BLACK HOLE POWERED NEBULA AROUND ULX IC342 X-1

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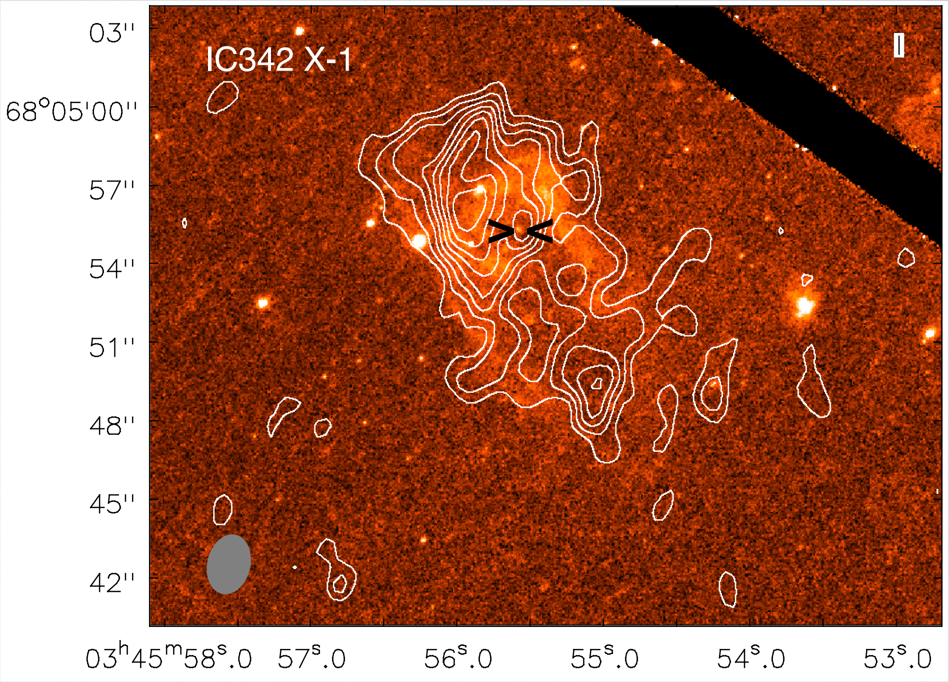
Outline



- Ultraluminous X-ray Sources (ULXs)

- How to power a ULX nebula?

- The total intrinsic power of a ULX

- Mass of the central black hole

- Jet inflated bubble?


Image credit: Heidi Sagerud

Introduction

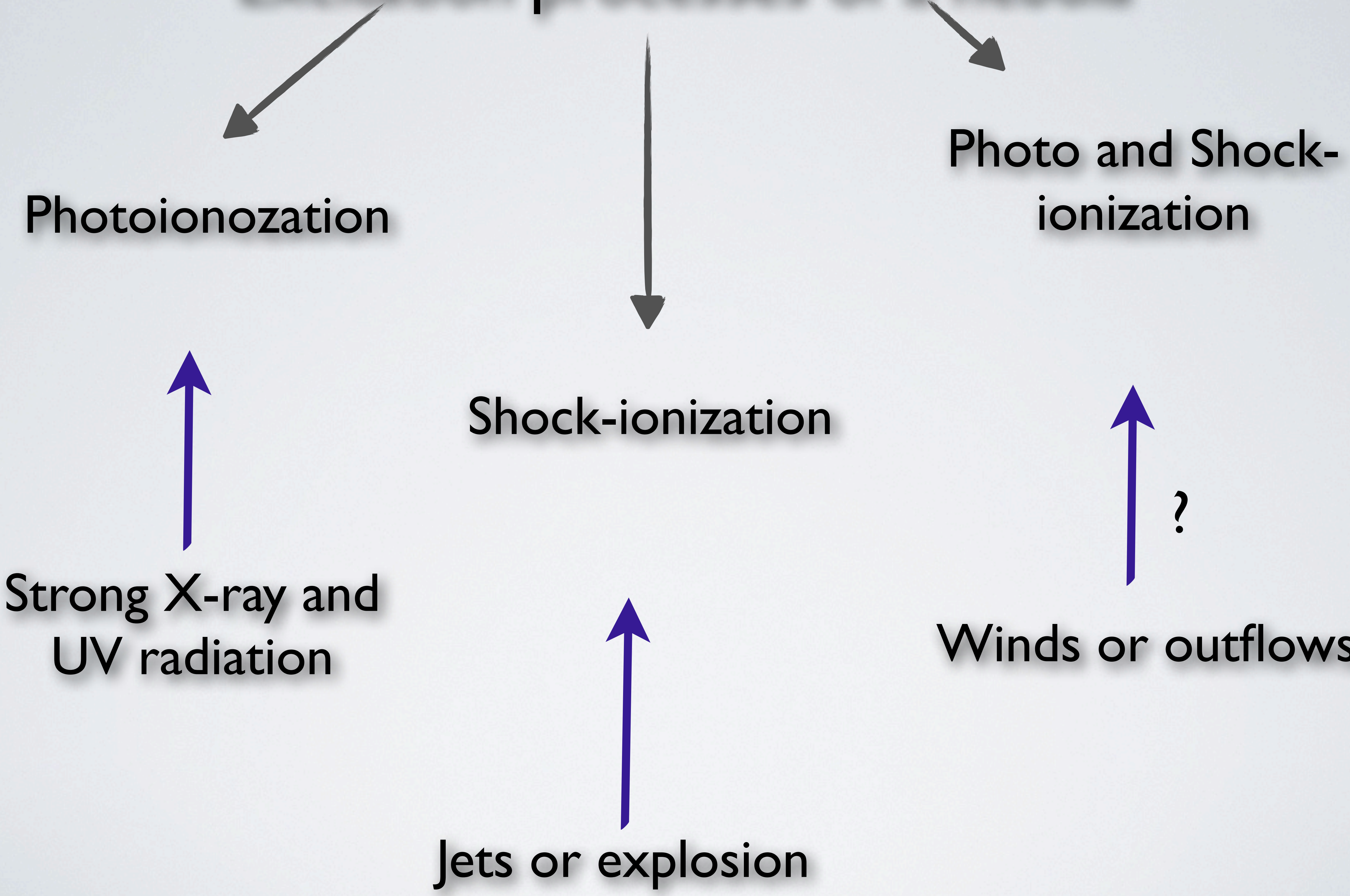
Explanations for the ULX phenomena:

- beamed (King+ 01, Kording+ 02)
- super-Eddington (Begelman 02)
- intermediate-mass black hole (Colbert & Mushotzky 99)
- mixture eg.: 100 $M_{\odot}$, mildly beamed, high accretion rate

Surrounding nebulae: (Pakull+ 02, Kaaret+ 03, Miller+ 04, Soria+ 06, Lang+ 07, Abolmasov+ 07)

- Can alter our knowledge in general
- Energy processes, evolution of the BH, feedback mechanisms, and even accretion rate

Excitation processes of a nebula



New observations

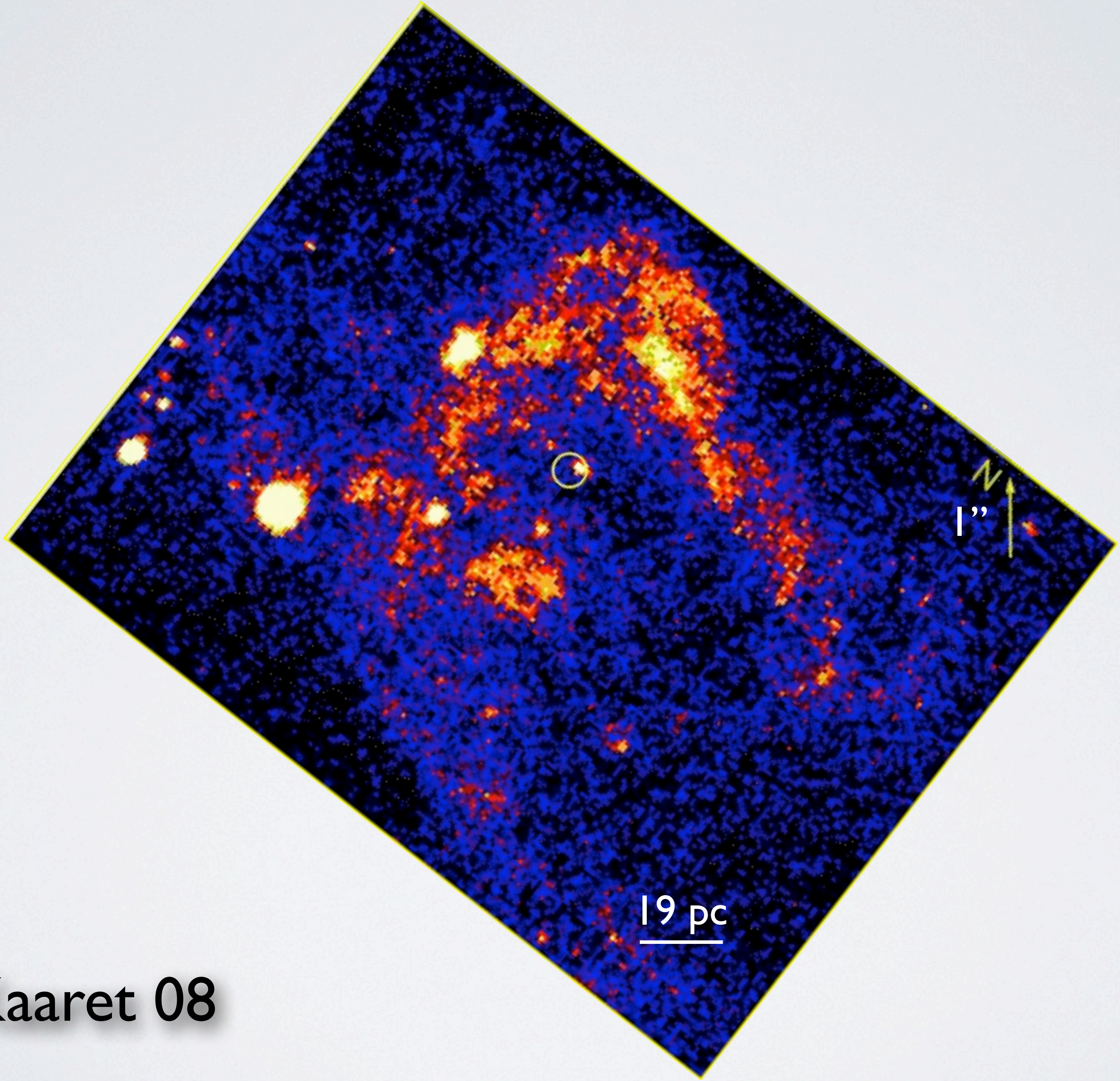
In radio:

Very Large Array (VLA): IC342 X-1 and Holmberg II X-1
Australia Telescope Compact array (ATCA): NGC5408 X-1

In optical:

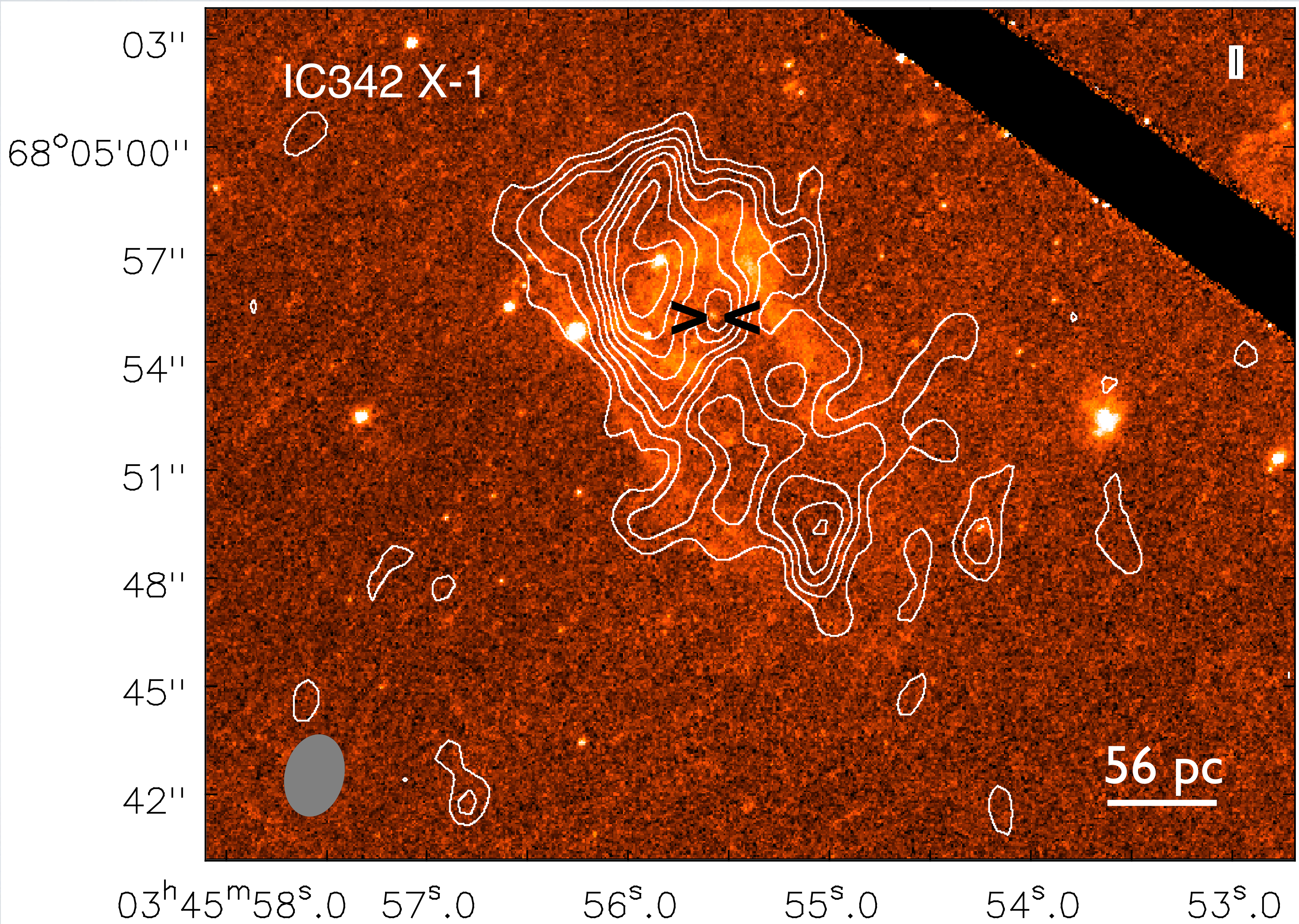
ESO Very Large Telescope (VLT) spectroscopy: NGC5408 X-1
Hubble Space Telescope (HST): NGC5408 X-1

Optical nebula around IC342 X-1

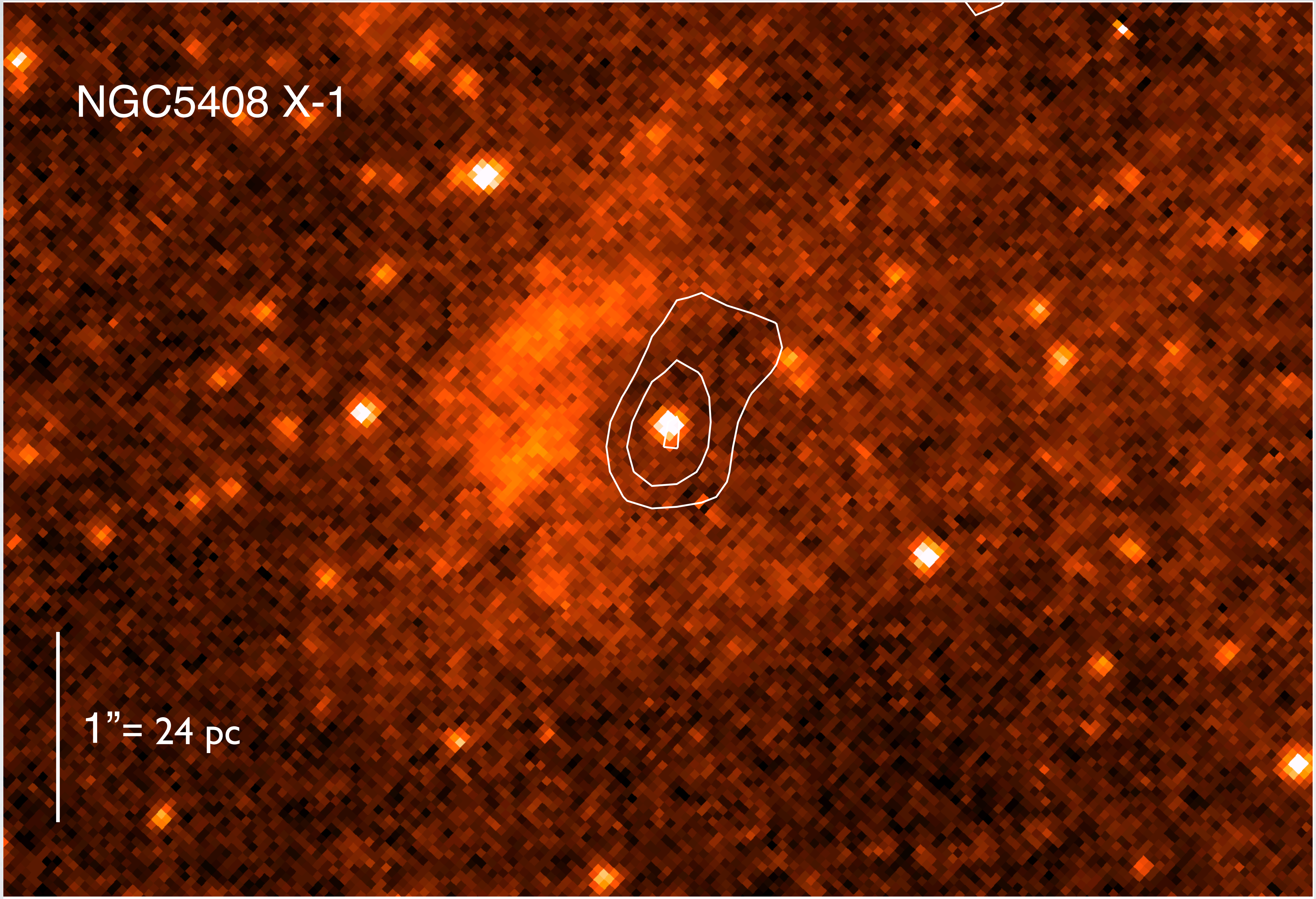


cf: Feng & Kaaret 08

Radio nebula around IC342 X-1

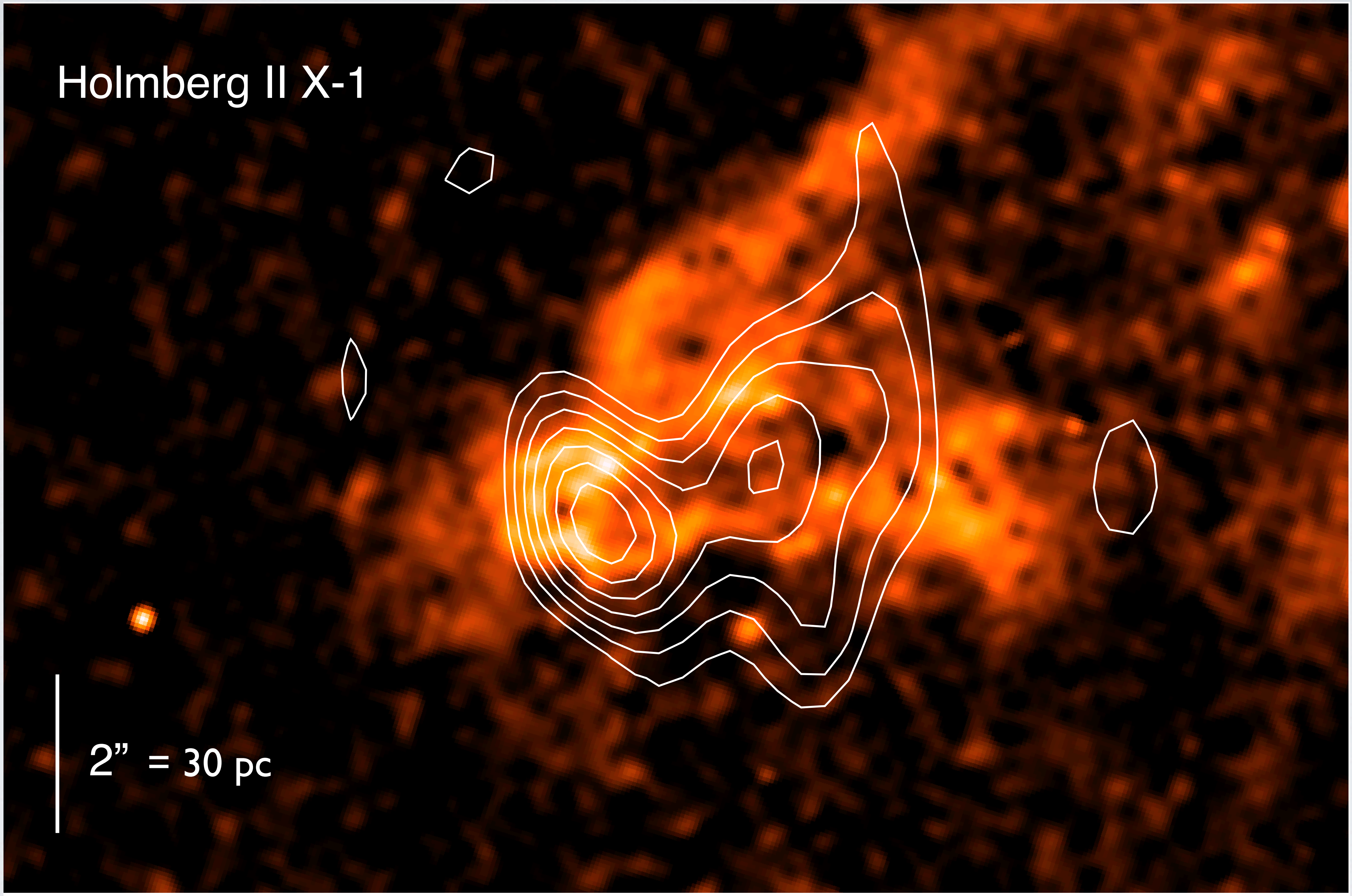


The radio nebula of NGC5408 X-1 at 18 GHz



Cseh+ 11 submitted; Grise+ 11 in press

The radio nebula of Holmberg II X-1



Cseh+ 11 sbm.; Kaaret+ 04

Energetics of the nebula of IC342 X-1

Optical nebula

- n electron density
- τ lifetime of the bubble
- $L_{kin}+L_{cool}+L_{thermal}$
- L_{tot} total mechanical luminosity
- E_{tot} total energy

Radio nebula

- B magnetic field strength
- E_{min} minimum energy
- N number of relativistic electrons
- τ_{sy} synchrotron lifetime of an electron

Characteristics:

Pressure driven snowplow stage: radiative phase, not adiabatic

(Weaver+ 77, Dopita+ 96)

Equipartition between relativistic electrons and magnetic field

(Longair 94)

Energetics of the nebula of IC342 X-1

Optical nebula

1) E_{tot} = 7.7×10^{52} erg
2) τ lifetime = 3.3×10^{5} yr
3) L_{kin} = 1.6×10^{39} erg/s
4) n = 5.6 cm^{-3}

1) E_{tot} ~ 100 SN explosion energy

2) τ lifetime << 10 Myr, the minimum age of stellar environment of the ULX

3) L_{kin} ~ Eddington luminosity of a standard BHB

Energetics of the nebula of IC342 X-1

Radio nebula

1) E_{min} = 9.2×10^{50} erg
2) $\tau_{synchrotron}$ = 18.8 Myr
3) B = 7.4 μG

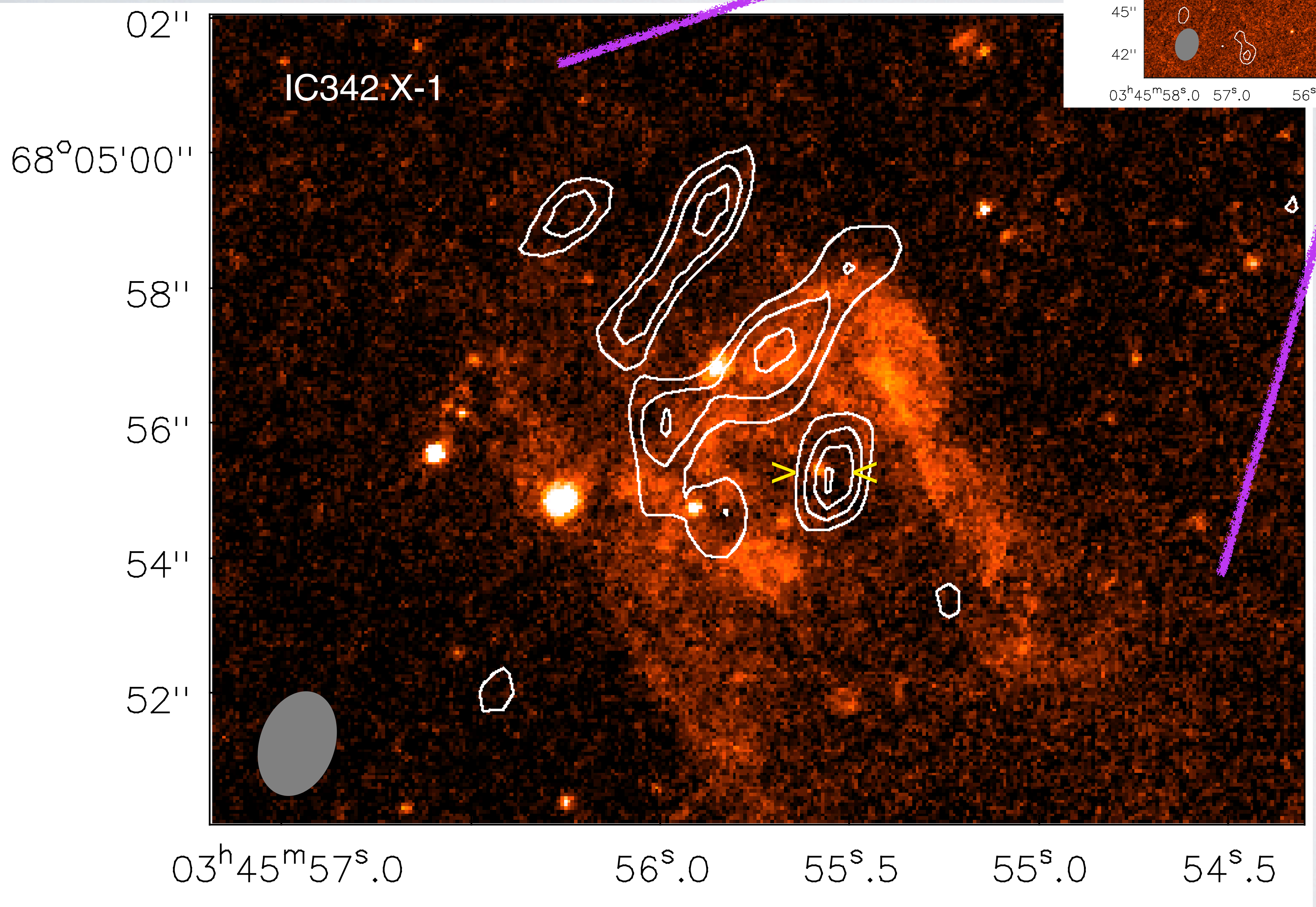
1) E_{min} is ~1% of total energy, 2 orders higher than for a SN

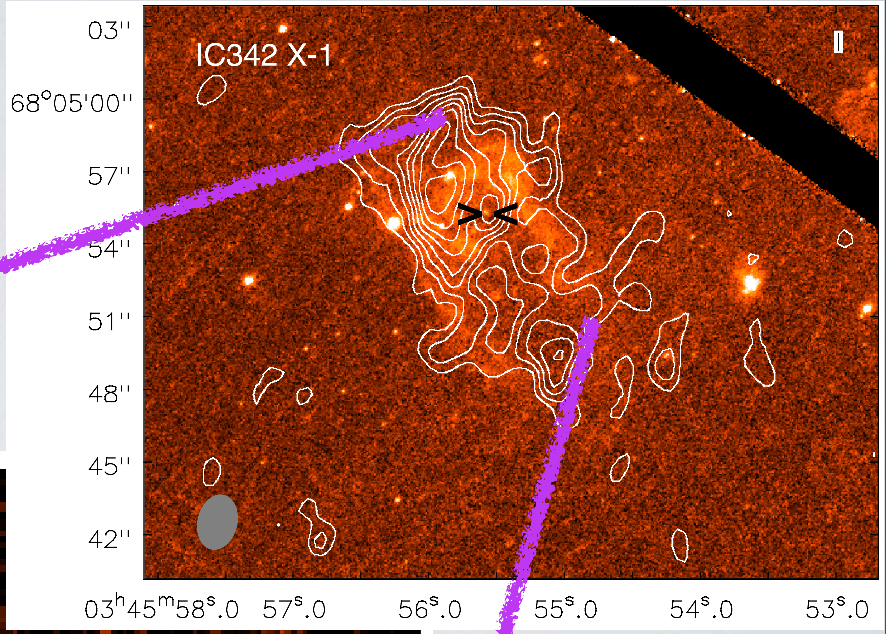
2) $\tau_{synchrotron}$ > 10 Myr, the minimum age of stellar environment of the ULX.

3) For a typical ISM: $B \sim 3n^{1/2}$ Equipartition might hold.

Let’s see the ULX point source

The radio nebula of IC342 X-1
A compact radio jet ?





Estimating the mass of the BH

The 'Fundamental Plane of BHs':

$$\log \boldsymbol{M_{BH}} = 1.55 \log \boldsymbol{L_R} - 0.98 \log \boldsymbol{L_X} - 9.95$$

(Merloni+ 03, Falcke+ 04, Kording+ 06, et al.)

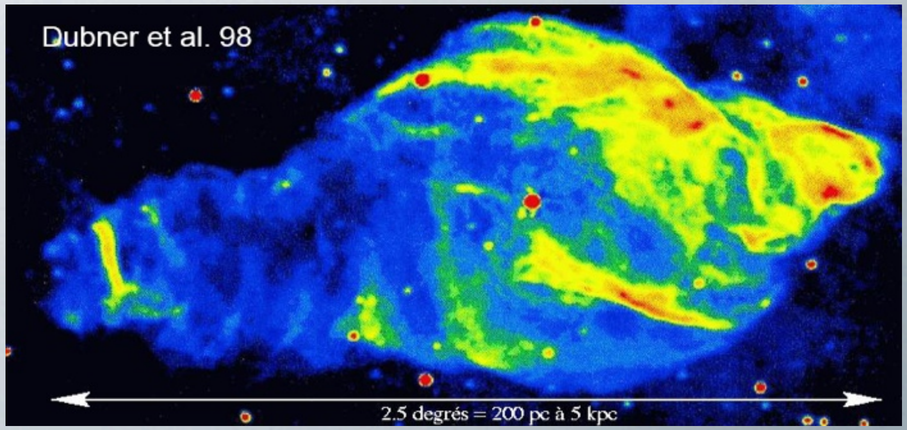
IC342 X-1:

- Hard State in all X-ray measurements
- Jets are ubiquitous in hard state (Corbel+ 04, Fender+ 04)
- Covering 2001-2007

- Variation of X-ray luminosity + scatter:

M_{BH}=1.2-14 x 10^3 $M_\odot$???

Comparison with non-ULXs



Name	L_X [10^{39}erg/s]	Q_{jet} [10^{39}erg/s]	M_{BH} [$M_\odot$]	$E_{tot,kin}$ [10^{51}erg]	E_{min} [10^{50}erg]	τ [10^5yr]
IC342 X-1	16	1.6	10^3-10^4	76	9.2	3.3
S26	6.2×10^{-3}	50	-	316	1	2
IC10 X-1	0.15	1.27	23-34	20	-	5
SS433	~ 10^{-4}	2	16	2	10^{-4}	0.2

No clear trends yet, but:

- Jet power is time averaged
- Large size ~ shock-ionization and higher E_{min}
- Emin of NGC5408 X-1 and Ho II X-1 is two orders higher than for SS433.

(Pakull+ 10, Soria+ 10, Dubner+ 98, Blundell+ 08, Fabrika 04, et al.)

Jet inflated nebula like SS433?

Indicatives: elongated morphology and shock-ionization

The jet carries a fraction of the available power: (Falcke+ 95,99)

$$Q_j = fQ_{acc} = f\dot{M}_{acc}c^2, \;\; f < 1$$

Jet mass flow rate: $\dot{M}_j$ =1.78 x 10^{18} g/s

Accretion rate: $\dot{M}$ =2.43 x 10^{20} g/s

Comparison:

A 10-$M_\odot$ object accretes at a canonical rate of 10^{18} g/s

The accretion rate of IC342 X-1 vs SS433 is ~10^{-3} vs GRS1915+105 is ~20. These sources are not in the low/hard state!

Conclusions

- IC342 X-1 is surrounded by a shock-dominated nebula
- E_{tot} ~ 100 SNe explosion energy

- The nebula formation is not necessarily related to the formation of the BH progenitor
- M_{BH}=1.2-14 x 10^3 $M_{\odot}$???

- Fraction of relativistic material is 2 orders higher than in SNe
- The nebula powering process can be consistent with jet inflation

- Very high accretion rate for a hard state object, and much lower than for a supercritical source