

THE BLACK HOLE MASS LIMIT FOR OPTICALLY DARK X-RAY BRIGHT SOURCES IN NEARBY GALAXIES

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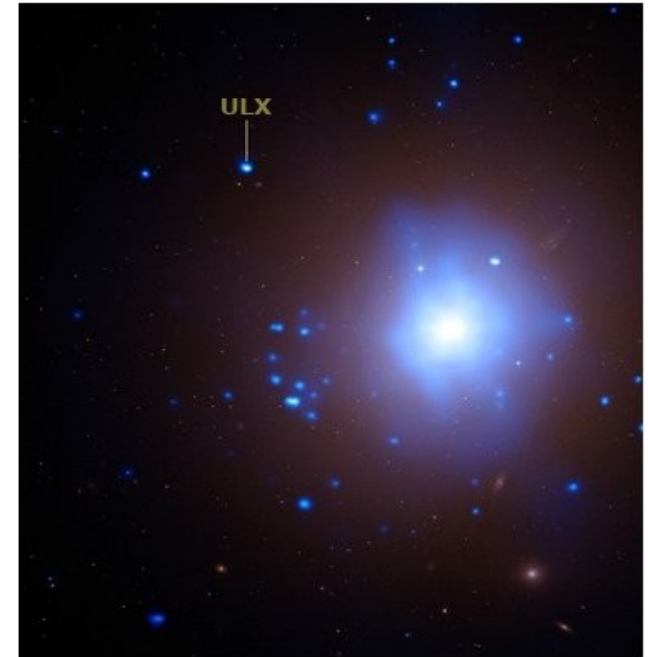
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Introduction

- Compact, off-nuclear X-ray point sources in nearby galaxies, with luminosities 10^{39} - 10^{41} ergs s^{-1} are referred as Ultra-luminous X-ray sources (ULXs).
- The observed luminosities of ULX sources exceeds the Eddington limit for a $10M_{\odot}$ black hole. Since ULXs are off-nuclear sources, their masses must be $< 10^5M_{\odot}$ from dynamical friction arguments [1].
- Thus the allowed black hole mass range for X-ray sources in nearby galaxies span five orders of magnitude ($10M_{\odot} < M < 10^5M_{\odot}$) and it is important to obtain tighter constrains.

ULX in NGC 1399



Credits: X-ray : NASA/CXC/UA/J. Irwin et al.
Optical : NASA/STScI

Observation & Analysis

- Selected a sample X-ray point sources from 13 elliptical galaxies [2,3] and searched the optical counterparts in HST archival images.
- Galaxy light was modeled based on the isophotes obtained using *ELLIPSEFIT* task and subtracting the model image.
- The object extraction was done on the residual image using *SEXTRACTOR*.
- Many of the *Chandra* X-ray sources have counterparts with in a positional off-set of few arc-seconds and constant offset applied to match these sources.

Sample Galaxy Properties

Galaxy	Distance (Mpc)	N_x	N_d
NGC 1399	18.3	26	4
NGC 4649	16.6	12	5
NGC 4697	11.8	11	3
NGC 1291	8.9	5	1
NGC 4365	20.9	4	3
NGC 1316	17.0	7	3
NGC 4125	24.2	3	3
NGC 3379	11.1	3	1
NGC 4374	17.4	2	1
NGC 4486	15.8	5	2
NGC 4472	15.9	1	0
NGC 1407	17.6	2	2
NGC 4552	15.9	3	0

Note : (1) Host Galaxy Name; (2) Distance to the galaxy; (3) Number of X-ray sources within HST field of view; (4) Number of X-ray sources without optical counterparts.

Results

- A total of 84 point sources were analyzed in 13 elliptical galaxies. Fifty six of them are having possible optical counterparts in their respective position. Twenty eight sources have no optical counterparts and named as **optically dark** X-ray sources.
- These optically dark sources are X-ray bright compared to their optical emission and hence are not foreground stars and from the X-ray-to-optical flux ratio, we can conclude that these are unlikely to be background AGNs.
- These sources are most likely to be bright X-ray binaries (or at least accreting systems) within the galaxy. An accretion disk around a compact object should also produce optical emission whose flux can be estimated by the standard accretion disk theory [4].

Results contd.

- The observed flux from the disk at a frequency ν is given by,

$$F_\nu = \frac{\cos i}{D^2} \int_{R_{in}}^{R_{out}} B_\nu(\nu, T(R)) 2\pi R dR$$

- Assuming that most contribution to F_ν arises from the region in the disk that are far away from the inner and outer radii, the expected observed flux is,

$$F_\nu \sim 7 \times 10^{-31} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ Hz}^{-1} \left(\frac{\lambda}{5000 \text{ \AA}}\right)^{-1/3} \left(\frac{\eta}{0.1}\right)^{-2/3} \\ \times \left(\frac{L_x}{10^{39} \text{ ergs s}^{-1}}\right)^{2/3} \left(\frac{D}{10 \text{ Mpc}}\right)^{-2} \left(\frac{M}{1000 M_\odot}\right)^{2/3}$$

- For optically dark sources, the predicted accretion flux should be less than the measured upper limit $F_{\nu, max}$. Thus one can estimate an upper limit on black hole mass (M_U) as,

$$M_U < 1000 M_\odot \left(\frac{F_{\nu, max}}{7 \times 10^{-31} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ Hz}^{-1}}\right)^{3/2} \\ \times \left(\frac{\lambda}{5000 \text{ \AA}}\right)^{1/2} \left(\frac{\eta}{0.1}\right) \left(\frac{L_x}{10^{39} \text{ ergs s}^{-1}}\right)^{-1} \left(\frac{D}{10 \text{ Mpc}}\right)^3$$

Results contd.

- For each source, we estimated this upper limit on the black hole mass and the ten best cases in ascending order of black hole mass limit is listed in the Table 2. The best case is for the ULX in NGC 4486, for which $M_U = 1244M_\odot$.

TABLE 2:
The Upper limit of Black hole Mass of Ten Optically Dark X-ray Sources

Galaxy	<i>R.A.</i> (J2000)	<i>Decl.</i> (J2000)	$\log L_x$	HST Filter	$F_\nu \times 10^{-30}$	F_X/F_O	$M_U(M_\odot)$
NGC4486	12 30 50.82	+12 25 02.66	$39.17^{+0.05}_{-0.04}$	F475W	0.409	533	1244
NGC4697	12 48 33.20	-05 47 41.17	$38.84^{+0.06}_{-0.05}$	F475W	0.752	243	2890
NGC4649	12 43 41.90	+11 34 33.83	$38.91^{+0.47}_{-0.11}$	F475W	0.402	164	3073
NGC4374	12 25 01.54	+12 52 35.59	$39.10^{+0.67}_{-0.22}$	F475W	0.441	347	3378
NGC1399	3 38 25.92	-35 27 42.37	$38.62^{+0.12}_{-0.09}$	F606W	0.370	228	3927
NGC1316	3 22 36.46	-37 13 24.68	$38.80^{+0.23}_{-0.08}$	F475W	0.449	179	4780
NGC1316	3 22 35.58	-37 13 14.10	$38.78^{+0.40}_{-0.07}$	F555W	0.520	287	6366
NGC1399	3 38 32.33	-35 26 45.73	$38.54^{+1.13}_{-0.41}$	F606W	0.377	186	7829
NGC1399	3 38 27.62	-35 26 48.76	$39.42^{+0.16}_{-0.14}$	F606W	0.766	702	7829
NGC4649	12 43 34.17	+11 33 41.93	$39.04^{+0.10}_{-0.11}$	F475W	0.912	97	8073

NOTE. — (1) Host galaxy name; (2) Right Ascension of shifted position in hours, minutes and seconds; (3) Declination of shifted position in degrees, arcminutes and arcseconds; (4) log of X-ray luminosity in *ergs/s*; (5) HST filter for which the upper limit on flux and the black hole mass limit is calculated; (6) Upper limit on Optical flux in *ergs/s/cm²/Hz*; (7) Lower limit on ratio of X-ray to optical flux; (8) M_U , Upper limit on black hole mass.

Optically Dark X-ray Bright Sources

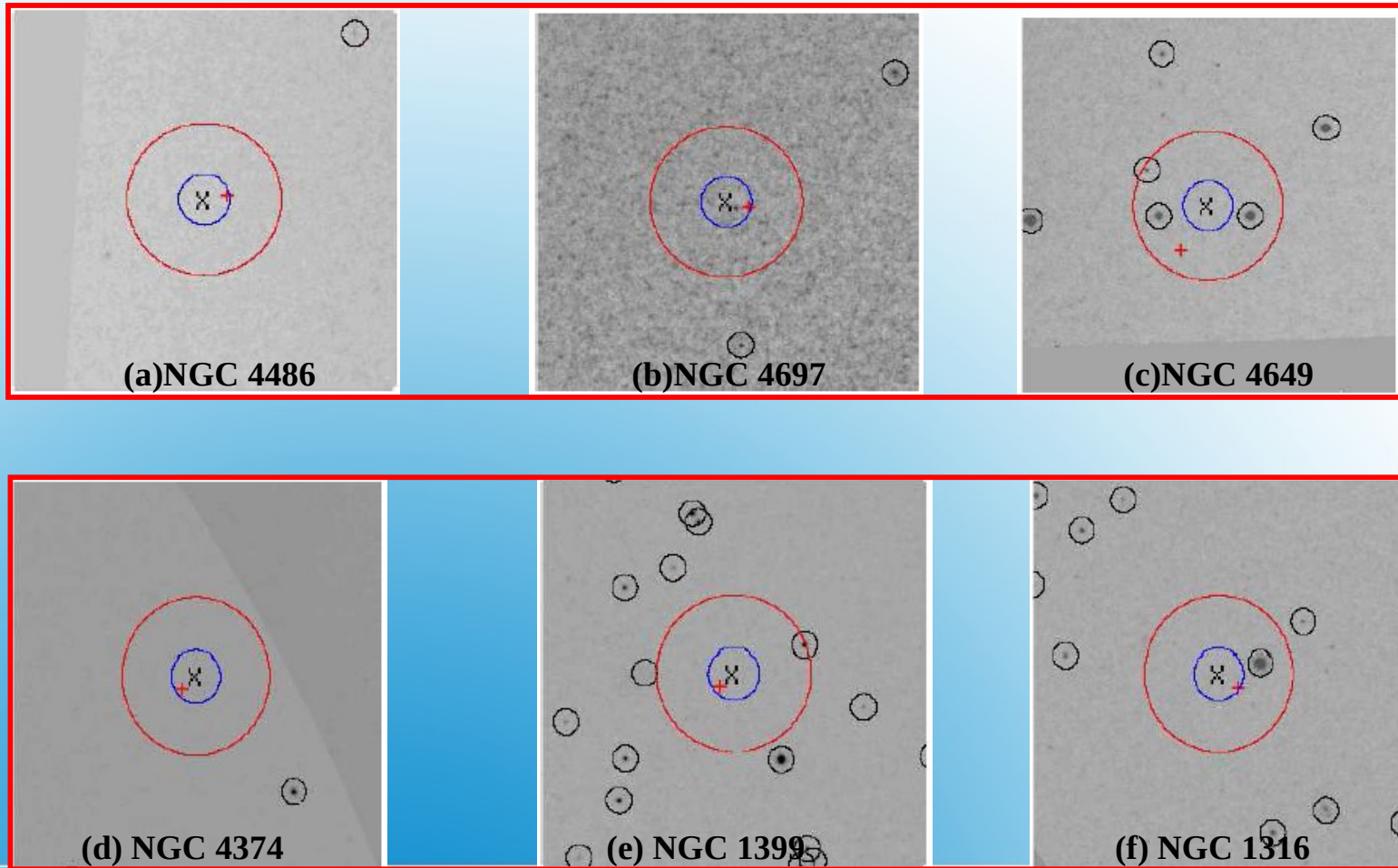


Fig 1 : The HST image of the first six X-ray sources listed in the table 2. Overlaid are 1'' and 3'' circles centered on the shifted *Chandra* positions. The plus sign marks the original *Chandra* positions. Note that for four of the images, there are no optical sources even within 3'' of the X-ray position.

Conclusions

- These optically dark X-ray sources cannot be foreground stars and are highly unlikely to be background AGNs.
- The non-detection of optical emission impose an upper limit on the black hole mass M_U . For ten sources $M_U < 10,000M_{\odot}$ and for one of the bright ULX sources in NGC 4486, the black hole mass is smaller than $1244M_{\odot}$.
- This is two order of magnitude smaller than the constrain obtained from dynamical friction arguments, 10^5M_{\odot} .
- The bright, nearby X-ray sources with luminosity $>10^{40}$ ergs s^{-1} , would have provided a better constrain on the black hole mass.

References and Acknowledgments

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