Detecting dark matter via the proper motion of microhalos

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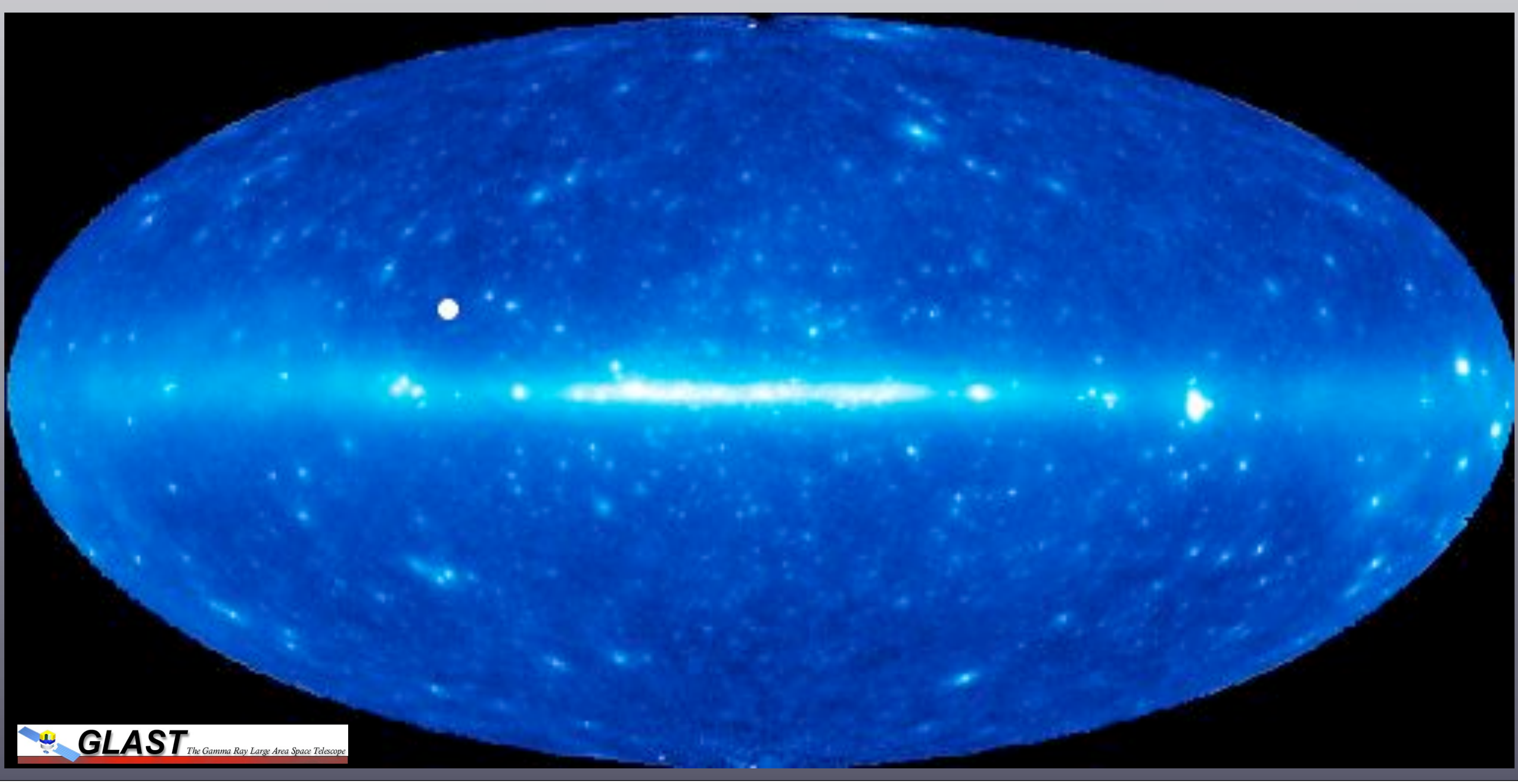
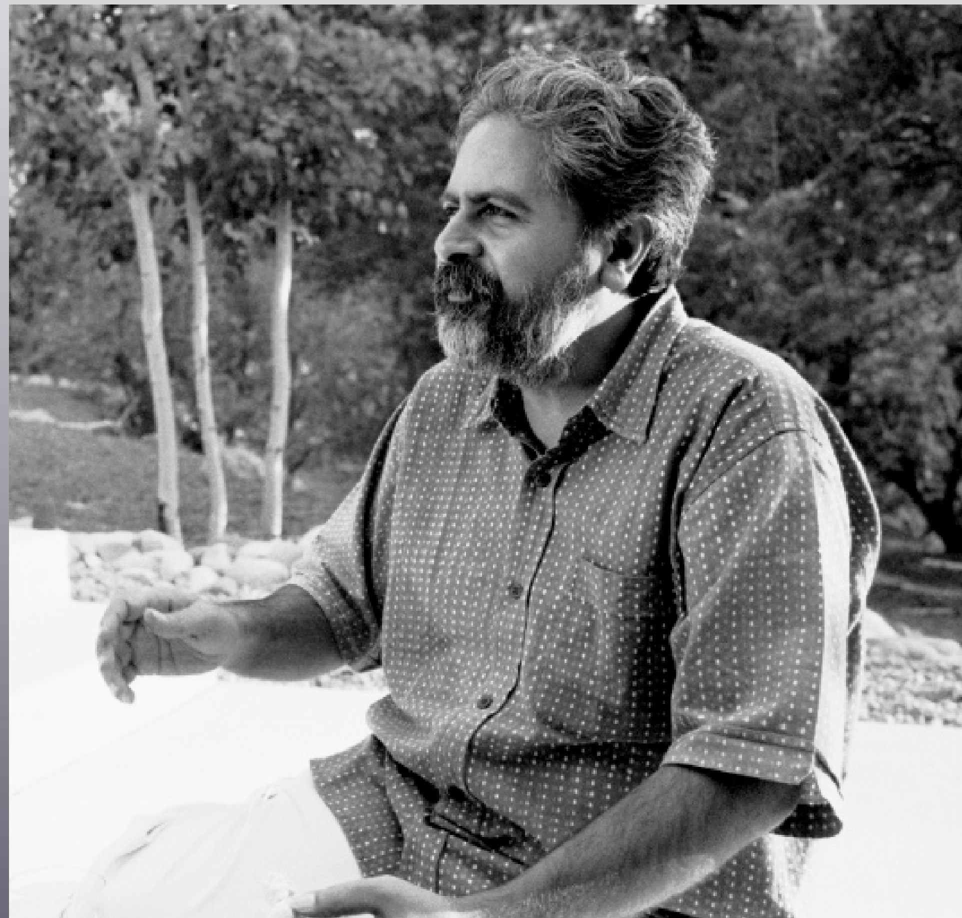
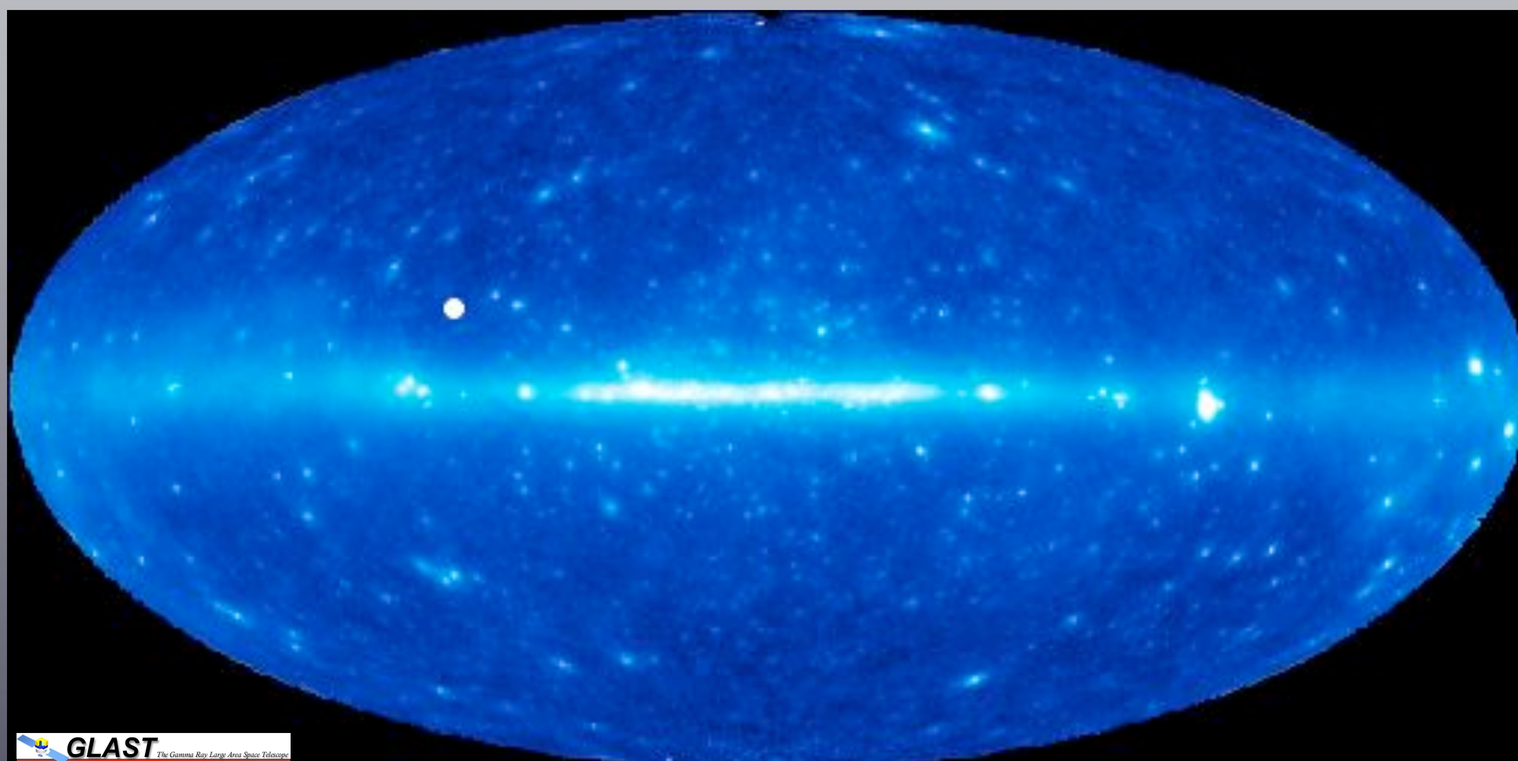


"…remember that, even though your halo finder finds many dark matter halos, we still don't know what the dark matter is!"

– Varun Sahni



WHAT CAN BE LEARNED FROM A γ-RAY ALL SKY MAP?



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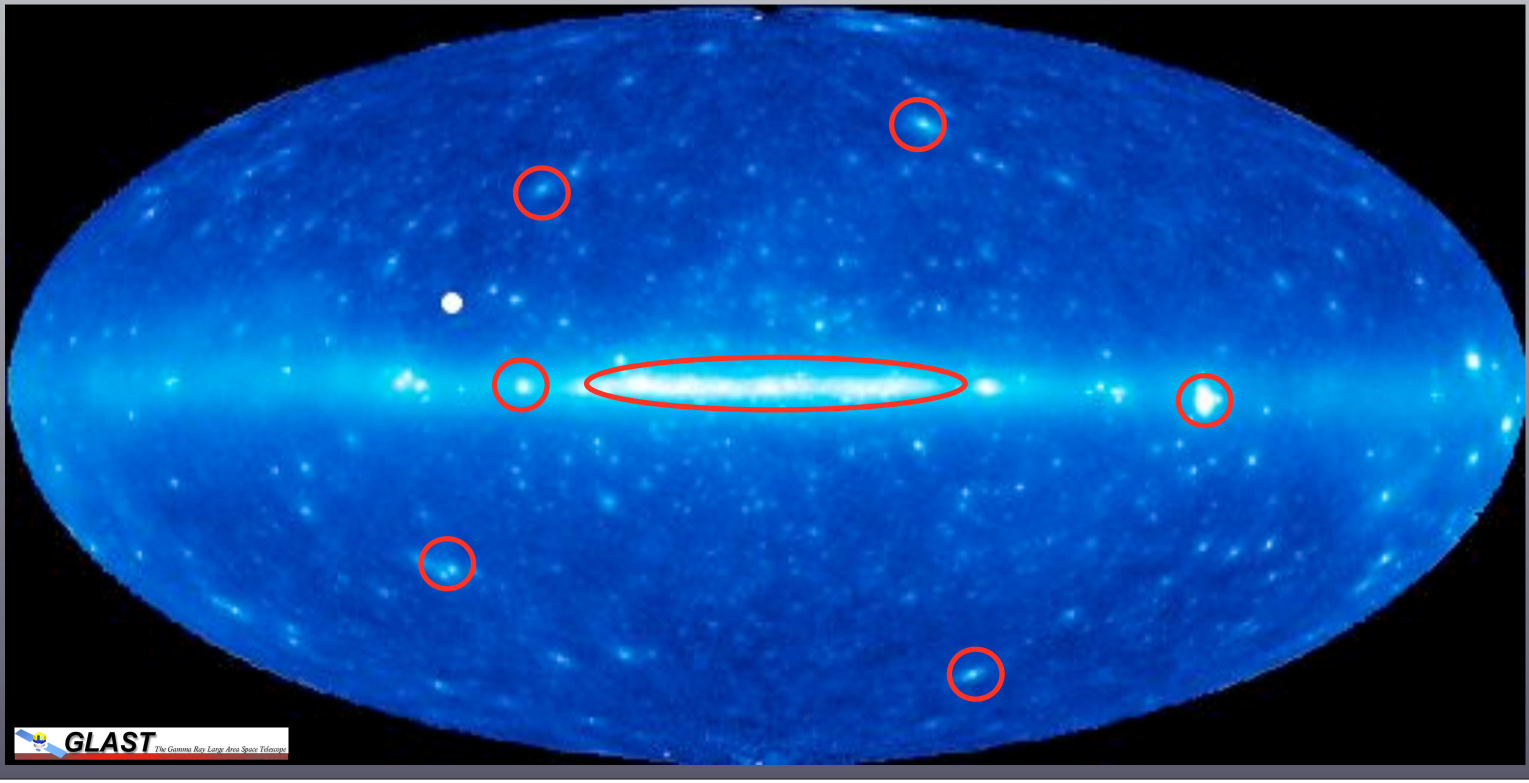
•A lot of astrophysics (compact binaries, active galactic nuclei, supernova remnants, γ-ray bursts, etc.)



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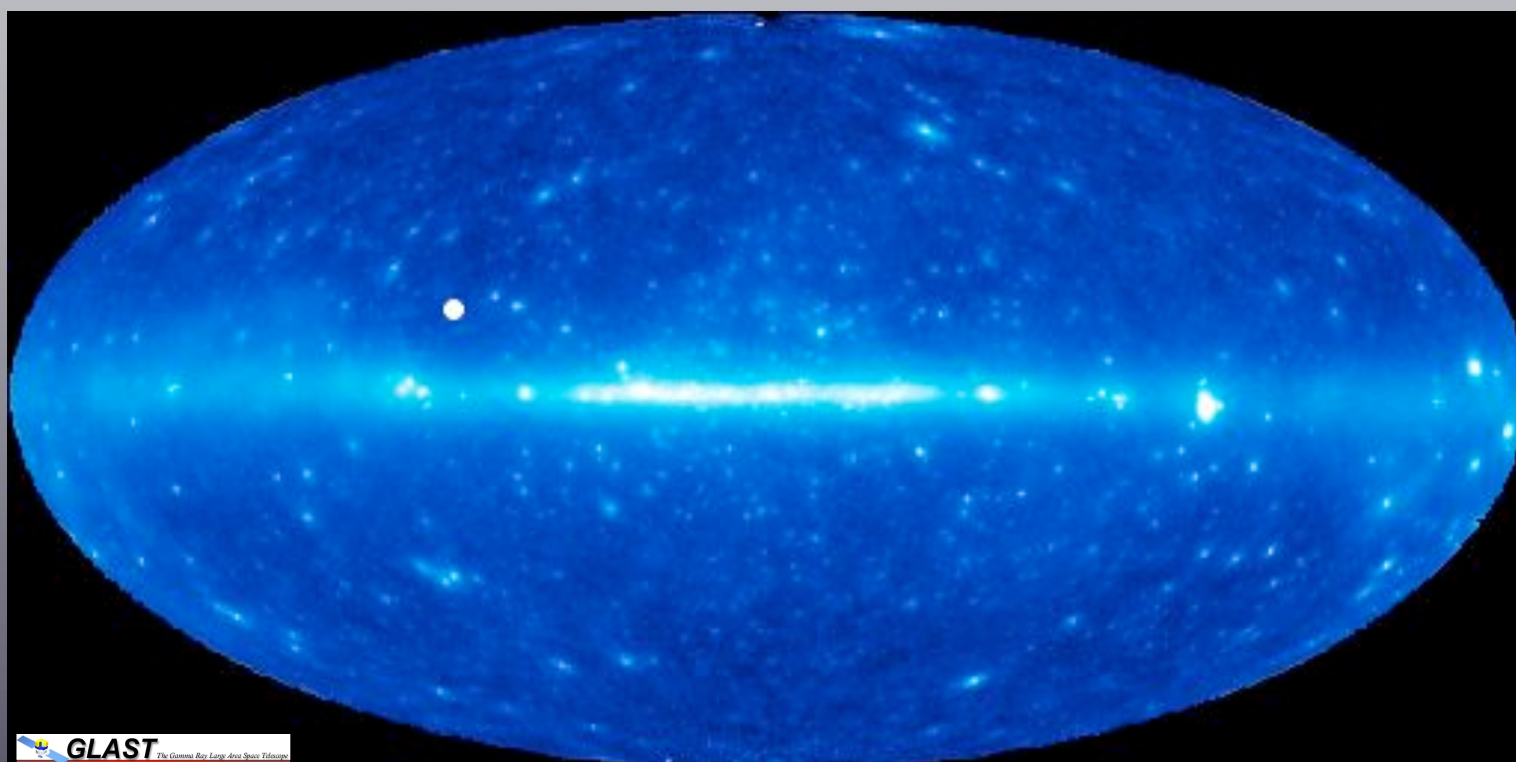
- Backgrounds: Resolved (population of sources) and diffused - look at angular fluctuations for hints (e.g., Miniati, Koushiappas & Di Matteo, astro-ph/0702083).



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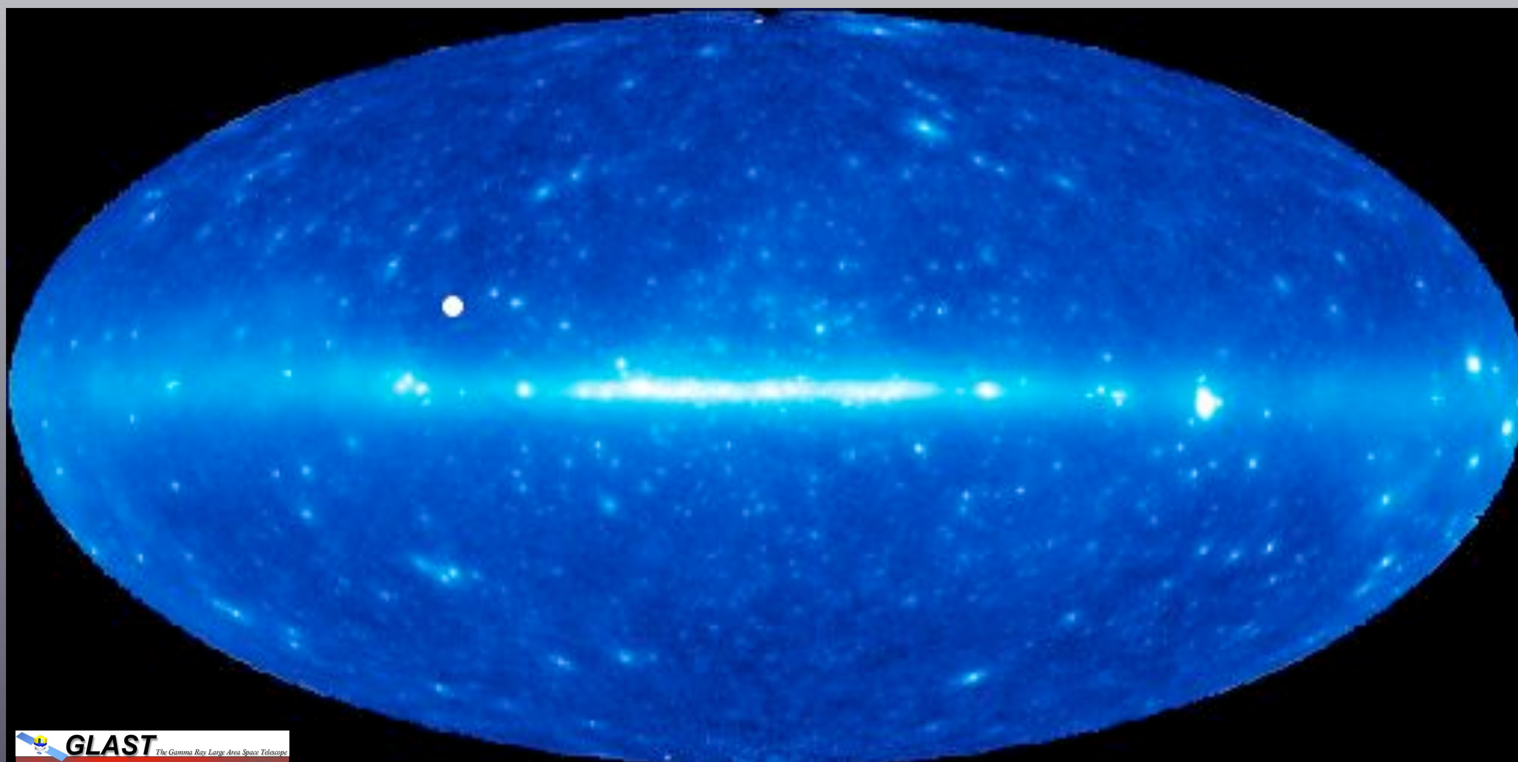

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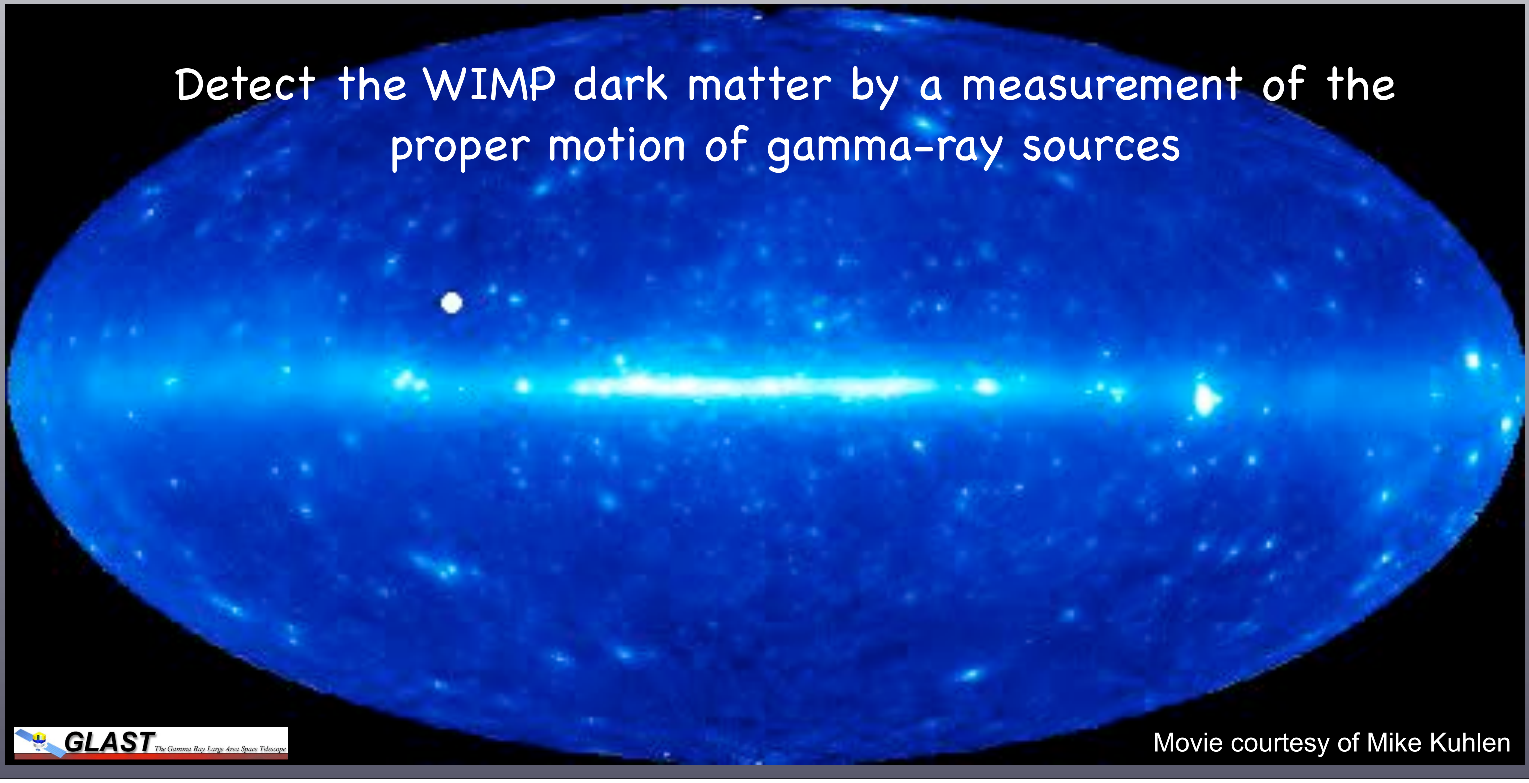

Microhalos: $M_m \geq 10^{-13} M_\odot$

Why are they interesting?

1. A possible detection can provide information about the particle physics properties of the dark matter particle.
2. A measured abundance in the Milky Way halo contains information on the hierarchical assembly of dark matter halos at very early times (survival/disruption), a task unattainable by any other method.

Schmid et al., Phys Rev. D 59, 043517 (1999)
Hofmann et al., Phys. Rev. D 64, 083507 (2001)
Chen et al., Phys Rev. D 64, 021302 (2001)
Berezinsky et al, Phys. Rev. D 68, 103003 (2003)
Green, Hoffmann and Schwarz, MNRAS 353, L23 (2004)
Green et al., JCAP 08, 003 (2005)
Loeb & Zaldarriaga , Phys. Rev. D, 71, 103520 (2005)
Profumo et al., Phys. Rev. Lett., 97, 031301 (2006)
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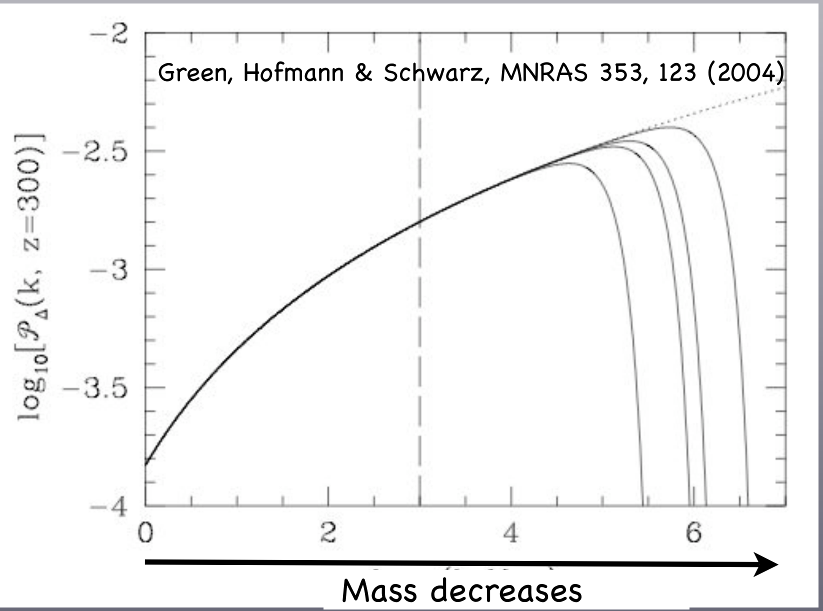
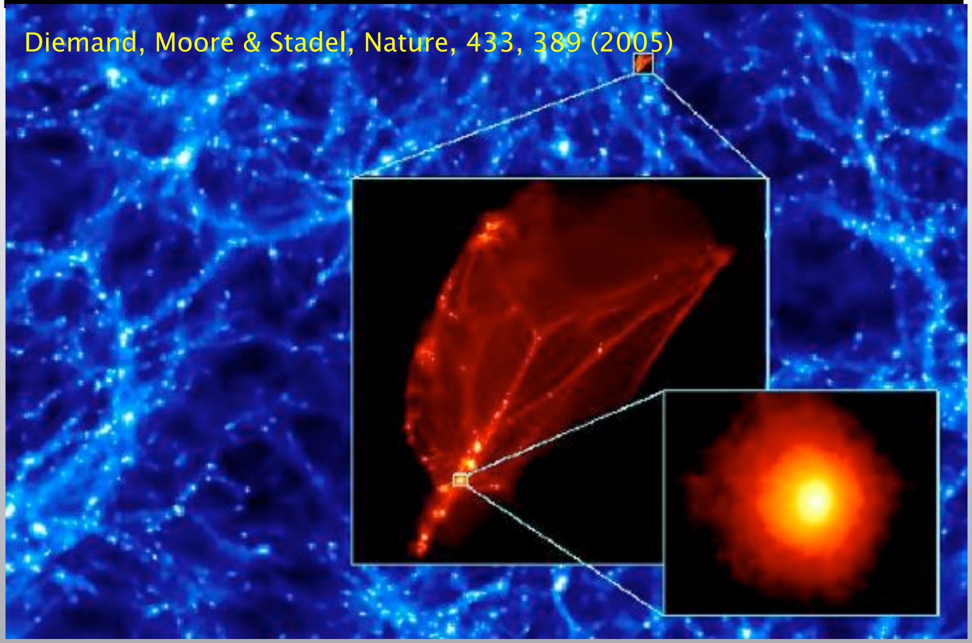


Given a power spectrum of fluctuations on microhalo scales

Simulated first collapsed dark matter structures



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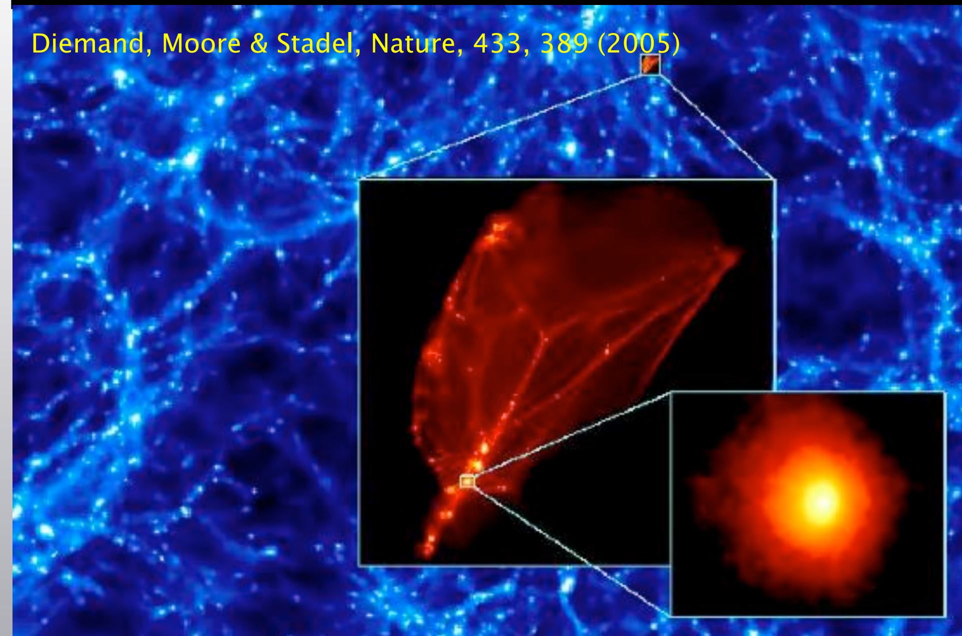


Given a power spectrum of fluctuations on microhalo scales

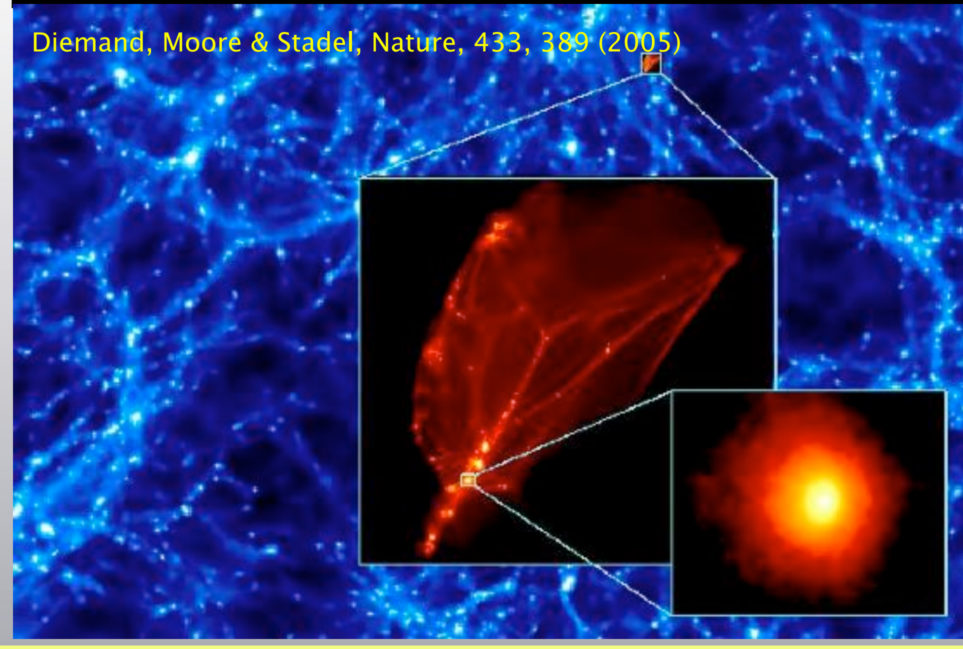
Fraction of mass in objects of mass $M_m = \mathrm{Constant} \sim [10^{-1} - \mathrm{few}]\%$

$$\frac{dN_m}{d\ln M_m} \sim M_m^{-1}$$

The microhalo mass function seems to be an extrapolation of the subhalo mass function down to microhalo scales (see also Berezinsky et al. Phys. Rev. D73, 063504 (2006)).

Given a power spectrum of fluctuations on microhalo scales

Simulated first collapsed dark matter structures



Diemand, Moore & Stadel, Nature 433 (2005) 389-391:"…They are stable against gravitational disruption, even within the central regions of the Milky Way…"

Zhao, Taylor, Silk & Hooper, astro-ph/0502049:"…most mini-halos reaching solar neighbourhood should experience strong impulses by individual stars…"

Moore, Diemand, Stadel & Quinn, astro-ph/0502213: "…we do not expect the tidal heating by Galactic stars to affect the abundance of micro-haloes…"

Zhao, Taylor, Silk & Hooper, astro-ph/0508215:"…the final dark matter distribution in the solar neighborhood is better described as a superposition of microstreams rather than as a set of discrete spherical clumps in an otherwise homogeneous medium…"

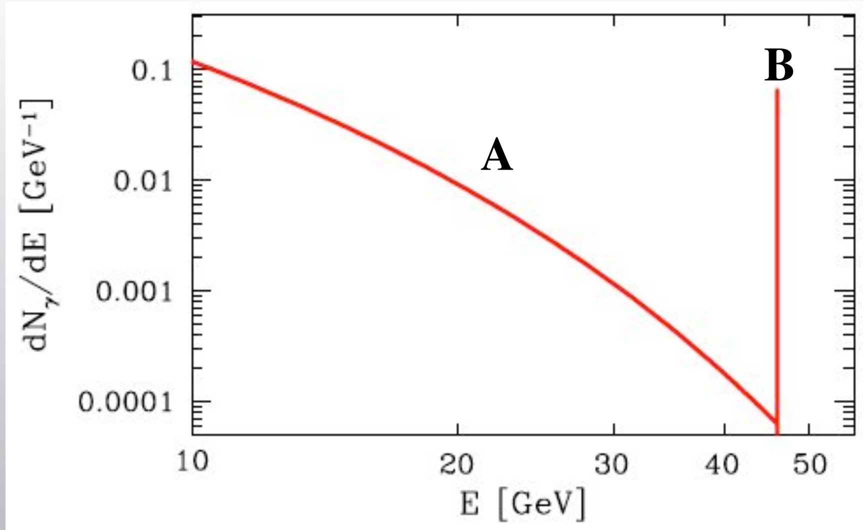
Goerdt et al, astro-ph/0608495: "…particle orbits deep in the cusp may remain adiabatically invariant to the perturbations and preserve the structure of the cusp…"

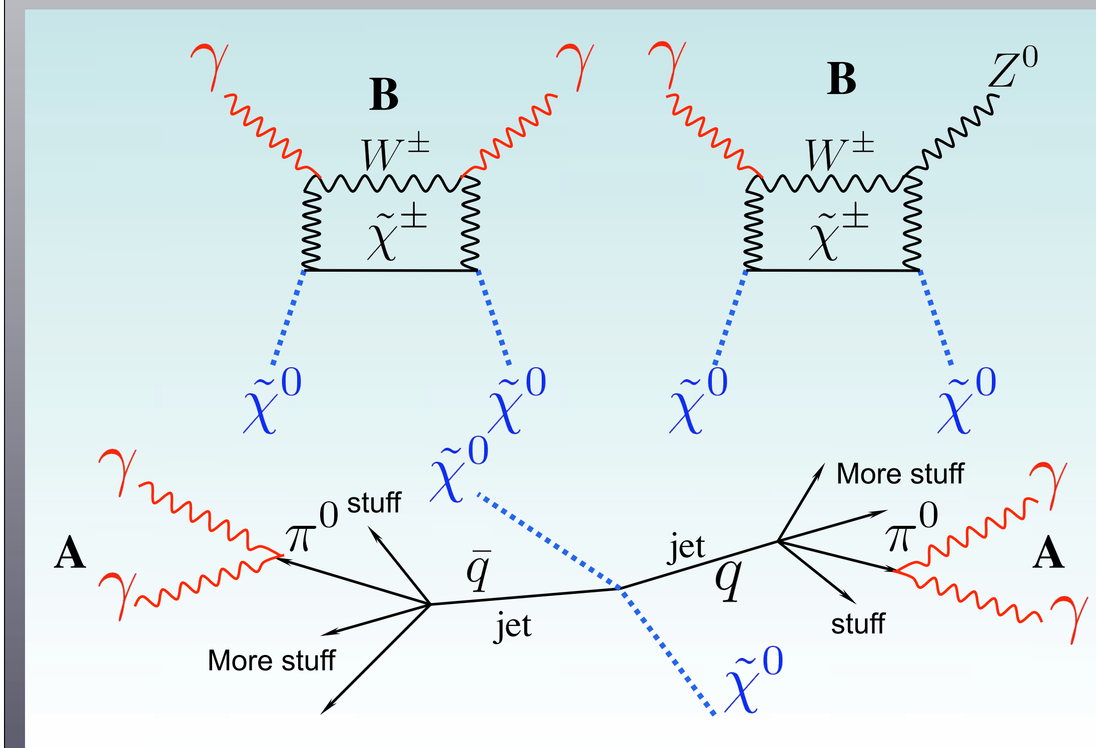
Angus & Zhao, astro-ph/0608580:"…we present the morphology of a microhalo at several epochs…"

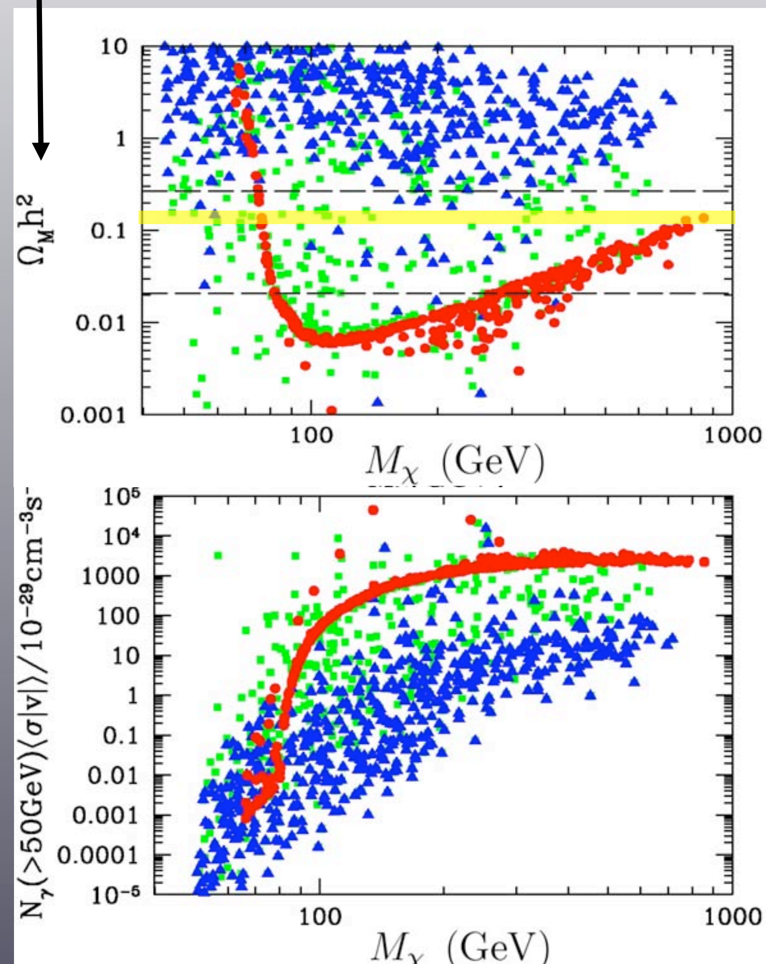
SUSY CDM Lightest neutralino

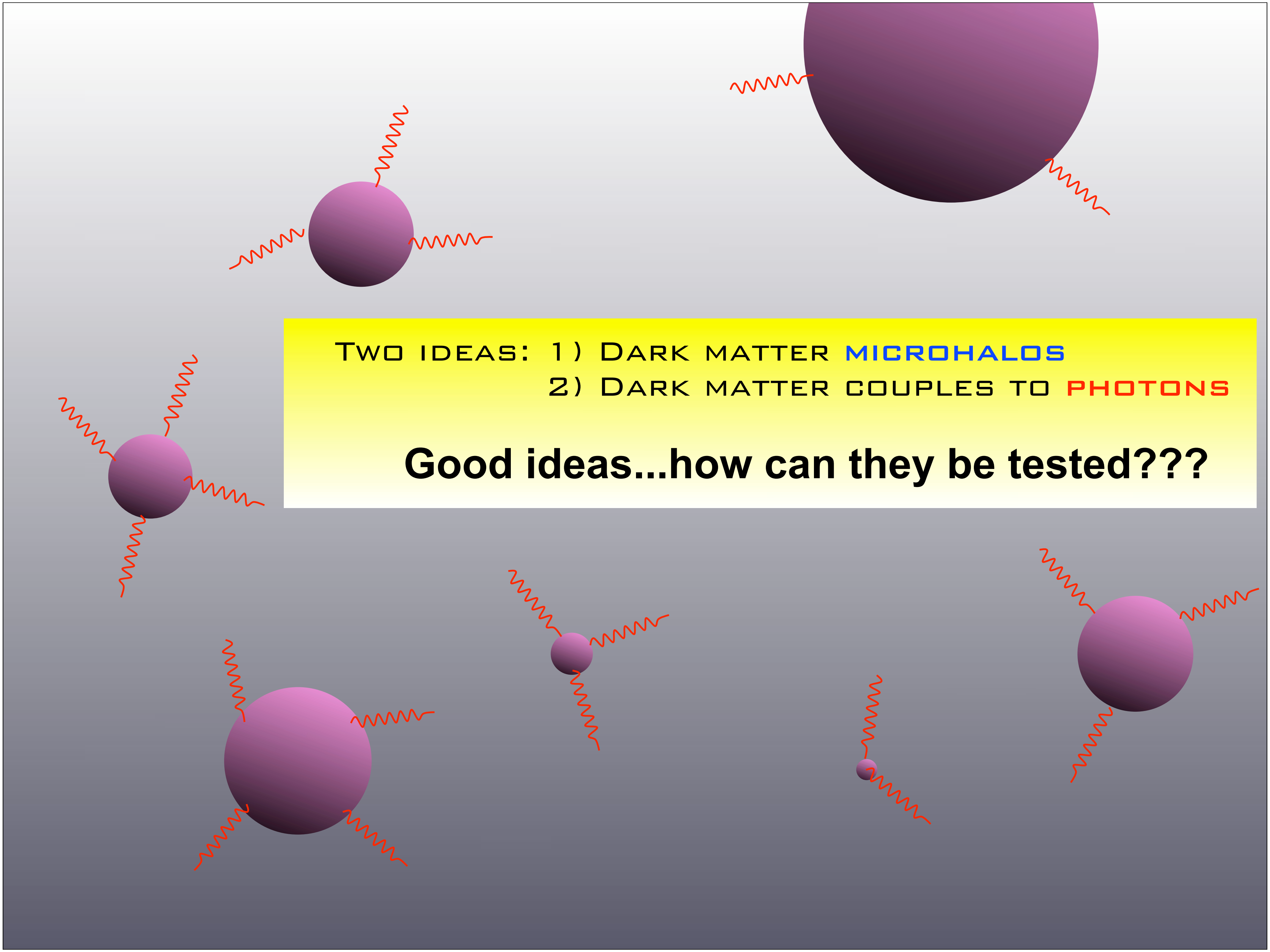
$$\tilde{\chi}^0 = \xi_1 \tilde{B} + \xi_2 \tilde{W}^3 + \xi_3 \tilde{H}_1^0 + \xi_4 \tilde{H}_2^0$$

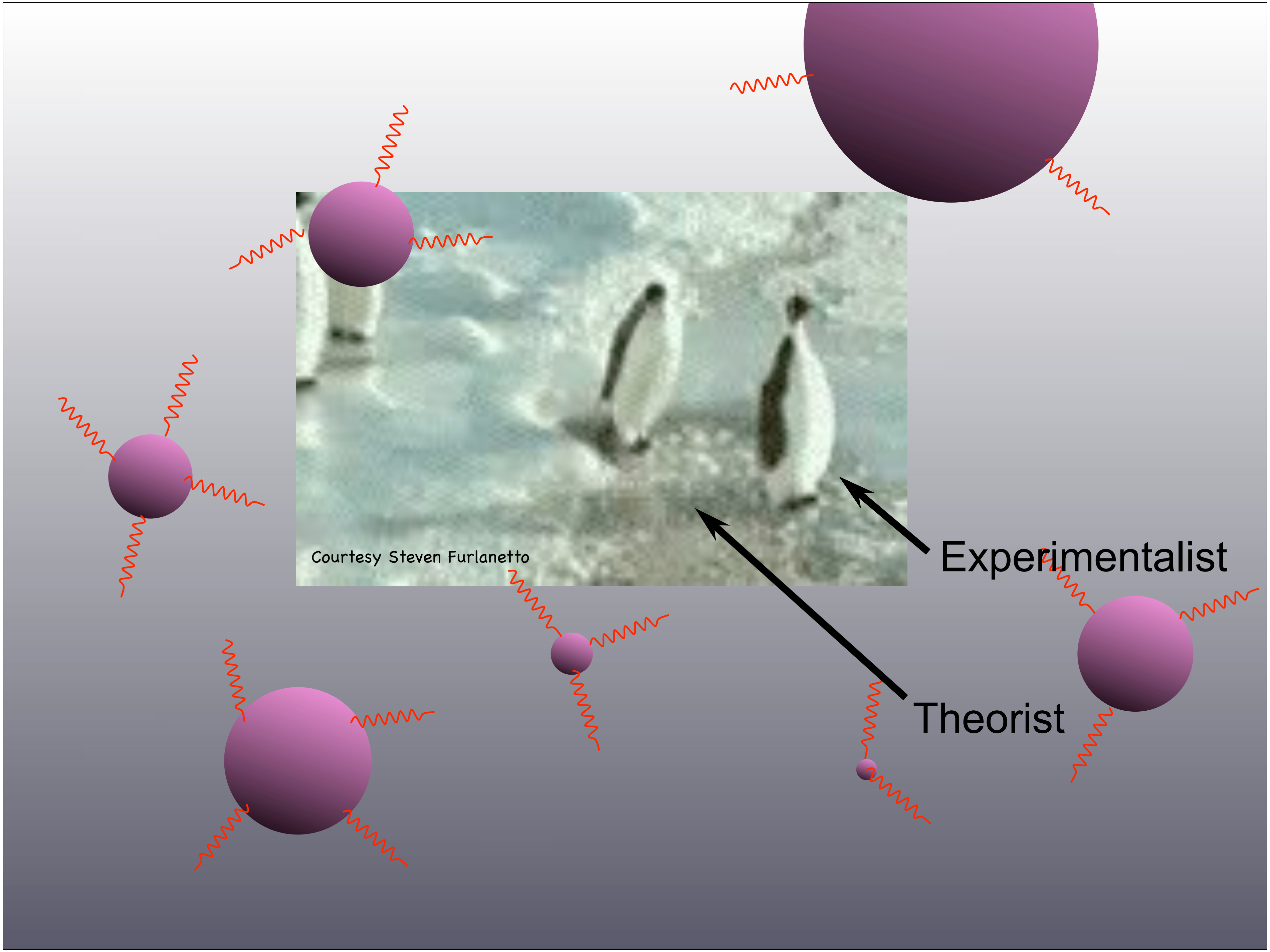
$$\Omega_\chi h^2 = 0.3 \left(\frac{x_f}{10}\right) \left(\frac{g_\star}{100}\right)^{1/2} \left(\frac{10^{-29}\mathrm{cm}^2}{\langle \sigma v \rangle}\right)$$

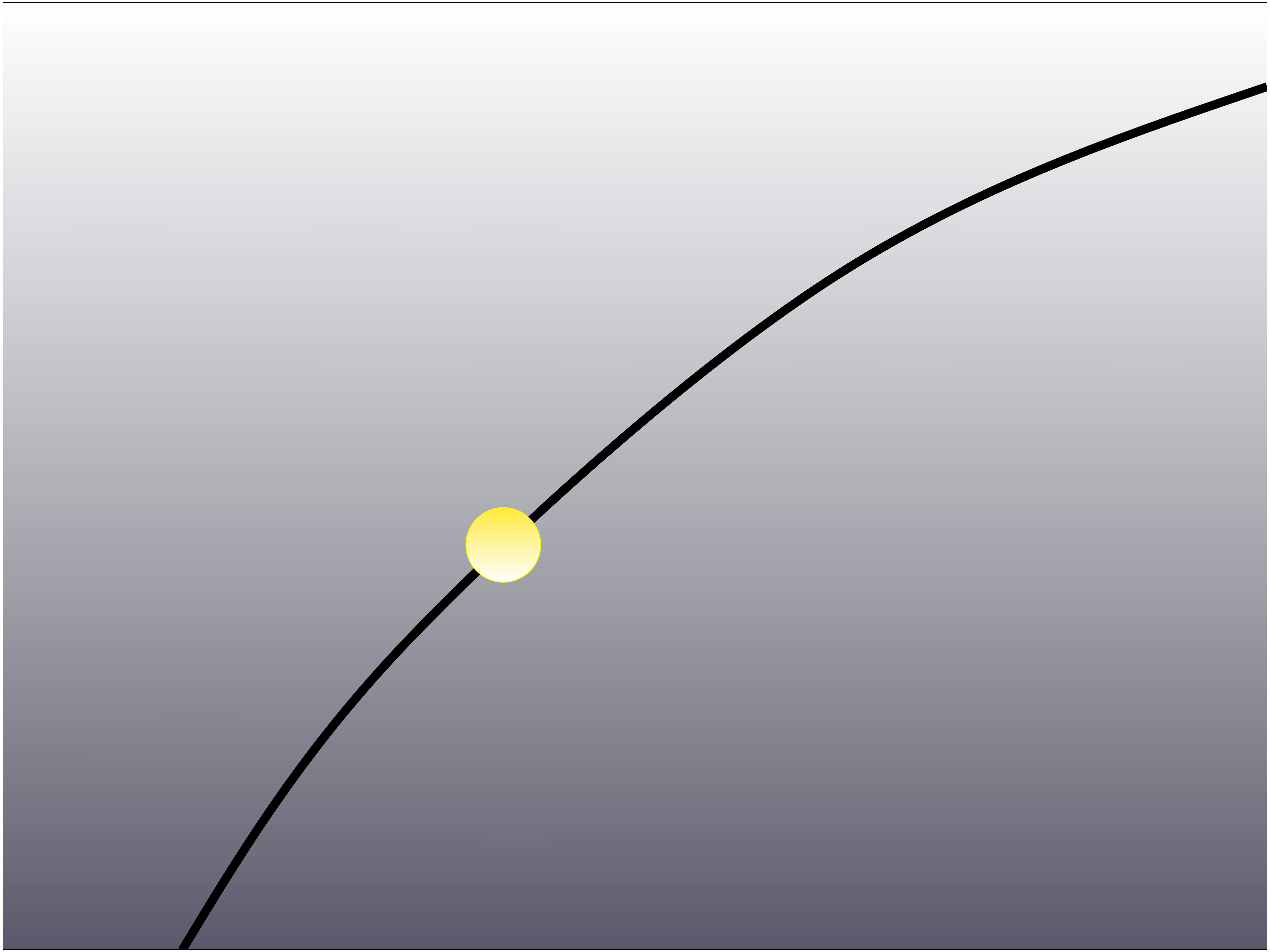


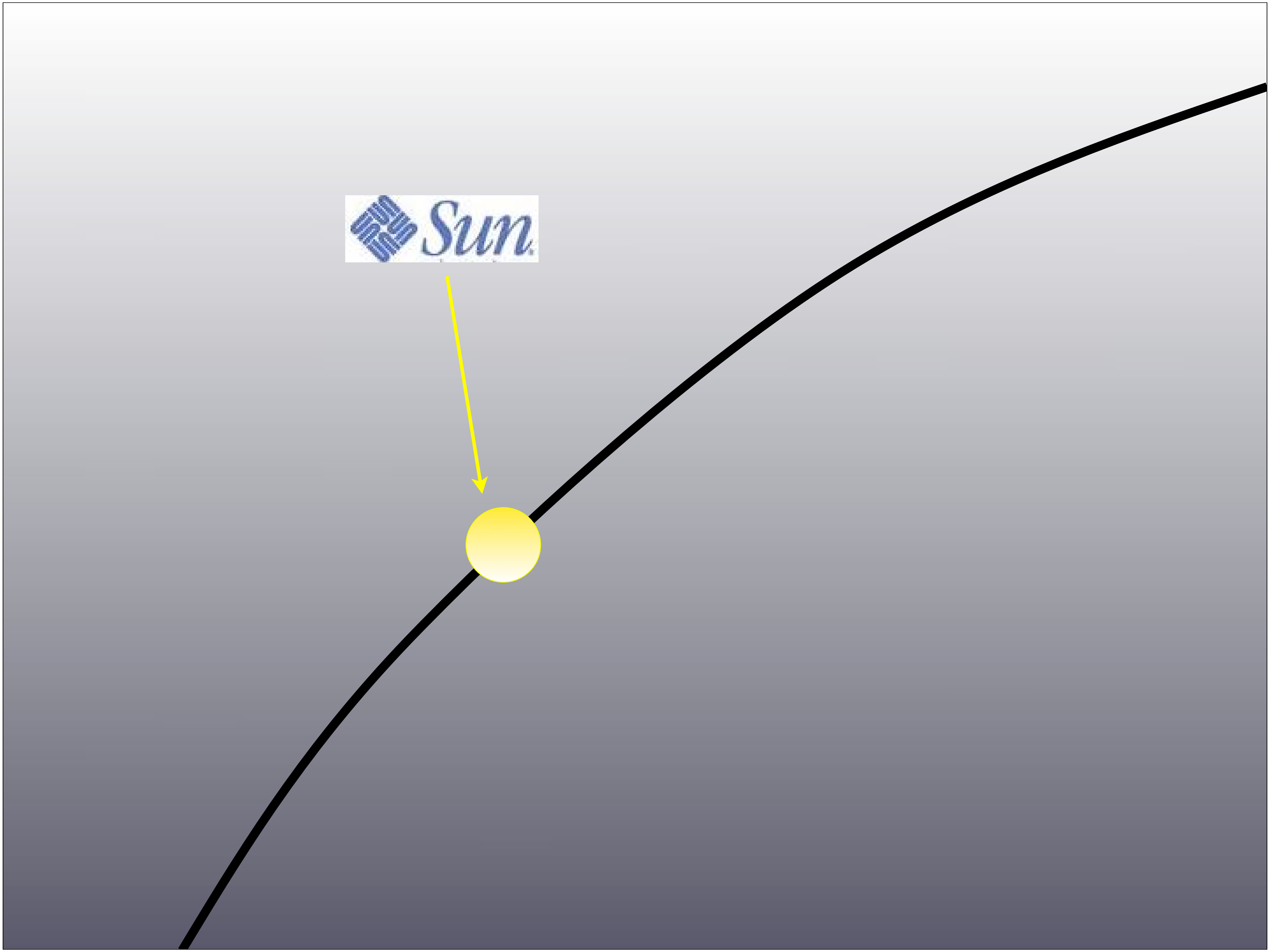


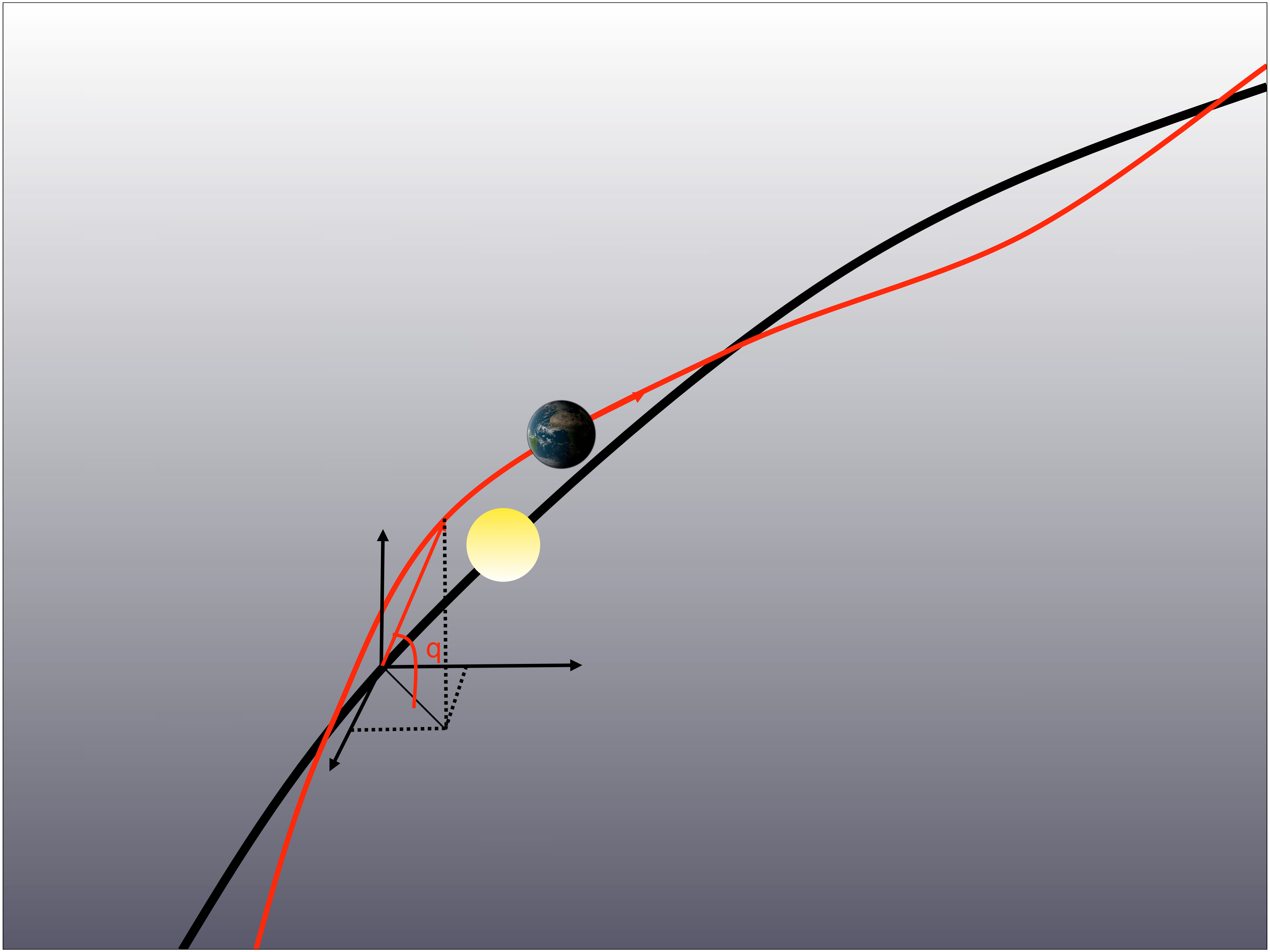


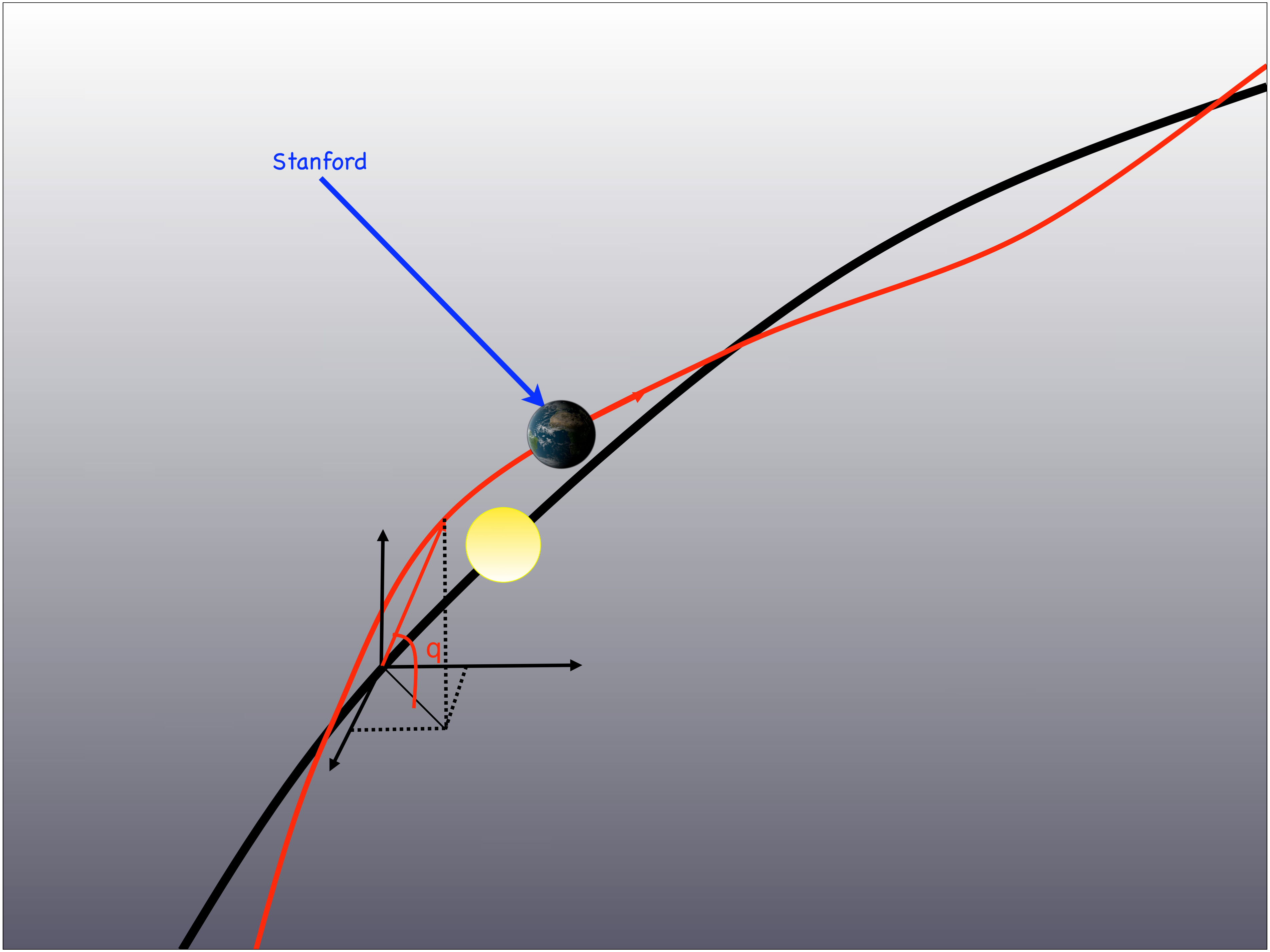

Two ideas: 1) Dark matter microhalos
2) Dark matter couples to photons
Good ideas...how can they be tested???

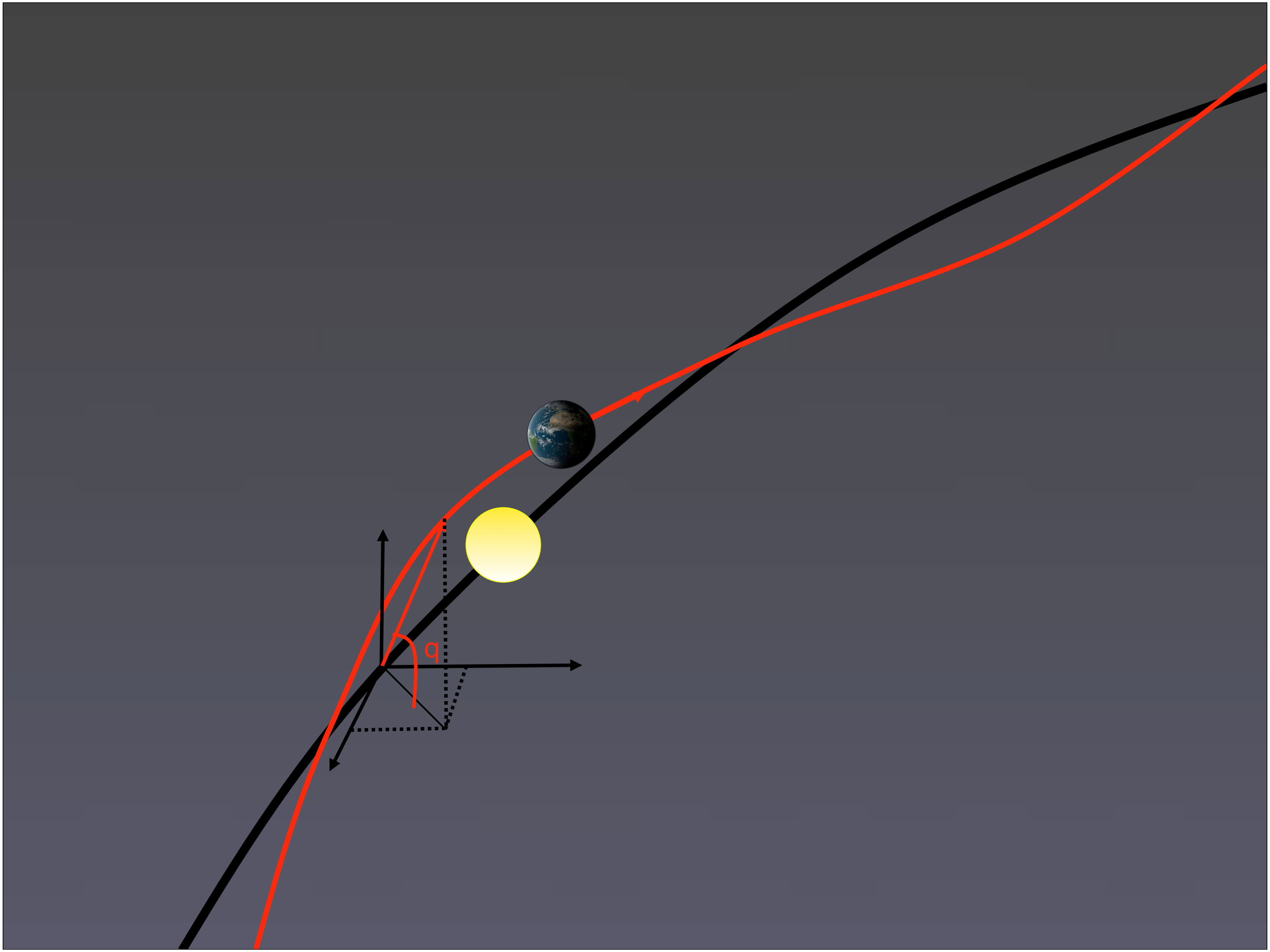

Courtesy Steven Furlanetto
Experimentalist
Theorist

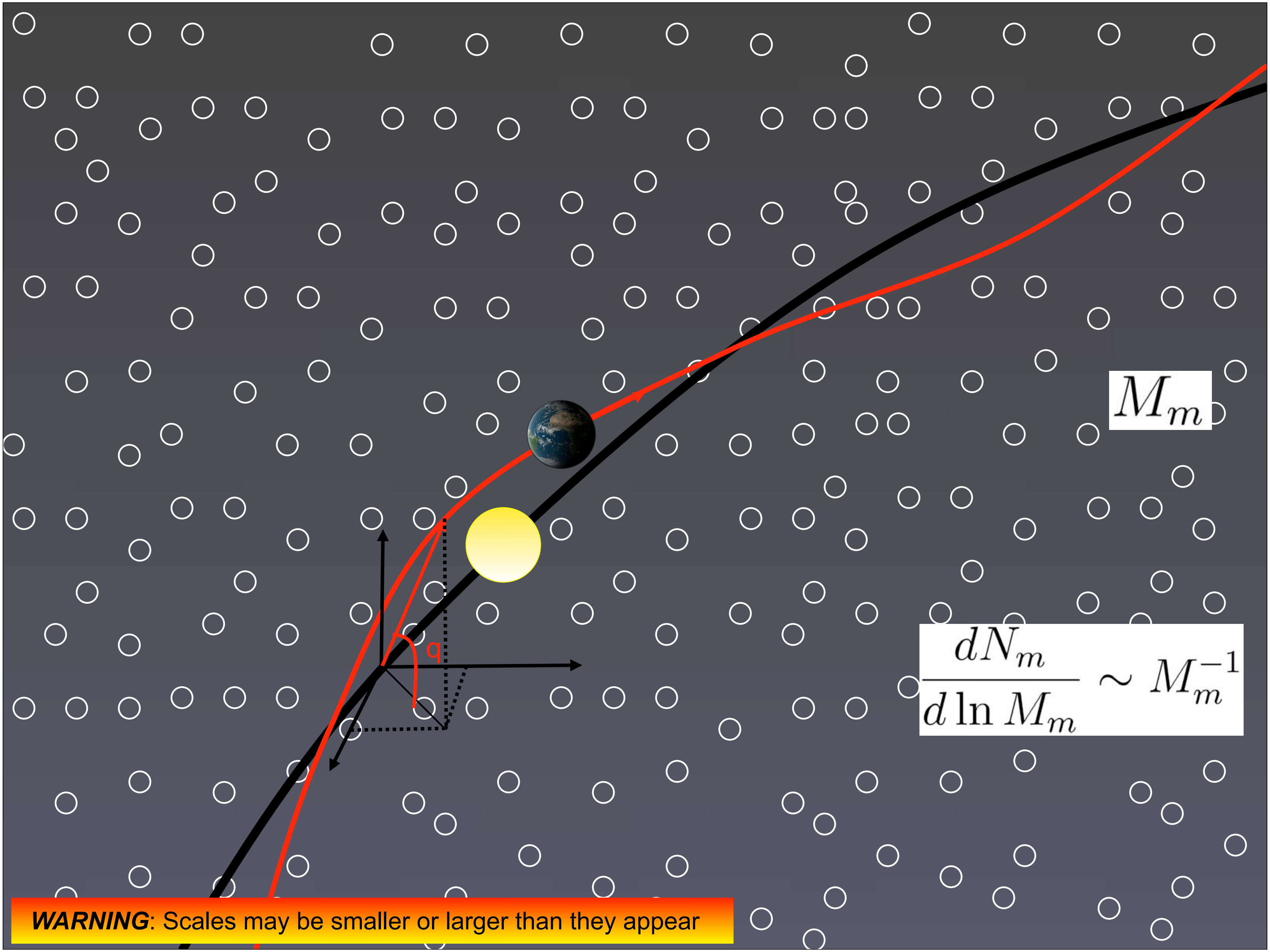


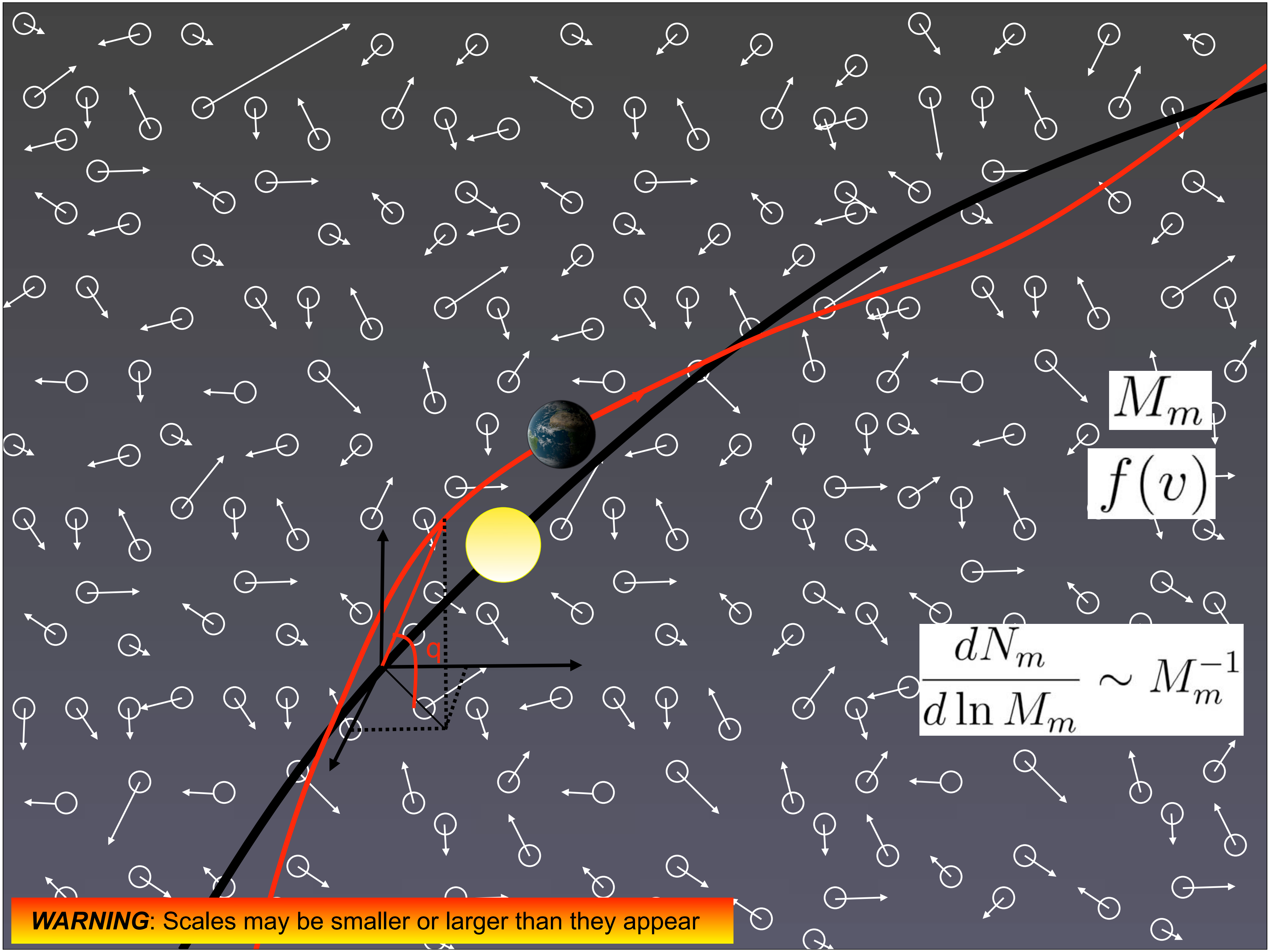

Sun


q


Stanford
q


q


M_m
q
$$\frac{dN_m}{d \ln M_m} \sim M_m^{-1}$$
WARNING: Scales may be smaller or larger than they appear



q
M_m
$f(v)$
$\frac{dN_m}{d \ln M_m} \sim M_m^{-1}$
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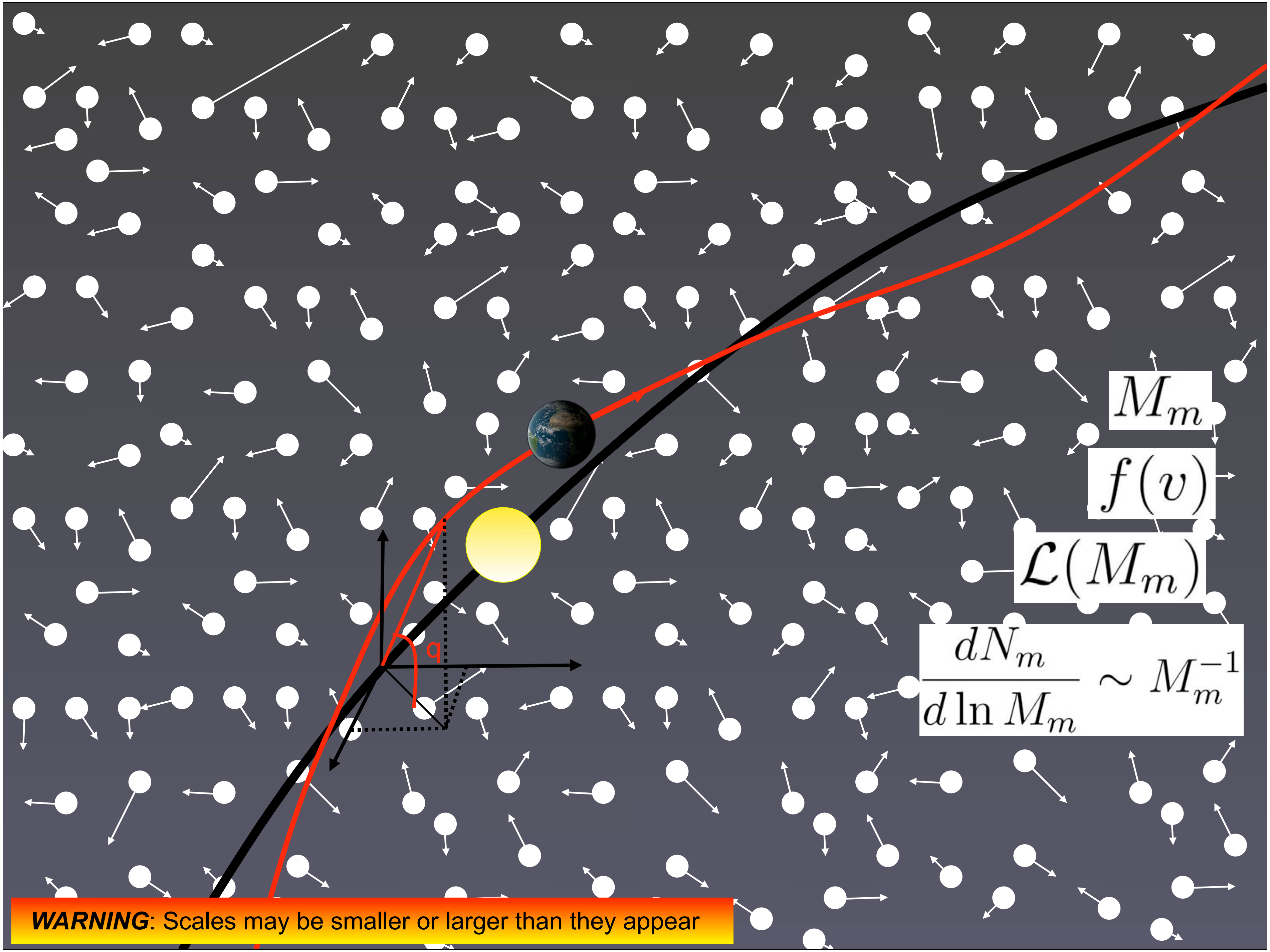

M_m
$f(v)$
$\mathcal{L}(M_m)$
$\frac{dN_m}{d\ln M_m} \sim M_m^{-1}$
q
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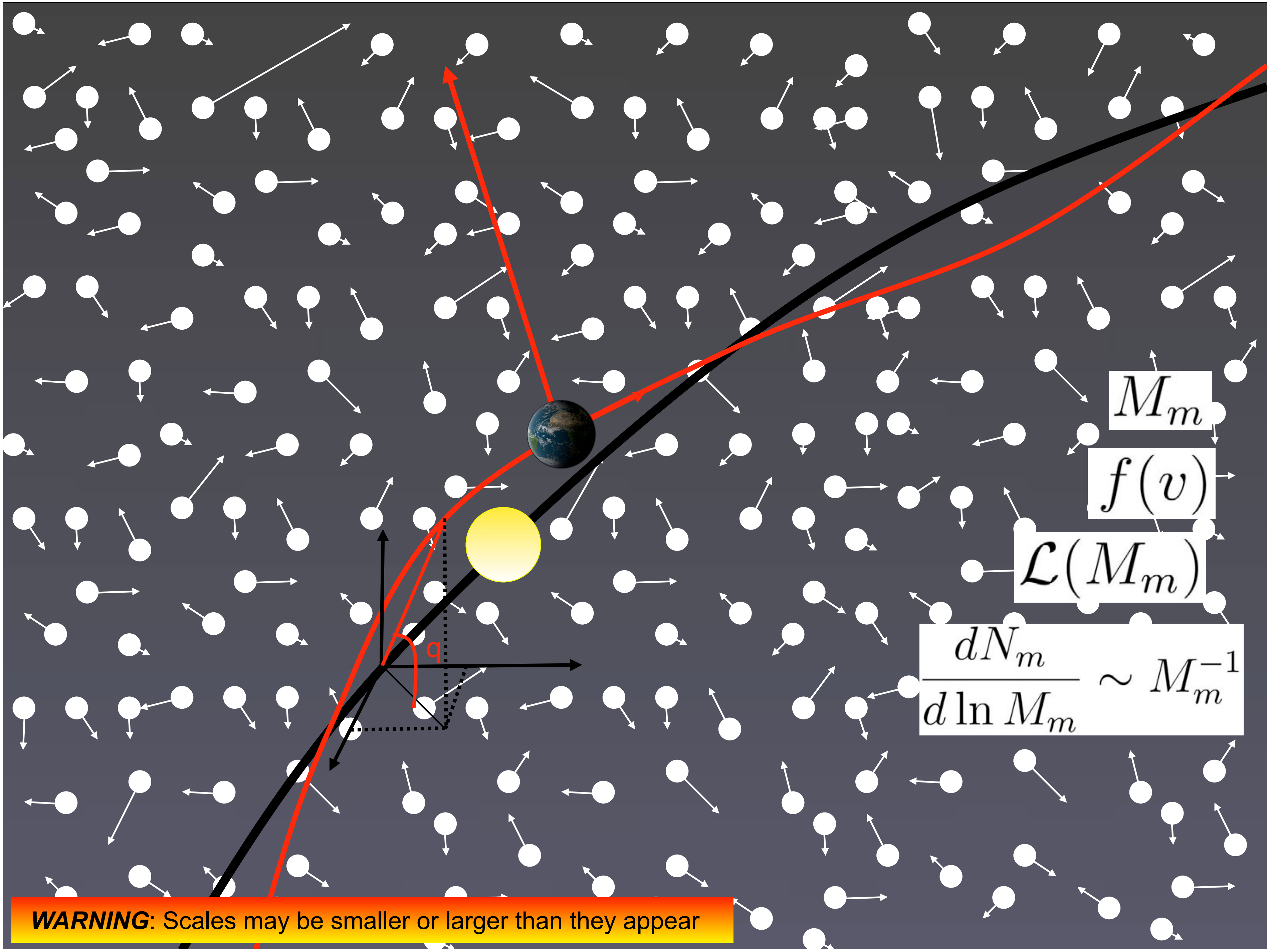
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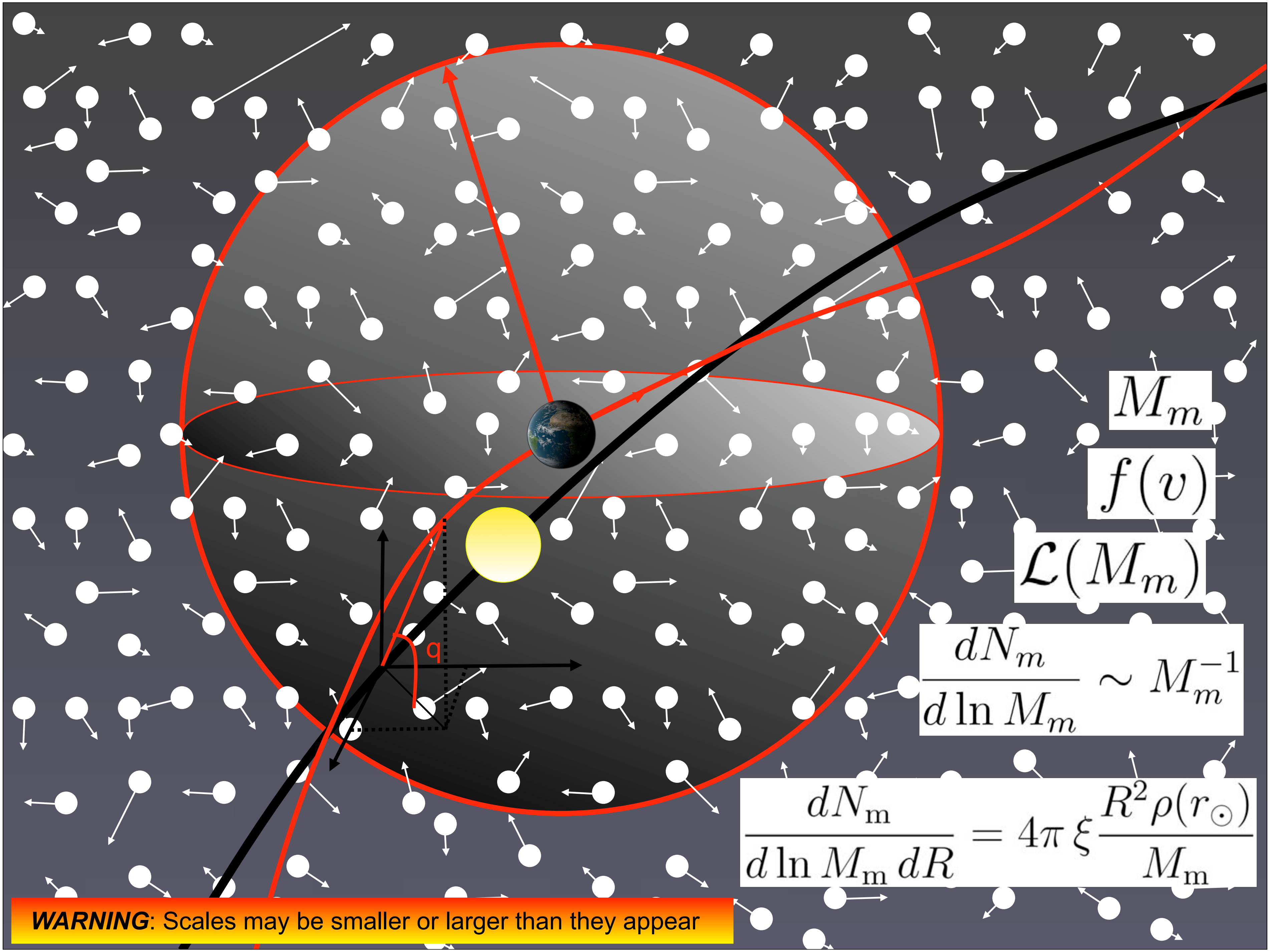


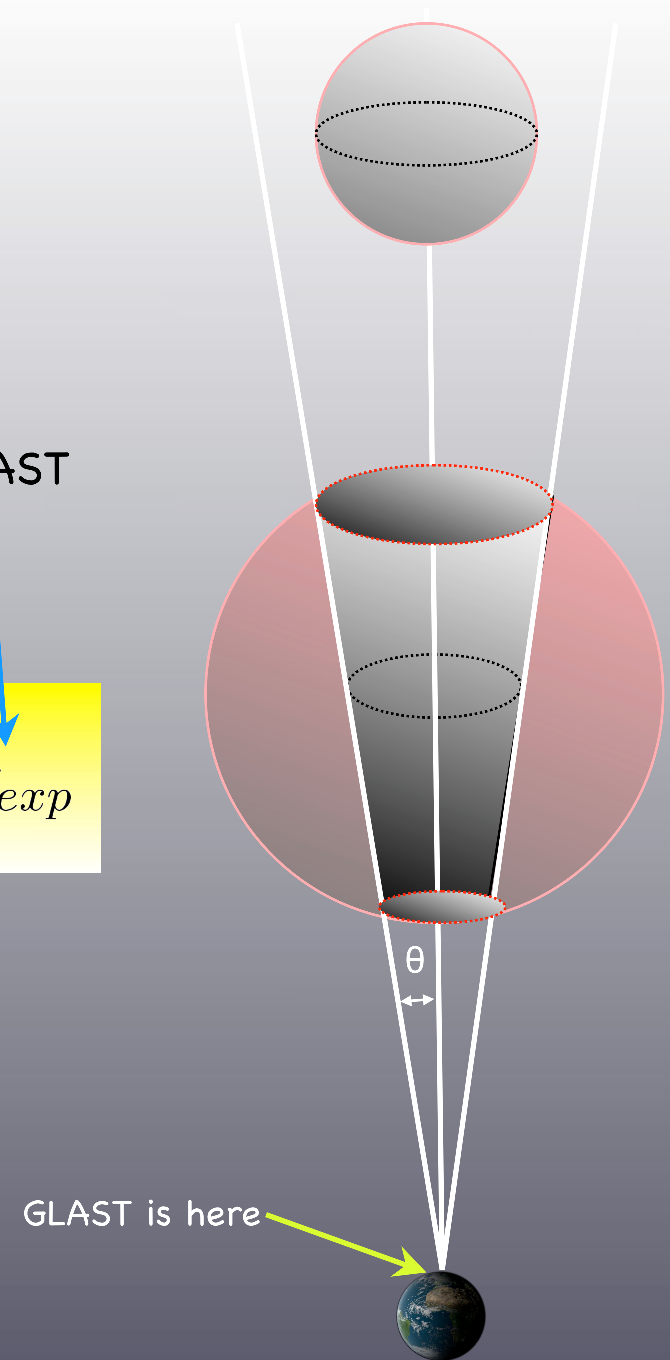
q
M_m
$f(v)$
$\mathcal{L}(M_m)$
$\frac{dN_m}{d\ln M_m} \sim M_m^{-1}$
$\frac{dN_{\rm m}}{d\ln M_{\rm m}\, dR} = 4\pi\,\xi \frac{R^2 \rho(r_\odot)}{M_{\rm m}}$
WARNING: Scales may be smaller or larger than they appear

Structure formation

Particle Physics

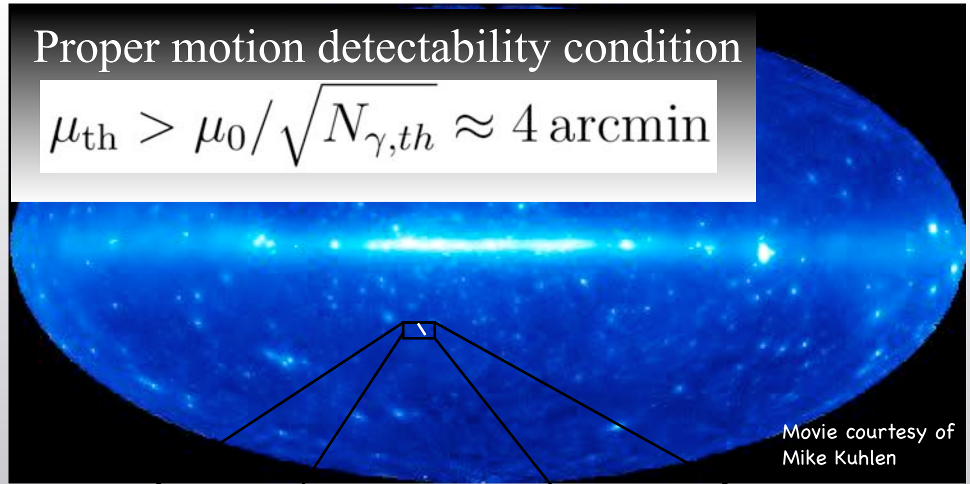
GLAST

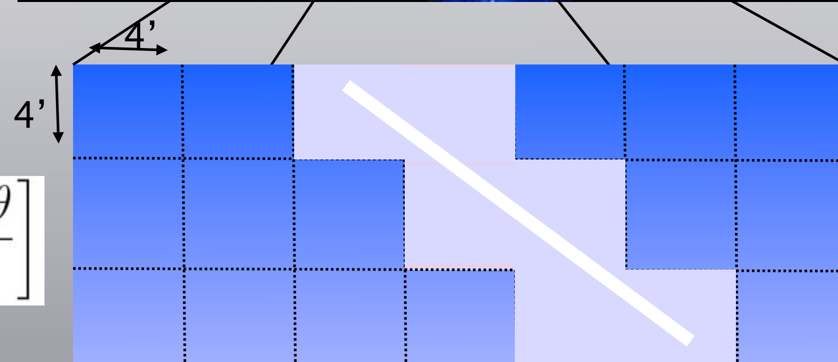
$$N_s = \frac{1}{4\pi} f[\langle \sigma v \rangle, M_\chi]\, g[\rho(r)] A_{eff} \tau_{exp}$$

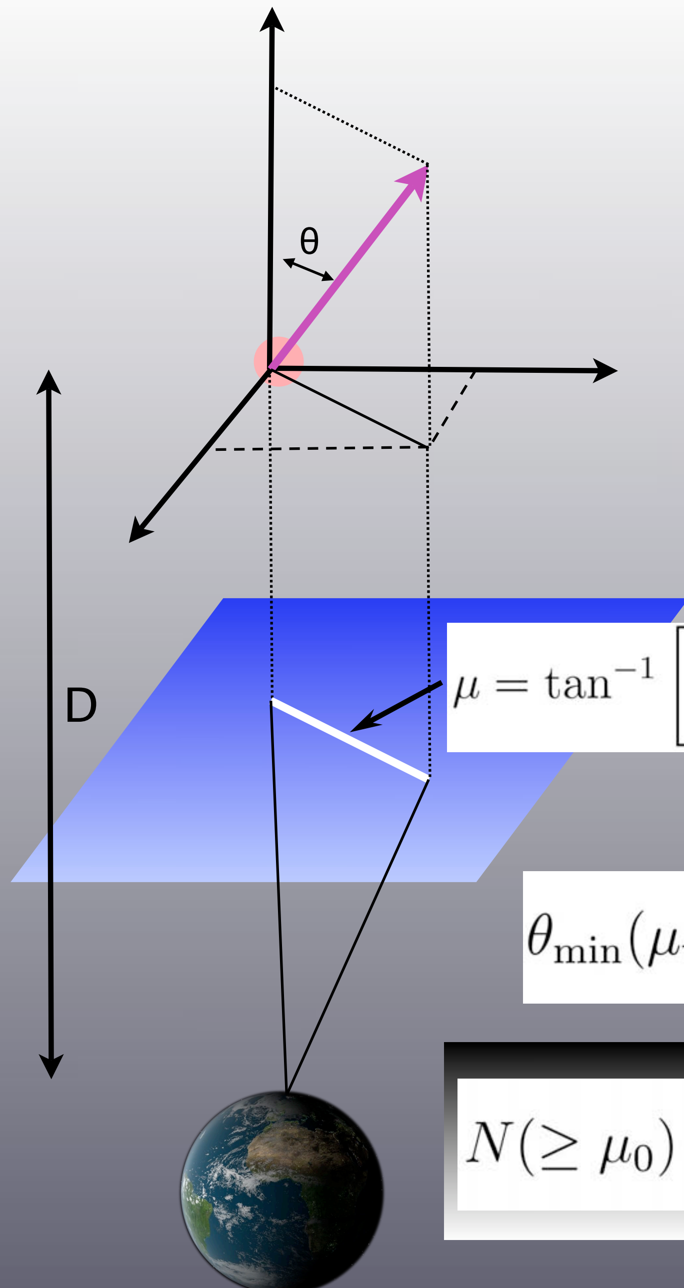


Proper motion detectability condition

$$\mu_{\rm th} > \mu_0/\sqrt{N_{\gamma,th}} \approx 4\,{\rm arcmin}$$



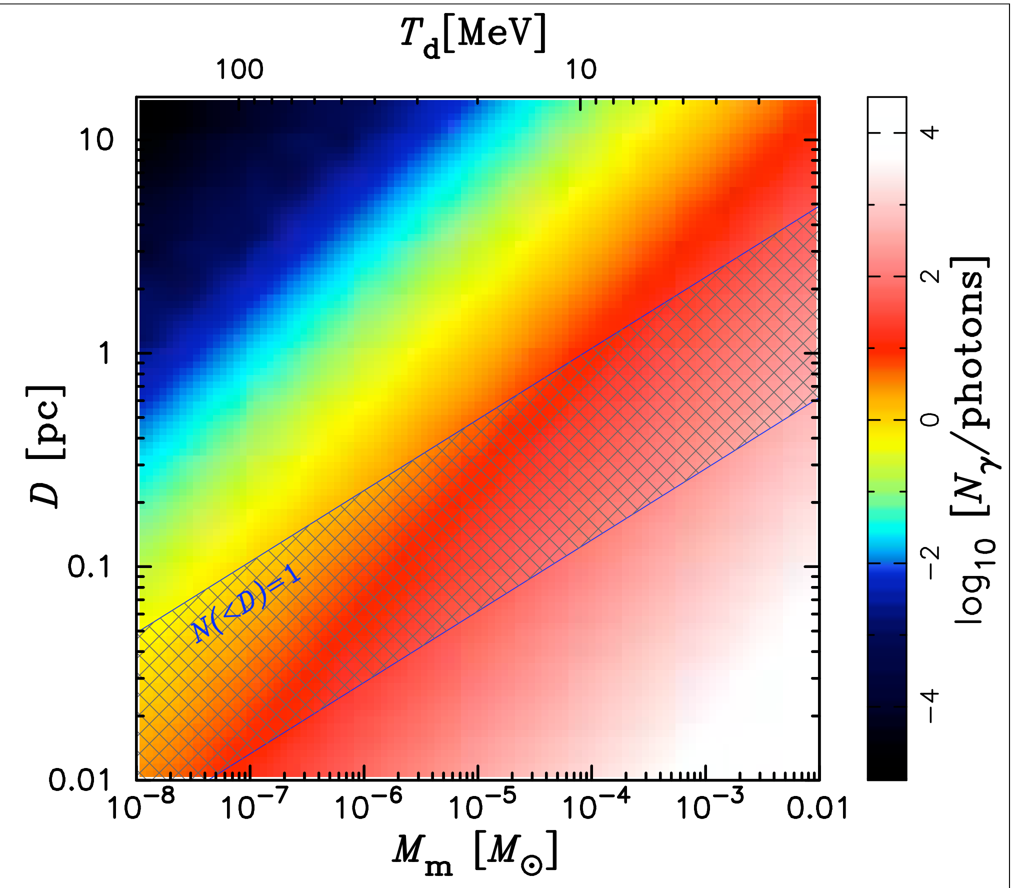




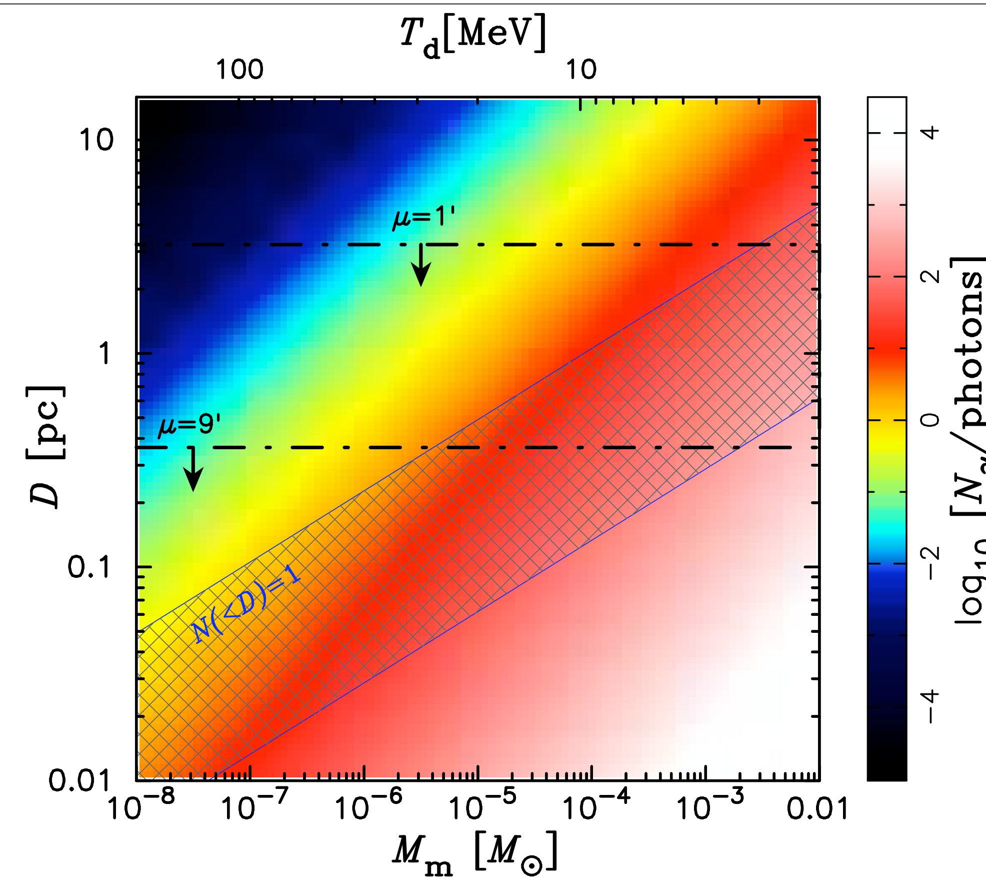
$$\mu = \tan^{-1}\left[\frac{\tau v \sin\theta}{\mathcal{D}}\right]$$

$$\theta_{\rm min}(\mu_{\rm th}, v, \mathcal{D}) = \sin^{-1}\left[\frac{\mathcal{D}\,\tan\mu_{\rm th}}{v\tau}\right]$$

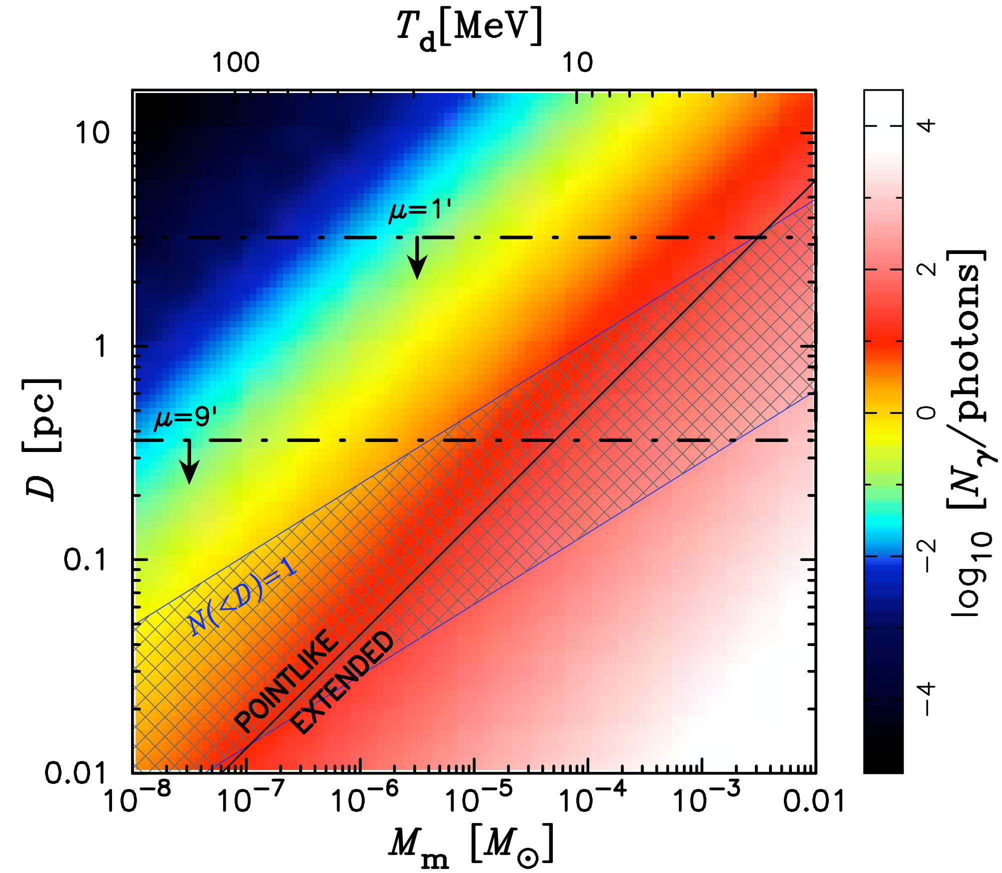
$$N(\geq \mu_0) = 4\pi \int_0^{\mathcal{D}_{\rm max}} \frac{dN}{d\mathcal{D}} \int_0^{\infty} f(v)\cos[\theta_{\rm min}(v,\mathcal{D})]\,dv\,d\mathcal{D}$$



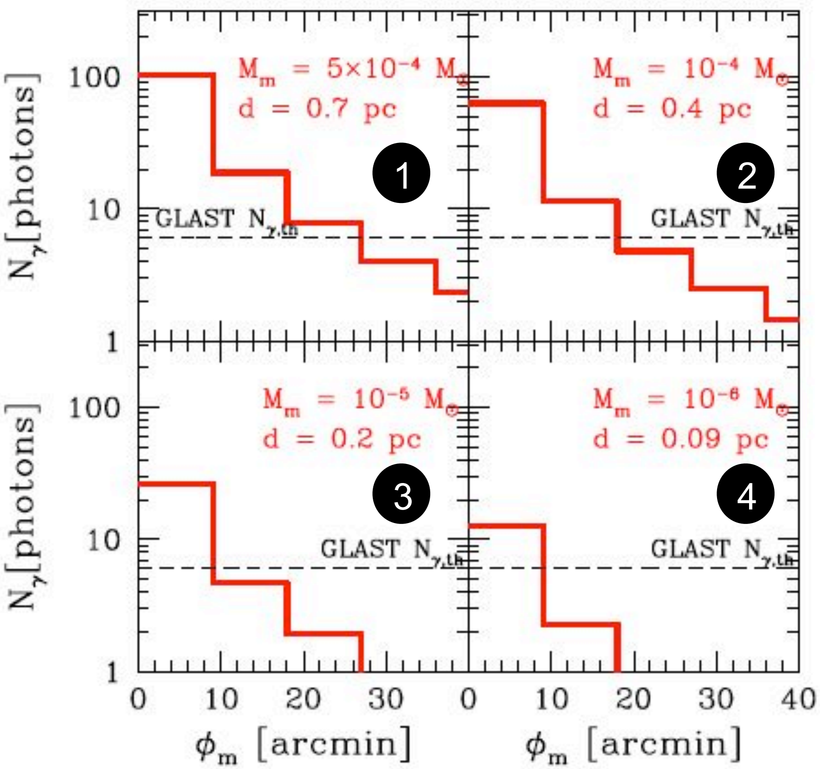
T_d[MeV]
100
10
D [pc]
10
1
0.1
0.01
$N(<D)=1$
10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 0.01
M_m [$M_\odot$]
$\log_{10}$ [N_γ/photons]
4
2
0
−2
−4

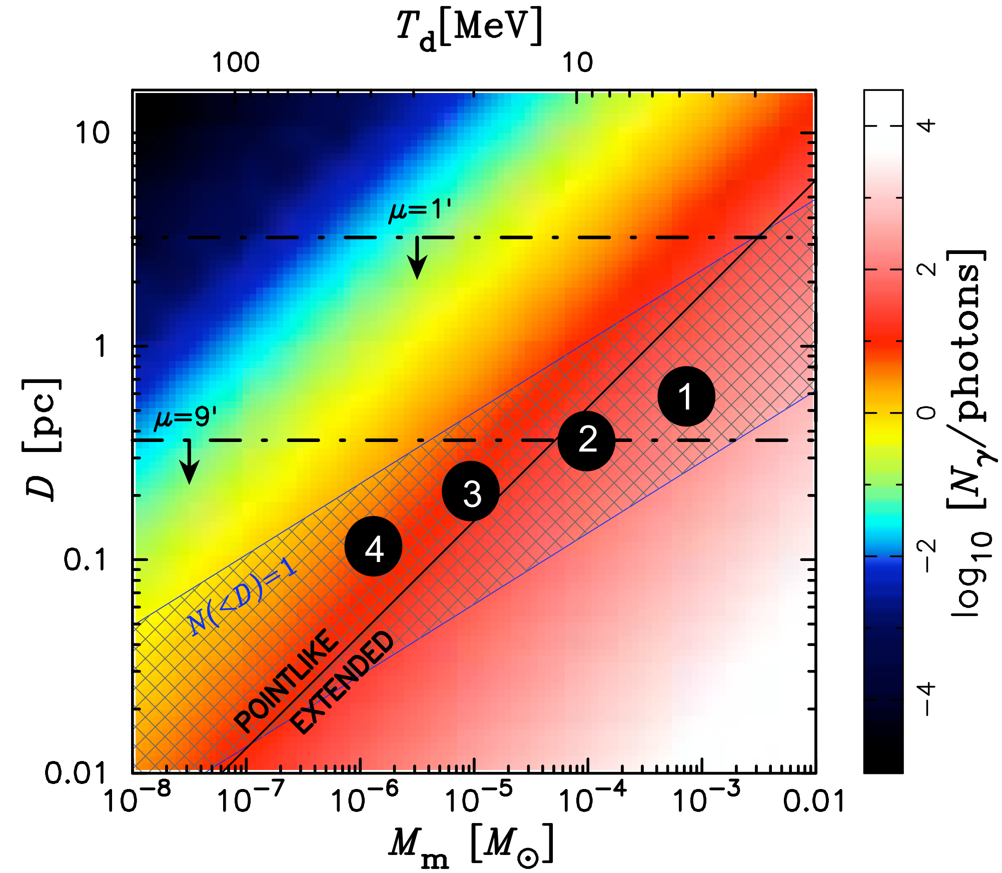


T_d[MeV]
100
10
10
1
0.1
0.01
D [pc]
μ=1'
μ=9'
$N(<D)=1$
10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 0.01
M_m [$M_\odot$]
4
2
0
−2
−4
$\log_{10}$ [N_γ/photons]



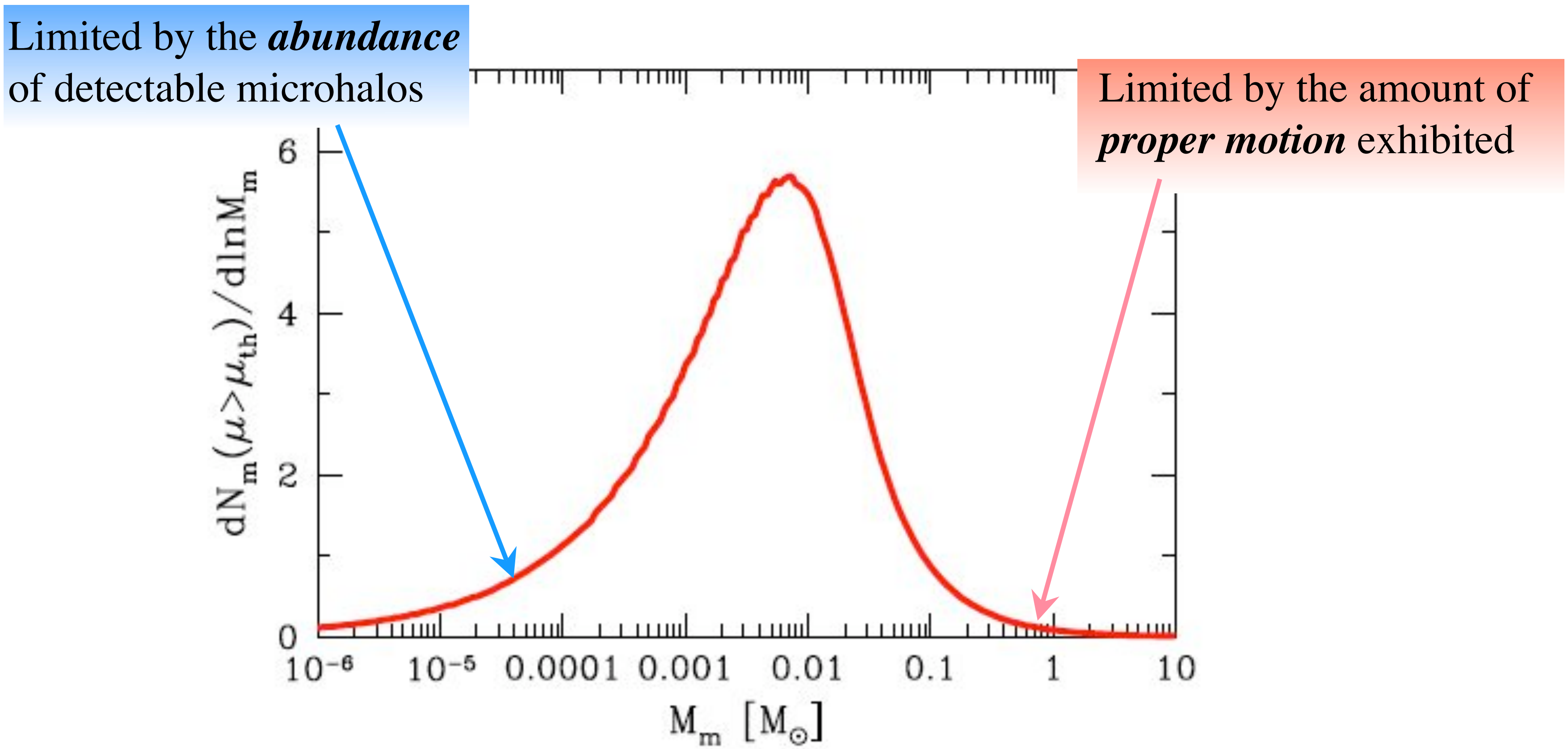
T_d[MeV]
100
10
μ=1'
μ=9'
$N(<D)=1$
POINTLIKE
EXTENDED
D [pc]
10
1
0.1
0.01
10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 0.01
M_m [$M_\odot$]
$\log_{10}[N_\gamma$/photons]
4
2
0
−2
−4





Excess counts from adjacent resolution bins
- Better localization of the source

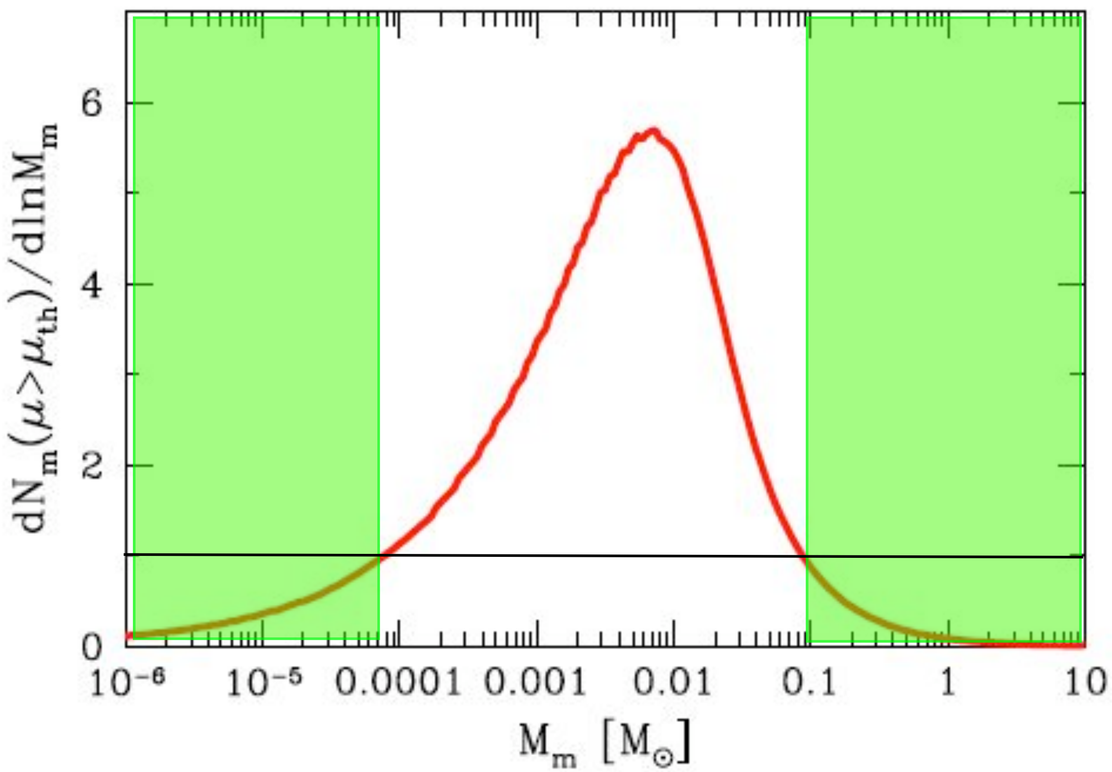
Increasing the angular resolution threshold
- Probability of detecting "massive" microhalos increases



26 potential sources will exhibit proper motion greater than 4 arcminutes

Example: Neutralino dark matter

- Neutralino mass = 46 GeV
- Annihilation cross section of $10^{-26}\text{cm}^3\text{s}^{-1}$
- Exposure time = 10 years
- Subhalo mass function damped due to tidal disruptions (only 20% survive)

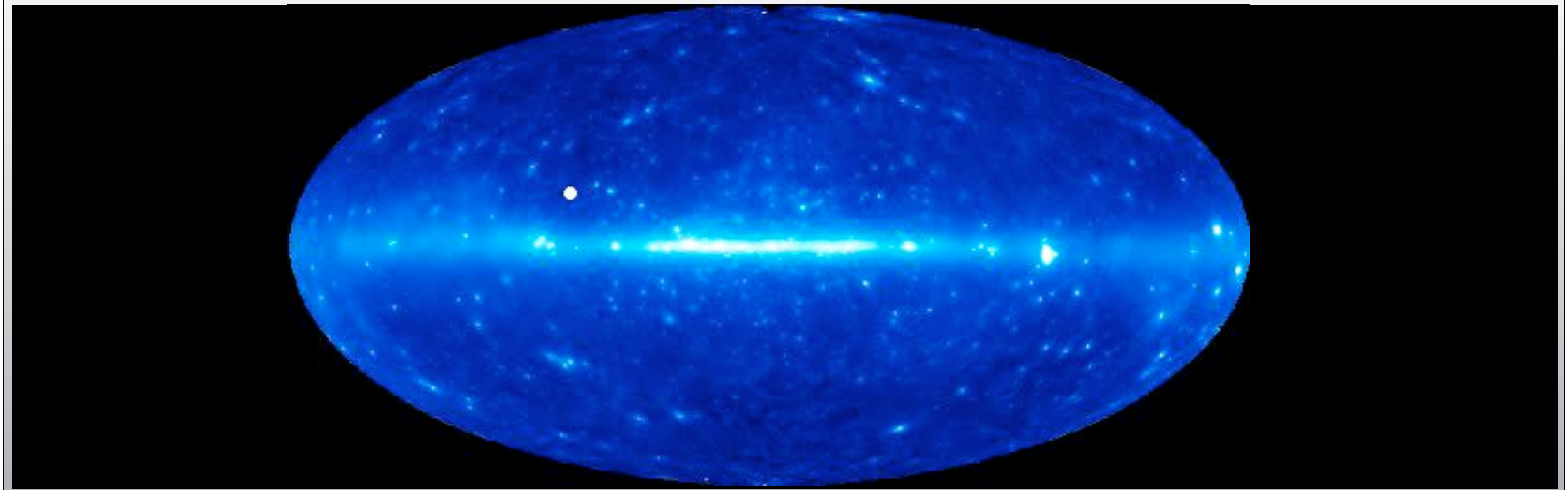


26 potential sources will exhibit proper motion greater than 4 arcminutes

Detection of *at least 1* microhalo with proper motion:

- Kinetic decoupling temperature must be 5 MeV < Td < 100 MeV
- Mass of the WIMP particle must be Mx < 600 GeV

SUMMARY



- Microhalos that survive in the Milky Way halo could be observed via their proper motion signal measured in γ-rays - A search for the proper motion of γ-ray sources in GLAST is essential
- Proper motions can be greater than 10 arcminutes in 10 years, fluxes are of order 100-1000 photons in 10 years
- An extremely clean signature of dark matter - No other known object can mimic this potentially detectable phenomenon!