Spherical Cows of Dark Matter

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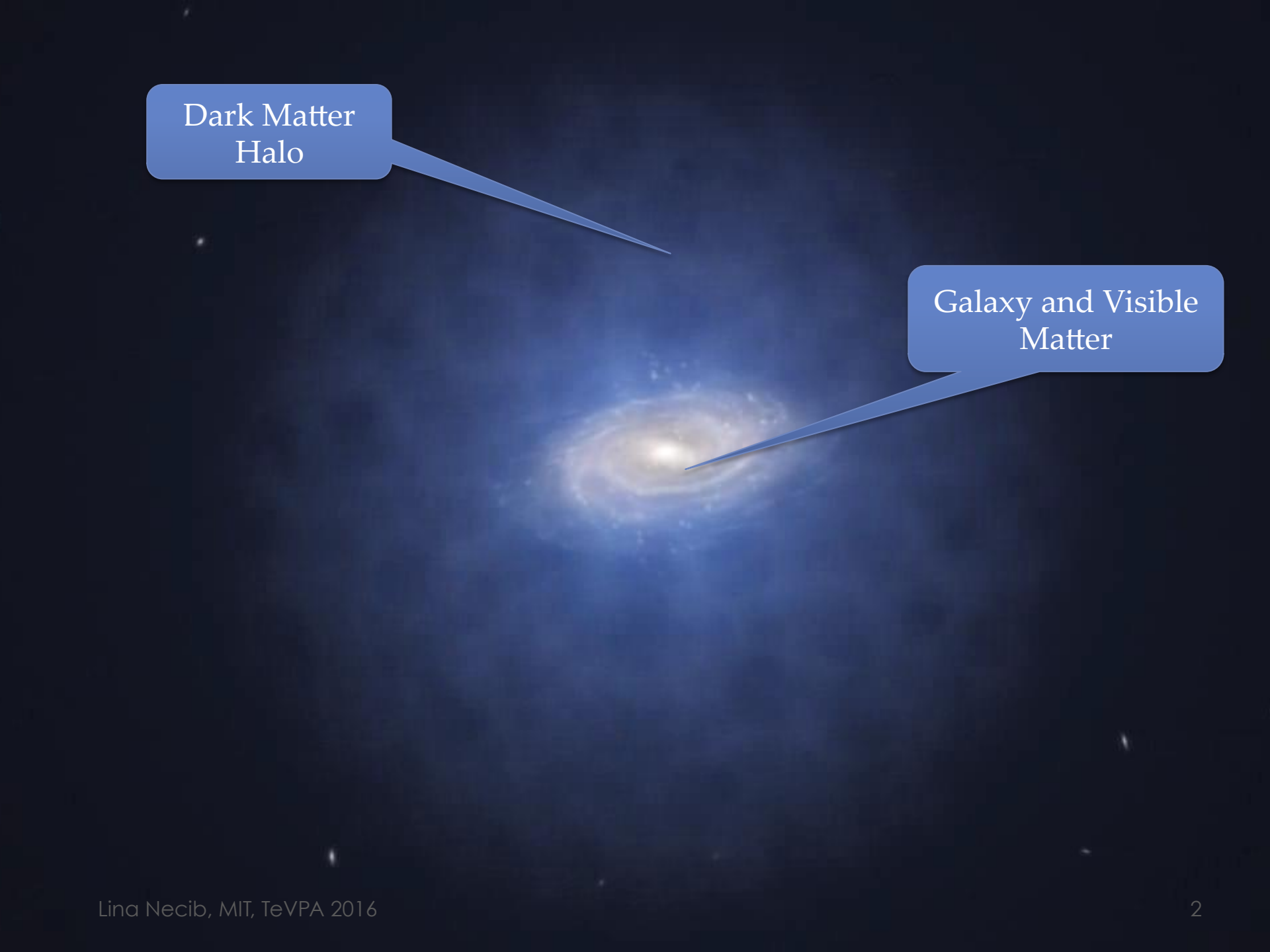
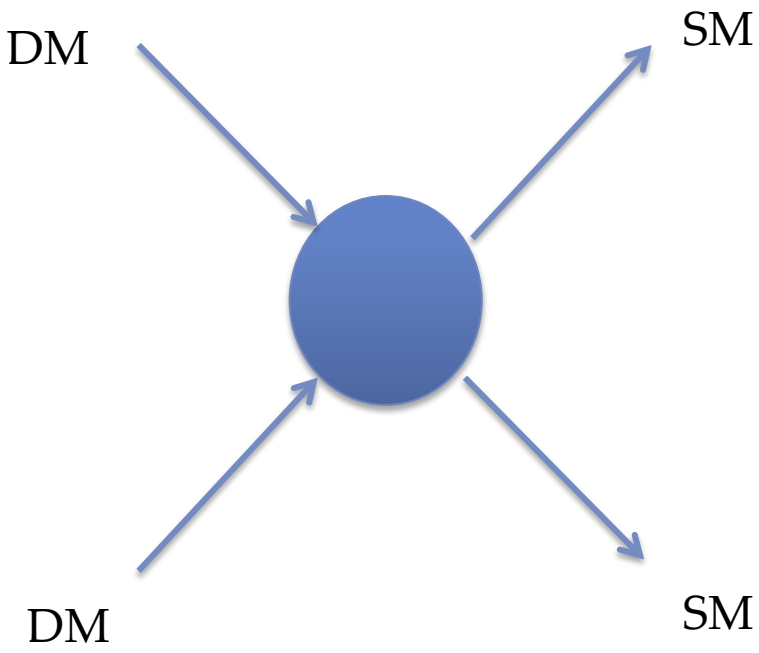
MIT
In collaboration with Nicolas Bernal and Tracy Slatyer

Based on arXiv:1606.00433


Dark Matter Halo
Galaxy and Visible Matter

Indirect detection



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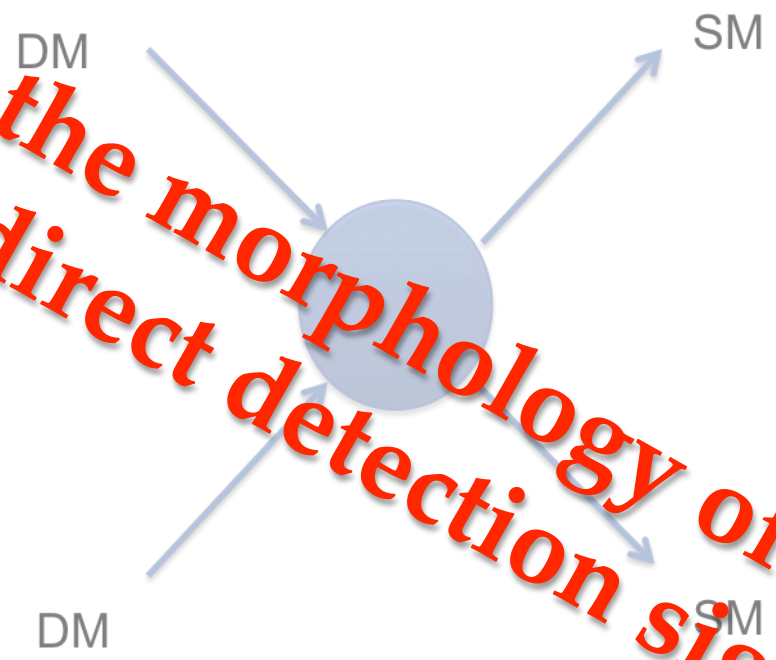
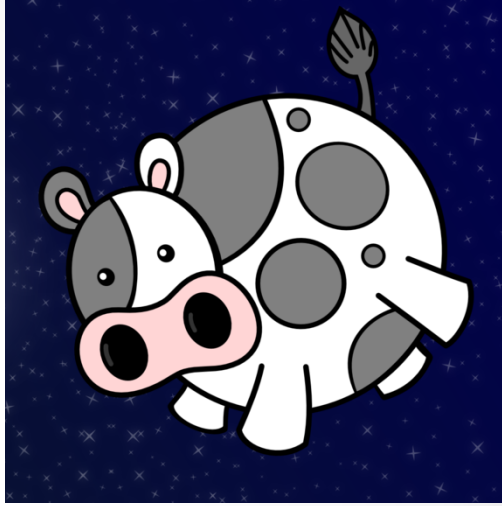


What is the morphology of Dark Matter indirect detection signals?



We always say that it is spherical.

But, from N-body simulations:

- Galactic signals ✓
- Extragalactic signals ✗

Illustris

- Publically available hydrodynamic simulation: It includes stars, gas, DM, and black holes.
- We use ~ 160 000 halos ranging in mass $5 \times 10^9 M_\odot - 3 \times 10^{14} M_\odot$
- We find 650 Milky-Way like halos!

For more details on the simulation, check back-up slides.

Outline

Galactic Analysis

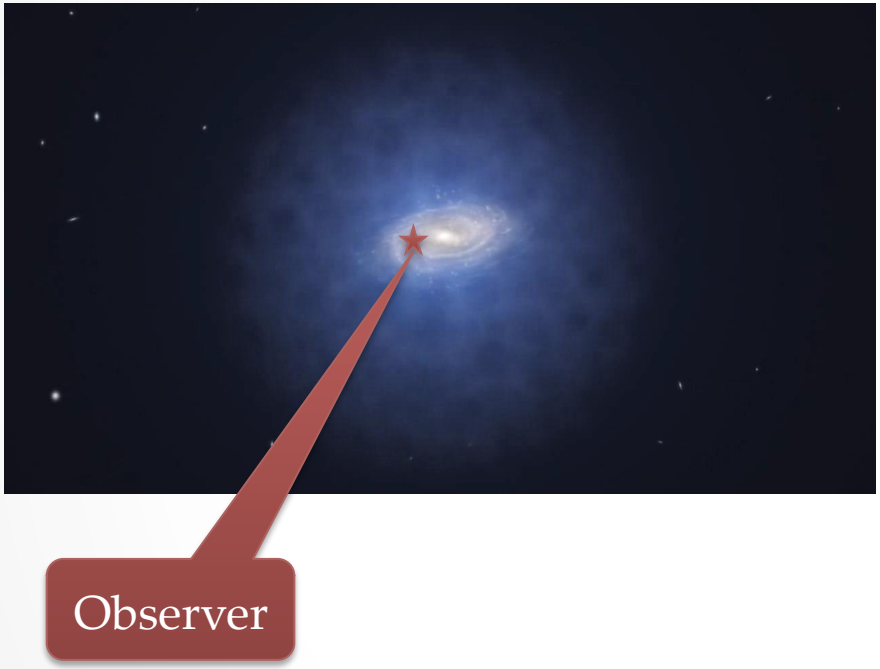
- Milky Way-like halos Morphology
- Comparison with GeV Excess

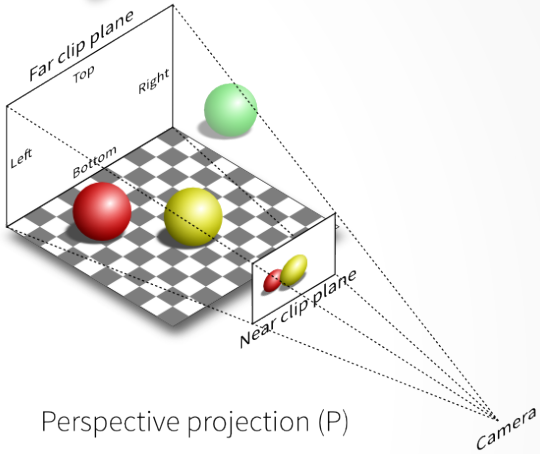
Extragalactic Analysis

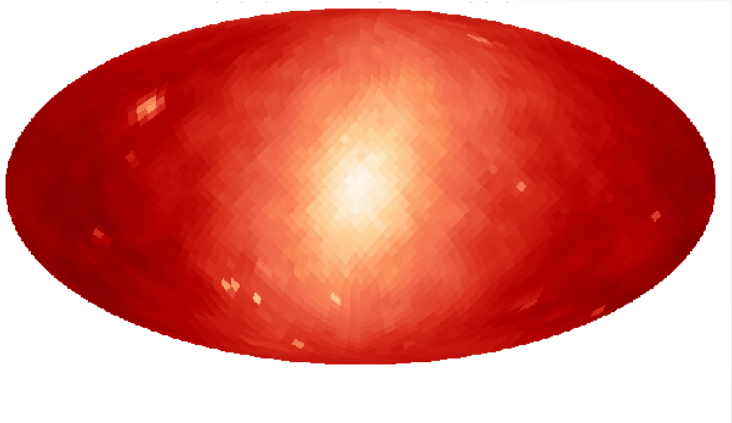
- Expected Morphology
- Effect of Mergers
- Comparison with Xray cluster data

Galactic Analysis

Galactic Analysis







Create maps of 1.6 10^5 halos for DM+baryons
Situate observer at 8.5 kpc from the center.

Existing Metrics

1 Generally axis ratios can be obtained by the eigenvalues of the moment of inertia tensor:

$$\mathcal{I}_{i,j} = \sum_n x_{n,i} x_{n,j}$$

This does not:

1. Distinguish decay signals from annihilation
2. Give importance to high signal regions. A far away weak signal can mess up the estimate.

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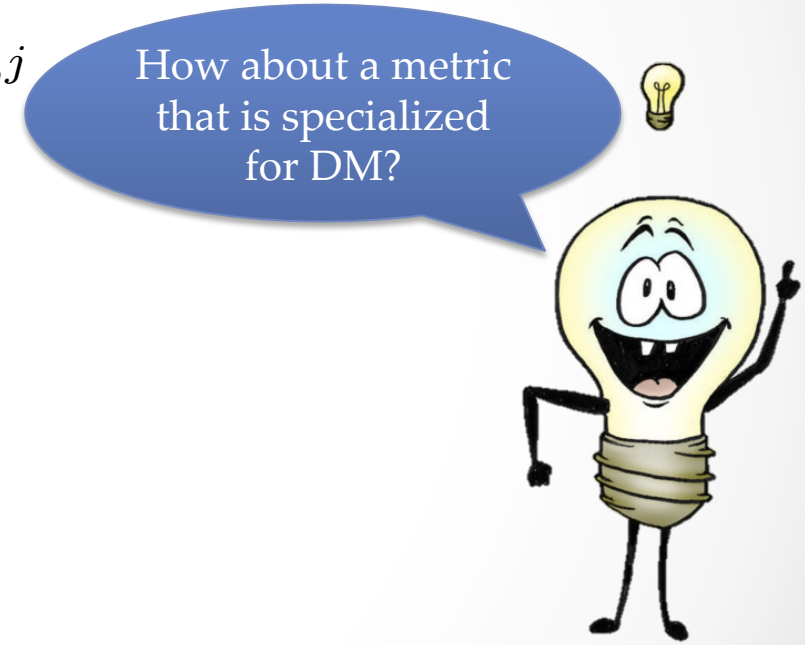
3 In template methods, use different templates with different axis ratios and minimize the test statistics.
This is computationally challenging!

Building a new metric

$$\mathcal{I}_{i,j} = \sum_n x_{n,i} x_{n,j}$$



Building a new metric

$$\mathcal{I}_{i,j} = \sum_n x_{n,i} x_{n,j}$$

How about a metric that is specialized for DM?

New Moment of Inertia Tensor:

$$\boxed{\mathcal{J}_{i,j} = \sum_n J(z_{n,i} z_{n,j}) z_{n,i} z_{n,j}}$$

Weighing by brightness in Dark Matter; Brightest spots: Highest J-factor

This is important because it can be used for indirect detection methods.

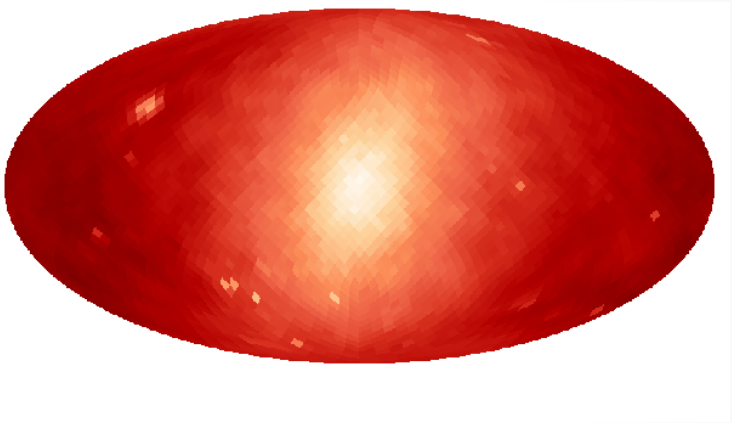
Galactic Analysis

New Moment of Inertia Tensor:

$$\mathcal{J}_{i,j} = \sum_n J(z_{n,i} z_{n,j}) z_{n,i} z_{n,j}$$

$$J_{\text{decay}} = \int_{l.o.s} \rho \; ds d\Omega$$

$$J_{\text{annihilation}} = \int_{l.o.s} \rho^2 \; ds d\Omega$$



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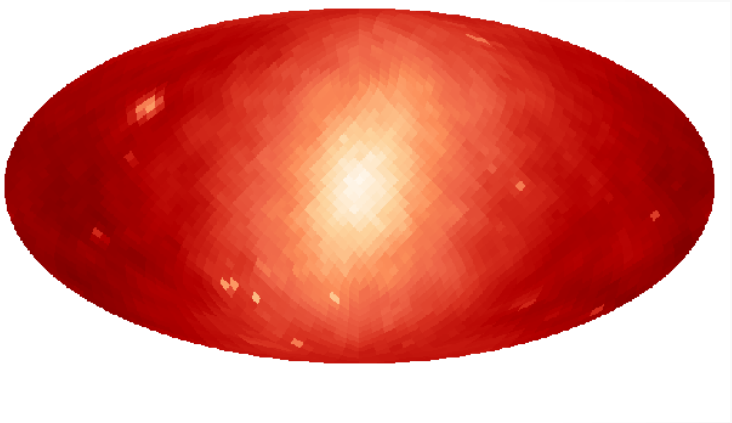


Find the MW-like halos:

- Stellar Mass requirement $4.5 \times 10^{10} M_\odot < M_S < 8.3 \times 10^{10} M_\odot$
- Total Mass requirement $5 \times 10^{11} M_\odot < M_{200} < 2.5 \times 10^{12} M_\odot$

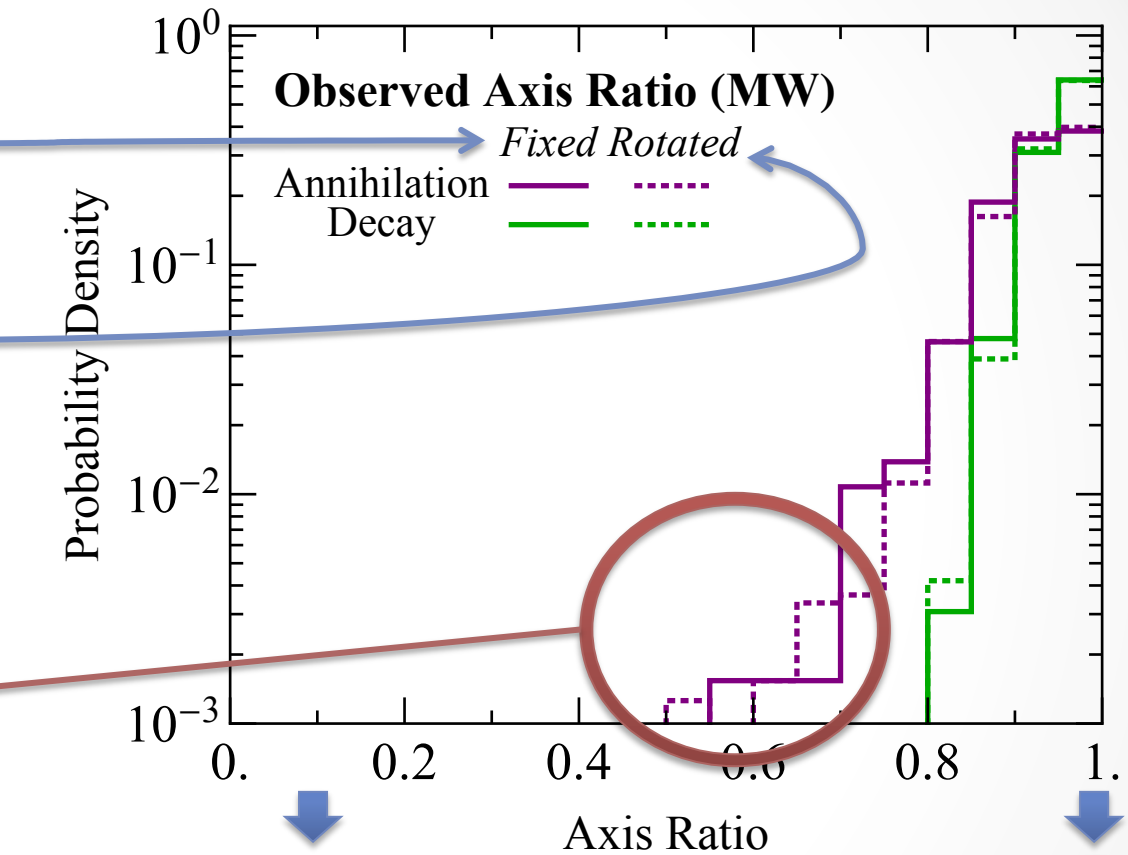
→ 650 Milky-Way like halos.

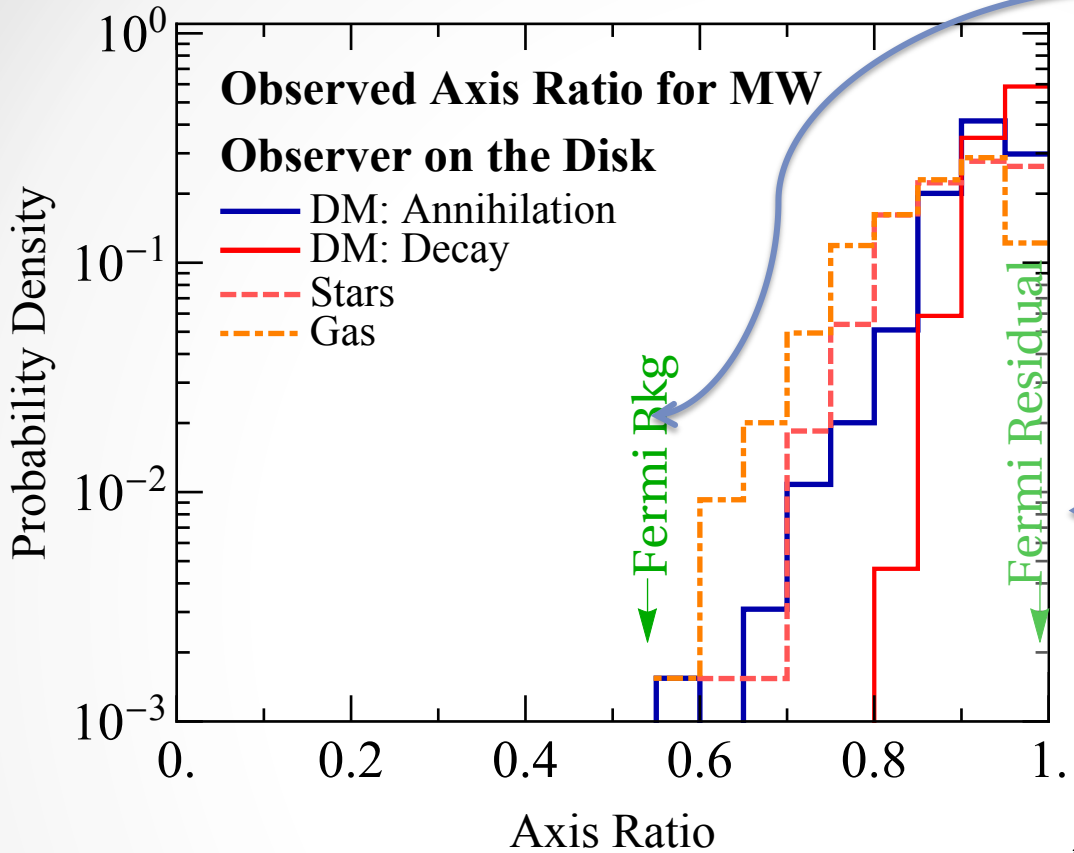
650 halos pass the MW-like cut.

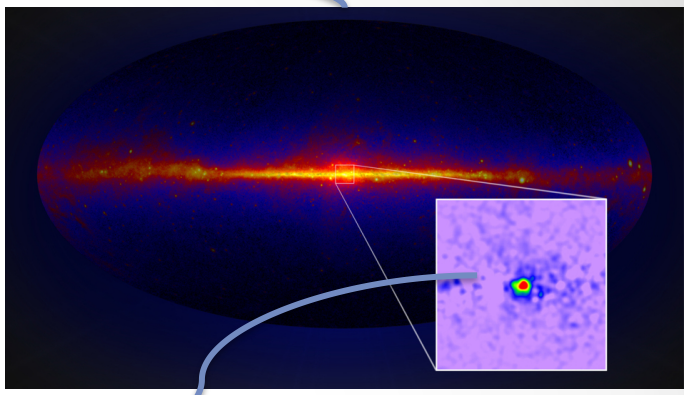
We rotate them in 12 directions to increase statistics.

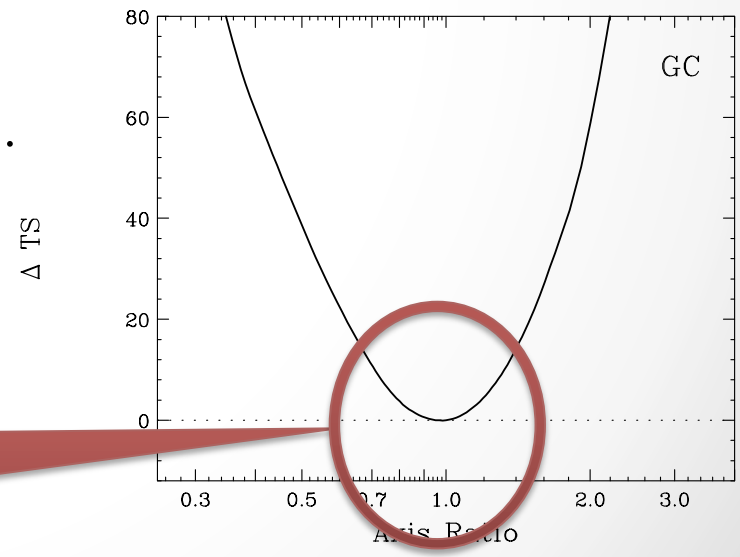
MW-like halos are mostly symmetric.

Annihilation enhances features by being proportional the square of the DM density, and thus appears less symmetric.





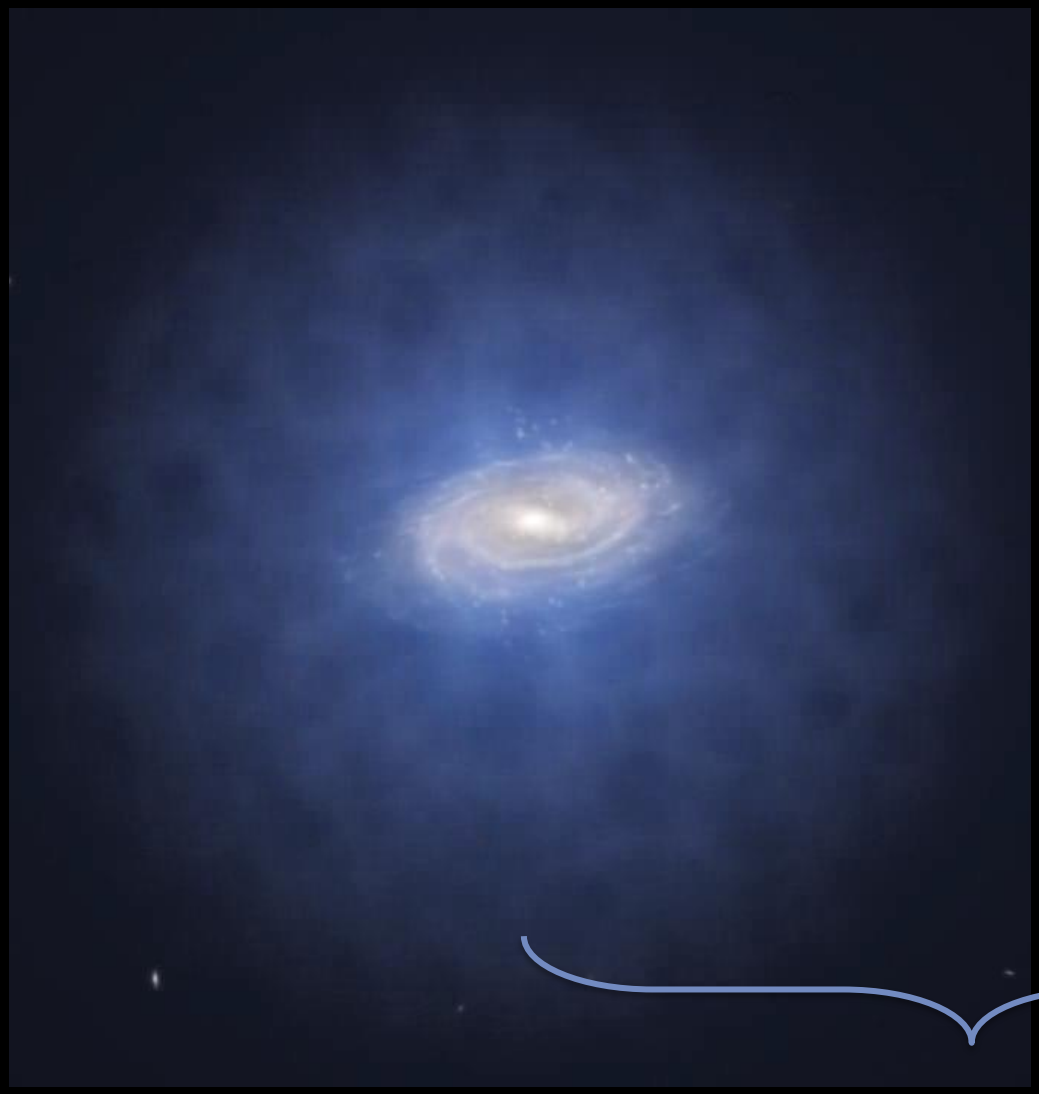


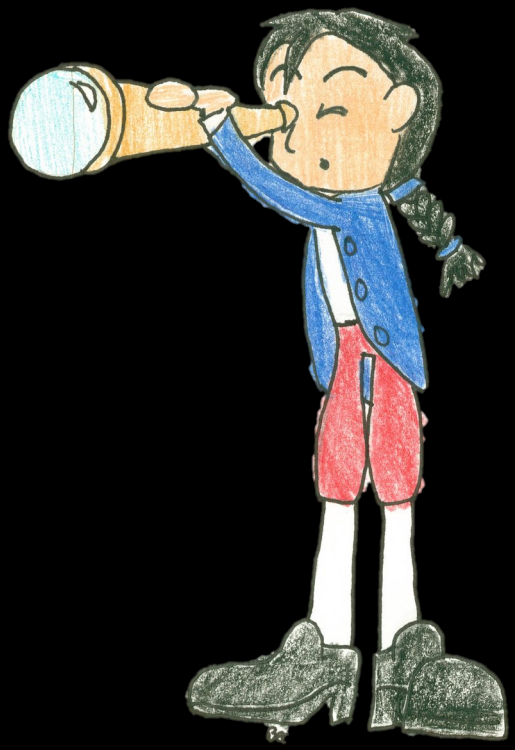


Hooper and Goodenough 0910.2998
Fermi 0912.3828
Daylan et al. 1402.6703
Calore et al. 1411.4647

Signal Residual is Spherical

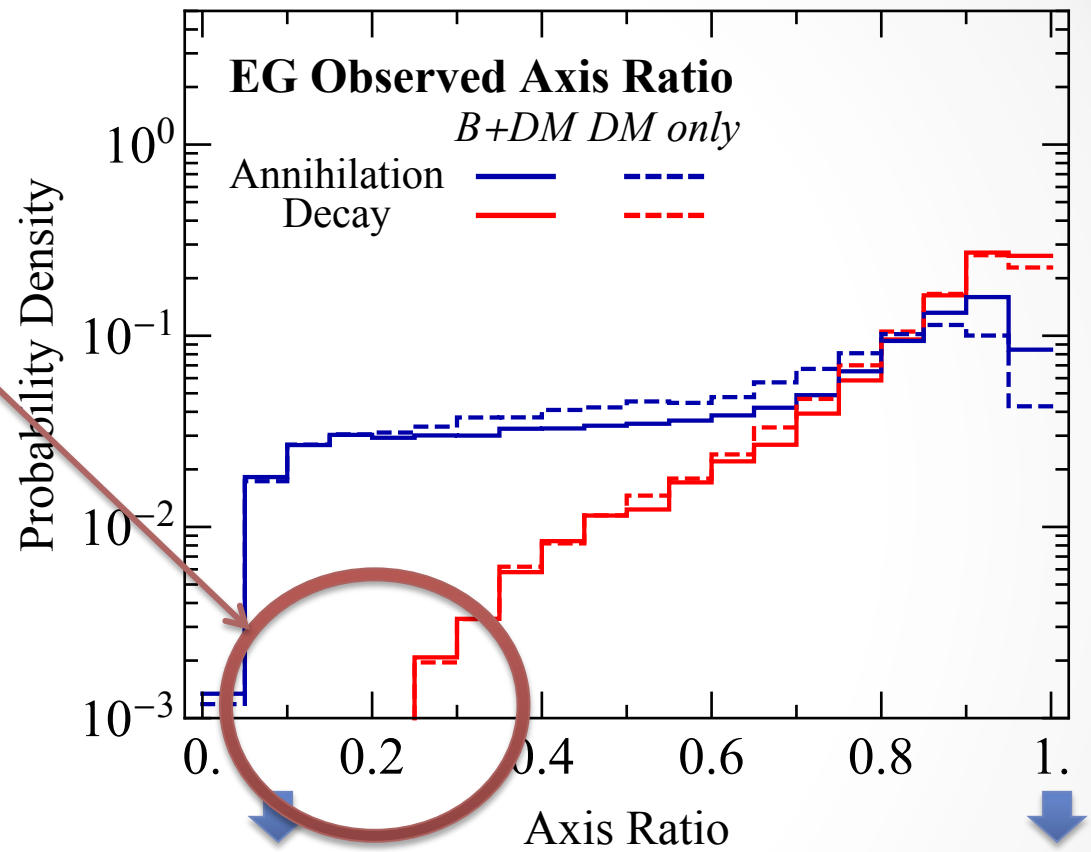
Extragalactic Analysis





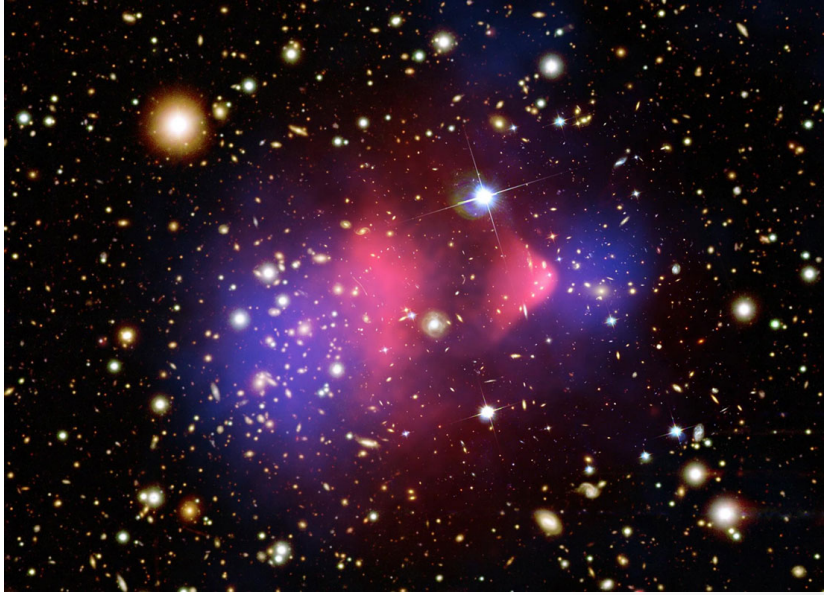
$2r_{200}$

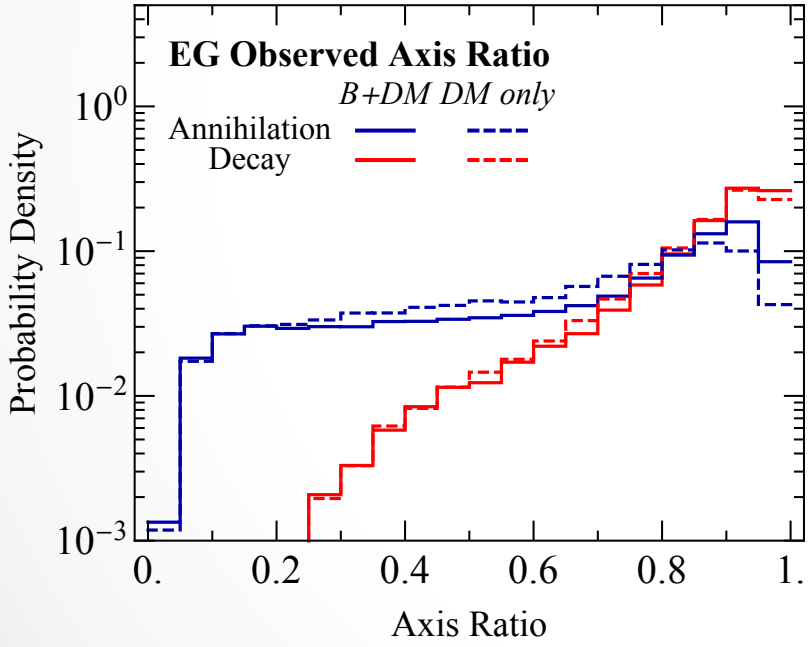
Extragalactic indirect detection signals are largely non-spherical!

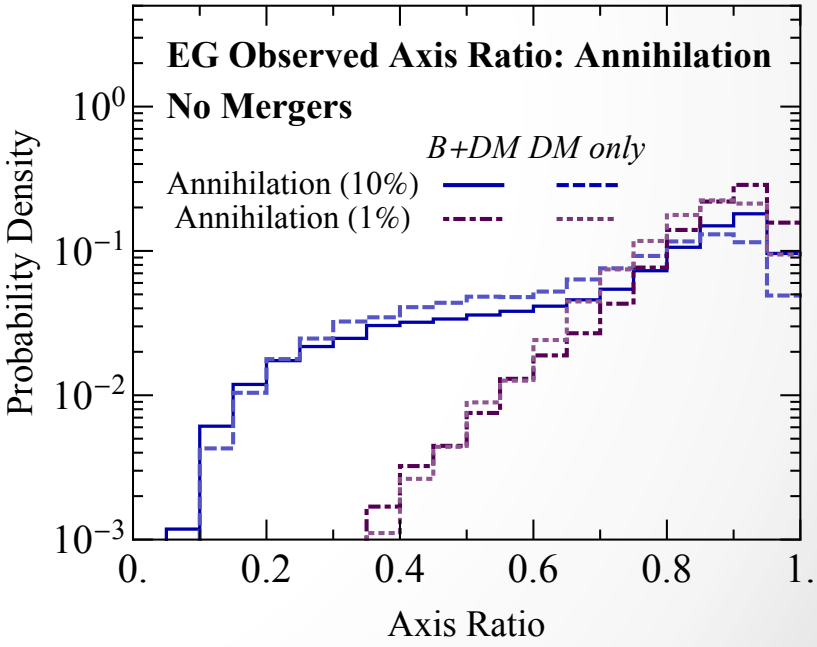


Mergers

We selected the halos in which the second subhalo is less than 10% (1%) of the total mass.







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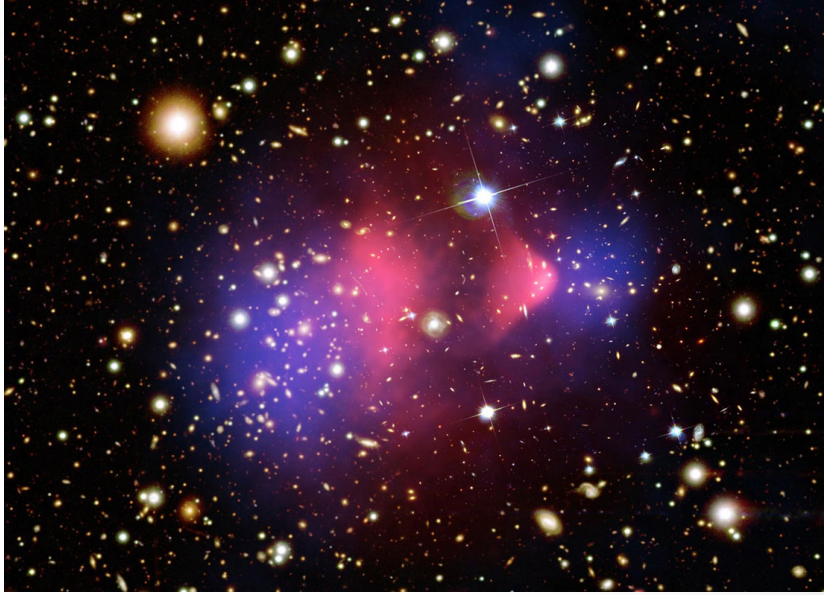
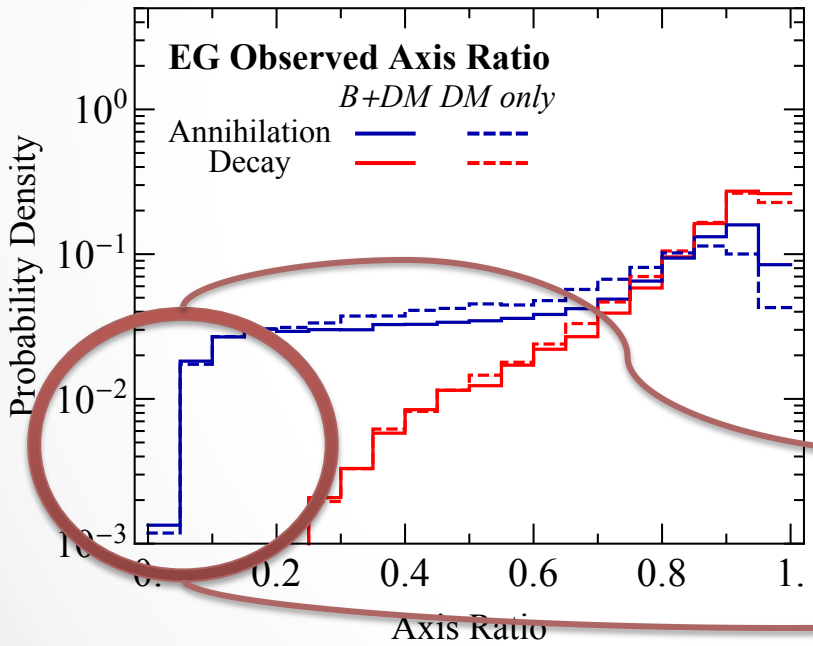
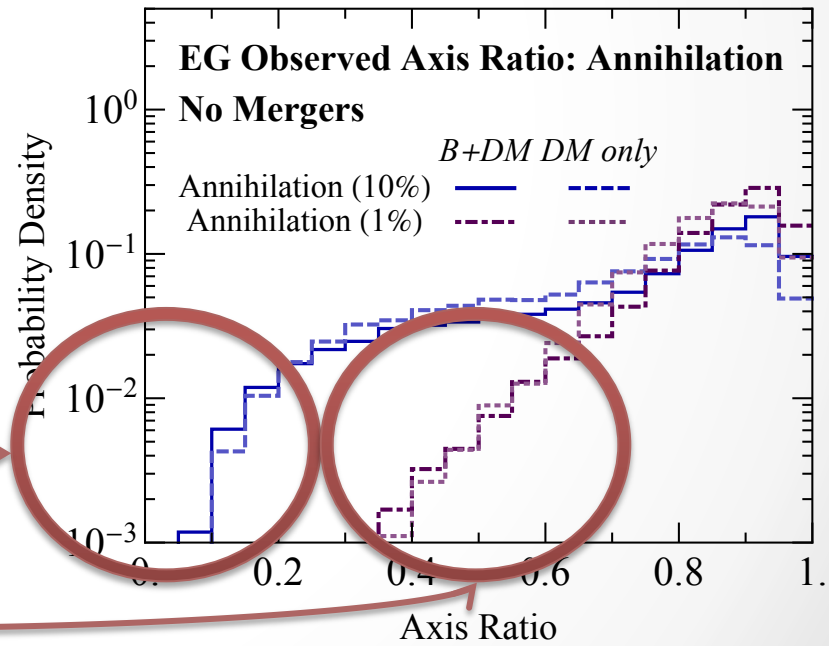
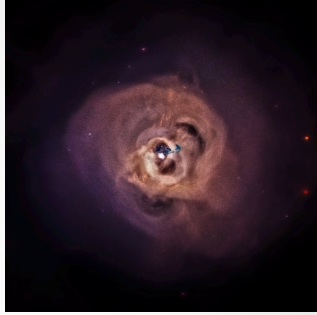
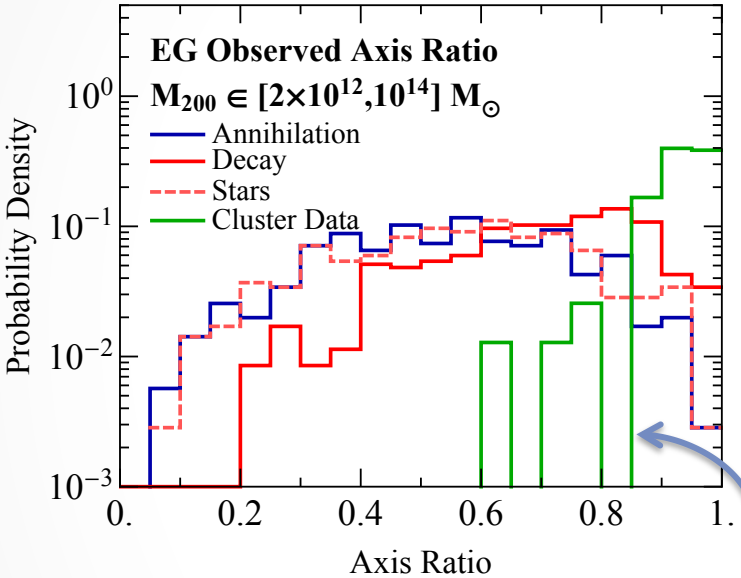


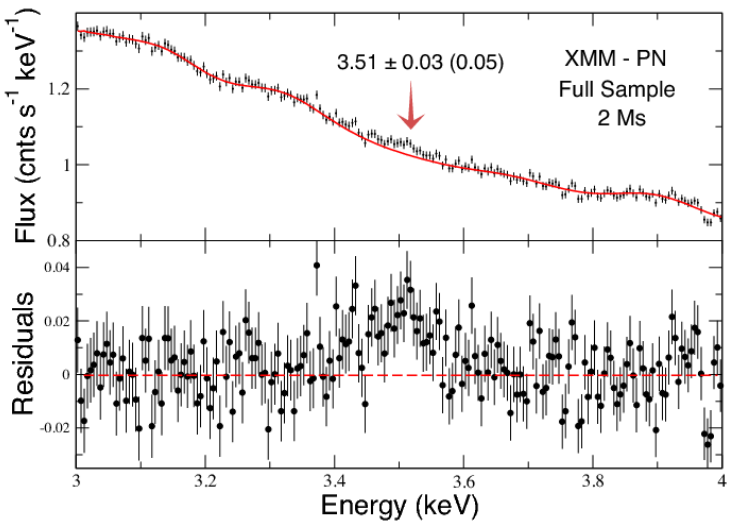




X-ray cluster data







Bulbul et al., 1402.2301
Bulbul et al., 1605.02034
Hitomi Collaboration, 1607.07420

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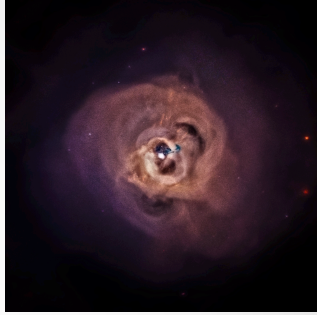

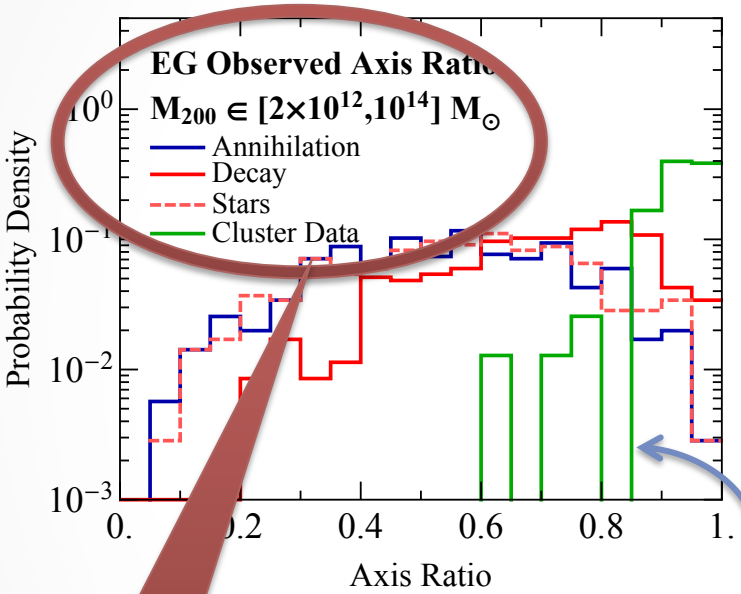

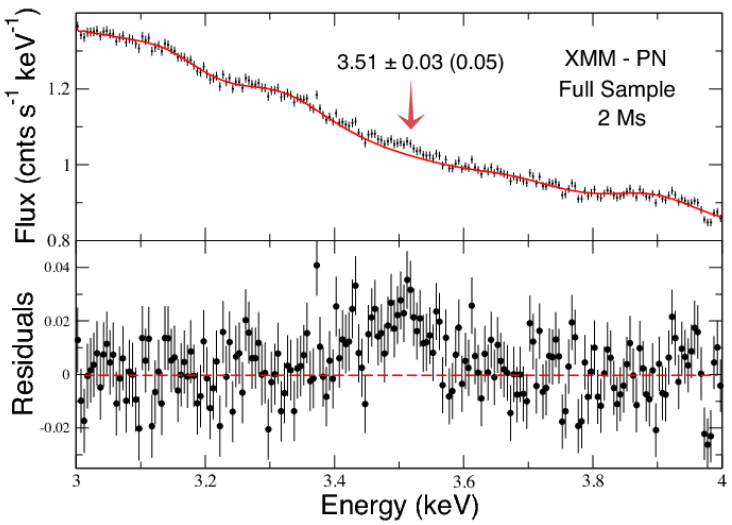

Mass cut!

Bulbul et al., 1402.2301
Bulbul et al., 1605.02034
Hitomi Collaboration, 1607.07420

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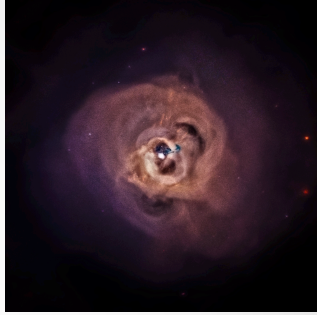
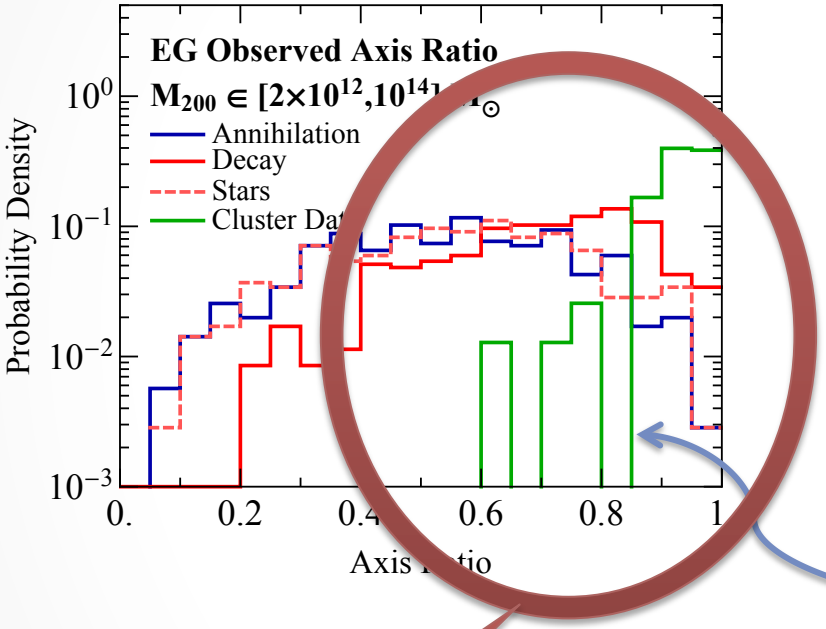
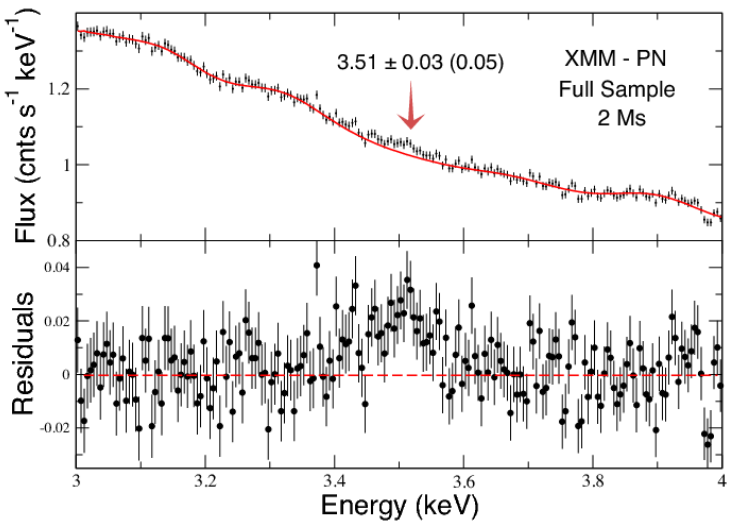


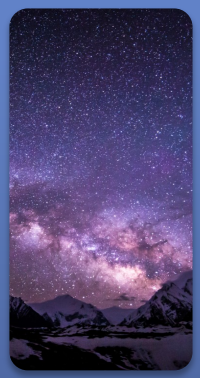




Cluster data more symmetric than simulations

Bulbul et al., 1402.2301
Bulbul et al., 1605.02034
Hitomi Collaboration, 1607.07420

Conclusions



Galactic Analysis

- Milky Way-like halos Morphology.
- Comparison with GeV Excess.

Extragalactic Analysis

- Expected Morphology
- Effect of Mergers
- Comparison with X-ray cluster data.

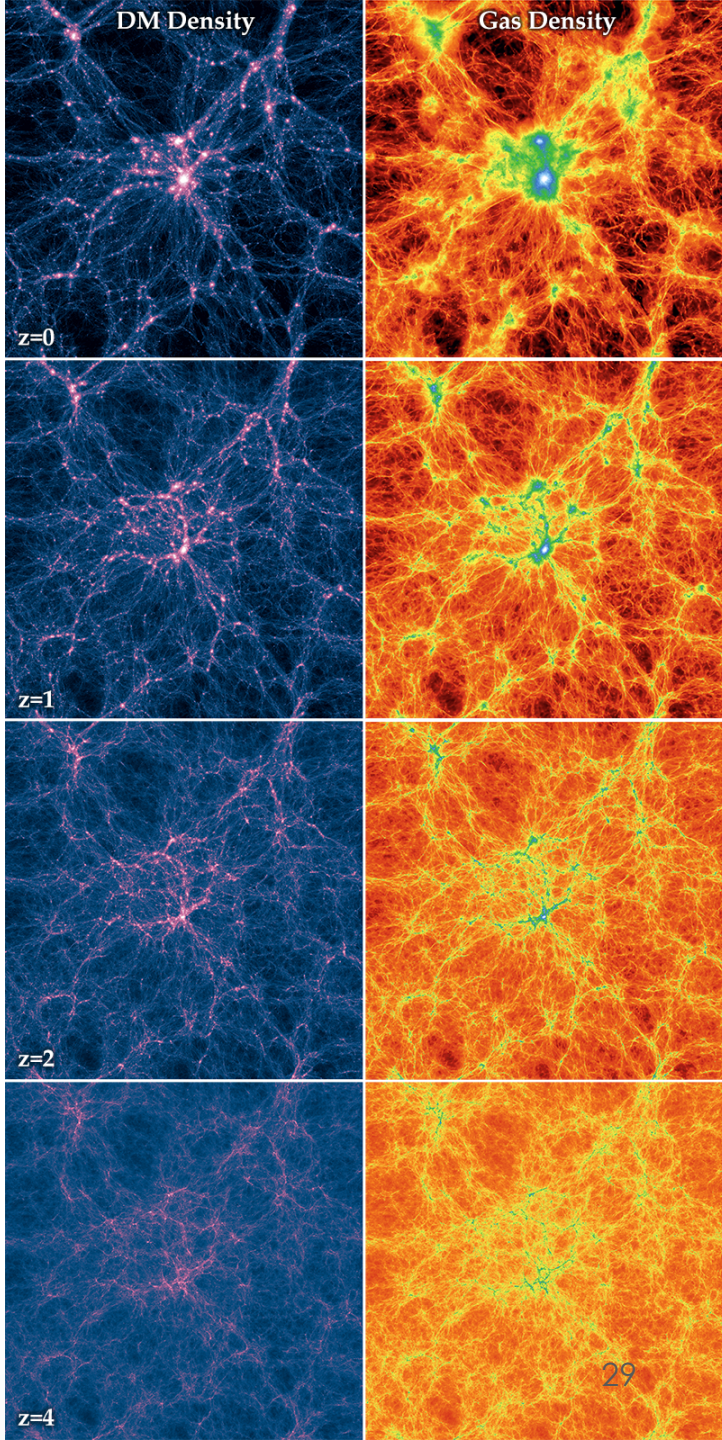
- Constructed a method that is easily implemented for indirect detection signals.
- Galactic signals are expected to be symmetric.
- Extragalactic signals are expected to be less symmetric!
- We compared these against the morphology of X-ray cluster data as well as the signal and background of the Galactic gamma rays.

Backup Slides

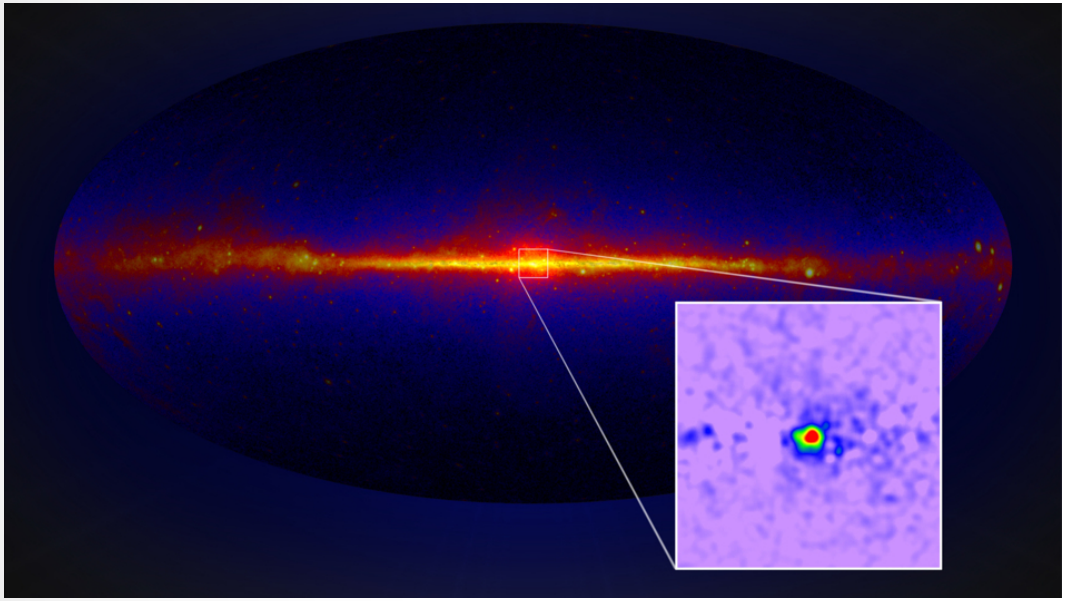
Illustris

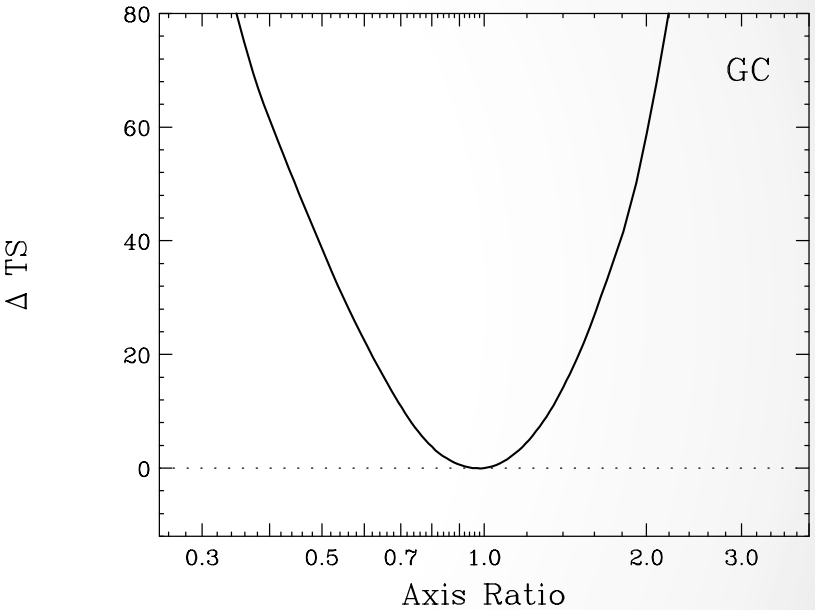
- Simulation traces the evolution of dark matter and baryons from z=127 to z=0.
- Volume = $(106.5\ \mathrm{Mpc})^3$
- Particle masses:
  - $m_{\mathrm{DM}} = 6.3 \times 10^6 M_\odot$
  - $m_{\mathrm{b}} = 1.3 \times 10^6 M_\odot$
- Softening length
  - $\epsilon_{\mathrm{DM}} = 1.4\ \mathrm{kpc}$
  - $\epsilon_{\mathrm{b}} = 0.7\ \mathrm{kpc}$
- AGN feedback/ Supernova feedback
- Number of particles 1.8×10^{10}

Vogelsberger et al. 1305.2913, 1405.1418, 1405.2921
Torrey et al. 1305.4931
Genel et al. 1405.3749

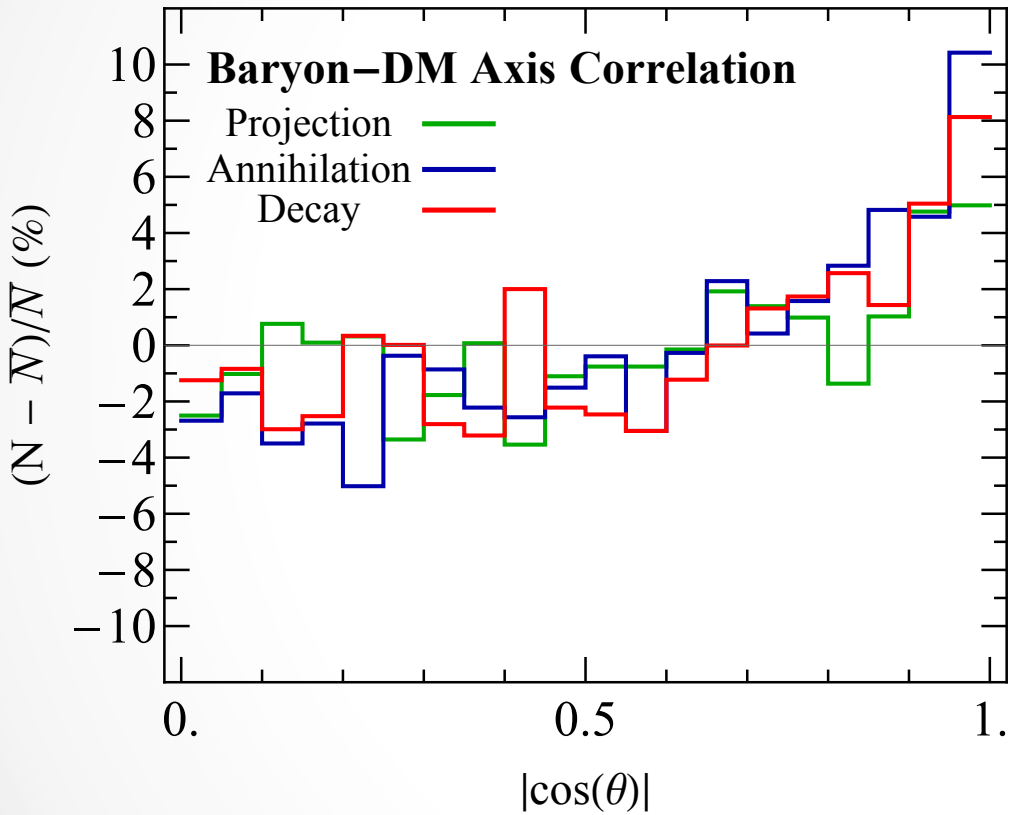


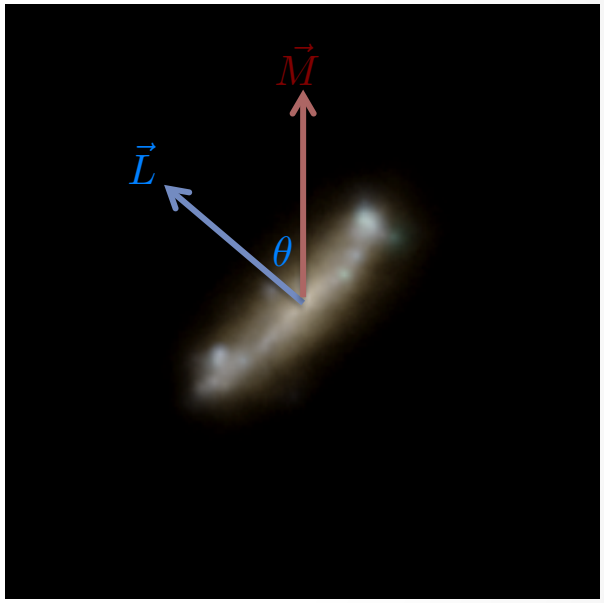
Expected Signal

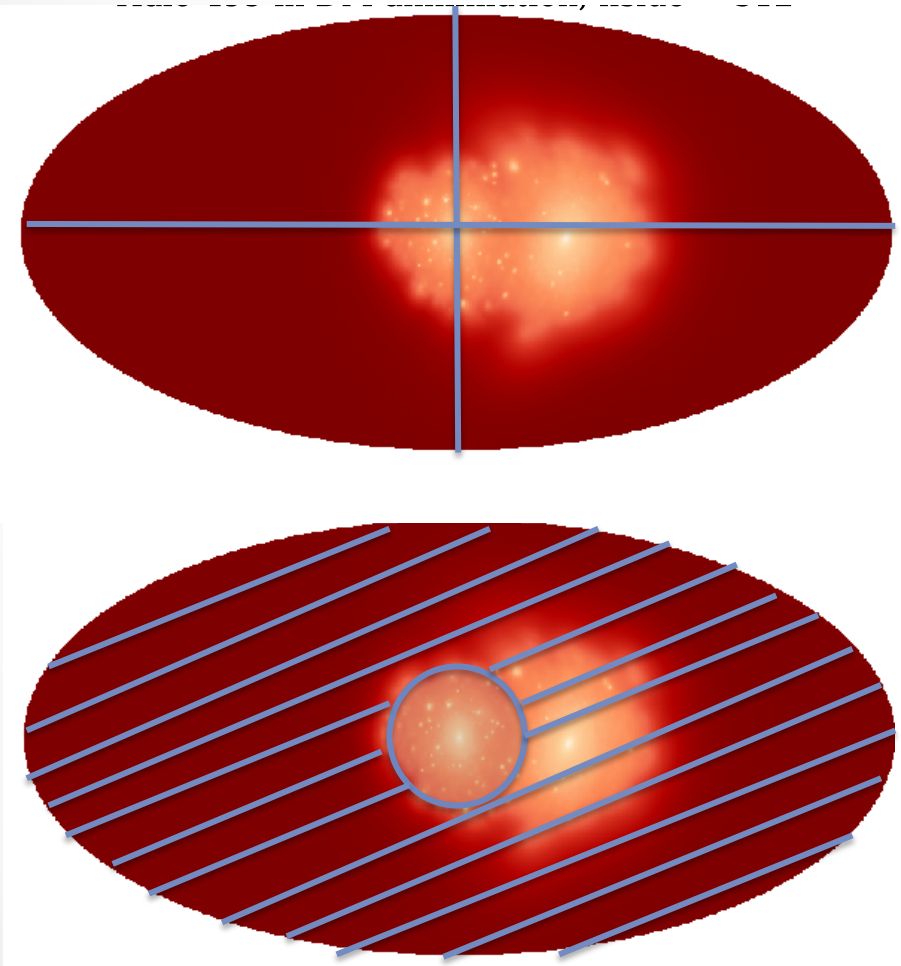




Axis Correlation







We compare the contribution from different quadrants.

$$R_{\rm adj} = \frac{(J_1 + J_2) - (J_3 + J_4)}{J_1 + J_2 + J_3 + J_4}$$

$$R_{\rm opp} = \frac{(J_1 + J_3) - (J_2 + J_4)}{J_1 + J_2 + J_3 + J_4}$$

We then also look at the inner 5 degrees.

Alternate way of understanding morphology