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

NGC 346 (N66) -
Green: V (F555W)
Red: I (F814W)
Blue: Hα (F658N)

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

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Value</th>
<th>Comments/Refs</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMC distance</td>
<td>$d_{SMC}$</td>
<td>60 kpc</td>
<td>Harries, Hilditch &amp; Howarth (2003)</td>
</tr>
<tr>
<td>Detected young stars</td>
<td>$N_{star}$</td>
<td>5150</td>
<td>Gouliermis et al. (2006)</td>
</tr>
<tr>
<td>Total young stellar mass</td>
<td>$M_{tot}$</td>
<td>$2.2 \cdot 10^4 , \solmass$</td>
<td>Sabbi et al. (2008)</td>
</tr>
<tr>
<td>Mass per catalogue source</td>
<td>$M_{cat}^{\alpha}$</td>
<td>$4.3 , \solmass$</td>
<td>$= M_{tot} \cdot N_{star}^{-1}$</td>
</tr>
<tr>
<td>SF duration</td>
<td>$\Delta t_{SFR}$</td>
<td>$5 \cdot 10^6 , \text{yr}$</td>
<td>Mokiem et al. (2006)</td>
</tr>
<tr>
<td>Gas-to-dust mass ratio</td>
<td>$r_{gd}$</td>
<td>1250</td>
<td></td>
</tr>
</tbody>
</table>

### Derived Quantity

| Young star surface density                   | $\Sigma_*$    | from star catalogue                              |
| Stellar mass surf. dens.                    | $\Sigma_{M_*}$ | $= \Sigma_* \cdot M_{cat}$                       |
| SFR surf. dens.                             | $\Sigma_{SFR}$ | $= \Sigma_{M_*} \cdot \Delta t_{SFR}^{-1}$       |
| Dust surf. dens.                            | $\Sigma_{dust}$ | from SED fitting                                  |
| Gas surf. dens.                             | $\Sigma_{gas}$ | $= \Sigma_{dust} \cdot r_{gd}$                   |
| Stellar mass fraction                      | $frac_{M_*}$  | $= \Sigma_{M_*} \left( \Sigma_{M_*} + \Sigma_{gas} \right)^{-1}$ |
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): \((\Sigma_{24\mu m}/\Sigma_{250\mu m} > 0.3)\) 
  \([\text{Mjy/sr}/(\text{Mjy/sr})]\)
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 $X_{\text{CO}}$
- Assumes gas and dust are well mixed and constant gas-to-dust mass ratio (appears valid in this case)
Basic correlation