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PHYSICAL SCENARIOS FOR SUPERSONIC GAS FLOWS OBSERVED IN H II REGIONS

M. Relaño,[1] J. E. Beckman,[1,2] and J. Dyson[3]

RESUMEN

Una fracción significativa de los perfiles espectrales en la línea de emisión Hα de una población de regiones H II en galaxias espirales presentan componentes situadas a $\sim \pm 50\,\mathrm{km\,s^{-1}}$ de los centros de las componentes principales. Estas alas de alta velocidad son características de cáscaras en expansión. Interpretamos estos fenómenos en términos de dos posibles escenarios: vientos producidos por las estrellas OB centrales que recogen masa de los grumos en el interior de las regiones o acoplamiento de la radiación con el gas a través del polvo que produce flujos de gas hacia el exterior.

ABSTRACT

Line profiles in Hα emission from H II region populations in spiral galaxies show emission features at $\sim \pm 50$ km s^{-1} from the main emission peaks of a significant fraction of regions, which are characteristic of expanding shells. We interpret these in two possible scenarios: mass-loaded wind outflows from the central OB stars, or dust-coupled, radiation-driven outflows, caused by the same objects.

Key Words: **H II REGIONS — ISM: JETS AND OUTFLOWS — STARS: MASS LOSS**

1. THE EVIDENCE FOR SUPERSONIC EXPANDING SHELLS

Using a scanning Fabry-Perot (TAURUS-2) on the 4.2 m WHT La Palma, we have produced data cubes in intensity and velocity of complete spiral galaxies imaged in their Hα emission. Figure 1 shows a set of four characteristic line profiles of intensity against velocity obtained from these cubes, for four separate regions in NGC 3359 and NGC 1530. As well as the main emission peak, we see subsidiary peaks to the blue and the red, at velocities of order $50\,\mathrm{km\,s^{-1}}$ with respect to the main peak. While the strengths of each shifted component are comparable, the red feature is a little broader than the blue one. The sound speed in the H II region gas is just over $10\,\mathrm{km\,s^{-1}}$ and we interpret the wing features as signatures of supersonic expanding shells: shells because the features are discrete, and expanding because the red line width implies broadening as the light passes through the region, i.e., the redshifted feature comes from behind the region. For further details of the observations see Relaño et al. (2003).

2. QUANTIFYING THE SHELL ENERGETICS

We estimate the electron density of the shell ($N_{\rm shell}$ in Table 1) via the wing feature emission measure compared with that of the central feature for the full region after estimating a mean value of the electron density in the H II region of $1.5\,\mathrm{cm^{-3}}$. Making the best estimate of the shell thickness from measurements of local H II regions (Chu & Kennicutt 1994), we obtain the ionized mass inside the shell. The shell kinetic energy is then found directly from $1/2 m_{\rm shell} v^2_{\rm shell}$. We compare this energy with input energies from the central stars, using the measured Hα luminosity of a region to derive an equivalent O star content (this gives a lower limit, since a fraction of the ionizing radiation can be escaping from the regions). Thence, assuming a mean lifetime of 10^6 years (also a lower limit) we can estimate the integrated radiative energy input and the integrated wind energy from the parameters of the stellar winds for OB stars calculated in Leitherer (1998). We also compute for comparison the turbulent kinetic energy of the whole region using the σ of the central peak as a measure of the turbulent velocity. A sample of these computed energies for 6 luminous regions for NGC 1530 and NGC 3359 is given in Table 1.

The linear momentum of the shell compared with those of the combined stellar winds, and the integrated radiation is also relevant. Using region 52 as an example, we find that the integrated wind momentum and radiation momentum each fall short of the value for the shell derived observationally, so that even their sum appears half an order of magnitude too small. To obtain satisfactory agreement we would need to assume a more realistic mean lifetime for the stars in the OB association, rather than the conservative lower limit cited above. A further refinement in our simple scenario would be to use a value for radiative momentum higher than the

[1]Instituto de Astrofísica de Canarias, Spain.
[2]Consejo Superior de Investigaciones Científicas, Spain.
[3]University of Leeds, UK.

TABLE 1

ENERGETICS OF THE SHELL AND TURBULENT COMPONENTS OF A SELECTED REGIONS OF NGC 3359 AND NGC 1530

(1) Region	(2) $\log L$	(3) $\langle v_{\rm shell} \rangle$	(4) EM	(5) $\langle N_{\rm shell} \rangle$	(6) $E_{\rm K}$	(7) $E_{\rm wind}$	(8) $E_{\rm turb}$	(9) $E_{\rm rad}$	(10) $E_{\rm total-rad}$
7	39.59	69.90	20.55	9.39	1.9	14.5	2.2	19.6	49.9
10	39.42	68.15	18.44	8.30	5.1	9.9	1.8	13.4	34.1
22	39.12	49.35	14.53	6.68	0.7	8.1	0.7	6.7	16.9
46	38.55	50.40	13.0	6.19	0.8	1.3	0.02	1.8	4.5
51	38.52	47.20	21.9	6.77	0.4	1.2	0.01	1.7	4.2
52	38.51	46.85	15.6	5.51	0.3	1.2	0.003	1.6	4.2

Columns: (1) Region reference number. (2) Log. of Hα luminosity (L in erg s^{-1}). (3) Measured shell expansion velocity. (4) Shell emission measure as a fraction of the total EM of the region. (5) Mean shell electron density. (6) Kinetic energy of the shell. (7) Combined kinetic energy of OB stellar winds. (8) Turbulent kinetic energy of the body of the H II region gas. (9) Combined energy of the ionizing radiation from the region OB stars. (10) Combined total radiative energy of region OB stars. All energies in units of erg s^{-1}.

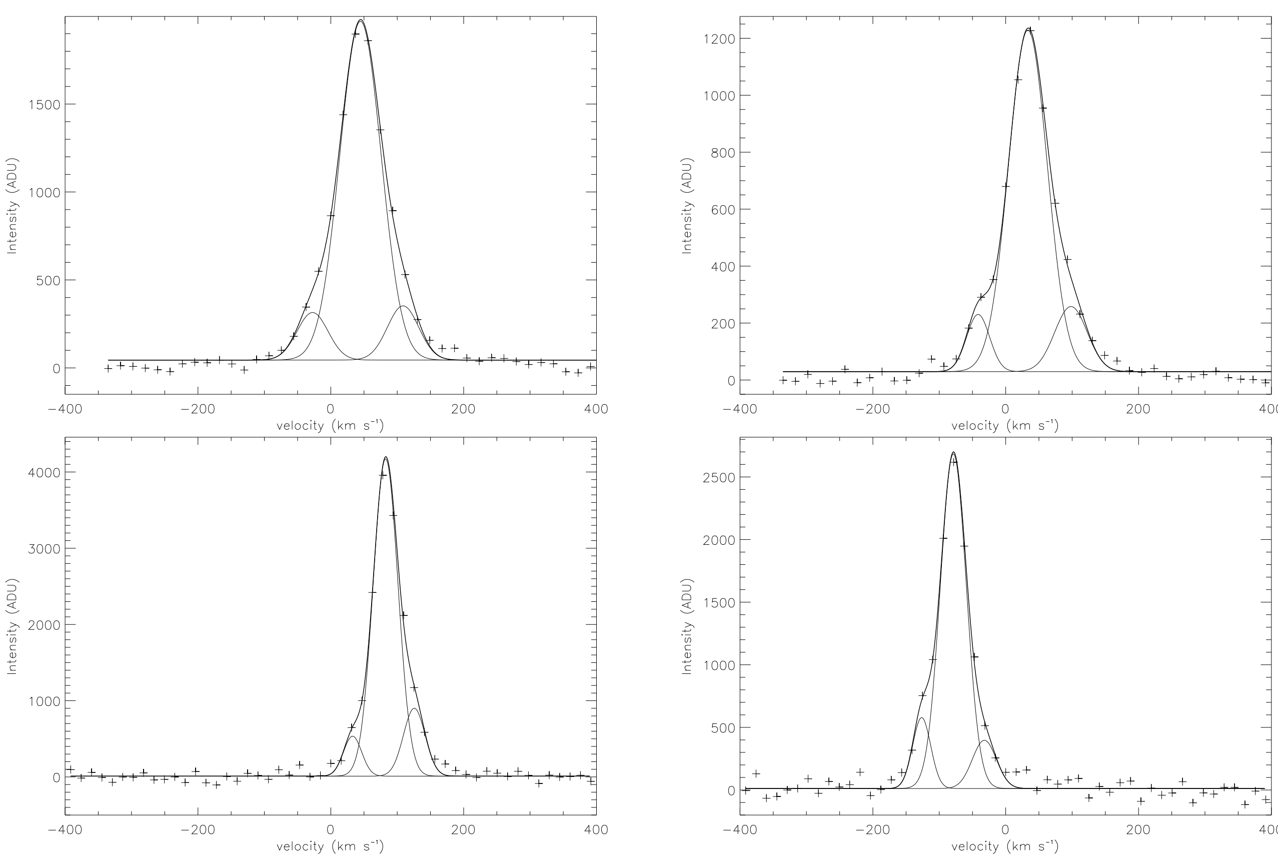

Fig. 1. Emission profiles in Hα integrated over the emitting areas of selected H II regions in NGC 3359 and NGC 1530, showing clearly the presence of the features at $\sim 50\,{\rm km\,s^{-1}}$ coming from the expanding shells.

standard value of L_*/c, since it has been shown by Elitzur & Ivezic (2001) that a better estimate would be $\tau L_*/c$ where τ is the dust optical depth, which can be greater than unity.

3. FEASIBLE DRIVING MECHANISMS

3.1. *Mass Loading*

The ablation of mass from dense clumps has been used in several papers by Dyson and coworkers, to account for the deceleration of stellar winds with velocities of order 2000 to 3000 $\mathrm{km\,s^{-1}}$, yielding much slower but still highly supersonic flows. Our detected outflows, at 50 $\mathrm{km\,s^{-1}}$ satisfy the criterion in Dyson, Williams, & Redman (1995) of speeds more than twice the sound speed, for high-dissipation mass loading. Although the theory was originally formulated for ultracompact H II regions, these ultraluminous regions do seem to satisfy its basic requirements: supersonic winds plus a high radiation field impinging on a clumpy surrounding medium. From our own radiative transfer studies in these regions we have shown that well over 90% of the mass in the dense clumps is neutral. Mass is ablated from the clumps by the fast wind, aided by photoionization, which falls in velocity as it picks up mass. This mass injection from the clumps occurs at a constant volume rate, and the flow remains steady though supersonic. Energy losses are radiated away and the gas temperature remains at its original value of some 10^4 K. Figure 2 shows the intensity variation of an emission line formed in a mass-loaded flow, computed from Dyson-type models. The model gives a fair qualitative account of the variation of the combined strengths of the line wing features with projected radial distance from the H II region center.

3.2. *Radiation Driving with Dust Coupling*

Table 1 shows that stellar radiation offers a huge potential momentum source to drive a shell. In galaxies of *normal* metallicity there will be a 1% admixture of dust in the H II region gas, and dust coupling can transfer radiation momentum to the molecules. Elitzur & Ivezic (2001) developed the necessary formalism. Here we only sketch some numerical parameters. The terminal velocity v_{inf} of a grain at a large distance from a star cluster is

$$v_{\mathrm{inf}} = (\alpha/R_o)^{1/2} \quad \text{where} \quad \alpha = 3L_*/8\pi c r \rho \,. \qquad (1)$$

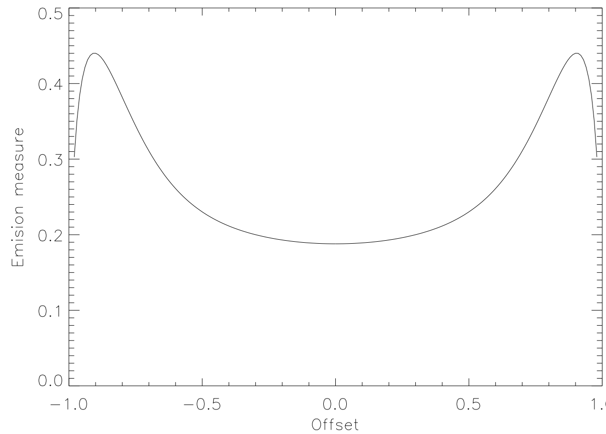

Fig. 2. Predicted emission line intensity against offset from the center of the region for a mass-loaded wind model outflow.

Here L_* is the stellar luminosity, r the grain radius, ρ the grain density, and R_{o} the initial distance from the cluster. Realistic values give $v_{\mathrm{inf}} \sim 700\,\mathrm{km\,s^{-1}}$ for dust without gas. If grains drag 100 times their mass in gas the result is $v_{\mathrm{inf}} \sim 70\,\mathrm{km\,s^{-1}}$ in the observational range. In this model, including its sophisticated forms, v_{inf} should rise as $L_*^{1/4}$, in broad agreement with observations (see Fig. 2 of Relaño et al. 2003). It is also easy to show that this velocity is almost independent of the radius of the shell for shell radii greater than $10\,R_{\mathrm{o}}$.

4. CONCLUSIONS

The detected outflows appear to be a feature of a major fraction of luminous H II regions. Both energy and momentum considerations allow normal OB star winds or radiation to be the driver. Observations at higher linear resolution would be valuable for resolving the many outstanding points.

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John E. Beckman and Mónica Relaño: Instituto de Astrofísica de Canarias, C/Vía Láctea s/n, 38200 Tenerife, Spain (jeb,mpastor@ll.iac.es).
John E. Dyson: Department of Physics and Astronomy, University of Leeds, Leeds, LS2 9JT, UK (phy6jed@phys-irc.leeds.ac.uk).