

# What sets where (and how many) massive stars form in a spiral galaxy?



Still much bigger than what we've been hearing about all week!



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## Collaborators & Key Data Sets

- **Frank Bigiel (graduate student at MPIA)**
- F. Walter (MPIA), E. Brinks, Erwin de Blok (THINGS)
- R.C. Kennicutt (SINGS)
- GALEX NGS (A. Gil de Paz et al. '07; B. Madore)
- BIMA SONG (T. Helfer et al. 2003)

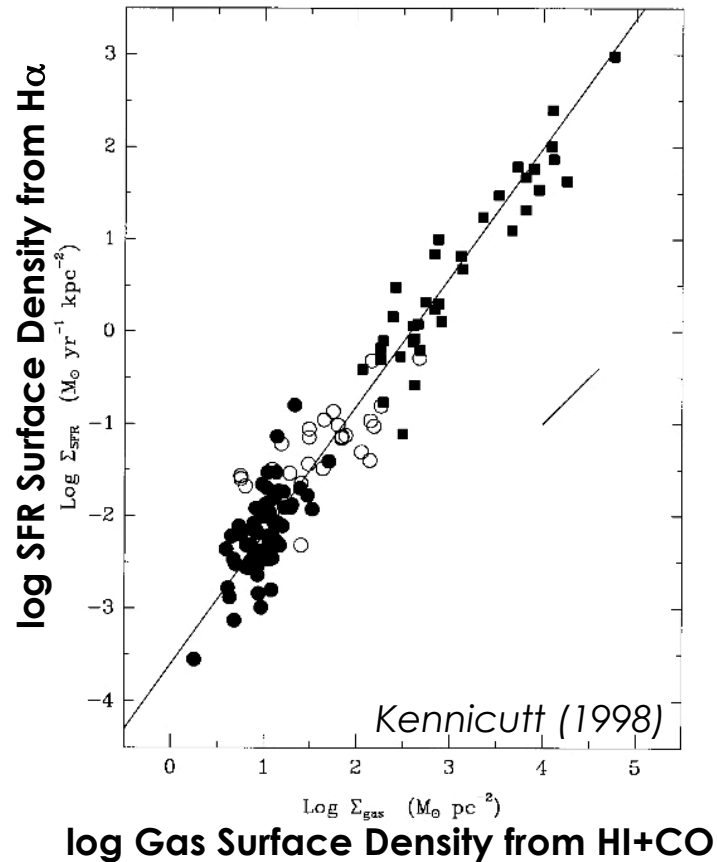
*In prep:*

*Bigiel et al. "The Star Formation Law on sub-Kiloparsec scales"*

*Leroy et al. "Tests of Star Formation Recipes in THINGS"*



# What Sets a Galaxy's Star Formation Rate?



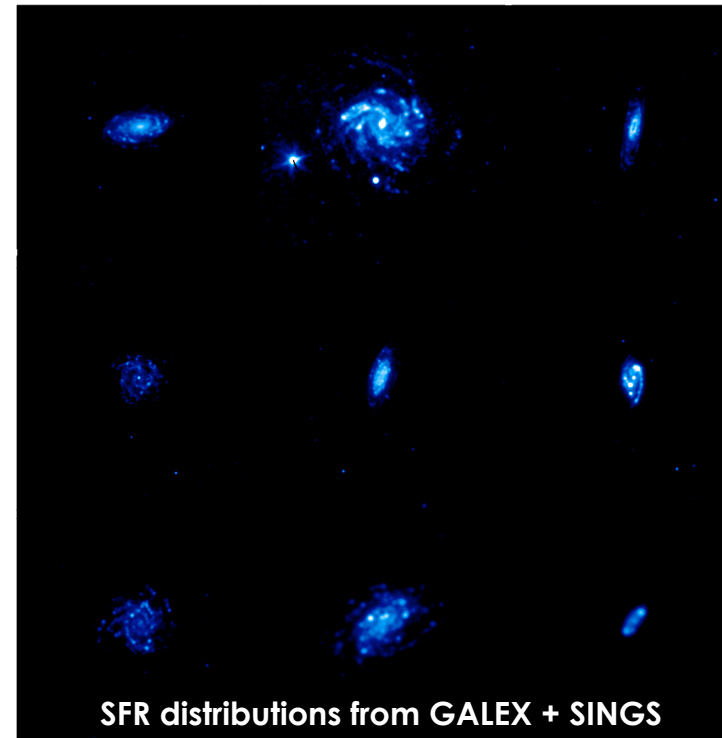
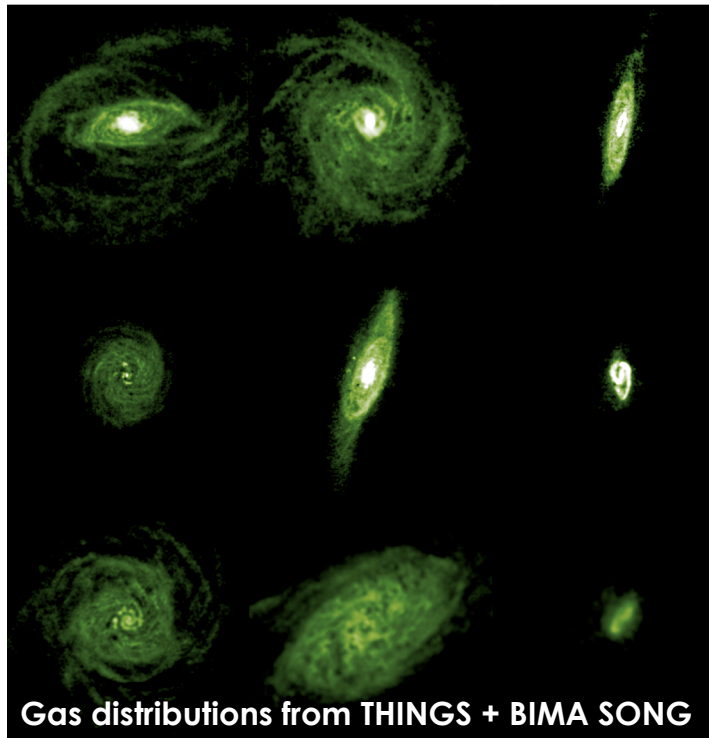
- Averaged over galaxy disks: Total gas (HI + H<sub>2</sub>) predicts SFR within a factor of ~2.
- **squares:** starbursts, **filled circles:** normal spirals, **open circles:** centers of spirals

# What sets where (and how many) massive stars form in a spiral galaxy?

- Total gas content (on galactic scales).

## What Sets the Local Star Formation Rate?

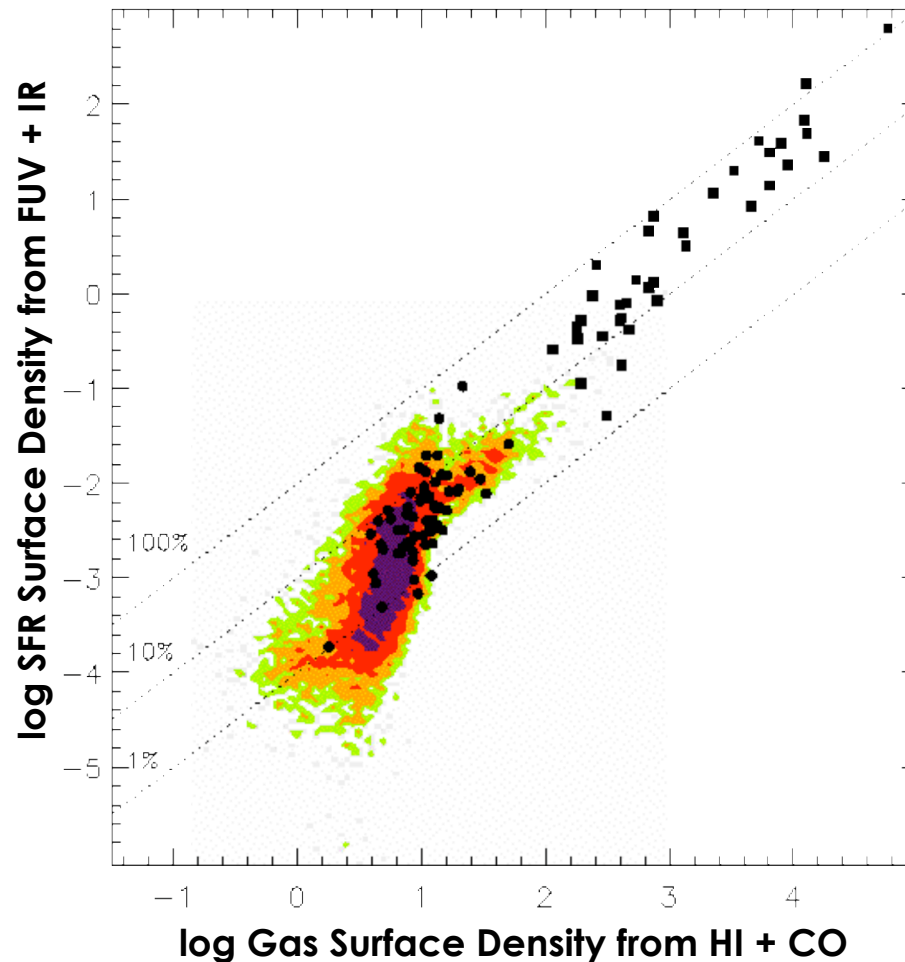
- Does the Kennicutt Schmidt law hold within galaxies?
- 10 THINGS spiral galaxies at a common spatial resolution of 500 pc.
- Gas maps: THINGS HI (atomic) + BIMA SONG CO (molecular)
- Star formation rate maps: GALEX FUV (unobscured) + MIPS 24 $\mu$ m (obscured)



THINGS:Walter et al. (2008); SONG:Helfer et al. (2003); NGS:Gil de Paz et al. (2007); SINGS:Kennicutt et al. (2003)  
SFR based on: Salim et al. (2007), Calzetti et al. (2005), Calzetti et al. (2007)

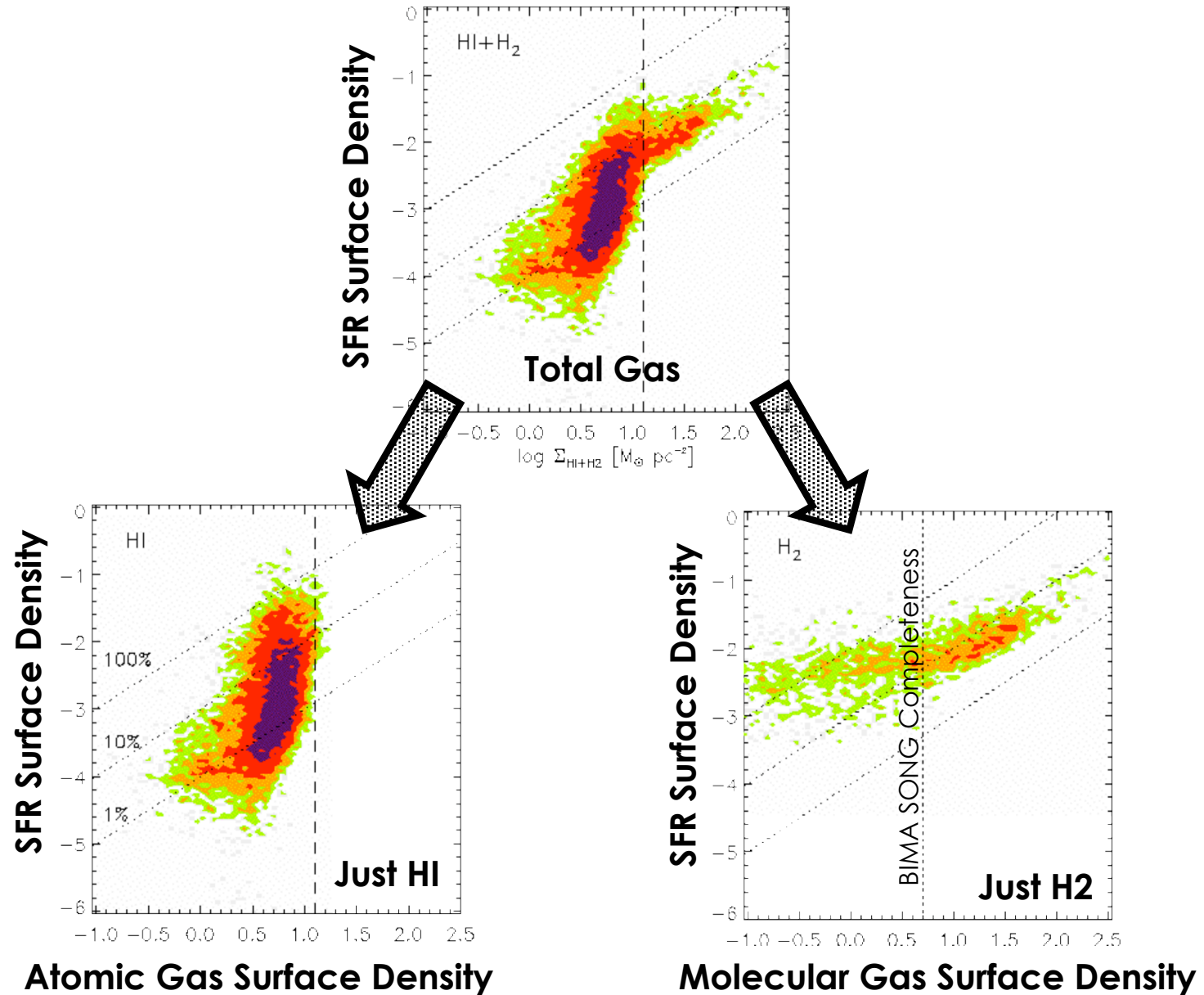
## What Sets the Local Star Formation Rate?

- Contours show pixel-by-pixel data over the optical disk of 10 spirals.
- THINGS overlaps low end of Kennicutt (1998) data (**black points**).
- Two regimes: Below  $\Sigma_{\text{gas}} \sim 10 M_{\text{sun}} \text{pc}^{-2}$  nearly vertical; almost linear above.



*In radial profile:  
Kennicutt '98  
Wong & Blitz '02*

# A Molecular Schmidt Law on 500pc Scales



# What sets where (and how many) massive stars form in a spiral galaxy?

- Total gas content (on galactic scales).
- **Molecular gas** surface density on 500 pc scales.  
(but sensitive high resolution CO maps still a big need).

*also:*

*Martin & Kennicutt '01*

*Wong & Blitz '02*

*Heyer et al. '04*

*Kennicutt et al. '07*

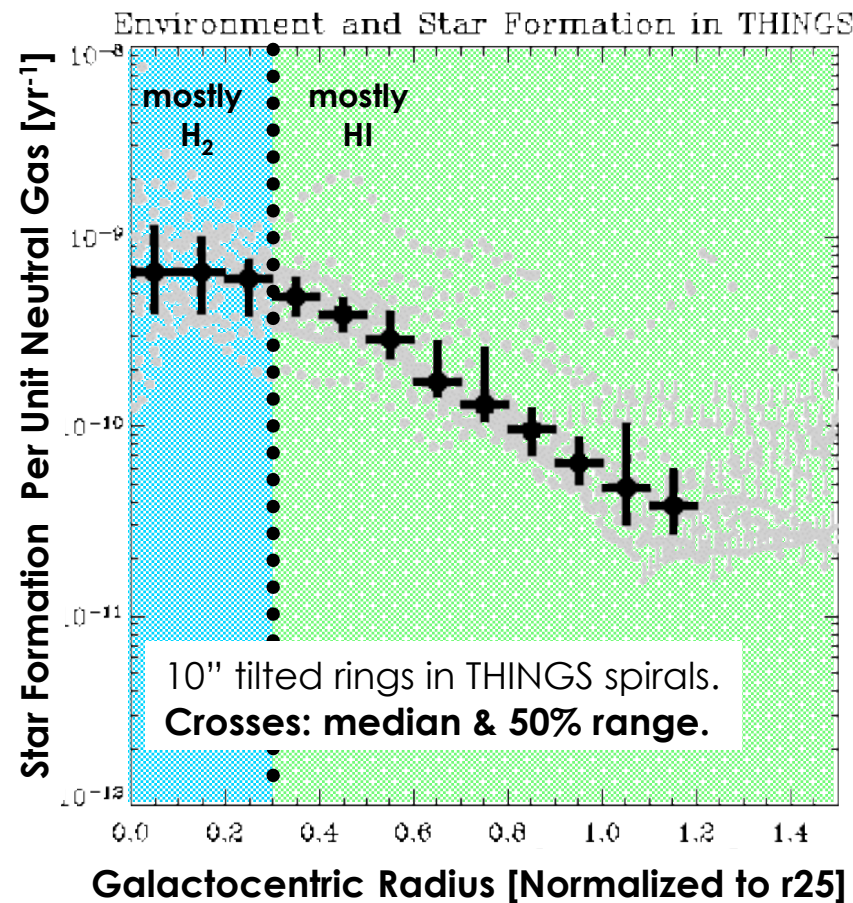
*could be expected from:*

*Krumholz & Mckee '05*



# What Sets the Fraction Gas in H<sub>2</sub>?

- The SFR per unit neutral gas is constant in molecule-dominated centers.
- In the HI-dominated regime it is a clear, strong function of radius.
- Radius: metallicity, (differential) rotation, stellar surface density, etc.



$\propto$  Fraction of the ISM in star-forming giant molecular clouds?

see also profiles in:  
Wong & Blitz ('02)  
Martin & Kennicutt ('01)

# What sets where (and how many) massive stars form in a spiral galaxy?

- Total gas content (on galactic scales).
- **Molecular gas** surface density (on 500 pc scales).
- Amount of ISM in the H<sub>2</sub> strong function of environment/radius.

# Star Formation Laws and Thresholds

- Suggestions for what regulates star formation in galaxy disks:



**Kennicutt Schmidt law**

*Gas-SFR correlation observed at galactic scales. (Kennicutt '98)*



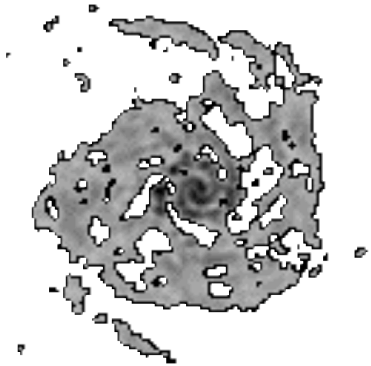
**Toomre Q Threshold**

*Instability in a rotating gas disk. (Martin & Kennicutt '01)*



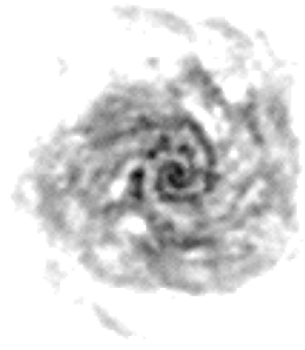
**Shear Threshold**

*Cloud formation competes with destruction by galactic shear. (Hunter, Elmegreen, & Baker '98)*



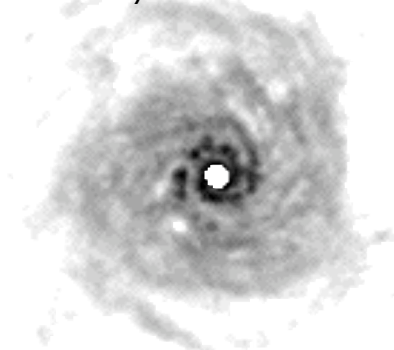
**Gas Column Threshold**

*Cannot form a cold phase below a gas threshold (Schaye '04, also e.g. Skillmann '96)*



**Pressure law**

*Midplane gas density governs conversion of HI to H<sub>2</sub> (Wong & Blitz '02, Blitz & Rosolowsky '06)*

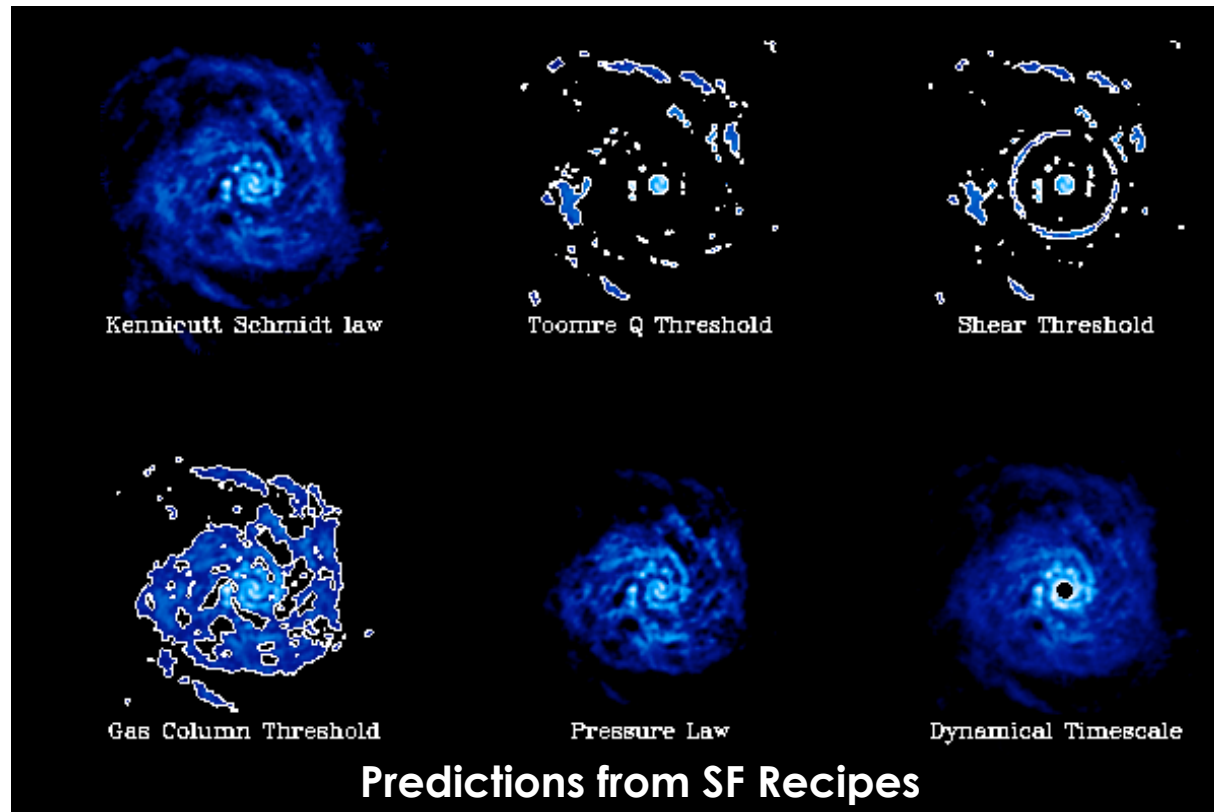


**Fixed Efficiency Per Orbit**

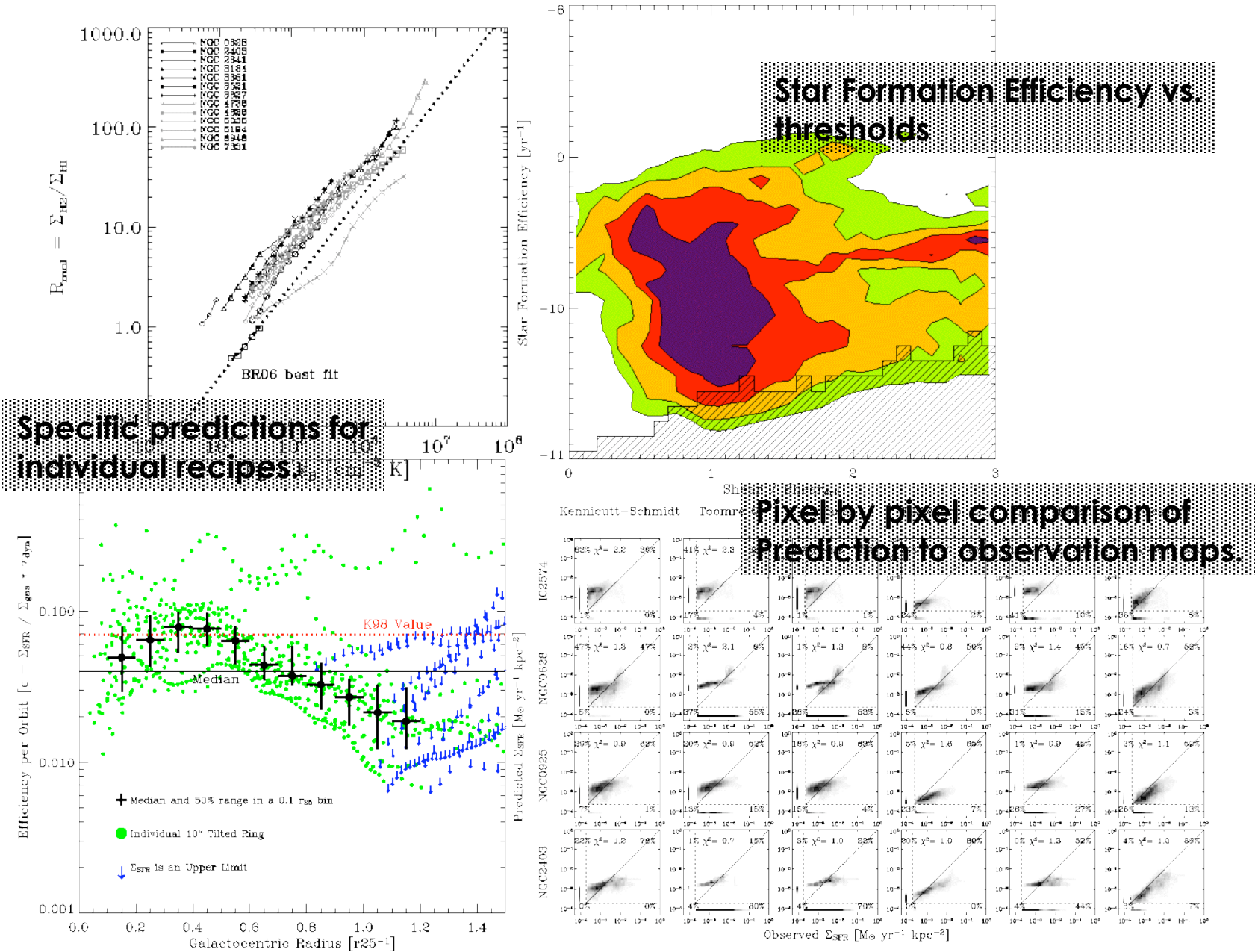
*Dynamical timescale sets SFR, e.g. via cloud-cloud collisions of spiral arms (Tan '00, Kennicutt '98, Silk '97)*

## Observations Confronting Theory

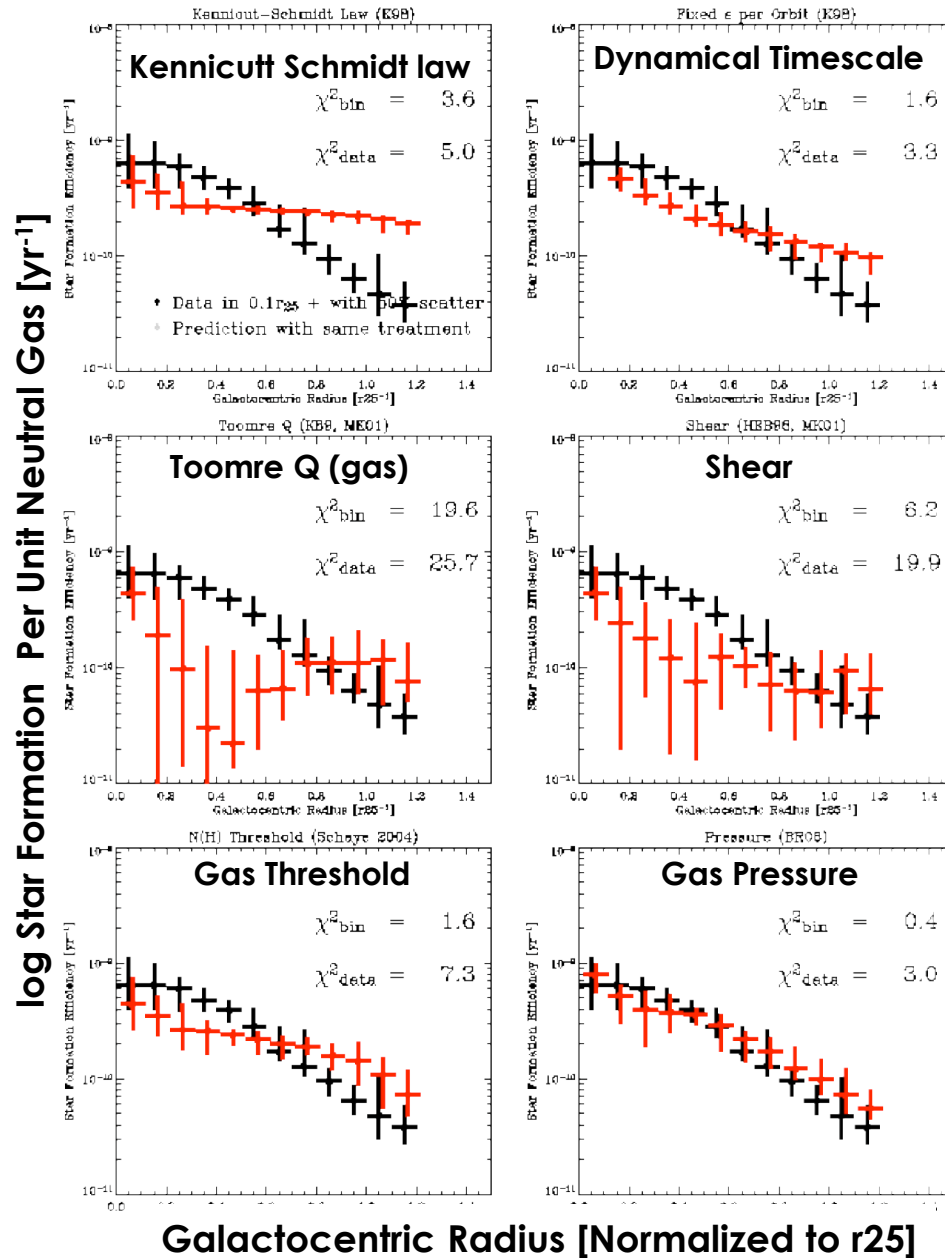
- Predicted SFR and threshold maps based on multiwavelength data.
- **Stellar surface density** from SINGS IRAC 3.6  $\mu\text{m}$ .
- **Rotation curves** fit from THINGS by de Blok et al. (2008).
- Tests: SFE vs. threshold, direct  $\chi^2$ , radial and spatial comparisons.



# Observations Confront Theory

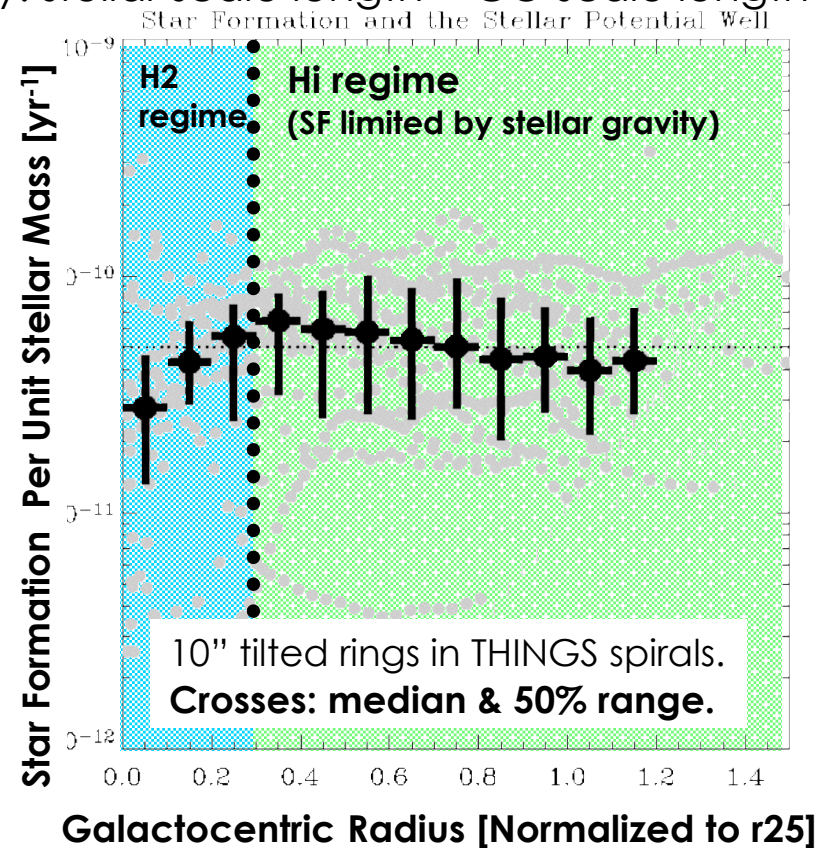


# Which Recipes Reproduce the Observations?



# Pressure, Star Formation, and Stars

- A volume density law (real “Schmidt” law); secret ingredient: stellar gravity.
- Hydrostatic equilibrium + observables → midplane pressure.  
(Wong & Blitz '02, Blitz & Rosolowky '04, '06)
- Observationally: stellar scale length ~ CO scale length ~ SFR scale length.



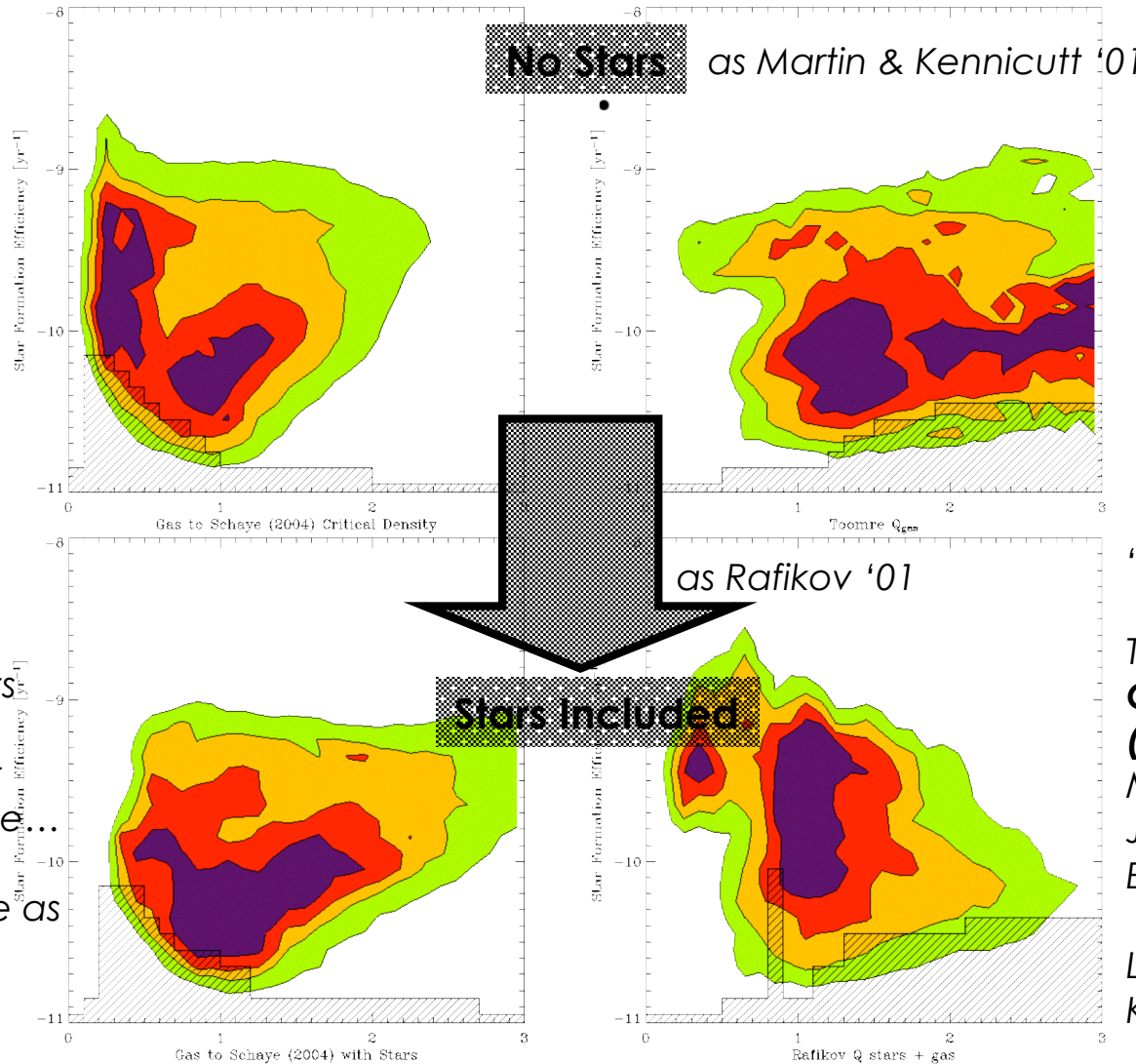
See also BIMA SONG CO vs. Stars: Regan et al. (2001); FCRAO Scale Lengths Young et al. (1995)

# Successful Recipes

- Common element in successful recipes is the stellar potential well:

Schaye (2004) Cold Phase Threshold

Toomre Q Parameter



Schaye on astro-ph gets an even stronger star dependence...

Almost same as 'pressure'

"Dripping pixels"

Thanks here:  
**C. Yang (poster #141)**  
 M. Mac Low  
 J. Dalcanton  
 E. Rosolowsky

Li, Mac Low, & Klessen (2006)



# What sets where (and how many) massive stars form in a spiral galaxy?

- Total gas content (on galactic scales).
- **Molecular gas** surface density (on 500 pc scales).
- Amount of ISM in the H<sub>2</sub> strong function of **environment/radius**.
- Recipes using only gas & kinematics struggle in **THINGS**.
- Substantial **stellar gravity** to compress HI to high density:

large scale instabilities\* or cold phase formation? metallicity?

- density law after Blitz & Rosolowsky '06 works to factor of ~2-3.

\* - see very nice poster by Yang et al. (#141) and their article on astro-ph.