Fast, gusty winds blowing from the core of the pre-Planetary Nebula M 2-56

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Abstract

We report optical long-slit spectra and direct imaging (ground-based and with the *Hubble Space Telescope (HST))* of the pre-planetary nebula M 2-56 obtained at different epochs. The optical nebula is composed of shock-excited material distributed in two pairs of nested lobes with different sizes and surface brightness. Within the ILs and the OLs, the velocity increases with the distance to the center, however, the ILs show expansion velocities larger than the OLs. Consistent with the large speeds reached by the ILs (of up to ~350 km s^{-1} at the tips), we have measured the expansive proper motions of the knots *(~0.03"yr^{-1}) by comparing HST images* taken in 1998 and 2002. Moreover, we have discovered remarkable changes with time in the continuum and line emission spectrum of M 2-56. In 1998, we detected a burst of H*α emission from the nebula nucleus that is* interpreted as an indication of a dense, fast (~350–500 km s^{-1}) bipolar wind from the nebula's core (referred to as "F1-wind"). Such a wind has been recently ejected (after 1989) probably as a short-duration mass-loss event. Our data also reveal an optically thick compact cocoon (or shell-like structure) and an HII region around the central star that result from further post-asymptotic giant branch (post-AGB) mass loss after the F1-wind. Recent brightening of the scattered stellar continuum as well as an increase of scattered H*α emission along the lobes* is reported, both results pointing to a decrease of the optical depth of the circumstellar material enshrouding the star.

Introduction

The shaping of planetary nebulae (PNe) is probably the most exciting, yet least understood problem in the late evolution of 1- 8$M_\odot$ stars. PNe evolve from the envelopes of AGB stars through the very short (~10^3yr) proto-planetary nebula (PPN) phase. During the PPN phase, the nebular morphology and kinematics are dramatically altered: the spherical, slowly expanding (V_{exp}~5-15km/s) AGB circumstellar envelope becomes a PN with clear departures from sphericity and fast (≥100km/s) outflows directed along one or more axis. This spectacular metamorphosis is thought to result from the hydrodynamic interaction between jet-like post-AGB winds and the slow AGB envelope. In spite of the growing evidence of jet-like ejections in pPNe, their origin, nature (episodic or continuous?), typical mass-loss rates, lifetimes, etc., are still very poorly known. **M2-56 basics:** B-type central star + optical nebula (shock excited gas) + hourglass-shaped molecular envelope surrounding optical nebulosity. *D*=2.1 kpc.

Observations: Multi-epoch, optical imaging and long-slit spectroscopy

Imaging: (Fig. 1)

2.5m INT (La Palma), WFC, **Hα, Harris-R** (2009)

HST archive: 1) WFPC2-PC, **F656N** (1998);

2) ACS/HRC, **F606W** (2002)

Long-slit spectroscopy: (1"-wide slit, Δv≈44-60 km/s @ Hα) (Figs. 2-5)

INT+IDS (1998): [6370-6770Å], 3 slits

INT+IDS (2000): [6234-6805Å] [4558-5330Å], 4 slits

2.6m NOT+ALFOSC (2009): [6330-6850Å], 1 slit

Nebular components: spatio-kinematic structure

1.OLs: expansion V∝r, <V_r>~50 (30-35) km/s [axial+shear]

2.ILs: V∝r, V_r~110 km/s @ tips (FWZI~360 km/s) → proper motions on HST images

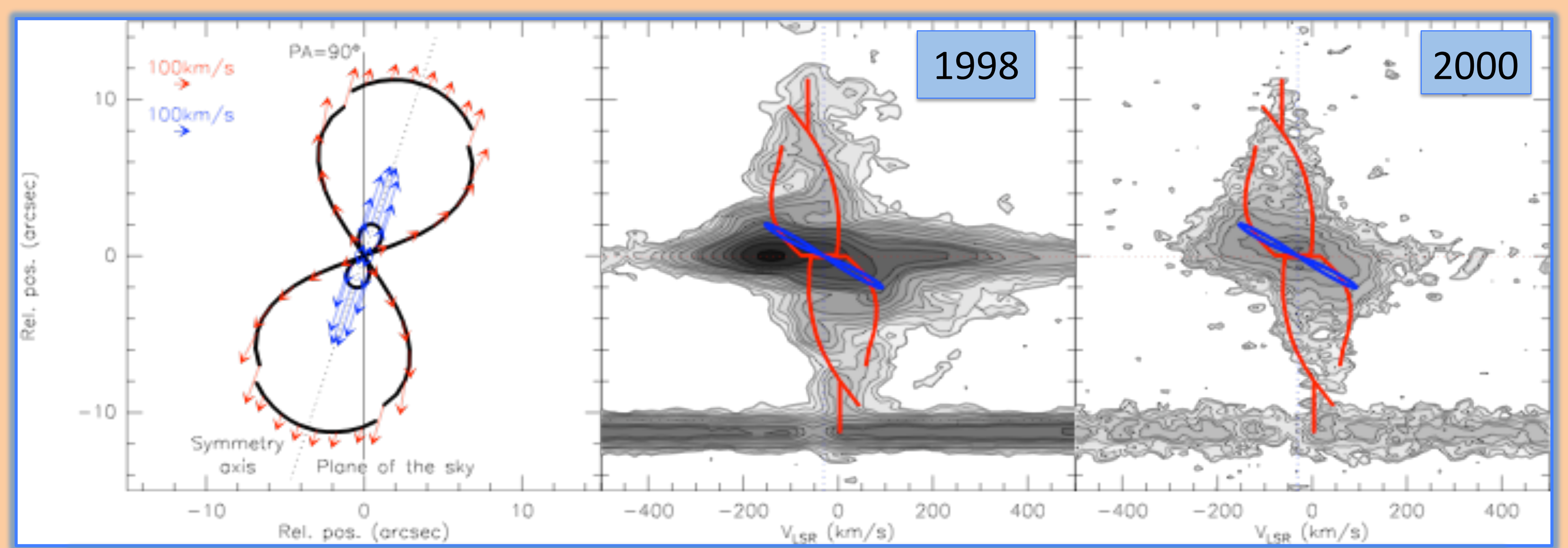

Figure 4. Left: Schematic geometry of M2-56: cut by a plane perpendicular to the plane of the sky in the direction of PA=90°. The velocity field is indicated by the arrows. Right: Hα spectra along PA=90°. The model position-velocity diagram is superimposed.

3.Fast wind (F1):

✓ blue-shifted → bipolar outflow receding side (west, red-shifted) obscured

✓ V_{exp}~110/sin(18º)~360 km/s; broad wings, blue-shift abs. →500 km/s

✓ Dense & short-lived: F1 1998 vanished in 2000 → full recombination in <2.9 yr → n_e> 2.6x10^4 cm^{-3} -- neutral in 2000! → detached from ★ (clump, bullet-type?)

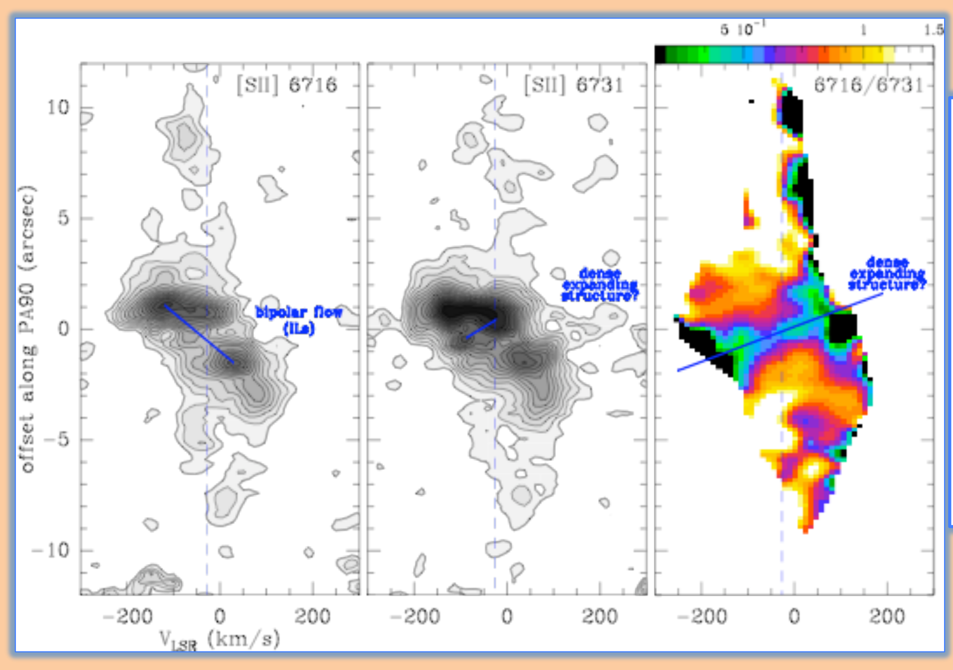

Figure 5. Position-Velocity diagram along PA=90º of the [SII] lines and their ratio (2009). The p-v distribution of the 6716/6731 ratio toward the center evidences a dense, equatorially expanding structure.

4. Equatorial flow: expansion V∝r, <V_r>~100 km/s (Fig. 5 – coeval OLs)

5. Dusty (cocoon?) structure: expanding? pierced? (decreasing optical depth)

6. Nuclear HII region & active shocks: V>500 (>1000?) km/s, FeII lines

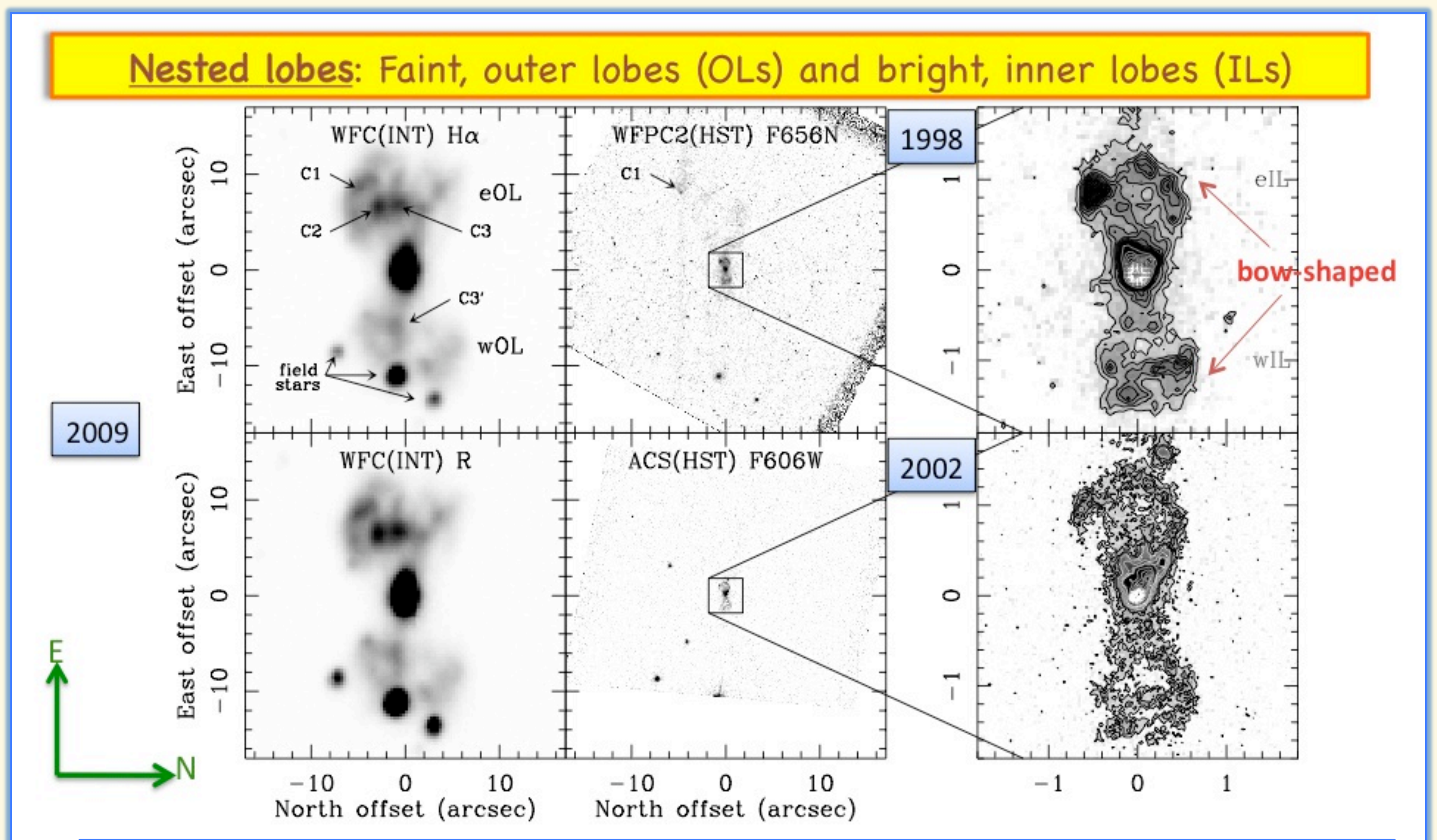

Figure 1. Left: Ground-based images of M2-56 through the Hα and R filters (top and bottom, respectively). Middle: HST images through the F656N (Hα) and F606W filters (top and bottom, resp.). Right: Inset of the HST images.

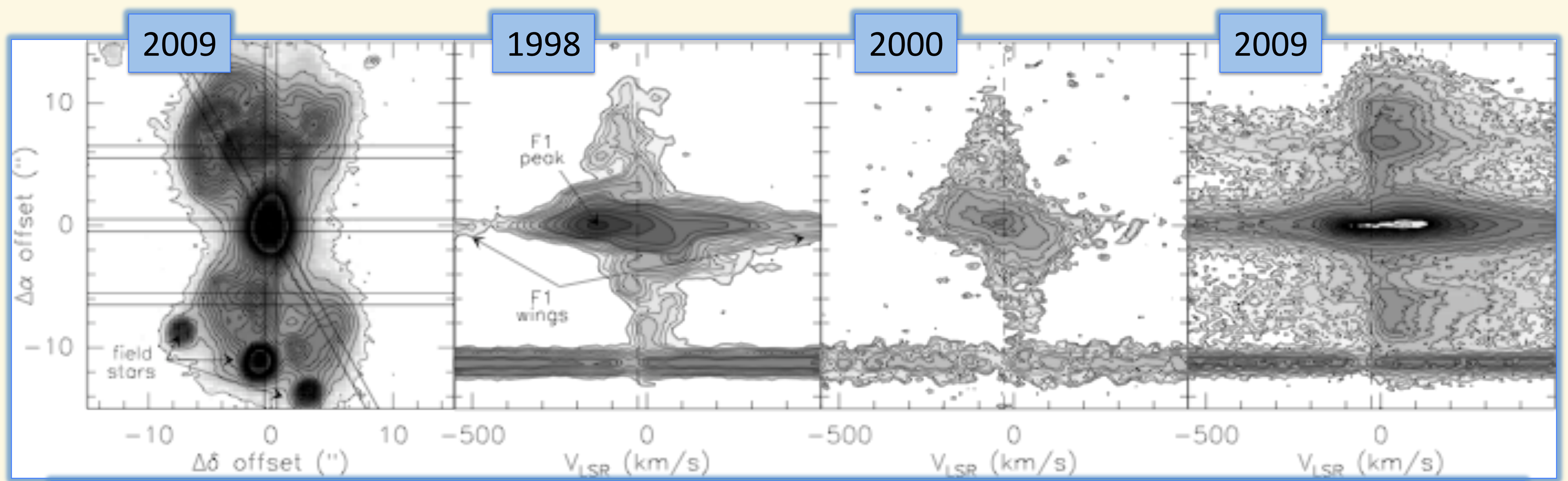

Figure 2. Long-lit Hα spectra along the nebula symmetry axis observed in 1998, 2000, and 2009. The ground-based Hα image is shown in the leftmost panel; slits positions are superimposed on the image. The intense, blue-shifted emission feature and its broad wings at the nebula center observed in 1998 (feature F1) are indicated by arrows.

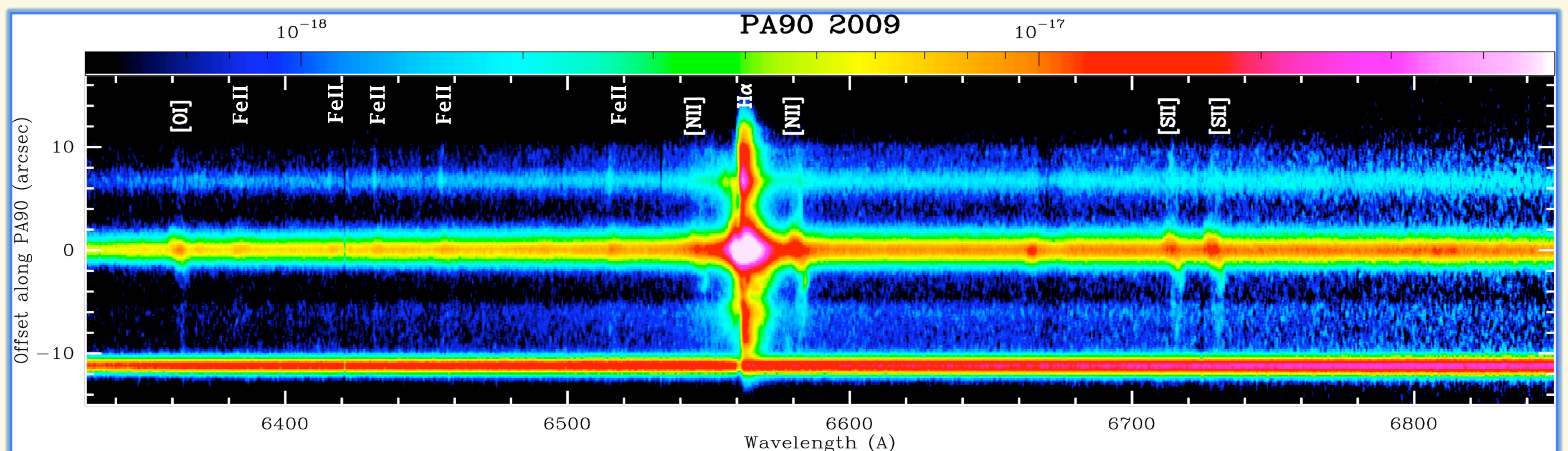

Figure 3. Long-lit spectrum along the nebula symmetry axis observed in 2009. Brightenning of the scattered continuum and scattered Hα, and the emergence of scattered FeII, SiII lines (shock tracers) from the nucleus are observed.

Post-AGB Mass-loss history.

The data presented here unveil the complex post-AGB mass-loss history of this object, whose rapid evolution is driven by multiple, short-lived episodes of mass outflow, not regularly spaced in time, leading to ***(1)*** acceleration of the molecular envelope that surrounds the optical nebula (kinematical age *tk~ 1400 yr),* ***(2)*** the optical OLs and the equatorial flow (*tk~ 350–400 yr),**(3)** the ILs (tk~ 40 yr),* ***(4)*** *the F1-wind (tk<10 yr), and* ***(5)*** *the nuclear cocoon and HII region (tk<2 yr?). The successive multiple post-AGB winds in M 2-56 are characterized by* ejection speeds increasing with time [from ~200->500 (1000?) km/s]. In contrast, the mass-loss rate and linear momentum show a time-decreasing trend [P_{OLs}~0.17 $M_\odot$km/s > P_{ILs}~0.05 $M_\odot$km/s > $P_{F1\text{-}wind}$~0.002 $M_\odot$km/s → decreased with time (P_{co} ↑) → << Pco~10 $M_\odot$km/s.]