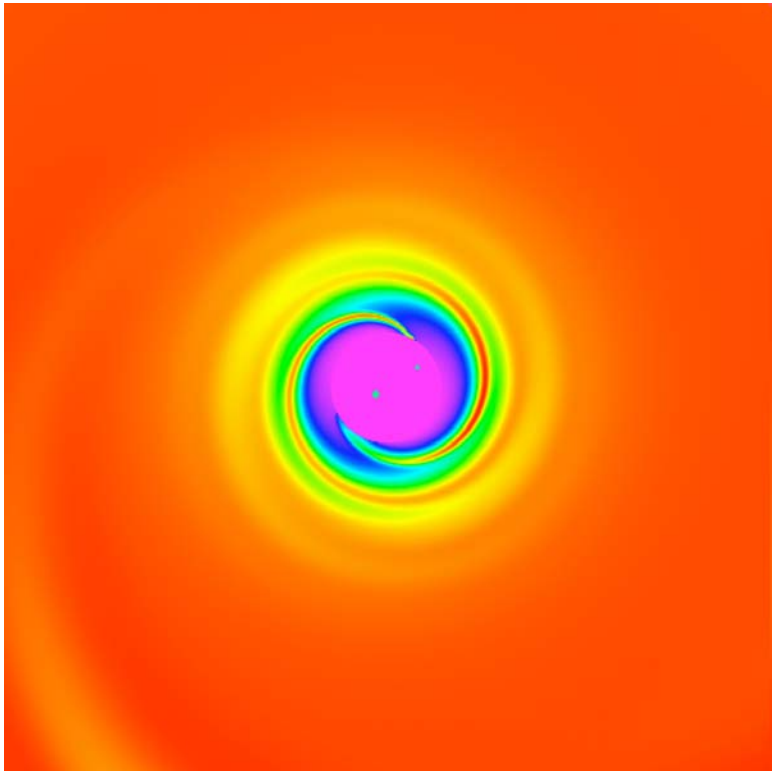
The dying gasps of merging supermassive black hole binaries



Priya Natarajan (Yale)
Work done with Phil Armitage (Boulder)

Case for circumbinary gas disks driving BH mergers

Consequences of gas driven BH mergers

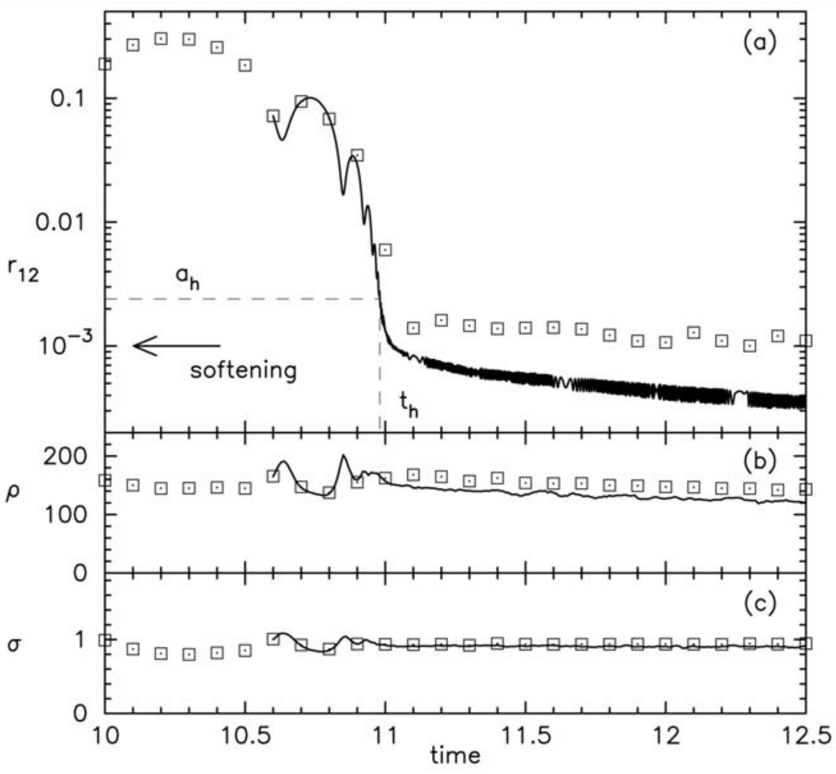
(a) For gravitational wave signatures - finite eccentricity at merger

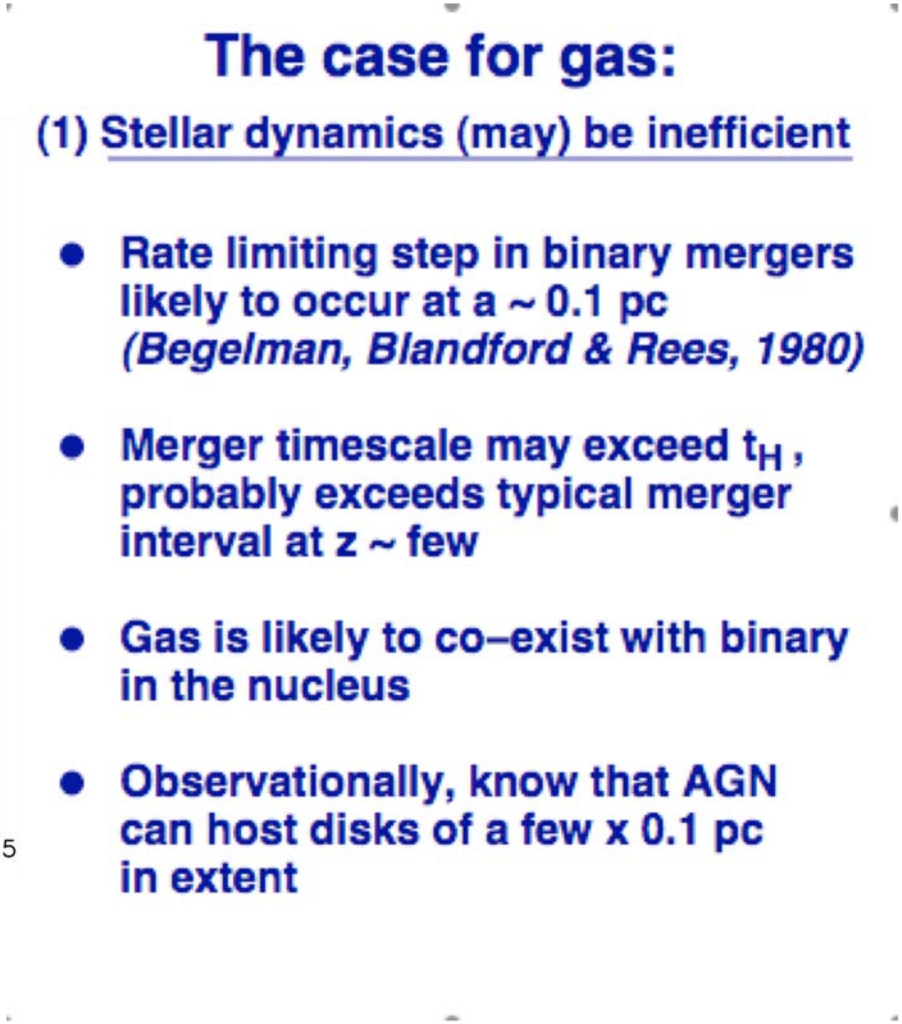
(b) For the existence of electromagnetic counter-parts to supermassive BH mergers

Can we distinguish gas driven mergers from stellar dynamics effected ones?

Armitage & PN (2002, 2005)

Gas or stellar dynamics?



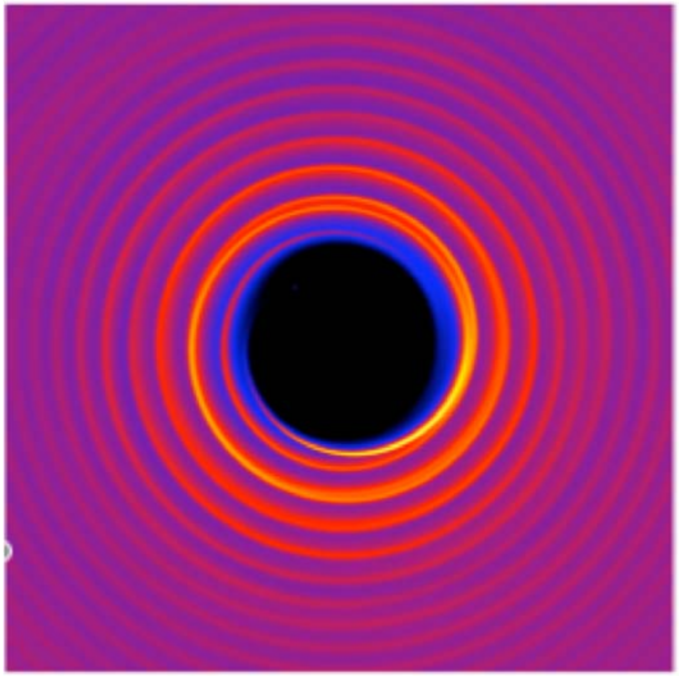


The case for gas:

(1) Stellar dynamics (may) be inefficient

- Rate limiting step in binary mergers likely to occur at a ~ 0.1 pc *(Begelman, Blandford & Rees, 1980)*
- Merger timescale may exceed t_H, probably exceeds typical merger interval at z ~ few
- Gas is likely to co–exist with binary in the nucleus
- Observationally, know that AGN can host disks of a few x 0.1 pc in extent

Yu & Tremaine, MM & Merritt



The case for gas:

(2) There's plenty of gas present

- Waves excited in a circumbinary disk allow binary to lose angular momentum to the gas
- Significant orbital decay requires gas mass comparable to the mass of the smaller black hole
- Typical mass ratio q ~ 0.1 *(eg Volonteri, Haardt & Madau 2002)*

Observationally: local BH mass density ~consistent with growth via accretion as optically bright QSOs *(eg Barger et al. 2001; Yu & Tremaine, 2002)*

Implies more than enough gas present – important for mergers unless stellar dynamics merges the holes before gas arrives

Expectations for gas driven mergers

(1) Definite predictions

Transition between:

- gas driven merger at large radius
- gravitational radiation inspiral at small radius

$$a_{\rm crit} = \left(\frac{128}{5}\right)^{2/5} \left(\frac{h}{r}\right)^{-4/5} \alpha^{-2/5} q^{2/5} \left(\frac{GM_1}{c^2}\right)$$

...transition radius depends on disk parameters and mass ratio

(2) Probable consequences

Disk interaction –> significant eccentricity of the binary

- probably for $q > 0.05$ *(Papaloizou, Nelson & Masset 2001)*
- possibly for lower q *(Goldreich & Sari 2002)*

Spin of the primary –> warped disk interior to the binary orbit

- timescale for realignment uncertain *(Natarajan & Pringle 1998)*

Disk response to a perturber

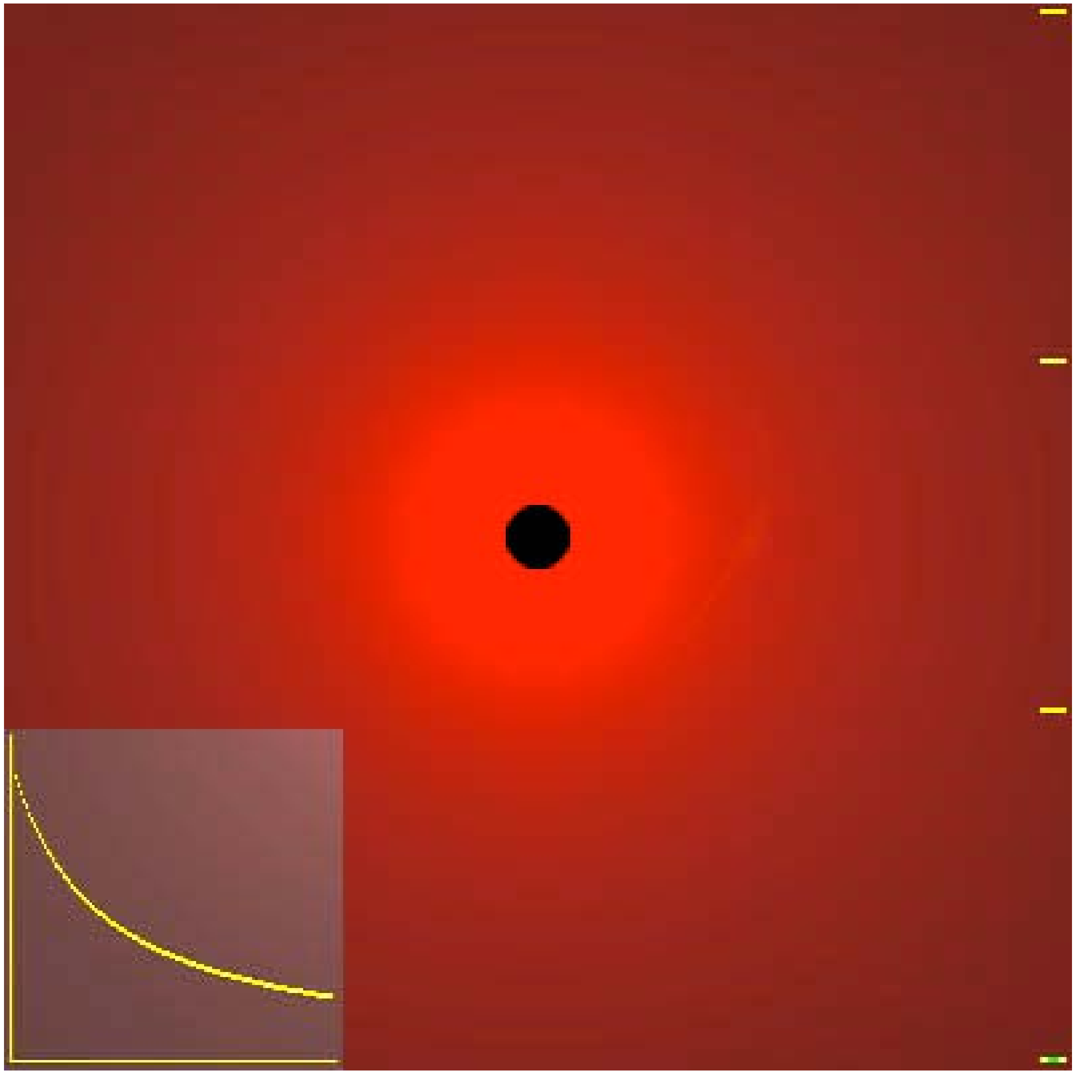
grows slowly, so that the disk is in almost a steady state

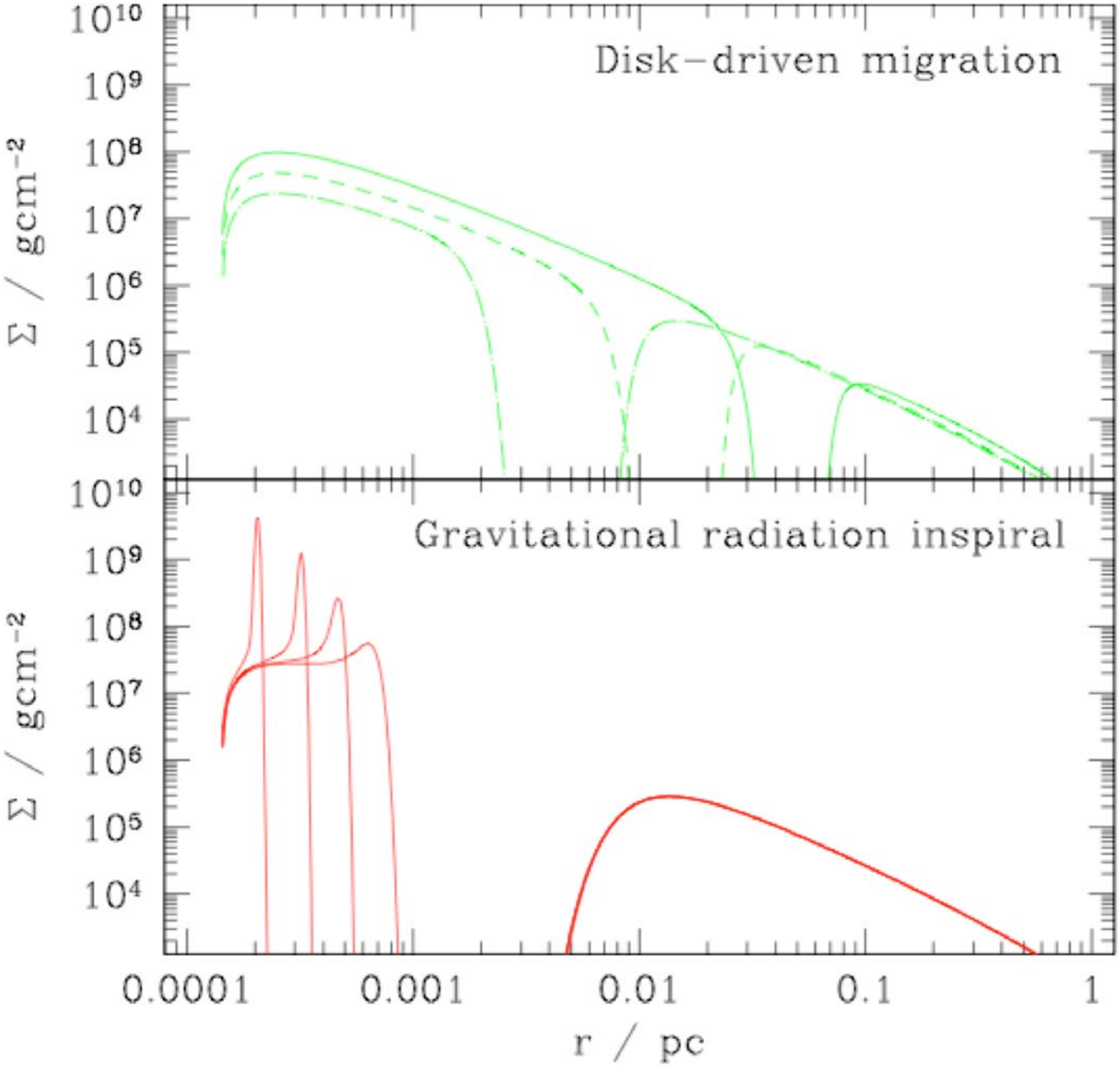
from $q=10^{-5}$ to 10^{-2}

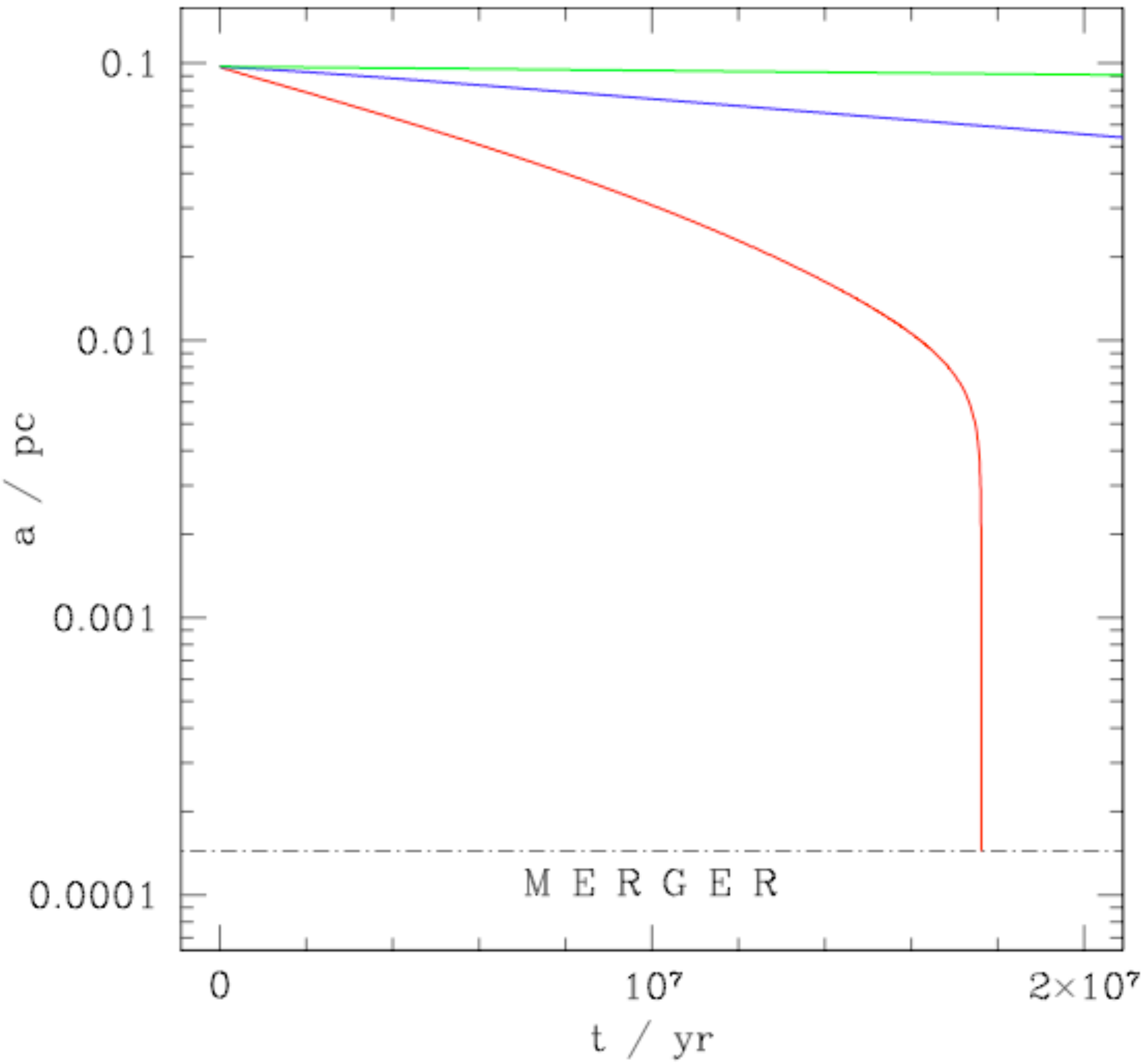
2D, hydro only

viscosity included such that alpha ~ 0.01 in the vicinity of the secondary.

In movie: inset shows azimuthally averaged surface density profile.

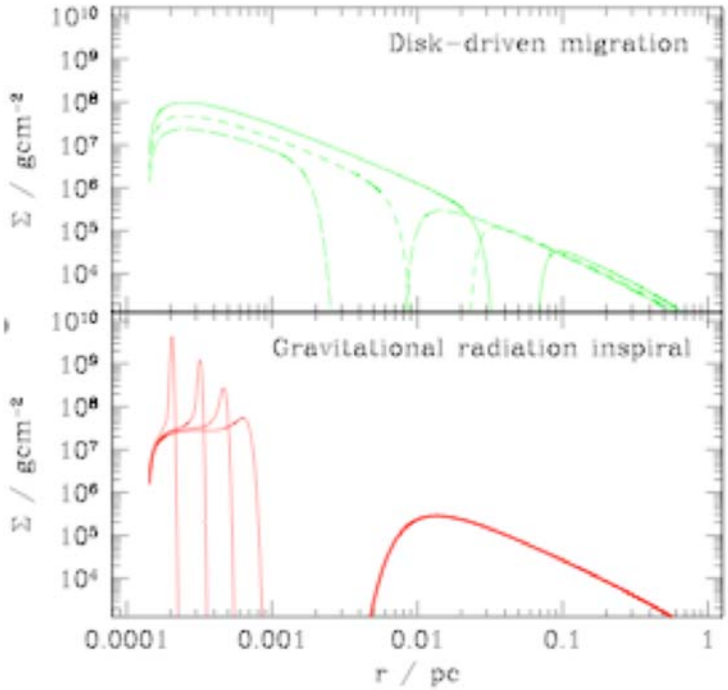


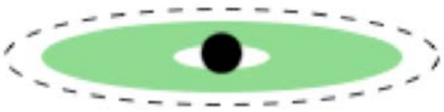

Disk−driven migration
Gravitational radiation inspiral
Σ / gcm⁻²
Σ / gcm⁻²
10¹⁰
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
0.0001
0.001
0.01
0.1
1
r / pc


0.1
0.01
0.001
0.0001
a / pc
0
10^7
2×10^7
t / yr
M E R G E R

Consequences for electromagnetic counterparts

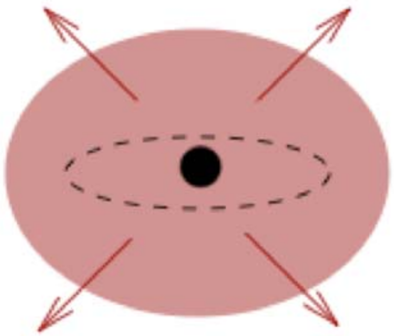
LISA will fail to identify host galaxies of supermassive black hole mergers unless there are identifiable electromagnetic counterparts





Forced disk inflow

Breakdown of thin disk approximation during final inspiral



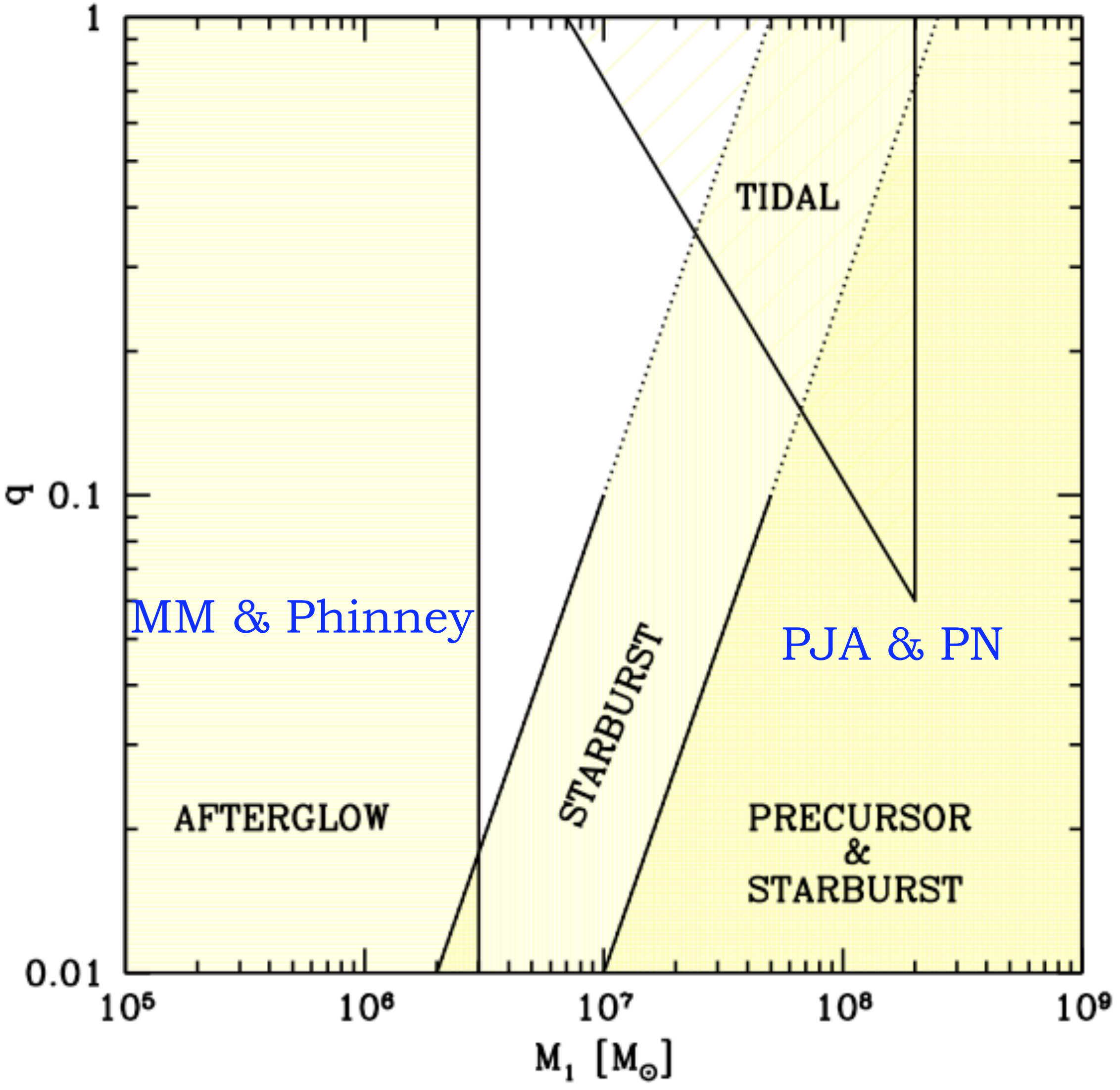
–> extremely high accretion rates

–> final ‘common envelope’ type merger + strong outflows

If a thin disk is involved, predict electromagnetic counterpart closely resembling a highly obscured, luminous quasar

Counter-parts signaling BBH mergers

- Electromagnetic counterparts: precursors and afterglows
- On longer timescales impulsive changes to the final BH spin following merger (Hughes & Blandford)
- Changes in directions of jets launched (Merritt & Ekers)
- Final eccentricity before merger (Armitage & PN) if disks catalyze low mass ratio binary mergers



Dotti et al. 2006

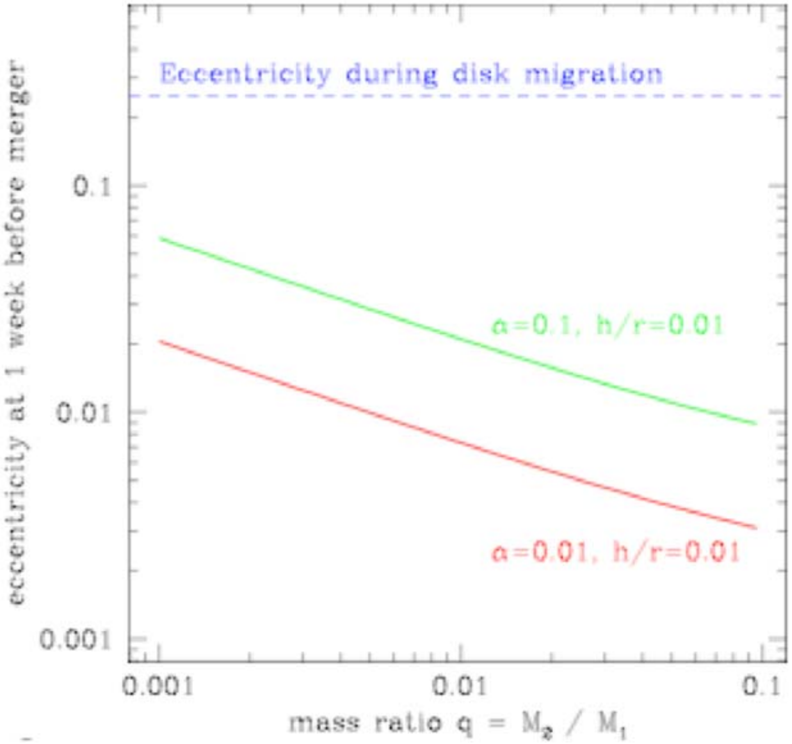
Consequences for gravitational radiation

Disk torques are negligible during final inspiral for all interesting mass ratios

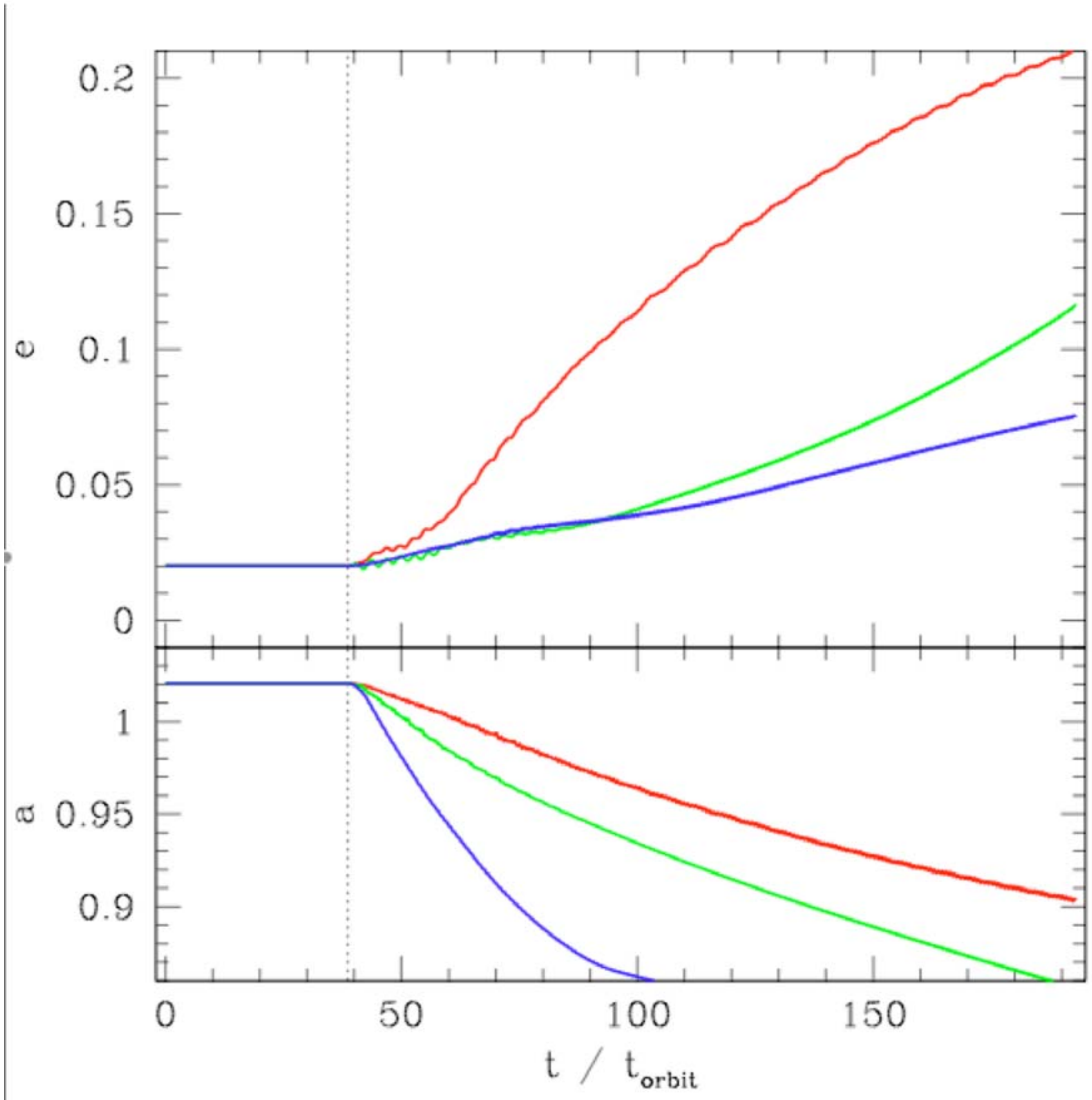
Eccentricity – if excited during disk interactions at low q, may not have time to damp to negligible values

Simple model:

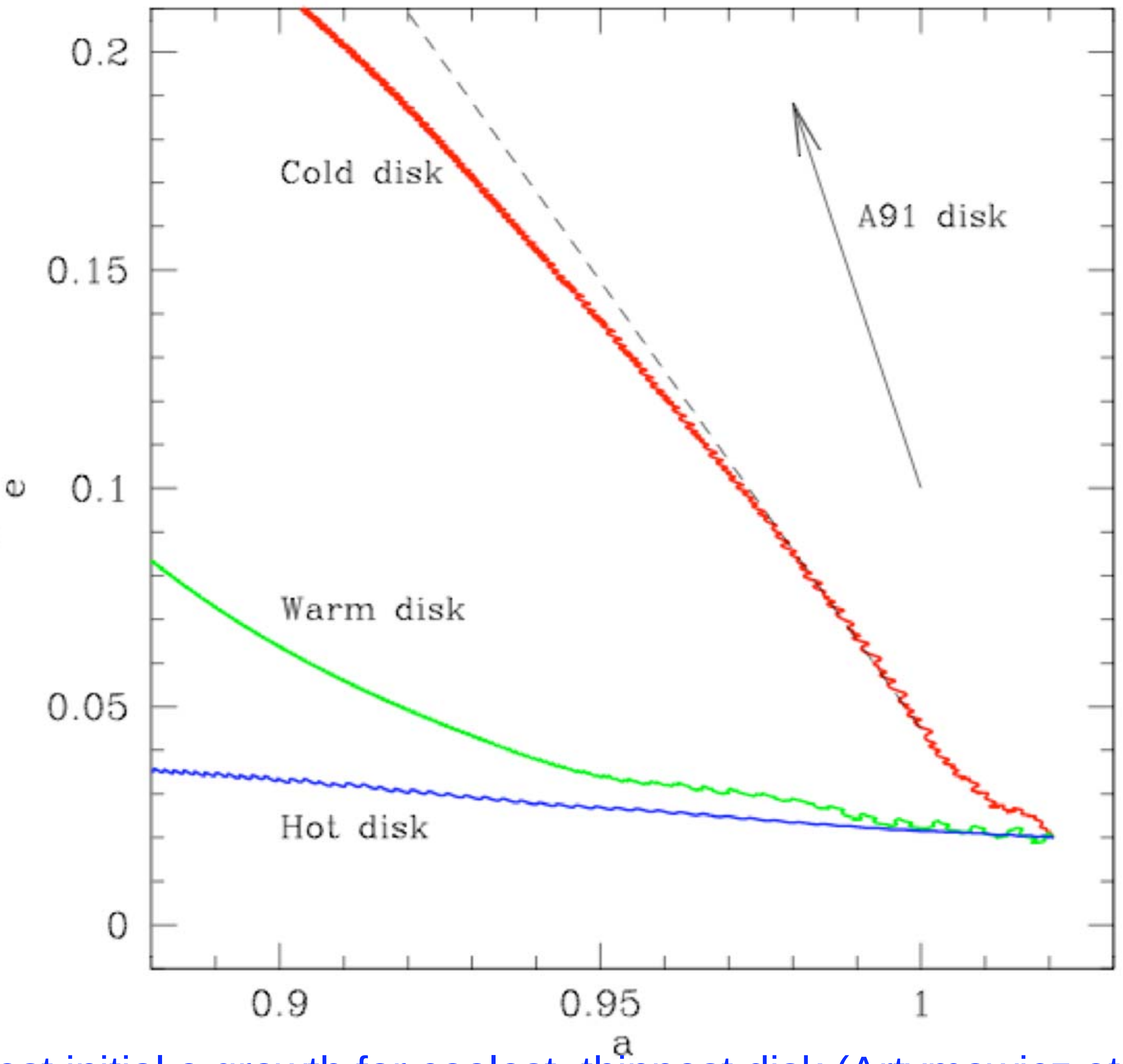
- **assume eccentricity driven to $e=0.25$ for $a > a_{crit}$**
- **for $a < a_{crit}$, eccentricity is damped by gravitational radiation**
- **plot eccentricity at 1 week prior to final merger**
- **small but non–zero $e \sim 0.01$, rising to more extreme mass ratios, seems possible**



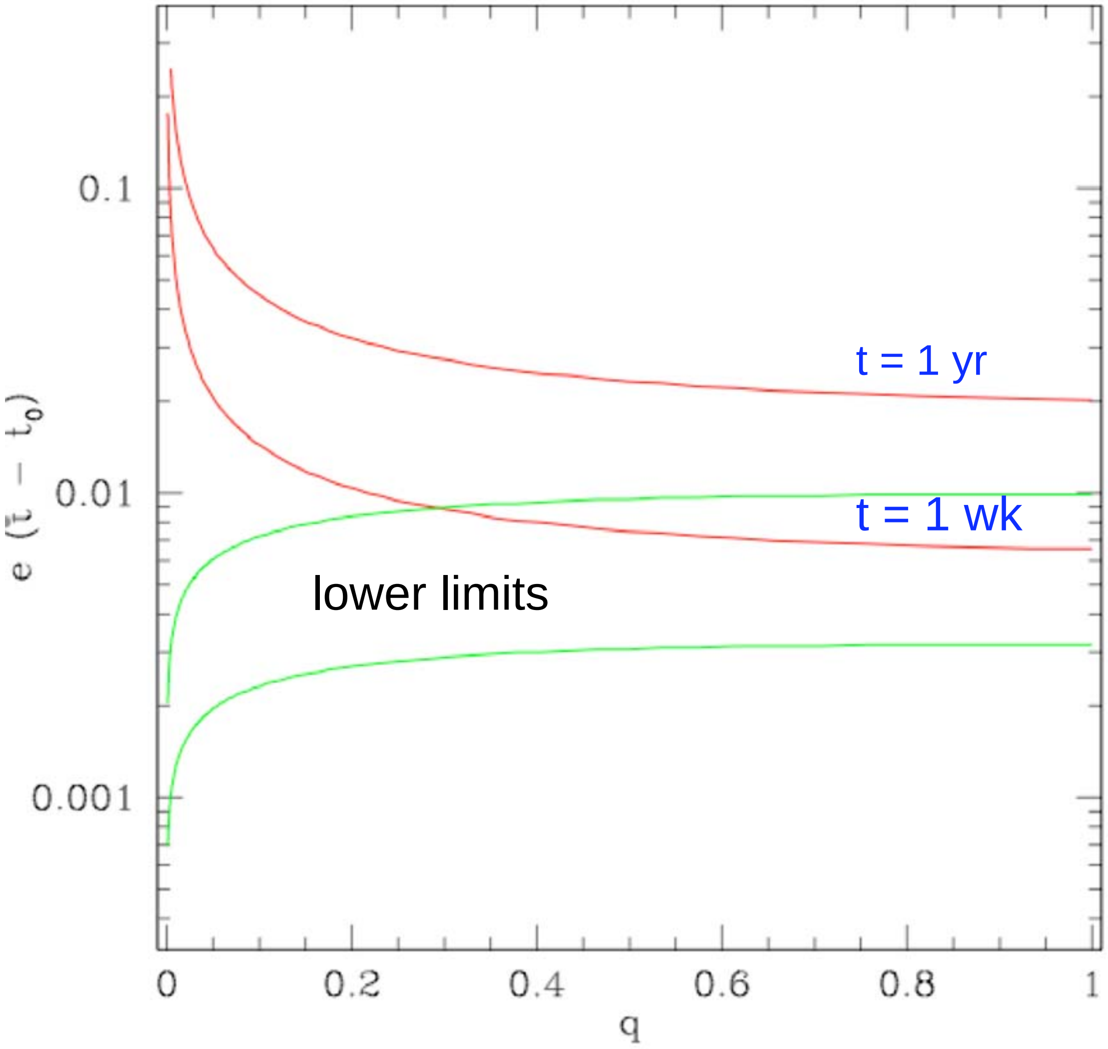
Disk driven stage



Cool disk (h/r ~ 0.05): red, Warm disk (h/r ~ 0.1): green,
Hot disk (h/r ~ 0.1): blue
Note hottest disk is the most viscous disk

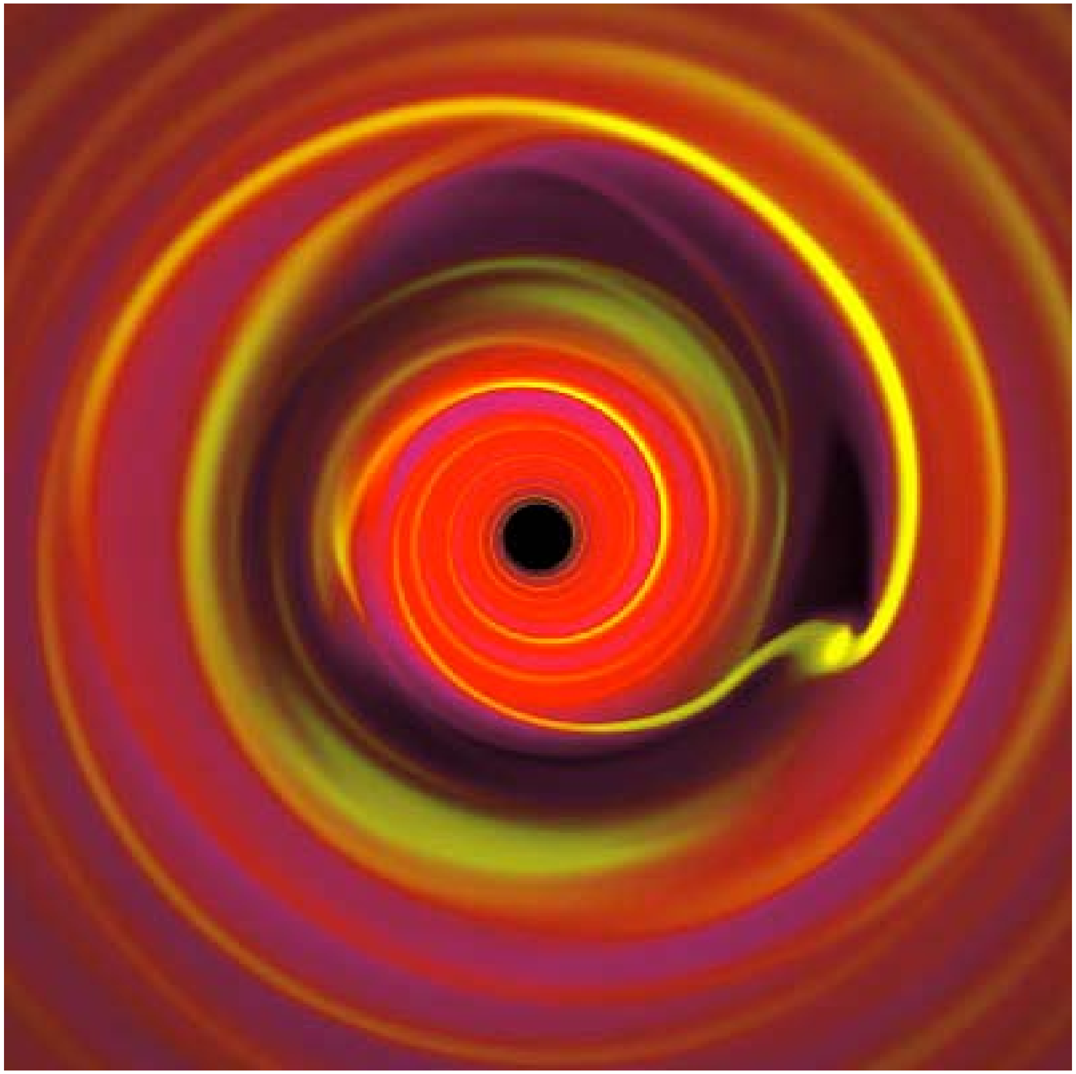


Highest initial e growth for coolest, thinnest disk (Artymowicz et al. 1991)



alpha = 0.01, e_init = 0.25 (gas driven stage), $M_1+M_2= 10^6$

Starting with a modestly eccentric orbit



same general behavior as before..