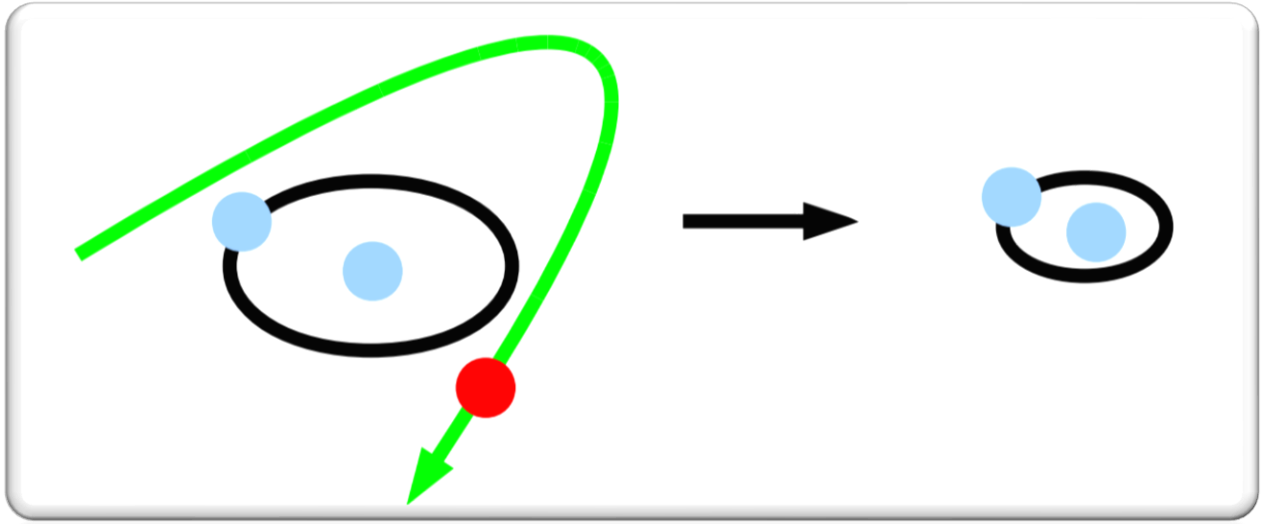
STELLAR BINARY HARDENING FROM SUB-SOLAR MASS PRIMORDIAL BLACK HOLES



Badal Bhalla

w/ Benjamin Lehmann, Kuver Sinha and Tao Xu

University of Oklahoma

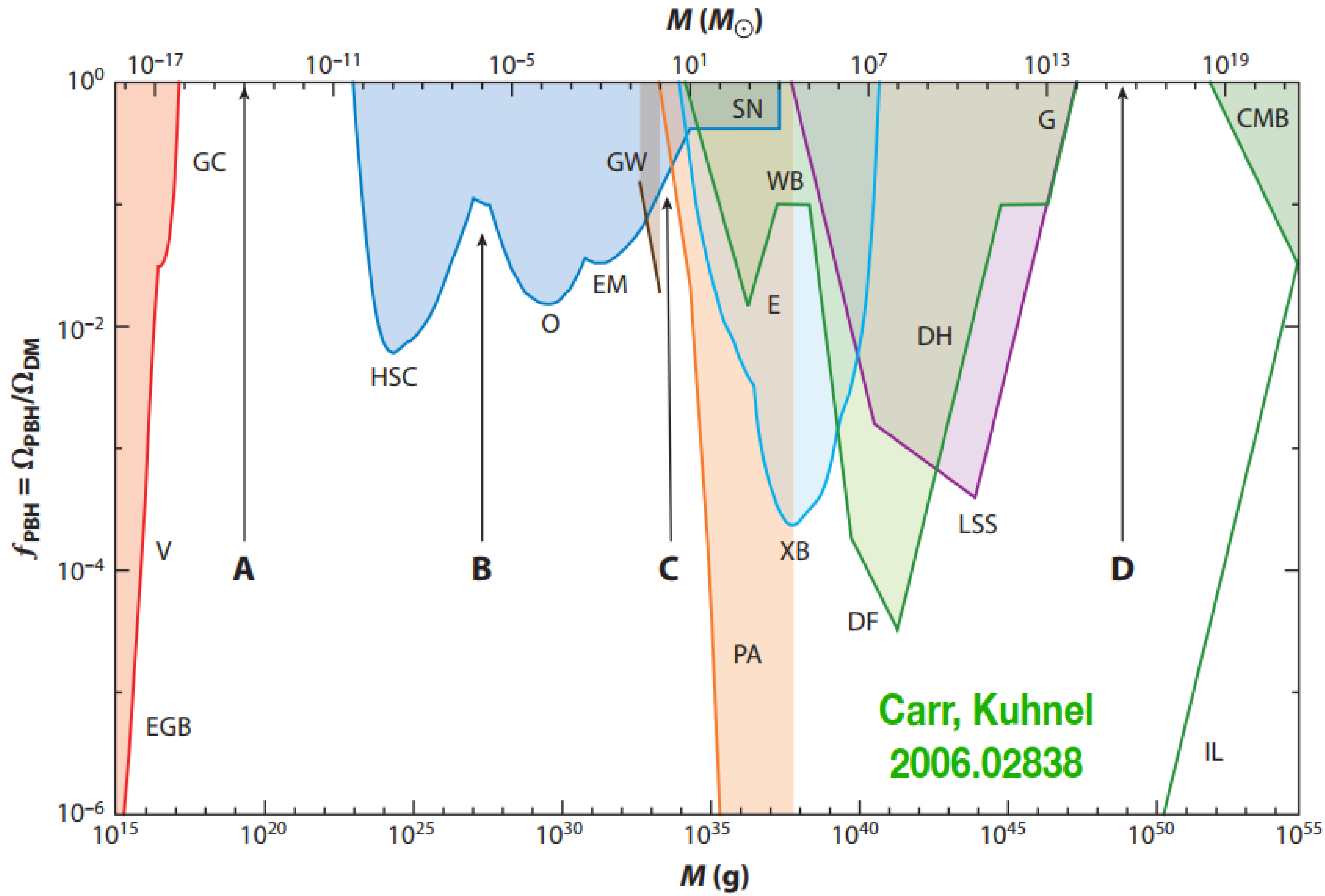
INTRODUCTION

- Dark Matter (DM) could be comprised of Primordial Black Holes (PBH).

- These Primordial Black Holes (PBHs) can exist in a wide mass window.

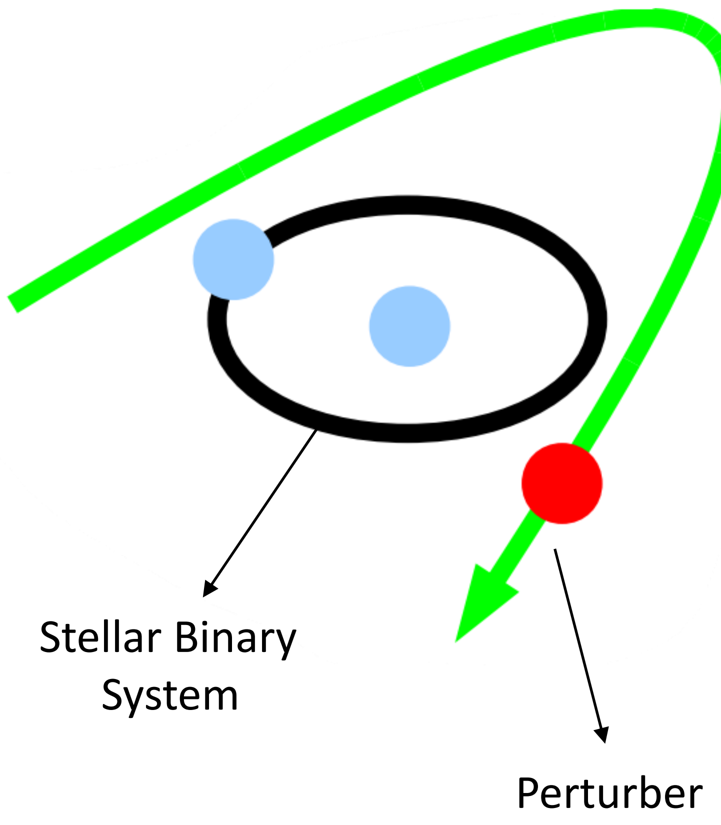
- Different methods are required to cover different PBH mass window.

- We are interested in sub-solar mass PBH and propose a new dynamical test to probe it.



M (M⊙)
10−17
10−11
10−5
10^1
10^7
10^13
10^19
10^0
10−2
10−4
10−6
10^15
10^20
10^25
10^30
10^35
10^40
10^45
10^50
10^55
M (g)
f_PBH = Ω_PBH/Ω_DM
GC
HSC
O
EM
GW
SN
WB
E
XB
PA
DF
DH
G
LSS
CMB
IL
V
EGB
A
B
C
D
Carr, Kuhnel
2006.02838

STELLAR BINARIES



M. Mapelli: Lecture notes

Binaries have an energy reservoir (their internal energy) that can be exchanged with stellar objects.

$$E_{int} = -\frac{G\, m_1\, m_2}{2\, a} = -E_b$$

CLASSIFICATION OF BINARIES

Binaries can be broadly classified into two categories

HARD BINARY

$$\frac{GM_1M_2}{2a} > \frac{1}{2}\,m\sigma^2$$

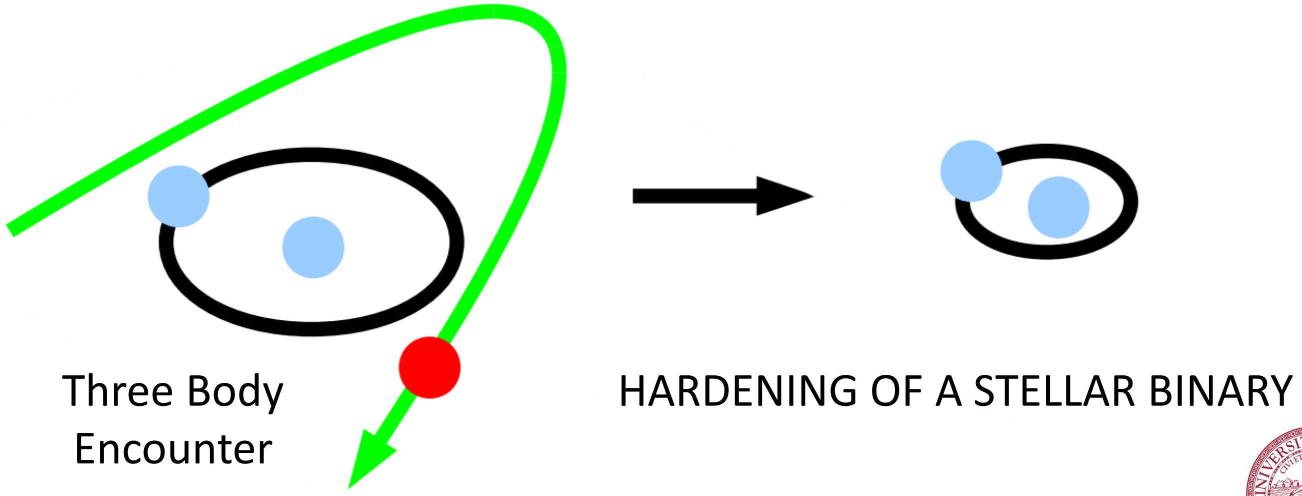
SOFT BINARY

$$\frac{GM_1M_2}{2a} < \frac{1}{2}\,m\sigma^2$$

HEGGIE'S LAW

Hard Binaries tend to become harder (shrink) and soft binaries tend to become softer (expand) as an effect of three body encounters.

10.1093/mnras/173.3.729



HARDENING RATE

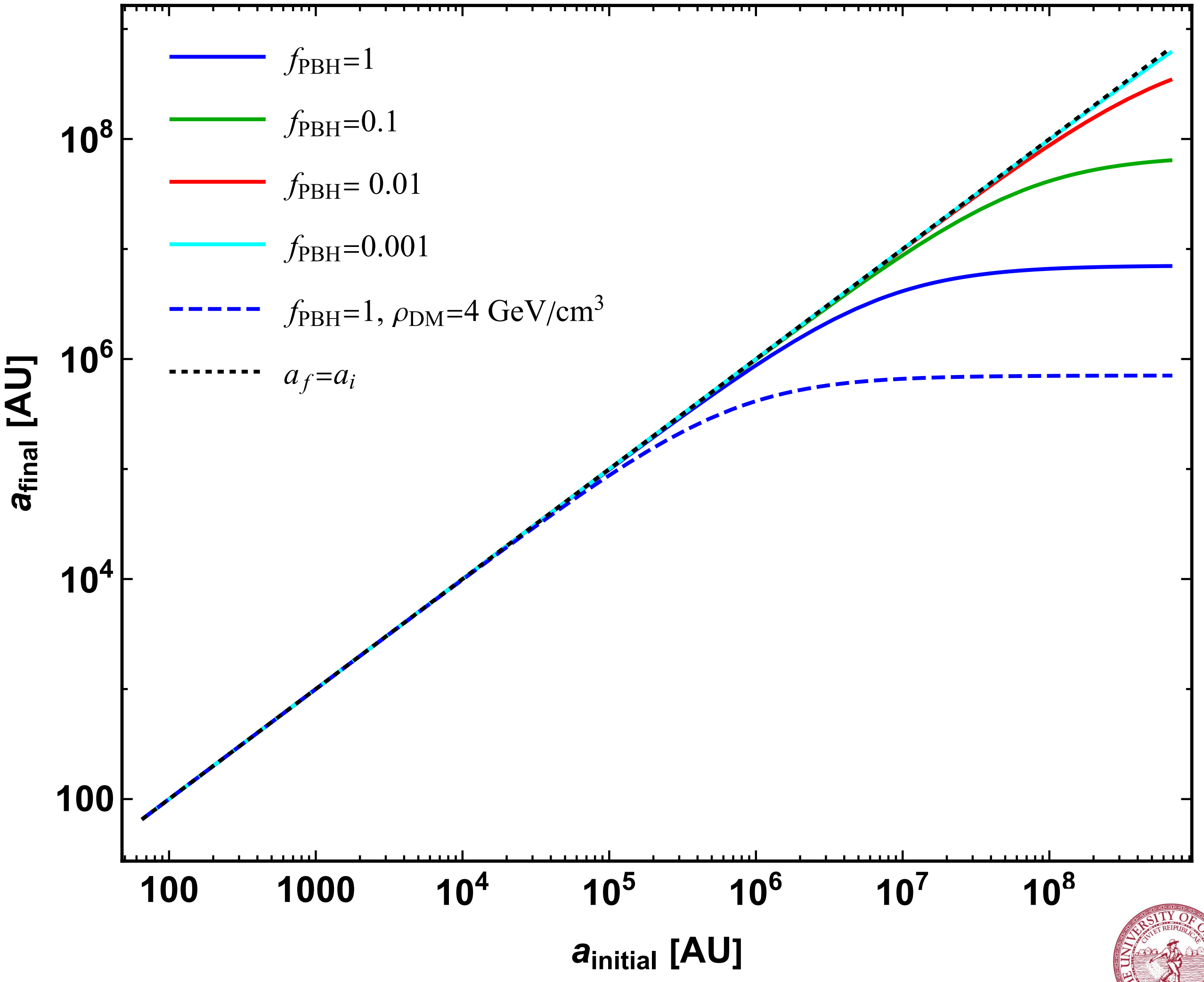
RATE OF BINDING ENERGY EXCHANGE

$$\frac{dE_b}{dt} = \pi\xi G^2 \frac{\rho}{\sigma} m_1 m_2$$

HARDENING RATE

$$\frac{da}{dt} = -2\,\pi\xi G \frac{\rho}{\sigma} a^2$$

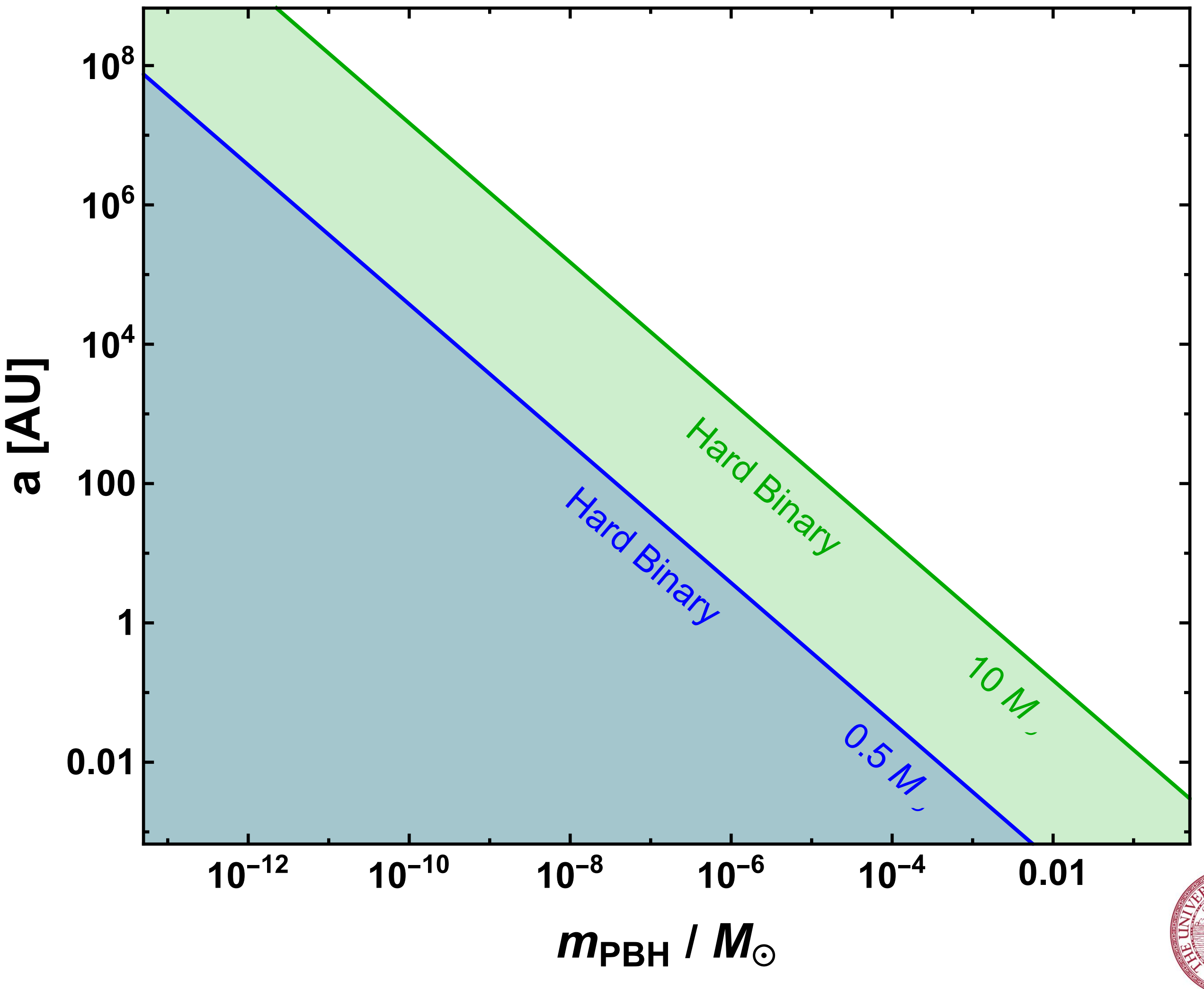
Independent of Perturber's mass!



HARDENING FROM SUB-SOLAR MASS PBHS

A binary acts as a hard binary if its binding energy is greater than the kinetic energy of the PBH.

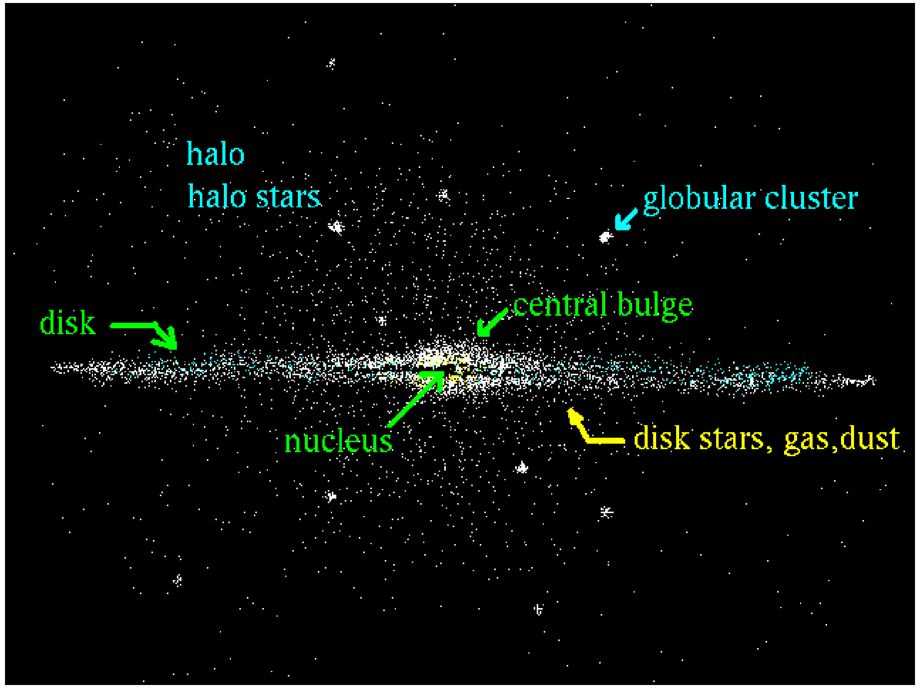
$$\frac{G M_1 M_2}{2a} > \frac{1}{2} m\sigma^2$$



HALO BINARIES

Halo Binaries spend a fraction of their lifetime in the disk and cross it at a very high speed.

$$a_f = \frac{1}{a_i^{-1} + 2\pi\, G\, \xi\, \langle \rho_\chi \rangle \frac{f_{\rm PBH}}{\sigma_{\rm PBH}}\, T - 16\sqrt{\frac{\pi}{3}}\frac{G\rho_d}{\sigma_d}\, xT \ln\Lambda}$$



DOMINANT PERTURBER:

PBH

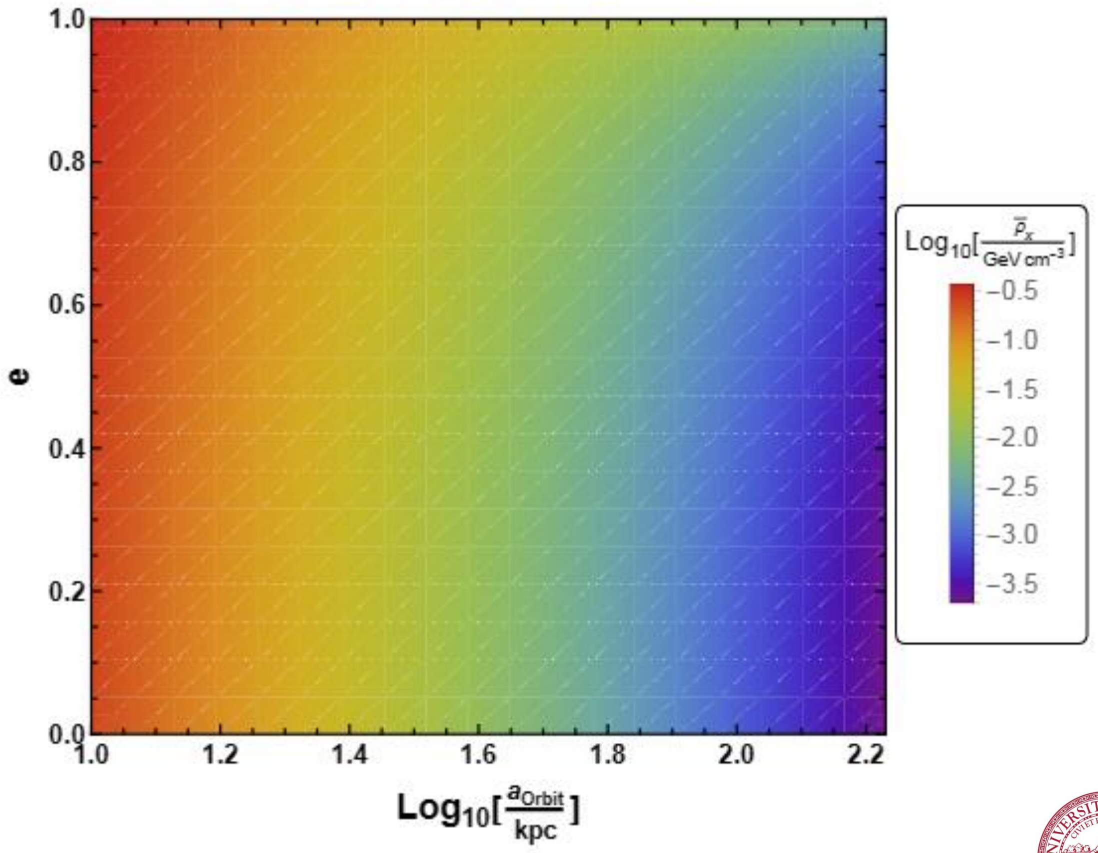
SUB-DOMINANT PERTURBER:

Astrophysical Objects

TIME-AVERAGED DARK MATTER DENSITY

Depending on the orbit, each binary experiences a time-varying DM density.

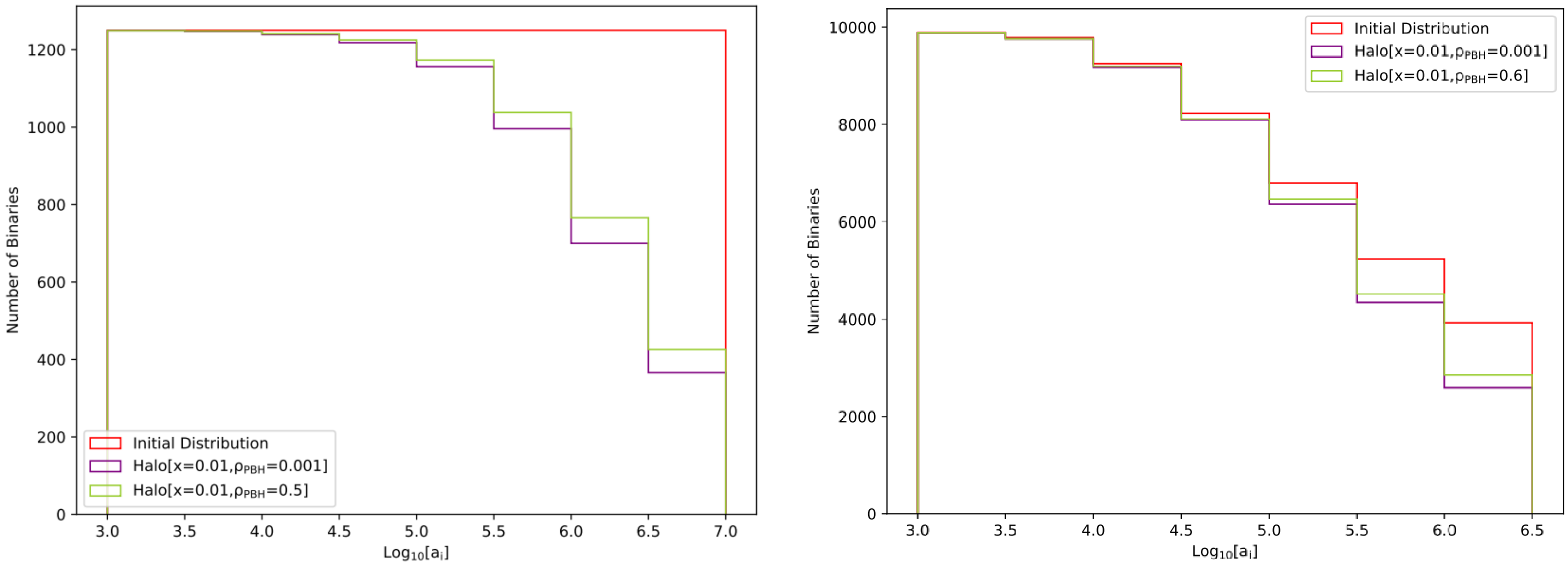
$$\bar{\rho}_\chi = \frac{\int_0^{2\pi} r^2(\theta)\rho_\chi(r)d\theta}{\int_0^{2\pi} r^2(\theta)d\theta}.$$



NFW

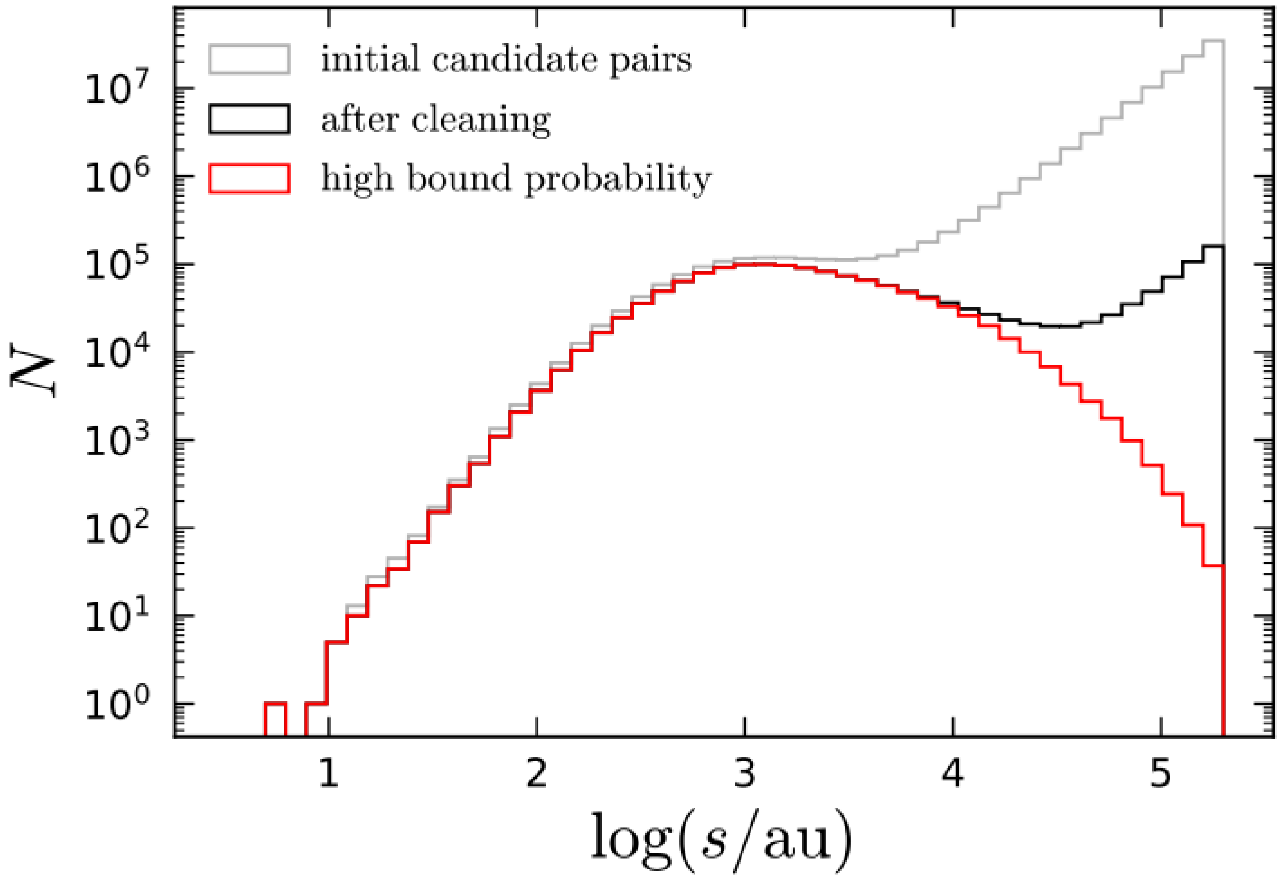
$$\rho_\chi(r) = \frac{\rho_s}{\frac{r}{r_s}(1+\frac{r}{r_s})^2}$$

SEARCH FOR A SUB-SOLAR MASS PBH: FINAL DISTRIBUTION OF HALO BINARIES



CONCLUSION

- Sub-solar mass PBHs would lead to the hardening of wide stellar binaries.
- A difference in the observed distribution of Halo wide binaries with same value of x but different DM density could be a sign of PBH presence.
- More analysis on the observed distribution of ultra-wide stellar binaries is required.

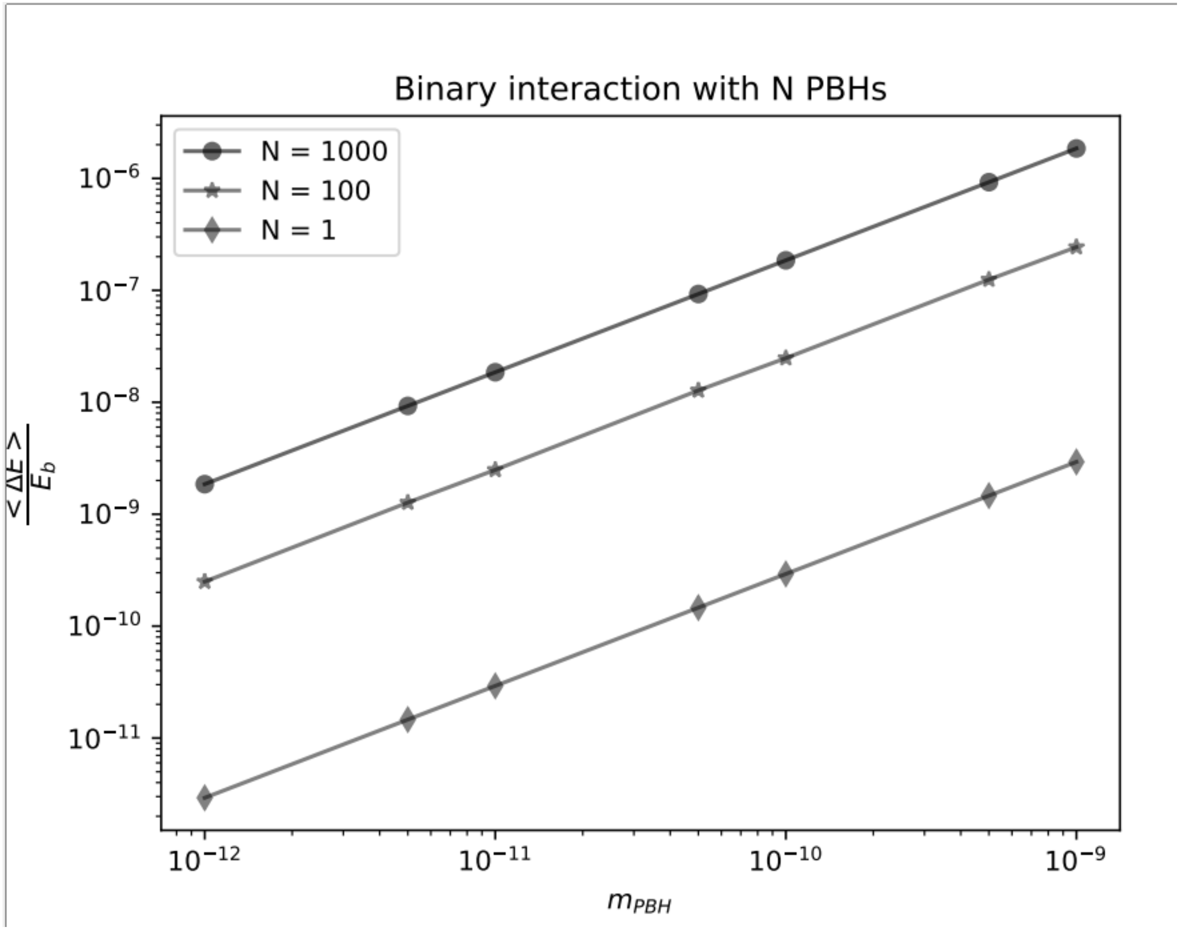


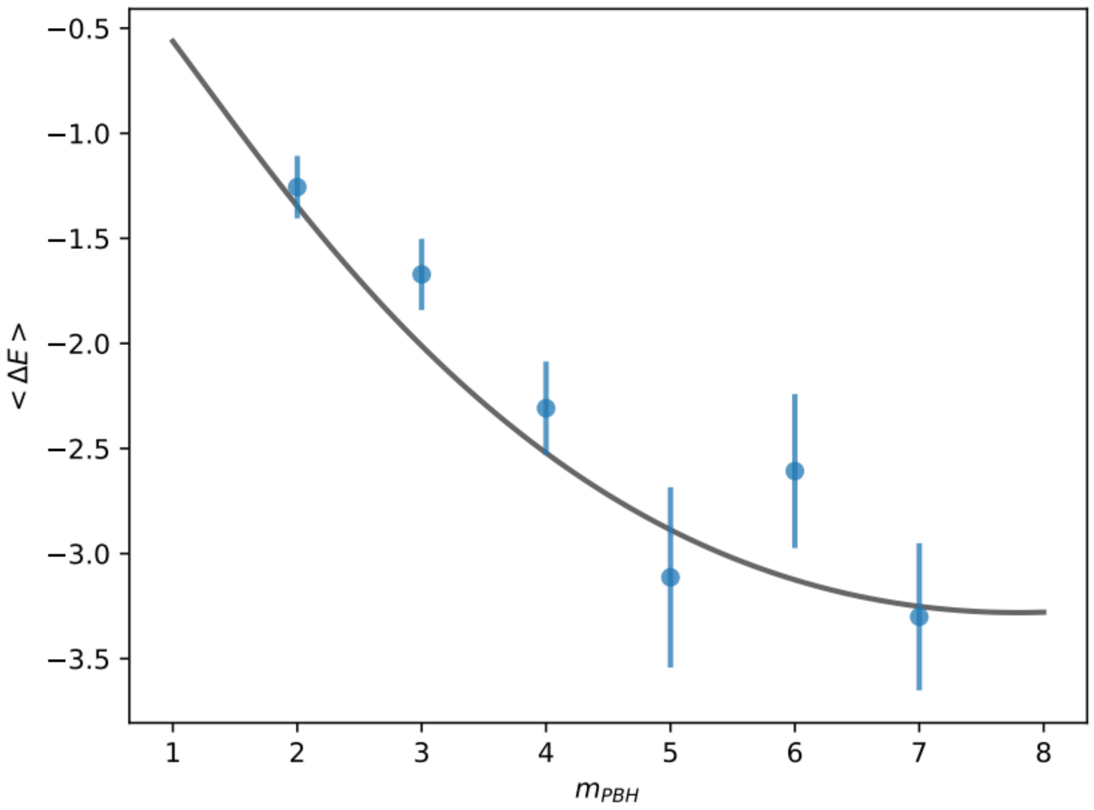
https://doi.org/10.1093/mnras/stab323

THANK YOU

BACKUP SLIDES

N-BODY SIMULATIONS





$$\langle \Delta E \rangle = \xi \frac{m_{\rm PBH}}{2m_\star} \frac{Gm_\star^2}{2a} = \xi \frac{m_{\rm PBH}}{2m_\star} |E_b|$$

$$\langle \Delta E \rangle = -\frac{4}{3}\sqrt{\frac{1}{3\pi}} \frac{Gm_*^2}{a} \ln \Lambda$$

SOFTENING

RATE OF BINDING ENERGY EXCHANGE

$$\frac{dE_b}{dt} = -8\sqrt{\frac{\pi}{3}}\frac{G^2 m_1 m_2 \rho}{\sigma}\ln\Lambda$$

J. Binney and S. Tremaine,
Galactic Dynamics

SOFTENING RATE

$$\frac{da}{dt} = 16\sqrt{\frac{\pi}{3}}\frac{G\rho}{\sigma}a^2\ln\Lambda$$