Modelling Supernova Remnant kinematics and X-ray emission: Some Examples.

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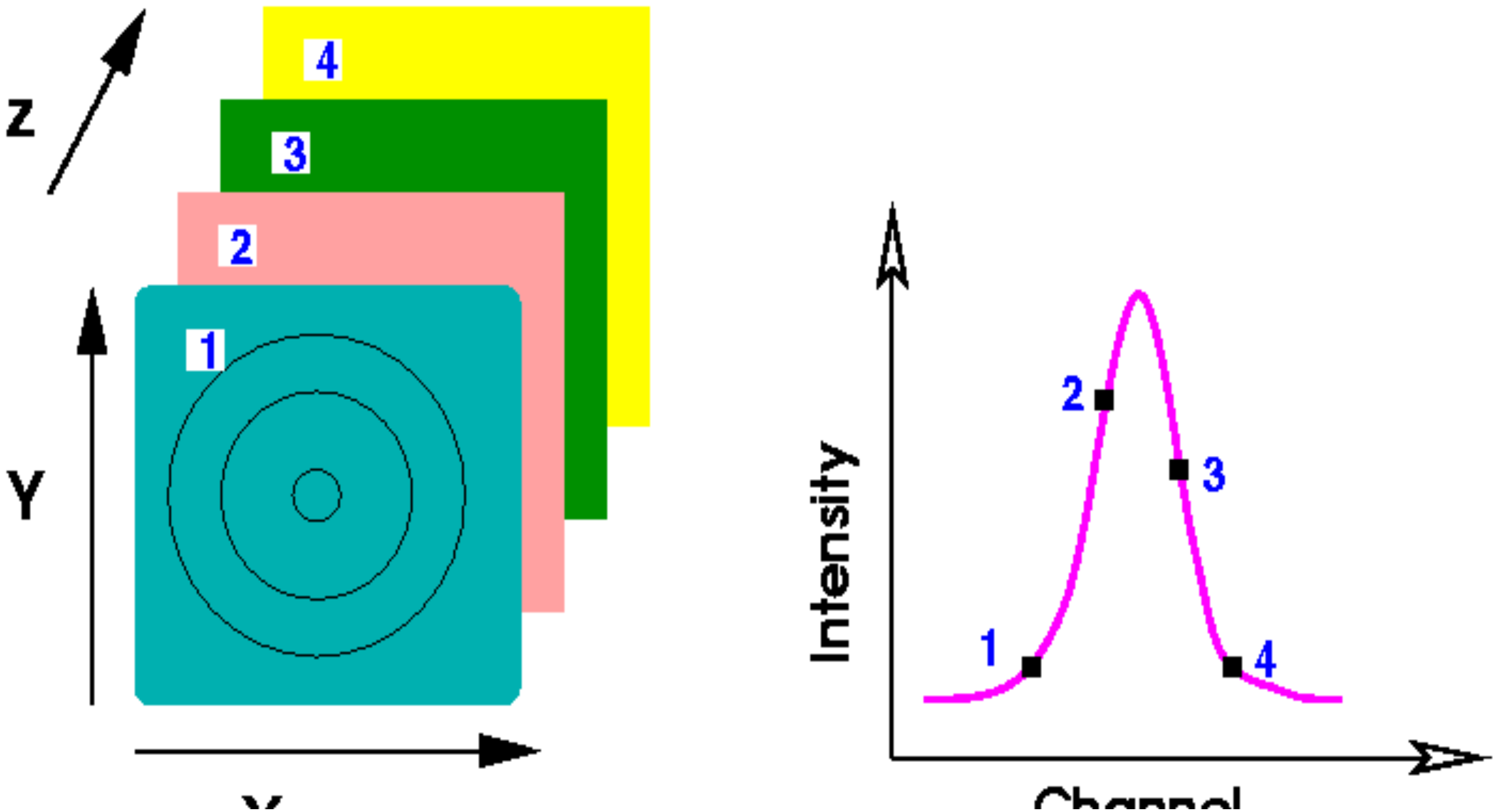
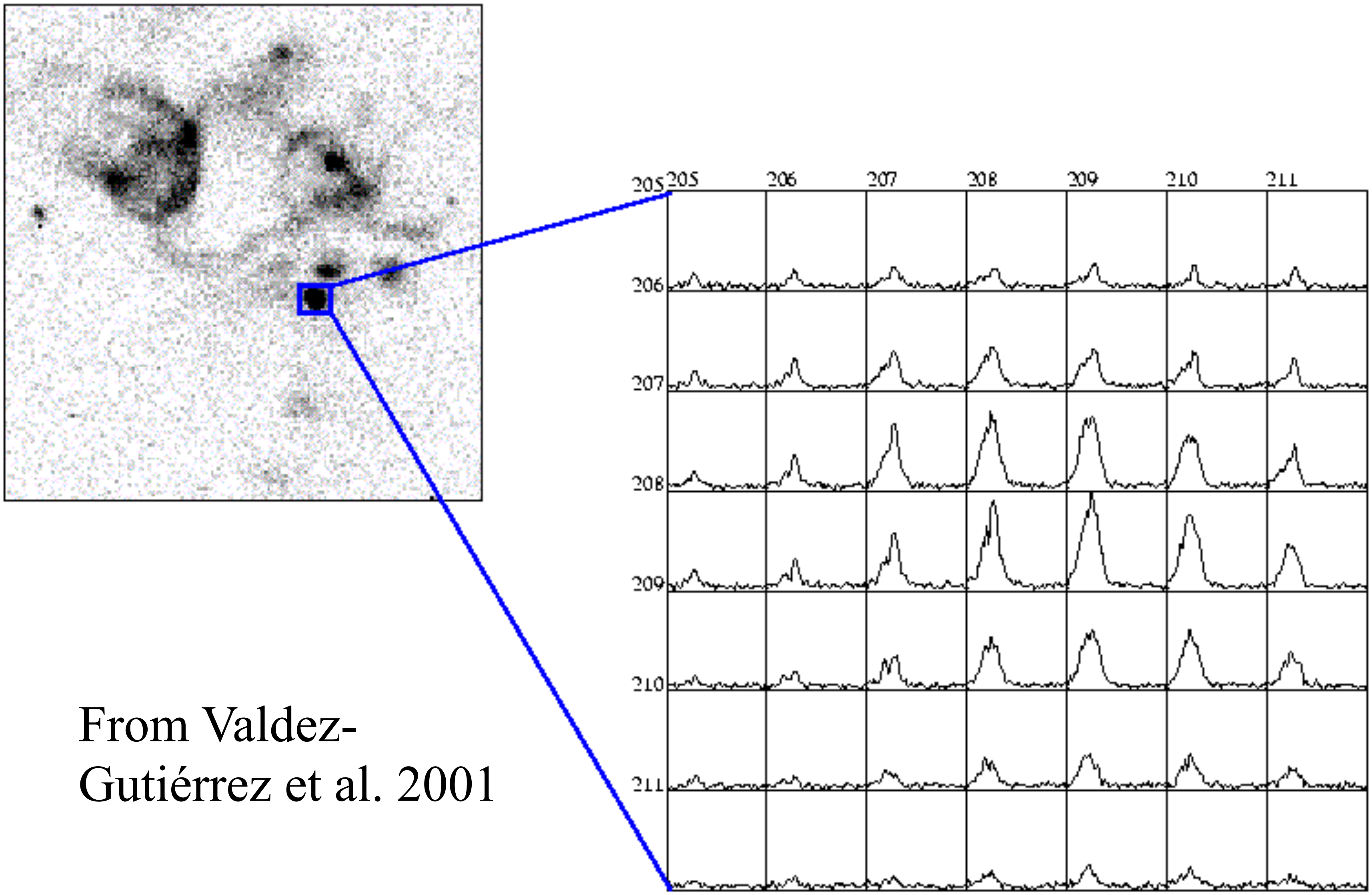
I. The Kinematics: By means of a FP Interferometer (i.e. the PUMA)



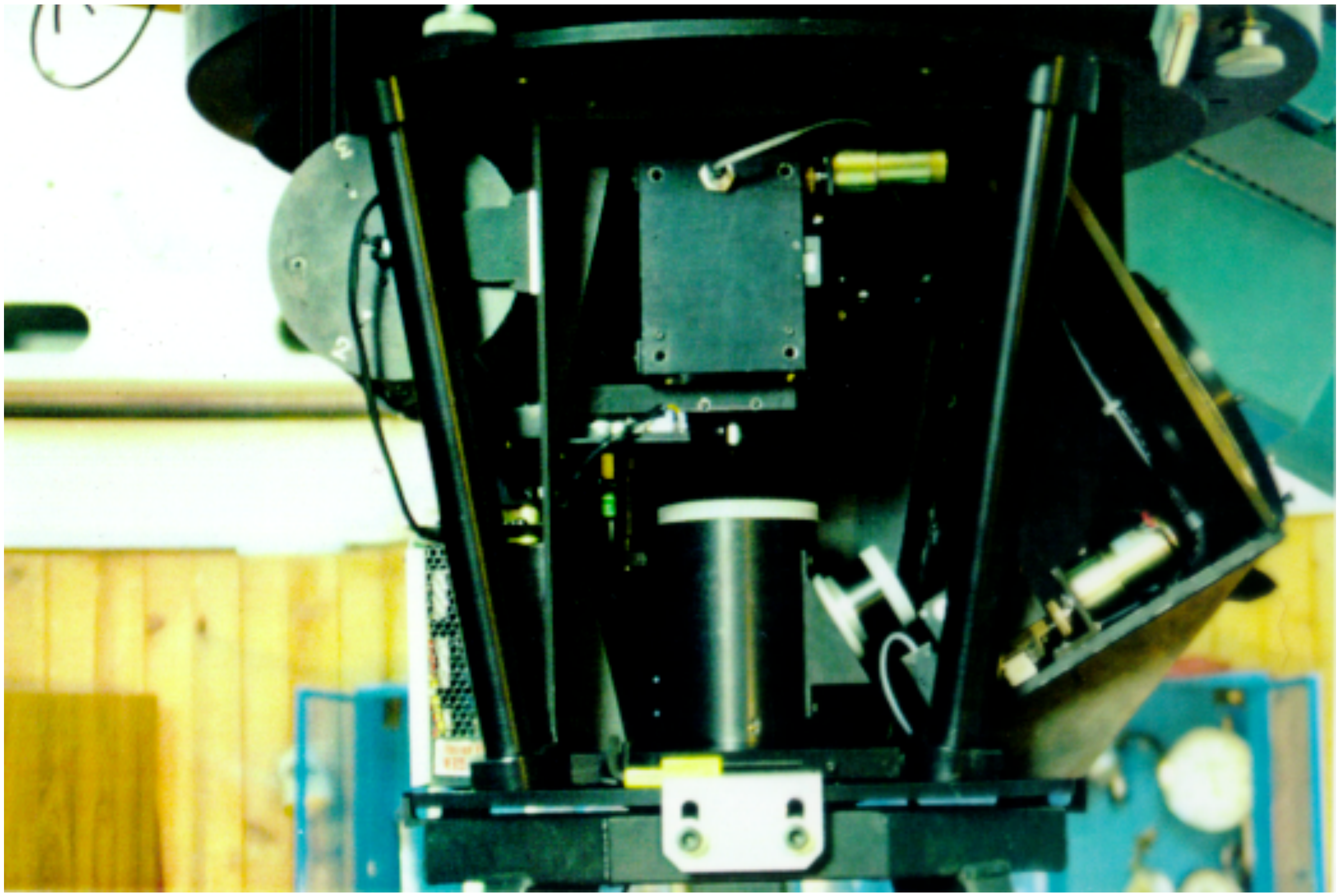
One gets millions of Halpha or [SII] profiles over the field.



From Valdez-Gutiérrez et al. 2001

OAN: San Pedro Mártir, B.C. Mexico

PUMA INTERFEROMETER

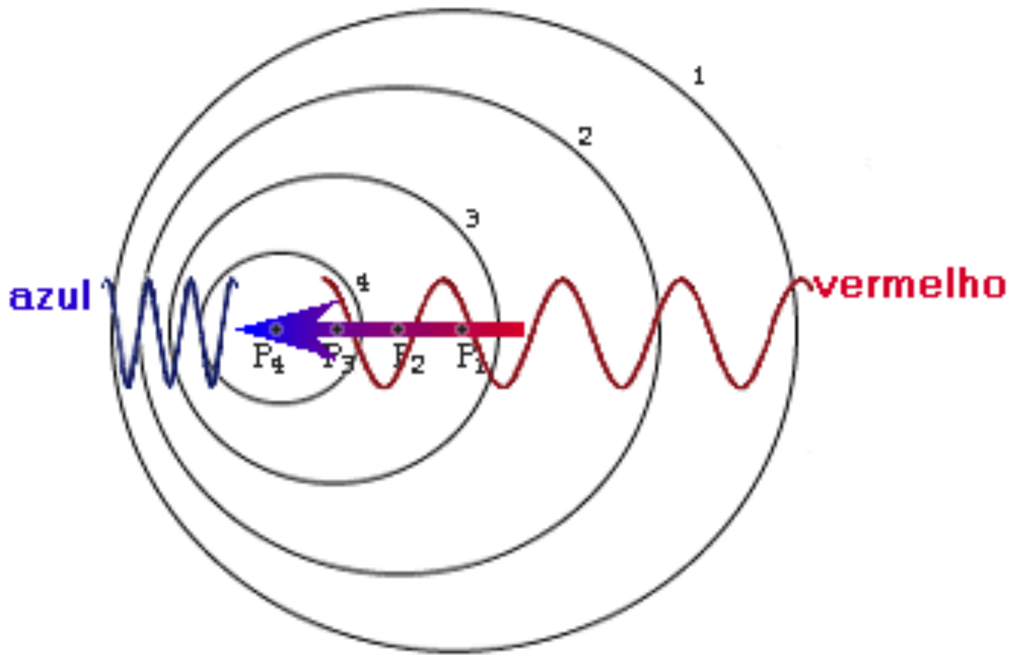


PUMA parameters

- Detector	CCD 1024x1024	
– FP scanning steps	48	
– Finesse	24	
– Spectral resolution	47.3 km s^{-1}	
– Plate scale	0.59 arcsec pix^{-1}	
– Filters	Hα	[SII]
– Central lambda [a]	6570	6720
– Interference order	330	332
– Free spectral range [b]	847	931
– Sampling step [c]	17.6	19.4
– Calibration line [a]	Hα (6562.7)	Ne (6717.04)

a) in units of angstroms, b) in km s^{-1}, c) in km s^{-1} $channel^{-1}$

Doppler Effect



$$\frac{\Delta\lambda}{\lambda} = \frac{v_r}{c}$$

Iso-velocity contours in our Galaxy

J. Brand & L. Blitz: The velocity field of the outer Galaxy 75

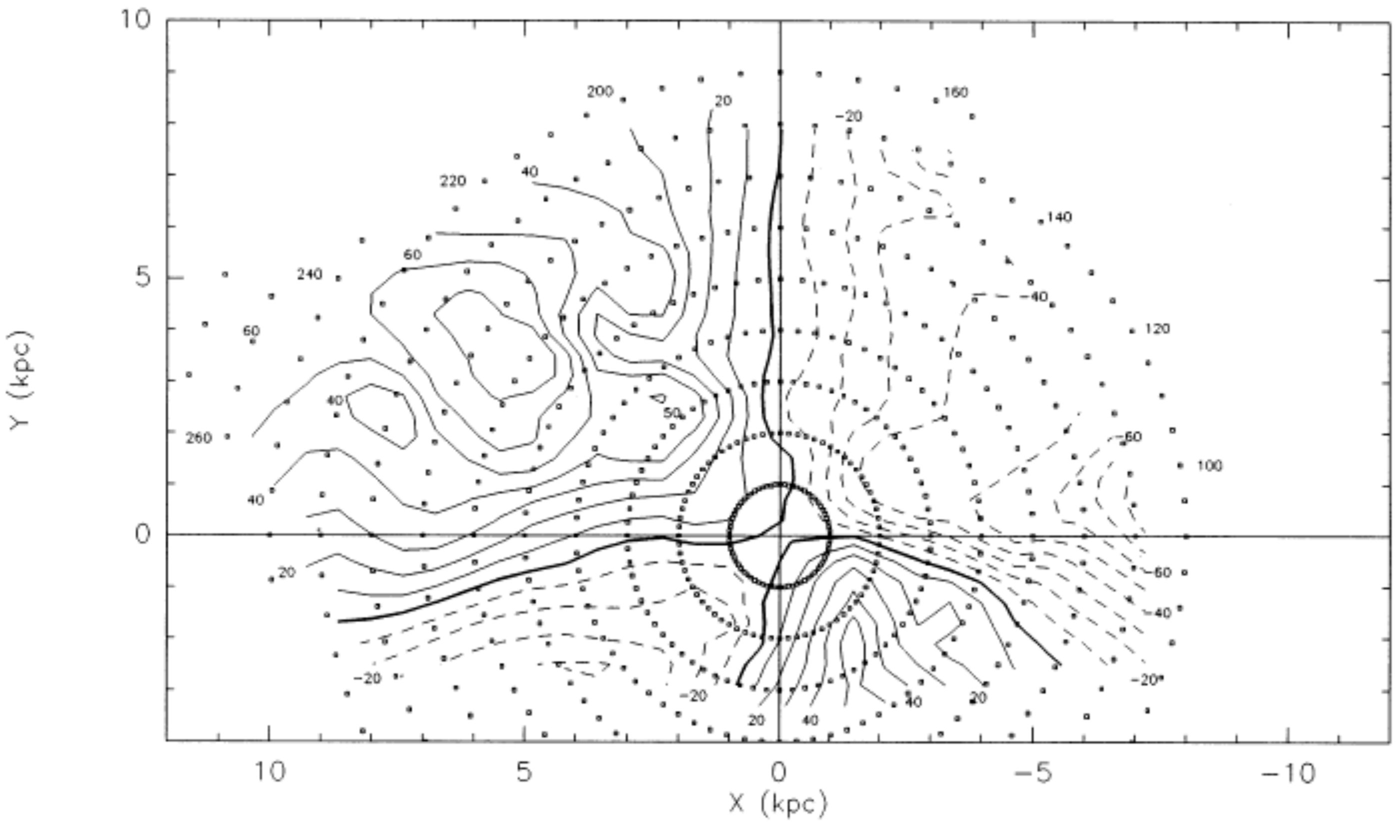


Fig. 2b. As Fig. 2a, but a grid has been superimposed, in which for every 5° in longitude distances have been marked every kiloparsec. This allows easier determination of kinematic distances for various combinations of longitude and velocity

Rotation curve of our Galaxy (also from Bland & Blitz)

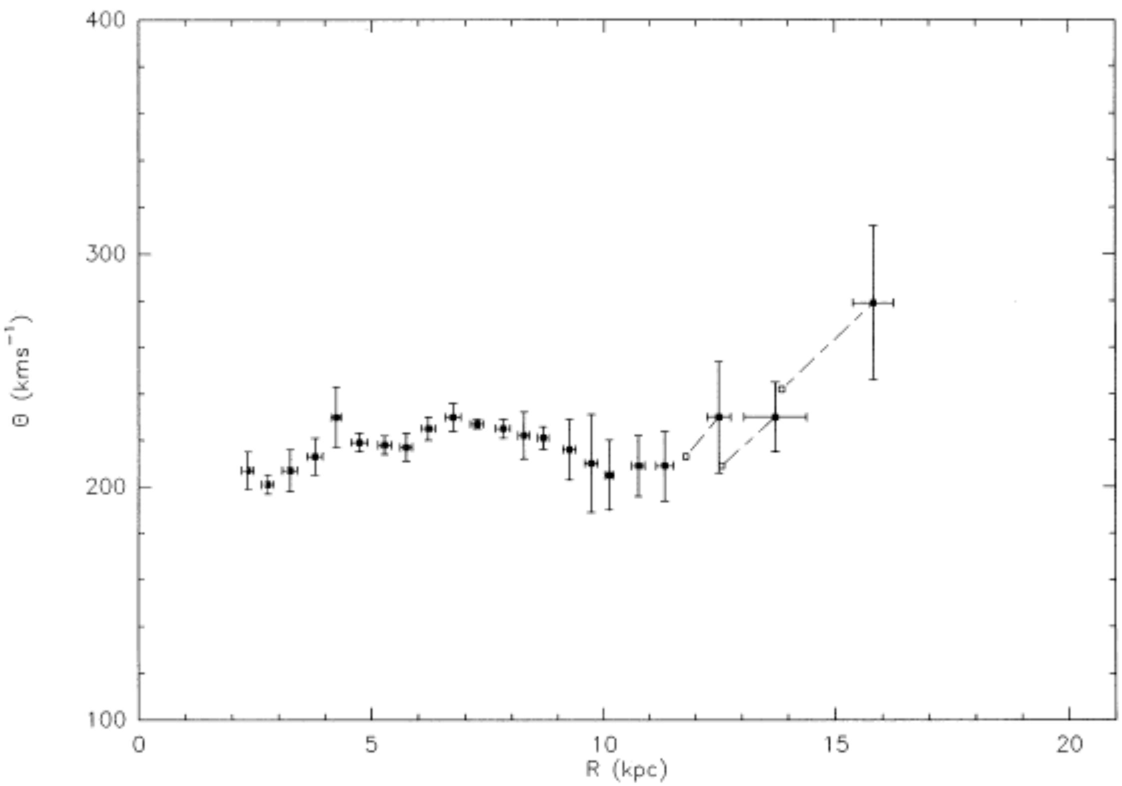
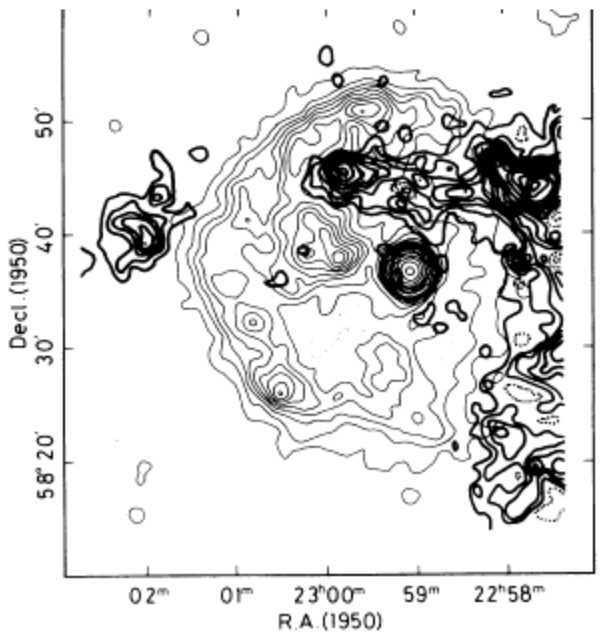


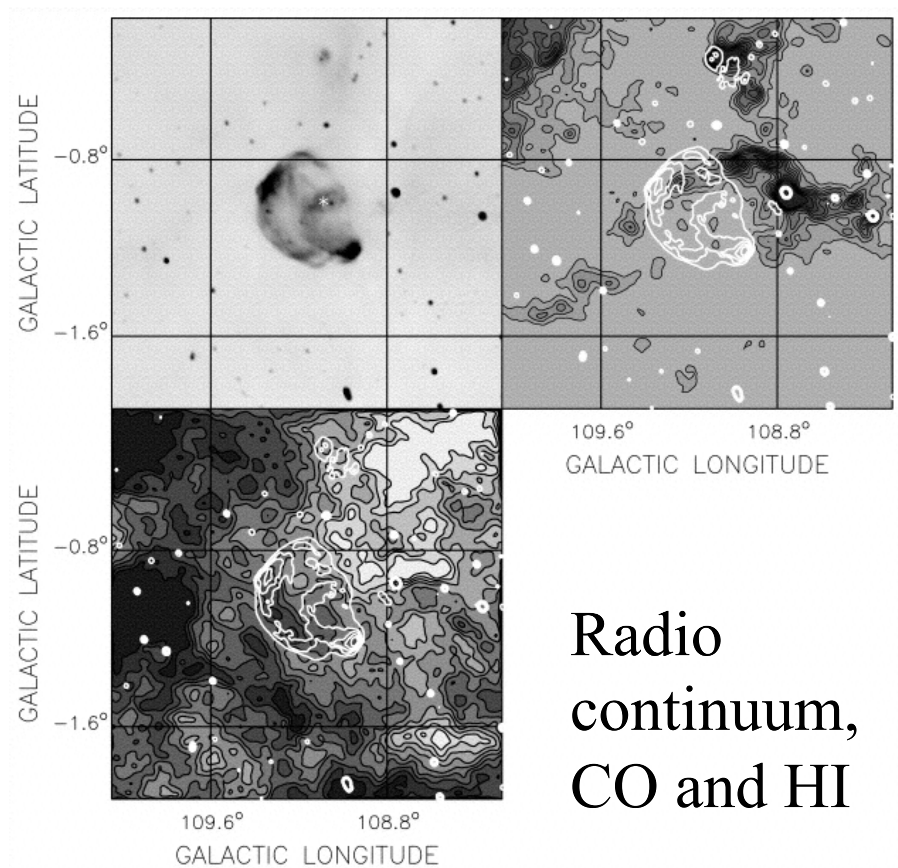
Fig. 5. As Fig. 4b, but with the data binned in R, and with velocities averaged. The error bars are $\pm 1\sigma$. Here the rise in the velocity of rotation of the outermost data points is shown to be a significant effect. The open symbols indicate how a change in R, Θ, due to a galactic abundance gradient, would affect the outermost data points. Indicated changes are 7% (at $R = 12.5$ kpc), 10% ($R = 14$ kpc), and 15% ($R = 16$ kpc), respectively (see Hron 1989)

The kinematics of SNRs is a powerful tool that we can use to estimate the DISTANCE, and other important parameters of those objects.

The Galactic SNR CTB 109 and the quest for its distance:



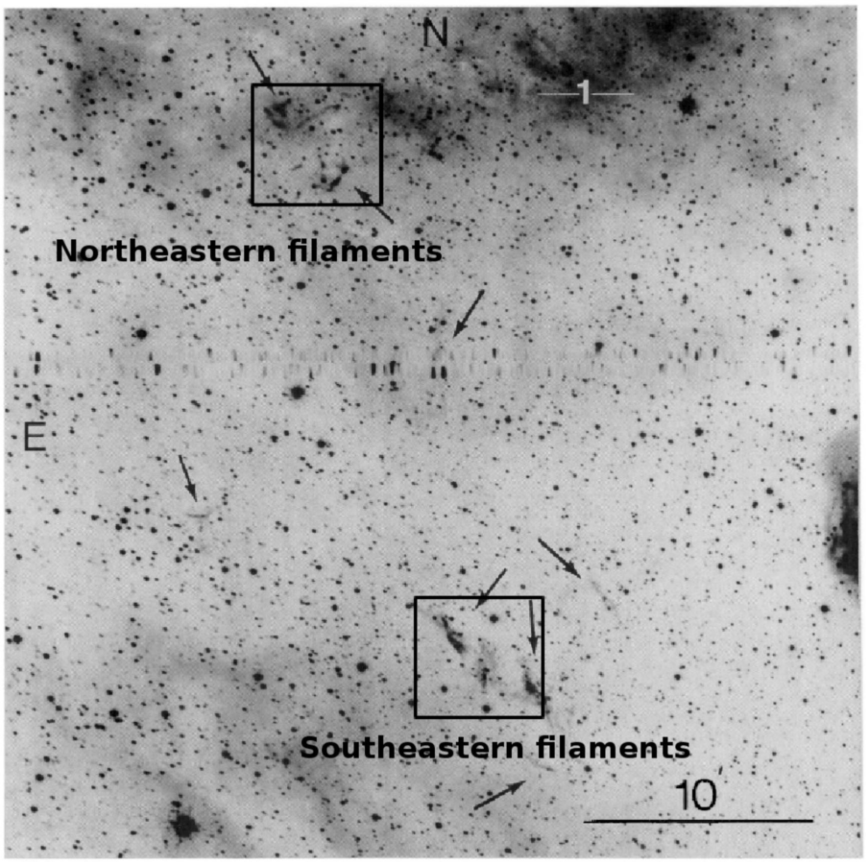
Einstein X-rays and CO

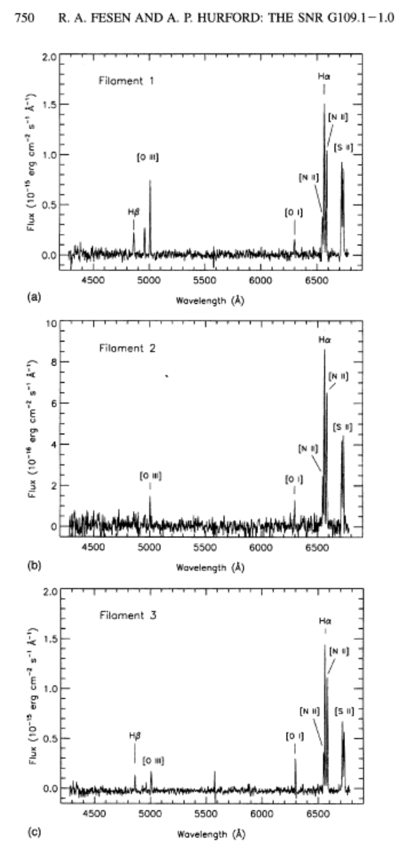


Radio continuum, CO and HI

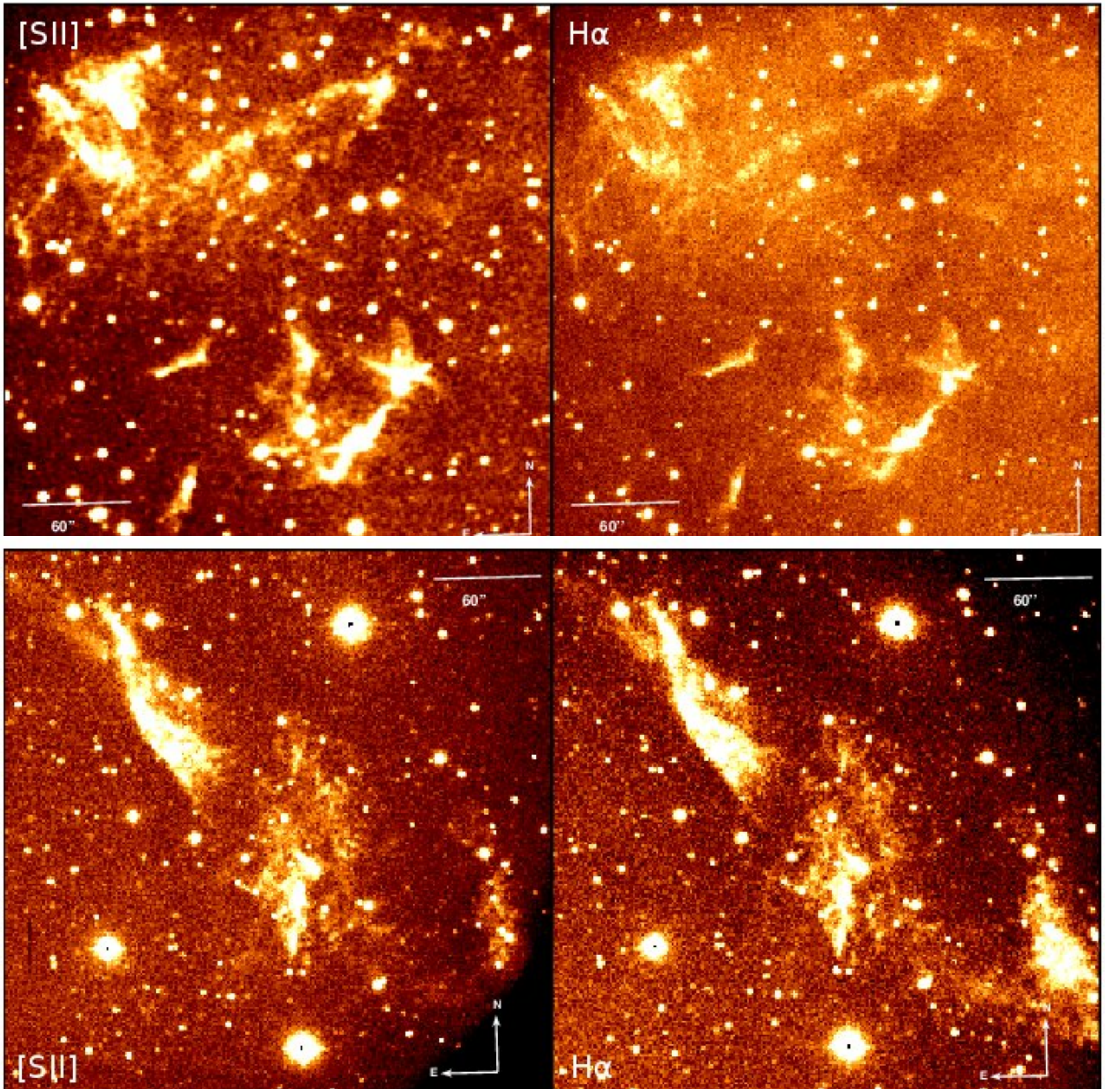
From Gregory & Falman (1980), Tatematsu et al. (1987), Kothes et al. (2002, 2006)

While in the optical:



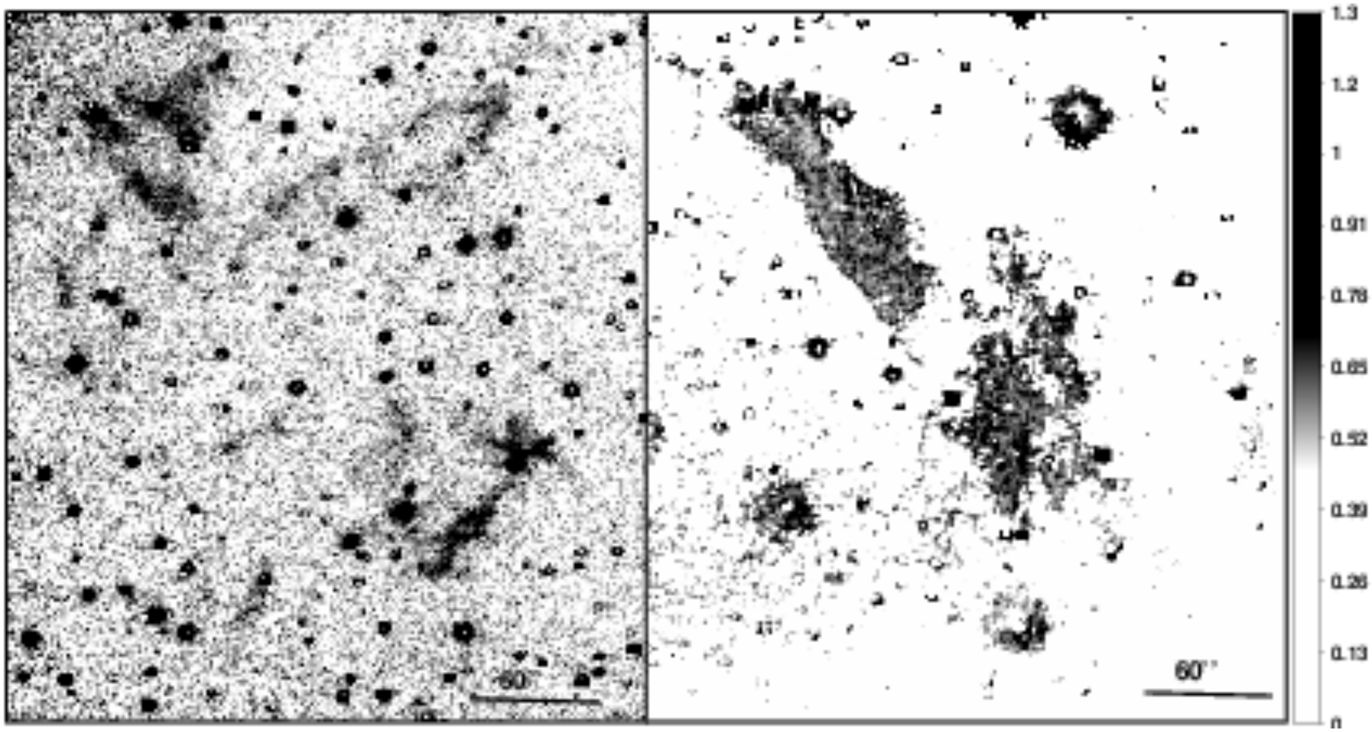


Hurford & Fesen (1995)

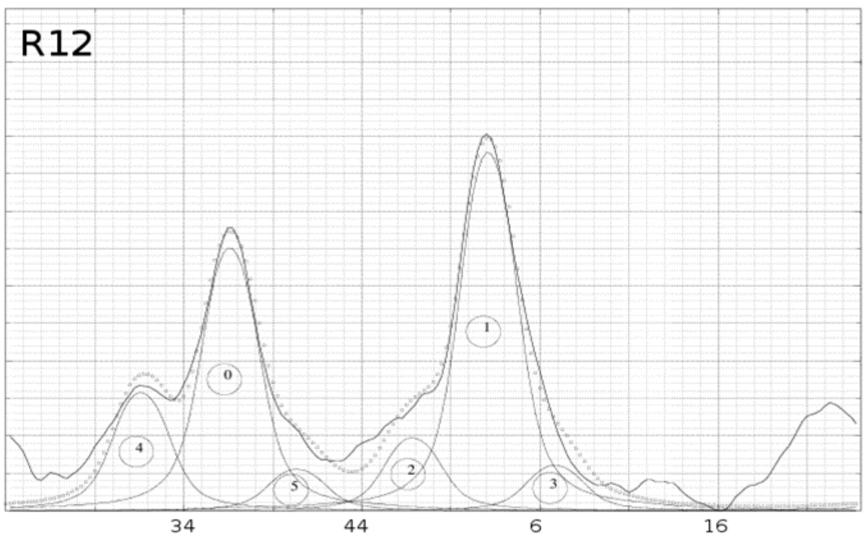


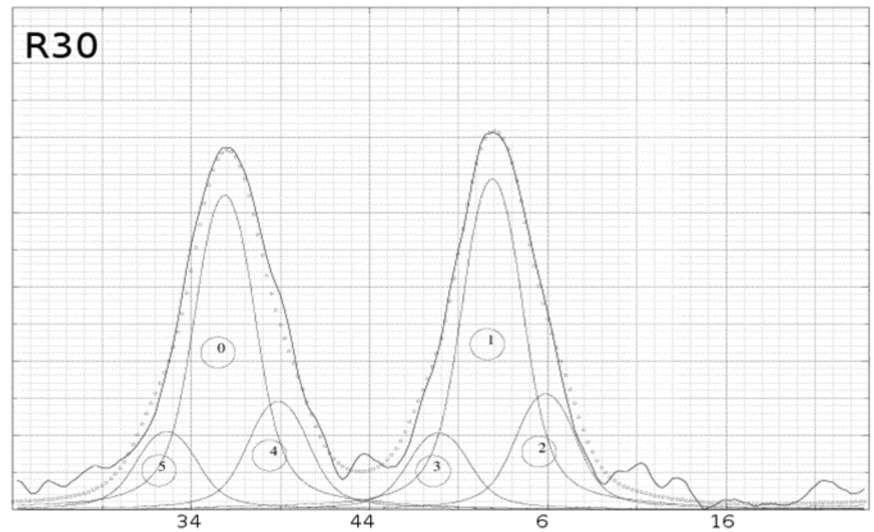
Sánchez
-Cruces
et al.
(2017)

2D [SII]/Hα line-ratios of the optical filaments ➔ a radiative shock



Typical [SII] velocity profiles of two regions:





➔ **SNR CTB 109 IS IN THE PERSEUS ARM**

➔ **THIS SNR HOSTING A MAGNETAR HAS RATHER TYPICAL INITIAL ENERGY**

II. X-ray emission important in identifying the nature of nebulae: SNR versus wind-blown bubbles.

The Classical Wind-blown Bubble Model

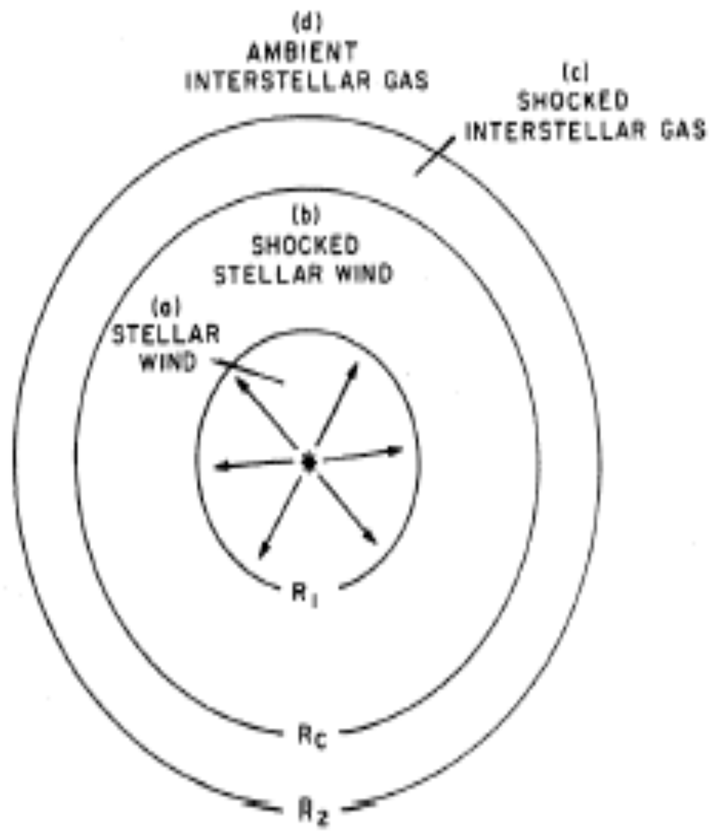
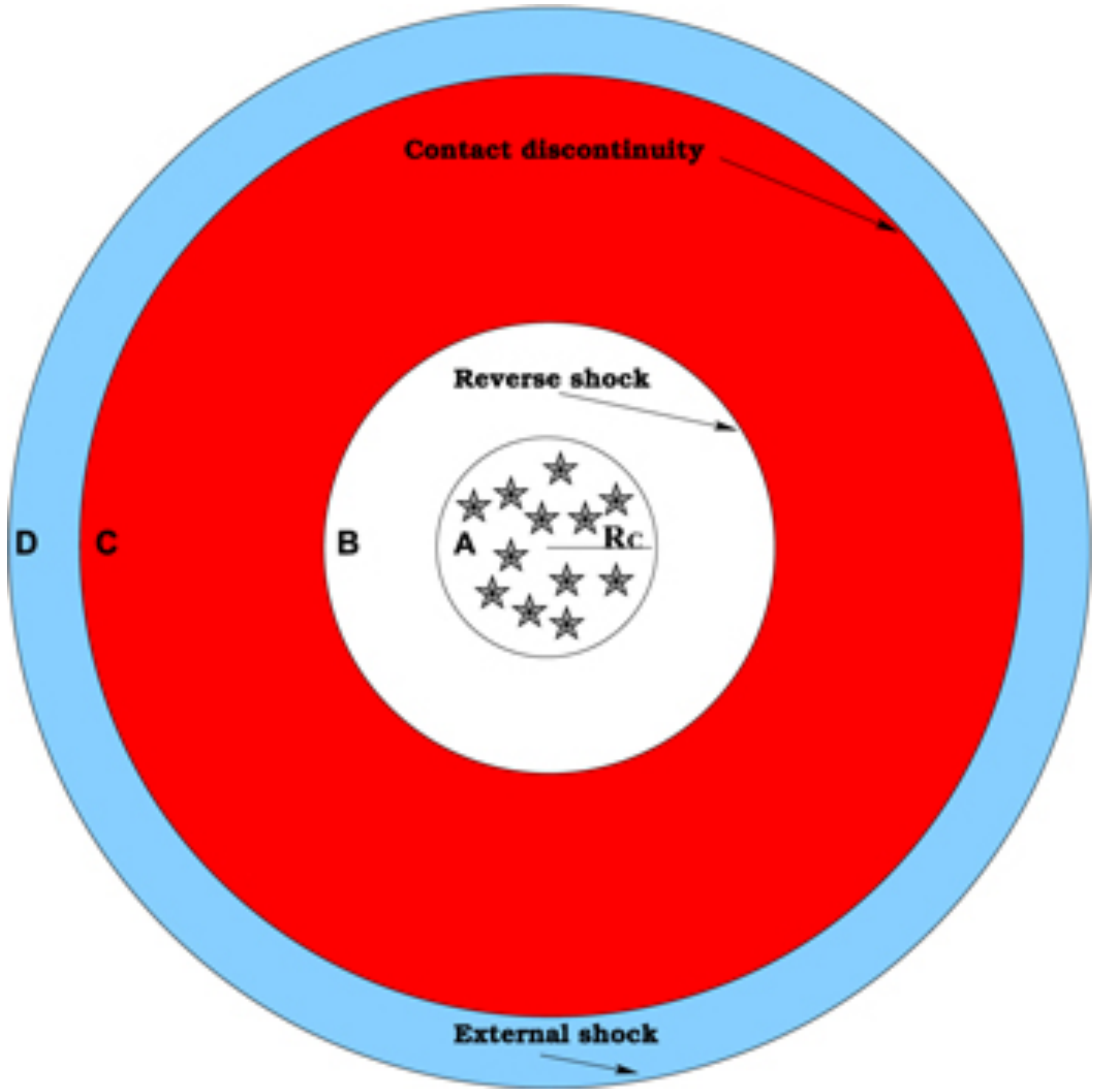
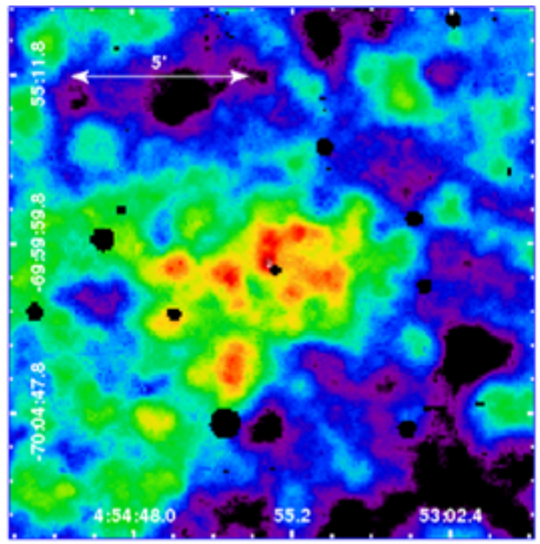


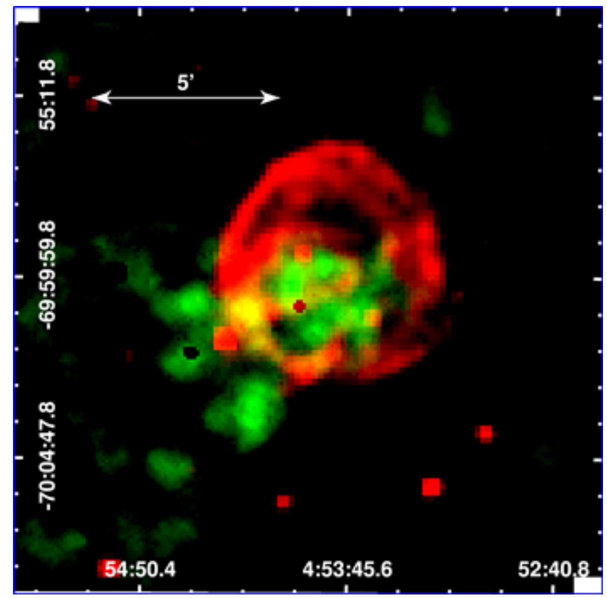
Fig. 1. Schematic structure of a pressure-driven interstellar bubble, from Weaver et al. (1977).

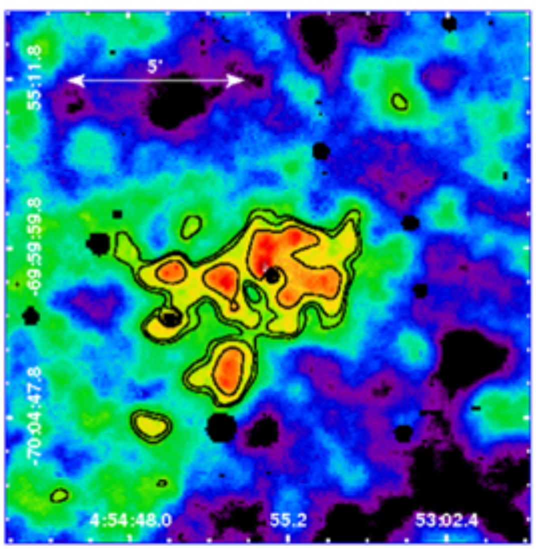
HD models of superbubbles (Rodríguez-González 2011)

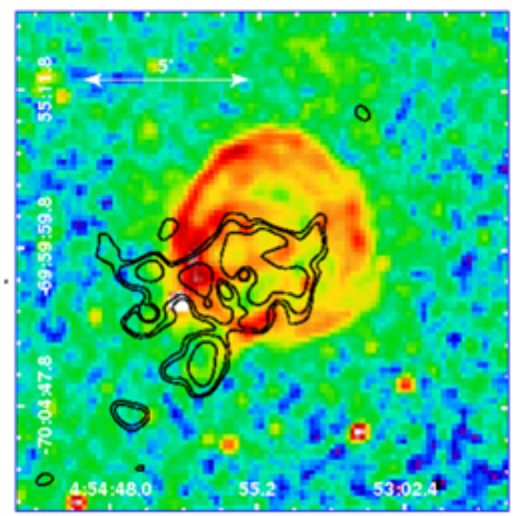


The X-rays: From archival XMM-Newton or Chandra (like here for N185 SNR in the LMC)



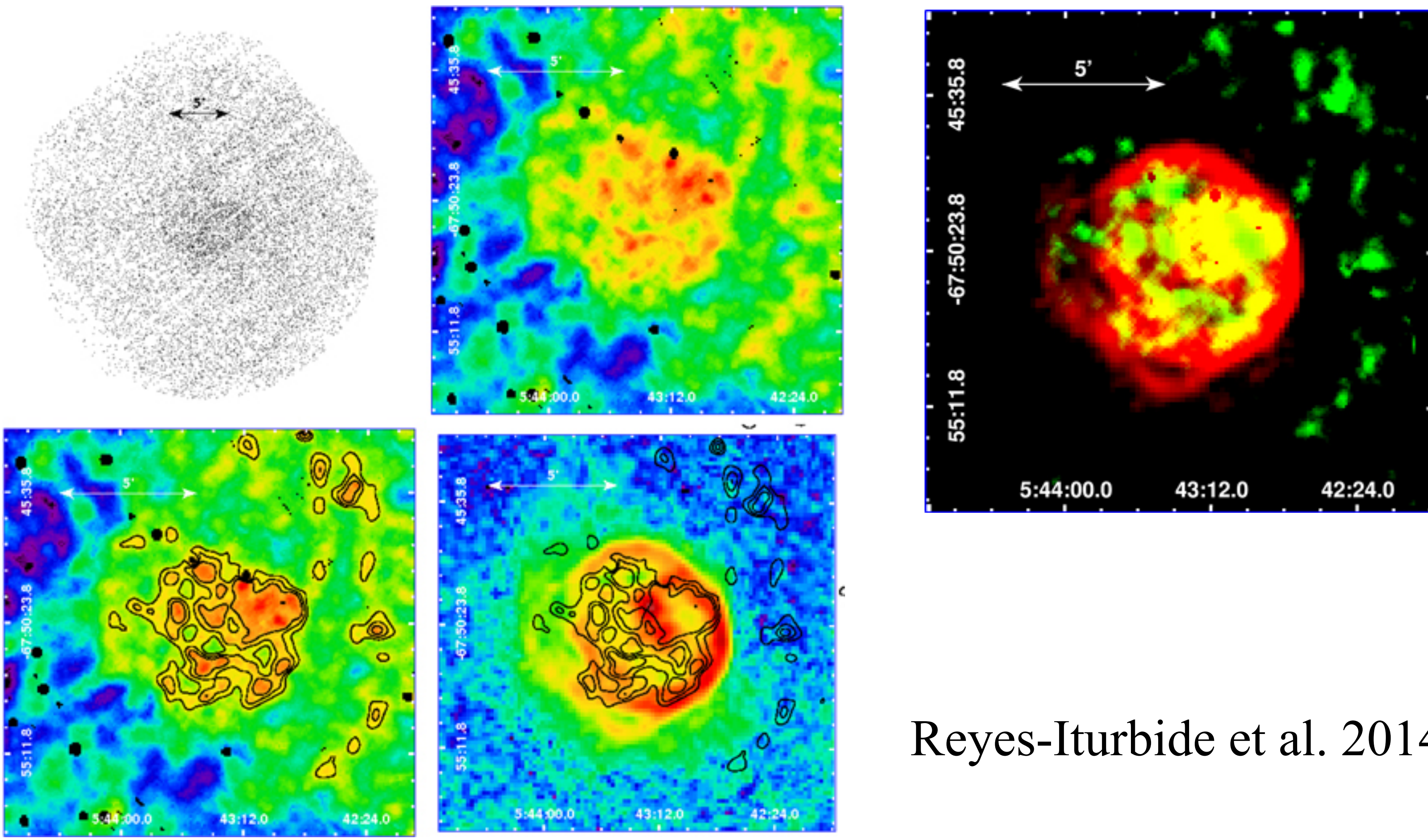






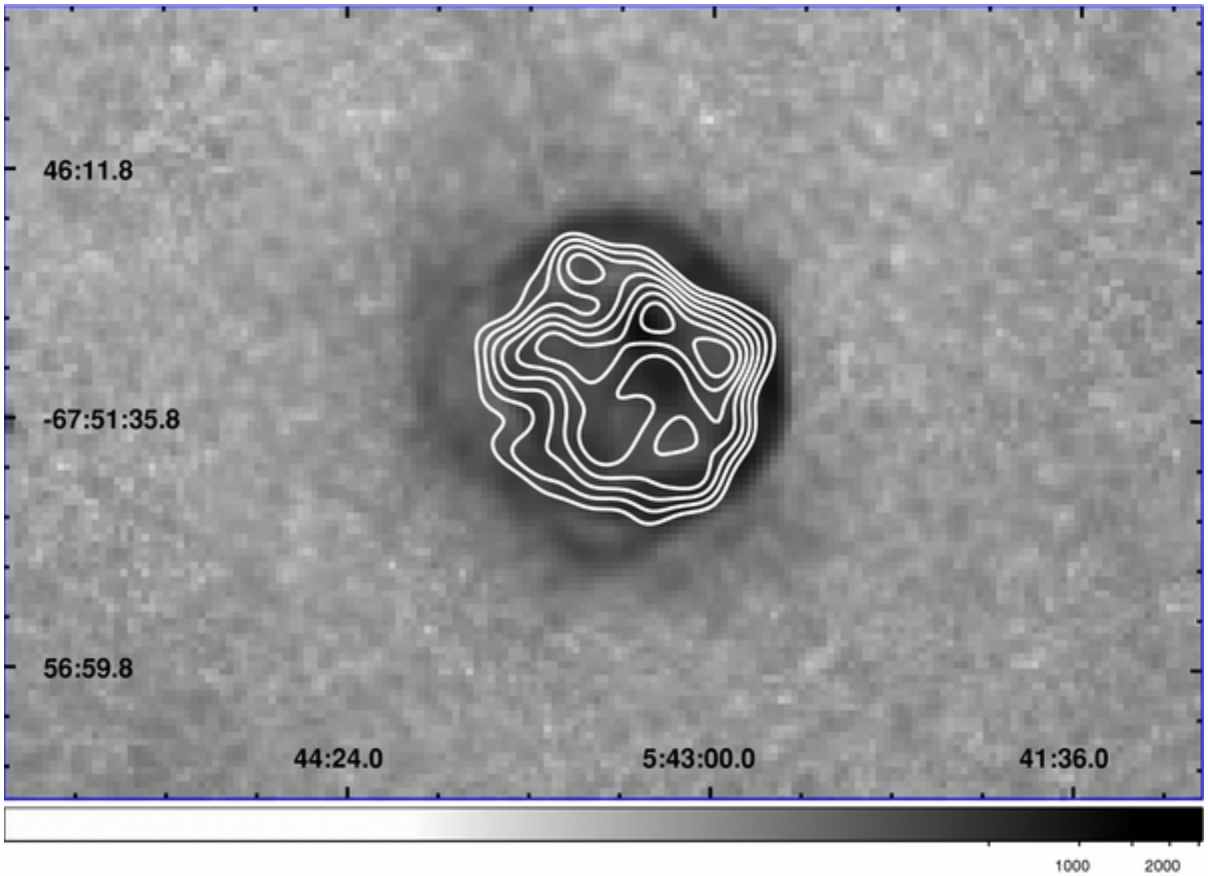
Reyes-Iturbide et al. (2014)

And for N70 SB in the LMC

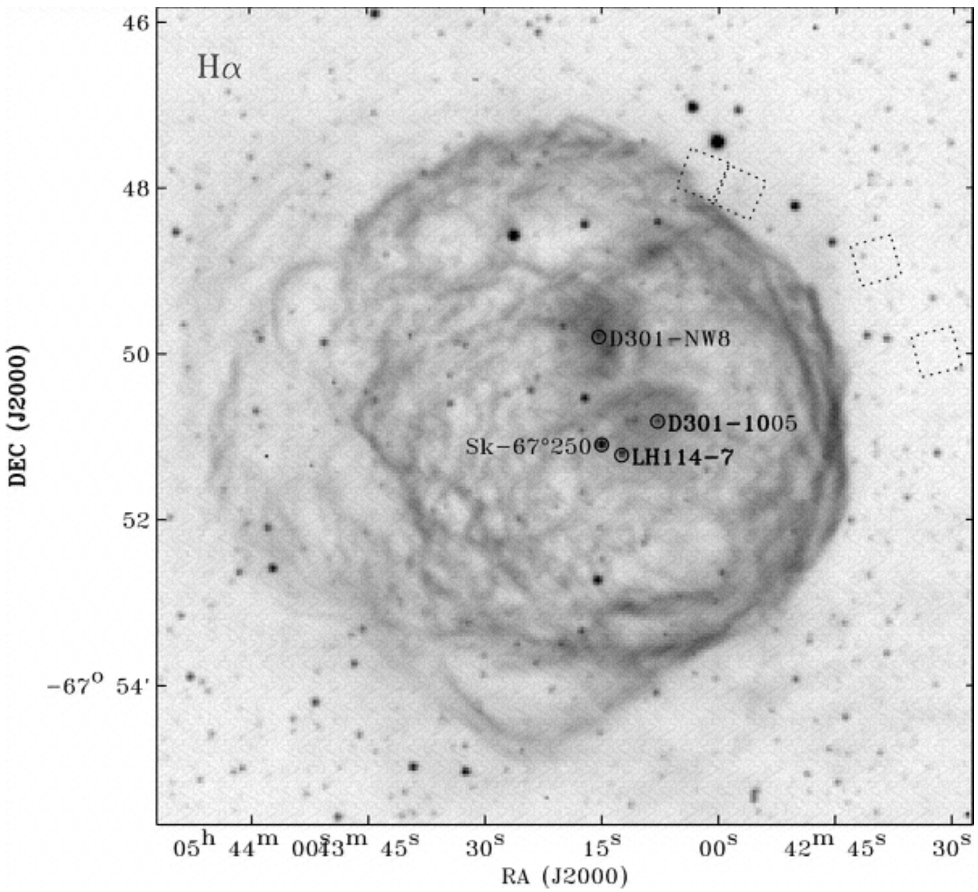


Reyes-Iturbide et al. 2014

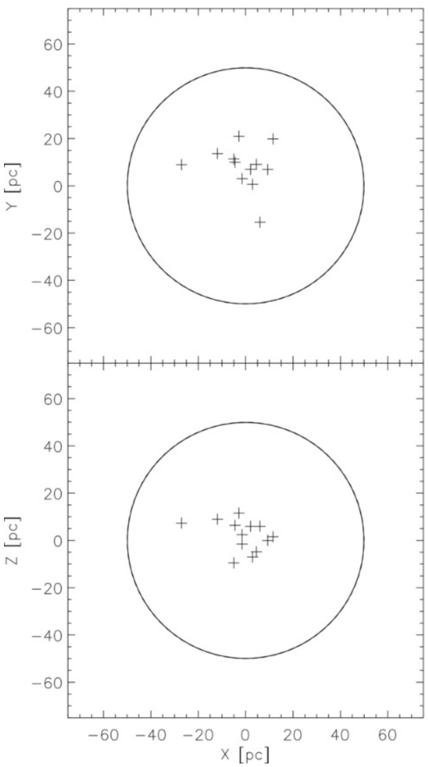
N 70 Superbubble in the LMC
(Rodríguez-González et al. 2011)



N 70



Hα
D301-NW8
D301-1005
Sk−67°250
LH114-7
DEC (J2000)
RA (J2000)
46
48
50
52
−67° 54′
05h 44m 00s
43m 45s
30s
15s
00s
42m 45s
30s



Y [pc]
Z [pc]
X [pc]
60
40
20
0
−20
−40
−60

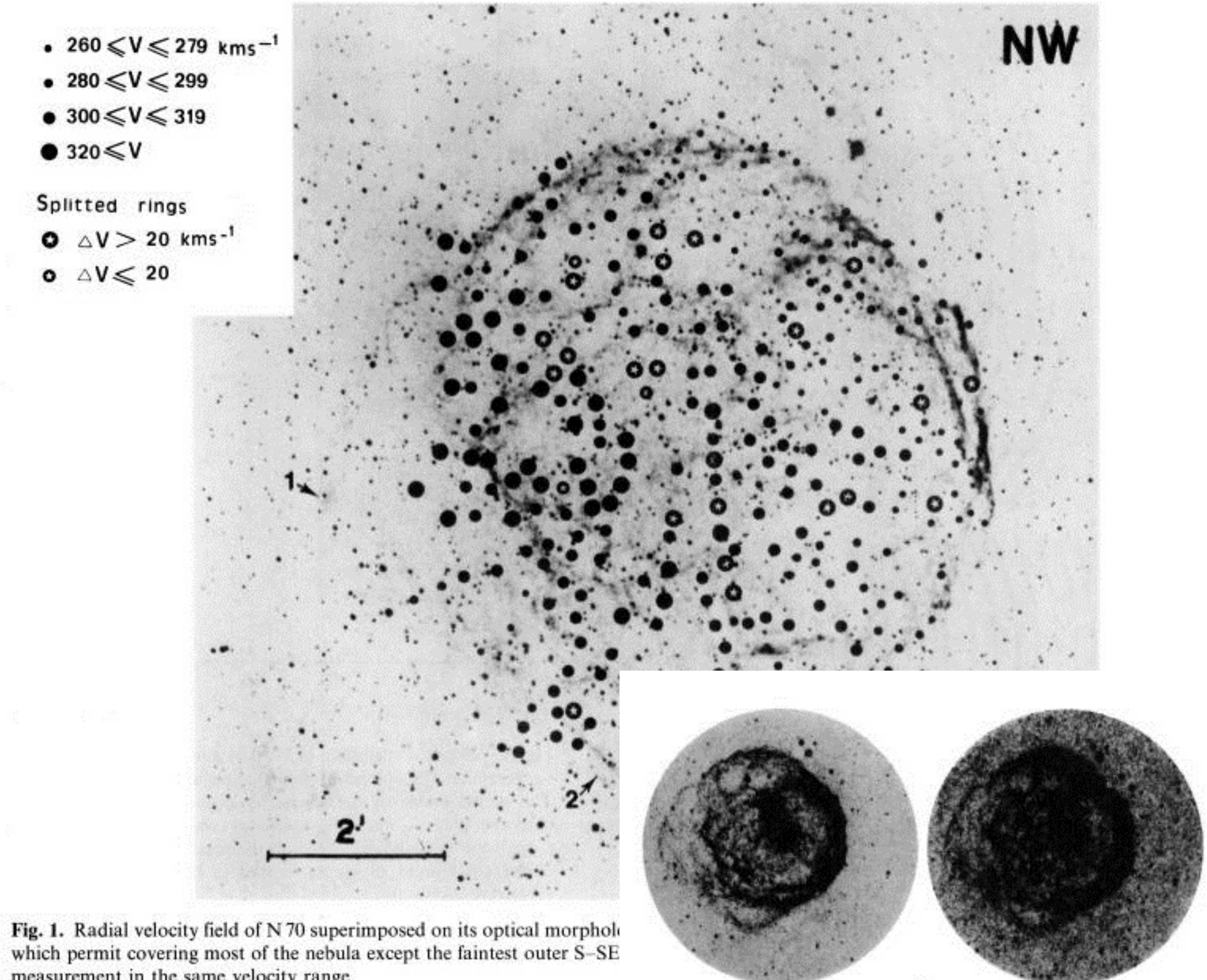


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Fig. 1. Radial velocity field of N 70 superimposed on its optical morphol
which permit covering most of the nebula except the faintest outer S–SE
measurement in the same velocity range

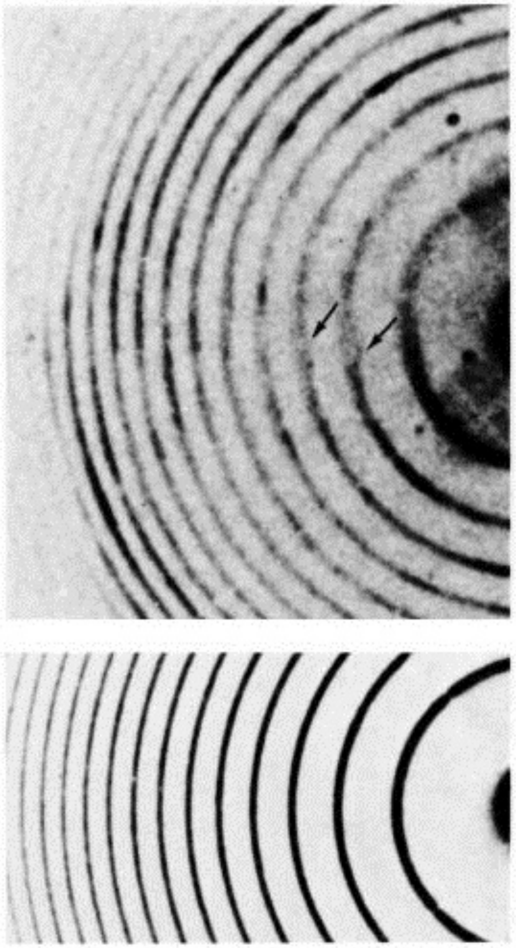


Fig. 2. Part of the Fabry-Perot rings of the nebula and of the calibration. A split ring showing two components is indicated by an arrow

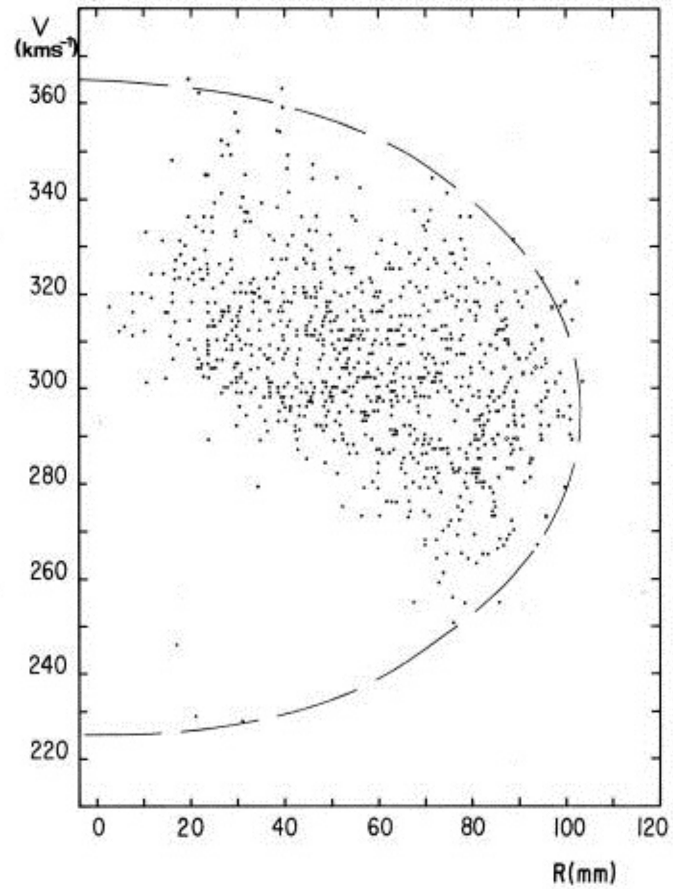


Fig. 3. Velocity distribution of N 70 as a function of the distance to the center. The outermost points correspond to profile splitting. The points inside of the ellipse have generally larger profiles, corresponding to unresolved velocity components. Black dots correspond to points belonging to the nebula. Crosses and empty circles correspond to points located in filaments 2 and 1, respectively, of Fig. 1

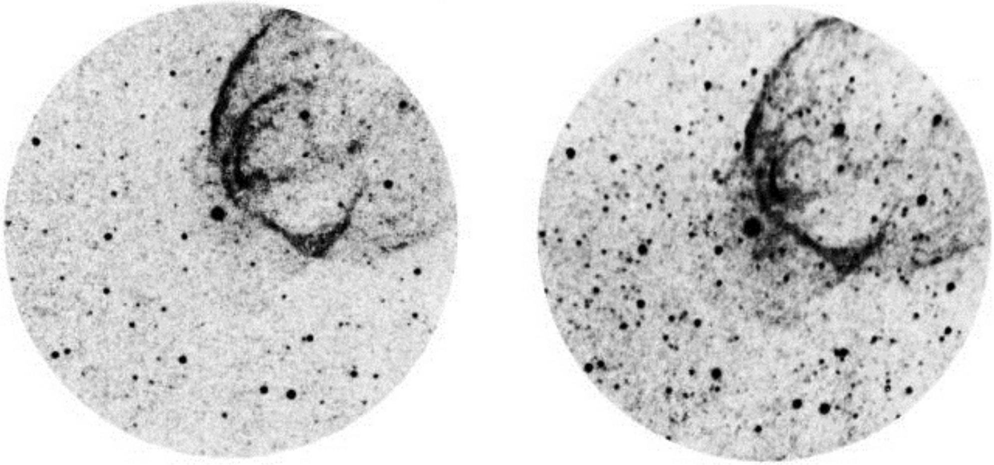


Fig. 4. N 185 in the light of Hα and [S II] (6717) taken at the ESO 152 cm telescope. These image tube photographs were taken in order to emphasize the filamentary structure and the faintest emission of this nebula

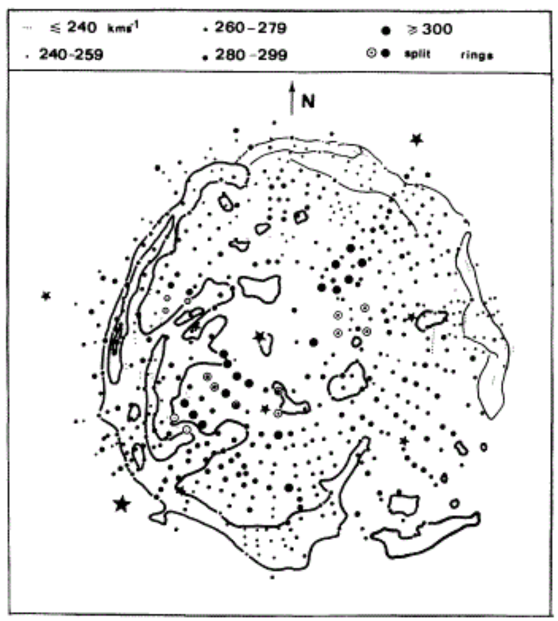


Fig. 2. Radial velocity field of N 185 established from three interferograms. Dots represent the average of two or three measures in the same velocity range

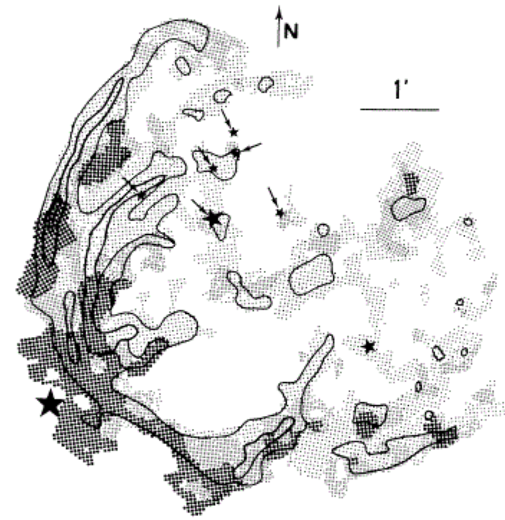


Fig. 5. [S II] (6717)/Hα ratio of N 185 obtained from the photographs shown in Fig. 2. The increasing greys correspond to the ranges 0.15–0.23; 0.23–0.37 and higher than 0.37. The positions of the exciting stars are indicated by arrows

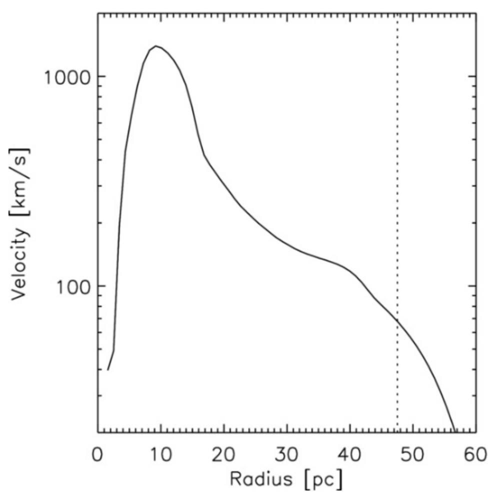
The HD models for N70 SB

Table 2
Numerical Models General Properties

Model	Winds	SN	SN Location
M1	No	Yes	Center
M2	13 stars	No	No
M3	13 stars	Yes	Center
M4	13 stars	Yes	Off-Center

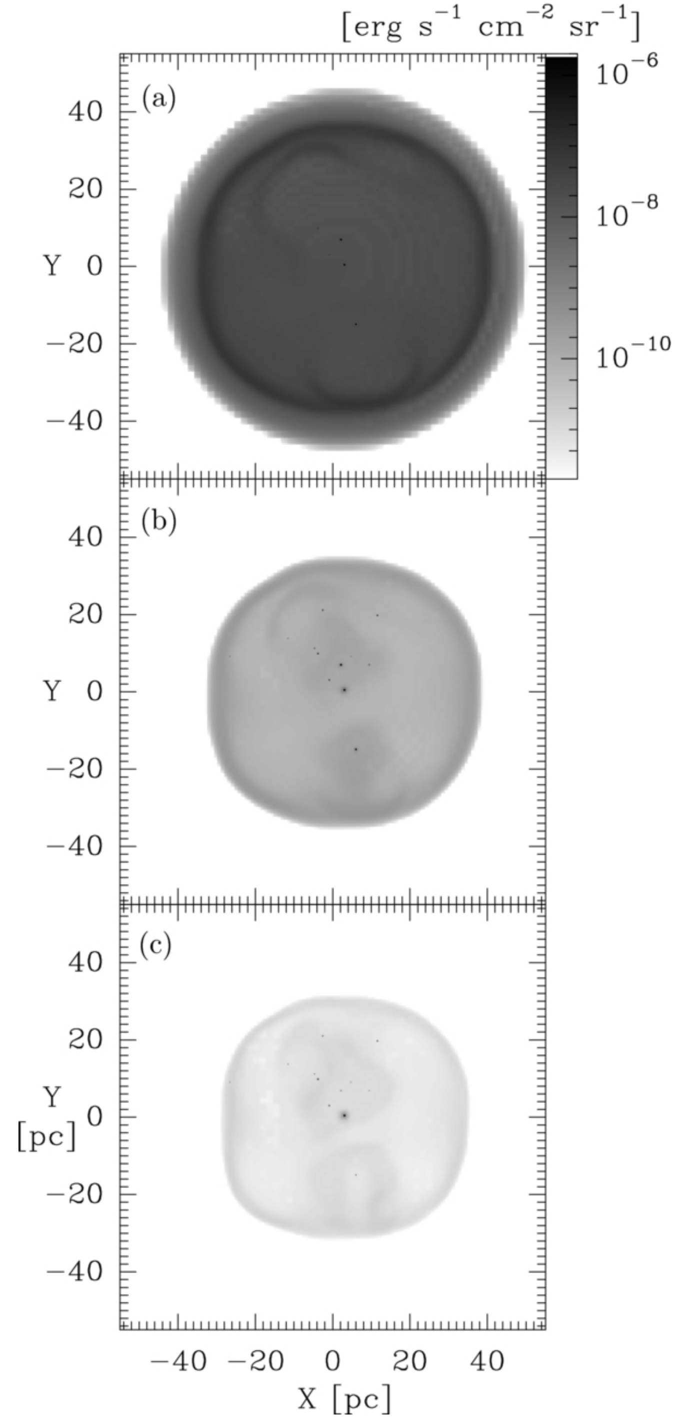
González-Rodríguez 2011

Predicted Kinematics:

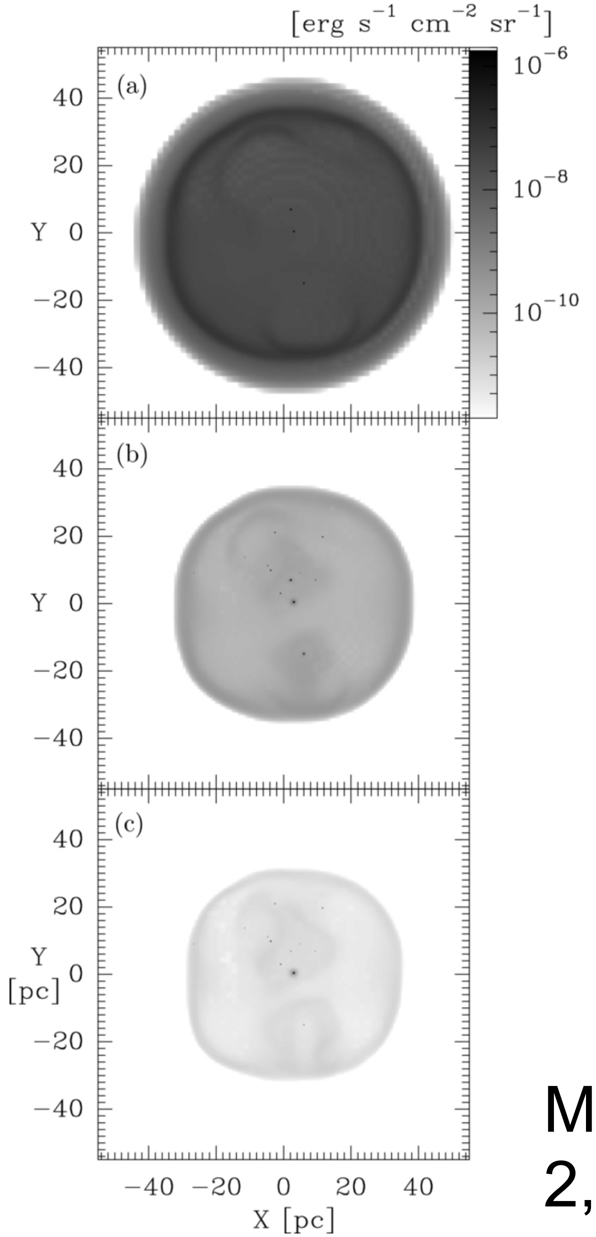


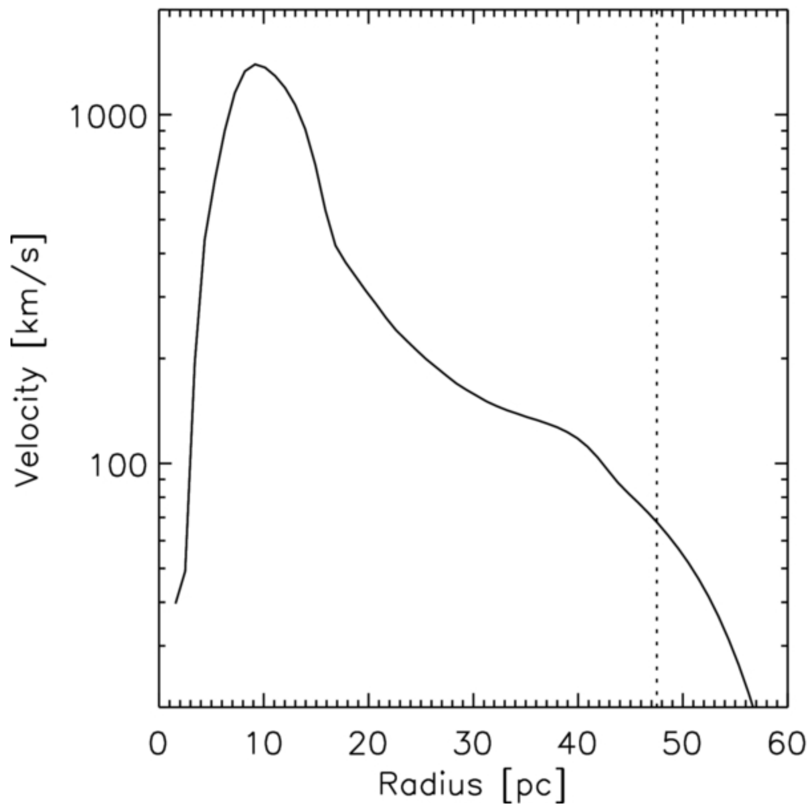
Off-center SN + Winds

Soft X-rays



Hard X-rays





Velocities for M4

Model M2: 0.2 to 2, 2 to 10 and 10 to 20 keV

Conclusions

- High-velocity superbubbles can be explained only if one adds a supernova explosión inside them in order to match the observed expansión velocity and X-ray emission.
- Models of stellar winds (M2) or only supernova explosions (M1) are unable to reproduce the observations.