Dark Cosmology Centre

Searching for decaying axion-like dark matter from clusters of galaxies

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Astro-ph/0703342, submitted to PRL

Dark Matter Candidates

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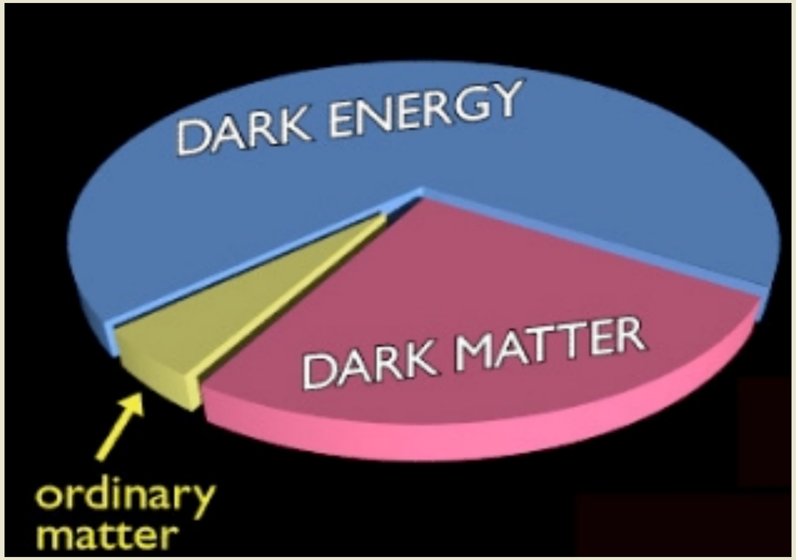
Dark matter solves gravity related problems of cosmology.

General properties of a dark matter candidate:

- Particle behavior
- Massive (gravitational effect)
- Not too much interacting
- Long lifetime (if thermal relic)



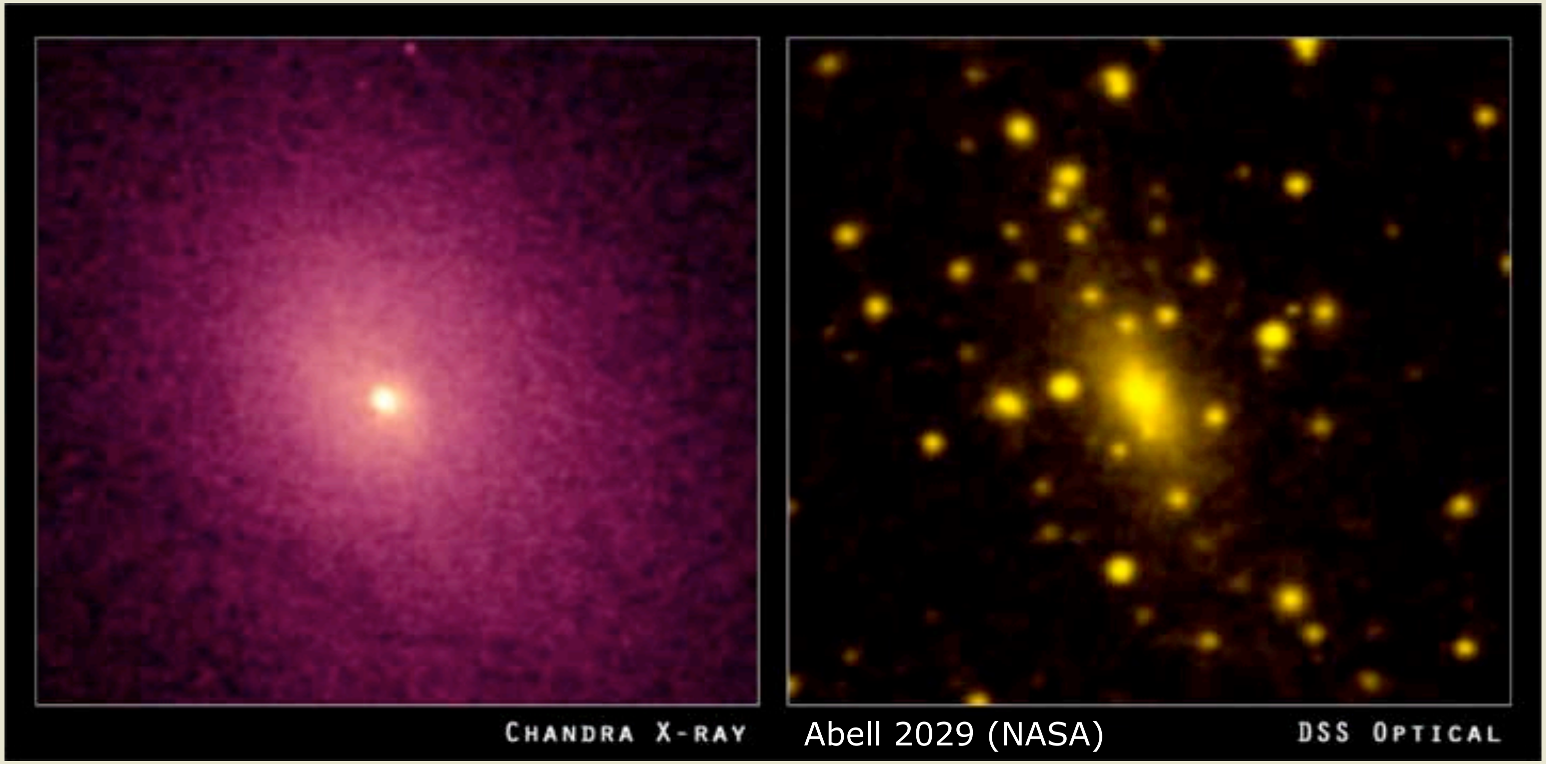
No good Standard Model particle candidate -> extensions:

- Super symmetry (SUSY)
- String theory
- Sterile neutrinos
- Extra dimensions -> axions
- Etc...

Some candidates allowed to decay with X-ray emission. General constraints on candidates

Clusters of Galaxies

Largest structures in virial equilibrium



Current knowledge about clusters of galaxies:

- 1–3% of mass in stars
- 10–20% in hot gas (~10 keV, optically thin for X-rays)
- 80–90% in dark matter (~10^{14}-$10^{15} M_\odot$)

Merging clusters

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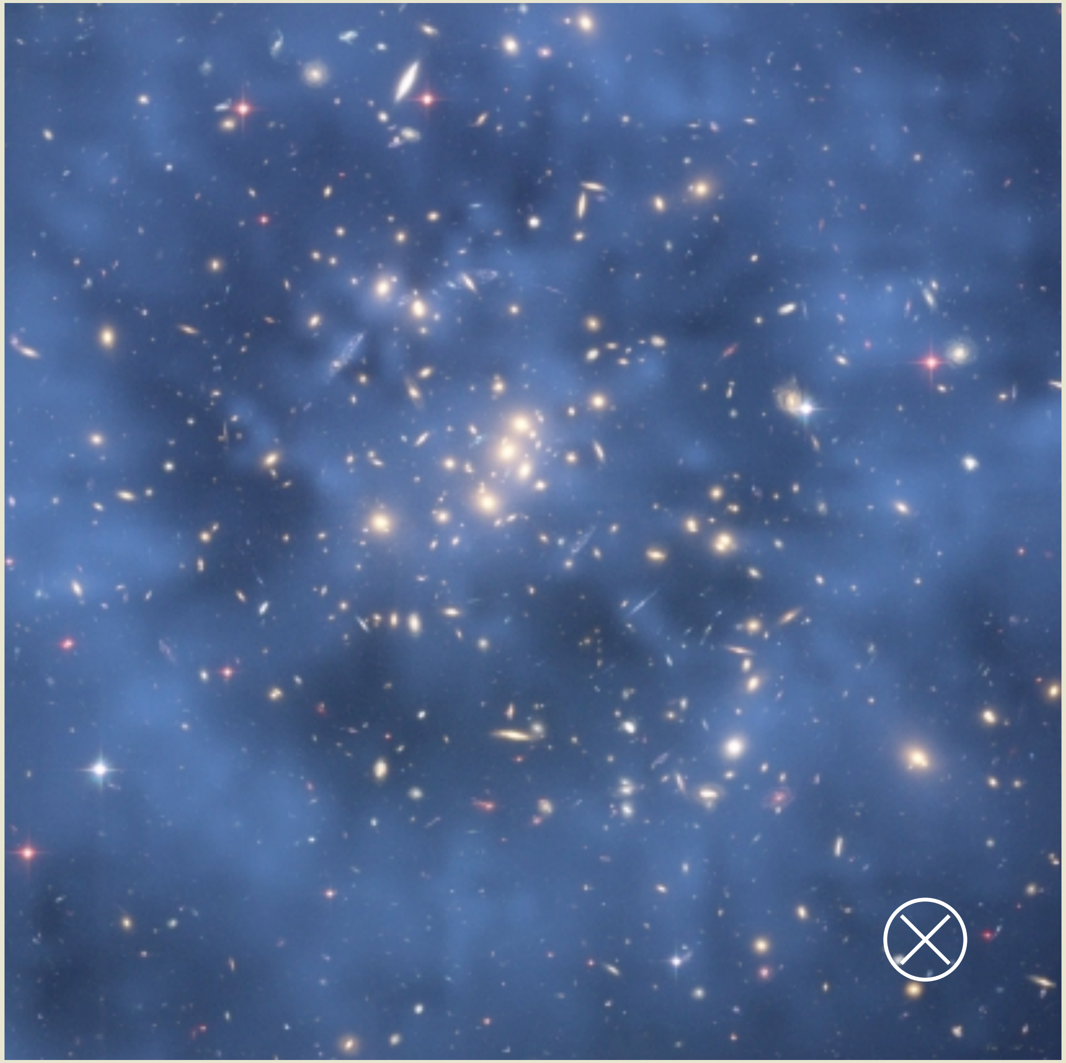
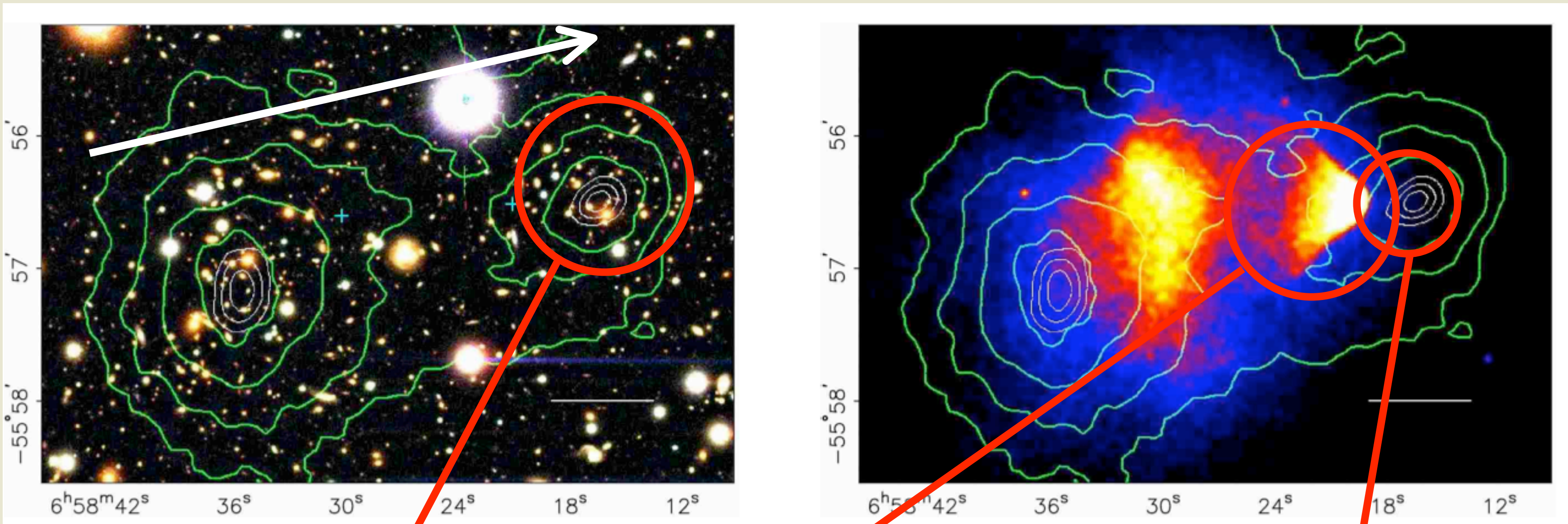


Dark matter "blobs"

Merging galaxy cluster systems with bow shock
features, side view preferred

The Bullet Cluster, 1E0657-558 (Clowe et al. 2006)

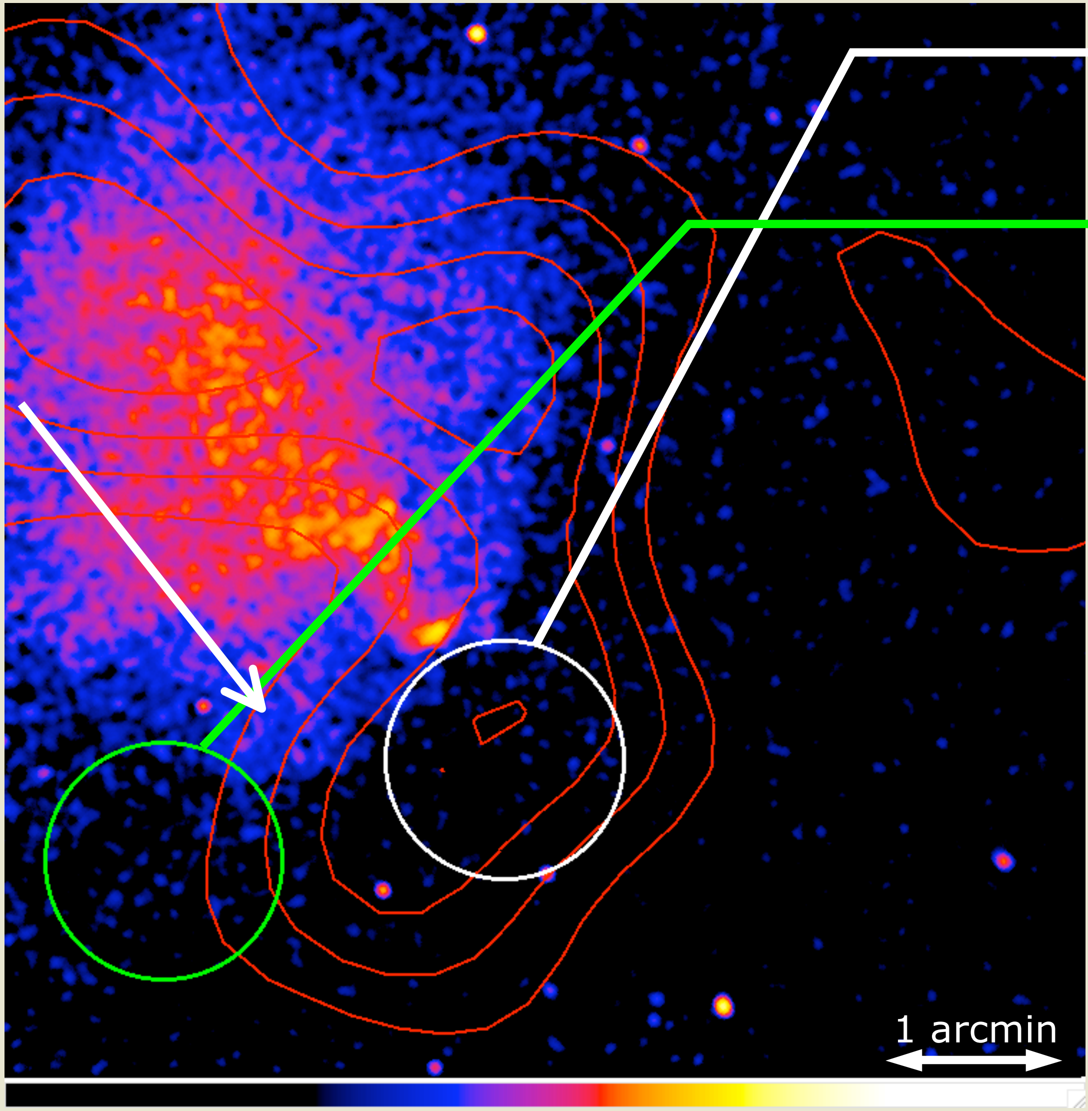


The galaxies follows the gravitational potential from weak lensing

The gas is displaced and heated because of interaction

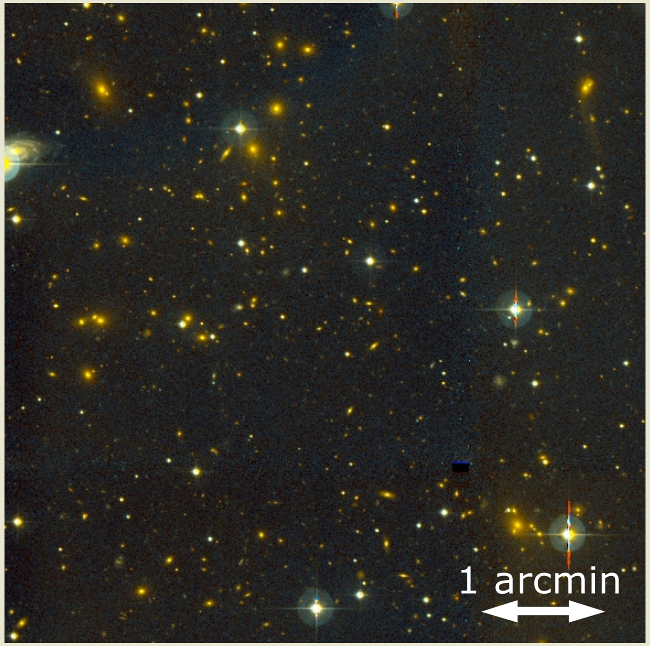
Dark matter blob with high mass and low fraction of baryonic matter

The Abell 520 dark matter blob



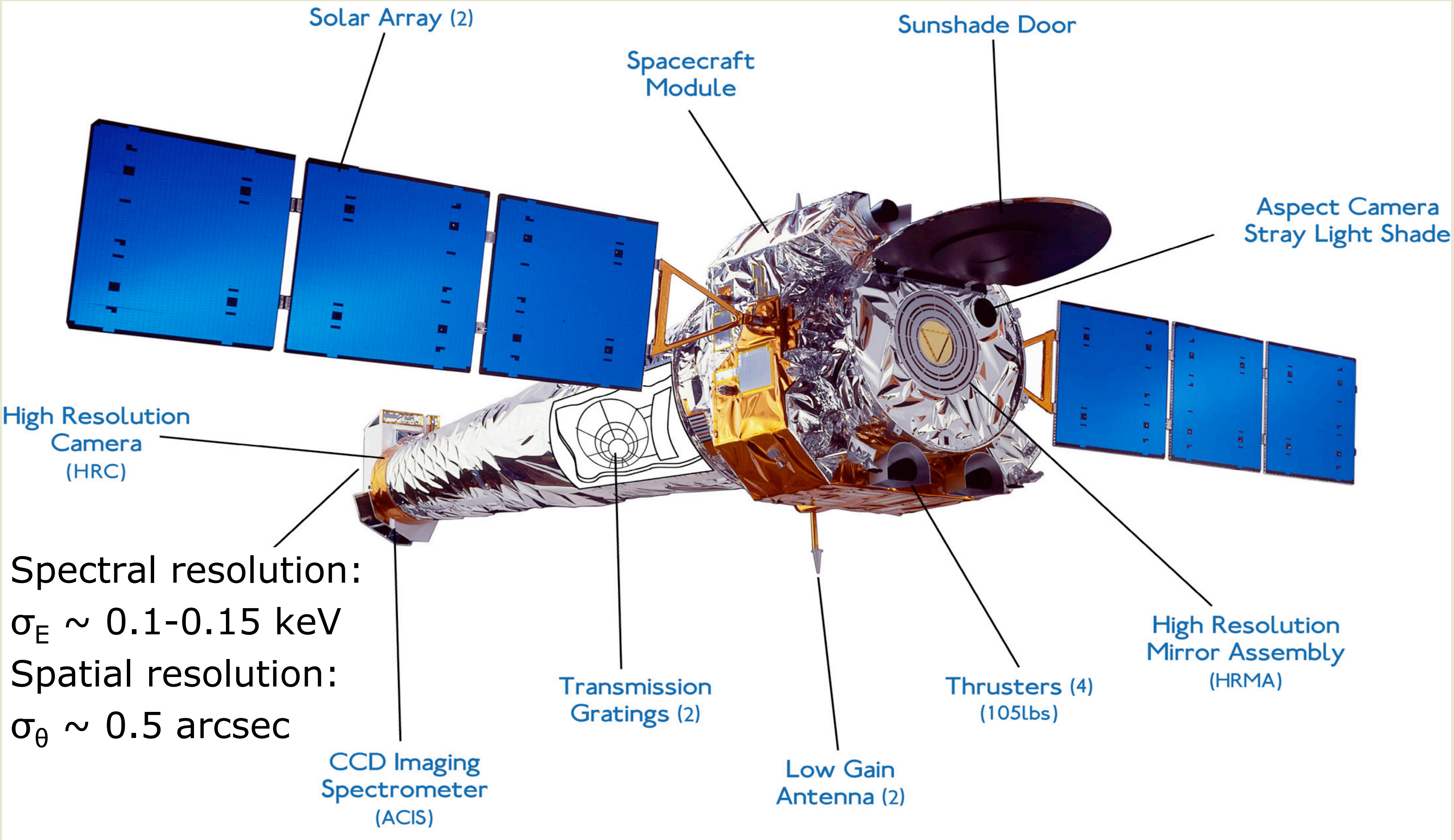
Blob region
$M_{blob} = 6x10^{13} M_{sun}$

Reference region
with low mass
$M_{ref} = 0.02x10^{13} M_{sun}$



Chandra X-ray Observatory

Launched by NASA in 1999. Photon energy range 0.3-10 keV



Spectral resolution:

$\sigma_E \sim 0.1\text{-}0.15$ keV

Spatial resolution:

$\sigma_\theta \sim 0.5$ arcsec

Where is the dark matter signal?

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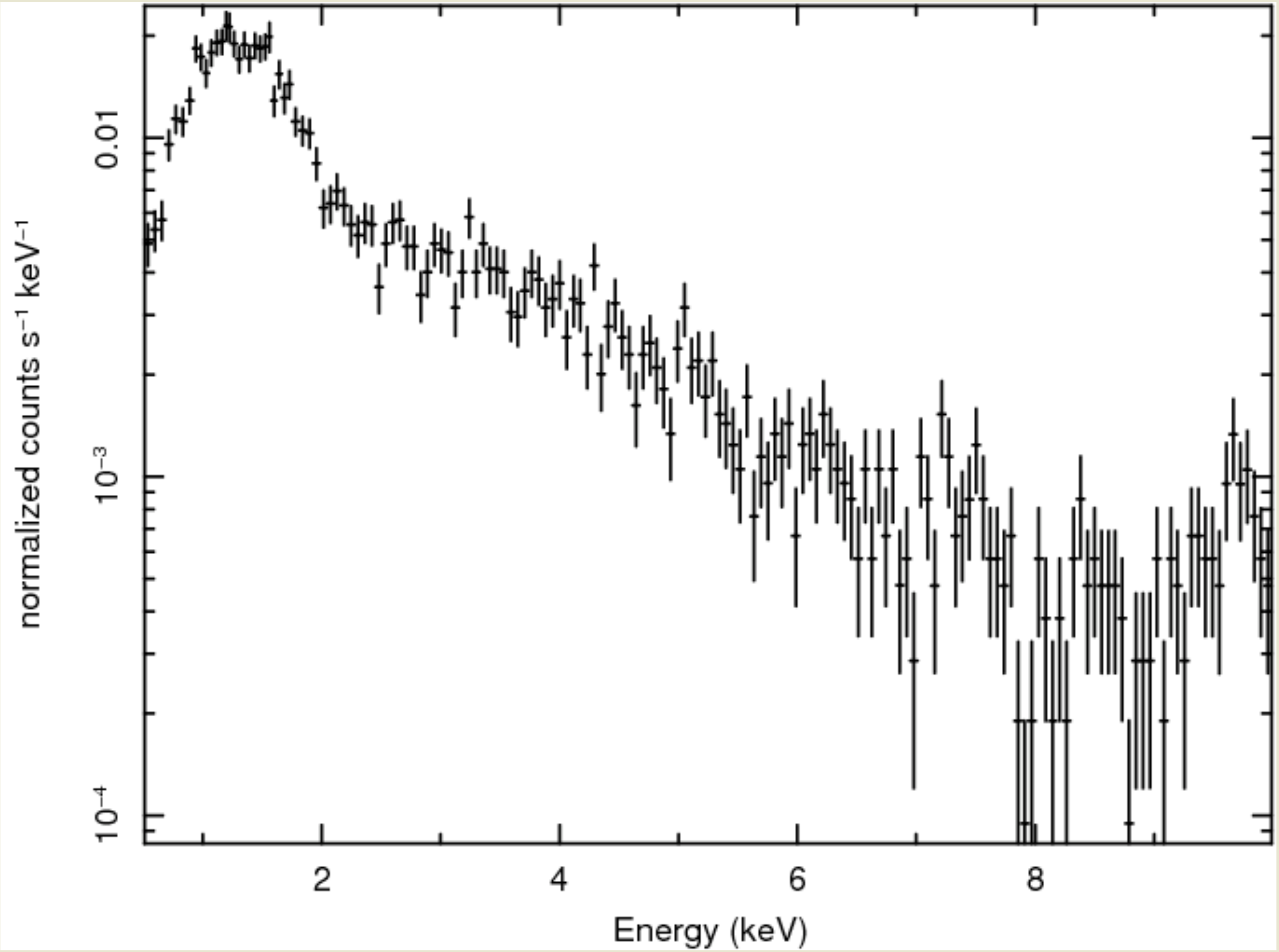
Spectrum of the Bullet cluster dark matter blob



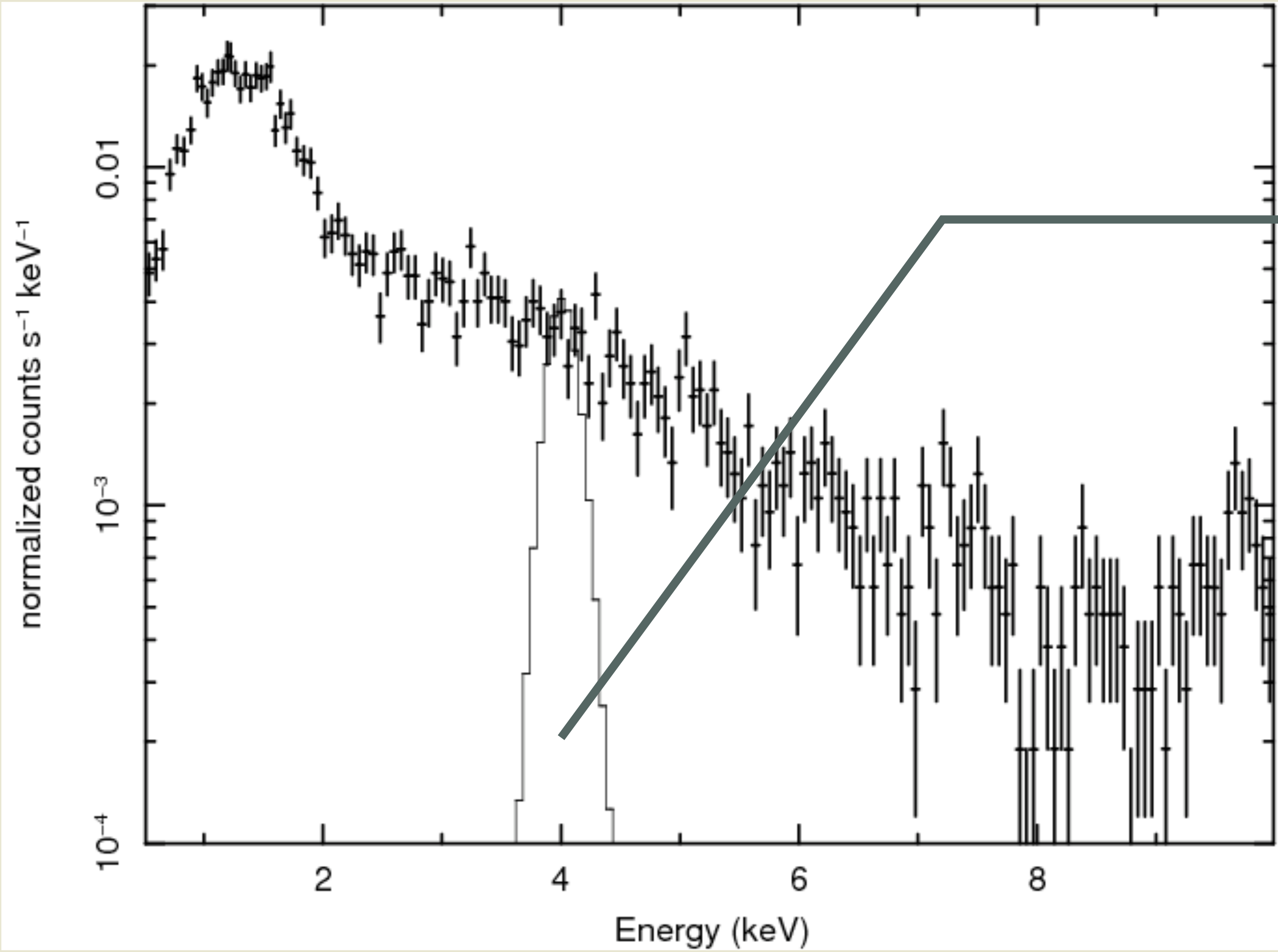
$$F \propto \frac{M\Gamma}{D_L^2}$$

$$L \propto M\Gamma$$

$$\Gamma = 1/\tau$$

The signature

Mono-energetic emission -> Gaussian because of instrumental resolution



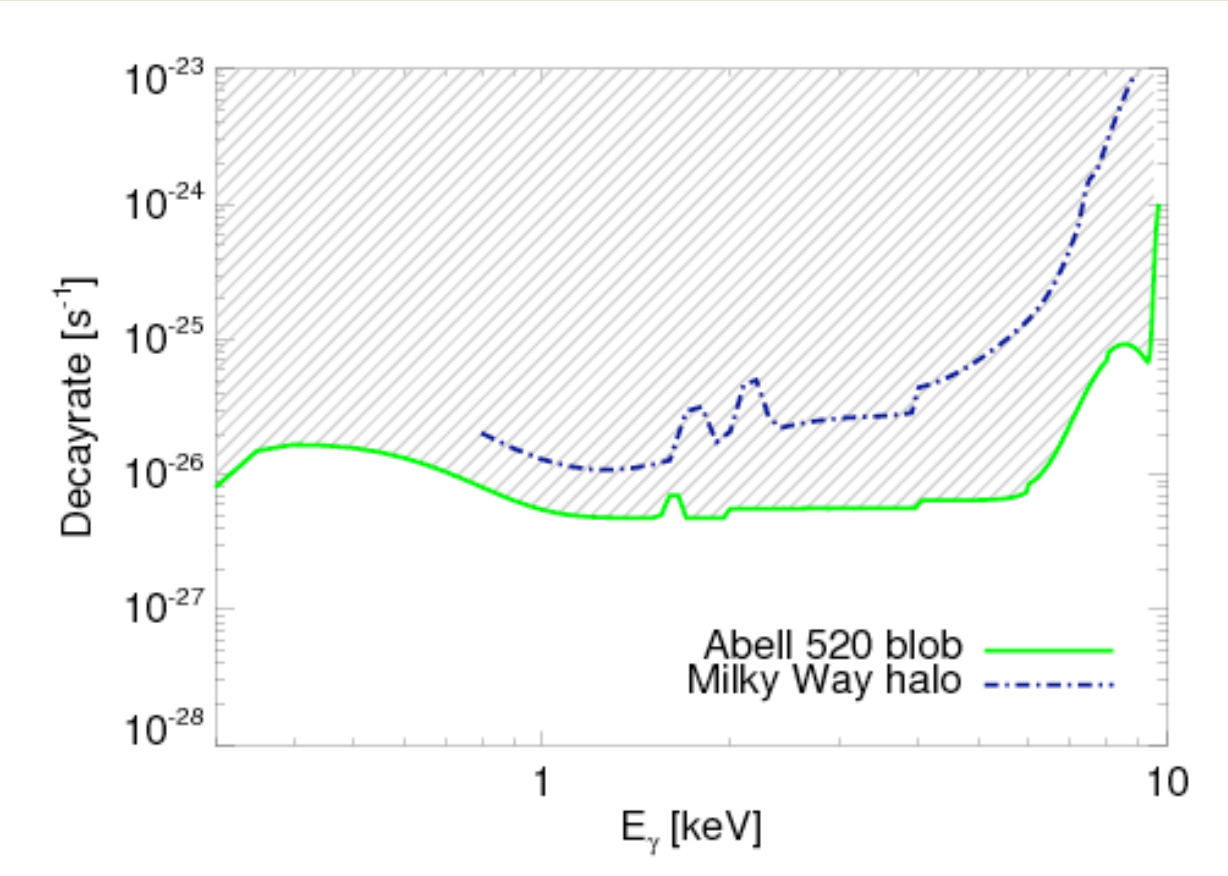
Chandra ACIS-I resolution: FWHM ~ 0.1 keV (energy dependent)

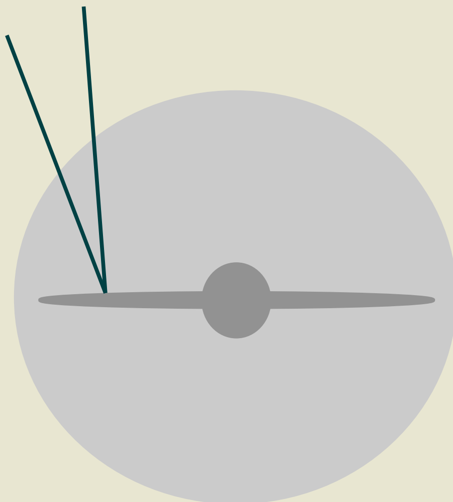
General constraint on decay rate

Applies to all dark matter candidates
with a two-body radiative decay

$$F = \frac{\mathcal{L}}{4\pi D_L^2} = \frac{M_{fov}\Gamma_\gamma}{8\pi D_L^2}$$

$$E_\gamma = m_s/2$$





Riemer-Sørensen et al. 2006,
Boyarsky et al, 2006

Uncertainties

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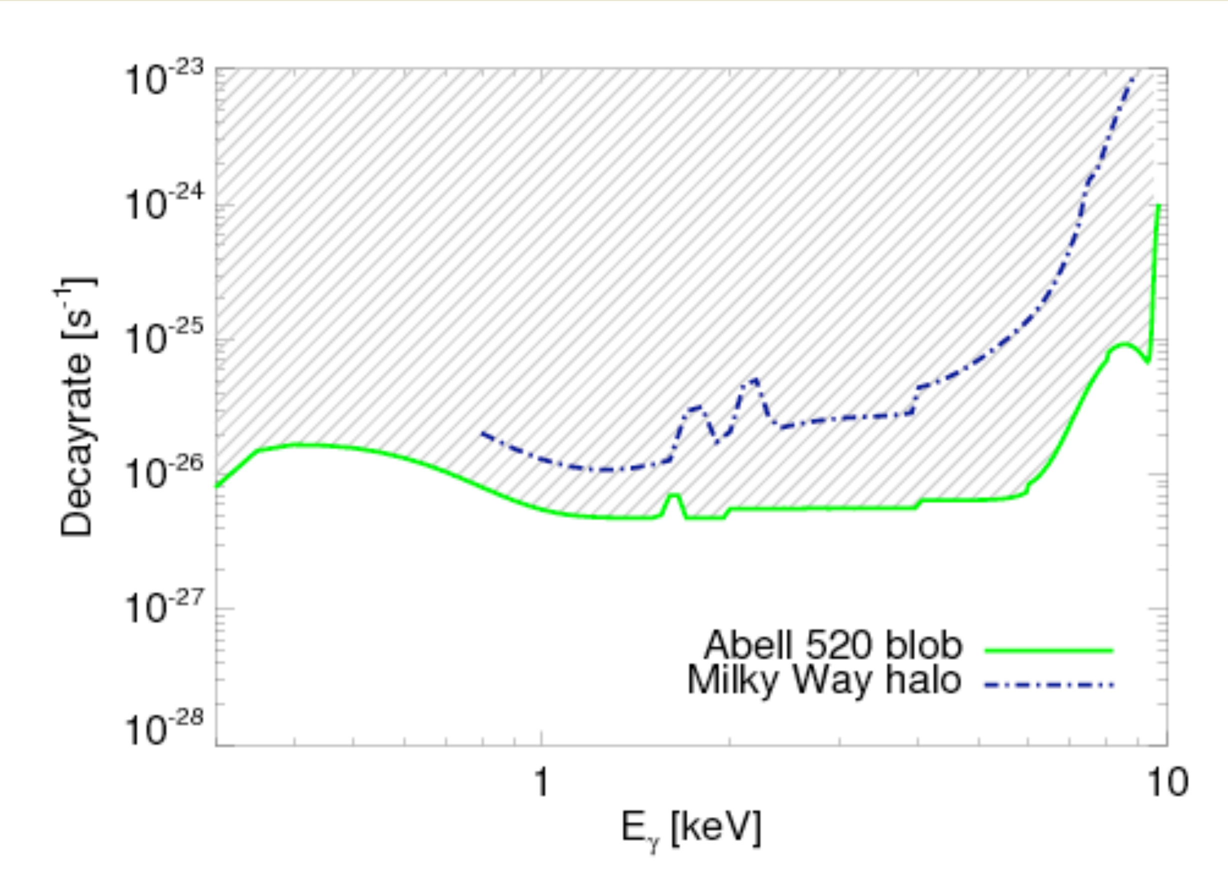
Orders of magnitude estimates



Uncertainties

Flux: ≈10-20%

Mass: ≈10-30%

Distance: ≈10-30%

Distance dominates

Age of the Universe ≈10^{17}sec

Kaluza-Klein Axions

Generic example of candidate with continuous signature

Extra space dimensions:

- Solution to hierarchy problem of particle physics
- Additional space dimensions are compactified with radius R
- Only gravity propagates in higher dimensions

Axions:

- Singlets under the standard model gauge group
- Can propagate in higher dimensions
- Compactification -> higher dimension axion field decomposed into a Kaluza-Klein tower of states with spacing 1/R

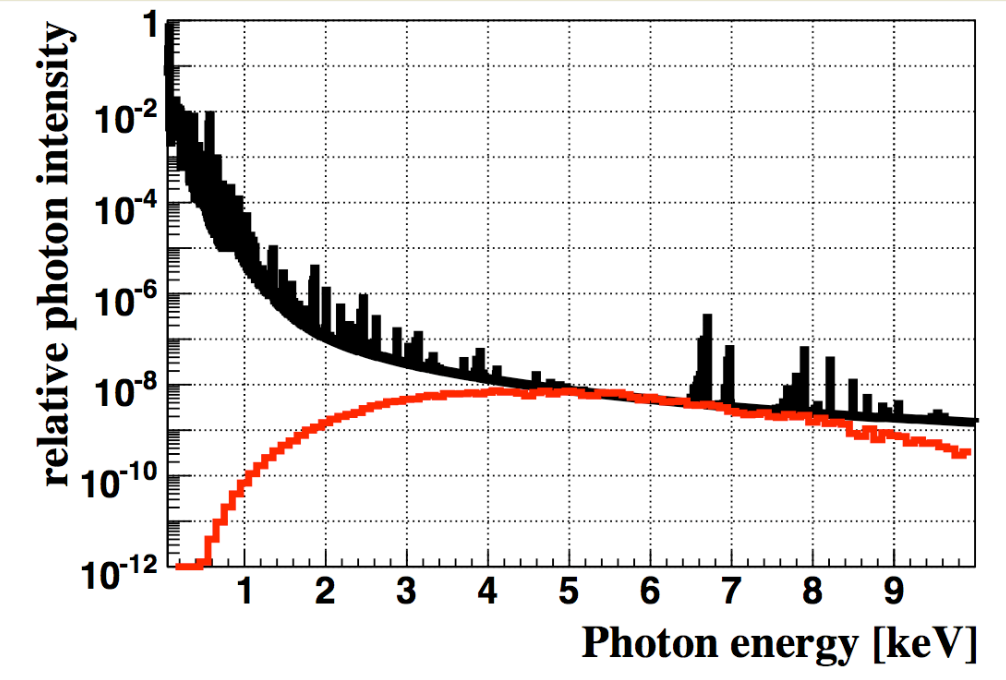
Arkani–Hamed, Dimopoulos & Dvali, 1998

Solar axions

Solar axions - motivated by X-ray emission from the solar corona region

Kaluza-Klein axions produced in core by $\gamma\gamma$ -> a and γZ -> aZ.
Trapped in orbits and decay.

DiLella & Zioutas, 2003



Derived X-ray spectrum from the Sun (black)

Orlando, Peres & Reales, 2001

Two-body decay with photon emission. Different masses -> different energies

All states up to the kinematic limit emitted

Solar axions

$$L_a \propto \tau_a^{-1} \propto g_{a\gamma\gamma} R^{\delta}$$

ASCA observations of solar minimum (2-8 keV)

Orlando, Peres & Reales, 2001

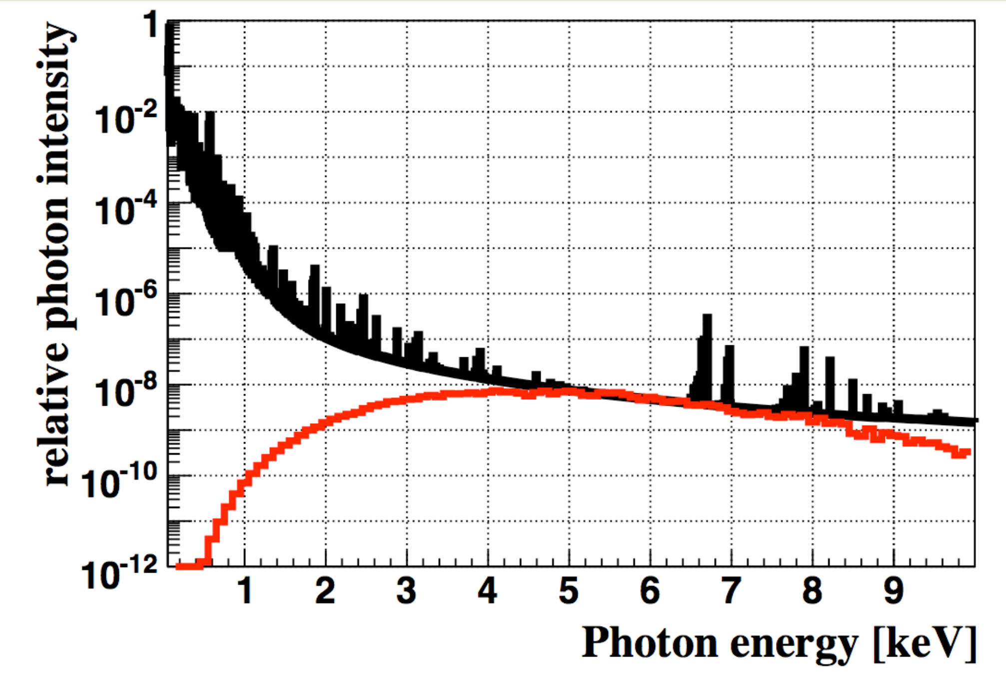
$\tau \approx 10^{20}$ sec ($g_{a\gamma\gamma} \approx 2 \times 10^{-13}$ GeV^{-1}) for $\langle m_a \rangle = 5$ keV

DiLella & Zioutas, 2003

Dark matter axions?

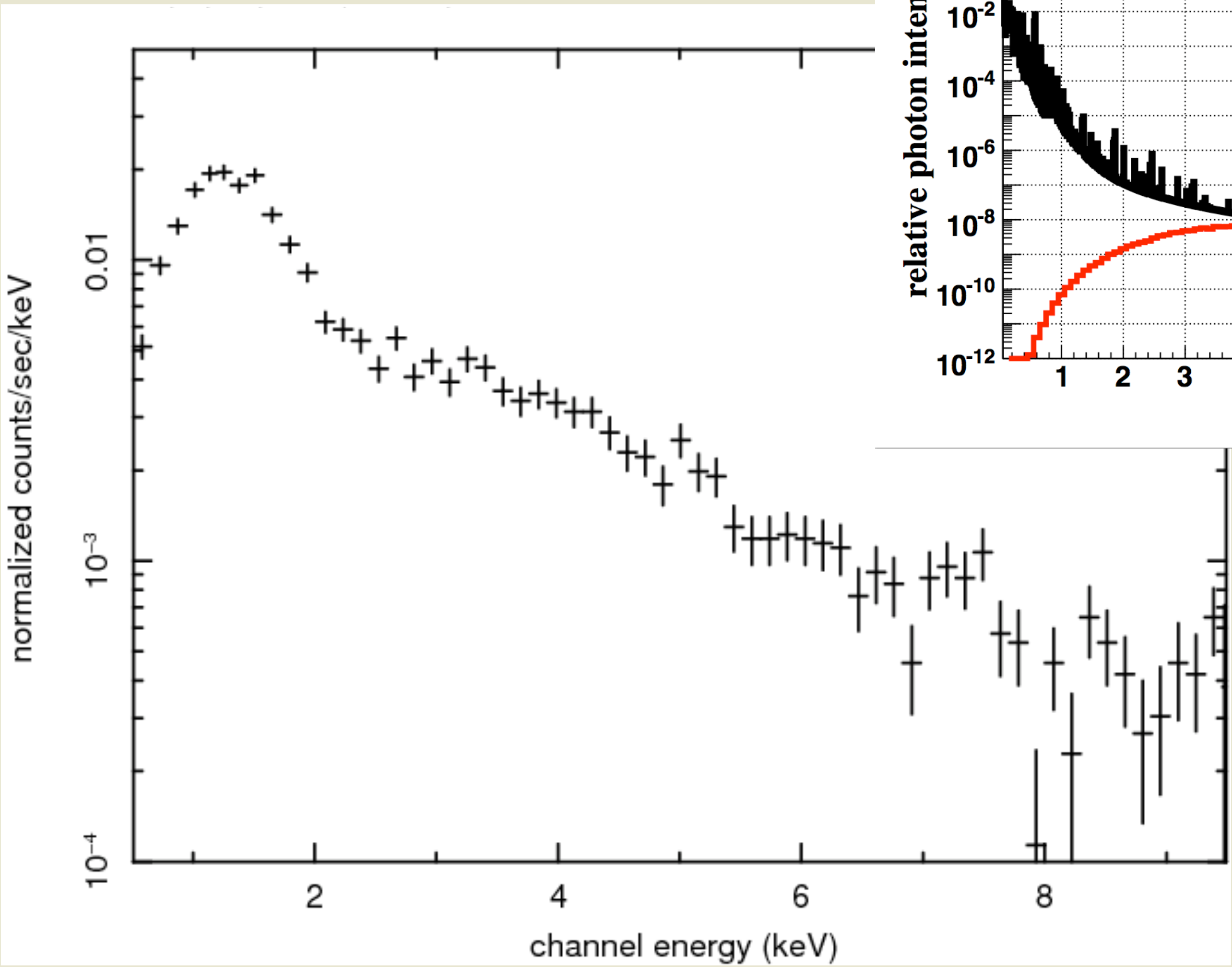
Axions created in stars (as solar axions), confined by gravitational potential in clusters of galaxies

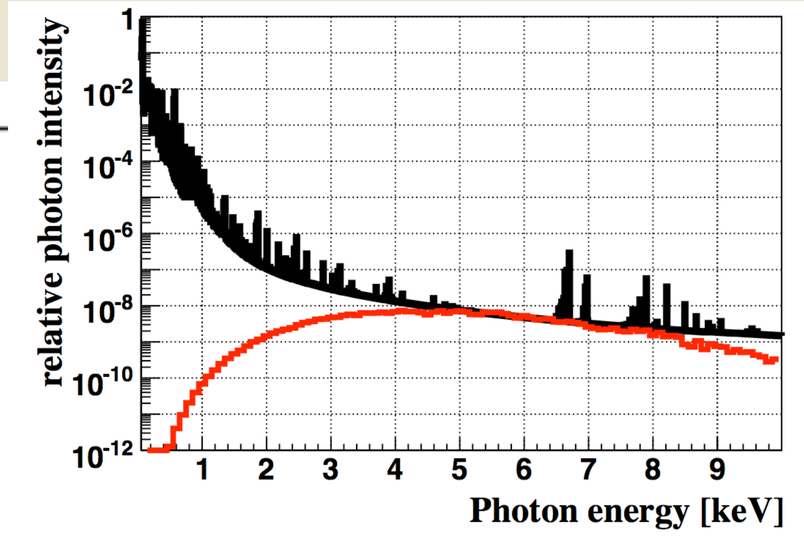
Expected signal from decaying axions. Can only move in intensity (and redshift due to distance).



Solar axions does not have to be the dark matter! And dark matter axions does not have to be solar.

The blob region emission





The blob region emission II

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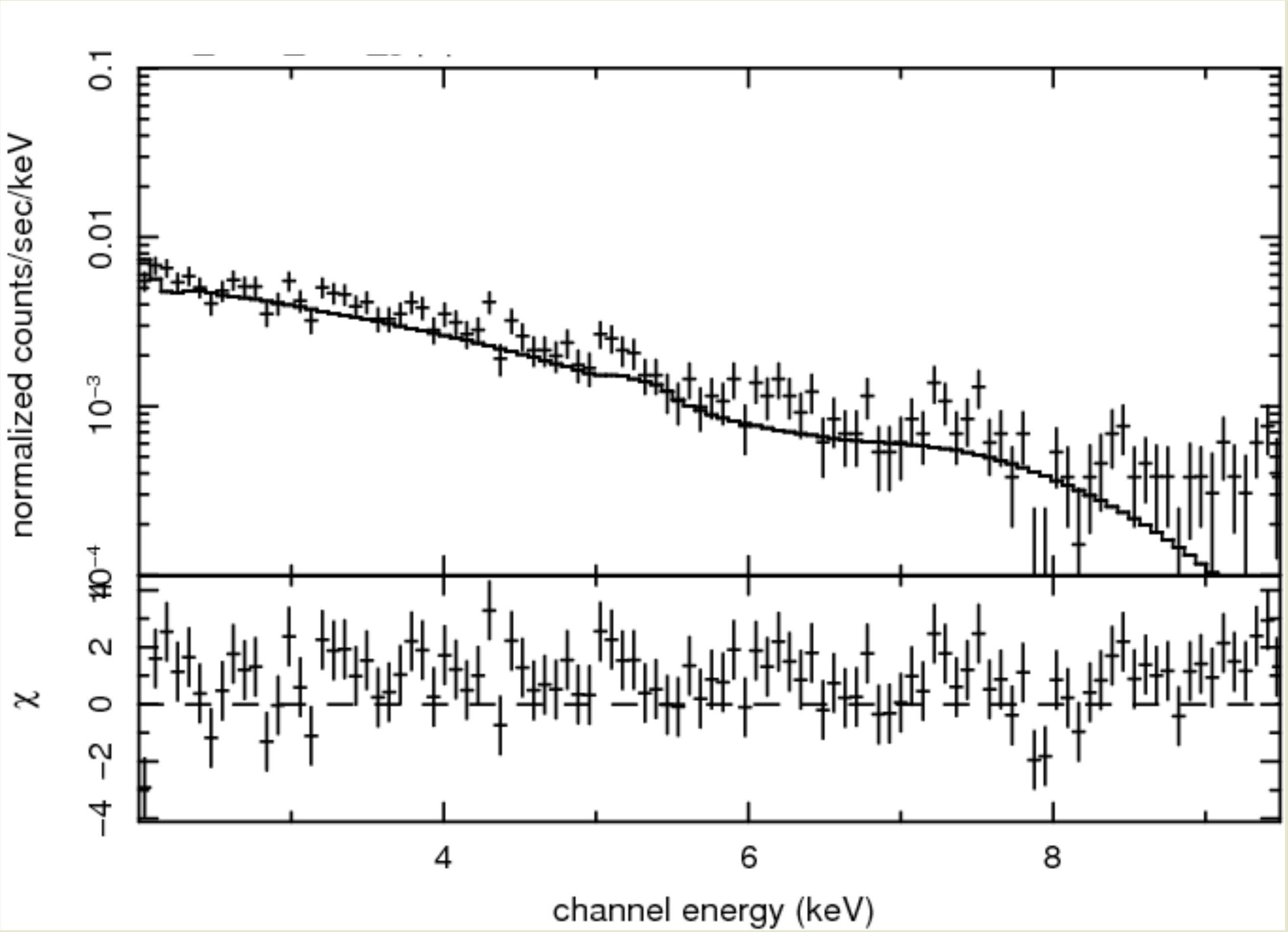
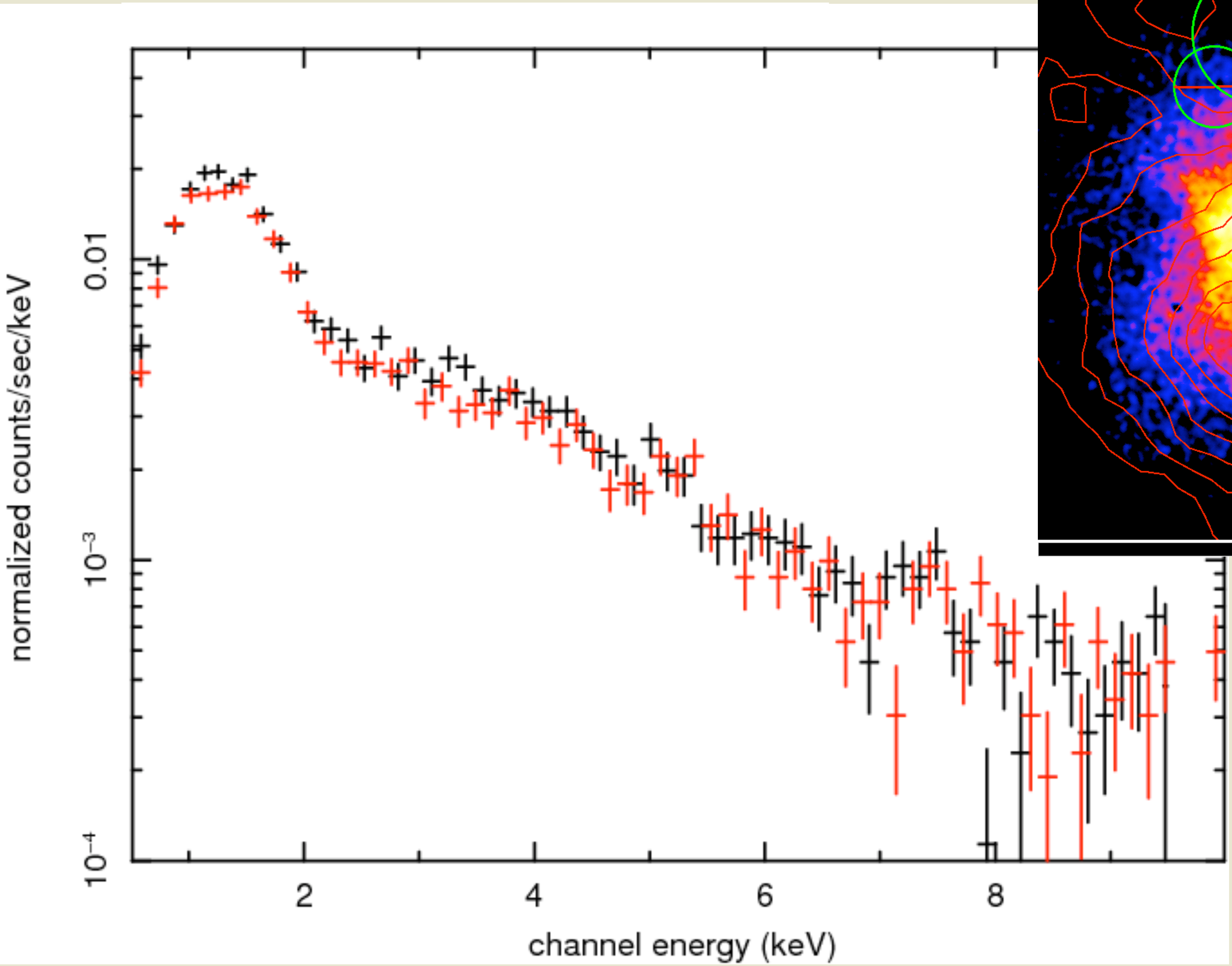
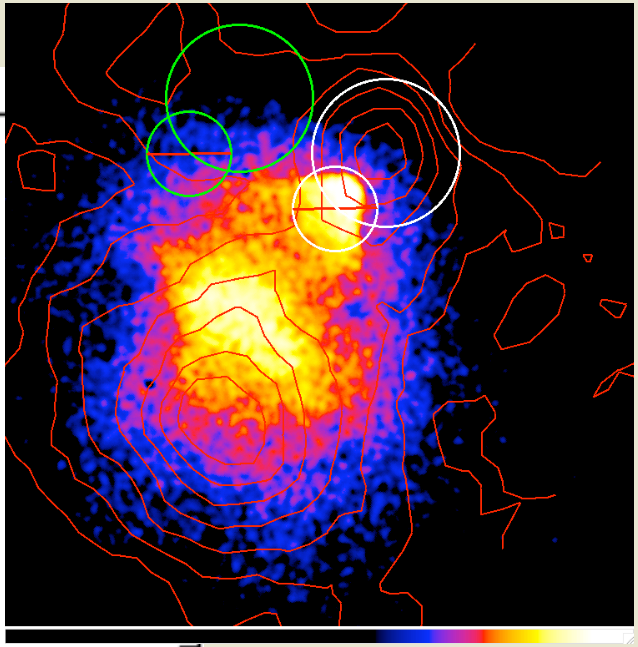
Very conservative upper limit on the luminosity, 2-9.5 keV, $L \leq 10^{44}$ ergs/sec



redχ^2 = 1.0


normalized counts/sec/keV
0.01
10^{-3}
10^{-4}
2
4
6
8
channel energy (keV)



Constraining the lifetime

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Upper limit on the luminosity, $L \leq 0.2 \times 10^{44}$ ergs/sec

Lower limit on the lifetime

$$\tau = \frac{1}{\Gamma} = \frac{2X_a M_{DM}}{L}$$

$\Rightarrow$ $\tau \geq 10^{24}$ sec ($g_{a\gamma\gamma} \leq 3 \times 10^{-15}$ GeV^{-1}) for Abell A520

Riemer-Sørensen et al. submitted to PRL

Lifetime for solar axions, $\tau \approx 10^{20}$ sec

DiLella & Zioutas, 2003

Consistent?

Only if solar axions are <1% of the dark matter

Solar axions does not have to be the dark matter! And dark matter axions does not have to be solar.

Summary

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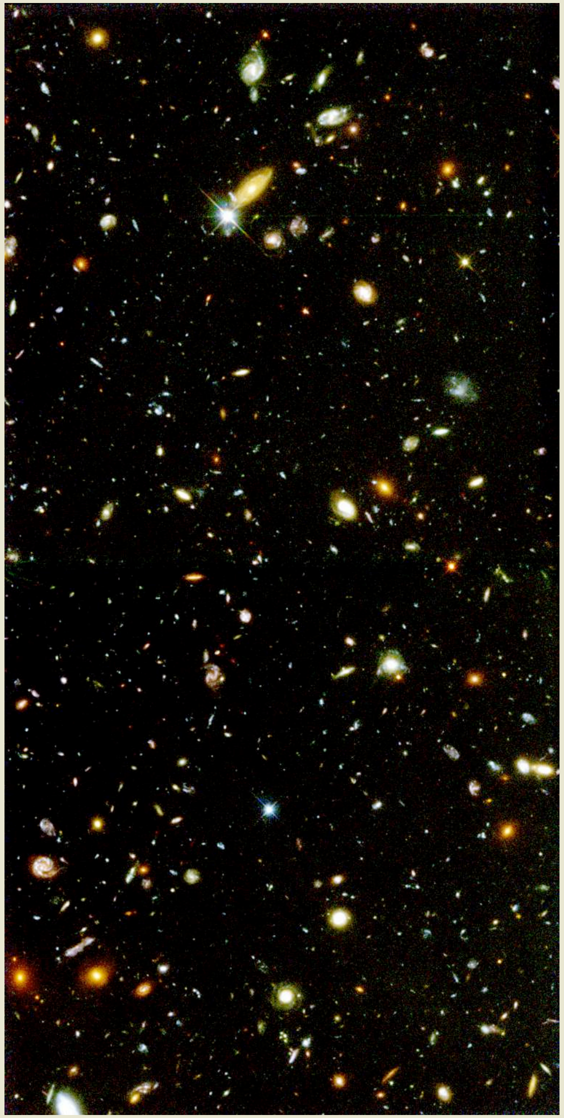


Dark matter dominates the gravity of the Universe

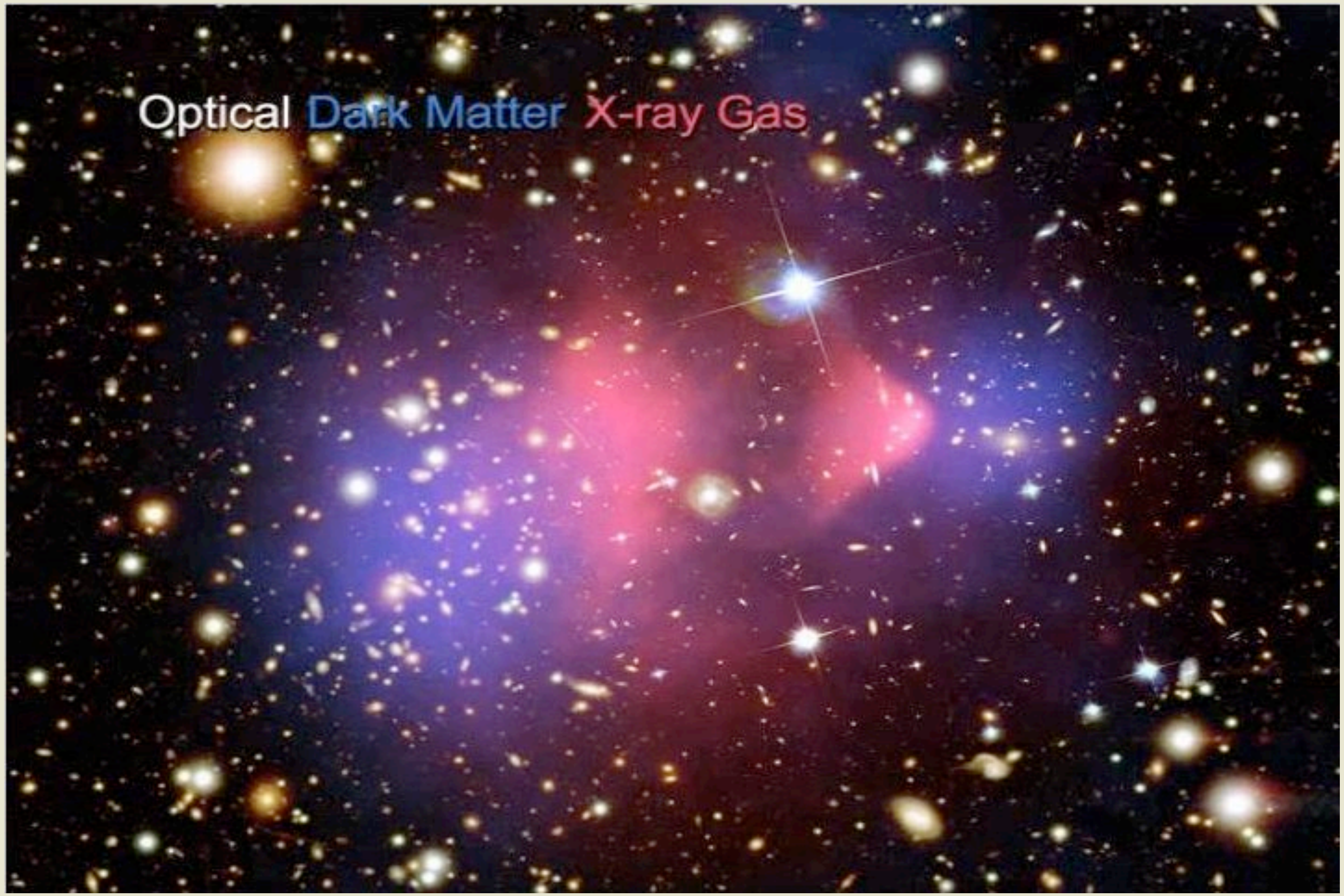
No Standard Model candidate -> extensions

Some particle candidates have X-ray signatures

KK-axions can be constrained from X-ray observations of clusters of galaxies

Lifetime constrained

Observations not consistent with solar axions being all of the dark matter (but does not exclude the existence of axions)


Optical Dark Matter X-ray Gas