Spatio-kinematics of the optical nebula M1-92 with HST/STIS

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Abstract

We report optical long-slit spectroscopy with **HST/STIS** of the well known pre-Planetary Nebula (pPN) **M1-92** (a.k.a. **Minkowski's footprint**). Long-slit echelle spectra with **Keck II+ESI** are also presented. We have used our **high-angular (~0.1'') resolution *HST* spectra** to characterize the spatio-kinematic structure of the optical nebula. From the analysis of the H_α (2D) profile we identify several distinct nebular components at different spatial scales. The blue-shifted absorption component of the broad 'P Cygni'-like profile of the H_α line is spatially and spectrally resolved and is found to be composed of not one but two different features centered at **V_{LSR}~-600 and -200 km/s**. To assist in the interpretation of the data, we have used a simple **spatio-kinematic model** which has allowed us to describe the main properties of the **fast, bipolar wind** (expanding with velocities of up to **~650 km/s**) running inside the reflection lobes of M1-92 that produces the absorptions. At the nebula center, we also discover an **equatorially extended H_α emitting region** that is **expanding** at moderate velocity **(<~100 km/s)** in the direction perpendicular to the lobes. We have estimated the column density of the inner post-AGB winds and other physical parameters needed for improving our understanding of the evolutionary history of M1-92.

Table 1

Luminosity ($L_\odot$)	Distance (kpc)	Mass CO ($M_\odot$)	Kinematical age (yr)
10^4 (1)	2.5 (1)	1 (3)	900 (3)

(1) Cohen &Kuhi (1977), (2) Solf, J. (1994), (3) Bujarrabal& Alcolea (1998)

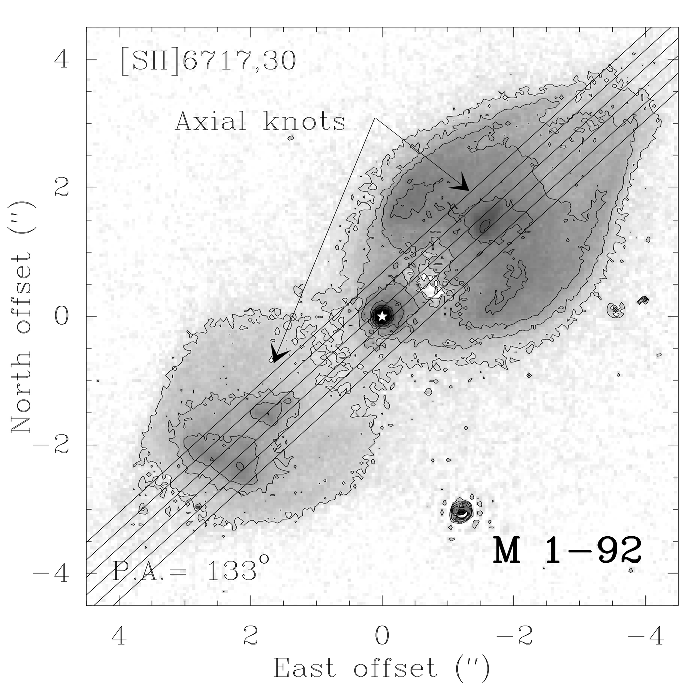
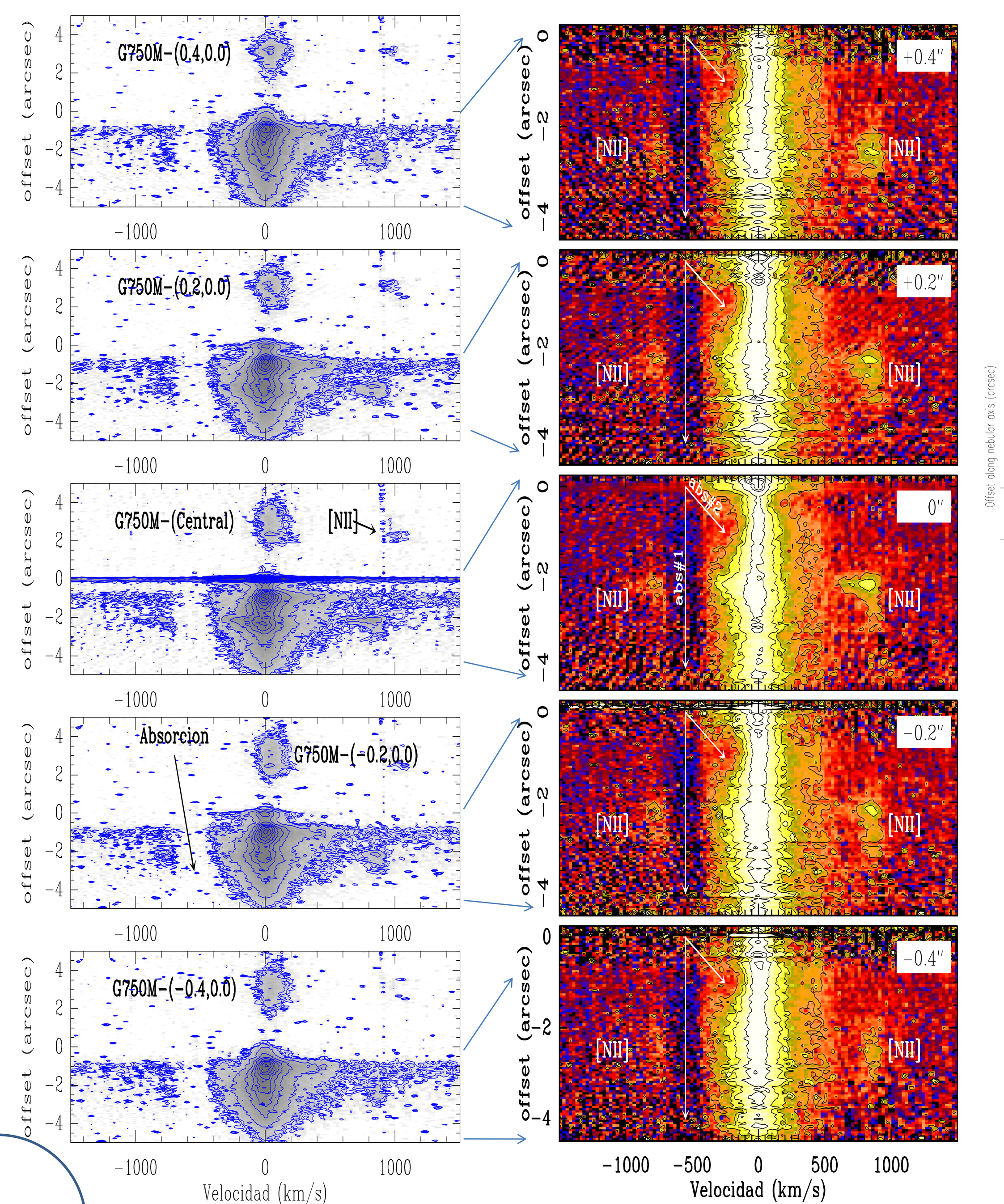


Fig. 1. *HST*-[SII]6717 image of the pre-PlanetaryNebula M 1-92. The brightest lobe (North) is approaching to us. The five slit positions used for HST/STIS spectroscopic observations are overplotted.



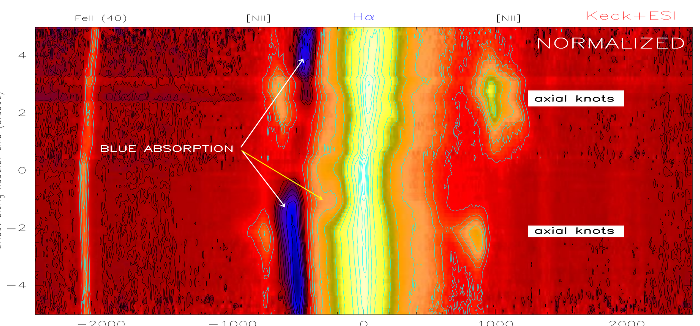


Fig. 2. Left) **Long-slitspectra** taken with HST/STIS centered on H_α. Right) H_α spectra normalized to the scattered continuum in the bright lobe. Note the **two** blue-shifted absorption features (abs1 and abs2). **Bottom panel:** normalized **Keck** spectrum around H_α. The **blue-shifted absorption abs1** is observed in BOTH the bright and the **faint lobe. abs2 is only identified in the bright (approaching) lobe.**

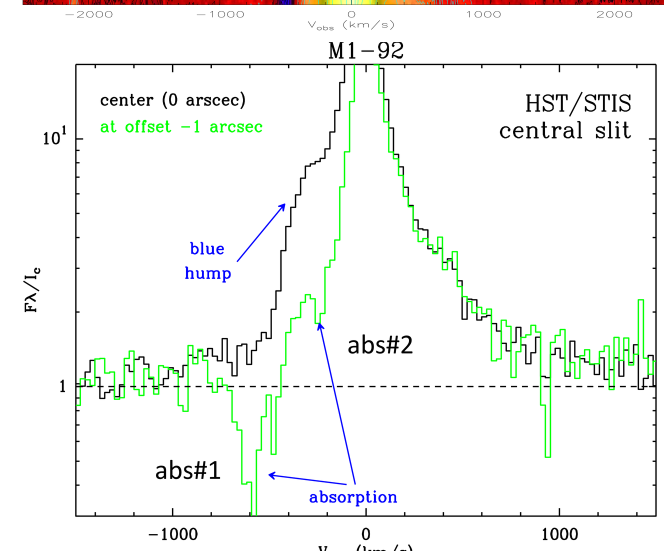


Fig. 3. 1D spectra extracted in a ~0.1''-wide region towards the nebula center (where the stellar continuum peaks; black line) and at offset -1'' in the bright lobe (green).

II. Results

We detect extended H_α emission from the reflection lobes. **P-Cygni** like absorption profiles are observed towards both lobes (**bright NW lobe** and **faint SE lobe**) but not towards the central star (Fig 2).

*** Central region:** Intense **stellar continuum** with all the **Hydrogen Balmer** emission **lines** and several recombination transitions of **Fe I** and **Fe II. H_α profile** towards the center is asymmetric, with an intense narrow core and blue and red wings. No absorption features are observed. Instead, there is a **blue-shifted emission** excess **at vlsr~-300 km/s; blue "hump")** (Fig. 3).

H_α emission towards the center is observed in all five slits → extends ~1arcsec along the equatorial direction. This component is unresolved along the axis → *equatorial disk?* No velocity gradient is observed along the equator → expansion velocity <~100 km/s.

*** Lobes:** Because the **H_α emission** profile from BOTH the receding and approaching lobes is (overall) **redshifted** we can reaffirm that **H_α** emission from the lobes is **mainly scattered** light originated in the central source.

We observe **local emission** lines like **H_α** or **[NII]** and **[SII]** corresponding to the emission from the **"knots"** at **-2.5''** along the nebula axis.

*** Absorption profile:abs1** is observed in the five spectra located at a typical velocity of **-600 km/s**, this absorption extends along the emission corresponding to the bright lobe. **FWHM=250 km/s.**

abs2 is also observed in the five spectra located at **-200 km/s** and **-1''**. Width: **~100 km/s**.

Thanks to **Keck** spectrum we can observe the **third absorption profile** along the **faint lobe**. (**-450 km/s).**

I. Observations (seeFigs 2 & 3)

- **HST/STIS:** we have obtained 0.1"-resolution, long-slit spectra using five 0.2"-wide slits parallel to the axis of symmetry of M1-92 (see Fig.1). The **spectral resolution** is **~75 km/s** around **H_α**.

-**Keck:** ground-based (~0.8"-resolution) long-slit spectra with a 0.5"-wide slit along the nebula axis and through the nebula center were also obtained. Spectral resolution is **~35 km/s** (Sánchez Contreras et al. 2008, for more details).

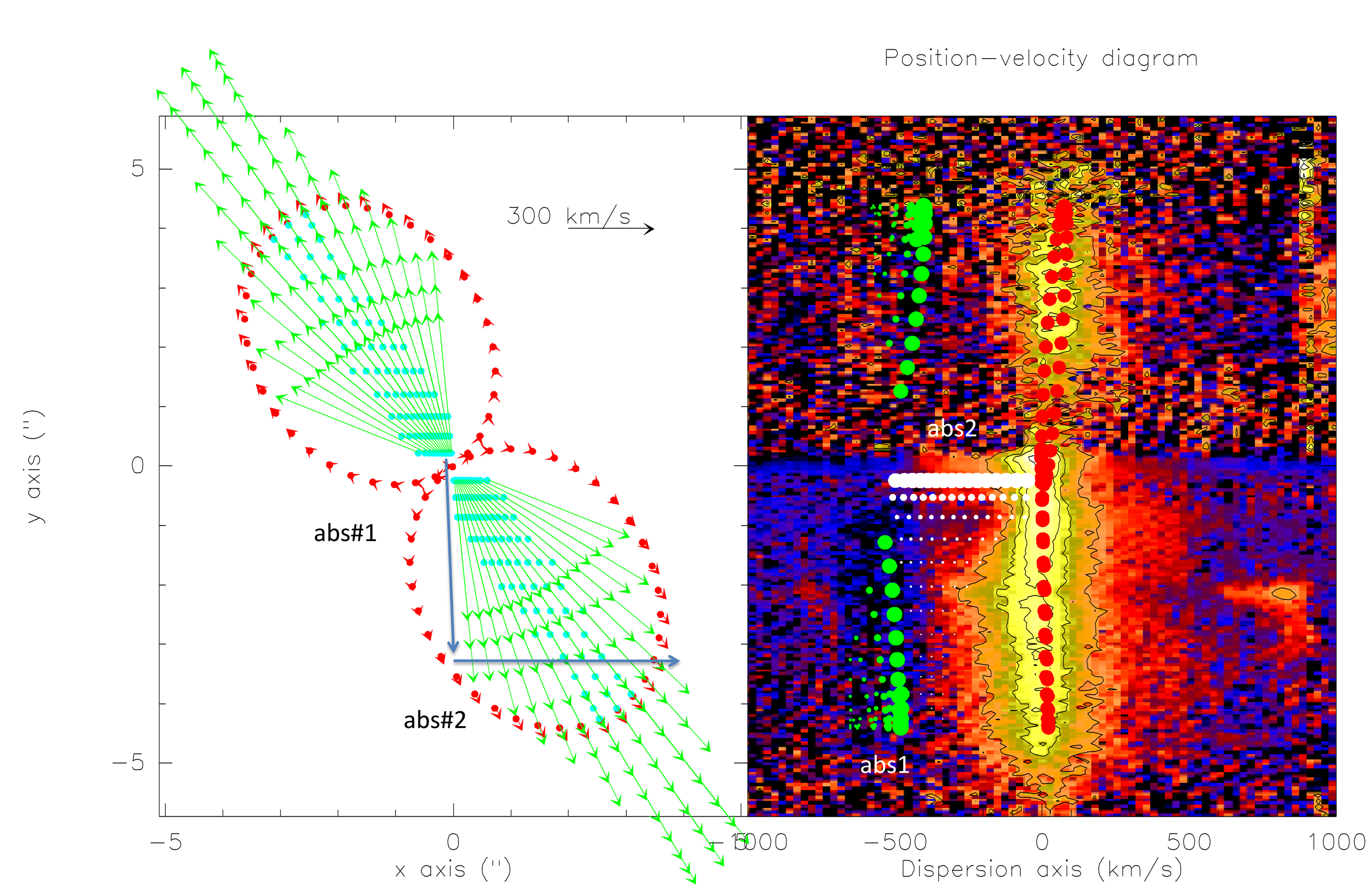


Fig. 5. Left panel: PPN scheme lobes are drawed like two ellipses **(red points)**. **Blue points** represent the inner wind and **green arrows** represent the velocity field and the bipolarity of the wind. **Right panel: Absorption 1→radial** (green points). Photons from the central source travel through the inner wind to the dust grains in the lobes producing abs. feature #1 at **-550 km/s. Absorption 2 →tangential** (white points) photons scattered in the reflection lobes cross again the inner fast wind in their journey to the observer [**-250 km/s** and **-1''**]. **Scattered emission from the lobes (red points). "Shear-flow" Vexp** from **20** to **80 km/s.**

III. Interpretation

The formation of the Hα P-cygni profile in M1-92 is explained adopting a similar scenario to that proposed for the pPN He3-1475 by *Sánchez-Contreras &Sahai (2001)* -- schematically represented in Fig. 4. The Hα emission is produced in the central HII region and is scattered by dust in the lobe walls along the l.o.s. The gas (partially neutral) inside the lobes produces the absorptions against the stellar continuum and the scattered Hα profile. **Absorption1** or **radial** is generated when photons from the central source travel through the inner wind to the dust grains in the lobes. **Absorption 2** or **tangential** is produced when photons scattered in the walls of the lobes cross again the inner fast wind in their journey to the observer.

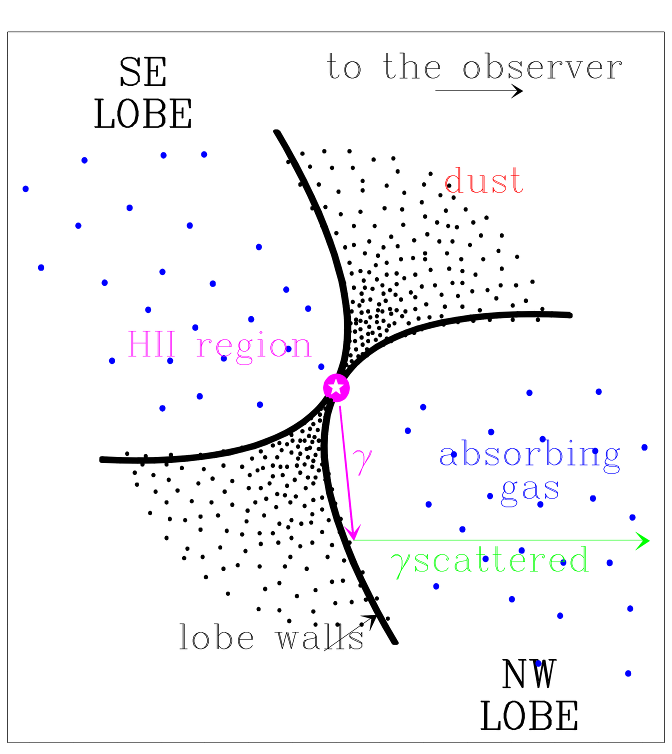


Fig. 4. Sketch of the main nebular components. Photons from the HII region to the lobes are absorbed producing abs1 and scattered photons from the lobe to the observer are absorbed again generating ab2.

IV. Analysis.

To improve our understanding of the spatio-kinematics of M1-92 we have performed a more cuantitative analysis based on the interpretation showed above.

Spatio-kinematics: The goal of our simple model is to reproduce the **H_α emission centroid (red points)** and the positions and widths of the **absorptions (green and white points)**. The **centroid** is well reproduced assuming that lobes expand following a **"shear-flow"** velocity field from **~20-80 km/s.** For the **absorptions** we present a fast bipolar wind from **450-650 km/s** accelerated in an inner region **r~<1.5''** and with a density law **ρ(r) ~ r^{-1}**(Fig. 5)

Normalization to "pseudo-continuum": We assume that the **H_α emission line** from the **HII central region** was originally symmetric and that the absorption is produced against the stellar continuum AND the line wings. So we have done a more "realistic" normalization taking into account the **continuum and wings** (**"pseudo-continuum"**). We create a **synthetic spectrum (I_0)** which is divided by the original one ($I_0 e^{-\tau}$). We obtain a better approximation for the **optical depth (τ)** (Fig. 6). **τ_1= 0.9 , N_1~2·10^{13} cm^{-2} , τ_2= 0.5, N_2~5·10^{12} cm^{-2} .**

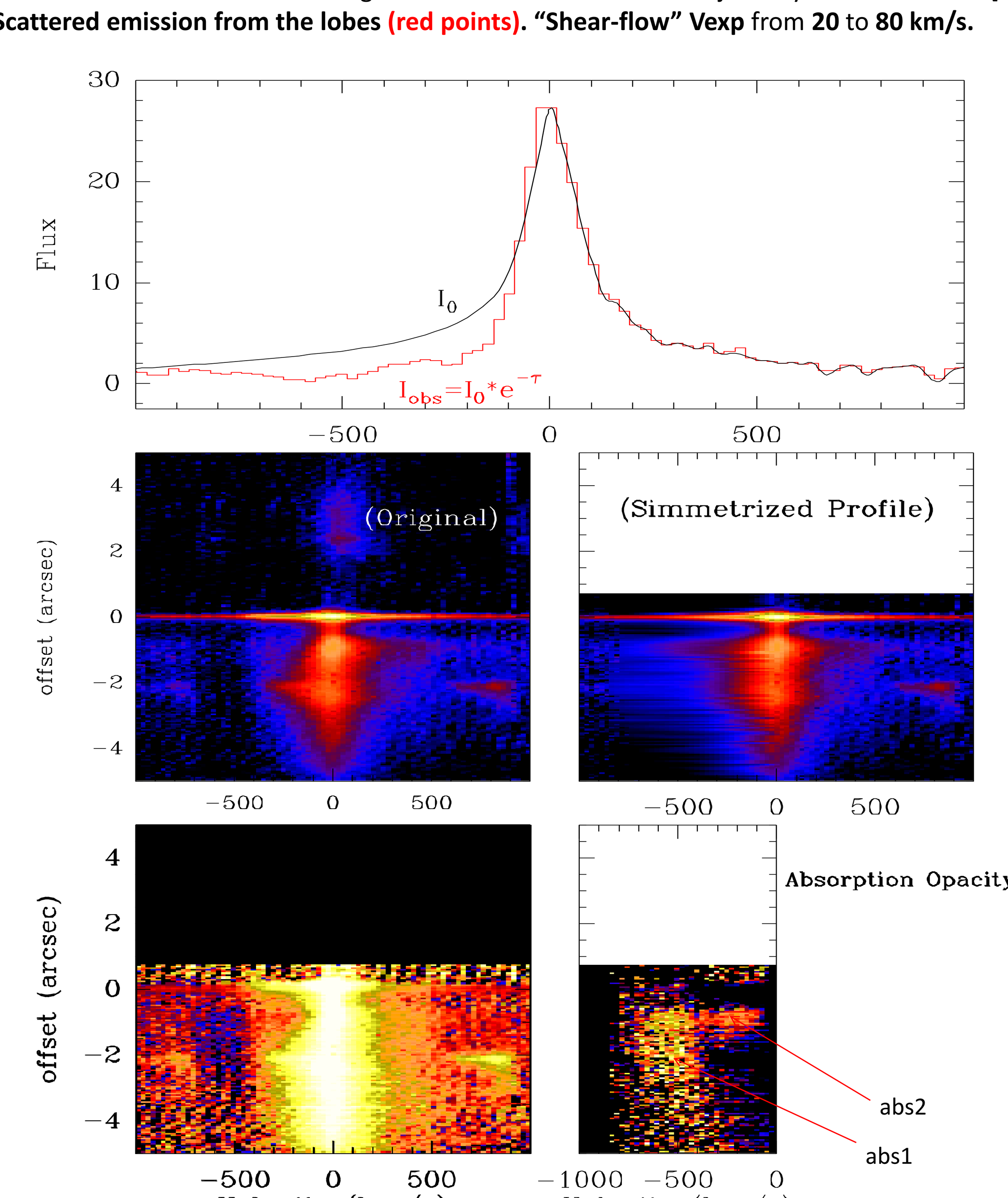


Fig. 6. At the top we observe the original H_α profile (1D) (red) and the symmetrized one (1D) (black). At the center (left) we observe the original H_α profile (2D) and the symmetrized one (2D) (right). At the bottom of the figure we present the spectrum normalized to the continuum (left) and the absorption opacity (τ) (right).

V. Components

Our study has allowed us to increase our knowledge about the spatio-kinematic structure of M1-92 and characterize their main nebular components.

-**Central region:**

In this region we find a wide **(1'')"disky" H_α emitting structure** that expands at velocity **<100 km/s**.

In the inner region of this **disky structure** we find another **H_α emitting component** that expands at moderate velocity **(300 km/s).** We assume that this structure is in **expansion** because the **emission line** is **blue-shifted.**

-**BipolarLobes**: Here we see **two** main different structures: the **lobe walls** and the **inner bipolar wind**.

- **Walls:** They are expanding at low velocities with a **"shear-flow"** velocity field from **20** to **80 km/s.** Their **kinematical age** is ~**900 yr.** The dust in the lobe walls lobes scatters the Hα emisson from the core.

- **Bipolar wind:** Is responsible for the absorption features observed in the spectrum. Our study suggests that it is expanding with a radial velocity from **450 to 650 km/s, accelerating** in a region **r<1.5''**. Its density falls in a "soft" way **ρ(r) α r^{-1}.**

-**Knots:** Intrinsic **emission,** i.e. locally produced (not scattered). **[SII] doublet ratio → Electron density** around **10^4 cm^{-3}** .

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