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THE KINEMATICS AND MORPHOLOGY of NGC 520: ONE, TWO, or THREE GALAXIES?

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ABSTRACT

The peculiar galaxy NGC 520 (Arp 157) is often interpreted as an interacting pair of galaxies. The identification of the two bulges and overall morphology of the two galaxies has long been a puzzle which we attempt to solve in this paper. New longslit optical spectroscopy and near-infrared images of NGC 520 are presented. These data suggest that the northwest peak is the bulge of one of two galaxies in the system. The other larger bulge is clearly evident in the K band image in the middle of the dust lane. The stellar radial velocity profile in the central 10" of the larger bulge is consistent with counterrotation seen in the molecular gas component. This kinematic subsystem could be the remains of a merged gas-rich irregular.

I. INTRODUCTION

Understanding the peculiar system NGC 520 (Arp 157) has been the goal of several workers using observations from many wavelength regions. One of the most basic questions about the system has been if the system is one disturbed galaxy or two interacting galaxies. From single dish H I mapping, Thuan and Wadiak (1983; hereafter TW) concluded that only one galaxy is present in the system. Stockton and Bertola (1980; hereafter SB) studied the optical emission line kinematics and concluded that there was evidence for two colliding galaxies in NGC 520.

An optical image of the system may be interpreted as a collision of two disk galaxies seen crossed and nearly edge-on. For ease of discussion, these disk-like structures shall be refered to as the east-west and southeast-northwest galaxies. The deep (~4.5 hours) photograph of NGC 520 in SB shows a long tidal tail apparently pulled from the southeast-northwest galaxy. This tail stretches south from the northwestern end of NGC 520, curving to the east and then north around the main body up to a distance of ~32 kpc (H_0=75 km s^{-1} Mpc^{-1}). Here we present new optical longslit spectroscopy and infrared imaging of NGC 520. These data suggest the location of two bulges within NGC 520. The presence of a counterrotating core in the larger bulge suggested by CO observations is consistent with the observed stellar kinematics in the central 10".

II. OBSERVATIONS

Longslit optical spectra were obtained with the GoldCam spectrograph on the 2.1 m telescope at KPNO in December 1988 with spectral coverage from 3880 to 4872 Å and a dispersion of 1.24 Å $pixel^{-1}$. The slit measured 2" by 4' with a spatial resolution of 0.78" $pixel^{-1}$. Two slit positions were observed at PA=87° and at PA=125°. Each night F, G and K type standard stars were observed to be used as velocity templates in the fourier quotient and cross-correlation analyses (hereafter FQ and XC, respectively; Sargent *et al.* 1977). Reductions were performed with IRAF[1] using standard procedures. Each aperture extracted from the two slit positions was the sum of three columns, which corresponds to a width of 2.34". Near-infrared JHK broadband images were obtained using IRIM on the 1.3 m telescope at KPNO on 11 December 1988 UT. The spatial resolution was 1.35" pixel^{-1} and the seeing was estimated to be 1.5-2" at the time of the observations. Exposures of the blank sky in each band at several positions near NGC 520 before and after the object images were used for sky-subtraction at each wavelength, which accounted for the subtraction of the dark count in the process. Flatfield images were obtained by median summing all the sky images obtained in the course of one night at each wavelength at each integration time. Observations were obtained of standard stars taken from Elias *et al.* (1982) to calibrate the photometry.

III. RESULTS

Radial velocity profiles of both optical spectroscopy slit positions were first obtained with the XC routine and then velocity dispersions were obtained with the FQ routine. The XC-determined velocities were used as input to the FQ program. Because of the low signal to noise ratio at most points along the slit, pairs of apertures were added in order to obtain more accurate velocity dispersions. Thus, the points in the plotted dispersion profiles represent 4.7" apertures. The XC radial velocities for slits 1 and 2 are shown in Figure 1, along with the velocity dispersions obtained from the FQ routine. All radial velocities shown in this paper are heliocentric. The zeropoint on the abscissa corresponds to the nucleus position of the east-west galaxy (henceforth called the primary nucleus), as determined from a K band image (see below).

A contour plot of the single frame K band image is presented in Figure 2 which covers the central 78" x 84" of NGC 520. Using the APPHOT package in IRAF, magnitudes were obtained of selected areas of the JHK images using 2.7" apertures as shown in Figure 2. The K band image shows one bulge in the middle of the east-west dust lane, and another peak which coincides with the optical northwest emission peak. The colors obtained at the larger bulge indicate that although there is a significant amount of obscuration and hot dust emission, the elongated shape in the central 10" is primarily due to stellar light.

IV. DISCUSSION

As stated in the introduction, the first question to be answered is whether NGC 520 is a single disturbed galaxy, or two interacting galaxies. Perhaps the most interesting and important

[1]Image Reduction and Analysis Facility is distributed by the NOAO, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.

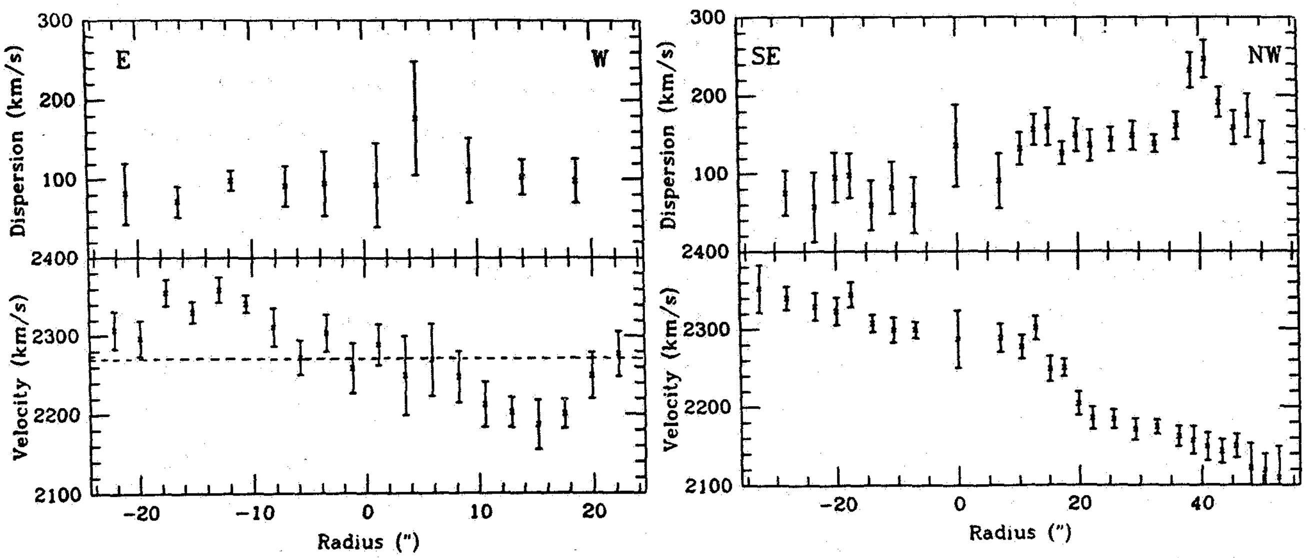

Figure 1. Radial velocity and dispersion profiles of slits 1 (left) and 2 (right). The velocities were obtained from the average of all slit 1 exposures, using the XC routine to find the radial velocties and the FQ routine to find the velocity dispersions. Except as noted in the text, each point represents a three column wide aperture ~2.3". The errorbars represent one σ errors. The zeropoint in radius is at the position of the primary nucleus. The horizontal dashed line in the slit 1 profile represents the systemic velocity of the nucleus.

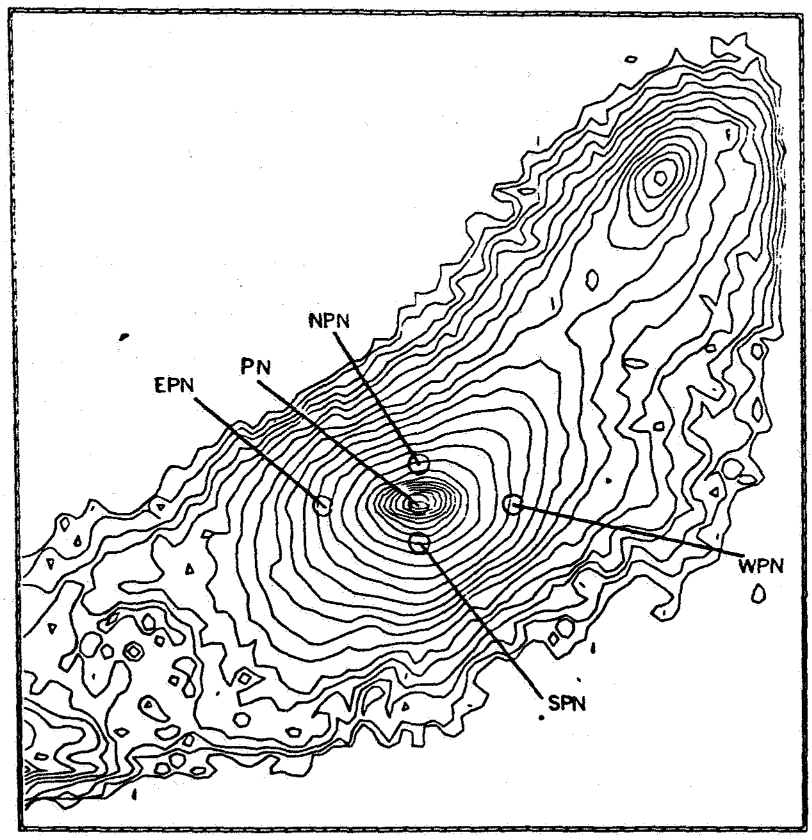

Figure 2. Contour map of the K band image. The lowest contour represents 19.0 magnitudes arcsec^{-2} and the contour interval is 0.2 magnitudes. The scale is 1.35 arcsec pixel^{-1} and the axes are in units of pixels. The positions of the small aperture photometry are shown by the circles whose diameter equals the aperture size.

result bearing on this question is seen in the velocity dispersion profile from slit 2. At the position of the northwest emission peak there is a sharp rise of 100 km s^{-1} to a peak value of 240 km s^{-1} which quickly drops back to ~140 km s^{-1} to the northwest. We believe that this dispersion peak is real because it is seen in the profiles determined separately from the night 3 and night 4 spectra. That the dispersion peak is due to the presence of a bulge is a natural explanation because galactic bulges have high dispersions. The calculated dynamical mass at the dispersion peak of ~1.5 x 10^{10} M_o is reasonable for a 1.5 kpc diameter region centered at a galactic bulge. We suggest that the northwest peak is one of the bulges of the galaxies in NGC 520.

Next, we discuss the slit 1 velocity profiles obtained for the east-west galaxy. The velocity at the nucleus position r=0 is taken to be the systemic velocity. The velocity profile has an overall S shape. Over the central 30"≈4.5 kpc, the radial velocity points can be fitted fairly well by a straight line, indicative of solid body rotation. In the central 15" of the slit 1 velocity profile, there is a hint of a series of velocity reversals. The error bars are too large for us to be confident in the reality of the reversals. However, they trace a pattern which is highly symmetric about the nucleus position and velocity. Moreover, this pattern is seen in the profiles obtained from the separate spectra of night 1 and night 3, lending credence to the reality of the reversals. Complicating the interpretation of the apparent bumps is that slit 1 may lie at an angle to the major axis of the east-west galaxy, and that the stellar light from the central 15" contains contributions from both bulge and disk stars.

The kinematics of the primary nucleus has also been investigated in the CO line (Sanders *et al.* 1988). The CO linecenter V_o(CO)=2261 km s^{-1} agrees with the systemic V_o(stellar)=2275 km s^{-1} found in the slit 1 velocity profile at the position of the primary nucleus. More interesting is that the CO profile over the central 6" is in counterrotation with respect to the overall decline in velocity in the east to west direction seen by SB and by us. The elongated morphology and the velocity profile of the CO emission shows that the molecular gas probably lies in a rapidly-rotating disk. The counterrotating molecular disk gives support to believing the reversals seen in our stellar radial velocity profile. Such velocity reversals have been observed in other galaxies (Kormendy 1984; Jedrzejewski and Schechter 1988; Balcells and Stanford 1989). The reversals have been described as counterrotation due to a cannibalized dwarf elliptical galaxy (Balcells and Quinn 1989) or to a young stellar disk formed out of an ingested irregular galaxy. There is one important problem with the counterrotation interpretation. SB found a monotonic decline in the optical emission line velocities over the central 6" at the primary nucleus, indicating the ionized gas does not also show counterrotation. No firm conclusion can be drawn on the possible velocity reversals until better longslit spectra can be obtained along the east-west galaxy.

At the primary bulge, Young, Kleinmann and Allen (1988) find apparently strong Hα emission veiled by dust. The Hα data argue in favor of current star formation within the central 20" of the primary bulge. The morphology of this region suggests an explanation of the star formation. At the primary nucleus, the K band image shows the same elongated structure seen in the CO source. The ratio of the axes at r=8" is about 2:1 in the K band light. We speculate that massive stars recently formed out of the CO disk, and have become red supergiants which dominate the K band light in the central 6". Hence, instead of the spherical shape seen in the K band contours at radii outside of the 12" diameter CO source, an elongated shape is seen in the central 6" because the dominant stars formed out of a nuclear disk. Furthermore, if we firmly believed that the primary contained a merged, counterrotating system, then we could further speculate that the kinematics of a counterrotating gas disk would be likely to cause a burst of star formation by producing a higher than normal cloud-cloud collision rate.

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