Dynamical interaction between astrophysical systems and DM substructure; constraints on the smallest DM structures.

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Motivation: Subsolar mass objects are the first to form in a CMD Universe...

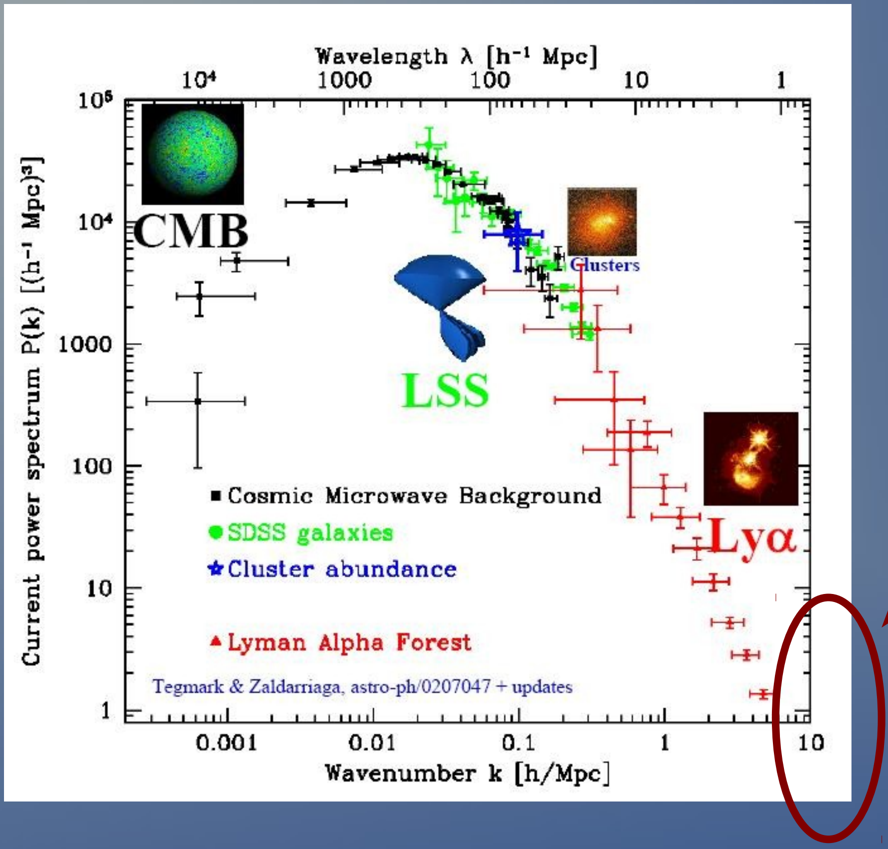
To restrict its mass and abundance has important consequences to the identification of the dark matter particle because:

(a) Different candidates predicts particular Cut-off in the mass power spectrum, i.e. a mass (size) limit on the smallest structure formed, depending on the particle model.

(b) Its presence in the Galactic halo modifies the density and momentum phase space, having important implications for direct and
indirect dark matter detection experiments.

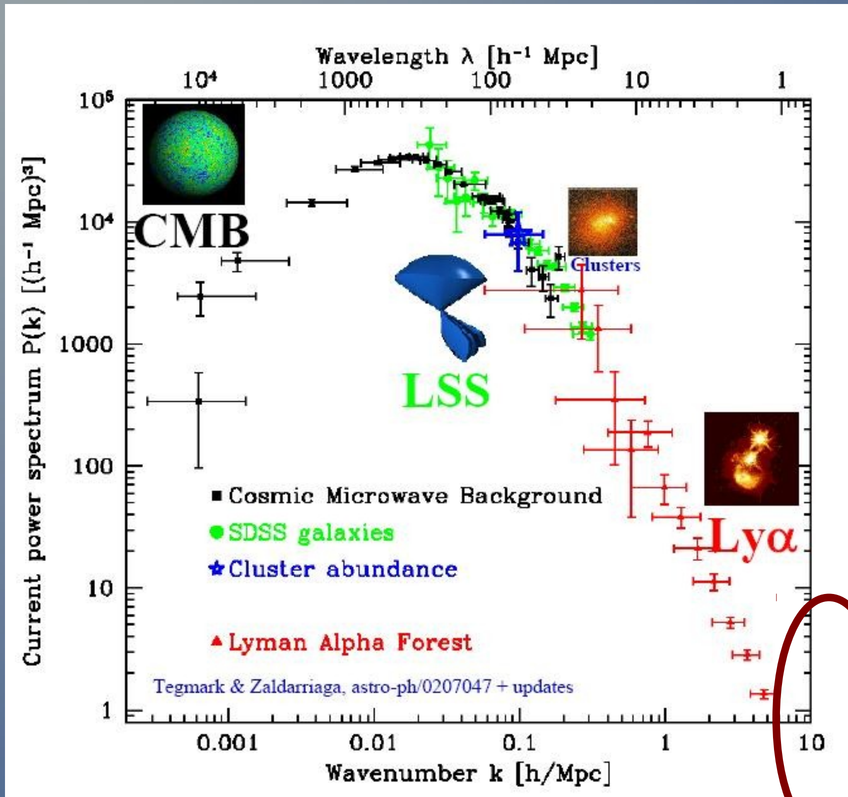
But...

There are no definitive observational constraints for mass power spectrum at the subgalactic scales



DM candidate	Mass of the smallest structure ($M_\odot$)
Neutralino	~ $10^{-4} – 10^{-6}$ (earth)
Axion	~ 10^{-15}
(WDM)	~ $10^{7\ (8)}$

But...



There are no definitive observational constraints for mass power spectrum at the subgalactic scales

Related with the old missing satellite problem

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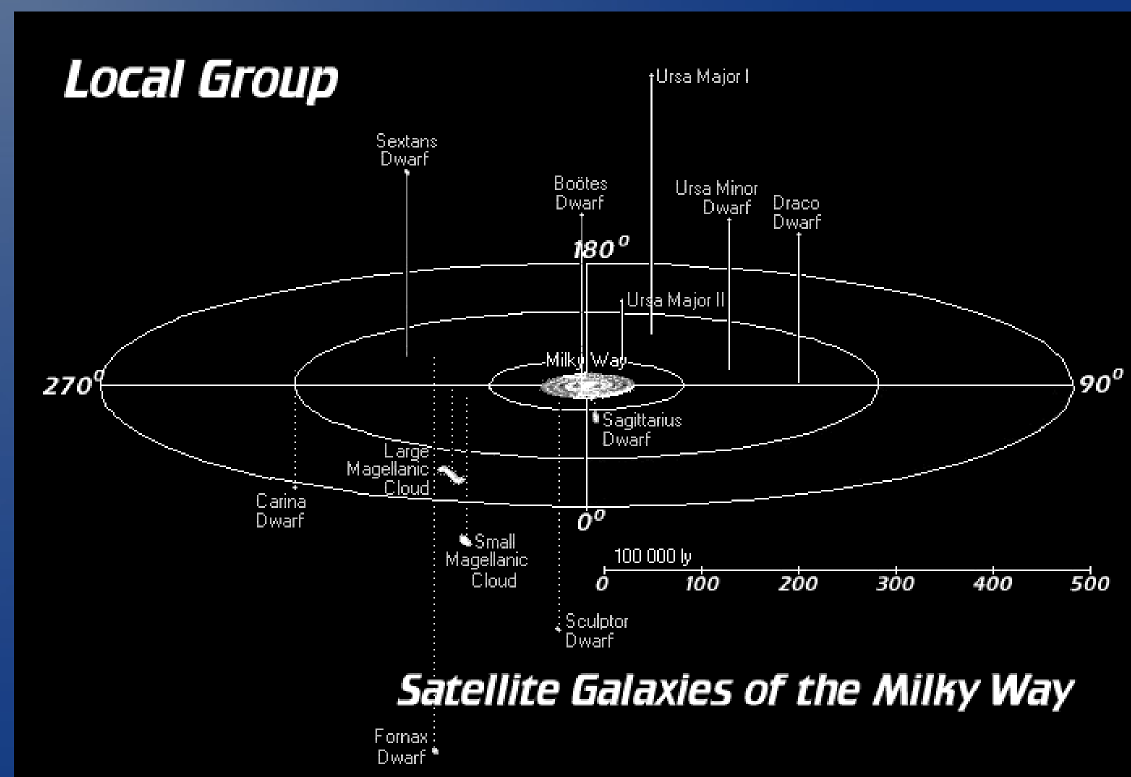
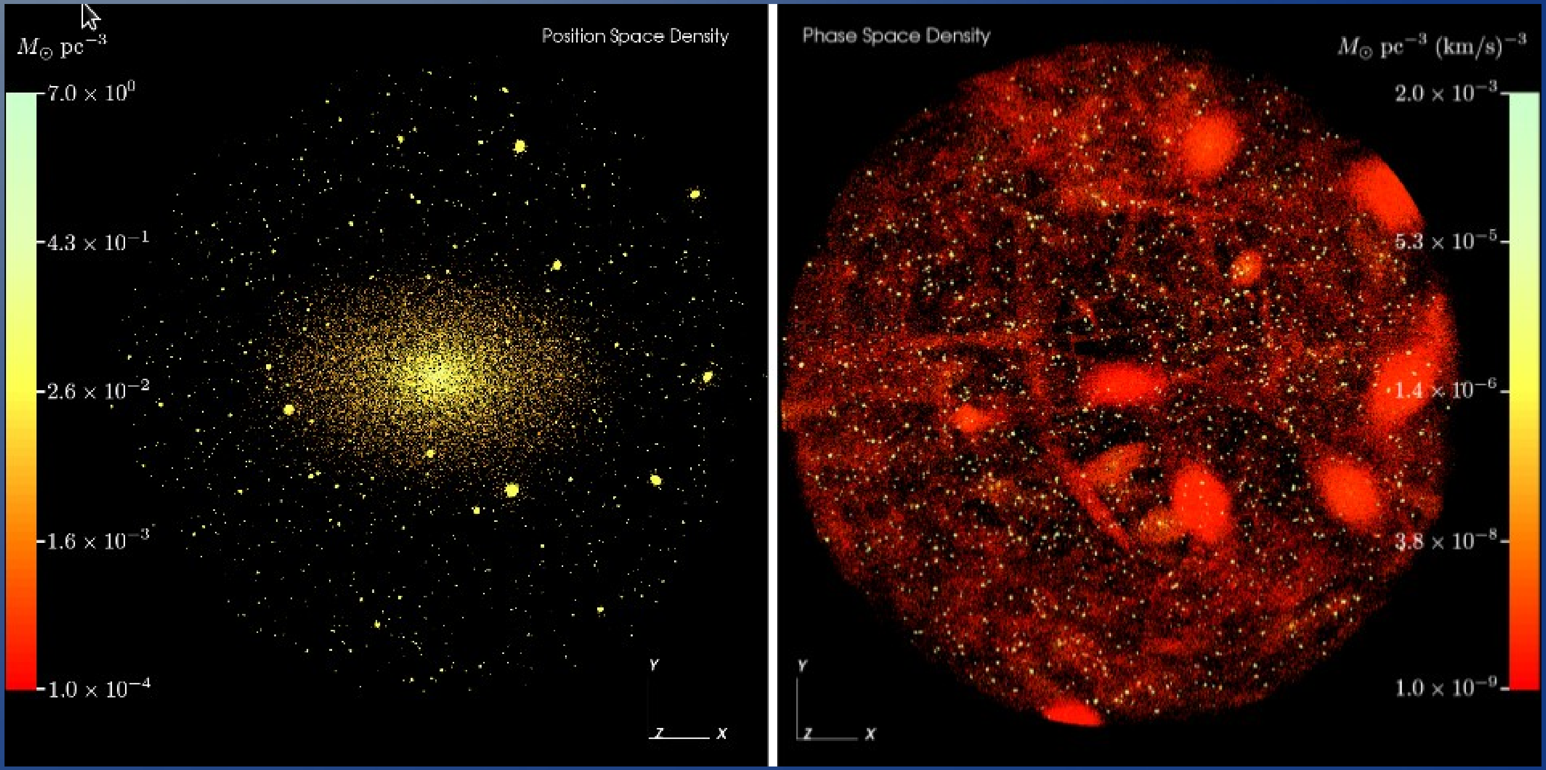


Tidal interactions and violent relaxation mechanisms could dissolve the small halos leading to dark streams instead.

N-body simulations are so useful to study the structure evolution, but don't reach the smallest scales (yet)...



Zemp et. al. 2008

Remark They are DM only and one have to extrapolate down over several orders of magnitude...

Some options to restrict the smallest scales of the PS

- Fluctuations in gravitational lensing fluxes, image position, etc... (Keeton et al., Moustakas et.al, others...)
- Future observations of the HI-21 cm at high redshift (LOFAR,SKA... SCI-HI)

*Sonda Cosmologica de la Isla Guadalupe para la Deteccion de HI a Alto Corrimiento al Rojo

SCI-HI* is an experiment to detect the HI global signal in Mexican radio quiet zones (ask about later...)

*Sonda Cosmologica de la Isla Guadalupe para la Deteccion de HI a Alto Corrimiento al Rojo

Some options to restrict the smallest scales of the PS

- Fluctuations in gravitational lensing observables (Keeton et al., Moustakas et.al, others...)
- Future observations of the HI-21 cm at high redshift (LOFAR,SKA)
- Detection of ultra faint galaxies with GAIA (future)
- From the interaction of astrophysical systems with dark microhalos (Peñarrubia 2010, Schneider 2009)...

*Sonda Cosmologica de la Isla Guadalupe para la Deteccion de HI a Alto Corrimiento al Rojo

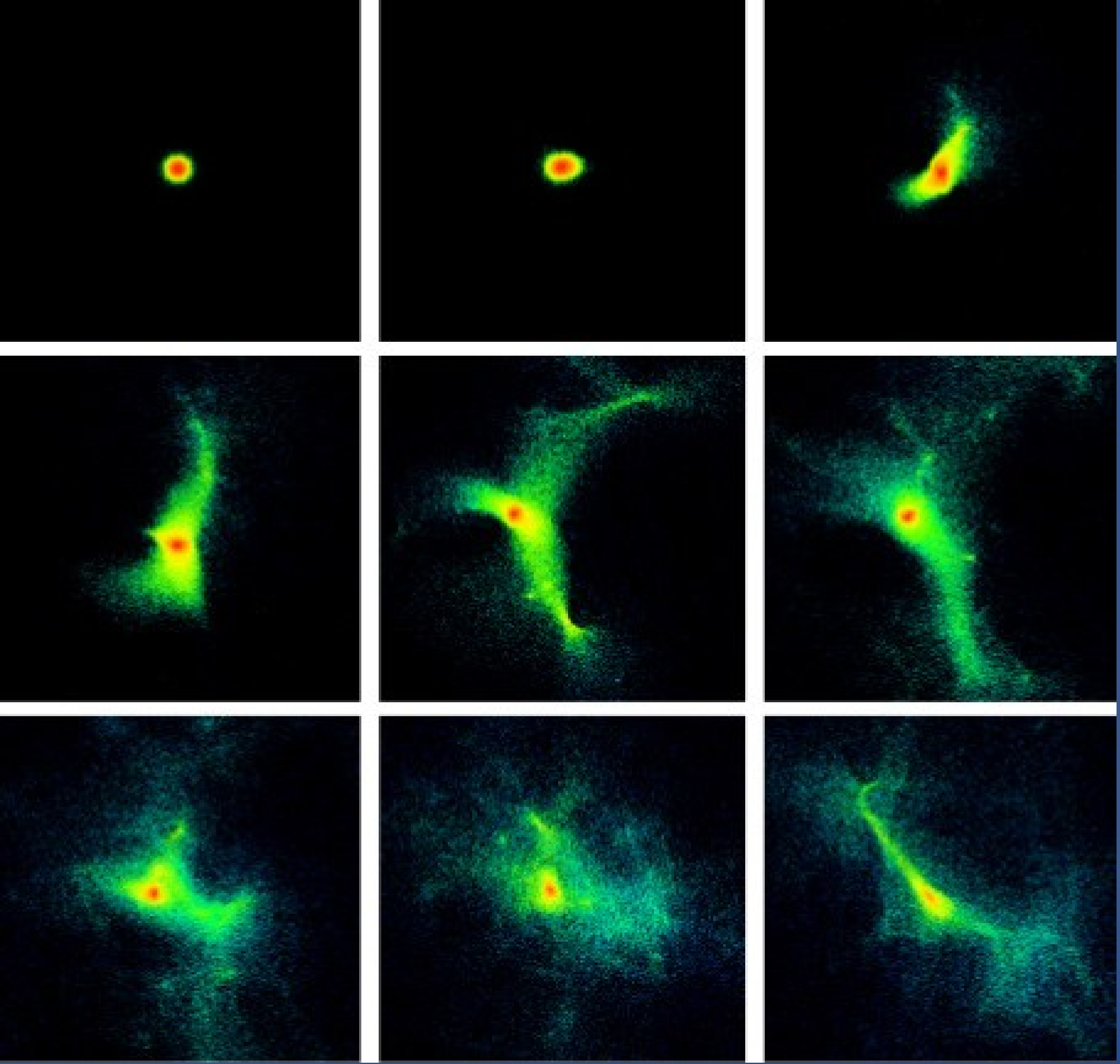


Fig. from Schneider et.al 2009

Zhao et. al.2005

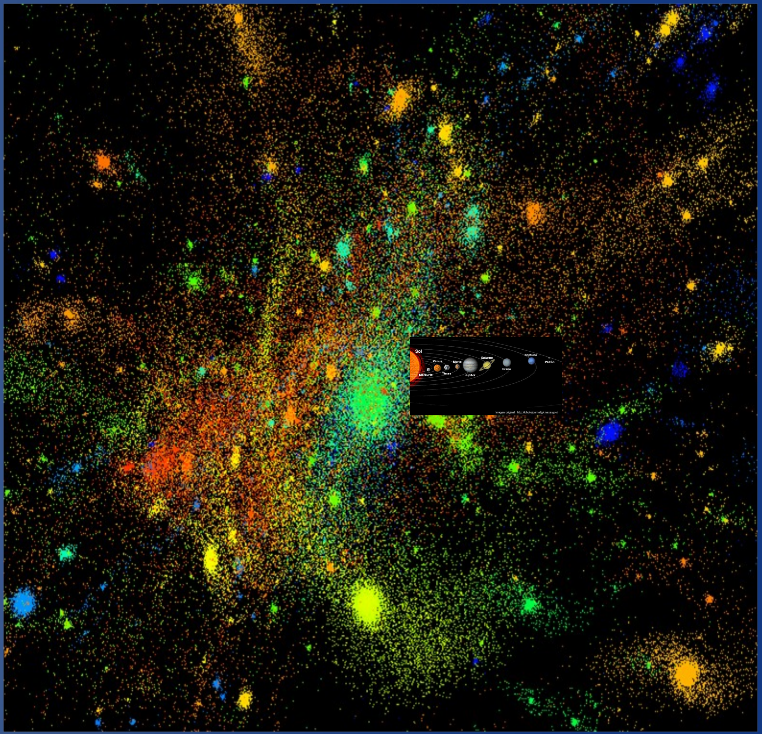
Many works about the evolution of small structures due to their tidal interactions with Stars...

… but what is the effect on the system bound to these stars?

What is the dynamic effect on the Solar system orbits?

The SS has been widely used to test gravity theories, due to high precision determination of orbital elements.

We perform Montecarlo experiments to estimate the energy perturbation over a SS orbit due to multiple encounters with dark micro-halos, and streams object, e.g. Neptune's and Earth-Moon orbit.



Observational limits

Standard deviation of exterior planet orbital elements

planet	a, $[6.68 * 10^{-12}\ AU]$ [11]
Saturn	4222
Uranus	38484
Neptune	478532
Pluto	3463309

Astrophysical Tidal Interaction with Subhalos (Binney & Tremaine)

- Energy rate in the impulsive and distant tide approximation

$$\frac{\Delta E}{|E_b|} = \frac{8GM_p^2}{3M_\odot V^2 b^4} a^3 U(b/r_h)$$

U(b/rh) is a function that depends on the density profile of subhalos. It approaches to 1 for large impact parameters

The velocity of the encounter "V" follows a Maxwell-Boltzmann distribution centered ~ 200 km/s.

The impact parameter "b" follows a nearest-neighborhood distribution. Depend on the numerical density of subhalos, given by the local DM density, the mass of the subhalos and the substructure fraction.

$$\nu = \frac{f_{sub}\rho_{dm}}{m_{mh}}.$$

Astrophysical Tidal Interaction with Streams (our work)

Energy rate in the impulsive and tidal approximation

Linear density

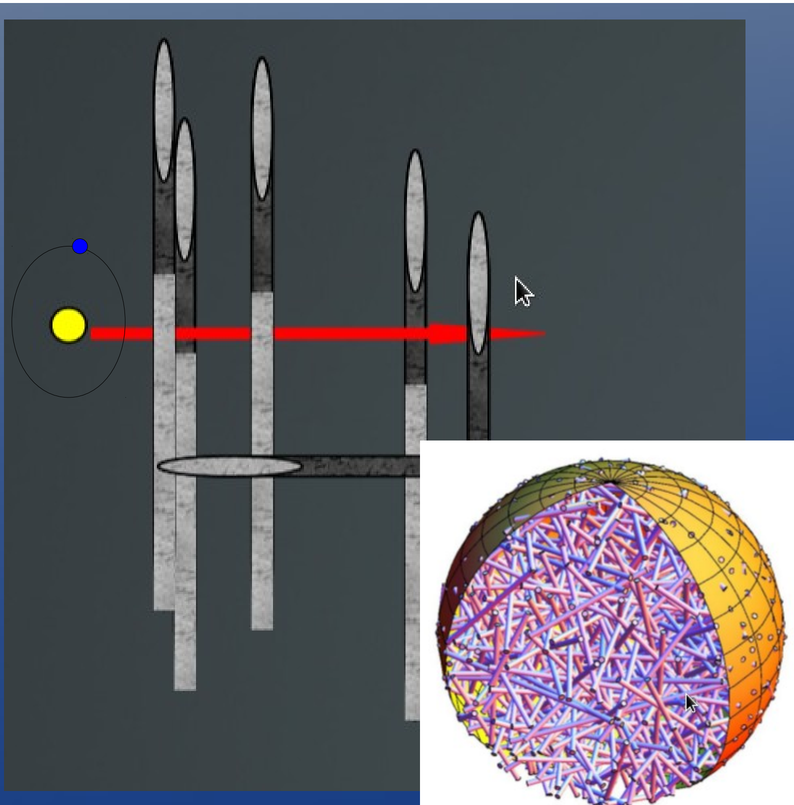
- 1-dimensional stream

$$\frac{\delta E}{|E_b|} = \frac{G}{M_\odot}\left(\frac{2\pi\lambda}{bv_0}\right)^2 a^3 \frac{\mathbb{T}}{\sin^2\theta},$$

- Constant cross section stream

$$\frac{\delta E}{|E_b|} = \frac{G}{M_\odot}\left(\frac{2\pi\lambda}{bv_0}\right)^2 a^3 \frac{\mathbb{T}\,\mathbb{B}^2}{\sin^2\theta},$$

T, B, C, D are functions of the orientation with respect to the ecliptic plane and of the structure of the stream (cross section)



- Power Law density, finite cross-section stream

Stream with a core

Note is b^2 not b^4
As for subhalos

$$\frac{\delta E}{|E_b|} = \frac{G}{M_\odot}\left(\frac{2\pi\lambda}{bv_0}\right)^2 a^3 \frac{\mathbb{C}}{\sin^2\theta},$$

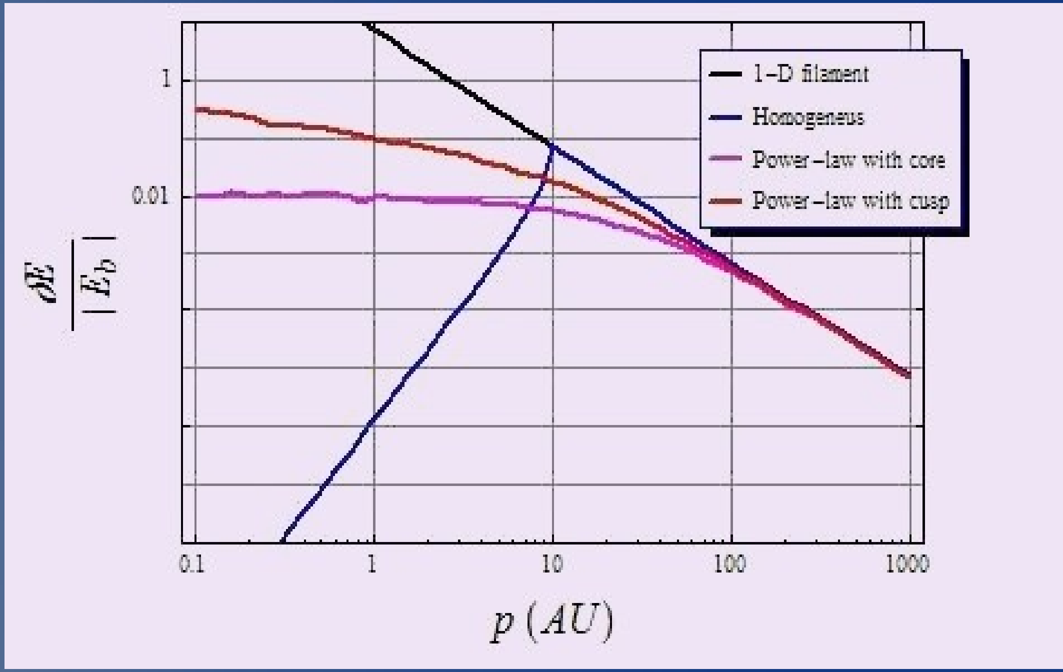
Stream with a core

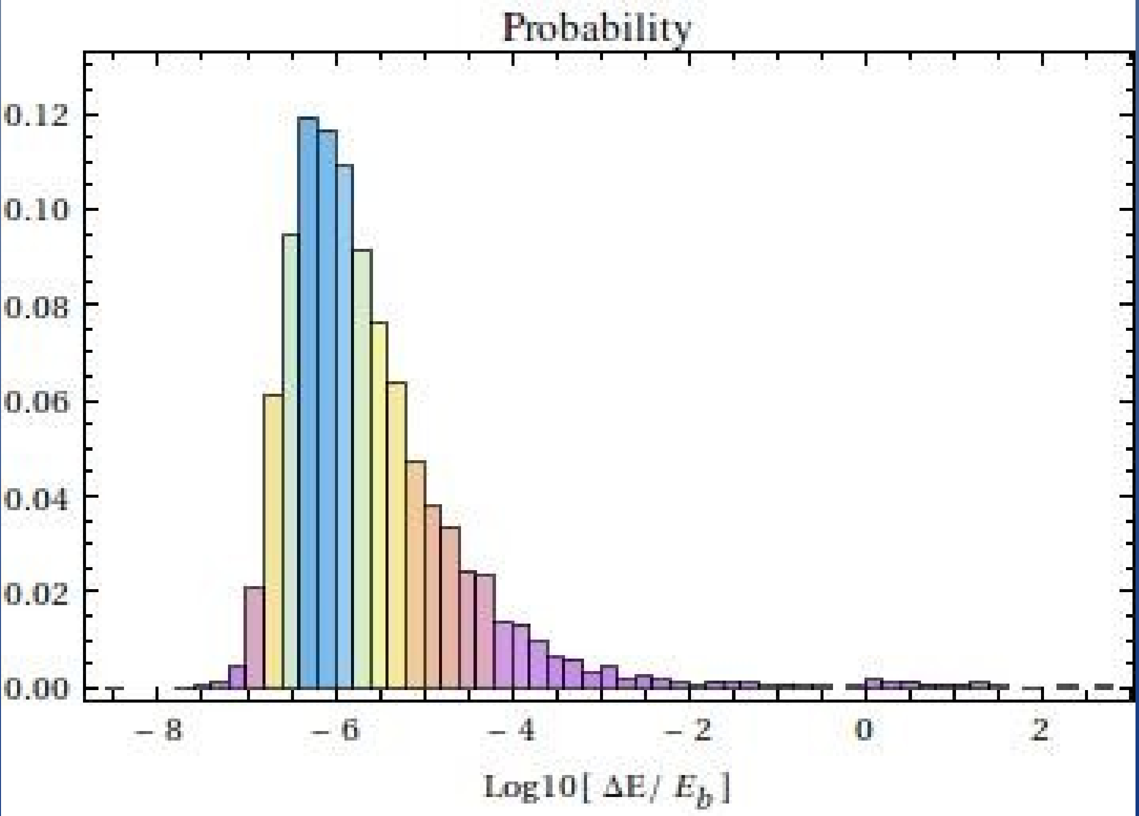
$$\frac{\delta E}{|E_b|} = \frac{G}{M_\odot}\left(\frac{2\pi\lambda}{bv_0}\right)^2 a^3 \frac{\mathbb{D}}{\sin^2\theta},$$

Θ is the direction of movement of the stream...

- energy perturbation over Neptune's orbit due to one single encounter

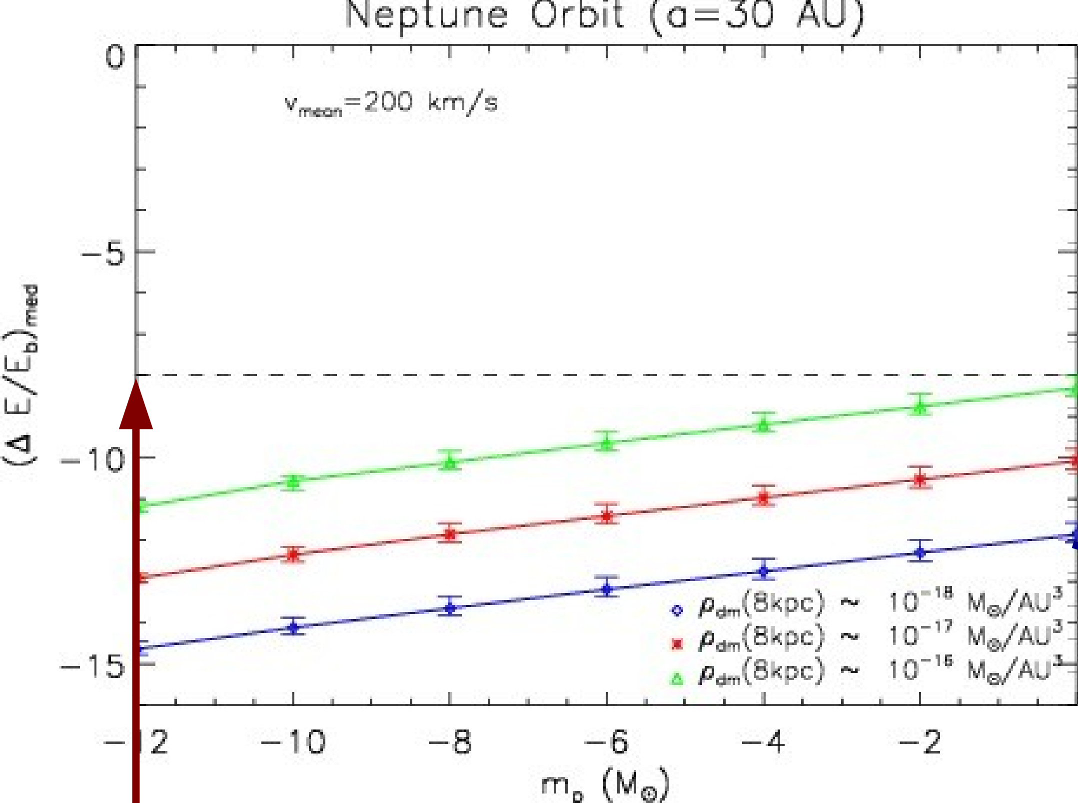
λstr= 10^{-3} Msun/AU
V0= 200 km/s





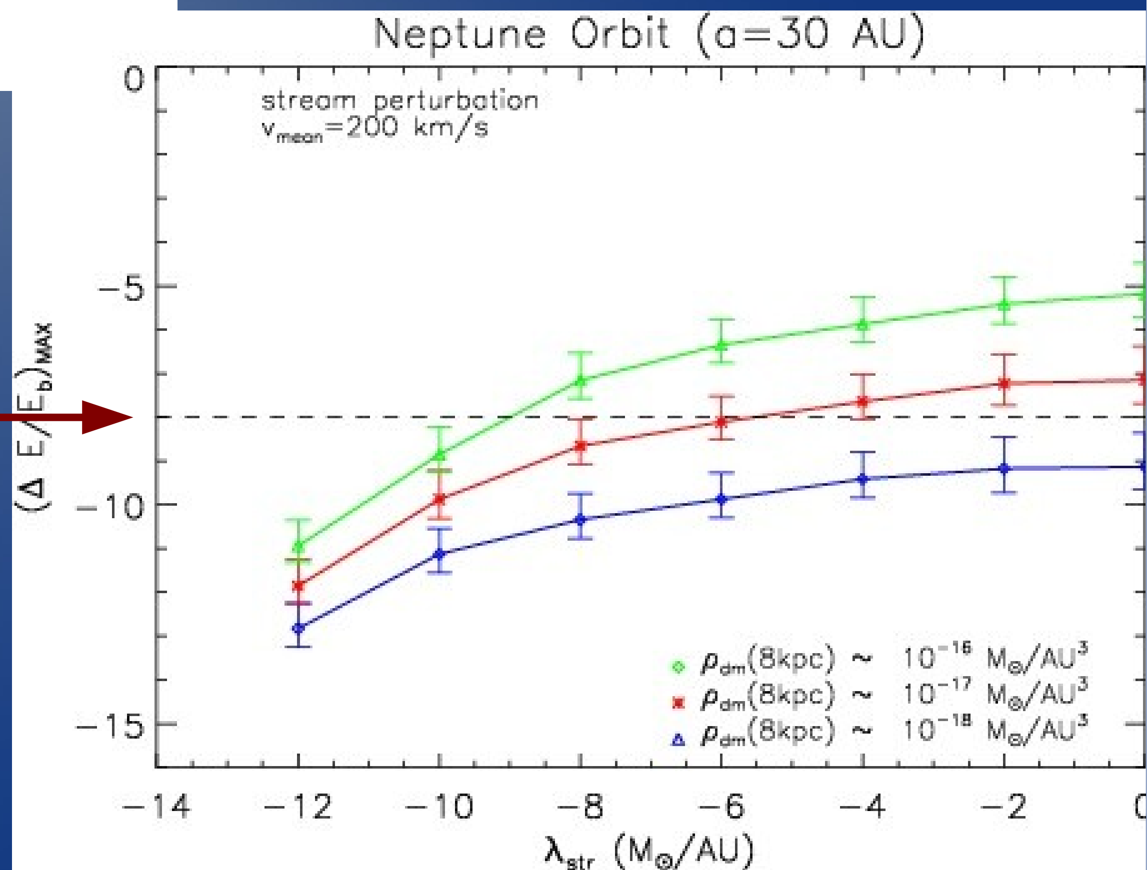
Multiple encounters

Probability distribution of the energy perturbation due to multiple encounters

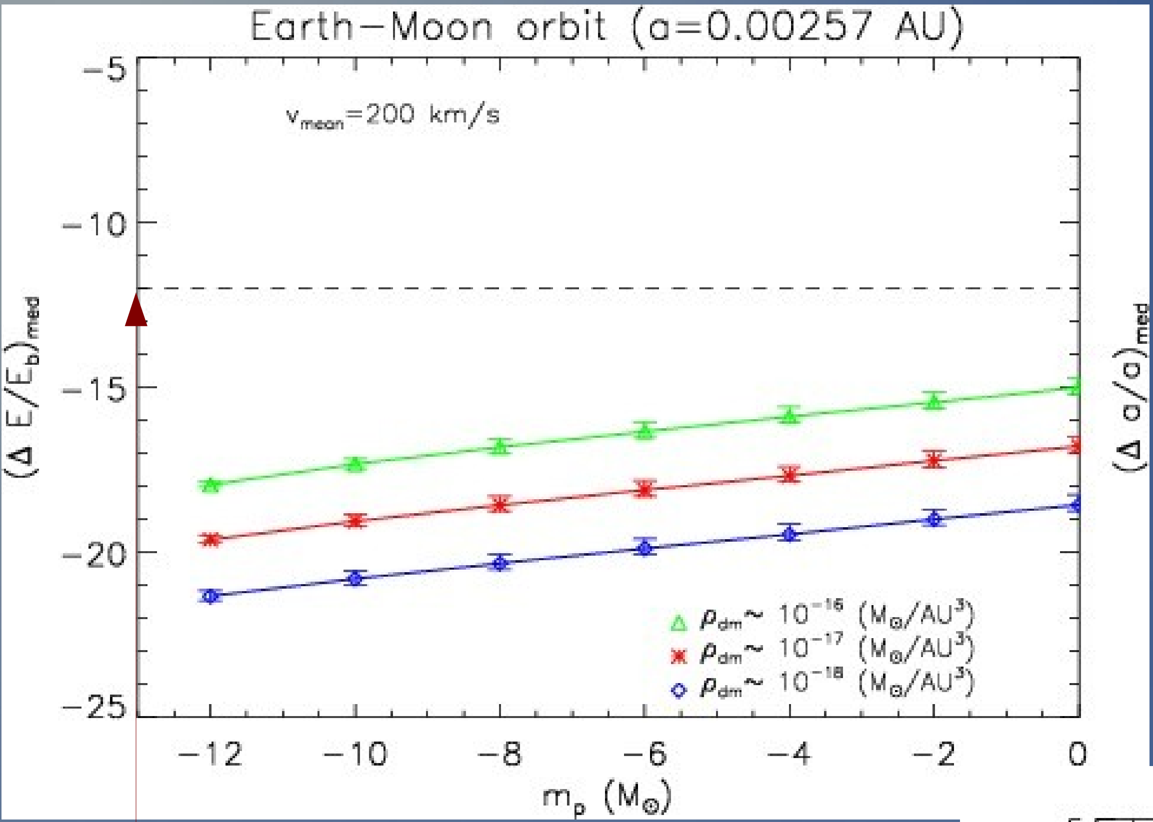


Cumulative Effect of multiple encounters Results for the Neptune orbit due to subhalos (left) and streams (right).

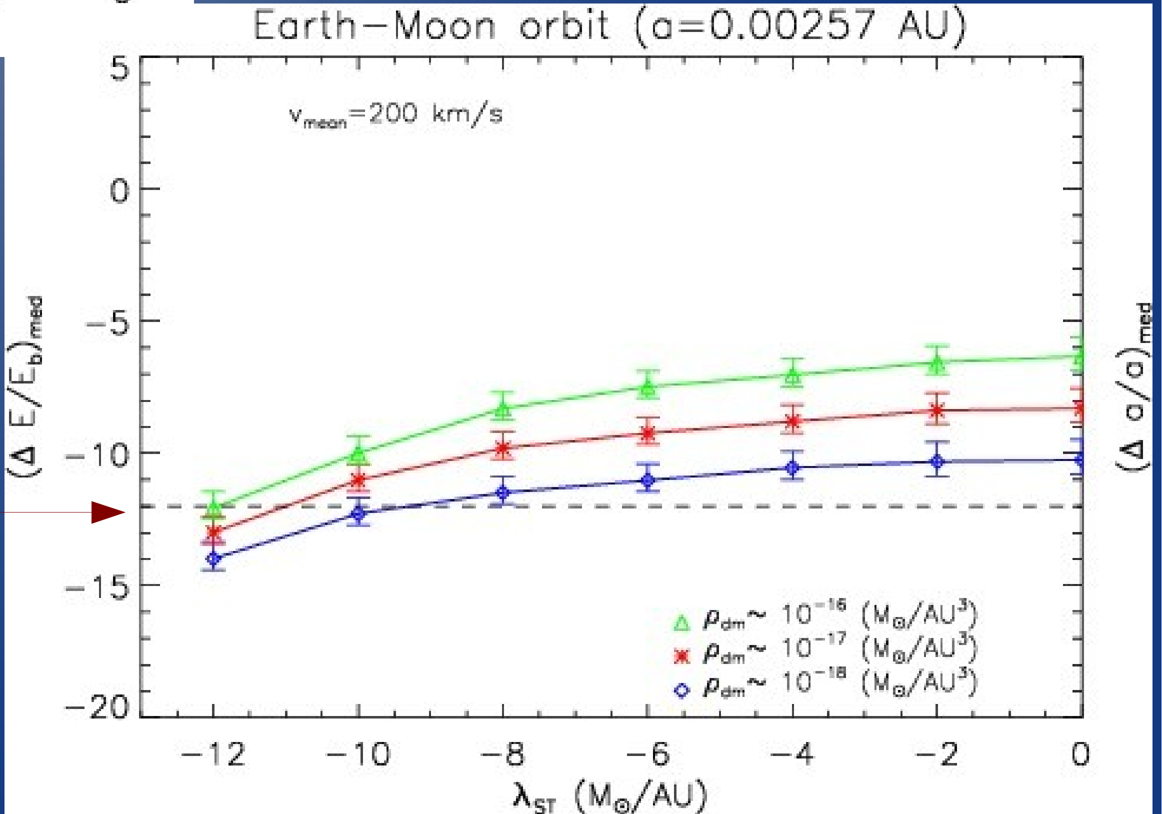
Canonical value of DM local density



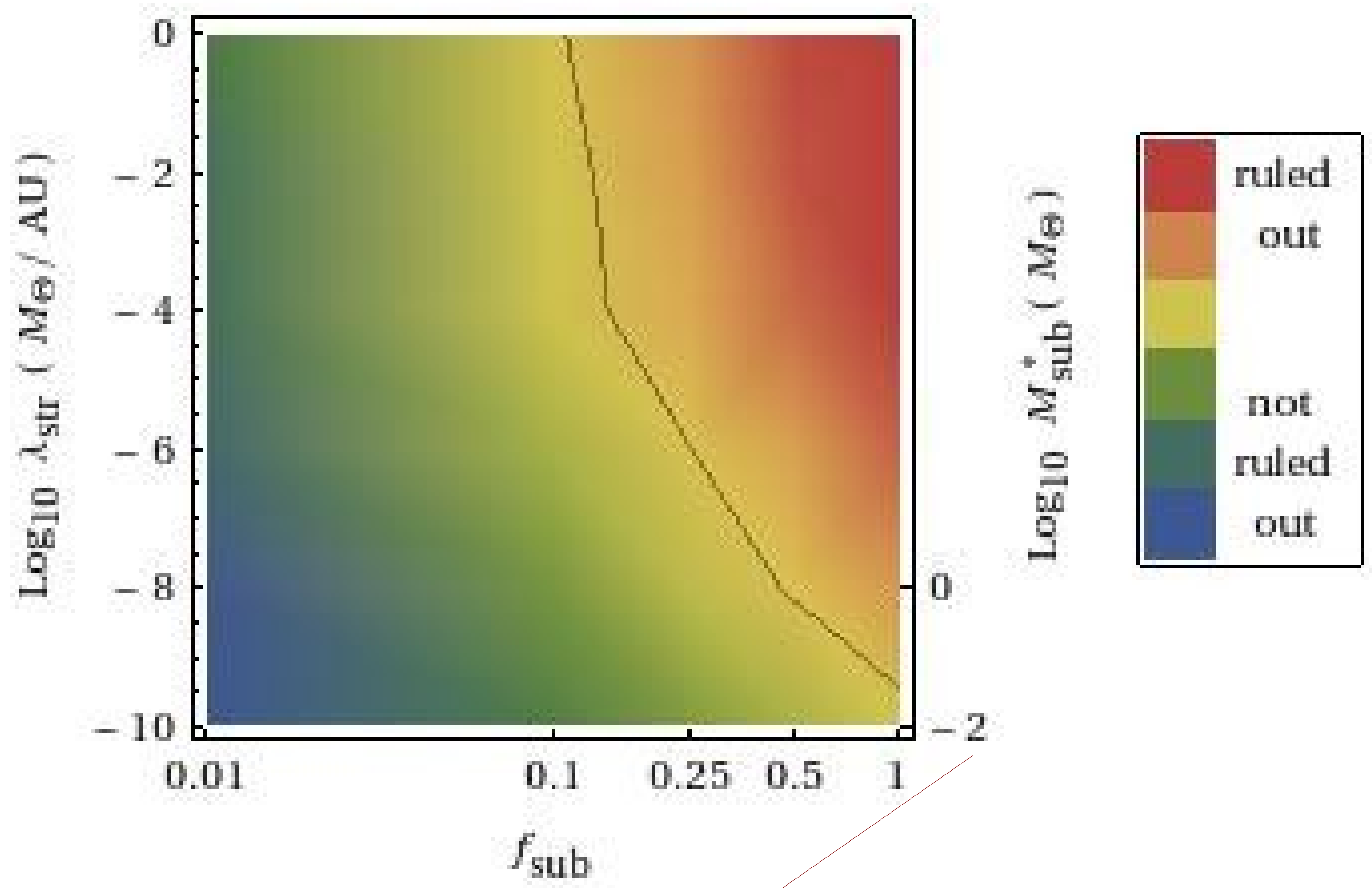
Uncertainty in the semi-major axis (E. V. Pitjeva and N.P. Pitjev 2012, I. B. Khriplovich and E. V. Pitjeva, 2009)



Cumulative Effect of multiple encounters Results for the Earth-Moon System due to subhalos (left) and streams (right).



Uncertainty in the semi-major axis (APOLLO- LLR; J. G. Williams, S. G. Turyshev, and D. H. Boggs 2009)

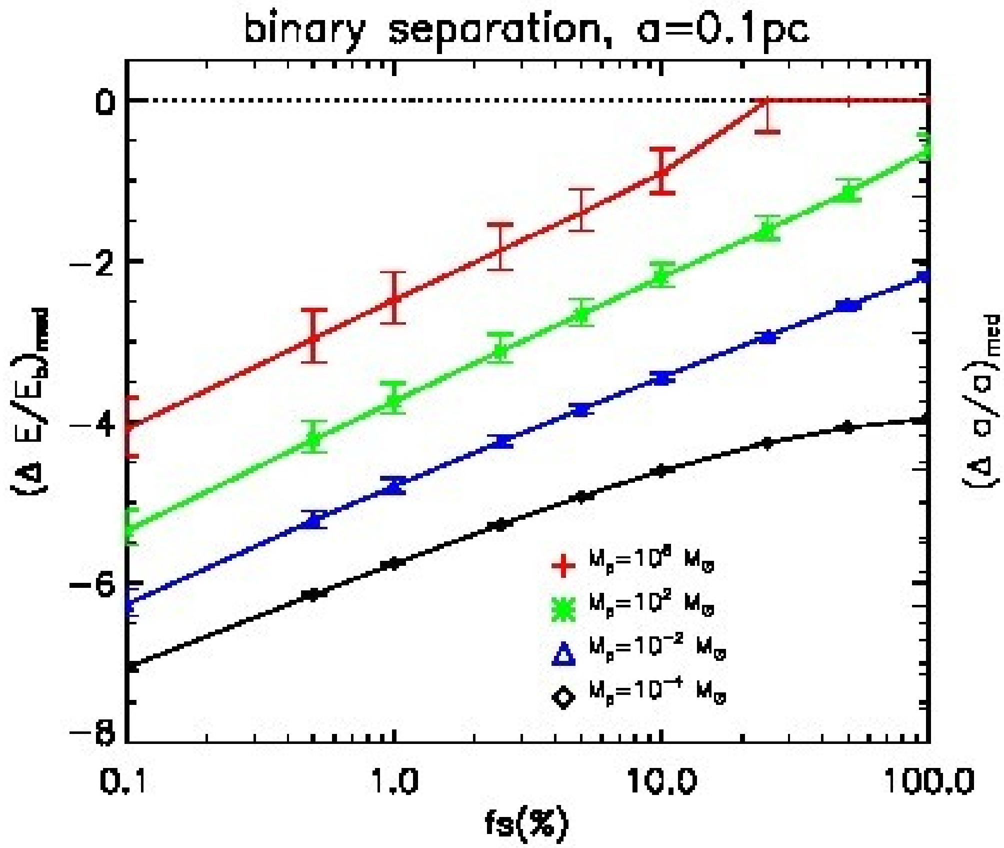


Earth-Moon exclusion regions for substructure fraction and linear density of streams

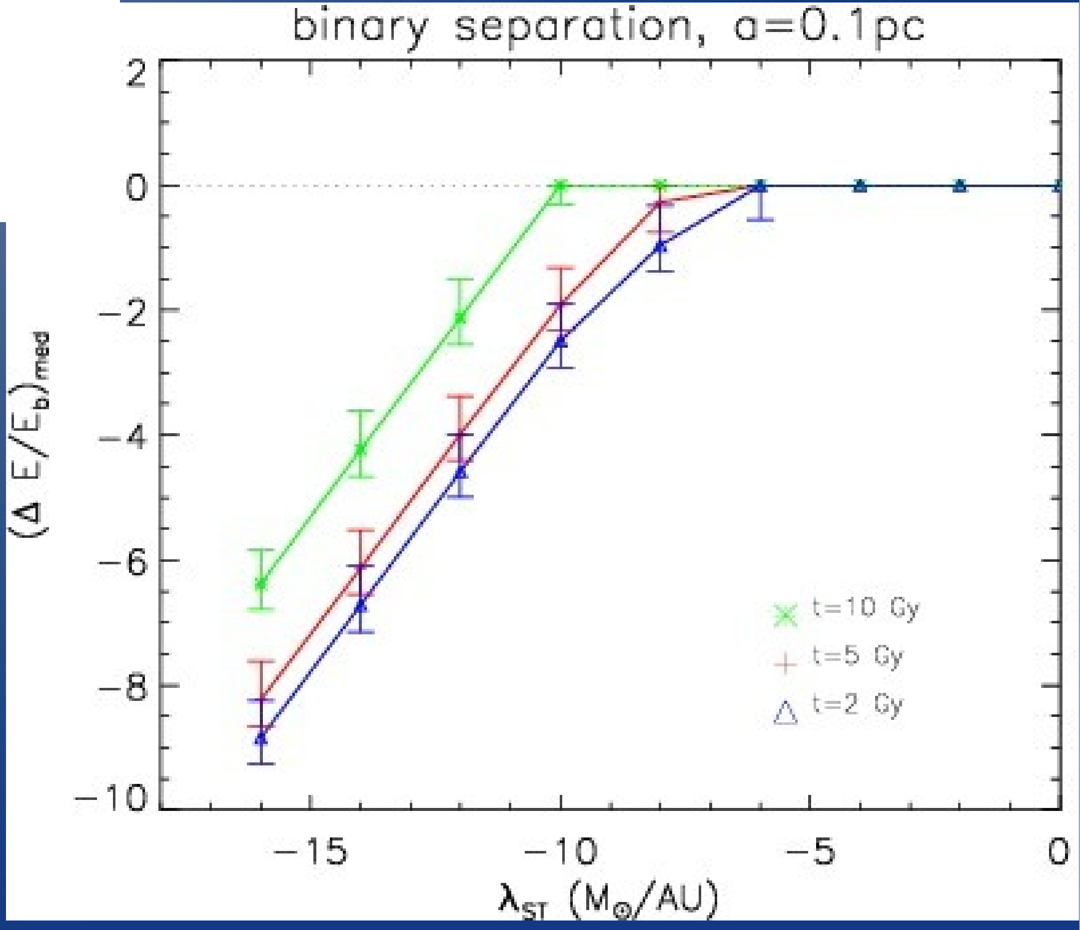
Simple approach, by computing the velocity dispersion of the initial subhalo, and assuming they have been under linear disruption for a Hubble time.

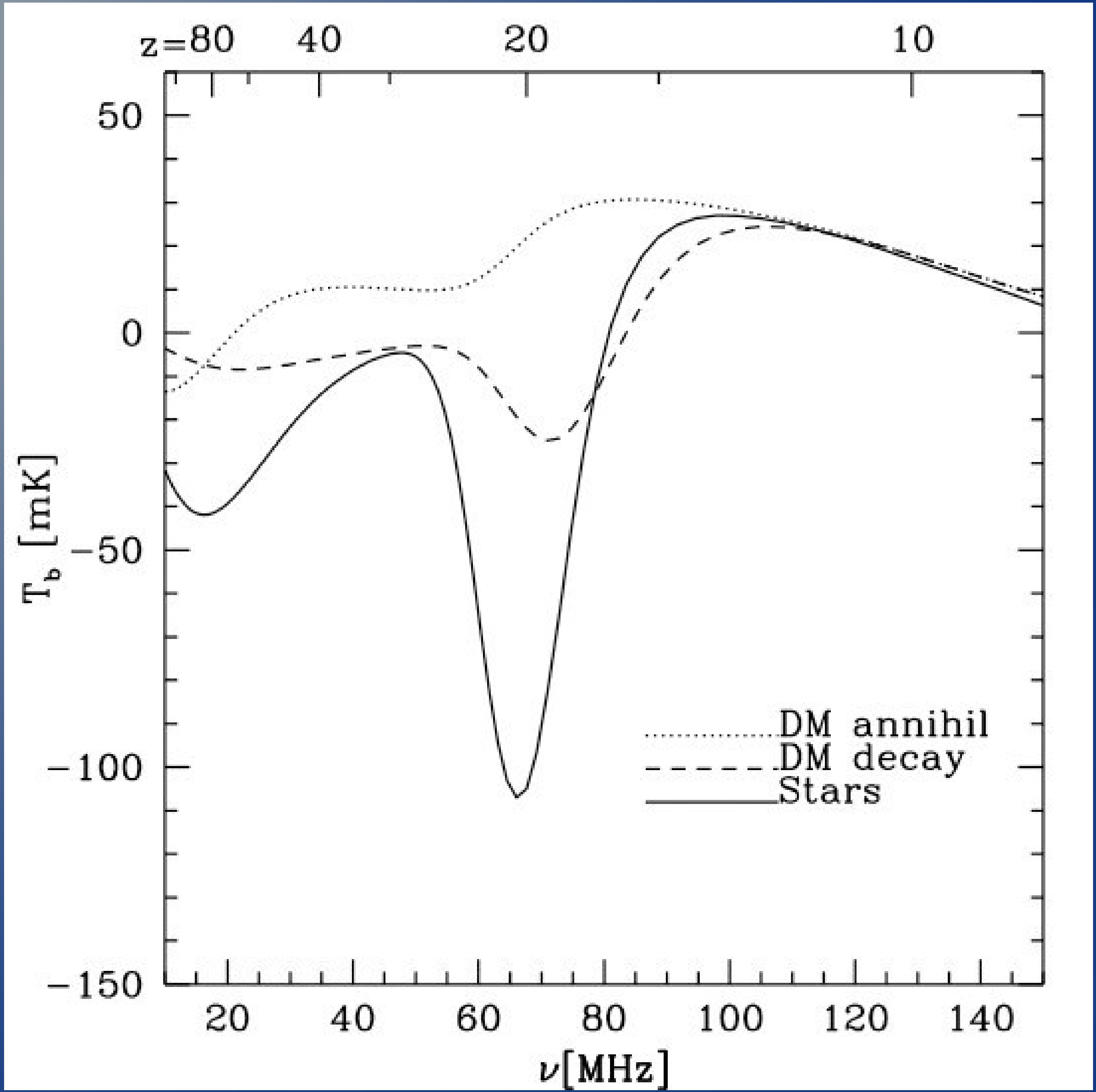
Final Remarks

- The dynamics of some astrophysical systems can be so sensitive that can be used to set constraints to the power spectrum cut-off.
- This avenue can be applied to binary stars, globular clusters and even extra-solar planets to test the distribution of DM substructure and try to constrain the PS.
- There can be a lot of dark substructure in the solar neighborhood and still being compatible with the Solar System dynamics. Direct and indirect detection experiments should take this into account; the spatial distribution and the fact that micro-halos and streams are kinematically colder than the soft component.
- Results are degenerate with the local density value and the substructure fraction, independent measurements of those will help. This avenue is totally independent of N-body simulations and very simple assumptions are done, the perturbed model can be as detailed as wanted though.

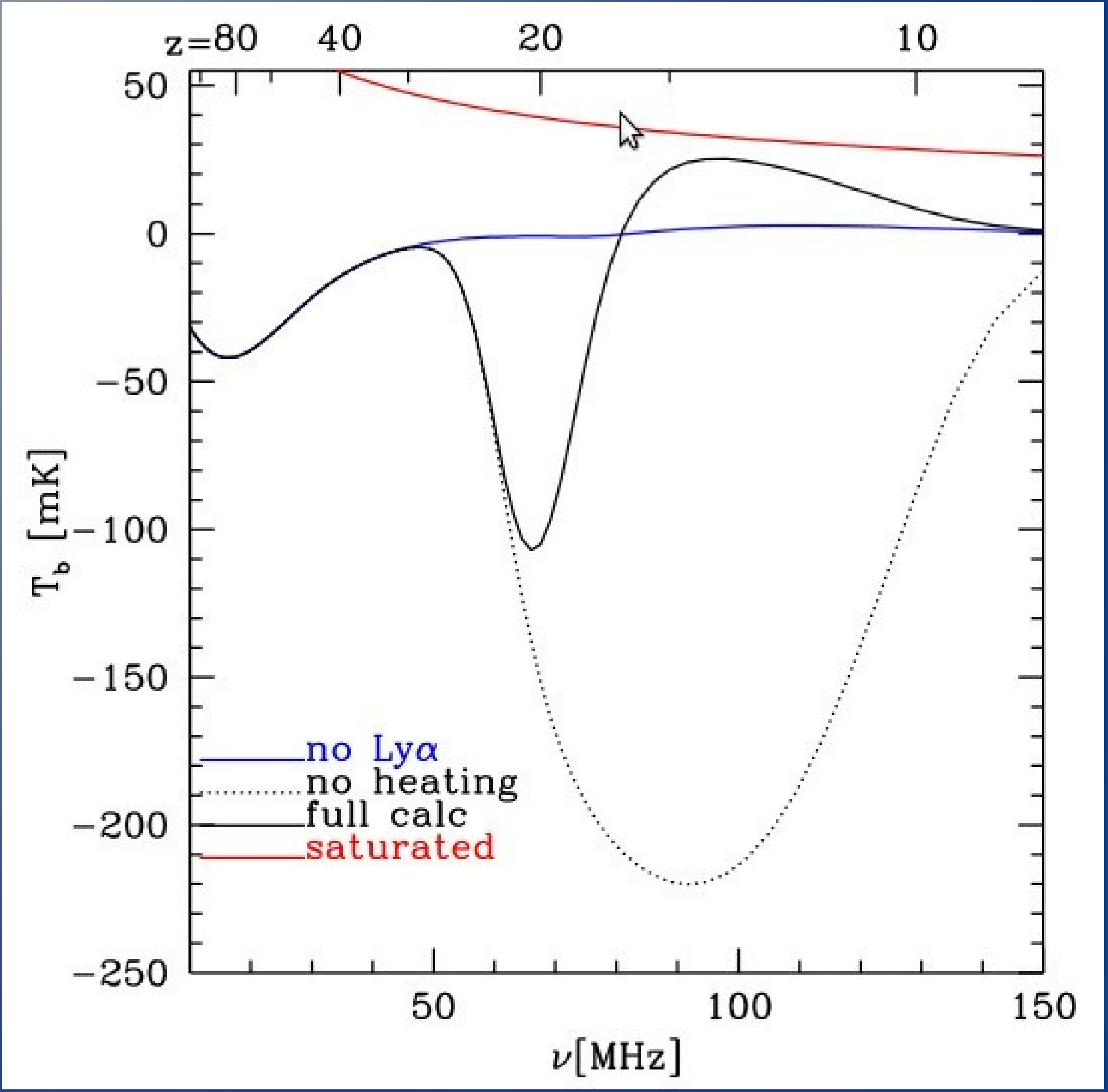


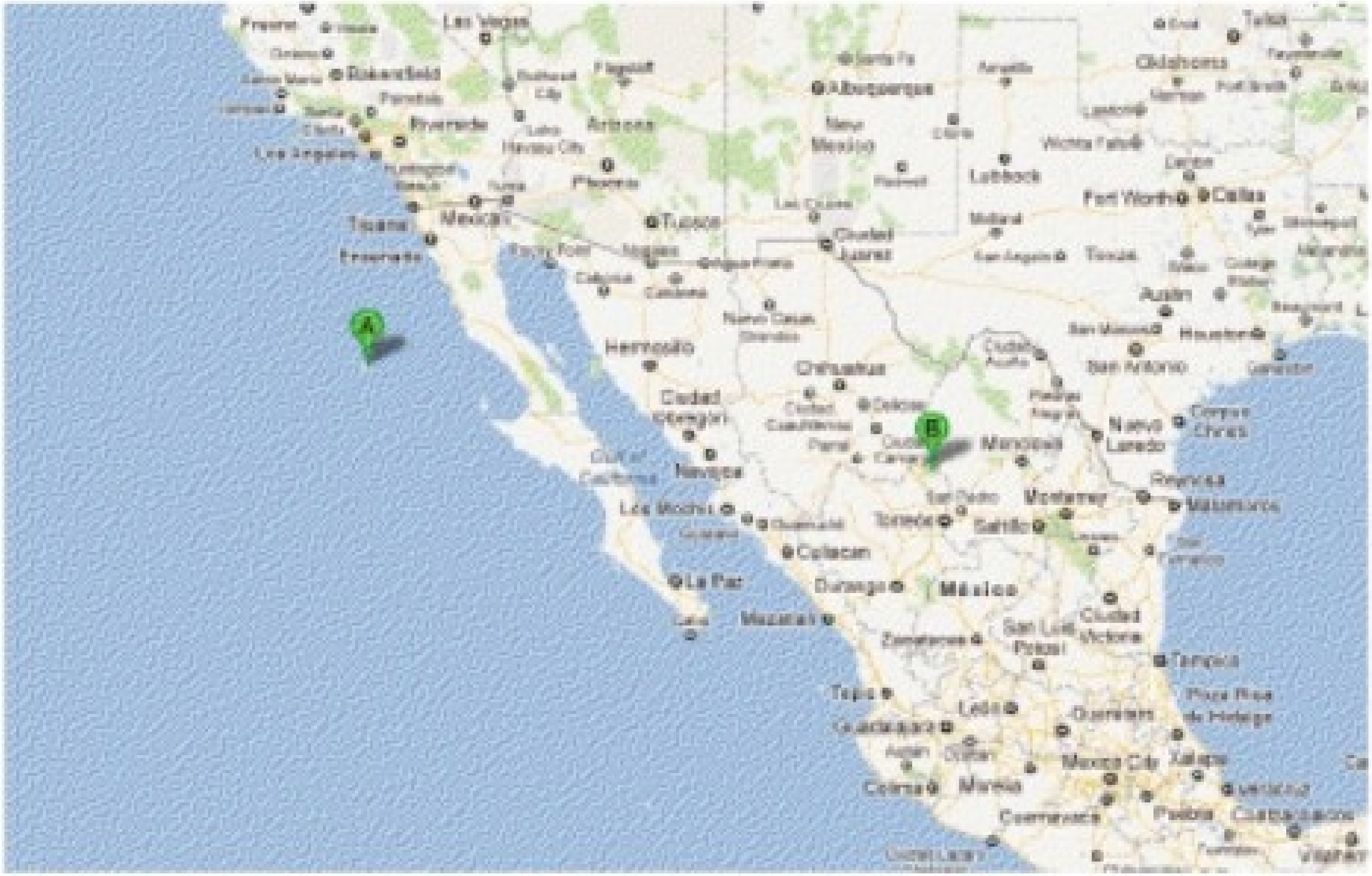
The case of wide binaries in the satellites of the Milky way.





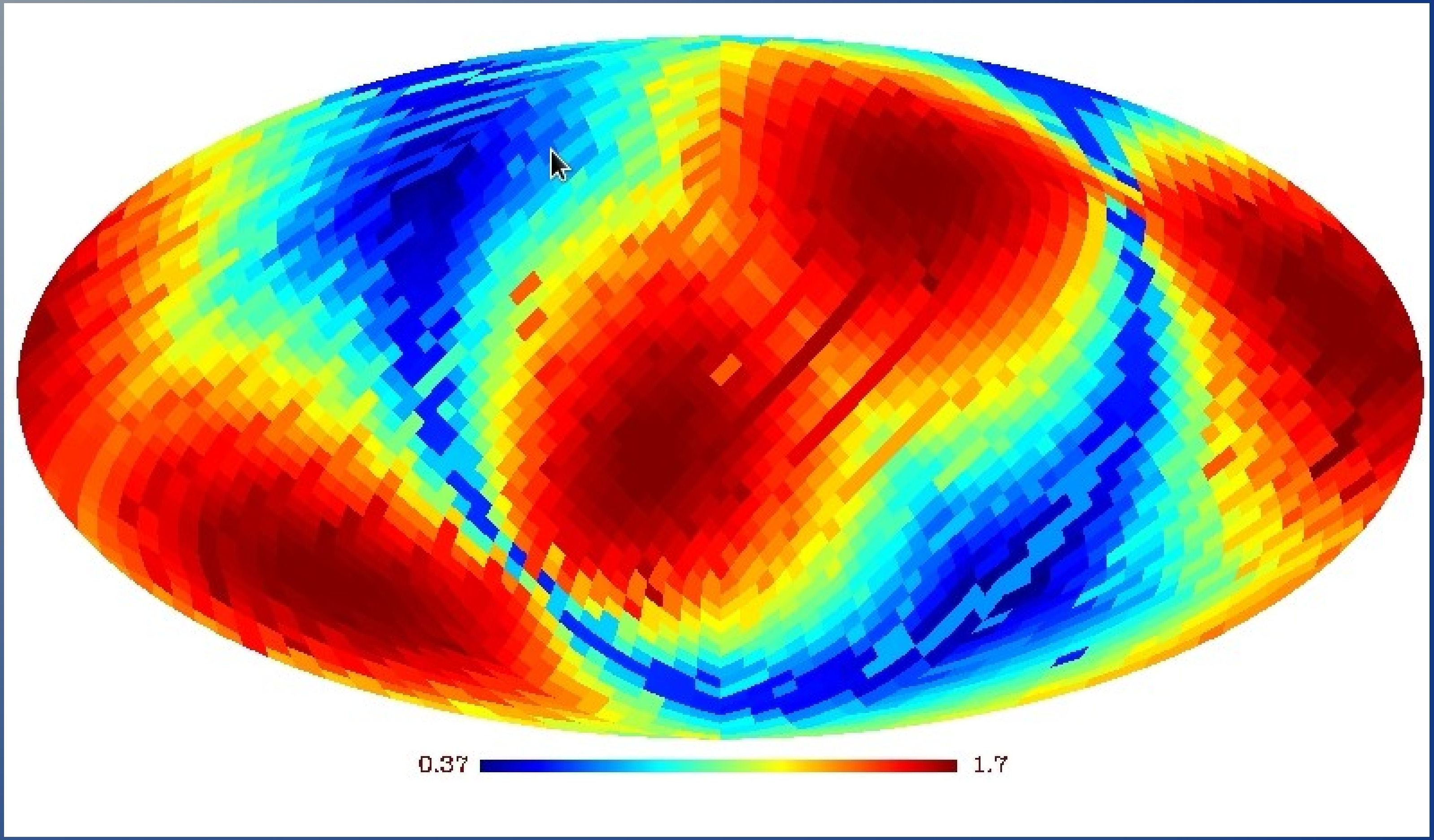
z=80
40
20
10
50
0
−50
−100
−150
T_b [mK]
20
40
60
80
100
120
140
ν[MHz]
DM annihil
DM decay
Stars

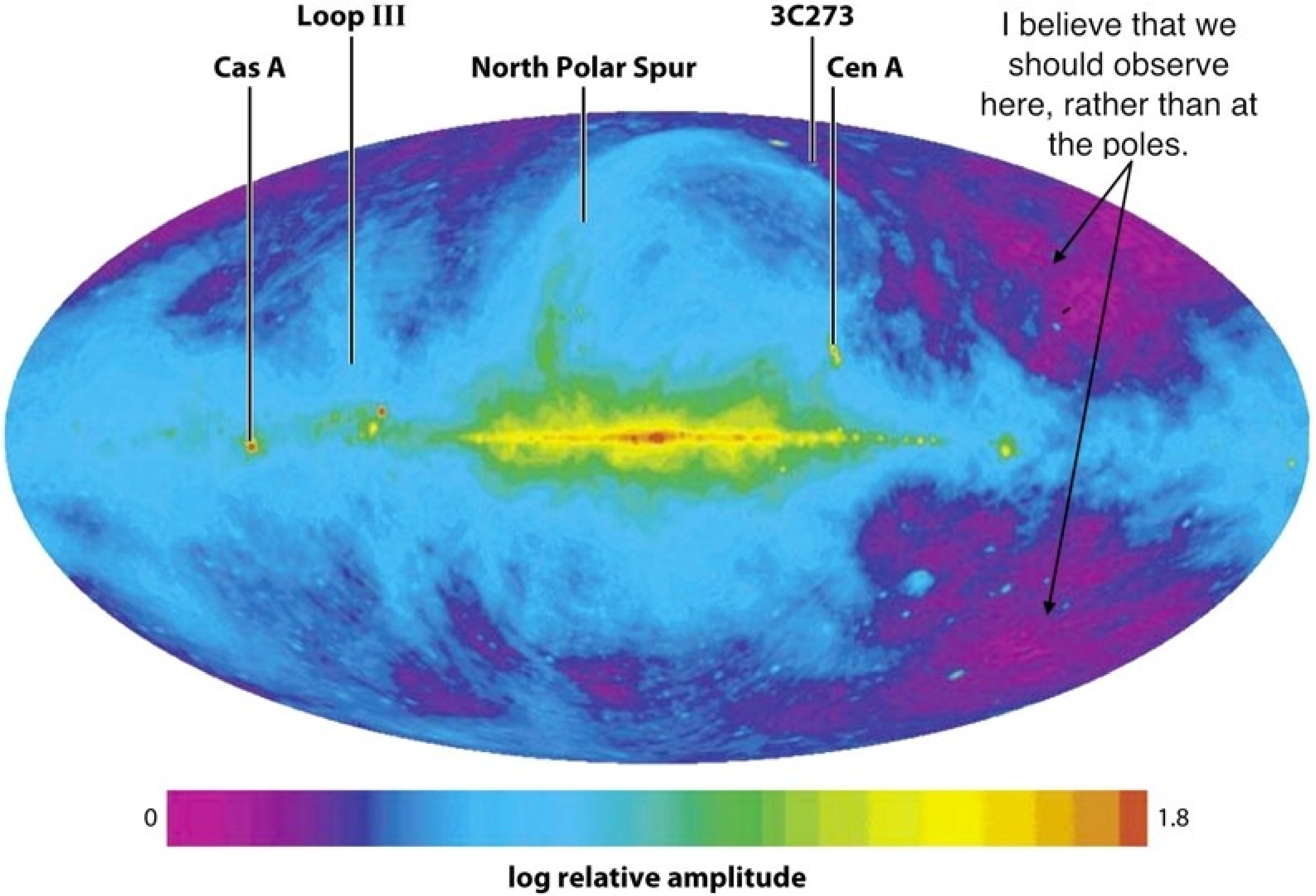

z=80
40
20
10
50
0
−50
−100
−150
−200
−250
T_b [mK]
no Lyα
no heating
full calc
saturated
50
100
150
ν[MHz]



A : Island of Guadalupe, Mexico – final antenna site

B : Zona del Silencio, Mexico – test site (winter 2011)


0.37
1.7


Loop III
3C273
I believe that we should observe here, rather than at the poles.
Cas A
North Polar Spur
Cen A
0
1.8
log relative amplitude