Spitzer & Chandra Views of Massive HII Regions

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1. 30 Doradus
2. Comparison to NGC 3603 (MW), NGC 346 (SMC), NGC 604 (M33)
3. Outlook beyond the Local Group (NGC 5253, NGC 4038/39)

Note:

This PDF document has been edited from the version presented at the meeting. The most significant modifications concern the expansion of animated slides over multiple pages for better visibility and the omission of preliminary and unpublished IRS spectra. For any questions please contact brandl@strw.leidenuniv.nl
### 30 Dor

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hα luminosity</td>
<td>$1.5 \times 10^{40} \text{ erg/s}$</td>
<td>Kennicutt 1984</td>
</tr>
<tr>
<td>Ly-c flux (30 Dor)</td>
<td>$1.1 \times 10^{52} \text{ \gamma/s}$</td>
<td>Kennicutt 1984</td>
</tr>
<tr>
<td>Ly-c flux (NGC2070)</td>
<td>$4.5 \times 10^{51} \text{ \gamma/s}$</td>
<td>Walborn 1991</td>
</tr>
<tr>
<td>NGC 2070</td>
<td>2400 OB stars</td>
<td>Parker 1993</td>
</tr>
<tr>
<td>mass (H$_2$)</td>
<td>$7 \times 10^7 \text{ M}_\odot$</td>
<td>Westerlund 1993</td>
</tr>
<tr>
<td>mass (HII)</td>
<td>$8 \times 10^5 \text{ M}_\odot$</td>
<td>Chu&amp;Kennicutt 1994</td>
</tr>
<tr>
<td>$E_{\text{kin}}$ (gas clouds)</td>
<td>$\geq 10^{52} \text{ erg}$</td>
<td>Chu&amp;Kennicutt 1994</td>
</tr>
<tr>
<td>$L_{\text{FIR}}$</td>
<td>$10^8 \text{ L}_\odot$</td>
<td>Werner et al. 1978</td>
</tr>
</tbody>
</table>

### 30Dor: a real Giant

- **R136**: Bright OB stars
- **Hodge 301**:年轻的恒星
- **N157B**: 超新星遗迹

**Distances**:
- 450 pc
- 30' (arcminutes)

**Images**:
- IRAC 4.0 – 5.0 μm
- IRAC 6.5 – 9.4 μm

*Brandl et al. (2005)*
30 Dor: Spitzer + Chandra – “the perfect team”

First there was Chandra – and then there came Spitzer ...

Chandra 0.5 – 0.7 keV
IRAC 3.2 – 4.0 µm
IRAC 6.5 – 9.4 µm

Chandra 1.1 – 2.3 keV
Chandra 0.5 – 0.7 keV
IRAC 6.5 – 9.4 µm
**X-ray Super-bubbles**

*“Standard view”* (Chu & Kennicutt (1986), Chu & Mac Low (1990), Chu & Kennicutt (1994)):

- Winds and outflows from O stars create cavities in the ISM
- O stars $\rightarrow$ SNe
- (off-center) SNe create high-velocity expanding sheels and fill the cavities with diffuse, hot X-ray gas

*What this implies:*

X-ray emission traces the *previous* generation of O-stars in 30 Dor

$\rightarrow$ What’s their origin???

### What about the next stellar generation(s)?

<table>
<thead>
<tr>
<th>Phase</th>
<th>Location</th>
<th>Stellar types</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Orion”</td>
<td>near center (N&amp;W)</td>
<td>IR sources</td>
<td>$\leq$ 1 Myr</td>
</tr>
<tr>
<td>“Carina”</td>
<td>center (R136)</td>
<td>O, WN stars</td>
<td>2-3 Myr</td>
</tr>
<tr>
<td>“Scorpius OB1”</td>
<td>everywhere</td>
<td>OB SGs</td>
<td>4-6 Myr</td>
</tr>
<tr>
<td>“h &amp; $\chi$ Persei”</td>
<td>3' NW of R136</td>
<td>B/A/M SGs</td>
<td>8-10 Myr</td>
</tr>
</tbody>
</table>

*Are there young, still embedded massive clusters in 30Dor? Or is R136 the end of the starburst?*

MCELS (Smith et al.) [637 – 733 nm]
There’s plenty of molecular gas left for star formation... ...and many luminous IR knots!

The R136 cluster

- weak PAHs
- high [Ne III]/[Ne II]

30 Doradus Nebula in the LMC

HST • WFPC2 • NICMOS

PCC09-33a • STScI OPO • N. Walborn (STScI), R. Barbá (La Plata Observatory) and NASA
**Side note: The [Ne III]/[Ne II] ratio**

\[
\begin{align*}
\text{[Ne I]} & \rightarrow \text{[Ne II]} \ (22 \text{ eV}) \\
\text{[Ne I]} & \rightarrow \text{[Ne III]} \ (41 \text{ eV})
\end{align*}
\]

*close in wavelength → excellent measure of the hardness of the radiation field*

<table>
<thead>
<tr>
<th>Starburst99 &amp; CLOUDY</th>
<th>popul. IMF with ( M_{up} = 100M_\odot )</th>
<th>single O star at ( T_{\text{eff}} = 50,000K )</th>
<th>single WN star at ( T_{\text{eff}} = 100,000K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Ne III] / [Ne II]</td>
<td>7</td>
<td>10</td>
<td>70</td>
</tr>
</tbody>
</table>

*... a strong function of time and \( M_{up} \):*

Rigby & Rieke (2004)

**Pos #10: a bright IR source in the North (near Hodge 301)**

- strong PAHs
- “low” [Ne III]/[Ne II]
- steeply rising continuum
  \( \rightarrow \) embedded protocluster(?)
Pos #16: IR peak near R136

- weak PAHs
- very high [Ne III]/[Ne II] (> R136)
  → another embedded cluster?

The most massive optically visible HII region in our Galaxy

- $L_{bol} \sim 10^7 L_\odot$ (Orion: $\sim 10^5 L_\odot$)
- > 50 O stars
- > $10^{51}$ Lyman continuum photons / s
- H$\alpha$ luminosity $2 \times 10^{39}$ erg/s
- central stellar density > R136
• asymmetric GMC: NGC3603 sits near the edge – just like Orion, R136, …

• molecular cloud extends much further (~20pc) southwest

• pillar-like structures visible all the way out
What about X-rays in NGC 3603?

mostly discrete sources
little diffuse emission
no “superbubble” (yet)

Largest SMC cluster (NGC 346 ⇔ N66)
Hα luminosity 60 × Orion
O-stars 33 [22 in center] (Massey et al. 1989)
Metallicity ~1/10 Z⊙ (lowest in the sample)
HST-ACS revealed 2500 PMS stars → age ~ 5 Myr
• MIPS reveals very little extended warm dust
• But luminous IR sources do exist ➔ youngest population < 5 Myr (?)
What about X-rays in NGC 346?

$L_{\text{X-ray}} = 1.5 \times 10^{34} \text{ erg/s}$ \hspace{1cm} (Nazé et al. 2002)

Will there be enough ISM to eventually develop super-bubbles?

C. NGC 604

“2nd most massive HII region in the Local Group”

Distance \hspace{1cm} 840 kpc

Hα luminosity \hspace{1cm} \sim \frac{1}{4} \text{ of 30 Dor but } 450 \times \text{Orion}
The diffuse 8\(\mu\)m PAH and neutral hydrogen trace each other remarkably well

\[ \downarrow \text{H}\alpha + 21\text{cm radio} \]

(Thilker et al. 2003)

What about X-rays in NGC 604?

...just like 30 Doradus: X-ray superbubbles!
totally different stellar distributions
R136: 1.80 */pc²
NGC604: 0.02 */pc²
very similar GMC structure at 8µm

NGC 60430 Dor
WFPC2 (F555W – Hα) (Hunter et al. 1996)
NICMOS (H-band) (Andersen et al. 2005)

One of the closest Wolf-Rayet galaxies
Distance 3.2 kpc (Freedman et al. 2001)
Metallicity ¼ Zₒ
Br-α flux (2") 1000 O7-star equivalents (Crowther et al. 1999)
extended SF in many smaller HII regions in the optical/NIR ...

...and a completely different picture in the mid-IR: almost all of the action is in one central cluster!

Do those massive starburst clusters have a different high-mass IMF?

\[ \text{[Ne III]/[Ne II]} \]
The $[\text{Ne III}]/[\text{Ne II}]$ ratio in NGC 5253…

probed with an IRS spectral map

…is a function of distance from the mid-IR peak

See next talk by Brad Whitmore…!
NGC 4038: [Ne III]/[Ne II] ~ weak
NGC 4039: [Ne III]/[Ne II] ~ strong
→ nucleus of NGC4039 more active!
BUT: young clusters in overlap region more active than either nucleus!

• Where do the SNe that produce the X-ray superbubbles come from?
• Why are massive clusters sitting at the edges of dense clouds?
• Why do most massive star-forming GMCs look so similar?
• What is the sub-structure and content of extragalactic IR SSCs?
• Is the simplistic view on the next slide correct?
• These questions need JWST (MIRI) – how can we support JWST?
thermal pressure \( P/k \)

Pop III stars
- high \([\text{NeIII}]/[\text{NeII}]\)
- coeval population
- large halo

Massive clusters in dwarf gals

Metallicity \( Z \)

Circum-nuclear starbursts
- low \([\text{NeIII}]/[\text{NeII}]\)

Low-mass SF in the MW

- large age spread \( \leftrightarrow \) gas
- UCHIIRs \( \leftrightarrow \) hide O*
- low spatial resolution