Very small HII regions embedded in massive accretion flows: two examples

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Massive ($O, M_\star > 16 M_\odot$) stars likely start burning H before they reach their final mass (Bernasconi & Maeder 96; Keto 03; etc).

- What happens when ionization turns on?
- Is accretion finished?
- How does the star reach its final mass?

How accreting B protostars become O stars?

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## PROPERTIES OF HII REGIONS

<table>
<thead>
<tr>
<th>Class of Region</th>
<th>Size (pc)</th>
<th>Density (cm(^{-3}))</th>
<th>Emis. Meas. (pc cm(^{-6}))</th>
<th>Ionized Mass (M(_\odot))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypercompact</td>
<td>(&lt;0.03)</td>
<td>(&gt;10^6)</td>
<td>(&gt;10^{10})</td>
<td>(\sim10^{-3})</td>
</tr>
<tr>
<td>Ultracompact</td>
<td>(&lt;0.1)</td>
<td>(&gt;10^4)</td>
<td>(&gt;10^7)</td>
<td>(\sim10^{-2})</td>
</tr>
<tr>
<td>Compact</td>
<td>(&lt;0.5)</td>
<td>(&gt;5 \times 10^3)</td>
<td>(&gt;10^7)</td>
<td>(\sim1)</td>
</tr>
<tr>
<td>Classical</td>
<td>(\sim10)</td>
<td>(\sim100)</td>
<td>(\sim10^2)</td>
<td>(\sim10^5)</td>
</tr>
<tr>
<td>Giant</td>
<td>(\sim100)</td>
<td>(\sim30)</td>
<td>(5 \times 10^5)</td>
<td>(10^3–10^6)</td>
</tr>
<tr>
<td>Supergiant</td>
<td>(&gt;100)</td>
<td>(\sim10)</td>
<td>(\sim10^5)</td>
<td>(10^6–10^8)</td>
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From Kurtz 05
LOOKING FOR HCHIIs WITH INDICATIONS OF ACCRETION OF

Sources
- A small sample of Hypercompact / small Ultracompact regions
- Span different levels of ionization

Properties Looked For In SMA And VLA Archive Data
- Compact free-free emission ($\theta_s < 1''$)
- Evidence of $\alpha \sim 1$ (where $S_\nu \propto \nu^\alpha$)
- Evidence of dense molecular gas with interesting kinematics

 Desired Data Set
- SMA: dense core tracers (CH$_3$CN, SO$_2$, etc) and outflow tracers (CO’s, SiO) at $\theta_B \approx 4'' - 0.4''$
- VLA: dense core tracer (NH$_3$) at $\theta_B \approx 4'' - 0.4''$
- SMA+VLA: ionized gas tracer (Radio Recomb Lines) at $\theta_B < 1''$
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THE SUBMILLILETER ARRAY

Moran 1998; Ho, Moran & Lo 2004; Blundell 2005

Picture by Sergio Martín
LOW IONIZATION: W33A

- $L \sim 1 \times 10^5 L_\odot$ ($d \approx 4$ kpc)
- 2 main mm (dust) cores separated by 20 000 AU (van der Tak+ 00, Faúndez+ 04)
- 2 or 3 faint ($\sim 1$ mJy) HCHIIIs at cm $\lambda$'s, with $\alpha \sim 1$ (van der Tak & Menten 05)

SMA Compact

- We detect mm1 and mm2
- mm1 has richer chemistry

from van der Tak+ 00, 10'' $\approx 40 000$ AU $\approx 0.2$ pc

VLA-A 43 GHz (7 mm), from van der Tak & Menten 05, 1'' $\approx 4000$ AU
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A ROTATING TOROID AND ITS OUTFLOW

Outflows
There are $\geq 2$ high-vel outflows

Zooming in (VEX Array)
- mm1 is resolved into two sources (counterparts of the weak HCHII)
- There is a molecular 'rotating toroid' in mm1-Q1 ($M_{\text{dyn}} \sim 10M_\odot$), perpendicular to the main outflow

Modelling with RT code (Keto)
G-M+ 09, in prep, 10'' $\approx$ 40 000 AU
blue = [4,28], red = [50,96], $V_{\text{sys}}$ $\approx$ 38.5 km s$^{-1}$
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- ≥ 3 massive stars are forming, 1 of them might become an O star
- Ionization is weak ⇒ (partially) quenched H II regions
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HIGHER IONIZATION: G20.08-0.14 N

- $L \sim 7 \times 10^5 \, L_\odot \, (d \approx 12 \, \text{kpc})$
- Molecular core of $\sim 1.5 \, \text{pc}$ (Plume+ 92, Klaassen & Wilson 08)
- Masers: OH (Ho+ 83); H$_2$O (Hofner & Churchwell 96); CH$_3$OH (Walsh+ 98)
- Broad cm RRLs (Sewilo+ 04, Garay+ 85)

- 3 (cm) continuum components (H II regions) in the inner 50 000 AU
- Only source A is brighter at 1.3 mm that at 1.3 cm

from Klaassen & Wilson 08, $\theta_{\text{beam}} \approx 15'' \approx 0.9 \, \text{pc}$

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The large-scale core surrounds the H II regions and apparently rotates from SW (blue) to NE (red), $V_{sys} \approx 42.0 \pm 0.8 \text{ km s}^{-1}$.

The absorption against the background H II regions shows infall.

$M_{H_2} \sim 2000 \, M_{\odot}$

VLA-D, NH$_3$, frames $\approx 30'' \approx 1.8$ pc
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VLA-D, NH\(_3\), frames \( \approx 30'' \approx 1.8 \text{ pc} \)
THE INNER 0.1 pc

All the SMA-VEX lines show a velocity gradient in SW(blue)-NE(red) direction exclusively toward A ⇒ rotation \( V_{sys} \approx 41.8 \pm 0.3 \text{ km s}^{-1} \)

The redshifted NH\(_3\) absorption at \( \theta_B \approx 0.5'' \) is dominated by source A ⇒ infall

\[ M_{dyn} \approx 50 - 100M_\odot = M_* + M_{gas} \]
\[ T_k \approx 400 \text{ K} \] toward the center

SMA-VEX, OCS \( J = 19 - 18 \) and CH\(_3\)CN \( J(K) = 12(3) - 11(3) \)
frames \( \approx 5'' \approx 60 000 \text{ AU} \approx 0.3 \text{ pc} \)
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Source A is best modeled by a sum of an H II region with a density gradient plus warm dust.

- $\tau_{L,C} << 1$ at 1.3-mm $\Rightarrow$ $S_L/S_C \approx \kappa_L/\kappa_C \approx 2.3 - 3.0$ for free-free.
- And $S_L/S_C$ (observed) $\approx 1.8$ $\Rightarrow$ 60 – 80% of the 1.3-mm continuum is free-free.
- $R_{H\text{II}} \approx 2500$ AU; $M_\star \approx 35$ $M_\odot$; $\gamma \approx 1.3$, where $n \propto r^{-\gamma}$.
Source A is best modeled by a sum of an H II region with a density gradient plus warm dust.

- \(\tau_{L,C} \ll 1\) at 1.3-mm \(\Rightarrow\) \(S_L/S_C \approx \kappa_L/\kappa_C \approx 2.3 - 3.0\) for free-free
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THE IONIZED GAS: RRLs

\[ \Delta V_{RRL} \] (pressure, thermal, turbulence, bulk) \[ \Rightarrow \Delta V_{bulk} \sim 10 - 20 \text{ km s}^{-1} \]

\[ V_{H30\alpha} \approx 40.3 \pm 0.4 \text{ km s}^{-1}, \text{ slightly blueshifted to } V_{sys} = 42 \text{ km s}^{-1} \]

The ionized gas appears to have a similar velocity gradient at \( R < 3000 \text{ AU} \approx R_d \)

Rotation + outflow in the ionized gas?

Top: RRL with SMA. Bottom: with VLA
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OVERALL INTERPRETATION FOR G20.08N

- Rotating natal core formed the cluster of continuum sources
- Current activity is localized in source A.
- The molecular gas around A is rotating and infalling.
- The ionized gas appears to have rotation+slow outflow
- This HCHII appears to have internal density gradients

- Source A is a very young HCHII, where O star(s) formed (are forming) by accretion of gas
- Current stage: photoevaporating disk?, photoevaporating envelope?, accretion through H II region? (Hollenbach+ 94; Keto 03,07; Lugo+ 04)

Need for more observations to image the outflow(s) and resolve the HCHII region A
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CONCLUSIONS

From these 2 sources plus partial analysis of other ∼ 4 objects:

- Some of the most compact H II regions are confined by molecular toroids that appear to be rotating
- The molecular gas also shows infall and/or outflow to/from these H II regions
- The H II regions themselves appear to have organized motions and density gradients
- They also appear to be time variable (not shown in this talk)
- The above phenomena can be interpreted as these H II regions being the inner, ionized part of the surrounding massive accretion flow
- Has accretion onto the central star(s) stopped?
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