

Kinematics and Proper Motion of the ansae in NGC 7009

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Abstract

A characterization of the kinematics of the ansae in NGC 7009 was made using high dispersion echelle spectra and public narrow band HST images for measuring radial velocities and proper motions, respectively. Assuming that the ansae are moving at equal and opposite velocity from the central star we obtain an average system radial velocity of -54 ± 2 km/s, the eastern ansa approaching and the western ansa receding at $v_r = 5.5 \pm 1$ km/s with respect to this value. Only the proper motion of the eastern ansa could be measured, leading to 2.8 ± 0.8 arcsec/century, or $v_t = (130 \pm 40)$ km/s, where d is the distance to the nebula in kpc. Additionally, the electron temperature and density for each ansa was measured using line intensity ratios. The results are $T_e \sim 9000$ K and $n_e \sim 2000$ cm⁻³ for both ansae. We estimate the age of the ansae to be ~ 900 yrs. and the proper motion of the central star in $\mu_{CS} \sim 1$ mas/yr.

Observations

The data for this project consist of a set of echelle spectra and two sets of public HST images, taken in 1996 and 2001.

The spectra were obtained on the night of July 29, 2002, with the CTIO 4m Echelle spectrograph. The instrument was set-up to cover the spectral range 410 – 720 nm. The dimensions of the slit were $1.2'' \times 6.6''$ and the typical seeing was $2''$. For wavelength calibration a Th-Ar lamp was used. For flux calibration the spectrophotometric standard star 58 Aql (HR 7596) was used. The observations were reduced using standard IRAF routines.

The HST images were obtained from the HST archive. The first set was taken in April 28, 1996 (Balick et al. 1998) using the Wide Field Planetary Camera 2 (WFPC2) and a [NII] 6583 narrow band filter. The second set was taken in May 11, 2001 also with the WFPC2 and the same filter (Palen et al. 2002). The 2001 images are shifted 20 arcseconds east from the 1996 images. As the latter covered the entire nebula, in the former the west ansa disappears from the field of view. The two images shown in Figure 1 are an average (for cosmic ray rejection) of each set.

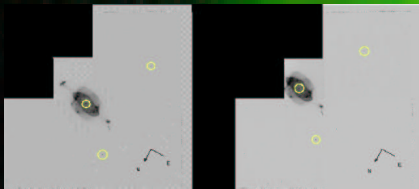
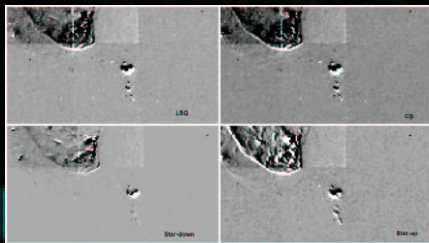


Figure 1: HST images taken in 1996 (left) and 2001 (right). The circles mark the stars used as reference points for Figure 2 and Table 3.

Eastern Ansa			Western Ansa		
Observed line (Å)	Rest λ (Å)	Radial velocity (km/s)	Observed line (Å)	Rest λ (Å)	Radial velocity (km/s)
[NII] 3753.48	3754.37	-56.43	[NII] 3753.46	3754.37	-47.44
H-ε 6581.54	6578.84	-26.25	H-ε 6581.59	6578.84	-48.33
[OII] 6907.48	6903.81	-46.73	[OII] 6907.24	6903.81	-50.44
[OI] 6299.01	6301.32	-41.13	[OI] 6299.29	6301.32	-49.65
[NII] 6548.76	6548.08	-50.58	[NII] 6547.00	6548.08	-48.36
H-α 6563.37	6562.82	-57.14	H-α 6563.75	6562.82	-48.92
[NII] 6583.12	6583.39	-57.87	[NII] 6582.38	6583.39	-46.02
[SII] 6715.13	6716.42	-57.62	[SII] 6715.28	6716.42	-46.45
[SII] 6720.50	6720.76	-57.83	[SII] 6720.75	6720.76	-48.51
[ATII] 7131.42	7130.80	-57.60	[ATII] 7131.61	7130.80	-49.97
Average		-59 ± 2	Average		-48 ± 2

Table 1: Radial velocities for the lines found in each ansa.

Figure 2: Difference between 2001 and 1996 images, taking several reference points



Background image credits: B. Balick, J. Alexander, Hajian, Y. Terzian, M. Perinotto, P. Patriarchi, NASA.

Radial Velocities, Electron Temperatures and Densities

The lines that could be identified in the spectra are listed in Table 1. The central wavelength of each line was measured by fitting a Voigt profile, using the IRAF task *splot*. The results for the Doppler shift of the emission lines of both ansae are listed in Table 1. The values of the rest wavelengths of forbidden lines were taken from Bowen (1960), while the values for permitted lines were taken from Moore (1945), taking averages in the case of HeI blended multiplets. The average result for the velocity of the eastern ansa is -59 ± 2 km/sec, and for the western ansa it is -48 ± 2 km/sec. Assuming symmetry about the CS, the system velocity is then -54 ± 2 km/s and each ansa is moving at $v_r = 5.5 \pm 1$ km/s respect to this value (the eastern ansa approaches and the western one recedes).

The line intensities were measured by fitting several Voigt profiles, each one with different end points, to get an estimate for the errors. The intensities were corrected for interstellar and atmospheric extinction. The ratios [N II] (6548 + 6583)/5755 and [S II] 6716/6731 were used to compute the electron temperatures and densities using the formulae of McCall (1984). Results are shown in Table 2.

Proper Motions

Estimations of the distance to NGC 7009 are quite uncertain (Acker et al. 1992), but a value of $d = 1 \pm 0.3$ kpc can be adopted, being a rough average of the measurements. One way to measure the proper motion of the ansae is with respect to the central star. The method consists in determining the position of the ansa, and measuring the angular separation of this point from the CS in the 1996 and 2001 images. For the measurement of the ansa's position, it was completely confined inside a square box of 5 arcsec on a side and then a centroid was calculated. Even though this is a good estimation for the angular displacement of the eastern ansa, it is also possible that the central star has moved. Therefore, it was desirable to have other reference points. The circles in Figure 1 indicate the position of two faint background stars in the same image. Figure 2 shows the difference between the 2001 and 1996 images, the former shifted and normalized by the average flux of the two background stars and central star. It can be seen that the motion of the eastern ansa occurs in the same direction as measured from all the reference points. The angular displacements in each frame are listed in Table 3. These measurement are all equal within the errors, therefore the value adopted here for the angular displacement corresponds to 0.14 ± 0.04 arcsec, yielding a tangential velocity of $v_t = (130 \pm 40)$ km/s, where d is the distance to the nebula in kpc.

Motion of the CS and the age of the ansae

If the angular separations between the ansae and the central star are measured in the 1996 images, one gets $24.85'' \pm 0.06''$ for the eastern, and $26.77'' \pm 0.06''$ for the western ansa. Assuming that they were ejected with the same velocity, the central star has moved $0.96''$ since ejection. This value divided by the proper motion of the eastern ansa yields 860 yr, which is an estimate for the time since ejection. The proper motion of the CS is then $\sim 0.96''/860\text{yr} = 1$ mas/yr.

Acknowledgments

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Eastern ansa			
Ratio	Observed	Corrected	Result
[NII]	111 ± 15	103 ± 15	$T_e = 9000 \pm 400$ K
[SII]	0.67 ± 0.04	0.67 ± 0.04	$n_e = 2600 \pm 500$ cm ⁻³
West Ansa			
Ratio	Observed	Corrected	Result
[NII]	120 ± 12	110 ± 12	$T_e = 8900 \pm 100$ K
[SII]	0.64 ± 0.04	0.64 ± 0.04	$n_e = 1900 \pm 300$ cm ⁻³

Table 2: Line intensity ratios and electron temperatures and densities for each ansa.

Reference Point	Angular displacement (")
Central star	0.17 ± 0.10
Upper star	0.16 ± 0.10
Lower star	0.10 ± 0.02
Average shift	0.13 ± 0.04
Least squares shift	0.14 ± 0.04

Table 3: Angular displacement between 2001 and 1996 images with respect to different reference points (Fig. 2)

HST • WFPC2