

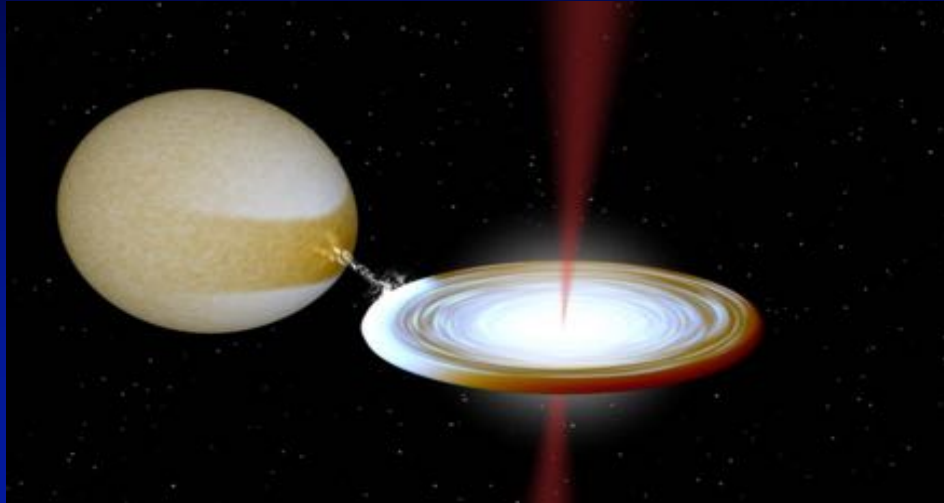
A common-envelope LBV(?) / ULX binary

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ULXs: superEddington X-ray binaries (incl. IMBHs ?)



- High-luminosity end of X-ray binary population; $L_x > 3 \times 10^{39}$ erg/s
i.e. $> L_{\text{edd}}$ of stellar mass (20 M_{sol}) BH; beaming or IMBH ?
None in LGG; $d > 3 \text{ Mpc}$
- 3 ULX pulsate \Rightarrow neutron stars, i.e. $M < 2 M_{\text{sol}}$; nature demonstrates that superEddington accretion exists. Mass transfer could be up to $10^{3-4} M_{\text{dot, Eddington}}$, i.e. like SS433
- Already dealt with by Shakura & Sunyaev (1973); more recent MHD simulations (Ohsuga & Mineshige 2011): winds and jets !

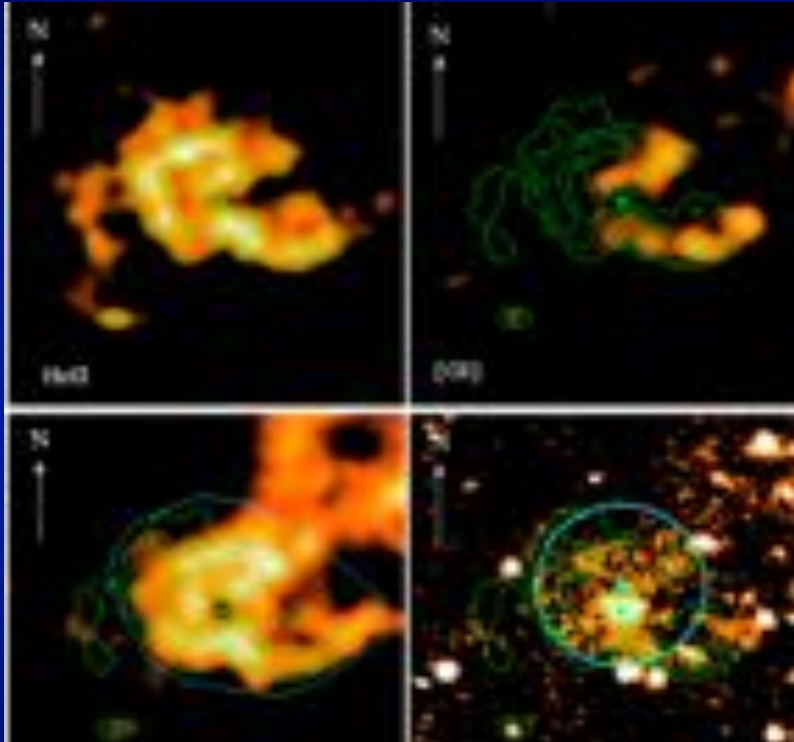
ULX: counterparts, nebulae and bubbles

- Optical counterparts are very faint $> 23\text{mag}$, except P13 in NGC~7793 (20 mag)

ULXs often interact with / act-on the IS medium:

- Photoionization of ISM; formation of X-ray ionized nebulae (XIN) \rightarrow independent measure of L_X (4π)
- Wind and jet driven ULX bubbles \rightarrow rad. shocks; measure of mechanical power P_{wind} or P_{jet} ; $P \sim L_X$
- XIN, ULXB: study history; detect 'hidden' ULX

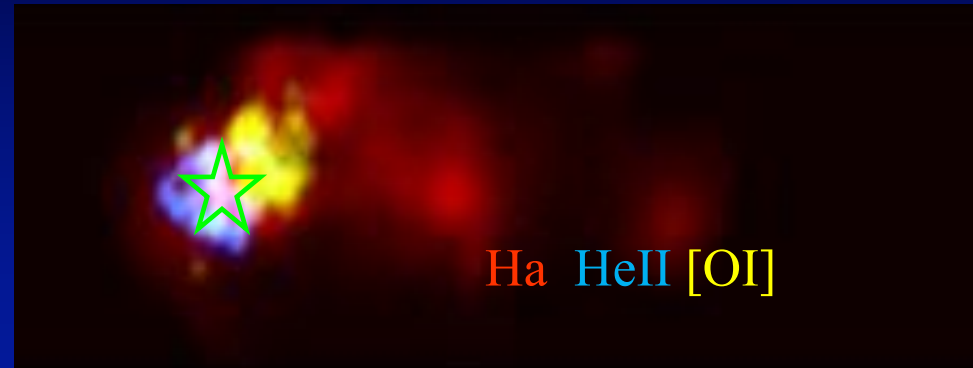
Xray ionised nebula (XIN) He III region around HoII X-1



HST ACS; Kaaret+04

Photon counting:

$$L_{4686} \sim 1/2000 * L(0.3-0keV)$$



Pakull & Mirioni 2002; Mirioni 2003 thesis;
CFHT broad-slit

HeIII region ionised by ULX with
recombination $L_{4686} = 2.5 \cdot 10^{36}$ erg/s
(also note strong [OI]6300 line !)

Using *Cloudy*, one derives integrated
(4π), mean X-ray luminosity

$$L_x \sim 6 \cdot 10^{39} \text{ erg/s } (\sim 4\pi d^2 F_x !)$$

→ largely isotropic mission i.e. no strong beaming here

NGC 5408 X-1

Sutton + 15

NGC 5408 Irr @ 4.9 Mpc

X-1 ($L_x \sim 10^{40}$ erg/s)

HST & Chandra

Credit NASA(Chandra)/ESA/J. Schmidt

NGC 5408 X-1

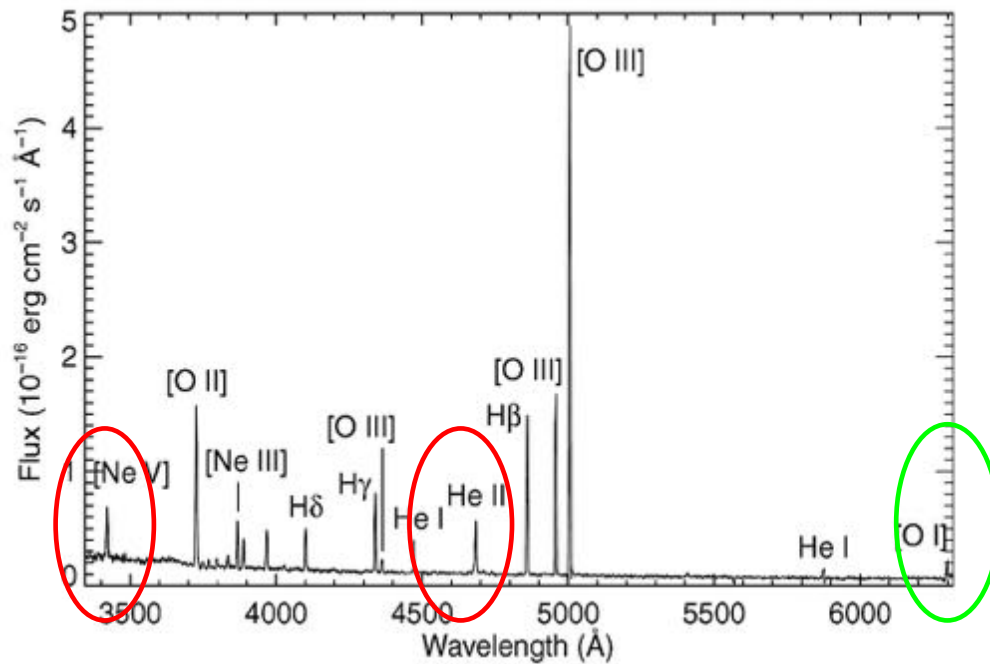
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NGC 5408 Irr @ 4.9 Mpc

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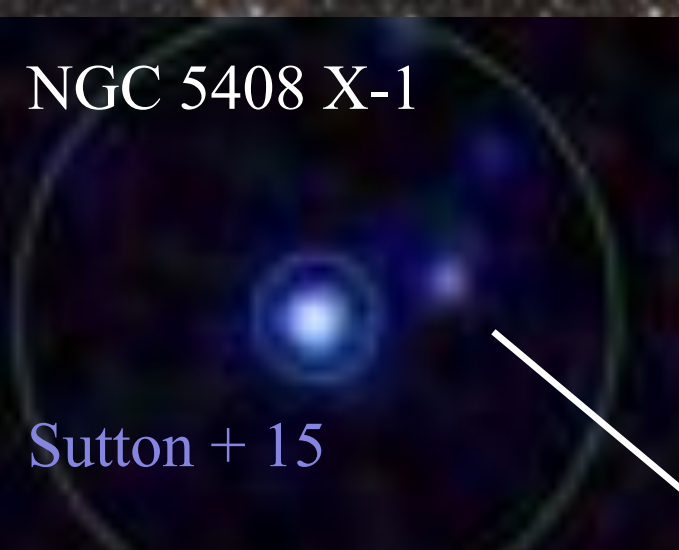


Kaaret & Corbel 2009:
 optical counterpart
 + detection of **XIN** around
 NGC 5408 X-1

NGC 5408 Irr @ 4.9 Mpc

X-1 ($L_x \sim 10^{40} \text{ erg/s}$)

Credit NASA(Chandra)/ESA/J. Schmidt



NGC 5408 Irr @ 4.9 Mpc

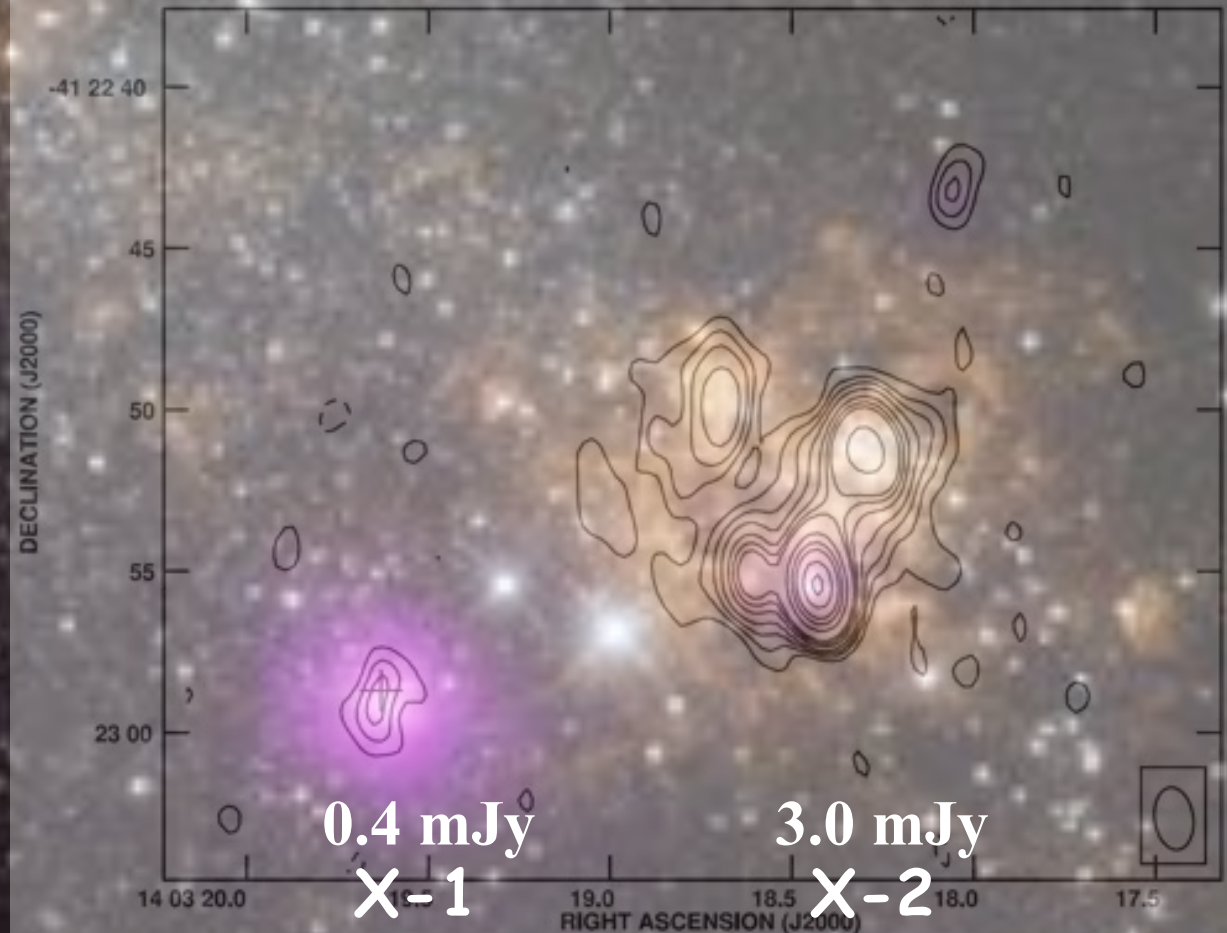
X-2 ($L_x \sim 10^{37}$ erg/s)

X-1 ($L_x \sim 10^{40}$ erg/s)

NGC 5408: Radio continuum

Lang et al 2007:
non-thermal
radio emission
(synchrotron
nebula) around
NGC 5408 X-1

(& other
thermal and
non-thermal
sources in Giant
HII region)



The brightest (non-thermal) 4.9 GHz radio source ($8 \times$ Cas A) is coincident with a faint X-ray source ("X-2")

NGC 5408 X-1 & X-2

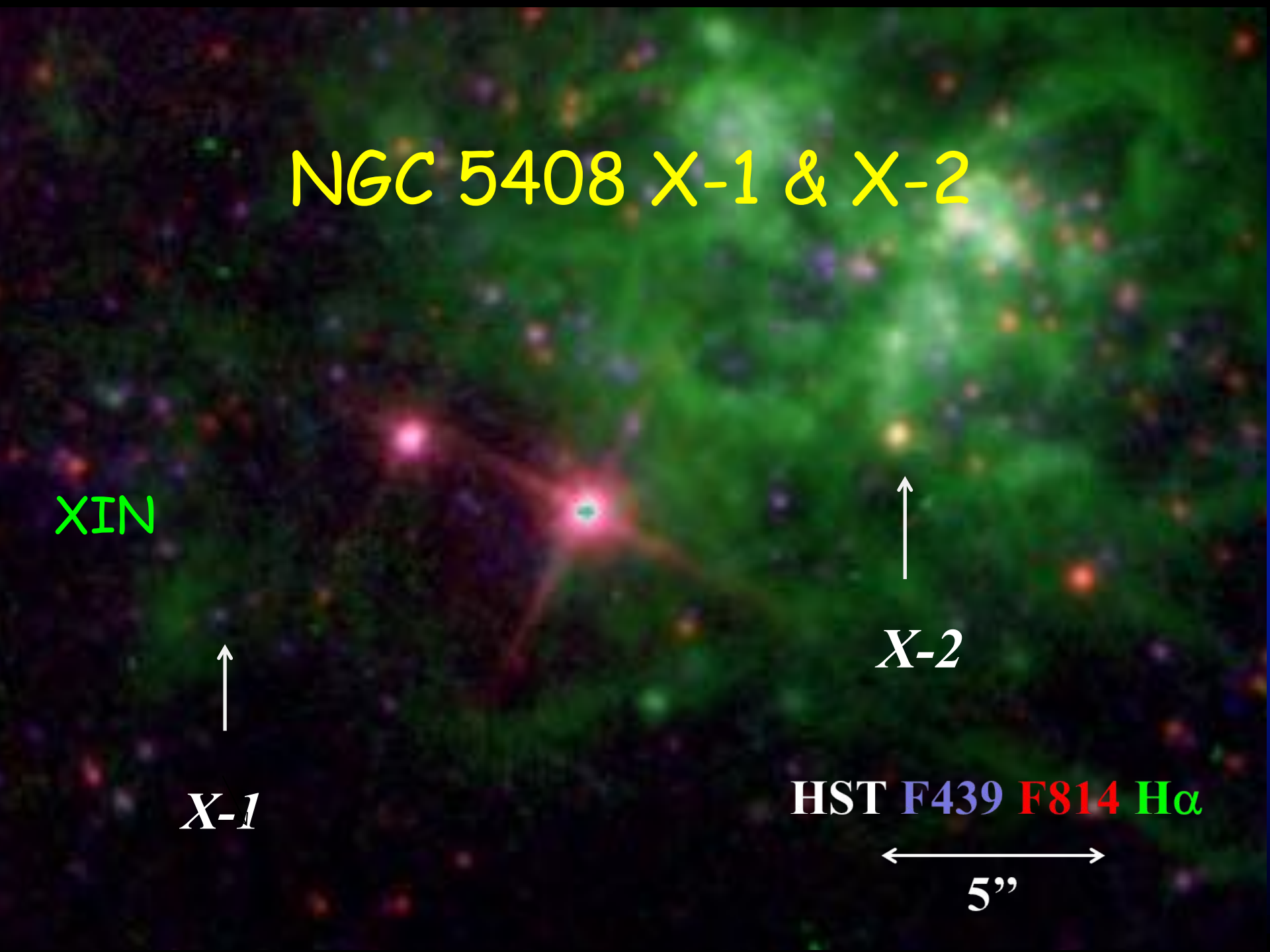
XIN

X-1

X-2

HST F439 F814 H α

5''

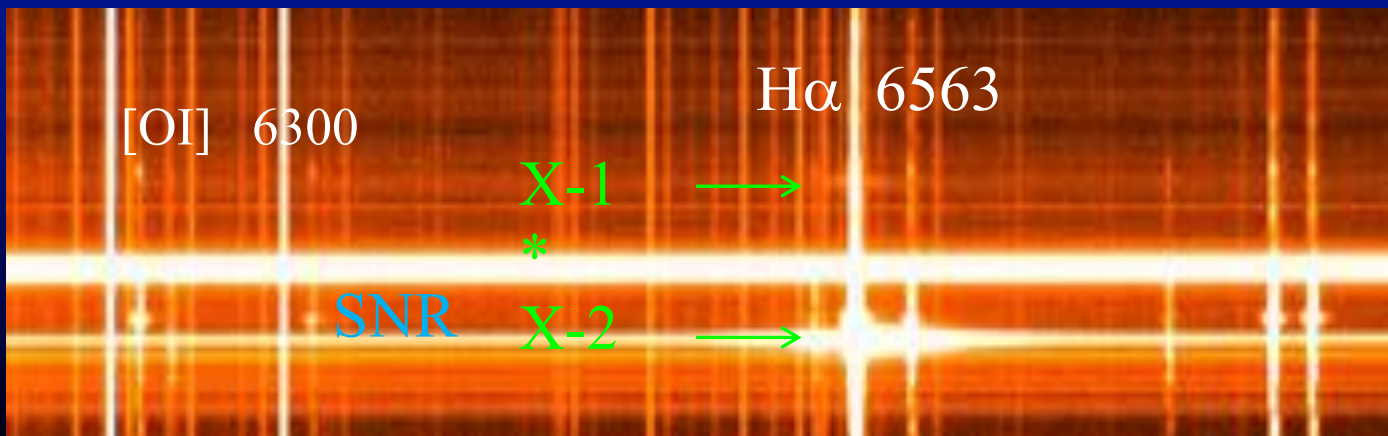
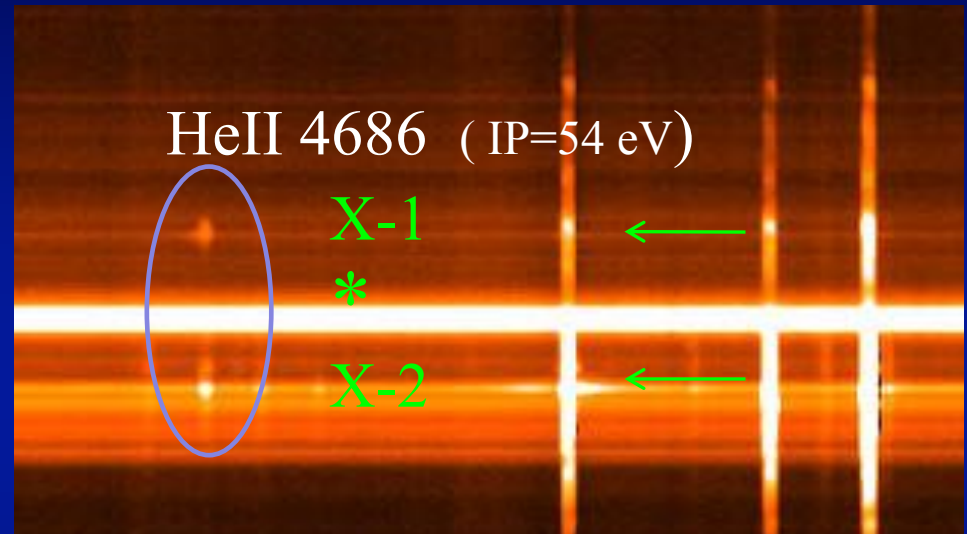
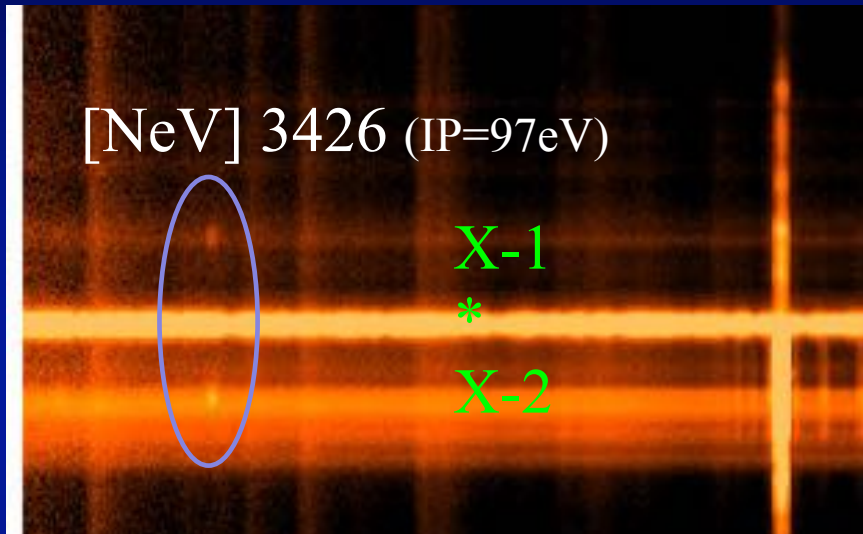


NGC 5408 X-1 & X-2

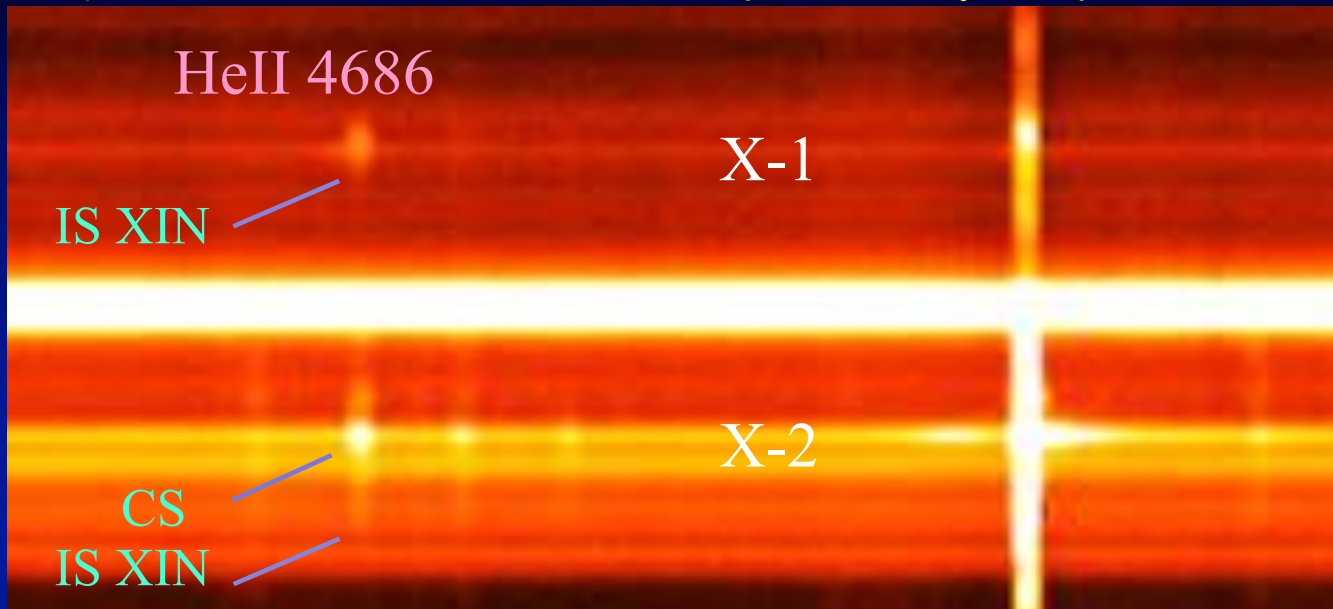
The image shows a dense field of stars in the NGC 5408 star cluster. The stars are predominantly green and blue, with some red and purple stars scattered throughout. Two white lines are drawn across the image, representing a slit used for spectroscopy. The slit is positioned to capture light from a specific region of the cluster, which includes two stars labeled X-1 and X-2.

Slit used for VLT spectroscopy of X-1
by Kaaret & Corbel (09), Cseh et al (11, 13)
serendipitously includes X-2 !

NGC 5408 X-1 & X-2



NGC 5408 X-1 & X-2



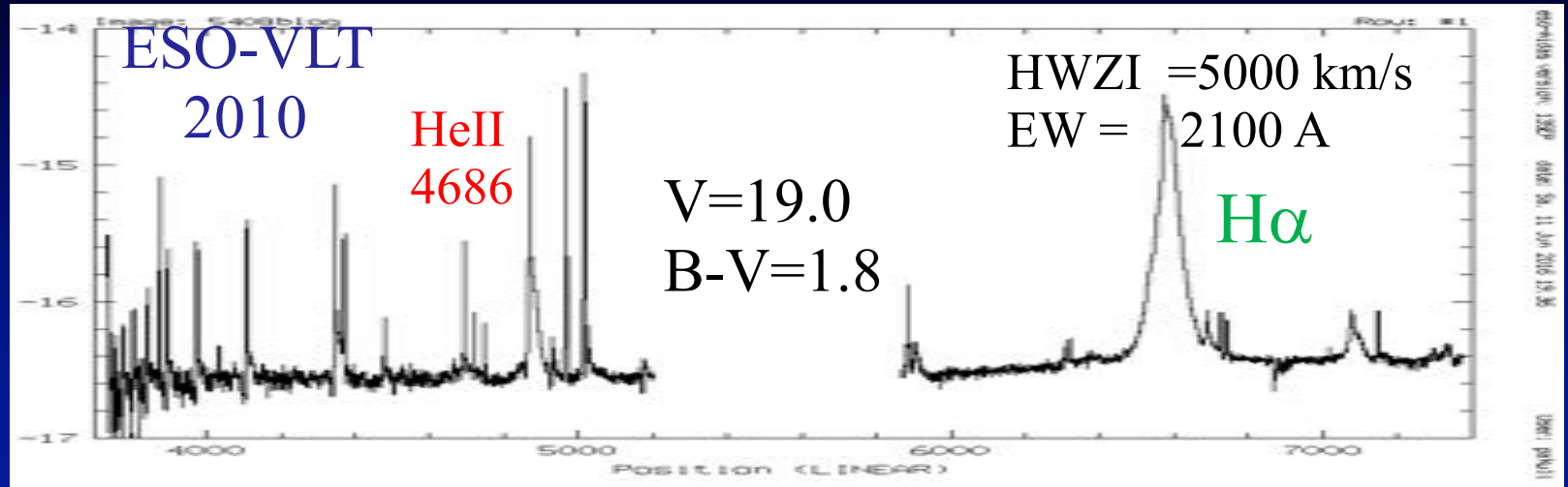
Presence of two X-ray ionized nebulae (XIN), namely around X-1 and X2 which are only $14'' = 340$ pc apart !!

The HeII λ 4686 and [NeV] λ 3426 fluxes show that the ionising (recent) X-ray luminosity of NGC 5428 X-2 is/was even higher than that of X-1; i.e. $L_x \sim \text{few } 10^{40}$ erg/s !

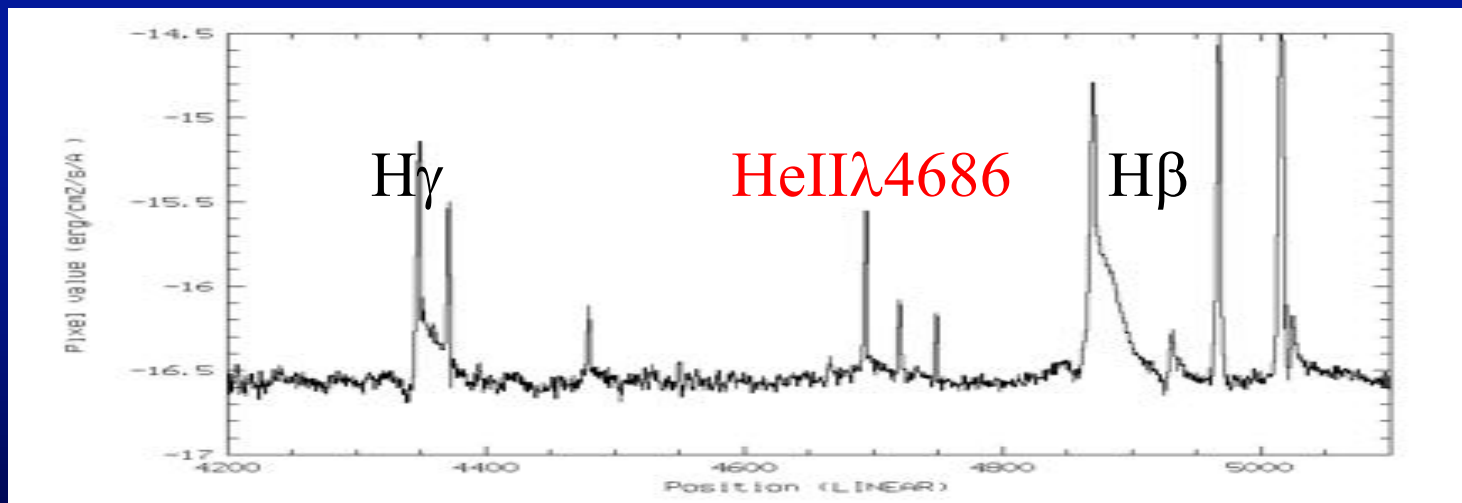
Short recomb. timescale for circumstellar component of λ 4686: $\tau = 8$ yrs \rightarrow X-2 blocked from direct view: thru thick disk ?

NGC 5408 X-2 counterpart

$\log F_\lambda$

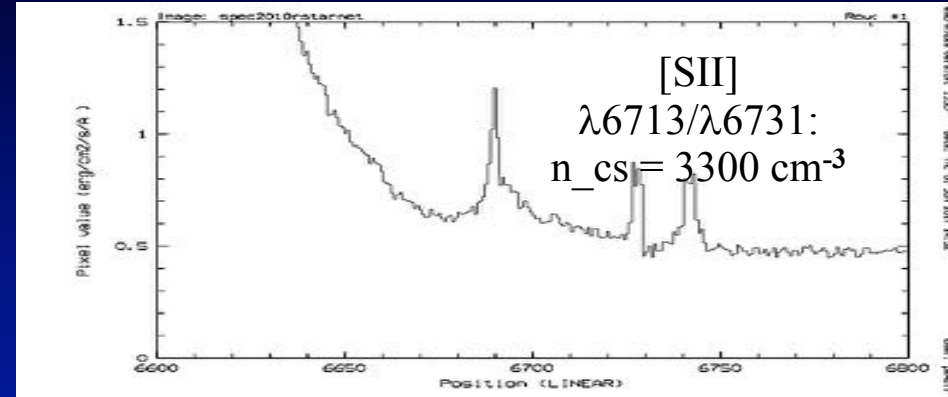
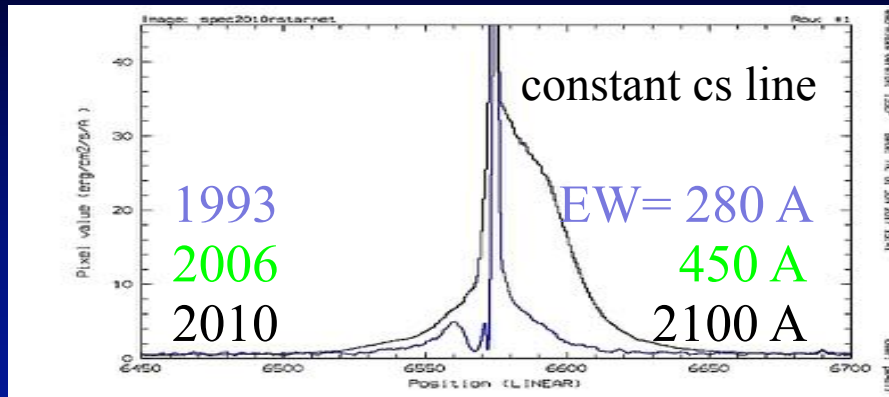


$\log F_\lambda$



Broad P Cyg lines + narrow lines from X-ray ionised circumstellar material (diffuse HII region subtracted).

NGC 5408 X-2 + "LBV" counterpart



Some interesting results:

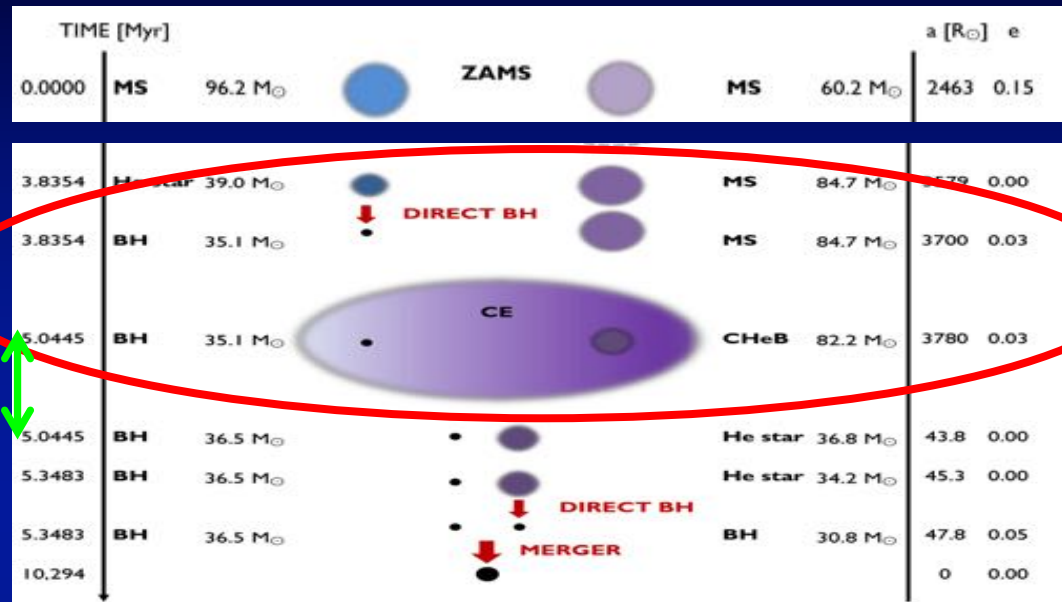
- > Extreme variability in broad lines; however constant narrow circumstellar lines & continuum @ $V=19.0$; $M_V \sim -10$; 'red' cont $\sim 5300\text{K}$ BB (convective); $R_{BB} \sim 600 R_{\odot}$ (\rightarrow orbit: $a \sim 2000 R_{\odot}$ & $P \sim$ few yrs)
- > Circumstellar (cs; narrow-line) cocoon) has high density $n_{cs} \sim 3000 \text{ cm}^{-3}$ ([SII], ArIV). Using $M_{cs} = 22 M_{\odot} \times (L_{\alpha,cs} / L_{\odot}) / n_{cs}$ we derive from the constant cs lines a cocoon mass $M_{cs} \sim 40 M_{\odot}$ within a cocoon radius of $\sim 0.5 \text{ pc}$.

Suggestion of (intermittent ?) common envelope evolution with previous strong mass loss (like $\eta \text{ Car}$)

NGC 5408 X-2: intermittent CE evolution towards BH+BH GW source ?

Belczynski+16

< 100yrs



- > Orbit of NGC 5408 X-2 estimated $a \sim 2000 R_{\odot}$, τ for spiral-in (towards BH-BH formation) here: > 25 yrs
- > orbital decay timescale depends strongly on stage of core He burning (c.f. Taam & Sandquist ARA&A 00).
- > Merging or ejection of CE ? \rightarrow X-2 is key object for study of massive binary evolution (CEE review: Ivanova+13; MT stability: Pavlovskii+16; episodic mass ejection: Clayton+17, WR+c: van den Heuvel+17, ULXs: Wiktorowicz+17 ...)

What have we learned

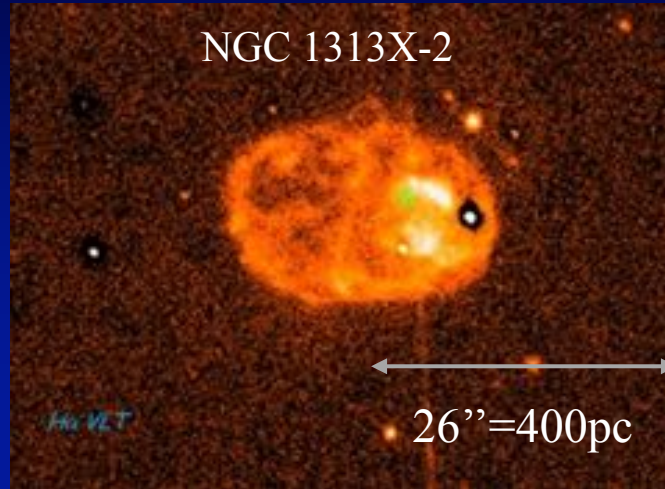
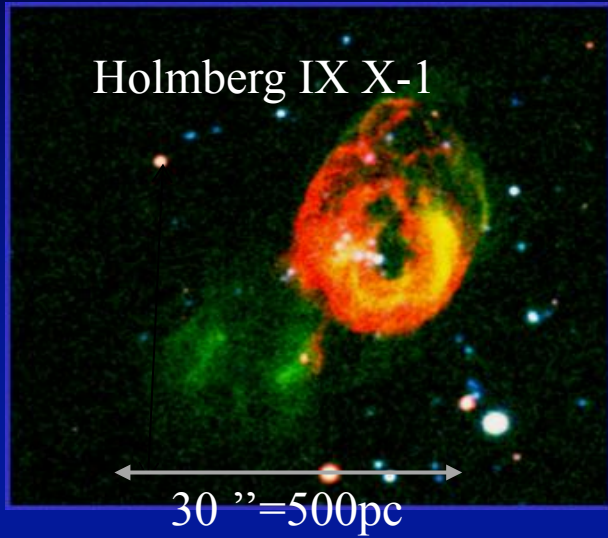
- Discovery of XIN (HeII4686, [NeV3426]) around apparently weak XRS NGC 5408 X-2 suggests intrinsic $L_x \sim \text{few } 10^{40} \text{ erg/s}$ (brighter than neighbour NGC 5408 X-1, 14" away)
- Reddish ($T_{\text{BB}} \sim 5300\text{K}$) very luminous counterpart ($M_v \sim -10$) has $R_{\text{BB}} \sim 570 R_{\odot}$; very bright ($\text{EW}(\text{H}\alpha) \sim 2100\text{\AA}$) & very broad (5000 km/s HWZI) Balmer /HeI emission & narrow highly ionized circumstellar lines due to $\sim 40 M_{\odot}$ cocoon.
- We suggest beginning/intermittent CE evolutionary phase of very massive ULX that might well result in future BH&BH merger.
- Archives of (V)LT observations contain many treasures to be discovered.

The end

Thank you

Merci & Danke schön

Some ULXBubbles

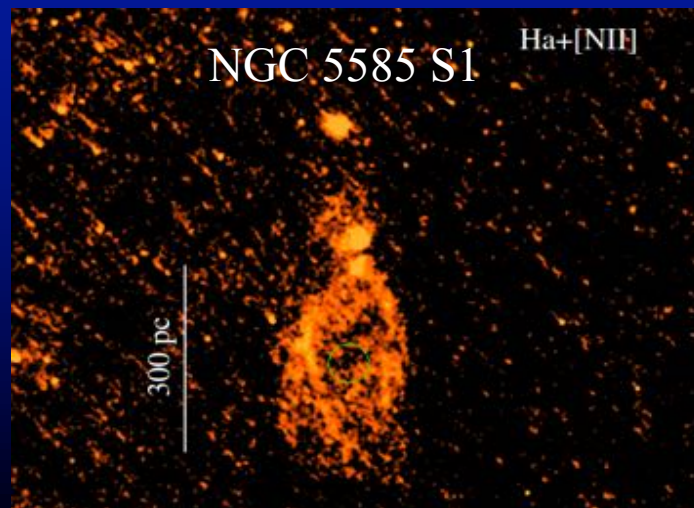
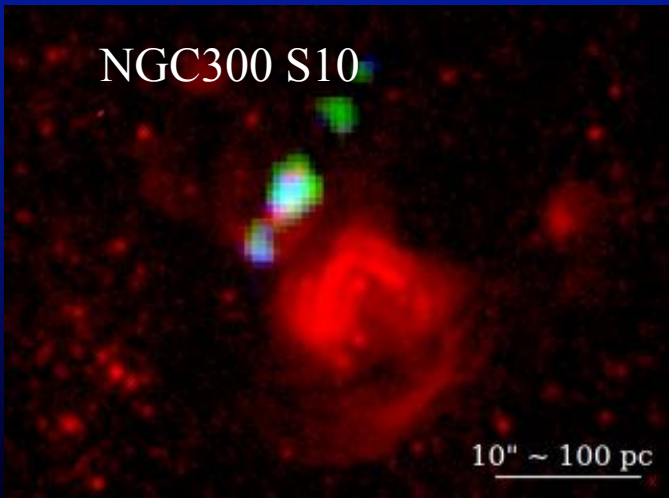


Large
(several 100pc),
rapidly expanding
 $V \sim 80 - 250$ km/s
shock-ionized
ULX bubbles

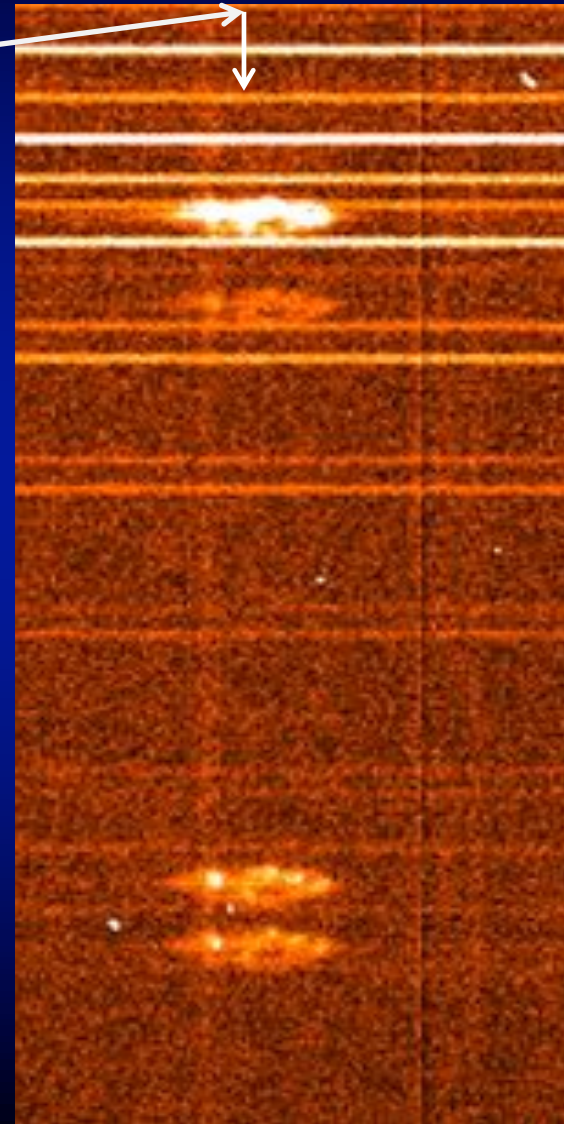
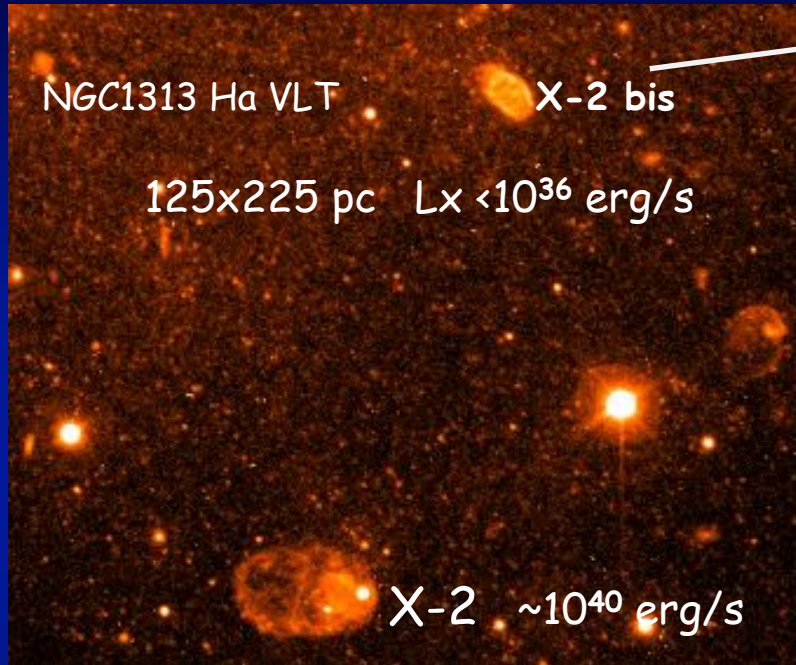
$L_w \sim 10^{39-40}$ erg/s
 $\sim L_X$

Age = $3/5 R/v_s$
 $\sim 10^6$ yrs

History: visible
long after
switch-off of
ULX activity!



NGC1313 X-2bis : another ULXB ?



X-2bis: $V_{exp} = v_s = 180$ km/s

-> expanding very energetic bubble

L_w ; $E_0 \sim 10^{39}; 10^{53}$ cgs

presently inactive ULX ?

ULX beamed-away from us ?