A Test for the Anisotropy of X-ray Emission from Ultraluminous X-ray Sources

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If the emission from ultraluminous X-ray sources (ULX) is anisotropic, the luminosities can be less than the Eddington Luminosity for a 15 $M_\odot$ black hole (2×10^{39} erg/s), weakening the need for intermediate mass black holes. We can test the isotropy condition because a fraction of the X-ray emission is absorbed by cold material, and much of this absorbed power will be reemitted isotropically by dust grains at infrared wavelengths. The ratio of the infrared luminosity to the absorbed X-ray luminosity is a measure of the anisotropy of the X-ray emission. We do not detect infrared emission from the ULX in NGC 1313 (X-2) using observations obtained with the IRAC and MIPS instruments on the Spitzer Observatory. For the ULX from Holmberg IX, IR emission is detected in two IRAC bands (3.6 μm, 4.5 μm) but not with MIPS. The detection and limits to the infrared power are well below the value expected if the X-ray emission is isotropic. Our model for the conversion of absorbed X-ray photons to dust reemission implies that the opening angle of the X-ray emission is less than 30 degrees (half-angle, two-sided jet), implying that the intrinsic X-ray luminosity is sub-Eddington.

The Problem with Ultraluminous X-ray Sources

L_x = 2E39 - 2E40 erg/s sustained luminosity in non-nuclear point sources in galaxies (usually spirals).
$L_{Eddington}$ = 1.4E39 (M_{BH}/10 $M_\odot$) erg/sec

The most massive stellar-mass black holes have M = 16 $M_\odot$
Stellar evolution models have difficulty producing more massive black holes.

Possible Solutions

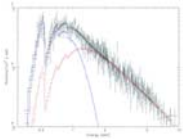
1. It is an *Intermediate Mass Black Hole*, of mass 10^2-10^4 $M_\odot$ with L < L_{Edd}

2. We are seeing a stellar-mass black hole of 10 $M_\odot$
   a. It exceeds L_{Edd} by an accretion disk + photon bubbles
   b. It is not radiating into 4π str and *only appears* over-luminous
      Emission is directional (may not be Doppler-boosted)

The evidence is split between these possibilities.

Our Test: Anisotropy of the X-ray Emission (test of 2b)

About 30-50% of the X-ray emission is absorbed from spectral fits.



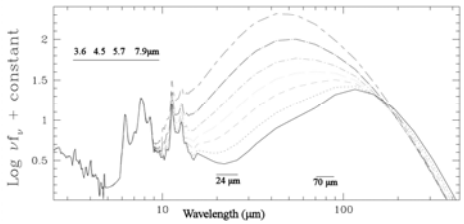
X-ray Spectral fits for NGC 1313 ULX (X-2) and Ho IX ULX have absorbed X-ray luminosities of 4.4E39, 7.6E39 erg/sec

Absorption likely to be local (< 30 pc) since it is a common aspect of ULXs.
This power will come out in other wavebands

Reemission in the IR regions if dust is present

Dust and gas is observed in both galaxies at these locations (optical, IR)

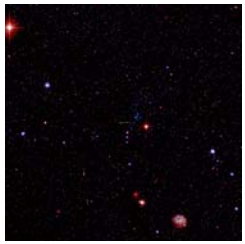
Measure the IR Reemission with the *Spitzer Observatory*



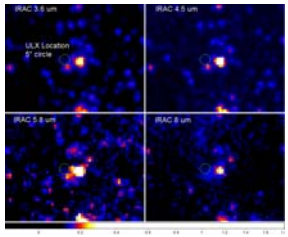
Model dust reemission; multiple lines show temperature dependence

Dale and Helou (2003)

NGC 1313: only upper limits for dust reemission

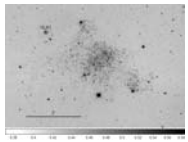


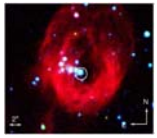
Optical ID from HST (Liu et al. 2007)

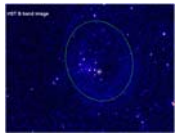


Null IRAC detections with Spitzer

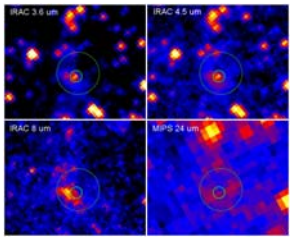
Holmberg IX ULX: detections at 3.6, 4.5 μm only



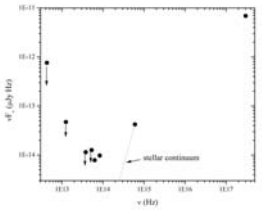




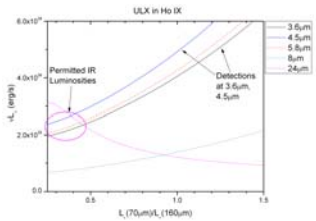
DSS image of Ho IX with ULX marked (above); Ground-based emission line image (top right; Pakull 2003); HST image with outline of nebula (14" high) and ULX marked (right)



Spitzer IR images with a 5" circle at the ULX and a 14" circle for the nebula.



Spectral Energy Distribution



Results of dust model fitting

Interpreting the results

L(IR) = (Solid Angle) x L(absorbed X-rays)

NGC 1313 ULX (X-2): Upper limit L(IR) < 6.5E37 erg/sec

Half angle of a radiation cone is 14° (one-sided cone) or 10° (two-sided cone)

Holmberg IX ULX: maximum value of L(IR) = 2.5E38 erg/sec

Half angle of a radiation cone is 21° (one-sided cone) or 15° (two-sided cone)

The inferred solid angle reduces the total luminosity of these two ULXs to lie well below $L_{Eddington}$ for a 10 $M_\odot$ black hole.

Could This Be Wrong (or, "what would mess this up")?

No dust present? (Not viable: dust emission is seen nearby and all over the galaxy)

Short duty cycle for the ULX; time averaged L_x < L_{Edd} (Viable, but if this were the case, the sources are not persistently super-Eddington in the first place. Also, sources are found to persist for > 20 years).