ULXs (ultraluminous X-ray sources)
What have we learned in 10 years?

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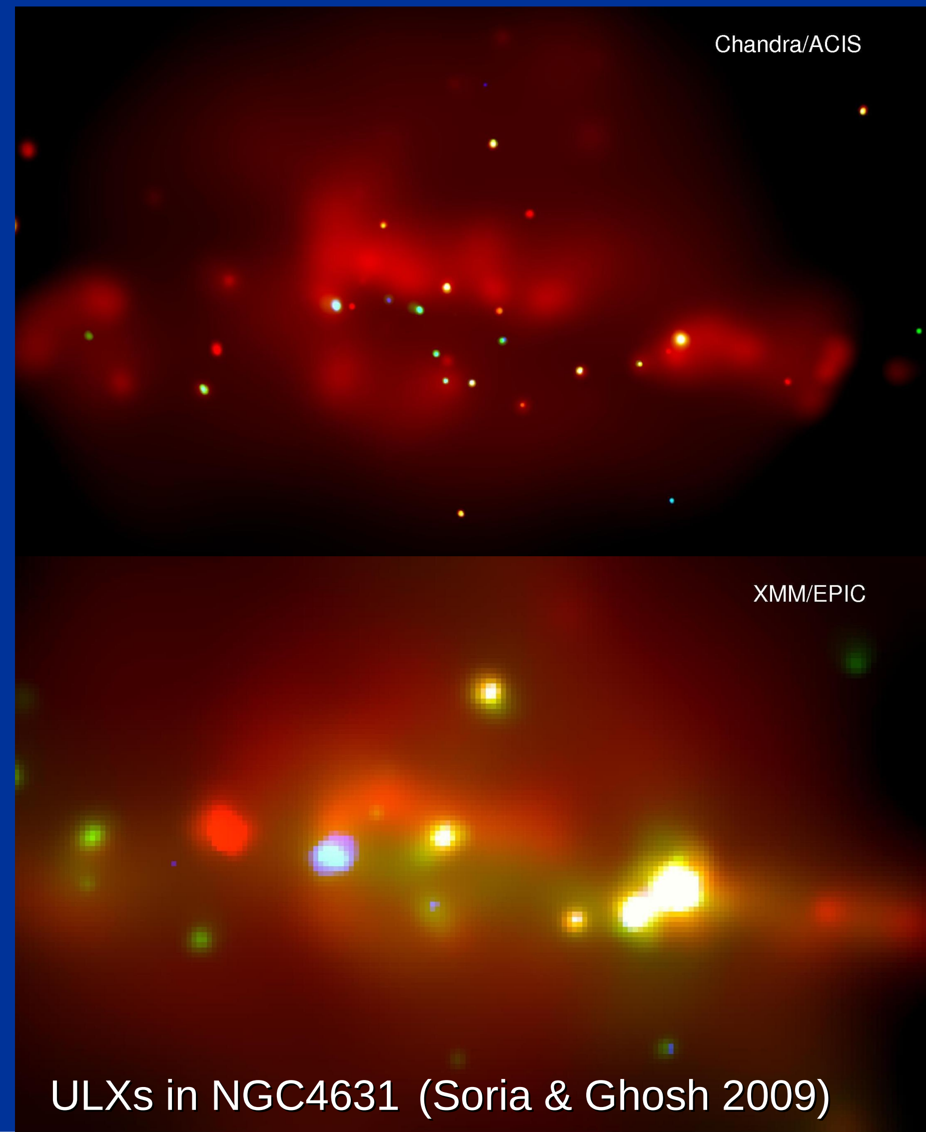


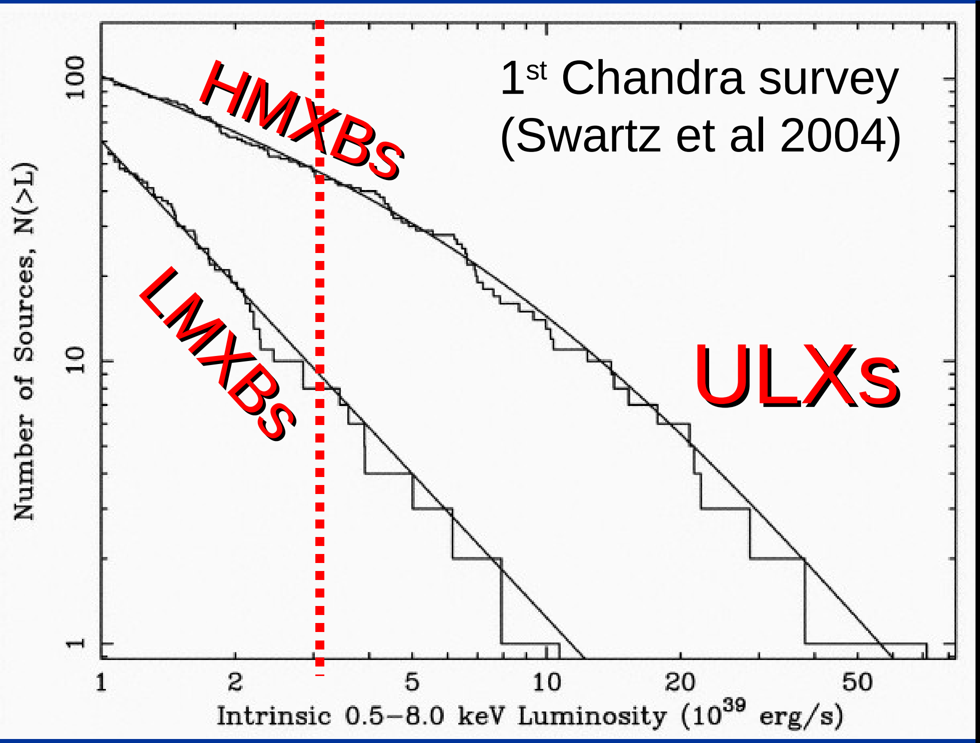
ULXs in NGC4631 (Soria & Ghosh 2009)

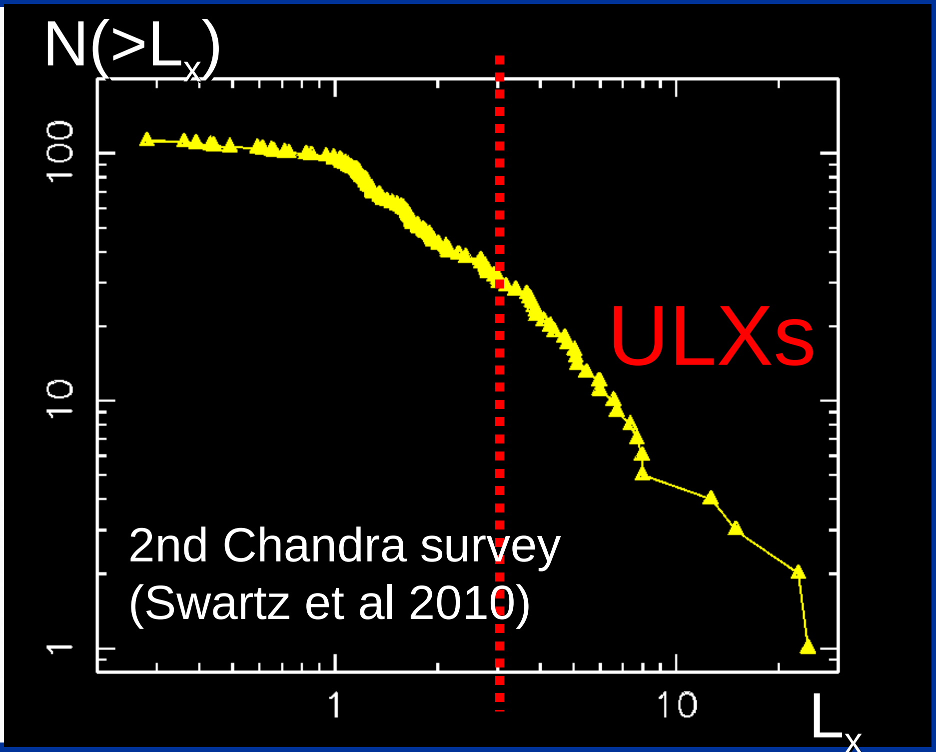
What we wanted to know in 1999

- Maximum luminosity of accreting non-nuclear BHs
- BH mass range
- BH accretion states
- Masses, ages, types of donor stars
- BH formation processes
- Power budget (radiation, advection, jet, wind?)
- Evidence of intermediate-mass BHs?

1. Luminosities

Strong beaming now ruled out (only <~ a few)





Cutoff or break at $L_X \approx (2-3)\times 10^{40}$ erg/s ?

Swartz et al 2004
Grimm et al 2003

(Most) ULXs = upper end of high-mass X-ray binaries?

1. Luminosities

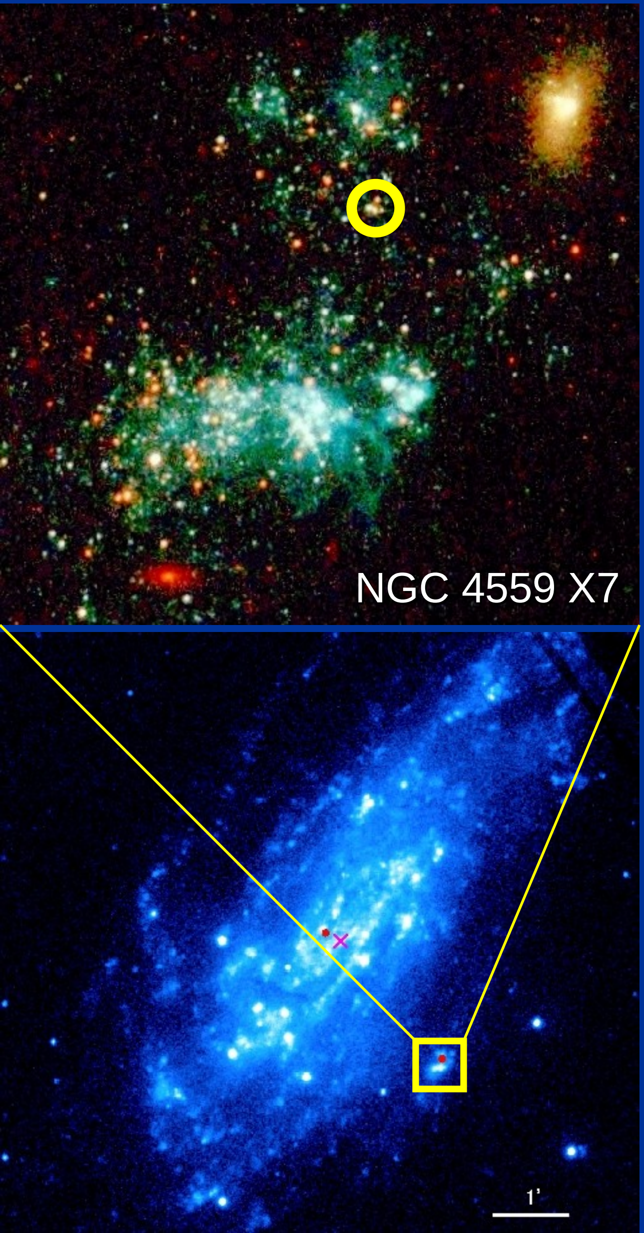
But also a few sources with $L_X > 3\times10^{40}$ erg/s

Cartwheel: $L_{0.3\text{-}10}$ ~ 1E41 erg/s
M82: $L_{0.3\text{-}10}$ ~ 1E41 erg/s
NGC2276: $L_{0.3\text{-}10}$ ~ 1E41 erg/s
NGC5775: $L_{0.3\text{-}10}$ ~ 8E40 erg/s
ARP240: $L_{0.3\text{-}10}$ ~ 7E40 erg/s
NGC7714: $L_{0.3\text{-}10}$ ~ 7E40 erg/s

ESO243-49: $L_{0.3\text{-}10}$ ~ 1E42 erg/s ???

Different populations? ULXs and HLXs?

2. Optical counterparts



Very few ULXs in super star clusters

Most ULXs in OB associations

Most ULXs in moderately young regions

Typical age of the stellar population ~ 10—25 Myr

Most ULXs consistent with
B-type donor filling its Roche Lobe

But also 2 Wolf-Rayet donors
(Prestwich et al 2007, Liu 2010)

Duration of active phase ~ 0.5—1 Myr

Ongoing efforts to determine mass functions

3. BH masses

No kinematic masses available (yet)

Only indirect methods to estimate BH masses

Eddington limit

Most ULXs with BH masses ~ 30—100 M_{sun} ?

X-ray spectra and time variability

Very model-dependent

In Galactic BHs, works well only for thermal state (standard disk)

4. BH accretion states

We thought it was so simple….

$\dot{m}$

1 — Very high state

Heavily Comptonized disk

Radio flaring

0.1 — High/Soft state

Standard disk

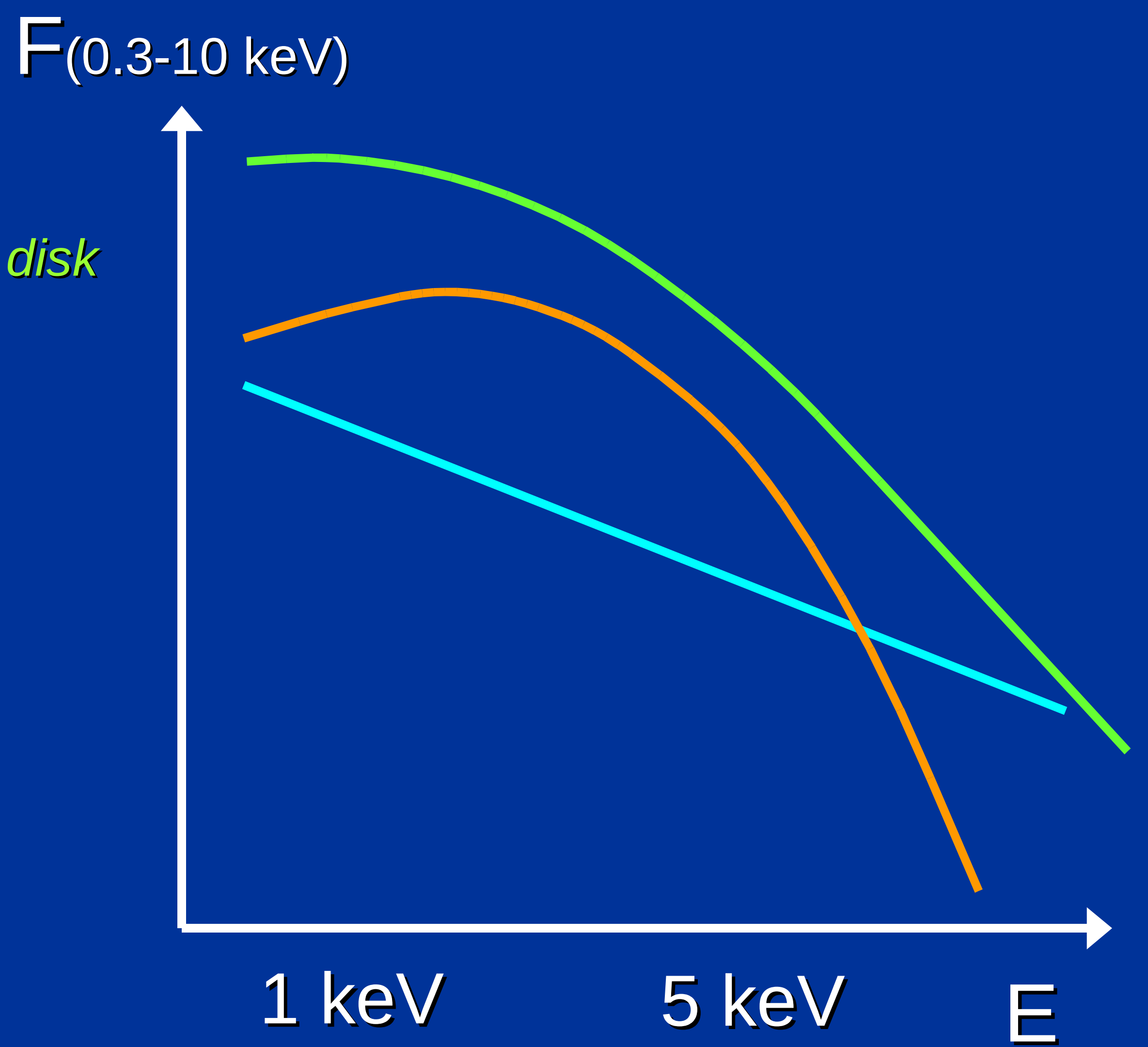
Radio quiet

0.01 — Low/Hard state

Jet? Corona?

ADAF? CENBOL?

Radio loud



4. BH accretion states

…but ULXs are different

- >~ 90% are dominated by Comptonized emission (“power-law”)

  Some have a minor “soft excess” at T ~ 0.2 keV

  (Outer disk? Smeared absorption? Reflection?)

  and/or a high-energy downturn (suggesting T_e ~ 5—10 keV)

- Most of the very luminous ULXs have hard spectrum

  (power-law photon index $1 < \Gamma < 2$, with L_x ~ 1E40 erg/s)

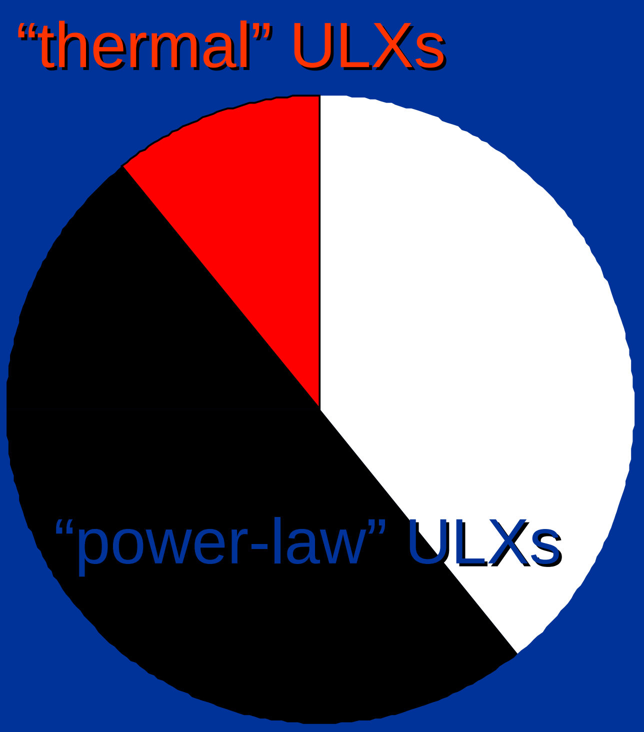
- ULX fluxes may fluctuate by a factor of 10 but…

  no hard-spectrum ULX has ever been seen

  to switch to high/soft state (standard thin disk)

4. BH accretion states

X-ray spectra dominated by Comptonized emission ("power-law")

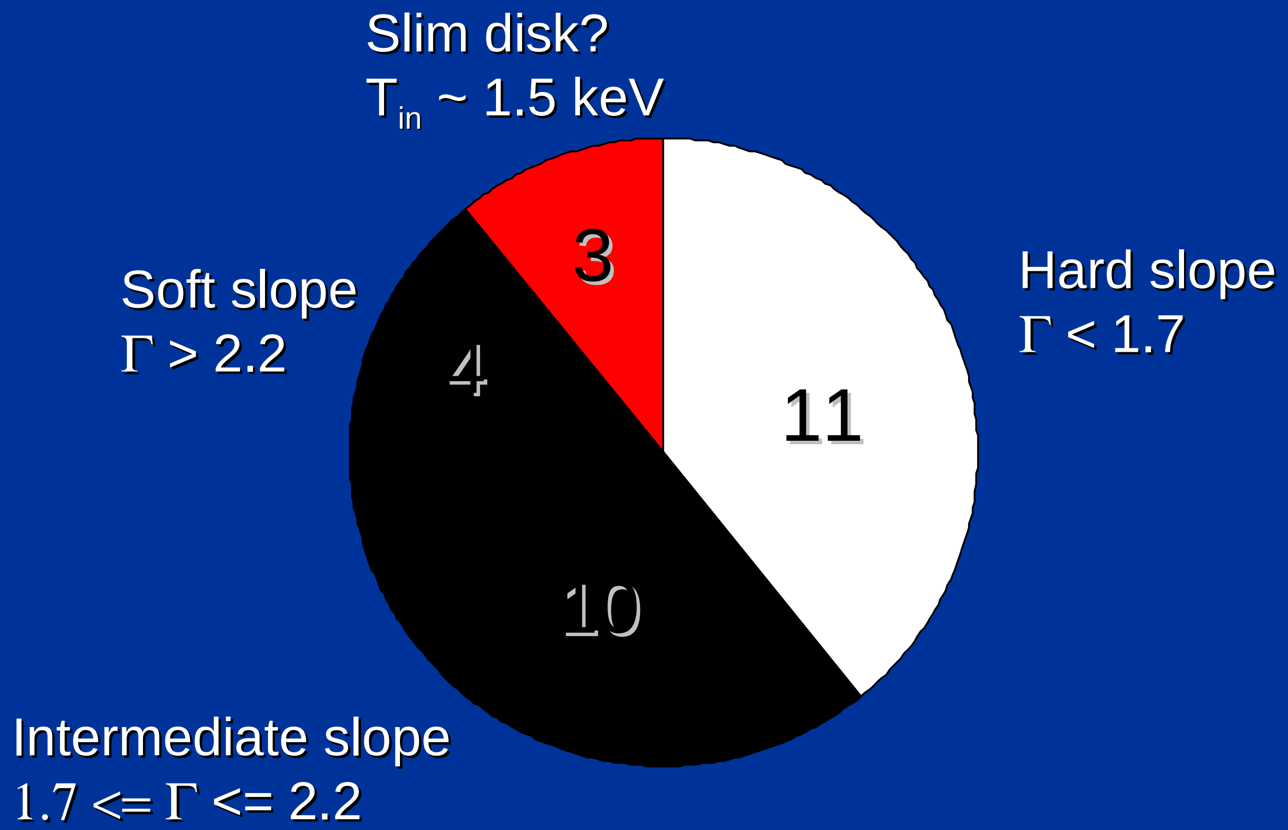


Chandra survey of 28 ULXs with L_x >= 1E40 erg/s

(Soria et al in prep)

4. BH accretion states

X-ray spectra dominated by Comptonized emission ("power-law")



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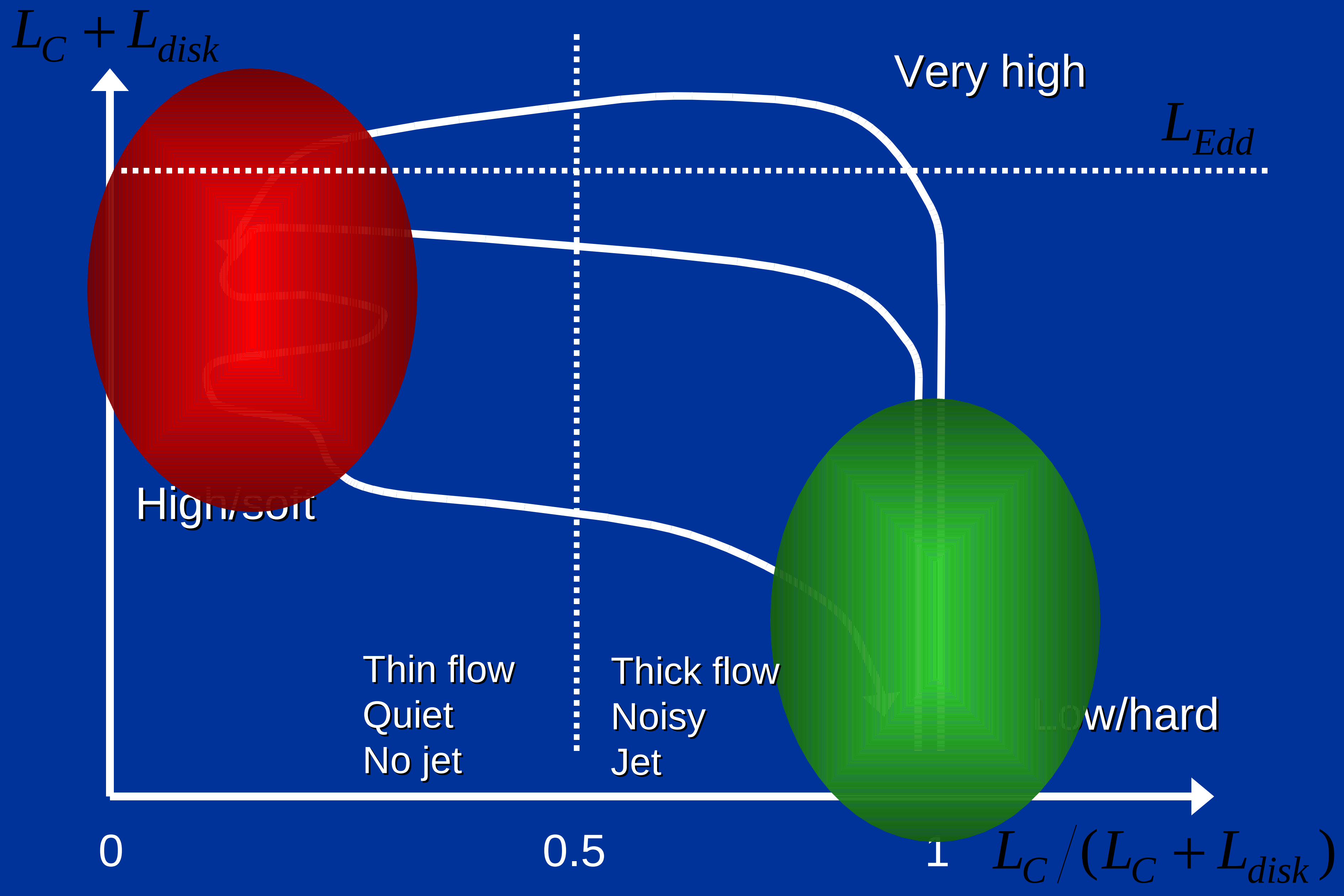
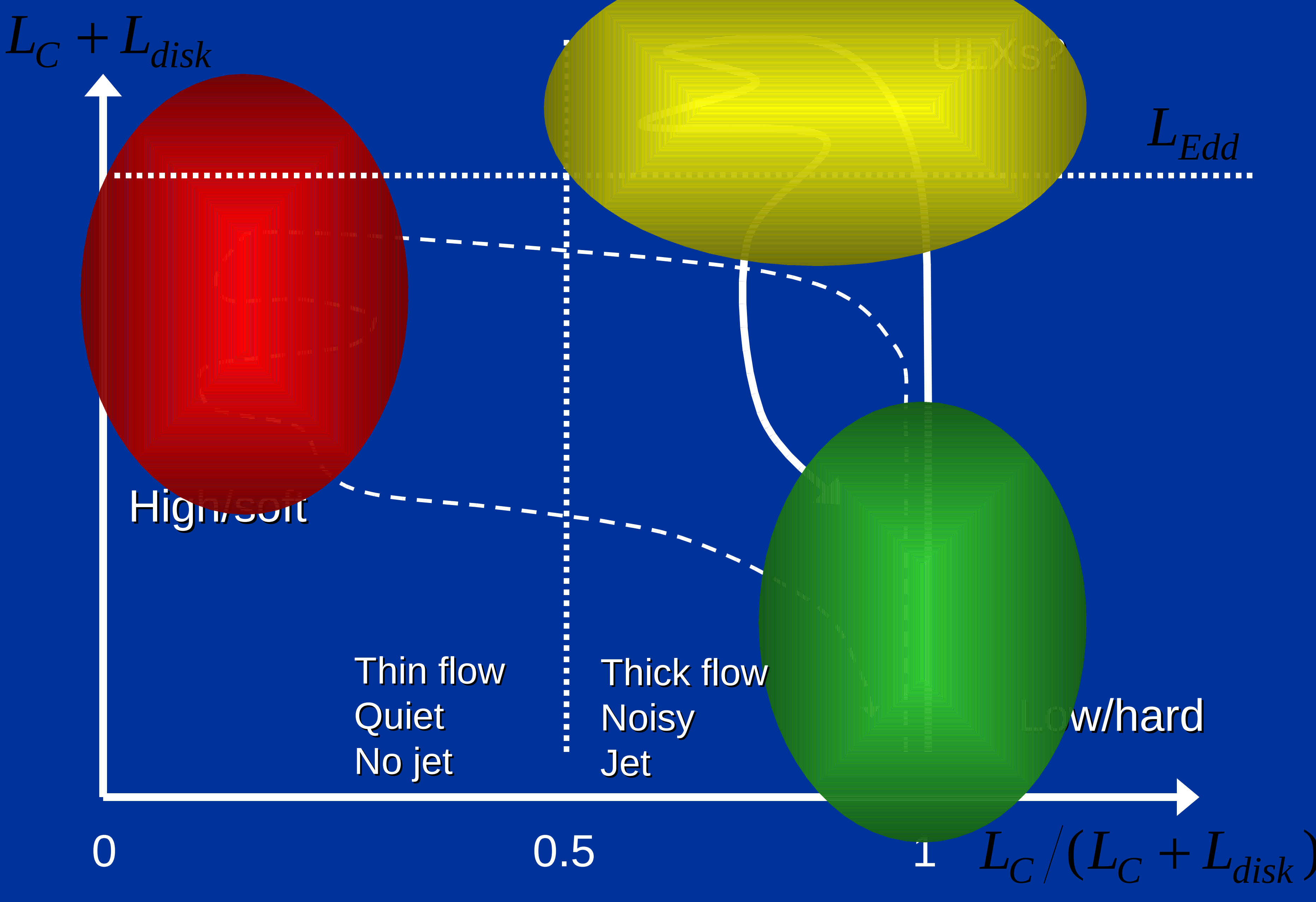


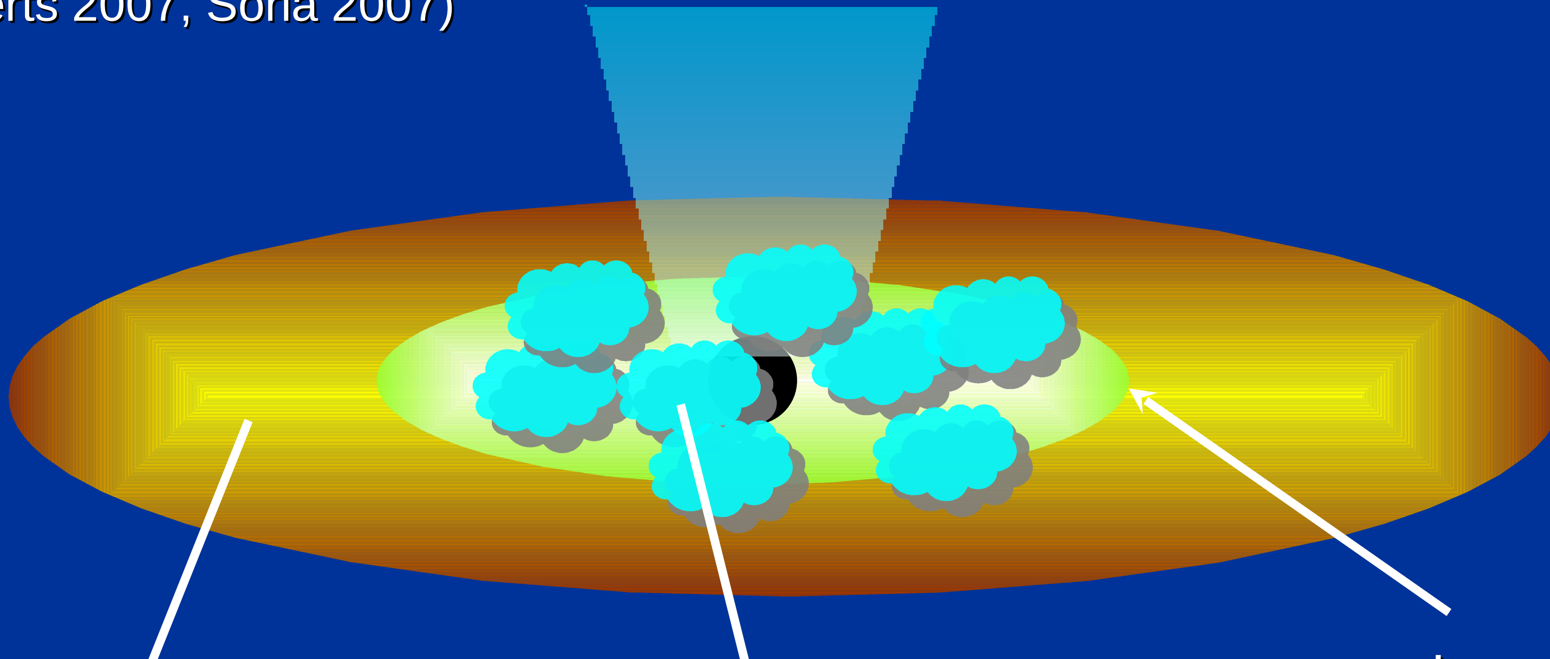
4. BH accretion states



"Ultraluminous state"?

4. BH accretion states

(Roberts 2007, Soria 2007)



Standard disk
Thermal emission
$L_{disk} <\approx 30\% L_X$

scattering region
Comptonized emission
$L_{po} \approx 70-100\% L_X$

Large R_c
Low T_{in}
Low f_{qpo}

mdot ~ 1—20
τ ~ a few
T_e ~ 5—10 keV

$$L_X \approx \left(1+\tfrac{3}{5}\ln \dot{m}\right) L_{Edd} <\sim 4L_{Edd}$$

$$M_{BH} < 100\, M_{sun}$$

4. BH accretion states

Why always Compton-dominated in the high state?

Why is the corona always there?
(denser, cooler than in low/hard state)

Higher accretion rate
+
Higher evaporation rate into corona

?

Difference between *magnetized accretion flows*
(low-mass BH binaries)
and *non-magnetized accretion flows*
(ULXs have OB donors)

?

(Soria & Wu 2010, in prep)

5. BH formation process

How to form a 50 M_{sun} BH?

Very massive stars (M_{in} ~ 100—150 M_{sun})

Metal poor environment (Z ~ 0.1 solar)

→ Direct collapse into massive BH

(work by Pakull, Zampieri, Prestwich, Soria, …)

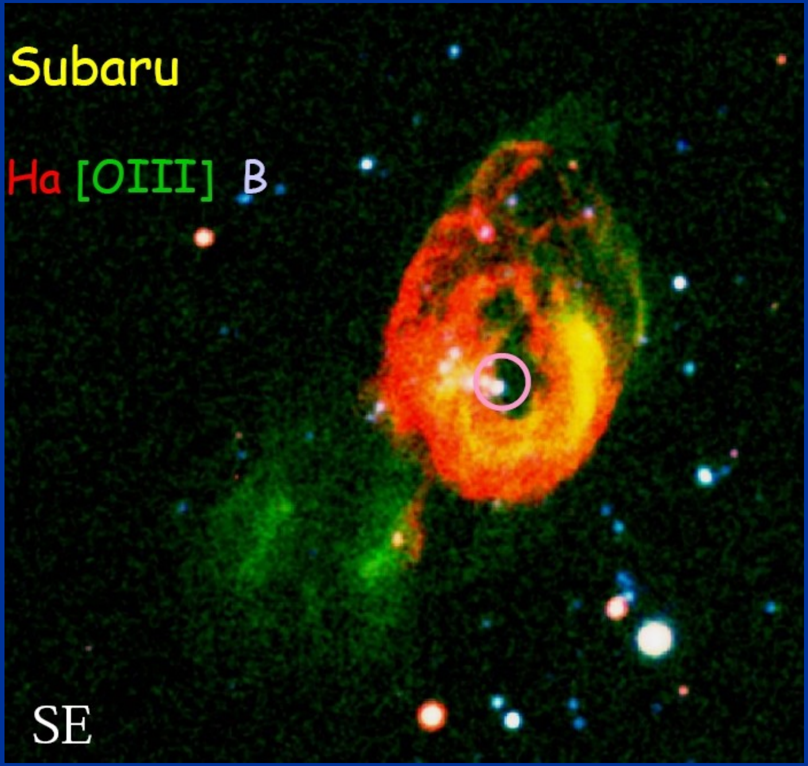
“Exotic” processes NOT NEEDED

(Pop III remnants, “superstars” in cluster cores, …)

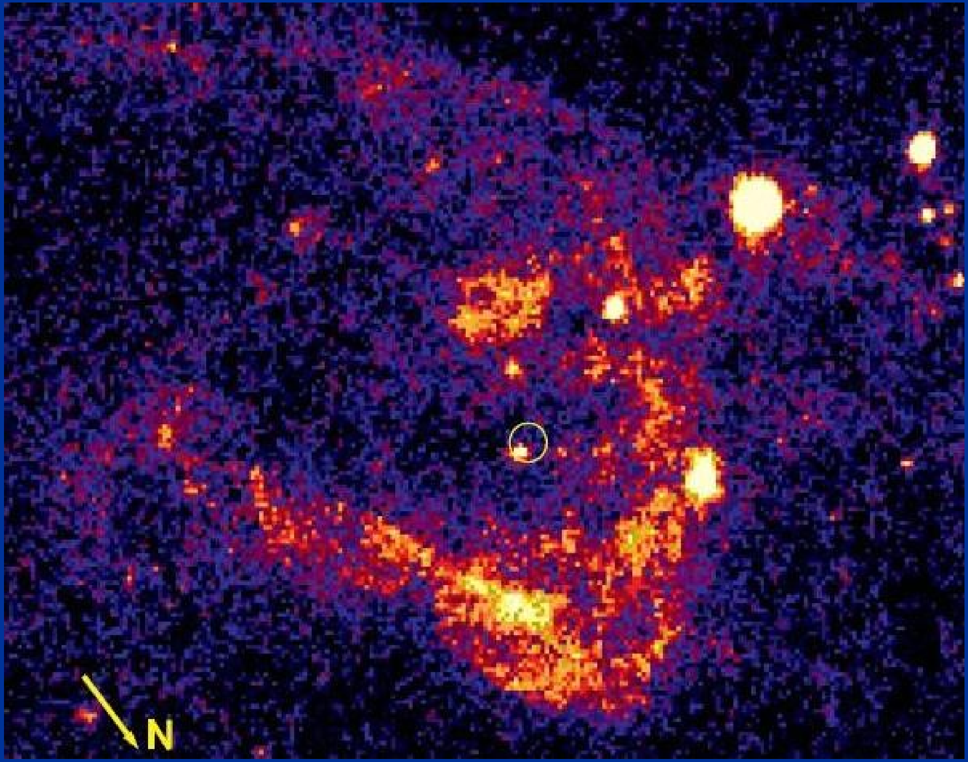
6. Jets and outflows

Often $P_J + P_w \sim L_x$

Many ULXs surrounded an optical or radio bubble



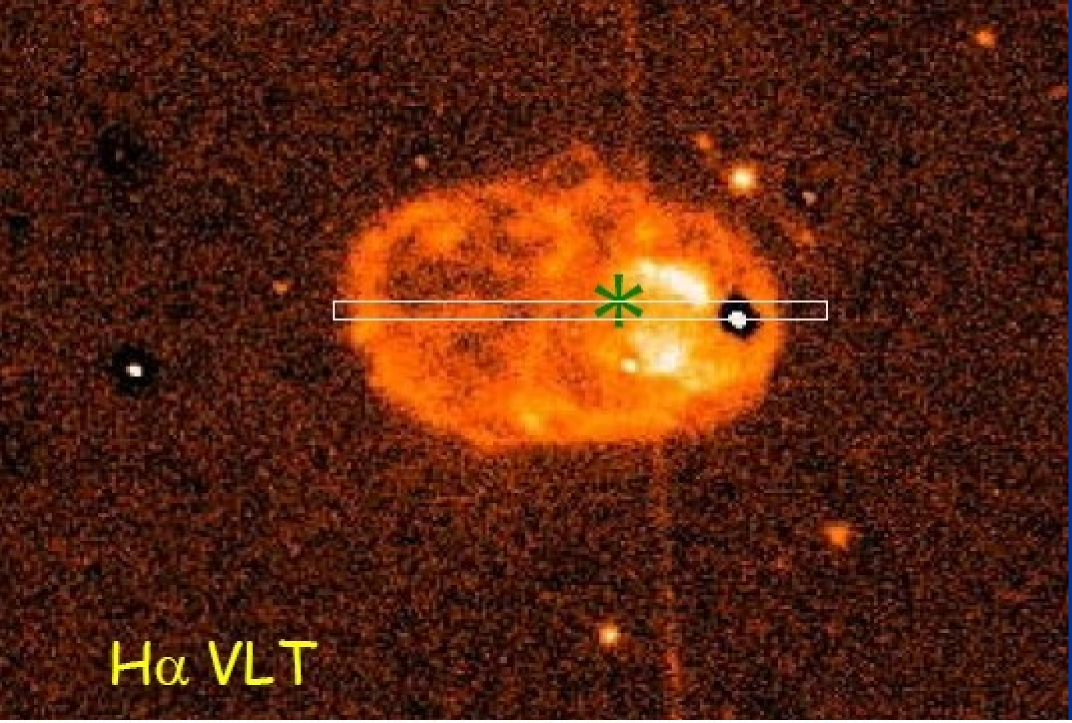
Holmberg IX X1
Pakull & Mirioni 2002; Grise' et al 2008



IC342 X1 ("foot nebula")
Pakull & Mirioni 2002; Feng & Kaaret 2008

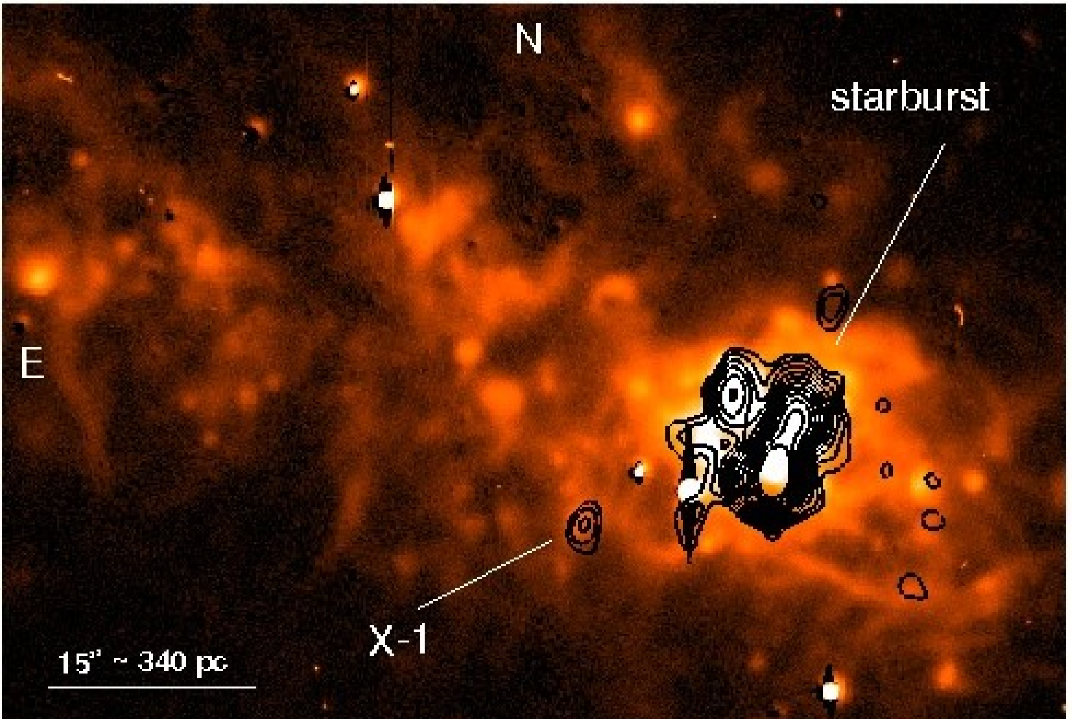
6. Jets and outflows

ULX bubbles



NGC1313 X2

Grise' et al 2008
Grise' et al 2010 in prep



NGC5408 X1

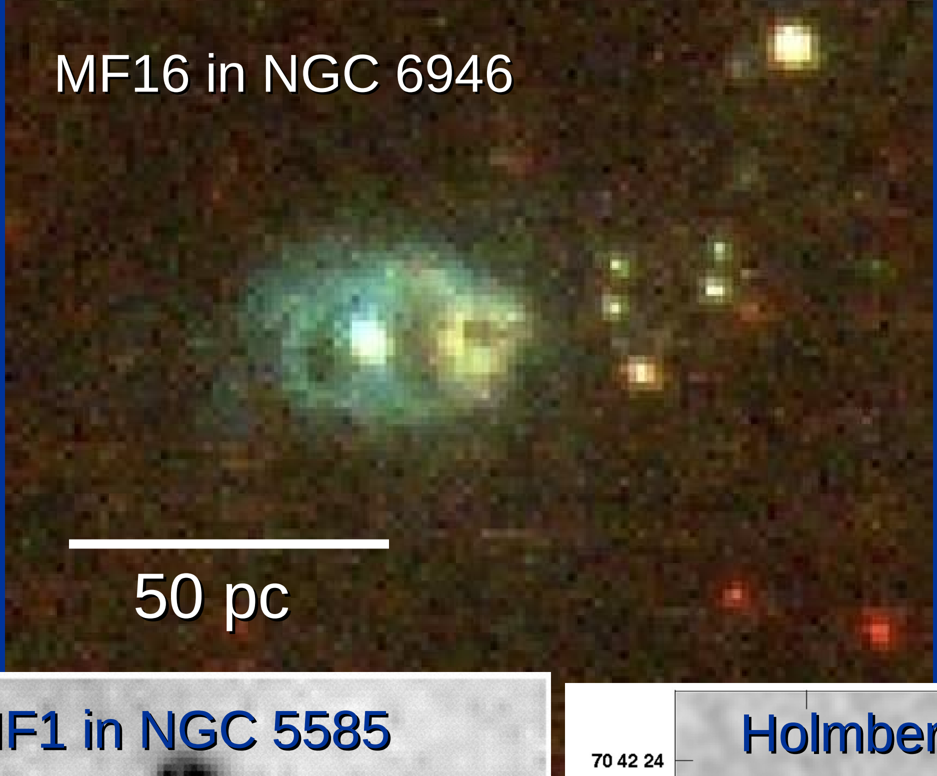
Kaaret et al 2003
Soria et al 2006
Lang et al 2007

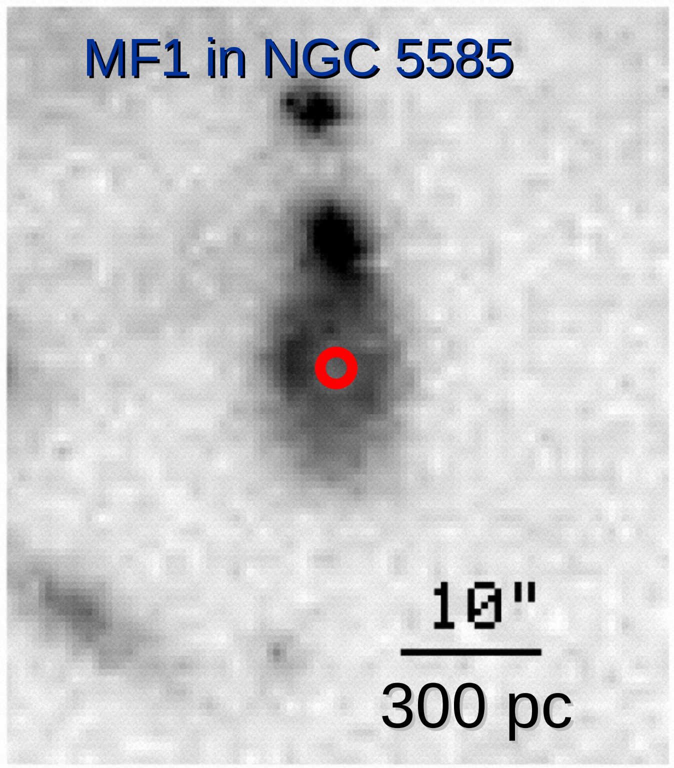
6. Jets and outflows

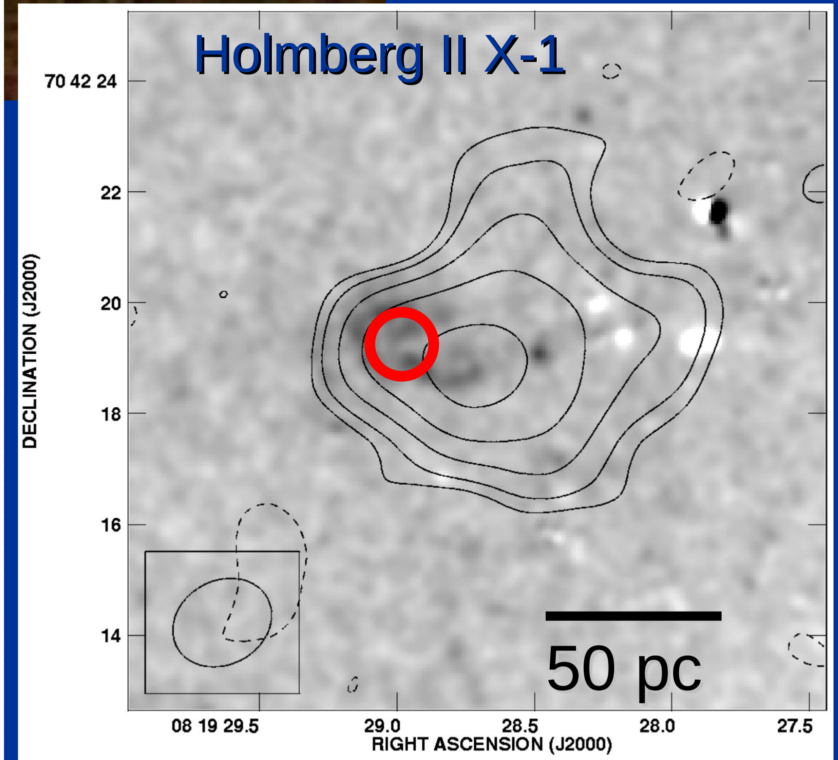
ULX bubbles

Size ~ 50—400 pc

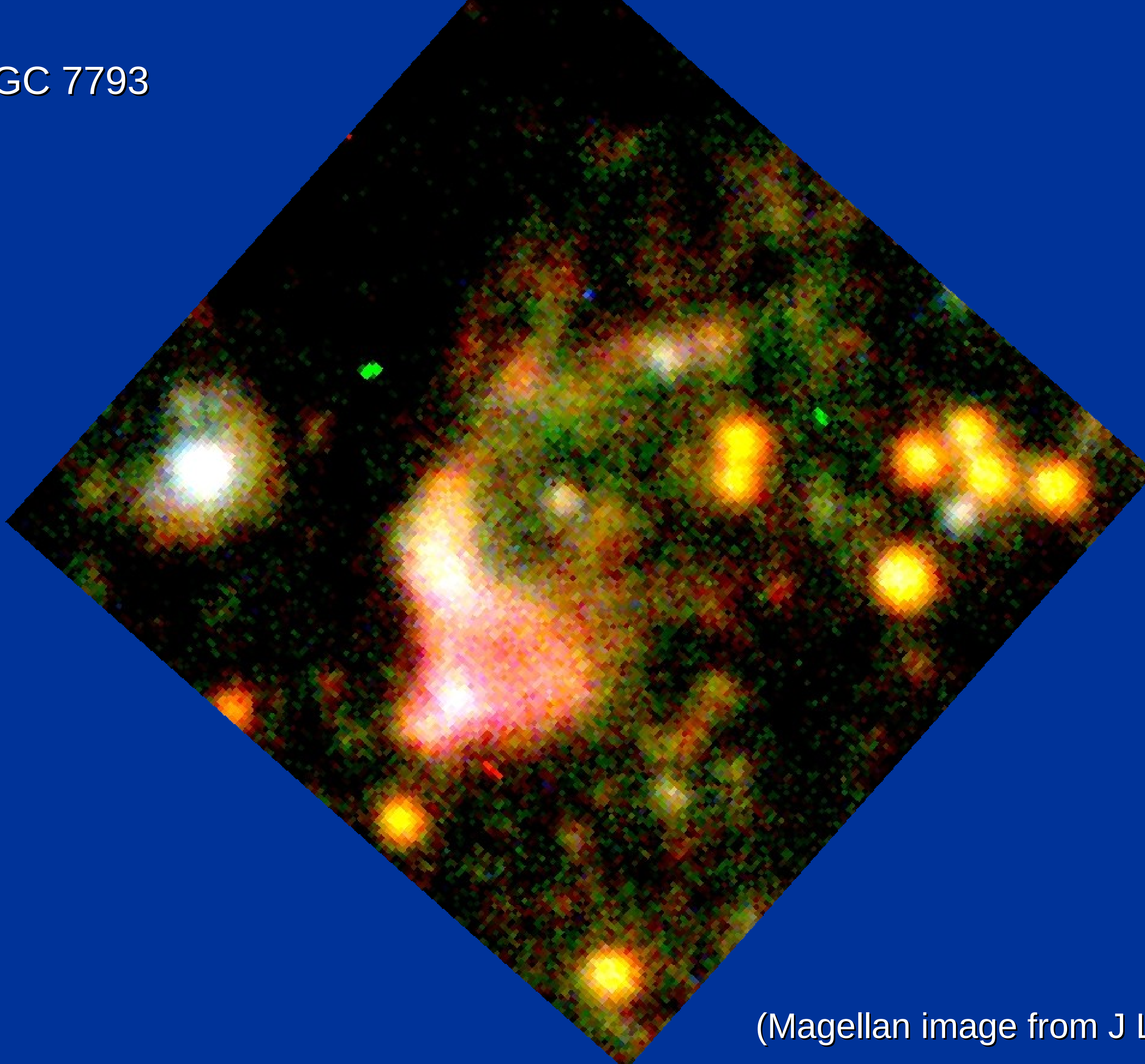
Age ~ 0.5—1 Myr



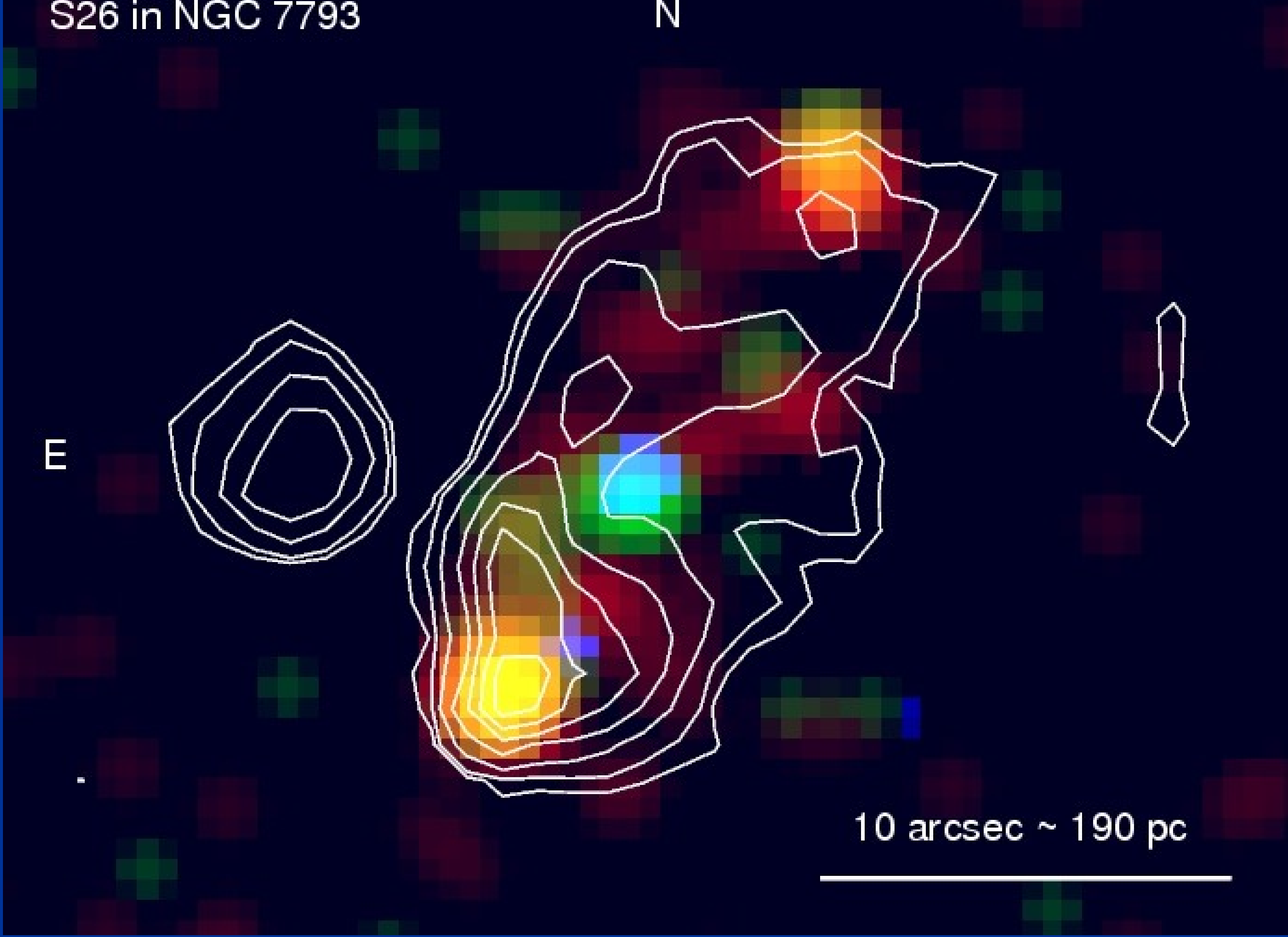


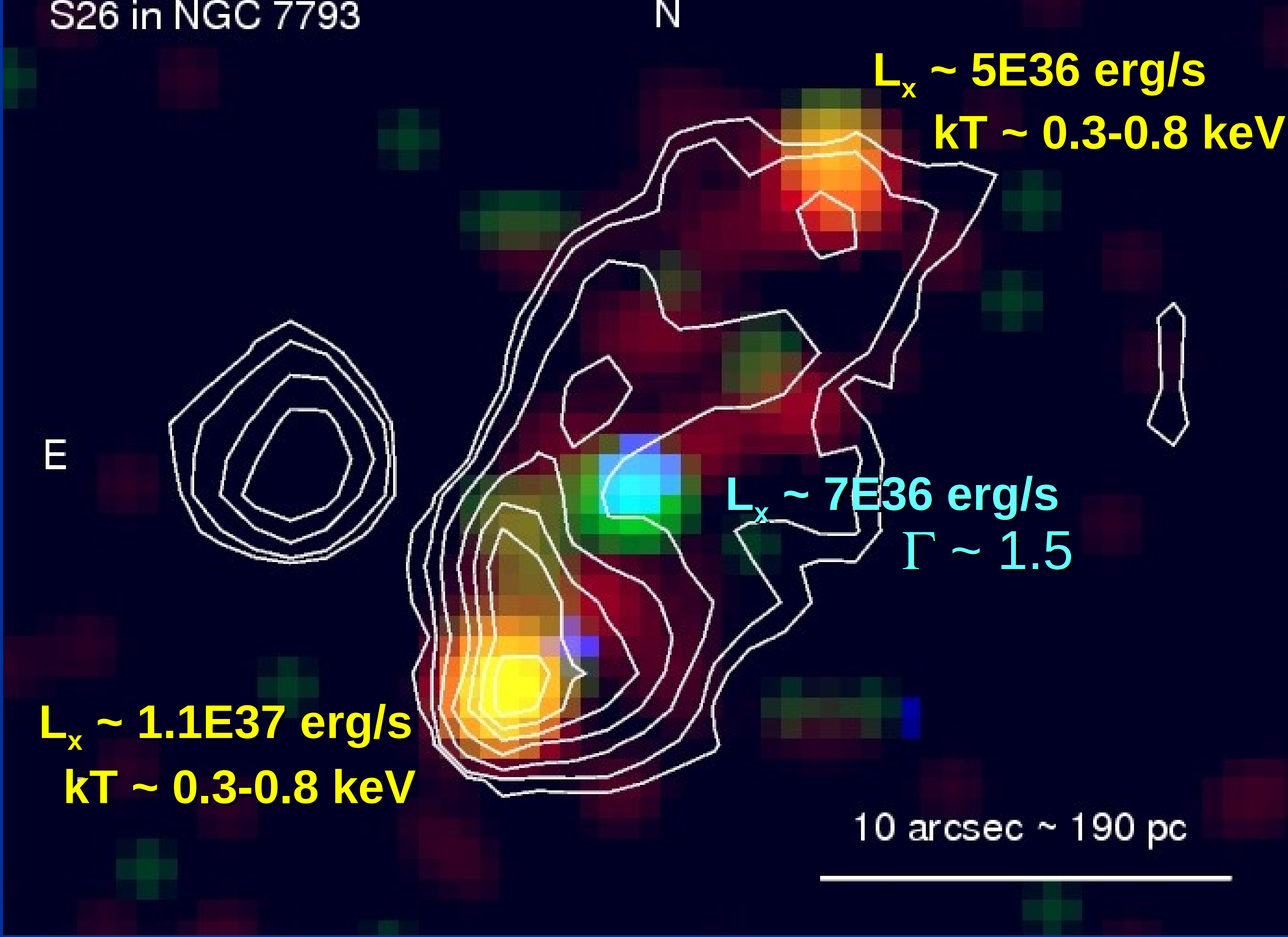


S26 in NGC 7793



(Magellan image from J Liu)


S26 in NGC 7793
N
E
10 arcsec ~ 190 pc



Chandra study: Pakull et al 2010, in prep
Hα contours from CTIO (SINGS survey)

6. Jets and outflows

ULXs blow bubbles

Energy in the bubbles ~ 1E52 erg (> SN)

In some sources,
L_x << 1E39 erg/s today, but P_w >~ 1E39 erg/s

"ULXs in low/hard state"

eg, S26 in NGC 7793

IC10 X1 (M_{BH} ~ 30 M_{sun}, Prestwich et al 2007)

Test for BH feedback at very high accretion rates
Comparisons with early quasars?

7. Outliers (IMBHs?)

ULX in M82 may be true IMBH candidate

Diskbb spectrum? (Feng & Kaaret 2009, in press)

Incipient nuclear BH of M82?
Nucleus of accreted satellite?

L_x ~ 5E40 erg/s

Nuclear BHs of satellite galaxies may be confused for ULXs

7. Outliers (IMBHs?)

3 or 4 “supersoft ULXs” (T_{bb} < 100 eV) still unexplained

(IMBHs? thick outflows, expanded WD photospheres?) (J Liu, A Kong et al)

Other “unusual ULXs” proved to be background AGN
or foreground CV

Claim of a ULX with L_x ~ 1E42, M_{BH} >~ 1000 M_{sun}

soft X-ray spectrum (Farrell et al 2009, Nature)
No optical counterpart down to V ~ 26.5 mag

But I suspect it’s a foreground neutron star,
perhaps with brown-dwarf or M-dwarf companion

How to make progress: we need…

- Timing studies, QPOs, power spectrum at ν > 1 Hz
- Kinematic BH masses from optical spectroscopy
- VLA studies of radio cores (5 GHz flux <~ 0.01 mJy)
- X-ray spectra > 10 keV,
  to measure photon index and cutoff energy