Galactic Halo

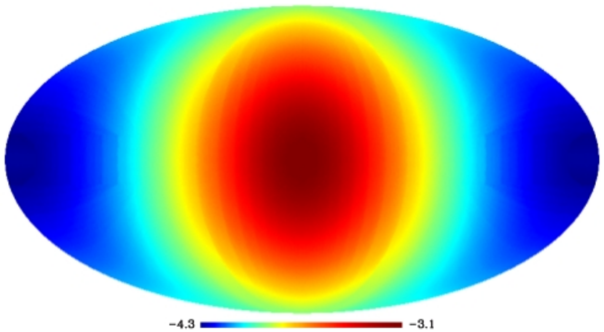
(Few to several kpc)

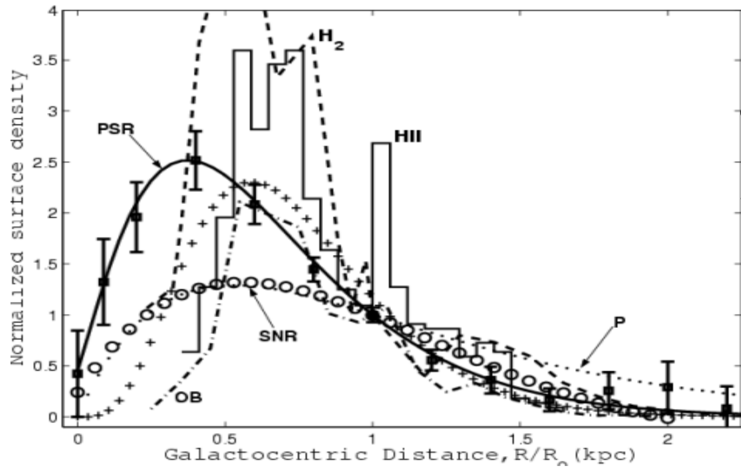
Diffuse emission is mostly dominated by CR.

For DM, look for regions with low CR content:

Central region

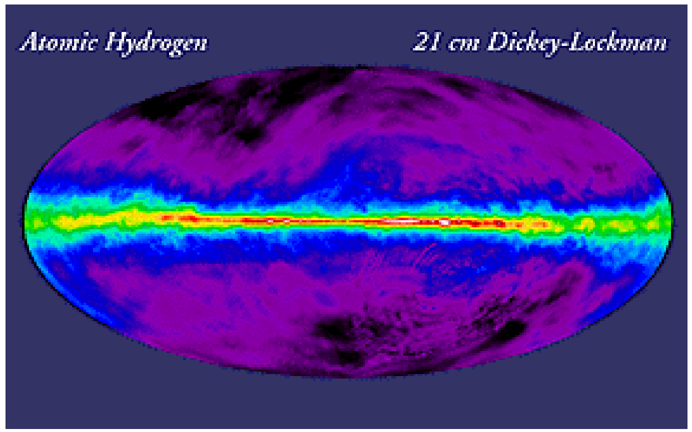
γ-ray map for a Burkert profile





A.Strong's talk (Princeton 2007)

Mid-high latitudes

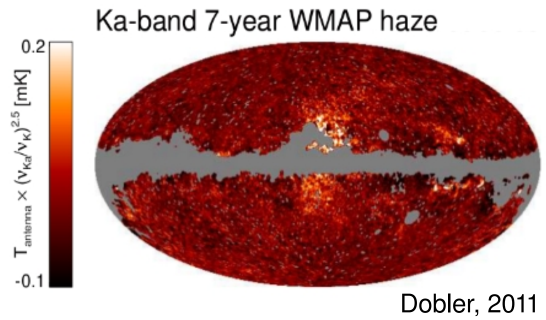


Milky-Way central region

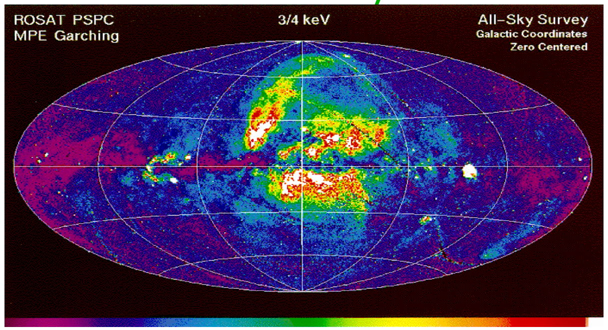
Central region ~ few kpc < 20 deg

One may think that the diffuse emission in this region can be understood from the large scale description of CR propagation (and DM). But:

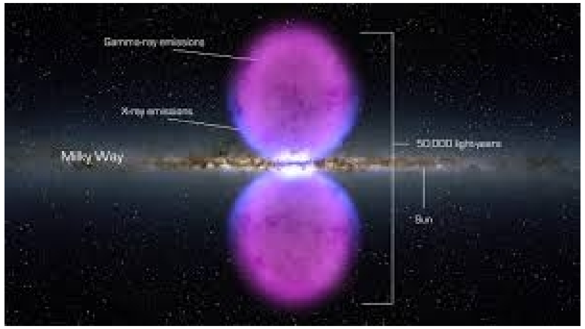
WMAP (and Planck) Haze



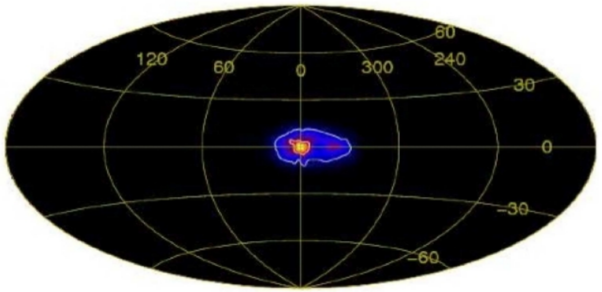
Rosat X-ray feature



Fermi Bubble



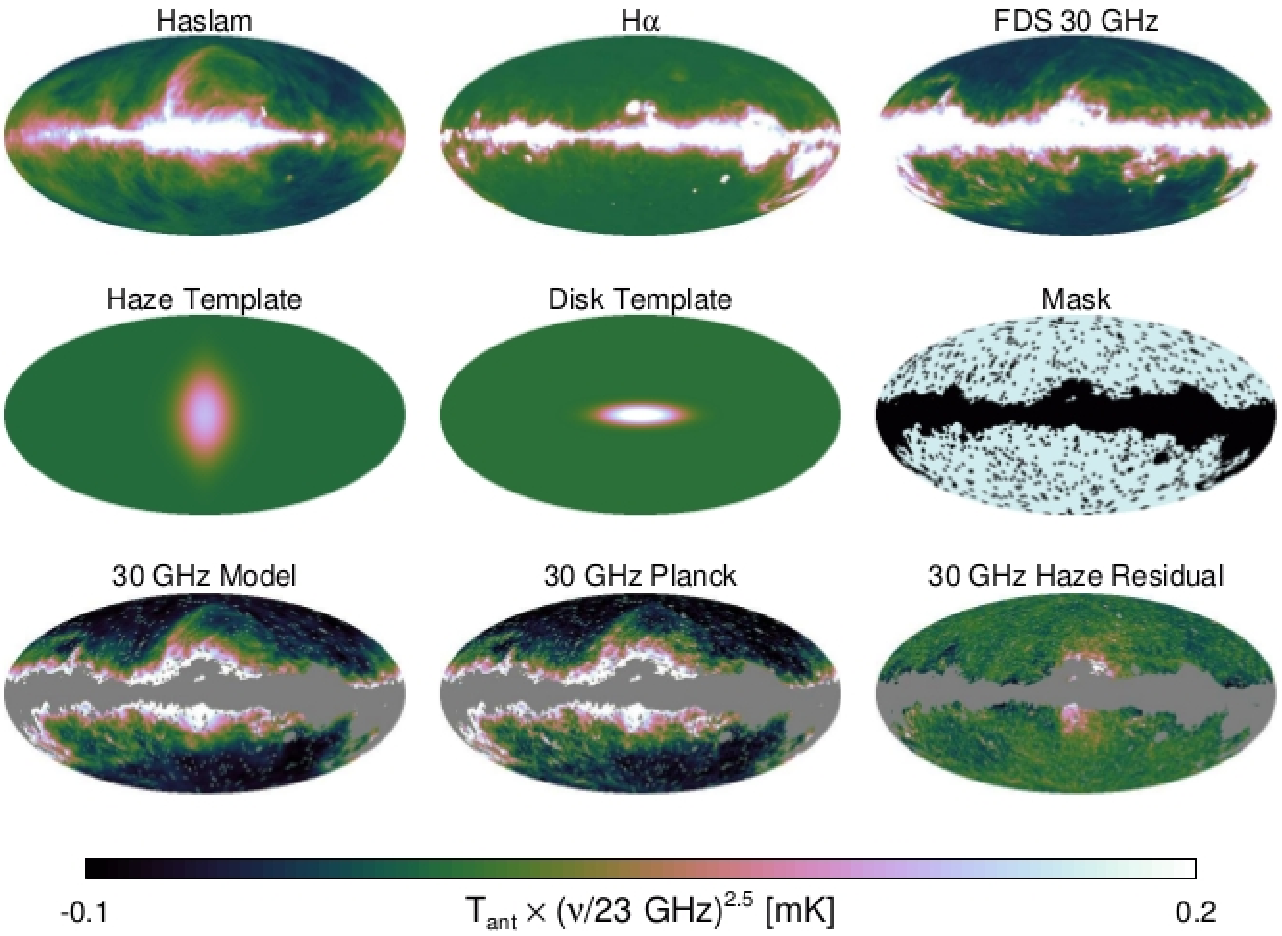
511 KeV line

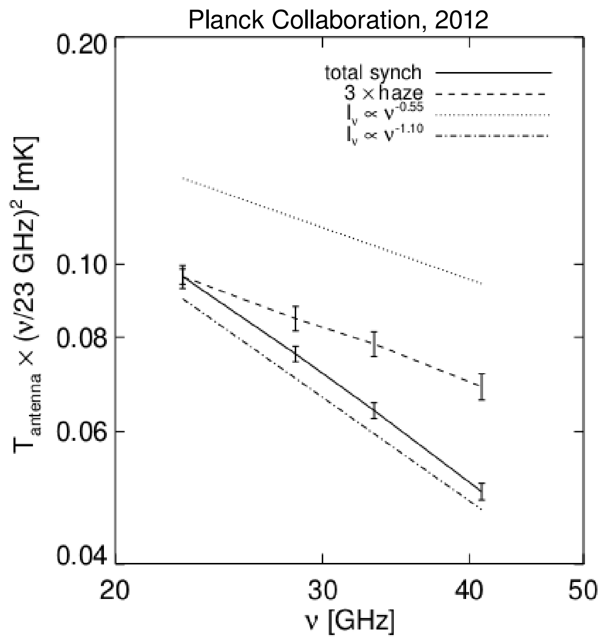


Milky-Way central region

WMAP Haze

First found with WMAP data (Finkbeiner, 2004) and recently confirmed with Planck data.





Milky-Way central region

Hooper 2012

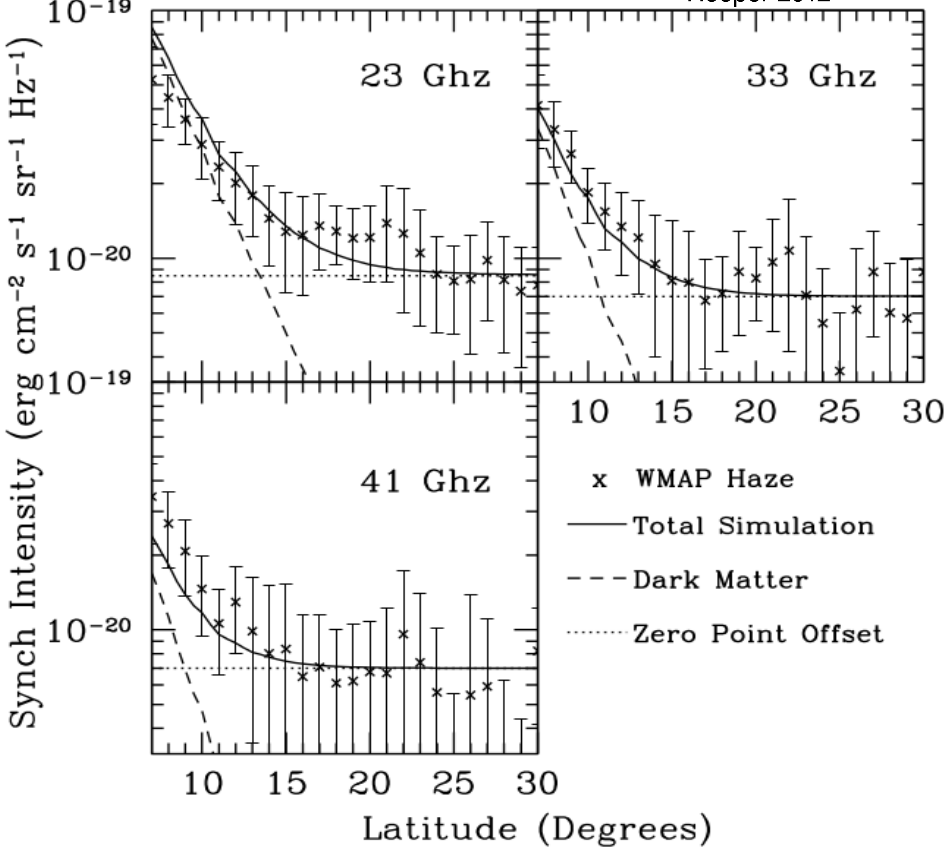
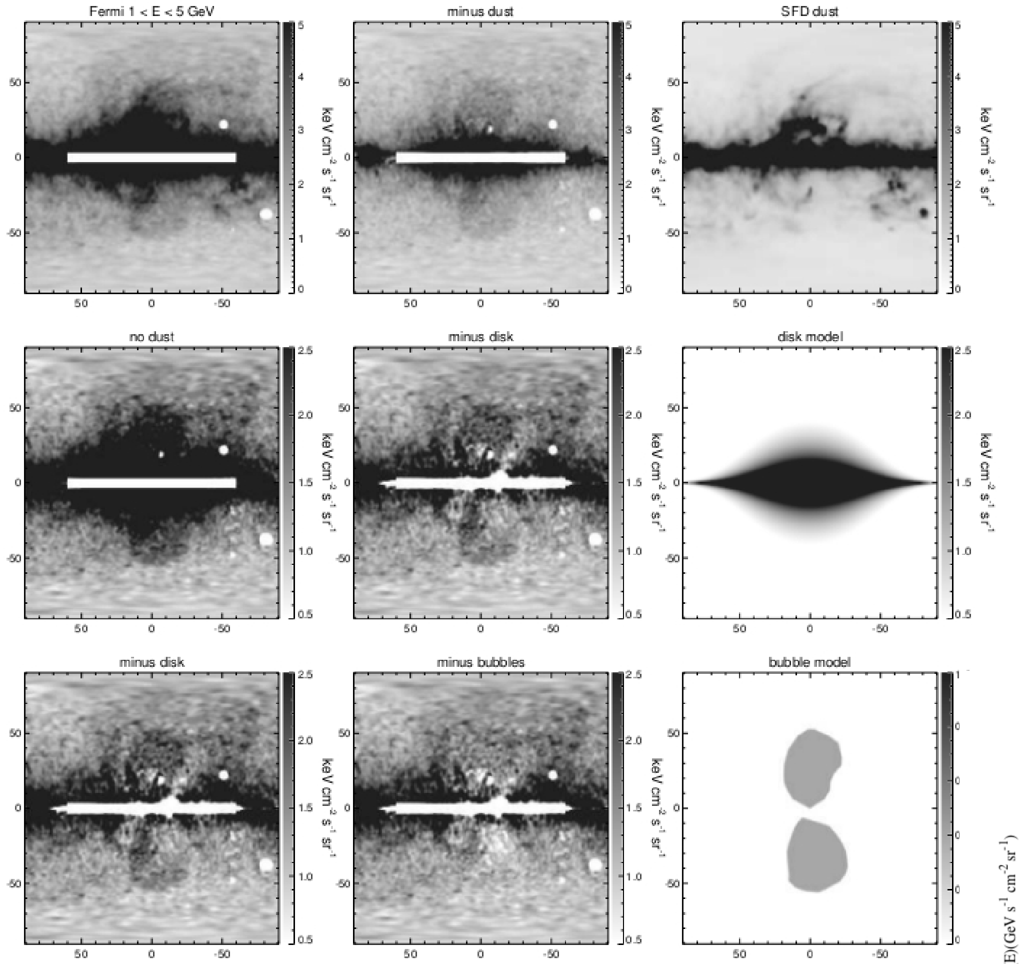


FIG. 5: Synchrotron emission from dark matter annihilations as a function of latitude below the Galactic Center for 10 GeV dark matter particles annihilating equally to e^+e^-, $\mu^+\mu^-$, and $\tau^+\tau^-$, distributed as $\rho_{\rm DM} = 0.35\,{\rm GeV/cm}^3 \times (r/8.5\,{\rm kpc})^{-1.33}$, and with a total cross section of σv = 7 x 10^{-27} cm^3/s. The magnetic field model used is given by $B(r,z) = 22\,\mu{\rm G}\ e^{-r/5.0\,{\rm kpc}}\,e^{-|z|/1.8\,{\rm kpc}}$. This

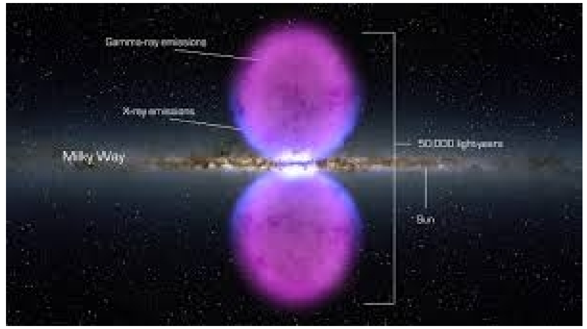
It has driven significant attention since DM annihilations is one of the possible explanations.

Cuspy profile
and
quite uncertain modeling

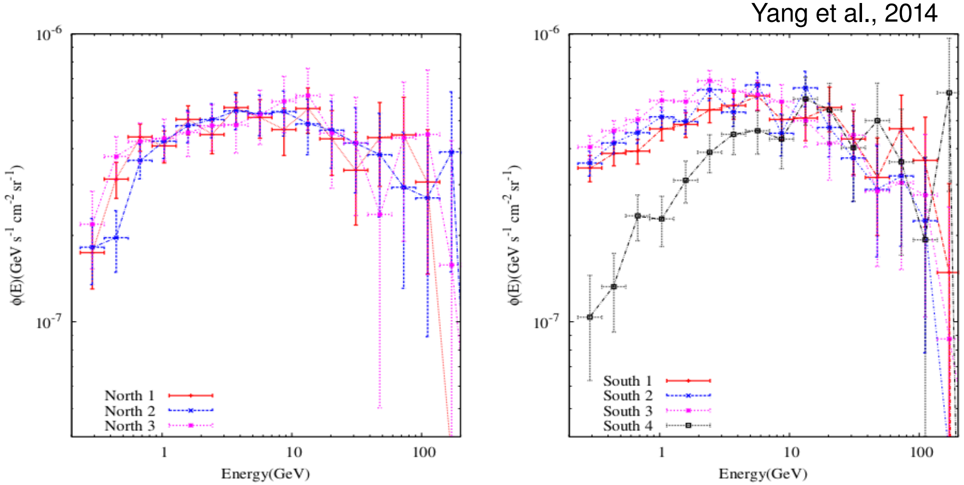
Milky-Way central region



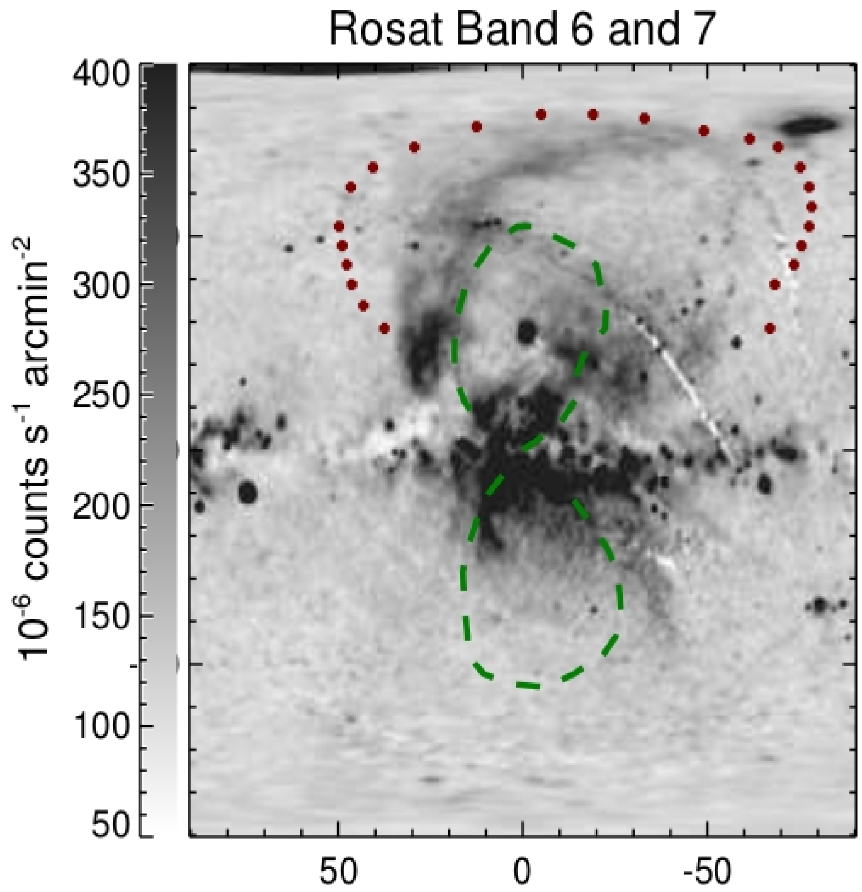
Fermi Bubble
(Su et al., 2010)

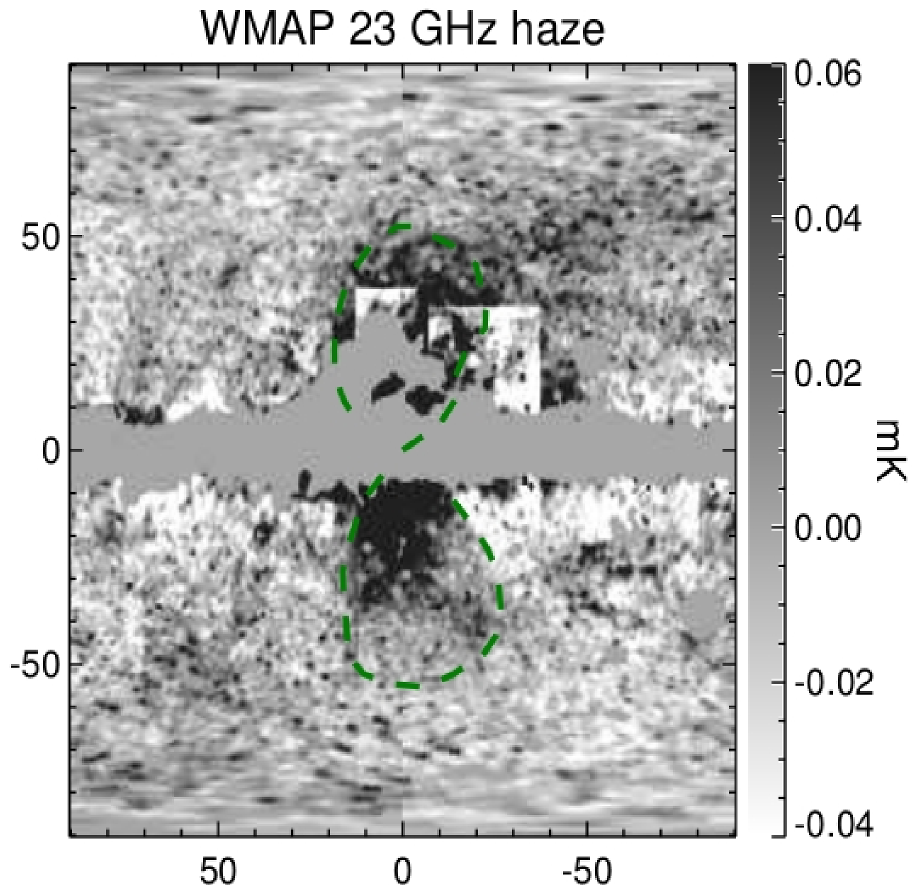


Yang et al., 2014



Milky-Way central region

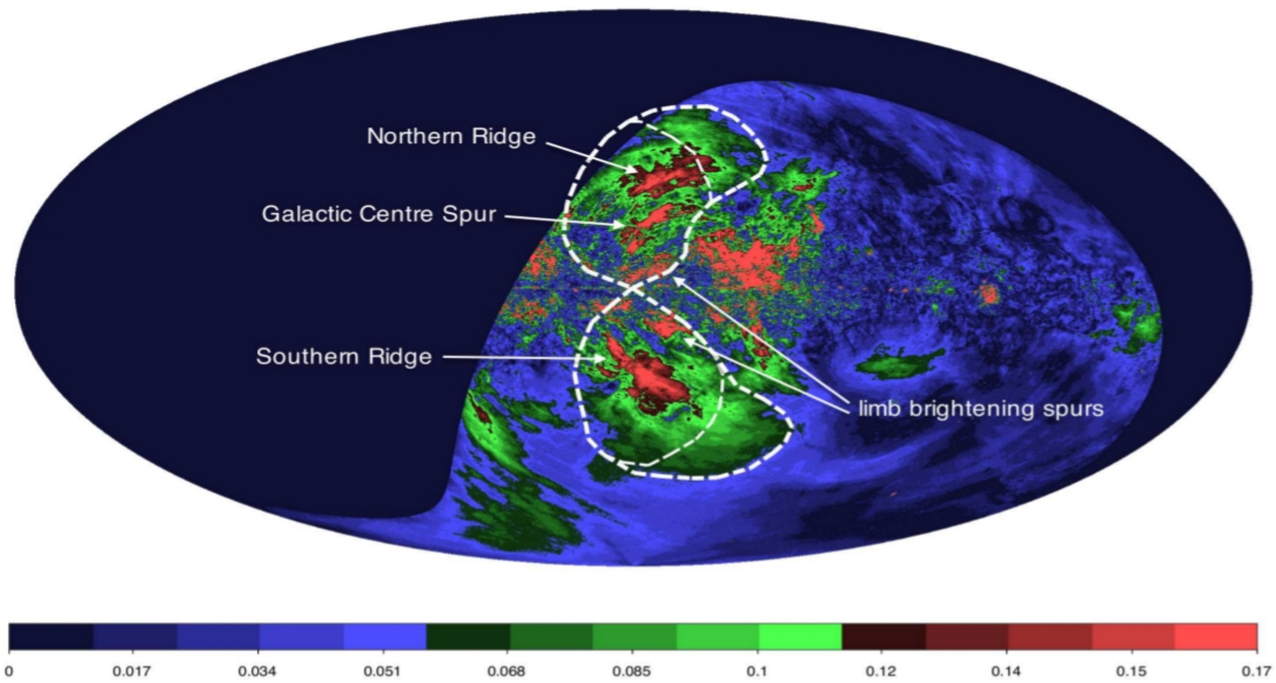




large-scale, biconical structures in X-rays
(Bland-Hawthorn&Cohen, 2003)

Milky-Way central region

Carretti et al., 2013



S-band Polarization All Sky Survey (S-PASS) mapped the polarized radio emission of the entire southern sky with the Parkes Radio Telescope at a frequency of 2.3 GHz and 9' angular resolution.

The emission is non-local.

Indications in favour of star-formation (rather than black hole) driven outflow.

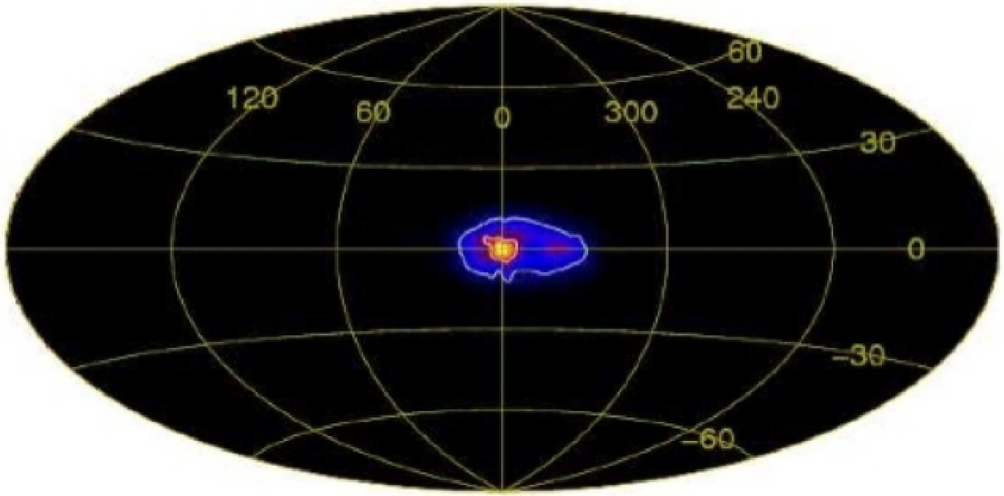
Milky-Way central region

The line is due to positronium formation → low energy positrons at GC
Detailed recent review in (Prantzos et al., 2010)

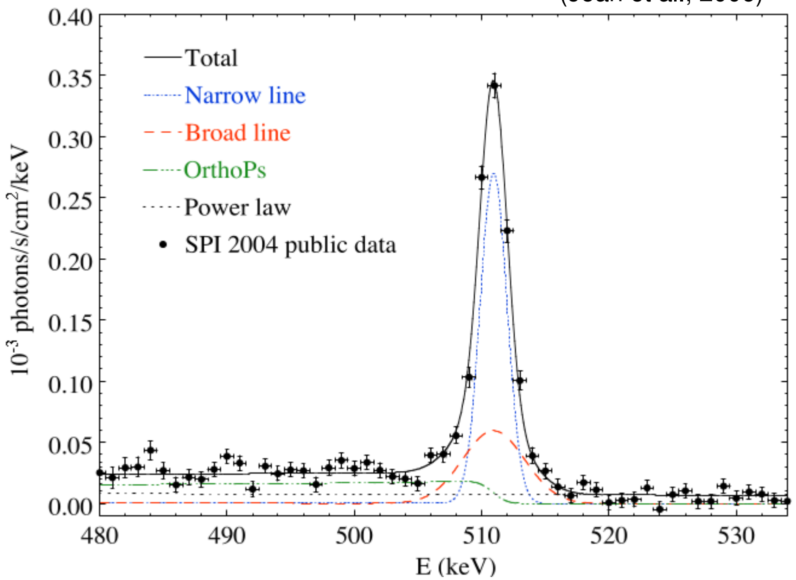
Puzzling: high bulge-to-disc ratio for the diffuse line emission

Explanation in terms of DM: light (MeV) DM or DM with almost mass degenerate excited states (MeV mass splitting)

INTEGRAL/SPI view
(Weidenspointner et al., 2008)



(Jean et al., 2006)



Milky-Way central region

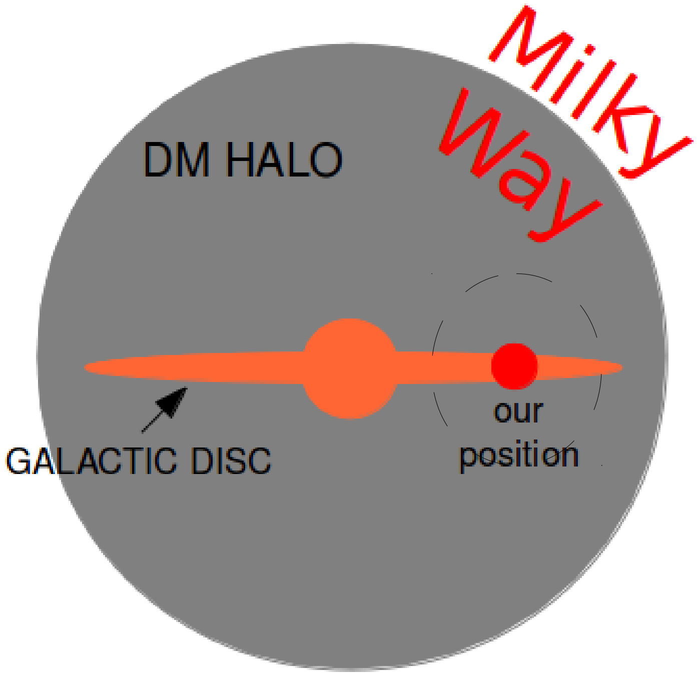
Take home message concerning the picture at the center of our Galaxy:

GC

and bottom

(see also Crocker et al., 2010)

Galactic Halo



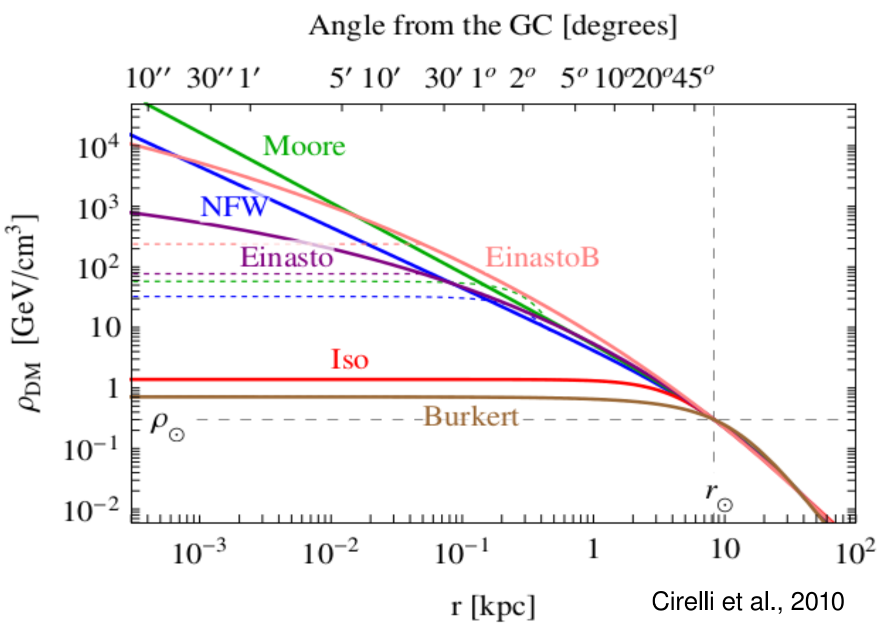
Let's now focus on mid-high latitudes (|b| > 20)

The signal mostly comes from the "local" region.

Fainter DM-induced emission wrt the GC in case of a cuspy profile, but more robust predictions.

Better knowledge of DM gravitational potential from star kinematics.

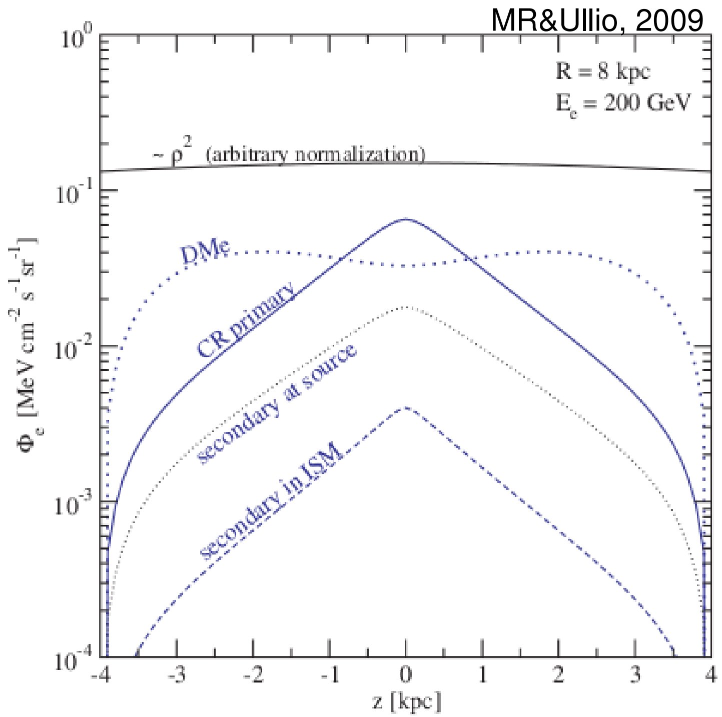
Description of transport of high-energy particles is tuned to locally measured CR spectra.

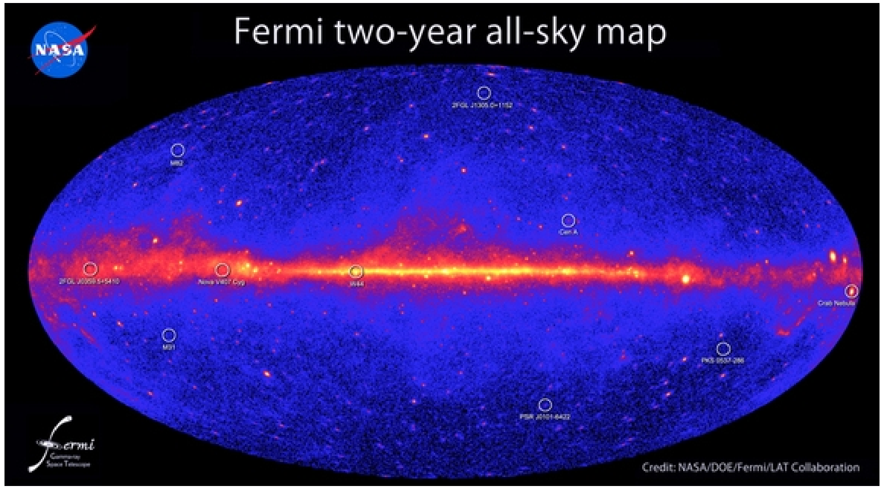


Cirelli et al., 2010

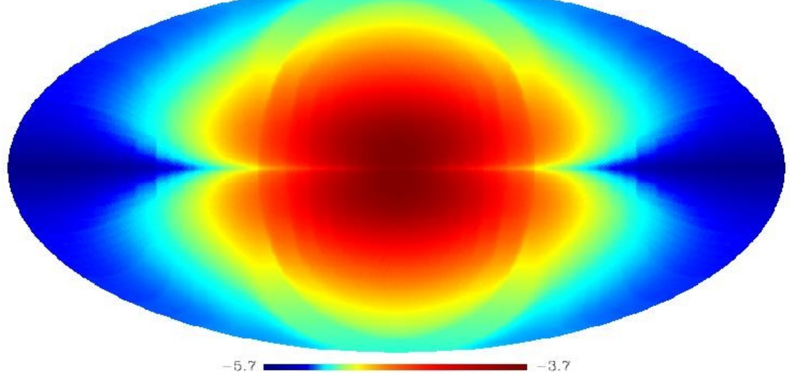
Galactic Halo

The spectral feature we look for is an extended (not confined to the stellar disk) and possibly spherical emission.





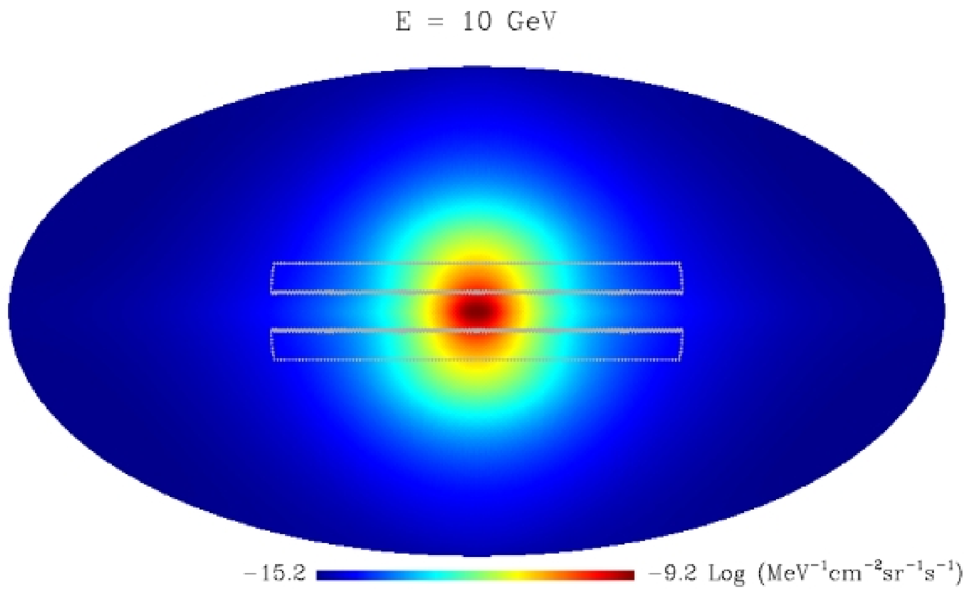
IC sky-map at 150 GeV from DM induced e^-+e^+

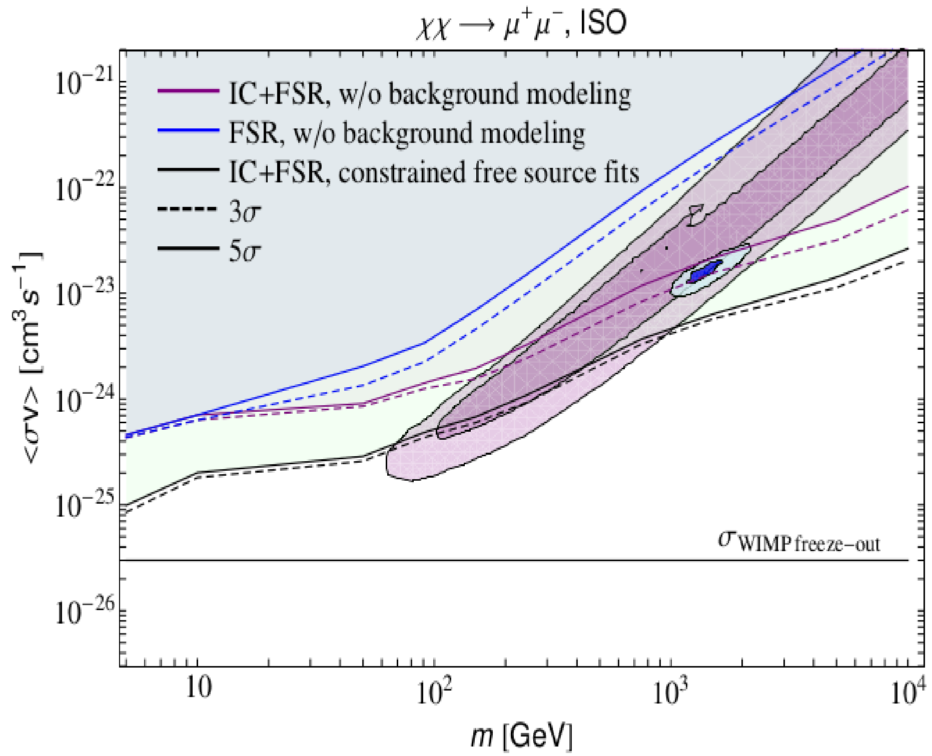


Galactic Halo

Tight complementarity with searches in local CR spectra.
E.g., strong test for PAMELA DM.

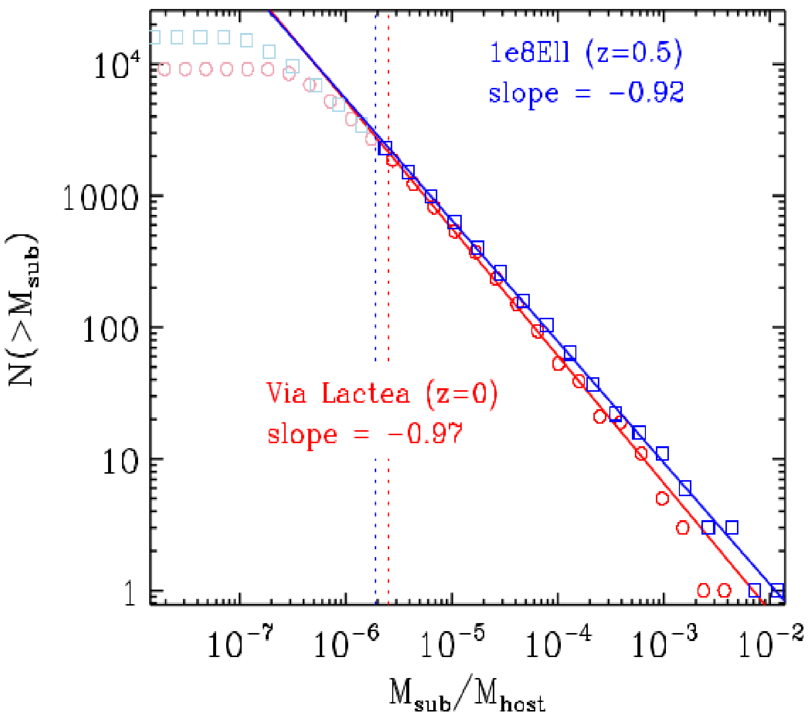
Fermi-LAT collaboration, 2012



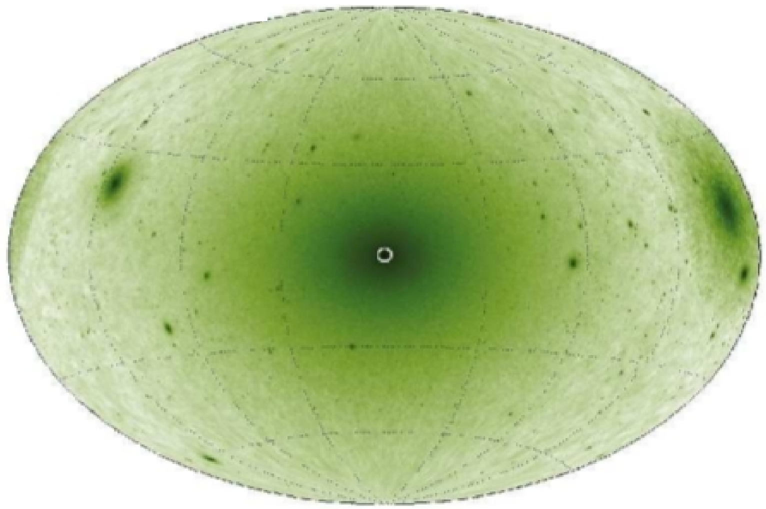


Galactic subhalos

Single Clumps

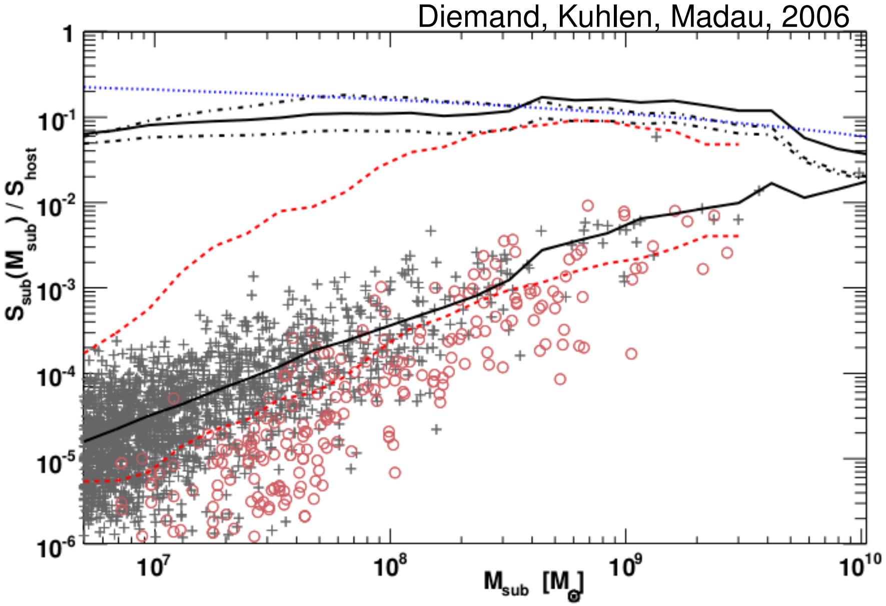


GAMMA



Via Lactea II, Kuhlen, Diemand, Madau, 2008

Galactic subhalos



No astrophysical contamination

but source identification?

Criteria often adopted:

- spectral features
- finite angular extents
- lack of counterparts at other wavelengths

After applying selection cuts, no source found to be compatible with a DM origin among the candidate UFOs in the 1FGL (Fermi-LAT Collaboration, 2012) and 2FGL (Zechlin&Horns, 2012)

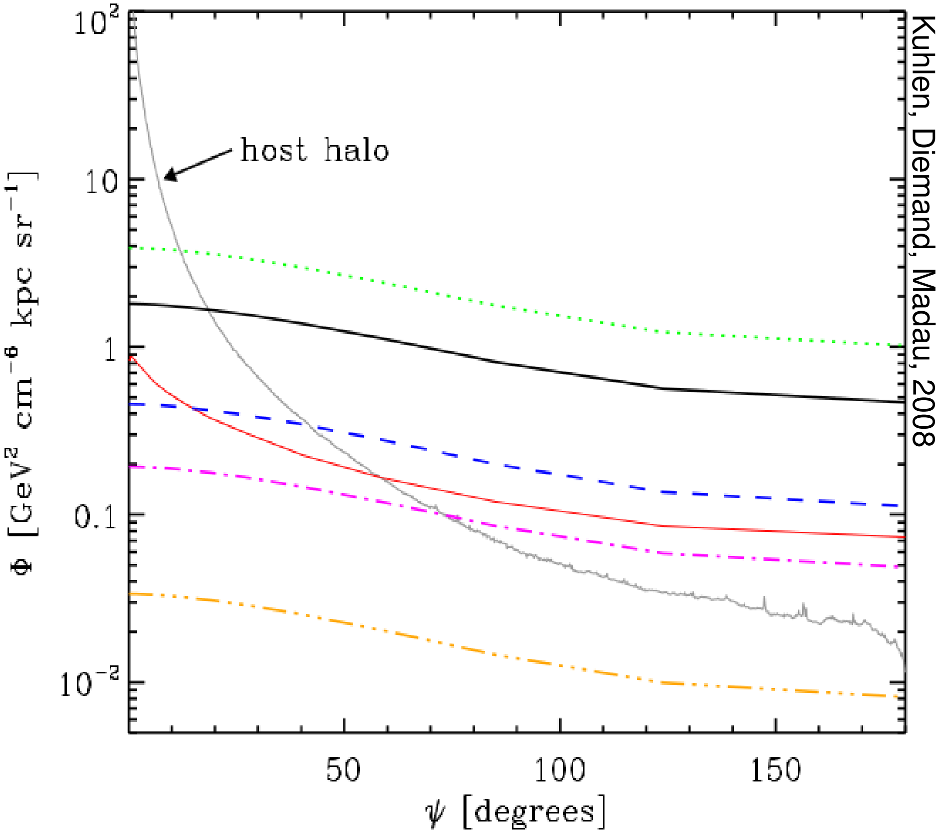
More difficult for radiative emissions (because of spatial diffusion)

Galactic subhalos

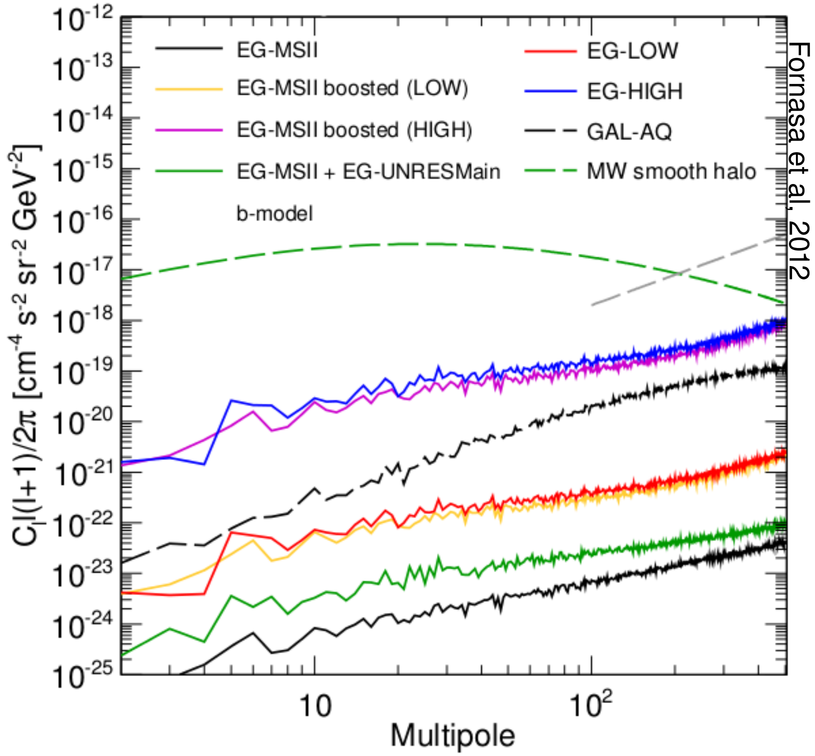
Total Subhalo contribution

$\langle\rho\rangle^2 \neq \langle\rho^2\rangle$

Diffuse flux from undetectable subhalos

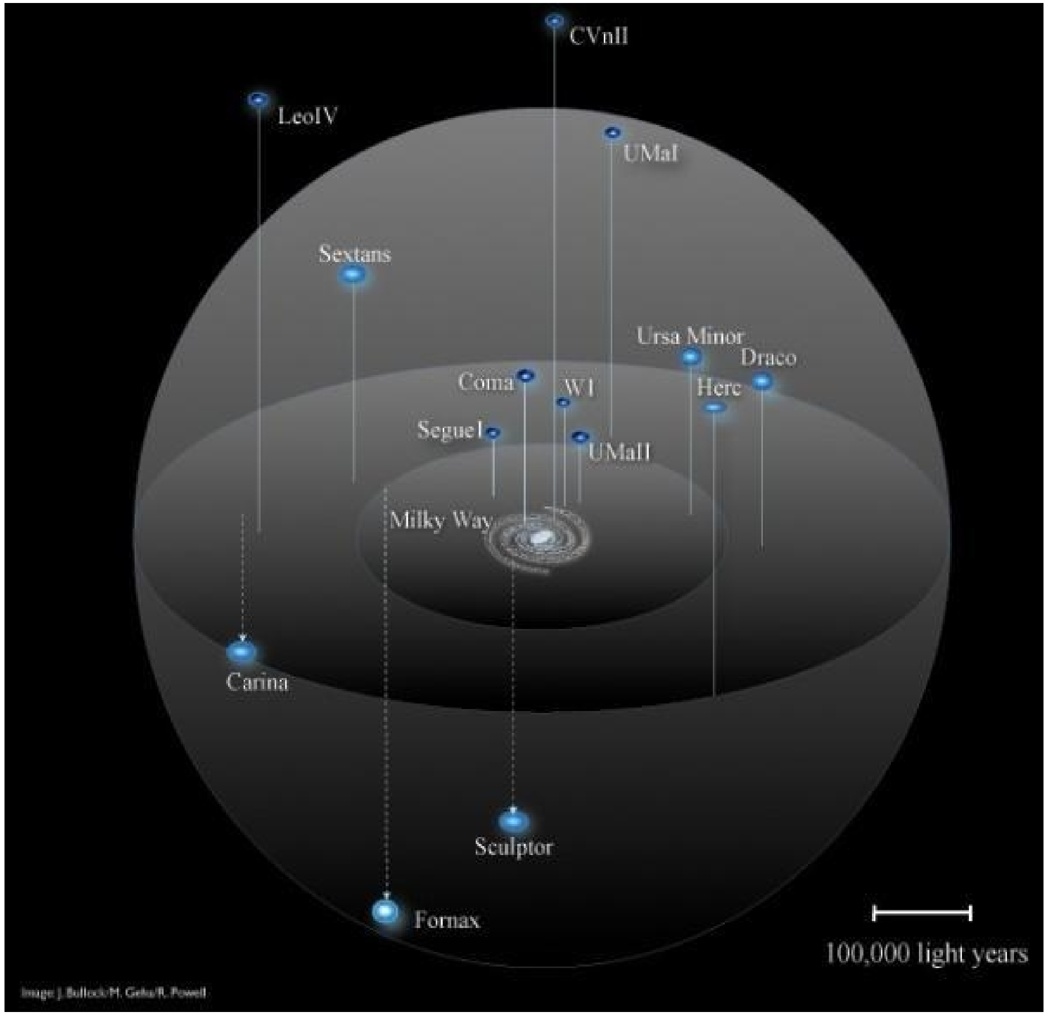


Anisotropies from Galactic subhalos



Dwarf Spheroidal Galaxies

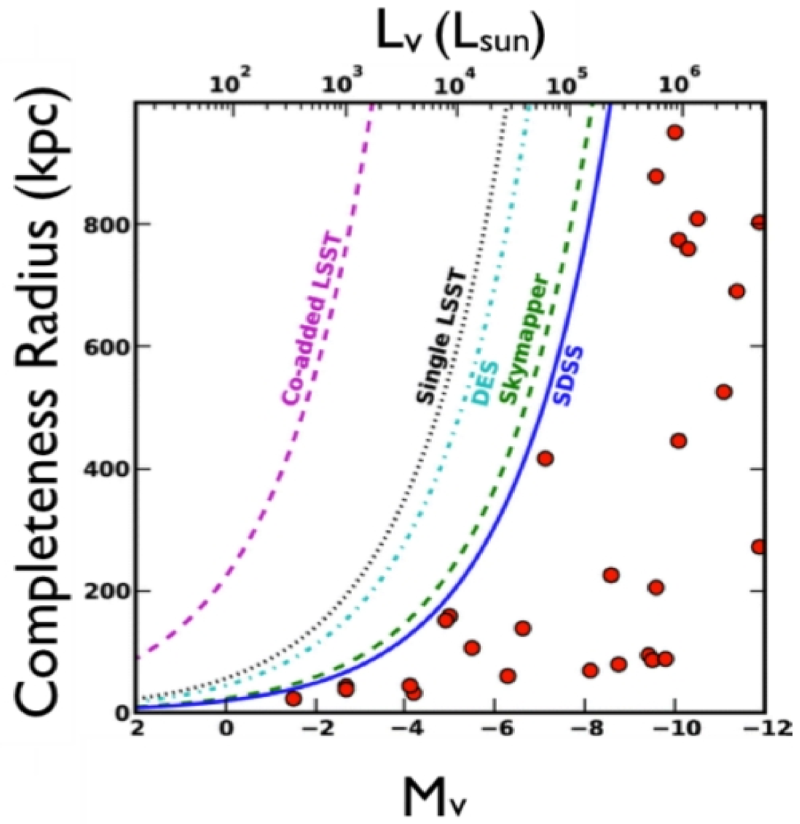
- Crucial objects for **near-field cosmology**
  - **Closest DM dominated objects** other than the Galaxy (Flux ~ d^{-2}).
    - Baryons highly **subdominant**



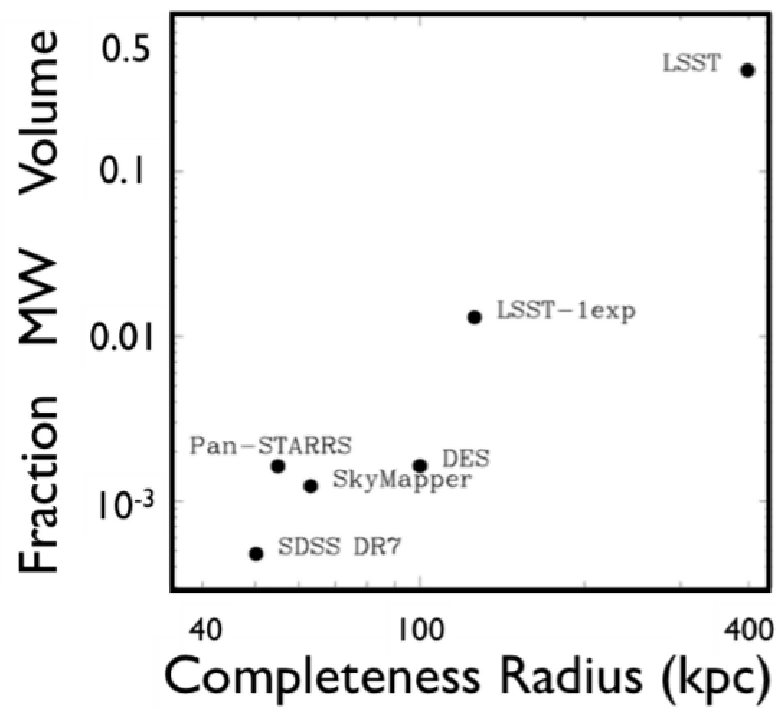
Dwarf Spheroidal Galaxies

SDSS has more doubled the number of known Local Group dSphs (25 new discoveries).

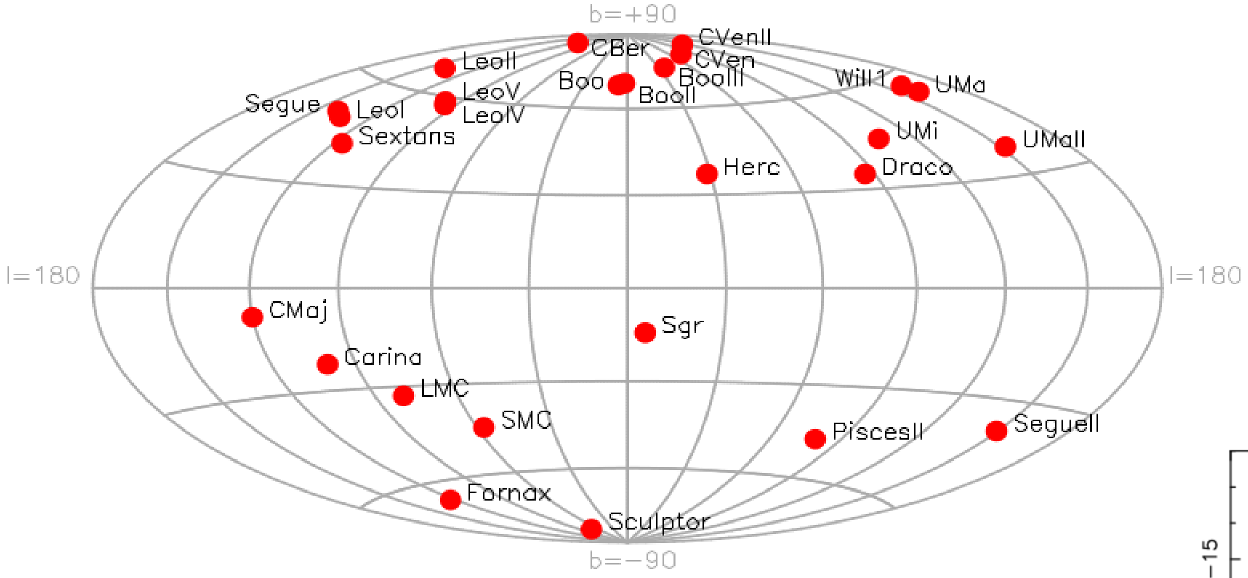
Many more to come from next-future optical surveys.

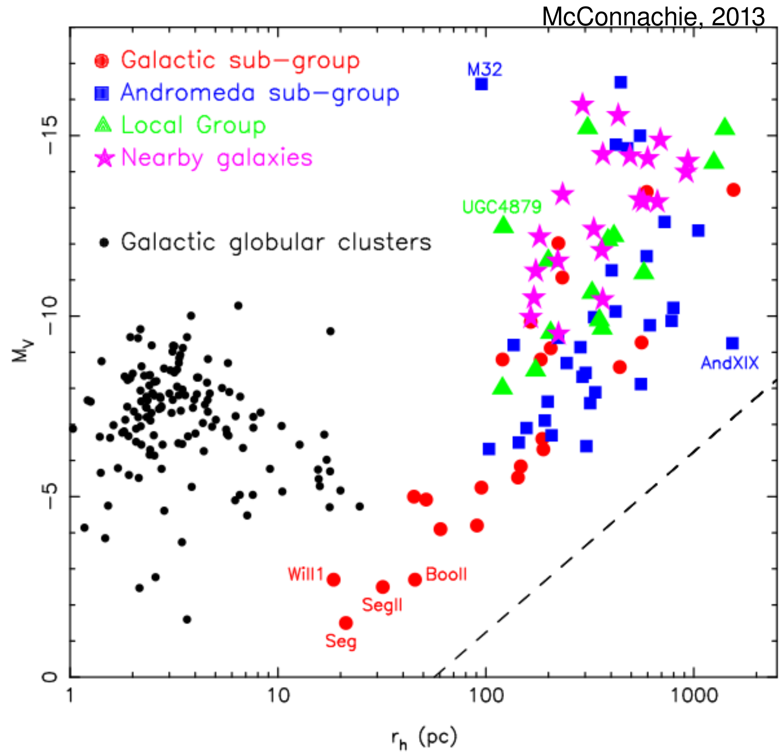


Tollerud et al. 2008

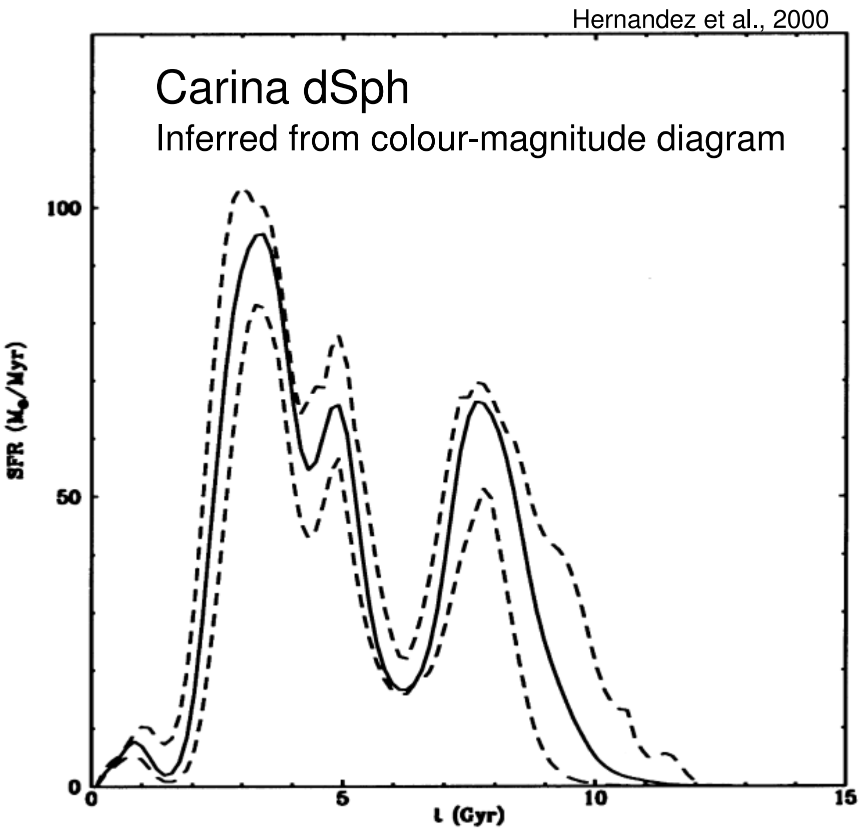


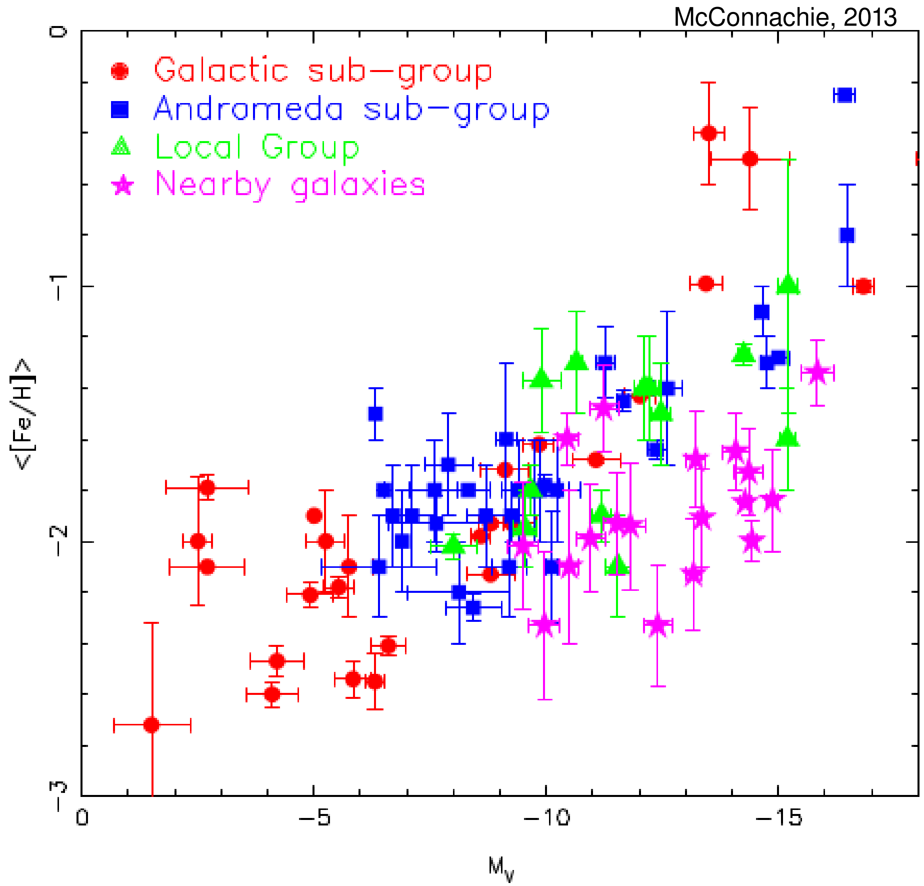
Local Group dSphs





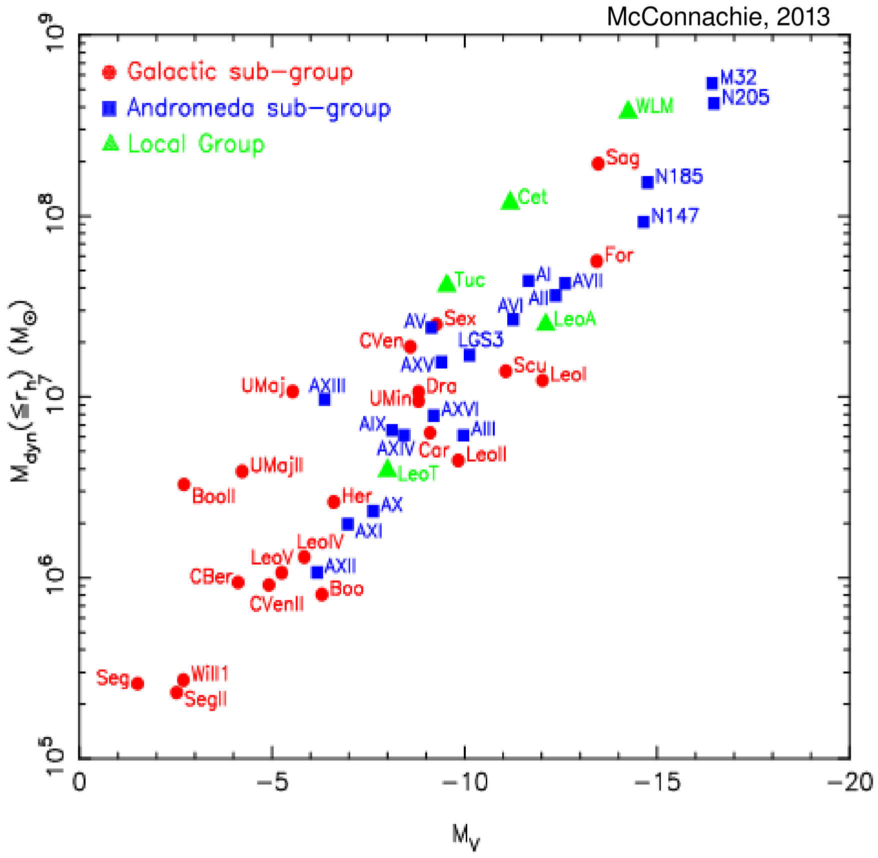
Local Group dSphs

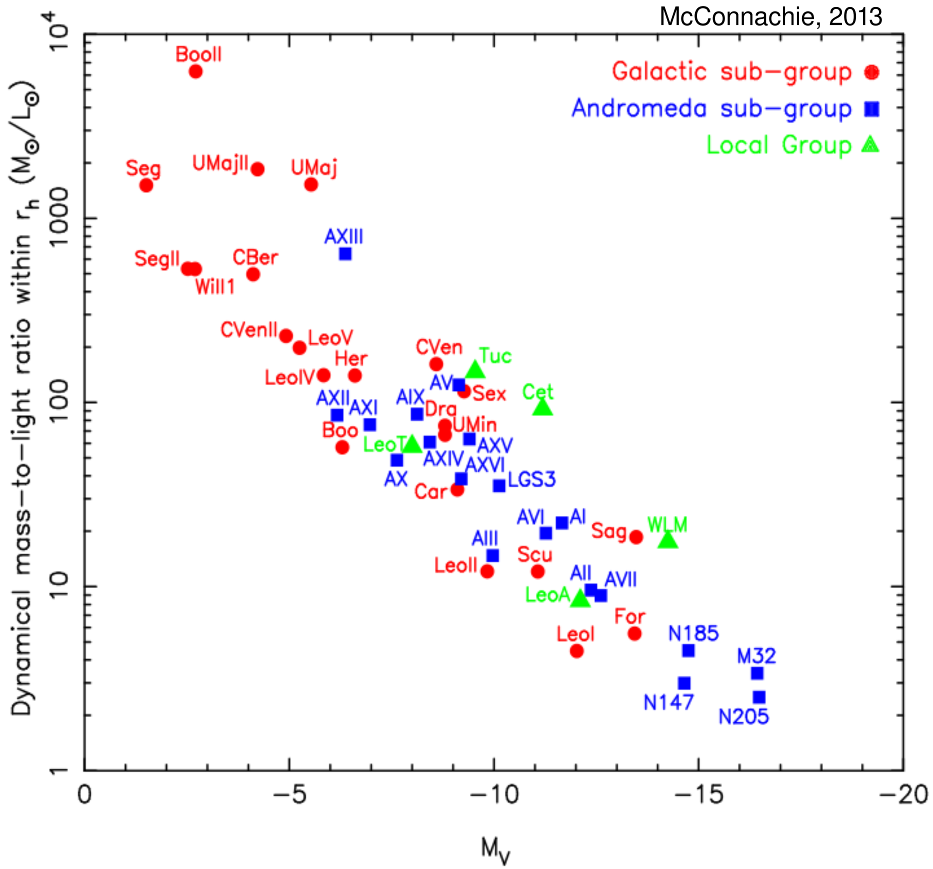




The **non-thermal emission** related to star-formation is expected to be **extremely low**.

Local Group dSphs



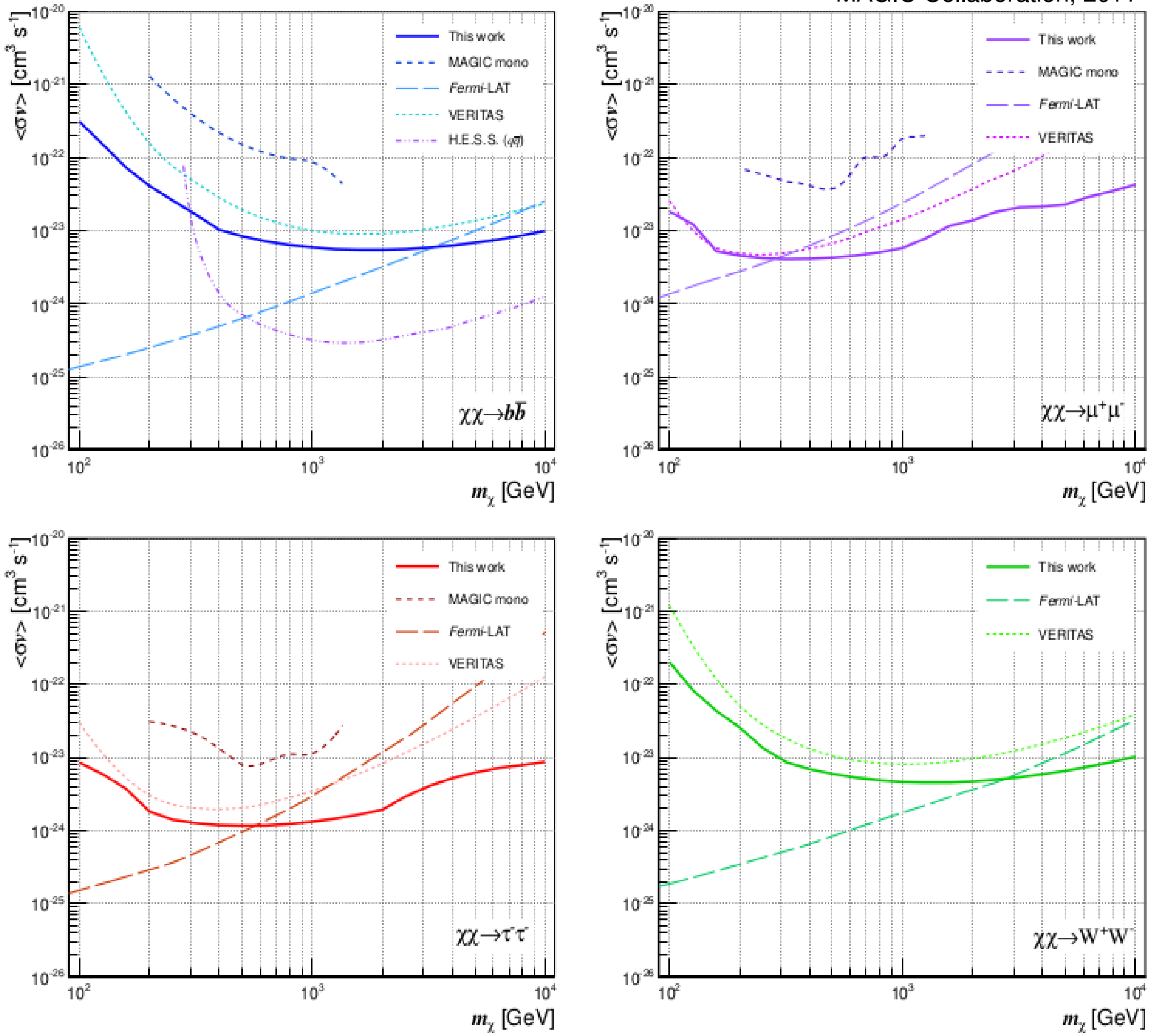


Very large mass-to-light ratio → Mass budget largely dominated by **DM**

Dwarf spheroidal galaxies

Gamma-rays

MAGIC Collaboration, 2014



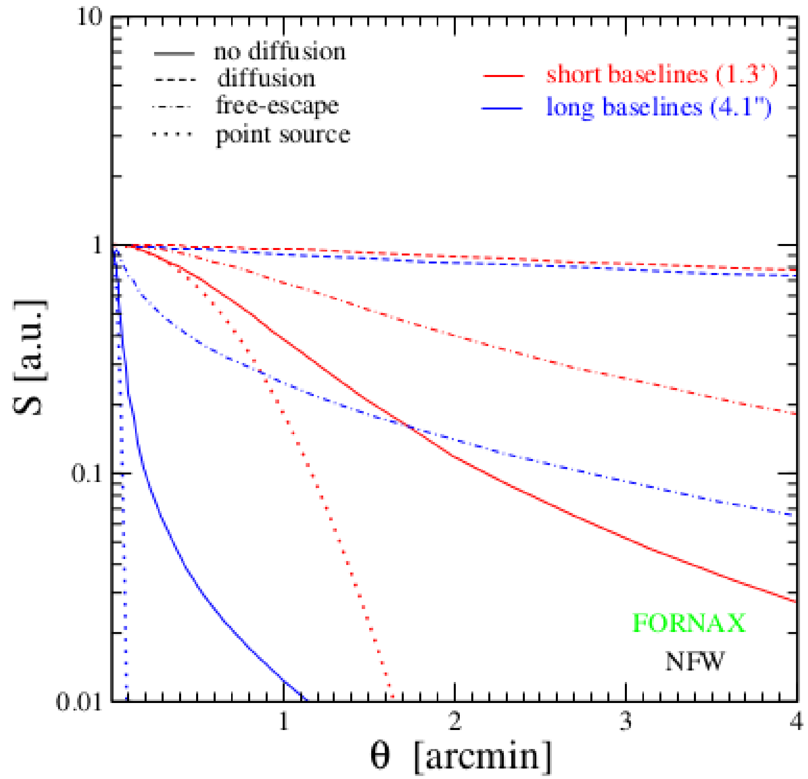
Usually considered as the cleanest indirect method.

In reality, some uncertainties in the halo profile determination might have been underestimated.

Dwarf spheroidal galaxies

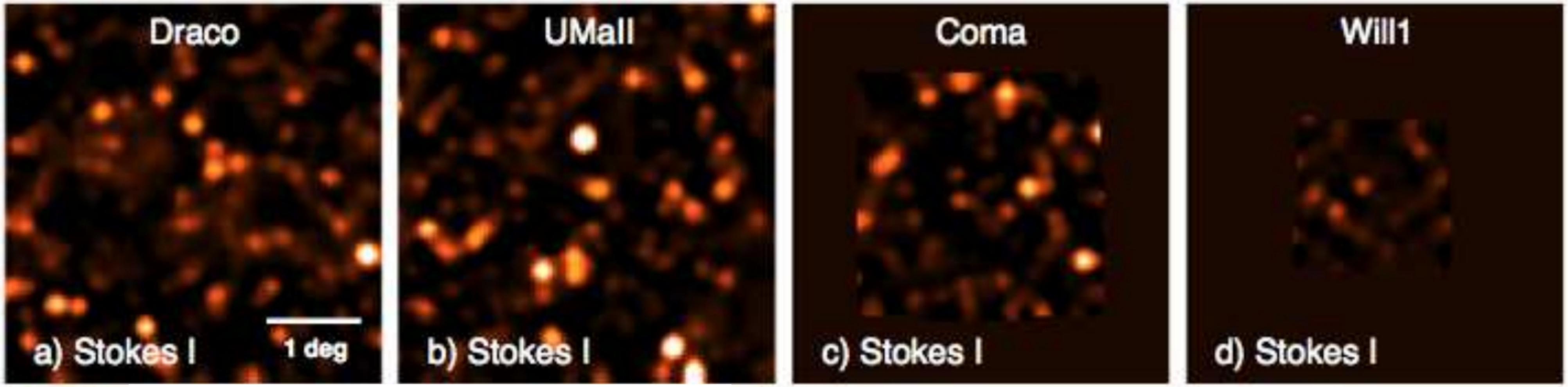
Radio

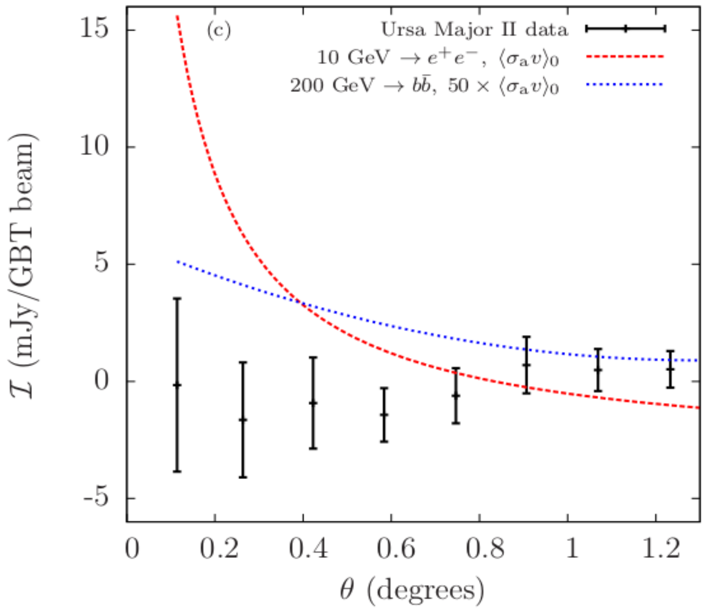
Large uncertainties in the dSph magnetic properties.
They affect both description of spatial diffusion of e+-e- and the synchrotron signal.
However, possibility to dramatically improve capability with the SKA

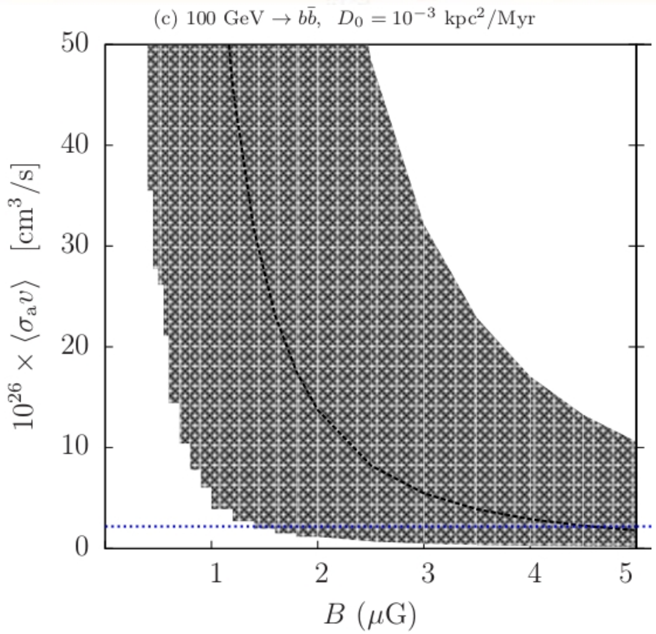


Dwarf spheroidal galaxies

Observations with the <u>single dish</u> Green Bank Telescope (Spekkens et al., 2013 and Natarajan et al., 2013)

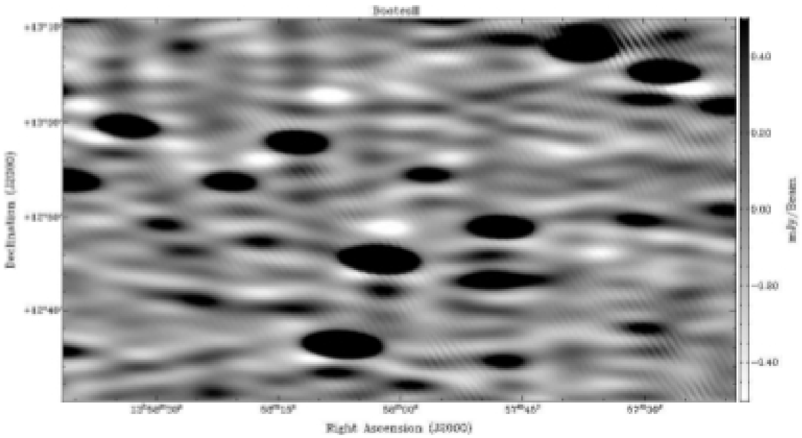


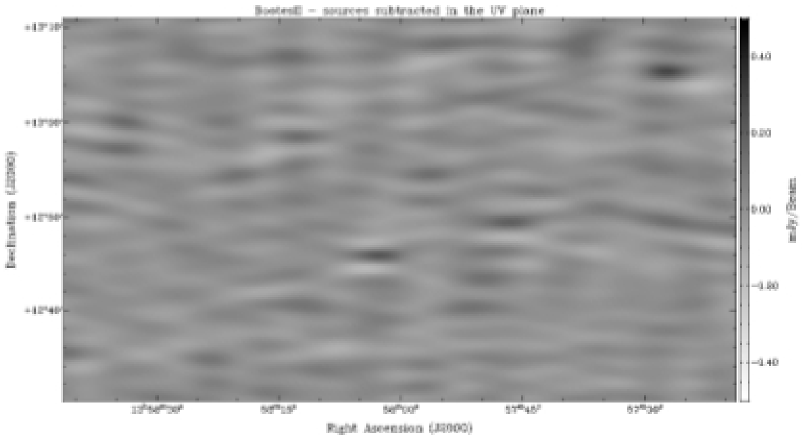




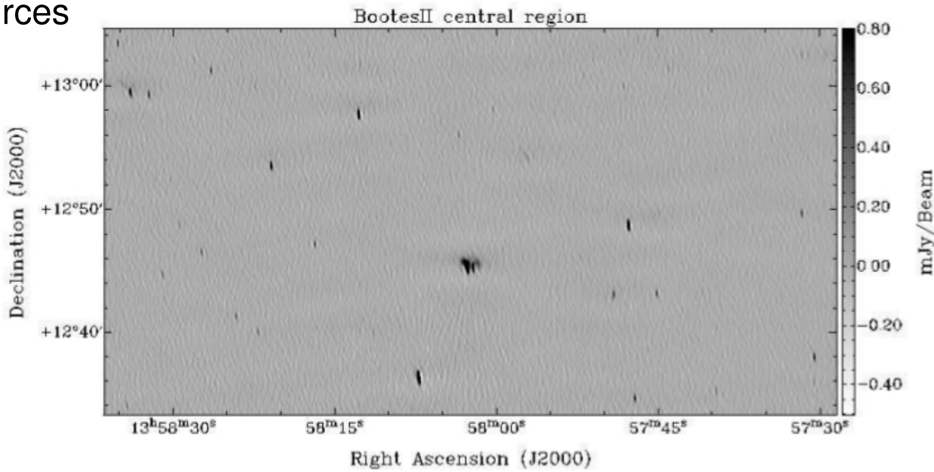
Dwarf spheroidal galaxies

Observations with the ATCA interferometric telescope (MR et al., 2014)



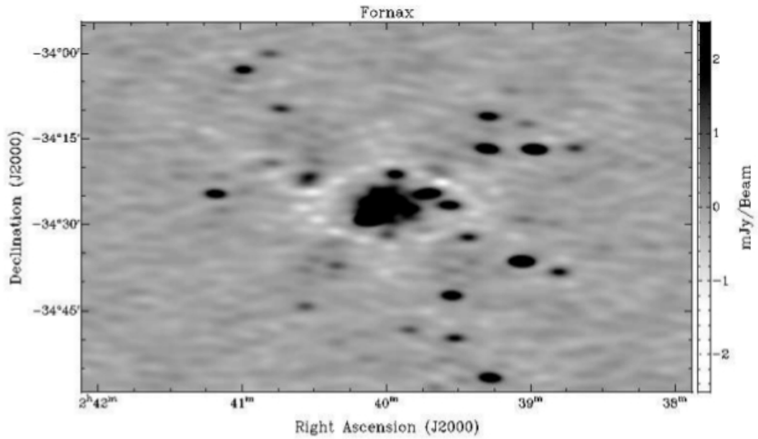


Subtraction of sources



Final map

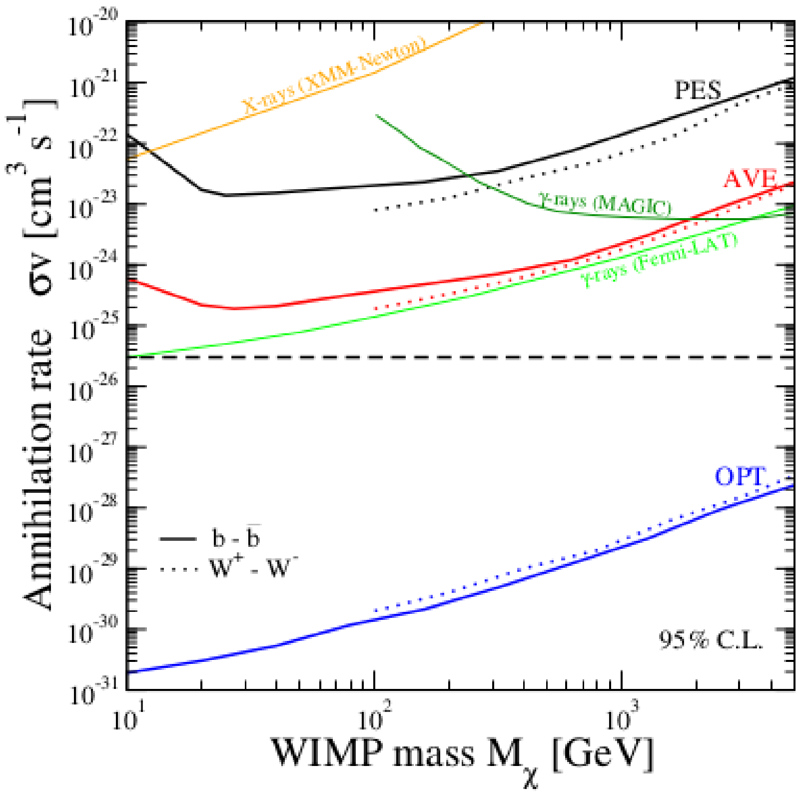
Expected emission



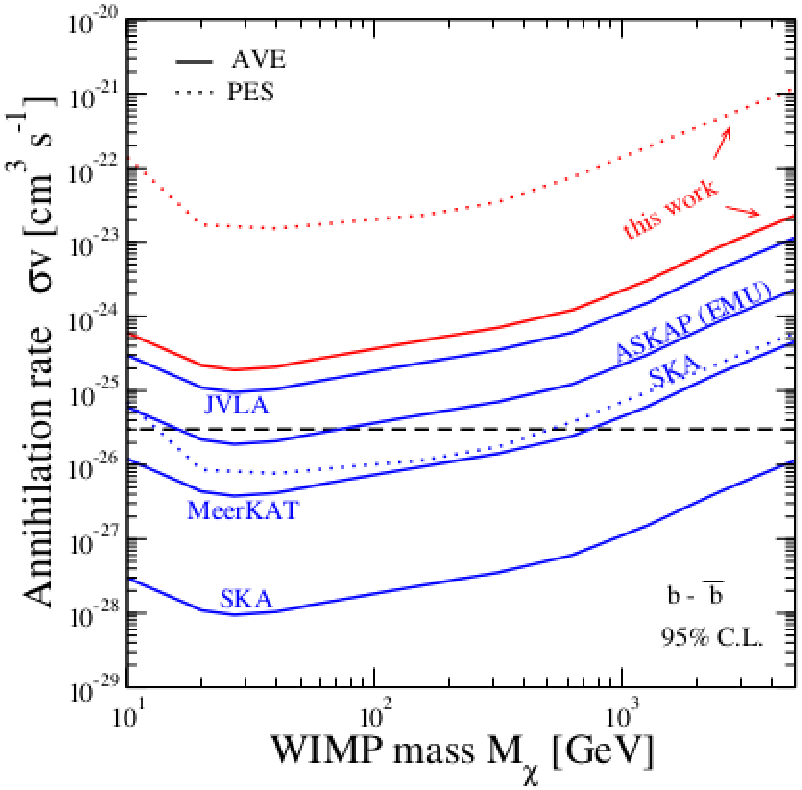
Dwarf spheroidal galaxies

C2499 ATCA project (MR et al., 2014)

Current reach



Prospects for the future



Dwarf spheroidal galaxies

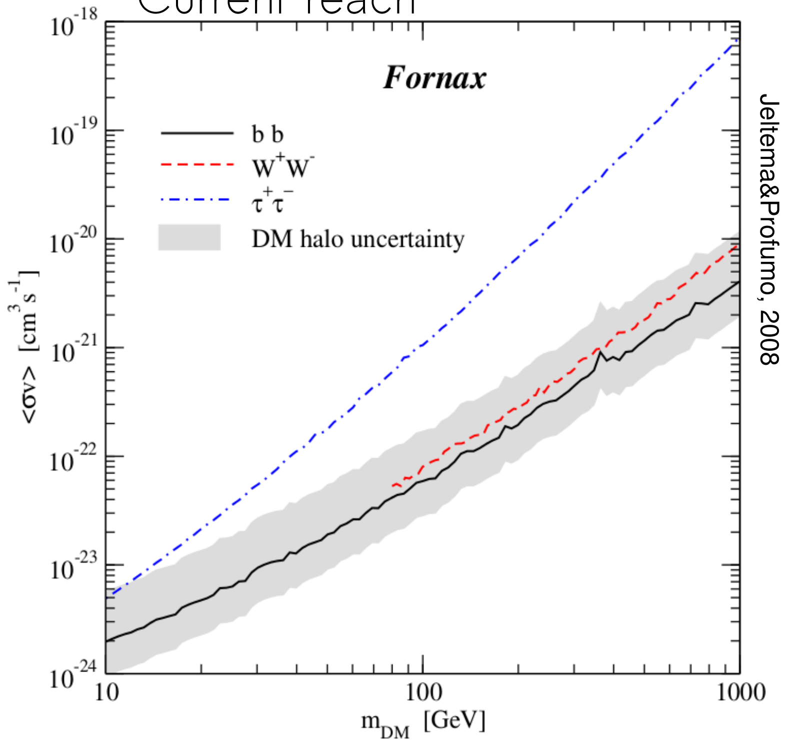
x-rays

Given by inverse Compton scattering on CMB photons (starlight should be subdominant)

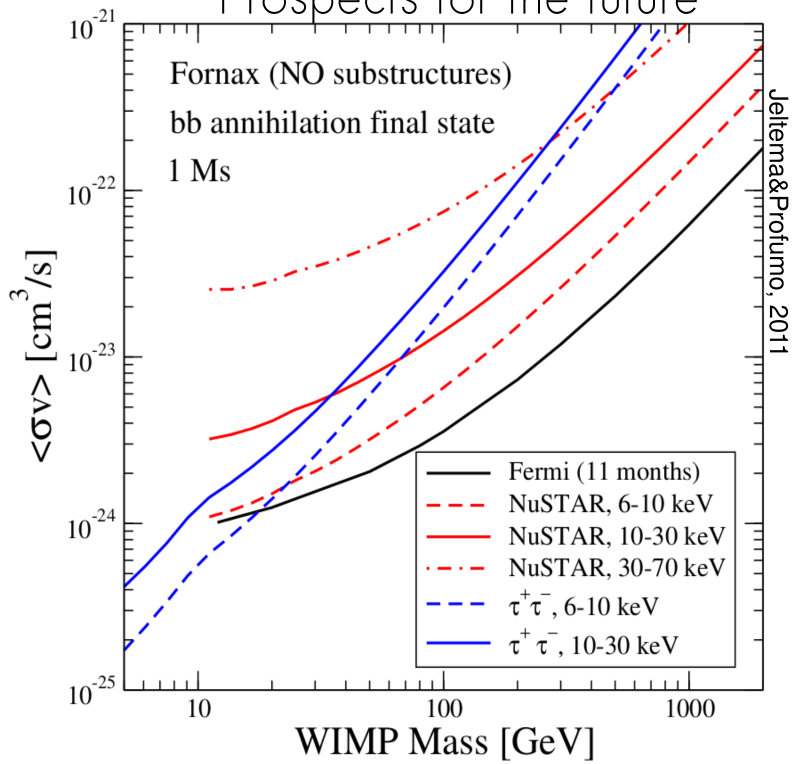
Less uncertainties than in the radio case since the target field is known.

Currently, weak capabilities but improved prospects in the near future (NuSTAR and Astro-H)

Current reach



Prospects for the future



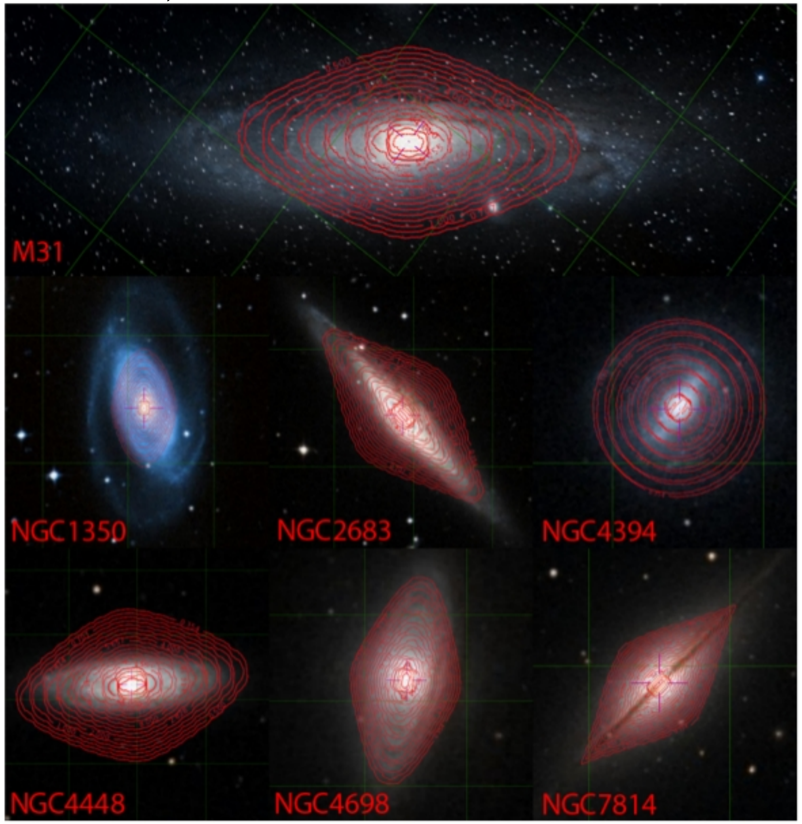
Nearby galaxies

Local Group: Magellanic clouds, M31 and M33.

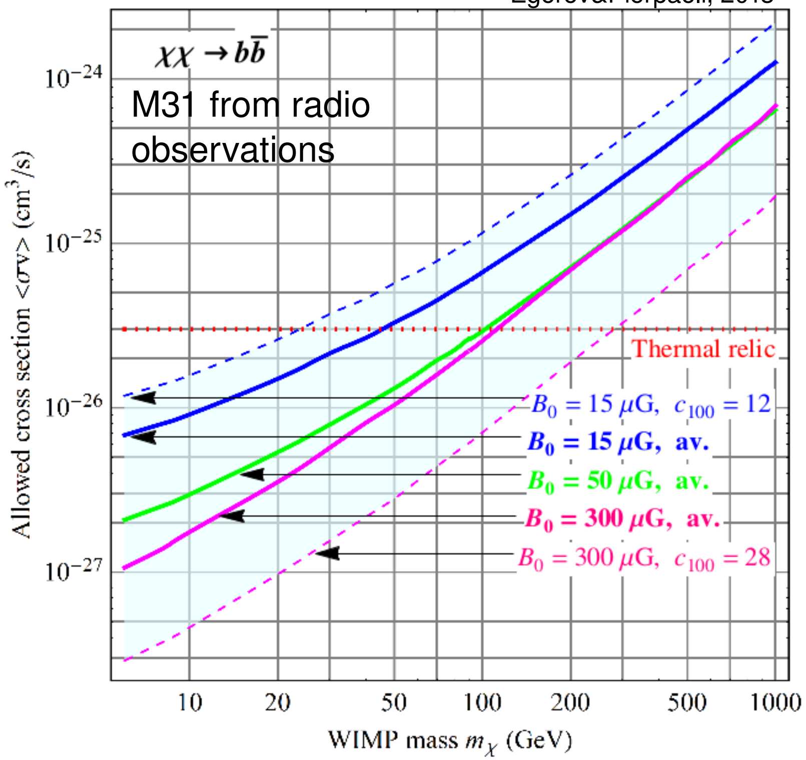
Facing similar issues as the MW for what concerns the disentanglement from the CR contribution (except we see them from outside)

What about nearby **edge-on galaxies**?

Carlson et al., 2012

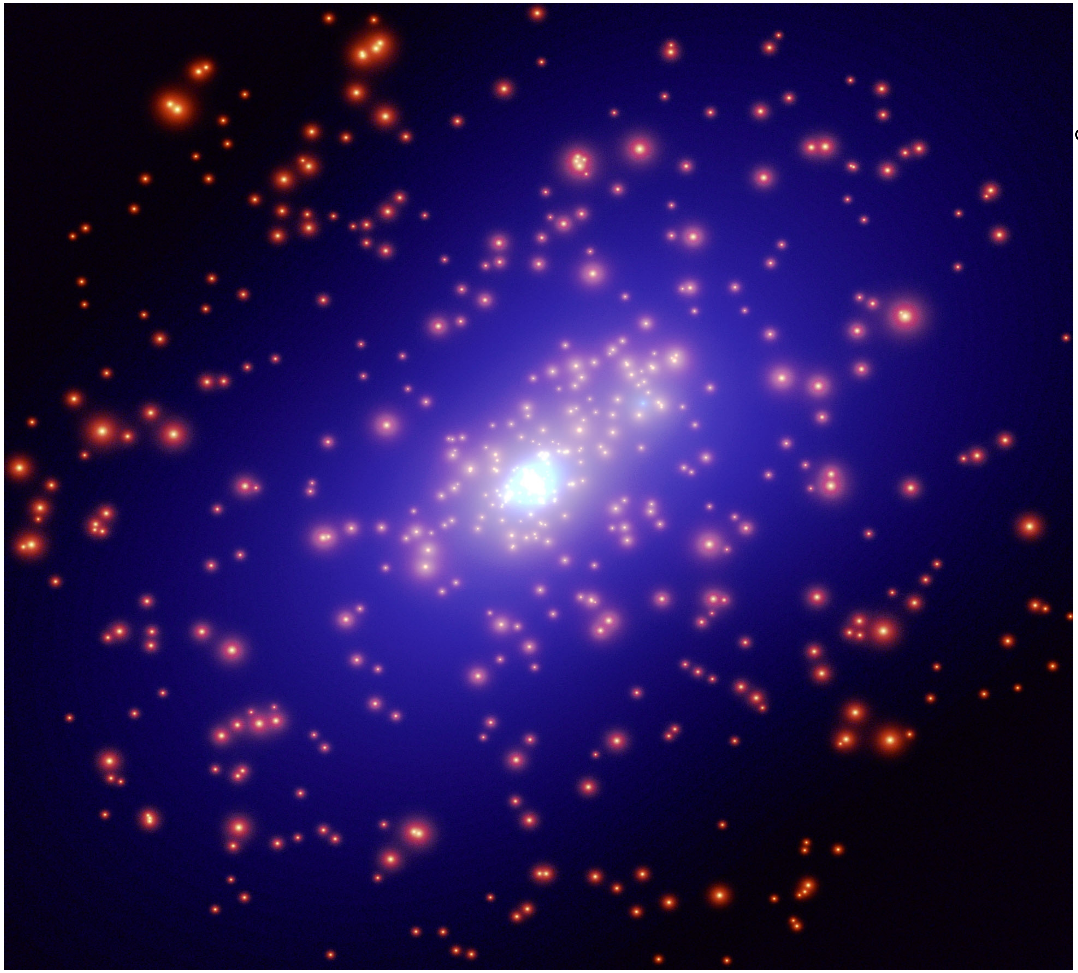


Egorov&Pierpaoli, 2013



Clusters of galaxies

Largest bound structure in the Universe and DM dominated.



ESA image of Cl0024+1654

Possible large boost to the annihilation signal from substructures.

Clusters of galaxies

An excursus to boost factors from substructures..

$$\mathcal{L}_a^{hh}(E,z,M) = E\,\frac{(\sigma_a v)}{2\,M_\chi^2}\int_0^{R_v} d^3r\,\frac{d\tilde{N}_i}{dE}\,[(1-f)\,\rho(M,r,z)]^2$$ for the host halo

$$\mathcal{L}_a^{sh}(E,z,M) = E\,\frac{(\sigma_a v)}{2\,M_\chi^2}\int_{M^s_{cut}}^{M} dM_s\,\frac{dn_s}{dM_s}(M_s,f,M)\int_0^{R_v} d^3r_s\,\frac{d\tilde{N}_i}{dE}\,\rho_s^2(M_s,r_s,z)$$ for subhalos

$$\frac{d\tilde{N}_\gamma}{dE} = \frac{dN_\gamma}{dE},$$ for prompt emission

$$\frac{d\tilde{N}_{\rm syn,IC}}{dE} = 2\int_{m_e}^{M_\chi} dE'\,\frac{P_{\rm syn,IC}}{E}\cdot\tilde{n}_e,$$ for radiative emission .

where $\tilde{n}_e(r,E) = n_e/A$, with $A_a = (\sigma v)/2\cdot(\rho/M_\chi)^2$

Normalization of subhalo mass function

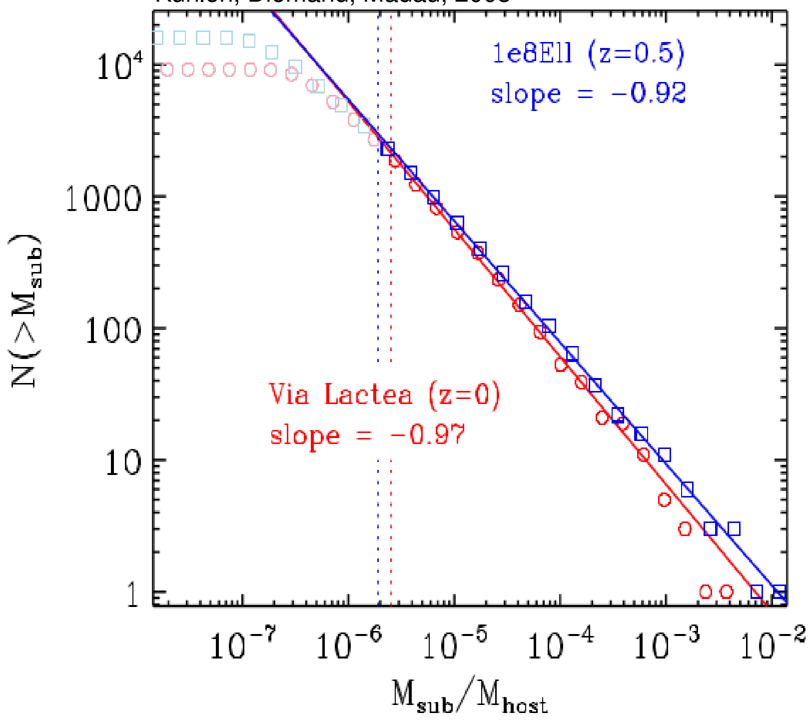
$$\int dM_s\,dn_s/dM_s\,M_s = f\,M$$

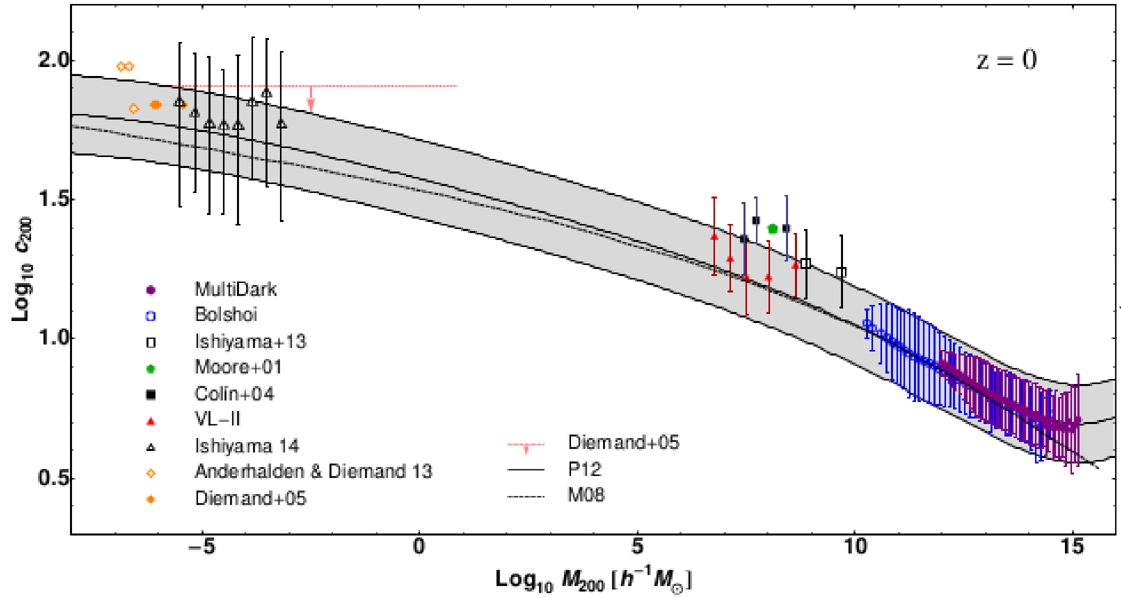
The fraction of mass in subhalos f can be chosen to match the amount of substructure resolved in current simulations (typically ~10%)

Clusters of galaxies

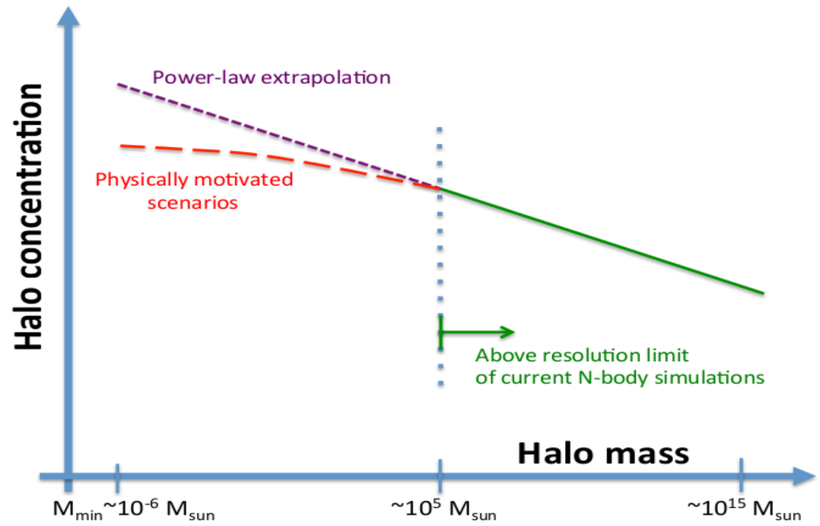
$$\frac{dn_s}{dM_s} = \frac{A(M_{vir})}{M_s^{1.9}}$$

Kuhlen, Diemand, Madau, 2008





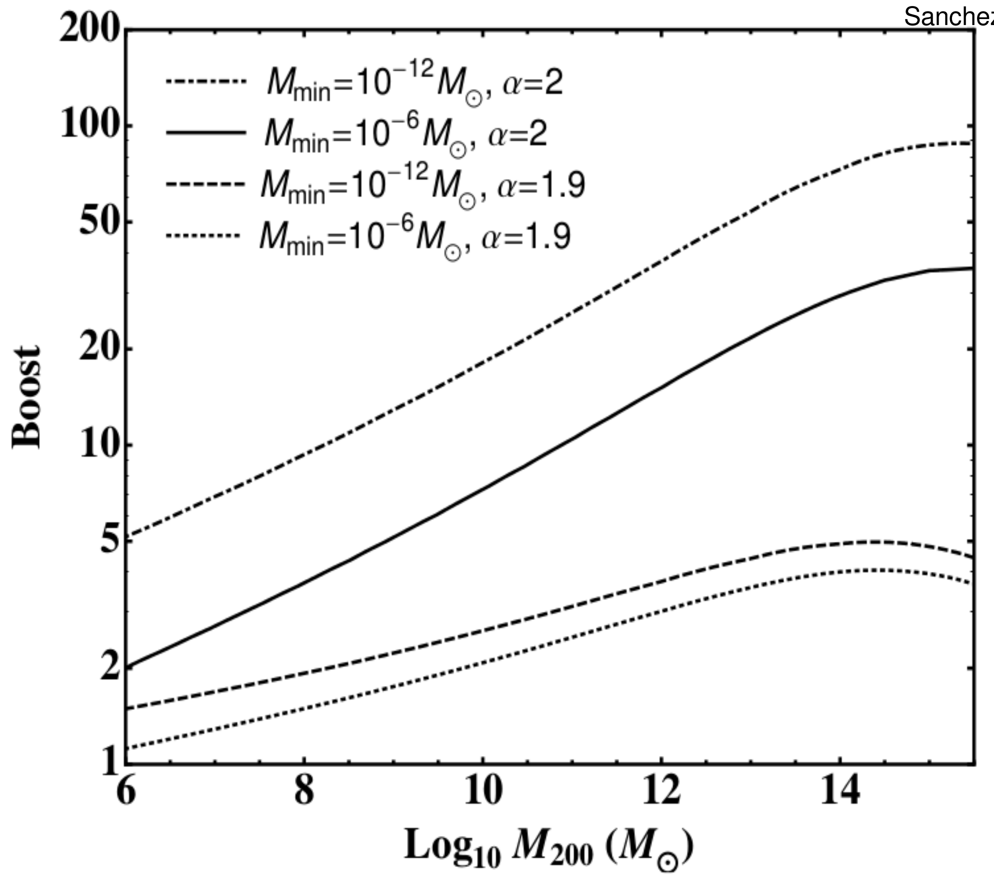
Sanchez-Conde&Prada, 2013

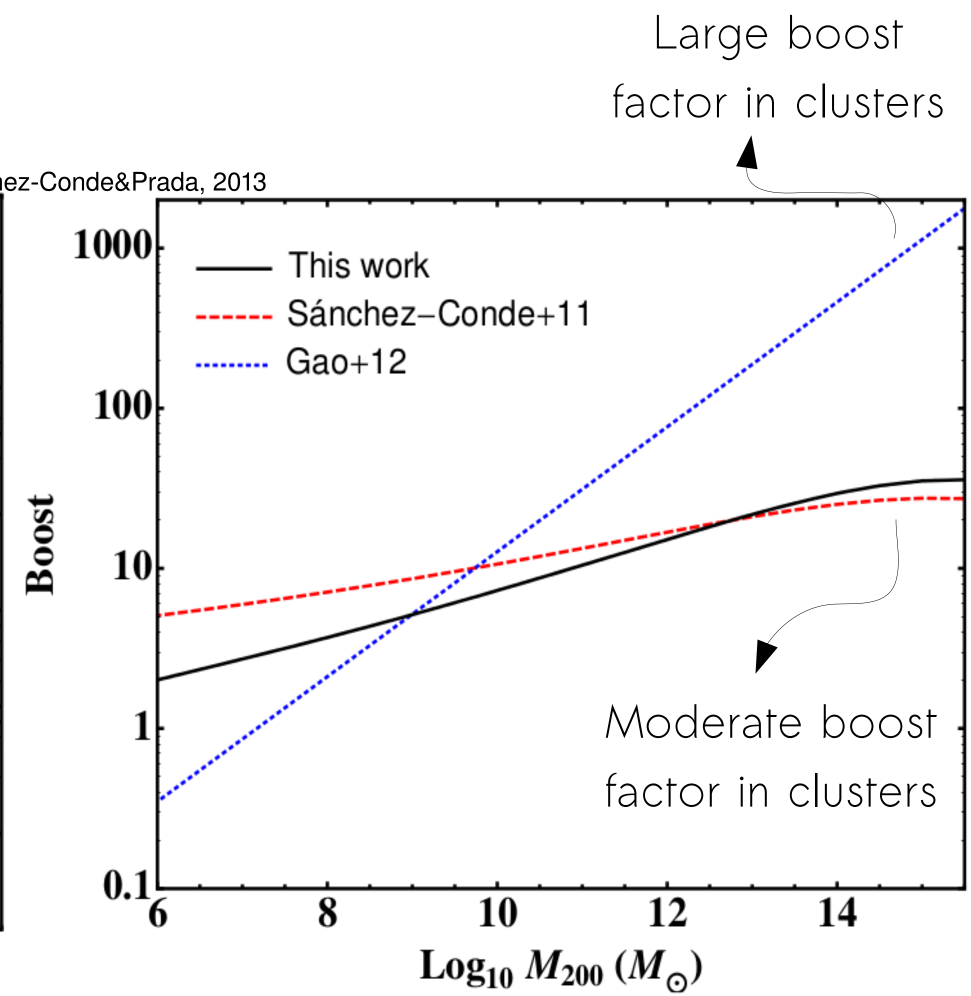


Sanchez-Conde talk, 2014

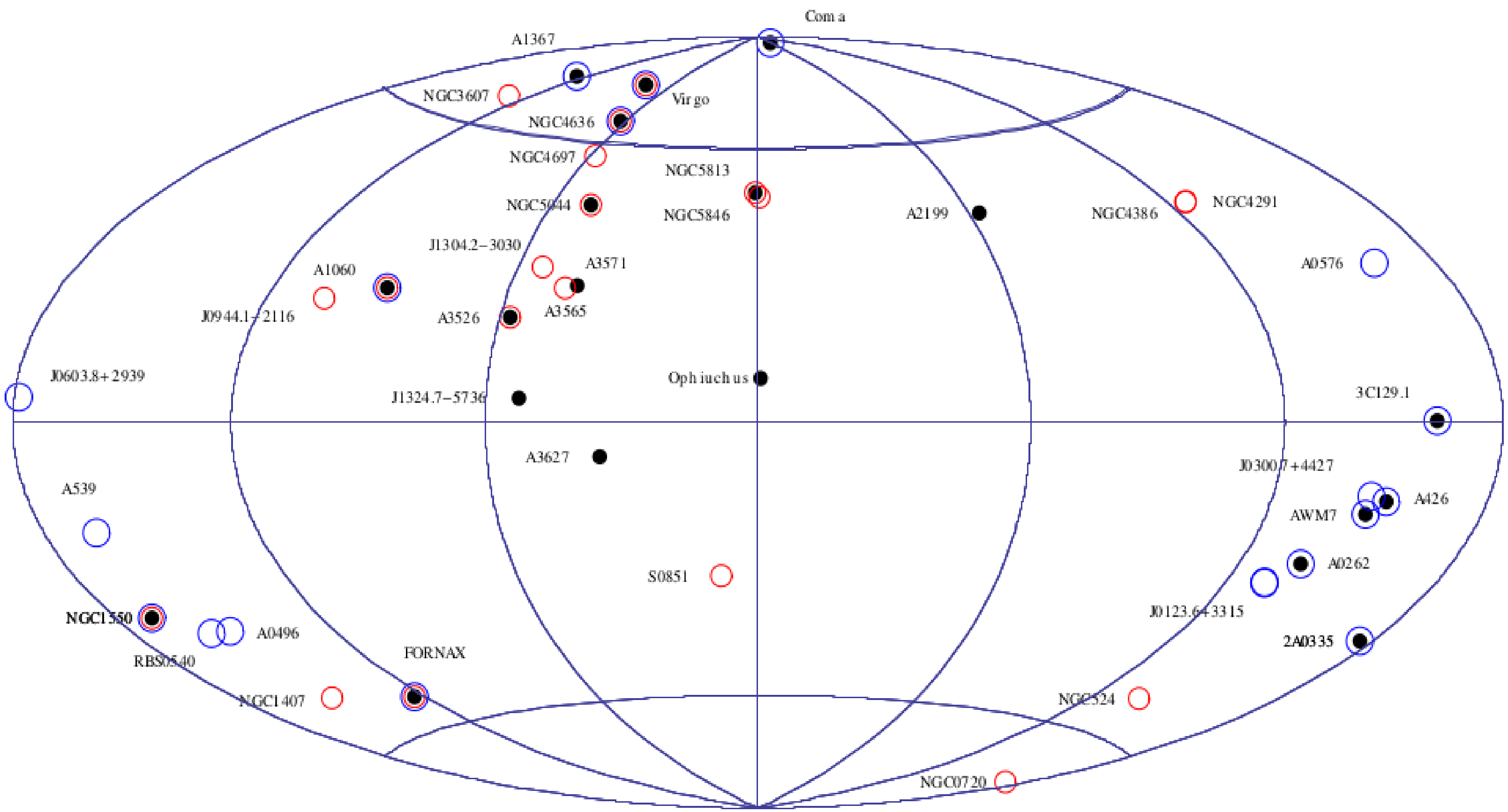
Mass function and concentration parameter have to be extrapolated below about $10^6 M_\odot$

Clusters of galaxies





Clusters of galaxies



20 closest (red circles), brightest (black points), and highest $J/J_{\rm Gal}$ (blue circles)

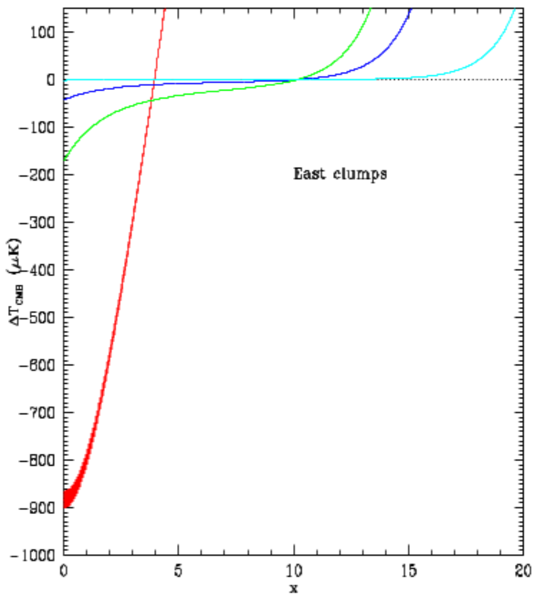
Nearby clusters are the most promising

but some improvements with stacking are possible (Nezri et al., 2012)

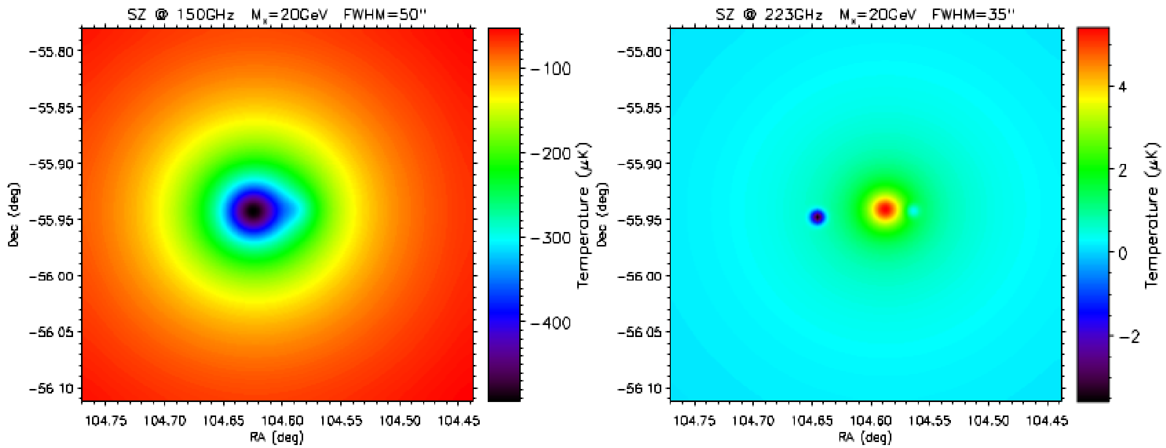
Clusters of galaxies

Additional potential signature provided
by the **non-thermal SZ effect**.
Spatial features of merging clusters
(i.e., Bullet-like systems)


X-ray: M.Markevitch et al.; Optical: D.Clowe et al.; Lensing Map: D.Clowe et al.

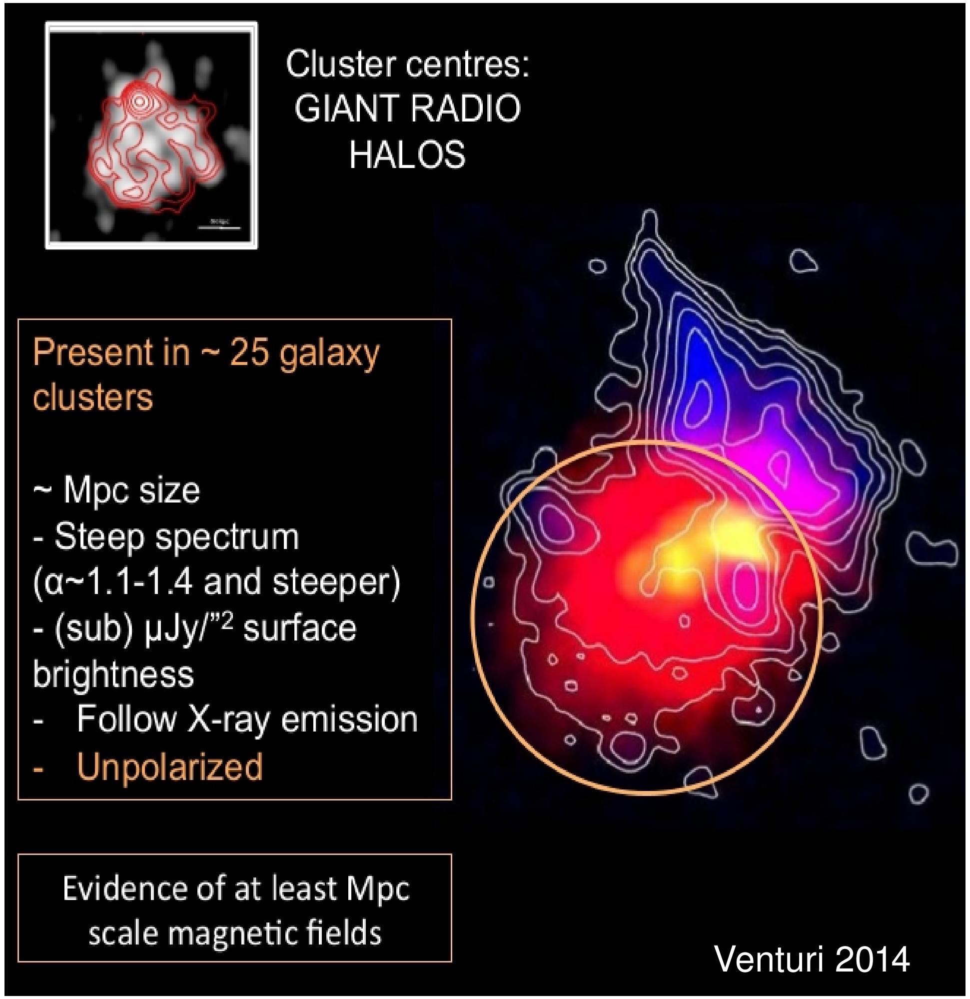


Colafrancesco et al., 2007

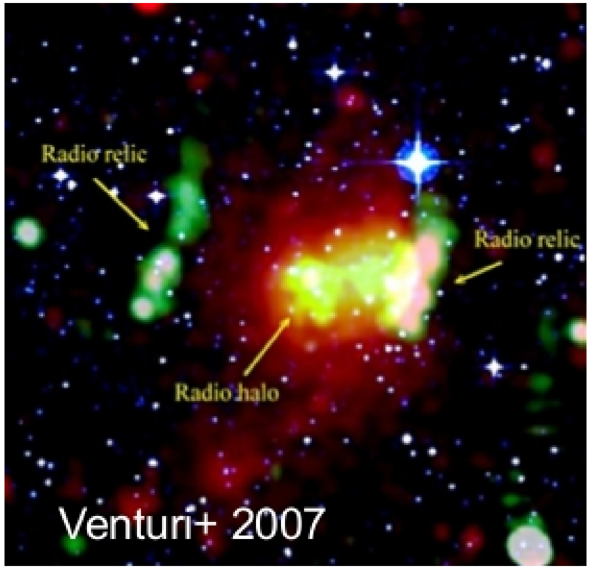


Clusters of galaxies

Complicated systems (needs numerical MHD simulations) and known to host strong CR sources

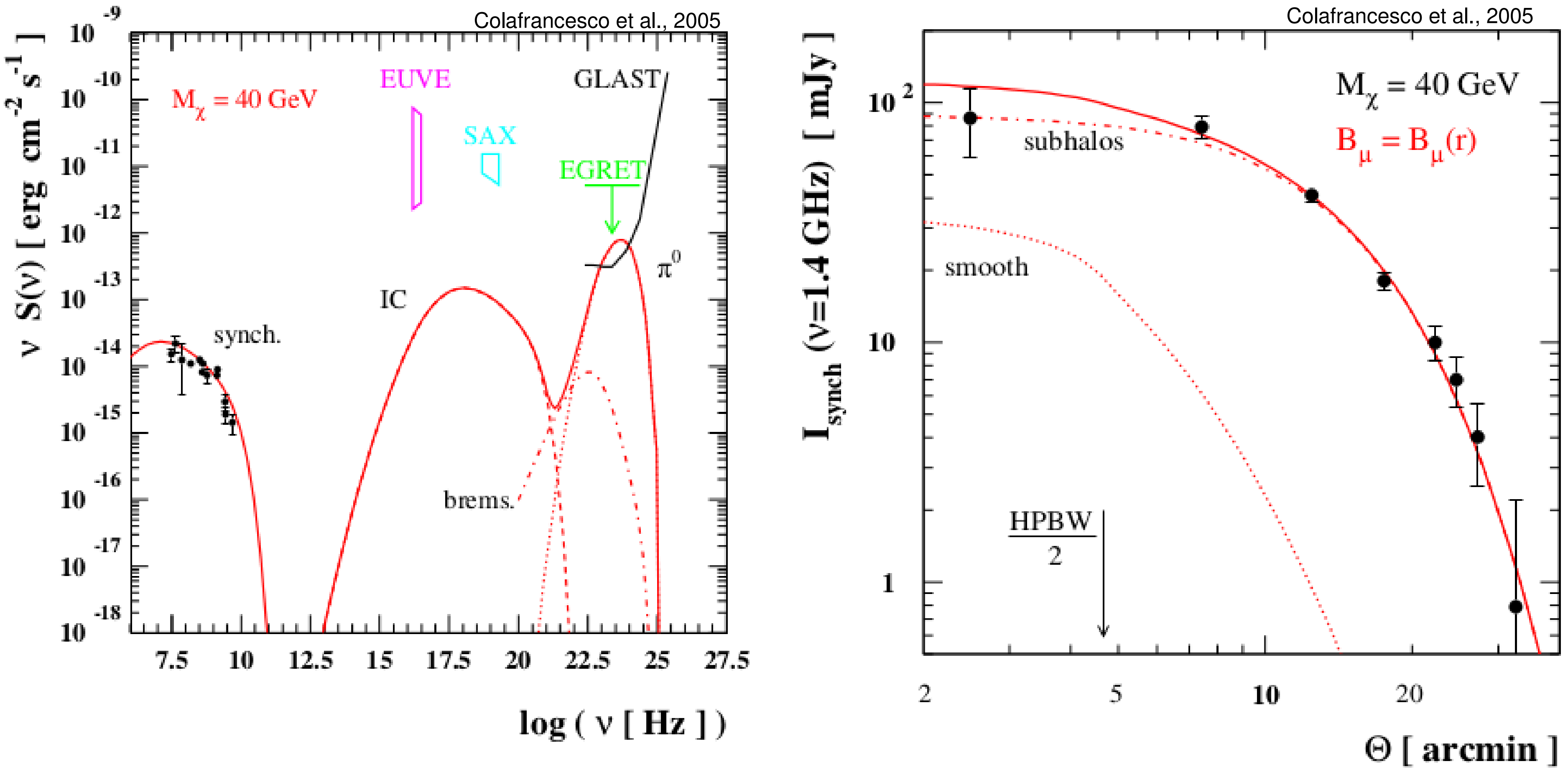


Radio halos (and relics) are far from being fully understood.



Diffuse emission / Clusters

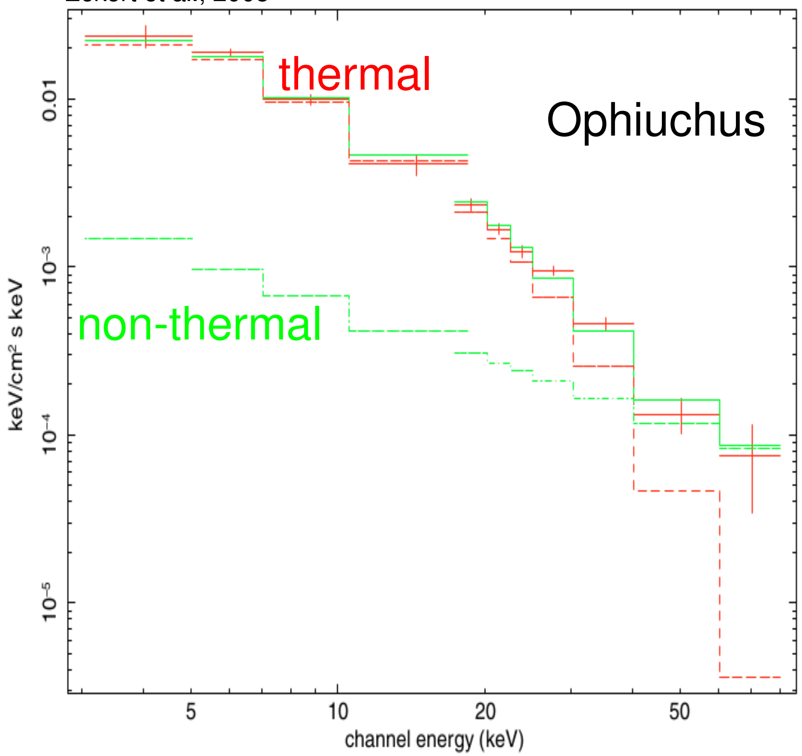
Coma

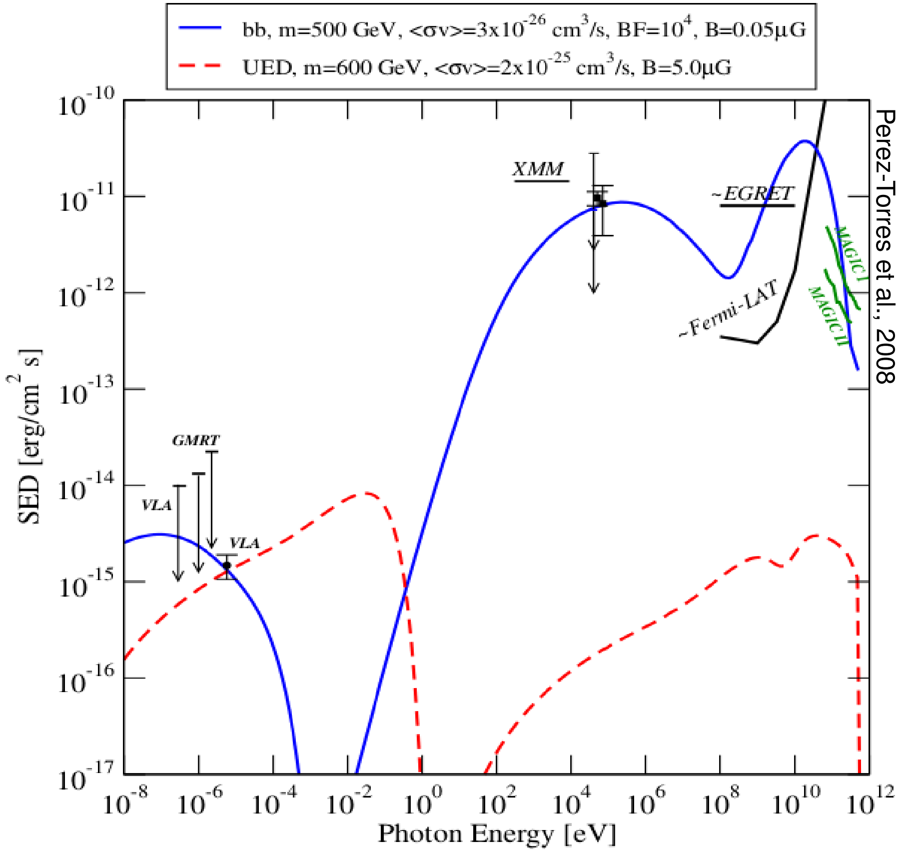


Clusters of galaxies

X-rays typically less sensitive than radio (and gamma-rays) for DM searches (magnetic field ~ 10 μG and energy density of CRs ~ 1 % of thermal ICM)

Eckert et al., 2008



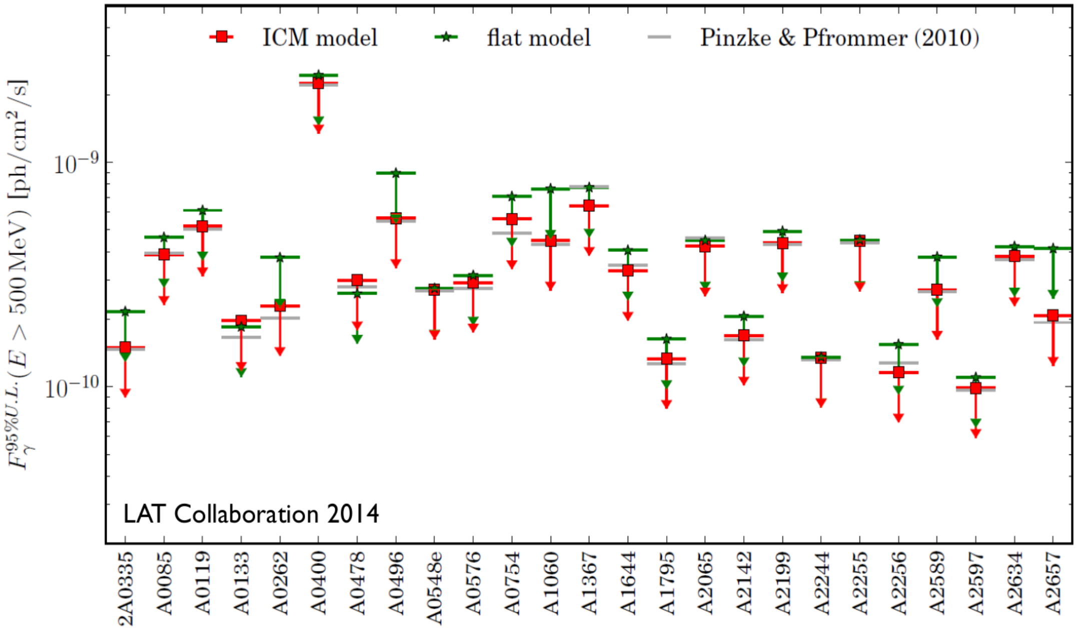


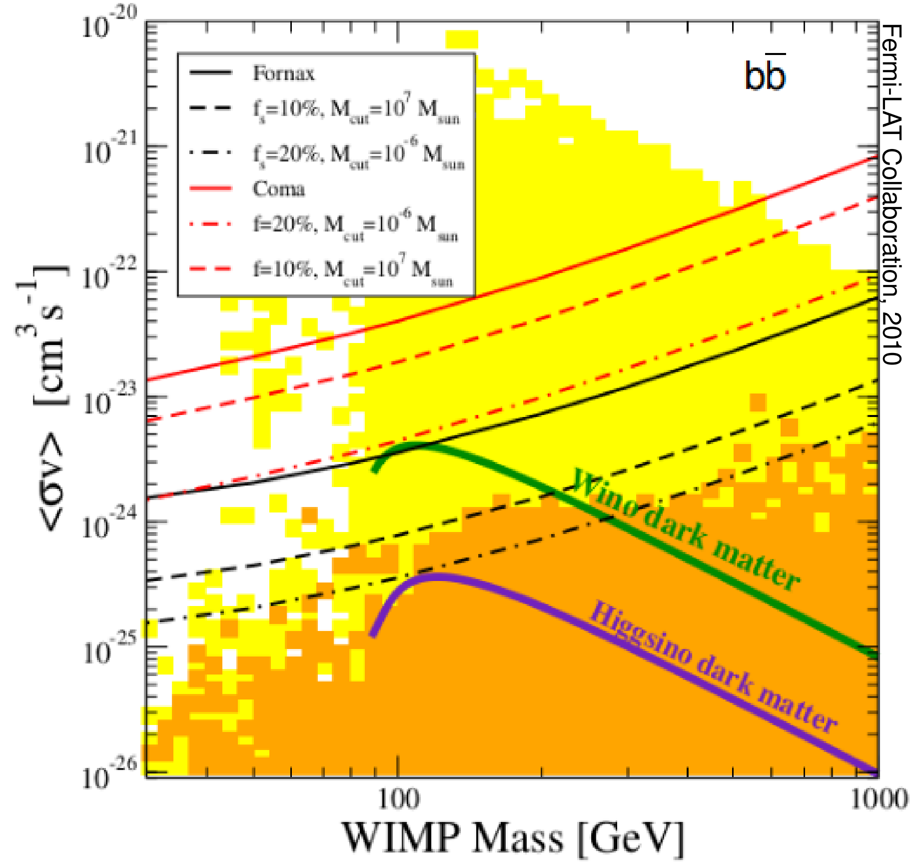
Perez-Torres et al., 2008

Clusters of galaxies

Clusters have been not yet detected by FERMI.

Constraints in particular on **hadronic models**.

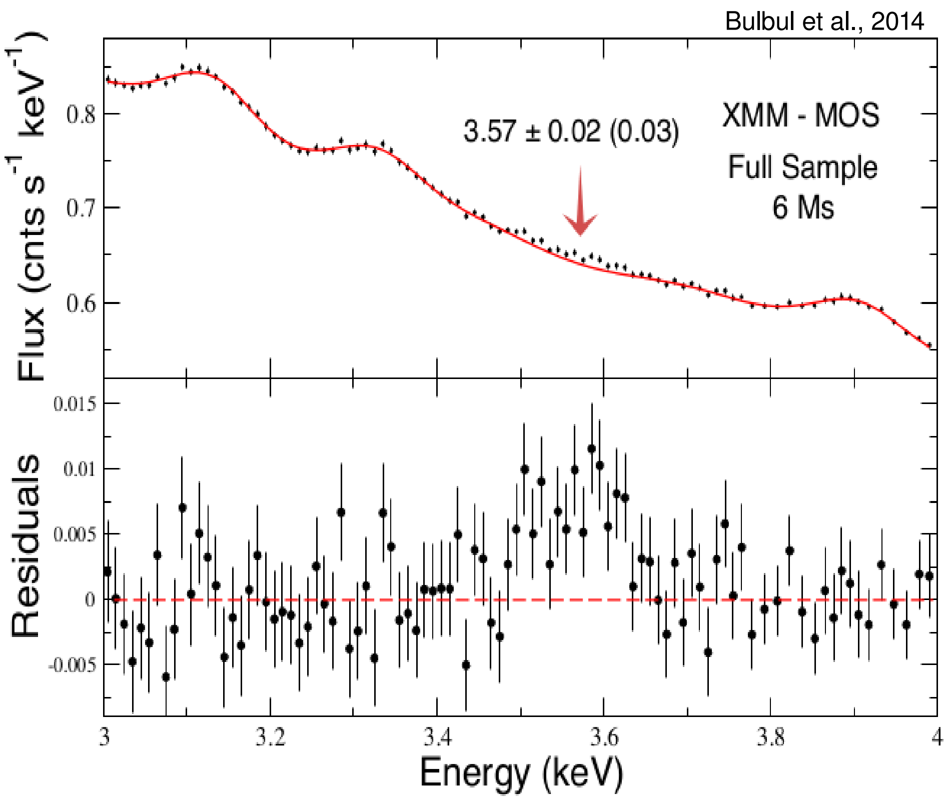




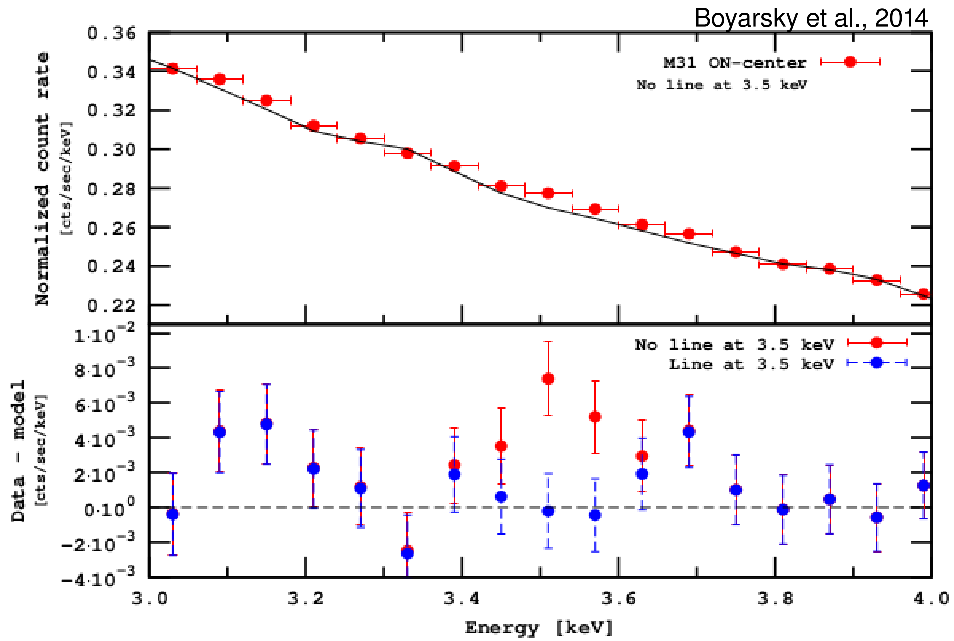
Clusters of galaxies

Unidentified emission line at E = 3.57 keV at 5σ

in a stacked XMM-Newton spectrum of 73 galaxy clusters



Possibly also in Andromeda



A number of open question for the DM interpretation but interesting possibility.