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Observational Cosmology and Astroparticle Physics

SCIPP
SANTA CRUZ INSTITUTE FOR PARTICLE PHYSICS

Fermi
Gamma-ray Space Telescope

DARK ENERGY SURVEY

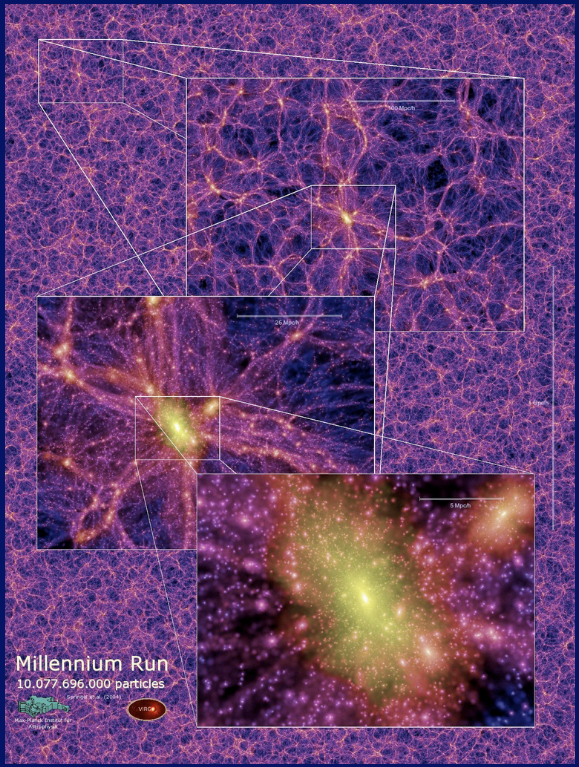
LICK OBSERVATORY

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

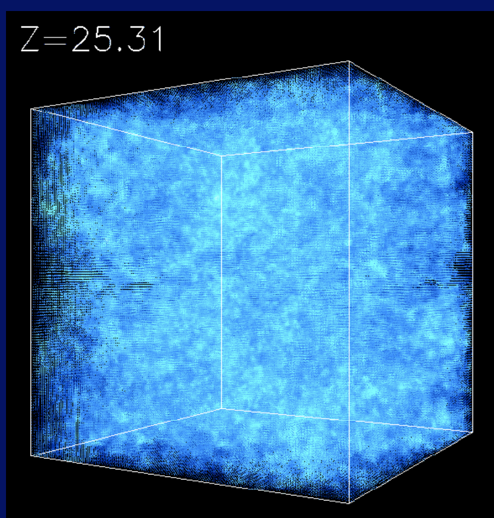


Cosmology with Galaxy Clusters

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



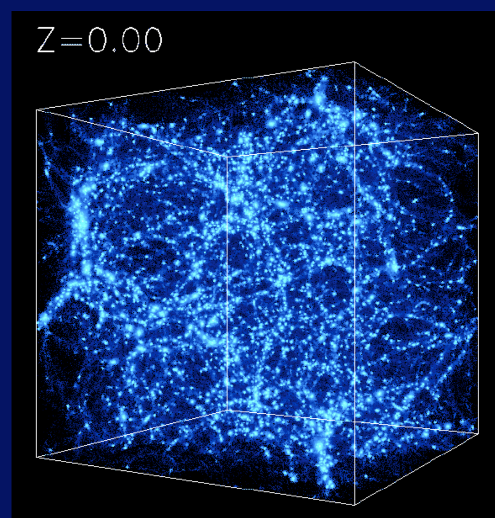
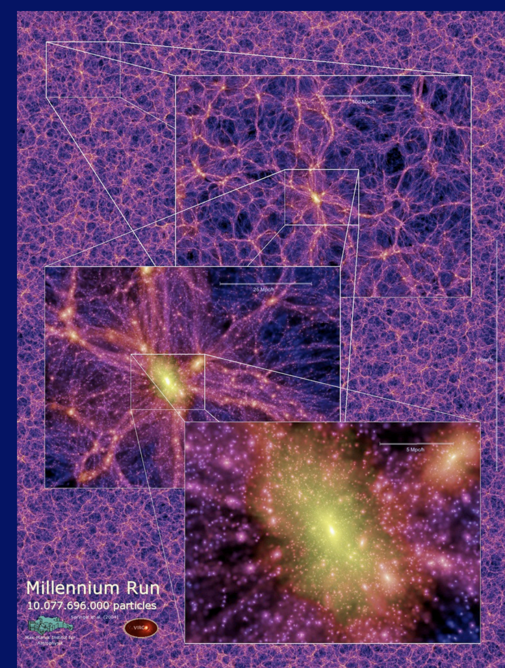


Image credit D. Nagai



Springel et al. 2004

Cosmology with Clusters

Clusters offer two methods to constrain cosmology:

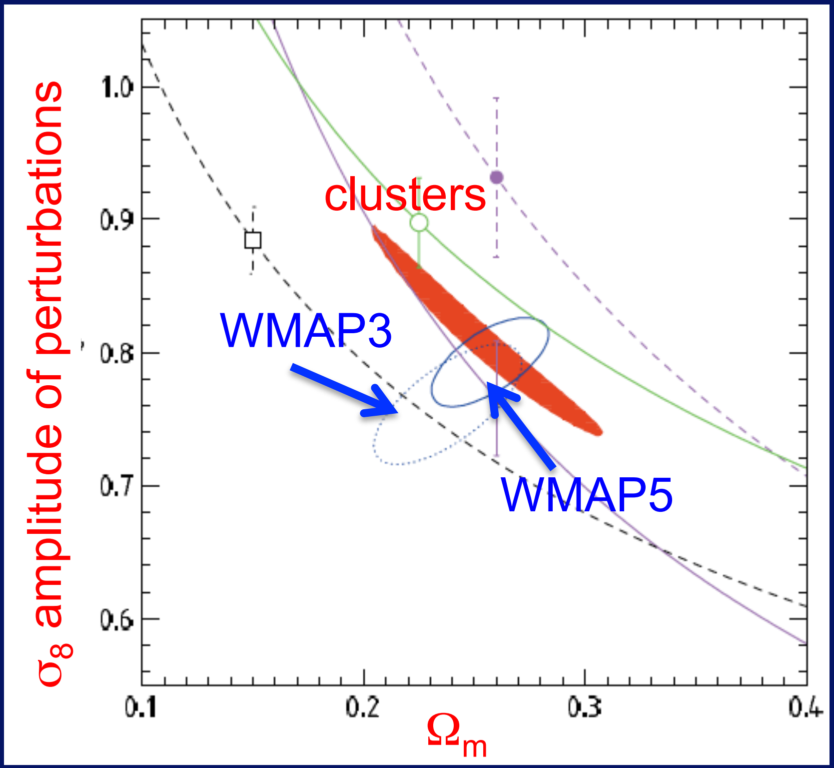
1. A growth of structure test

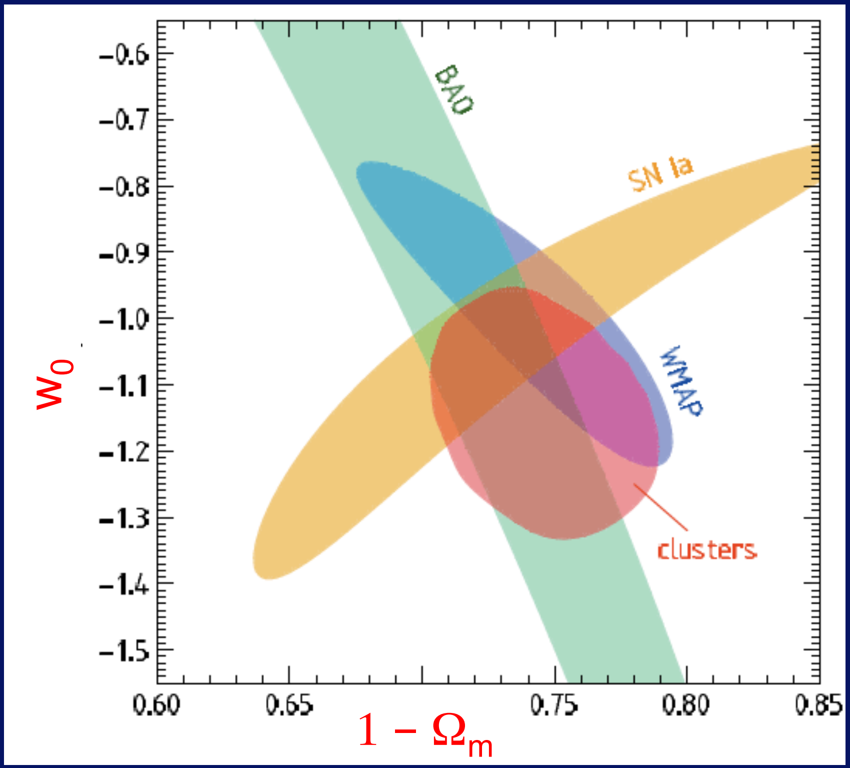
   The evolution in cluster number density with redshift constrains the amplitude of density fluctuations and the dark matter and dark energy densities.

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

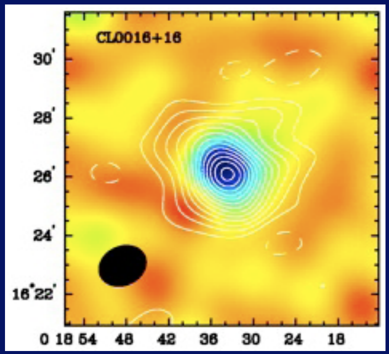




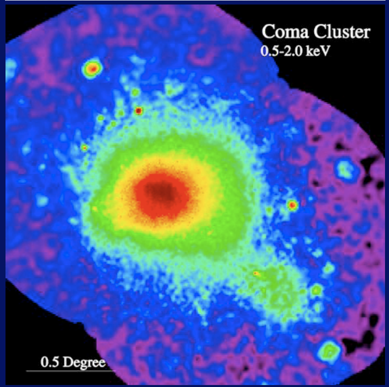
Vikhlinin et al. 2009

A Bright Future: Large Surveys

- Sunyaev-Zeldovich Effect: SPT, ACT, Planck
  - inverse Compton scattering of CMB off hot ICM
  - roughly redshift independent



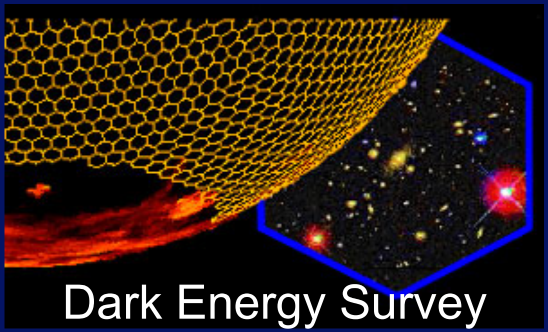
- X-ray: eROSITA (all sky), ATHENA (?)
  - thermal bremsstrahlung from hot gas



- 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

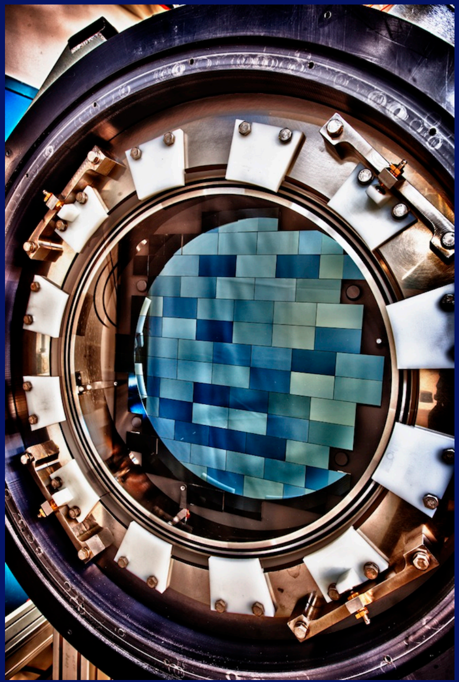
e.g. Enzo simulations, joint Chandra and CHFT weak lensing, X-ray and Keck follow-up of DES

The Dark Energy Survey

- Multiband (grizY) optical imaging survey of 5000 deg^2 of the southern sky using the Blanco 4-m at CTIO.

- DES will detect ~150,000 clusters to z ~ 1.5.

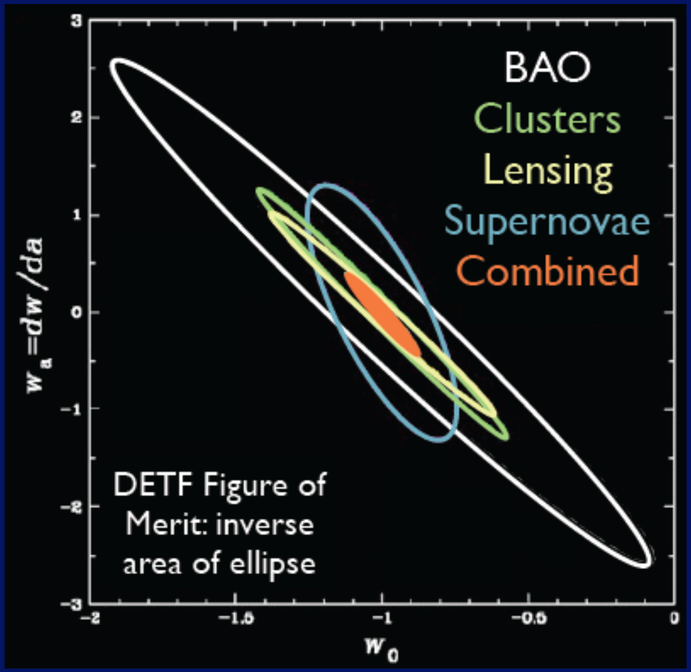
- I am primarily involved in the DES cluster survey including preparations for survey start.



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.

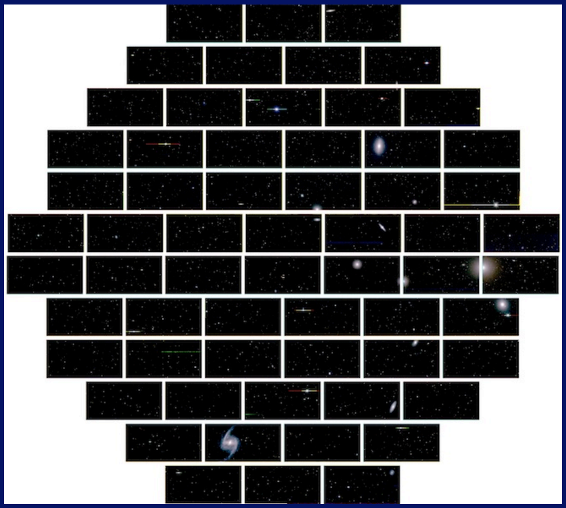
DES Timeline

- First light September 12, 2012!

- Now in science verification phase.

- Survey start in September!

- The full survey will run for 5 years. The first year of data will include some areas to full depth allowing early science.



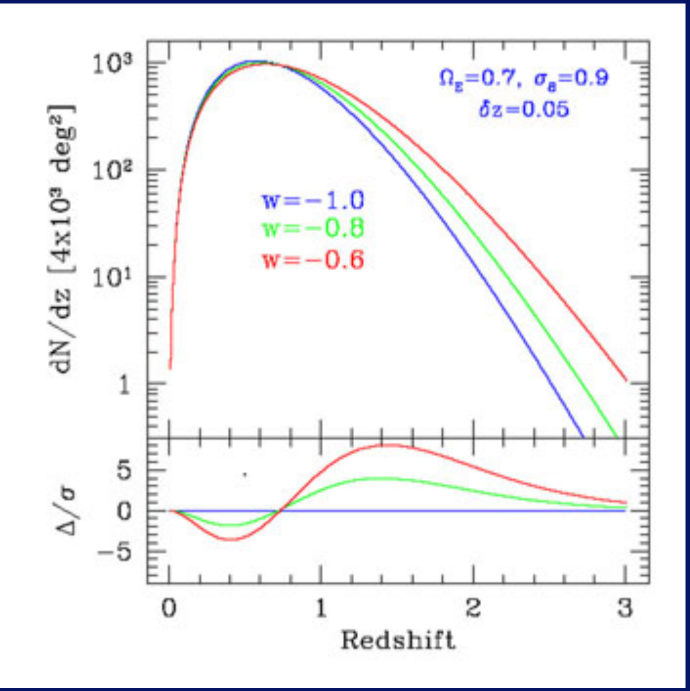
Cosmology with DES Clusters

Constraints on dark energy:

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

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

hard part:
understanding the relationship between observables and cluster mass



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

Multiwavelength Cluster Observations

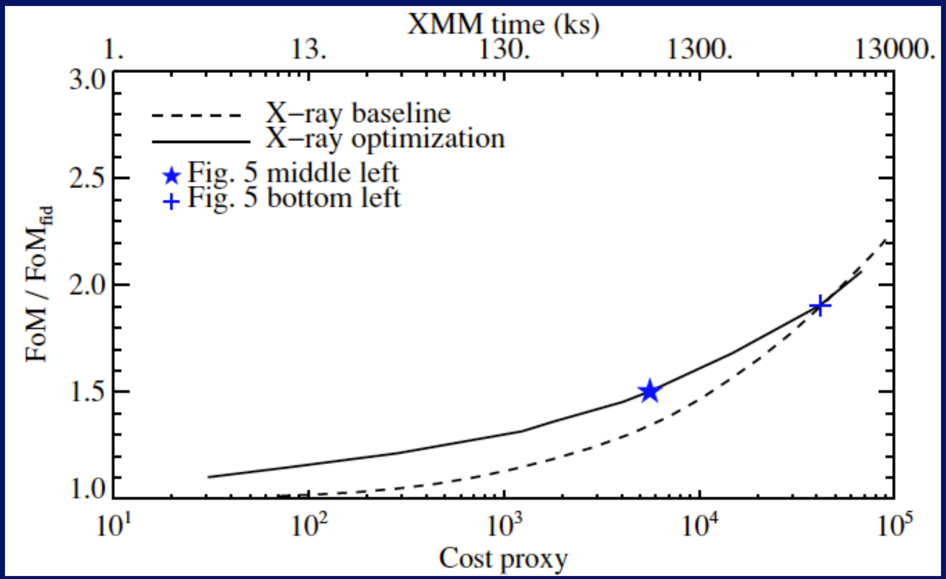
➢ Relatively small follow-up programs giving a low scatter observable can give a factor of ~ 2 improvement in DETF FoM from DES alone.

scatter in
richness-mass relation

~ 30%

scatter for
X-ray, SZ observables

~ 7-10%



Wu, Rozo, & Wechsler 2010

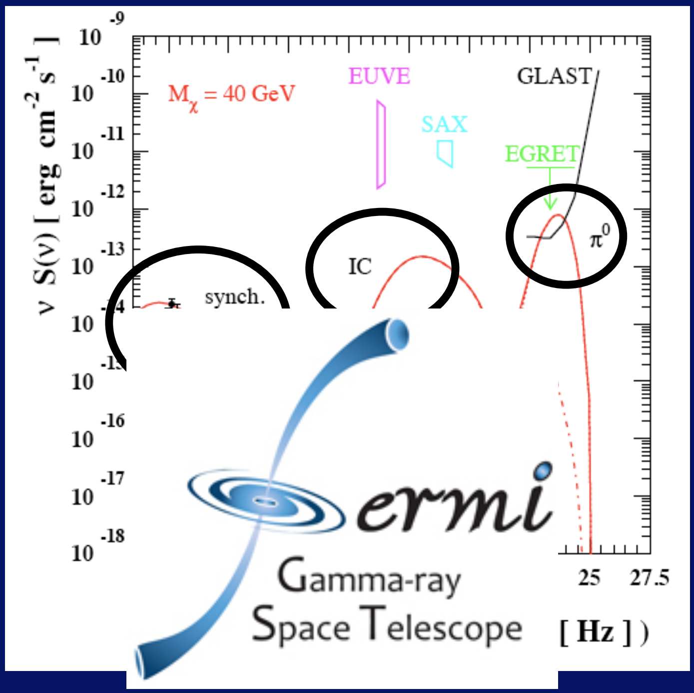
Indirect Detection of Dark Matter

Observing Dark Matter

- Dark matter can annihilate or decay to Standard Model particles potentially giving observables signatures.

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

- Gamma-ray observations are placing strong constraints on particle physics models



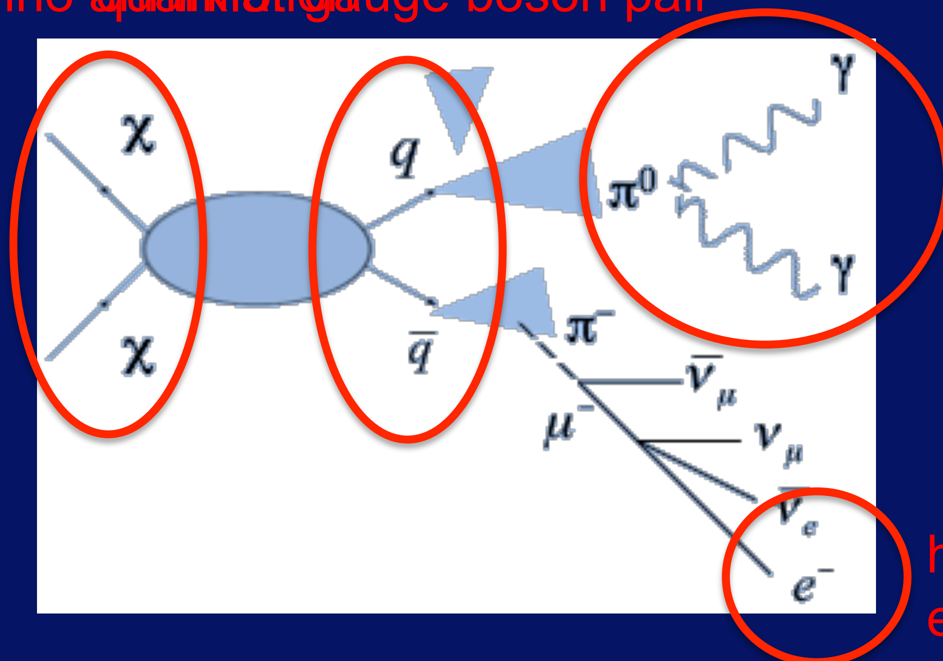
Example spectrum of DM annihilation in the Coma cluster (Colafrancesco et al. 2006)

Gamma Rays from Dark Matter Annihilation

π^0 decay to γ

neutralino annihilation

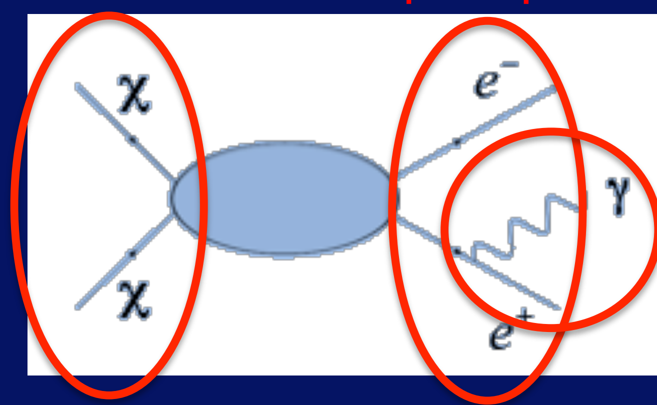
quark or gauge boson pair



high energy e^- and e^+

Secondary gamma rays from π_0 decays

Gamma Rays from Dark Matter Annihilation



Lepton pair production

("leptophilic", not typical for neutralino annihilation, but popular as an explanation of the PAMELA positron excess)

Dark Matter Searches with Fermi

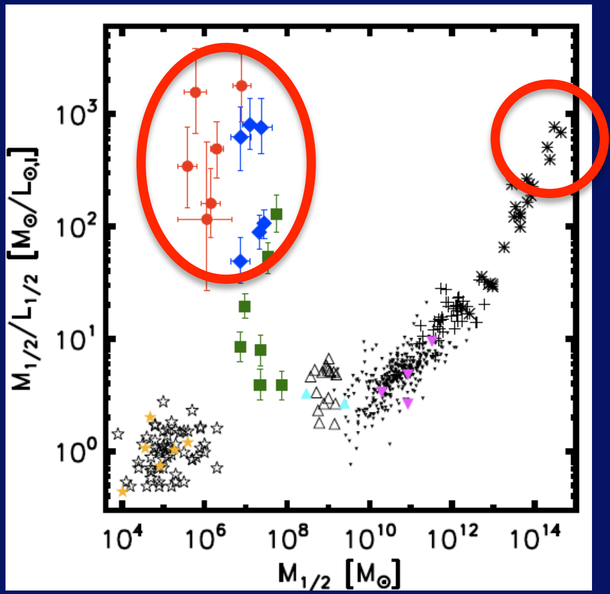
Dwarf spheroidal galaxies give strong constraints on dark matter annihilation.

Clusters of galaxies constrain:

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

Strong constraints also from Fermi observations of the Milky Way halo and the extragalactic gamma-ray background.

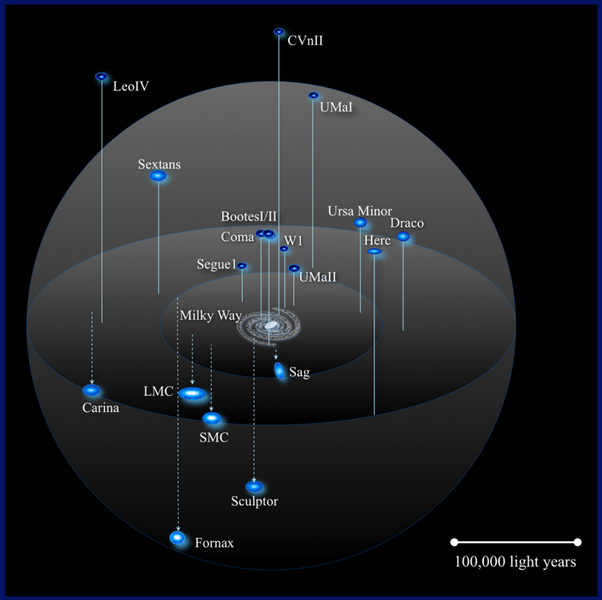
dwarfs clusters

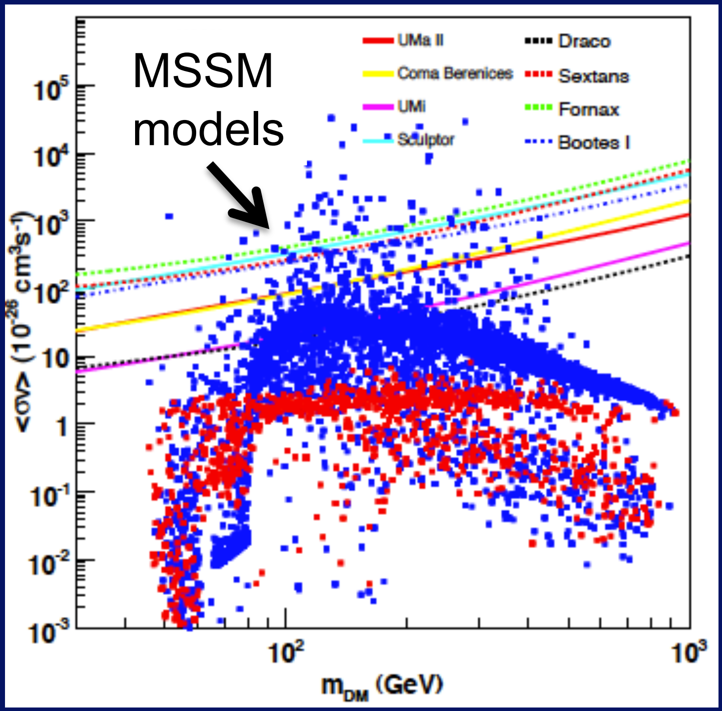


Wolf et al. 2009

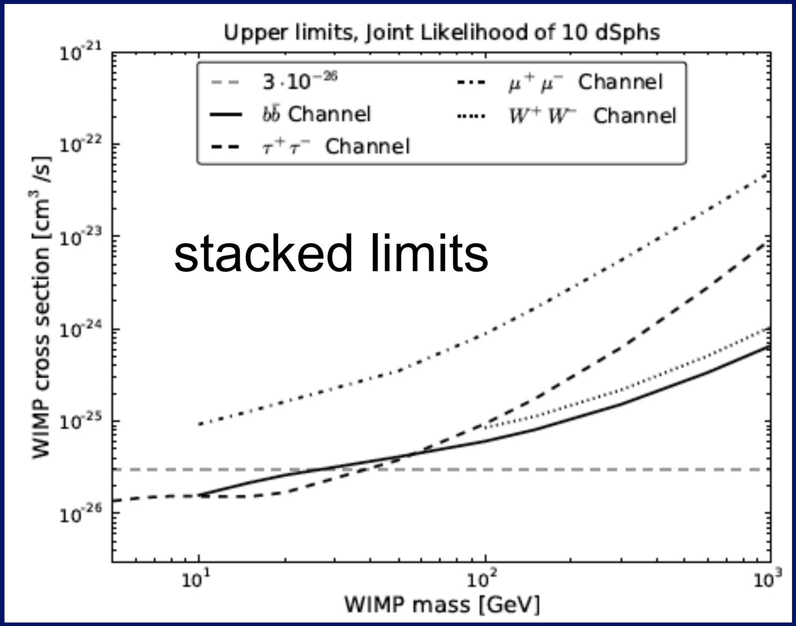
Dark Matter Annihilation

Dwarf Spheroidal Galaxies



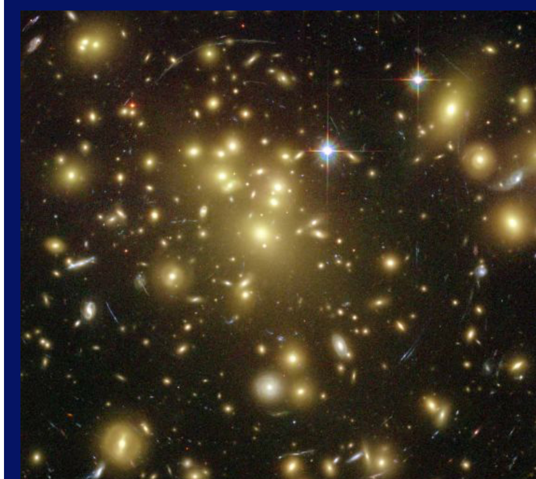


Abdo et al. 2010

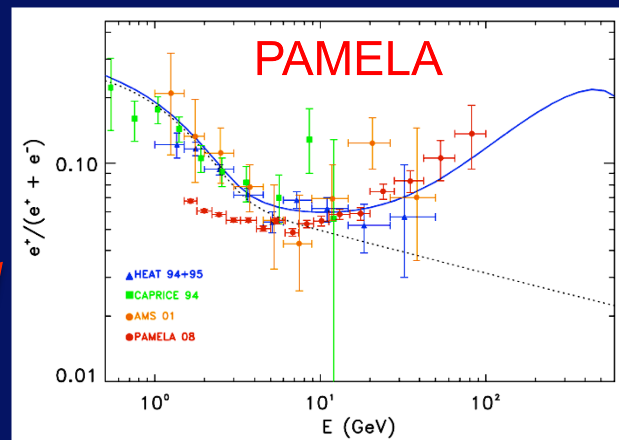


Ackermann et al. 2011

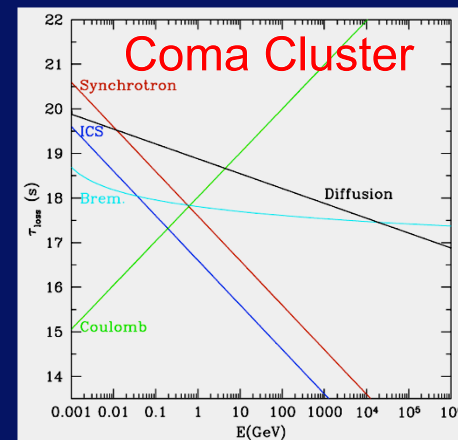
Constraining Dark Matter with Clusters of Galaxies



leptophilic
dark matter

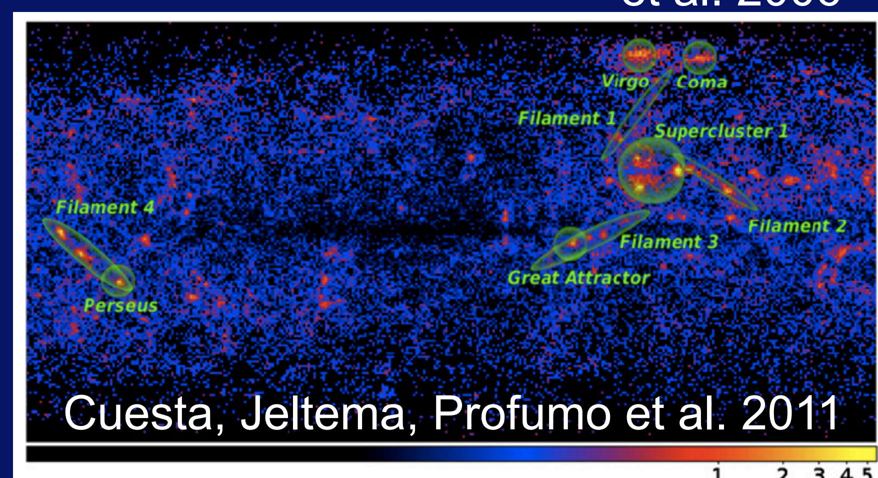


Adriani et al. 2009



Colafrancesco
et al. 2006

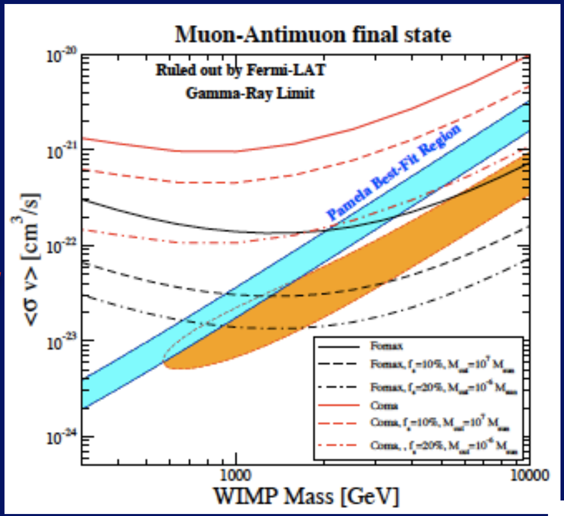
dark matter
decay



Cuesta, Jeltema, Profumo et al. 2011

Constraining Dark Matter with Clusters of Galaxies

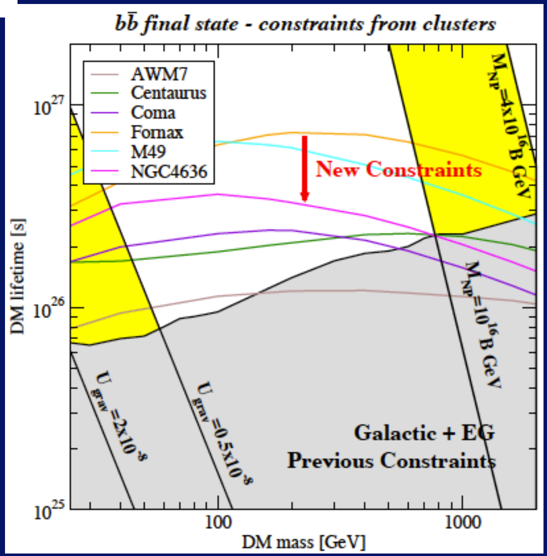
leptophilic
dark matter



Ackermann et al. 2010

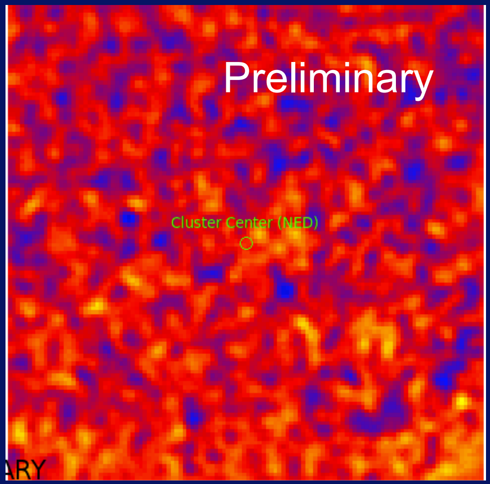
dark matter
decay

Dugger, Jeltema, &
Profumo 2010



Current Fermi Work

- Stacking of Fermi observations of clusters (with student E. Storm and other collaboration members)



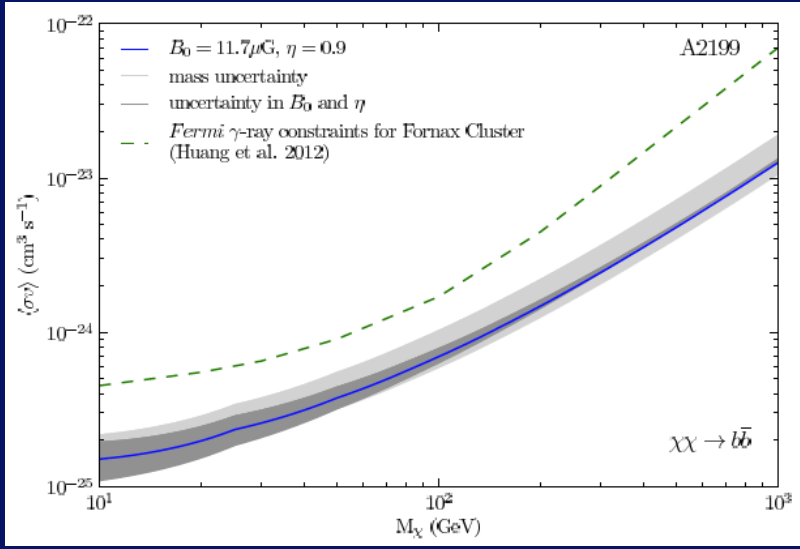
- Bayesian analysis of dark matter annihilation at the Galactic Center with Fermi-LAT

Multiwavelength Dark Matter Detection

Radio:

- e^+ e^- produced in DM annihilation/decay would lead to synchrotron emission in cluster B-fields.
- The non-detection of radio emission from nearby clusters places stronger limits than gamma-ray.

Storm, Jeltema, Profumo, & Rudnick 2012

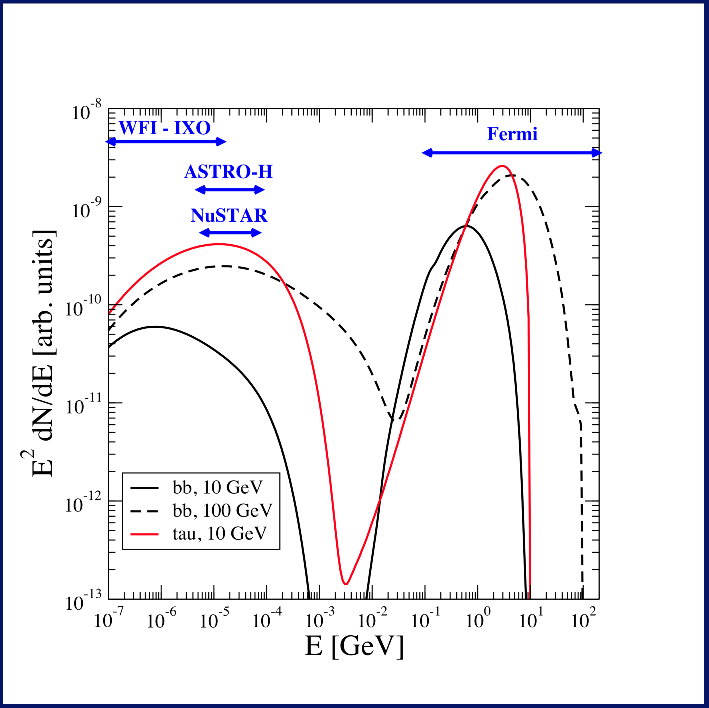


Multiwavelength Dark Matter Detection

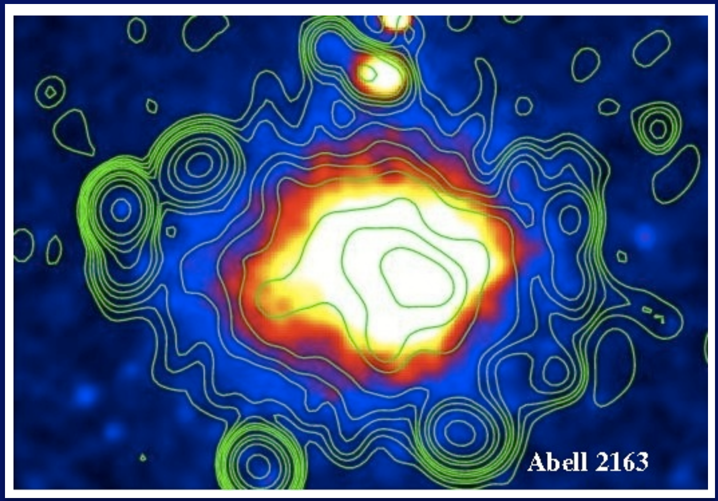
X-ray:

➢ For many DM models, IC emission from the scattering of the CMB by $e^+ e^-$ produced in DM annihilation/decay peaks in the hard X-ray band.

Jeltema & Profumo 2012



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) and simulations (Hallman & Jeltema 2011).