AGN Feedback in Highly-Luminous Clusters of Galaxies

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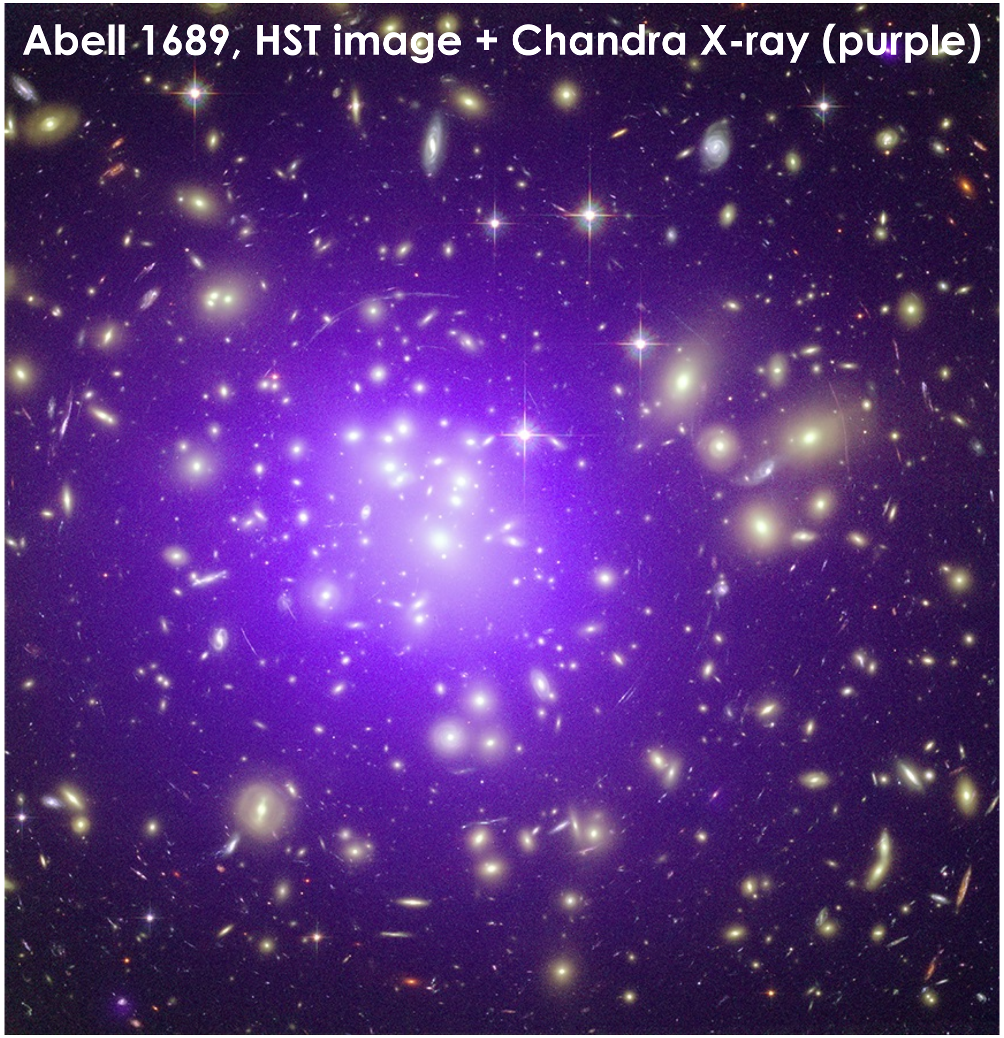
Highly-luminous clusters of galaxies?



Clusters are the most X-ray luminous extended sources:

$L_{x\text{-}ray} = 10^{43\text{-}46}$ erg/s

Highly-luminous cool core clusters:

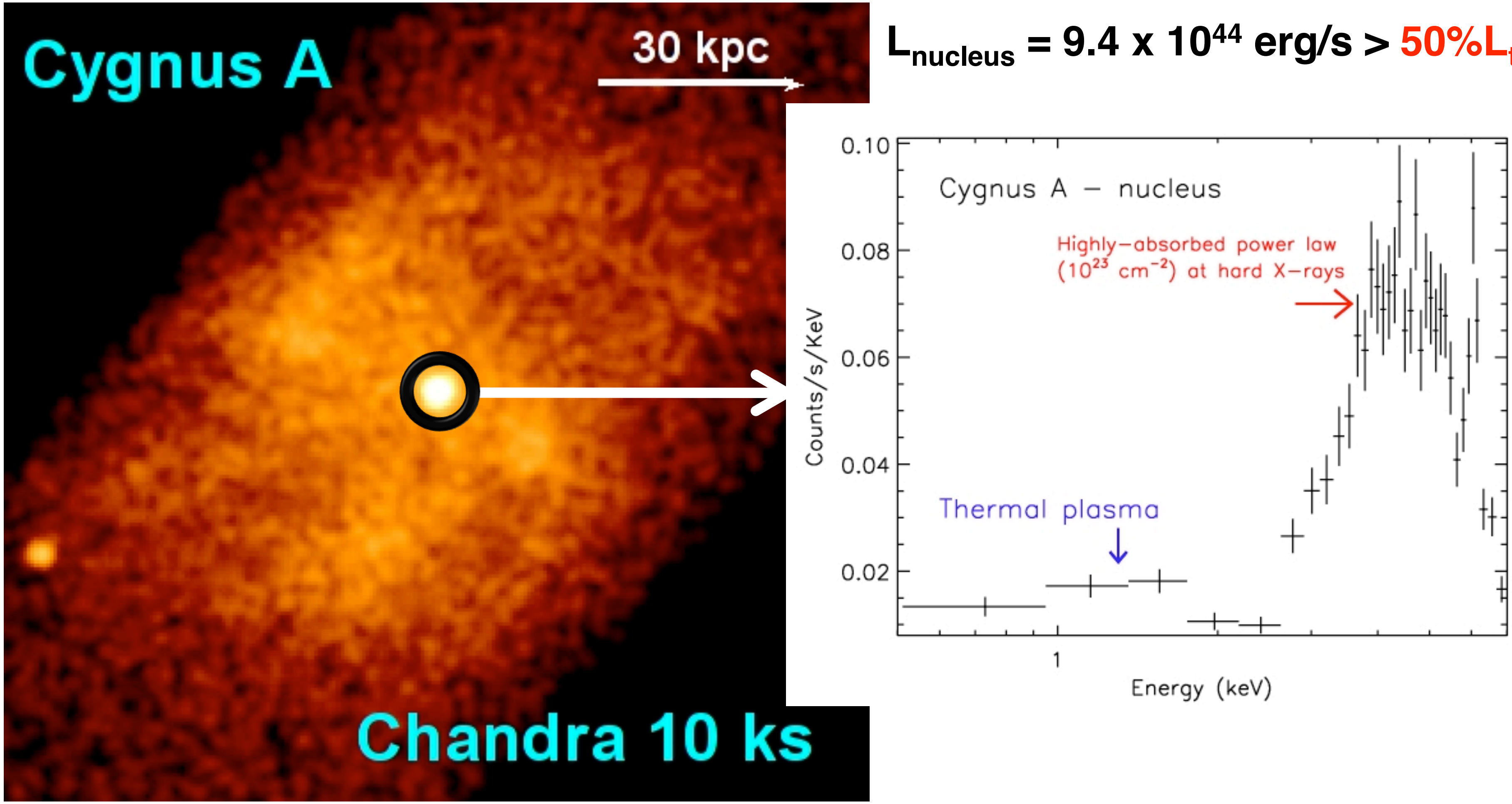
- $L_{x\text{-}ray} \geq 10^{45}$ erg/s
- $t_{cool} \leq 3$ Gyr

➔ Need extreme feedback from their central AGN (10^{45} erg/s)

Cygnus A: highly-luminous cool core

$L_{cluster+nucleus}$ = 14.3 x 10^{44} ergs/s

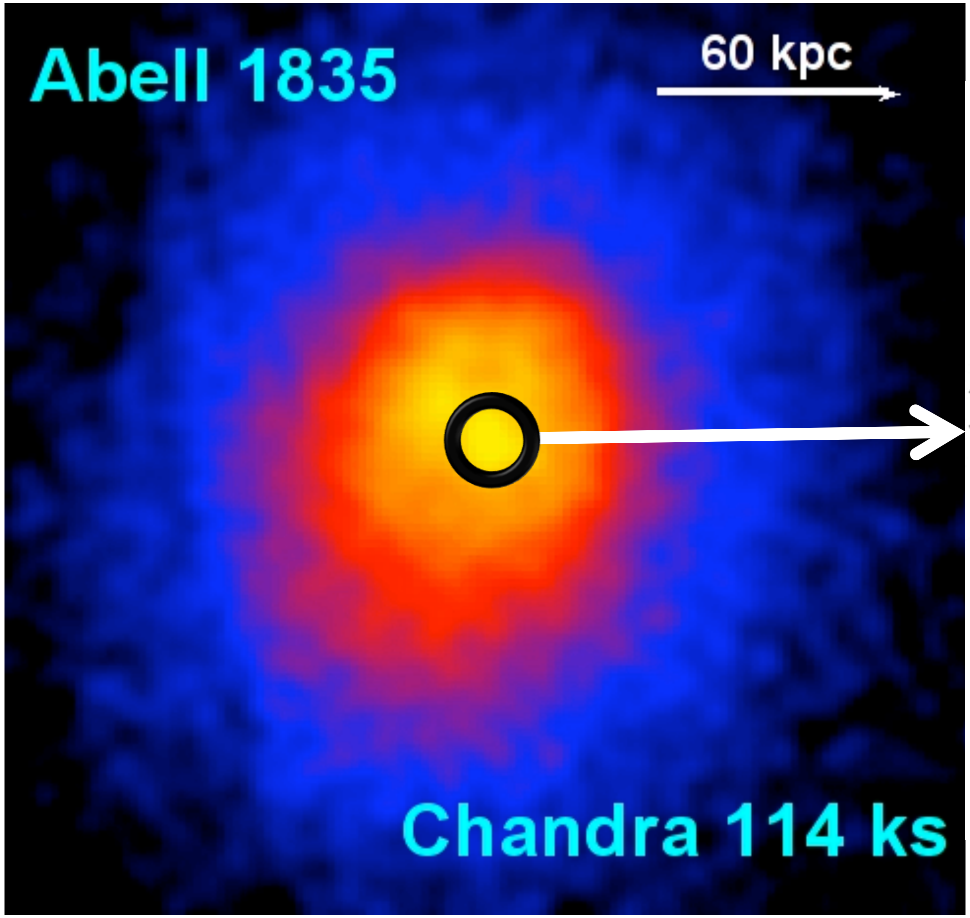
$L_{nucleus}$ = 9.4 x 10^{44} erg/s > 50%L_{tot}

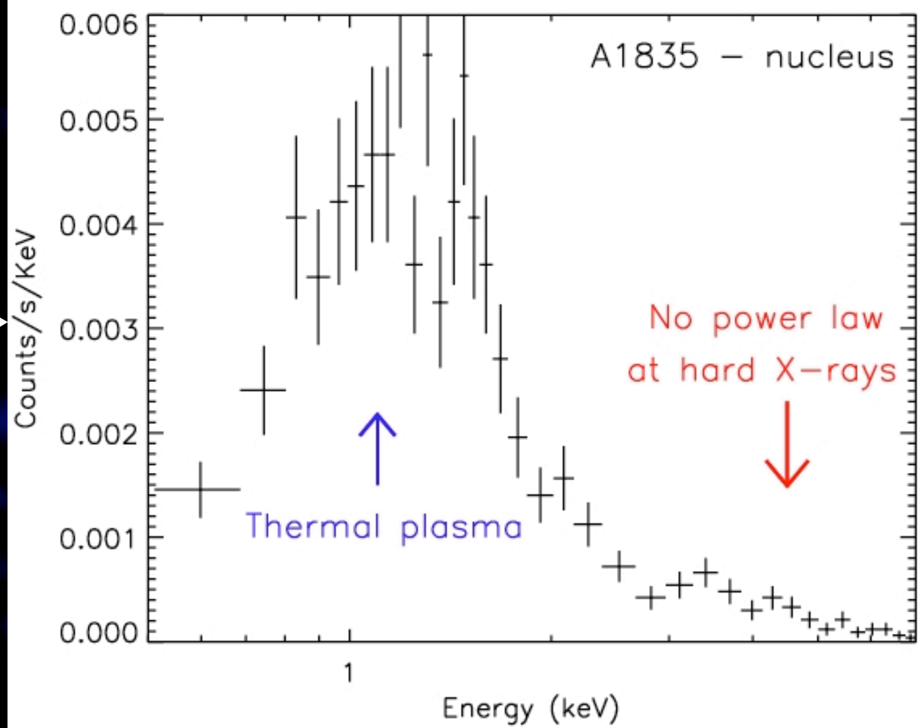


Abell 1835: highly-luminous cool core

$L_{cluster}$ = 34.4 x 10^{44} ergs/s

$L_{nucleus}$ < 0.12 x 10^{44} ergs/s < 0.5%L_{tot}

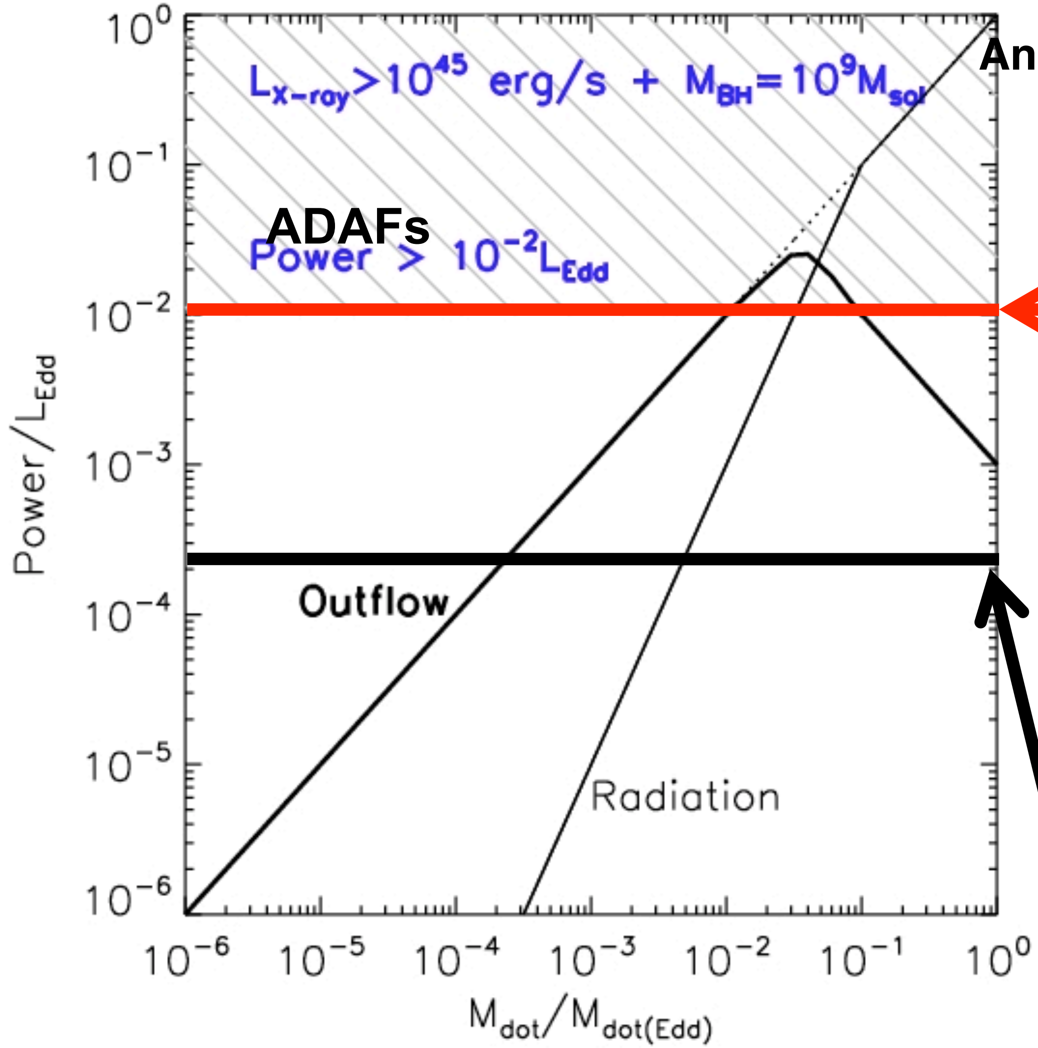




Problem: we should have a point source

Churazov et al. 2005

Analogy with stellar mass black-holes



$P_{outflow} \approx P_{radiation}$

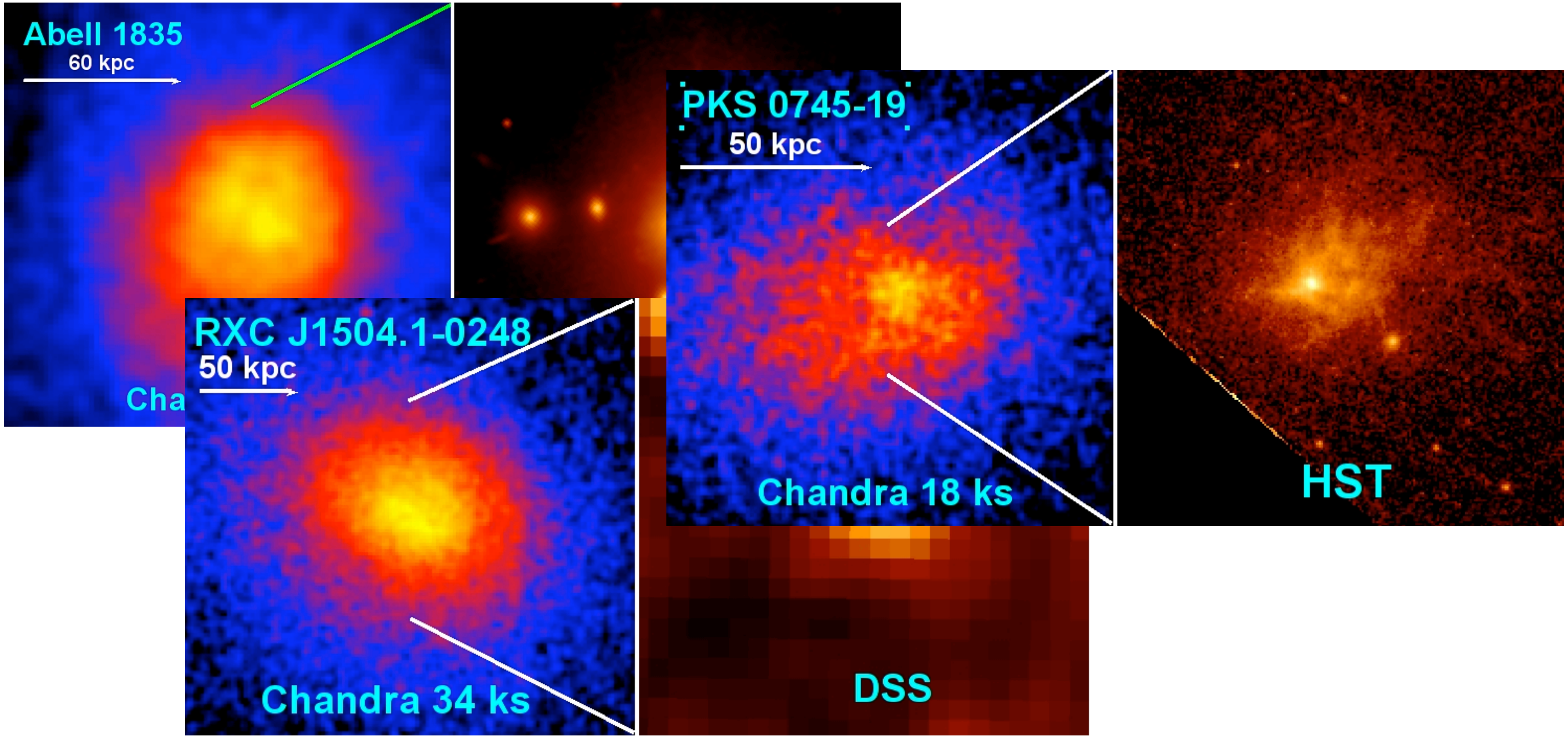
Abell 1835:

$P_{outflow} >> P_{radiation}$

Centaurus cluster:
$L_{outflow} \approx 10^{43}$ erg/s + $M_{BH} \approx 4*10^{8}$ M_{sol}
Radiatively-inefficient AGN

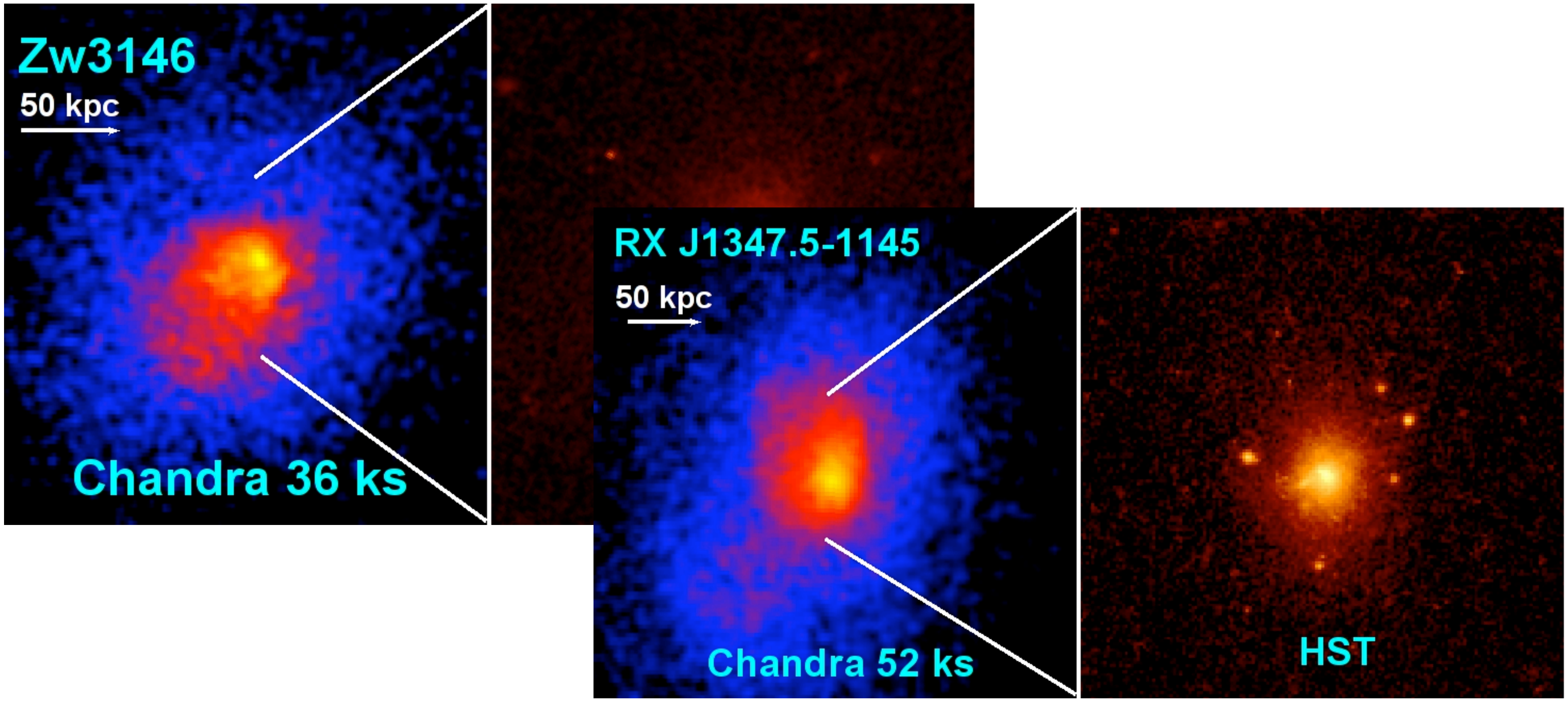
Sample of objects like Abell 1835

Chandra archive: $L_{x\text{-}ray} \gtrapprox 10^{45}$ erg/s and $t_{cool} < 3$ Gyr
13 clusters with NO X-ray point source



Sample of objects like Abell 1835

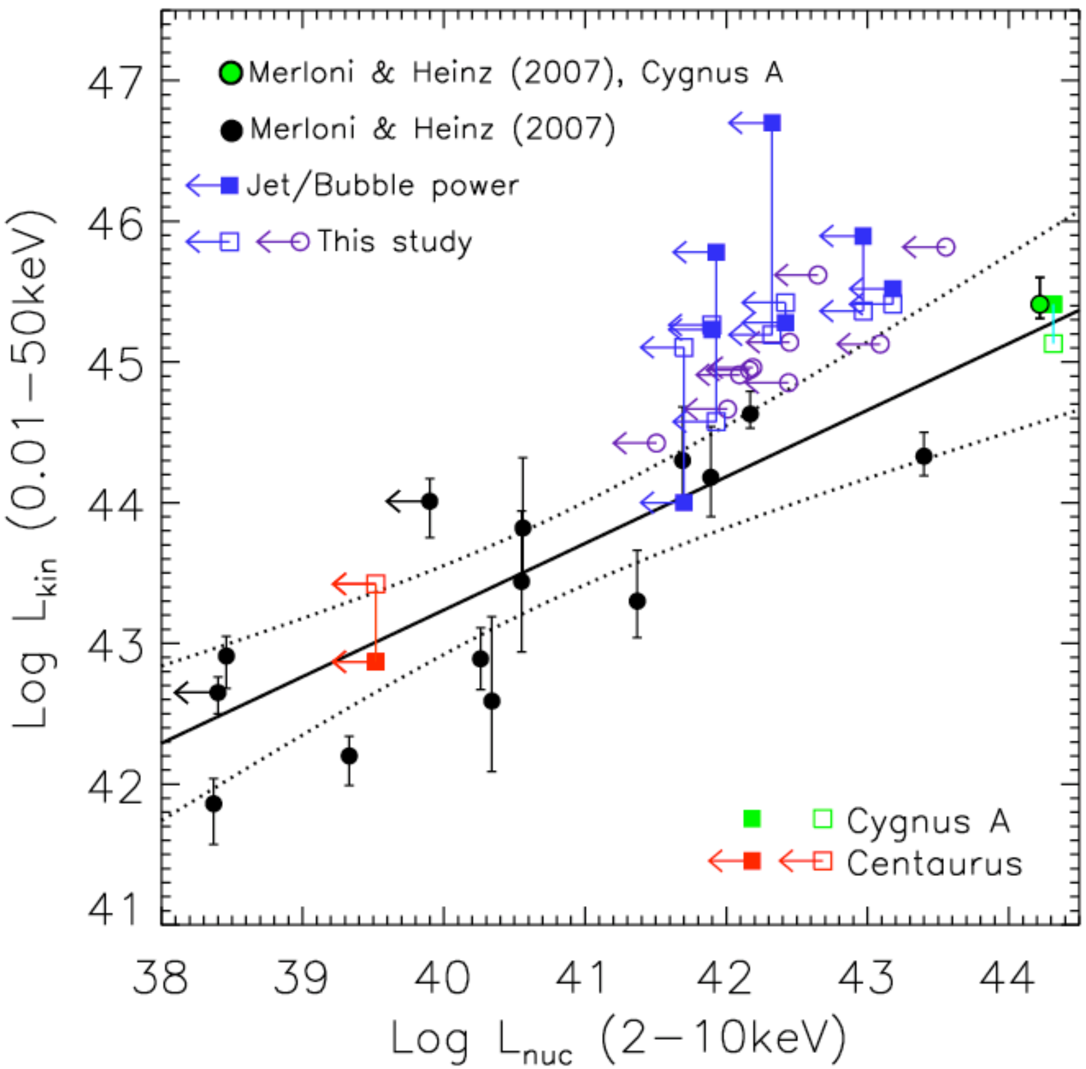
Chandra archive: $L_{x\text{-}ray}$ ~> 10^{45} erg/s and t_{cool} < 3 Gyr
4 clusters with a hint of an X-ray point source



Results: $L_{nucleus} \leq 0.5\% * L_{outflow}$

: **Merloni & Heinz 2007**

Correlation between $\mathbf{L_{kin}}$ and $\mathbf{L_{nuc}}$ for X-ray point sources AGN (sub-Eddington)



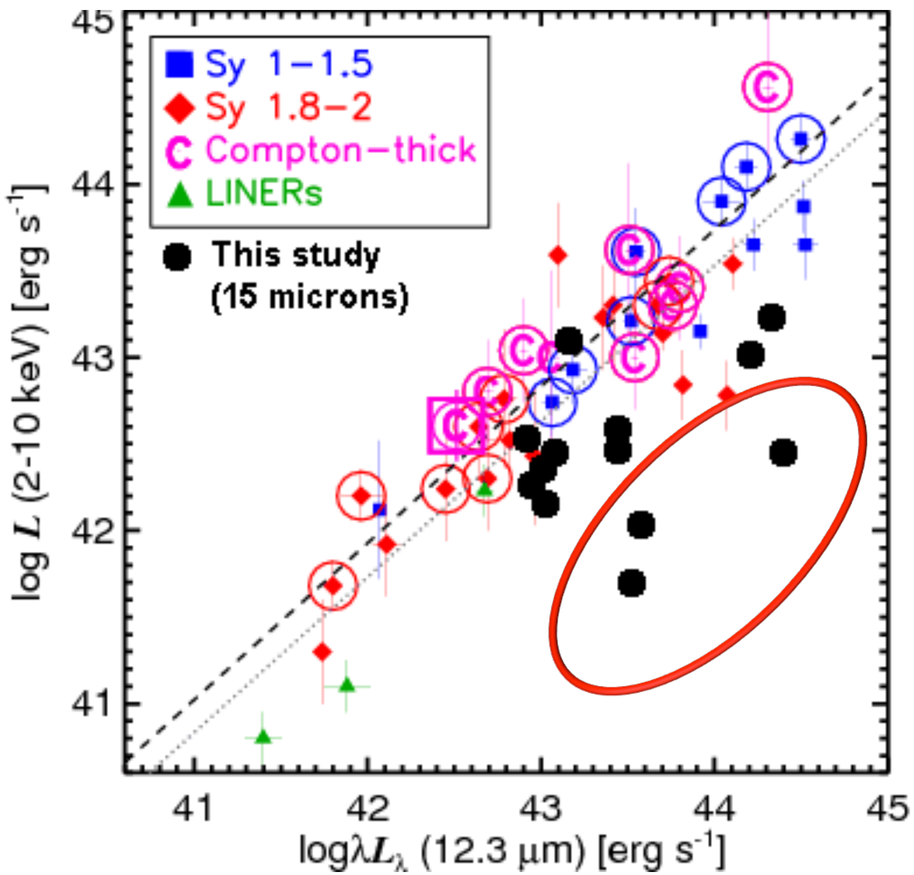
Why are these AGN so faint in the X-rays?

Gandhi et al. 2009

1. Highly-absorbed AGN?

A1835, A1664 and PKS0745
➔ Could be highly-absorbed

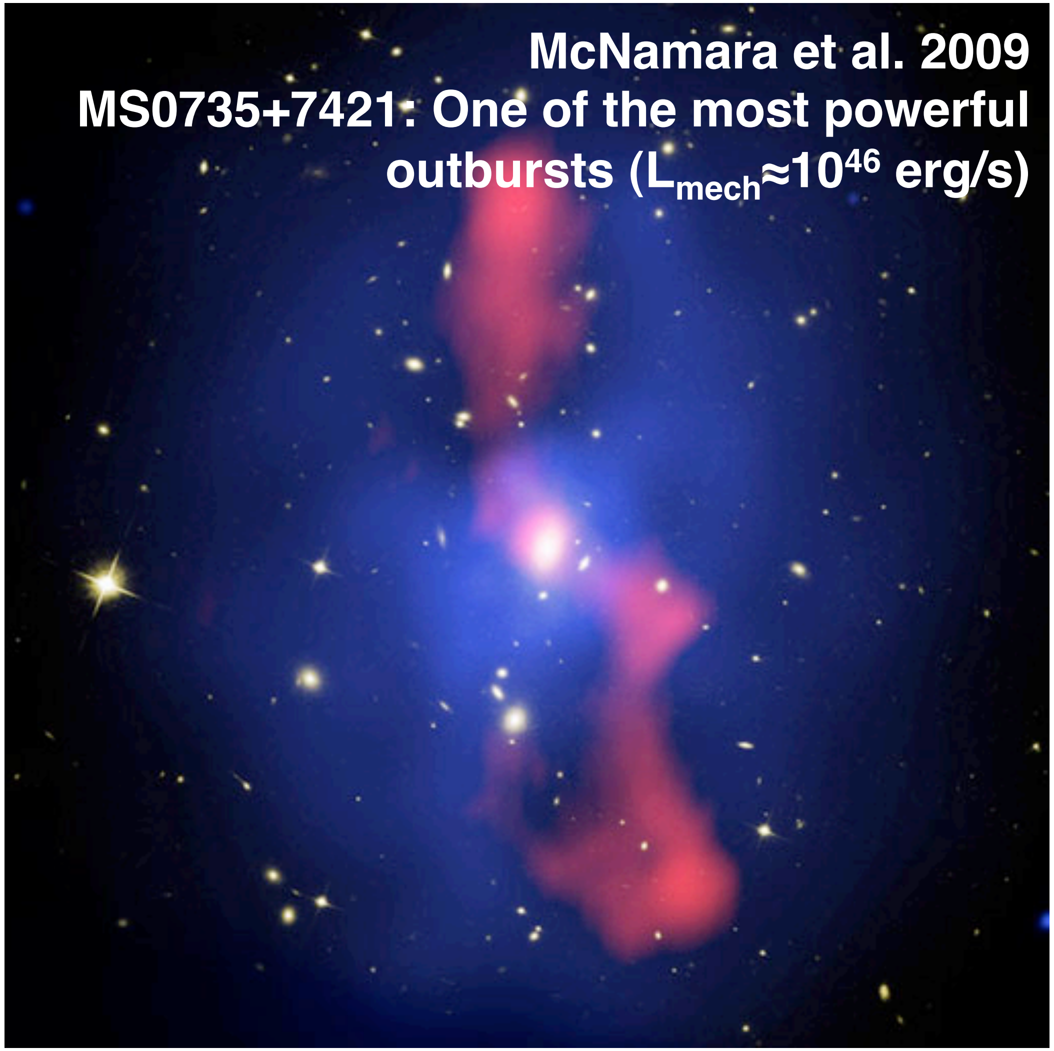
Others are consistent with Ghandhi et al. 2009, so maybe not absorbed (but λL_λ from Spitzer).



Why are these AGN so faint in the X-rays?

2. Spin-powered black holes?

- ➔ To avoid the high accretion rates needed to power strong jets, the black hole could have a high spin parameter (j≥0.9).
- ➔ **This would imply that highly-rotating black holes are not rare.**



Why are these AGN so faint in the X-rays?

Churazov et al. 2005

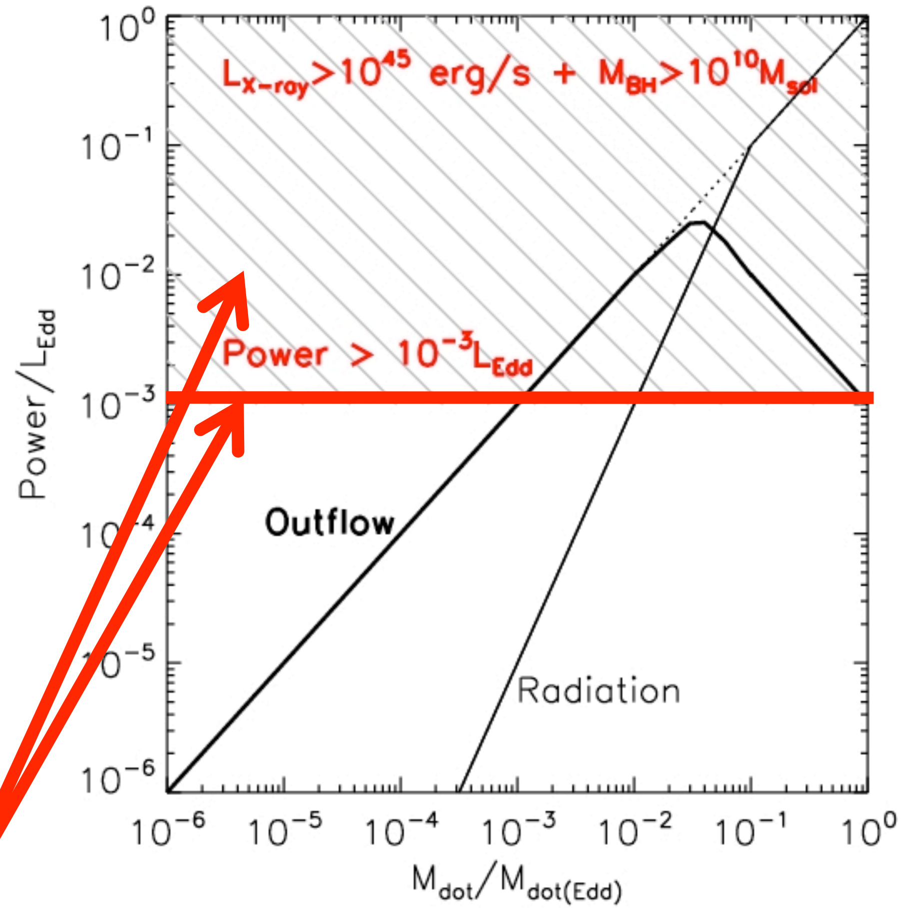
3. Ultramassive black holes?

AGN power > 10^{45} erg/s

$M_{BH} \approx 10^9 M_{sol}$
➔ $L_{AGN\ feedback} > 10^{-2}\ L_{edd}$

$M_{BH} \approx 10^{10} M_{sol}$
➔ $L_{AGN\ feedback} > 10^{-3}\ L_{edd}$

➔ **Has been proposed for MS 0735+7421**



$P_{outflow} >> P_{radiation}$

Concluding remarks

- We present a sample of clusters which require extreme jet powers, yet their AGNs are not detected in the X-ray.
- **$L_{nucleus} \leq 0.5\% * L_{outflow}$**
- Some may be highly-absorbed (3 clusters), others may have jets aligned with plane of sky, **but the only one coherent explanation to account for all our results is that they have ultramassive black holes**.
- **Understanding this carries important implications for the origin and operation of jets.**

Hlavacek-Larrondo & Fabian 2011, MNRAS, 413, 313 (arXiv 1007.1974)

Why are these AGN so faint in the X-rays?

1. Relativistic and geometric effects?

Jets would have to align with plane of sky (and $\beta = v/c > 0.9$)

2. Advection dominated accretion flows (ADAFs)?

Loose much matter through winds, difficult to create extreme jets needed…

3. Duty cycles?

4. Magnetically-dominated accretion flows into black holes?

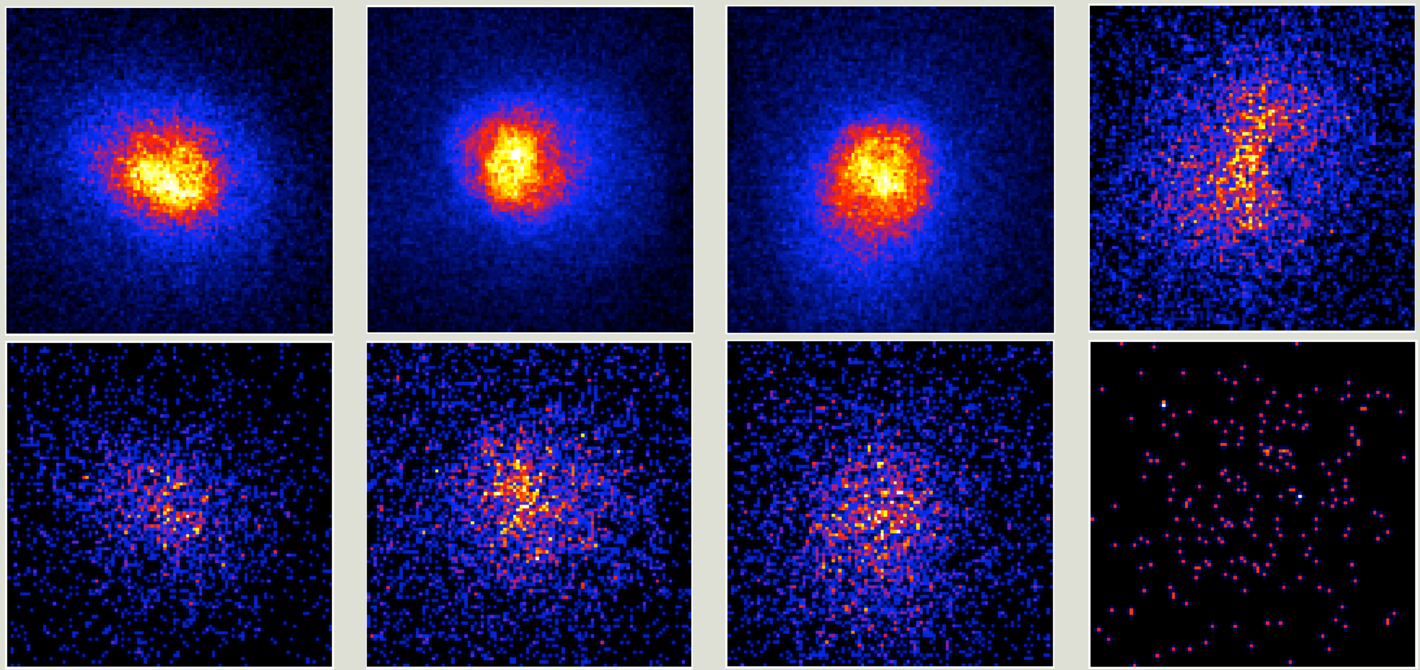
Sample

1. 13 clusters (no X-ray point source)

R1504 A2204 A1835 Z2701

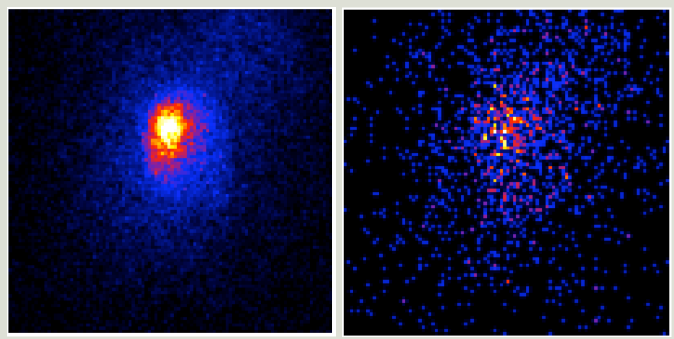
0.5-7keV

5-7keV



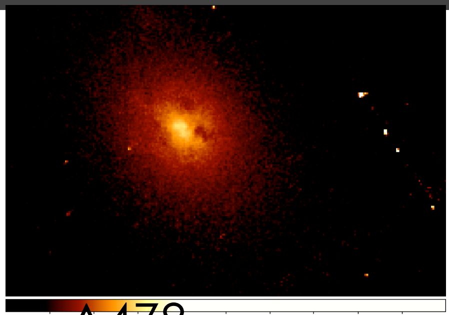
2. 4 clusters (with a possible hint of a point source)

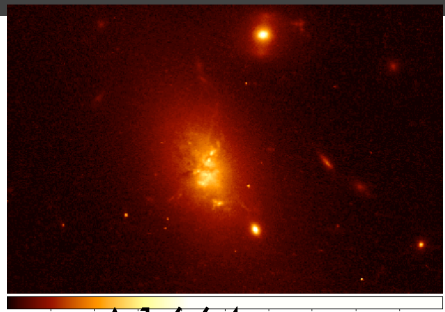
R1347



0.5-7keV 5-7keV

Clusters in optical - Hubble


A478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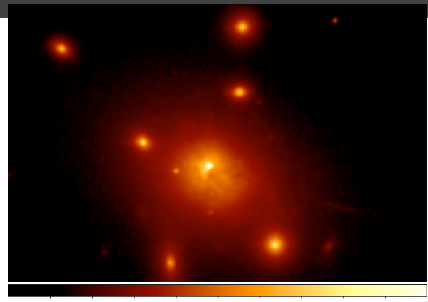
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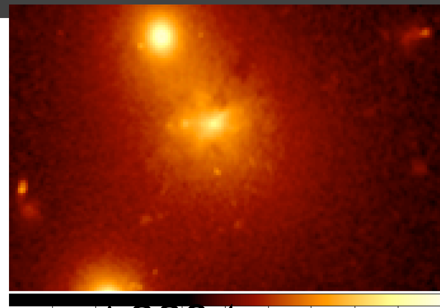
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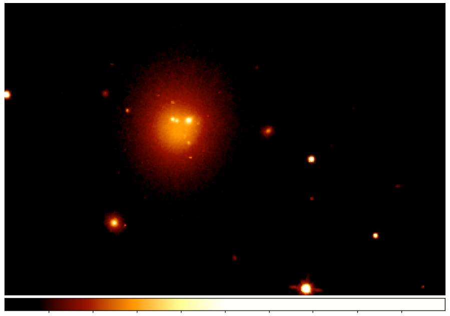
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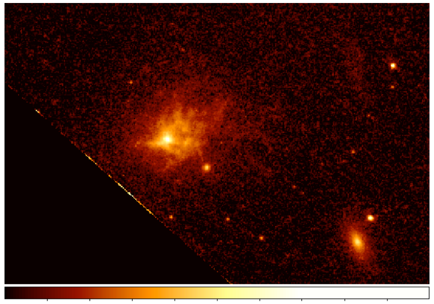
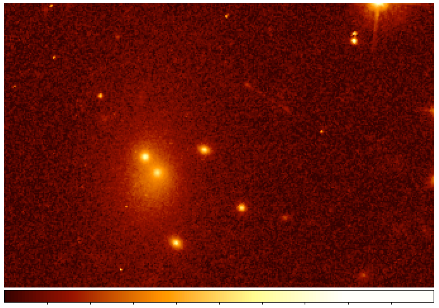

P0745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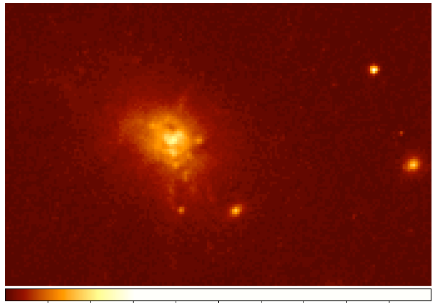
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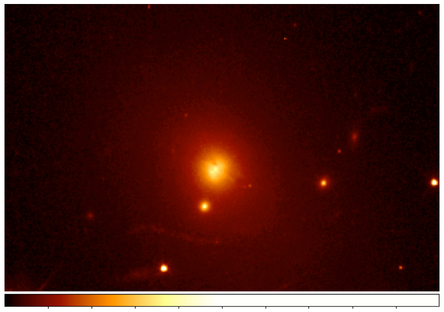
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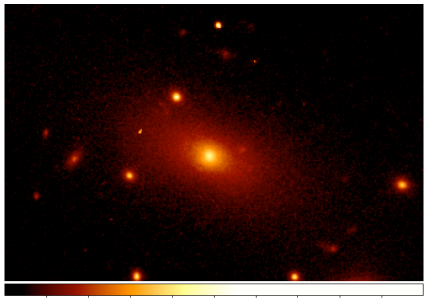
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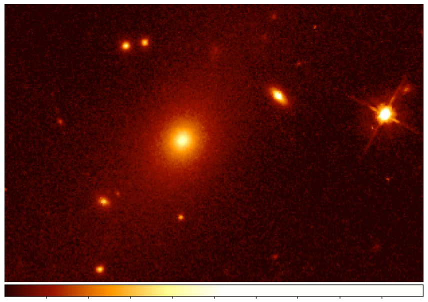
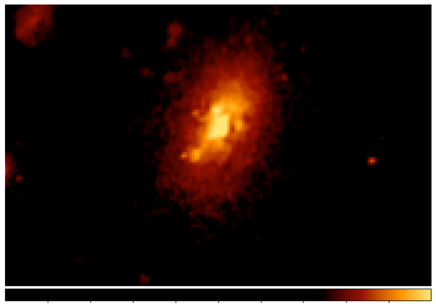

Z2701


Z3146