The astrophysics of extreme mass-ratio inspiral sources

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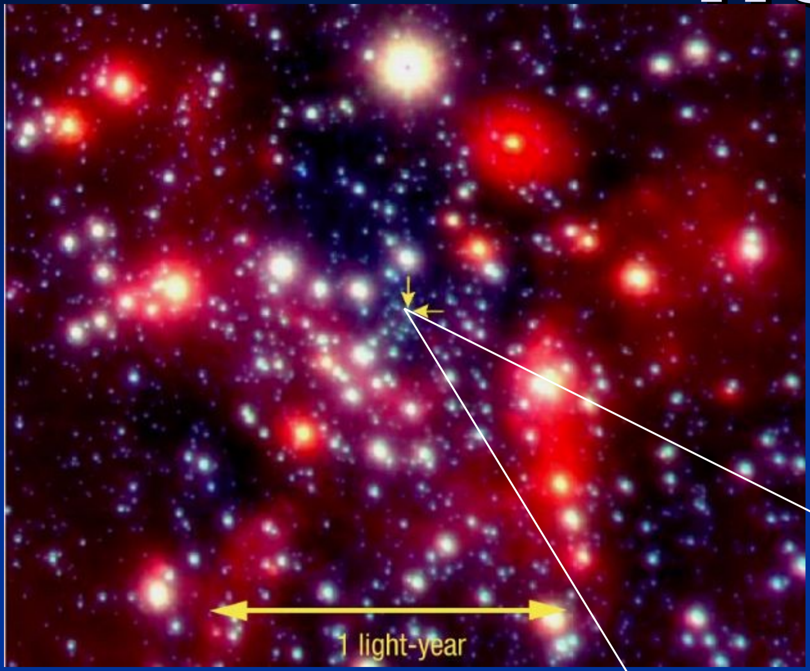
Overview

- Motivation: why EMRIs?
- Stellar dynamics and content near massive black holes
- Part I: the pure inspiral problem
  - Inspiral dynamics
  - A critical length scale
  - Mass segregation
  - Resonant relaxation
  - Eccentricity distribution
- Part II: alternative routes to EMRIs
  - EMRI formation in accretion disks
  - Binary disruption
  - Remnants of ultra-luminous X-ray sources

Why are EMRIs important?

- Detailed tests for general relativity
- Stellar content very close to massive black holes
- Stellar dynamics very near massive black holes
- Mass distribution of massive black holes
- Spin distribution of massive black holes; merger history
- Accretion disks
- Do intermediate mass black holes exist?
- Are massive black holes really black holes? (Or, let's say, boson stars?)

Stars near massive black holes



Infra-red observations of the Galactic center

- Very dense environment of stars
- Density diverges as a power-law: $n \sim r^{-(1.5-2)}$ (Alexander 1999)
- Short relaxation times (t_r<10 Gyr)
- Black hole dominates dynamics within ~1 pc.

See talks by Tal Alexander and Melvyn Davi

Bahcall & Wolf 1976, 1977; Alexander 1999; Genzel et al. 2003

Part I

The pure inspiral problem

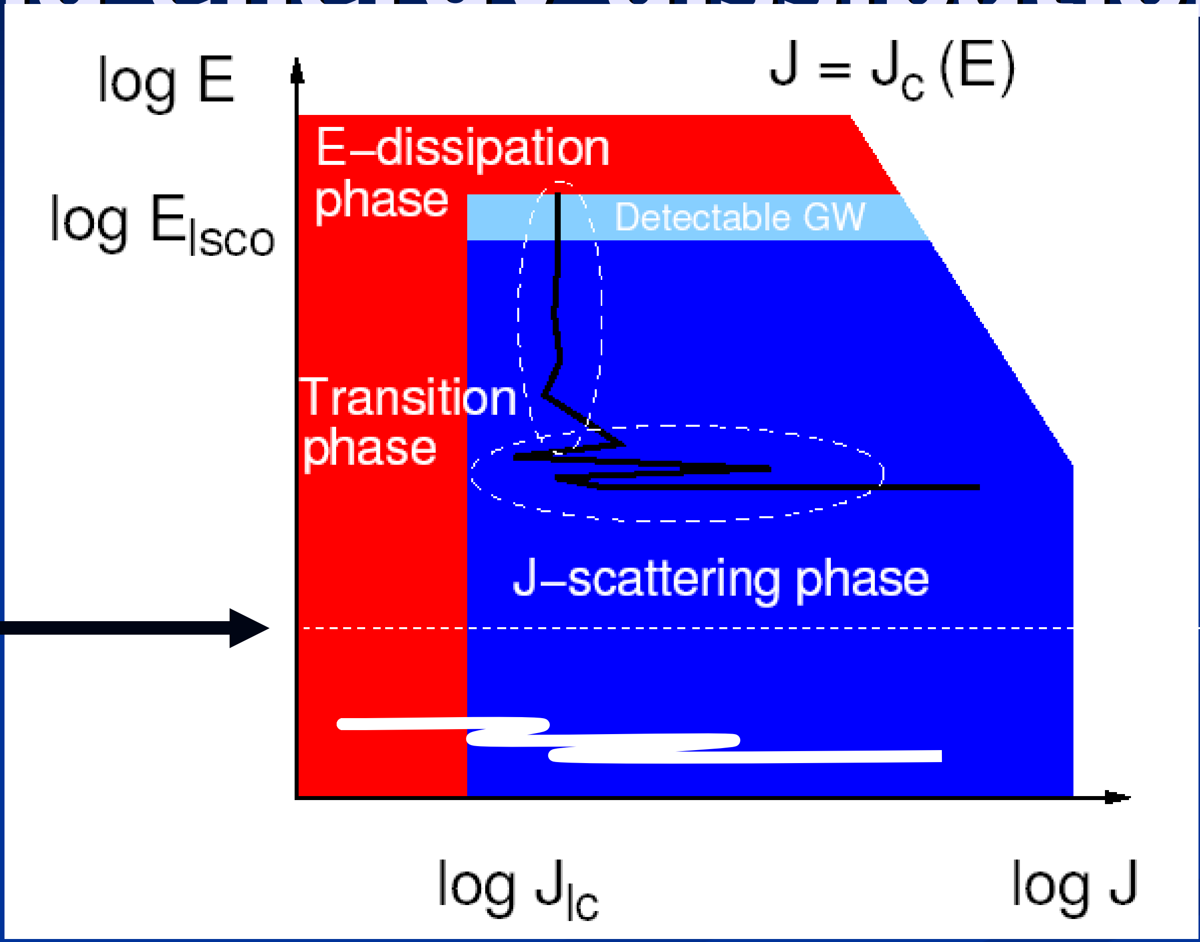
"What is the rate at which detectabl
form in a system of single point part
near a massive black hole?"

Hils & Bender 1995; Sigurdsson & Rees 1997; Miralda-Escude & Gould 200
Freitag 2001, 2003; Ivanov 2002; Gair et al 2004; Hopman & Alexander 20
De Freitas Pacheco et al. 2006

How to get near a massive BH

Bursts of GWs may be observable in our own Galactic center (Rubbo et al. 2006)

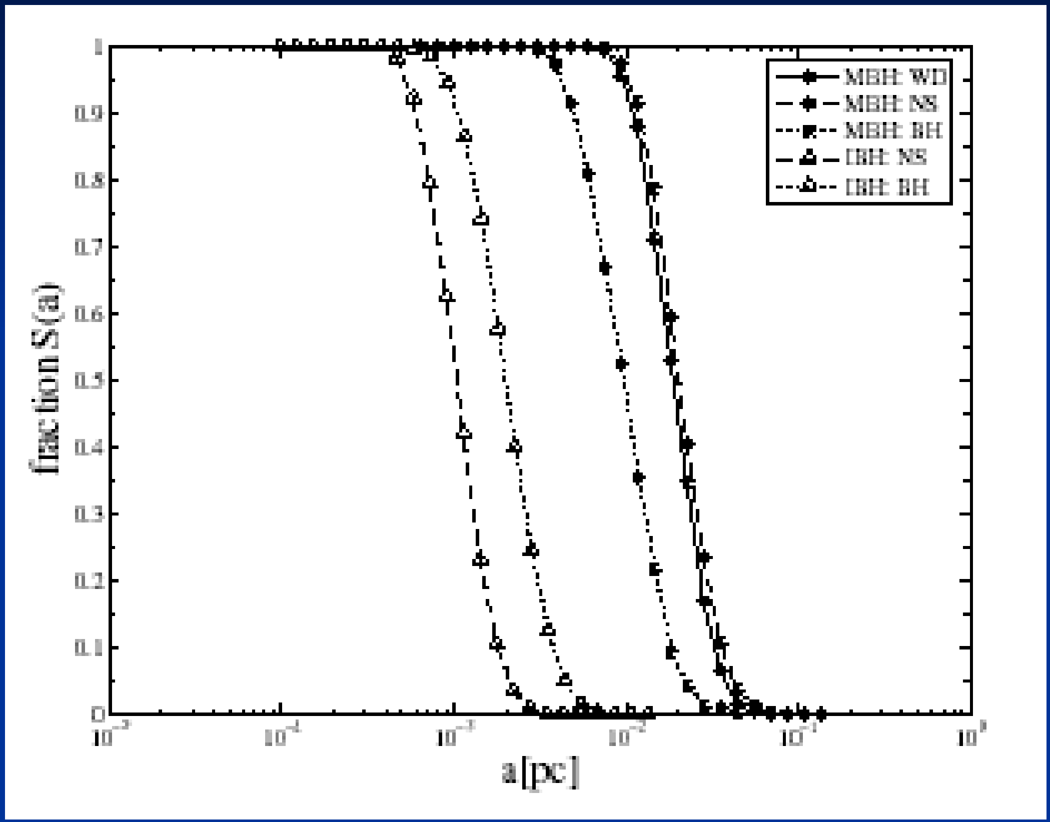
Angular momentum scattering and energy dissipation



Critical scale determined by equating inspiral time and scatter time near the LSO

Hils & Bender (1995); Hopman & Alexander (2005)

EMRI event rate

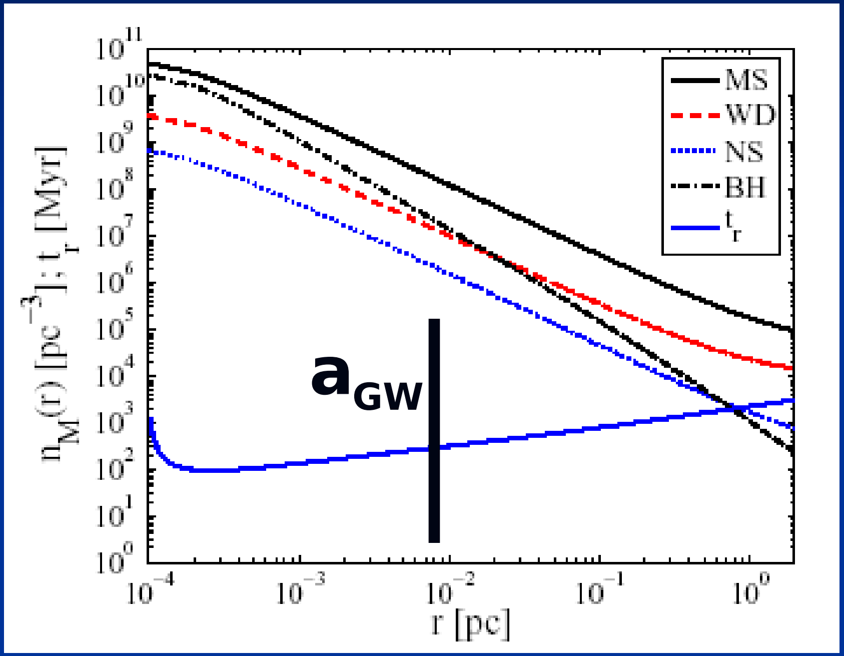


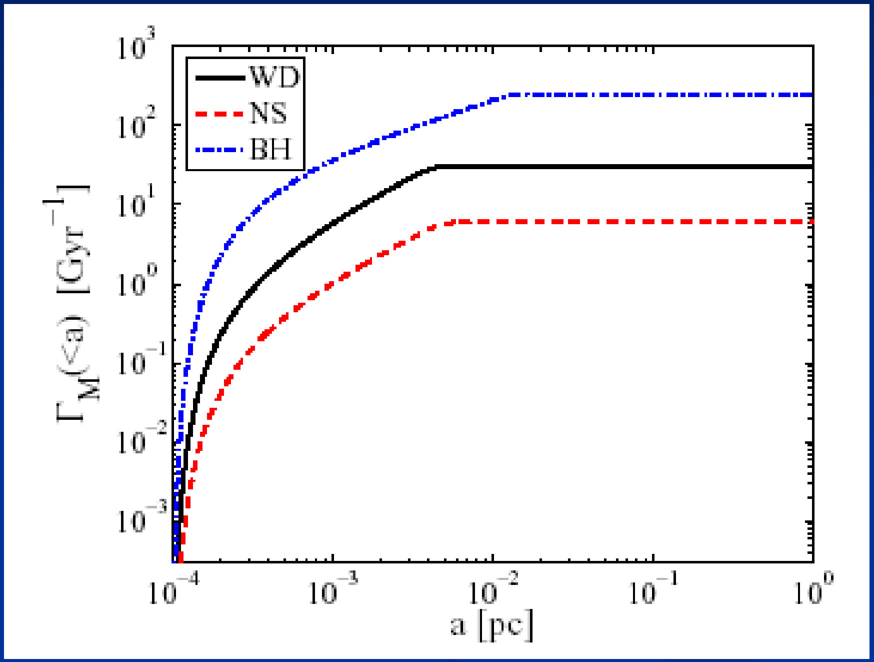
Hopman & Alexander (2005)

- Critical distance at a_{GW} =0.01 pc
- Nature of EMRIs determined by dynamics < a_{GW}
- Event rate: integrate diffusion expression over inspiral probability

$$\Gamma_i = f_s \int_0^\infty \frac{\mathrm{d}a N(a) S(a)}{\ln(J_m/J_{lc}) t_r(a)}$$

Dynamics within a_{GW} : mass segregation

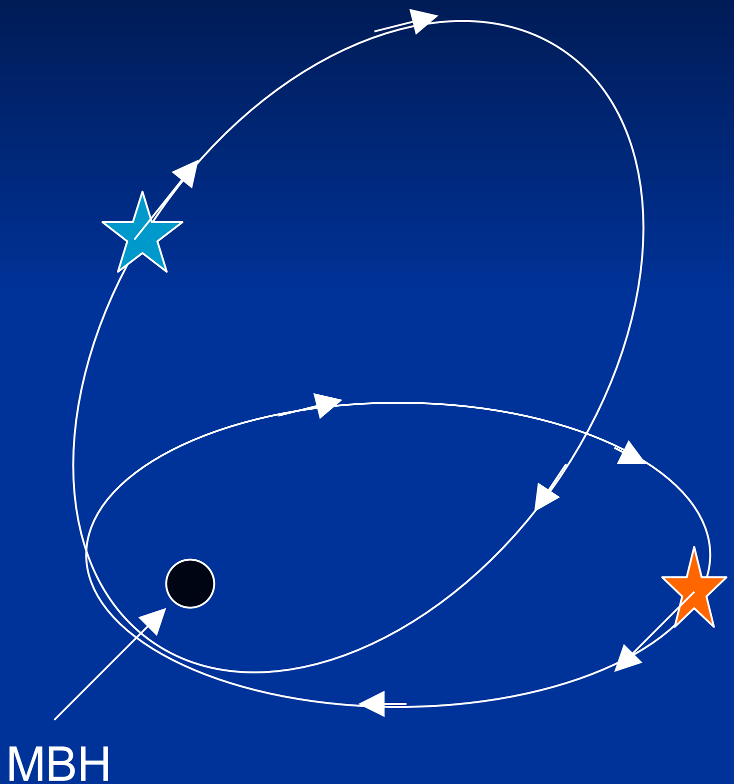


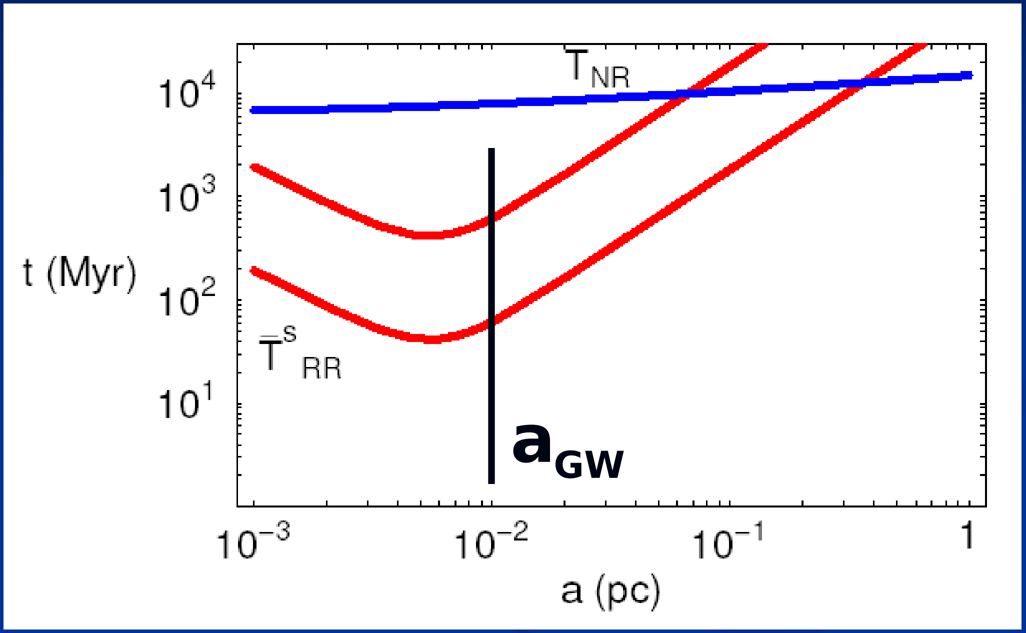


- Stellar BHs sink to center and dominate dynamics withi
- Relaxation time decreases due to presence of stellar BH

Hopman & Alexander (2006), Freitag, Amaro-Seoane & Kalogera (2006)

Dynamics within a_{GW} : resonant relaxation





T~(Mbh/Ms)P(a)

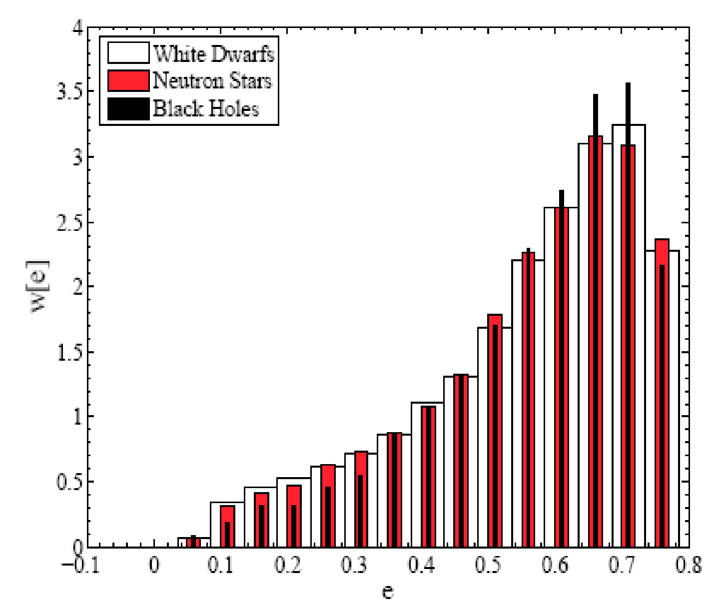
Resonant relaxation increases EMRI by
Crucial to include general relativity!

Rauch & Tremaine (1995); Rauch & Ingalls (1998)

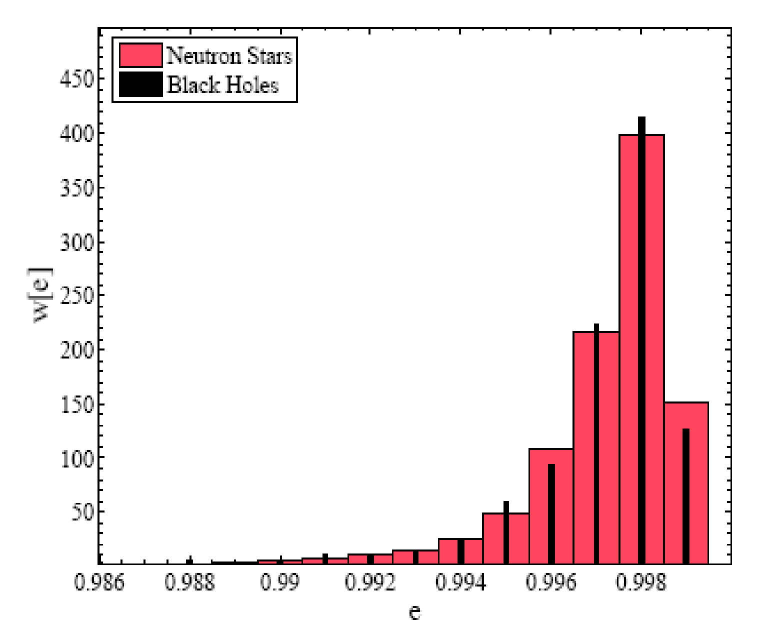
Hopman & Alexander (20

LISA EMRIs: high eccentricities at P=3 hrs

Massive Black Holes:



Intermediate Mass Black Holes:



Hopman & Alexander (2005)

Orbits must be modeled (pseudo-)rela
Hopman & Alexander 2005; Gair et al

Issues that should be addressed

- Mass segregation (Freitag 2001, 2003, 2006; Hopman & Alexander 2006b)
- Resonant relaxation (Hopman & Alexander 2006a)
- Simultaneous energy and angular momentum (Freitag 2001, 2003, 2006)
- General relativistic inspiral (Hopman & Alexander; Gair et al 2005)
- High resolution of inspiral (Hopman & Alexander)
- Stellar dynamics beyond radius of influence (Freitag 2001, 2003, 2006)
- Stellar population dependence on host galaxy (De Freitas Pacheco et al. 2006).
- Deviations from spherical symmetry (nobody (?))
- Non-relaxed systems (nobody(?))

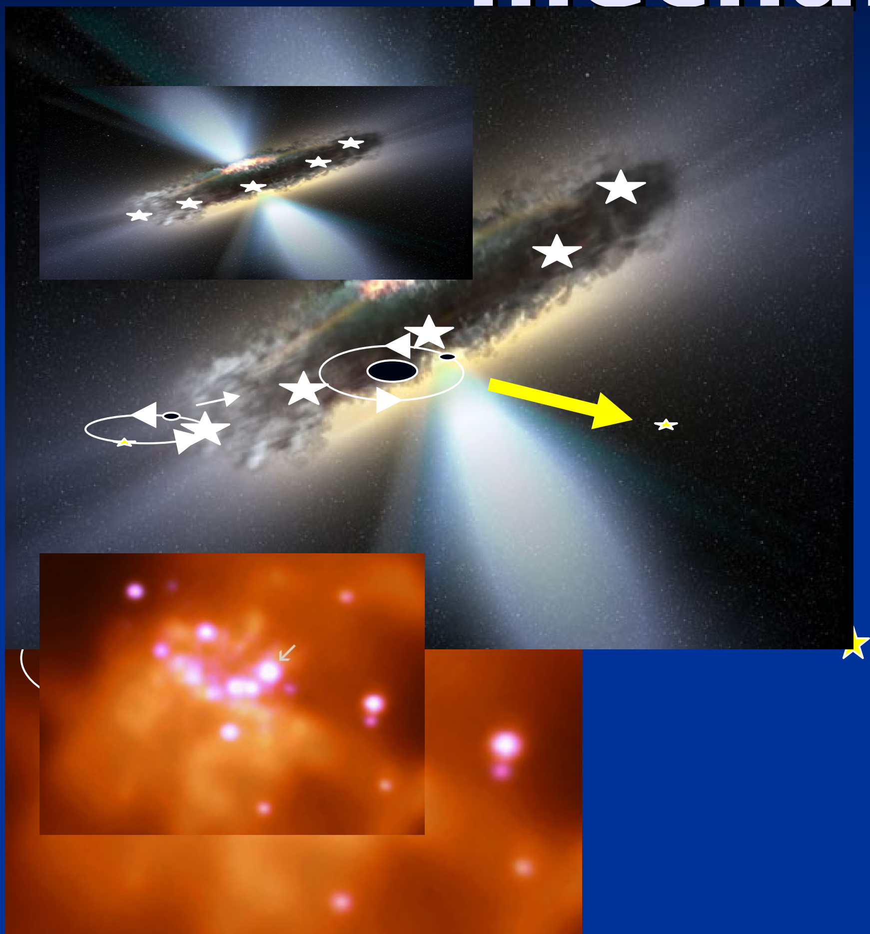
Part II

Alternative routes to EMRIs

**"What is the rate at which detectable
form by other mechanisms than the p
inspiral problem?"**

Levin 2003, 2006; Miller et al. 2005; Hopman & Portegies Zwart 20

Indirect EMRI capture mechanisms



Stars can be formed in accretion disks and spiral in due to interaction with gas (Levin 2003, 2006)

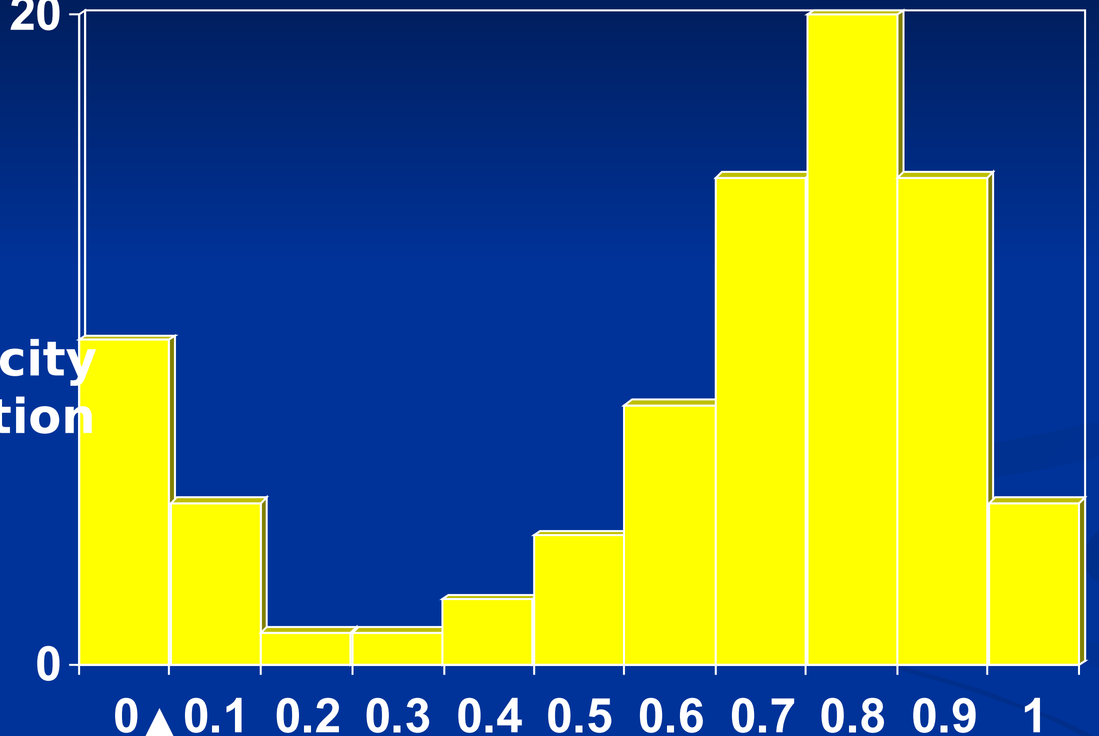
Binary stars are tidally disrupted, forming a hyper-velocity star and an EMRI (Miller, Freitag & Hamilton 2005)

Stars can be tidally captured by intermediate mass BHs. After an ultraluminous X-ray phase, they leave the main sequence and spiral in (Hopman et al 2004, Hopman & Portegies Zwart 2005)

Efficient loss-cone refilling by triaxiality (Holley-Bockelman et al. 2006) and massive perturbers (Perets, Hopman & Alexander 2006)

Indirect EMRI formation leads to *low* eccentricity

A bimodal distribution of eccentricities?



Eccentricity distribution

Eccentricity

Indirect EMRI formation (accretion disk, binary disruption, tidal capture, …)

Direct captures

Conclusions

- Direct captures: event rate of ~100/Gyr/MBH, but rather uncertain. Stellar BHs dominate rate
- Rates depend on dynamics within a_{GW}~0.01 pc: mass-segregation, resonant relaxation, ...
- Direct capture sources are eccentric
- Indirect capture leads to low eccentricity EMRIs