Third Workshop of the Coordinated Project "Estallidos de Formación Estelar en Galaxias"

Tenerife, December 2-3, 2004

Searching for the footprint of shock excitation in wind-driven nebulae

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Motivation of the study (I)

The study of the environments of stars provides important clues to their evolution. The history of a changing stellar output of winds and ejecta is written in the close environments of massive and intermediate mass stars. Wolf-Rayet Ring Nebulae (WRN), surrounding the evolved descendant of massive OB stars, and multiple shell planetary nebulae (MSPNe), constitute ideal laboratories to study the history of the stellar mass loss in these nebulae. These Planetary Nebulae are surrounded by faint structures such as shells, haloes and other irregular outer structures. These outer haloes are of great interest as they are presumably the remains of the original stages of mass loss from the progenitor stars. WR Ring nebulae typically show a wind-blown bubble of interstellar material that, in some cases, presents ejecta of matter processed by the star.

Motivation of the study (II)

It has been claimed that the haloes of some MSPNe (e.g. NGC 6543, NGC 6826, and NGC 7662) are hotter than their respective cores (Manchado & Pottasch 1989, Meaburn et al. 1991, Middlemass et al. 1989, Middlemass et al. 1991). Middlemass et al. have shown that photo-electric heating is not able to reproduce the high temperatures observed in the halo of NGC 6543, and an extra heating source is required. A candidate for the extra energy source is the fast wind passing the cold filamentary knots observed in the haloes of these Planetary Nebulae. A similar scenario is expected to operate in the WR nebulae (Chu et al. 2003, García-Segura et al. 1996, Langer et al. 1998), though in this case, physical processes such as the socalled mass-loaded flows (Hartquist et al. 1986) can play an important role. Both scenarios of nebulae formation open the door to the presence of shock excitation of their gaseous material.

Motivation of the study (III)

The aim of this work is the detection and study of substructures of these nebulae that are good candidates to host shock-heated gas, in particular in their haloes. Our new approach to this problem makes use of the 2D information of the ionization structure of the haloes and outer shells of a selected group of nebulae.

The Sample

OBJECT	RA	Dec	Type	Instrument	Filters
G2.4+1.4	17:45:47.00	-26:10:29.0	WR-ring	INT-WFC	Hα, [OII], [OIII],[SII], B, r, g
M1-67	19:11:30.89	+16:51:38.1	WR-ring	CAHA 2.2-BUSCA	Hα, Hβ, [NeIII], [OIII], [SIII], V, b, y, I
M1-67	19:11:30.89	+16:51:38.1	WR-ring	INT-WFC	Hα, [OII], [OIII], [SII], B, r
NGC2359	07:18:29.09	-13:13:01.5	WR-ring	INT-WFC	Hα, [OII], [OIII], [SII], r, g
NGC246	00:47:03.34	-11:52:19.0	Pn-halo	CAHA 2.2-BUSCA	Hα, [NeIII], [OIII], [SIII], V, b, y, I
NGC6210	16:44:29.00	+23:48:00.0	Pn-halo	CAHA 2.2-BUSCA	Hα, Hβ, [NeIII], [OIII], [SIII], V, b, y, I
NGC6543	17:58:33.40	+66:37:58.9	Pn-halo	INT-WFC	Hα, [OII], [OIII], [SII], B, r, g
NGC6720	18:53:35.00	+33:01:43.0	Pn-halo	CAHA 2.2-BUSCA	Hα, Hβ, [NeIII], [OIII], [SIII], V, b, y, I
NGC6804	19:11:31.00	+09:13:31.0	Pn-halo	CAHA 2.2-BUSCA	Hα, Hβ, [NeIII], [OIII], [SIII], V, b, y, I
NGC6826	19:44:48.00	+50:31:30.0	Pn-halo	CAHA 2.2-BUSCA	Hα, [NeIII], [OIII], [SIII], V, b, y, I
NGC6888	20:12:26.90	+38:21:17.6	WR-ring	INT-WFC	Hα, [OII], [OIII], [SII], B, r, g
NGC6891	20:15:09.00	+12.42.17.0	Pn-halo	CAHA 2.2-BUSCA	Hα, [NeIII], [OIII], [SIII], V, b, y, I
NGC6894	20:16:24.00	+30:33:54.0	Pn-halo	CAHA 2.2-BUSCA	Hα, [NeIII], [OIII], [SIII], V, b, y, I
NGC7009	21:04:11.0	-11:21:50.0	Pn-halo	CAHA 2.2-BUSCA	Hα, [NeIII], [OIII], [SIII], V, b, y, I
NGC7662	23:25:53.99	+42:32:06.0	Pn-halo	INT-WFC	Hα, [OIII], r, g
NGC7662	23:25:54.00	+42:32:06.0	Pn-halo	CAHA 2.2-BUSCA	Hα, Hβ, [NeIII], [OIII], [SIII], V, b, y, I
S308	06:50:50.90	-23:49:14.0	WR-ring	INT-WFC	Hα, [OII], [OIII], [SII], r, g

The Sub-Sample

NGC 6543

- Multiple shell planetary nebula (MSPNe)
- Of + WR central star
- Expansion velocity < 4.6 km s^{-1}
- Distance 1001 ± 269 pc

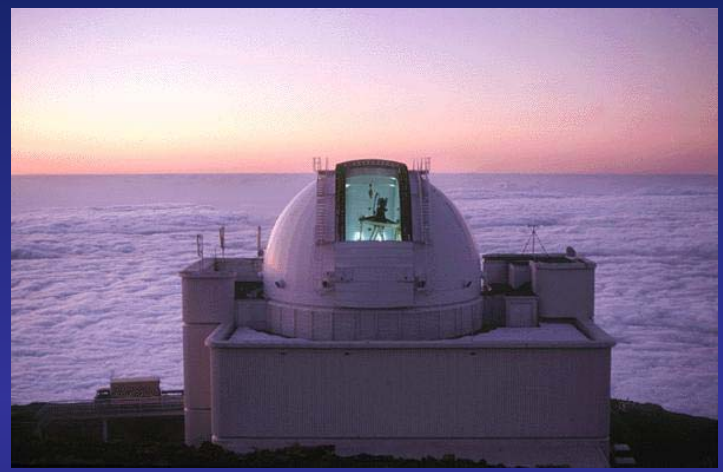
NGC6888

- Ring nebula.
- WR central star
- Expansion velocity ~85 km s^{-1}
- Distance ~1.8 Kpc

Observations: Telescopes and cameras (I)

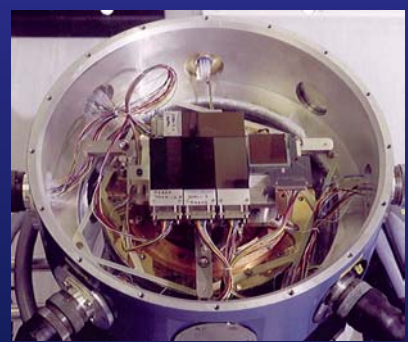
INT Telescope

- Located in ORM (La Palma)
- 2.5 m diam. primary mirror



Wide Field Camera (WFC)

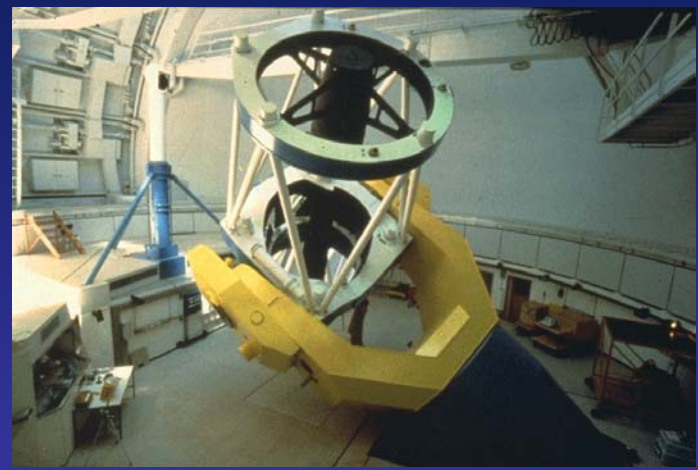
- 4 CCD's mosaic
- Pixel size – 13.5 μm x 13.5 μm
- Pixel scale – 0.333 arcsec / píxel
- Field of view – 34 arcmin x 34 arcmin
- Working temperature – 153 K



Observations: Telescopes and cameras (II)

2.2m-CAHA Telescope

- Located in CAHA (Calar Alto, Almeria)
- 2.2 m diam. primary mirror



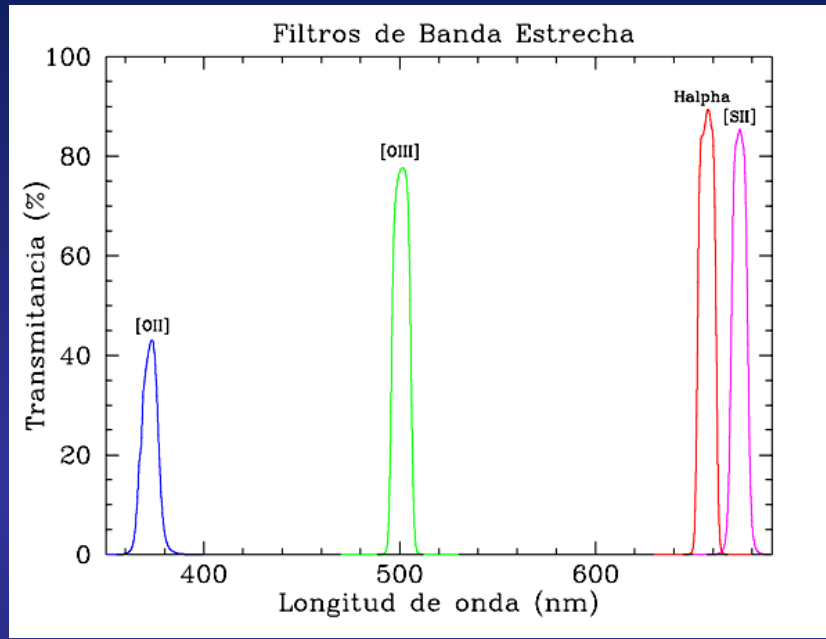
BUSCA Camera

- CCD camera system which allows simultaneous direct imaging of the same sky area in four colors
- 3 CCD's (4096 x 4096 pixels), frontside devices and 1 CCD backside thinned (in the uv channel).
- Pixel size – 15 μm x 15 μm
- Pixel scale – 0.176 arcsec / píxel
- Field of view – 12 arcmin x 12 arcmin



Observations: Filters

- Narrow band filters.
- Hα narrow band filter contains [NII] line.



Filter	λ (Å)	Δλ (Å)
Hα	6568	95
[OIII]	5008	100
[OII]	3727	100
[SII]	6725	80

Data Reduction

- Bias correction
- Flat field correction
- Astrometry
- Fotometry in narrow band filters

Flux Calibration

- **The flux calibration was accomplished using spectrophotometric standard stars. Sequence of images with different times were obtained in order to cover the large dynamic range of these nebulae.**

$$\{F^*\}_{\Delta\lambda}^{obs} = \left[\frac{N^o\,Cuentas^*}{T_{\exp}}\right]^{inst} \cdot 10^{-0.4(-k_\lambda MA)}$$

$$\{F^*\}_{\Delta\lambda}^{esp} = \int_{\lambda}^{\lambda+\Delta\lambda} \{F^*\}^{teor} \cdot T_\lambda^{filtro} \cdot d\lambda$$

$$m_{instrumental(\lambda)} - m_{teorica(\lambda)} = C_\lambda + k_\lambda\, MA$$

C^F_λ is our system's photometric constant in erg cm^{-2} s^{-1}/counts s^{-1}

Results

- Spectrophotometry.

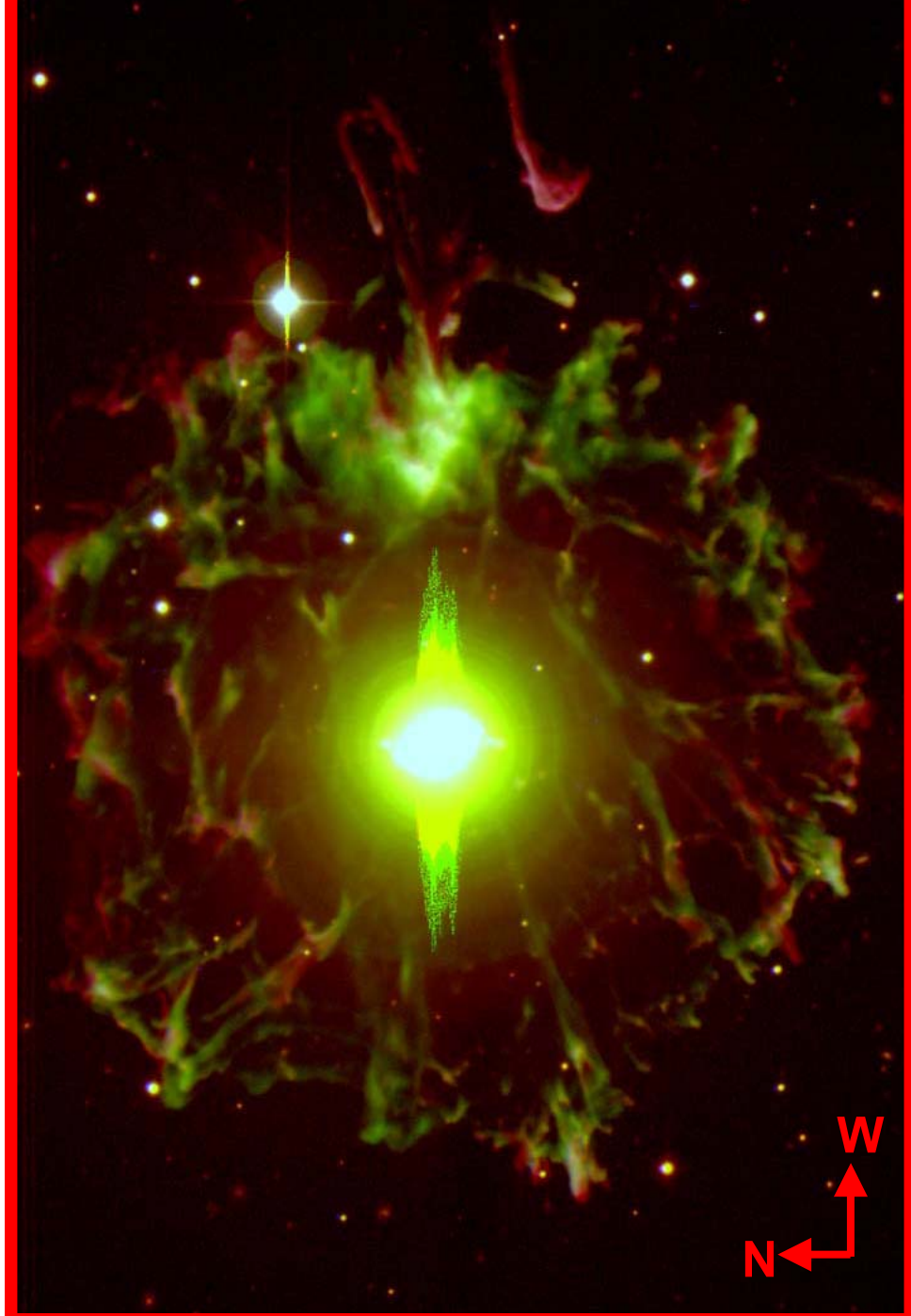
  We obtain flux density (erg $cm^{-2}s^{-1}$) for different emission lines (Hα, [OIII], [OII] y [SII]) in the sub-sample (NGC 6543 and NGC 6888)

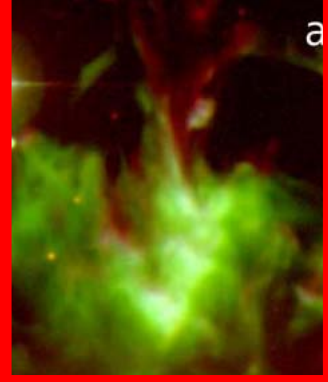
- Ionization structure.

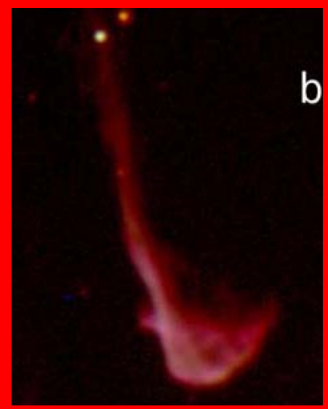
  2D ionization structure.

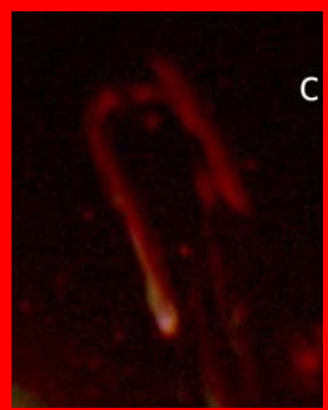
  - RGB composition of emission in Hα, [OIII] and [OII] lines.
  - Ionization quotients: [OIII]/Hα, [OII]/[OIII], [SII]/Hα.

- Diagnostic diagrams (in progress).











NGC 6543

RGB Composition

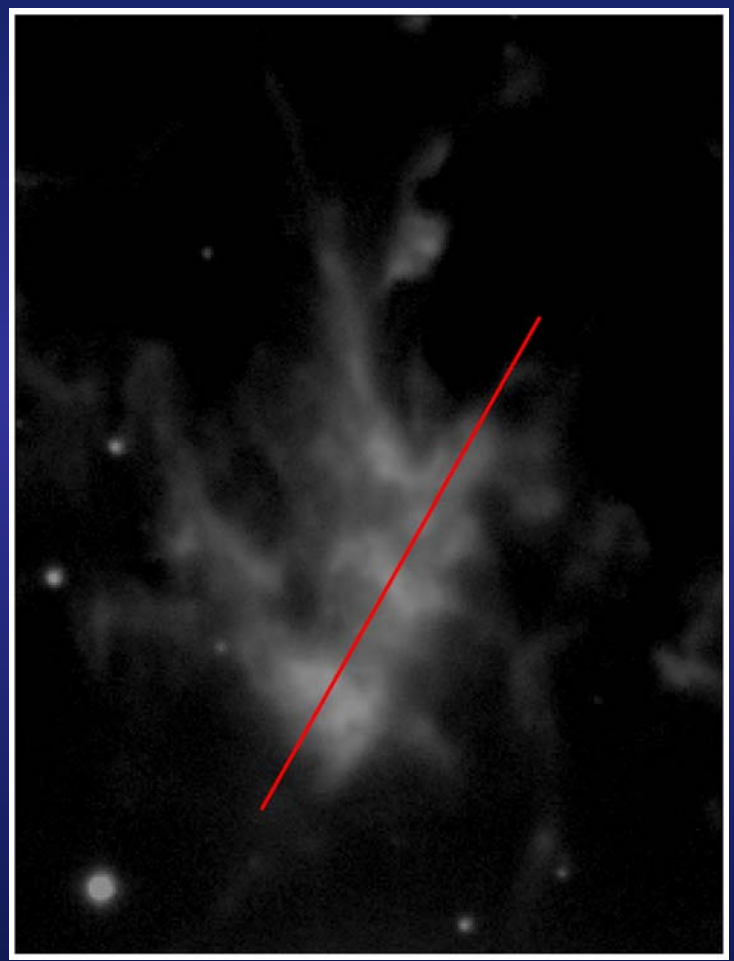
The composite image of NGC 6543 made with the Hα + [NII] (Red), [OIII] (Green) and [OII] (Blue) emission line images displayed with linear intensity.

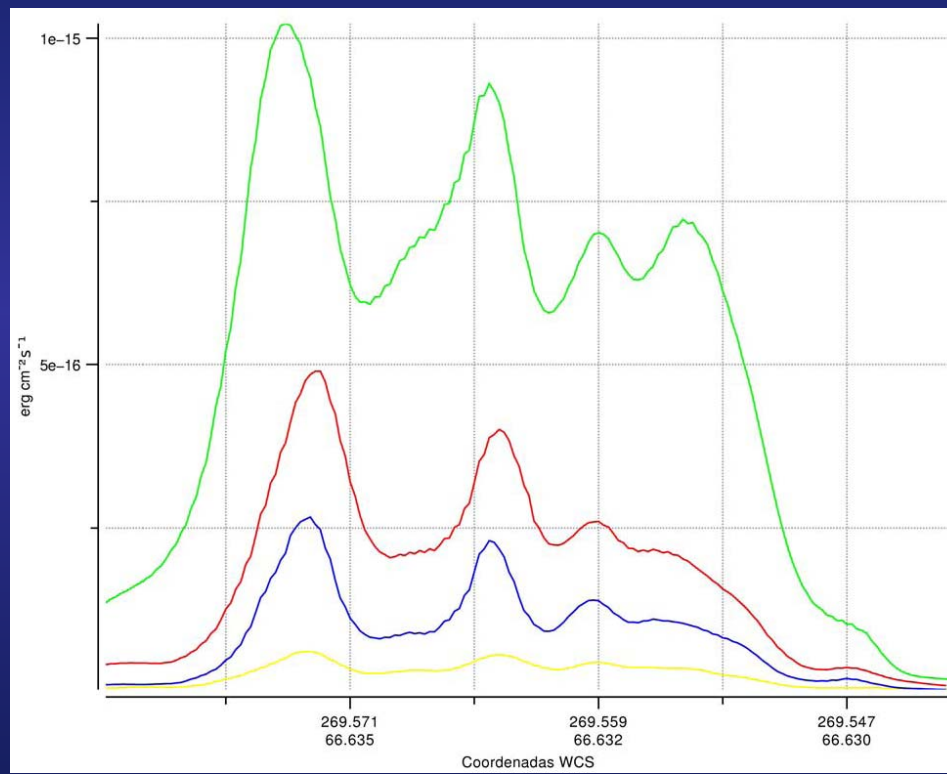
This false-color image is made three (RGB) 8-bit image. This image shows the fine-scale structures of the halo.

Fig. 2a, 2b and 2c show parts o the halo of NGC 6543.

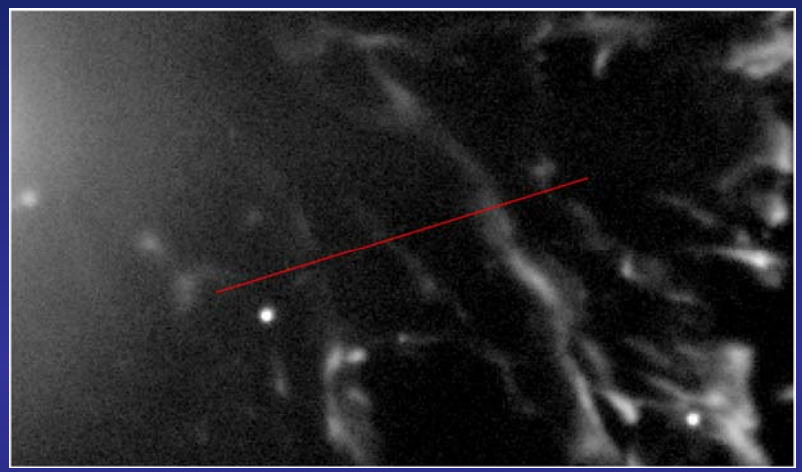
Fig. 2d shows a close-up of the concentric rings observed in NGC 6543 (e.g. Balick, Wilson Hajian 2001).

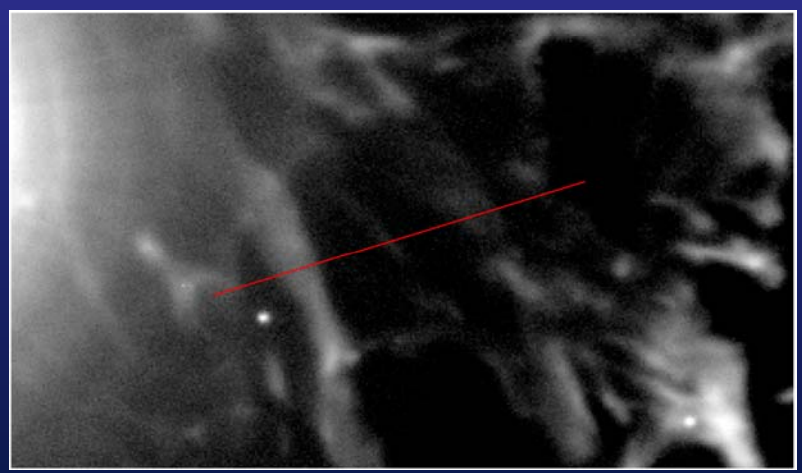
NGC 6543: Spatial Cut

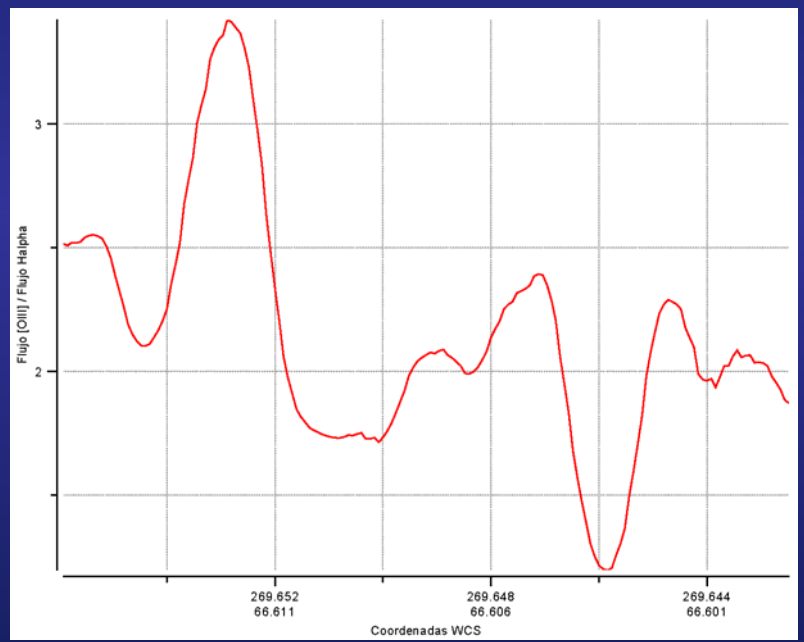




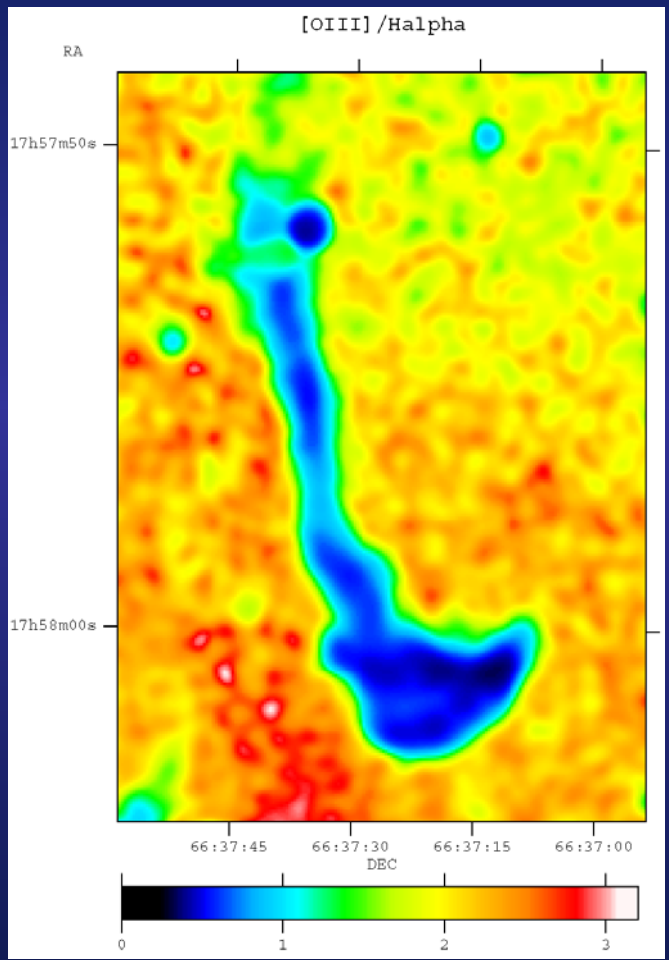
NGC 6543: Spatial Cut

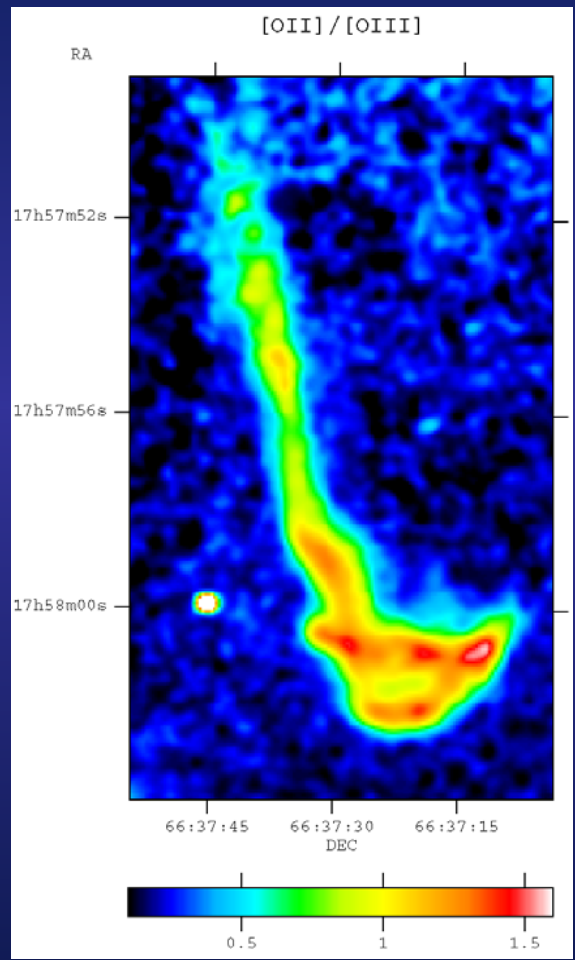




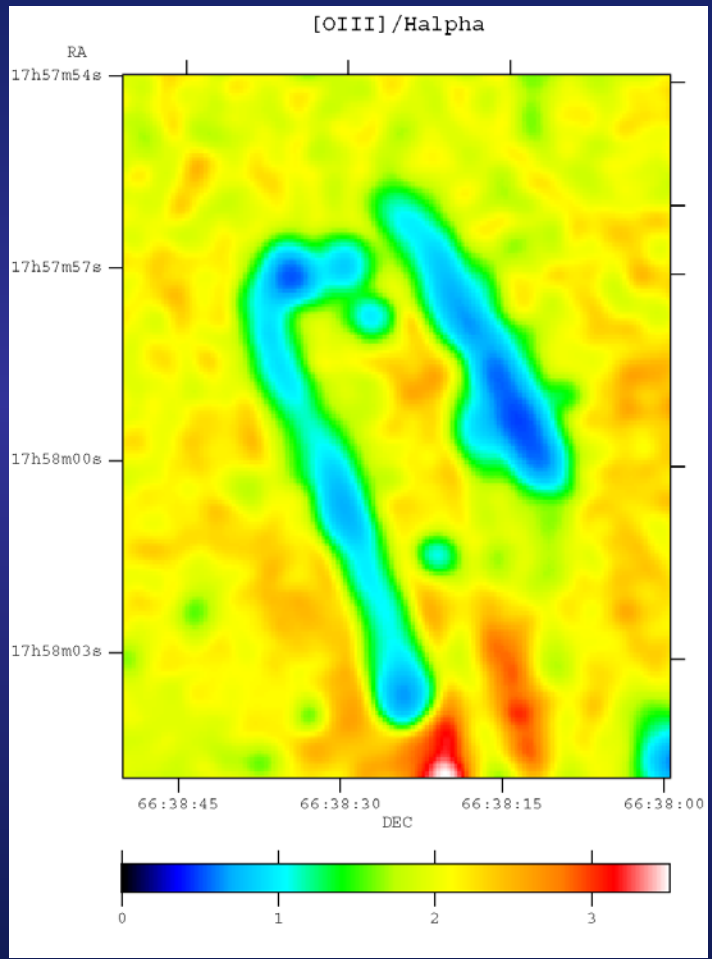


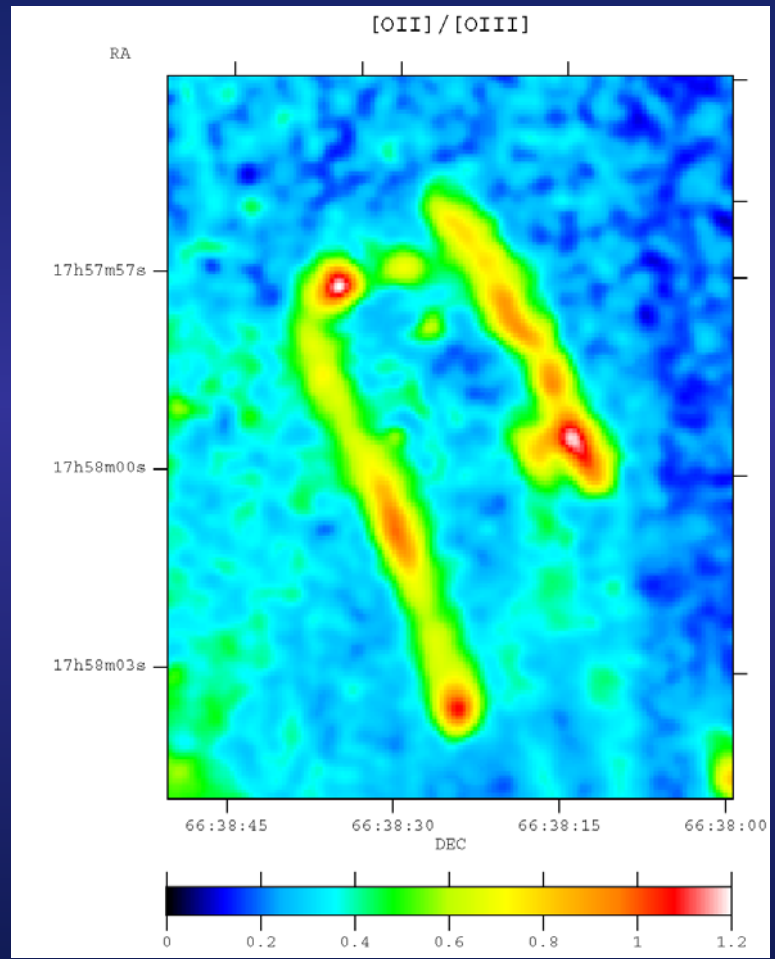
NGC 6543: Quotients

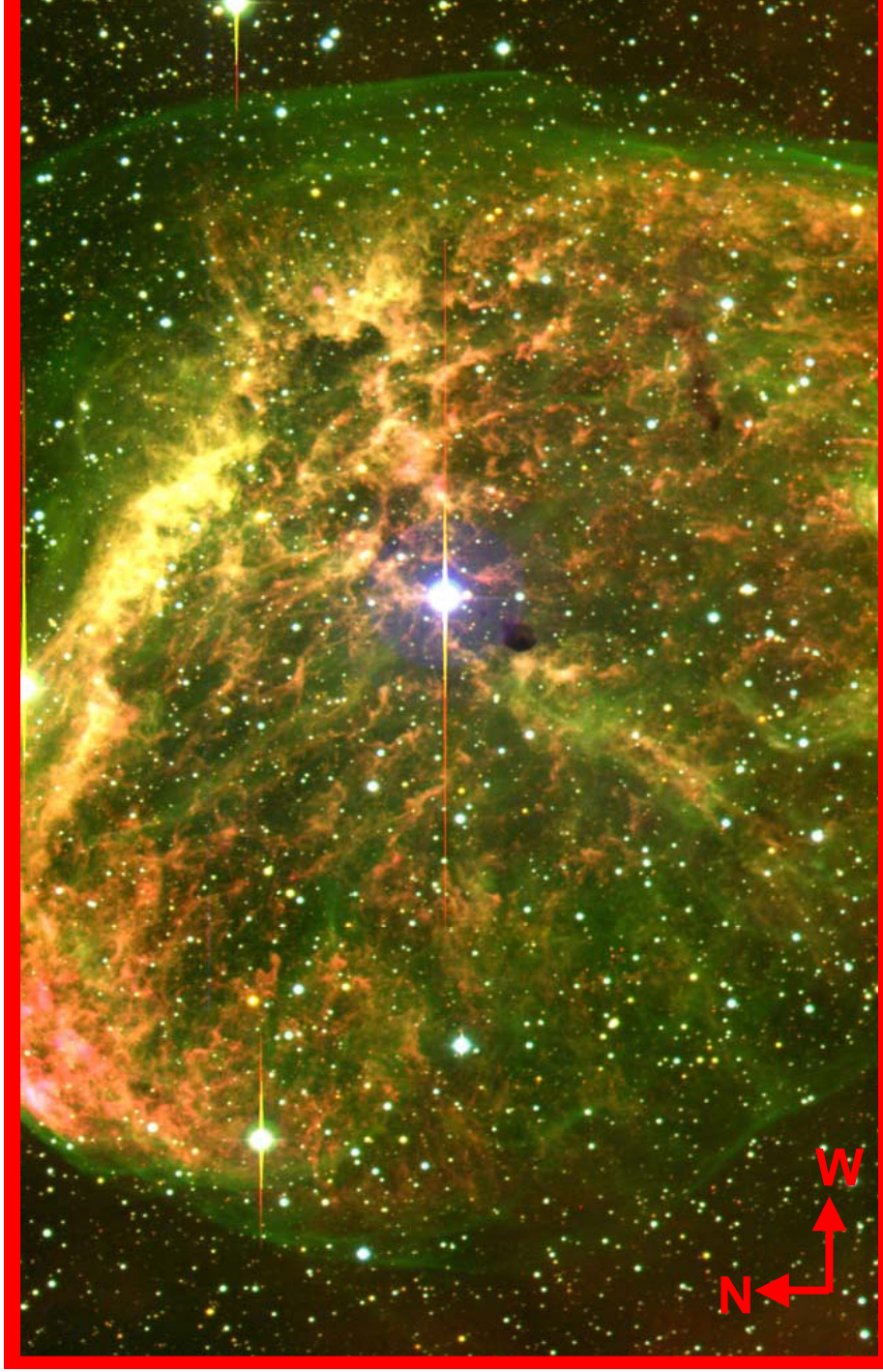




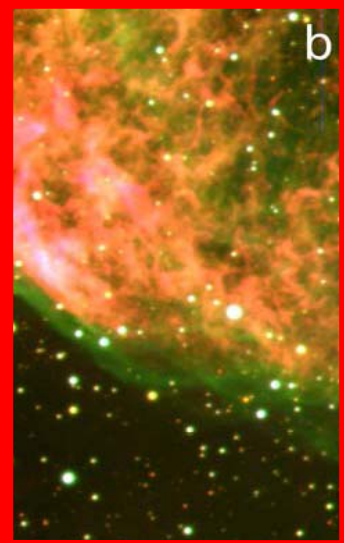
NGC 6543: Quotients

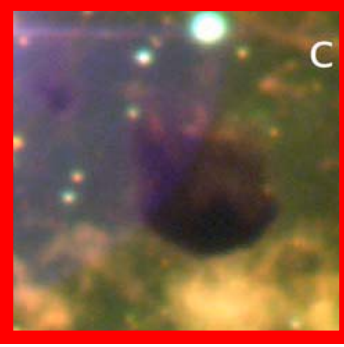












NGC 6888

RGB Composition

The composite image of NGC 6888 made with the Hα + [NII] (Red), [OIII] (Green) and [OII] (Blue) emission line images displayed with linear intensity.

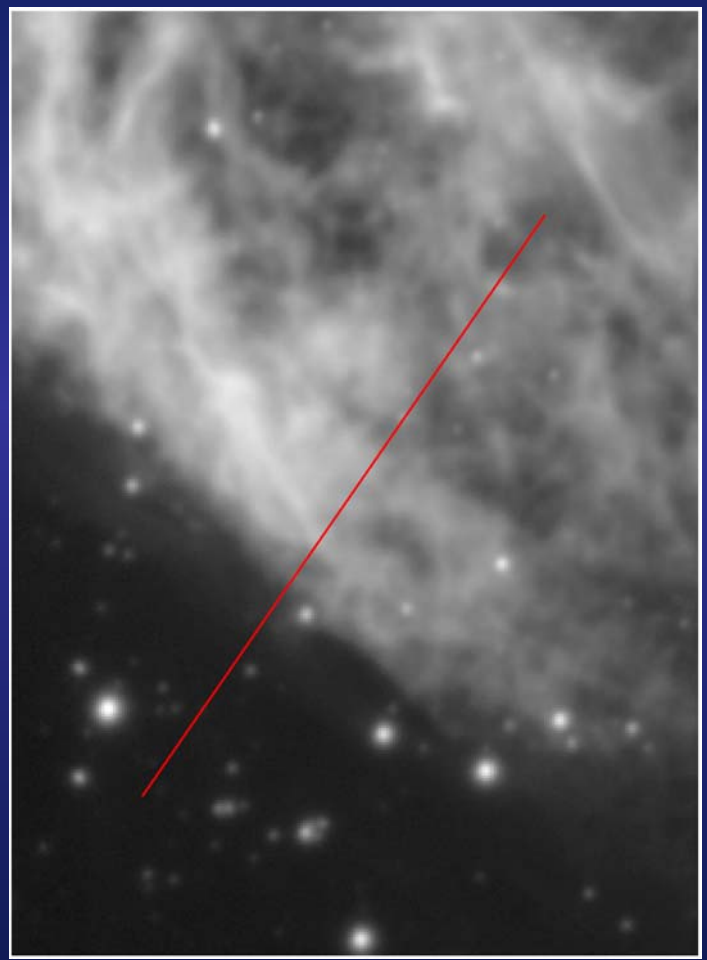
This false-color image is made of three (RGB) 8-bit image. This image shows the fine-scale structures of the halo.

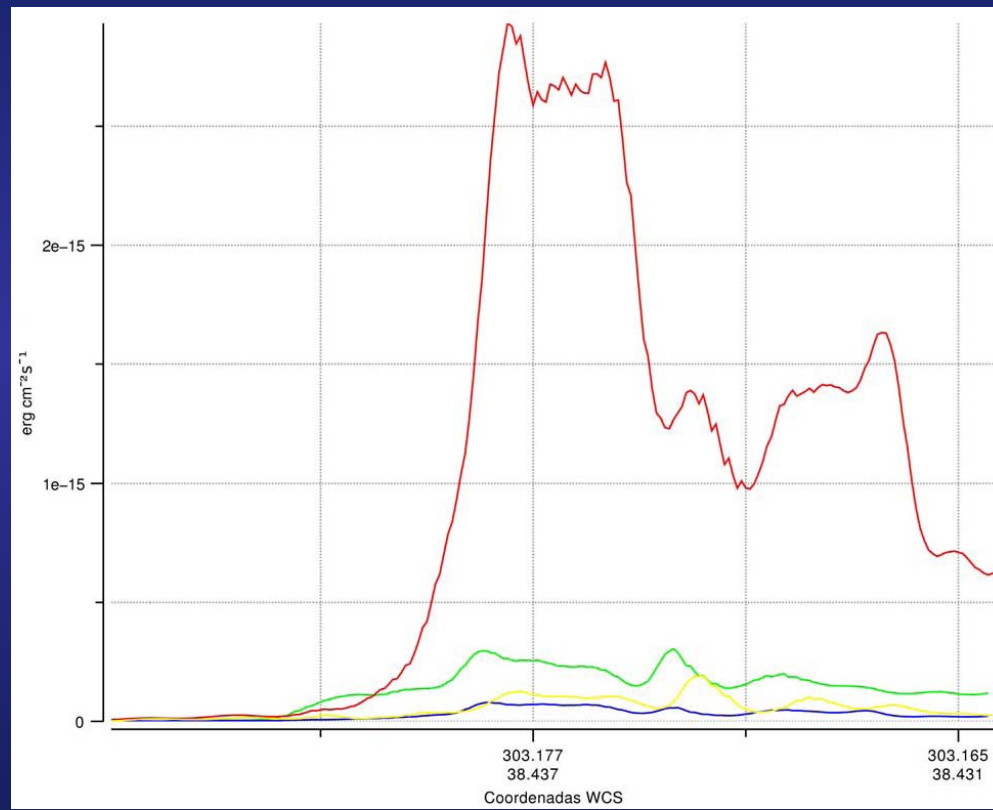
Fig. a shows parts of the halo of NGC 6888.

Fig. b shows the northest Bubble Boundary.

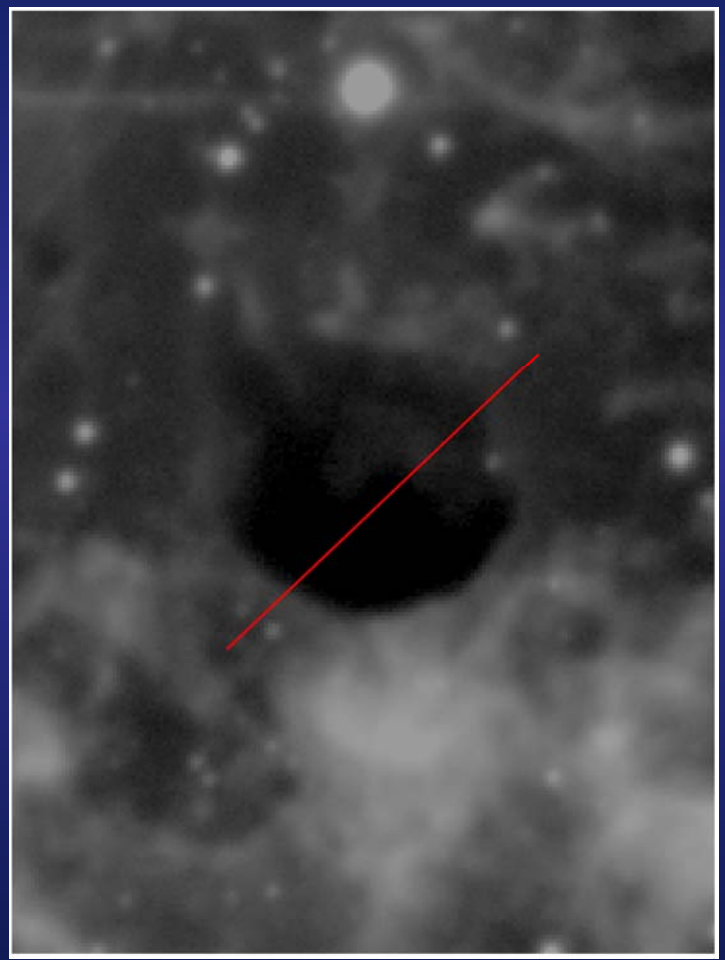
Fig. c shows a dust cloud that seems to be physically associated to the nebula.

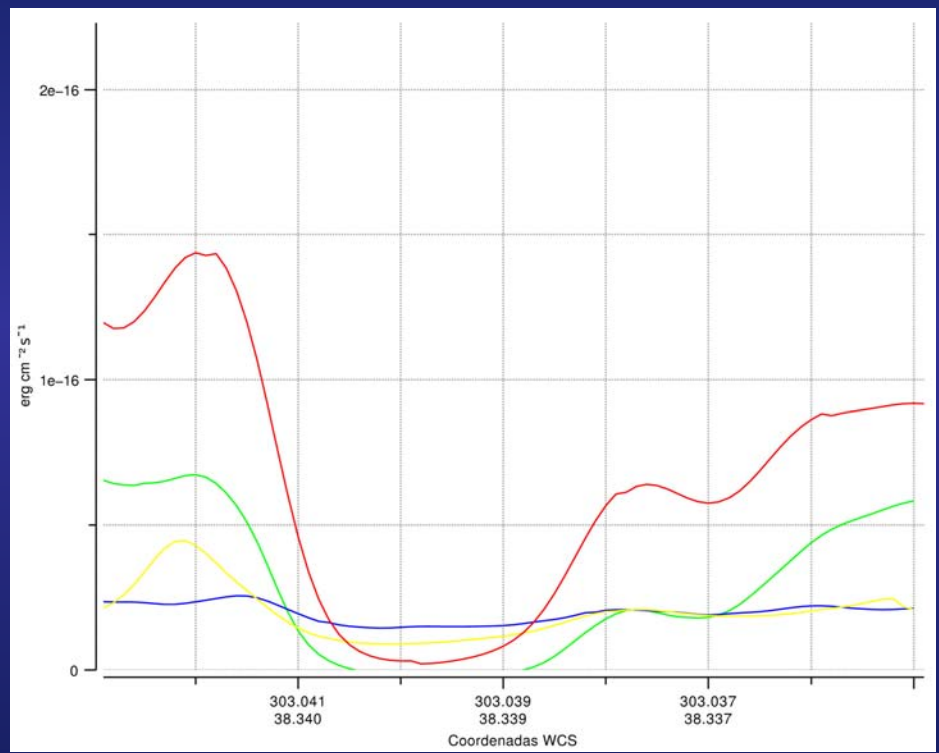
NGC 6888: Spatial Cut



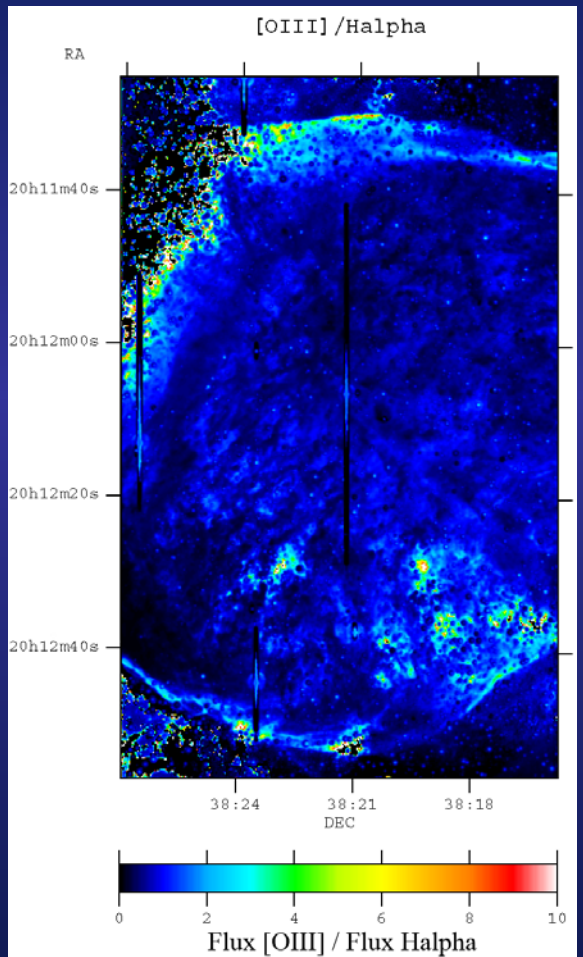


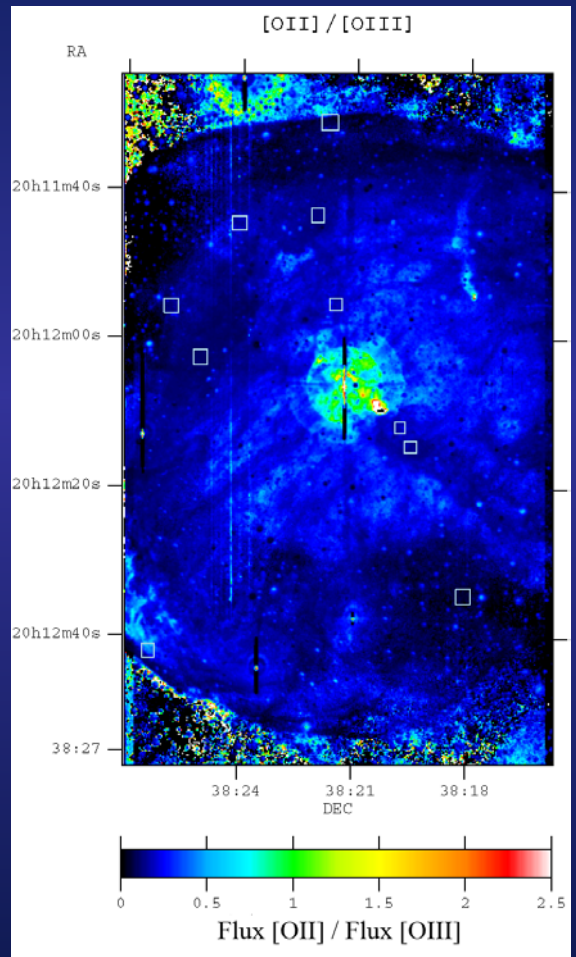
NGC 6888: Spatial Cut



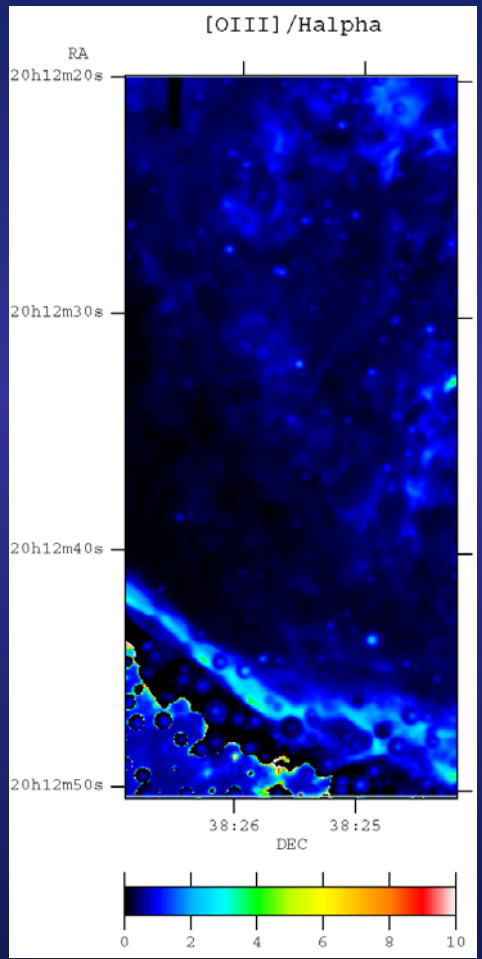


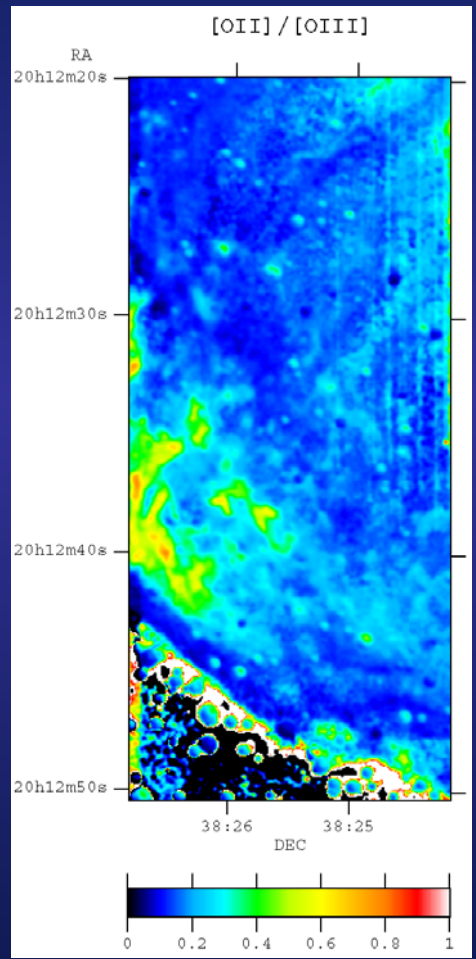
NGC 6888: Quotients





NGC 6888: Quotients





Future Work

- Detailed analysis of results for the sample.
- Comparison between observed ionization structure and:
  - Photoionization models (CLOUDY and MAPPINGS Ic).
  - Hidrodynamic simulations (YGUAZU)
  - Theoretical models.
- High (spectral & spatial) resolution spectrophotometry of candidate nebulae selected from our 2D Ionization Structure Maps (in progress).