SVOM White paper :

Other extra-galactic objects : Ultra Luminous X-ray sources (ULXs) and Tidal Disruption Events (TDEs)

F. Grisé (Strasbourg Obs.)

on behalf of N. Webb (IRAP), H. Feng (Tsinghua Univ.)
X.-L. Zhou (NAOC, CAS)

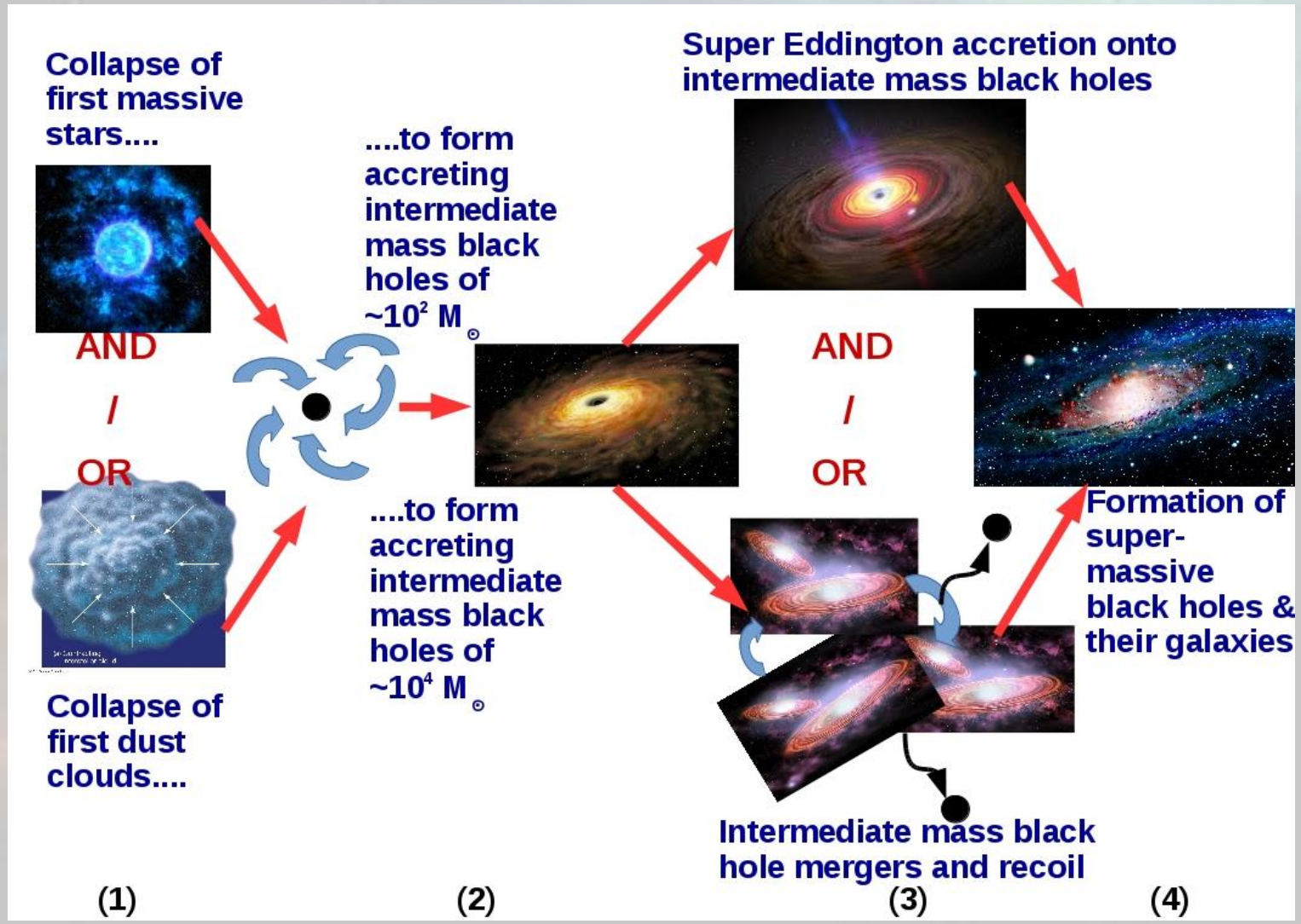
Scientific justification

How do the supermassive black holes form and evolve?

i.e. $M_{BH} \sim 2 \times 10^9 M_\odot$ @ z~7 (Mortlock et al. 2011)

- require **intermediate mass black holes** (IMBH, $10^{2-5} M_\odot$) and **super-Eddington Accretion**

But do IMBH exist and what physics describes super-Eddington accretion?



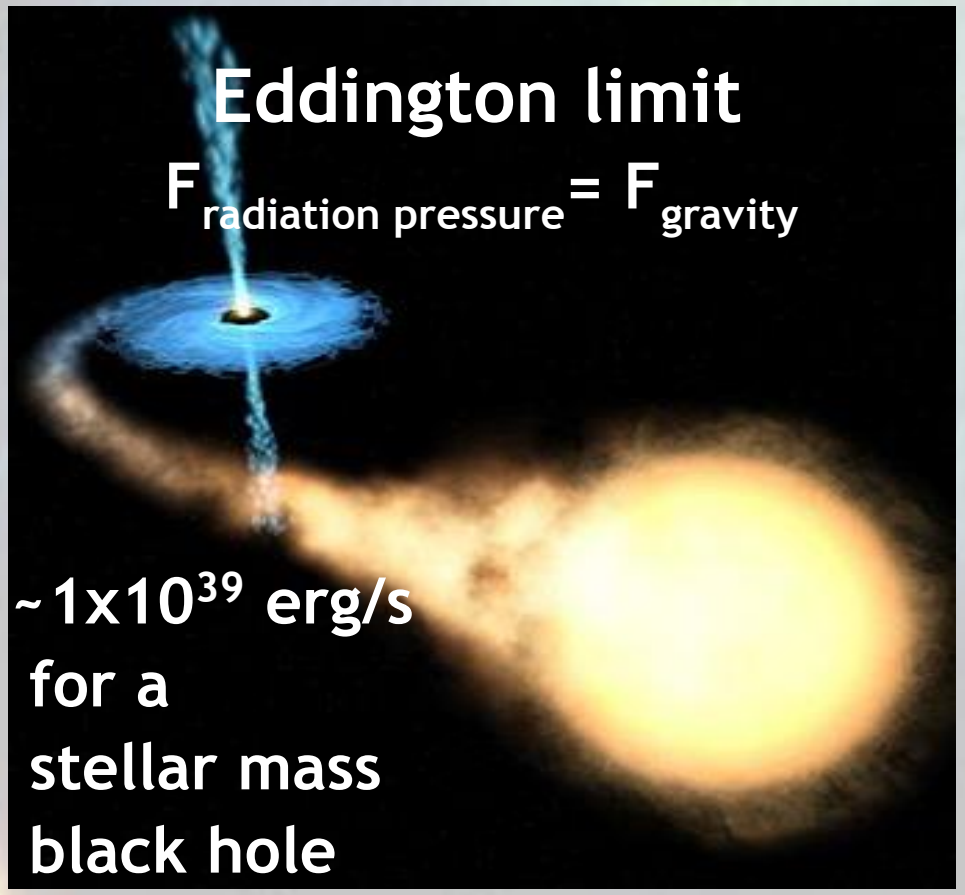
Ultra-Luminous X-ray Sources (ULX)

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

Located **outside the nucleus** of their host galaxy

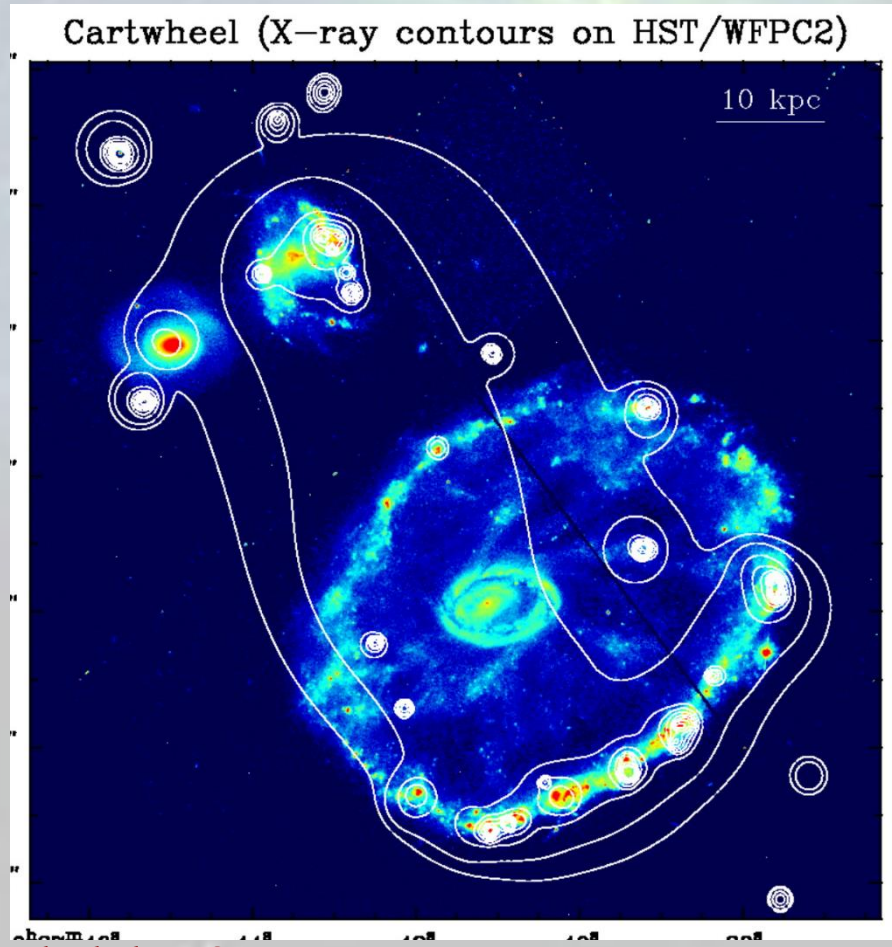
Many believed to be black holes

If accretion is spherical, implies intermediate mass black holes



Ultra-Luminous X-ray Sources (ULX)

(From Gao et al. 2003)



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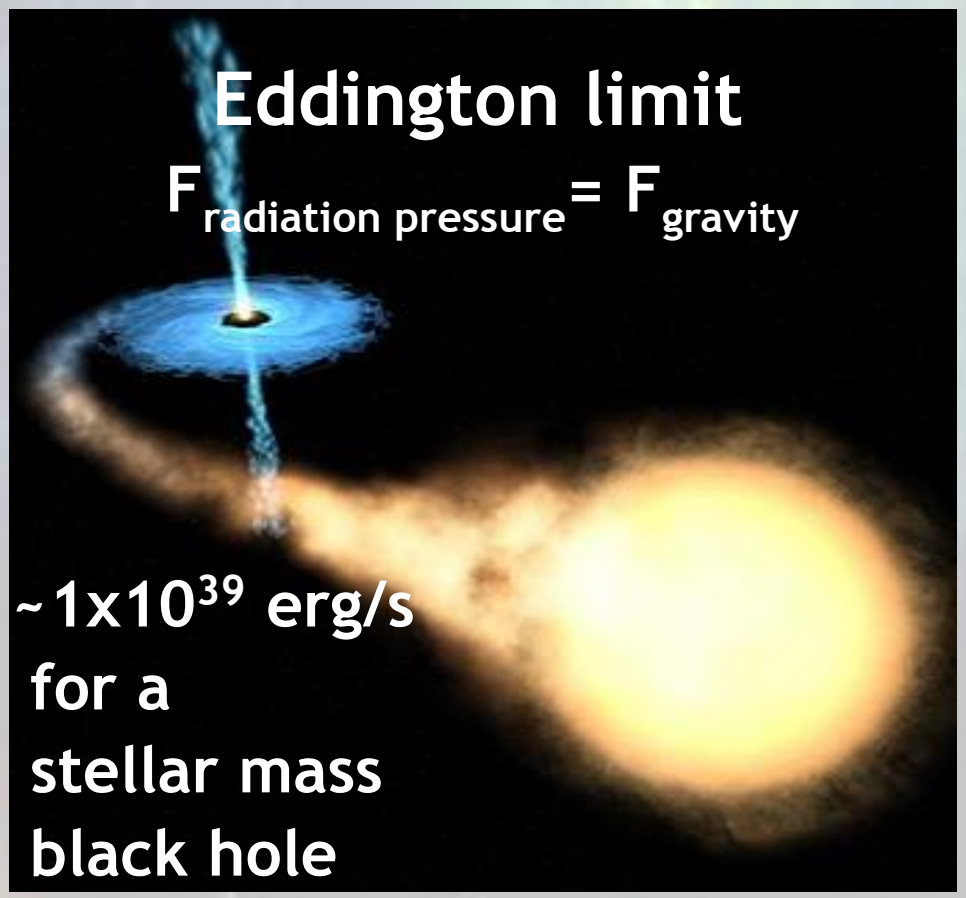

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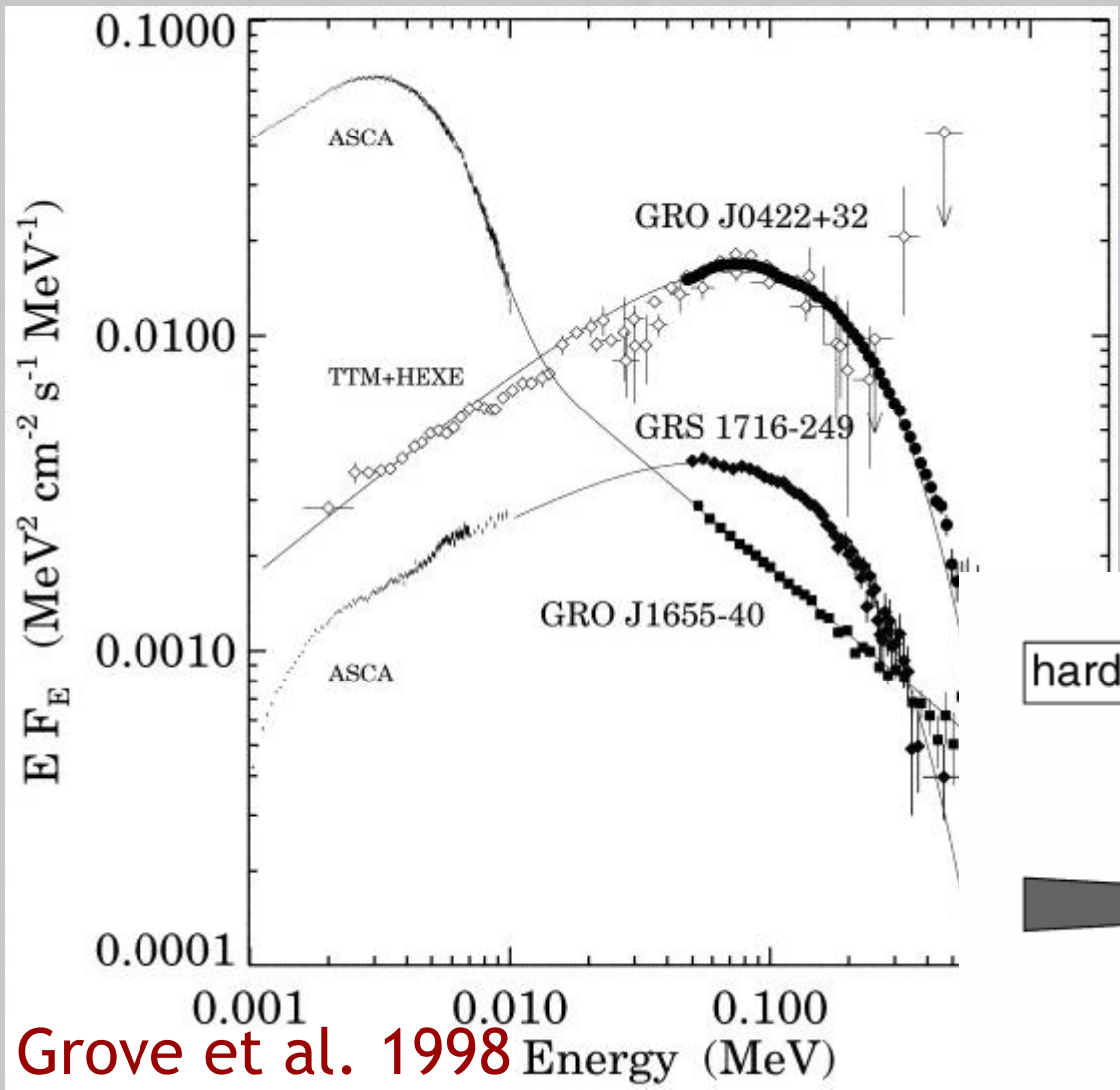
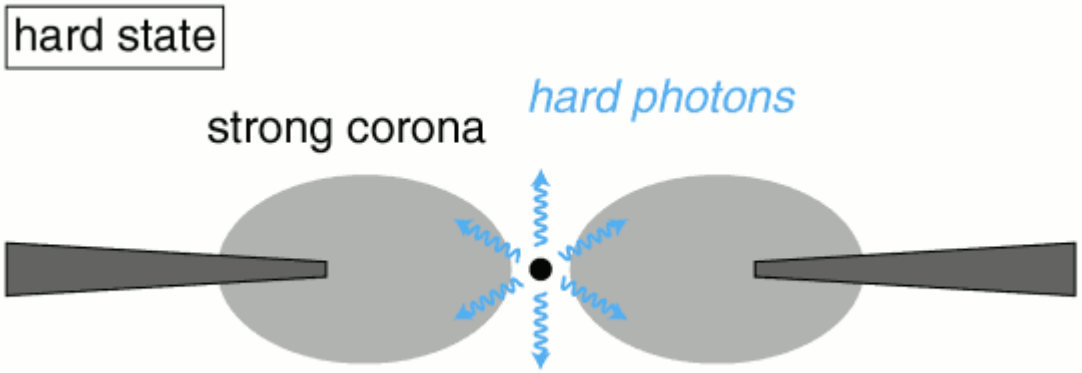
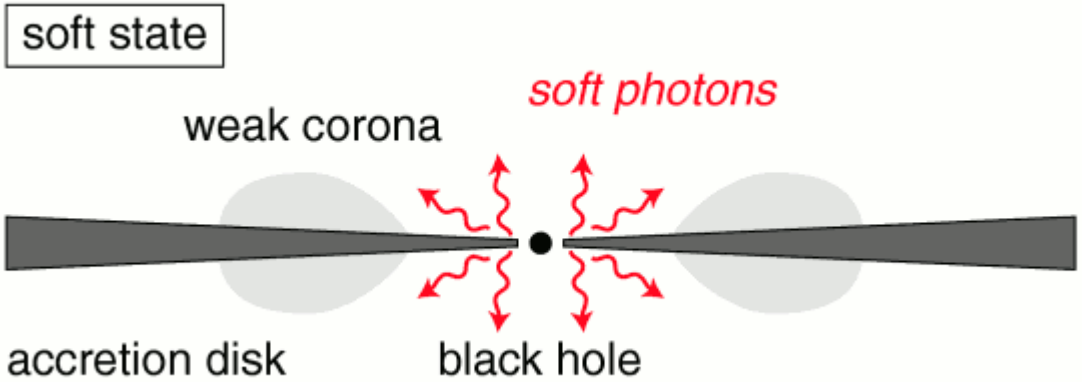
Emission can appear to exceed Eddington limit if collimated (geometrically thick accretion disc/ relativistic boosting)

Canonical black hole states

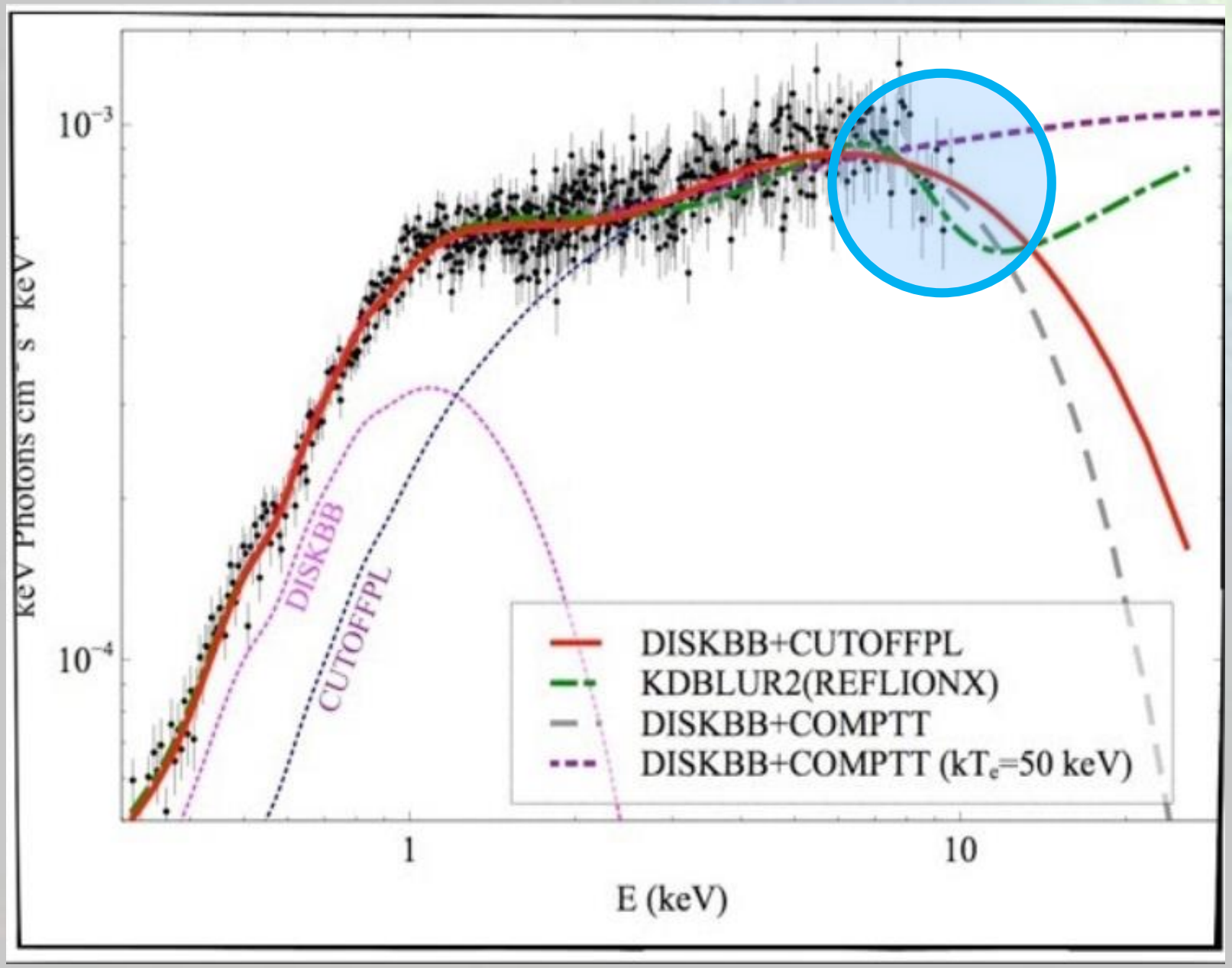


Grove et al. 1998



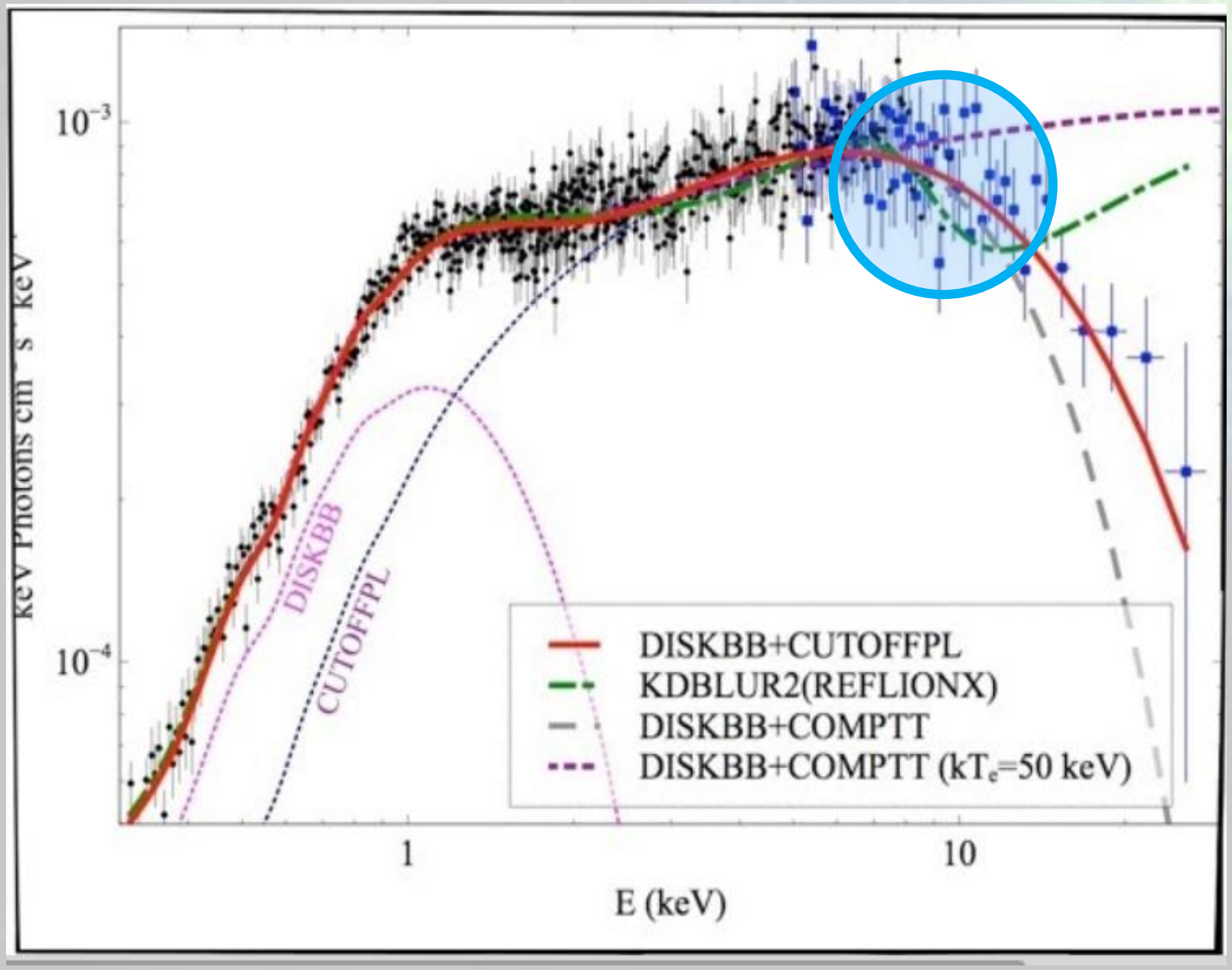


...but what about ULXs?



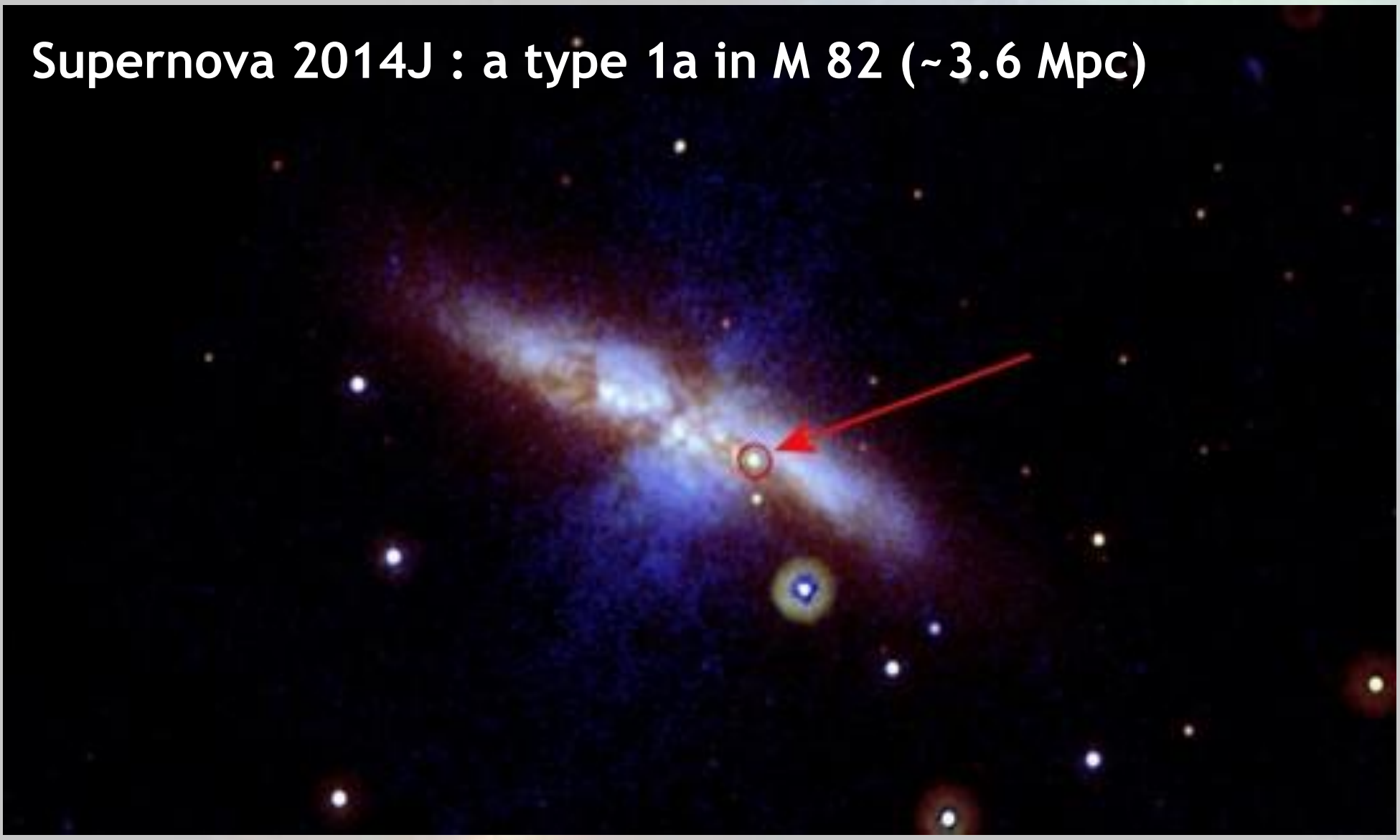
NGC 1313 X-1 (Bachetti et al. 2013)

The NuSTAR contribution



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

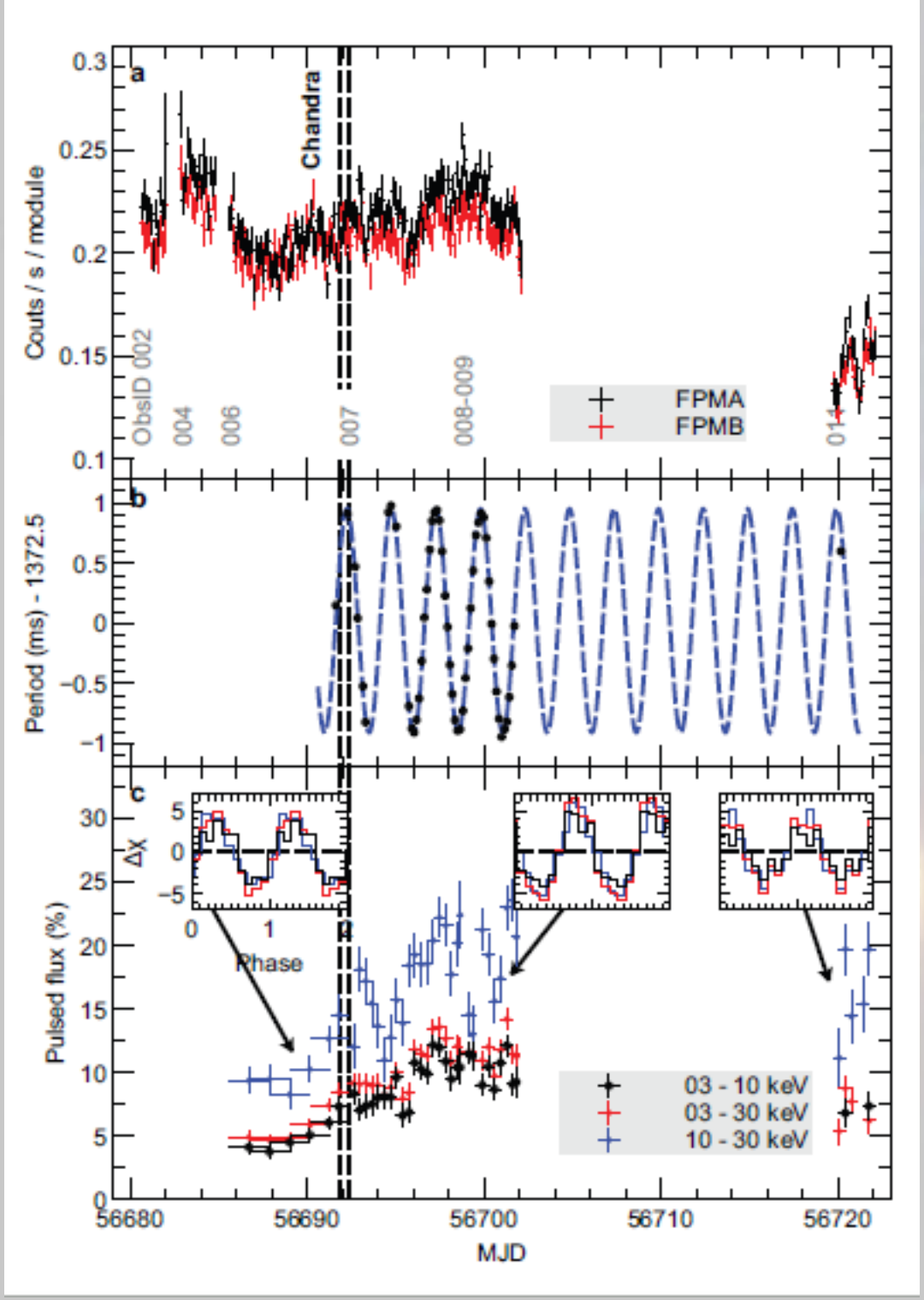
…..but not all ULXs house black holes....



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

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

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



Timing analysis

Pulse period = 1.37 s (30s)
Spin up = -2 x10^{-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)

What can we learn from SVOM observations of ULXs?

- Are all ULXs different aspects of the same family?
- What are the compact objects in ULXs?
  Black holes – if so what mass? Neutron stars? Other?
- Do intermediate mass black holes exist ?
- How can the Eddington limit be exceeded?

Need to understand:

- X-ray spectral states observed and the state transitions
- The nature of the companion to constrain compact object mass and accretion rates

How can we do this?

- **Survey known ULXs in X-ray + optical** (18 galaxies with >30 ULXs) to :
  1) search for periodicities 2) observe different spectral states
- **Search for new ULXs in survey**

Example: **optical lightcurve reveals companion + black hole mass**

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

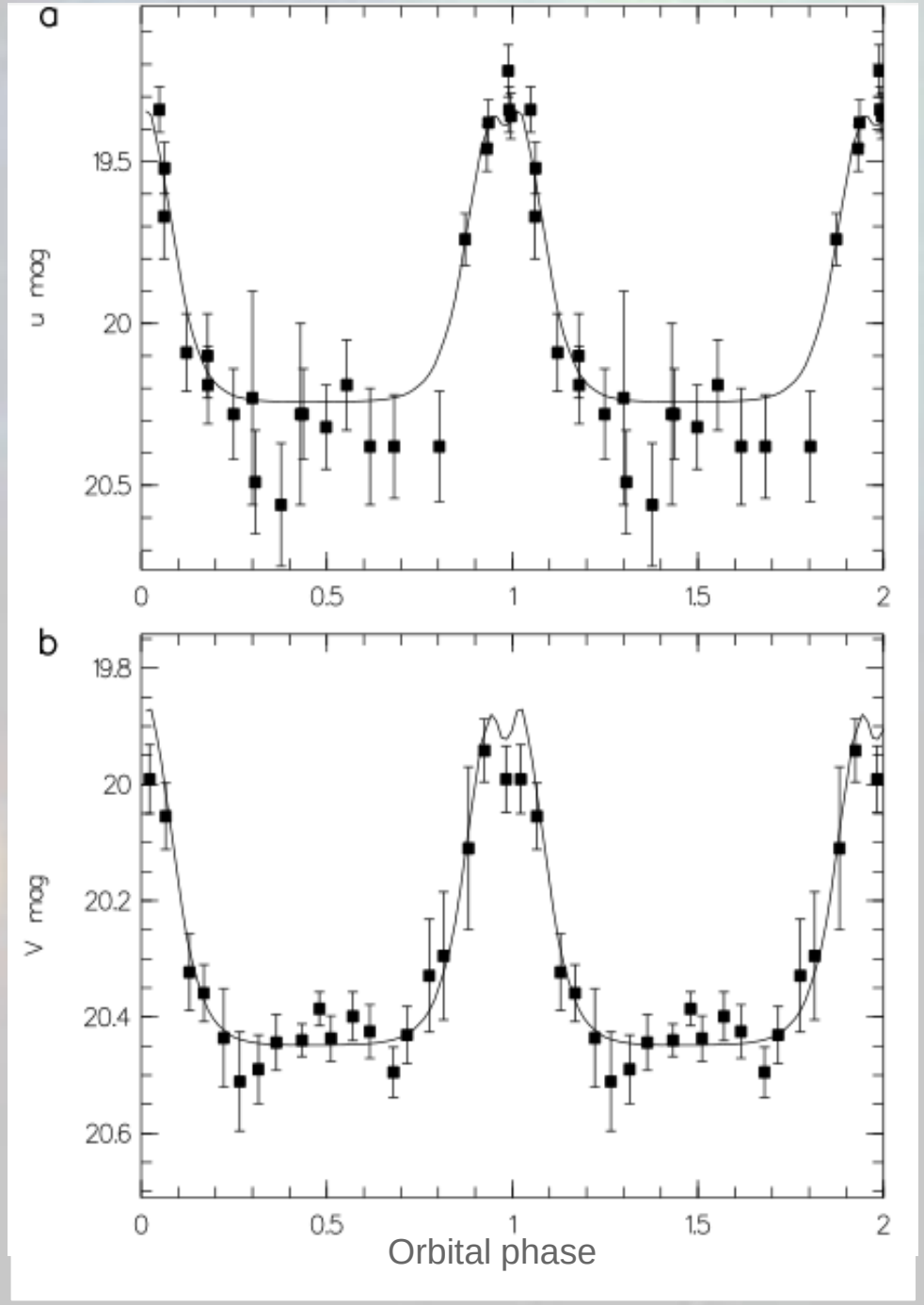
Optical photometry shows a 64 day orbital period

Counterpart = B9Ia star

Modelling => $M_{BH} < 15\ M_{\odot}$

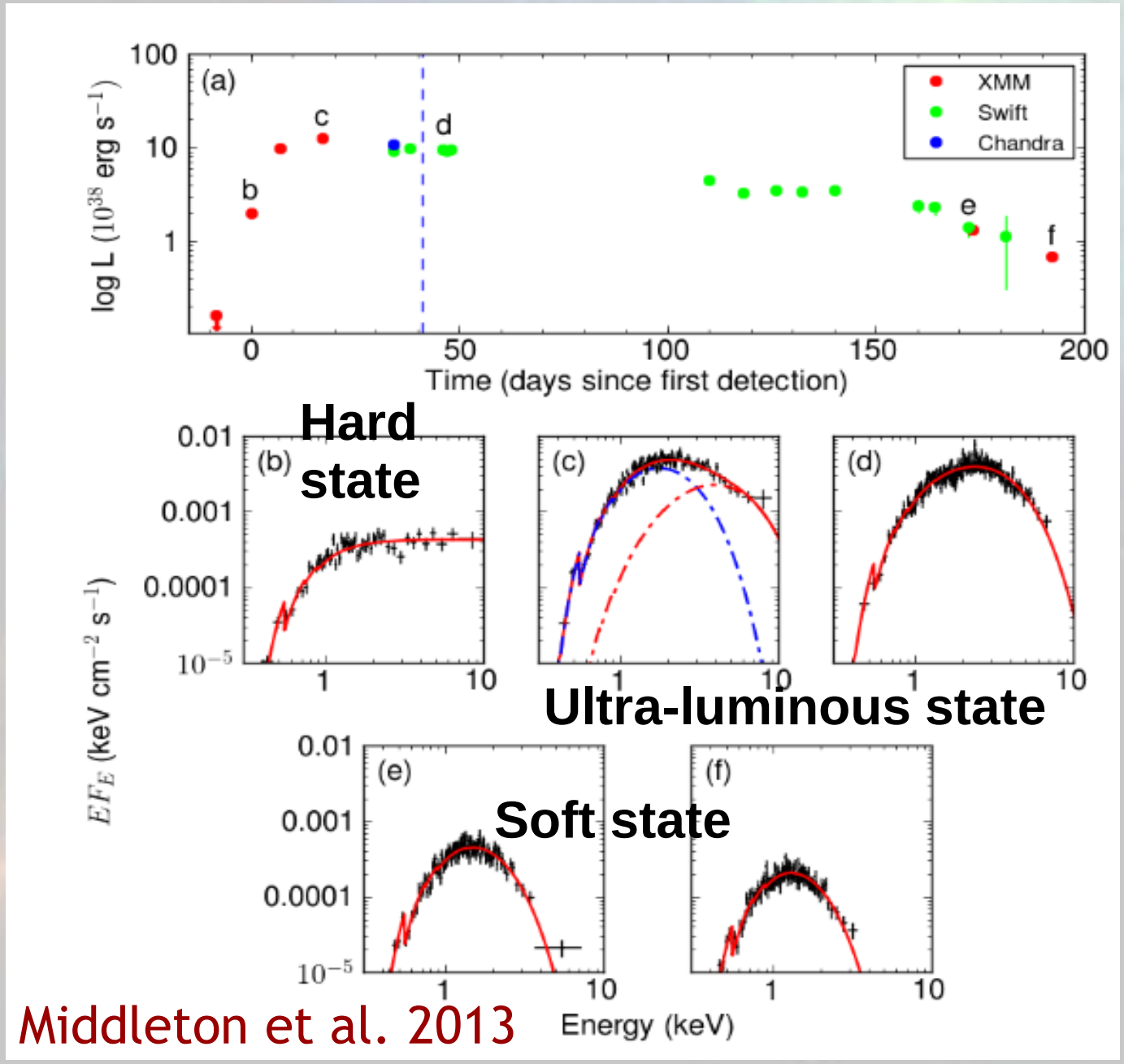
Accretion via Roche Lobe over-flow and up to twice Eddington

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



Example: X-ray monitoring reveals the spectral evolution of a transient ULX in M31

(and implies ULX state is a super-Eddington state of X-ray binaries)



Middleton et al. 2013

Tidal disruption events (TDE)

(Rees, Nature, 1988)

Tidal radius inside black hole event horizon for masses > $10^8 M_\odot$

Observe TDE from lower mass BHs

~10^{-5} – 10^{-4} event/gal./yr

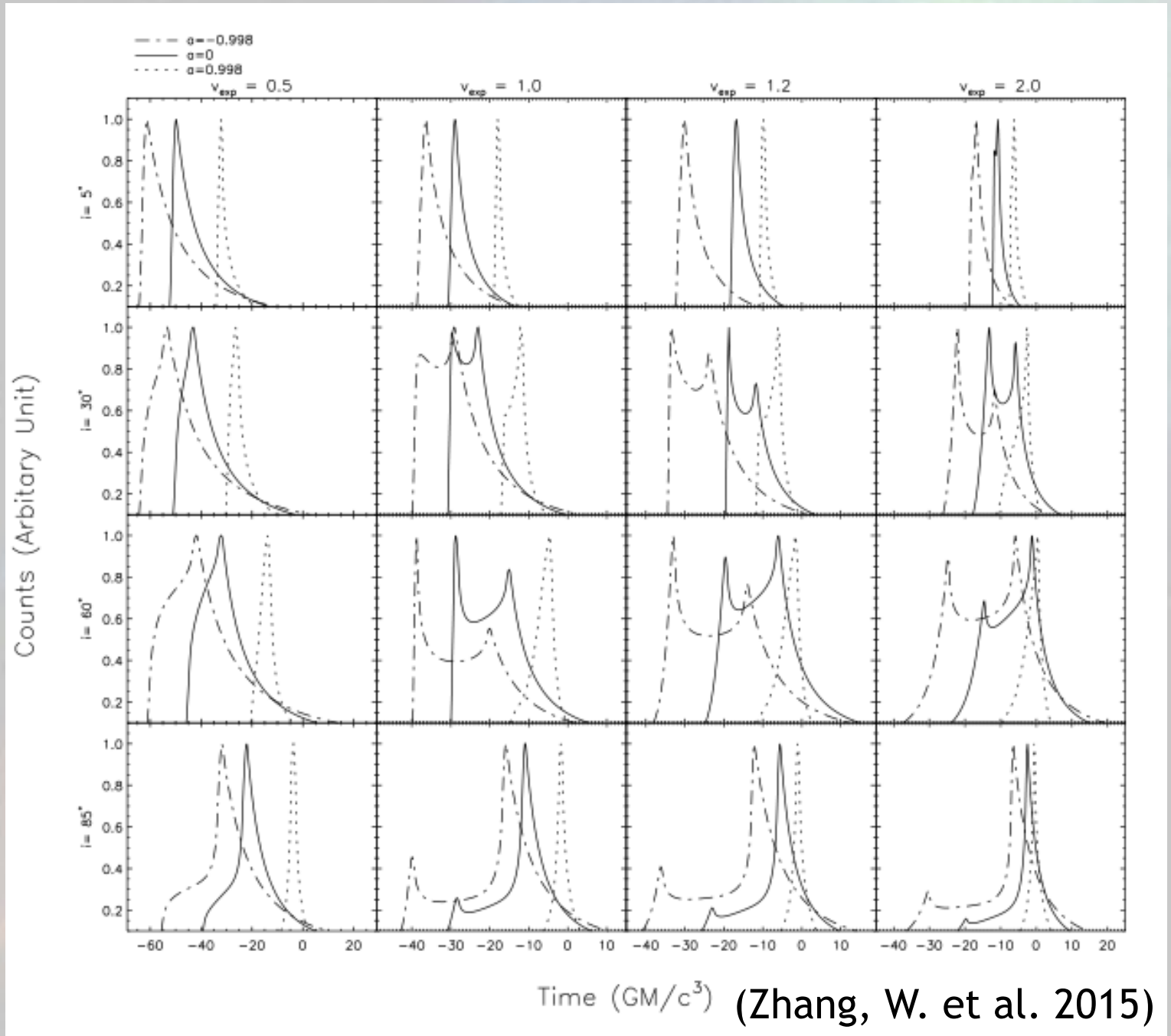
~30 events observed
(Komossa, 2015)

Accretion likely to be super-Eddington

Modelling X-ray spectrum gives black hole mass

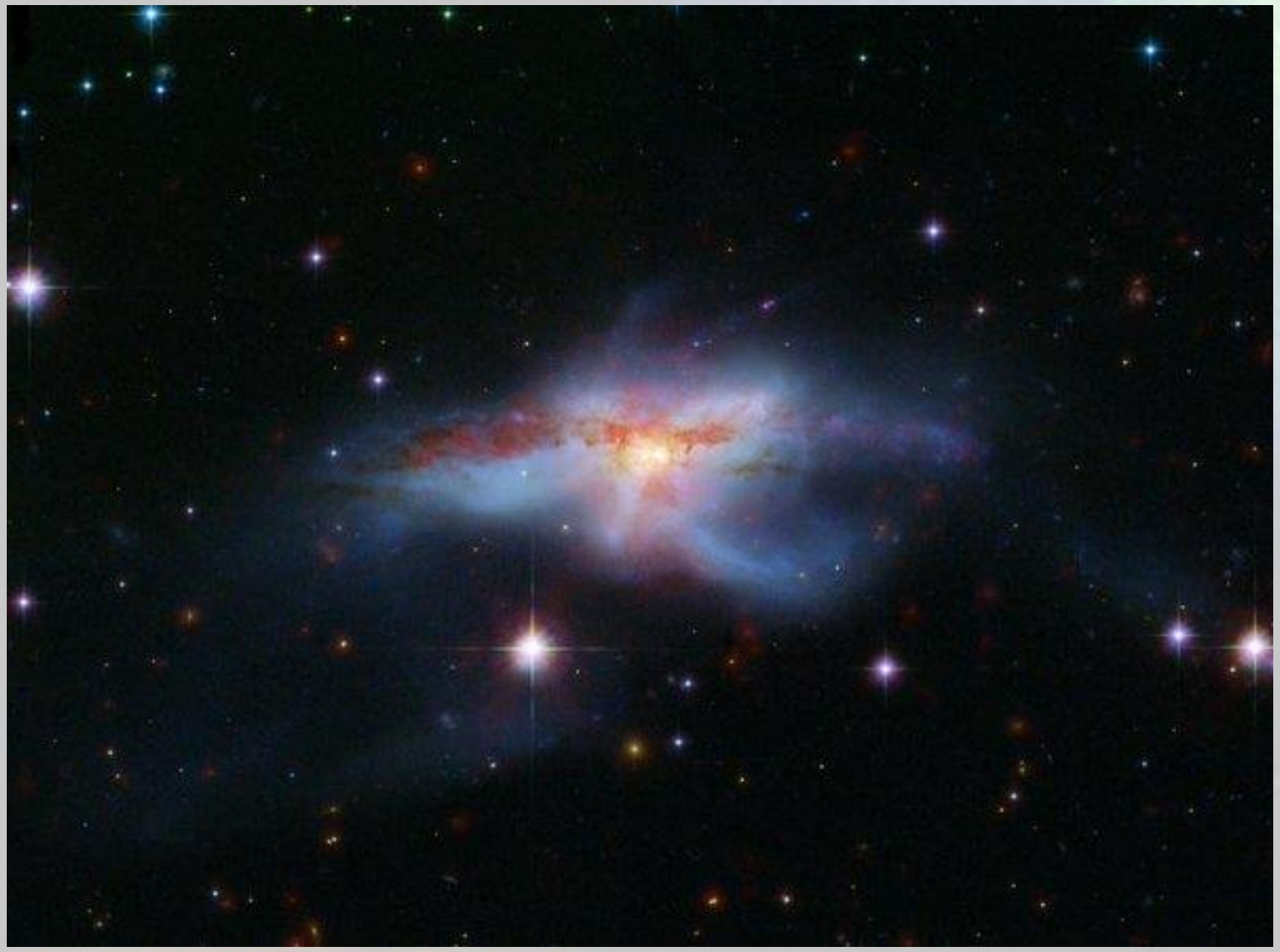
Iron line detection would give black hole spin, inclination, etc

X-ray spectra will give clues to physics of super-Eddington accretion



(Zhang, W. et al. 2015)

10 times more tidal disruption events in post merger galaxies (Arcavi et al. 2014)



Survey post-merger galaxies to increase detection likelihood

Strengths of SVOM for ULXs and TDEs

- Understand the super-Eddington regime in ULXs:
Survey known ULXs in X-ray + optical (18 galaxies with >30 ULXs)
+ eROSITA survey

Trigger multi-wavelength observations in different spectral regimes

- Constrain the nature of the companion to constrain compact object mass and accretion rates:
Search for periodicities in the optical (VT + ground based telescopes)

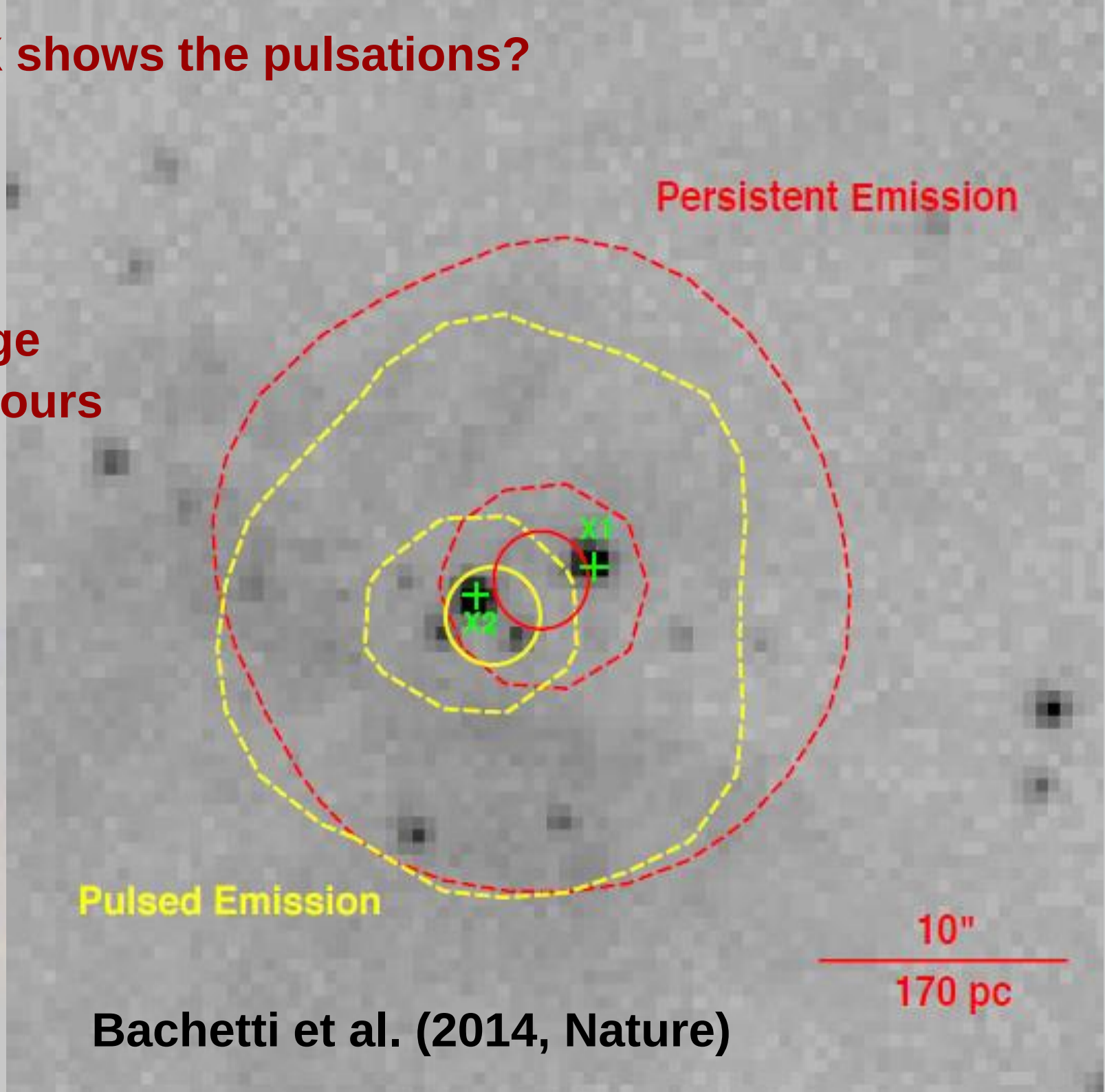
- Search for new ULXs in survey (esp. transient ones)

- TDEs: constrain parameters of BH (mass, spin)
Survey post-merger galaxies to increase detection likelihood

Extra slides

But which ULX shows the pulsations?

Chandra image
NuSTAR contours



Bachetti et al. (2014, Nature)

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