Star Formation as a Function of Circular Velocity in Bulgeless Disk Galaxies

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Background: Dalcanton et al. (2004)

- Study of 49 edge-on, late-type disk galaxies

- Objects with $v_{\text{circ}} > 120$ km/s (high mass) show well-defined dust lanes

- Objects with $v_{\text{circ}} < 120$ km/s (low mass) show no dust lanes

Dalcanton et al. (2004)
Background: Dalcanton et al. (2004)

\[ Q_i = \frac{\kappa \sigma_i}{\pi G \Sigma_i} \]

\( Q < 1 \): unstable

\( Q > 1 \): stable

Dalcanton et al. (2004)
Is there a transition in star formation efficiency at the dust and cold ISM scale height transition of $v_{\text{circ}} = 120$ km/s?
Motivation – Mid Plane Pressure Model

- Larger scale height $\Rightarrow$ lower gas volume density $\Rightarrow$
  lower gas pressure $\Rightarrow$ lower molecular fraction $\Rightarrow$
  lower SFR surface density
Motivation – Krumholz et al. (2009) Model

- No obvious scale height dependence

= Atomic-molecular complex with constant molecular SFE
NGC 4713 ($v_{\text{circ}} = 111 \text{ km/s}$)

$\text{H}\alpha$

IRAC 8 $\mu$m PAH

IRAC 3.6 $\mu$m

IRAC 4.5 $\mu$m

$21'' = 1.5 \text{ kpc}$

HI intensity
Star Formation Relation – Total Gas

Watson et al. (2012)
Star Formation Relation – Total Gas

Watson et al. (2012)
No Star Formation Transition at Any Circular Velocity

\[ \log(\text{SFE}) = \log(\Sigma_{\text{SFR}}/\Sigma_{\text{HI}} + n_z) \text{ [yr}^{-1}] \]

\[ v_{\text{circ}} \text{ (km/s)} \]
Consequences of Star Formation Relation Results

• We find no transition in star formation efficiency at $v_{\text{circ}} = 120$ km/s, or at any circular velocity probed by our sample.

• Differences in the scale height of the dust and cold gas at the level found by Dalcanton et al. (~factor of 2 level) do not affect the molecular fraction or star formation efficiency.

• Our results suggest that star formation is affected by physical processes that act on smaller scales than the tens of parsecs probed by dust scale heights.
low-mass

high-mass

● = Molecular cloud with constant molecular SFE
Comparison to Mid-Plane Pressure Model

\[ \log(\text{SFE}) = \log(\frac{\Sigma_{\text{SFR}}}{\Sigma_{\text{gas}}}) [\text{yr}^{-1}] \]

\[ \log(P_h / k_B [\text{K/cm}^3]) \]

\[ P_h \approx \frac{\pi}{2} G \Sigma_{\text{gas}} \left( \Sigma_{\text{gas}} + \frac{\sigma_{\text{gas}}}{\sigma_{*,z}} \Sigma_* \right) \]

Leroy et al. (2008)
Comparison to Krumholz et al. (2009) Model
No Stability Transition at $v_{\text{circ}} = 120$ km/s

$Q_{\text{gas}} = \frac{\kappa \sigma_{\text{gas}}}{\pi G \Sigma_{\text{gas}}}$

$Q_{\text{stars}} = \frac{\kappa \sigma_{*,r}}{\pi G \Sigma_{*}}$

$Q < 1$: unstable
$Q > 1$: stable
Summary

• We find no transition in star formation efficiency or stability at $v_{\text{circ}} = 120$ km/s, or at any circular velocity probed by our sample.

• Differences in the scale height of the dust and cold gas at the level found by Dalcanton et al. do not affect the molecular fraction or star formation efficiency.

• Our results may indicate that star formation is affected by physical processes that act on smaller scales than the tens of parsecs probed by dust scale heights.

• Our results are somewhat more consistent with the Krumholz et al. (2009) star formation model than the mid-plane pressure model.
The Important Players in Star Formation

- What physical processes are important for determining the star formation rate (SFR) in galaxies?

Bigiel et al. (2008)
The Kennicutt-Schmidt Relation

\[ \log \Sigma_{SFR} \left( \frac{M_{\odot}}{\text{yr}^{-1} \text{kpc}^{-2}} \right) = \log \Sigma_{\text{HI+H}_2} \left( \frac{M_{\odot}}{\text{pc}^{-2}} \right) - \frac{1}{2} \]

- M51 (Kennicutt et al. 07) – Apertures
- M51 (Schuster et al. 07), NGC4736 & NGC5055 (Wong & Blitz 02), NGC6946 (Crosthwaite & Turner 07) – Radial Profiles
- Non-starburst Spirals (Kennicutt 98) – Global
- Starburst Galaxies (Kennicutt 98) – Global
- LSB galaxies (Wyder et al., in prep.) – Global

Bigiel et al. (2008)
Star Formation Models

Balance between the creation and destruction of molecular hydrogen:

\[ \log \Sigma_{\text{SFR}} \left( M_{\odot} \text{yr}^{-1} \text{kpc}^{-2} \right) \]

\[ \log \Sigma_{\text{HI+H}_2} \left( M_{\odot} \text{pc}^{-2} \right) \]
Star Formation Models

Mid-plane gas pressure sets the molecular fraction:

Leroy et al. (2008)
The Data

• Sample: 20 nearby, moderately inclined, bulgeless disk galaxies

• Gas surface density ($\Sigma_{\text{gas}}$):
  - $\Sigma_{\text{HI}}$ from VLA 21 cm data
  - $\Sigma_{\text{H}_2}$ from IRAM 30m CO J=1-0 2.6 mm data

• Star formation rate surface density ($\Sigma_{\text{SFR}}$):
  - MDM 2.4m H$\alpha$ data
  - Spitzer IRAC PAH (8 $\mu$m) data

• Stellar mass and estimated oxygen abundance:
  - Spitzer IRAC 4.5 $\mu$m data
Deriving Circular Velocities

Watson et al. (2011)

UGC 6446
Star Formation Relation – Atomic Gas

\[ \log(\Sigma_{\text{SPR}} \text{ [M}_\odot\text{/yr/kpc}^2]) \]

\[ \log(\Sigma_{\text{HI}} \text{ [M}_\odot\text{/pc}^2]) \]

- \( v_{\text{circ}} < 120 \text{ km/s} \)
- \( v_{\text{circ}} > 120 \text{ km/s} \)

Bigiel et al. (2008)
Star Formation Relation – Molecular Gas

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**Figure:**

A scatter plot showing the relationship between the star formation rate (Σ_{SPR}) and the molecular gas surface density (Σ_{H2}). The plot includes data points from Bigiel et al. (2008).

- **Logarithmic scale:**
  - Y-axis: log(Σ_{SPR} [M_☉/yr/kpc^2])
  - X-axis: log(Σ_{H2} [M_☉/pc^2])

- **Legend:**
  - Red squares: v_{circ} < 120 km/s
  - Blue triangles: v_{circ} > 120 km/s

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**Note:**

Bigiel et al. (2008) data points are represented by red squares for low circular velocities and blue triangles for high circular velocities.