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Letter to the Editor

A most peculiar galaxy: IC 860

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Summary:

The peculiar galaxy IC 860 has been observed in CO (λ = 2.6 mm) and compared to existing data in HI (λ = 21 cm) and OH (λ = 18 cm). Morphology and efficiency of star formation are discussed.

Keywords: galaxies:active - galaxies: individual:IC 860 - galaxies: kinematics - interstellar medium:clouds

1. Introduction:

The main discovery made by the IRAS survey is that far infrared emission dominates the total luminosity of a great number of galaxies. Based upon their luminosity, Sanders et al. (1988) divide far infrared galaxies into three categories : Moderate luminosity $10^{10} < L(FIR)/L_\odot < 10^{11}$, high luminosity $10^{11} < L(FIR)/L_\odot < 10^{12}$ and ultraluminous galaxies with $L(FIR)/L_\odot > 10^{12}$. As indicated by Soifer et al. (1987), IC 860 has a $L(FIR) = 1.26\ 10^{11}\ L_\odot$ and flux densities at 60 μm and 100 μm, respectively equal to 18.4 Jy and 17.9 Jy. The receding velocity c x z = 3862 Km s^{-1}.

In a study of the large-scale distribution of galaxies, Tifft and Gregory (1976) infer that IC 860 or Z 130-23 is at 4°8 from the center of the Coma cluster; its apparent blue magnitude is 14.8 (Zwicky and Herzog, 1963). At present, no data exist concerning the morphology type and the inclination of this galaxy.

The detection of IC 860 in the 21 cm HI and 18 cm OH lines was first reported by Schmelz et al. (1986). Apart from the absorption features observed in HI and OH, a marginal emission at both 1667 and 1665 MHz appears in the OH spectrum, on the red side of each of the absorptions (Baan et al. 1987). On top of the high infrared luminosity (Soifer et al. 1987) and the optical singularities (Tifft and Gregory, 1976) of IC 860, the complex OH spectra add an extra point to its peculiar aspect. At zero intensity level, the overall velocity extent of the strong OH absorptions is 170 Km s^{-1}, i.e. smaller than that of the HI absorption, which is about 340 Km s^{-1}. If the OH emissions were real, the overall velocity extent of the OH spectra would practically coincide with that of HI (Fig. 1).

In this letter we report recent molecular line observations of CO at λ = 2.6 mm, which tend to confirm an overall velocity extent of OH including the possible emissions. Furthermore, we discuss the morphology of IC 860 and the efficiency of star formation in the light of these recent observations.

2. Observations and results:

^{12}CO (J = 1 → 0) observations were made in January 1988 with the Nobeyama 45-m millimeter radio telescope. The HPBW of the instrument is 17 arcsec at 115 GHz. The total system temperature was about 600 K. The backend consisted of three 250 MHz wideband, 2048-channel acousto-optical spectrometers mounted in parallel and used simultaneously in order to check sensitivity and baseline effects. The widths of the spectrometers correspond to a velocity coverage of 650 Km s^{-1}. Spectra were taken using a normal observing procedure: the position switching mode with two symmetric reference positions 5 arcmin East and West from the position of the galaxy. For pointing calibration, using the SiO maser source, T-COM, close to the position of IC 860 proved to be somewhat difficult. Therefore, besides T-COM, two other sources, I+10273 and a continuum source, BL LAC, were chosen for a more reliable pointing calibration. Nevertheless, to overcome possible pointing inaccuracies, spectra at points: East, Center, West, North, Center, South were taken 10 arcsec around the position of the galaxy with the same reference positions 5 arcmin away. After averaging the spectra at each position, signals corresponding to the center position were found to be comparable to each other using this special observing procedure, and

* NRO, a branch of the Tokyo Astron. Obs., is a facility open for researchers in the field of Astronomy and Astrophysics.

to the signal detected using the normal observing procedure. At other positions there was no significant signal. Figure 1 (second upper panel) shows the obtained CO spectrum for the center position after approximately two hours of integration on- and off-source and after smoothing to a resolution of 32 channels or 10 Km s^{-1}. The two lower panels of figure 1 show the HI and OH spectra reported by Schmelz et al. (1986).

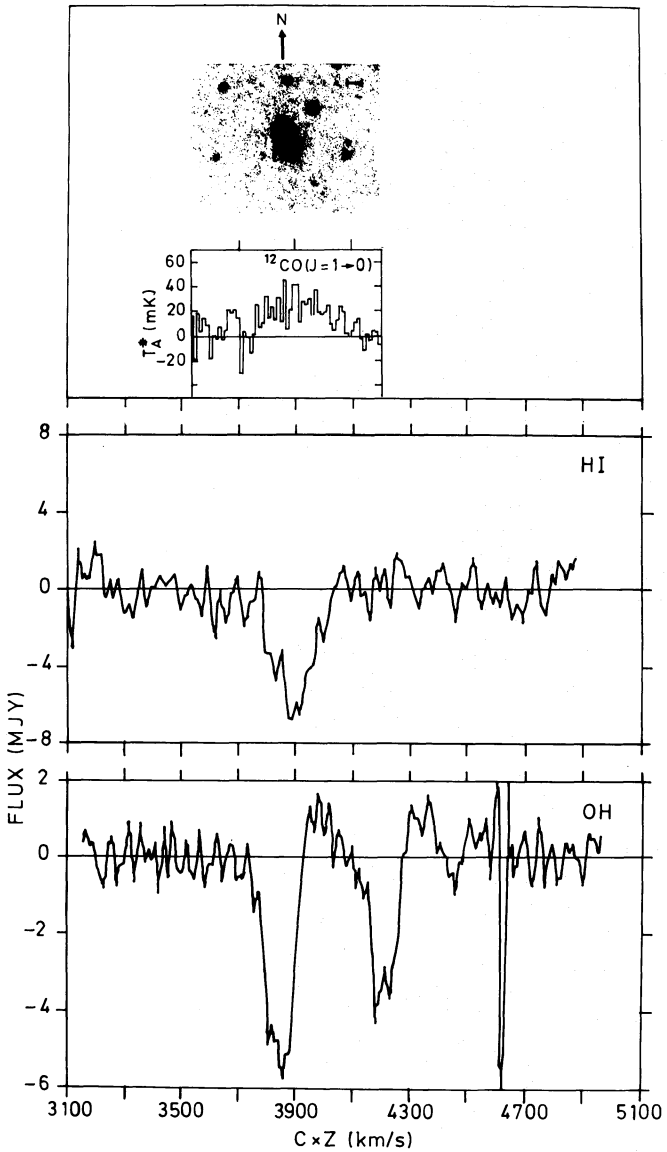

Fig. 1: Enlargement (approx. 18 times) of IC 860 from the Palomar Sky Survey. The 17 arcsec ^{12}CO beam size is indicated on the photograph (Upper panel).
^{12}CO spectrum obtained with the Nobeyama 45 m radio telescope (Second upper panel).Lower panels are reproductions of HI and OH spectra obtained by Schmelz et al. (1986).

The detected broad CO line is at about 3-sigma, one of the weakest signals observed with the Nobeyama 45 m dish. The shape of the line is not quite symmetric and approximately Gaussian. A Gaussian fitting gives an integrated intensity of $I_{CO} = \int T^*_A \, dv$ = 6.7 K Km s^{-1}, a peak T^*_A = 27 mK and a width at half intensity of 270 Km s^{-1}. The velocity applied is c x z = 3887 Km s^{-1}, which puts IC 860 at about 52 Mpc, assuming Ho = 75 Km s^{-1} Mpc^{-1}. Using the conversion factor of Young and Scoville (1982) and by taking into account the aperture and beam efficiencies of the FCARO 14-m telescope and the 45-m telescope, we obtain a conversion formula: $N(H_2)$ cm^{-2} = 6±3 10^{20} I_{CO} K Kms^{-1} .The mass of molecular hydrogen is given by $M(H_2) = 2m_H N(H_2)\, d^2/4$, where d = 4.29 Kpc is the telescope beam diameter at the distance of the source. Hence for IC 860 a mass of molecular hydrogen equel to 0.8±0.4 10^9 Mo is deduced.

TABLE 1. Molecular and atomic velocity properties of IC 860

	Center velocity*	Line width* at half intensity	Total velocity* coverage
Optical	3870(a)		
CO	3933	270	3730-4169
HI	3900	151	3730-4048
OH(1667)	3841	106	3730-3927-4093(c)
OH(1665)	3857(b)	100	3742-3923-4074(c)

* in Km s^{-1} (a 1-sigma error is of the order of 10 Km s^{-1}).
(a) From Tifft and Gregory (1976).
(b) Allowing 352 Km s^{-1} for the Λ-doubling shift of the two OH mainlines.
(c) Total OH extent including the marginal emission.

3. Discussion:

In table 1 the velocity properties of the IC 860 constituents are assembled. Several remarks can be made. The difference in center velocity between the OH spectra and those of CO and HI suggests that the absorbed OH does not occupy the same region in space as the two other species. Moreover, a comparison of the linewidths at half intensity seems to show that the kinematics among the constituents may be different. A comparison of the nucleus of IC 860 with that of our Galaxy might provide an explanation for these discrepancies. In the direction of Sgr A the spectrum corresponding to the HI clouds in the line of sight occupies a velocity range of about 200 Km s^{-1}, while the much narrower feature (50 Km s^{-1}) corresponding to the molecular cloud of OH moves away (or expands) from the nucleus at a velocity of 40 Km s^{-1}. If the same picture is applicable to IC 860, we may conclude from table 1 that the OH cloud moves away from the nucleus at a velocity of 60 Km s^{-1}.

Nevertheless, the blue wings of the CO, HI and OH spectra are likely to correspond to gas in front of the radio continuum source. The diffuse atomic gas envelope resides in the outer portions of the dense molecular disk, which seems to be tilted edge-on resulting in a very high optical depth of 0.27 (Schmelz et al. 1986) for the OH tracer.

Located closer to the core of the nucleus, the existing infrared radiation is presumably the pump responsible for the inversion of the OH molecules in the foreground of the continuum source (Baan 1985). It is possible that the tilt of the molecular disk is such that the OH molecules are absorbed rather than inverted, thus partly occulting the masing process.

In this scenario it appears, considering the red wing, that the total velocity range of the HI and the OH tracers are very similar. This is not the case for CO which extends 120 Km s^{-1} farther than HI and about 80 Km s^{-1} farther than the total OH extent. It may be concluded that the molecular disk extends as far as behind the continuum source and that the observed CO emission is a mixture of the emission from gas clouds in front of and behind the nucleus.

This picture of IC 860 may be confronted with the spectroscopic observations reported by Tifft and Gregory (1976). The authors point out a redshift discontinuity or extreme tilt over a distance of 3.5 arcsec (1.2 Kpc). The velocities corresponding to the individual redshifts are 3500 Km s^{-1} and 3959 Km s^{-1}, the higher being the dominant one. In figure 1 there is no signal at 3500 km s^{-1}, while 3959 km s^{-1} is comparable to our center velocity of about 3933 km s^{-1} for the three species. Therefore, the presented results suggest an extreme tilt rather than a redshift discontinuity. Presumably the tilt occurs in the nucleus of the galaxy because, as mentioned below, IC 860 may possess an active core. Moreover, our CO observations (using the special observing procedure, see above) show that the emission of the molecule is confined to a small, possibly nuclear volume.

Based on the results by Tifft and Gregory (1976), the mean redshift of the Coma cluster is 6900 km s^{-1}, and the lowest redshift of any bright galaxy is about 4556 Km s^{-1}. Therefore, IC 860 seen at about 3900 Km s^{-1} is possibly an isolated galaxy. Moreover, most if not all galaxies of the Coma cluster have the morphology of S0 or elliptical galaxies (Chamaraux, private communication). The Palomar Sky Survey shows at the position of IC 860 (R.A. = 13h12m40s.1 and Decl. = + 24°52'52") a compact elliptical spot with extending plumes along the major axis in the direction N-NE and in the opposite direction southward; the intensity decreases quite abruptly beyond the dimensions of the galaxy which are 43 by 27 arcsec. Because of the sharp intensity distribution, IC 860 cannot be an elliptical galaxy: it is plausibly a disk galaxy, namely either an S0 or a spiral galaxy. Now, because of the existence of the plumes and of the blue PSS image (Figure 1, upper panel), we suggest a spiral morphology. Note that the photograph of the PSS is over-exposed which may explain why the spiral arms, if they exist, do not show.

From the comparison of total IR and CO luminosities (H_2 masses) in 122 galaxies, Young (1986) finds a general correlation. The scatter observed is highly correlated with dust temperature. Moreover, galaxies with high value of $L(FIR)/M(H_2)$ have high dust temperatures. Quantitatively, dust temperatures of 40-50 K would correspond to $L(FIR)/M(H_2)$ of 20-50 and 1-2 Kpc extragalactic cores (Sanders and Mirabel, 1985). Assuming a λ^{-1} emissivity, the dust temperature of IC 860 deduced from the 60/100 μm flux ratio is 49 K. If high dust temperatures and $L(FIR)/M(H_2)$ express massive star formation, then IC 860 has a very productive core since T_d = 49 K and $L(FIR)/M(H_2)$ = 160 $L_\odot$ $M_\odot^{-1}$ comparable to that of Mrk 231.

4. Concluding remarks:

Our measured central velocity of 3933 Km s^{-1} for CO seems very close to those measured for HI and OH. As mentioned in our discussion, we suggest a disk morphology, maybe spiral, for IC 860. Considering its star formation efficiency as compared with that of other spiral galaxies, it may be added that IC 860 behaves both like an interacting and like a starburst galaxy.

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Note added in proof

The CO detection reported in this letter is marginal, but potentially very interesting. It has been confirmed by observations made in April 1988 with the IRAM 30-m telescope.

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