Thick Disk Star Formation in Spiral Galaxies

Extraplanar Dust and H II regions in Three Edge-On Spiral Galaxies

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Abstract: The interstellar thick disks of spiral galaxies contain all of the phases of the interstellar medium found in the thin disk, including a cold dense phase. We present evidence for thick disk star formation in three spiral galaxies. Our high resolution LBT, WIYN, and Hubble Space Telescope imaging of these galaxies reveal numerous extraplanar H II regions and associated stellar continuum light from the underlying young stars. We also present confirming spectroscopy from the Keck observatory for an extraplanar H II region in the galaxy NGC 891 at ~650 pc of the midplane. We use these images and spectra to constrain the evolutionary status of the thick disk stellar associations, including their age and massive star content. These observations also provide constraints on the physical conditions in the thick disk interstellar medium. Additionally, they can be used to measure and study the vertical metal distribution in these galaxies, which will probe the infalling primordial material from the surrounding intergalactic medium.

Figure 1: NGC 4013 HST and WIYN (BVI) composite image.

Figure 2: NGC 4302 HST and LBT (RVI) composite image.

Extraplanar Dust: Dense, dusty clouds in the thick disk are a common feature of most edge-on spiral galaxies (Howk & Savage 1999). Such clouds are observed through their extinction of the background starlight, as seen for two galaxies in Figures 1 and 2. These clouds likely represent a dense, cold neutral phase of the interstellar thick disk (Howk & Savage 1997, 2000). The clouds seen in these images individually have masses of >10^4 to >10^5 M_SUN and are seen to z ~ 2 kpc from the midplane.

Figure 3: H-alpha images of NGC 4013 (grayscale inverted). Candidate extraplanar H II regions are circled in red, with the spectroscopically confirmed nebulae marked with a “C” in NGC 4013, taken with the Lick 3.5m. We show two stretches for NGC 4013 to separately emphasize the faint and bright emission.

Figure 4: H-alpha images of NGC 4302 (grayscale inverted). Candidate extraplanar H II regions are circled in red, with the spectroscopically confirmed nebulae marked with a “C” in NGC 4302, taken with the Lick 3.5m. The H-alpha images, taken with WIYN, show the presence of extraplanar diffuse ionized gas in all three galaxies. In addition, we have found small-scale features (often point sources) at |z|> 400 pc in the continuum-subtracted H-alpha images that we identify as extraplanar H II region candidates. The regions are circled in Figure 3-5. These may represent regions of extraplanar (thick disk) star formation. Most have not been spectroscopically confirmed, and some may be background galaxies (e.g., Werk et al., 2010). The majority have associated continuum emission tracing the underlying stellar populations.

Figure 5: H-alpha images of NGC 891 (grayscale inverted). Candidate extraplanar H II regions are circled in red, with the spectroscopically confirmed nebulae marked with a “C” in NGC 891, taken with the Keck I + LRIS. The H-alpha images were taken with WIYN, showing the presence of extraplanar diffuse ionized gas in all three galaxies. In addition, we have found small-scale features (often point sources) at |z|> 400 pc in the continuum-subtracted H-alpha images that we identify as extraplanar H II region candidates. The regions are circled in Figure 3-5. These may represent regions of extraplanar (thick disk) star formation. Most have not been spectroscopically confirmed, and some may be background galaxies (e.g., Werk et al., 2010). The majority have associated continuum emission tracing the underlying stellar populations.

Extraplanar H II Regions: The H-alpha images, taken with WIYN, show the presence of extraplanar diffuse ionized gas in all three galaxies. In addition, we have found small-scale features (often point sources) at |z|> 400 pc in the continuum-subtracted H-alpha images that we identify as extraplanar H II region candidates. The regions are circled in Figure 3-5. These may represent regions of extraplanar (thick disk) star formation. Most have not been spectroscopically confirmed, and some may be background galaxies (e.g., Werk et al., 2010). The majority have associated continuum emission tracing the underlying stellar populations.

H II Region Spectroscopy: We have obtained a confirming spectrum of an extraplanar H II region in NGC 891 with LRIS on Keck-I. The hydrogen Balmer and oxygen emission lines confirm this object is an H II region at the radial velocity of NGC 891. A faint stellar continuum is also seen. The stellar continuum rises into the blue, with a very weak Balmer break, suggesting a young stellar population dominated by early type stars. Preliminary analysis of the emission lines, using the R23 strong-line method (McGaugh 1991, Kobulnicky et al. 1999), suggest the oxygen abundance of this H II region is consistent with the solar abundance. Both the emission lines and the continuum strongly suggest the presence of a small OB association at z ~ 650 pc.

In comparing our spectrum with models of single stellar populations (SSP) of ages 1, 10, and 20 Myr, our spectrum fits best with a <10 Myr SSP, likely on the order of a few Myr. This preliminary analysis of the H II spectrum will be focus of our future work.

Discussion: In addition to this H II region in NGC 891, we have confirmed another H II region in NGC 4013 while Tüllman et al. (2003) have confirmed one in NGC 55. Thus, it seems small numbers of star forming regions may be a common feature of the thick disks of spirals. It seems plausible that these stars have formed in situ from the dust-laden thick disk clouds (e.g., Figures 1 and 2). Future work will determine the star formation rate of the thick disk and determine metallicities for the other H II regions. The metallicities can place limits on amount of primordial gas that has mixed with the ejected material in the thick disk.