*The Interplay among Black Holes, Stars and ISM*
*in Galactic Nuclei*
*Proceedings IAU Symposium No. 222, 2004*
*T. Storchi-Bergmann, L. C. Ho & H. R. Schmitt, eds.*

DOI: 10.1017/S1743921304002303

# Nebular excitation of low-luminosity emission nuclei

**Joseph C. Shields**[1] **and the SUNNS Collaboration**†

[1]Department of Physics & Astronomy, Ohio University, Athens, OH 45701, USA
e-mail:shields@phy.ohiou.edu

**Abstract.** Low-luminosity nebular emission is found in the centers of a large fraction of galaxies, and in many cases the energy source powering these systems is ambiguous. This is particularly true for H II/LINER "transition" objects, although a reasonable explanation for these sources is that their emission is the composite result of a weak accretion-powered system surrounded by star-forming regions. This contribution describes results from a *Hubble Space Telescope* spectroscopic survey that probes the structure of nearby transition objects and other emission nuclei. The results provide only limited support for the composite picture for these sources; the emission nuclei do not show a strong tendency for the nebular classification to depend on aperture size. The strongest variations in forbidden line ratios appear to be mediated by a gradient of decreasing nebular density with increasing radius.

## 1. Introduction

Optical spectra play a key role in identifying and understanding energetic phenomena in the centers of galaxies. Ground-based spectroscopic surveys indicate that a large fraction of galaxy nuclei are nebular sources; many have low luminosities, comparable to giant HII regions. The classification of nuclear nebulae relies on optical line ratios and widths, and beyond taxonomy, the hope has been that such classifications can be mapped to the underlying sources of energy in a straightforward way. This goal has proven challenging, since the nebulae continuously span a wide range of emission line ratios, and over much of this space it can be difficult to distinguish quite different physical processes: for example, photoionization by an energetic continuum, shock ionization, and turbulent mixing layers.

A class of objects that pose a particular challenge to identification of the underlying energy source(s) is that of "transition nuclei," which by definition are intermediate between LINERs and H II regions in line-ratio diagrams. In the literature these are also sometimes labeled "composite nuclei" or "weak-[O I] LINERs." Several researchers have suggested that a natural interpretation for these objects is that they represent a weak accretion-powered nebula with circumnuclear H II regions that are blended in measurements obtained through typical apertures employed in ground-based spectroscopy. Véron et al. (1997) have summarized evidence that the two components can be kinematically distinguished in some sources, with the accretion-powered emission displaying broader profiles than the H II region emission. If an accretion source is indeed present in transition objects, we would expect that observations with sufficient sensitivity would reveal in many such nuclei unambiguous signatures of accretion, such as high brightness-temperature radio cores, quasar-like broad lines, or hard X-ray emission. Relevant results in this regard have been reported by Filho et al. (2001, 2002), who find flat-spectrum radio cores in a quarter of transition objects surveyed.

† SUNNS is a collaboration of A. J. Barth, A. V. Filippenko, L. C. Ho, D. H. McIntosh, H.-W. Rix, G. Rudnick, W. L. W. Sargent, M. Sarzi, & J. C. Shields

High spatial resolution observations that resolve the central nebula provide an interesting means of investigating the nature of transition objects and other emission nuclei. A prediction of the composite model for transition objects is that the nucleus should appear more AGN-like when viewed through a small aperture that excludes part of the circumnuclear emission. The degree to which emission nuclei show line ratio gradients is of more general interest for understanding the physics of accretion sources and nebular structure. Small-aperture spectroscopy also provides an avenue for increasing sensitivity to broad nebular (H$\alpha$ in particular) lines, by minimizing circumnuclear starlight that impedes the detection of low-contrast emission features.

## 2. SUNNS

To investigate the nature of emission nuclei on small scales, we carried out a **Survey of Nearby Nuclei with STIS** (SUNNS) using the *Hubble Space Telescope*, which resulted in optical spectra for a distance-limited sample of 23 galaxies known from ground-based observations to harbor nuclear nebulae. The targets include H II, Transition, LINER, and Seyfert nuclei. The spectra were acquired with a 0.2″-wide slit, and to study the nuclei we employed an extraction width along the slit of 0.25″. For the median galaxy distance of $\sim$ 13 Mpc, the equivalent aperture radius of 0.13″ corresponds to a metric scale of $\sim$ 8.2 pc. Full details of the observations are presented by Shields et al. (2004, in preparation). The resulting data have proven to be a rich resource, allowing us to study double-peaked Balmer emission that apparently traces accretion disks (Shields et al. 2000; Ho et al. 2000), measure or place constraints on central black hole masses (Sarzi et al. 2001, 2002), investigate the relationship between gas kinematics and morphology (Ho et al. 2002), and quantify the star-formation history on small scales (M. Sarzi, this conference). The data are also valuable for addressing some of the questions concerning nebular structure and energetics noted in §1.

A simple way of quantifying radial variations in emission properties is by comparing measured quantities as a function of aperture radius. The *HST* spectra by themselves have limited signal-to-noise ratio off-nucleus, but we can approach this problem by comparing the SUNNS measurements with data obtained as part of the Palomar Spectroscopic Survey of nearby galaxies (Filippenko & Sargent 1985; Ho et al. 1997), which was used as a basis for sample selection. The Palomar spectra were acquired with a $2'' \times 4''$ aperture, which is approximately an order of magnitude larger in linear dimension and $\sim 100\times$ larger in area than the SUNNS aperture. Comparison of nebular fluxes obtained for the same object shows that the measured *HST* flux is $\sim 10 - 100\times$ less than the Palomar flux, indicating that the nebular gas is resolved by *HST*. The H II nuclei show the largest reduction in flux and in a number of cases are undetected in the small aperture; in contrast, the Seyfert nuclei show the smallest reductions, reflecting a significant degree of concentration in nebular surface brightness.

The aperture dependence of emission-line ratios is shown in Figure 1, which displays the "ratio of ratios" for [N II]$\lambda$6583/H$\alpha$, [O I]$\lambda$6300/H$\alpha$, and [S II]$\lambda\lambda$6716, 6731/H$\alpha$, with SUNNS relative to Palomar. Several patterns can be seen in the figure. [O I]/H$\alpha$, where measurable, generally shows an increase in the small aperture. The behavior is more varied in the other two line ratios, although it is notable that the Seyferts in particular show rather little change, and to the extent that different ratios are measured by SUNNS, the [S II]/H$\alpha$ ratio *decreases* in the small aperture. This collection of behavior almost certainly reflects the influence of high nebular densities particularly in the Seyfert nuclei, since the [S II], [N II], and [O I] lines represent a progression of increasing critical density. Higher densities in the SUNNS aperture are indicated directly by the [S II]$\lambda$6716/$\lambda$6731

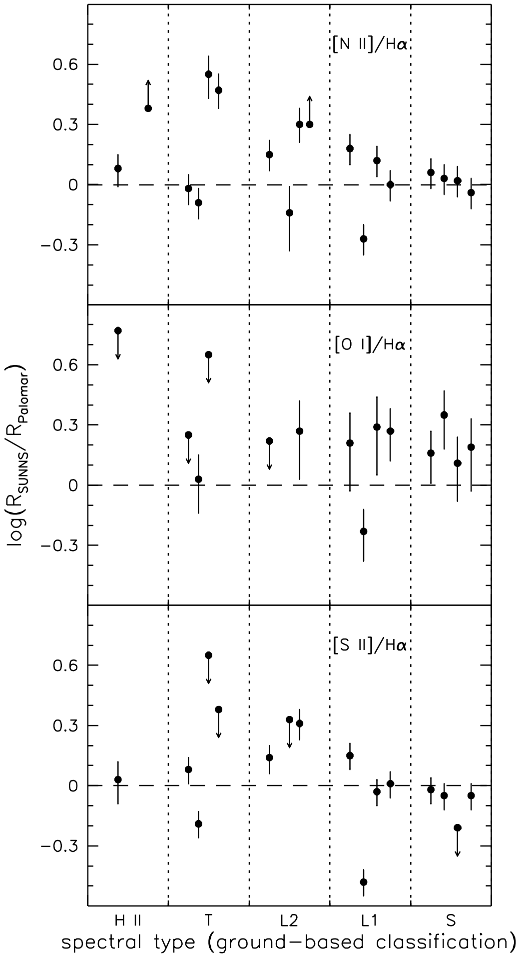

**Figure 1.** Line flux ratio as measured by SUNNS divided by ratio measured at Palomar. The ordering on the x-axis approximately reflects the degree to which nuclei show evidence of an "active" nucleus, where T = transition type, L2 = LINER 2, L1 = LINER 1, and S = Seyfert 1.9 or 2.

ratio, which is lower in the SUNNS aperture for all nuclei in the sample (Figure 2). These findings extend previous results with *HST* (Barth et al. 2001) as well as indirect evidence from line width-critical density correlations (e.g., Pelat et al. 1981; Filippenko & Halpern 1984) pointing to an increase in density with decreasing radius in the narrow-line regions of AGNs.

## 3. Discussion

For the transition objects to appear more "AGN-like" in the small aperture, we would expect the line ratios considered in Figure 1 to increase in the SUNNS measurement. It is remarkable that in this admittedly small sample, only half of the transition sources show this behavior, calling into question the composite model for these objects. This result may implicate an important role for spatially distributed sources of energy in

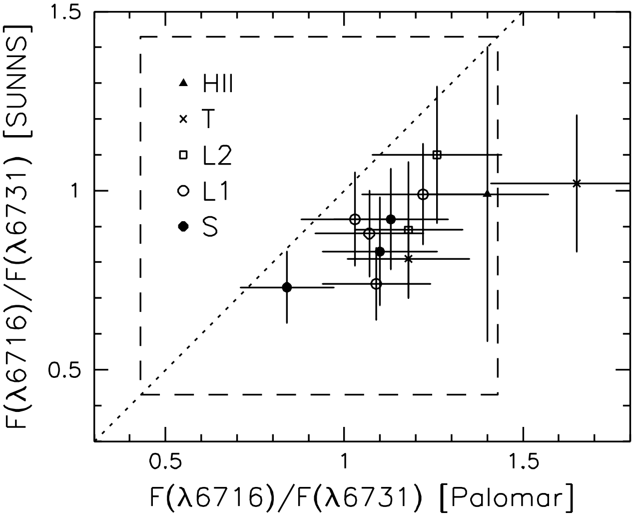

**Figure 2.** [S II] λ6716/λ6731 flux ratio from the Palomar and SUNNS measurements of galaxy nuclei. The systematically lower ratio found in the smaller (SUNNS) aperture is indicative of larger electron densities at smaller radii.

powering the nebular emission in these sources, perhaps involving stellar remnants or shocks. Another surprising finding is that the observations reveal no new detections of broad H$\alpha$ emission in sources identified as narrow-line (type 2) nuclei in the Palomar data, despite the substantial reduction in continuum starlight in the SUNNS data. In short, there is rather little tendency for the emission nuclei to change their identity or classification with varying aperture radius. For the accretion-powered systems, ionization gradients may be shallow as a result of the significant gradient in gas density. Further investigation of larger samples is required to determine the general behavior of transition objects and to provide a more definitive test of the composite picture for these sources.

## References

Barth, A. J., Ho, L. C., Filippenko, A. V., Rix, H.-W., & Sargent, W. L. W. 2001, ApJ, 546, 205
Filho, M. E., Barthel, P. D., & Ho, L. C. 2000, ApJS, 129, 93
Filho, M. E., Barthel, P. D., & Ho, L. C. 2002, ApJS, 142, 223
Filippenko, A. V., & Halpern, J. P. 1984, ApJ, 285, 458
Filippenko, A. V., & Sargent, W. L. W. 1985, ApJS, 57, 503
Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, ApJS, 112, 315
Ho, L. C., et al. 2000, ApJ, 541, 120
Ho, L. C., Sarzi, M., Rix, H.-W., Shields, J. C., Rudnick, G., Filippenko, A. V., & Barth, A. J. 2002, PASP, 114, 137
Pelat, D., Alloin, D., & Fosbury, R. A. E. 1981, MNRAS, 195, 787
Sarzi, M., et al. 2002, ApJ, 567, 237
Sarzi, M., et al. 2001, ApJ, 550, 65
Shields, J. C., et al. 2000, ApJ, 534, L27
Véron, P., Gonçalves, A. C., & Véron-Cetty, M.-P. 1997, A&A, 319, 52