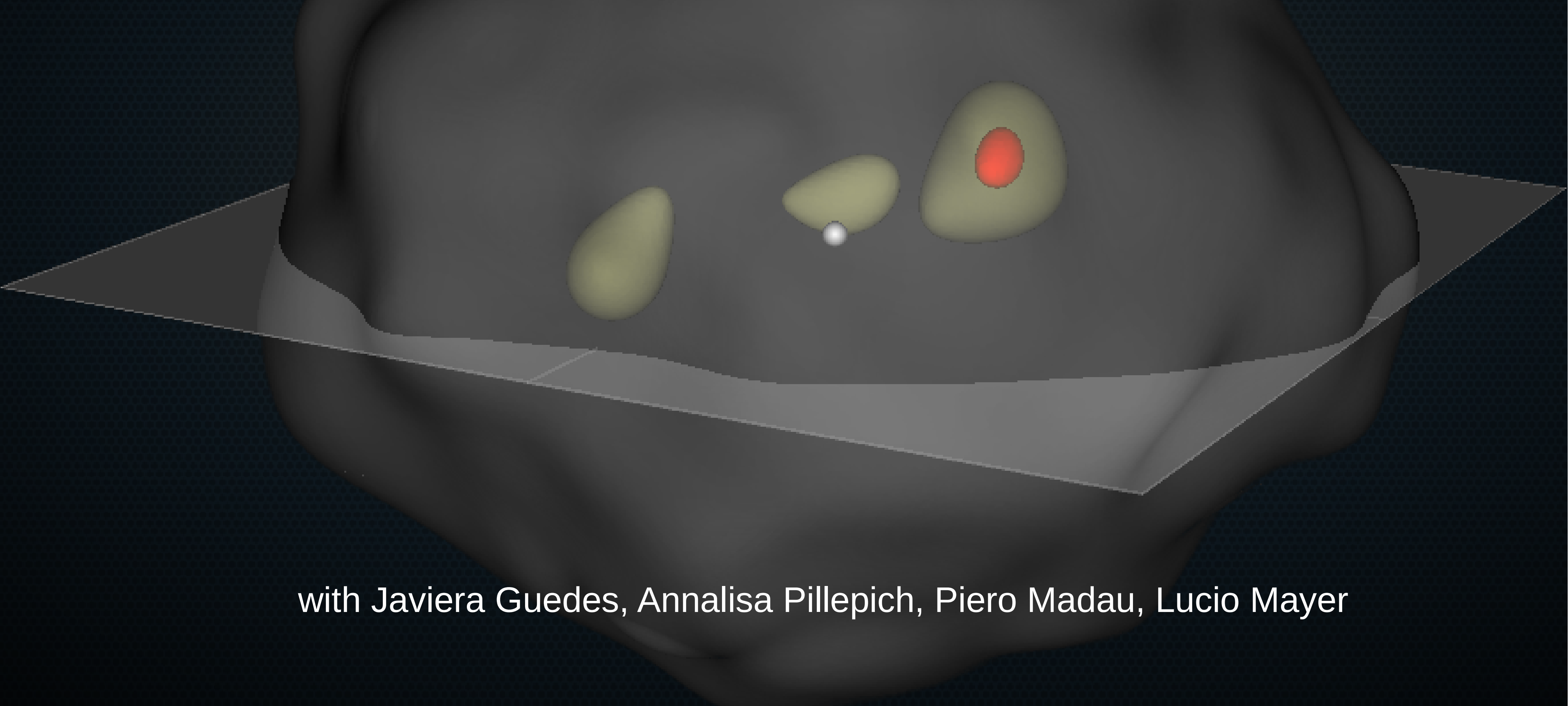
An off-center density peak in the Milky Way's Dark Matter halo?

AKA: Impact of baryonic physics on DM detection experiments

Michael Kuhlen, Berkeley

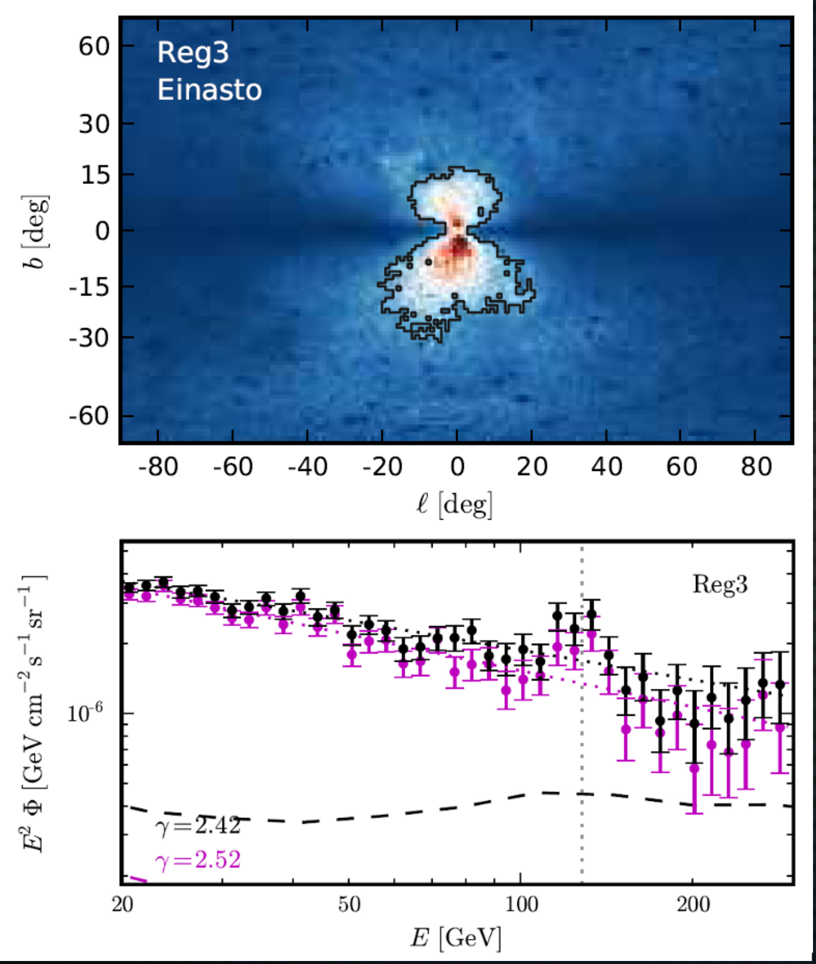


with Javiera Guedes, Annalisa Pillepich, Piero Madau, Lucio Mayer

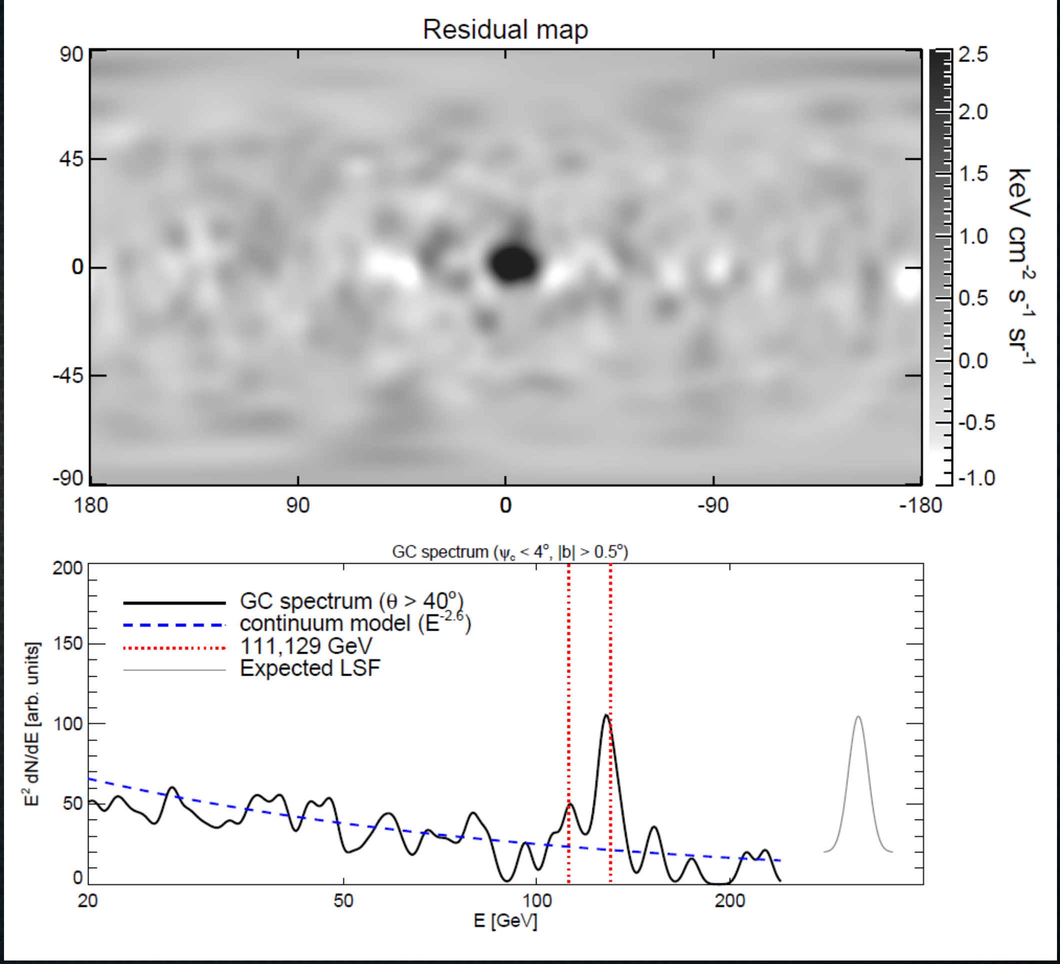
2012 Santa Cruz Galaxy Workshop

Aug. 16th 2012

Motivation: 130 GeV gamma-ray line from the Galactic Center



Weniger 2012

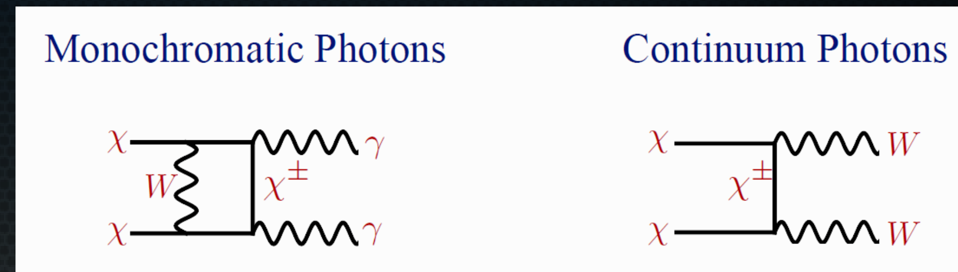


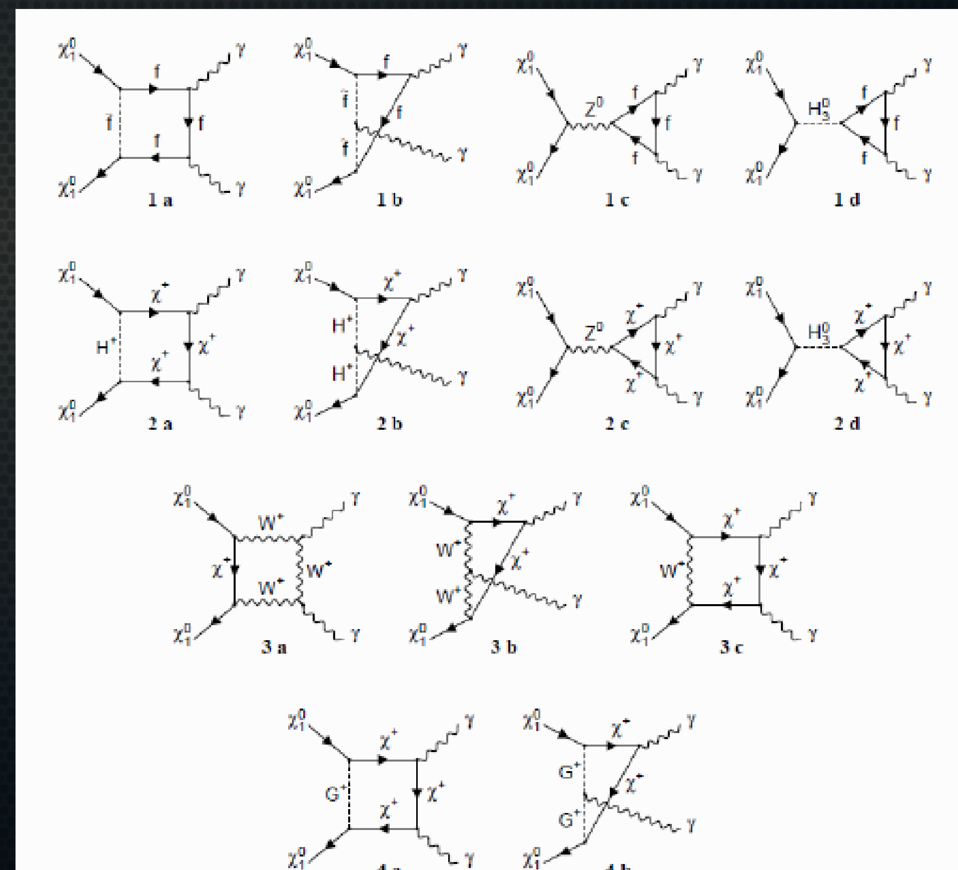
Su & Finkbeiner 2012

Is this DM annihilation?

DM annihilation?

- 2-body annihilation: $\chi\chi \rightarrow \gamma\gamma,\ \gamma Z,\ \gamma h$
- Normally “loop suppressed“ ($10^{-2} – 10^{-4}$) compared to continuum radiation.
- But models with enhanced lines exist, e.g.:
  Singlet DM (Profumo et al. 2010)
  “Higgs in Space“ (Jackson et al. 2010)





Bergström & Ullio 1997

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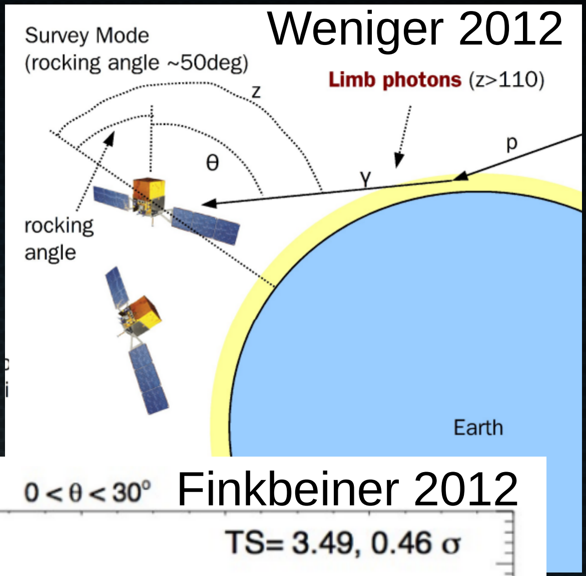
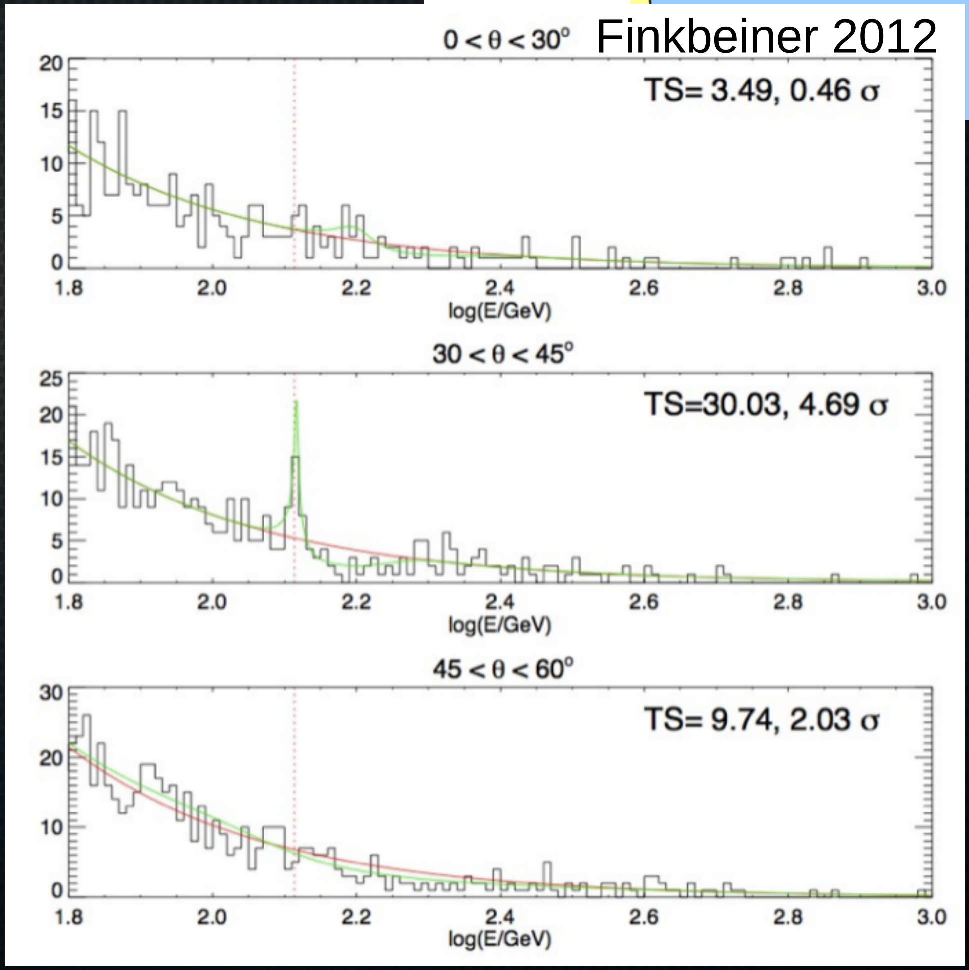
Instrument systematics?

- Earth limb photons of intermediate incidence angle show a similar line...





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Astrophysical explanations?

- Broken power-law mimics line?
  (Profumo & Linden 2012)
- Inverse Compton in the Klein-Nishina regime with ~130 GeV mono-chromatic electrons from multiple pulsars?
  (Aharonian et al. 2012)

Cold ultrarelativistic pulsar winds as potential sources of galactic gamma-ray lines above 100 GeV

Felix Aharonian[1,2], Dmitry Khangulyan[3], Denis Malyshev[4]

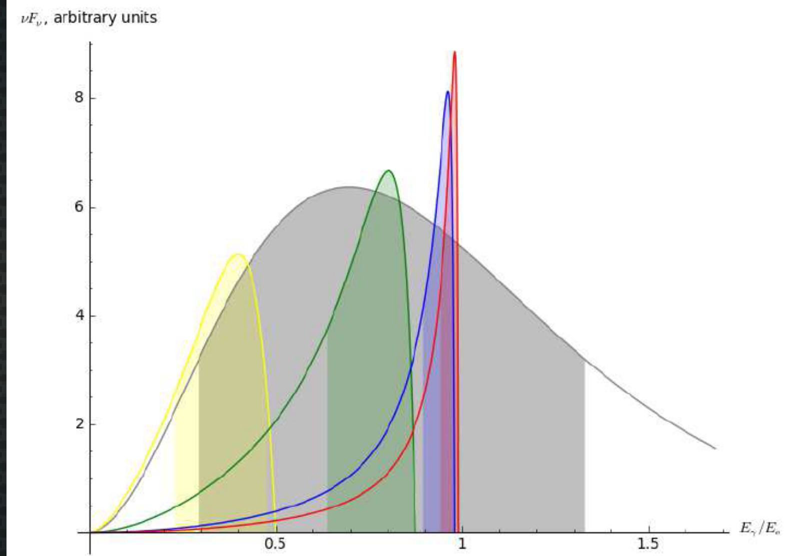
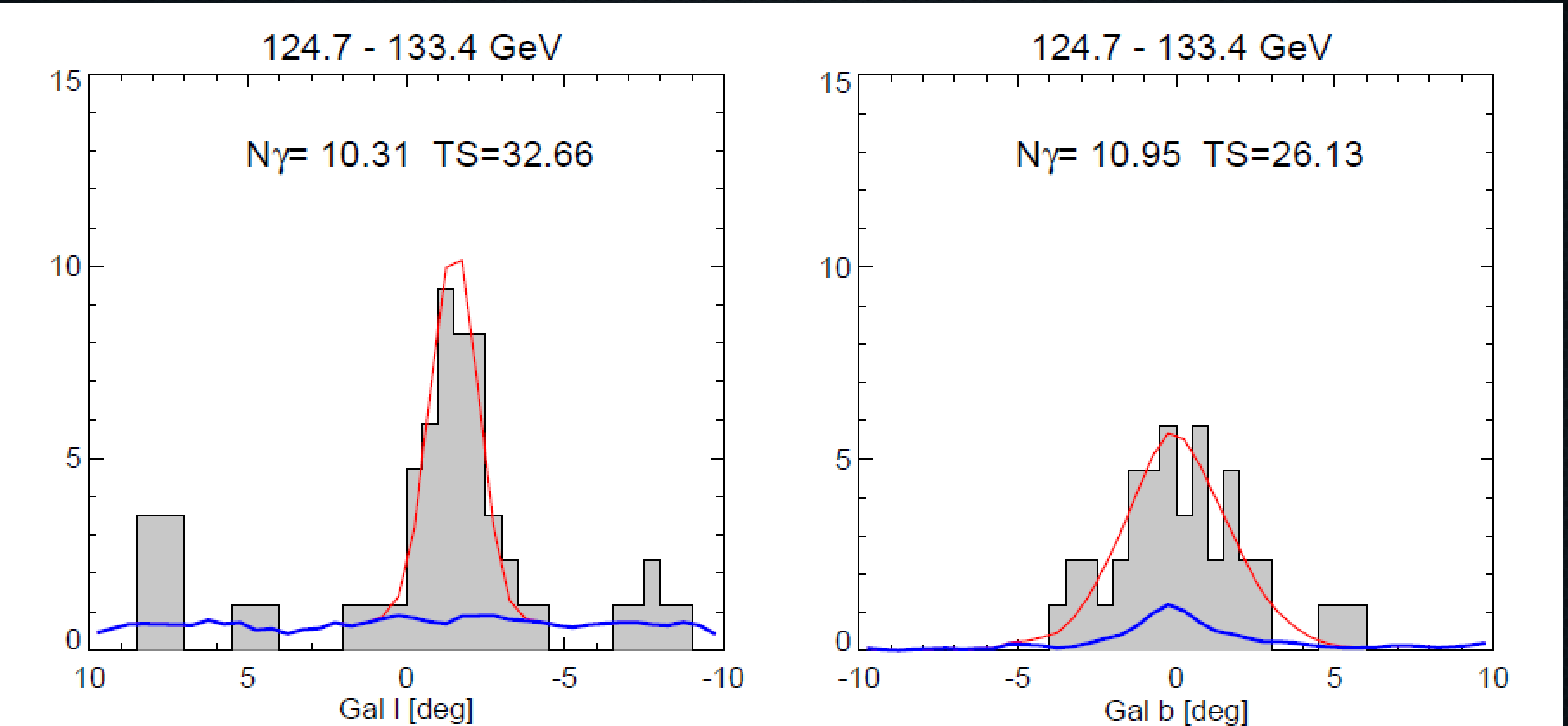


Fig. 1. *Colour*: energy spectra of the inverse Compton radiation of mono-energetic electrons upscattering isotropic target photons for 4 different values of the parameter b: 1, 7, 50 and 100. The energy of gamma-rays is in units of the electron energy. *Grey*: the gamma-ray spectrum produced by electrons with relativistic Maxwellian distribution; in this case the photon energies are in units of 4Θ, where Θ is the "temperature" of Maxwellian distribution.

The line is not exactly at the Galactic Center



Su & Finkbeiner 2012

The significance of the signal is maximized at (ℓ,b) = (-1.5º,0º), or about **200 projected pc** from Sgr A*.

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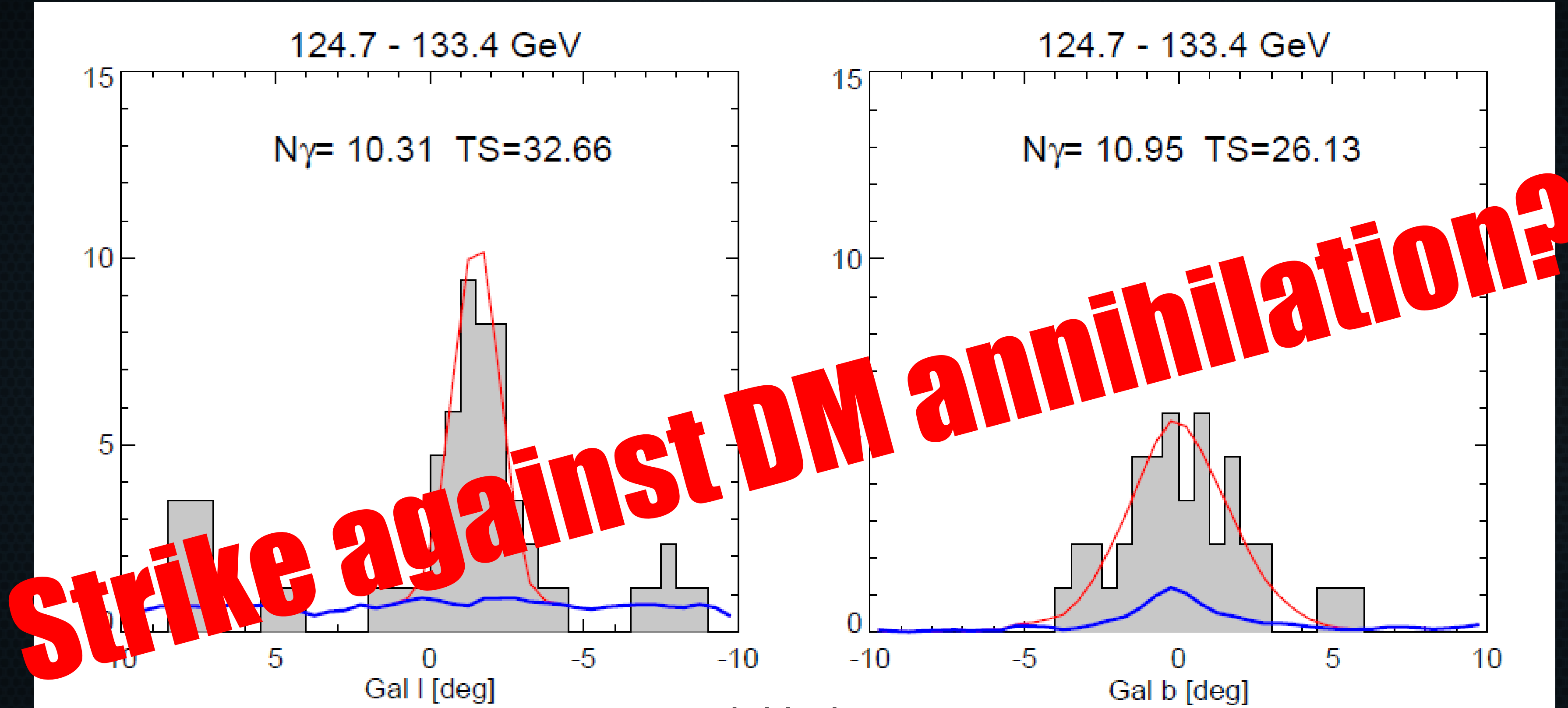

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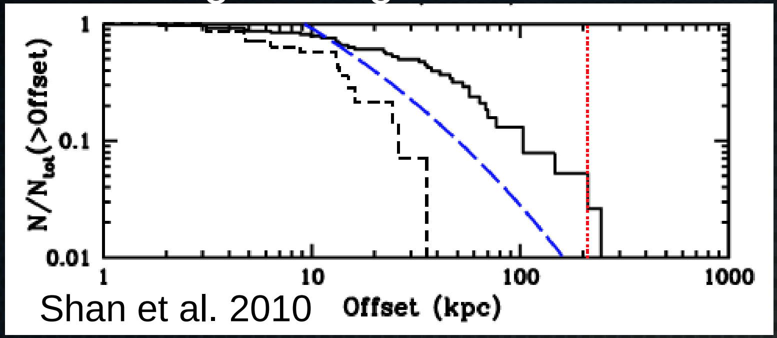
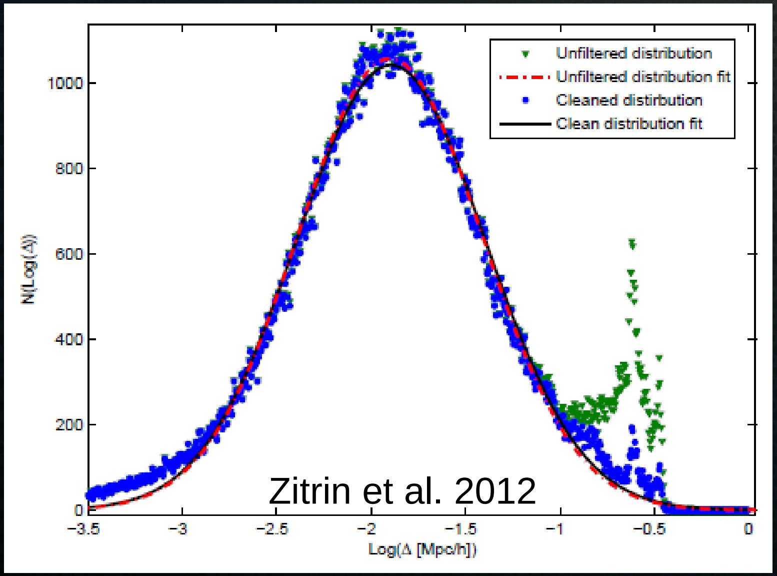
Example of DM offsets

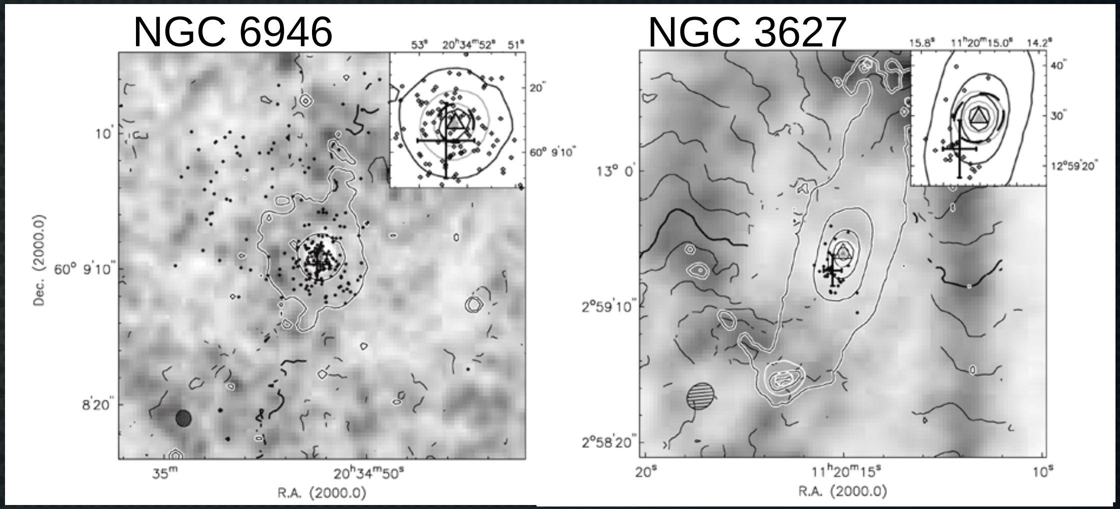
38 clusters measured in X-rays and with strong lensing.



10,000 SDSS clusters: offset between BCG and strong lensing center



2 out 15 THINGS galaxies with well constrained photometric centers have offsets between the dynamical and photometric centers of 1-2 radio beams (150-700 pc) (Trachternach et al. 2008).



Galaxy clusters commonly exhibit offsets of tens of kpc between the center of the DM halo and the BCG / X-ray center.

The Eris Simulation

For more details see Guedes et al. 2011

Cosmological SPH Zoom-in Simulation

7 million DM particles (10^5 $M_\odot$)

3 million gas particles (2×10^4 $M_\odot$)

8.6 million star particles ($4\text{-}6\times10^3$ $M_\odot$)

- radiative cooling
  (Compton, atomic, low-T metallicity-dependent)
- heating from cosmic UV
  (~ Haardt & Madau 1996)
- Supernova feedback (ε_{SN}=0.8)
  (Stinson et al. 2006)
- Star formation
  - threshold: n_{SF} = 5 atoms/cm^3
  - efficiency: ε_{SF} = 0.1
  - IMF: Kroupa et al. 1993
  - No AGN feedback

Results in a realistic looking Milky-Way-like spiral disk galaxy at z=0.

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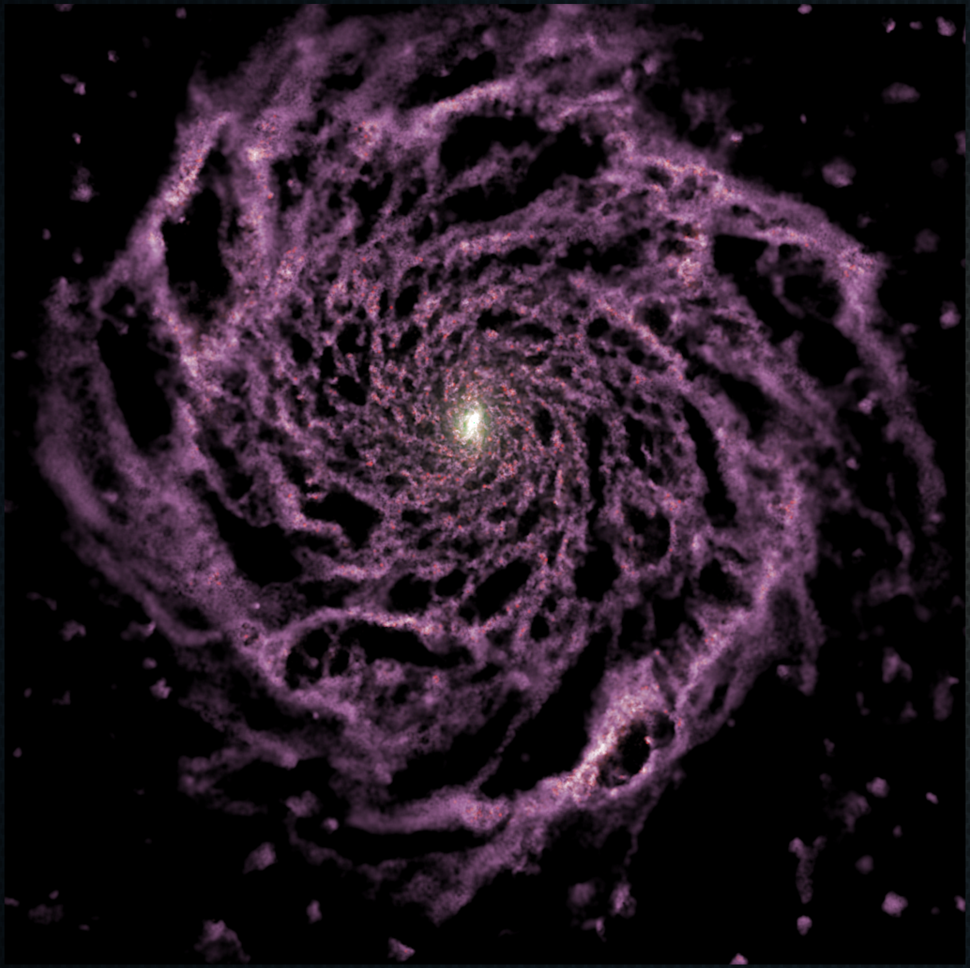

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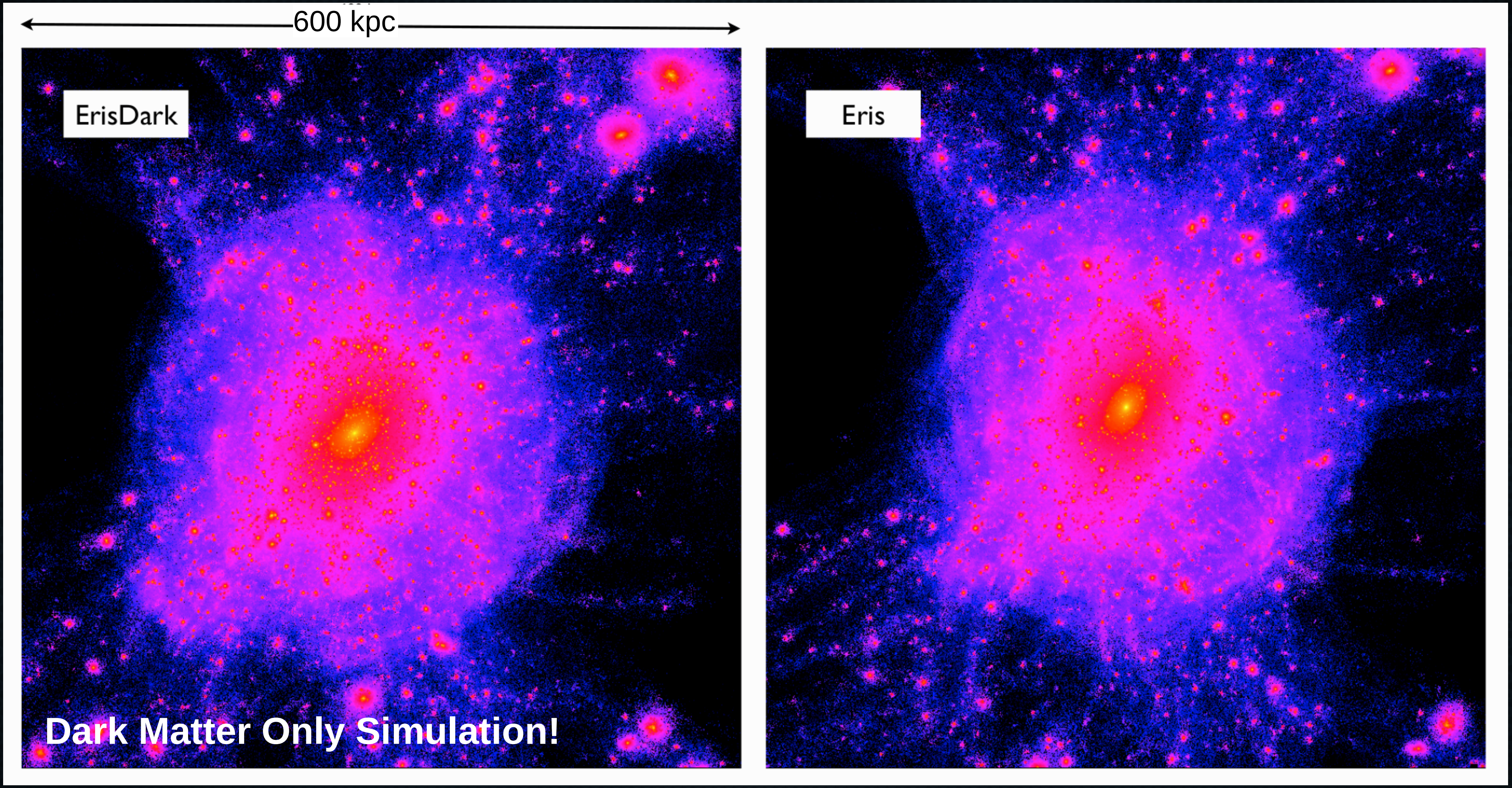
Eris & ErisDark

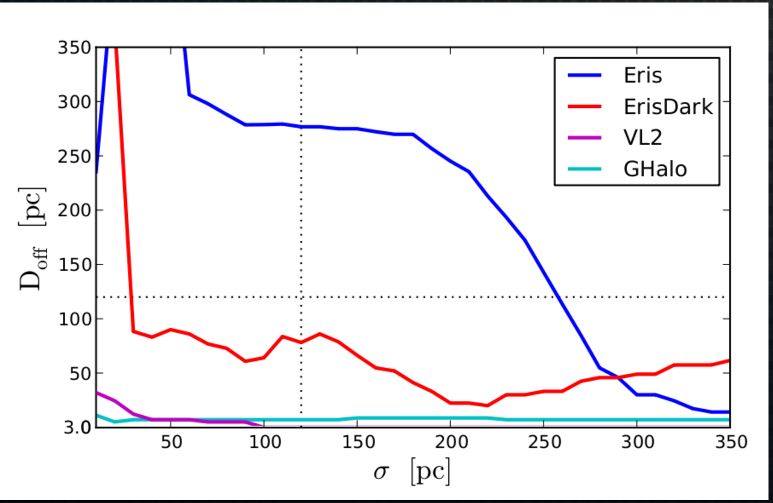


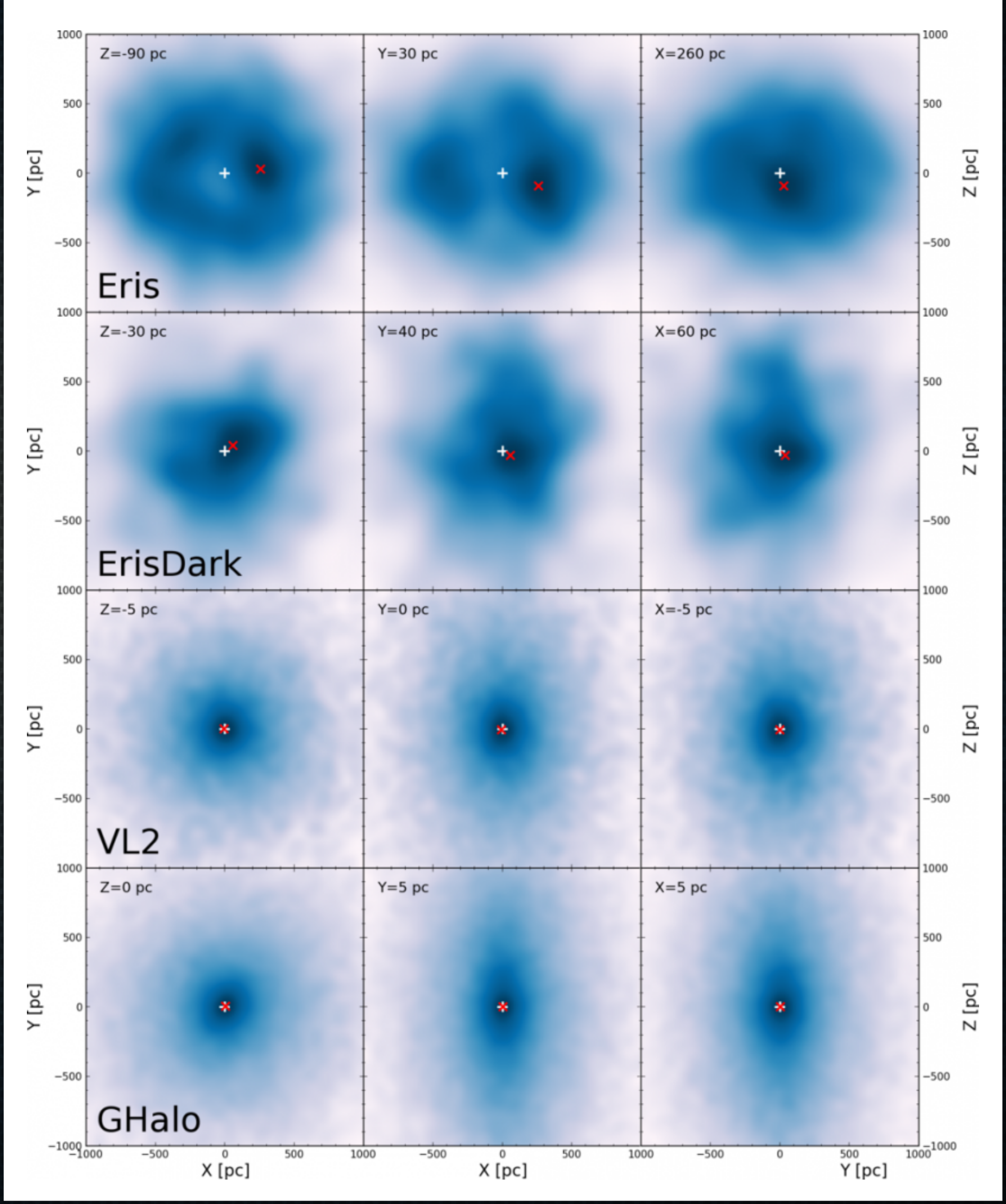
ErisDark has the same initial conditions as Eris, except that all of the matter is treated as dark matter. (Pillepich et al., in prep.)

DM offset in Eris

In the dissipational simulation (Eris), the maximum of the DM density is displaced from the minimum of the potential (dynamical center).

The DM-only runs show no such offset (to within one grav. softening length).



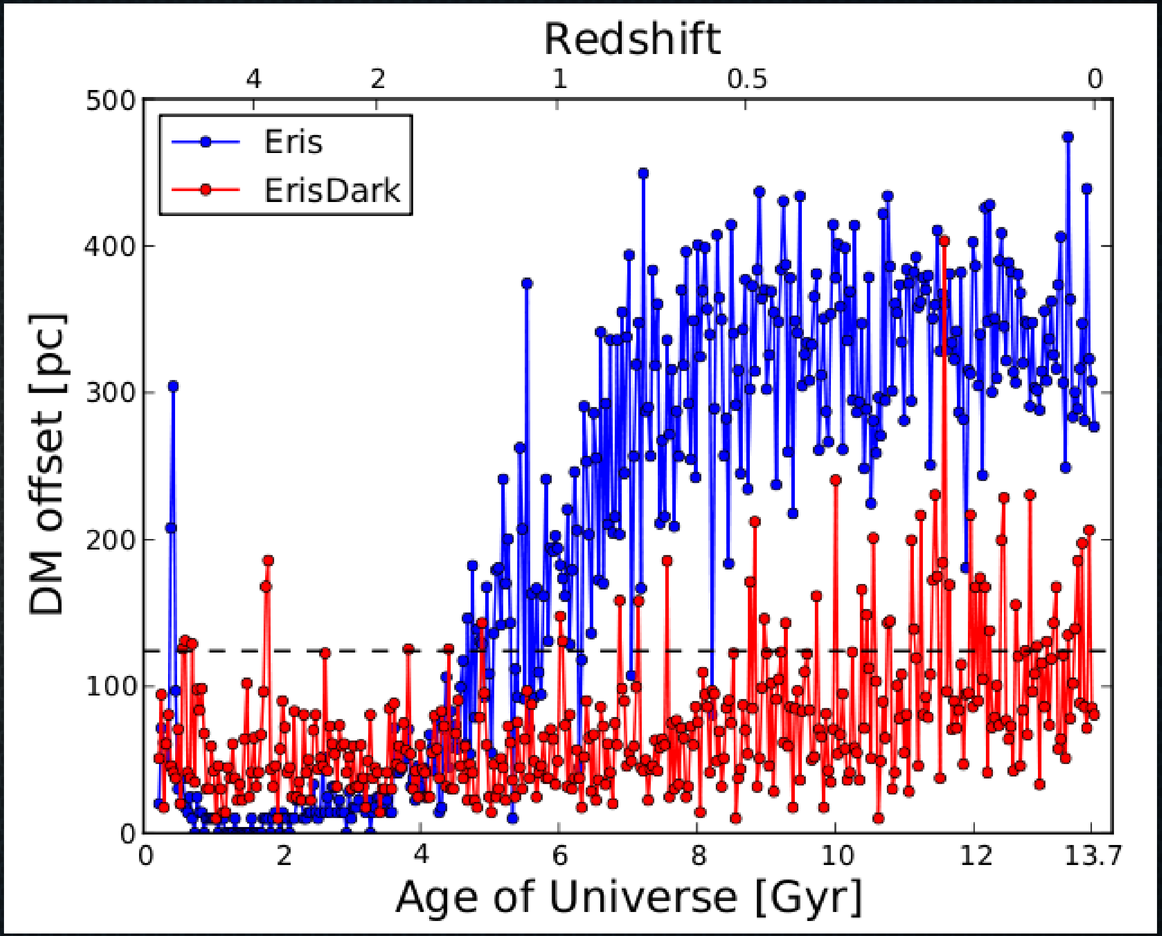


Formation and Evolution of the Offset

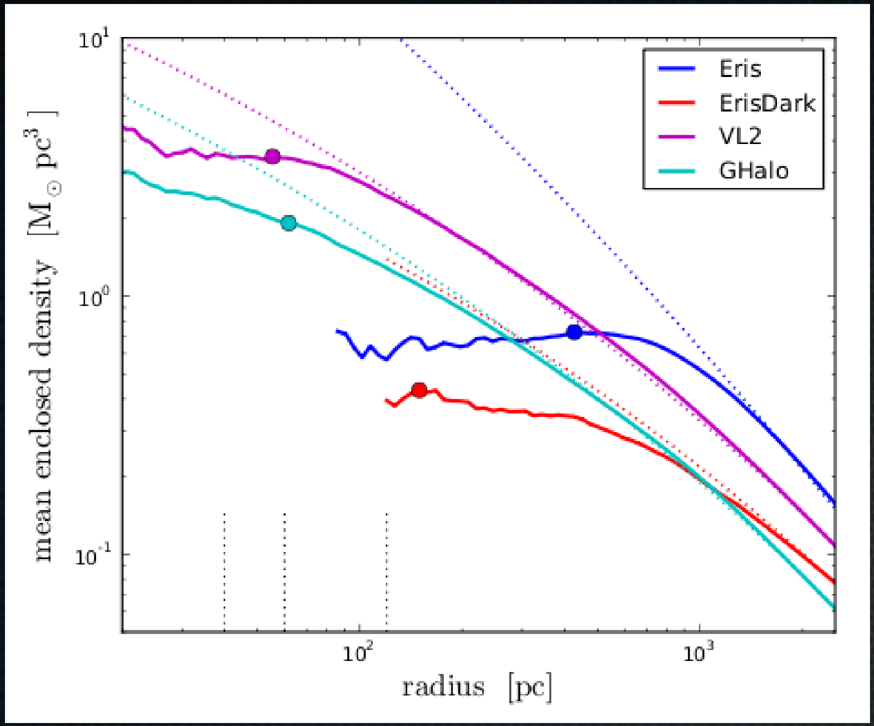
The offset is no fluke – it appears around z=1.5 and persists afterwards.

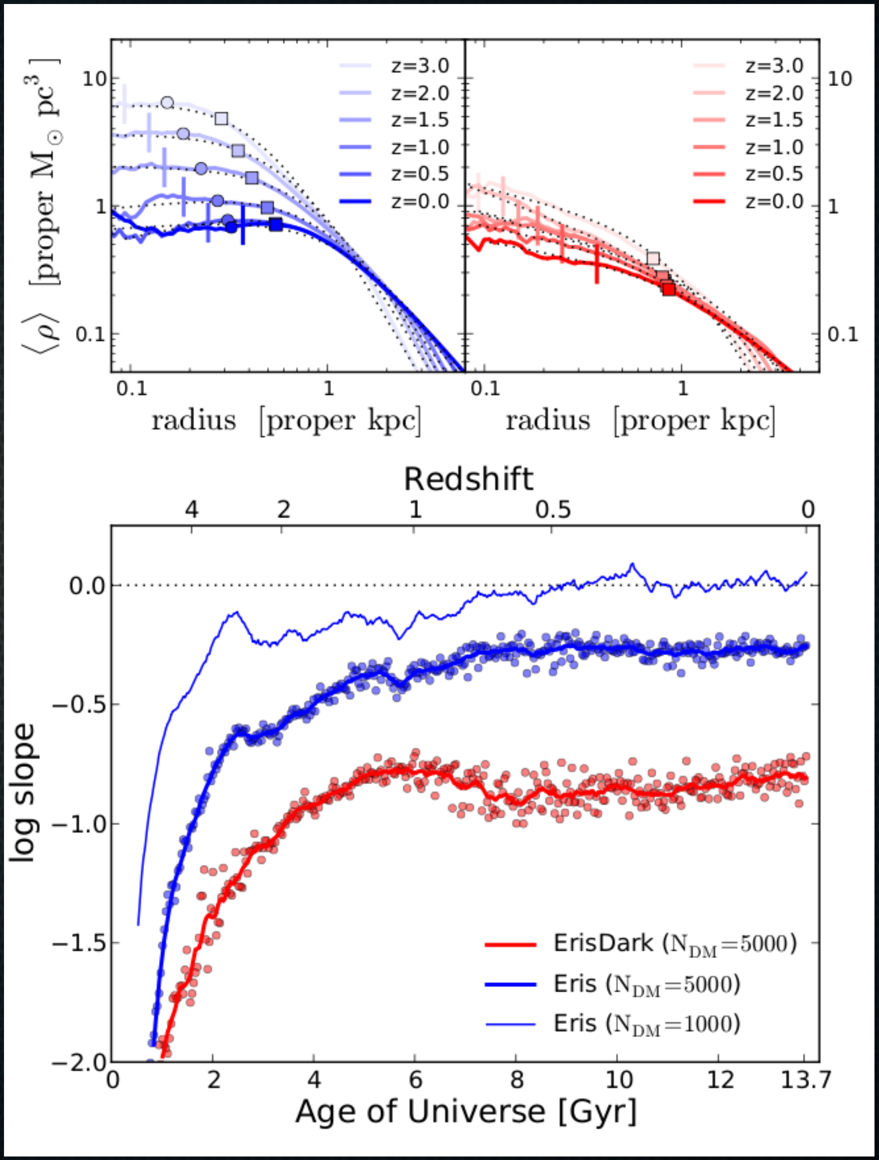
$\langle D_{off} \rangle$ = 340 pc (almost 3 ϵ_{soft}).

In ErisDark the offset remains below ~1ϵ_{soft}.



Formation and Evolution of the Offset





The formation of the offset seems to correlate with a flattening of the central density profile.

A common mechanism?

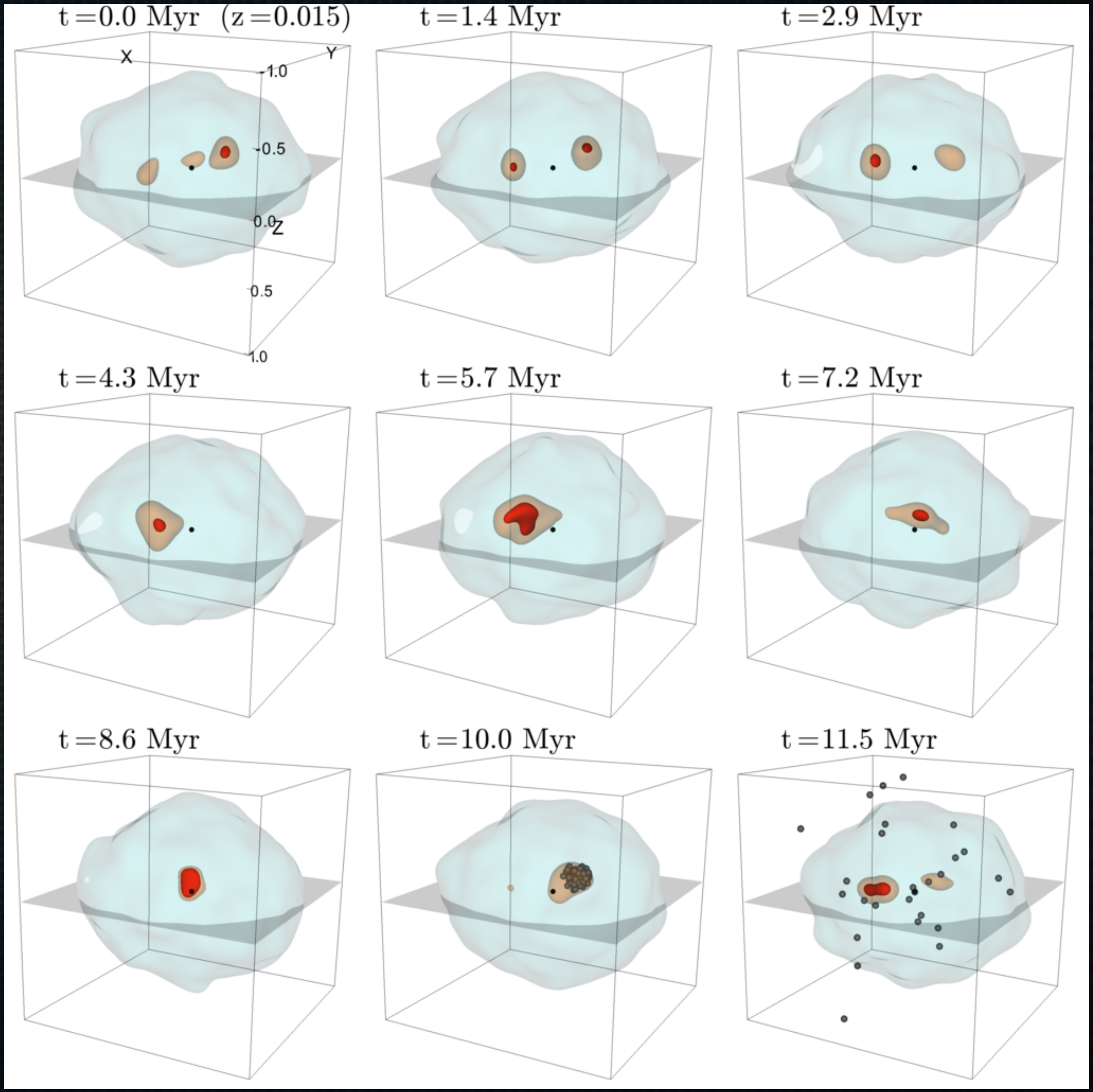
Formation and Evolution of the Offset

Eris output are spaced ~35 Myr – too long for dynamical analysis.

High output cadence re-run of the last few hundred Myr of Eris.

Typically close to the disk plane:
$\langle \Delta R \rangle = 340 \pm 51$ pc
$\langle \Delta z \rangle = 64 \pm 46$ pc

Not stationary.
Not coherent.
Sometimes multiple peaks.



Possible Explanations

Statistical Fluctuation?

Perhaps the density peak is a Poisson fluctuation due to the small number of particles in the center?

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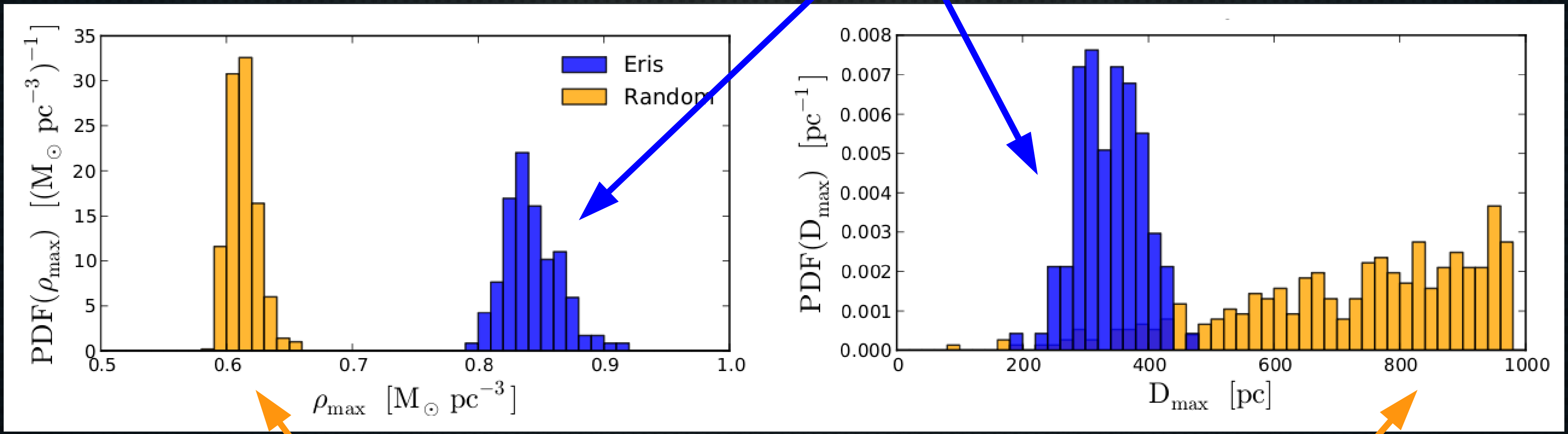
Last 120 Eris outputs.



500 random realizations with same mean particle number density as in Eris: 5100 DM particles / kpc^3.

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~~Statistical Fluctuation?~~

Incompletely disrupted subhalo?

- Dynamical friction is inefficient in a constant density core... Maybe a subhalo's core is orbiting around the center?

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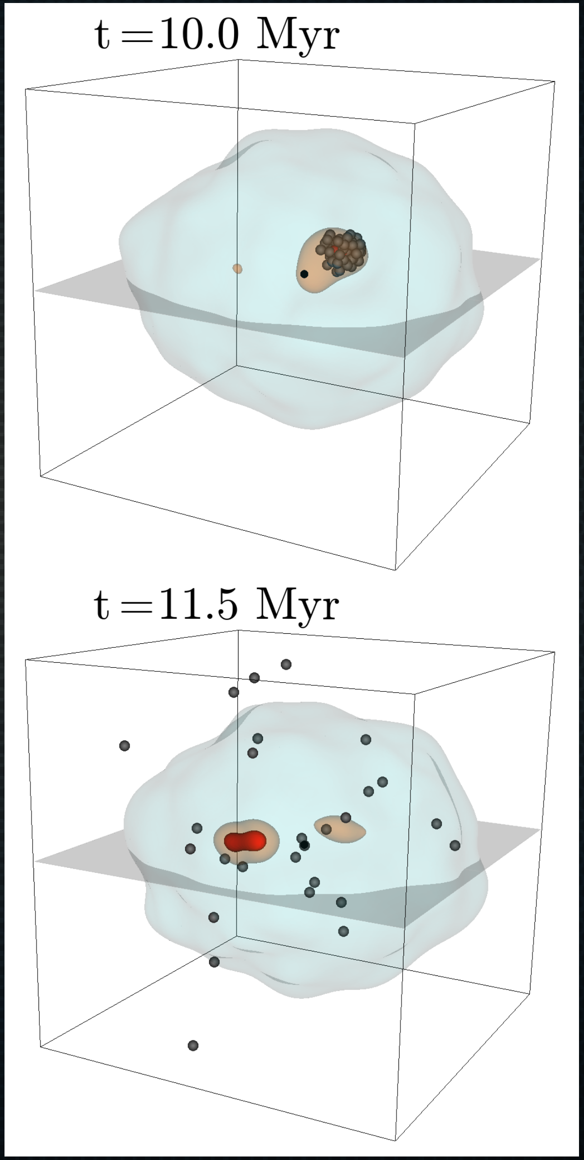
Particles within 1 ϵ_{soft} of the offset peak at one time are no longer part of the offset peak as short as 1.5 Myr later.

Not a coherent, bound structure. Not a subhalo.



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External perturbation displaces stellar disk?

The stars and gas are self-bound.
An external perturber could displace
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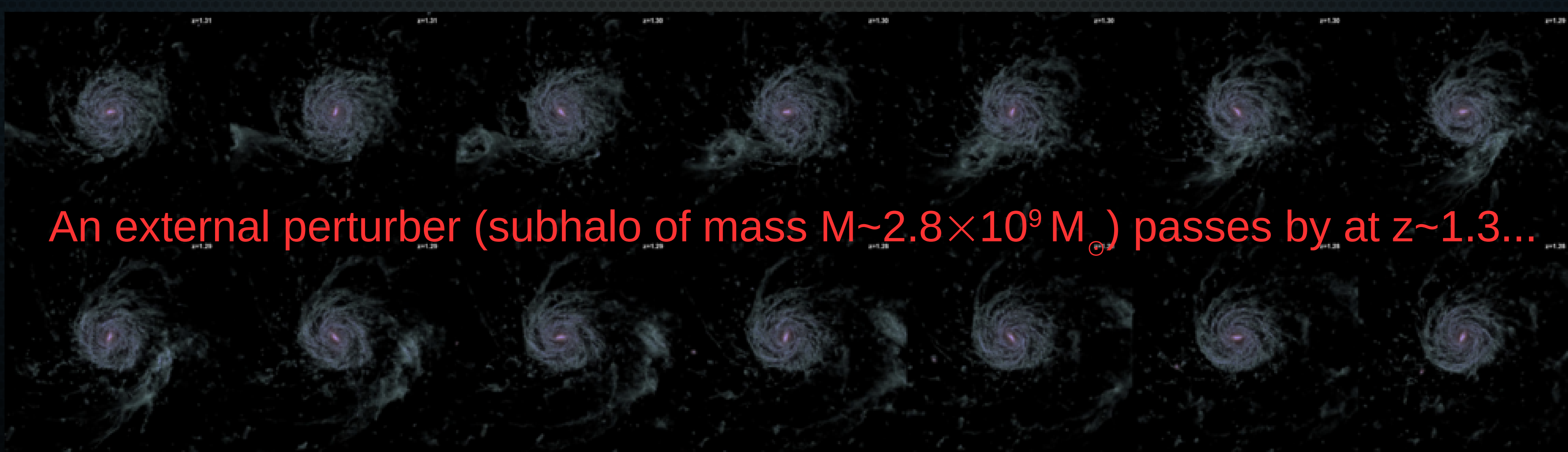

An external perturber (subhalo of mass $M \sim 2.8 \times 10^9 M_\odot$) passes by at $z \sim 1.3$...

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External perturbation displaces stellar disk?

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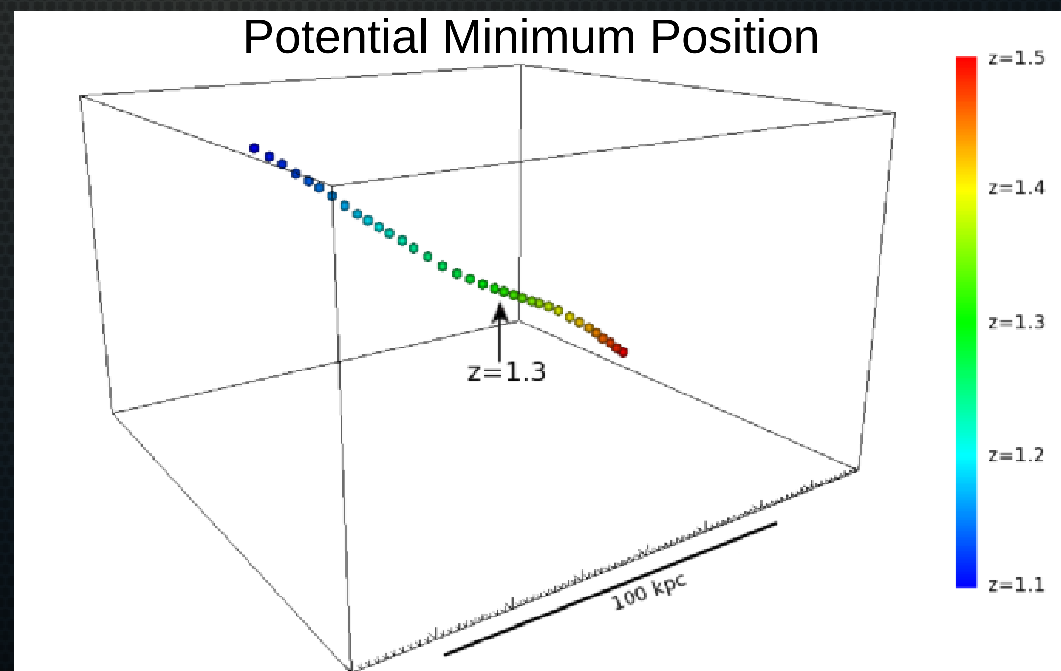
But: no sign of any abrupt displacement of the potential mimimum at that time...



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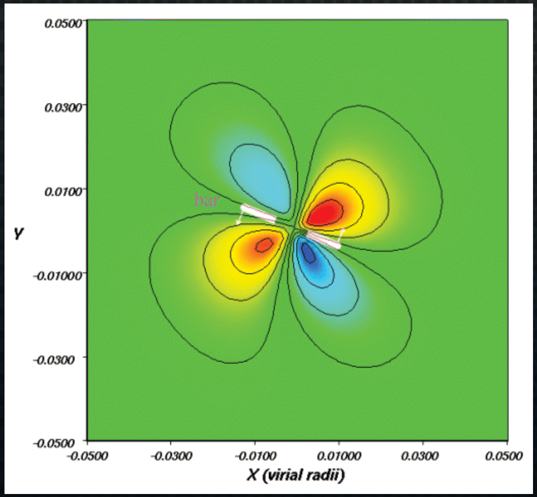
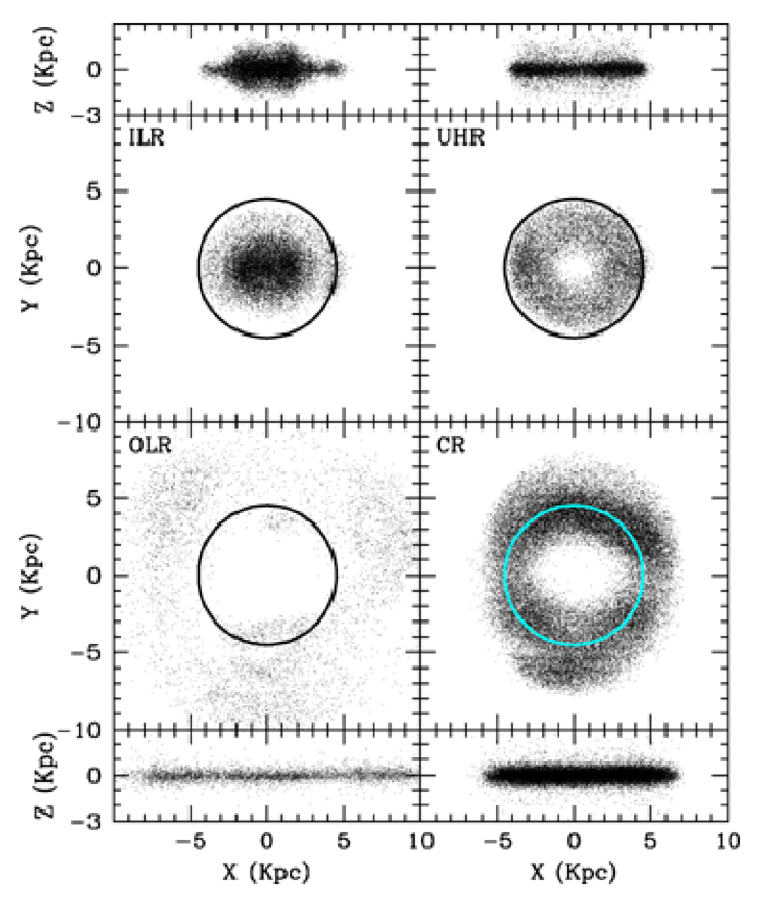
Resonant interaction with the stellar bar?

At times Eris has a very pronounced stellar bar. Maybe orbital resonances could lead to a density-wave-like excitation?



Weinberg & Katz 2002, 2007



Ceverino & Klypin 2007

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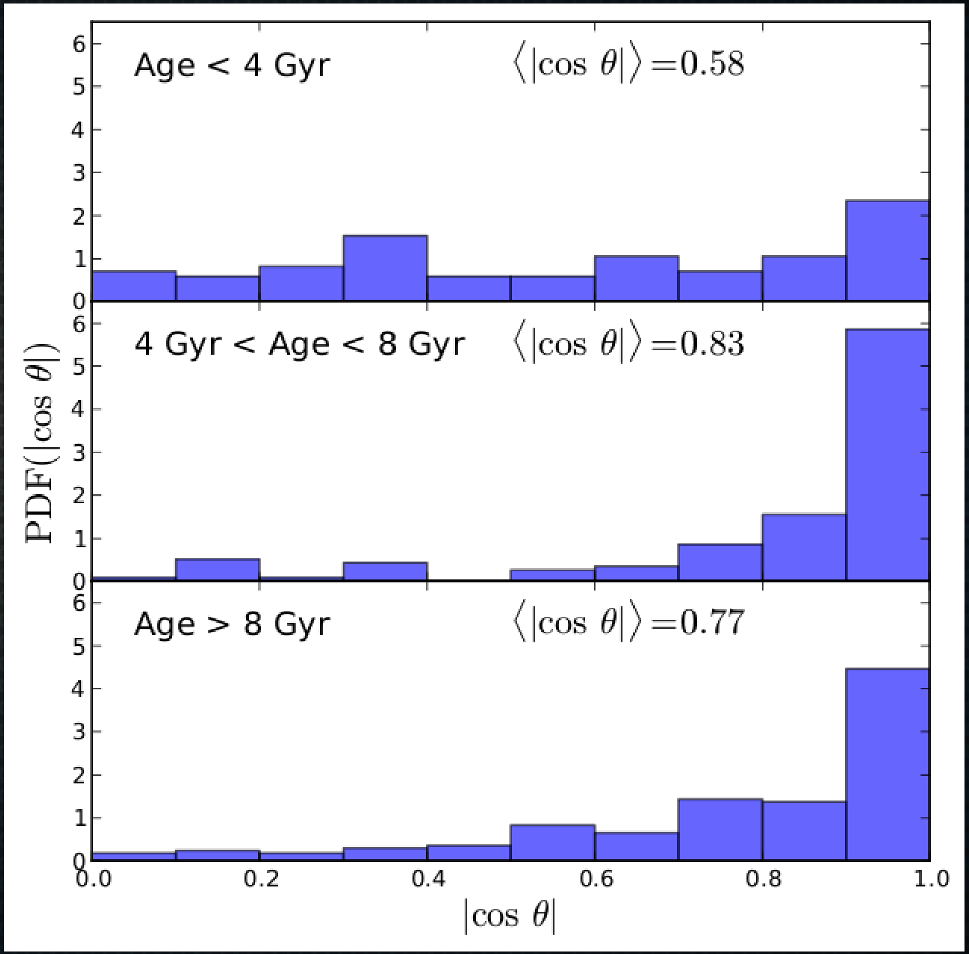
The direction of the DM offset is aligned with the orientation of the stellar bar in Eris.



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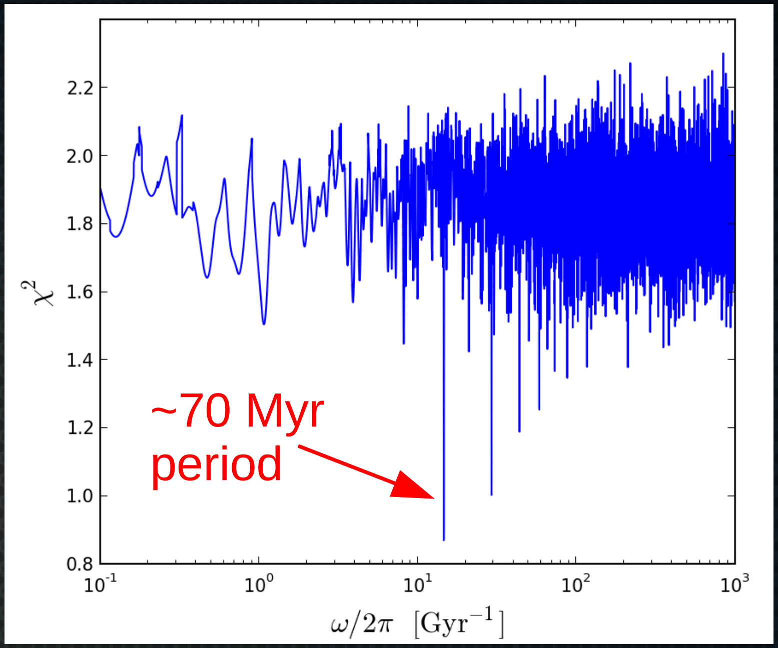
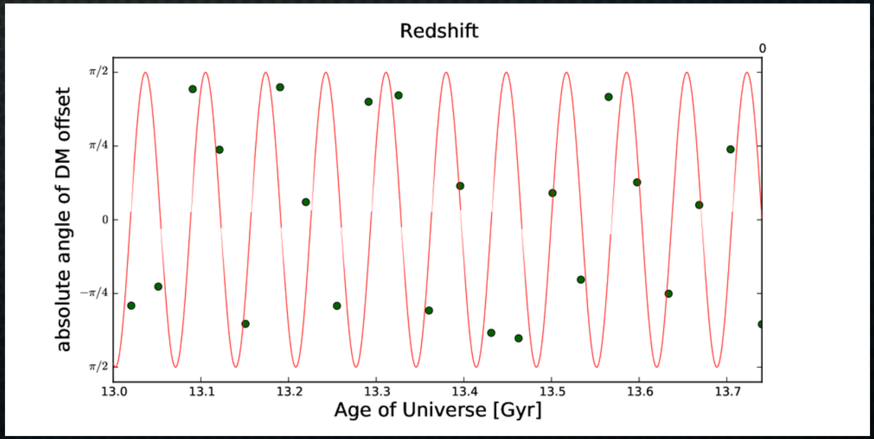
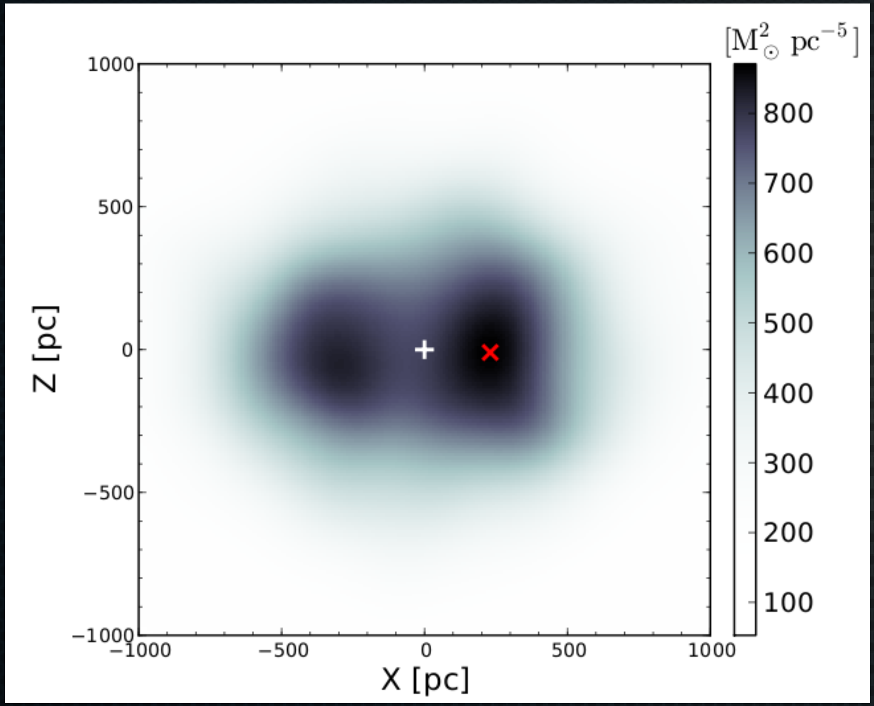


The angle in the disk plane to the offset shows periodic behavior.



DM annihilation implications?



At the resolution of the Eris simulation the contrast in DM annihilation surface brightness between the peak and the Galactic Center is only ~10-15%.

Such a low contrast is not compatible with a DM annihilation interpretation of the 130 GeV line.

HOWEVER: WE DO NOT RESOLVE THE OFFSET PEAK!
The contrast may increase with higher resolution...

Conclusions

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More general conclusion:

Extrapolating density profiles obtained from pure-DM simulations (NFW, Einasto, etc.) all the way to tens of parsec from the Galactic Center may not be such a good idea.