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

AKA: Impact of baryonic physics on DM detection experiments

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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)  
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**Monochromatic Photons**

**Continuum Photons**

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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 $\sim$130 GeV mono-chromatic electrons from multiple pulsars? (Aharonian et al. 2012)
The line is not exactly at the Galactic Center

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Example of DM offsets

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

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).

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

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

Cosmological SPH Zoom-in Simulation

- 7 million DM particles ($10^5 M_\odot$)
- 3 million gas particles ($2 \times 10^4 M_\odot$)
- 8.6 million star particles ($4-6 \times 10^3 M_\odot$)
  - radiative cooling
    (Compton, atomic, low-T metallicity-dependent)
  - heating from cosmic UV
    (~ Haardt & Madau 1996)
  - Supernova feedback ($\epsilon_{SN}=0.8$)
    (Stinson et al. 2006)
  - Star formation
    - threshold: $n_{SF} = 5$ atoms/cm$^3$
    - efficiency: $\epsilon_{SF} = 0.1$
    - IMF: Kroupa et al. 1993
    - No AGN feedback

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

For more details see Guedes et al. 2011
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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.

$<D_{\text{off}}> = 340$ pc (almost $3 \epsilon_{\text{soft}}$).

In ErisDark the offset remains below $\sim 1 \epsilon_{\text{soft}}$. 
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:
\(<\Delta R> = 340 \pm 51 \text{ pc} \>
\(<\Delta z> = 64 \pm 46 \text{ 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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500 random realizations with same mean particle number density as in Eris: 5100 DM particles / kpc$^3$. 

Last 120 Eris outputs.
Possible Explanations

**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 $1 \epsilon_{\text{soft}}$ 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.
Possible Explanations

Statistical Fluctuation?

Incompletely disrupted subhalo?

External perturbation displaces stellar disk?
  The stars and gas are self-bound.
  An external perturber could displace them from the center and they would “slosh“ around the DM halo?
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An external perturber (subhalo of mass $M \sim 2.8 \times 10^9 M_\odot$) passes by at $z \sim 1.3$...
Possible Explanations

Statistical Fluctuation?

Incompletely disrupted subhalo?

External perturbation displaces stellar disk?
   The stars and gas are self-bound. An external perturber could displace them from the center and they would “slosh“ around the DM halo?

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

Statistical Fluctuation?

Incompletely disrupted subhalo?

External perturbation?

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?


Ceverino & Klypin 2007
Possible Explanations

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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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- No such offset is seen in pure-DM simulations, implying that baryonic physics may be responsible in some way.
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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.