The accreting intermediate mass black hole candidate ESO 243-49 HLX-1

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Scientific rationale

Stellar mass: $\sim 3-20 \, M_{\odot}$

Supermassive: $\sim 10^6-10^7 \, M_{\odot}$ (SMBH)
Scientific rationale

Intermediate mass: \( \sim 10^{-2.5} \, M_\odot \) (IMBH)

Supermassive: \( \sim 10^{6-10} \, M_\odot \) (SMBH)

Stellar mass: \( \sim 3-20 \, M_\odot \)

IMBH are thought to play a major role in the formation of SMBH
Greene (2012)

- Big bang
  - 200 Myr: Direct collapse
  - 500 Myr
  - 1 Gyr: Few halos are seeded, but seeds are ~10^4 solar masses
  - 3 Gyr: Black holes grow via accretion and merging.
  - 6 Gyr
  - 13.6 Gyr: Today virtually all >10^{10} solar mass galaxies contain supermassive black holes.

- Death of massive stars
  - Most halos are seeded but seeds are ~100 solar masses
  - Some black holes are ejected by gravitational wave radiation.

- Observational consequences
  - ~60% of ~10^9 solar mass galaxies contain >10^5 solar mass black holes
  - ~100% of ~10^9 solar mass galaxies contain ~10^5 solar mass black holes
Searching for new compact objects

2XMM : 22\textsuperscript{nd} August 2007
– 191870 unique sources

2XMMi (DR3) : 15\textsuperscript{th} April 2010
– 262902 unique sources

3XMM (DR4) : 23\textsuperscript{rd} July 2013
– 372278 unique sources

See poster I 10

Watson et al. (2009)
HLX-1
2XMM J011028.1-460421 Spectrum, $\Gamma = 3.4 \pm 0.3$
~8” from nucleus of ESO 243-49 (z=0.0224, ~95 Mpc)

Webb et al. (2010);
HLX-1

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(Wiersema, Farrell, Webb, et al., 2010)

Na I D from galaxy detected in blue arm confirms galaxy z

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(Wiersema, Farrell, Webb, et al., 2010)
HLX-1 X-ray luminosity

Associated with ESO 243-49 $\Rightarrow L_x = 1.1 \times 10^{42}$ erg s$^{-1}$ (0.2-10.0 keV)

$\Rightarrow$ from the Eddington luminosity ($L_{\text{Edd}}$), $M = 5000 M_{\odot}$

Superceding $L_{\text{Edd}}$ by a factor 10 (Begelman 02) $\Rightarrow M > 500 M_{\odot}$
HLX-1 X-ray luminosity
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=> from the Eddington luminosity ($L_{\text{Edd}}$), $M = 5000 \, M_\odot$
Superceding $L_{\text{Edd}}$ by a factor 10 (Begelman 02) => $M > 500 \, M_\odot$
X-ray variability

Fitting thermally dominated spectra with relativistic models (BHSPEC, KERRBB, slimbh, Kawaguchi, 2003) constrains mass to $10^3 - 10^5 \, M_\odot$

Accretion sub/near Eddington

(Godet et al., 2009; Davis et al., 2011; Servillat et al., 2011; Godet et al., 2012 Straub et al. sub)
Lasota et al. (2011)
Outburst 2012

Webb et al. 2014

Rapid optical/ X-ray rise indicates matter impacts disc close (~10^{11} cm) to black hole.

Matter propagated through disc by waves (not viscosity as in standard disc instability model).
Peak
average
0.030
± 0.002 ct/s

Peak
average
0.020
± 0.002 ct/s
SPH modelling (Gaburov et al. 2010)
Can a highly eccentric binary form and remain bound?
Results of modelling show it is possible
Likely that the donor is something like a white dwarf
But accretion rates are then difficult to understand
(Godet et al., sub.)
Radio observations

7 x 12 hrs ATCA 5 + 9 GHz observations
(Webb et al., Science, 2012)
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Co-add 5+9 GHz detections: 8.2 σ, 45 μJy
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All non-detections: 3 σ upper limit, 21 μJy (5+9 GHz)
Mass estimate of HLX-1

- Radio flares from Galactic black hole binaries when the X-ray luminosity is 10-100% Eddington luminosity (e.g. Fender, Belloni & Gallo 2004)

- HLX-1 shows similar behaviour to Galactic black hole binaries

- Assume HLX-1 radio flares occur at 10-100% Eddington

=> black hole mass between $9.2 \times 10^3 \, M_\odot$ and $9.2 \times 10^4 \, M_\odot$

Webb et al (Science, 2012)
Where do intermediate mass black holes form and evolve today?

Courtesy of Kathryn Johnston
HST, six band image (Farrell et al. 2012)
HLX-1, size on sky <40 pc (Farrell et al. 2012)
Host Farrell et al (2012)

Age: $<1.3 \times 10^7$ years
Mass: $4 \times 10^6 \, M_\odot$
Disc irradiation: $8 \times 10^{-7}$
$X^2$ (d.o.f.): 23.38 (27)

Farrell et al (2012)

Age: $1.3 \times 10^{10}$ years
Mass: $6 \times 10^6 \, M_\odot$
Disc irradiation: 0.098
$X^2$ (d.o.f.): 24.28 (27)
$10^6 \, M_\odot$ too small to form $10^4 \, M_\odot$ black hole (e.g. Mapelli et al. 2012)

Possible radial velocity offset of ~400 km/s compared to ESO 243-49 (Soria, Hau & Pakull 2013)

May be a dwarf galaxy that has been stripped in a merger with ESO 243-49 (Webb et al. 2010, Mapelli et al. 2013)

Currently analysing two further HST/XMM datasets, X-shooter data and will have MUSE integral field observations next week 😊
Summary

First good intermediate mass black hole (IMBH) candidate discovered with mass between $9 \times 10^3 \, M_\odot$ and $9 \times 10^4 \, M_\odot$.

Difficult to understand the accretion mechanism.

May reside in stellar cluster, possibly due to minor merger.