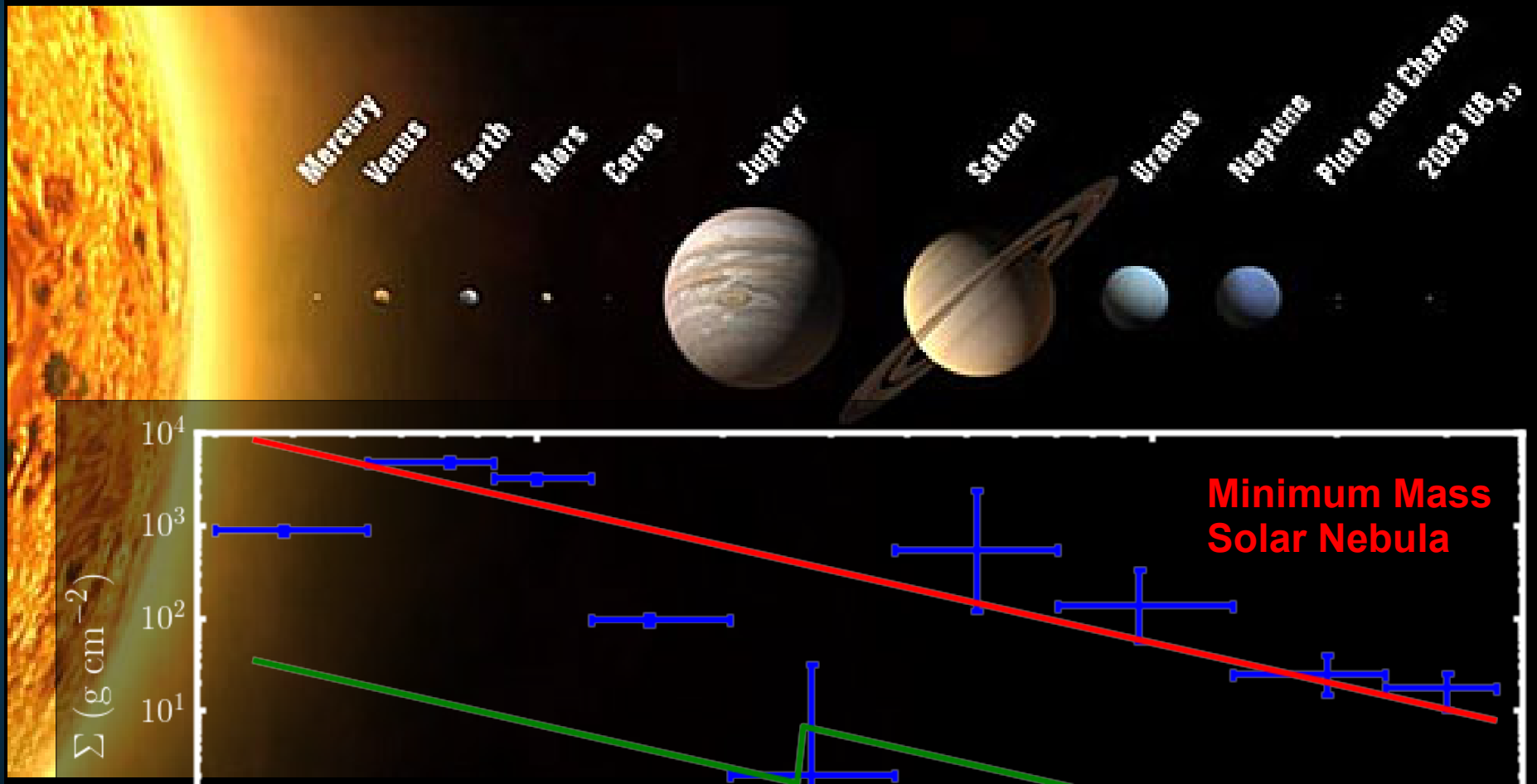
Transporting Planetary Building Blocks in Protoplanetary Disks

Katherine Kretke
UCSC → SwRI (Boulder)

D.N.C. Lin, C. Baruteau,
P. Garaud, S. Ida

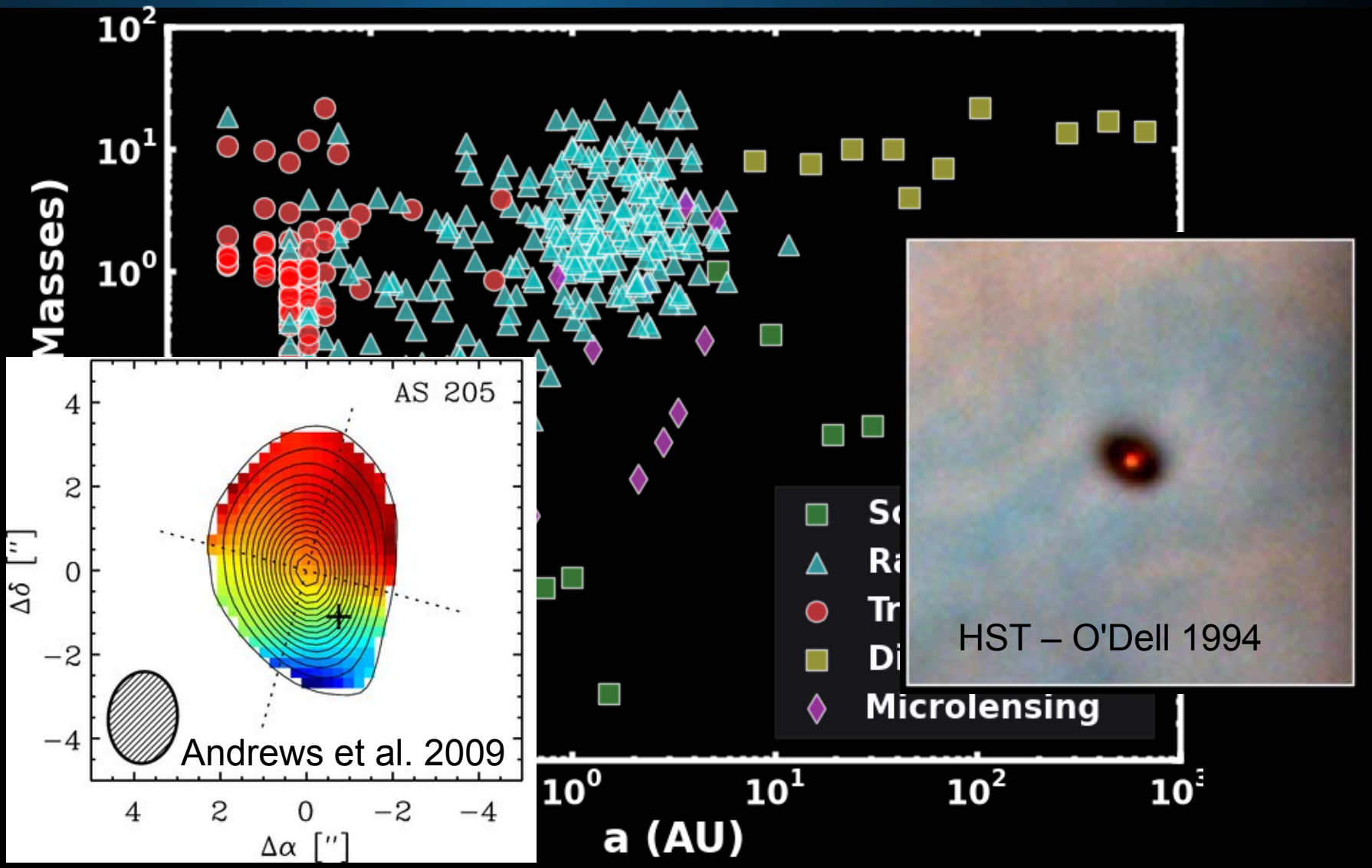
ISIMA
July 7, 2010

Planets ↔ Protoplanetary Disks?



Weidenschilling 1977, Hayashi 1981

Planets ↔ Protoplanetary Disks?



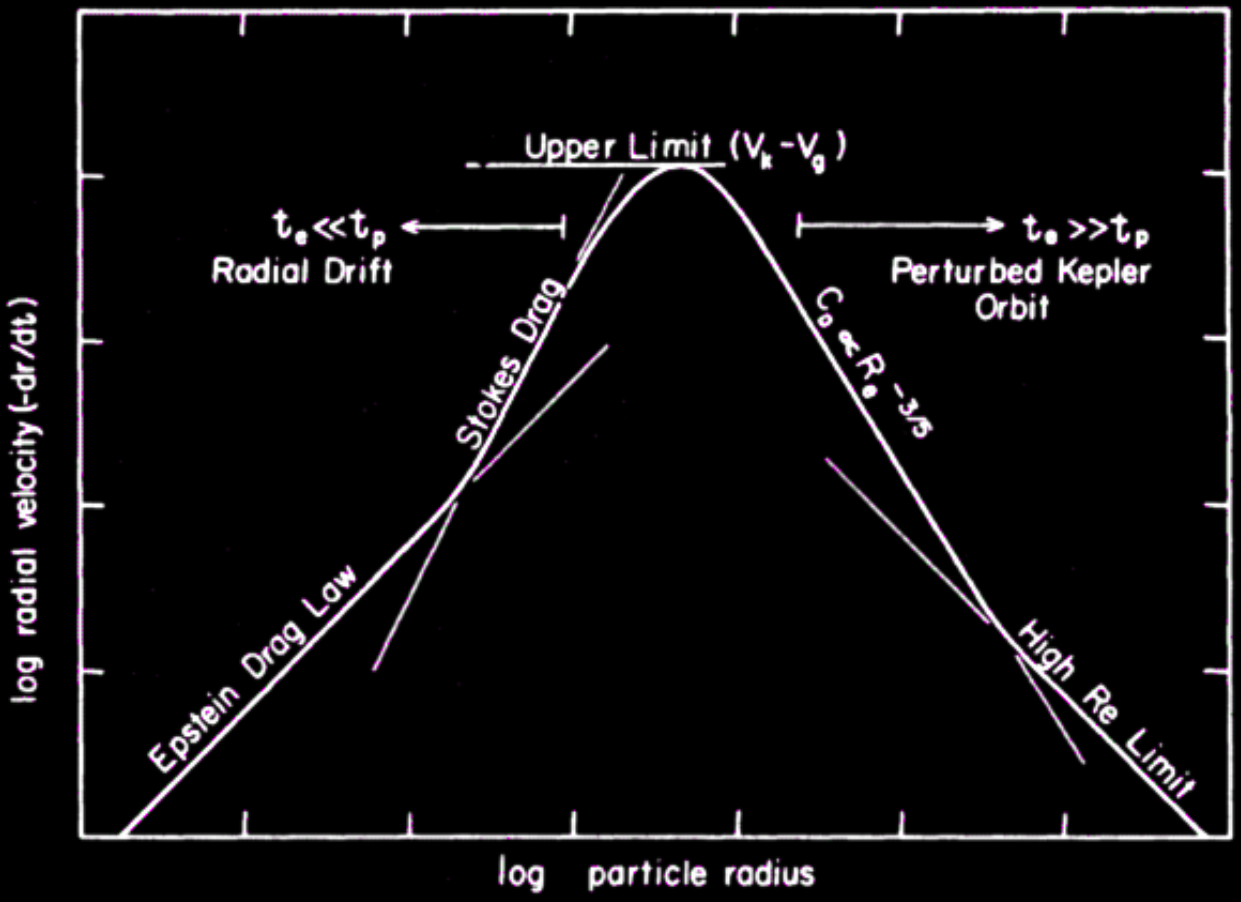
Transport Processes for Solids in Gaseous Disk

Radial drift

Type I Migration

Type II Migration

$$v_r \propto \frac{\partial P}{\partial r}$$



Wiedenschilling 1977

Transport Processes for Solids in Gaseous Disk

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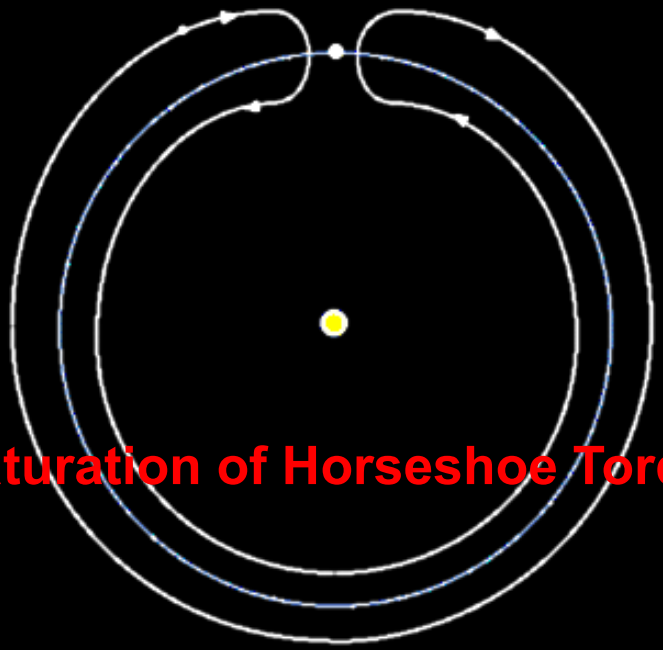
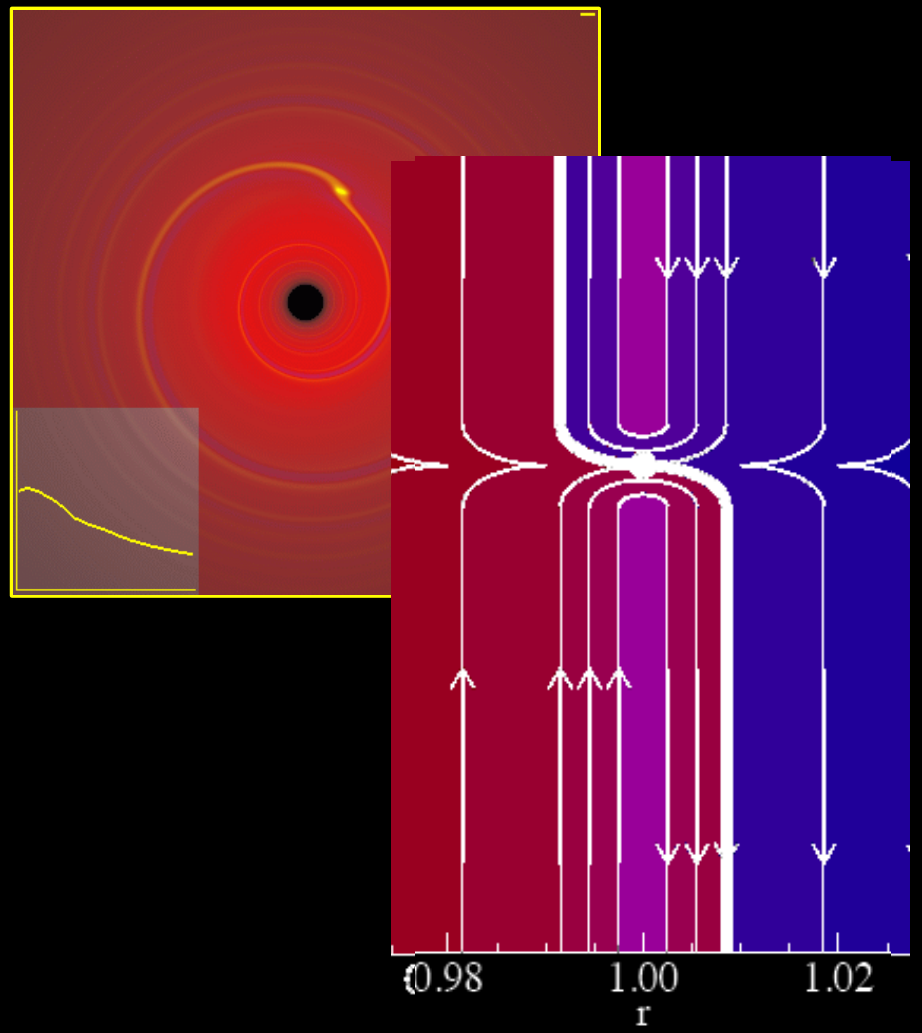


Saturation of Horseshoe Torques

Armitage & Rice



Paardekooper et al. 2009, 2010

Transport Processes for Solids in Gaseous Disk

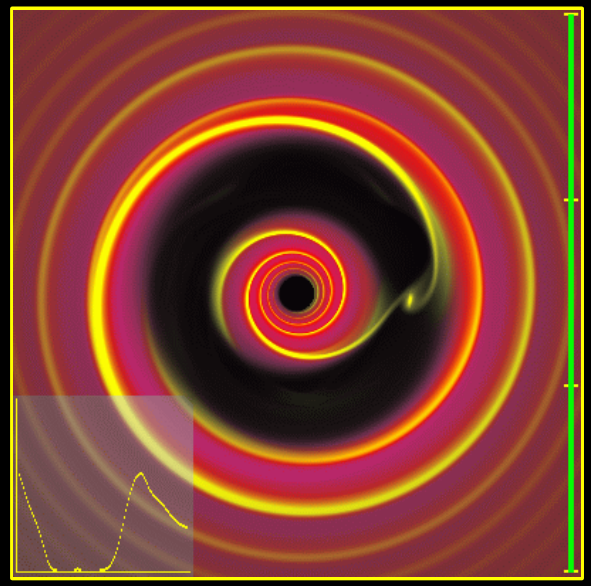
Radial drift

Type I Migration

Type II Migration

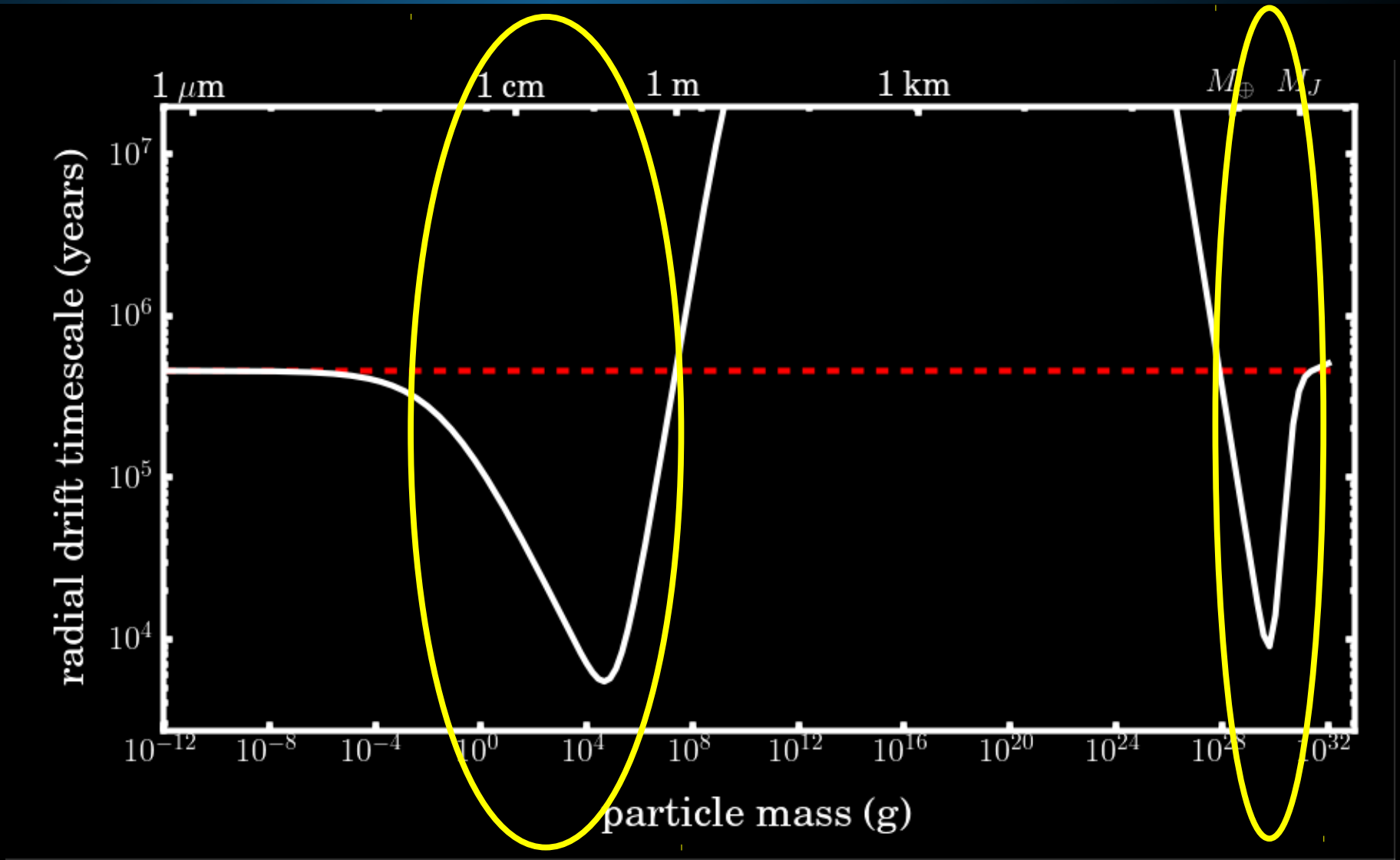
Other physical mechanisms... with or without gas

(type III migration, planet-planet scattering, Kozai, planetesimal driven-migration, etc.)



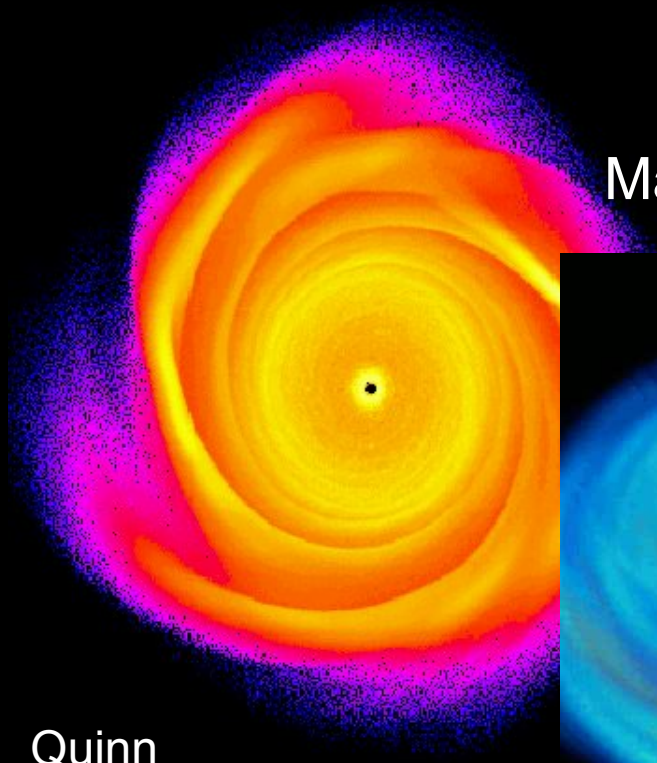
Armitage & Rice

Transport as a Challenge to Planet Formation... in MMSN



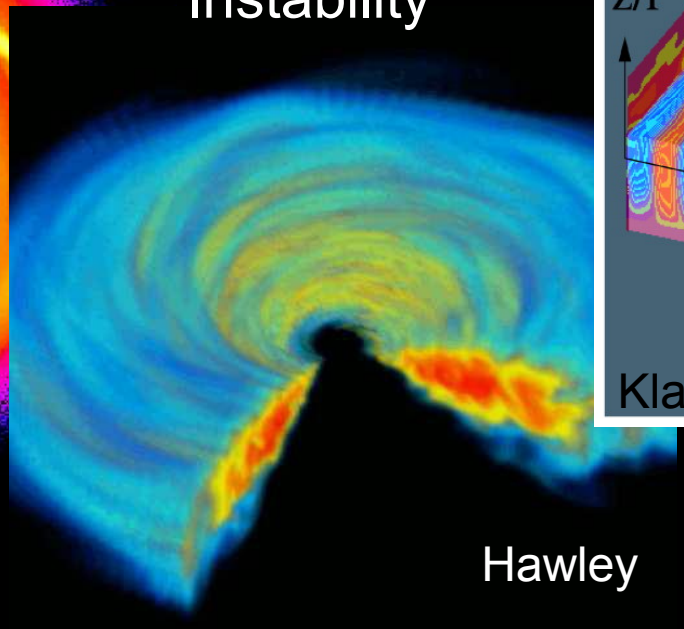
Structure of Protoplanetary Disk

Gravitational Instability



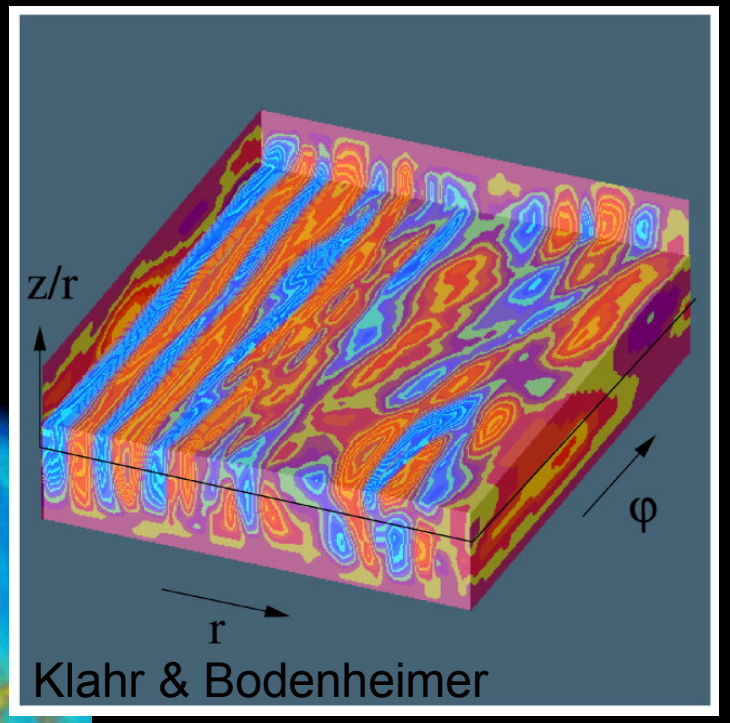
Quinn

Magneto-Rotational Instability



Hawley

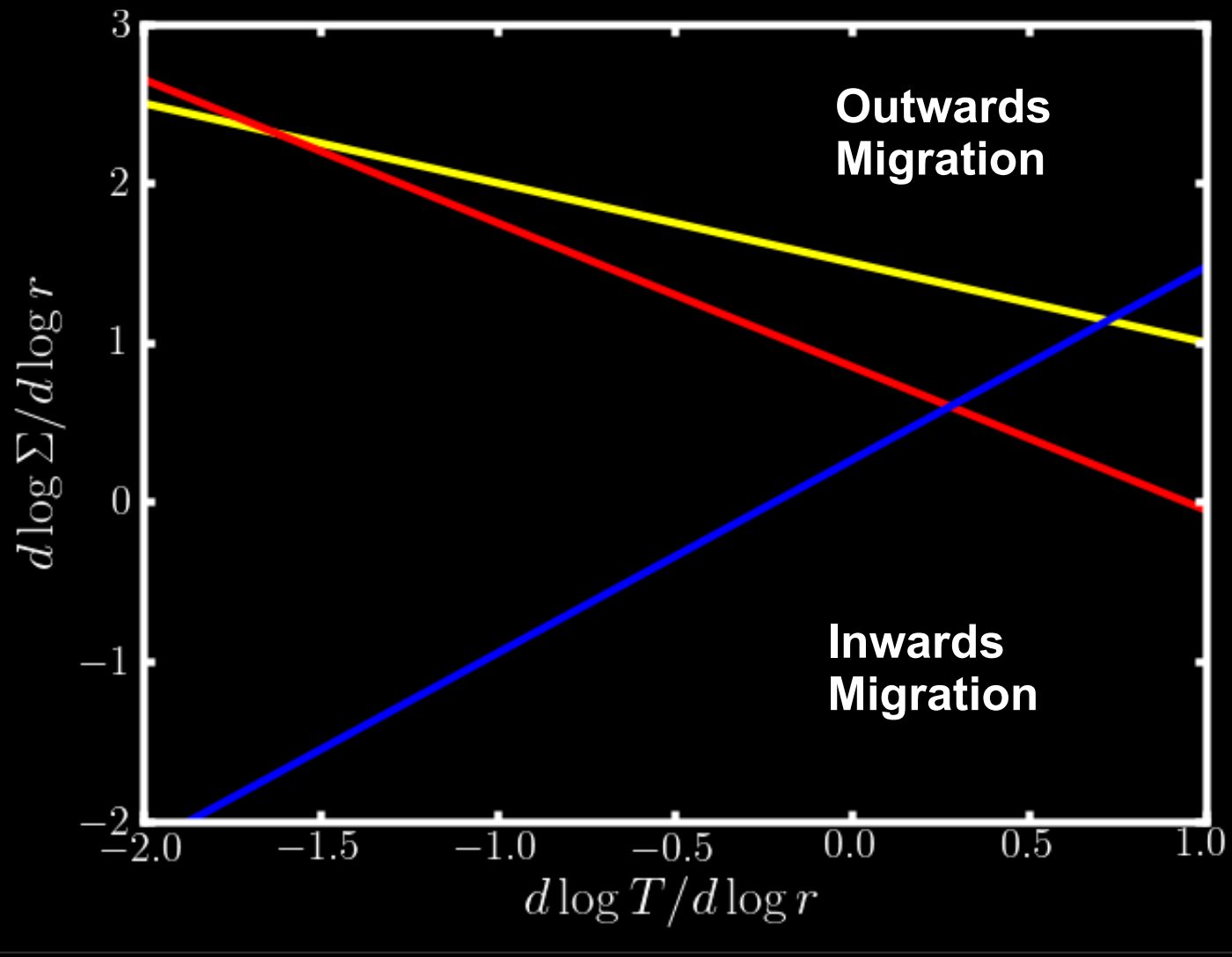
Baroclinic Instability



$$\nu = \alpha c_s h$$

$$\Sigma = \frac{\dot{M}}{3\pi\nu}$$

Migration directions



Aerodynamic Drag

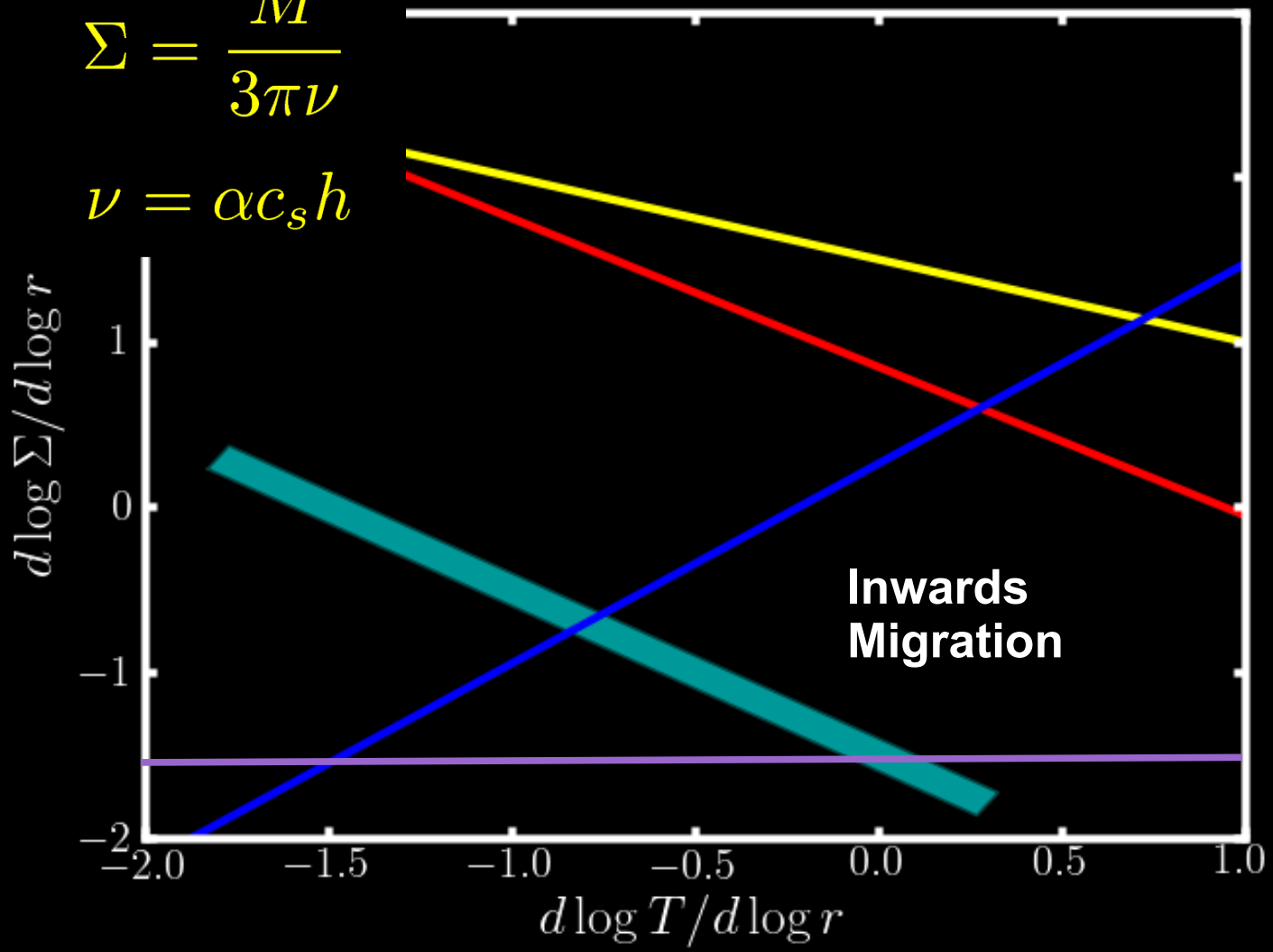
Type I Migration - Saturated Horseshoe torques

Type I Migration - Adiabatic Unsaturated Horseshoe torques

Where do disk models lie?

$$\Sigma = \frac{\dot{M}}{3\pi\nu}$$

$$\nu = \alpha c_s h$$



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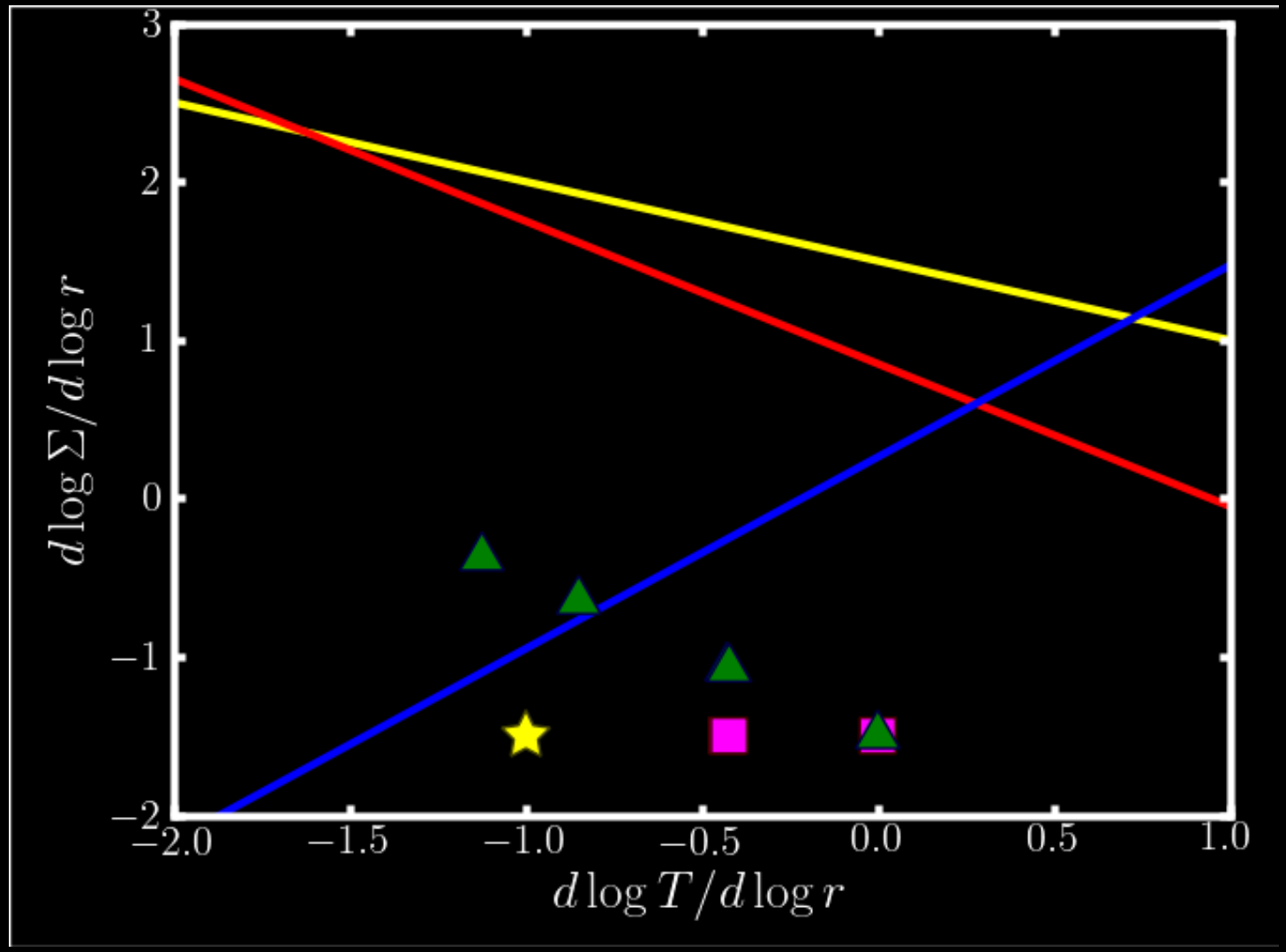
MMSN

α-disk

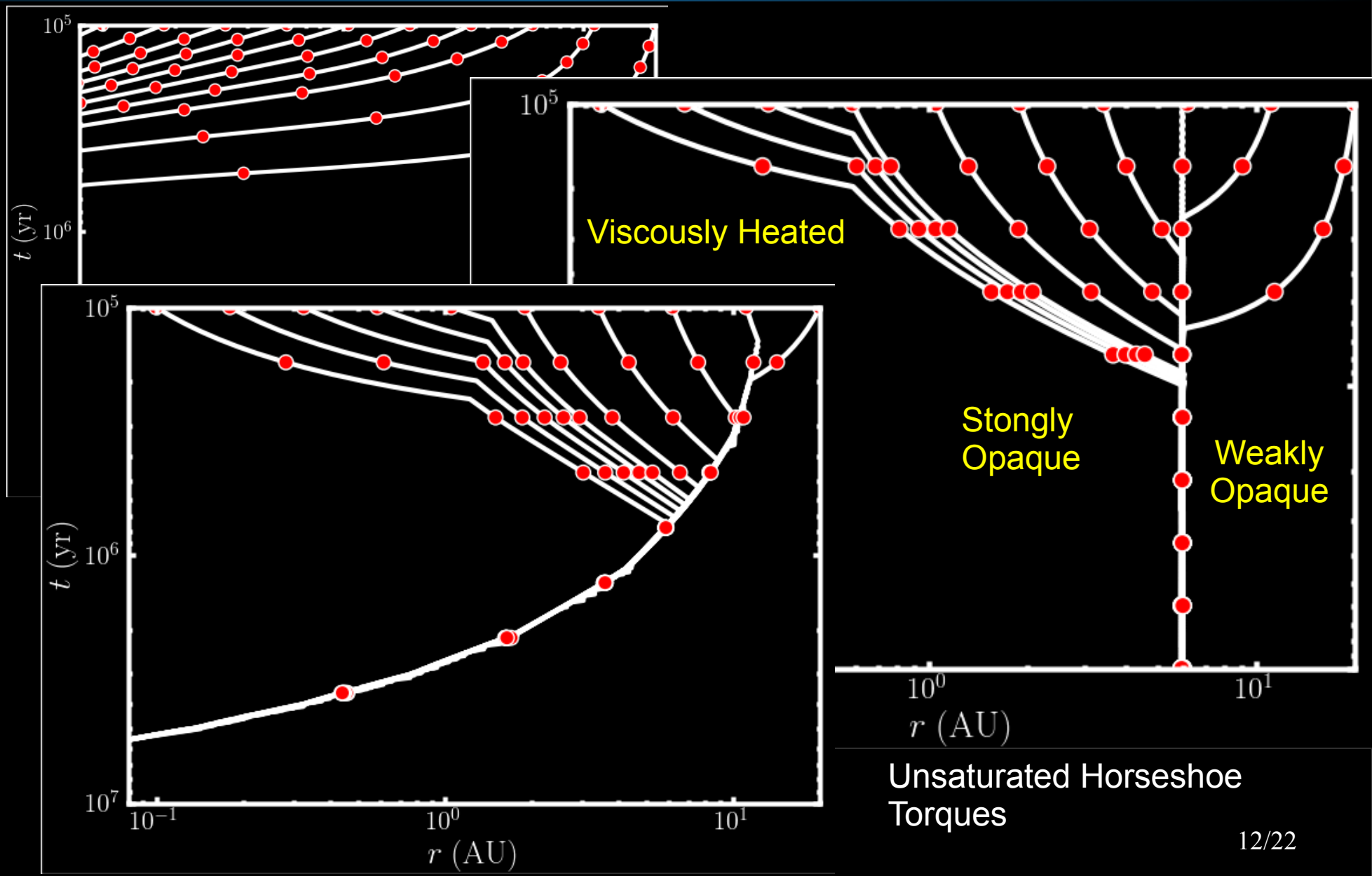
Where do disks models lie?



Garaud & Lin 2007

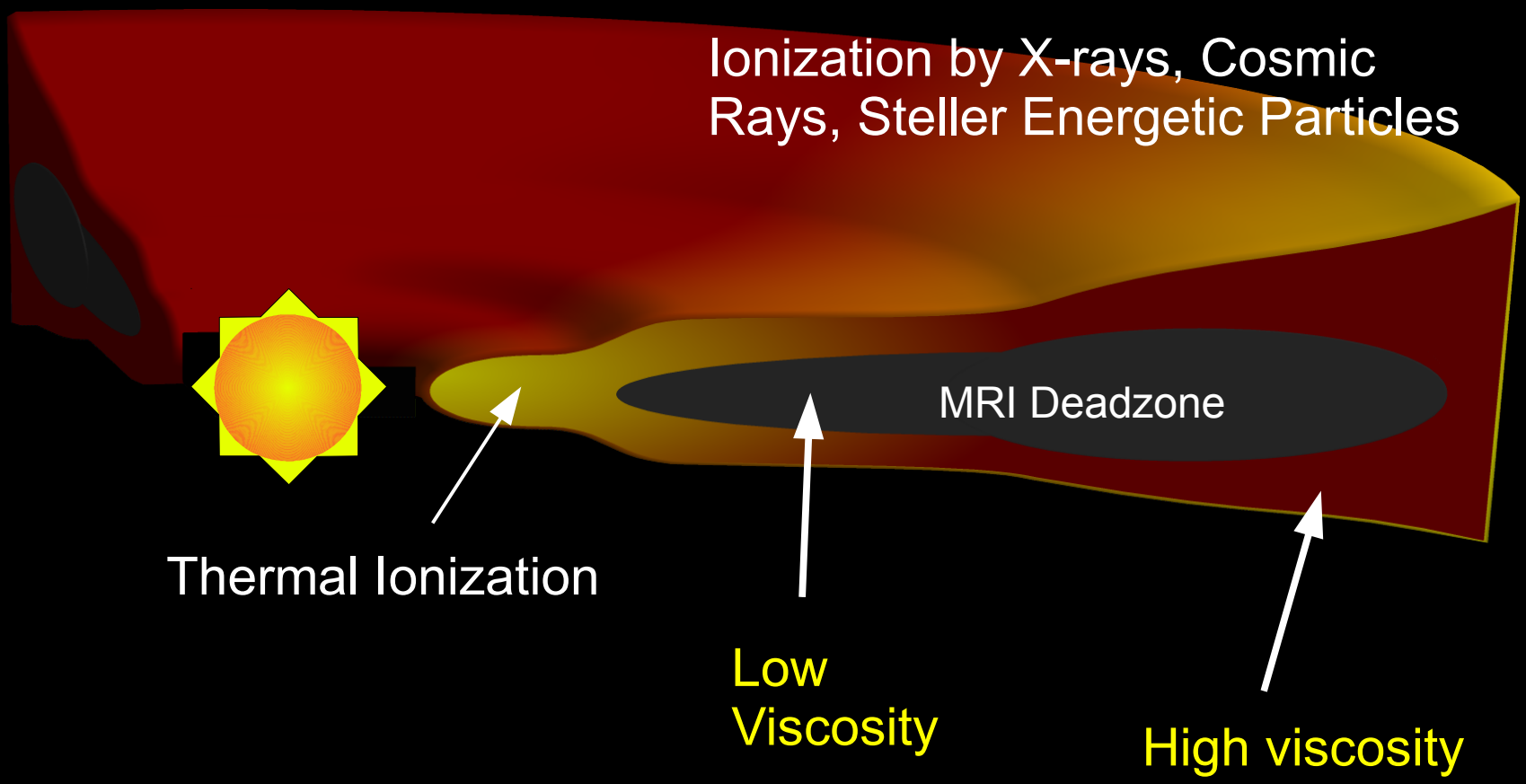
Models Involving MMSN

Migration in an α Disk



Unsaturated Horseshoe Torques

Layered MRI-active Disk



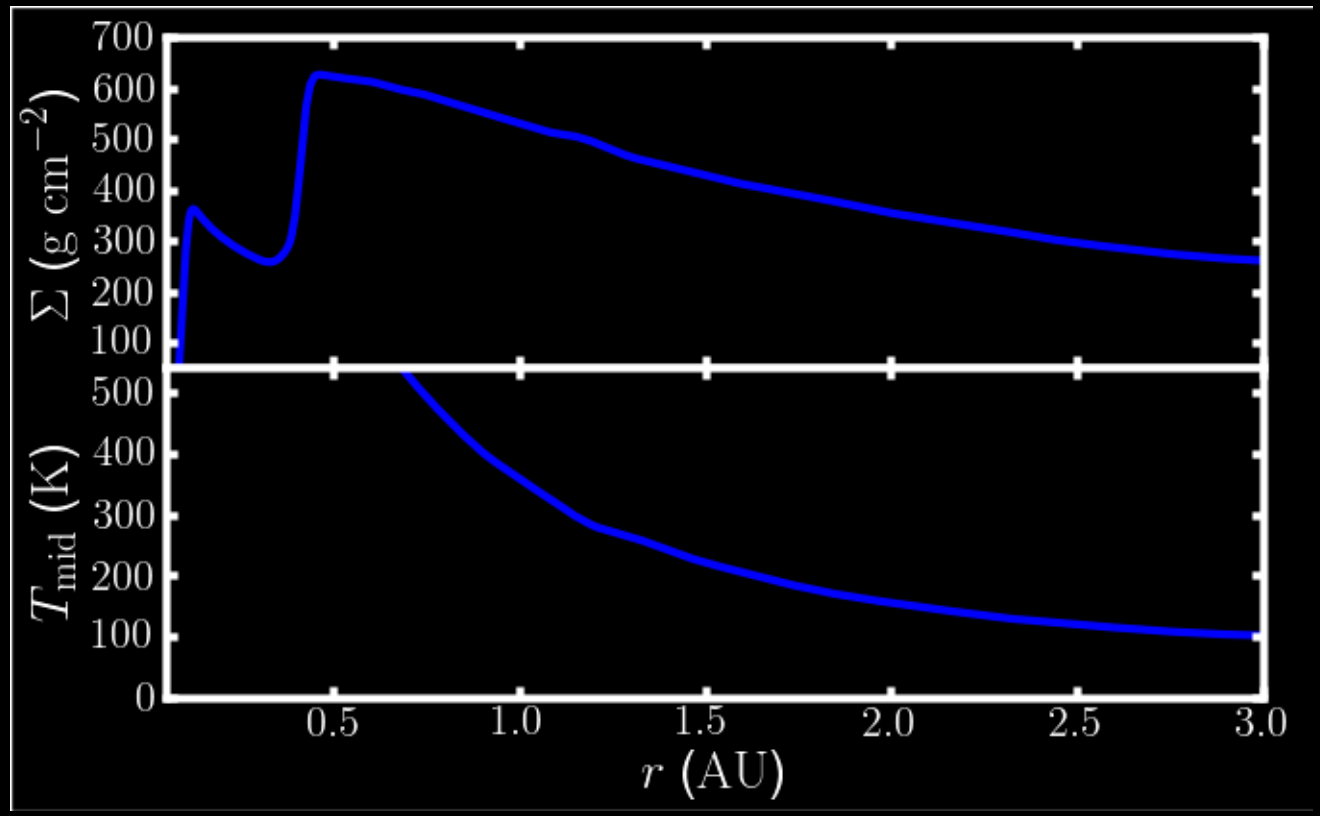
Impact of Sublimation Fronts

Ionization

Recombination on Grains

$$\zeta n_n = \beta n_e n_i + n_e c_e S_e \pi a_{\rm gr}^2 n_{gr}$$

Gas-Phase Recombination



f = 0.02

Kretke & Lin (submitted)

Impact of Sublimation Fronts

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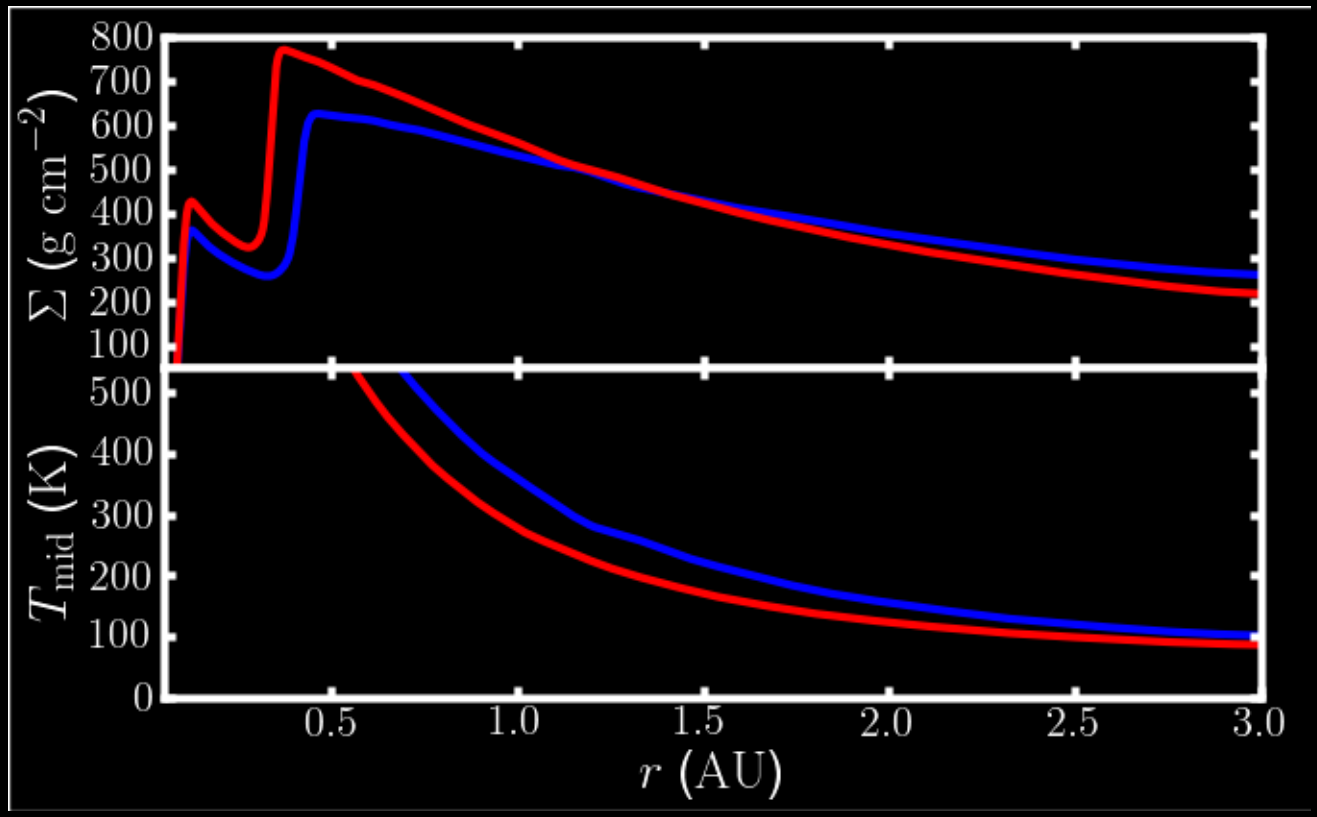

f = 0.01

f = 0.02

$$\Sigma = \frac{\dot{M}}{3\pi\nu}$$

$$\nu = \alpha c_s h$$

Kretke & Lin (submitted)

Impact of Sublimation Fronts

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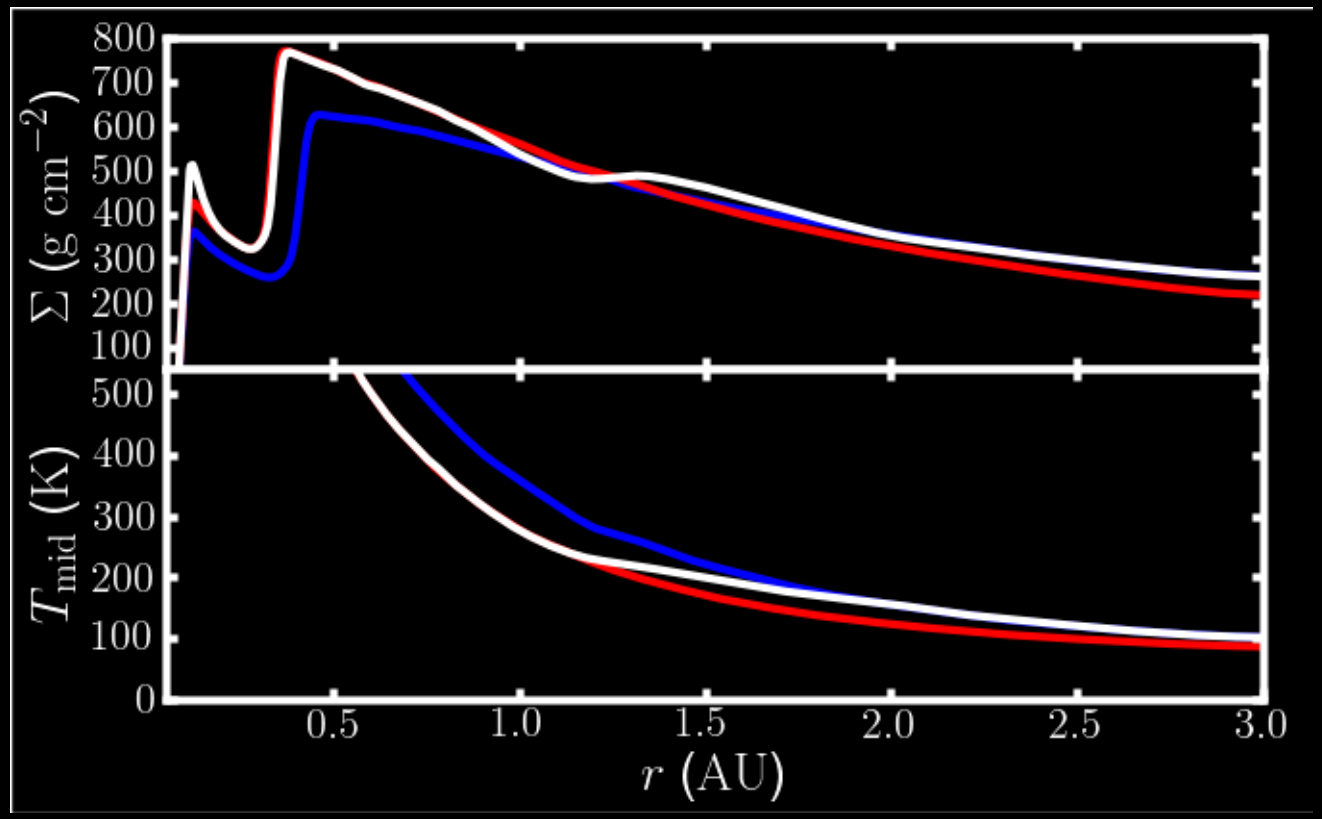

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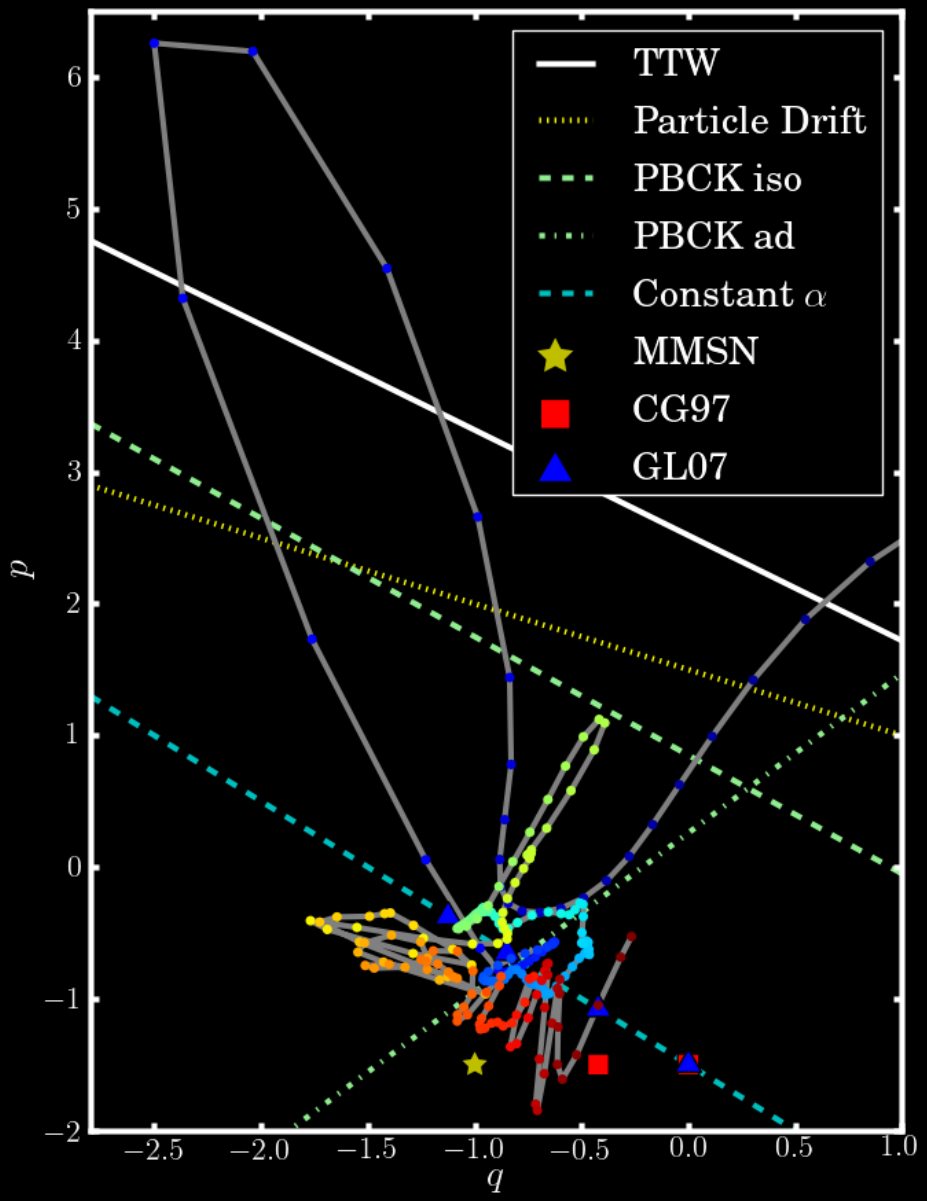
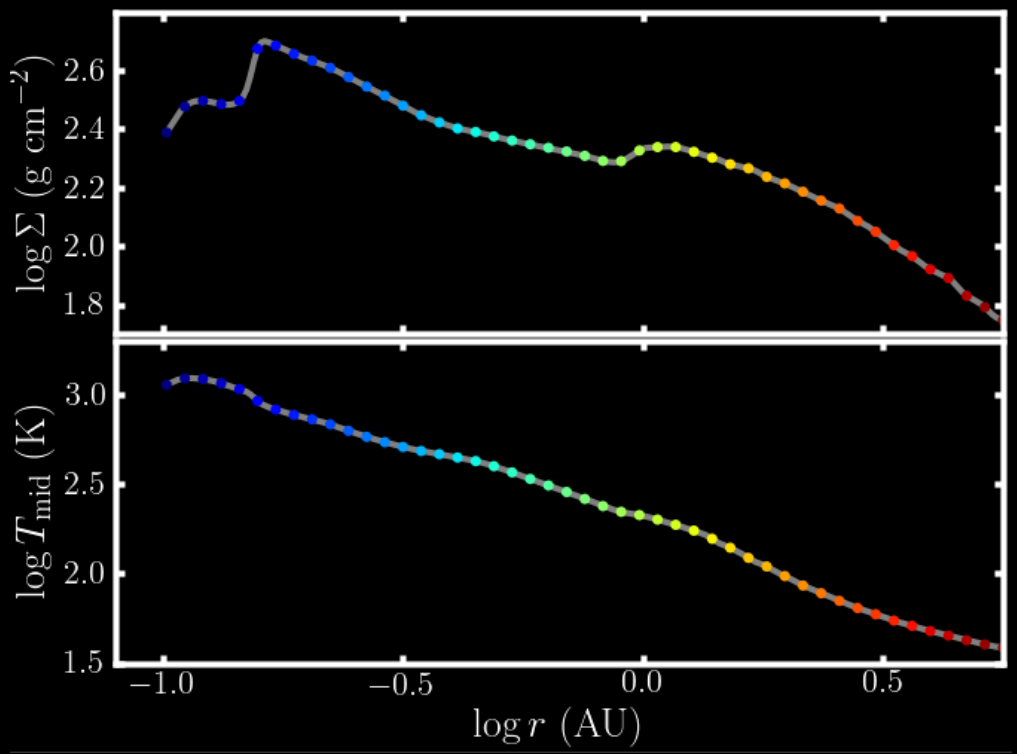
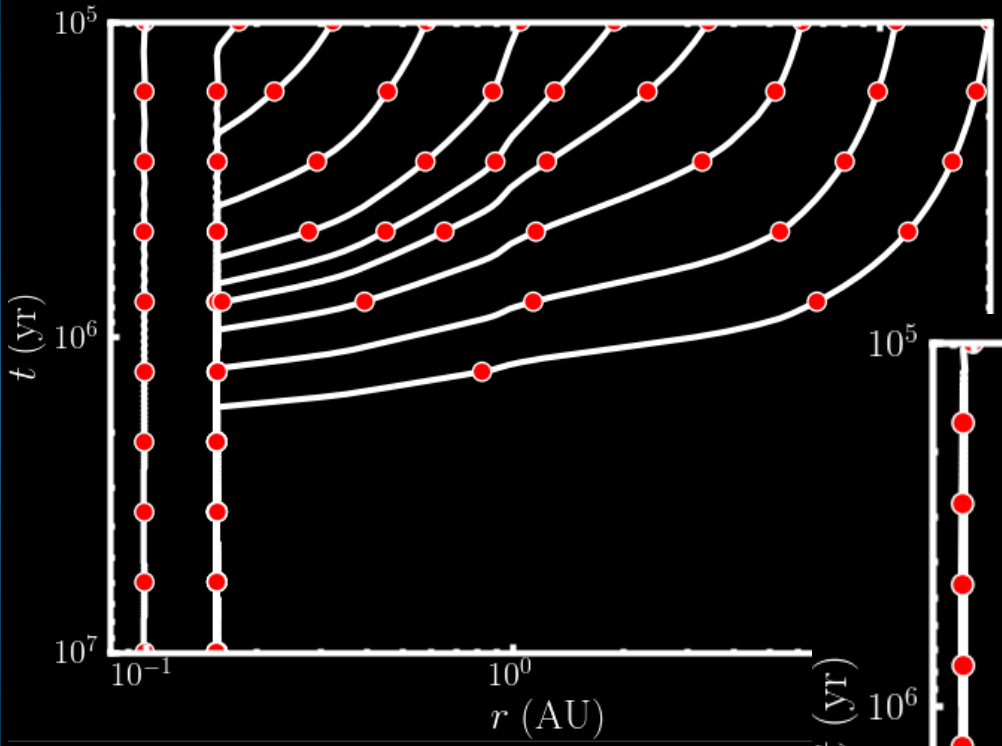
Kretke & Lin (submitted)

Migration in MRI-active disk



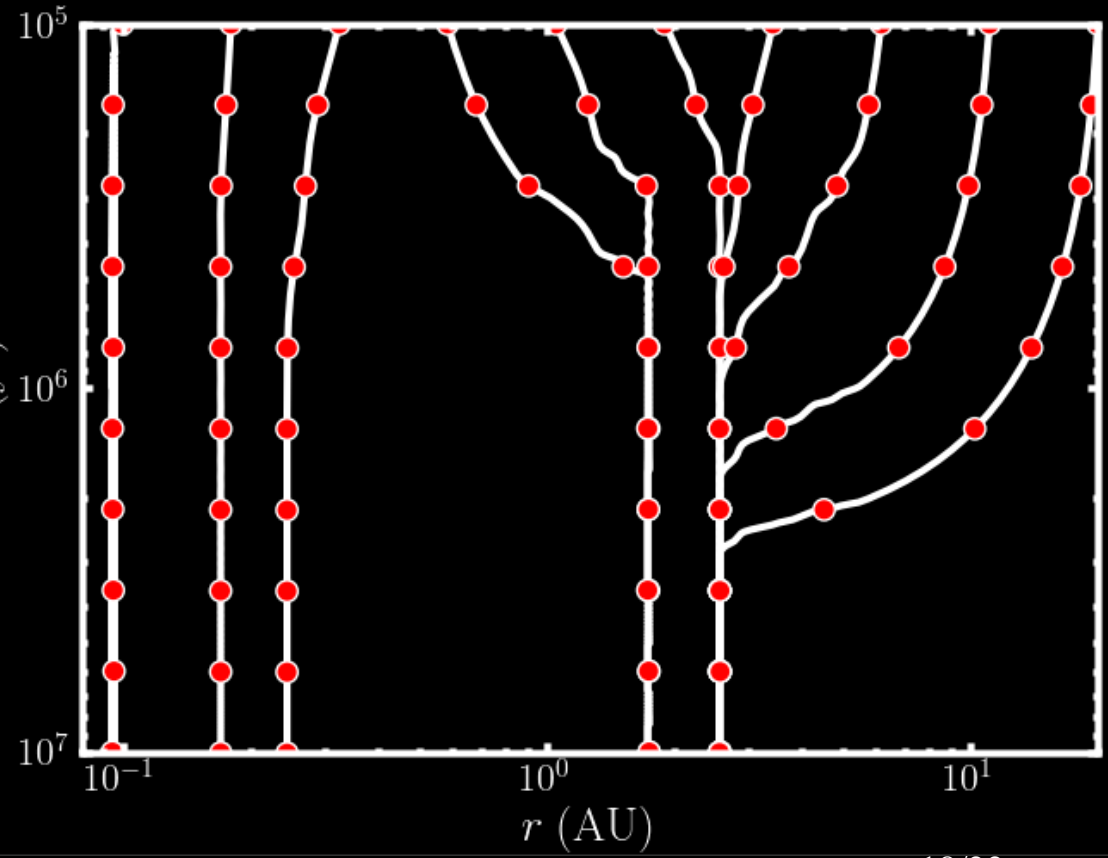


Planet Migration in a Static MRI-active Disk



Fully Saturated Horseshoe Torques

Fully Unsaturated Horseshoe Torques

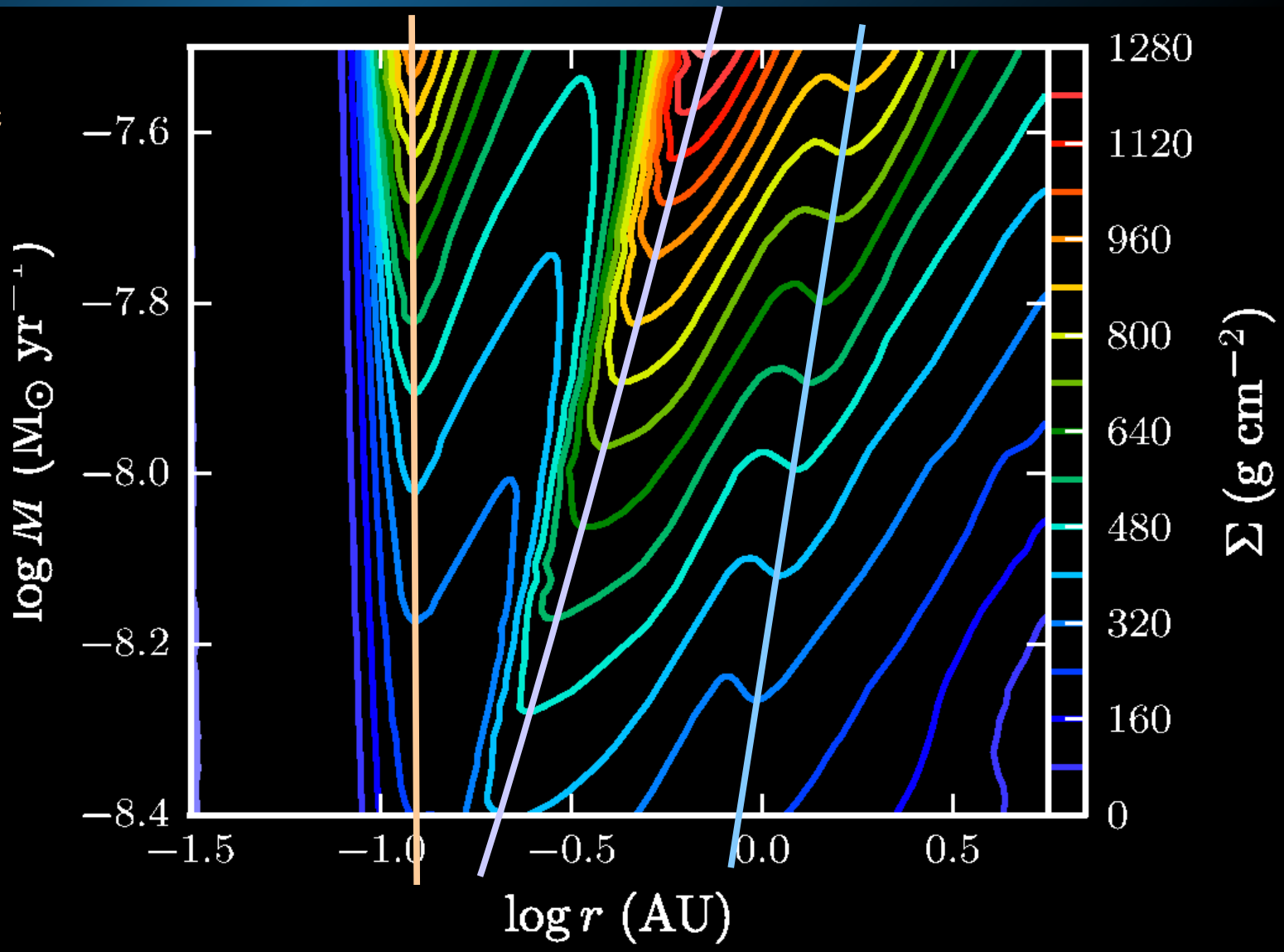


Disk Evolution

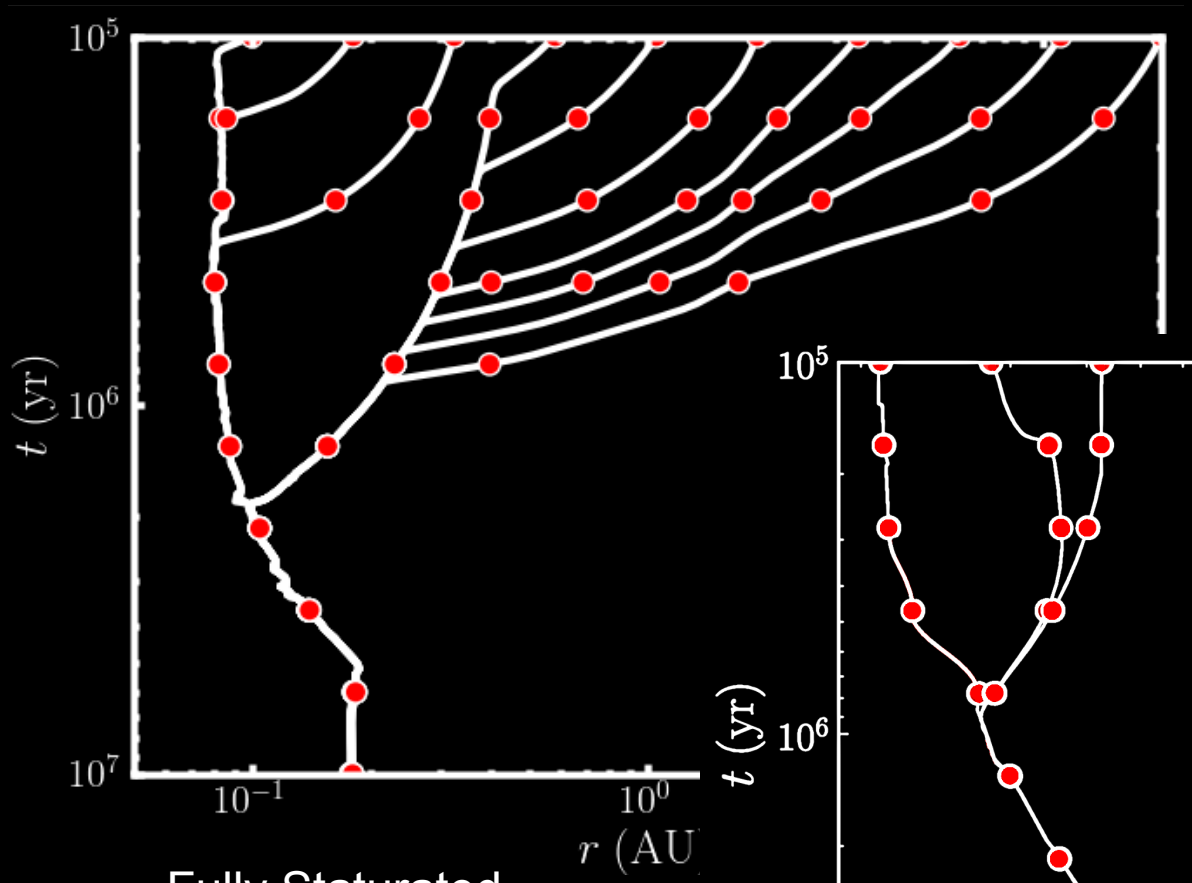
Magnetospheric Truncation Radius

Inner Edge of the Dead Zone

Snow Line

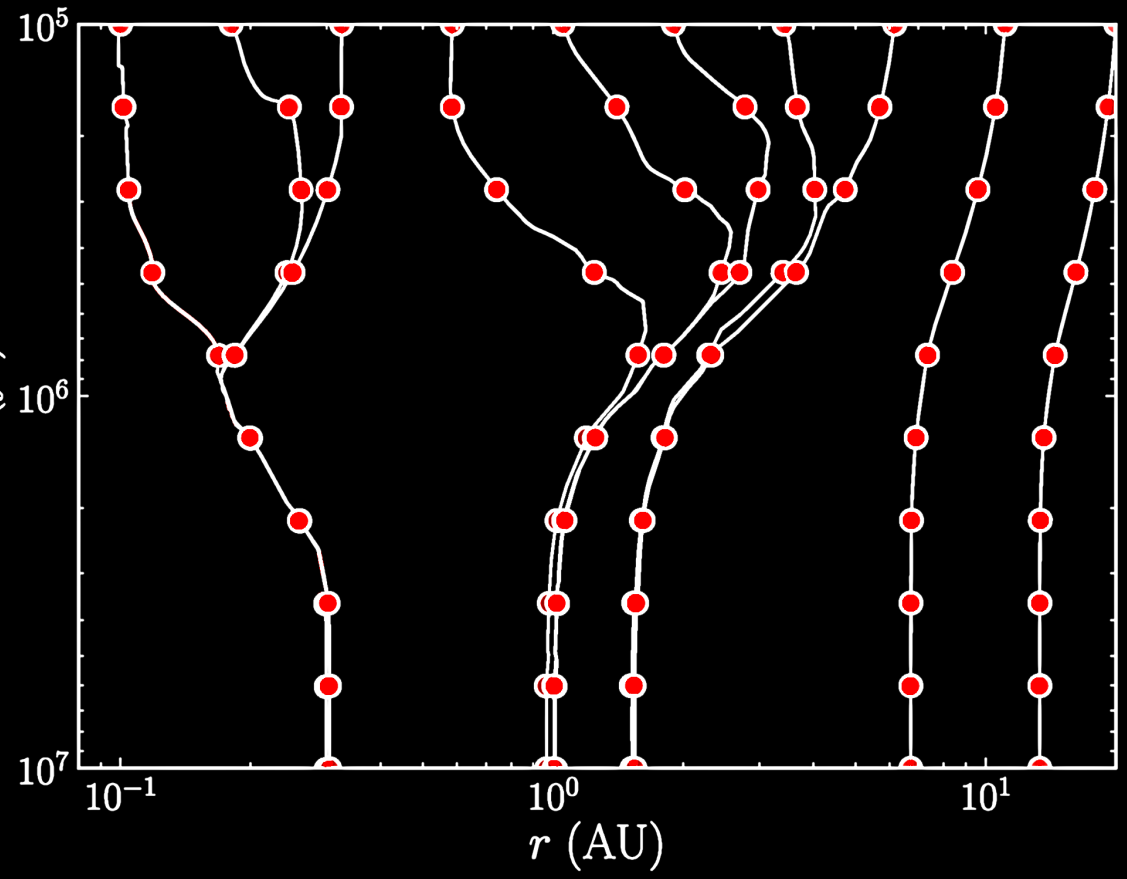


Planet Migration in an Evolving MRI-active Disk

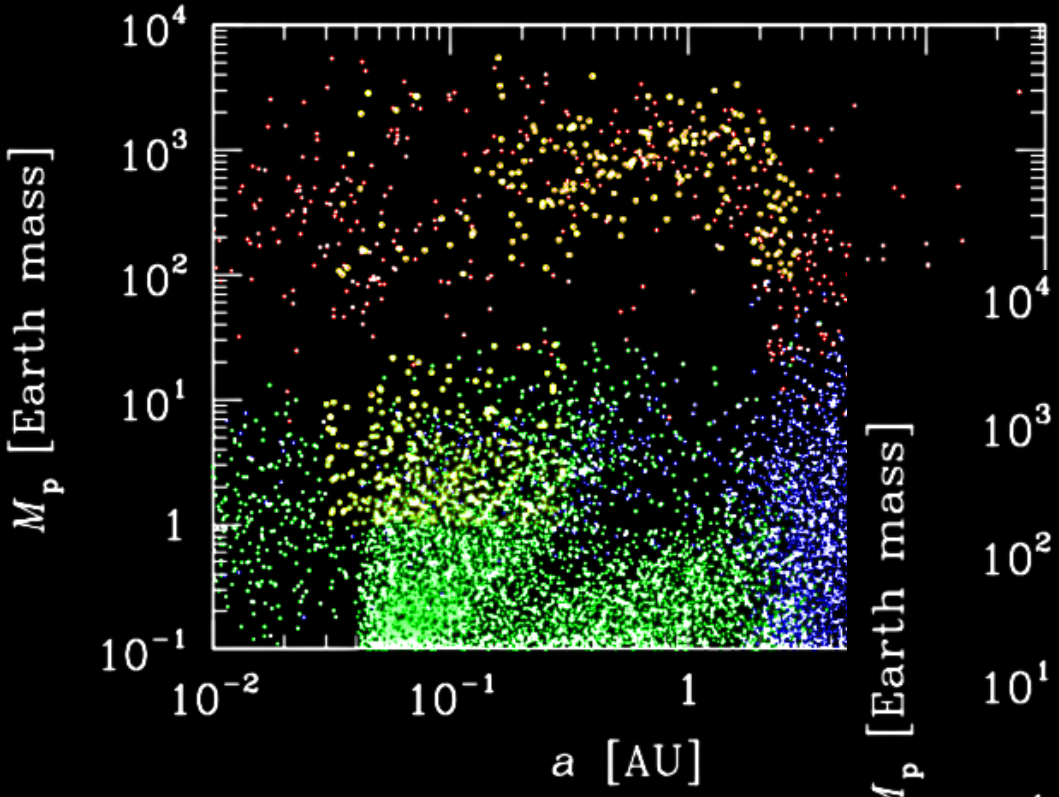


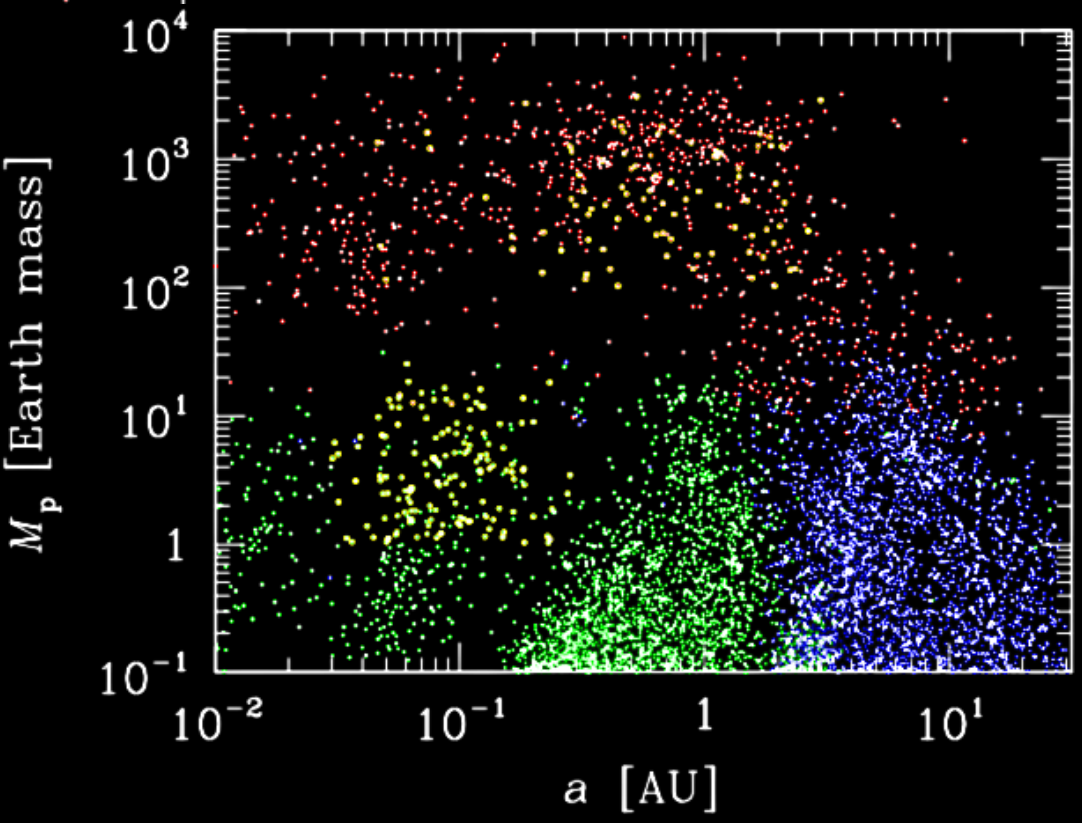
Fully Staturated
Horseshoe Torques

Fully Unsaturated
Horseshoe Torques



Preliminary Results



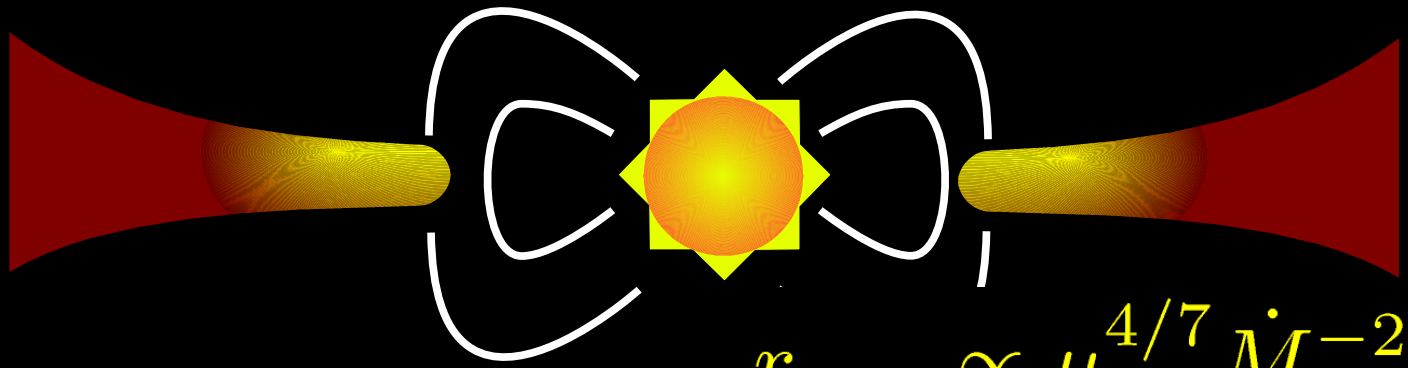


Ida & Lin Population Synthesis Model

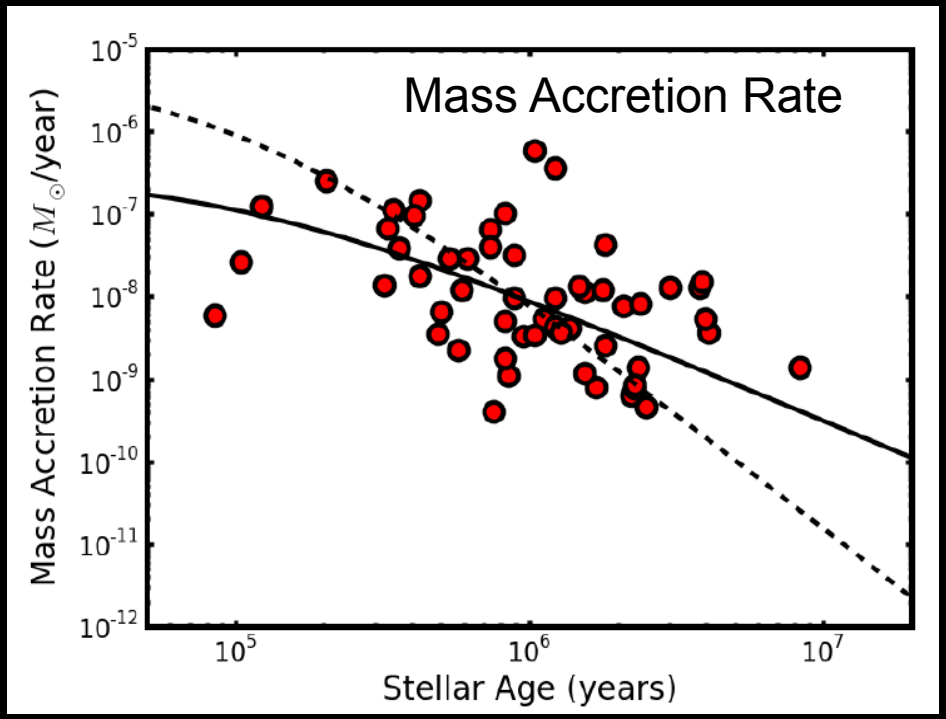
Conclusions

- Solids are mobile in protoplanetary disks, they accumulate at pressure maxima or in locations where gravitational torques balance
- MRI leads to axisymmetric planet “traps”
- The existence / location of planet traps change with time in an evolving disk
  - Planet formation can be enhanced by grain trapping at various locations in protoplanetary disks
  - The migration of low-mass planets will depend upon the disk structure
- Planet distribution can tell us about protoplanetary disk structure

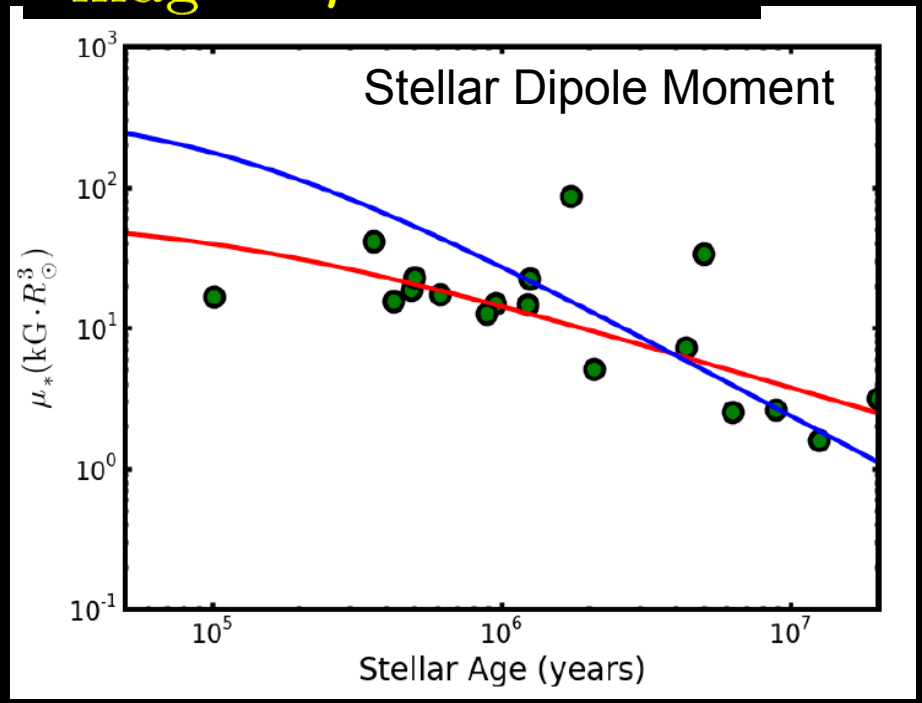
Magnetospheric Truncation Radius



$$r_{\rm mag} \propto \mu_*^{4/7} \dot{M}^{-2/7}$$

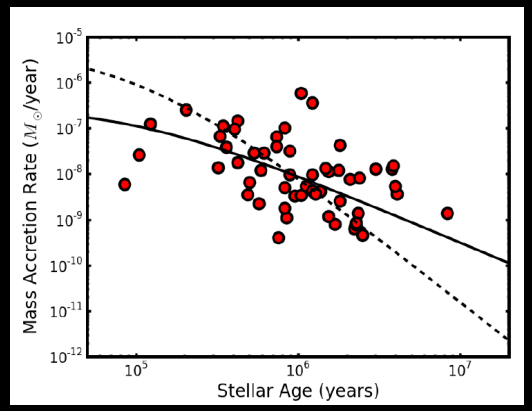


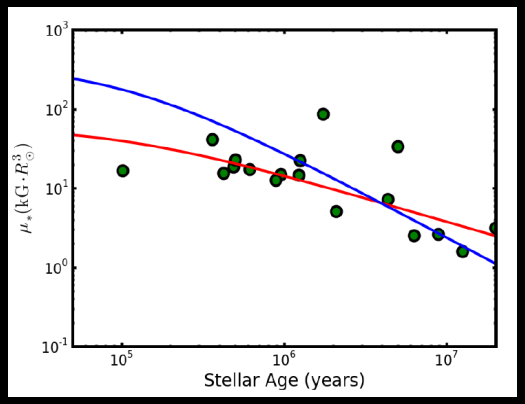
Hartmann et al. 1998

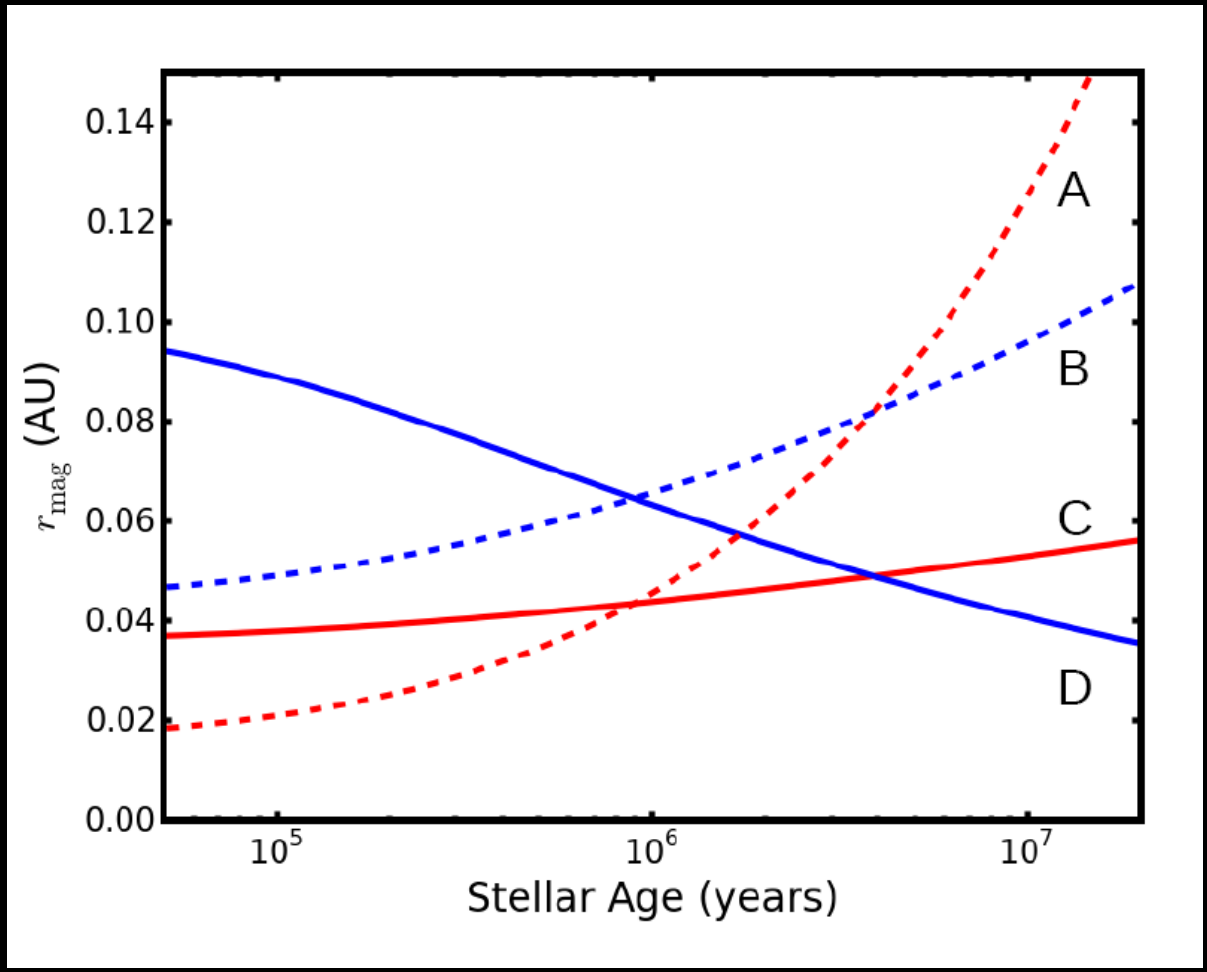


Johns-Krull 2007; Yang et al. 2008

Evolution of the Truncation Radius ($r_{\rm mag}$)

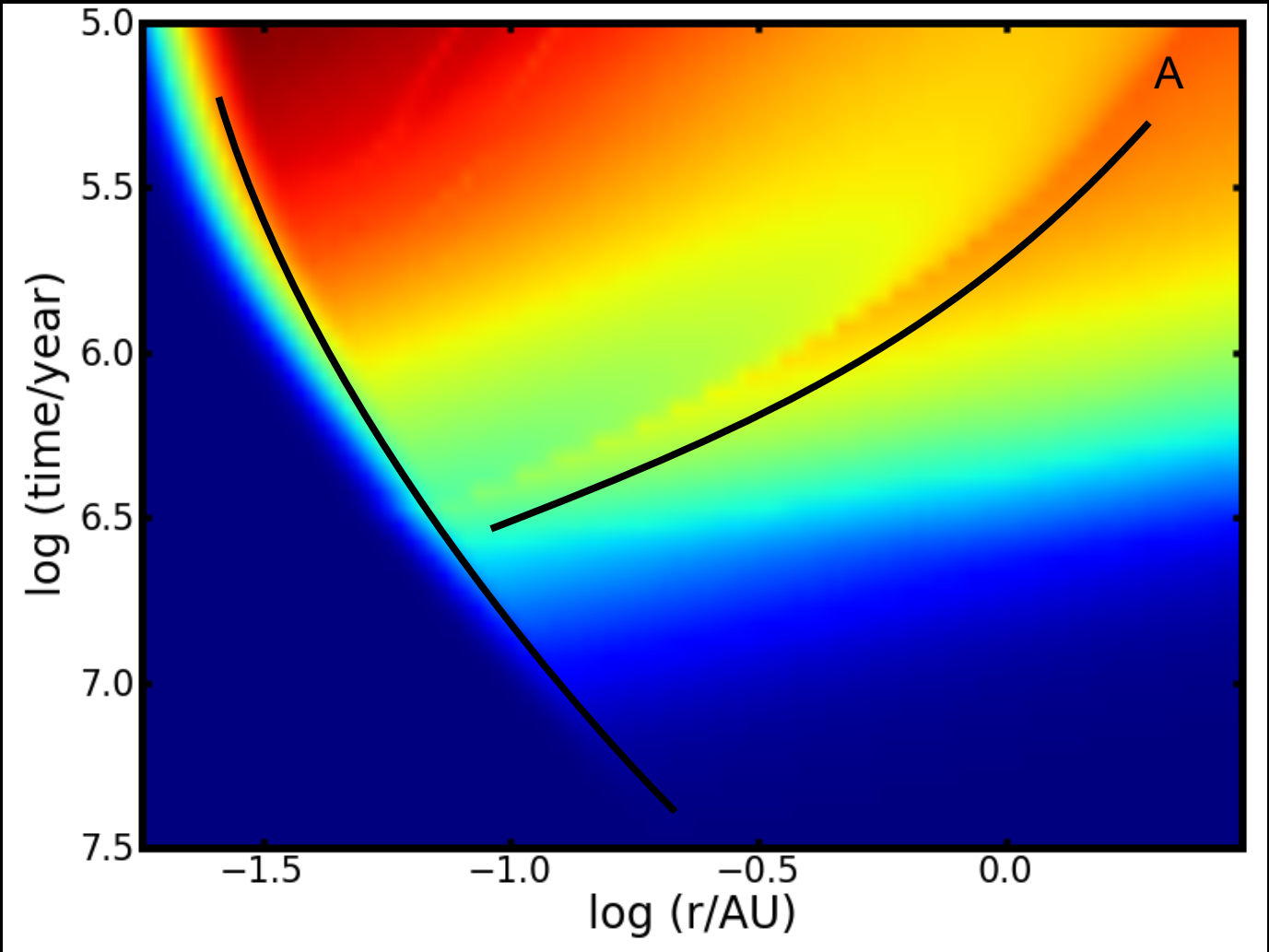


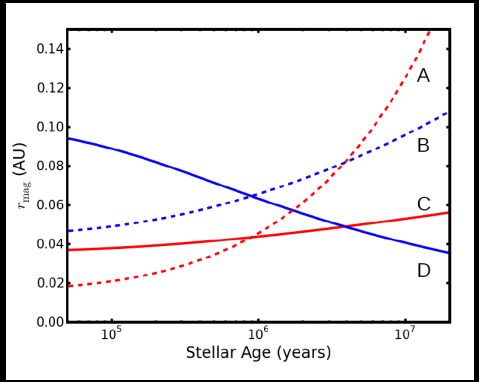




Kretke & Lin (in prep)

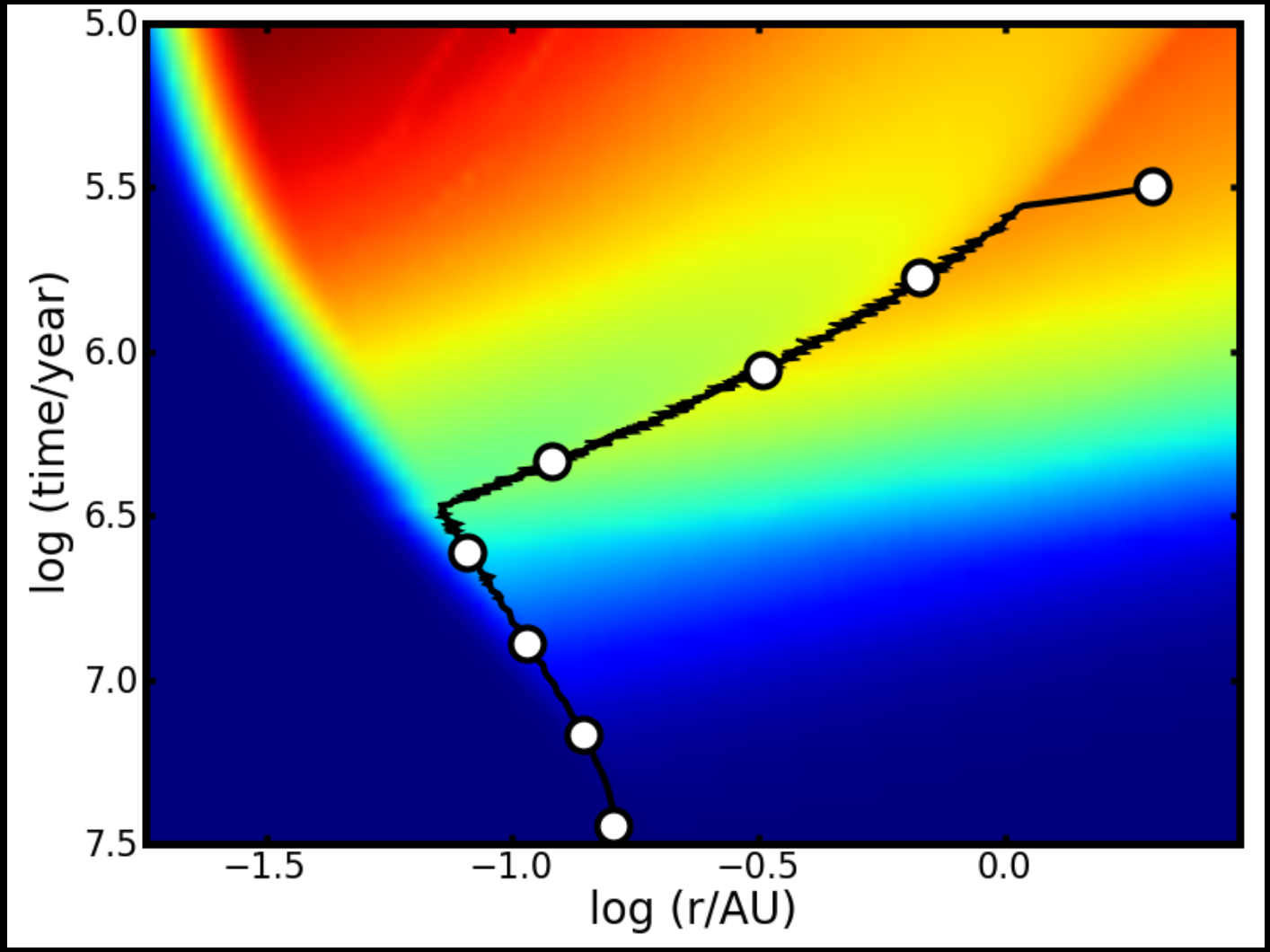
Evolution of Disk





Kretke & Lin (in prep)

Planet Migration



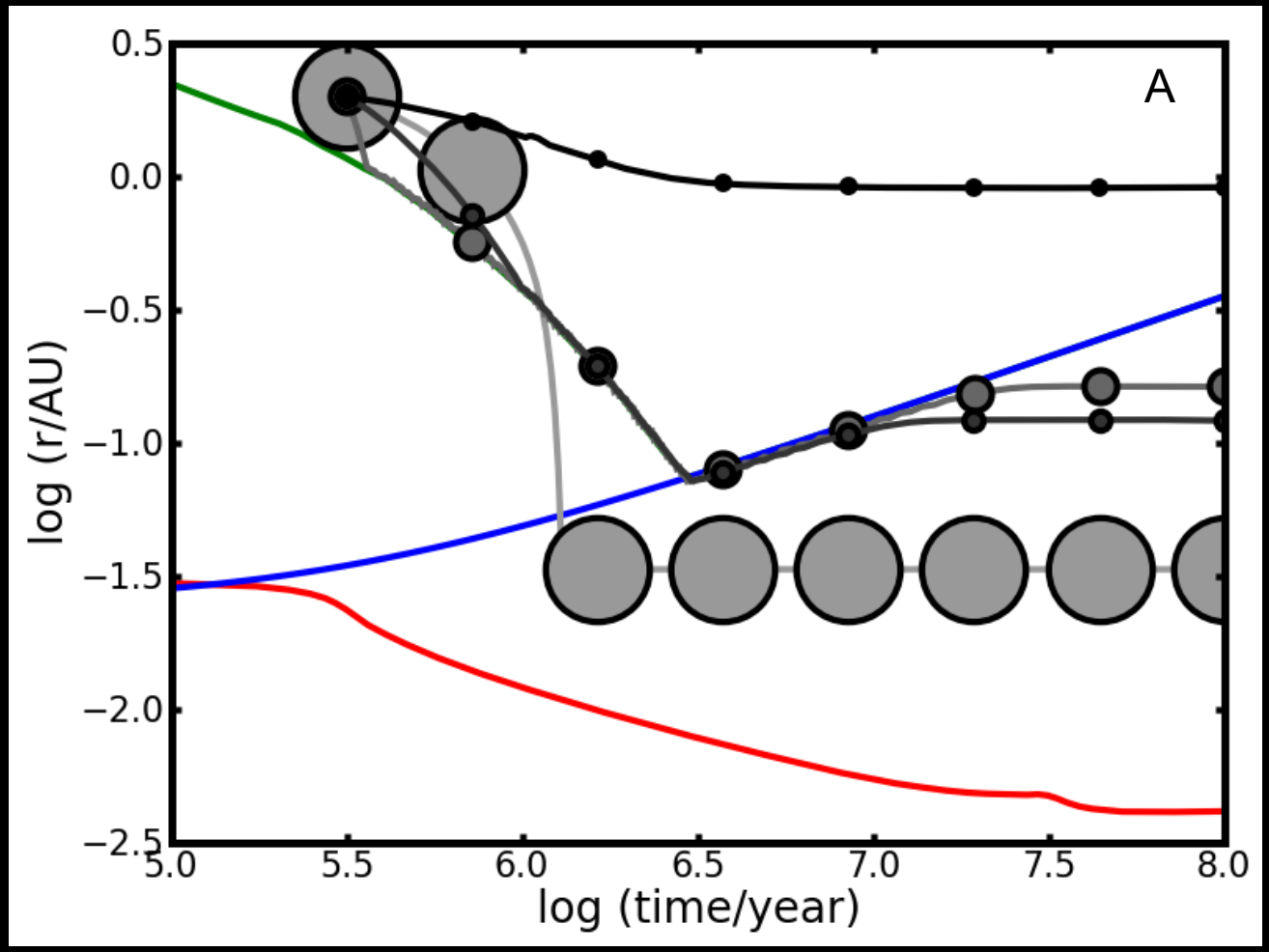
Kretke & Lin (in prep)

Migration of Various Mass Planets

$r_{\rm crit}$

$r_{\rm mag}$

Stellar Radius



½ Earth

5 Earth

2 Earth

Jupiter

Kretke & Lin (in prep)

Diversity of Systems