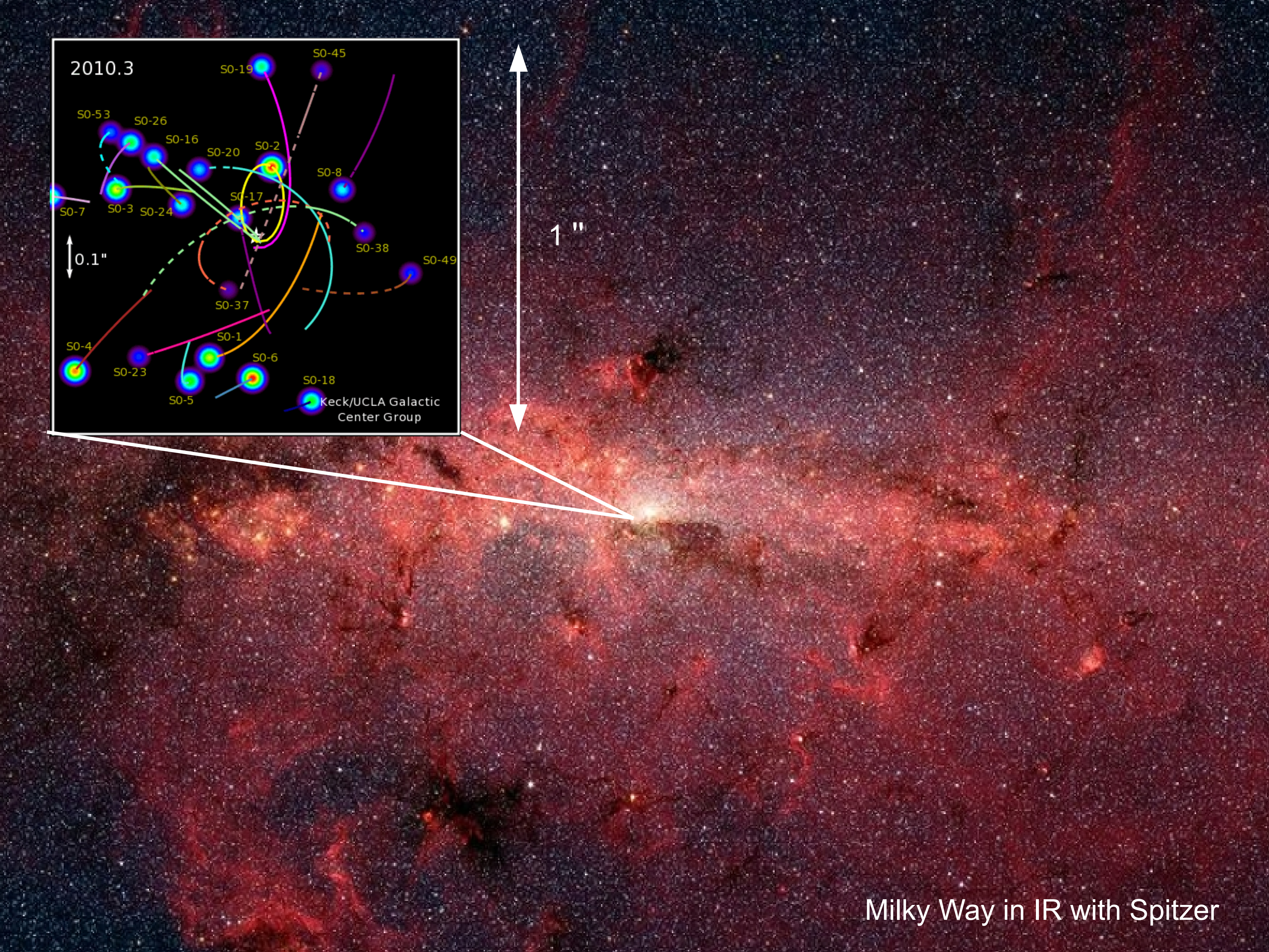
International Summer Institute for Modeling in Astrophysics, July 8th 2010

Binary stars migrating in a gaseous disk: Where are the Galactic Center binaries?

C. Baruteau, J. Cuadra & D.N.C. Lin, submitted

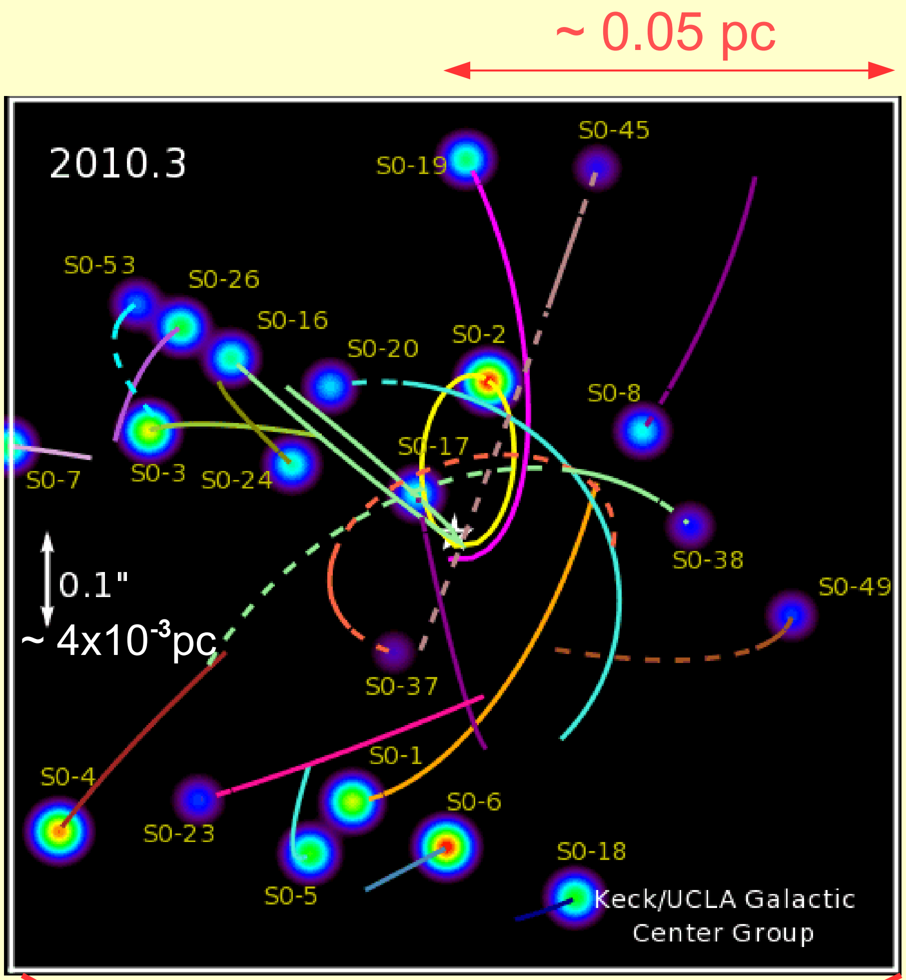
Clément Baruteau

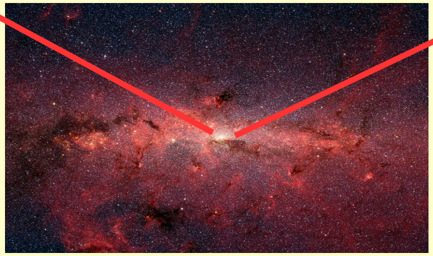
University of California at Santa Cruz



2010.3
S0-19
S0-45
S0-53
S0-26
S0-16
S0-20
S0-2
S0-8
S0-7
S0-3
S0-24
S0-17
S0-38
0.1"
S0-49
S0-37
S0-1
S0-4
S0-23
S0-6
S0-18
S0-5
Keck/UCLA Galactic Center Group
1 "
Milky Way in IR with Spitzer

Puzzling stars near the Galactic Center



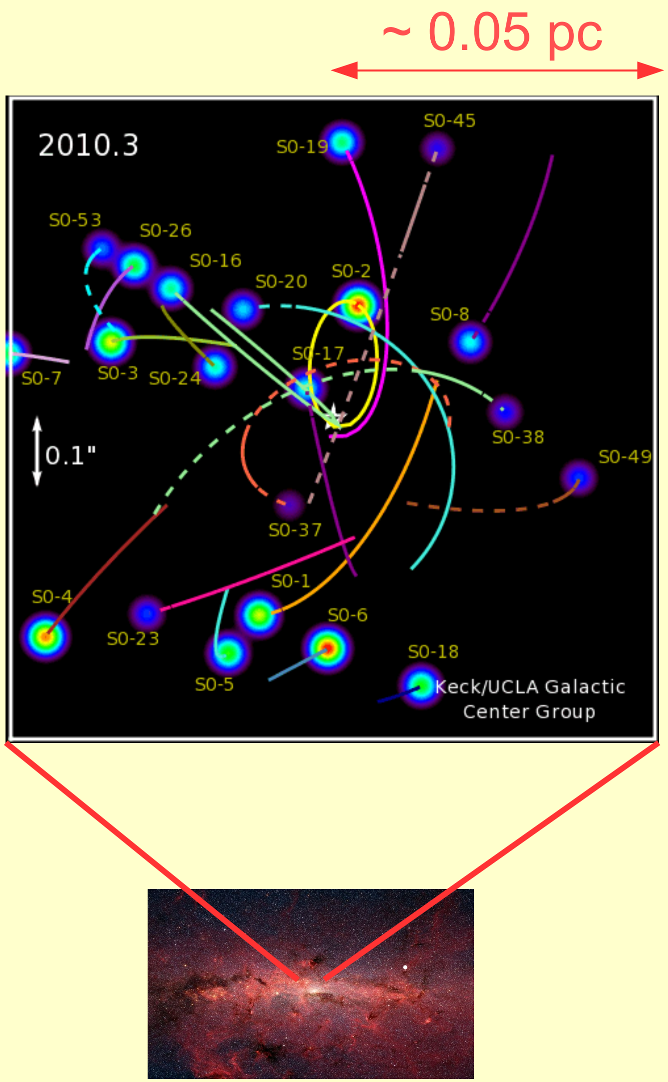


- **Supermassive black hole** ~ $4x10^6$ M_{sun}

- **S-stars cluster** (d< 0.1pc)
  . ~ 50 main-sequence B stars
  . M ~ $10M_{sun}$ age ~ $x10^7$ yrs
  . typical eccentricity > 0.8
  . random inclination

- **Young stellar disk(s)** (0.05pc < d < 0.5pc)
  . ~ 100 OB type stars
  . M > $10M_{sun}$ age ~ $x10^6$ yrs
  . typical eccentricity ~ 0.4 (up to 0.8)
  . moderately thin disk

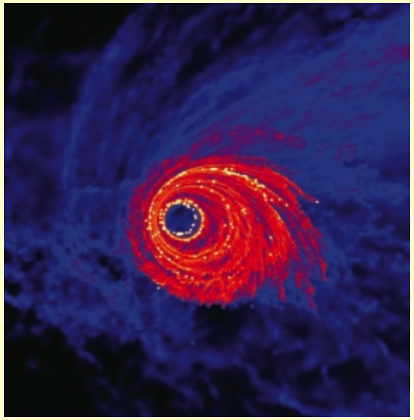
How did the S stars form?



In-situ formation?

→ formation of a thin gaseous disk by tidal disruption of a molecular cloud

Bonnell & Rice (2008)

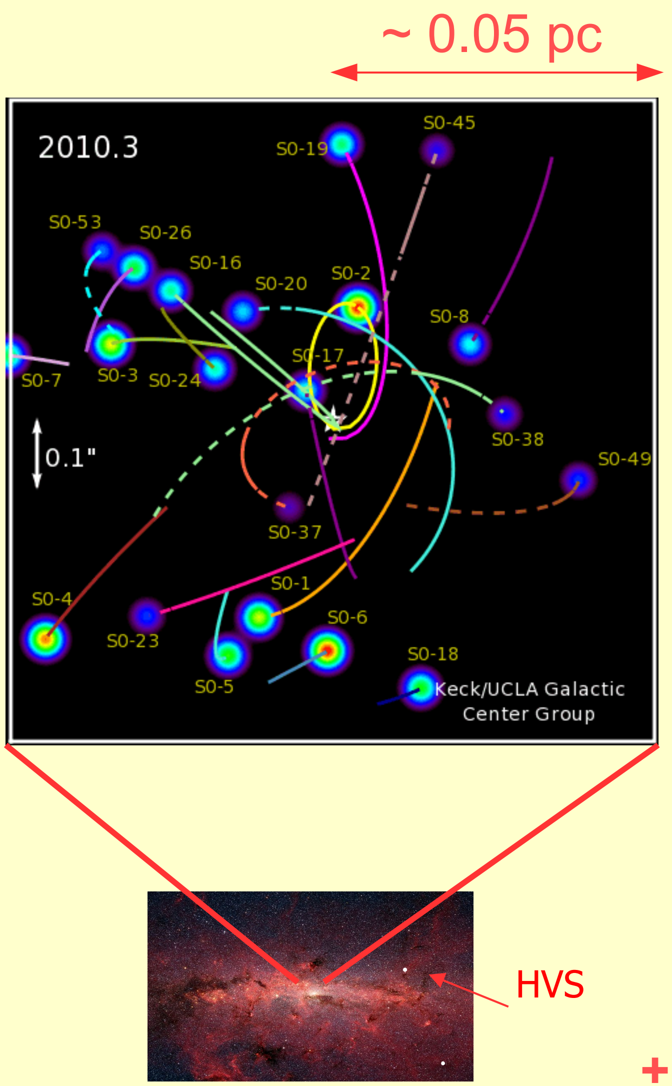


Formation further out + migration?

→ dense stellar cluster — Gerhard (2001)

→ planet-like migration — Levin (2007)

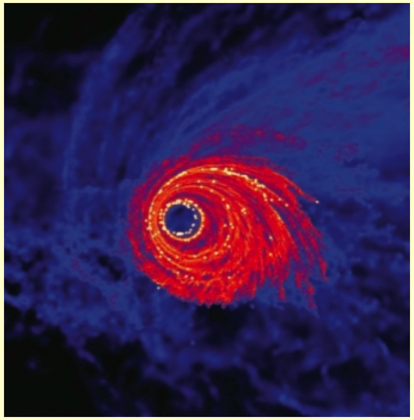
How did the S stars form?



In-situ formation?

→ formation of a thin gaseous disk by tidal disruption of a molecular cloud

Bonnell & Rice (2008)



Formation further out + migration?

→ dense stellar cluster Gerhard (2001)

→ planet-like migration Levin (2007)

Origin of the large eccentricities?

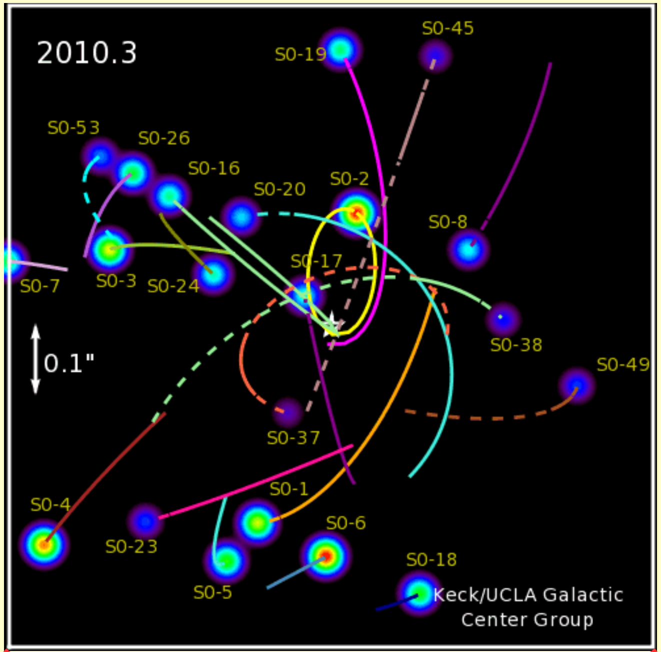
→ tidal disruption of a binary star

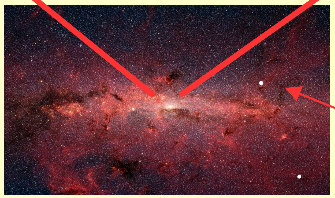
+ other companion could be one of the hypervelocity stars,
- requires a compact binary on a highly elliptical orbit,
- where are the binaries near the Galactic Center?

Gould & Quillen (2003) Perets (2009)

How did the S stars form?

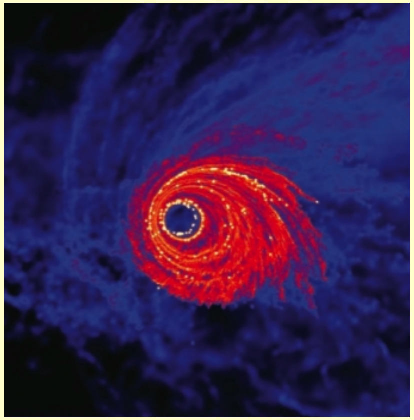
~ 0.05 pc





HVS

In-situ formation?



→ formation of a thin gaseous disk by tidal disruption of a molecular cloud

Bonnell & Rice (2008)

Formation further out + migration?

→ dense stellar cluster Gerhard (2001)

→ **planet-like migration** Levin (2007)

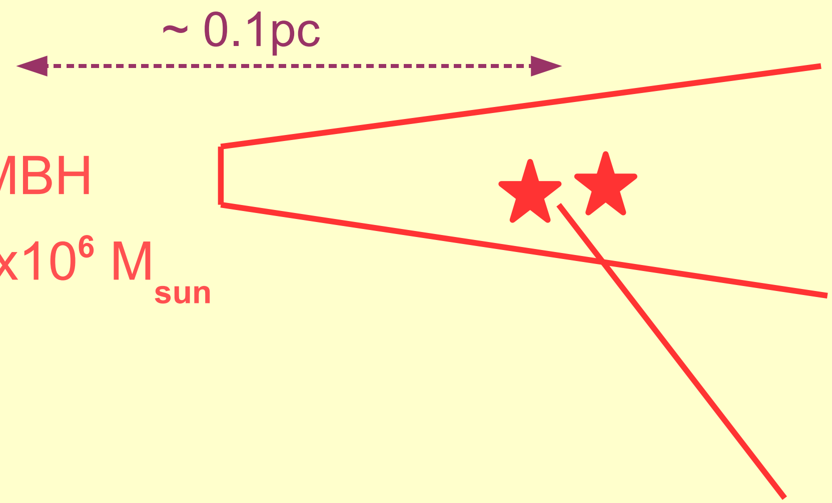
Origin of the large eccentricities?

→ **tidal disruption of a binary star**

+ other companion could be one of the hypervelocity stars,
- requires a compact binary on a highly elliptical orbit,
- where are the binaries near the Galactic Center?

Gould & Quillen (2003) Perets (2009)

Physical model



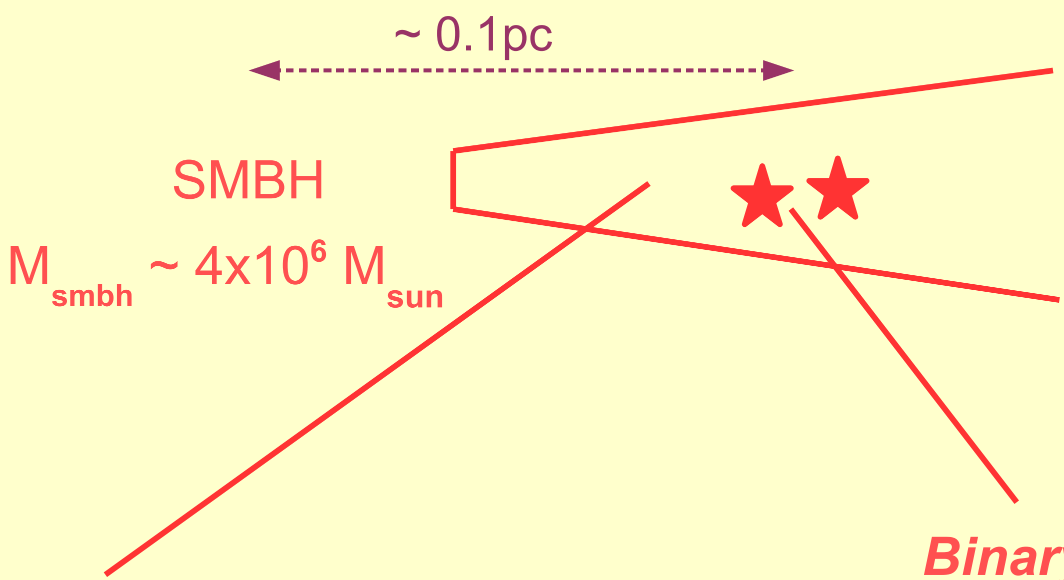
SMBH

$M_{smbh} \sim 4 \times 10^6 \ M_{sun}$

Binary star

- equal-mass, $M_{bin} \sim 10^{-5} \ M_{smbh}$
- prograde, circular orbit
- $a_{bin} \sim 0.3 \ R_{hill} \sim 10^{-3}$ pc

Physical model



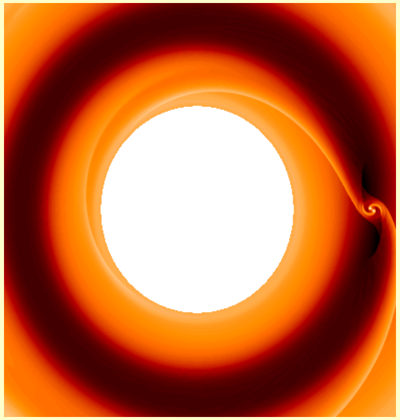
Gaseous disk

→ properties of disk *after star formation*?

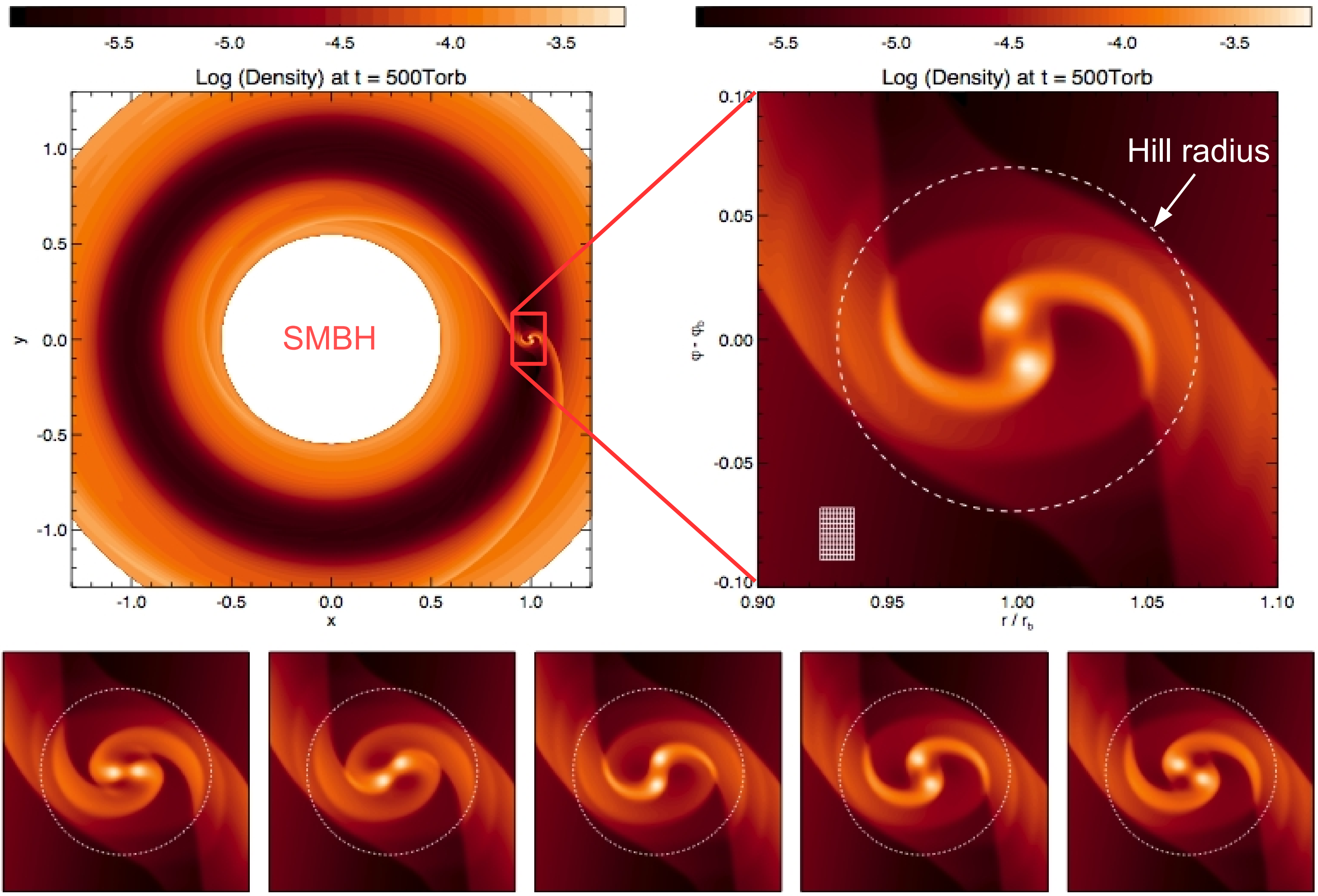
- disk assumed to remain **thin** (aspect ratio~1% at ~0.1pc), and locally isothermal
- gas density is a free parameter (self-gravity discarded)
- viscosity

Binary star

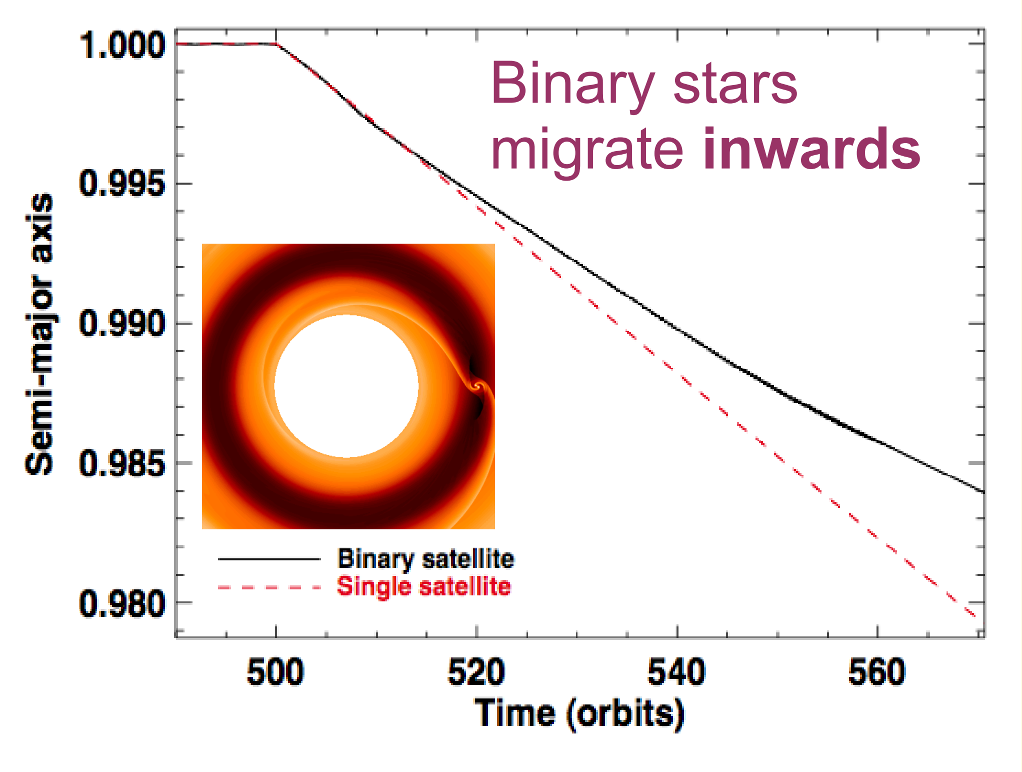
- equal-mass, $M_{bin} \sim 10^{-5}\ M_{smbh}$
- prograde, circular orbit
- $a_{bin} \sim 0.3\ R_{hill} \sim 10^{-3}$ pc



So you want binary stars to migrate in a gas disk...

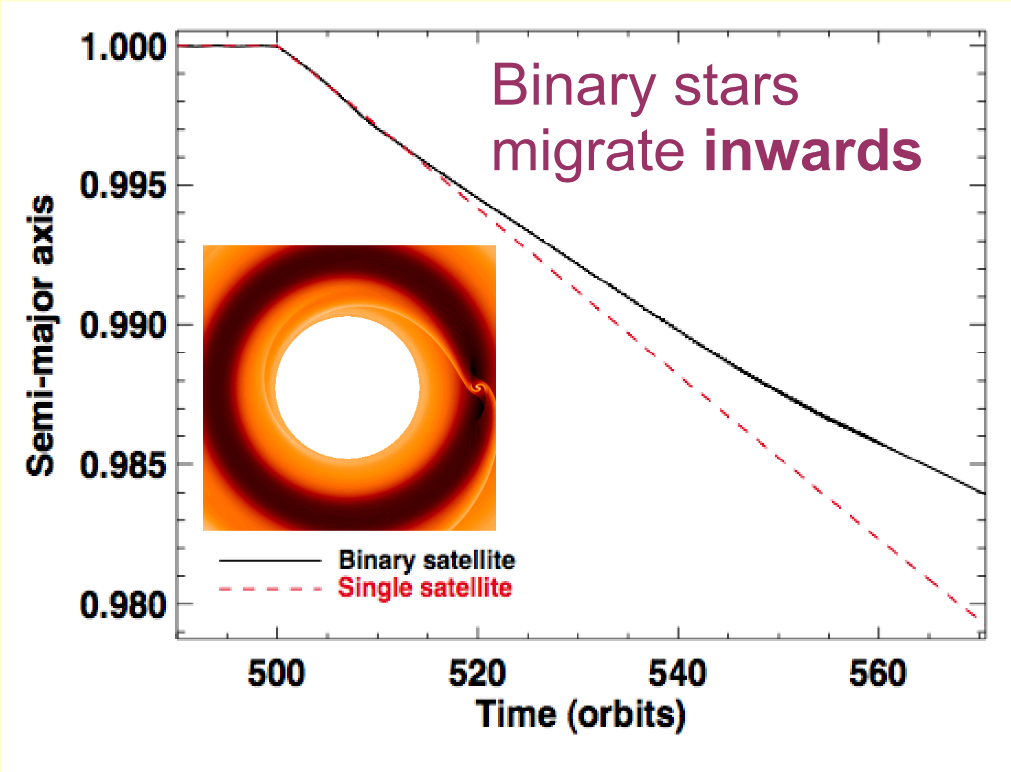


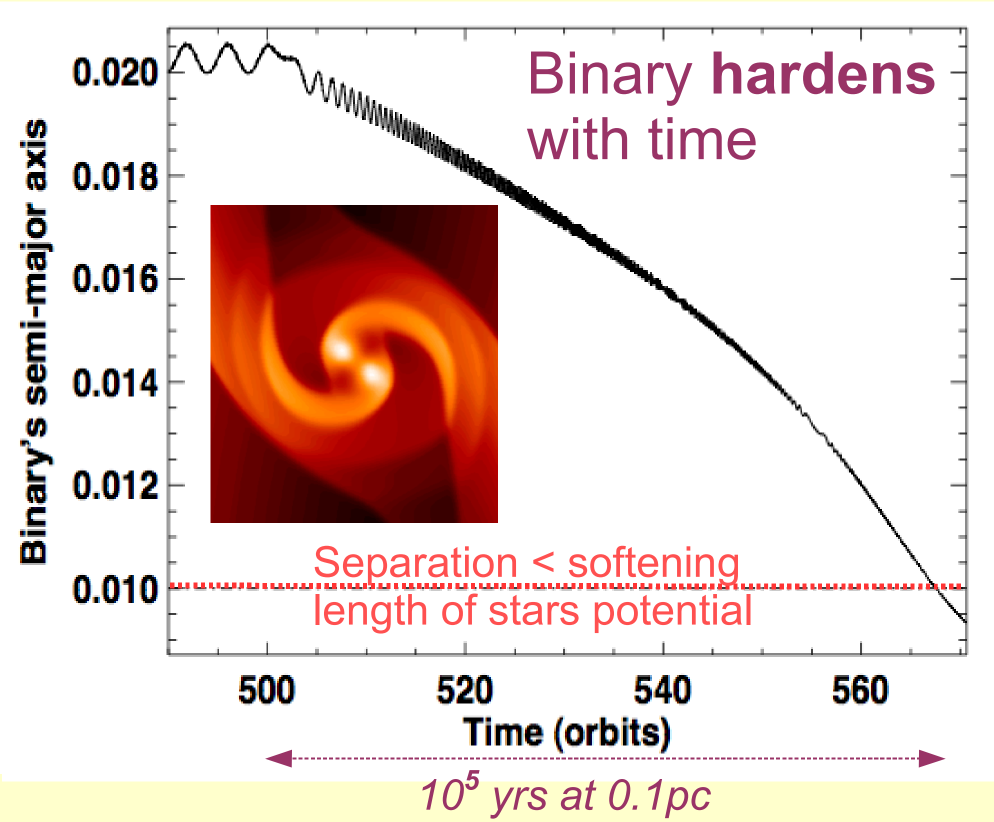
So you want binary stars to migrate in a gas disk...



- Migration rate similar to that of single satellite of same mass

So you want binary stars to migrate in a gas disk...

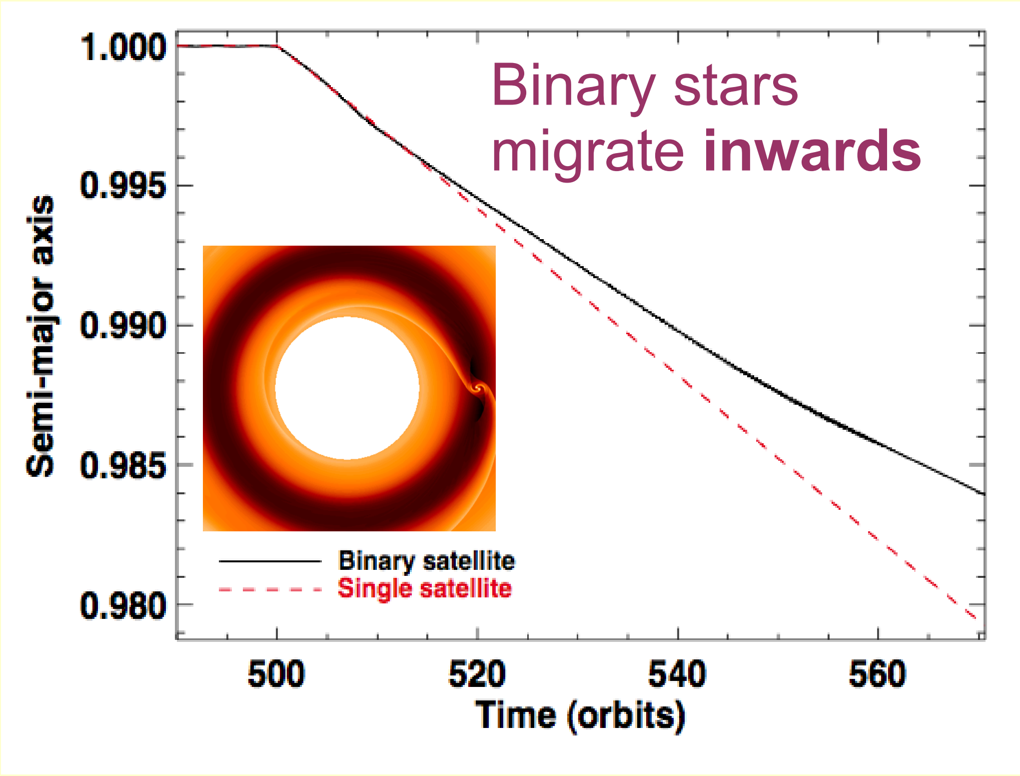


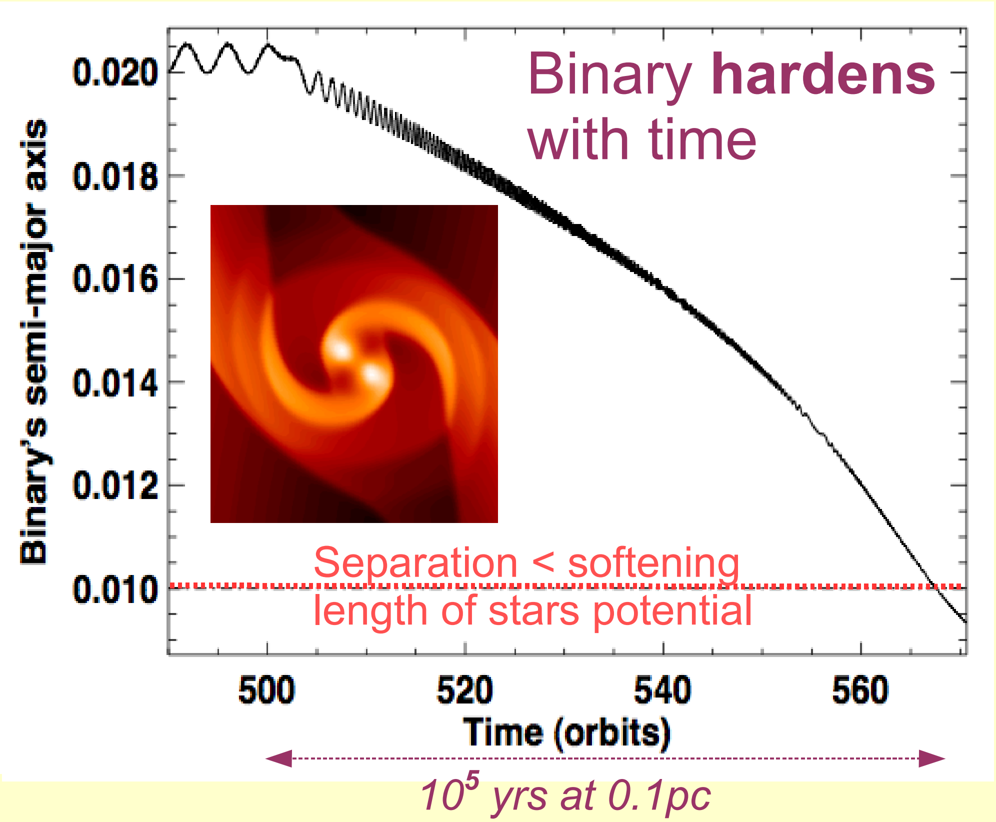


- Migration rate similar to that of single satellite of same mass

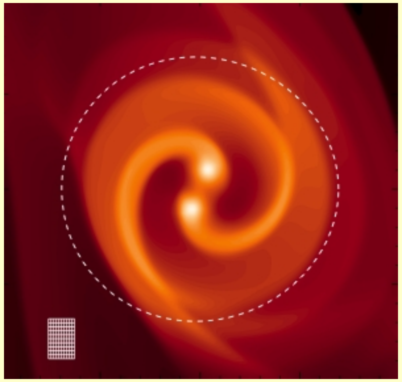
- Hardening rate mostly controlled by the gas inside of the binary's Hill radius.

So you want binary stars to migrate in a gas disk...





- Migration rate similar to that of single satellite of same mass
- Hardening rate mostly controlled by the gas inside of the binary's Hill radius.
- Retrograde binaries also harden! →



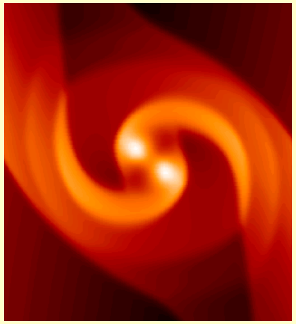
Conclusion: final outcomes of the binary's hardening?

Massive binary (M_{bin} ~ $30M_{sun}$) embedded in a thin (h~1%) gas disk, with $\alpha \sim 10^{-3}$, Q~30:

- hardening timescale ~ a few 10^4 yrs at 0.1pc
- migration timescale ~ a few 10^7 yrs at 0.1pc

Binary mass

>~ $10M_{sun}$



(this talk)

~ $1M_{sun}$

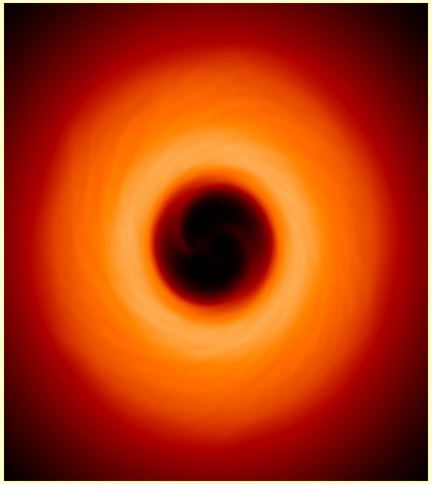
Analytic prediction
by Stahler (2010):
fast hardening?

Time

Conclusion: final outcomes of the binary's hardening?

Massive binary (M_{bin} ~ $30M_{sun}$) embedded in a thin (h~1%) gas disk, with α ~10^{-3}, Q~30:

- hardening timescale ~ a few 10^4 yrs at 0.1pc
- migration timescale ~ a few 10^7 yrs at 0.1pc



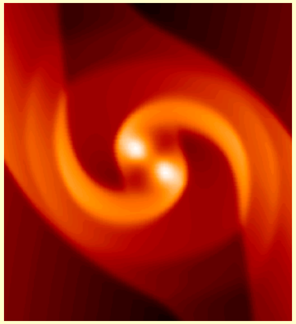
Cuadra et al. (2009)

Binary mass

>~ $10M_{sun}$

~ $1M_{sun}$

Analytic prediction by Stahler (2010): fast hardening?



(this talk)

Opening of a cavity?

Yes: formation of a **circumbinary disk**

Problem similar to **type II migration** (binary's tidal torque competing with disk's viscous torque), and analogous to the shrinking of binary black holes

e.g. Pringle (91), Ivanov et al. (99)

No: stars may merge

hardening timescale ~ a few 10^6 yrs at 0.1pc, comparable to the stars lifetime

- merge
- explosive disruption (primary → supernova)

Time