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

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3D Spectroscopy 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 I - Imaging

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

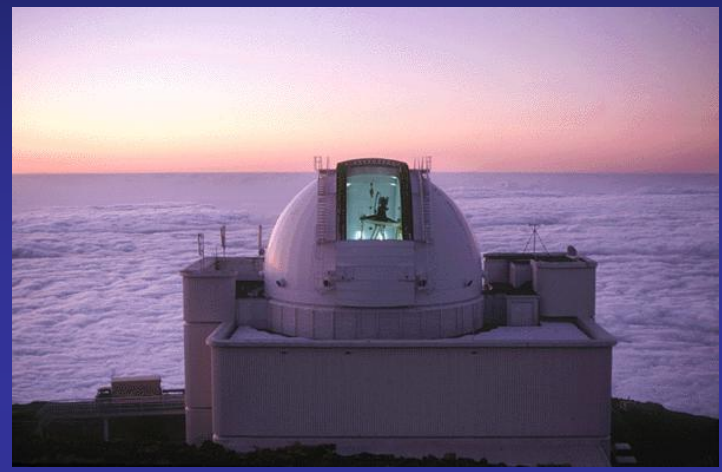
The Sample II - 3D spectroscopy

OBJECT	RA	Dec	Type	Gratings	Pointings
M1-67	19:11:30.89	+16:51:38.1	WR-ring	V300	2
NGC6543	17:58:33.40	+66:37:58.9	Pn-halo	R1200 & V300	4
NGC6888	20:12:26.90	+38:21:17.6	WR-ring	R1200 & V300	4
NGC7662	23:25:53.99	+42:32:06.0	Pn-halo	V300	3

Observations: Telescopes and instrument (I)

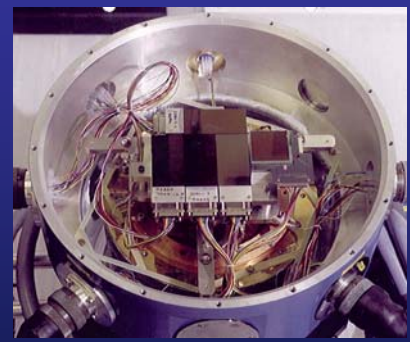
INT Telescope

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



Wide Field Camera (WFC)

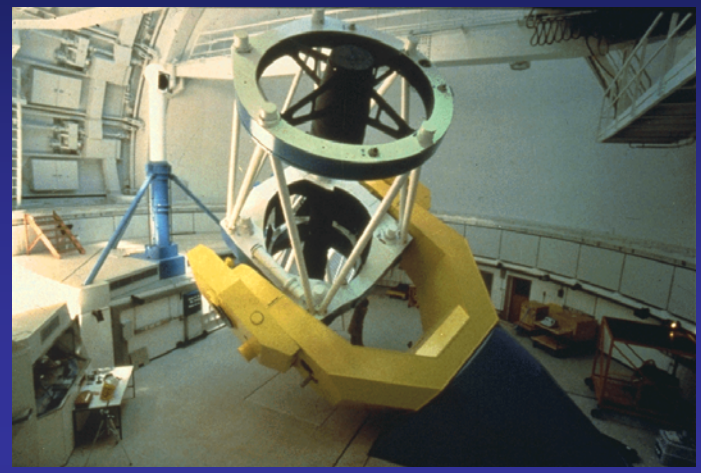
- 4 CCD's mosaic
- Pixel size – 13.5 μm x 13.5 μm
- Pixel scale – 0.333 arcsec / píxel
- Field of view – 34 arcmin x 34 arcmin
- Working temperature – 153 K



Observations: Telescopes and instruments (II)

2.2m-CAHA Telescope

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



BUSCA Camera

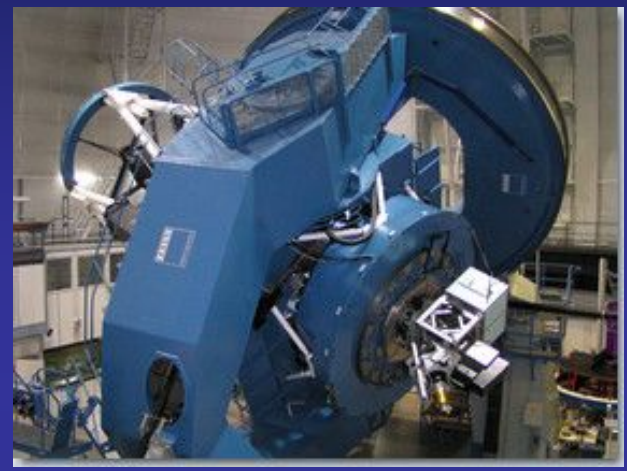
- CCD camera system which allows simultaneous direct imaging of the same sky area in four colors
- 3 CCD's (4096 x 4096 pixels), frontside devices and 1 CCD backside thinned (in the uv channel).
- Pixel size – 15 μm x 15 μm
- Pixel scale – 0.176 arcsec / píxel
- Field of view – 12 arcmin x 12 arcmin



Observations: Telescopes and instruments (III)

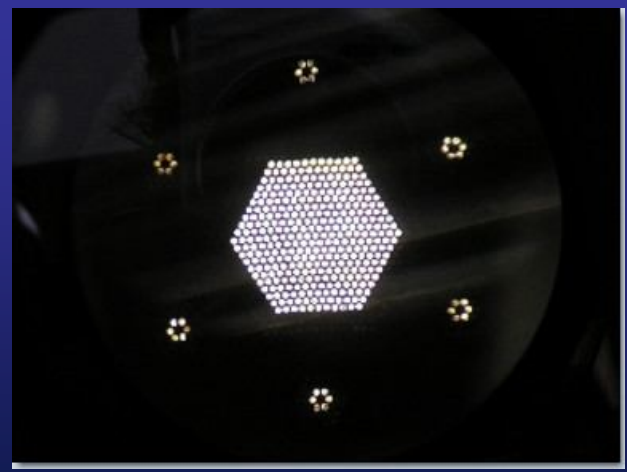
3.5m-CAHA Telescope

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



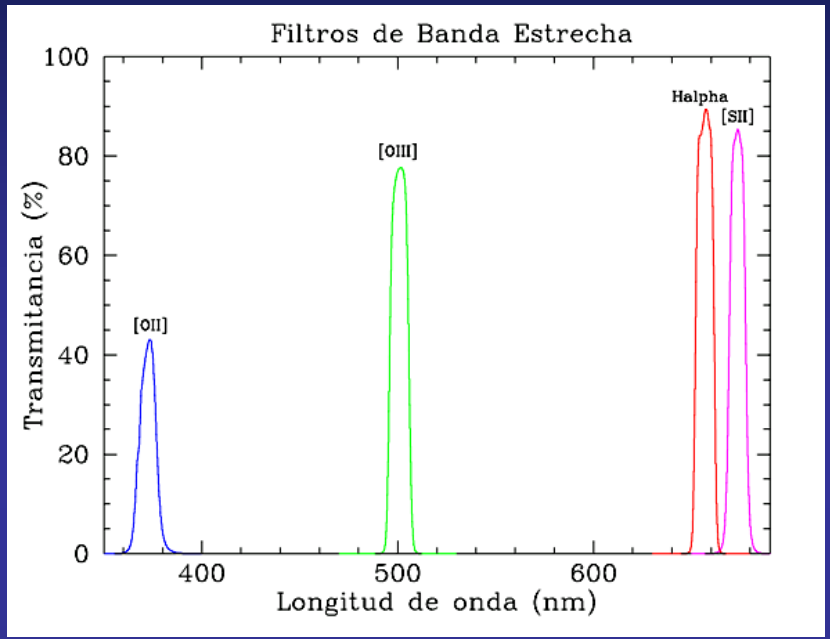
PMAS/PPAK Spectrograph

- 331 densly packed optical fibers
- Spatial sampling - 2.7 arcseconds per fiber
- Field of view – 74 arcsec x 65 arcsec



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

Observations: Gratings

- High and low resolution gratings.

Grating	λ_1 (Å)	λ_2 (Å)	FWHM (Å)
R1200	6212	6871	~2.77
R1200	4322	5061	~2.77
R1200	3663	4428	~2.76
V300	3701	7102	~10.7

Data Reduction - Imaging

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

Data Reduction – 3D Spectroscopy

- Find the position of the spectra in the raw frame
- Trace the position of the spectra along the spectral direction
- Extract the spectra
- Correct for the distortion & dispersion
- Fiber-to-fiber transmission correction
- Calibration with standard stars

The Sub-Sample

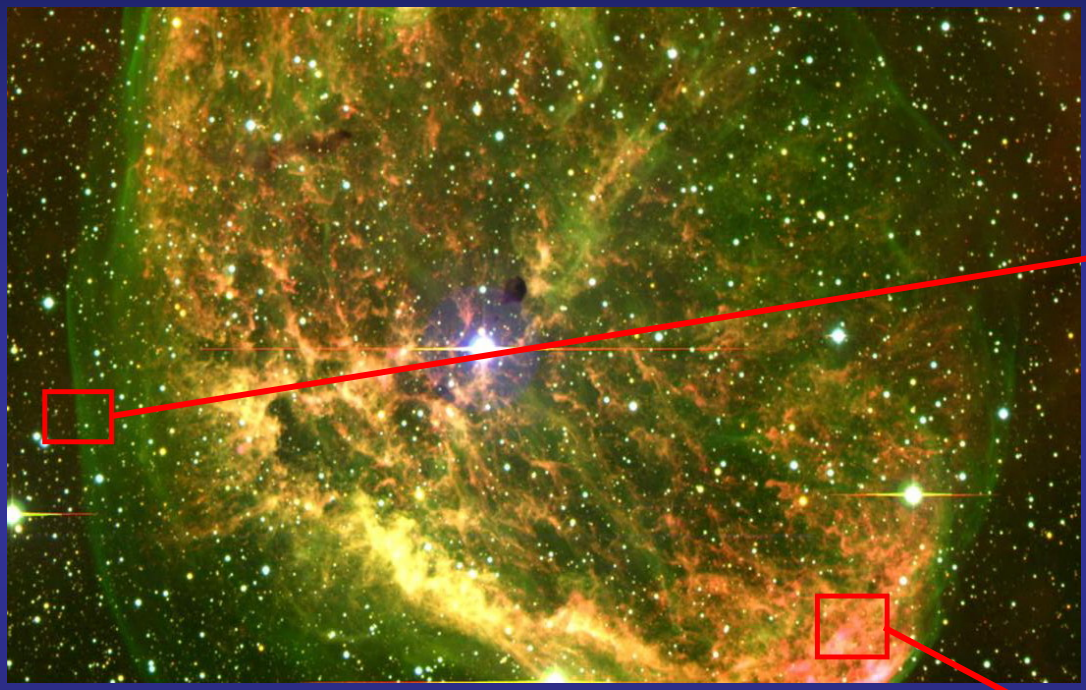
NGC 6543

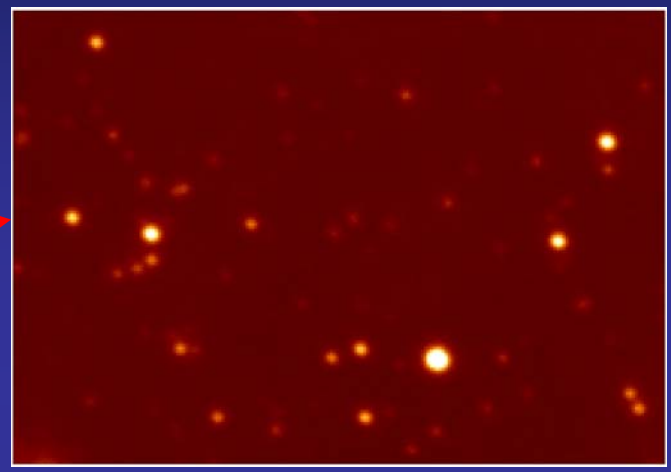
- Multiple shell planetary nebula (MSPNe)
- Of + WR central star
- Expansion velocity < 4.6 km s^{-1}
- Distance 1001 ± 269 pc

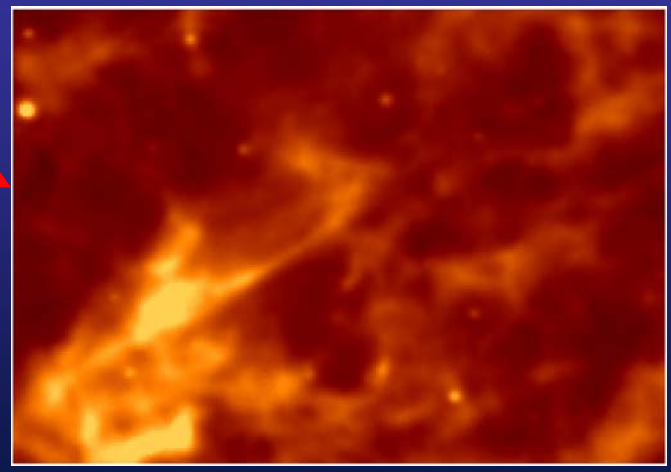
NGC6888

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

NGC 6888



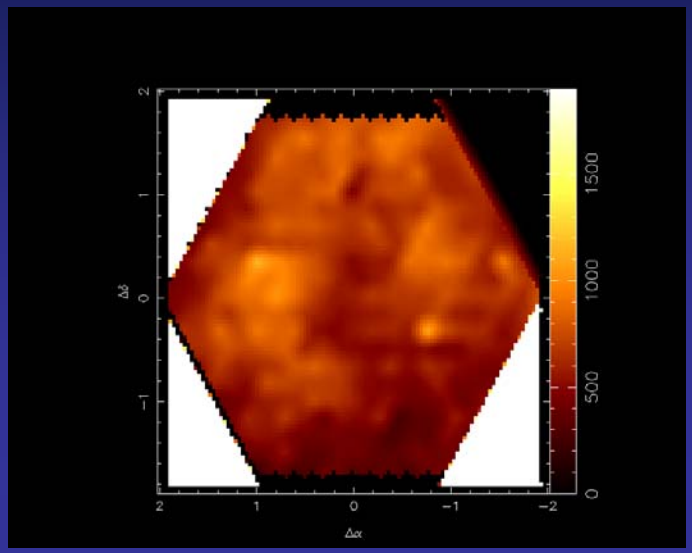




The composite image of NGC 6888 made with the Hα + [NII] (Red), [OIII] (Green) and [OII] (Blue) emission line images displayed with linear intensity.

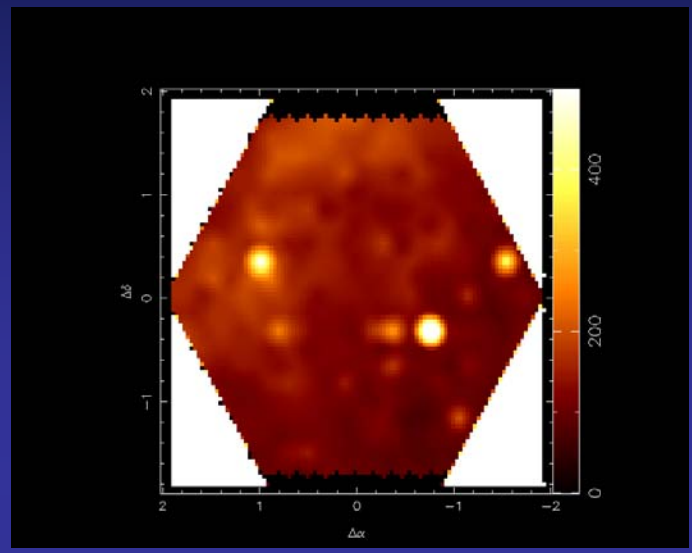
This false-color image is made of three (RGB) 8-bit image. This image shows the fine-scale structures of the halo.

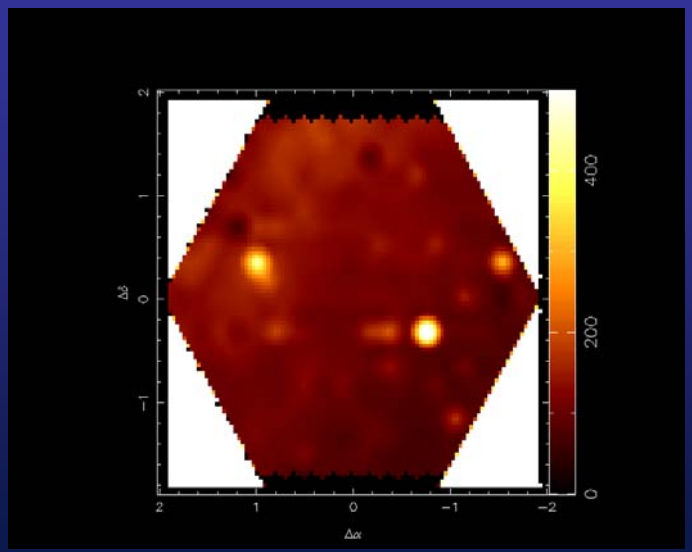
NGC 6888: outer zone



Hα emission map

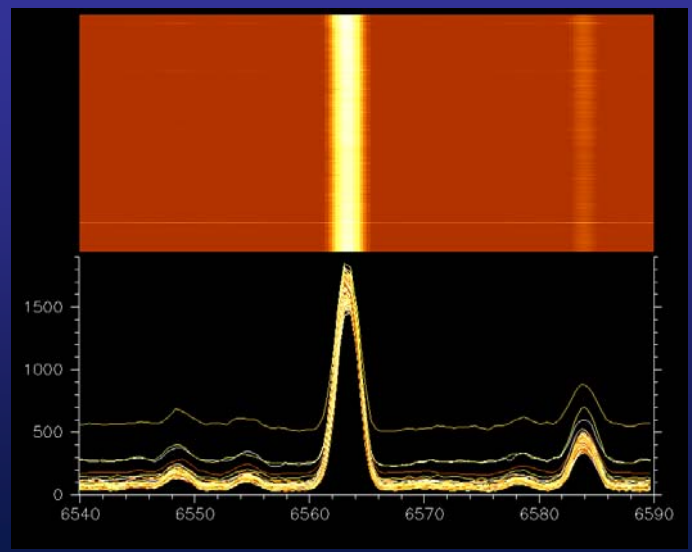
[NII] 6584Å emission map



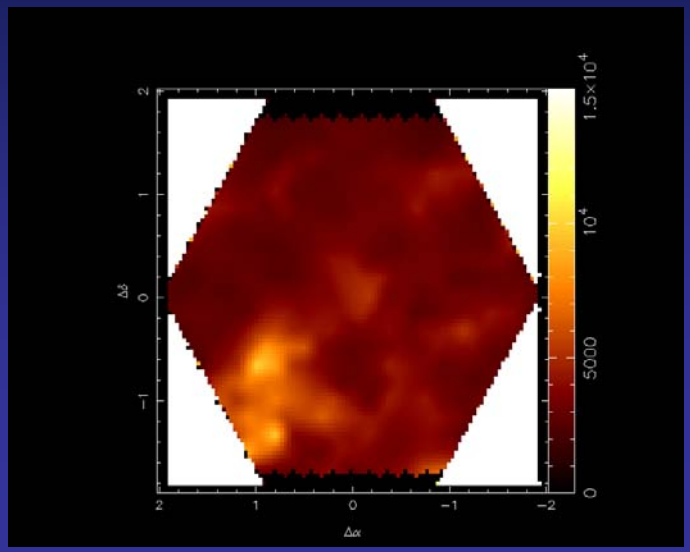


[SII] 6717Å emission map

Hα and [NII] emission lines in all fibers

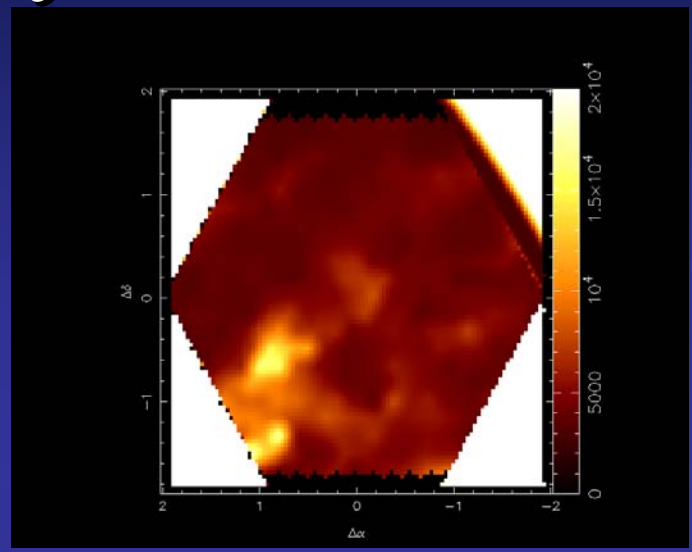


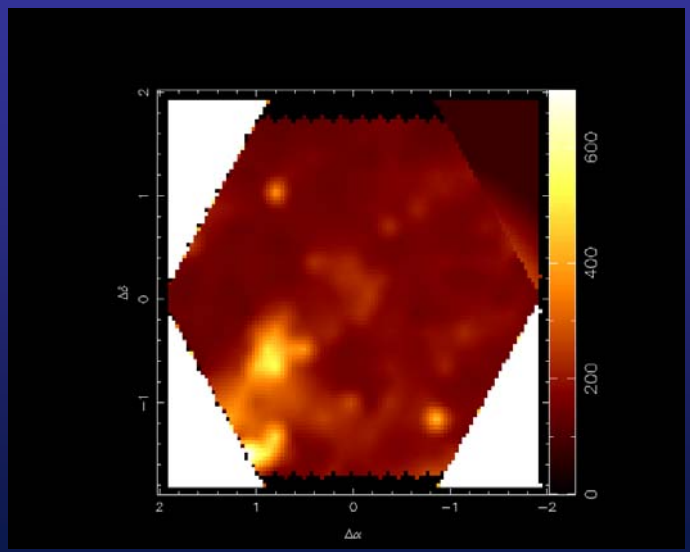
NGC 6888: x-ray zone



Hα emission map

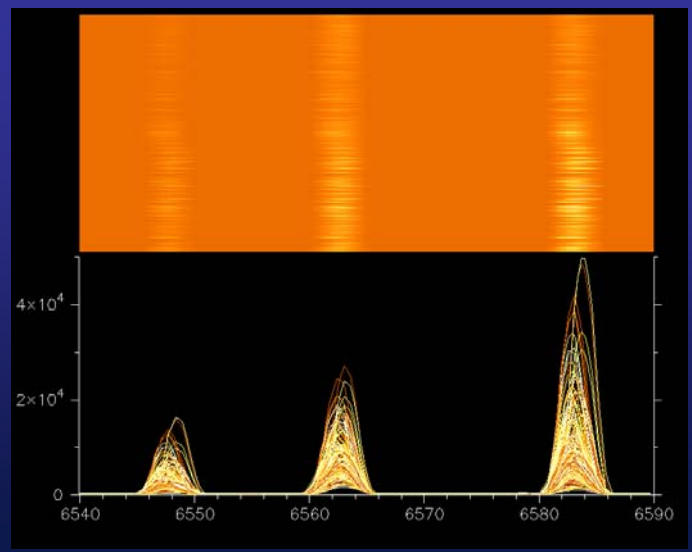
[NII] 6584Å emission map



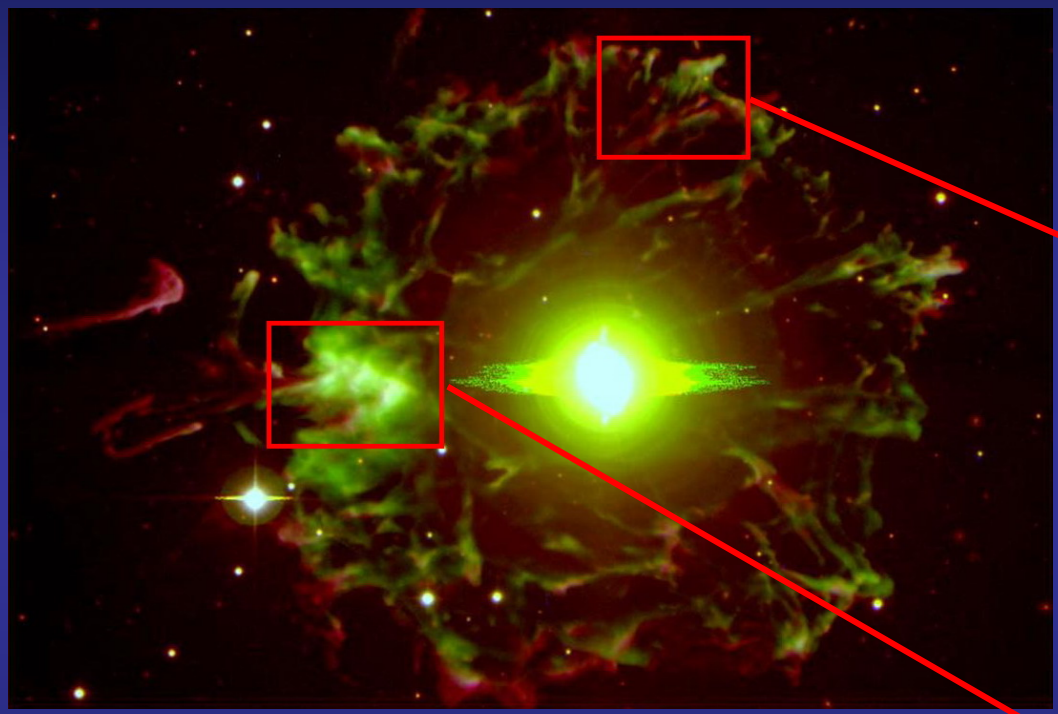


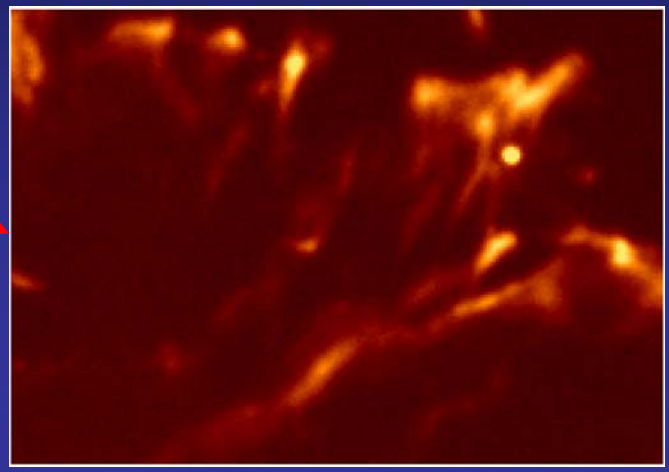
[SII] 6717Å emission map

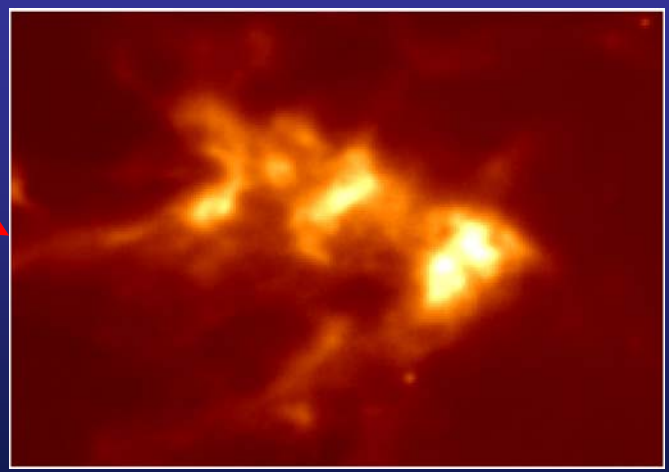
Hα and [NII] emission lines in all fibers



NGC 6543



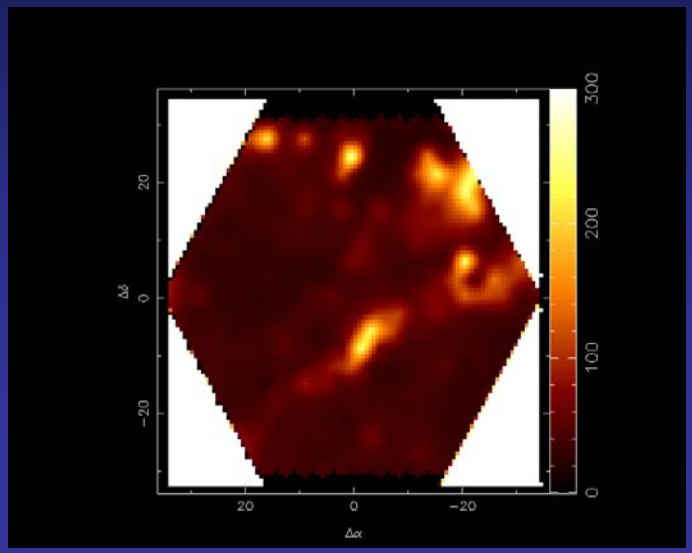




The composite image of NGC 6543 made with the Hα + [NII] (Red), [OIII] (Green) and [OII] (Blue) emission line images displayed with linear intensity.

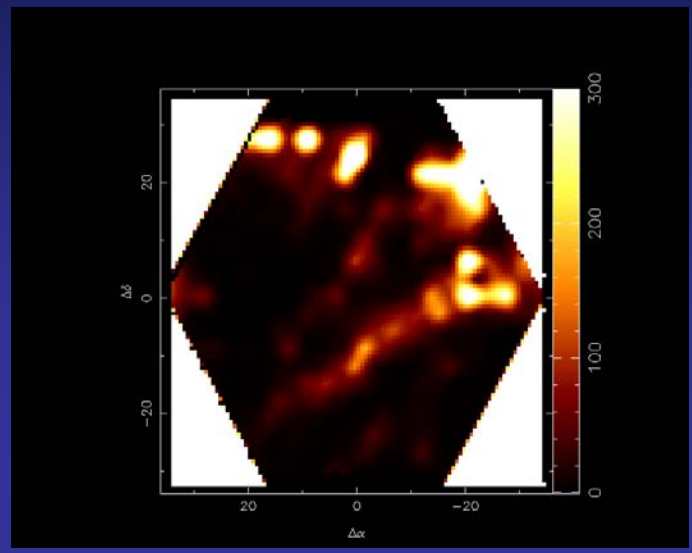
This false-color image is made of three (RGB) 8-bit image. This image shows the fine-scale structures of the halo.

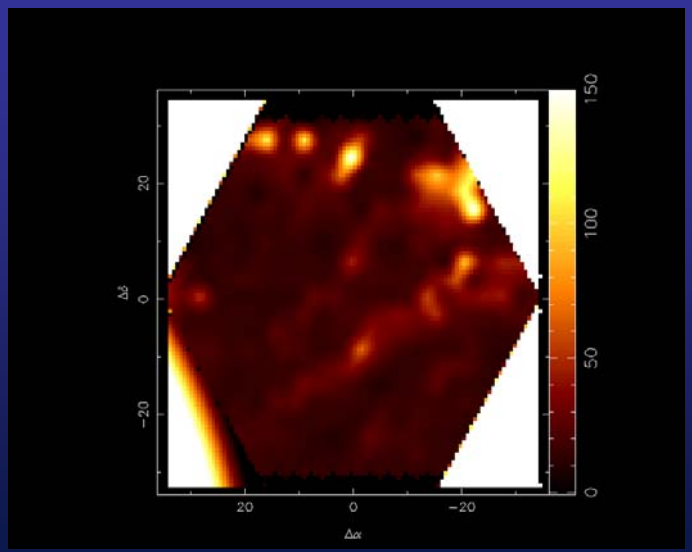
NGC 6543: halo



Hα emission map

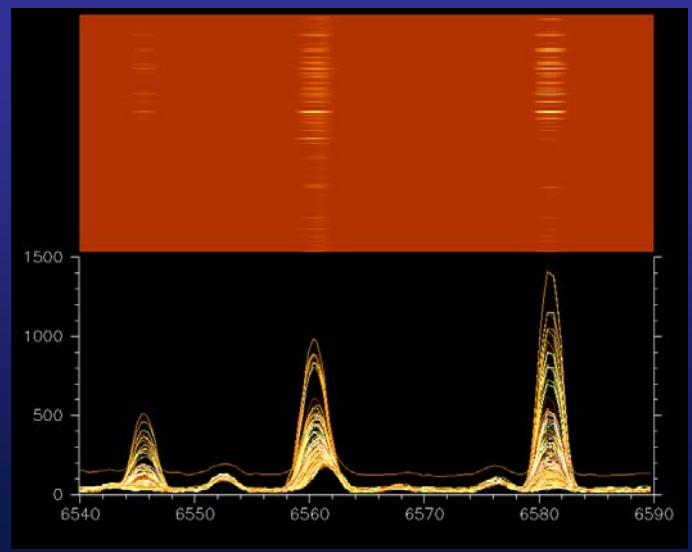
[NII] 6548Å emission map



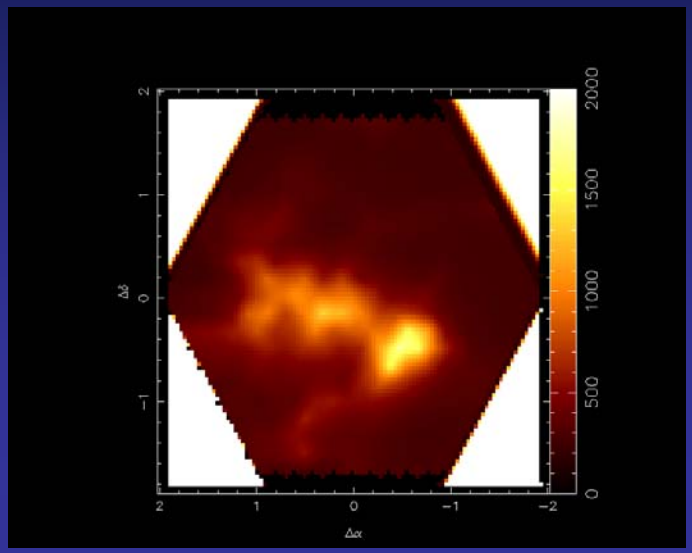


[SII] 6717Å emission map

Hα and [NII] emission lines in all fibers

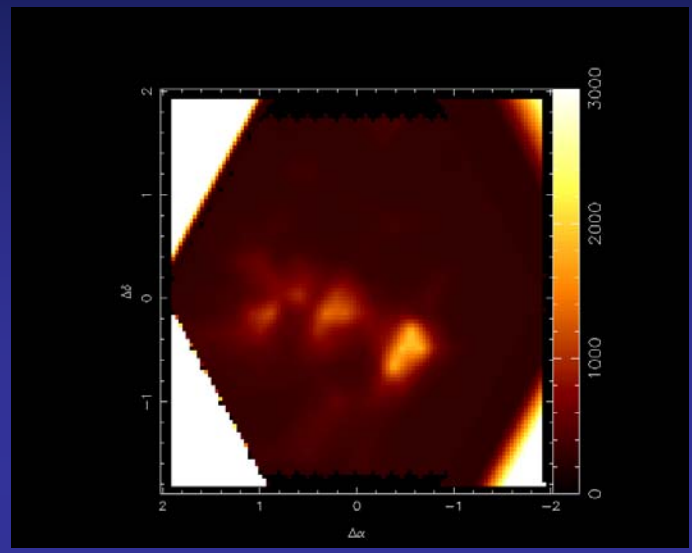


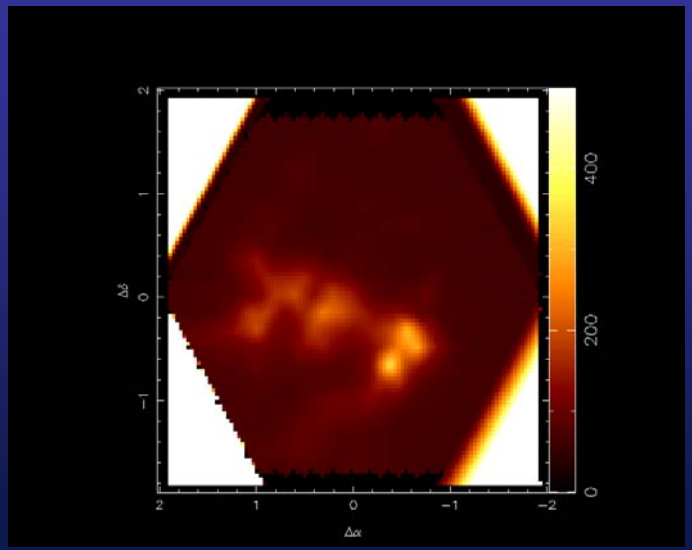
NGC 6543: knot



Hα emission map

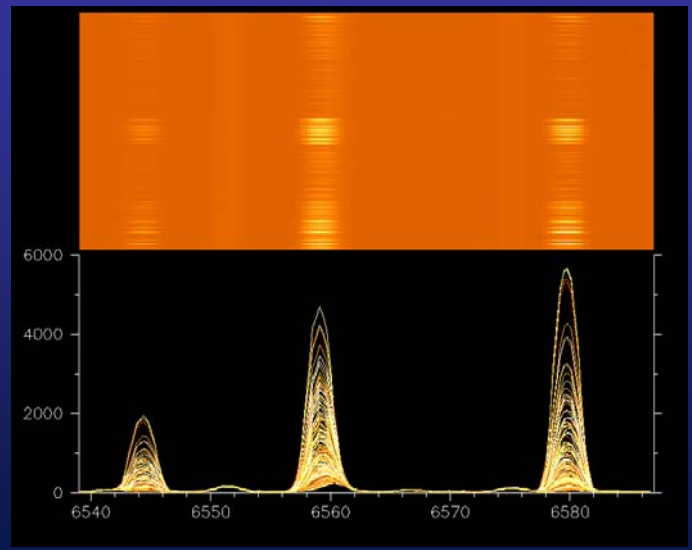
[NII] 6584Å emission map



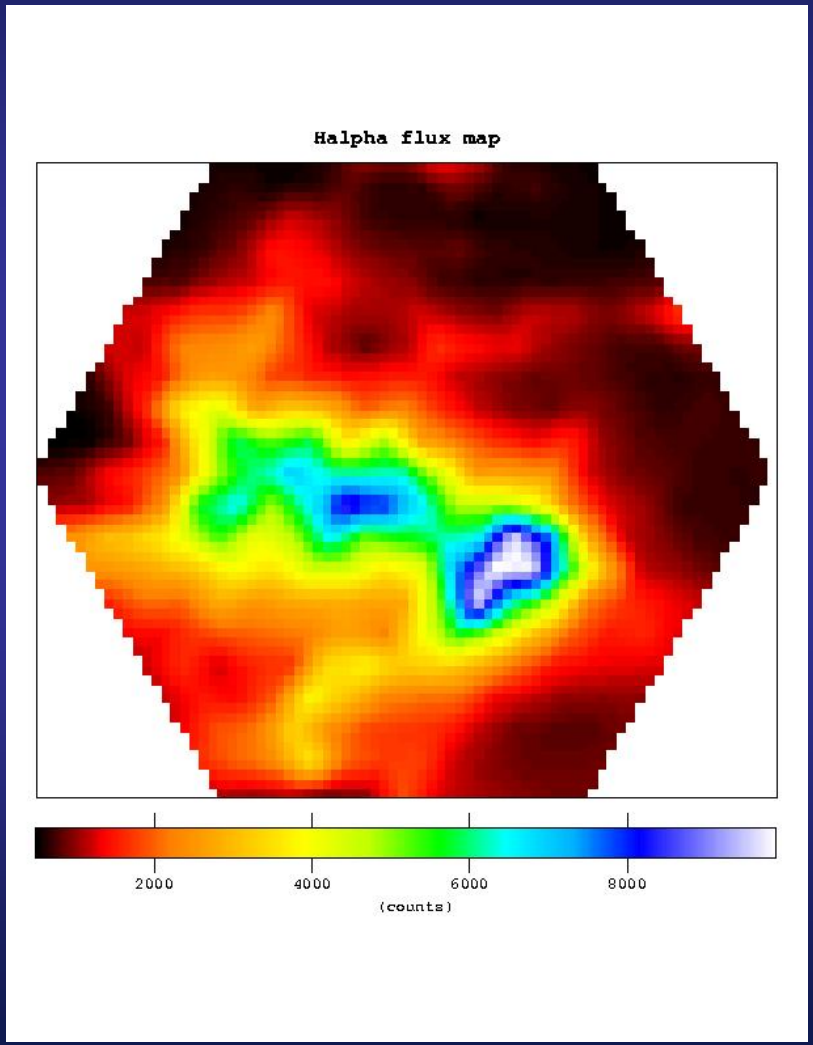


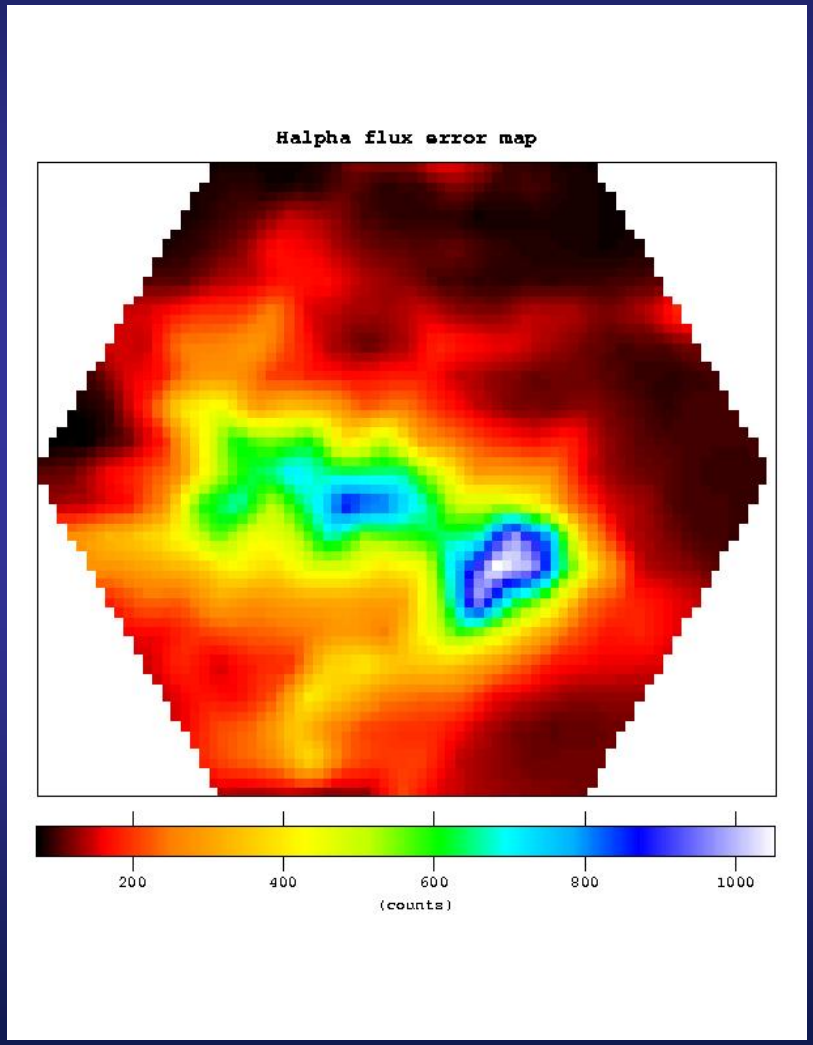
[SII] 6717Å emission map

Hα and [NII] emission lines in all fibers

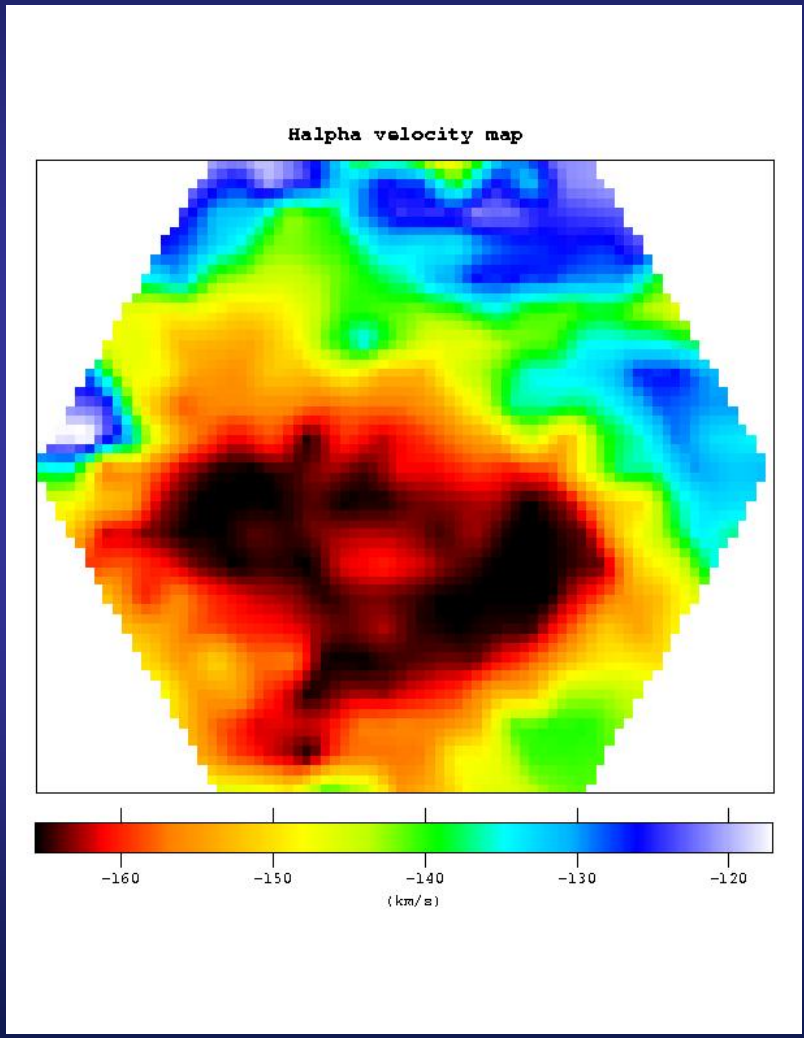


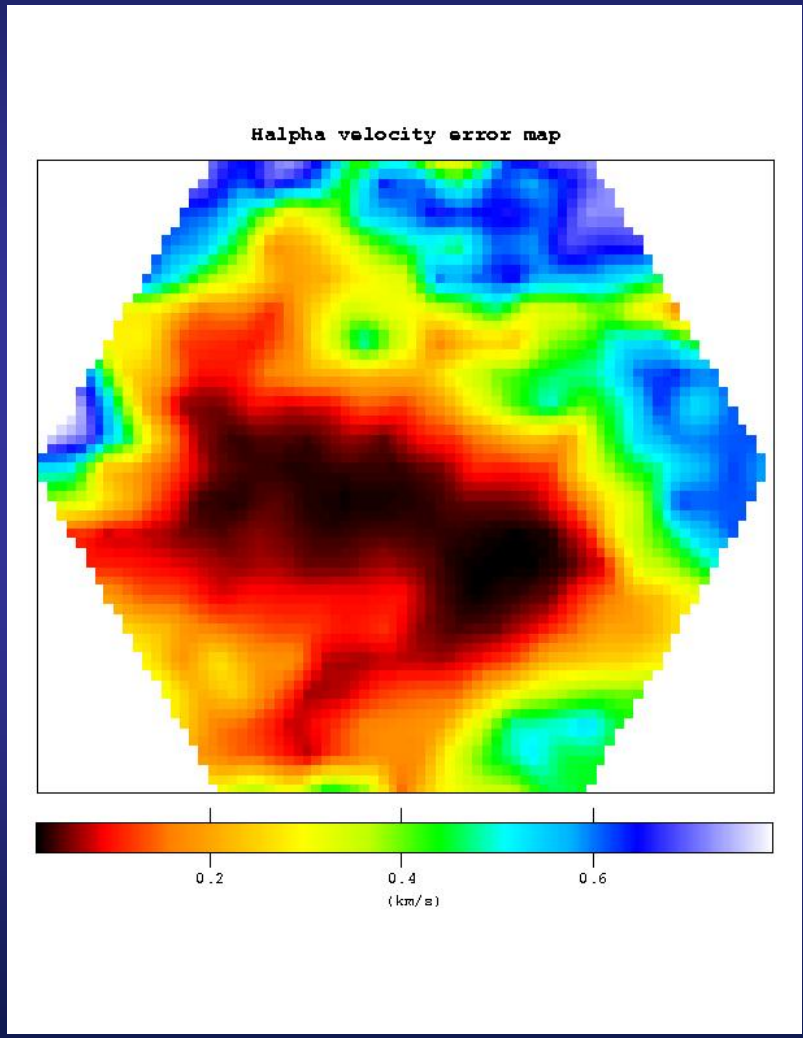
NGC 6543: knot (flux)





NGC 6543: knot (radial velocity)

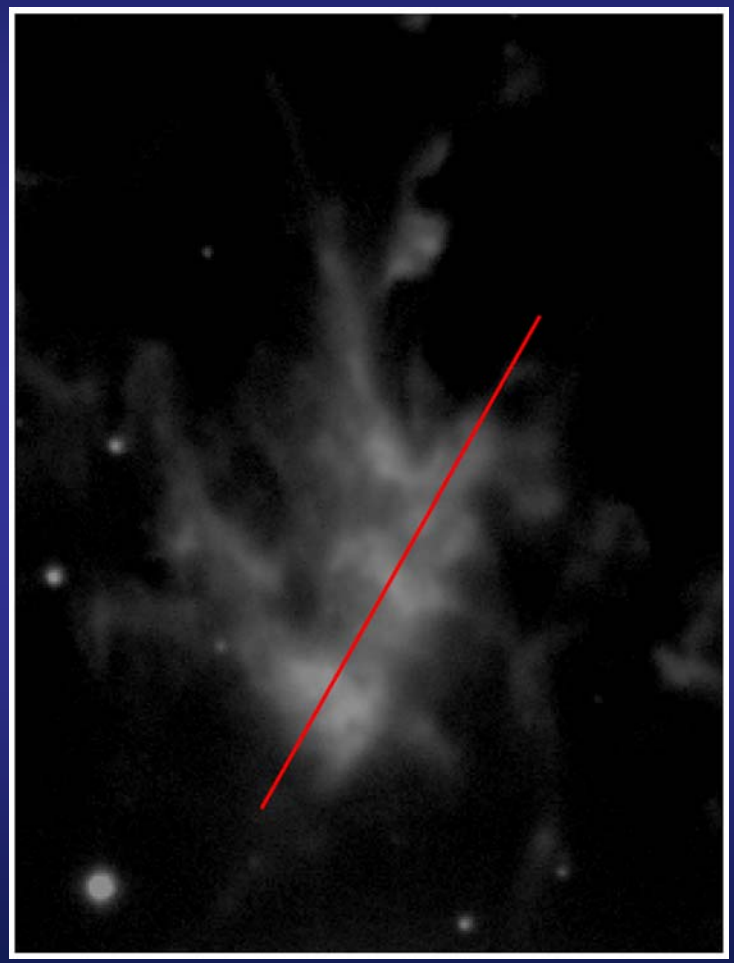


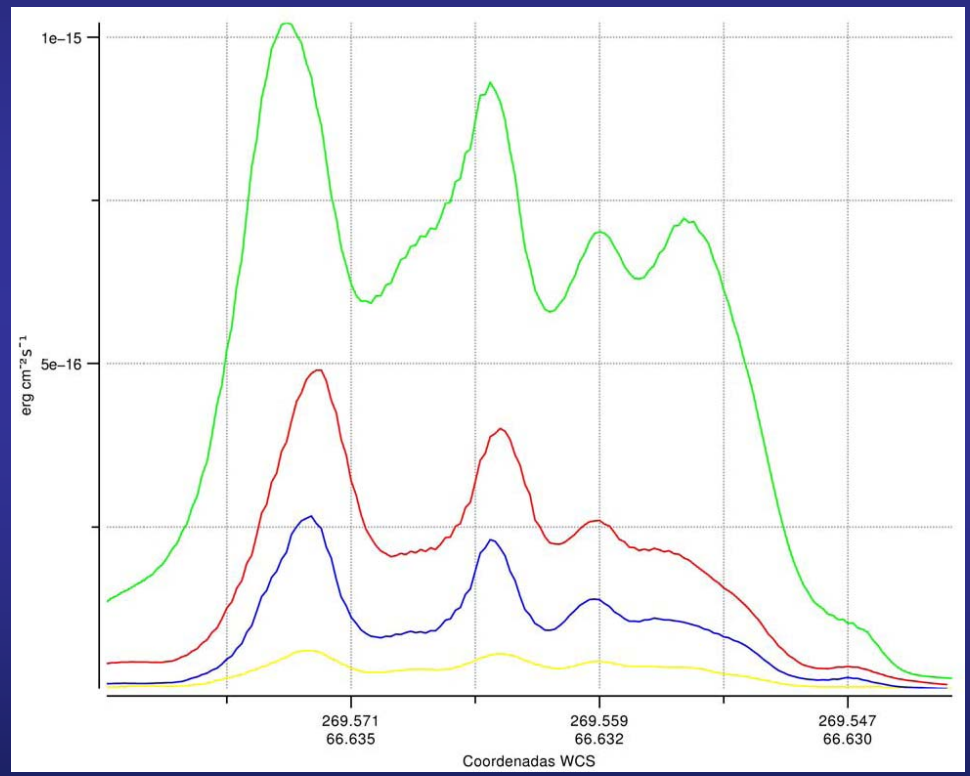


Future Work

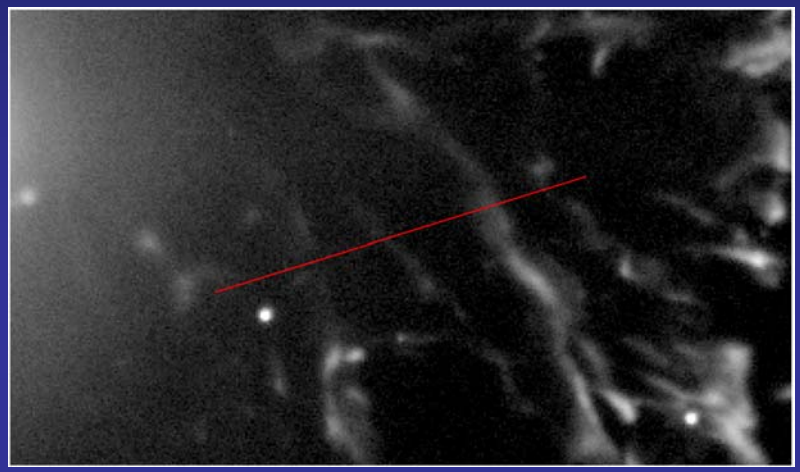
- Detailed analysis of results for the sample.
- Comparison between observed ionization structure and:
  - Photoionization models (CLOUDY and MAPPINGS Ic).
  - Hidrodynamic simulations (YGUAZU)
  - Theoretical models.
- Wavelets Analisys (in progress)

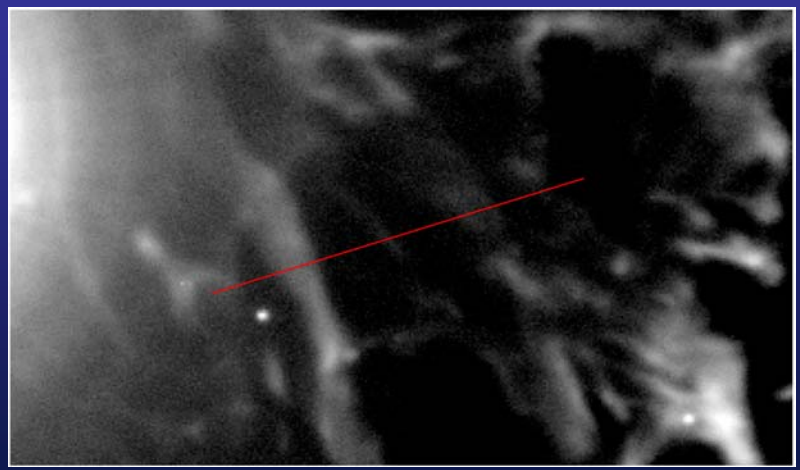
NGC 6543: Spatial Cut

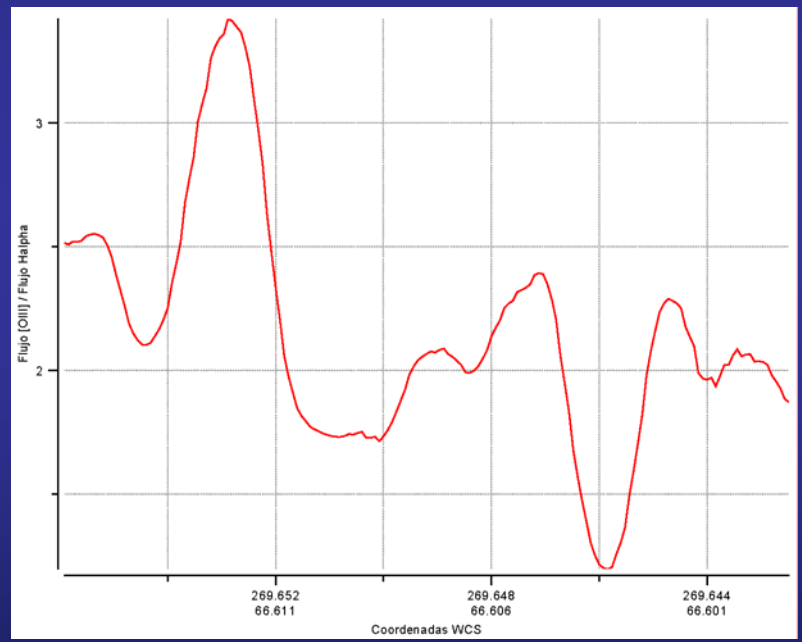




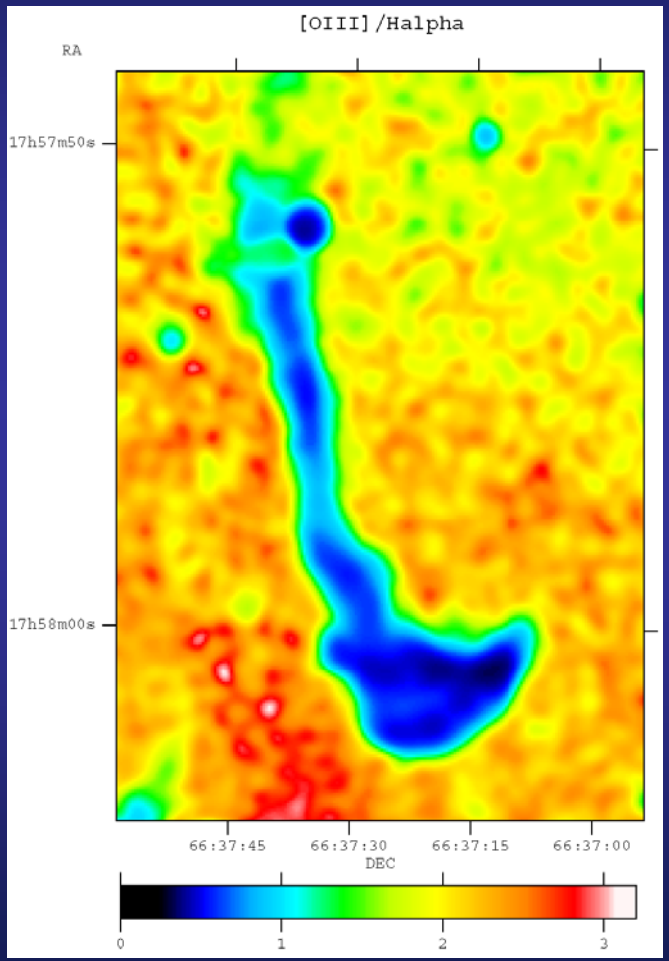
NGC 6543: Spatial Cut

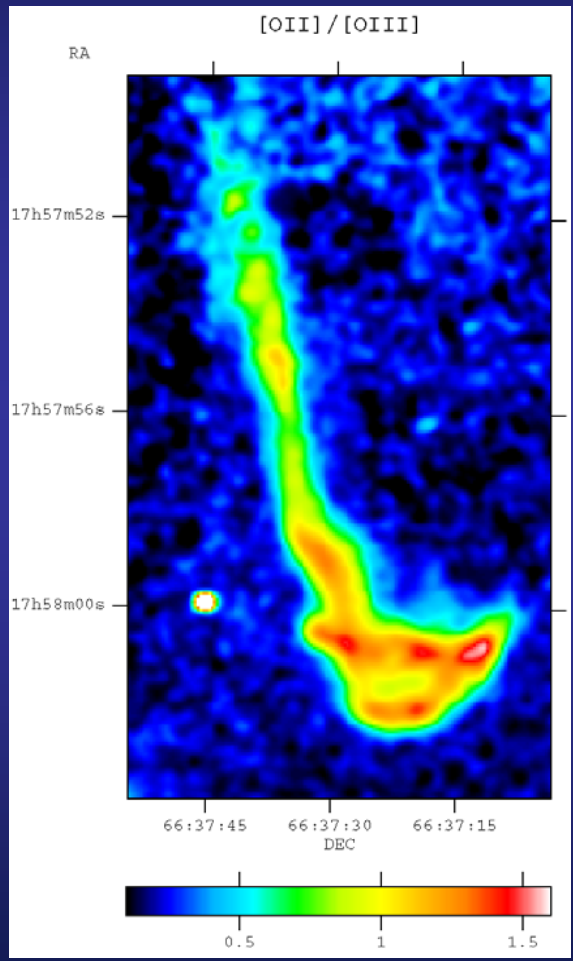




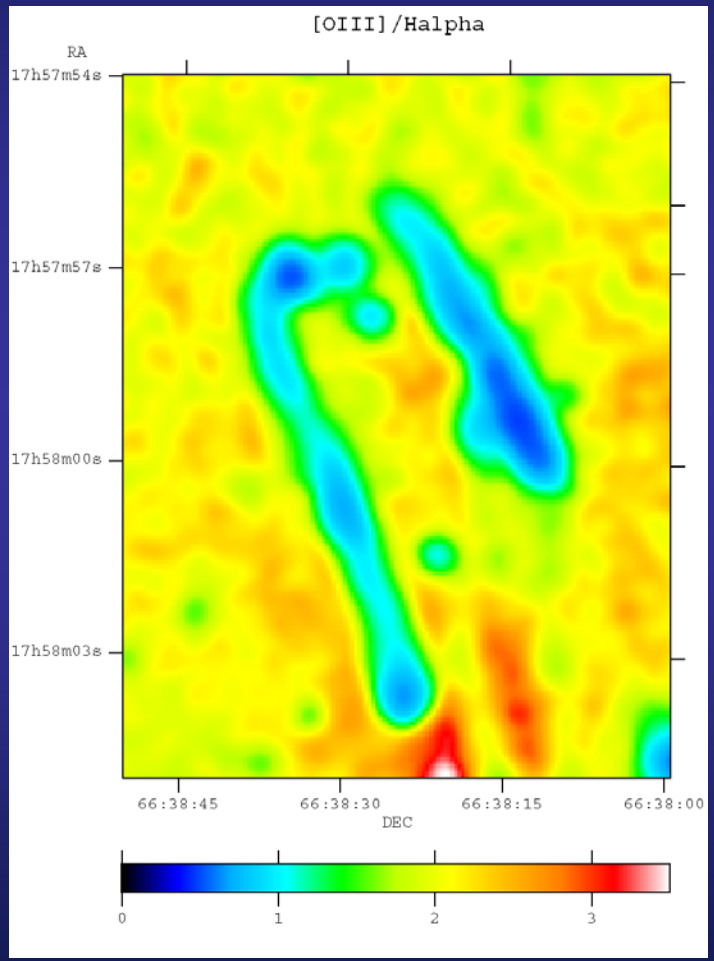


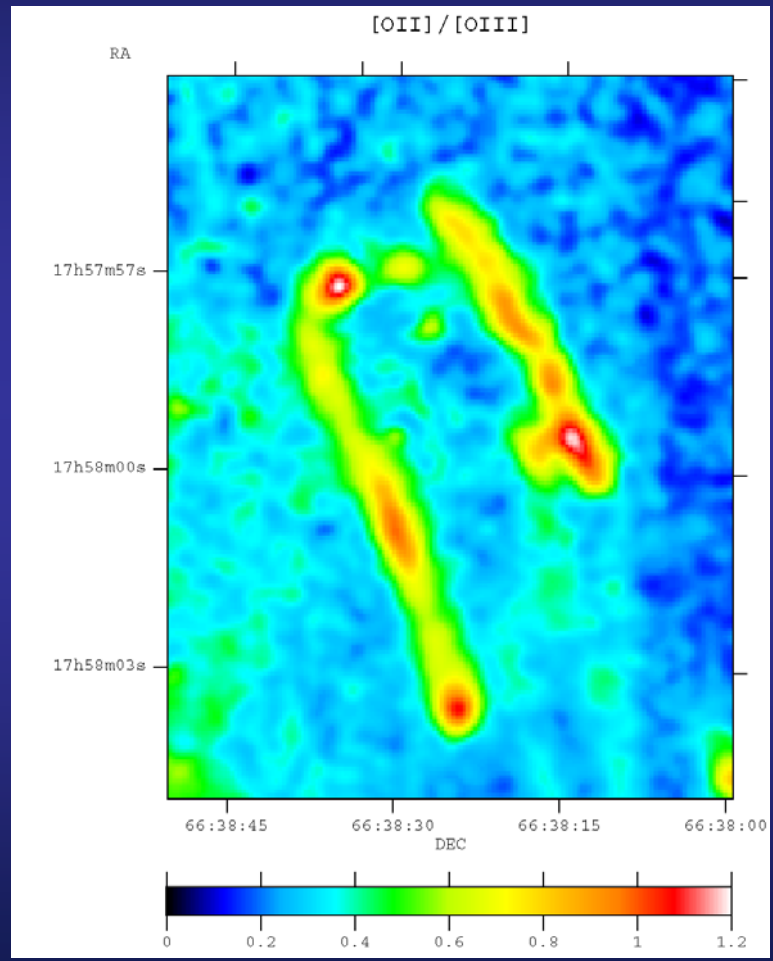
NGC 6543: Quotients



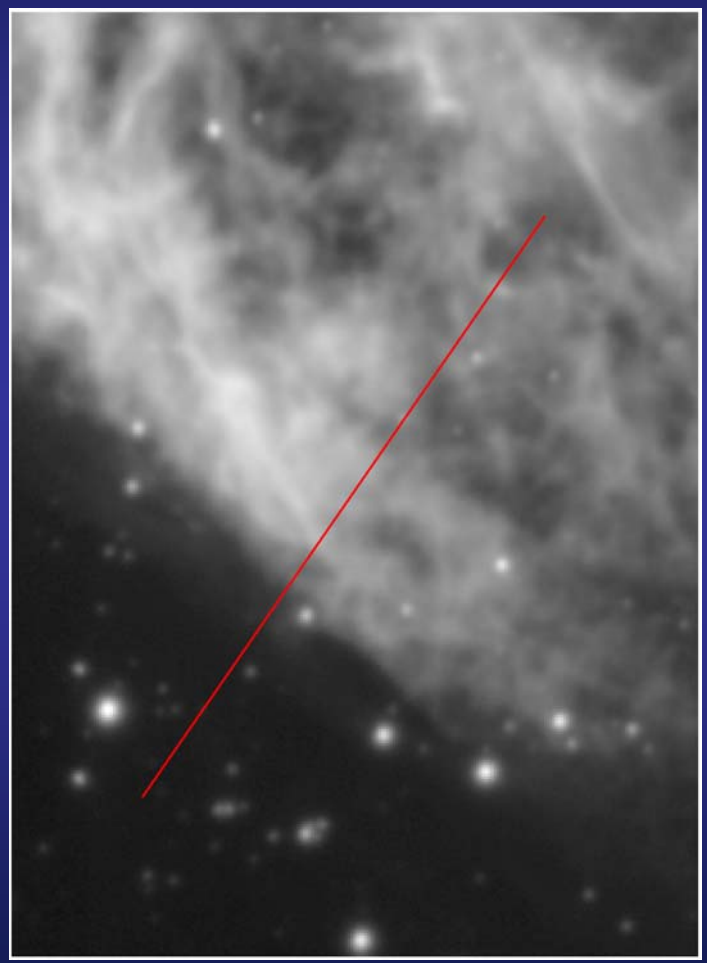


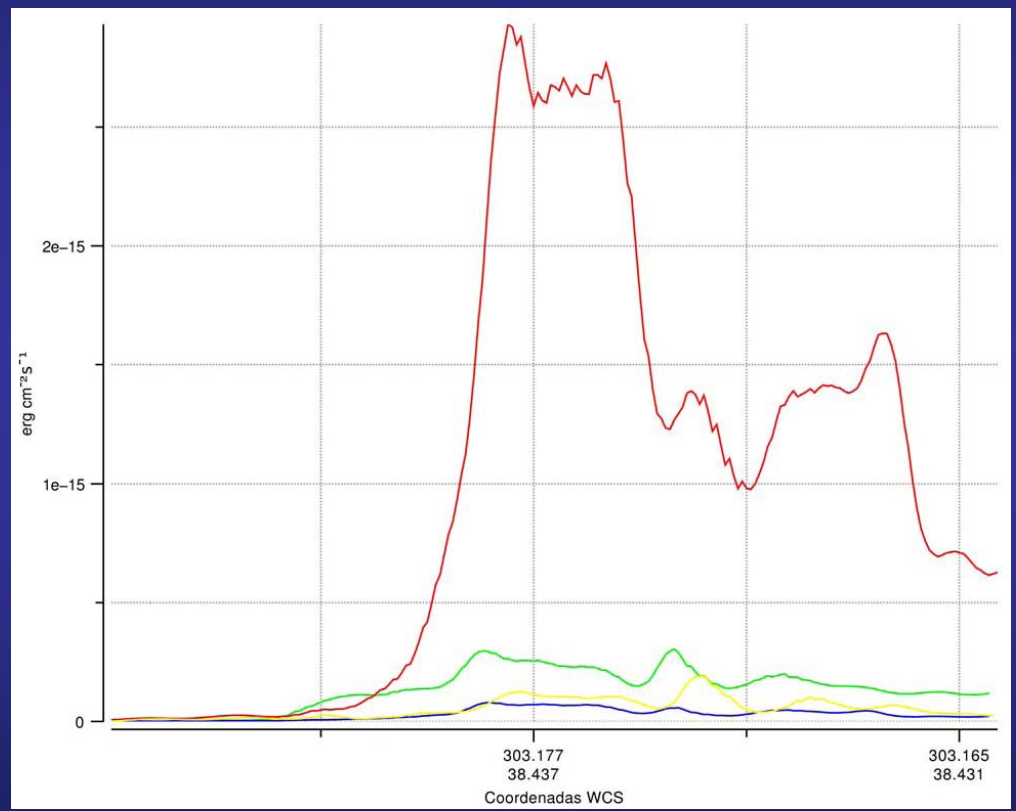
NGC 6543: Quotients



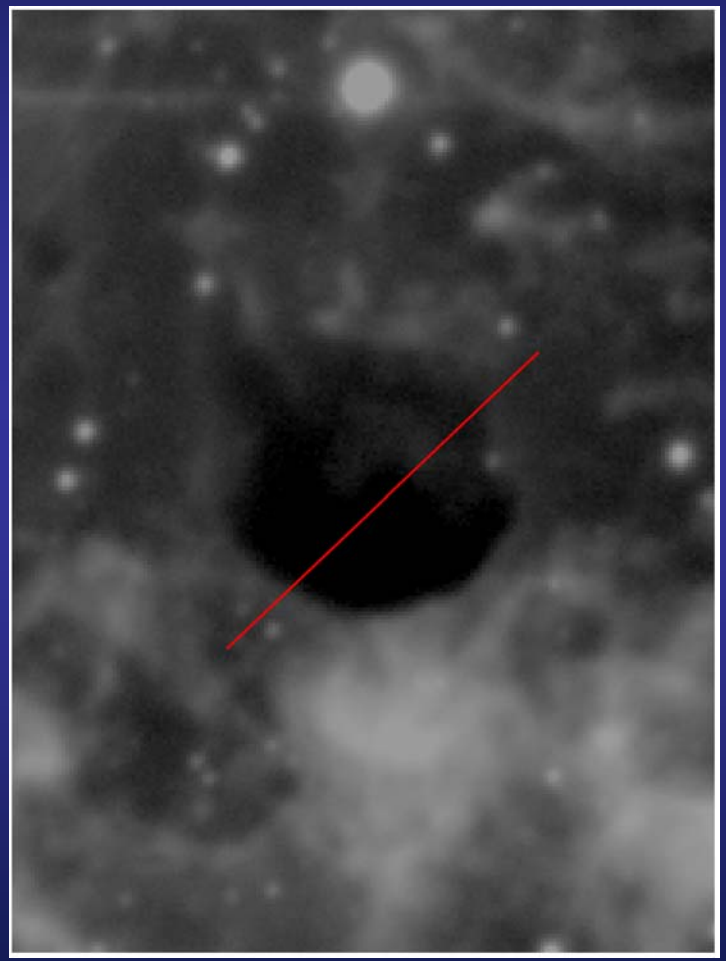


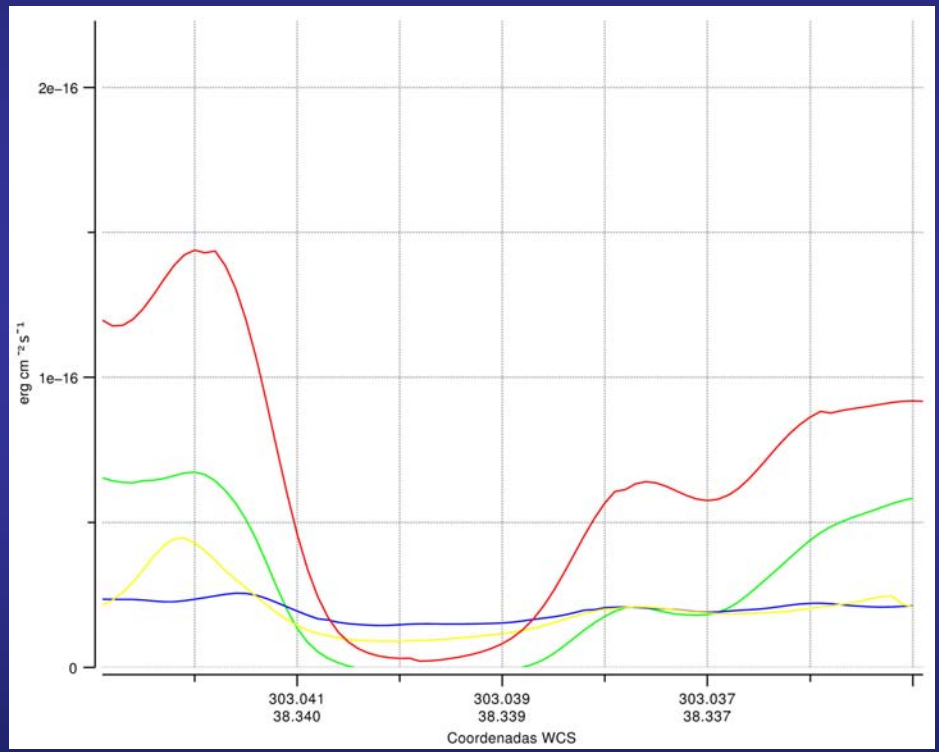
NGC 6888: Spatial Cut



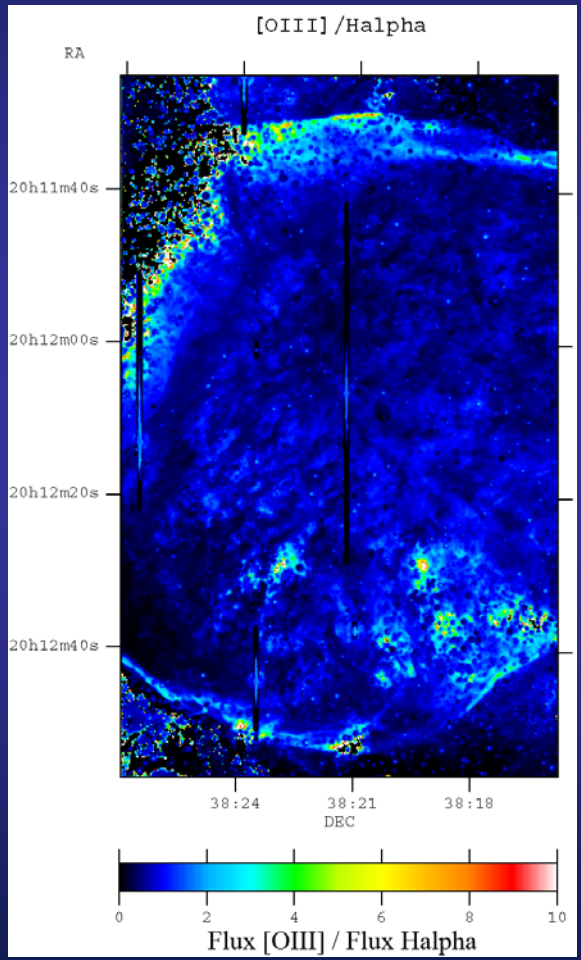


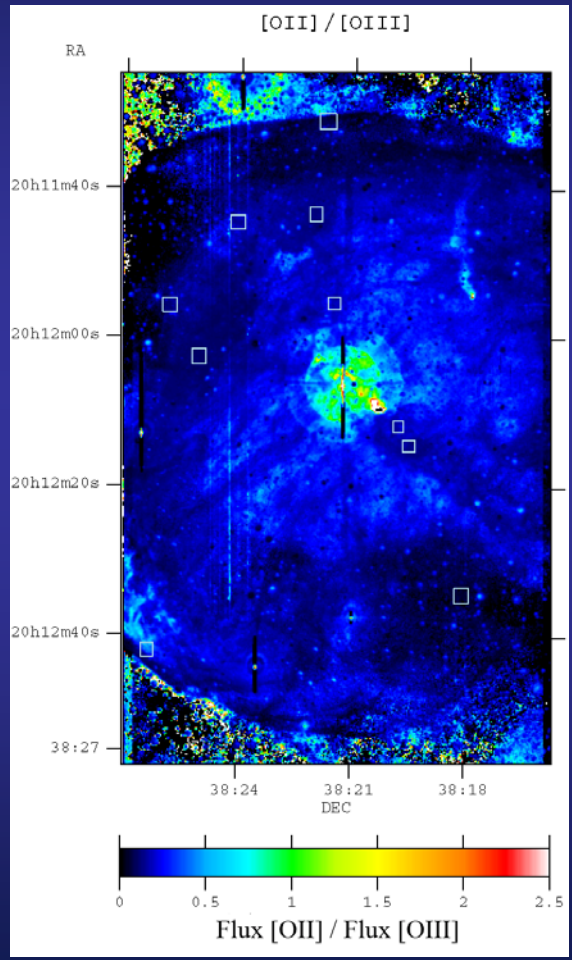
NGC 6888: Spatial Cut





NGC 6888: Quotients





NGC 6888: Quotients

