Multiwavelength Searches for Dark Matter

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Fermi
Gamma-ray Space Telescope

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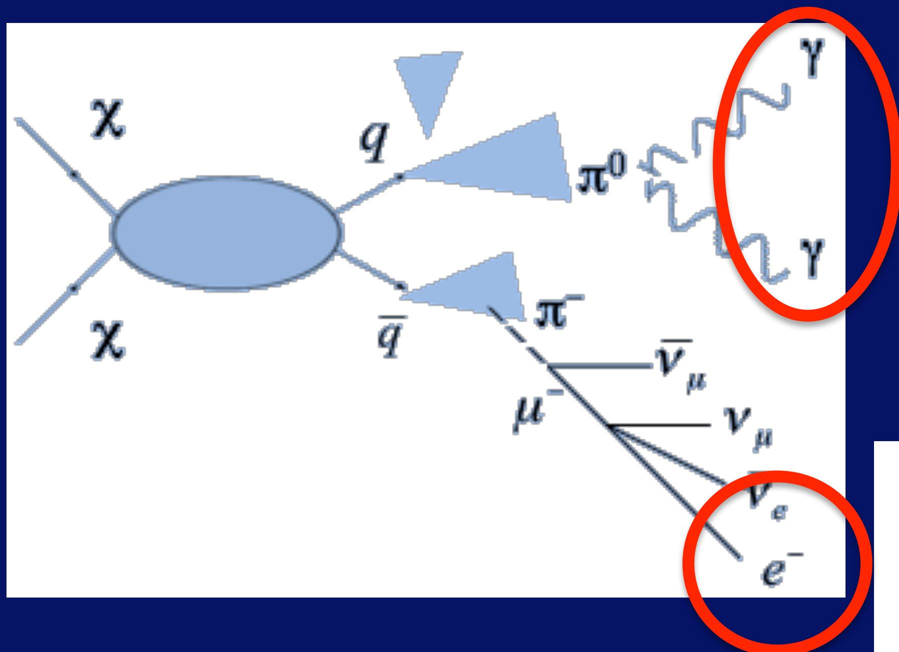
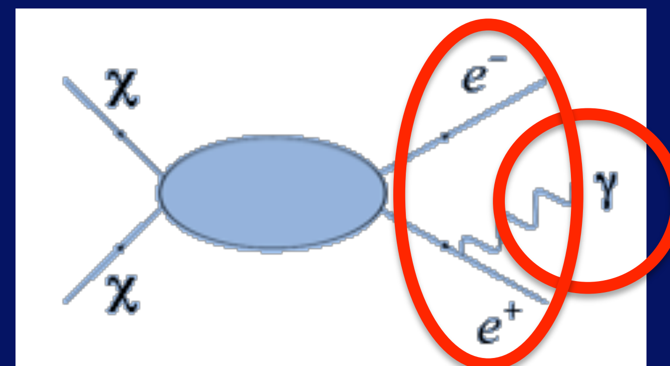
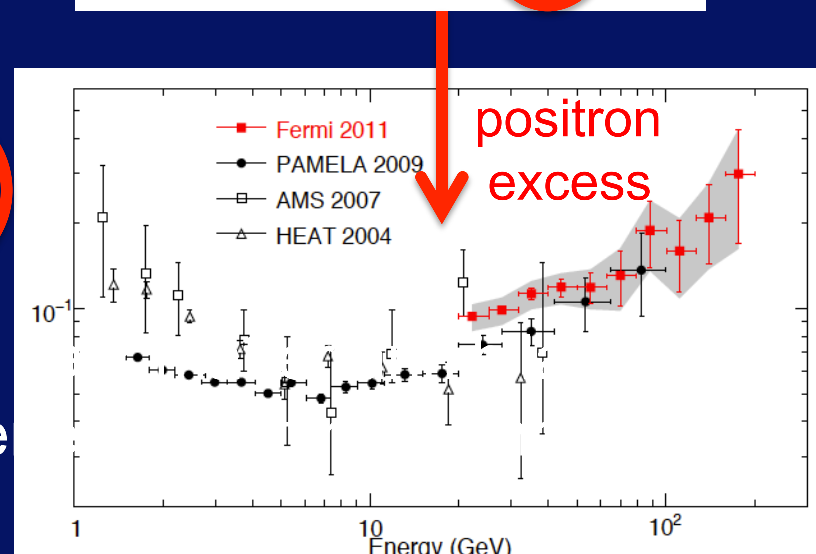
Outline

- Multiwavelength signals from dark matter
- Targets for multiwavelength searches
- Current radio and X-ray constraints – example using clusters of galaxies
- Future Telescopes

Signatures of Dark Matter Annihilation







Ackermann et al. 2011

- In addition to gamma-rays, and decay can produce high e positrons.

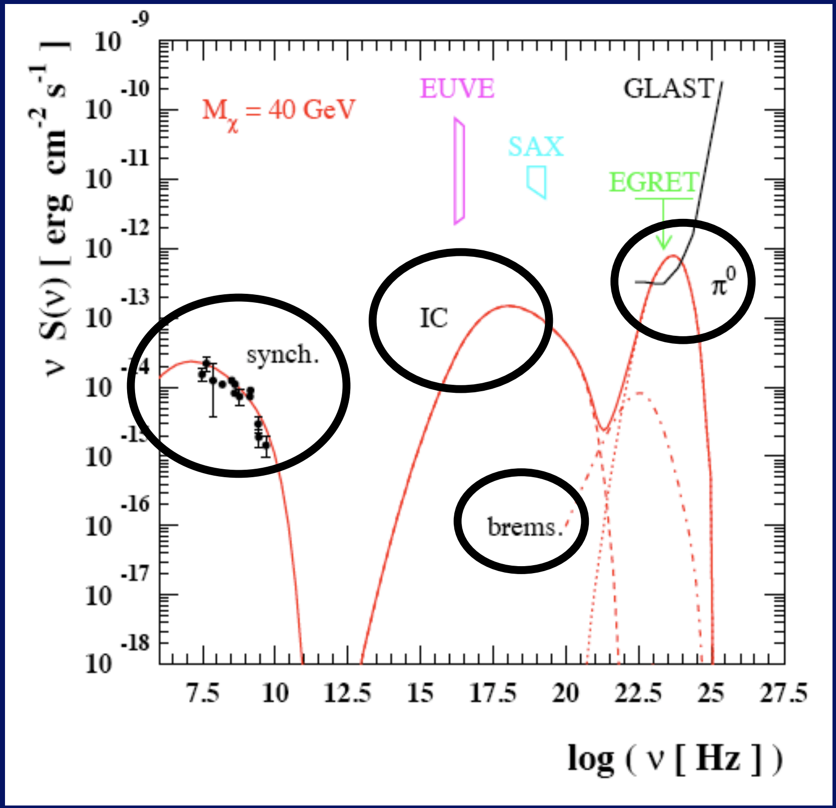
Observing Dark Matter

➢ 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

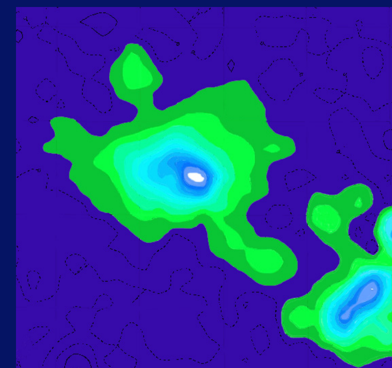
Radio: synchrotron emission in a magnetic field



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

Targets for Multiwavelength Searches

Clusters

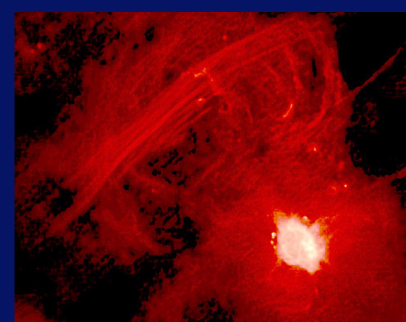


e.g. Storm, Jeltema, & Profumo 2012
Jeltema & Profumo 2012

Dwarfs ??
Extragalactic Background ??

e.g. Spekkens et al. 2013
Hooper et al. 2012
Profumo & Jeltema 2009
Jeltema & Profumo 2008

Galactic Center



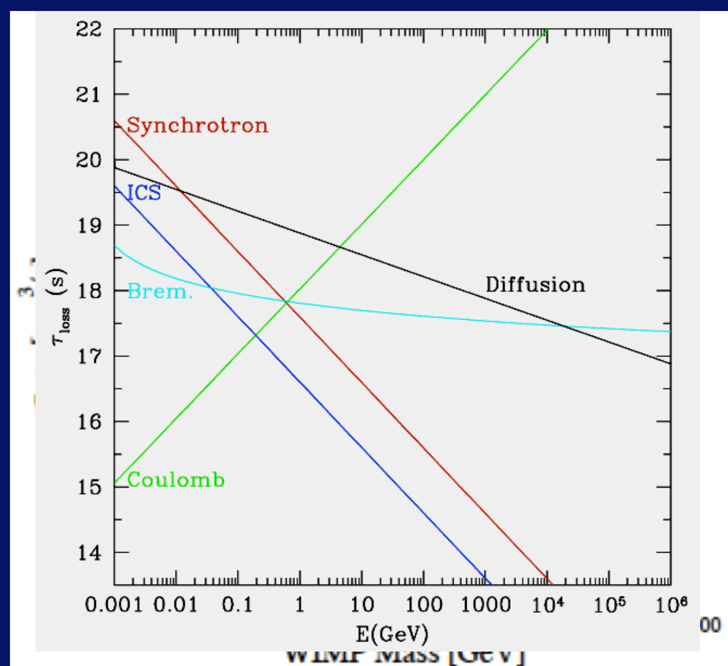
e.g. Laha et al. 2013
Linden et al. 2011

- ➢ Need to understand diffusion and magnetic field!

Clusters for Dark Matter Searches

Good targets for searches for secondary radiation because:

1. The energy loss timescale is much shorter than the diffusion time
2. They have large-scale magnetic fields

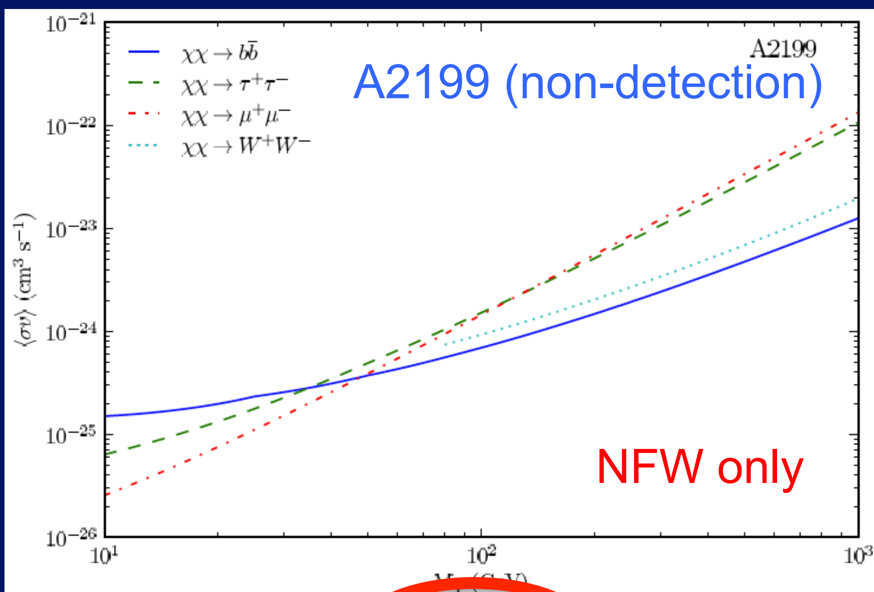


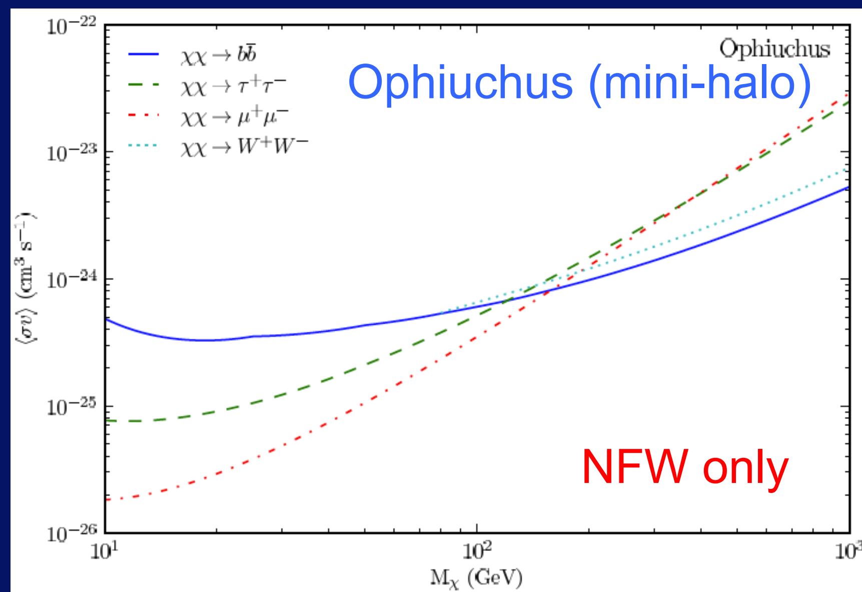
Colafrancesco et al. 2006

Ackermann et al. 2010

Radio Observations of Clusters

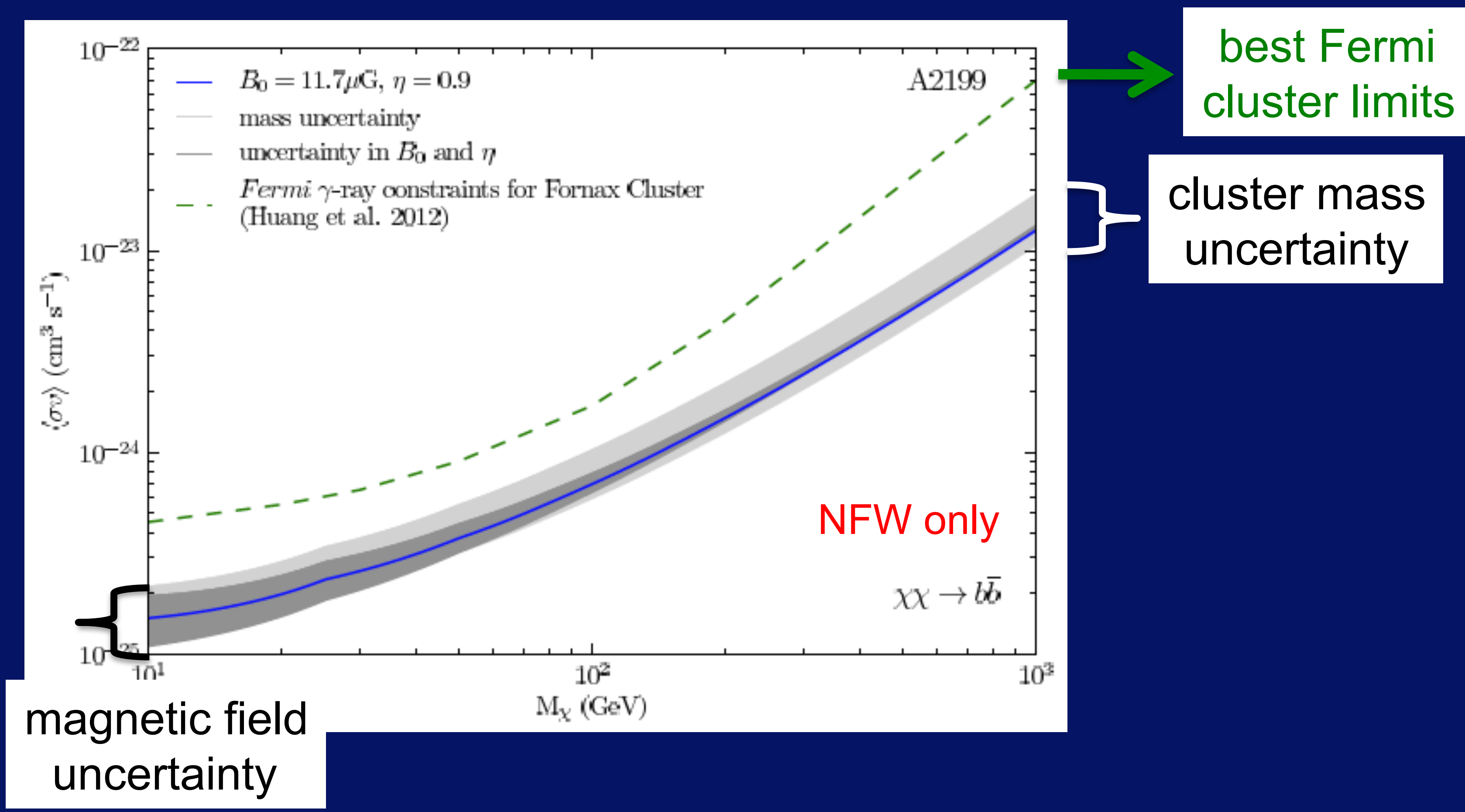
- The non-detection or weak detection of radio emission from nearby clusters places stronger limits on DM annihilation than Fermi
- At low mass, limits approach thermal cross-section even for conservative density profile





Storm, Jeltema, Profumo, & Rudnick 2012

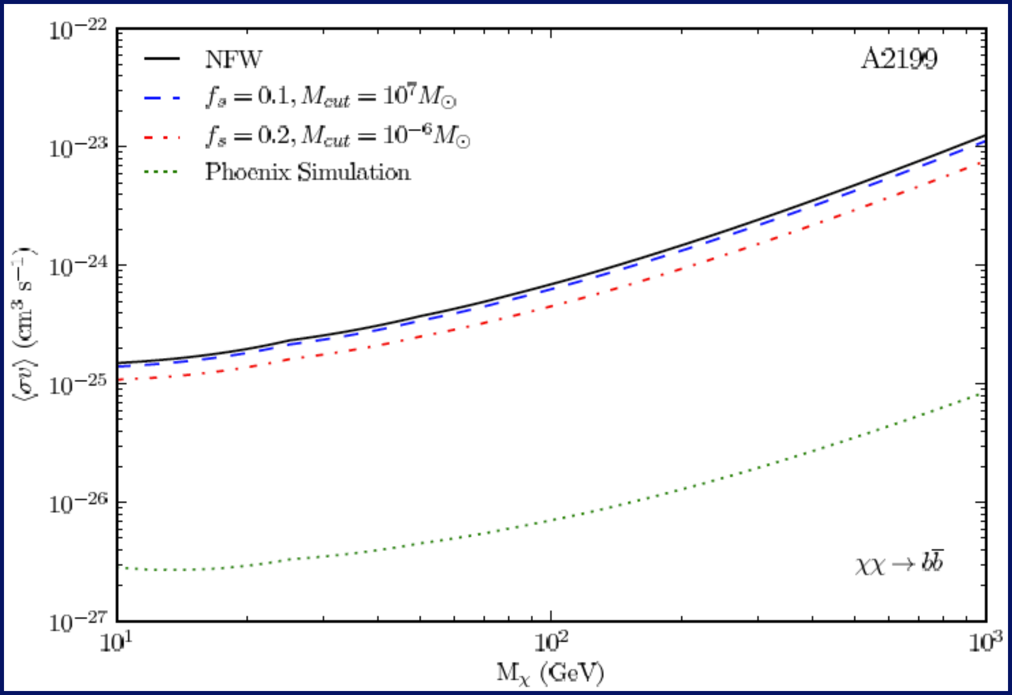
Dark Matter Annihilation Limits



Storm, Jeltema, Profumo, & Rudnick 2012

Dark Matter Annihilation Limits - Substructure

➢ If you include substructure obviously the limits can be much stronger, but very model dependent.

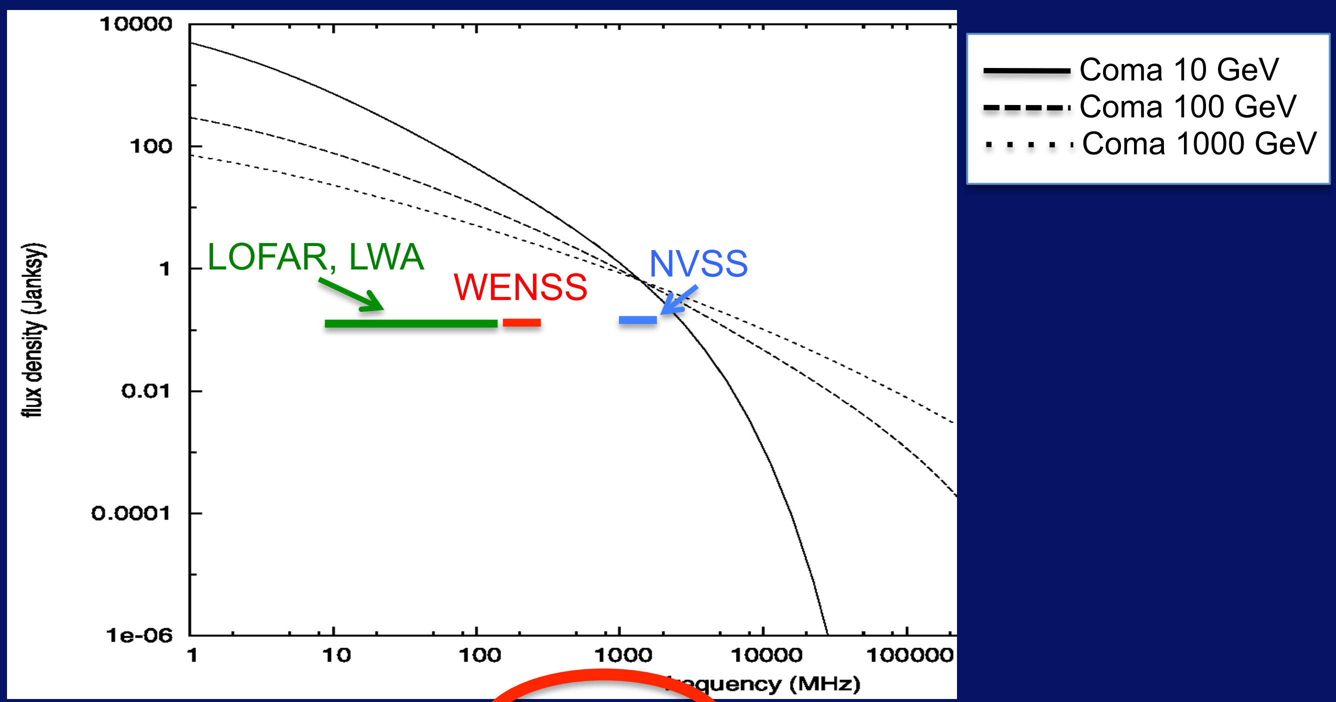


Storm, Jeltema, Profumo, & Rudnick 2012

Future Radio Observations

Near term improvements from:

- New low frequency capabilities
- Better understanding of magnetic fields

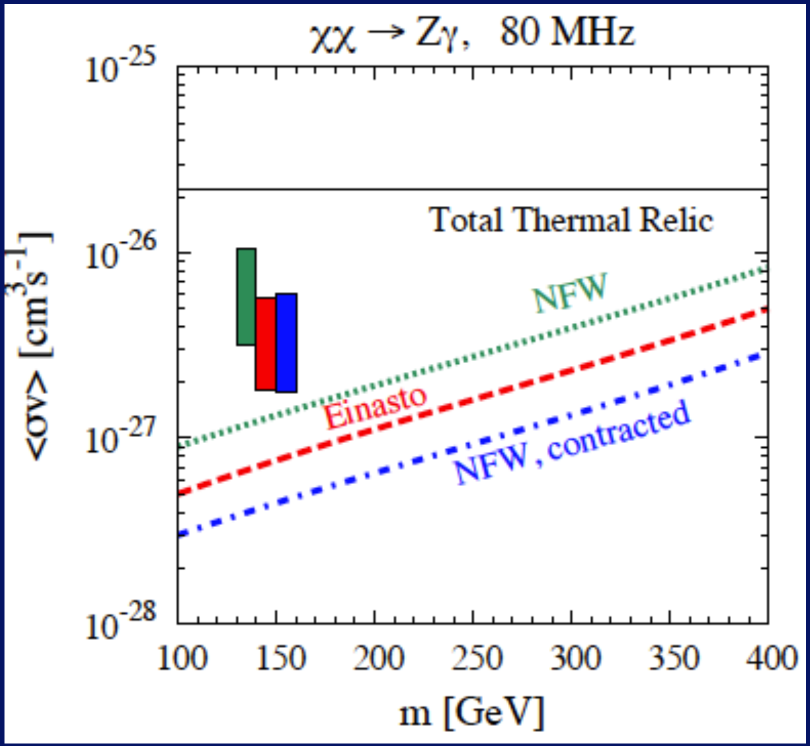


Courtesy of E. Storm

Galactic Center in Radio

- Radio observations of GC also give strong constraints, particularly on DM origin of positron excess (e.g. Crocker et al. 2010, Bertone et al. 2009, Regis & Ullio 2008)
- DM signal from radio filaments, WMAP haze? (e.g. Linden et al. 2011, Hooper et al. 2007)
- Potential to test DM origin of 130 GeV line (Laha et al. 2013)

Predictions for LWA



Laha et al. 2013

(primary uncertainties from density profile and magnetic field)

Future Radio Telescopes

Low Frequency:

- LOFAR: 10 - 240 MHz, ~20,000 small antennas over 100 km, partially operational now
- LWA: 10-88 MHz, 13,000 antennas over 400 km, 1/53 stations working

SKA pathfinders:

- Australian SKA Pathfinder: 0.7 - 1.8 GHz, 36 12-m dishes, in commissioning
- MeerKAT: 0.5 –14 GHz, 64 13.5-m dishes, 2016-18

Square Kilometer Array (SKA): circa 2024, collecting area equal to 1 km^2, longest baseline >=3000 km

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

- Existing or near-term telescopes:

  NuSTAR – 5-80 keV,
  10” resolution

  ASTRO-H – 10-600 keV plus high resolution soft band spectroscopy, launch 2014

X-ray Emission from Dark Matter

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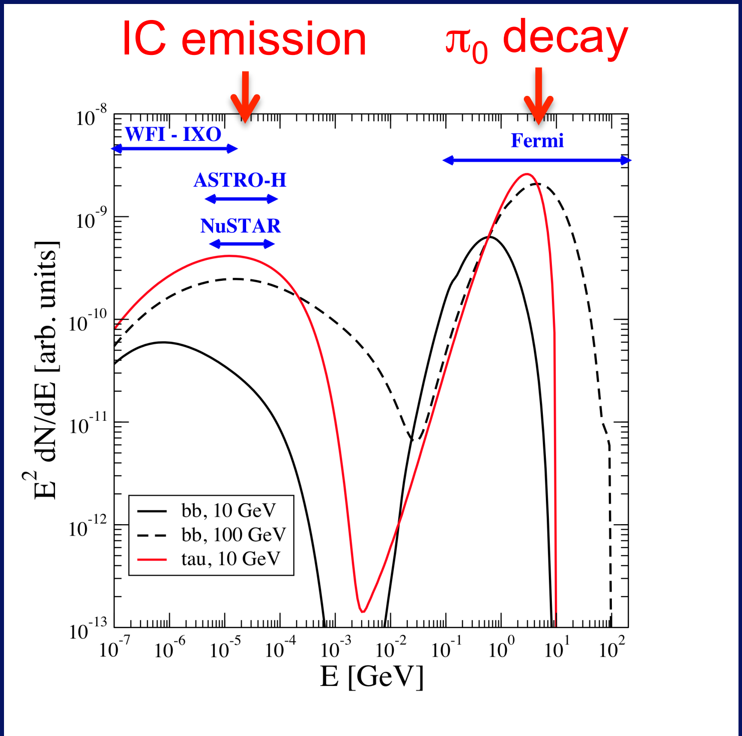
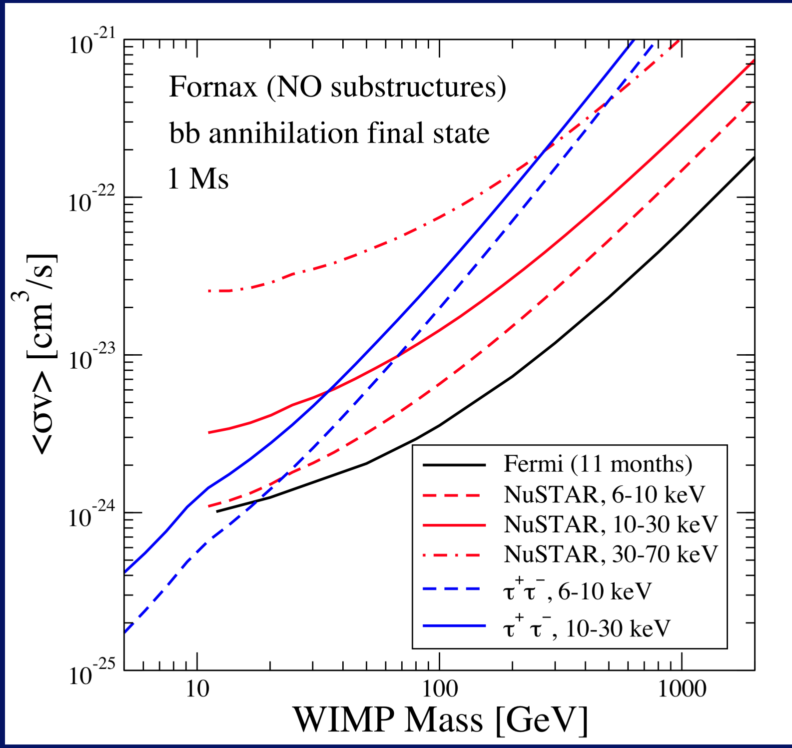


Jeltema & Profumo 2011

Comparison of NuSTAR and Fermi

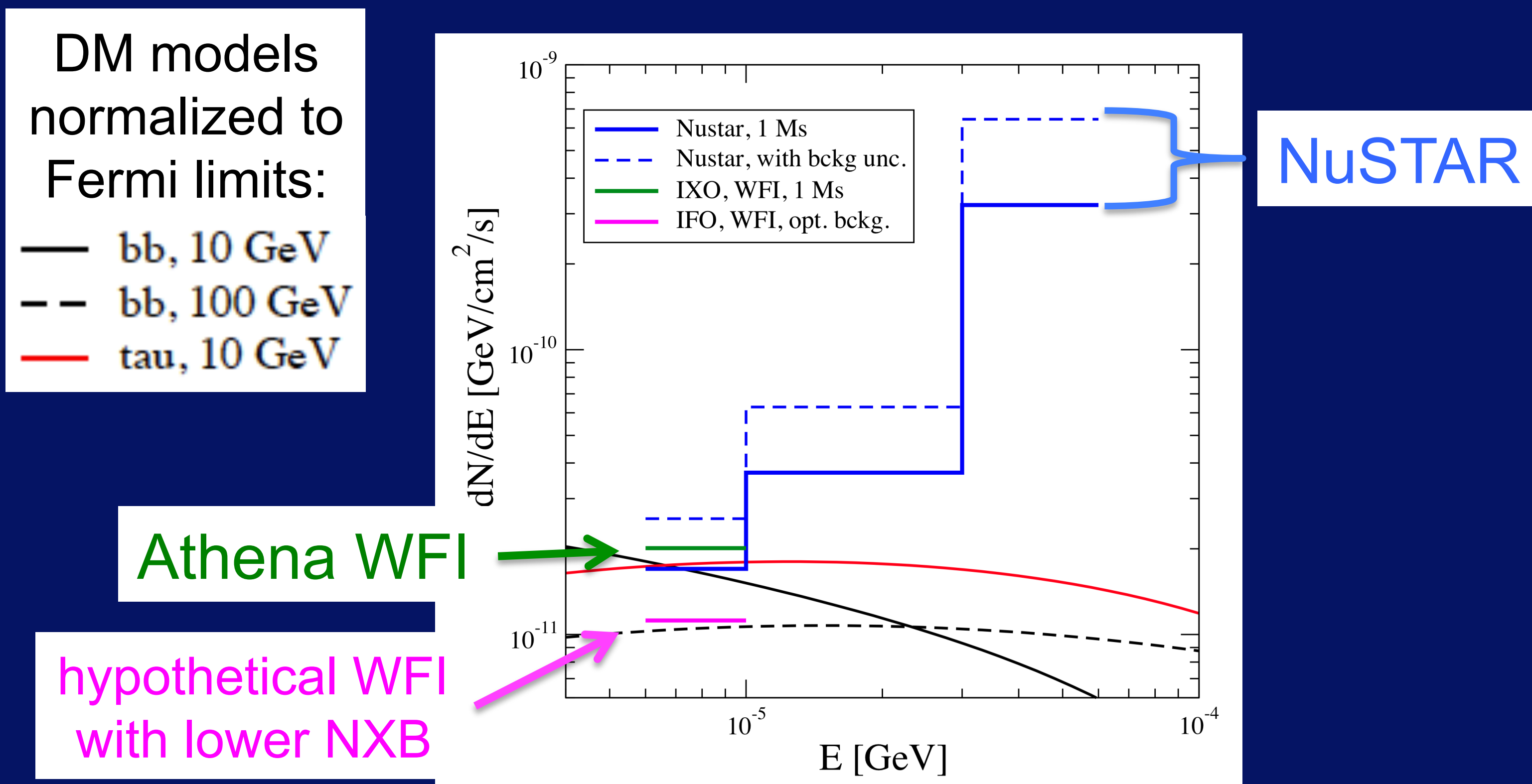
Predictions for a long NuSTAR observation of the Fornax Cluster



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

Jeltema & Profumo 2011

Predicted X-ray Sensitivity



* 6-10 keV bin includes background from cluster thermal emission.

Jeltema & Profumo 2011

Potential for Future X-ray Telescopes

- Interesting constraints could be within reach with an appropriately planned mission.
  - low background orbit
  - large field of view
  - large effective area ~> 10 keV

- High Energy X-ray Probe (HEX-P) Mission Concept proposed to NASA but not selected

Next X-ray telescope???

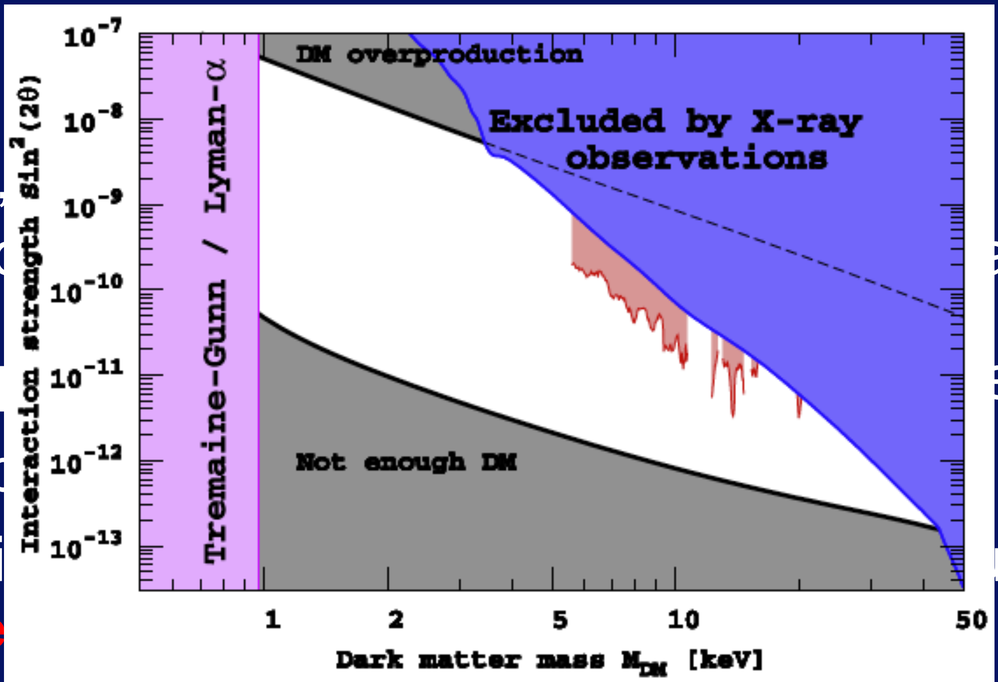
X-ray Lines

- From decay of ~ few keV scale DM (sterile neutrinos, moduli: Kusenko et al. 2012)

Future:

- NuSTAR, and spectral reso al 2012)
- Large im ed mission
  - high sp
  - large fi tion ok)

(e.g. Xenia, de



Boyarsky et al. 2012

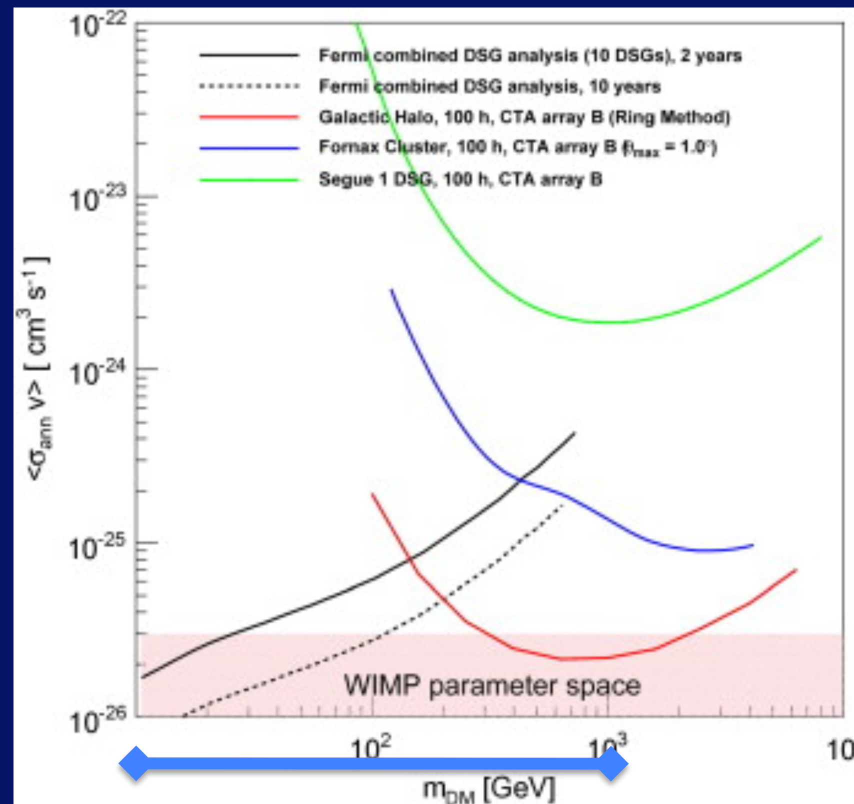
Next X-ray telescope???

Complementary to CTA

Doro et al. 2012

- CTA will only be sensitive to large DM masses
  >~ 100 GeV

- Radio and X-ray can be used to probe smaller DM particle masses
  ~ 10 GeV – 1 TeV



mass range probed by radio, X-ray

Summary

- Searches for secondary emission from DM annihilation/decay in radio and X-ray are an important probe
- 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. Also important for keV scale DM searches
- A multiwavelength approach is highly complementary to future high energy gamma-ray searches