Ultra Luminous X-ray Sources

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astrophysique & planétologie

What I will mention:

- ✔ Stars/globular clusters
- ✔ Compact objects
- ✔ Magnetic fields
- ✔ Accretion/ejection
- ✔ Supermassive black hole formation
- ✔ Galaxy evolution
- ✔ The early Universe

What I will not mention:

- ✗ Planets/small bodies
- ✗ Inter Stellar Medium
- ✗ ...and everything else !

Ultra-Luminous X-ray Sources (ULX)

X-ray sources with $L > 10^{39}$ erg s^{-1}

Located outside the nucleus of the host galaxy

Many believed to be black holes

If accretion is spherical, implies intermediate mass black holes

Difficult to reconcile with the mass available for star formation and the star formation rate (King 2004)

Emission can appear to exceed Eddington limit if collimated (geometrically thick accretion disc/ relativistic boosting)

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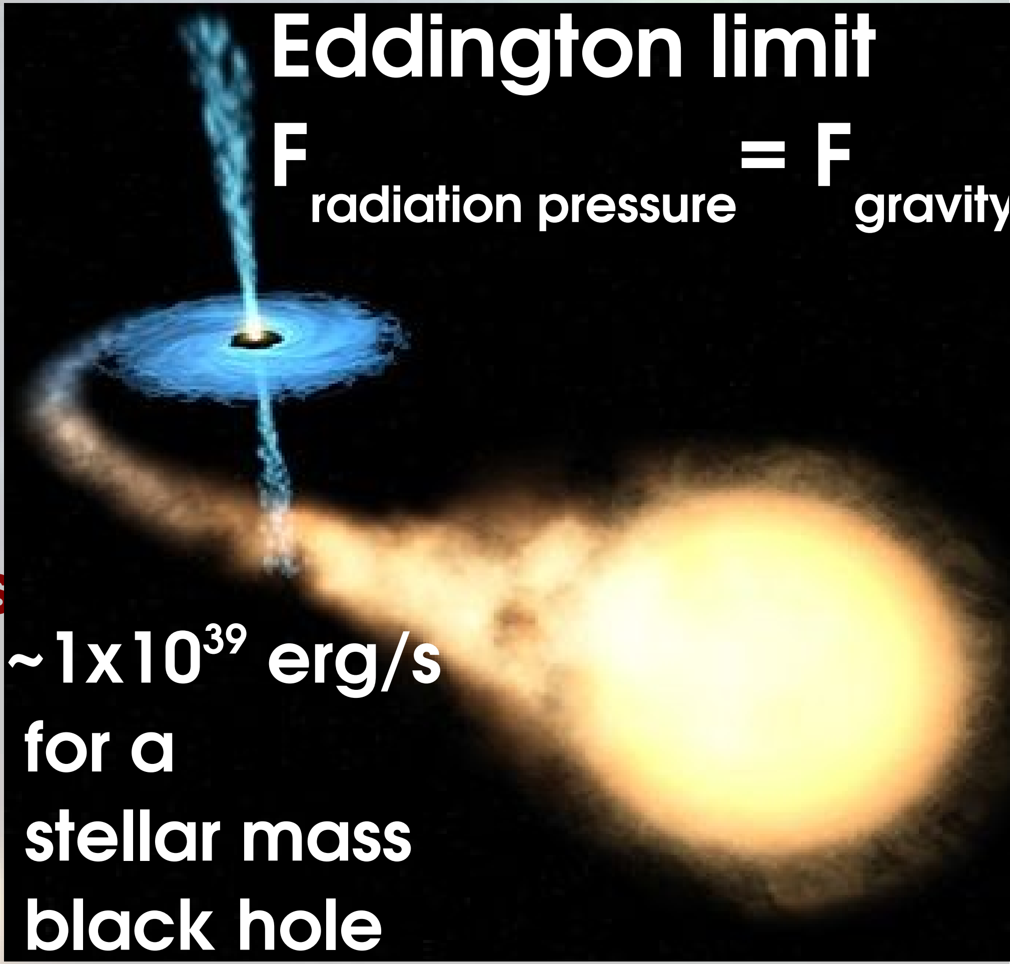

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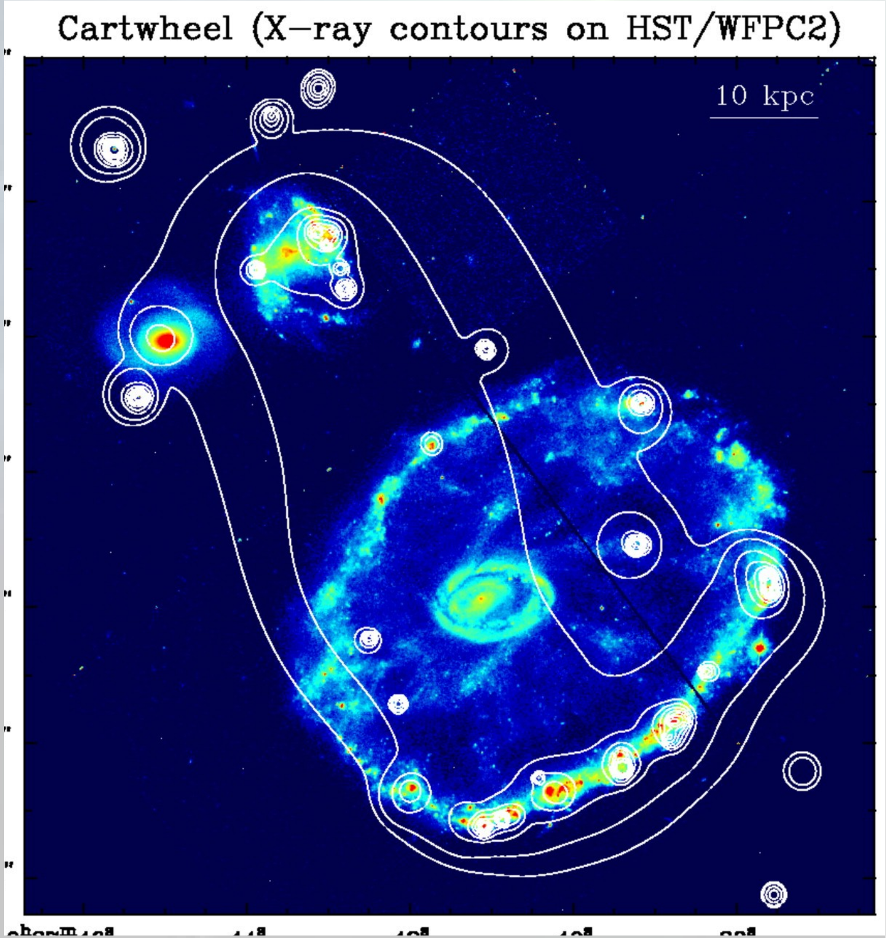
(From Gao et al. 2003)



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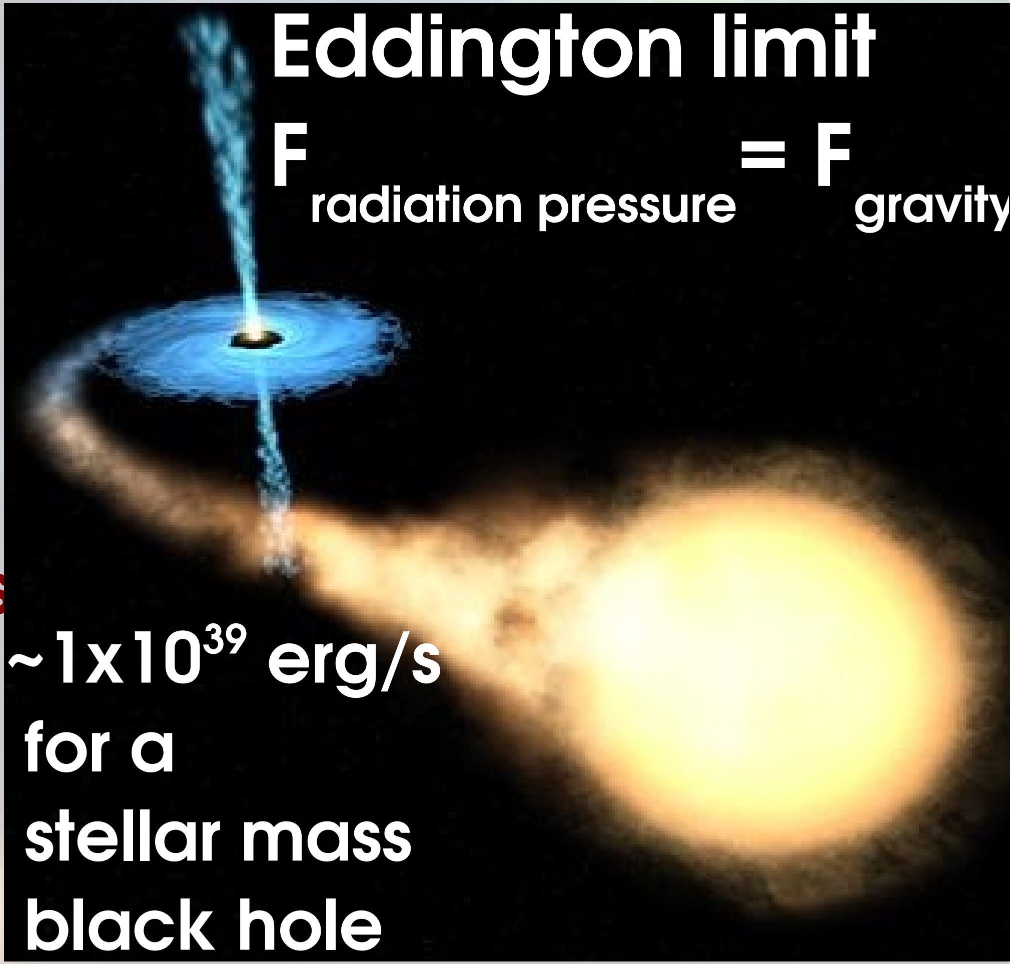

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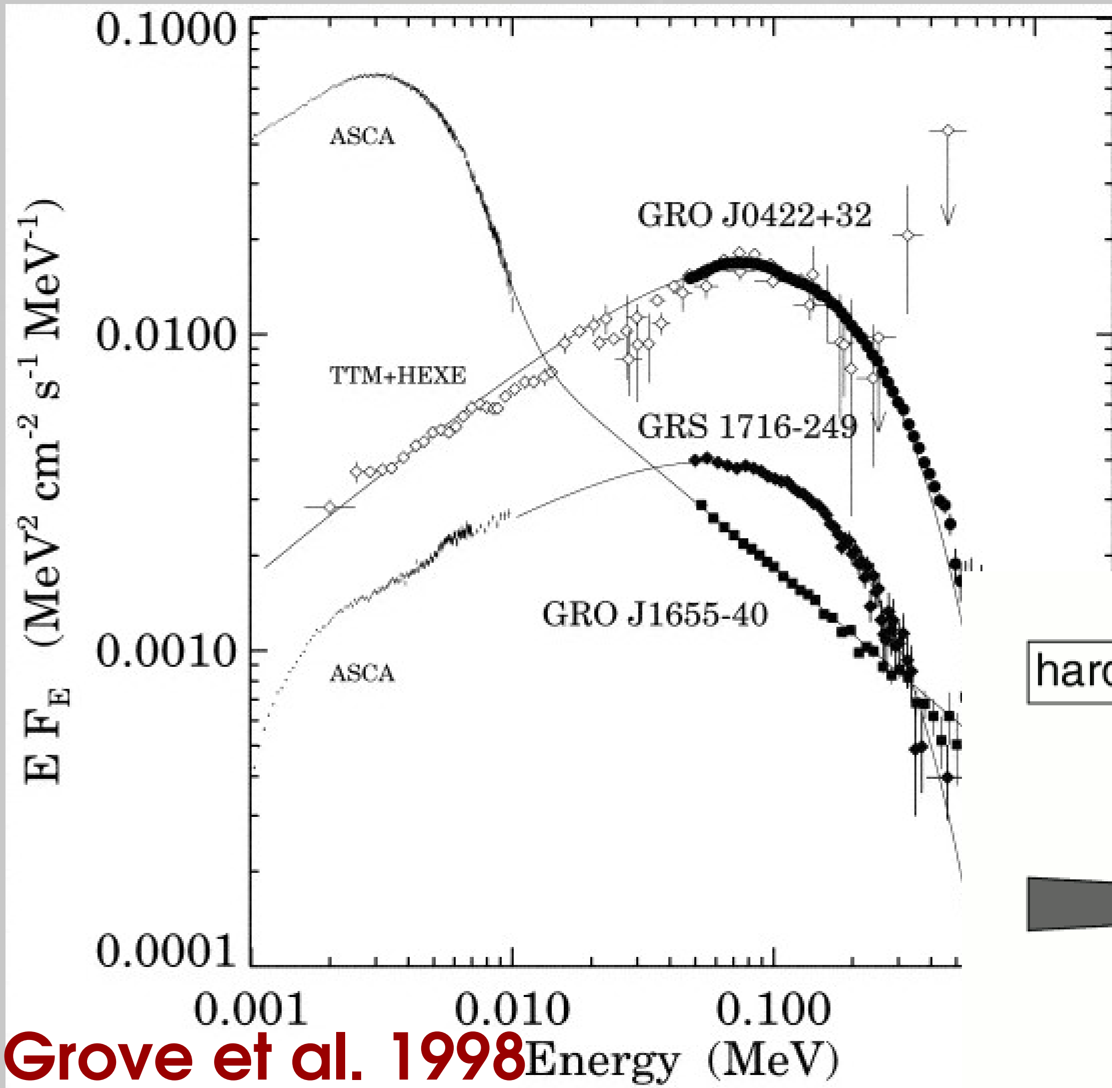
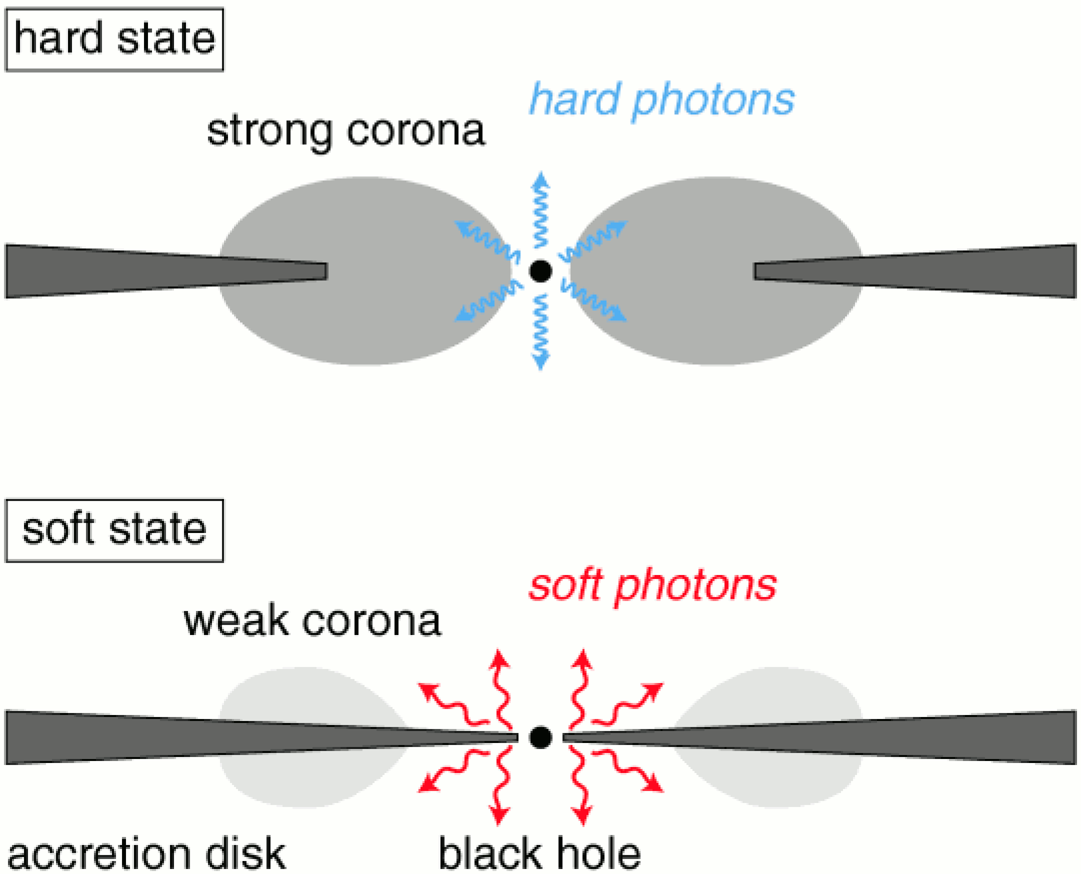
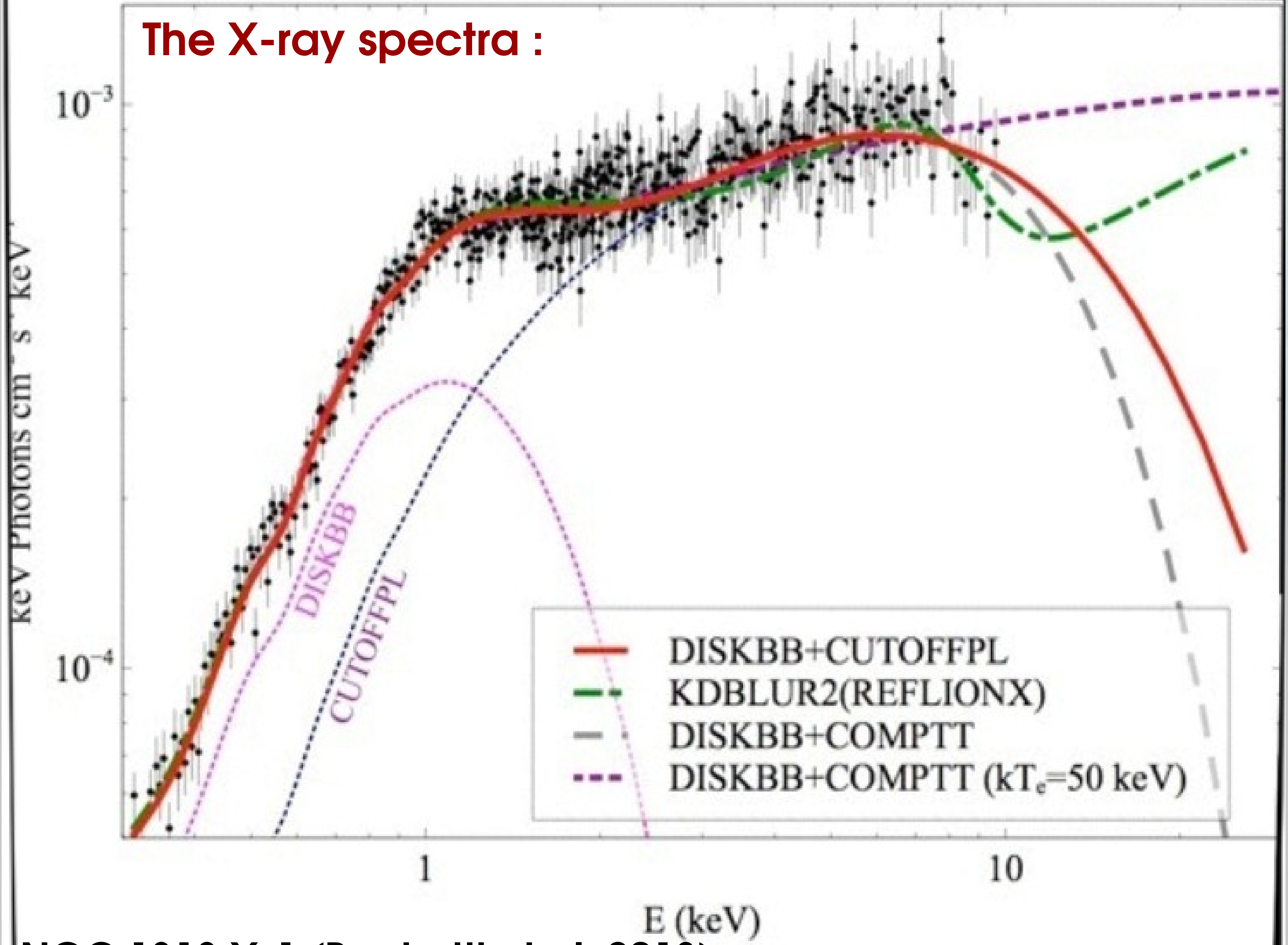
Canonical black hole states



Grove et al. 1998



The X-ray spectra :



NGC 1313 X-1 (Bachetti et al. 2013)

What are ULXs and how do they accrete?

Do intermediate mass black holes exist or can the Eddington limit be exceeded?

Super-Eddington accretion proposed to account for the early (Z>6) massive Active Galactic Nucleii ($M > 10^9 M_\odot$) (e.g. Volonteri 2012; Willott et al. 2010)

What are the mechanisms and circumstances in which the Eddington limit can be exceeded?

The nature of ULXs

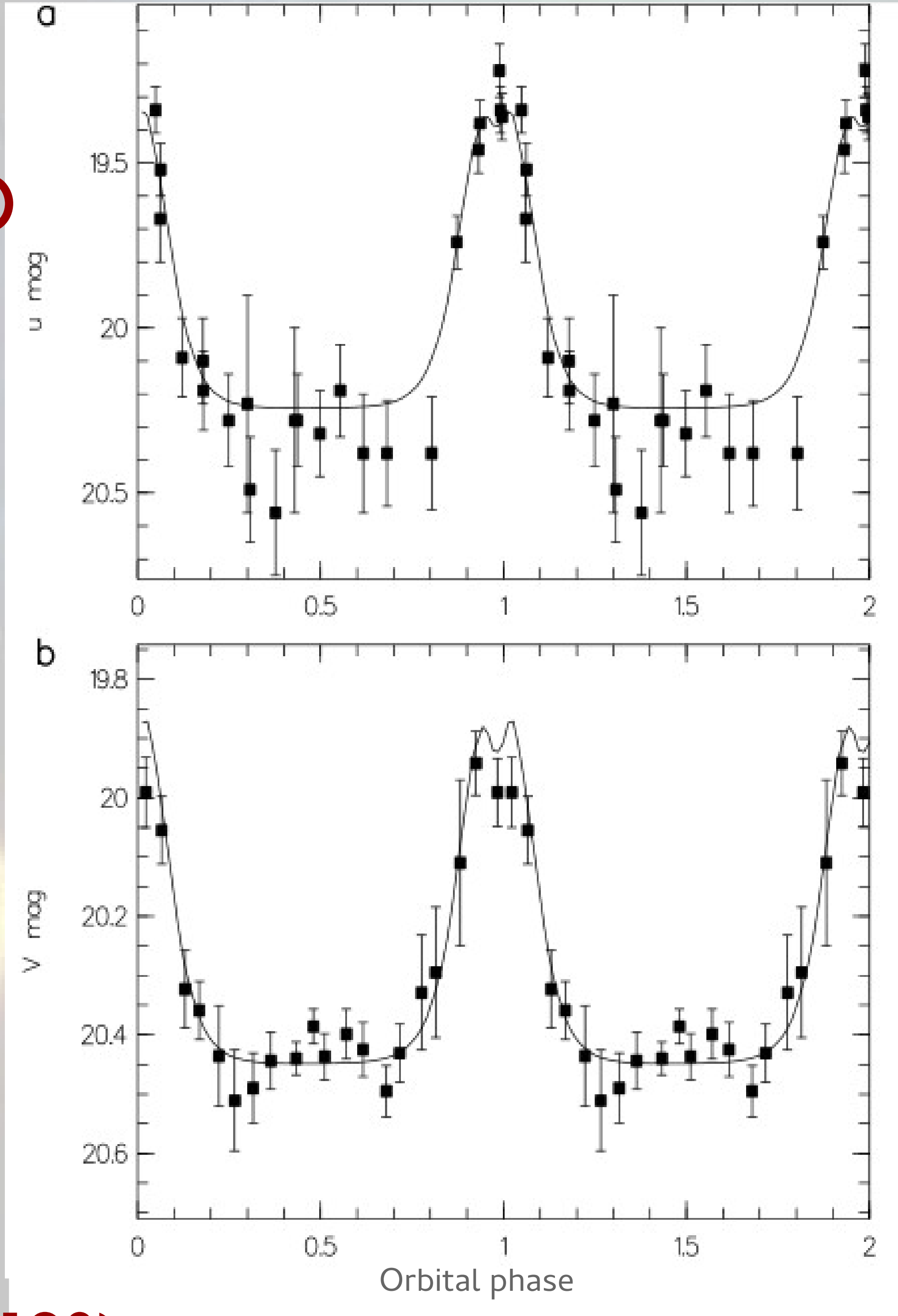
X-ray & optical observations of ULX P13 in NGC 7793 (@3.6 Mpc)

Optical photometry (confirmed with spectroscopy) shows a 64 day orbital period

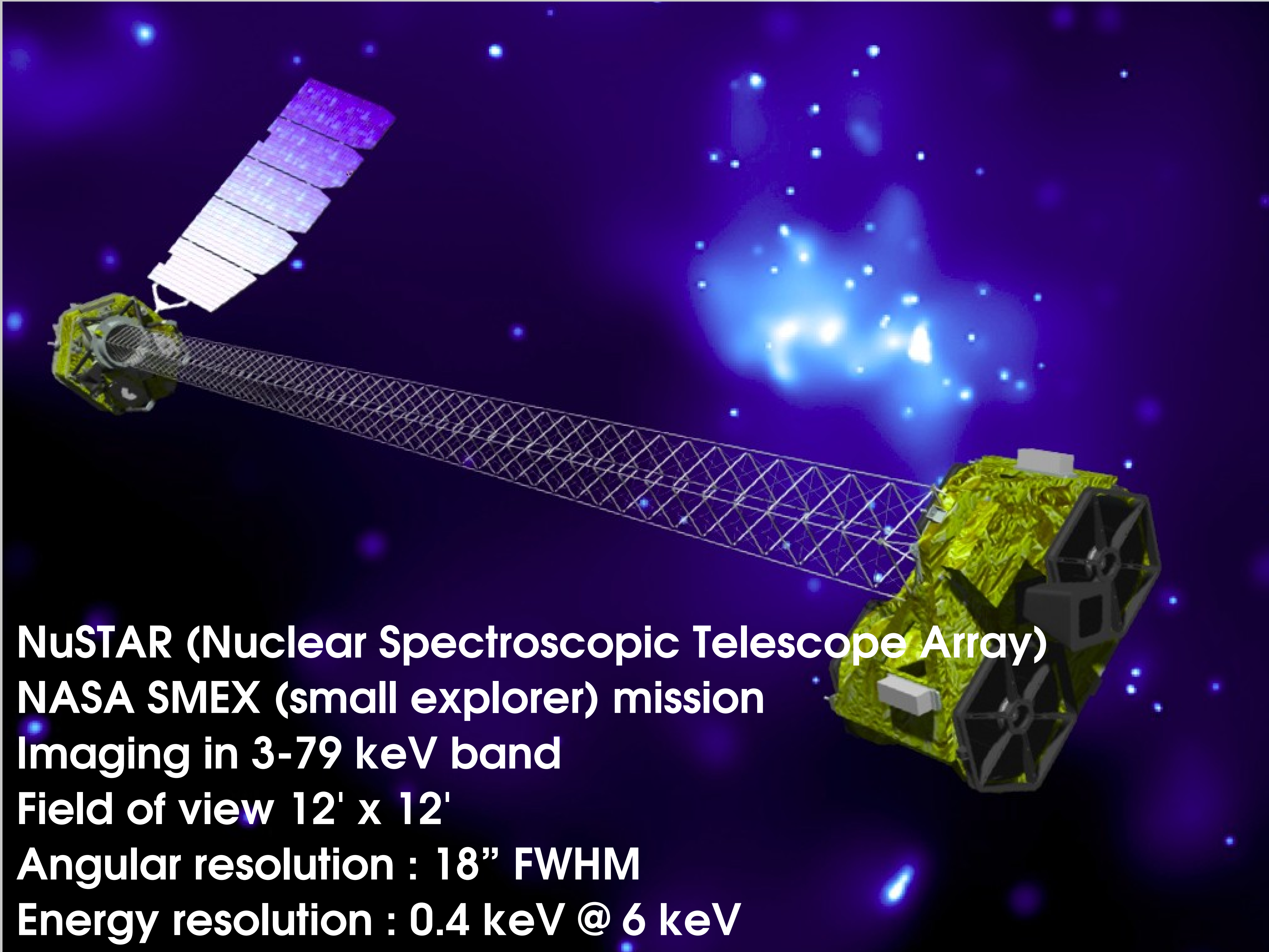
Counterpart = B9Ia star

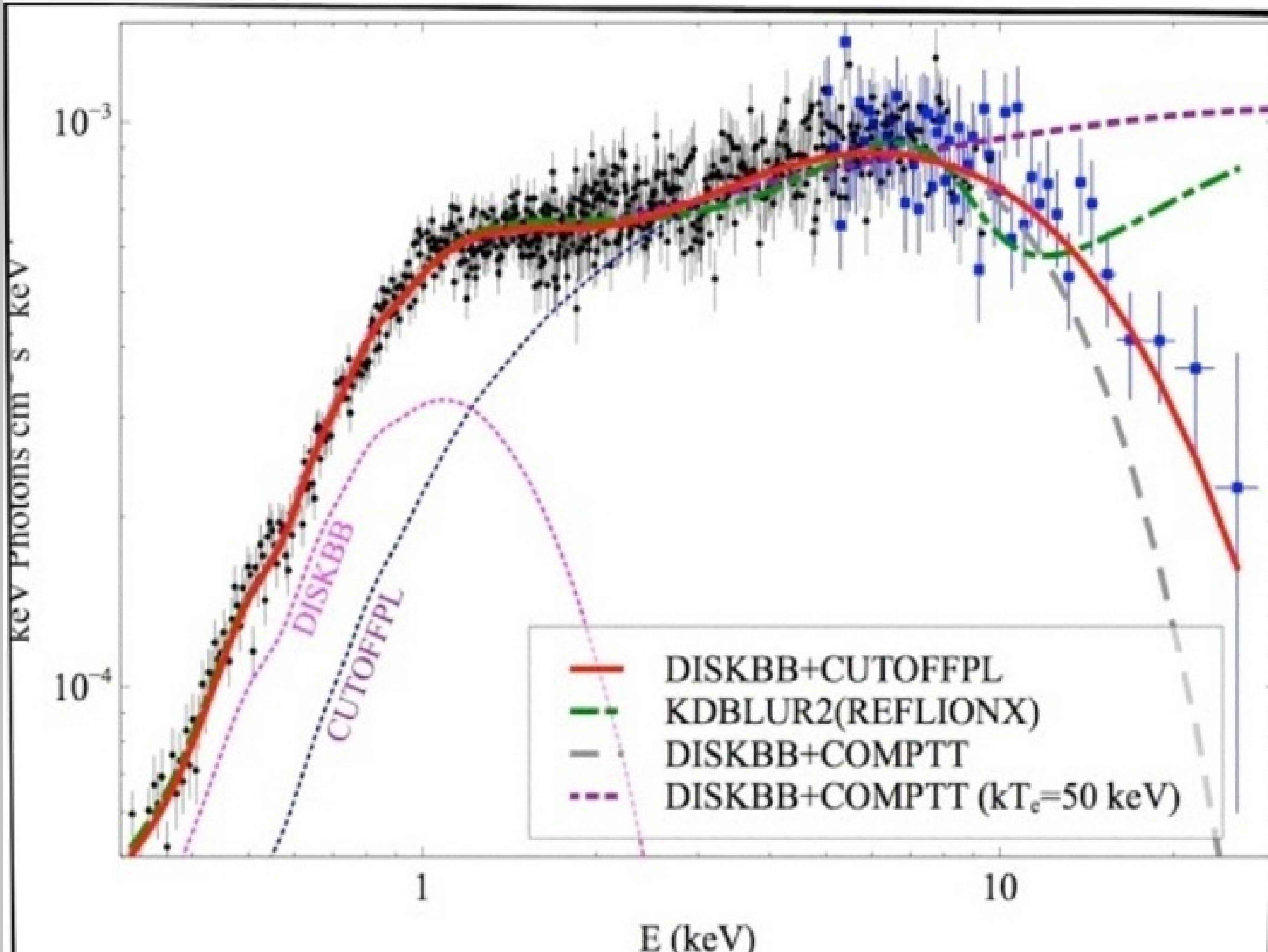
Modelling demonstrates black hole mass < 15 $M_{\odot}$

Accretion via Roche Lobe over-flow and up to twice Eddington



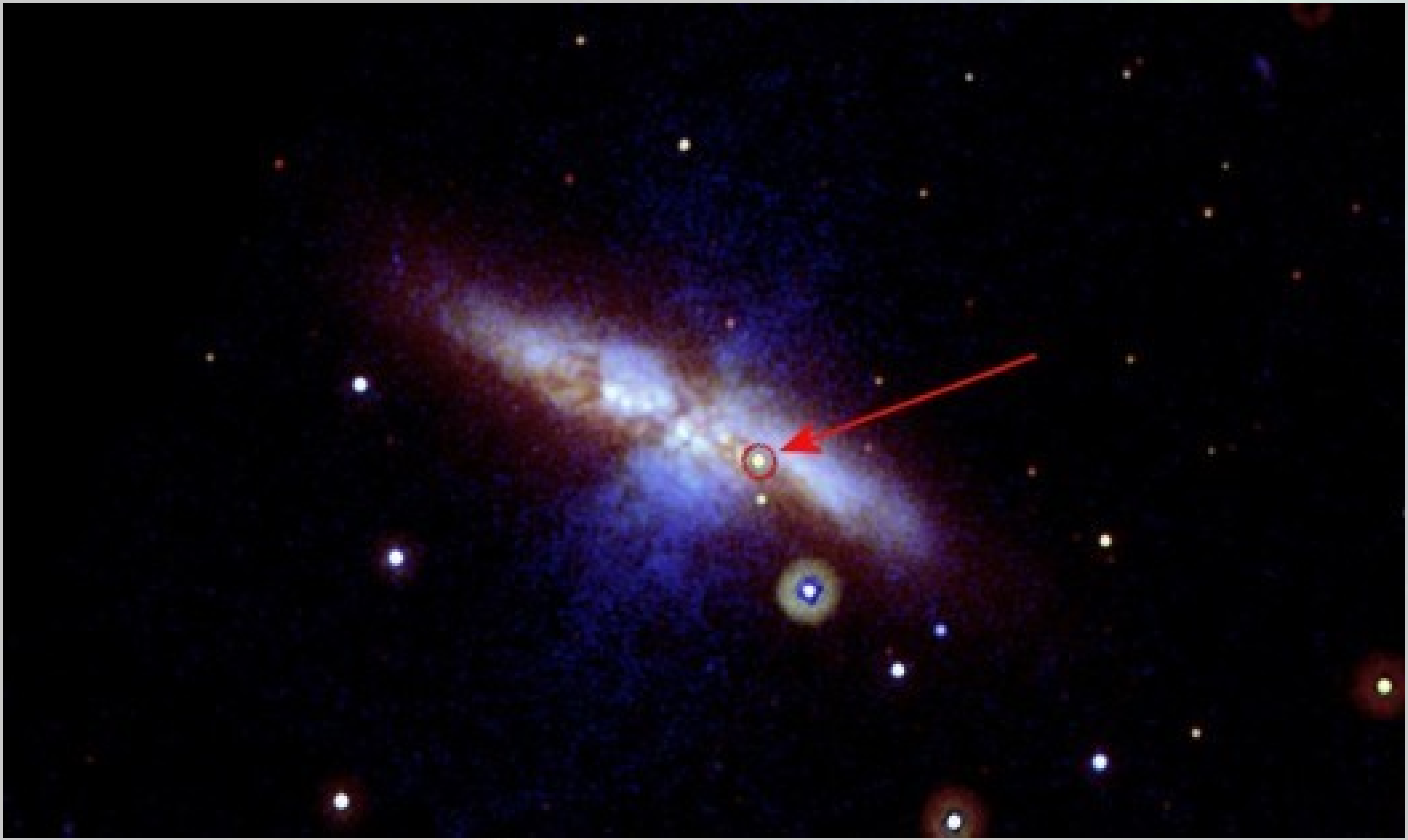
(Motch et al. 2014, Nature, 514, 198)


NuSTAR (Nuclear Spectroscopic Telescope Array)
NASA SMEX (small explorer) mission
Imaging in 3-79 keV band
Field of view 12' x 12'
Angular resolution : 18” FWHM
Energy resolution : 0.4 keV @ 6 keV



NGC 1313 X-1 (Bachetti et al. 2013)

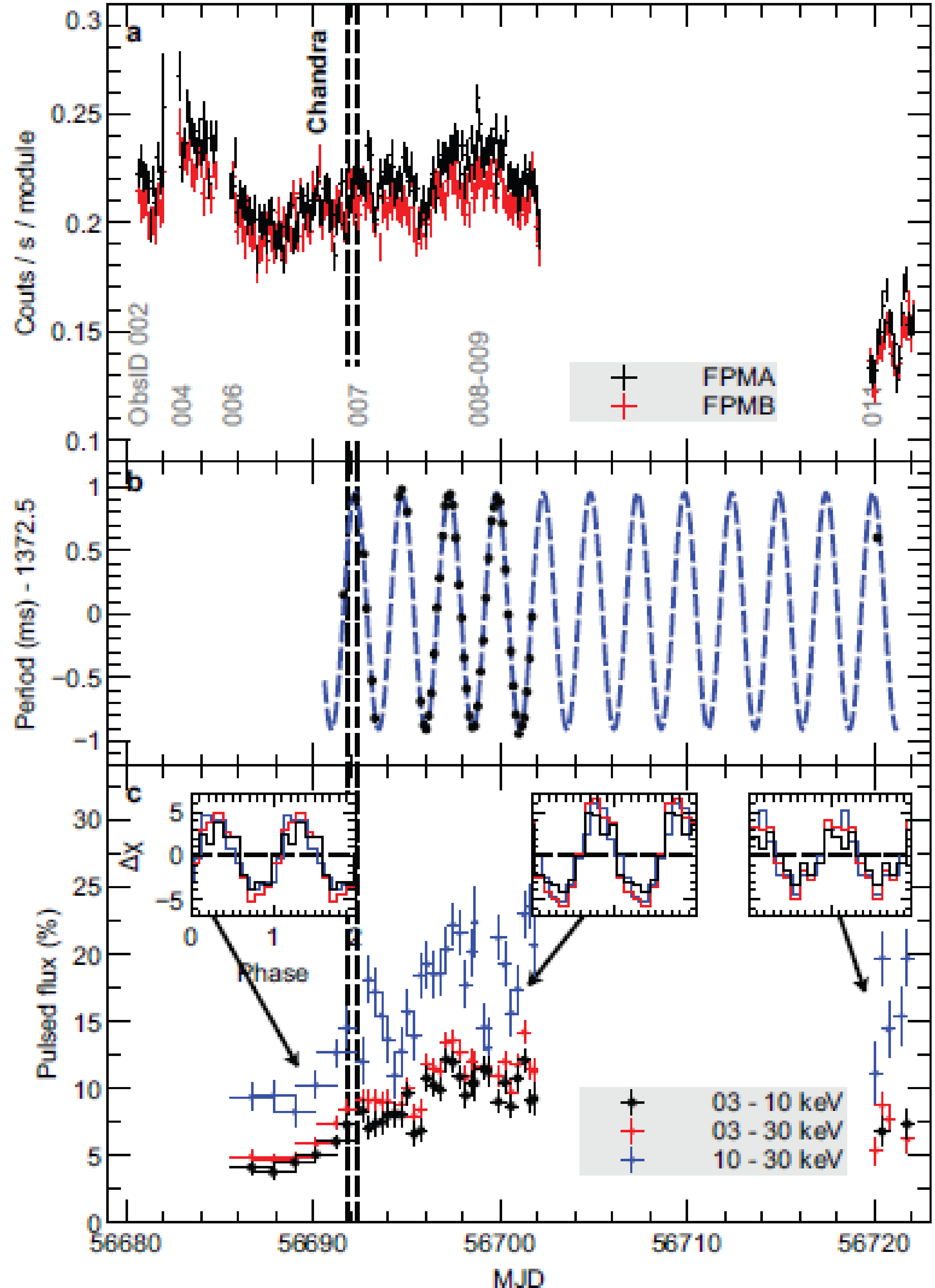
Supernova 2014J : a type 1a in M 82 (~3.6 Mpc)



7 observations from 23 Jan - 6 March 2014 (1.91 Ms)

2 luminous ULXs (sep. 5”): M82 X-1($L_{max\ (0.3-10.0\ KeV)}$ ~10^{41} erg s^{-1})

M82 X-2($L_{max\ (0.3-10.0\ KeV)}$ ~$1.8\ x10^{40}$ erg s^{-1})



Timing analysis

Pulse period = 1.37 s (30σ)
Spin up = -2×10^{-10} s/s
Sinusoidal period = 2.53 d
Eccentricity < 0.003

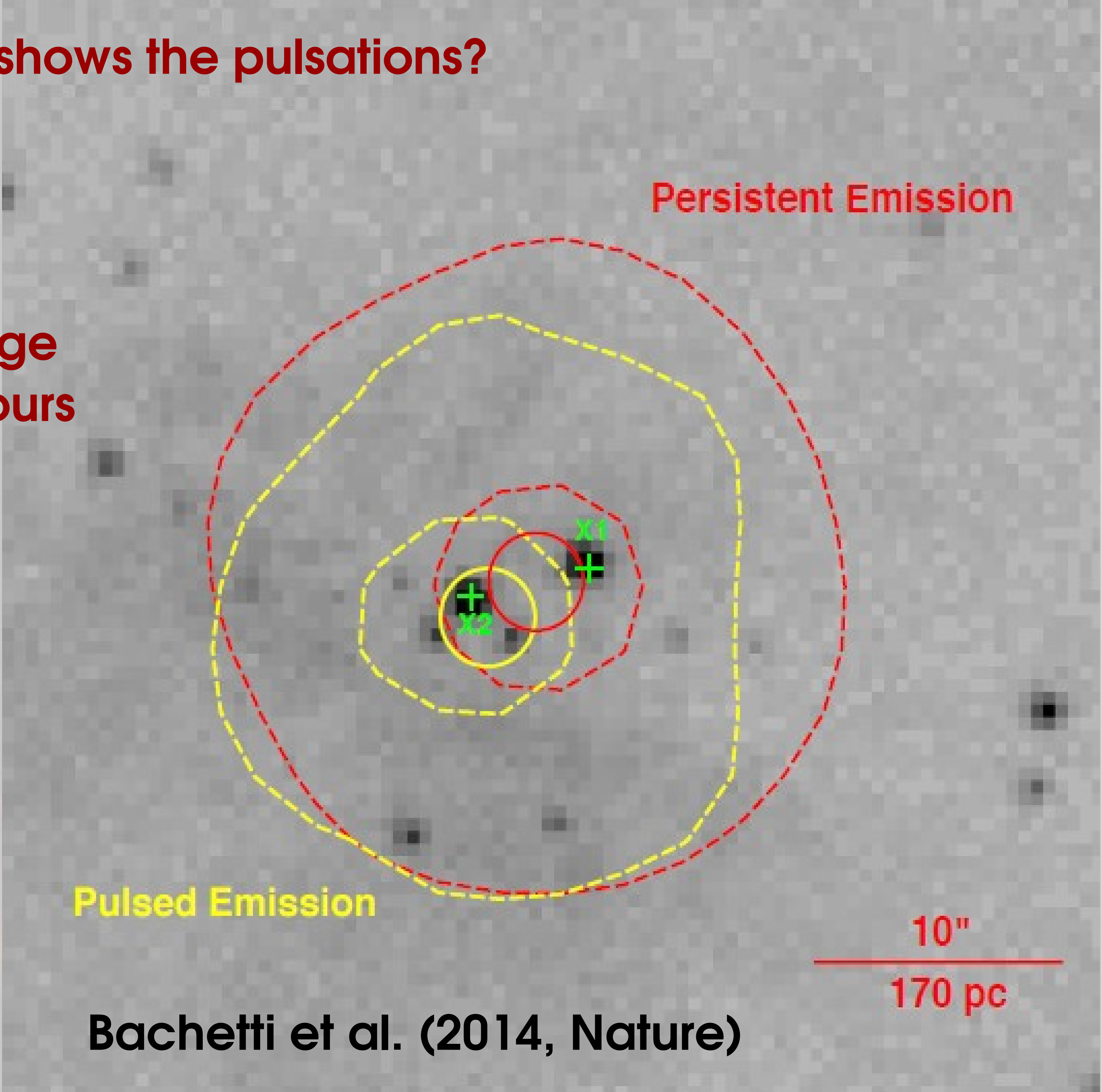
Pulse period and spin up
=> neutron star (NS)

Lack of eclipse => i < 60°
If M_{NS} ~1.4 $M_{\odot}$
=> $M_{companion}$ > 5.2 $M_{\odot}$

Bachetti et al. (2014, Nature)

But which ULX shows the pulsations?

Chandra image
NuSTAR contours



Bachetti et al. (2014, Nature)

M82 X-2 has a maximum luminosity, $L_{(0.3-10.0\ KeV)}$ ~1.8×10^{40} erg s^{-1}

This is ~100x greater than the Eddington limit for a neutron star

With high magnetic field (B) > 10^{13} G (Basko & Sunyaev 1976) the X-ray luminosity can exceed the L_{Edd}

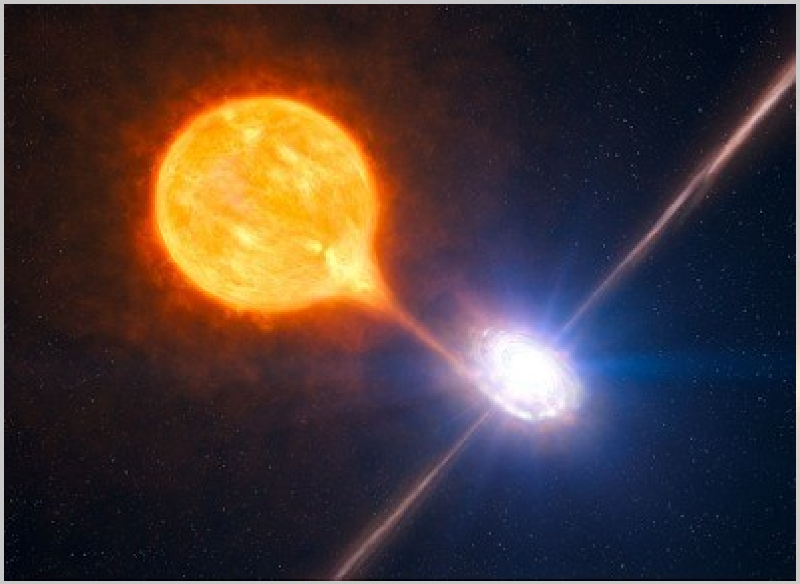
B > 10^{14} G can affect the electron scattering opacity (Canuto et al. 1971) and thus increase L_{Edd}

But the spin up rate => B ~ 10^{12} G

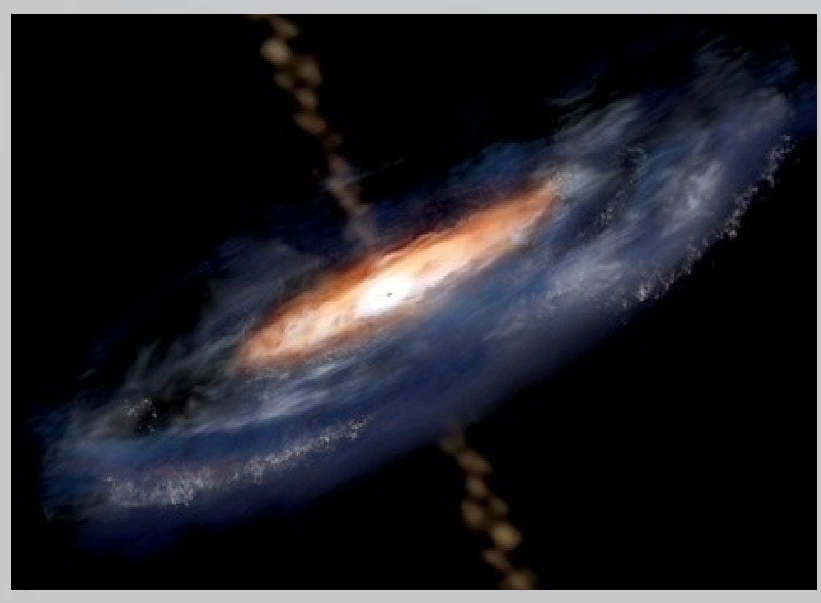
However, maybe a fan beam geometry (Gnedin & Sunyaev 1973) could provide the necessary accretion column?

The observations suggest that highly super-Eddington sources may exist and that ULXs may also host accreting neutron stars

Intermediate mass black holes

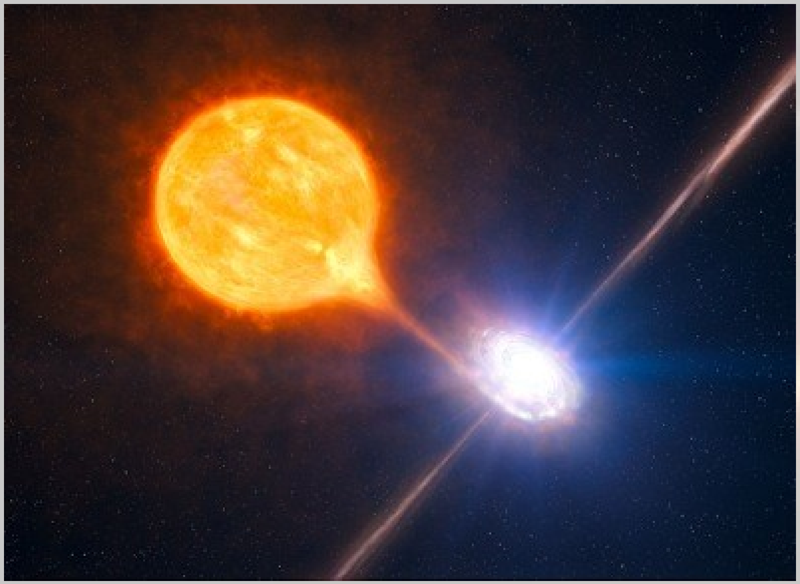


Stellar mass: ~3-20 $M_\odot$



Supermassive:~10^{6-10} $M_\odot$

Intermediate mass black holes



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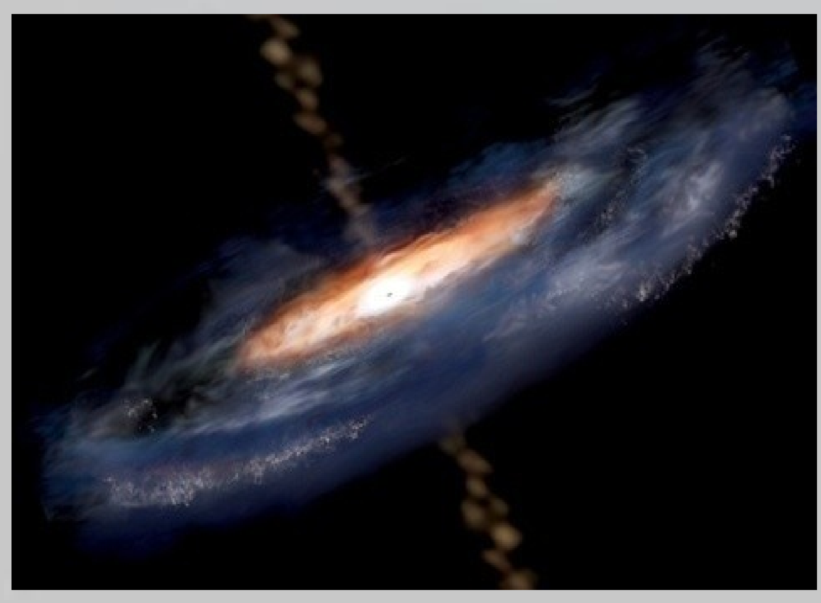
Intermediate mass: $\sim 10^{2-5}\ M_\odot$



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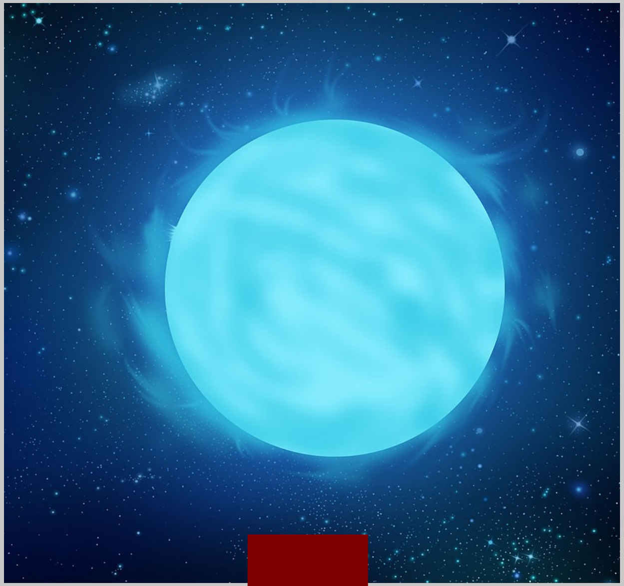

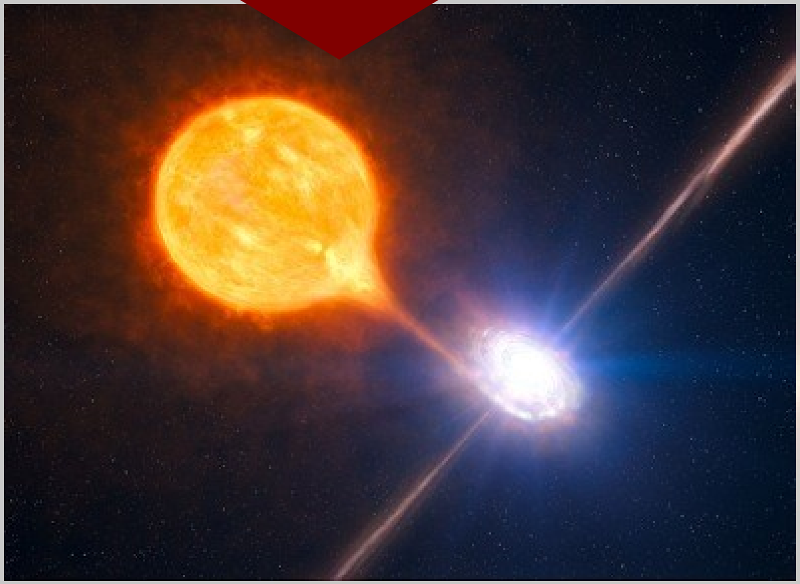

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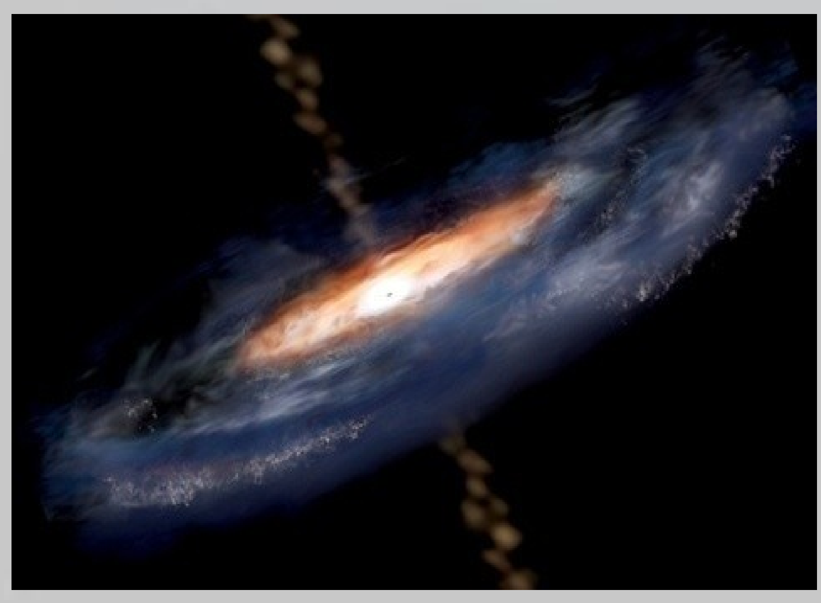

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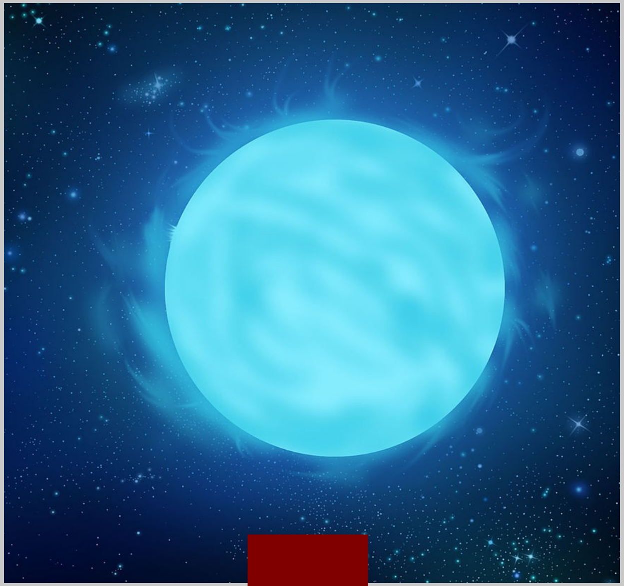

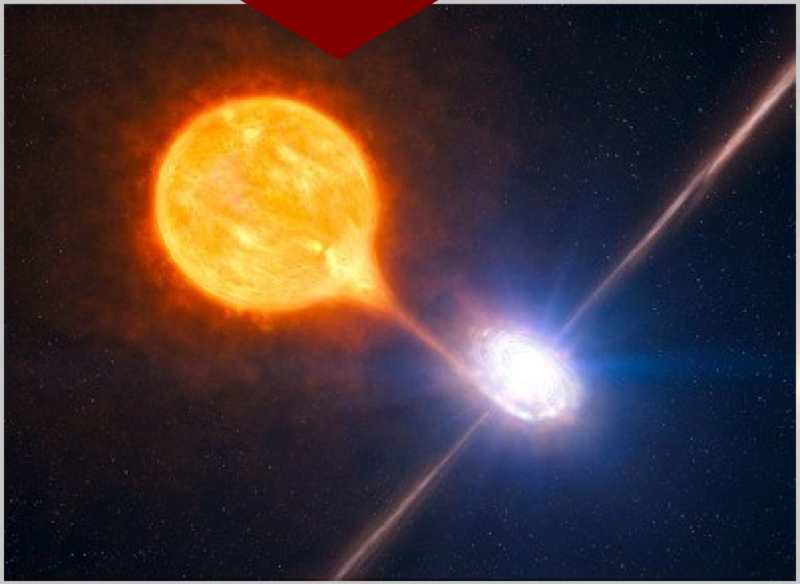

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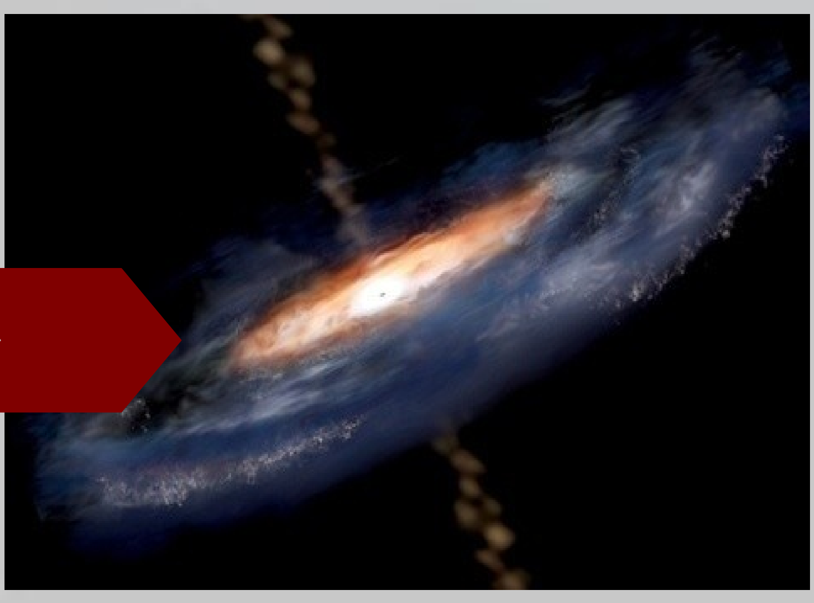

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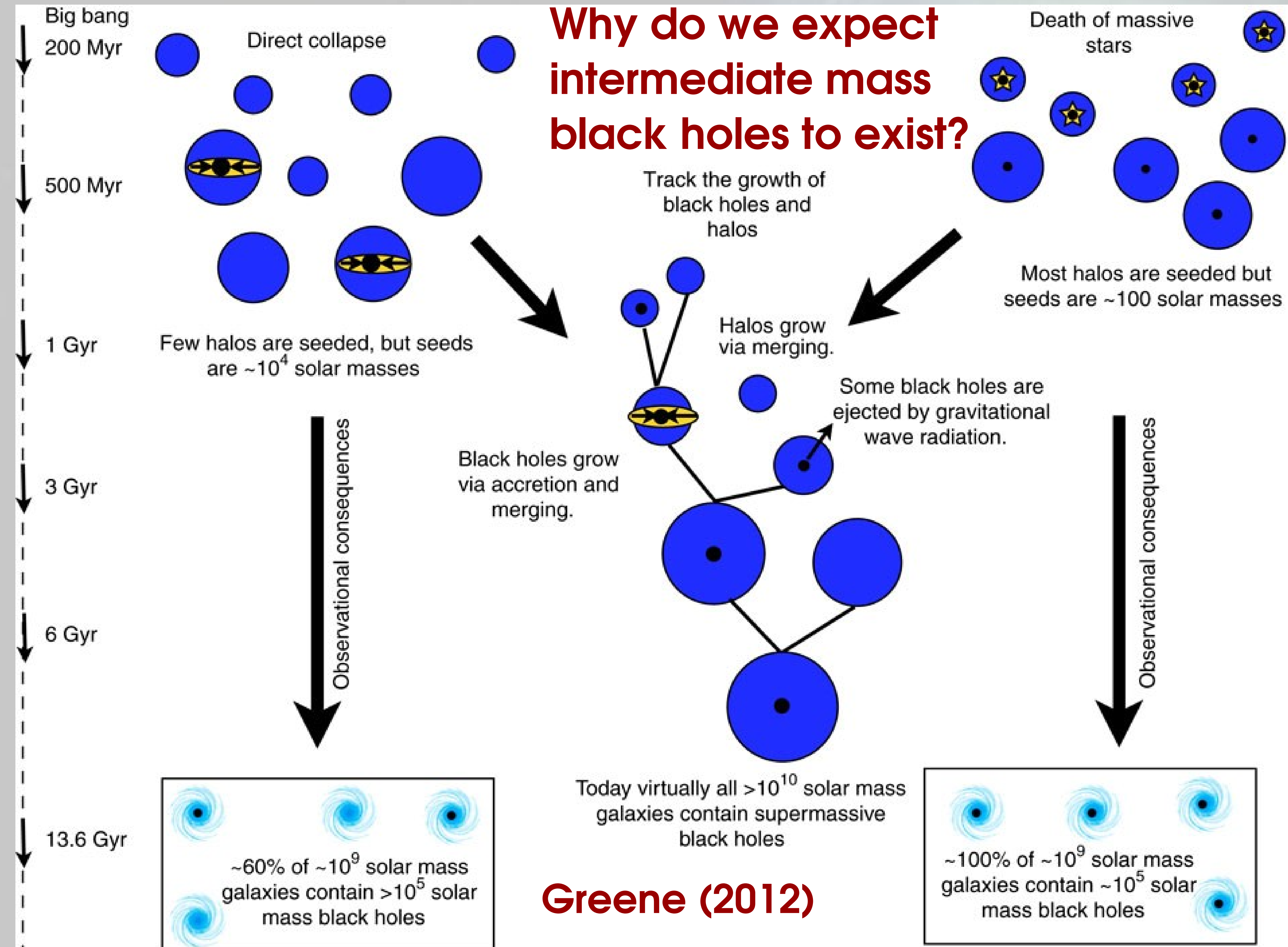
Why do we expect intermediate mass black holes to exist?



Greene (2012)

Scientific rationale

May play a role in the stability of globular clusters
(e.g. Hut et al. 1992)

Could be strong sources of gravitational waves
(e.g. Miller & Colbert 2004)

Dark matter may be detectable around IMBH
(e.g. Fornasa & Bertone 2008)

May have participated in cosmological ionisation
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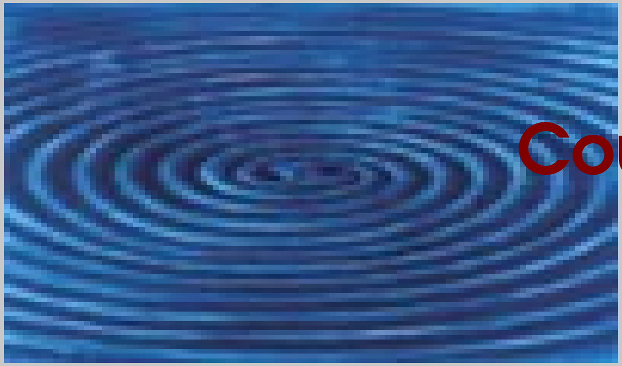

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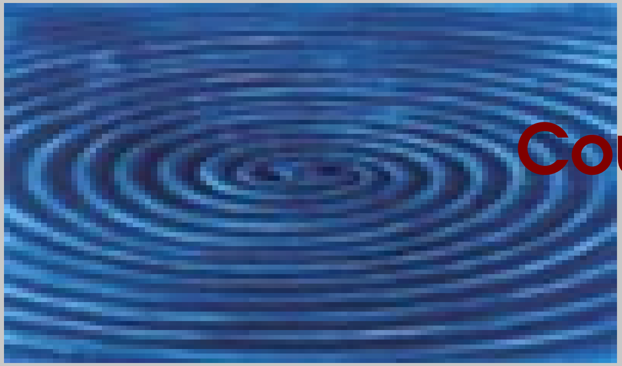

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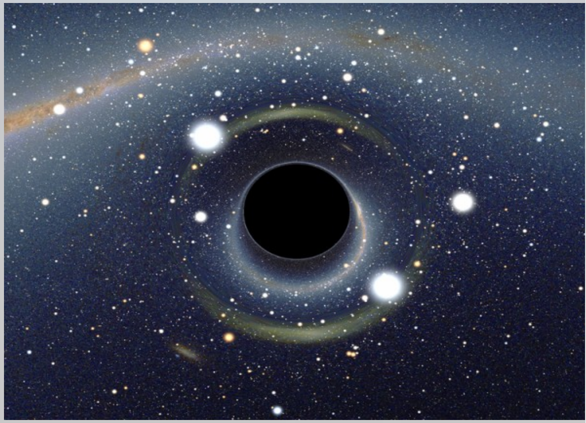

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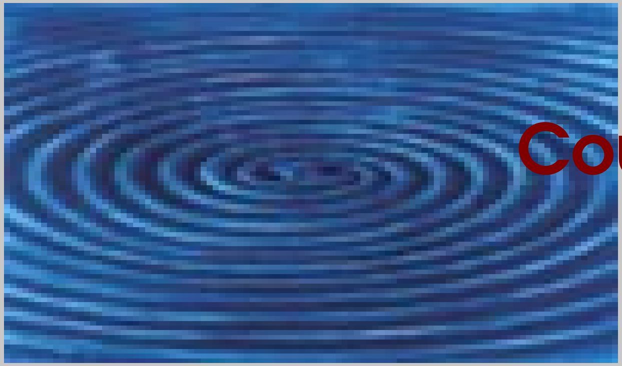

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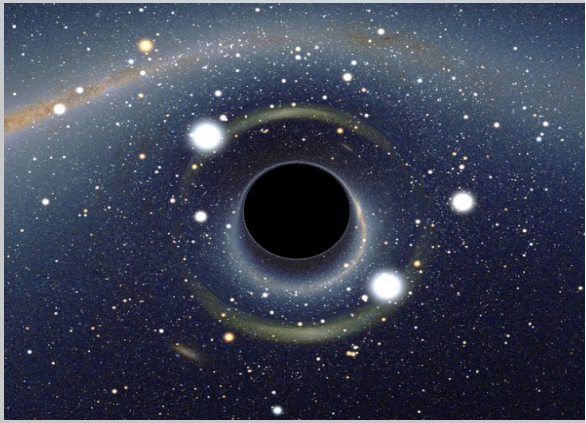

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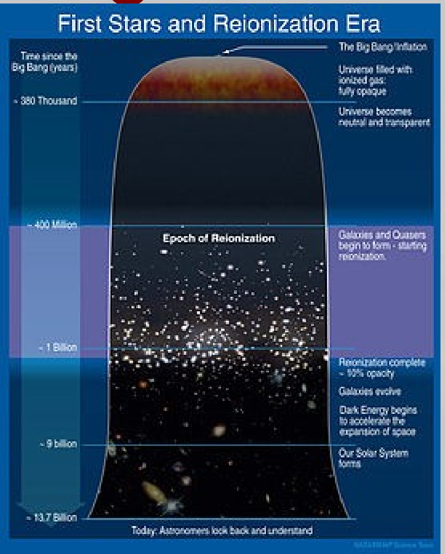

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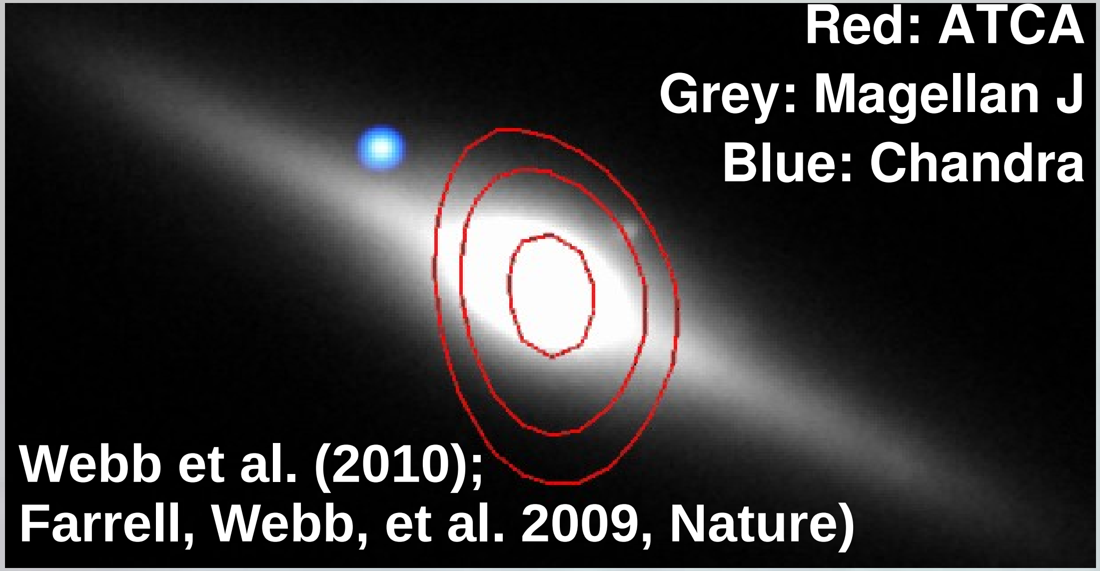
HLX-1

2XMM J011028.1-460421
Spectrum, Γ= 3.4±0.3
~8” from nucleus of ESO 243-49 (z=0.0224, ~95 Mpc)



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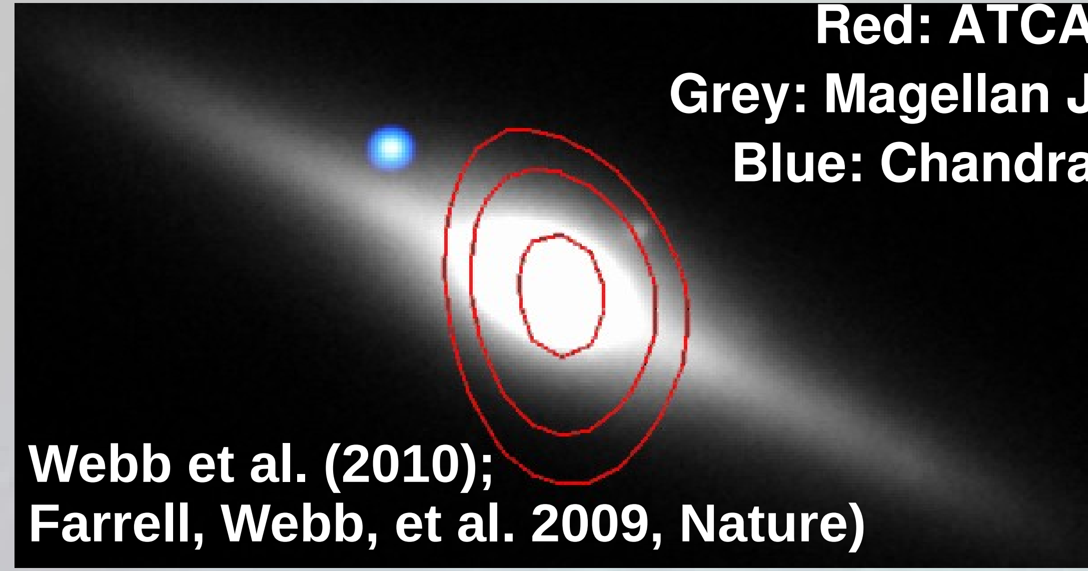
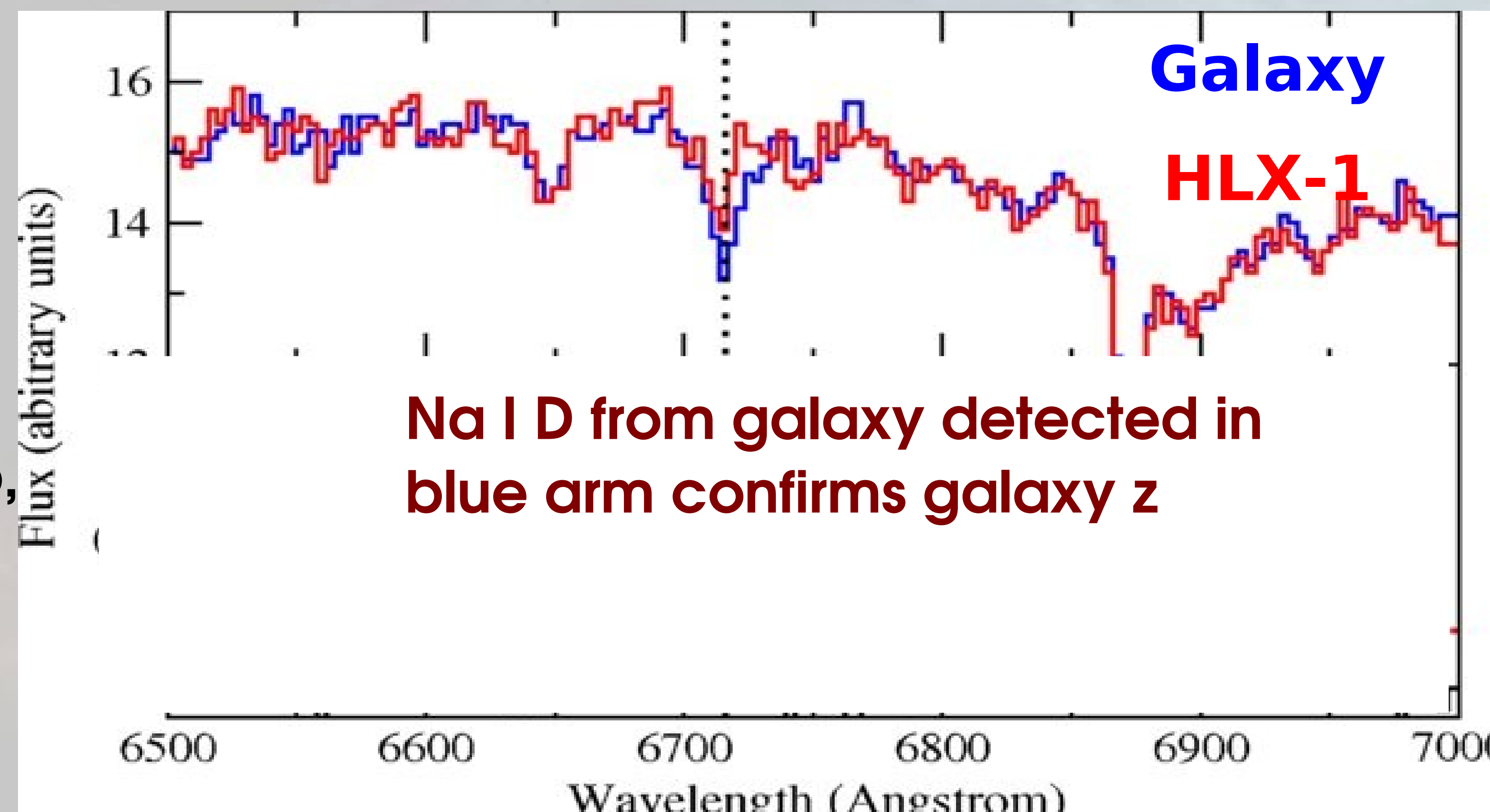


(Wiersema, Farrell, Webb, et al., 2010)



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

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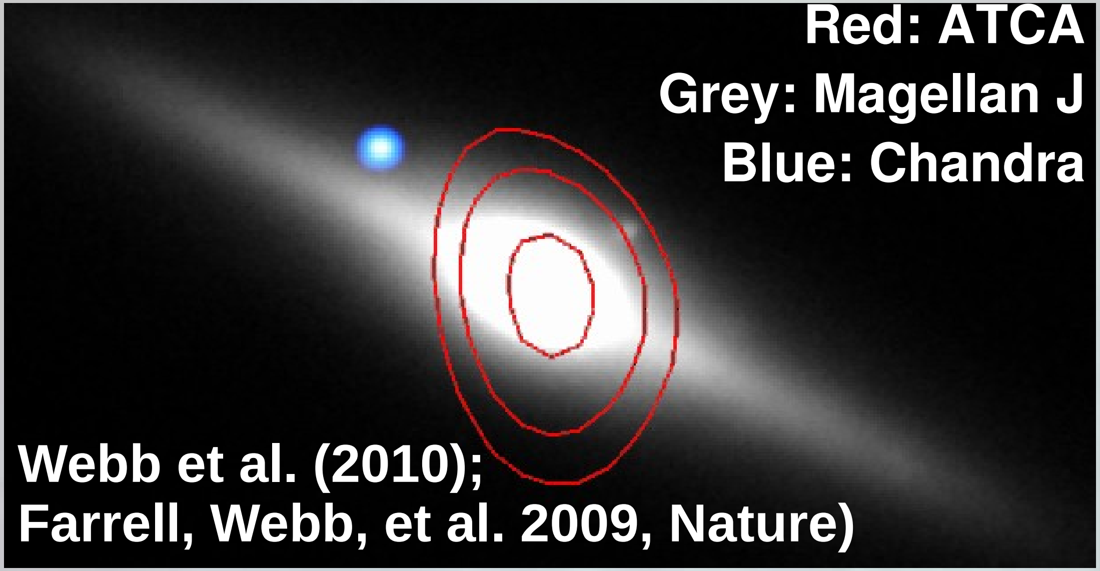

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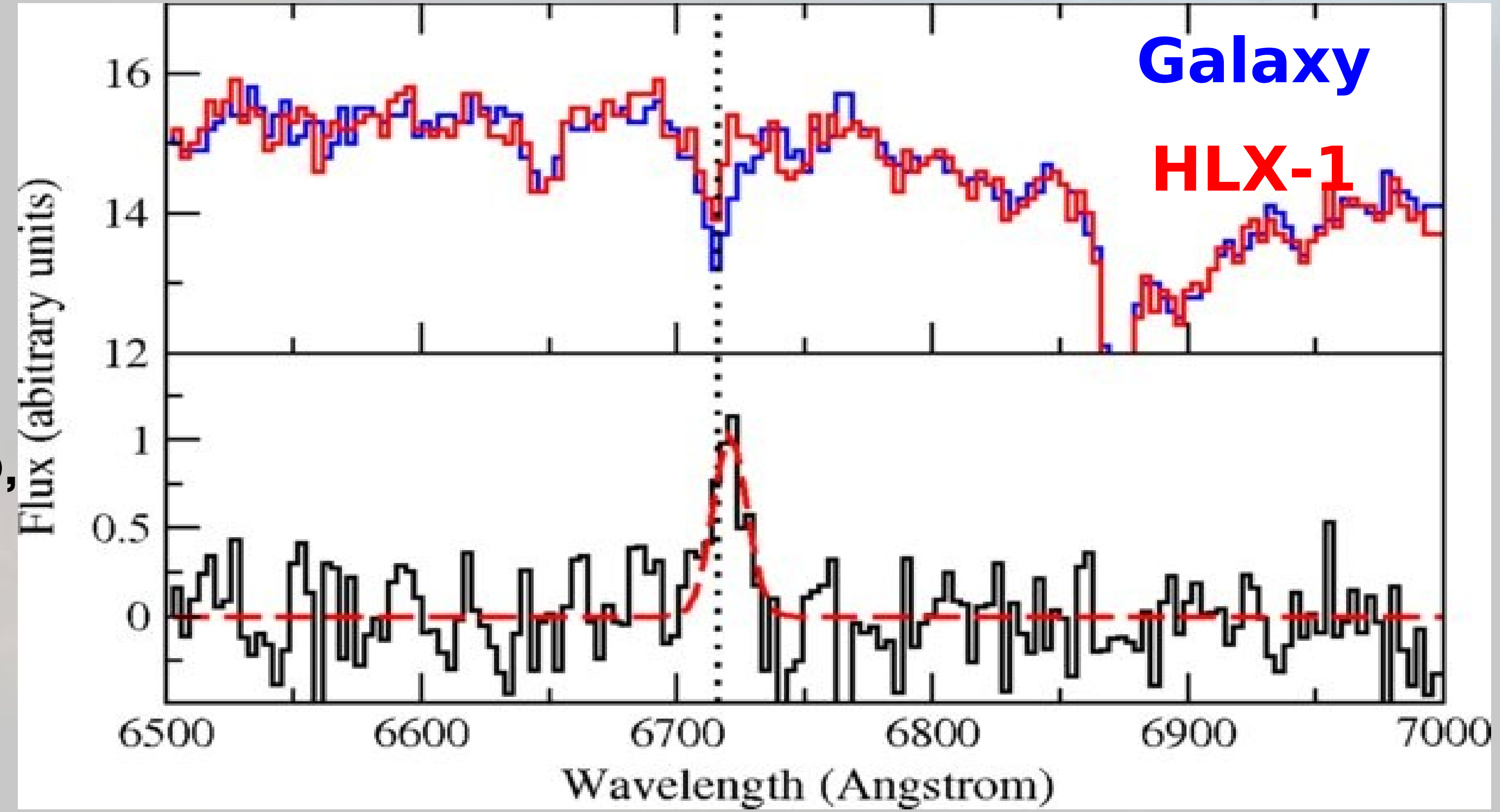

HLX-1 X-ray luminosity

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

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

Superceding L_{Edd} by a factor 10 (Begelman 02) => M > 500 $M_\odot$

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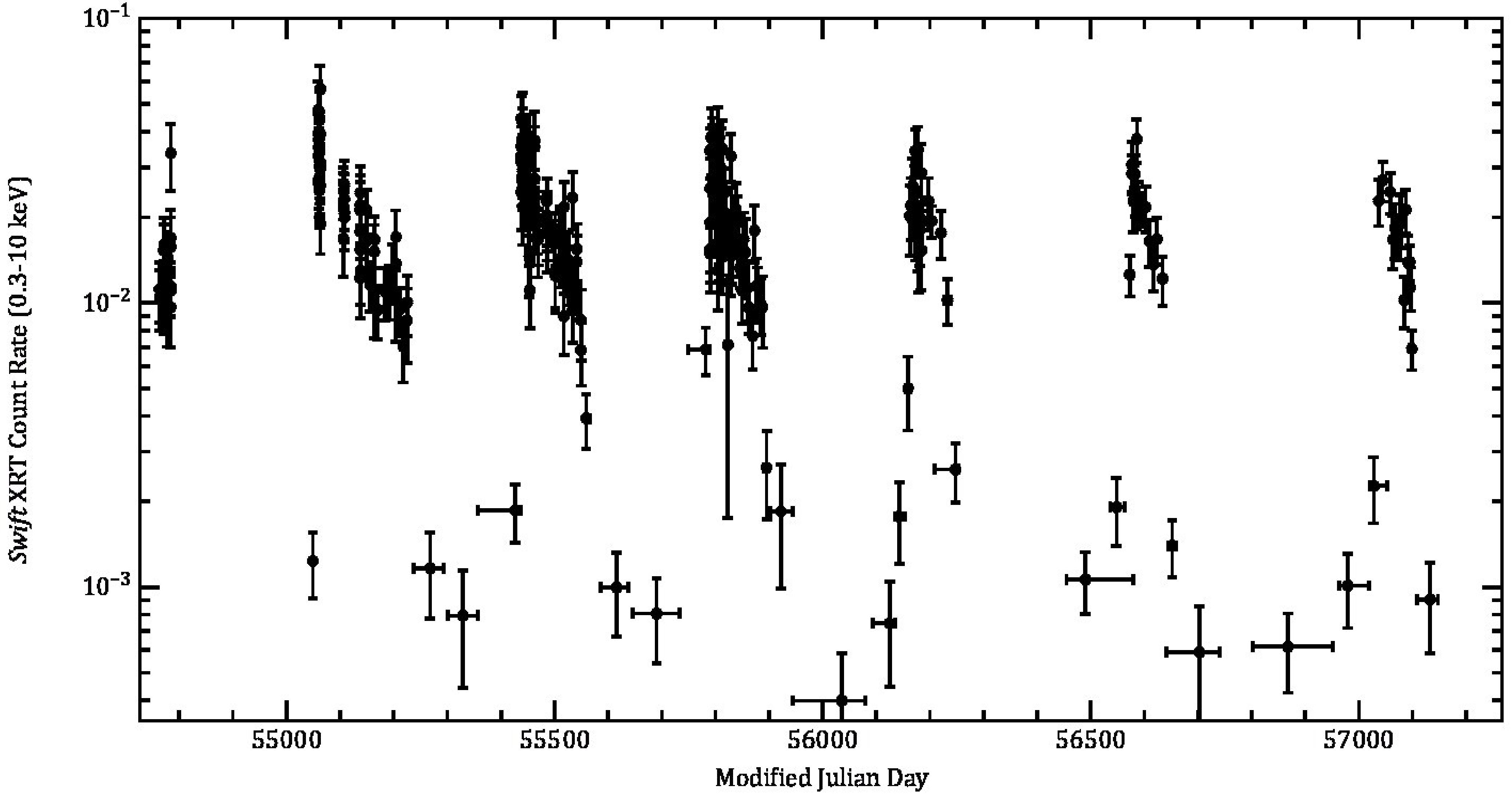
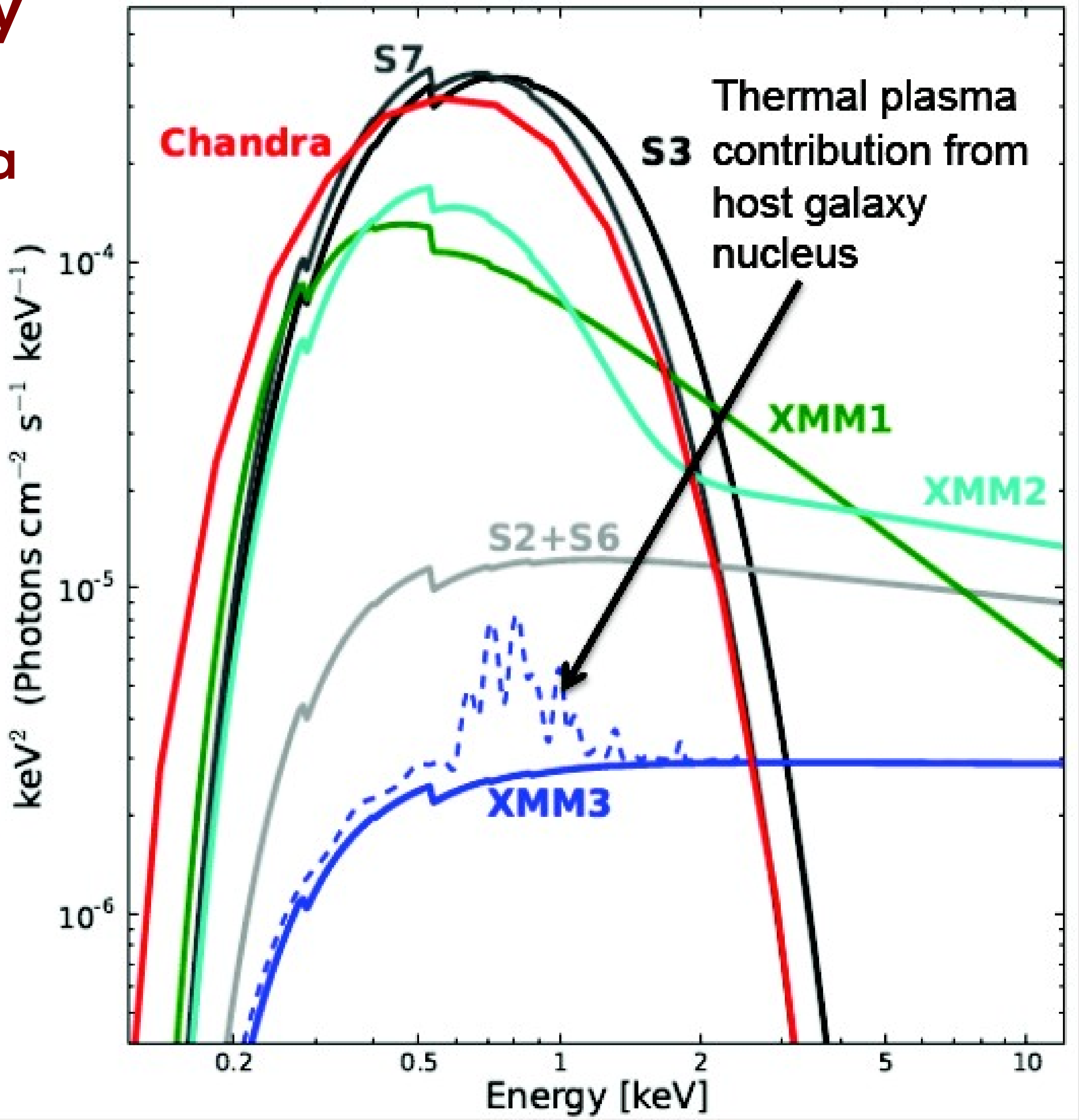


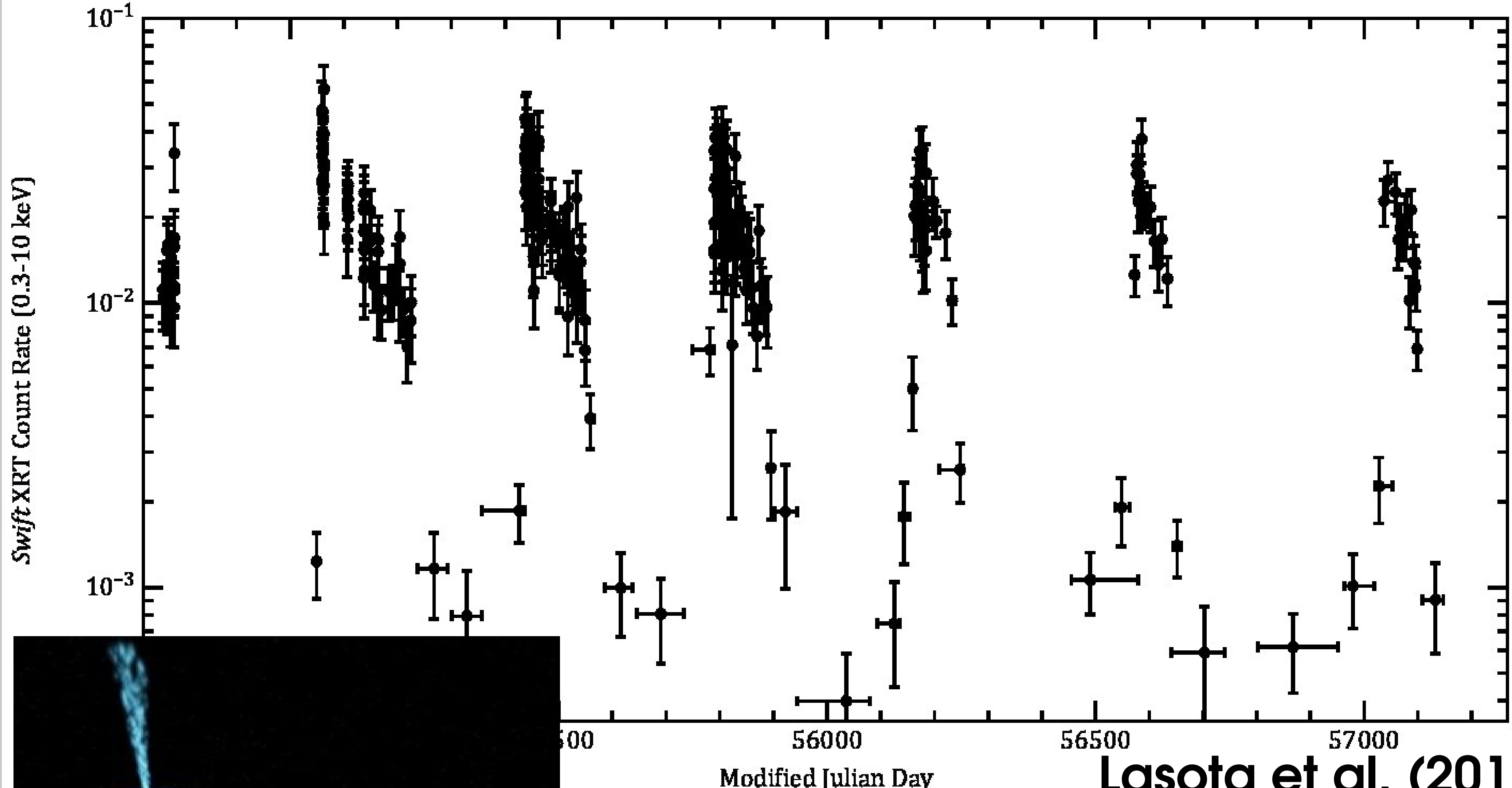
X-ray variability

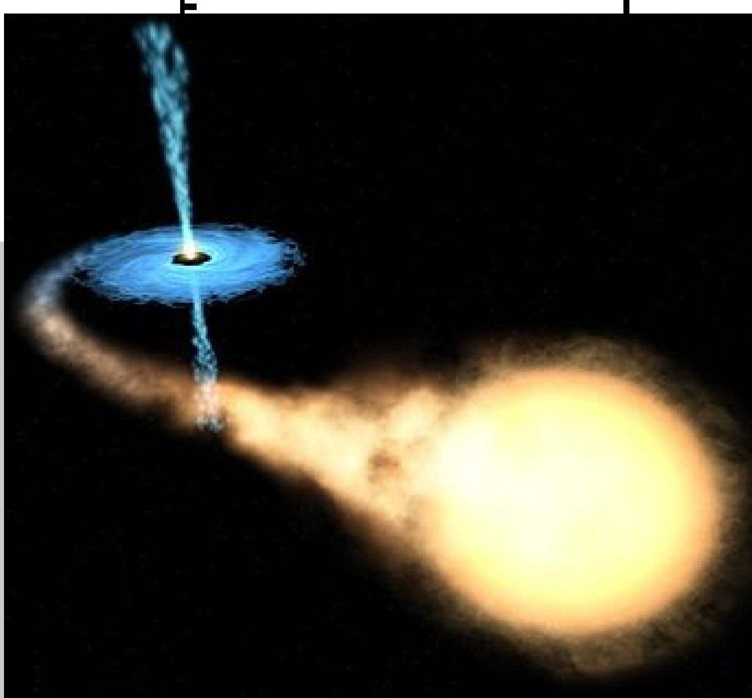
Fitting thermally dominated spectra with relativistic models (BHSPEC, KERRBB, slimbh Kawaguchi, 2003) constrains mass to 10^3 - 10^5 $M_\odot$

Accretion sub/ near Eddington

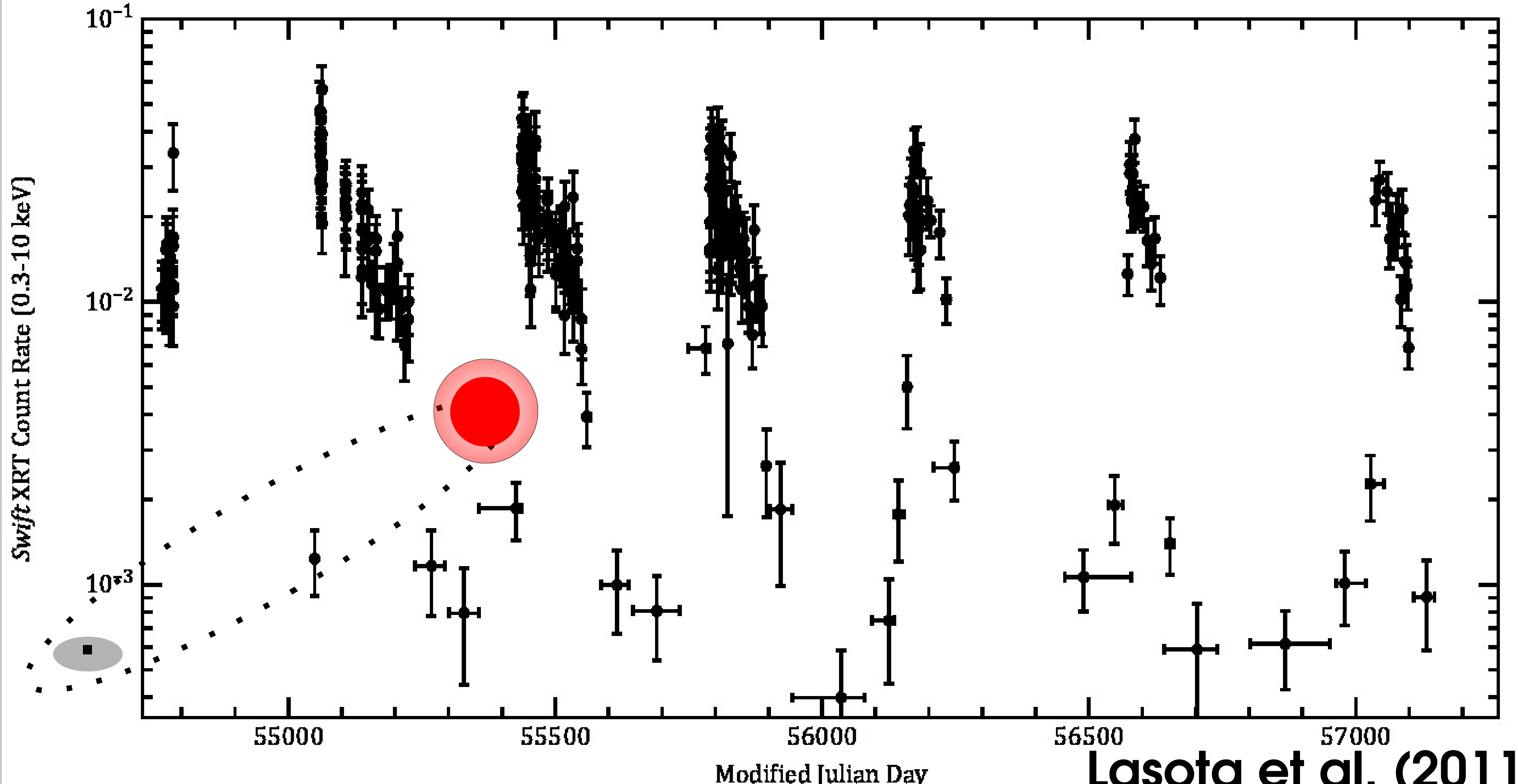
(Godet et al., 2009; Davis et al., 2011; Servillat et al., 2011; Godet et al., 2012; Straub et al. 2014)







Lasota et al. (2011)



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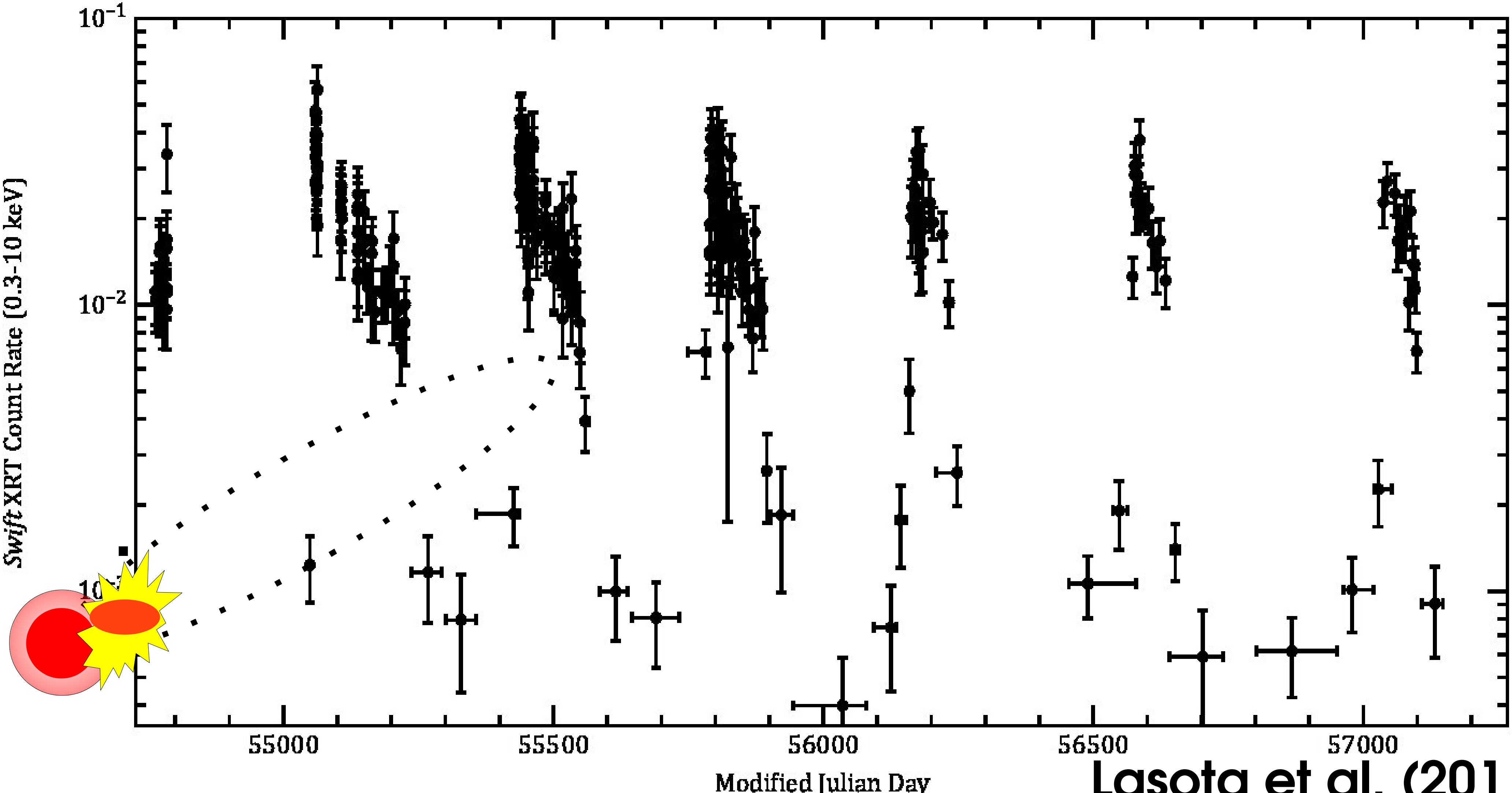

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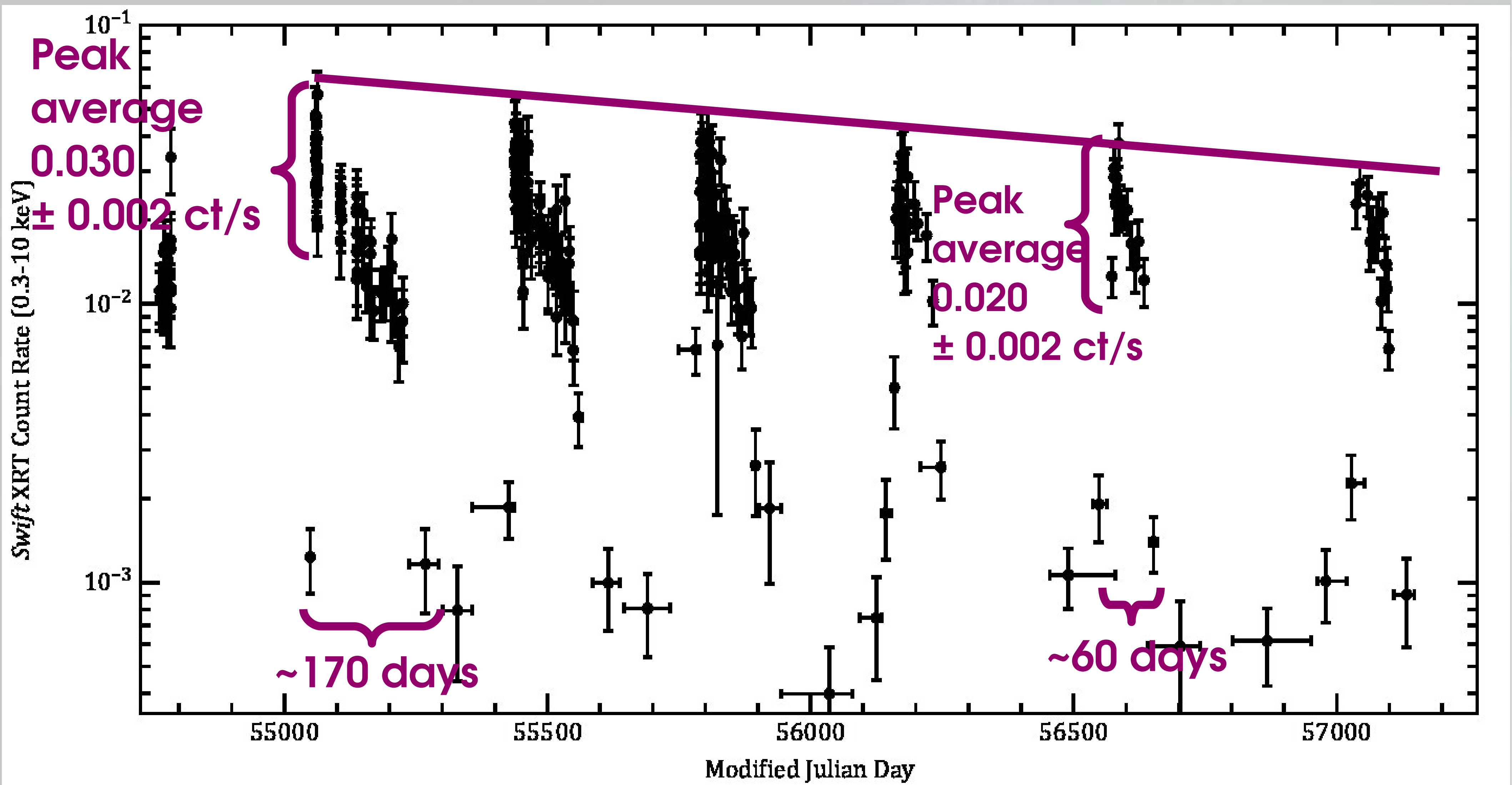
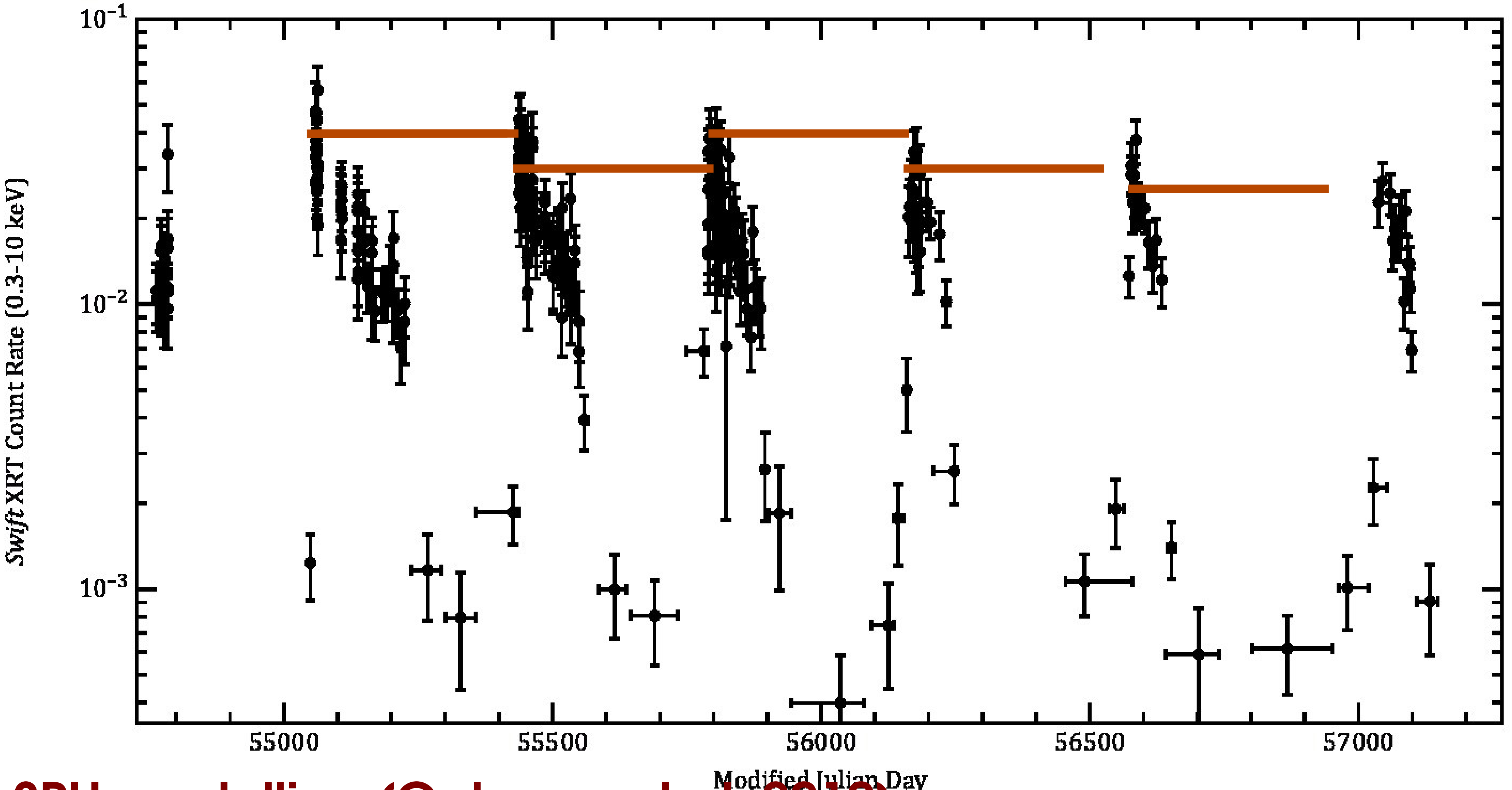


SPH modelling (Gaburov et al. 2010)

1 yr orbit, periastron at 200 $R_\odot$, companion initially 20 $M_\odot$

$Mass_{BH}$ ~ 20000 $M_\odot$, eccentricity ~ 0.9997

(Godet et al. 2014)



SPH modelling (Gaburov et al. 2010)

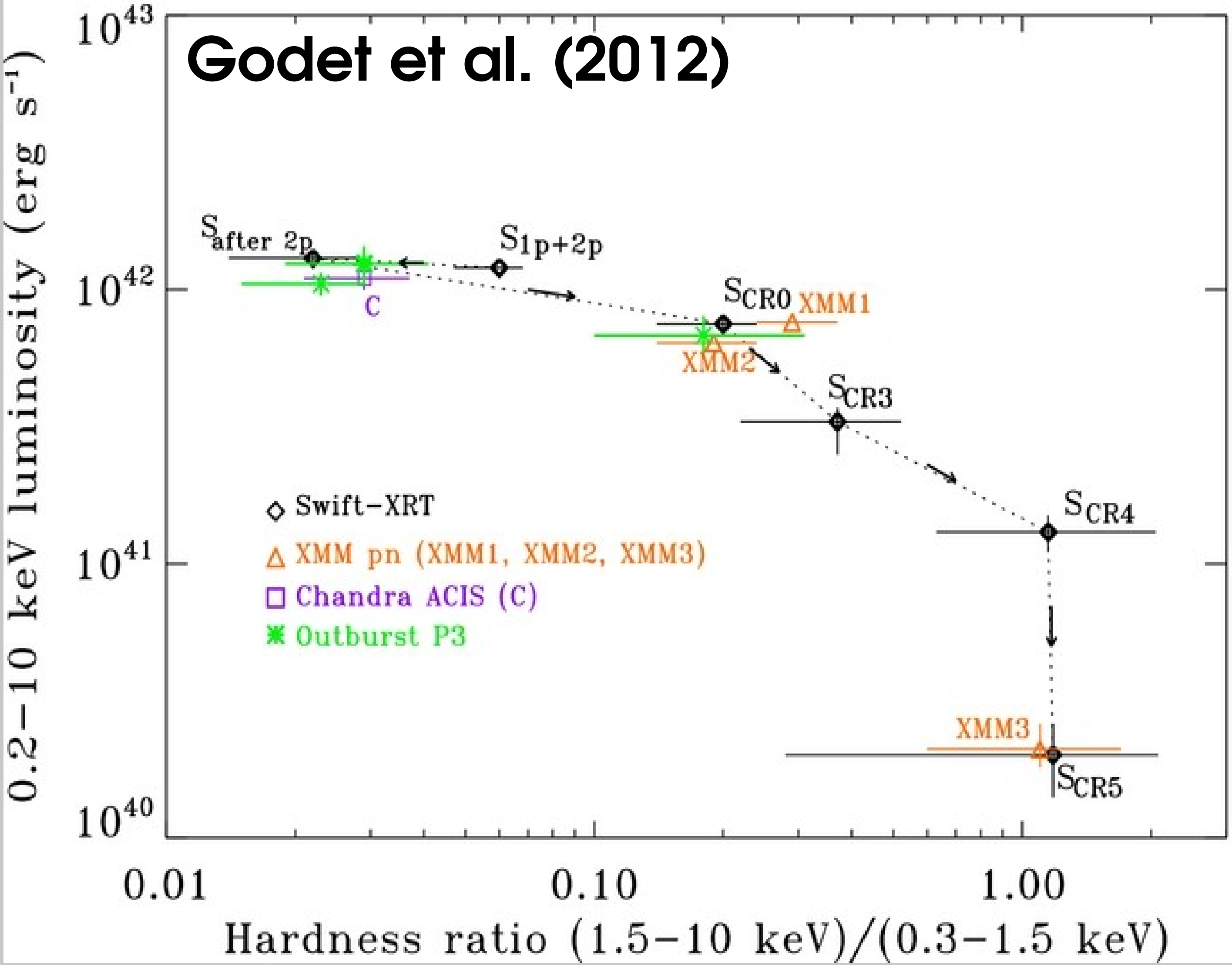
Can a highly eccentric binary form and remain bound?

Results of modelling show it is possible

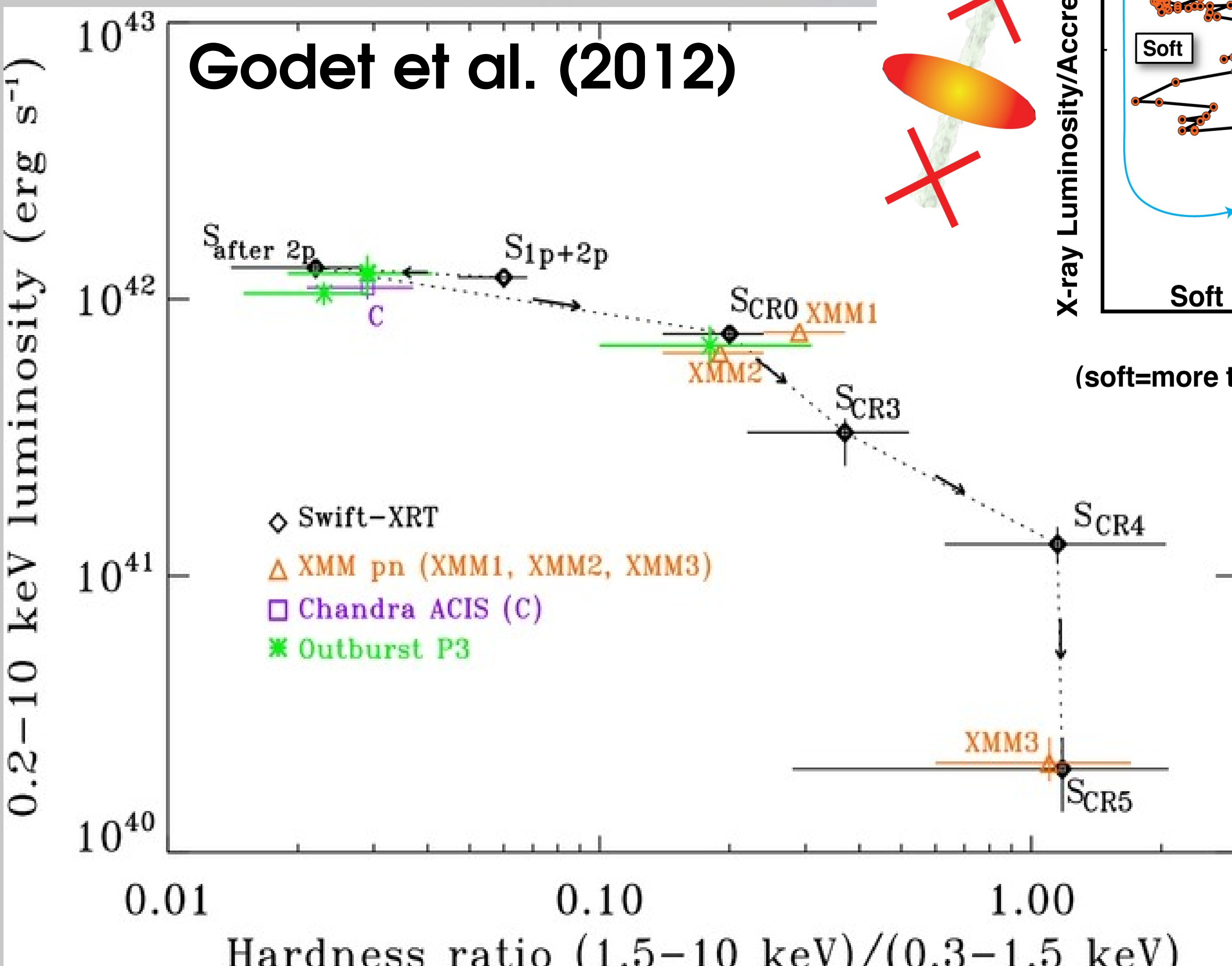
Likely that the donor is something like a white dwarf

But accretion rates are then difficult to understand

(Godet et al., 2014)



Godet et al. (2012)
0.2−10 keV luminosity (erg s⁻¹)
Hardness ratio (1.5−10 keV)/(0.3−1.5 keV)
S after 2p
S 1p+2p
S CR0
XMM1
XMM2
C
S CR3
S CR4
XMM3
S CR5
Swift-XRT
XMM pn (XMM1, XMM2, XMM3)
Chandra ACIS (C)
Outburst P3


Godet et al. (2012)
0.2–10 keV luminosity (erg s^{-1})
10^{43}
10^{42}
10^{41}
10^{40}
0.01
0.10
1.00
Hardness ratio (1.5–10 keV)/(0.3–1.5 keV)
$S_{after\ 2p}$
S_{1p+2p}
C
S_{CR0}
XMM1
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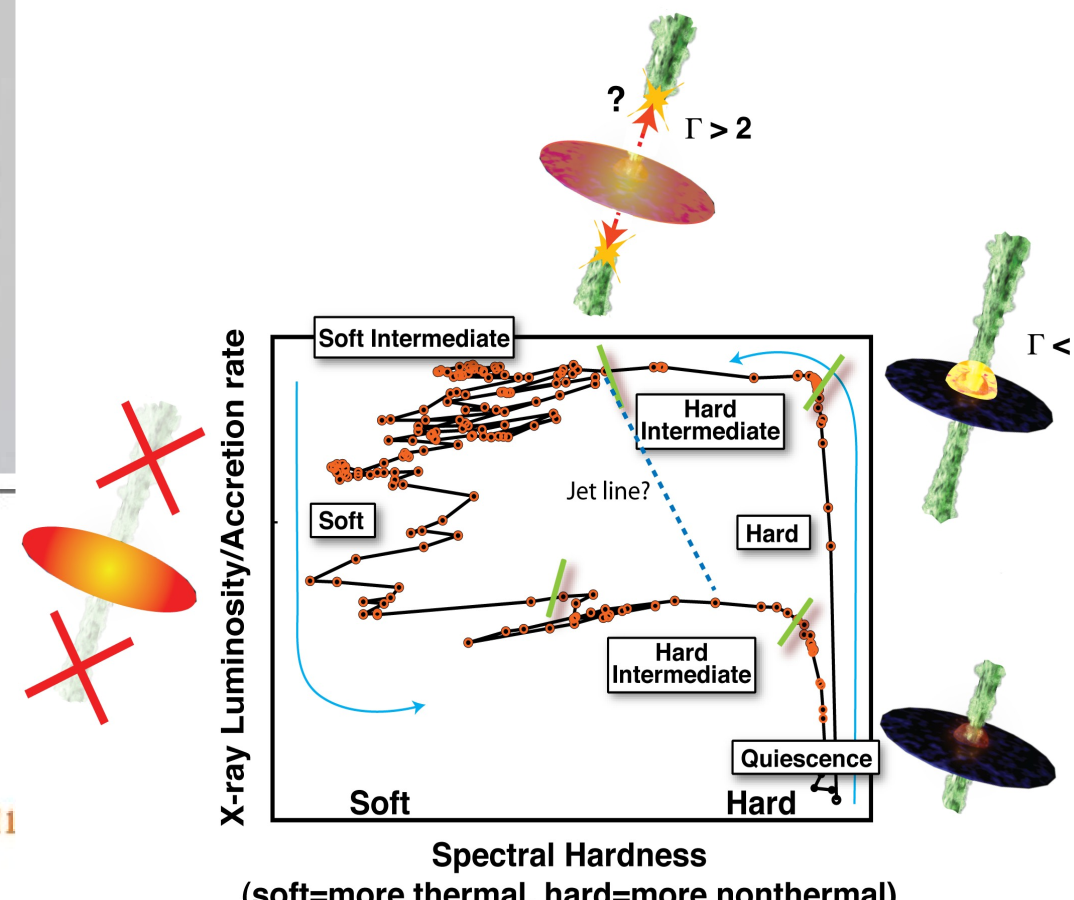
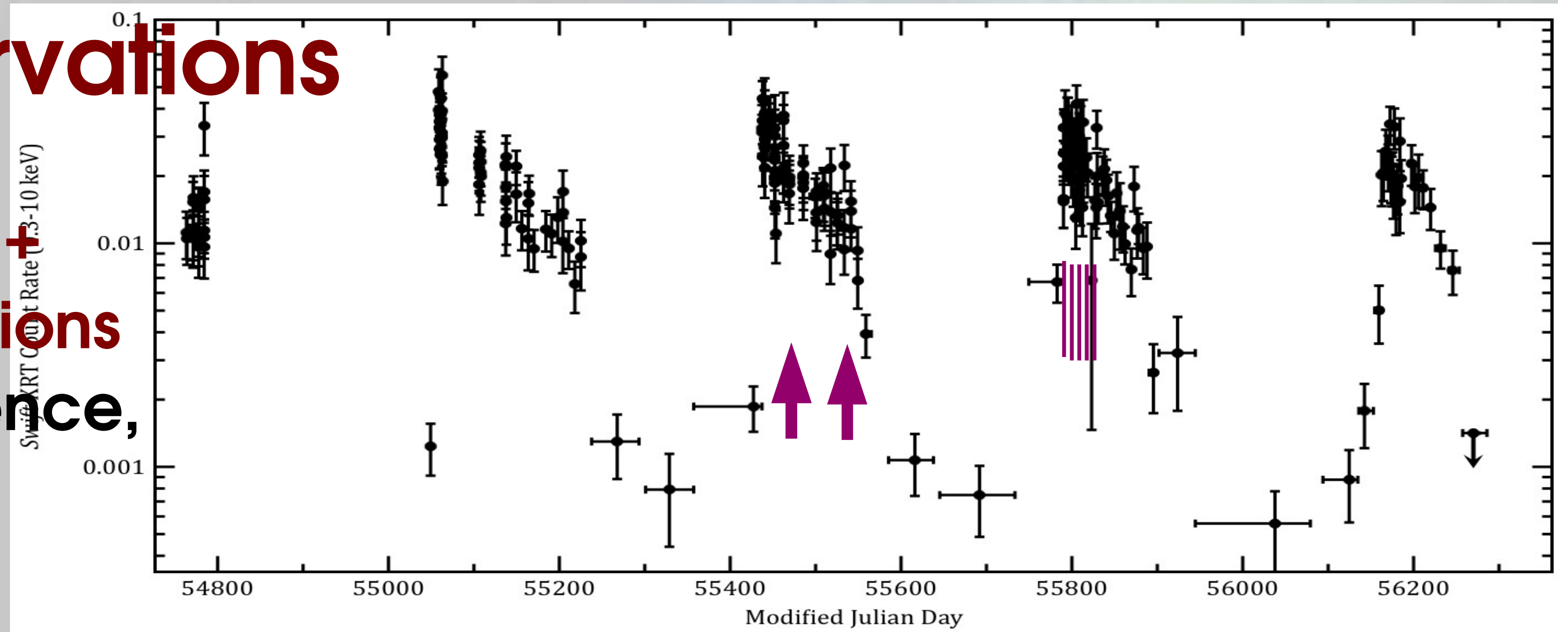

?
Γ > 2
Γ < 2
Soft Intermediate
Hard Intermediate
Soft
Jet line?
Hard
Hard Intermediate
Quiescence
Soft
Hard
X-ray Luminosity/Accretion rate
Spectral Hardness
(soft=more thermal, hard=more nonthermal)

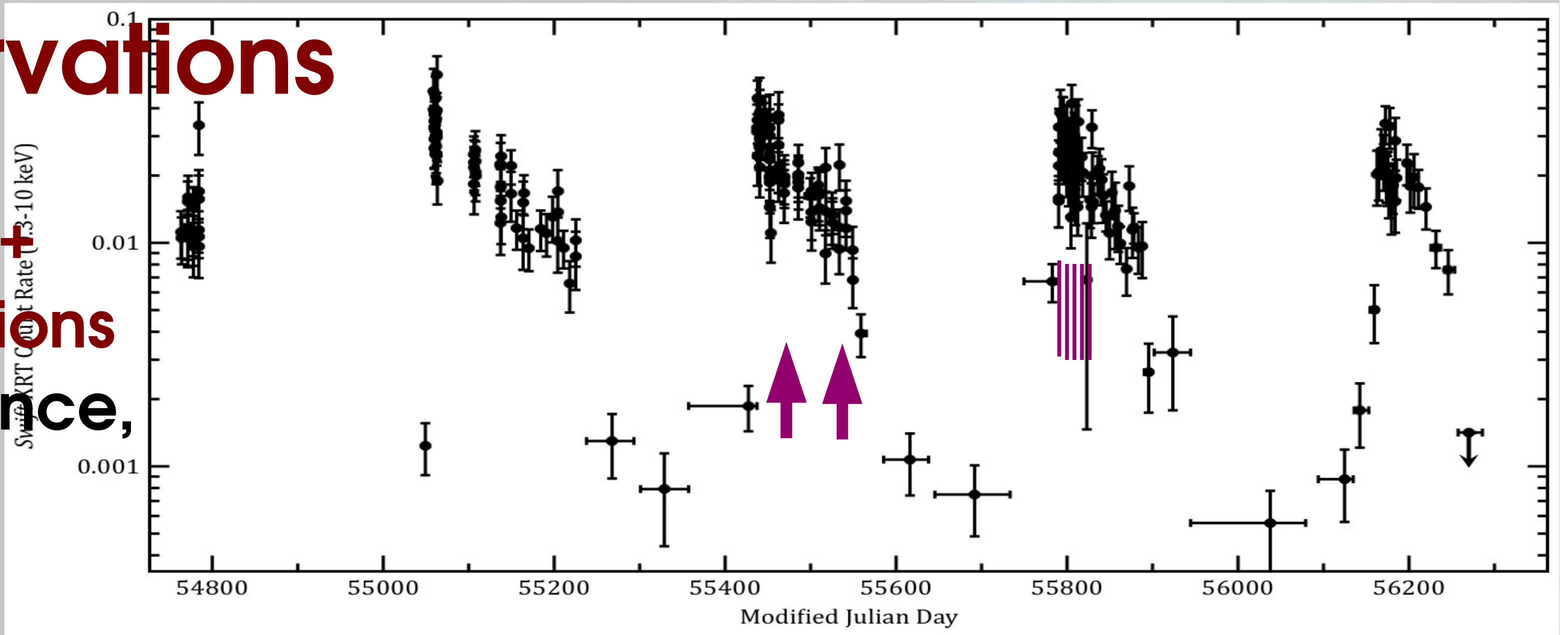
Radio observations

7 x 12 hrs ATCA 5 + 9 GHz observations

(Webb et al., Science, 2012)



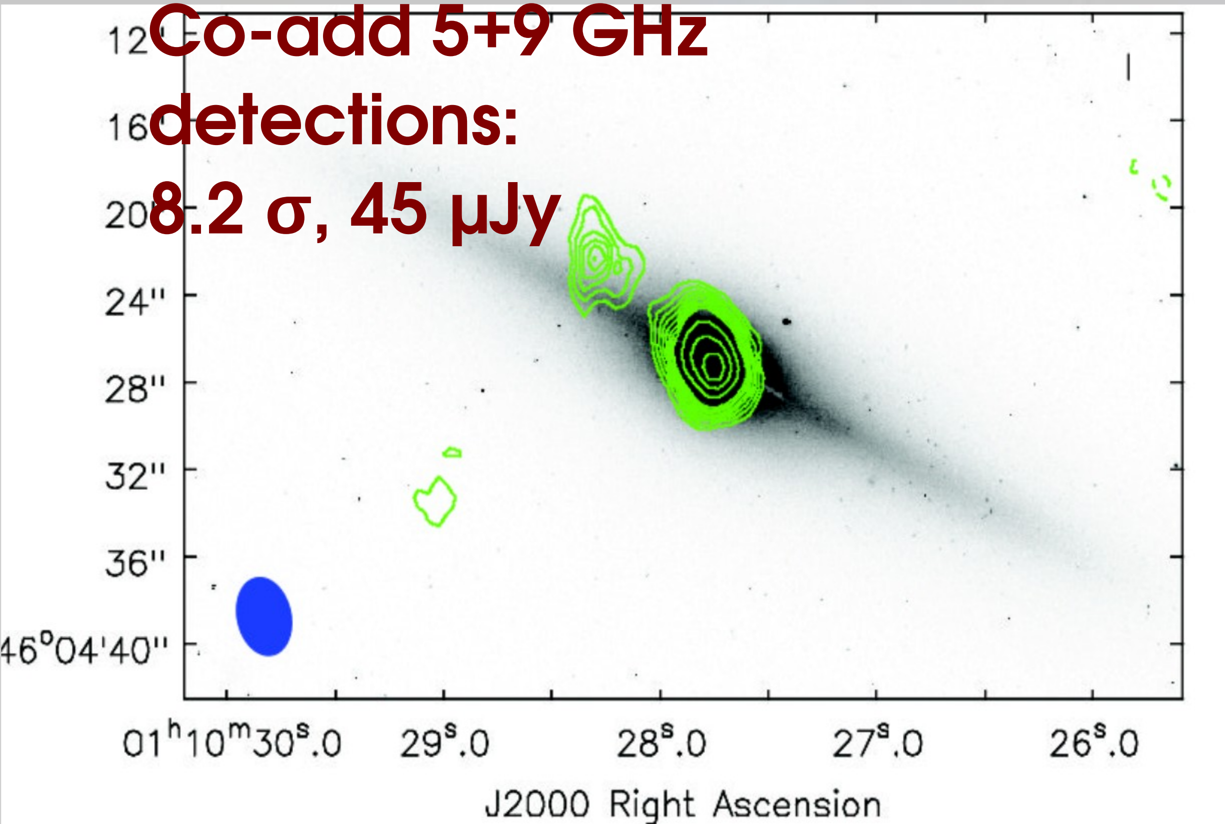
Radio observations



7 x 12 hrs ATCA 5 + 9 GHz observations

(Webb et al., Science, 2012)

Co-add 5+9 GHz detections: 8.2 σ, 45 μJy



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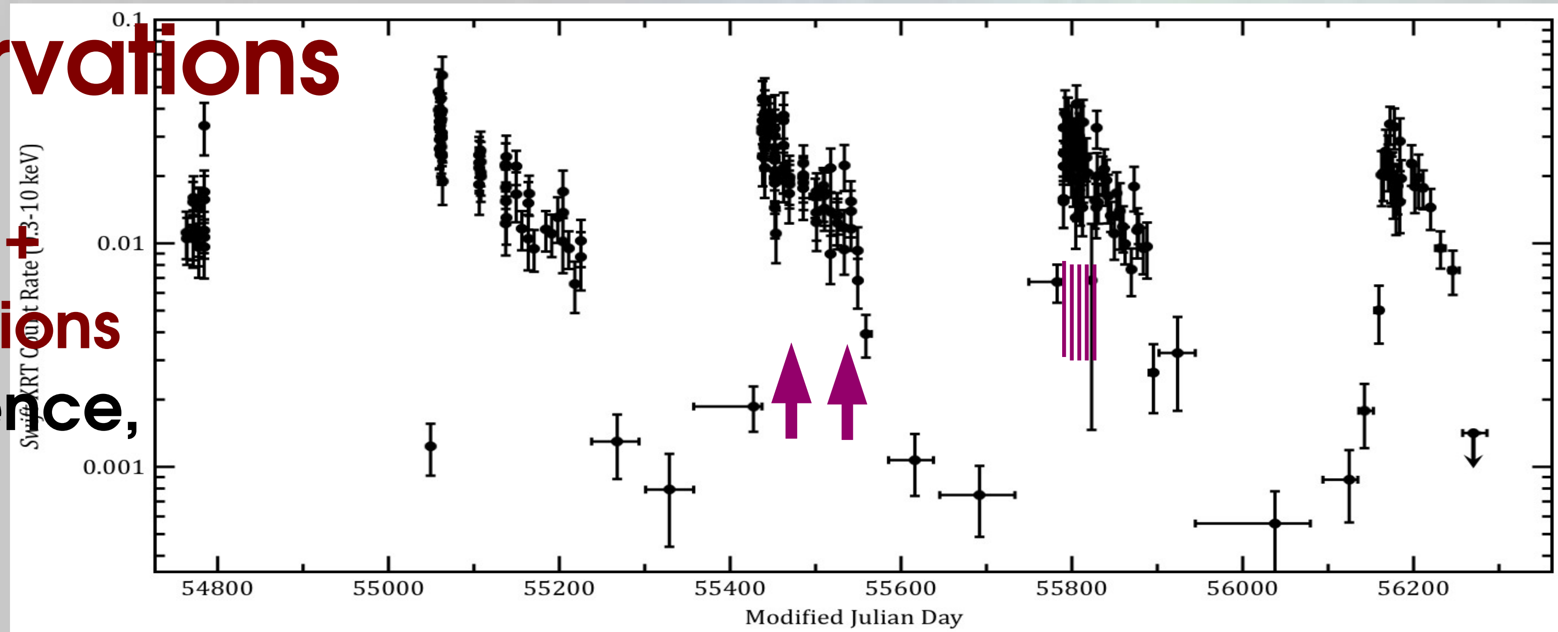

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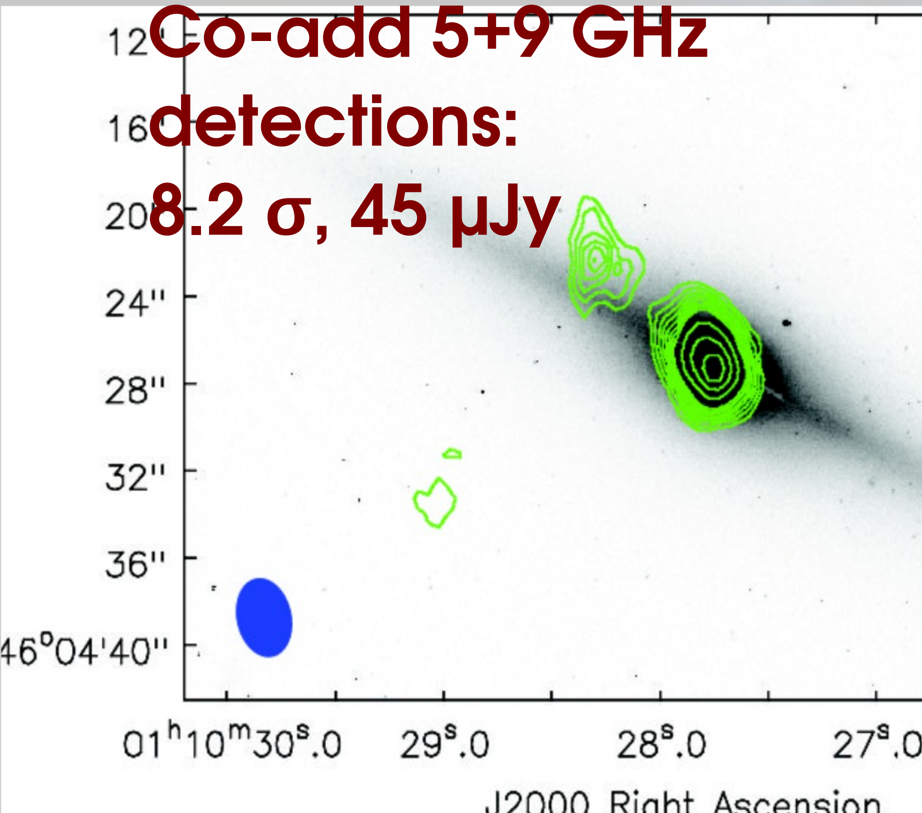
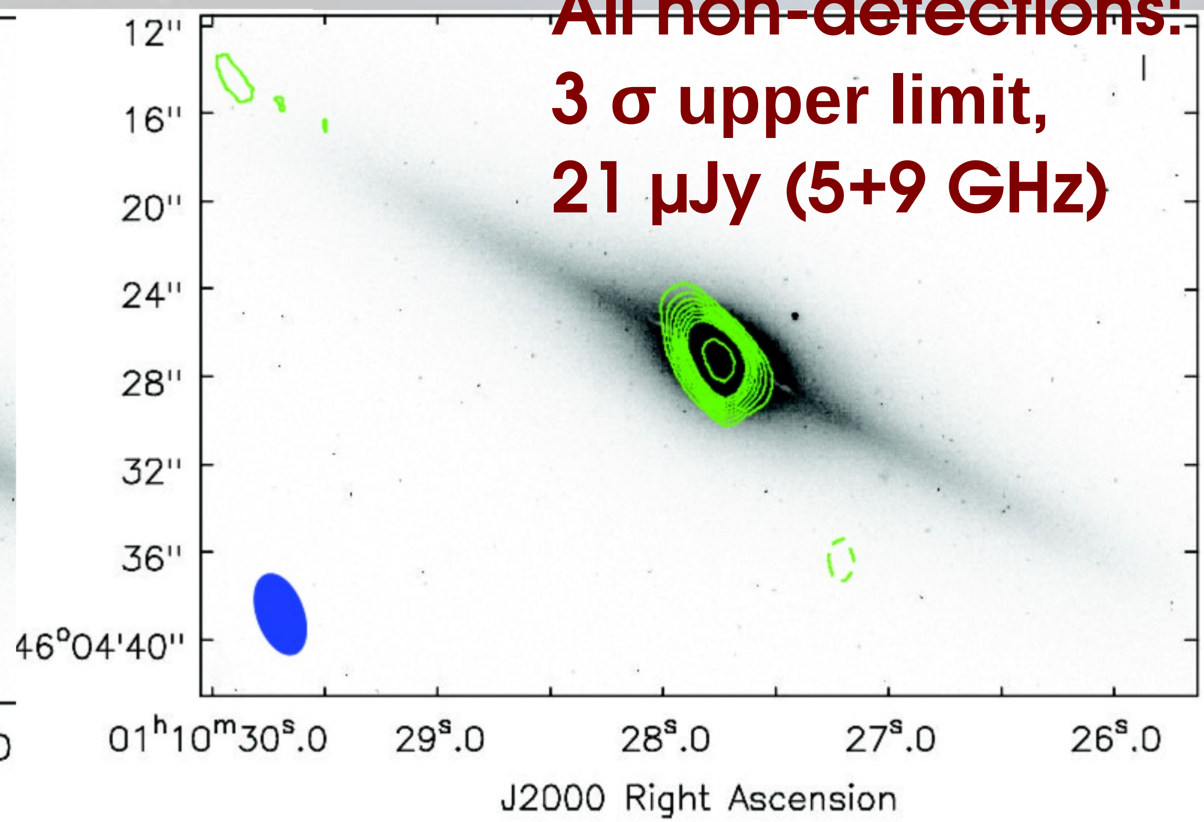


All non-detections:
3 σ upper limit,
21 μJy (5+9 GHz)



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)

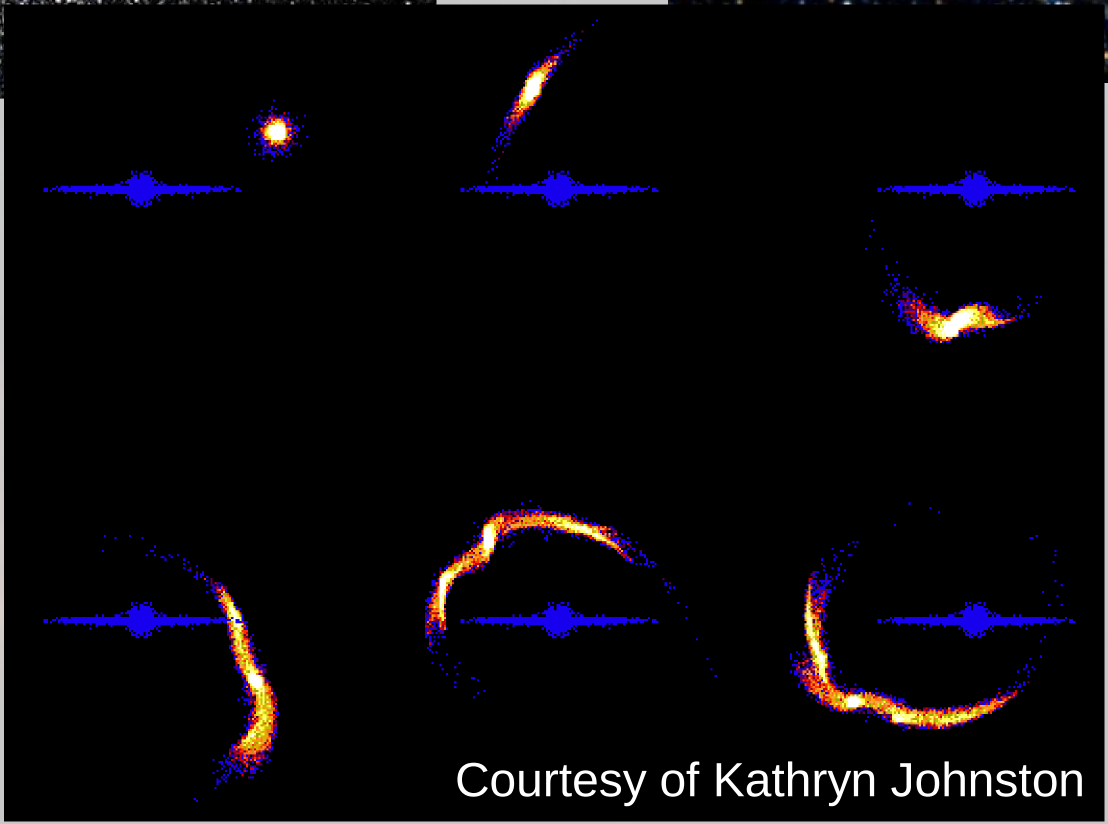
- HLX-1 shows similar behaviour to Galactic black hole binaries

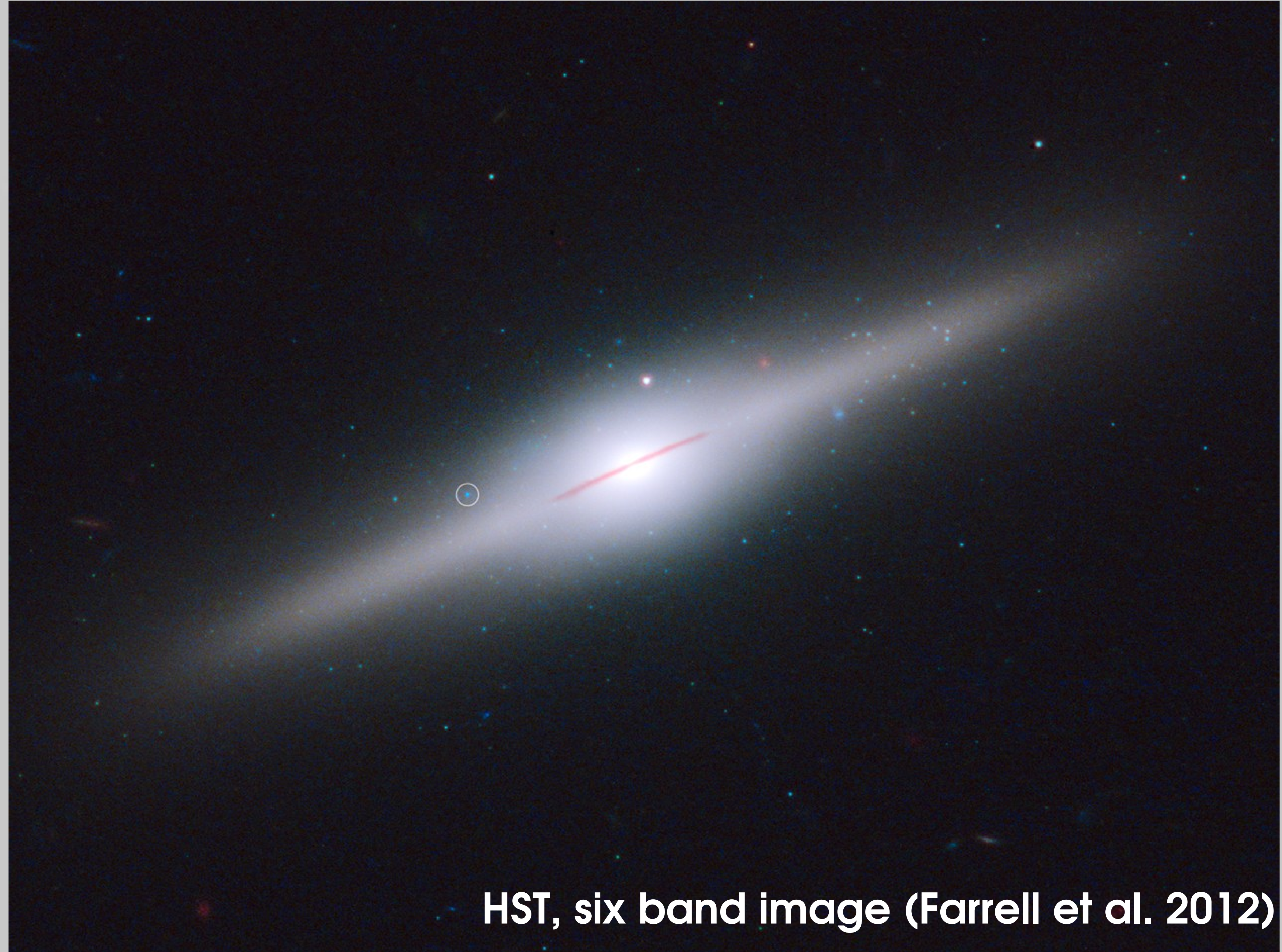
- Assume HLX-1 radio flares occur at 10-100% Eddington

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

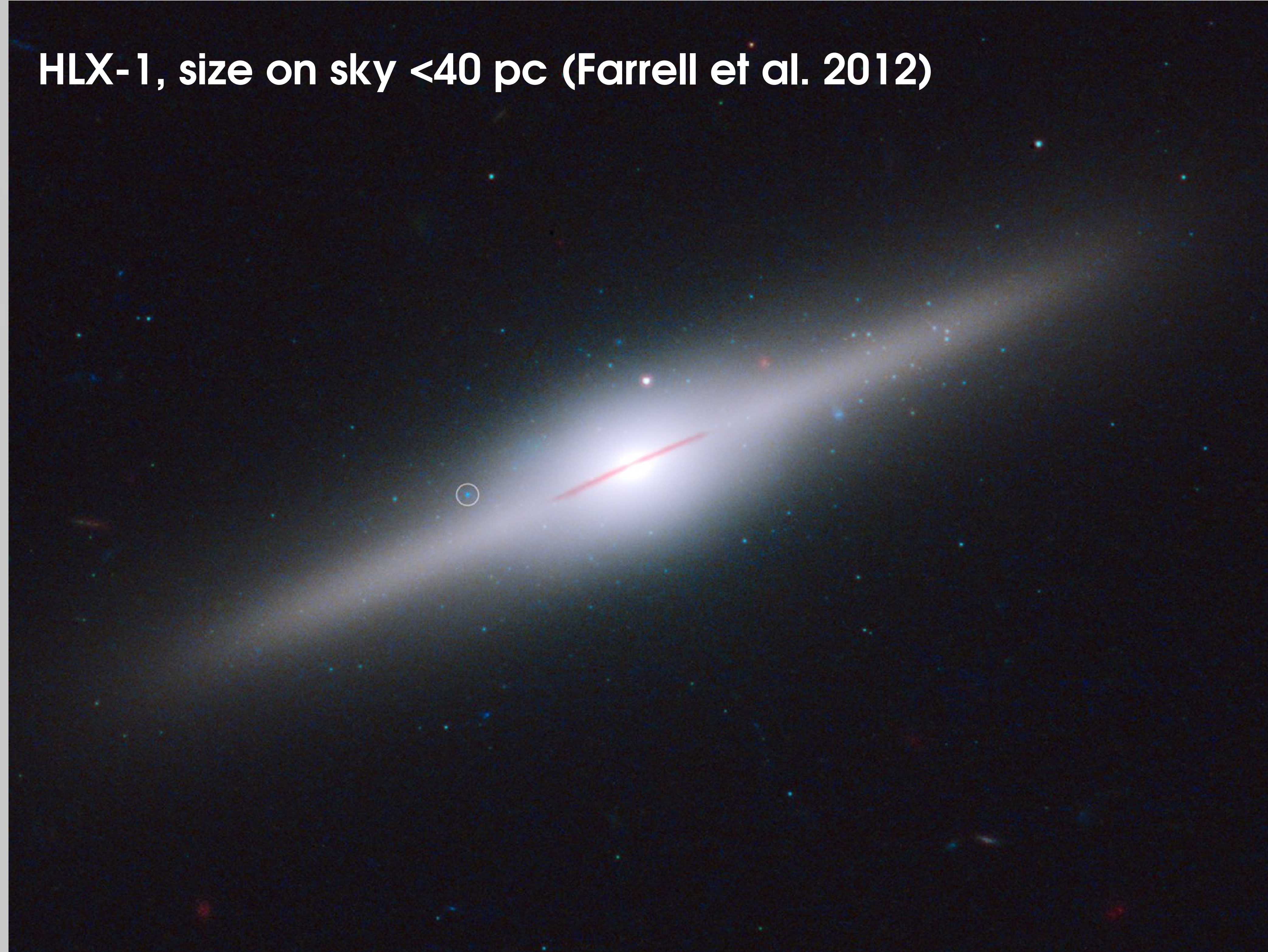
Webb et al (Science, 2012)

Where do intermediate mass black holes form and evolve?

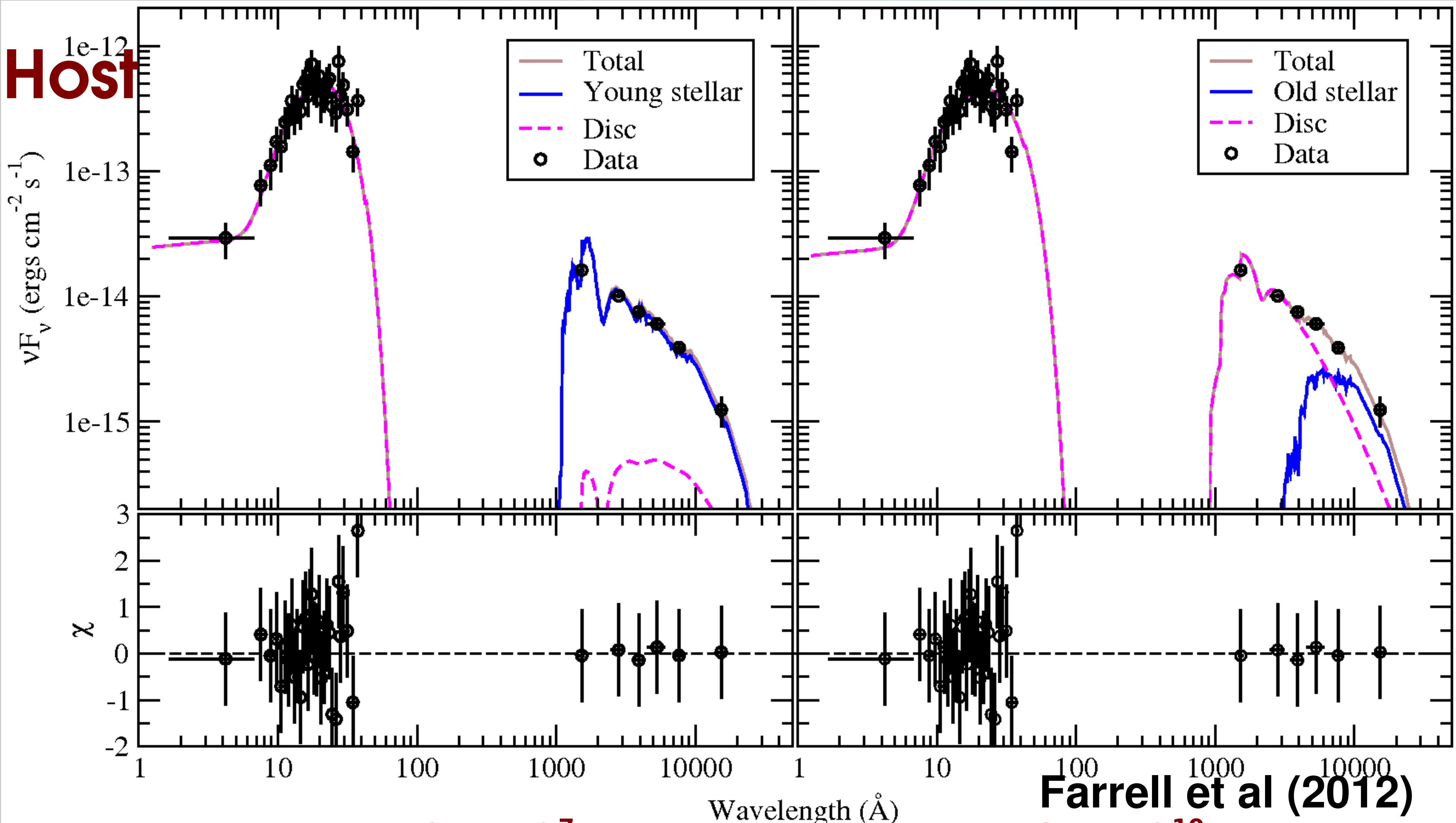




HST, six band image (Farrell et al. 2012)


HLX-1, size on sky <40 pc (Farrell et al. 2012)

Host



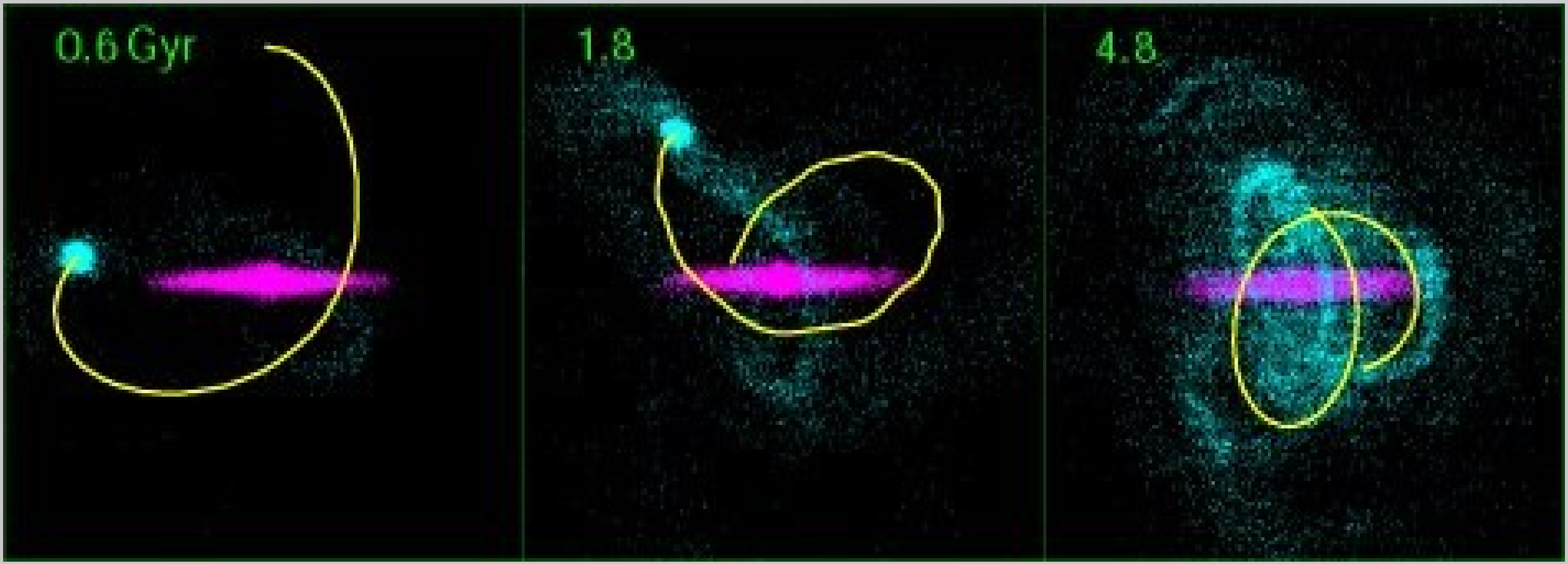
Farrell et al (2012)

Age:	**<1.3 x 10^{7} years**	**1.3 x 10^{10} years**
Mass:	**4 x 10^{6} $M_{\odot}$**	**6 x 10^{6} $M_{\odot}$**
Disc irradiation:	**8 x 10^{-7}**	**0.098**
X^{2} (d.o.f.):	**23.38 (27)**	**24.28 (27)**

$10^6 M_\odot$ too small to form $10^4 M_\odot$ black hole (e.g. Mappelli et al. 2012)

May be a stripped dwarf galaxy (Webb et al. 2010

But little HI gas in ESO 243-49, $M < 10^8 M_\odot$ (Musaeva et al. 2015)
=> dwarf galaxy would have been (at best) gas poor



Conclusions

ULX nature diverse. Compact objects can be massive stellar mass black holes, accreting neutron stars or intermediate mass black holes!

Evidence for continuous accretion up to 100x the Eddington limit

First good intermediate mass black hole discovered (HLX-1) for which there is a plethora of data to study origin & evolution