Bubbles and Superbubbles

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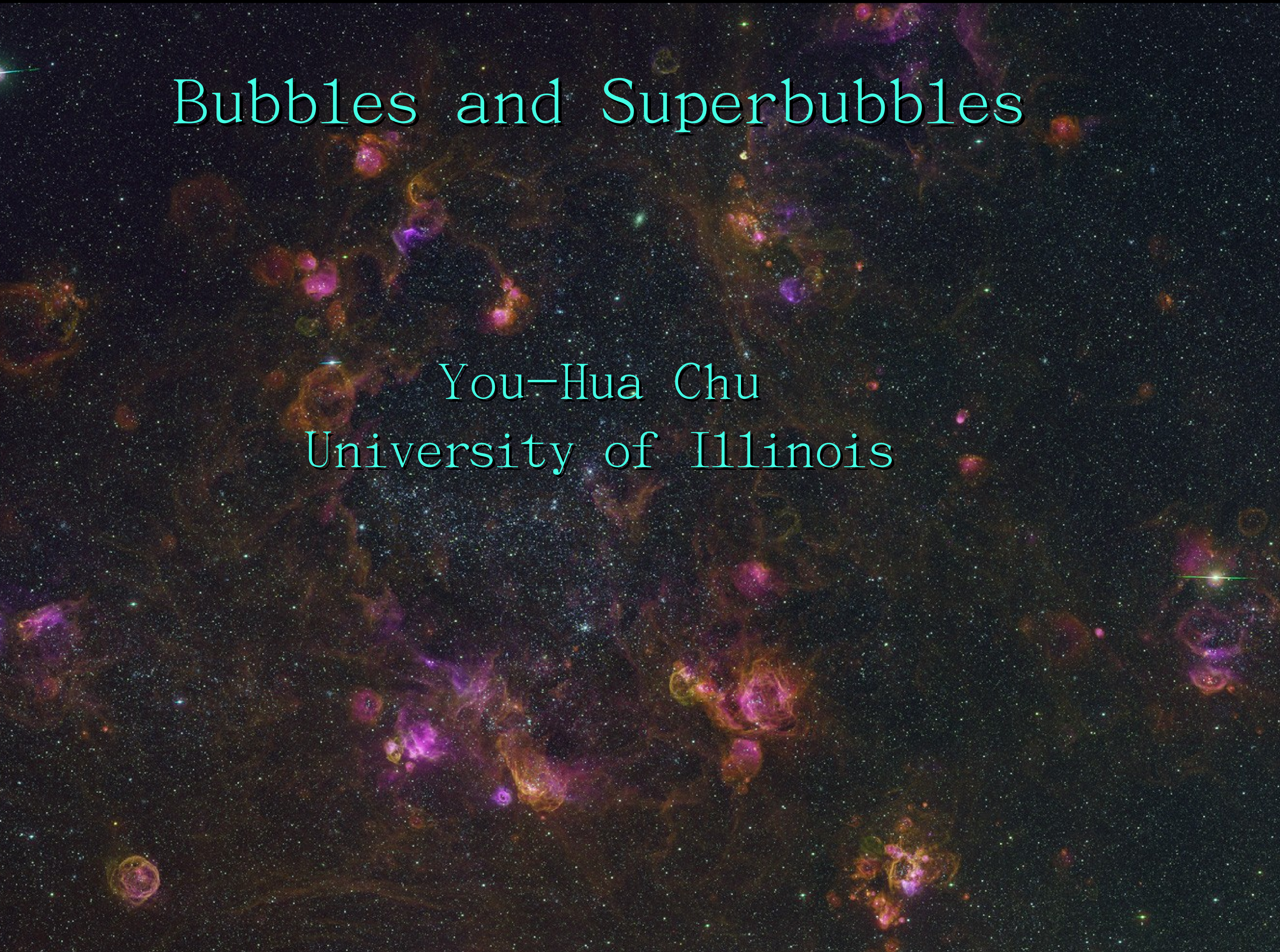
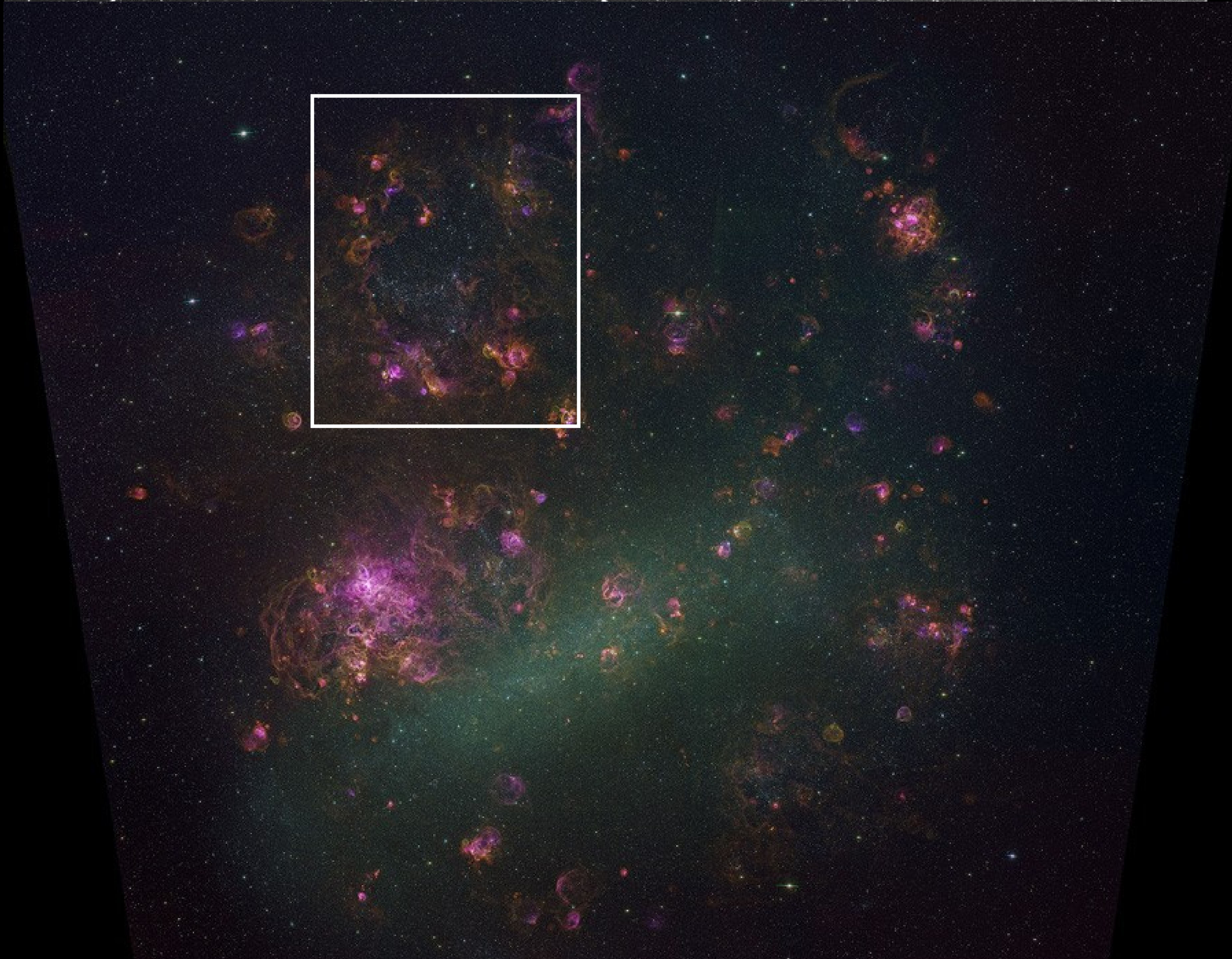
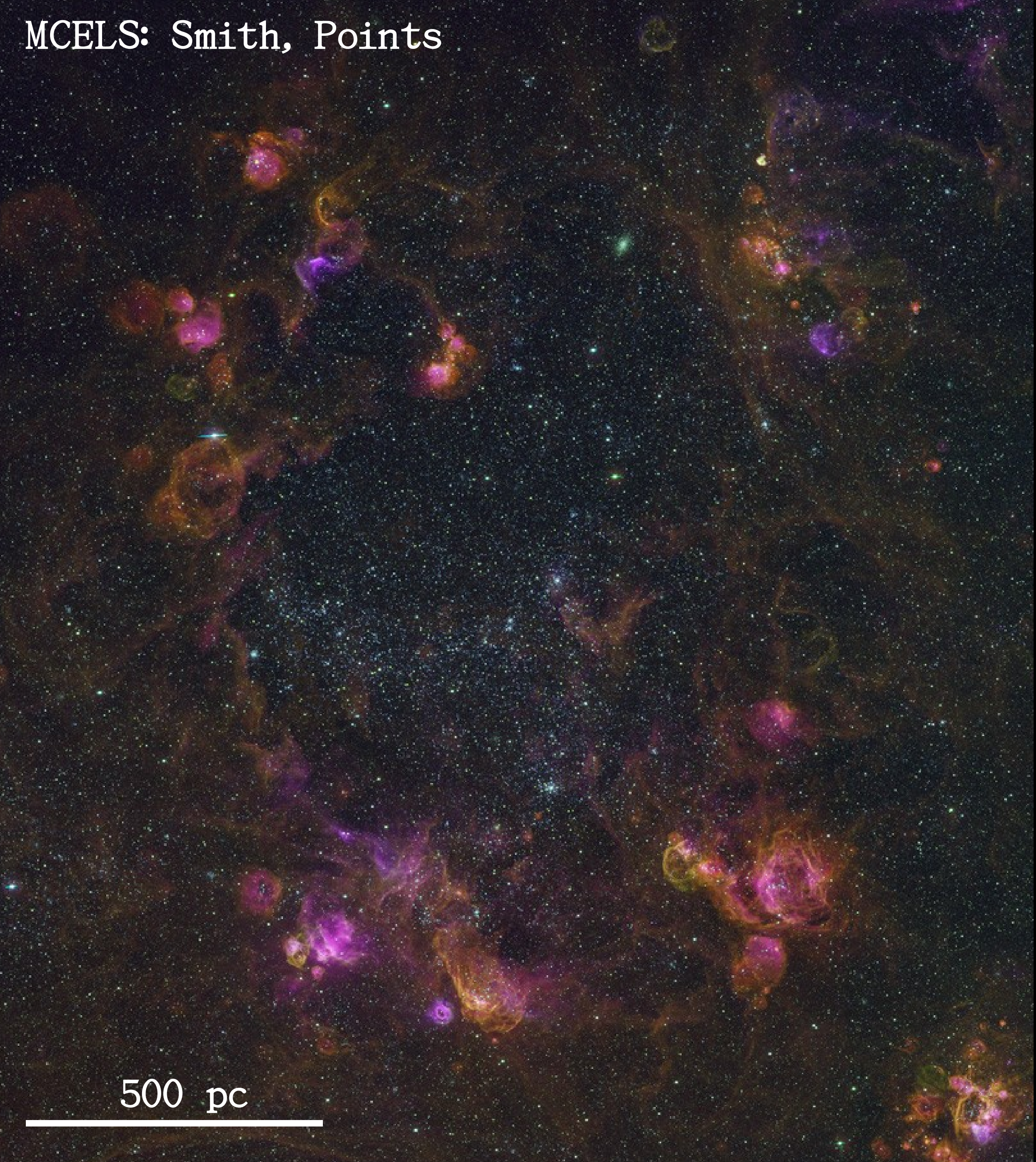






Supergiant shells
~ 1000 pc
~ 10^7 yr
(multi generations)

Superbubbles
~ 100 pc
~ 10^6 yr
(OB associations)

Bubbles, SNRs
~ 10 – 50 pc
~ 10^3 — 10^5 yr
(single star)

R – Hα
G – [S II]
B – [O III]

Interstellar & Circumstellar Bubbles

O star → LBV → WR (60 $M_{\odot}$)

O star → RSG → WR (35 $M_{\odot}$)

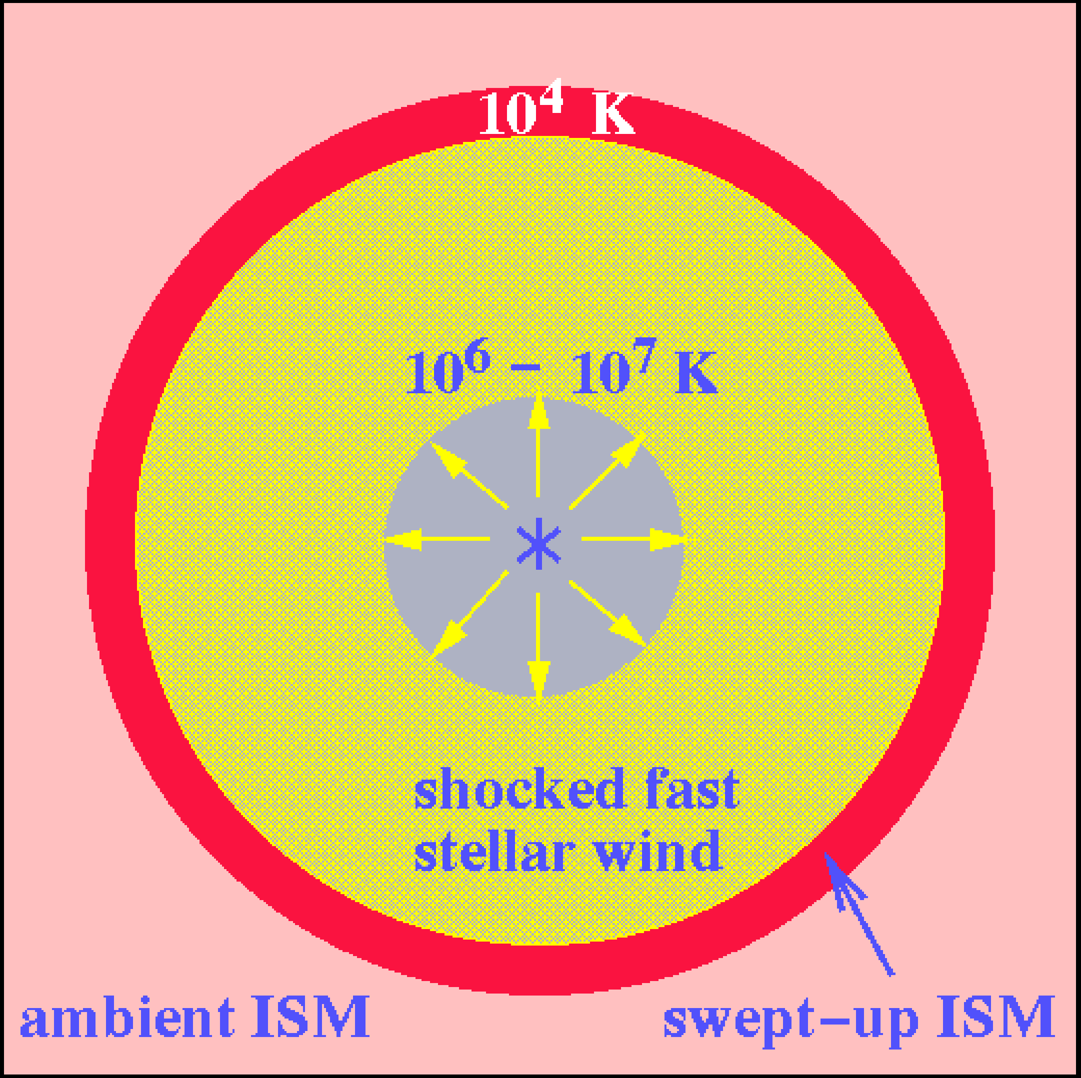
fast wind slow wind fast wind

1000 – 2000 km/s 10 – 50 km/s 2000 – 3000 km/s

10^{-7} $M_{\odot}$/yr 10^{-4} $M_{\odot}$/yr 10^{-5} $M_{\odot}$/yr

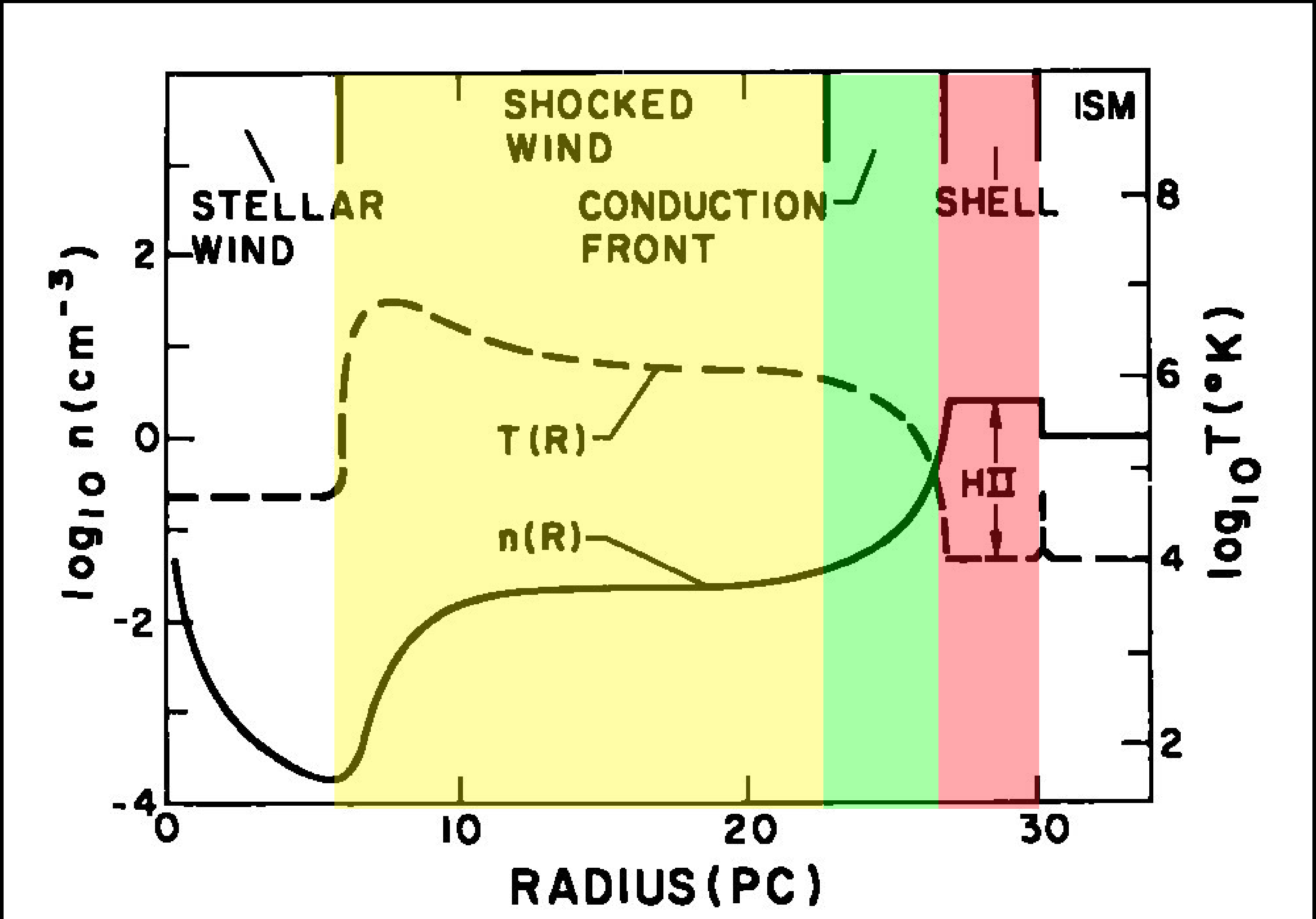
Low-mass ★ → RG, AGB → planetary

Interstellar Bubble



Castor, McCray, Weaver 1975
Weaver et al. 1977

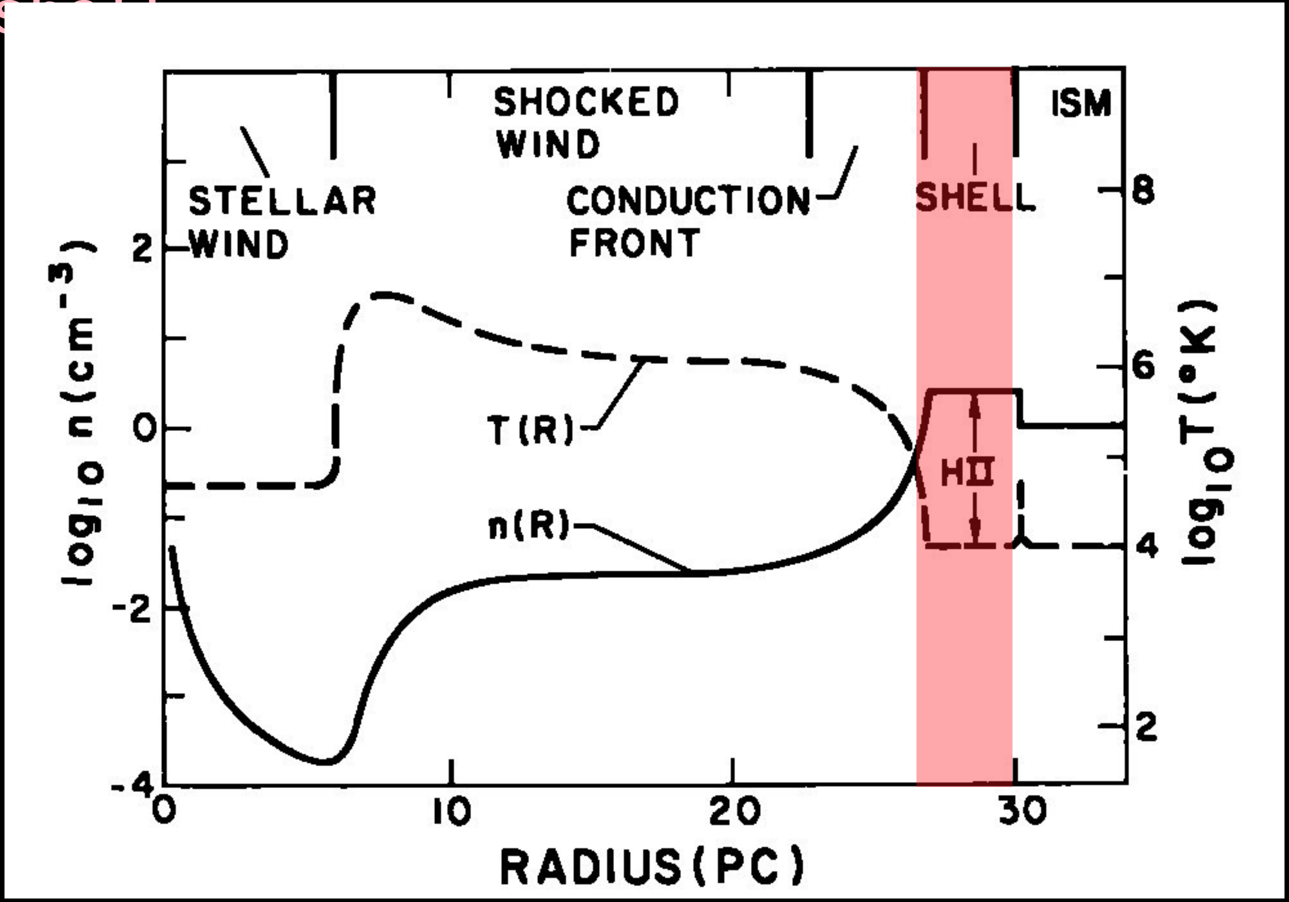
Schematic Bubble Structure



Weaver et al. 1977

I. Dense Swept-up Shell

Hα from H II shell, 21-cm from HI shell

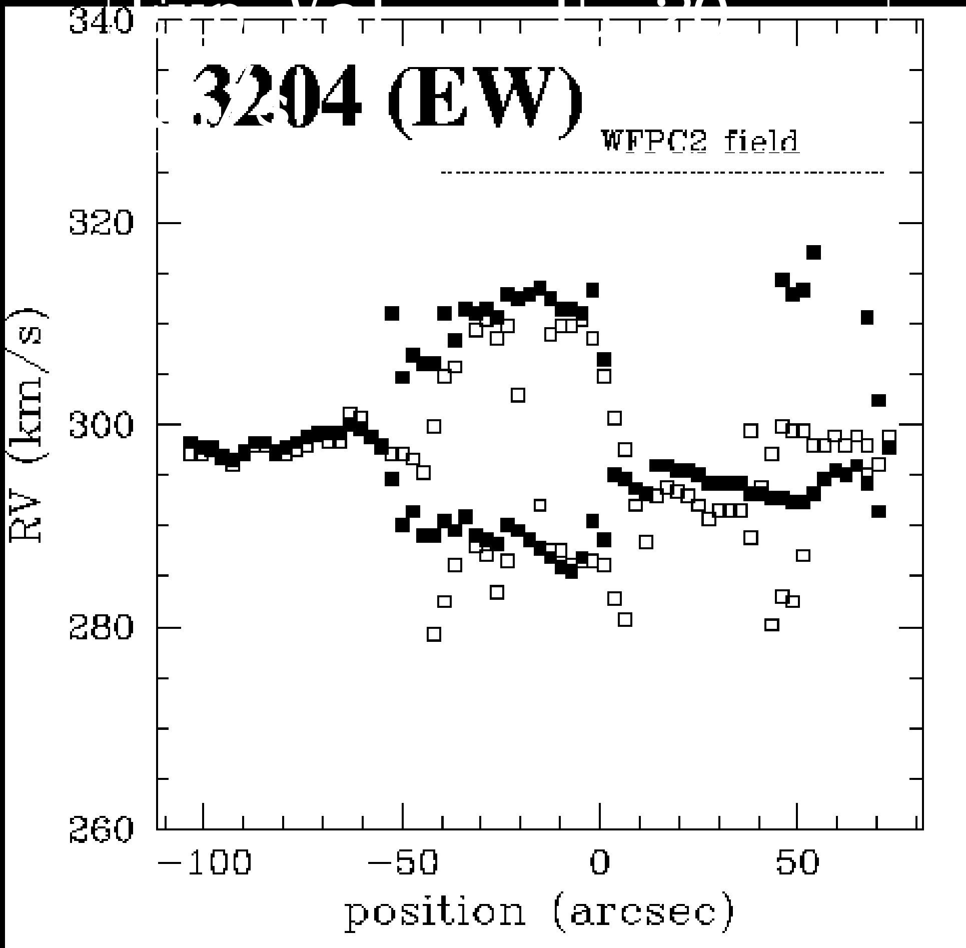


The Bubble Nebula

N11B – Home of LH10

Bubble Size ~ 15 pc

Exp. Vel. ~ 15-20



Ionized shell (H II)

- sound vel ~ 10 km/s
- no strong shocks
- no large density jump
- no limb-brightening

Neutral shell (H I)

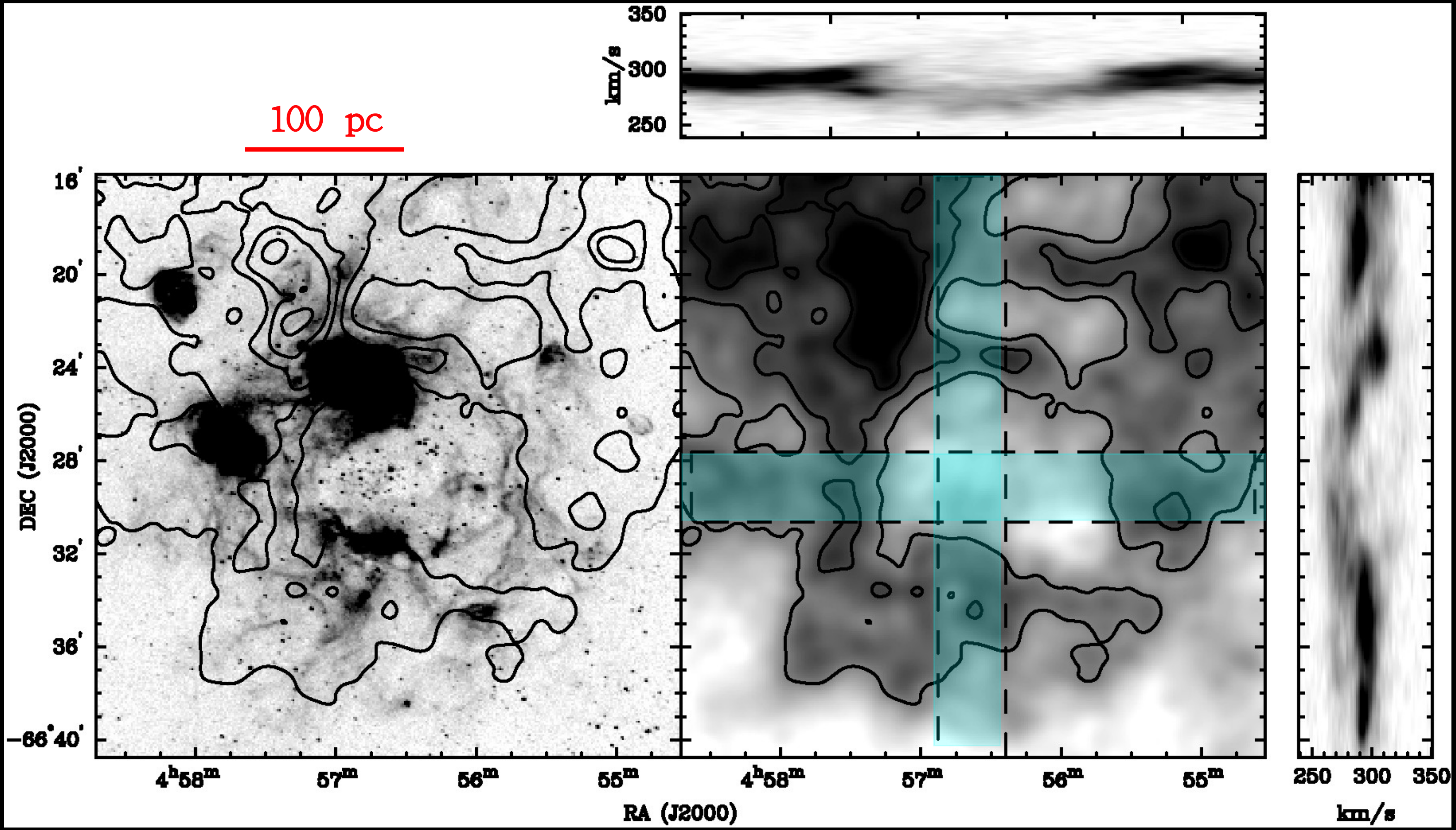
- sound vel ~ 1 km/s
- large density jump
- limb-brightening
- frequently seen

aze, et al. 2001, AJ, 122, 921

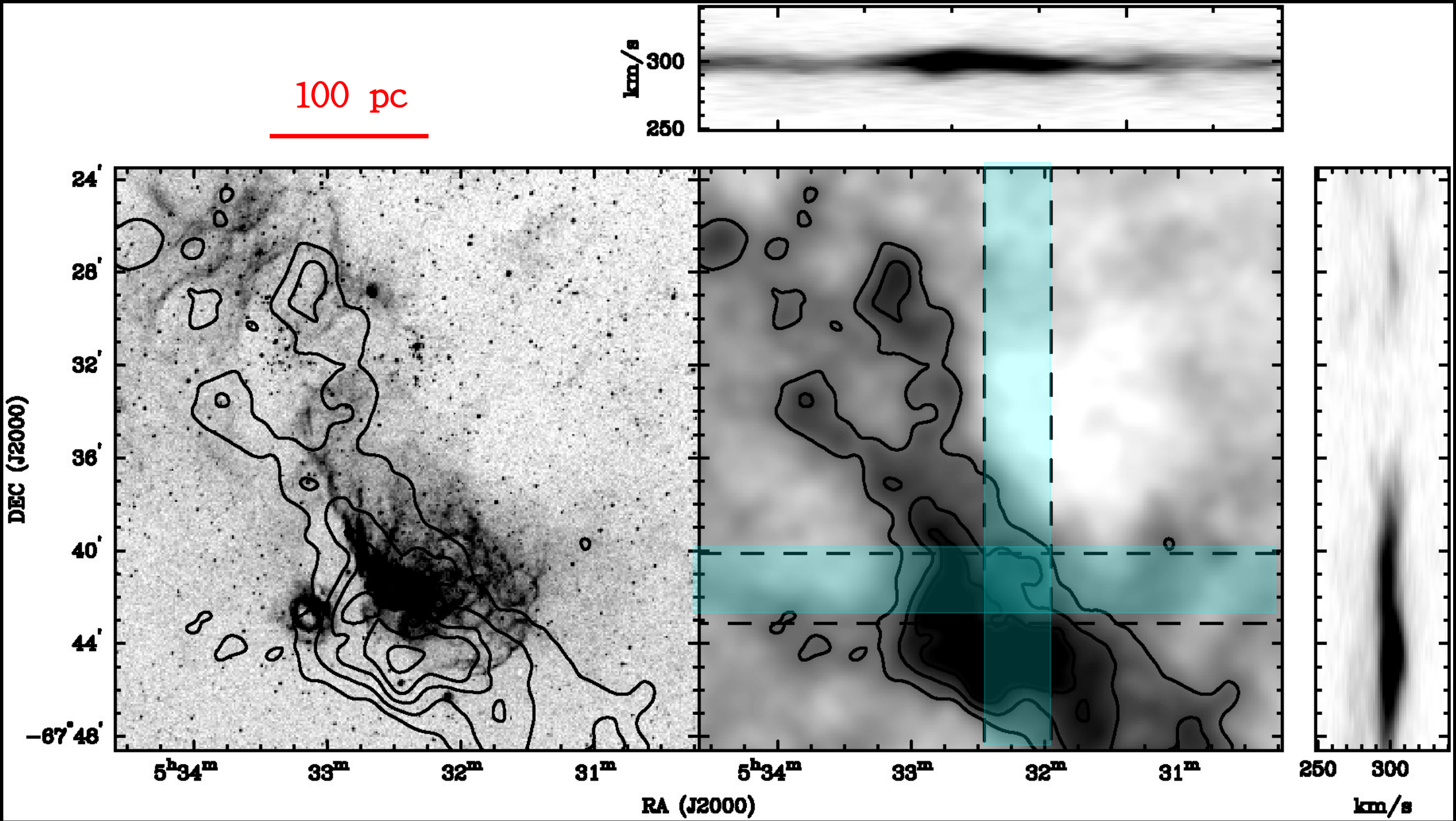
I. Dense Swept-up Shell

- Why aren't there more interstellar bubbles?
- clumpy / inhomogeneous ambient ISM

HII and HI Shells of N11



HII and HI Shells of N57



I. Dense Swept-up Shell

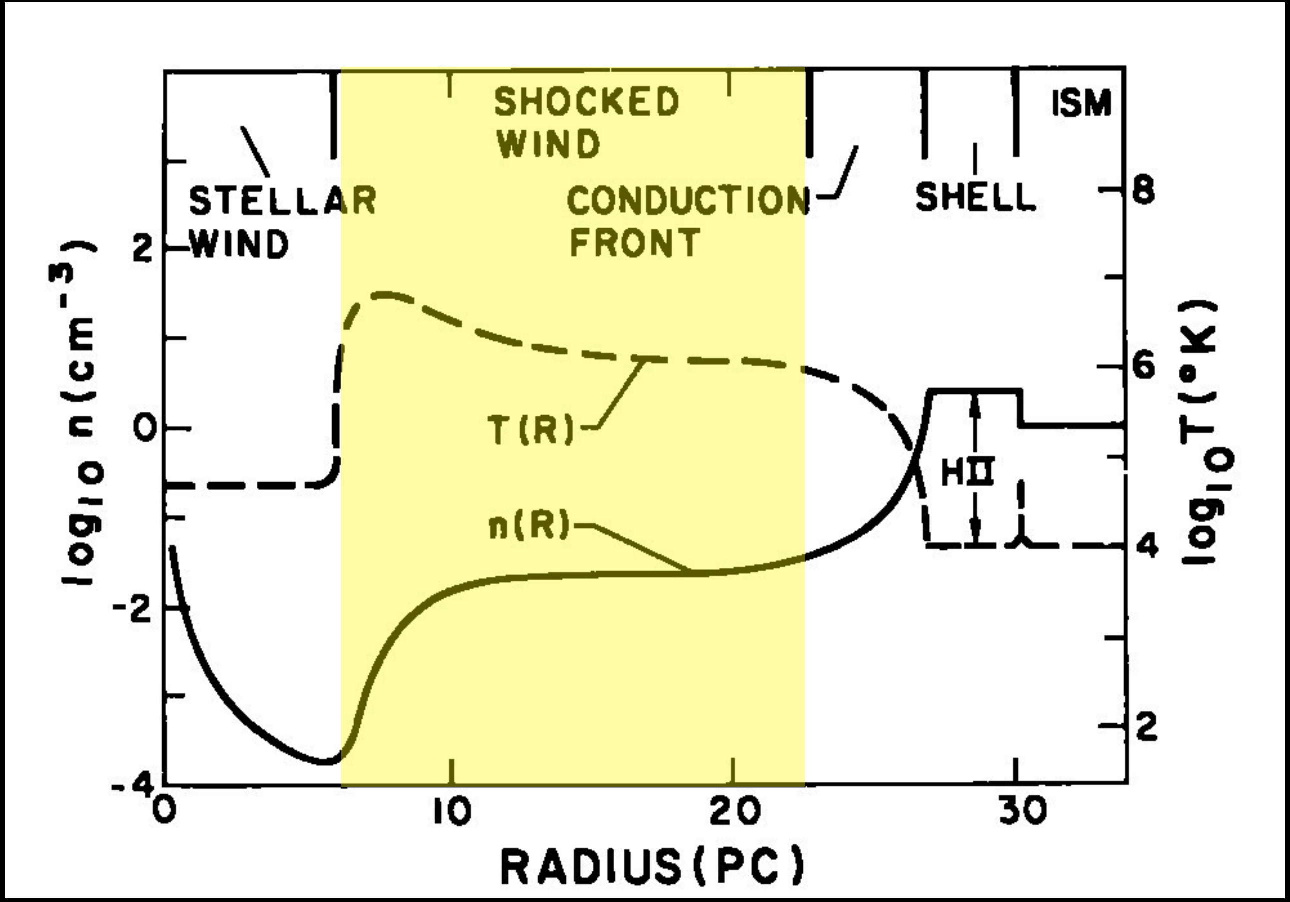
Why aren't there more interstellar bubbles?

- clumpy / inhomogeneous ambient ISM
- clumpy circumstellar bubble

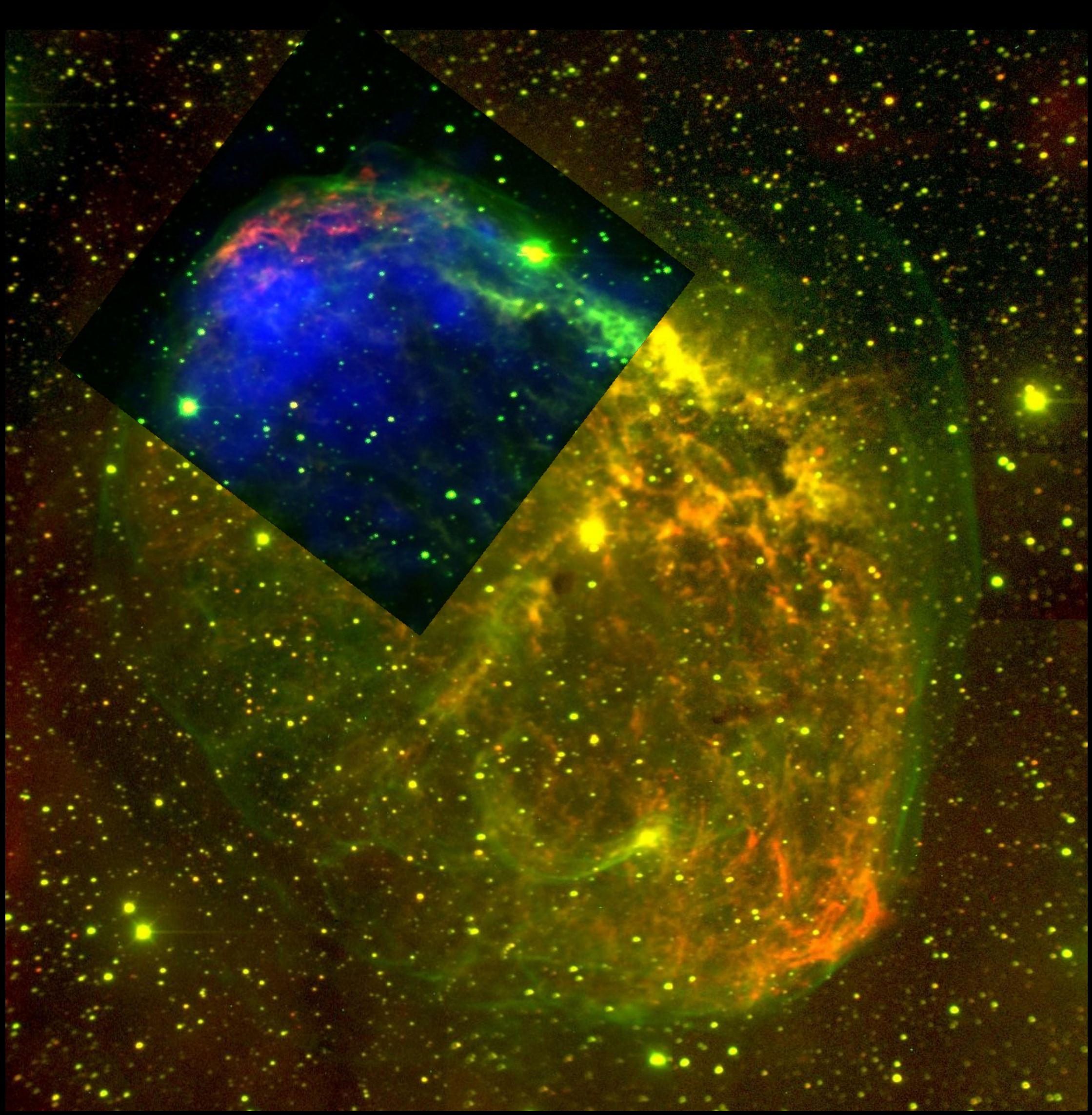
Observed bubble dynamics does not match that expected from bubble models; e.g., observed kinetic energy is too low.

II. Hot Bubble Interior

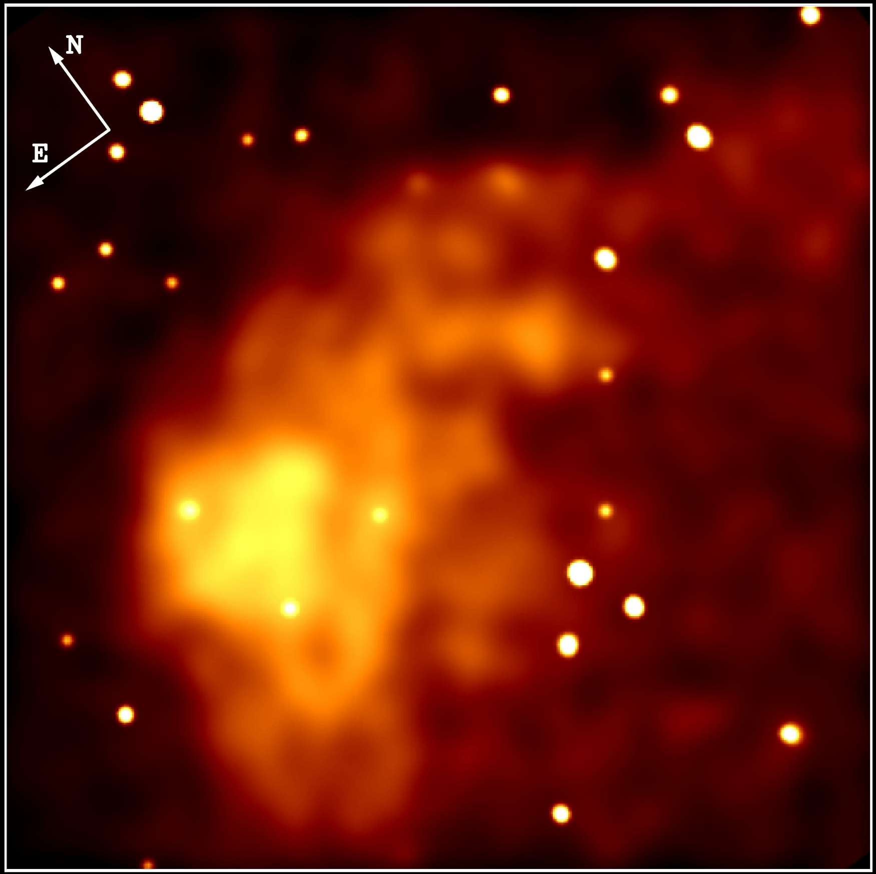
X-ray emission from bubble interior



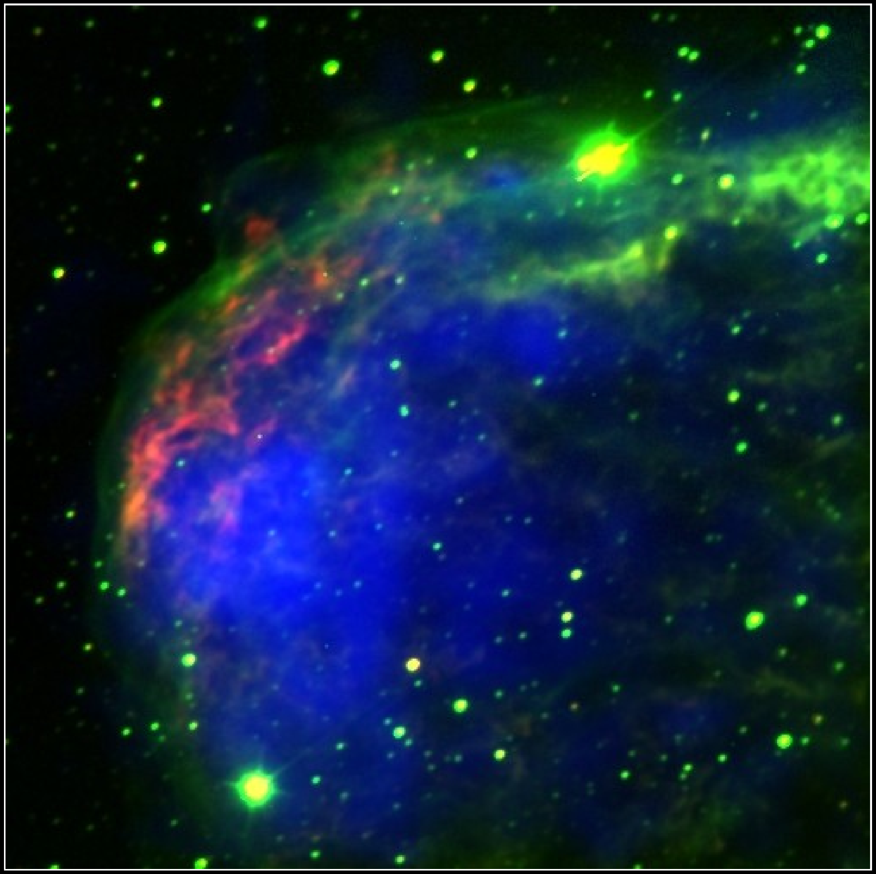
Circumstellar Bubble NGC 6888



Chandra X-ray Image of NGC 6888

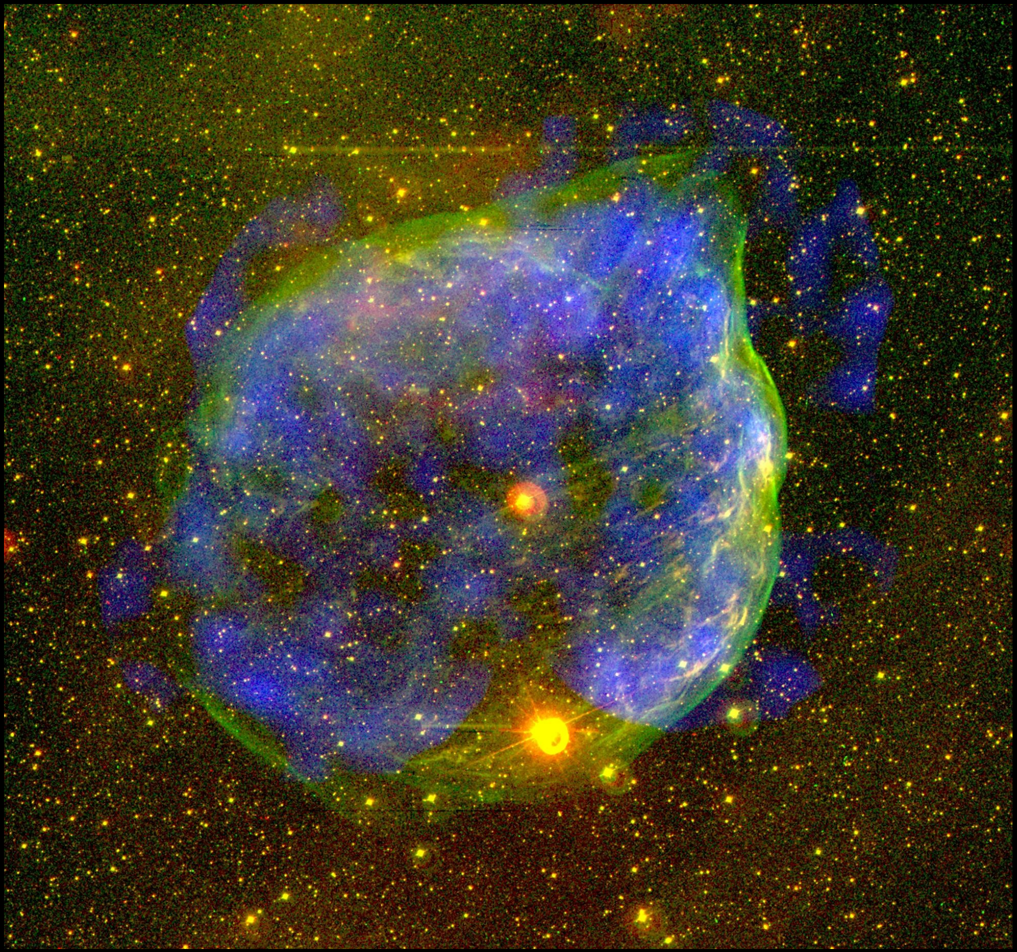


Gruendl, Guerrero, Chu
2008, in prep.



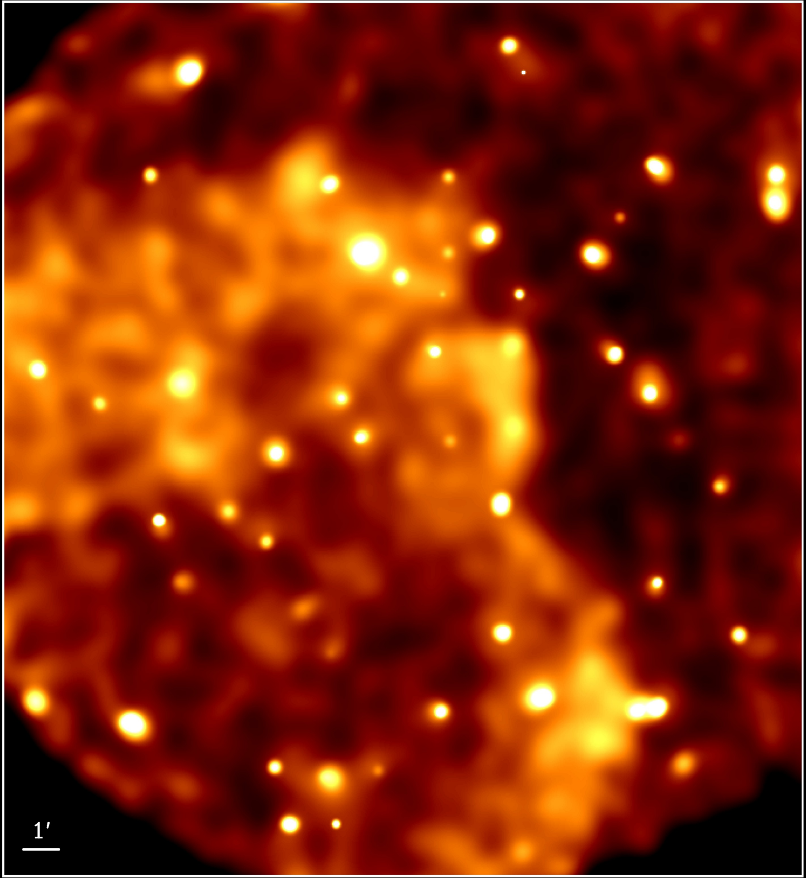
R: Hα G: [O III] B: X-ra

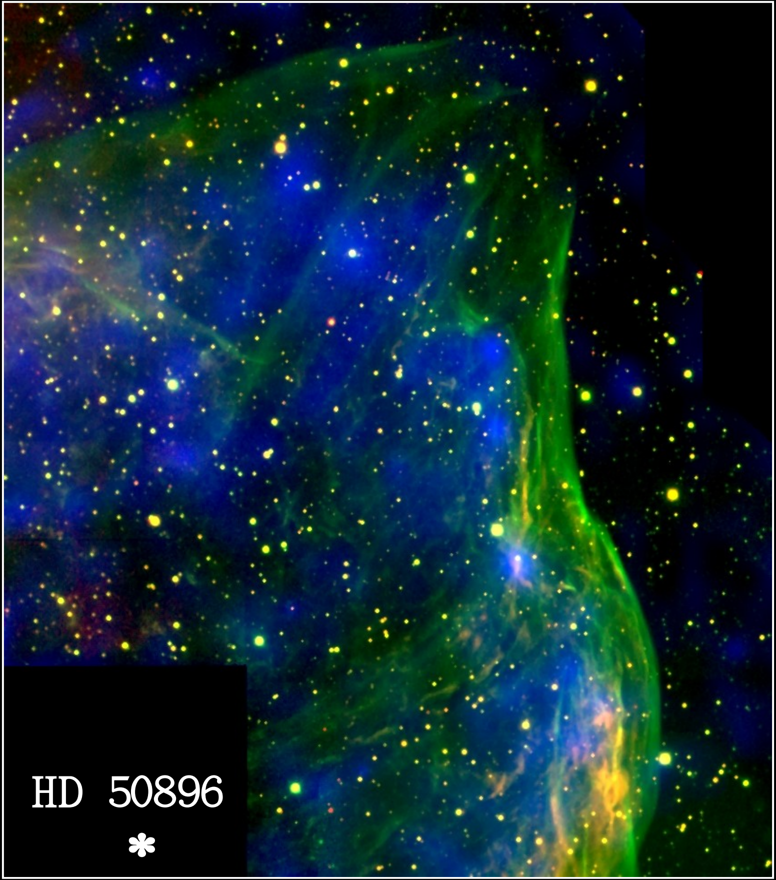
S 308 – a WR Circumstellar Bubble



Red: Hα Green: [O III] Blue: X-ray

S 308 – a Detailed Look at Its Shell



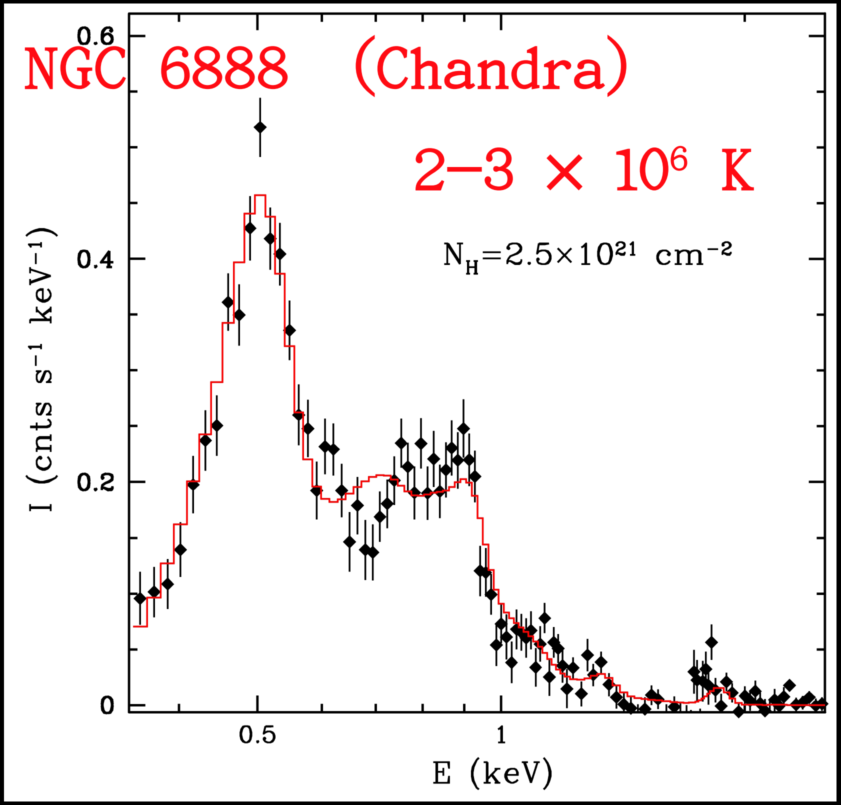


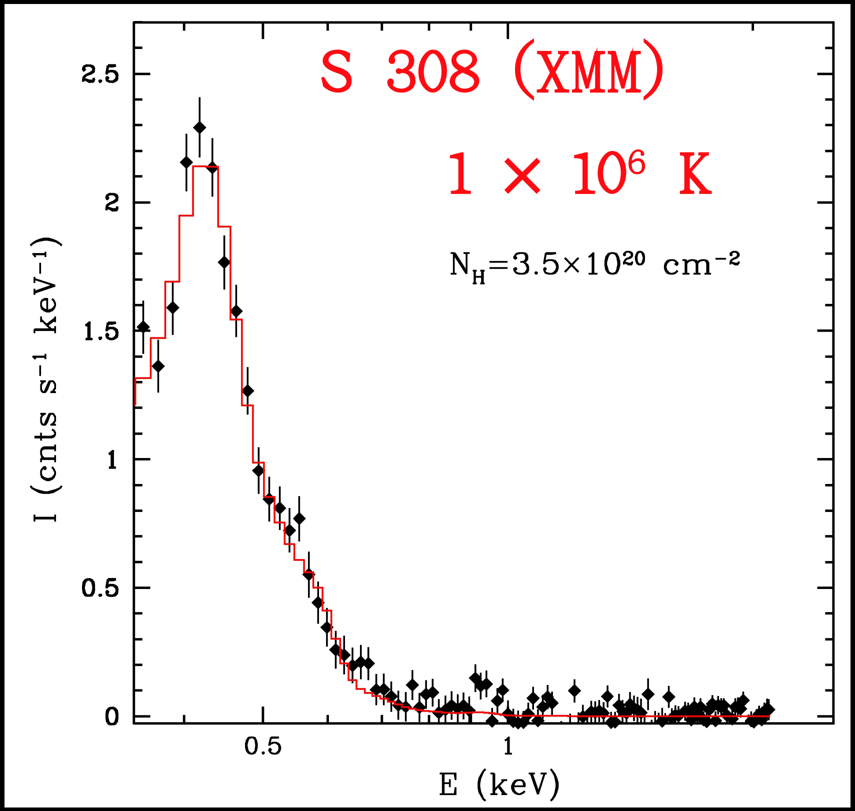
Chu et al. 2003, ApJ, 599, 1189

R: Hα G: [O III] B: X-ray

II. Hot Bubble Interior

- X-ray emission from bubble interior
- Why aren' t more bubbles detected in X-rays?





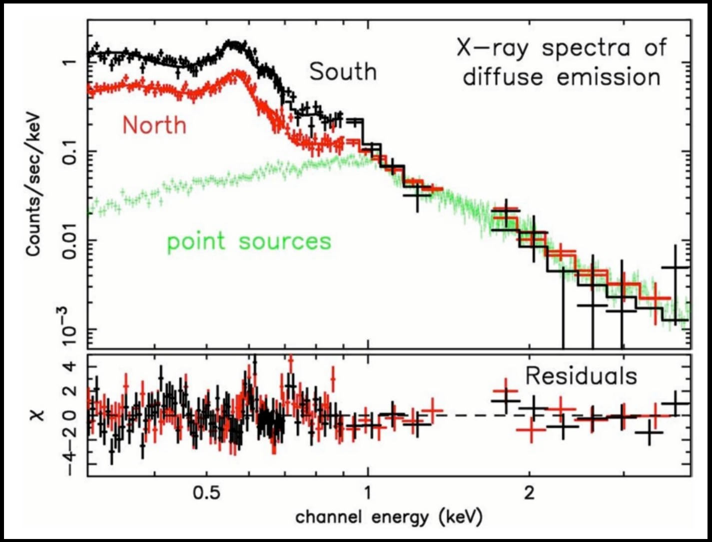
Hot Gas in the Orion Nebula

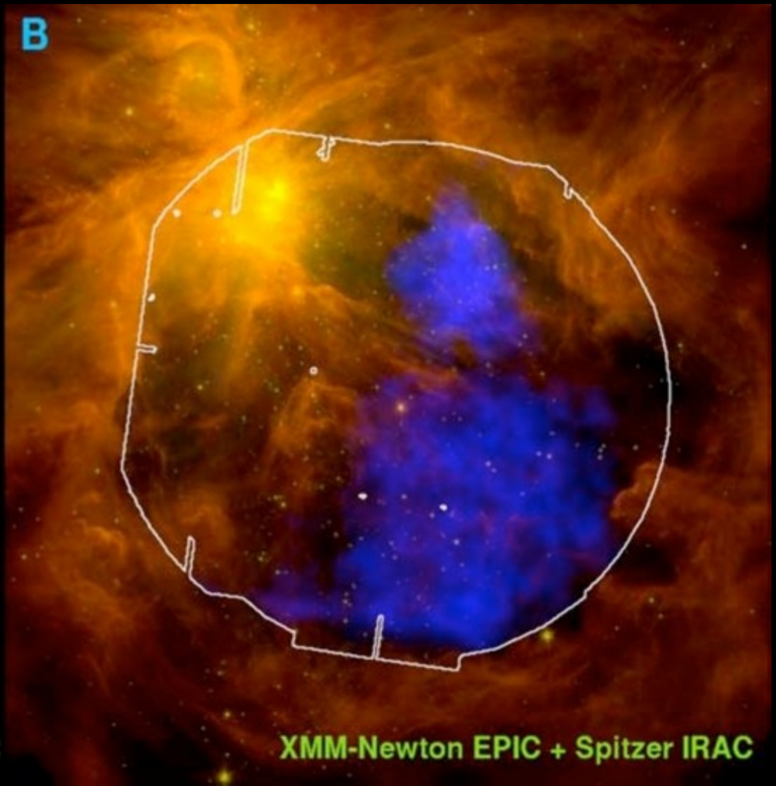
$T \sim 2 \times 10^6$ K

$L_X \sim 5.5 \times 10^{31}$ erg/s

3.5 pc in diameter

Güdel et al. 2008



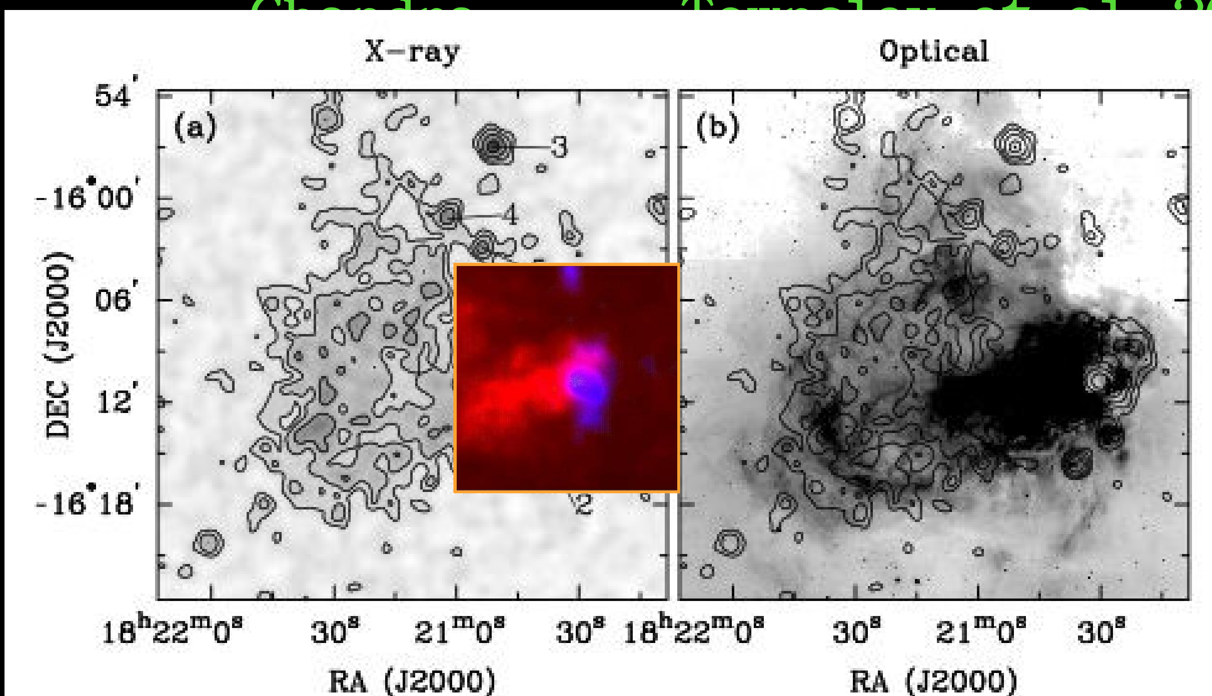


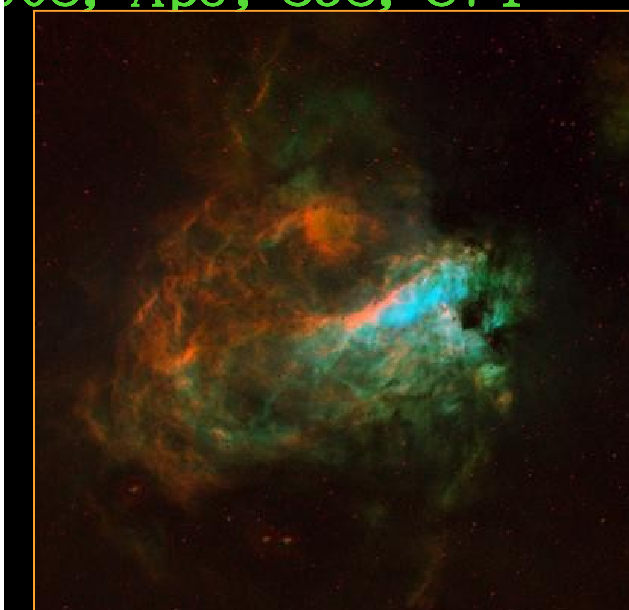
Hot Gas in the Omega Superbubble

Two young superbubbles are detected in X-rays by Chandra: Omega and (Rosette)

ROSAT – Dunne et al. 2003, ApJ, 590, 306

Chandra – Townsley et al. 2003, ApJ, 593, 874





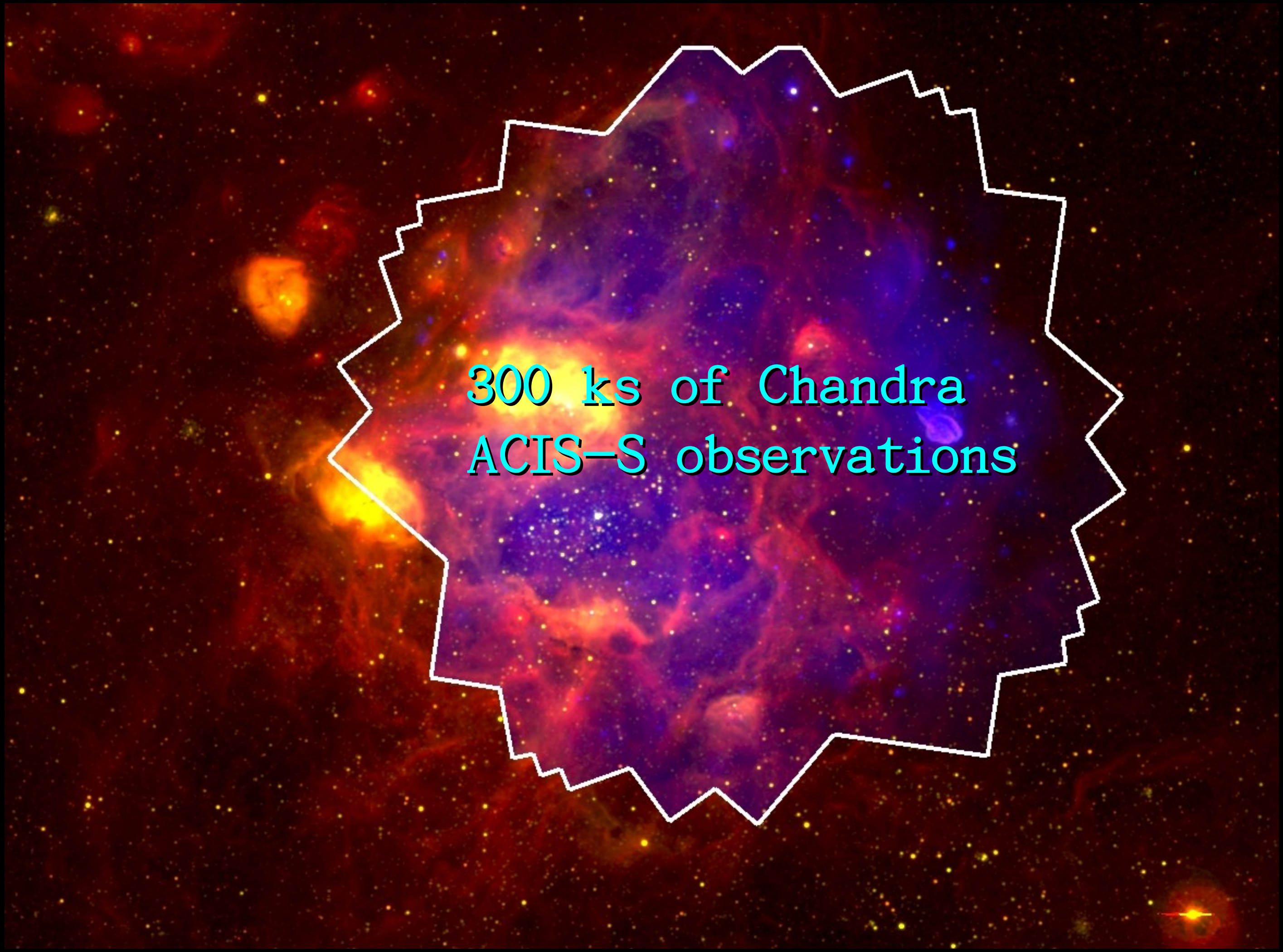
LMC Superbubble: N70

Red: Hα Green: [O III] Blue: X-ray

LMC Superbubble: N57

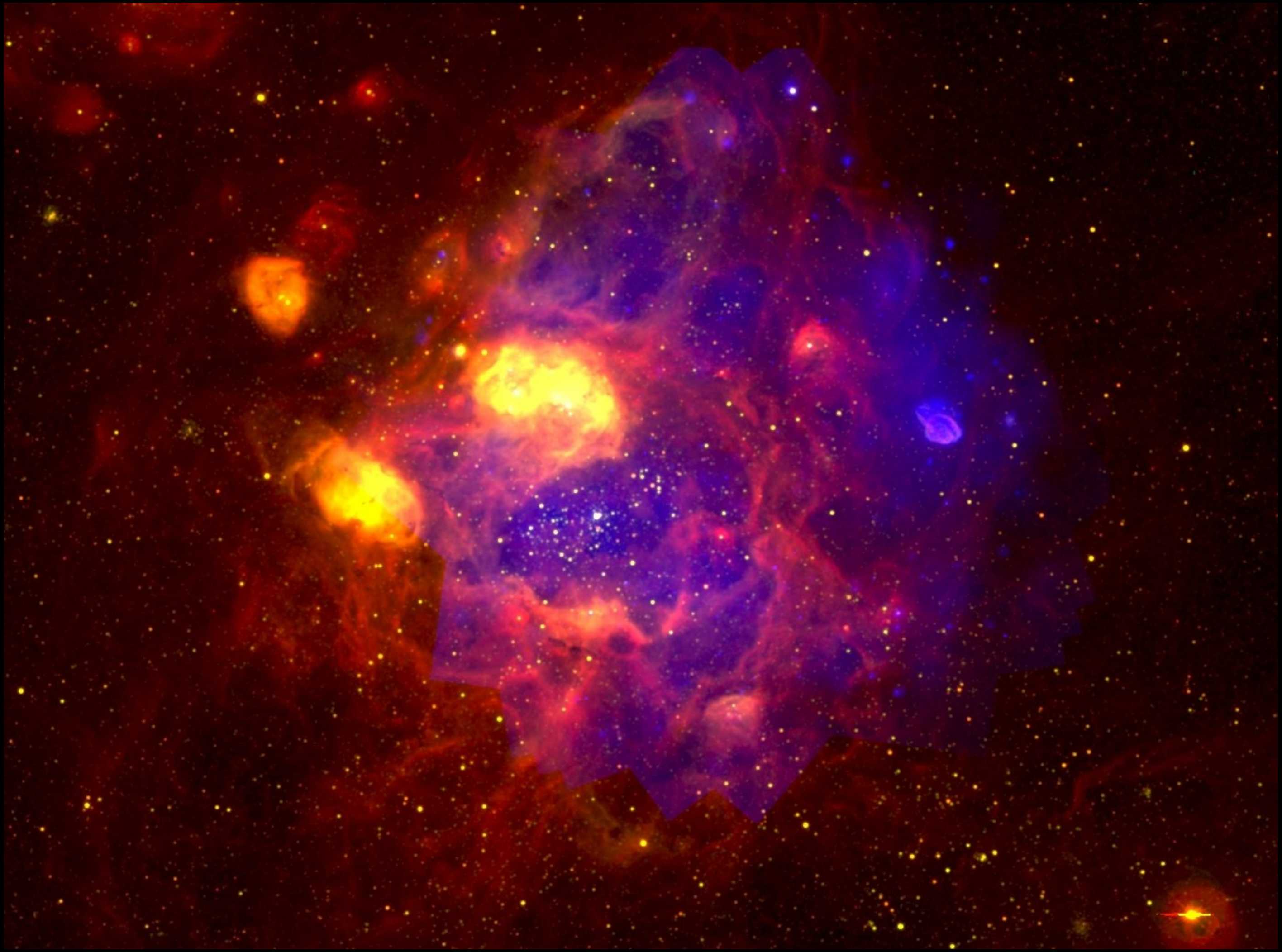
Red: Hα   Green: [O III]   Blue:

LMC Superbubble: N11



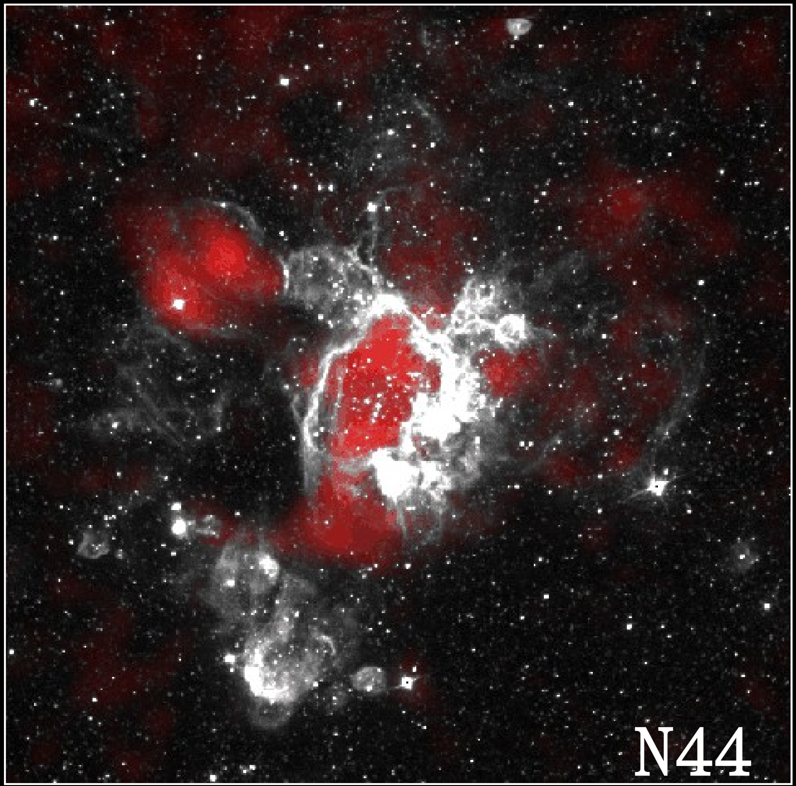
Red: Hα Blue: X-ray

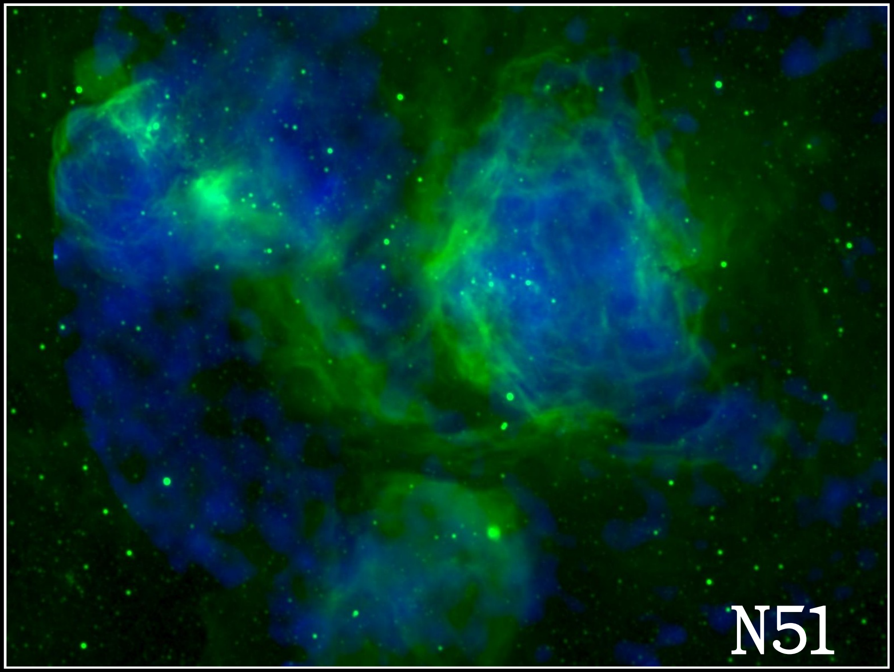
LMC Superbubble: N11



Red: Hα   Blue: X-ray

LMC Superbubbles N44 and N51D





ed: X-ray ;   White: H-alpha

hu et al. 1993, ApJ

Blue: X-ray, Green: H-alpha

Cooper et al. 2004, ApJ

X-ray Observations of Bubbles

- Detection of hot gas associated with fast winds
  - 12 PNe, 2 WR bubbles, several superbubbles

- Properties of the hot gas:

	L_X [erg/s]	T_e [10^6 K]	N_e [cm^{-3}]
PN	$10^{31} - 10^{32}$	$1-3 \times 10^6$	100
”		”	
WR		$1-2 \times 10^6$	1

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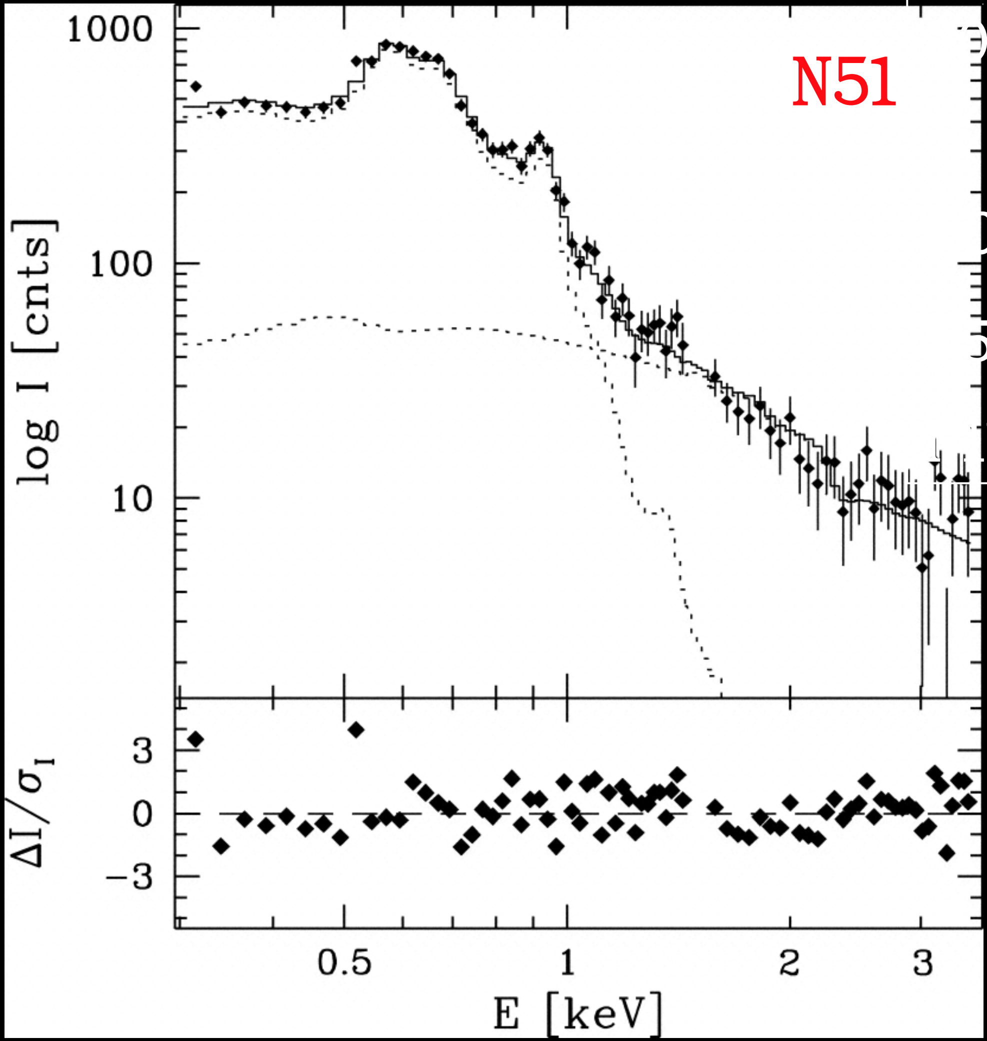
Nonthermal X-ray Emission



0.2 keV thermal + power-law

) Dor C – Bamba et al.
– Smith, War
CW38 – Wolk et al.
51 – Cooper et al.
1 – Maddox et al.

Parizot et al. 2004

acceleration by repeated shocks and turbulence

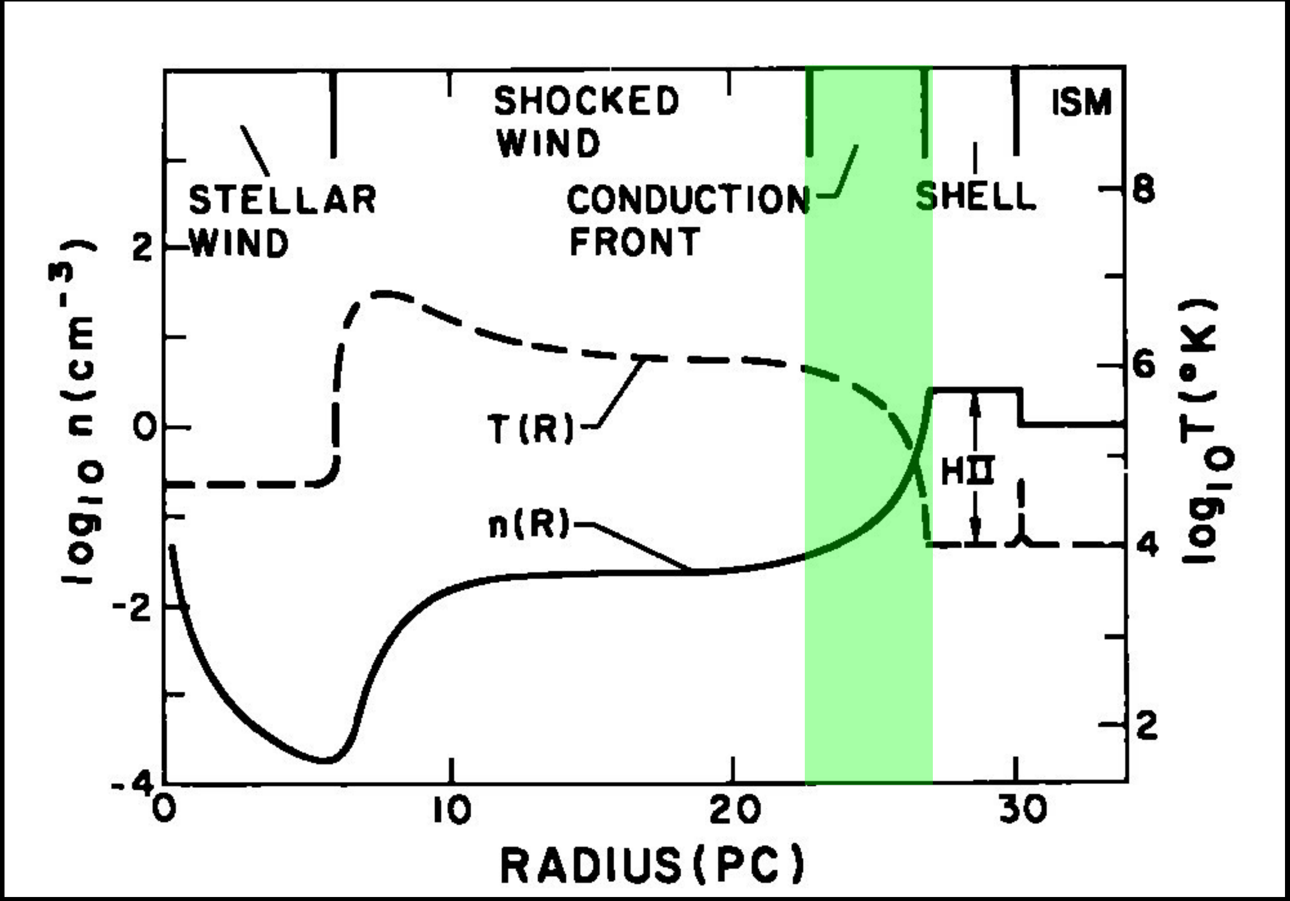
Synchrotron?
Inverse Compton?
???

II. Hot Bubble Interior

- X-ray emission from bubble interior is soft and can thus be absorbed easily.
- X-ray emission depends on:
  - wind properties
  - concentration of massive stars
  - clumpy structure of the ambient medium
  - magnetic fields
  - supernova explosions
- Nonthermal X-ray emission!!!

III. Conduction Layer

- Probe the thermal conduction layer
  High ions produced by thermal collisions



Probes of the Conduction Layer

C IV

N V

1548, 1550 | 1238, 1242 | 1031, 1037

HST/STIS | *HST*/STIS | *FUSE*

47.9 | 77.5

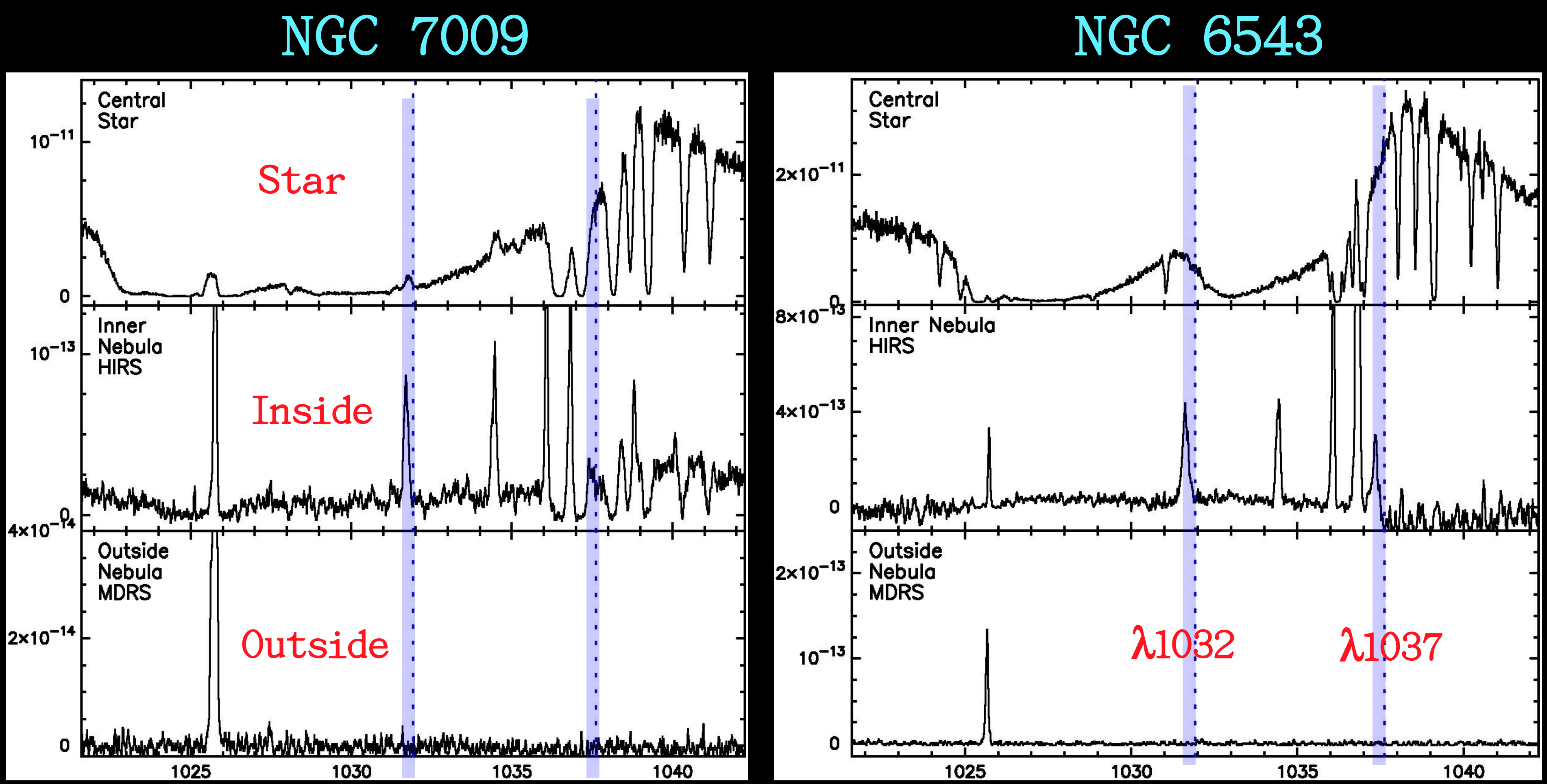
K) 1.(

Collisional ionization

Photo-ionization

K) > 35,0ᴗᴗ > 75,000 > 125,000

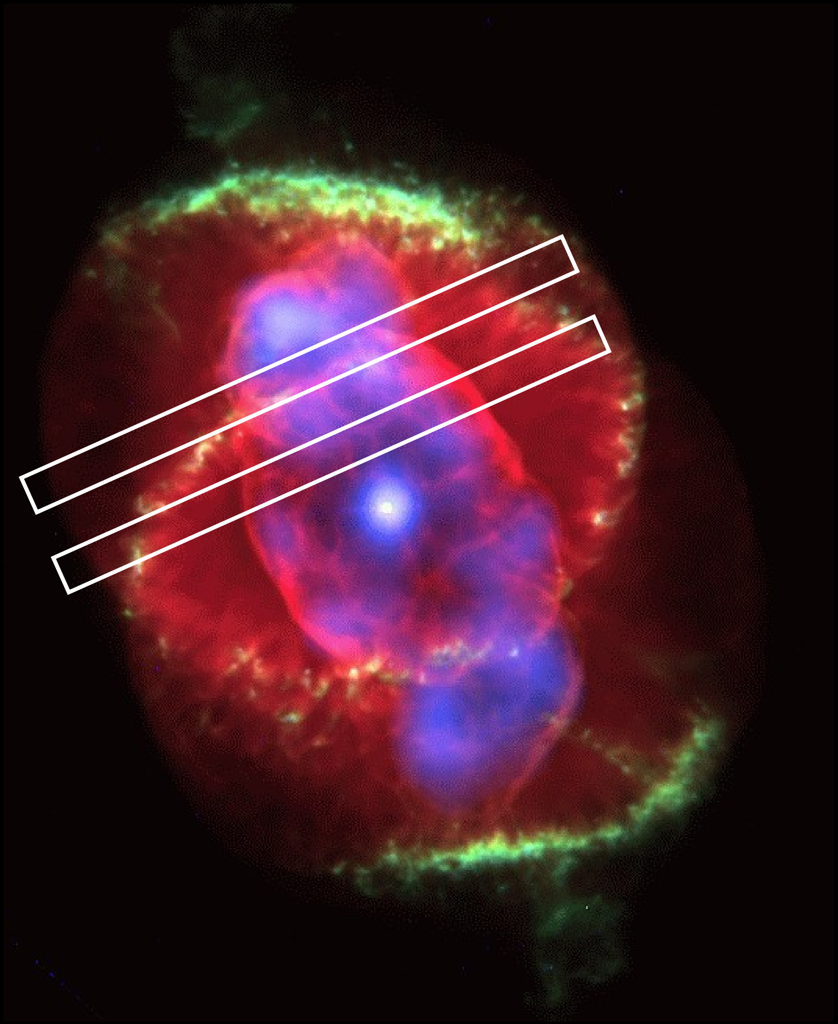
OVI Absorption vs. Emission



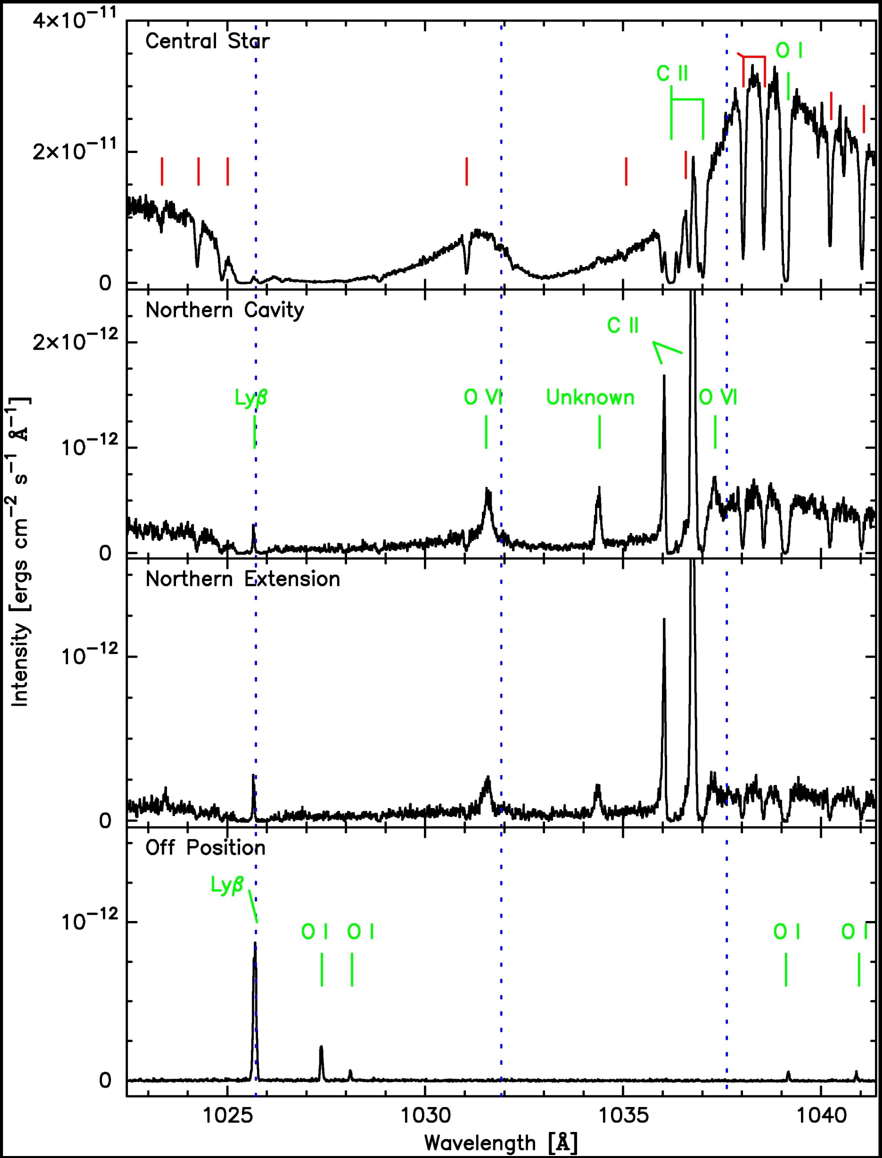
Observations by Iping et al.

Stellar P Cygni profile; nebular O VI emission

FUSE Observations of NGC 6543



Gruendl et al. 2004

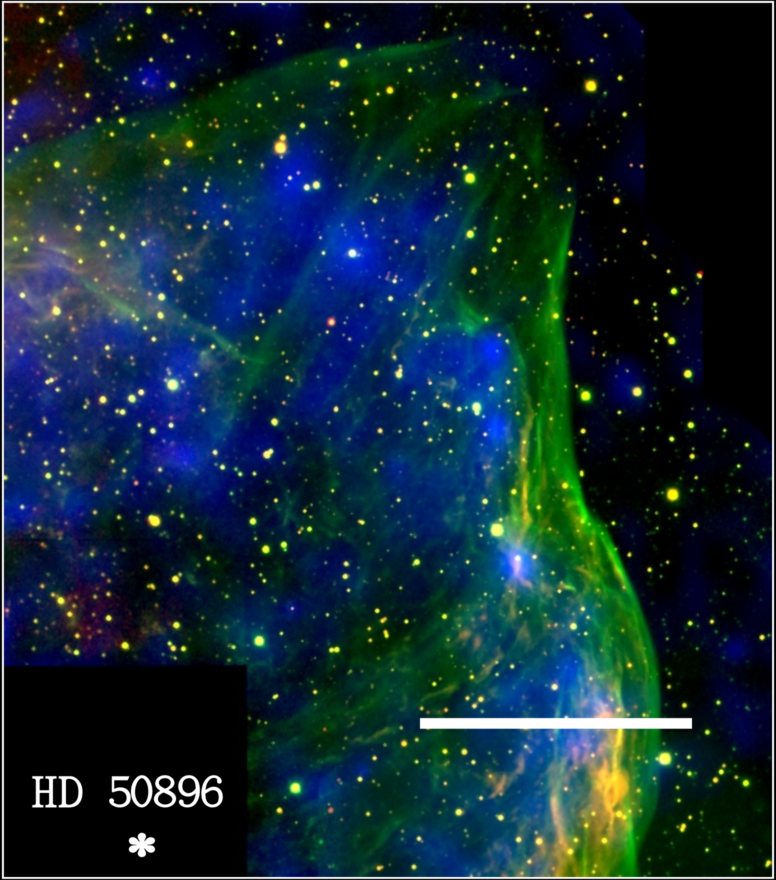


Circumstellar WR Bubble S 308

Boroson et al. (1997)
detected
N V absorption from the
conduction layer.

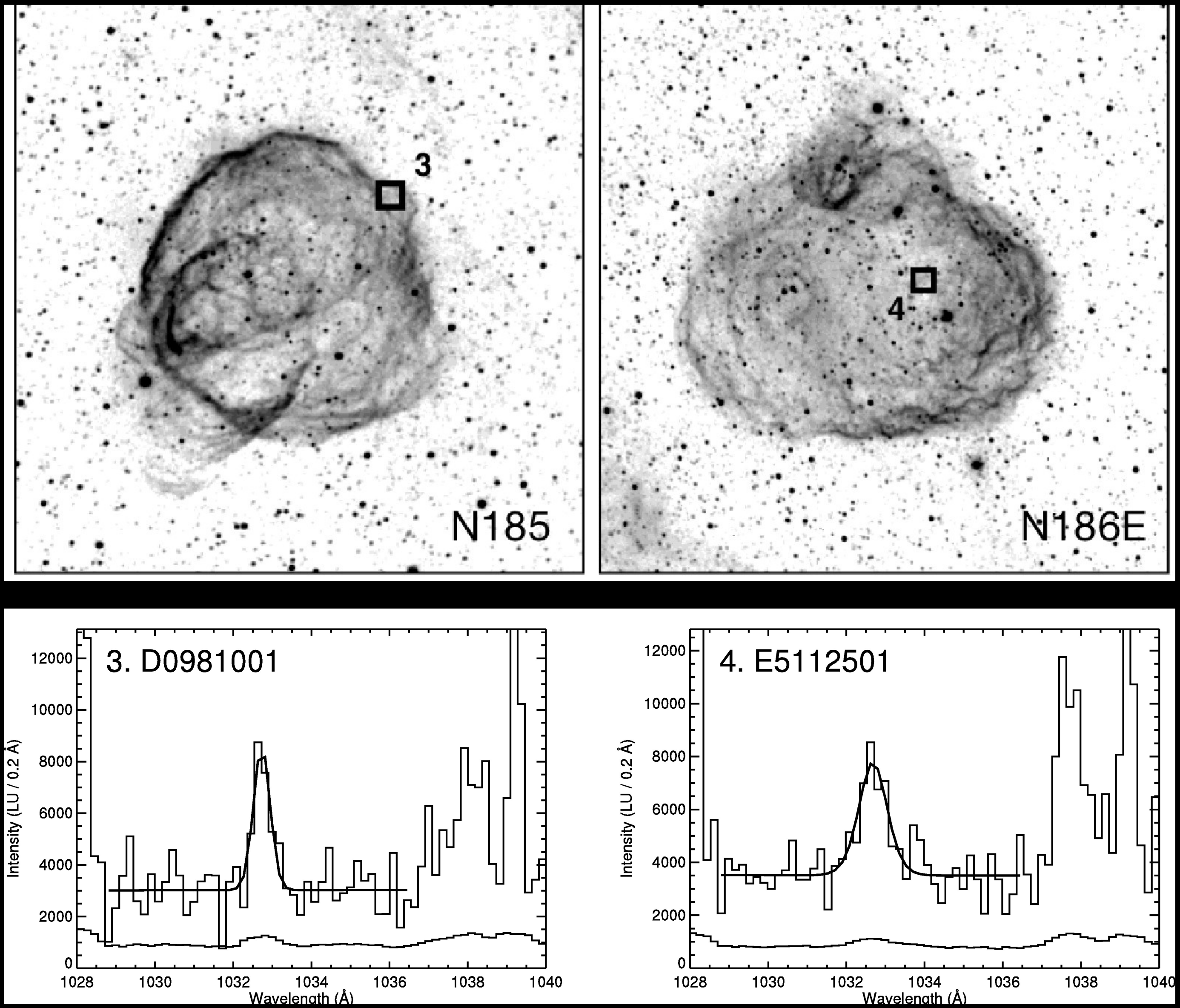
HST STIS observation of N
V
and C VI emission was
scheduled, but STIS died.

FUSE observations of O VI
were awarded, and it died,
too.



R: Hα G: [O III] B: X-ray

O VI Emission Detected in Superbubbles N185, N186E
Sankrit & Dixon 2007



III. Conduction Layer

– Probe the thermal conduction layer with
high ions produced by thermal collisions

– NGC 6543: given the boundary conditions
of hot interior and warm shell, thermal
conduction appears to be consistent, but
does not explain the low X-ray luminosity.

Final Words

Multi-wavelength observations are needed to study the physical structure of ISM bubbles.

ISM bubbles need to be studied in conjunction with the history and distribution of massive Star formation.