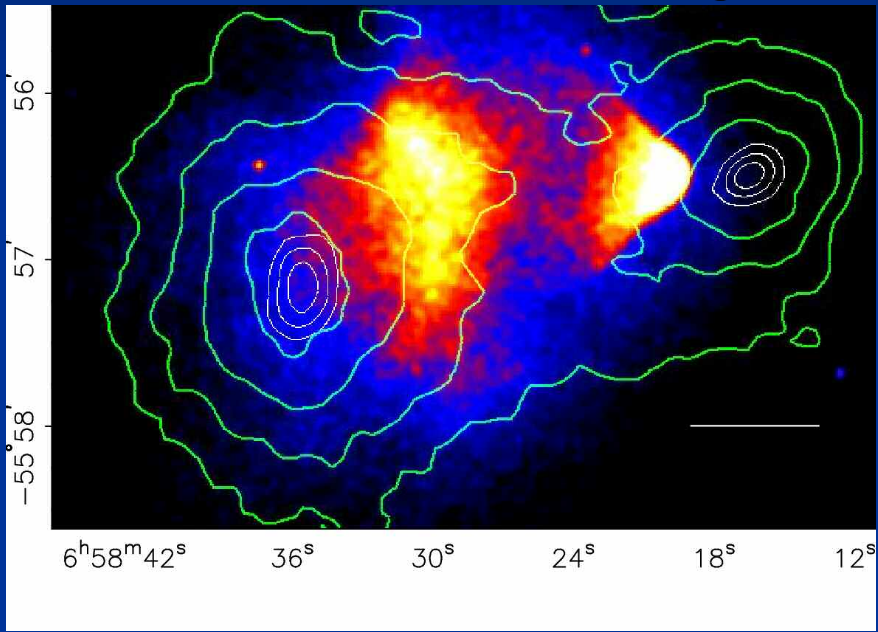
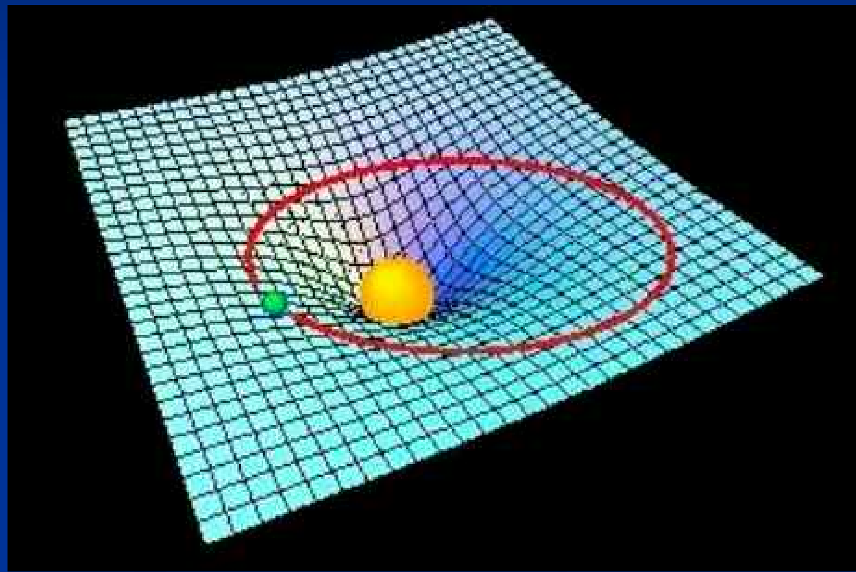
What astronomers cannot tell: exotic DM, neutrinos or Modified gravity?





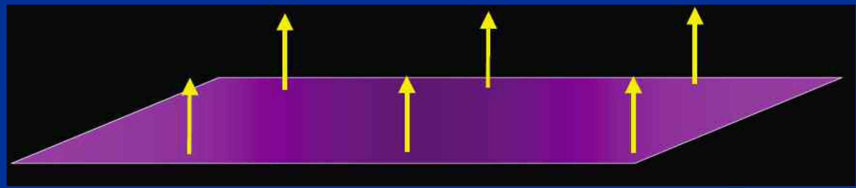
Clowe et al. (2006) NASA press release

Angus, Zhao et al (0609125) ApJ Letter

Added value to modify GR? Effective DM+DE

Lagrangian Density

$= L_{\text{known matter}} + L_V$
$+ L_{\text{curvature}}$

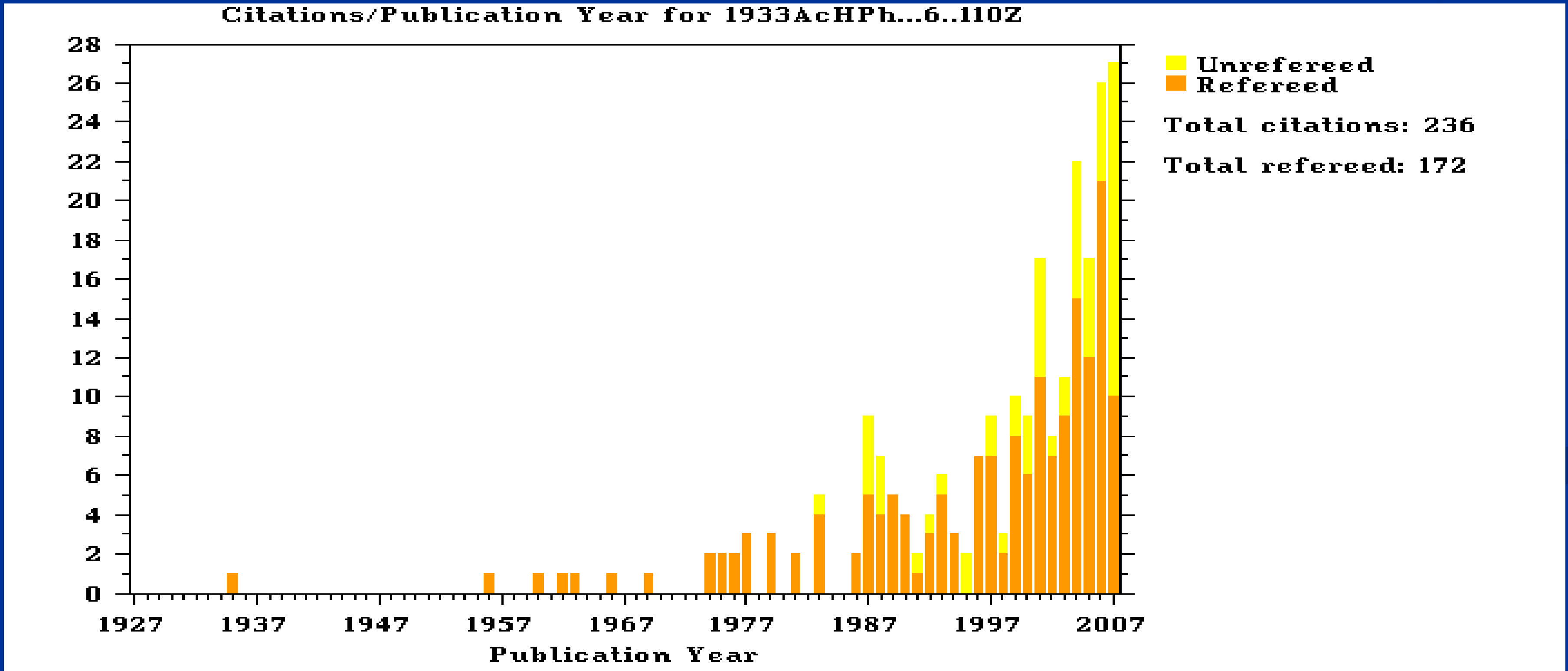


$\sim L_{DM} + L_{DE}$

Zlosnik's vector field
~ Jacobson's aether
~ Bekenstein's TeVeS
~ Effective DM+DE bending space-time

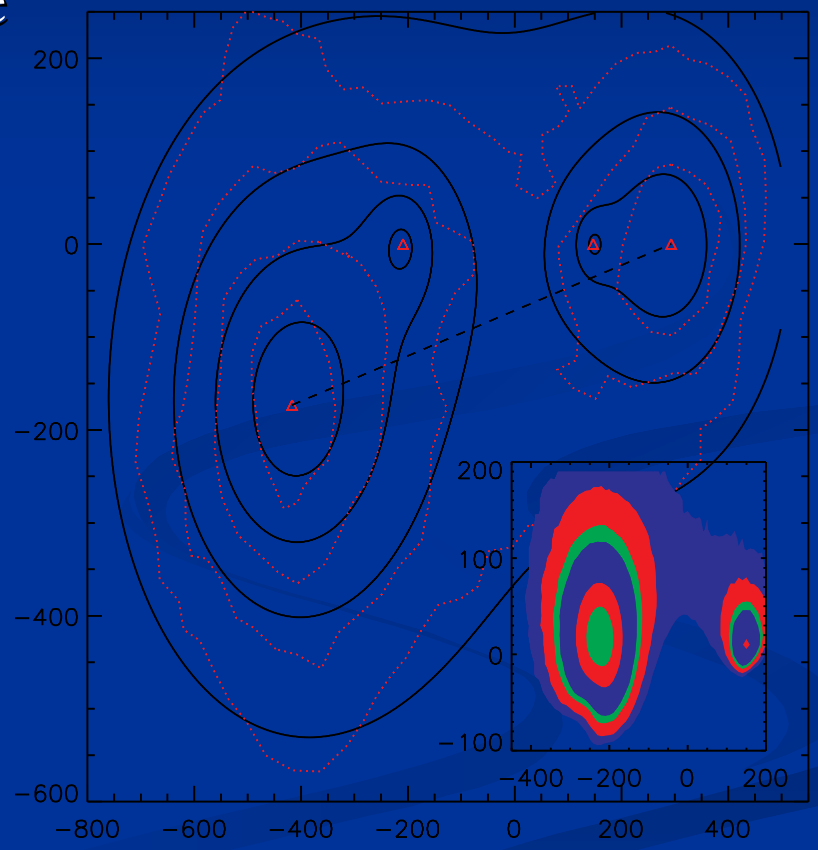
Historical performance of DM: "stock chart" 1933-2007

citation =236 for Zwicky 1933 hypothesis



MOND explains Bullet Cluster & Dark Energy

- MOND+neutrino perverse CDM +Einsteinblunder?
  - Lambda ~ 10^{-60} Higgs scale?
  - What if LHC Proves Omega_SUSY ~ Omega_neutrino ~ 0.03?
- MOND explains DE (Zhao, ApJ submitted)



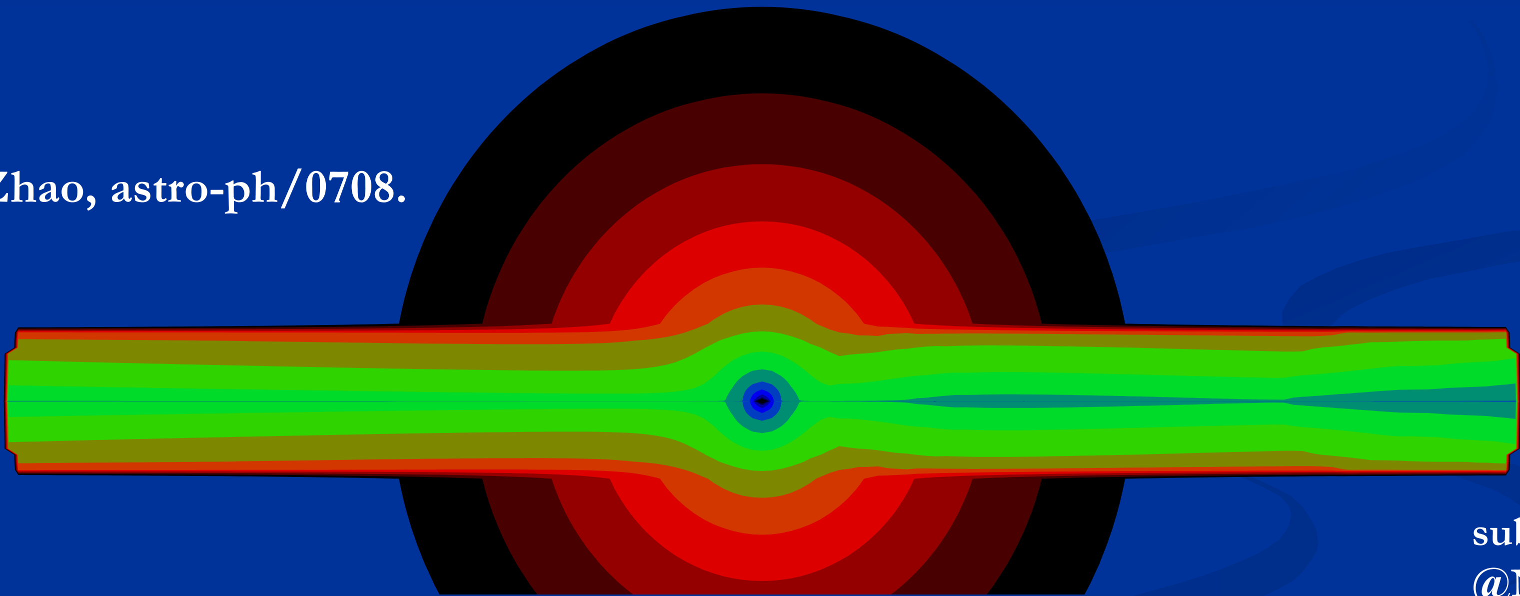
Angus, Shan, Famaey, Zhao 0609125

Proof of XX →e-e+ from moving subhalo

HongSheng Zhao

(St. Andrews, UK)

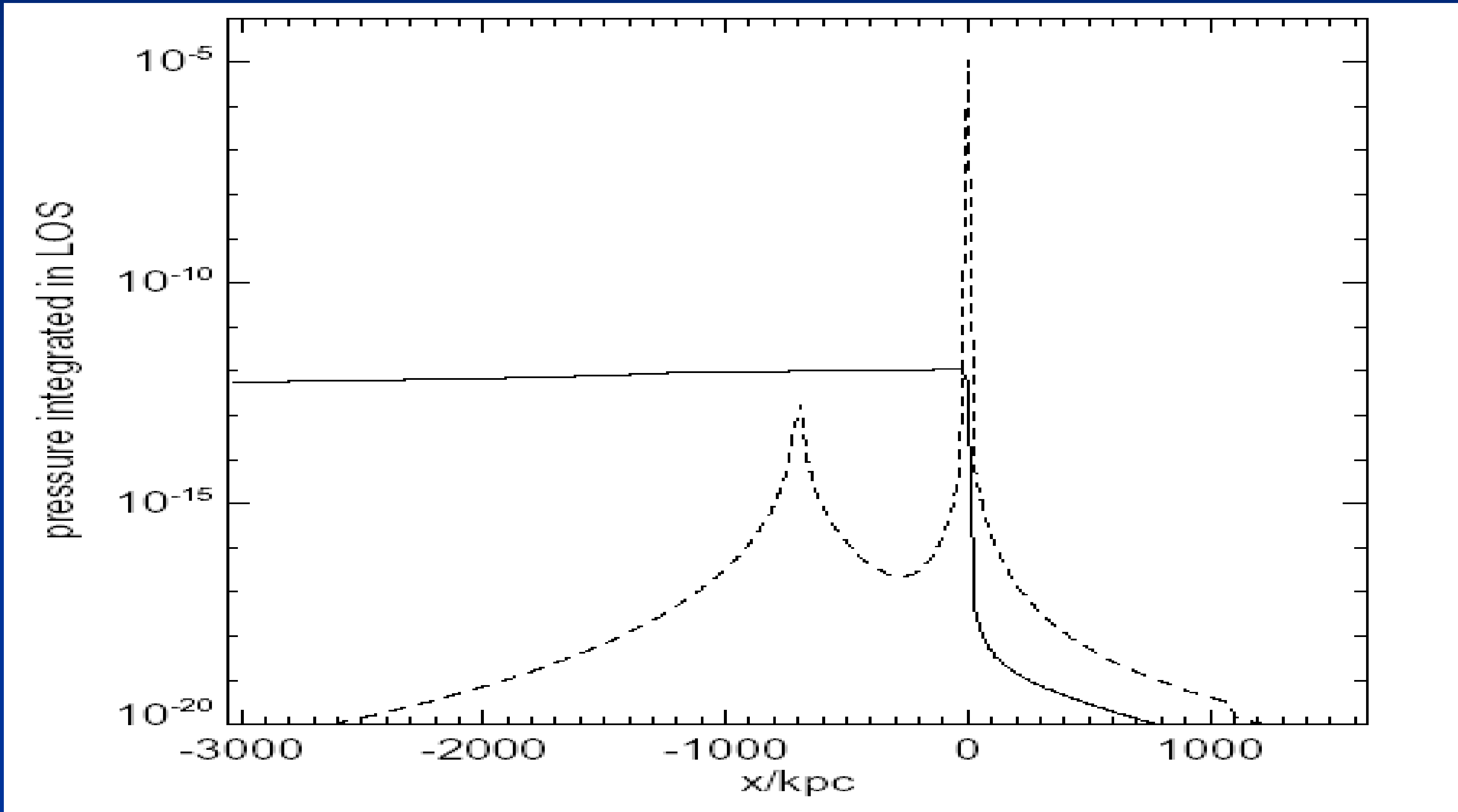
Bi & Zhao, astro-ph/0708.



subhalo
@NOW

→ Older cooler condensation Younger hotter →

Spread NFW for charged e



Assumptions

- **Subhalos are not stationary!**
  - **Clusters Merge**
- **Magnetic field non-zero!**
  - Diffusion length ~ 10kpc (Confine e^-e^+ locally)

Condensation of e-e+ along trails of subhalo

- **Subhalos annihilation far away from baryons**
- **e-e+ Spectrum position-dependent!**

Confined Propagation

The electrons/positrons from dark matter annihilation will undergo the processes of diffusion and energy loss in the intracluster medium. The diffusion equation is given by

$$\frac{\partial}{\partial t}\frac{dn_e}{dE} = \frac{\partial}{\partial E}\left(b(E)\frac{dn_e}{dE}\right) + Q(E,t;\mathbf{r}) \quad , \qquad (4)$$

where we have dropped the spatial diffusion term

Bi & Zhao astro-ph/0708.

Mapping DARK Trajectory of Bullet Cluster

Cooling (observable) by IC & Sync

$$b(E) = b_0 \left(\frac{E}{1GeV} \right)^2 = (b^0_{IC} + b^0_{syn} B^2_\mu) \left(\frac{E}{1GeV} \right)^2 ,$$

- Inverse Compton scattering of CMB photons
- [SZ effect]

Electron density solved

The solution at any epoch t, position $\mathbf{r}$ and energy E is

$$n_e(E, \mathbf{r}, t) = \frac{1}{b(E)} \int_E^{m_\chi} dE_e Q(E_e, t_e; \mathbf{r}) \qquad (10)$$

with the emitting time

$$t_e = t - \tau(E \leftarrow E_e) = t - \int_E^{E_e} \frac{dE'}{b(E')} = t + \frac{1}{b_0}\left(\frac{1}{E_e} - \frac{1}{E}\right), \qquad (11)$$

where τ is the time to cool an electron from E_e to E. The initial condition is take as $n_e = 0$ at about 10G years ago.

Source Function

The source function of electrons and positrons from DM annihilation can be written as

$$Q(E_e, \mathbf{r}) = \frac{\langle \sigma v \rangle}{2m_\chi^2} \frac{\mathrm{d}N}{\mathrm{d}E} \rho^2(\mathbf{r}) = f(E_e)\rho^2(\mathbf{r}), \qquad (1)$$

with the underlying dark matter density given as

$$\rho_X(t; \mathbf{r}) = \sum_{i=1}^{2} \rho_{NFW}(|\mathbf{r} - \mathbf{r}_i(t)|) + \rho_{sub}(|\mathbf{r} - \mathbf{r}_i(t)|(7)$$

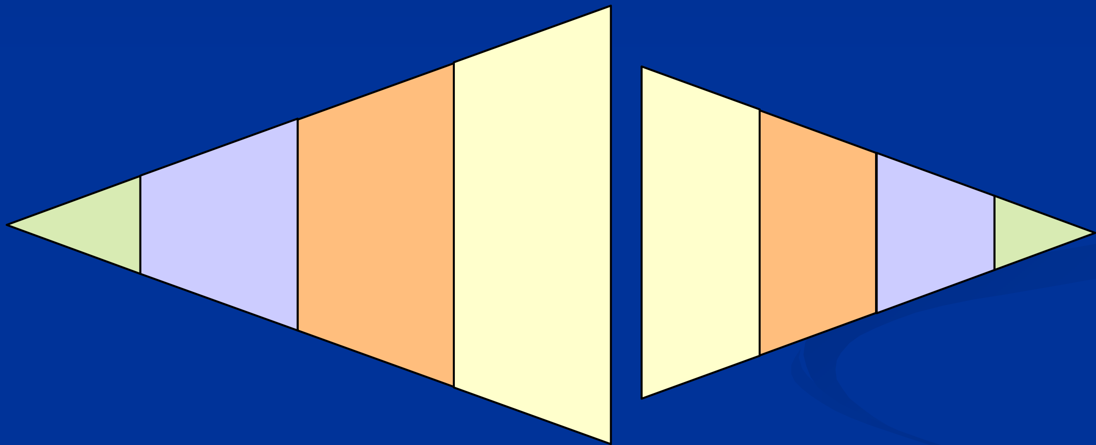
$$= 0, \qquad t \leq 0 \qquad (8)$$

coordinates of the cluster centers in the past are given by

$$\mathbf{r}_i(t) = \mathbf{r}_{i,now} + \int_t^{t_{now}} \mathbf{V}_i dt', \qquad (9)$$

Including subhalos in each smooth cluster

$$\rho^2(\mathbf{r}) \to \langle \rho^2(\mathbf{r}) \rangle = \rho^2_{\mathrm{smooth}}(\mathbf{r}) + \langle \rho^2_{\mathrm{sub}}(\mathbf{r}) \rangle,$$



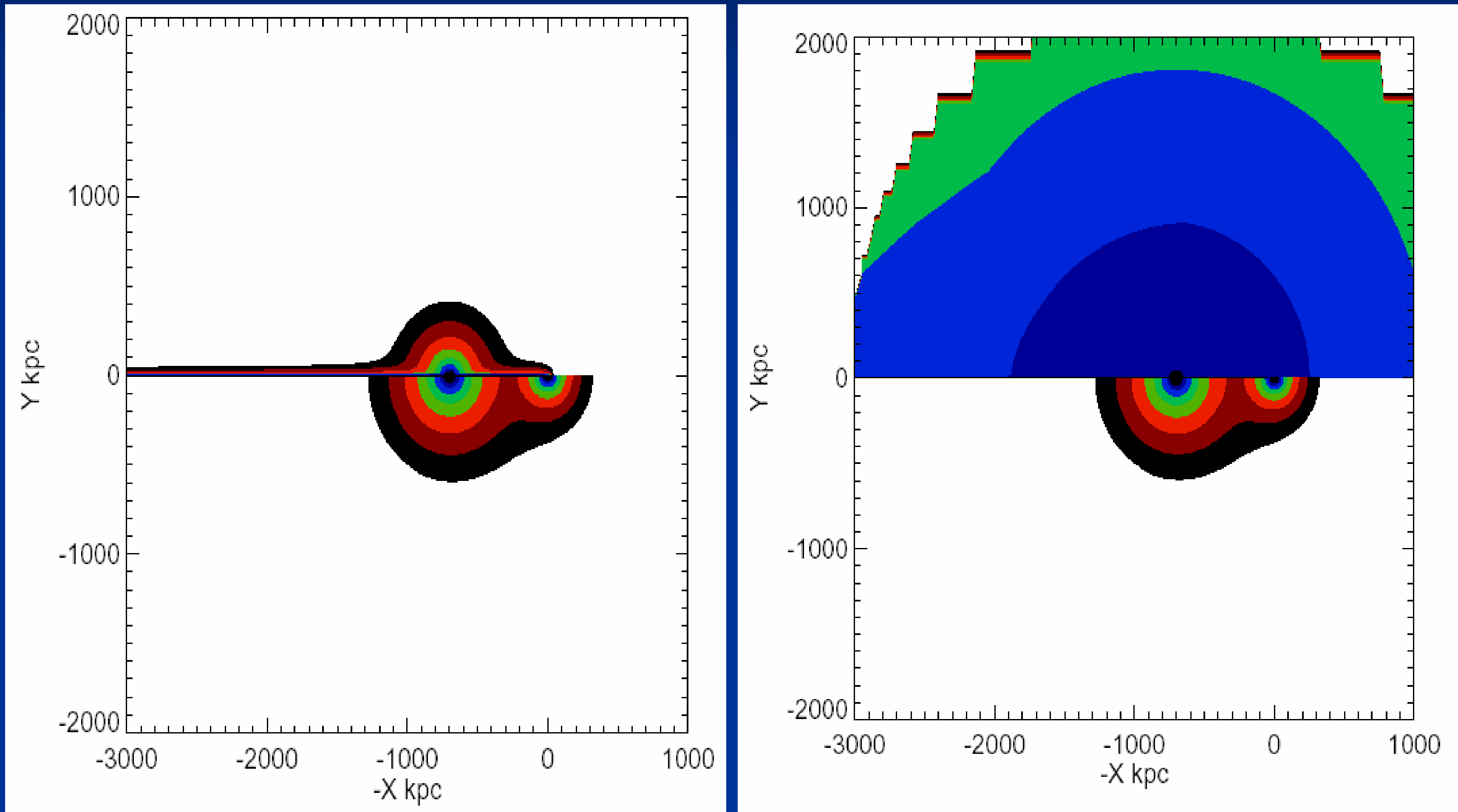
$$n(m_{\mathrm{sub}}, r) = n_0 \left(\frac{m_{\mathrm{sub}}}{M_{\mathrm{vir}}} \right)^{-1.9} (1 + (r/r_H)^2)^{-1} ,$$

$$\langle \rho^2_{\mathrm{sub}}(\mathbf{r}) \rangle \; = \; \int_{m_{min}}^{m_{max}} n(m_{\mathrm{sub}}, r) \left(\int \rho^2_{\mathrm{sub}} \mathrm{d}V_{\mathrm{sub}} \right) \cdot \mathrm{d}m_{\mathrm{sub}}$$

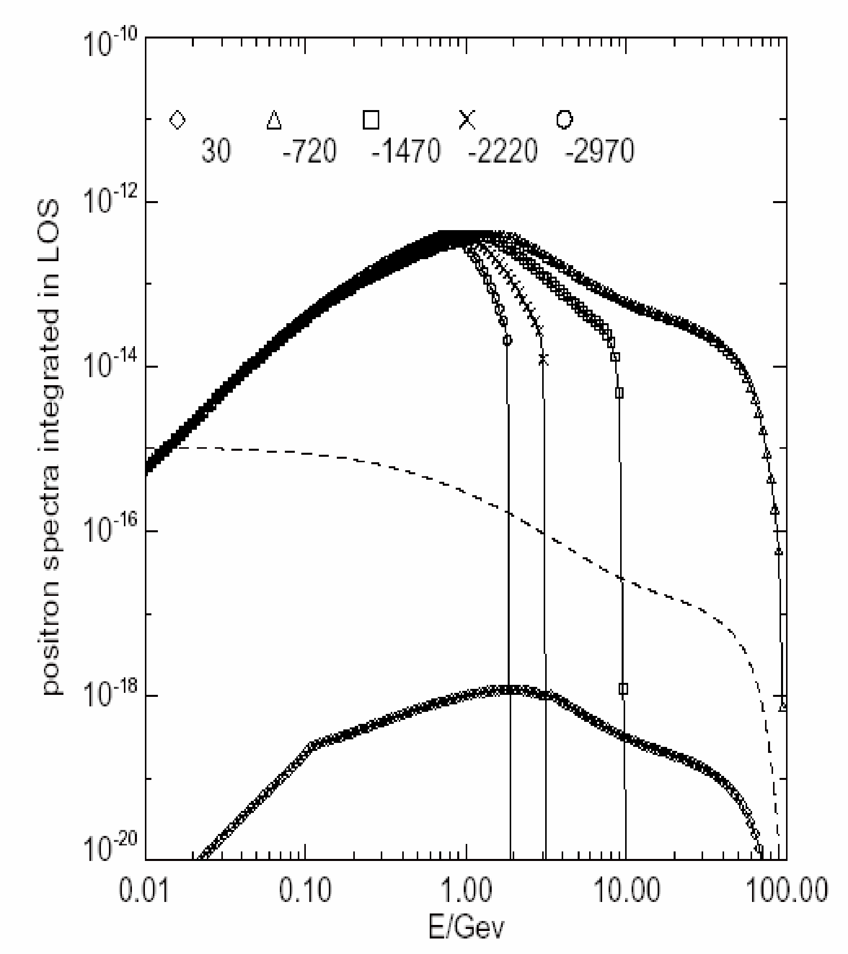
Feasibility of non-thermal SZ effect (Colafrancesco et al.)

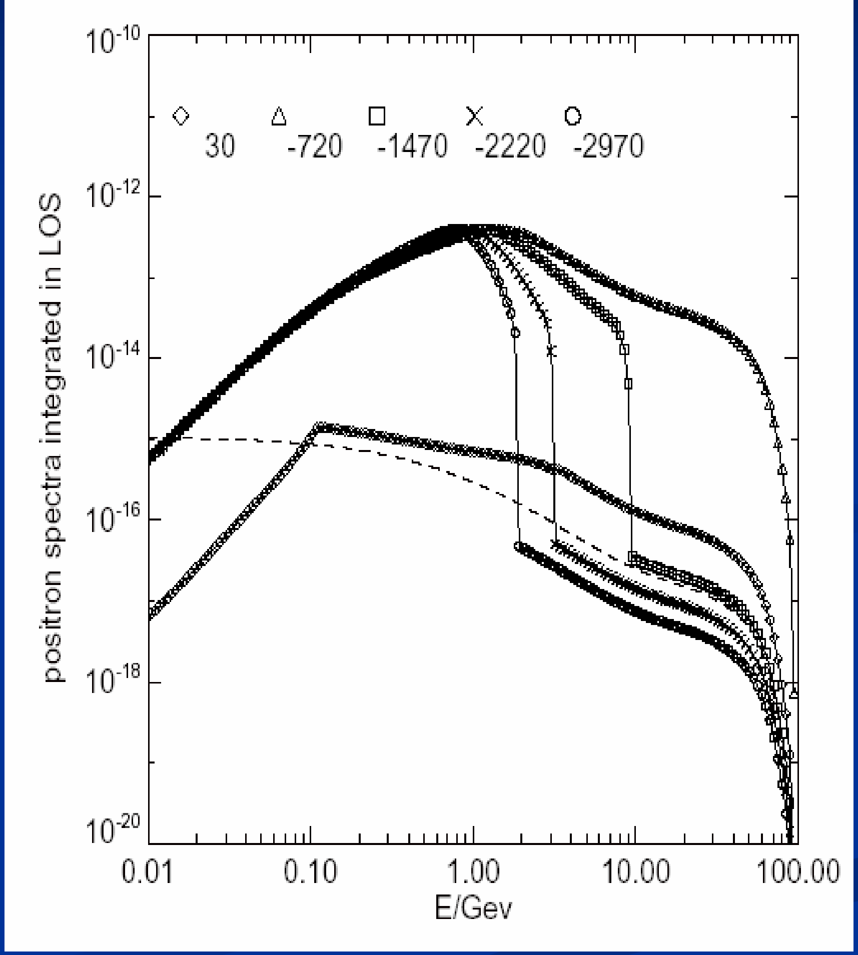
The non-thermal relativistic positrons/electrons from annihilation distort the CMB spectra at frequencies much higher than the usual SZ-effect due to keV thermal electrons. Without actually computing the SZ effects in detail, we note that the original conclusion of Colafrancesco et al. (2007) that the non-thermal SZ signals of the DM are both separable from the thermal SZ-effects and detectable with future experiments likely remains valid for

e^-e^+ in Colliding halos (+ subhalos)



e-Spectrum is position-dependent!



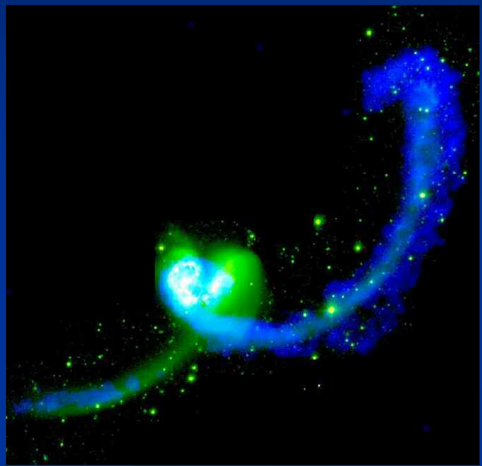


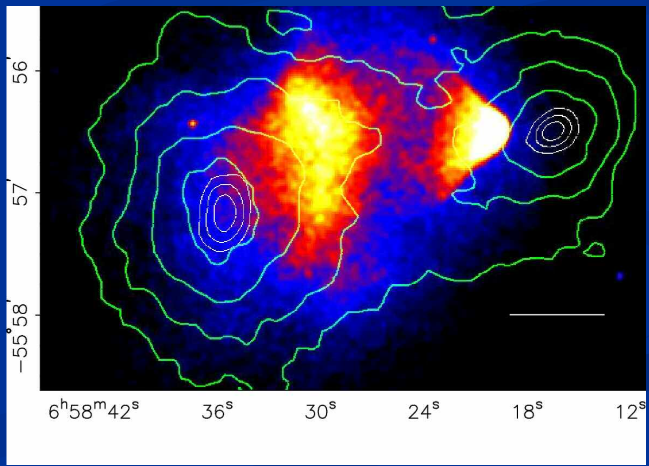
Easier to detect DM Annihilation in a moving dark substructure

- injects a plasma of charged relativistic particles *(Colafrancesco et al)*
  - which lag (due to B-field) behind neutral particles.
- *Synchrotron spectrum change along the cooling (=aging) tails.*
- No confusion by astronomical sources
- *Less demanding for spatial resolution*

Targets for Future

- Synchrotron from Merging Coma Cluster
  - nearer the better
  - Tails easier to resolve
- Nearby merging galaxies
  - +Subhalos in Milky Way
- SZ effects of high-z clusters
  - Distance-insensitive
  - Very Promising





Obs. Status on Bullet Cluster

A halo of synchrotron emission has been observed in radio for this cluster [3], which might be associated with the elongated emission of the X-ray gas. However, no indication for any enhancement near the DM clump locations. A SZ map of 1ES0657-556 have also been obtained with ACBAR [4], which again does not show any enhancement, at the centres of the dark halos, although the resolution $\sim 4.5' \sim 100?$ kpc at the cluster's redshift ($z = 0.3$). Recently Colafrancesco et al. [5] made a new calculation of the SZ effect by the nonthermal electrons from dark matter annihilation. They conclude that a detection of such effect is feasible in the future observations.

Relaxed angle resolution/sensitivity

our model: the earlier model likely underestimated the boosting factor of annihilation due to the internal substructures inside each NFW cluster halo. More importantly angular resolution is less critical because of the larger separation (about 2000 kpc, or 13 arcmin) between the positron tail from the thermal electrons; in Colafrancesco et al's case, the separation is only about 200 kpc, which is near the resolution of ground experiments like South Pole Telescope (Ruhl et al. 2004), Actama Cosmology Telescope (Kosowsky 2003), and balloon-borne experiments like OLIMPO (Masi et al. 2005). The relaxed threholds for sensitivity and angular resolution should increase the chance of annihilation-induced SZ effects being detected. The detection of a trail-like SZ signal would firm up the proof of dark matter in the Bullet Cluster (Clowe et al. 2006).