[Eccentric massive black holes for LISA]

Pau Amaro-Seoane

[Physical scenario]

Physical scenario

Clustered clusters 24pt

I. Hierarchical models ⇝ formation structures, down to galaxies

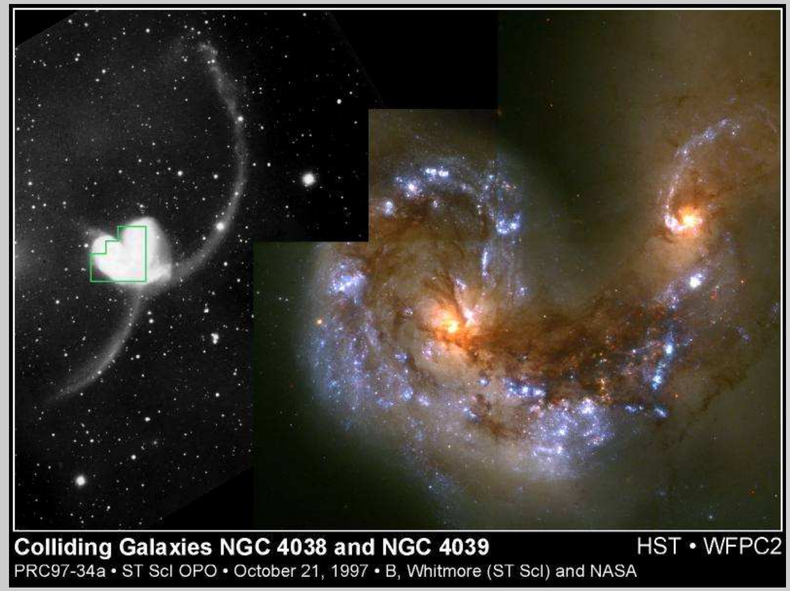
II. Galaxies at least one merger

III. Example → The Antennæ

IIII. Young massive star clusters form in such perturbed-gas- rich enviroments (HST)

𝍸. Gas piles up → collision → grav unstabil. → SF

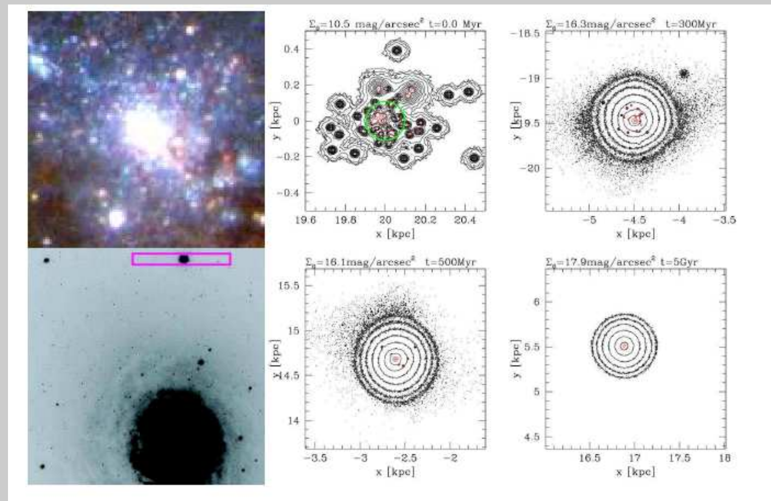
𝍸 I. SF simul. suggest result off-centre collision of two clouds → binary stel cluster (Fujimoto & Kumai 97, Bekki et al. 04)



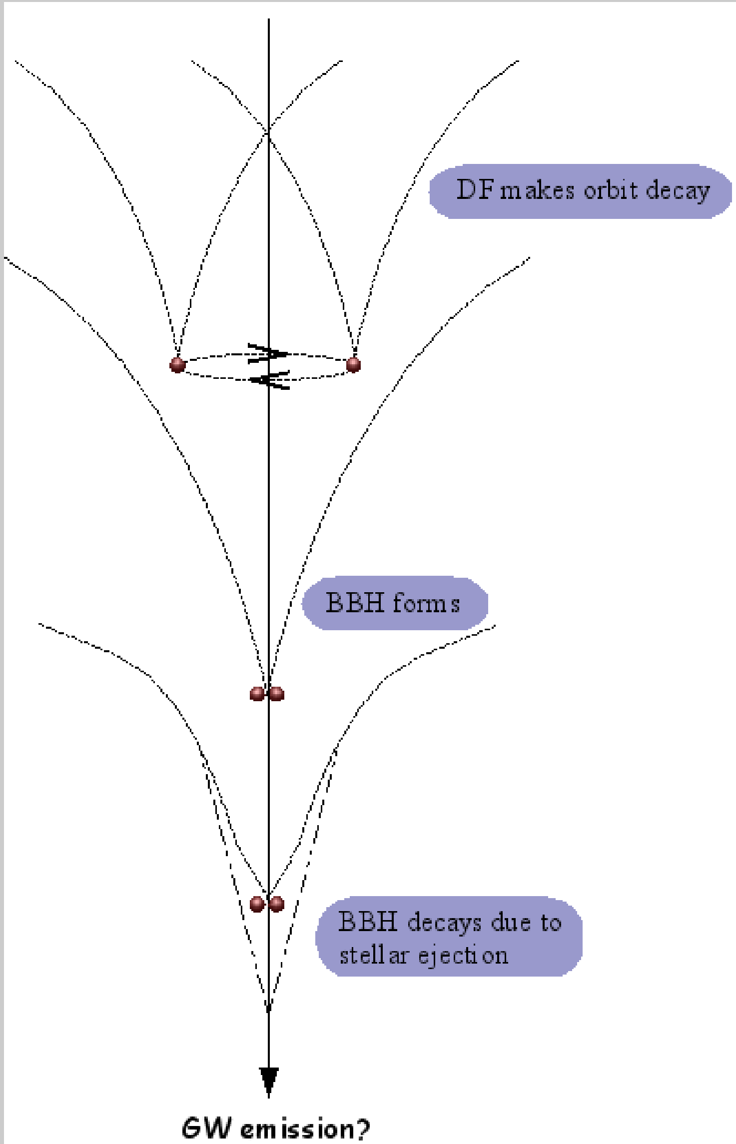
Clustered clusters

- Complexes $\sim$ few 100 pc
- Clusters harbour $\sim 10^5$ stars within $\sim$ few pcs and are older than 5 Myrs

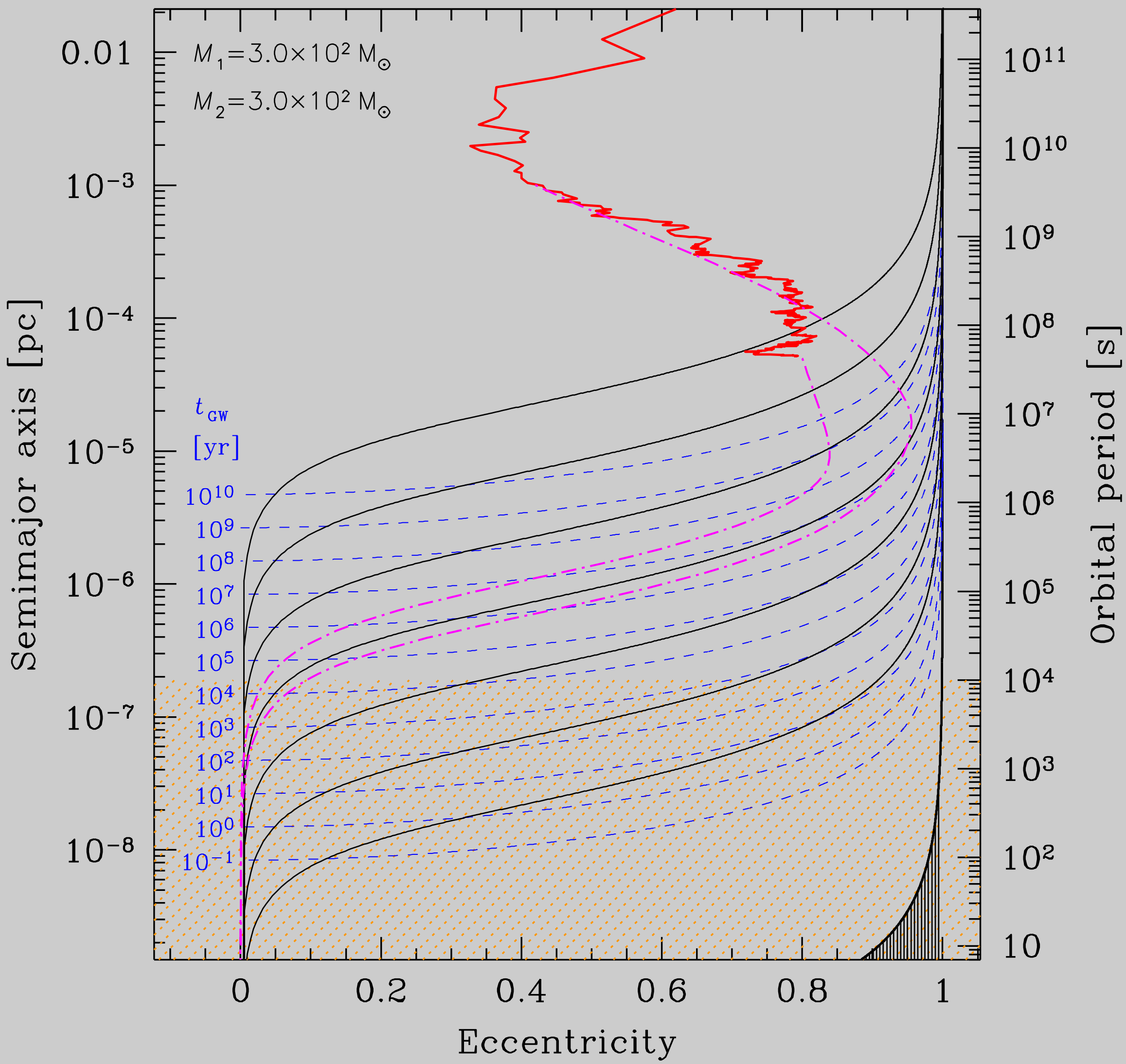
- Clust complexes progenitors of UCDGs (Fellhauer & Kroupa 02, 05)
- Dieball et al 02: Significant fraction of clusters is member of a bound group
- In the MCs the clusters significantly flattened suggesting rotation due to off-centre collisions
- Formation of W3 in NGC7252 as prod of clust mergers
- IMBHs lurking in their centres



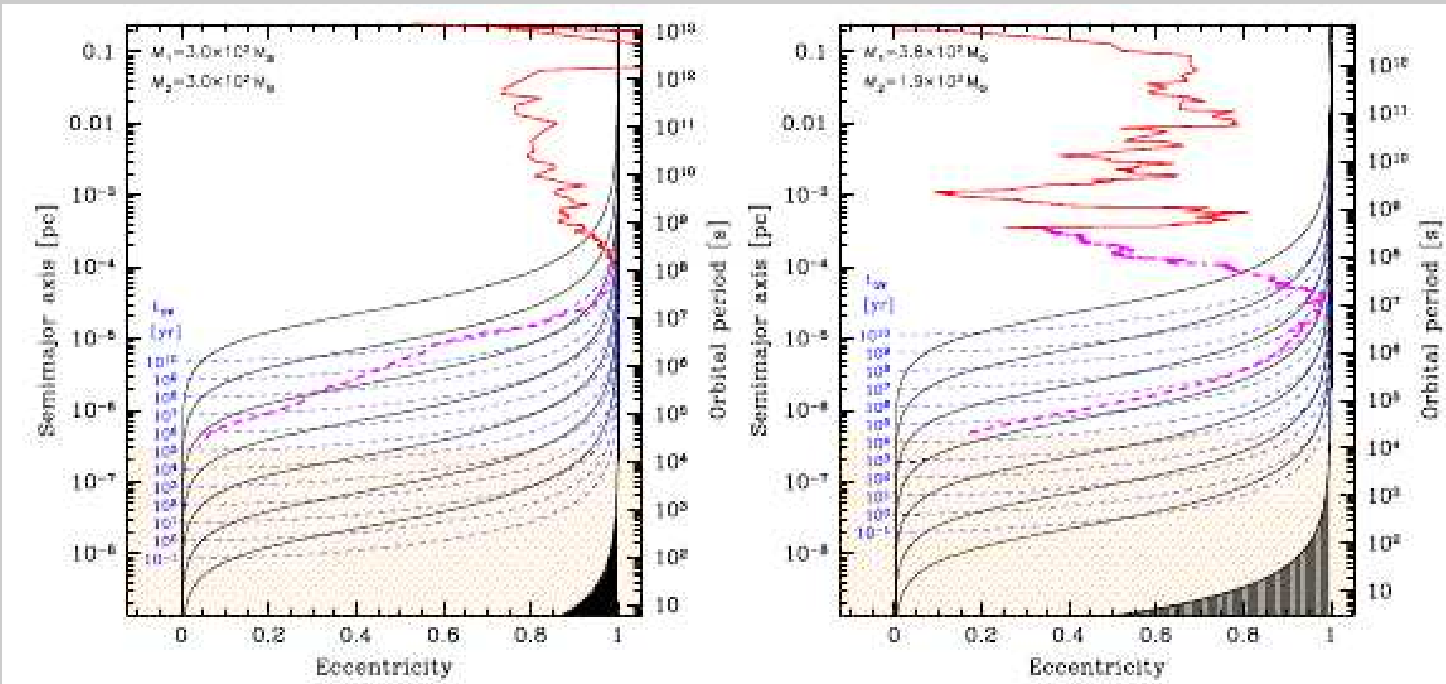
[What happens
to the binary?]



- ☐ DF sink $\mathcal{M}_{\bullet}$s to the centre
- ☐ Binary forms
- ☐ Slingshot ejections help decay
- ☐ Is there a "hang up"?
- ☐ How will the binary evolve?
- ☐ We solve the initial evolution with direct-summation $N-$body code and the ulterior phase with scattering processes with PN corrections

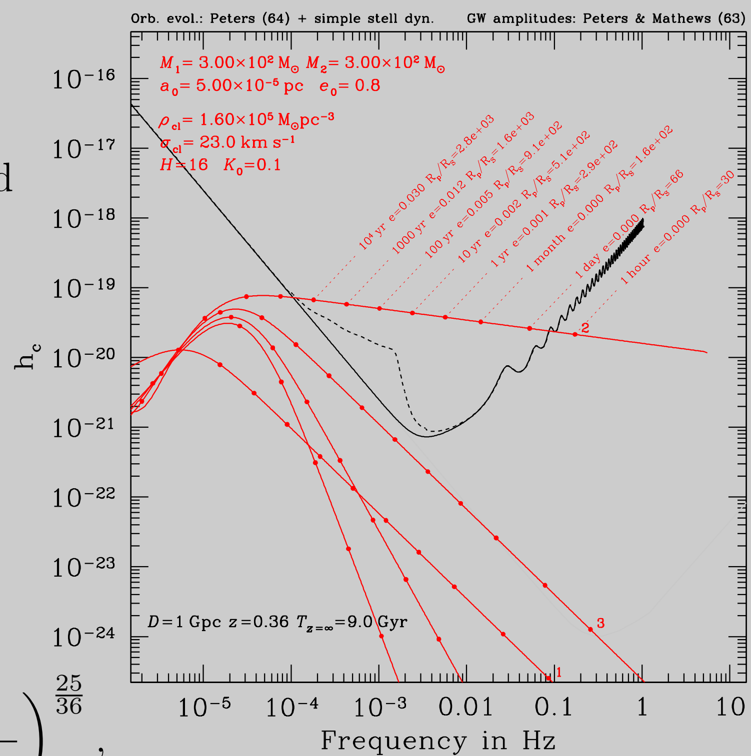


M_1=3.0×10² M☉
M_2=3.0×10² M☉
t_{GW} [yr]
Semimajor axis [pc]
Orbital period [s]
Eccentricity


Semimajor axis [pc]
Orbital period [s]
Eccentricity
Semimajor axis [pc]
Orbital period [s]
Eccentricity

[What will see LISA?]

- Char ampl first 5 harm quad grav rad ($300\,M_\odot + 300\,M_\odot$)
- Orbit evolved according to analyt. model from last point simul
- Source at a distance $D = 1\,\mathrm{Gpc}$
- Noise curve $\sqrt{f\,S_h(f)}$ for LISA + Galactic binary white dwarf confusion background (grey)
- Position of the source at various times
- The small residual eccentricity induces a difference in the phase evolution of the $n = 2$ signal compared to a circular inspiral
- If source followed from a time t_{mrg} before merger until merger, the accumulated phase shift is



$$\Delta\psi_e \simeq 1.0 \left(\frac{e_{10^{-4}\mathrm{Hz}}}{0.05}\right)^2 \left(\frac{t_{\mathrm{mrg}}}{1\,\mathrm{yr}}\right)^{\frac{17}{12}} \left(\frac{\mathcal{M}_z}{1000\,M_\odot}\right)^{\frac{25}{36}},$$

- with $\mathcal{M}_z \equiv (1+z)(M_1 M_2)^{3/5}(M_1+M_2)^{-1/5}$ is the redshifted chirp mass
- For $e_{10^{-4}\mathrm{Hz}} = 0.07$, the eccentricity should be detectable ($\Delta\psi_e \geq 2\pi$) if observations span at least the last 3-4 years before merger
- Whilst for the $e_{10^{-4}\mathrm{Hz}} = 0.3$ case, it shrinks to 17 days (!)

[What our old friend the photon cannot tell us about]

- ▷ With AO (i.e. HST) we can eyeball a couple of km/s measures (being very optimistic), if the target is about 5 kpc away and the timebasis is of 10 years
- ▷ The measures depends on many things, such as the availability of a hell lodestar for the AO, the possibility of having a good astrometric reference system
- ▷ Sensitivity limits will be those corresponding to a K-band magnitude of ~ 15, (B- MS stars at 8 kpc, like S2 in the GC)
- ▷ In order to "see" an IMBH with traditional Astronomy, one has to resort to the VLT Interf. and one of the n-g instruments, the VSI or GRAVITY
- ▷ Only in this case can we hope to improve the astrometric accuracy by $\sim$ a factor of 10
- ▷ Then, and only then, we could be able to detect IMBHs, as we monitor(ed) SgrA* in our Gal. Centre
- ▷ Caveat: GRAVITY will not be ready until 2014 the soonest and it's not obvious at all whether the VLTI infrastructure will ever fullfil the necessary requirements, "`the technical problems are enormous`" (but, honestly, LISA is not exactly a toy, either, though LISA Pathfinder will fly soon)

What about GW Astronomy?

- We have clean sources: “Far away” from SMBHs binaries, EMRIs and WD background
- Detecting their GWs will tell us for *sure* that these are BHs and not other exotic objects
- The information contained in the waveforms will tell us about the IMBHs masses, distances, spins, inclinations, sky position etc
- For some of these parameters, the absolute error is as small as 1% (Porter & Cornish, 2008)
- This new source of GWs for LISA is a “clean” one, so that...
- The DA of these sources should not be too complicated and extracting the information buried in the waveforms will have tell-tale consequences

For **Theoretical Astrophysics**: Dynamics, Cosmography, evolution of Globular Clusters, checking the $M - \sigma$ relationship; For **General Relativity**:test of GR and alternative theories; test of no-hair Theorem (Kerr?)