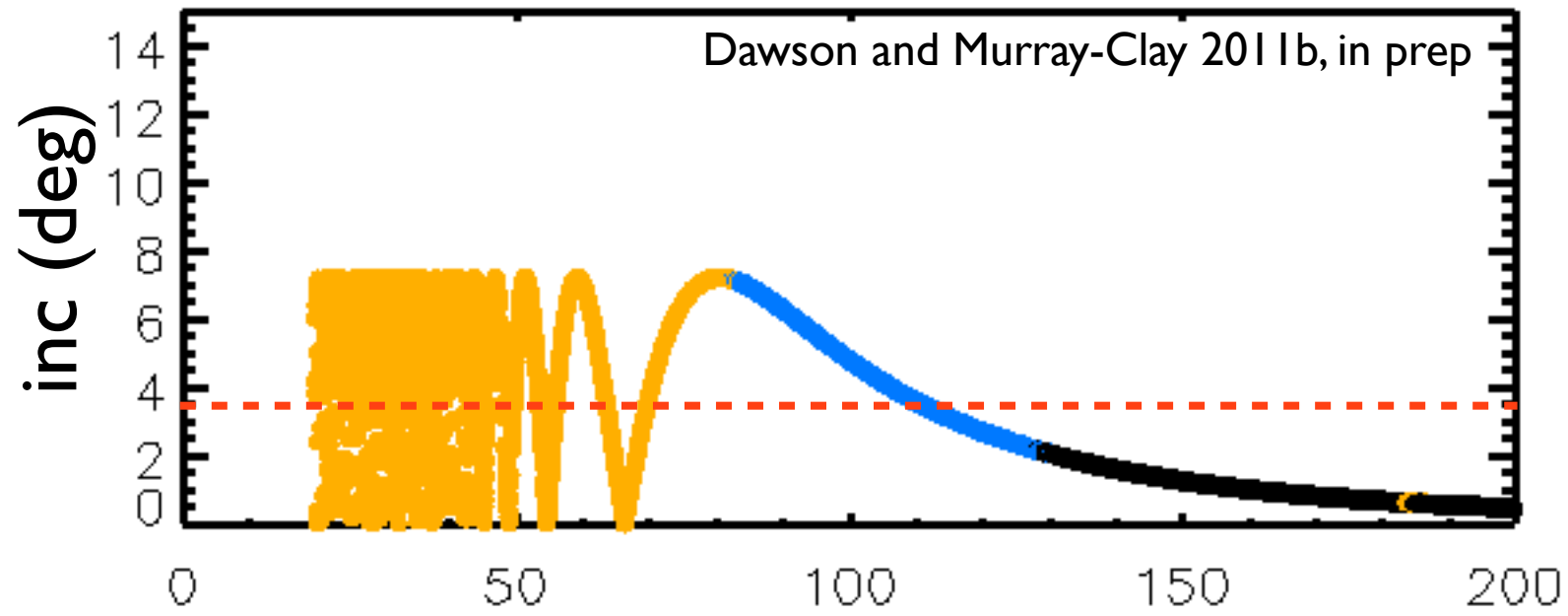




Secular

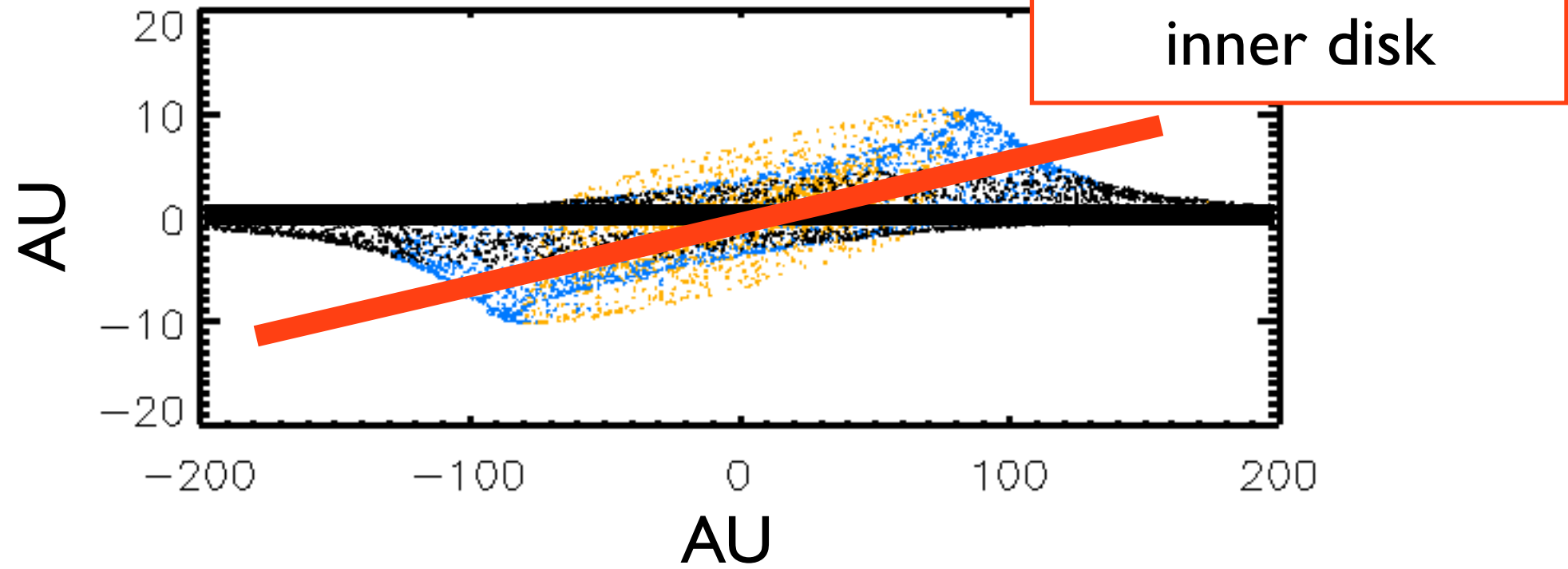
Evolution

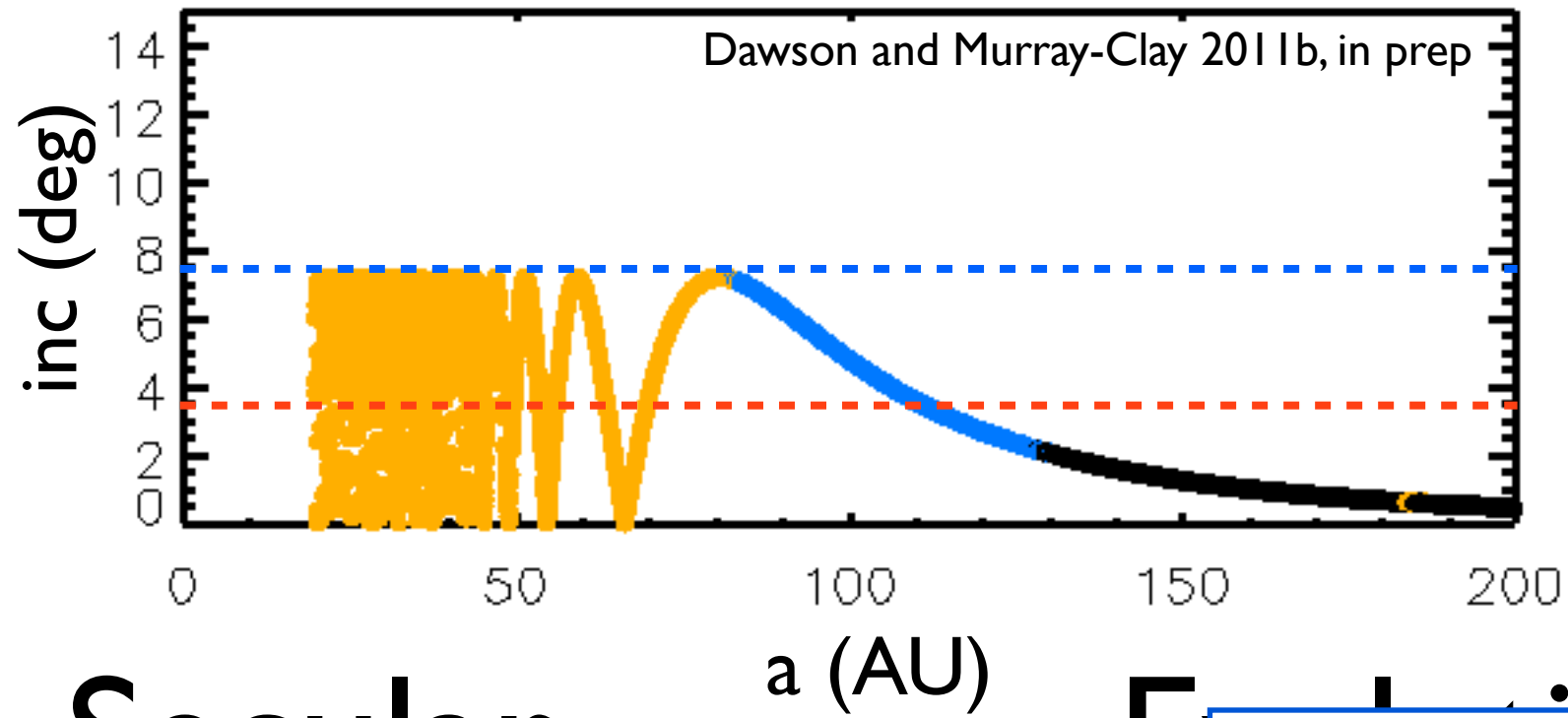




Secular Evolution

13.68 Myr



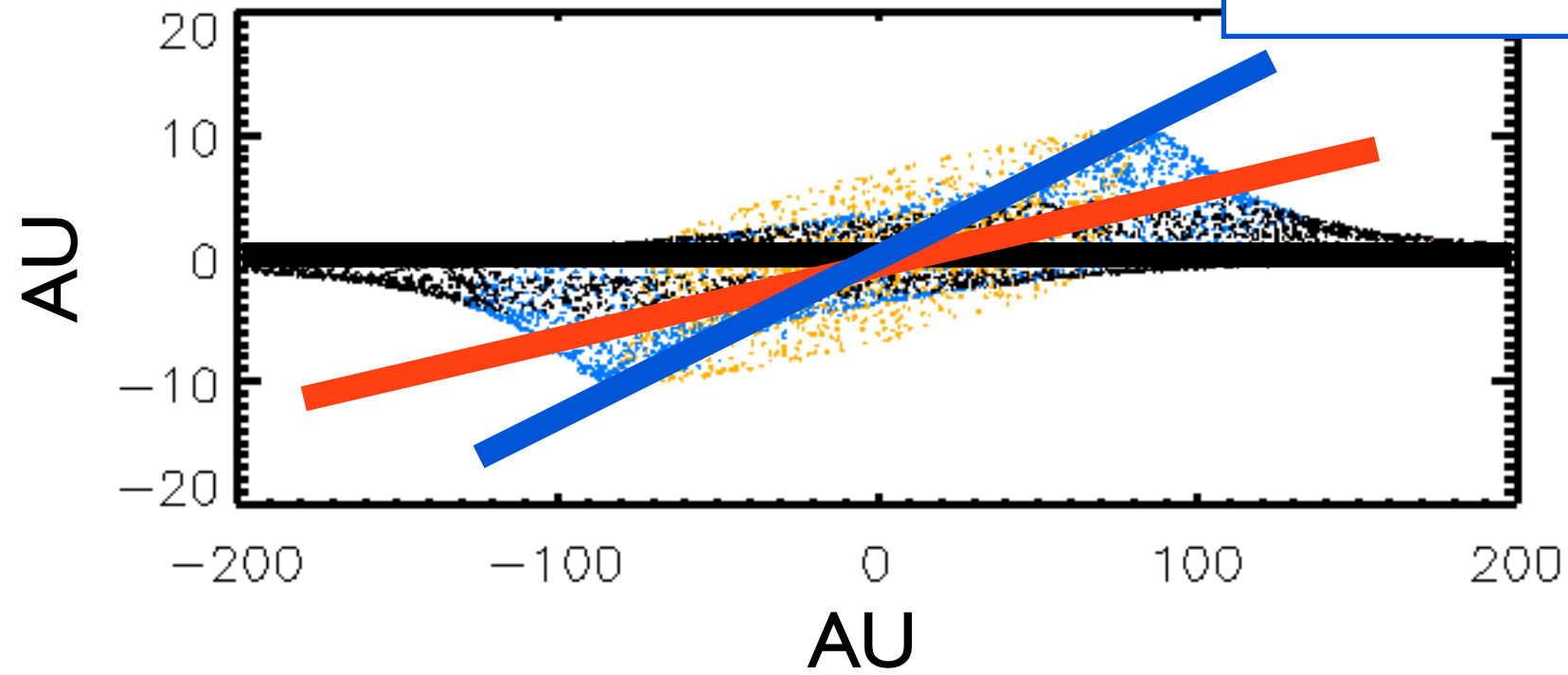


Secular

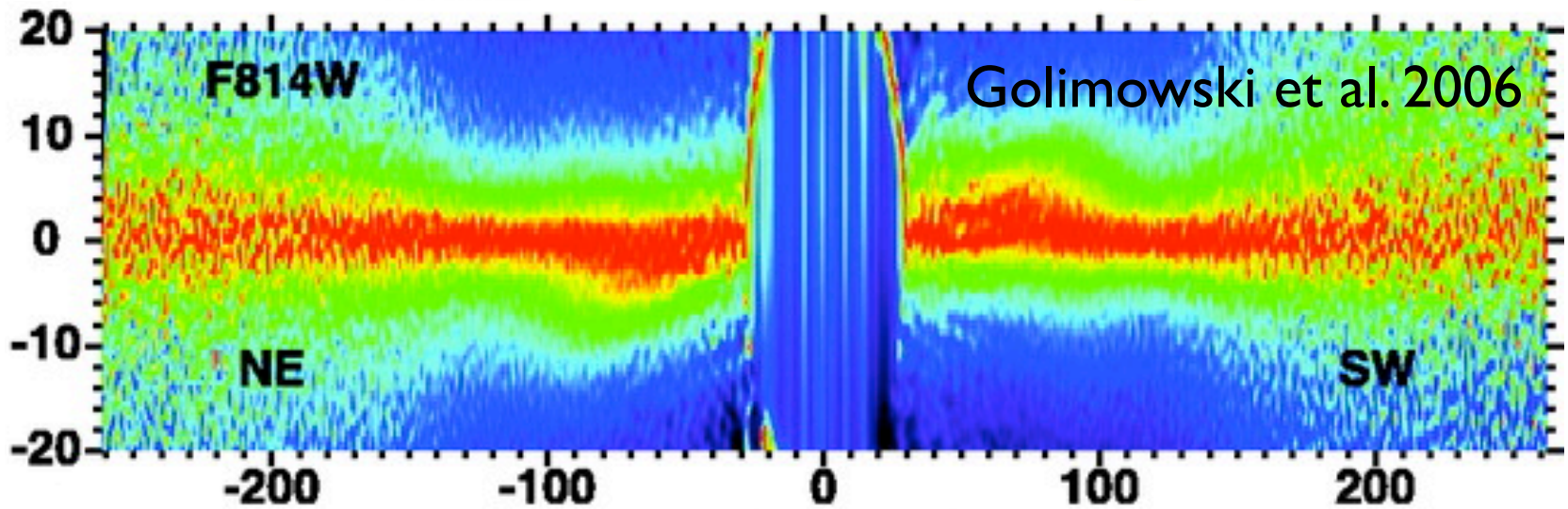
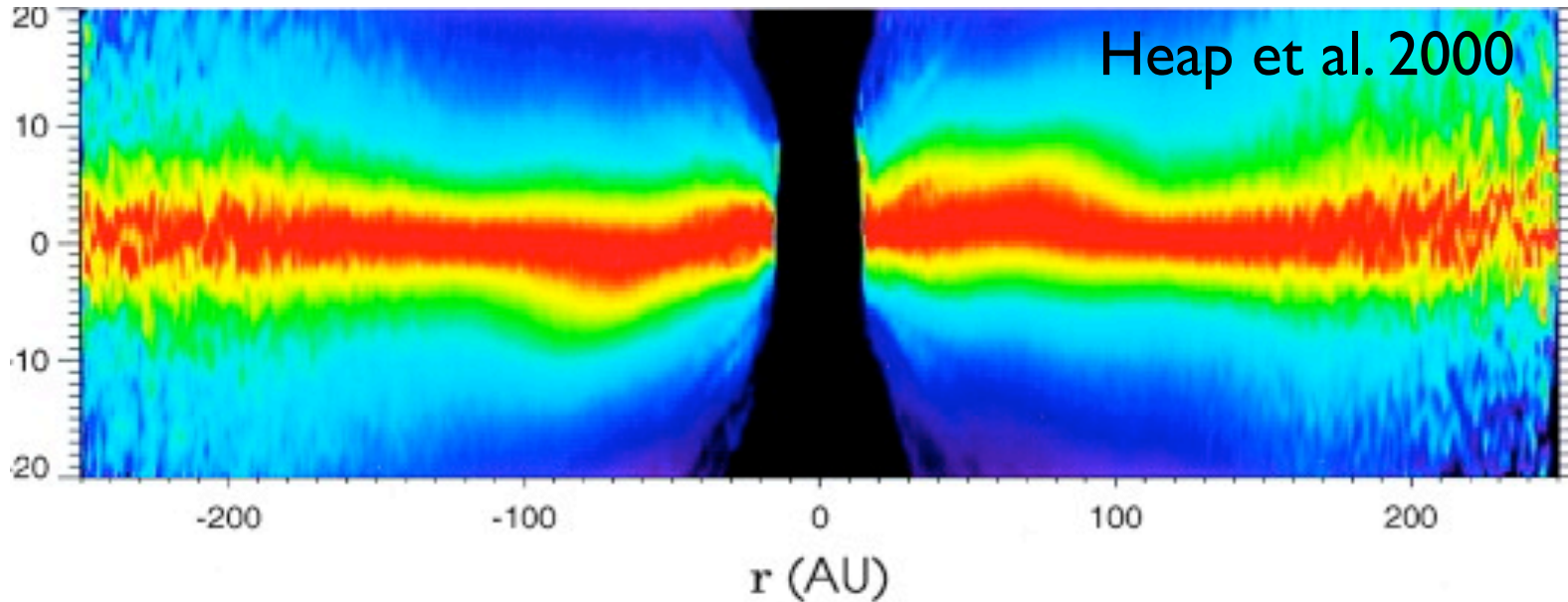
13.68 Myr

Evolution of

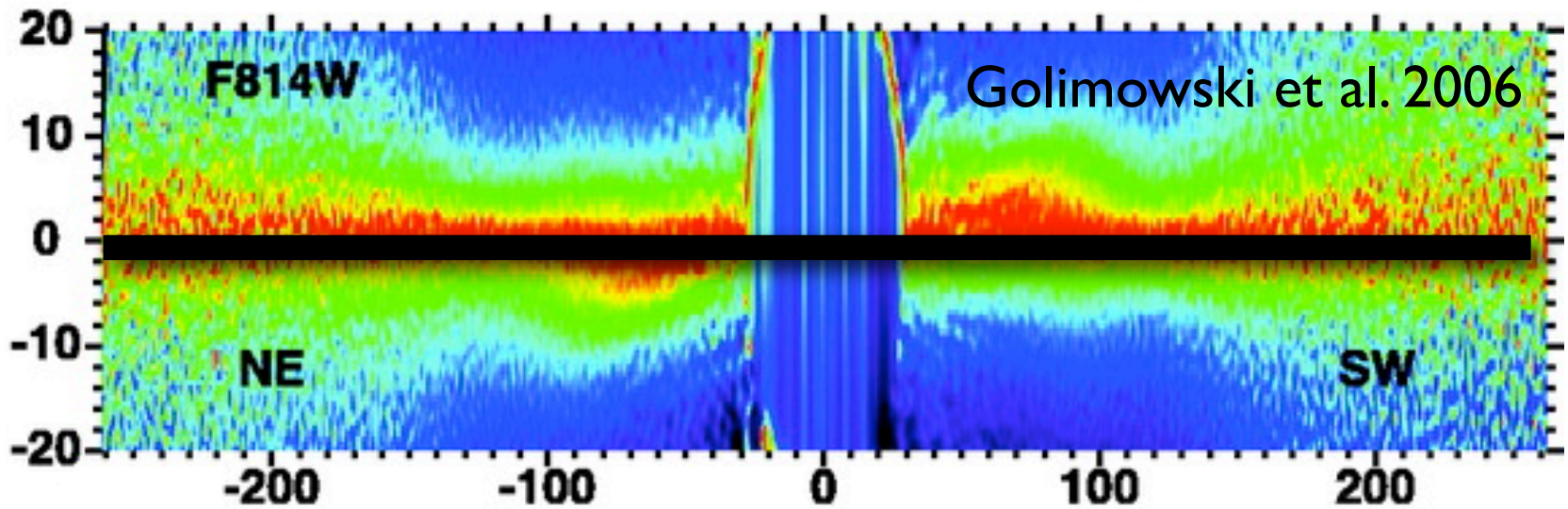
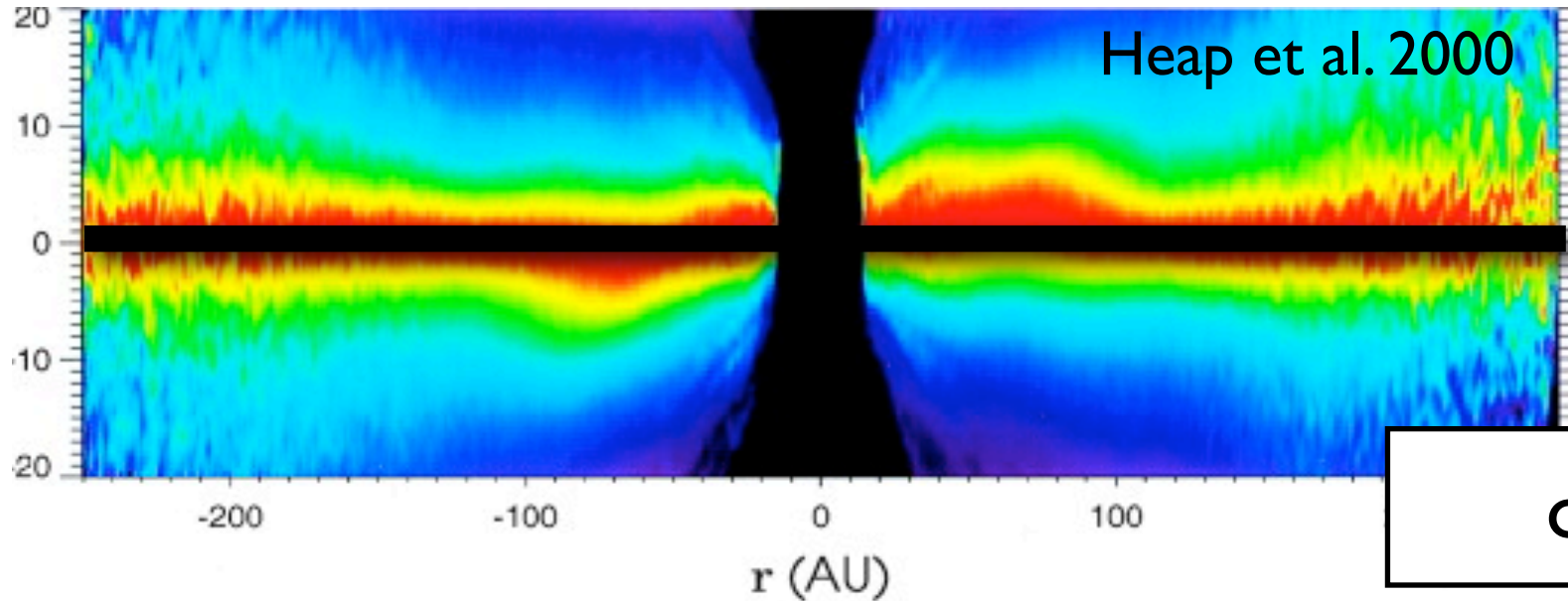
warp



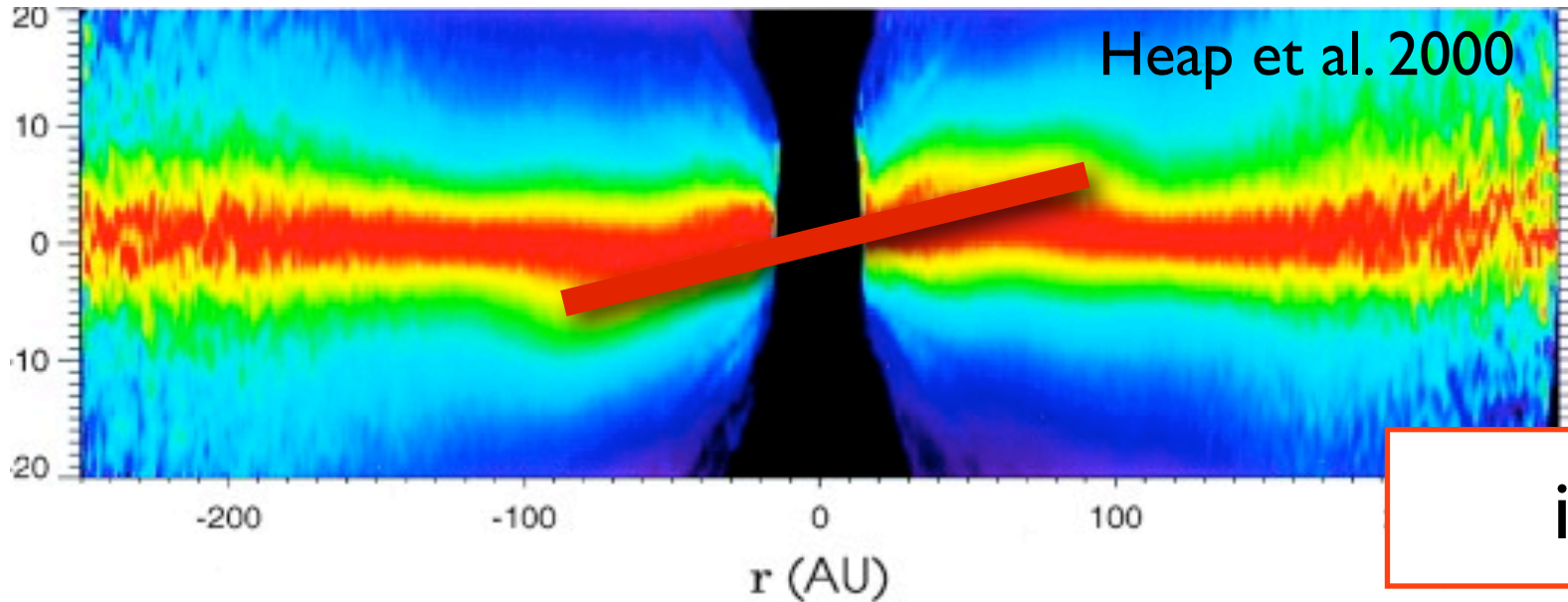
The Warped Disk of Beta Pic



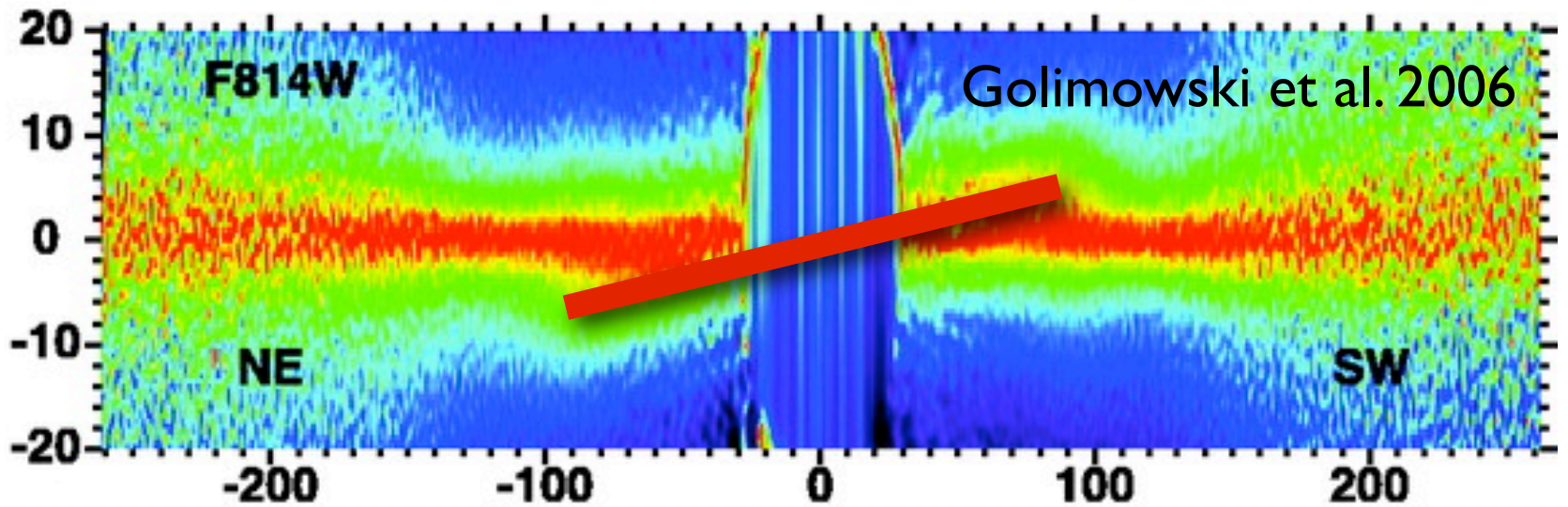
The Warped Disk of Beta Pic



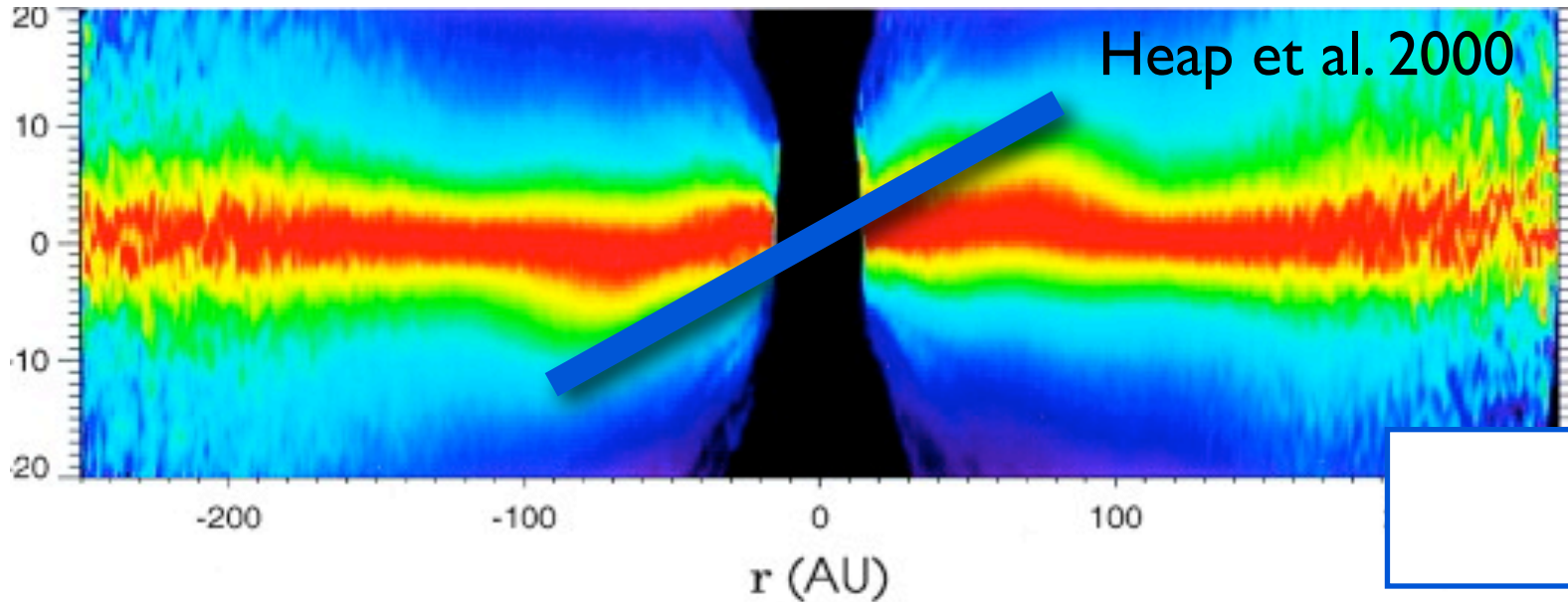
The Warped Disk of Beta Pic



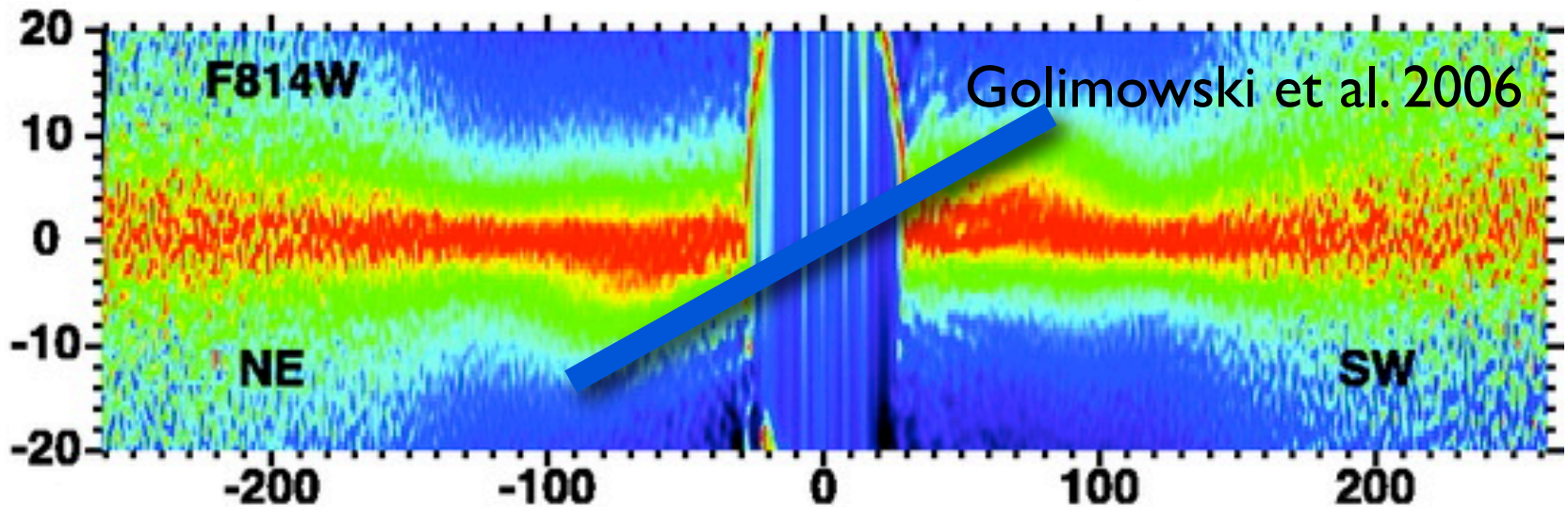
inner disk



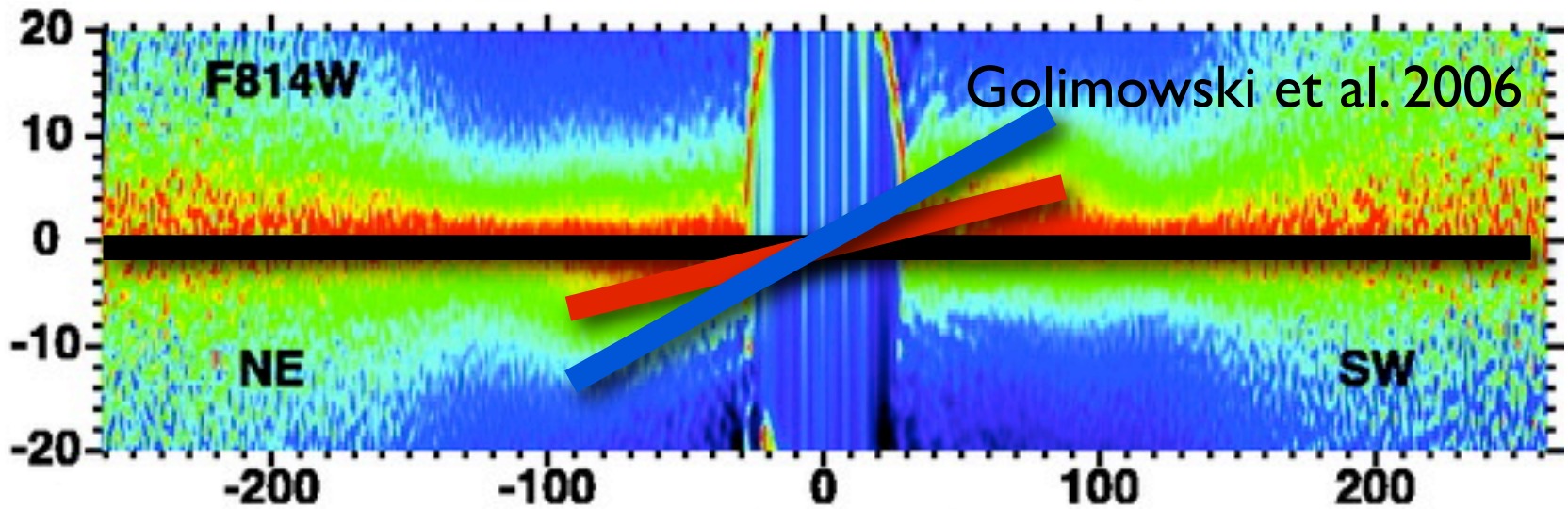
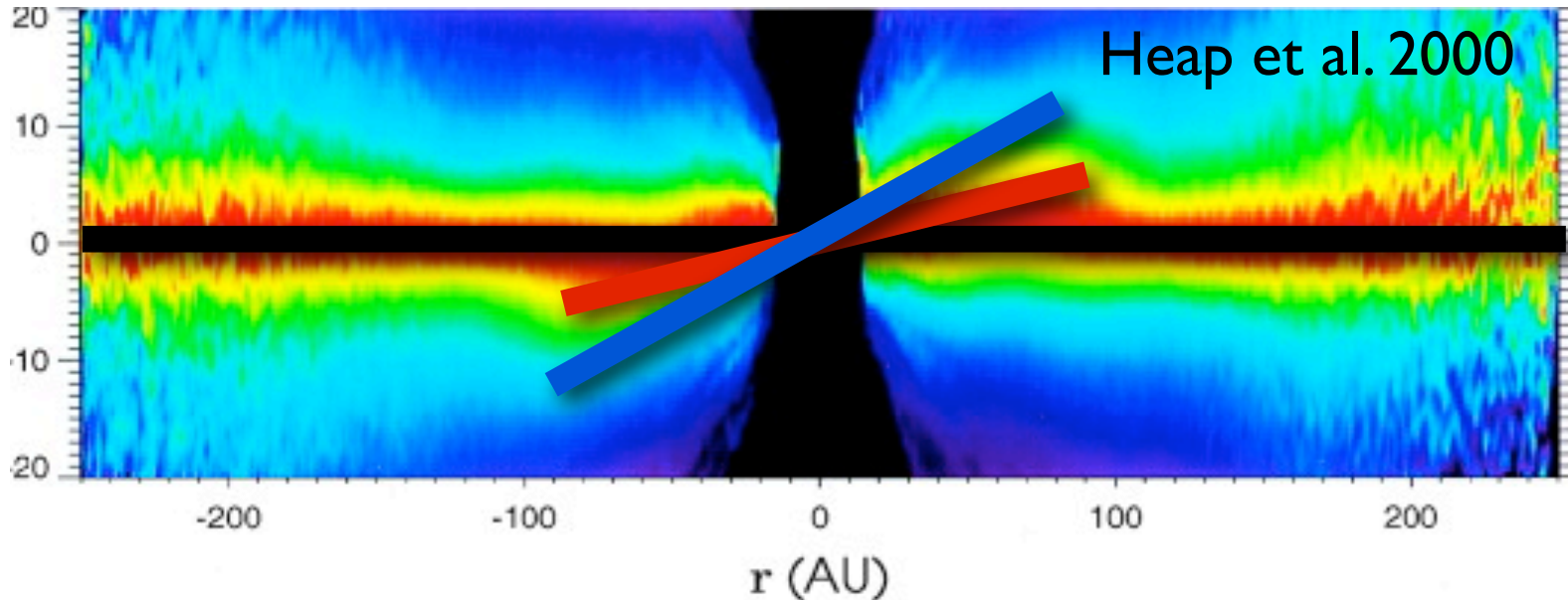
The Warped Disk of Beta Pic



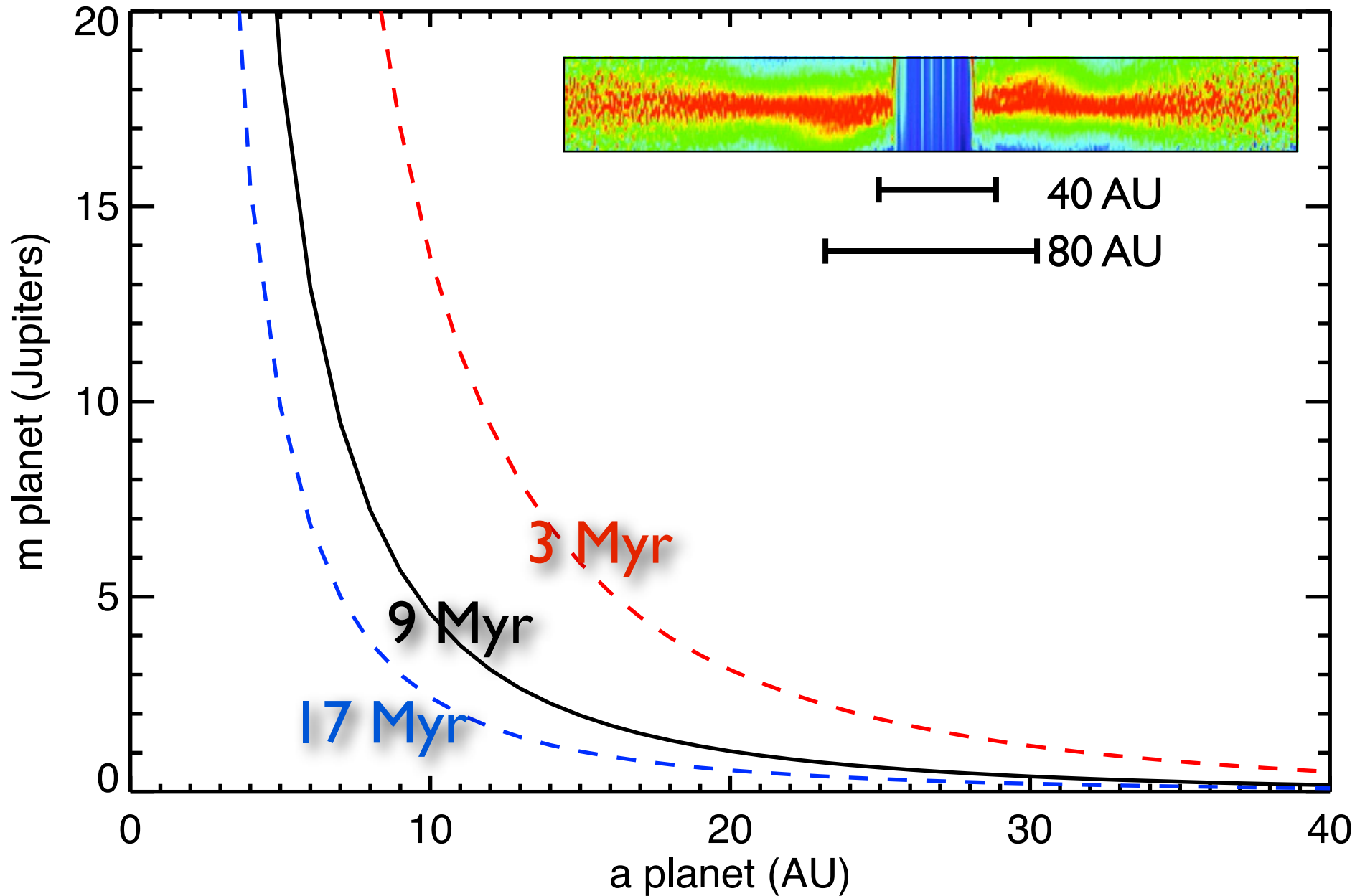
warp



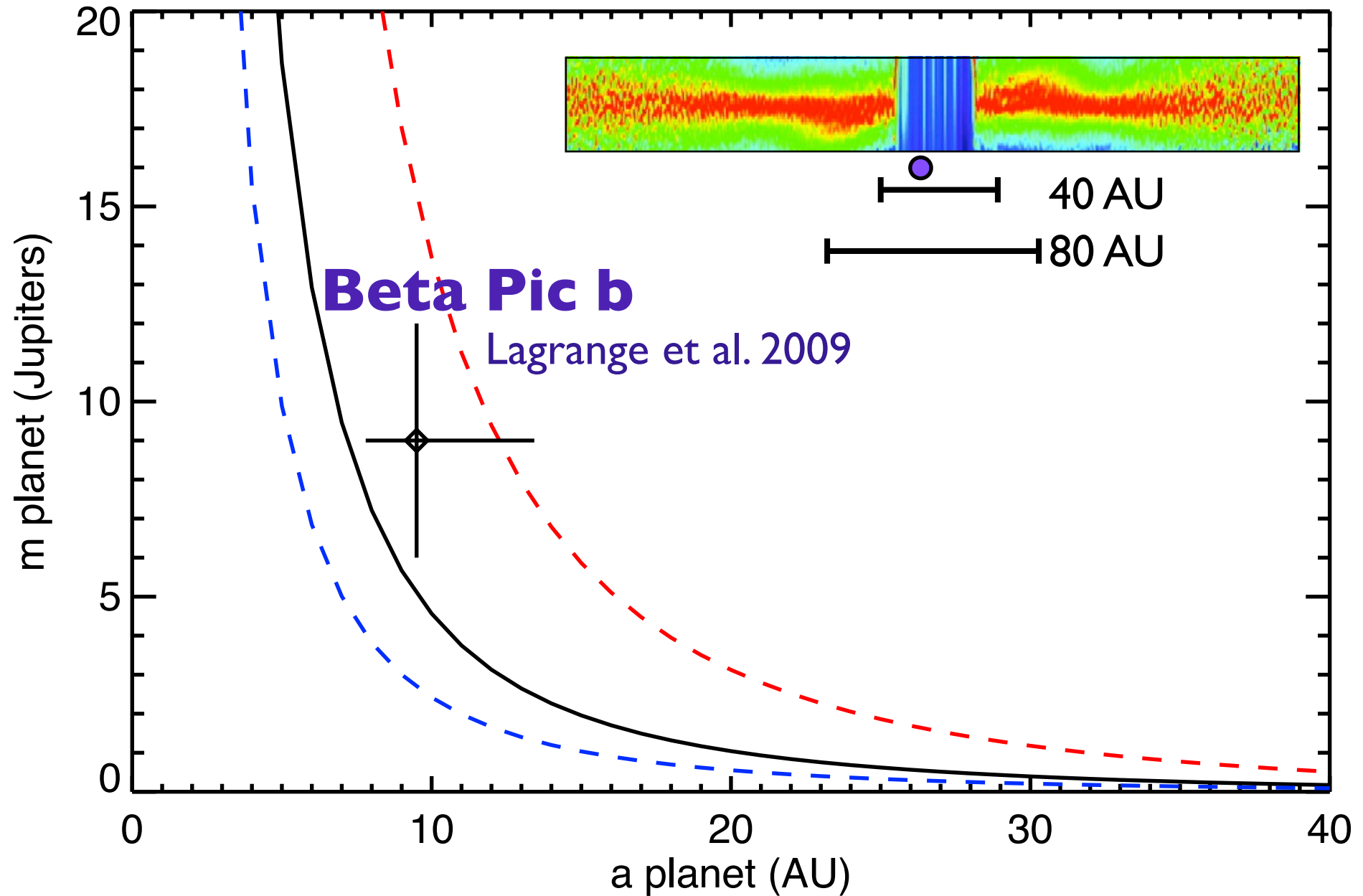
The Warped Disk of Beta Pic



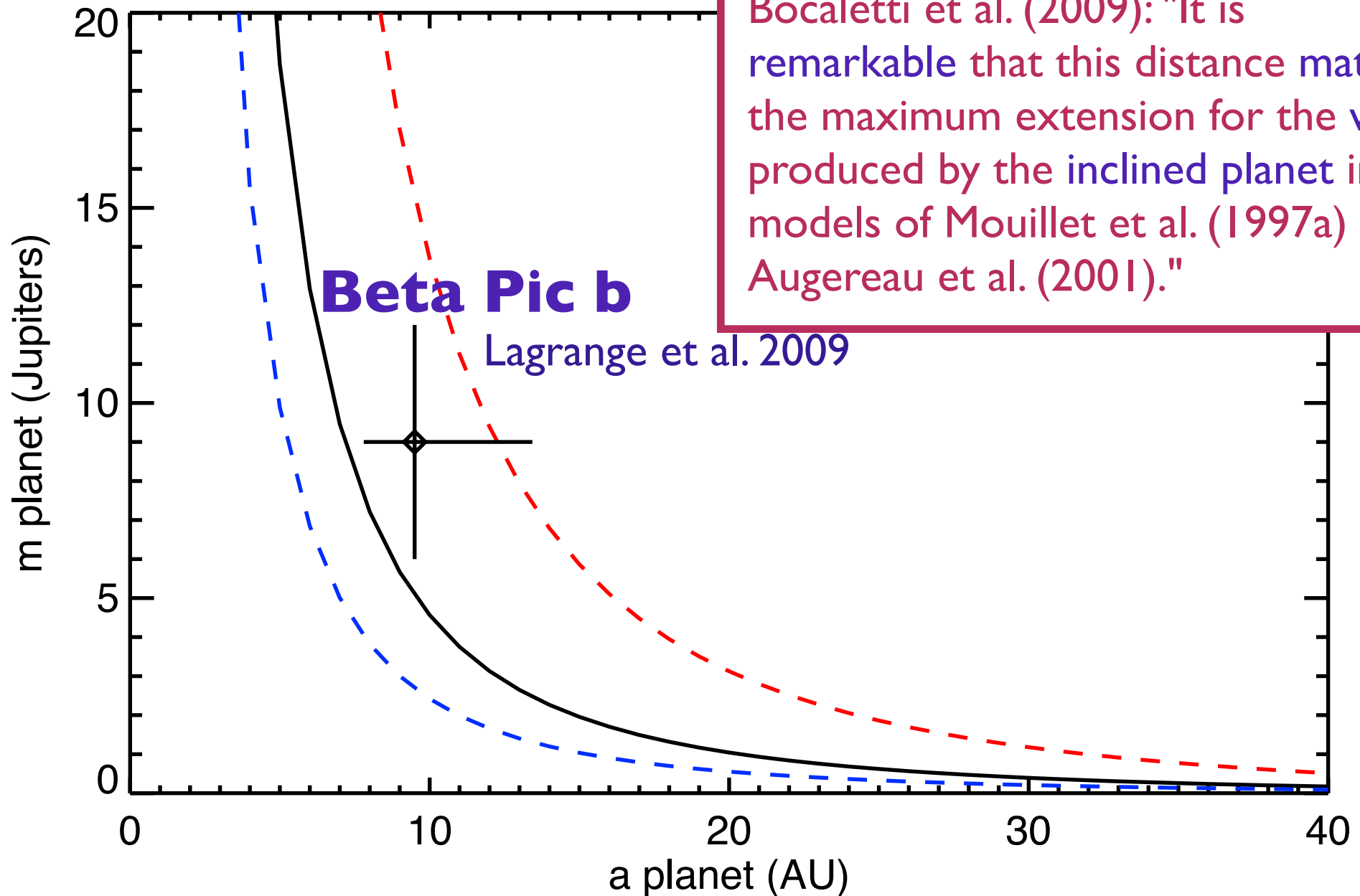
Planet parameters for 80 AU warp



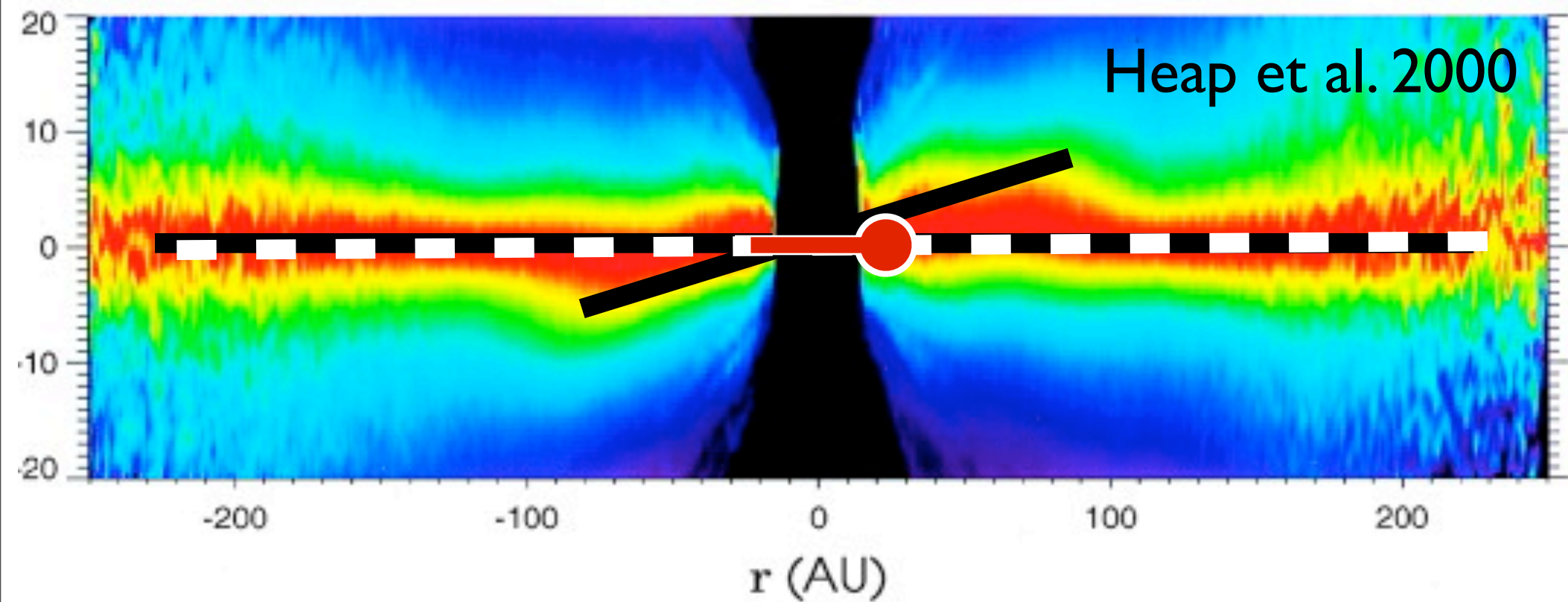
Planet parameters for 80 AU warp



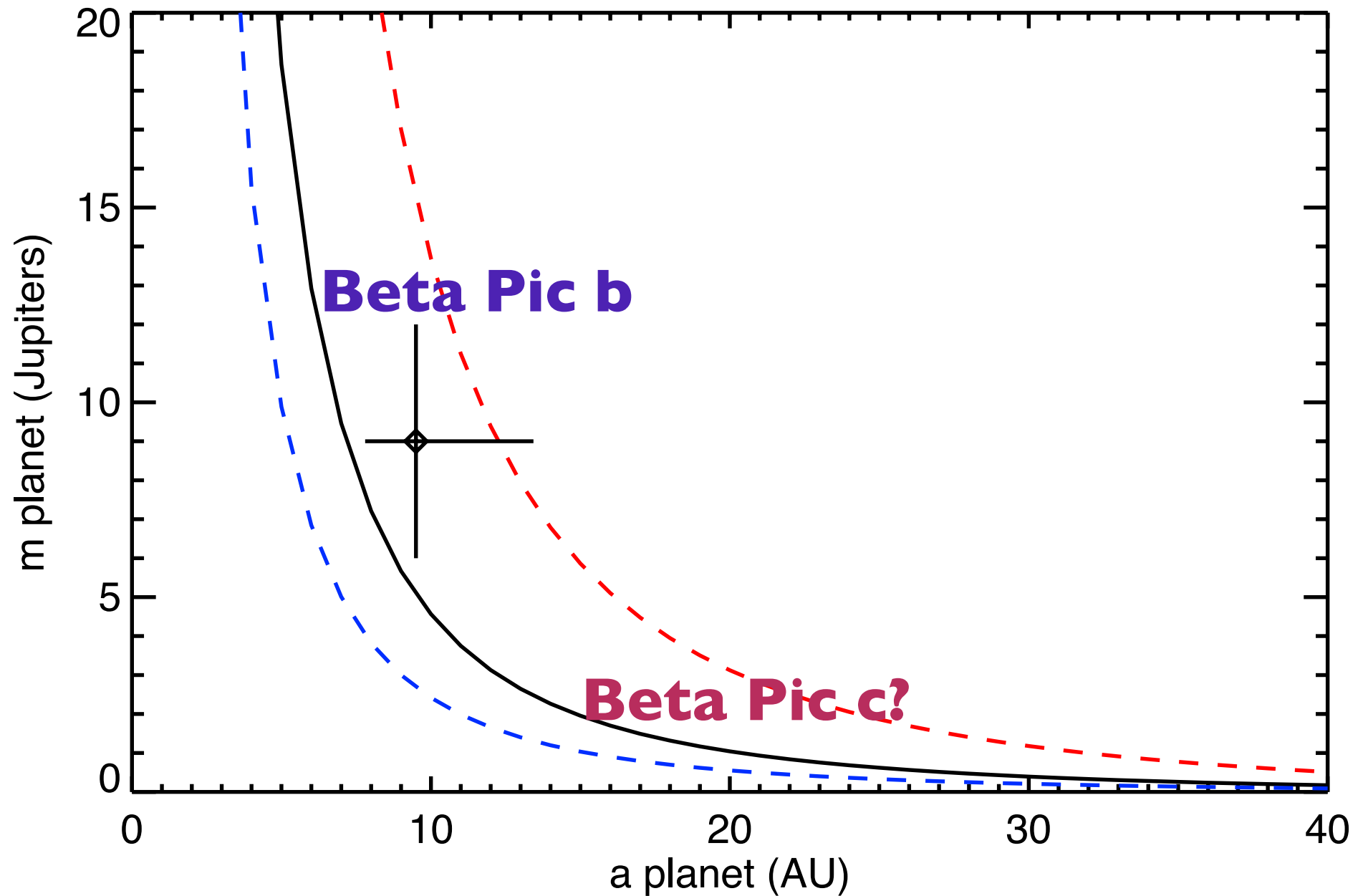
Planet parameters for 80 AU warp



Currie et al. 2011: Beta Pic b is aligned with flat *outer* disk

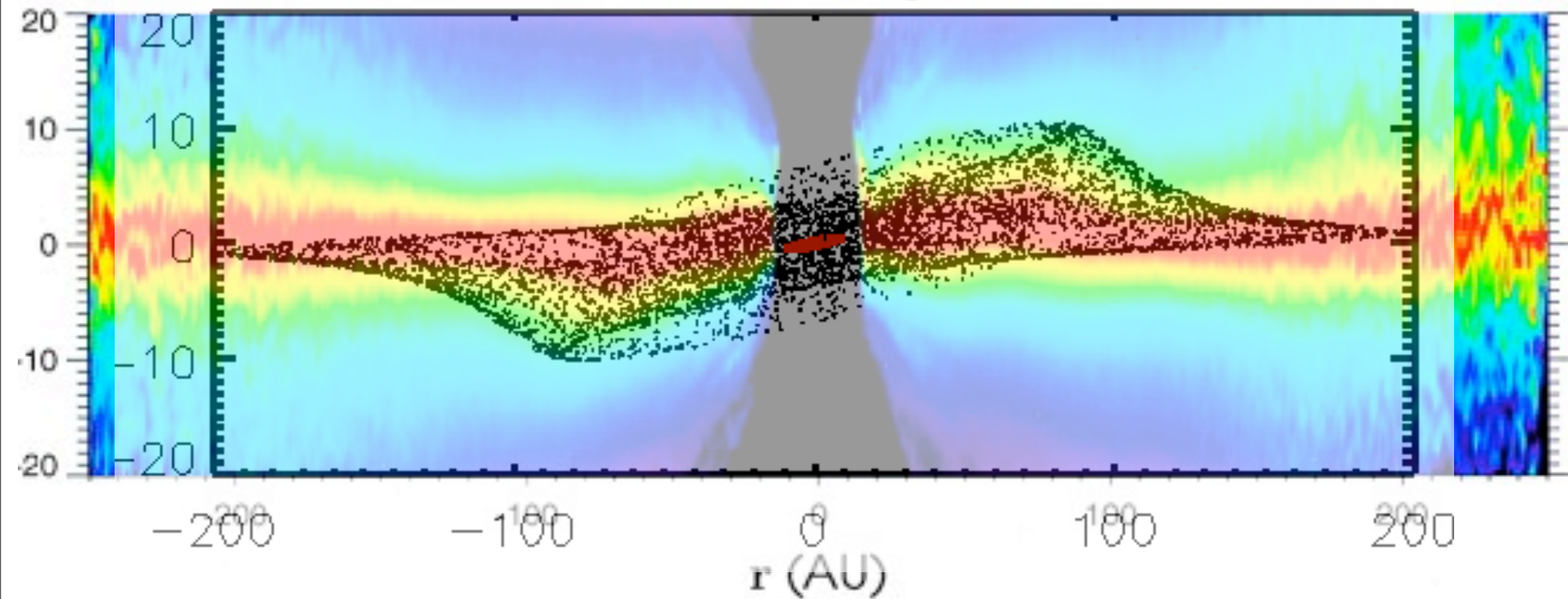


Planet parameters for 80 AU warp



Observed planet can create observed warp

R. Dawson, 09/14/2011, ESS II

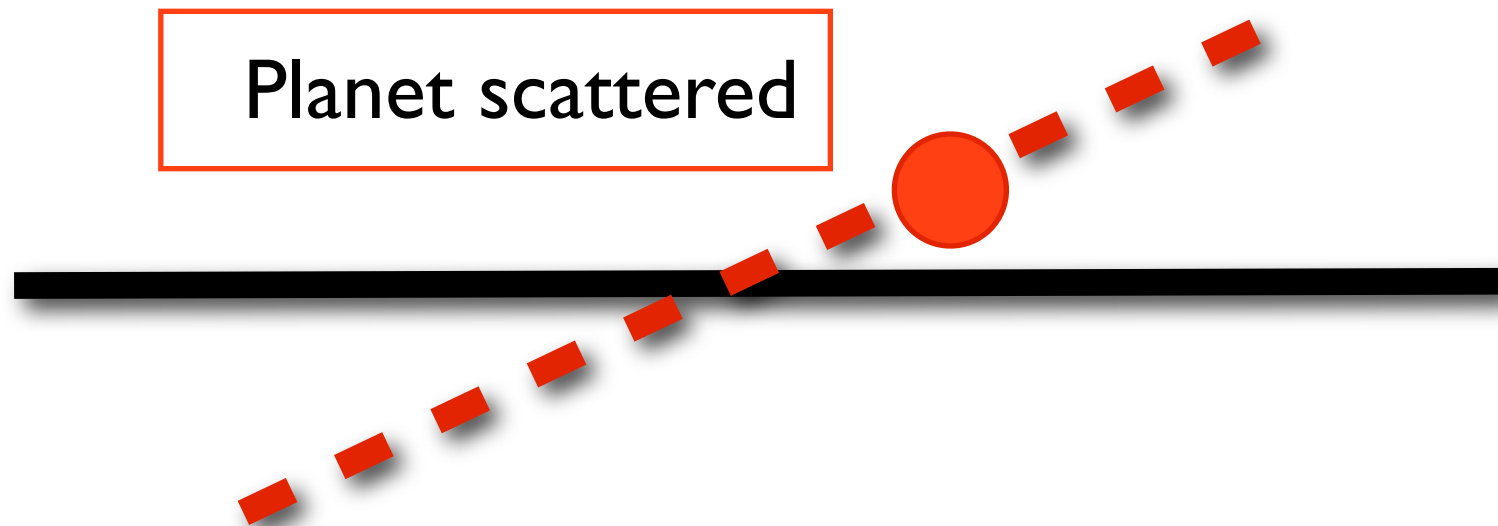


The inclination of Beta Pic b could
have been damped

Cold Disk

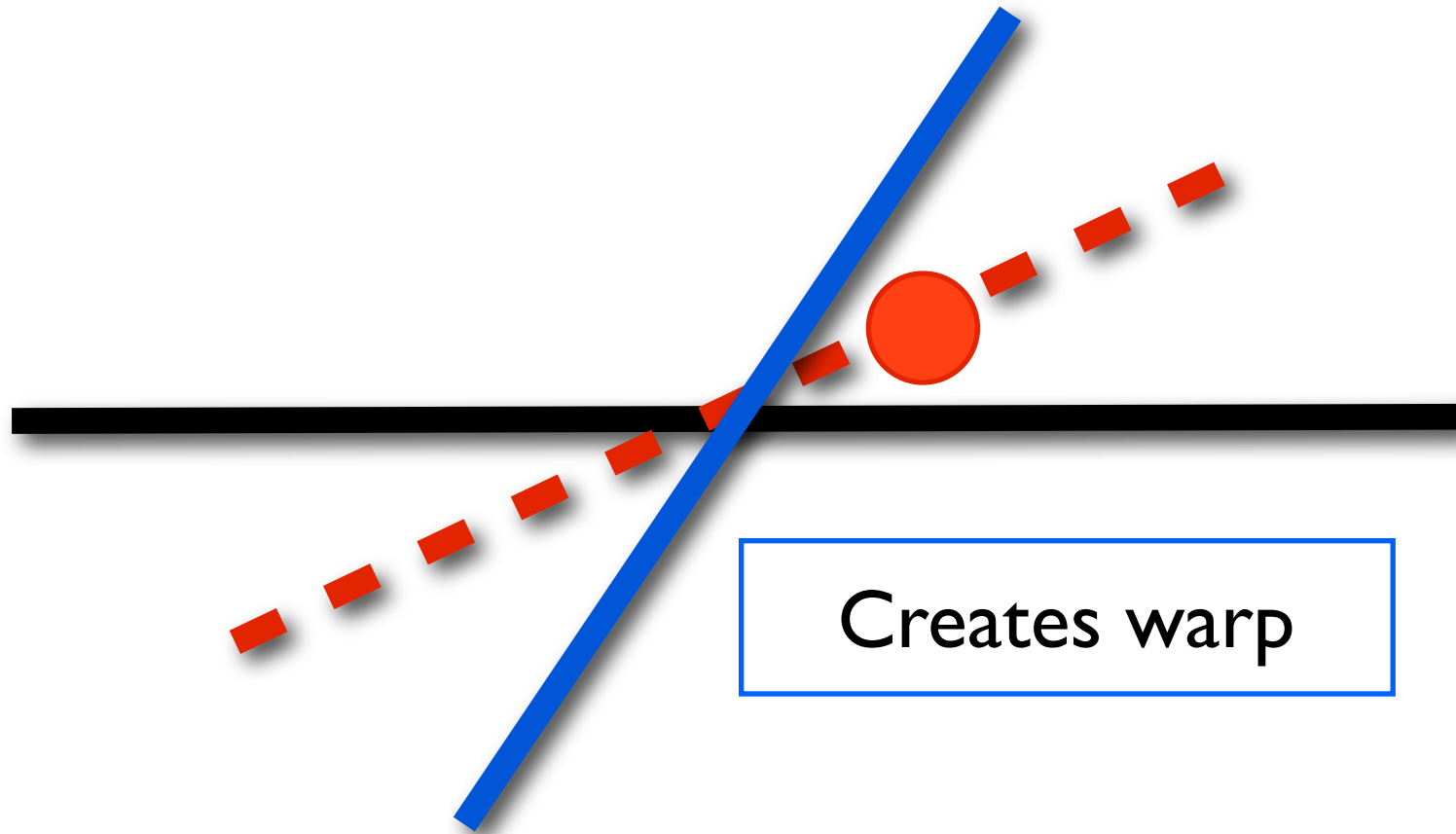


The inclination of Beta Pic b could have been damped

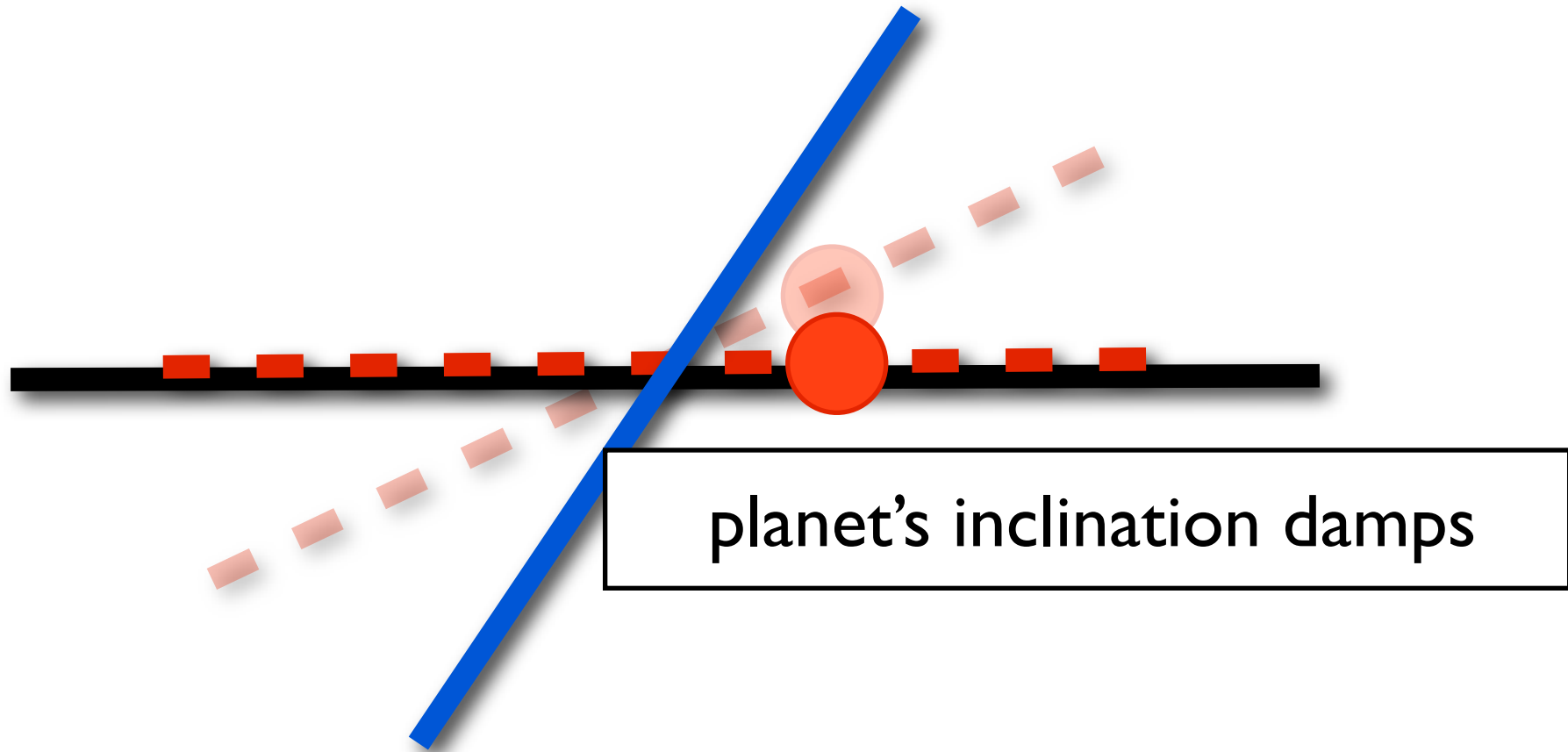


(angles exaggerated)

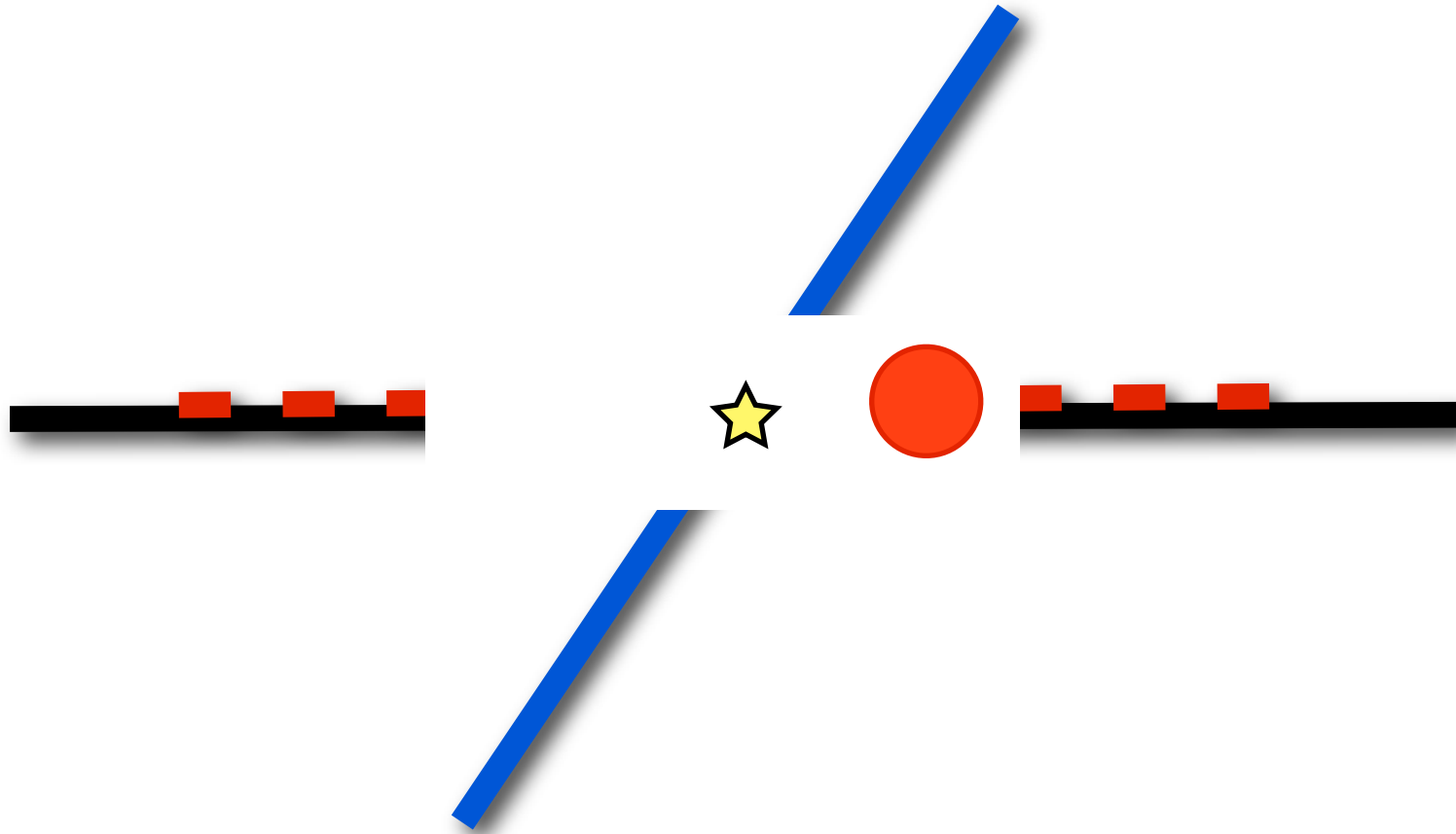
The inclination of Beta Pic b could have been damped



The inclination of Beta Pic b could have been damped

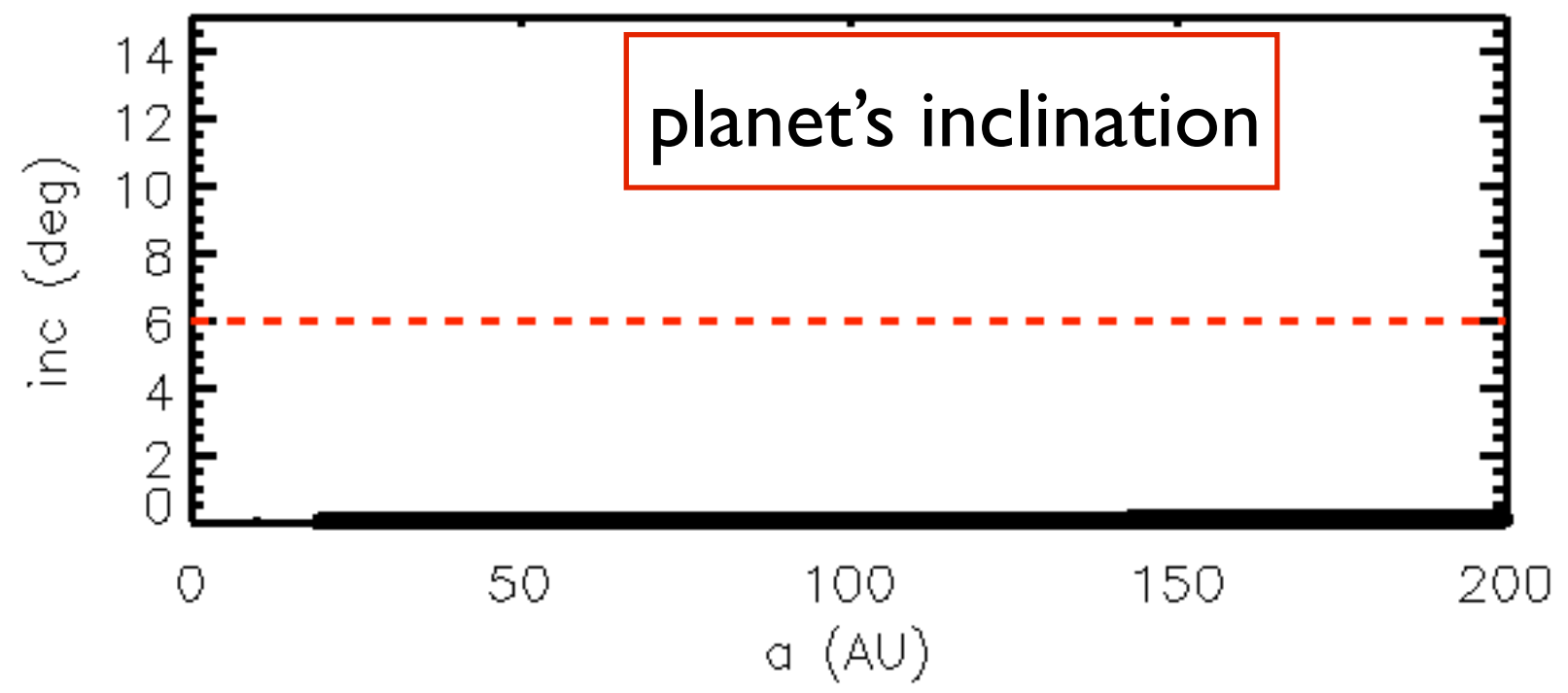


The inclination of Beta Pic b could have been damped

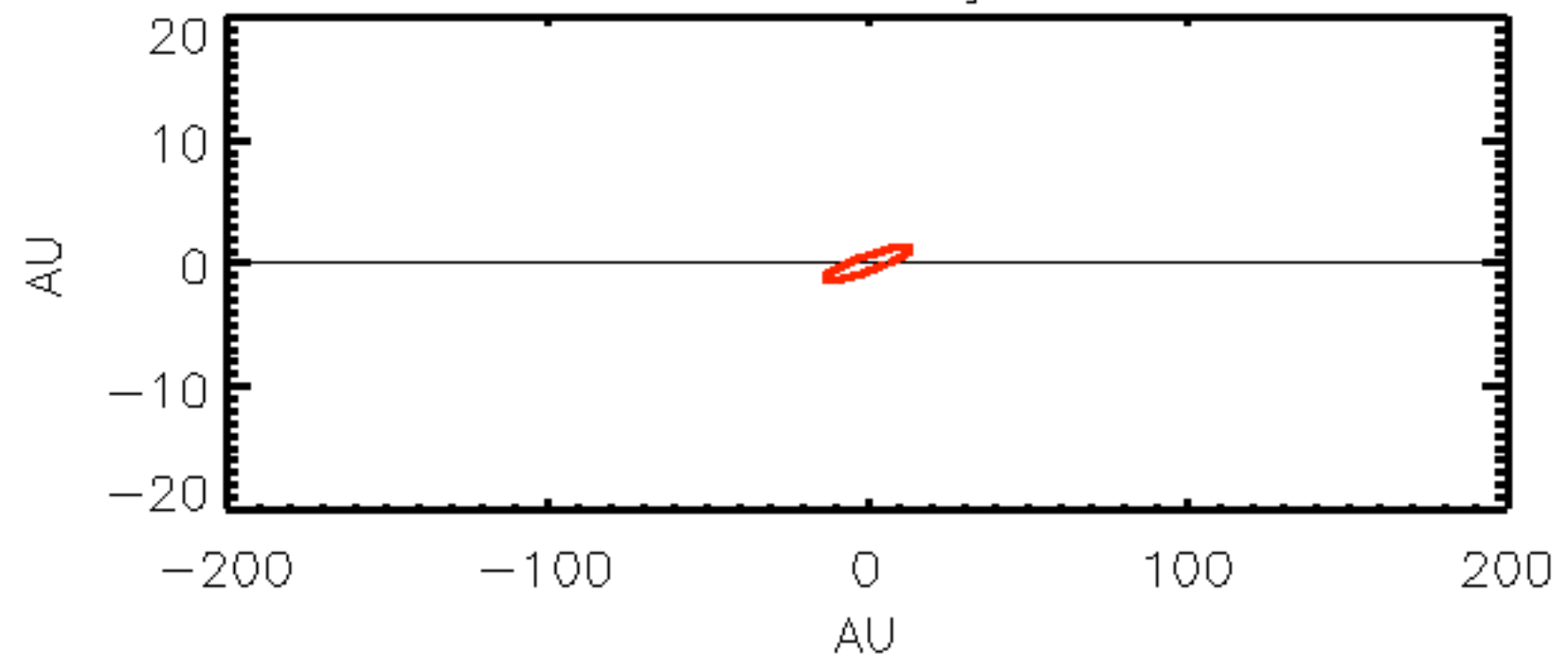


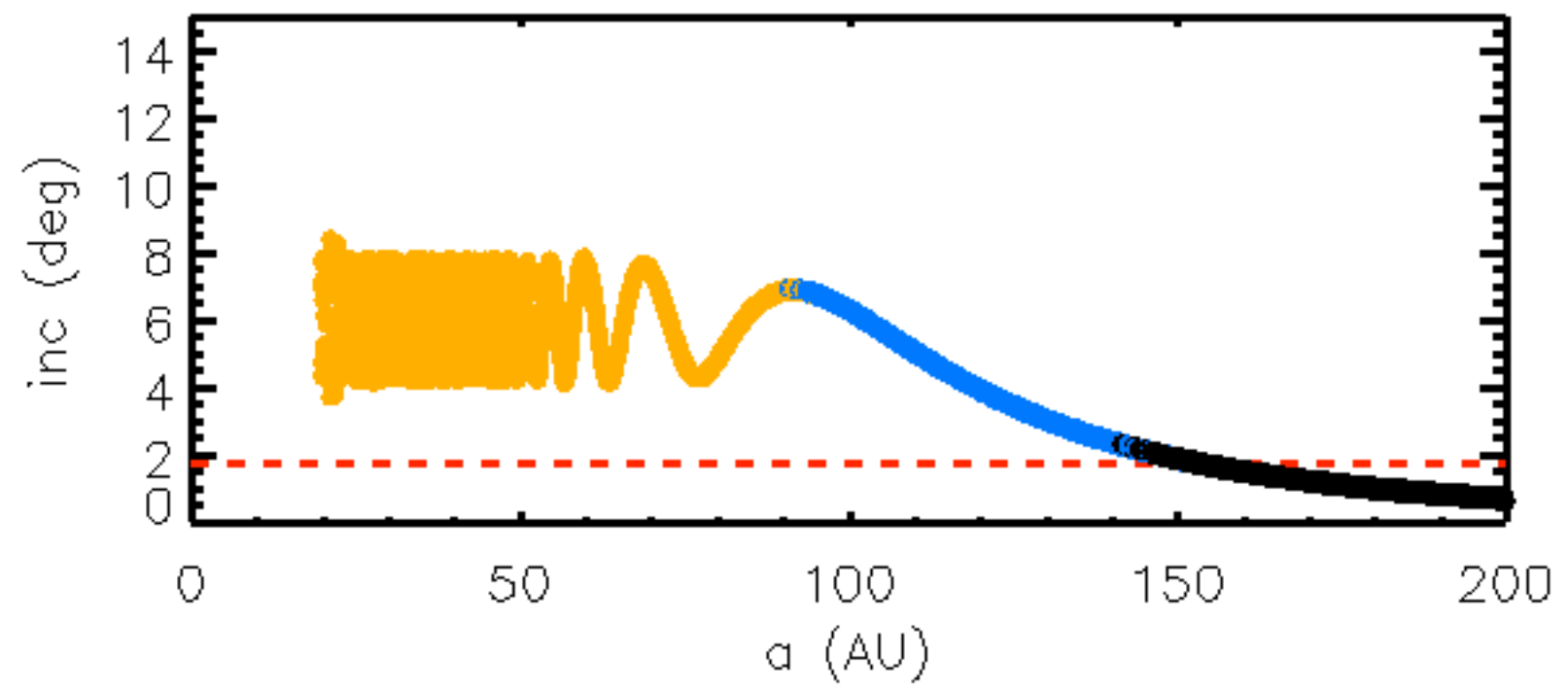
Planet has already cleared out its region:
damping stage has ended

planet's inclination

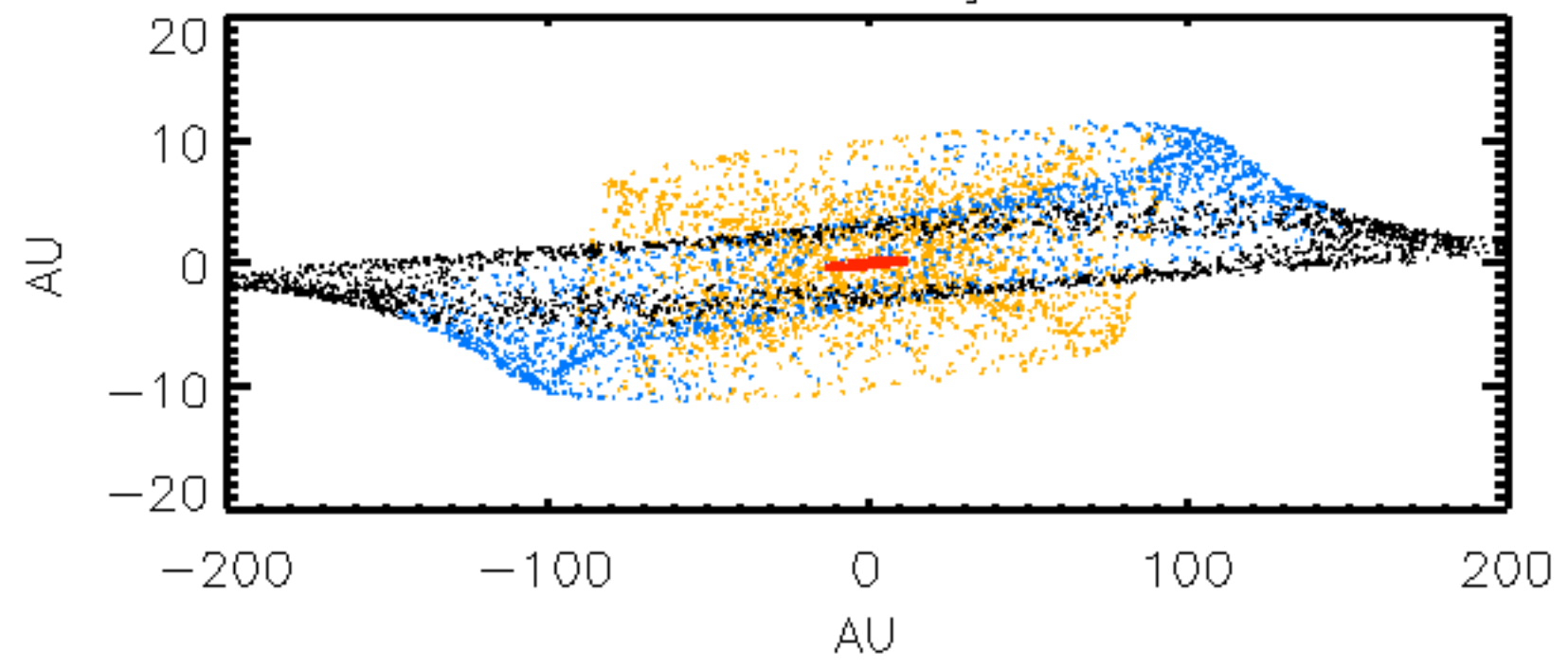


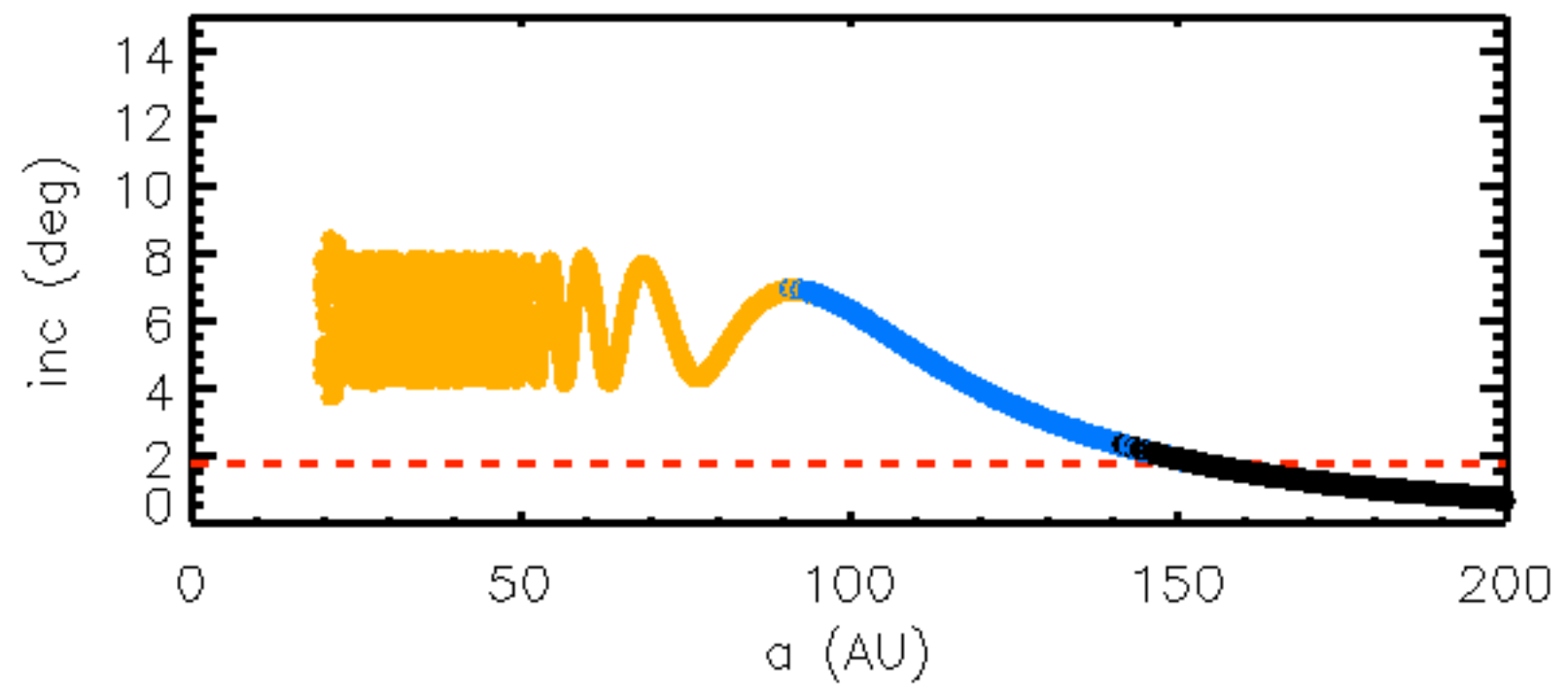
0.000 Myr



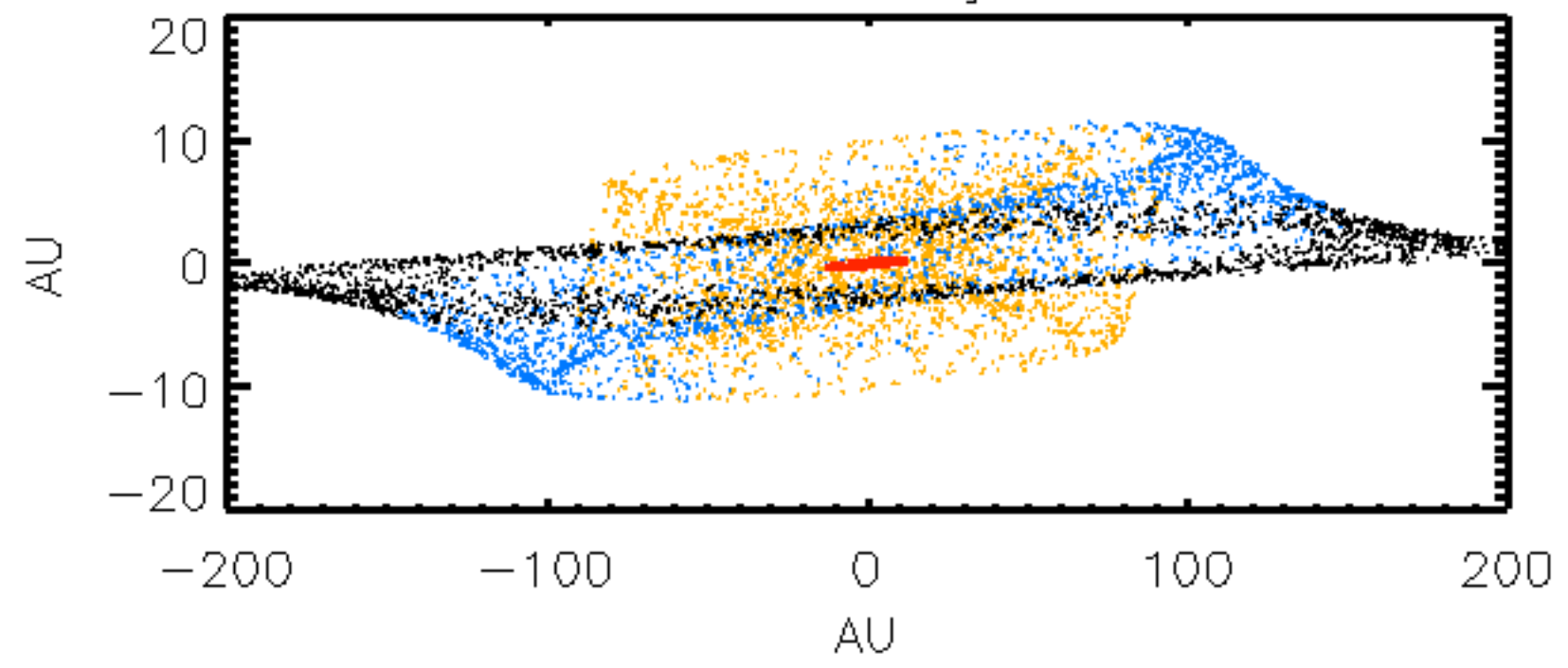


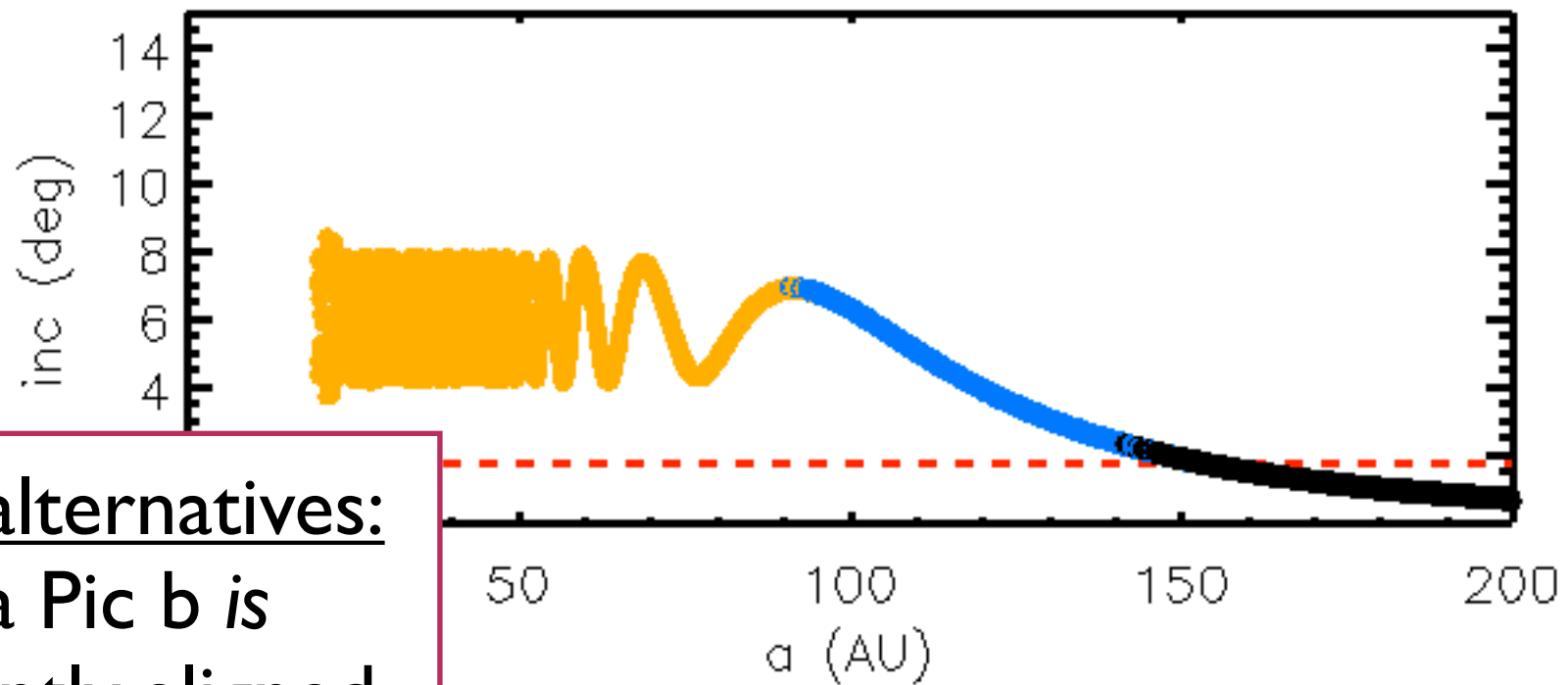
5.530 Myr





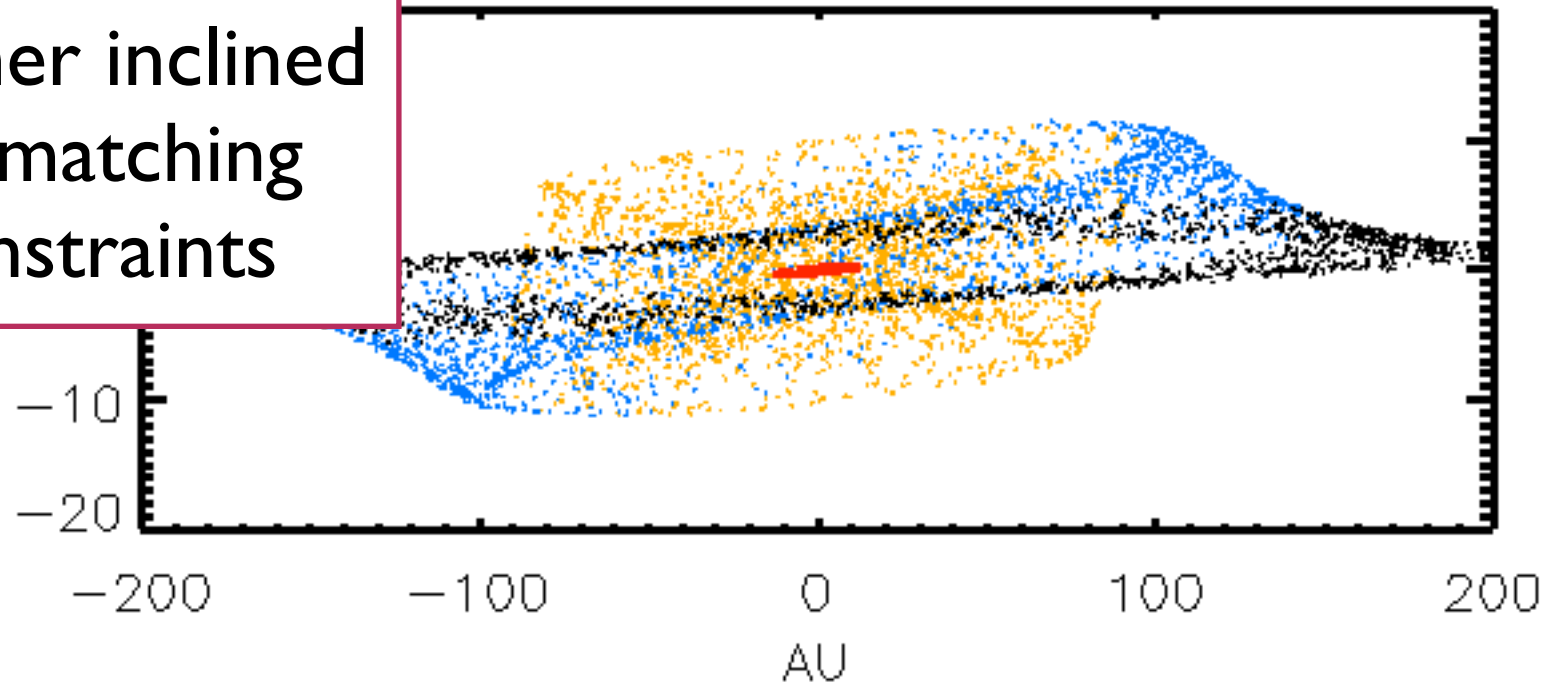
5.530 Myr

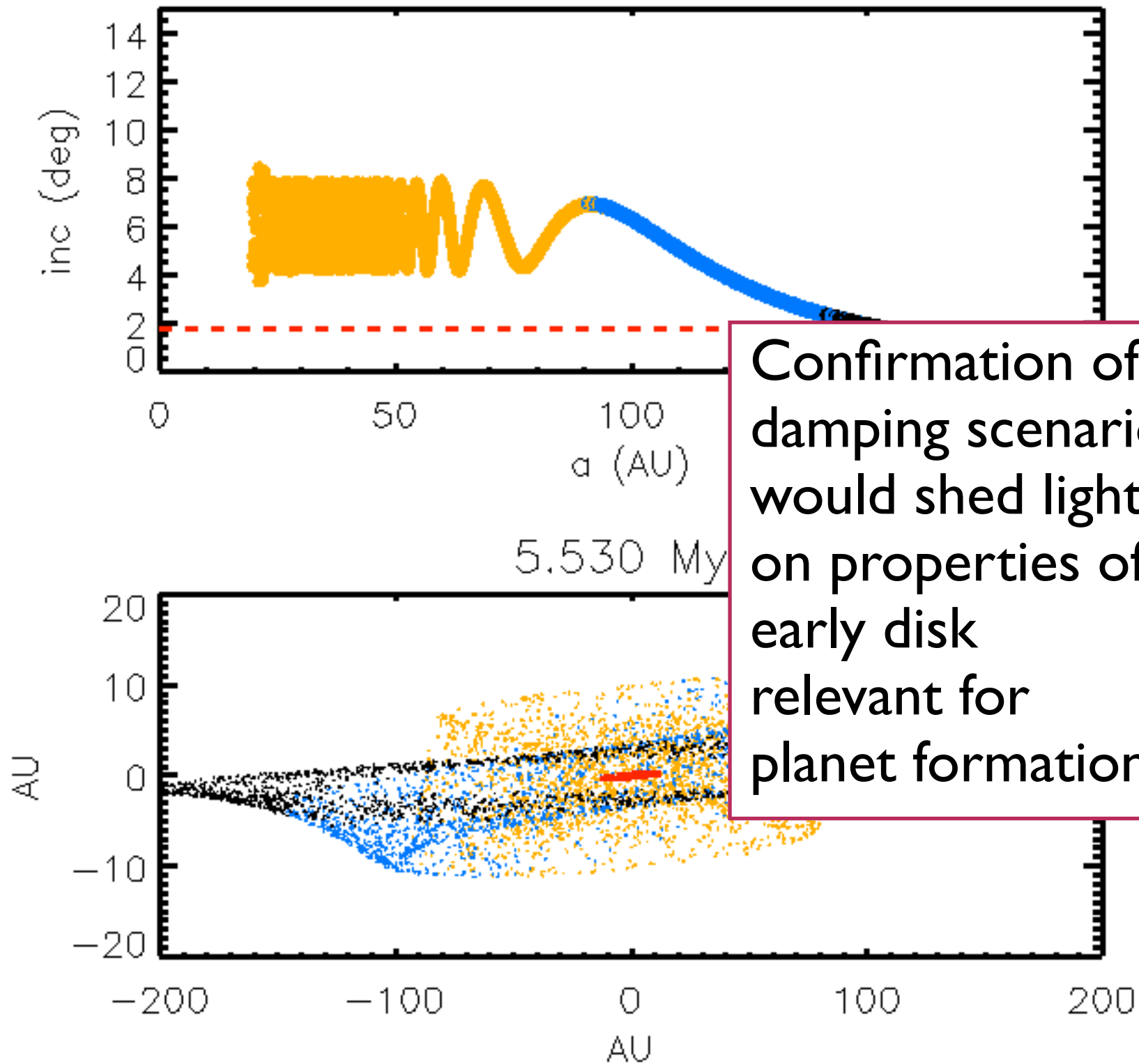




Two alternatives:

- Beta Pic b is currently aligned with inclined disk
- Another inclined planet matching the constraints








Confirmation of damping scenario would shed light on properties of early disk relevant for planet formation

Extreme Solar Systems II

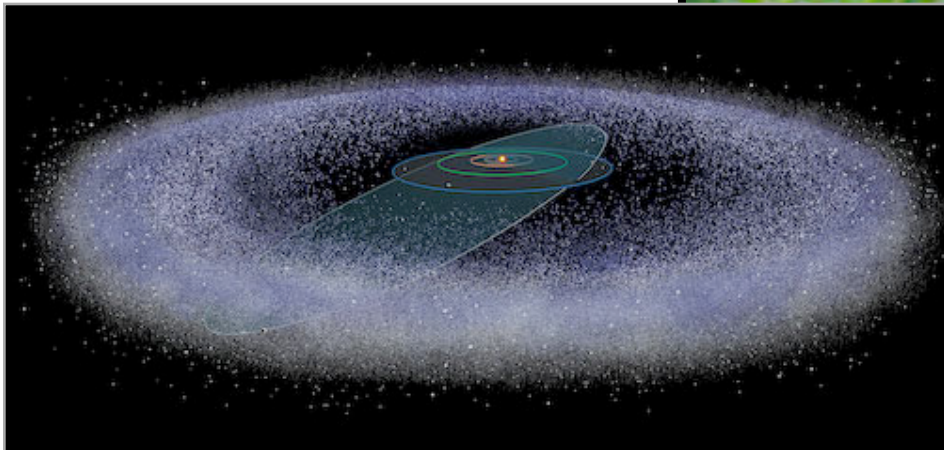
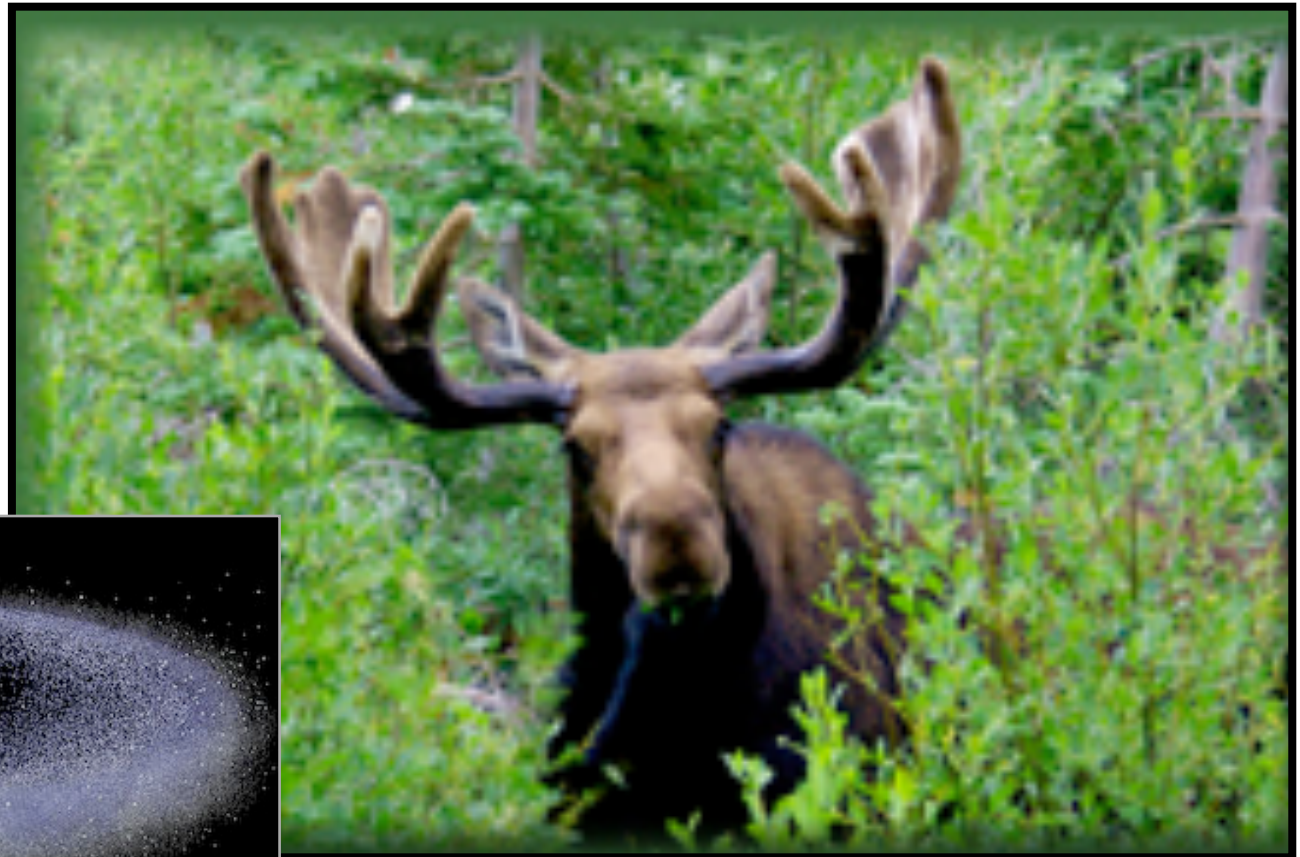


<http://ciera.northwestern.edu/Jackson2011/>

Visited ▾ Schedules ▾  SAO/NASA ADS ...  WD Exoplanets  Earth an

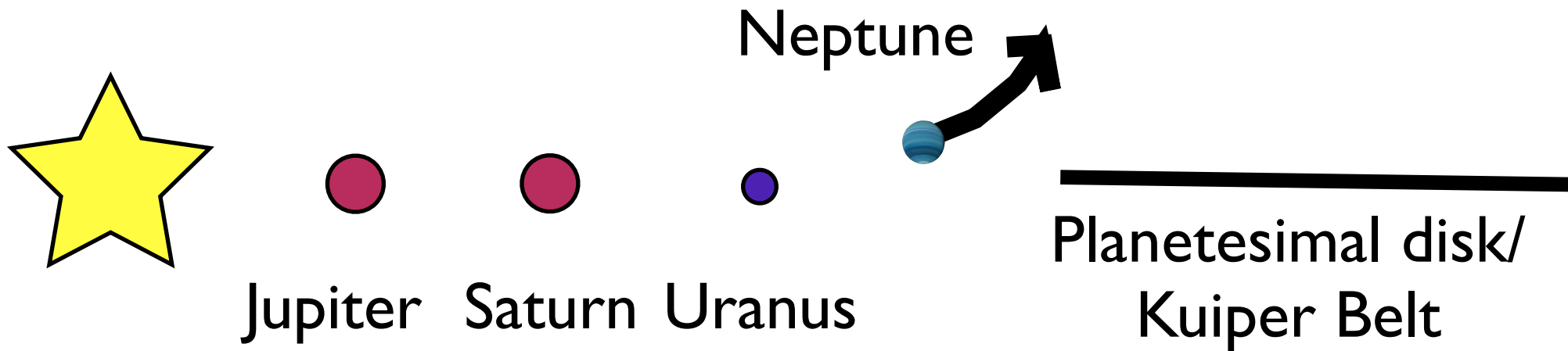


Is this creature an inhabitant of an Extreme Solar System?



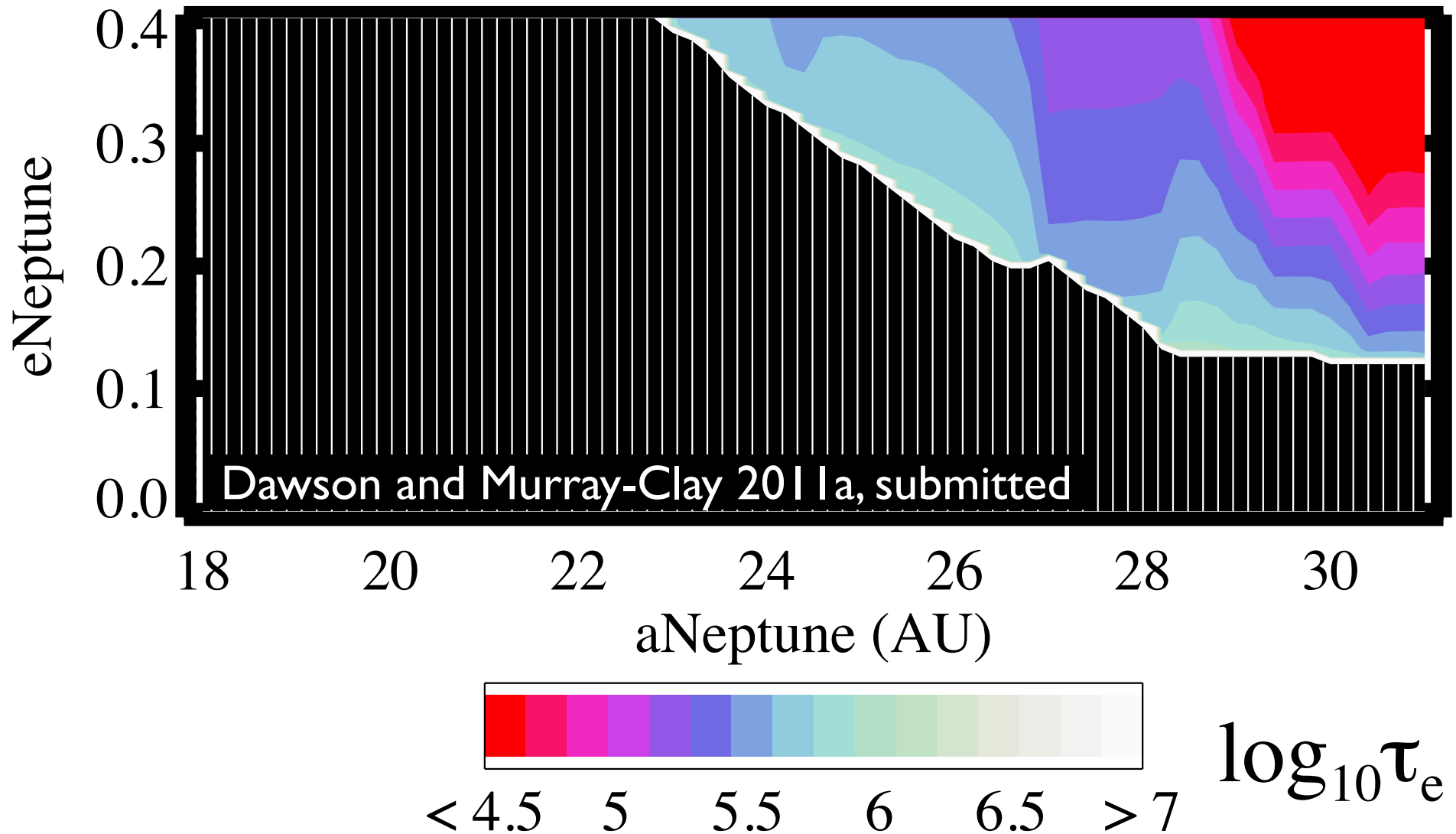
Planet-Planet Scattering:

Do you know where your Neptune is?

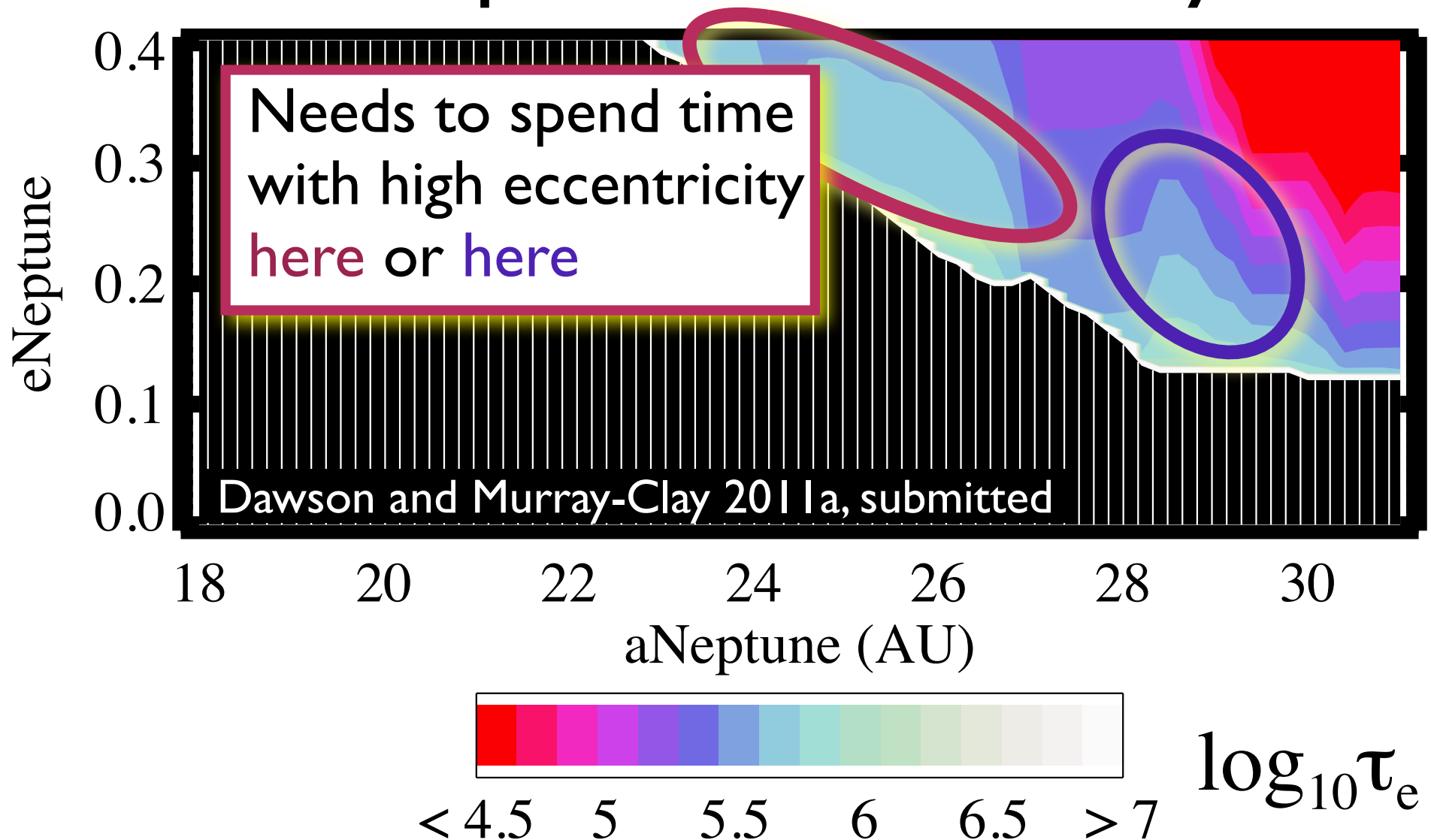


See Levison et al. 2008 for Kuiper Belt sculpting in the context of the Nice model.

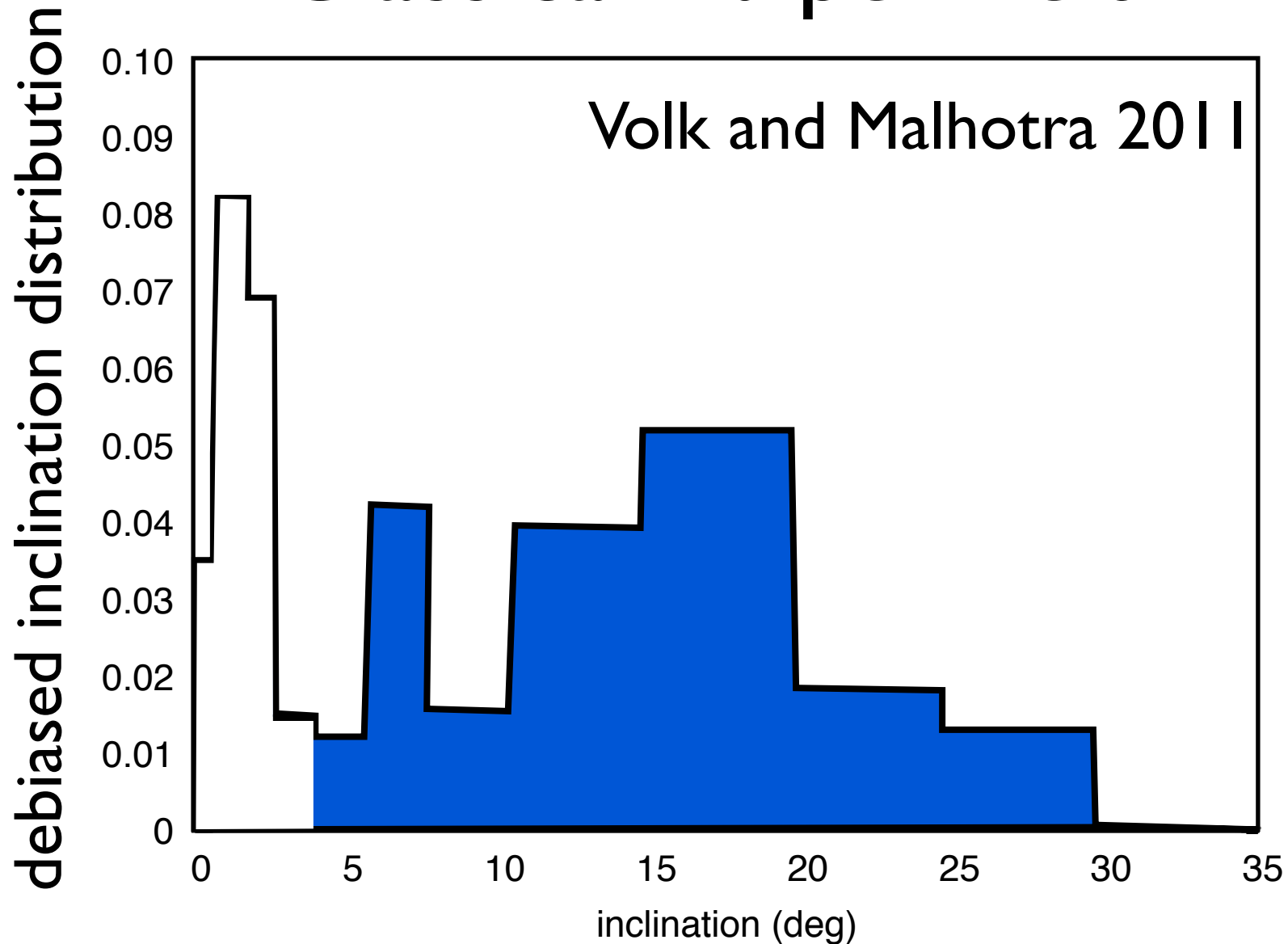
Neptune's wild days: constraints on Neptune's eccentricity



Neptune's wild days: constraints on Neptune's eccentricity



High-Inclination Objects in the Classical Kuiper Belt

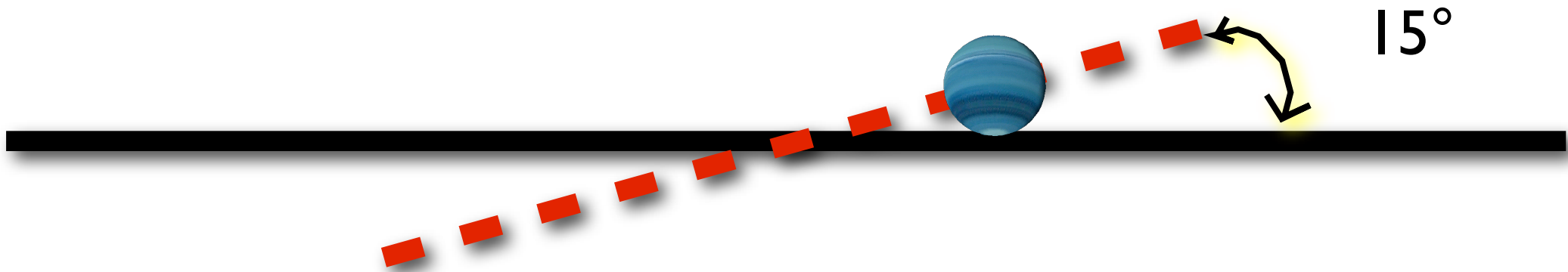


Creation of High Inclination KBOs

Cold Disk

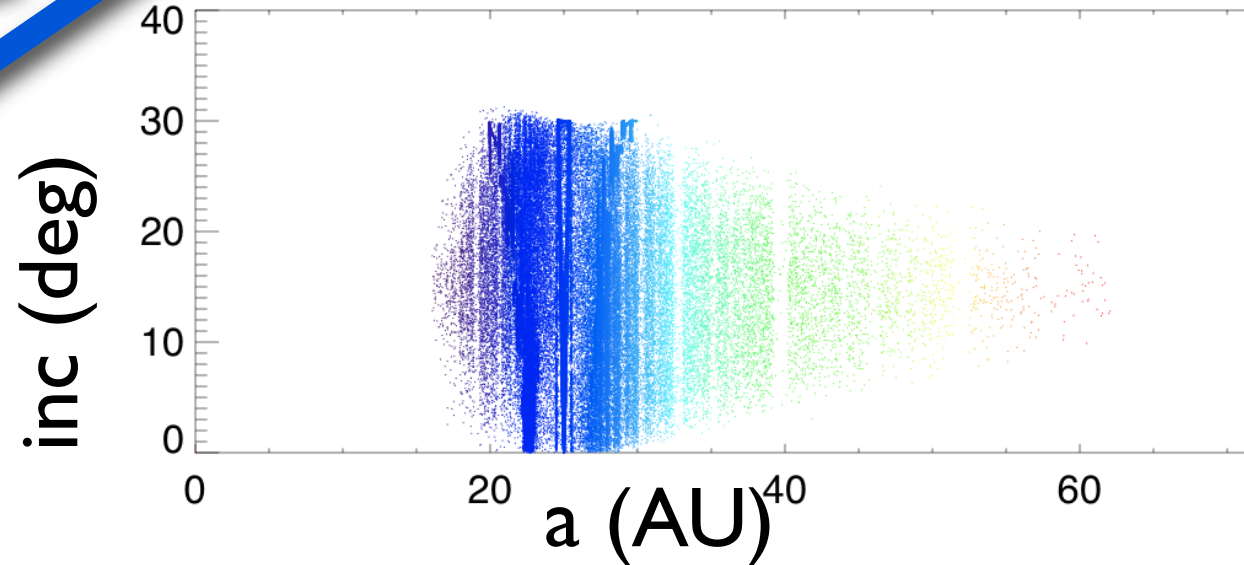
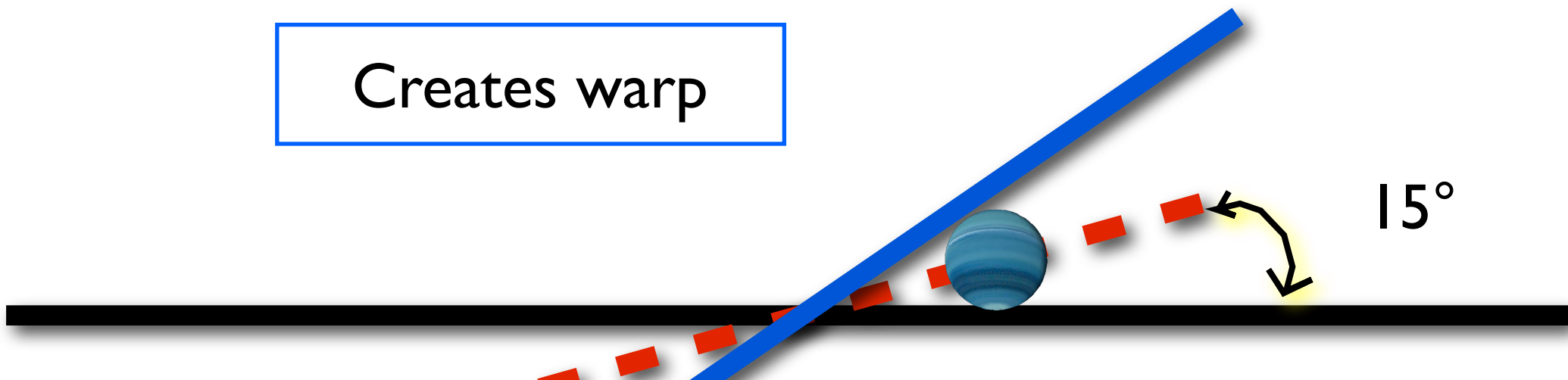
Creation of High Inclination KBOs

Neptune scattered
to high inclination

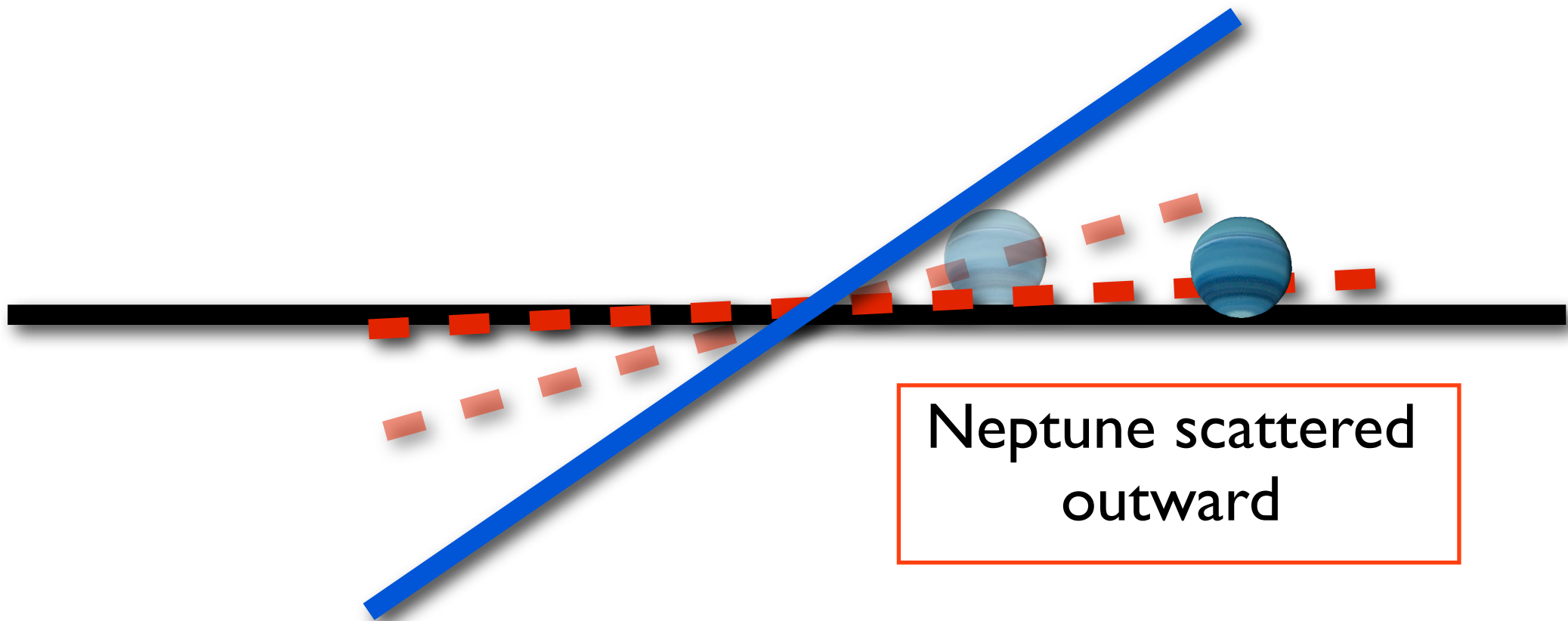


Creation of High Inclination KBOs

Creates warp

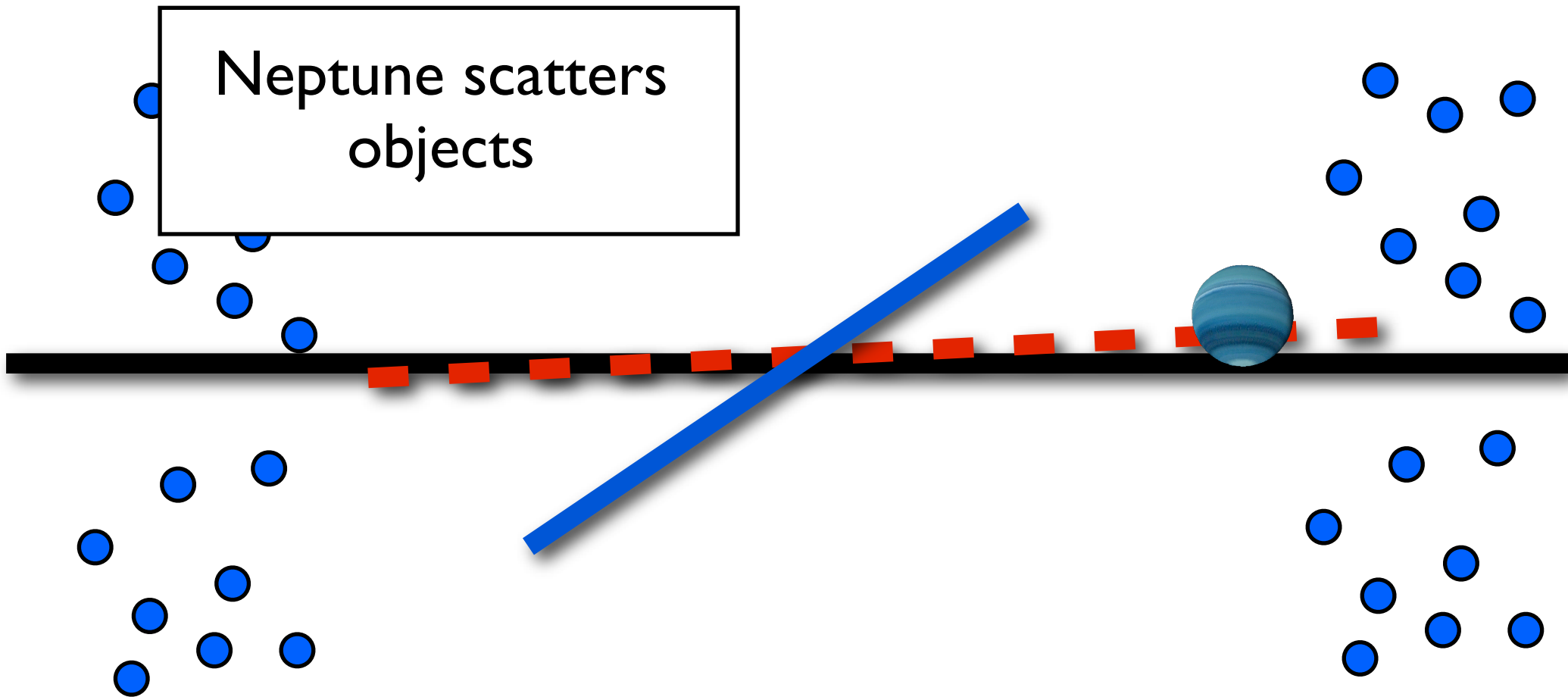


Creation of High Inclination KBOs



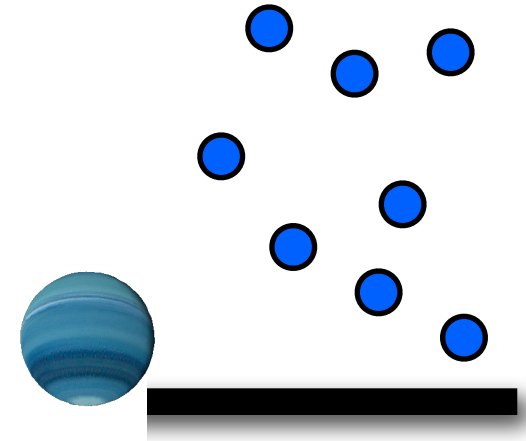
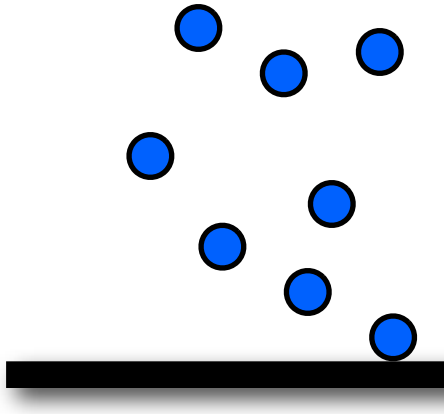
Creation of High Inclination KBOs

Neptune scatters
objects

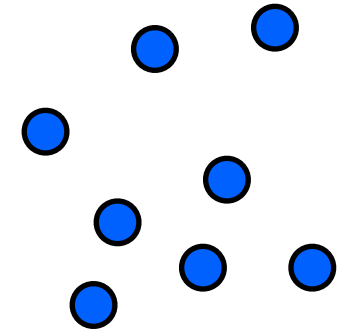
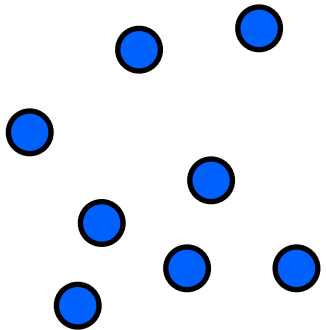


Creation of High Inclination KBOs

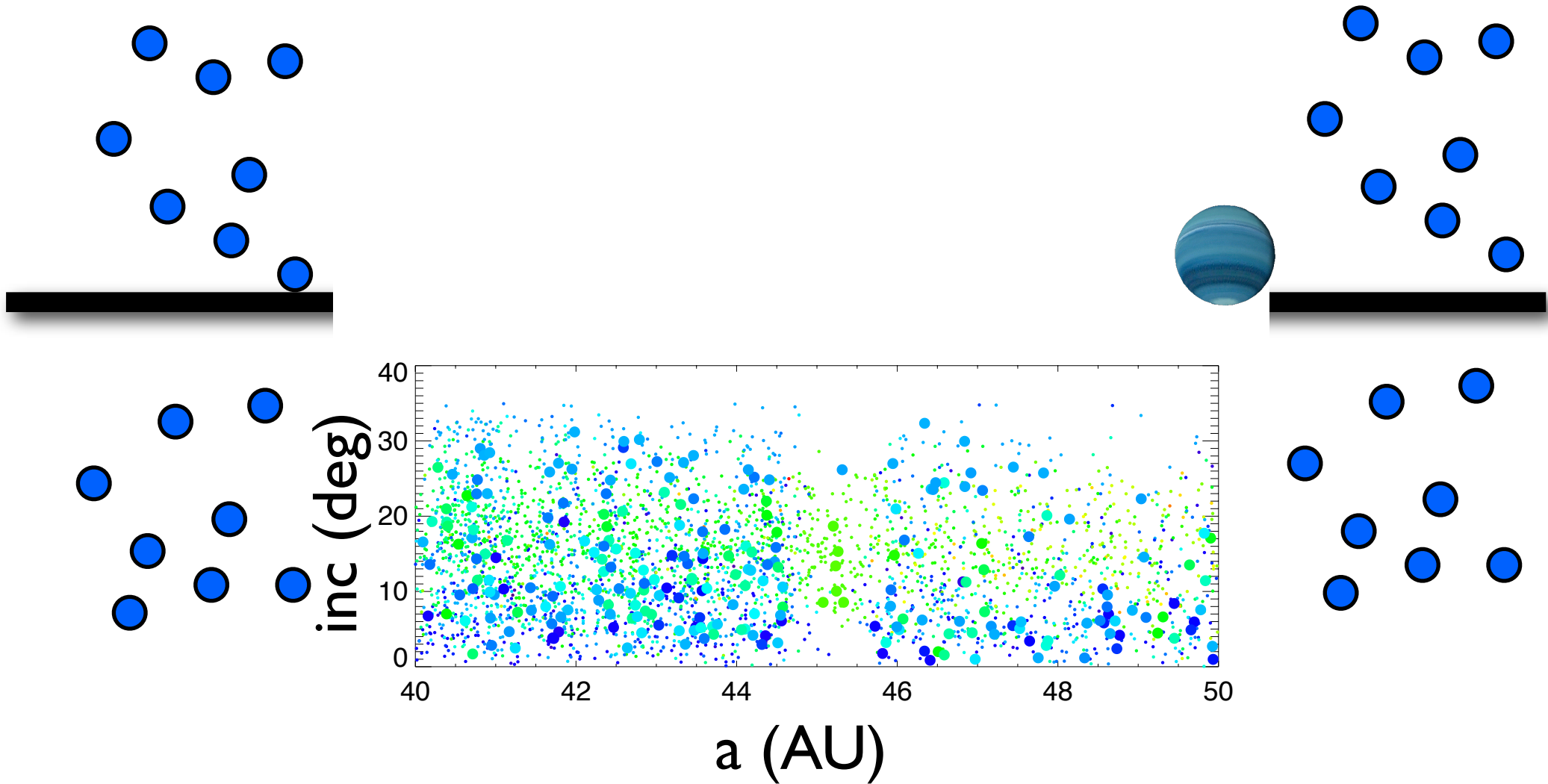
Clean up



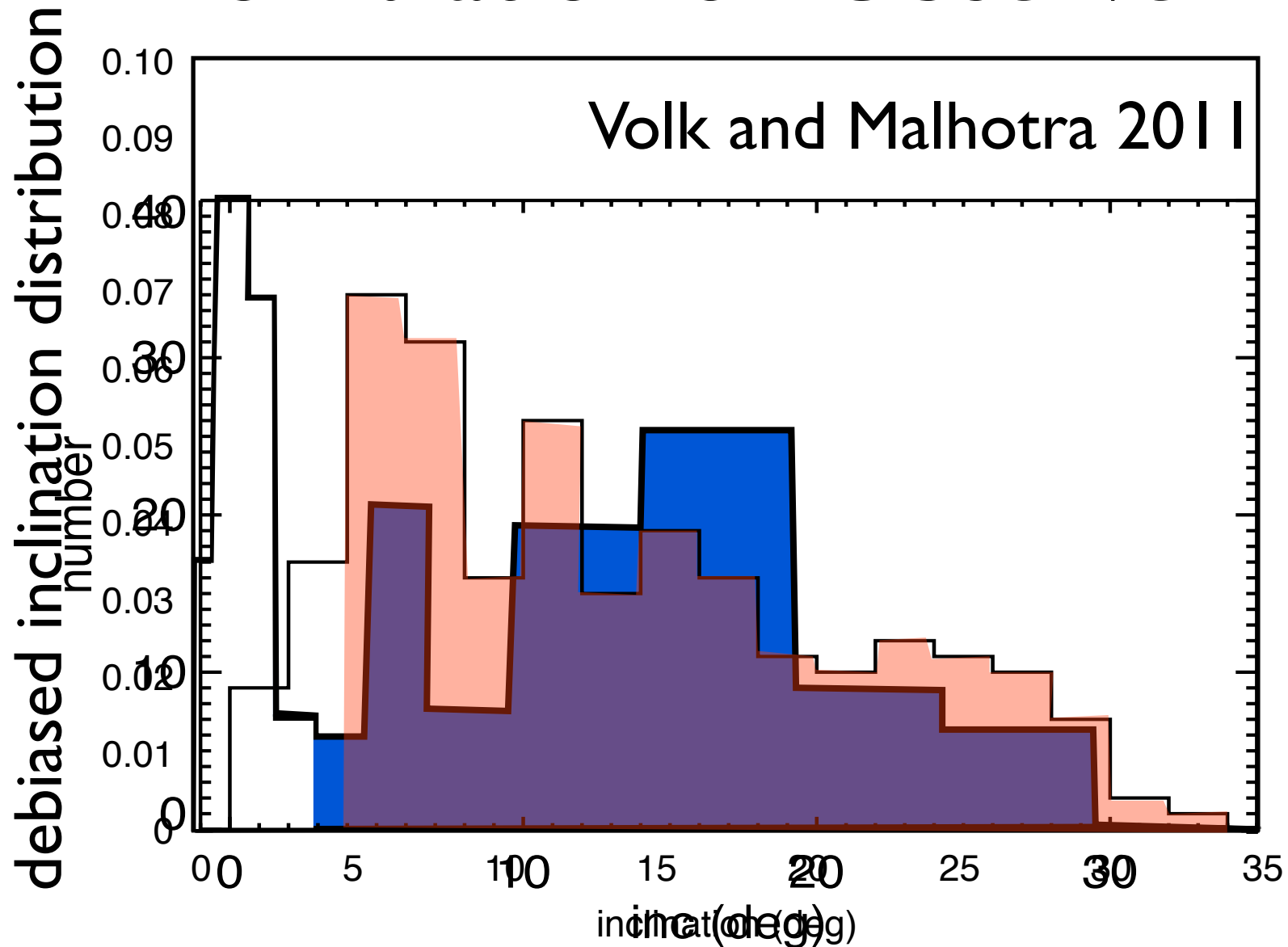
Superposition of
low and high inclination
objects



Creation of High Inclination KBOs



Overlay Histogram from Simulation on Observed



Planetesimal disks are tracers of planet-planet scattering



- The Beta Pictoris disk could have been warped by Beta Pic b, even if -- due to planetesimal damping -- its orbit today is aligned with the flat outer disk
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