Unveiling the Massive Stars in the Galactic Center (GC)

Hui Dong (NOAO), Jon Mauerhan (UC, Berkeley), Mark R Morris (UCLA), Daniel Wang (Umass), Angela Cotera (SETI)

Oct 1st, 2013

2013 Galactic Center Workshop, Santa Fe
Introduction

• Galactic Center is the only galactic nucleus, where we can resolve individual young massive stars near a SMBH
  – The star formation mode near a SMBH
  – The properties of the clusters
  – The star formation efficiency
• Three star clusters in the Galactic Center, the Arches, Quintuplet and Central Clusters
• More and more ‘field’ evolved massive stars found in the GC
  – HII regions, Cotera+99
  – Narrow-band filters from ground-based telescope, Homeier+03
  – X-ray and near-IR counterparts, Mauerhan+09
  – Paschen-α emission lines, Dong+11
180 Paα emitting sources, ~80 outside of the three clusters
Diamond: WN, Square: WC, Triangle: WNE, Circle: OB supergiant, Star: LBV,
Pentagon: Unclassified, solid symbol: with X-ray counterparts
Intrinsic F190N magnitude vs Equivalent Width at F187N

WN: large EW, correlation between the EW and F190N, although with large uncertainty. The WN with smallest F190N consistent with that predicted by Figer et al 1995. We should detect most of the WN

WC: large EW range, determined by the dust component

O supergiant: small EW, weaker wind

Unclassified: combination of dusty WC and OIF+ Dong+12
Intrinsic F190N magnitude vs Equivalent Width at F187N

WN: large EW, correlation between the EW and F190N, although with large uncertainty. The WN with smallest F190N consistent with that predicted by Figer et al. 1995. We should detect most of the WN.

WC: large EW range, determined by the dust component.

O supergiant: small EW, weaker wind.

Unclassified: combination of dusty WC and OIF+

Mauerhan et al. 10c

Table 5

Distribution of WR Subtypes in the GCR

<table>
<thead>
<tr>
<th>Group</th>
<th>WNE</th>
<th>WNL</th>
<th>WCE</th>
<th>WCL</th>
<th>WR$_{tot}$</th>
<th>WC/WN</th>
<th>WCL/WC</th>
<th>WC/WR$_{tot}$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCR “isolated”</td>
<td>2</td>
<td>14</td>
<td>0</td>
<td>10</td>
<td>26</td>
<td>0.63</td>
<td>1.00</td>
<td>0.38</td>
<td>1, 2, 3, 4, 5, 6</td>
</tr>
<tr>
<td>Arches</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>n/a</td>
<td>0.00</td>
<td>0.00</td>
<td>7</td>
</tr>
<tr>
<td>Quintuplet</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>11</td>
<td>16</td>
<td>2.20</td>
<td>1.00</td>
<td>0.69</td>
<td>2, 8, 9</td>
</tr>
<tr>
<td>Central</td>
<td>1</td>
<td>17</td>
<td>1</td>
<td>12</td>
<td>31</td>
<td>0.72</td>
<td>0.92</td>
<td>0.42</td>
<td>10</td>
</tr>
<tr>
<td>GCR total</td>
<td>4</td>
<td>50</td>
<td>1</td>
<td>33</td>
<td>88</td>
<td>0.63</td>
<td>0.97</td>
<td>0.39</td>
<td>...</td>
</tr>
</tbody>
</table>

References. (1) This work; (2) Mauerhan et al. 2010b; (3) Cotera et al. 1999; (4) Homeier et al. 2003; (5) Muno et al. 2006; (6) Mikles et al. 2006; (7) Figer & Kim 2002; (8) Liermann et al. 2009; (9) Figer et al. 1999c; (10) Paumard et al. 2006.
The origin of the `field’ evolved massive stars

• Massive stars prefer to form in clusters
• Two possible origins
  – Previous members of the three star clusters
three field evolved massive stars (WN 8-9 h) near the Arches Cluster less than 1-2 pc in projection, Mauerhan+10
The origin of the ‘field’ massive stars

- Massive stars preferred to form in clusters
- Two possible origins
  - Previous members of the three star clusters
  - Stars belong to isolated small star clusters
    - Sgr A A-D, Yusef-Zadeh+10, Mills+11
    - SiO clumps found near Sgr A*, potential early star formation process, Yusef-Zadeh+13
Evolved massive stars with nearby HII regions.

Evolved massive stars could provide enough UV photons to ionize the HII regions.
GNIRS: H and K bands, three sources, NIFS: K band, five sources
Aim: Using radial velocities to derive the relationship between stars, nearby HII regions and the Arches cluster
Method: He II 2.189, NIII 2.247/2.251 doublets
Proper motion: assuming the stars ejected from the Arches cluster when they were formed. The 3D velocity relatively to the Arches cluster: ~60-140 km/s, low limit.

unreddened CMD: Lines: Genova, 1, 2, 4, 6.3 Myr

These eight stars are < 7 Myr old. P100, P107 and P36 are older than the Arches cluster.
Grey shaded area: the Arches cluster -98(8) km/s Figer+02
‘cross’ : eight massive stars
Red lines: nearby HII regions from Bry
Blue lines: nearby HII regions from H92α, Lang et+01
Cyan lines: nearby molecular clouds, Serabyn & Guesten, 87, Tsuboi+99, 11
P35 in H2. The ionized gas is blueshifted, compared to the stars and nearby molecular clouds. No H$_2$ 2.121. Not the bow shock, Pressure-driven flow model?
Pressure-Driven flows:
Stars is nearly stable relatively to the ISM
Stas have strong stellar wind
1) Stars are in front of the molecular cloud
2) No $\text{H}_2$ 2.121 micron needed
3) The radial velocity of the ionized gas can be accelerated to very high

Zhu Qing-Feng+08
Molecular clouds follow an infinite ($\infty$) shape, the orbital period is \(~ 3\) Myr. 
-30-0 km/s is behind the Sgr A* now. -30-0 km/s and Sgr A* could meet \(~ 2\) Myr ago. The strong stellar wind in the Central cluster triggered the star formation in H1/H2.
Summary

• Evolved Massive Stars pervade the GC
• Most WN stars have been identified, but we still miss many WC stars and O supergiants
• Our new Gemini GNIRS/NIFS spectra
  – A new O If+ star, P97, <1.5’ (3.6 pc) from Arches cluster, potential former members
  – H5, a runaway star, interlopers unassociated to nearby molecular cloud
  – H1/H2, pressure-driven flow model, indicating in-situ star formation
Thank you
Simulation of 3-body interaction
Gvaramadze+11. Circle: mean velocity. Diamond: top 10%. Star: top 1%.
The eight stars could be ejected from the Arches cluster.
color-magnitude diagram for Paα emitting sources near-IR magnitude from SIRIUS and 2MASS catalog
Black dots: SIRIUS GC catalog, most of them are Red Clump, Red Branch Stars and asymptotic giant branch stars.
Color symbols: Paα emitting sources in and outsider the three clusters
Most of the `field’ Paα emitting sources are indeed in the GC

Dong et al., 2012
Bow shock:
Stars quickly move into the ISM
1) Stars are behind the molecular cloud
2) $\text{H}_2$ 2.121 micron shock lines
3) Near the vertex, the radial velocity of the ionized gas is roughly equal to the radial velocities of the massive stars

Zhu Qing-Feng+08