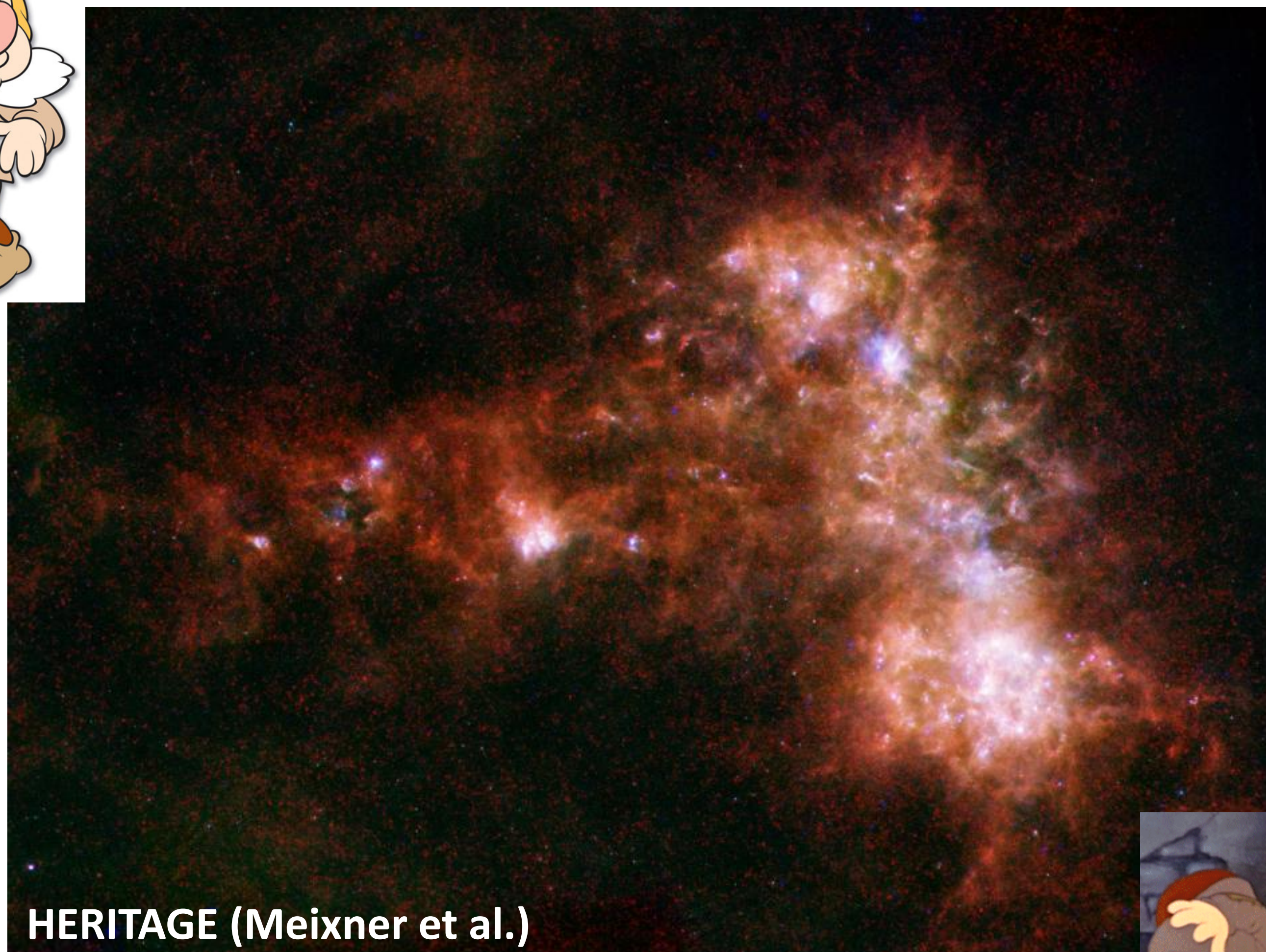
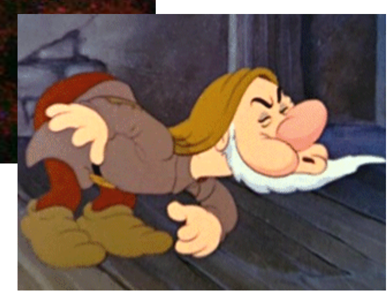
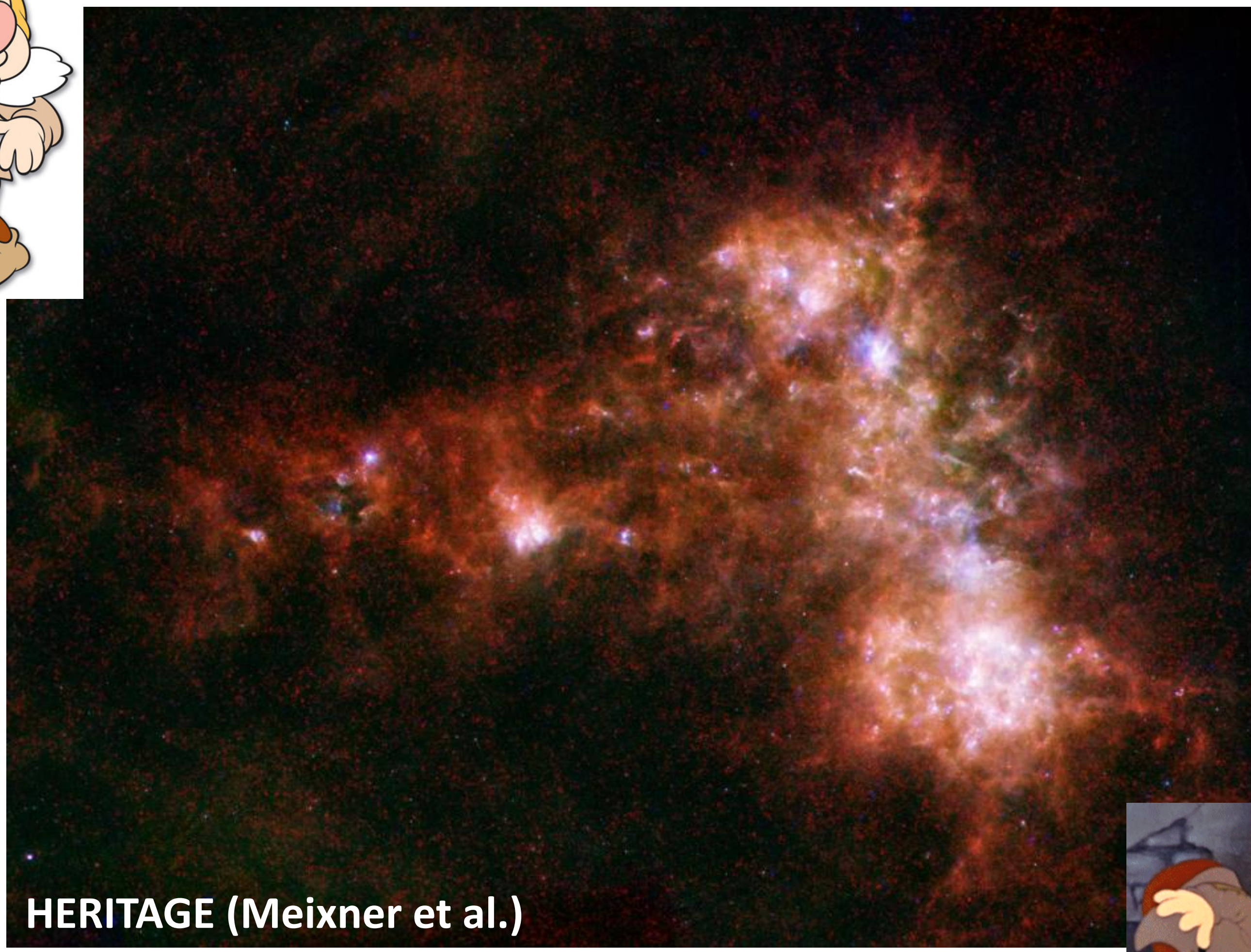
Dust in Dwarf Galaxies





Adam Leroy
National Radio Astronomy Observatory

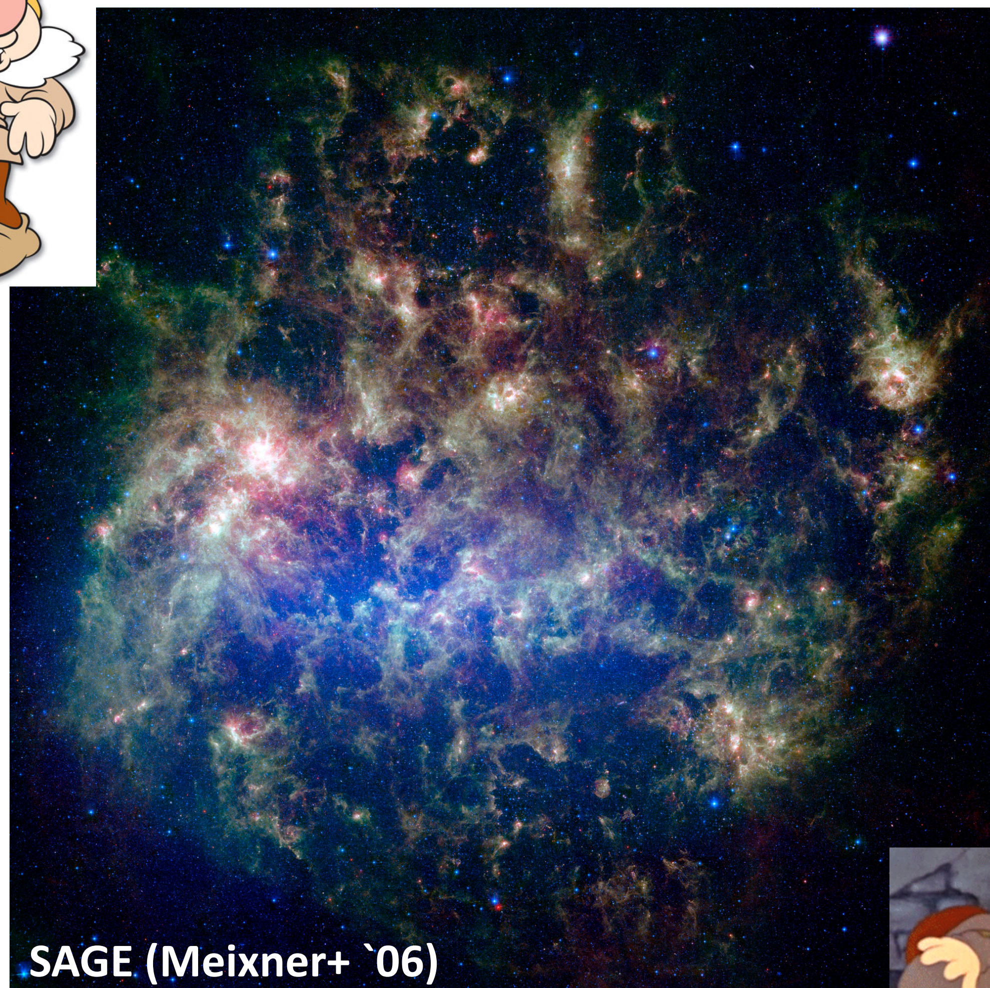
Dust in Dwarf Galaxies



HERITAGE (Meixner et al.)

Adam Leroy
NATIONAL RADIO ASTRONOMY OBSERVATORY

Dust in Dwarf Galaxies



Based on work
by many of the folks here…

Dust in Dwarf Galaxies is …

D/G **Less abundant** than in spiral galaxies…
… even more than you expect given the metallicity (?)

SED The dust that is present is **deficient in PAHs**…
… **rich in small grains** (and/or hotter) …
… and **exhibits a mysterious long-wavelength excess**.

ISM This dust is mixed with gas, making it an **ISM tracer…**
… especially useful for hard-to-see **molecular gas.**

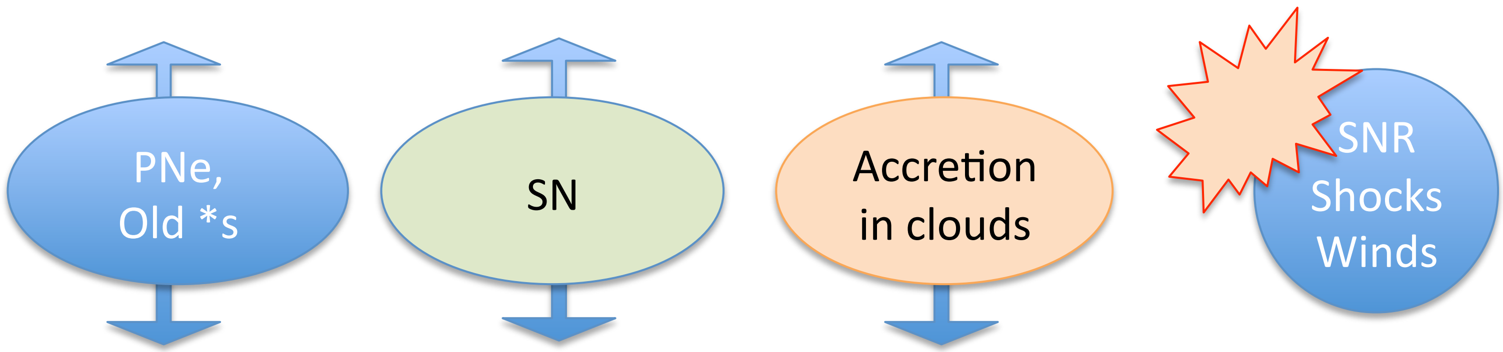
SFR And dust appears to help **regulate star formation…**
… influencing the balance of H_2-and-HI.

D/G

How Much Dust in Dwarf Galaxies?

Dust-to-Gas Ratio

Ratio of dust mass to total gas mass in the ISM.

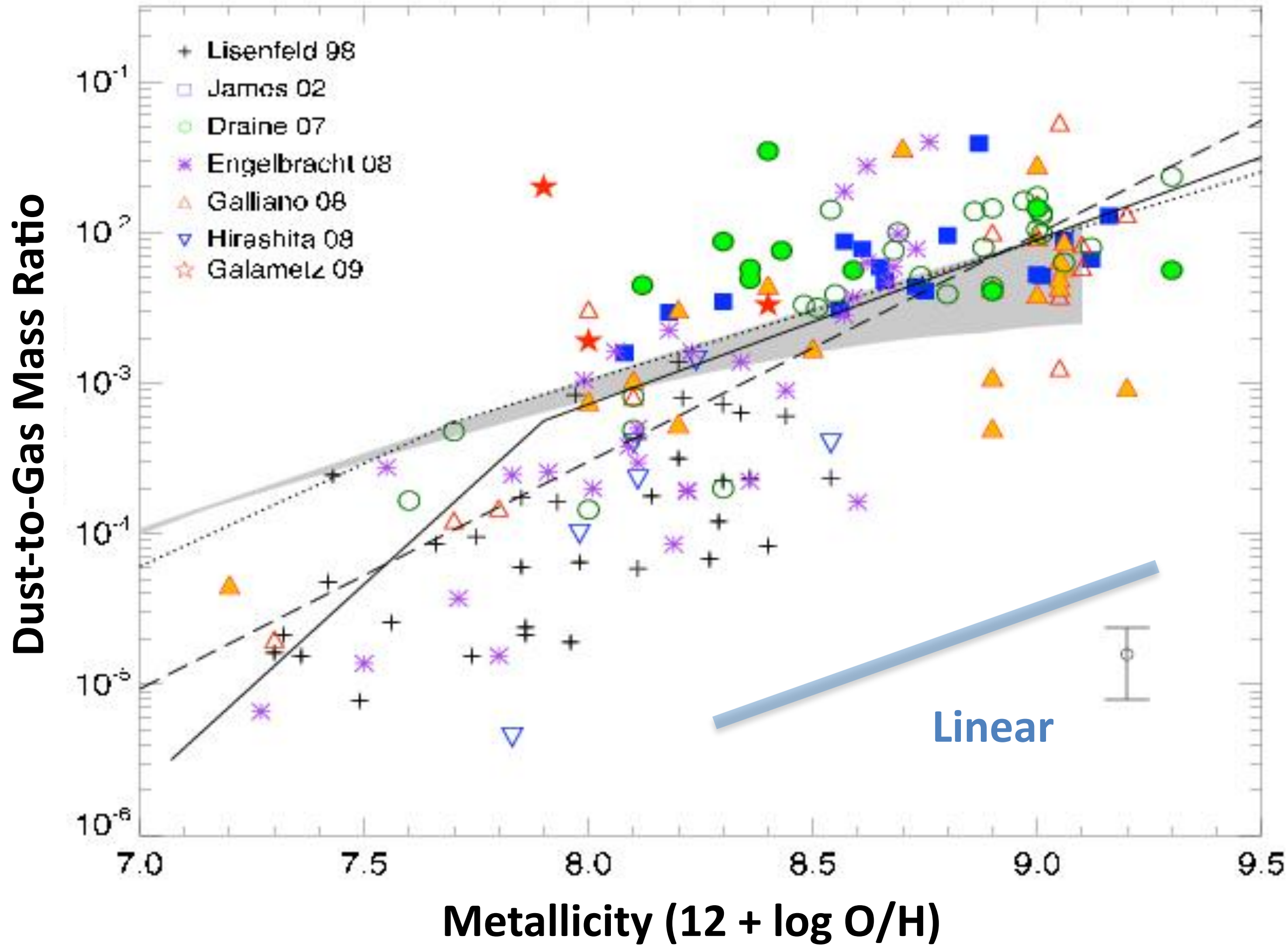


Relation to Metallicity?

Metallicity – ratio of heavy elements to gas mass.
Significant fraction of heavy elements in dust in MW (Si, Mg, Fe; most C).
Same in dwarfs? Expect roughly linear relation…

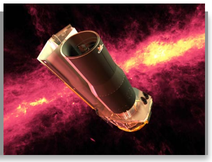
D/G Current Ensemble of Measurements

GALAMETZ, MADDEN, ET AL. ’11 : D/G in dwarf irregulars declines faster than metals
… following LISENFELD & FERRARA `98, DRAINE+ `07, etc.
… much more limited if only sub-mm observations used

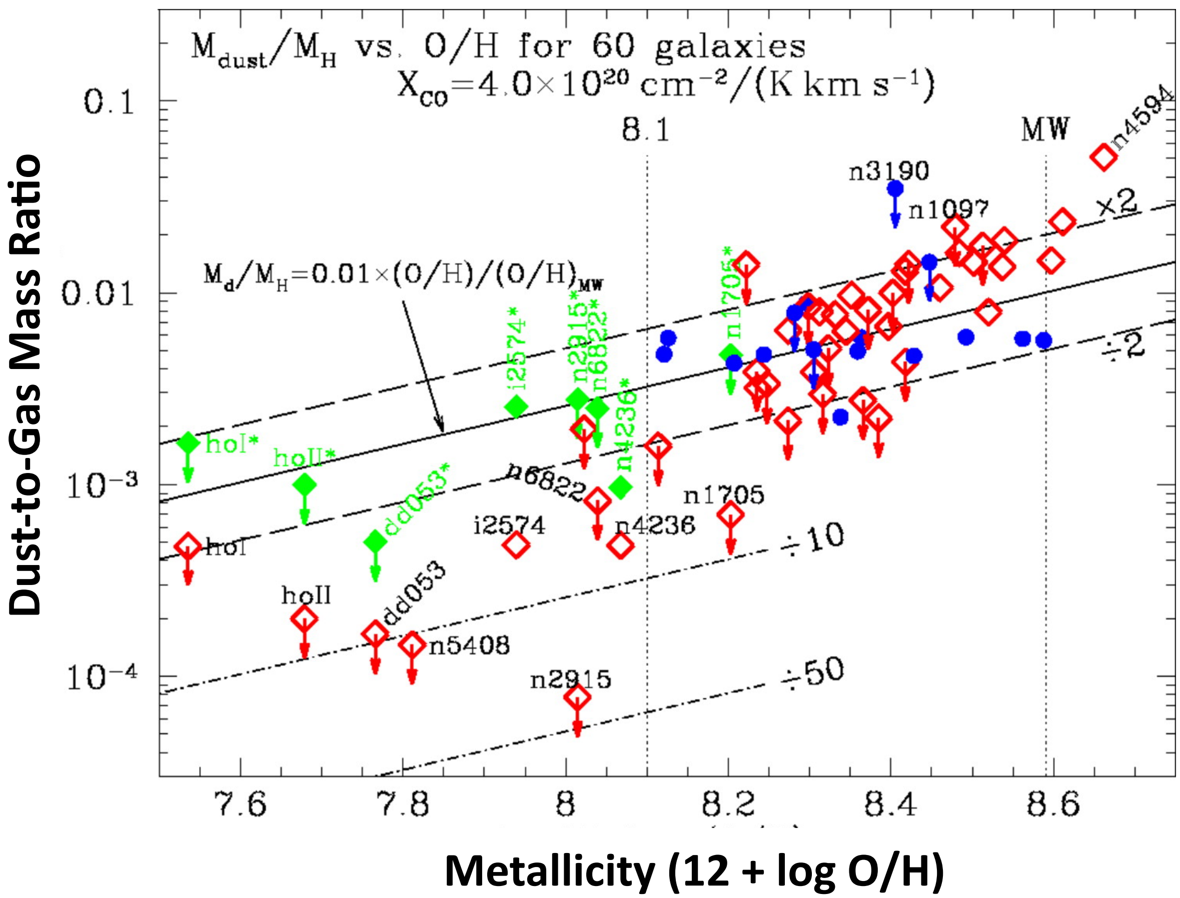


Points: *whole galaxies from wide-net literature trawl*

Semi-Resolved: Dust-Poor Envelopes?

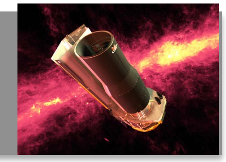


DRAINE ET AL. '07: Aperture definition strongly affects D/G in SINGS dwarfs.

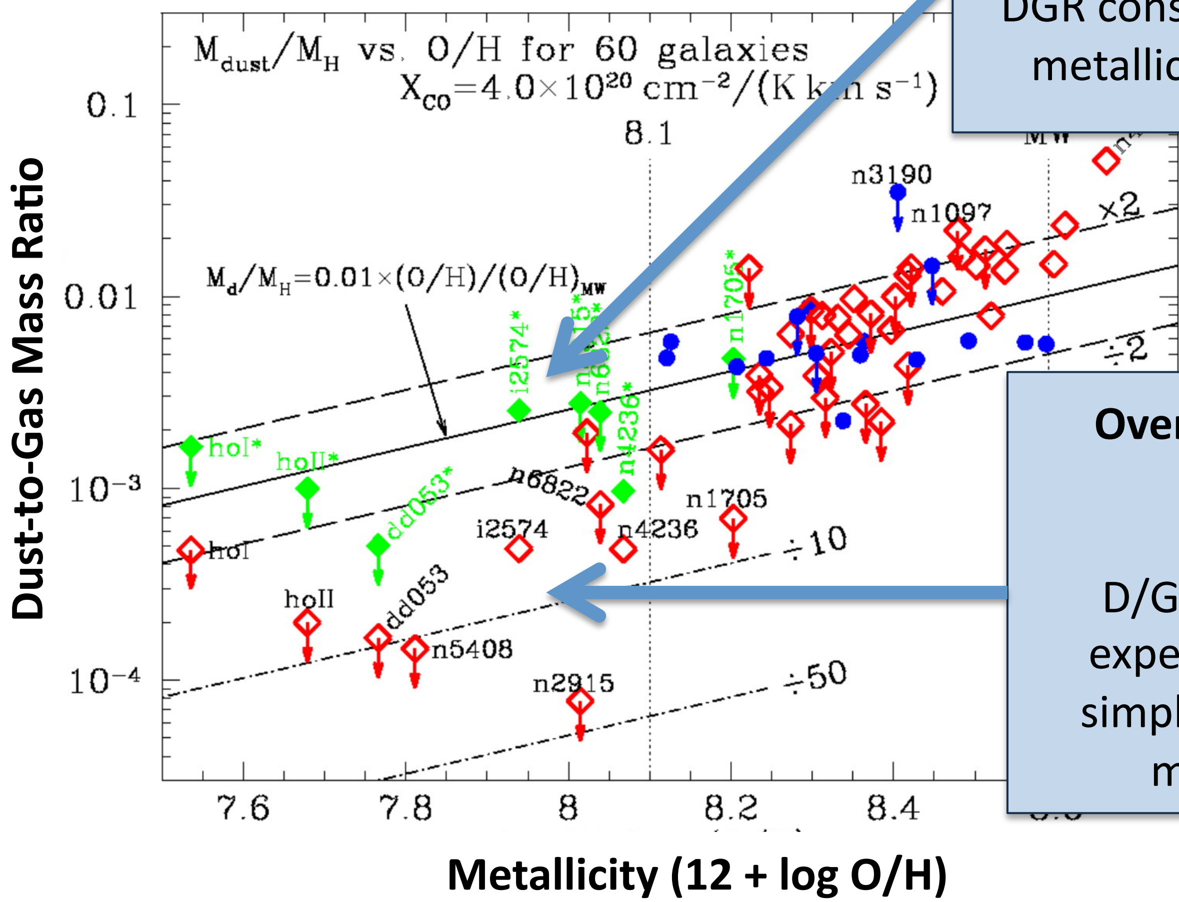


Points: *whole SINGS galaxies but dwarfs treated with varying aperture*

Dust-Poor Envelopes?



DRAINE ET AL. '07: Aperture definition strongly affects D/G i



Only over IR Region

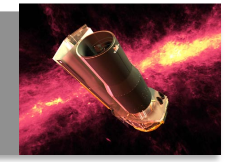
DGR consistent with metallicity trend.

Over the Whole Galaxy

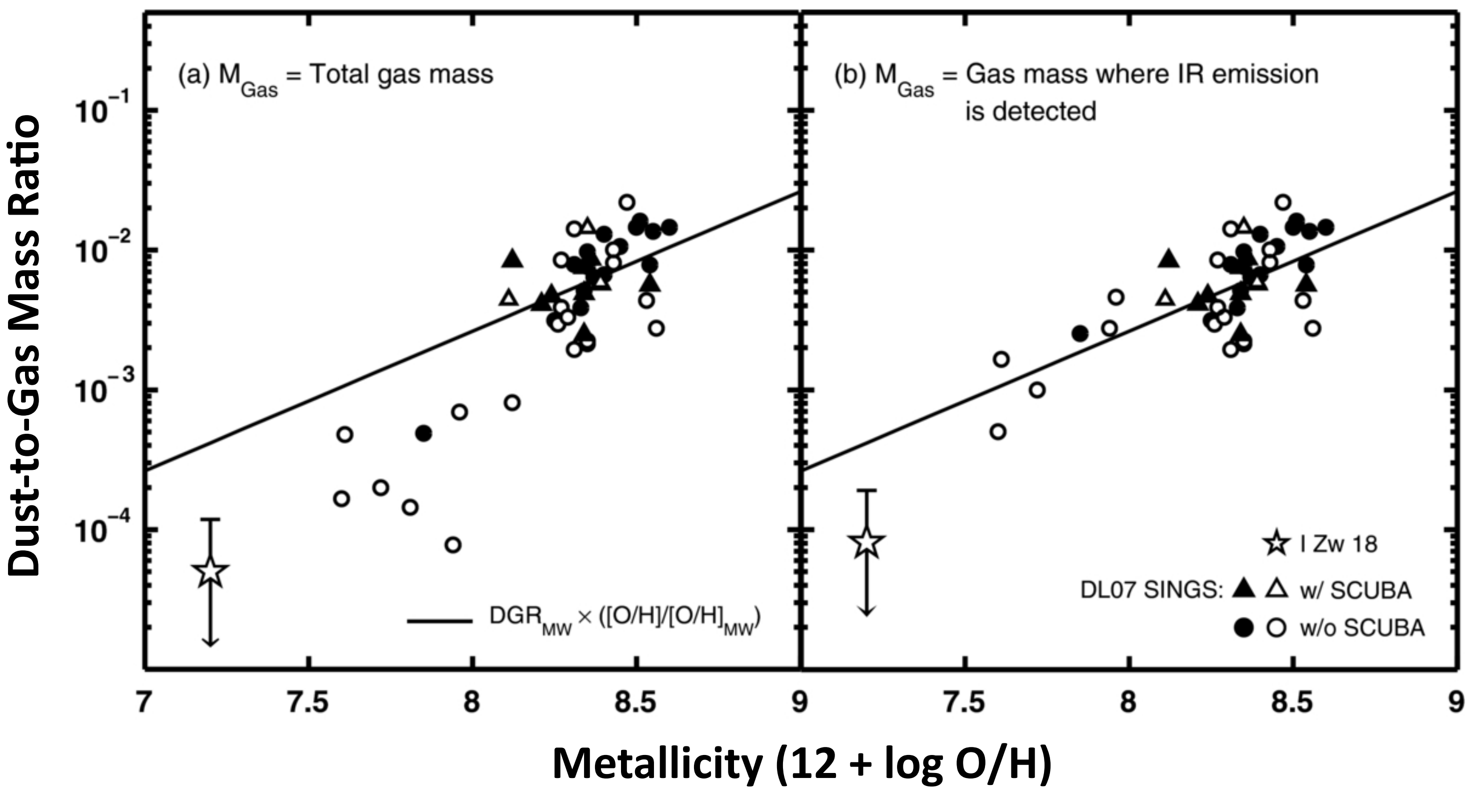
D/G lower than expected given a simple trend with metallicity

Points: *whole SINGS galaxies but dwarfs treated with varying aperture*

But it Does Break… Eventually



HERRERA-CAMUS ET AL. (2012): I Zw 18 upper limit rules out linear D/G vs. z

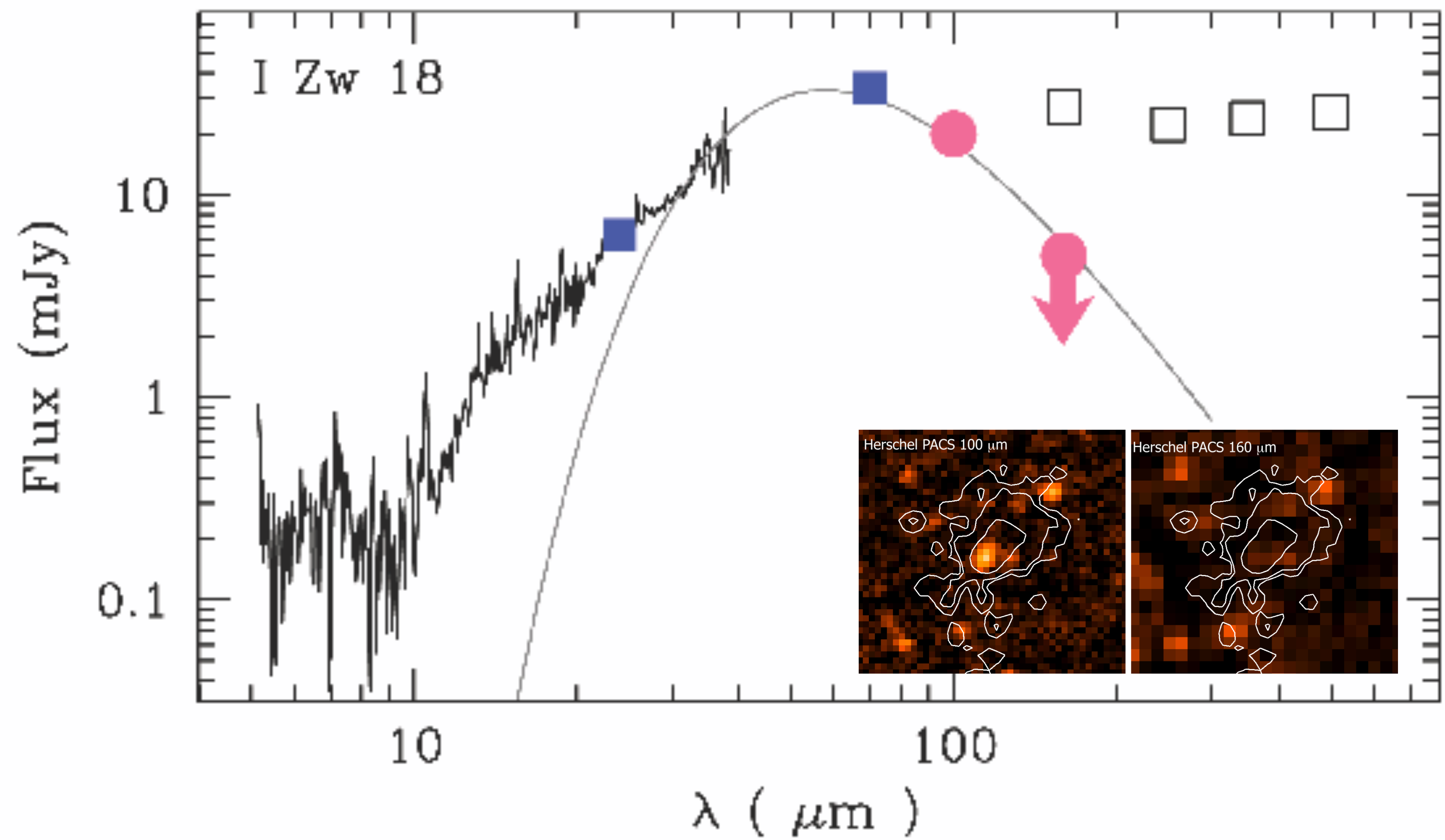


Points: *whole SINGS galaxies + I Zw 18*

D/G

But it Does Break… Eventually

FISHER, BOLATTO ET AL. (IN PREP.): *Herschel* constrains I Zw 18 SED to be very hot ➔ low mass



Points: *SED of the very low-metallicity BCD I Zw 18 (courtesy D. Fisher)*

Dust in Dwarf Galaxies is …

D/G

Less abundant than in spiral galaxies…

… even more than you expect given the metallicity (?)

SED

Dust Spectral Energy Distribution

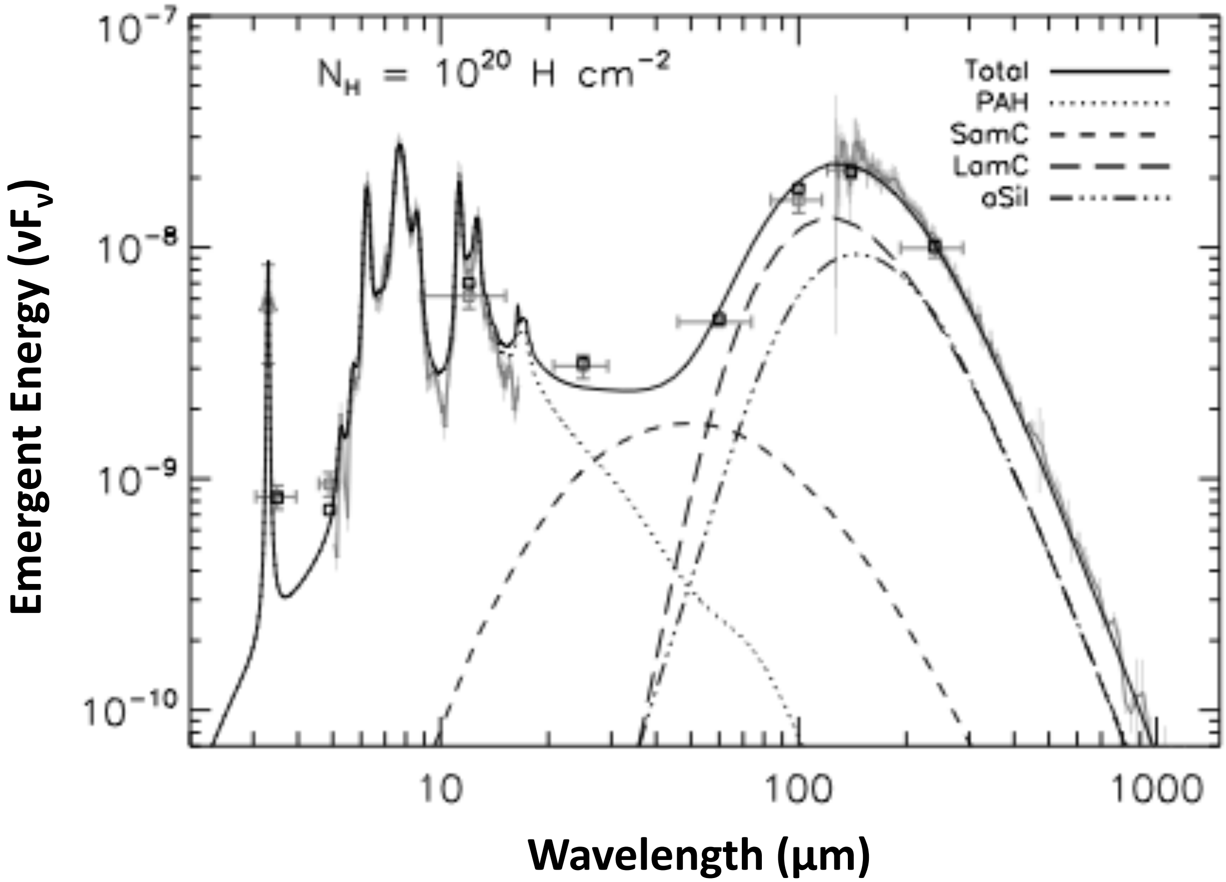
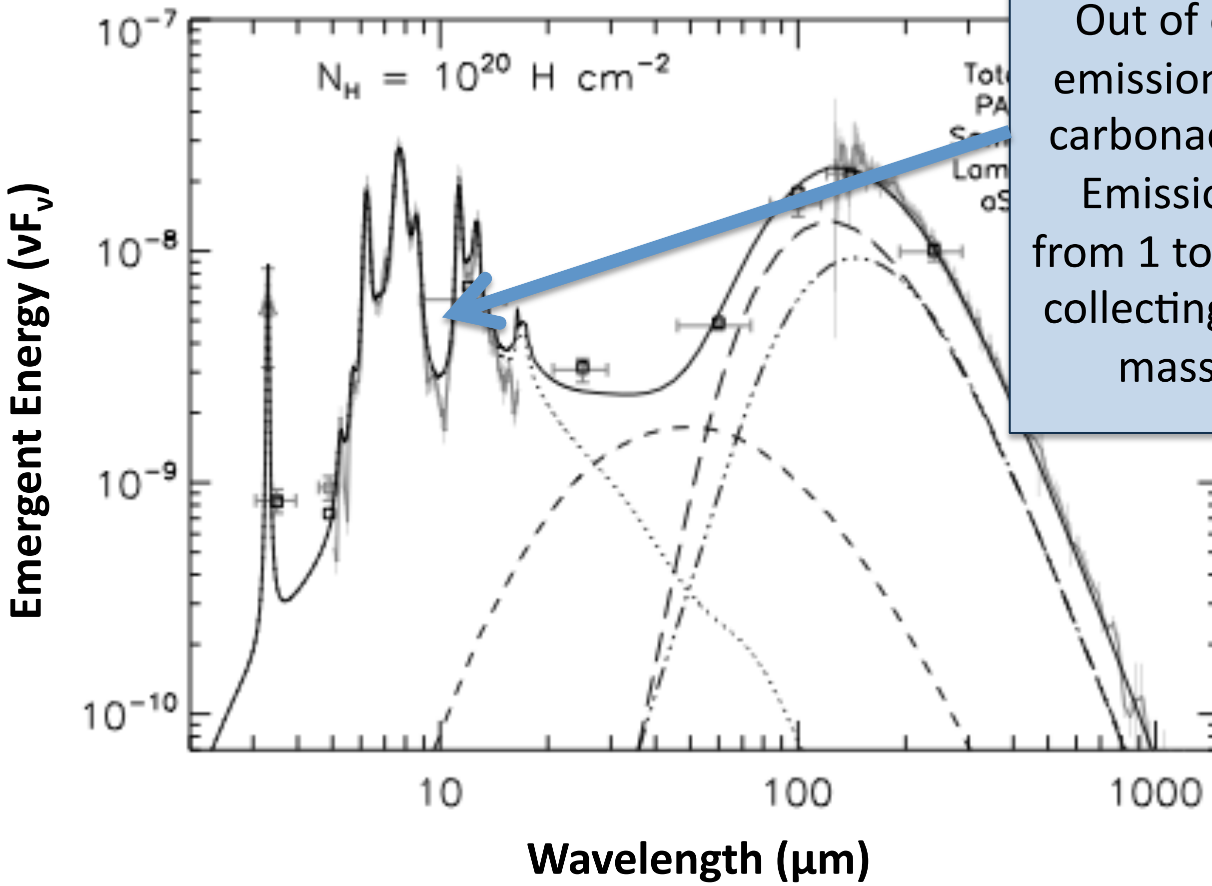


Illustration: *DustEM Model from Compiègne+ `11*

Dust in Dwarf Galaxies



PAH Emission

Out of equilibrium emission from small, carbonaceous grains. Emission in bands from 1 to 20 μm. Large collecting area, minor mass fraction.

Illustration: *DustEM Model from Compiègne+ `11*

Dust Spectral Energy Distribution

Small Grain Emission

Emission from small dust grains out of equilibrium with the ISRF (stochastic heating). Contribute from 10 - 100 μm.

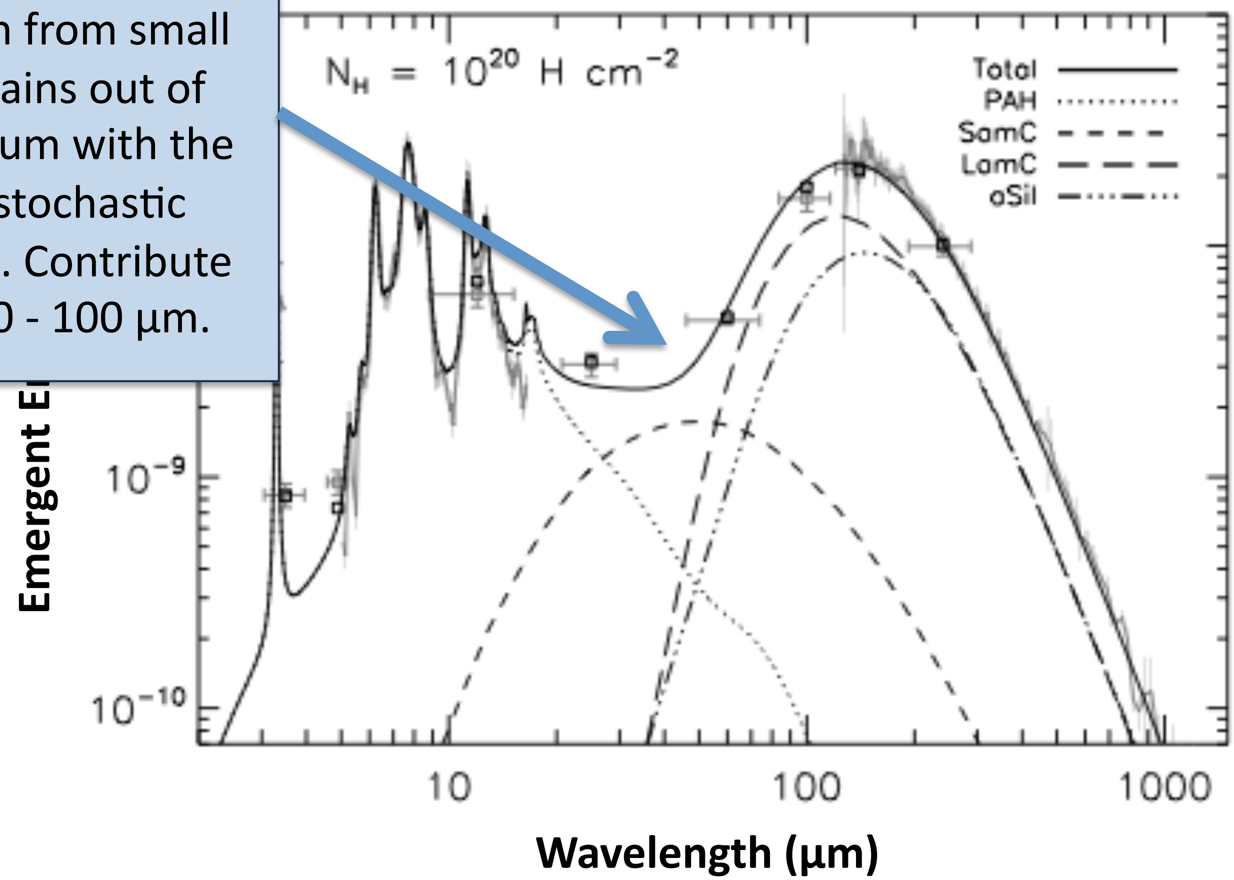
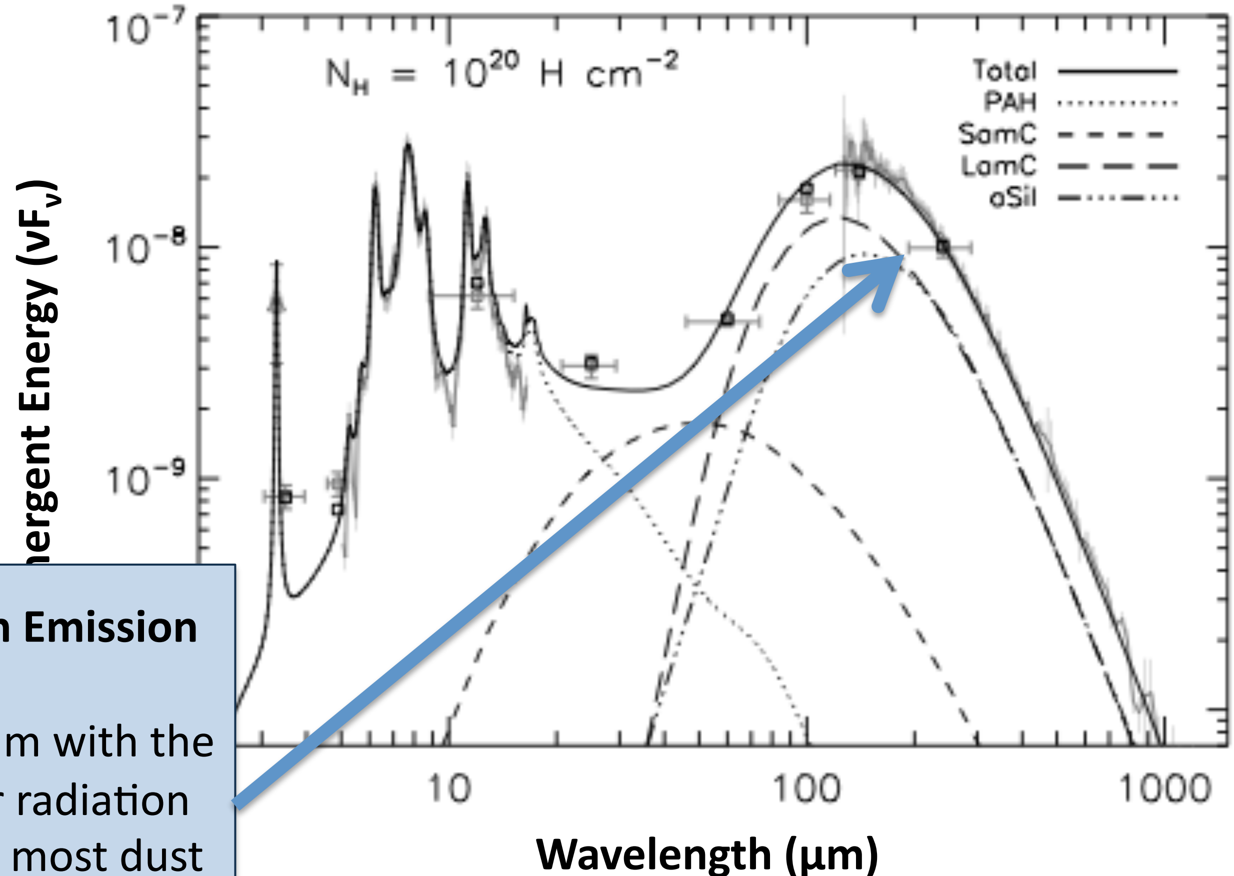


Illustration: *DustEM Model from Compiègne+ `11*

Dust Spectral Energy Distribution



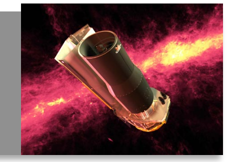
Large Grain Emission

In equilibrium with the interstellar radiation field. Holds most dust mass, dominates above 100 µm.

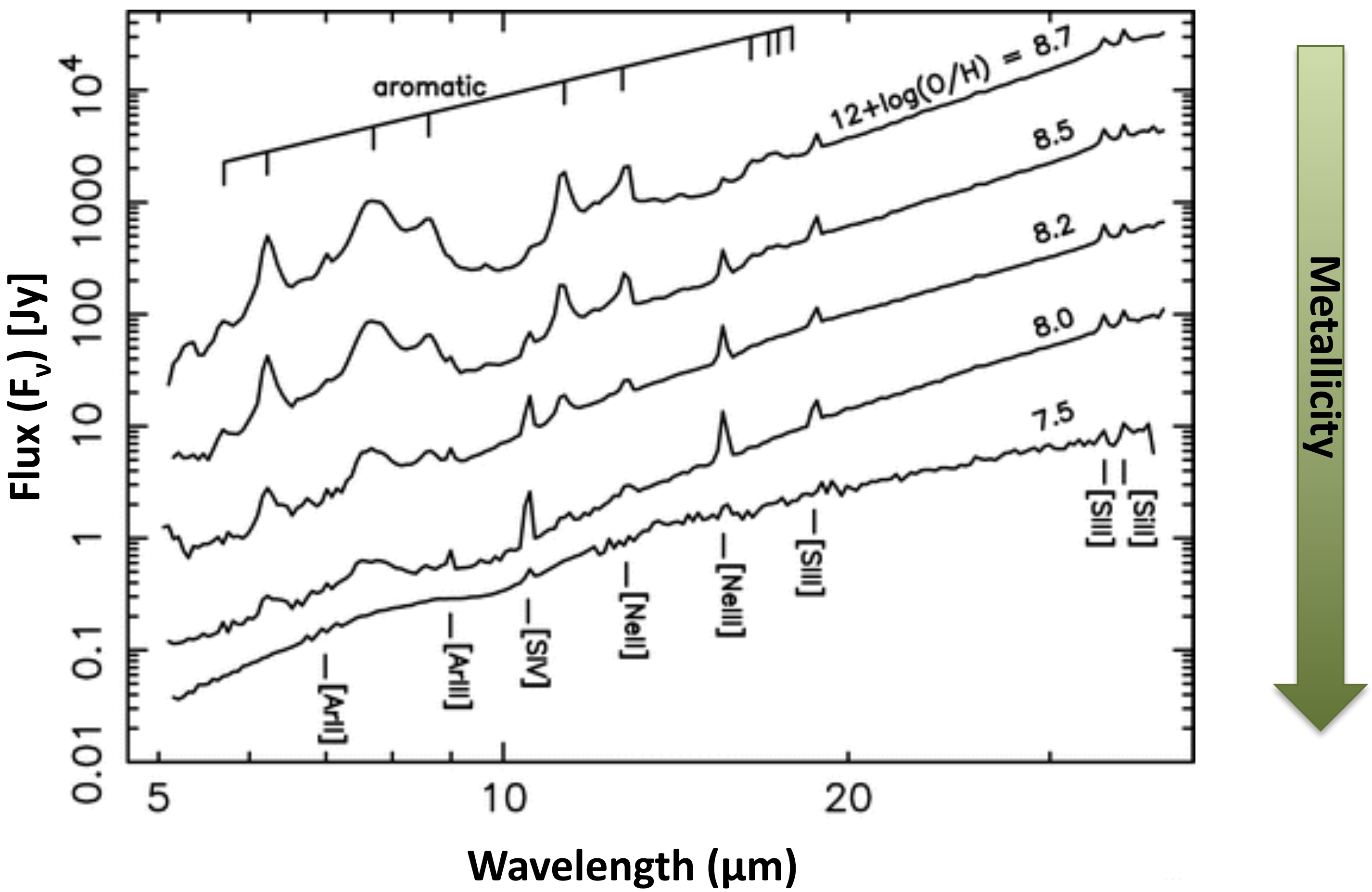
Illustration: *DustEM Model from Compiègne+ `11*

SED

PAH Features vs. Metallicity



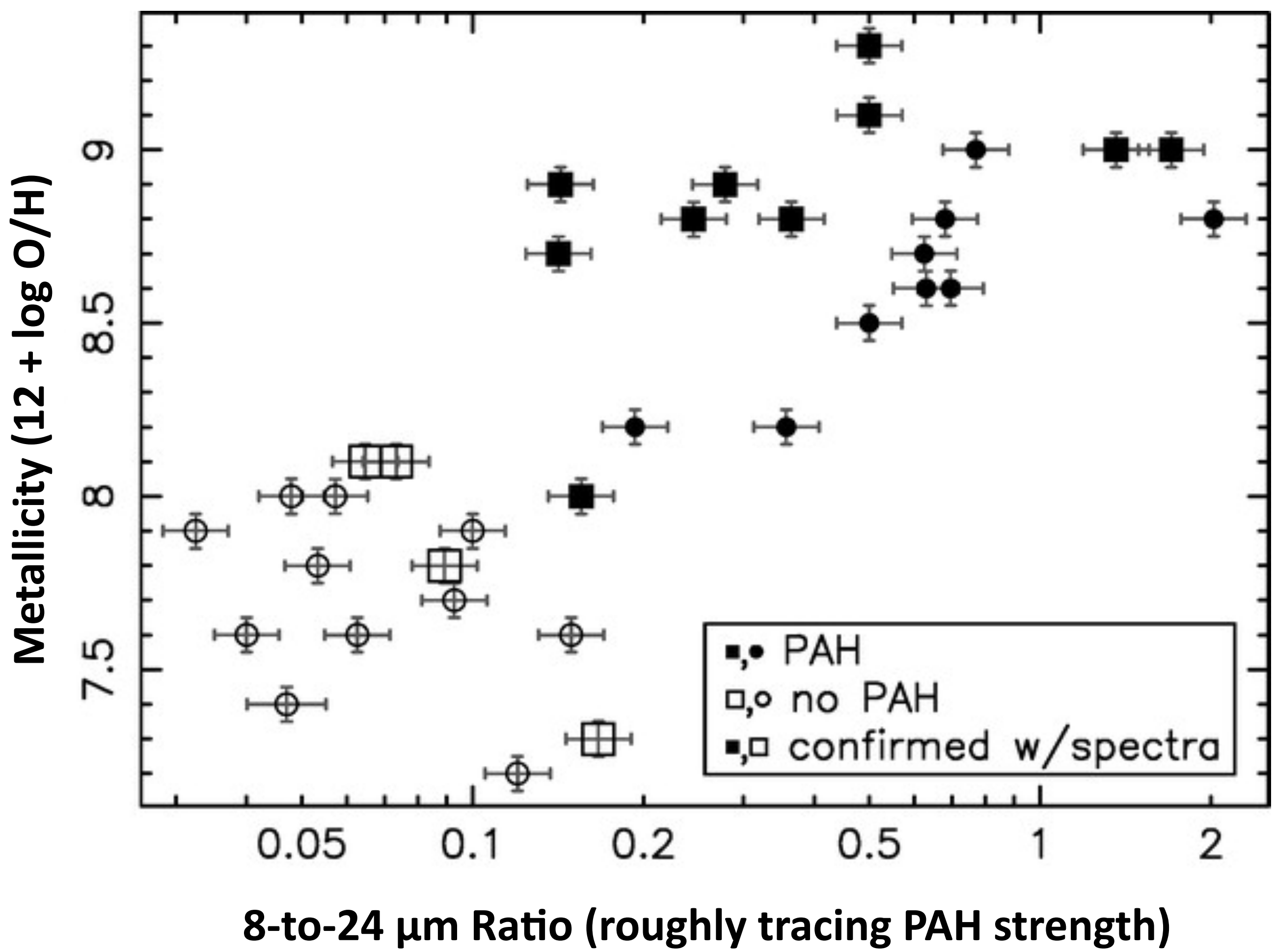
ENGELBRACHT+ `05, `08; MADDEN `06: PAH emission systematically declines with metallicity.



Spectra: *IRS spectra of many galaxies binned and stacked by metallicity.*

PAH Emission vs. Metallicity

ENGELBRACHT+ `05, `08: (Broadband) PAH strength drops around 12+log O/H = 8.2

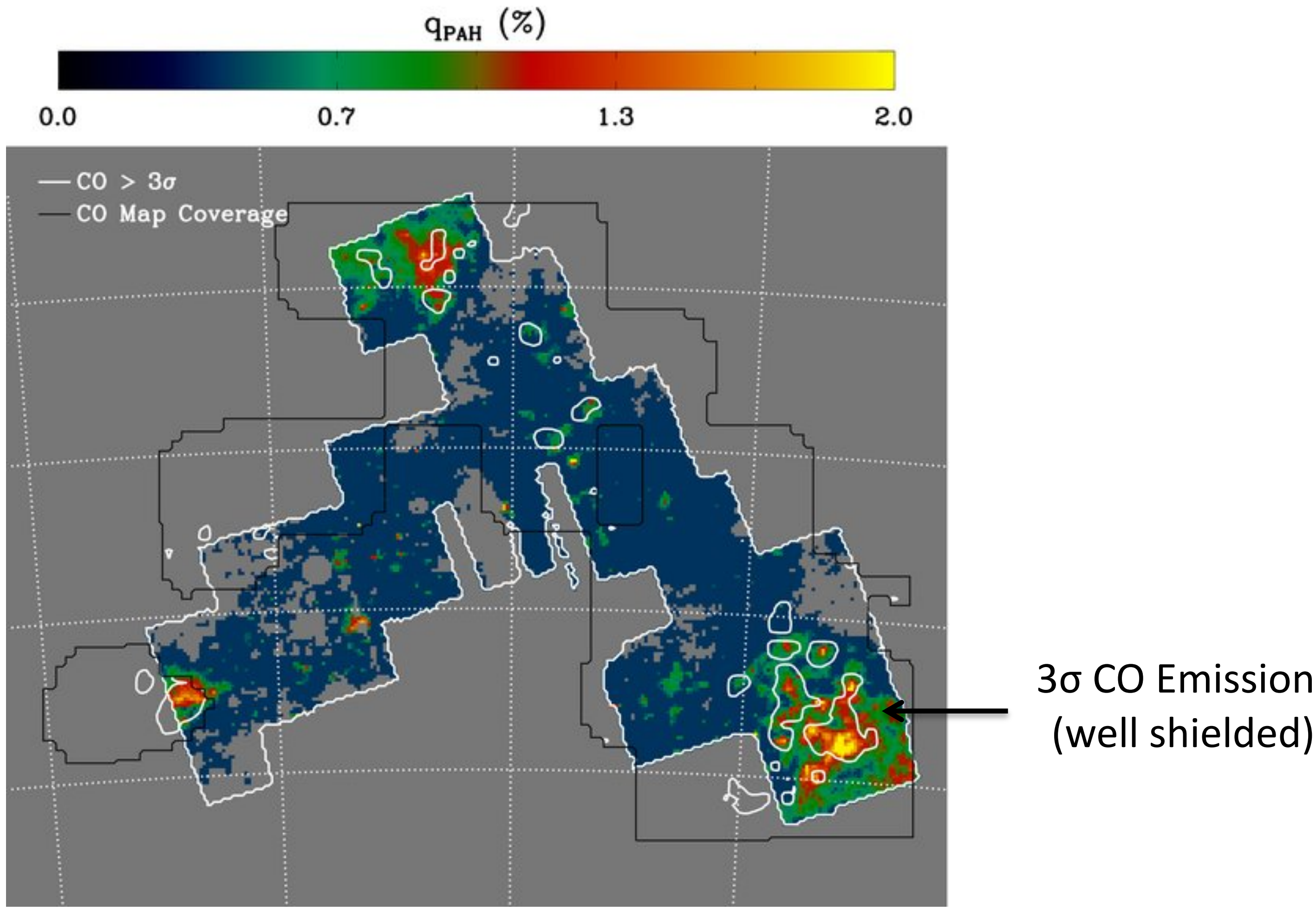


Each point: *one galaxy*

SED

Resolving Suppression of PAHs

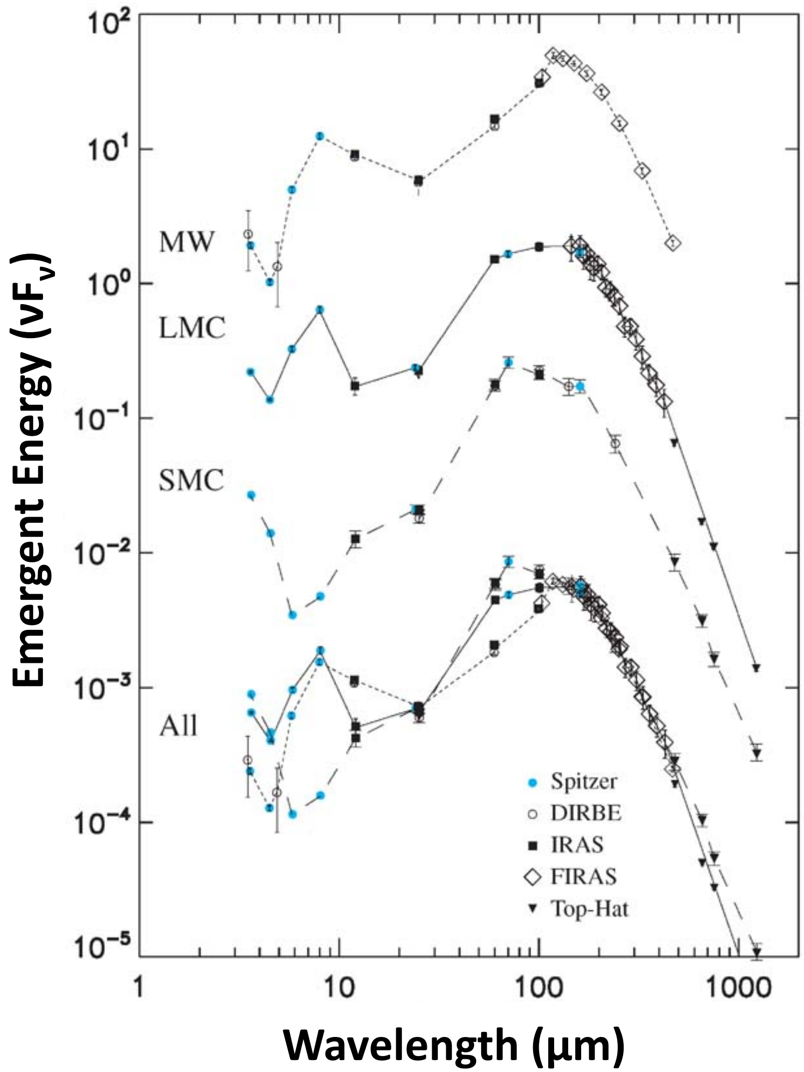
SANDSTROM+ `10: PAHs coincident with CO emission, shielding.



Map: *Local PAH mass fraction (q_{PAH}) in the Small Magellanic Cloud*, **Contour:** *NANTEN CO*

"Bluer" IR-Colors

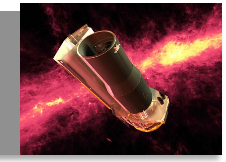
BERNARD+ `08: (M31) ➔ Milky Way ➔ LMC ➔ SMC progressively bluer far-IR color.



Spectra: *SEDs of Milky Way, LMC, SMC*

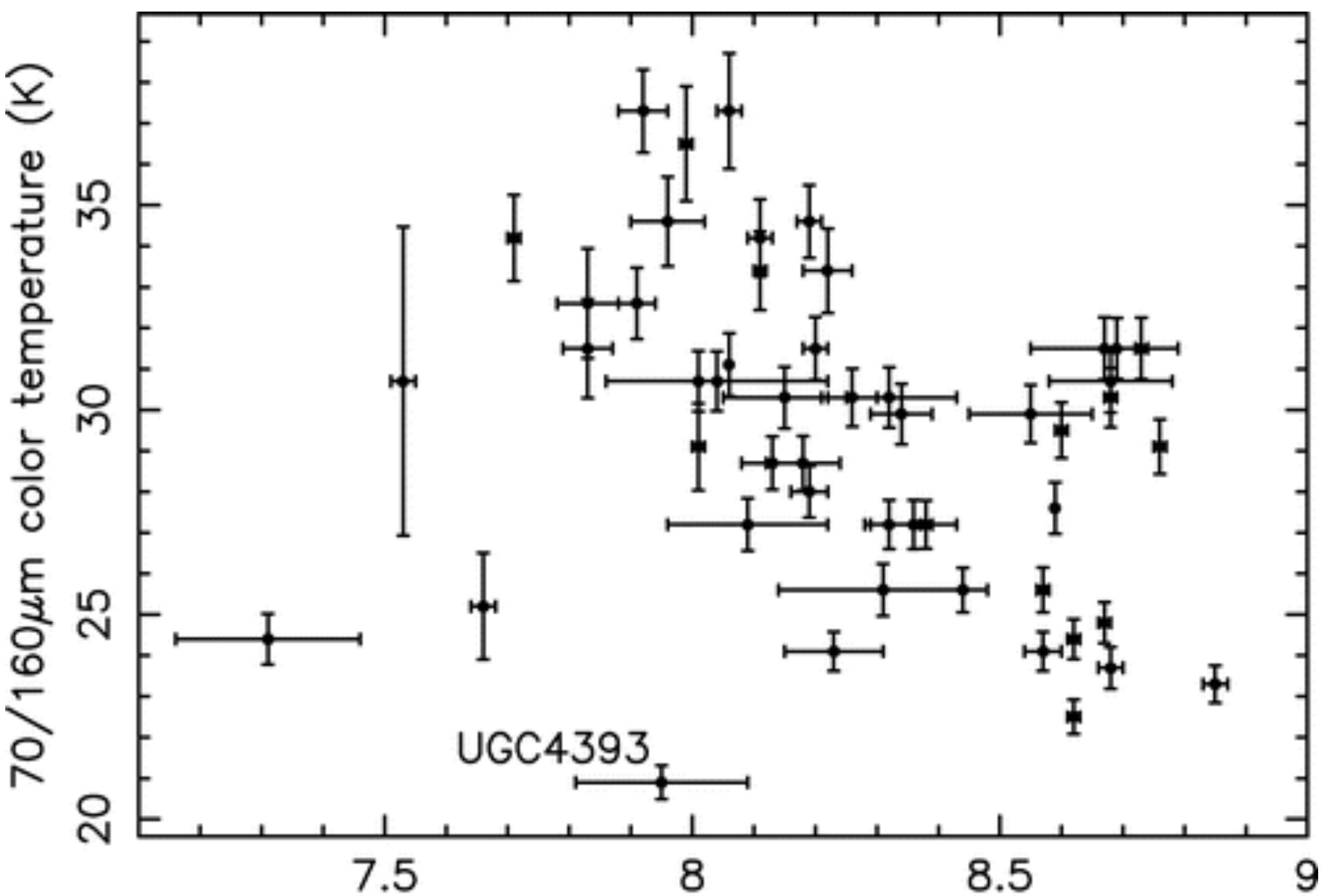
SED

“Bluer” IR Colors



ENGELBRACHT+ `05: 70/160 color correlates with metallicity. Temperature? Smaller grains?

70-to-160 μm Ratio
(Temperature or VSG Contribution)

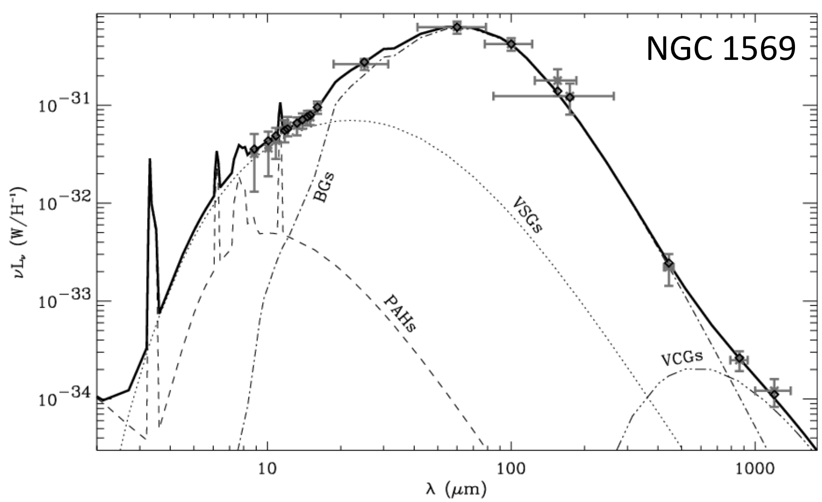


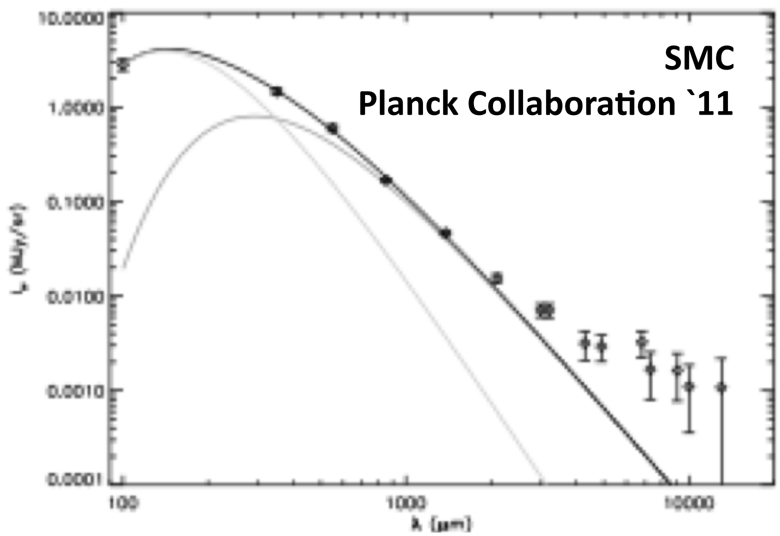
Metallicity (12 + log O/H)

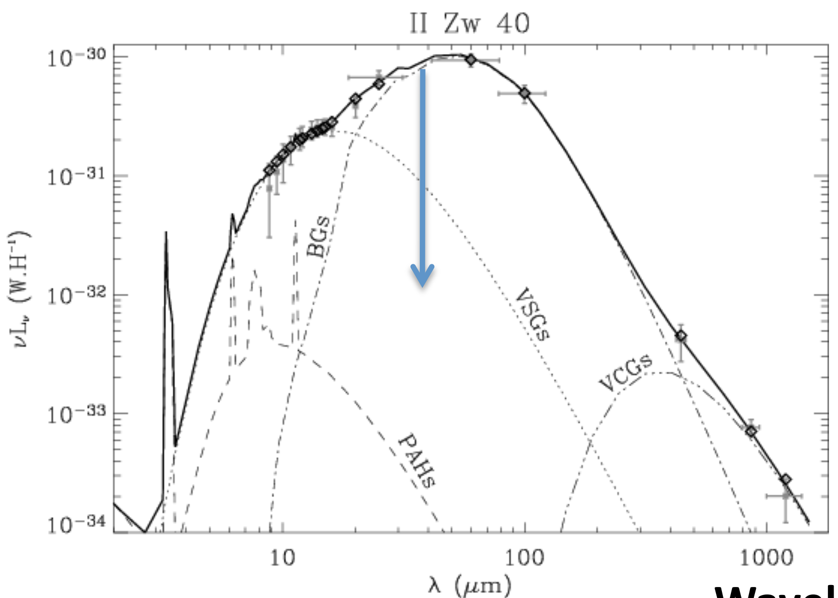
Points: *Individual galaxies*

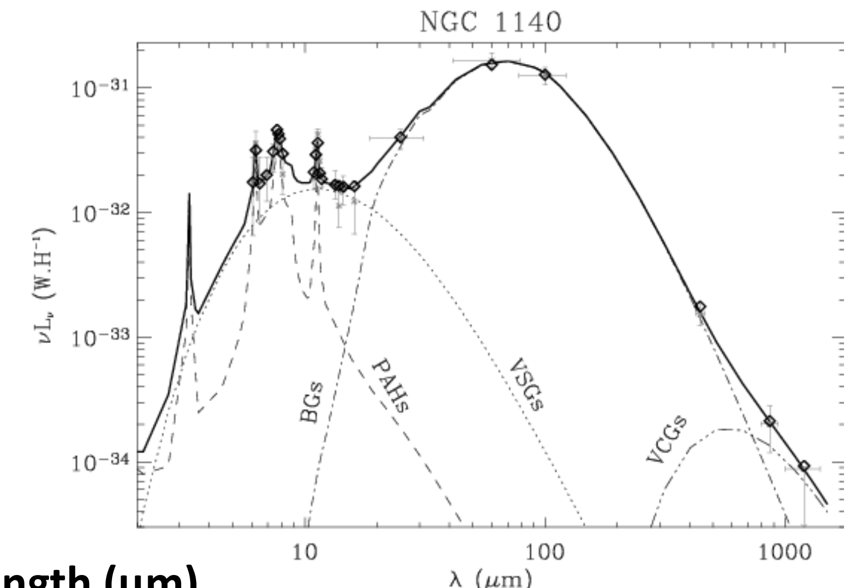
SED — Long Wavelength Emission

GALLIANO+ `03,`05, GALAMETZ `09: mm emission from dwarfs higher than expected for β=2.
… Planck Collaboration `11 … these extend to longer wavelengths.in the SMC









Wavelength (μm)

Long Wavelength Emission

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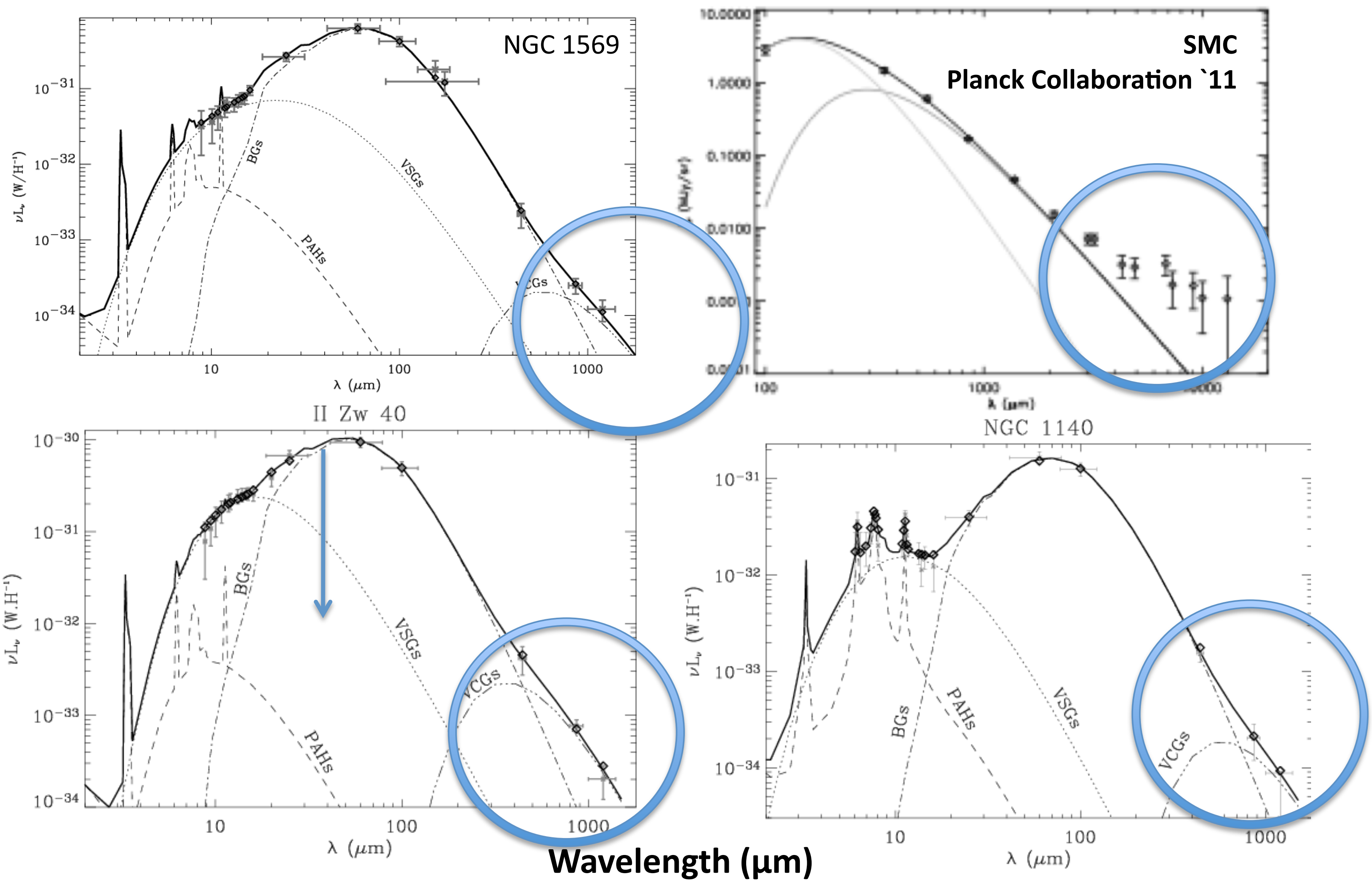
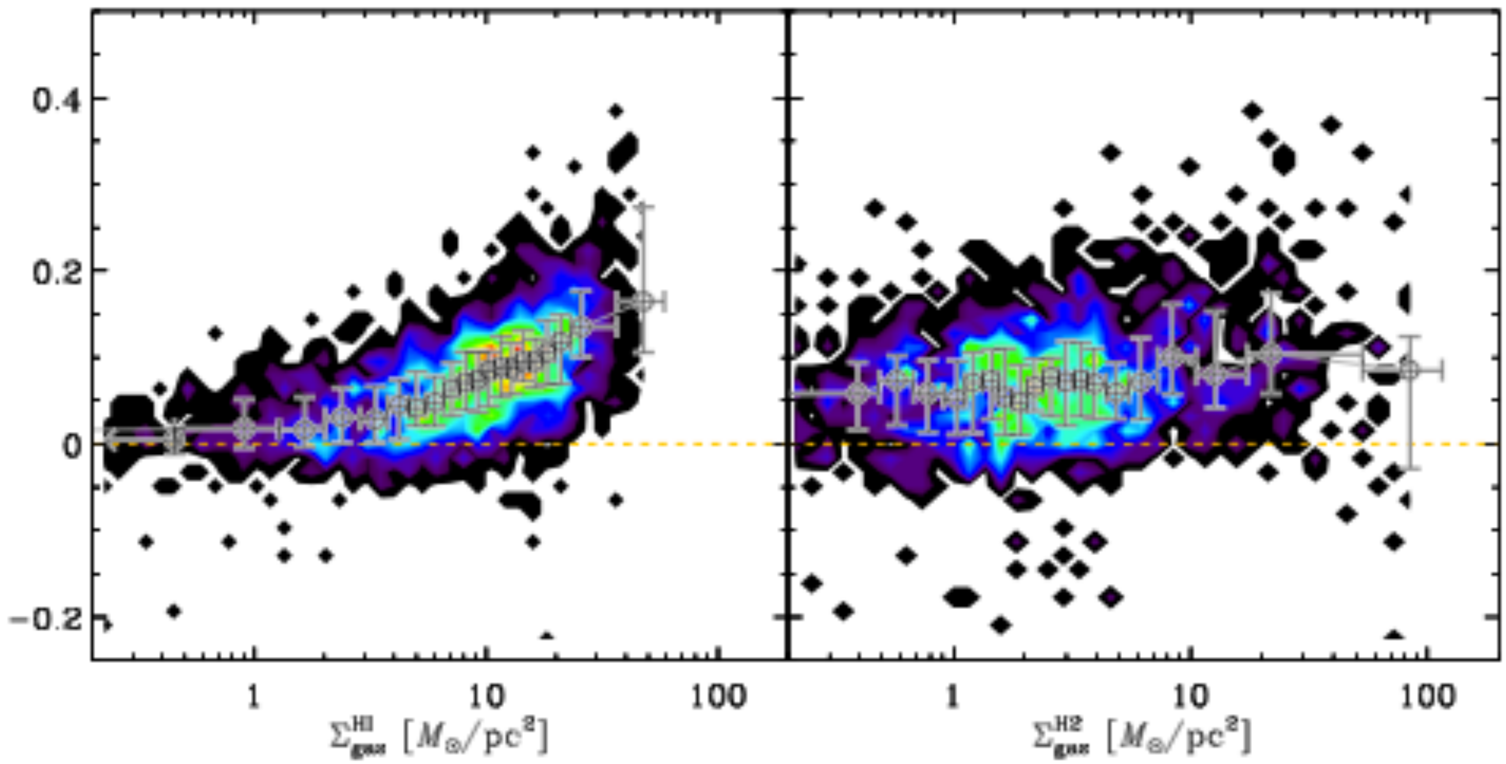


Long Wavelength Emission

GALLIANO+ `11: Large Magellanic Cloud … sub-mm excess not correlated with H_2

Excess Emission Above Standard Fit to SED in SPIRE 500 μm Band



HI Surface Density

H_2 Surface Density

Contours: *Data distribution for excess measured line of sight by line of sight in the LMC*

Dust in Dwarf Galaxies is …

SED

The dust that is present is **deficient in PAHs**…

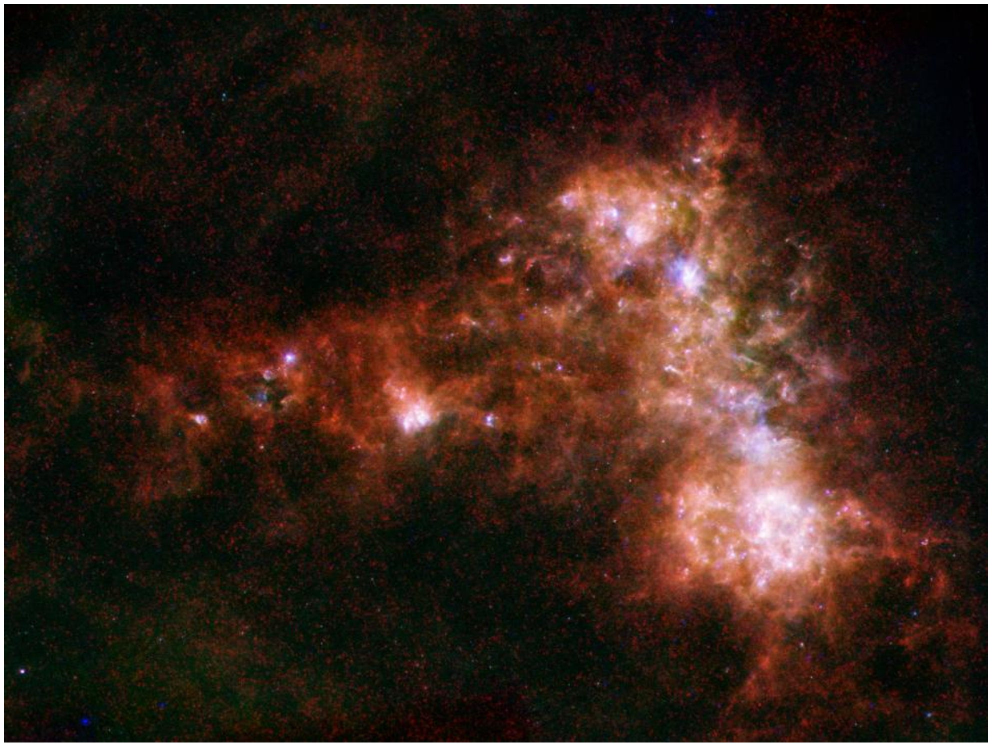
… **rich in small grains** (and/or hotter) …

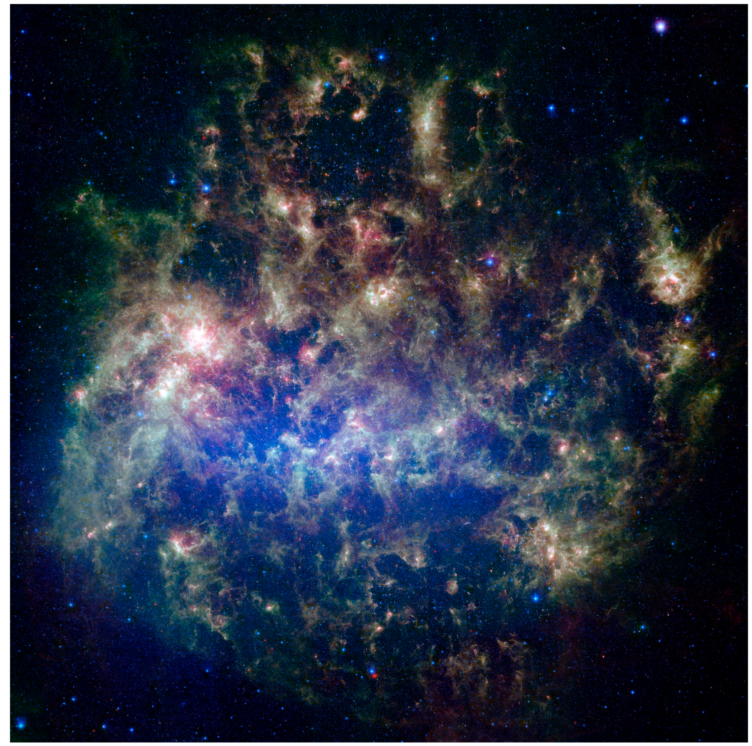
… and **exhibits a mysterious long-wavelength excess**.

ISM

Dust as an ISM Tracer

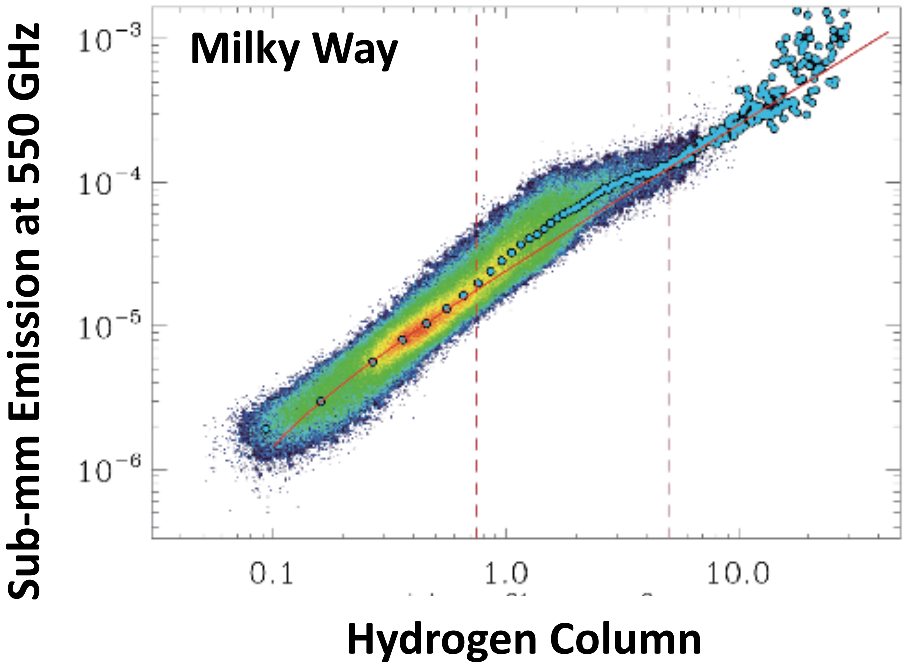
HERITAGE, SAGE, SAGE-SMC: Dust maps are ISM maps…

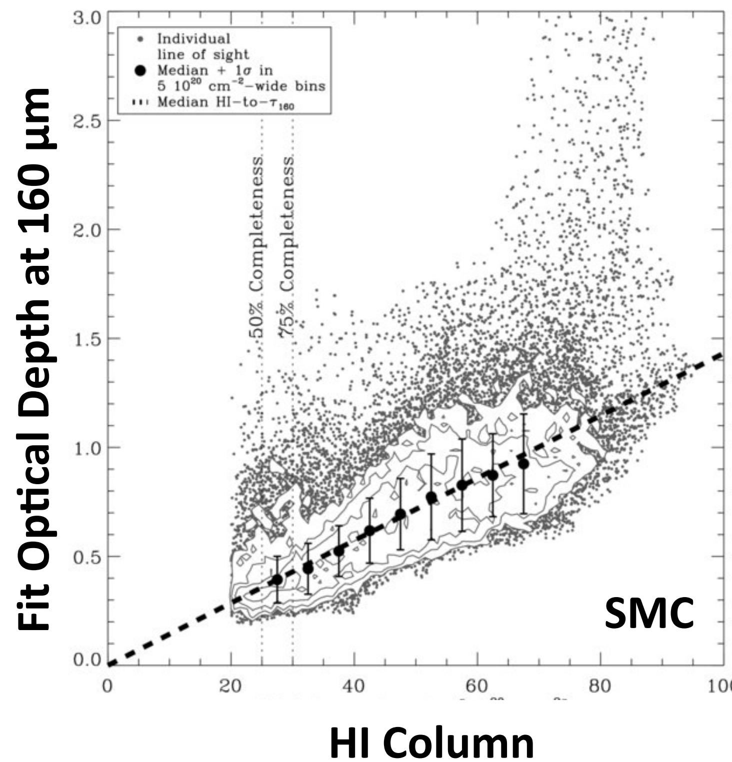




Dust as an ISM Tracer

PLANCK COLLABORATION+ `11, LEROY+ `09: Correlation of dust emission, H in MW, SMC





Data: *IR or sub-mm emission vs. gas column for individual lines of sight*

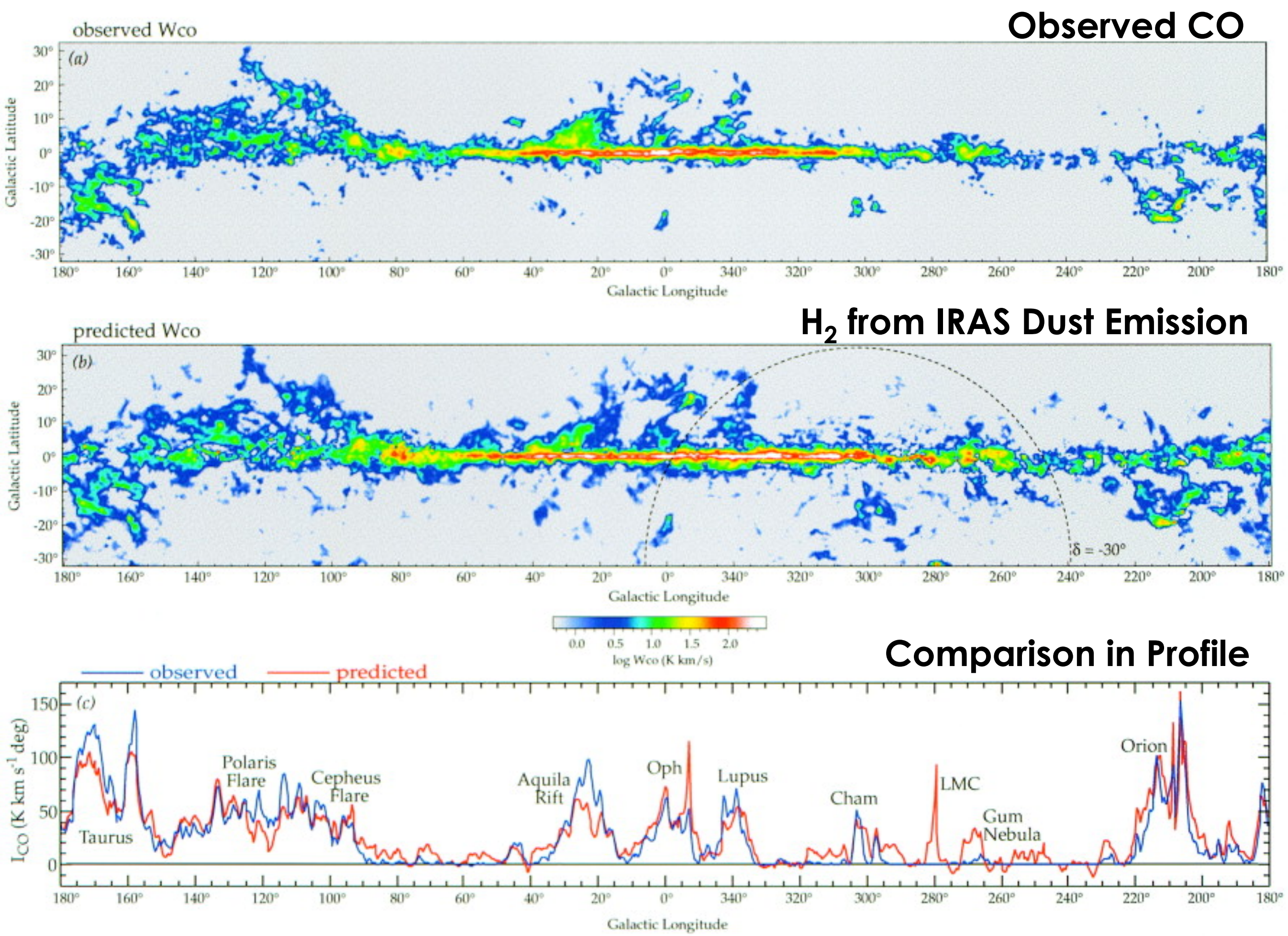
Dust as an ISM Tracer

- Dust traces the total (HI + H_2) gas column
- Estimate dust from IR emission, measure HI
- Get gas-to-dust ratio by comparison with HI

$$\Sigma_{H2} = (\Sigma_{dust} \times \text{GDR}) - \Sigma_{HI}$$

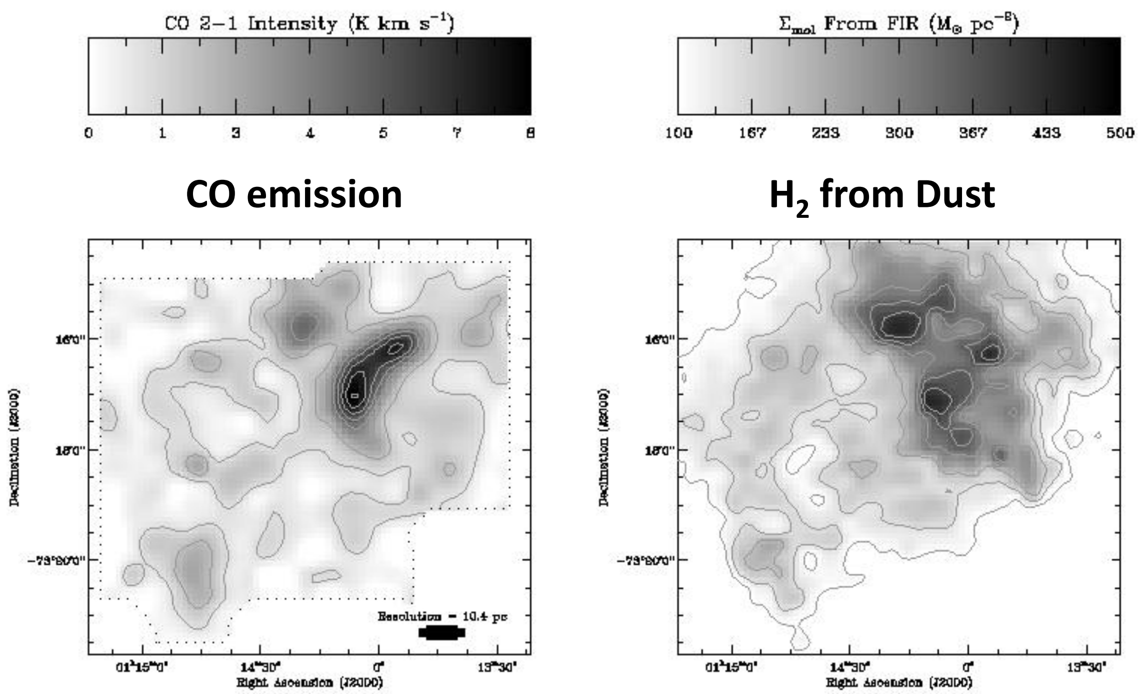
Dust as an ISM Tracer

DAME+ `01: Works to match CO distribution in Milky Way



Dust as an ISM Tracer

LEROY+ `09: Reveals similar structure to CO mapping on small scales (10 pc) in SMC.



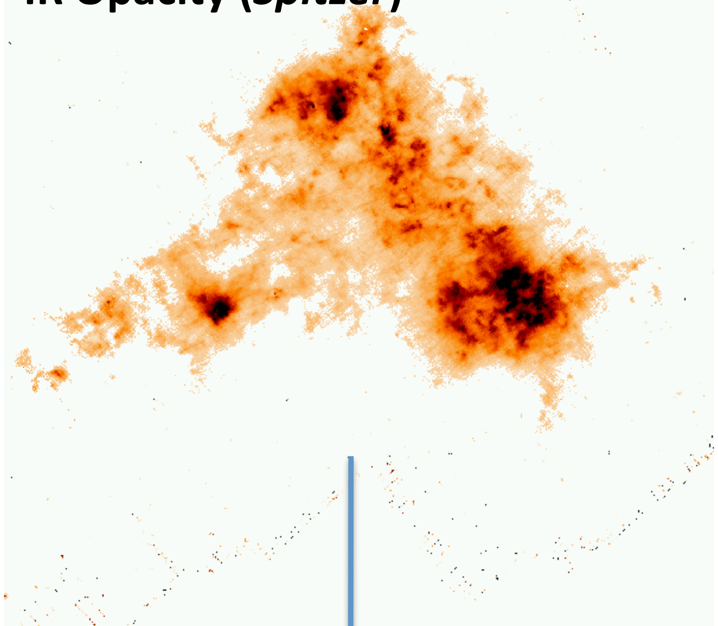
Maps: *CO (left) and H2 estimated from IR emission (right) in the SMC star-forming complex N83/N84*

ISM

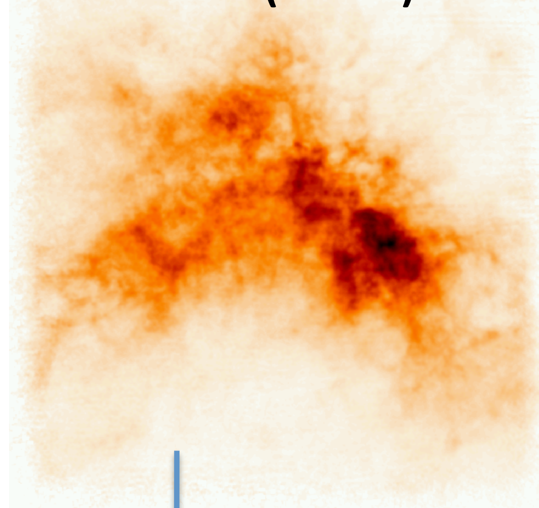
Dust as an ISM Tracer

BOLATTO+ `11, LEROY+ `07: Combine IR imaging, HI to infer H_2 distribution in the SMC

IR Opacity (*Spitzer*)



Atomic Gas (21-cm)

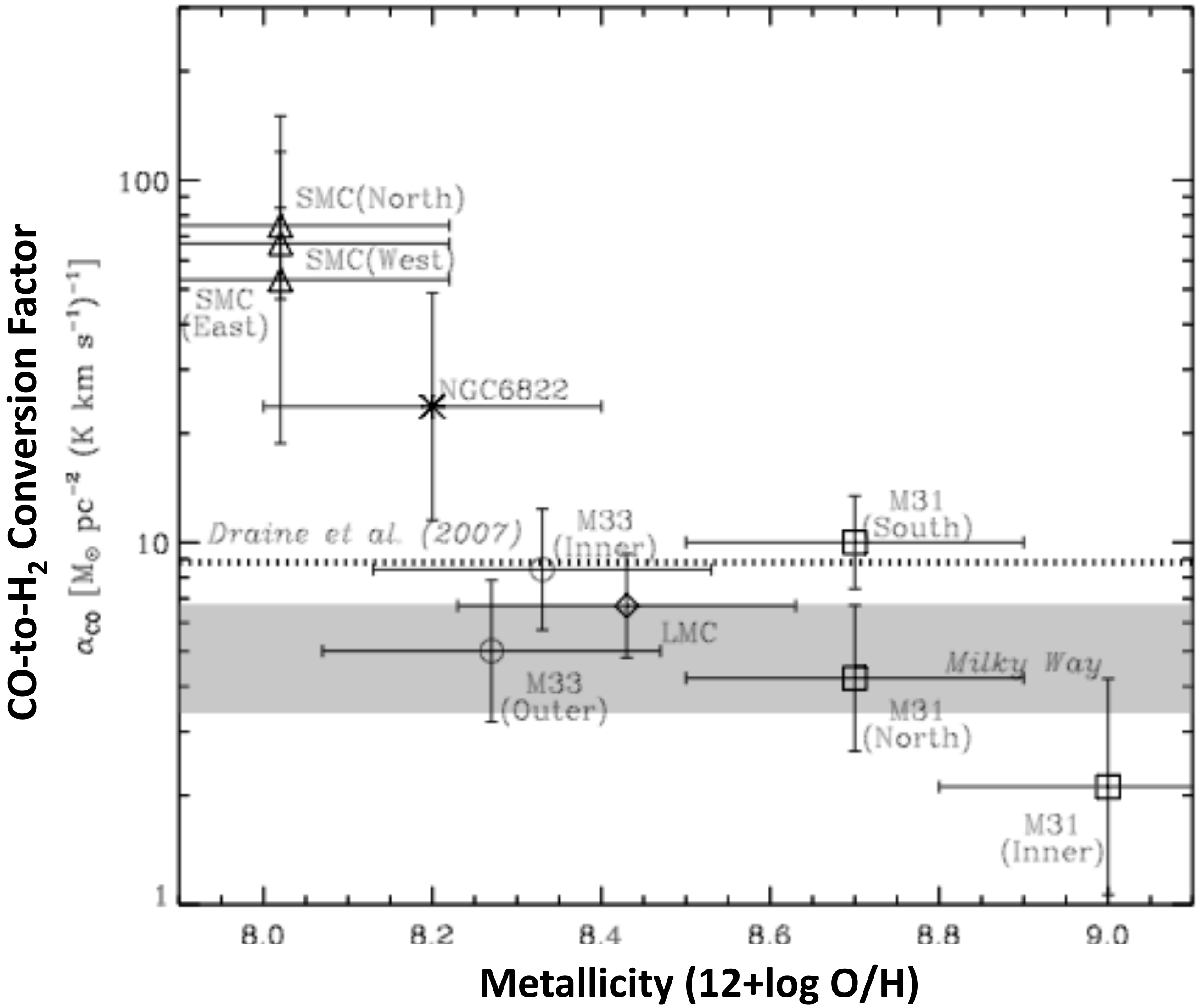


$$\Sigma_{H2} = (\Sigma_{dust} \times GDR) - \Sigma_{HI}$$

Molecular Gas

Dust as an ISM Tracer

LEROY+ `11: Conversion factor rises sharply at low metallicity. Dust a good alternative…



Points: *Dust-driven solutions for the conversion factor in parts of Local Group galaxies*

Dust in Dwarf Galaxies is …

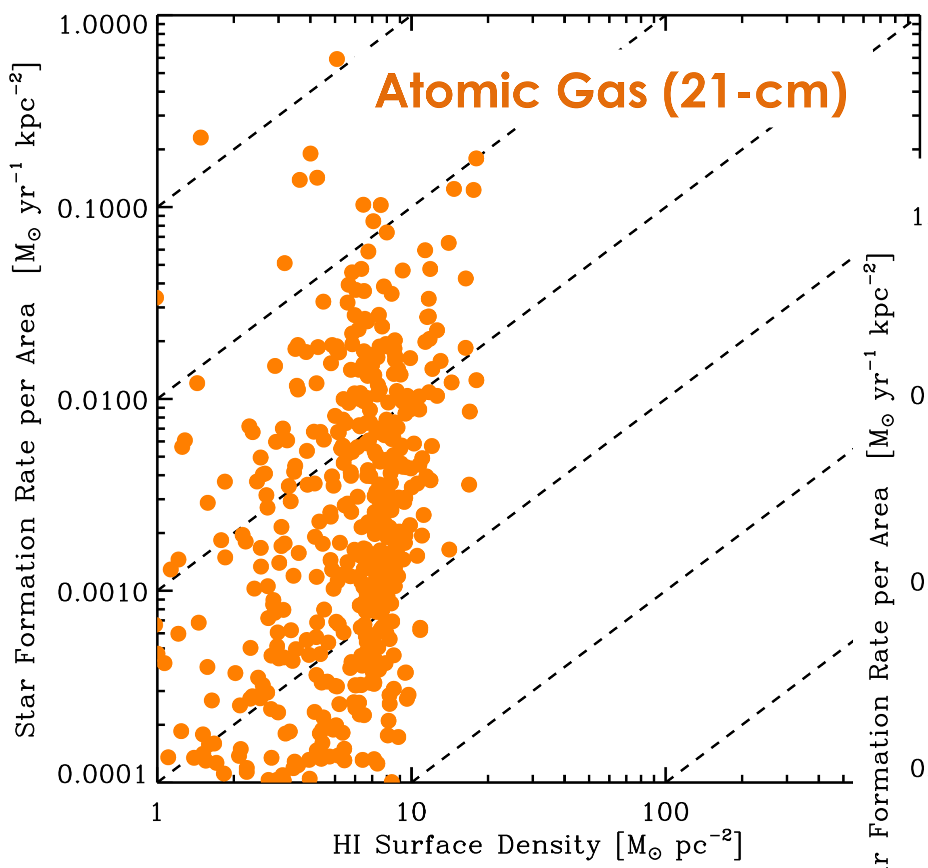
ISM

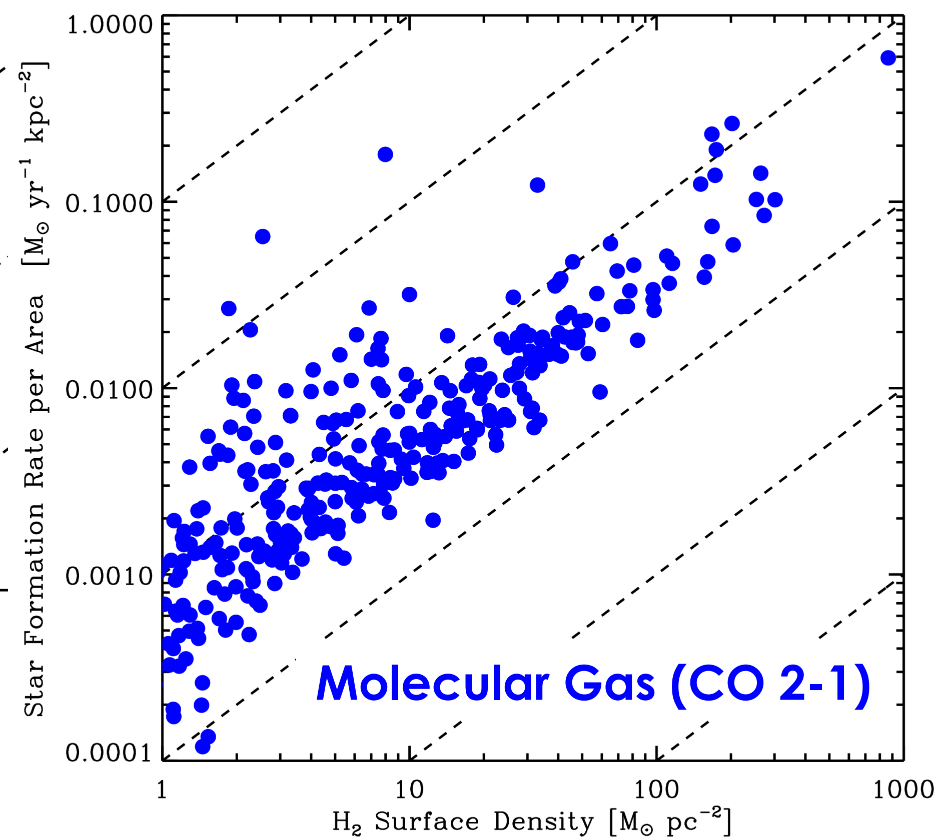
This dust is mixed with gas, making it an **ISM tracer…**

… especially useful for hard-to-see **molecular gas.**

Dust as a Star Formation Regulator

SCHRUBA+ `11: Correlation of star formation with molecular and atomic gas



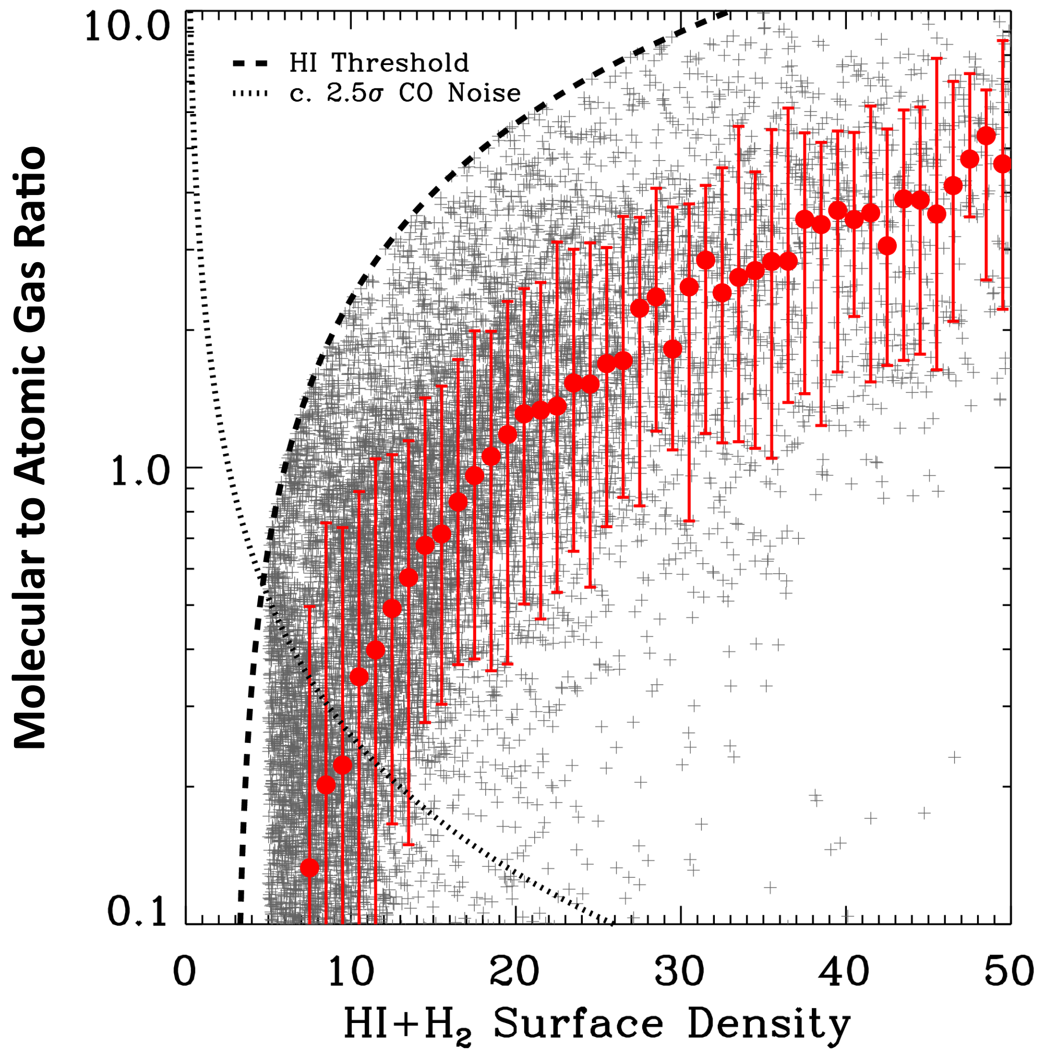


Points: *Rings (azimuthal averages) in 30 disk galaxies*

SFR

Dust as a Star Formation Regulator

LEROY+HERACLES/KINGFISH (IN PREP.): Molecular to atomic ratio follows gas surface density.



Points: *kpc-resolution lines of sight in 22 disk galaxies*

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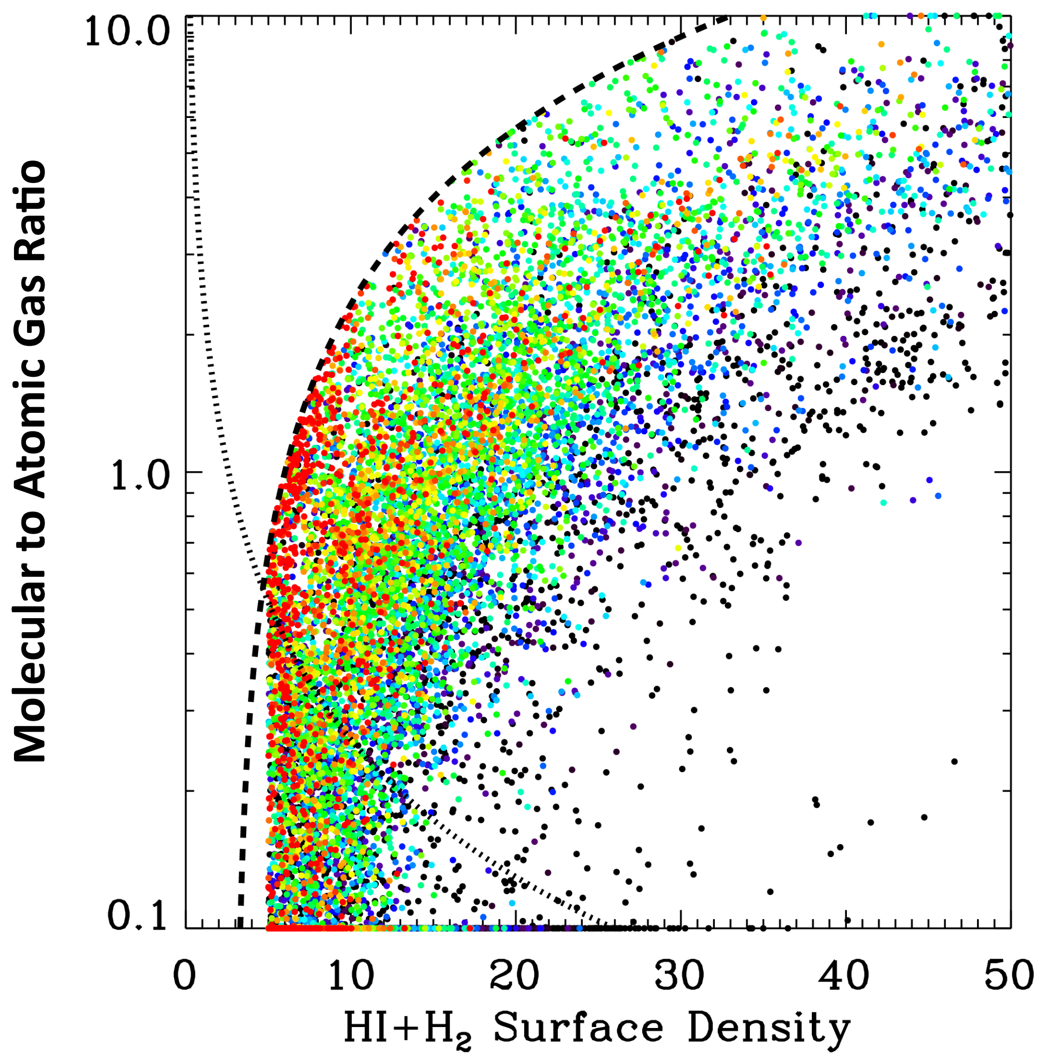

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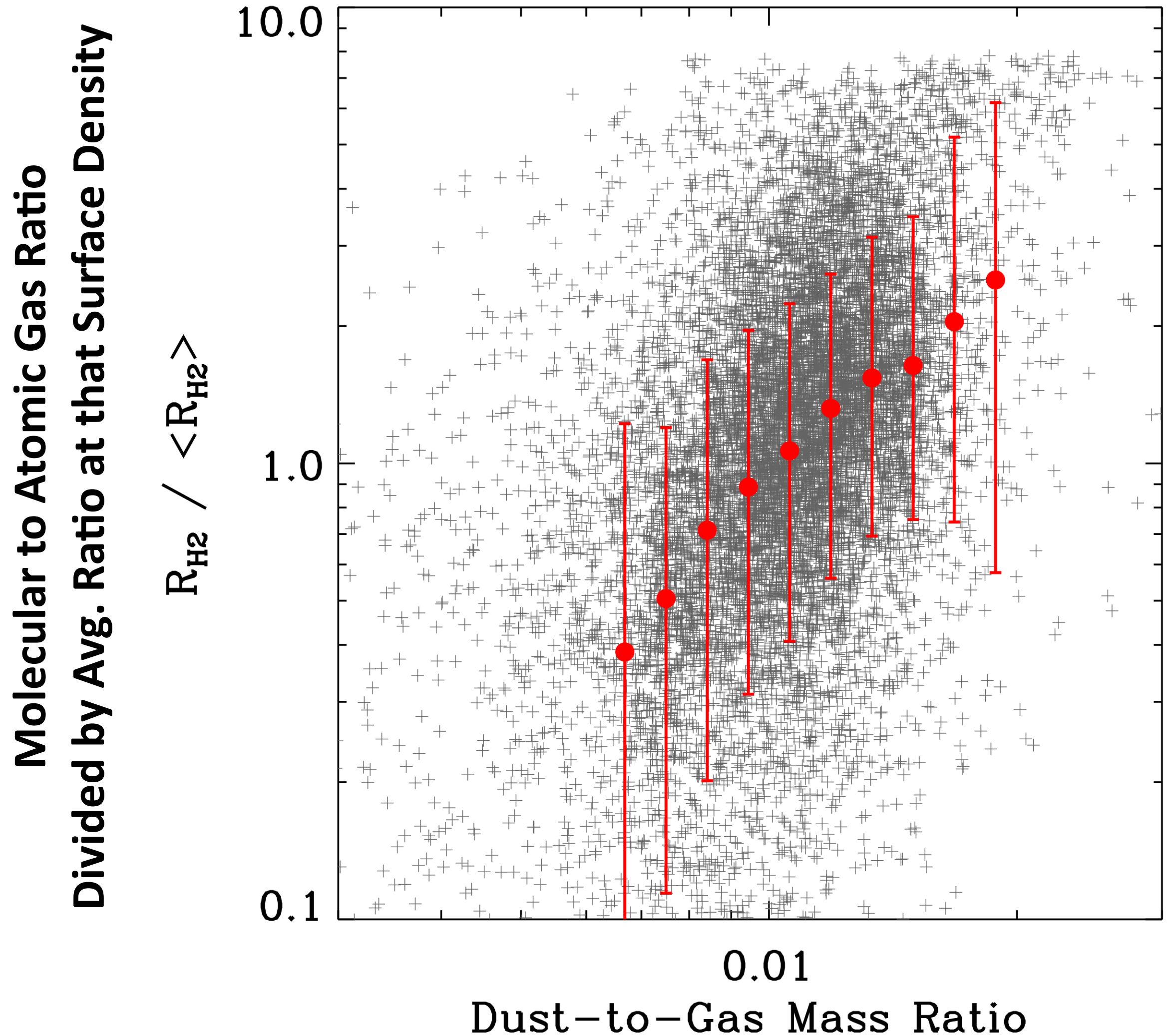

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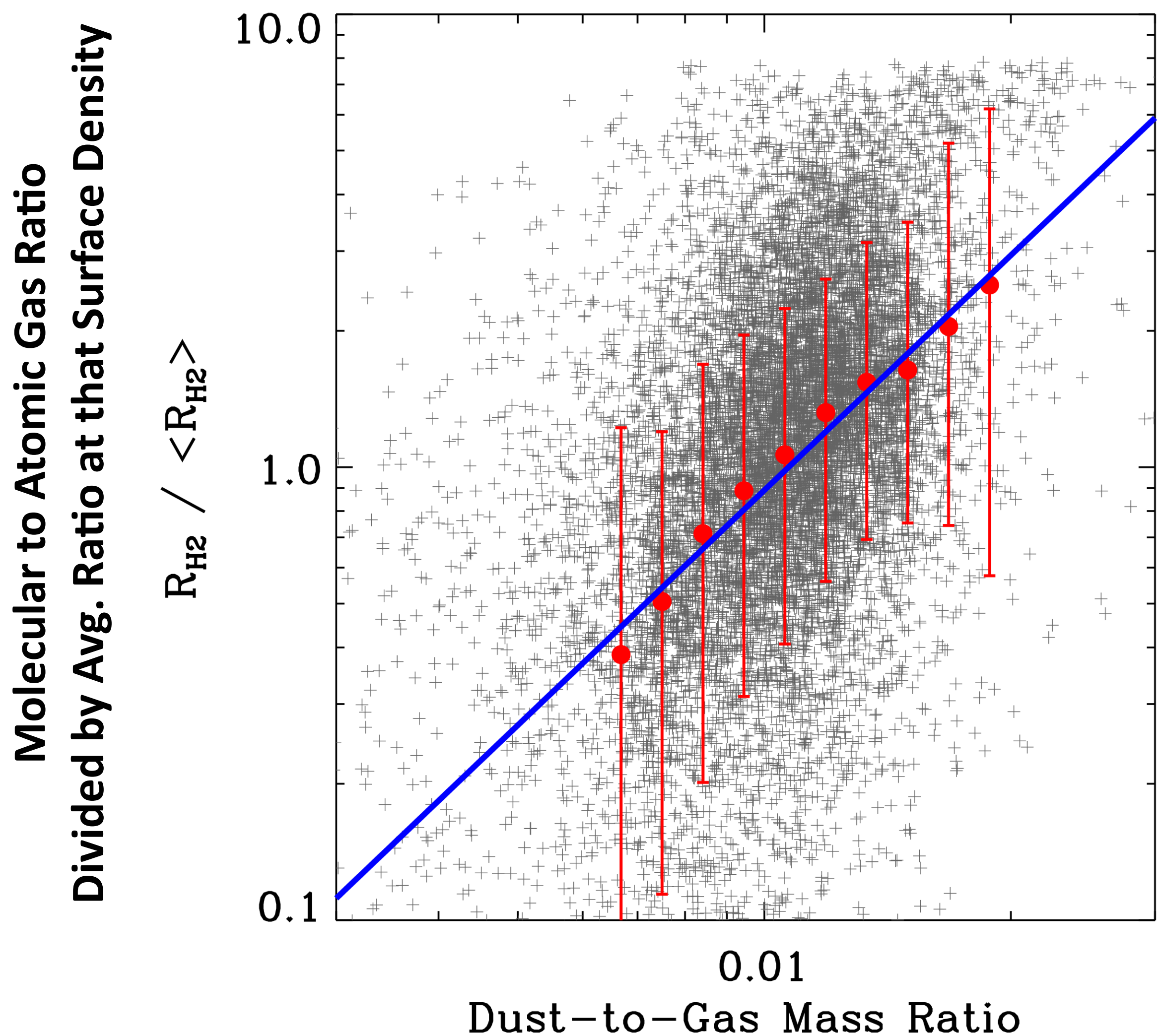

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SFR

And dust appears to help **regulate star formation…**

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