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The complex structure and peculiar internal motions of the planetary nebula NGC 6210

[1]

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ABSTRACT

A comprehensive kinematic study has been carried out on the planetary nebula (PN) NGC 6210. Multiple long-slits, echelle spectra have been obtained over the face of this nebula mapping its full shell structure, the opposite pairs of extended, twisted arms and the bipolar collimated outflows and bullets. Public *HST* imagery has been used to identify kinematic elements with structural components. The long-slit spectroscopic information has been combined into channel maps that greatly facilitate visualizing the otherwise intricate expansion pattern of this planetary nebula. The global morphology of NGC 6210 is reminiscent of other planetary nebulae with extended X-ray emission, suggesting the presence of a central hot bubble produced by shocked stellar wind. In spite of the dramatic structure of this PN substantial expanding radial motions are only found in the material surrounding the central, inner shell. The slow radial motions of the collimated outflows and the bullet-like knots indicate that they are moving away from the core very close to the plane of the sky, nearly perpendicular to the line of sight

Key words. Planetary Nebulae: individual (NGC 6210) – ISM: kinematics and dynamics – ISM blowout – techniques: imaging spectroscopy

1. INTRODUCTION

NGC 6210 is a bright and relatively large PN in the northern sky. The first photographic image of NGC 6210 was published by Duncan (1937). In this old, fuzzy, image the twisted arms protruding from the bright core of the nebula are apparent. Several studies have discussed possible kinematic models for this object (Osterbrock et al. 1966; Weedman 1968; Becker, Gieseking and Solf, 1984; Icke, Preston and Balick, 1987). None of these studies had both, the spatial coverage and spectral resolution needed to produce a reliable spatio-kinematic model of this PN. More recently, Cuesta & Phillips (1992) obtained 8 long-slits throughout the face of the nebula with but with only limited, medium spectral resolution. From these data and the already available *HST* images at the time they suggested a reasonable kinematic model for NGC 6210. NGC 6210 jumped into fame from the *HST* images obtained K. Borkowski (1996) program No XXX and Robert Rubin (1997-1998) program YYYY. These images showed for the first time the extraordinary complex looking morphology of NGC 6210. Hajian, Terzian and Bignell (1995) derive a distance to NGC 6210 from expansion parallax of xxx whereas . We shall the later distance (GAIA?)

In this work we present the most complete and thorough mapping of all the morphological structures of the PN, obtained at high spectral resolution. These data allow us to disentangle the various spatio-kinematic components and provide and overall view of its evolution.

The planetary nebula NGC 6210 is also known as "the turttle" given its main body and extended arms that resemble the shell of a turttle and its fins. Its very complex structure was revealed by [O 3] and [N 2] images obtained by http://archive.stsci.edu/

In Section 2, we describe our observations and the data-reduction steps, In Section 3 we describe the velocity-channel map of emission. In Section 4, we discuss the radial velocities and proper motions of the nebula. In Seccion 5 we present the discussion and conclusion.

2. OBSERVATIONS AND DATA REDUCTION

Long-slit, echelle, spectroscopic observations of the nebula NGC 6210 were performed with the 2.1 m telescope at the Observatorio Astronómico Nacional at San Pedro Mártir, (OAN-SPM), Baja California, México. We used the Manchester Echelle Spectrometer (MES-SPM) (Meaburn et al. 2003) on the 2.1 m telescope in its $f/7.5$ configuration. The MES-SPM is a long-slit, echelle spectrometer that has no cross-disperser; it isolates single orders using interference filters. For the 2003, 2004 and 2011 of the present observations, we used a SITE-3 CCD detector with 1024 × 1024 square pixels, each 24 μm on a side (≡0.312 arcsec pixel^{-1}). The detector was set to a binning of 2 × 2 in both the spatial and spectral directions. Consequently, 512 increments, each $0''.624$ long gave a projected slit length of $5'.32$ on the sky. A TEK-1 CCD detector was used for the 1998 data set with 1024×1024 pixels^2 with sides measuring 24 μm, using 2×2 binning (≡0.62 arcsec pixel^{-1} and 3.5 km s^{-1}pixel^{-1}). For the 2001 and 2013 we used a Marconi CCD detector with 2048 × 2048 square pixels, each 13.6 μm on a side. The detector was set to a binning of 2 × 2 in both the spatial and spectra directions. Consequently, 1024 increments, each $0''.352$ long gave a projected slit length of $5'.47$ on the sky.

We used a 90 Å and 50 Å bandwidth filter to isolate the 87th and 114th orders containing the $\mathrm{H}\alpha + [\mathrm{N\,2}]\,6584$ and $[\mathrm{O\,3}]\,5007$ Å nebular emission lines, respectively. We used a 70 μm (≡0.95″) slit, giving a velocity resolution of 9.2 km s^{-1} (≡0.312 arcsec pixel^{-1} and 150 μm (≡$1''.9$ and ≡11.5 km s^{-1}) slit.

We obtained 23 consecutive and tightly spaced positions over the NGC 6210. The slit positions are indicated and labeled in Figure 1 on a WFPC 2 image of the NGC 6210 obtained from the HST archive. In order to establish the exact position of the slit in each pointing, the slit position on the sky was recorded with an automatic procedure available in MES-SPM prior to the spectroscopic exposure.

The log of spectroscopy observation is given in Table 1 divided into dates, number of spectra, exposure times, spectral range, resolution, slit wide, position angle and name of the slit (see Figure 1). The high resolution data are available in San Pedro Mártir Kinematic Catalogue of Galactic Planetary Nebulae (http://kincatpn.astrosen.unam.mx) (López et al. 2012).

Due to saturation of several slit positions on the nebula, we obtained a new set of observation on August 13, 2015. We used the same detector as that used for the 2015 dataset, which was a E2V-4240 (Marconi 2) detector with 2048×2048 pixels^2 with sides measuring 13.5 μm, using 2×2 binning (≡0.531 arcsec pixel^{-1}. Spectra were obtained at 11 different positions across the nebula, with exposure times of 1800 seconds. The slit was oriented N-S.

An additional slit was placed outside the nebula to detect The outer halo of NGC 6210. The observation was carried out on 18 September 2019. The spectrum was obtained in order 87 (H alpha and [N II] lines) with the 150 micron slit oriented at position angle of 56 degrees. The detector was an E2V 2048x2048 CCD with 13.5 μ/pix used in binning 3×3. The spectral dispersion was 0.084 Å/pix and the plate scale 0.175″/pixel.

The characteristics of the observations are listed in Table 2.

All data was reduced (bias removal and cosmic-ray removal) by using standard IRAF[1]. This was followed by rectification and first-order wavelength calibration of the two-dimensional spectra based on the comparison the spectrum of a Th/Ar lamp to an accuracy of ±1 km s^{-1} when converted to radial velocity. All spectra presented in this paper are corrected to heliocentric velocity ($V_{\rm hel}$). The Figure 3 shows the position-velocity (P-V) arrays of Hα 6563 Å [N 2] 6584 , [O 3] 5007 Å, respectively, where the heliocentric velocities are used, and positions are specified as arcsecond offsets (x,y).

Using FORTRAN and phython routines, we produced velocity cubes in [N 2] 6584 and [O 3] emission lines, in order to ...

The resulting data cubes for the Hα 6563 Å and [N 2] 6584 lines are shown in Figure 3 as isovelocity channel maps, each isovelocity map is 20 km s^{-1} wide.

3. KINEMATICS

The Figure 3 shows the Hα 6563 Å, [O 3] 5007 Å, and [N 2] 6584 velocity arrays, P–V, for all individual slit position, observed on 2015 epoch: Hα P–V is shown on the left panel, on the middle panel is the corresponding [O 3] 5007 Å P–V and [N 2] 6584 on the right panel. Spatial offsets are in arcseconds. The stellar continuum from the central star has not been subtracted. We derive a heliocentric systemic velocity, $V_{\rm sys}$= 40 km s^{-1} by using the slits position f (epoch 2003) and which passes through the central star. The expansion velocity of the inner shell, v$_{exp}$ = 28 km s^{-1}.

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science foundation

4. PROPER MOTIONS

4.1. Hubble Space Telescope Data

The data used in this study to measure the proper motions of the turttle nebula consist of images which were retrieved from the HST archive. The [N 2] observations were made in two separate observing runs: on 1998 June 30, as part of program 7501, with Hajian, Arsen R., as PI. During this run, six images were obtained with the WFPC2, with an exposure time of 100 s (three images) y 40 s (three images) using the F658N filter. The second-epoch data were obtained on 2008 January 18, from the science program 11122, with Bruce Balick, as PI, who employed the same configuration as in program 7501 to acquire three images with the F658N filter, using 400 s exposure times for all of them. For all of the images, we used the drizzled images (processed with Astrodrizzle).

Table 1. Log of Time-resolved Observations of **NGC 6210**.

	Spectroscopy hight resolution/ 2.1m OAN-SPM						
Run	Exp. Time	Range	slit	P. A.	slit		
DD/MM/YYYY	frame	(s)	(Å)	(Å)	(mμ)	(degree)	name
28/06/1998	30	Hα	150	90	o		
28/06/1998	300	Hα	150	90	n		
28/06/1998	1200	Hα	150	90	m,p,q		
05/06/2003	1800	Hα	70	0	f,e,d,h,i,k,b		
16/10/2003	1800	Hα	70	−21	t		
16/10/2003	1800	Hα	70	−68	v		
17/10/2003	1800	Hα	70	77	w		
13/06/2004	1800	O III	70	−9	r		
13/06/2004	1800	O III	70	−19	s		
14/06/2004	1800	S II	150	−19	s		
13/06/2004	1800	O III	70	−56	u		
14/06/2004	1800	O III	150	0	a,l		
21/05/2011	1800	Hα	150	0	g		
21/05/2011	600	O III	150	0	g		
06/07/2013	1800	Hα	150	0	c,i,j		
20/08/2005	3	1800	Hα, [OIII]	0.26	70	0	h, j, k

Table 2. Log of Time-resolved Observations of **NGC 6210**. Epoch 2015

	Spectroscopy hight resolution/ 2.1m OAN-SPM						
Run	Exp. Time	Range	slit	P. A.	slit		
DD/MM/YYYY	frame	(s)	(Å)	(Å)	(mμ)	(degree)	name
18/08/2015	1800	Hα, [OIII]	70	0	c, d, e, f, g		
19/08/2015	1800	Hα, [OIII]	70	0	b, a, i		
19/08/2015	1800	Hα	70	0	b, a, i		
18/09/2019	1800	Hα	150	56			

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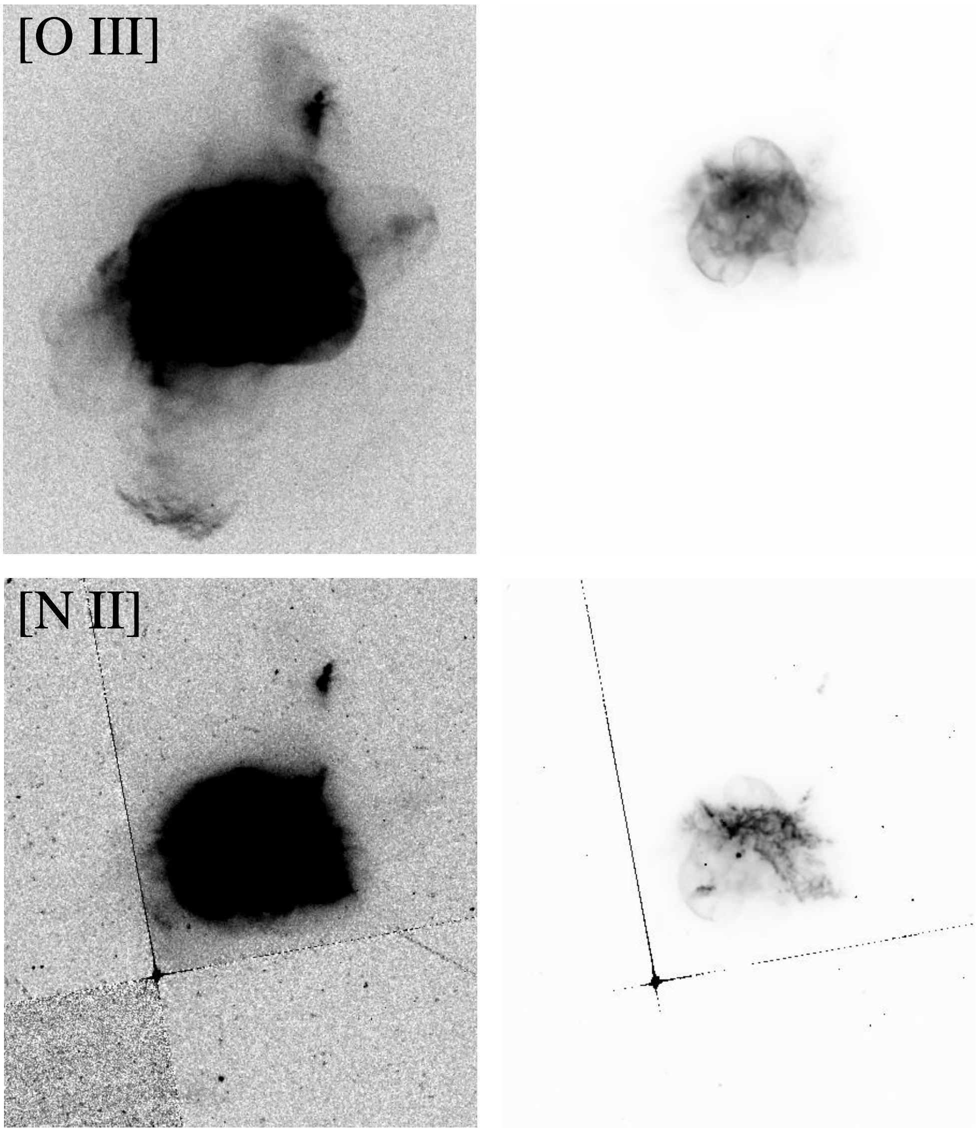


Fig. 1.

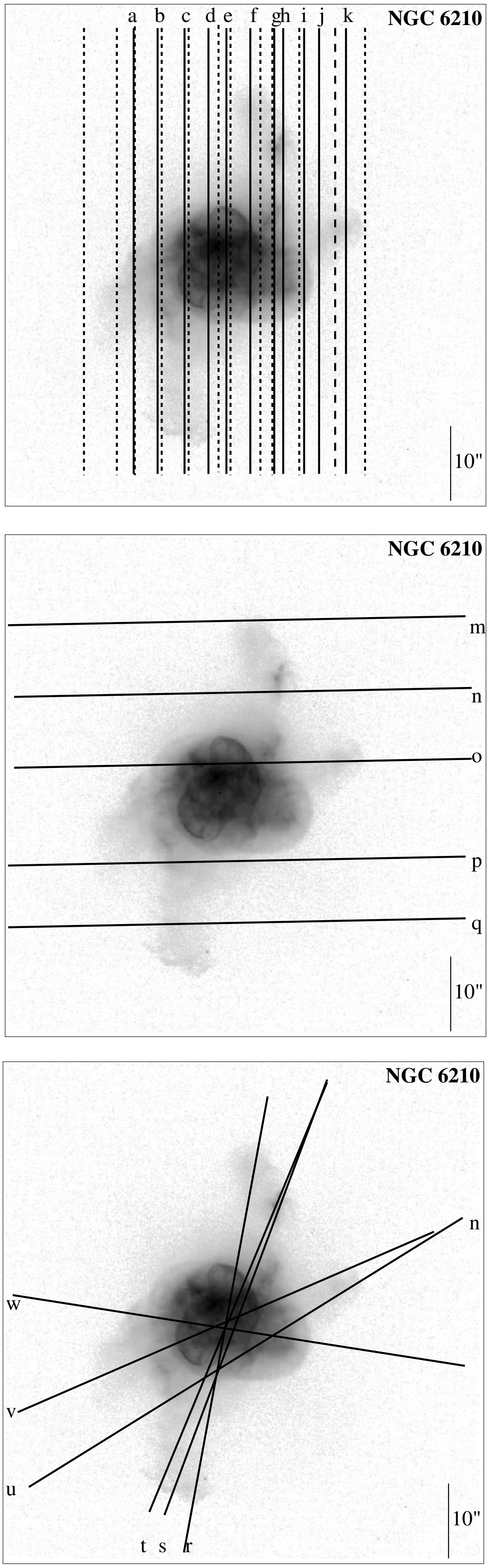

a b c d e f g h i j k
NGC 6210
10"
NGC 6210
m
n
o
p
q
10"
NGC 6210
n
w
v
u
t s r
10"

Fig. 2.

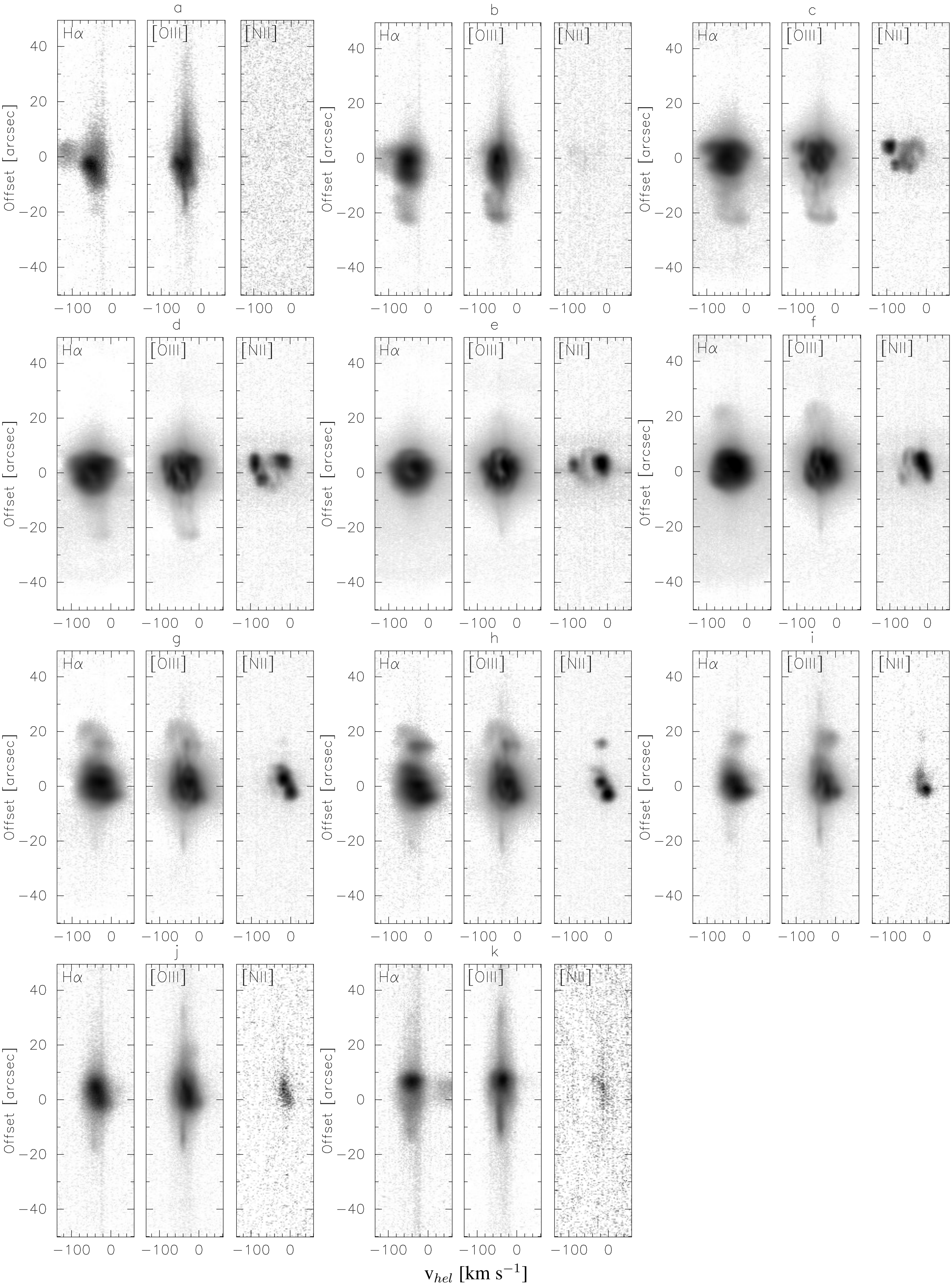

a
b
c
d
e
f
g
h
i
j
k
Hα
[OIII]
[NII]
Offset [arcsec]
40
20
0
−20
−40
−100
0
v$_{hel}$ [km s^{-1}]

Fig. 3.

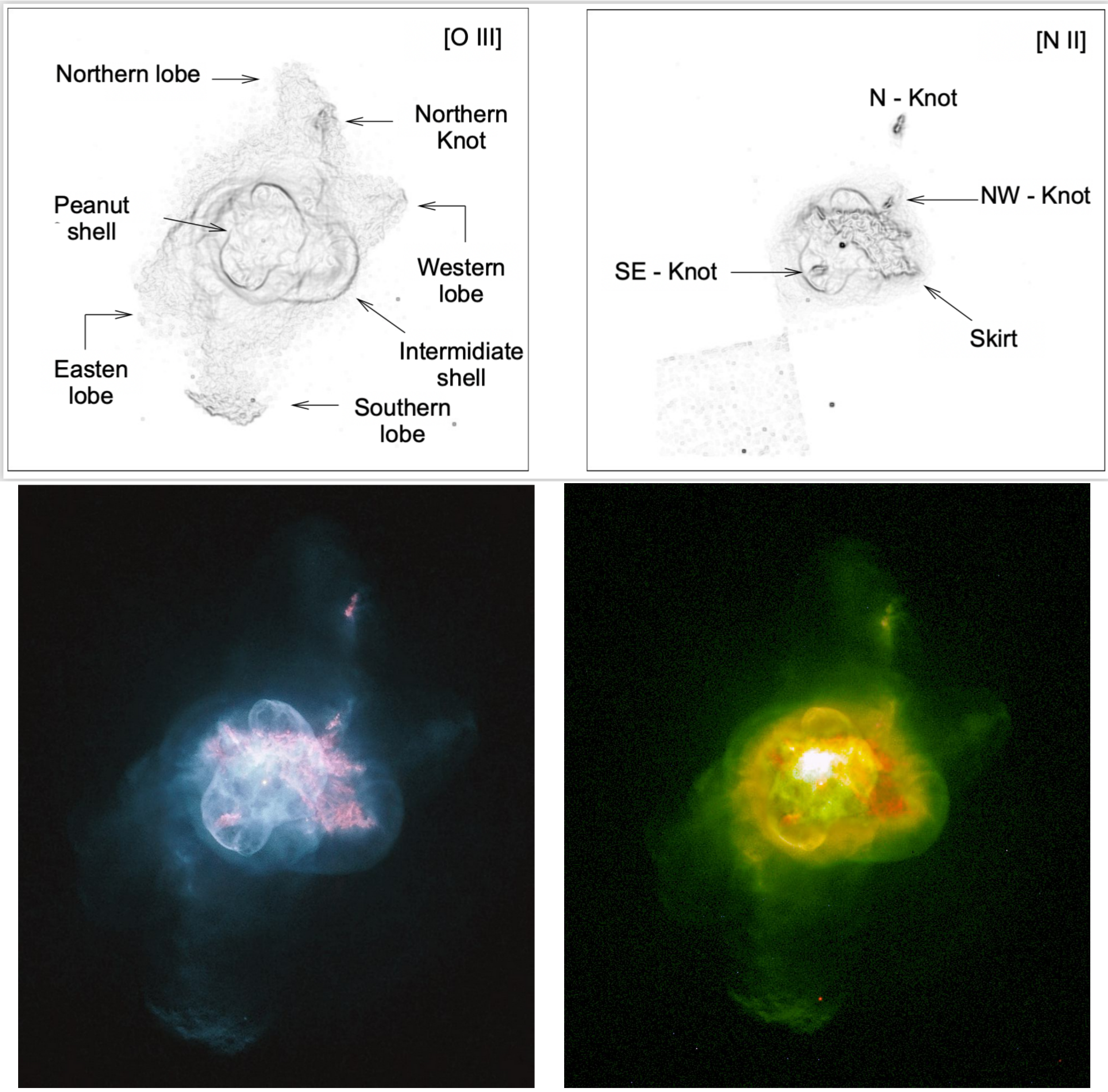
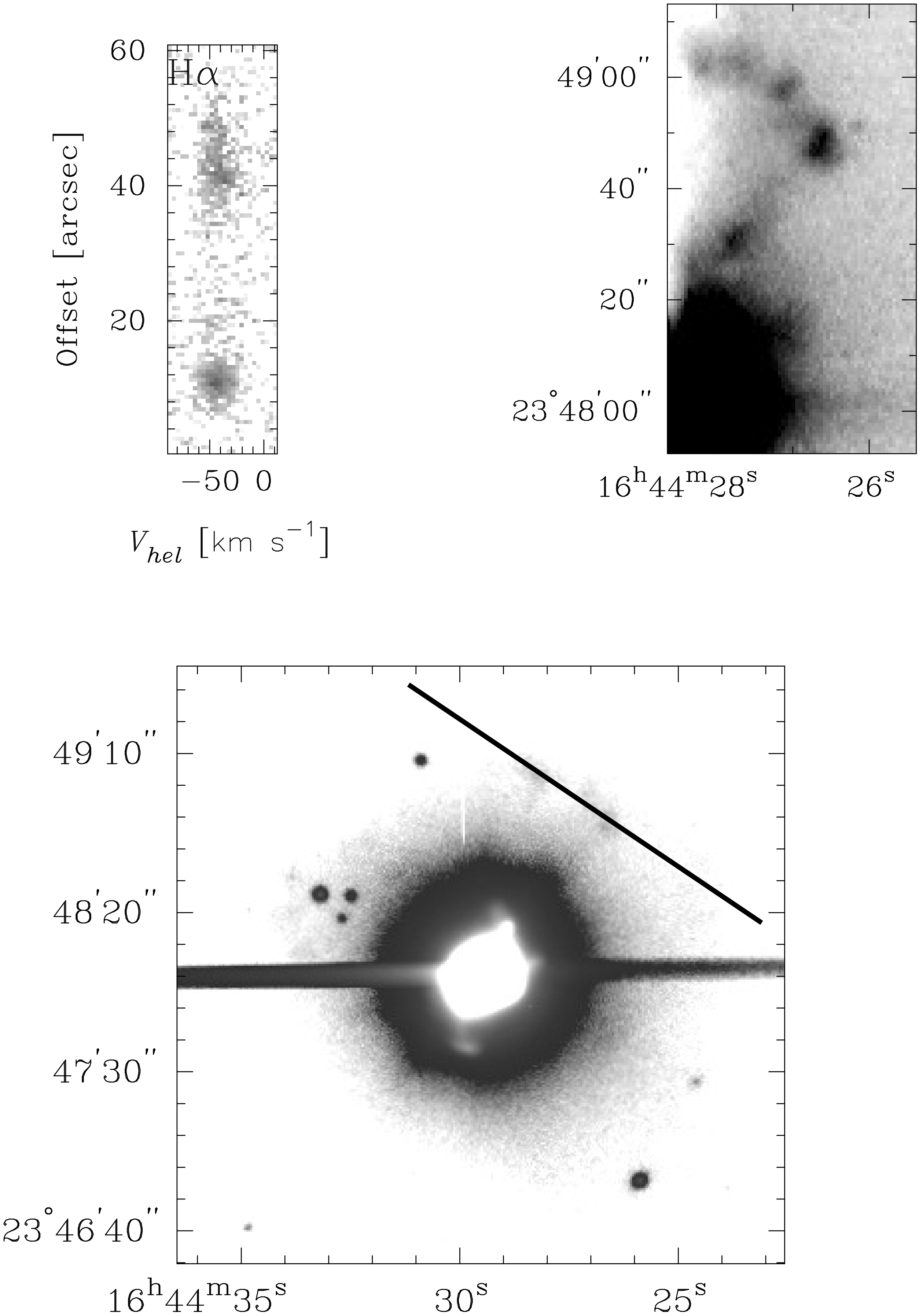

[O III]
Northern lobe
Northern Knot
Peanut shell
Western lobe
Easten lobe
Intermidiate shell
Southern lobe
[N II]
N - Knot
NW - Knot
SE - Knot
Skirt

Fig. 4.



Hα
Offset [arcsec]
60
40
20
−50 0
V_{hel} [km s^{-1}]
49′00″
40″
20″
23°48′00″
16h44m28s
26s
49′10″
48′20″
47′30″
23°46′40″
16h44m35s
30s
25s

Fig. 5.

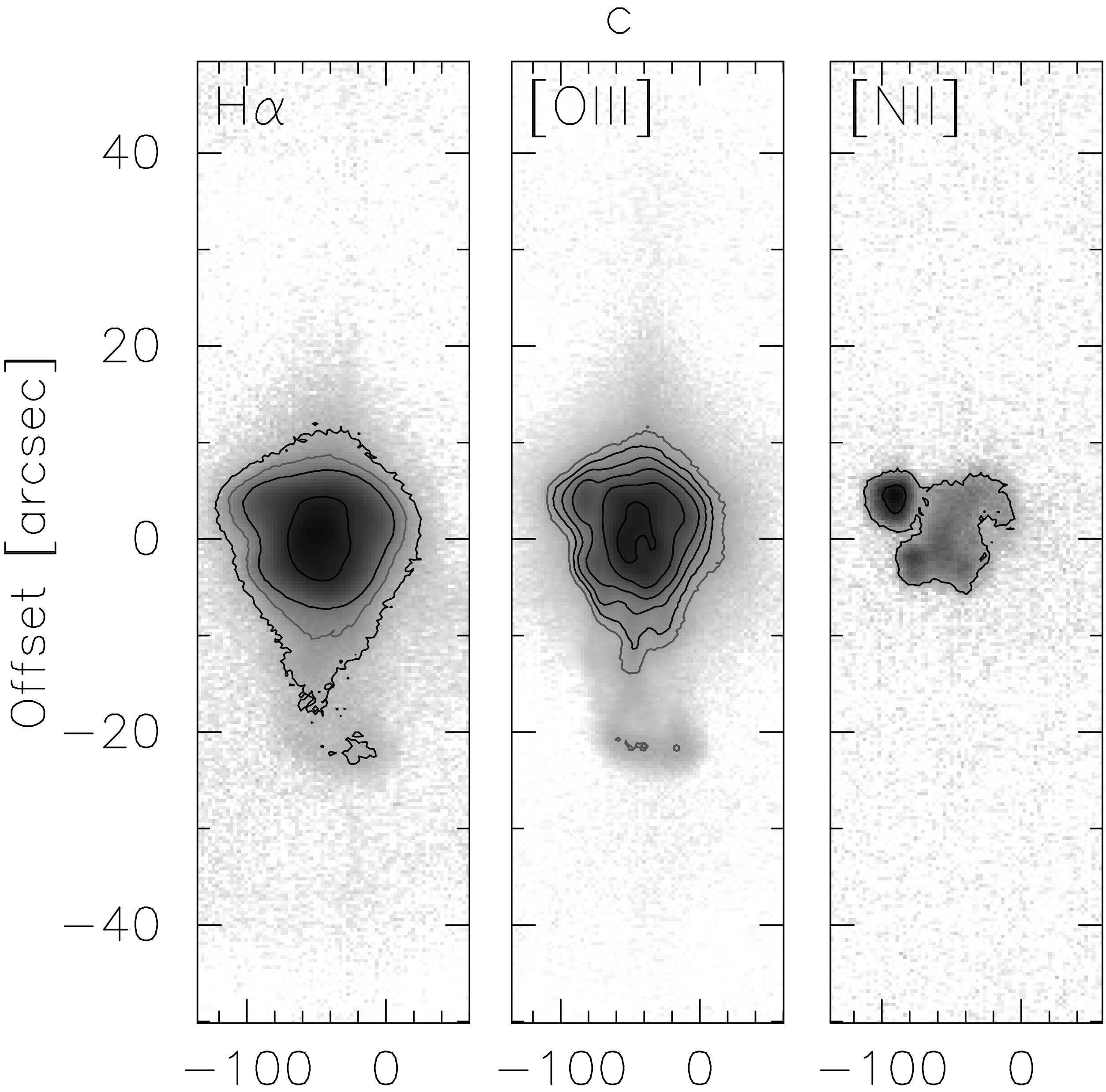


Fig. 6.

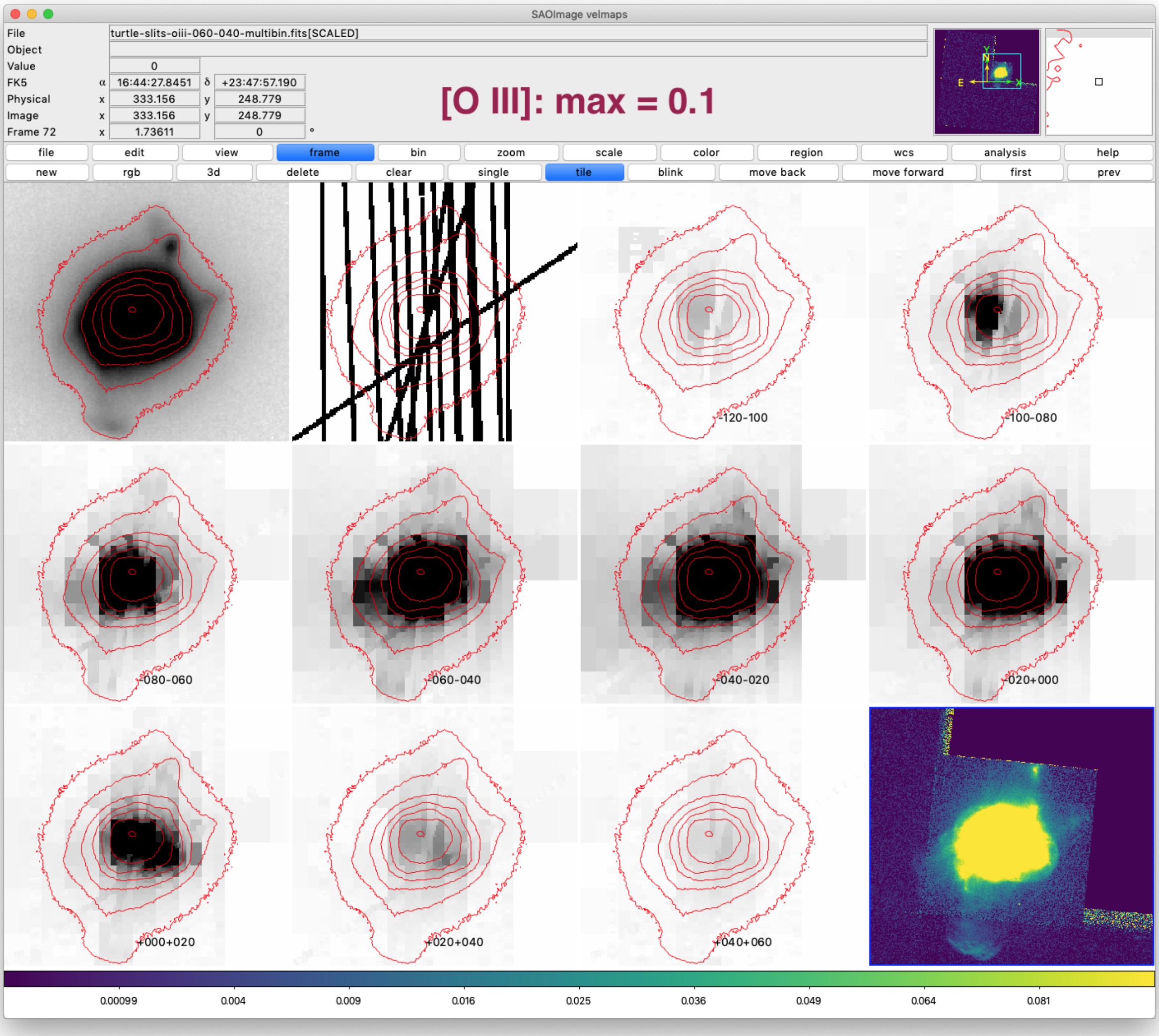
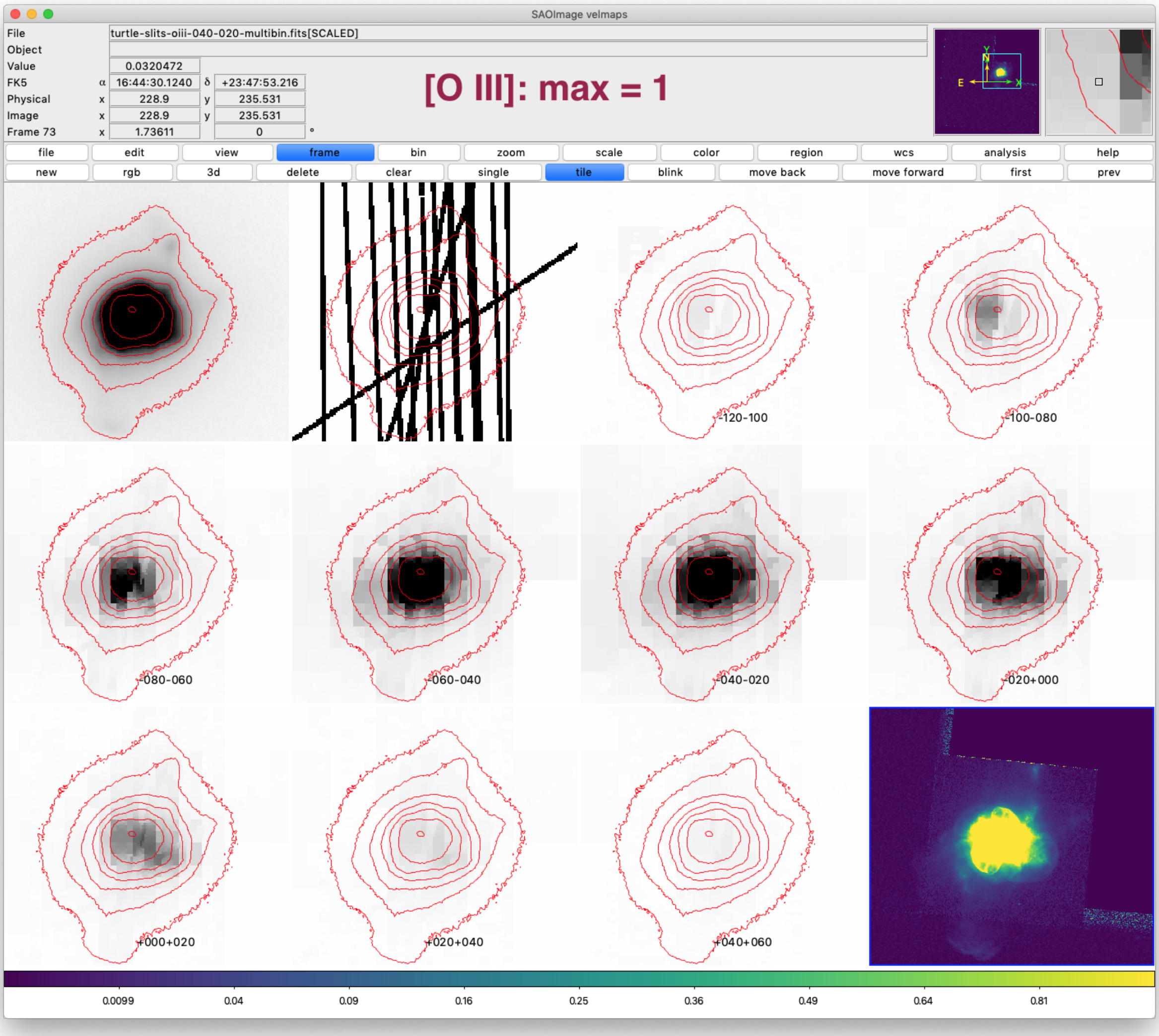


Fig. 7. los canales son de 20 km/s, con límites heliocéntricos marcados. El panel 1 es la imagen mediana de [O III] construida de todas las exposiciones I+S. El panel 2 muestra las posiciones de las rendijas, que te da una idea de la resolución efectiva en RA. Y el último, en color, es la imagen HST en [O III]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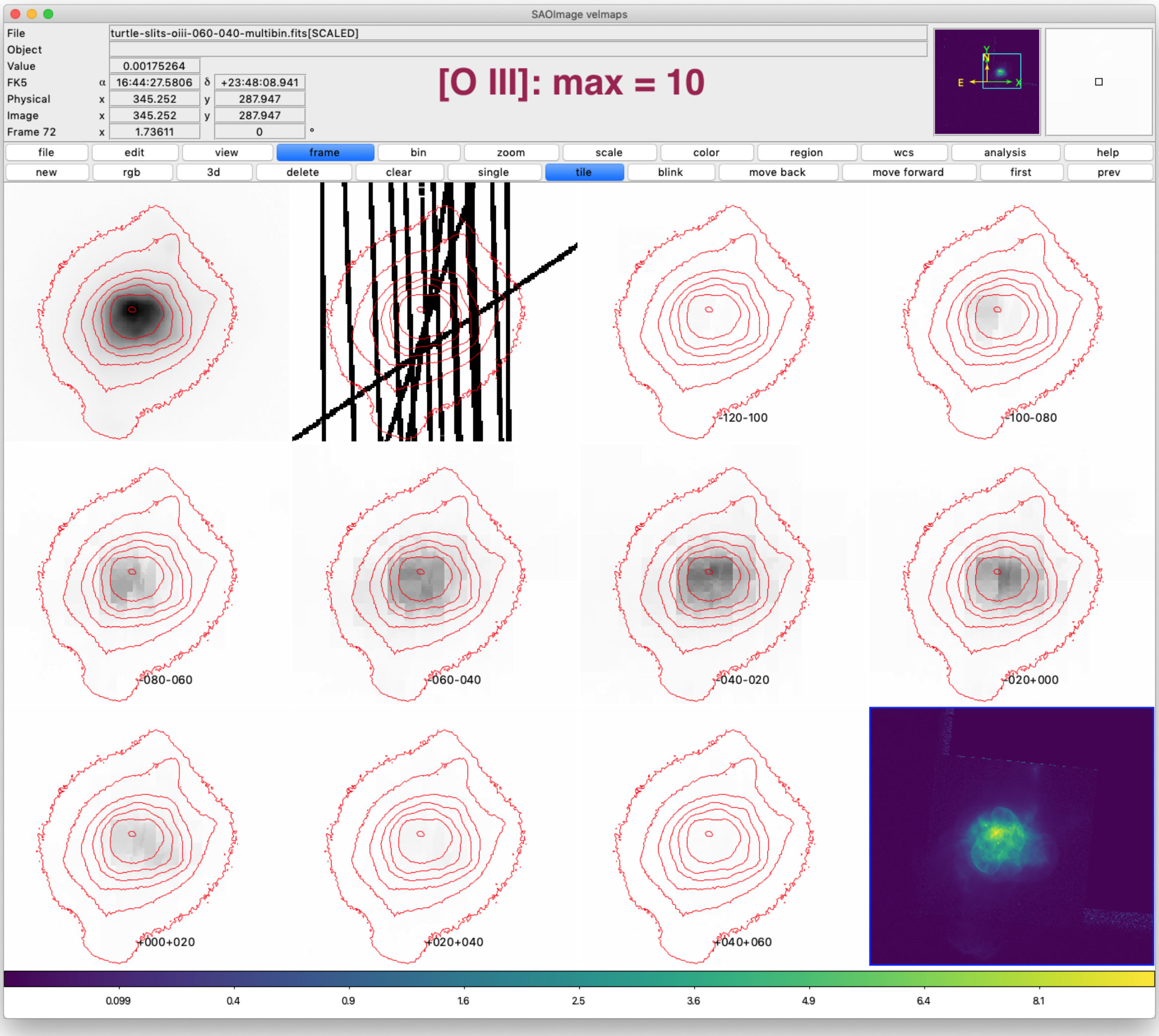
File turtle-slits-oiii-040-020-multibin.fits[SCALED]
Object
Value 0.0320472
FK5 α 16:44:30.1240 δ +23:47:53.216
Physical x 228.9 y 235.531
Image x 228.9 y 235.531
Frame 73 x 1.73611 0 °
[O III]: max = 1
file edit view frame bin zoom scale color region wcs analysis help
new rgb 3d delete clear single tile blink move back move forward first prev
-120-100
-100-080
-080-060
-060-040
-040-020
-020+000
+000+020
+020+040
+040+060
0.0099
0.04
0.09
0.16
0.25
0.36
0.49
0.64
0.81

Fig. 8.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FK5
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+23:48:08.941
Physical
345.252
287.947
Image
345.252
287.947
Frame 72
1.73611
0
[O III]: max = 10
file
edit
view
frame
bin
zoom
scale
color
region
wcs
analysis
help
new
rgb
3d
delete
clear
single
tile
blink
move back
move forward
first
prev
-120-100
-100-080
-080-060
-060-040
-040-020
-020+000
+000+020
+020+040
+040+060
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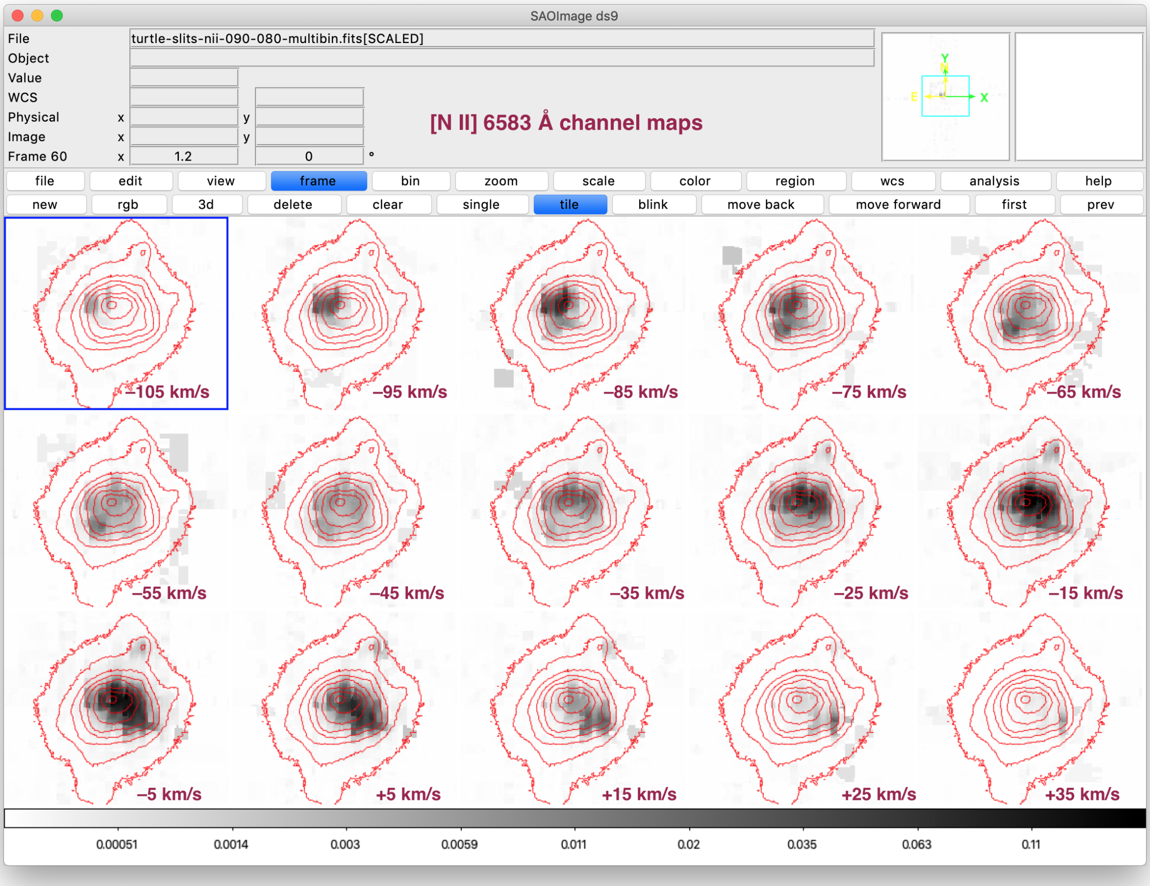
0.4
0.9
1.6
2.5
3.6
4.9
6.4
8.1

Fig. 9.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turtle-slits-nii-090-080-multibin.fits[SCALED]
Object
Value
WCS
Physical
Image
Frame 60
1.2
0
[N II] 6583 Å channel maps
file
edit
view
frame
bin
zoom
scale
color
region
wcs
analysis
help
new
rgb
3d
delete
clear
single
tile
blink
move back
move forward
first
prev
−105 km/s
−95 km/s
−85 km/s
−75 km/s
−65 km/s
−55 km/s
−45 km/s
−35 km/s
−25 km/s
−15 km/s
−5 km/s
+5 km/s
+15 km/s
+25 km/s
+35 km/s
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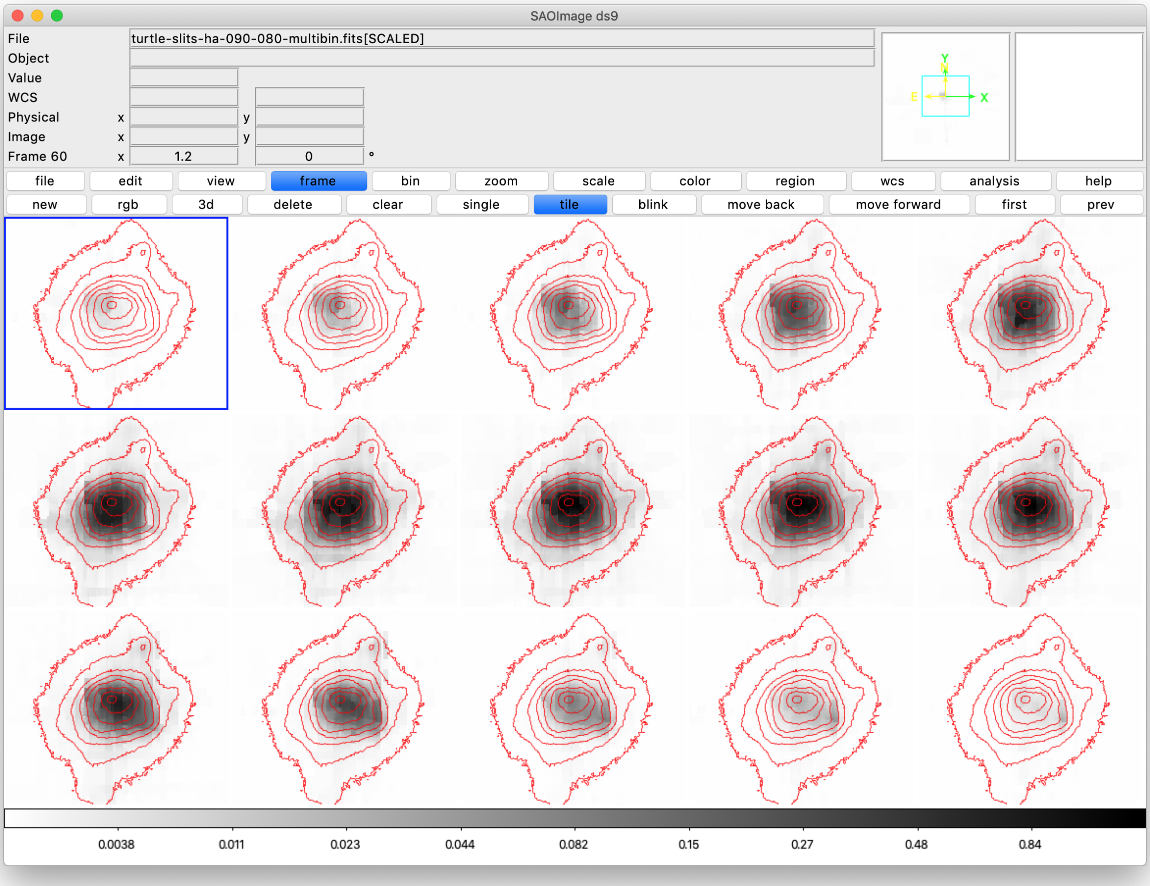
0.0014
0.003
0.0059
0.011
0.02
0.035
0.063
0.11

Fig. 10.


SAOImage ds9
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Object
Value
WCS
Physical x y
Image x y
Frame 60 x 1.2 0 °
file edit view frame bin zoom scale color region wcs analysis help
new rgb 3d delete clear single tile blink move back move forward first prev
0.0038 0.011 0.023 0.044 0.082 0.15 0.27 0.48 0.84

Fig. 11.

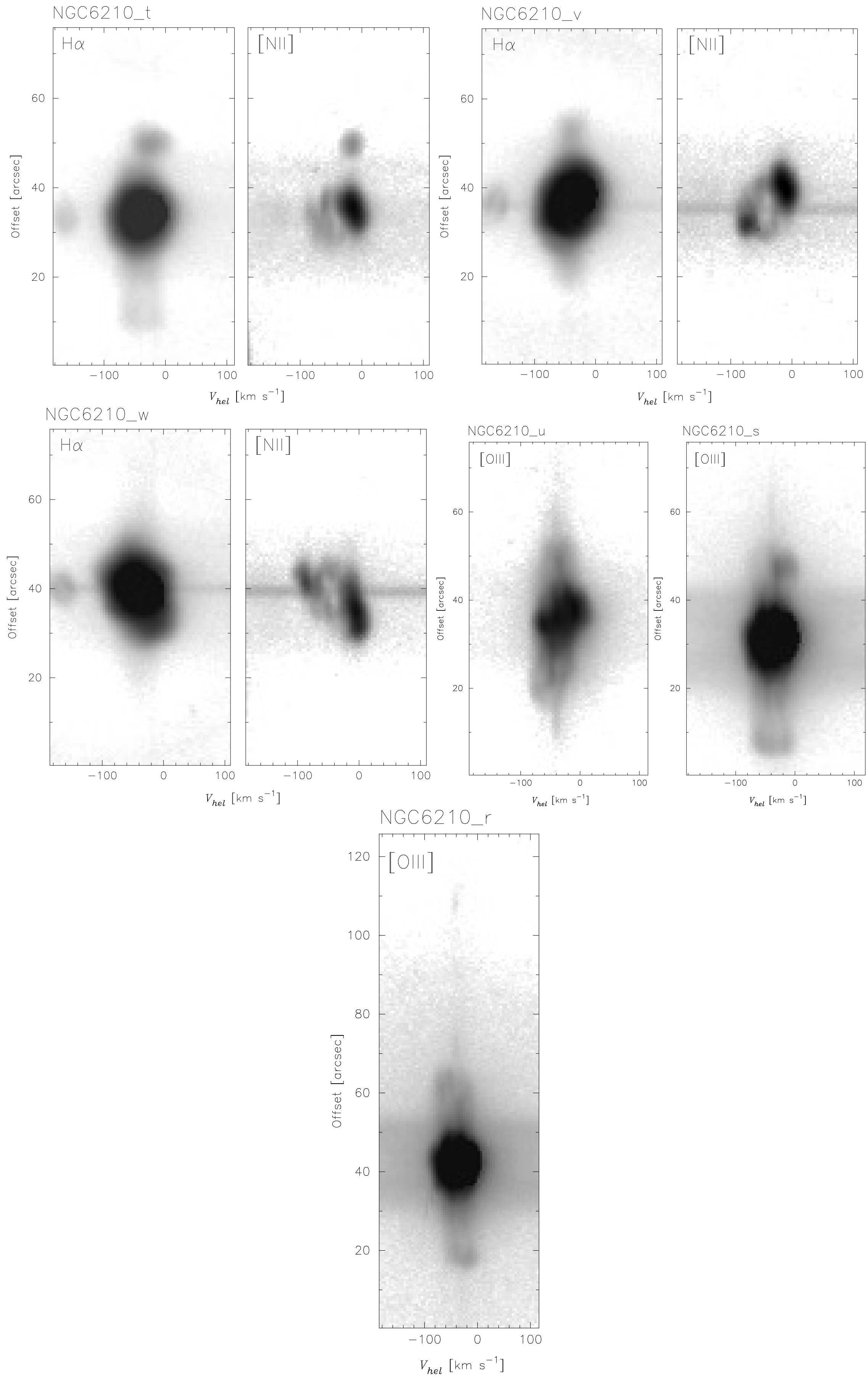
NGC6210_t
Hα
[NII]
NGC6210_v
Hα
[NII]
NGC6210_w
Hα
[NII]
NGC6210_u
[OIII]
NGC6210_s
[OIII]
NGC6210_r
[OIII]
Offset [arcsec]
V_{hel} [km s^{-1}]

Fig. 12.