Hyper and Ultra-Compact HII regions

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Outline

• Introduction
• HCHII/UCHII Properties
• Distribution and Statistic of UCHII Regions
• Results from the CORNISH and ATLASGAL Surveys
• Future Surveys and Summary
Hyper and Ultra-Compact HII regions

Introduction
Hyper and Ultra-Compact HII regions

Introduction

- Compact bubbles of photoionized gas excited by a massive young stellar object ($L_{\text{bol}} > 10^3 L_\odot$)
- One of the most reliable tracers of recent massive star formation
- Still deeply embedded within their natal molecular clump
- Most UCHIIs to date have been identified by their centimetre-wavelength free-free emission
- Radio-wavelength radiation is able to penetrate the dense molecular cores

<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>$\lesssim 0.03$</td>
<td>$\gtrsim 10^6$</td>
<td>$\gtrsim 10^{10}$</td>
<td>$\sim 10^{-3}$</td>
</tr>
<tr>
<td>Ultracompact</td>
<td>$\lesssim 0.1$</td>
<td>$\gtrsim 10^4$</td>
<td>$\gtrsim 10^{7}$</td>
<td>$\sim 10^{-2}$</td>
</tr>
<tr>
<td>Compact</td>
<td>$\lesssim 0.5$</td>
<td>$\gtrsim 5 \times 10^3$</td>
<td>$\gtrsim 10^7$</td>
<td>$\sim 1$</td>
</tr>
<tr>
<td>Classical</td>
<td>$\sim 10$</td>
<td>$\sim 100$</td>
<td>$\sim 10^2$</td>
<td>$\sim 10^5$</td>
</tr>
<tr>
<td>Giant</td>
<td>$\sim 100$</td>
<td>$\sim 30$</td>
<td>$5 \times 10^5$</td>
<td>$10^3 - 10^6$</td>
</tr>
<tr>
<td>Supergiant</td>
<td>$&gt; 100$</td>
<td>$\sim 10$</td>
<td>$10^5$</td>
<td>$10^6 - 10^8$</td>
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Kurtz 2005, IAUS, 227, 111
Hyper and Ultra-Compact HII regions
Thermal Bremsstrahlung Emission

- Turnover frequency for UCHII region with densities of order $10^4$ cm$^{-3}$ and sizes of 0.1 pc is $\sim 5$ GHz or 6 cm
- However, for HCHII regions with densities of $10^6$ cm$^{-3}$ and sizes of 0.03 pc the turnover frequency is $\sim 50$ GHz or 0.6 cm
- The flux density of an HCHII region is up to 100 times lower than the peak at 6 cm
- Only a few 10 of HCHII regions have been detected
• Turnover frequency for UCHII region with densities of order $10^4$ cm$^{-3}$ and sizes of 0.1 pc is $\sim$5 GHz or 6 cm

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• The flux density of an HCHII region is up to 100 times lower than the peak at 6 cm

• Only a few 10 of HCHII regions have been detected
## Hyper and Ultra-Compact HII regions

### Current Samples of UCHIIIs

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### Targeted Surveys

- Specific Regions
- Unbiased Surveys

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High-Mass Star Formation in the Era of Herschel and ALMA

Lorentz Center 22/01/2013
Hyper and Ultra-Compact HII regions

Spectral Index: G75.78+0.34


Kurtz 2005, IAUS, 227, 111
Hyper and Ultra-Compact HII regions

HCHII Region: NGC 7538 IRS1

Sandell et al., 2009, ApJL, 699, 34
Hyper and Ultra-Compact HII regions

HCHII Region: G34.26+0.15

Hyper and Ultra-Compact HII regions

Radio Recombination Line Widths

- Radio recombination Line (RRL) profiles
- HCHII Regions RRL > 40 km/s
- UCHII Regions RRL ~ 30 km/s

## Hyper and Ultra-Compact HII regions

### Radio Recombination Line Widths

<table>
<thead>
<tr>
<th>Source</th>
<th>RRL</th>
<th>FWHM (km s(^{-1}))</th>
<th>Dist (kpc)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 7538</td>
<td>H66(\alpha)</td>
<td>180</td>
<td>3.0</td>
<td>1</td>
</tr>
<tr>
<td>G25.5+0.2</td>
<td>H42(\alpha)</td>
<td>161</td>
<td>14.5</td>
<td>2</td>
</tr>
<tr>
<td>Sgr B2</td>
<td>H66(\alpha)</td>
<td>80</td>
<td>8.5</td>
<td>3</td>
</tr>
<tr>
<td>W49 AA</td>
<td>H66(\alpha)</td>
<td>50</td>
<td>11.4</td>
<td>4</td>
</tr>
<tr>
<td>W49 AB</td>
<td>H66(\alpha)</td>
<td>60</td>
<td>11.4</td>
<td>4</td>
</tr>
<tr>
<td>W49 AG</td>
<td>H66(\alpha)</td>
<td>45</td>
<td>11.4</td>
<td>4</td>
</tr>
<tr>
<td>M17-UC1</td>
<td>H52(\alpha)</td>
<td>47</td>
<td>2.2</td>
<td>5</td>
</tr>
<tr>
<td>G28.2−0.0</td>
<td>H92(\alpha)</td>
<td>74</td>
<td>9.1</td>
<td>6</td>
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Hyper and Ultra-Compact HII regions

Size vs. Line Width

- High frequency lines narrower
- No distinct brake between UCHIIls and HCHIIls

Hoare et al., 2007, PPV, 181

Keto et al., 2008,
Hyper and Ultra-Compact HII regions

Radio to IR ratio vs. Speed

- Big distinction between UCHIIls and MYSOs
- No clear break between UCHII/ HCHIIls at 40-60 km/s

Hoare et al., 2007, PPV, I81
Hyper and Ultra-Compact HII regions
Radio vs. IR Luminosity

- Clear distinction between UCHIIs and MYSOs at luminous end
- MYSOs also distinguished from OB star winds — MS OB stars not detected yet

Hoare & Franco, 2007
Hyper and Ultra-Compact HII regions
RMS Sample of UCHIIs

- The Red MSX Source (RMS) survey is a colour selected sample of embedded massive YSOs and HII regions
- Compiled the most complete sample of UC and Compact HII regions
- Consists of ~600 HII regions distributed across the Galaxy
- Incorporates nearly all of the HII regions identified by the various radio continuum surveys

Robert Hurt of the Spitzer Science Center
Mottram et al. 2011, ApJL, 730, 33 (Updated)


Luminosity Distribution and Lifetimes

- Still predicts that stars above ~30 Mo are accreting whilst in the UCHII phase
- Some HII regions exciting stars exhibit MYSO spectral features of accretion like the CO bandhead
Hyper and Ultra-Compact HII regions
RMS Sample of UCHIIs

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Hyper and Ultra-Compact HII regions
Transition Objects

HII/YSO example – MS accretion

MYSO driving HII region – star has $T_{\text{eff}} \sim 36000\text{K}$
($L > 2 \times 10^5 L_\odot$)
Fit to CO profile =>
$M \sim 25 M_\odot$, $r_{\text{in}} \sim 0.6\text{au}$, $r_{\text{out}} \sim 5\text{au}$,

Highest luminosity MYSOs live in HII regions – harder to study in detail

### Hyper and Ultra-Compact HII regions

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Hyper and Ultra-Compact HII regions

**Co-Ordinated Radio ‘N’ Infrared Survey for High-mass star formation**

- High resolution 5 GHz VLA survey of the Galactic Plane (10° < l < 65°, |b| < 1°)
- Uses VLA config B and BnA which yields a resolution of 1.5″ and r.m.s of 0.4 mJy/beam
- Optimised to detect emission on scales of < 12″
- Catalogue is 90% complete at a flux density of 2.7 mJy for unresolved sources
- Detected ~3,000 sources above a 7σ
- Most common sources found: HII regions, planetary nebular, radio-galaxies


High-Mass Star Formation in the Era of Herschel and ALMA
Hyper and Ultra-Compact HII regions

ATLASGAL Survey

- APEX 870 µm continuum survey of the inner Galactic plane (300° < l < 60°, |b| < 1.5°)
- Angular resolution of ~19" and sensitivity of 60 mJy/beam
- Sensitive to clumps with masses ~1,000 M☉ to 20 kpc
- Detected ~12,000 compact sources above 3σ threshold
  - ~6,000 presented by Contreras et al., 2013
  - [http://atlasgal.mpifr-bonn.mpg.de/cgi-bin/ATLASGAL_DATABASE.cgi](http://atlasgal.mpifr-bonn.mpg.de/cgi-bin/ATLASGAL_DATABASE.cgi)
Hyper and Ultra-Compact HII regions

ATLASGAL-CORNISH Matches

- Unbiased sample located between $l = 10-60^\circ$ and $|b| < 1^\circ$
- Identified ~200 embedded HII regions
- Angular off $\sim 0'' \pm 4''$ between radio and submm peaks
Hyper and Ultra-Compact HII regions
UCHII Region Morphologies

• Important as they can provide clues as to the state of the surrounding medium
• Morphological types first classified by Wood and Churchwell (1989)
  • Cometary
  • Spherical
  • Shell
  • Irregular
  • Core-Halo
  • Bipolar — added by Churchwell (2002)
Hyper and Ultra-Compact HII regions

Morphologies: Cometary

High-Mass Star Formation in the Era of Herschel and ALMA

Lorentz Center 22/01/2013
Hyper and Ultra-Compact HII regions
Morphologies: Spherical
Hyper and Ultra-Compact HII regions
Morphologies: Spherical at Higher Resolution

Hyper and Ultra-Compact HII regions
Morphologies: Irregular
Hyper and Ultra-Compact HII regions

Morphologies: Core-Halo
Hyper and Ultra-Compact HII regions

Morphologies: Bipolar
Hyper and Ultra-Compact HII regions

Morphologies: Evolving

NGC 7538 IRS1


G5.89-0.39


G25.78+0.08 A1


High-Mass Star Formation in the Era of Herschel and ALMA
Hyper and Ultra-Compact HII regions
Associated Clump Properties
Hyper and Ultra-Compact HII regions
UCHII Ionizing Photon Flux
Hyper and Ultra-Compact HII regions
ALMA Observations: Continuum

ATLASGAL 870 μm

CORNISH 5 GHz

High-Mass Star Formation in the Era of Herschel and ALMA
Hyper and Ultra-Compact HII regions
ALMA Observations: Continuum

7 pointings

ATLASGAL 870 μm

CORNISH 5 GHz
Hyper and Ultra-Compact HII regions

ALMA Observations: Radio Recombination Lines (RRLs)

\[ \frac{\Delta v^I}{\Delta v^D} = 0.142 \left( \frac{n}{100} \right)^{7.4} \left( \frac{N_e}{10^4} \right) \]

\[ \int \frac{T_L dv}{T_c} \approx 6.76 \times 10^3 v^{1.1} T_e^{-1.15} \]

Courtesy of Pamela Klaassen

Max-Planck-Institut für Radioastronomie

High-Mass Star Formation in the Era of Herschel and ALMA

Lorentz Center 22/01/2013

33
High-Mass Star Formation in the Era of Herschel and ALMA

Hyper and Ultra-Compact HII regions

ALMA Observations: Radio Recombination Lines (RRLs)

ATLASGAL 870 μm

CORNISH 5 GHz

W51e2

H53α


SO2


Hyper and Ultra-Compact HII regions

Future Surveys

Current and Future Surveys

- CORNISH
- GloStar
- MeerGal

JVLA

MeerKAT
Hyper and Ultra-Compact HII regions

Future Surveys: CORNISH
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Hyper and Ultra-Compact HII regions

Future Surveys: GloStar

GloStar

- Uses the JVLA with its more sensitive receivers
- Combines B and D Configurations with Single Dish Effelsberg for short spacings
  - sensitive to angular scales from 1" to a few arcminutes
- 2 GHz continuum (4.2-5.2 GHz and 5.9-6.9 GHz) → 40 µJy sensitivity
- 6.7 GHz methanol masers (0.18 km/s; 370 km/s) → 20 mJy sensitivity
- 4.8 GHz H$_2$CO absorption (0.25 km/s; 260 km/s) → 20 mJy sensitivity
- 7 RRL (3-4 km/s; ~400 km/s) → 5 mJy sensitivity

K.M. Menten, C. Carrasco-Gonzales, A. Brunthaler, F. Wyrowski, T. Csengeri, J. Urquhart, B. Winkel (MPIfR); M.J. Reid, (CfA); J. Ott, M. Claussen (NRAO); J. Pandian (Hawaii); P. Hofner (NMT); H. Beuther (MPA)
Hyper and Ultra-Compact HII regions

Future Surveys: GloStar

Improvement to Large Angular Scales

Glostar (D+B)

CORNISH (B-only)
Hyper and Ultra-Compact HII regions
Future Surveys: GloStar

Advantage of Including Single Dish Data

G59.0+0.0
Hyper and Ultra-Compact HII regions

Future Surveys: GloStar

Spectral Lines

Methanol Maser

4.8 GHz $H_2CO$ absorption

RRL
Hyper and Ultra-Compact HII regions

Future Surveys: GloStar

Sensitivity to HCHIIls
Hyper and Ultra-Compact HII regions

Future Surveys: GloStar

Sensitivity to HCHIIIs

[Graphs and diagrams showing sensitivity to HCHIIIs]
Hyper and Ultra-Compact HII regions
Future Surveys: GloStar

Sensitivity to HCHIIs
Hyper and Ultra-Compact HII regions

Future Surveys: MeerGal

- Will use the MeerKAT high frequency band to explore the Milky Way’s population of high frequency objects
- Survey the southern Gal. Plane at 14 GHz
- Due to begin with the commissioning of the high freq. band in 2018
Hyper and Ultra-Compact HII regions
Future Surveys: MeerGal

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Summary

• Still unclear whether HCHII regions are a distinct class of object or simply smaller and denser HII regions

• Next generation of radio continuum surveys will provide a much better picture of this evolutionary stage

• Galactic population of UCHIIs ~600 and ~300 with luminosities of O6 stars

• Stars more massive than > 30 $M_\odot$ are associated with and most are associated with Compact HII regions rather and UCHIIs

• All UCHIIs are associated with clumps with masses > 1,000 $M_\odot$ and peak flux densities of > 1 Jy at 870 $\mu$m and so readily observable with ALMA