Star formation in AGN #1 in the past and the present day wind accretion

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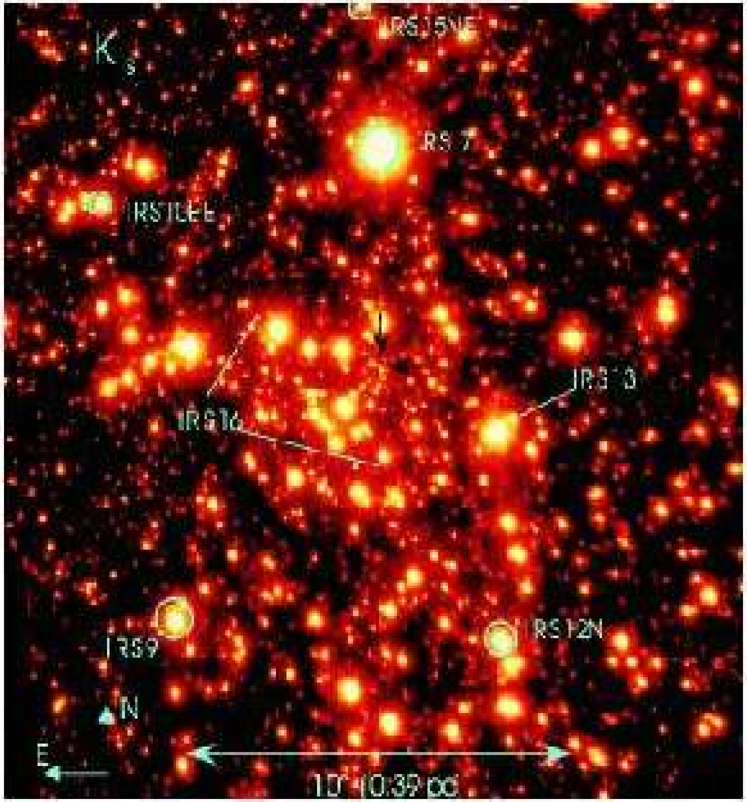
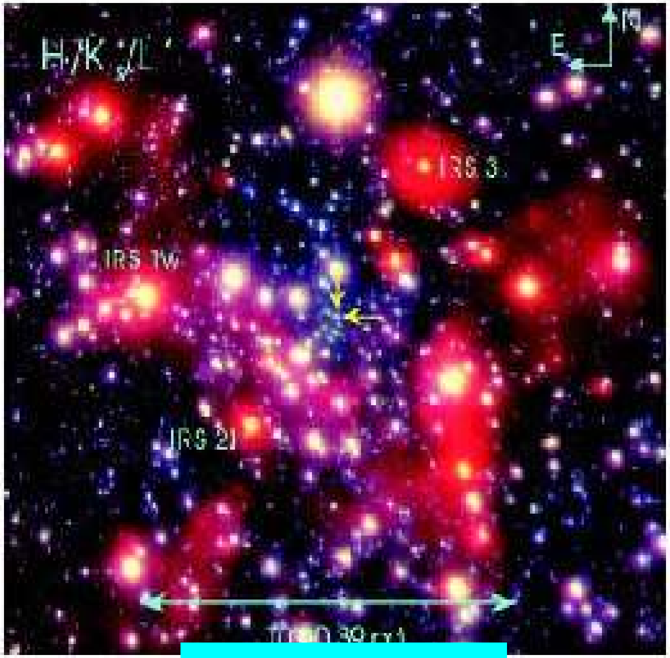
Outline

- **Testing the models for recent star formation via stellar orbits:**
  - **Star formation inside accretion disk**
  - **Infalling massive star cluster**
- AGN unification schemes
- Using close stars to constrain accretion rate on Sgr A*
- **Sgr A* feeding SPH simulations** (see J. Cuadra's poster)
- Conclusions

Young massive stars



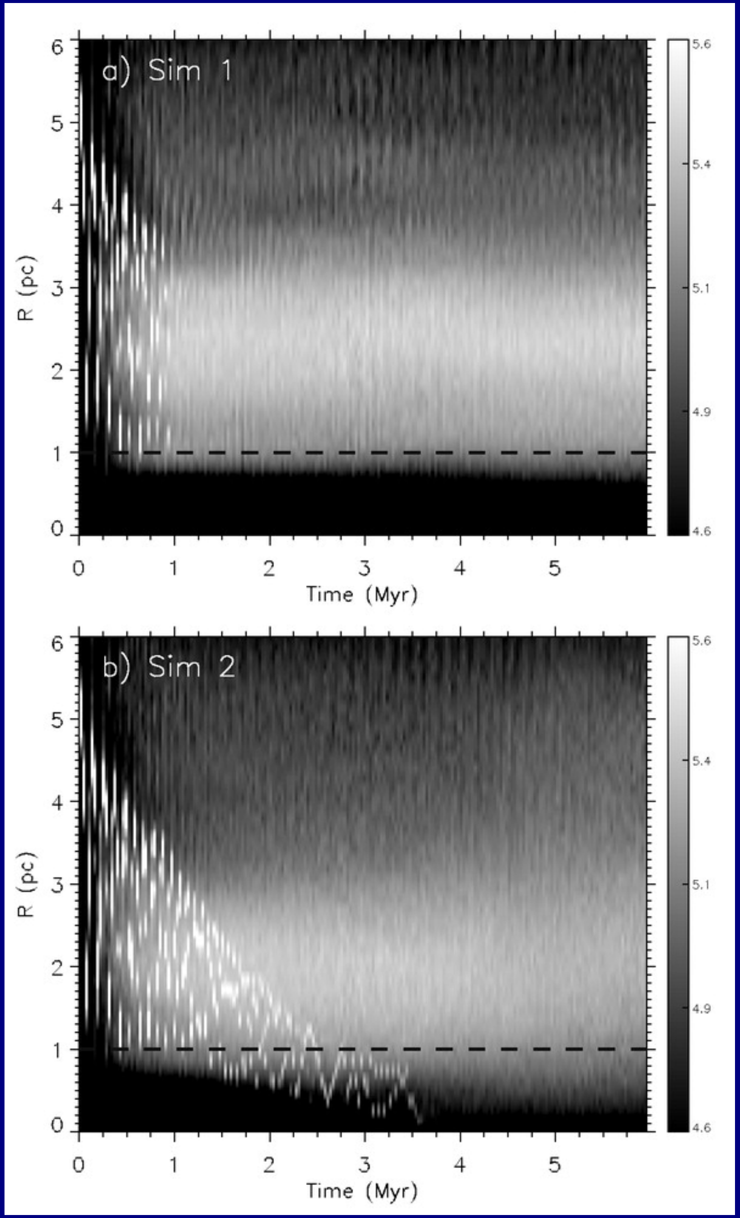
Genzel et al 2003

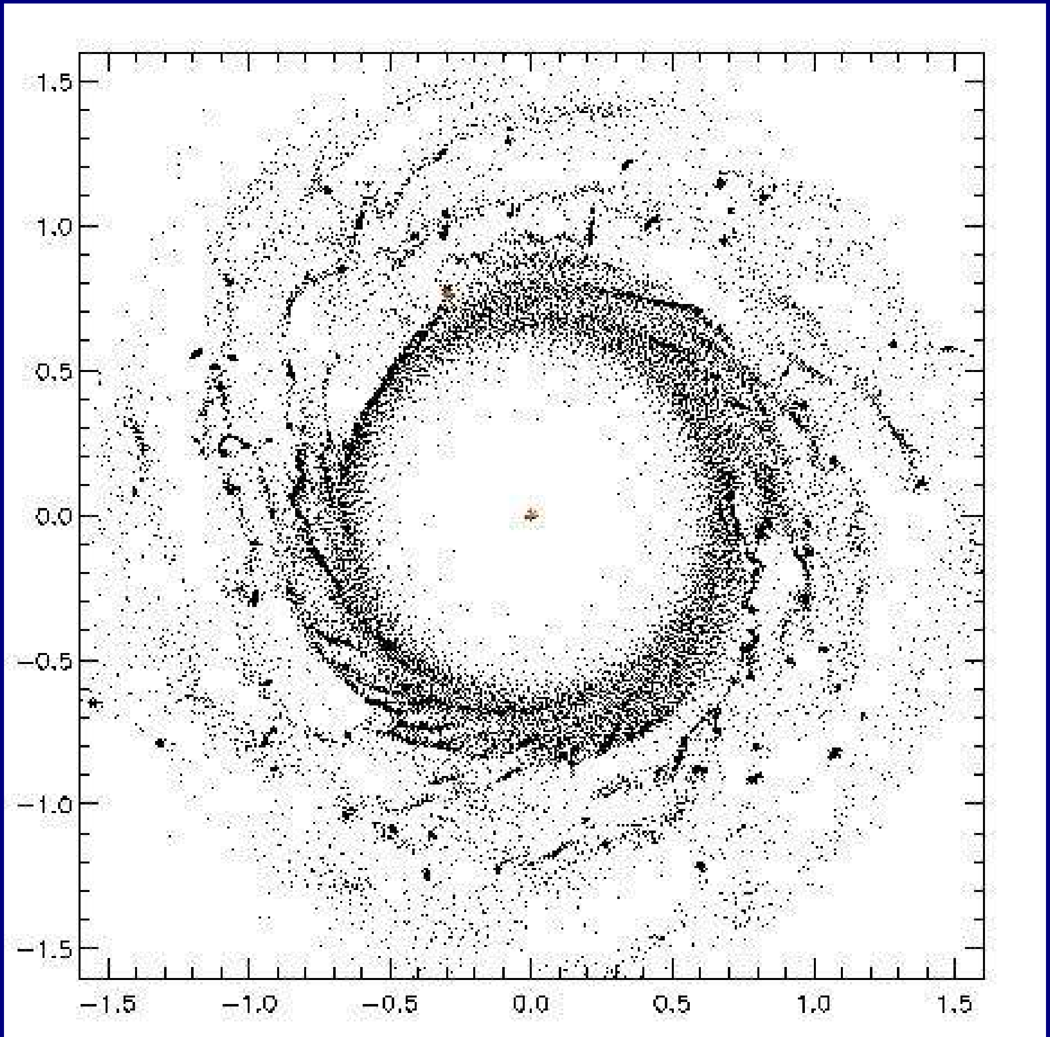


10'' or 0.4 pc

- Young (t < few Myr) "He I stars": how did they get within ~ 0.2 parsec of a SMBH? Need n_H > 10^10 particles/cm^3.
- Young S0-x stars (Ghez et al. 2003) need n_H > 10^14 cm^{-3}

1. Assume that stars stars were formed via one of the two processes.



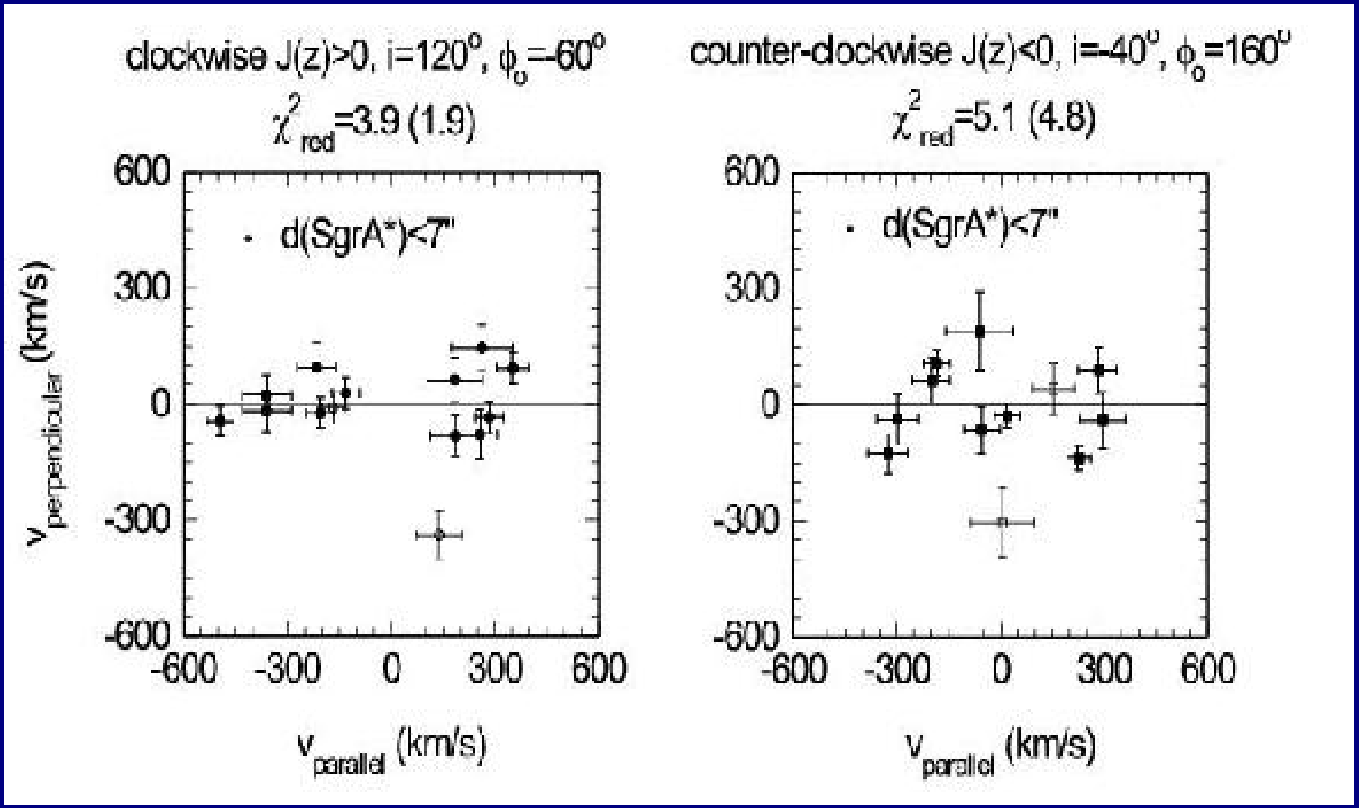


Gadget-2 run with M_d = 6 x 10^4 Msun

Kim, Figer & Morris 2004

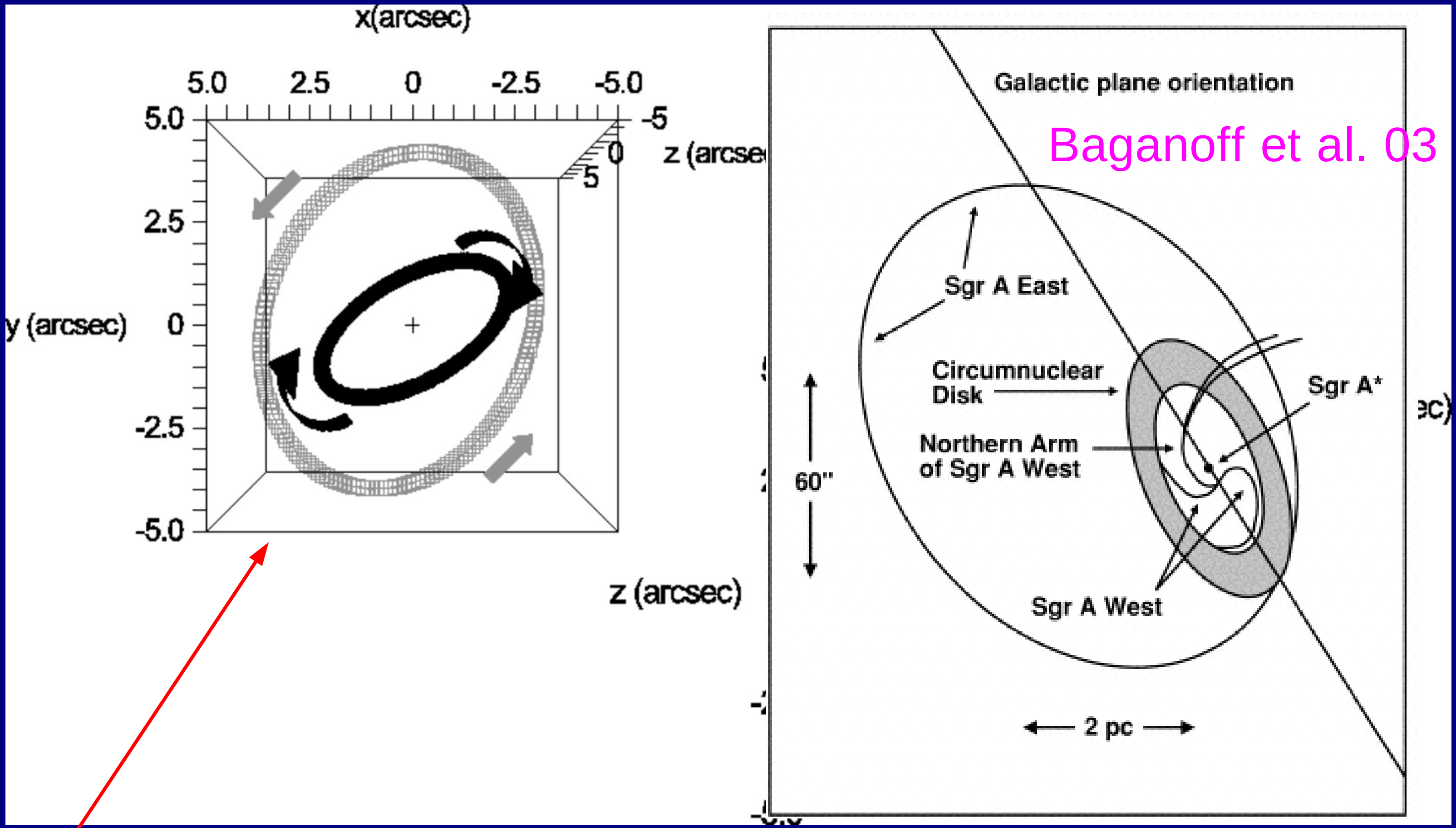
2. Astro-paleontology with stellar orbits:
What would these orbits look like today?

`Outer' young stars: two stellar rings.



- Levin & Beloborodov 03, Genzel et al. 2003: The young stars belong to one of the two rings, not alligned with Galactic plane

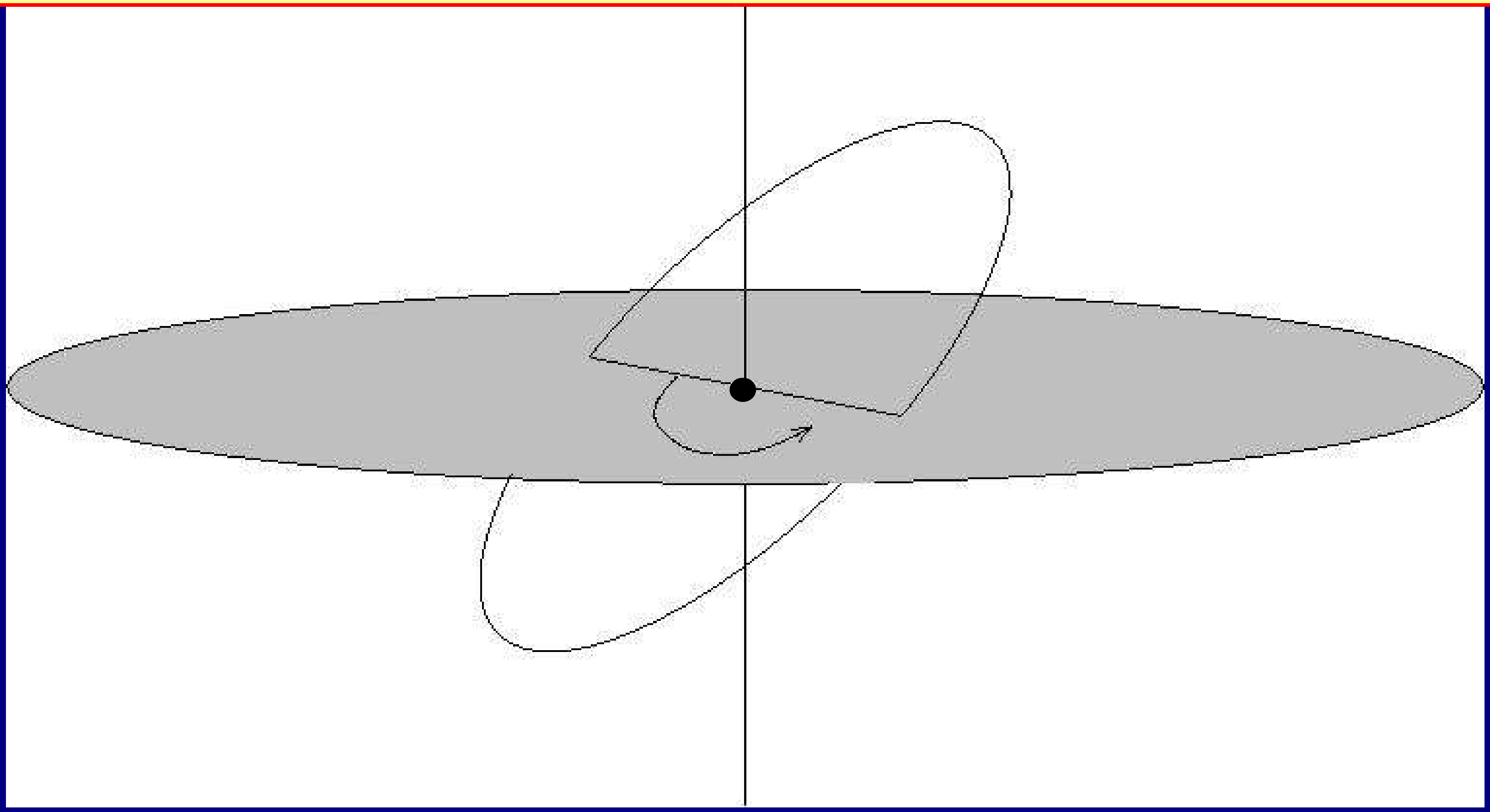
Geometry of the young stellar rings



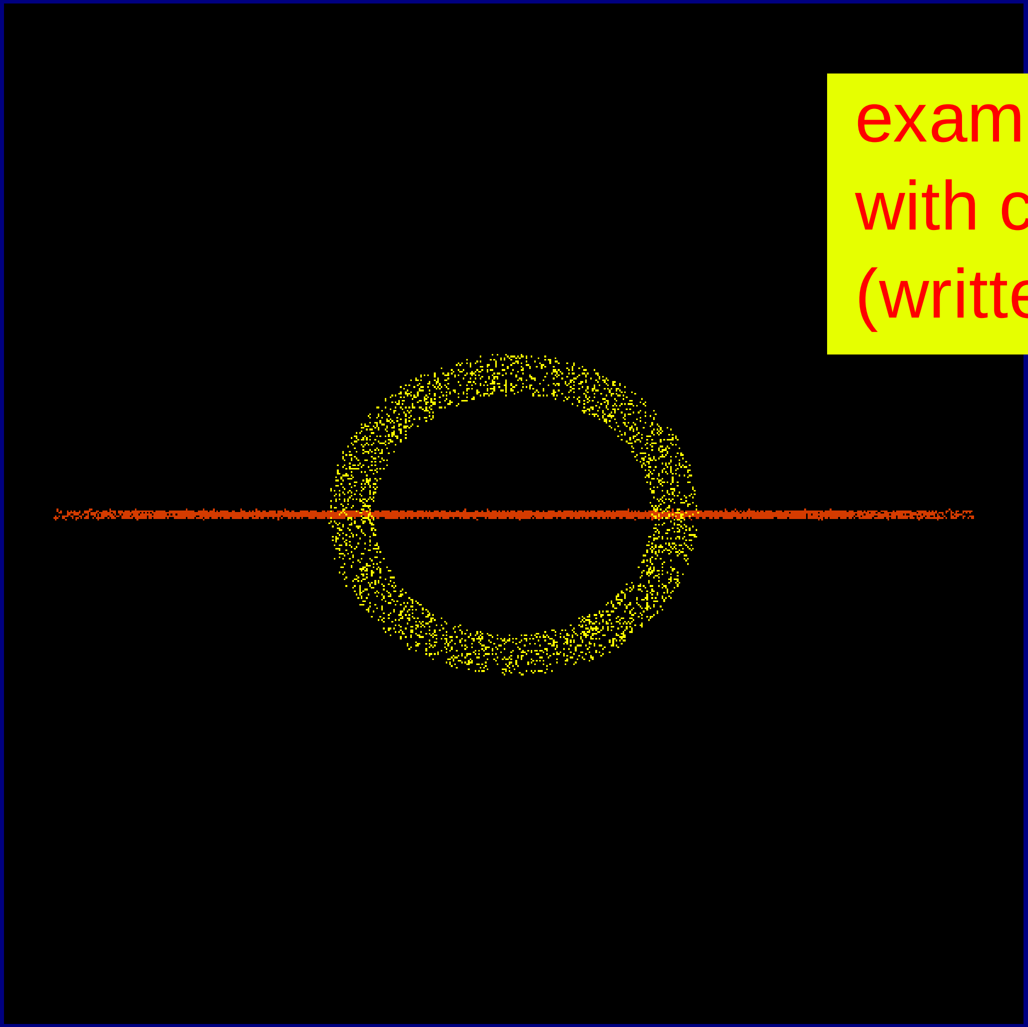
View of the rings on the plane of the sky (Genzel et al. 03)

Method: orbital precession in axisymmetric potential

1. We have two stellar disks (I don't know why!)
2. Orbits at different R precess at different rates. A planar disk will be warped.
3. Models yielding too strong a warping rejected.



Warping by a stellar ring



example: N-body simulations
with code gyrfalcON
(written by W. Dehnen)

Analytical estimates (circlar orbits)

$$\frac{\omega_p}{\Omega_K} \approx -\frac{3M_{\rm ring}}{4M_{\rm BH}} \cos\beta \frac{R^3 R_{\rm ring}^2}{\left[R^2 + R_{\rm ring}^2\right]^{5/2}}$$

(N 2005a)

$$\Delta\phi = \omega_p t \propto \frac{M_{\rm ring}}{M_{\rm BH}} \cos\beta \frac{t}{T} F(R/R_{\rm ring})$$

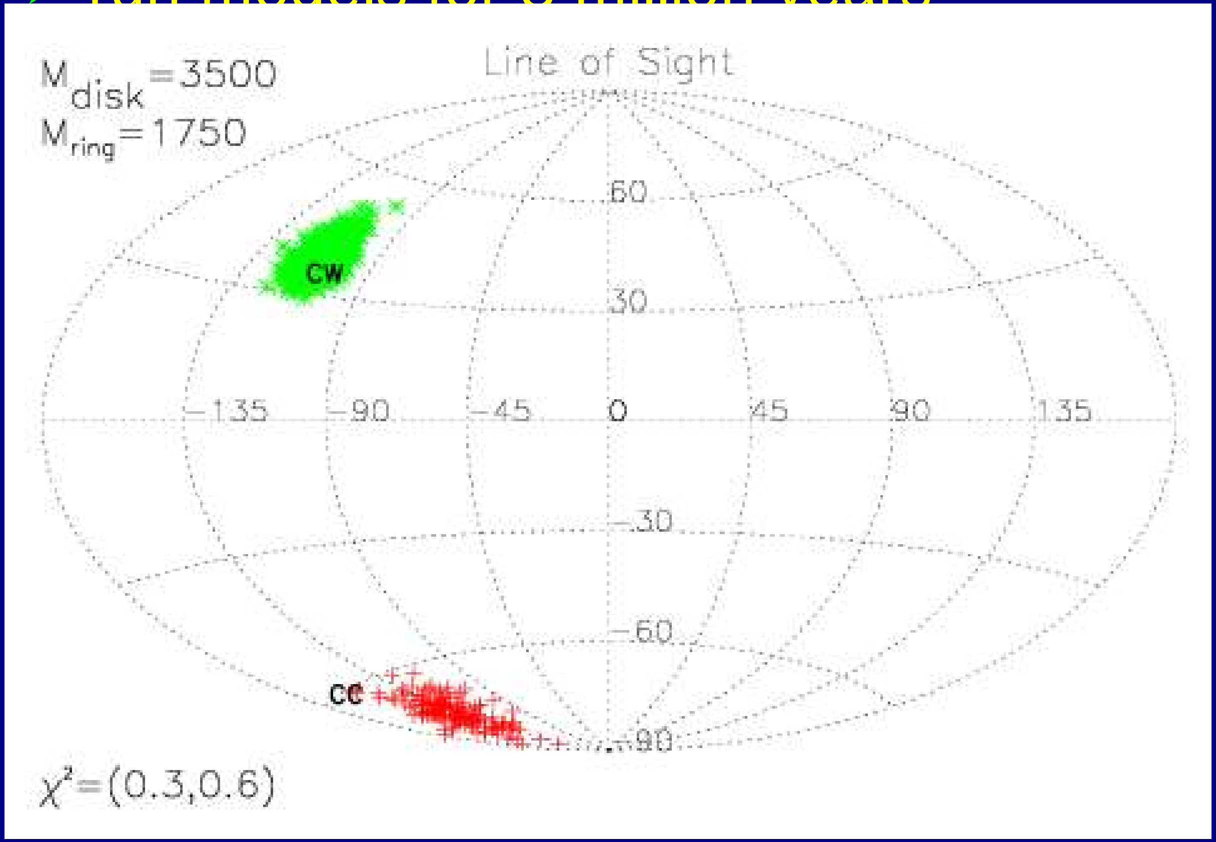
Since $\cos\beta F(R/R_{\rm ring}) < 1$,

$$\Delta\phi \sim \frac{M_{\rm ring}}{M_{\rm BH}} N_{\rm orb} \sim 10^3 \frac{M_{\rm ring}}{M_{\rm BH}}$$

Can test regime M_disk ~ 3 x 10^3 M_sun

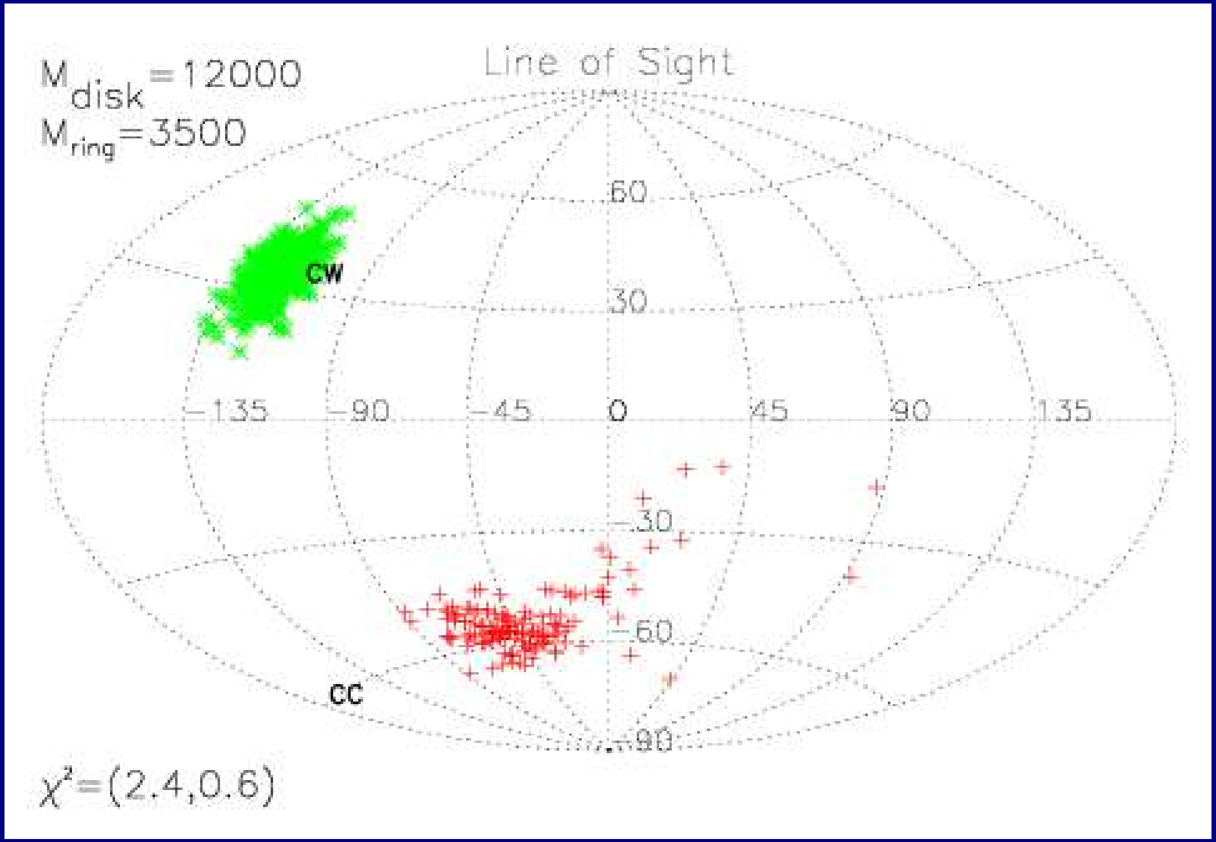
N-body simulations: the accretion disk case

- populate clockwise system (disk) by stars from 2 to 5''
- populate counter-cw system (ring)   5-7'' (also tested 4-5'')
- angle of 113 degrees between two orbital planes
- Initial velocities: circular Keplerian
- run models for 3 million years



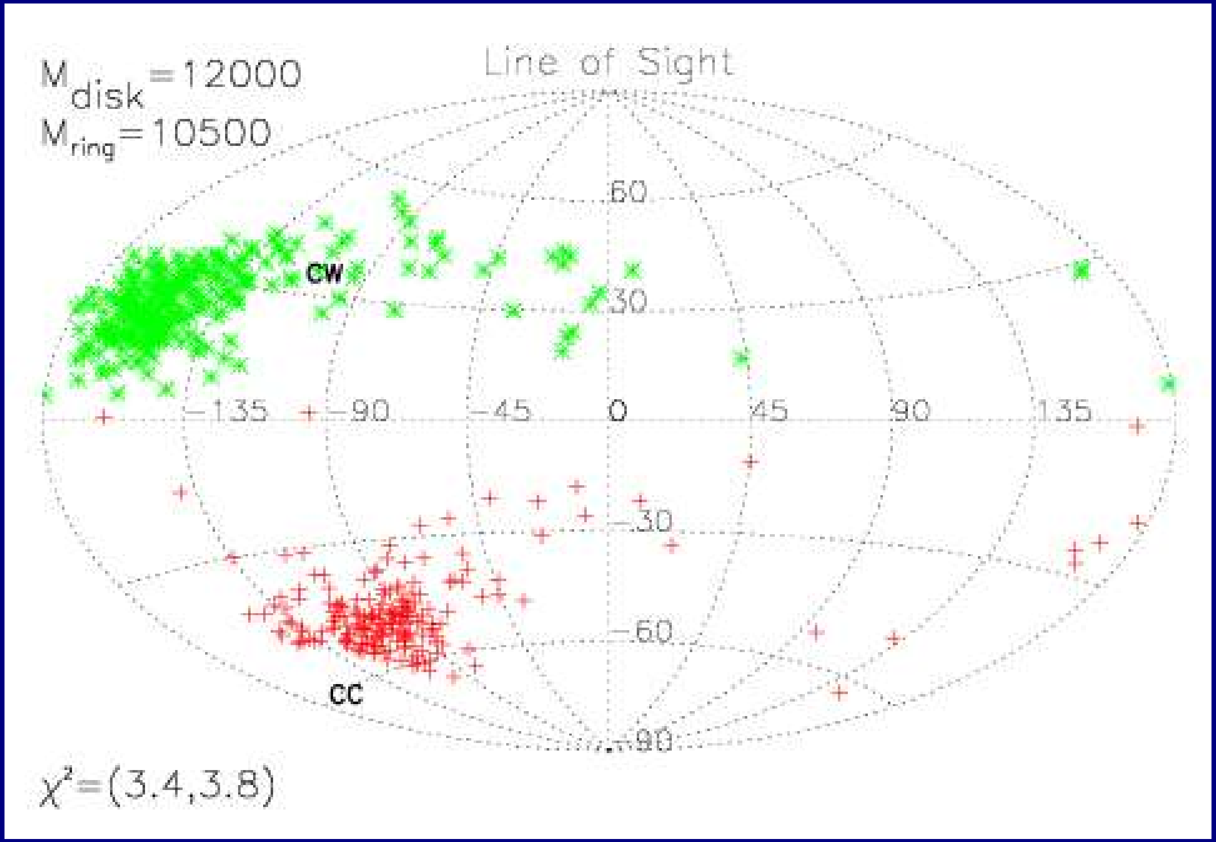
OK

Higher disks masses



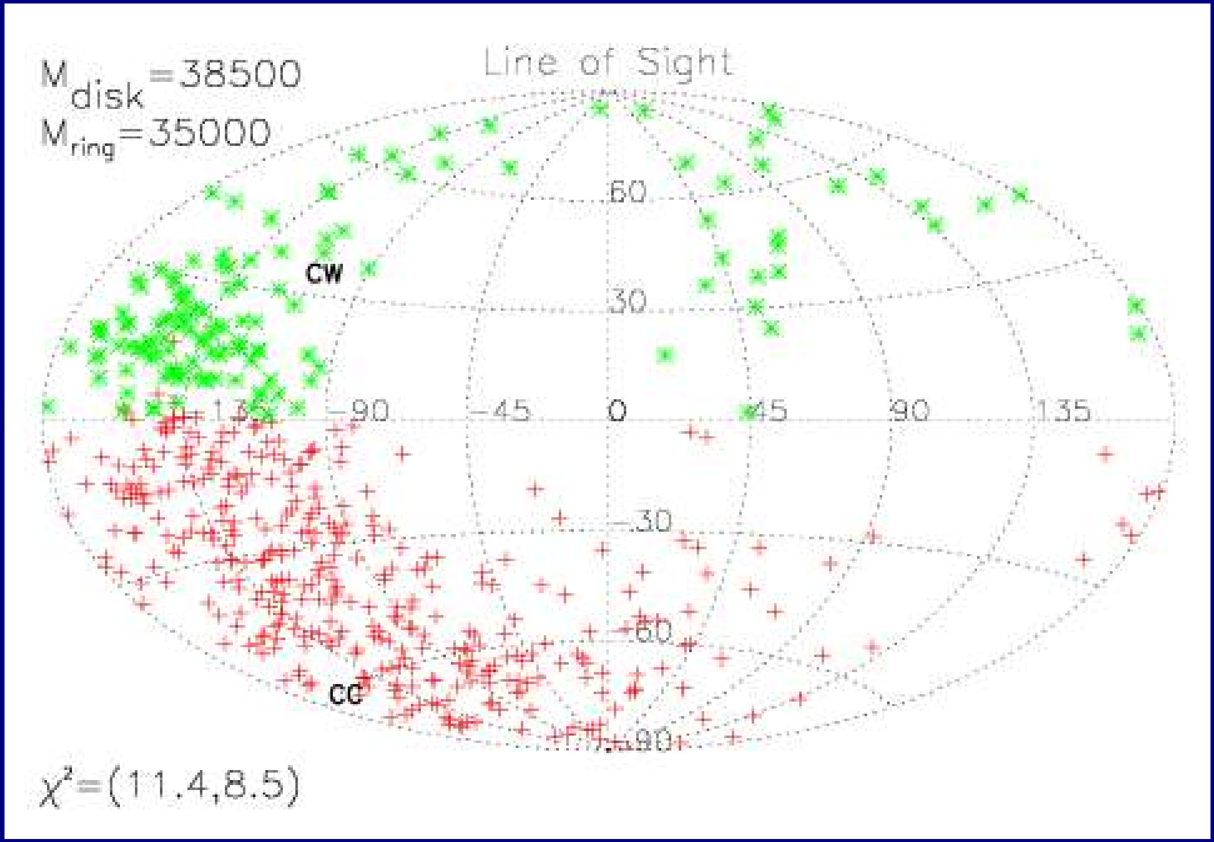
still OK

Higher disks masses



poor

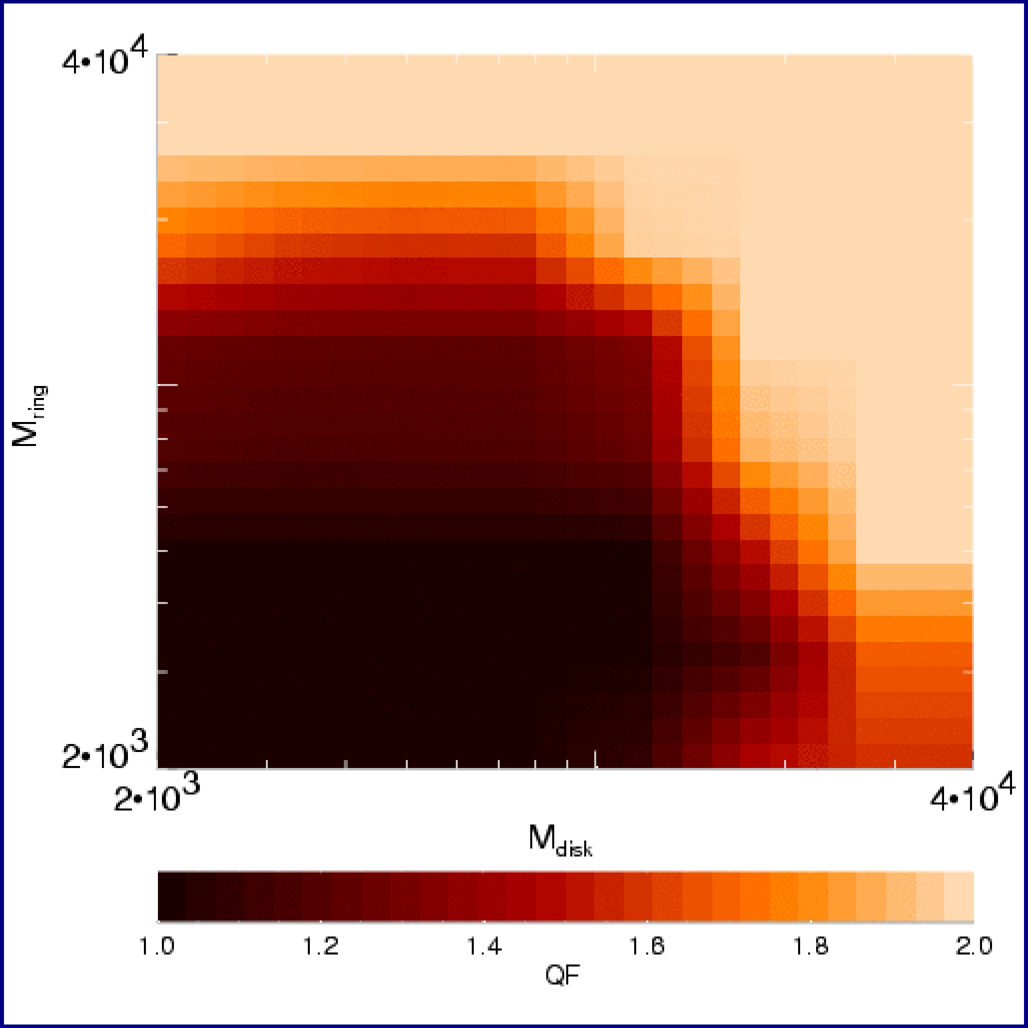
Higher disks masses



horrible!

Reduced chi^2 map

- Extrapolate between models on a grid to get a 2-D map of chi^2
- Reject models that have QF >~ 1.5

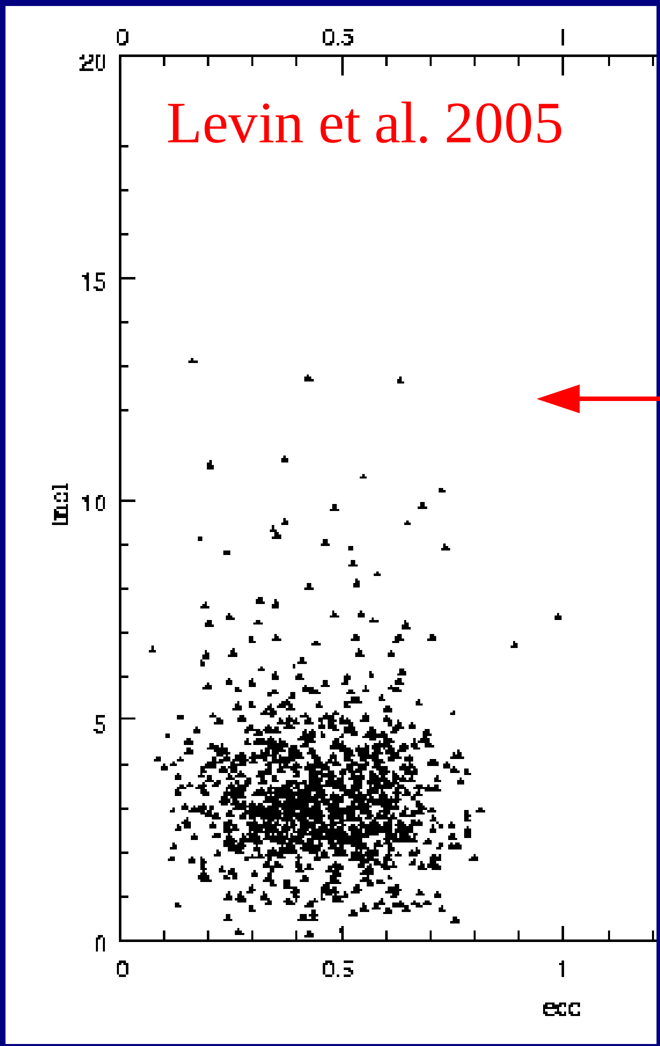


$$QF = \max[1, \frac{\chi^2}{\chi^2_{\rm obs}}]$$

$$QF = \sqrt{QF_1\, QF_2}$$

$$M_{\rm cw} \lesssim 2 \times 10^4\, {\rm M}_\odot$$
$$M_{\rm cc} \lesssim 10^4\, {\rm M}_\odot$$

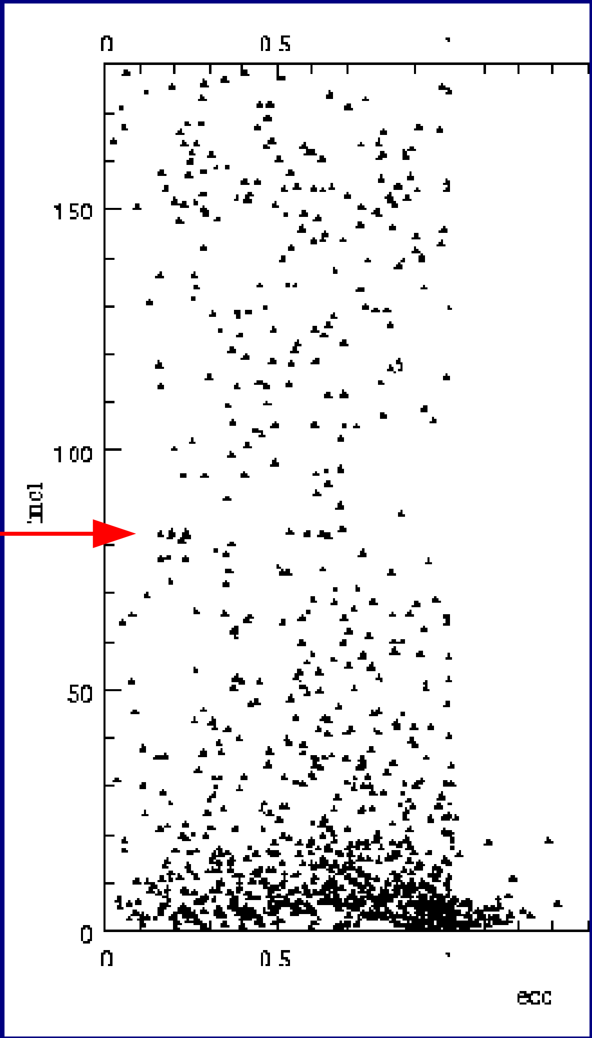
Infall of a massive cluster



Initial stellar orbits distribution for

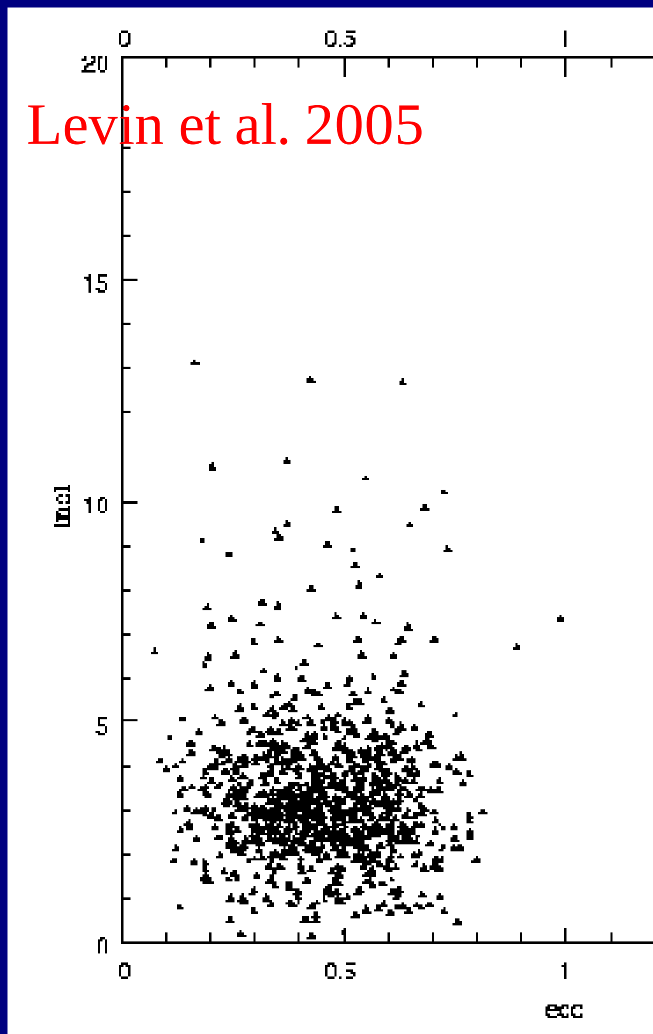
circular inspiral

eccentric inspiral

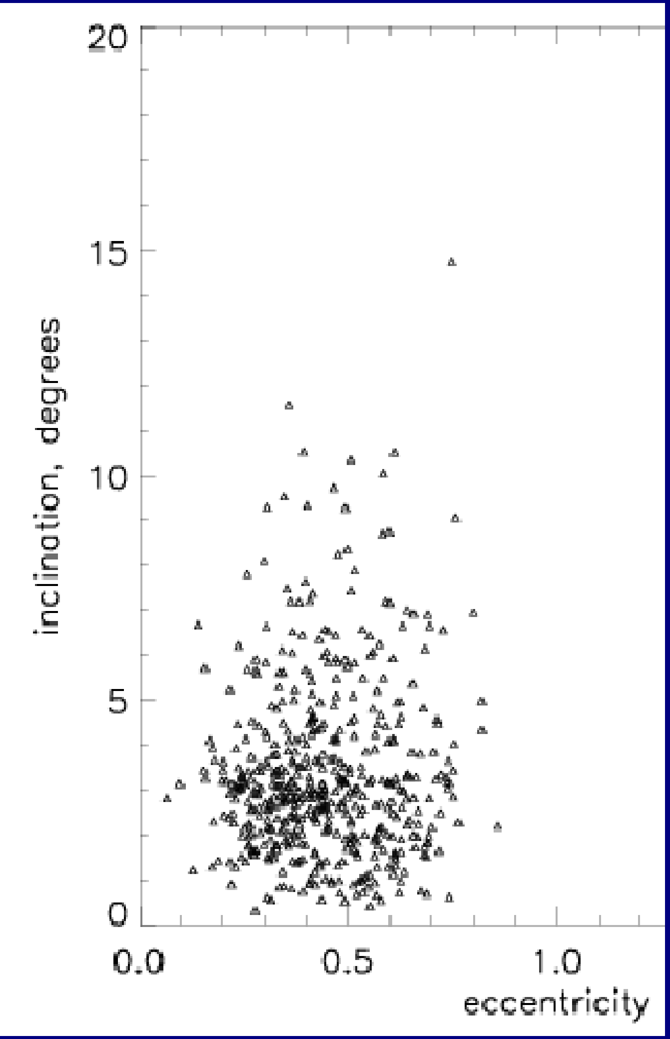


Initial orbits are eccentric even for circular inspiral

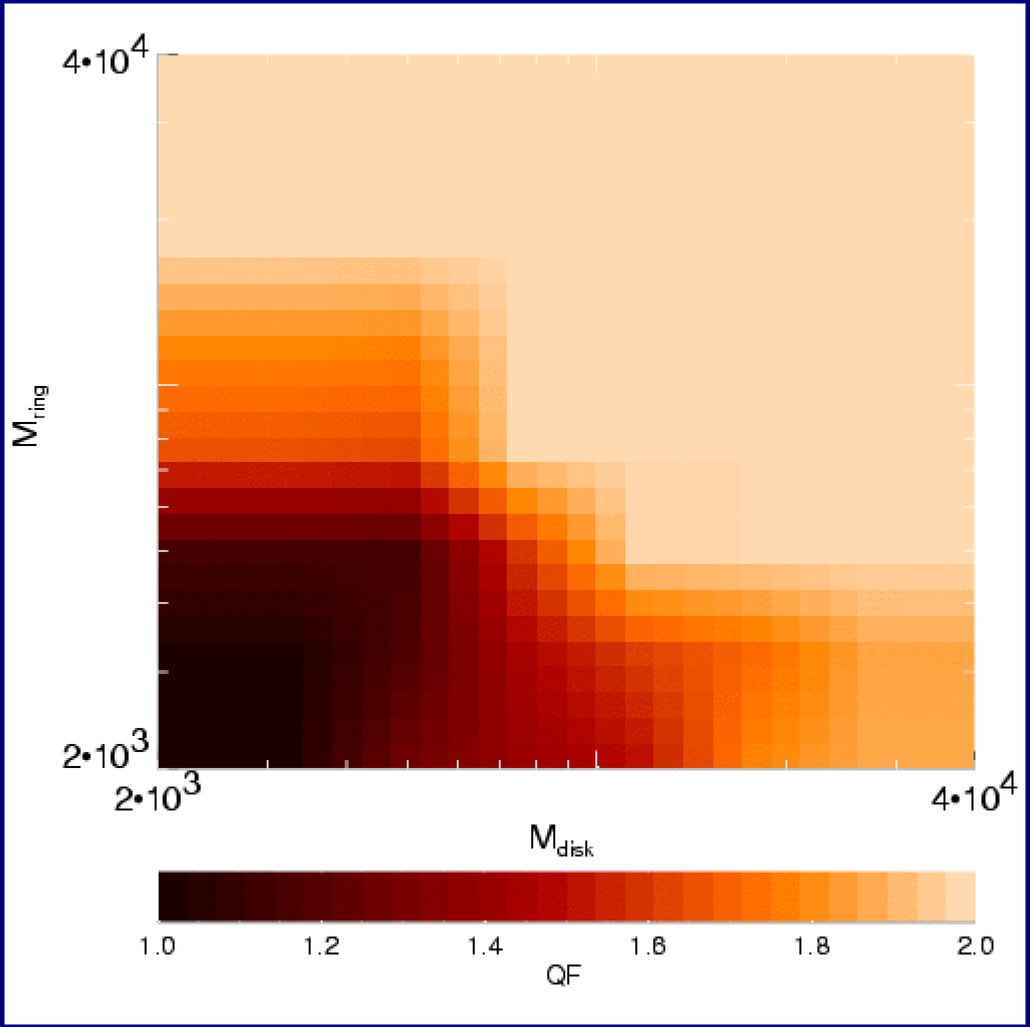
Iinitial conditions for cluster case



Levin et al. 2005

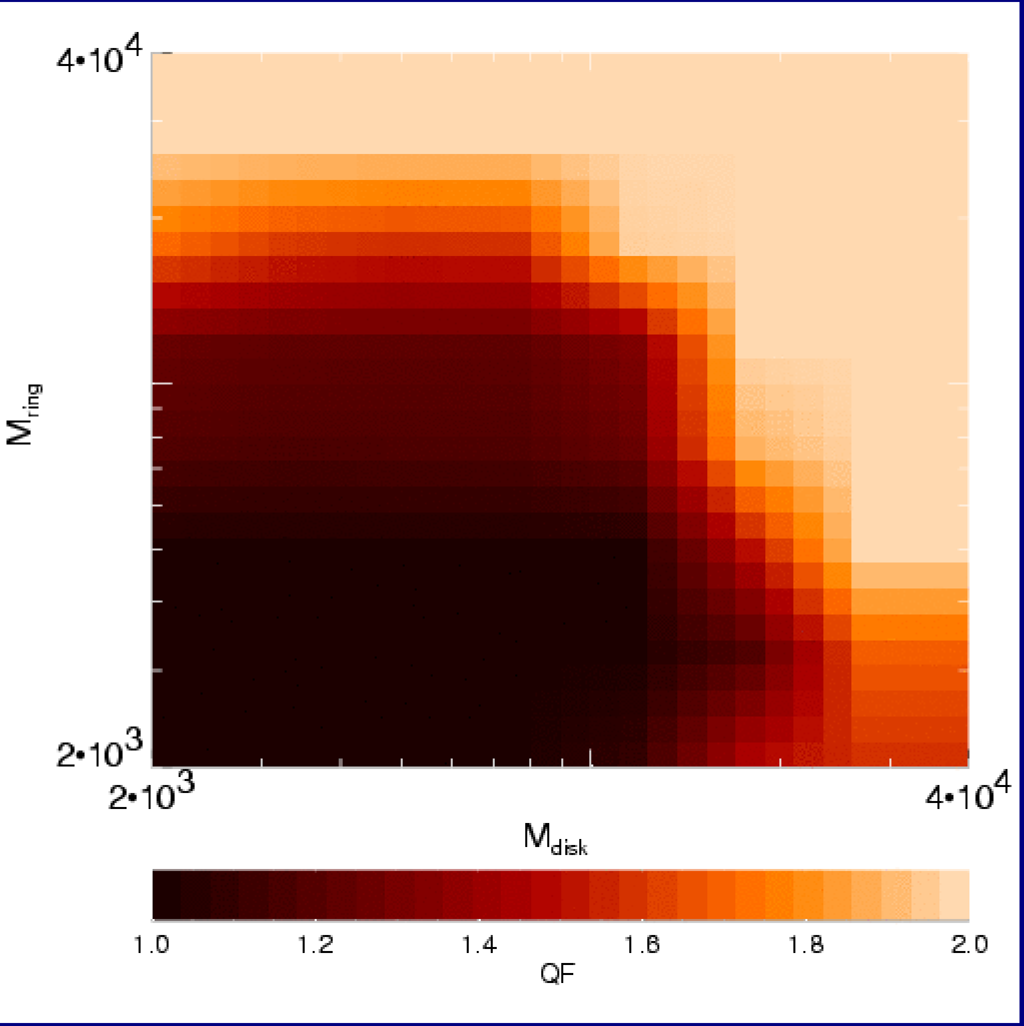


Reduced chi^2 map



$$M_{\rm cw} \lesssim 8 \times 10^3\,{\rm M}_\odot$$
$$M_{\rm cc} \lesssim 6 \times 10^3\,{\rm M}_\odot$$

Reduced chi^2 map



$$QF = \max[1, \frac{\chi^2}{\chi^2_{\rm obs}}]$$

$$QF = \sqrt{QF_1\, QF_2}$$

$$M_{\rm cw} \lesssim 2 \times 10^4\, {\rm M}_\odot$$
$$M_{\rm cc} \lesssim 10^4\, {\rm M}_\odot$$

How much mass is there now?

- If we start with disks as thick as observed, and
- wait 10^6 years
- how much would the disk be warped?

$$M_{\rm cw} \lesssim 6 \times 10^3\,{\rm M}_\odot$$
$$M_{\rm cc} \lesssim 3 \times 10^3\,{\rm M}_\odot$$

Total mass of low mass stars is

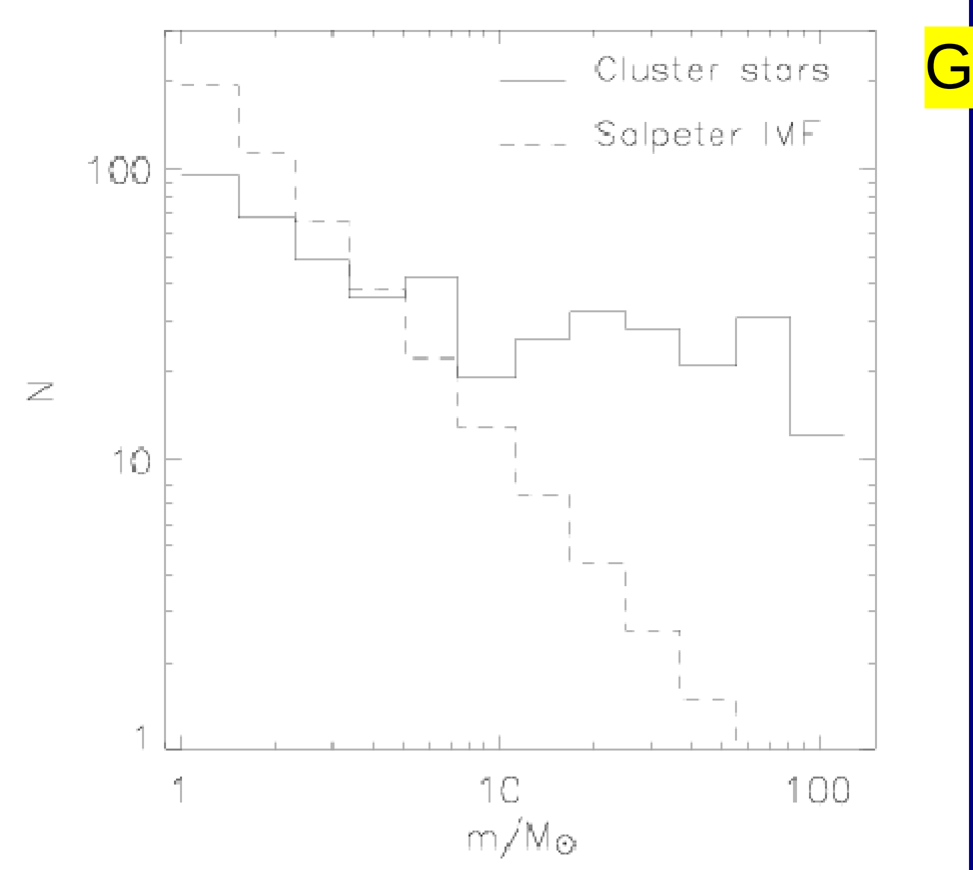
$$M_{\rm lowmass*} \lesssim M_{\rm disk} - M_{\rm highmass*} \sim 4 \times 10^3\,{\rm M}_\odot$$

Thus,

$$M_{\rm lowmass*} \sim M_{\rm highmass*}$$

For both models the IMF of the stars in the inner 5'' should be very top heavy.

Infalling cluster: comparison with models



Gurkan & Rasio 2005

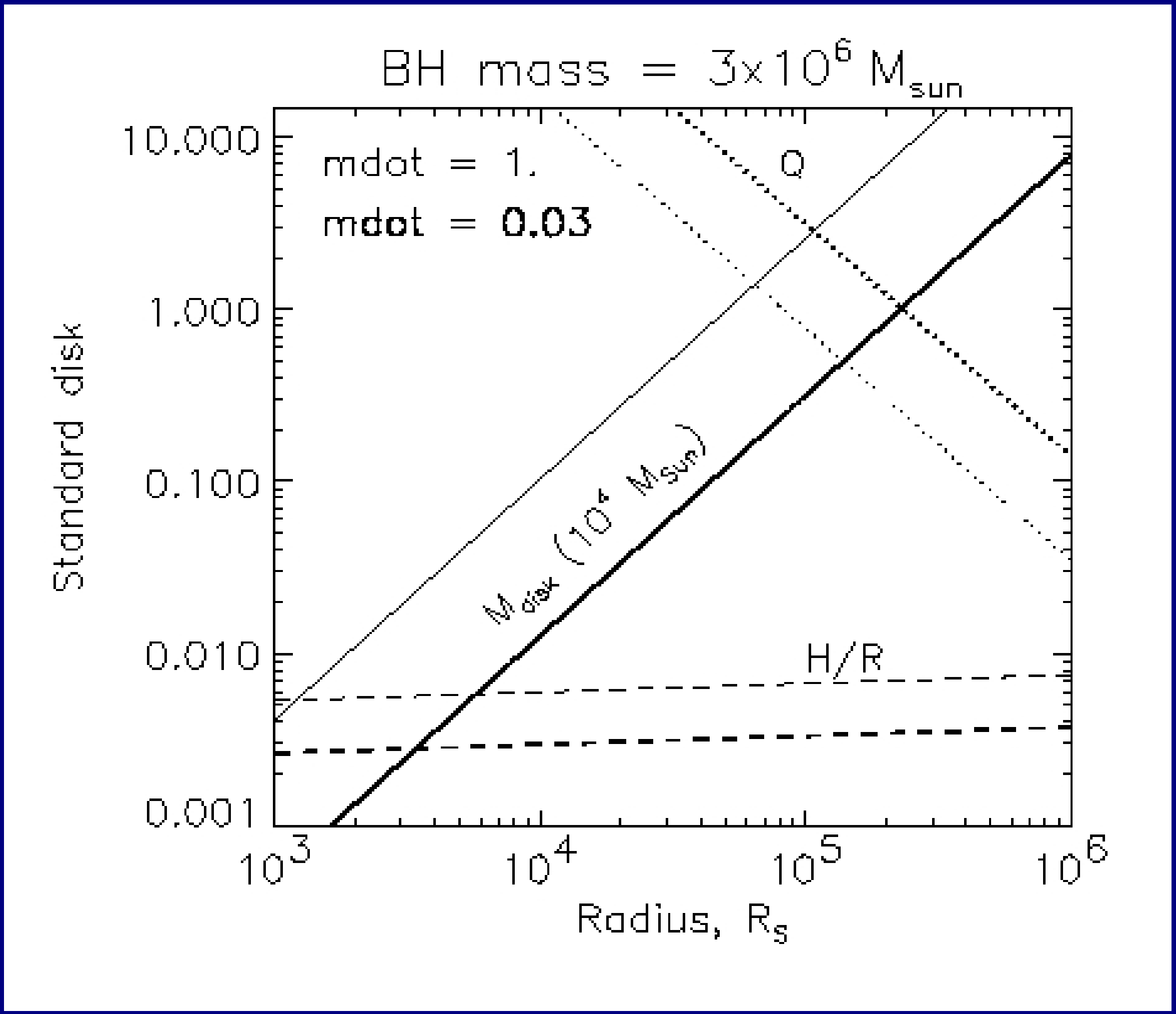
For circular cluster inspiral:

$$M_{\rm cw} \lesssim 8 \times 10^3\,{\rm M}_\odot$$
$$M_{\rm cc} \lesssim 6 \times 10^3\,{\rm M}_\odot$$

Low mass stars are deposited at large R, while high mass stars at low R:

Consistent with both the maximum stellar disk mass and top-heavy IMF constraints, but only for nearly circular inspiral.

Star formation in a disk

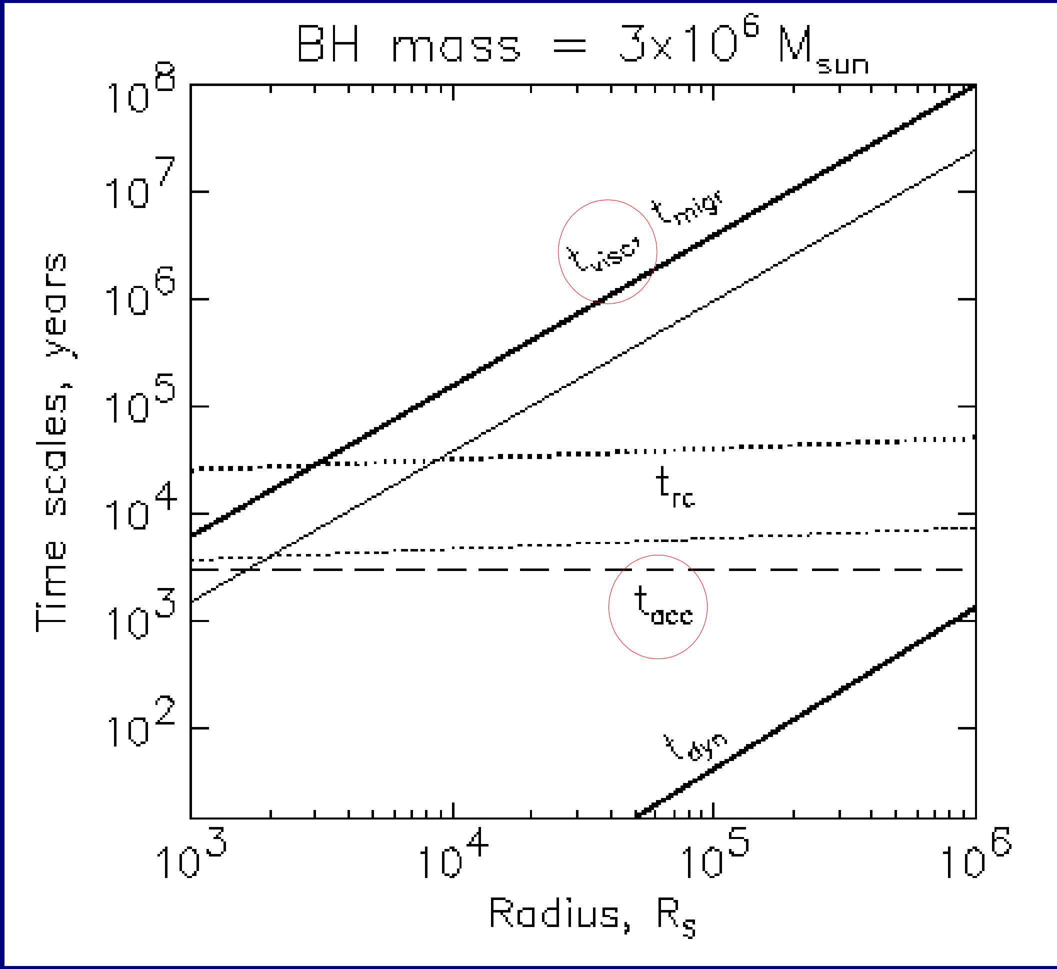


Nayakshin & Cuadra 2005

Minimum M_disk ~ 5 x 10^3 M_sun:

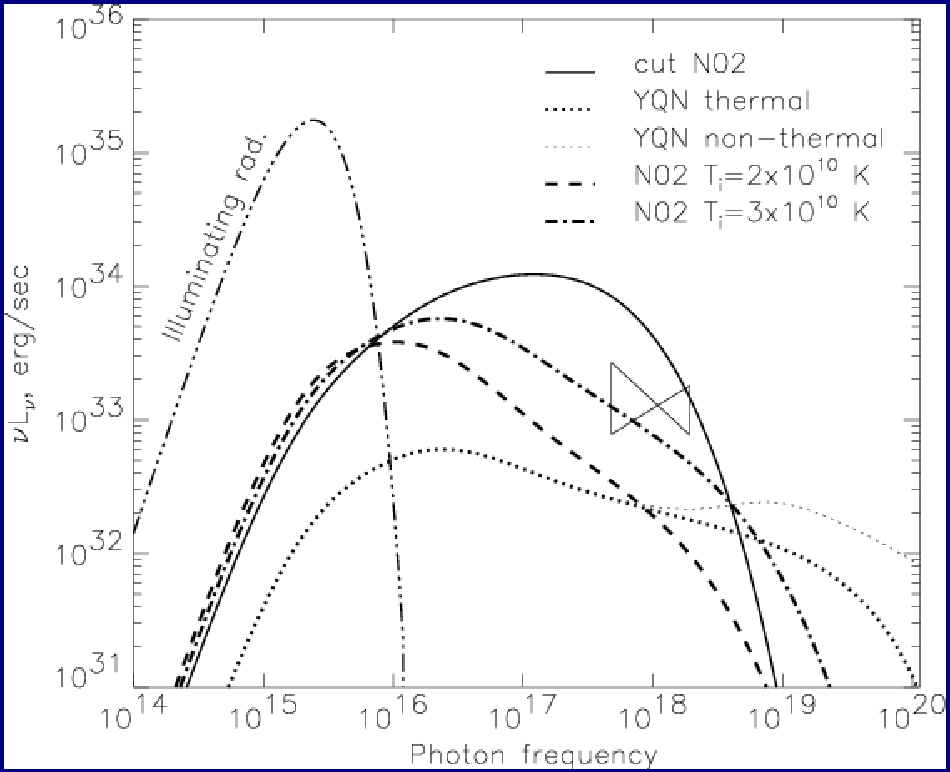
Consistent with warping constraint of ~ 2 x 10^4 M_sun

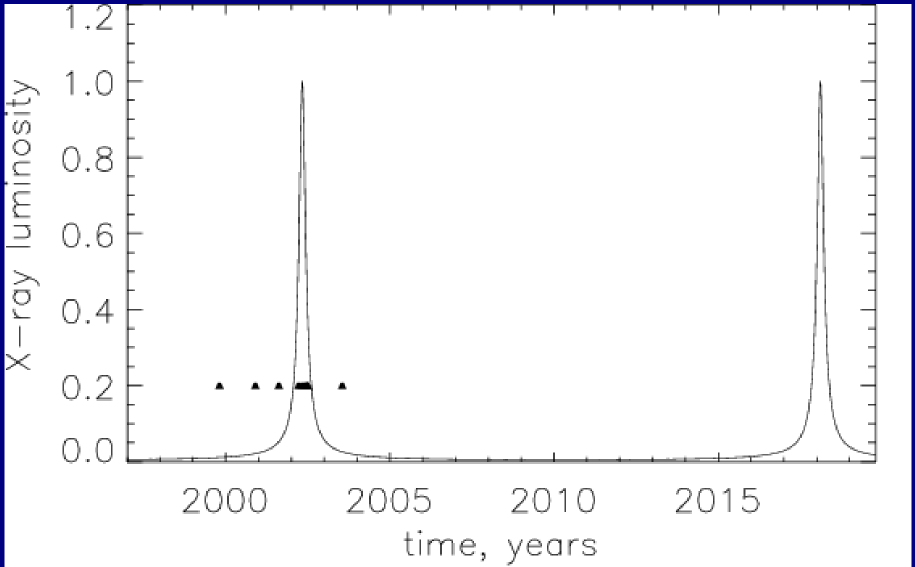
Top-heavy IMF in the disk?

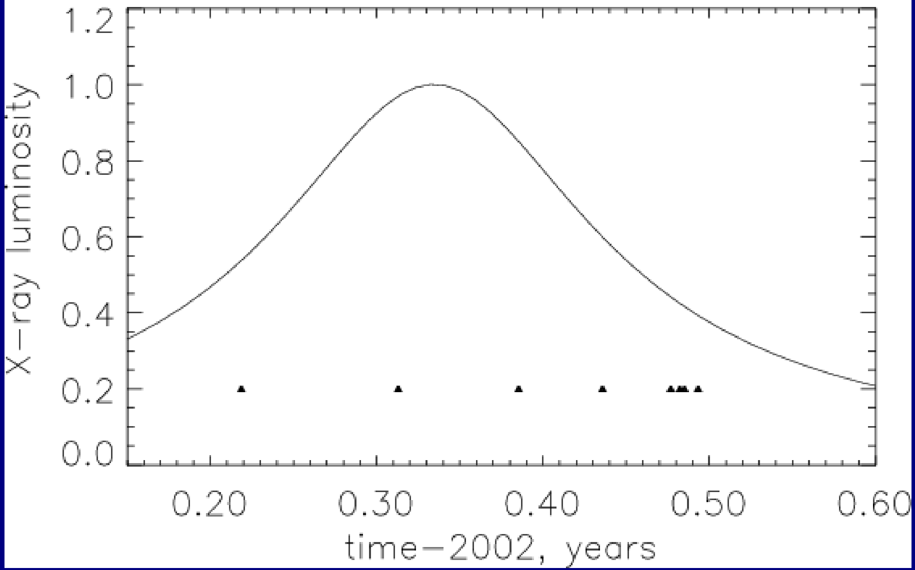


- Gas accretion on embedded stars is very rapid.
- High gas densities favor high mass star formation (Bonell, Bate)
- Stellar feedback cannot expell gas and stop star formation in the disk.

Comptonization of stellar radiation





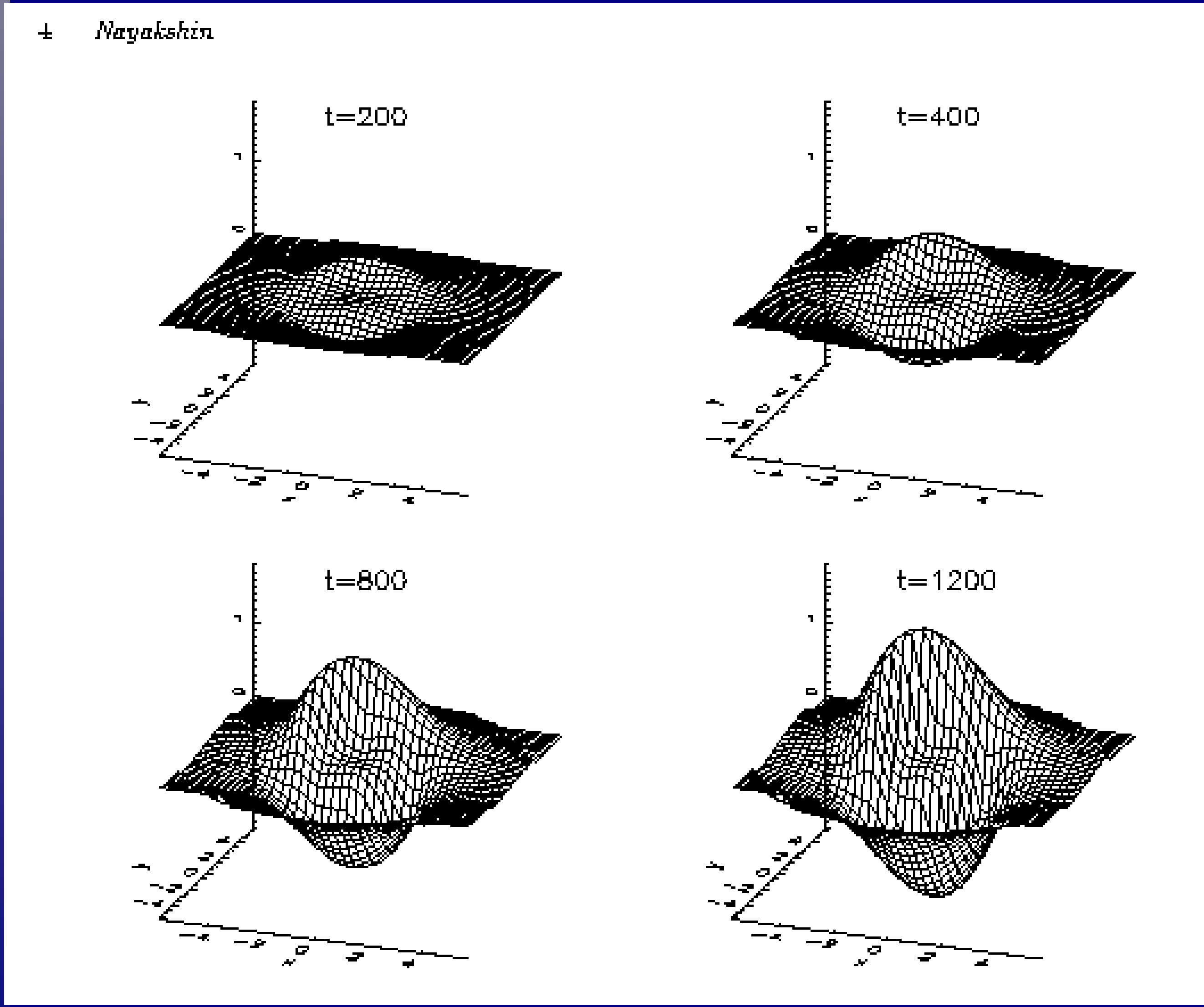


- Sgr A* X-luminosity has not varied much in 2002 (Baganoff, priv. comm), thus

Mdot ~< 3 x 10^-7 Msun/year

(Nayakshin 2005b)

AGN obscuration



Nayakshin 2005a

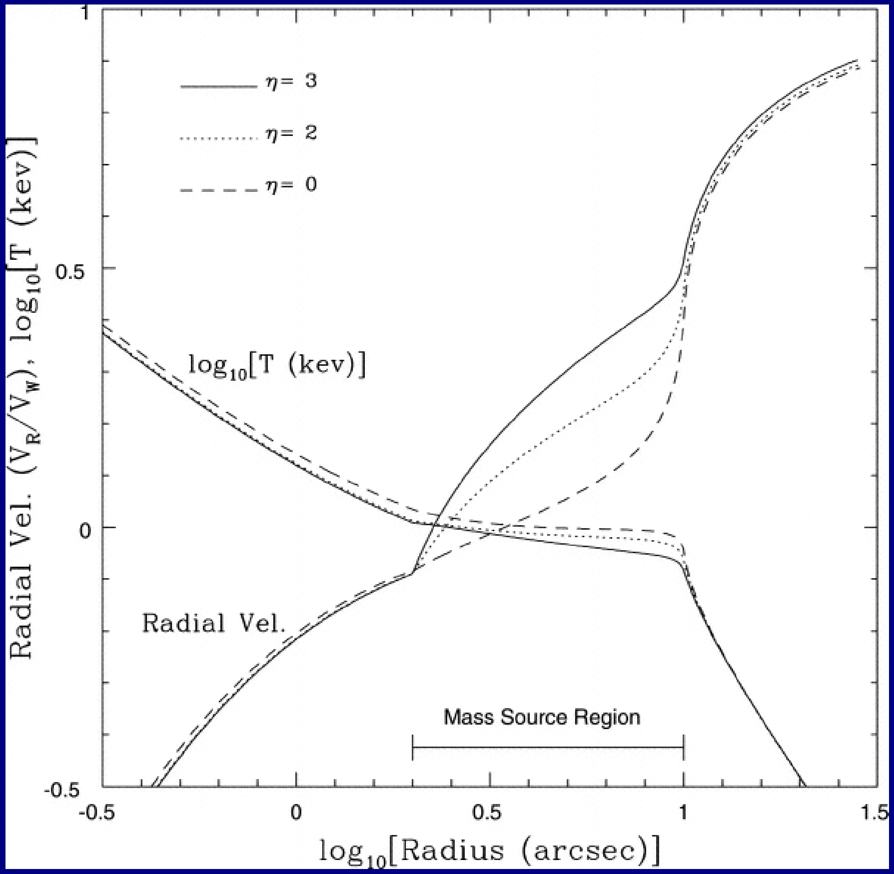
$$\theta = 45^{\circ}$$

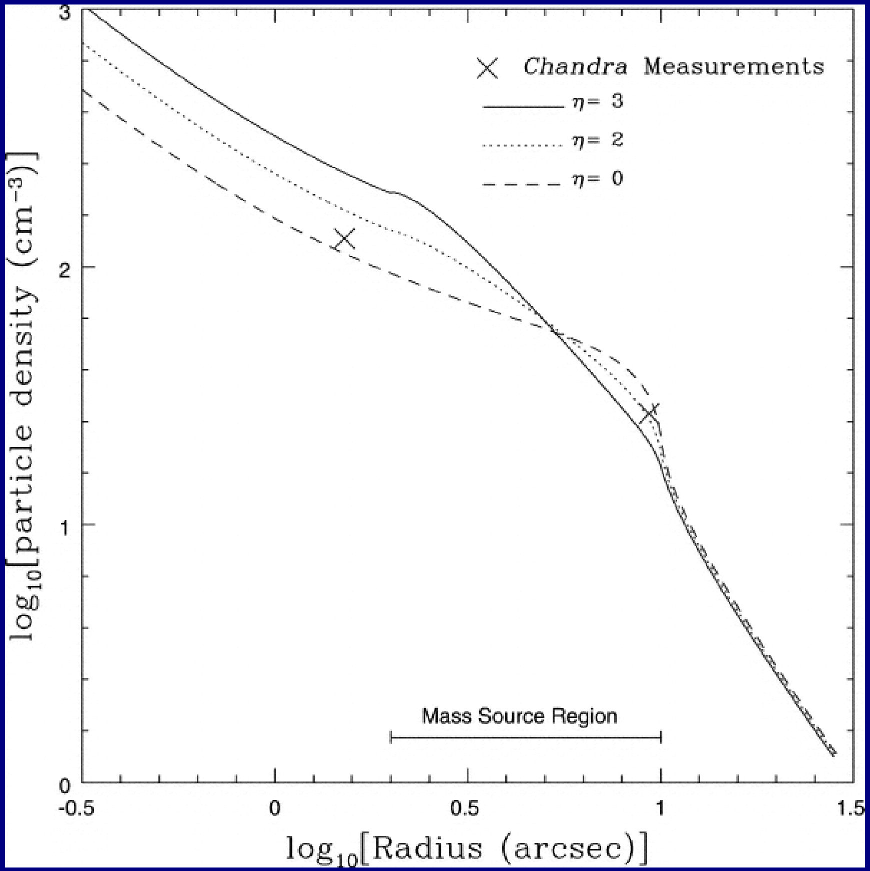
Side comment:

Such warped disks could be responsible for AGN obscuration (type I / type II division)

Sgr A* feeding (previous work)

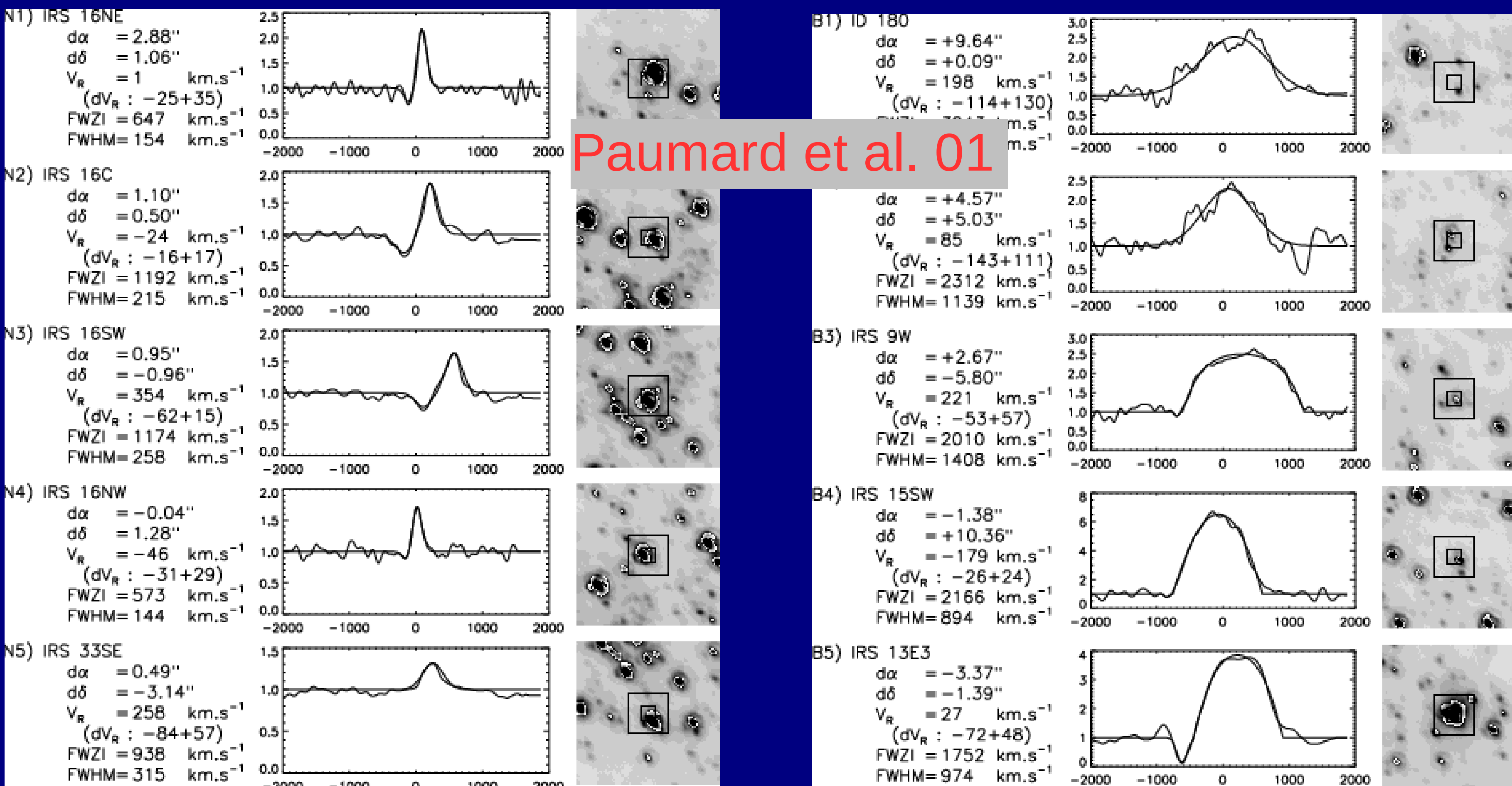
- Melia 92, 94 used Bondi model to describe Sgr A* properties.
- Coker & Melia 97 used Zeus-3D with fixed stars; no radiative cooling.
- Rokefeller et al. 04: same approach but SPH and more stars
- Quataert 2004: sperically symmetric model.





Sgr A* feeding (see Jorge Cuadra's poster)

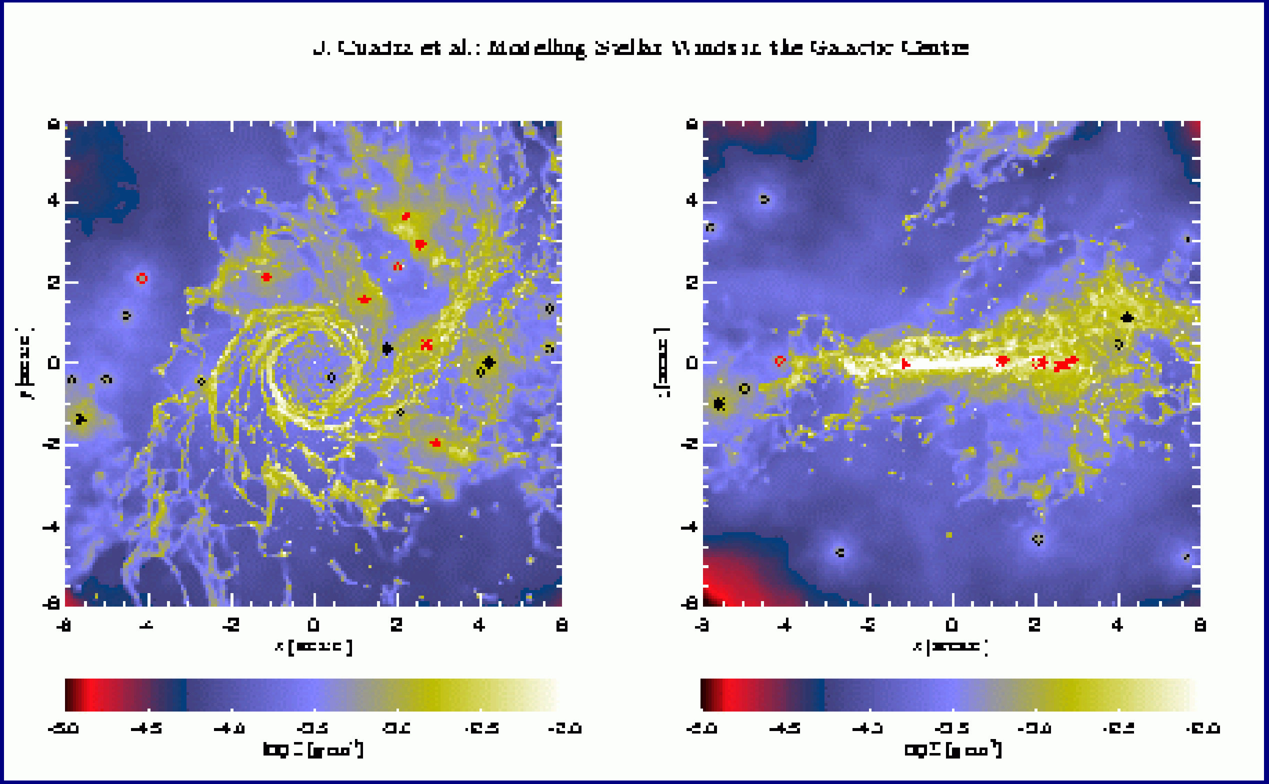
- there are also <u>narrow line</u> winds: cooling may be important
- Stars are locked into two rings (thus angular momentum!!)



Paumard et al. 01

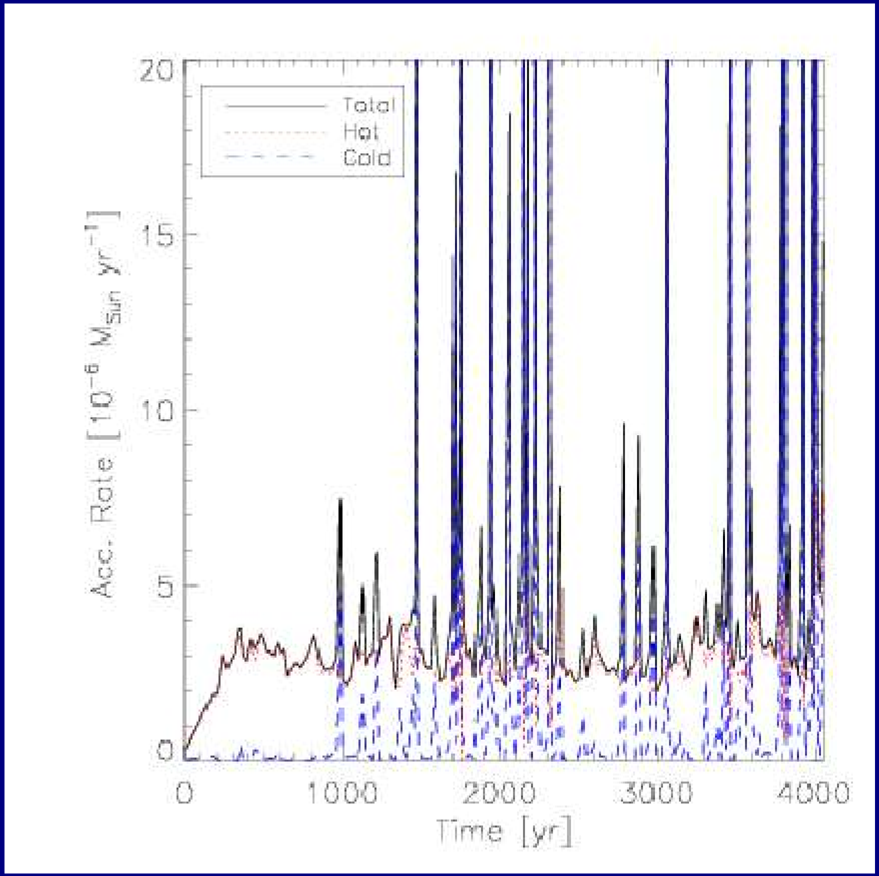
Stars in two perpendicular rings

- Use Gadget-2 with BH modeled as a sink particle
- Set ~ 20 stars on realistic circular orbits around BH
- Stars emit SPH particles to model winds
- Include radiative cooling



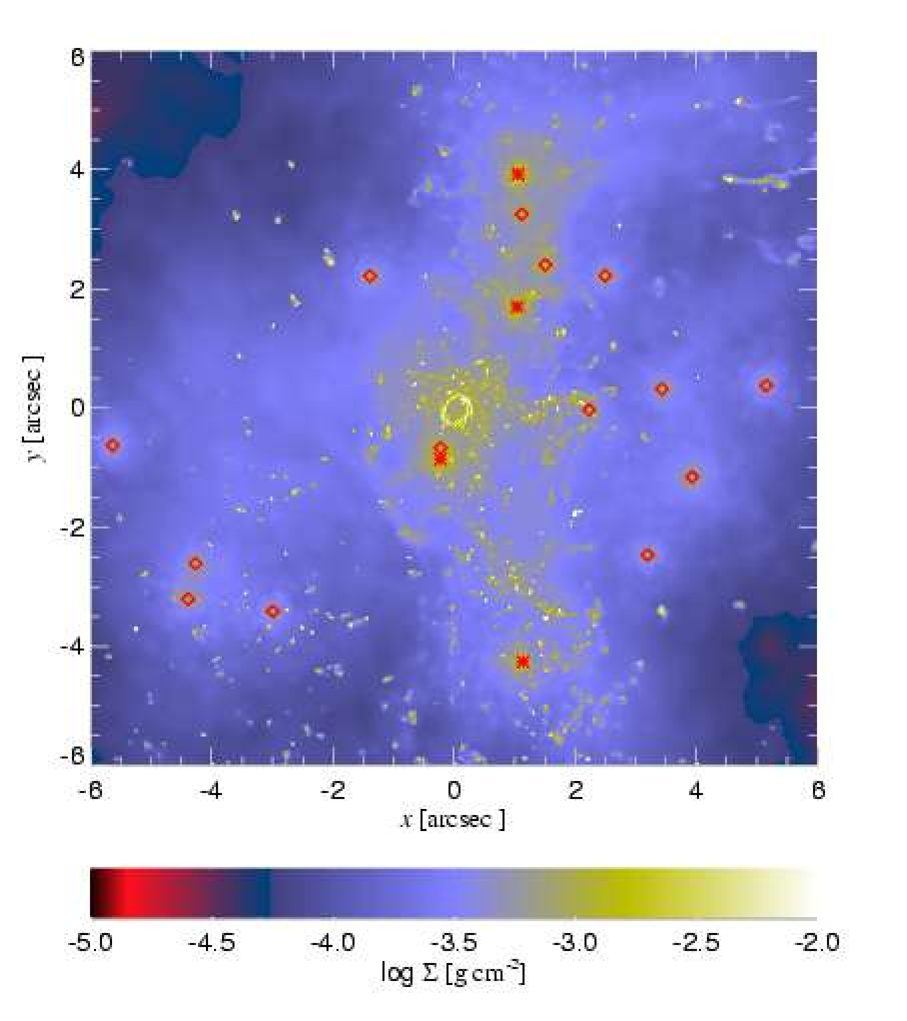
Stars in two perpendicular rings

- Slow winds cool radiatively and form clumps, filaments and a disk
- Inner arcsecond contains both hot and cold gas
- Accretion rate is highly variable in time.



Stars in an isotropic cluster

- Results strongly depend on stellar orbits, mass outflow rates:
- Need better observational constraints on the stellar winds.



Same stars but in an isotropic cluster

Conclusions

- Disk warping require initial stellar masses of ~ 10^4 Msun
- IMF of young stars should be dominated by high mass stars.
- Both models pass the mass constraints, but the infalling cluster model is fine tuned (circular infall; very massive initial cluster)
- Sgr A* wind-fed accretion is two-phase and is highly variable on hundreds to a thousand years time scale.