ULX Bubbles: Energetic Hypernova Remnants or Jet-Inflated Nebulae

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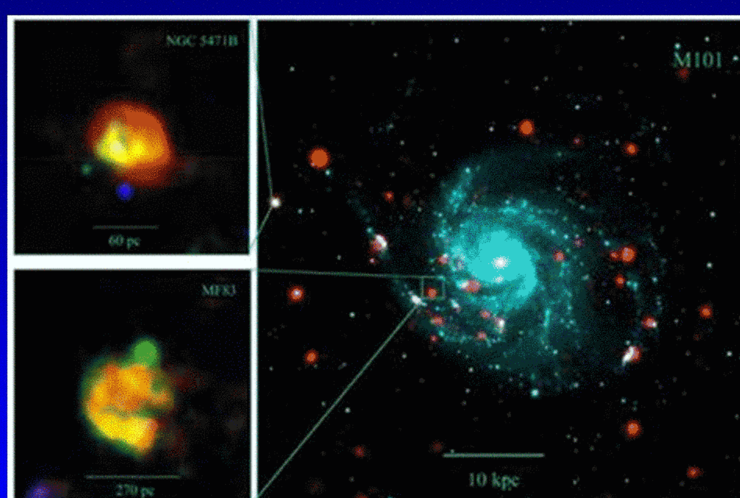
Kitp, Supernova and gamma-ray burst remnants, Febr. 7, 2006

"Hypernova Remnants"



Q.D. Wang 1999: Several luminous (few 10^{38} erg/s) ROSAT X-ray sources in M101 are coincident with SNRs

$[R, v_{exp}, n_o(\text{X-ray})] \rightarrow E_o \sim$ few 10^{53} erg : HNR

"Hypernova" Remnants: false alarm

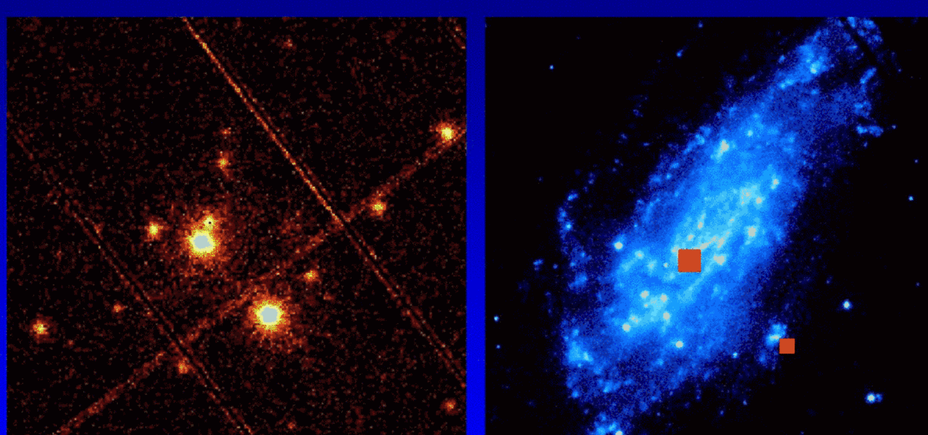
Announcement of detection of several nearby X-ray bright Hypernova Remnants (L_x~10^{38-39} erg/s)
→ expand into high IS density → Eo ~ few 10^{53} erg)

- ✓ Holmberg IX_X-1, M101_*NGC* 5471B; M101_MF83;
- ✓ NGC6946_X-1, …

This was based on *wrong* assumption that (ROSAT) X-ray spectra due to SNR thermal emission (c.f. Chu et al.).

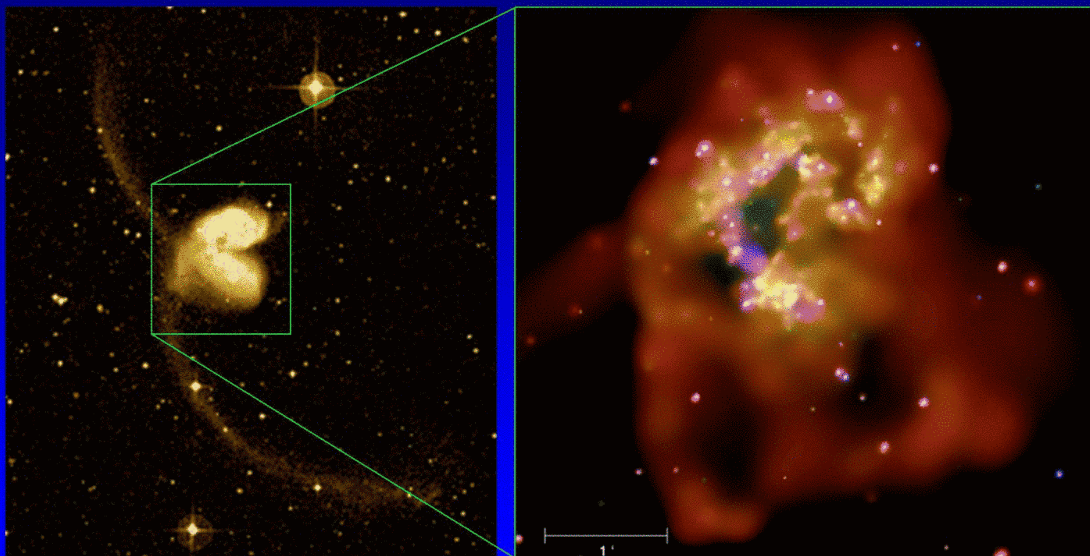
Rather, X-ray emission is due to *variable* accreting *compact* sources (MXRB, ULX) located in SNR-like nebulae

ULX = Ultraluminous X-ray Sources



XMM UV and EPIC observations of *NGC* 4559 by Cropper et al 2004:
Two bright variable non-nuclear X-ray sources in NGC4559
ULX: $L_x > 10^{39.5}$ erg/s

The Antennae



18 ULXs ! (Lx > 10^{39} erg/s) Fabbiano et al. (2003)

Why are ULX so exiting ?

- Brightest non-nuclear sources in galaxies;

(Lx ~ $10^{39.5\text{-}41}$erg/s > total X-ray output of *LGG* !);

new phenomenon

- Eddington limit: L_{edd} = 1.3 10^{39} $M/(10M_{\odot})$ erg/s

→ Potentially Intermediate Mass Black Holes *(IMBH) :*

Colbert & Mushotzky (1999), Makishima et al. (2000);

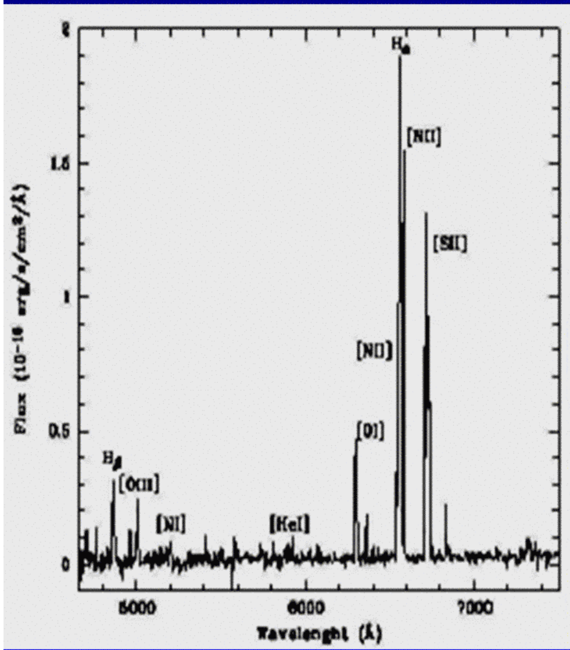
created by runaway merging in massive clusters ?

Ebisuzaki et al. (2001)

- or (non-isotropic) emission: geometric or relativistic;
- or due to low $Z/Z_{\odot}$ binary evolution (M_{BH} ~ 50 $M_{\odot}$)

It appears: ULX are MXRB with massive BH accretors

ULX IC 342 X-1

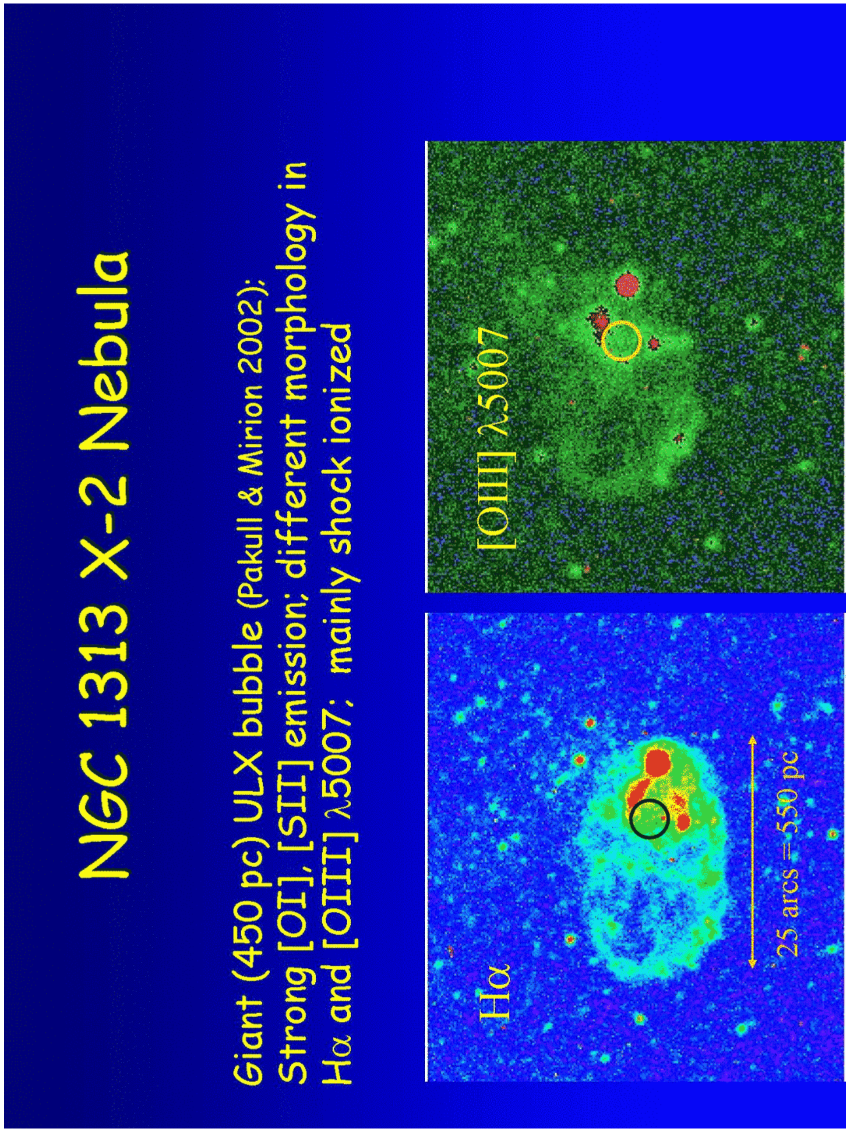


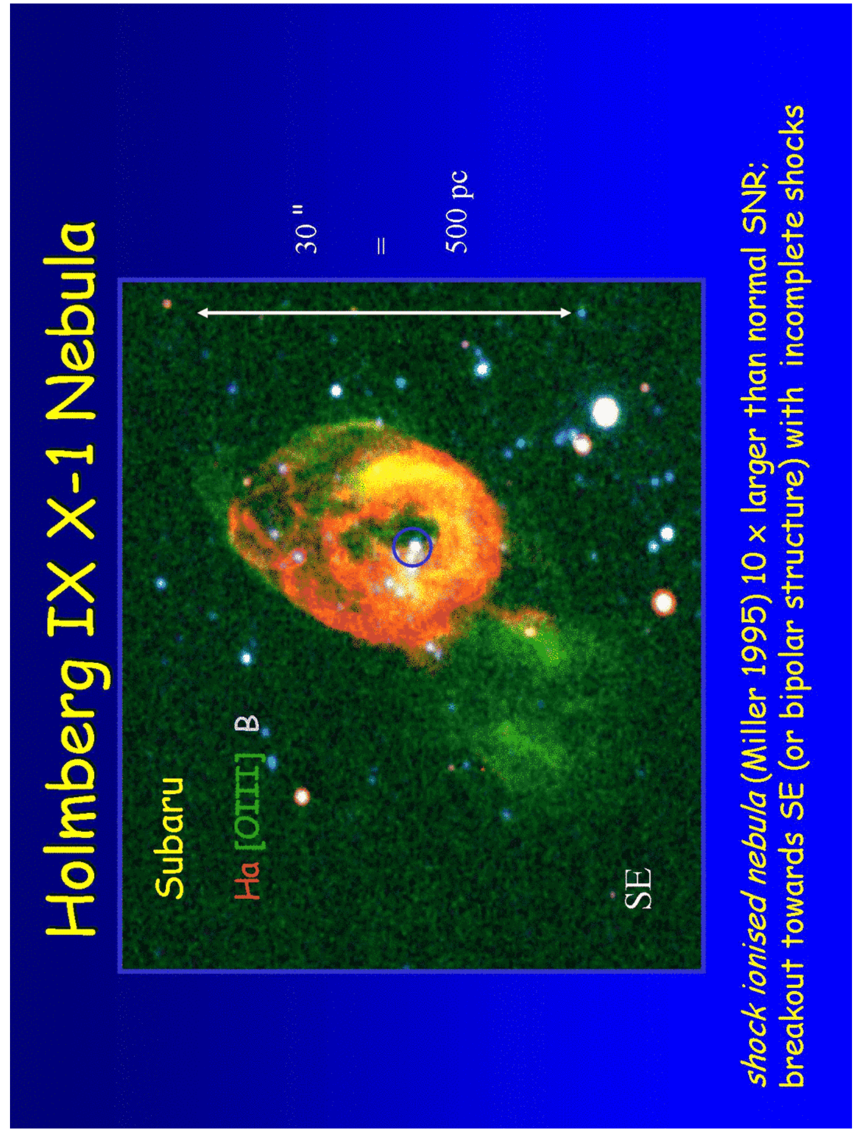
- "Tooth" nebula situated in spiral arm has a diameter of 220pc (Pakull & Mirioni 2002; Roberts et al 2003).
- SNR-like spectrum
  [SII]/Hα=1.2
  [OI]λ6300/ Hα=0.4
  (X-ray) or shock ionisation ?
- Recent detection of (supersonic) expansion

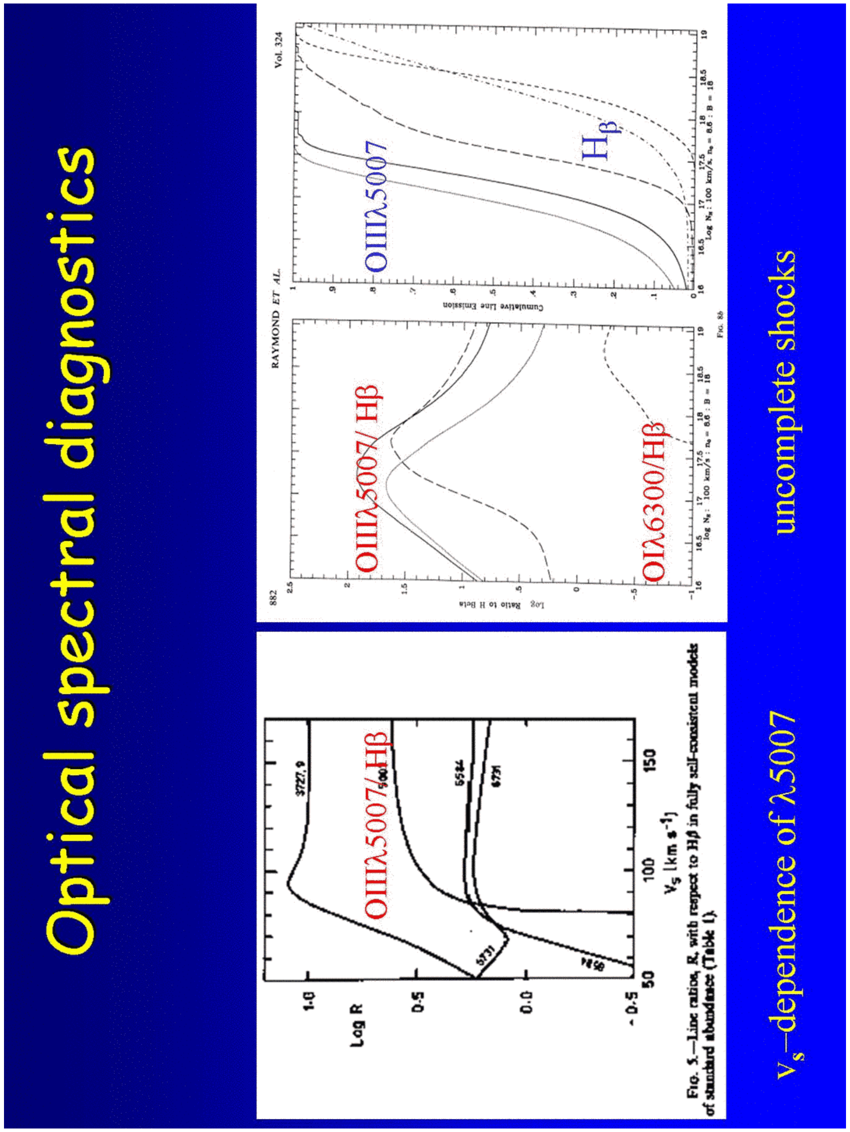
ULX Bubbles

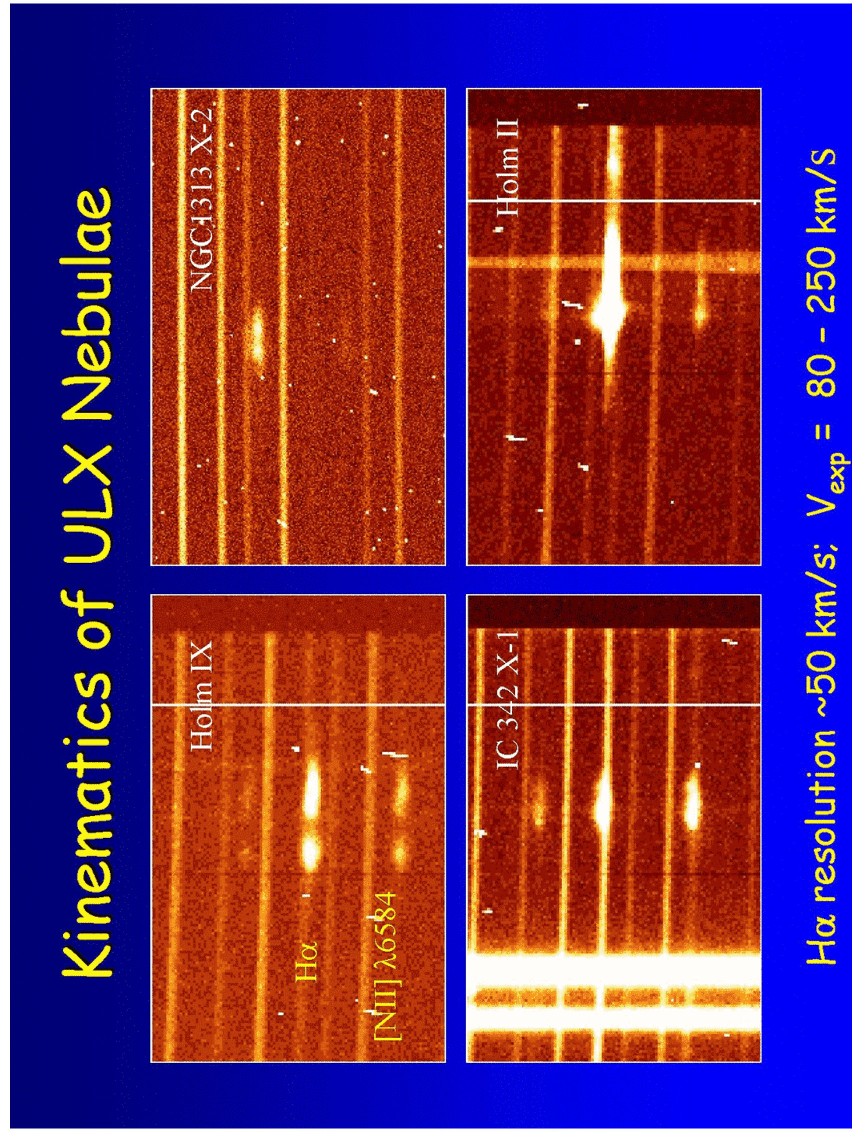
- Optical follow-up observations of ULX in nearby galaxies:
ULX reside in large (50-800 pc) bubble nebulae
(Pakull & Mirioni 2002, Roberts et al. 2003, Kaaret et al. 2005, Ramsey et al. 2006…)

Purpose of this talk is to show that:
- the bubbles are intimately linked to accretion/ejection processes in the ULX (and sometimes exited by X-ray photoionisation)
and/or
- they reflect the formation of the putative massive black holes in the ULX systems GRB remnants ?

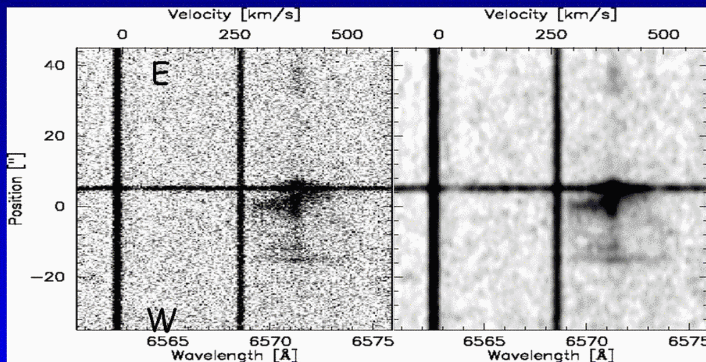

NGC 1313 X-2 Nebula
Giant (450 pc) ULX bubble (Pakull & Mirion 2002);
Strong [OI], [SII] emission; different morphology in
Hα and [OIII] λ5007; mainly shock ionized
Hα
25 arcs = 550 pc
[OIII] λ5007


Holmberg IX X-1 Nebula
Subaru
Hα [OIII] B
30 " = 500 pc
SE
shock ionised nebula (Miller 1995) 10 × larger than normal SNR;
breakout towards SE (or bipolar structure) with incomplete shocks


Optical spectral diagnostics
OIIIλ5007/ Hβ
OIλ6300/Hβ
OIIIλ5007
Hβ
uncomplete shocks
OIIIλ5007/Hβ
Log R
Fig. 5.—Line ratios, R, with respect to Hβ in fully self-consistent models of standard abundance (Table 1).
v_s–dependence of λ5007


Kinematics of ULX Nebulae
NGC1313 X-2
Holm II
Holm IX
IC 342 X-1
Hα
[NII] λ6584
Hα resolution ~50 km/s; V_exp = 80 - 250 km/s

Kinematics of ULX nebulae 2



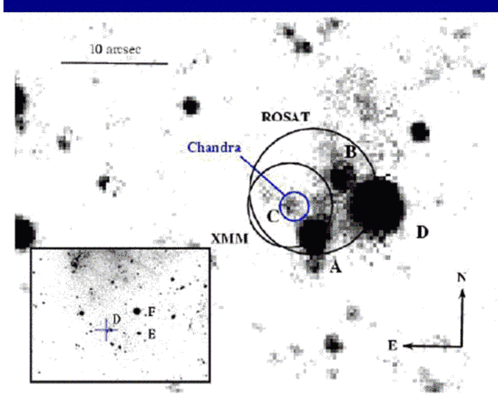
NGC 1313 X-2

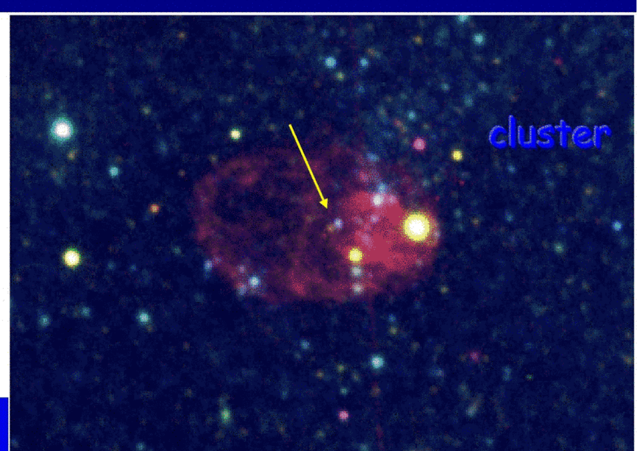
Hα resolution
~ 18 km/s

Ramsey et al. 2006: v_{exp} = 100 km/s (good agreement with our earlier lower resolution data)

Assuming Sedov-Taylor (or snowplow-phase) we find bubble age:
$t = 2/5\ R/v_{exp}$ ~ 0.4x 200 pc/100 km/s ~ 1×10^6 years

NGC 1313 X-2 cluster



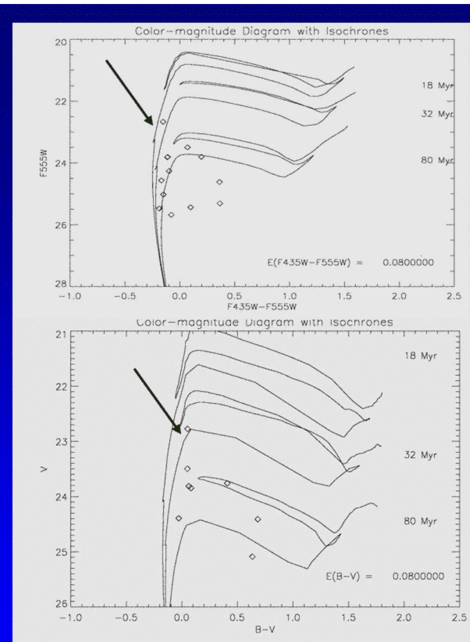


Zampieri et al. 2004
3.6m ESO R
star C likely counterpart

Pakull et al. 2005; 8m ESO B V H_α

It's the blue component !
ULX is member of faint cluster (age ~$10^{7.6}$ yrs)

Holmberg IX X-1 cluster



Isochrone fitting of poor cluster (10^4 $M_\odot$) suggests age of 60 Myrs, much older than the bubble (10^6 yrs)

→ mass of mass donor in ULX <~ 8 $M_\odot$

Energetics of ULX Bubbles 1

Sedov-Taylor (SNR kin. Energy E_0, adiabatic)

- $R \sim 12.8$ pc $(E_{51}/n)^{1/5}\, t_4^{2/5}$
- $V \sim 500$ km/s $(E_{51}/n)^{1/5}\, t_4^{-3/5}$
- $t \sim 6\ 10^5$ yrs R_{100}/V_{100}
- $E_0 \sim 2\ 10^{52}$ erg $R_{100}^3\, V_{100}^2\ n$

Wind/jet fed bubble (mech. luminosity L_W)

- $R \sim 26.2$ pc $(L_{36}/n)^{1/5}\, t_4^{3/5}$
- $V \sim 15.4$ km/s $(L_{36}/n)^{1/5}\, t_4^{-2/5}$
- $t \sim 4\ 10^5$ yrs R_{100}/V_{100}
- $L_W \sim 4\ 10^{39}$ erg/s $R_{100}^2\, V_{100}^3\ n$ (!)

Complete radiative shock, then intensity I_α:

- $I\alpha \sim 1.8\ 10^{-6}$ erg/cm²/s/sr $V_{100}^{2.41}\ n$

Energetics of ULX Bubbles 2

Application of these relations to ULX bubbles yields:

$t \sim 10^6$ yrs (robust);

from Iα we find $n \sim 0.2 - 1$ cm^{-3}

→ $E_0 \sim 10^{53}$ erg; too much even for Hypernova

or

→ $L_W \sim$ few 10^{39} erg/s during last 10^6 yrs;

corresponding to wind of ~1000 massive stars or

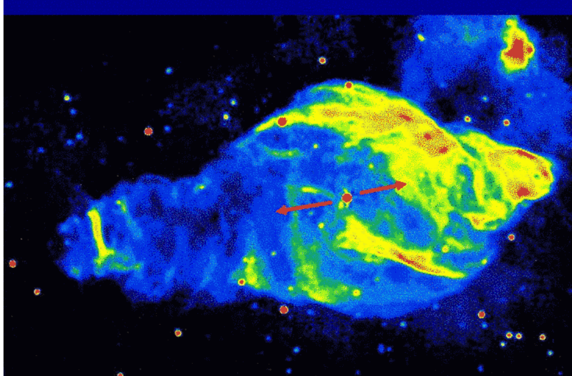
100 SNe in last 10^6 yrs. Superbubble ?

No! Cluster too small (10^4 $M_\odot$; only ~30 massive stars).

But mildly relativistic ULX jet source (SS433-like !)

$M_{dot} \sim 10^{-6} M_{sol}$ /yr and $v_W \sim$few 0.1 c would do the trick.

Dubner et al. 1998
SS433 & W50



Bubble diameter ~ 50x100 pc

SNR and/or « beambags » ?

$P_{jet} \sim 10^{39-40}$ erg/s inflate "ears"

Gallo et al 2005
Cyg X-1 & neb

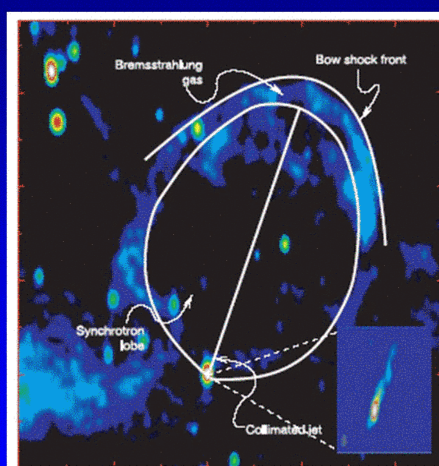


Figure 2 | The ring of Cygnus X-1: sketch of the model. The ring is the result

Bubble diameter ~ 5pc
$P_{jet} \sim 10^{36-37}$ erg/s

Energetics of ULX Bubbles 3

Yet …

- much smaller IS density (n~0.01 in excavated wind-driven superbubbles) in the past would lessen E_0
- v_s (optical) not necessarily = v_{exp} of blastwave (X-ray); the IS medium is *cloudy*, like in real SNR
- "normal" E_0 (~10^{51} erg) SNR excluded for ULX bubbles;

  but E_o ~few 10^{52} erg (Nomoto's hypernova ?) may be feasible
- more work is needed to better understand energetics of ULX bubbles (thermal- versus magnetic energy content in postshock region)

What have we learnt ?

- A significant fraction (> 50%) of ULXs blow huge IS bubbles
- Extent and supersonic expansion velocity of ULX bubbles yields estimate of energetics ⇨ clues to ULX formation and/or mass-loss (jets) history
- some ULX are members of ~50 Myr old poor clusters; ⇨ mass donors have <~ 8 $M_\odot$,
- if ULX bubbles (~1 Myr old) are SNRs ⇨ pre-SNe

  were not massive either (<~ 8 $M_\odot$); that would exclude presence of IMBHs in ULX, and invalidate Hypernova hypothesis

  › *bubbles are most likely jet-driven rather than HNRs*