A 3.55 keV Photon Line and its Morphology from a 3.55 keV ALP Line

arXiv:1403.2370 [hep-ph]
with M. Cicoli, J. Conlon, D. Marsh

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Outline

1. The 3.55 keV photon line and its morphology
2. $\mathrm{DM} \to a \to \gamma$
3. $\mathrm{DM} \to a \to \gamma$ **vs** $\mathrm{DM} \to \gamma$ **morphology**

The 3.55 keV photon line

[Bulbul, Markevitch, Foster, Smith, Loewenstein, Randall '14]

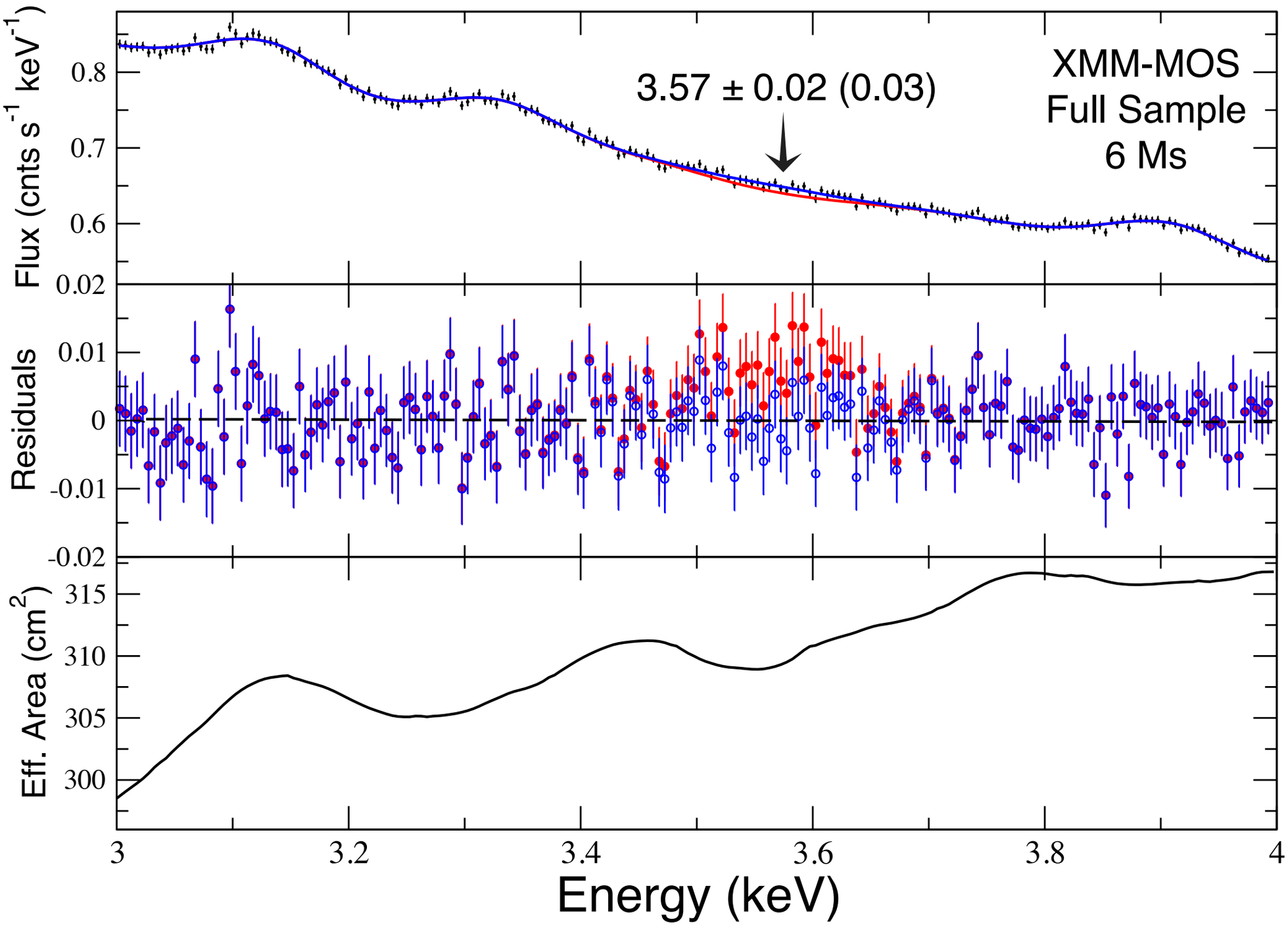
- Stacked data of 73 galaxy clusters ($0.01 < z < 0.4$)
- Detected independently in XMM-Newton PN and MOS instruments at 4-5 sigma
- Detected in all three subsamples (Perseus - also with Chandra, Coma+Ophiuchus+Centaurus, all others)

[Boyarsky, Ruchayskiy, Iakubovskyi, Franse '14] [see Talk by J. Franse]

- Detected in Perseus Cluster and Andromeda galaxy with XMM-Newton MOS data

The observed line

[Bulbul, Markevitch, Foster, Smith, Loewenstein, Randall '14]



Possible origins of the line

Instrumental effect?

☒ Seen by 4 different detectors (2 XMM, 2 Chandra)

☒ De-redshifting of clusters leaves line at 3.55 keV

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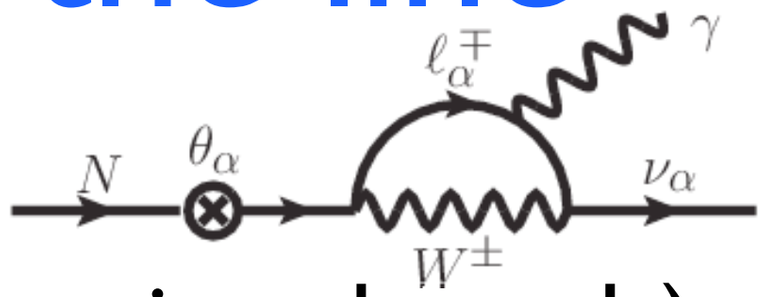
Atomic line?

☒ No known atomic line at this energy. Apart from known lines exceeding expectation by factor ~20

☒ Line also detected in Andromeda (no hot gas!)

Possible origins of the line

Dark matter decay/annihilation?



- Sterile neutrinos (compatible with previous bounds)

$$\Gamma_\gamma(m_s, \theta) = 1.38 \times 10^{-29}\ \mathrm{s}^{-1} \left(\frac{\sin^2 2\theta}{10^{-7}}\right) \left(\frac{m_s}{1\ \mathrm{keV}}\right)^5$$

- ALP (Axion Like Particle) DM, Axinos, excited states of DM, Gravitinos, ...

[Bulbul, Markevitch, Foster, Smith, Loewenstein, Randall;
Czerny, Hamaguchi, Higaki, Ibe, Ishida, Jeong, Nakayama, Takahashi, Yanagida, Yokozaki;
Jaeckel, Redondo, Ringwald; El Asiati, Hambye, Scarna;
Dudas, Heurtier, Mambrini; Bomark, Roszkowski; Frandsen, Sannino, Shoemaker, Svendsen;
Kolda, Unwin; Finkbeiner, Weiler; Kubo, Lim, Lindner; Choi, Seta; Baek, Okada, Toma;
Lee, Park, Park; Chen, Liu, Nath; Ishida, Okada; Geng, Huang, Tsai; Chiang, Yamada;
Dutta, Gogoladze, Khalid, Shafi; Rodejohann, Zhang]

...roughly fits the signal...

... only roughly fits the signal...

XMM-Newton MOS: [Bulbul, Markevitch, Foster, Smith, Loewenstein, Randall '14]

	Full Sample (73 cluster)	Coma +Centaurus +Ophiuchus	Perseus (without core)	Perseus (with core)
$\sin^2(2\theta)$ (10^{-11})	$6.8^{+1.4}_{-1.4}$	$18.2^{+4.4}_{-3.9}$	$23.3^{+7.6}_{-6.9}$	$55.3^{+25.5}_{-15.9}$

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- Signal in Perseus ~8 times stronger than in full sample
- Half of the Perseus Signal is within the central 20 kpc but $R_{DM} \simeq 360$ kpc

$\Rightarrow$ Dark matter to photon may not fit the morphology

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Dark matter to axion to photon

$$\mathrm{DM} \to a \to \gamma$$

- Axions transform to photons in cluster/galactic magnetic fields
- Theoretically equally well motivated as $\mathrm{DM} \to \gamma$ (axions are typically associated to a high scale)
- Signal strength follows DM density **and** strength of the magnetic field

$\Rightarrow$ Signal peaks on scales of the cluster magnetic field! (Perseus)

Dark matter to axion decays

DM is a scalar

Decay via $\frac{\Phi}{\Lambda}\partial_\mu a \partial^\mu a$ with lifetime

$$\tau_\Phi = \left(\frac{7.1\ \mathrm{keV}}{m_\Phi}\right)^3 \left(\frac{\Lambda}{10^{17}\ \mathrm{GeV}}\right)^2 1.85 \times 10^{27}\ \mathrm{s}$$

or DM is a fermion (cosmological moduli problem, unless [Linde '96, Takahashi, Yanagida '11])

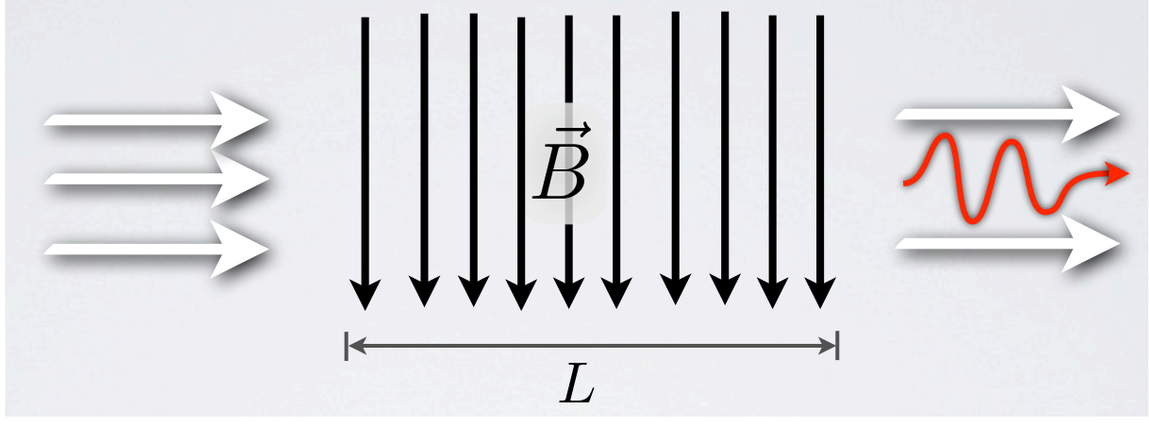
Decay via $\frac{\partial_\mu a}{\Lambda}\bar{\psi}\gamma^\mu\gamma^5\chi$ with lifetime

$$\tau_\psi = \left(\frac{7.1\ \mathrm{keV}}{m_\psi}\right)^3 \left(\frac{\Lambda}{10^{17}\ \mathrm{GeV}}\right)^2 0.92 \times 10^{27}\ \mathrm{s}$$

Axion-photon conversion

Axion-photon coupling in

$$\mathcal{L} = \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2} m_a^2 a^2 + \frac{a}{M}\mathbf{E}\cdot\mathbf{B}$$



induces [Raffelt, Stodolsky '87]

$$P(a \to \gamma) = \sin^2(2\theta)\sin^2\left(\frac{\Delta}{\cos 2\theta}\right)$$

with $\theta \sim \frac{B_\perp E_a}{M\, n_e}$, $\Delta \sim \frac{n_e L}{E_a}$ (for $m_a < 10^{-11}$ eV)

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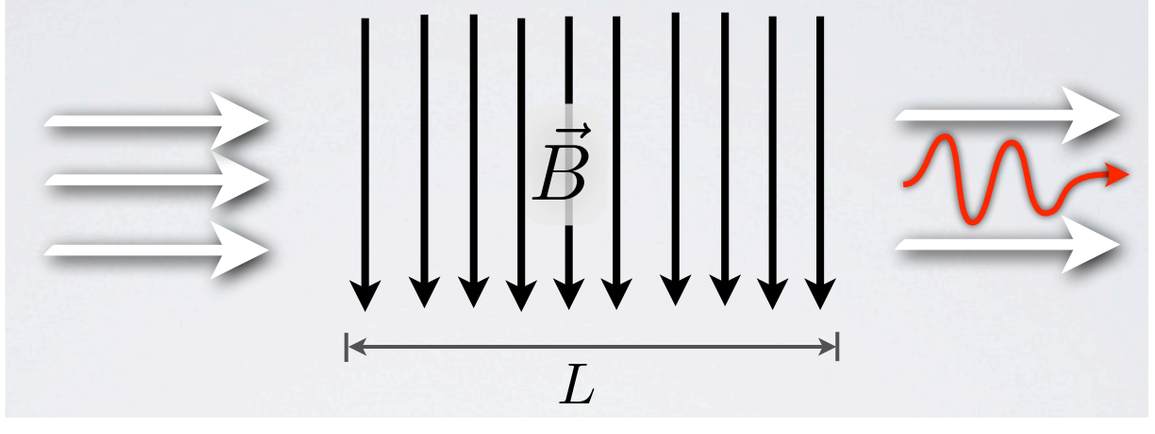

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$$P_{a\to\gamma}^{\text{cluster}} \sim \frac{B^2\, L\, R_{\text{cluster}}}{M^2}$$

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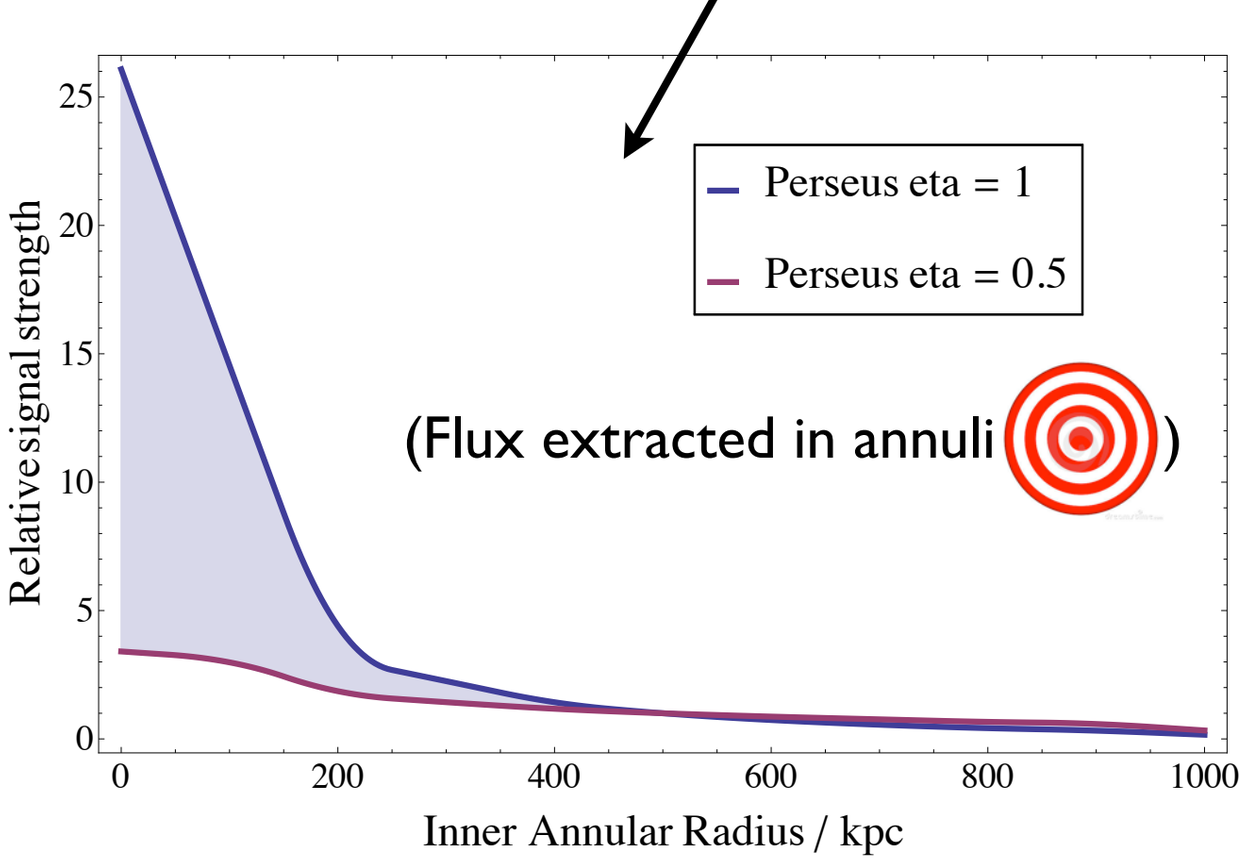
Predictions: Cluster morphology

$$F_{DM\to a} = \frac{\Gamma_{DM\to a}}{4\pi d(z)^2}(1+z)\int_V \frac{\rho_{DM}}{m_{DM}} P_{a\to\gamma}\, dV$$

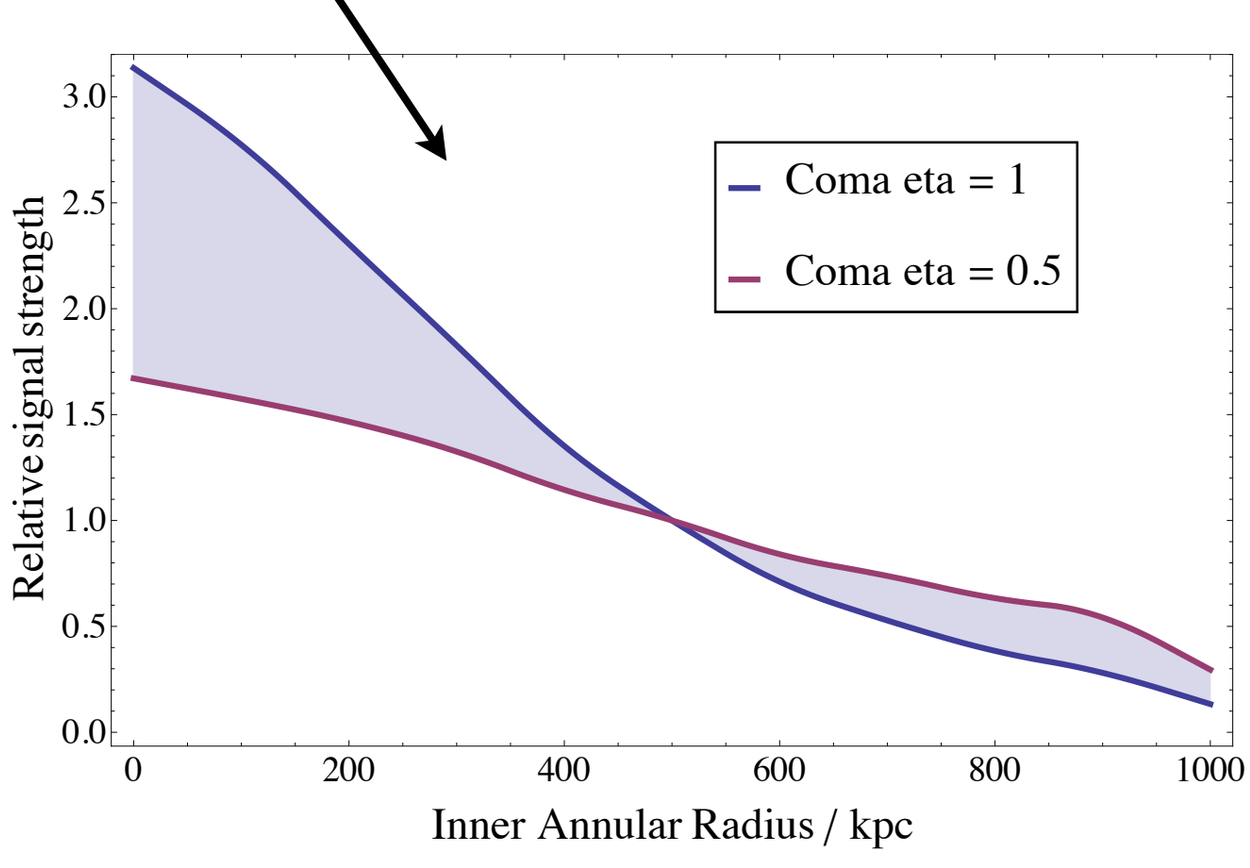
$$F_{DM\to\gamma} = \frac{\Gamma_{DM\to\gamma}}{4\pi d(z)^2}(1+z)\int_V \frac{\rho_{DM}}{m_{DM}}\, dV$$

[Conlon, Powell '14]

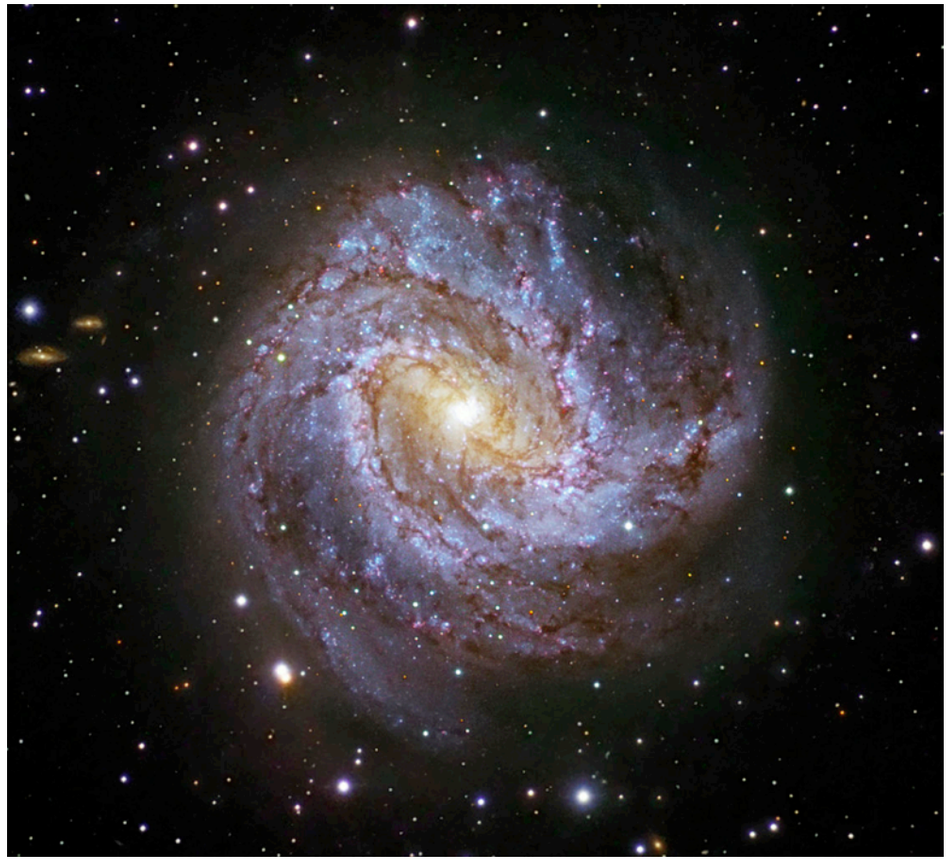
$\Rightarrow$ Cool-core vs non-cool-core



(Flux extracted in annuli)



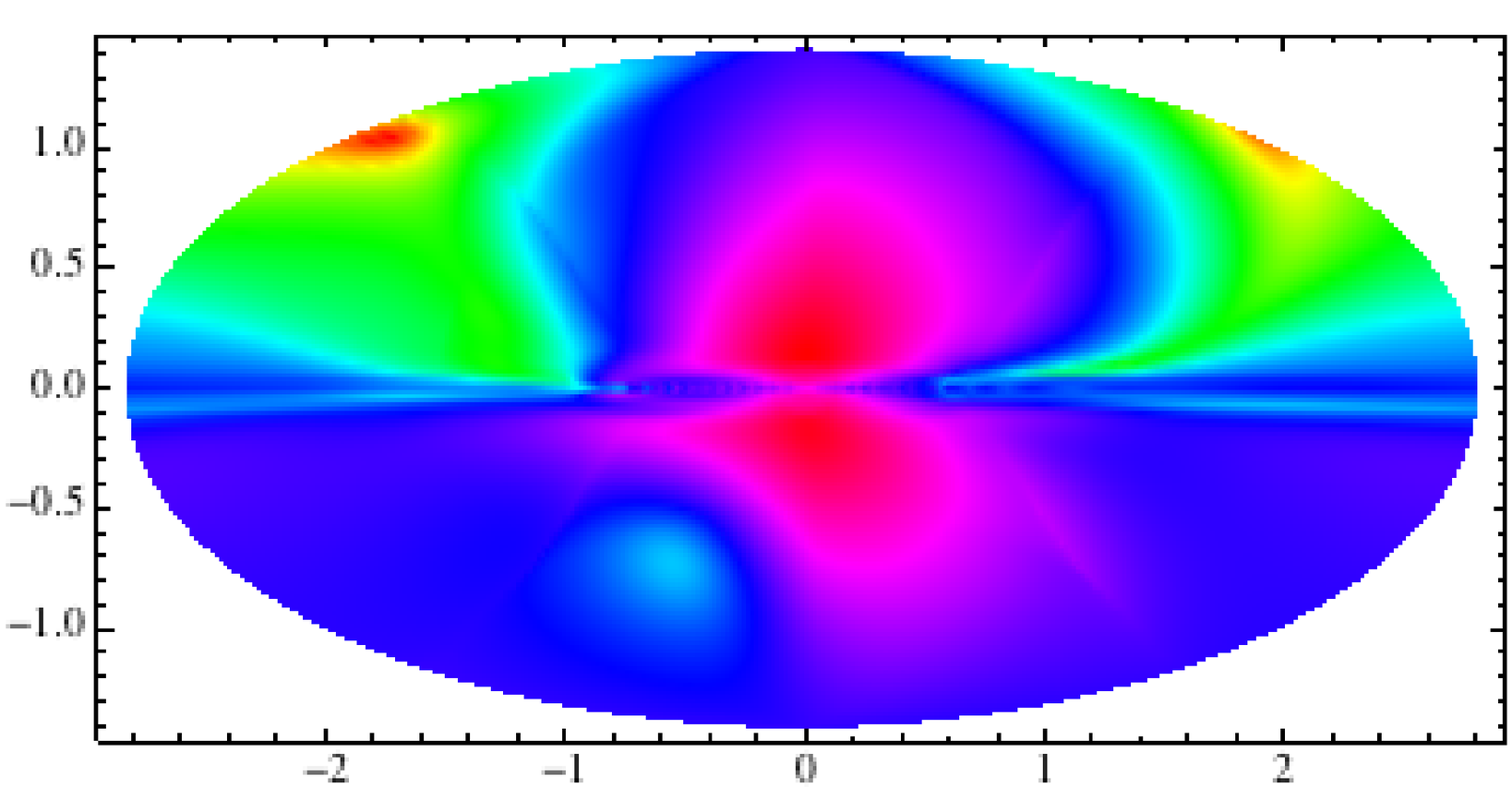
Predictions: Galaxies

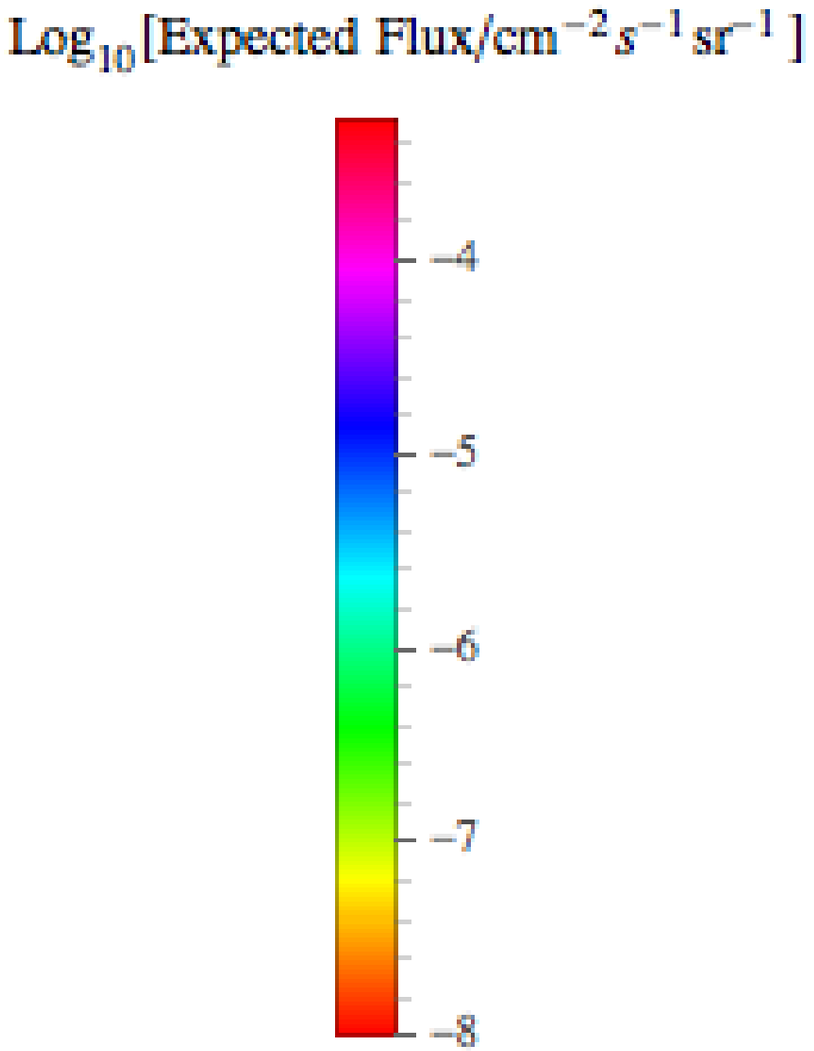


- Signals from **edge on** galaxies should be stronger than from **face on**
- What about the Milky Way, Andromeda?

Predictions: Milky Way

$\mathrm{DM} \to a \to \gamma$ [Conlon, Day '14]





Predictions: Milky Way

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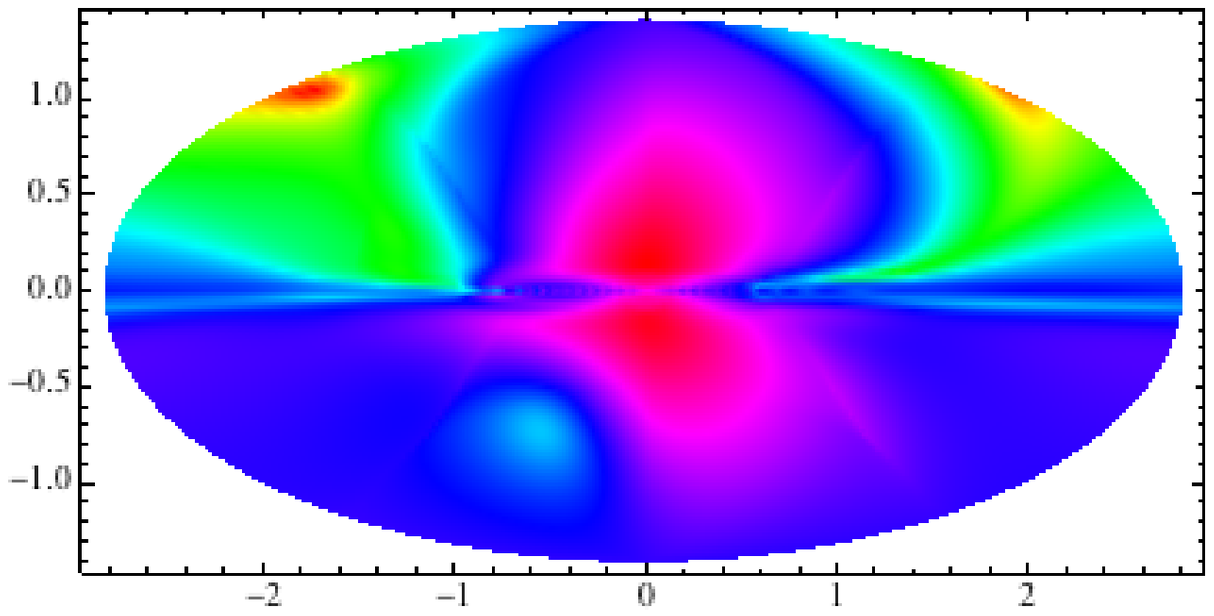
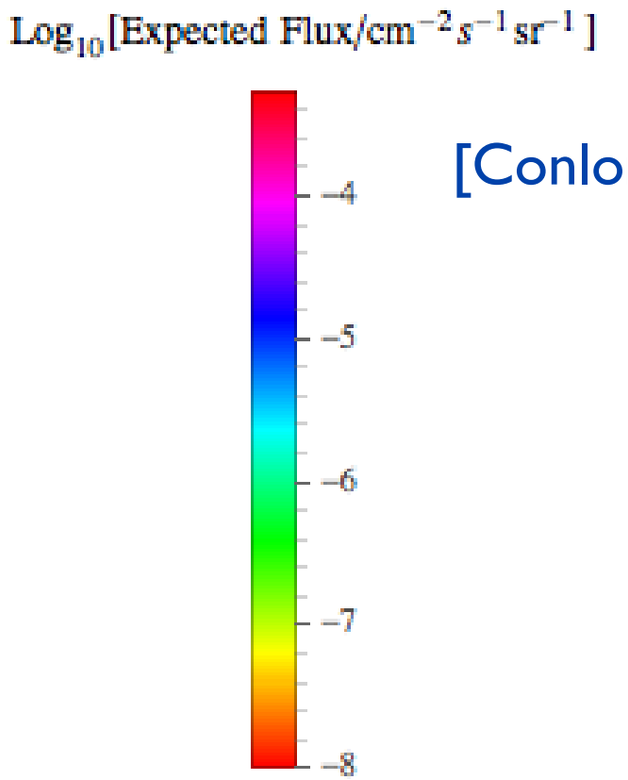
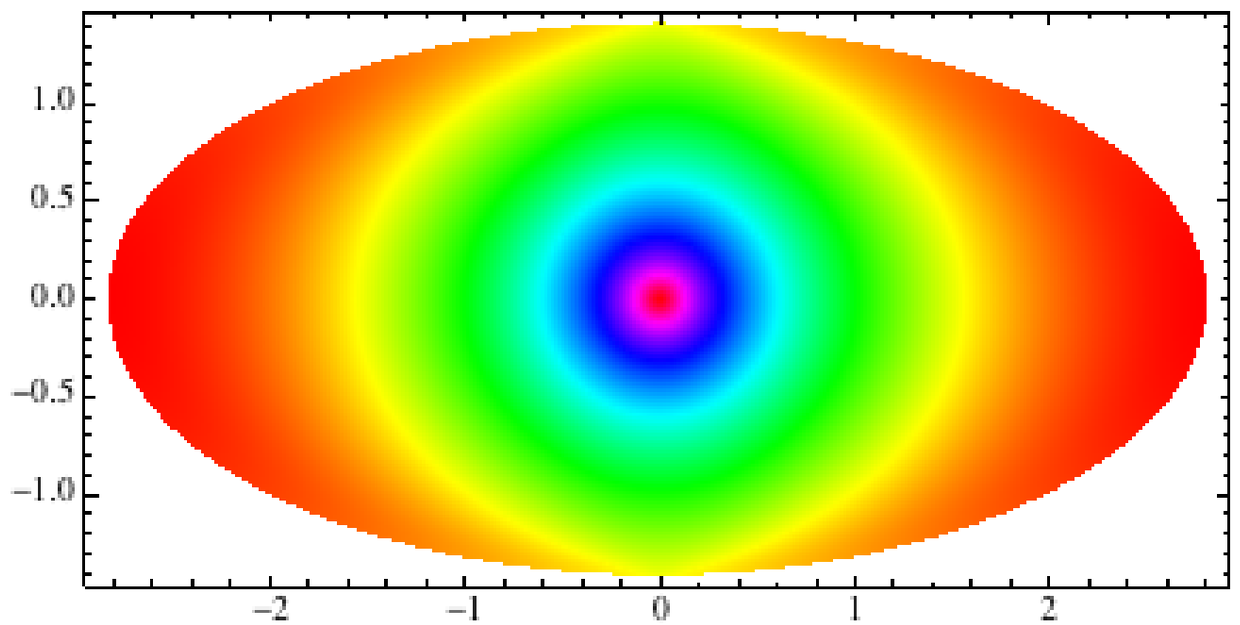
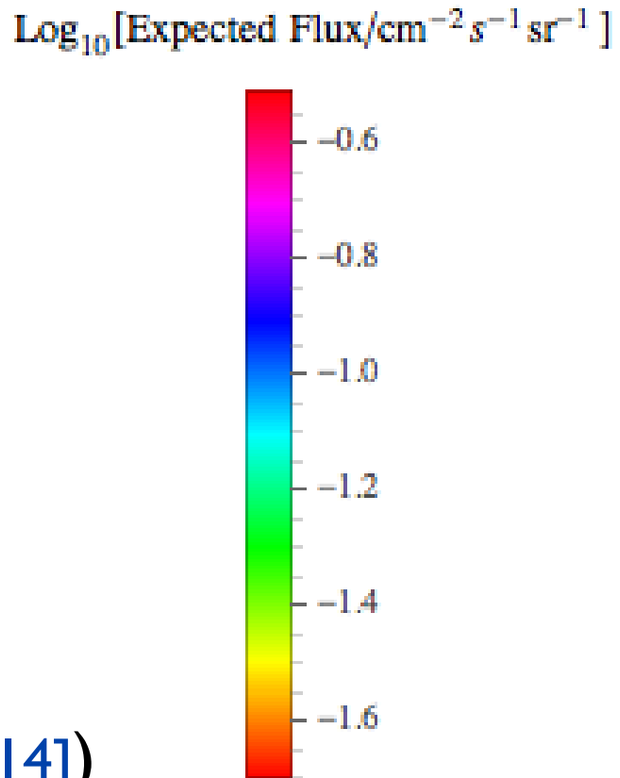




[Conlon, Day '14]

$\mathrm{DM} \to \gamma$





(Not found in Chandra data [Riemer-Sorensen '14])

Conclusions

- For $\mathrm{DM} \to a \to \gamma$ photon signal is convolution of DM density and magnetic field along l.o.s.
- Different morphology of cluster and galaxy signals than $DM \to \gamma$: (non-)cool core, edge/face on
- Observable flux effectively depends on one free parameter $F_{DM\to a\to\gamma} \propto \tau_{DM\to a}/M^2$ (as $DM \to \gamma$)
- Predictions will be tested in the near future

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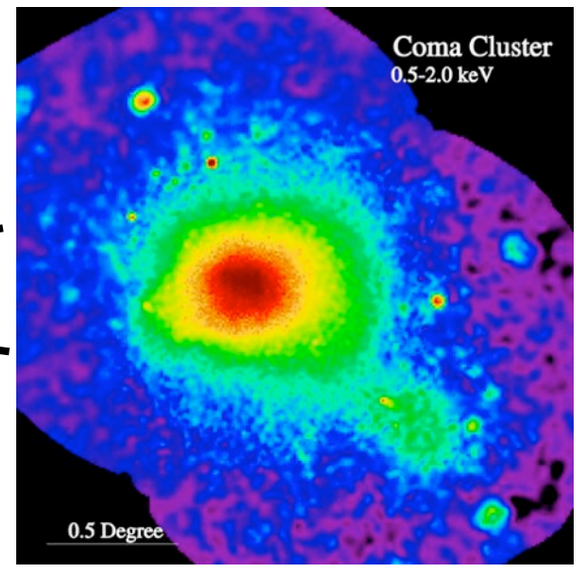
Thank you for your attention!

Predictions: Clusters

- Nearby cluster do not fit in Field of view of XMM (2-3 sigma excess of nearby clusters over full sample)

XMM

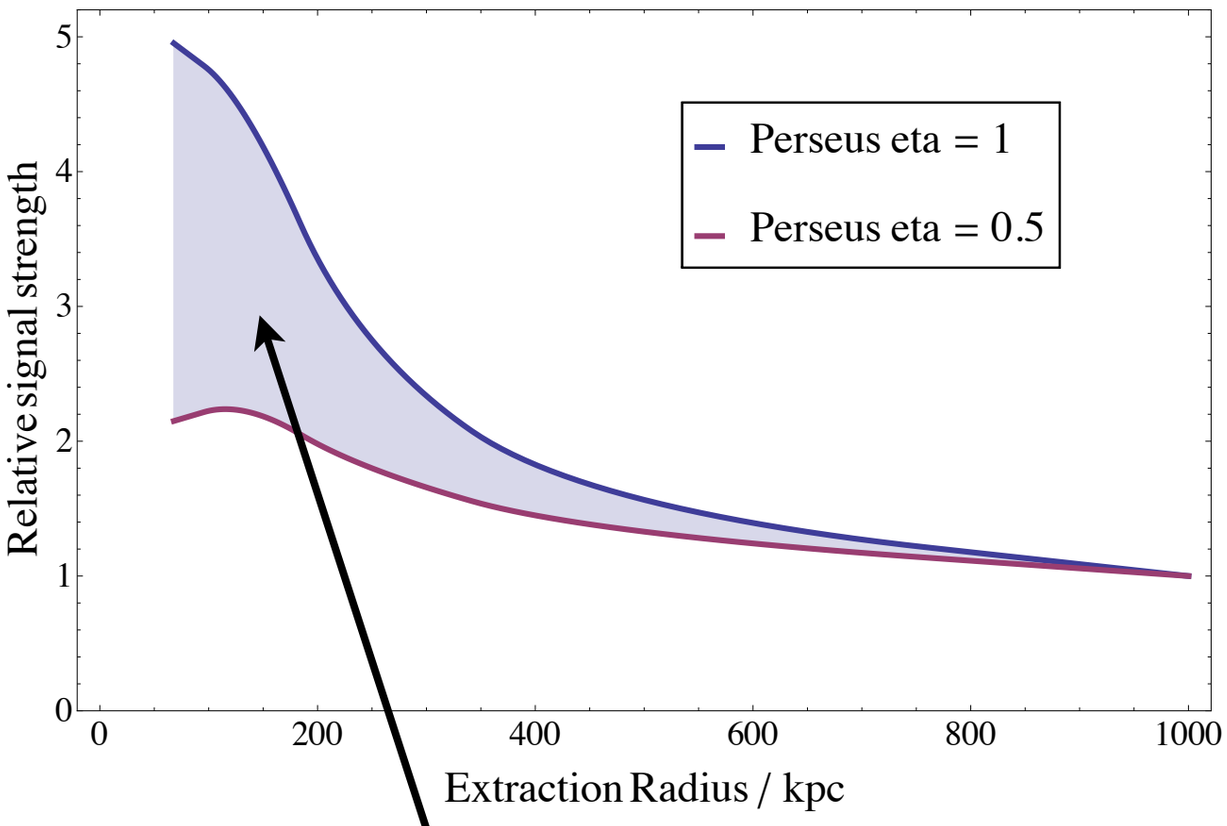
Field of view $\sim 0.5^\circ$

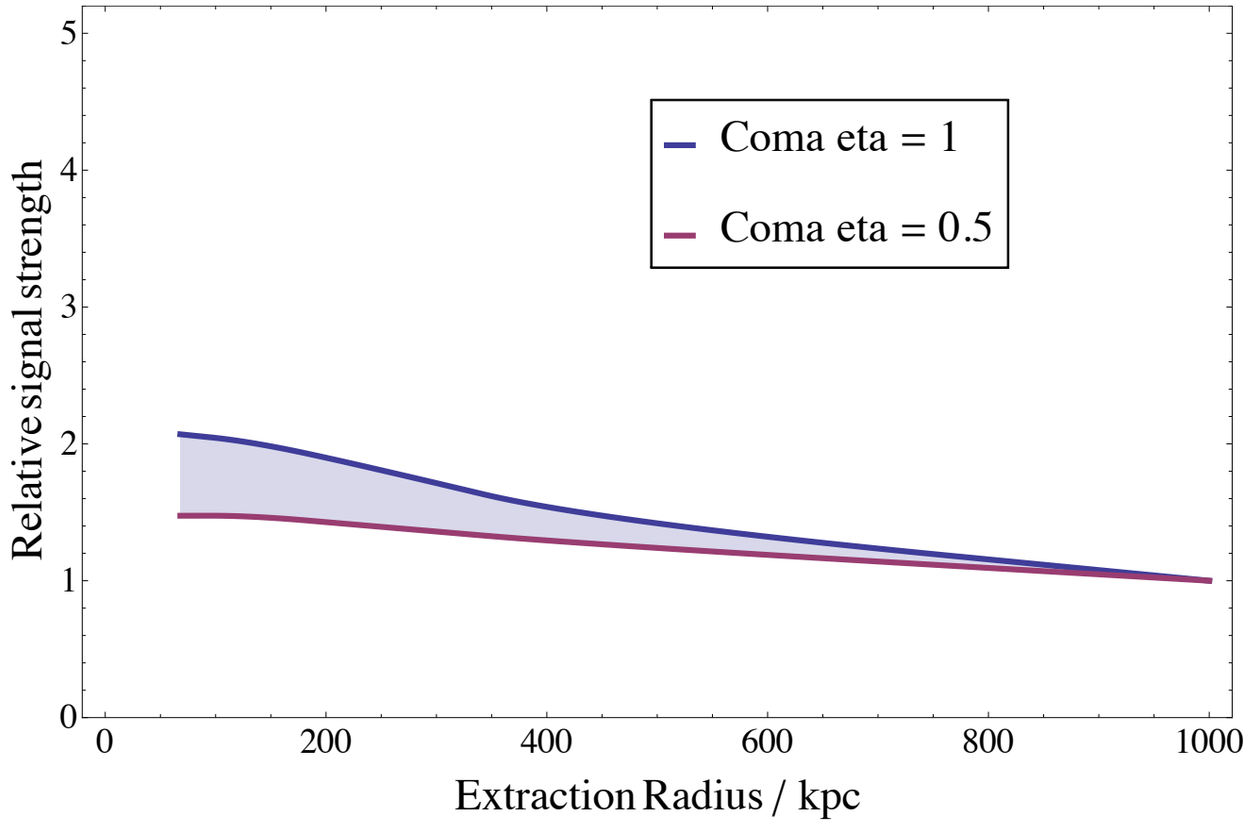


$\mathcal{O}(1^\circ)$

Predictions: Clusters

Instruments have different FOV





[Conlon, Powell '14]

Seems to be already in the data!