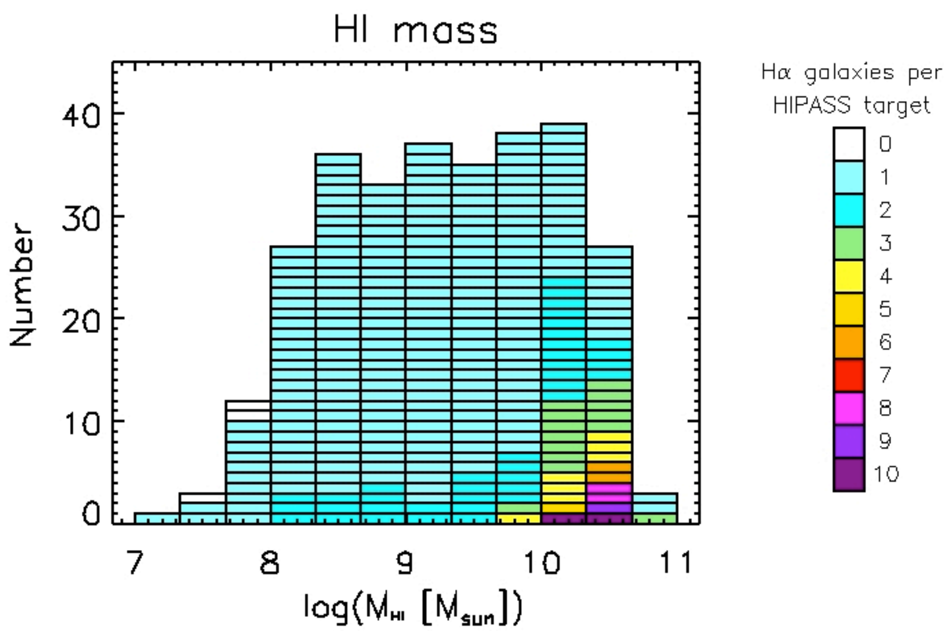
Motivation

- ❑ Gas and star formation strongly correlated
- ❑ Key physics of gas
  - ◆ Dissipation of energy
  - ◆ Conservation of angular momentum
  - ➢ they make disks
- ❑ Disks stabilize
- ❑ Can this be the basis of correlations we see in star formation surveys?



Disks stabilize

- ❑ Stability parameter Q (Toomre 1964)

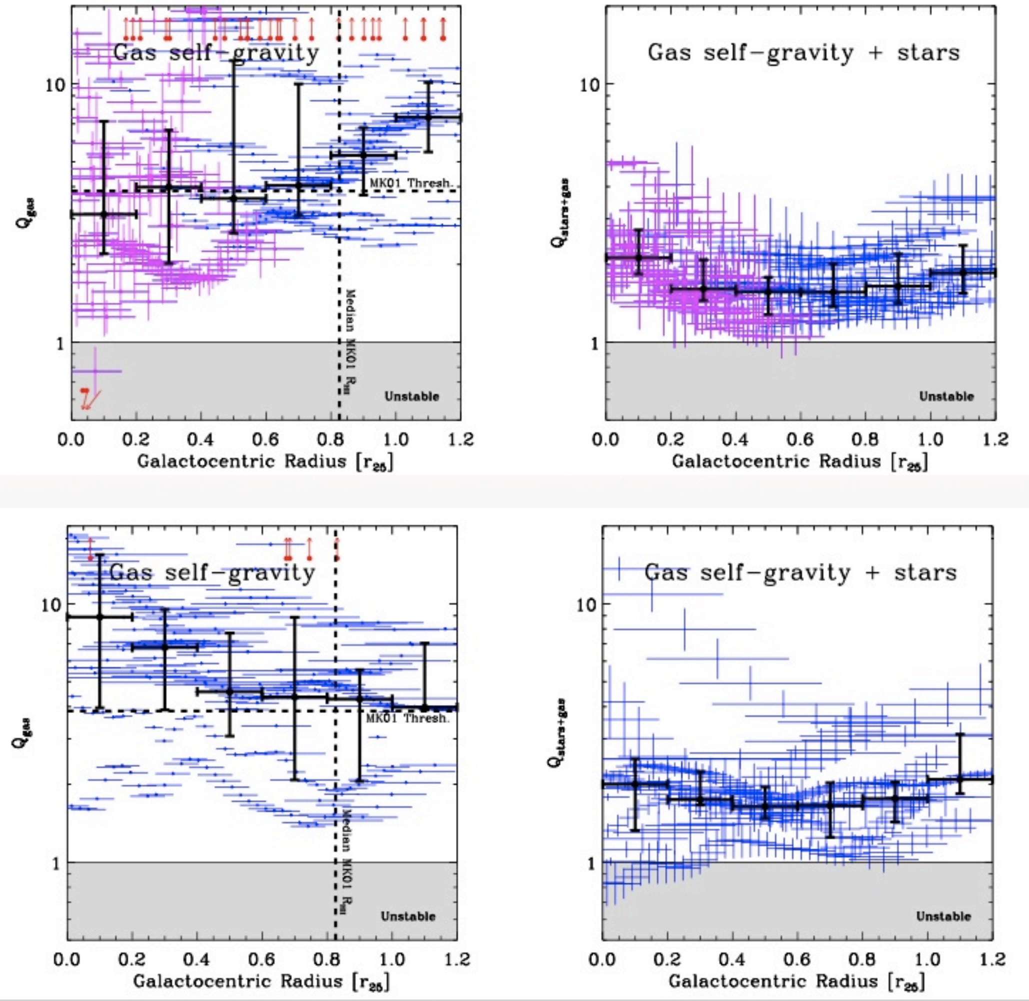
$$Q = \frac{\sigma\kappa}{\pi G \Sigma}$$

- ❑ General form for 2 fluid stability parameter

$$\frac{1}{Q_{2f}} = \frac{p_g}{Q_g} + \frac{p_s}{Q_s}$$

- e.g. (Jog & Solomon 1984, Wang & Silk, 1994, Rafikov 2001, Romeo & Wiegert 2011)

- ❑ Disks have uniform stability when 2 fluid stability considered E.g. Leroy et al. (2008)



Outer disks – the Bosma relation

- Bosma (1981, AJ, 86, 1825)
  - Galaxies have flat RCs
  - HI traces total mass at large radius
  - Implies HI traces DM!
  - $\Sigma_{DM} \sim 1/R$
- Previous explanations
  - Gaseous form of Dark Matter
    - Carignan & Beaulieu (1989, ApJ, 347, 760)
    - Pfenniger et al. (1994, A&A, 285, 79)
    - Pfenniger & Combes (1994, A&A, 285, 94)
    - Hessman & Ziebert (2011, A&A, 532, 121)
  - MOND
    - Broeils (1992, A&A, 256, 19)
    - Milgrom (1983, ApJ, 260, 365)
    - Milgrom (1988, ApJ, 333, 689)

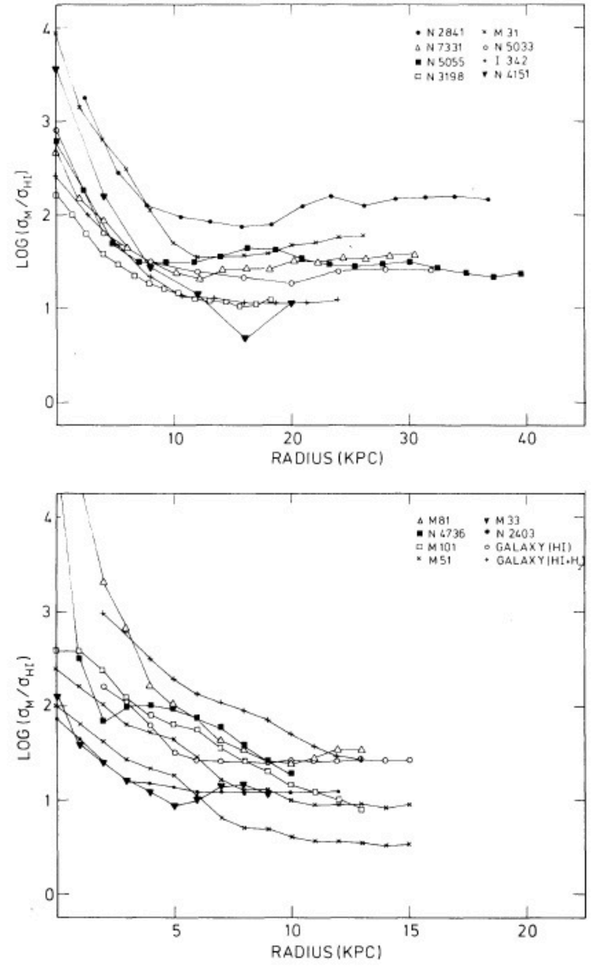


FIG. 7. Radial variation mass to H I gas mass surface density ratio in various galaxies. σ_M has been taken from Fig. 4; σ_{HI} has been calculated from averages over the azimuthal direction of the H I column density distributions, multiplied by cos i; no corrections for optical depth have been applied.

Stable disks and flat RCs

- Toomre Q parameter

$$Q = \frac{\sigma\kappa}{\pi G \Sigma}$$

- Epicyclic frequency κ

$$\kappa = \frac{V}{R}\sqrt{2\left(1 + \frac{R}{V}\frac{dV}{dR}\right)}$$

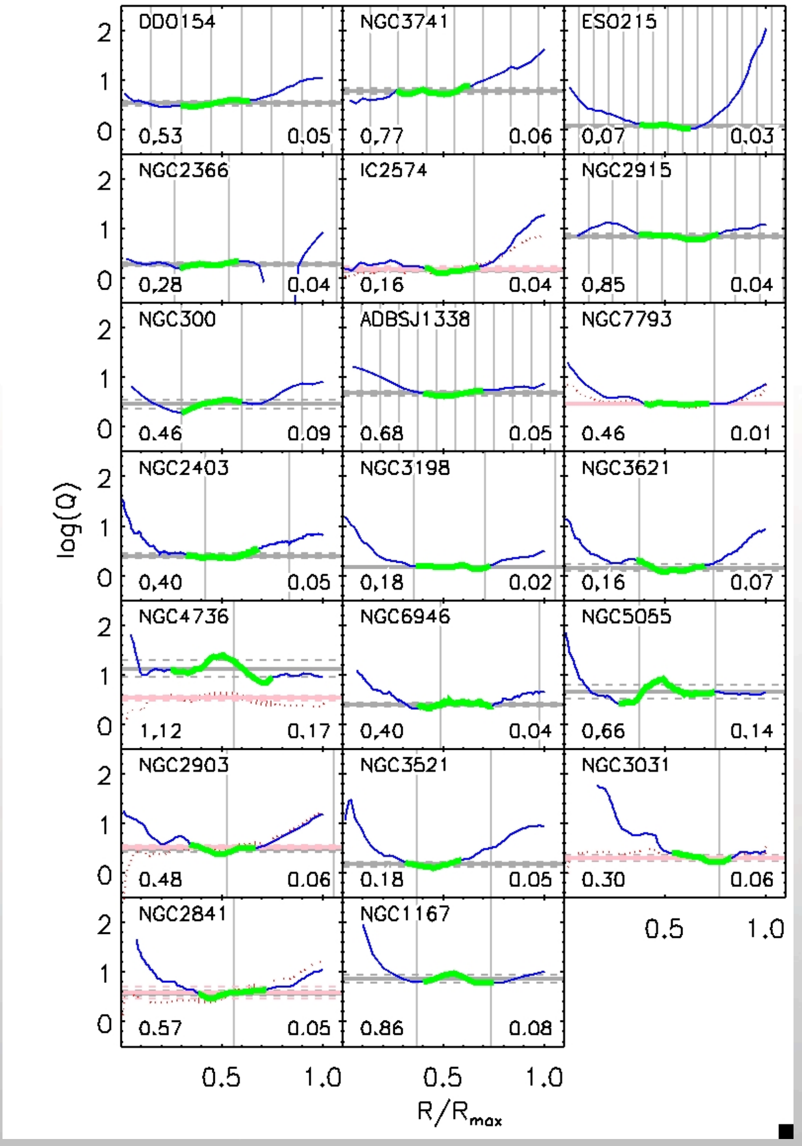
- Limit of flat rotation curve

$$\Sigma \propto \frac{1}{R}$$

"projected" DM surface mass density also alls off as R^{-1} !

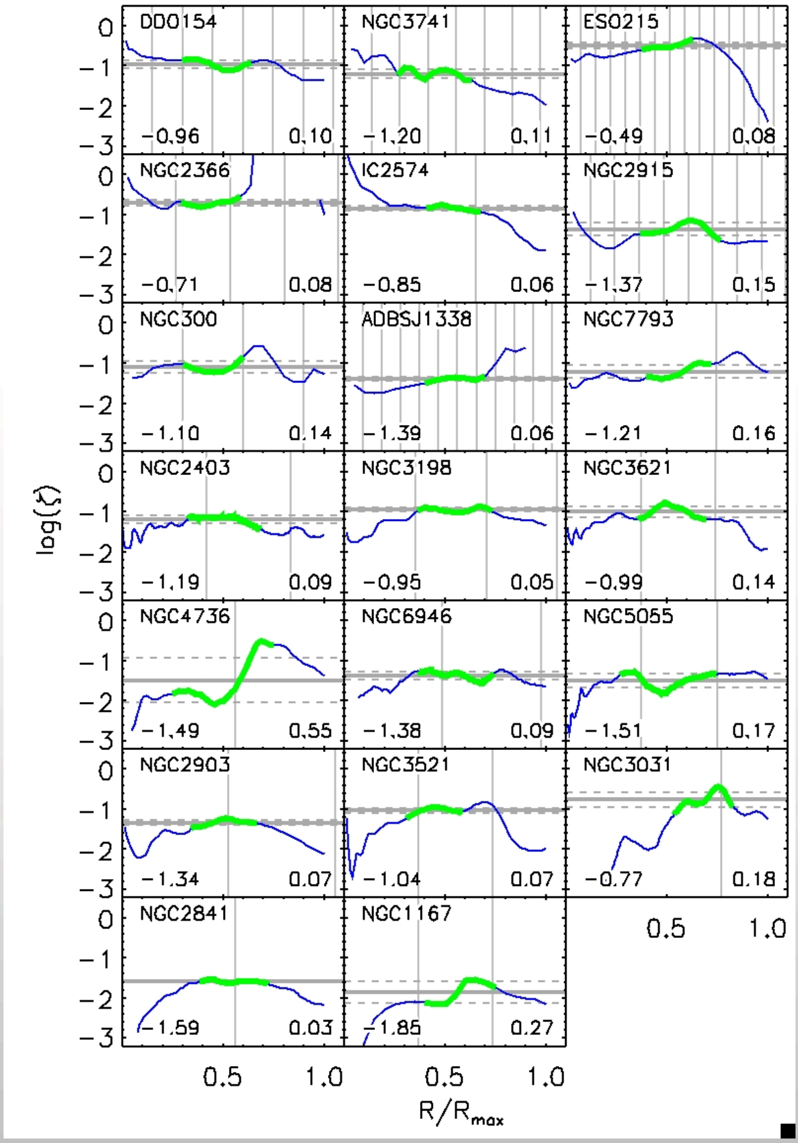
Meurer, Zheng & de Blok (2013, MNRAS)

- ❑ Outer disks have constant stability
  (Q profiles are flat)
- ❑ $\zeta = \Sigma_g/\Sigma_M$ flat too (but not as flat as Q)
- ❑ RCs not always flat…
- ❑ Σ_g follows κ
  - ◆ N power law index in Σ_g
  - ◆ M power law index in κ
  - ◆ This Is why Q is flat while RC is not
- ❑ Global ζ anti-correlates with V_{max}



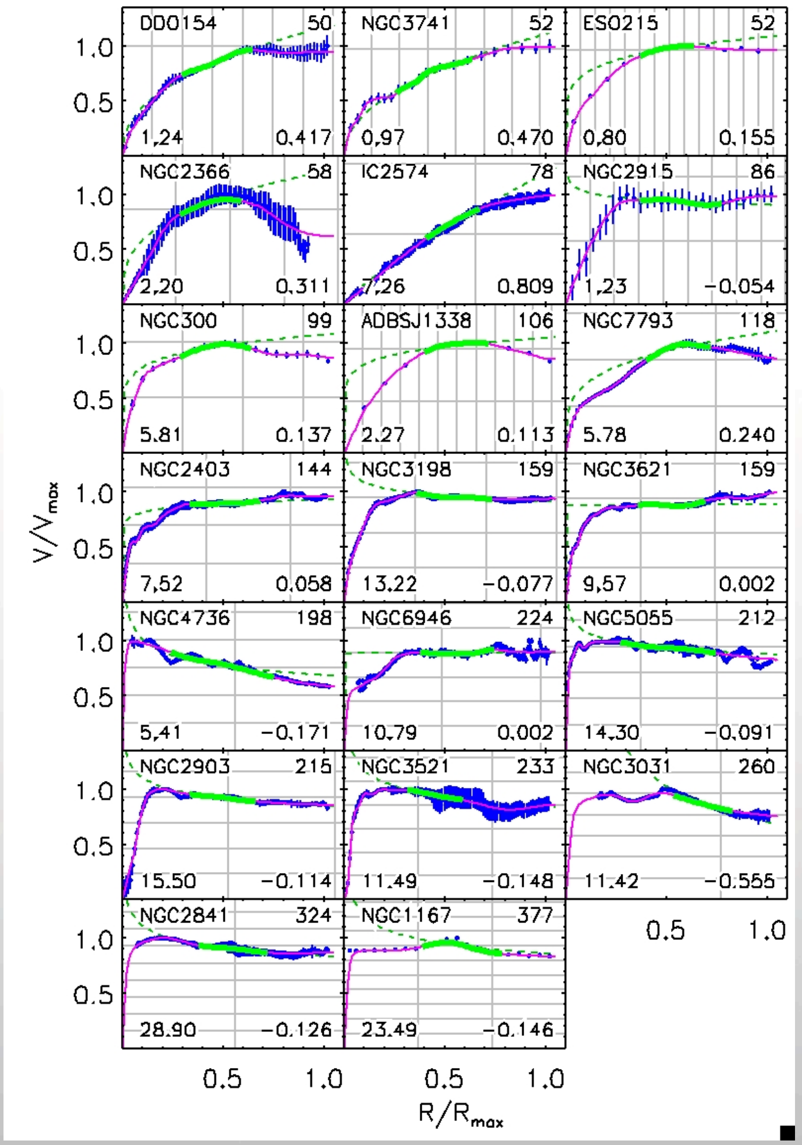
Meurer, Zheng & de Blok (2013, MNRAS)

- ❑ Outer disks have constant stability
  (Q profiles are flat)
- ❑ $\zeta = \Sigma_g/\Sigma_M$ flat too (but not as flat as Q)
- ❑ RCs not always flat…
- ❑ Σ_g follows κ
  - ◆ N power law index in Σ_g
  - ◆ M power law index in κ
  - ◆ This Is why Q is flat while RC is not
- ❑ Global ζ anti-correlates with V_{max}



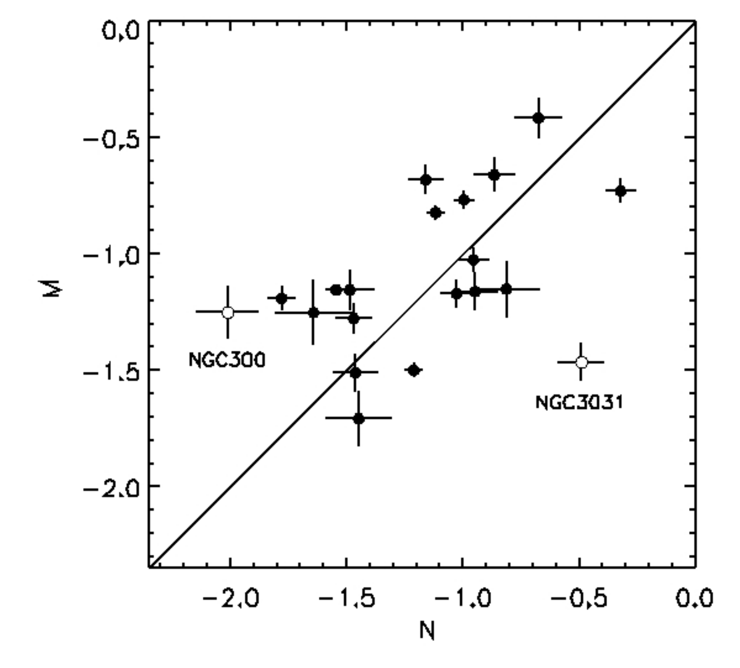
Meurer, Zheng & de Blok (2013, MNRAS)

- ❑ Outer disks have constant stability
  (Q profiles are flat)
- ❑ $\zeta = \Sigma_g/\Sigma_M$ flat too (but not as flat as Q)
- ❑ RCs not always flat…
- ❑ Σ_g follows κ
  - ◆ N power law index in Σ_g
  - ◆ M power law index in κ
  - ◆ This Is why Q is flat while RC is not
- ❑ Global ζ anti-correlates with V_{max}



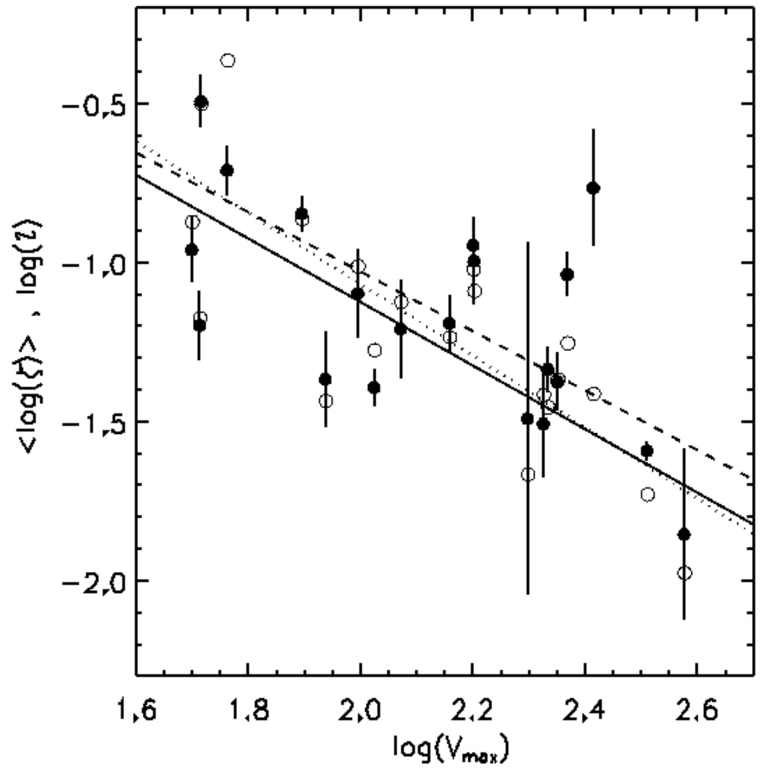
Meurer, Zheng & de Blok (2013, MNRAS)

- Outer disks have constant stability
  (Q profiles are flat)
- $\zeta = \Sigma_g/\Sigma_M$ flat too (but not as flat as Q)
- RCs not always flat…
- Σ_g follows κ
  - N power law index in Σ_g
  - M power law index in κ
  - This Is why Q is flat while RC is not
- Global ζ anti-correlates with V_{max}



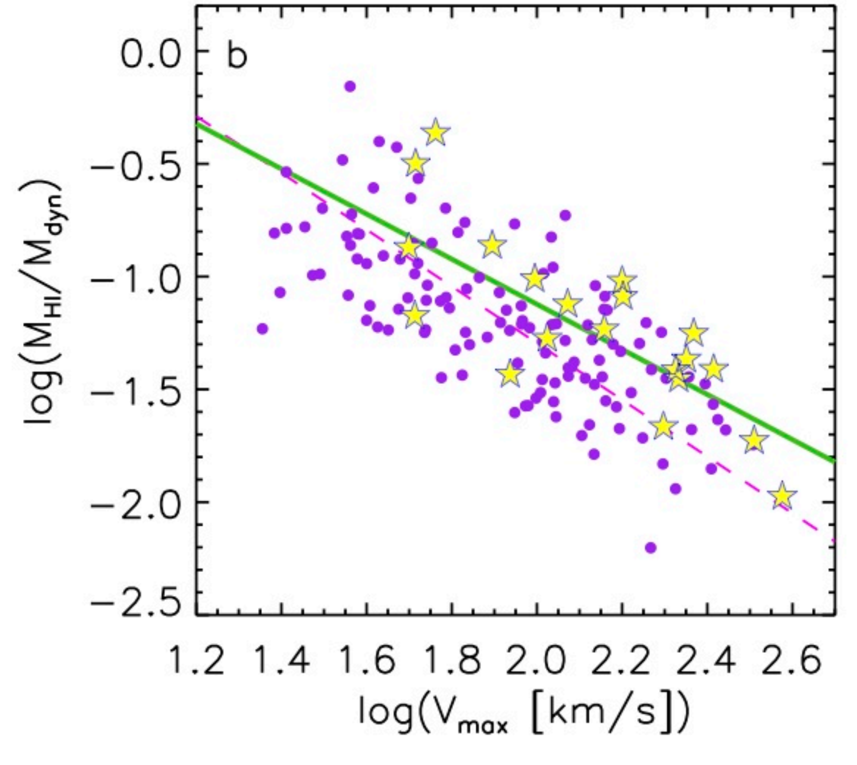
Meurer, Zheng & de Blok (2013, MNRAS)

- ❑ Outer disks have constant stability
  - (Q profiles are flat)
- ❑ $\zeta = \Sigma_g/\Sigma_M$ flat too (but not as flat as Q)
- ❑ RCs not always flat…
- ❑ Σ_g follows κ
  - ◆ N power law index in Σ_g
  - ◆ M power law index in κ
  - ◆ This Is why Q is flat while RC is not
- ❑ Global ζ anti-correlates with V_{max}



Meurer, Zheng & de Blok (2013, MNRAS)

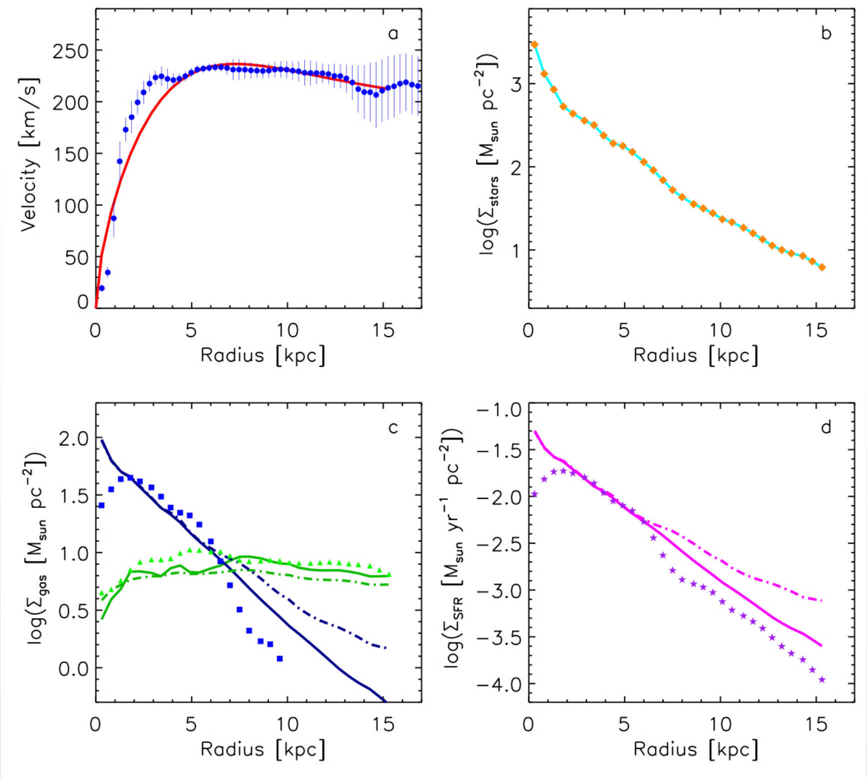
- Outer disks have constant stability
  (Q profiles are flat)
- $\zeta = \Sigma_g/\Sigma_M$ flat too (but not as flat as Q)
- RCs not always flat…
- Σ_g follows κ
  - N power law index in Σ_g
  - M power law index in κ
  - This Is why Q is flat while RC is not
- Global ζ anti-correlates with V_{max}



We have a good model for how to distribute the ISM in the outer disk.

Gas and SF in a constant Q disk

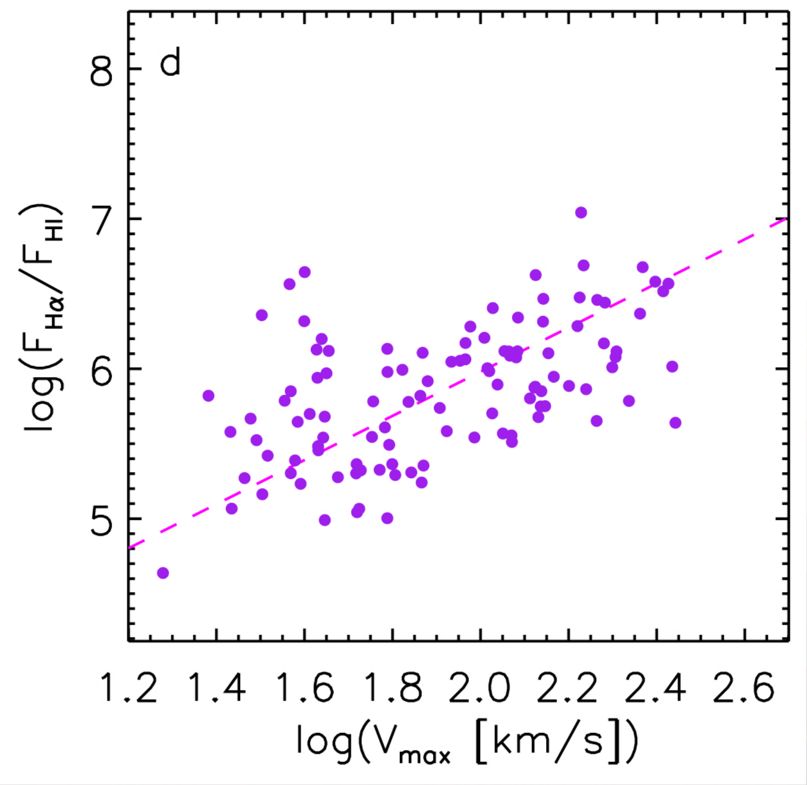
- Zheng, Meurer et al. (2012, MNRAS, submitted)
- Algorithm
  - Constant Q_{2f}
    - 4 recipes trialed
    - Not much difference between them
  - Gas phases calculated $R_{mol} = \Sigma_{H2}/\Sigma_{HI}$
    - Three recipes trialed
    - Linear correlation with Σ_s works best
  - Star formation intensity from Star Formation Law
    - 8 SFLs trialed
    - Versions that separate H2 and HI work best
- Inputs
  - RC
  - Σ_s profile
- Results
  - Reasonable, but not precise fits
  - Centers often problematic



SF scaling relations in SINGG / SUNGG

- SINGG: Survey of Ionization in Neutral Gas Galaxies
- SUNGG: Survey of Ultraviolet emission in Neutral Gas Galaxies
- Both are follow-up star formation surveys using HIPASS as the parent sample

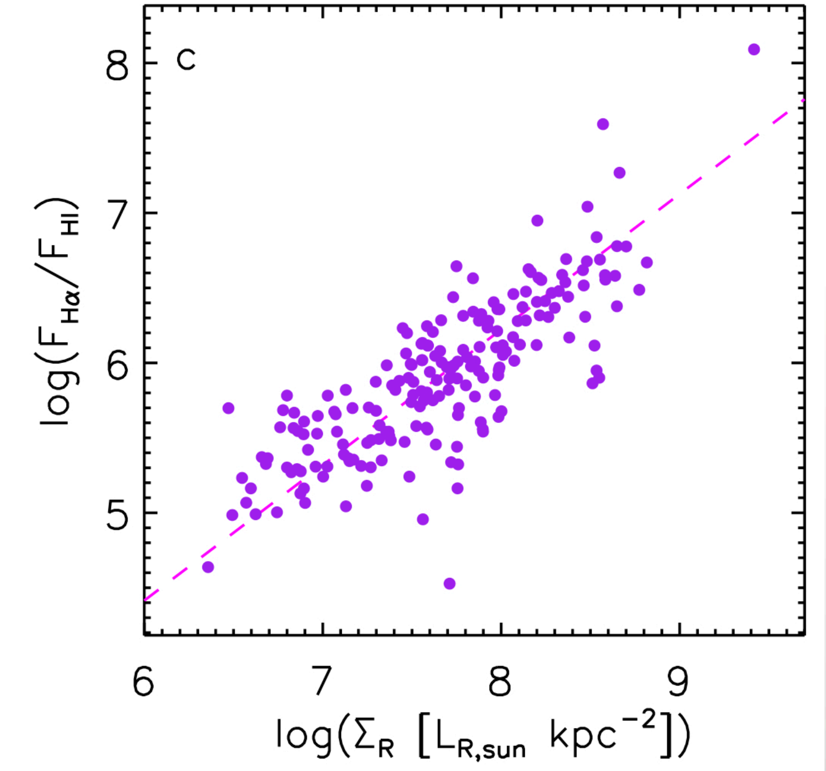
- SFE = SFR(Hα)/M_{HI} ~ $F_{H\alpha}/F_{HI}$
  - Correlates with V_{max}
  - Correlates better with surface brightness



SF scaling relations in SINGG / SUNGG

- SINGG: Survey of Ionization in Neutral Gas Galaxies
- SUNGG: Survey of Ultraviolet emission in Neutral Gas Galaxies
- Both are follow-up star formation surveys using HIPASS as the parent sample

- SFE = SFR(Hα)/M_{HI} ~ $F_{H\alpha}/F_{HI}$
  - Correlates with V_{max}
  - Correlates better with surface brightness

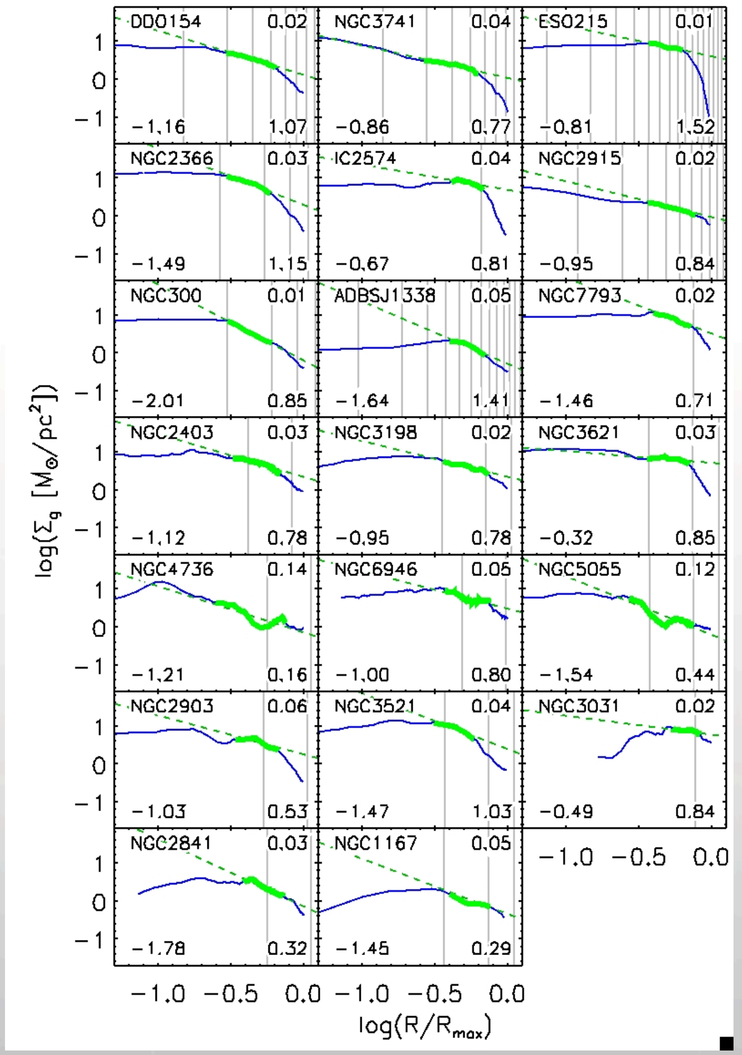


Modeling SFR/HI with CQ-disk

- Adopt some common scaling relations
  - Assume pure exponential disk dominates
  - Tully-Fisher V_{max} -> L_R
  - Surface brightness – luminosity -> $\Sigma_s(R)$
  - Universal Rotation Curve -> $V_{rot}(R)$
- Calculate CQ-disk model with these inputs
  - Truncate gas profile Σ_g (min) = 2.5 M_{sun}/pc^2
  - Try different prescriptions for R_{mol}
- Results
  - Follows data very well!
  - Clear preference for $R_{mol} \sim \Sigma_s$ prescription

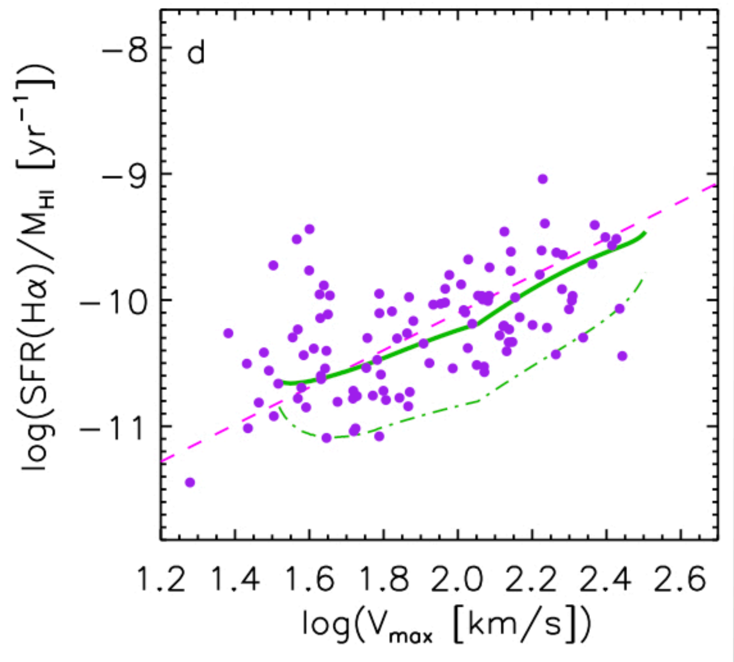
- Correlation with Σ_R can be understood crudely as due to SFL
  - For molecular SFL $\Sigma_{H2} \sim \Sigma_{SFR}$ (Bigiel et al. 2008)
  - SFR/HI -> H2/HI = R_{mol}
  - R_{mol} correlates with $\Sigma_s \sim \Sigma_R$

- (Meurer, Zheng, Wong in prep…)



Modeling SFR/HI with CQ-disk

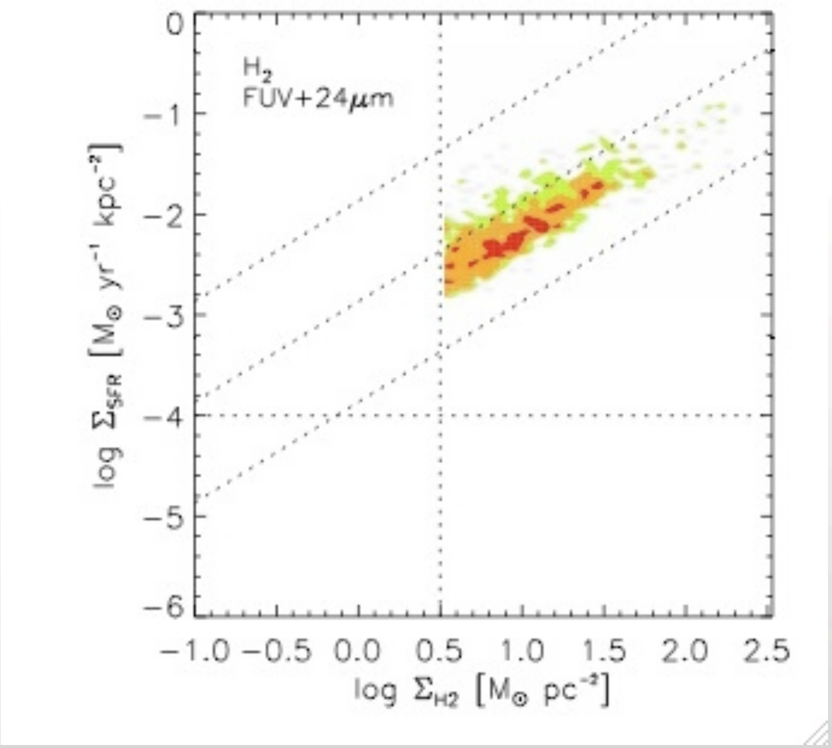
- Adopt some common scaling relations
  - Assume pure exponential disk dominates
  - Tully-Fisher V_{max} -> L_R
  - Surface brightness – luminosity -> $\Sigma_s(R)$
  - Universal Rotation Curve -> $V_{rot}(R)$
- Calculate CQ-disk model with these inputs
  - Truncate gas profile Σ_g (min) = 2.5 M_{sun}/pc^2
  - Try different prescriptions for R_{mol}
- Results
  - Follows data very well!
  - Clear preference for $R_{mol} \sim \Sigma_s$ prescription



- Correlation with Σ_R can be understood crudely as due to SFL
  - For molecular SFL $\Sigma_{H2} \sim \Sigma_{SFR}$ (Bigiel et al. 2008)
  - SFR/HI -> H2/HI = R_{mol}
  - R_{mol} correlates with $\Sigma_s \sim \Sigma_R$
- (Meurer, Zheng, Wong in prep…)

Modeling SFR/HI with CQ-disk

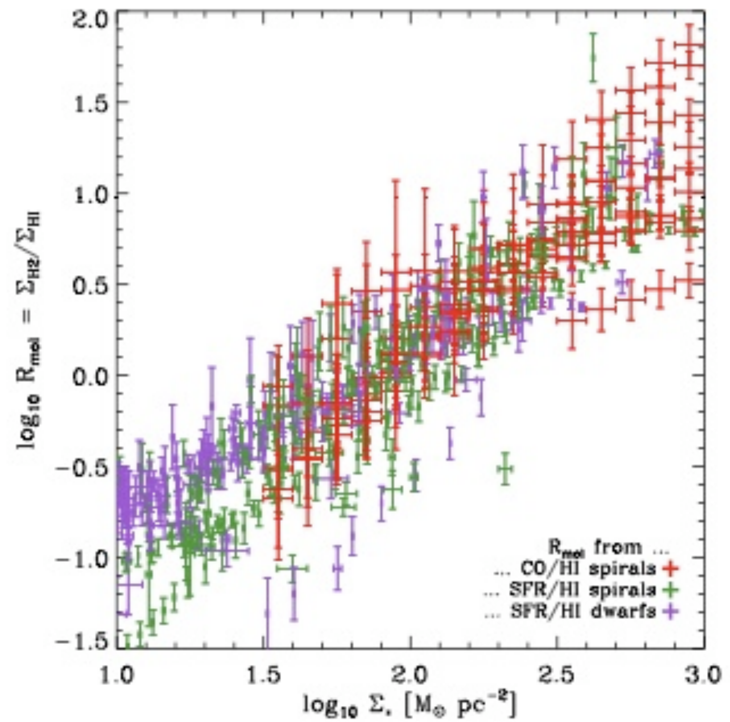
- Adopt some common scaling relations
  - Assume pure exponential disk dominates
  - Tully-Fisher V_{max} -> L_R
  - Surface brightness – luminosity -> $\Sigma_s(R)$
  - Universal Rotation Curve -> $V_{rot}(R)$
- Calculate CQ-disk model with these inputs
  - Truncate gas profile Σ_g (min) = 2.5 M_{sun}/pc^2
  - Try different prescriptions for R_{mol}
- Results
  - Follows data very well!
  - Clear preference for $R_{mol} \sim \Sigma_s$ prescription



- Correlation with Σ_R can be understood crudely as due to SFL
  - For molecular SFL $\Sigma_{H2} \sim \Sigma_{SFR}$ (Bigiel et al. 2008)
  - SFR/HI -> H2/HI = R_{mol}
  - R_{mol} correlates with $\Sigma_s \sim \Sigma_R$
- (Meurer, Zheng, Wong in prep…)

Modeling SFR/HI with CQ-disk

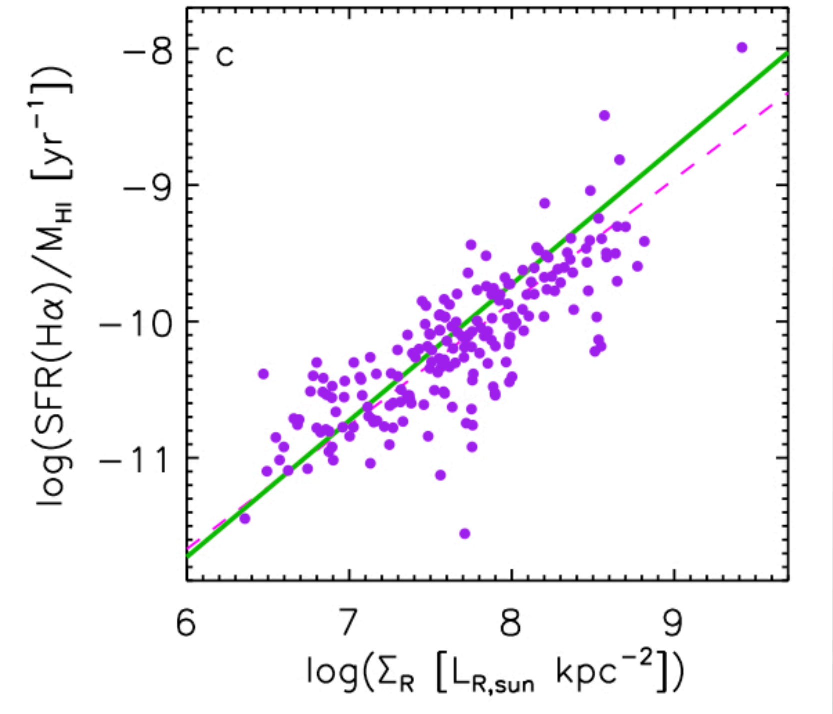
- Adopt some common scaling relations
  - Assume pure exponential disk dominates
  - Tully-Fisher V_{max} -> L_R
  - Surface brightness – luminosity -> $\Sigma_s(R)$
  - Universal Rotation Curve -> $V_{rot}(R)$
- Calculate CQ-disk model with these inputs
  - Truncate gas profile Σ_g (min) = 2.5 M_{sun}/pc^2
  - Try different prescriptions for R_{mol}
- Results
  - Follows data very well!
  - Clear preference for $R_{mol} \sim \Sigma_s$ prescription



- Correlation with Σ_R can be understood crudely as due to SFL
  - For molecular SFL $\Sigma_{H2} \sim \Sigma_{SFR}$ (Bigiel et al. 2008)
  - SFR/HI -> H2/HI = R_{mol}
  - R_{mol} correlates with $\Sigma_s \sim \Sigma_R$
- (Meurer, Zheng, Wong in prep…)

Modeling SFR/HI with CQ-disk

- Adopt some common scaling relations
  - Assume pure exponential disk dominates
  - Tully-Fisher V_{max} -> L_R
  - Surface brightness – luminosity -> $\Sigma_s(R)$
  - Universal Rotation Curve -> $V_{rot}(R)$
- Calculate CQ-disk model with these inputs
  - Truncate gas profile Σ_g (min) = 2.5 M_{sun}/pc^2
  - Try different prescriptions for R_{mol}
- Results
  - Follows data very well!
  - Clear preference for $R_{mol} \sim \Sigma_s$ prescription



- Correlation with Σ_R can be understood crudely as due to SFL
  - For molecular SFL $\Sigma_{H2} \sim \Sigma_{SFR}$ (Bigiel et al. 2008)
  - SFR/HI -> H2/HI = R_{mol}
  - R_{mol} correlates with $\Sigma_s \sim \Sigma_R$
- (Meurer, Zheng, Wong in prep…)

Potential uses for CQ-disk model

- ❑ Initial conditions for detailed simulations (e.g. create two normal galaxies to collide into each other).
- ❑ SAM prescription to paint realistic galaxies on to halos
  - ◆ Comparison of SF vs. HI, CO surveys
  - ◆ Model ρ_{HI}, ρ_{H2}, ρ_{SFR} in local universe
  - ◆ … and evolution? (e.g. Hanish et al. 2006)
- ❑ Fake HI data cubes with realistic HI velocity profiles
- ❑ Fake multi-wavelength images

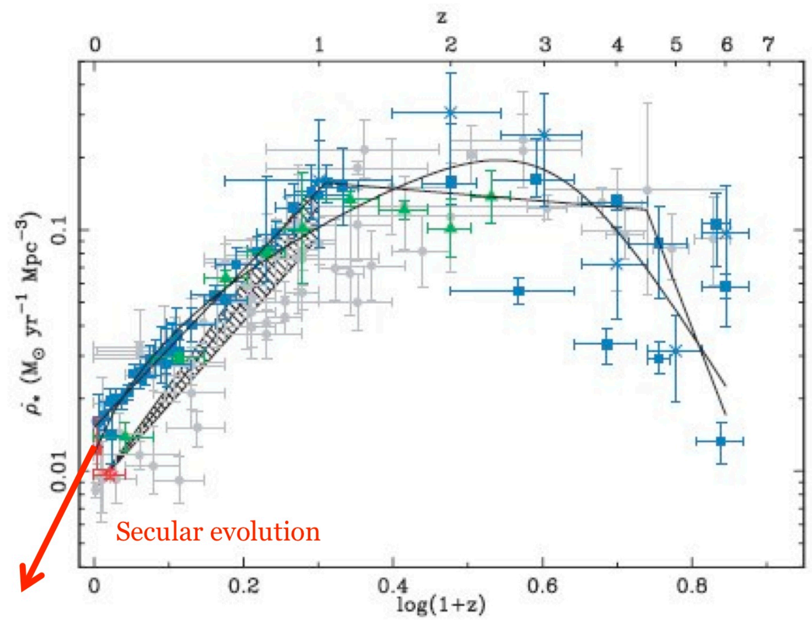
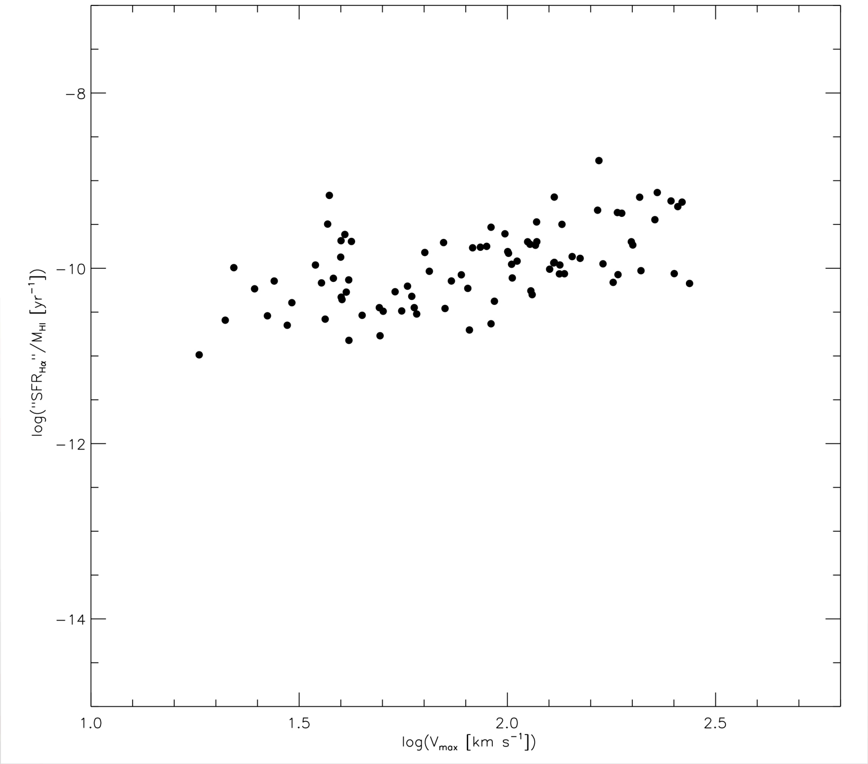


FIG. 1.—Evolution of SFR density with redshift. Data shown here have been scaled, assuming the SalA IMF. The gray points are from the compilation of Hopkins (2004). The hatched region is the FIR (24 μm) SFH from Le Floc'h et al. (2005). The green triangles are FIR (24 μm) data from Pérez-González et al. (2005). The open red star at $z = 0.05$ is based on radio (1.4 GHz) data from Mauch (2005). The filled red circle at $z = 0.01$ is the Hα estimate from Hanish et al. (2006). The blue squares are UV data from Baldry et al. (2005), Wolf et al. (2003), Arnouts et al. (2005), Bouwens et al. (2003a, 2003b, 2005a), Bunker et al. (2004), and Ouchi et al. (2004). The blue crosses are the UDF estimates from Thompson et al. (2006). Note that these have been scaled to the SalA IMF, assuming they were originally estimated using a uniform Salpeter (1955) IMF. The solid lines are the best-fitting parametric forms (see text for details of which data are used in the fitting). Although the FIR SFH of Le Floc'h et al. (2005) is not used directly in the fitting, it has been used to effectively obscuration-correct the UV data to the values shown, which are used in the fitting. Note that the top logarithmic scale is labeled with redshift values, not $(1 + z)$.

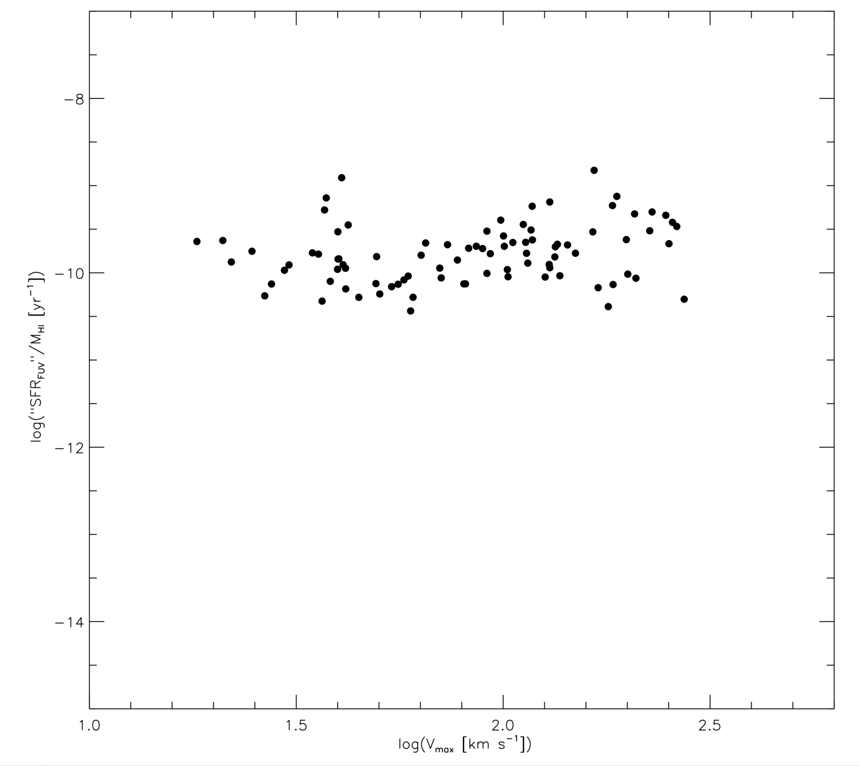
Further work

- ❑ UV does not behave the same as Hα
- ❑ Probably due to IMF variations
    - ◆ Hoversten & Glazebrook (2008)
    - ◆ Meurer et al. (2009)
    - ◆ Lee et al. (2009)
    - ◆ Gunawardhana et al. (2011)
- ❑ Include IMF variations in models
- ❑ Include evolution in models



Further work

- ❑ UV does not behave the same as Hα
- ❑ Probably due to IMF variations
  - ◆ Hoversten & Glazebrook (2008)
  - ◆ Meurer et al. (2009)
  - ◆ Lee et al. (2009)
  - ◆ Gunawardhana et al. (2011)
- ❑ Include IMF variations in models
- ❑ Include evolution in models



Further work

- ❑ UV does not behave the same as Hα
- ❑ Probably due to IMF variations
  - Hoversten & Glazebrook (2008)
  - Meurer et al. (2009)
  - Lee et al. (2009)
  - Gunawardhana et al. (2011)
- ❑ Include IMF variations in models
- ❑ Include evolution in models