Discovery of the Most Luminous ULX:
Evidence for an Intermediate Mass Black Hole?

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Overview

- Brief intro to Ultra-Luminous X-ray sources

- Discovery of the ULX in ESO 243-49
  - Initial X-ray results

- Multi-wavelength follow-up
  - X-ray (Swift, Chandra)
  - UV (GALEX, Swift UVOT)
  - Near-infrared (Magellan)
  - Radio (ATCA)

- Concluding remarks

Introduction to ULXs

- Ultra-Luminous X-ray sources (ULXs):
  - extragalactic X-ray sources
  - located outside nucleus of host galaxy
  - bolometric luminosities > 10^{39} erg/s
  - X-ray spectra consistent with accreting black holes

- If luminosity isotropic, implies black hole mass >> 10 M_{sun} or super-Eddington accretion

- Alternative: radiation could be beamed (geometric/relativistic)

- Hundreds of ULXs currently known, most with $L_x \sim 10^{39} – 10^{40}$ erg/s

- Handful of hyper-ULXs with $L_x \sim 10^{41}$ erg/s

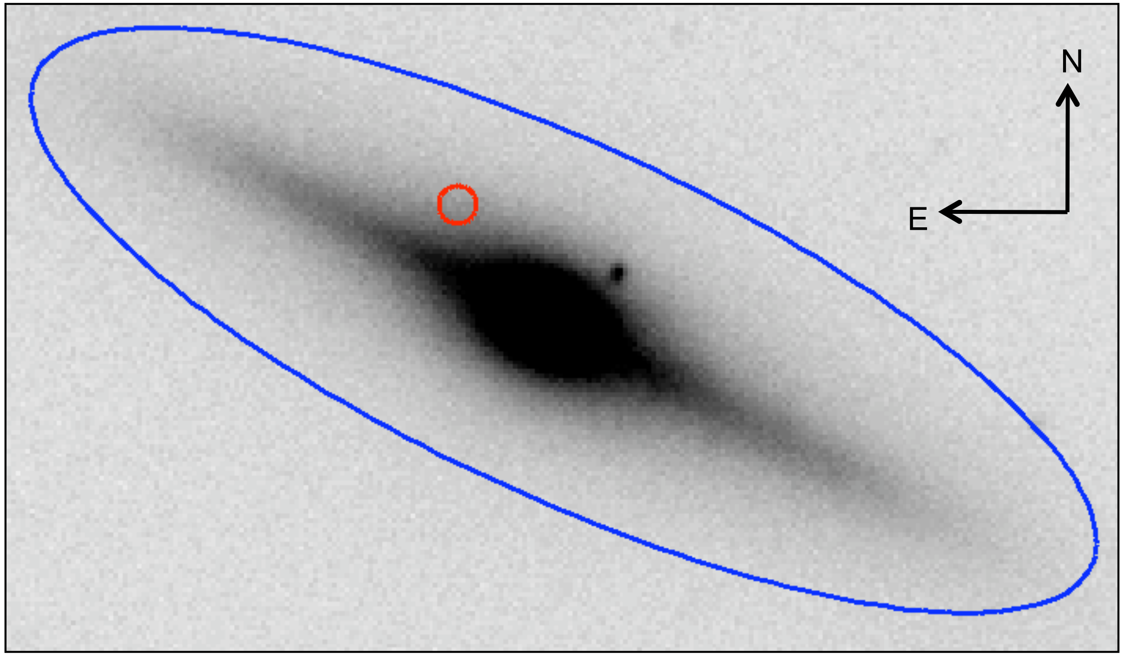
ESO 243-49 HLX-1

- While hunting for soft-spectrum objects in 2XMM catalogue, identified 2XMM J011028.1-460421 (aka HLX-1)
- HLX-1 coincident with galaxy ESO 243-49, ~8” from bulge
- Steep power law spectrum ($\Gamma = 3.4$) consistent with other ULXs
- At galaxy distance (95 Mpc) unabsorbed 0.2-10 keV $L_x \sim 10^{42}$ erg/s
- Derived L_x ~ order of magnitude above previous record holder

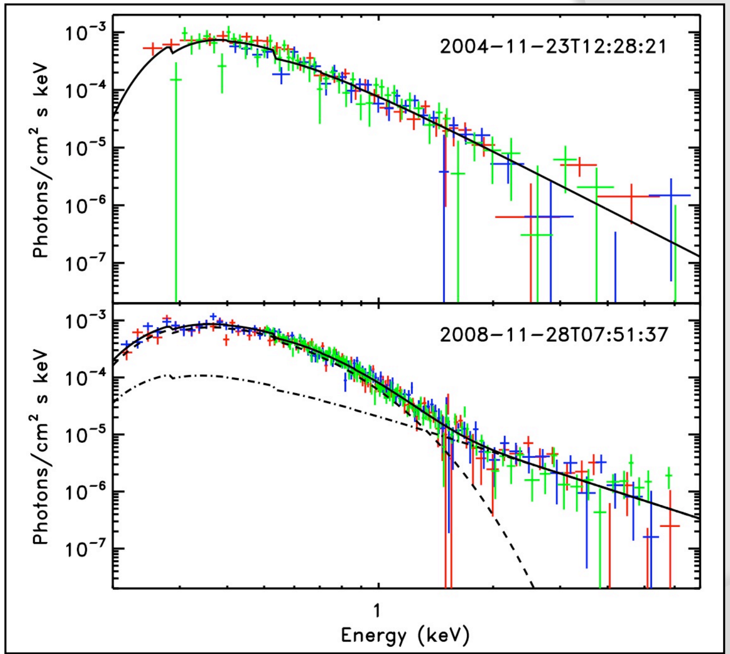
Initial X-ray Results

- Initially observed serendipitously in Nov 2004 by XMM-Newton
- ToO observation with Swift in Nov 2008 suggested spectrum had changed
- Follow-up DDT observation with XMM-Newton in Nov 2008 found L_x had dropped slightly (~6 x 10^{41} erg/s)
- Second XMM spectrum inconsistent with first: new spectrum best fit by power law (Γ = 2.2) + disc black body (kT = 0.18 keV) model
- Disc black body contributes ~76% of 0.2 – 10 keV luminosity

ESO 243-49 HLX-1



VLT r-band image of ESO 243-49 with the position of HLX-1 marked (red circle)



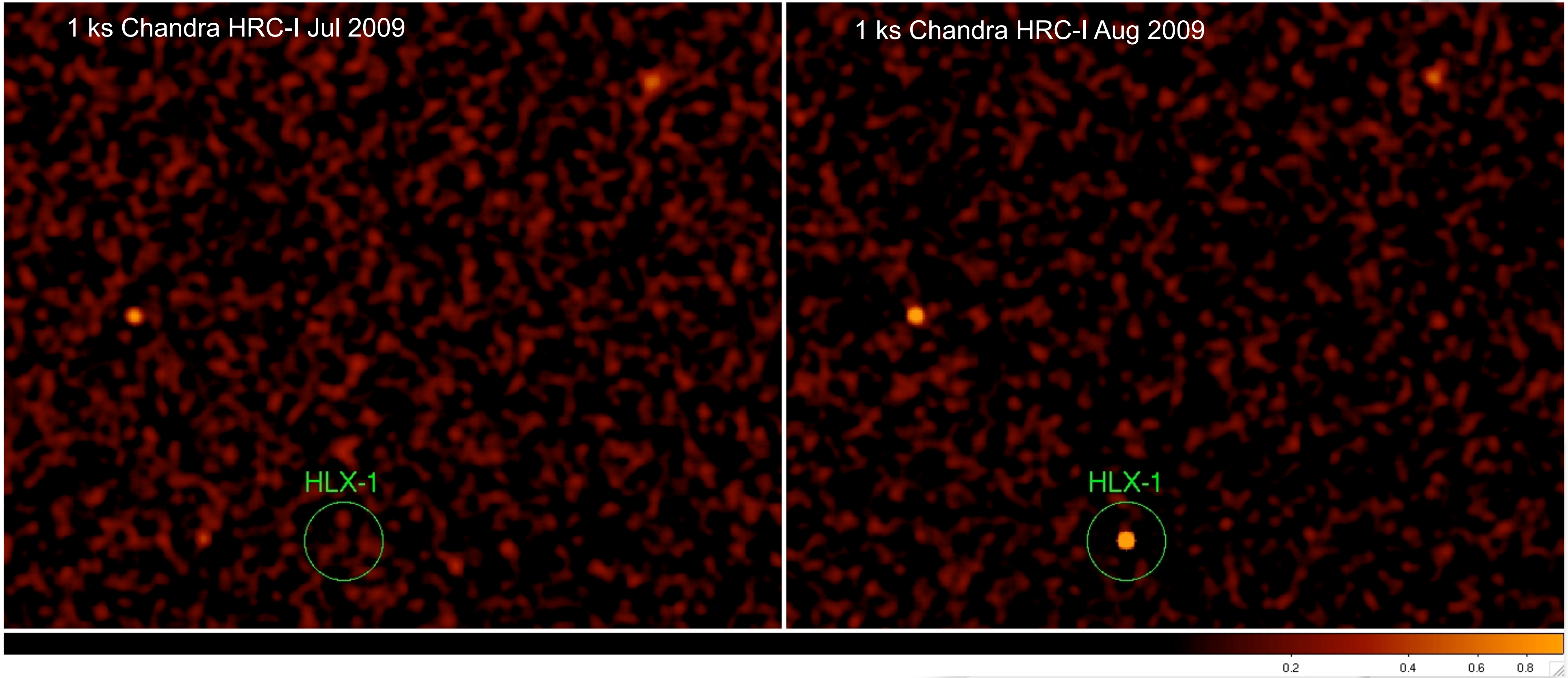
Unfolded EPIC spectra showing steep power law (top) and power law + disc black body (bottom) fits

Farrell et al., 2009, Nature, 460, 73

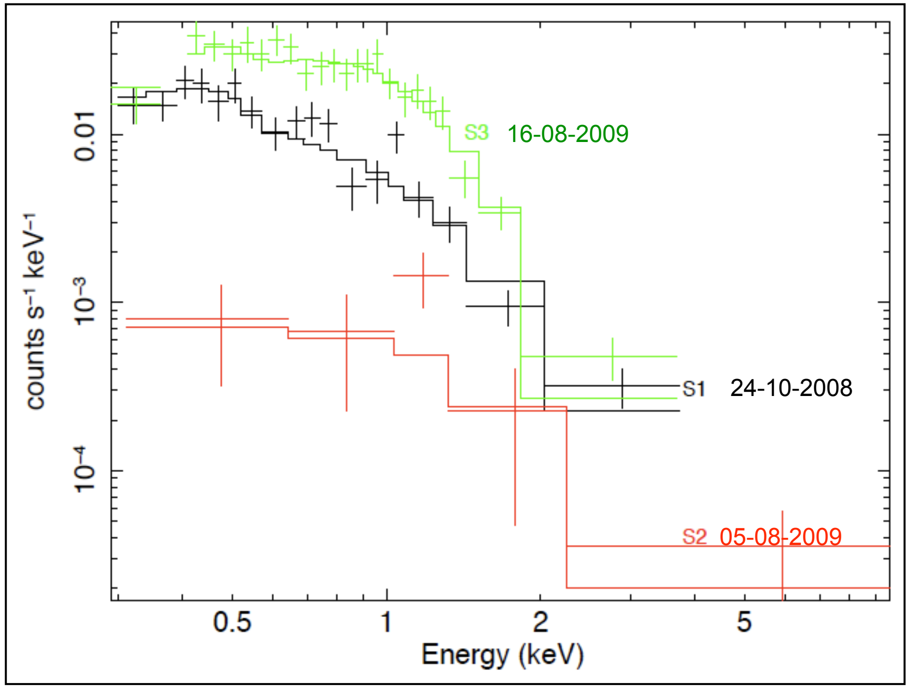
Follow-up: X-ray

- Obtained 1ks DDT observation with Chandra in Jul 2009
- HLX-1 not detected down to conservative upper limit of ~6 counts (expected ~35 counts)
- Monitoring campaign with Swift commenced in Aug 2009
  - HLX-1 detected clearly in ~19 ks with flat power law spectrum (Γ = 2.2) and $L_x \sim 6 \times 10^{40}$ erg/s
  - Additional observation 11 days later found flux had increased ($L_x \sim 1.1 \times 10^{42}$ erg/s) and spectrum purely thermal
- Obtained additional 10 ks DDT obs with Chandra in Aug 2009
- HLX-1 clearly detected (~600 counts)

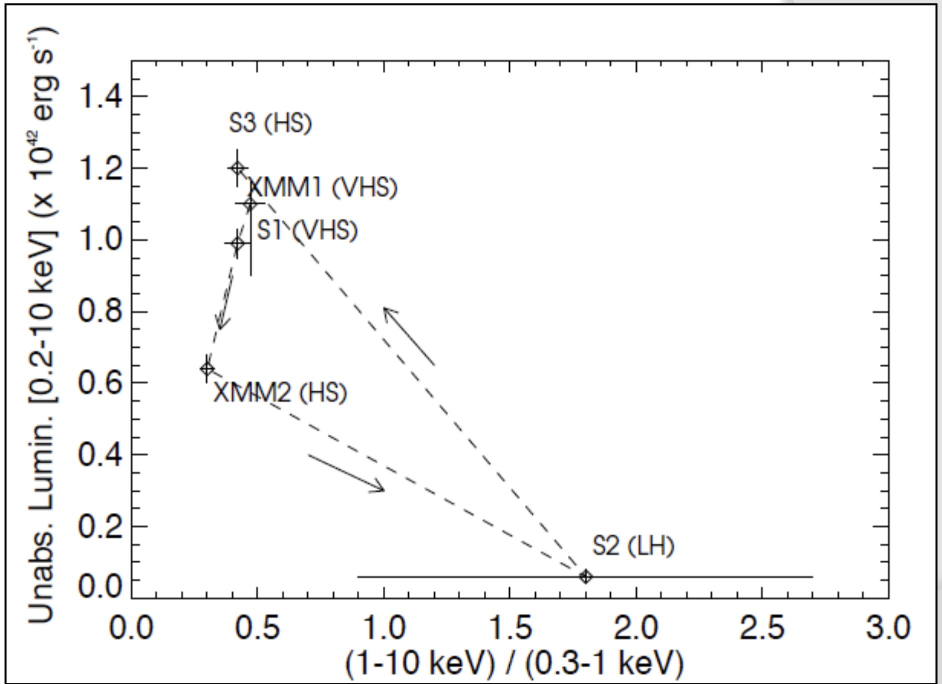
Follow-up: X-ray



Follow-up: X-ray



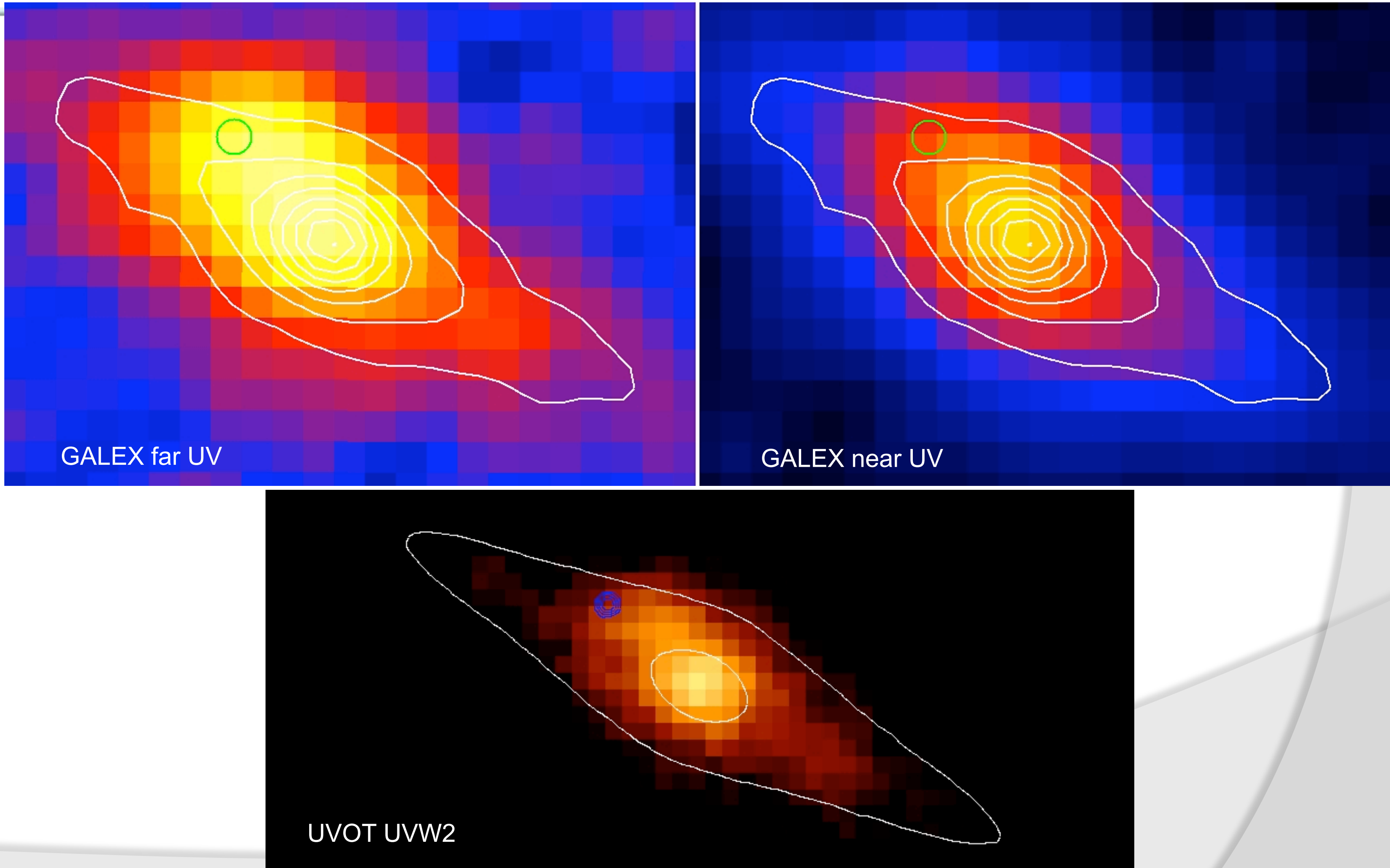
Swift XRT spectra showing steep power law (black), flat power law (red) and disc black body (green) fits



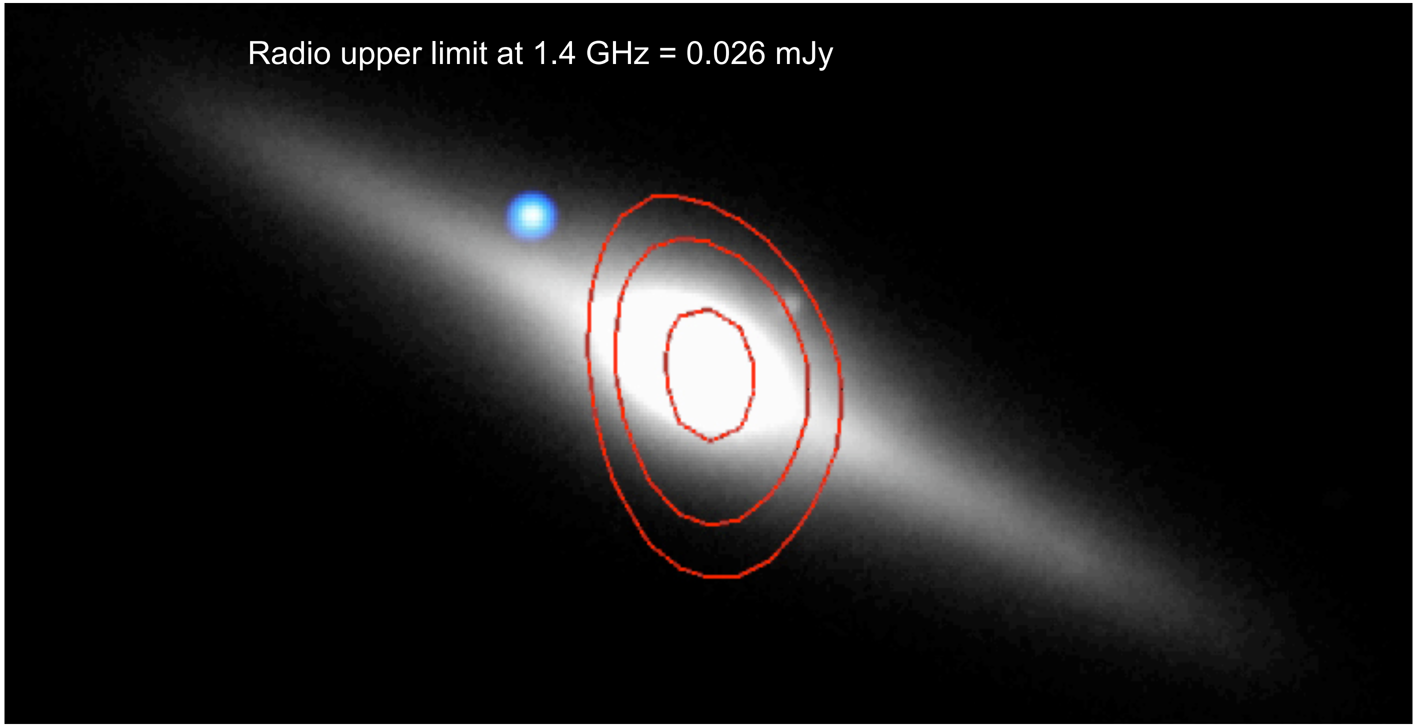
Hardness-Intensity diagram for XMM & Swift detections

Godet et al., 2009, ApJ, submitted

Follow-up: UV



Follow-up: NIR + Radio



Composite image showing the radio detection (red contours) overlaid on the J-band image of the galaxy (grey) from Magellan, and the X-ray data (blue) from Chandra

Webb et al., 2009, ApJ, in preparation

Conclusions

- Could it be a foreground object? Very unlikely as:
  - F_x/F_{opt} very high, ruling out most Galactic objects
  - X-ray spectra inconsistent with SNR, star, CV, neutron star XRB
  - Spectra + variability very consistent with Galactic black hole XRB
  - High state luminosity if its Galactic too low (< 10^{34} erg/s)

- Could it be a background object? Also unlikely as:
  - Steep spectra inconsistent with most AGN
  - High F_x/F_{opt} seems inconsistent with narrow line Seyfert 1
  - Lack of radio counterpart rules out blazar
  - Timescale of spectral state changes inconsistent with super-massive black hole

Conclusions

- Variability definitively rules out multiple lower luminosity sources
- If emission isotropic and below Eddington limit, implies > 5400 M_{sun}
- Geometric beaming seems incompatible with spectral state transitions, as varying inner disc radius should effect beaming factor
- Eddington ratio of ~400 (assuming 20 M_{sun} black hole) should produce Lorentz factor of ~5–10, leading to relativistic beaming
- Lack of radio emission and steep spectra in high/very-high states argues against presence of jets
- Left with super-Eddington accretion: if maximum L_x = 10 x L_{Ed}, implies **mass > 500 M_{sun}** (or possibly something even more exotic?)