Irradiated shocks in the W28 A2 (G5.89-0.39) massive star-forming region: sites for CR acceleration ?

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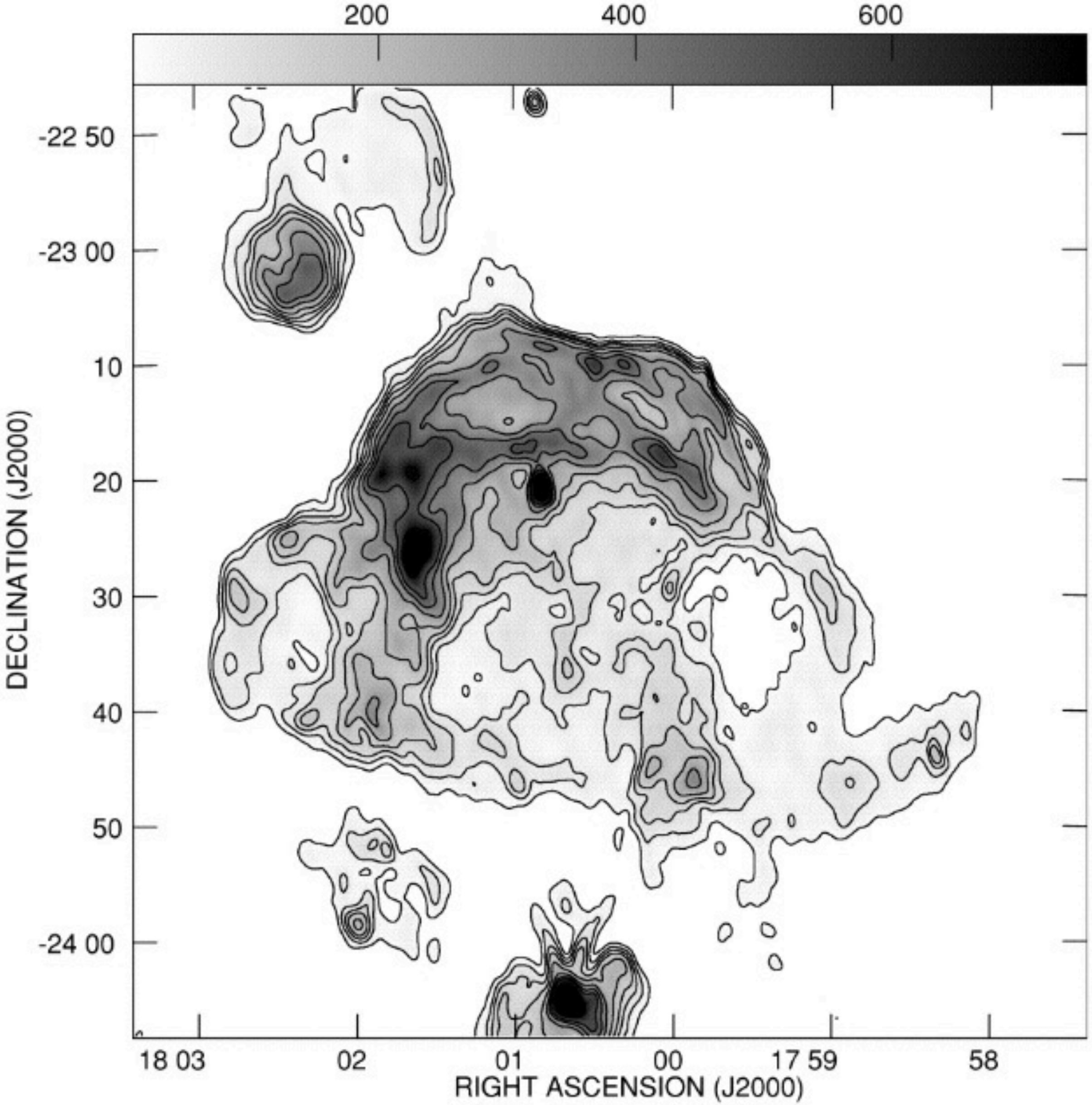
Sibylle Anderl,	IPAG, Grenoble, France
Rolf Güsten,	MPIfR, Bonn, Germany

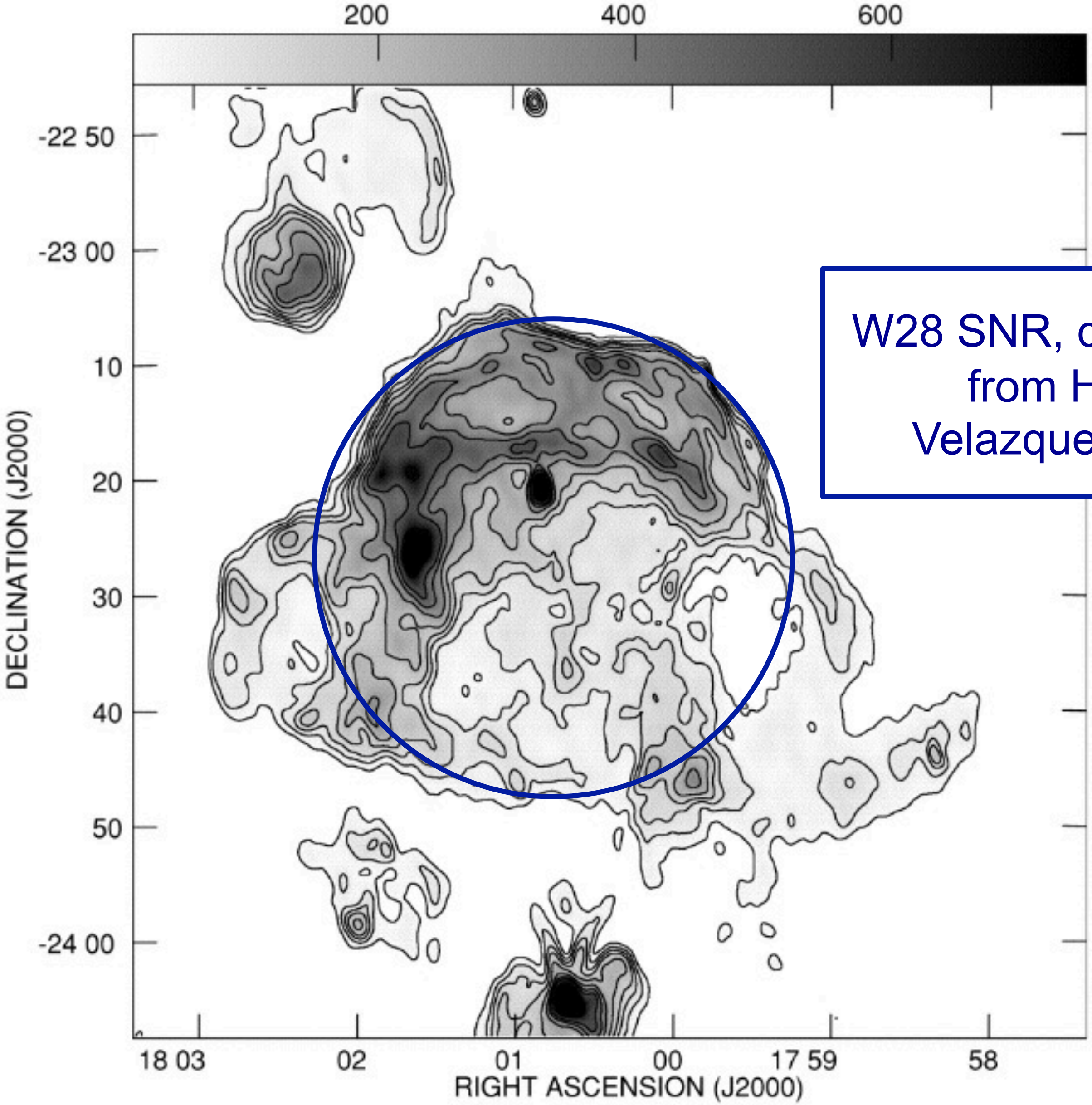
…and the PRISMAS Team

The W28 'region'



Dubner et al. 2000
1415 MHz

The W28 'region'



W28 SNR, d = 1.9+/-0.3kpc
from HI velocity,
Velazquez et al. 2002

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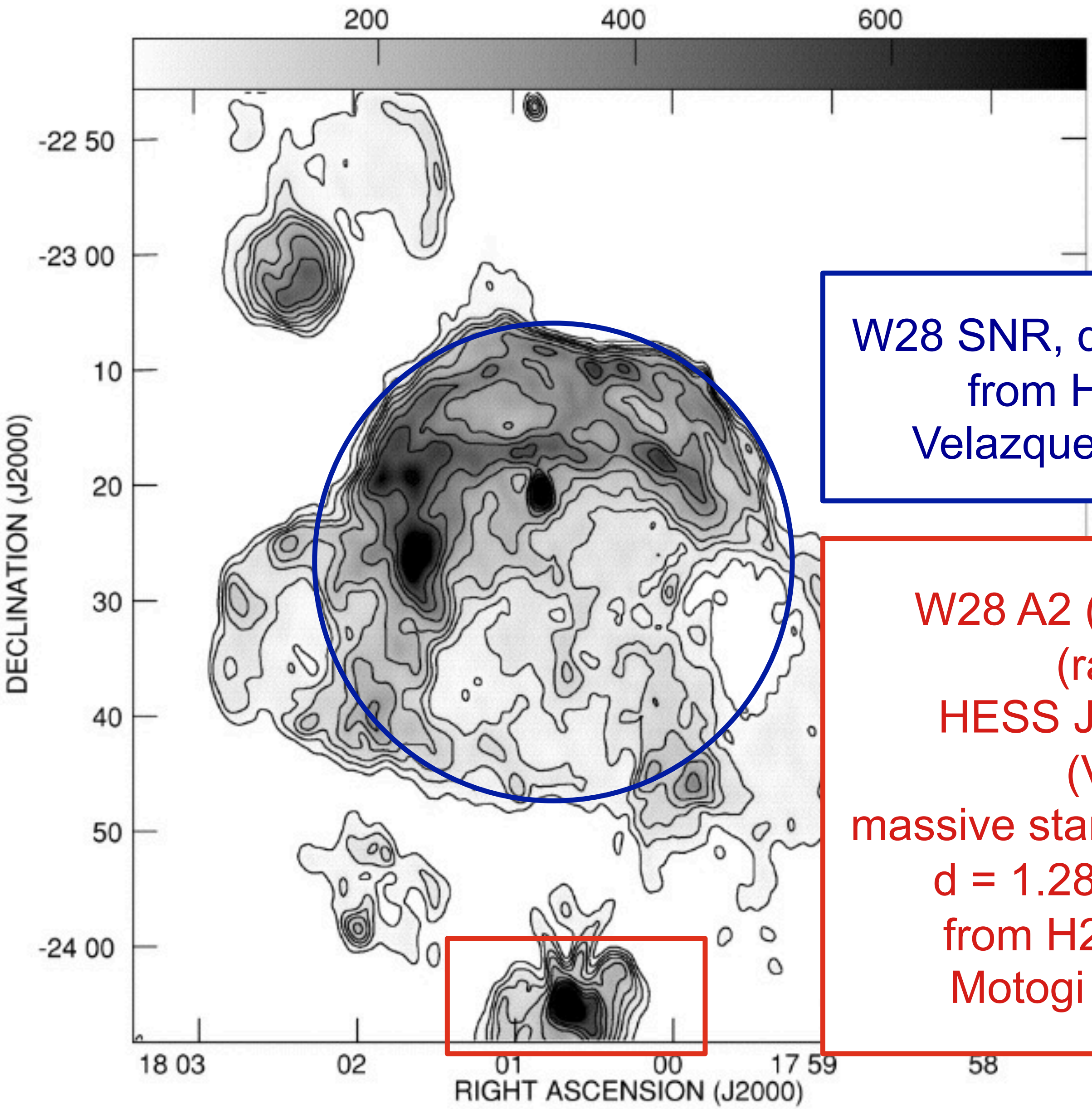

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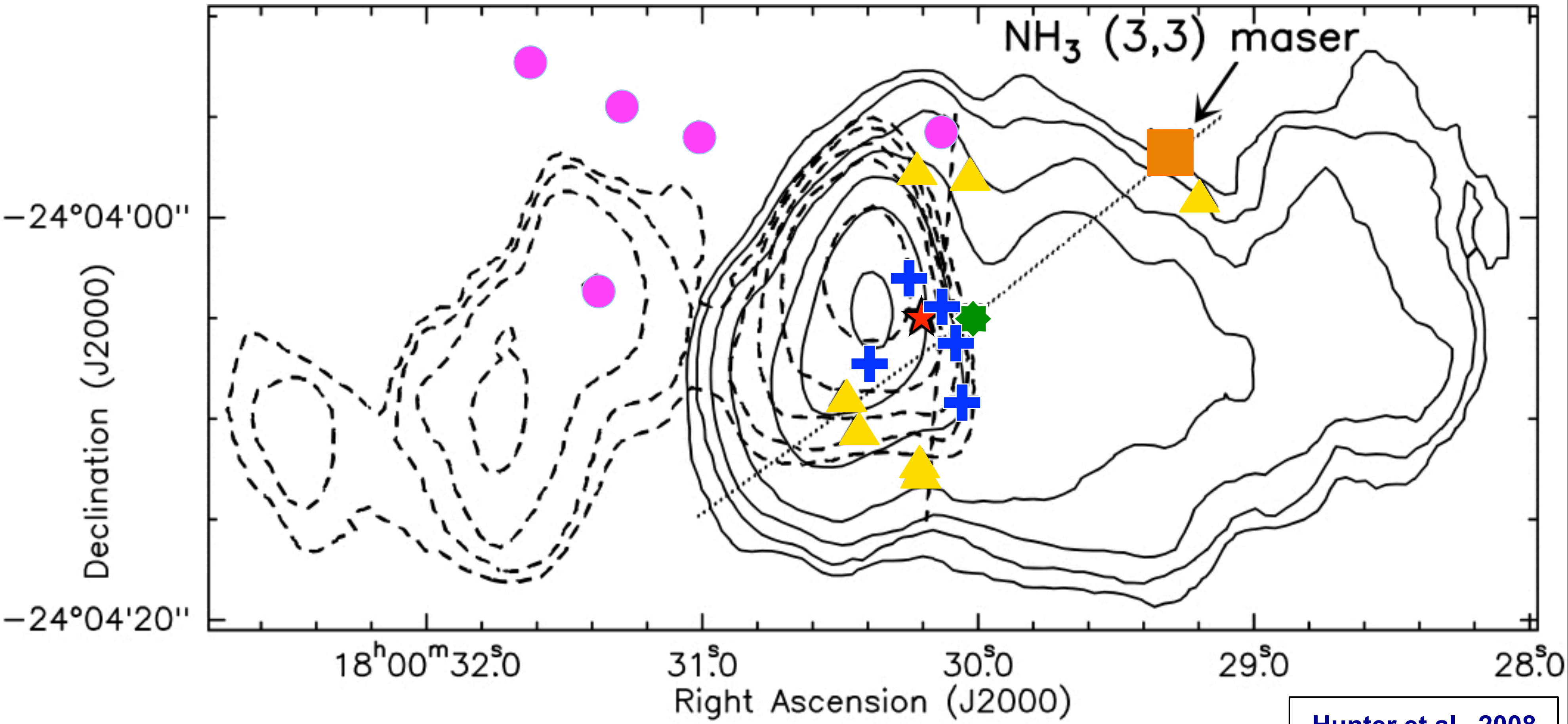
W28 A2 (G5.89-0.39) (radio),
HESS J1800-240 B (VHE)
massive star forming region
d = 1.28+/-0.08 kpc from H2O masers, Motogi et al. 2011

What is the W28 A2 outflow ?

Also known as "G5.89-00.39", or the "Harvey & Forveille 1988" outflow



Hunter et al., 2008

- - CO (1-0) 20 to 58 km s^{-1} —— CO (1-0) 0 to -37 km s^{-1}

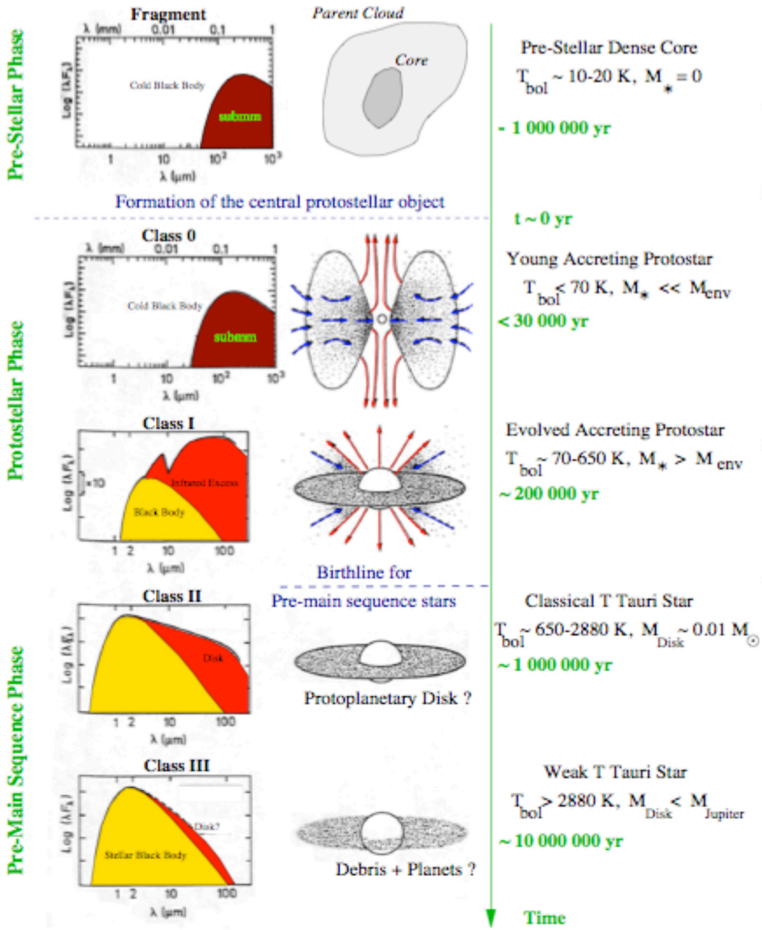
Outline

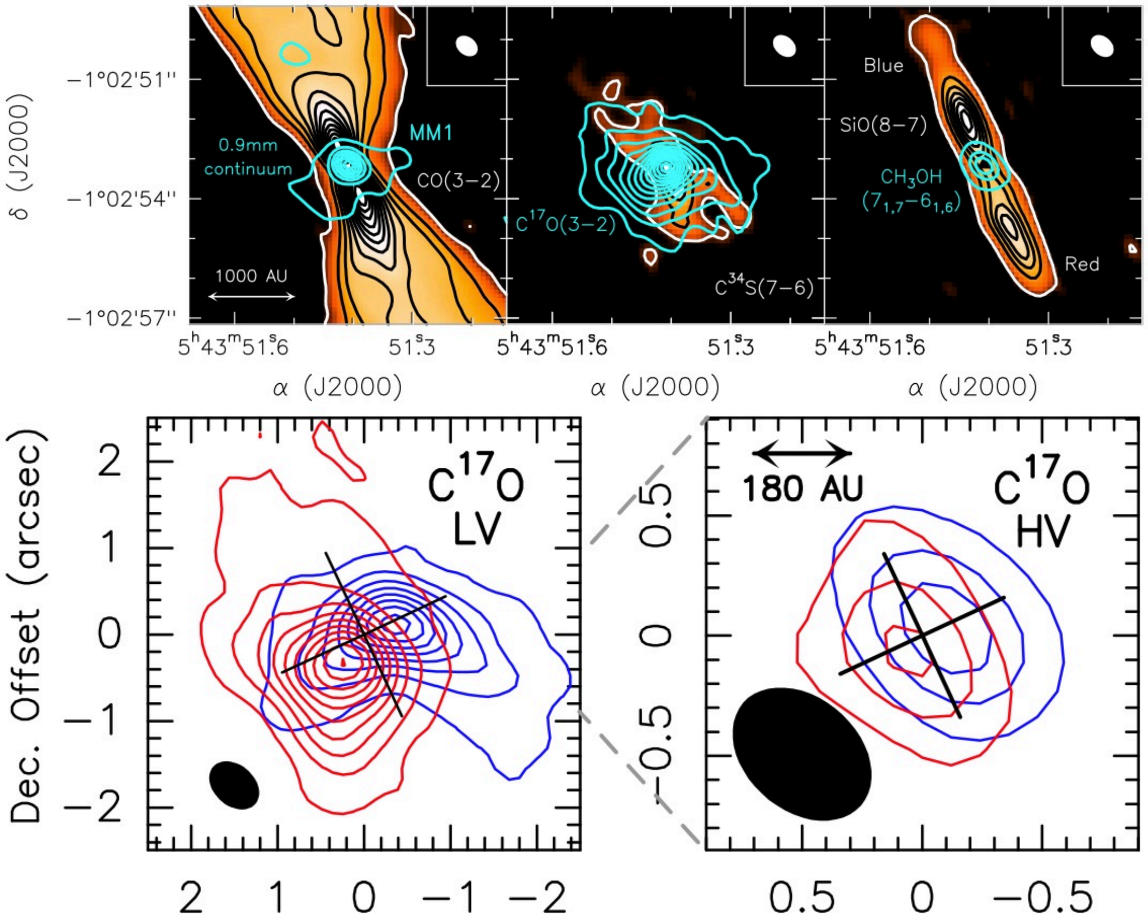
- WHY STUDY SHOCKS IN THE INTERSTELLAR MEDIUM ?
- THE RATHER COMPLEX W28 A2 REGION
- THE INTERSTELLAR CONTENT IN W28 A2
- A COSMIC RAYS ACCELERATOR ?
- PERSPECTIVES

Why study shocks in the interstellar medium ?

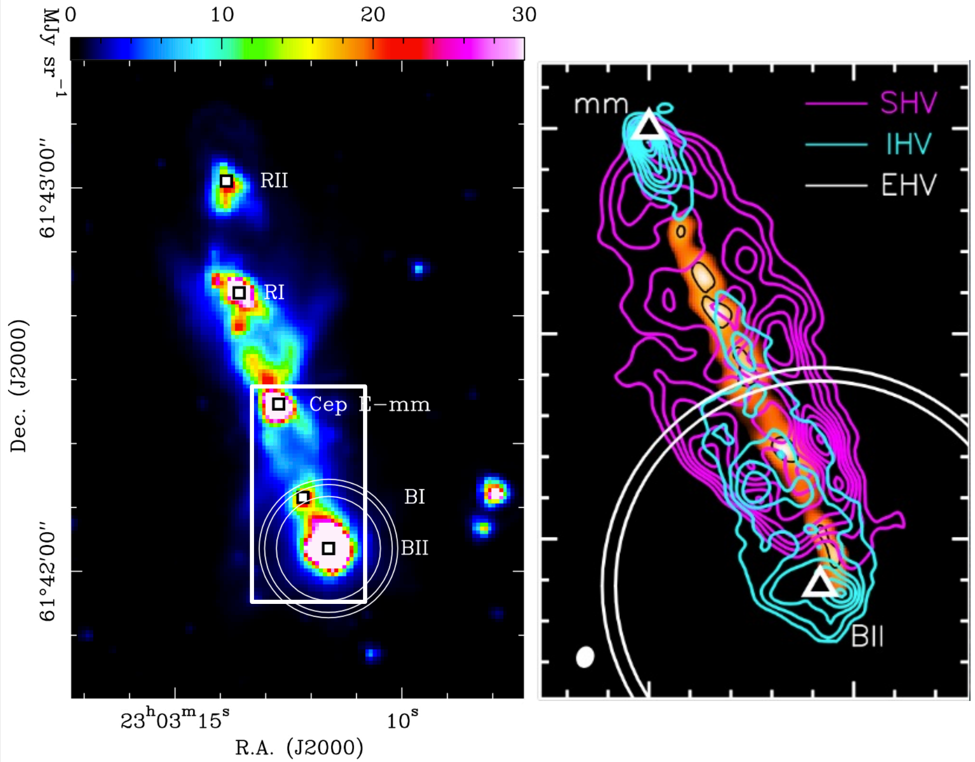
Star formation: from low mass…

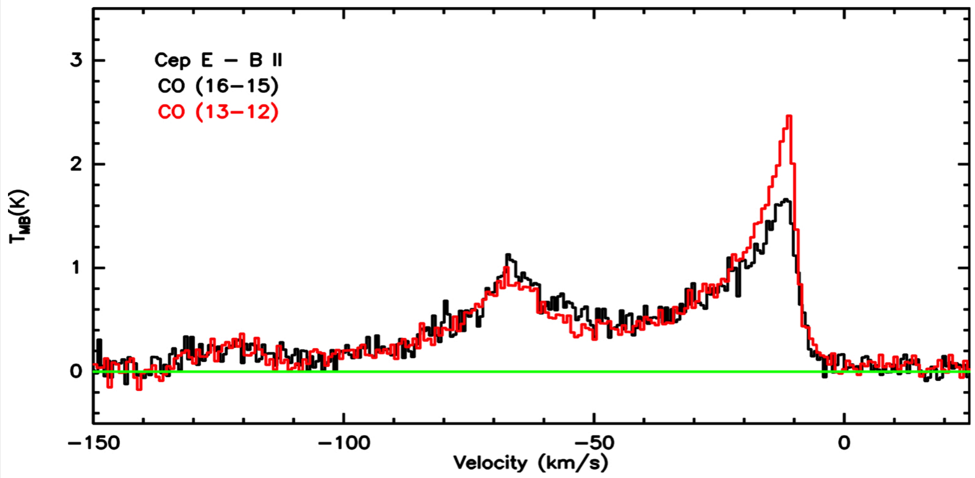
- HH212 ALMA observations by Codella et al., subm:
  - validating the paradigm of low-mass SF
  - using the SiO (and CO) emission to understand the launching of the jet





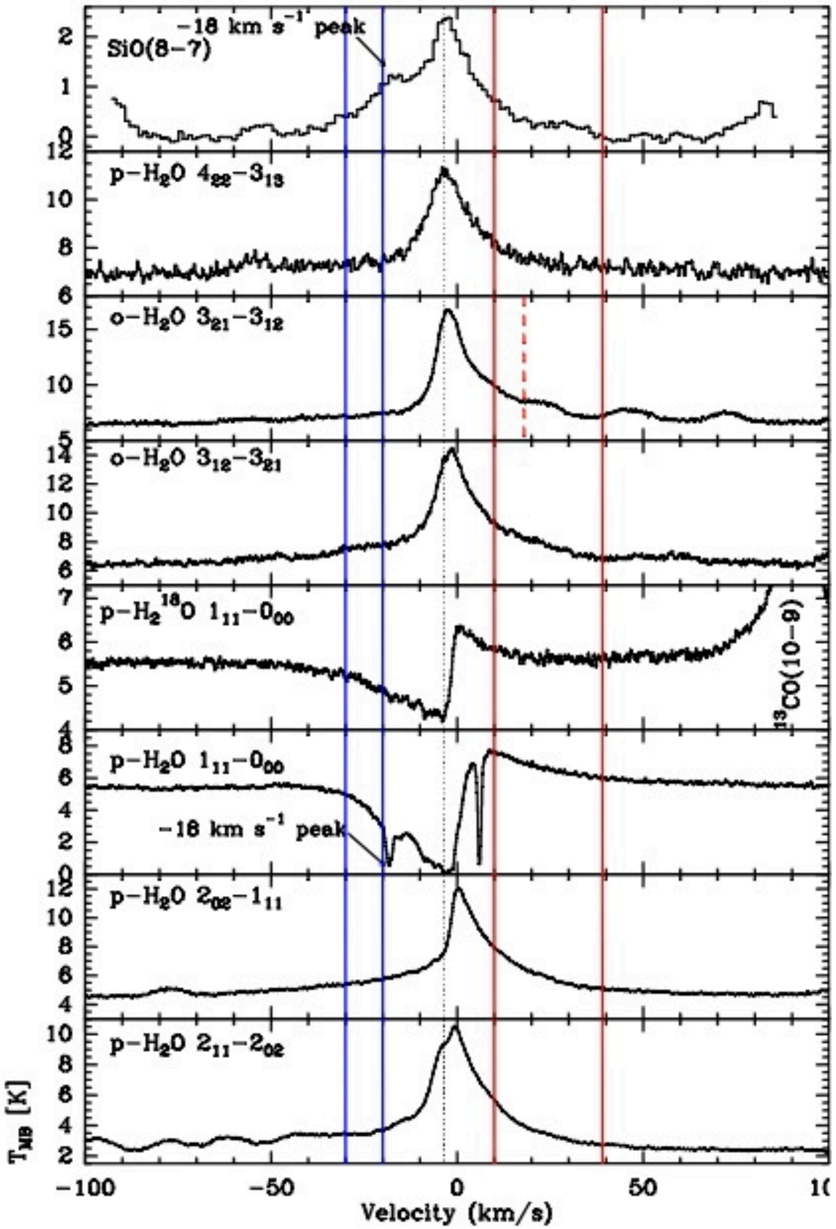
Star formation: towards higher mass…

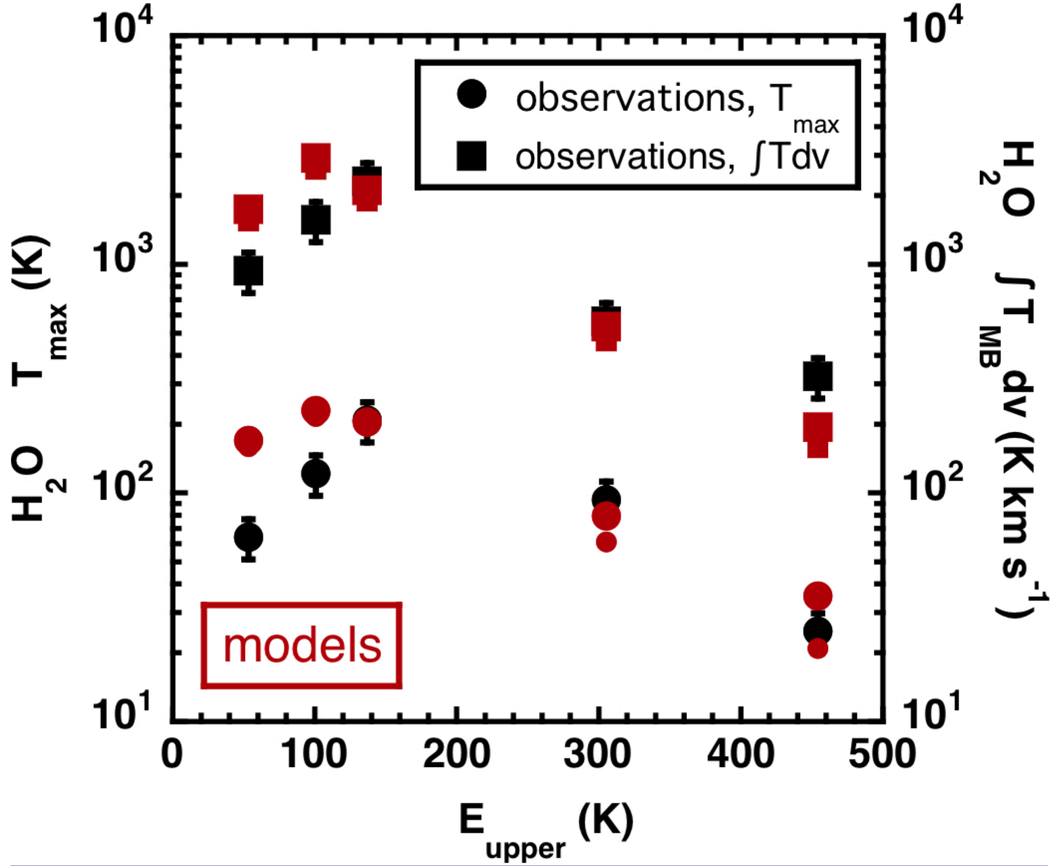




- Cep E study initiated in Gomez-Ruiz et al. 2012:
  - understanding the formation of more massive stars
  - quantitatively comparing the ejection activity throughout the mass scale
  - intermediate-mass forming star 80$L_\odot$, predicted final mass 3$M_\odot$
  - see also e.g. Gomez-Ruiz et al., subm, Lefloch et al., in prep.

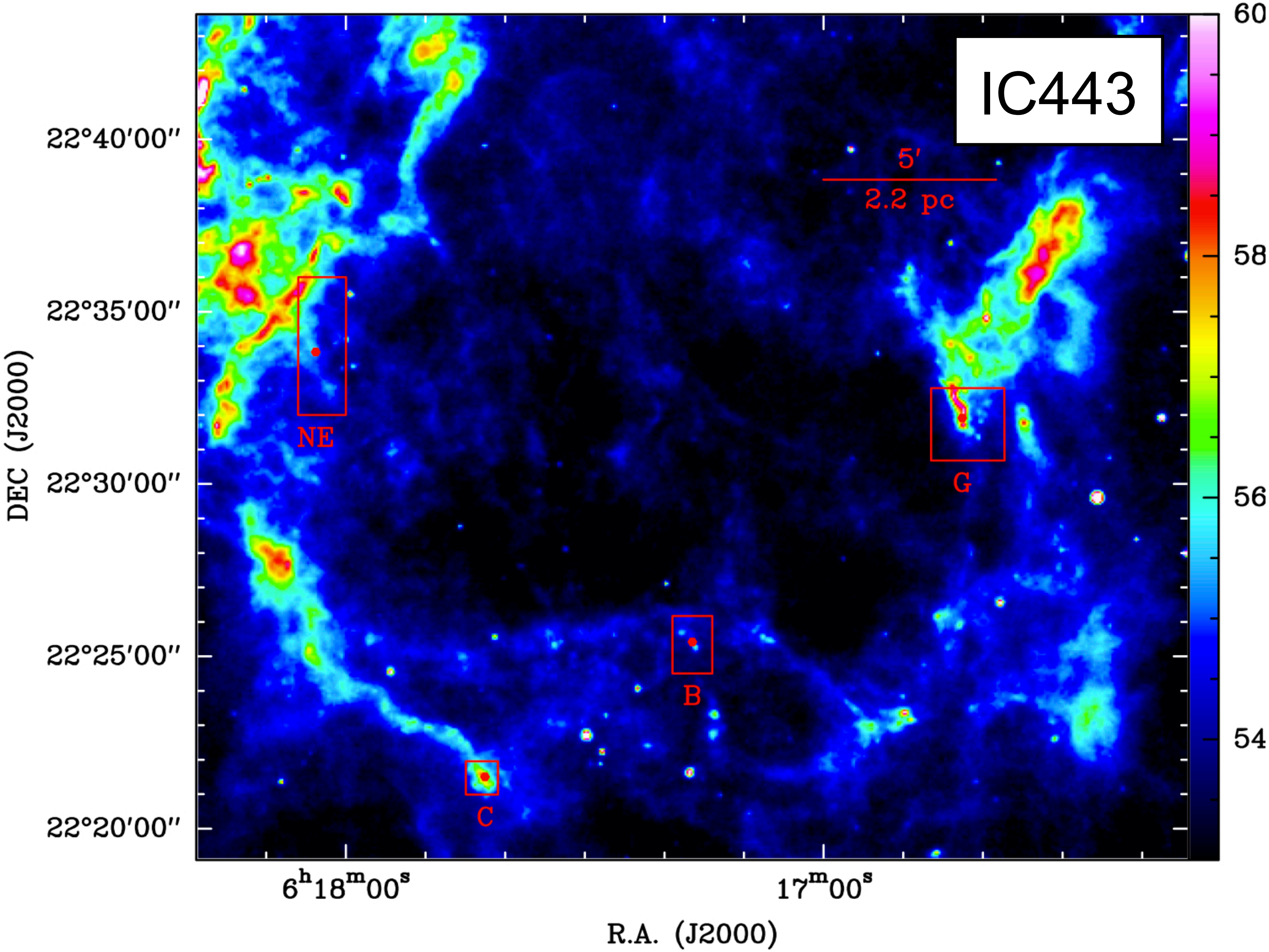
Star formation: towards higher mass…





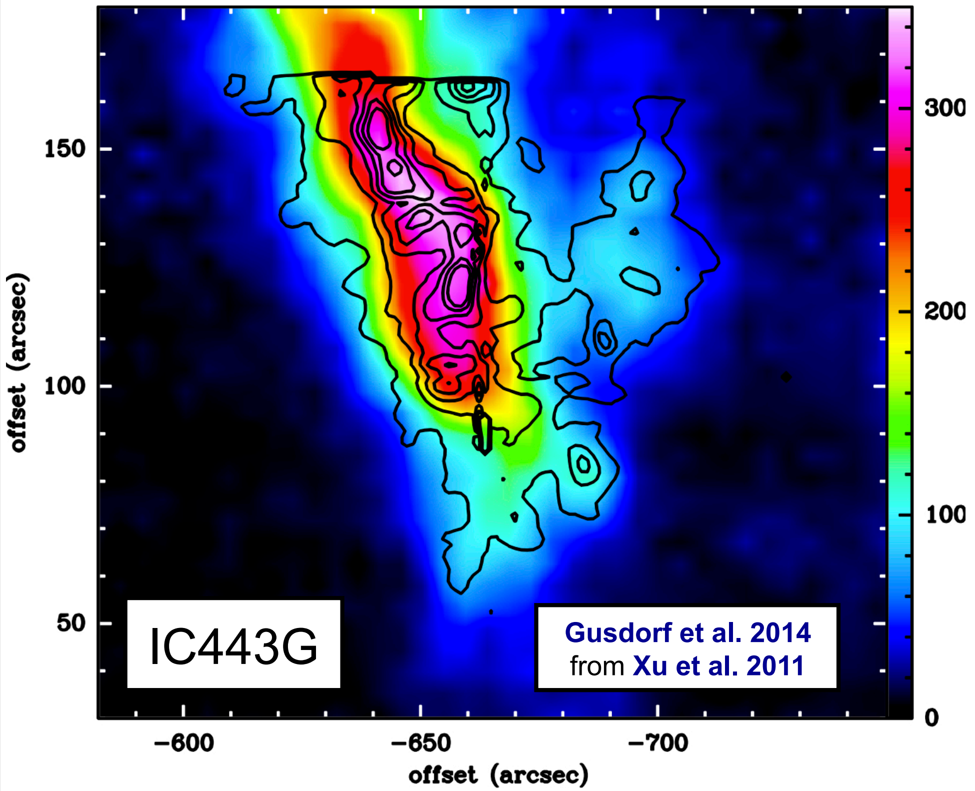
- The IRAS 17233-3606 massive SFR Leurini et al. 2013, 2014:
  - C-type models, $n_H = 10^6$ cm^{-3}
  - irradiation effect on lower-lying transitions, upper limit on H_2O mass

Star formation: triggered



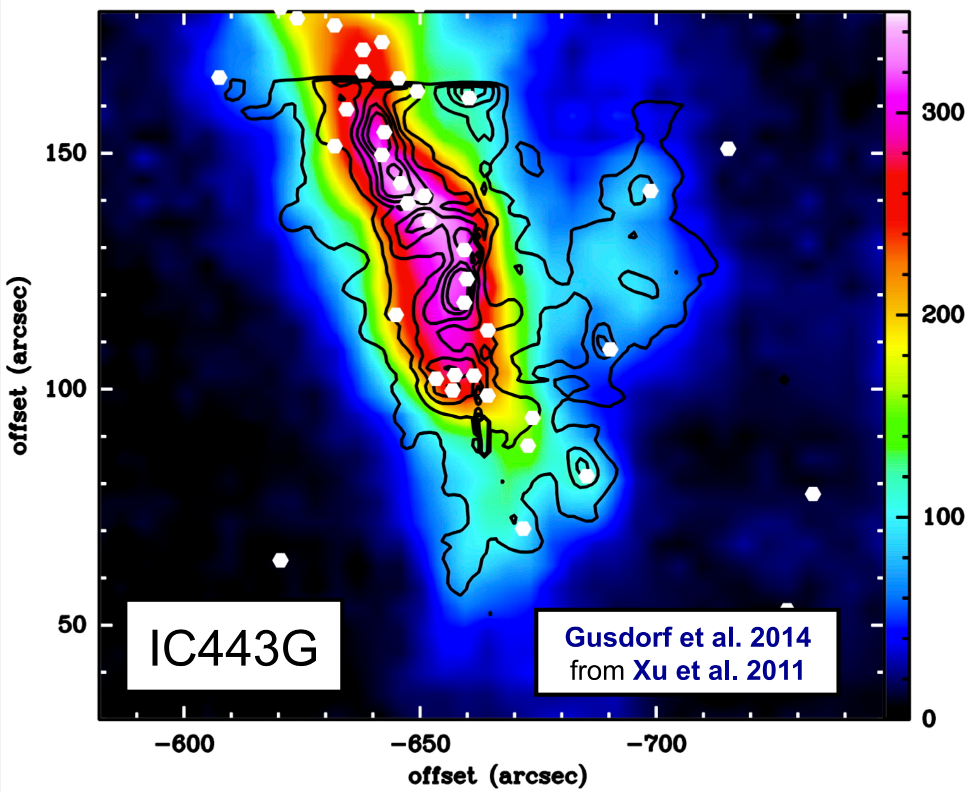
Star formation: triggered

- IC443 : CO (6-5) + H_2 0-0 S(5)



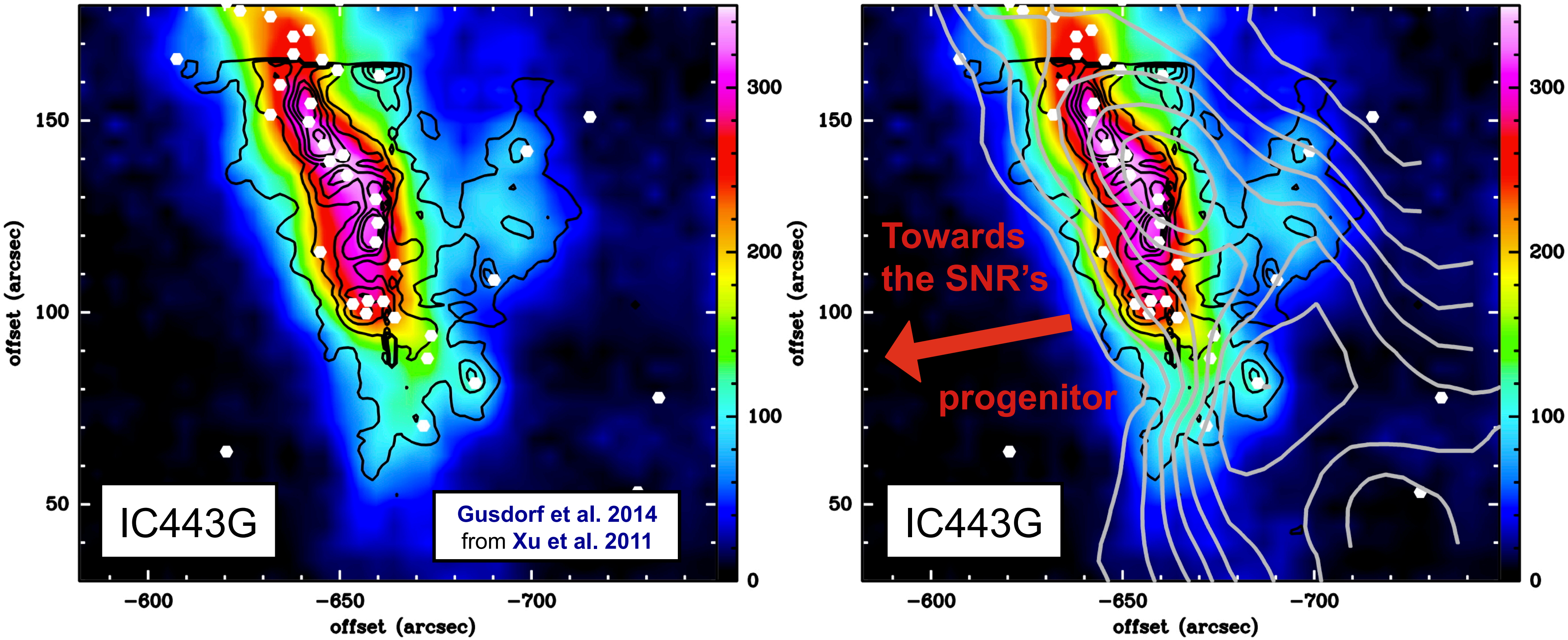
Star formation: triggered

- IC443 : CO (6-5) + H_2 0-0 S(5) + YSOs

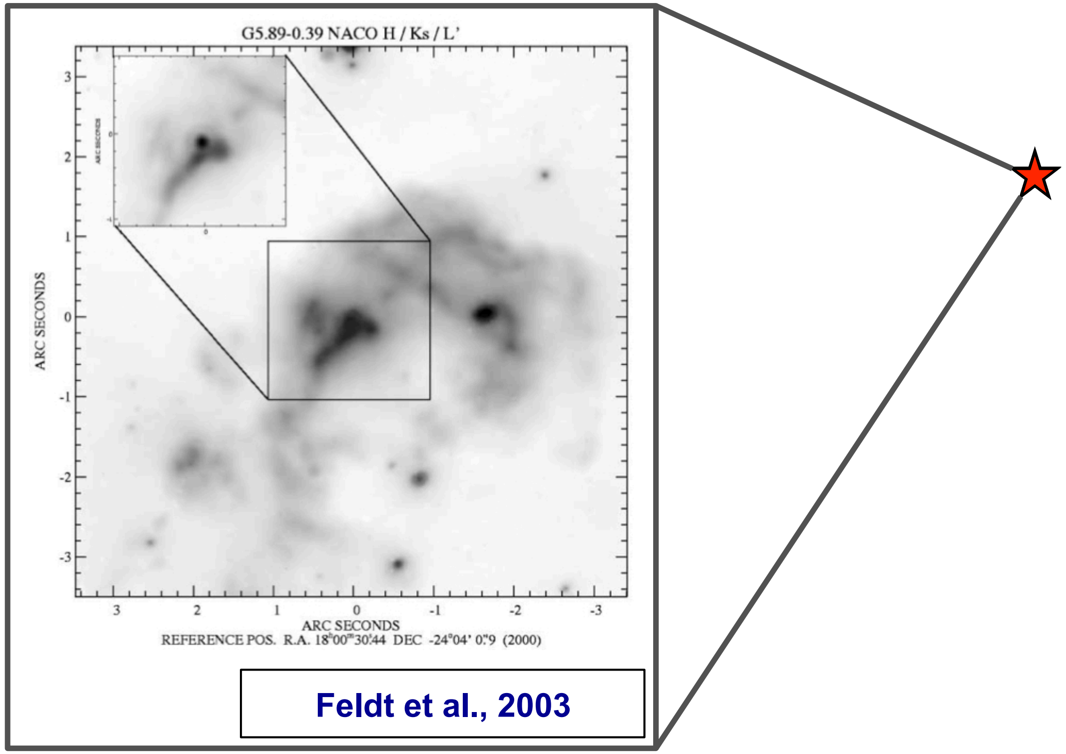


Star formation: triggered

- IC443 : CO (6-5) + H_2 0-0 S(5) + YSOs + molecular cloud CO (1-0)



THE RATHER COMPLEX W28 A2 REGION



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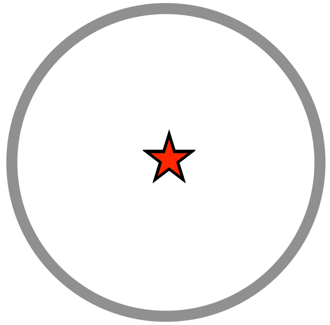

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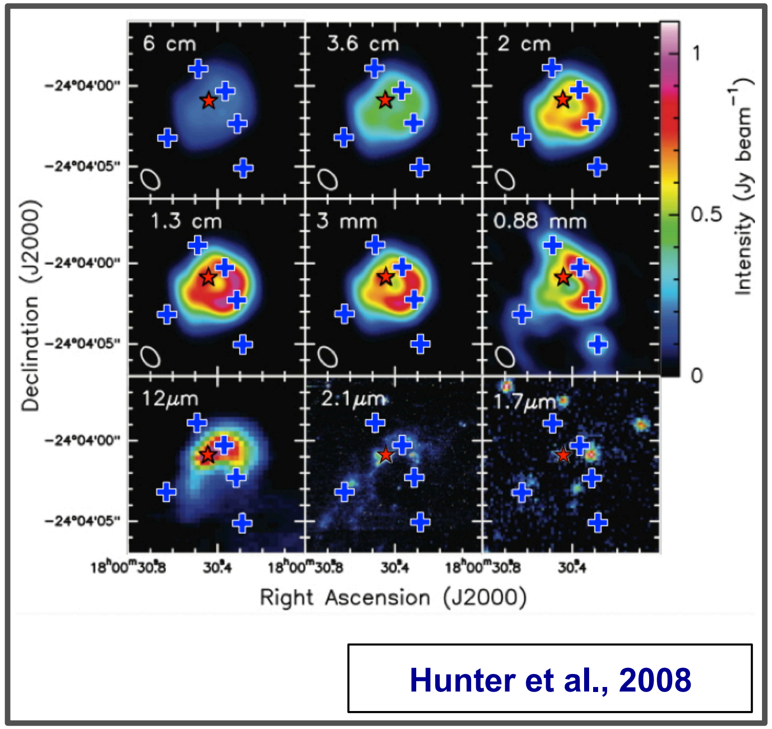

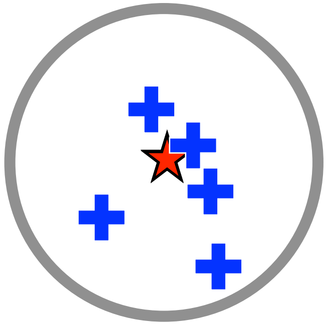

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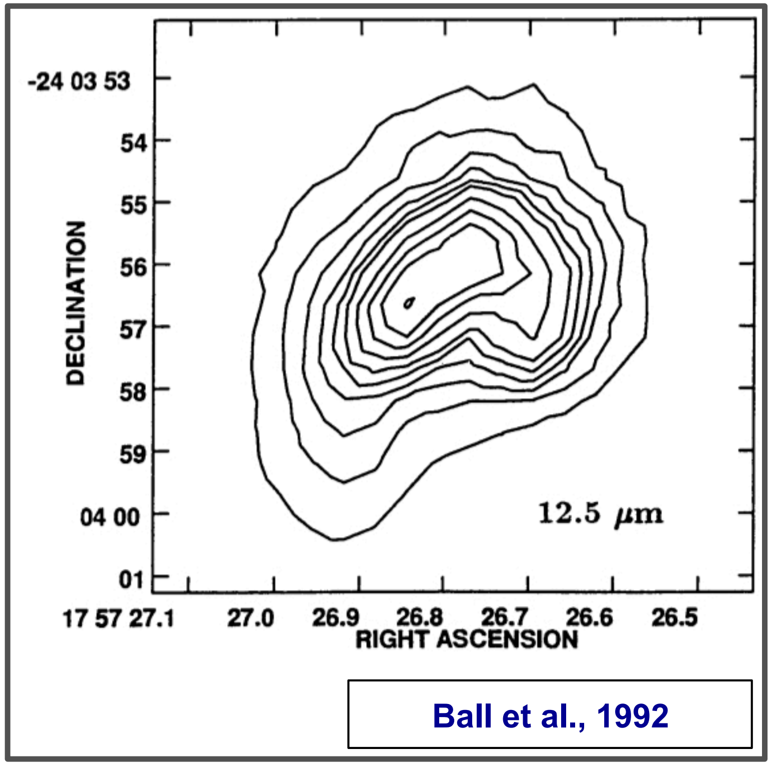

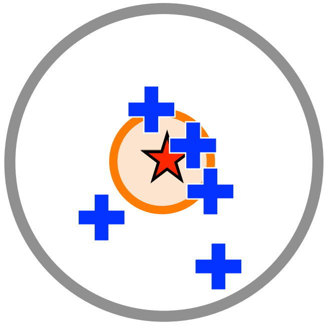

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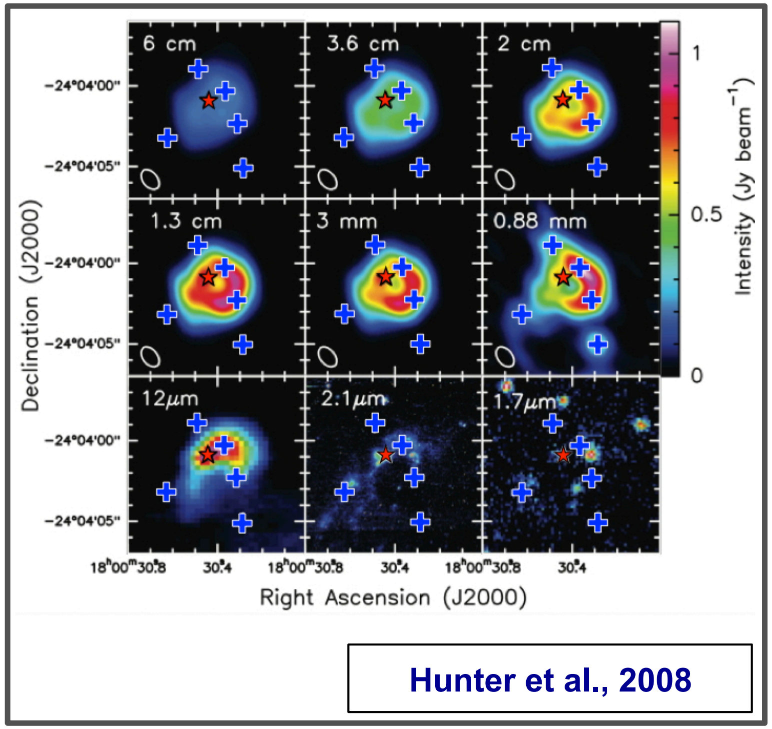

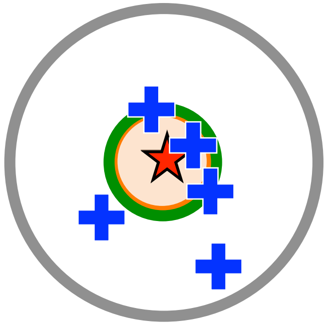

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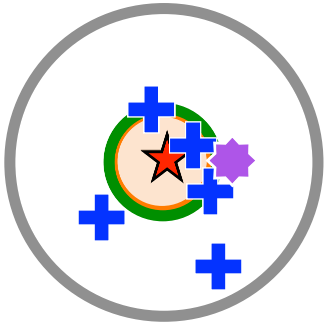

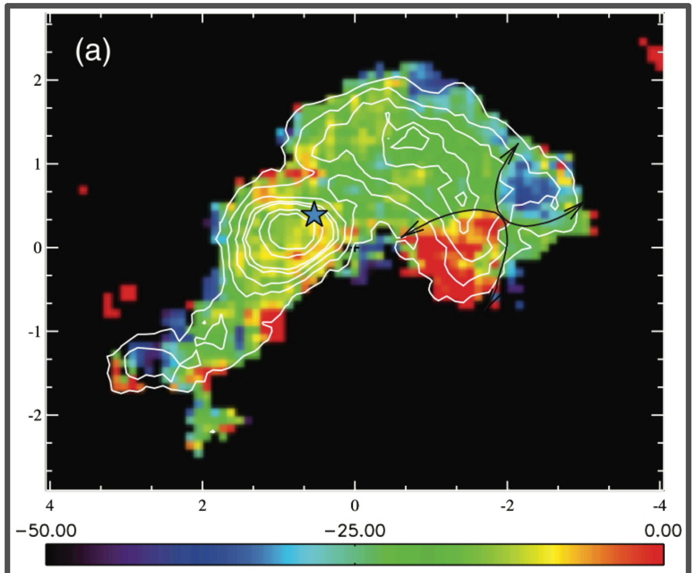

Puga et al., 2006

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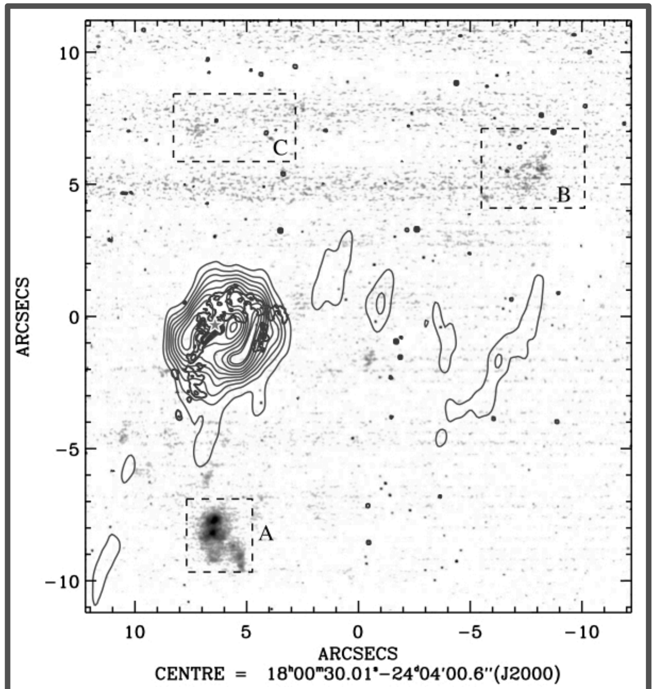

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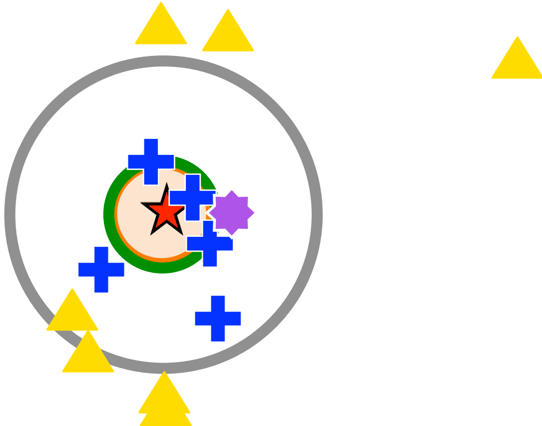

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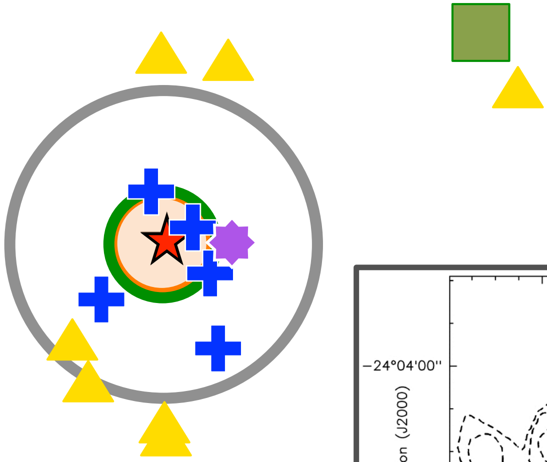

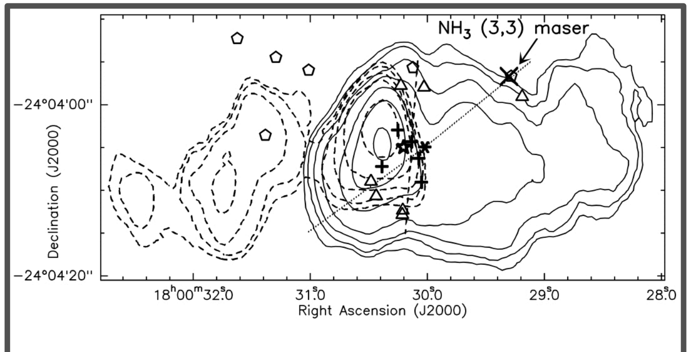

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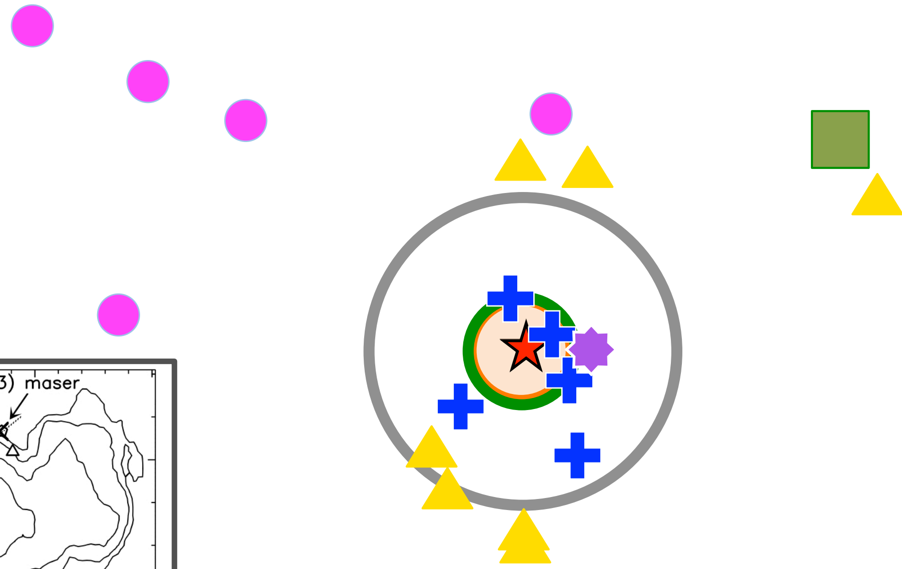

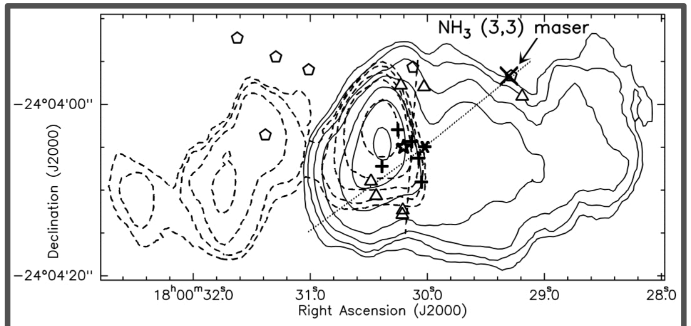

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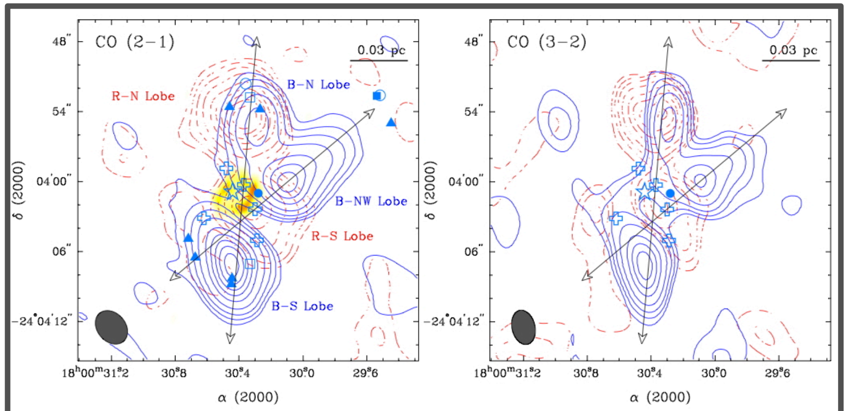
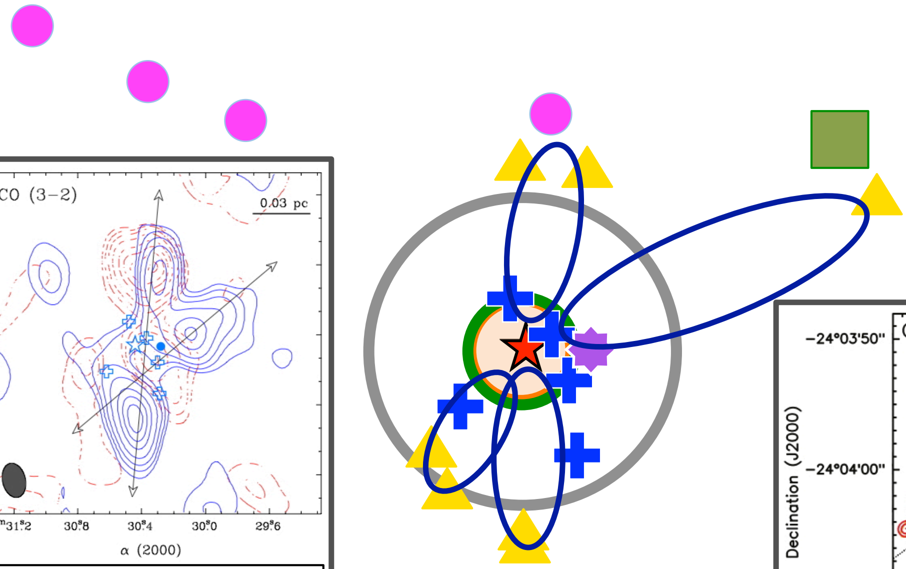
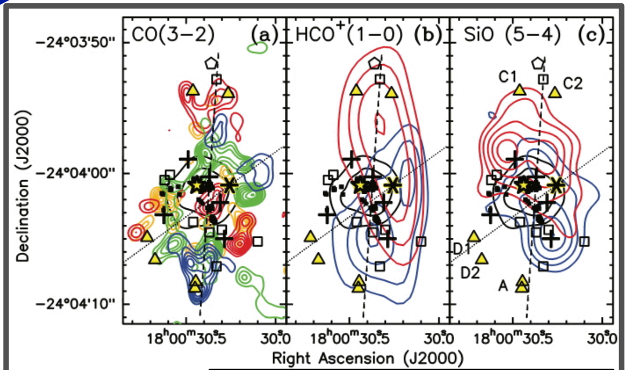


Su et al. 2012





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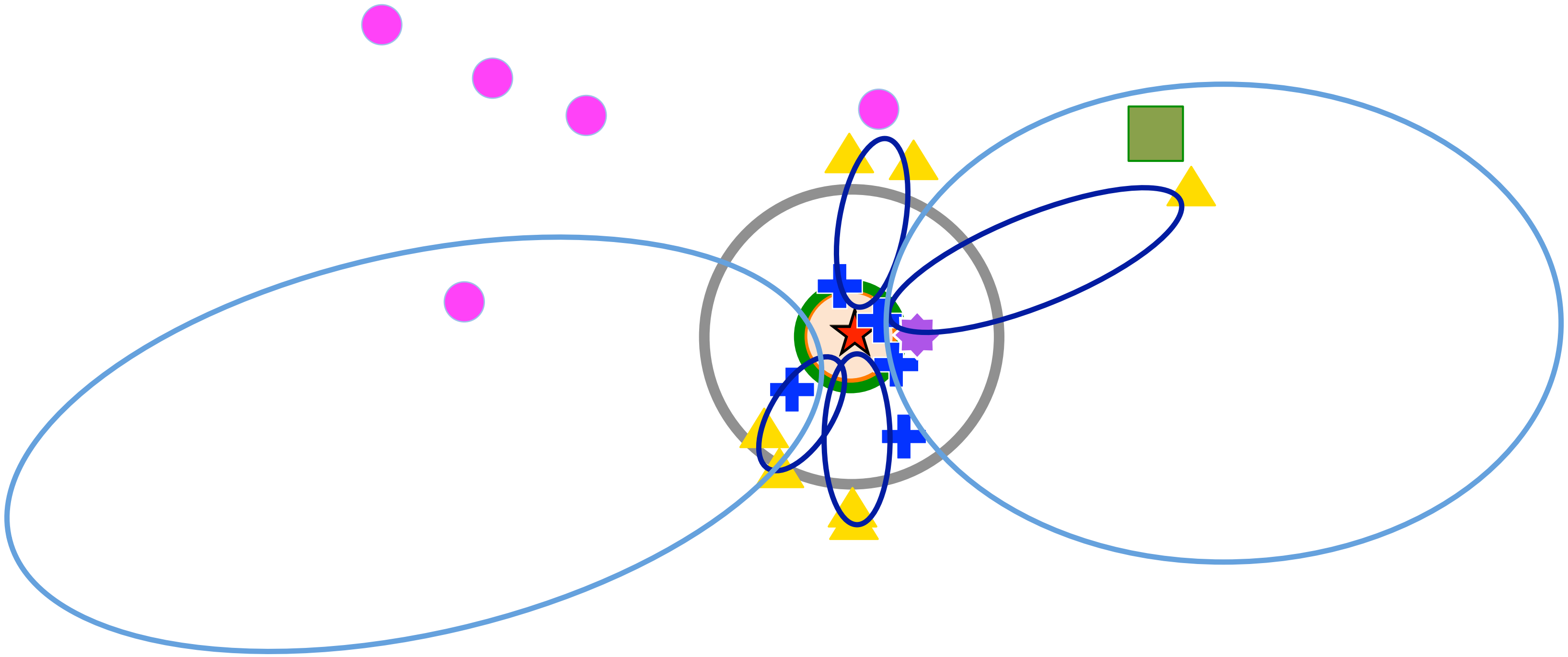

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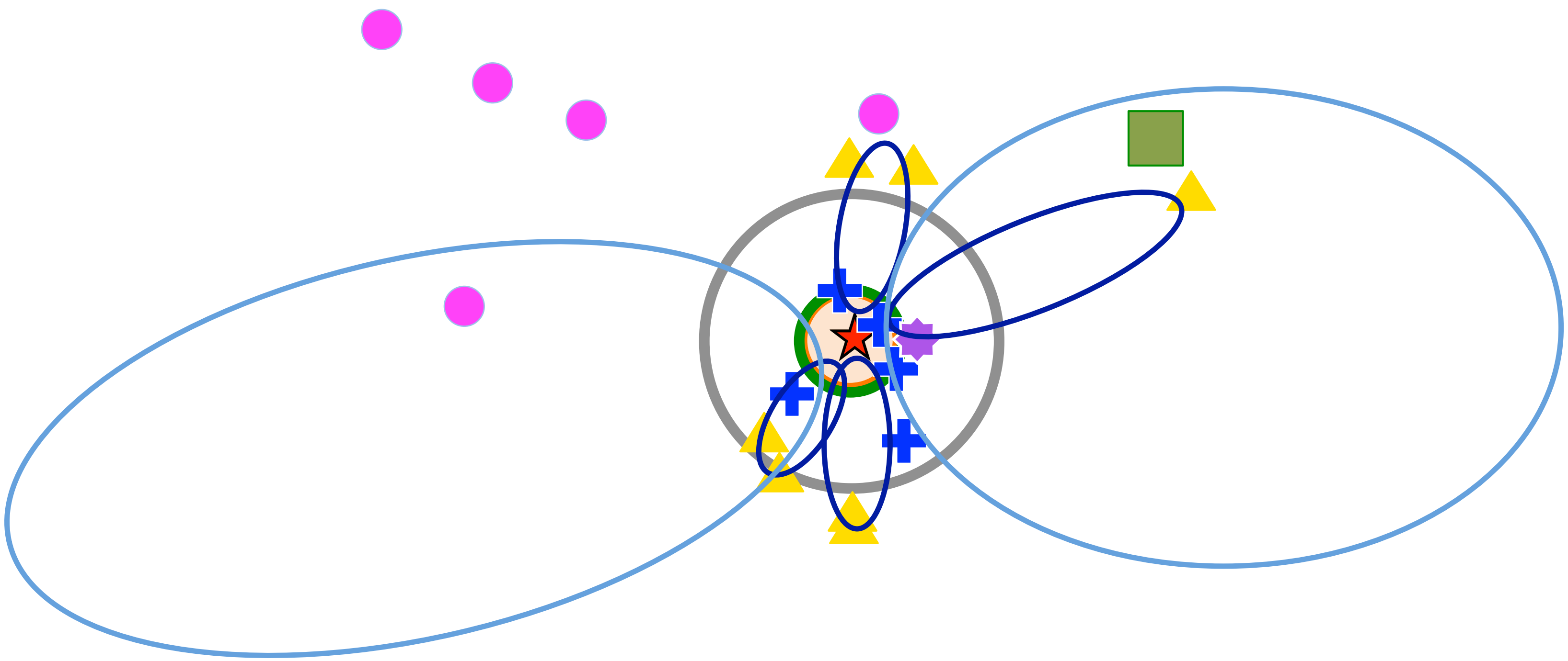

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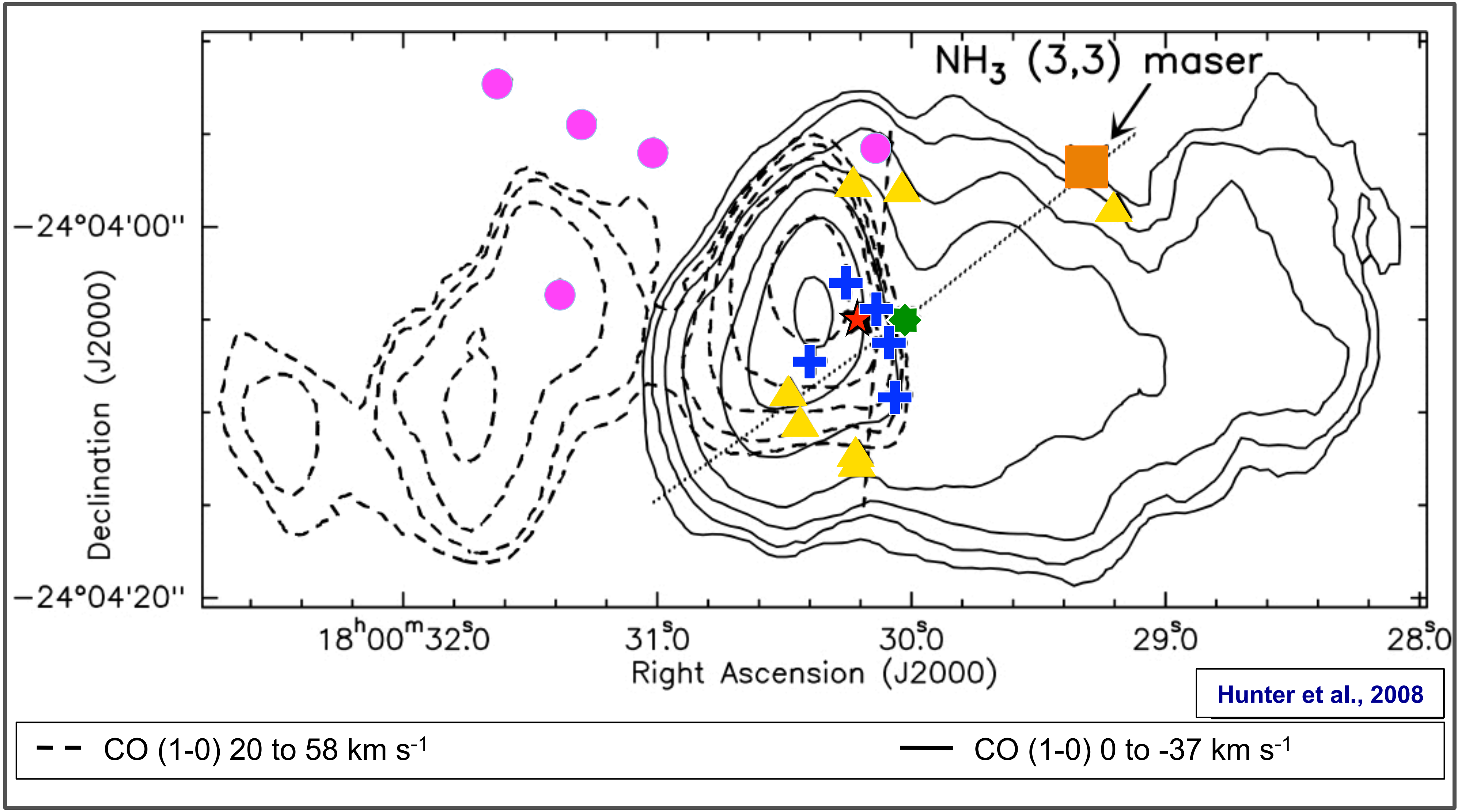
- Also not shown: H_2O masers (Hofner & Churchwell 1996), and OH masers (Stark et al. 2007)

The wide scale

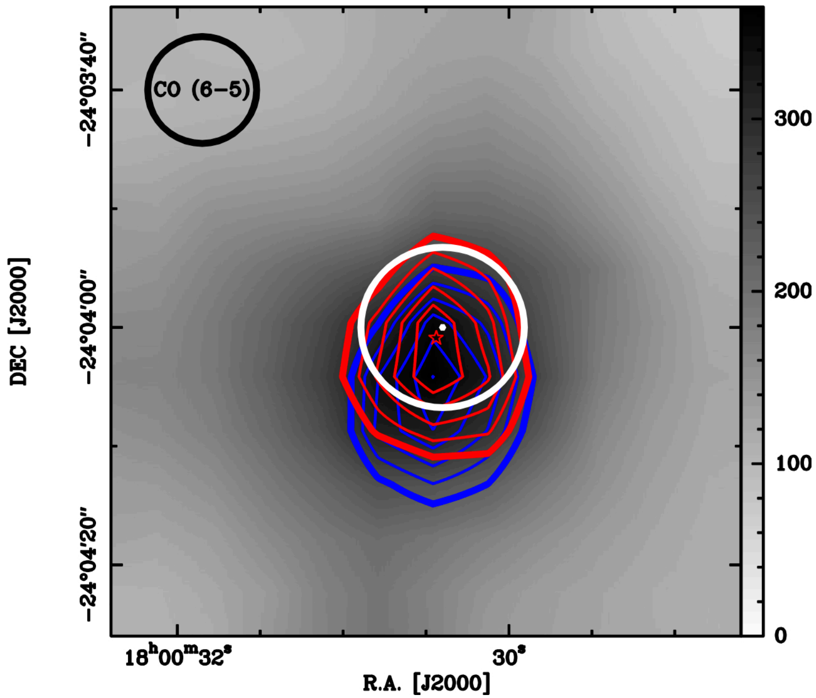


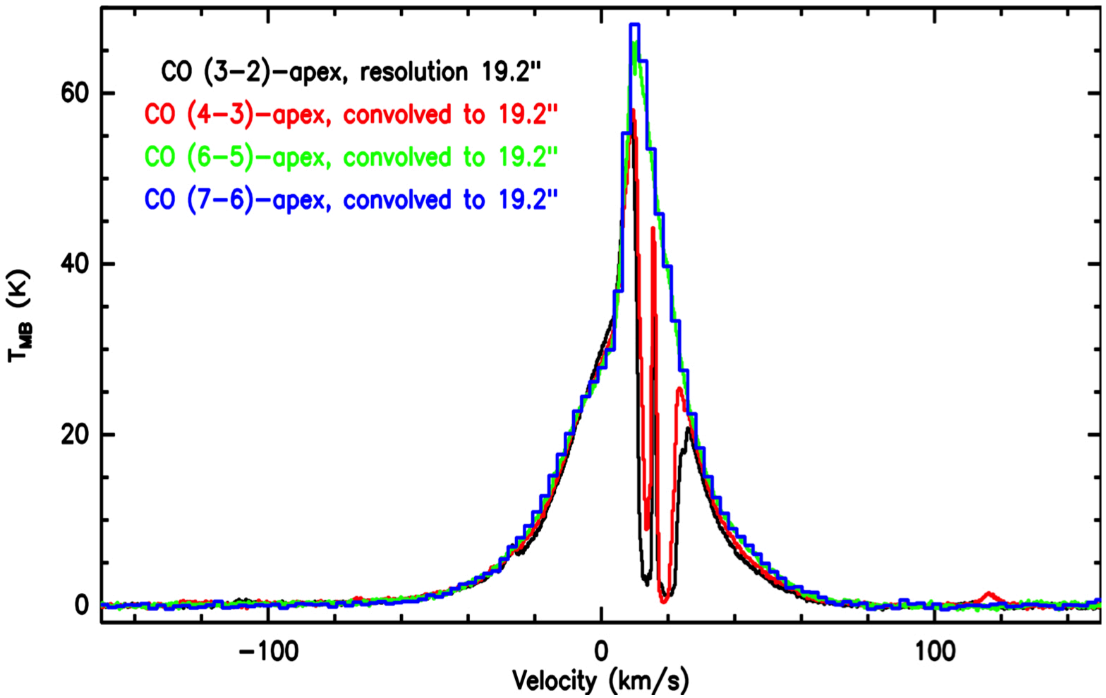
Other existing constraints

- **Distance:**
  - Old estimates: 1.9-4 kpc (Velazquez et al. 2002, Fish et al. 2003) ; Hunter et al. 2008 used 2.6 kpc
  - more recently: 1.28 kpc, by Motogi et al. 2011
- **The central star:**
  - Direct observations by Feldt et al. 2003 : O5
  - Classification by Motogi et al. 2011 : O8
- **Magnetic field:**
  - OH masers : 1.49 mG (Caswell 2001), [-2.4;1.2] mG (Fish & Reid 2006), [-2;2] mG (Stark et al. 2007)
  - Dust continuum polarization studies : 2-3 mG (Tang et al. 2009)
- **Spectral index:** of the HII region: 0.15-0.20 between 1.95 - 73.5 cm i.e. 408 MHz to 15.75 GHz (Goudis et al. 1976)

THE INTERSTELLAR CONTENT IN W28 A2

APEX CO observations: the data



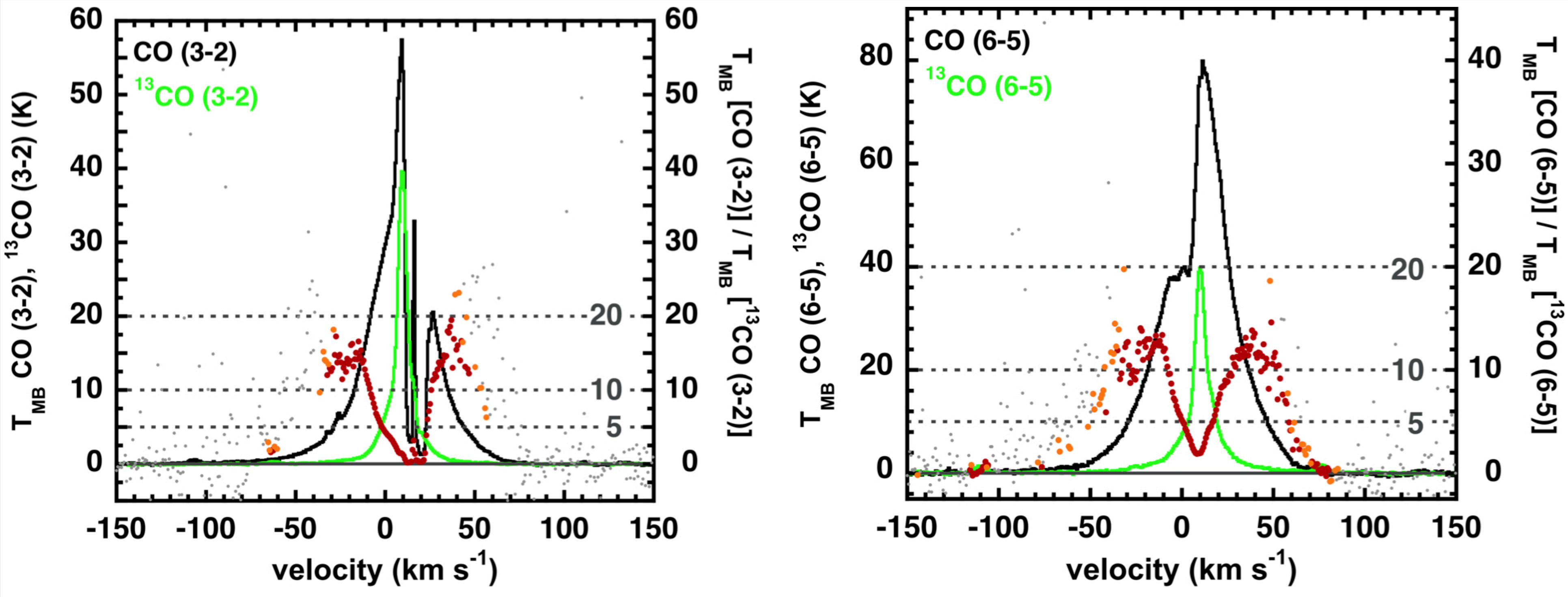


- APEX CO (6-5) line map:
  - ambient integrated intensity 4 to 16.5 km/s
  - blue-shifted integrated intensity -100 to 4 km/s
  - red-shifted integrated intensity 16.5 to 100 km/s

- The white beam is the beam of our analysis ~12.5”

=> We consider a filling factor of 1 for CO

APEX CO observations: optical thickness



- Red dots: 3σ detection for ^{13}CO

Orange dots: 2σ detection for ^{13}CO

Grey dots: less than 2σ detection for ^{13}CO

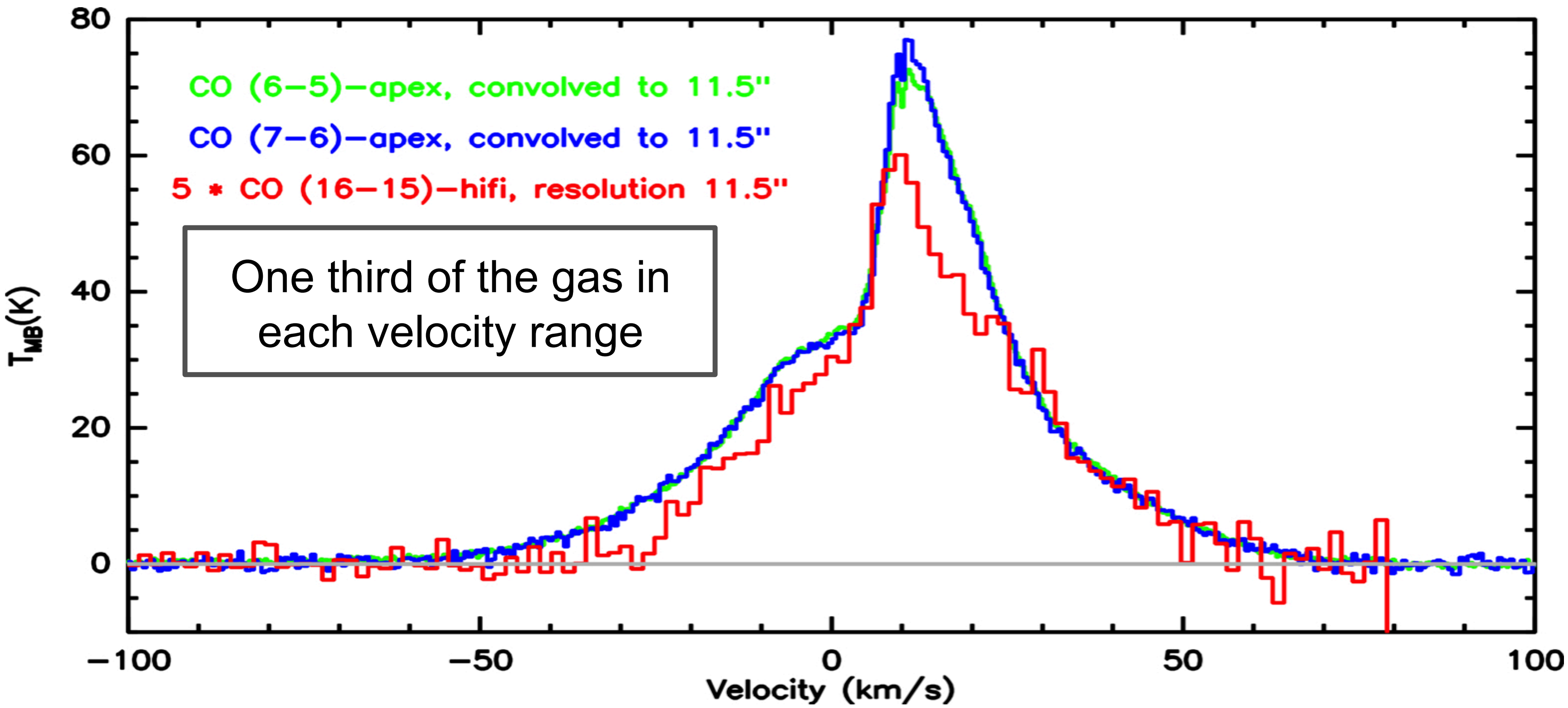
Line ratio ~ 5 to 15 => optical thickness ~ 3 to 12.5

=> CO lines accessible from the ground are optically thick, even in the wings

Herschel CO observations

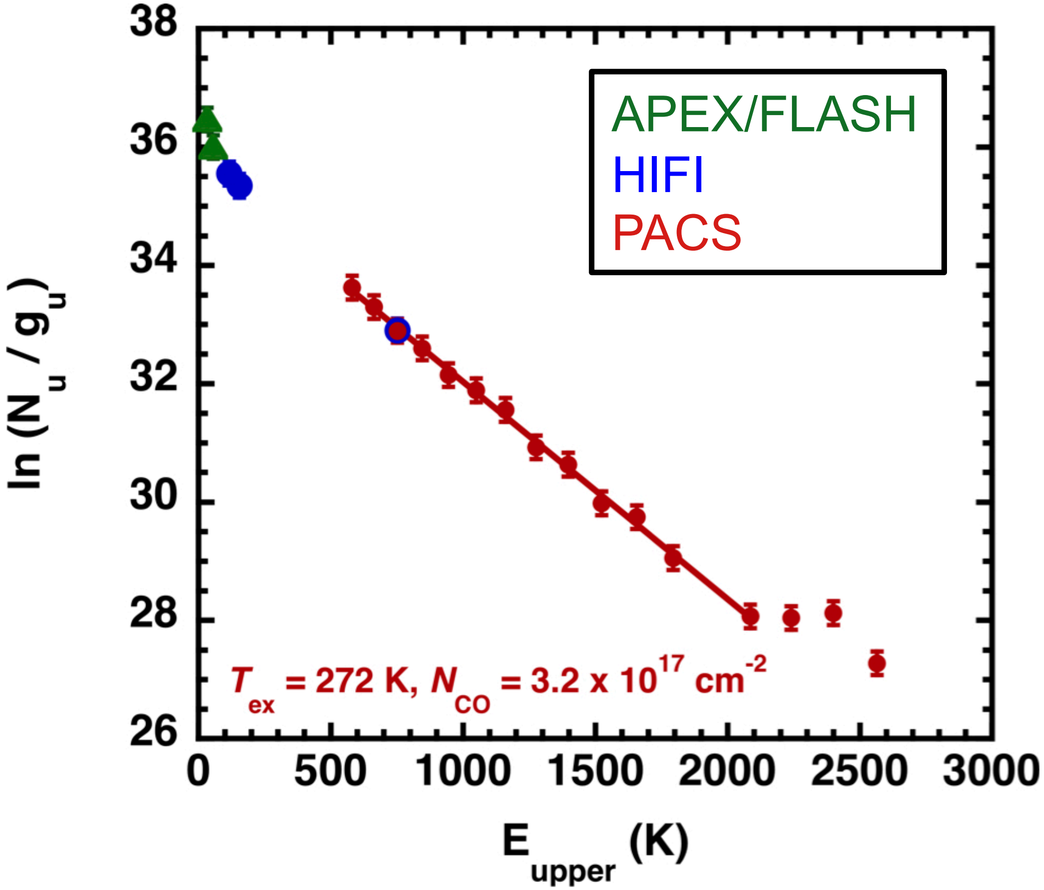
- Two lines are of particular importance:
  - CO (16-15) by HIFI & PACS, single pointing => calibration & gas distribution over the whole velocity range
  - CO (15-14) PACS ^{12,13}CO observations => ratio ~ 47 optically thin !

=> Rotational diagram over a 12.5” area

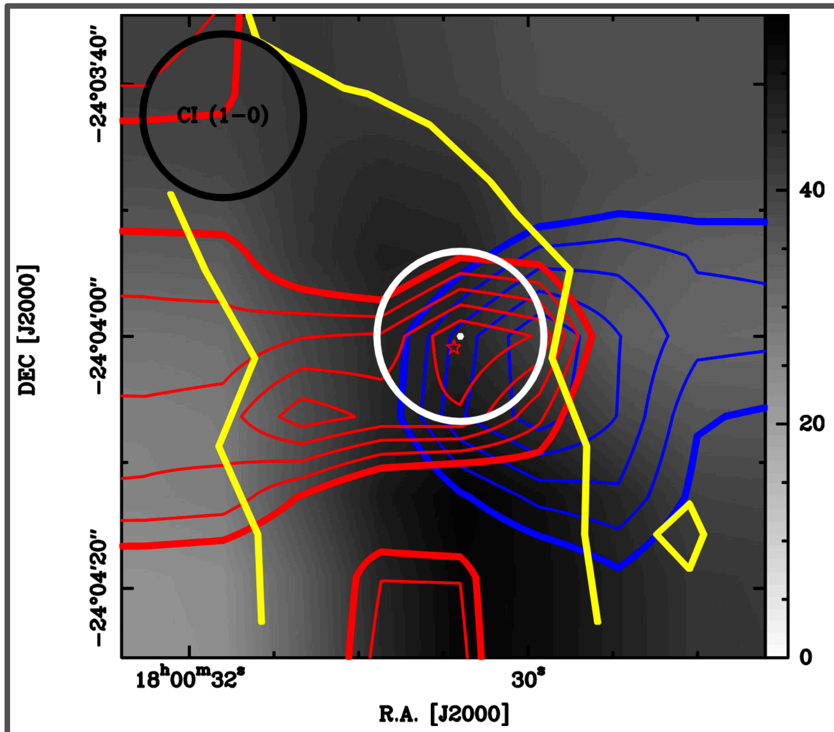


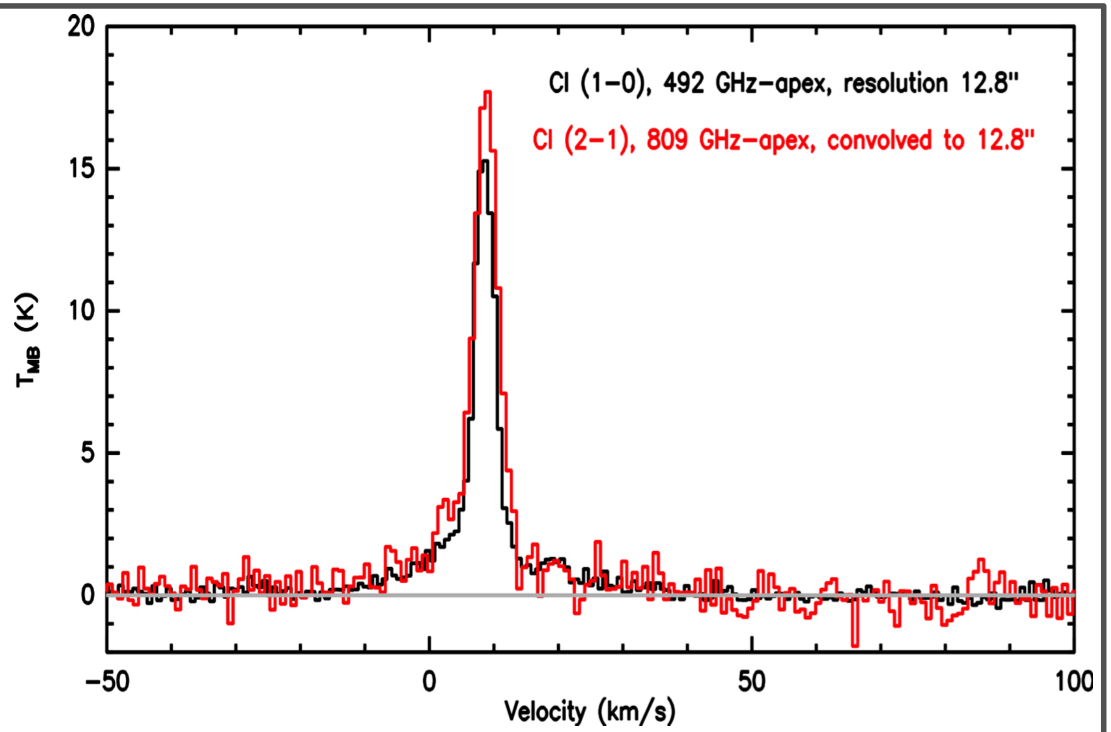
Herschel CO observations

- Summary:
  - APEX => filling factor = 1 for beam of 12.5”, low-*J* are optically thick
  - *Herschel* => higher-*J* lines optically thin, HIFI-PACS cross-calibration
  - Both show a similar gas distribution in the line wings



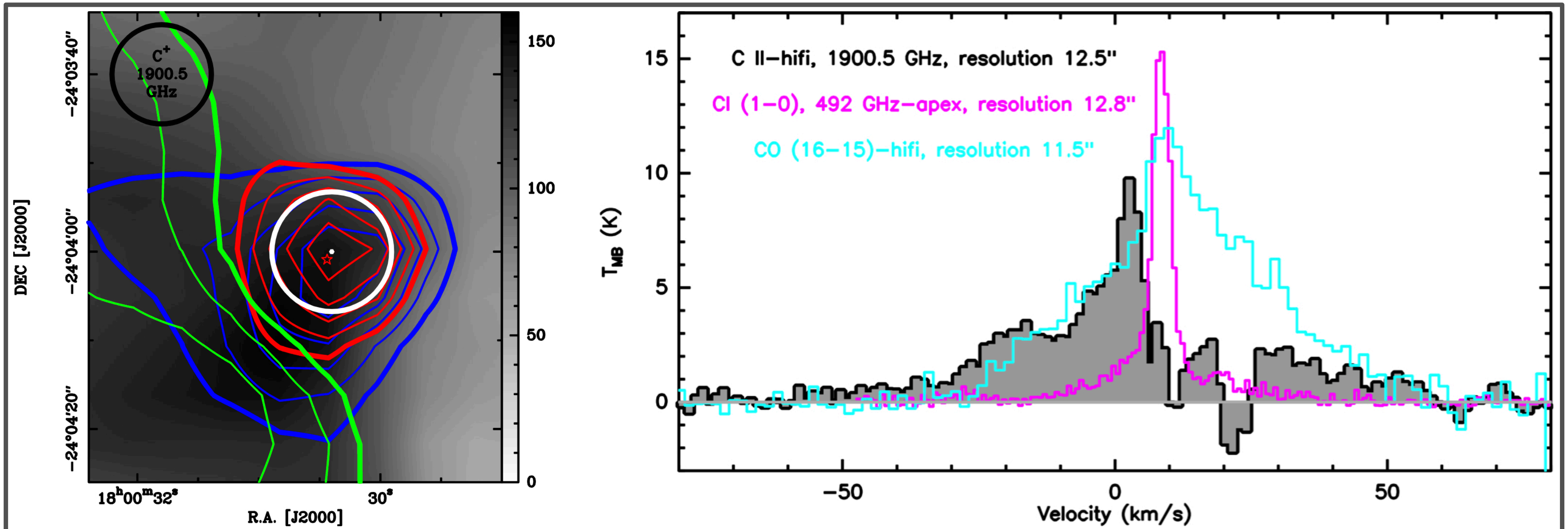
APEX CI observations: the data





- APEX CI (1-0) line map:
  - ambient integrated intensity 4 to 16.5 km/s
  - blue-shifted integrated intensity -20 to 4 km/s
  - red-shifted integrated intensity 20 to 40 km/s
  - ambient CI (2-1) component, 4 to 16.5 km/s
- LVG analysis: N = 1.5-3 x 10^{17} cm^{-2}, $T_{kin, min}$ = 55 – 140 K per component

Herschel C+ observations: the data



- *Herschel* C+ line map:
  - total integrated intensity -80 to 80 km/s
  - blue-shifted integrated intensity -80 to 4 km/s
  - red-shifted integrated intensity 25 to 80 km/s
  - ambient integrated intensity 4 to 16.5 km/s

- LTE/optically thin line assumptions: N ~ 0.5-1.2 x 10^{18} cm^{-2} in the blue lobe, N ~ 1.5-3.5 x 10^{17} cm^{-2} in the red lobe

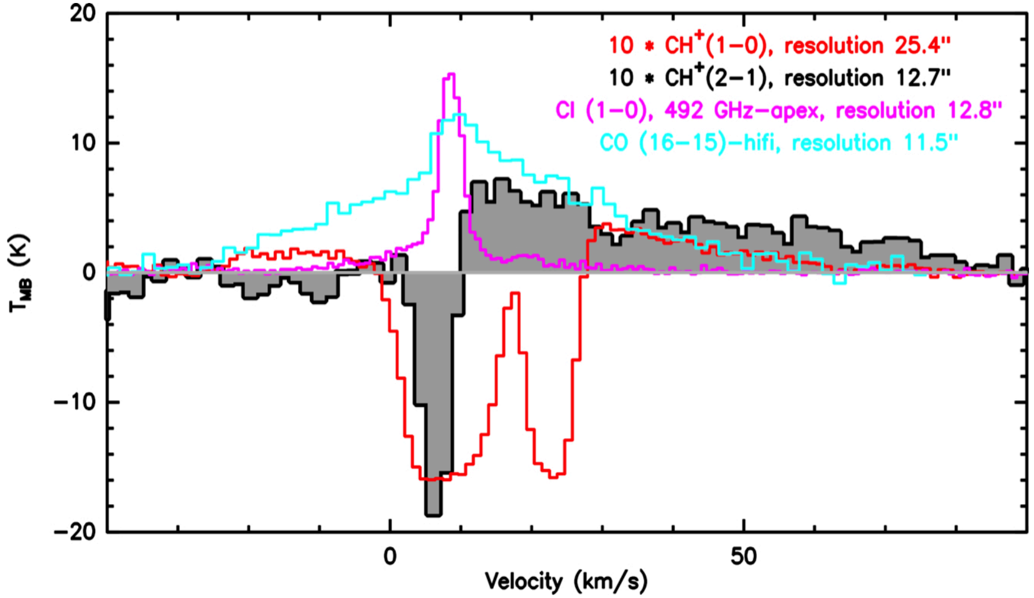
Energetic impact

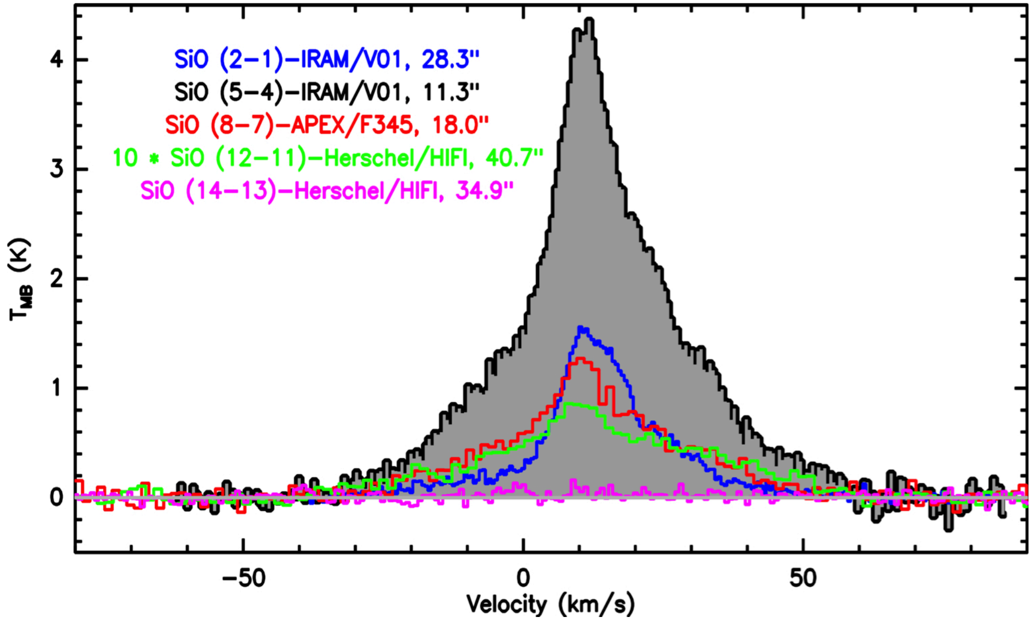
- Very rough calculations based on Beuther et al. 2002 example, with $[CO + CI + C^+] / H_2 \sim 1.4 \times 10^{-4}$ and t_{dyn} and δv_{max} similar for H_2 and C^+

=> we found typical values for a massive outflow around an O-type star

component	blue	red	total
N (10^{21} cm^{-2})	8–16	>(4–8)	>(12–24)
M ($10^{-2} M_\odot$)	6–12	>(3–6)	>(9–18)
δv_{max} (km s^{-1})	50	50	50
t_d (yr)	760	760	760
$\dot{M}$ ($10^{-5} M_\odot$ yr^{-1})	8–16	>(4–8)	>(12–24)
P ($M_\odot$ km s^{-1})	3–6	>(1.5–3)	>(4.5–9)
F_m ($10^{-3} M_\odot$ km s^{-1} yr^{-1})	4–8	>(2–4)	>(6–14)
E_k (10^{45}erg)	1.5–3	>(0.8–1.5)	>(2.3–4.5)
L_{mech} ($L_\odot$)	16–33	>(8–16)	>(24–49)

Chemical impact: CH^+ and SiO





- CH^+ LTE with T_{kin} ~ 50-150 K: (red-shifted component only)
  N ~ 4.4-12.7 x 10^{12} cm^{-2}
  N/N(H_2) ~ 0.6-3 x 10^{-9}

- Rotational diagram for SiO: (with assumption on emission size ~ 12.5")
  N ~ 4-6 x 10^{14} cm^{-2}
  N/N(H_2) ~ 3-16 x 10^{-8}
  T_{kin} ~ 75-80 K
  per component

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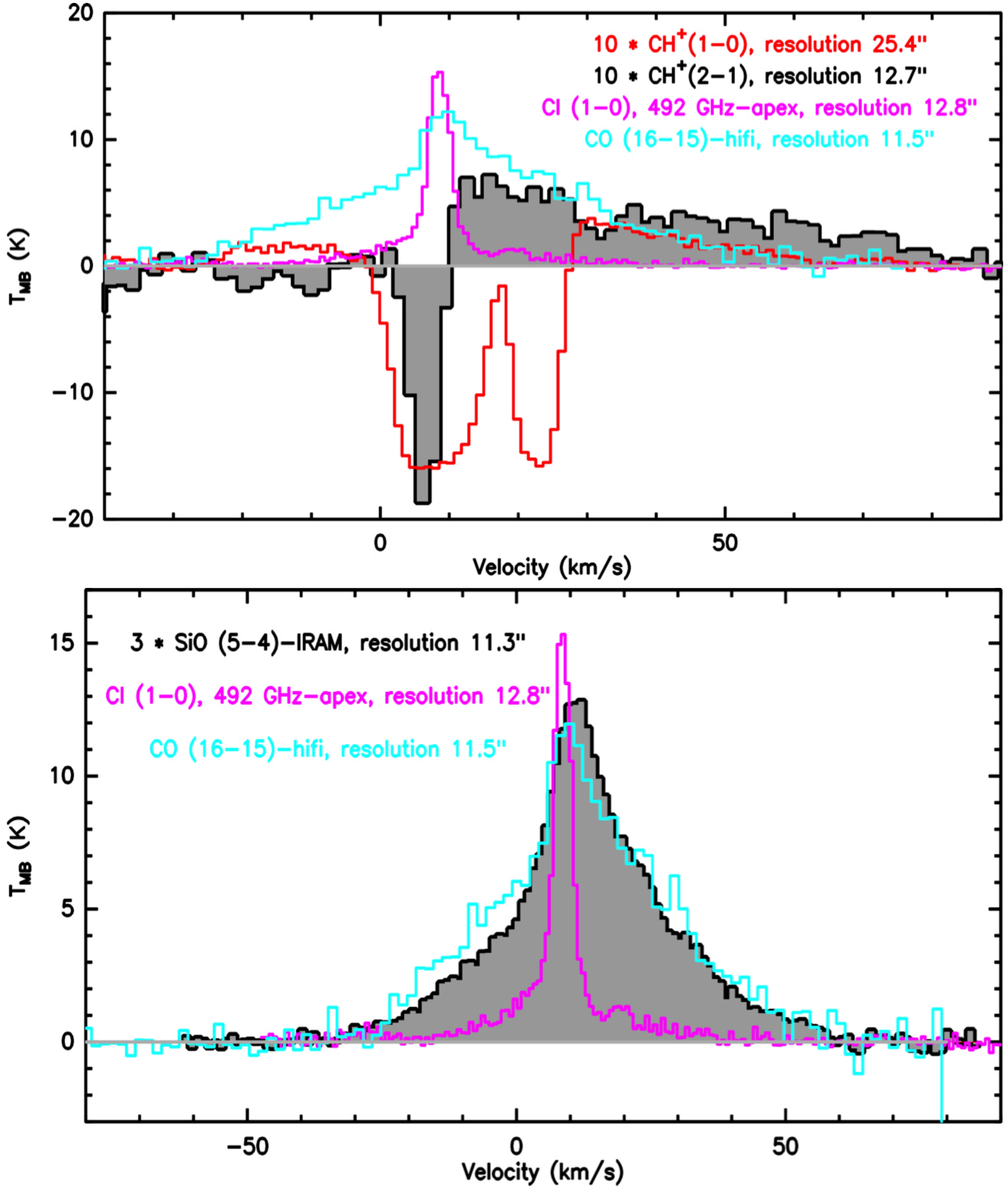

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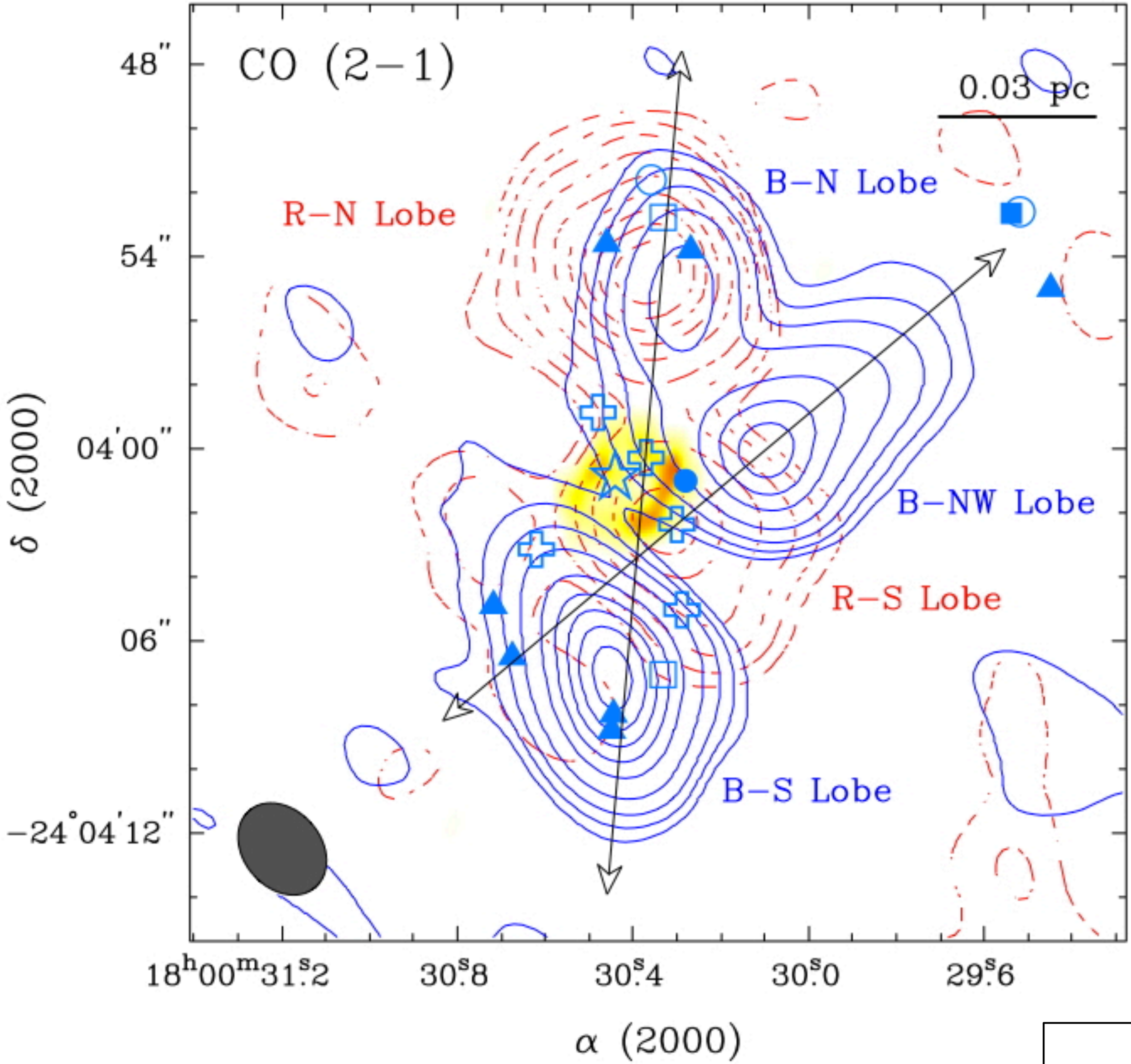
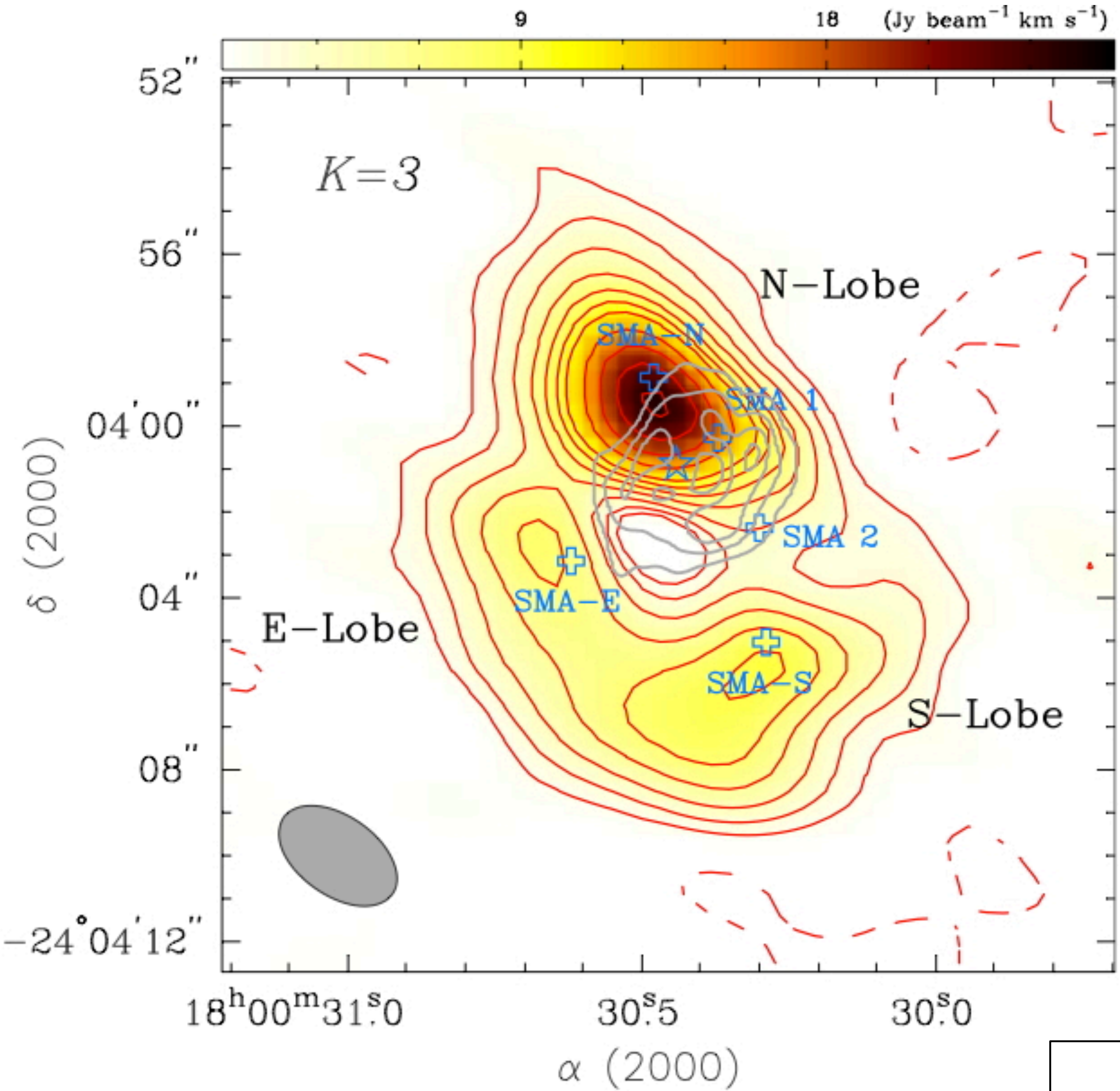
A COSMIC RAY ACCELERATOR ?

A cosmic ray accelerator ? Mechanical energy…



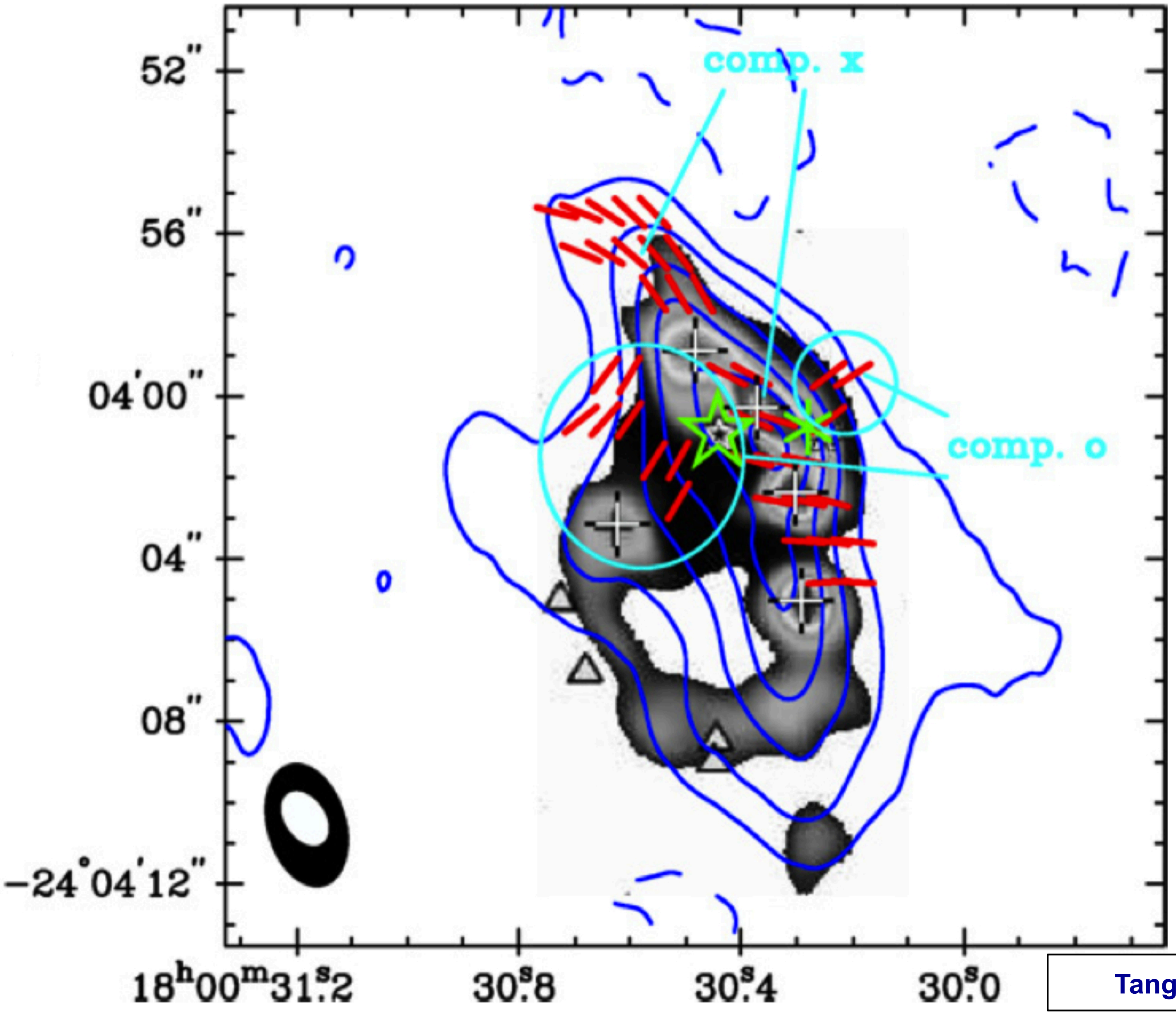
Su et al. 2012

A cosmic ray accelerator ? …an HII region…



Su et al. 2009

A cosmic ray accelerator ? …strong magnetic fields…



Tang et al. 2009

A cosmic ray accelerator ? Massive stars and CRs

- From the SNOBs of Montmerle et al. 1979 to hot stars…:
  - OB star wind terminal shocks Voelk & Forman 1982
  - synchrotron emission in hot stars environments White 1985
  - Non thermal X- and γ-rays phenomena in WF stars Pollock 1987

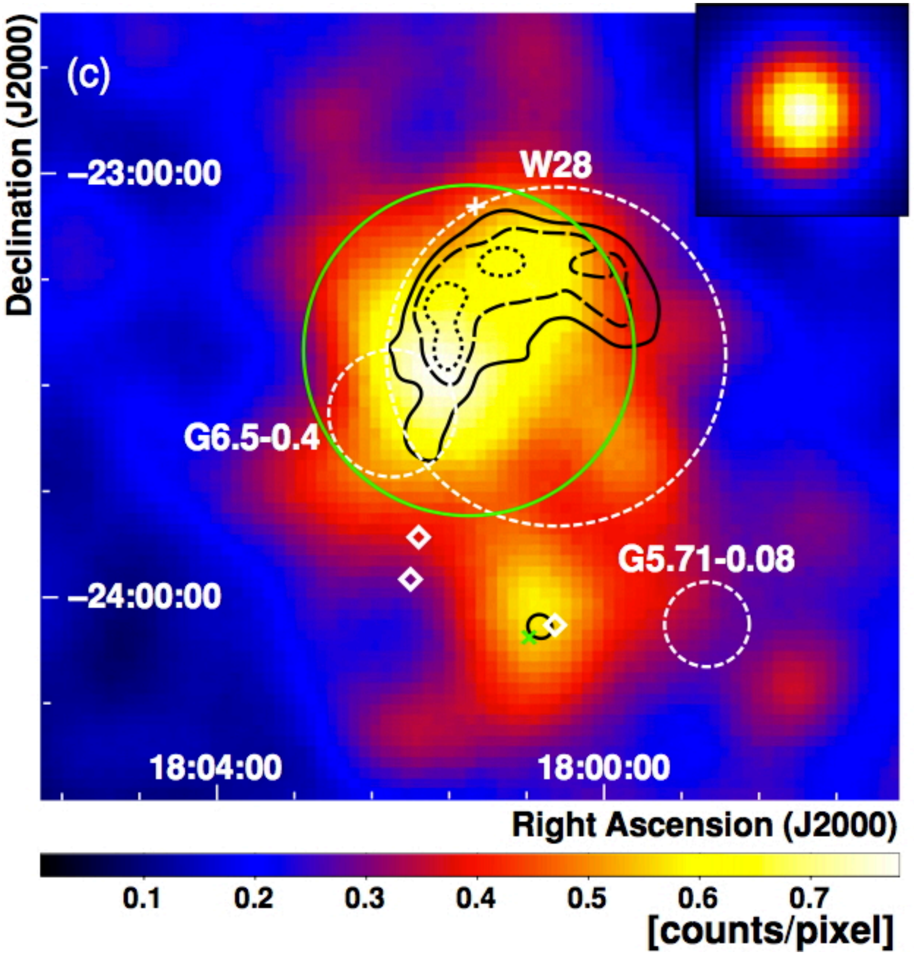
- OB SFRs correlation with EGRET sources, Romero et al. 1999

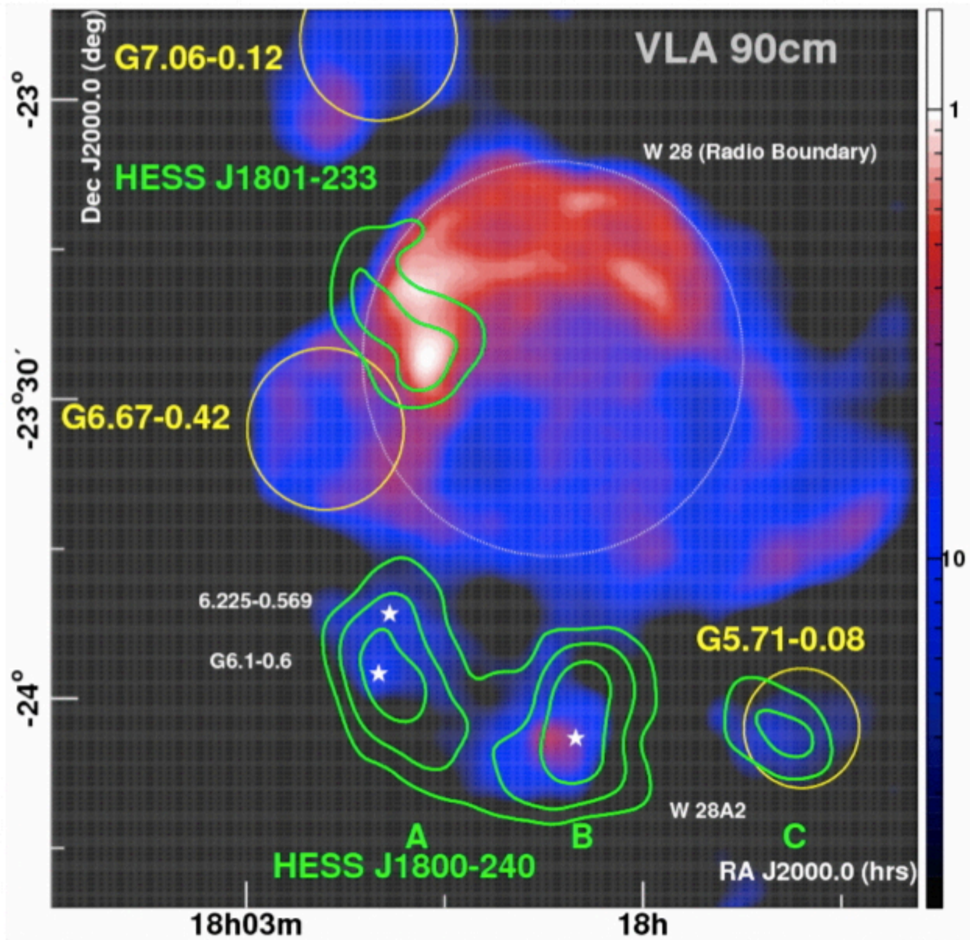
massive young Galactic objects correlation with Fermi sources, Munar-Adrover et al. 2011

- TeV detection in massive SFRs:
  - Cynus OB2 association region with HEGRA, Aharonian et al. 2002
  - Wes2 young star cluster with HESS (>380 GeV), Aharonian et al. 2007
  - SFR W43 with Fermi (TeV range), Lemoine-Goumard et al. 2011
  - Cyg X superbubble with Fermi (TeV range), Ackermann et al. 2011

- Theory : Araudo et al. 2007, Bosch-Ramon et al. 2010: IRAS 16547-4247

A cosmic ray accelerator ?





- The Fermi-lat count map

2-10 GeV with 0.2° resolution

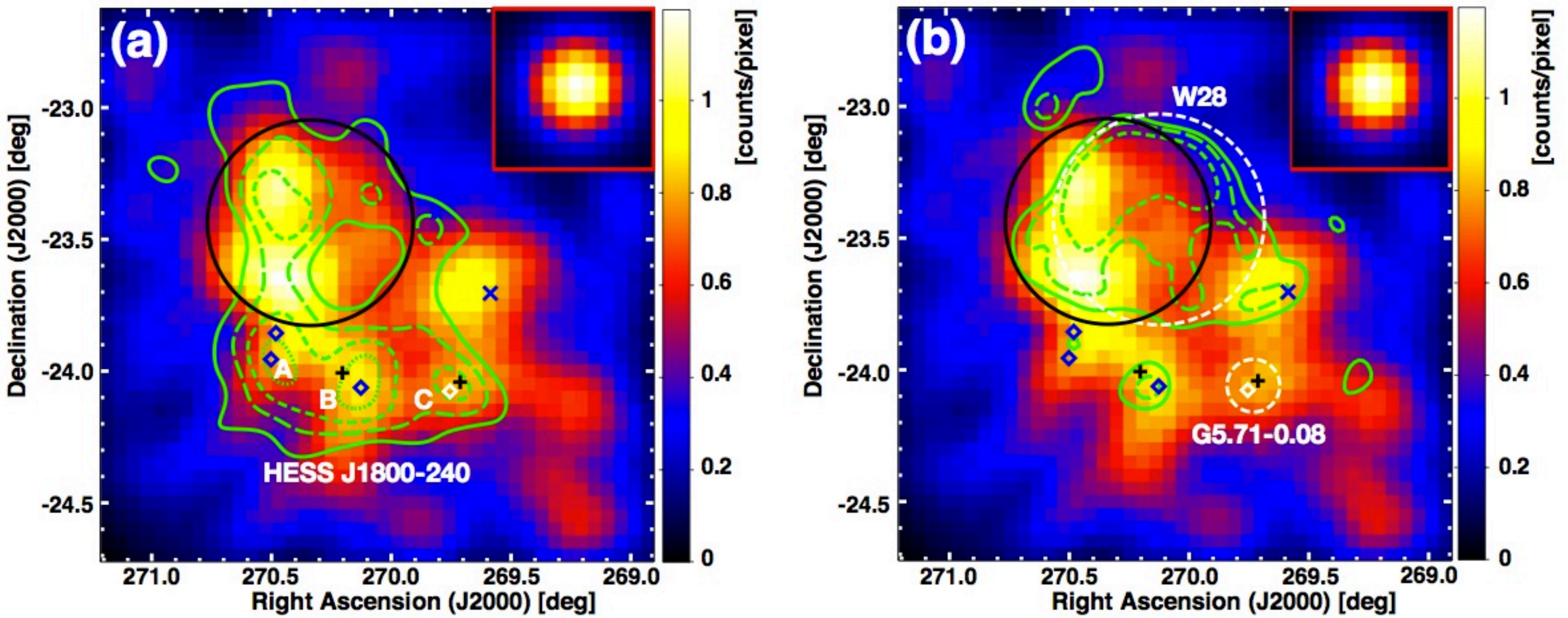
Abdo et al. 2010

- The HESS count map

Above 320 GeV with 5-6’ resolution

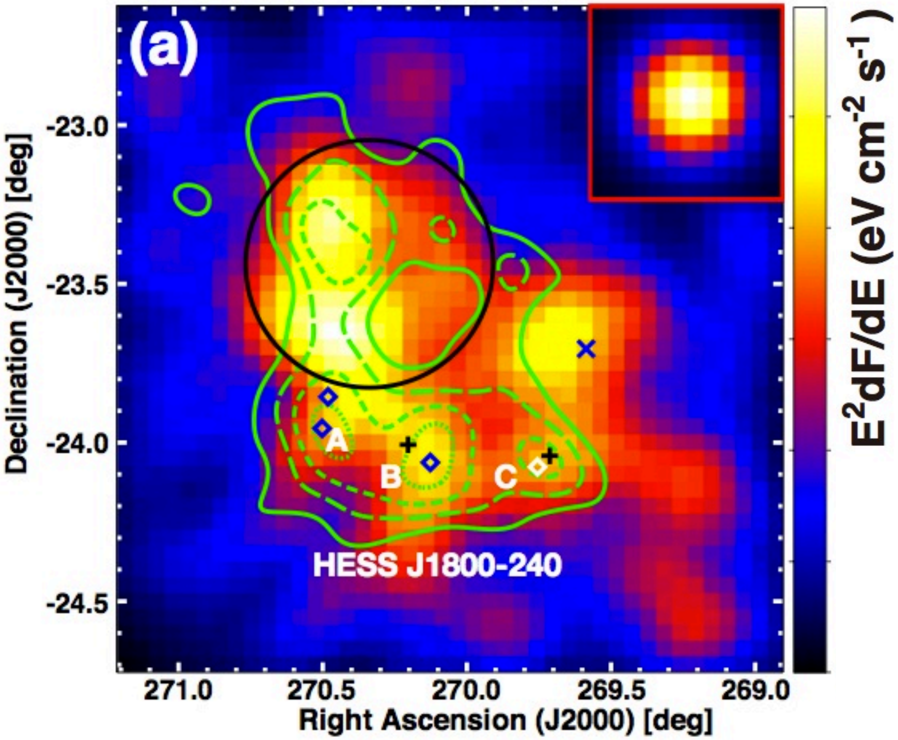
Aharonian et al. 2008

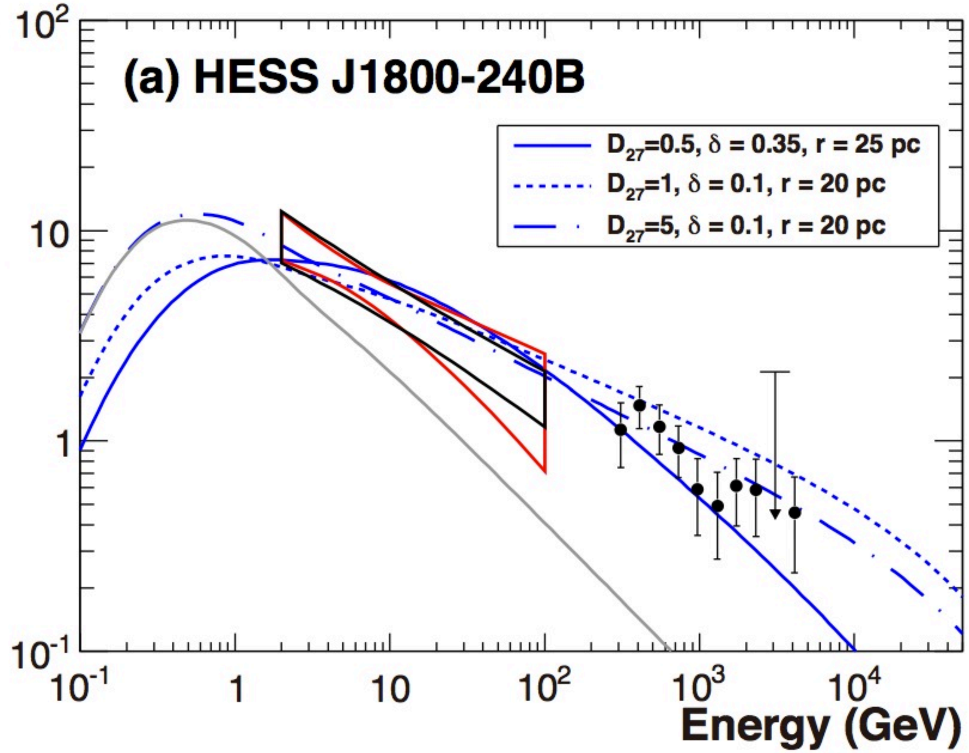
A cosmic ray accelerator ?



Hanabata et al. 2014

A cosmic ray accelerator ?

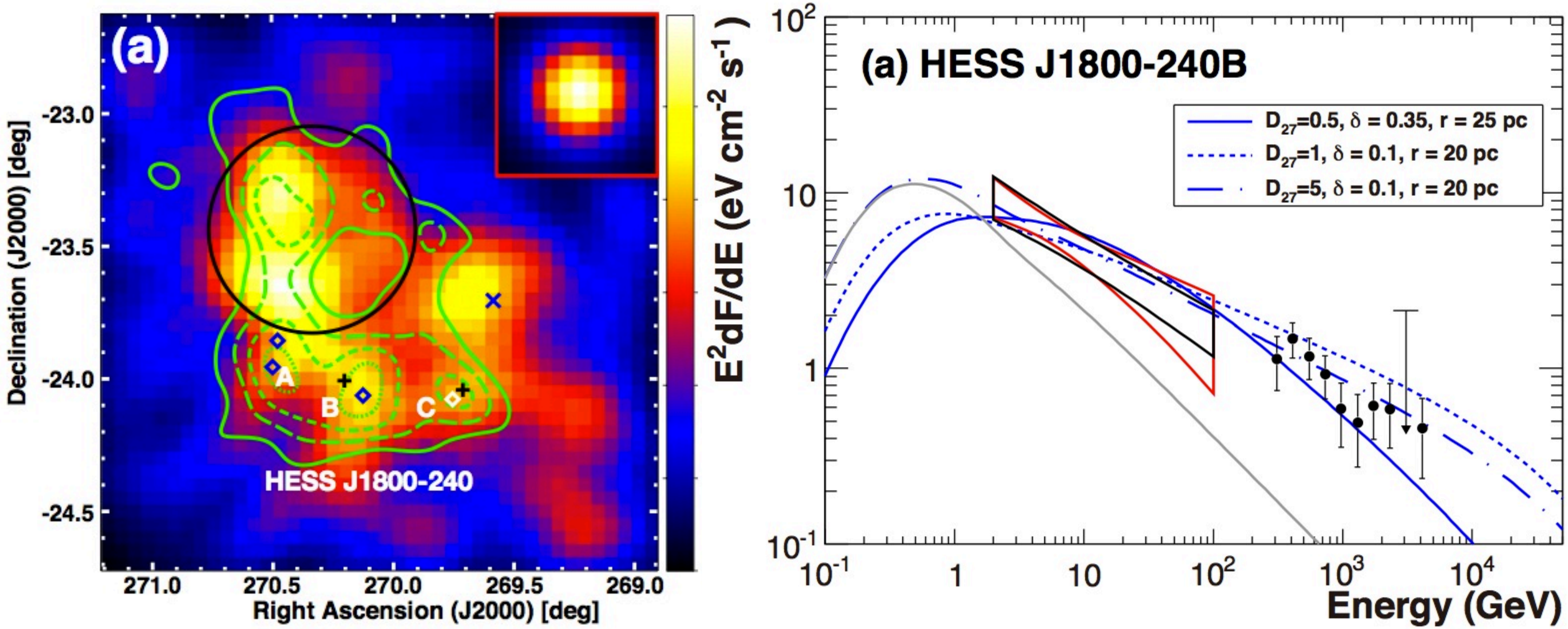




- HESS points
- 68% confidence range of LAT
- upper limit of the γ-ray emission produced by the sea of Galactic CRs in the same CR-illuminated cloud

Hanabata et al. 2014

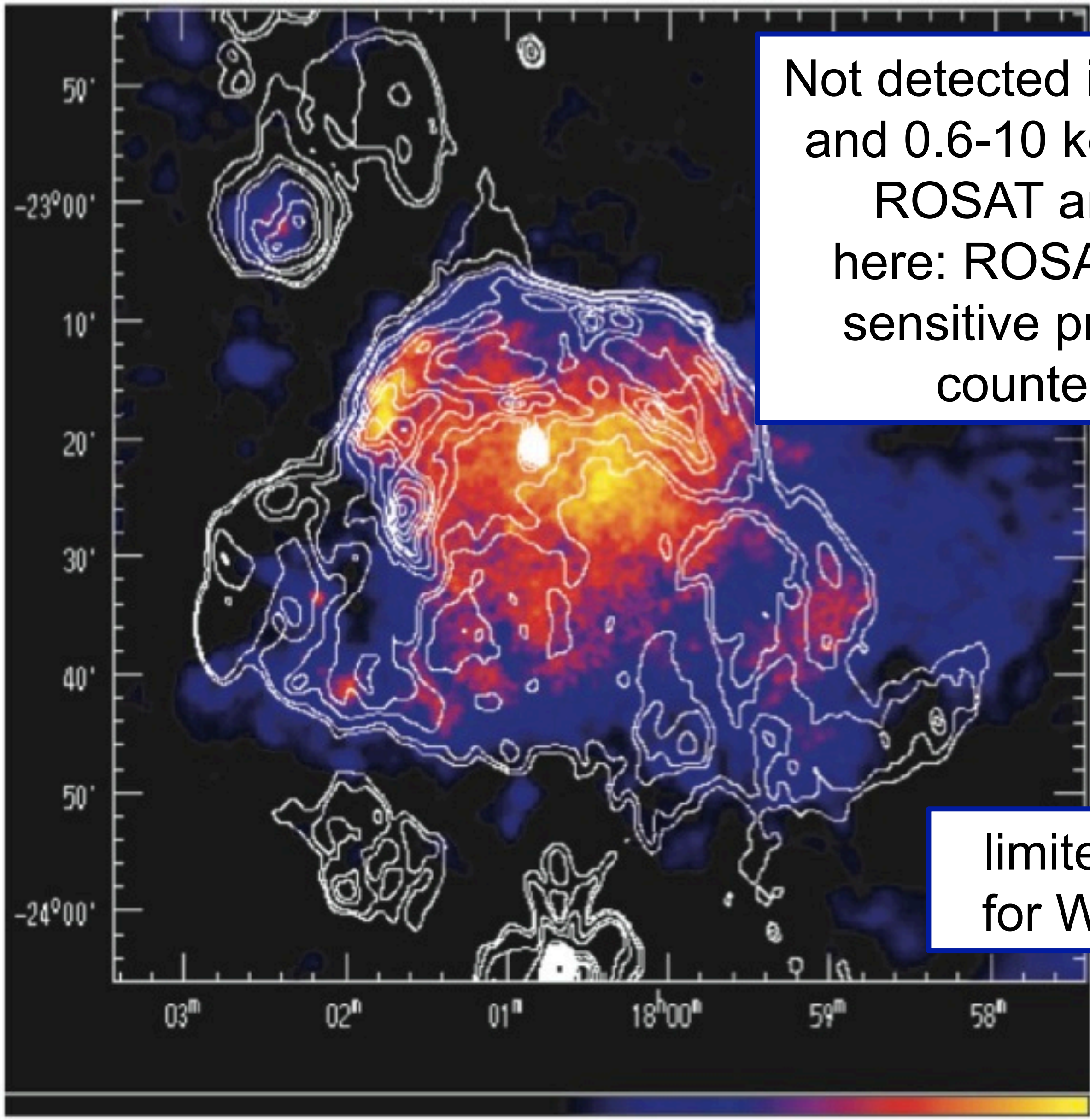
A cosmic ray accelerator ?



'There is no model for multi-TeV particle acceleration in such HII regions'

Hanabata et al. 2014

A cosmic ray accelerator ? X-rays

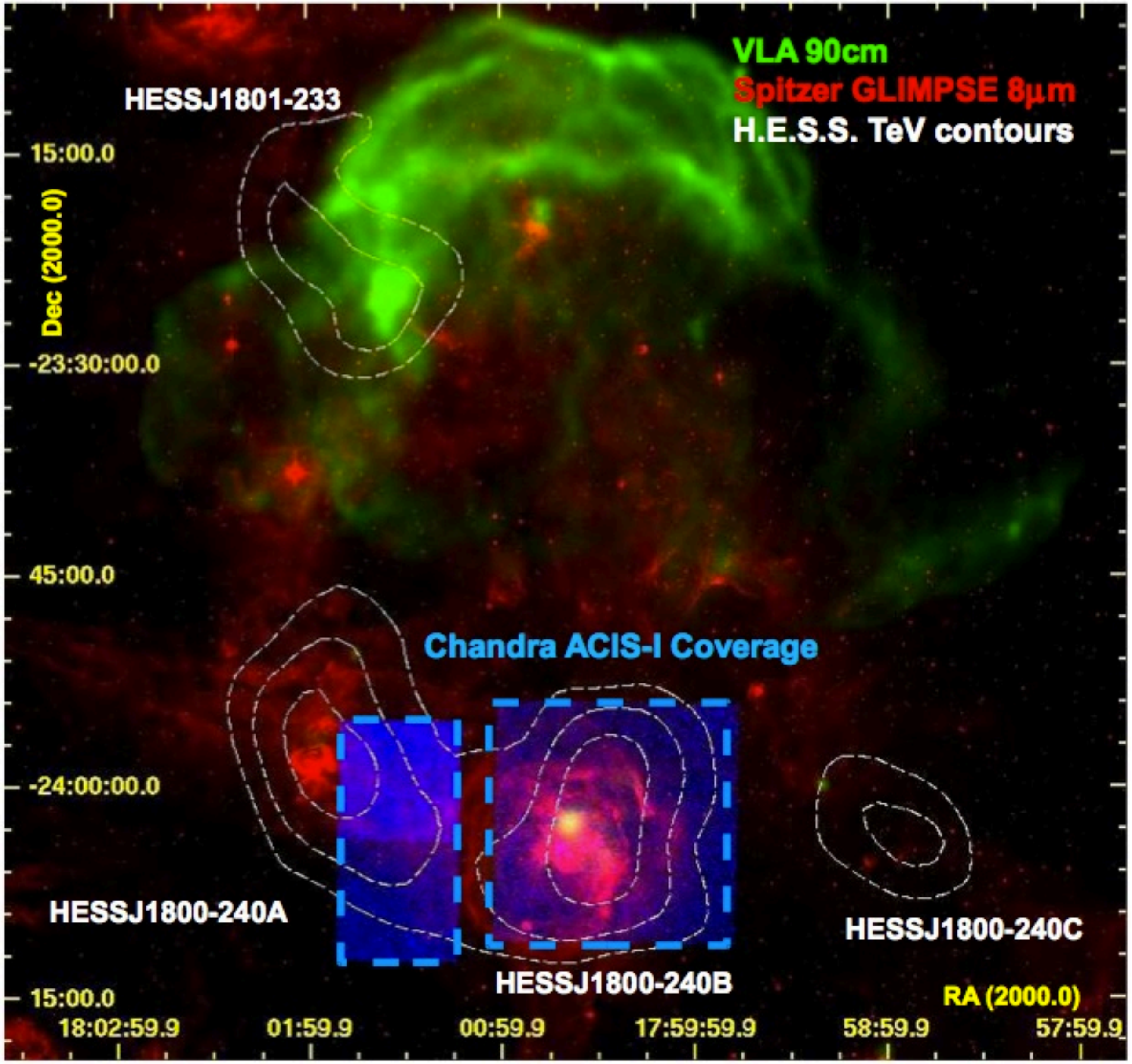


Not detected in the 0.5-2.4 and 0.6-10 keV range by ROSAT and ASCA
here: ROSAT ‘position sensitive proportional counter’ map

limited exposure for W28 A2: 4 ks

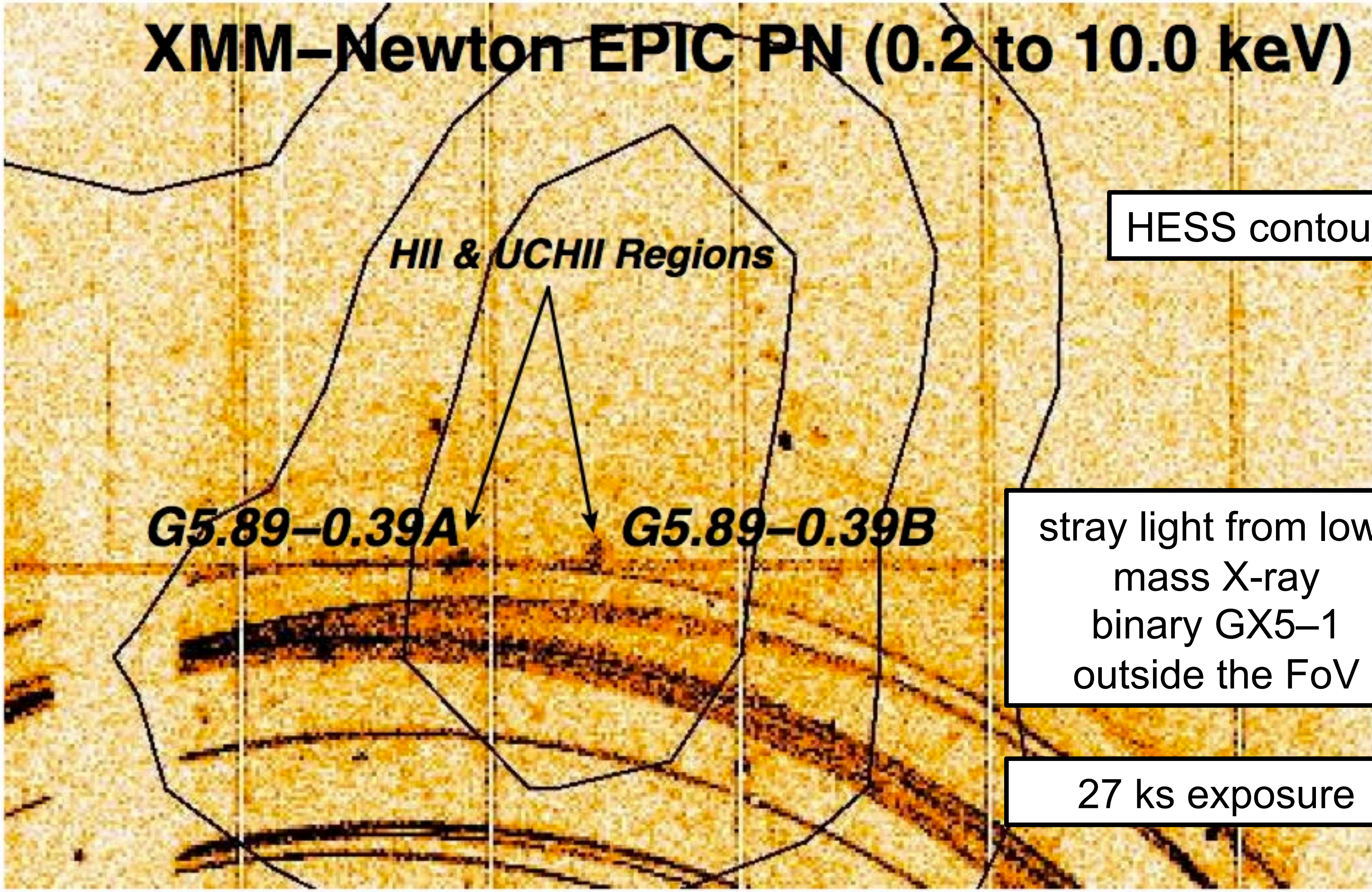
Rho et al. 2002

A cosmic ray accelerator ? X-rays



Rowell et al. 2010 'preliminary'

A cosmic ray accelerator ? X-rays



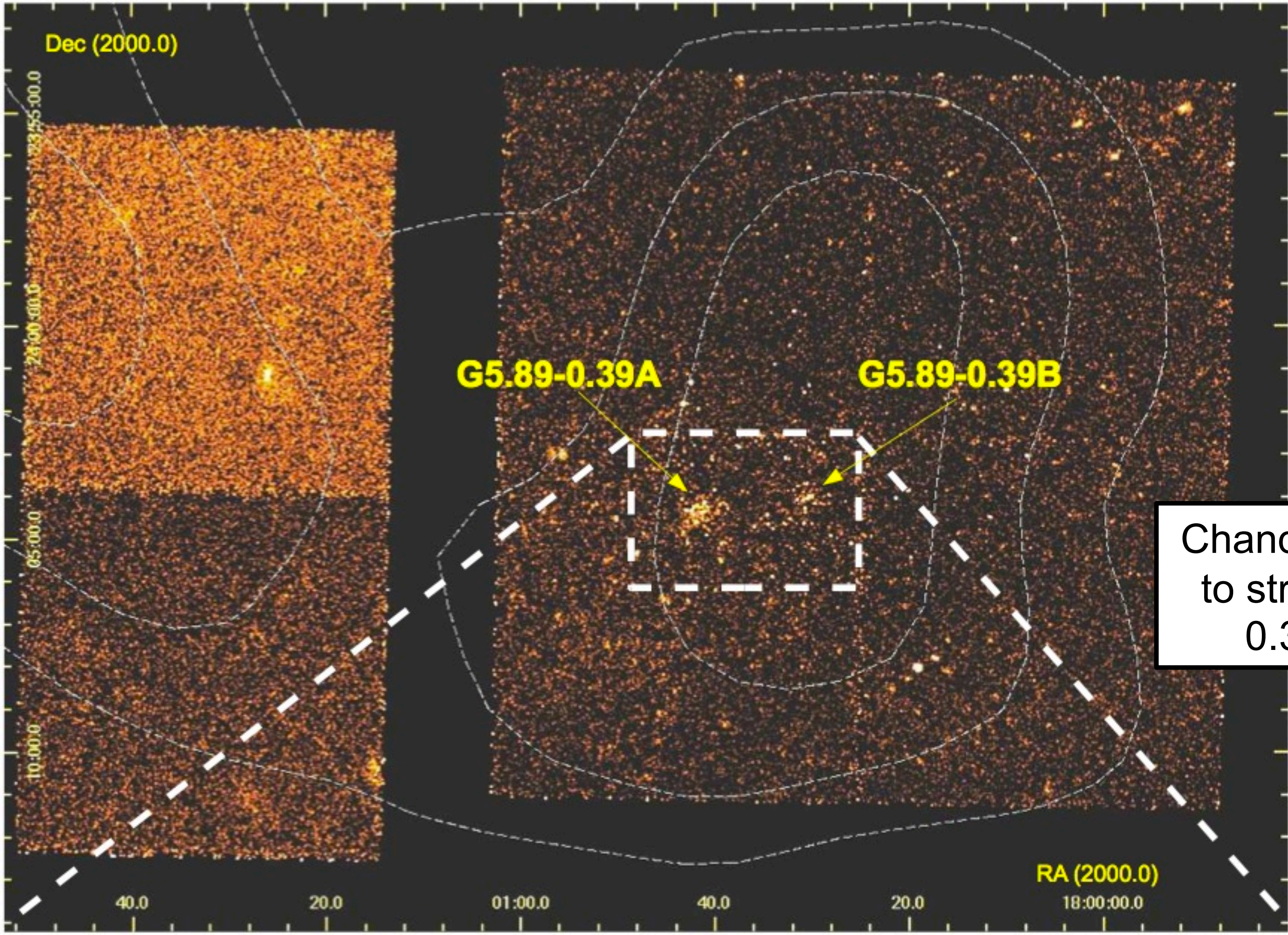
HESS contours

stray light from low-mass X-ray binary GX5–1 outside the FoV

27 ks exposure

Rowell et al. 2010 'preliminary'

A cosmic ray accelerator ? X-rays



Chandra, insensitive to straylight, 80 ks 0.3 to 10 keV

Rowell et al. 2010 'preliminary'

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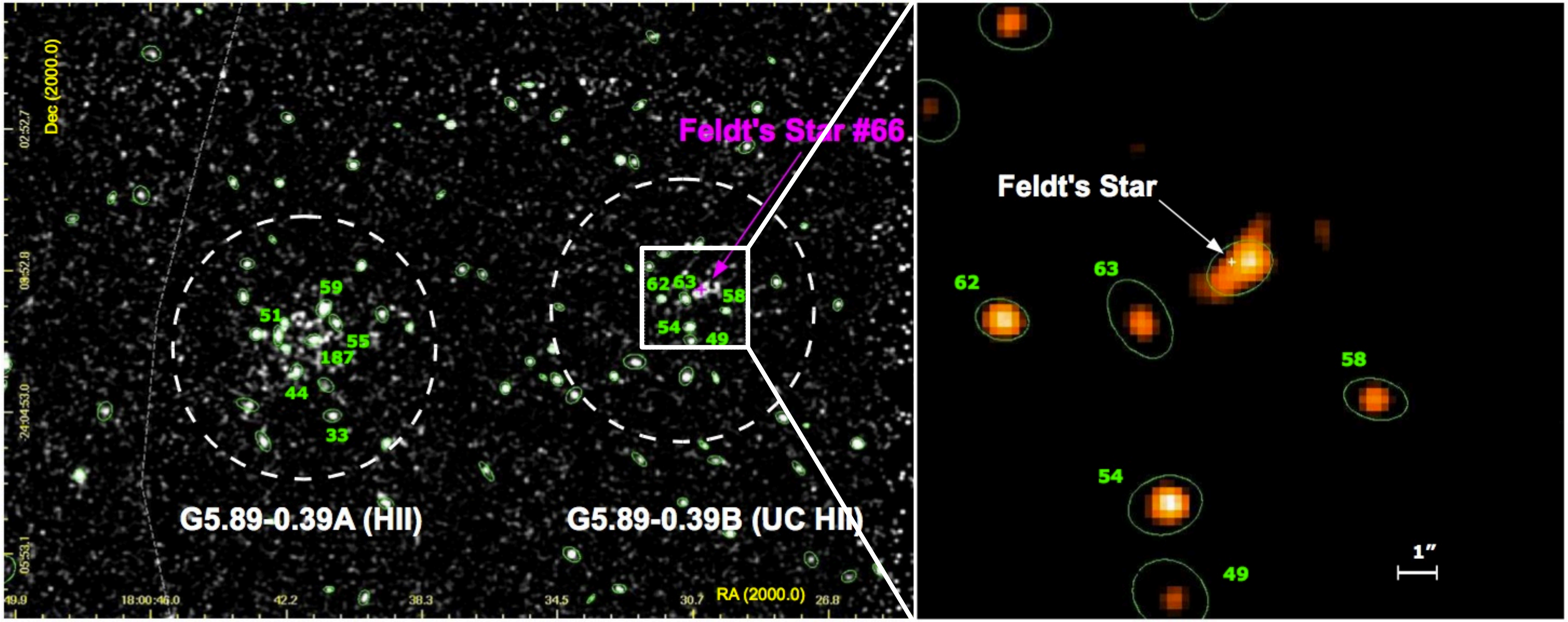

Rowell et al. 2010
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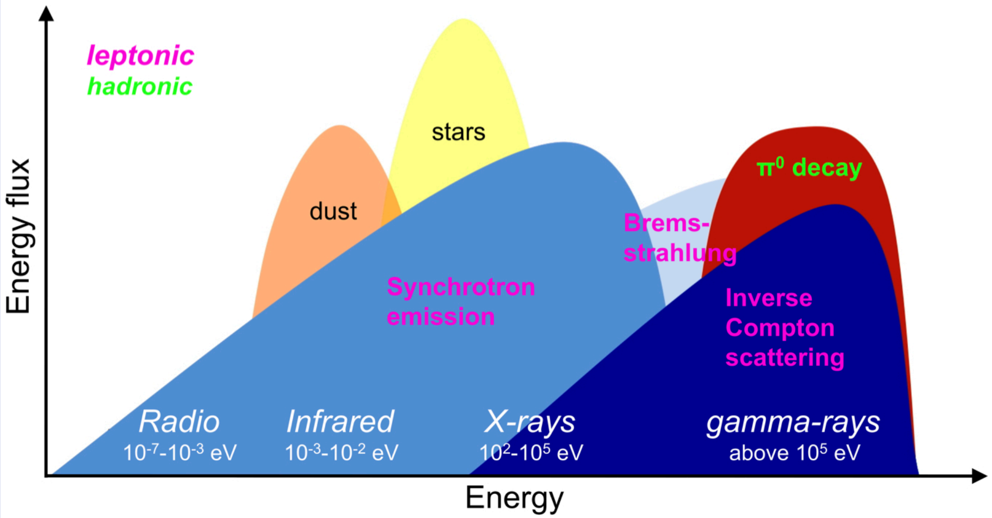
PERSPECTIVES

Perspectives: the very-high energy point of view



- hadrons – ISM :
  - π^0 decomposition => γ-rays

- electrons :
  - Bremsstrahlung – ISM
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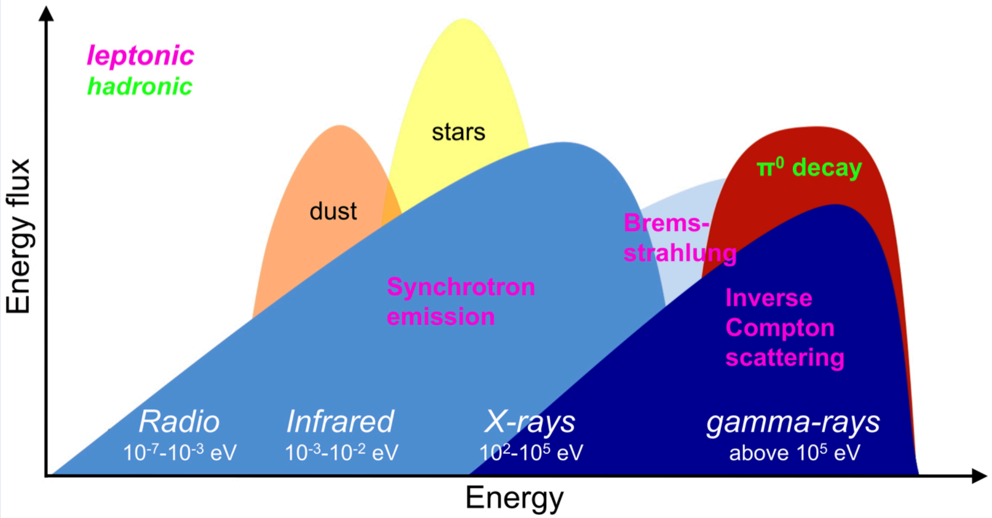

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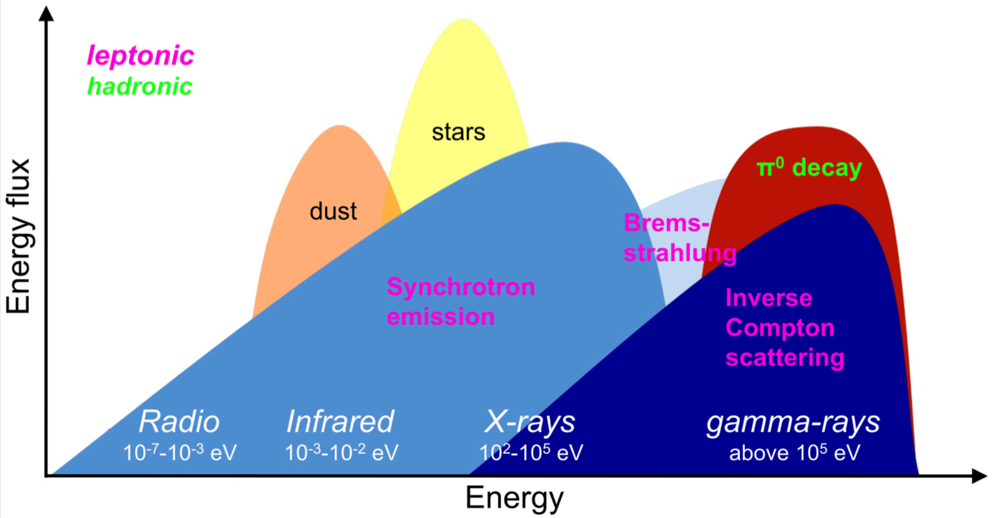

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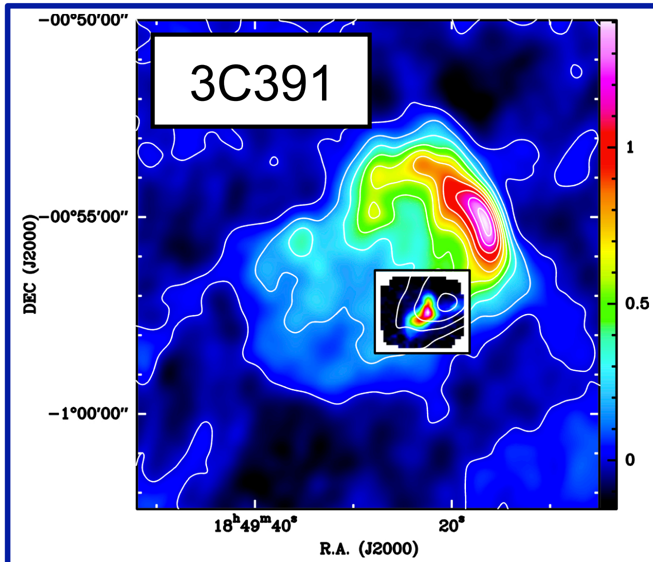

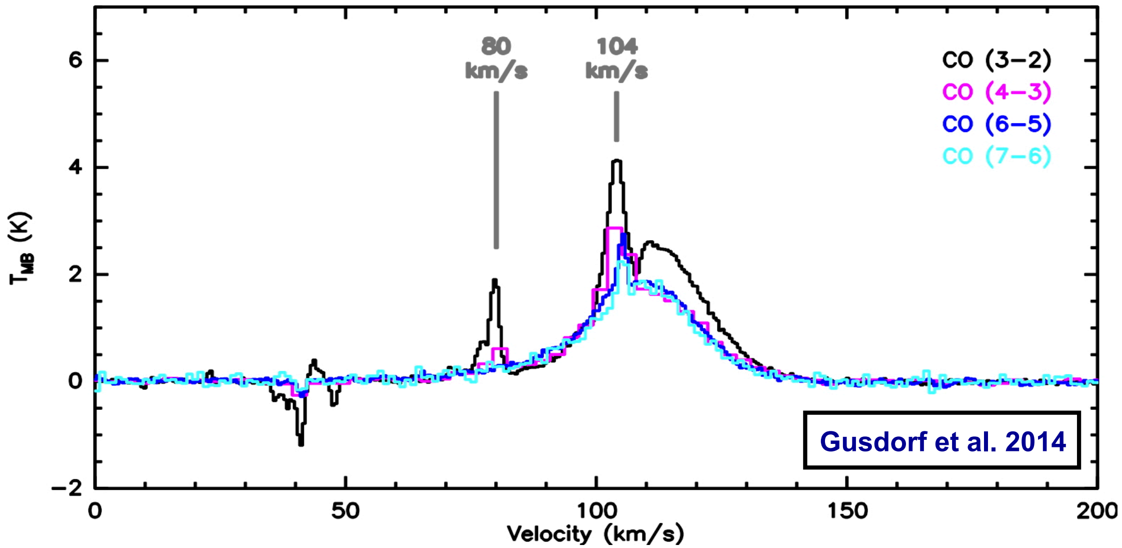

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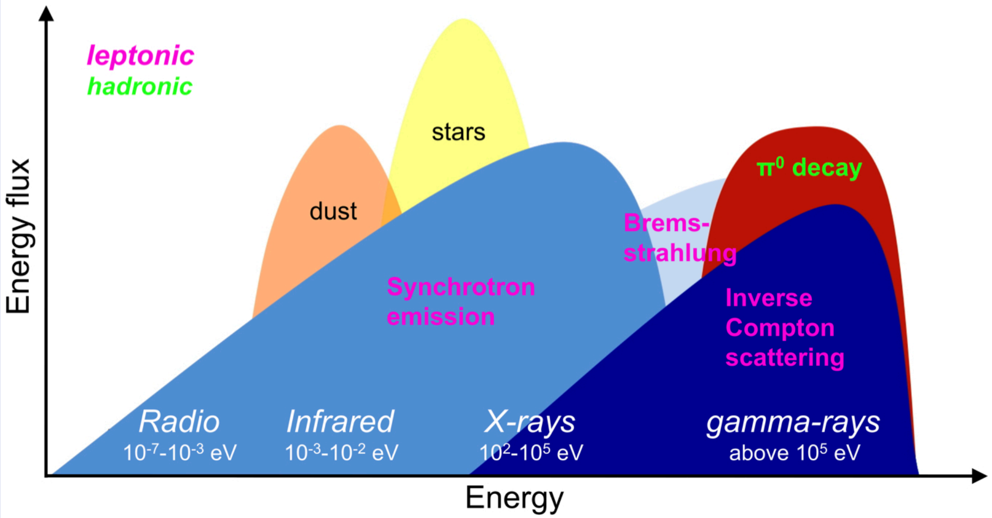

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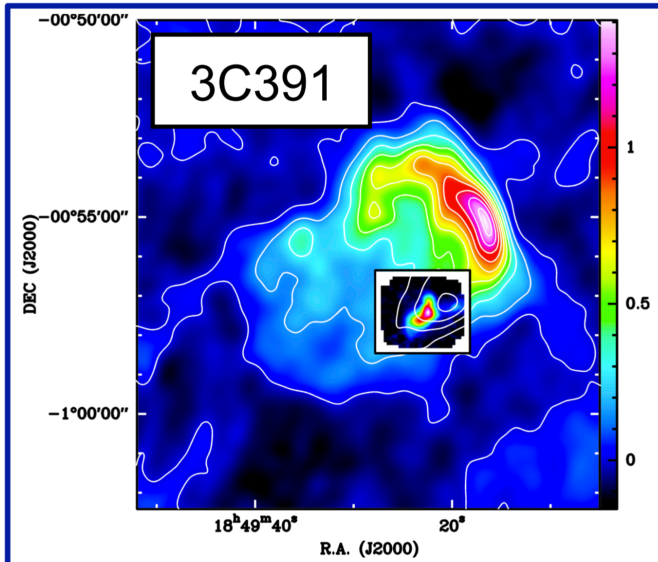

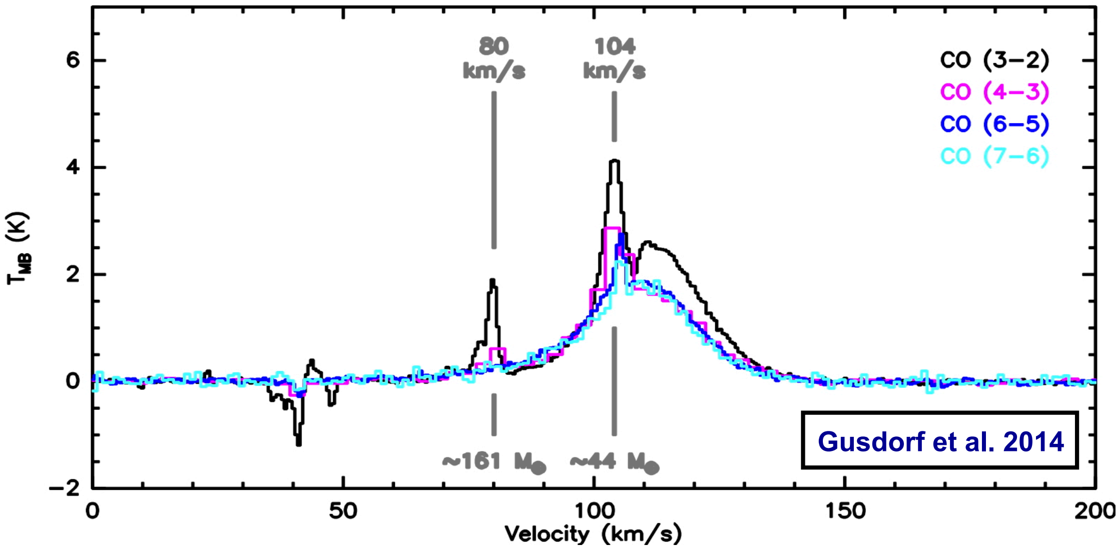

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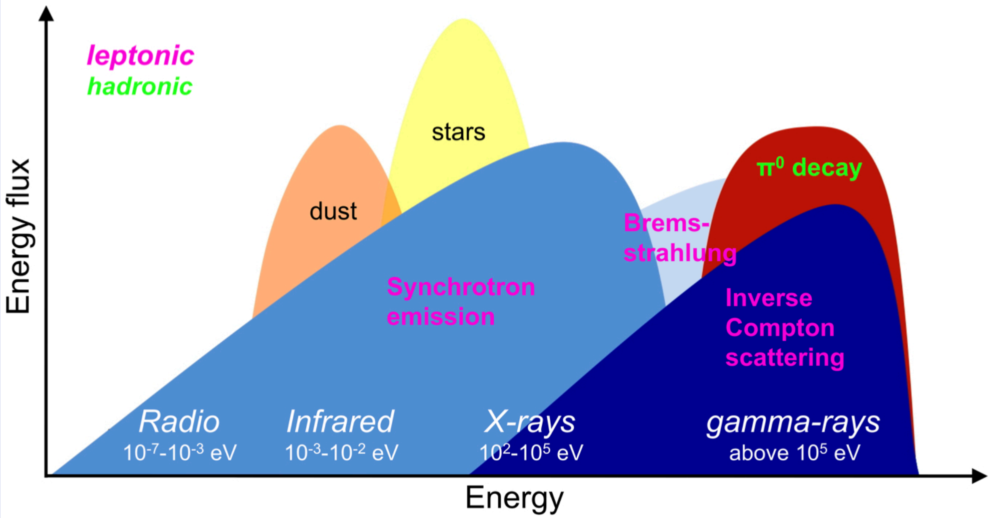

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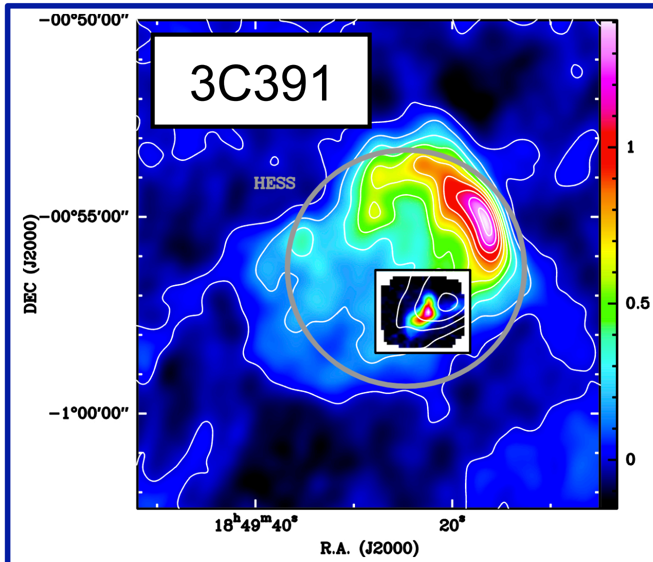

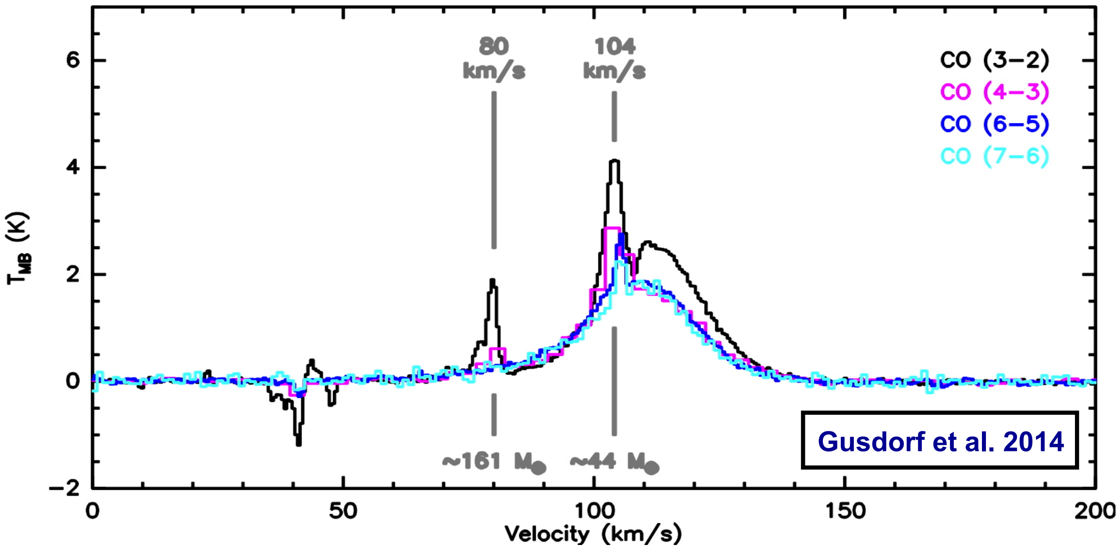

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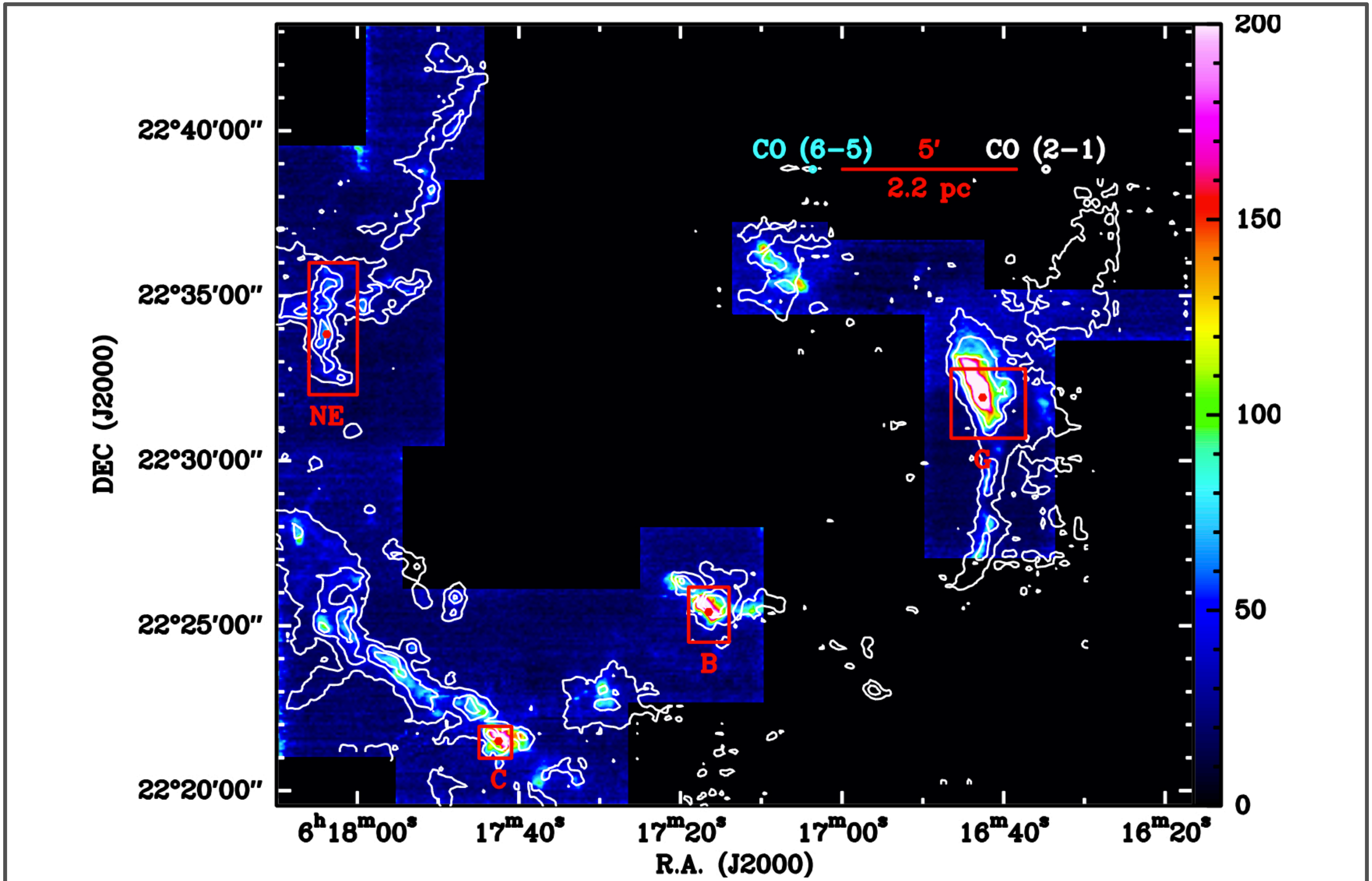

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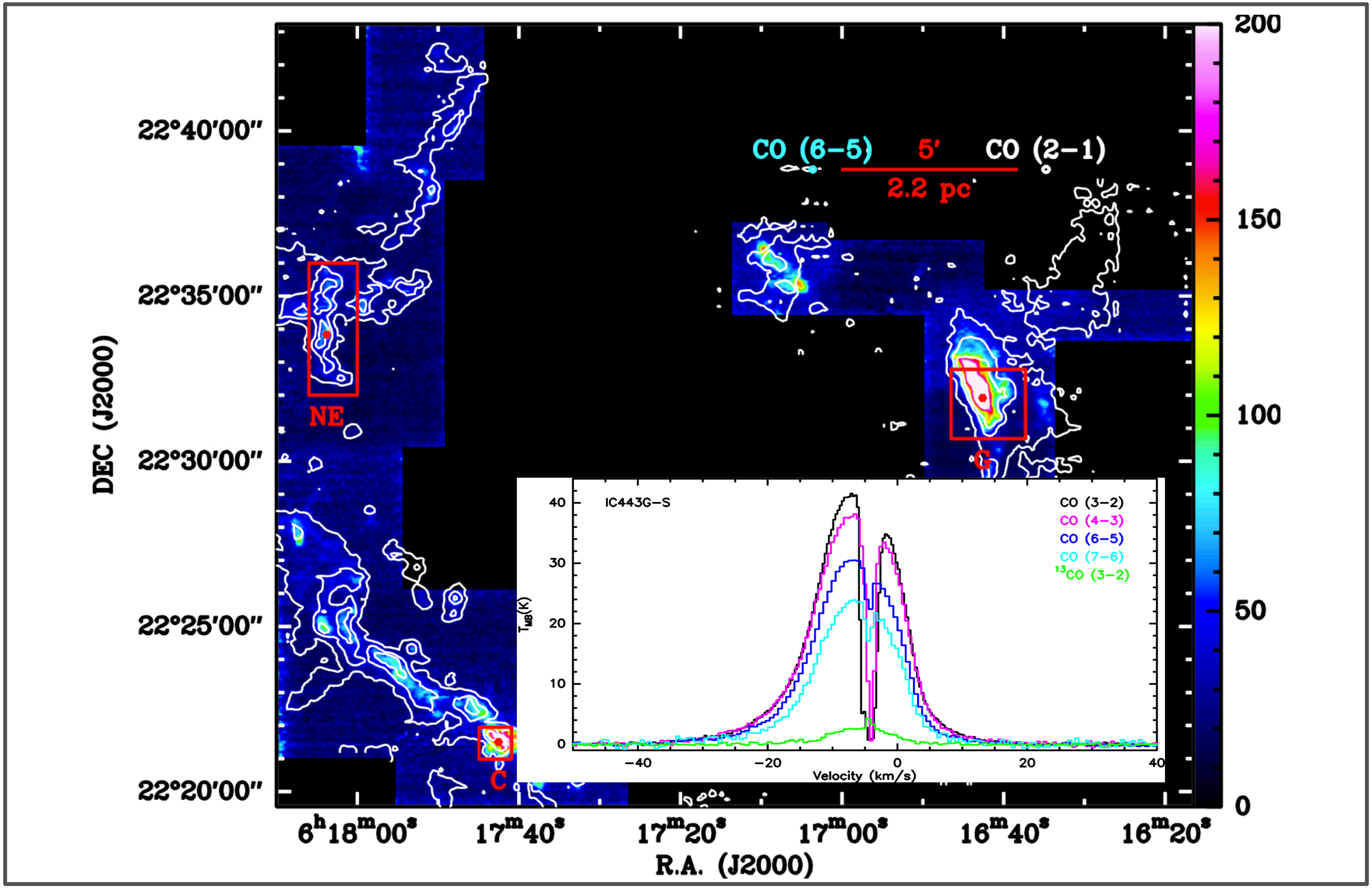

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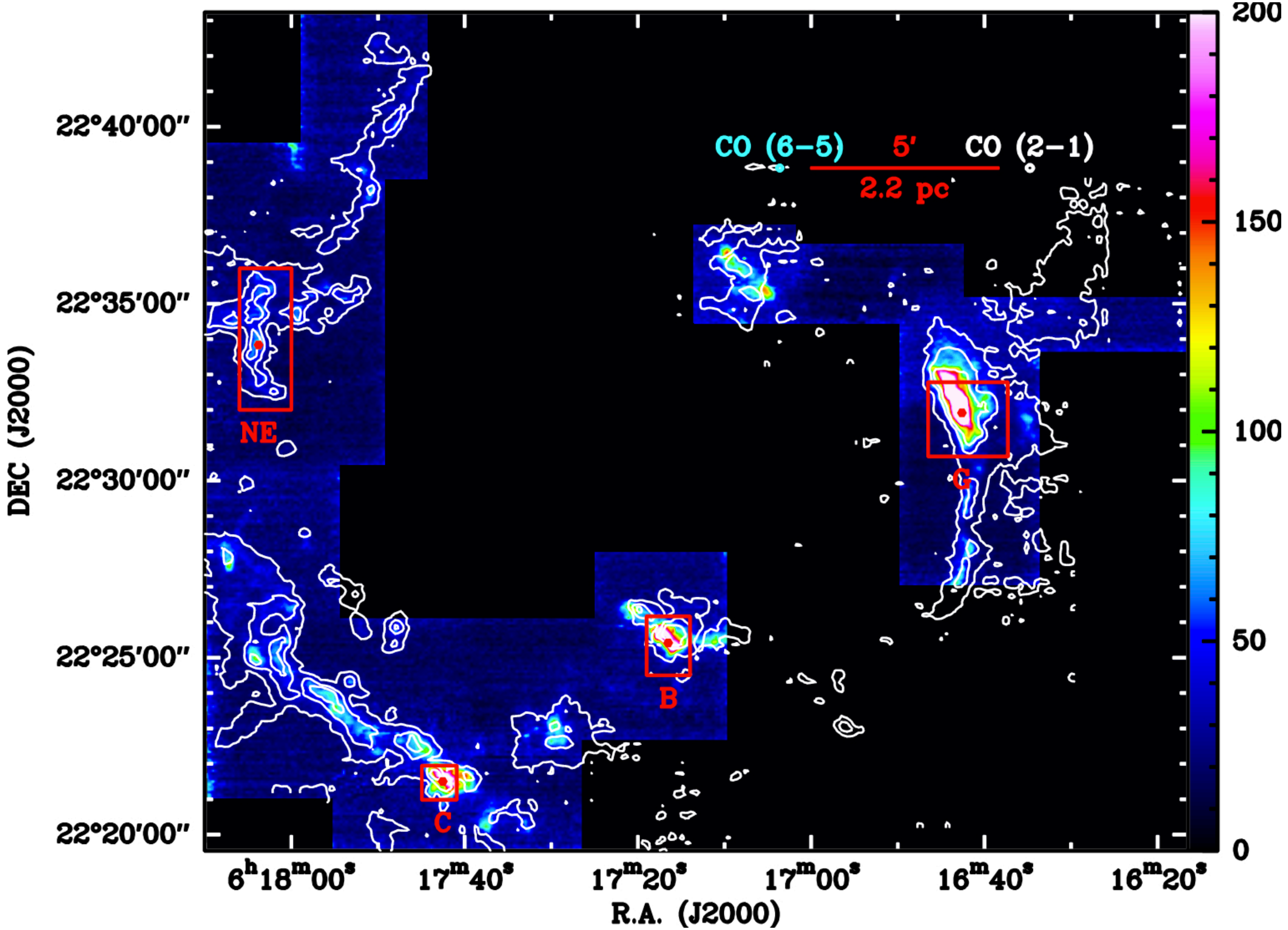

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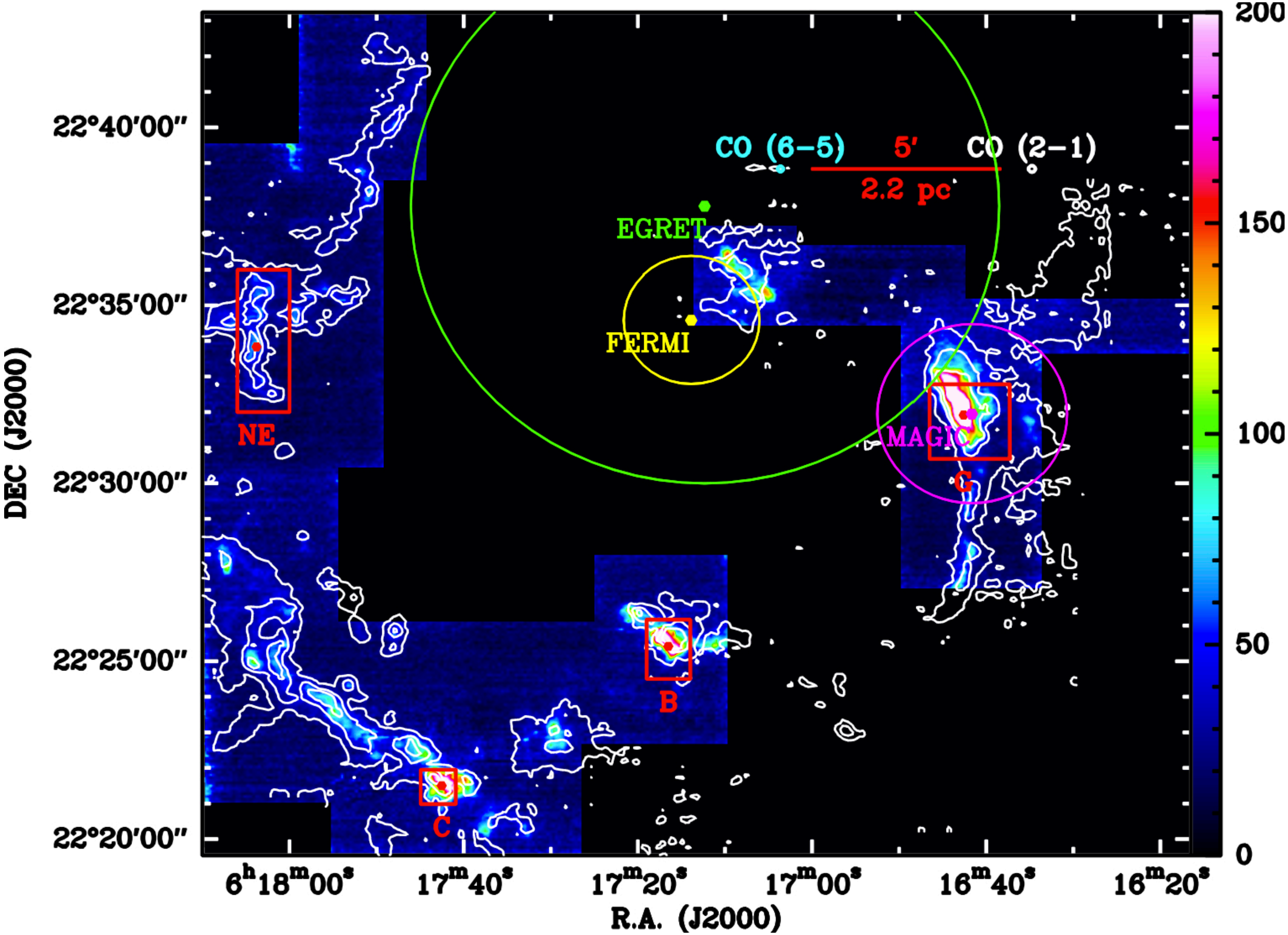

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