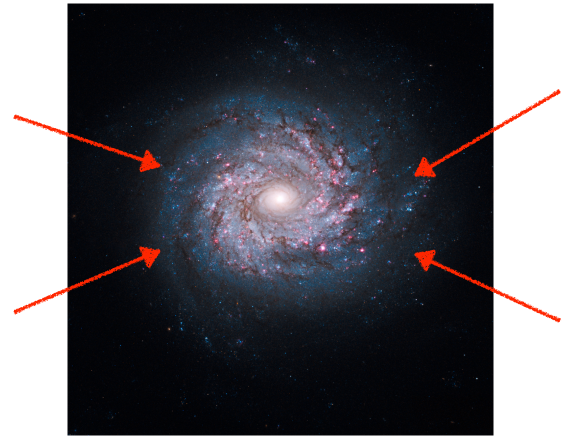
Star Formation & Gas

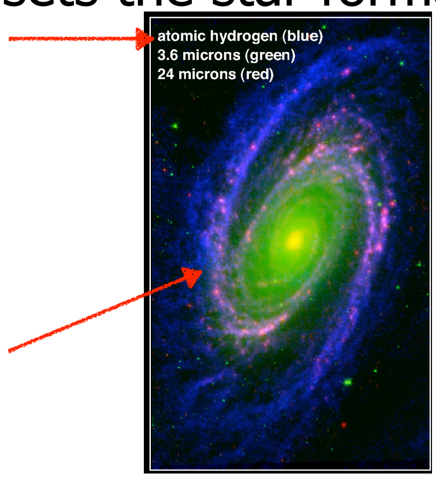
- Controlling factors for the SFR
- Global Schmidt Law
  - Scaling argument for origin
- Schmidt Law within Galaxies
  - SF efficiency
  - Correlations with HI, H_2, total gas
- SF thresholds
- Regimes of SF efficiency
- Implications for SF histories

What sets the star formation rate?



1. Gas into galaxies

What sets the star formation rate?

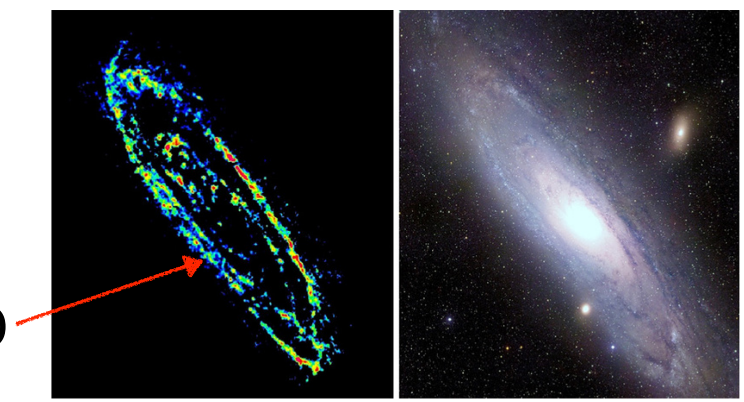


2. Formation of neutral/cool ISM (primarily HI)

http://www.cv.nrao.edu/course/astr534/images/M81IRHI.jpg

What sets the star formation rate?

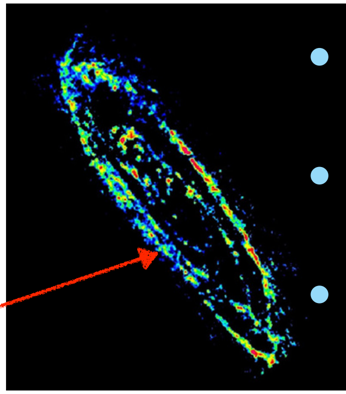
CO



3. Conversion of neutral to molecular gas

https://www.mpg.de/722581/zoom-1293749571.jpeg

What sets the star formation rate?

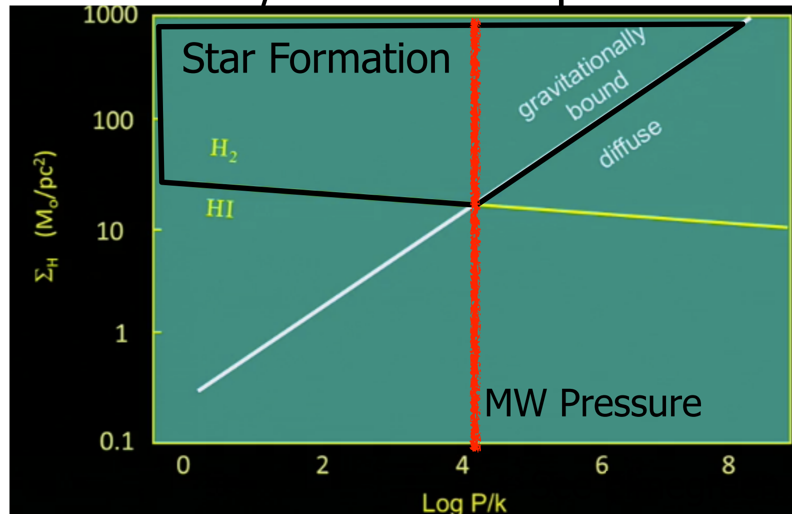


- Formation of (quasi-) bound HI-clouds
- Formation of cool neutral phase
- Formation of molecular gas

3. Conversion of neutral to molecular gas

https://www.mpg.de/722581/zoom-1293749571.jpeg

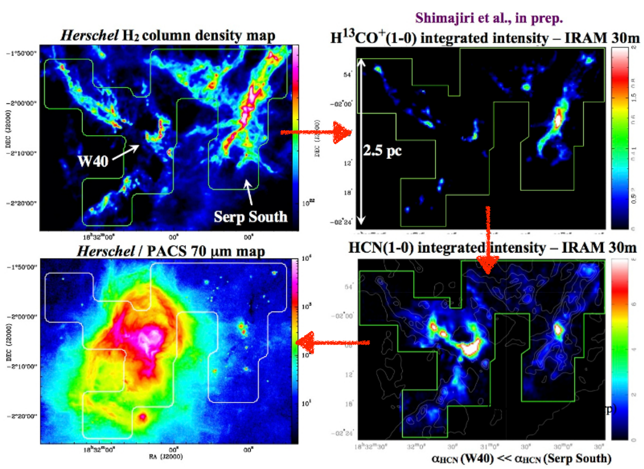
Caveat: Not 100% clear whether H2 and/or bound required.



1993

http://realserver4v.stsci.edu/t/data/2017/03/5379/RobKennicutt032917.mp4

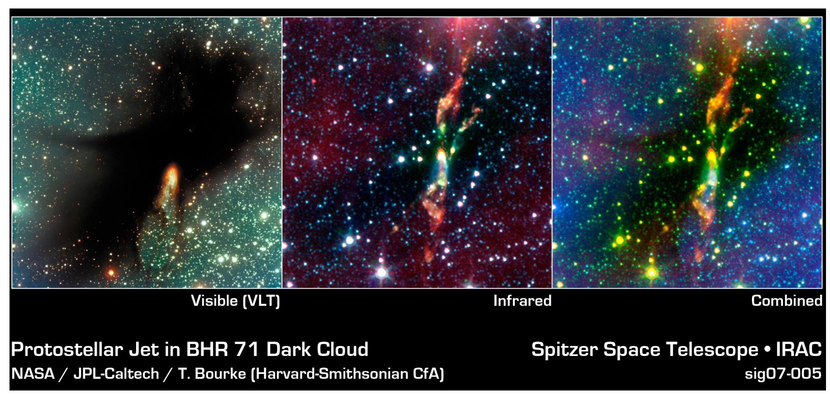
What sets the star formation rate?



4. Formation of dense molecular clouds & cores

http://www.mpia.de/homes/stein/EPoS/2016/C/PhilippeAndre.jpg

What sets the star formation rate?



5. Formation of stars from molecular cores

http://www.spitzer.caltech.edu/uploaded_files/images/0008/2126/sig07-005.jpg

What sets the star formation rate?

Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

The overall SFR will be set by whichever of these is the "rate limiting process*"

 *Limit can be set by different processes in different situations, though

What sets the star formation rate?

Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

Galaxies in dense cluster environments can have low SFR because they're gas starved.

What sets the star formation rate?

Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

At high redshift, the SFR closely follows the expected gas accretion rate, so initial gas supply is likely to be the rate limiting step when gas cooling and SF is efficient

What sets the star formation rate?

Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

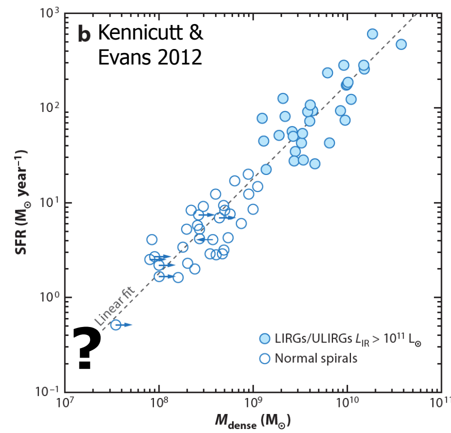
Galaxies like ellipticals can have low SFRs because their shock-heated halo gas is too hot/diffuse to cool

What sets the star formation rate?

Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

We'll concentrate on some of these issues today and in coming weeks.

First data point: Global SFR scales linearly with dense gas (HCN)

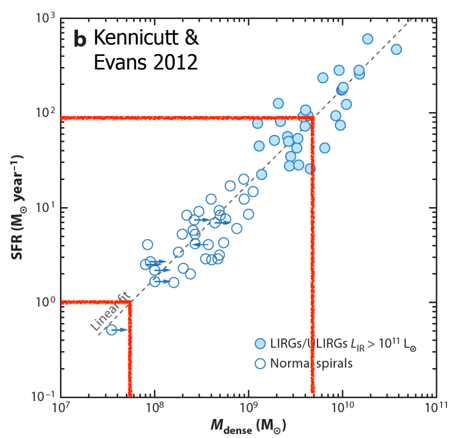


Once you make dense molecular gas, tends to convert to stars with constant efficiency, across wide range of environments.

But, see Bigiel et al 2017…

text. (*b*) Corresponding relation between the total (absolute) SFR and the mass of dense molecular gas as traced in HCN. The dashed gray line is a linear fit, which contrasts with the nonlinear fit in panel *a*. Figure adapted from Gao & Solomon (2004). Reproduced by

Global SFR scales linearly with dense gas (HCN)



$M_{dense} = 5\times10^{7} M_\odot$

$SFR = 1 M_\odot/yr$

$t_{consumption} = 50 Myr$

This is quite short, so need to replenish dense gas to sustain

text. (*b*) Corresponding relation between the total (absolute) SFR and the mass of dense molecular gas as traced in HCN. The dashed gray line is a linear fit, which contrasts with the nonlinear fit in panel *a*. Figure adapted from Gao & Solomon (2004). Reproduced by

What sets the star formation rate?

Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

Linear, 50Myr

Last step does not seem to be rate limiting. Once you get dense gas, you get stars quickly.

Second data point: SFR also seems to be close to linear with CO

Bigiel et al 2011

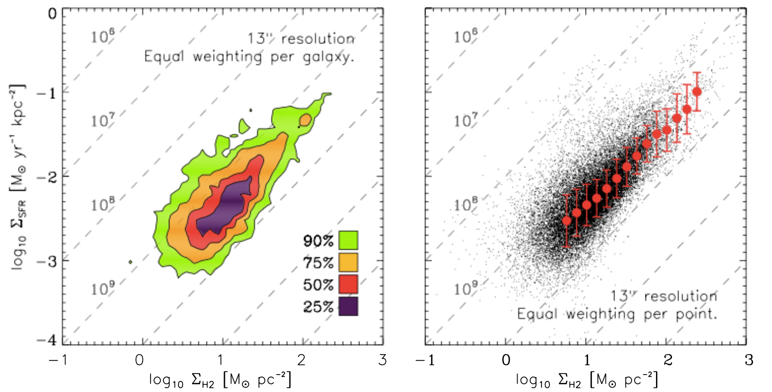


Figure 1. Star formation rate surface density, Σ_{SFR}, estimated from FUV+24 μm emission as a function of molecular gas surface density, Σ_{H2}, estimated from CO $J = 2 \rightarrow 1$ emission for 30 nearby disk galaxies. The left panels show data density with equal weight given to each galaxy. Purple, red, orange, and green contours encompass the densest 25%, 50%, 75%, and 90% of the data. The right panels show each measurement individually as a black dot. The red points indicate running medians in Σ_{SFR} as a function of Σ_{H2} and the error bars show the 1σ log scatter in each Σ_{H2} bin. In both panels, dotted lines indicate fixed H_2 depletion times in years. Measurements in the top panels are on a common angular scale of 13'', those in the bottom panels are on a common physical scale of 1 kpc. All panels show a strong correlation between Σ_{SFR} and Σ_{H2} with the majority of data having $\tau_{Dep}^{H2} \sim 2.3$ Gyr.

Second data point: SFR also seems to be linear with CO…

Bigiel et al 2011

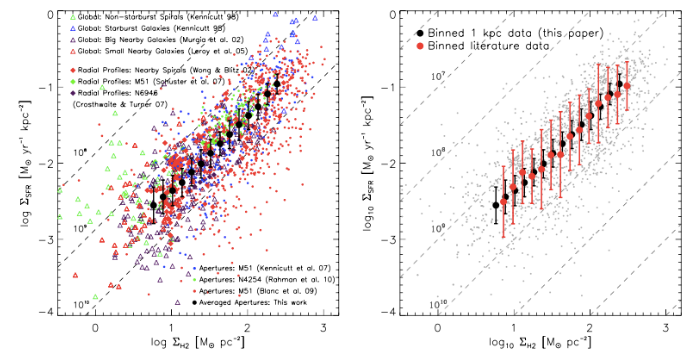
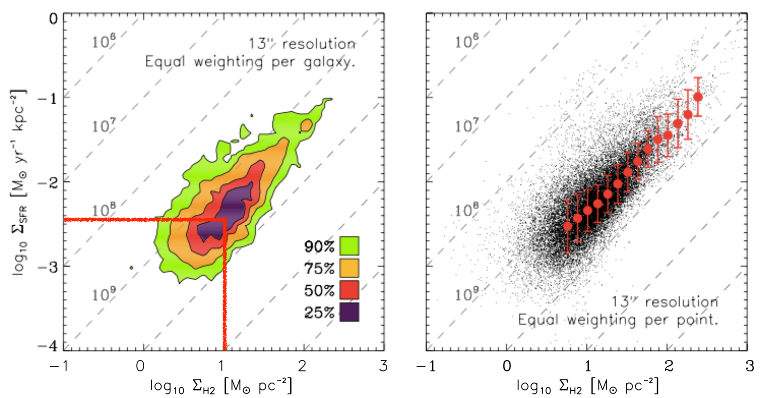


Figure 3. Σ_{SFR} vs. Σ_{H2} for a compilation of literature measurements and our binned data. In the left panel, we label individual studies, which employ a wide range of star formation tracers, sampling schemes, and physical scales. The black points indicate the running medians for our 1 kpc data from Figure 1. In the right panel, we treat all literature measurements equally (gray points) and construct a running median (red points) in the same way that we binned our data (black points) in Figure 1. Both panels show excellent agreement between our measurements and the literature data and suggest an emerging consensus on the basic, approximately linear, Σ_{SFR}–Σ_{H2} relation in nearby disk galaxies.

…albeit with significant scatter

Molecular gas consumption time?

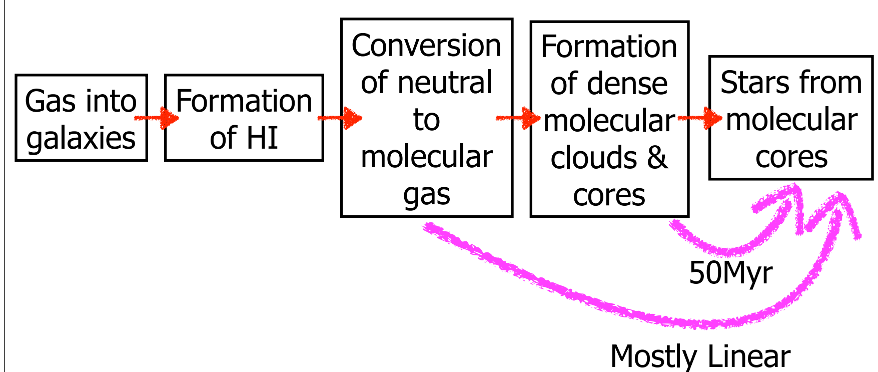
Bigiel et al 2011



$\Sigma_{H2}=10\ M_\odot/pc^2$ $\quad \Sigma_{SFR}=10^{-8.5}\ M_\odot/yr/pc^2$

$t_{consumption}$ = 2-3 Gyr

What sets the star formation rate?



Once you get generic molecular gas, you get stars in proportion to H_2.

What sets the star formation rate?

Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

50Myr

Mostly Linear, 2-3 Gyr

But, only a tiny fraction of H_2 is relevant: $t_{dense}/t_{H2} \sim 0.02$

Plus, significant scatter, so fraction of dense gas must vary significantly too.

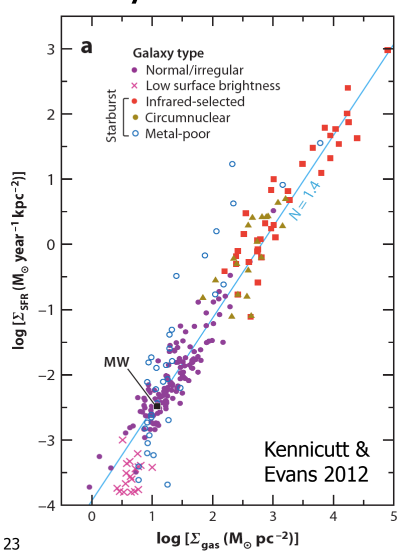
What sets the star formation rate?

Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

?

This correlation is better studied, given ease of HI observations.

From galaxy to galaxy, total gas surface density correlates strongly with <SFR>/area



Σ_{SFR} = Star formation rate per unit area

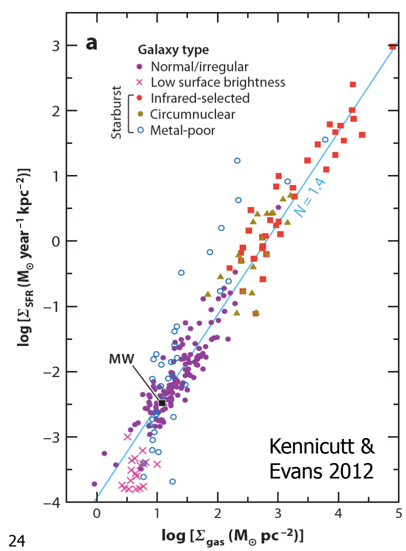
Σ_{SFR} = Gas mass per unit area ($HI+H_2$)

Higher gas density, more star formation

Figure 11

(*a*) Relationship between the disk-averaged surface densities of star formation and gas (atomic and molecular) for different classes of star-forming galaxies. Each point represents an individual galaxy, with the SFRs and gas masses normalized to the radius of the main star-forming disk. Colors are used similarly as in **Figure 9**: Purple points represent normal spiral and irregular galaxies, red points infrared-selected starburst galaxies [mostly luminous and ultraluminous infrared galaxies (LIRGs and ULIRGs, respectively)], and dark yellow points denote circumnuclear starbursts with star-formation rates (SFRs) measured from Paα measurements. The Milky Way (*black square*) fits well on the main trend seen for other nearby normal galaxies. Magenta crosses represent nearby low-surface-brightness galaxies, as described in the text. Open blue circles denote low-mass irregular and starburst galaxies with estimated metal (oxygen) abundances less than 0.3 $Z_\odot$, indicating a systematic deviation from the main relation. For this plot, a constant $X(CO)$ factor was applied to all galaxies. The light blue line shows a fiducial relation with slope $N = 1.4$ (not intended as a fit to these data). The sample of galaxies has been enlarged from that studied in Kennicutt (1998b), with many improved measurements as described in the

But, correlation is not linear



Gas mass per unit area

$$\Sigma_{SFR} \sim \Sigma_{gas}^{1.4}$$

Star formation rate per unit area

"Global Schmidt Law"

Schmidt 1959 proposed power-law

Figure 11

(*a*) Relationship between the disk-averaged surface densities of star formation and gas (atomic and molecular) for different classes of star-forming galaxies. Each point represents an individual galaxy, with the SFRs and gas masses normalized to the radius of the main star-forming disk. Colors are used similarly as in **Figure 9**: Purple points represent normal spiral and irregular galaxies, red points infrared-selected starburst galaxies [mostly luminous and ultraluminous infrared galaxies (LIRGs and ULIRGs, respectively)], and dark yellow points denote circumnuclear starbursts with star-formation rates (SFRs) measured from Paα measurements. The Milky Way (*black square*) fits well on the main trend seen for other nearby normal galaxies. Magenta crosses represent nearby low-surface-brightness galaxies, as described in the text. Open blue circles denote low-mass irregular and starburst galaxies with estimated metal (oxygen) abundances less than 0.3 $Z_\odot$, indicating a systematic deviation from the main relation. For this plot, a constant $X(CO)$ factor was applied to all galaxies. The light blue line shows a fiducial relation with slope $N = 1.4$ (not intended as a fit to these data). The sample of galaxies has been enlarged from that studied in Kennicutt (1998b), with many improved measurements as described in the

What sets the star formation rate?

Non-linear

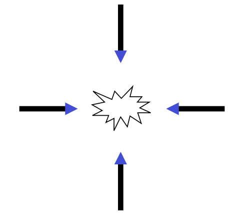
Gas into galaxies → Formation of HI → Conversion of neutral to molecular gas → Formation of dense molecular clouds & cores → Stars from molecular cores

Non-linear

Linear, 2-3 Gyr

Cool gas turns into dense gas more easily when mean gas density is higher

Traditional Derivation of non-linear Schmidt Law:



blob-o-gas

Star formation rate per unit volume

Gas density

$SFR_{vol} \propto \varepsilon_{sf}\, \rho_{gas}/t_{ff}$ ⟹ $SFR_{vol} \propto \varepsilon_{sf}\, \rho_{gas}^{1.5}$

Star formation efficiency

Free-fall time of the gas $(G\rho_{gas})^{-0.5}$

sheet-o-gas ρ_{gas} z

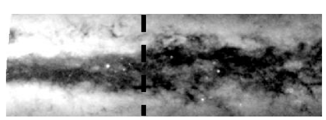
If the thickness of the gas layer is **constant**:

$SFR_{area} = z \times SFR_{vol}$

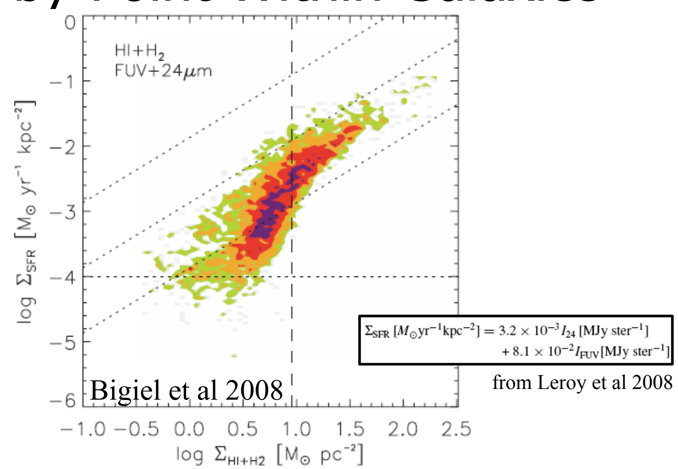
$\Sigma_{gas} = z \times \rho_{gas}$

$SFR_{vol} \propto \varepsilon_{sf}\, \rho_{gas}^{1.5}$

$SFR_{area} \propto \varepsilon_{sf}\, \Sigma_{gas}^{1.5}$

Though, not necessarily true: 

Point-by-Point Within Galaxies



$\Sigma_{SFR}\,[M_\odot yr^{-1} kpc^{-2}] = 3.2 \times 10^{-3} I_{24}\,[MJy\ ster^{-1}] + 8.1 \times 10^{-2} I_{FUV}\,[MJy\ ster^{-1}]$

from Leroy et al 2008

More Gas = More Star Formation

But, not One Single Power Law

Point-by-Point Matches Global Relationship

But better population of low density end.

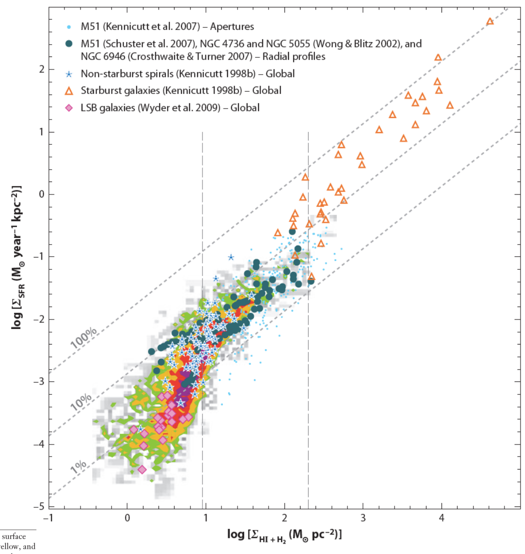


Figure 12

Relation between star-formation-rate (SFR) surface densities and total (atomic and molecular) gas surface densities for various sets of measurements (from Bigiel et al. 2008). Regions colored gray, green, yellow, and red show the distribution of values from measurements of subregions of SINGS galaxies. Overplotted as light blue dots are data from measurements in individual apertures in M51 (Kennicutt et al. 2007). Data from radial profiles from M51 (Schuster et al. 2007), NGC 4736 and NGC 5055 (Wong & Blitz 2002), and NGC 6946 (Crosthwaite & Turner 2007) are shown as dark blue filled circles. The disk-averaged measurements from 61 normal spiral galaxies (*dark blue stars*) and 36 starburst galaxies (*orange triangles*) from Kennicutt (1998b) are also shown. The magenta-filled diamonds show global measurements from 20 low-surface-brightness (LSB) galaxies (Wyder et al. 2009). In all cases, calibrations of initial mass function (IMF), *X*(CO), etc., were placed on a common scale. The three dotted gray diagonal lines extending from lower left to upper right reflect a constant global star-formation efficiency. The two vertical lines denote regimes that correspond roughly to those discussed in Section 6 of this review. Figure taken from Bigiel et al. (2008).

Gas Consumption Timescale:

$$\boxed{t_{gas} = \Sigma_{gas} / \Sigma_{SFR}}$$

How long it would take to use up gas at current star formation rate

Star Formation Efficiency:

$$\boxed{SFE = \Sigma_{SFR} / \Sigma_{gas}}$$

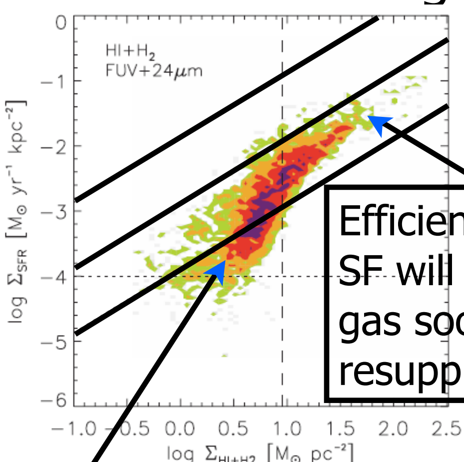
Given as percentage of gas used up in fixed time interval (i.e. X% per 10^8 yrs)

SF More Efficient at High S_{gas}

100% efficiency
$t_{gas}=10^8$ yrs

10% efficiency
$t_{gas}=10^9$ yrs

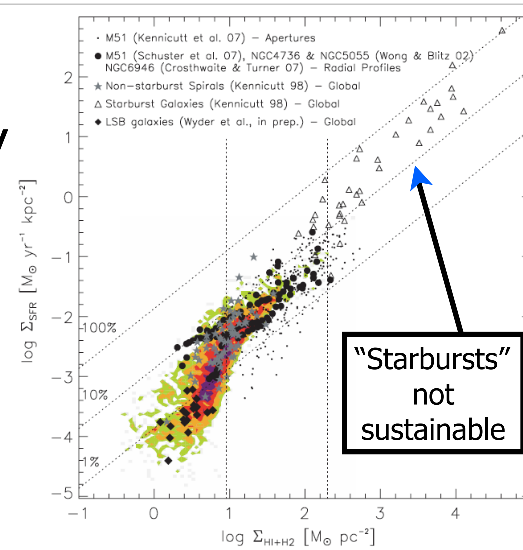
1% efficiency
$t_{gas}=10^{10}$ yrs



Efficient:
SF will exhaust gas soon, unless resupplied

Inefficient:
SF can go on for t_{Hubble}

Star-bursts are extremely efficient



"Starbursts" not sustainable

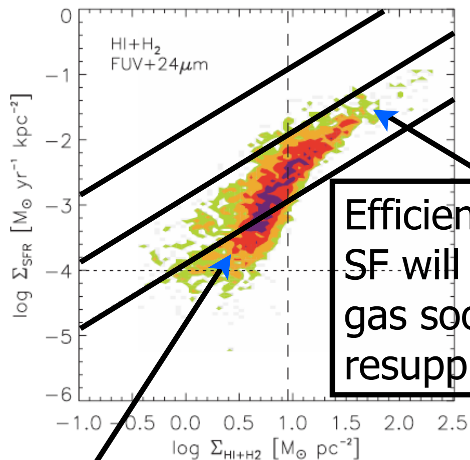
Figure 15. Σ_{SFR} vs. Σ_{gas} from this paper in colored contours (compare the middle-right panel of Figure 8) and for individual galaxies from other analyses (see Figure 14). The diagonal dotted lines and all other plot parameters are the same as in Figure 4. Overplotted as black dots are data from measurements in individual apertures in M51 (Kennicutt et al. 2007). Data points from radial profiles from M51 (Schuster et al. 2007), NGC 4736, and NGC 5055 (Wong & Blitz 2002) and from NGC 6946 (Crosthwaite & Turner 2007) are shown as black filled circles. Furthermore, we show disk-averaged measurements from 61 normal spiral galaxies (filled gray stars) and 36 starburst galaxies (triangles) from K98. The black filled diamonds show global measurements from 20 low surface brightness galaxies (Wyder et al. 2008). Data from other authors were adjusted to match our assumptions on the underlying IMF, CO line ratio, CO-to-H_2 conversion factor and galaxy inclinations where applicable. One finds good qualitative agreement between our data and the measurements from other studies despite a variety of applied SFR tracers. This combined data distribution is indicative of three distinctly different regimes (indicated by the vertical lines) for the SF law (see discussion in the text).

Implications for SF histories:

100% efficiency
$t_{gas}=10^8$ yrs

10% efficiency
$t_{gas}=10^9$ yrs

1% efficiency
$t_{gas}=10^{10}$ yrs



Efficient:
SF will exhaust gas soon, unless resupplied

Inefficient:
SF can go on for t_{Hubble}

Implications for SF histories:

100% efficiency
$t_{gas}=10^8$ yrs

10% efficiency
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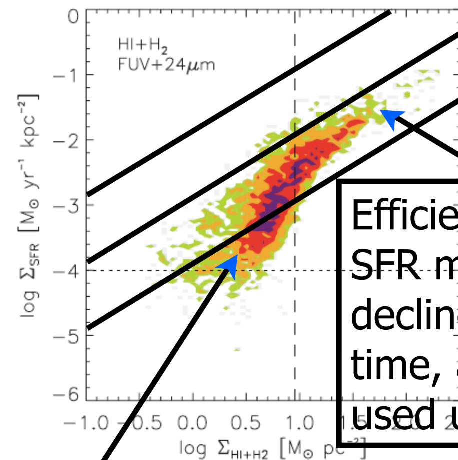


Barring refueling...

Efficient:
SFR must decline with time, as gas is used up

Inefficient:
SFR is low, so Σ_{gas} constant. SFR constant.

Low SF Efficiency at Large Radii

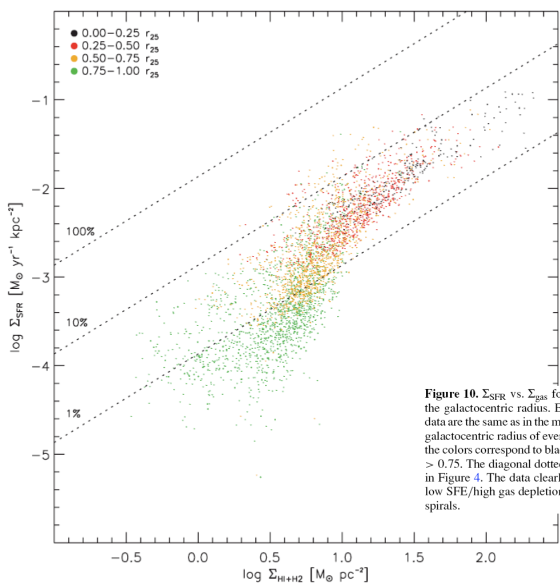
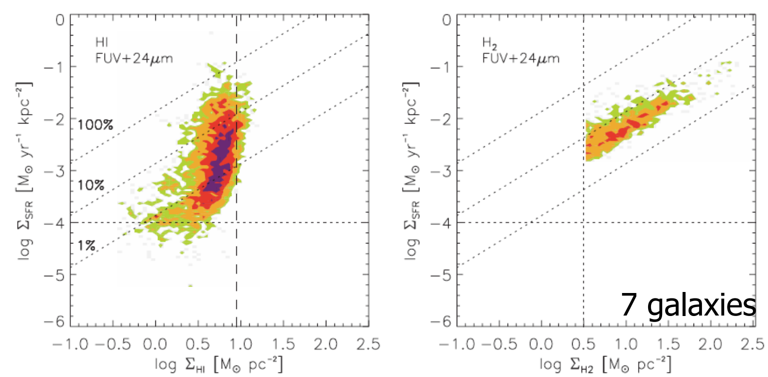


Figure 10. Σ_{SFR} vs. Σ_{gas} for the spiral galaxies with data colored according to the galactocentric radius. Every data point represents one sampling point; the data are the same as in the middle-right plot of Figure 8. We show the normalized galactocentric radius of every sampling point via its color, where, in units of r_{25}, the colors correspond to black < 0.25, red 0.25–0.5, orange 0.5–0.75, and green > 0.75. The diagonal dotted lines and all other plot parameters are the same as in Figure 4. The data clearly break up according to galactocentric radius, with low SFE/high gas depletion time points corresponding to the outer parts of the spirals.

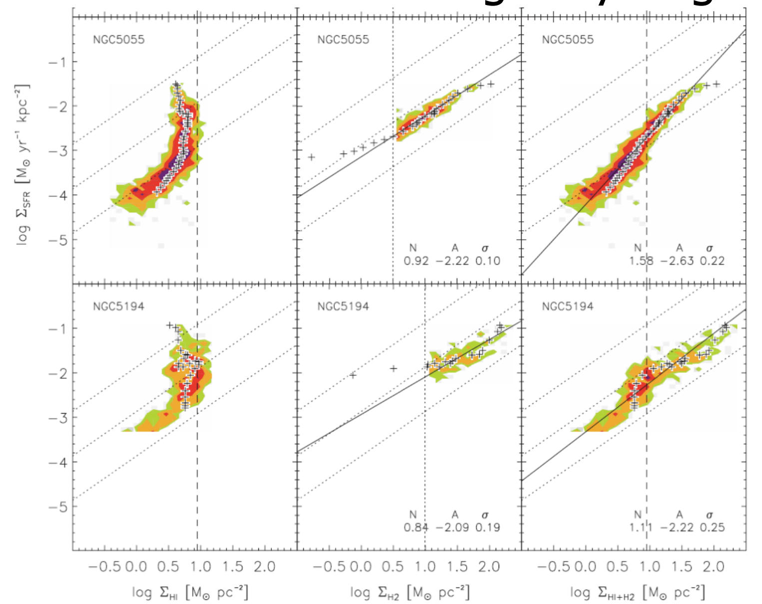
i.e., all low surface density regions act similarly

Correlation Strongest with H_2



Linear Relation with H_2
Weak dependence with HI
Σ_{SFR} vs Σ_{gas} will depend on fraction of HI

Mean correlation varies galaxy to galaxy



Variation Galaxy-to-Galaxy

$$\Sigma_{\rm SFR} = a \left(\frac{\Sigma_{\rm HI,H2,gas}}{10\ M_\odot\ {\rm pc}^{-2}} \right)^N$$

Table 2
Fitted Power-Law Parameters at 750 pc Resolution

Galaxy	H_2			HI+H_2		
	Coefficient (*A*)	Index (*N*)	Scatter	Coefficient (*A*)	Index (*N*)	Scatter
NGC 628	−1.99	0.98	0.16	−2.35	2.74	0.39
NGC 3184	−2.16	1.12	0.18	−2.45	2.50	0.31
NGC 3521	−2.19	0.95	0.10	−2.75	2.12	0.19
NGC 4736	−1.79	0.95	0.15	−2.00	1.44	0.19
NGC 5055	−2.22	0.92	0.10	−2.63	1.58	0.22
NGC 5194	−2.09	0.84	0.19	−2.22	1.11	0.25
NGC 6946	−1.94	0.92	0.23	−2.33	1.46	0.29
Average	−2.06 ± 0.17	0.96 ± 0.07	...	−2.39 ± 0.28	1.85 ± 0.70	...

Very little variation galaxy-to-galaxy w/ H_2

Much more scatter w/ total gas

What leads to break in the Σ_{SFR} vs Σ_{gas} correlation?

Transition at Σ_{gas}~10 $M_\odot/pc^2$

Note: Most low mass galaxies w/ V_c<120 km/s fall entirely below this threshold.

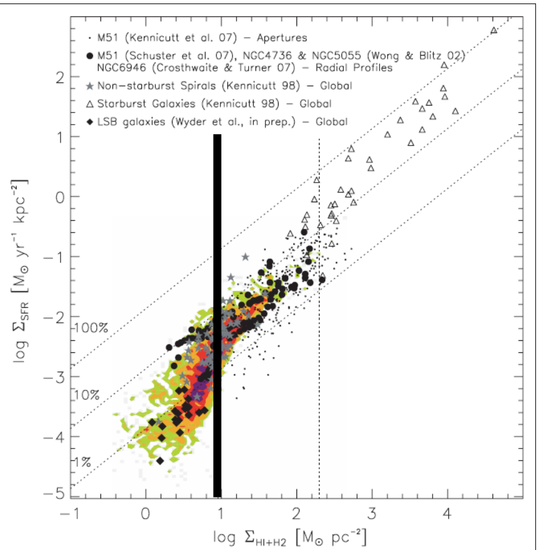
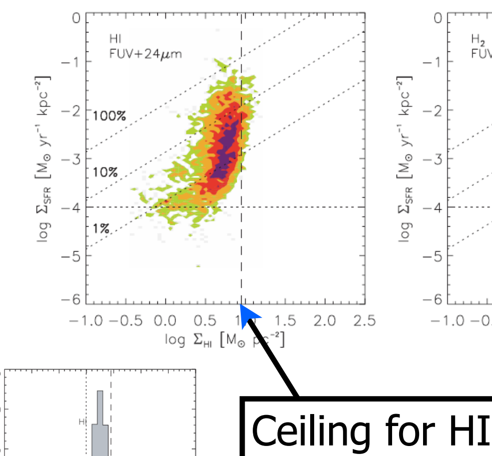
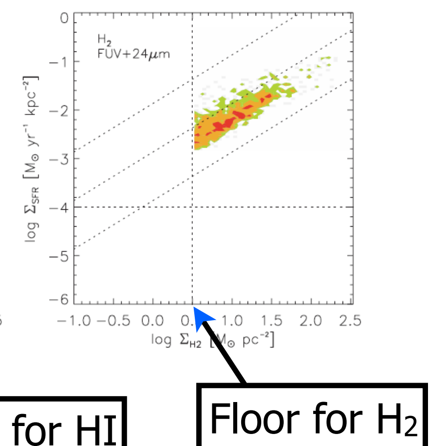
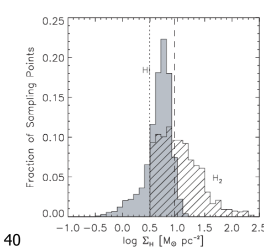


Figure 15. Σ_{SFR} vs. Σ_{gas} from this paper in colored contours (compare the middle-right panel of Figure 8) and for individual galaxies from other analyses (see Figure 14). The diagonal dotted lines and all other plot parameters are the same as in Figure 4. Overplotted as black dots are data from measurements in individual apertures in M51 (Kennicutt et al. 2007). Data points from radial profiles from M51 (Schuster et al. 2007), NGC 4736, and NGC 5055 (Wong & Blitz 2002) and from NGC 6946 (Crosthwaite & Turner 2007) are shown as black filled circles. Furthermore, we show disk-averaged measurements from 61 normal spiral galaxies (filled gray stars) and 36 starburst galaxies (triangles) from K98. The black filled diamonds show global measurements from 20 low surface brightness galaxies (Wyder et al. 2008). Data from other authors were adjusted to match our assumptions on the underlying IMF, CO line ratio, CO-to-H_2 conversion factor and galaxy inclinations where applicable. One finds good qualitative agreement between our data and the measurements from other studies despite a variety of applied SFR tracers. This combined data distribution is indicative of three distinctly different regimes (indicated by the vertical lines) for the SF law (see discussion in the text).

Break is near transition to molecular

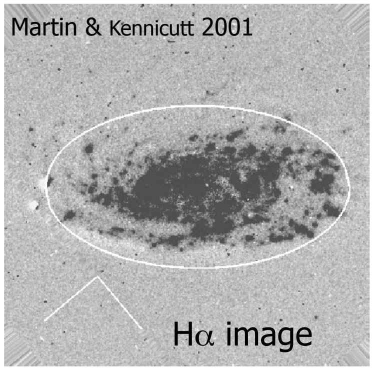


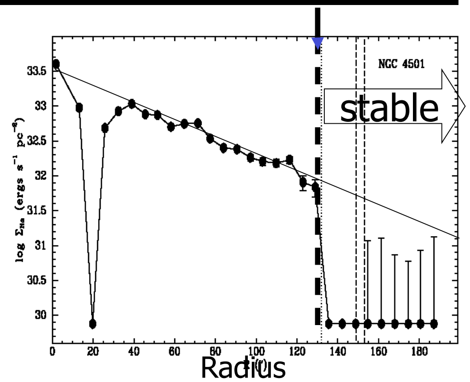




Kennicutt Star Formation Threshold

Sharp drop in Ha surface density



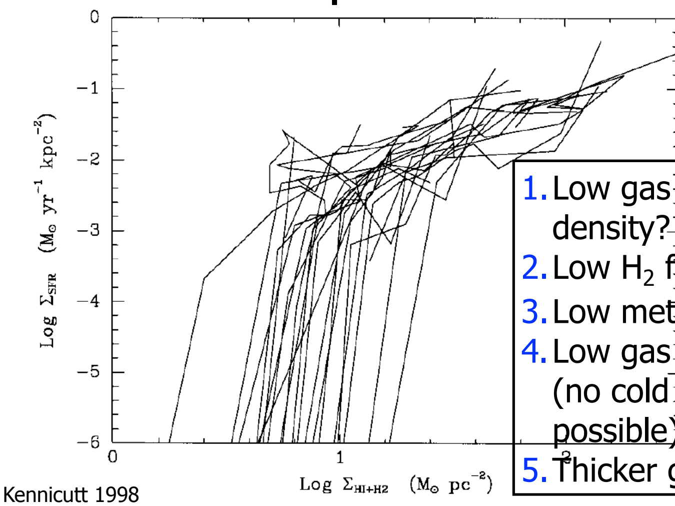


Interpreted as sharp cutoff in SFR

Seemed to correlate best with Toomre Q>1

$Q(R) \equiv \frac{\sigma\kappa}{\pi G\mu}$

Lots of other possible mechanisms



1. Low gas surface density?
2. Low H_2 fraction?
3. Low metallicity?
4. Low gas pressure (no cold phase possible)?
5. Thicker gas layer?

Kennicutt 1998

FIG. 3.—Profiles of the azimuthally averaged SFR per unit area as a function of gas density for 21 spirals with spatially resolved Hα data.

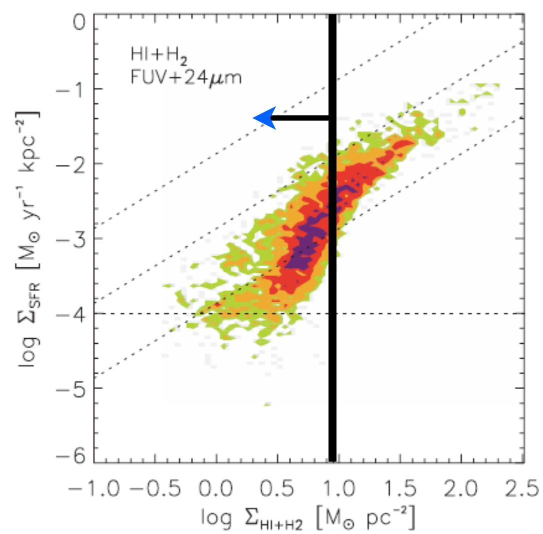
Not clear if "threshold" exists

XUV Disks

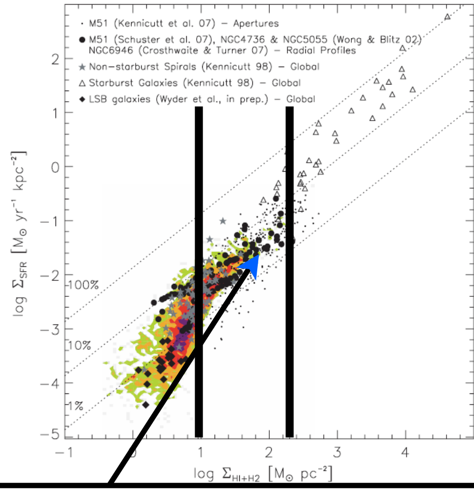
In 25-30% of galaxies, UV emission extends well beyond radius at which Hα truncates

NGC 1512 Thilker et al

However, drop in SF efficiency is real

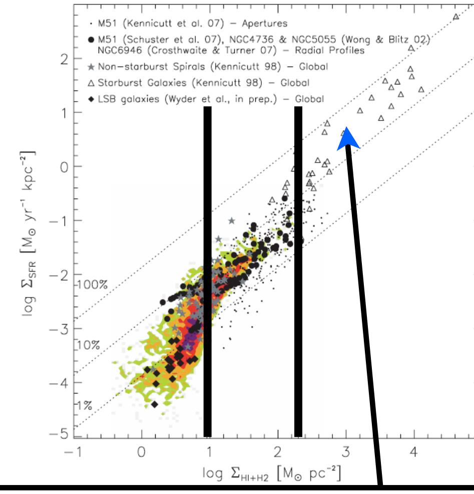


Three Different Regimes



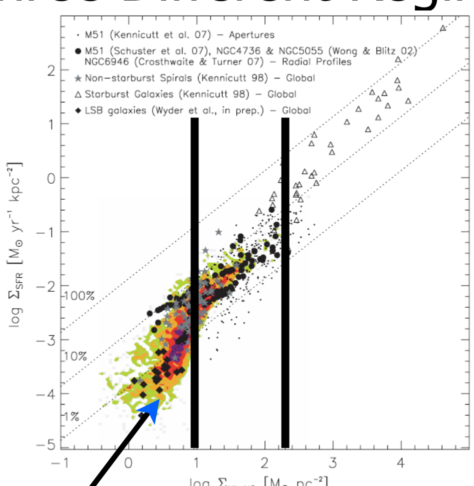
Linear:
Reflects # of Giant Molecular Clouds per beam

Three Different Regimes



High efficiency: Beam filled with GMCs. CO optically thick, so doesn't trace total gas mass.

Three Different Regimes



Low efficiency: Who knows?

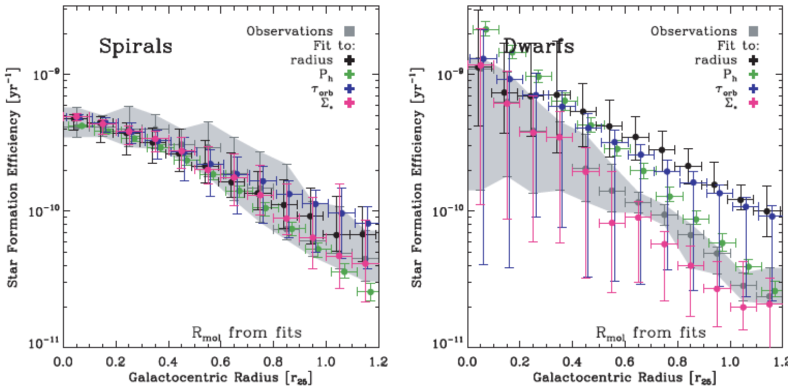
What Controls Global SF Efficiency?

Table 1
Star Formation Laws and Thresholds

Theory	Form	Observables
	Star Formation Laws	
Disk free-fall time		
. . . fixed scale height	$\mathrm{SFE} \propto \Sigma_{\mathrm{gas}}^{0.5}$	Σ_{gas}
. . . variable scale height	SFE or $R_{\mathrm{mol}} \propto \frac{\Sigma_{\mathrm{gas}}}{\sigma_{\mathrm{g}}}\left(1+\frac{\Sigma_*}{\Sigma_{\mathrm{gas}}}\frac{\sigma_{\mathrm{g}}}{\sigma_{*,z}}\right)^{0.5}$	$\Sigma_{\mathrm{gas}}, \Sigma_*, \sigma_g, \sigma_*$
Orbital timescale	SFE or $R_{\mathrm{mol}} \propto \tau_{\mathrm{orb}}^{-1} = \frac{v(r_{\mathrm{gal}})}{2\pi r_{\mathrm{gal}}}$	$v(r_{\mathrm{gal}})$
Cloud–cloud collisions	$\mathrm{SFE} \propto \tau_{\mathrm{orb}}^{-1} Q_{\mathrm{gas}}^{-1}(1-0.7\beta)$	$v(r_{\mathrm{gal}})$
Fixed GMC efficiency	$\mathrm{SFE} = \mathrm{SFE}(\mathrm{H}_2)\frac{R_{\mathrm{mol}}}{R_{\mathrm{mol}}+1}$	Σ_{H_2}
Pressure and ISM phase	$R_{\mathrm{mol}} \propto (\Sigma_{\mathrm{gas}}(\Sigma_{\mathrm{gas}}+\frac{\sigma_{\mathrm{g}}}{\sigma_{*,z}}\Sigma_*)P_0^{-1})^{1.2}$	$\Sigma_{\mathrm{gas}}, \Sigma_*, \sigma_{\mathrm{g}}, \sigma_*$
	Star Formation Thresholds	
Gravitational instability		
. . . in the gas disk	$Q_{\mathrm{gas}} = \left(\frac{\sigma_g \kappa}{\pi G \Sigma_{\mathrm{gas}}}\right) < 1$	$\Sigma_{\mathrm{gas}}, \sigma_{\mathrm{g}}, v(r_{\mathrm{gal}})$
. . . in a disk of gas and stars	$Q_{\mathrm{stars+gas}} = \left(\frac{2}{Q_{\mathrm{stars}}}\frac{q}{1+q^2} + \frac{2}{Q_{\mathrm{gas}}}R\frac{q}{1+q^2R^2}\right)^{-1} < 1$	$\Sigma_{\mathrm{gas}}, \Sigma_*, \sigma_{\mathrm{g}}, \sigma_*, v(r_{\mathrm{gal}})$
Competition with shear	$\Sigma_{\mathrm{gas}} > \frac{2.5 A \sigma_g}{\pi G}$	$\Sigma_{\mathrm{gas}}, \sigma_{\mathrm{g}}, v(r_{\mathrm{gal}})$
Cold gas phase	$\Sigma_{\mathrm{gas}} > 6.1\ M_\odot\ \mathrm{pc}^{-2} f_{\mathrm{g}}^{0.3} Z^{-0.3} I^{0.23}$	$\Sigma_{\mathrm{gas}}, \Sigma_*, Z, I$

Many different suggestions!!!!

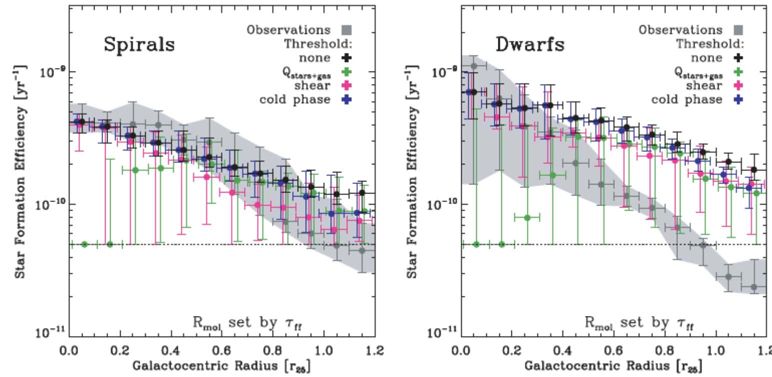
Compare Predictions to Data (grey)



Leroy et al 2008

A number of prescriptions work OK in spirals, but overpredict SFE in dwarfs

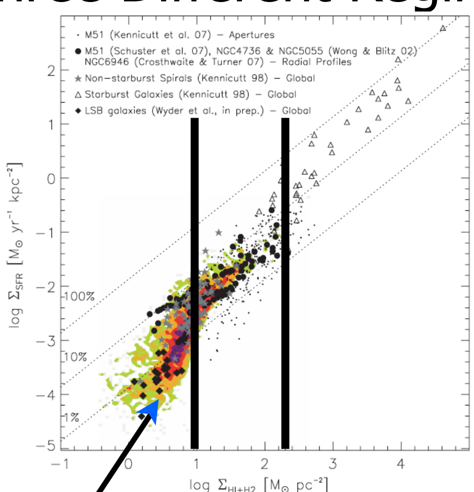
Compare Predictions to Data (grey)



Leroy et al 2008

Threshold models don't work as well, and again are too efficient in dwarfs

Three Different Regimes



Low efficiency: Must require physics that simple prescriptions don't yet include

What Controls Global SF Efficiency?

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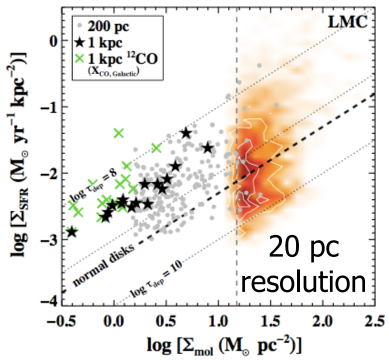
Cold gas phase	$\Sigma_{gas} > 6.1\ M_\odot\ \mathrm{pc}^{-2} f_g^{0.3} Z^{-0.3} I^{0.23}$	$\Sigma_{gas}, \Sigma_*, Z, I$

Solution is more likely to be based on local (GMC-scale) processes. No simple behavior with easy to measure global properties.

Global relations break down at small spatial scales

Molecular gas inferred from dust mapping: Jameson et al 2016



- At 20pc resolution, higher gas densities, no correlation
- With more spatial averaging, better correlation

FIG. 5.— Σ_{SFR} as a function of Σ_{mol} for the LMC (left) and SMC (right) at various resolutions. The red color scale shows the two-dimensional distribution at a resolution of r = 20 pc with the white contours indicate levels that are 20%, 40%, 60%, and 80% of the maximum density of points. The vertical gray dashed line indicates the estimated 2σ sensitivity cut of the r = 20 pc data ($\Sigma_{mol} \sim 15\ M_\odot$ pc^{-2}). The grey circles and black stars show the data at resolutions r = 200 pc and r = 1 kpc, respectively. The green stars show Σ_{mol} derived from NANTEN CO data at a resolute of r = 1 kpc using a Galactic CO-to-H_2 conversion factor. Here we present the SMC data corrected by a higher inclination angle of $i = 70°$, as opposed to results from Bolatto et al. (2011) that used $i = 40°$, which results in a diagonal shift to lower surface densities.The dotted lines indicate constant molecular depletion times τ_{dep}^{mol} = 0.1, 1, and 10 Gyr. The dashed line shows the typical depletion time for normal galaxies $\tau_{dep}^{mol} \sim 2$ Gyr (Bigiel et al. 2008, 2011; Rahman et al. 2012; Leroy et al. 2013a).

Weak spatial correlation between gas and SF until several 100 pc

Molecular gas inferred from dust mapping: Jameson et al 2016

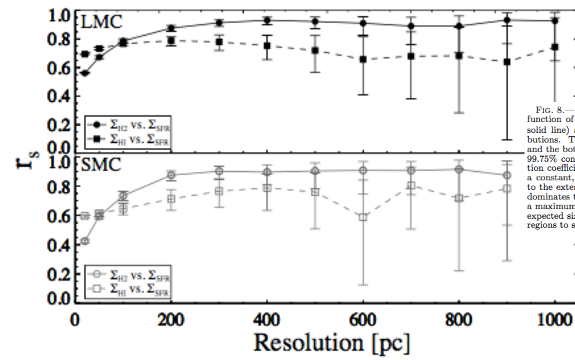
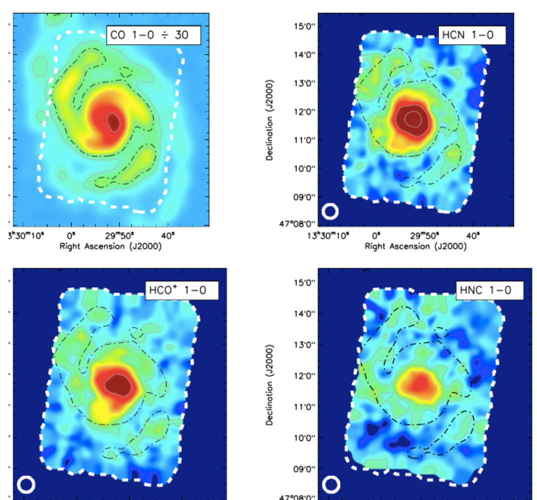


FIG. 8.— The Spearman rank correlation coefficient (r_s) as a function of image resolution for the Σ_{H_2} vs. Σ_{SFR} (circles with solid line) and Σ_{HI} vs. Σ_{SFR} (squares with dashed line) distributions. The top plot shows the rank correlations for the LMC and the bottom show those for the SMC. The error bars show the 99.75% confidence interval ($\sim 3\sigma$) of the measured rank correlation coefficient. The correlation between H I and SFR remains at a constant, high level of $r_s \sim 0.7$ across size scales in part due to the extended nature of both the H I gas and Hα emission that dominates the SFR. The correlation between H_2 and SFR reaches a maximum value of $r_s \sim 0.9$ at a size scale of 200 pc, which is the expected size scale to average over enough individual star-forming regions to sample a range of evolutionary states.

And then, primarily with H_2, not HI

Similar breakdowns when looking at dense gas in detail

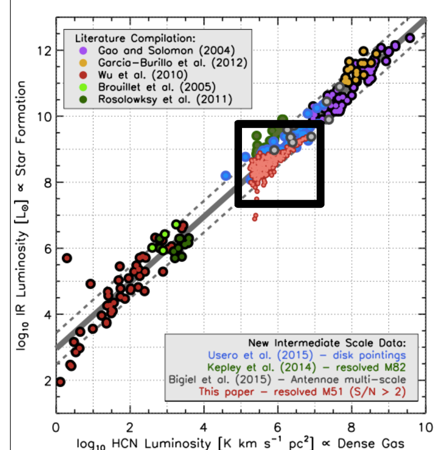


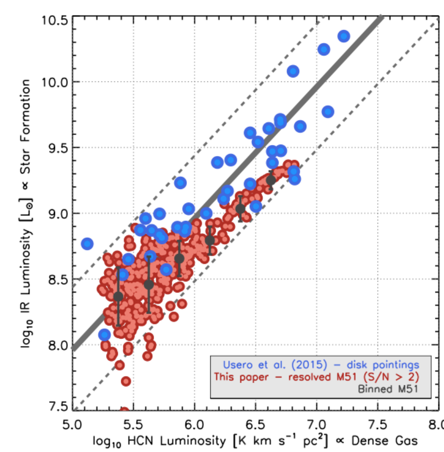
Dense gas tracers in M51

Bigiel et al 2016

Global SFR vs HCN

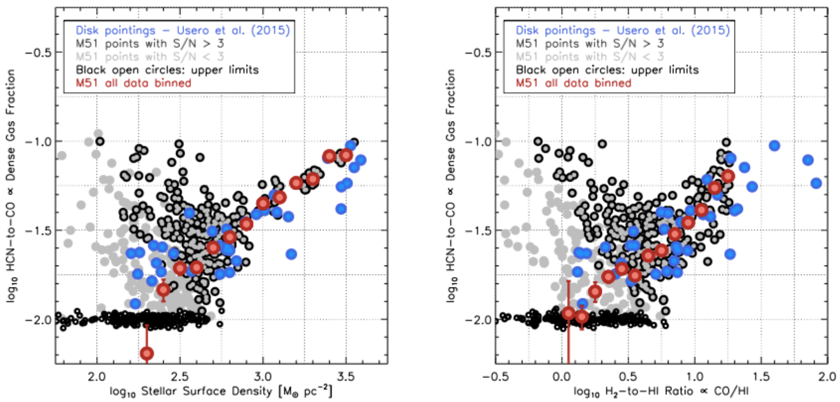
Within M51





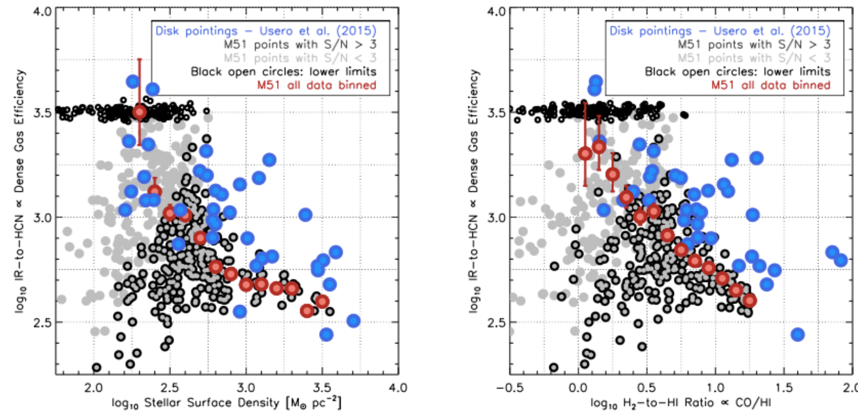
Bigiel et al 2016

Dense gas fraction goes up…



Bigiel et al 2016

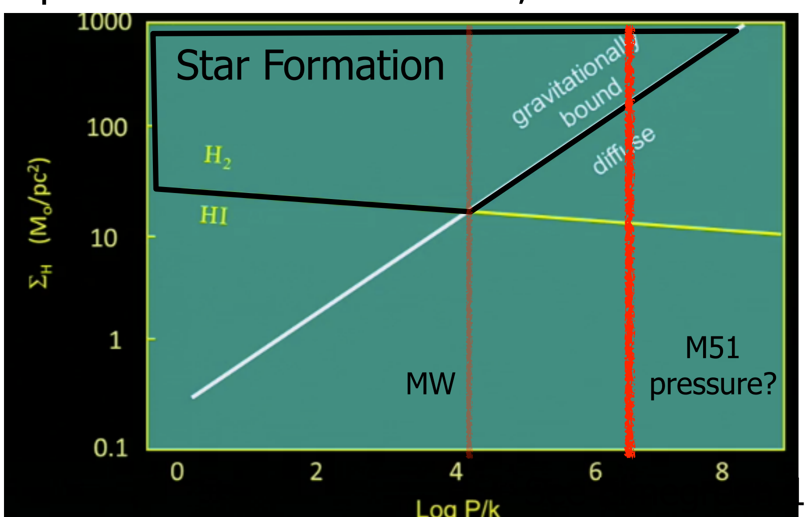
But, SFE in regions of high stellar pressure goes down



Which seems weird.

Bigiel et al 2016

Maybe in a regime where high confining stellar pressure makes molecules, but not bound?



1993

 http://realserver4v.stsci.edu/t/data/2017/03/5379/RobKennicutt032917.mp4