SFR Estimates Across the Electromagnetic Spectrum

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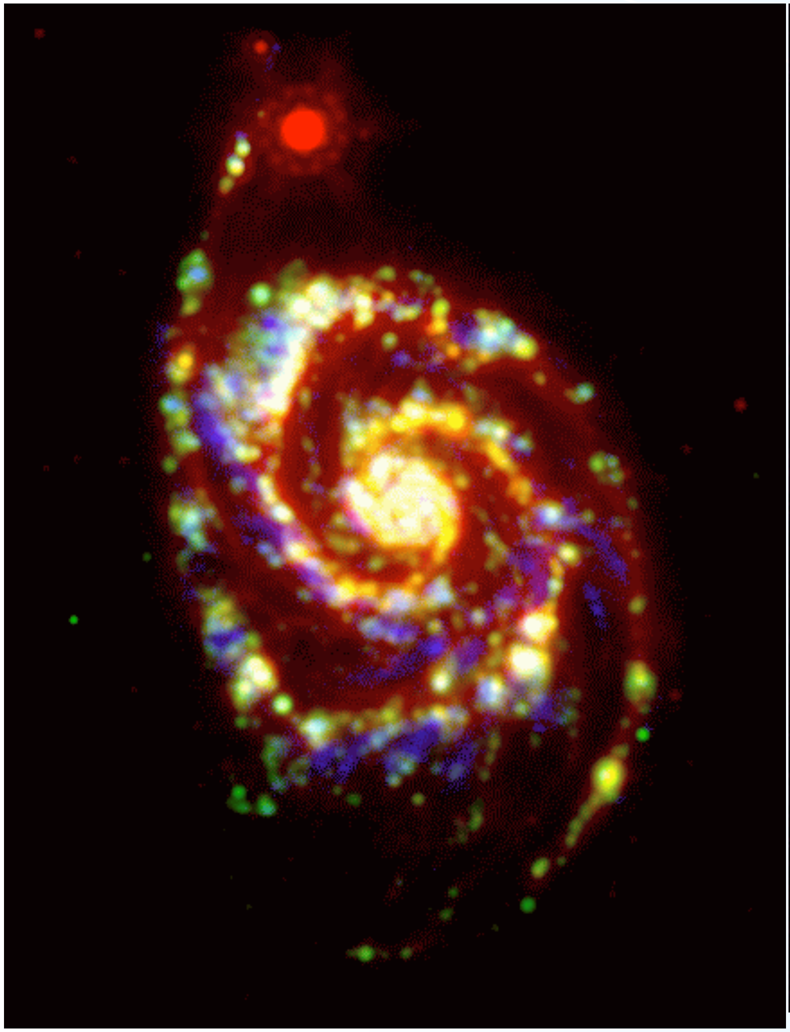
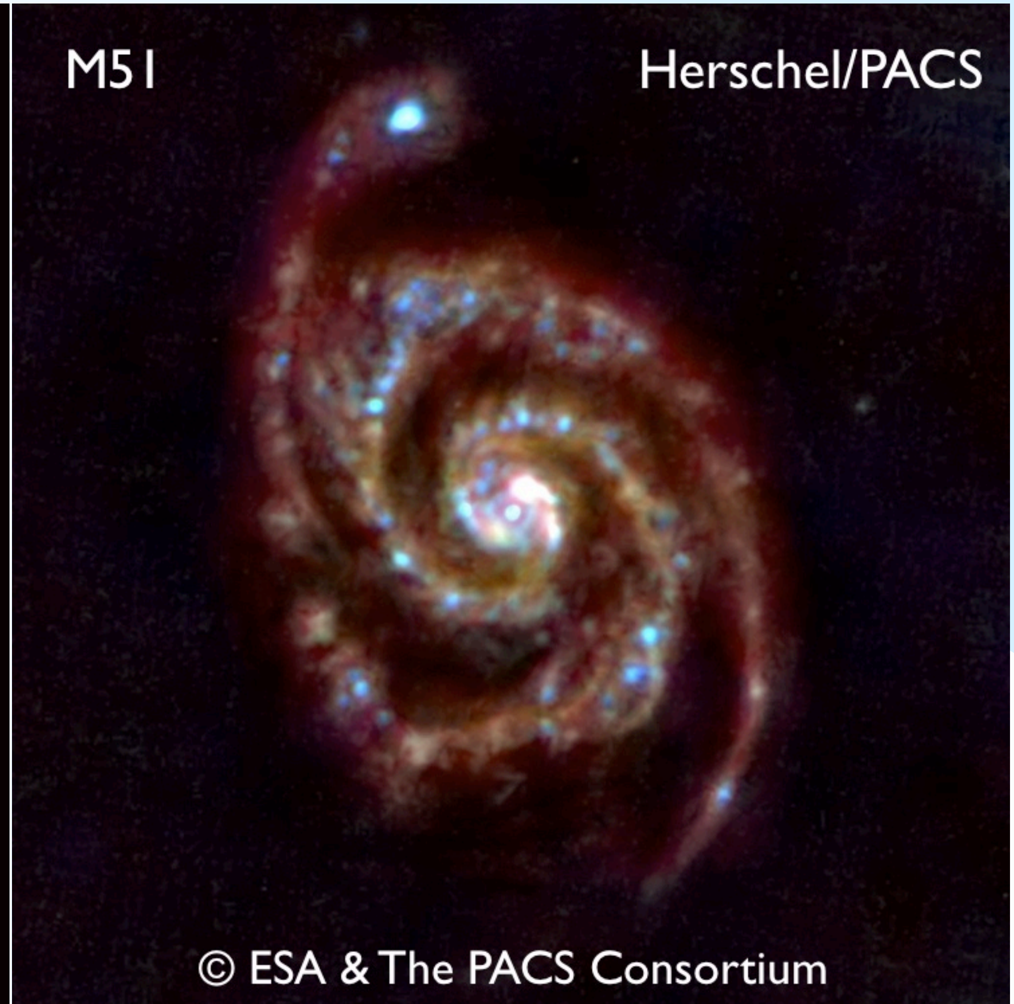
SFR@50, Abbazia di Spineto, Siena (Italy), July 5-10, 2009



SINGS: Galex+Hα+Spitzer



Herschel

What, Why, Where, When?

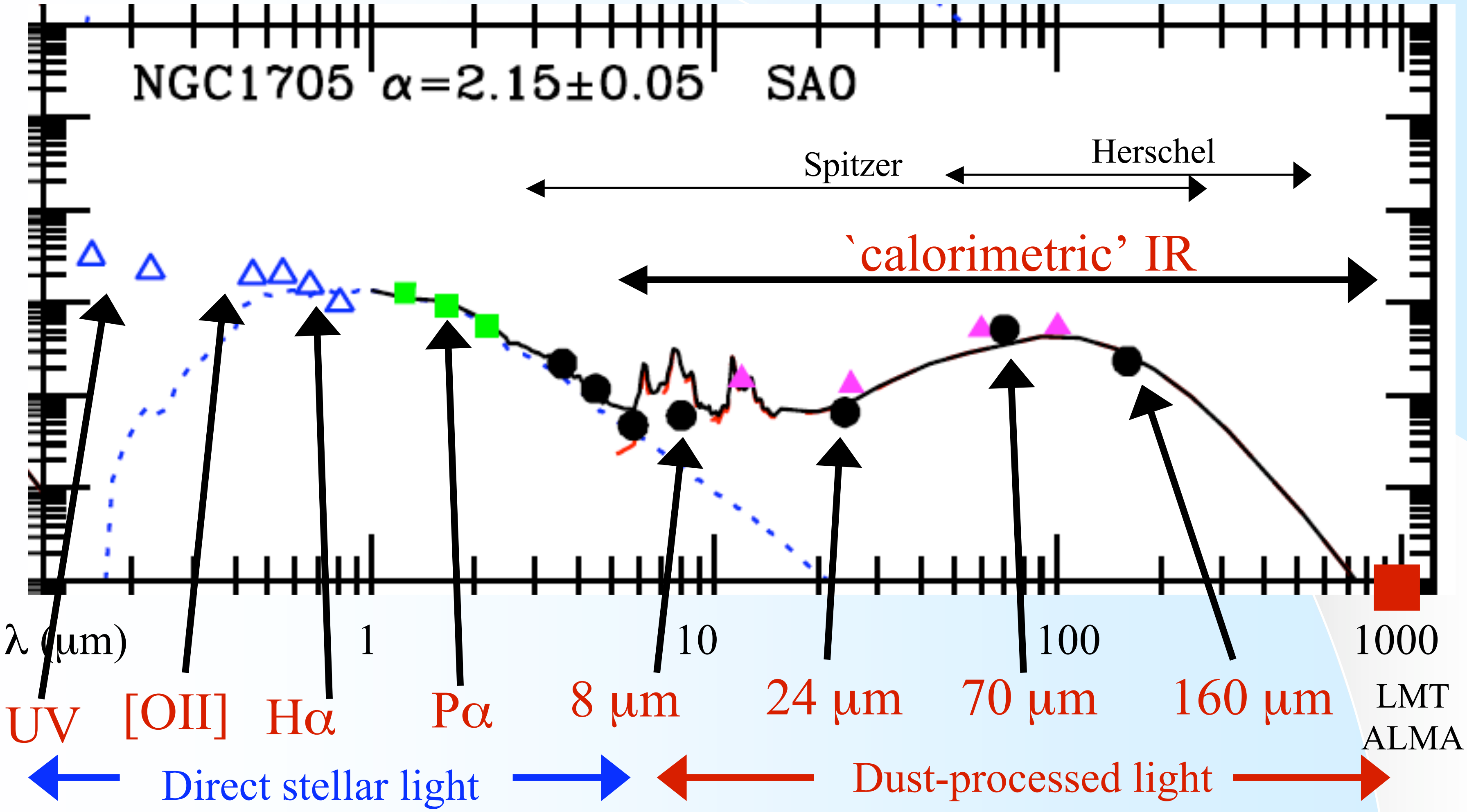
- What? SFRs are measurements of luminosity. We usually `hope' to measure a luminosity that traces young stars -> massive stars. Beware of:
  - Effects of dust extinction (at UV/optical)
  - Effects of SFH (`contamination' from long-lived, evolved/old stars)
  - Effects of `timescales'

- Why? SFRs are among the fundamental parameters to describe/characterize, e.g., galaxies, SF regions, etc. and their evolution (see, e.g., the impact of the `Madau' diagram)

- Where? Measures of SFRs are moving from the `global' (whole galaxies, Kennicutt 1998) to the `local' (galactic regions) and to the `faint' (dwarfs/LSB galaxies) regimes. Beware of:
  - Effects of SFH
  - Effects of IMF variations (???)

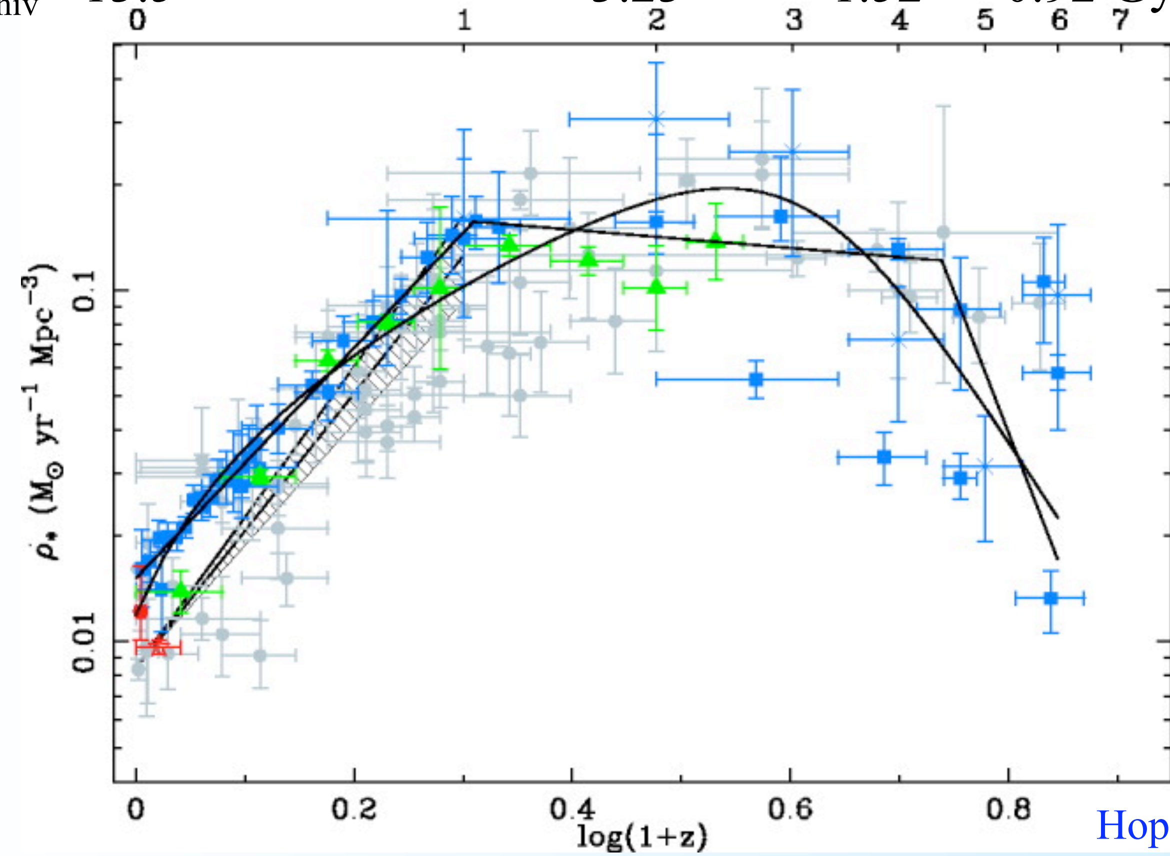
- When? Applications of `recipes', esp. for corrections of contaminants, may depend on the evolutionary state of a galaxy (= age = redshift)

SFR tracers


NGC1705 α=2.15±0.05 SA0
Spitzer
Herschel
`calorimetric' IR
λ (μm)
1
10
100
1000
UV
[OII]
Hα
Pα
8 μm
24 μm
70 μm
160 μm
LMT
ALMA
Direct stellar light
Dust-processed light

Cosmic Star Formation

Age_{Univ}= 13.5 3.23 1.52 0.92 Gyr



Hopkins & Beacom 2006

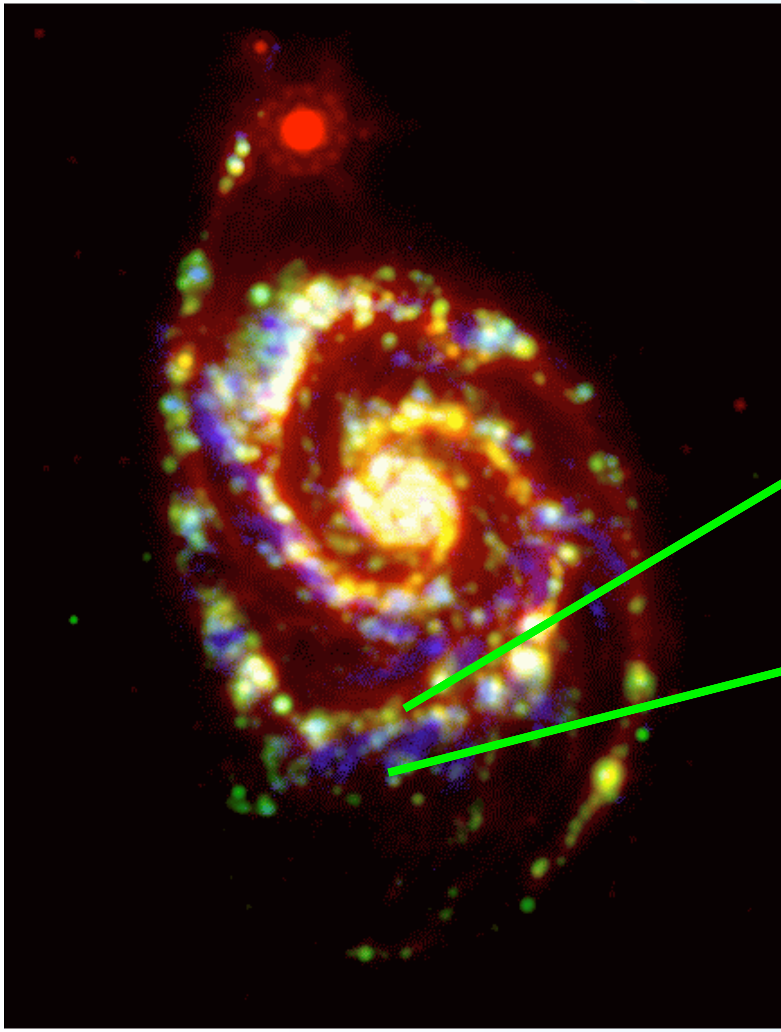
Let's Dwell on the `Why?':

- How, when, and where do galaxies convert gas into stars?
  - How is the low density HI collected into dense cold clouds?
  - Under what conditions do the cold clouds produce stars?
  - What is the underlying physical mechanism for this `production (triggers, etc.)?
  - Is there a threshold for star formation? Is it `universal'?
  - What determines the efficiency of SF?
  - Do we have a single `mode' of star formation?
  - Is the stellar Initial Mass Function universal? Can we produce a theory for the IMF?

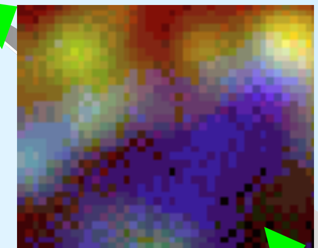
Many of the questions above require investigating spatially-resolved data from galaxies.

The Unique Challenges of Sub-galactic SFRs…

M51, UV(GALEX)+Hα+24(Spitzer)

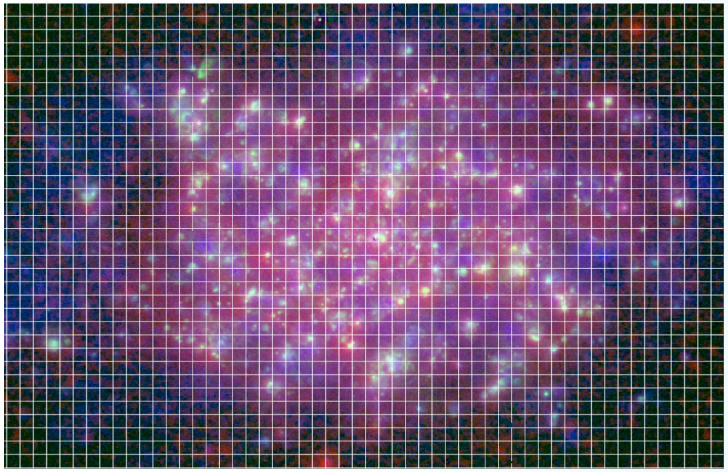


(C. et al. 2005; Rellano & Kennicutt 2009)

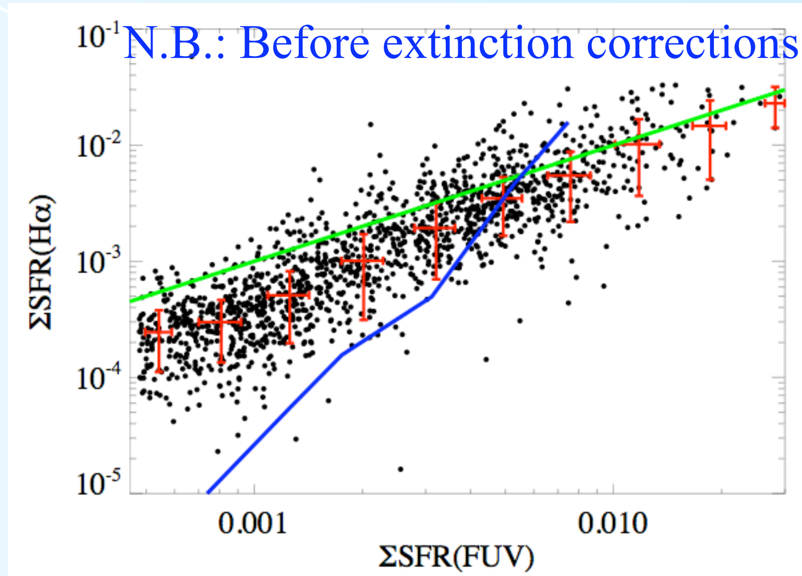


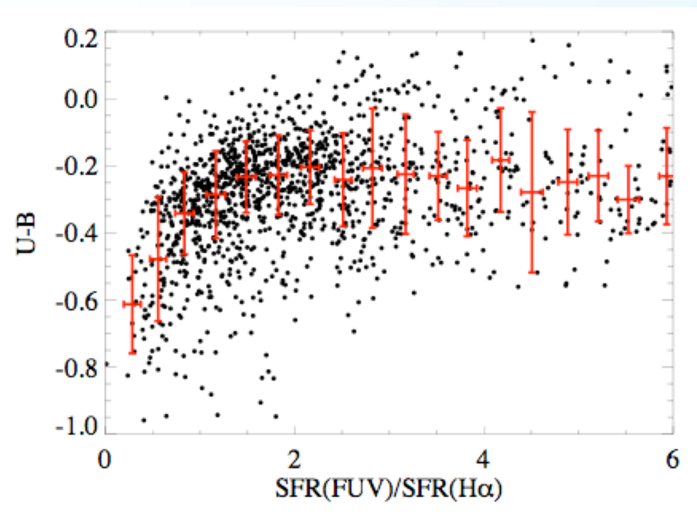
Not uncommonly, regions of UV emission in spiral galaxies are physically separated from regions of ionized gas and dust emission.

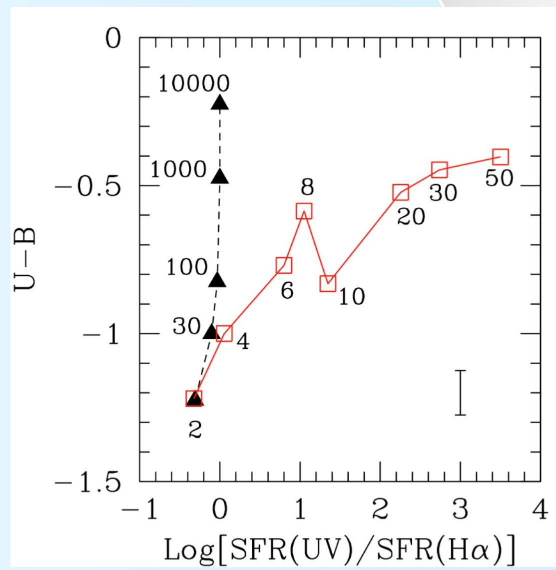
Effects of Timescales/SFH



NGC7793, D=3.82 Mpc

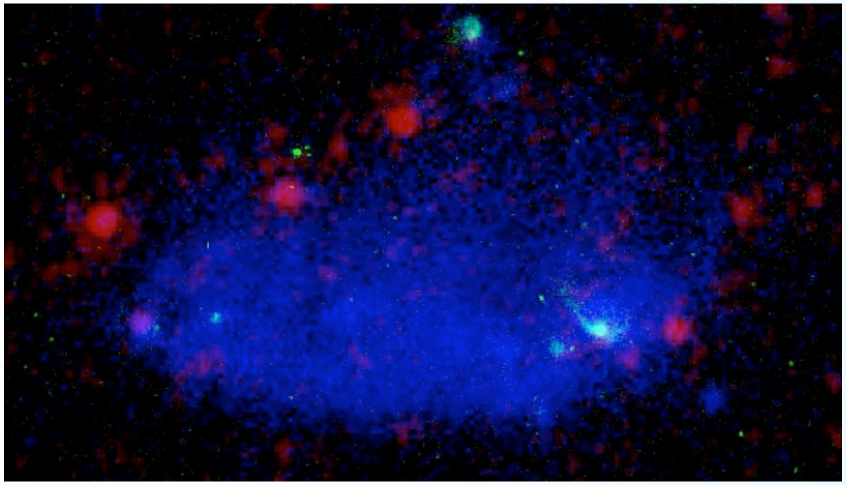


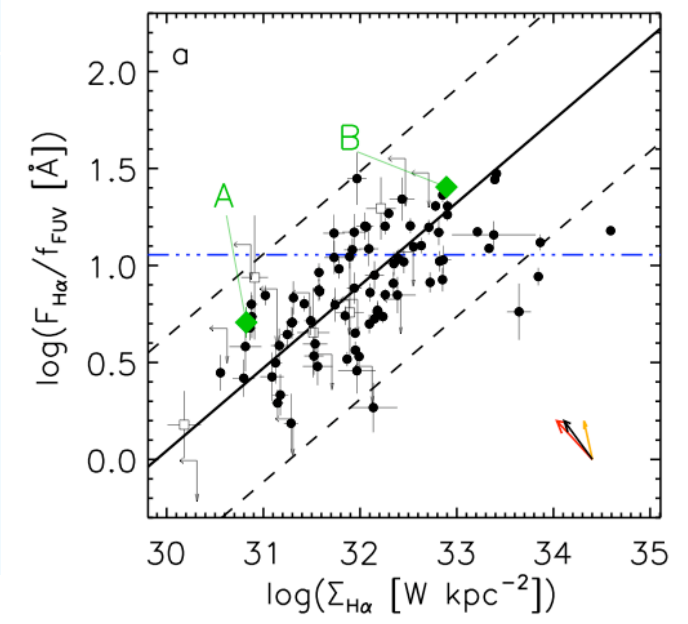




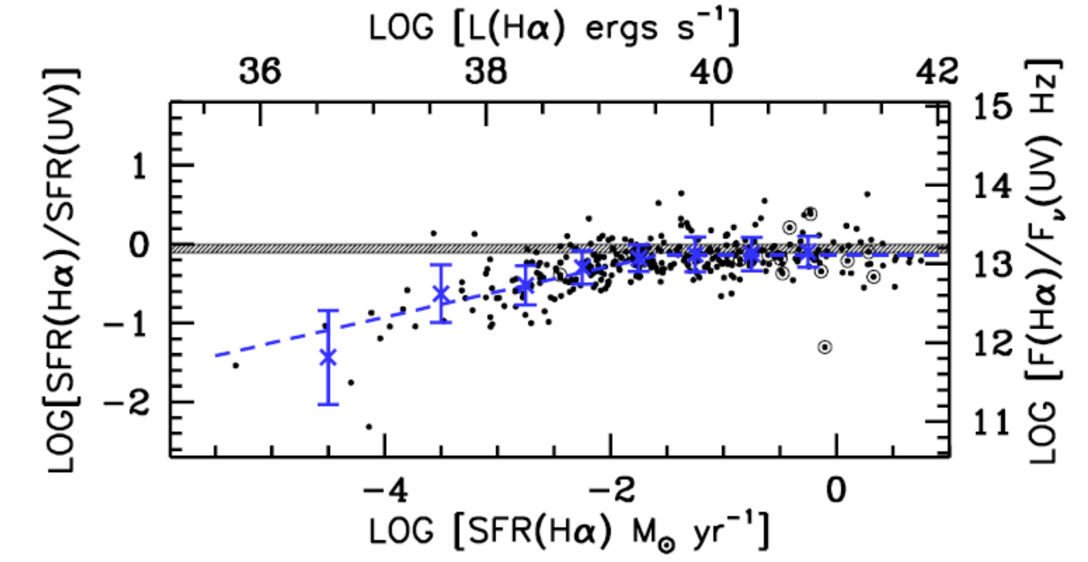
…and of faint galaxies SFRs

UGC8201, UV(GALEX)+Hα+24(Spitzer)



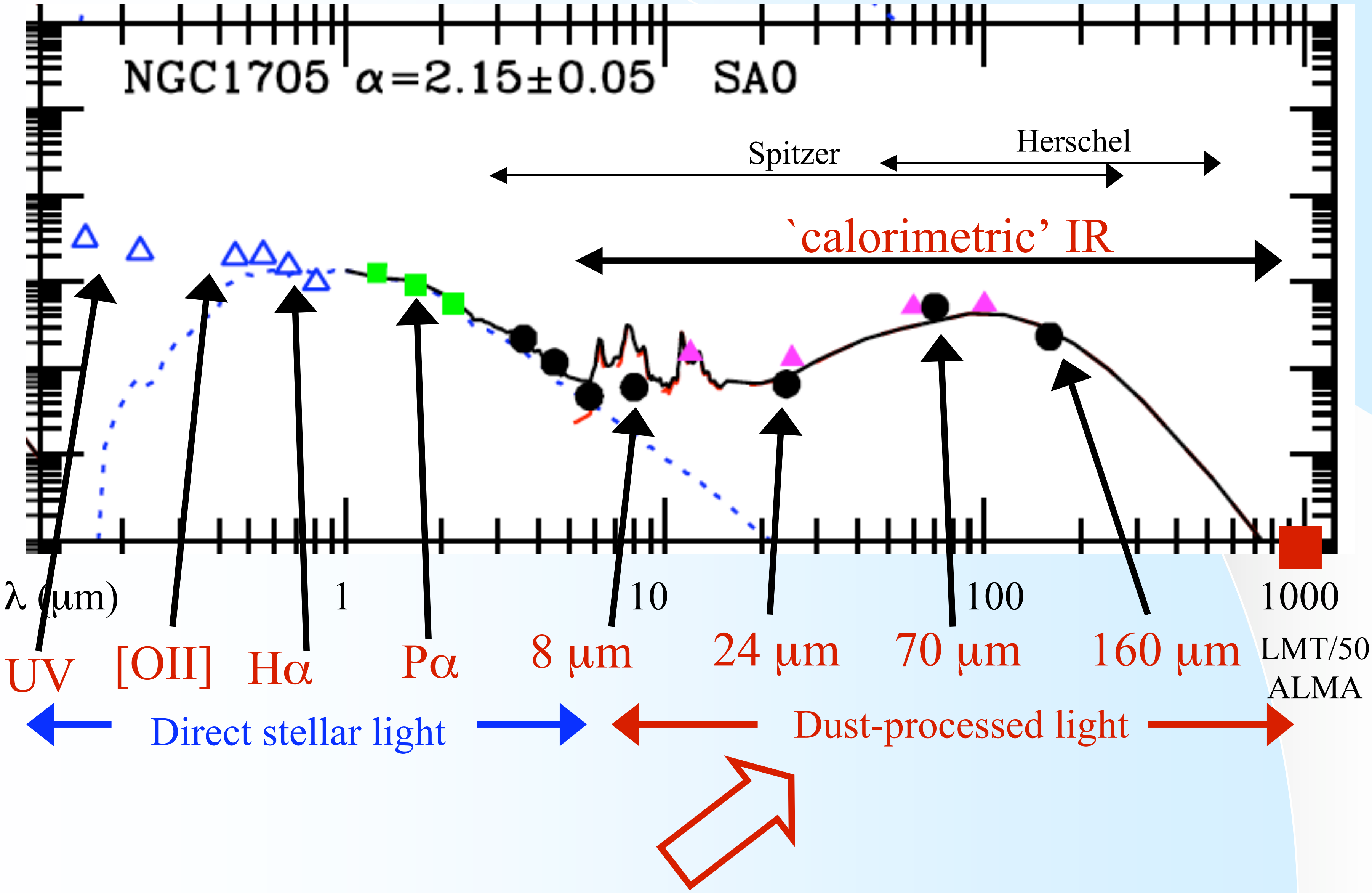


(Meurer et al. 2009)

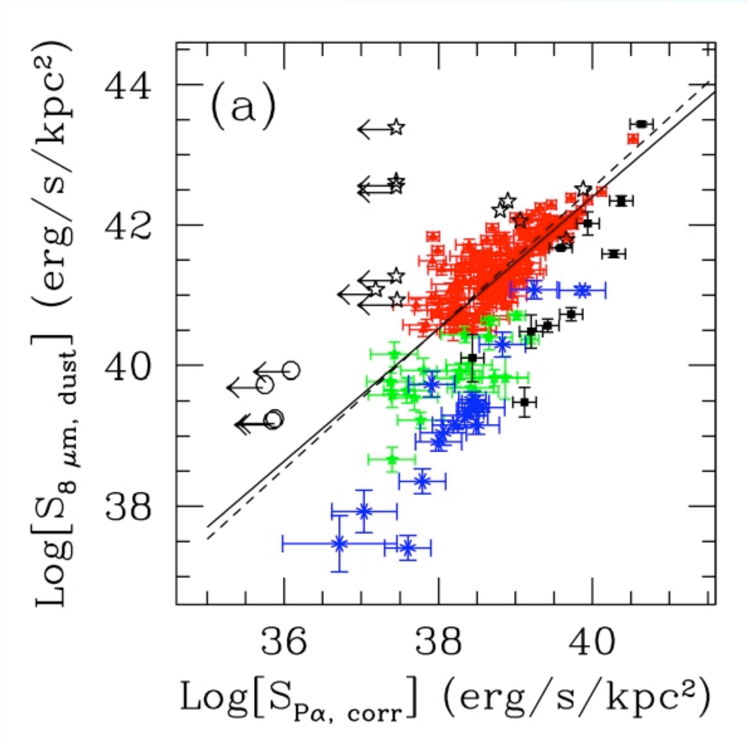


(Janice Lee et al. 2009)

Moving to longer λ



SFR(8) - Fair

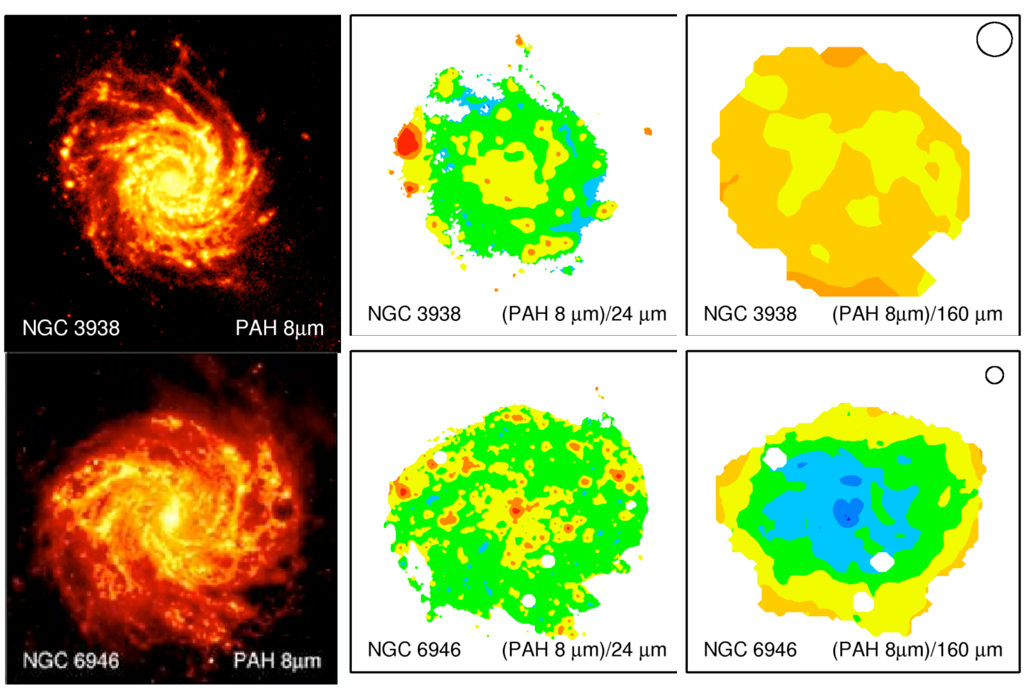


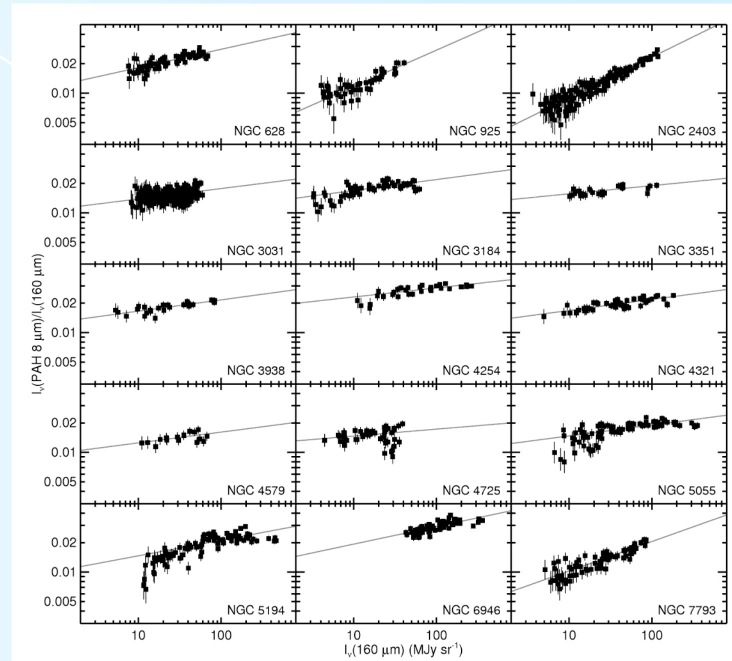
C. et al.2007

Red: High Metallicity SF regions
Green: Medium Metallicity SF regions
Blue: Low Metallicity SF regions
Black symbols: Low Met Starbursts and LIRGs

1. Slope is `sub-linear'
2. Strong dependence on metallicity (Engelbracht et al. 2005, 2008; Rosenberg et al. 2006, Wu et al. 2006, Draine et al. 2007)
3. Dependence on region sampled

Dust versus Stars

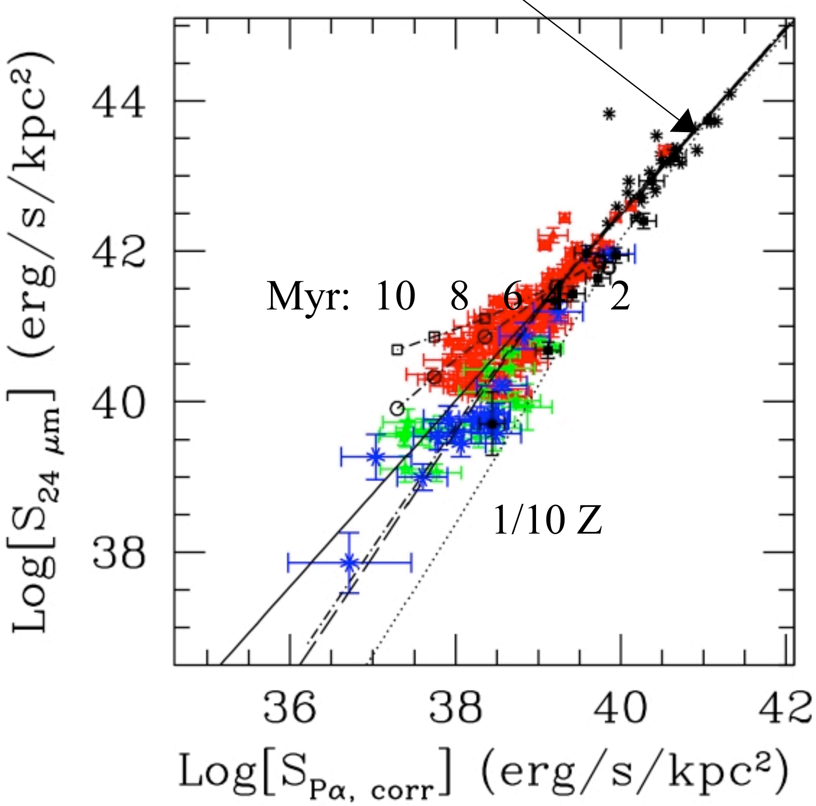




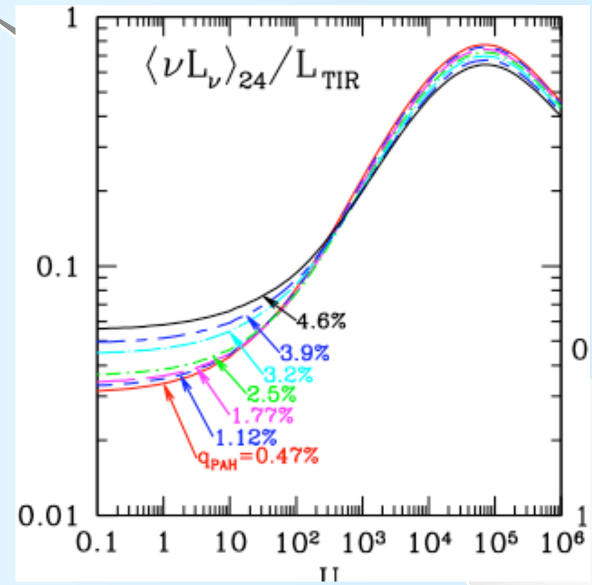
- L(PAH) shows large scatter relative to L(24), but well correlated with L(160) (on ~ 2 kpc scales); PAHs associated with cool dust in galaxies (Bendo et al. 2008)
- Herschel will provide the ultimate test!

SFR(24)

4 Myr burst (or 100 Myr constant) SF, solar metallicity



L(IR) ~ L(Pα) for E(B-V) > 1 mag
How do we get a super-linear slope?



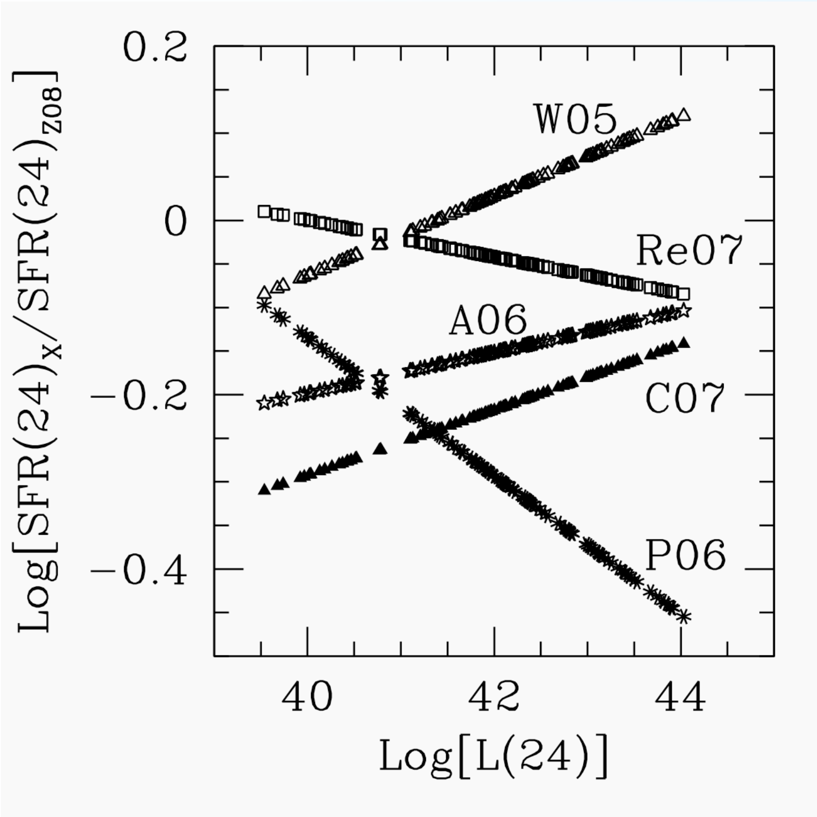
Draine & Li 2007

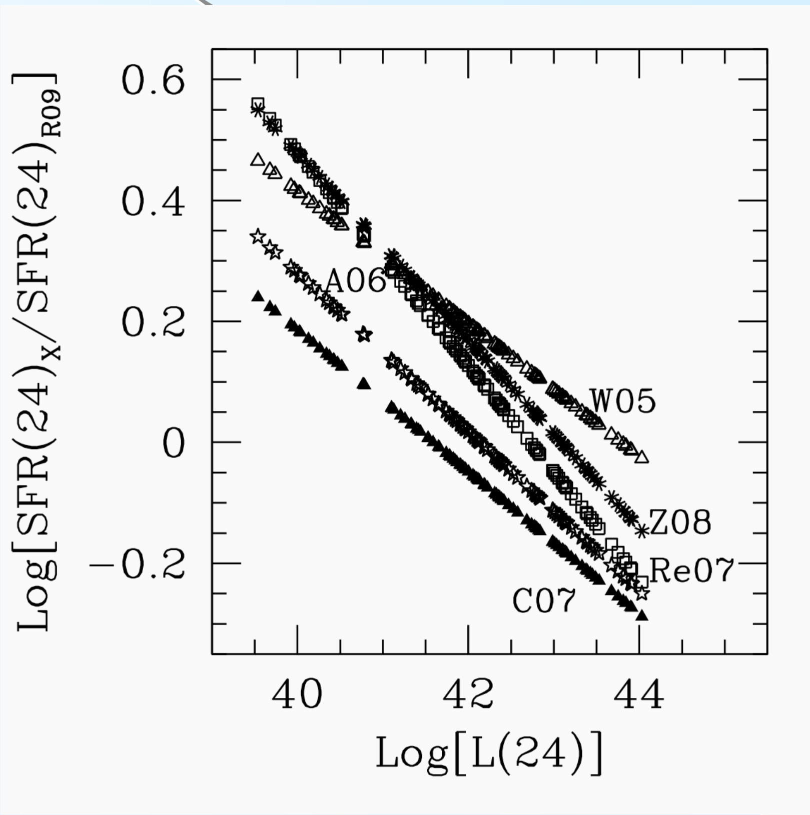
$SFR(M_o\ yr^{-1}) = 1.27 \times 10^{-38}\ [L_{24}(erg\ s^{-1})]^{0.885}$

- o Larger-than-unity slope (in log-log scale) is effect of increasing `dust temperature' + increased opacity at high L
- o Non-linear behavior at decreasing luminosities is due to increasing transparency of the ISM (see Walter et al. 2007, Cannon et al. 2005, 2006)
- o Spread due to range of HII regions ages (~2-8 Myr)

C. et al.2007

Beware of non-linear relations!



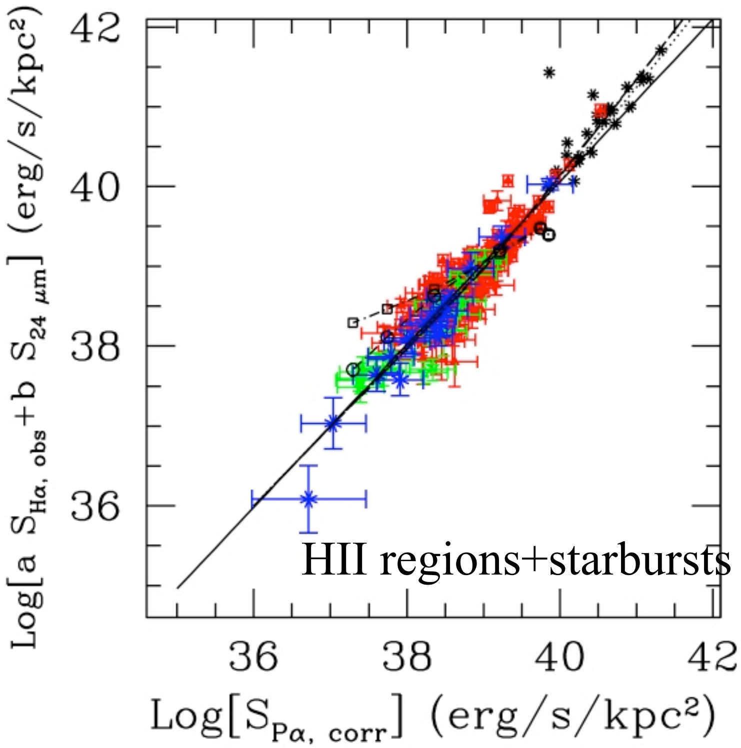


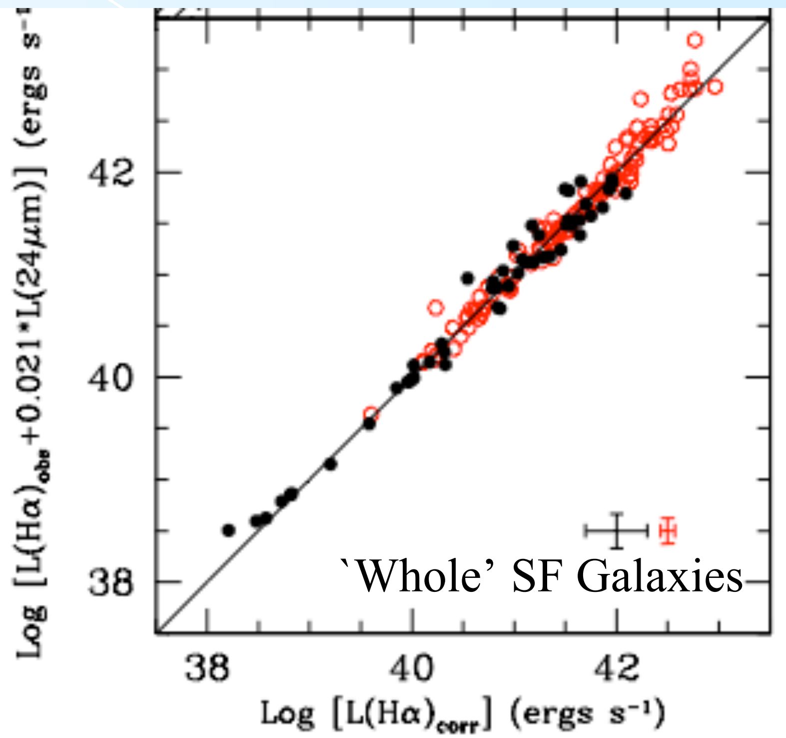
(C. et al. 2009, in prep.)

A Robust Measure of SFR

L(Hα) = unobscured SF; L(24μm) = dust-obscured SF

a L(Hα)+b L(24 μm)





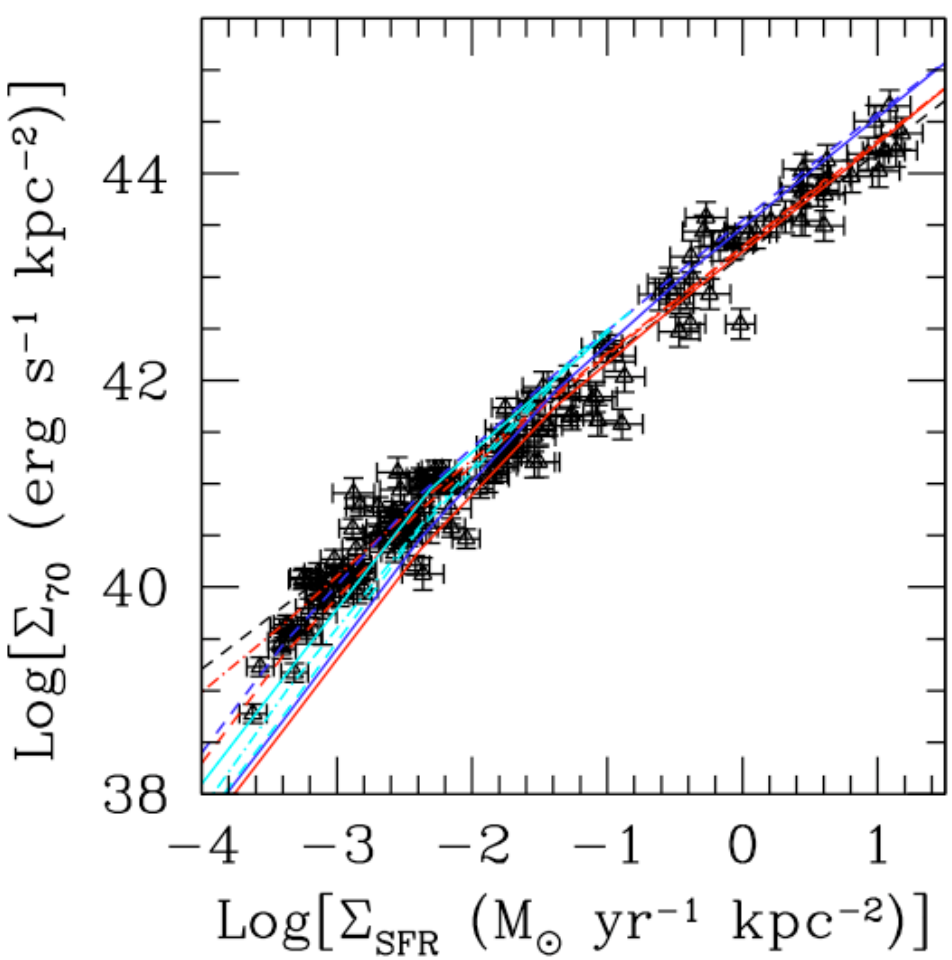
SFR (M_o yr^{-1}) = 5.3 x 10^{-42} [$L_{H\alpha,\ obs}$ + 0.031 (0.021) $L_{24\mu m}$ (erg s^{-1})]

Not necessarily `practical' for high-z studies

C. et al. 2007, Kennicutt et al. 2007, 2009

SFR(70)

Whole galaxies



Advantage: close to peak of IR emission

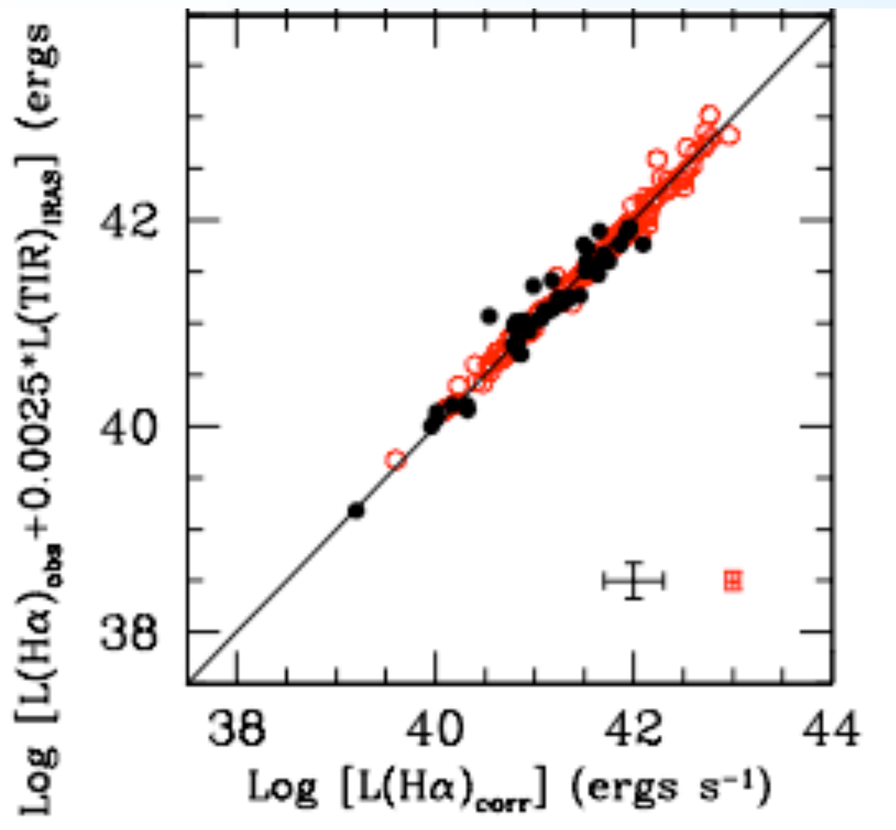
However, scatter increases relative to 24 µm (by ~30%): increasing contribution from evolved stars.

Similar analysis for 160 µm leads to ~2x increase in scatter.

C. et al. 2009, in prep.

SFR(TIR)

Whole Galaxies



TIR=L(3-1000 μm)

L(Hα) = tracer of unobscured SF

L(TIR) = tracer of dust-obscured SF

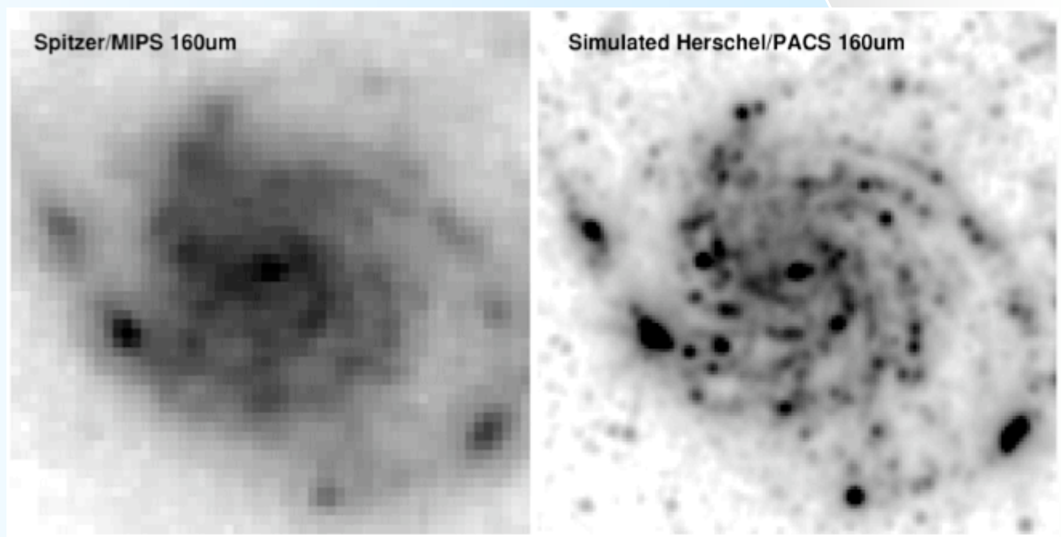
Kennicutt et al. 2009

The Next Step

- ❑ Test the limitations (besides the obvious ones, like `no dust') of monochromatic IR SFR indicators on resolved stellar populations/clusters
  - ❑ Need higher angular resolution than Spitzer: Herschel;

- ❑ Test the limitations of other mixed SFR indicators (e.g., UV+IR, etc.) on sub-galactic regions
  - ❑ Mainly tested on whole galaxies or large regions
  - ❑ Unclear dependence on sub-population star formation history.

KINGFISH: Key Insights on Nearby Galaxies: a Far Infrared Survey with **Herschel** will address, among others, these questions.



Summary

As the investigation of the physics of star formation moves from galaxy-integrated to sub-galactic scales (star formation's `own' physical scale), we need to understand and `correct' for local effects:

- SFH,
- SFR timescales,
- IMF variations
- (dust)

This will be enabled by the combination of current/near-past (Spitzer, HST) and on-their-way/near-future (Herschel, ALMA, LMT, JWST) facilities are enabling the investigation of star formation on its own physical scales

- Spitzer has enabled the derivation of mid-IR/far-IR monochromatic SFR indicators, that will help leverage the deep surveys planned with, e.g., Herschel
- It has also shown that simple prescriptions for dust attenuation correction are not applicable to all galaxies, and normal SF galaxies will require a different treatment from e.g., starbursts
- Upcoming infrared and mm facilities will open unexplored corners in the investigation of the laws and calibration of star formation.