Proplyds and Silhouette Disks in the Carina Nebula

Adapted from NOAO Press Release 03-01, which was featured jointly with results from Keck in a press conference at the January 2003 AAS meeting in Seattle (Subsequent media coverage included the Associated Press and Reuters wire services, CNN-TV Headline News and CNN.com, USA Today, Space.com and SCIENCE)

Observers using the Mosaic II imager on the Blanco 4-m have reported the discovery of what may be dozens of bright "proplyds" and dark silhouette disks within the hostile environment of the Carina Nebula.

Both proplyds and silhouette disks are generally recognized to be circumstellar matter surrounding young stars that is rendered visible by ionizing photons from nearby hot stars. As their name suggests, silhouette disks are seen in absorption against bright-background line emission from an HII region. In the case of the proplyds, the circumstellar material is itself lit up as it is ionized by photons from the hot star. Proplyds are, thus, sources of bright line emission. The name "proplyd" is derived from the likelihood that the circumstellar material harbors a protoplanetary disk.

The well-known images of proplyds in the Orion Nebula are some of the most arresting obtained with the Hubble Space Telescope (HST). They graphically illustrate how the radiation environment of young stars is responsible for sculpting and eroding (through photo-ablation) circumstellar material.

The new study of proplyds in the Carina Nebula (Smith, Bally, Thiel, and Morse, 2003; submitted to *ApJ Letters*) is the first to detect large numbers of proplyds outside Orion. The inset image on the *Newsletter* cover shows some of the detected bright proplyds (top row) and silhouette disks (middle row). The bottom row of the image shows objects with unusual shapes not seen in Orion, such as large round heads and thin tails. Each panel in the figure is 15 × 15 arcsec.

"These intriguing proto-planetary systems in the Carina Nebula are located near several of the hottest and most massive stars known in the Milky Way," says Nathan Smith of the University of Colorado. The Carina Nebula is indeed impressive—it spans several square degrees and is powered by more than 60 O stars. The Lyman continuum luminosity of the nebula is larger than that in Orion by a factor of approximately >100. Although the central star clusters have cleared most of the remnant molecular cloud material from the core of the nebula, regions of ongoing star formation have been previously identified at the edges.

Because of the harsh radiation environment even at the edges of the nebula, proplyds are expected far from their ionizing sources, at an angular distance more than a degree away. These large angular scales could be surveyed efficiently using the large field-of-view provided by Mosaic II on the Blanco 4-m telescope.

In their Hα, [SII], and [OIII] survey, Smith et al. found that despite the inhospitable environment, the proplyds they detected were large, ~4 to 5 arcsec in size (~10^4 AU) and several times the physical size of the proplyds in Orion. The lack of smaller proplyds is, in part, a selection effect since the Carina Nebula is five times more distant than Orion. In addition, the survey was carried out from the ground rather than with HST.

Nevertheless, the detection of large proplyds is surprising—where are their counterparts in Orion? Smith et al. speculate that the larger Carina proplyds may result from the evaporation of larger, more massive disks such as those expected for the progenitors of Herbig AeBe stars. These young, intermediate-mass stars are expected to be more numerous than in the Orion Nebula since the Carina Nebula is a far richer star-forming region.

"One explanation for this peculiar situation may be that the Carina proplyds have more massive protoplanetary disks than those in Orion, since the whole region of Carina tends to give birth to more massive stars," explains John Bally (University of Colorado). An alternative explanation discussed by Smith et al. is that the larger proplyd sizes are due to higher far ultraviolet/extreme ultraviolet flux ratios in the Carina Nebula.

Further observations are required to confirm that the identified proplyds do indeed harbor young embedded stars and protoplanetary disks, as well as to answer the new questions raised by these observations.

"More intensive imaging and spectroscopy are needed with the sharper view of HST to see if these objects really are proplyds like those in Orion, since some may turn out to be starless molecular globules. HST images are also needed to look for smaller ones, comparable in size to those in Orion, to determine if they too can survive in the less hospitable environment," Smith notes. "Thanks to the Mosaic II images from the CTIO 4-m, we now know where to point HST."

A Warp in the Disk of the Large Magellanic Cloud?

A new study of the shape of the Large Magellanic Cloud (LMC) by CTIO Research Experiences for Undergraduates student Colette Salyk of MIT and NOAO astronomer Knut Olsen has revealed evidence for a warp in the disk of this nearby galaxy.

Salyk and Olsen observed 50 fields in the LMC with the CTIO 0.9-m (see figure 1). In each of the fields, they identified and measured the brightness of the "red clump" stars. These intermediate-age, metal-rich, core helium burning stars shine with a well-defined luminosity and color. Since red clump stars are both bright and numerous, they are a useful relative distance indicator.

Salyk and Olsen used the observed color of the clump in each field to estimate the extinction to the field, and they used the extinction-corrected brightness of the clump to determine the distance to each field. By mapping the changes in the relative brightness of the clump stars from field to field, they were able to trace out the geometry of the LMC.

The results of this study are illustrated in figure 2. The first panel (a) shows the relative positions of the fields studied, as projected on the plane of the sky, where each field is depicted as a dot. The second panel (b) shows what the LMC would look like if it was rotated along the horizontal axis (of panel a) to an angle (~90 degrees) where the LMC is seen approximately edge-on. The vertical axis in the plot shows the relative differences in the brightness of the clump stars in magnitudes. The length of the cigar-shaped points corresponds approximately to the measurement errors.

The third panel (c) shows what the LMC would look like if it were further rotated (from the configuration shown in panel b) along the vertical axis until the line of nodes is reached. This shows that the LMC is tilted by ~35 degrees out of the plane of the sky. This result agrees with that obtained previously by van der Marel and Cioni (2001) using AGB and TRGB stars, although the new result is a substantial improvement due to the higher spatial resolution of the study.

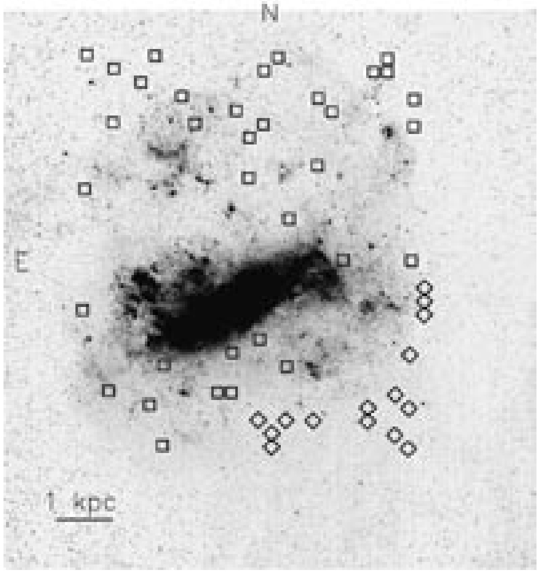


Figure 1

In a new wrinkle, however, Salyk and Olsen find that the disk of the LMC also appears to be bent. The southwest portion of the disk (the right edge in panel c) clearly deviates from the plane of the disk, with features extending 2.5 kpc out of the plane towards the Earth. "This discovery fits nicely into a picture where an interaction with the SMC or the Milky Way pulled out this material—the warp is aligned with the long axis of the LMC's elliptical shape," Olsen says. This interpretation is supported by the kinematics of the LMC's carbon stars, which also show a disturbance in this region of the galaxy.

These results were reported by Salyk and Olsen at the January 2003 AAS meeting and have been published recently in the *Astronomical Journal* (Olsen and Salyk 2002, *AJ*, vol. 124, p.2045).

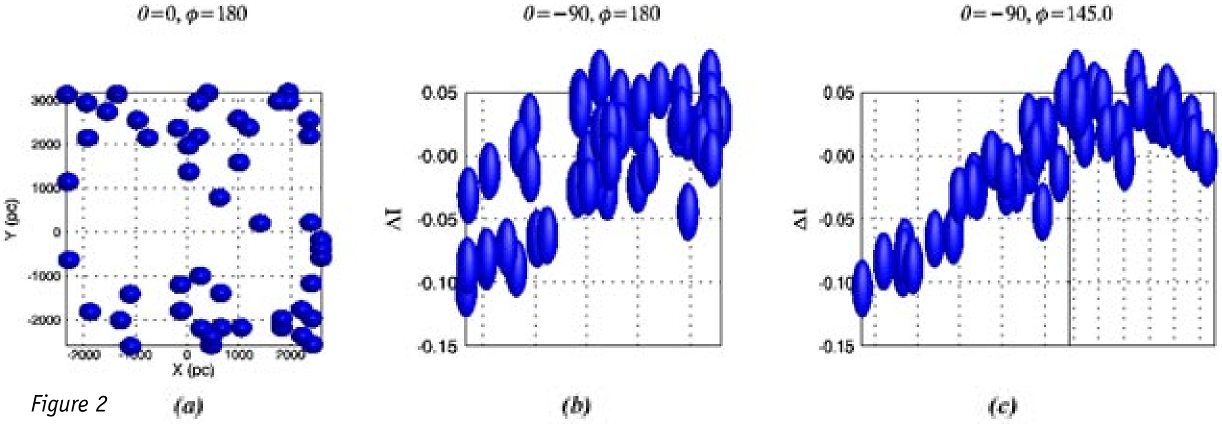


Figure 2

Clustering of Red Galaxies in the NOAO Deep Wide-Field Survey

The study of the large-scale structure of galaxies is one of the most direct methods by which we may learn about the mechanisms responsible for the origin and growth of inhomogeneities in our otherwise nearly homogeneous Universe. At the same time, galaxies clearly form and evolve in the context of large-scale structure. As a result, there is considerable interest in studying the evolution of the structure traced by different galaxy populations.

In a paper recently submitted to the *Astrophysical Journal*, NOAO astronomers Michael J.I. Brown, Arjun Dey, Buell Jannuzi, Tod Lauer, and coauthors Glenn Tiede and Valerie Mikles (University of Florida), used the initial 1.2-square degree release of the NOAO Deep Wide-Field Survey (NDWFS; see *www.noao.edu/noao/noaodeep* and *www.archive.noao.edu/ndwfs*) to measure the clustering evolution of the red population of galaxies out to z ~1.

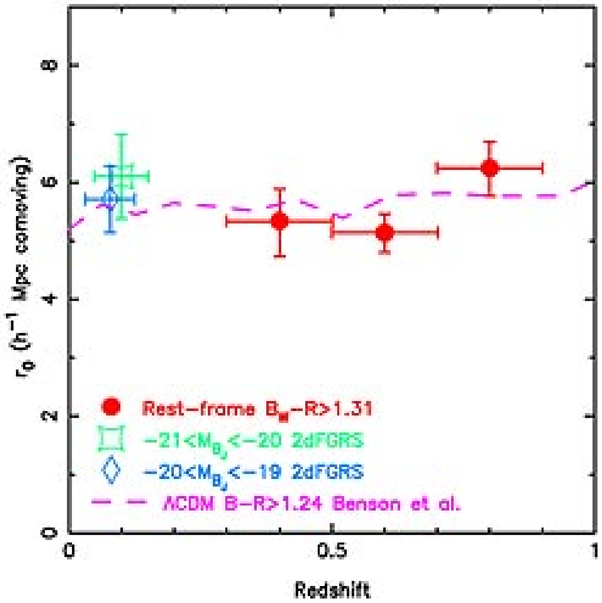
Measuring the clustering evolution of individual galaxy populations requires very large galaxy sample sizes, and large-area, deep-imaging surveys such as the NDWFS are well suited to this task. NDWFS is a multiband (B_W RIJHK) survey of two 9-square degree fields of sky. The survey depth (R ~26, K ~19.5) is designed to enable studies of the evolution of galaxies and large-scale structure to z < ~5.

Many previous measurements of clustering at high redshift were obtained from apparent magnitude-limited samples. These samples contain a broad range of galaxy types and luminosities and consequently may average over considerable detail, since clustering may depend significantly on galaxy rest-frame color and luminosity.

For their study, Brown et al. chose to study the clustering of the red galaxy population in the redshift range 0.3 < z < 0.9. Their focus on red galaxies is advantageous because these galaxies likely constitute a homogeneous population, and robust photometric redshifts can be derived for red galaxies.

In a departure from previous studies, Brown et al. used galaxy spectral evolution models to predict how the red galaxy population would evolve as a function of redshift in B_W RI colors. Appropriate color selection criteria were then used to identify the evolving red galaxy population in the NDWFS data. The selection criteria were matched to those used by the 2dF Galaxy Redshift Survey (2dFGRS) and the Sloan Digital Sky Survey (SDSS) to measure the clustering of low-redshift (z < 0.15) early-type galaxies.

Remarkably, the red galaxy population shows little clustering evolution between z ~1 and the present, in good agreement with the recent predictions of ΛCDM models. The figure shows the evolution in the spatial correlation function parameter r_0 as a function of redshift for the NDWFS red galaxy sample (solid symbols). When compared with the results from the 2dFGRS and SDSS at low redshift, it is clear that little clustering evolution has occurred between z ~1 and the present. A similarly slow rate of evolution is predicted by the ΛCDM model of Benson et al. (2001; long dashed line).



These results illustrate the ability of deep, wide-field surveys to begin to probe the evolution of clustering in the galaxy population. "By measuring the clustering as a function of the physical properties of galaxies rather than the observables, we have gained a significant advantage in measuring the evolution of large-scale structure," says Michael Brown.

More definitive studies will be possible when the full NDWFS data set (more than 15 times larger) is available for analysis. The larger data set will reduce the statistical errors of similar studies, as well as enable clustering studies of a larger number of galaxy subpopulations and to larger redshifts (z ~5). "This preliminary result, obtained with just 6% of the survey area, shows the potential of the NDWFS," Brown comments. "We are looking forward to extending this work to higher redshifts, and further constraining models of structure evolution and galaxy formation."

Solar Hα Zeeman Spectropolarimetry

K.S. Balasubramaniam, Han Uitenbroek (NSO) & Eugenia B. Christopoulou (University of Patras)

The Hα spectral line at 6562.808 Å is exceptional in its sensitivity to chromospheric activity. However, inferring magnetic fields in Hα (or for that matter, any chromospheric spectral line) is difficult because the spectral line is formed under a complicated set of non-LTE conditions. K.S. Balasubramaniam, E.B. Christopoulou (2001 NSO Summer Research Assistant from the University of Patras, Greece), and H. Uitenbroek are researching the Zeeman spectropolarimetric properties of Hα observed in a sunspot using the HAO/NSO Advanced Stokes Polarimeter.

Comparing Stokes V profiles of photospheric lines (Fe I λ 6301.5, 6302.5 Å) with that of Hα, it was found that the Stokes V profiles are easily seen in sunspots and active regions, and at the site of flares (marked by an "o" in figure 1), where the core of the Stokes intensity profile in Hα is seen to undergo a self reversal. The Stokes V profile in the core of the spectral line is formed in absorption, while in the wing of the spectral line it is formed in emission. This causes a polarization double reversal. In figure 2, this double reversal is shown as a plot, comparing it with a normal Stokes V in the umbra. If not correctly interpreted, this exceptional behavior of Hα showing the normal and the inverse Zeeman effect can lead to the misinterpretation that the magnetic fields in the umbral chromosphere are reversed. The authors have reproduced the Hα Zeeman self reversal using a complete radiative transfer treatment of the spectral line, including partial redistribution in a strong magnetic field, and under the influence of a model flare atmosphere.

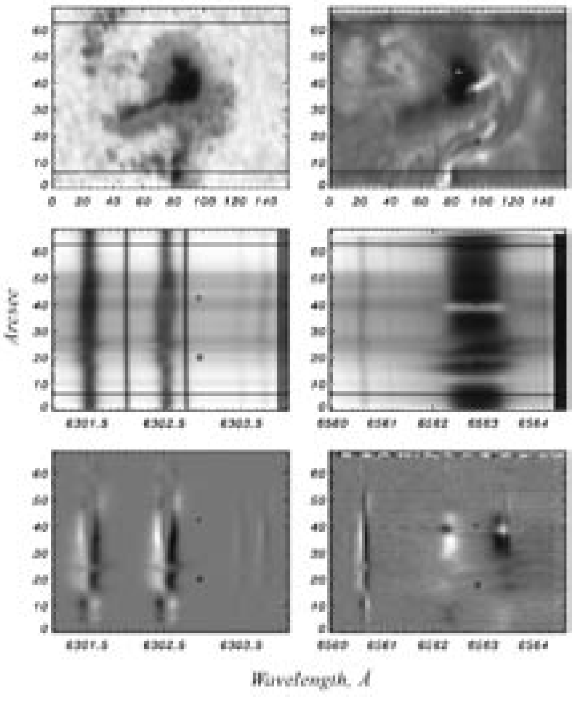


Figure 1. Comparison of Stokes I and V profiles in the 6300 Å region (left panels) and Hα (right panels).

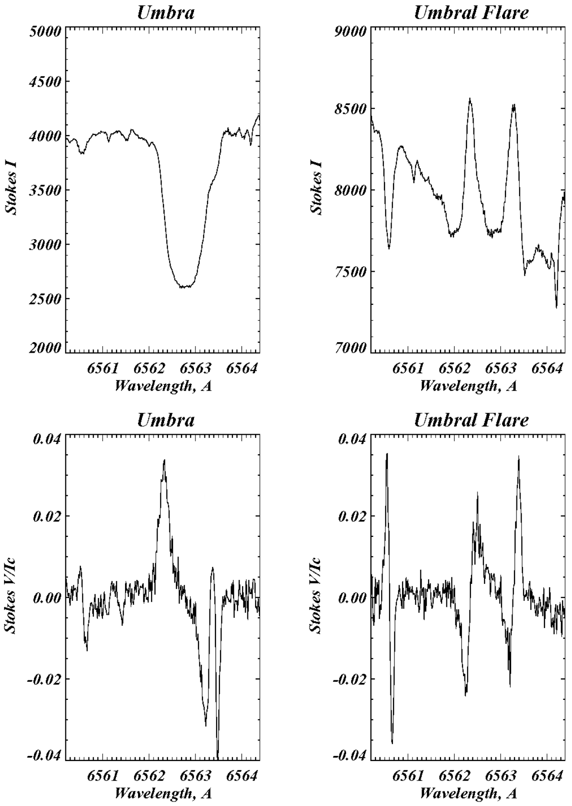


Figure 2. Plot of normal and double-reversed polarization profiles.