New observations of ULX supershells, and their implications

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In collaboration with:

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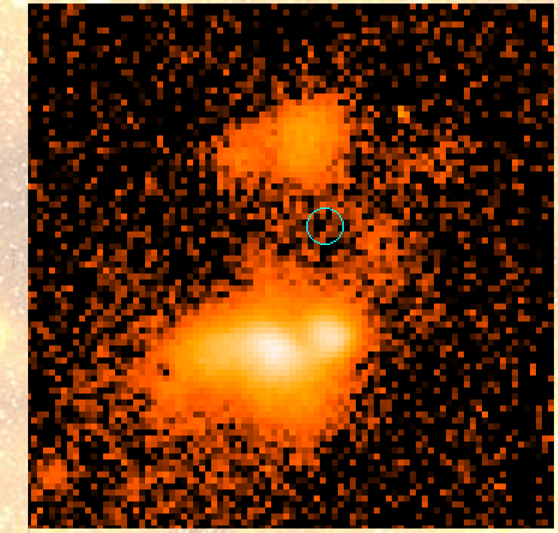
Ultra-Luminous X-ray Sources and Middle Weight Black Holes,
24–26 May 2010, ESAC, Madrid

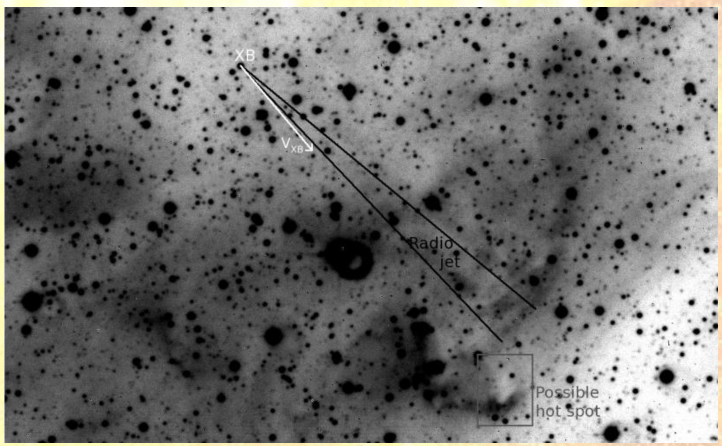
What's to come?

→ Brief introduction to nebulae & supershells associated with ULXs (ULXN)

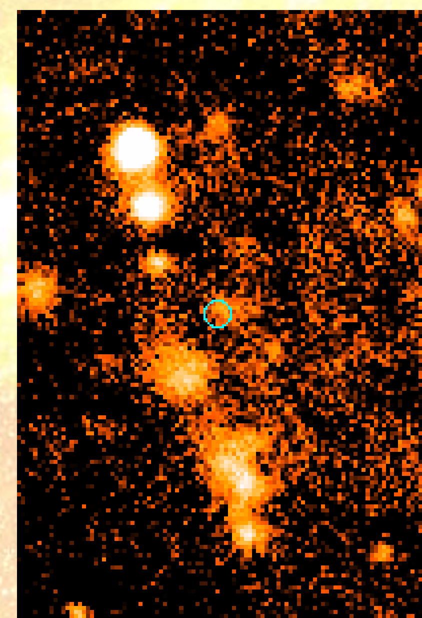


→ Energetics: photon and collisional excitation

→ Analogies to nebulae associated with normal X-ray binaries and AGN



→ New results: 5 galaxies, 8 ULXs, how many nebulae?



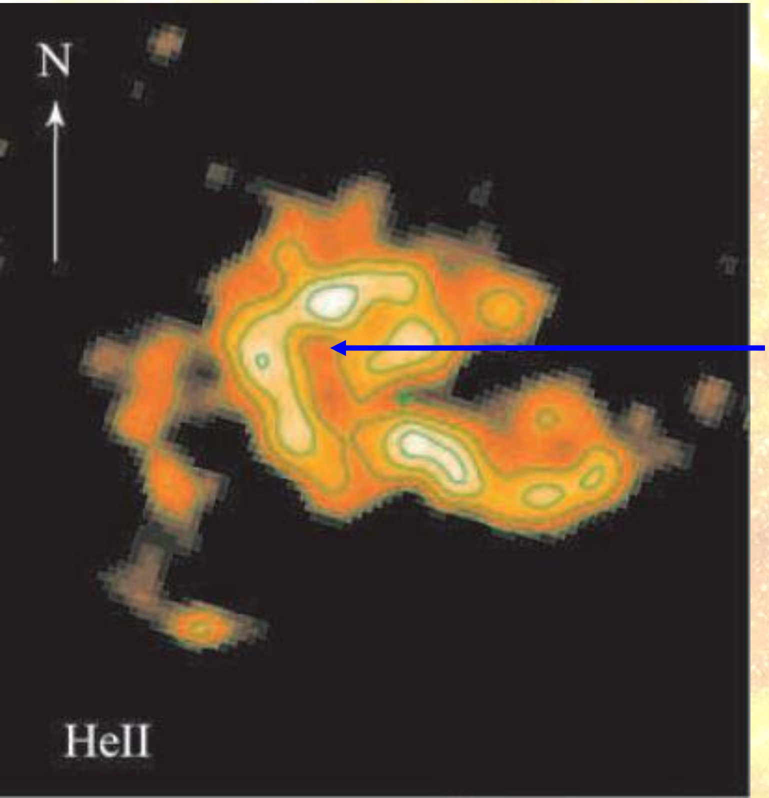
→ Summary

What are supershells / bubbles?

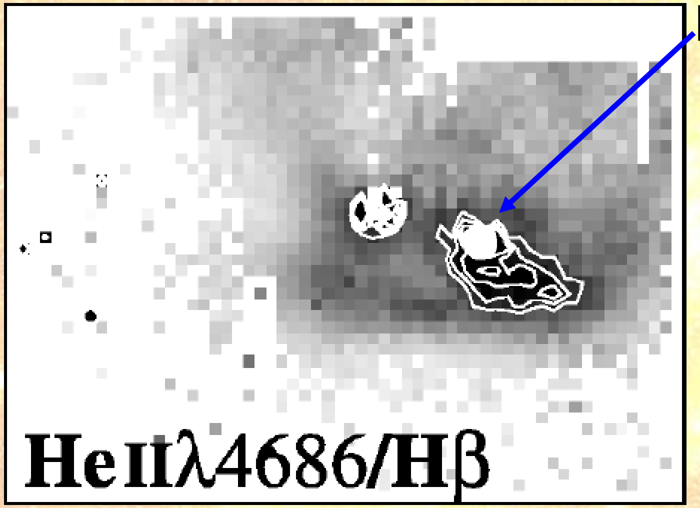
Demonstration by example:

- ULX Holmberg II X-1
- He III region surrounding ULX
- Excitation from UV or X-ray source
- Consistent with Lx of ULX if isotropic
- Kaaret et al. (2004) - HST imaging

1” = 15 pc



X-ray Ionized Nebulae (XIN) have been detected before: LMC X-1 (Pakull & Angebault 1986, Cooke et al. 2008)



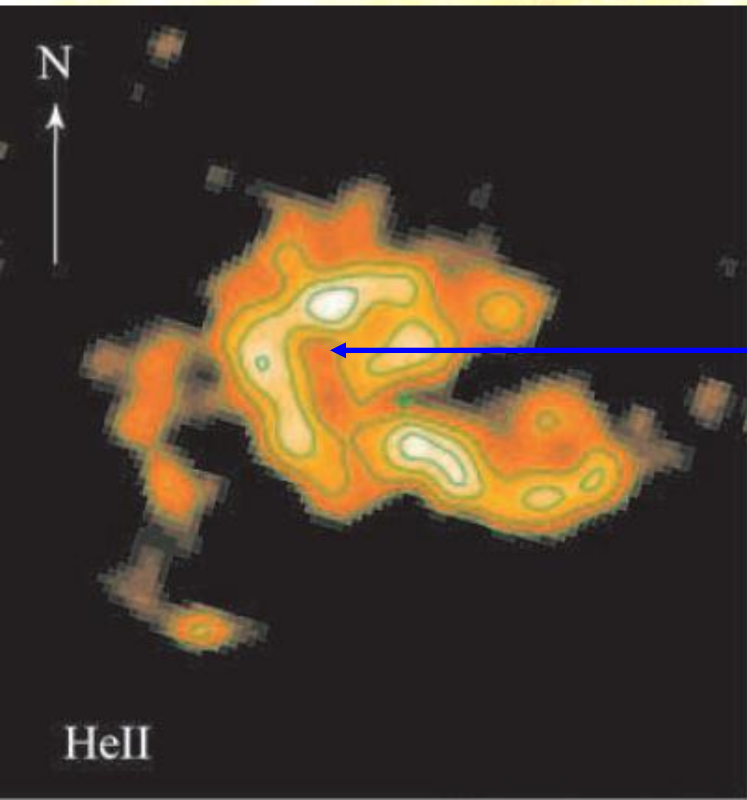
What are ULXN / supershells?

Demonstration by example:

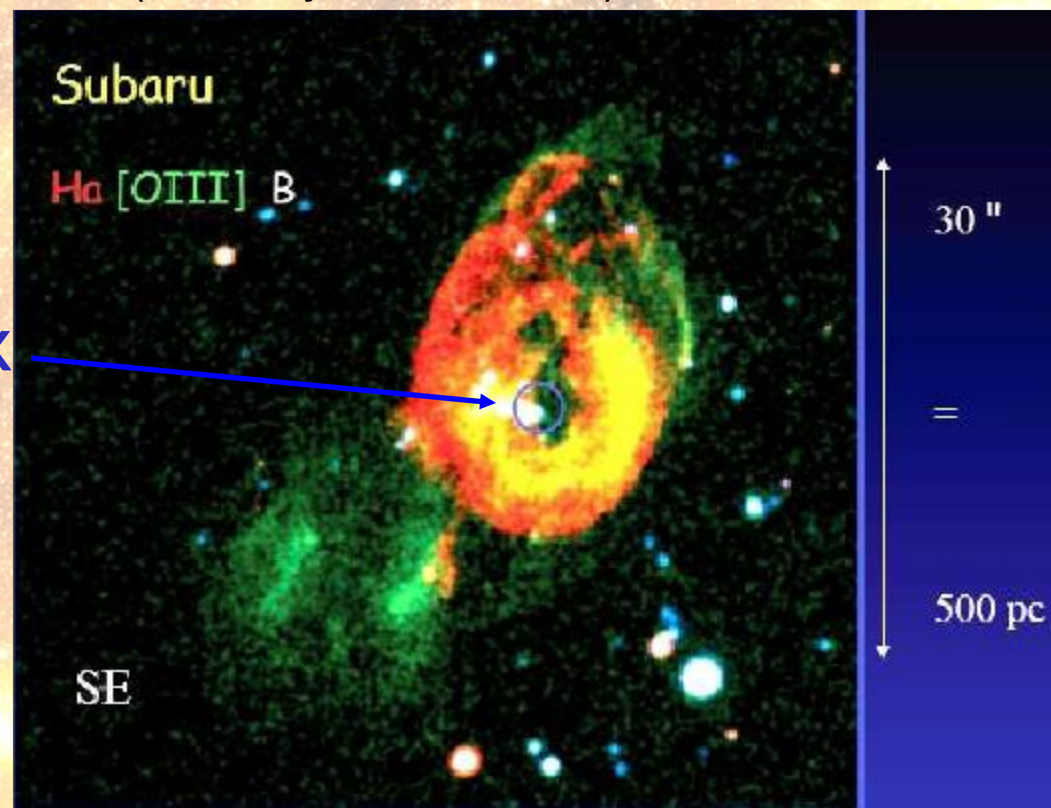
- ULX Holmberg II X-1
- He III region surrounding ULX
- Excitation from UV or X-ray source
- Consistent with Lx of ULX if isotropic
- Kaaret et al. (2004) - HST imaging

- ULX Holmberg IX X-1
- Shell 1 order of magnitude larger (e.g. Miller 1995, Pakull & Grisé 2008)
- Kinetic energy of the shell is 10^52 erg/s, from expansion velocity and density → not SNR (Ramsey et al. 2006)

1” = 15 pc

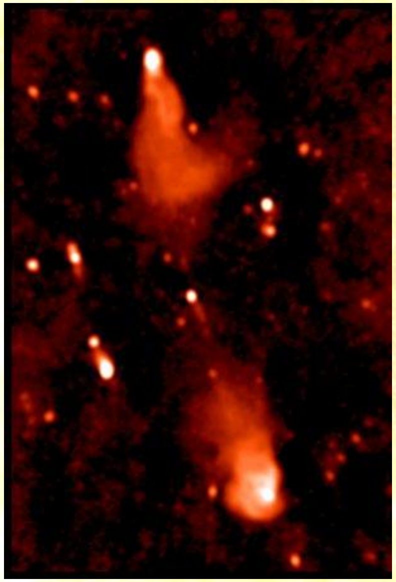


ULX



Quasars and Microquasars

Radio lobes



FR II Radio Galaxy
NVSS 2146+82
at 1.4 GHz
(Palma et al. 2000)

Cen A
Multiwavelength
(Kraft et al. 2008)

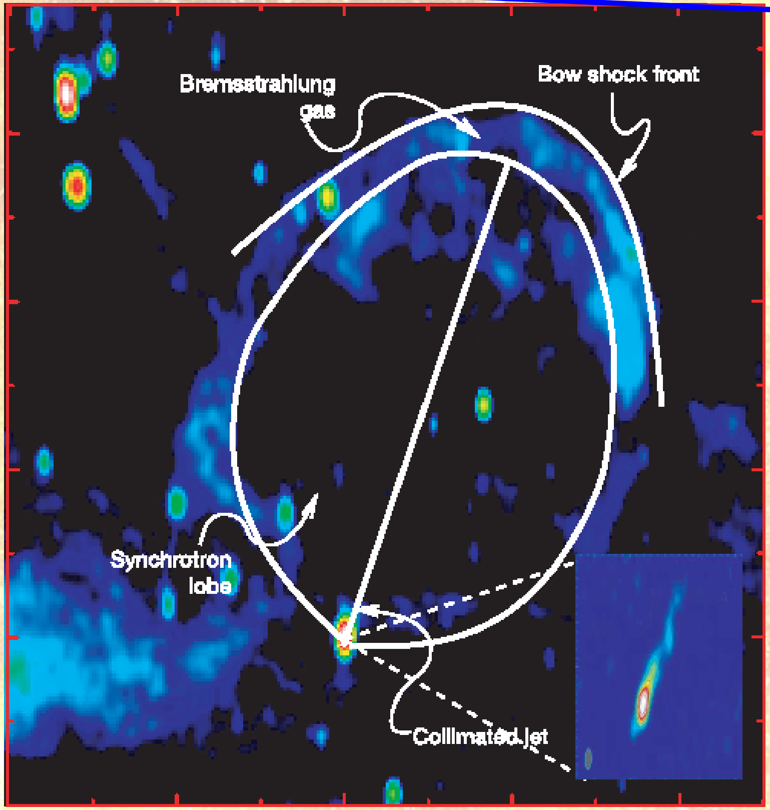
Supermassive black hole jets

Stellar-mass black hole jets

Black Hole X-ray Binary
1E 1740.7-2942
(Mirabel et al. 1992)

Black Hole X-ray Binary
GRS 1758-258
(Martí et al. 2002)

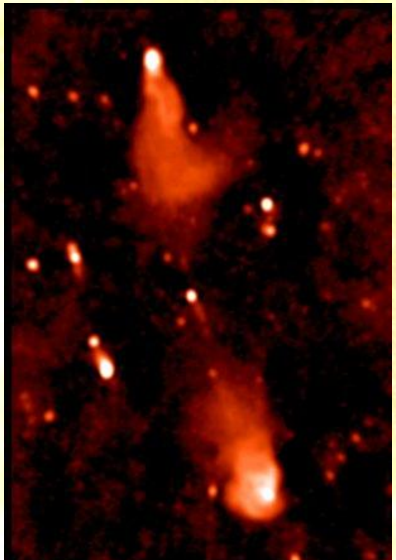
Bow shocks



Cygnus X-1: Gallo et al. 2005, Russell et al. 2007

Quasars and Microquasars

Radio lobes



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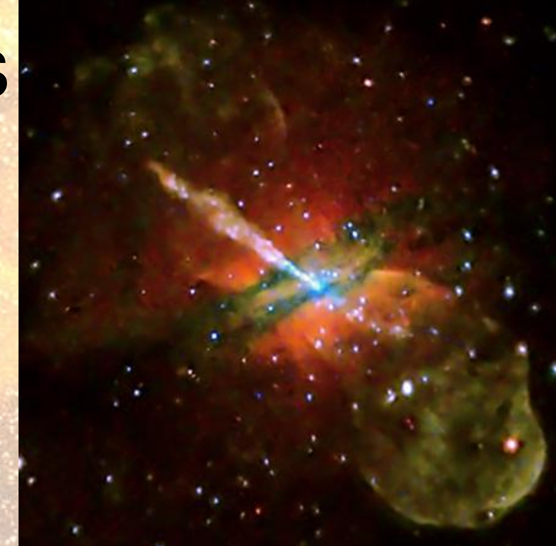
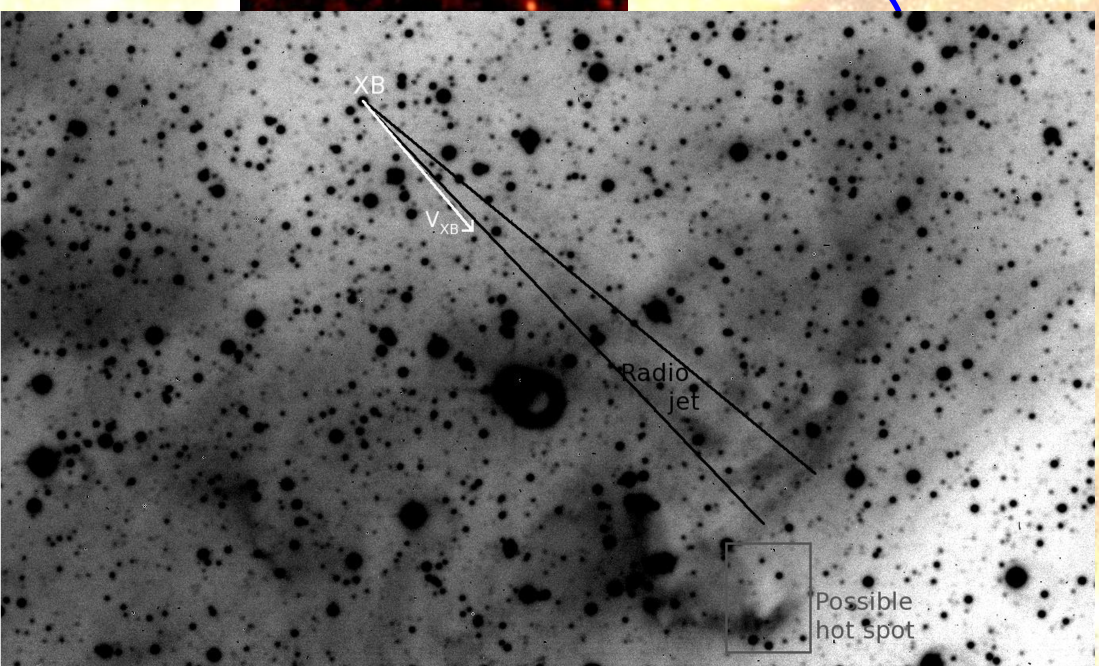
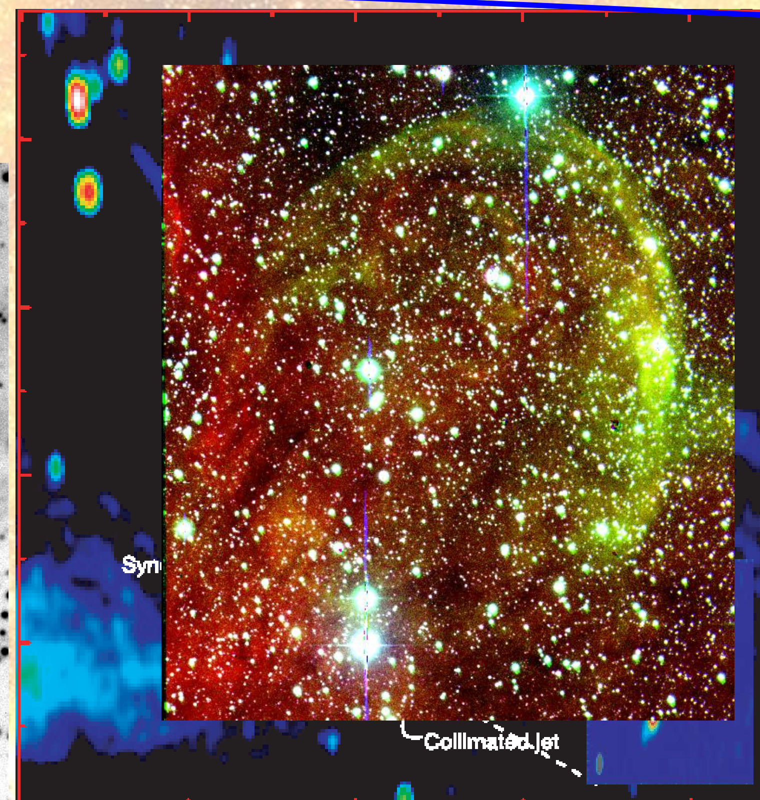


Supermassive black hole jets



GRO J1655-40 (Miller-Jones, Russell, et al. in prep.)

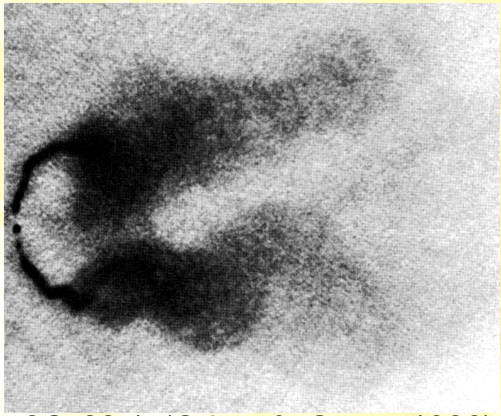


Cygnus X-1: Gallo et al. 2005, Russell et al. 2007

Quasars and Microquasars

Cen A
Multiwavelength
(Kraft et al. 2008)

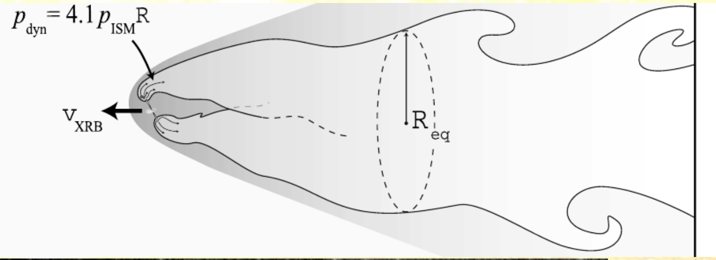
Head-tail trails



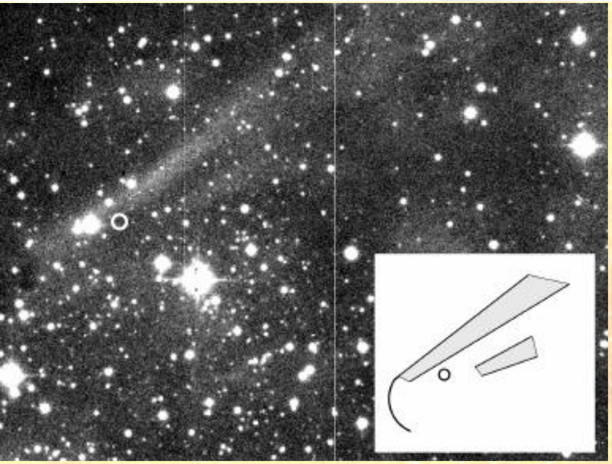
3C 83.1 (Odea & Owen 1986)

FR II Radio Galaxy
NVSS 2146+82
at 1.4 GHz
(Palma et al. 2000)

Supermassive black hole jets



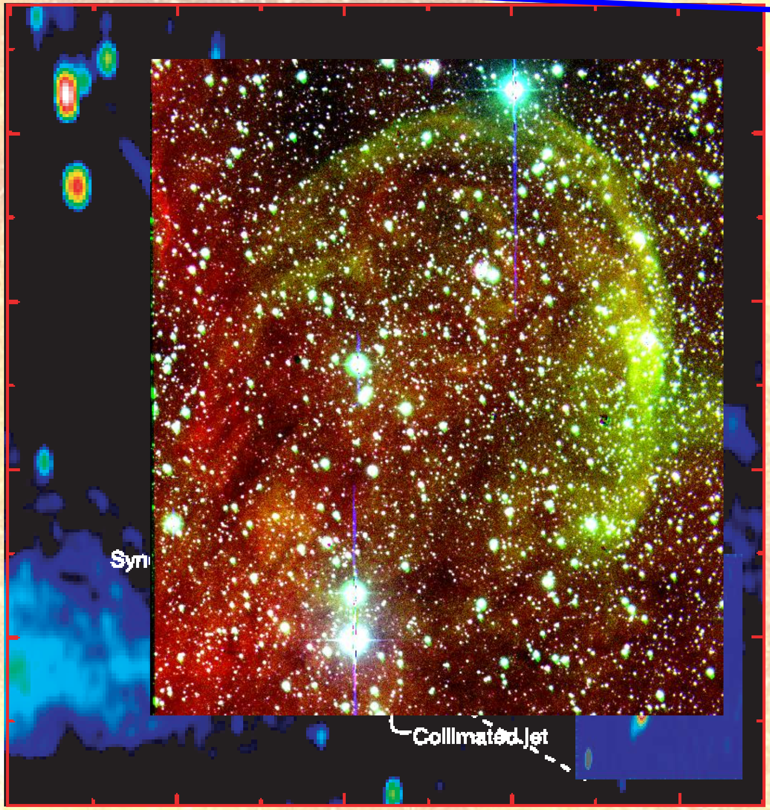
Stellar-mass black hole jets



Predicted by
Heinz et al. 2008 for
fast moving LMXBs

Possible first
detected XB
head-tail source:
SAX J1712.6-3739
(Wiersema et al. 2009)

Bow shocks



Cygnus X-1: Gallo et al. 2005, Russell et al. 2007

New observations

- We imaged 5 galaxies containing ULXs using 2 telescopes:
  The Isaac Newton Telescope and Wide Field Camera (La Palma; north)
  The Danish 1.5m Telescope and EFOSC (La Silla, Chile; south)

- Many emission line filters:

[O II]	3727 Å	
He II	4686 Å	
Hβ	4861 Å	
[O III]	5007 Å	
Hα	6563 Å	
[S II]	6716 + 6731 Å doublet	

- Continuum subtraction using redshifted Hα line filter and V-band

- Gemini North + GMOS : 48 mins of integration on NGC 5204 X-1
  PI: J. Gladstone
  Slit 0.75”x330”, spectral coverage 3250–6000 Å
  orientated north–south, strong nebula lines detected

NGC 5204 X-1

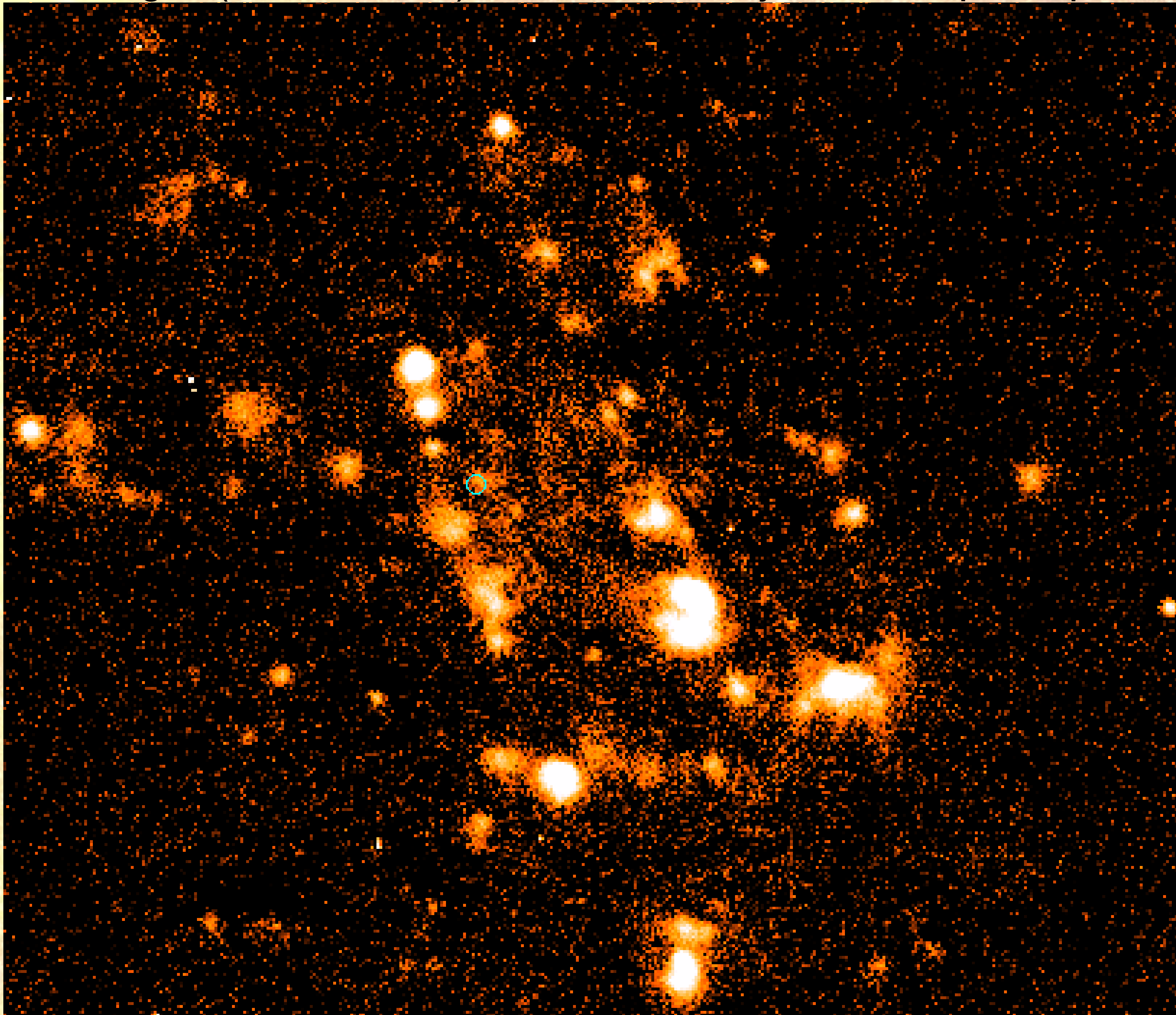
ULX has Lx = 7 x 10^39 erg/s (0.5 - 8 keV)

Galaxy is a warped spiral

- Continuum:

Hα redshifted
600 sec

- Optical counterpart: e.g. Roberts et al. papers
- Hα (continuum subtracted) taken with CFHT (Pakull & Mirioni 2002)
- Abolmasov et al. 2007: nebula lines
- [S II] (continuum subtracted)
- He II (continuum subtracted)
- [O II] (continuum subtracted)
- [O III] (continuum subtracted)

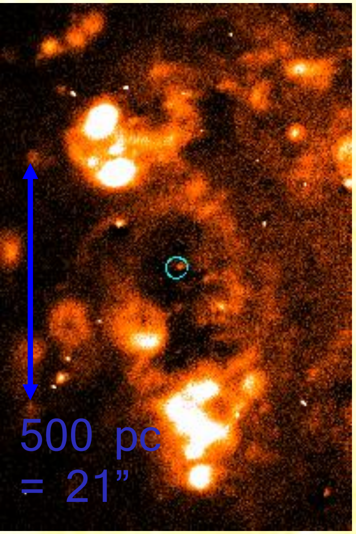


NGC 5204 X-1

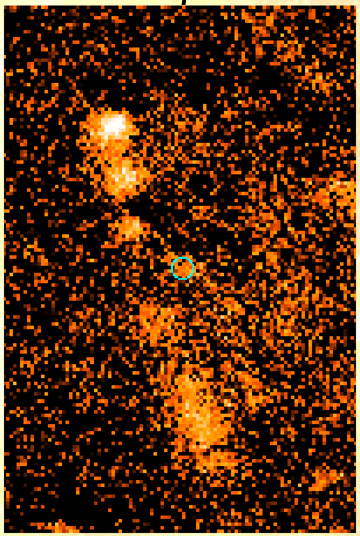
ULX has Lx = 7 x 10^39 erg/s (0.5 - 8 keV)

Galaxy is a warped spiral
D = 4.8 Mpc

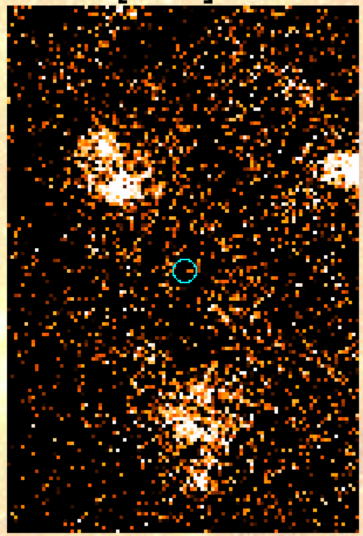
Hα



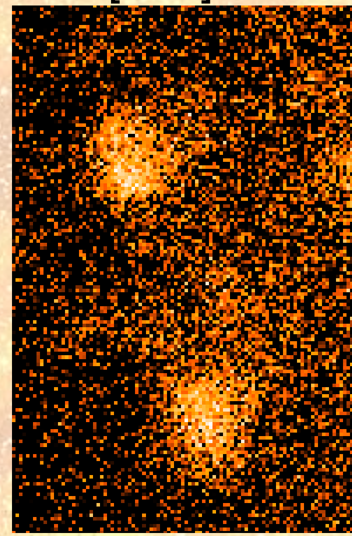
Hβ



[S II]

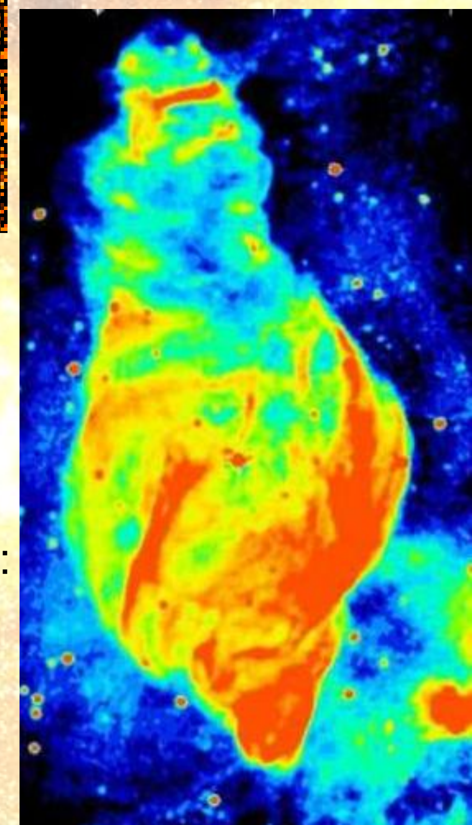


[O II]

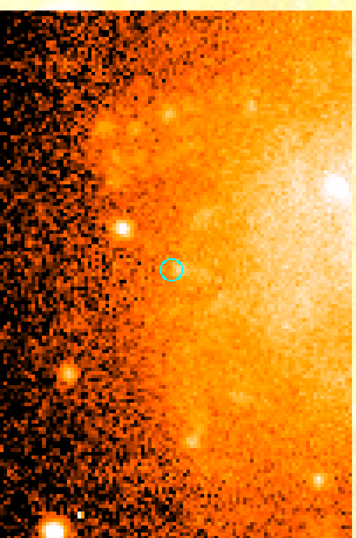


Strong [S II], [O II], [O III], weak He II

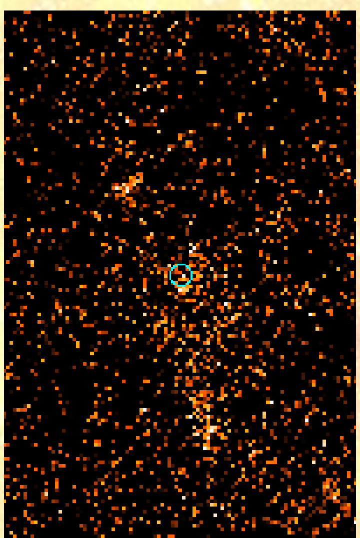
SS 433 / W50 complex



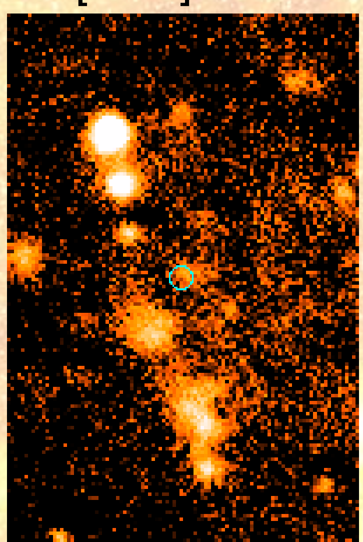
Continuum



He II



[O III]



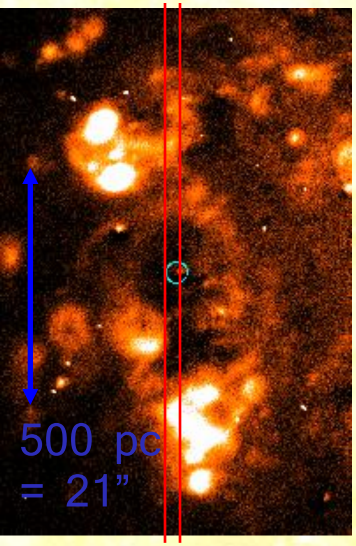
- ULXN: similar morphology to W50, about 2.5 times larger

- Gemini spectra: a further 6 lines are detected

NGC 5204 X-1

ULX has Lx = 7 x 10^39 erg/s (0.5 - 8 keV)

Galaxy is a warped spiral
D = 4.8 Mpc



Gemini GMOS spectra:

- 10 nebula emission lines are detected
- Balmer decrement constrained: E(B-V) = 0.44 +- 0.04
- Preliminary results:

- We compare the de-reddened line ratios to models of radiative shock waves (MAPPINGS; Allen et al. 2008)
- We infer a probable shock velocity of ~ 200 km/s
- May be powered by the jets of the ULX? Further investigation required.

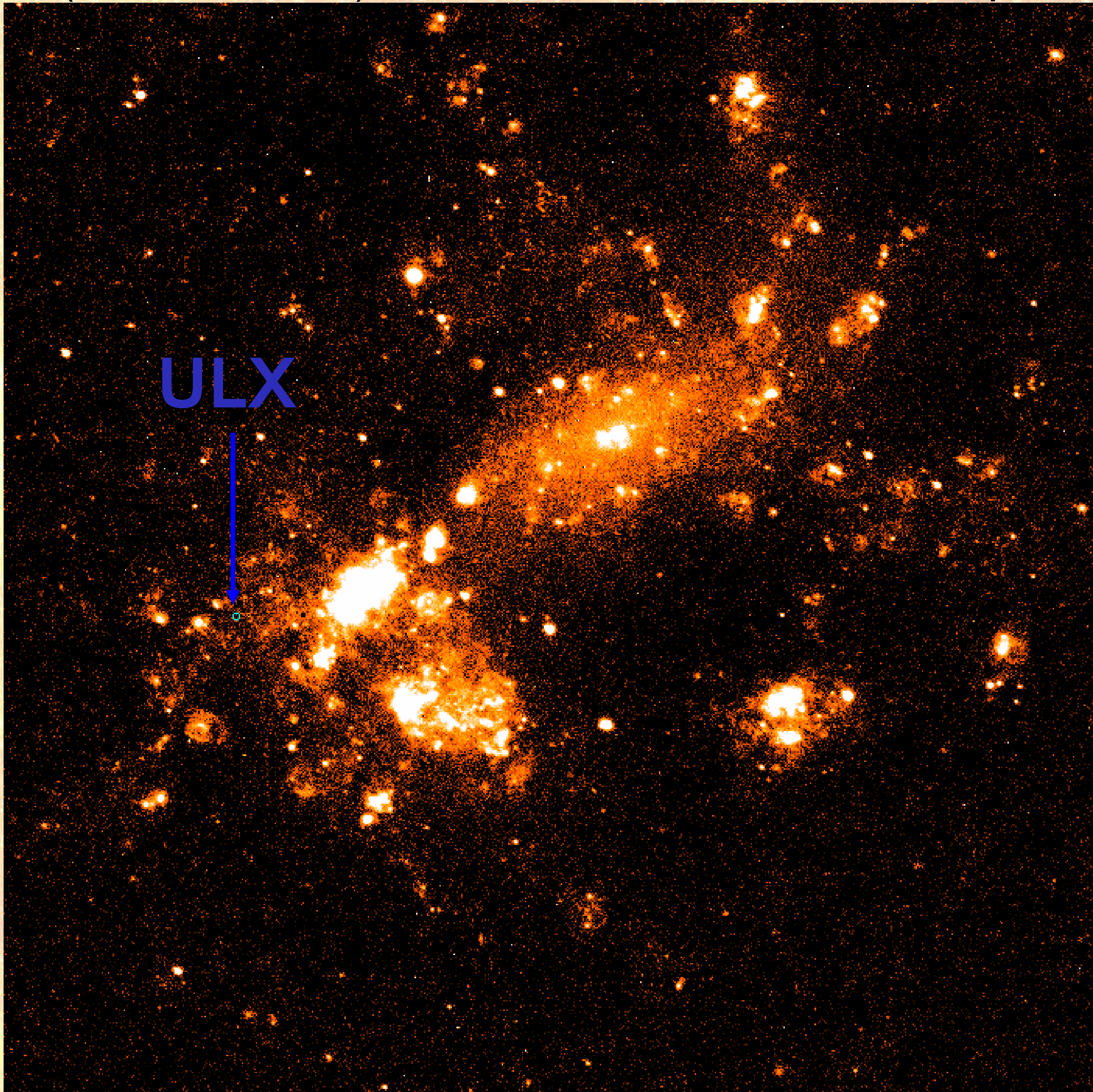
NGC 4395 X-1

ULX has Lx = 2 x 10^39 erg/s (0.1 - 2.4 keV)

D = 3.6 Mpc

No nebula reported so far,
But galaxy is close

Hα 1200 sec

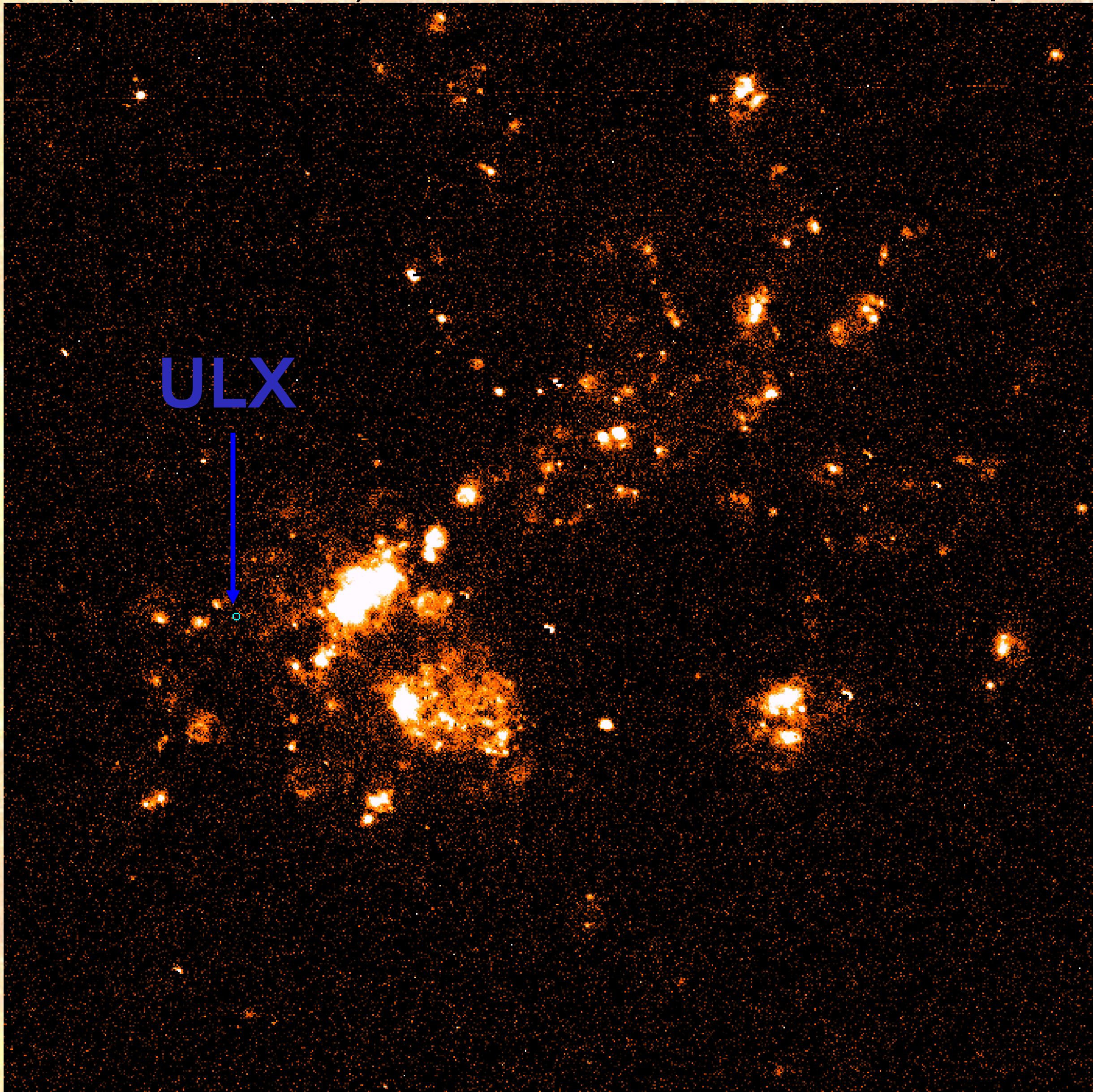


NGC 4395 X-1

ULX has Lx = 2 x 10^39 erg/s (0.1 - 2.4 keV) D = 3.6 Mpc

No nebula reported so far,
But galaxy is close

Hα 1200 sec
Continuum subtracted
using H-alpha redshifted
1200 sec



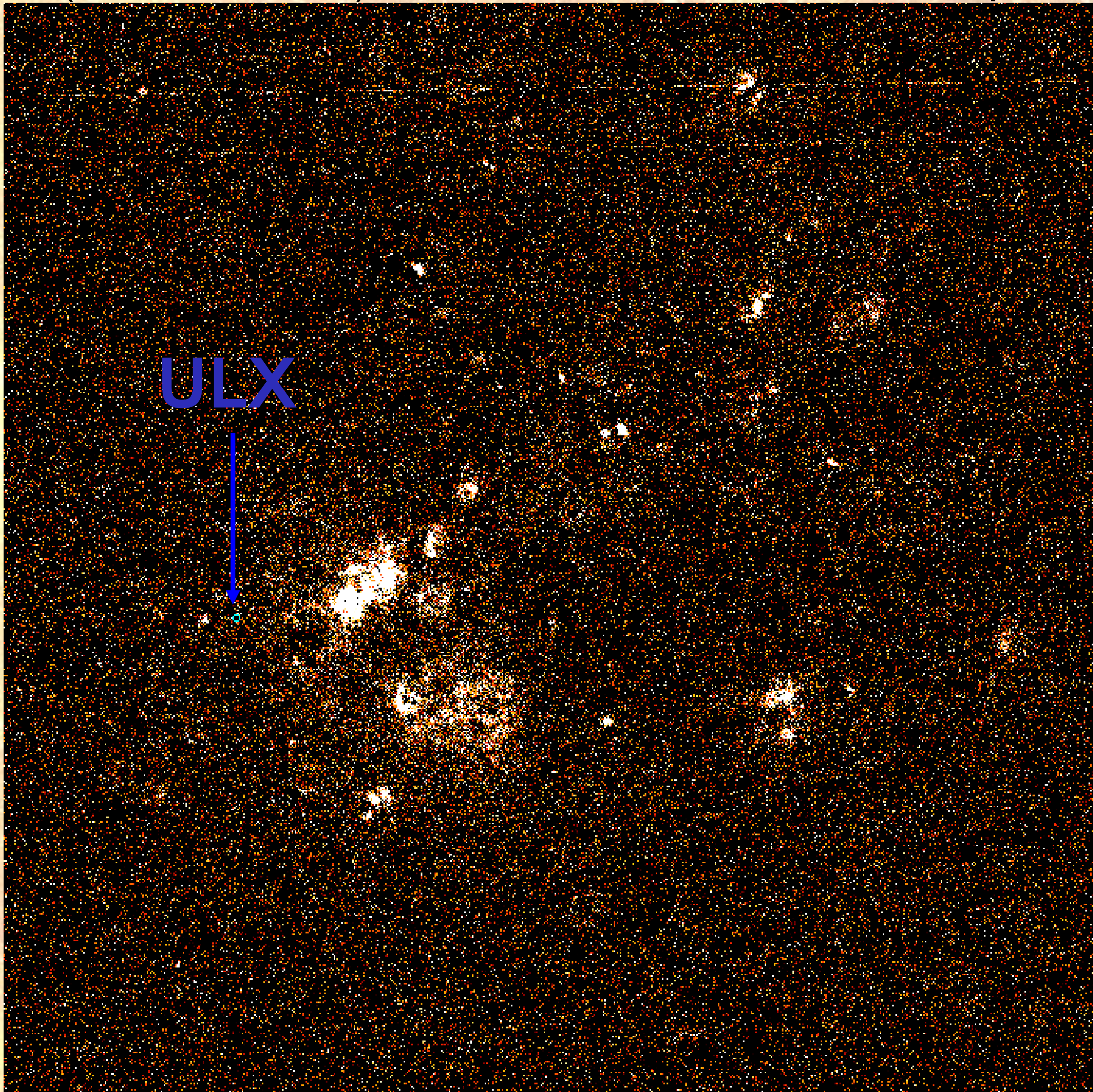
NGC 4395 X-1

ULX has Lx = 2 x 10^39 erg/s (0.1 - 2.4 keV) D = 3.6 Mpc

No nebula reported so far,
But galaxy is close

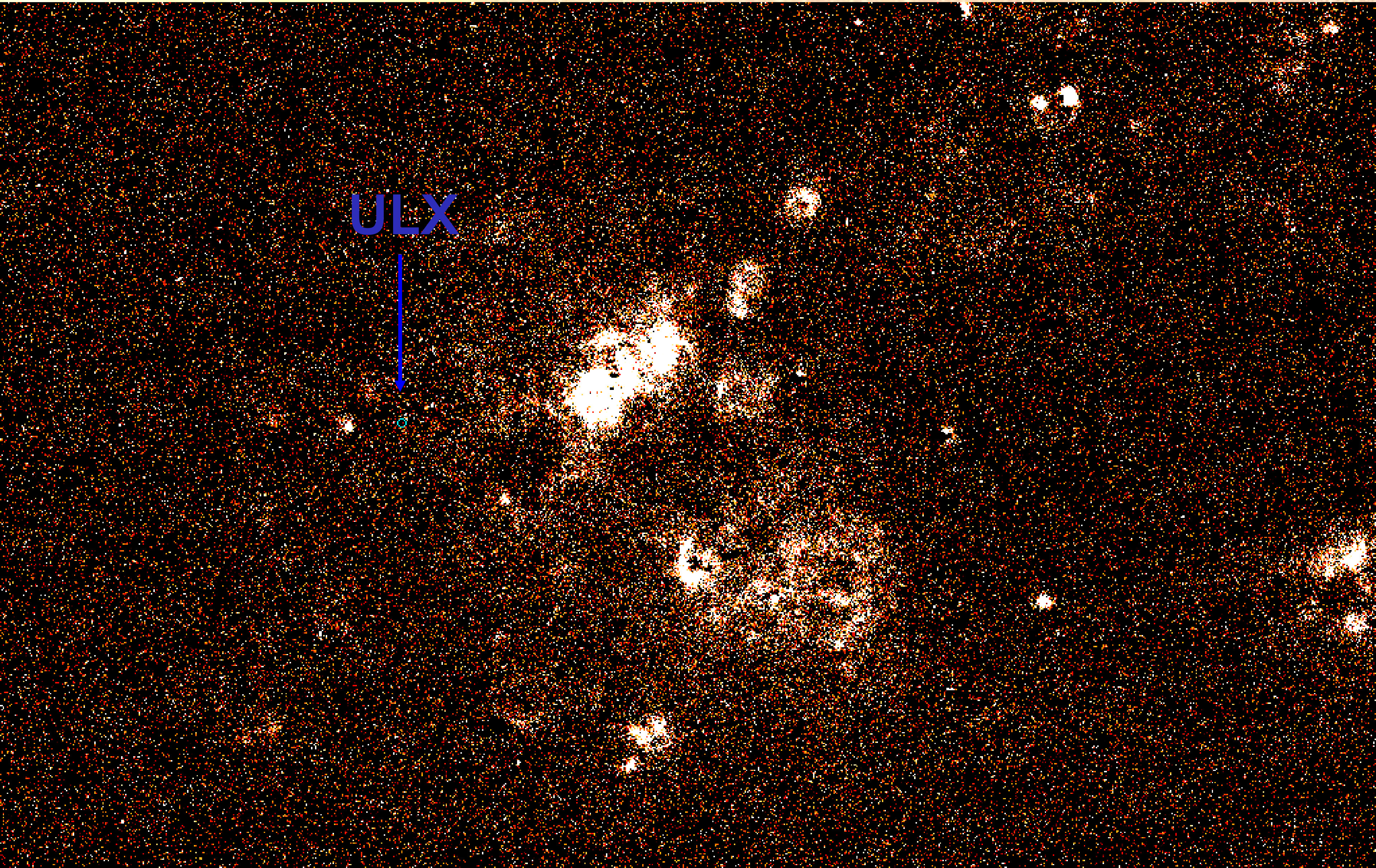
Hα 1200 sec
Continuum subtracted
using H-alpha redshifted
1200 sec

[S II] 1200 sec
Continuum subtracted



NGC 4395 X-1

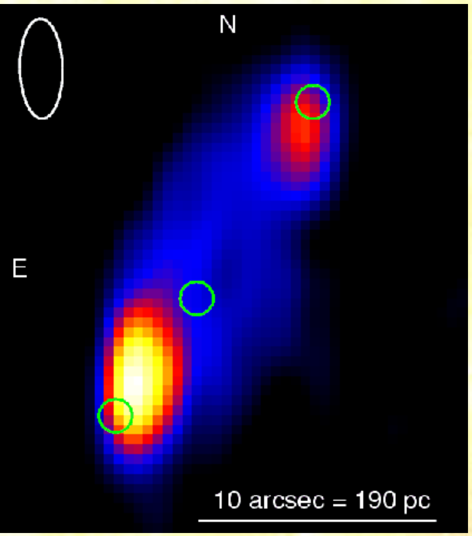
ULX has Lx = 2 x 10^39 erg/s (0.1 - 2.4 keV) D = 3.6 Mpc



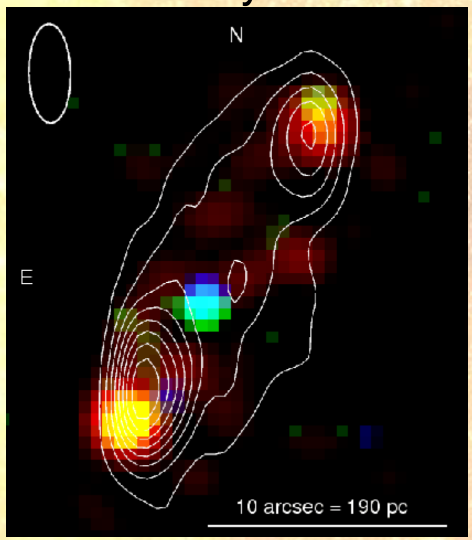
NGC 7793

Central X-ray source has Lx = 6 x 10^36 erg/s (0.3 - 8 keV)   D = 3.9 Mpc

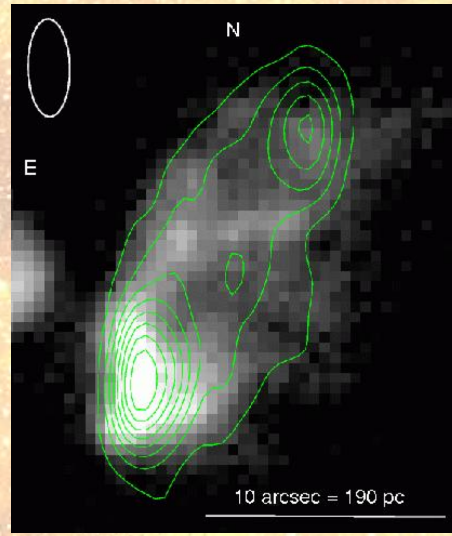
Radio



X-ray

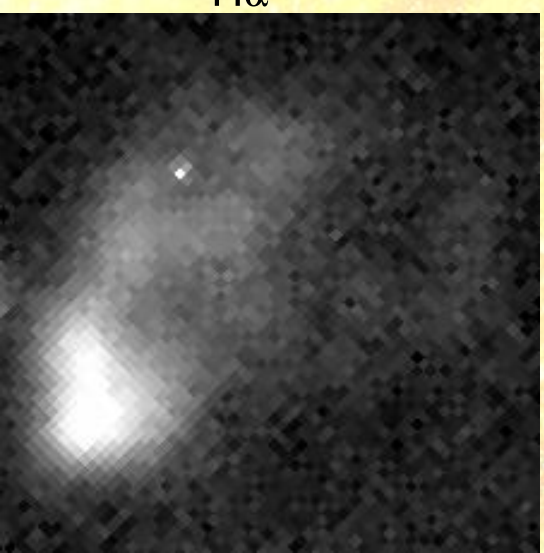


Hα

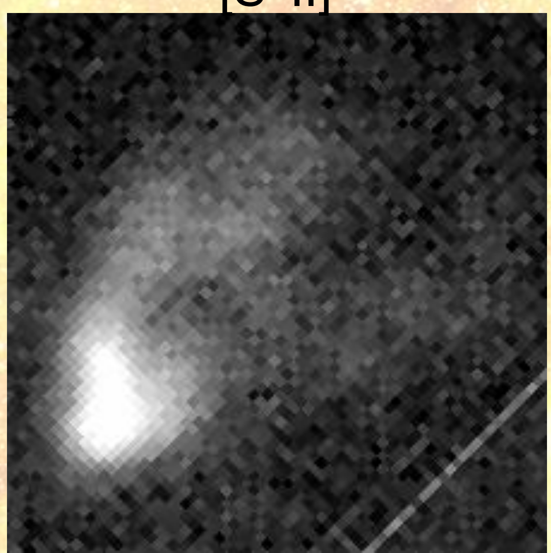


Pakull & Grisé (2008); Soria et al. (2009): three X-ray sources coincident with radio and Hα nebula

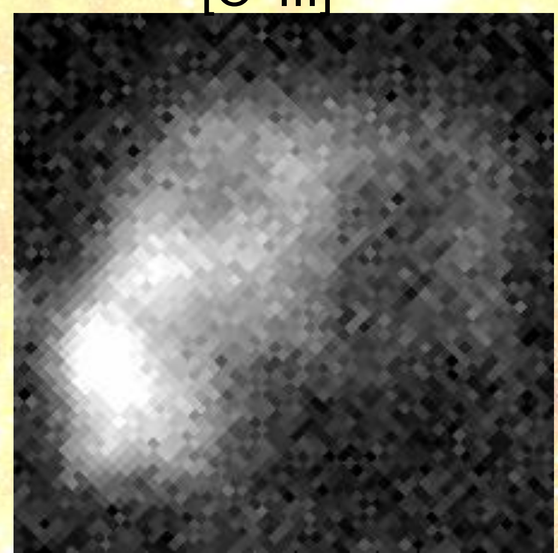
Hα



[S II]



[O III]

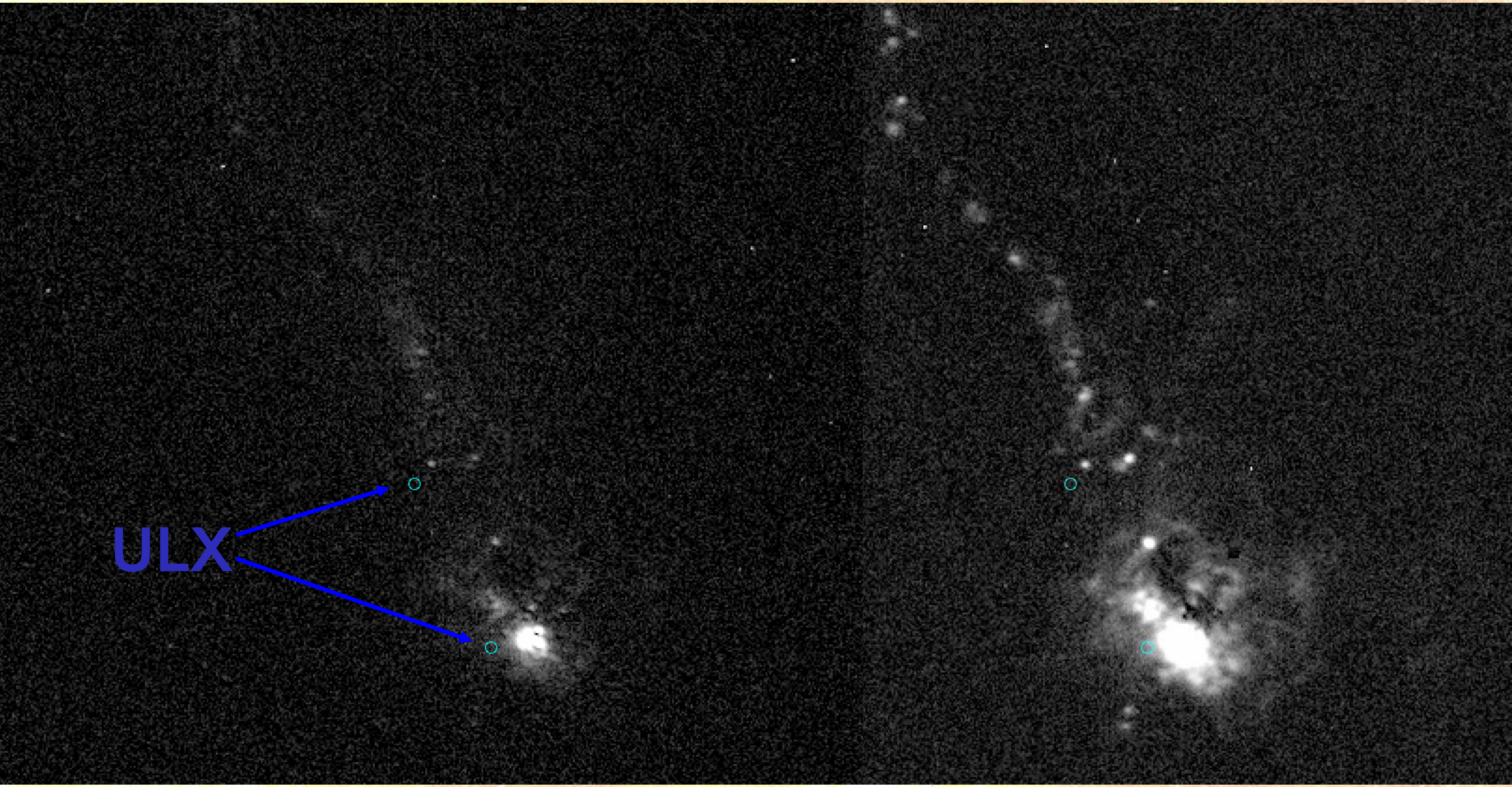


Our data

NGC 4861: 2 ULXs

Lx = 6 x 10^39 and 2 x 10^40 erg/s (2 - 10 keV) D = 17.8 Mpc

[S II] - continuum Hα - continuum



Hα nebulae close to both ULXs (mentioned also in Pakull & Mirioni 2002)

NGC 4559: 3 ULXs

Lx = 2 x 10^40, 1 x 10^40 and 3 x 10^39 erg/s (0.3 - 10 keV)   D = 9.7 Mpc

Continuum:
Hα redshifted   1200 sec

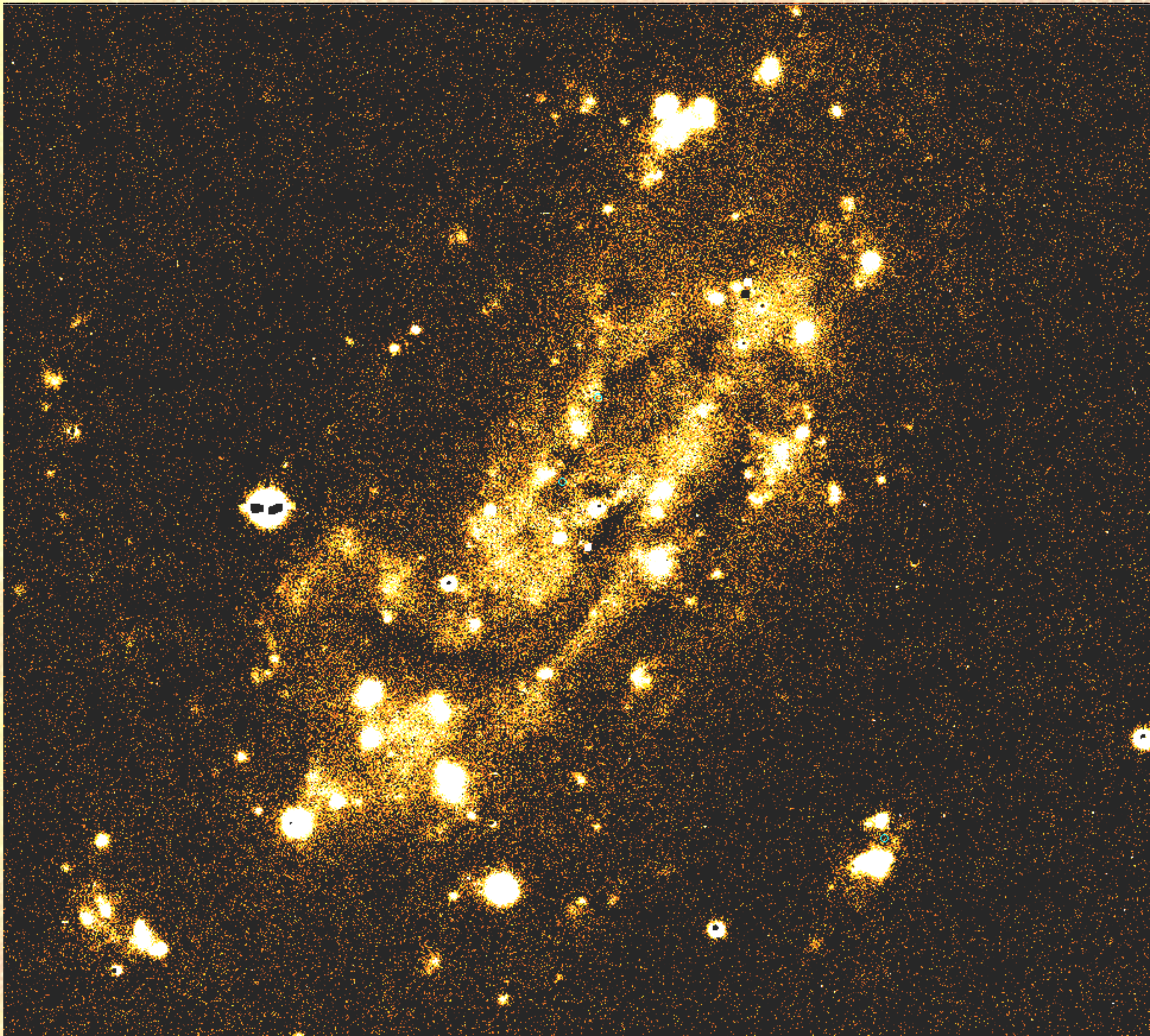
Hα 1200 s (-continuum)

[S II] 1200 s (-continuum)

He II 1200 s (-continuum)

[O II] 1200 s (-continuum)

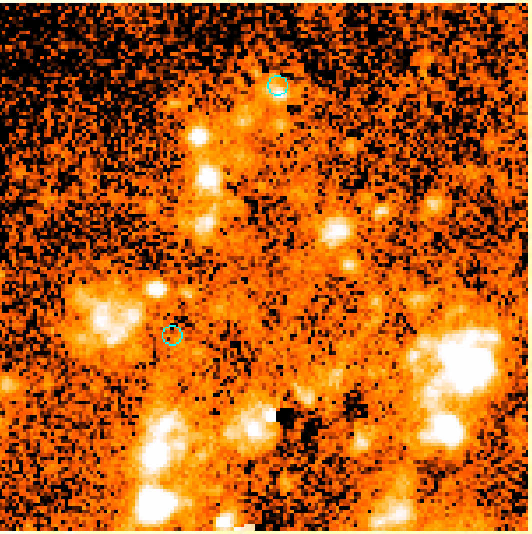
[O III] 1200 s (-continuum)



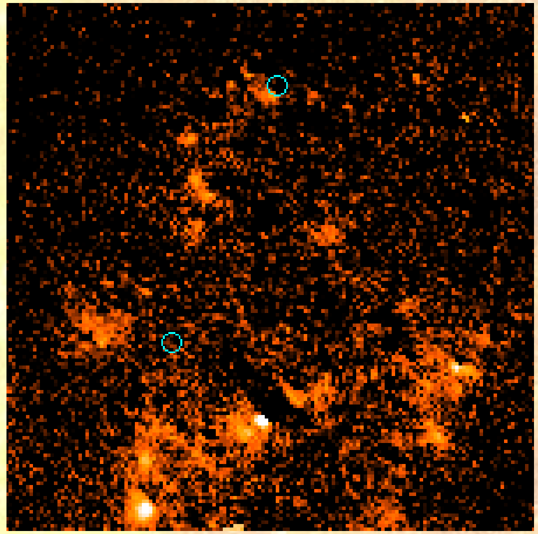
NGC 4559: 3 ULXs

Lx = 2 x 10^40, 1 x 10^40 and 3 x 10^39 erg/s (0.3 - 10 keV)   D = 9.7 Mpc

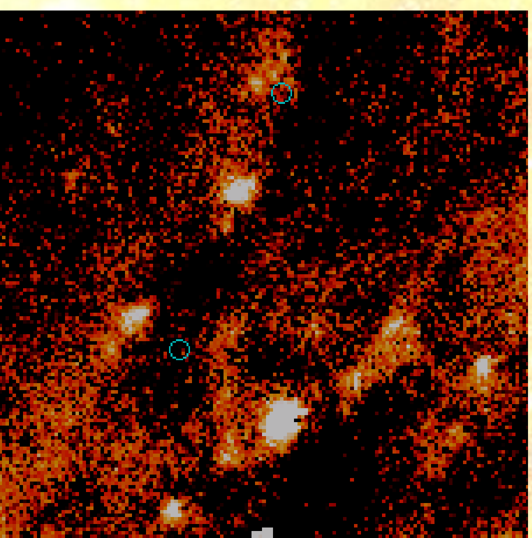
Hα



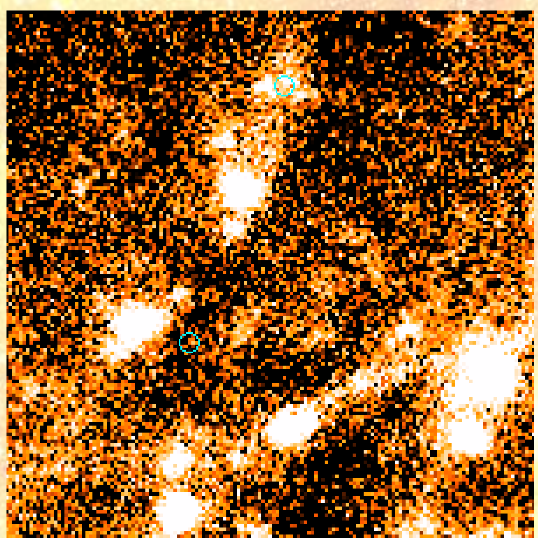
[S II]



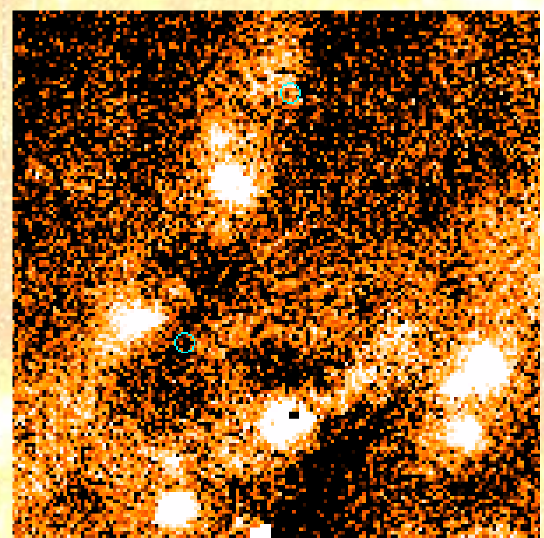
He II



[O II]



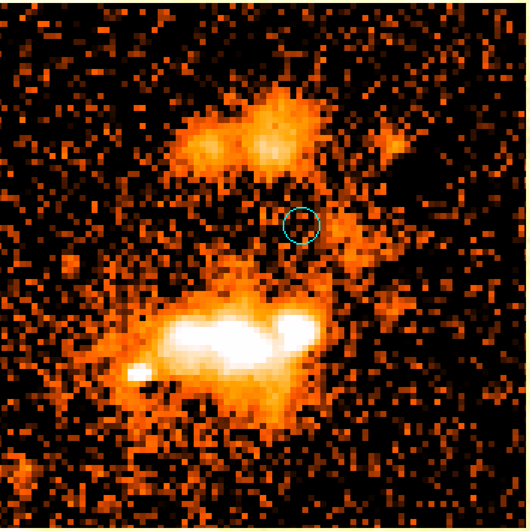
[O III]



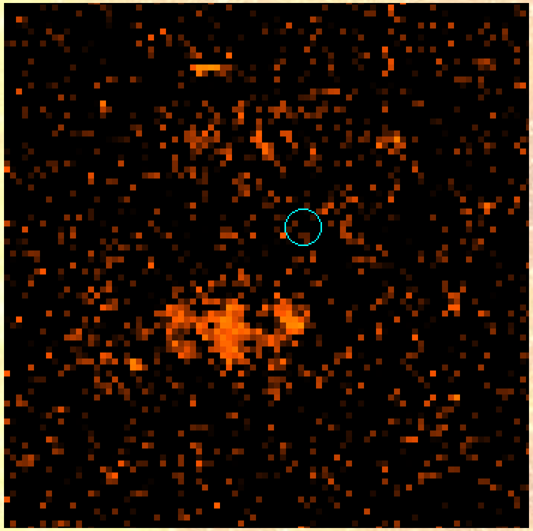
NGC 4559: 3 ULXs

Lx = 2 x 10^40, 1 x 10^40 and 3 x 10^39 erg/s (0.3 - 10 keV)   D = 9.7 Mpc

Hα

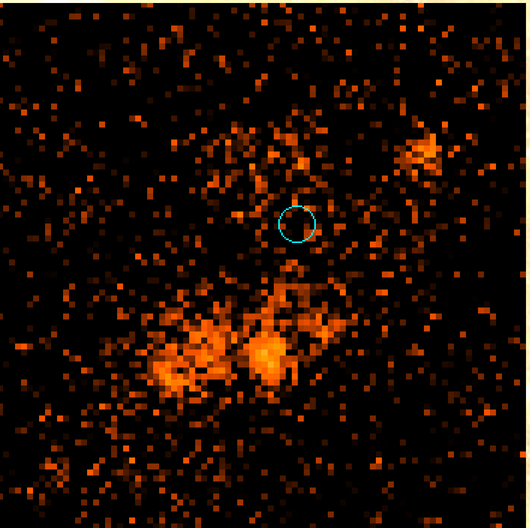


[S II]



Hα nebula also mentioned in Pakull & Mirioni (2002)

He II



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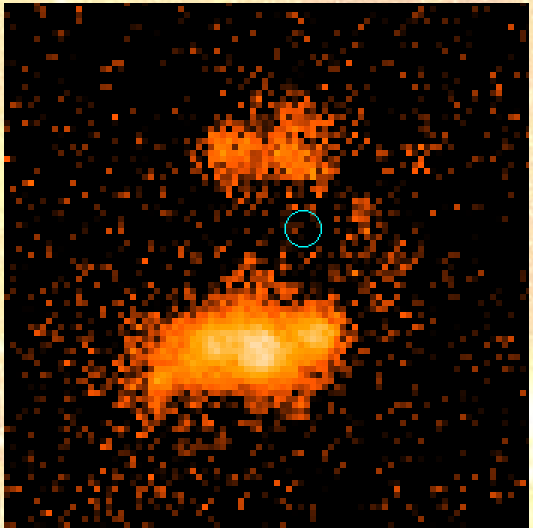
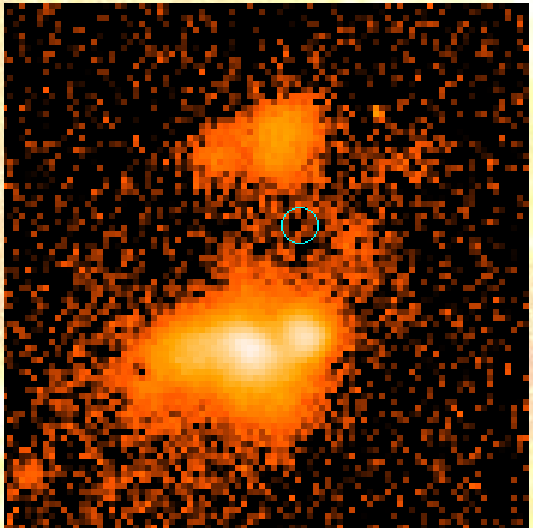
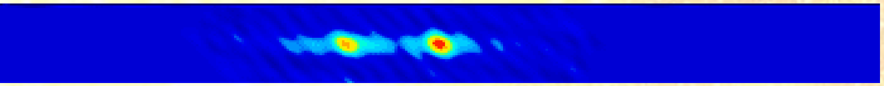


[O III]



X-ray Binary Jets

Black hole XB: GRO J1655-40



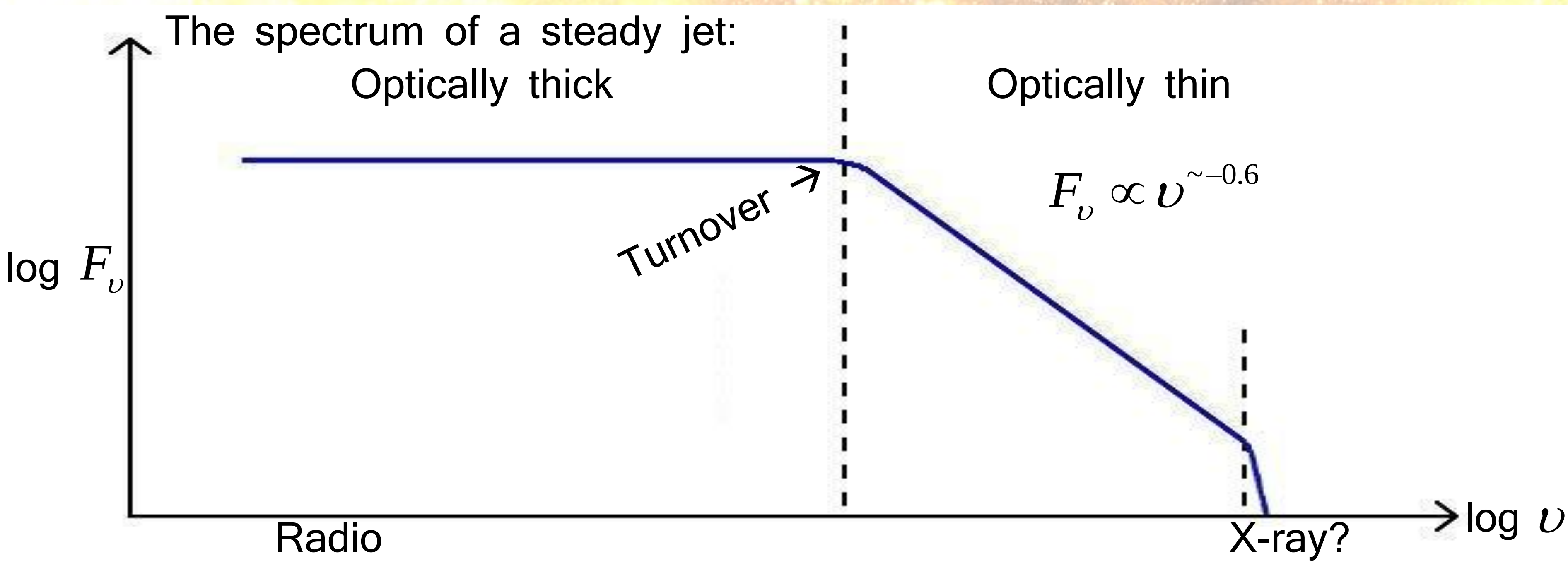
Tingay et al. 1995

Neutron star XB: Sco X-1

Fomalont et al. 2001

Radio emission: → is synchrotron in nature

→ originates in collimated outflows (2 types of jet)



The power carried in the jets is uncertain and highly dependent on the position of the turnover

Summary

- Many ULXs are associated with hundred-pc scale superbubbles - we may have discovered some examples (results are preliminary)
- These emission line nebulae seem to be visible with moderate size telescopes, but their Galactic analogues are fainter
- Photoionized nebulae may be the easiest way to infer UV spectra of ULXs and constrain beaming of X-rays
- Many ULXs are likely to be microquasars; some show bipolar nebulae
- It may be possible to constrain the jet/wind power in ULXs - this is very difficult in most microquasars! (at least using jet–ISM interactions)