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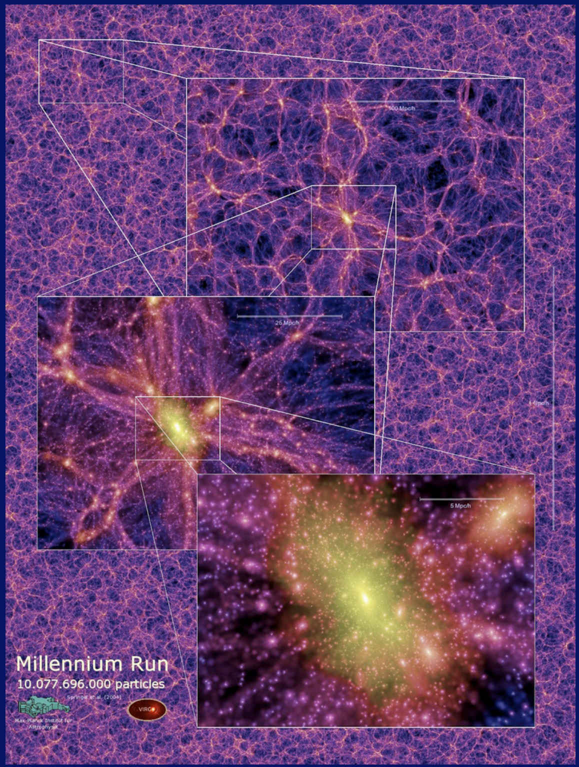
Observational Cosmology and Astroparticle Physics

Research Program

Research theme: using the evolution of large-scale structure to reveal the fundamental nature of the universe

Topics including:

- Cosmology
- Indirect Dark Matter Detection
- Galaxy Evolution

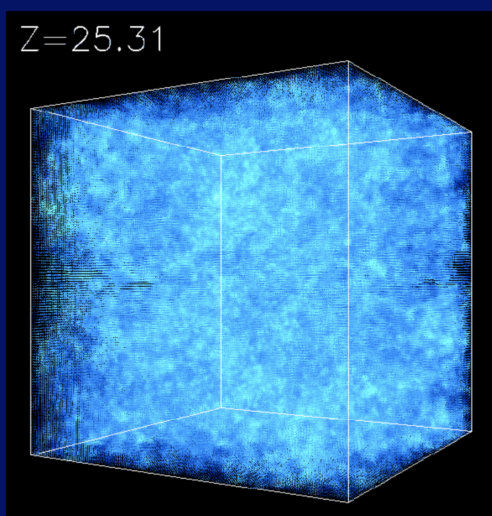


Cosmology with Galaxy Clusters

Clusters of Galaxies

- Clusters represent the high-density tail of initial perturbations and have only recently collapsed

- Masses around 10^{15} $M_{\odot}$, of which ~ 2% in stars, ~ 13% in hot gas, ~ 85% in dark matter



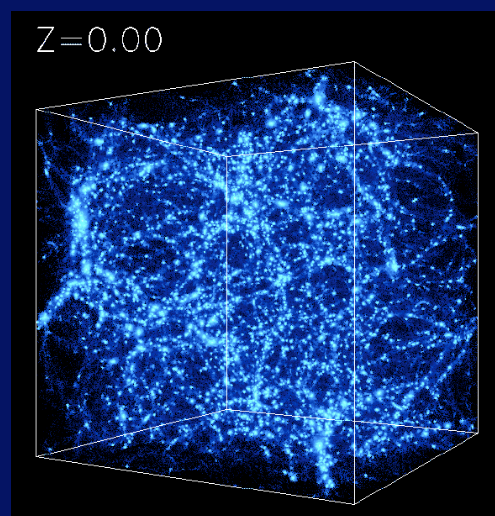
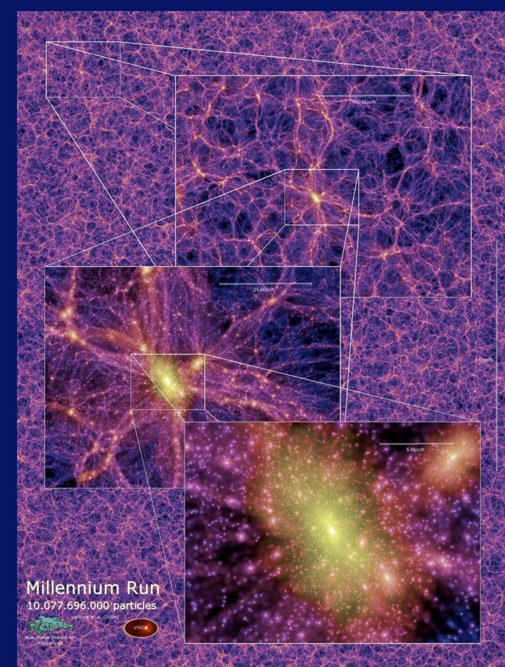


Image credit D. Nagai



Springel et al. 2004

Cosmology with Clusters

Clusters offer two methods to constrain cosmology:

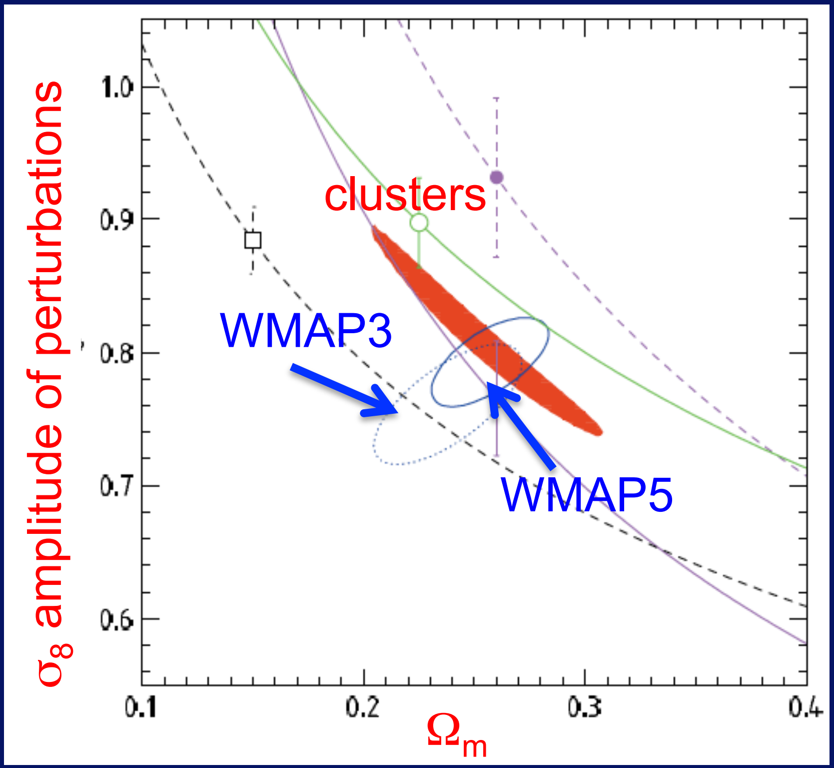
1. A growth of structure test

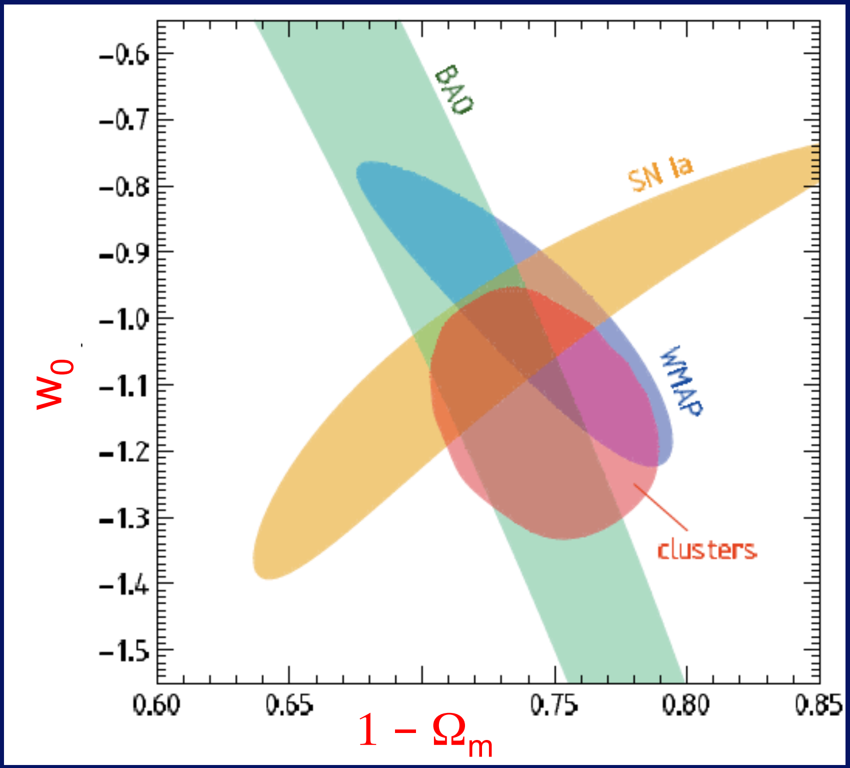
   The evolution in cluster number density with redshift constrains the amplitude of density fluctuations and the dark matter and dark energy densities.

2. A geometric test

   The fraction of cluster mass in baryons is constant with redshift, giving a standard ruler which constrains the dark matter and dark energy densities.

Example of Current Constraints



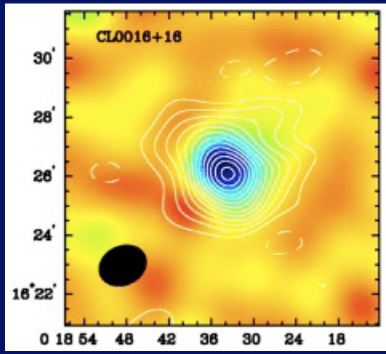


Vikhlinin et al. 2009

A Bright Future: Large Surveys

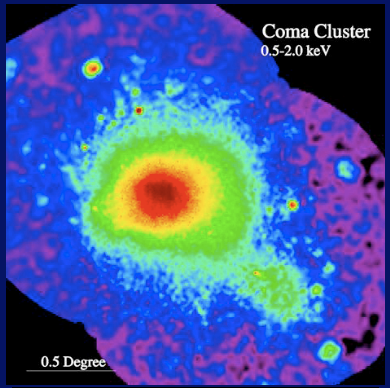
- Sunyaev-Zeldovich Effect: SPT, ACT, Planck

  - inverse Compton scattering of CMB off hot ICM
  - roughly redshift independent



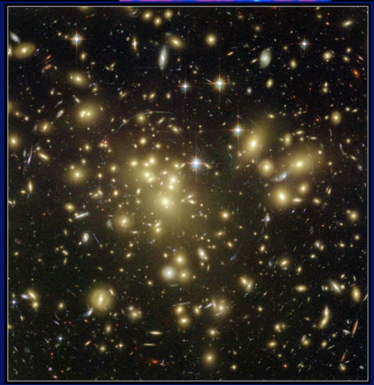
- X-ray: eROSITA (all sky), ATHENA (?)

  - thermal bremsstrahlung from hot gas



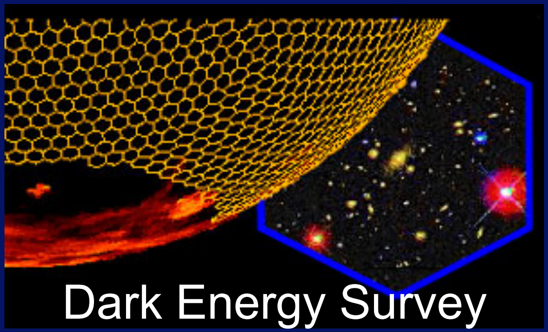
- Optical: DES, LSST
  (plus spectroscopic like BigBOSS)

  - distribution of galaxies
  - weak lensing



A Bright Future

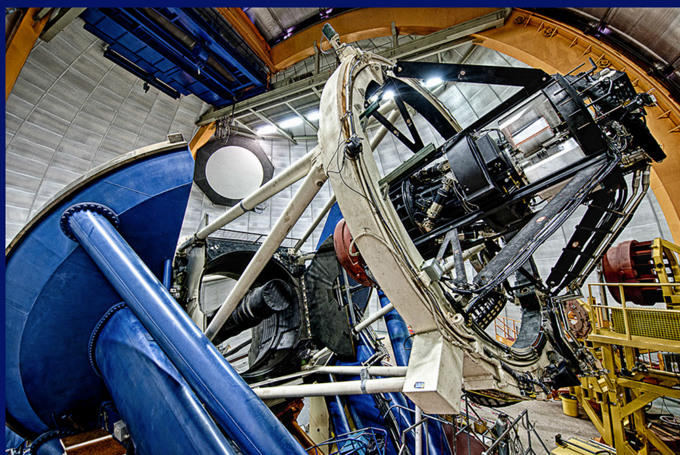
- Large area surveys
  - ➔ great statistics

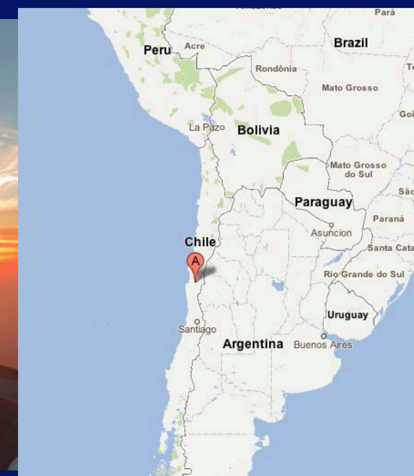


- Multiwavelength follow-up and cosmological simulations
  - ➔ good control of systematics, selection

e.g. Enzo simulations, joint Chandra and CHFT weak lensing, X-ray and Keck follow-up of DES

The Dark Energy Survey





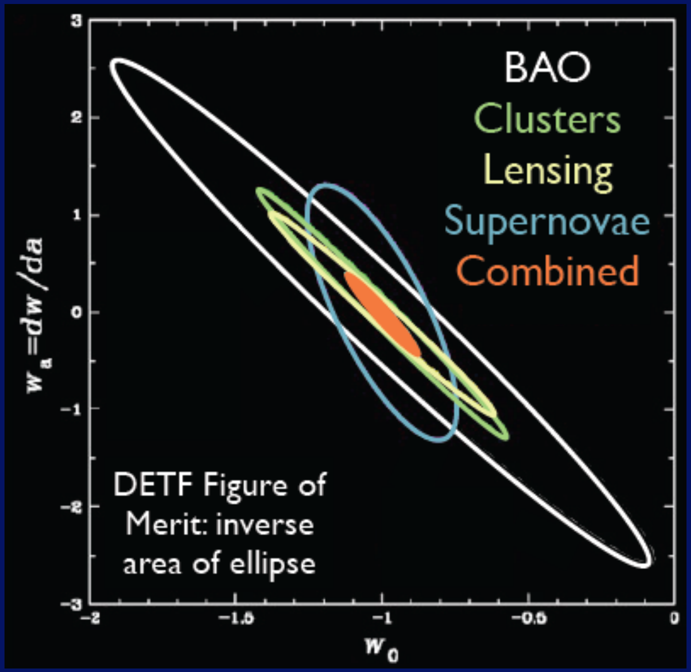
DECam on the Blanco 4m at CTIO

- Optical imaging survey with 4-m Blanco telescope at CTIO in Chile
- 5000 deg^2 (1/8 of the full sky) in grizY bands
- 30 deg^2 SNe fields revisited
- DECam: 570 Megapixel Camera with 3 deg^2 FOV
- Runs 2013-2018, 525 nights

Cosmology with the Dark Energy Survey

Four ways to constrain cosmology:

- Clusters of Galaxies
- Gravitational Lensing
- Baryon Acoustic Oscillations
- Supernovae



Will give a factor of 5 improvement in the Dark Energy Task Force figure of merit.

Cosmology with DES Clusters

Constraints on dark energy:

The number of clusters which form depends on the balance between gravity and dark energy (also effects volume).

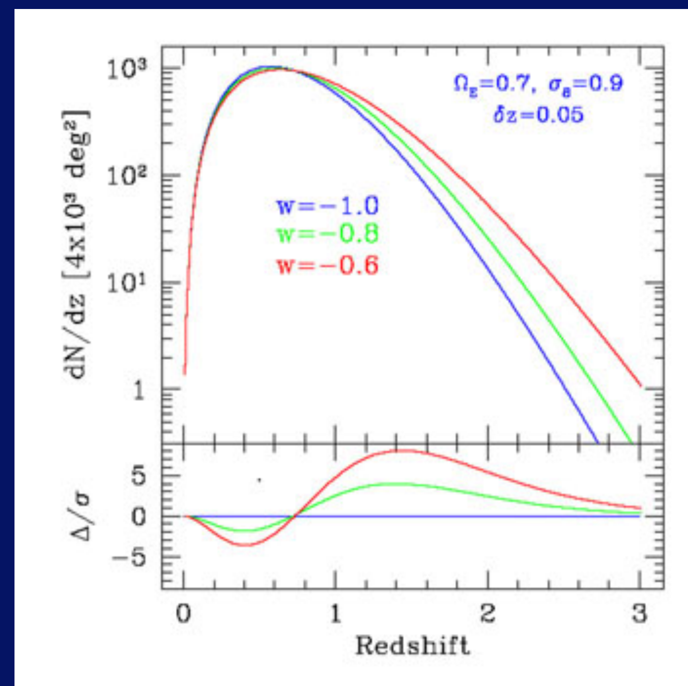
- DES will detect ~100,000

$$\frac{d^2N(z)}{dz\,d\Omega} = \frac{c}{H(z)} D_A^2 (1+z)^2 \int_0^\infty f(M,z) \frac{dn(z)}{dM} dM$$

- I am primarily involved in the DES cluster survey including science verification and cluster follow-up.

hard part:

understanding the relationship between observables and cluster mass



Multiwavelength Cluster Observations

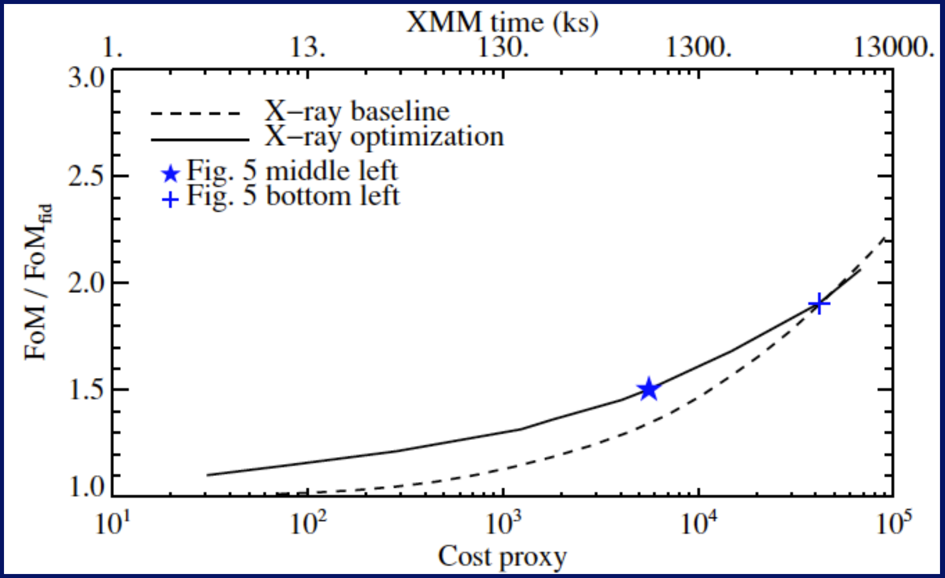
➢ Relatively small follow-up programs giving a low scatter observable can give a factor of ~ 2 improvement in DETF FoM from DES alone.

scatter in
richness-mass relation

~ 30%

scatter for
X-ray, SZ observables

~ 7-10%



Wu, Rozo, & Wechsler 2010

DES Cluster Mass Calibration

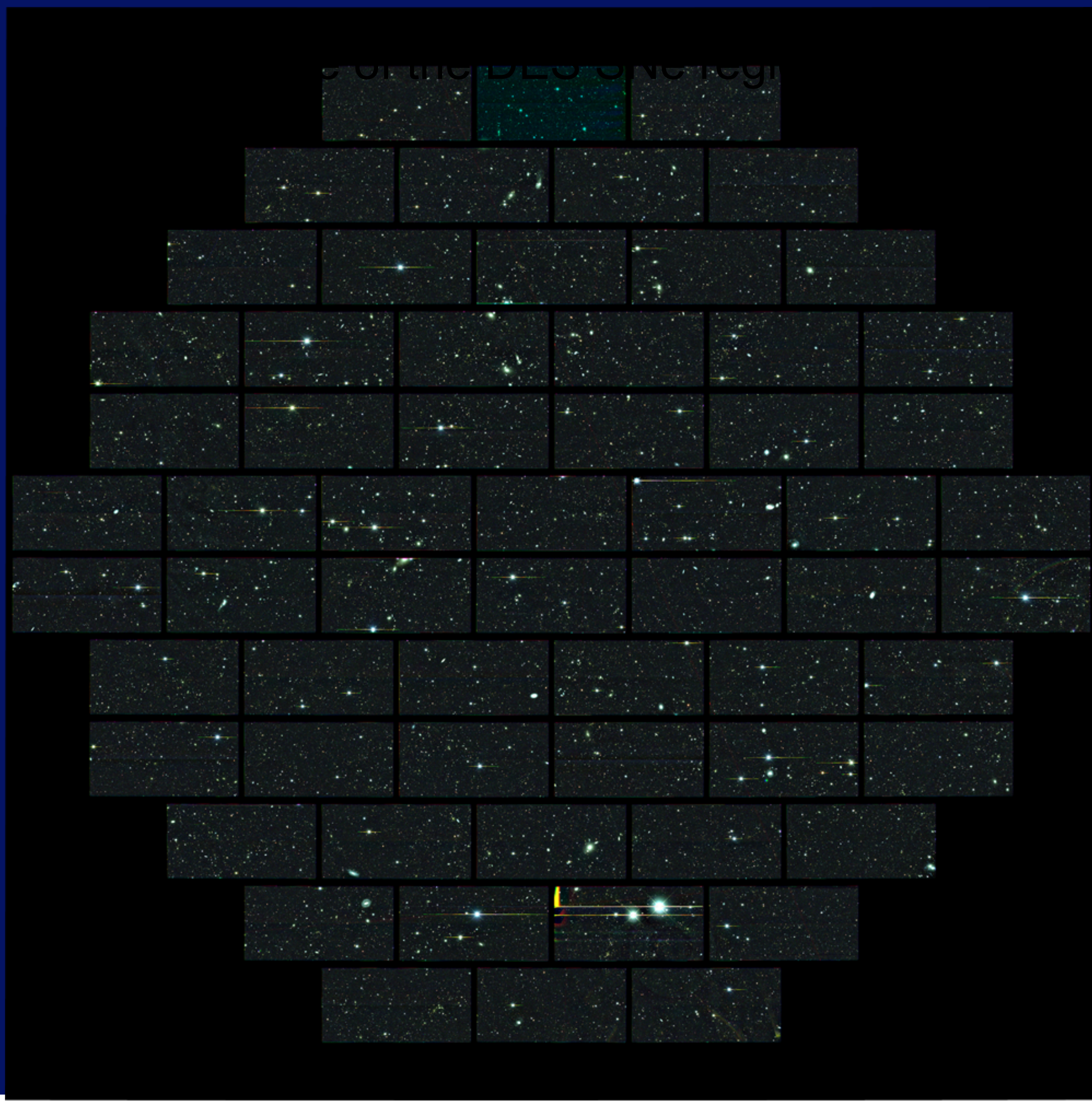
Calibrate optical richness (DES observable) with:

- Simulations, self-calibration, and weak lensing from DES alone

- Overlapping surveys: SPT (SZ) and eROSITA (X-ray)

- Dedicated follow-up of relatively small sub-samples (100-1000 clusters) with current telescopes
  - X-ray follow-up with Chandra and XMM
  - spectroscopic follow-up with Keck

DES Survey Underway!



Survey Start
August 31, 2013

DECam image of
NGC1398 in Fornax cluster

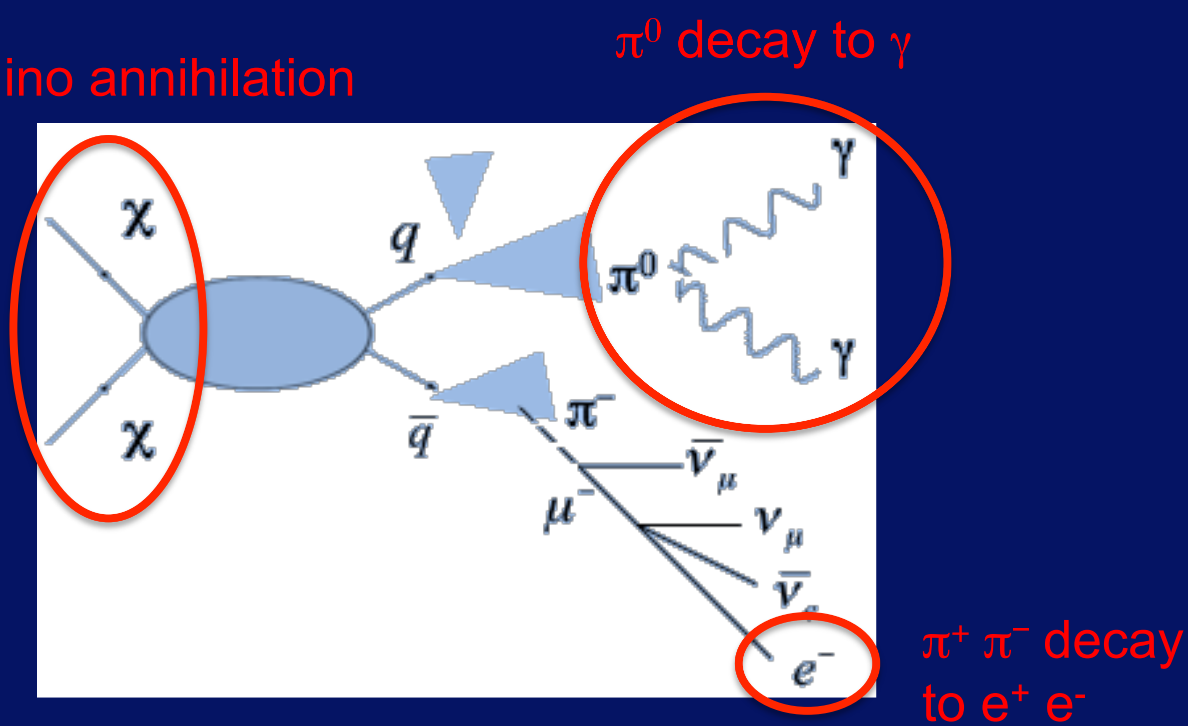
DES Timeline

- Imager installation: Aug. 30, 2012
- First light: Sept. 12, 2012
- Commissioning: late Aug. to Oct. 2012
- Science Verification: Nov 2012 – Feb 2013

  ~115 deg^2 of data to full depth are now public
- First season: started August 31, 2013
- Raw DES survey data public after 12 months
- 2 public releases of DES coadd images & catalogs

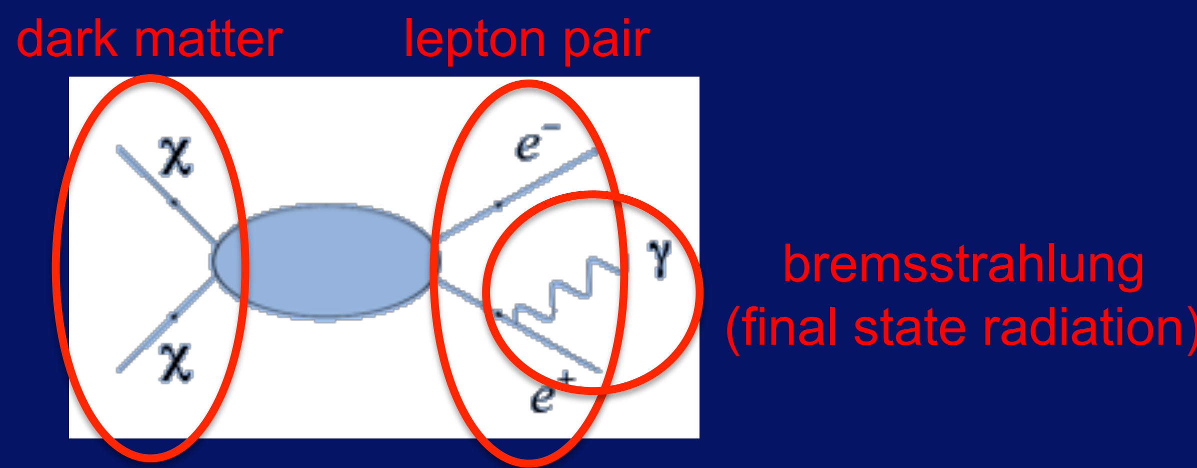
Indirect Detection of Dark Matter

Products of Dark Matter Annihilation



- Dark matter annihilation and decay can produce gamma-rays and high energy electrons and positrons.

Products of Dark Matter Annihilation



Lepton pair production

- Dark matter annihilation and decay can produce gamma-rays and high energy electrons and positrons.

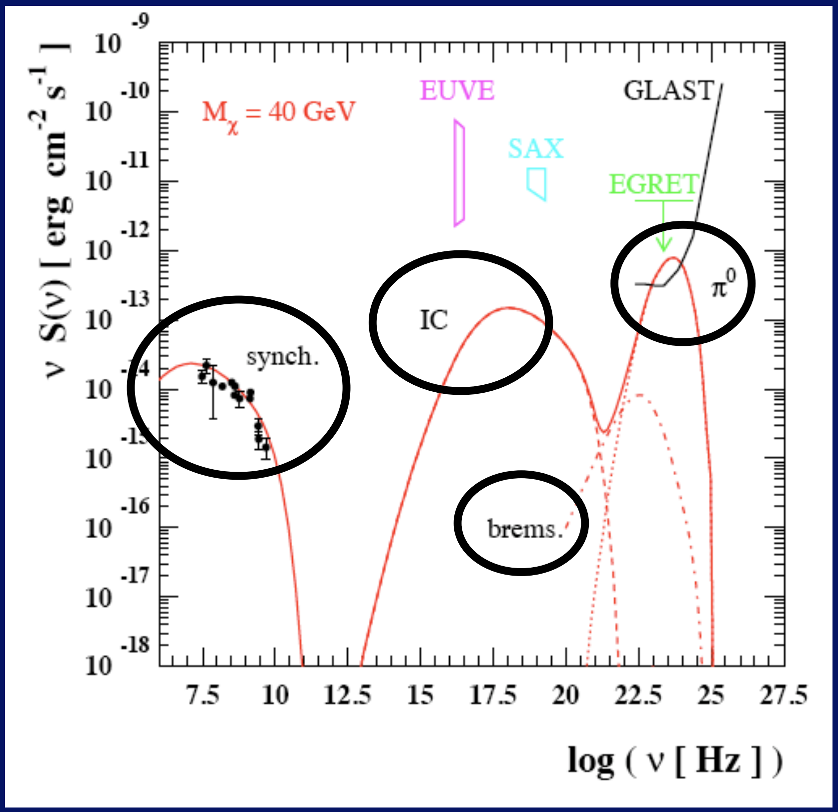
Observing Dark Matter

- Dark matter annihilation/decay can lead to a broad spectrum of emission.

Gamma-ray: π^0 decay, direct production

X-ray: IC scattering of CMB by energetic e^+e^- produced

Radio: synchrotron emission in a magnetic field



Example spectrum of DM annihilation in the Coma cluster (Colafrancesco et al. 2006)

Gamma-Ray Searches with Fermi

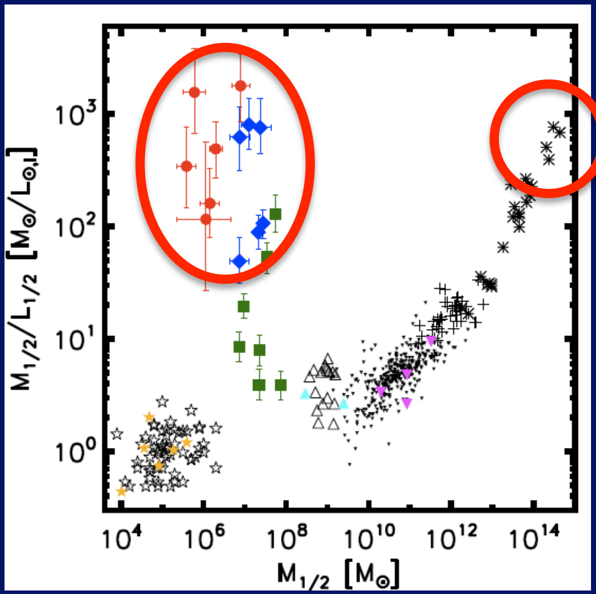
Dwarf spheroidal galaxies give strong constraints on dark matter annihilation.

Clusters of galaxies constrain:

- dark matter decay
- leptophilic dark matter when IC emission dominate (models fitting the PAMELA positron excess)

(Abdo et al. 2010; Ackermann et al. 2010; Dugger, Jeltema, & Profumo 2010; Ackermann et al. 2011)

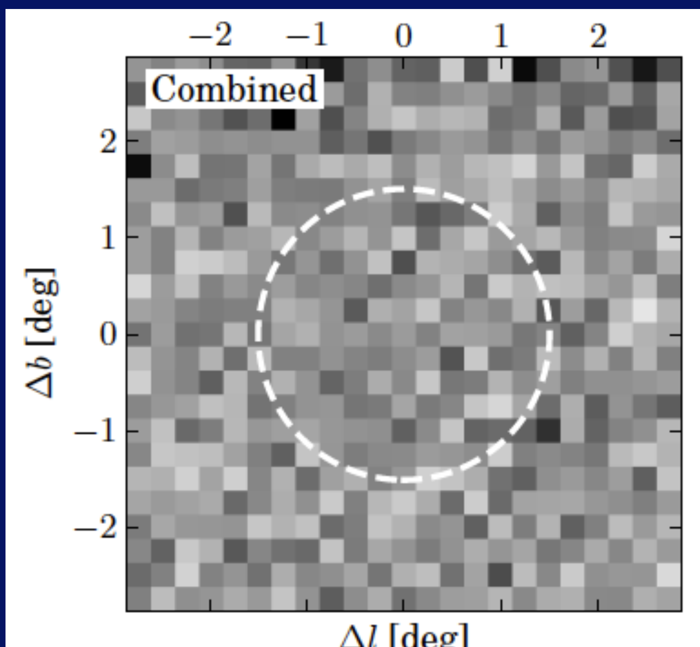
dwarfs clusters

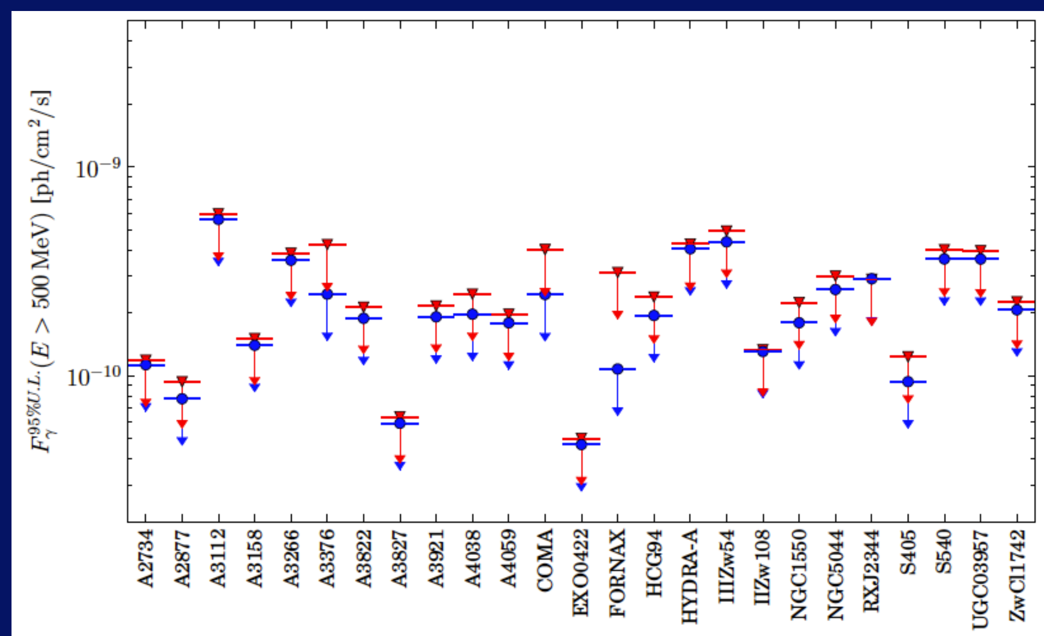


Wolf et al. 2009

Upcoming from Fermi: Cluster Stacking

➢ Fermi does not detect gamma-ray emission from clusters even for a joint fit of 50 clusters with 4 years of data.

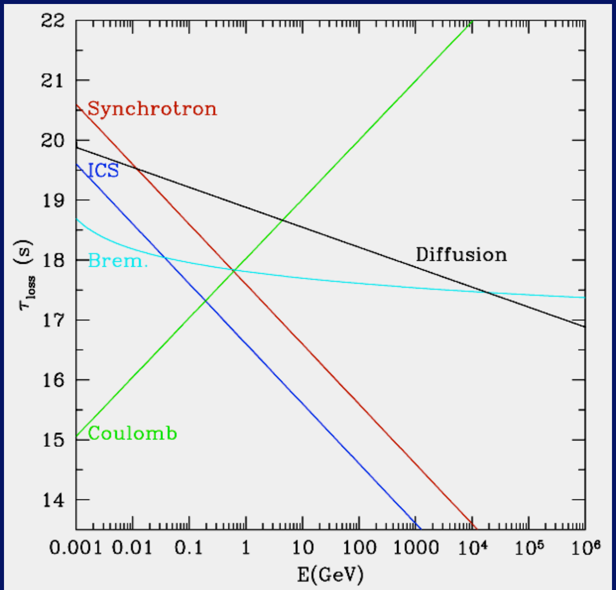




Ackermann et al. 2013, arXiv:1308.5654

Multiwavelength Dark Matter Searches

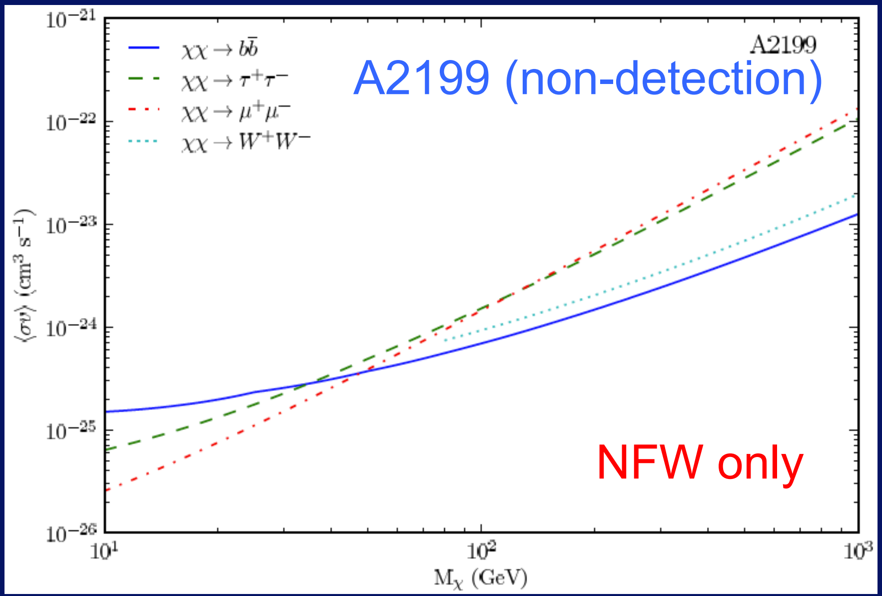
- Clusters are excellent targets for searches for secondary synchrotron and IC radiation:
  1. The energy loss timescale is much shorter than the diffusion time
  2. They have large-scale magnetic fields

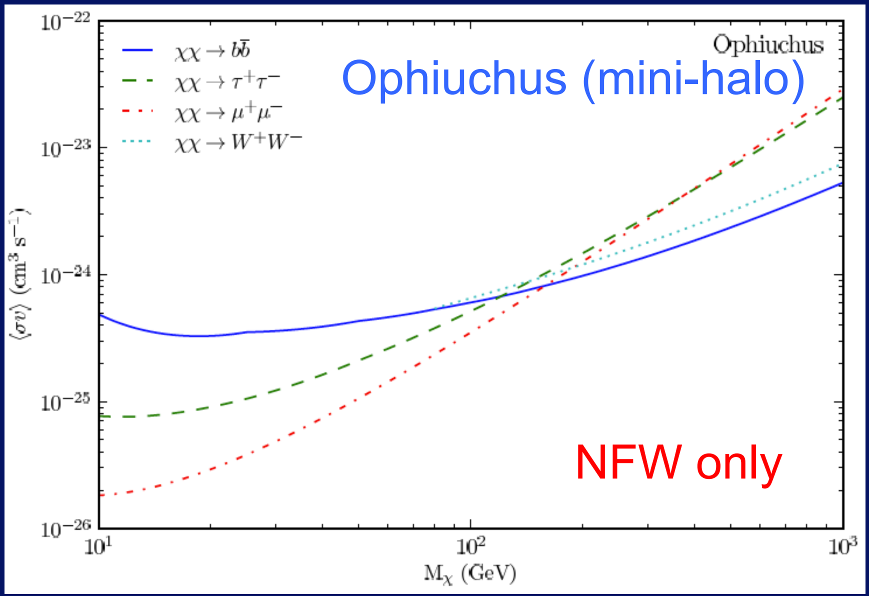


Colafrancesco et al. 2006

Radio Observations of Clusters

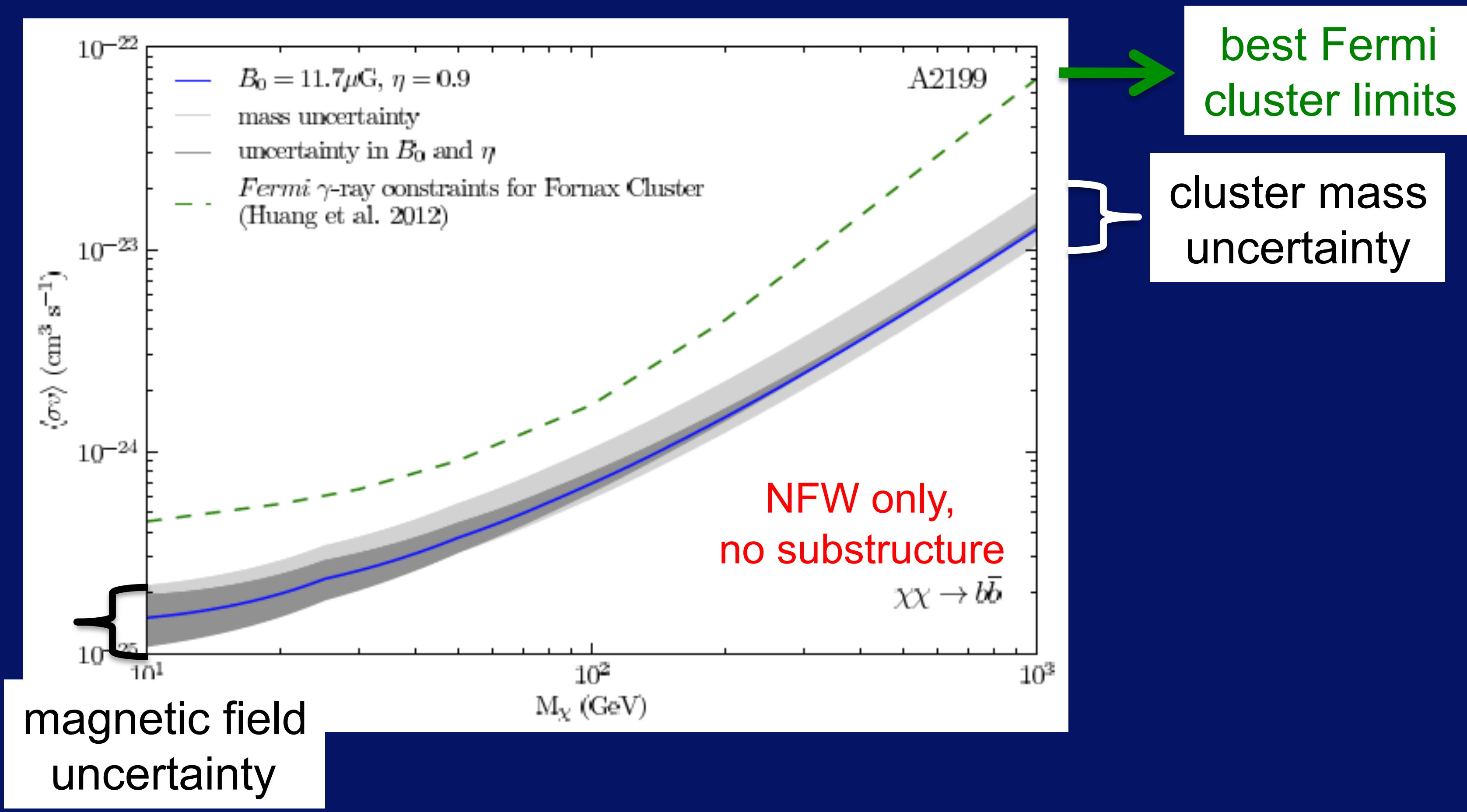
- The non-detection or weak detection of radio emission from nearby clusters places stronger limits on DM annihilation than current Fermi
- At low mass, limits approach thermal cross-section even for conservative density profile





Storm, Jeltema, Profumo, & Rudnick 2013

Dark Matter Annihilation Limits

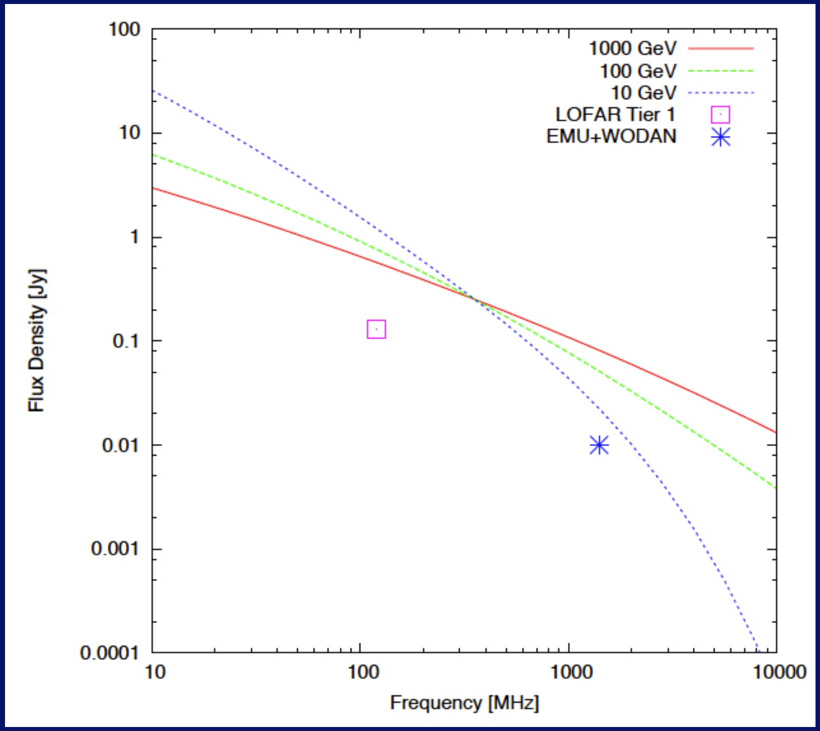


Storm, Jeltema, Profumo, & Rudnick 2013

Future Radio Observations

Large near term gains from:

- New low frequency capabilities (LOFAR, LWA)
- Increased sensitivity at GHz frequencies (ASKAP, APERTIF, MeerKAT)

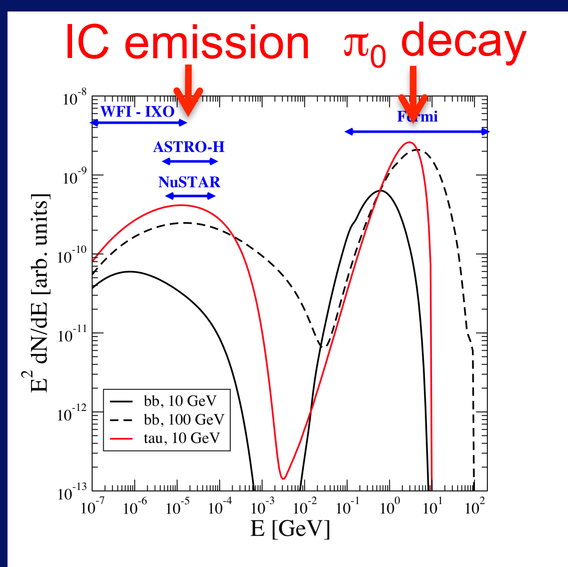


Order of magnitude gains from planned surveys alone!

X-ray Emission from Dark Matter

- For a range of DM models, IC emission from the scattering of the CMB by the $e^+ e^-$ produced peaks in the hard X-ray band.

- Again clusters are a good target – diffusion negligible, thermal X-ray emission drops off steeply at high energy



Jeltema & Profumo 2012

- Planned X-ray telescopes will have (at best) similar sensitivity to Fermi.

Dark Matter Summary

- Observations of clusters across the electromagnetic spectrum can probe dark matter models

- Gamma-ray: Strong constraints on decay and leptophilic models, upcoming gains from stacking

- Radio: Current constraints are competitive with gamma-ray in some cases, and new facilities are imminent

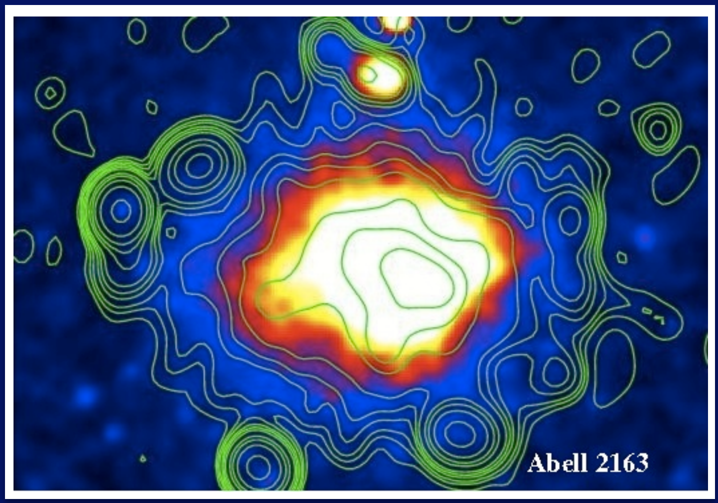
- X-ray: limits are not currently competitive, but could be with an appropriately planned telescope.

- A multiwavelength approach is highly complementary to future high energy gamma-ray searches

Cosmic Rays in Clusters

➢ Accelerated in accretion/merger shocks, AGN, and SNe

➢ Radio synchrotron emission from CR electrons in the cluster magnetic field observed on Mpc scales!



➢ Gamma ray emission
- CR proton collisions with ICM
- IC scattering by CR electrons

➢ Constrain the CR density and origin of the radio emission using gamma-ray observations (Jeltema & Profumo 2011; Ackermann et al 2013; Storm et al. in prep)