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KINEMATICS OF THE STARS IN THE STARBURST NUCLEUS OF M82: JUST ANOTHER NORMAL STELLAR BULGE?

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RESUMEN

Usando el borde de la cabeza de banda de la absorción estelar $(2\text{-}0)^{12}$CO hemos medido la velocidad de dispersión de los 5″ centrales en la galaxia con brote de formación estelar M82. Usando tanto ajustes de mínimos cuadrados como deconvolución de máxima entrópia, hemos derivado la velocidad de dispersión de 100 km/s para la región central, $r < 7.5$ pc. El cociente masa-luz que esto implica es más de 10 veces mayor que en las regiones circundantes de la galaxia, y es comparable a la misma región espacial en nuestra galaxia. Esto significa que la luz estelar del núcleo brillante en el infrarrojo cercano está dominada por una población más vieja, de estrellas gigantes y no por supergigantes formadas en el brote de formación estelar.

ABSTRACT

Using the sharp edge of the $(2\text{-}0)^{12}$CO stellar absorption bandhead, we have measured the velocity dispersion from the central 5″ of the starburst galaxy M82. Using both minimum least squares fitting and maximum entropy deconvolution we have derived a velocity dispersion for the central $r < 7.5$ pc of 100 km/s. The mass-to-light ratio this implies is more than 10 times higher than in the surrounding regions of the galaxy, and is comparable to the same spatial region in our own galaxy. This implies that the starlight from the near-infrared-bright nucleus is dominated by an older population of giants and not by supergiants formed in the starburst.

Key words: **GALAXIES: INDIVIDUAL (M82) — GALAXIES: KINEMATICS AND DYNAMICS — GALAXIES: NUCLEI — GALAXIES: STARBURST — GALAXIES: STELLAR CONTENT — TECHNIQUES: SPECTROSCOPIC**

1. INTRODUCTION

M82 (NGC 3034) is the closest (D = 3 Mpc) and best studied example of a galaxy undergoing a nuclear starburst. For this reason, it has often been used as a prototype for more distant, luminous starburst systems. However, the source of the large luminosity, be it young supergiants or old bulge giants, in even this nearby starburst is not clear. Using the ratio of mass to light, which is sensitive to the mass range of stars which dominate the continuum, we can determine which mass range of stars is responsible for its characteristically

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high near infrared luminosity. This has been the motivation behind previous kinematic studies of M82 (Rieke et al. 1980, Beck et al. 1979). However, because of the sensitivity limitations of infrared spectrometers at that time, they relied on bright emission lines to measure the kinematics. In active regions, such as starburst nuclei, the impact of gas flows on kinematics of these regions can rival the motions due to gravitational forces. Hence, mass estimates in these regions calculated using emission lines can be misleading. It is important to examine the kinematics of the stars in these galaxies directly, as their motions will not be influenced by shocks or other non-gravitational forces which can effect the kinematics of the gas. Optical absorption line studies in M82, similar to those done for elliptical galaxies, have been hampered by high extinction towards the starburst nucleus. With the commissioning of the CSHELL echelle spectrometer at the NASA Infrared Telescope Facility (IRTF), we can now measure the stellar kinematics in this and other heavily obscured regions.

In this study, we have used the (2-0)^{12}CO absorption bandhead to measure the radial velocity and velocity dispersion across the central 5″ of M82. We chose this absorption feature because it is both strong (> 50% drop in the continuum level) and sharp in the absence of velocity smearing. Thus, it has a significant amount of Fourier power distributed across a wide frequency range. Because the bandhead absorption is strongly dominated by a single absorber, its shape is not a function of the metallicities of the stars in the galaxy. The band also has a very well defined shape. Finally, it is a well studied feature in the spectra of stars, and has been well reproduced in the spectra of a wide range of stars (see Smith & Suntzeff 1989).

2. Technique

We observed M82 with with the CSHELL spectrometer (Tokunaga et al. 1990) on the NASA IRTF on 1992 April 28. The instrument was used with a slit width of 1″ and a 256× 256 HgCdTe NICMOS III array. The resulting spectrum was four times oversampled with a resolution of 15 km/s. Wavelength calibrations were carried out with Ar and Kr emission lamps internal to the instrument. The errors in our wavelength solutions were less than 3 km/s. Pointing and guiding were checked using the instrument's direct imaging capability, thus no corrections for differential atmospheric refraction between the near-infrared and optical images were needed. More details of the observations and data reduction are found in Gaffney, Lester, & Telesco (1993). One dimensional spectra were extracted using 1″ apertures centered on 0.5″ spacings along the slit. The resulting spectrum for the central 1″ ($r < 7.5$ pc at the distance to M82) appears in Figure 1.

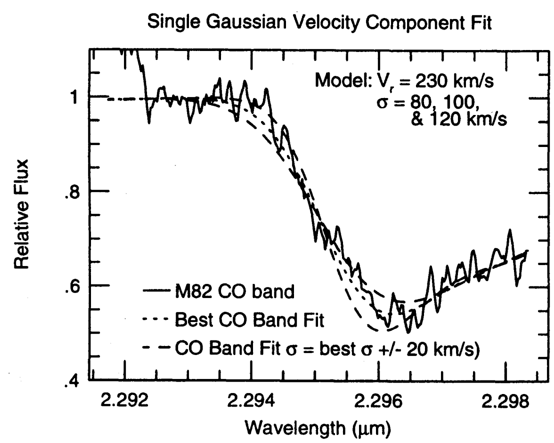

Figure 1 — The observed CO spectrum from the central 1″ of M82 with our best fit to the data using a modeled stellar CO spectrum smoothed with a V_r = 230 km/s and σ = 100 km/s.

In order to extract velocity information from the spectra, we needed a template for the CO band in the absence of velocity dispersion. Because of the flexibility that models provided in exploring the behavior of the CO band, we chose to model the stellar CO template using standard model atmosphere calculations. Using line transition strengths from Smith & Suntzeff (1989) and model atmospheres calculated with a recent version of the MARCS code (Gustafsson et al. 1975), we calculated a grid of model spectra. Our analysis of these spectra demonstrated that a single parameter which completely characterizes the shape of the CO band is its equivalent width, regardless of any peculiarities in the stellar atmosphere. We have therefore used a model CO spectrum with the same CO equivalent width as seen in M82.

We derived the kinematical profile in two independent ways: by minimizing the variance between the model CO bands smoothed by Gaussians with different V_r and σ, and, where the signal-to-noise was sufficient, using a maximum entropy routine outlined in Lester et al. (1986). Where both were employed, the derived velocity profiles were consistent. The resulting rotation curve and velocity dispersion measurements are found in Figure 2. The error bars indicate the range of parameter space in which the fit is consistent with the data.

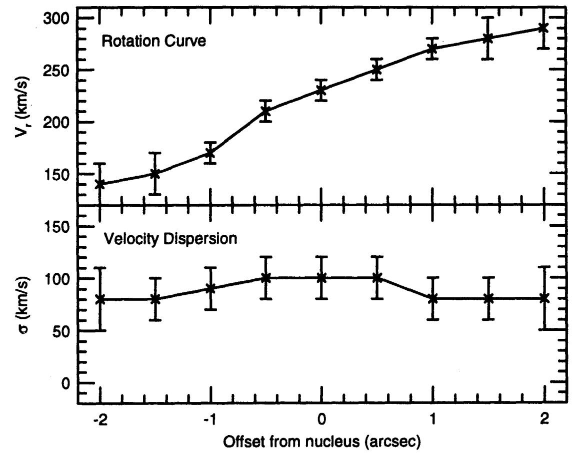

Figure 2 — The stellar rotation curve and velocity dispersion measured across the central 5″ of M82. Note that the rotation curve is essentially linear, and the velocity dispersion is roughly constant.

3. Mass of the Nucleus

From these data, we have derived these parameters for the central $r < 7.5$ pc (0.5″) of M82: $V_r = 230$ km/s, $\frac{dV_r}{dr} = 50$ km/s/arcsecond, $\sigma = 100$ km/s, and $\frac{d\sigma}{dr} = 0$ km/s. Using the first moment of the collisionless Boltzmann equation (McGinn et al. 1989):

$$M(<r) = \frac{r\sigma^2(r)}{G} \times \left(-\frac{d\ln n(r)}{d\ln r} - \frac{d\ln \sigma^2(r)}{d\ln r} + \frac{V_r^2(r)}{\sigma^2(r)} \right)$$

where σ is the pure velocity dispersion (uncontaminated by the effects of unresolved rotational motions), n is the stellar number density, and V_r is the pure rotational motion of the stars at the radius r. We estimated the change in the number density of stars ($\frac{d\ln n(r)}{d\ln r}$) using the K band flux density ($F_K(<r) \propto r^{1.2}$), which implies that $n(r) \propto r^{-1.8}$. As noted in Gaffney, Lester, & Telesco (1993), the inflation of σ by unresolved rotation in the central 1″ is minimal ($<$ 5% of the observed σ), and we have ignored it in this discussion. From these numbers, we find M(r<7.5 pc) = $3 \pm 1 \times 10^7 M_\odot$.

Comparing the mass-to-light ratio of the central 1″ to that seen in the central 30″ is quite revealing. The K-band flux from the central 1″, interpolated from the data of Pipher et al. (1988) and Telesco et al. (1991), and in the central 30″ (Rieke et al. 1980) are 26 mJy and 2.5 Jy respectively. The masses for these two regions are $3 \times 10^7 M_\odot$ (this work) and $3 \times 10^8 M_\odot$ (Rieke et al. 1980). These measurements indicate that the mass-to-light ratio goes down by a factor of 10 as one moves outward from the nucleus. This supports the model for M82 with the near infrared light from the central few arcseconds being dominated by an older population of giant stars surrounded by a starbursting disk in which supergiants dominate the near infrared continuum.

We can compare the mass-to-light ratio in the central r $<$ 7.5 pc of M82 with the same region of our own galaxy. The dereddened K band luminosities of M82 and our Galaxy are $1 \times 10^8 L_\odot$ and $6 \times 10^7 L_\odot$ (Bailey 1980) respectively. Both regions have masses of $3 \times 10^7 M_\odot$ (M82: this work, the Galactic Center: McGinn et al. 1989). Thus, the mass-to-light of the central r $<$ 7.5 pc of M82 and the Galactic center are similar, indicating that they are dominated by the same mass range of stars.

4. The Future of the Technique

Clearly, these results demonstrate the potential of this technique for measuring stellar kinematics in galaxies. Using a strong, sharp, near infrared absorption feature to probe the kinematics of dust shrouded galactic nuclei should lead to many interesting discoveries, including the existence of previously undetected mergers and massive cores. While the easiest method of extracting the velocity information has been through a least squares fit of the smoothed models to the data, this method introduces the prejudice that we are looking at systems with simple single-component velocity profiles. Because we do not sample enough of the CO band to have continuum points on both side of the band edge, standard Fourier methods of deconvolution produce large "ringing" effects which overpower the actual velocity profile. We have started to explore the potential of other deconvolution methods which do not rely on Fourier transforms, including the Richardson-Lucy method, CLEAN, and maximum entropy. Because of the sharp non-symmetrical appearance of the unsmoothed CO band, we found the CLEAN and Richardson-Lucy methods to be extremely sensitive to the noise in the spectrum, resulting in very peculiar and unrealistic velocity profiles. Because of the ability to "tune" the maximum entropy deconvolution to overcome the noise, it can be used more reliably in situations such as this. As the results of our initial tests appear promising, we are currently working on improvements to our algorithm to more reliably deconvolve multiple velocity component profiles.

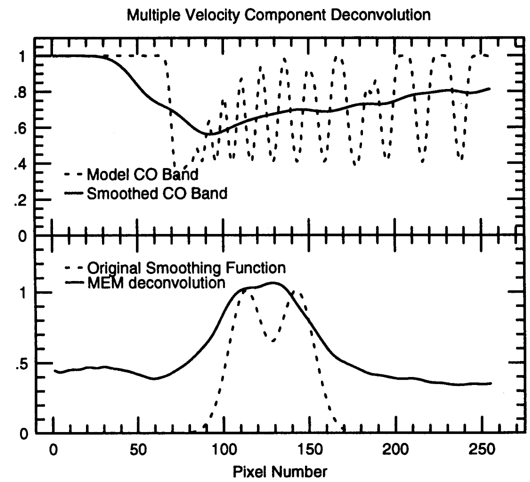

Figure 3 — A deconvolution test case, showing that the model CO band smoothed with two component velocity profile (upper plot), and the maximum entropy result compared to the original smoothing function (σ = 50 km/s separated by 120 km/s) (lower plot). Currently, our maximum entropy algorithm is barely able to distinguish these two components.

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