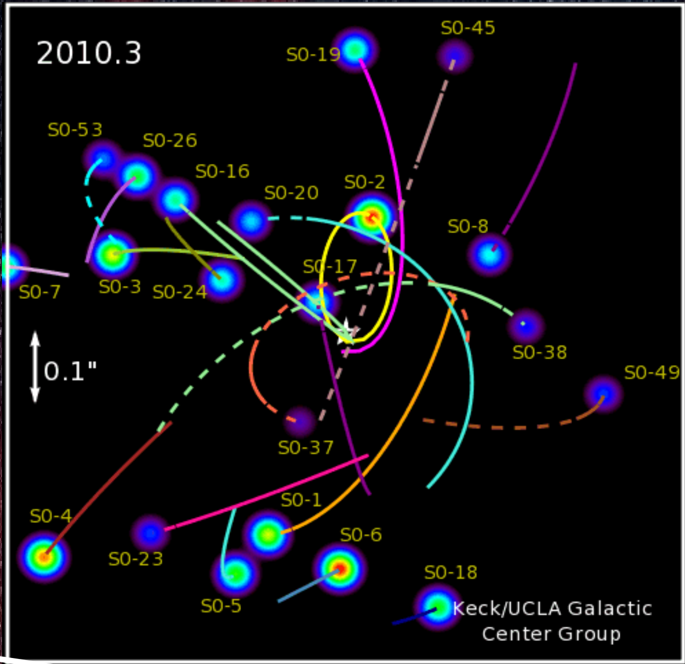


1 "
(~0.04pc)

Binaries migrating in a gaseous disk: Where are the Galactic center binaries?

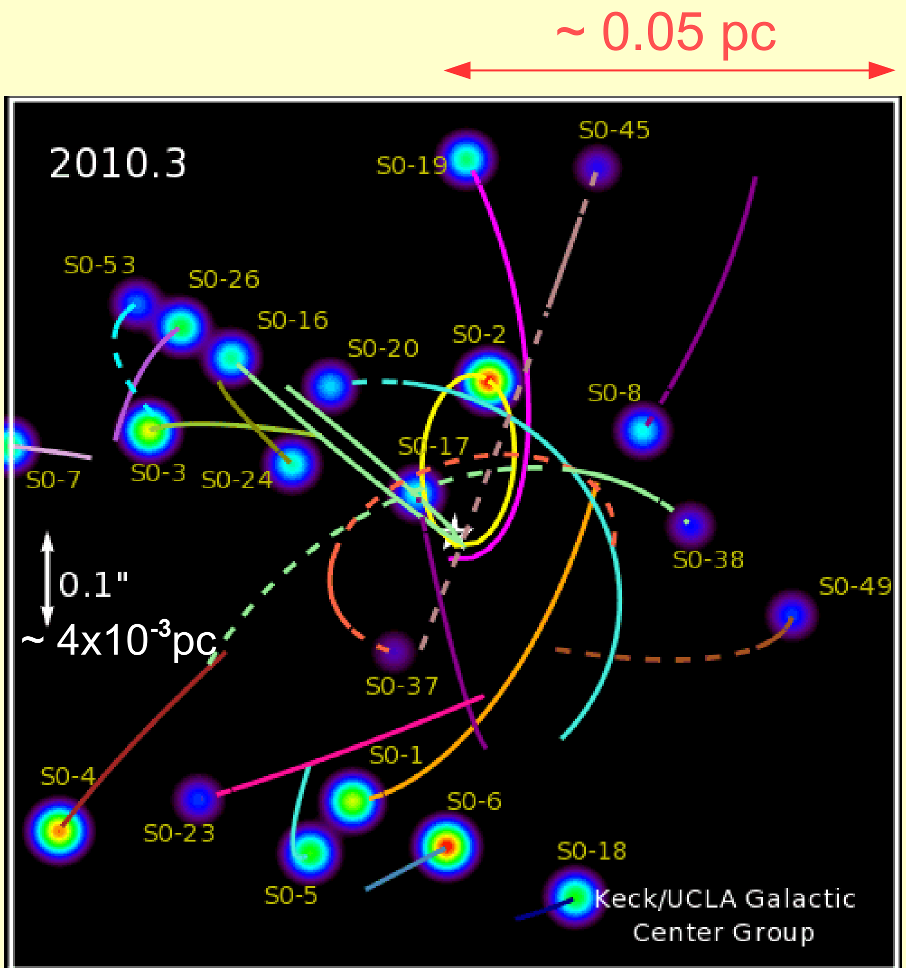
Baruteau, Cuadra & Lin, 2011, ApJ

Clément Baruteau (把瑠都)
DAMTP, University of Cambridge

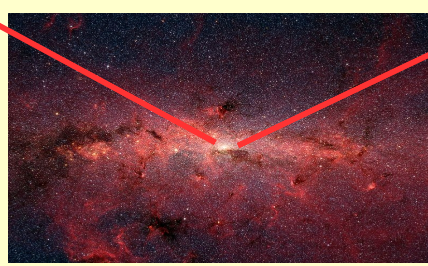
Milky Way in IR with Spitzer

NAOJ Star Formation Workshop, Feb. 25th 2011

Puzzling stars near the Galactic Center



With high-resolution IR imaging + spectroscopy



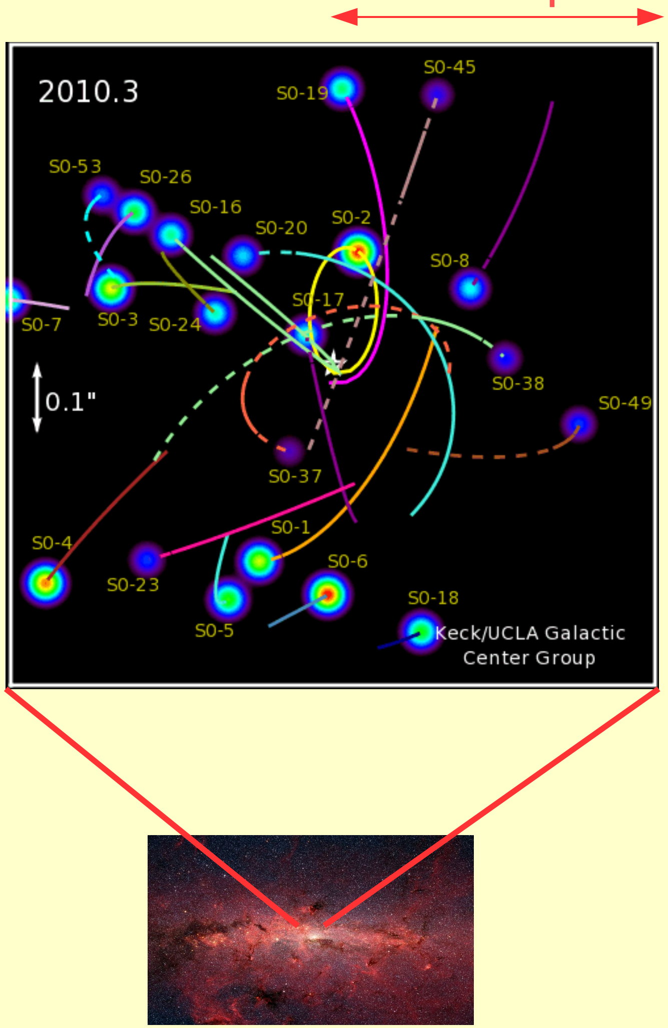
- **Supermassive black hole** (SgrA*) ~$4\times10^{6}M_{sun}$

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

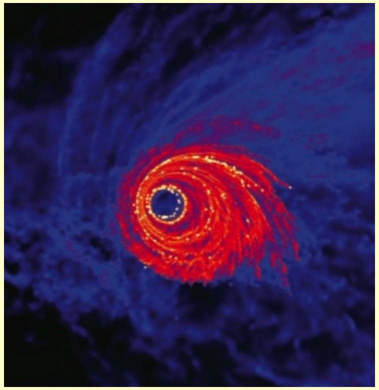
- **Young stellar disk(s)** (0.1pc < d < 0.5pc)
  - . ~ 100 OB type stars
  - . M > $10M_{sun}$ age ~ $x10^{6}$ yrs
  - . typical eccentricity ~ 0.4 (up to 0.8)
  - . moderately thin disk (aspect ratio ~ 0.1), evidence for a second one

How did the S stars form?

~ 0.05 pc



Common disk origin for the S-stars and the disk stars?



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

Bonnell & Rice 08

In-situ formation of S-stars unlikely, did they **form further out** in a/the disk, **and migrated in**?

→ dynamical friction of a massive star cluster

Gerhard 01

→ interaction with the gas disk: ”planet-like migration” Levin 07

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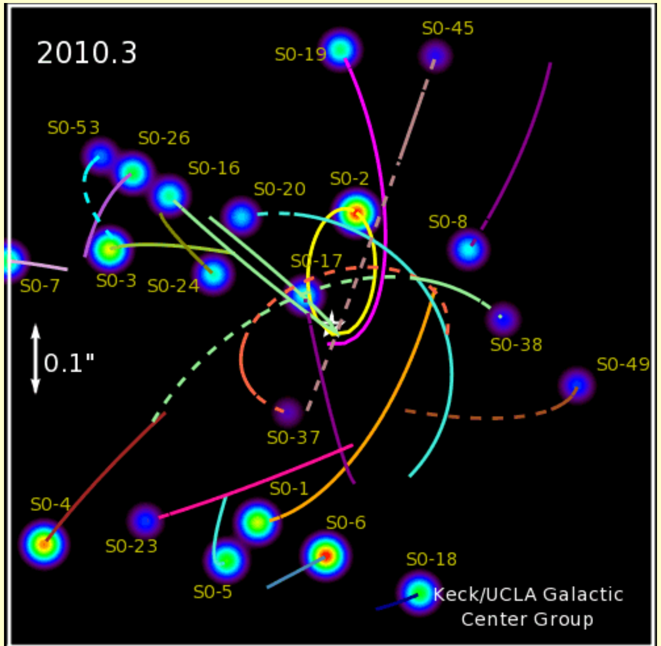

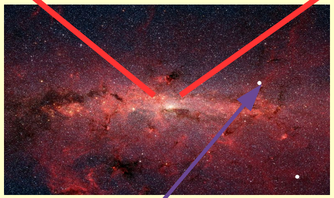

Hyper-Velocity Stars (galactic rest-frame velocities > 300-400 km/s)

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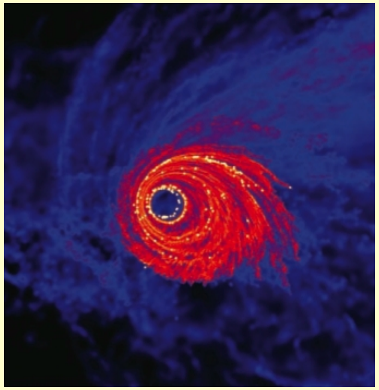

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Origin of the S-stars **eccentricities and inclinations**?

→ star-star dynamical interactions

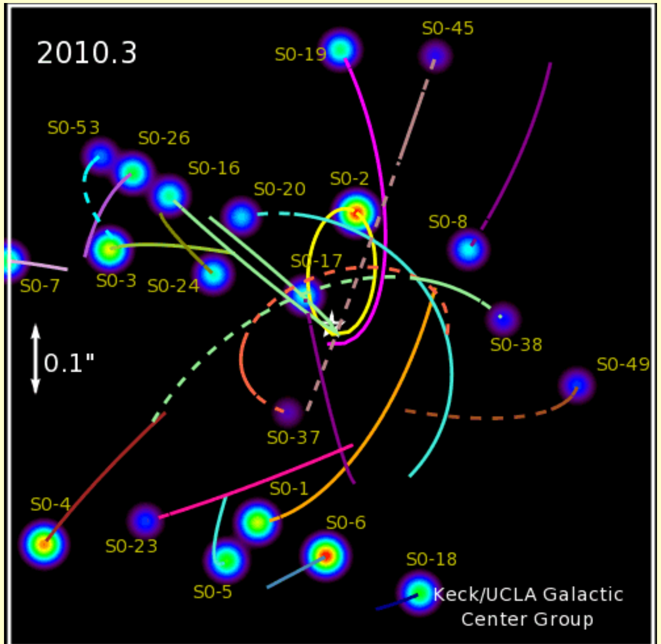
Cuadra+ 08, Perets+ 09

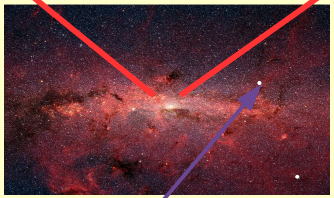
→ tidal disruption of a *binary star*

Gould & Quillen 03

How did the S stars form?

~ 0.05 pc





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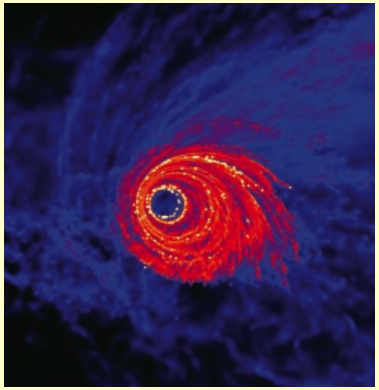

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→ <u>interaction with the gas disk: ”planet-like migration”</u> Levin 07 Baruteau+ 11

Origin of the S-stars **eccentricities and inclinations**?

→ star-star dynamical interactions

Cuadra+ 08, Perets+ 09

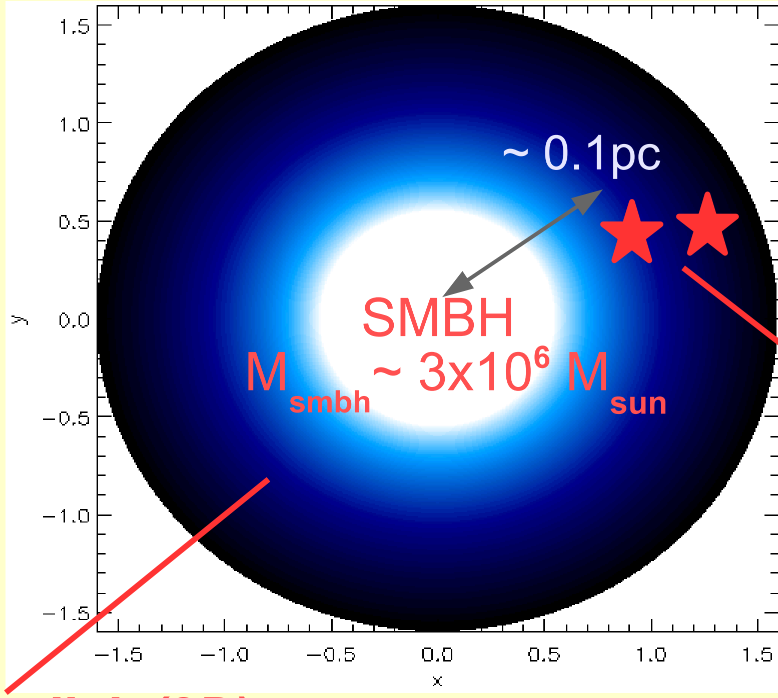
→ tidal disruption of a binary star

Gould & Quillen 03

→ <u>supernova disruption of a binary star</u>

Baruteau+ 11

Physical model

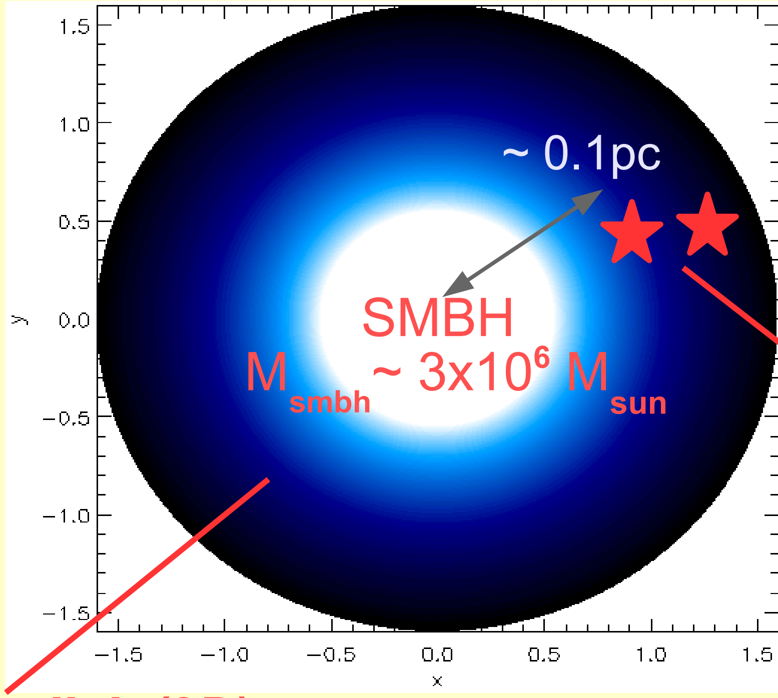


Gaseous disk (2D)

(one) binary star

- equal-mass, $M_{bin} \sim 30 M_{sun} \sim 10^{-5} M_{smbh}$
- prograde, circular orbit
- $a_{bin} \sim 0.3\ R_{Hill} \sim 10^{-3}$ pc ~ 200 AU

Physical model



Gaseous disk (2D)

→ properties *after star formation*?

- disk assumed to remain **thin** (aspect ratio~1% at ~0.1pc), and locally isothermal

- gas density ranges from 40 to 200 g cm^{-2} at 0.1 pc (Toomre Q ~ 2 to 10, self-gravity discarded), no accretion onto the stars

- viscosity? → $\alpha \sim 10^{-3}$

(one) binary star

- equal-mass, $M_{bin} \sim 30 M_{sun} \sim 10^{-5} M_{smbh}$

- prograde, circular orbit

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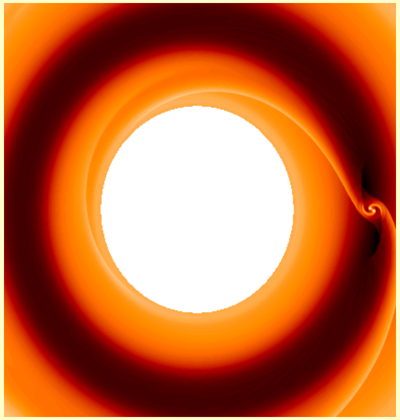
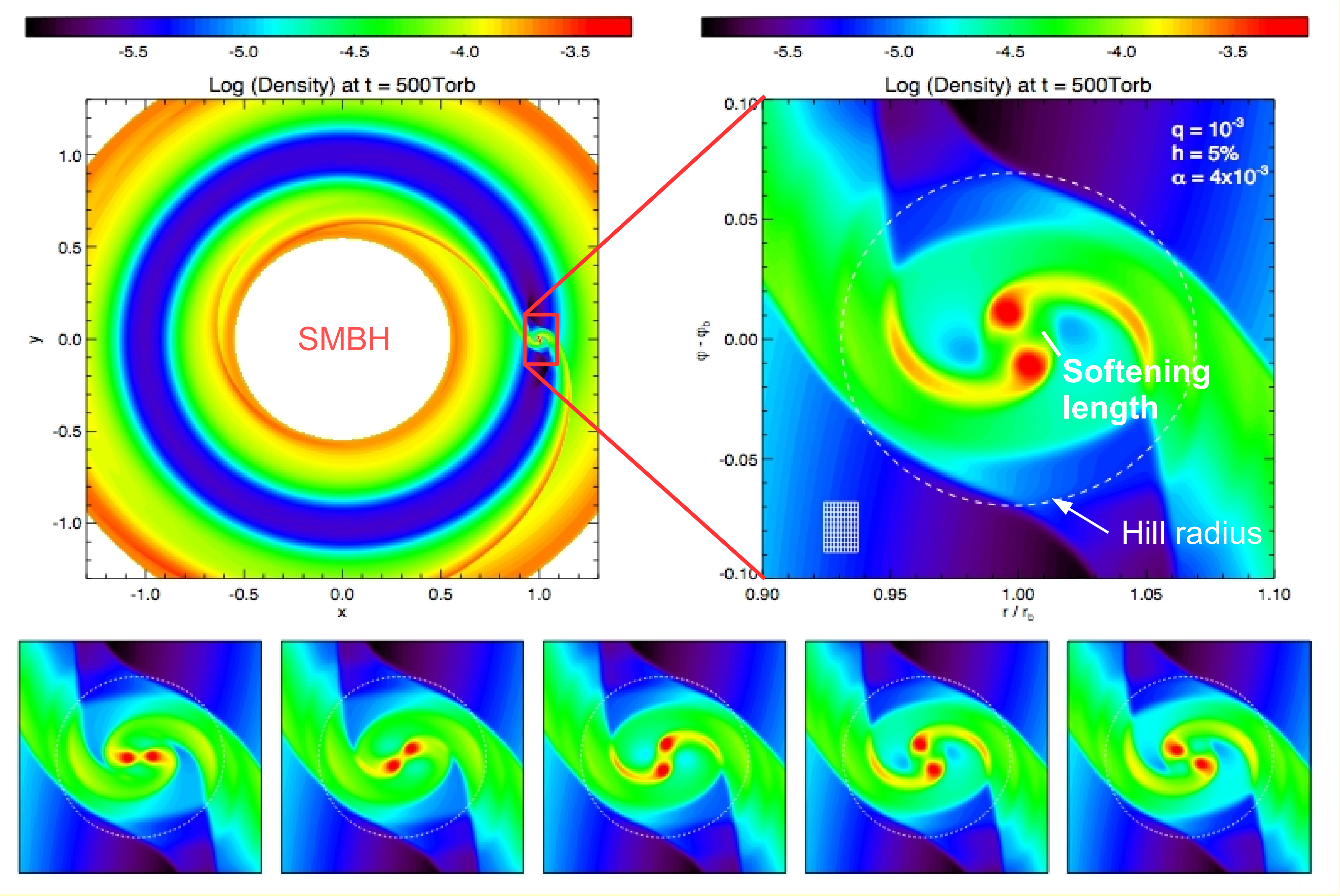
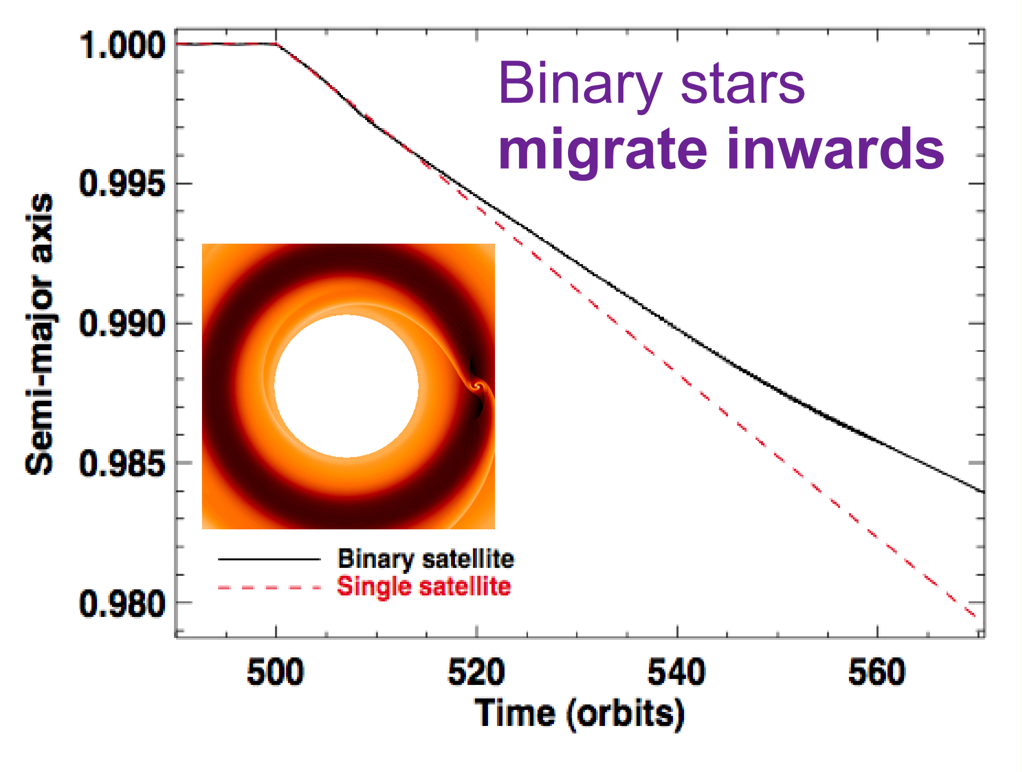


So you want binary stars to migrate in a gas disk...

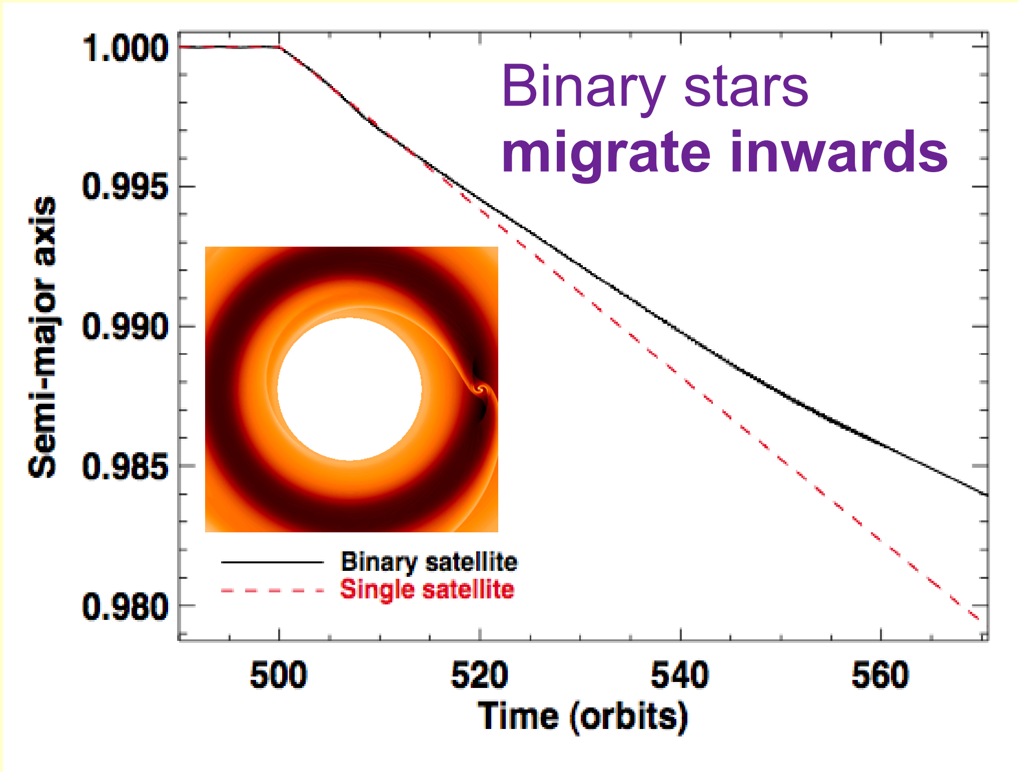


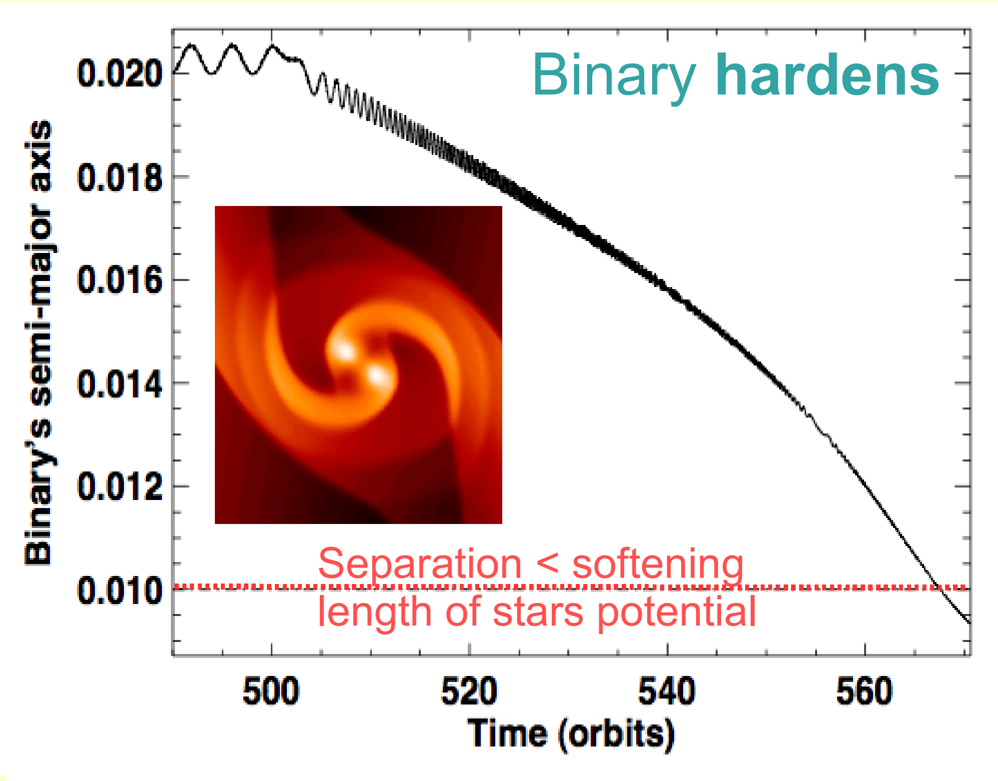
Outcome of the disk-binary tidal interaction



- **Migration timescale** similar to that of a single satellite with same mass, <u>about 10^7 yrs at 0.1pc</u>

Outcome of the disk-binary tidal interaction



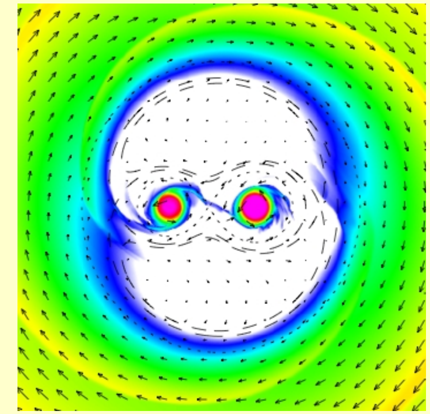


- **Migration timescale** similar to that of a single satellite with same mass, **about 10^7 yrs at 0.1pc**

- Hardening rate mostly controlled by the gas inside of the binary's Hill radius. **Hardening timescale** much shorter than migration timescale. Back to the original problem, it is only **a few 10^4 yrs at 0.1pc**

Outcomes of the binary's hardening?

Hanawa+ 10



Binary mass

No: stars
may merge

Opening of a cavity?

Yes: formation of a **circumbinary disk**

>~ $10M_{sun}$

(this talk) hardening timescale ~ a few **10^4 yrs** at 0.1pc

hardening timescale ~ a few **10^6 yrs** at 0.1pc, <u>comparable to the stars lifetime</u>

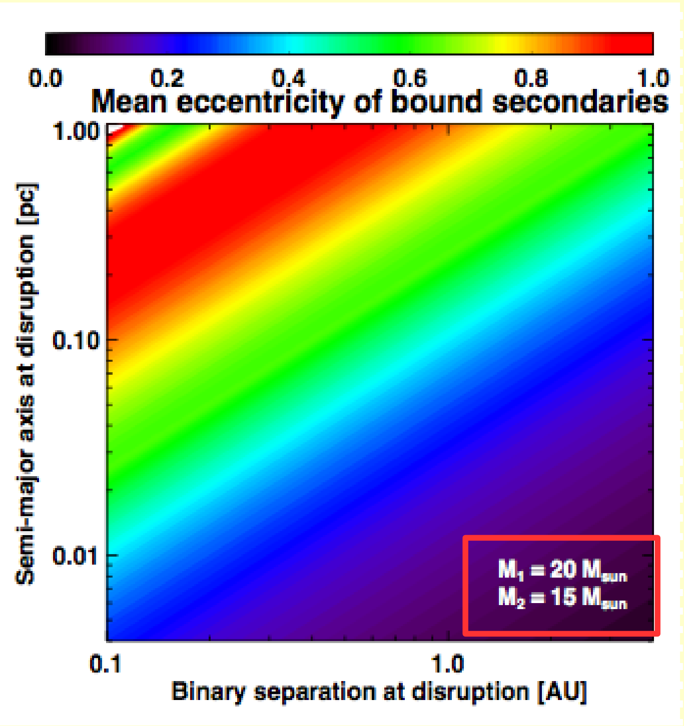
Ivanov+ 99, Baruteau+ 11

~ $1M_{sun}$

Analytic prediction by Stahler 10: short hardening timescale (~10^3 yrs)

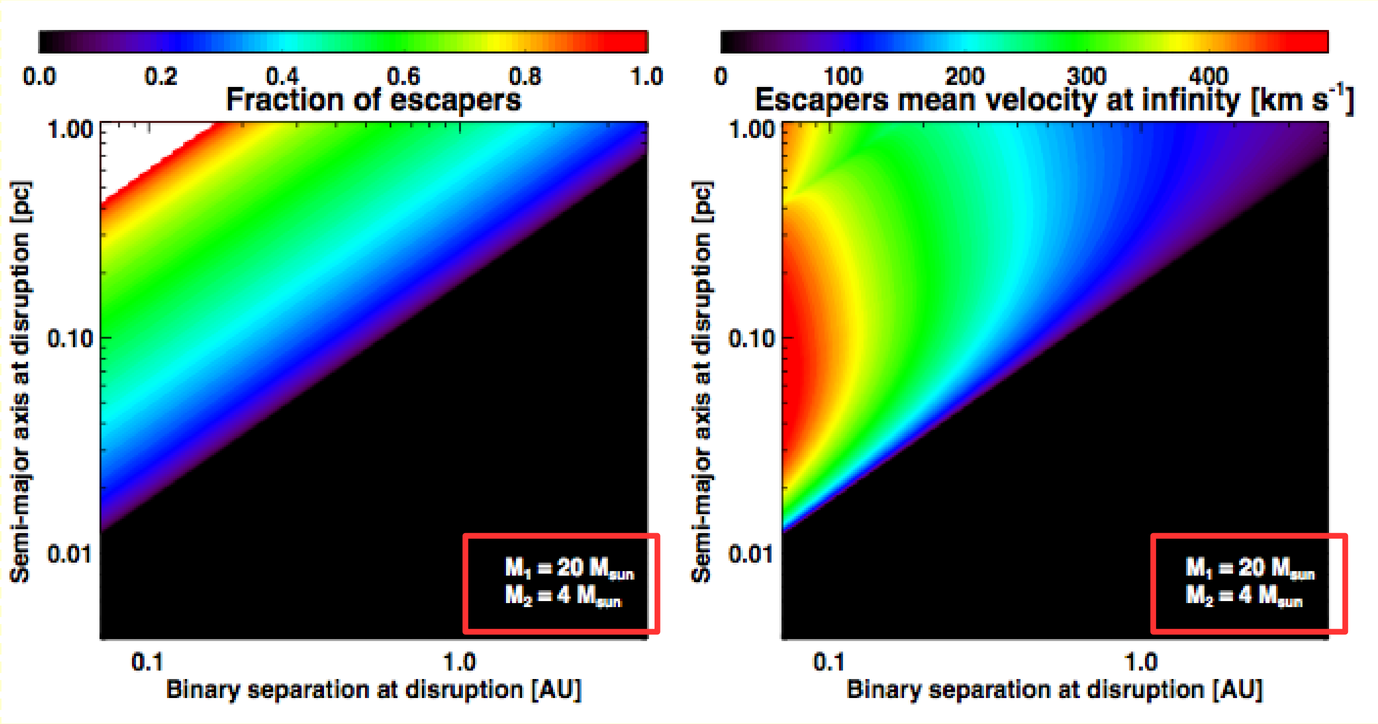
Time

S-stars and Hypervelocity stars:
by-products of binary supernova disruptions?



→ possible to get eccentricities comparable to those of the S-stars. Same for inclination, if internal and angular momentum vectors are *misaligned*

S-stars and **Hypervelocity stars**: by-products of binary supernova disruptions?



→ possible to get velocities at infinity comparable to those of the hypervelocity stars, but ~ maximally hard binaries are required before disruption

Summary

Tidal interaction between binary stars and their natal gas disk leads to both inward migration and hardening of binaries

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

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

Caveats:
- gas accretion? disk depletion timescale?
- star-star interactions?
- what happens before (low-mass binaries)?
- what happens next (merge, cavity opening)?

Supernova disruption scenario:

. may account for both the S-stars and the hypervelocity stars
. probability distribution? → need for population synthesis models including the migration and the hardening of binaries