1. Motivation: The Baryon Cycle

Galaxy disks have only 10–30% of the baryons expected from their dark-matter halo masses and the cosmic baryon fraction [1,2]. The remainder were expelled or prevented from accreting early on, and about 20–30% of the "missing" baryons are in bound galaxy halos [3]. These baryons slowly accrete onto the galaxy and are the long-term fuel for star formation. Meanwhile, stellar feedback expels baryons from the disk in a galactic wind or fountain [4,5]. The rate at which these processes occur determines the stellar population, but observational constraints are poor.

We would like to know...

- The accretion rate of fresh gas
- Feedback mass loading factors
- The longevity of halo gas in either form
- How these quantities change with galaxy type and cosmic time, and how they depend on galaxy environment.

... but we need to be able to distinguish between accreted gas and feedback ejecta.

2. A New Way to Detect Halo Gas

The metal content of halo gas distinguishes between "fresh" accreted material and feedback exhaust, but it is hard to measure. Halo gas is most easily detected in emission around edge-on galaxies (X-ray or 21-cm emission for hot and cold gas respectively), but the most reliable indicators of metallicity are absorption lines in the spectra of background quasars. The number of sight-line samples is limited, especially close to the disk.

The discovery that dust is common in galaxy halos [6] suggests a way to distinguish between accreted gas and feedback. Near the disk, dust scatters light leaking out of the galaxy, producing reflection nebulae around edge-on galaxies like off-axis searchlight beams (these have already been seen in starburst winds [7,8]).

The dust modifies the input spectrum in a way that depends on composition:

\[
F_{\text{nebula}} = \frac{F_{\text{galaxy}}}{1 - e^{-\tau_{\text{scat}}}}
\]

\[
\tau_{\text{scat}} = \sigma_{\text{ex}} \left( \frac{\sigma_{\text{scat}}}{\sigma_{\text{ex}}} \right) \frac{M_{\text{dust}}}{M_{\text{gas}}} N_H
\]

Data

Models & Fits

\[
\text{Fits with height}
\]

\[
\text{Extinction law depends on ratio of carbonaceous, silicate dust grains [8]}
\]

Thus, from the nebulosity and galaxy spectrum we can determine the type of dust. With additional 21-cm data we can get the dust-to-gas ratio.

3. Sample

Our sample includes highly inclined ($i > 65\degree$), late-type galaxies (Sa-Sd) within 100 Mpc with Swift/UVOT and 21-cm data. We detect diffuse UV around ~100 galaxies where we can rule out Pf whis and instrumental artifacts. About 40% have high quality data.

Because the halo surface brightness is a small fraction of the background, we must carefully remove instrumental scattered light artifacts from each UVOT exposure. We typically clean 96-99% of the artifical light.

Halos are visible to 5-15 kpc from the disk, and are bluer than the (edge-on) host galaxies. Specific halo UV luminosity is strongly correlated with the host galaxy luminosity (below we show values for nearby galaxies where we can estimate the SFR). The data are consistent with reflection nebulae but not stellar halos. We measure halo flux in the five GALEX+UVOT bands (FUV 1516Å, UVW2 1918Å, UVM2 2246Å, NVV 2267Å, UBV1 2600Å).

4. Method and Results (Case Study: NGC 5775)

We measure SEDs at various heights around each galaxy with enough data, and fit the data with synthetic SEDs made from galaxy spectra templates, dust models (here we show MW, LMC, and SMC models from [9]), and filter response curves (two overlap at the 2175Å "UV bump"). We determine what combination of galaxy model/dust, if any, fits best. A "red leak" in the ultraviolet (and uvw2) filter means we must also account for the stellar halo with optical data. The best fits are for a galaxy model matching the observed galaxy type and an extinction law more like SMC dust than MW dust (i.e., carbon-rich).

Here we show NGC 5775, whose SED and best-fit dust type changes with height:

5. Summary and Future Work

Dust-scattered reflection nebulae are ubiquitous around nearby, late-type galaxies. Their SEDs tell us how much dust there is and its chemical nature. Although the derived metallicities and masses are more model dependent than in QSO studies, we have ~1500 candidates within 100 Mpc, where GALEX’s spatial resolution is sufficient. Some galaxies also have very deep images where we can map the SED (see Julian Cafmeyer’s poster).

6. If you remember only one thing...

Dust in galaxy halos produces UV reflection nebulae that provide new insight into the composition and origin of halo gas.

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References


The Ultraviolet Halos of Nearby Galaxies

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