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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 ($\sigma \sim 1-2 \ M_{\text{sun}} \ pc^{-2}$)
- 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 ~ $5 \times 10^{19} \ cm^{-2}$ per channel map
- Walter et al. (2008), AJ Special Issue (2008)
- Public at www.mpia.de/THINGS
• **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/\~an HI-to-H\textsubscript{2} transition.

• **To first order, SFR/H\textsubscript{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\textsubscript{CO} variations.*
  - Starbursts in galaxy centers appear more efficient.

• **H\textsubscript{2}–HI ratio depends systematically on local conditions.**
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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
Total gas behavior consistent with previous “thresholds:”

Each Point:
Azimuthal average (ring) in one galaxy, 30 galaxies combined
H$_2$-to-HI Balance and the Star Formation “Threshold”

- “Threshold” a product of changing molecular gas fraction:

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

SCHRUBA+ '11
• 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.
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

H$_2$ Surface Density from CO

LEROY+ ‘12, LEROY+ SUBMITTED
Each Point:
1 kpc resolution line of sight
30 (top)/22 (bottom) galaxies combined

$\Sigma_{\text{H}_2}$ Surface Density from CO

SFR Surface Density

Varying Conversion Factor

Wolfire+ '10

Sandstrom+ in prep.

Sandstrom+ in prep., Leroy+ Submitted
Swapping CO Tracer

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

H$_2$ Surface Density from CO
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.

- 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
Trend With Dust-to-Gas Visible Locally

Each Point:
1 kpc resolution line of sight in a galaxy, 30 galaxies combined
But SFR/CO Varies With Mass and Metallicity

Each Point: Whole-galaxy average
Conversion Factor Variations?

Each Point:
Whole-galaxy average
What We Learn From A kpc-Scale View of the ISM

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• Second variations of SFR/CO are clearly visible:
  ○ Low mass, low metallicity galaxies show depressed CO.
    Most sensible explanation are $X_{CO}$ variations.
Efficient Star Formation at Galaxy Centers

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

Log \( H_2 \)/SFR Normalized to Galaxy Average

Radius

Gas Surface Density

\sim ISM Pressure

\text{Fixed } \alpha_{\text{CO}}

\text{log } \frac{\tau_{\text{exp}}}{\langle \tau_{\text{exp}} \rangle_{\text{gal}}}

\text{Galactocentric Radius [kpc]}

\text{log } 10 \, \Sigma_{\text{H}_2} \, [M_\odot \, \text{pc}^{-2}]

\text{log } 10 \, \Sigma_{\text{H}_2} \, \Sigma_{\text{H}_2}^{0.5} \, [(M_\odot \, \text{pc}^{-2})^{0.5}]
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

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

LEROY+ SUBMITTED, SANDSTROM+ IN PREP.
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• Second variations of SFR/CO are clearly visible:
  1. Low mass, low metallicity galaxies show depressed CO.
     Most sensible explanation are $X_{CO}$ variations.
  2. Starbursts in galaxy centers appear more efficient.
What We Learn From A kpc-Scale View of the ISM

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

LEROY+ IN PREP.
H$_2$-to-H$\text{I}$ and Pressure

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

Blitz & Rosolowsky (2006)
Each Point:
1 kpc resolution line of sight in a galaxy, 22 galaxies combined
What We Learn From A kpc-Scale View of the ISM

• Stars form from molecular gas in nearby disks.  
  SFR tracers correlate \( \sim \) linearly with CO even where most gas is HI.

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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 $\text{H}_2$-to-HI?

Color shows dust-to-gas mass ratio.

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

LEROY+ IN PREP.
Residual $H_2$-to-HI vs. Dust-to-Gas Mass Ratio

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

LEROY+ IN PREP.
Residual H$_2$-to-HI vs. Dust-to-Gas Mass Ratio

Each Point:
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LEROY+ IN PREP.
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• H\(_2\)-HI ratio depends systematically on local conditions.
  o First order variations with either total gas column or pressure.
  o Second order variations with dust-to-gas ratio.