Studying the Milky Way via its Extragalactic Analogs

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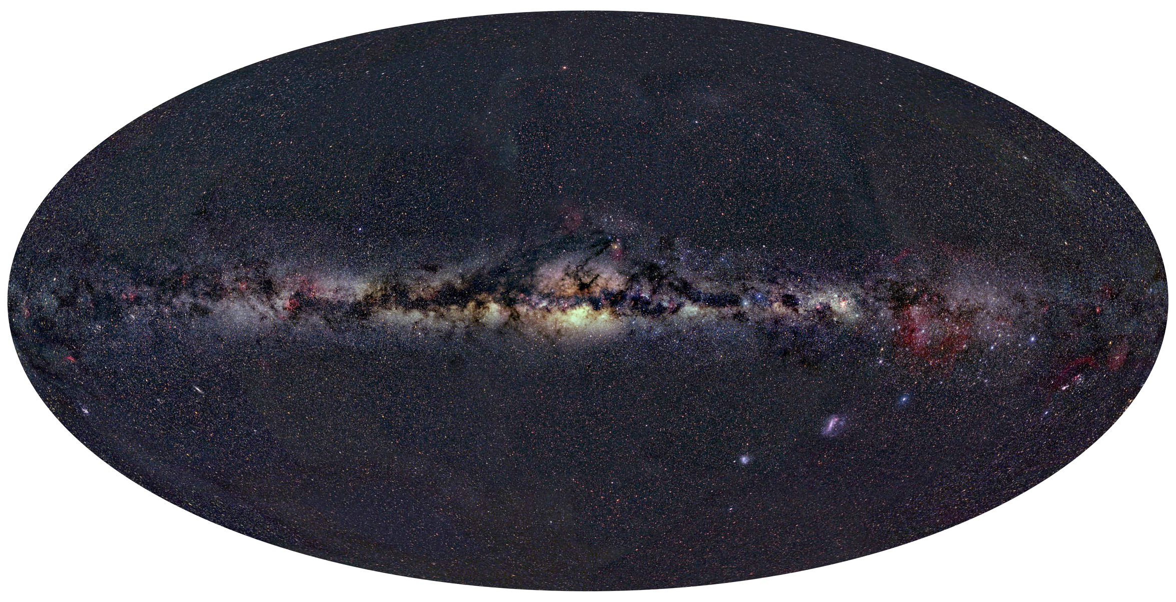
Measuring the Milky Way is Hard!

- We live in the middle of the disk.
- It spans the entire night sky.
- Interstellar dust either alters or blocks almost all of the light from other stars.
- Results usually rely on and are highly sensitive to a multitude of assumptions made about the structure and demographics of the Galactic population.



- **For these reasons, measurements of the global properties of the Milky Way, such as its star formation rate (SFR) and stellar mass ($M_\star$), remain scarce in the literature today.**

Improved SFR and $M_\star$ Estimates From Hierarchical Bayesian Methods

- We statistically combine the prior literature estimates for the Milky Way parameter of interest in order to infer a single a aggregate result using a hierarchical Bayesian analysis method[1].
- This technique yields drastically improved constraints by incorporating the information from a variety of independent observational data and methods.
- A hierarchical formalism allows us to account for the possibility that any one estimate may be inaccurate or have underestimated error bars[2,3], e.g., due to omitting possible systematic errors.

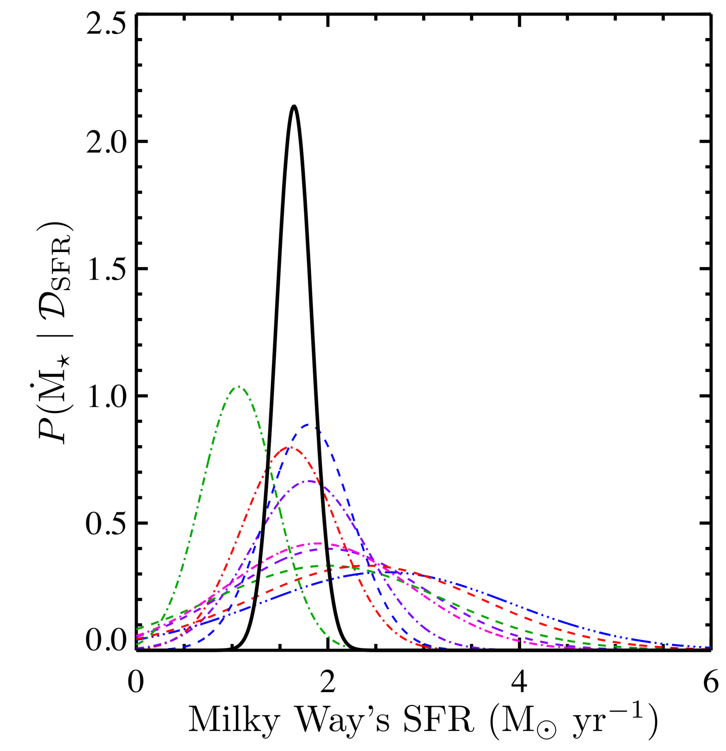


Figure 1. The posterior results of a hierarchical Bayesian meta-analysis for the Milky Way's star formation rate (left panel) and stellar bulge mass (right panel) shown as solid black curves. In each panel, we overlay the individual literature estimates used in our analyses as color dashed/dotted curves for comparison. All SFR estimates have been renormalized to the Kroupa IMF and tabulated by Chomiuk & Povich (2011). All bulge estimates have been renormalized to a consistent IMF (Kroupa 2003), a uniform definition of stellar mass (Bruzual & Charlot 2003), and consistent assumptions about the structure and demographics of the stars in the our Galaxy (Bovy et al. 2013; Gillessen et al. 2009); these are tabulated in Licquia & Newman (2014).

- We find the total star formation rate of the Milky Way is $\mathbf{\dot{M}_\star = 1.65 \pm 0.19\ M_\odot\ yr^{-1}}$.
- We find the stellar mass of the bulge component is $\mathbf{M^B_\star = 0.91 \pm 0.07 \times 10^{10}\ M_\odot}$.
- Combining our bulge mass estimate with a single-exponential model of the disk (Bovy et al. 2013), we find the total stellar mass of the Milky Way is $\mathbf{M_\star = 6.08 \pm 1.14 \times 10^{10}\ M_\odot}$.

See Licquia & Newman (2014) for more details!

Identifying Milky Way Analogs

- Our basic strategy is to randomly select a sample of galaxies whose distribution of SFR and $M_\star$ values matches the actual observations and their uncertainties of the Milky Way.
- We can then determine the rest-frame absolute magnitude and color of these Milky Way analogs.
- This sample of objects with $M_\star$ and SFR distributions matching the Milky Way values and uncertainties may be useful for a variety of projects. Here, we use the absolute magnitudes and colors of these Milky Way analogs to constrain the properties of our own Galaxy.
- This method relies on making the Copernican assumption that the Milky Way is not atypical for galaxies of similar SFR and $M_\star$.

Samples Used:

SDSS DR8 spectroscopic catalog + MPA-JHU SFR & $M_\star$ catalogs Brinchmann et al. (2004; B+04)

Restrict to objects which meet SDSS Main Survey criteria and have clean photometry + spectra.

Measuring Properties

Using *kcorrect*[4], determine rest-frame z=0 absolute magnitudes for remaining galaxies.

Recalculate SFR & M* values by applying methods from B+04 to DR8 photometry.

Restrict to objects with accurately measured, absolute mags, SFRs, and stellar masses.

Select Volume-Limited Sample:

Require $0.03 < z < 0.09$; sample is volume-limited down to faintest MW analogs.

Figures 2 & 3 show density contours for this sample.

Restrict to Useful Milky Way Analogs:

Randomly select an $M_\star$ and SFR value for the Milky Way from the observed distributions.

Find all objects that lie within a small range of these values in parameter space.

Randomly select one non-edge-on object within this range: a Milky Way analog! (One red point in Fig. 2)

Repeat 5,000 times

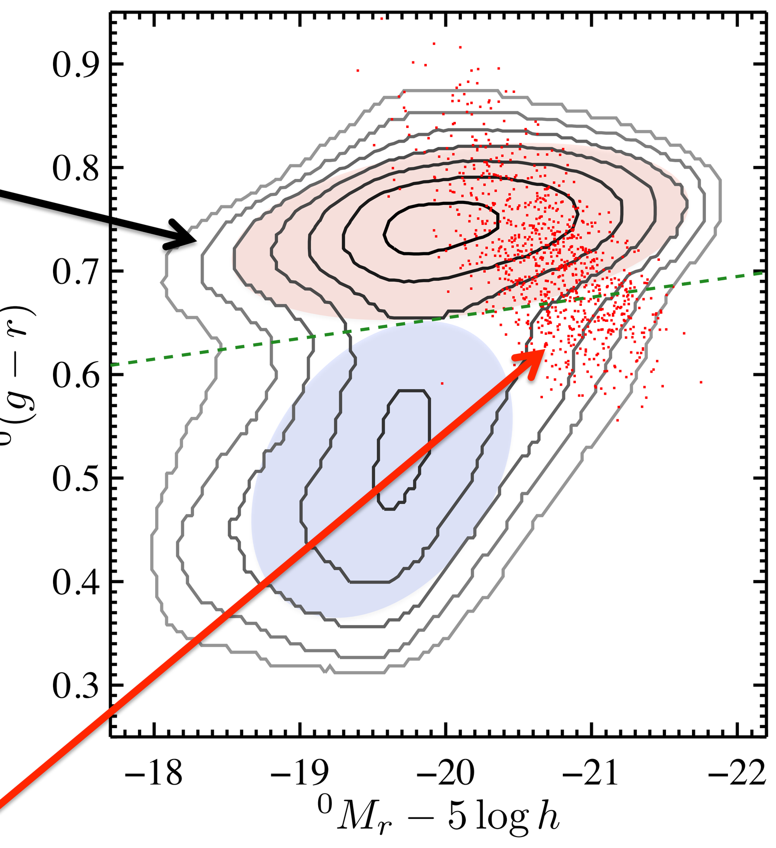


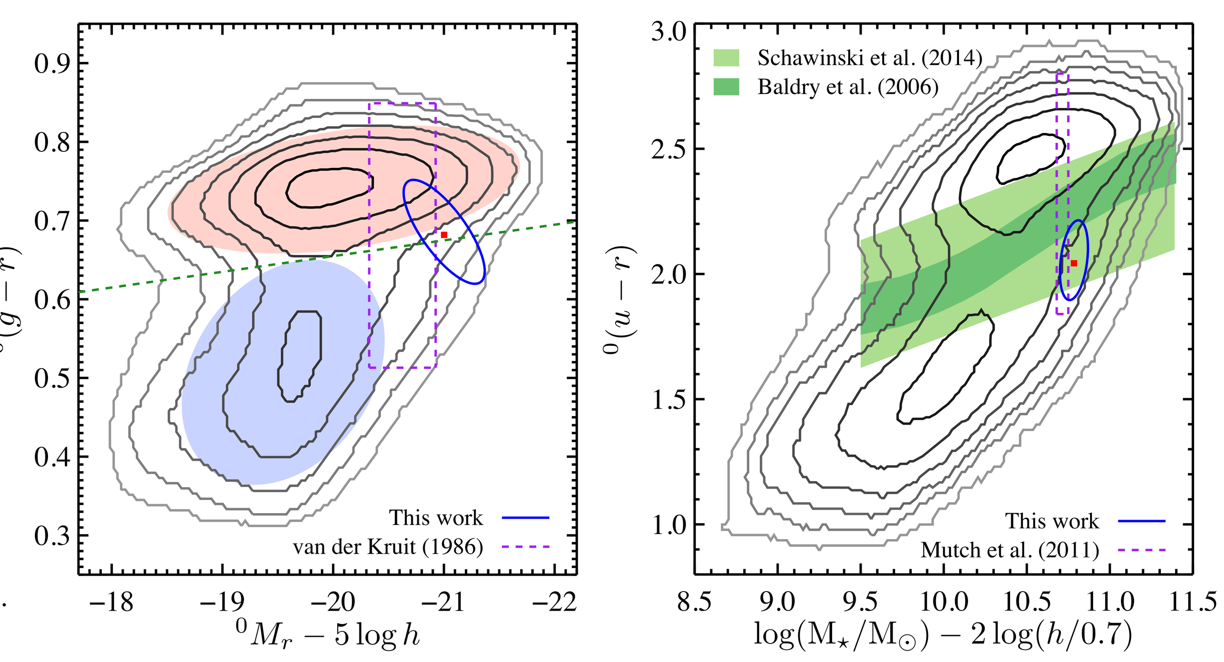
Figure 2. Red points mark the position of Milky Way analogs in rest-frame SDSS $^0(g\text{-}r)$ color vs. absolute ^0r-band magnitude space. Greyscale lines depict log-spaced contours of constant density for clean galaxies in the volume-limited sample. The shaded regions schematically represent the blue cloud and red sequence. The dashed green line shows a simple color division (G. Graves, priv. comm.).

Comparing the Milky Way to Other Galaxies

- As an example, we can determine the mean value of absolute ^0r-band magnitude (^0M_r) and rest-frame $^0(g\text{-}r)$ color, as well as their covariance, from the analog sample (see Figure 3, which is corrected for Eddington bias and inclination/reddening effects).
- We find that the Milky Way is one of the brightest and reddest spiral galaxies in the local universe. It most likely lies between the blue cloud and red sequence; i.e., in the so called "green valley"[5].
- This hints that our Galaxy may be in a transitional evolutionary stage where star formation is quenching, and hence is moving on a trajectory through the below plots toward the quiescent red population.
- Our results provide a vast improvement in our knowledge of how the Milky Way compares to other galaxies.

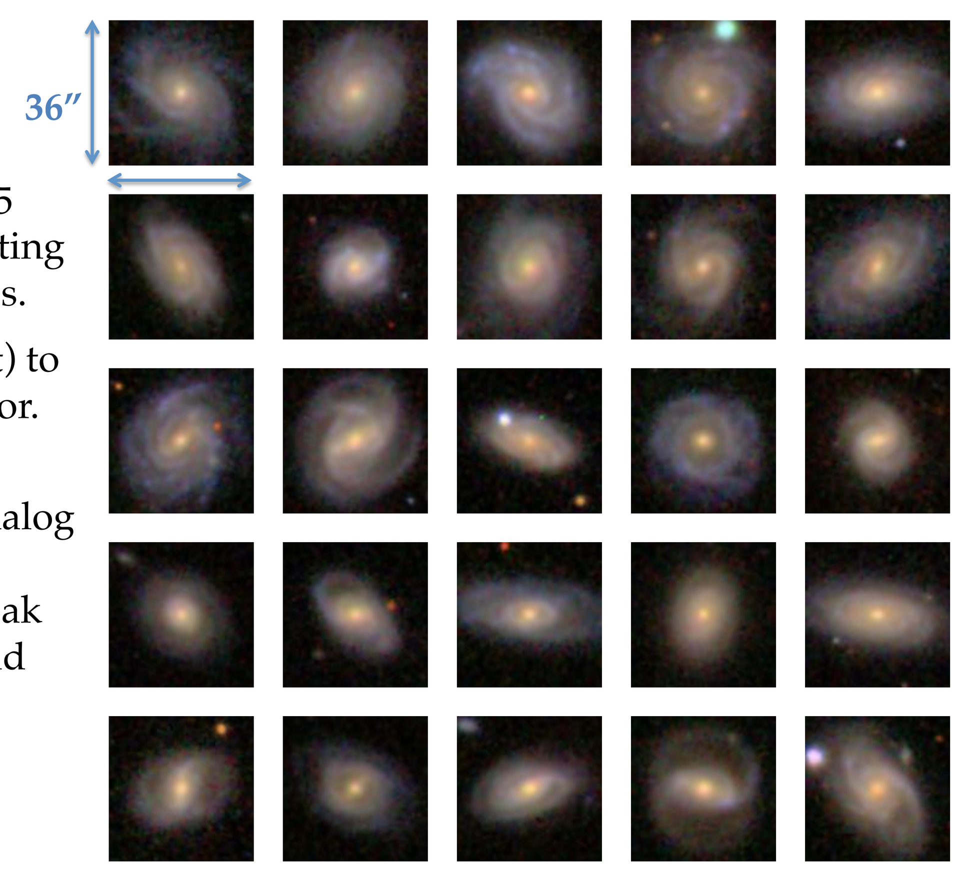
See Licquia et al. (2014) for more details!

Figure 3. The Milky Way's location (red dot with blue 1σ ellipse) in $^0(g\text{-}r)$ vs. ^0M_r space (left panel) and $^0(u\text{-}r)$ vs. $M_\star$ space (right panel). In the right panel, we show an empirical definition of the green valley (dark green) and an alternate definition for reddening-corrected galaxies (light green). The previously-best 1σ constraints for the Milky Way's position are shown by the dashed purple lines.



An Outside-In View of the Milky Way

- At right are SDSS postage stamp images of 25 Milky Way analogs with $0.04 < z < 0.055$, putting them on roughly identical physical-size scales.
- They are shown in order from bluest (top left) to reddest (bottom right) in rest-frame $^0(g\text{-}r)$ color.
- The larger image below shows SDSS J083909.27+450747.7, a face-on Milky Way analog of typical color, obtained using the MOSAIC camera on the 4m Mayall telescope at Kitt Peak by Armin Rest (STScI) and Brittany McDonald (McMaster University).
- Our overall sample would be suitable for a variety of 3D follow-up studies!



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