Synergies between SKA and ALMA: observations of Nearby Galaxies

Rosita Paladino
Università di Bologna - INAF IRA

and

Jan Brand, Emanuela Orrù, Viviana Casasola, Elisabetta Liuzzo, Marcella Massardi, Arturo Mignano
Some still open questions about star formation:

- Importance of local (disk or cloud instability) versus global effects (spiral density waves, tidal forces, magnetic fields) in triggering SF.
- How the properties of SF depend on various environmental parameters.
- How SF might differ in nuclear regions or in burst and quiescent modes.
- Which is the role of the relativistic phase (cosmic rays and magnetic field) in SF processes.
- Do giant molecular clouds care about the galactic structure?
In our own Galaxy

CO(2-1) map with IRAS point sources
In our own Galaxy

Dust continuum APEX map at 0.87 mm

C$^{18}$O(1-0) contours

A GMC 178 x 41 pc @ 7.5 kpc

In our own Galaxy

Dust continuum APEX map at 0.87 mm

A GMC 178 x 41 pc @ 7.5 kpc
Six substructures detected 1-2 pc large

In our own Galaxy

Radio detections indicating that these three candidates are **Ultra compact HII regions**

In our own Galaxy

Ionized gas
Shock shell
Dense molecular gas

G331.512-0.103
Diameter ~ 1pc

Colour: ALMA $^{13}$CO$^+$ (4-3)
Black contours: ALMA SiO(8-7)
Red contours: 8.64GHz

M51 @ 7.6 Mpc

1.4 GHz image (VLA)
CO(1-0) contours (IRAM)
Resolution ~ 1 arcsec ~ 40 pc


Evidence of GMCs sensitive to their galactic environments
In very nearby galaxies: M51, M33, SMC

(Hughes et al. 2013)

M33 @ 840 kpc

CO(2-1) (IRAM – 30m)
Resolution ~ 12 arcsec ~ 49 pc

Druard et al., 2014
NGC3627 @ 11 Mpc

CO(1-0) image (BIMA)
Resolution ~ 6 arcsec ~ 320 pc
Helfer et al., 2003

CO(1-0) image (IRAM)
1.4 GHz contours (VLA)
Resolution ~ 2 arcsec ~ 100 pc

Paladino et al., 2008

Typical size of a Milky Way GMC is 40 pc
at 10 Mpc we don't resolve them
Arp 217 @ 18.7 Mpc

HST image
3.6 cm contours (VLA)

<table>
<thead>
<tr>
<th></th>
<th>$\alpha^{1.3\text{cm}}$</th>
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<tbody>
<tr>
<td>Arp 217 A</td>
<td>0.2 ± 0.3</td>
</tr>
<tr>
<td>Arp 217 B</td>
<td>-0.0 ± 0.2</td>
</tr>
<tr>
<td>Arp 217 C</td>
<td>-0.7 ± 0.4</td>
</tr>
<tr>
<td>Arp 217 D</td>
<td>...</td>
</tr>
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<td>Arp 217 E</td>
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$S_v \sim v^{-\alpha}$

3 thermal sources
1 non-thermal source

Aversa et al., 2011
To estimate the relative fluxes of non-thermal and thermal sources

Standard non-thermal source: **SNR Cas A @ 2.8 kpc** (the canonical young core-collapse SNR in the galaxy)

- 2260 Jy @ 1.4 GHz
- 740 Jy @ 5 GHz
- 612 Jy @ 8 GHz

(Baars et al., 1977)

Standard thermal source: **W49 A @ 14.1 kpc** (one of the most luminous star forming regions in the Galaxy)

- 47.2 Jy @ 1.4 GHz
- 57.7 Jy @ 5 GHz
- 66 Jy @ 8 GHz

(Mezger et al., 1967)
### 1σ detection sensitivity of Cas A and W49 A up to 100 Mpc

<table>
<thead>
<tr>
<th>Distance (Mpc)</th>
<th>Cas A (μJy)</th>
<th>W49A (μJy)</th>
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<td>177 58 48</td>
<td>93 114 131</td>
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<td>0.9 1.1 1.3</td>
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### Band, Freq (MHz), Max res (arcsec), Sensitivity (μJy hr\(^{-1/2}\))

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<td>650 - 1670</td>
<td>1.9 – 0.8</td>
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SKA-1 mid @ 1.4 GHz would detect both Cas A and W 49 A in galaxies up to 100 Mpc at 1 σ in ~ 2 hrs
@ 5 and 8 GHz 1 hr is enough for a 1 σ detection

In early science phase observations 4x longer

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### SKA resolution

<table>
<thead>
<tr>
<th></th>
<th>Max res (arcsec)</th>
<th>Scale (pc) @ 10 Mpc</th>
<th>Scale (pc) @ 25 Mpc</th>
<th>Scale (pc) @ 50 Mpc</th>
<th>Scale (pc) @ 75 Mpc</th>
<th>Scale (pc) @ 100 Mpc</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKA – 1 sur 1.4 GHz</td>
<td>0.9</td>
<td>44</td>
<td>110</td>
<td>218</td>
<td>327</td>
<td>436</td>
</tr>
<tr>
<td>SKA 1 mid 1.4 GHz</td>
<td>0.22</td>
<td>10</td>
<td>27</td>
<td>53</td>
<td>80</td>
<td>106</td>
</tr>
<tr>
<td>SKA 1 mid 5 GHz</td>
<td>0.06</td>
<td>3</td>
<td>7</td>
<td>14</td>
<td>22</td>
<td>29</td>
</tr>
<tr>
<td>SKA 1 mid 8 GHz</td>
<td>0.04</td>
<td>2</td>
<td>5</td>
<td>9</td>
<td>14</td>
<td>20</td>
</tr>
</tbody>
</table>

**SKA-1 sur** will be able to identify GMCs up to 10 Mpc but not to resolve single compact HII regions.

**SKA-1 mid** will be able to identify GMCs up to 100 Mpc.

**SKA 2**

20x better resolution compact HII regions resolved at all frequencies in galaxies at 100 Mpc.

At 10 Mpc scales of 0.1 pc will be accessible.
ALMA resolution

<table>
<thead>
<tr>
<th>Band</th>
<th>Freq (GHz)</th>
<th>FoV (arcsec)</th>
<th>min res (arcsec)</th>
<th>max res (arcsec)</th>
<th>Scale @ 10 Mpc (pc)</th>
<th>50 Mpc (pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31.3 - 45</td>
<td>145 - 135</td>
<td>13 - 9</td>
<td>0.14 - 0.1</td>
<td>5</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>67 - 90</td>
<td>91 - 68</td>
<td>6 - 4.5</td>
<td>0.07 - 0.05</td>
<td>2.5</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>84 - 116</td>
<td>72 - 52</td>
<td>44.9 - 3.6</td>
<td>0.05 - 0.038</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>125 - 163</td>
<td>49 - 37</td>
<td>3.3 - 2.5</td>
<td>0.035 - 0.027</td>
<td>1.3</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>211-275</td>
<td>29-22</td>
<td>2.0 - 11.1</td>
<td>0.021 - 0.016</td>
<td>0.77</td>
<td>5</td>
</tr>
</tbody>
</table>

Not yet available
In Band 2 DCO⁺ (1-0); DCN and NH₂D predicted from simulations in starburst or CR enhanced regions (Bayet 2010)

CO(1-0); HCN(1-0); HCO⁺ (1-0)

DCO+ (2-1)

CO (2-1); HCN (3-2); HCO+ (3-2); SO₂

ALMA will provide in band 3 a spatial resolution of some pc in galaxies up to 50 Mpc.
ALMA will allow observations of the continuum dust emission

W49A
JCMT-SCUBA image at 0.4 mm
Resolution = 8 arcsec

SMA image at 1.1 mm
Resolution = 2.5 arcsec

Galvàn-Madrid et al., 2014
Comparison between thermal free-free and molecular emission

Lines and continuum observations in 4 GHz bands @ 220 and 230 GHz
resolution: 2 arcsec to 0.8 arcsec
More than 50 molecules (isotopologues) Have been identified.

CO(2-1) integrated flux
$1.23553 \times 10^5 \text{ Jy km s}^{-1}$
rms = 4.8 Jy beam$^{-1}$ km s$^{-1}$

**W49A**
CO(2-1) SMA image
Contours 3.6 cm free free emission

Galván-Madrid et al., 2014
Comparison between thermal free-free and molecular emission

W49A
CO(2-1) SMA image
Contours 3.6 cm free free emission

W49A zoomed-in
CO(2-1) SMA image
Contours 3.6 cm free free emission

Galván-Madrid et al., 2014
Comparison between thermal free-free and molecular emission

W49A
CO(2-1) SMA image
Contours 3.6 cm free free emission

W49A
HC$_3$N SMA image
Contours 3.6 cm free free emission

Galván-Madrid et al., 2014
Comparison between thermal free-free and molecular emission

W49A
CO(2-1) SMA image
Contours 3.6 cm free free emission

W49A
SO$_2$ SMA image
Contours 3.6 cm free free emission

Galván-Madrid et al., 2014
Comparison between thermal free-free and molecular emission

W49A
CO(2-1) SMA image
Contours 3.6 cm free free emission

W49A
CH$_3$CCH SMA image
Contours 3.6 cm free free emission

Galvàn-Madrid et al., 2014
### W49 A molecular emission

<table>
<thead>
<tr>
<th>Line</th>
<th>Rest freq (GHz)</th>
<th>SMA flux (Jy km s(^{-1}))</th>
<th>Flux scaled @ 10 Mpc</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(^{18})O (2-1)</td>
<td>219.56</td>
<td>1.7 x 10(^4)</td>
<td>0.034</td>
</tr>
<tr>
<td>13CO (2-1)</td>
<td>220.39</td>
<td>1.23 x 10(^5)</td>
<td>0.244</td>
</tr>
<tr>
<td>SO</td>
<td>219.94</td>
<td>3.0 x 10(^3)</td>
<td>0.006</td>
</tr>
<tr>
<td>HC(_3)N</td>
<td>218.32</td>
<td>322</td>
<td>6 x 10(^{-4})</td>
</tr>
<tr>
<td>SO(_2)</td>
<td>221.96</td>
<td>305</td>
<td>6 x 10(^{-4})</td>
</tr>
<tr>
<td>CH(_3)CCH</td>
<td>222.09</td>
<td>33</td>
<td>6 x 10(^{-5})</td>
</tr>
</tbody>
</table>

Observations from Galvàn-Madrid 2014

**ALMA sensitivity @ 220 GHz**
- 1 km/s resolution
- 8 hrs of integration time
- is 0.4 mJy

CO isotopologues will be very easily detected @ 10 Mpc
@ 100 Mpc 6 \(\sigma\) detections will be possible

Other less abundant molecules could also be observed @ 10 Mpc but not with high S/N
In summary

SKA-1 mid
@ 1.4 GHz would detect both Cas A and W 49 A in galaxies up to 100 Mpc at 1 $\sigma$ in ~ 2 hrs
@ 5 and 8 GHz 1 hr is enough for a 1 $\sigma$ detection

ALMA will provide in band 3 a spatial resolution of some pc in galaxies up to 50 Mpc.

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**SKA 2**

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The combination of them will make Nearby Galaxies even closer!

Grazie