SOUTH POLE NEAR INFRARED ASTRONOMY: SITE CHARACTERISTICS AND DEEP SPIRAL GALAXY IMAGING

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Abstract

The Center for Astrophysical Research in Antarctica (CARA) operates a 0.6 m infrared telescope at the earth's South Pole. Using this telescope, we have confirmed that the South Pole has the world's darkest skies in the thermal portion of the K band atmospheric window. Based on K_{dark} band (2.29–2.43 μm) observations, we find evidence of extended halo emission in the edge-on spiral galaxy ESO/Uppsala 240-G11. After NGC 5907, 240-G11 is the second edge-on spiral for which there is recent direct-imaging evidence of halo emission.

1 Introduction

Since early 1994, the Center for Astrophysical Research in Antarctica (CARA) has operated a 60 cm infrared telescope at the earth's geographic South Pole. Initially, much of the telescope time was dedicated to site characterization. As a result, a comprehensive picture of the infrared observing conditions at the South Pole is emerging. We have also begun to make a number of scientific observations. These programs, emphasizing very deep K_{dark} band (2.29–2.43 μm) imaging or 24 hour observing, were selected to exploit the unique advantages of the South Pole site. This paper briefly summarizes the current state of our knowledge of the South Pole's site characteristics, the scientific advantages that arise from these unique conditions, and provides some preliminary results from our program of very deep K_{dark} band surface photometry of spiral galaxies. Our goals include measuring disk scale lengths and scale heights as well as searching for faint emission which may be associated with dark matter halos.

We have found evidence for very extended K_{dark} band emission perpendicular to the disk of the edge-on spiral galaxy ESO/Uppsala 240-G11. In the morphologically and dynamically similar edge-on spiral NGC 5907, Sackett *et al.* [8] argue that the observed R band halo emission falls off less steeply with radius than any known luminous component in spiral galaxies. After NGC 5907 (see for example [8, 5, 4, 7]), 240-G11 is the second edge-on spiral for which there is recent direct-imaging evidence of halo emission . As such, follow-up observations of 240-G11 at optical and near infrared wavelengths can provide a valuable complement to the growing body of data on NGC 5907.

Although these measurements provide evidence that at least some spiral galaxies have detectable optical and near infrared halo emission, it is not yet clear that this emission traces dark matter. Sackett *et al.'s* [8] detection in NGC 5907 of an R band halo has been confirmed at V and I bands by Lequeux *et al.* [5], at J and K bands by James and Casali [4], and at J and K_{short} (1.98–2.32 μm) bands by Rudy *et al.* [7]. However, Sackett *et al.'s* [8] conclusion that NGC 5907's shallow luminosity profile is consistent with the inferred dark matter halo has not yet been convincingly confirmed. With its low K_{dark} band background, the South Pole offers the best prospect for determining near infrared surface brightness profiles at the necessarily faint limits.

From an instrumental perspective, the South Pole offers several compelling advantages as an infrared site. These include the world's lowest thermal background, the world's lowest precipitable water vapor, and 6 months of continuous darkness. These advantages are partially offset by seeing which has a median value of 1.7 arcsec at visual wavelengths.[1] Most of this seeing originates in a strong temperature-inversion layer in the lower 200 m of the atmosphere. Microthermal experiments suggest that elevating the telescope a few 10s of meters can significantly improve the seeing. Similarly, because most of the turbulence is so close to the telescope, the isoplanatic angle is large, and simple adaptive image-sharpening techniques such as tip-tilt should be very effective at infrared wavelengths.

2 South Pole Site Characterization

Our initial site characterization program focused on determining the South Pole's 2-5 μm background, seeing, atmospheric transmission, and photometric stability. A high priority early goal was exploring the scientific potential of an optimized K_{dark} filter.

The K band atmospheric window extends from about 2.0–2.5 μm. The K_{dark} filter admits the long wavelength portion of this window from 2.29–2.43 μm. At wavelengths shorter than 2.27 μm, the near infrared background at all ground based sites is dominated by a forest of intense, narrow, and highly variable OH lines. For the most part, these lines originate in reactions between atomic hydrogen and ozone molecules in a 9 km thick layer 87 km above sea level [2]. At temperate sites and at wavelengths longer than 2.27 μm, thermal emission from the telescope and atmosphere contributes a total background comparable to the OH emission at shorter wavelengths. At the South Pole however, winter temperatures are usually less than -60 °C and the background at the thermal end of the K-window is greatly reduced.

We find that under average observing conditions, the atmospheric component of the South Pole's K_{dark} band background is ~17 mag arcsec^{-2} at one airmass. On the days that we made the deep K_{dark} band galaxy observations, some of which are reported here, the K_{dark} band

[1]Atmospheric turbulence theory predicts that FWHM scales as $\lambda^{-1/5}$ yielding FWHM = 1.5, 1.3, and 1.0 arcsec in K_{dark} , L' , and 10 μm bands respectively.

background ranged from 16.3 mag arcsec^{-2} at zenith to 17.3 mag arcsec^{-2} at zenith. Moreover, because the low-emissivity telescope is colder than overlying air layers, the total background is always very close to the atmospheric background.[2] These South Pole figures compare with a total K' band background of ~14 mag arcsec^{-2} at zenith reported for Mauna Kea on a T=275 K night [10]. These values are somewhat darker than the 162±67 μJy arcsec^{-2} (~16.5 mag arcsec^{-2}) K_{dark} values reported in 1996 by ourselves [6] and confirmed by our Australian collaborators [1]. However, our more recent numbers may be more representative of typical clear observing conditions. Also, since our earlier papers, the telescope has been moved to a slightly higher location.

Although the South Pole's K_{dark} band background is over an order of magnitude lower than typical K-window backgrounds at other ground based sites, it is higher than one might expect based on theoretical atmospheric transmission models. However, we believe that the observations can be adequately explained by semi-empirical models which contain additional continuum opacity contributions from water vapor and ice crystals. For example, standard atmospheric models like LOWTRAN and HITRAN do not include any opacity due to ice, and we know that blowing snow and a phenomenon called "diamond dust" are commonly present at some level at the South Pole. Diamond dust is composed of fine ice crystals which selectively form within the cold boundary layer below approximately 200 m altitude. Since the scale heights of both blowing snow and diamond dust are small, useful reductions in background may result from modest increases in the elevations of future telescopes.

3 Halo Light in the Edge-on Spiral Galaxy 240-G11

The South Pole is the world's premier site for imaging the faint isophotal structure of nearby galaxies at infrared wavelengths. Such observations place important constraints on galaxy formation models [9], and may constrain the nature of dark matter in spiral galaxies. Surface photometric observations are limited by flat fielding, and flat fielding on large angular scales is limited in practice to about 0.1% of the background (see for example [8]). Because the ultimate limitation is flat fielding, the South Pole 0.6 m telescope is an order of magnitude more sensitive to extended K window emission than any other telescope, irrespective of aperture.

We have begun imaging a sample of nearby spirals with published rotation curves as deeply as possible in K_{dark} band. Our goals include measuring disk scale lengths, thick disk scale heights, disk flaring, and searching for halo emission that may trace dark matter. In the edge-on spiral 240-G11, we have identified faint K_{dark} band halo emission extending to vertical heights $z \sim 31 h_{80}^{-1}$ kpc away from the disk. Figure 1 shows the 240-G11 image incorporating 8 hr of total integration (~4 hr on-source). The image reaches a limiting SNR=1 isophote of 23.7 mag arcsec^{-2}.

Figure 2 shows radial cuts through the nucleus of 240-G11. A line was fit to each cut using a sigma-clipping algorithm to reject stars, possible clumps of infalling material, and bad pixels. In each case, we started by assuming a non-detection. After fitting, however, each slice showed a negative intensity gradient that was significant at the 2 sigma level. These gradients were robust against a variety of variations in the flat fielding procedure and deconvolving an instrumental point spread function covering the full area over which the intensity gradient was measured.

Working at these faint levels is very challenging, and our detection of halo emission in 240-G11 needs to be confirmed. Moreover, it is important to remember that detecting halo

[2]Because of the strong temperature inversion driven by radiative cooling of the snow surface, the effective temperature of the atmosphere is typically 20 °C warmer than the surface temperature.

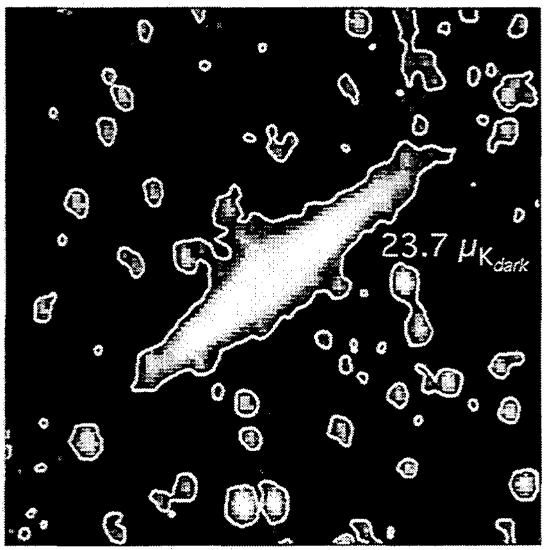

Figure 1: This K_{dark} band image of the edge-on spiral 240-G11 reaches a SNR = 1 limiting isophote of 23.7 mag arcsec^{-2} with 4 hr of on-source integration. This conclusion is not substantially altered by variations in flat fielding or deconvolving the instrumental point spread function. K_{dark} band light is detectable $\sim$31h_{80}^{-1} kpc from the nucleus in all directions.

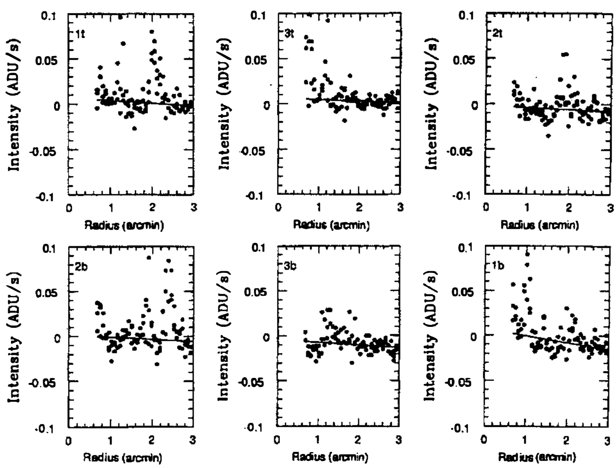

Figure 2: Radial cuts were taken through the nucleus at position angles (PA) = 90°, 45°, 0°, 270°, 225°, and 180° (PA=0° is North and PA increases counterclockwise). The ordering is from left to right across the top and then from right to left across the bottom. Each cut shows a negative slope that is $\sim 2\sigma$ above the fitting error.

emission, in and of itself, does not imply dark matter. In addition to detecting halo light, it is essential to demonstrate that the the luminosity profile is consistent with an $\sim r^{-2}$ mass density profile. The cuts shown in Figure 2 do not have adequate signal-to-noise for this. As a consequence, we are working on modeling the galaxy well enough to subtract the nucleus and disk and fit isophotes averaging over much larger numbers of pixels.

4 Conclusion

Since 1994, CARA has operated an 0.6 m infrared optimized telescope at the earth's geographic South Pole. Using this telescope, we have confirmed that the South Pole has the world's darkest skies in the K_{dark} portion of the K band atmospheric window from 2.27–2.43 μm.

We find evidence of extended halo emission in the edge-on spiral galaxy ESO/Uppsala 240-G11. After NGC 5907, 240-G11 is the second edge-on spiral for which there is recent direct-imaging evidence of halo emission. This result is robust against variations in flat fielding and deconvonvling the instrumental point spread function. However, due to the difficulty of working at these faint limits, this result needs to be confirmed. For this reason, 240-G11 is the highest priority target in our faint spiral galaxy imaging program this year.

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