# Star formation and ISM on parsec scales

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*(submitted)*

## *N66 in the Small Magellanic Cloud*

Catalogue of PMS stars from Hubble ST photometry
(PI: Nota)
ISM properties from dust continuum data
(PIs: Gordon, Meixner, Hony)

# Simple and **direct** methods

- Counting PMS stars → SFR
- Dust SED radiative transfer modeling → dust mass

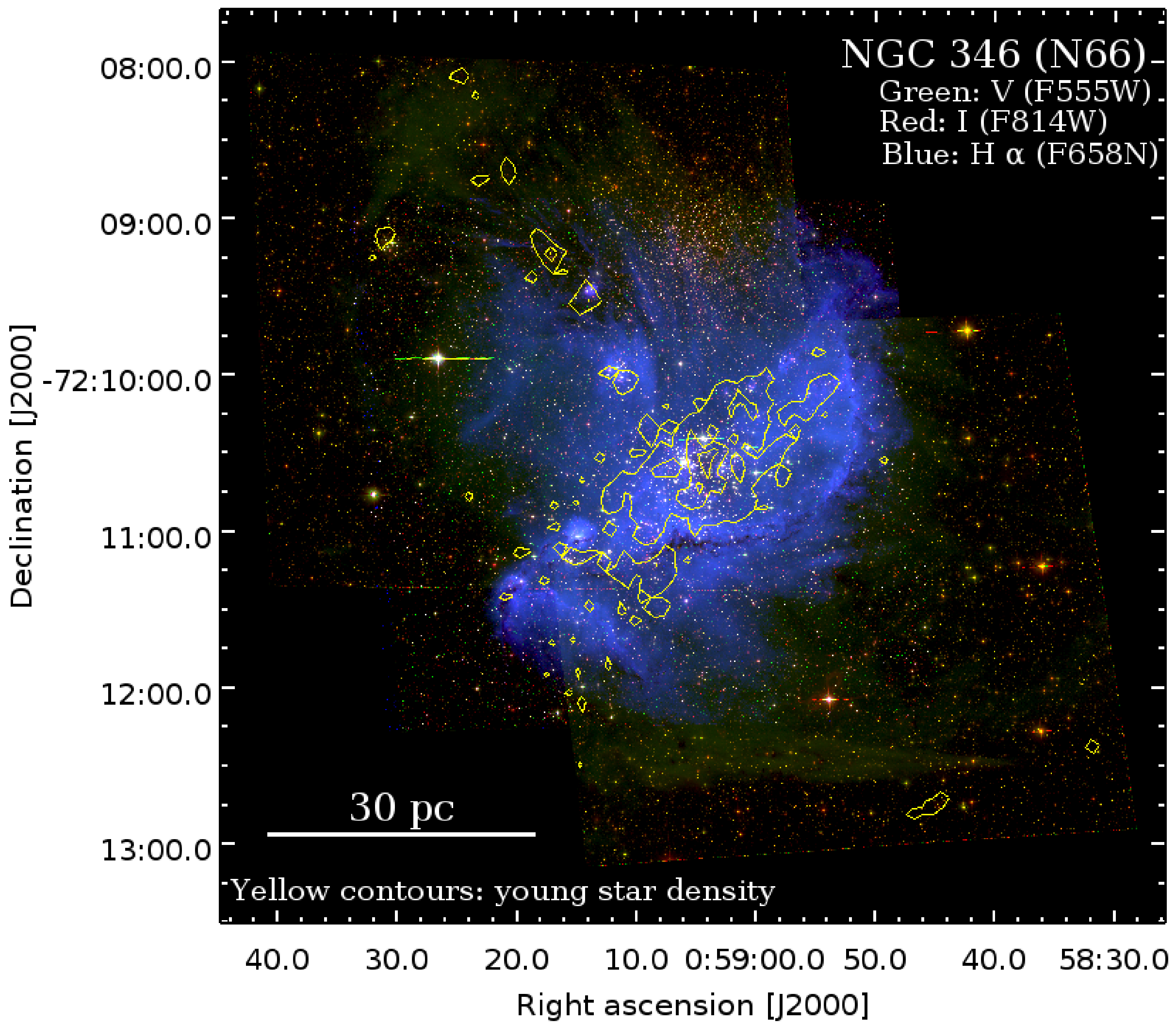
With some **care** one can obtain

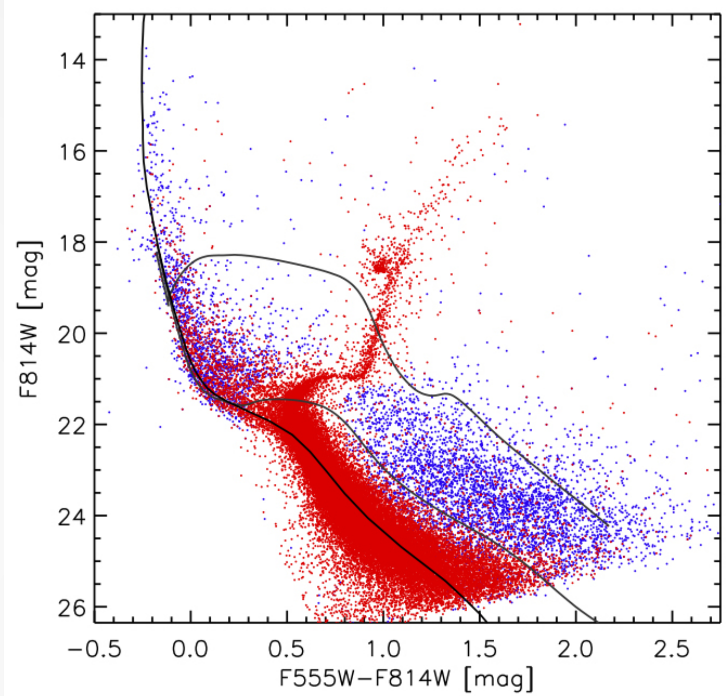
- Quantitative information on the distribution of young stars
- Relation of stars and ISM on otherwise inaccessible scales

New physical insights for N66:

- **Clustered** SF is **more efficient** than **dispersed** SF

# The Star-Forming Complex N66




**Photometric Catalogs:**

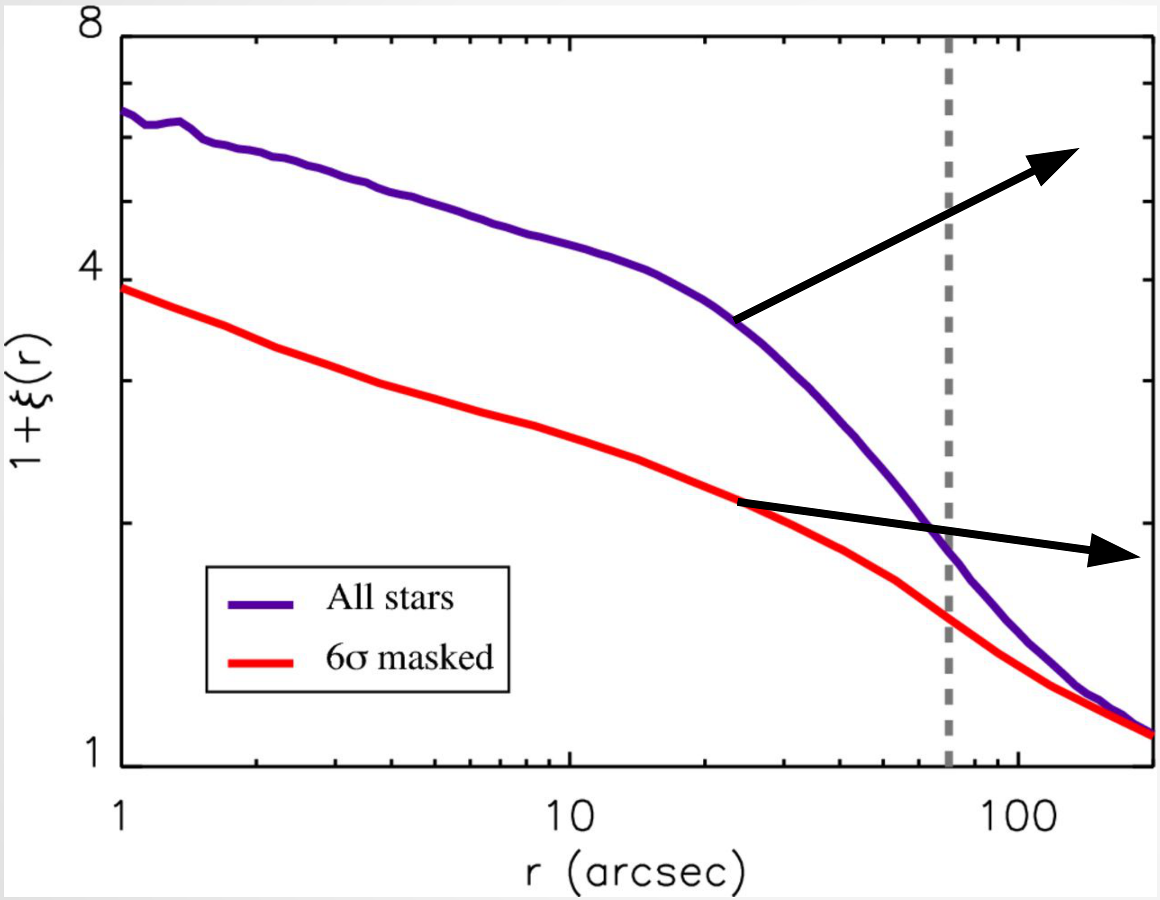
> 5000 PMS stars

Ages 0-5Myr

- Very rich central part
- PMS detected everywhere

(Nota et al. 2006; Gouliermis et al. 2006)

# Observed auto-correlation function




Full ACF has a break around 20”
→ Not a single type of distribution

Without central concentration: power-law behaviour
→ Cluster on top of dispersed distribution

**Gouliermis, Hony & Klessen 2014**

# What about the ISM?

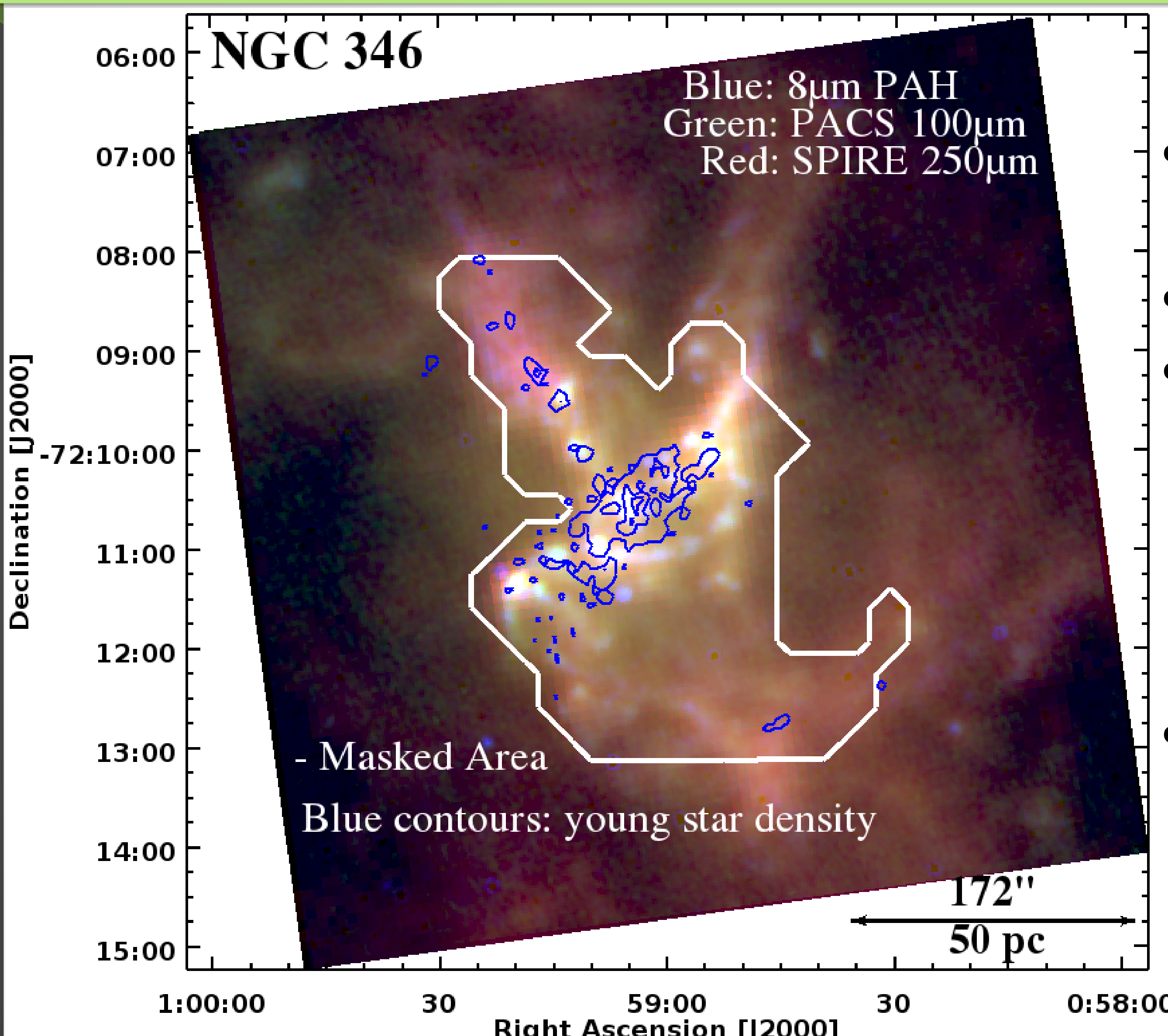
**How well do the young stars follow the ISM?**

*Is this bimodal distribution reflected in the ISM?*

- *Spitzer*/SAGE-SMC (PI Gordon)
- *Herschel*/HERITAGE (PI Meixner)
- APEX/Laboca (PI Hony)

→ Full dust SED → (3.6 - 870 µm) @ 20” resolution
→ Constrain ISM column densities

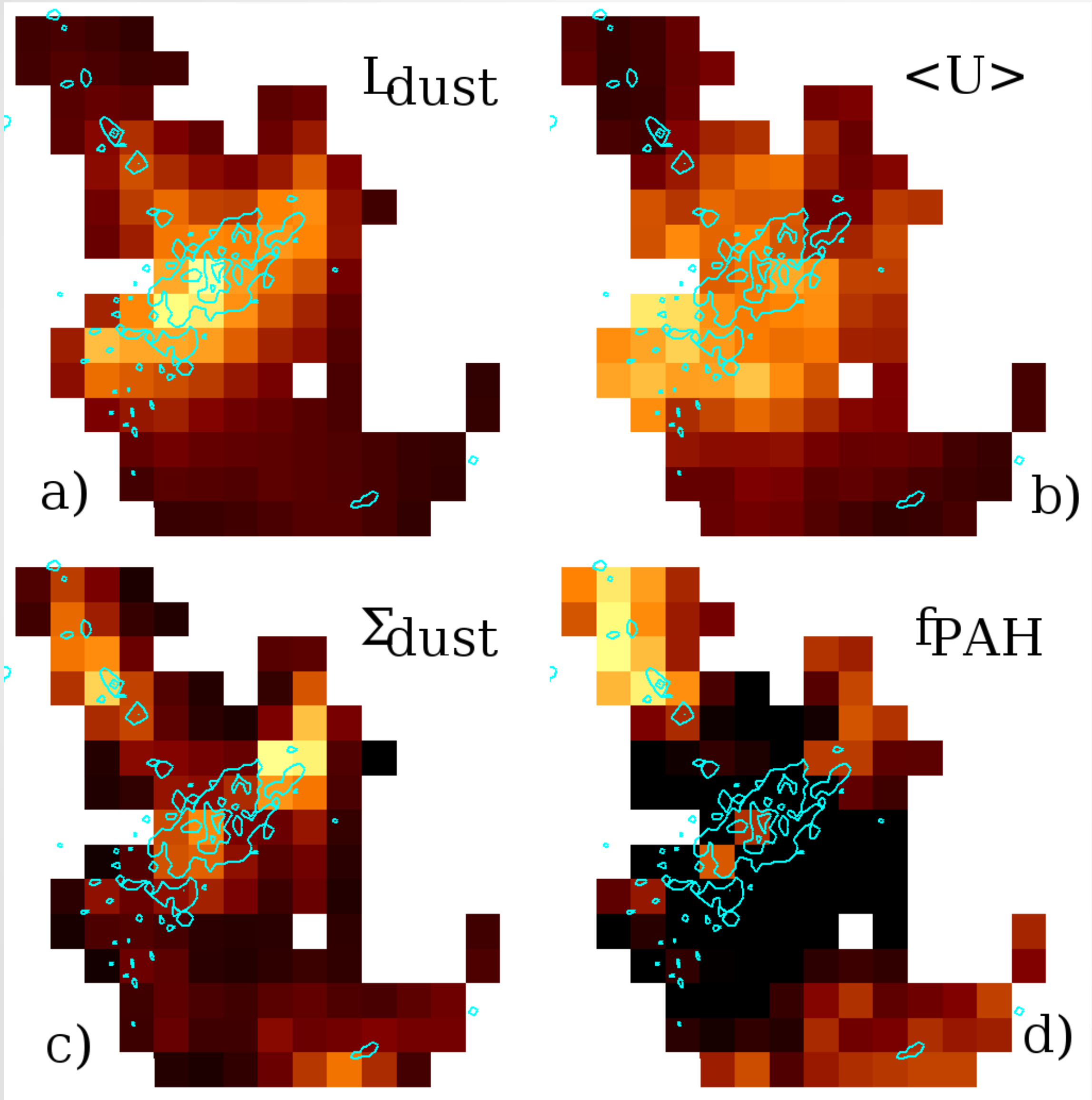
# N66 in ISM tracers




- 115 independent pixels
- ~50 pc radius
- Covering main cluster but also field and northern molecular “spur”

- Masked area is where stars and Laboca are well defined

# Radiative transfer modeling




Realistic materials with measured optical properties

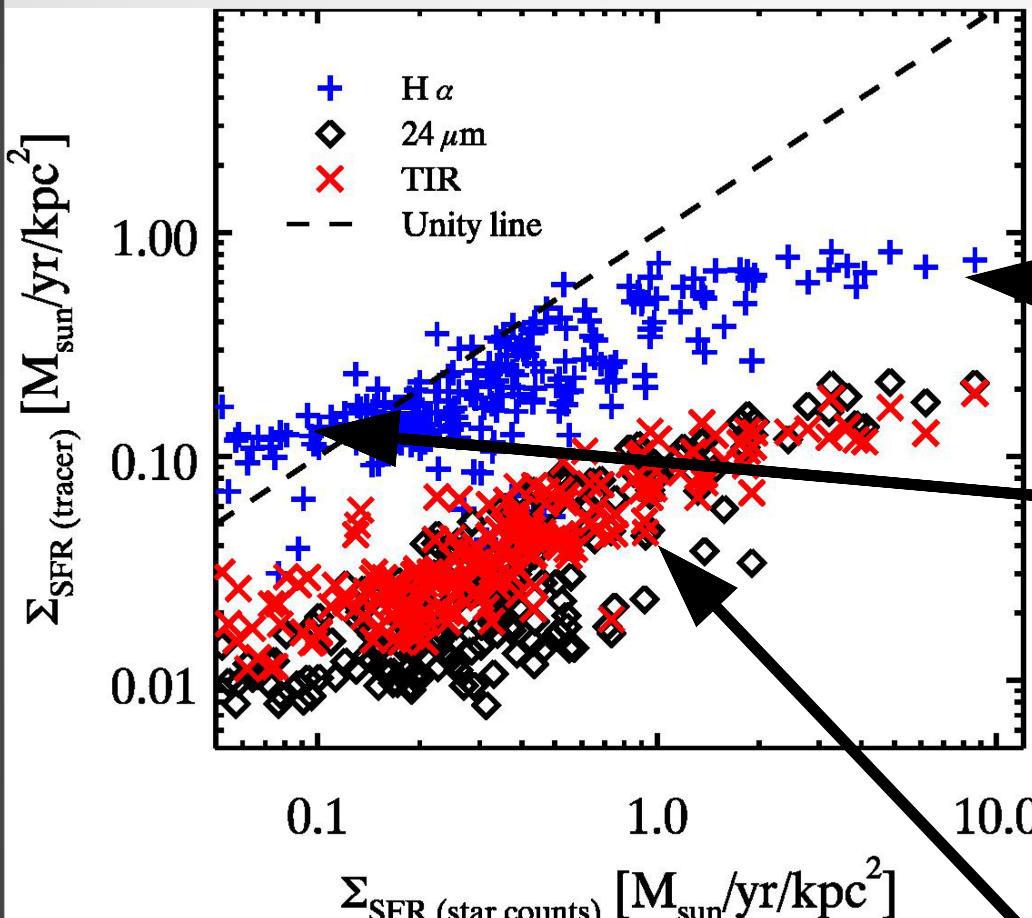
Monte-Carlo estimates of uncertainties

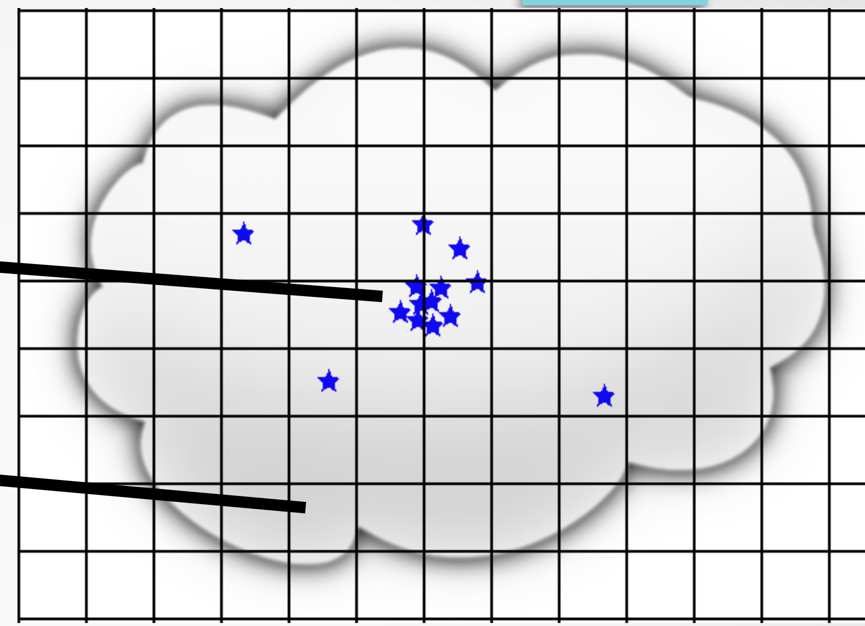
Yields:
ISM conditions and **dust surface density**

# Conversion factors

| Quantity | Symbol | Value | Comments/Refs |
|---|---|---|---|
| SMC distance | $d_{\rm SMC}$ | 60 kpc | Harries, Hilditch & Howarth (2003) |
| Detected young stars | $N_{\rm star}$ | 5150 | Gouliermis et al. (2006) |
| Total young stellar mass | $M_{\rm tot}$ | $2.2 \cdot 10^4$ $M_\odot$ | Sabbi et al. (2008) |
| Mass per catalogue source | $M_{\rm cat}$ [a] | 4.3 $M_\odot$ | $= M_{\rm tot}\ N_{\rm star}^{-1}$ |
| SF duration | $\Delta t_{\rm SFR}$ | $5 \cdot 10^6$ yr | Mokiem et al. (2006) |
| Gas-to-dust mass ratio | $r_{\rm gd}$ | 1250 | |
| Derived Quantity | | | |
| Young star surface density | $\Sigma_\star$ | | from star catalogue |
| Stellar mass surf. dens. | $\Sigma_{\rm M_\star}$ | | $= \Sigma_\star \cdot M_{\rm cat}$ |
| SFR surf. dens. | $\Sigma_{\rm SFR}$ | | $= \Sigma_{\rm M_\star}\ \Delta t_{\rm SFR}^{-1}$ |
| Dust surf. dens. | $\Sigma_{\rm dust}$ | | from SED fitting |
| Gas surf. dens. | $\Sigma_{\rm gas}$ | | $= \Sigma_{\rm dust} \cdot r_{\rm gd}$ |
| Stellar mass fraction | $frac_{\rm M\star}$ | | $= \Sigma_{\rm M_\star}\ (\Sigma_{\rm M_\star} + \Sigma_{\rm gas})^{-1}$ |

# SFR compatible with Hα or TIR?



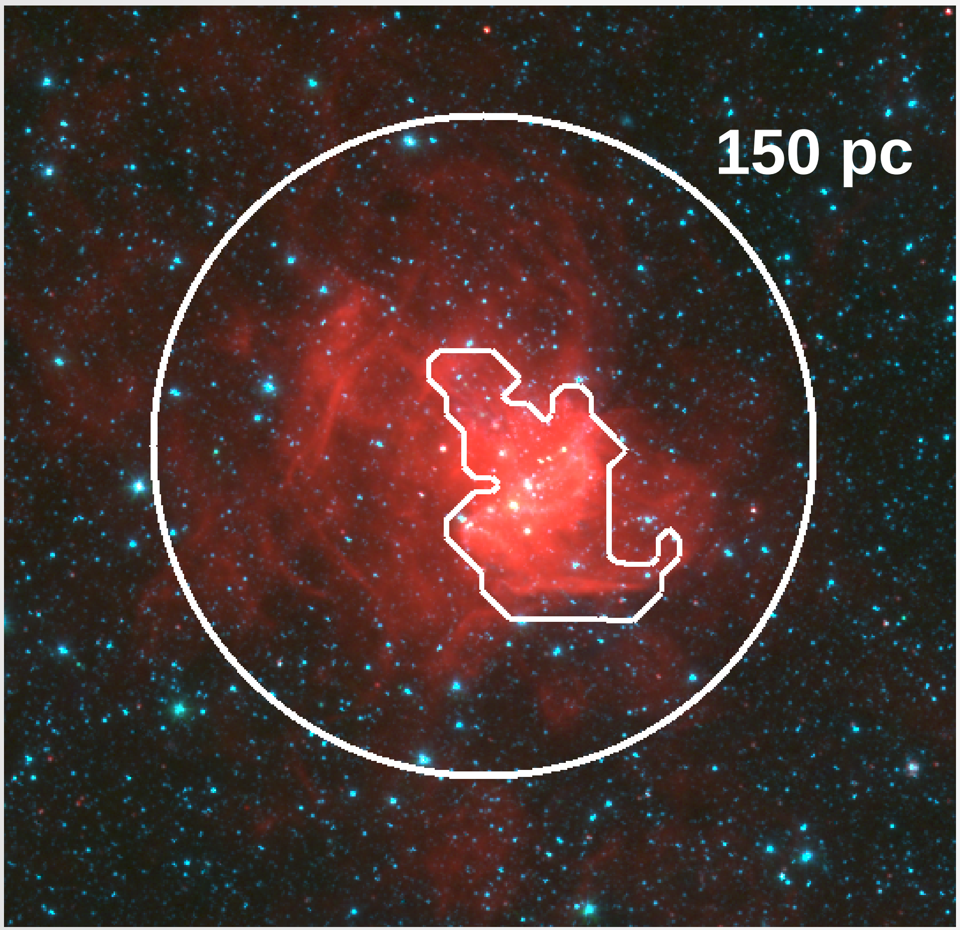
These tracers are not local on ~10 parsec scales

**Would break SK even if stars follow ISM**

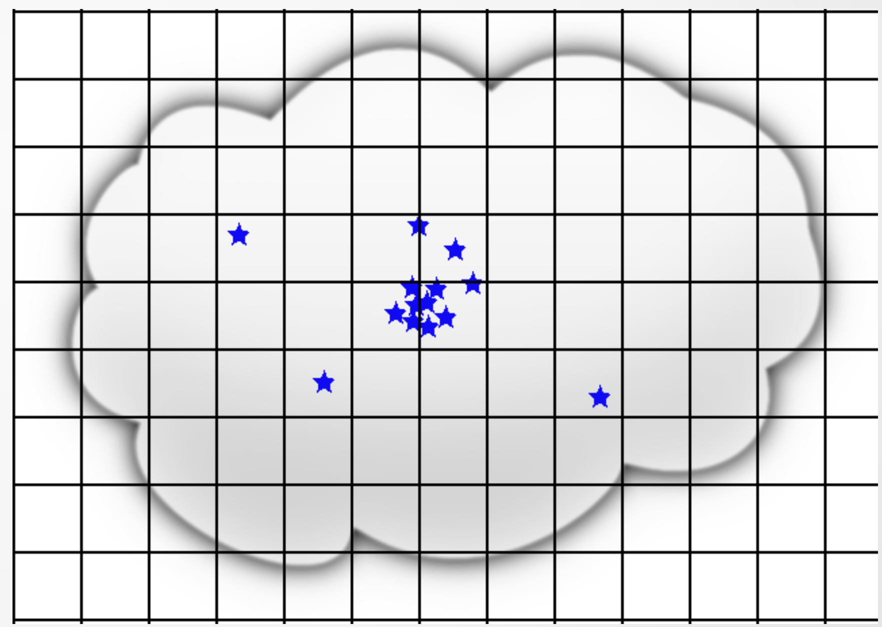
Not locally and not with dust because of little dust

*(Direct effect of low metallicity and low dgr of SMC)*

# The Hα nebula is large

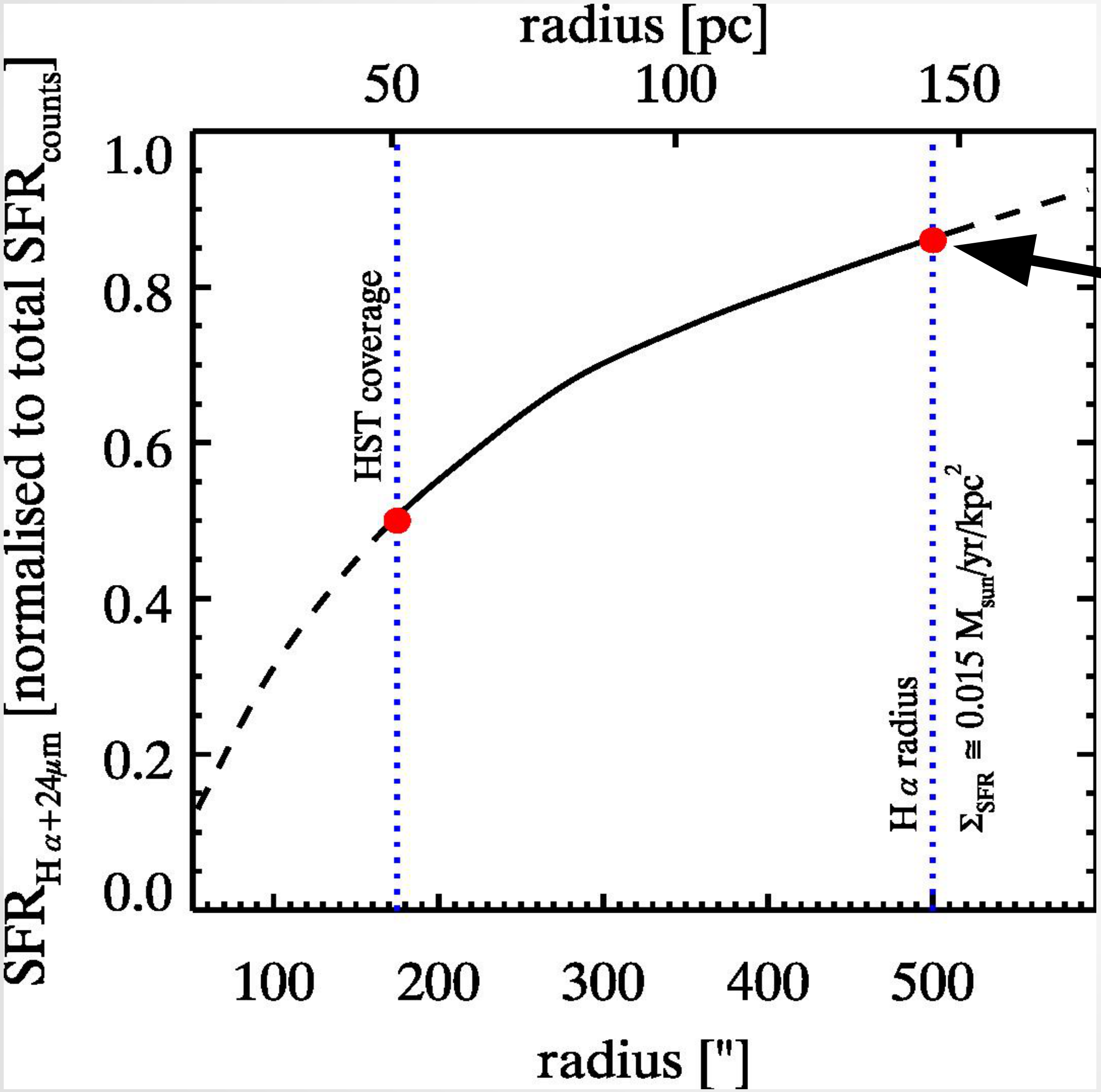



*Cartoon is quite accurate*



Hα MCELS (Smith et al 2000, Points priv comm.)
Stars (Sage-SMC Gordon et 2011)

# Remission tracers require averaging

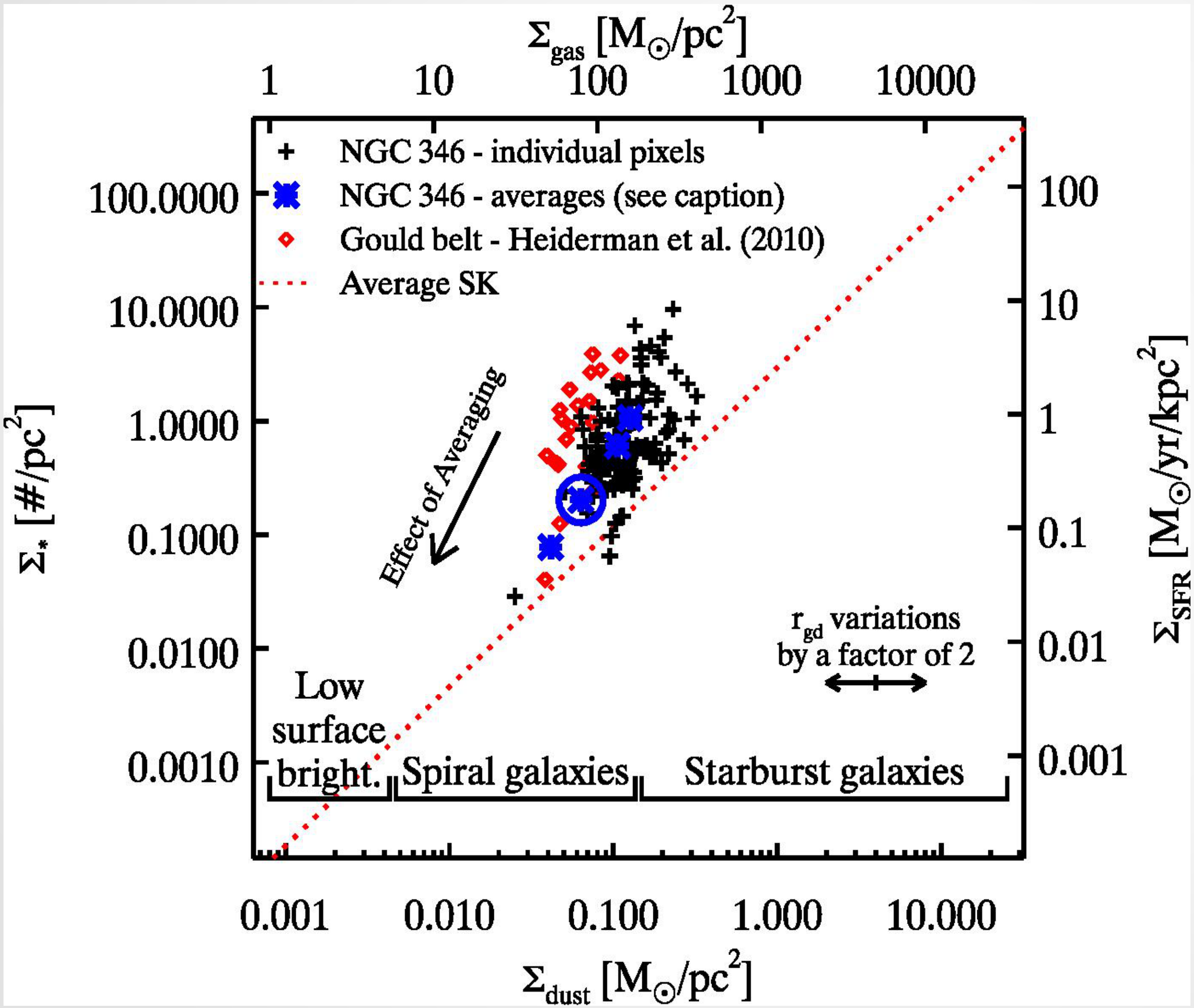



Works globally when taking into account the entire Hα nebula

Absolute calibration is "correct"

Direct SFR tracers needed to study small scale variations

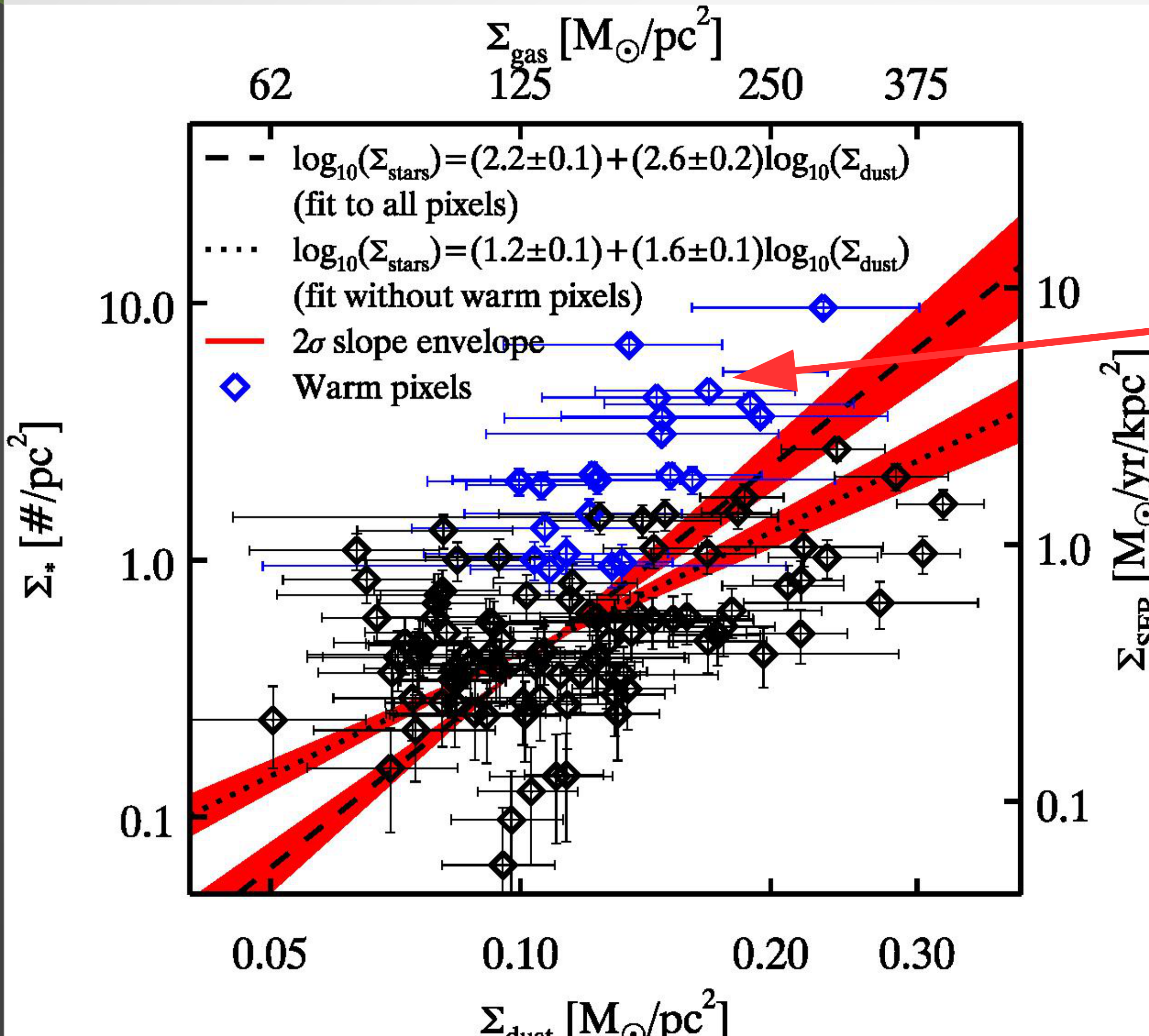
# Comparing to Schmidt-Kennicutt




Individual points lay systematically above SK

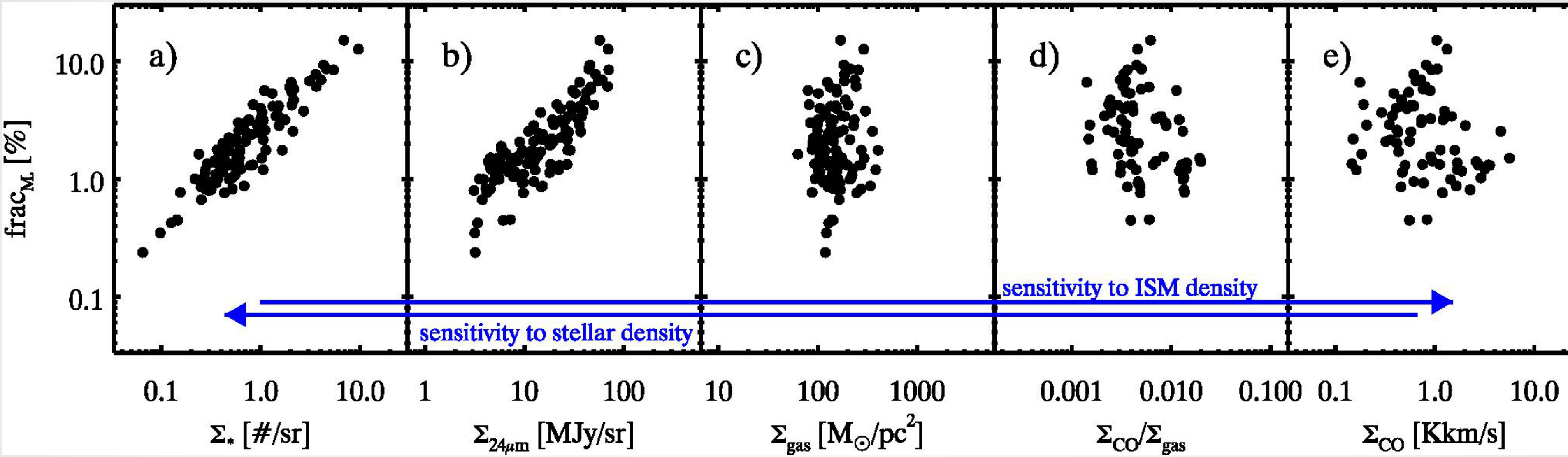
- **Averaging** over Mask, 50, 90 and 150 pc brings points closer
- Similar to Heiderman et al 2010.

# Zoomed in view




- Some correlation with a lot of scatter
- Highest points are all warm (near the main cluster): $(\Sigma_{24\mu m}/\Sigma_{250\mu m}>0.3)$ [(Mjy/sr)/(Mjy/sr)]

# Stellar mass fractions vs X




Correlates best with **direct stellar tracers** (radiation field, stellar density) and much less with **ISM conditions**.

Interpretation: *ISM **conditions** that led to cluster formation have already been erased.*

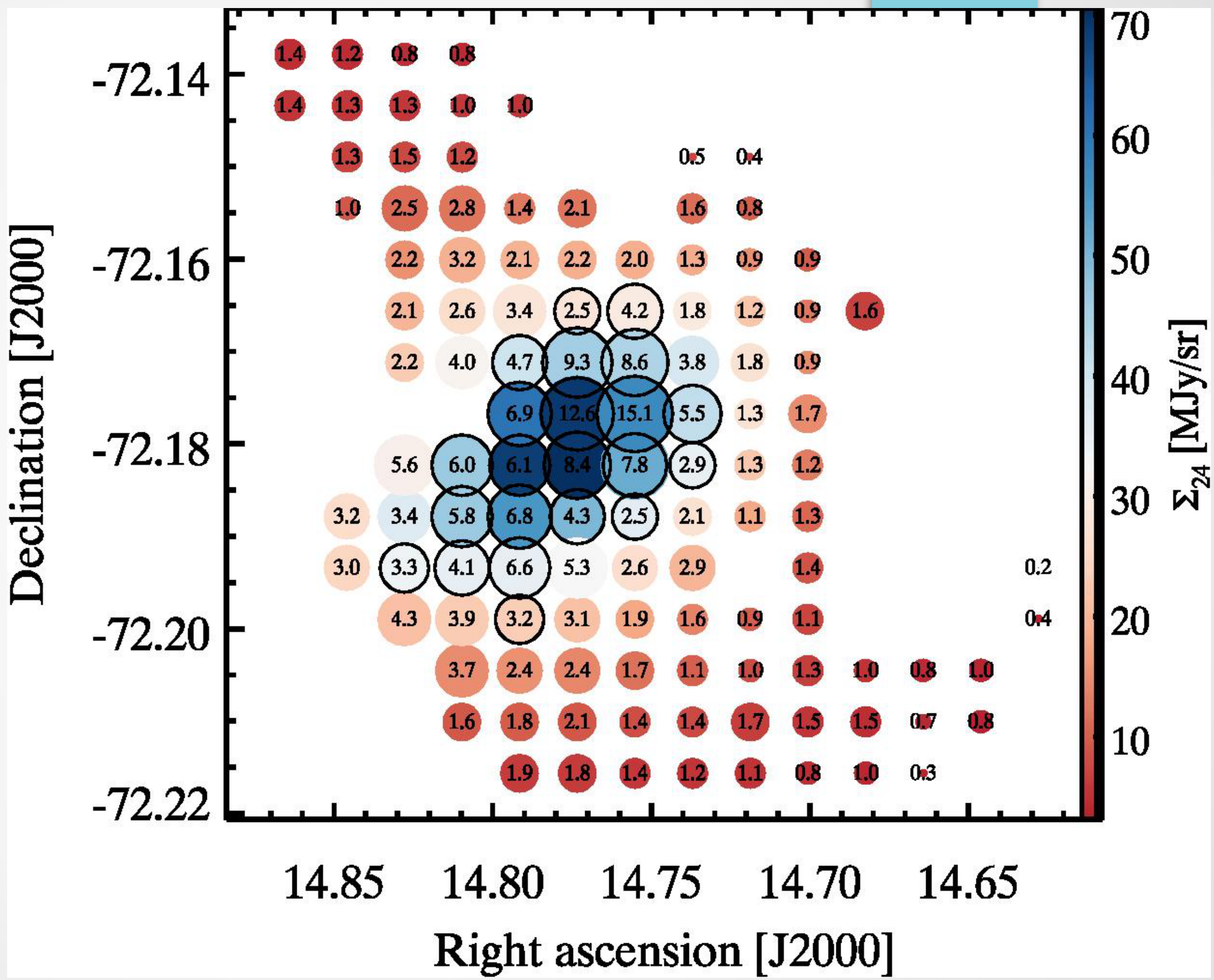
# Stellar mass fraction map

Variations (scatter) is **not random**!

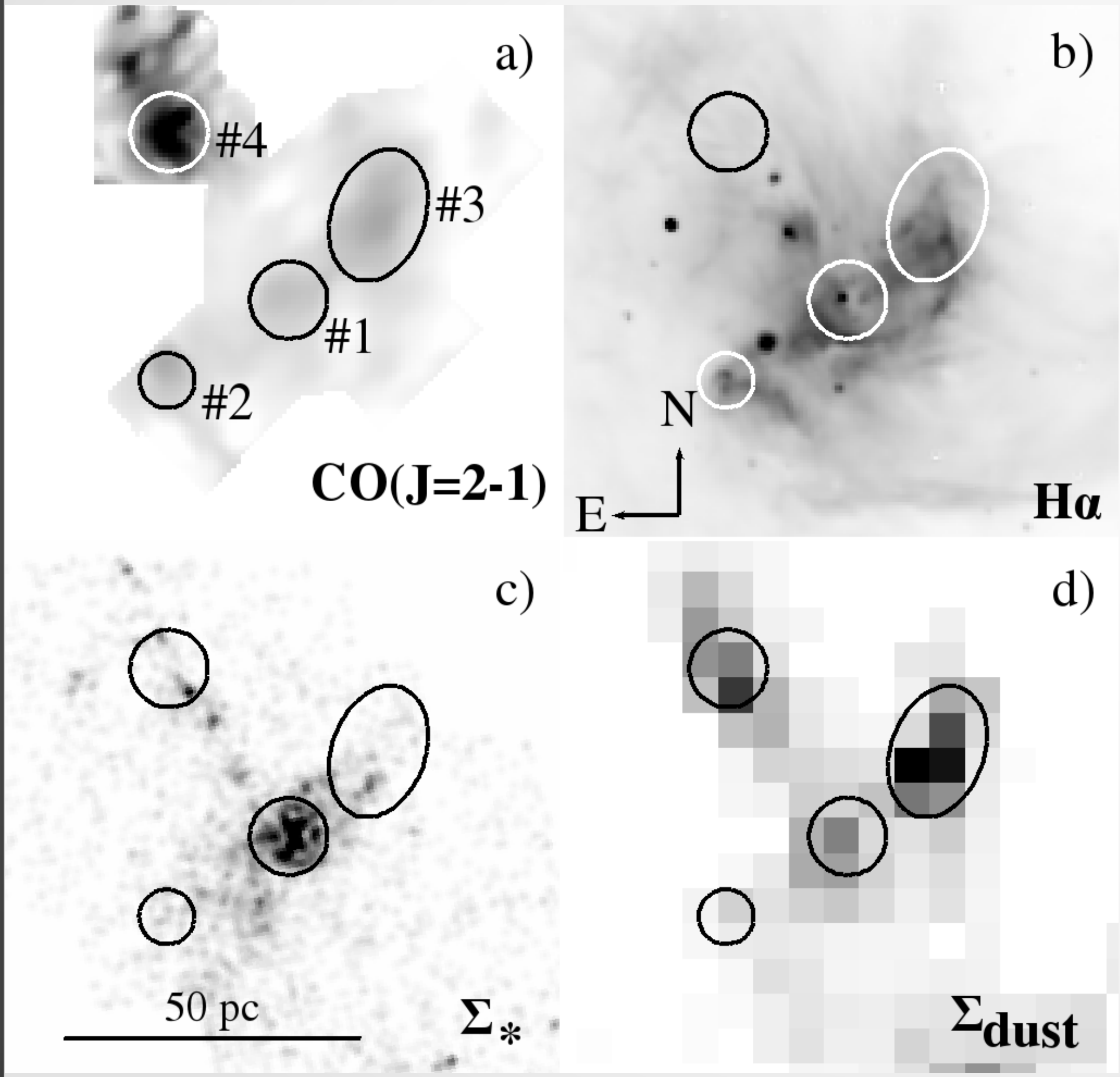
Mostly between 0% and 2% (size of points)

High tail to ~ 15% towards the cluster

High values correlate with 24µm emission (colour of points)



# Variety of environments: snapshot

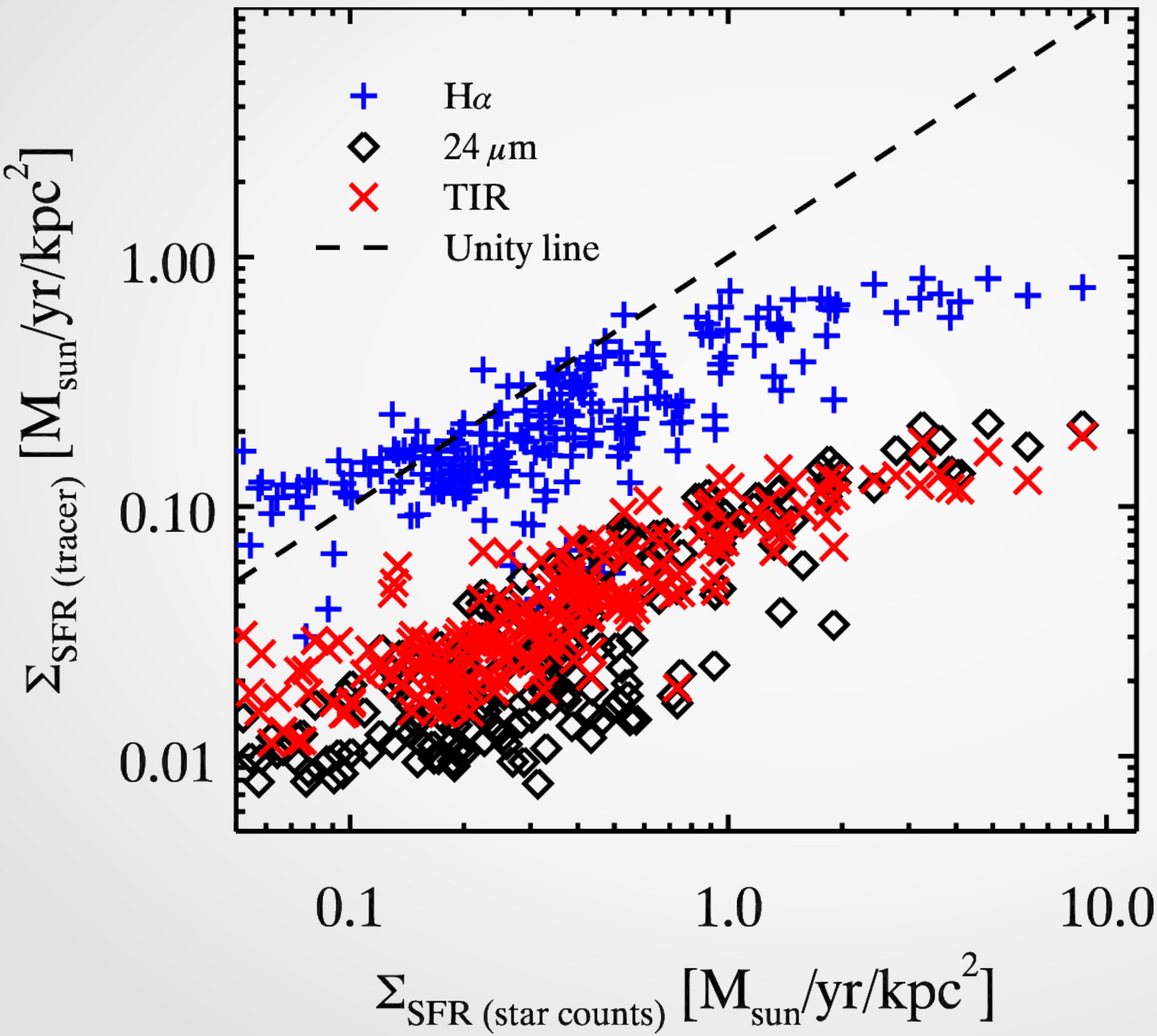



**#1**: many stars, little CO, highest SFE
**#2:** intermediate SFE
**#3:** lots of dust, little CO, low SFE
**#4:** lots of dust, strong CO, low SFE

#4 could become like #1 if strong new SFE will occur

#2 and #3 will probably not

# Dust emission and Hα are tightly correlated




Less than 20% variations in their ratio

Variations do not resemble SFE map

If ~optically thin, ratio measures the chance to be absorbed by gas or dust

→ no **strong** variations in gas-to-dust

# Conclusions

PMS star counts are a **powerful tool** to study star formation

## N66:

Rich cluster (>2000 PMS) **embedded** in fractal distribution

N66 averaged SFE over 90 pc is high compared to SK by a factor of 3

Stars and ISM correlate **even on small scales** (6x6pc) with scatter

Variations are **not random** but highest values (by factor of 3-5) are **all** cluster environment

***High SFE in clustered environment***

# Advantages

**Star counts:**

- Does not require assumed **mass function** or **ages**
- Access to **smaller spatial** scales (~pc) than traditional tracers

**Dust method:**

- Large/Complete coverage
- Not sensitive to gas state or $X_{CO}$
- Assumes gas and dust are **well mixed** and **constant gas-to-dust mass ratio** (appears valid in this case)

# Basic correlation