European Science Foundation

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Universidad de Valencia

15 November 2010

Pulsars as probes for the existence of IMBHs

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Layout

- Known Black Hole classes
- Formation scenarios for the IMBHs
- IMBH candidates
- IMBH candidates (?) from Radio Pulsar data analysis
- Perspectives for the direct observation of IMBHs from Pulsar searches

Classes of Black Holes

Stellar mass Black Holes resulting from star evolution are supposed to be contained in many X-ray binaries: for solar metallicity, the max mass is of order few 10 M_{sun}

Massive Black Holes seen in the nucleus of the galaxies: masses of order ≈ 10^6 M_{sun} to ≈ 10^9 M_{sun}

Are Intermediate Mass Black Holes (IMBH) of masses ≈ 100 - 10,000 M_{sun} also part of the astronomical landscape ?

N.B. ULX in the Globular Cluster RZ2109 of NGC 4472 may be a stellar mass BH likely in a triple system [Maccarone et al. 2007 - 2010]

Formation mechanisms for IMBHs

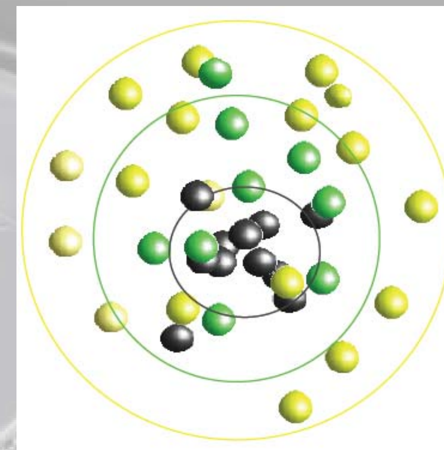
- 1 - Mass segregation of compact remnants in a dense star cluster

- 2 – Runaway collisions of massive stars in a dense star cluster

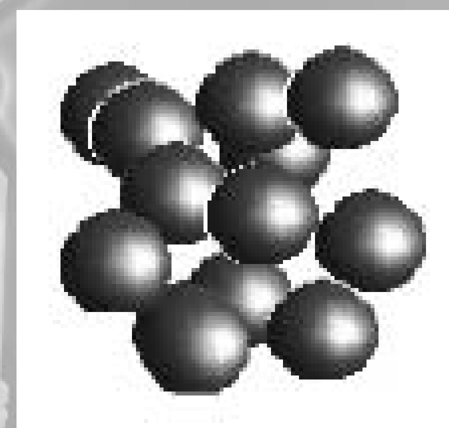
In both cases, the seed IMBH can then grow by capturing other "ordinary" stars in the cluster

Formation mechanisms for IMBHs - I

Dynamical friction leads to BH confinement in the core, creating a population of BHs in binaries evolving almost in isolation



Close gravitational encounters btw BHs lead to a hierarchical BH mass growth (via mergers & exchanges) with two outcomes:



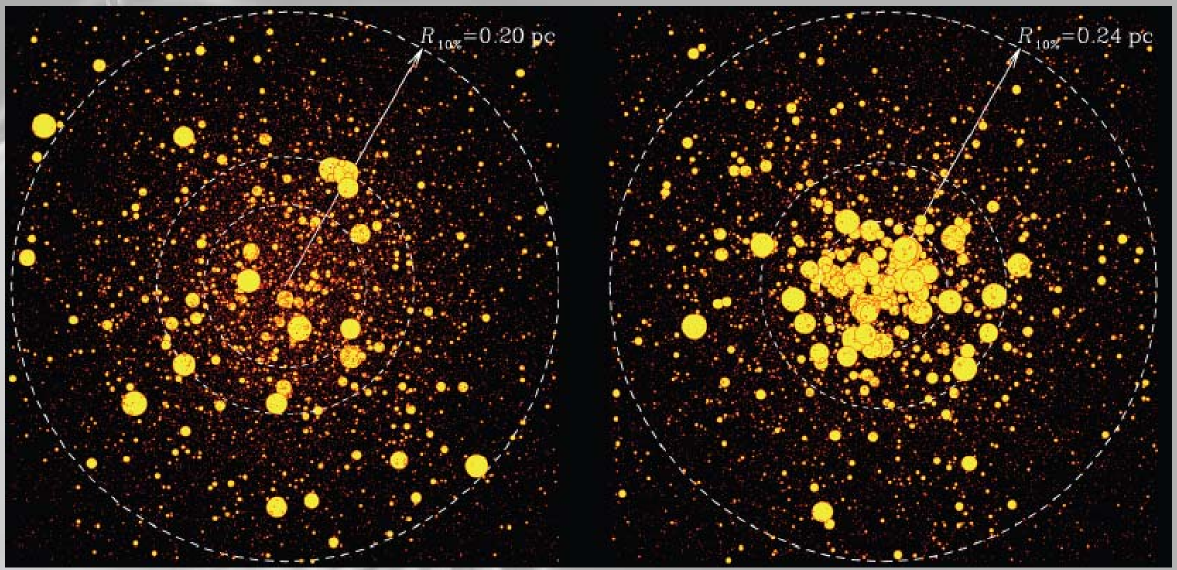
a] COMPLETE EVAPORATION OF ALL THE BHs

b] ONLY ONE IMBH (or binary IMBH) LEFT IN THE CORE

[Sigurdsson & Hernquist 1993]
[Kulkarni, Hut & McMillan 1993]
[Port.-Zwart & McMillan 2001]
[Miller & Hamilton 2002]
[Colpi et al. 2003]
[Miller & Hamilton 2004]

Formation mechanisms for IMBHs – II

Mass segregation of the more massive star speeds core collapse (Spitzer instability).



Core collapse happens on the dynamical friction time scale of the more massive stars:

$$t_{cc} \simeq 3\mathrm{Myr} \left(\frac{R_{\mathrm{h}}}{1\mathrm{pc}}\right)^{3/2} \left(\frac{M_{cl}}{5 \times 10^5\, M_\odot}\right)^{1/2}$$

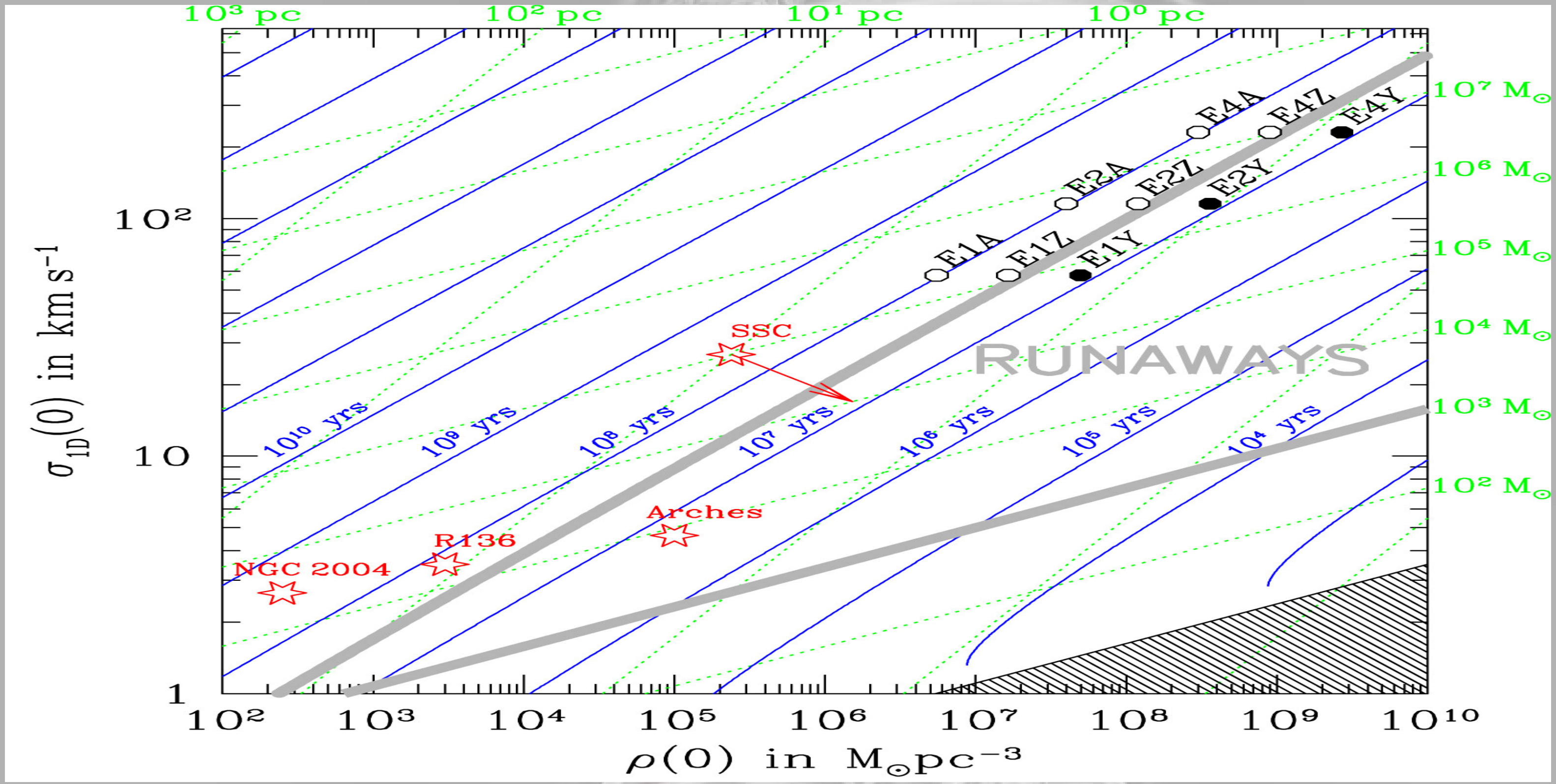
Collisions between stars can then proceed in a runaway fashion: growth of a very massive stars

At the onset of SuperNova explosiona (3 Myr) the very massive star collapses directly into a IMBH

[Portegeis-Zwart & McMillan 2002]
[Freitag, Gurkan & Rasio 2006 ; Gurkan, Fregeau, Rasio 2006]

Formation mechanisms for IMBHs – II

Special conditions for growing a IMBH in a young stellar cluster



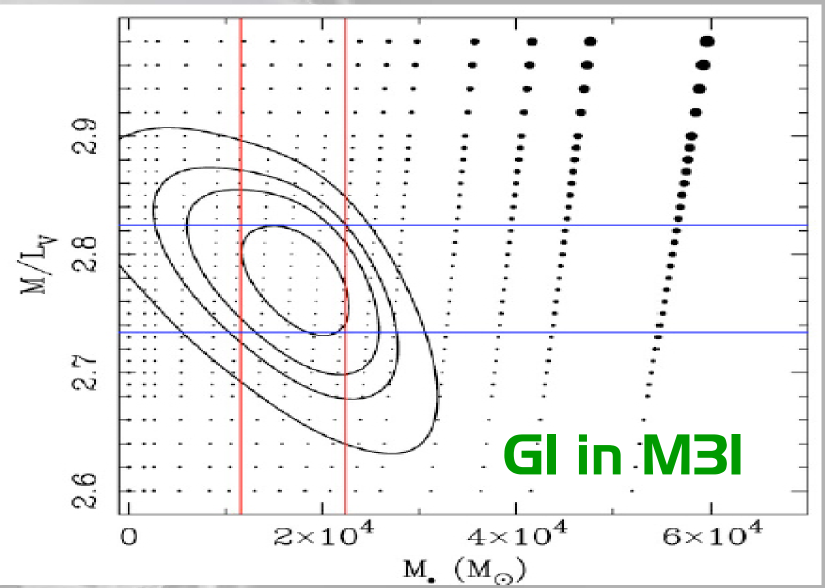
[Freitag et al. 2004]

Moreover, low metallicity seems required for having a low mass loss via wind and an efficient growth of a very mass star beyond 100 Msun [Glebbek et al. 2009]

Thus the "runaway star collision" scenario could be more likely applied to metal poor stellar systems

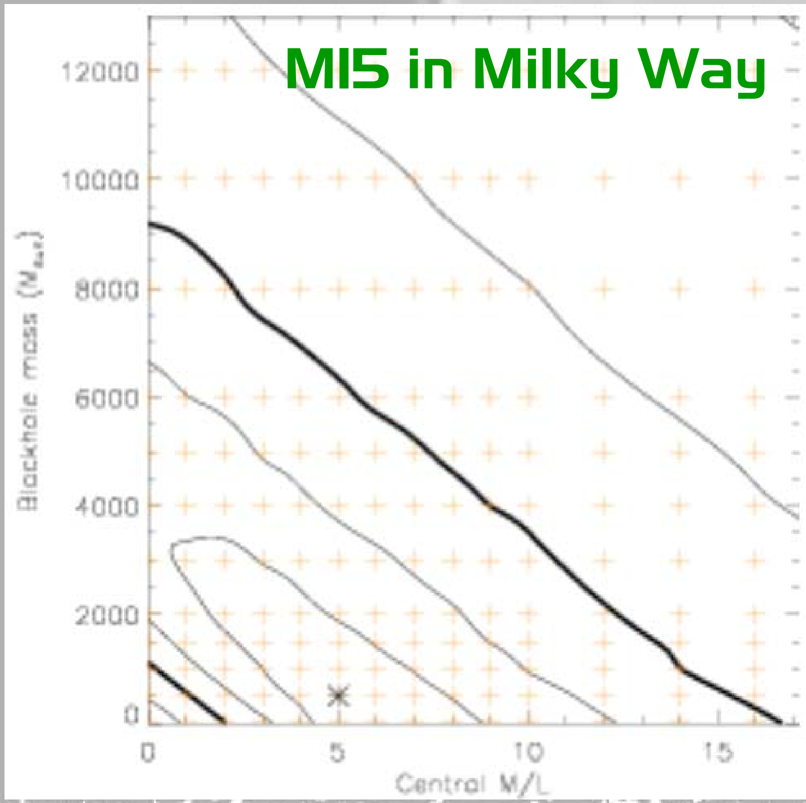
Non radio pulsar related observational evidences for IMBH candidates

HST surface brightness profile and the velocity profile (Keck spectra) suggest a 1.8 (±0. 5) x 10^4 M_{sun} IMBH on the basis of axi-symmetric models



[Gebhardt, Rich, Ho 2005]

[Van den Bosch et al. 2006]



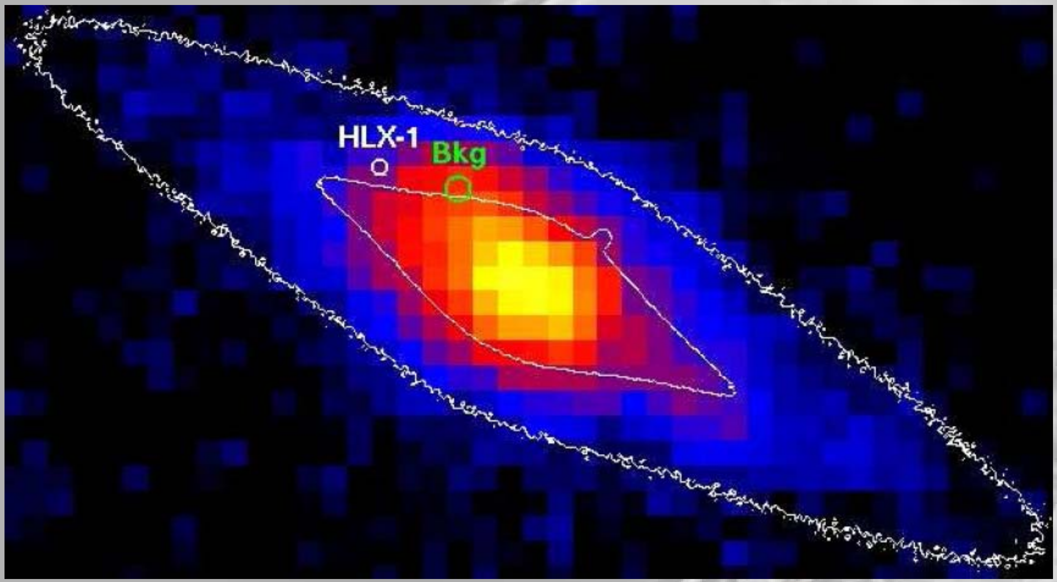
Orbit-based axi-symmetric models fit ground and HST l.o.s velocities and proper motions (a) to constrain the M/L ratio as a function of radius and (b) to infer a limit on the mass of 3400 M_{sun} in the central 0.05 pc --> a density of $7 \times 10^6 M_{sun}$ /pc^3

The central 4" appears to rotate

Non radio pulsar related observational evidences for IMBH candidates

[Farrell et al. 2009, 2010]

HLX-1 in the spiral galaxy ESO243-49



Hyper-luminous X-ray source with a luminosity of up to 10^{42} erg/s

X-ray, UV, optical and radio obs suggest it is an IMBH of $> 500\ M_{sun}$

Other non radio pulsar related signatures for IMBH candidates

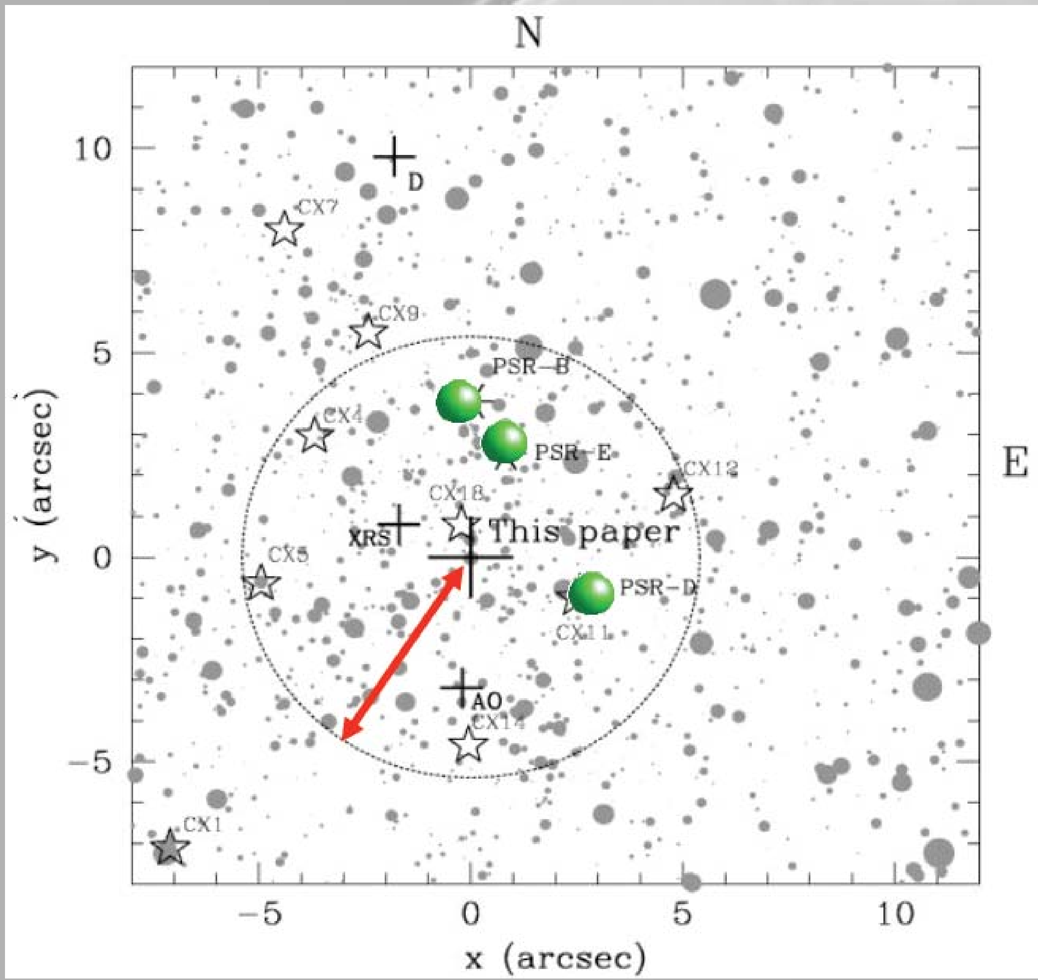
GCs showing a large ratio R_{core} / $R_{half\text{-}light}$:
compatible with about 30% of GCs in the Milky Way
[Baumgardt et al. 2005] [Trenti 2008][Umbreit et al 2009]

Keplerian rising velocity dispersion close to the sphere of influence R_{imbh} of the IMBH :
difficult to test due to small R_{imbh}
e.g. recently [Ibata et al. 2009 on M54] [Noyola et al 2008; Sollima et al 2009; van der Marel & Anderson 2010 on Omega Centauri]

N.B. Revised mass constraints [Maccarone & Servillat 2010]
from L_x and L_{radio} of the globular clusters :
now roughly compatible with the M_{BH}-σ relation [Tremaine et al 2002] seen for the central BHs in the Galaxies

Interesting cases from radio pulsar data: NGC 6752

5 MSPs discovered and timed @ Parkes in the GC NGC 6752



[D'Amico et al 2002]

3 MSPs close to the GC center of mass

all with high value of $|(dP/dt)/P|$

and two with negative (dP/dt)

…ascribing the negative dP/dt - as it is usually assumed – to the effect of the cluster potential well…

$$\left(\dot{P}/P\right)_{\rm obs} = (a_l/c) + \left(\dot{P}/P\right)_{\rm int}$$

$$|a_l/c| > |(\dot{P}/P)_{\rm obs}|$$

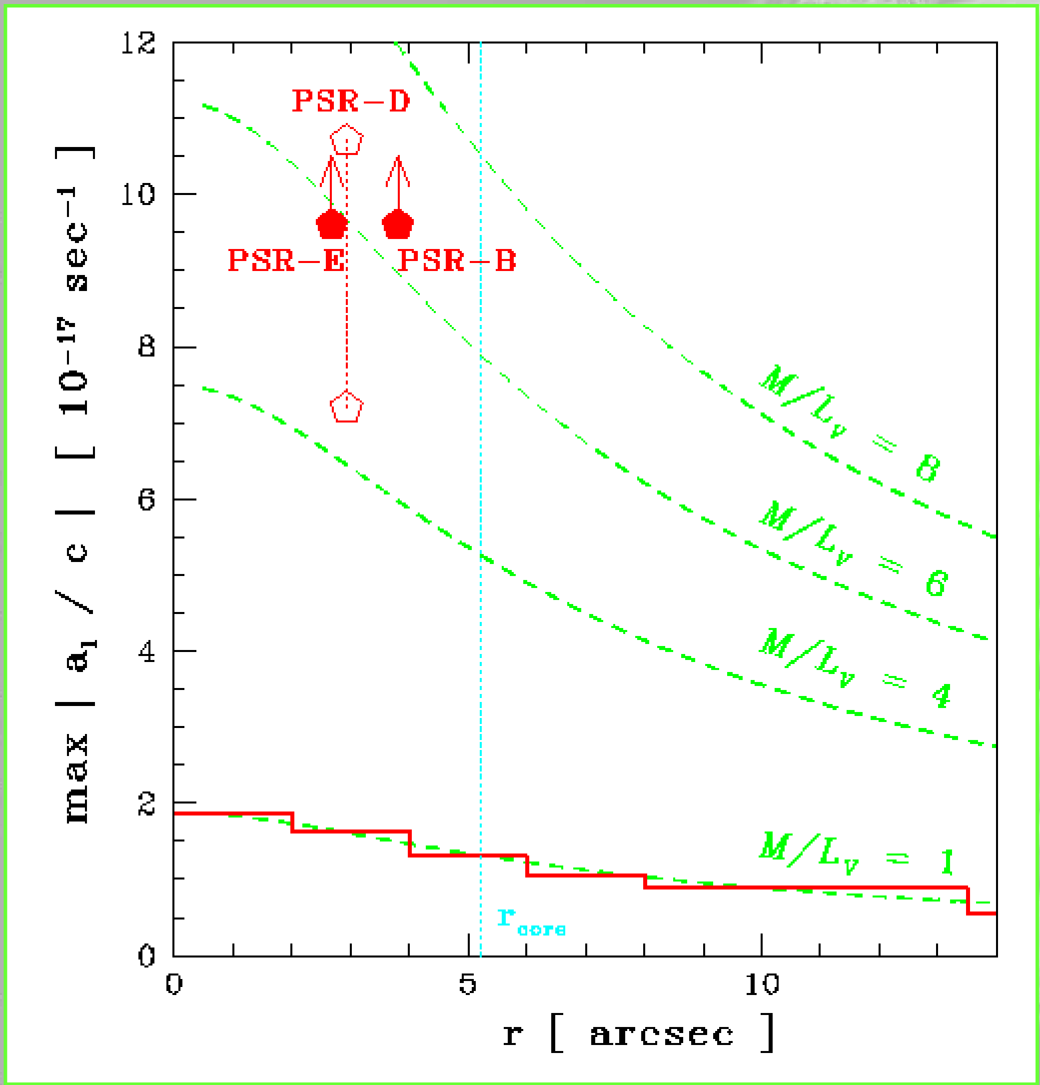
$$|\frac{a_{l,max}}{c}| \sim \frac{G}{c}\frac{M_{\rm cyl}(<\Theta_\perp)}{\pi D^2 \Theta_\perp^2}$$

$$|\frac{\dot{P}}{P}(\Theta_\perp)|_{\rm obs} < 5.1\times 10^{-18}\frac{M}{L_V}\frac{\Sigma_V(<\Theta_\perp)}{10^4 L_{V\odot}{\rm pc}^{-2}}{\rm sec}^{-1}$$

[Phinney 1992]

…one can derive **a lower bound to the Mass-to-Luminosity ratio M/L** for the central region of the globular cluster…

The case of the 3 MSPs in the core of NGC 6752



a unusually high

M/L>6-7

in the central regions of the cluster

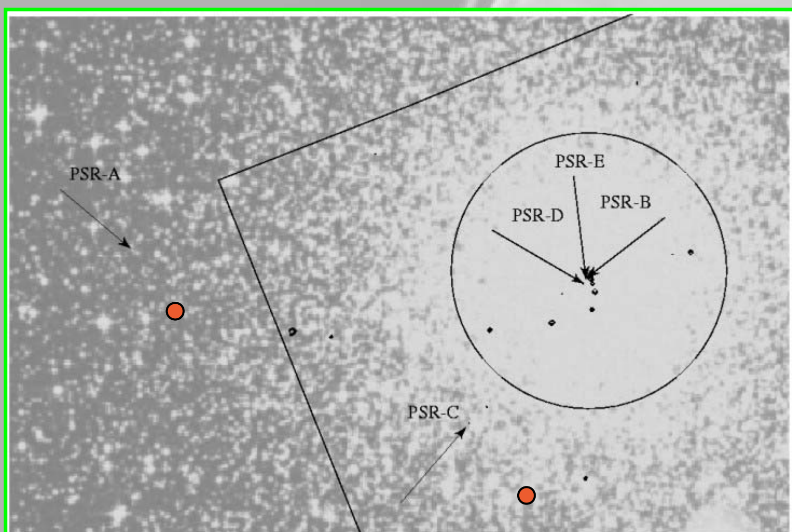
≈ 3400 Msun

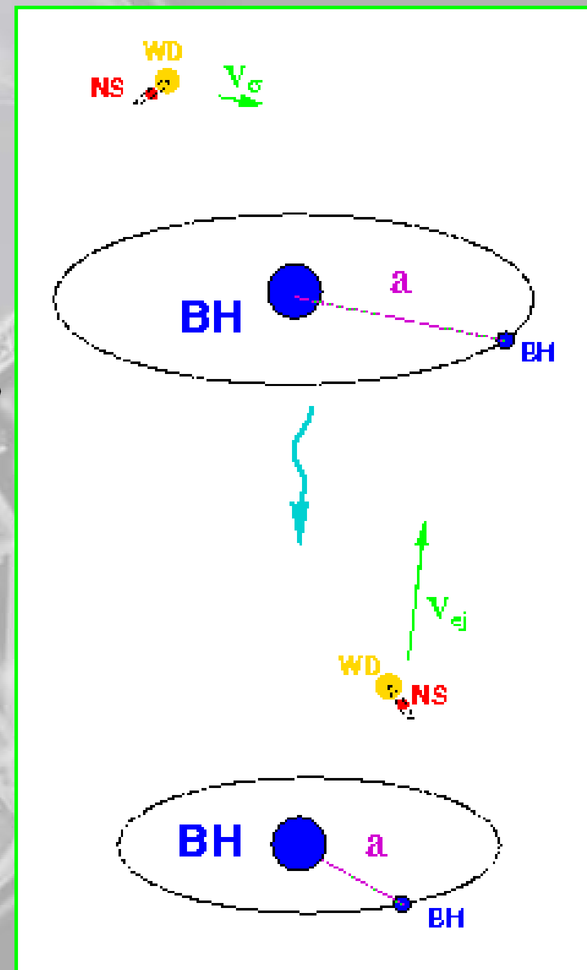
of low-luminosity matter in the inner 0.076 pc

[D'Amico et al 2002] [Ferraro et al 2003]

moreover…PSR-A in NGC 6752 is the most offset pulsar ever detected in a globular cluster and PSR-C is also a very offset one…

both pulsars probably ejected in the halo by a dynamical encounter in the cluster core occurred less than ≈ 1.0 Gyr ago
[Colpi, Possenti & Gualandris 2002]





a binary IMBH of mass [10-50 M_{sun}] appears the most probable center of scattering if the MSP has been recycled before the scattering

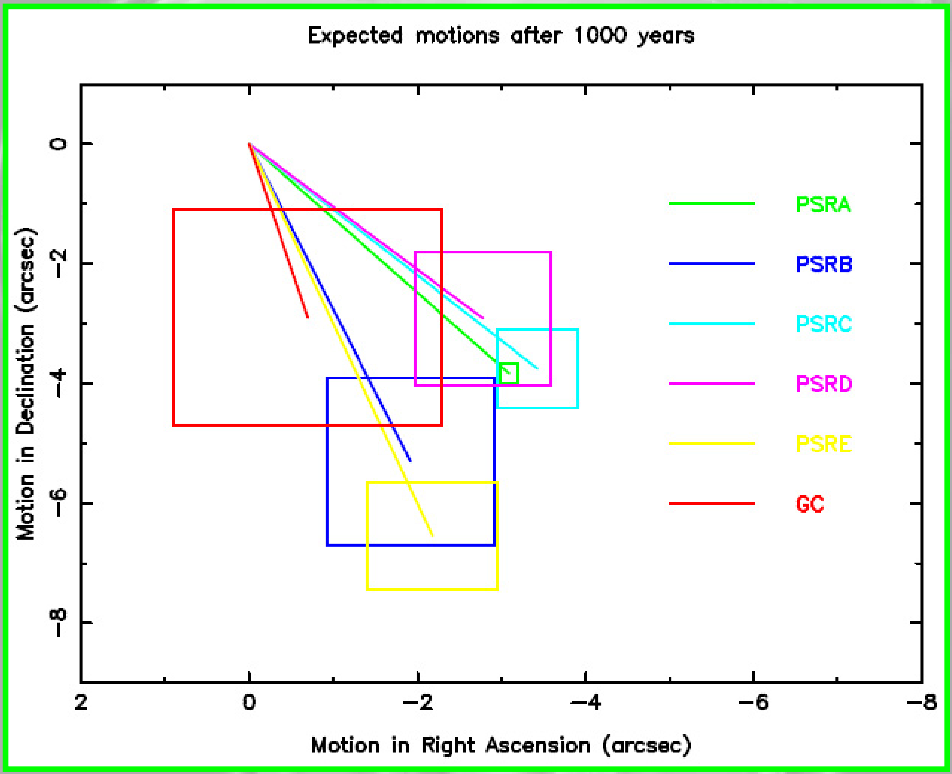
a single IMBH of 500 M_{sun} is viable if the MSP has been reycled after the scattering

[Sigurdsson 2003, Mar]
[Colpi, Mapelli, Possenti 2004]

..but is PSR-A really belonging to the globular cluster ?

The radial velocity of the binary "could" be compatible with a MSP+WD(of 0.2 M_{sun}) system at the cluster distance [Cocozza et al 2006, Bassa et al 2006]

… what about MSPs' proper motions?



[Corongiu et al 2011, in preparation]

The projected velocity vectors of PSR-A and PSR-C are consistent with each other and with that of PSR-D (one of the inner MSPs), but unconsistent wrt the optical determination of the cluster proper motion, and with the proper motion of the two inner MSPs with a negative dP/dt

Interesting cases from radio pulsar data: NGC 6624

After 19 years of timing @ Jodrell Bank of the isolated MSP PSR B1820-30A (P_{spin} = 5.44 ms)

[Lyne at al, in preparation]

the combination of the measured values of
dP/dt
d^2P/dt^2
& upper limits on d^3P/dt^3

↓

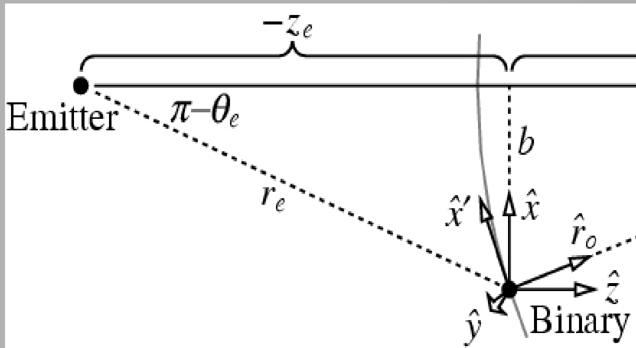
a unusually high M/L > 30-300 in the central regions of the cluster ?

↓

a IMBH of 100-5000 M_{sun} orbited by the MSP ?

Needed the measurement of d^3P/dt^3 for confirmation…

IMBH effects on timing of pulsars in GCs



[Jenet et al. 2005]

Calculated the expected TOA fluctuations induced by space-time oscillations due to a binary IMBH lying close to the line-of-sight btw a PSR and the Earth

For the case of a binary IMBH consisting of $10M_{sun}$ and 10^3M_{sun} components and a 10 year orbital period:

Globular Cluster	Pulsar	b (lyr)	R_I (ns)	R_{II} (ns)	Reference
47 Tuc	J0024-7204O	0.26	0.8	11	Freire et al. (2003)
47 Tuc	J0024-7204W	0.34	0.5	4	Camilo et al. (2000)
NGC 6266	J1701-3006B	0.18	1.6	50	Possenti et al. (2003)
NGC 6624	B1820-30A	0.37	0.4	3	Biggs et al. (1994)
M28 (NGC 6626)	B1821-24	0.12	4	200	Rutledge et al. (2004)
NGC 6752	J1910-5959B	0.38	0.4	2	D'Amico et al. (2002)
NGC 6752	J1910-5959E	0.49	0.2	0.9	D'Amico et al. (2002)
M15 (NGC 7078)	B2127+11D	0.19	1.4	40	Anderson (1993)
M15 (NGC 7078)	B2127+11H	0.37	0.4	3	Anderson (1993)

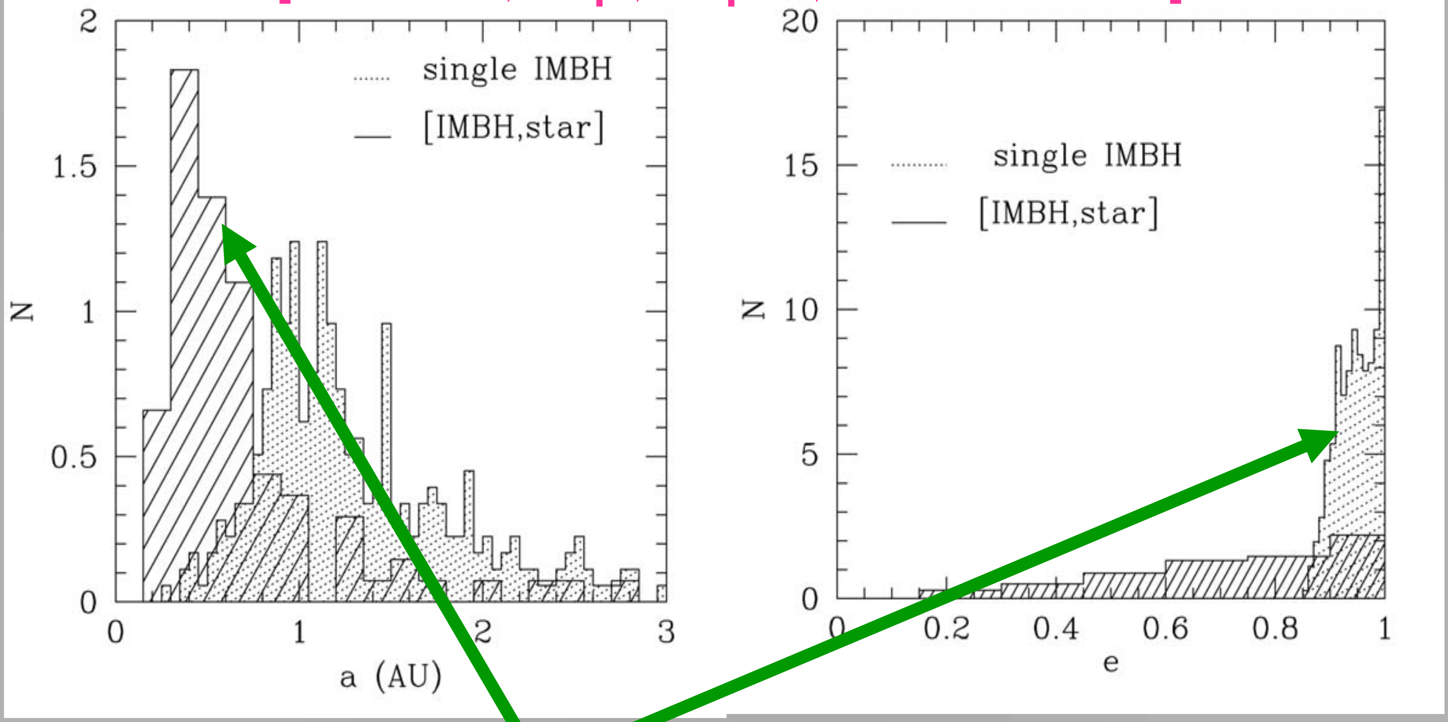
In similar geometrical configurations, the Shapiro delay effects are also very small [Larchenkoval & Lutovinov 2009]

Needed the measurement of the effects on at least TWO MSPs

Recycled Pulsar + IMBH binary in globular clusters ?

Statistical study of the process of dynamical capture of a MSP by a single or binary IMBH (100-300 M_{sun}) in a globular cluster

[DeVecchi, Colpi, Mapelli, Possenti 2007]



Typical orbital parameters of the captured MSP are
orbital separation ≈ 0.5-1.5 AU and eccentricity > 0.8

Recycled Pulsar + IMBH binary in globular clusters ?

Given the orbital parameters, the formed [MSP+IMBH] have relatively short lifetime before coalescence: of order ≈ 10^8 - 10^9 yr

The formation rate of [MSP+IMBH] is quite low: of order ≈ 10^{-11} yr

⇓

Given the number of known MSPs in GCs of the Galaxy (≈ 150) , the expected number of observable [MSP+IMBH] is of order $N_{MSP+IMBH} \approx 0.1$

if all the GCs with a known MSP would contain a IMBH

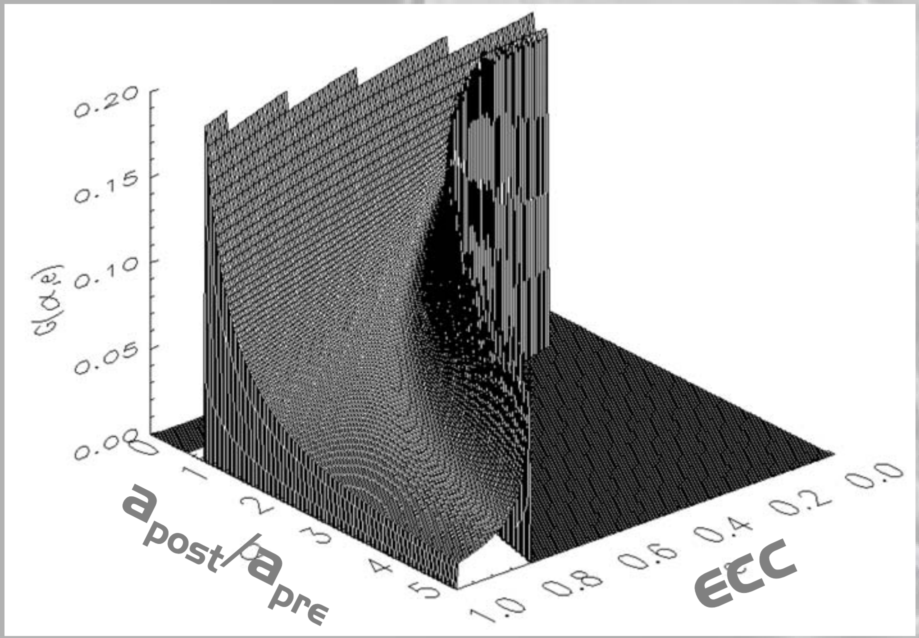
If SKA will unveil a 10 times larger population of MSPs in GCs then $N_{MSP+IMBH} >\approx 1$

i.e. SKA will discover a MSP+IMBH if 100-300 M_{sun} IMBHs are common in the GCs

[DeVecchi, Colpi, Mapelli, Possenti 2007-2008]

Young PSR+IMBH in dense super star clusters ?

Assuming that the very bright ULX sources (> 10^{40} erg/sec) are IMBHs accreting from a massive (> 15 M_{sun}) star [e.g. P.Zwart et al. 2004] one may study the conditions for the X-ray binary to become a [IMBH+YoungPSR] binary



[Patruno, Colpi, Faulkner, Possenti 2005]

The binary survives Supernova in the 99% of the case, even including strong kicks span

Post Supernova and orbital separation ≈ 1-10 AU while eccentricity span the whole range 0 - 1

Given those parameters, detection of a Young (<10 Myr) PSR in one such system would have been technically possible in the PM Survey

Young PSR+IMBH in dense super star clusters ?

So why no detection ? Assuming:

R = the ratio btw the # of [IMBH+massiveMS] binary ending as a IMBH+PSR binary and the # of bright ULX

f = the ratio btw the # of bright ULX and the total # of ULX N_{ULX}

b = the beaming factor

τ_{PSR} = characteristic life-time of the PSR

τ_X = characteristic life-time of the X-ray phase

$$N_{\mathrm{IMBH-PSR}} \simeq 20 f \left(\frac{\tau_{\mathrm{PSR}}}{10\,\mathrm{Myrs}} \right) \left(\frac{10\,\mathrm{Myrs}}{\tau_{\mathrm{X}}} \right) \frac{\Re}{200} \frac{10}{b} N_{\mathrm{ULX}}$$

[Patruno et al 2005]

Assuming no additional bias for detection wrt isolated Young PSRs:

$N_{IMBH-PSR}$ (observed in PMSurvey) = $f\ N_{ULX}$

Chances for LOFAR and SKA (sensitive to PSR at distances where $N_{ULX} >> 1$) ?


Thanks !!