Indirect Detection of Dark Matter at the Galactic Centre

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TIFF (Uncompressed) decompressor
are needed to see this picture.

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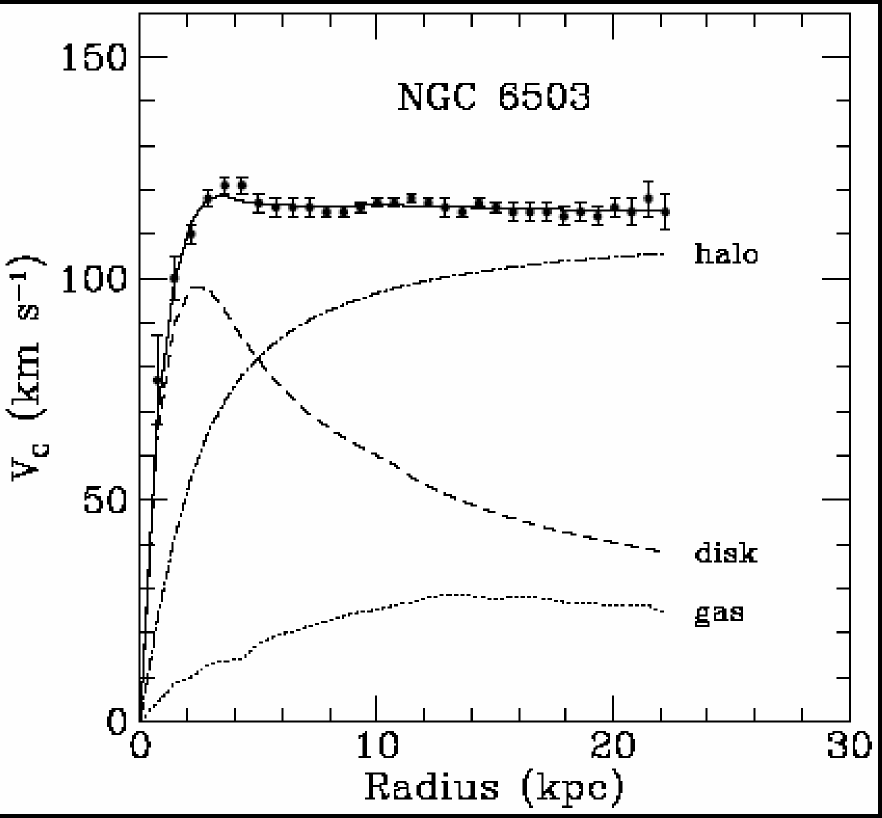
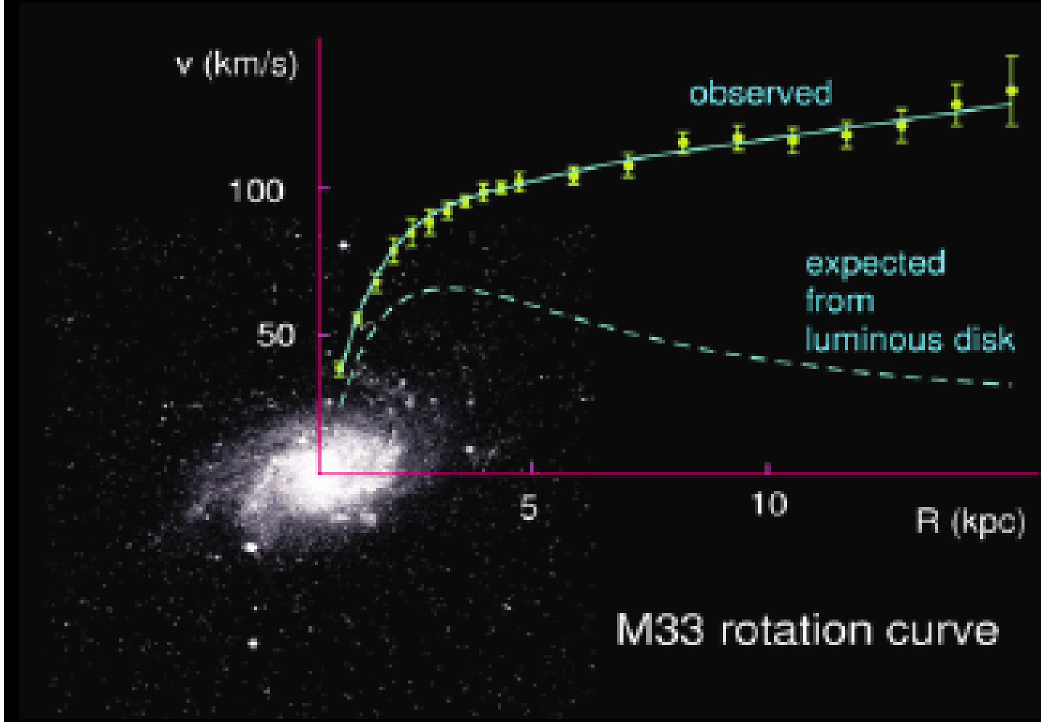
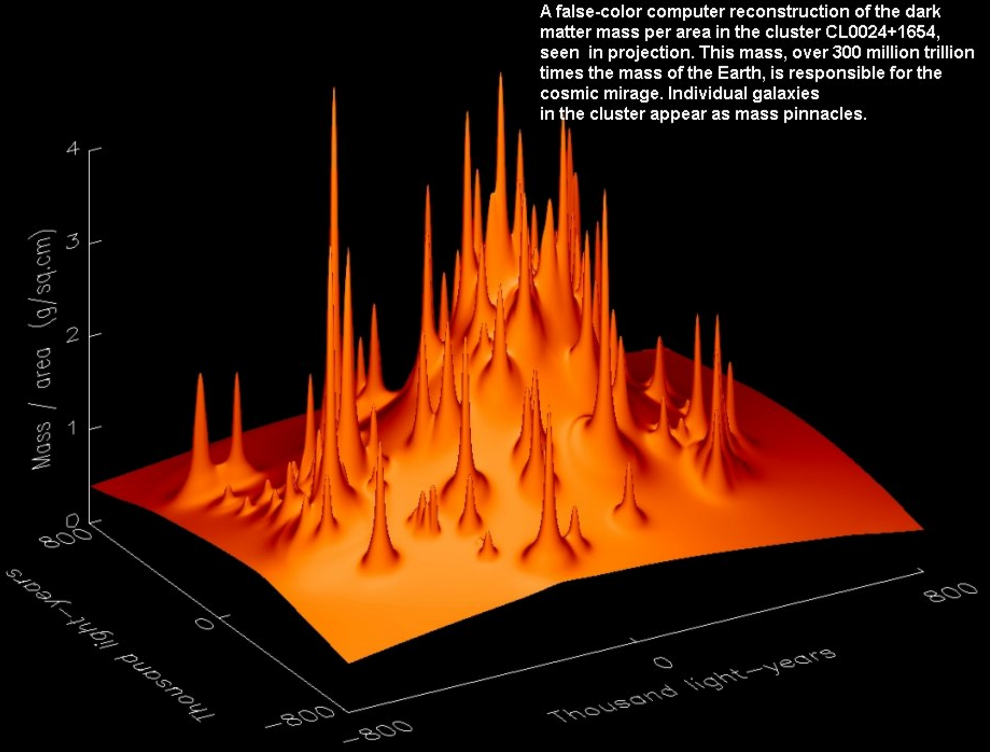
Evidence for Dark Matter





Evidence for Dark Matter

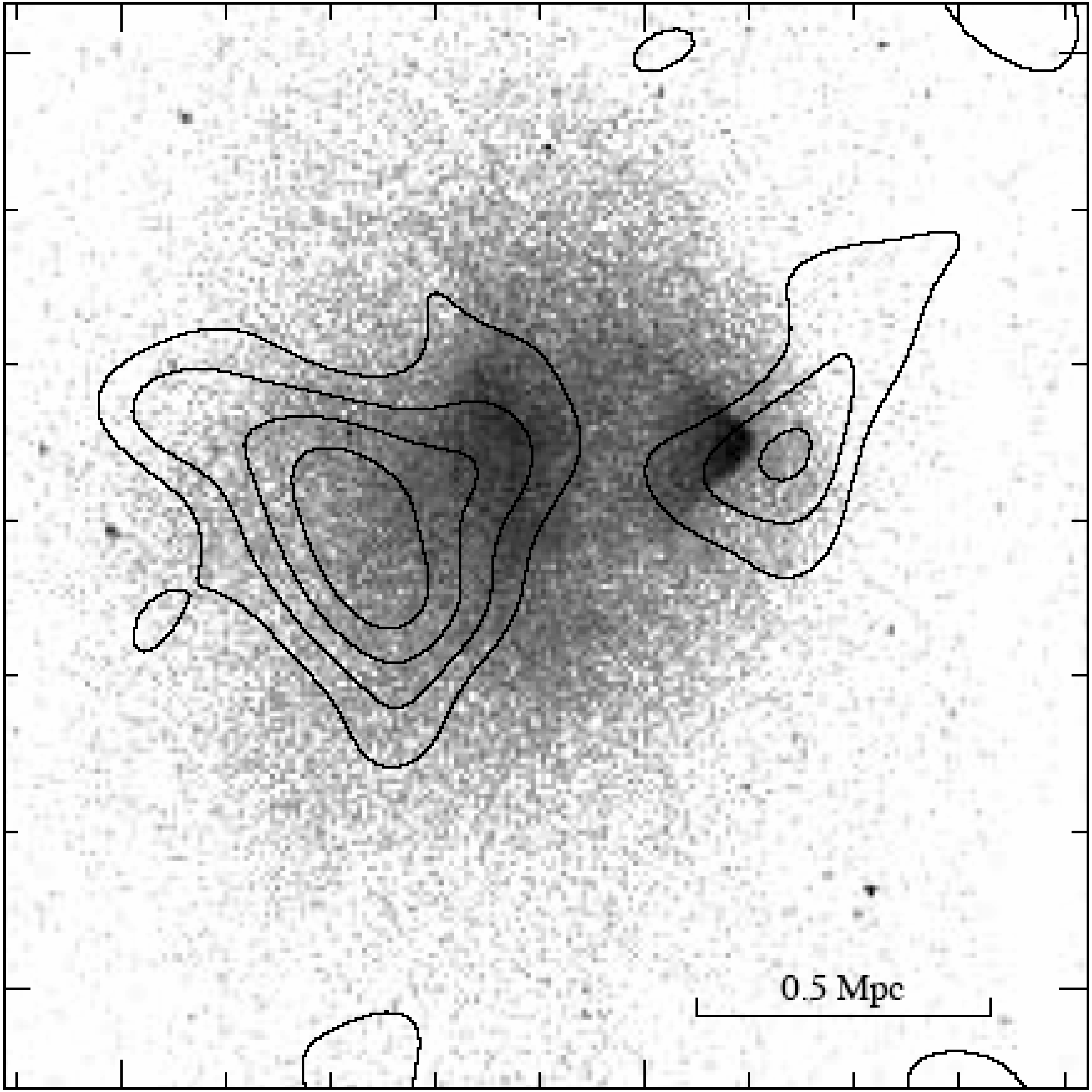


Lensing study of cluster CL0024+1654 (Tyson et al. Astro-ph/9801193)

WMAP Evidence for Dark Matter

Table 3: Goodness of Fit, $\Delta\chi^2_{eff} \equiv -2\ln\mathcal{L}$, for WMAP data only relative to a Power-Law ΛCDM model. $\Delta\chi^2_{eff} > 0$ is a worse fit to the data.

	Model	$-\Delta(2\ln\mathcal{L})$	N_{par}
M1	Scale Invariant Fluctuations ($n_s = 1$)	8	5
M2	No Reionization ($\tau = 0$)	8	5
M3	No Dark Matter ($\Omega_c = 0, \Omega_\Lambda \neq 0$)	248	6
M4	No Cosmological Constant ($\Omega_c \neq 0, \Omega_\Lambda = 0$)	0	6
M5	**Power Law ΛCDM**	0	6
M6	Quintessence ($w \neq -1$)	0	7
M7	Massive Neutrino ($m_\nu > 0$)	0	7
M8	Tensor Modes ($r > 0$)	0	7
M9	Running Spectral Index ($dn_s/d\ln k \neq 0$)	−3	7
M10	Non-flat Universe ($\Omega_k \neq 0$)	−6	7
M11	Running Spectral Index & Tensor Modes	−3	8
M12	Sharp cutoff	−1	7
M13	Binned $\Delta^2_{\mathcal{R}}(k)$	−22	20



Bullet Cluster:

Evidence against MOND?

Markevitch et al.

astro-ph/0309303

Indirect Detection of Dark Matter

WIMP in equilibrium with the plasma at early times may self-annihilate today

$$\chi + \bar{\chi} \rightarrow x + \bar{x}$$

WIMPS

SM particles

Several good WIMP candidates e.g. axion, but here we will consider SUSY WIMPS and lightest KK particle in universal extra dimension scenario

Dark Matter Density

Number of annihilation events goes like square of the density

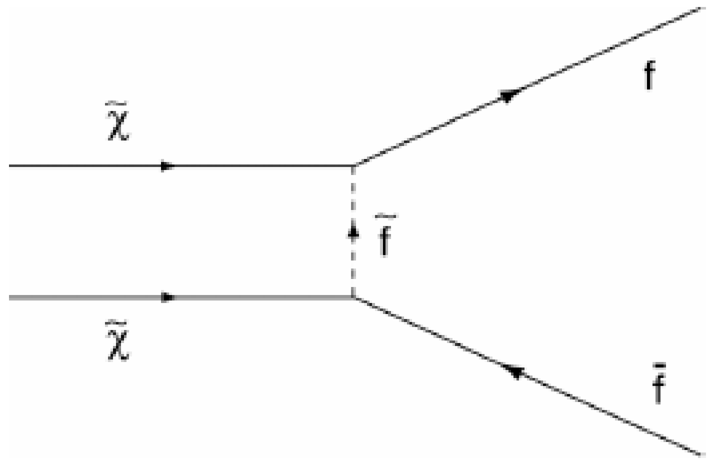
$$\frac{dn}{dt} = \langle \sigma v \rangle \left(\frac{\rho}{m_\chi} \right)^2$$

N-body simulations of galaxies predict

$$\rho(r) \propto r^{-\gamma}$$

- $\gamma=1$ Navarro, Frenk and White
- $\gamma=1.5$ Moore et al. 2000
- $\gamma=1.12$ Diemand et al. 2004

Decay into Fermions

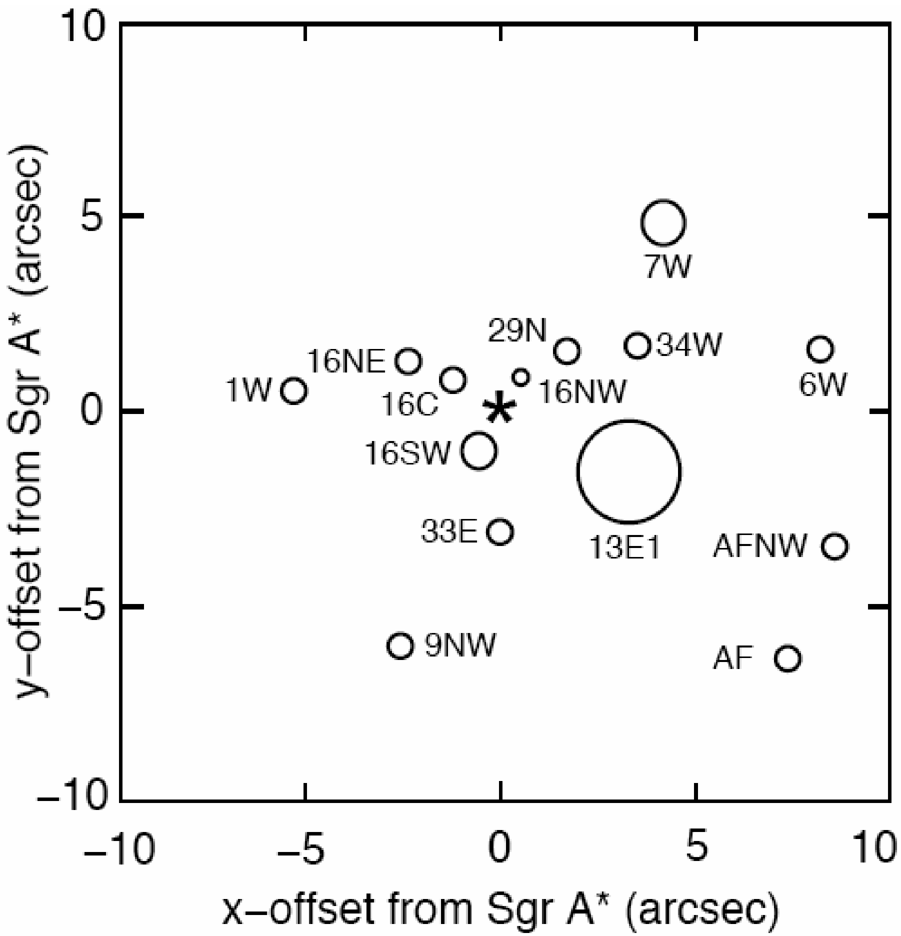


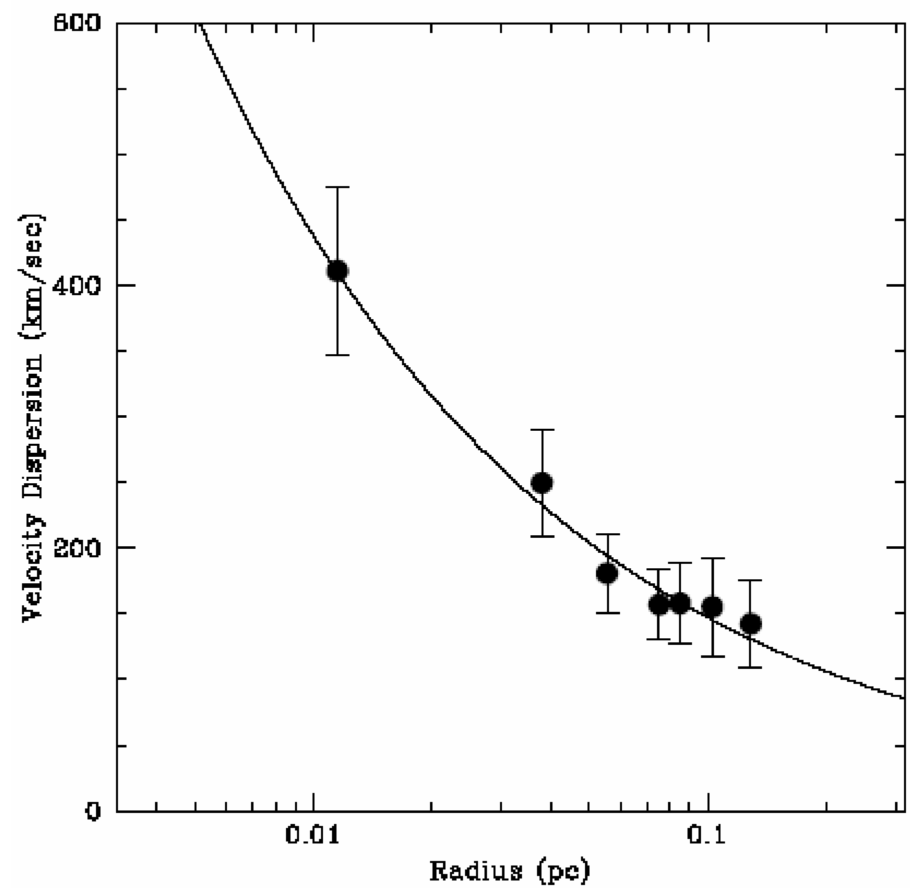
This process is helicity suppressed for neutralinos but not for KK particles.

- ❑ Electrons from SUSY WIMPS secondary (soft)
- ❑ Electrons from KK wimps primary (hard)

Can therefore use synchrotron radiation to distinguish between candidates

Centre of the Galaxy

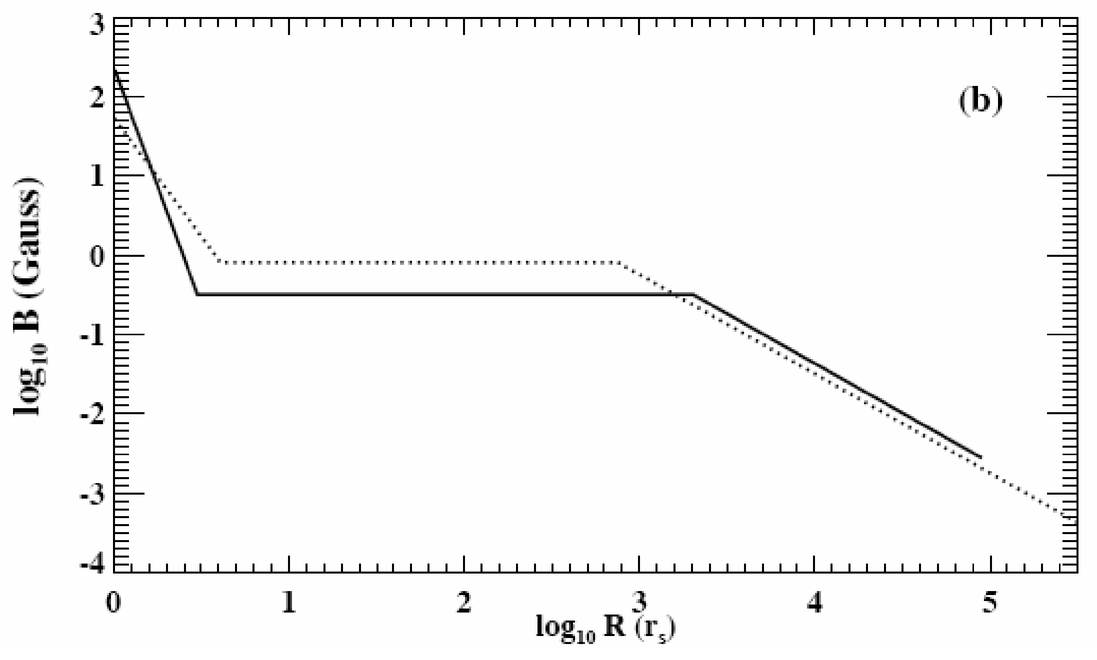




Astrophysical Environment

Coker Melia astro-ph/9909411

- Spherical infall at sub-Eddington rate
- Equipartition magnetic fields at r>10,000 rbh
- B at lower radii lowered due to reconnection



Diffusion Equation

$$-\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2K(E,r)\frac{\partial}{\partial r}N(E,r)\right]+\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2v(r)N(E,r)\right]-\frac{1}{3r^2}\left[\frac{\partial}{\partial r}\left[r^2v(r)\right]\right]\left[\frac{\partial}{\partial E}EN(E,r)\right]+$$

Diffusion in space

Diffusion in space due to advection

Diffusion in momentum due to advection

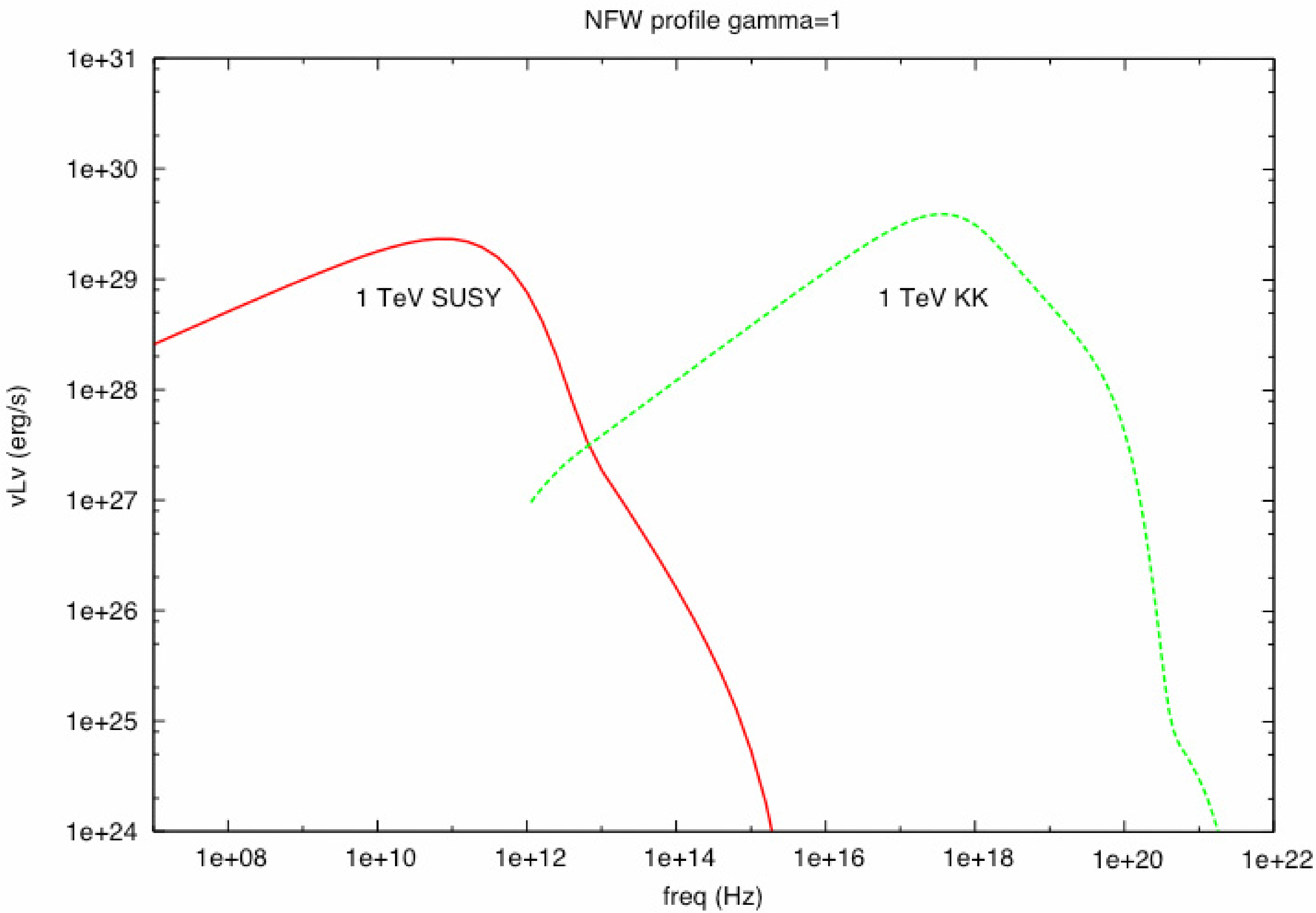
$$\frac{\partial}{\partial E}\left[N(E,r)\dot{E}(E,r)\right]-\frac{\partial}{\partial E}\left[\beta^2E^2K_{pp}(E,r)\frac{\partial}{\partial E}\frac{N(E,r)}{E^2}\right]=Q(E,r)$$

Energy loss

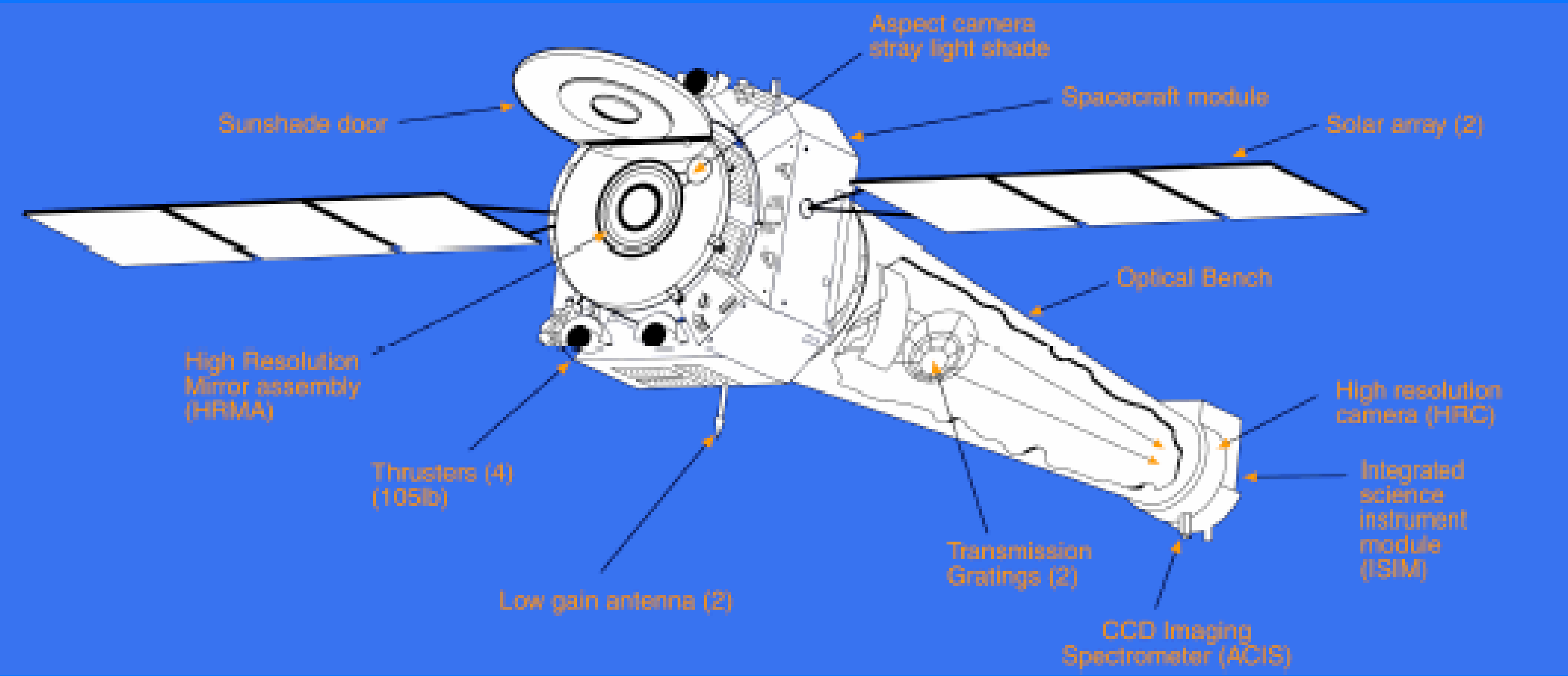
Diffusion in momentum space

Injection

Predicted Spectrum

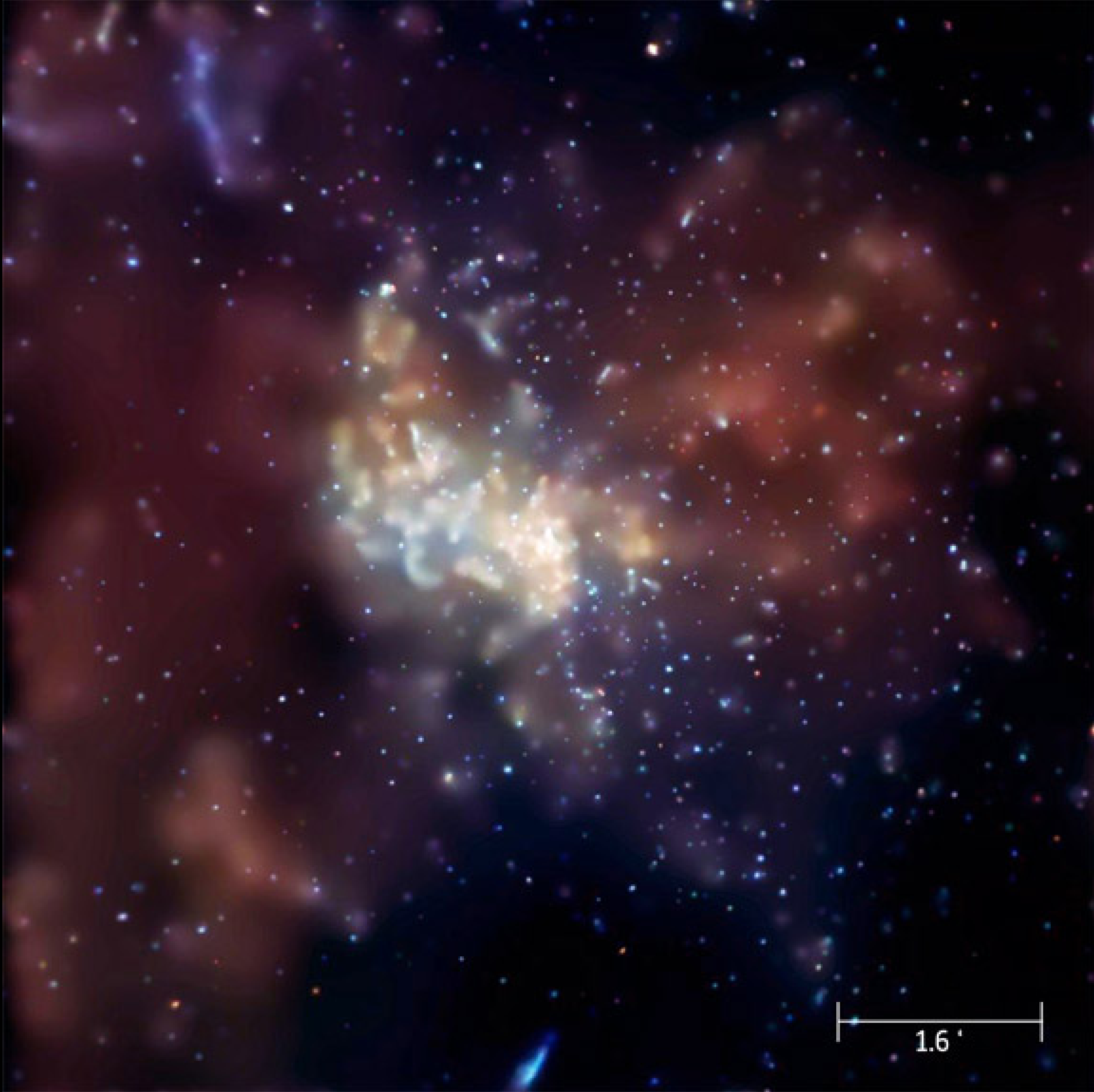


Chandra X-ray Telescope



Chandra View of Sag A*

0.25 pc

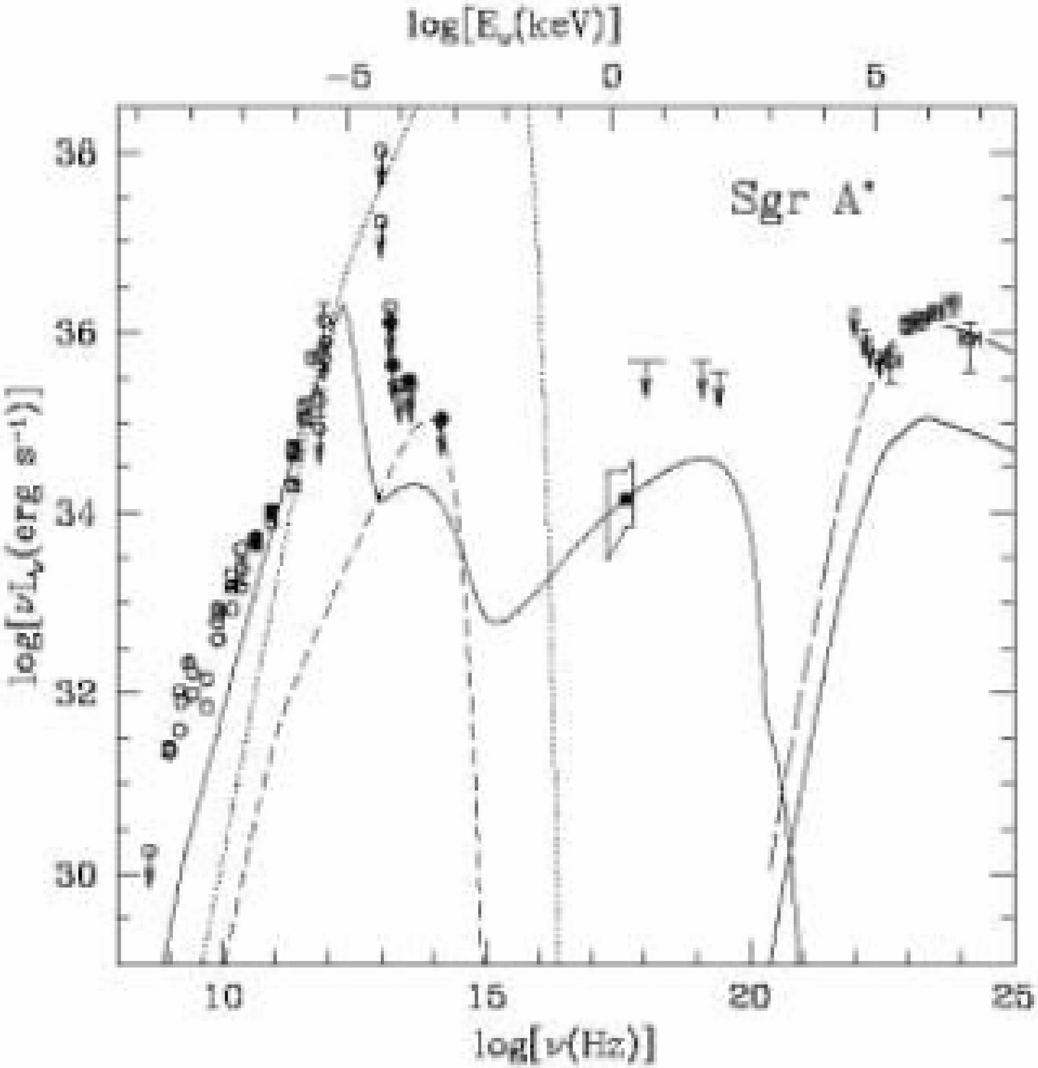


Baganoff et al.

Energy Flux from Sagittarius A*

γ=1 TeV WIMP central 0.01 pc

$$\dot{E} = 2(0.01\text{pc})^3 \dot{n} m_\chi \approx 10^{30}\text{erg/s}$$



Dark Matter hard to observe!! However, we expect help from BARYONIC CONTRACTION…

Baryonic Contraction

(Eggen et al. 1962, Zeldovich et al. 1980, Blumenthal et al. 1986)

- Take galaxy made of dark matter
- Convert fraction f into baryons
- Baryons cool and sink to core (unlike dark matter)
- Dark matter flows into this potential well

Assume circular orbits (no shell crossing). Ang. mom. cons. then gives

$$r_Y \left[M_B^Y(r_Y) + M_{DM}^Y(r_Y) \right] = r_X M_{DM}^X(r_X)$$

Y is galaxy with baryons

X is dark matter only galaxy

How good an approximation is circular orbits?

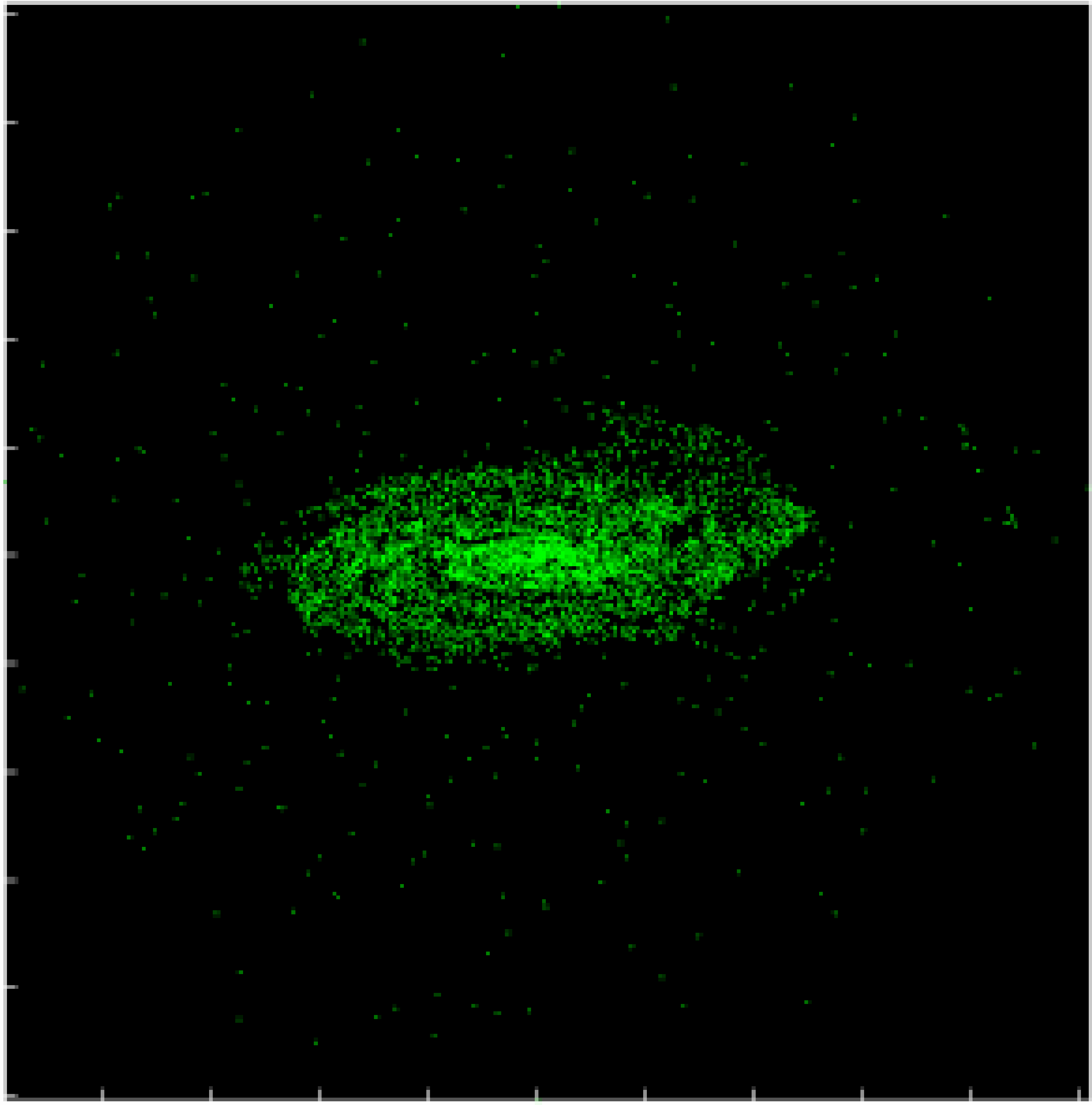
Using Simulations to test baryonic contraction

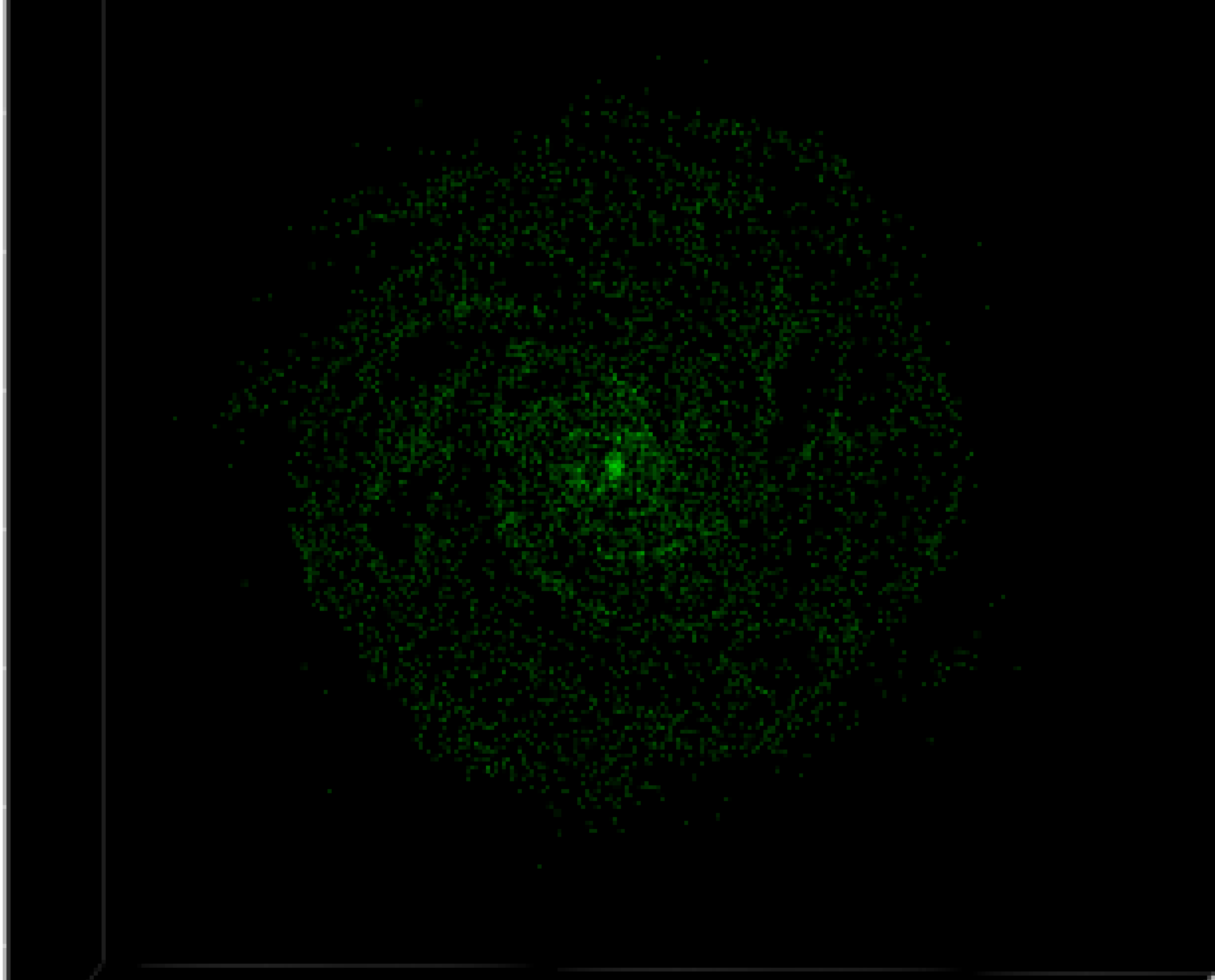
Simulations with baryons contained

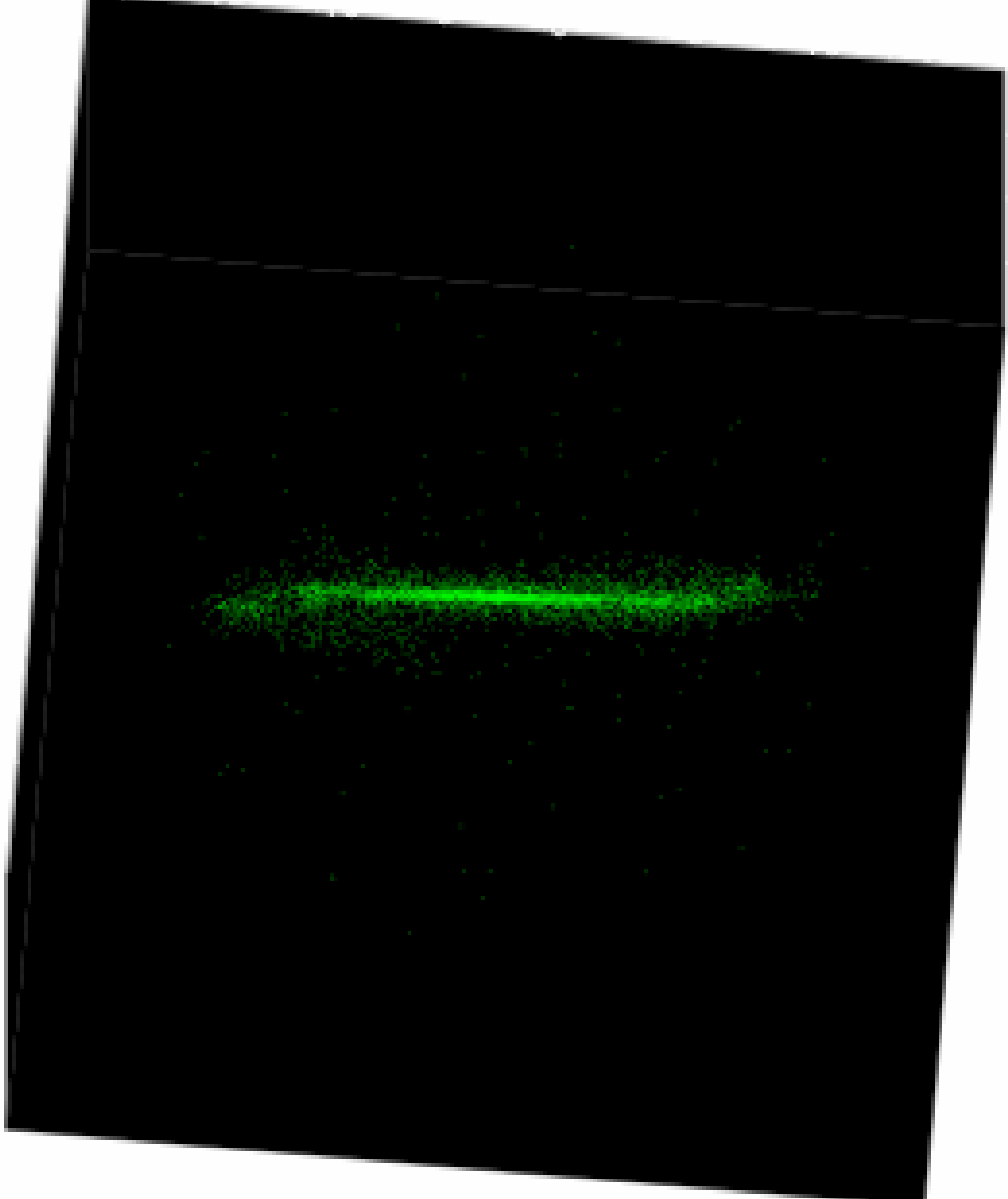
- ~200,000 dark matter particles
- ~55,000 stars
- ~4.000 gas particles

Simulations without baryons contain ~200,000 dark matter particles

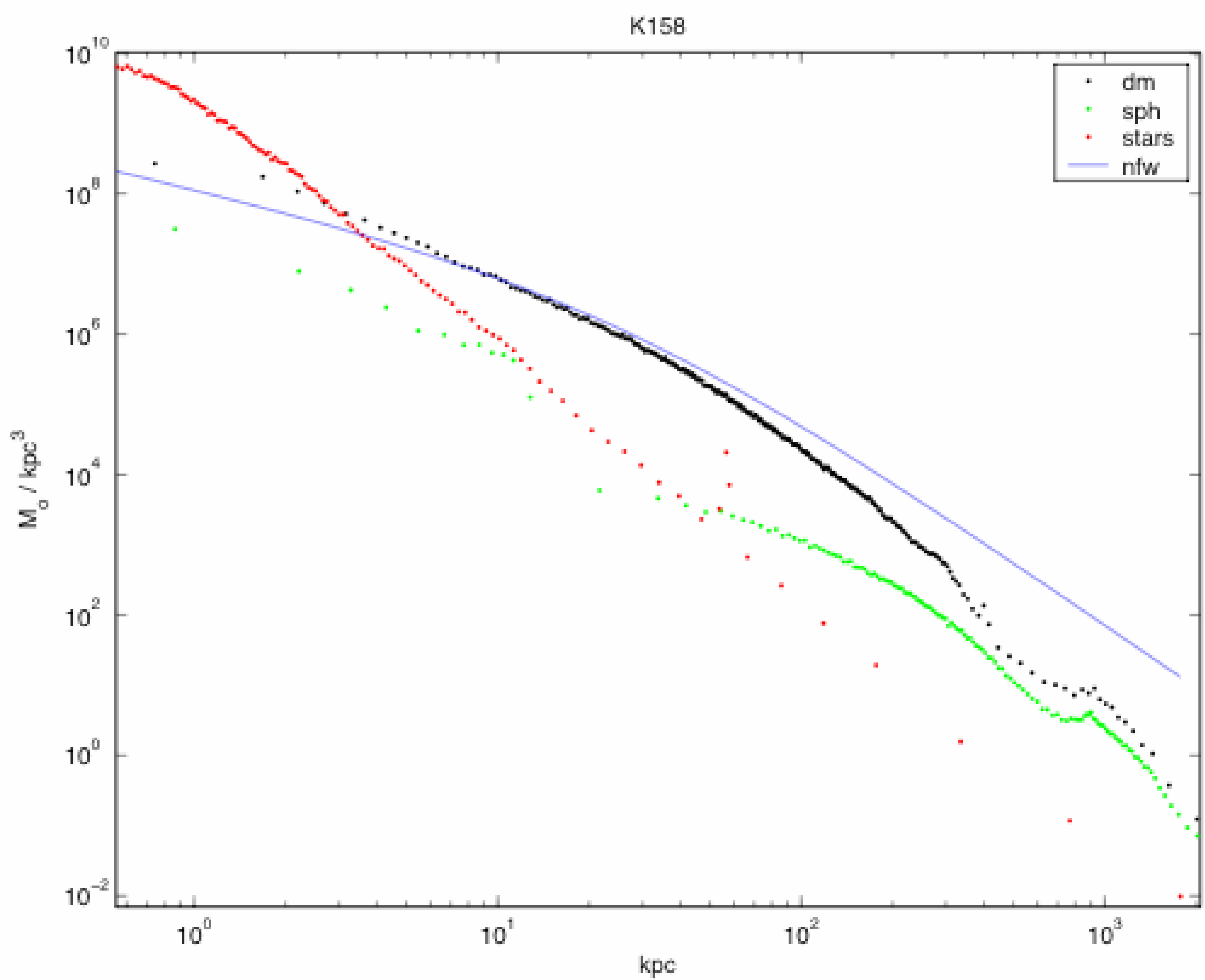
(Jesper Sommer-Larsen, Martin Gotz and Laura Portinari astro-ph/0204366)



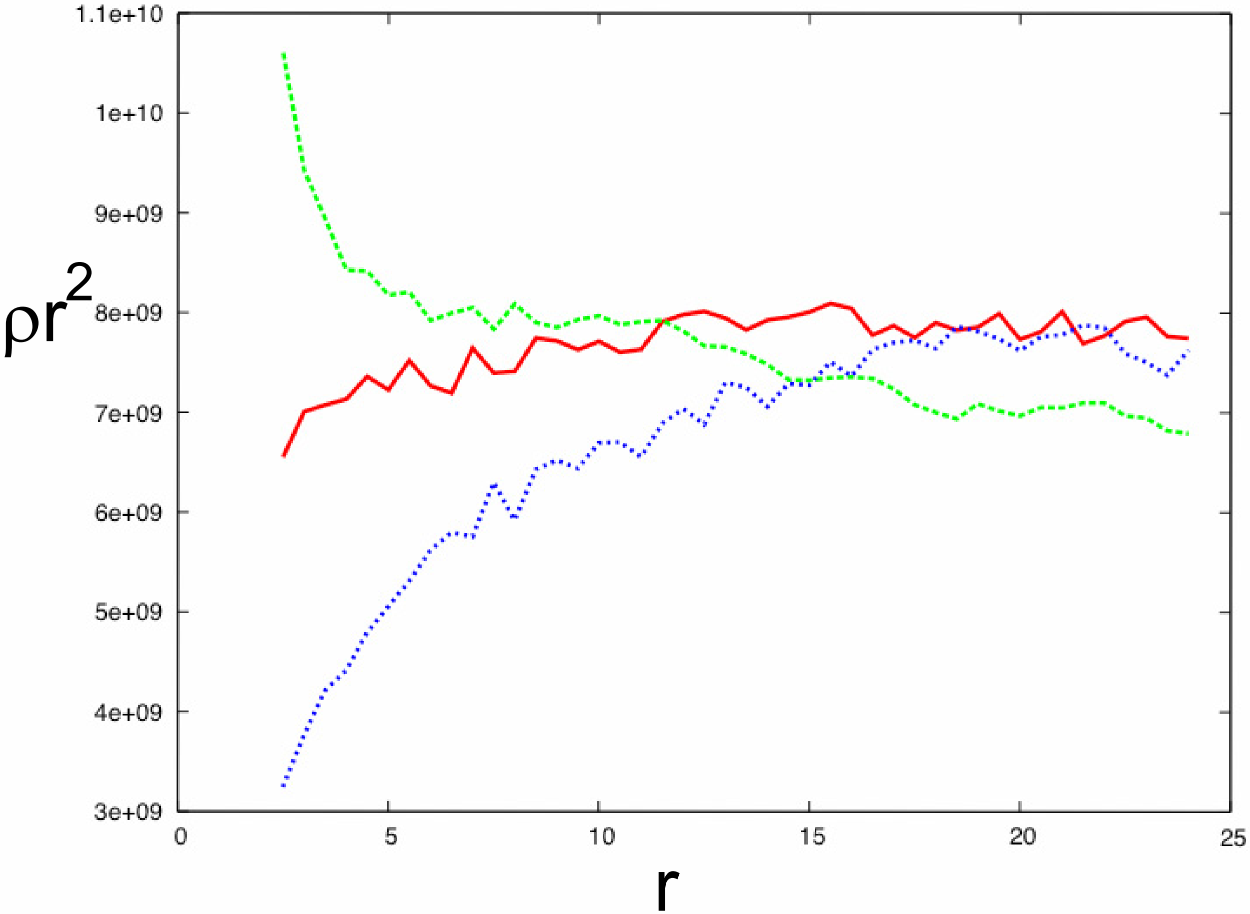




Density Profiles of Simulations



Circular Orbits



Modified Adiabatic Contraction

(Gnedin et al 2004)

Can use modified contraction rule to take into account ellipticity

$$r_Y \left[M_B^Y(\bar{r_Y}) + M_{DM}^Y(\bar{r_Y}) \right] = r_X M_{DM}^X(\bar{r_X})$$

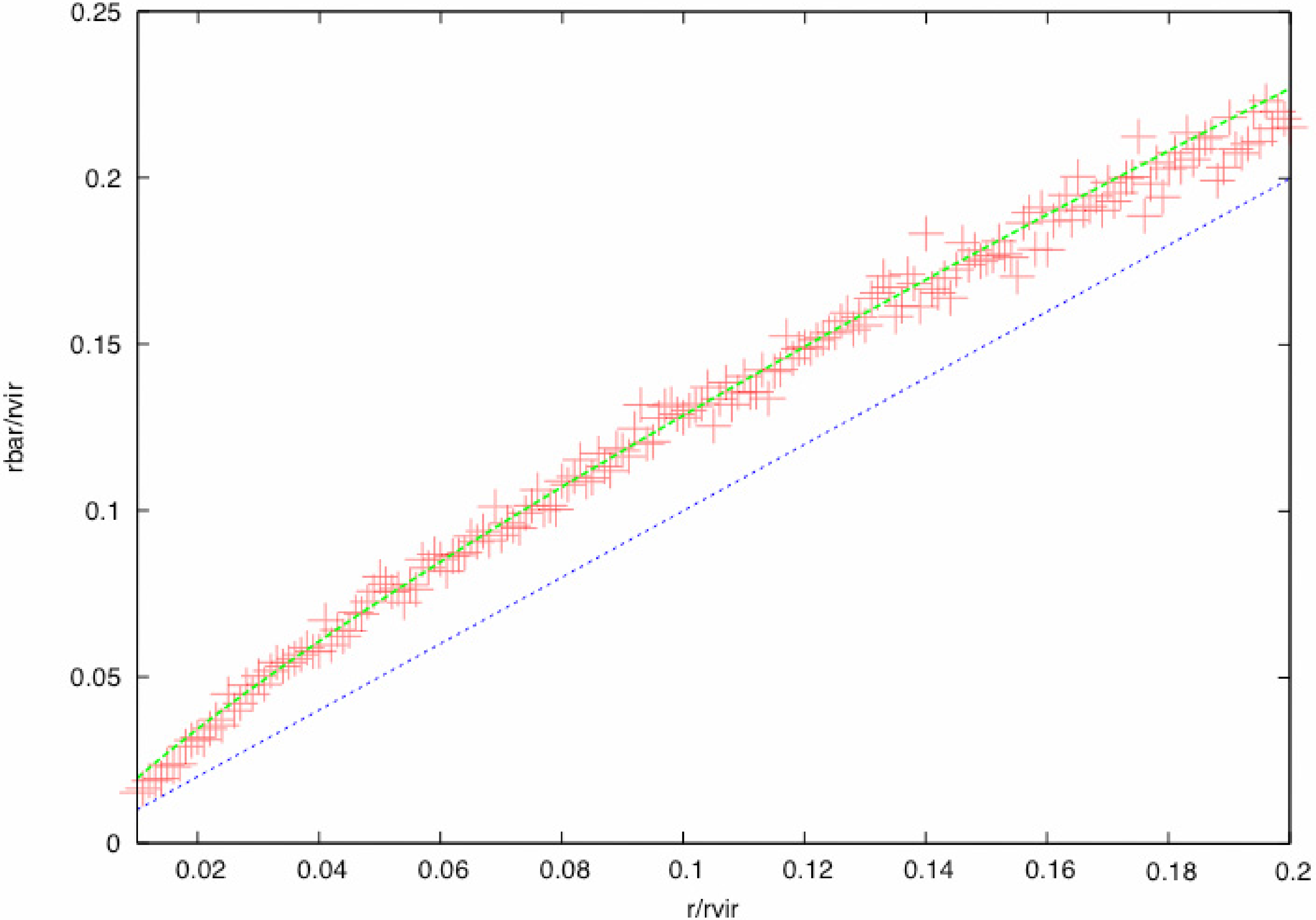
Where now we use the time average radius

$$\bar{r} = \frac{1}{T} \int \frac{r}{v_r} dr$$

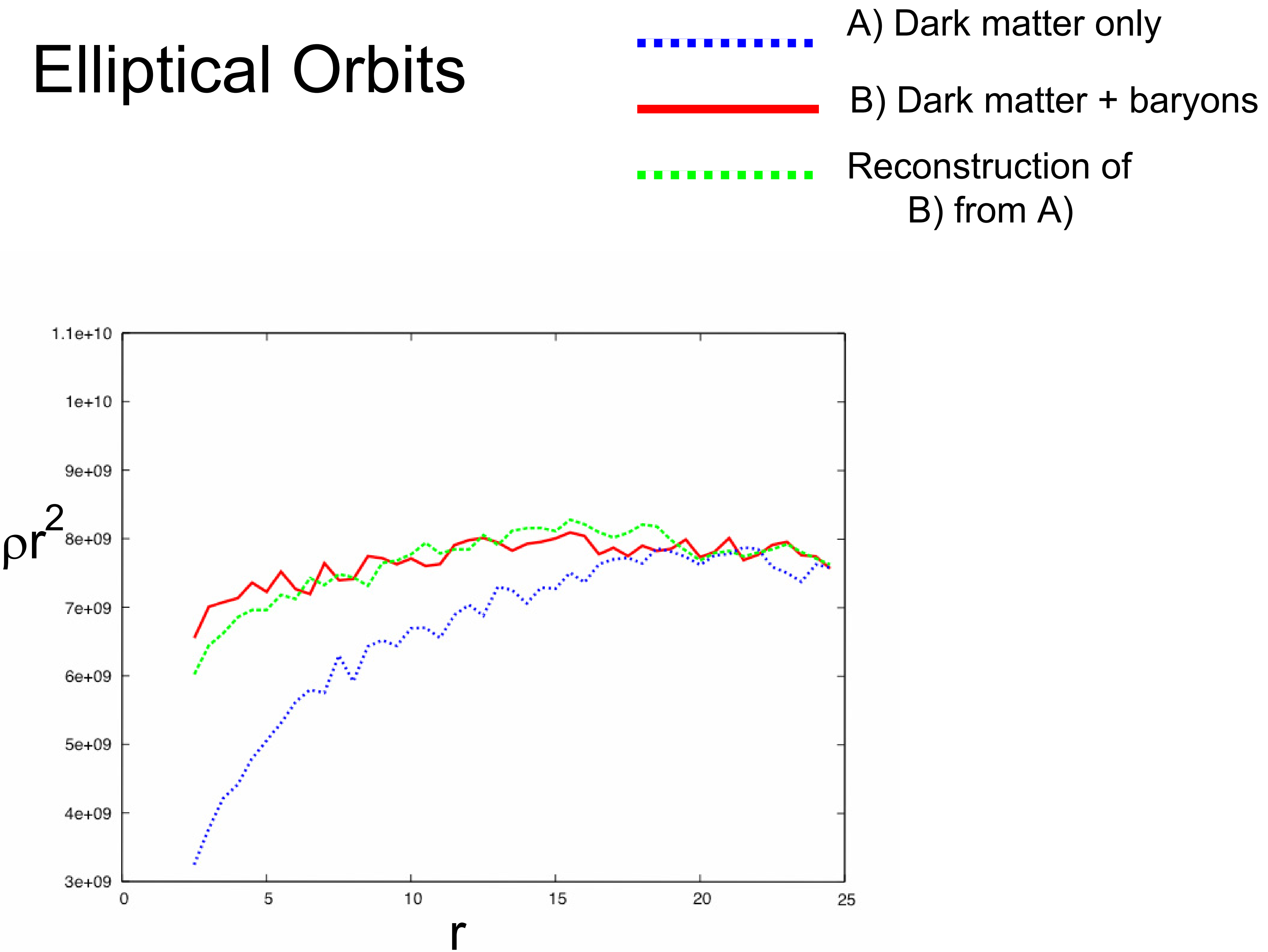
In practice they suggest a polynomial approximation

$$\bar{r} = r_{vir} A \left(\frac{r}{r_{vir}} \right)^w$$

Power Law assumption Valid?

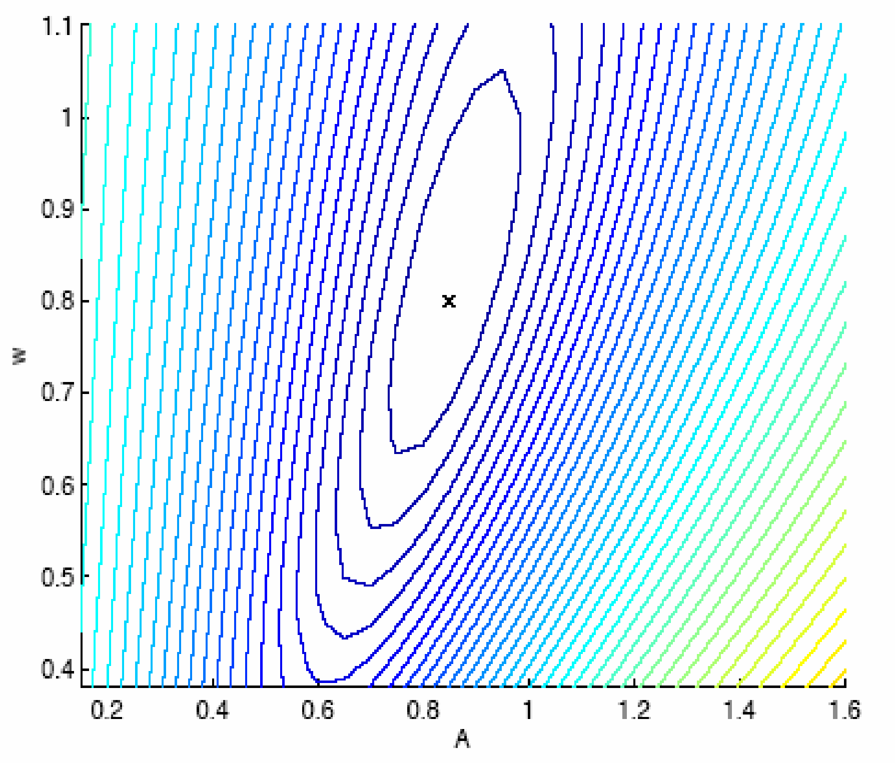


Elliptical Orbits

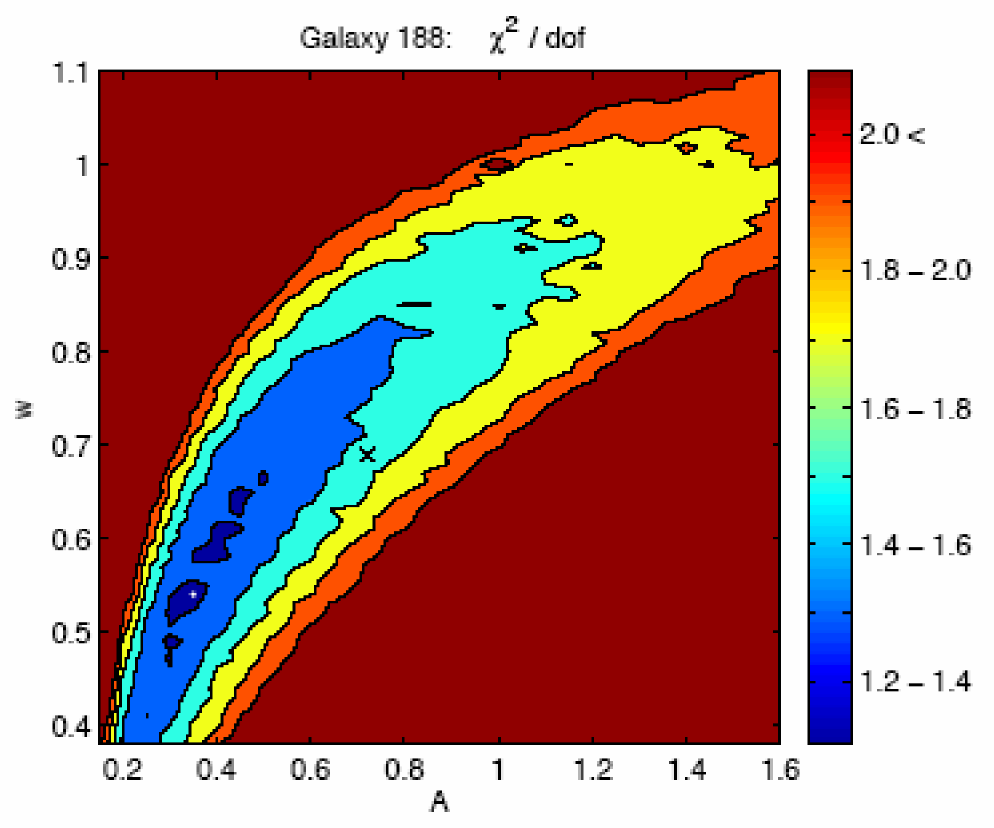


Testing Modified Model

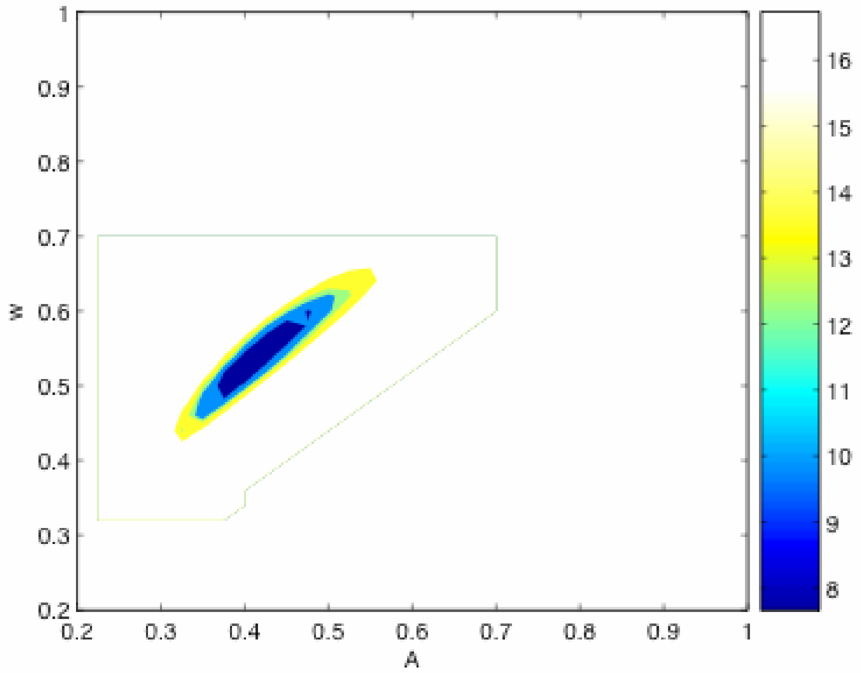
Prediction for A and w from ellipticities



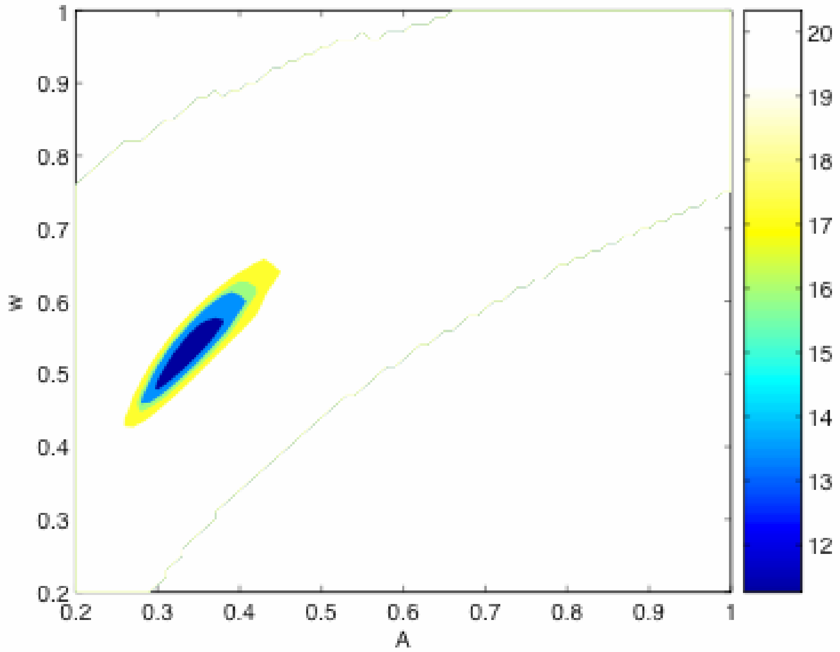
Actual best fit values of A and w from contraction



Confidence Levels



Galaxy 15

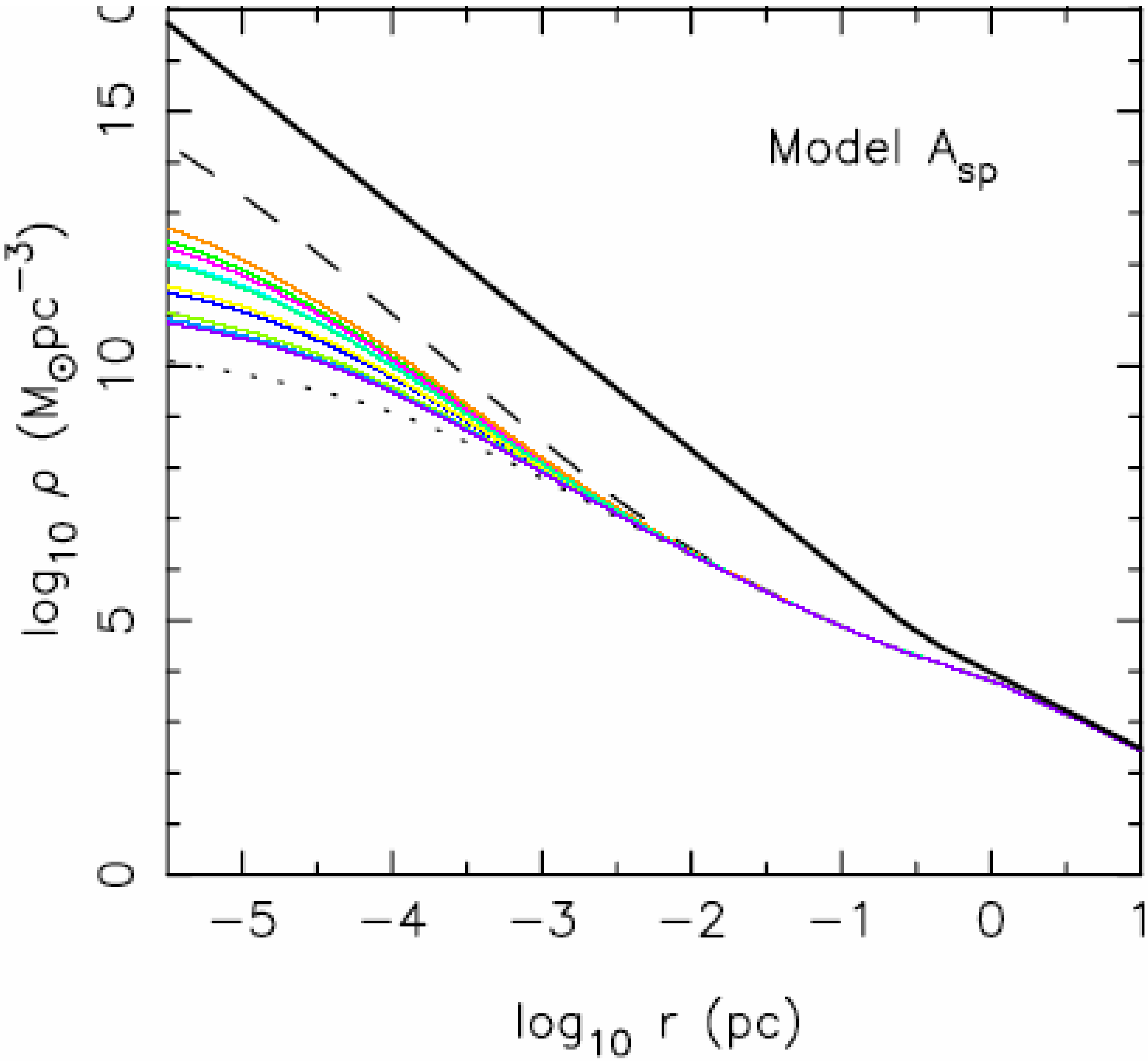


Galaxy 18

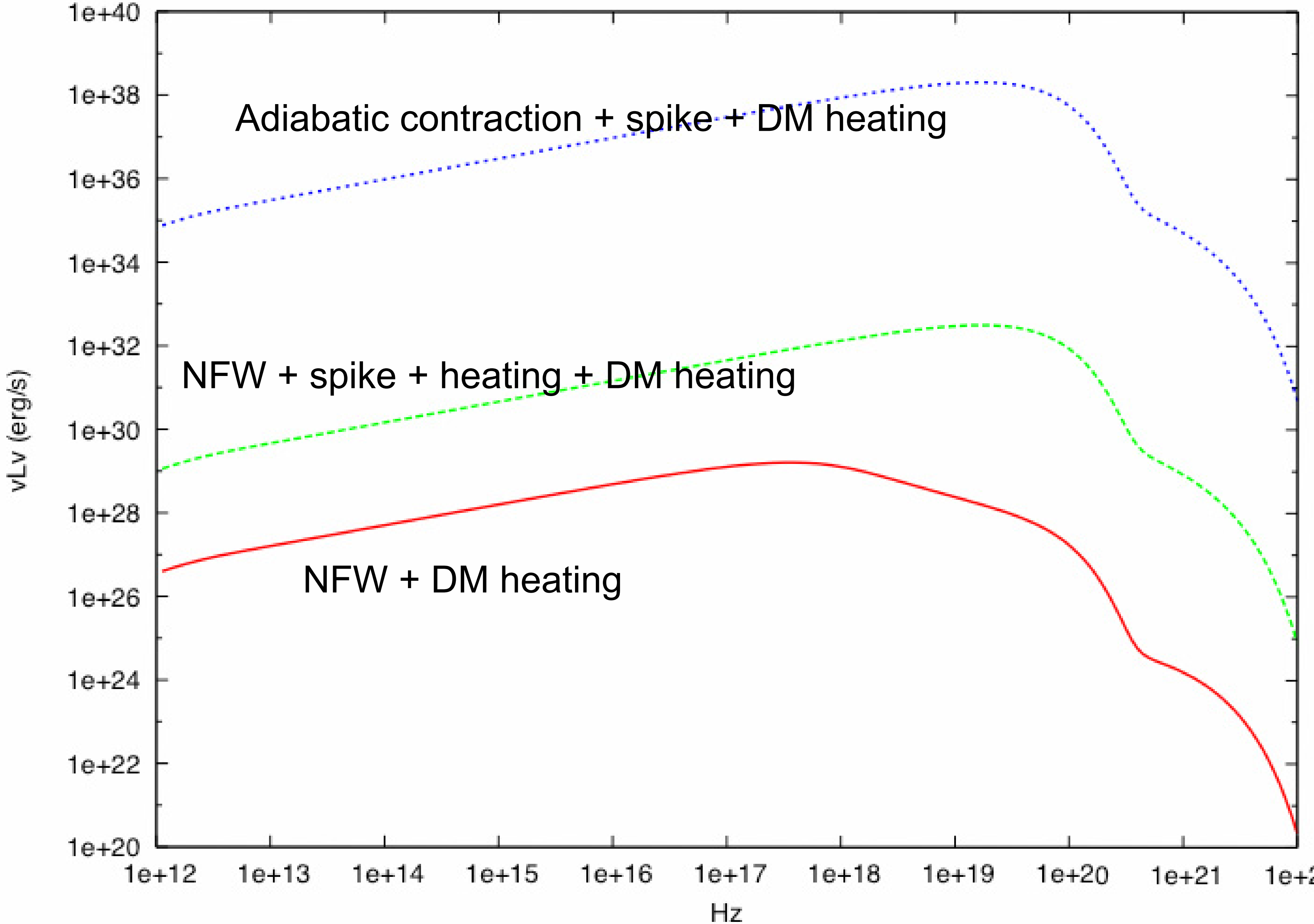
How big is the enhancement?

+Adiabatic contraction
+ formation of spike at centre (Gondolo & Silk ‘99)
-self annihilation limit (Berezinsky et al ‘94)
-Heating of dark matter due to interaction with stars (Bertone Merritt ‘05)
= increase of 10,000 in flux from central region (at least)

Evolution of Central DM Spike

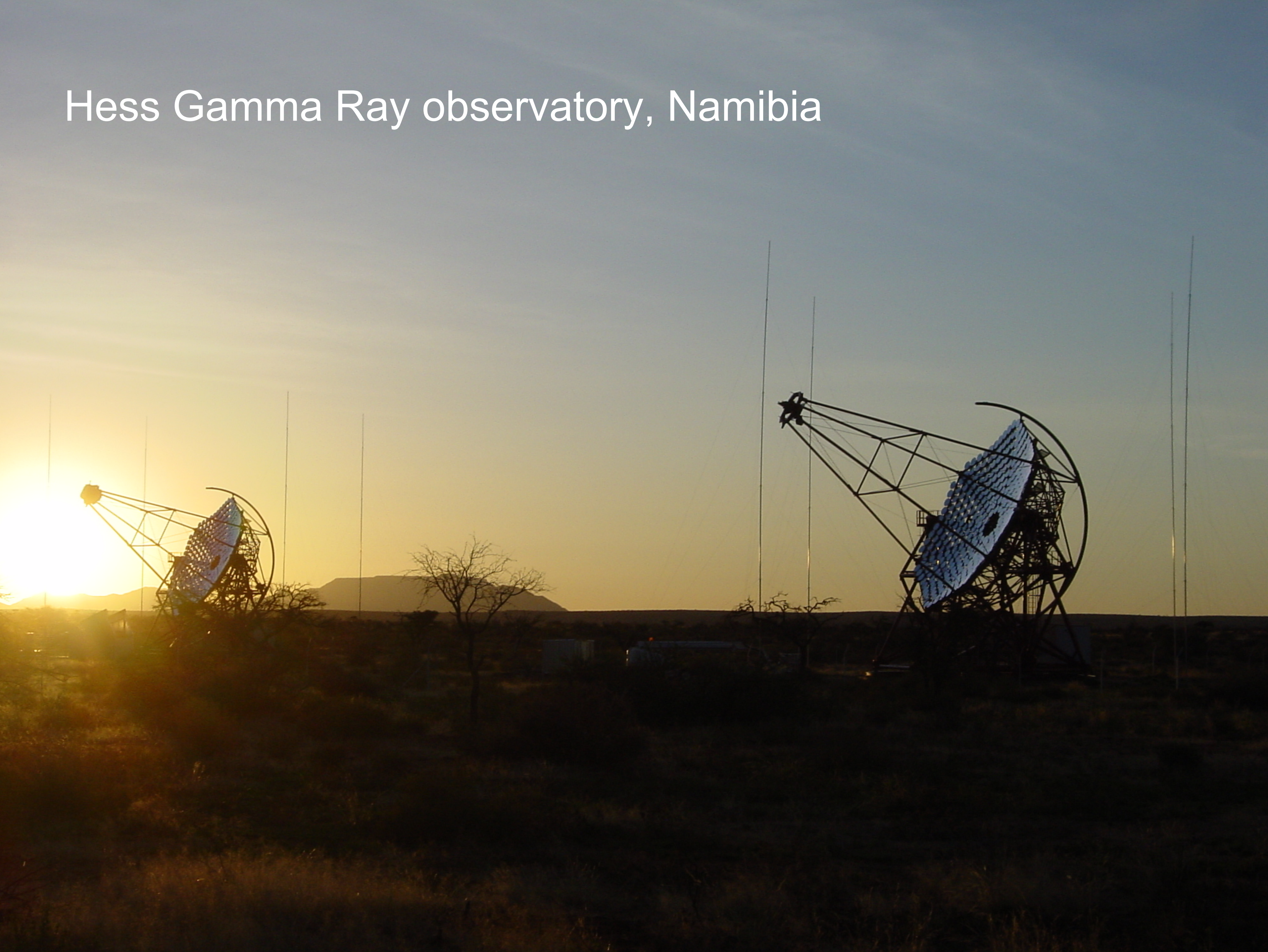


Bertone and Merritt 2005

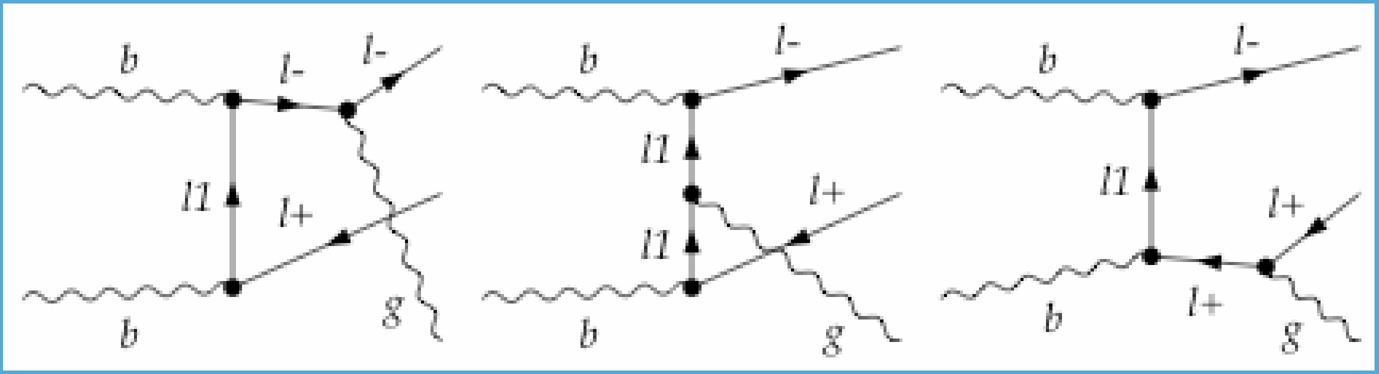


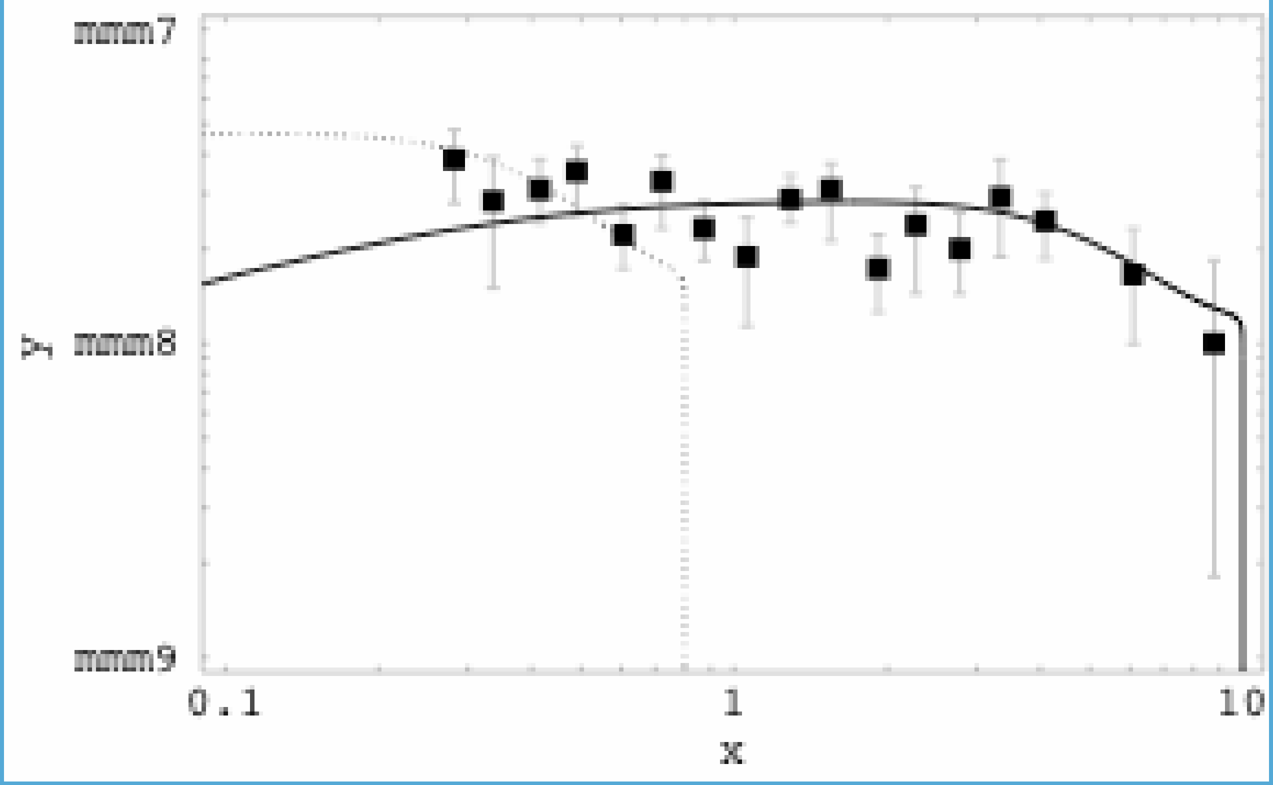
Adiabatic contraction + spike + DM heating
NFW + spike + heating + DM heating
NFW + DM heating
vLv (erg/s)
Hz
1e+40
1e+38
1e+36
1e+34
1e+32
1e+30
1e+28
1e+26
1e+24
1e+22
1e+20
1e+12
1e+13
1e+14
1e+15
1e+16
1e+17
1e+18
1e+19
1e+20
1e+21

Hess Gamma Ray observatory, Namibia



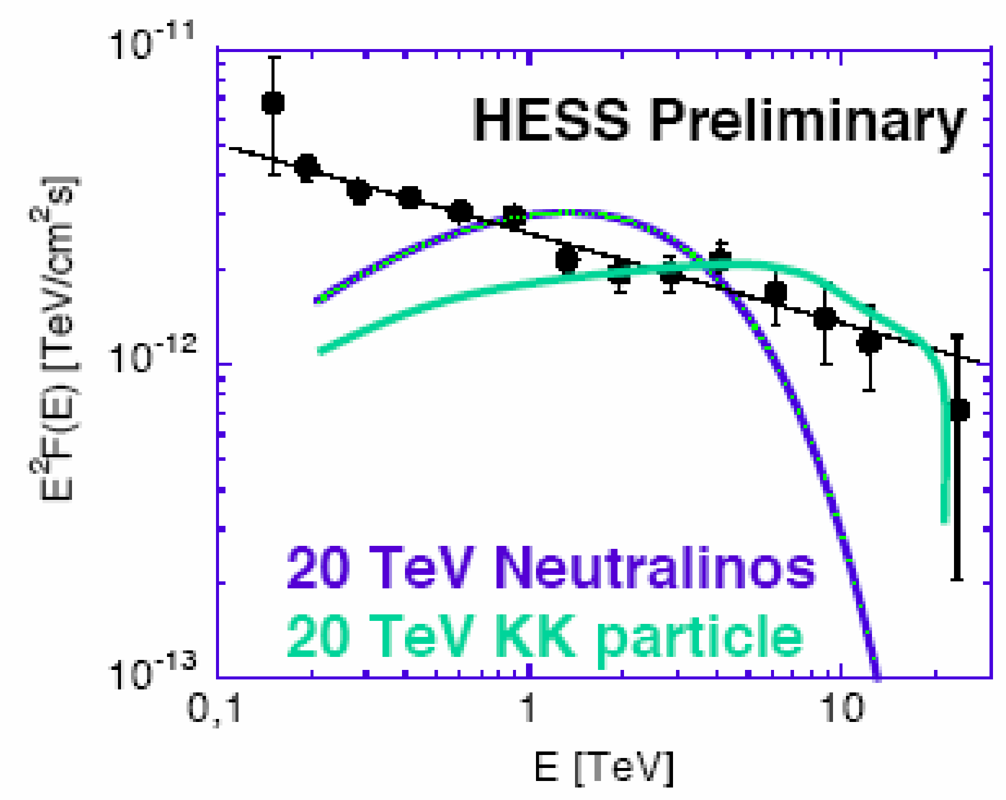
KK gamma rays vs. HESS data



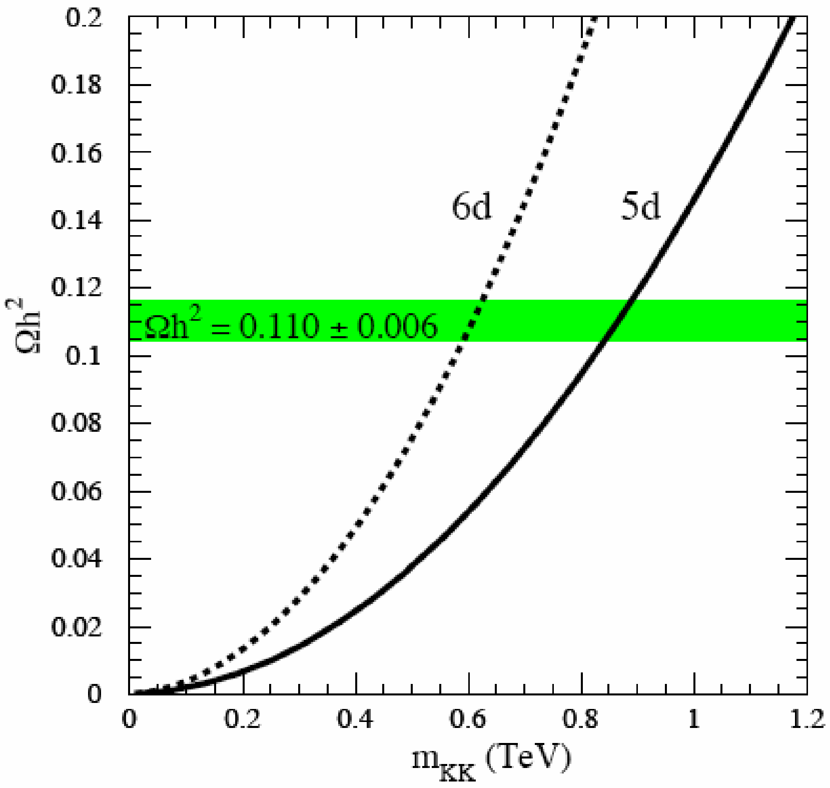


Bergström, Bringmann, Eriksson and Gustaffsson 2005

KK gamma rays vs. HESS data

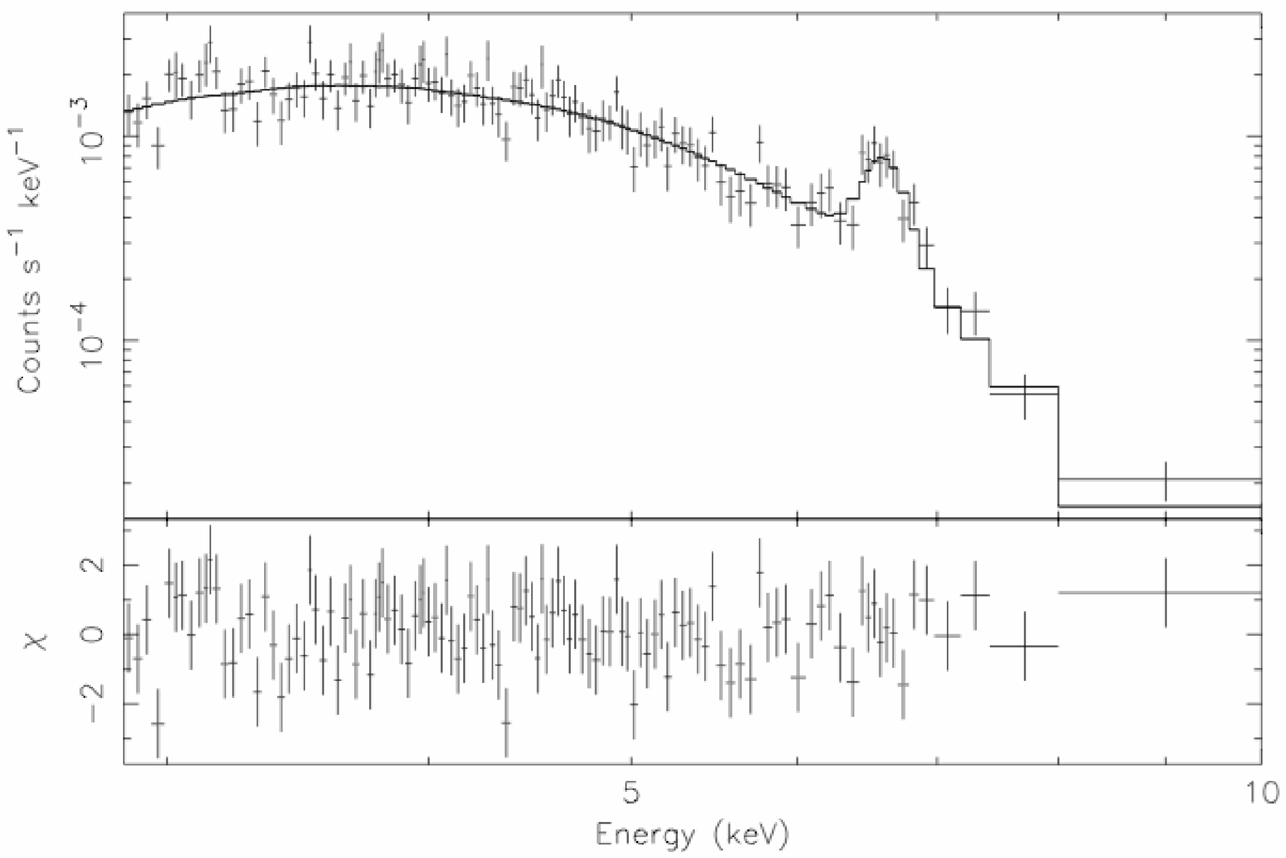


Vincent 2005

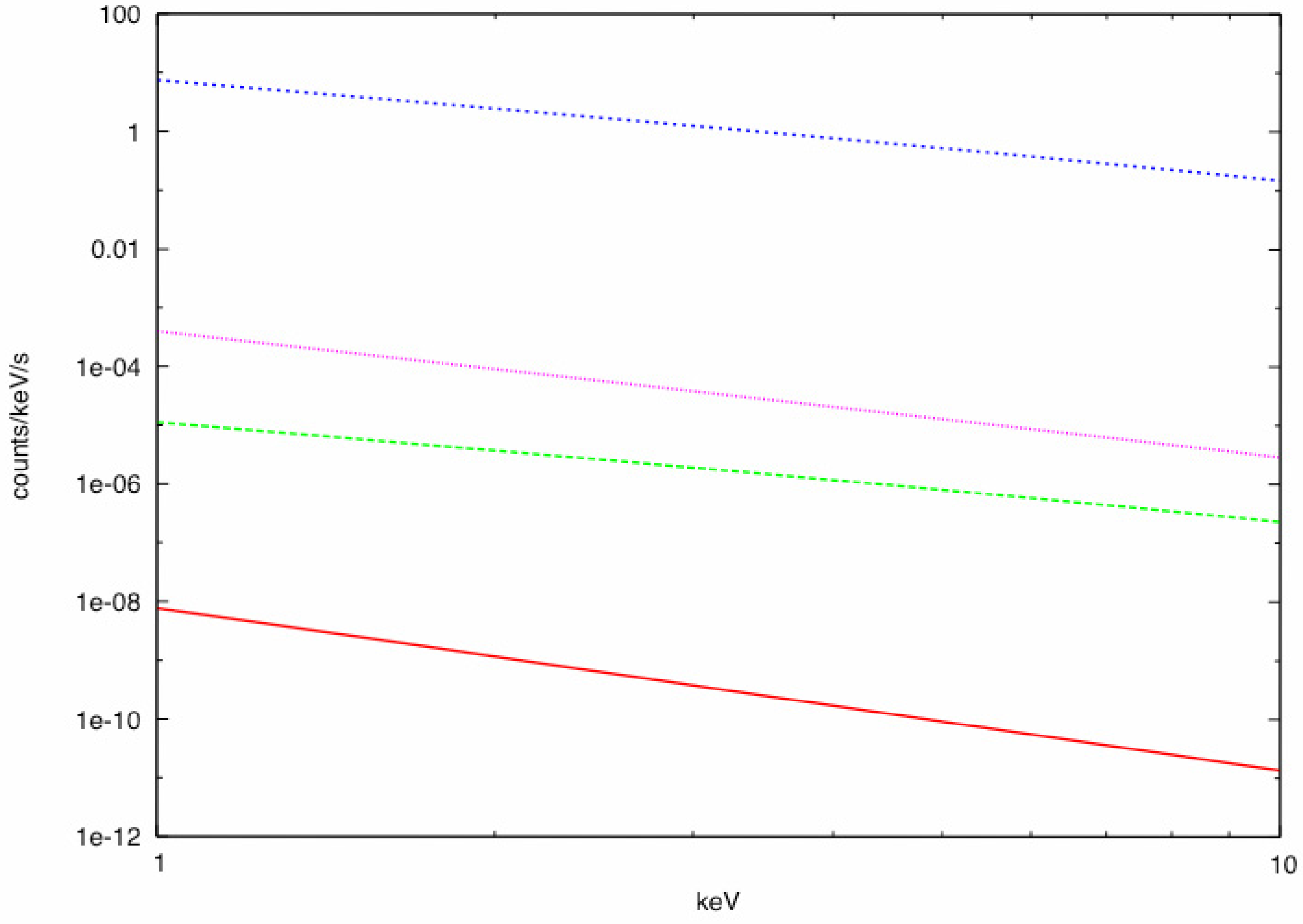


Servant and Tait 2003

X rays from chandra data



X rays Predicted from KK dark matter



Conclusions

- KK dark matter gives hard leptons in the X-ray region which could already have been ruled out by Chandra
- Baryonic Contraction important, but changes from halo to halo. Existing technology not yet complete.
- If we get more confident about astrophysics we may rule out candidates
- Dark matter signal from Sag A* close in magnitude to normal emission, if we are lucky, much smaller if we are unlucky.