The HERACLES and THINGS View of Star Formation

What We Learn From A kpc-Scale View of the ISM

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HERACLES & THINGS: kpc-Scale People

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Our view of the ISM: HERACLES & THINGS

- IRAM 30m Large Program to map CO J = 2→1 line
- Instrument: HERA receiver array operating at 230 GHz
- 48 galaxies: dwarfs to starbursts and massive spirals
- Very wide-field (~ r_{25}) and sensitive (σ ~ 1-2 M_{sun} pc^{-2})
- First maps Leroy et al. (2009) ~ 10 papers so far
- Public at www.nrao.edu/~aleroy/HERACLES

H2-HI Transition?

- VLA HI maps of 34 galaxies: Sa - Irr
- Resolution ~ 6-10" (100-500 pc) by 5 km s^{-1}
- Sensitivity ~ 5 x10^{19} cm^{-2} per channel map
- Walter et al. (2008), AJ Special Issue (2008)
- Public at www.mpia.de/THINGS

What We Learn From A kpc-Scale View of the ISM

- **Stars form from molecular gas in nearby disks.**
  SFR tracers correlate ~linearly with CO even where most gas is HI.
  The "Star Formation Threshold" coincides with/is an HI-to-H_2 transition

- **To first order, SFR/H_2 is fixed in big, normal disks.**
  CO and SFR tracers correlate closely and roughly linearly.

- **Second variations of SFR/CO are clearly visible:**
  - Low mass, low metallicity galaxies show depressed CO.
    Most sensible explanation are X_{CO} variations.
  - Starbursts in galaxy centers appear more efficient.

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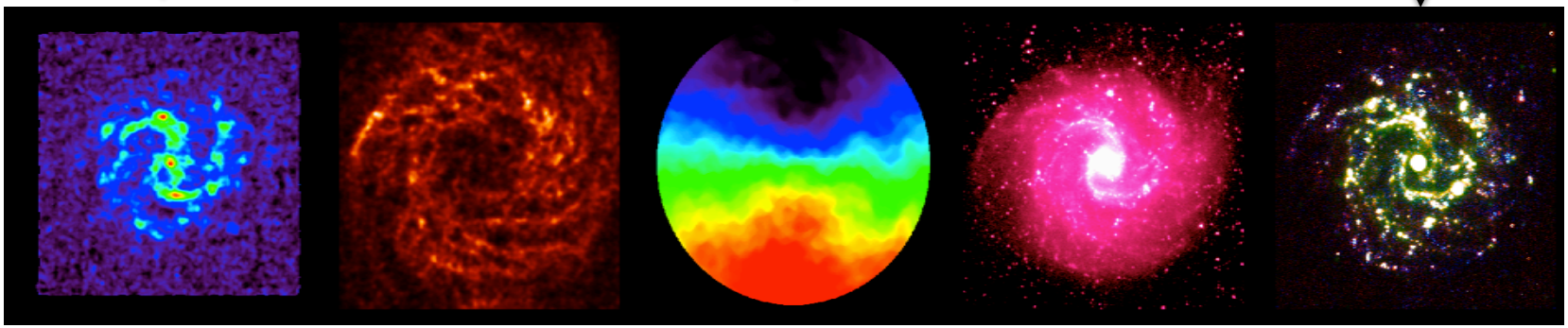
A Multiwavelength View of SF in Disks

Molecular Gas
Peak CO intensity
From HERACLES

Kinematics
Here from HI line
Also from CO

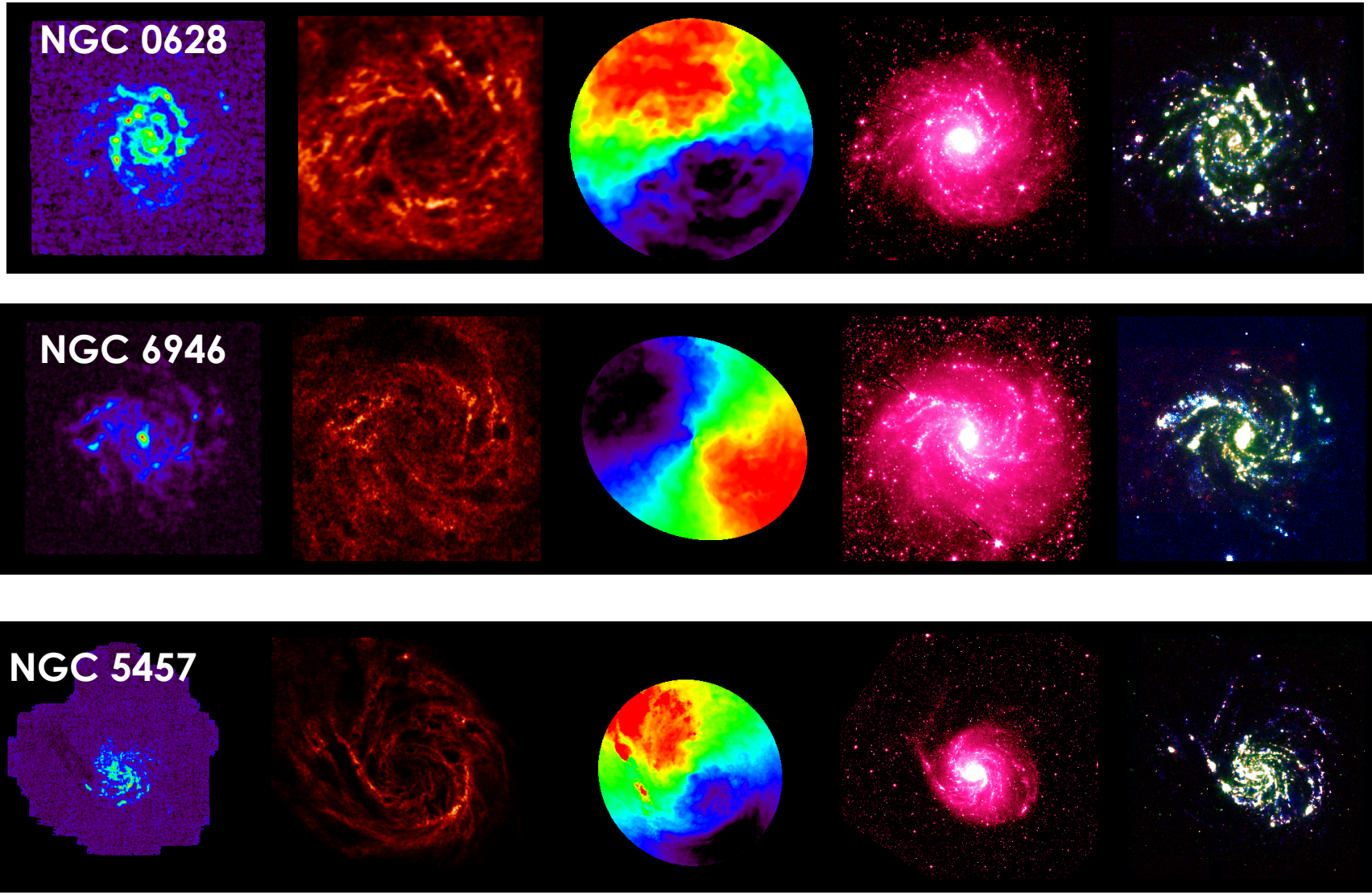
Recent Star Formation
Composite of **FUV** (GALEX),
mid-IR (SINGS/LVL),
and **Hα** (SINGS/LVL)



Atomic Gas
VLA 21cm data THINGS +
new & archival

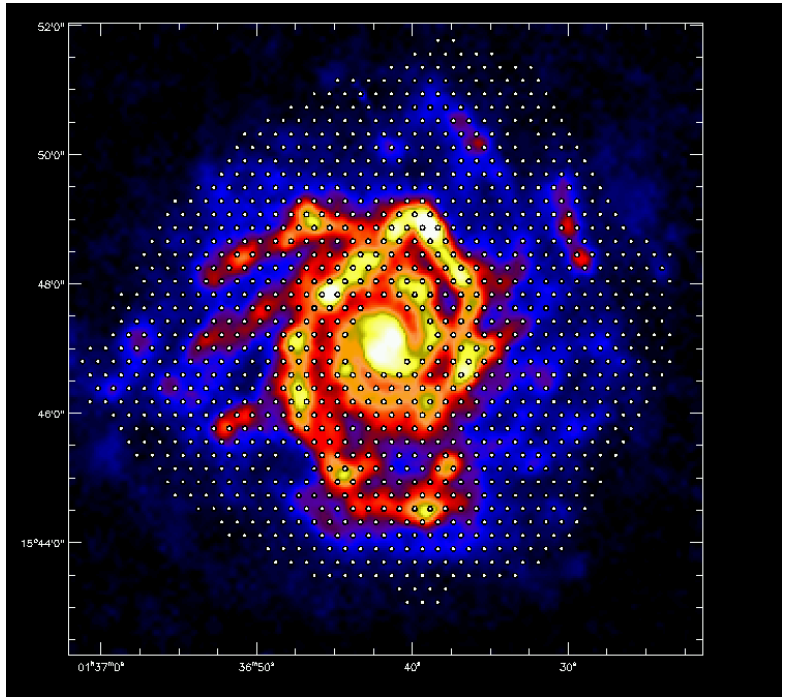
Old Stars
Near infrared intensity
From SINGS and LVL

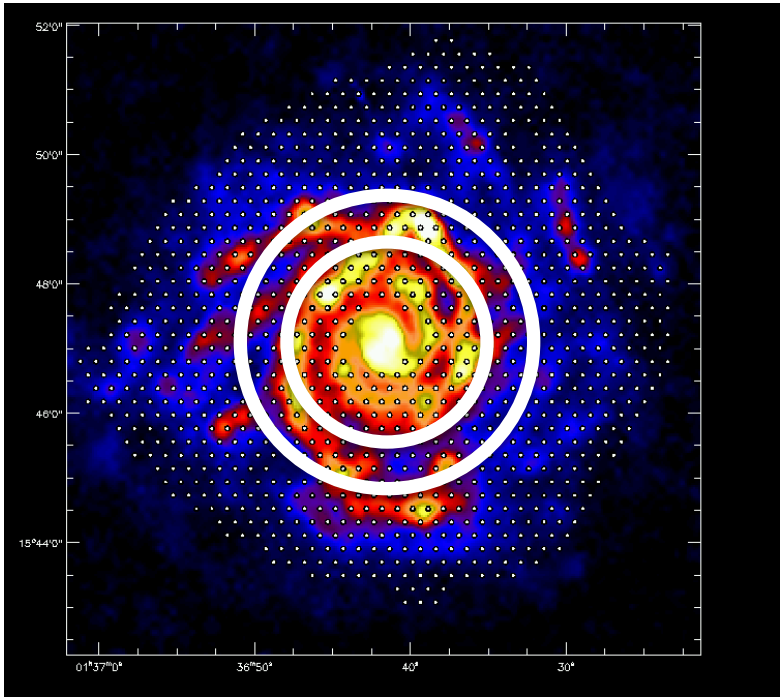
A Multiwavelength View of SF in Disks



A Multiwavelength View of SF in Disks

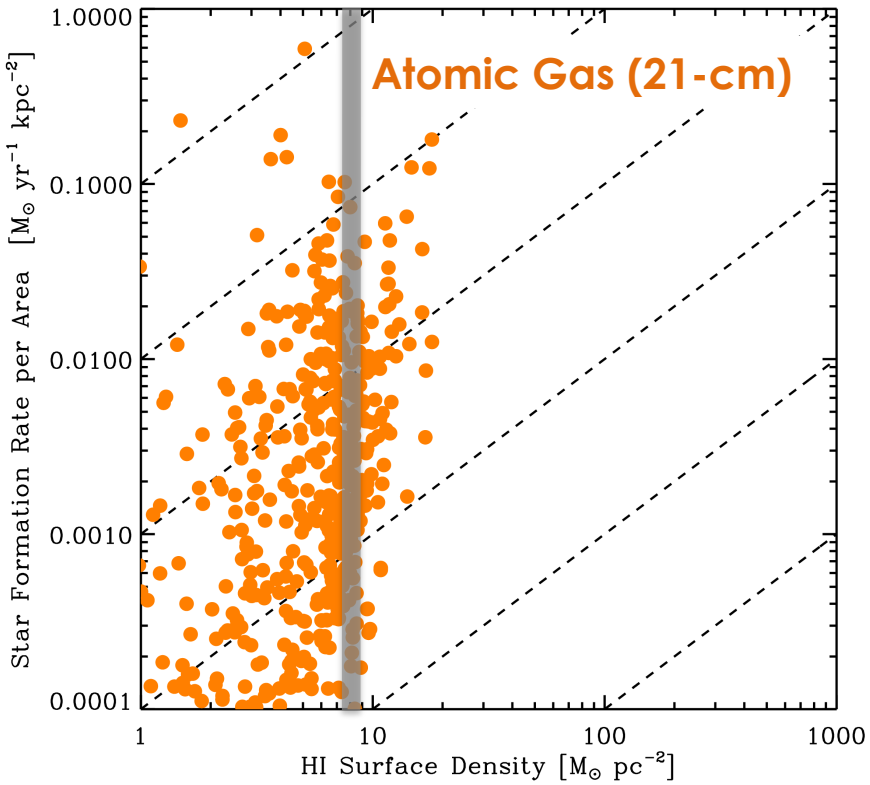
- Convolve all targets to "1 kpc distance."
- Sample CO, HI, IR, Opt., UV on a 500 pc-spaced hexagonal grid.
- For sensitivity, "spectral stacking" to obtain deep profiles (Schruba+ '11).

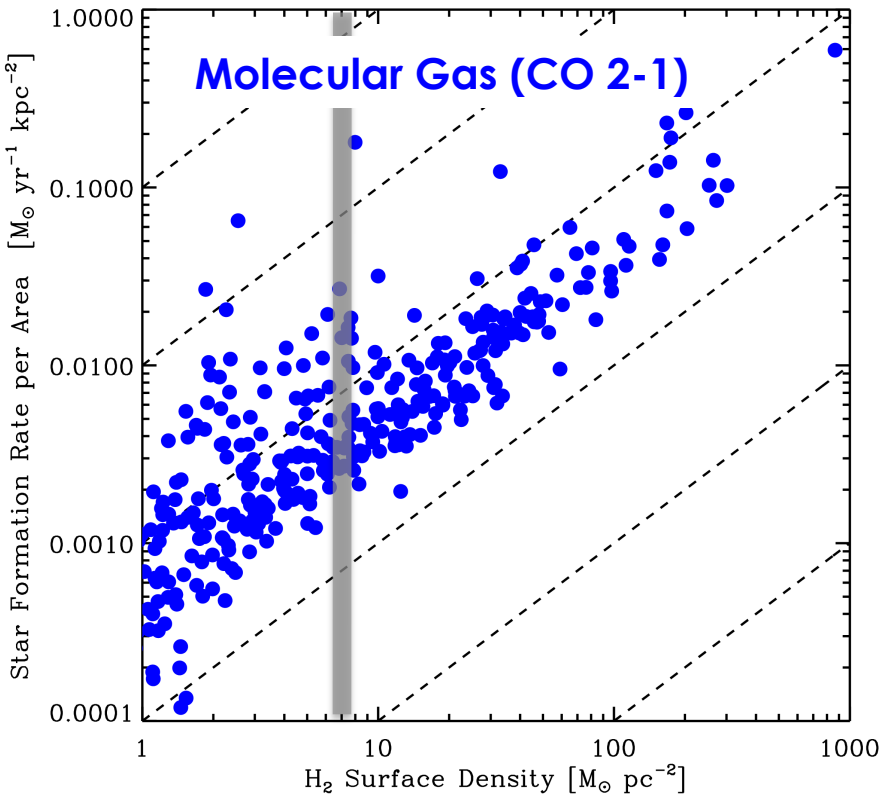




Stars Form From Molecular Gas

- Star formation and different gas types for stacked profiles:



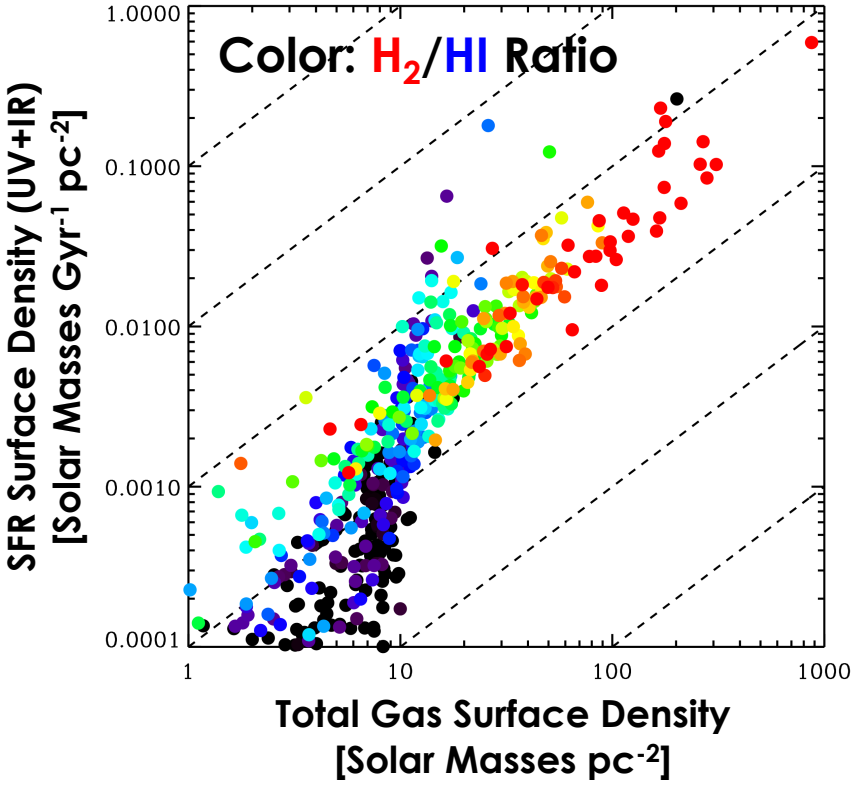


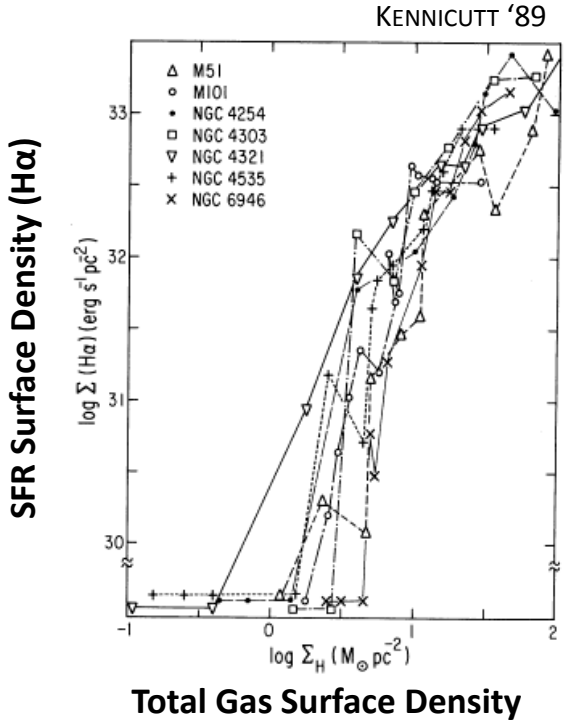
Each Point:
Azimuthal average (ring) in one galaxy, 30 galaxies combined

SCHRUBA+ '11, BIGIEL+ '08

H_2-to-HI Balance and the Star Formation "Threshold"

- Total gas behavior consistent with previous "thresholds:"





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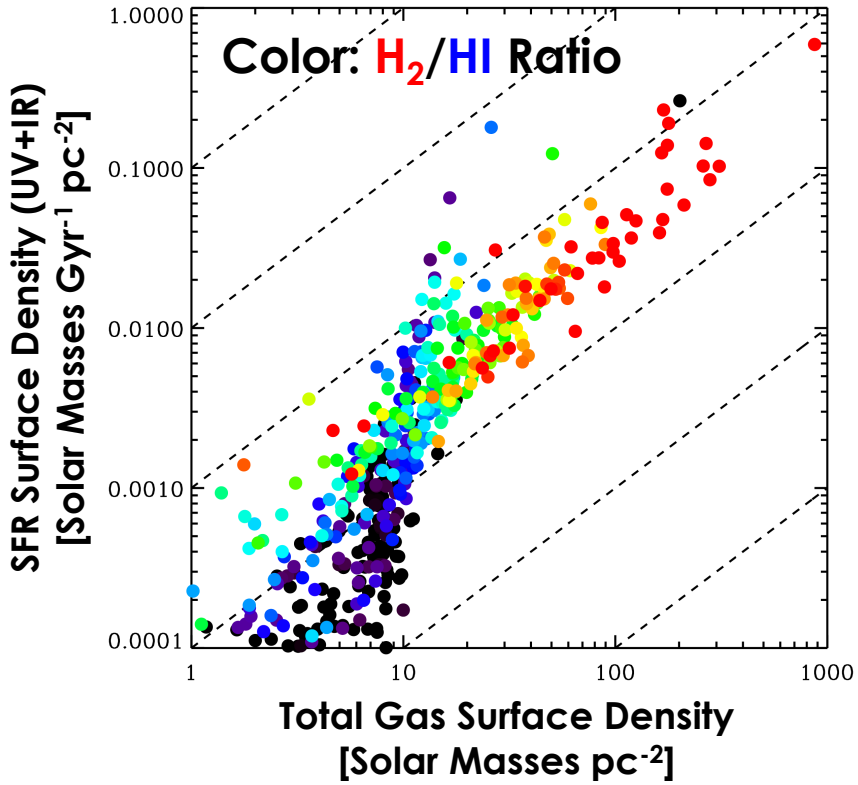
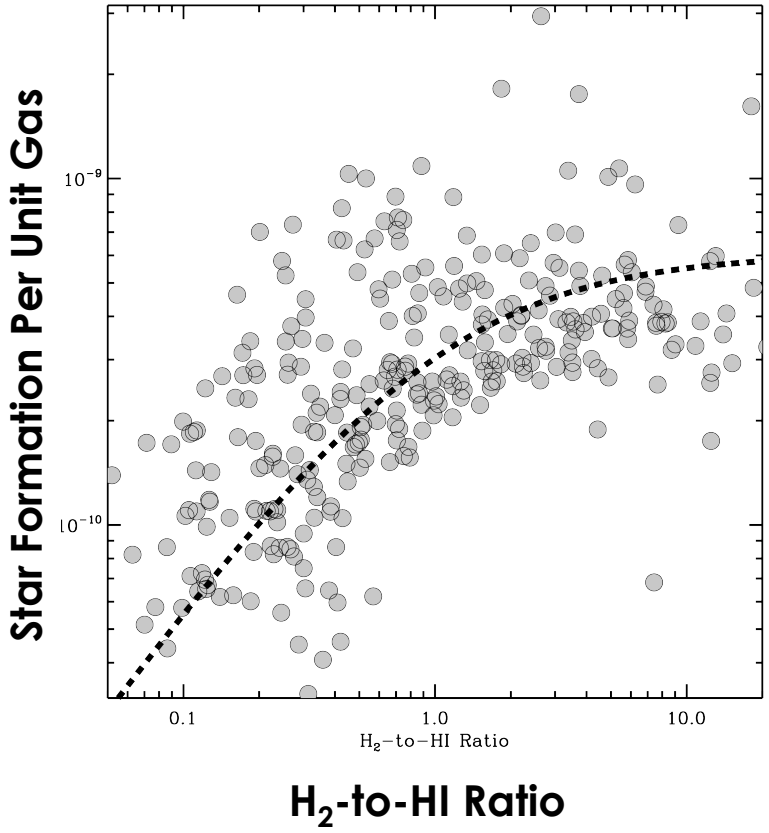
SCHRUBA+ '11

H_2-to-HI Balance and the Star Formation "Threshold"

- "Threshold" a product of changing molecular gas fraction:





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SCHRUBA+ '11

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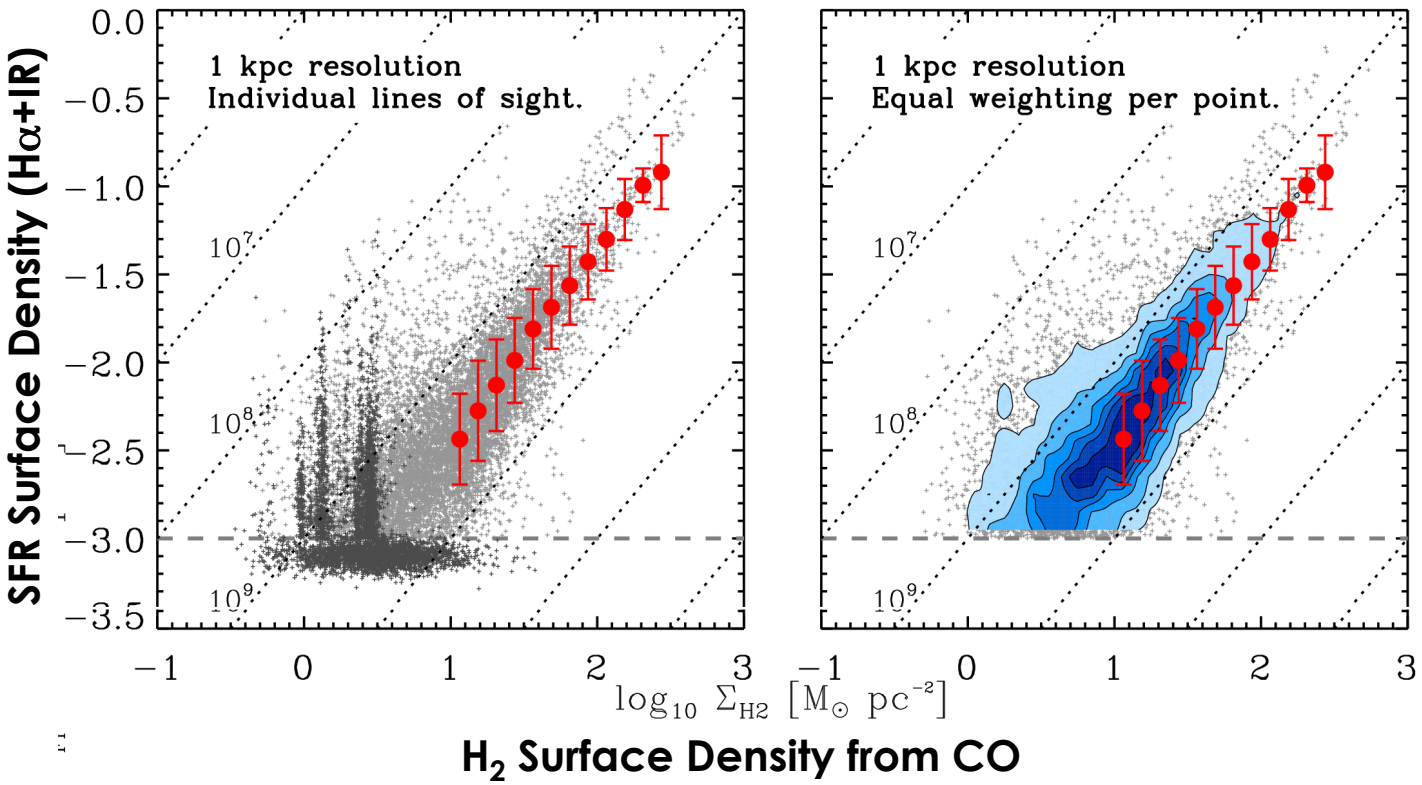
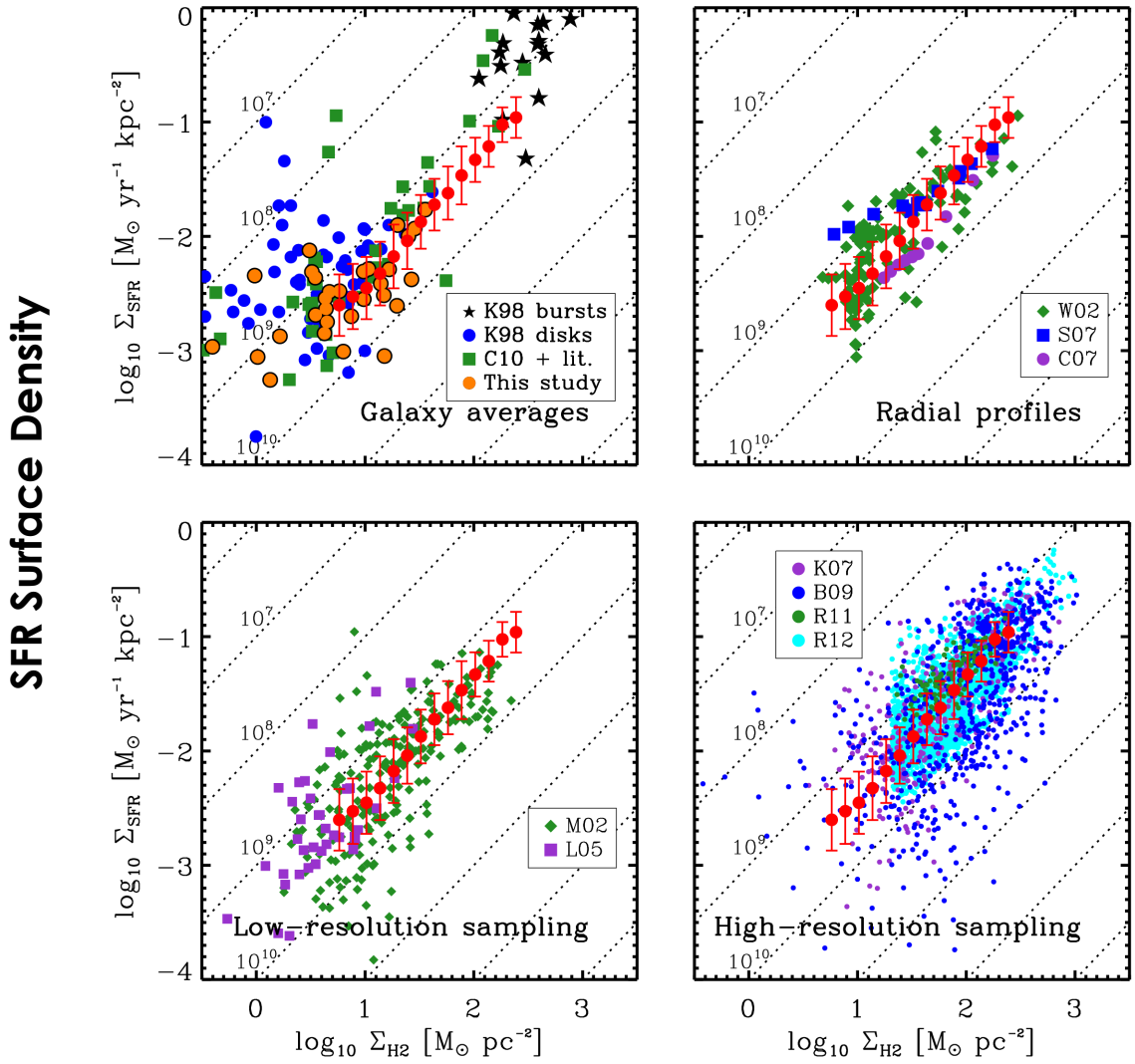
SFR-per-H_2 in Disks: Fixed to First Order



Each Point:
1 kpc resolution line of sight in a galaxy, 30 galaxies combined

BIGIEL+ '11, LEROY+ SUBMITTED

Comparison to Literature Measurements

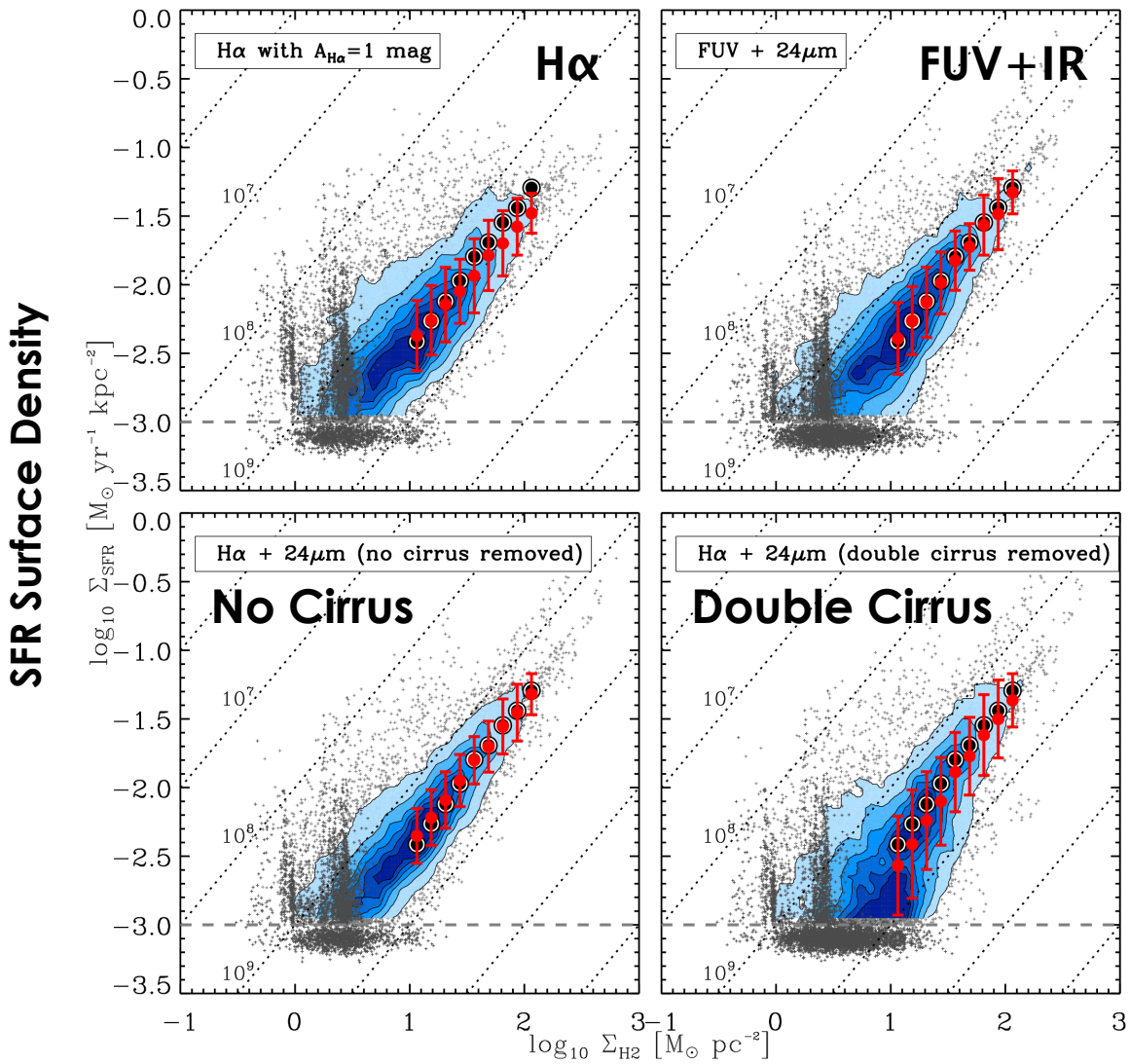


Each Point:
One literature measurement

H_2 Surface Density from CO

LEROY+ SUBMITTED

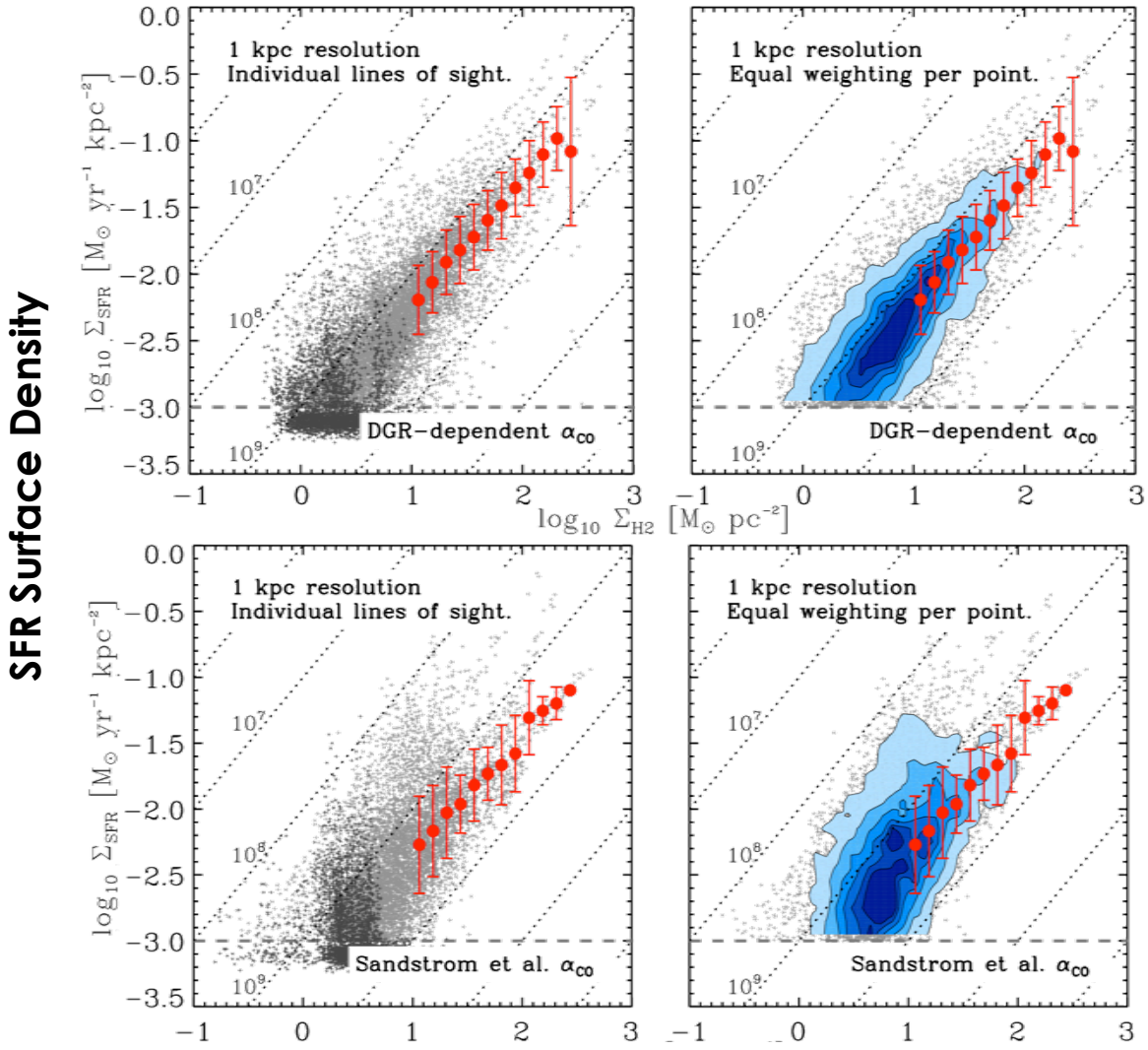
Varying SFR Approach



Each Point:
1 kpc resolution line of sight in a galaxy, 30 galaxies combined

LEROY+ '12, LEROY+ SUBMITTED

Varying Conversion Factor



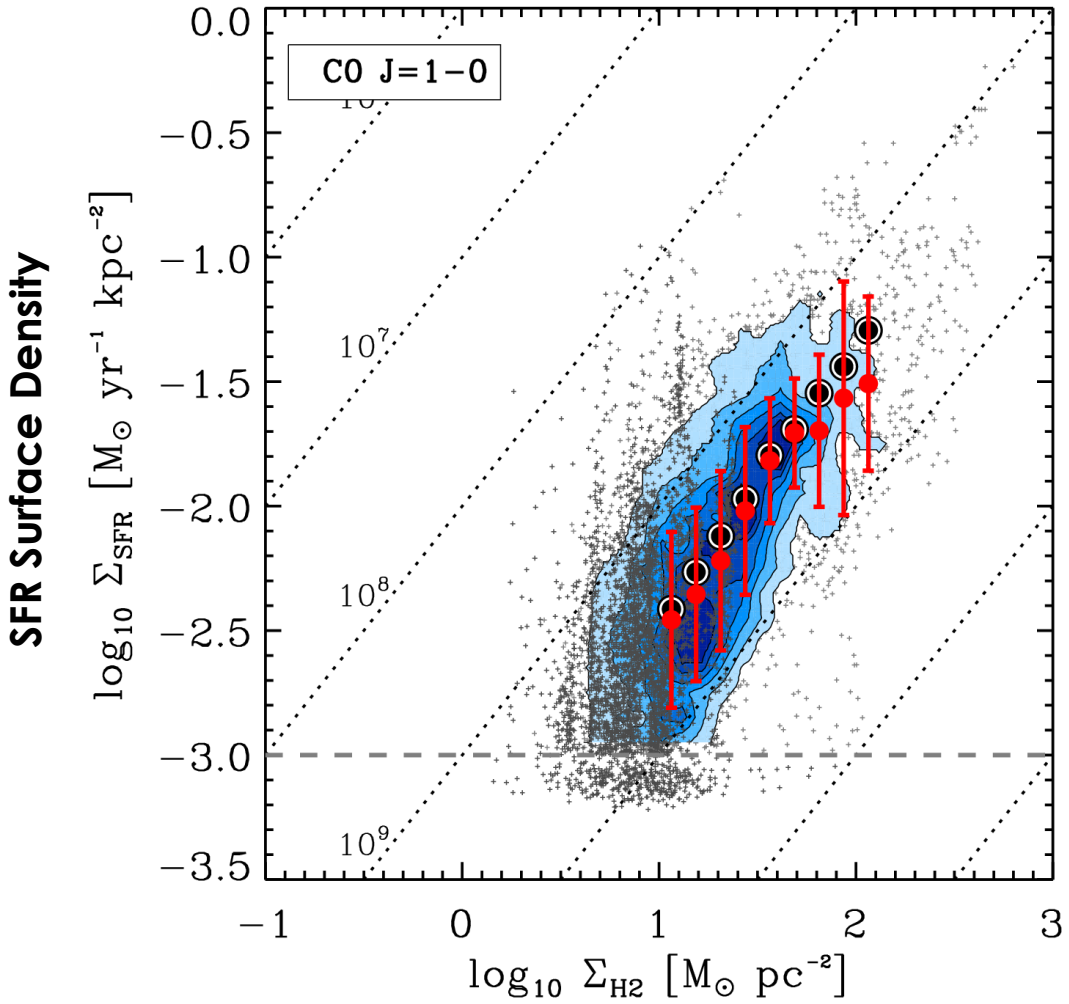
Wolfire+ '10

Sandstrom+ in prep.

Each Point:
1 kpc resolution line of sight
30 (top)/22 (bottom) galaxies combined

SANDSTROM+ IN PREP., LEROY+ SUBMITTED

Swapping CO Tracer



Each Point:
1 kpc resolution line of sight
15 galaxies with BIMA/NRO – repeats allowed

LEROY+ SUBMITTED

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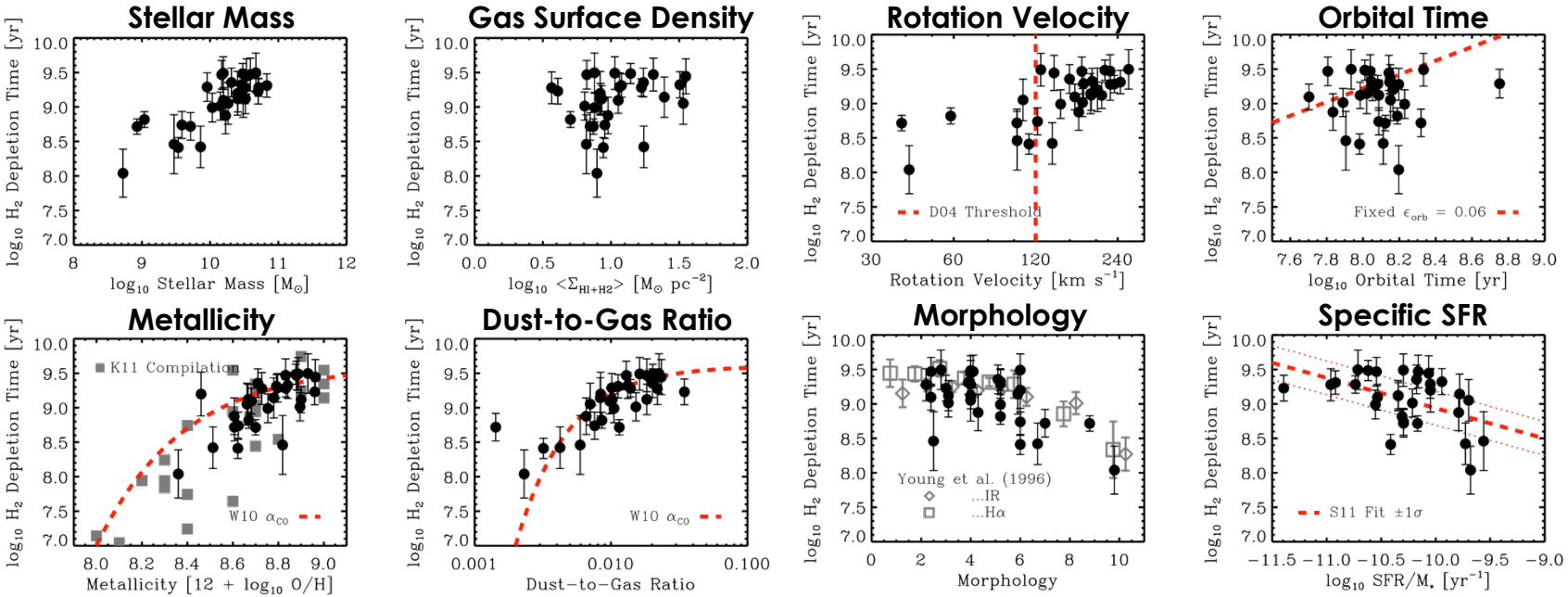
- **To first order, SFR/H_2 is fixed in big, normal disks.**
  CO AND SFR TRACERS CORRELATE CLOSELY AND ROUGHLY LINEARLY.

But SFR/CO Varies With Mass and Metallicity

CO Divided by SFR - Each Point 1 Galaxy

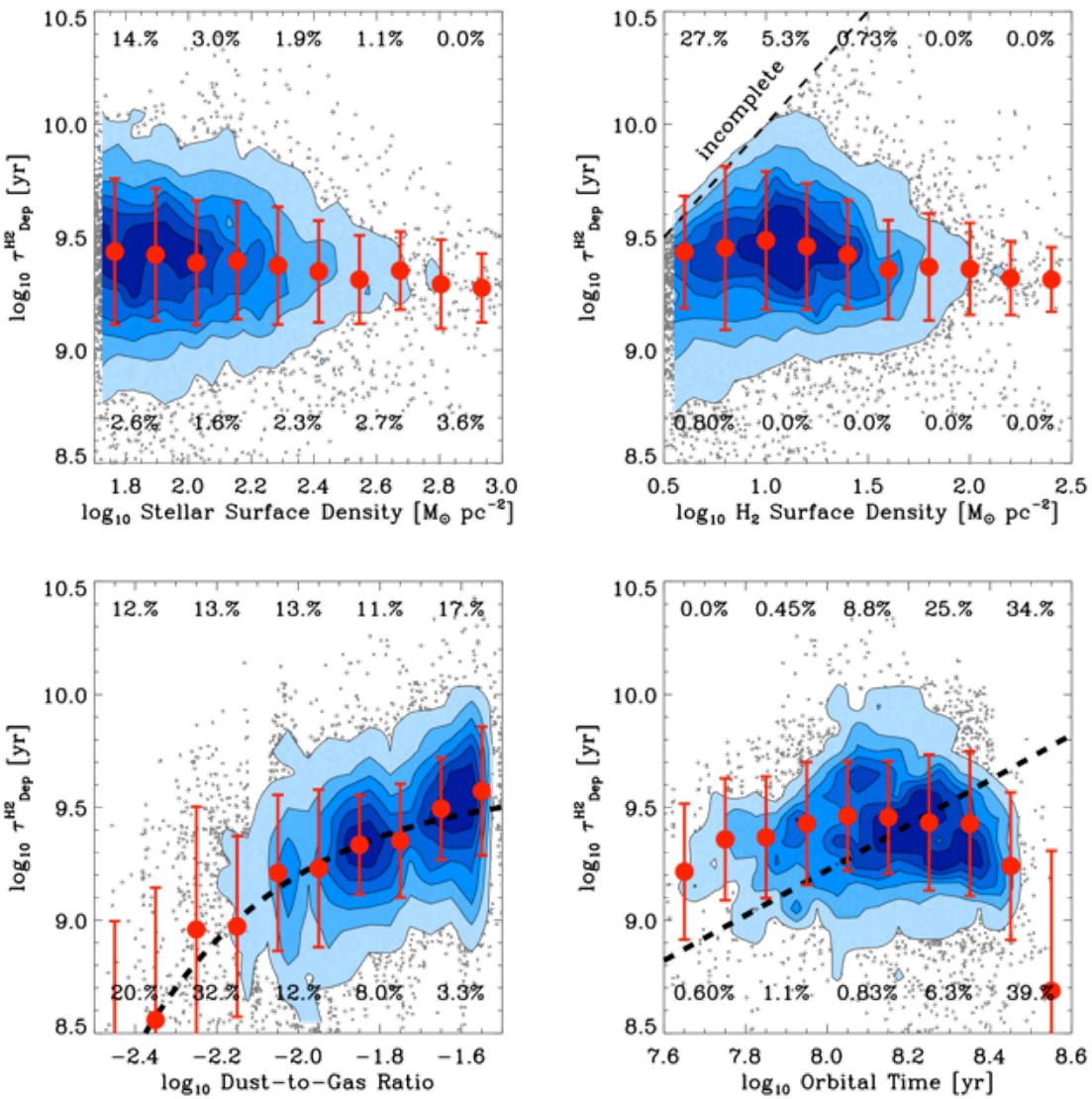


Each Point:
Whole-galaxy average

LEROY+ SUBMITTED

Trend With Dust-to-Gas Visible Locally

CO Divided by SFR [Gyr]
Each Point 1 kpc

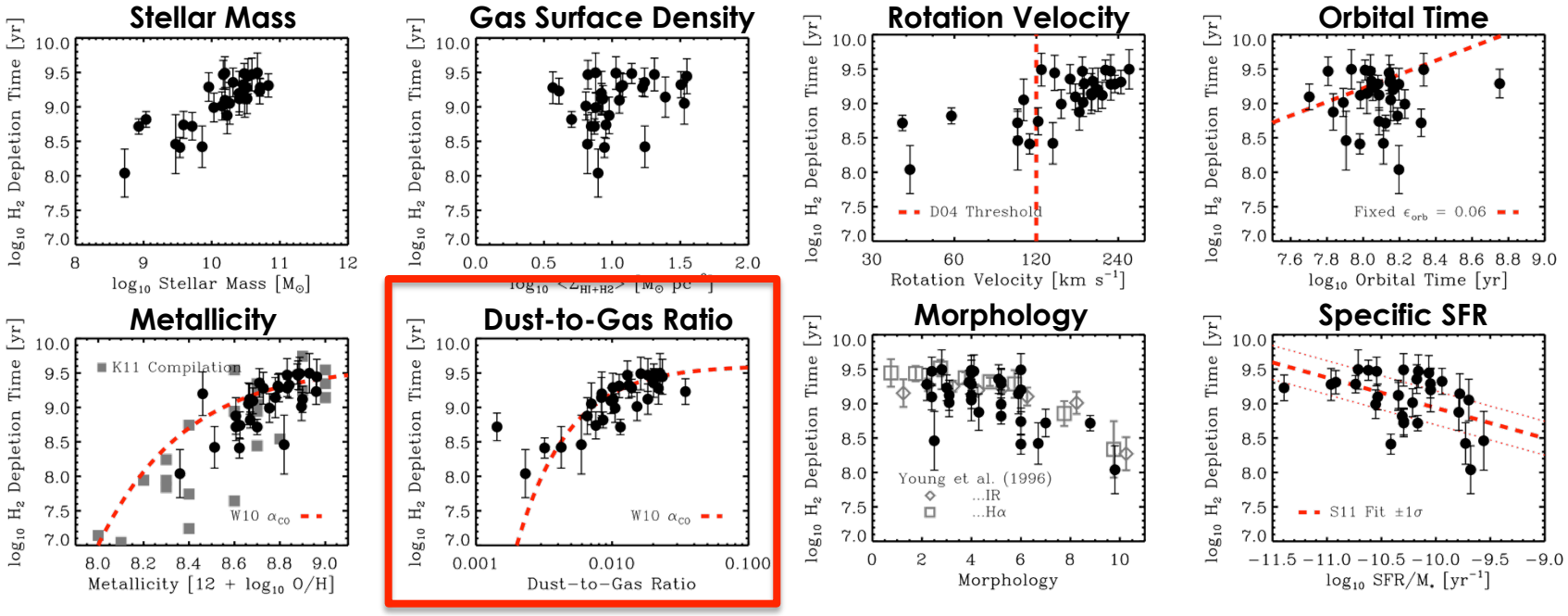


Each Point:
1 kpc resolution line of sight in a galaxy, 30 galaxies combined

LEROY+ SUBMITTED

But SFR/CO Varies With Mass and Metallicity

CO Divided by SFR - Each Point 1 Galaxy

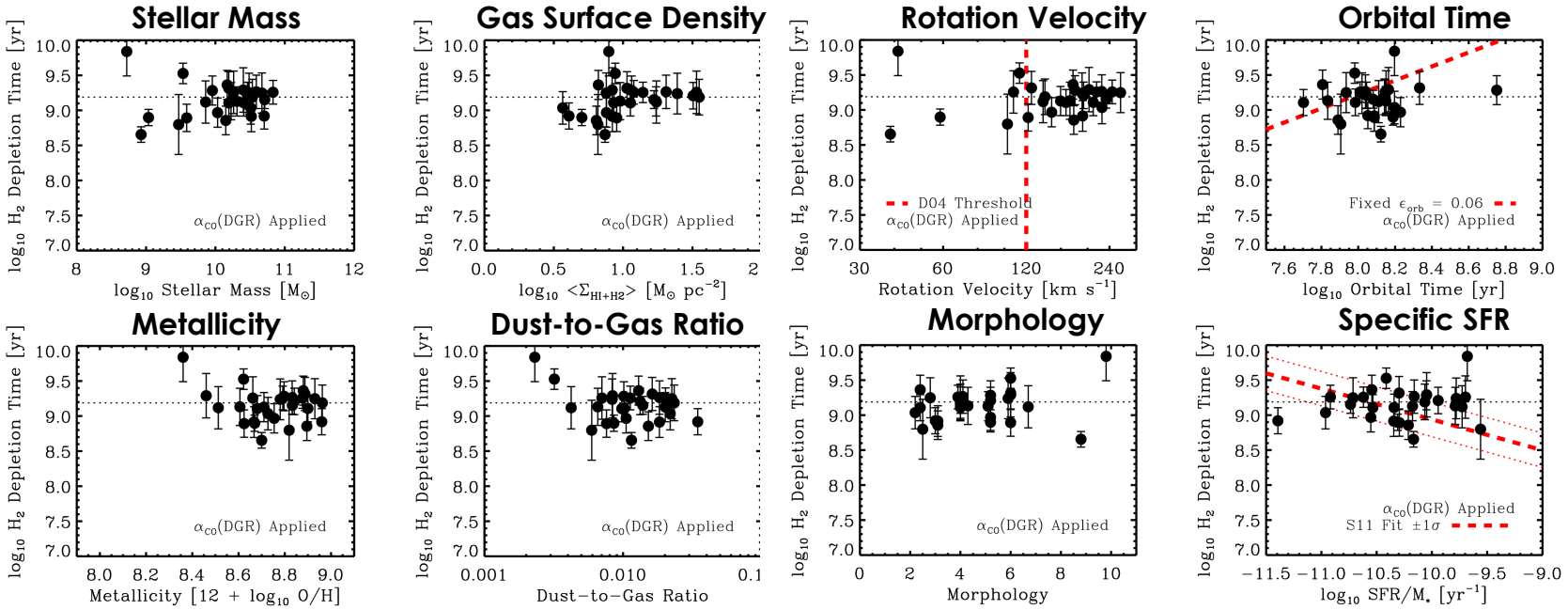


Each Point:
Whole-galaxy average

LEROY+ SUBMITTED

Conversion Factor Variations?

CO Divided by SFR - Each Point 1 Galaxy



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Whole-galaxy average

LEROY+ SUBMITTED

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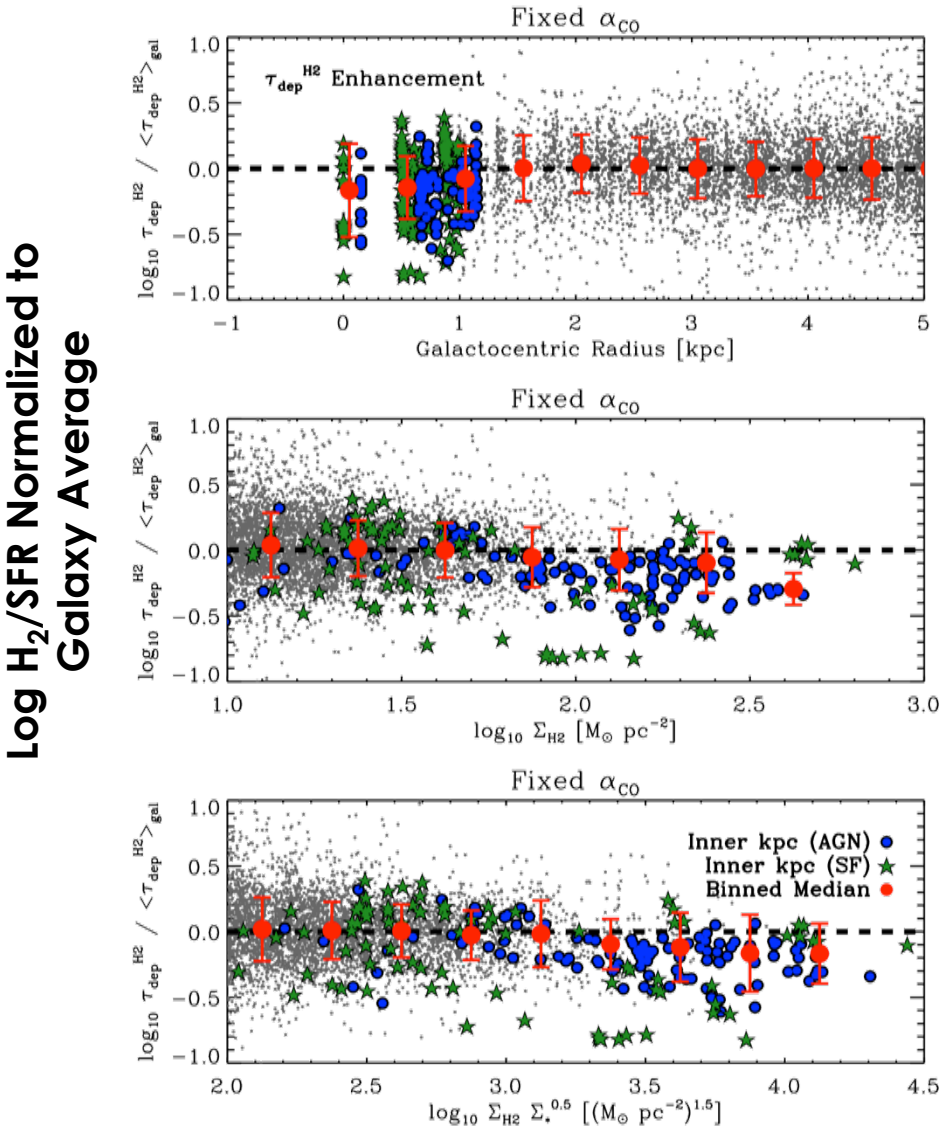
    MOST SENSIBLE EXPLANATION ARE X_{CO} VARIATIONS.

Efficient Star Formation at Galaxy Centers



Radius

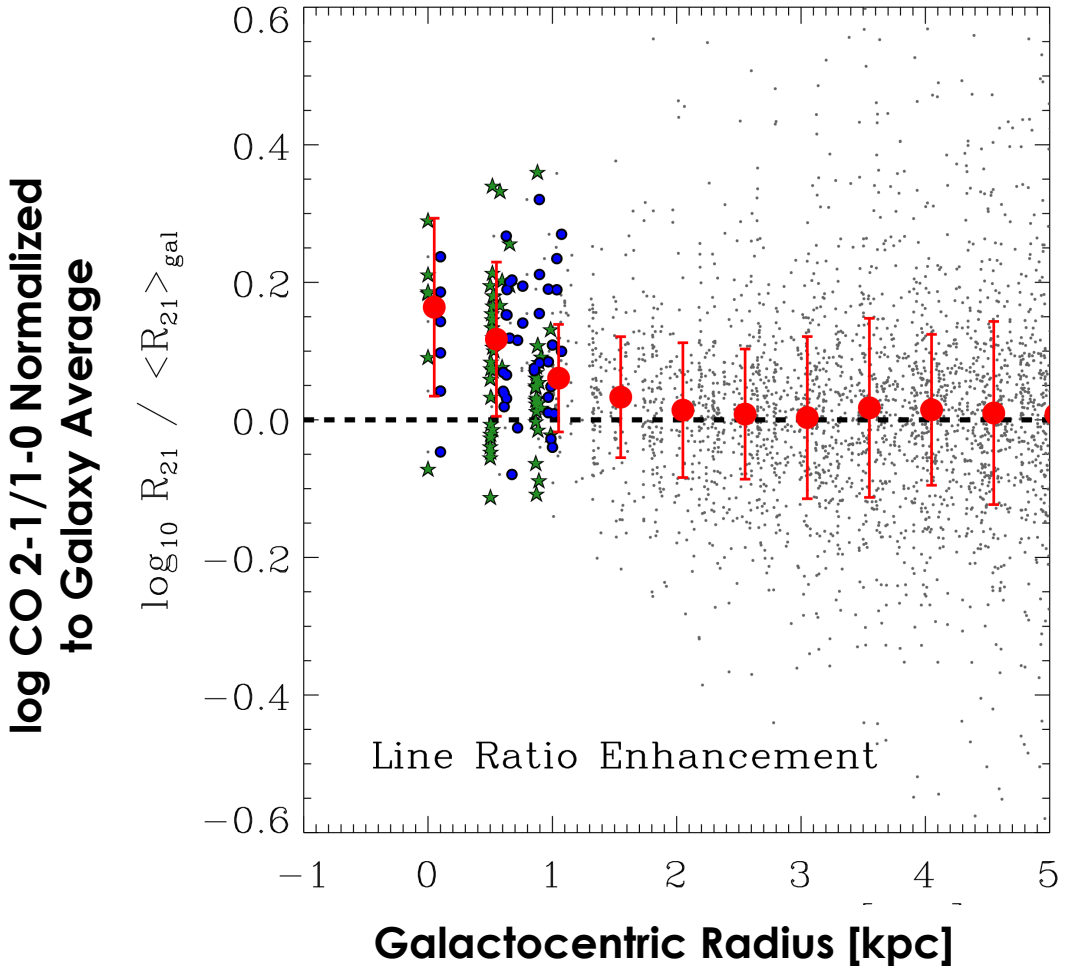
Gas Surface Density

~ ISM Pressure

Each Point:
1 kpc resolution line of sight in a galaxy, 30 galaxies combined

LEROY+ SUBMITTED

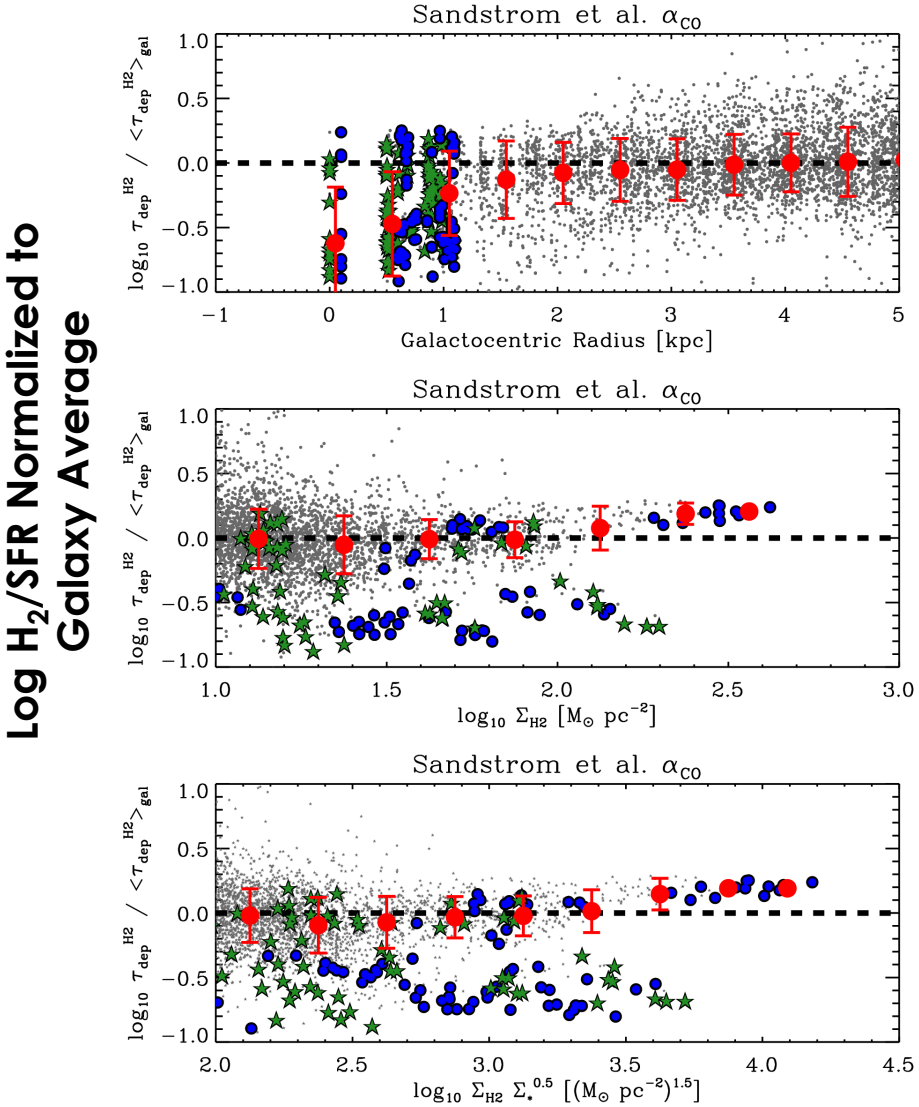
Excited Gas at Galaxy Centers



Each Point:
1 kpc resolution line of sight in a galaxy
15 galaxies combined

LEROY+ '09, LEROY+ SUBMITTED

Efficient Star Formation NOT Conversion Factor



Radius

Gas Surface Density

~ ISM Pressure

Each Point:
1 kpc resolution line of sight in a galaxy
22 galaxies combined

LEROY+ SUBMITTED, SANDSTROM+ IN PREP.

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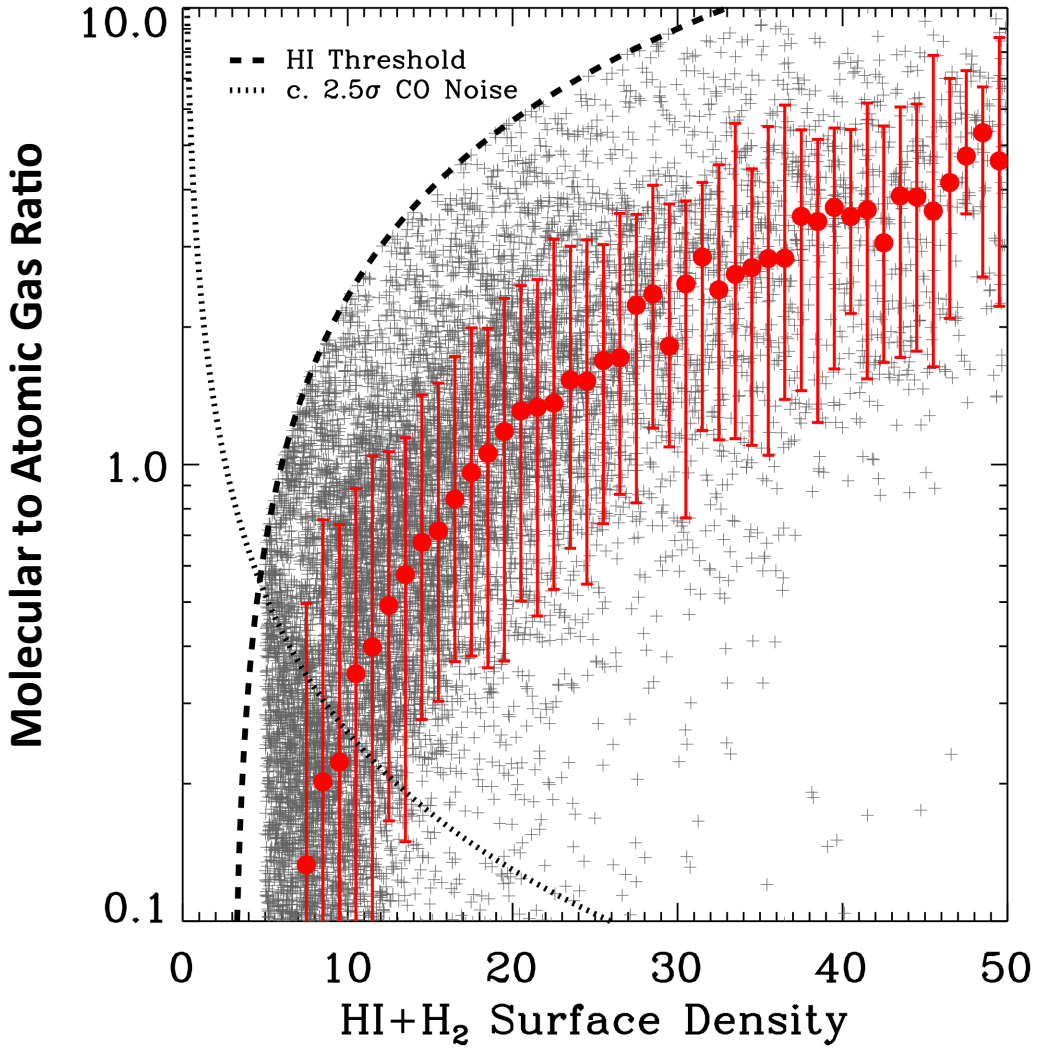
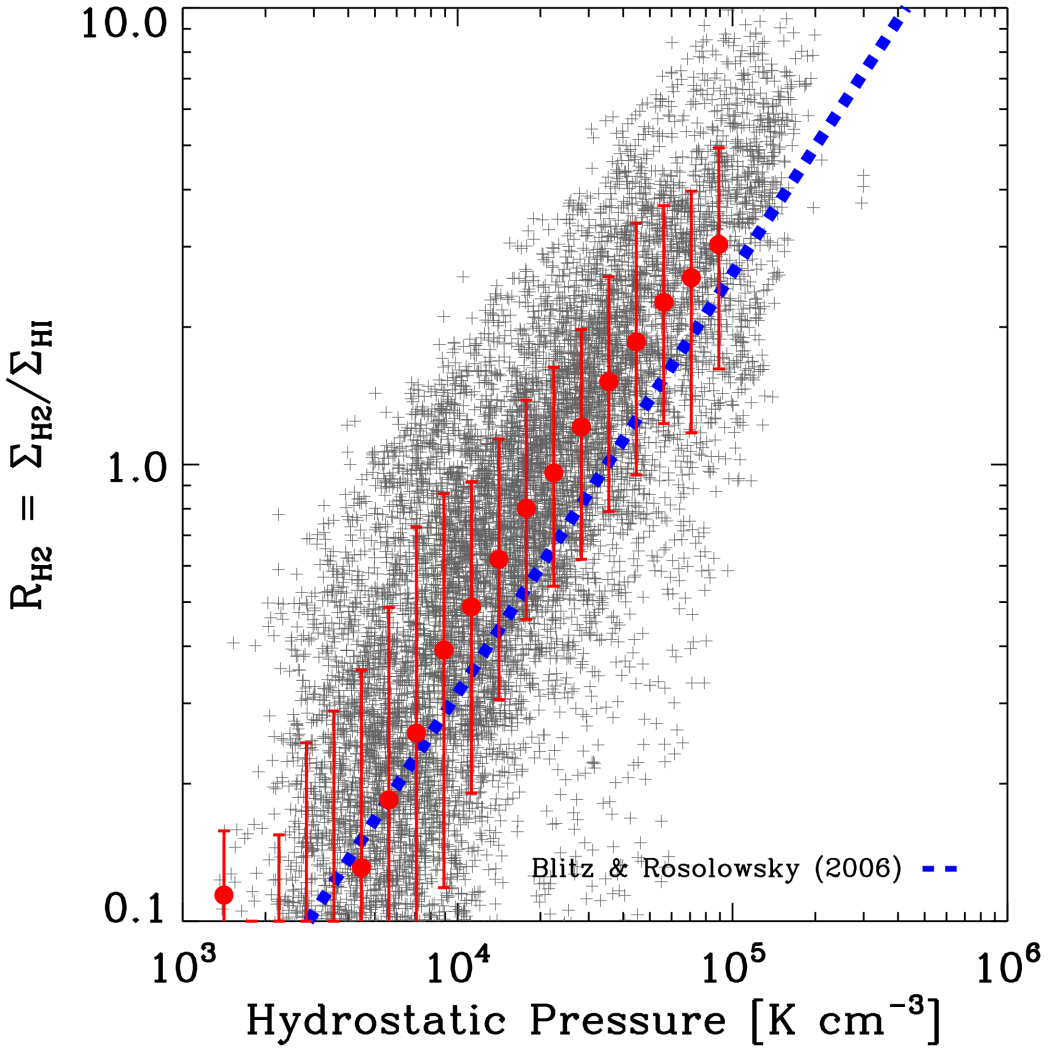


Each Point:
1 kpc resolution line of sight in a galaxy, 22 galaxies combined

LEROY+ IN PREP.

H_2-to-HI and Pressure



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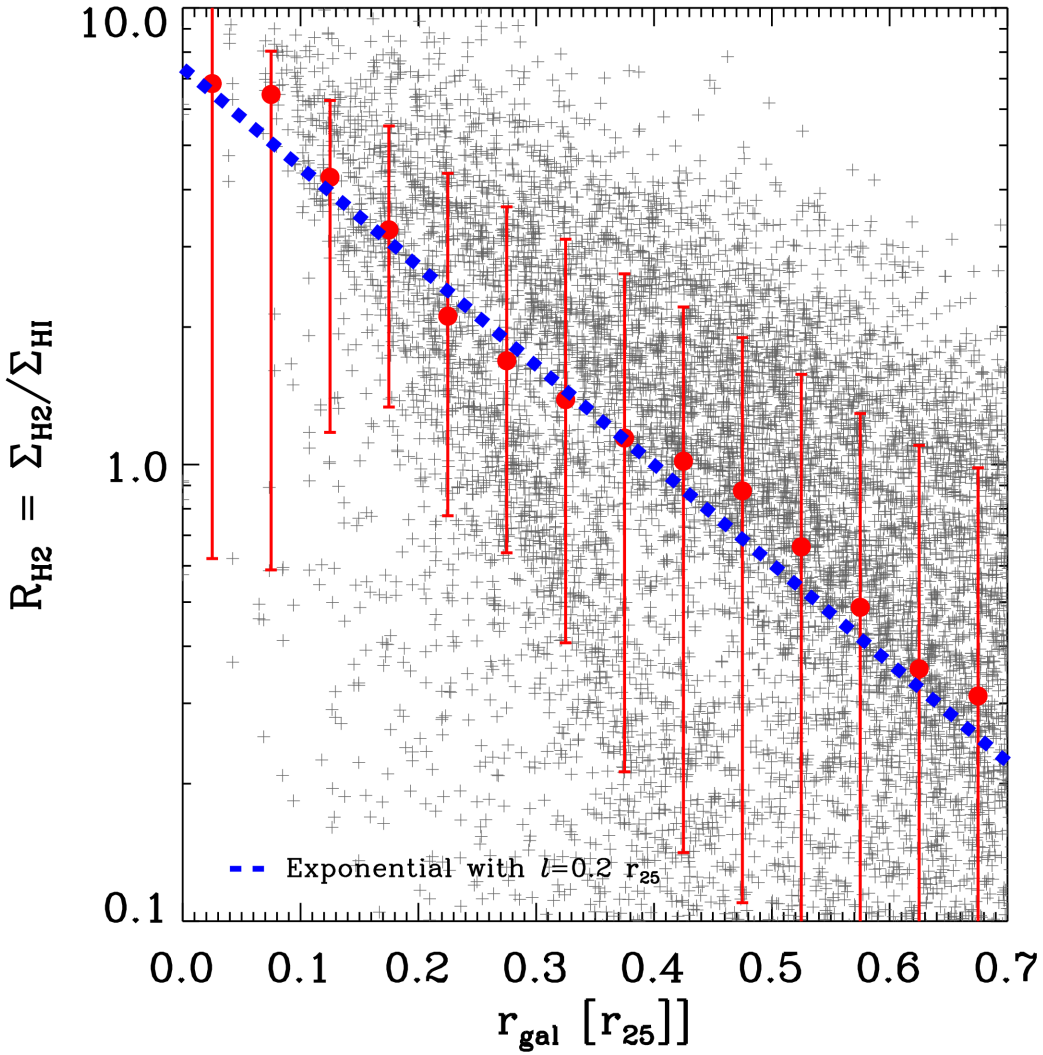
LEROY+ IN PREP.

H_2-to-HI and Radius



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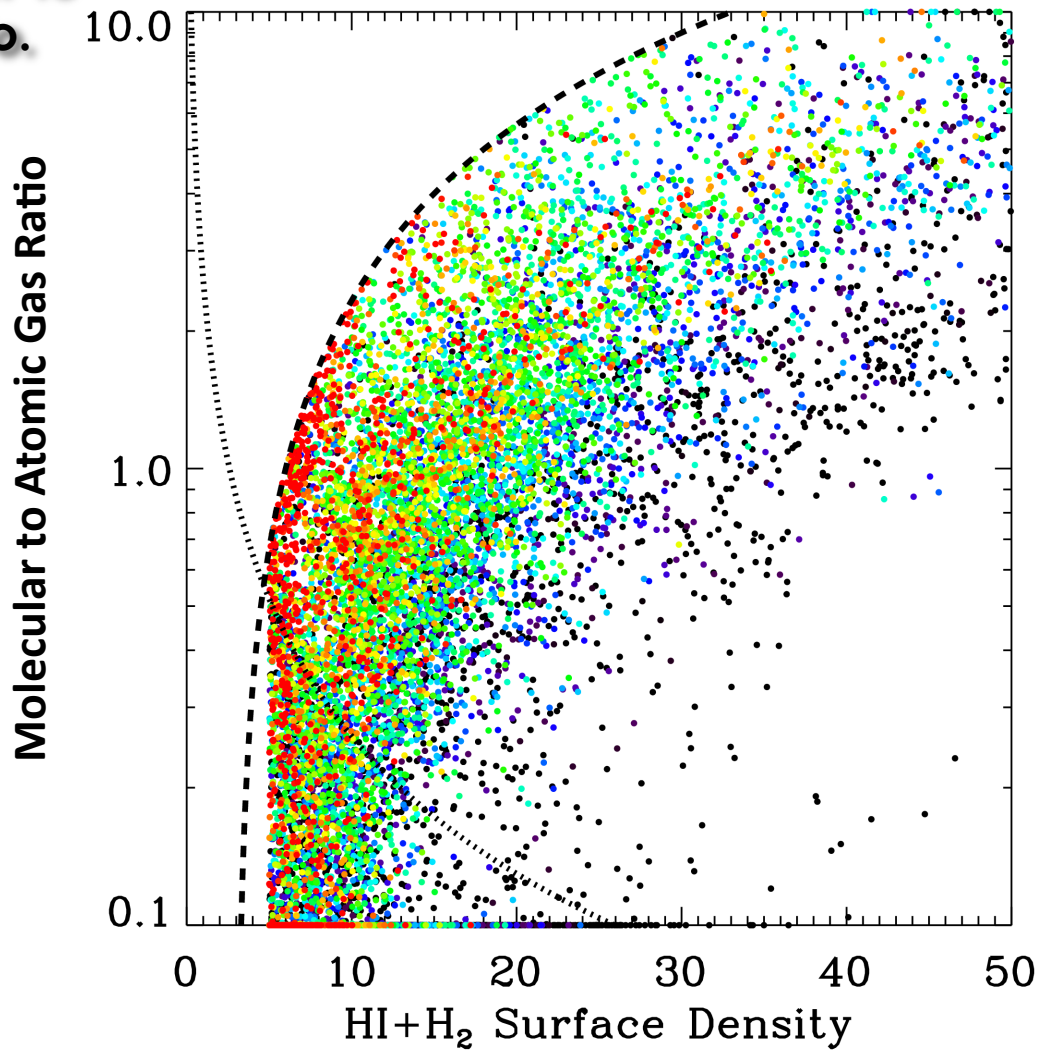
- **H_2–HI ratio depends systematically on local conditions.**
  - **First order variations with either total gas column or pressure.**

Whence the Scatter in H_2-to-HI?

Color shows dust-to-gas mass ratio.



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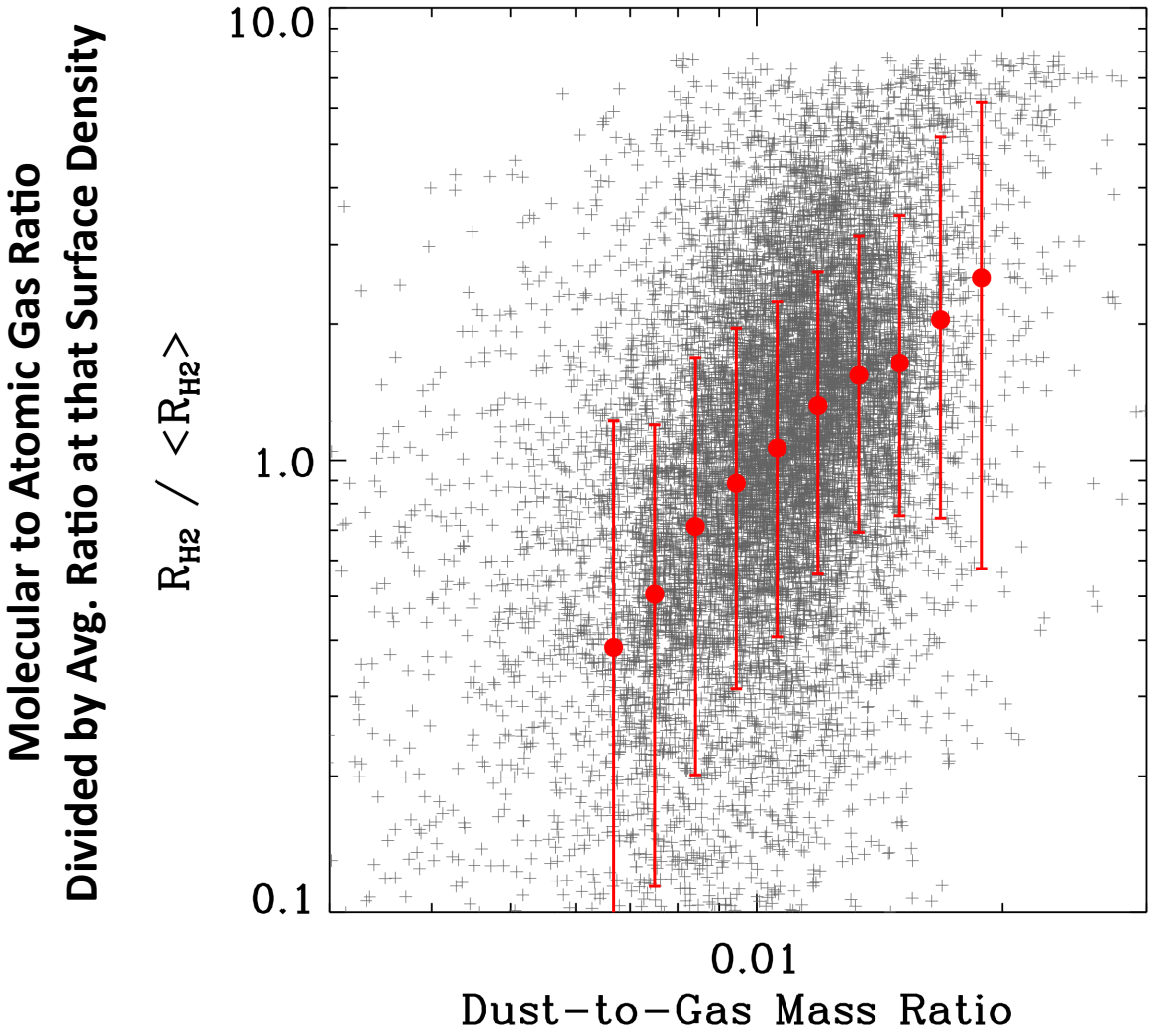
LEROY+ IN PREP.

Residual H_2-to-HI vs. Dust-to-Gas Mass Ratio



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LEROY+ IN PREP.

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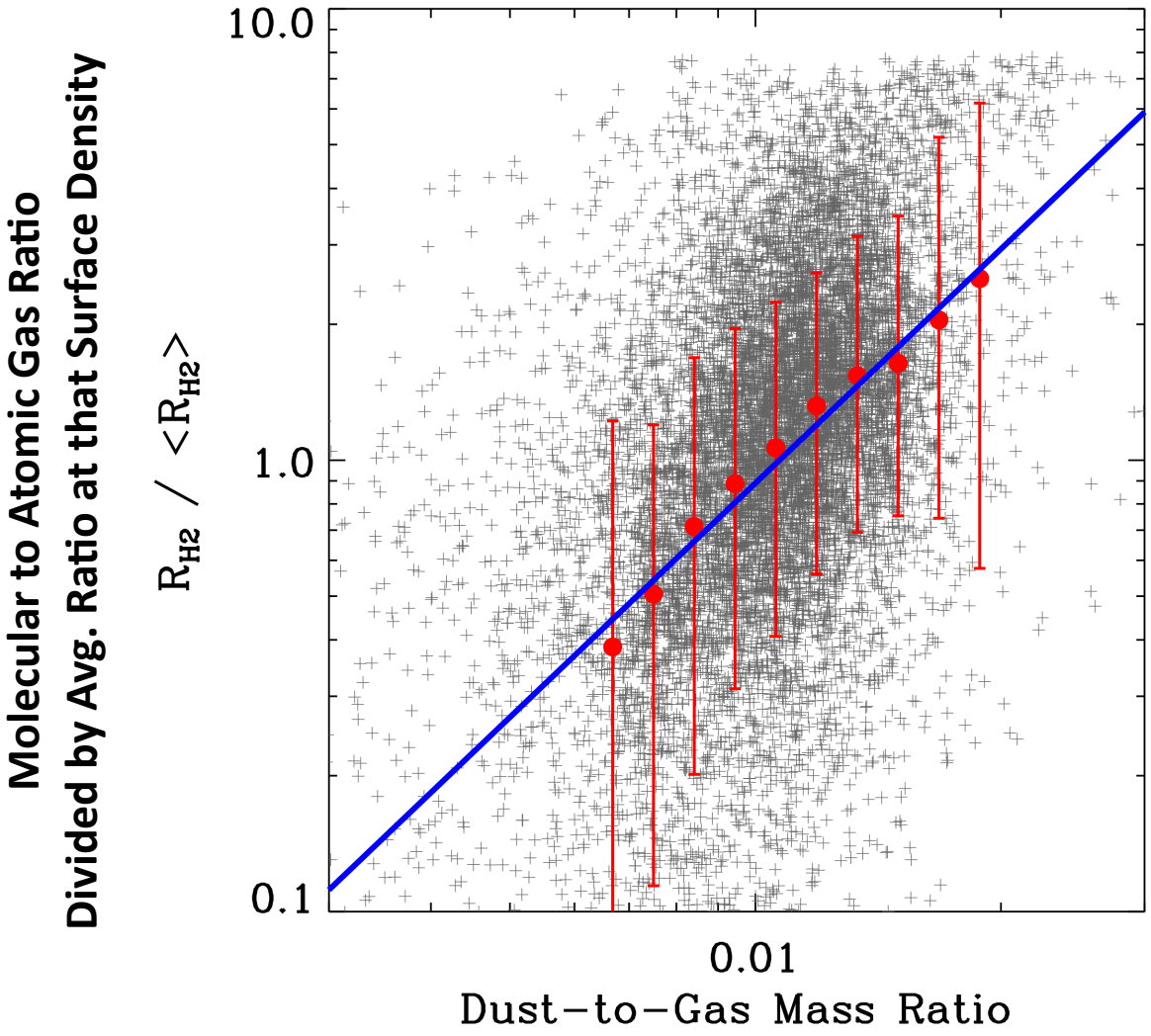

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  - **Second order variations with dust-to-gas ratio.**