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THE NUCLEAR STELLAR CLUSTER IN NGC 1068

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RESUMEN

Hemos obtenido imágenes de un cúmulo estelar compacto de 50 pc de tamaño, hacia el núcleo de NGC 1068, utilizando imágenes espectroscópicas de las líneas de absorción estelares en las bandas *H* y *K* del cercano IR. La luminosidad estelar emitida en estas bandas es debida a una población con tipo espectral medio M0. La relación masa luminosidad obtenida indica que la edad de este cúmulo nuclear es a lo sumo 4×10^9 años. El cúmulo mismo contribuye al menos con 5% de la luminosidad bolométrica nuclear. La posición del cúmulo coincide con la del máximo de brillo en la banda *K* y con el centro dinámico de la galaxia. Las imágenes en la línea molecular H_2 S(1), a 2.12 μm, muestran un anillo de ~100 pc de radio. Imágenes en la transición de CO J=2→1, a 1.3 mm, muestran el anillo rotando con velocidad ~100 km s^{-1}.

ABSTRACT

We have imaged a compact stellar cluster, with a characteristic size of 50 pc, toward the nucleus of NGC 1068, using near IR imaging spectroscopy of stellar absorption features in the *H* and *K* bands. The near IR stellar light is attributed to a population of late type stars, with an average spectral type of M0. Based on light-to-mass ratio measurements, we derive an upper limit for the age of the nuclear cluster of 4×10^9 years. The stellar cluster contributes a non-negligible fraction of the total nuclear bolometric luminosity, a value of 5% being a very conservative lower limit. The compact stellar distribution identifies the dynamical center of the galaxy as being coincident with the peak of the *K* band emission. The morphology of the excited molecular gas, revealed by mapping the H_2 S(1) line at 2.12 μm, shows a molecular ring with a radius of ~100 pc. Millimeter interferometric imaging in the CO J=2→1 transition at 1.3 mm shows the ring to be rotating with velocities of ~100 km s^{-1}.

Key words: **GALAXIES: INDIVIDUAL: NGC 1068 — GALAXIES: NUCLEI — GALAXIES: SEYFERT — GALAXIES: STAR CLUSTERS — GALAXIES: STELLAR CONTENT — INFRARED: GALAXIES**

1. THE NUCLEAR STELLAR CLUSTER

Using the MPE 3D integral field spectrograph (Weitzel et al. 1996) and the tip-tilt adaptive optics system ROGUE II (Thatte et al. 1995) at the 4.2-m William Herschel Telescope, we have obtained imaging spectroscopy of the nuclear region of NGC 1068 in the *H* and *K* bands. After appropriate processing of the data (calibration, flat-fielding, dead pixel correction, division by a reference stellar spectrum, and absolute flux calibration), we obtained maps in three absorption features arising from late-type stars: the Si feature at 1.59 μm, the CO (6,3) bandhead feature at 1.62 μm and the CO (2,0) bandhead feature at 2.29 μm. Origlia, Moorwood, & Oliva (1993) explain the use of these stellar features to characterize the stellar population. In NGC 1068, all three features are substantially diluted by the presence of non-stellar continuum emission in the nuclear region. Oliva et al. (1995) use the fact that the Si feature and the CO (6,3) feature are very closely spaced in wavelength to determine the dilution toward the nuclei of Seyfert 2 galaxies. They conclude that the dilution insensitive ratio of equivalent widths EW(Si 1.59 μm)/EW(CO (6,3) 1.62 μm) is a very good indicator of stellar temperature. Knowing the intrinsic stellar spectral type, they can then determine the dilution by comparing the observed EW of the CO (6,3) feature with the intrinsic width for the determined spectral type.

We find that in the central few hundred parsecs of NGC 1068 the average spectral type is M0. Using the spectral type information obtained from the *H* band images, and the variation of EW with spectral type,

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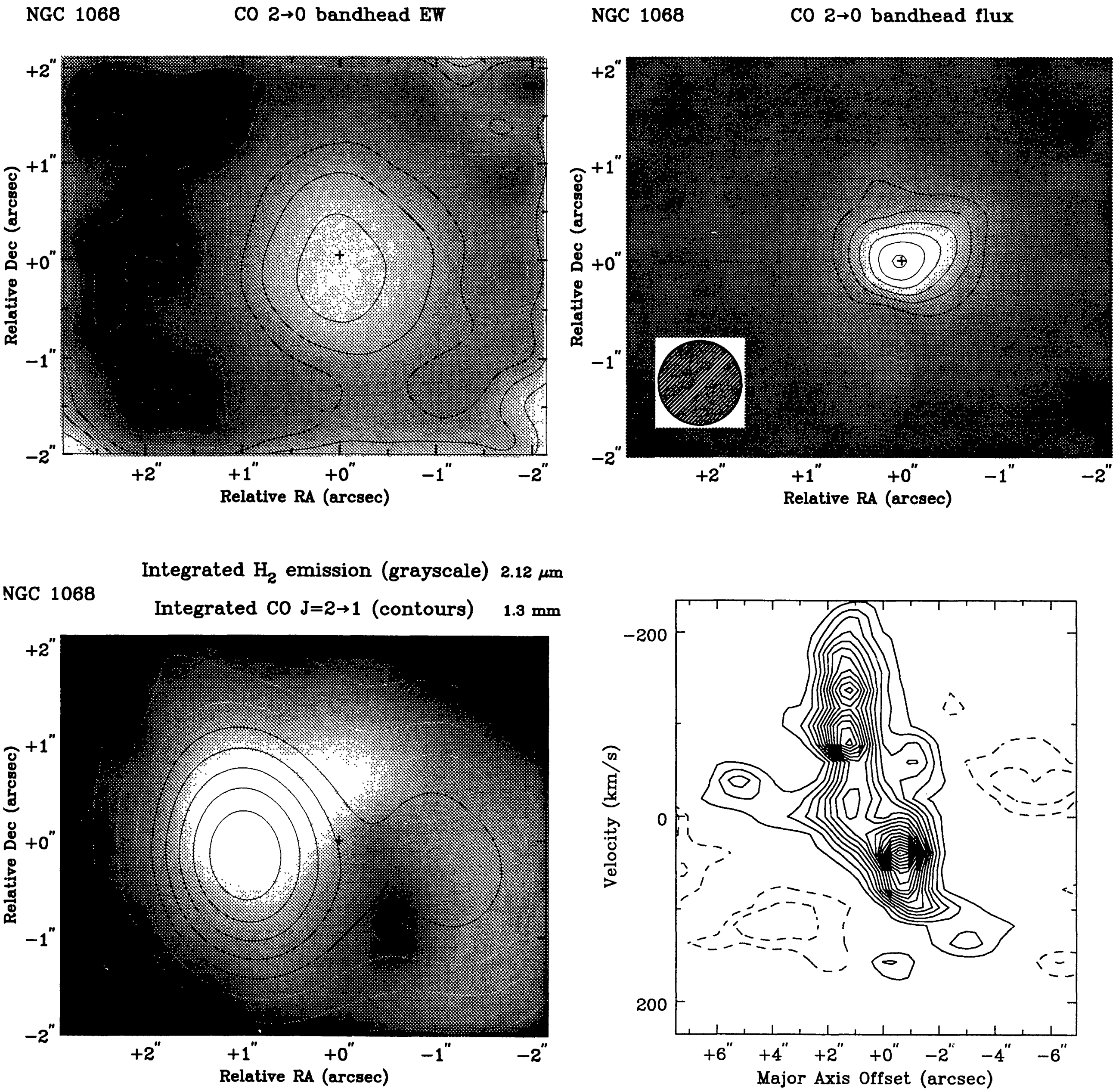

Fig. 1. *(a)*(top left) Equivalent width of the CO (2,0) bandhead feature at 2.29 μm. The position of the nucleus is indicated by a +. Contours are equi-spaced in intervals of 1Å. *(b)* (top right) Map of the absorption flux in the CO (2,0) bandhead feature. The seeing during the observations is indicated by the beam in the lower left corner of the picture.it (c) (bottom left) Map of the molecular gas distribution. The warm molecular gas, traced by the 2.12 μm H_2 S(1) line, is shown in grey scale, while the millimeter CO J=2→1 emission is shown in contours. A ring geometry is evident, with a bright spot close to the location of the narrow line region.*(d)* (bottom right) Position-velocity plot along the kinematic major axis of the molecular gas ring. A double peaked profile, characteristic of a rotating disk, is seen.

we obtained the dilution fraction at 2.29 μm using the observed EW of the CO (2,0) bandhead feature (see Figure 1*a)*. The K band dilution varies from 94% within the central 1″ to 54% at a distance of 2.″25 (150 pc) from the nucleus. The H band dilution has a maximum value of 71% in the central arc-second, decreasing to 47% at 150 pc from the nucleus. Figure 1*b*, shows a map of the absorption flux in the CO (2,0) bandhead feature. This map *truly* represents the spatial distribution of light from late type stars, even in the presence of dilution. The nuclear stellar cluster is spatially resolved, with an intrinsic FWHM of 0.″7 (48 pc). Stars are the best available tracers of gravitational potential, and the centroid of this compact stellar distribution represents the true dynamical location of the nucleus in NGC 1068. We have obtained relative astrometry, allowing us to pinpoint the location of the dynamical nucleus (which is coincident with the peak of the K band emission) relative to the peak of the V band emission (Thatte et al. in preparation). The position is almost coincident with the location of the 12 μm emission peak determined by Braatz et al. (1993).

By comparing the observed $V - K$ color in the central 2.″8 with the predicted color for a moderate age stellar population, we derive an A_V of 2.0 magnitudes toward the stellar cluster. This implies 1.35×10^8 $L_\odot$ for the total K band luminosity from stars in the central 5″. Using measured velocity dispersions toward the nucleus of NGC 1068, we obtain a *lower* limit on the light-to-mass ratio (L_K/M) for the central cluster of 0.084. Comparing this with models of stellar evolution provides an upper limit to the cluster age of 4×10^9 years. Comparing these values with the observed bolometric luminosity of the nucleus of NGC 1068, we find that *at least* 5% of the bolometric luminosity of the nucleus is attributable to stars. This number is a very conservative lower limit, since we expect the mass in the central 50 pc to the dominated by the mass of the Seyfert nucleus.

The non-stellar continuum emission dominates the nuclear light in the H and K windows. We find that the ratio of H to K band non-stellar light, as well as the spectral slope of the continuum in the K band perfectly fits a thermal emission spectrum. Assuming an emissivity law for the warm dust which scales as $\lambda^{-1.5}$, we derive a dust temperature of 715 K in the central 1″.

2. MORPHOLOGY OF THE MOLECULAR GAS

Figure 1*c* shows the spatial distribution of warm molecular hydrogen, imaged in the 2.12 μm H_2 S(1) line with MPE 3D. The cold molecular gas, traced via the J=2→1 transition of CO at 1.3 mm, is depicted in contours. The warm molecular gas has a ring morphology with a radius of ~100 pc, with a bright spot which is best interpreted as the interaction zone of the narrow line region with the molecular material. The molecular gas distribution is asymmetric, being more pronounced north of the nucleus with very little gas south-west of the nucleus. This would provide a natural explanation for the absence of a narrow line region south-west of the nucleus. The molecular gas ring is rotating, with a rotation velocity of 92 km s^{-1}, as is evident from the kinematic major axis position-velocity plot shown in Figure 1*d*. Taking into account the different resolution, the cold molecular material, traced by the millimeter emission, shares the same morphology as the warm molecular material traced in the near IR. It is extremely likely that the ring of molecular material represents an inner Lindblad resonance, and the bar (Thornson et al. 1989; Scoville et al. 1988) is responsible for feeding molecular material into the ring. There does not seem to be any star-forming activity associated with the molecular ring, as we see no evidence for stellar absorption features in the near IR which resemble the morphology of the molecular ring.

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