

CHEMICAL ABUNDANCES IN LOW SURFACE BRIGHTNESS GALAXIES:
IMPLICATIONS FOR THEIR EVOLUTION

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Low Surface Brightness (LSB) galaxies are an important but often neglected part of the galaxy content of the universe. Their importance stems both from the selection effects which cause them to be under-represented in galaxy catalogs, and from what they can tell us about the physical processes of galaxy evolution that has resulted in something other than the traditional Hubble sequence of spirals. An important constraint for any evolutionary model is the present day chemical abundances of LSB disks. Towards this end, we have obtained spectra for a sample of 75 H II regions distributed in 20 LSB disks galaxies. Structurally, this sample is defined as having $B(0)$ fainter than $23.0 \text{ mag arcsec}^{-2}$ and scale lengths that cluster either around 3 kpc or 10 kpc. In fact, structurally, these galaxies are very similar to the high surface brightness spirals which define the Hubble sequence. Thus, our sample galaxies are not dwarf galaxies but instead have masses comparable to or in excess of the Milky Way. The basic results from these observations can be summarized as follows:

- Despite having disk masses similar to those galaxies which define the Hubble Sequence, LSB galaxies have substantially subsolar abundances. Specifically, 90% of the measured H II regions have $\log(O/H) < -3.6$.

- The LSB galaxies with the lowest metallicities are as low as any known extragalactic objects with the exception of I Zw 18 and SBS 0335 - 052. It is possible that objects with $\log(O/H) \leq -4.3$ are undergoing their first episode of star formation. The very blue continuum colors (particularly B-I) of these objects would support this.

- Although quite metal poor, these LSB disks do not cluster around any preferred value of O/H indicating a broad spectrum of enrichment timescales/star formation histories.

- Despite being quite deficient in molecular gas (e.g., CO) some star formation is occurring. The H II region luminosities/sizes indicate ionization by several stars with $M \geq 60 M_{\odot}$. The distribution of the Balmer decrement indicates that some dust is present in these systems.

- Unlike the case for HSB galaxies, there is no correlation between the H II region ionization parameter (U) and the oxygen abundance. This argues that the observed correlation is a selection effect associated with only measuring the brightest (or most conspicuous) H II regions. Studies of more diffuse H II regions in normal galaxies would then remove the apparent correlation.

- Most H II regions in LSB galaxies have low values for the ionization parameter indicating that star formation is occurring in a more diffuse environment in these diffuse galaxies.

- The Nitrogen abundance in LSB galaxies is independent of the Oxygen abundance over an order of magnitude range in O/H . This unprecedented situation suggests an anomalous IMF as Nitrogen is mainly produced as a secondary product in the CNO cycles of 2-8 M_{\odot} stars and oxygen is produced in more massive stars. This is the most curious aspect of the data which defies any current model.

- A well defined abundance floor exists for Sulfer and Neon, and, like Nitrogen, they exhibit an extremely weak dependence on O/H .

Selecting galaxies for low surface brightness obviously is an effective means for discovering low metallicity objects. Furthermore, the data indicate a substantially different element enrichment history that is adhered to by Hubble sequence spirals. In fact, the N,O,S,Ne abundance ratios which are observed practically demand a pre-enriched source of gas, which produced most of the N,S and Ne in order to keep their levels independent of O, despite the galaxies' best attempt to evolve. Alternatively, the IMF could be skewed in non-standard directions – a situation which generally will produce a LSB, high M/L galaxy. Finally, it seems clear that the low degree of chemical evolution shown by this sample confirms earlier speculation that LSB disks evolve rather slowly over a Hubble time. Indeed, the low abundances coupled with the very blue continuum disk colors argue that the mean ages of these systems must be rather young. Given the lack of CO emission, it would seem that the surface density of H I, at the time of formation, is the critical parameter which determines the evolutionary timescale. That LSB galaxies can remain relatively unevolved to the present epoch implies that selection effects may mask the true range of galaxy properties. Undoubtedly, there are more LSB galaxies awaiting discovery with even more extreme properties than those discussed here which may provide even more profound challenges of our understanding of galaxies and their evolution; hopefully this will require a future meeting near these mountains.