Dark Cosmology Centre

Constraining dark matter from X-ray observations of clusters of galaxies

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Astro-ph/0703342, submitted to PRL

Dark Matter Candidates

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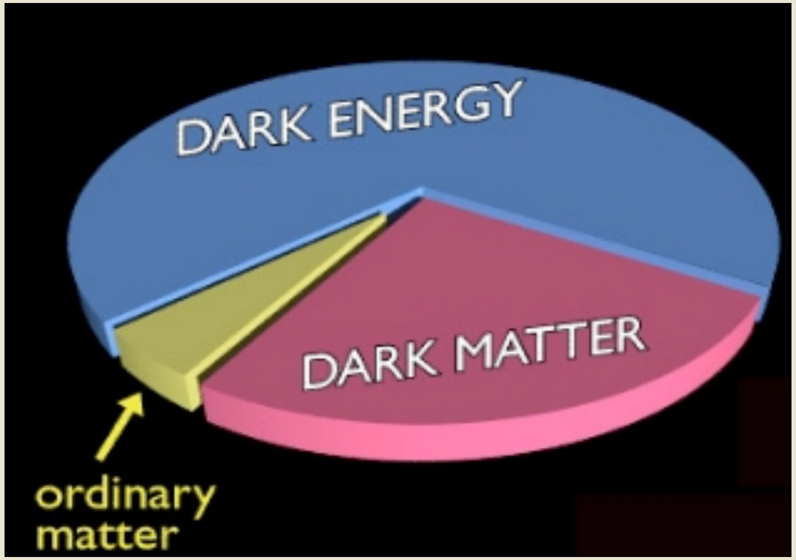
Dark matter solves gravity related problems of cosmology.

General properties of a dark matter candidate:

- Particle behaviour
- Massive (Gravitational effect)
- Not too much interacting
- Long lifetime



No good Standard Model particle candidate -> extensions:

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

Some candidates allowed to decay with X-ray emission.

To be continued...

Chandra X-ray Observatory

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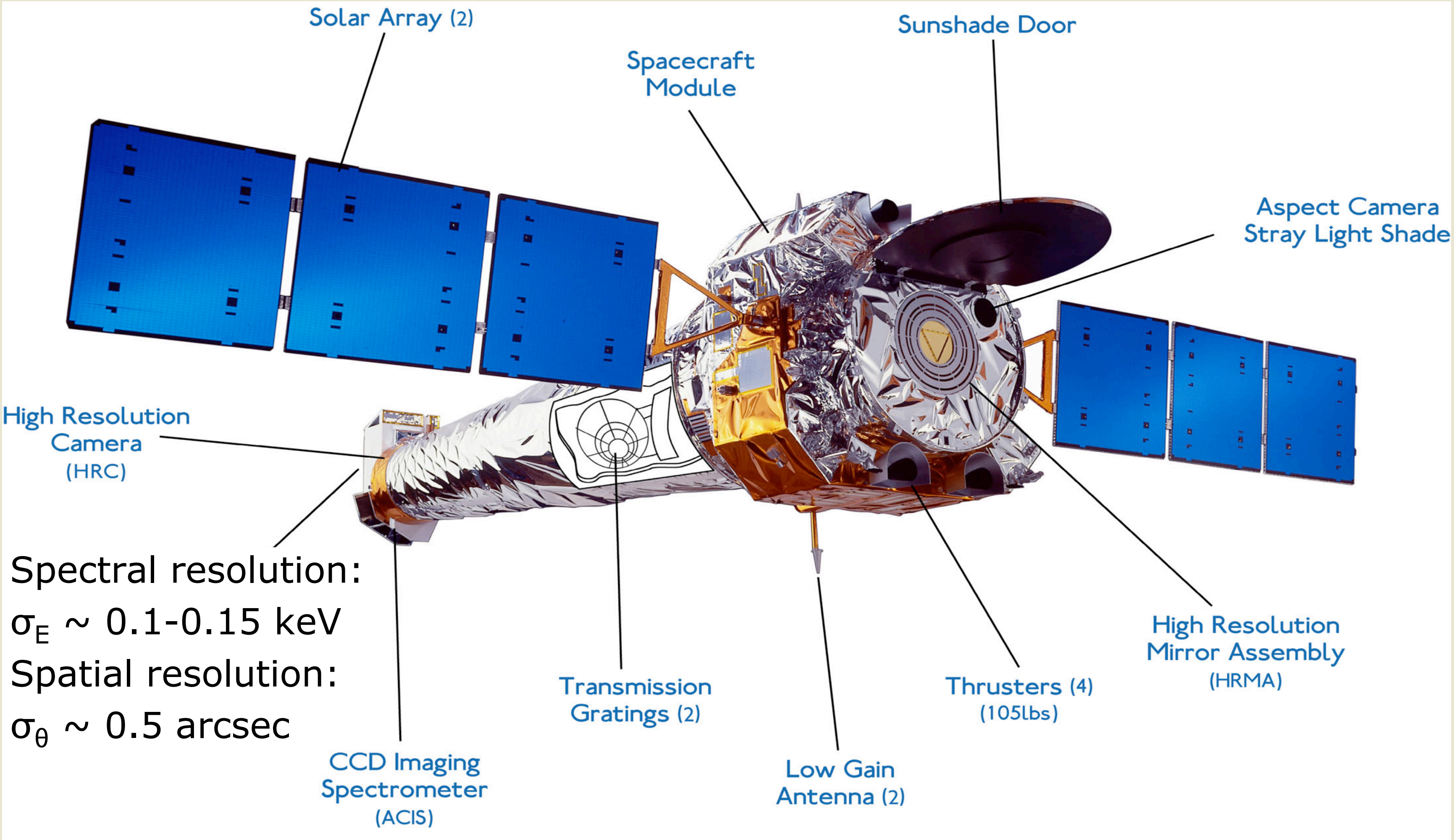
Launched by NASA in 1999. Photon energy range 0.3-10 keV



Spectral resolution:

$\sigma_E \sim$ 0.1-0.15 keV

Spatial resolution:

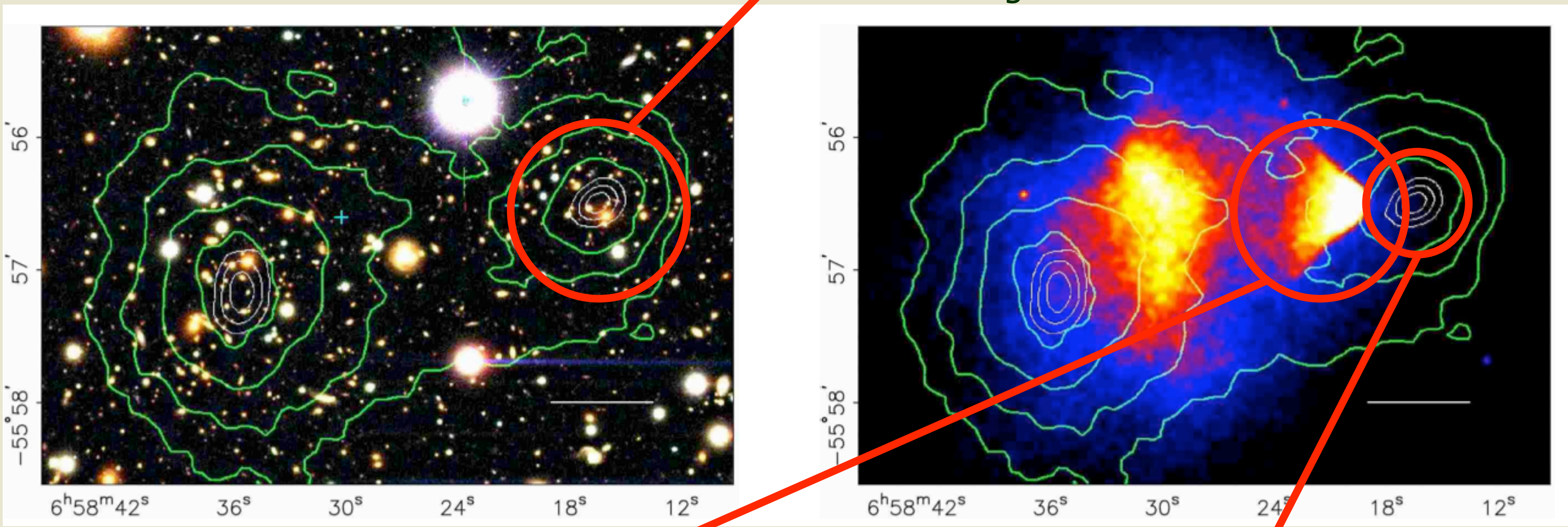
$\sigma_\theta \sim$ 0.5 arcsec

Dark matter "blobs"

Merging galaxy cluster systems with
prominent bow shocks

The Bullet Cluster, 1E0657-558

The galaxies follows the gravitational potential from weak lensing



Clowe et al. 2006

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

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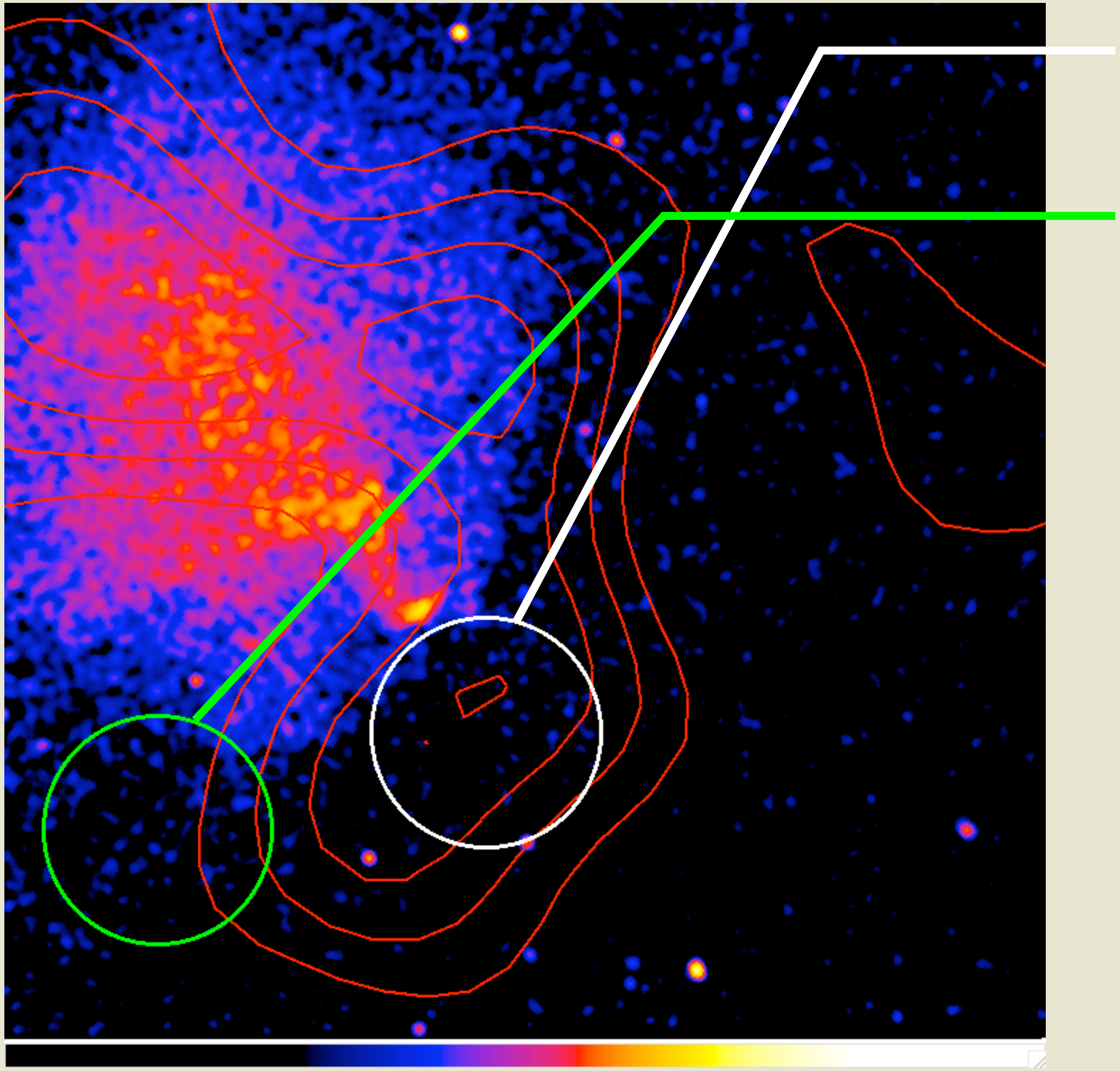

Blob region
$M_{blob} = 6 \times 10^{13} M_{sun}$

Reference region
with low mass
$M_{ref} = 0.02 \times 10^{13} M_{sun}$

Where is the dark matter signal?

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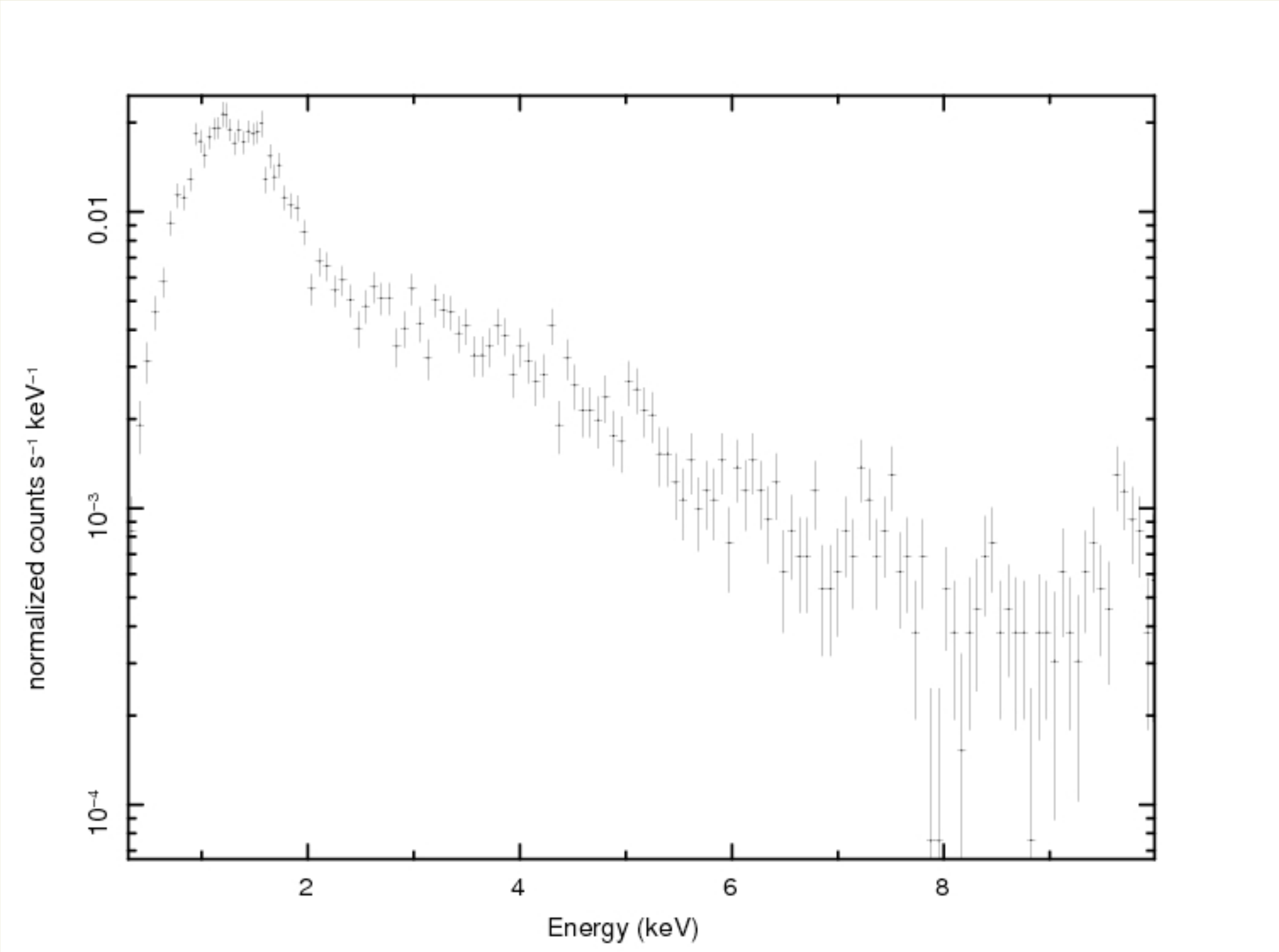
Spectrum of the Bullet cluster dark matter blob



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

$$L \propto M\Gamma$$

$$\Gamma = 1/\tau$$

Generic example of a mono-energetic signal

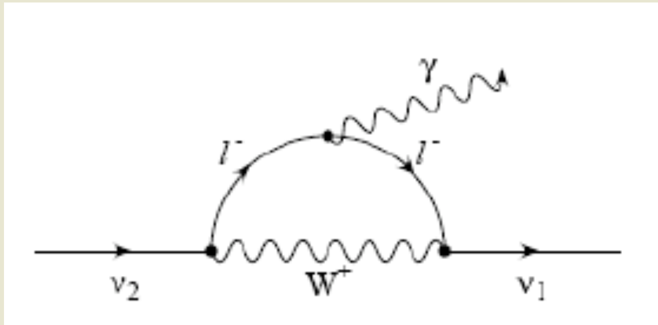
Right-handed neutrinos added to the Standard Model by hand -> νMSM

Dodelson & Widrow 1993, Shaposnikov et al. 2005-2006

Mass 0.5 keV (Tremaine-Gunn limit for fermions) to approx. 400 MeV (structure)

Does not interact except through oscillations

$$\begin{pmatrix} \nu_\alpha \\ \nu_s \end{pmatrix} = \begin{pmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$



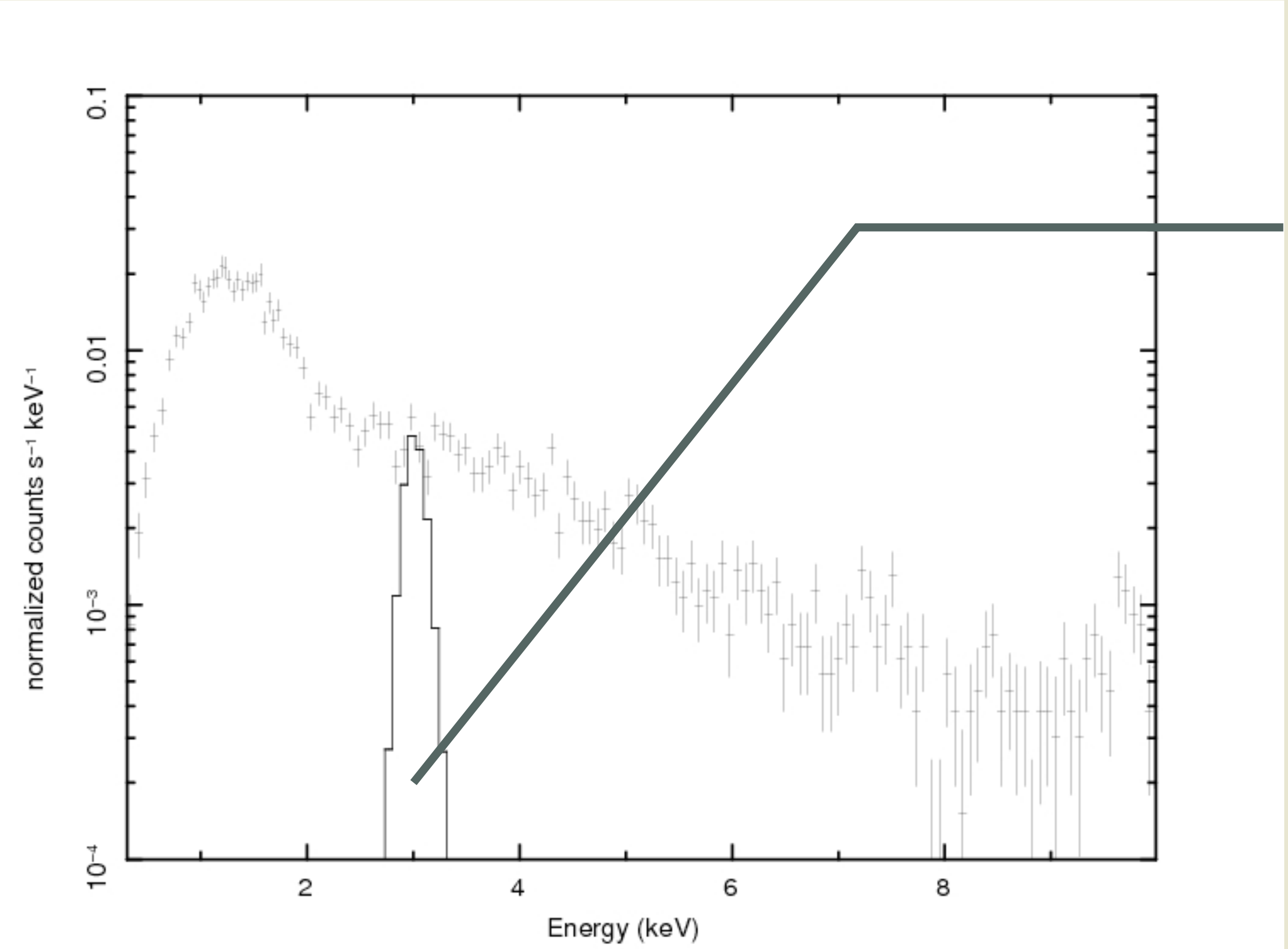
Two-body radiative decay: $\nu_s \rightarrow \nu_\alpha + \gamma$ $E_\gamma = m_s/2$

Dolgov & Hansen, 2000

The signature

Mono-energetic emission -> Gaussian because of instrumental resolution

$$\nu_s \rightarrow \nu_\alpha + \gamma$$



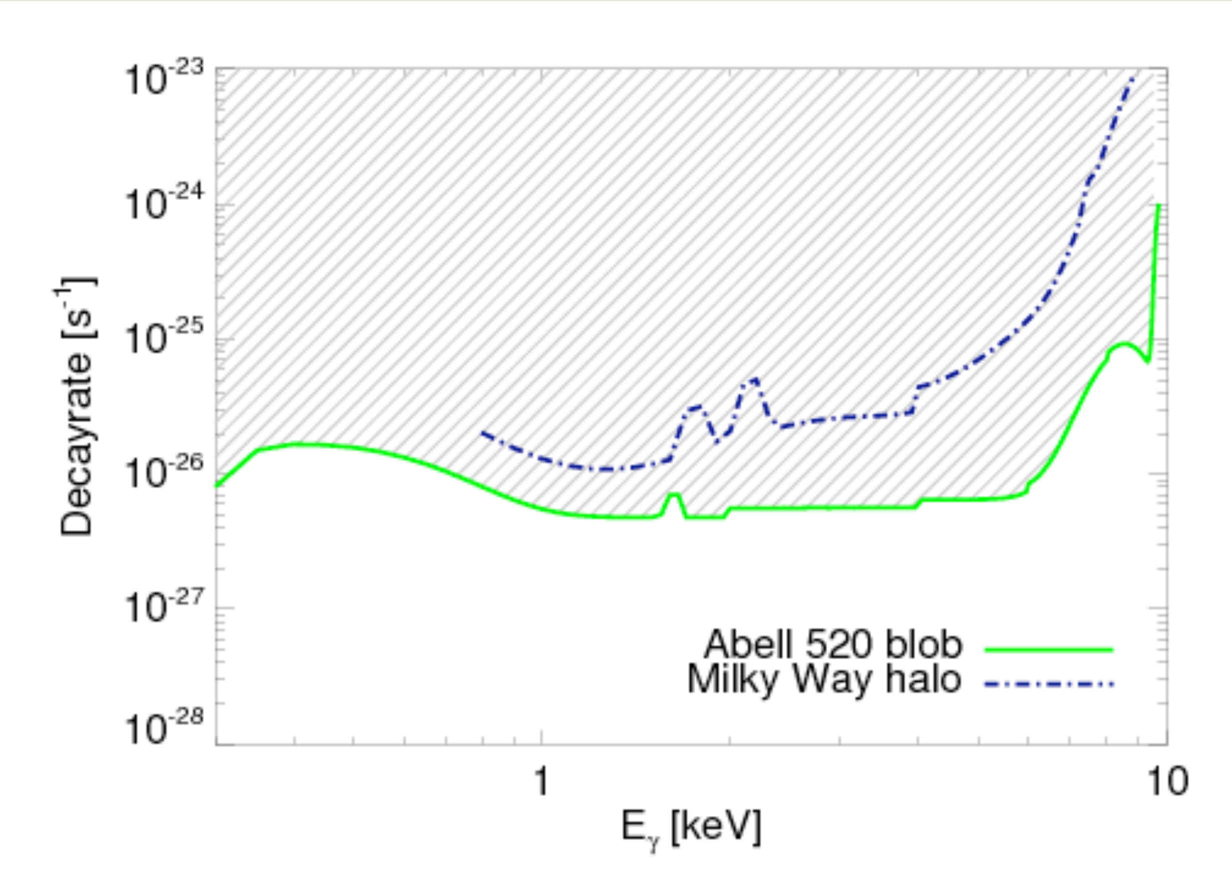
Chandra ACIS-I resolution: FWHM ~ 0.1 keV (energy dependent)

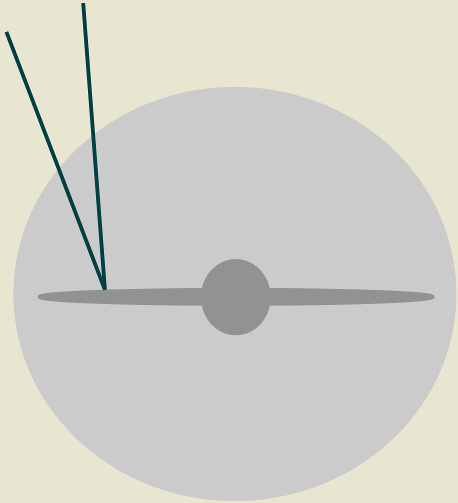
General constraint on decay rate

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

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

$$E_\gamma = m_s/2$$

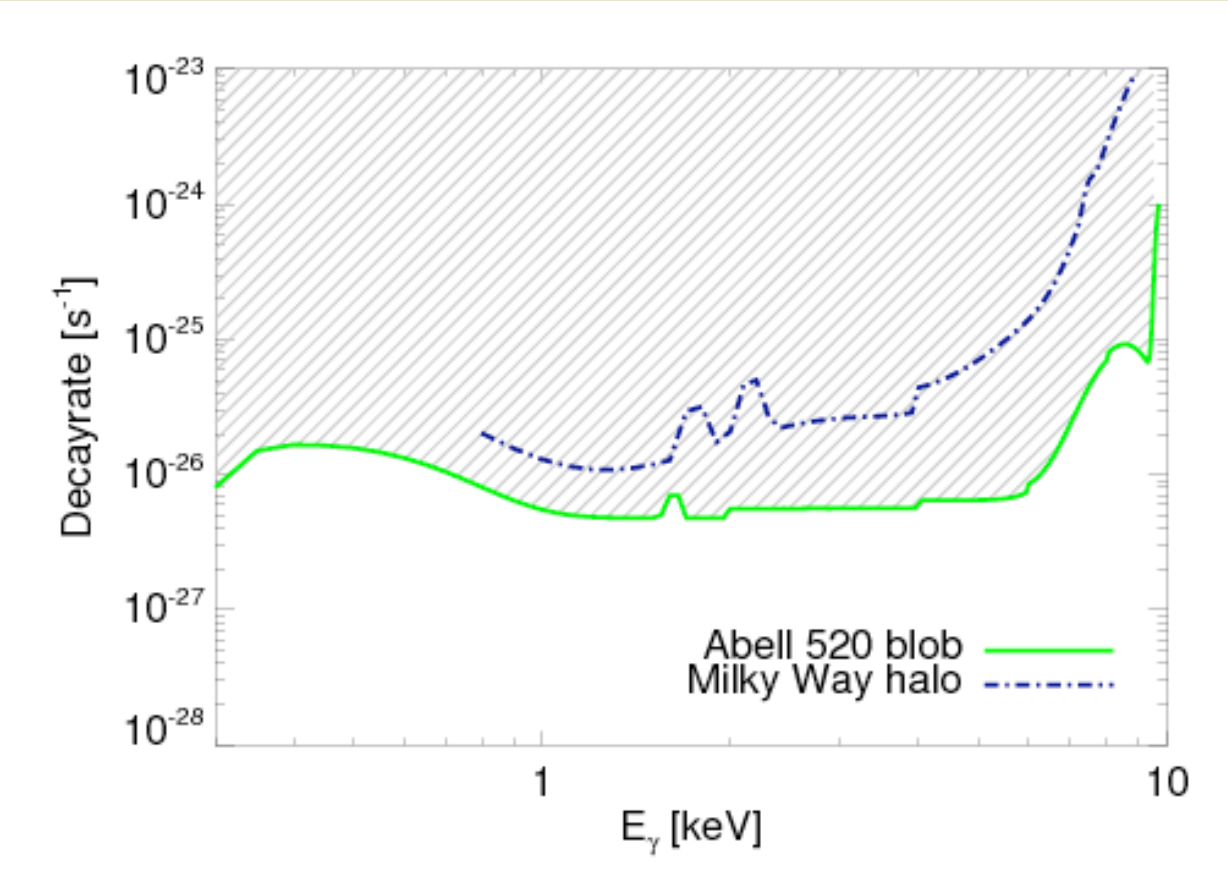




Riemer-Sørensen et al. 2006,
Boyarsky et al, 2006

Uncertainties

Orders of magnitude estimates



Uncertainties

Flux: ≈10-20%

Mass: ≈10-30%

Distance: ≈10-30%

Distance dominates

Age of the Universe ≈10^{17}sec

The mass-mixing angle parameter space

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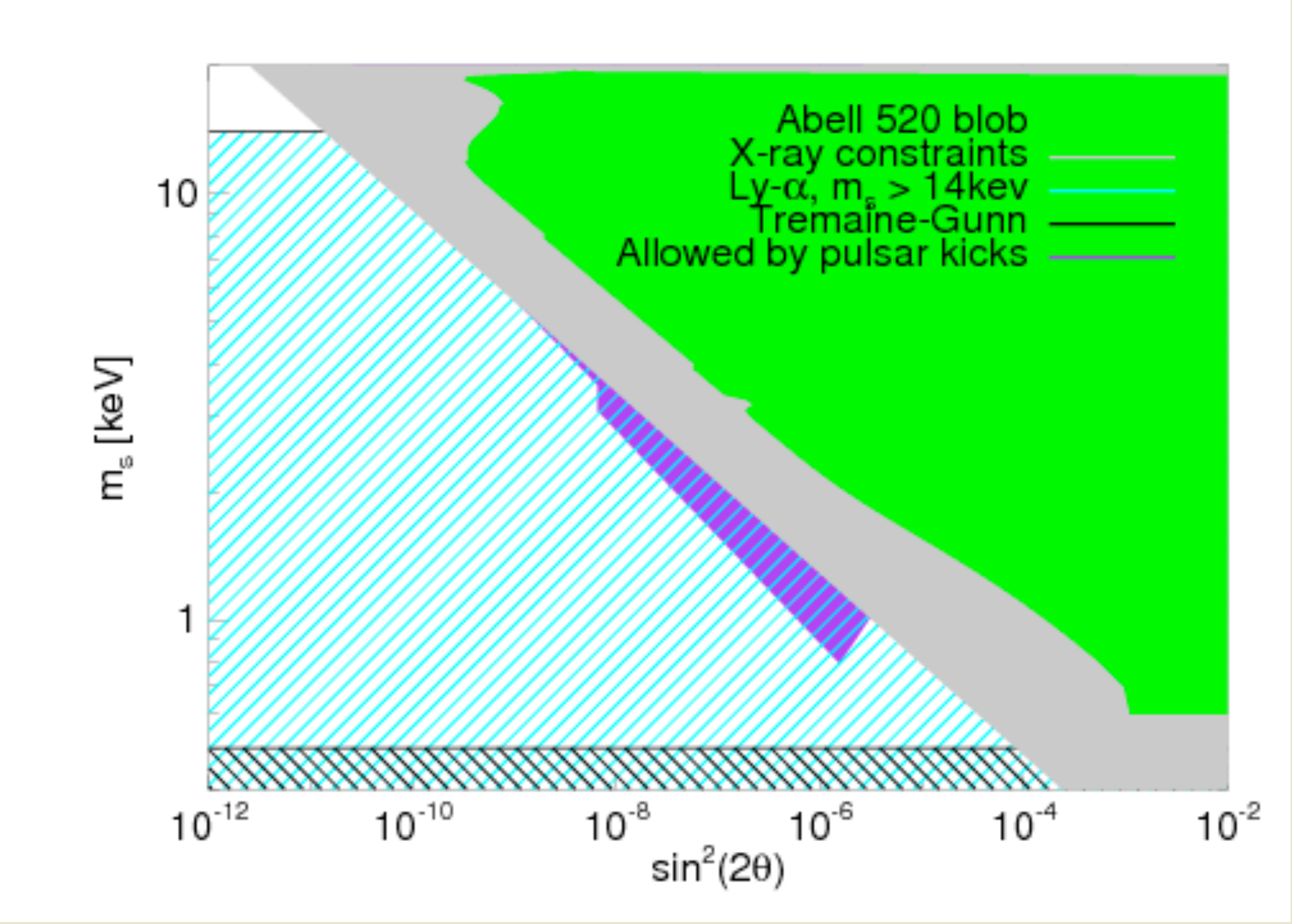

X-ray:

Boyarsky et al., Abazajian et al., Watson et al.

Ly-alpha:

Viel et al., Seljak et al.

Pulsar kicks:

Kusenko

Axions

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Generic example of multi-energy signal with known shape

Extra space dimensions:

- Solution to hierachy 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

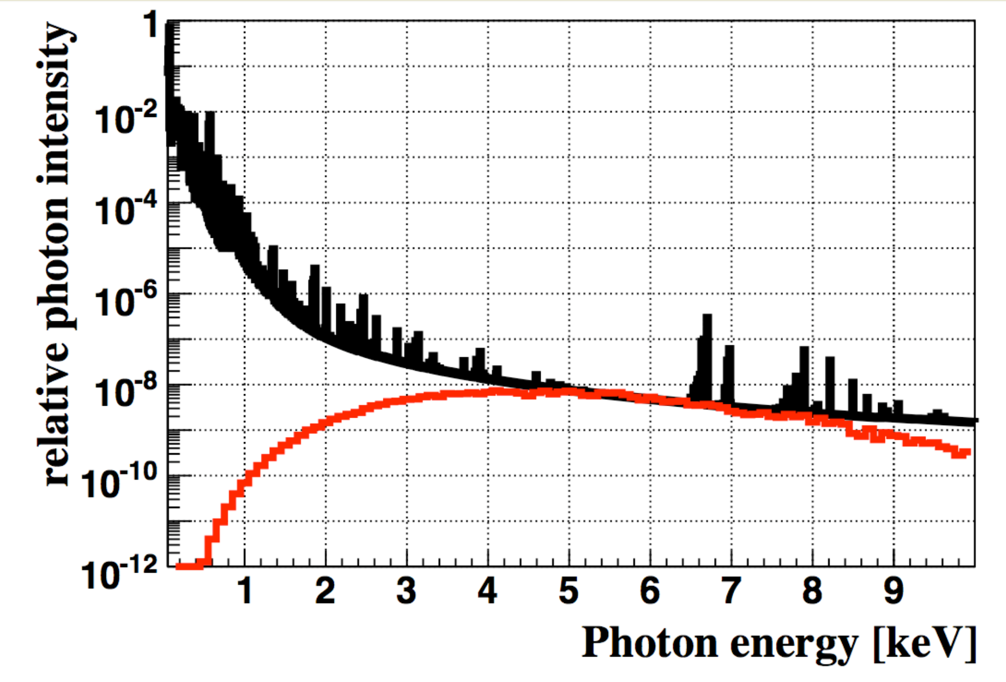
Arkani–Hamed, Dimopoulos & Dvali, 1998

Solar axions

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

Kaluza-Klein axions produced in core by $\gamma\gamma \to a$ and $\gamma Z \to aZ$.
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

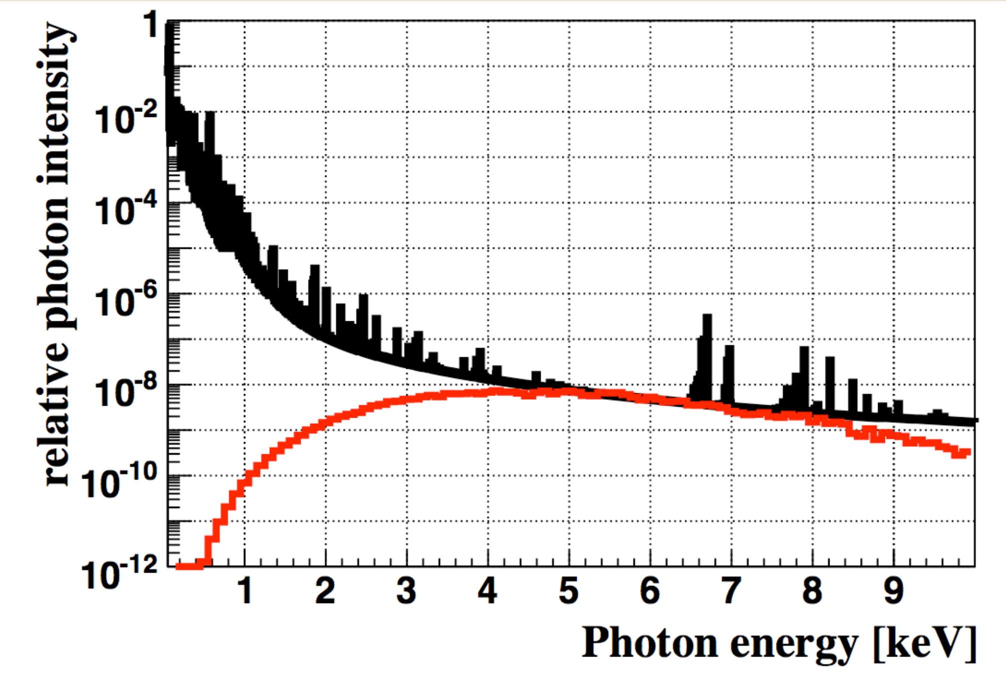
$\tau \approx 10^{20}$ sec ($g_{a\gamma\gamma} \approx 2\text{x}10^{-13}$ GeV^{-1})

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

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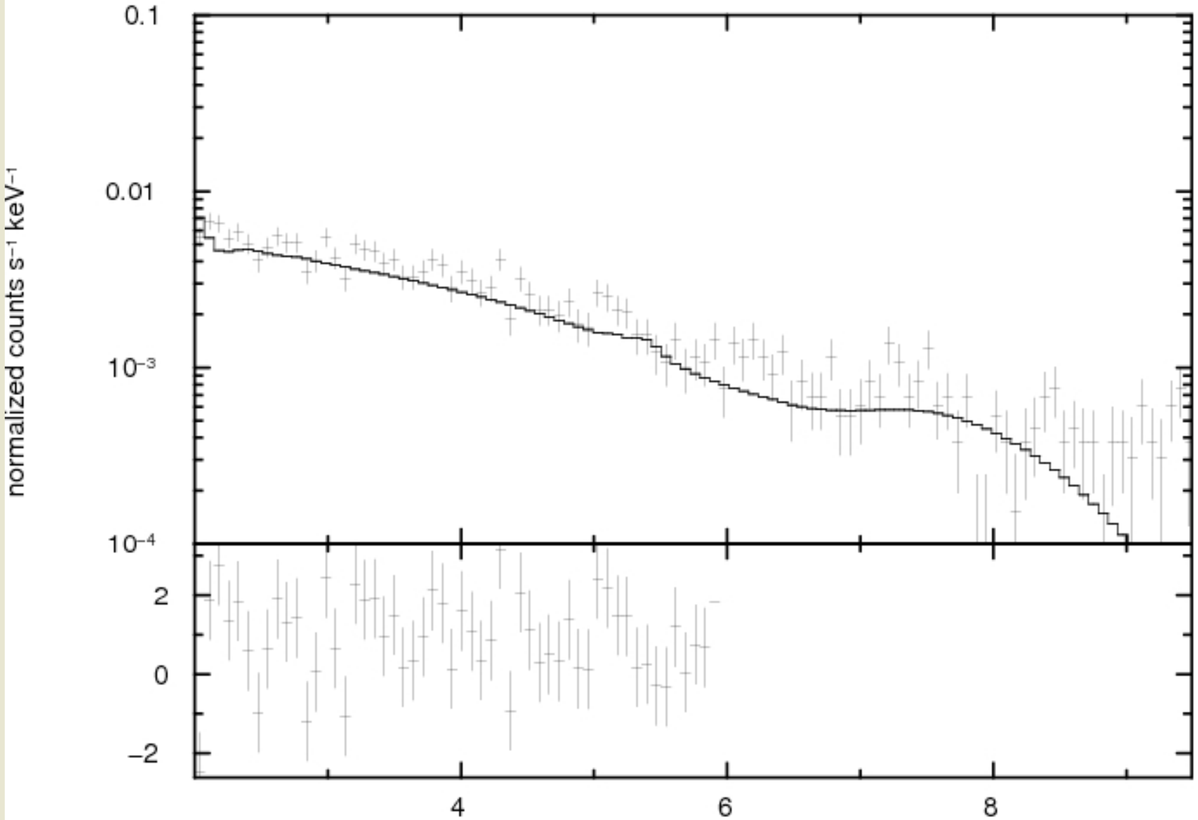
Very conservative upper limit on the luminosity, 2-9.5 keV, L ≤ 10^{44} ergs/sec



redχ^2 = 1.0

The baryonic emission from the reference region

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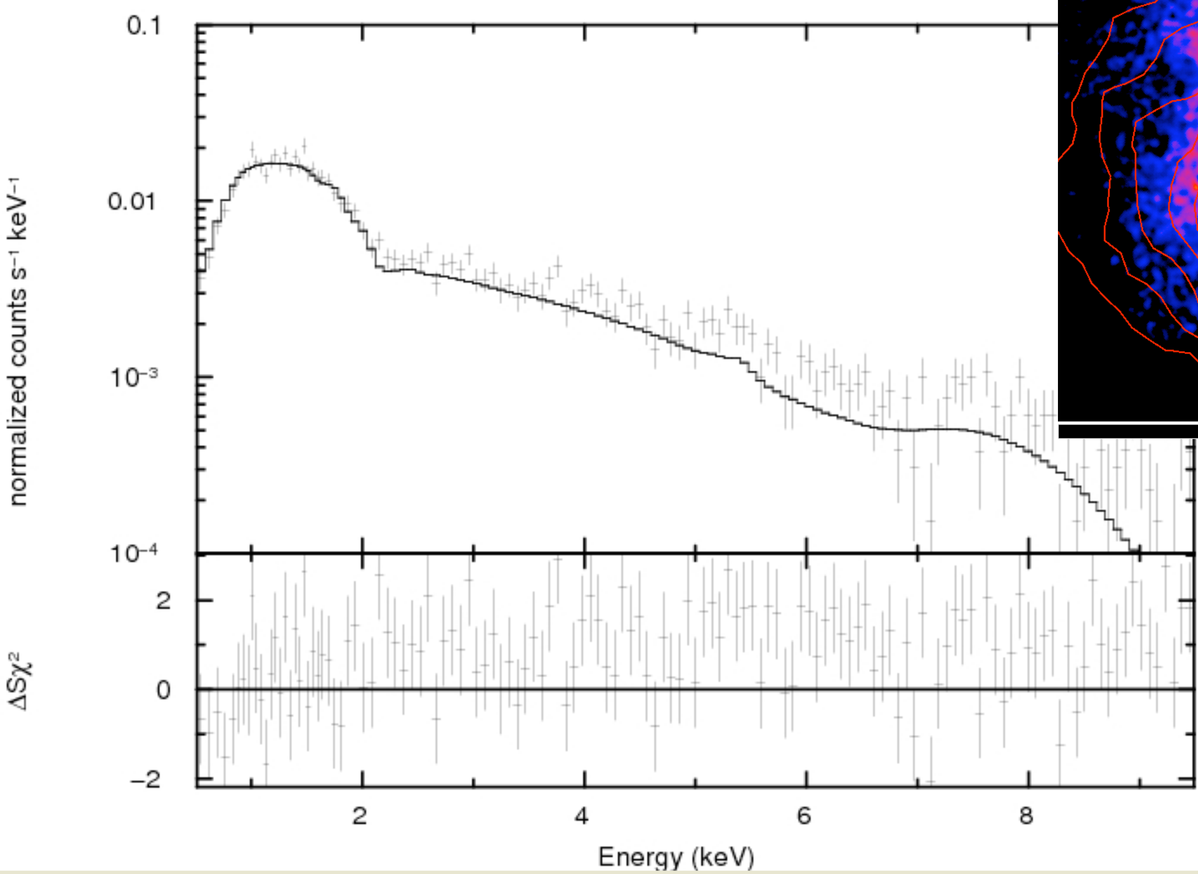
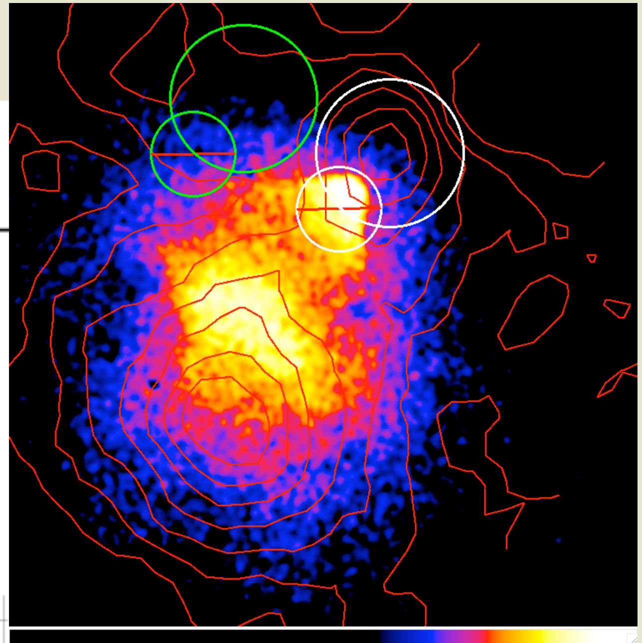
redχ^2 = 1.0

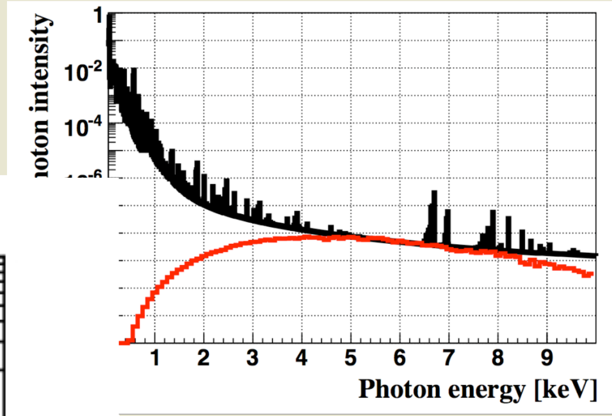
Reference region



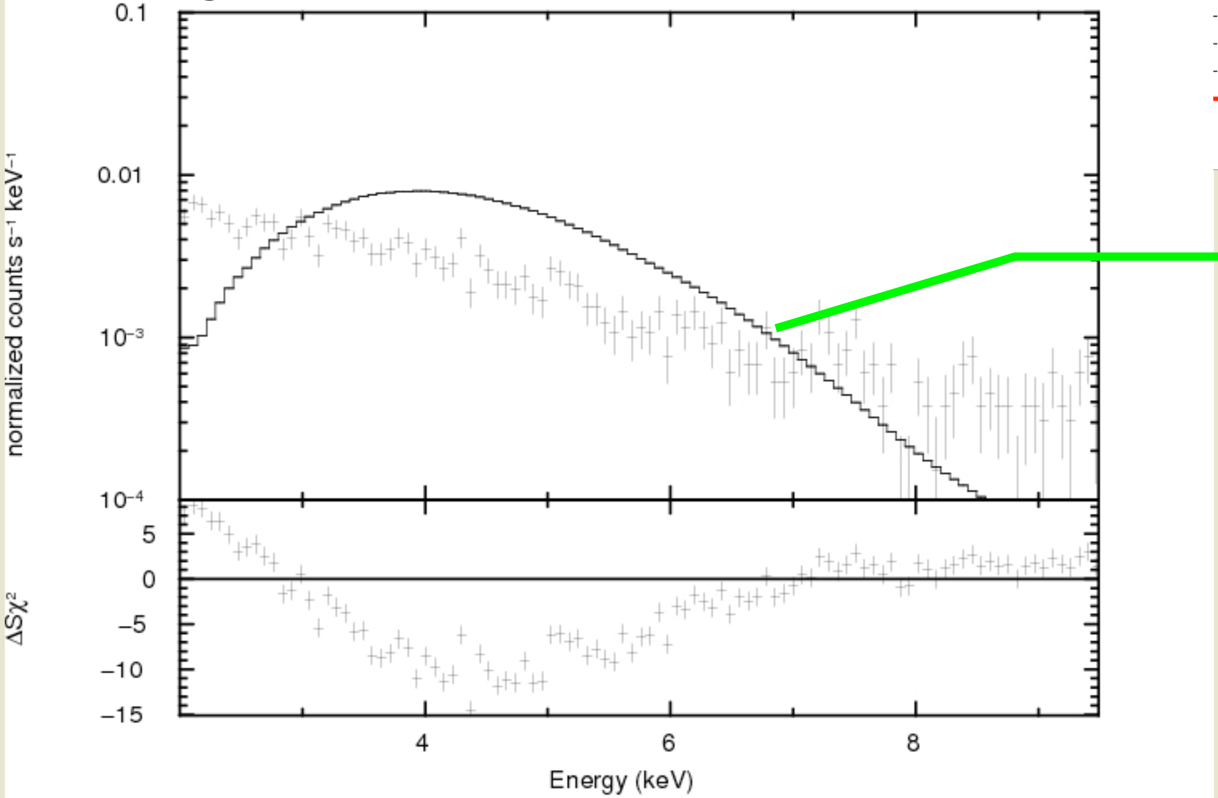


The blob region emission II

Reference region model with free normalization plus expected dark matter flux



Blob region



Integrate to get 3σ upper limit on luminosity

Constraining the lifetime

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 -> entensions

Some particle candidates have X-ray signatures

Models can be constrained from X-ray observations

Sterile neutrinos: Generic example of mono-energetic emission

Decay rate and mass/mixingangle constrained

Axions: Lifetime constrained for specific model

Observations not consistent with solar axions being all of the dark matter