l'Observatoire de Paris | LERMA

Laboratoire d'Études du Rayonnement et de la Matière en Astrophysique et Atmosphères

ENS

Département de Physique
École normale supérieure

Old supernova remnants: an interstellar perspective

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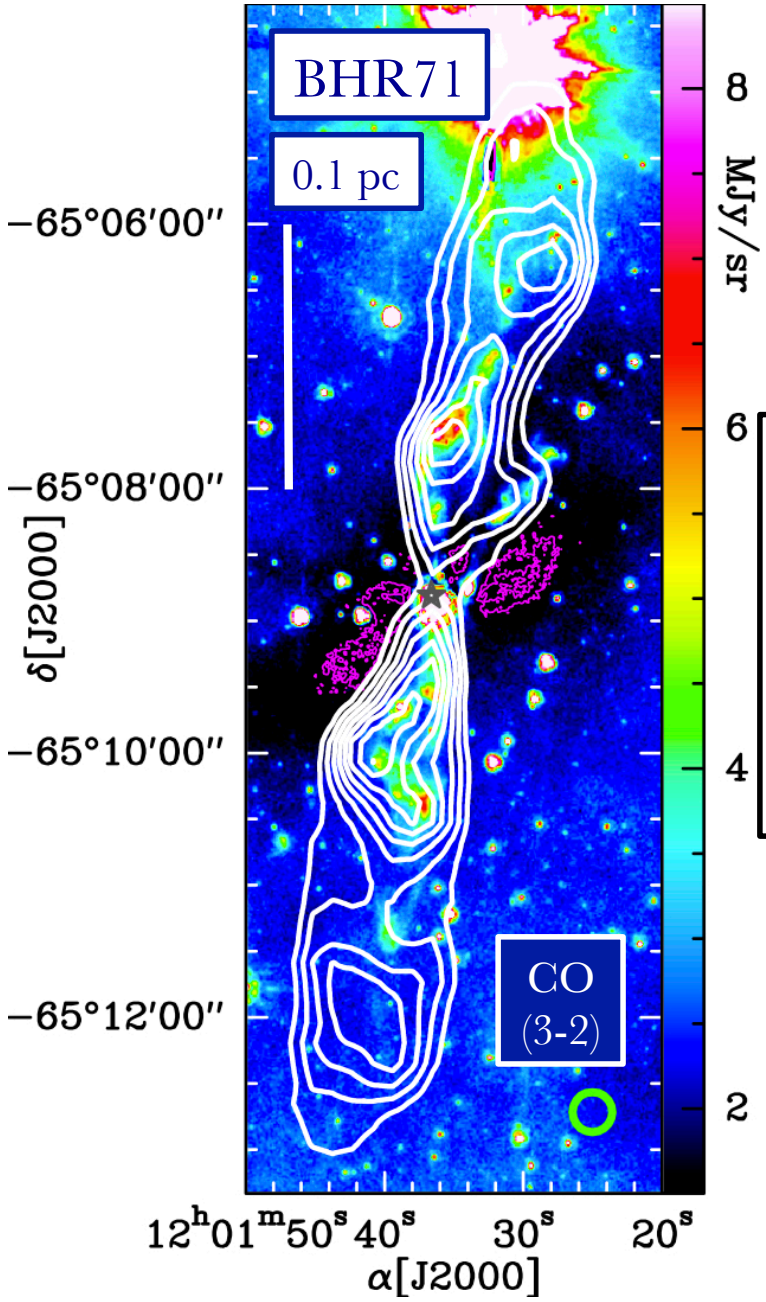
Denise Riquelme,	MPIfR, Bonn, Germany

Outline

- Interstellar shocks
- A template SNR shock study: W28F
- SNRs and the interstellar medium
- SNRs and cosmic rays
- Perspectives

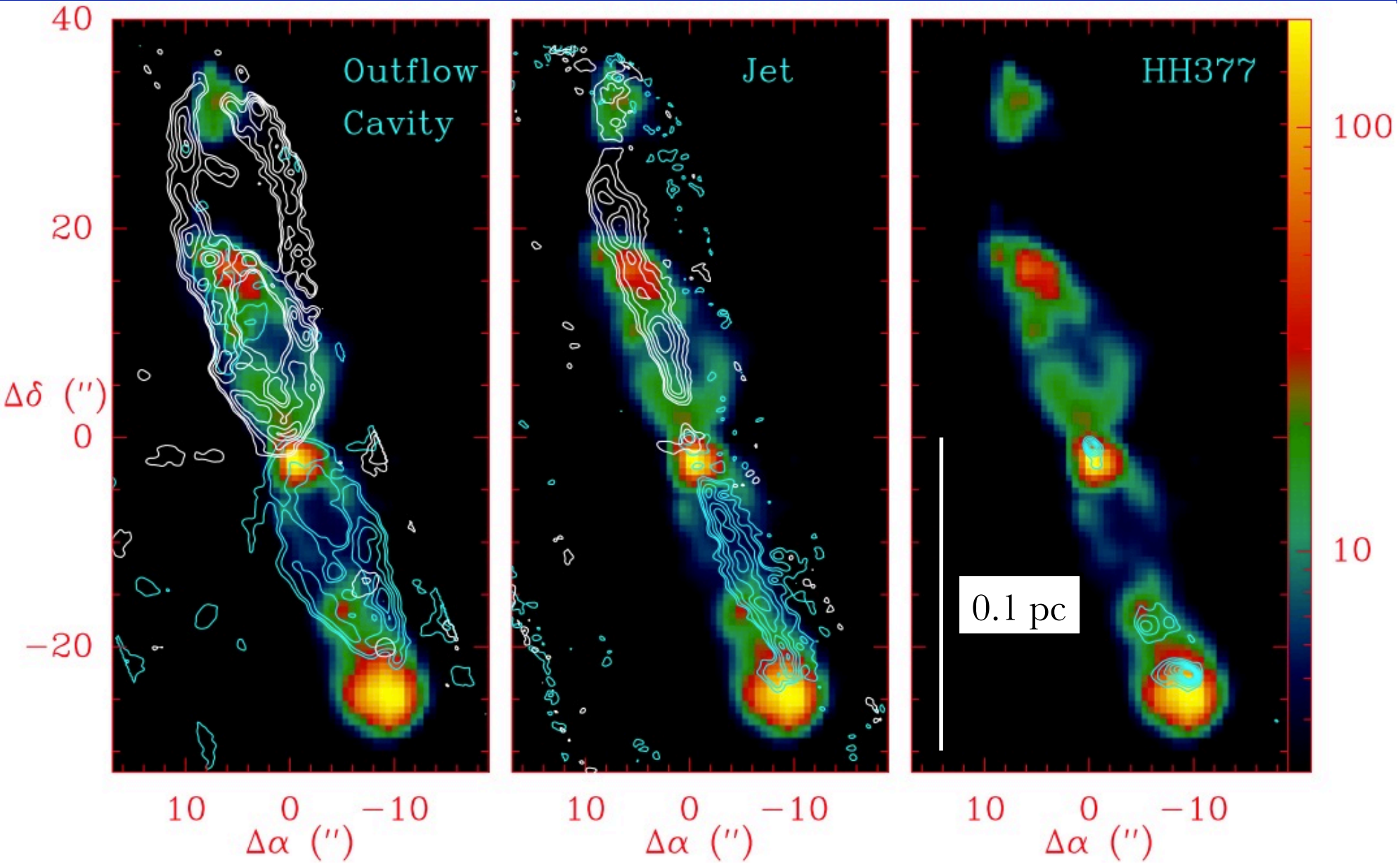
Interstellar shocks

Interstellar shocks



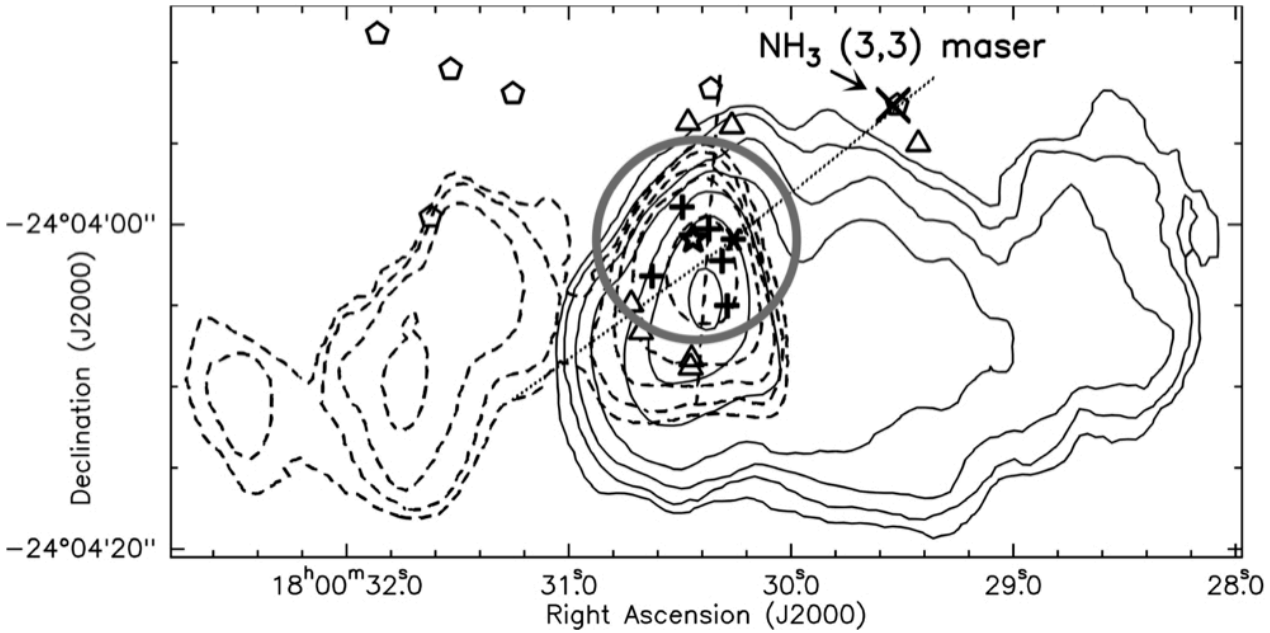
The BHR71 low-mass protostellar outflow system, *Spitzer*/IRAC 8 μm and CO (3-2), Gusdorf et al. 2015

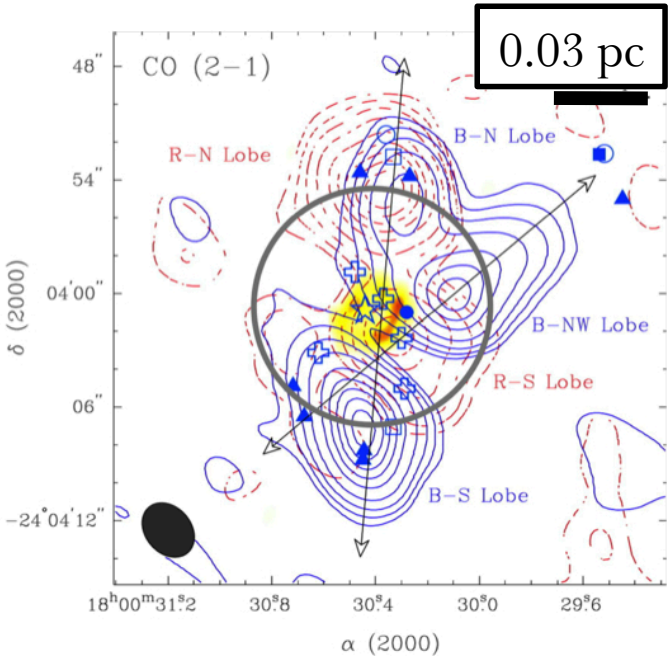
Interstellar shocks



The Cep E intermediate-mass outflow in CO (2-1) by the PdBI, Lefloch et al. 2015

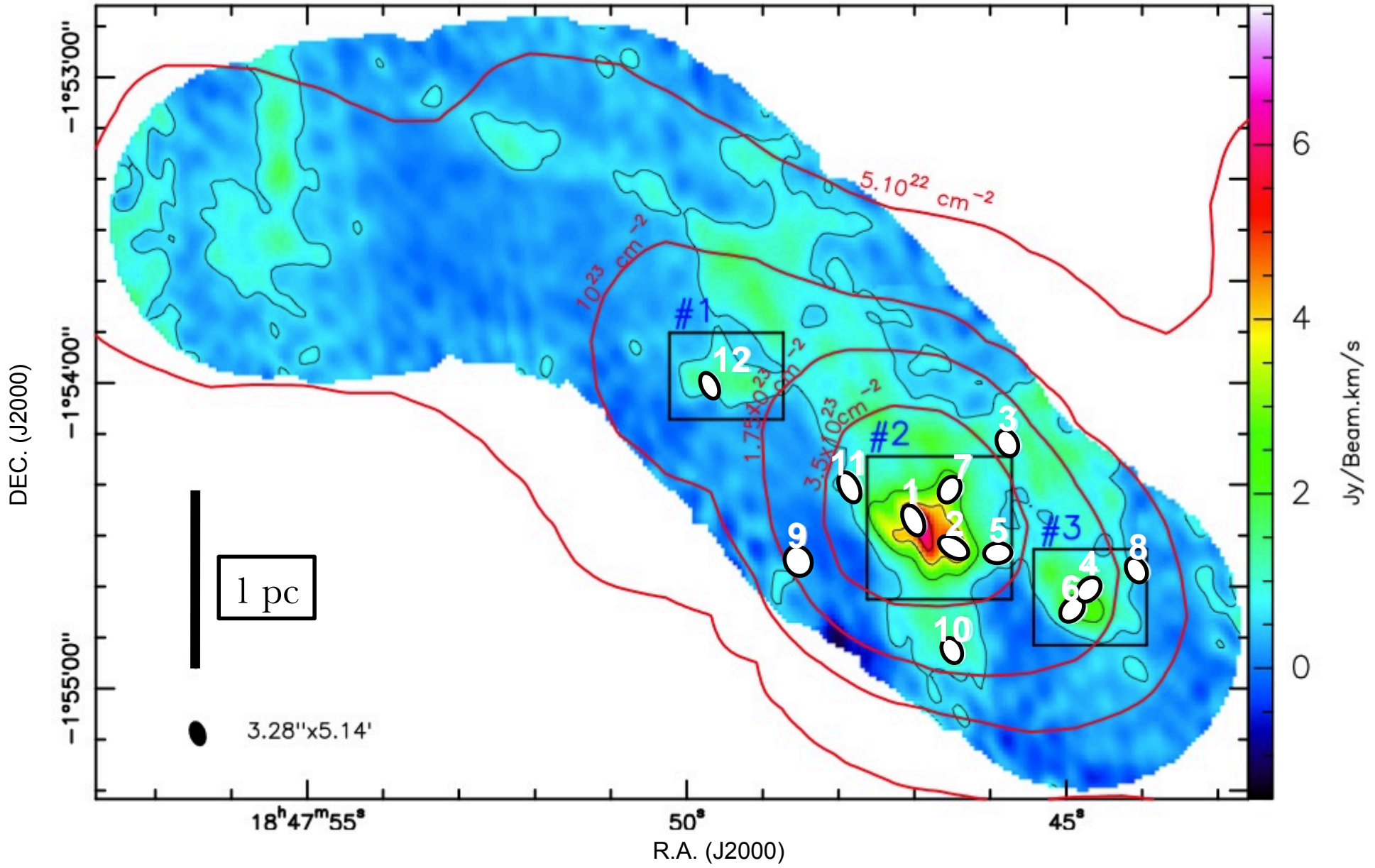
Interstellar shocks





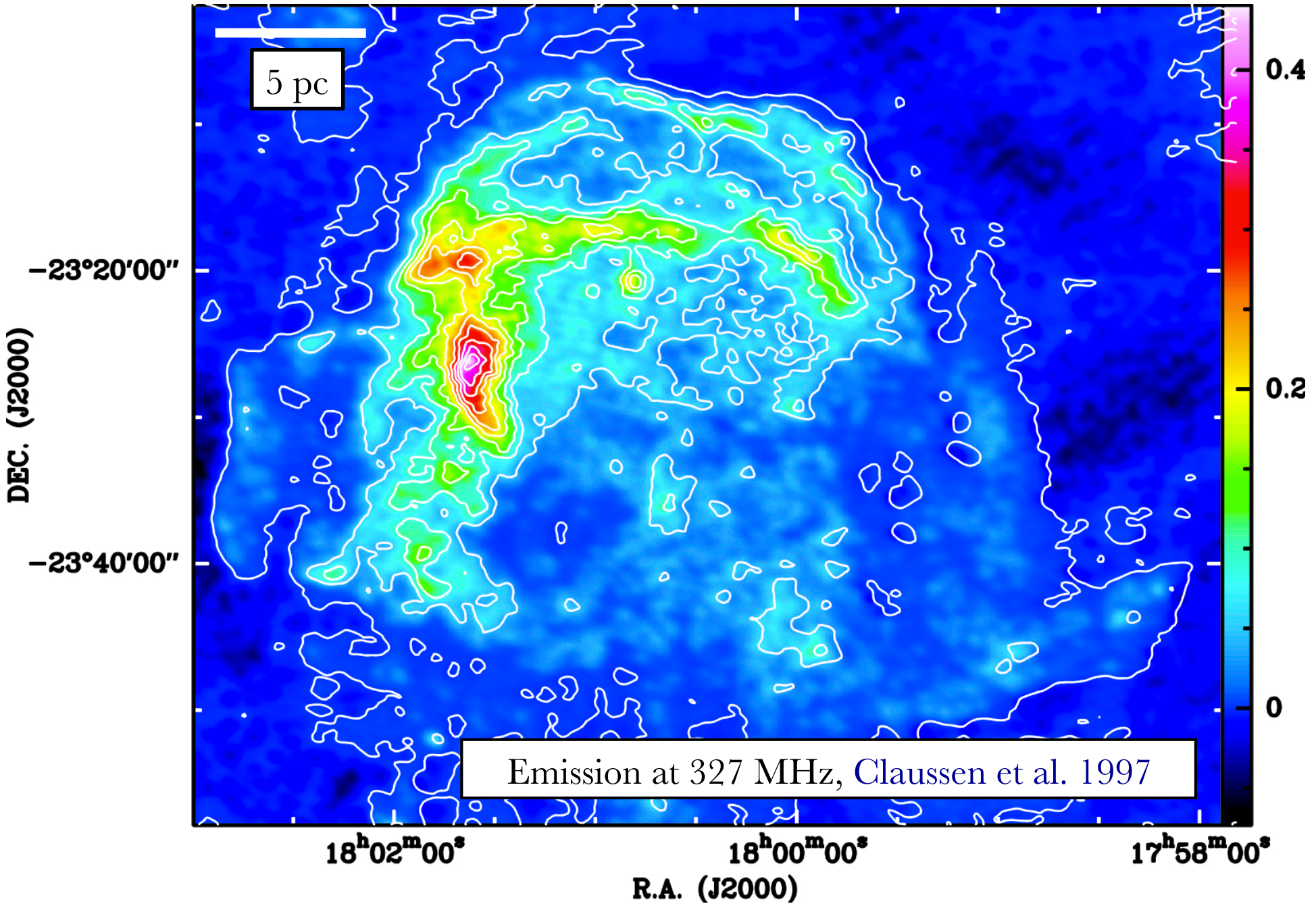
The G5.89-00.39 massive star forming region
in single-dish CO (1-0) Hunter et al. 2008, and SMA CO (2-1) Su et al. 2012

Interstellar shocks



The W43MM1 filament in SiO (2-1), Nguyen Luong et al. 2013, Louvet et al. 2014

Interstellar shocks



A template SNR shock study: W28F

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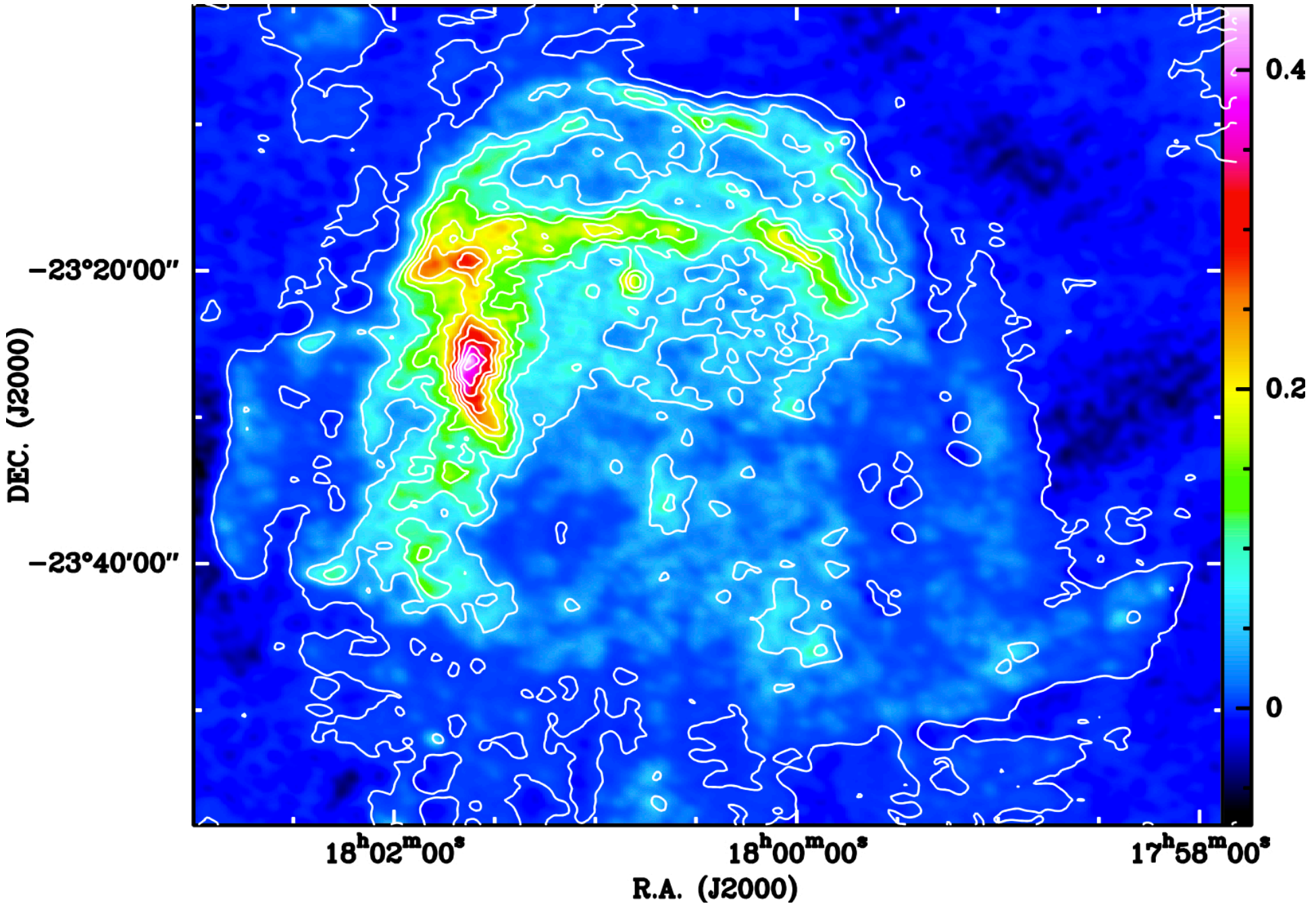

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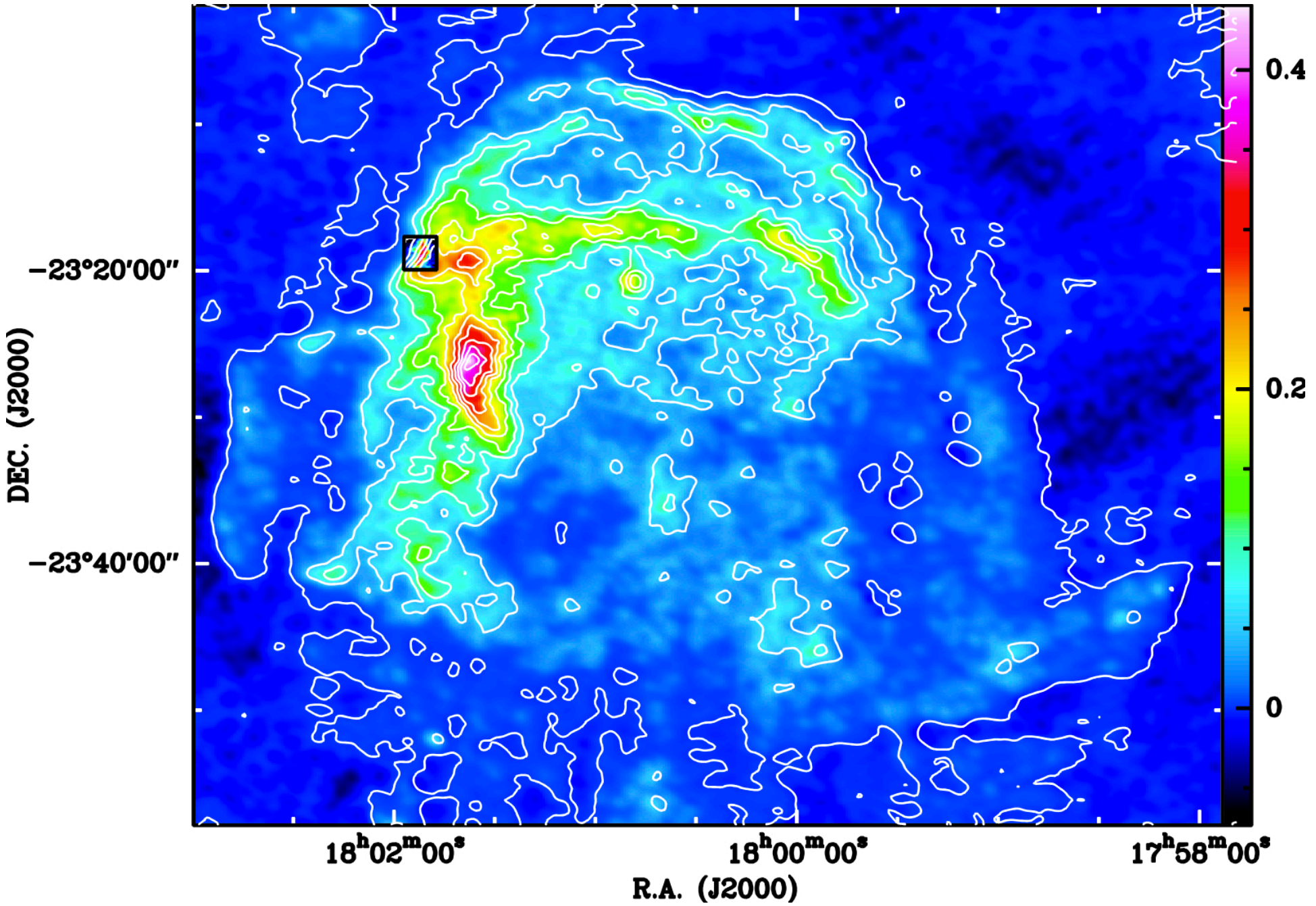

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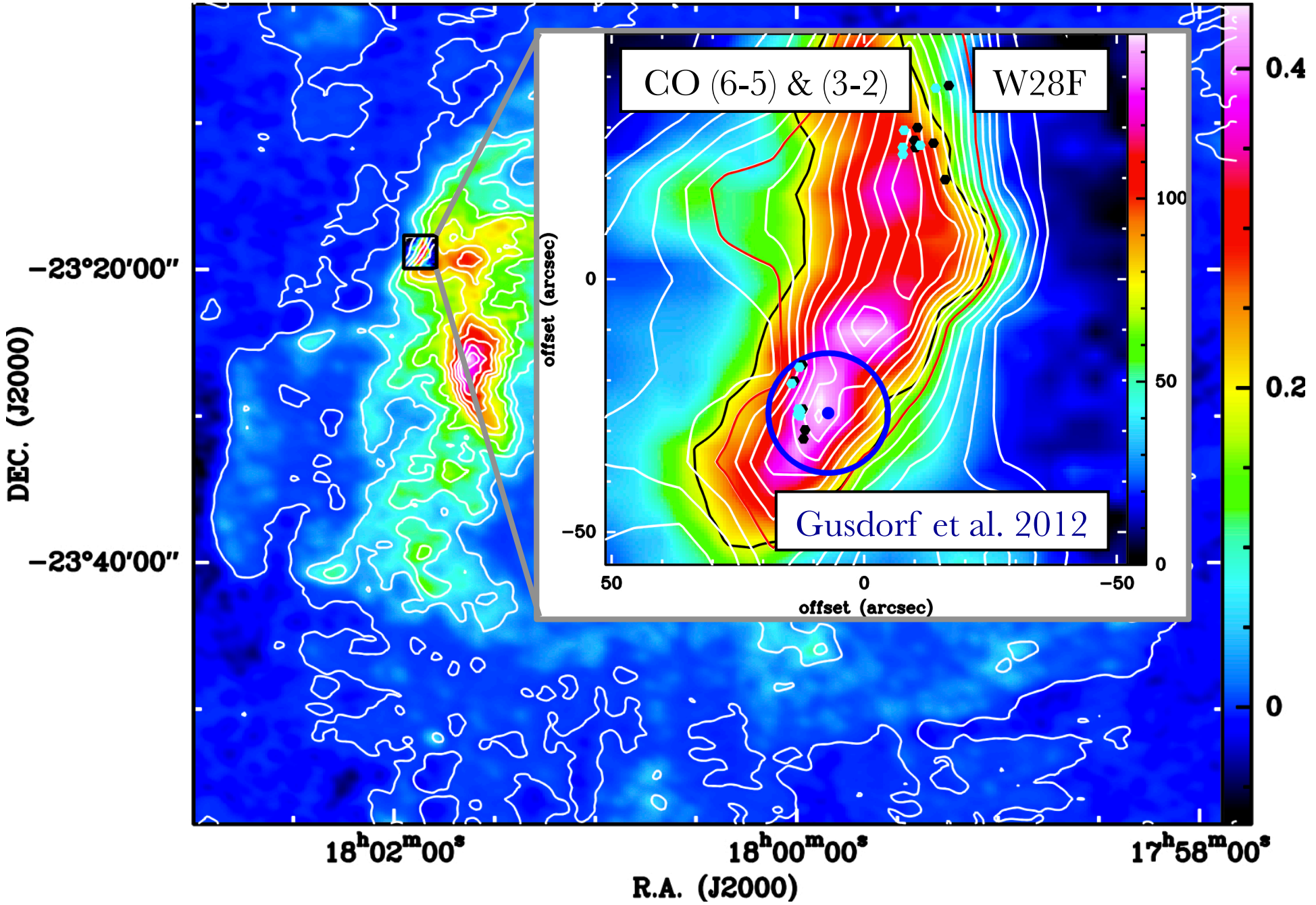

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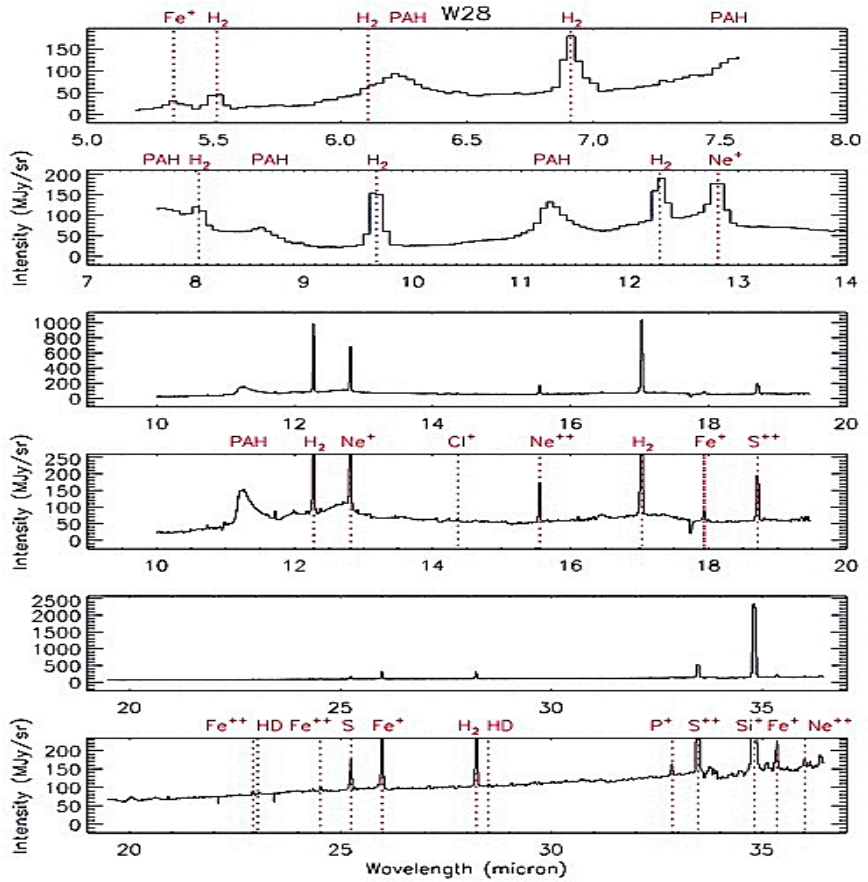

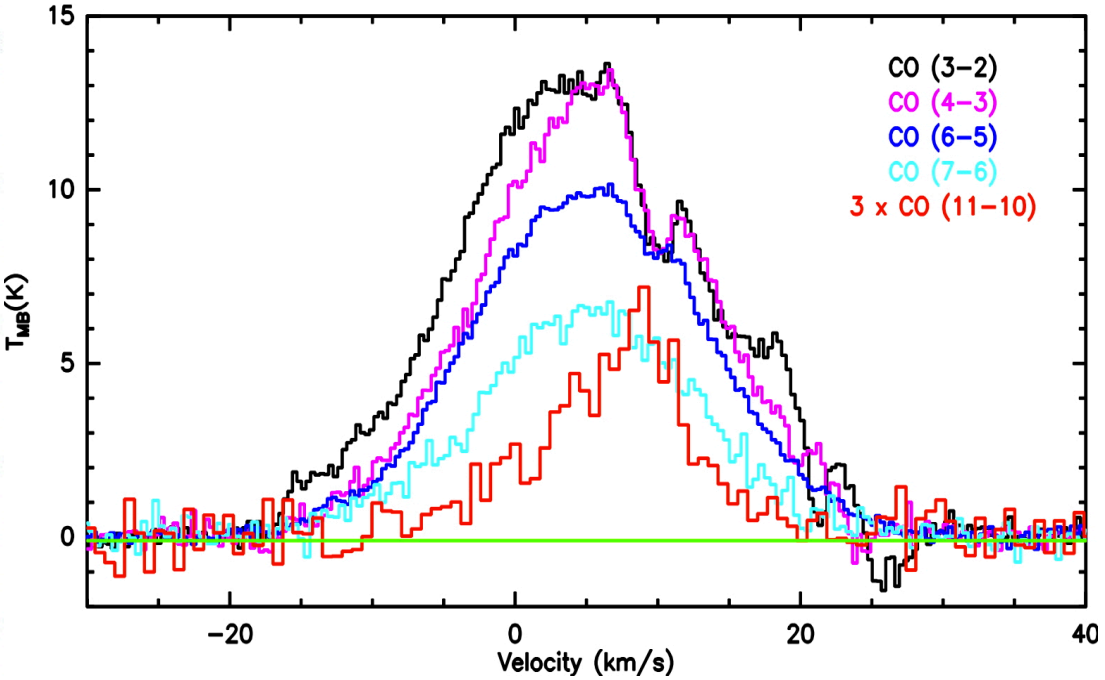

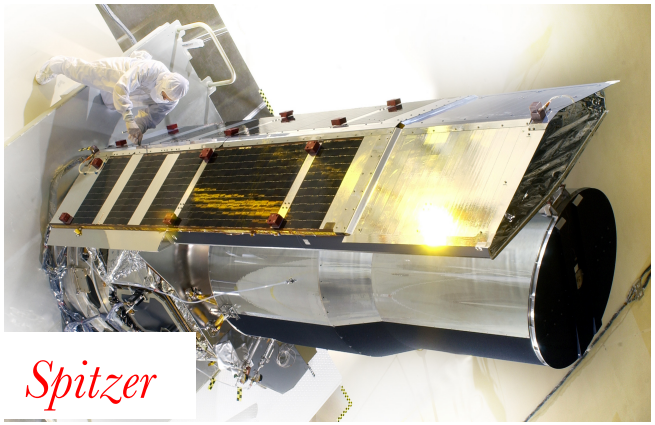

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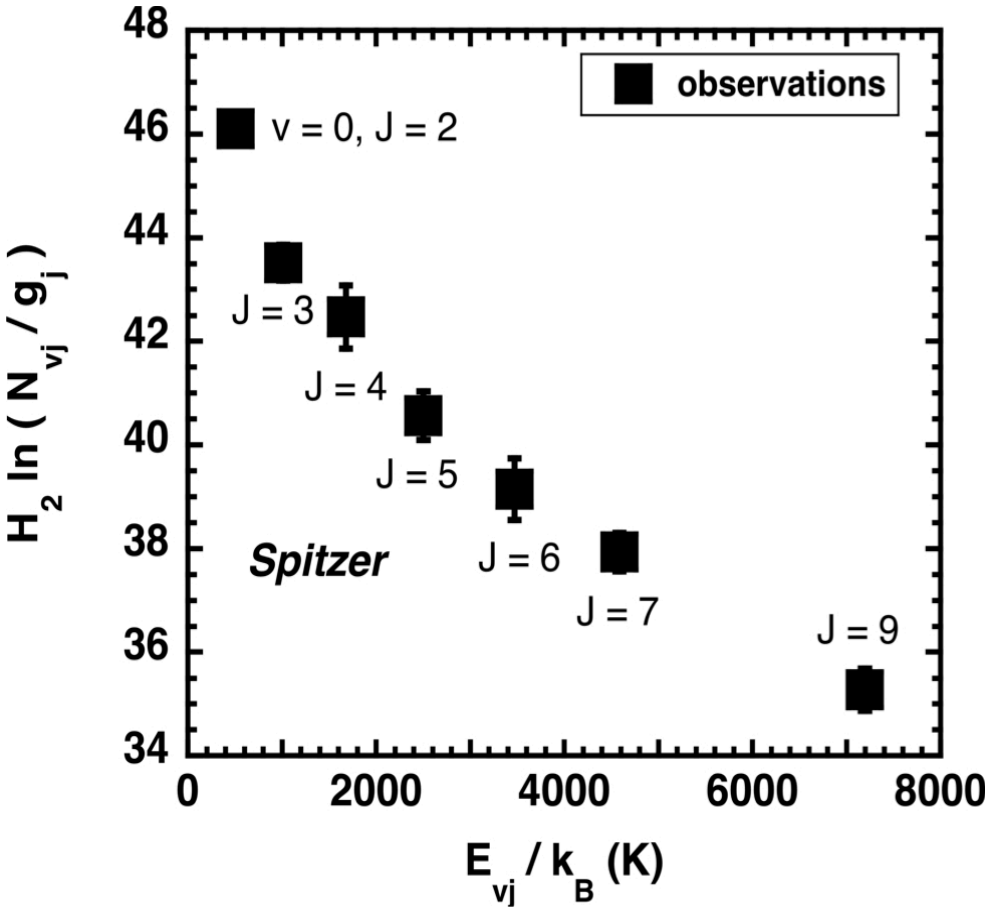

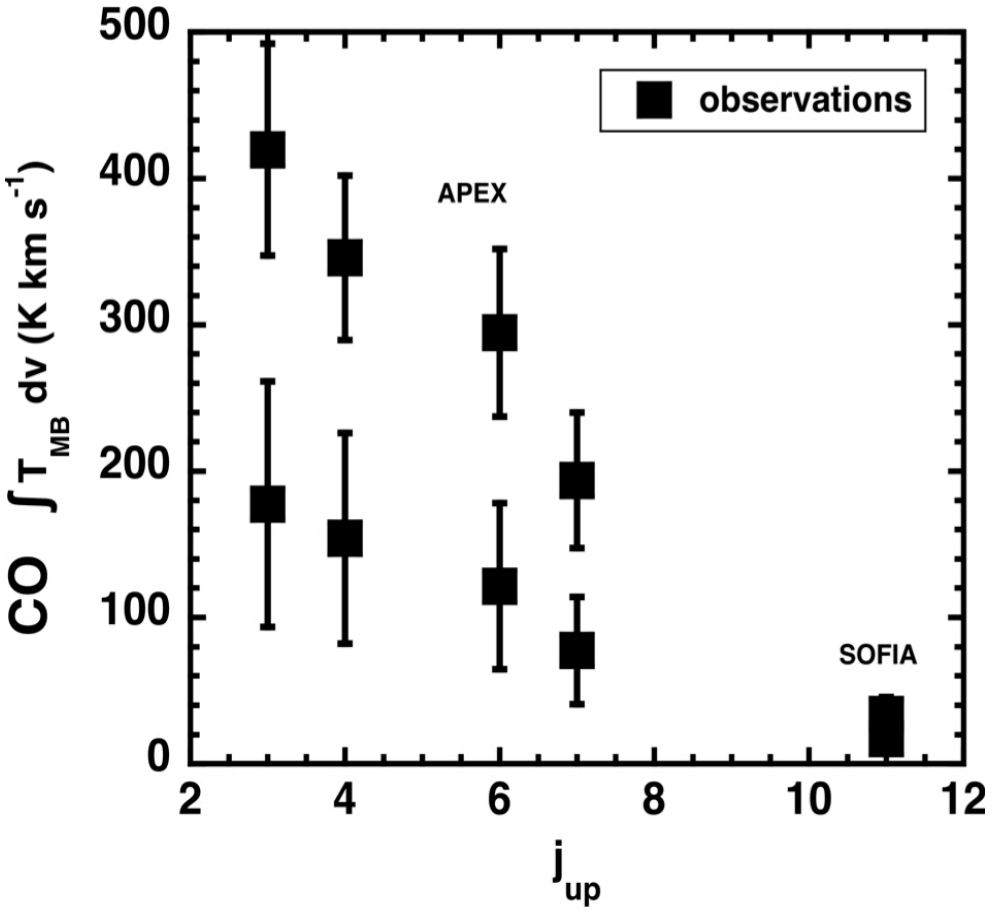

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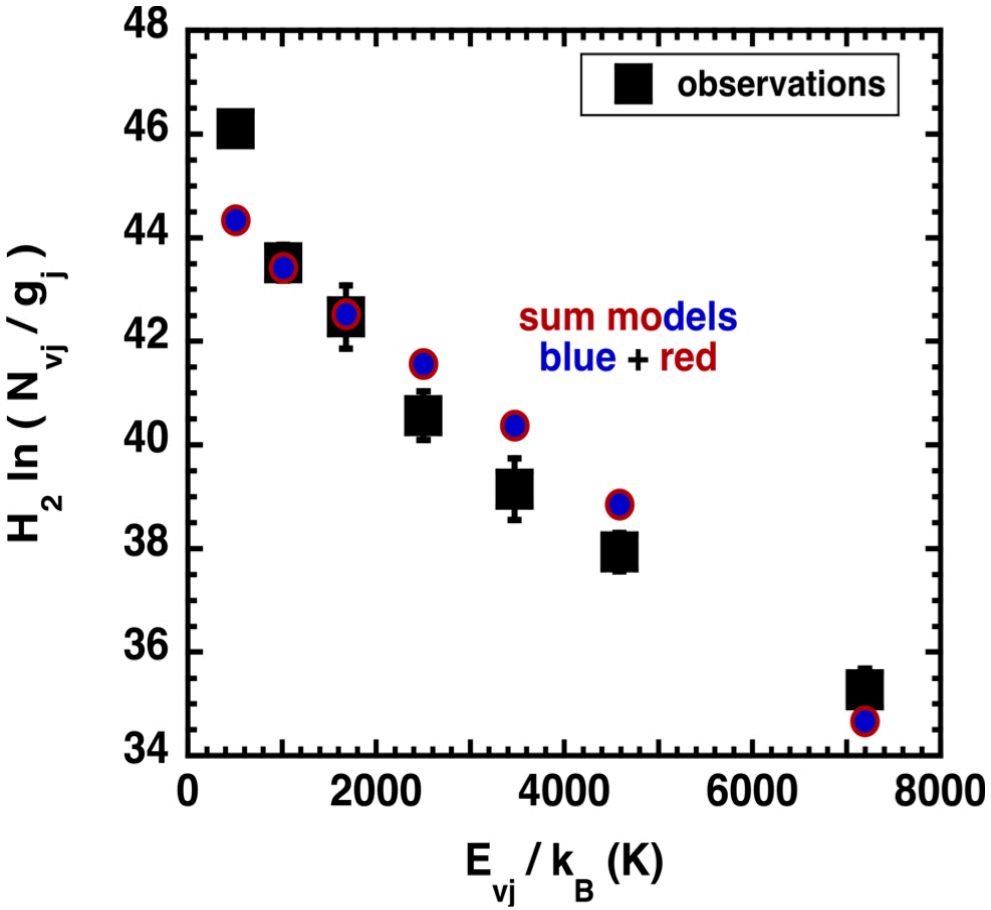
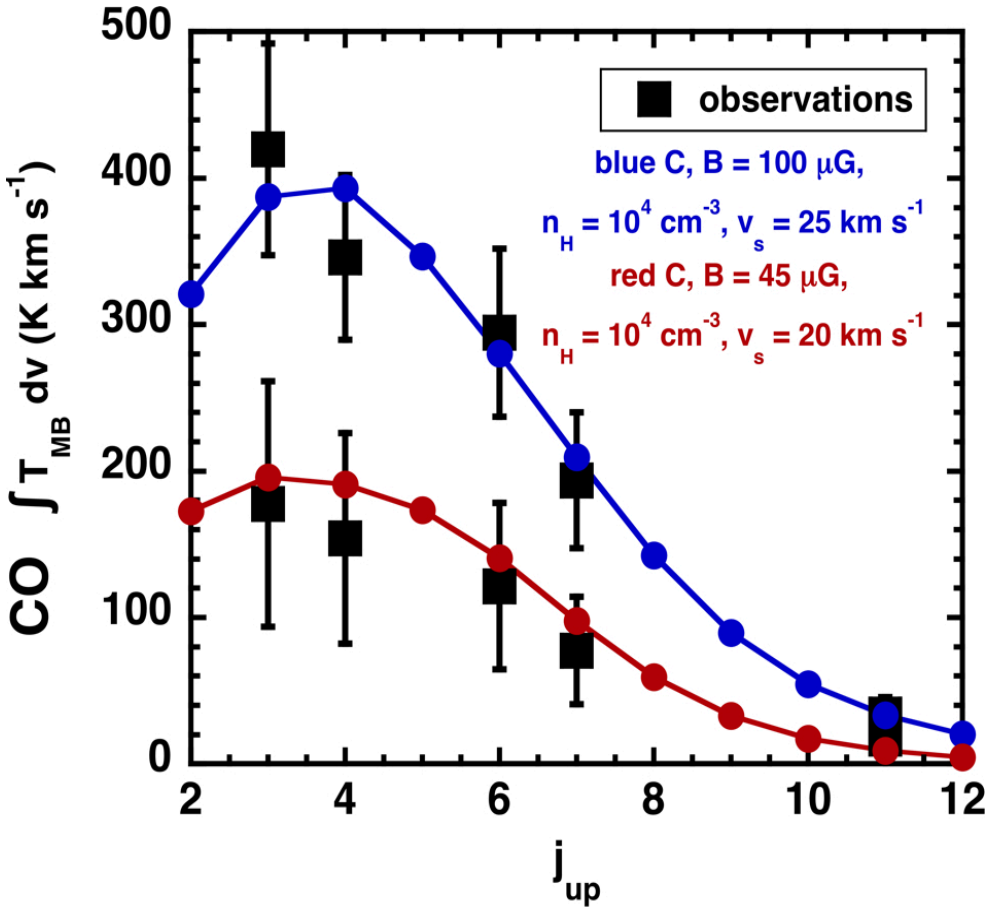




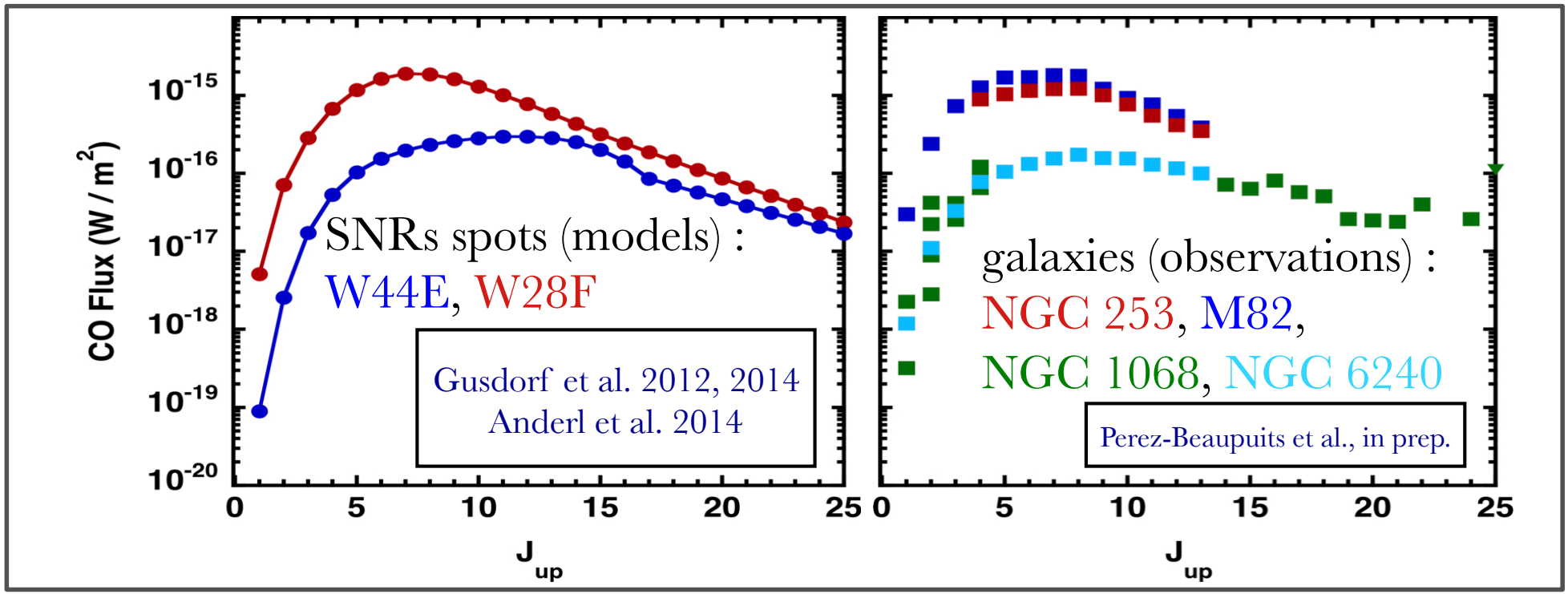
Paris-Durham MHD shock models: grid of ~2000 1D models

C-type, B = 100 μG, $n_H = 10^4$ cm^{-3}, v_s = 25 km s^{-1}

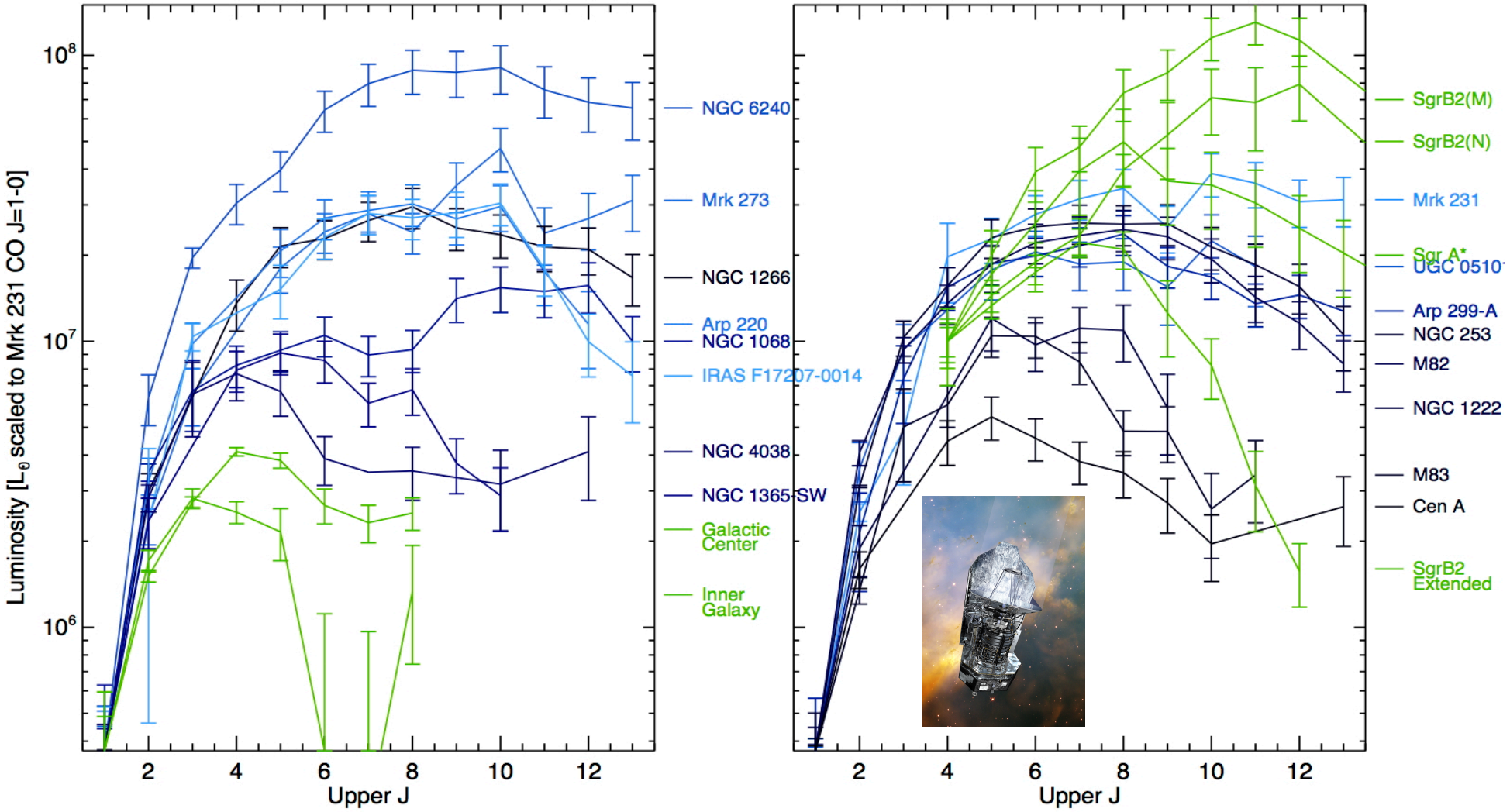
C-type, B = 45 μG, $n_H = 10^4$ cm^{-3}, v_s = 20 km s^{-1}

SNRs and the interstellar medium

SNRs and the ISM: energetics



SNRs and the ISM: energetics



Kamenetzky et al. 2014

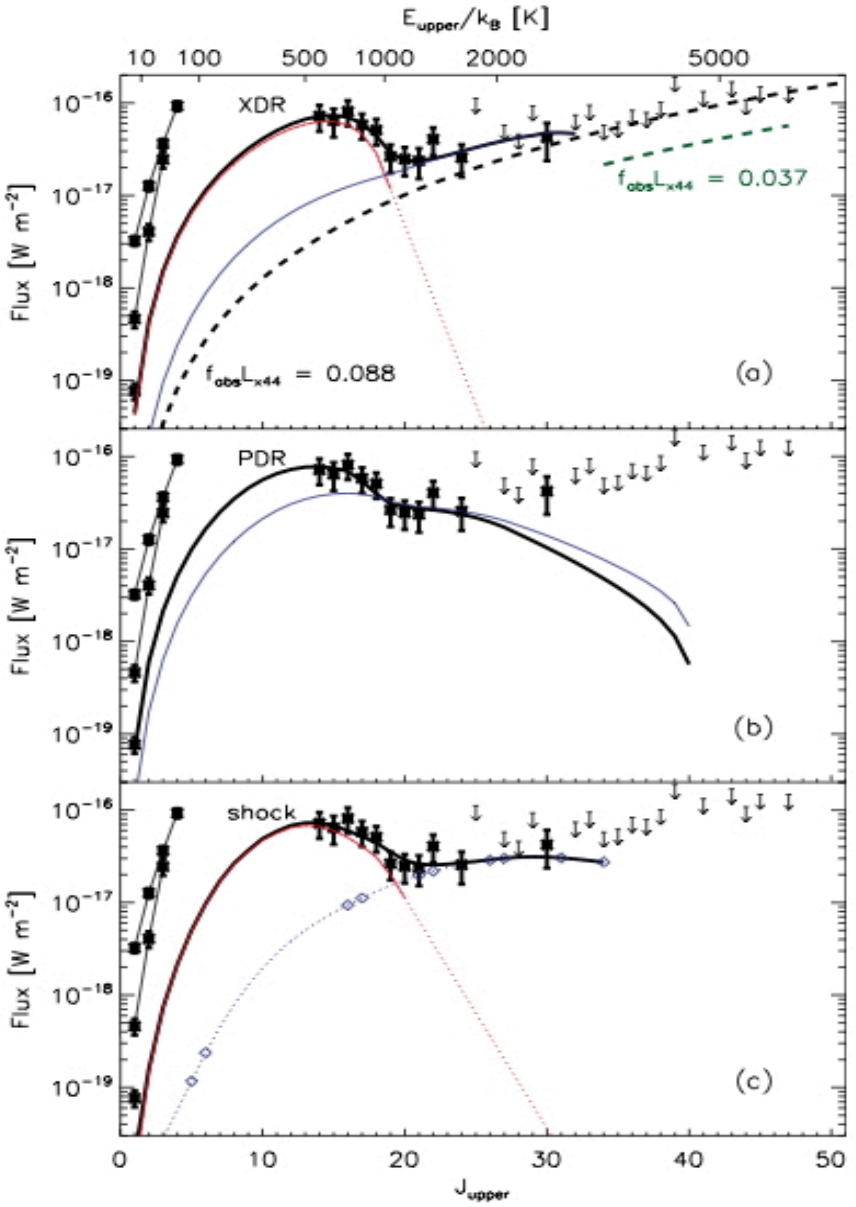
SNRs and the ISM: energetics

The case of NGC 1068,
Hailey-Dunsheath et al. 2012

Table 4
Heating Mechanisms

	ME	HE	Full
XDR	$n_{\rm H} = 10^{5.75}$ cm^{-3}	$n_{\rm H} = 10^{5.25}$ cm^{-3}	...
	$F_X = 9$ erg cm^{-2} s^{-1}	$F_X = 160$ erg cm^{-2} s^{-1}	...
	$A \sim (130\ {\rm pc})^2$	$A \sim (21\ {\rm pc})^2$	...
PDR	...	$n_{\rm H} = 10^{6.5}$ cm^{-3}	$n_{\rm H} = 10^{6}$ cm^{-3}
	...	$G_0 = 10^{4.75}$	$G_0 = 10^{5}$
	...	$L_{\rm FUV} \sim 2 \times 10^{9}\ L_\odot$	$L_{\rm FUV} \sim 10^{10}\ L_\odot$
Shock	C-shock	C-shock	...
	$n_0 = 2 \times 10^{5}$ cm^{-3}	$n_0 = 10^{6}$ cm^{-3}	...
	$v = 20$ km s^{-1}	$v = 40$ km s^{-1}	...
	$A \sim (150\ {\rm pc})^2$	$A \sim (16\ {\rm pc})^2$	...

Notes. Details for the models used in Figure 9. XDR and PDR models are from Meijerink et al. (2007), ME C-shock model is from Flower & Pineau Des Forêts (2010), and HE C-shock model is from Kaufman & Neufeld (1996).



SNRs and the ISM: energetics

- In W28F: C shocks, $n_H = 10^4$ cm^{-3}, v_s = 20-25 km/s, B = 45-100 μG:
  - shocked mass: $6 - 20\ M_\odot$ /beam
  - momentum: $140 - 420\ M_\odot$ km s^{-1} /beam
  - energy: $(6 - 18) \cdot 10^{38}$ J /beam

- In W44: Anderl et al. 2014

CJ shocks (< 3000 yrs),

$n_H = 10^4$ cm^{-3},

v_s = 20-35 km/s,

B = 100-200 μG:

- shocked mass:

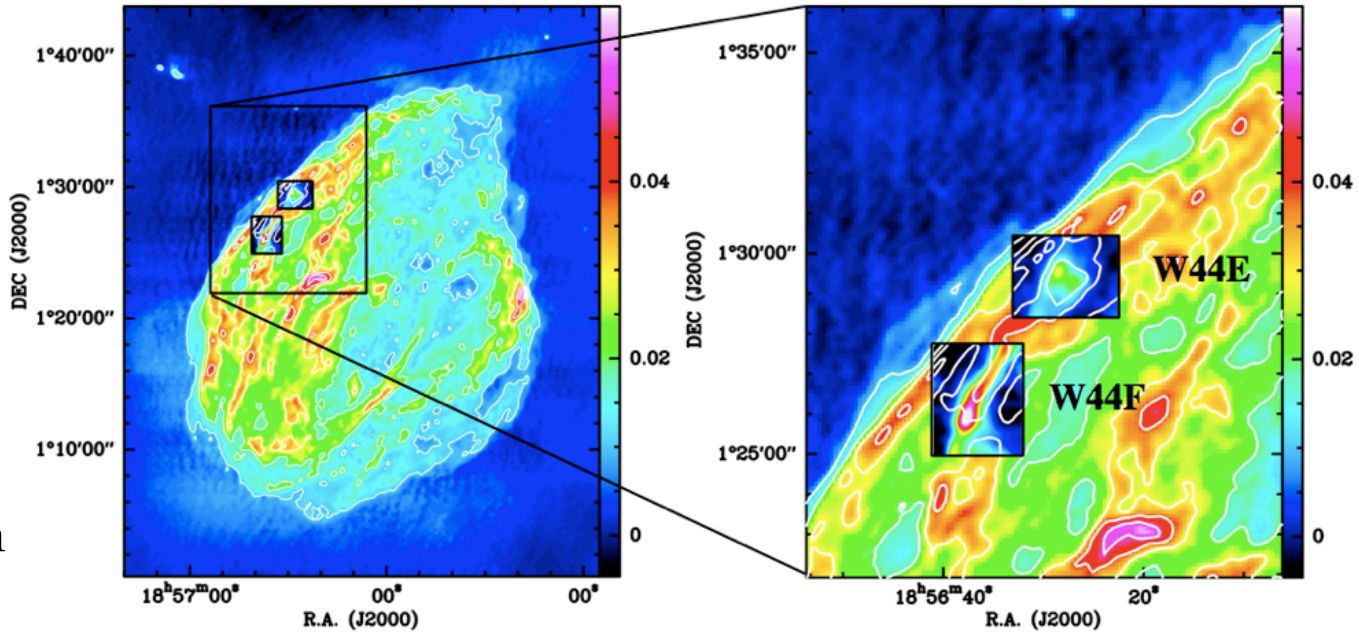
$1 - 2\ M_\odot$ /beam

- momentum:

$10 - 50\ M_\odot$ km s^{-1}/beam

- energy:

$(1 - 8) \cdot 10^{38}$ J /beam



SNRs and the ISM: induced star formation

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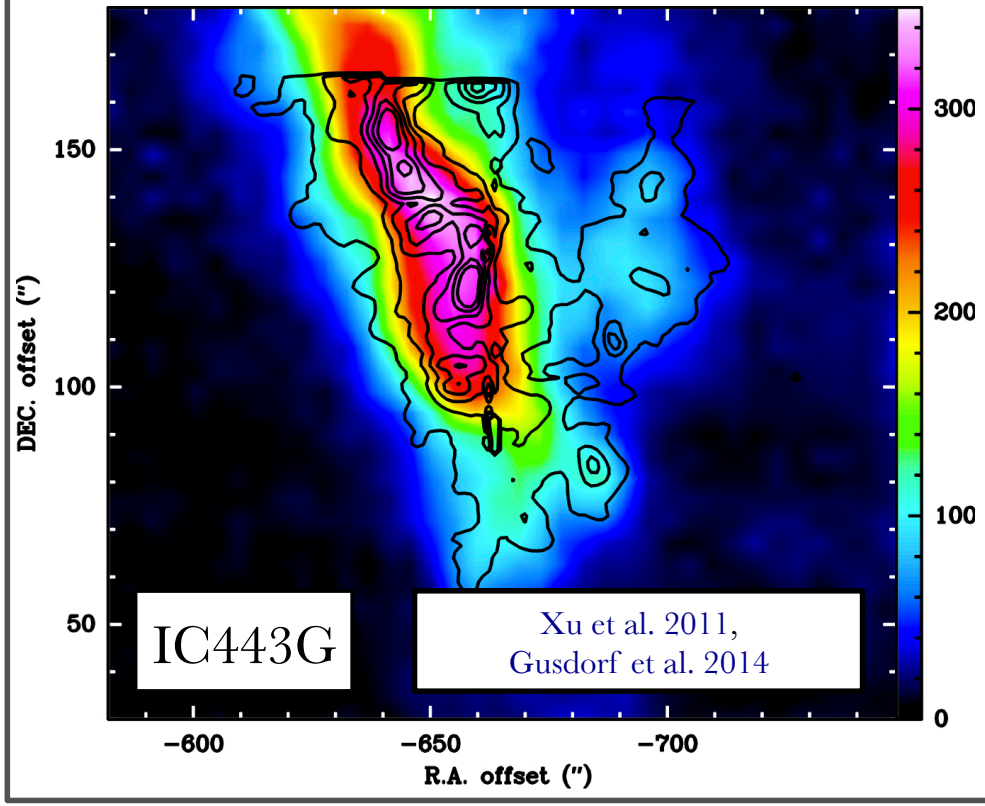
- IC443 : CO (6-5) + H_2 0-0 S(5)



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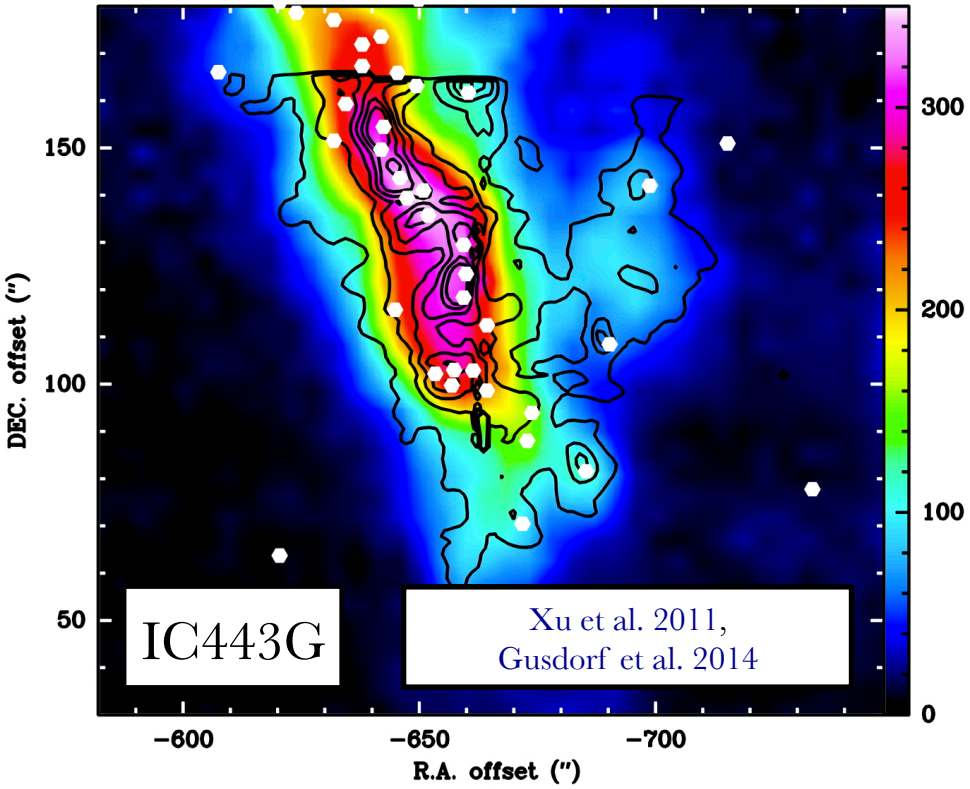
- IC443 : CO (6-5) + H_2 0-0 S(5) + YSOs



SNRs and the ISM: induced star formation

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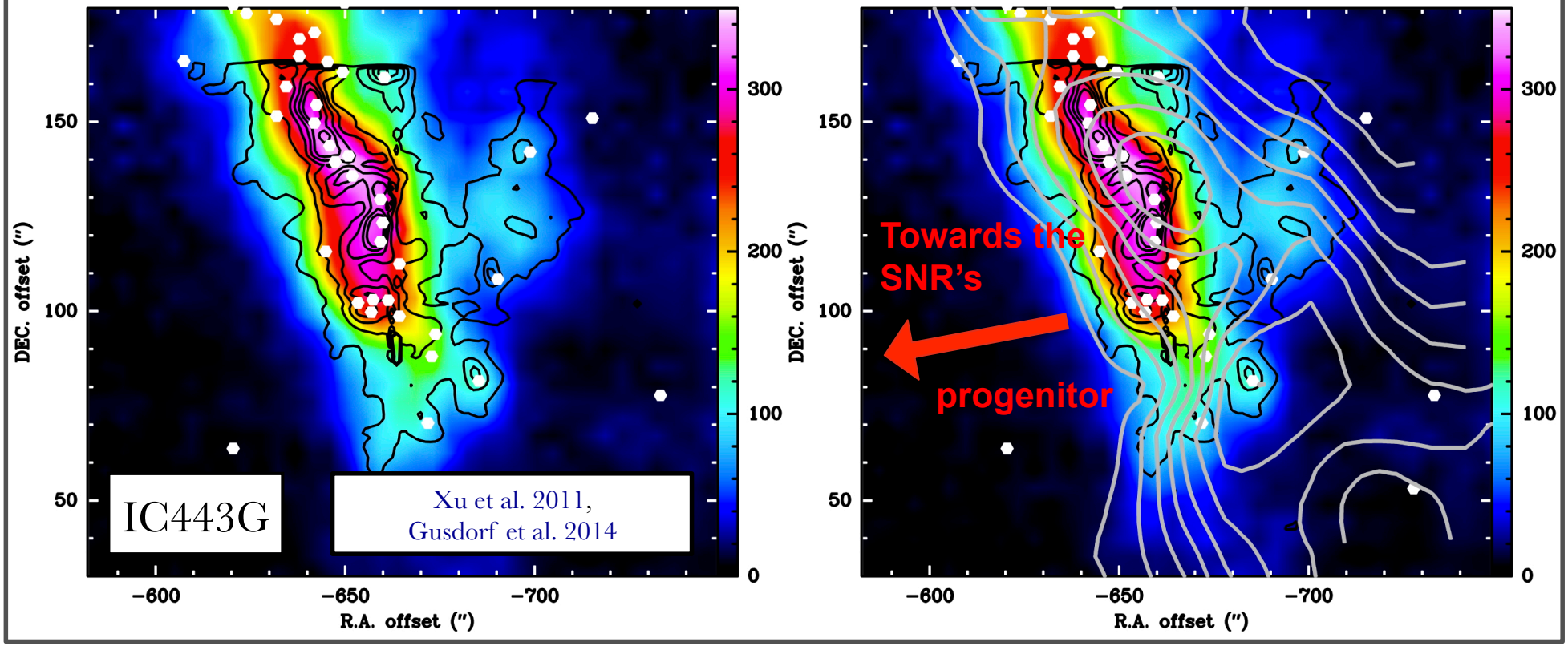
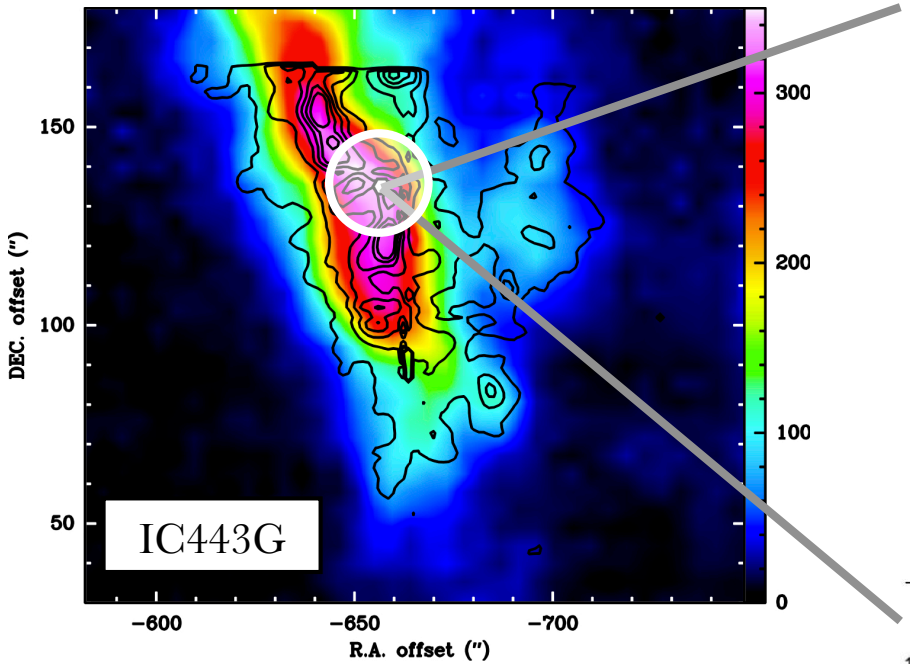
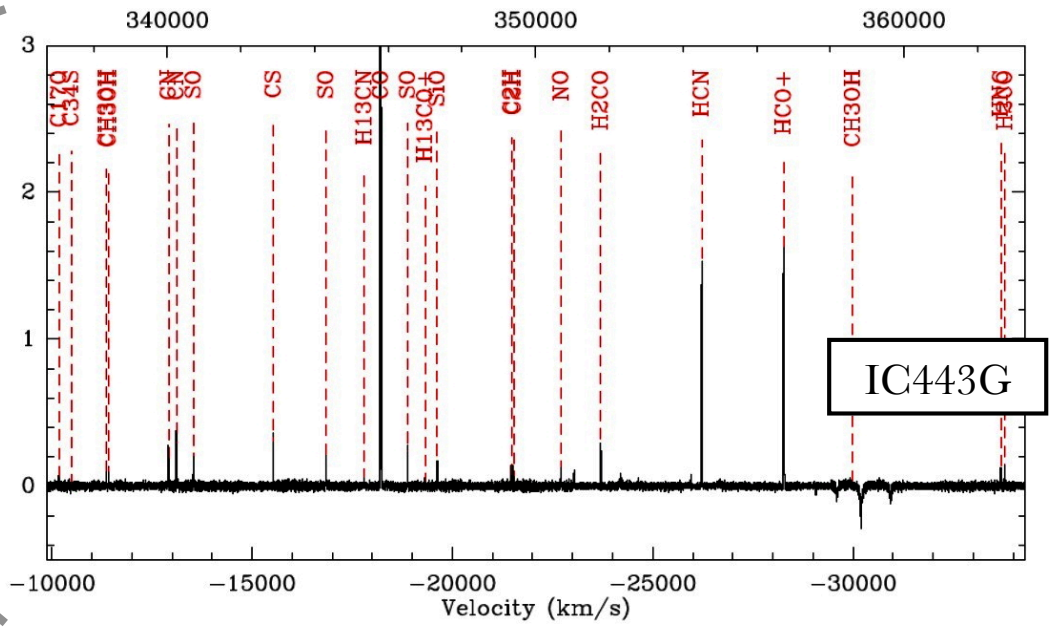
  - injected energy: $(6 - 18) \cdot 10^{38}$ J per position

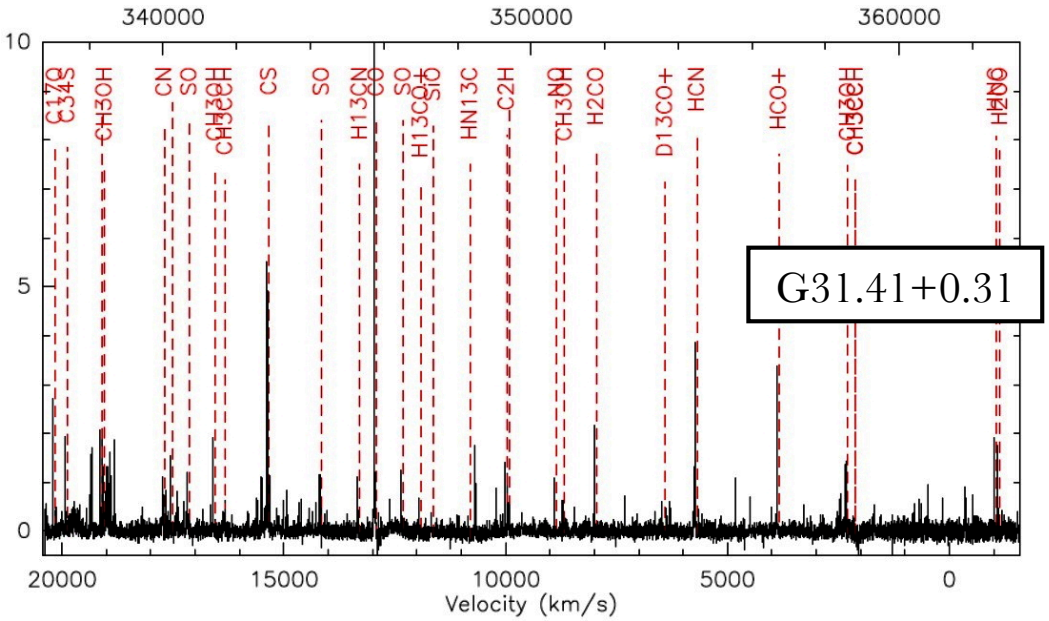
- IC443 : CO (6-5) + H_2 0-0 S(5) + YSOs + molecular cloud CO (1-0)



SNRs and the ISM: chemistry



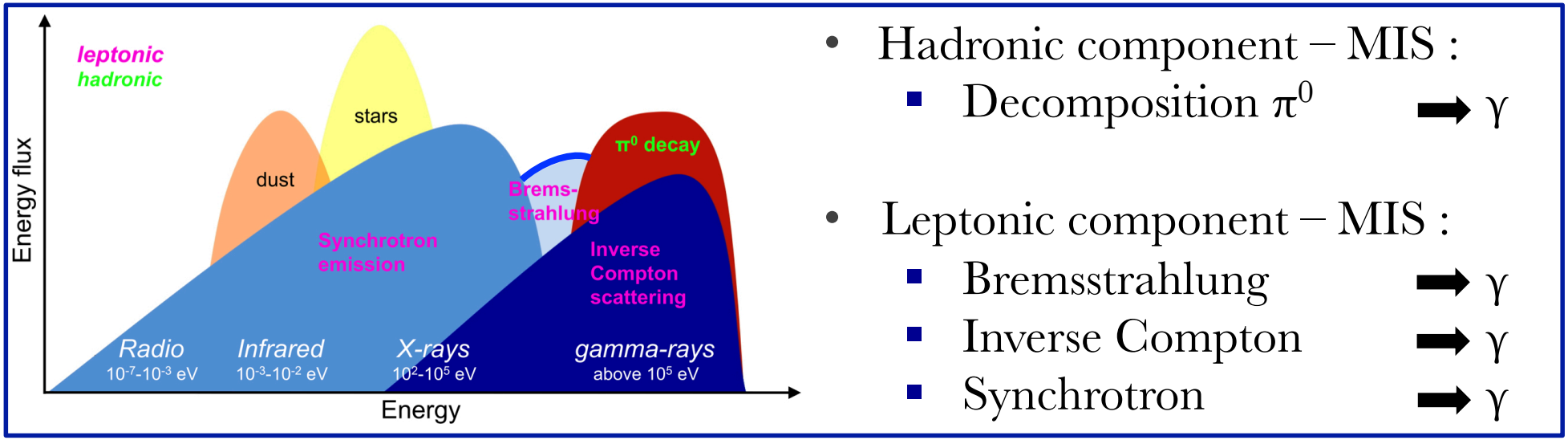




- Riquelme et al., in prep. :
  - Spectral survey IC443G
  - compared to hot core G31.41+0.31
  - X-, γ- rays, and cosmic rays

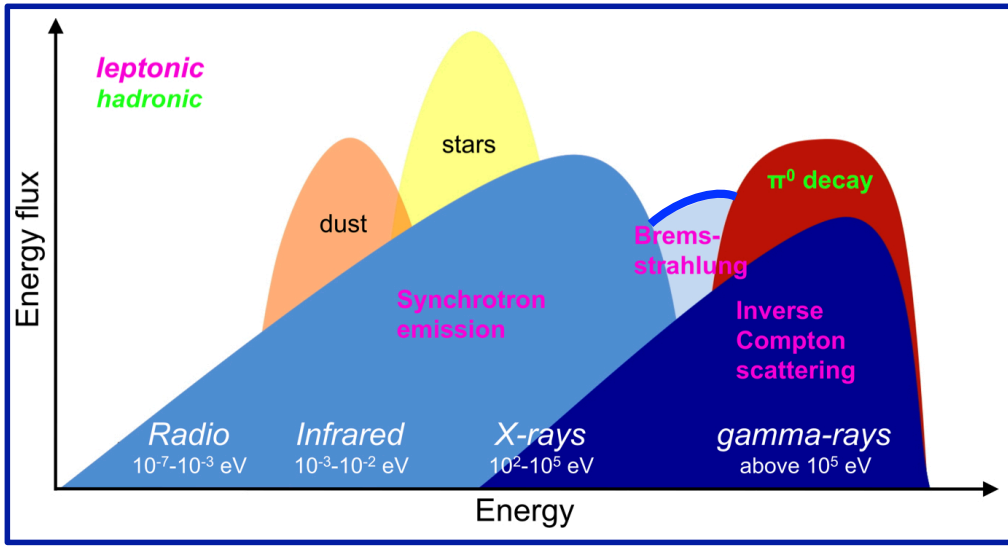
SNRs and cosmic rays

SNRs and CRs



- Hadronic component – MIS :
  - Decomposition π^0 ➡ γ
- Leptonic component – MIS :
  - Bremsstrahlung ➡ γ
  - Inverse Compton ➡ γ
  - Synchrotron ➡ γ

SNRs and CRs



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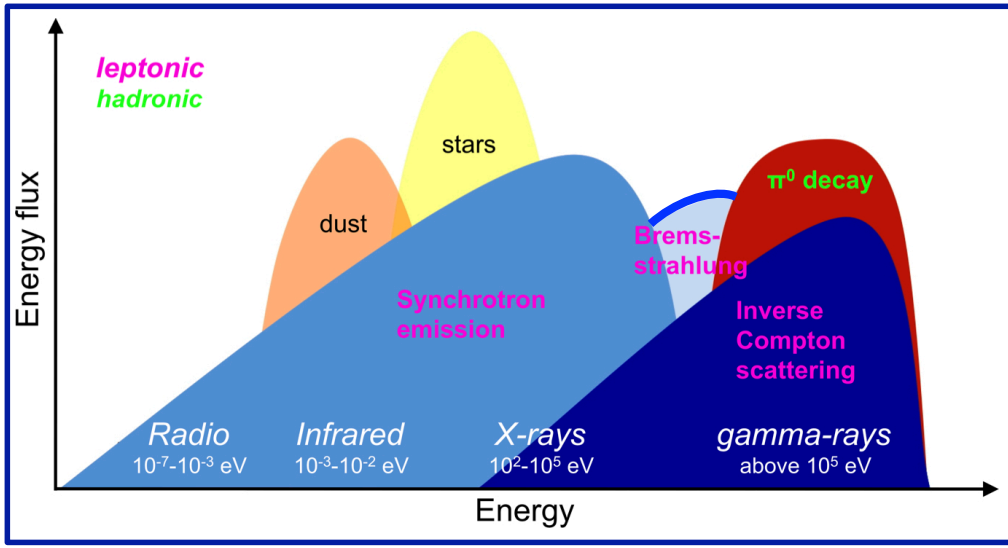
- W28F : 2 C shocks, $n_H = 10^4$ cm^{-3}, v_s = 20-25 km/s, B = 45-100 μG

shocked mass : 6 – 19 $M_\odot$ /beam

SNRs and CRs



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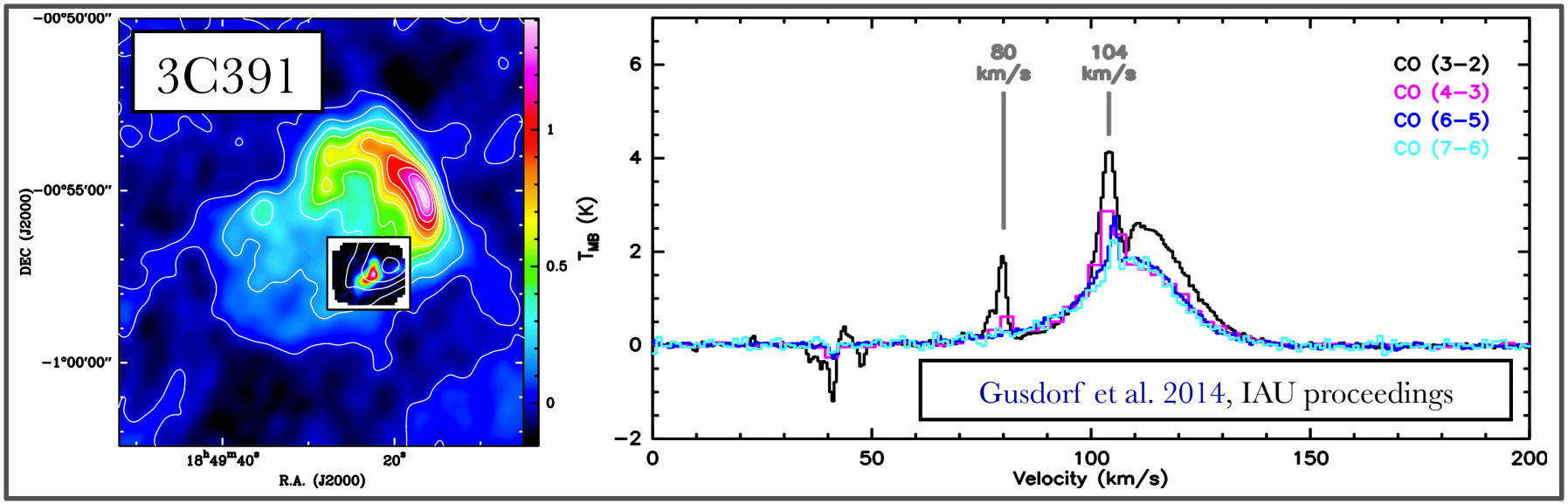
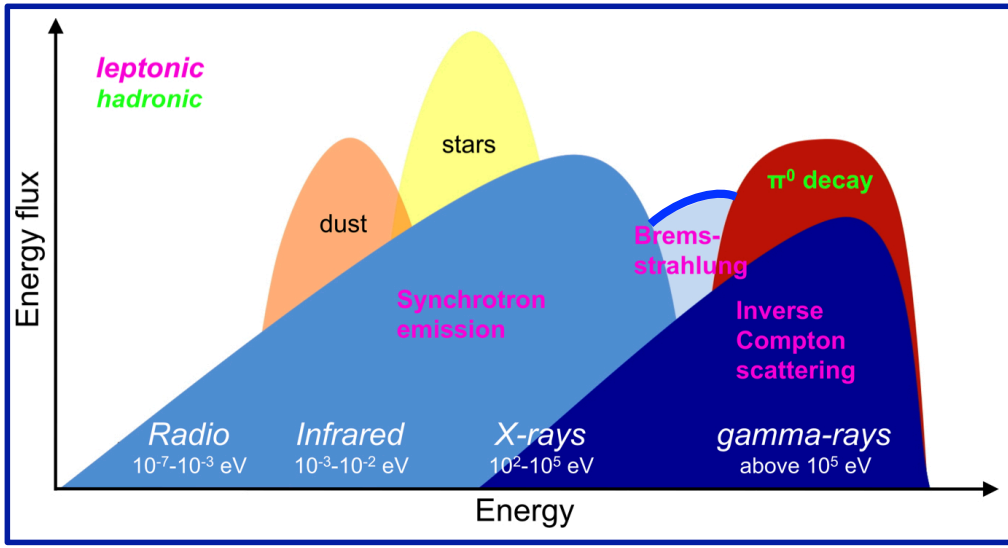


SNRs and CRs



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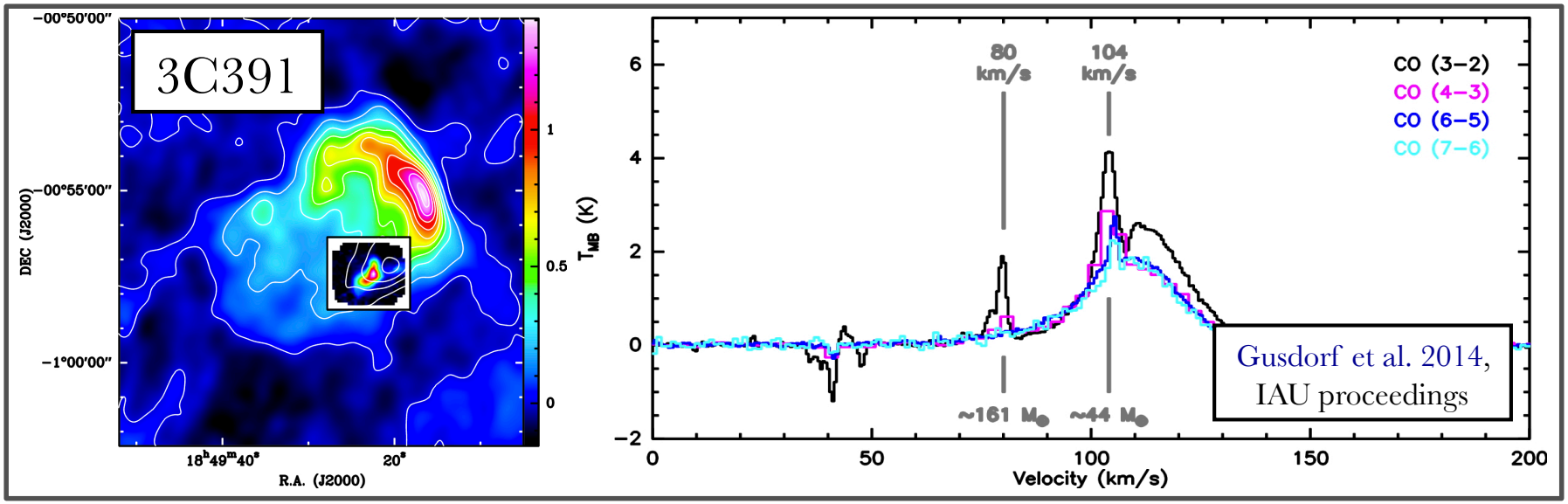

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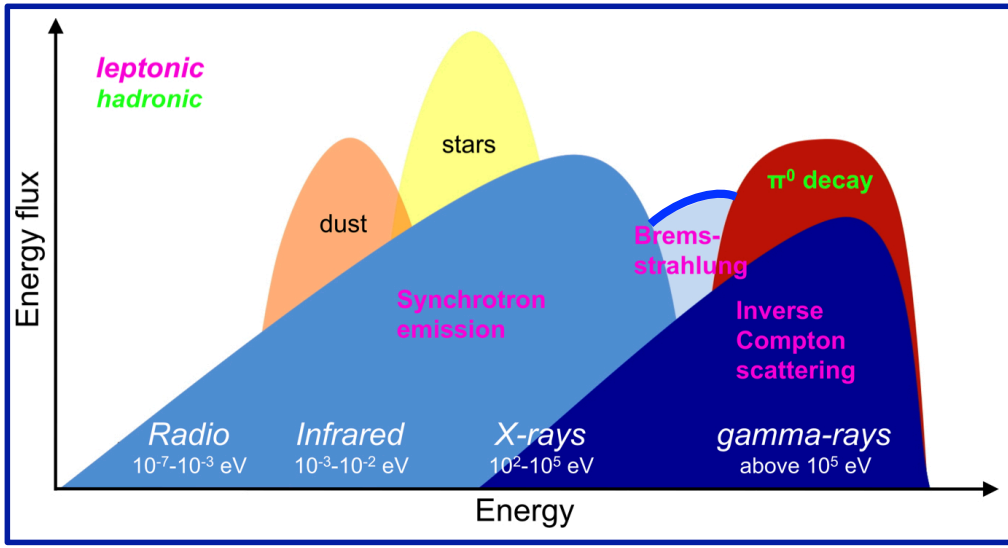

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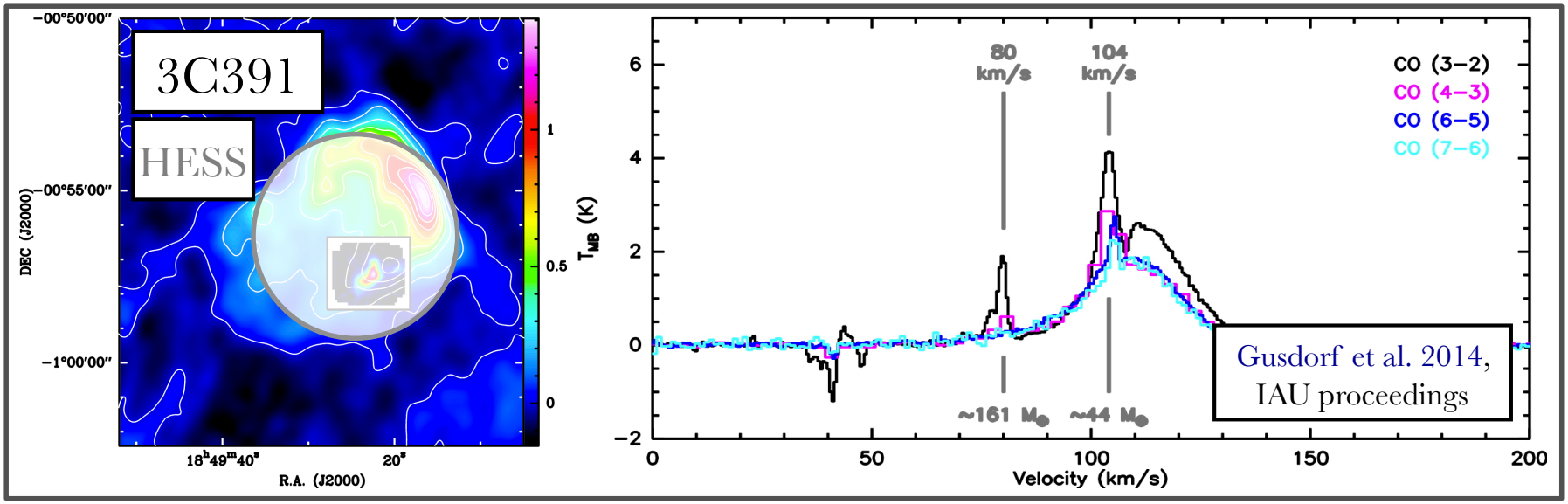

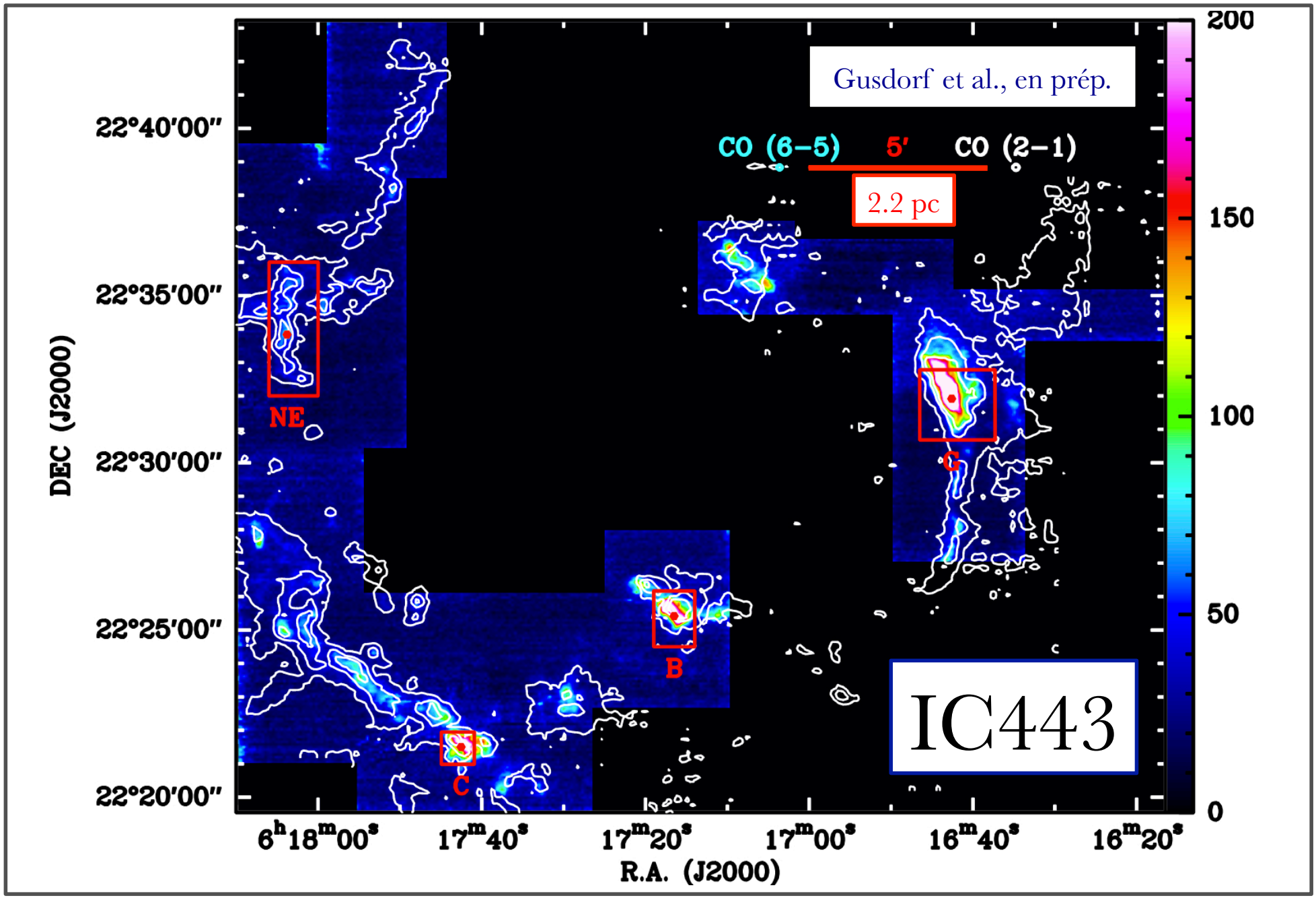
Gusdorf et al., en prép.
CO (6–5)
5′
CO (2–1)
2.2 pc
NE
B
C
C
IC443
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22°35′00″
22°30′00″
22°25′00″
22°20′00″
DEC (J2000)
6h18m00s
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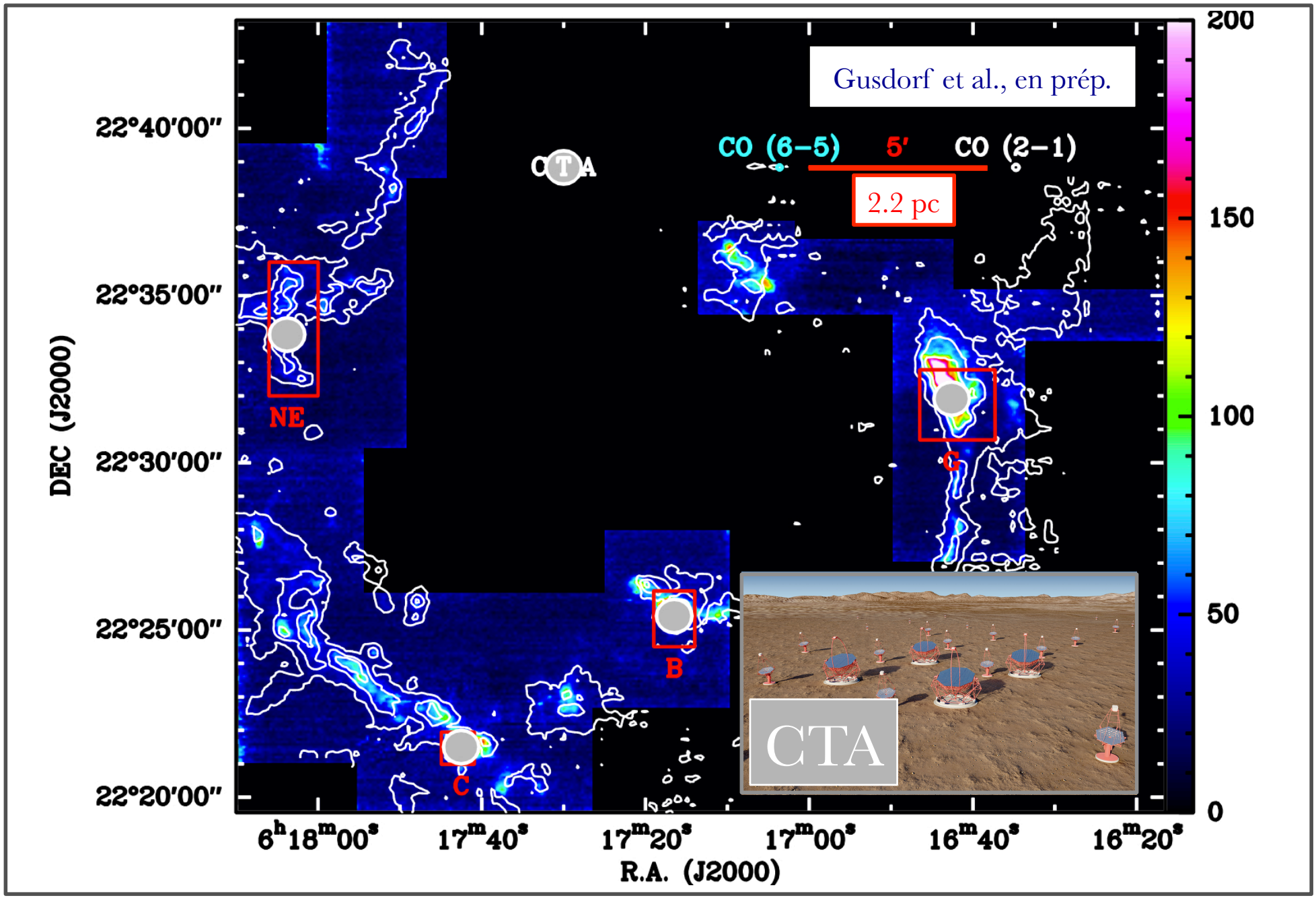
Gusdorf et al., en prép.
CO (6–5)
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CO (2–1)
2.2 pc
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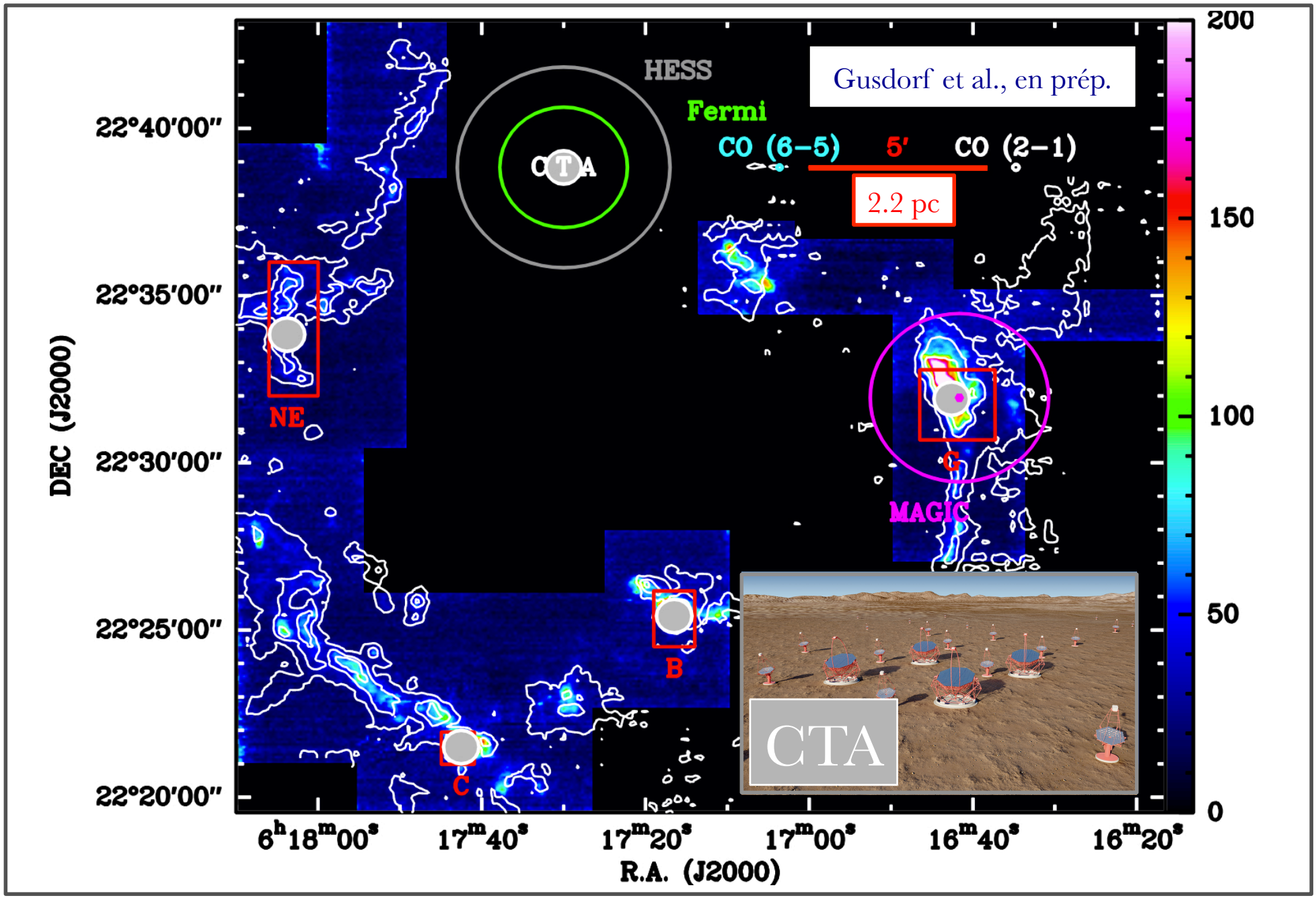
SNRs and CRs


Gusdorf et al., en prép.
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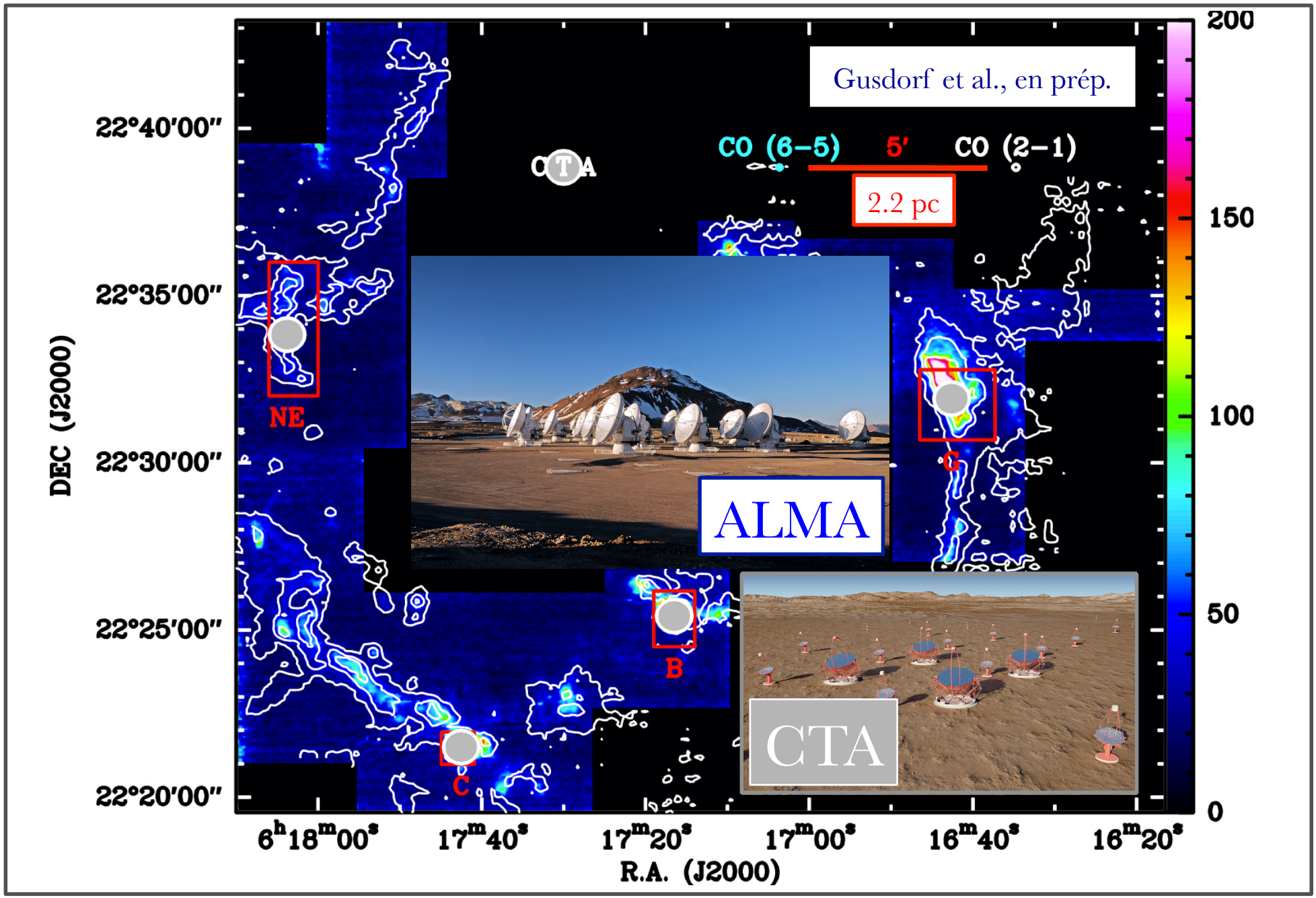
Gusdorf et al., en prép.
CO (6–5)
5′
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CTA
ALMA
CTA
NE
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22°25′00″
22°20′00″
DEC (J2000)
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17m00s
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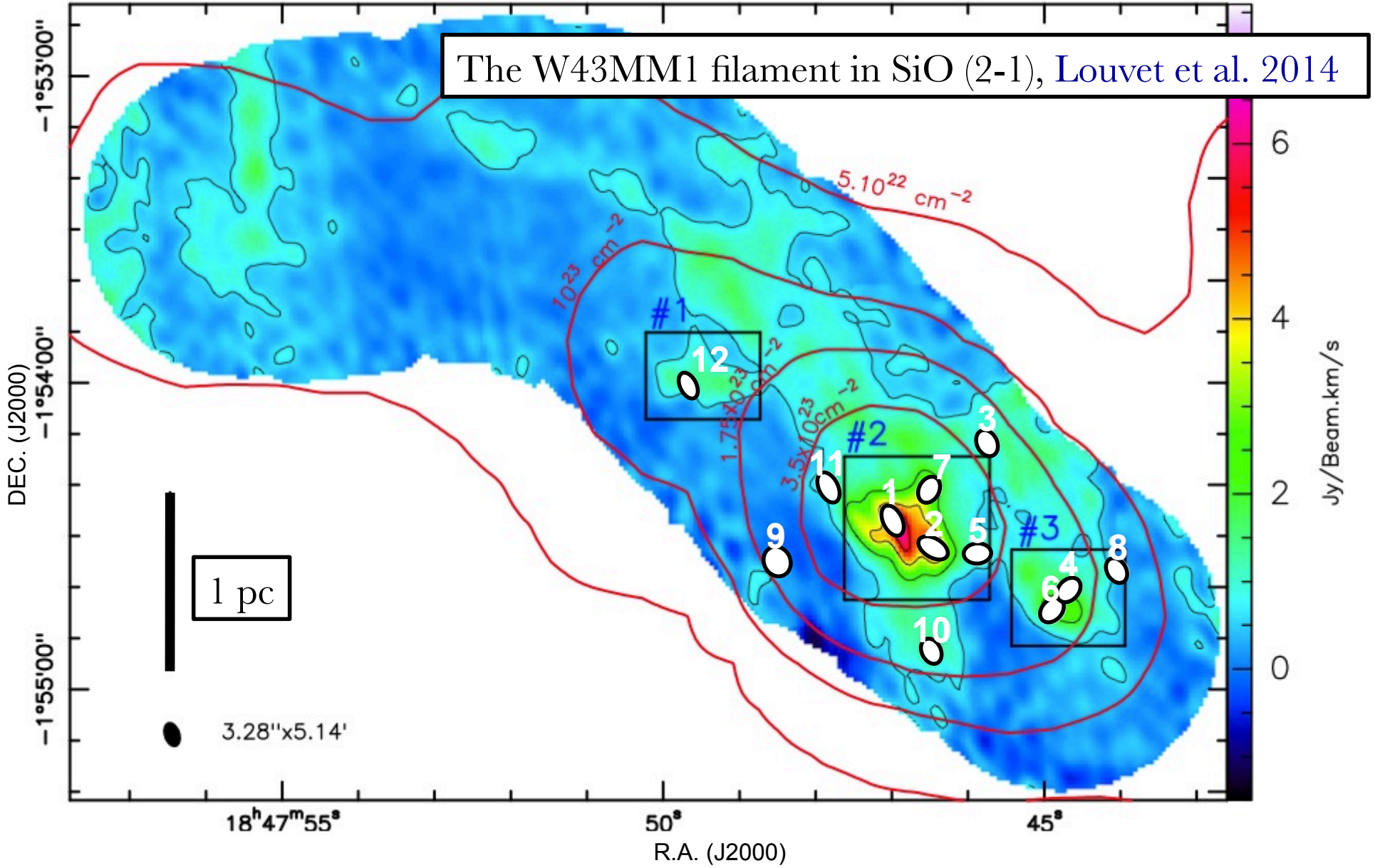
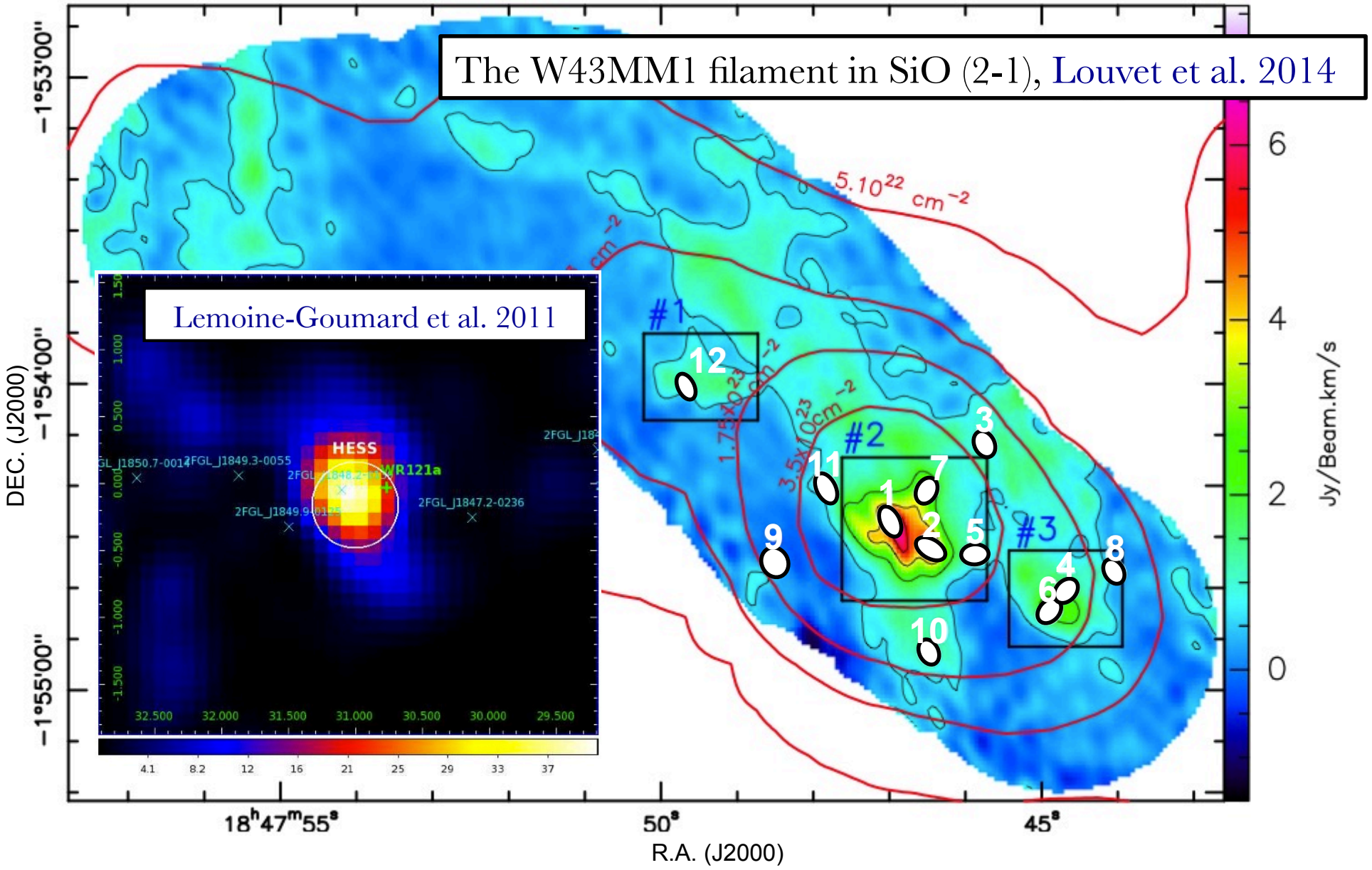
Perspectives

Ubiquity of CR-related questions in shocked regions



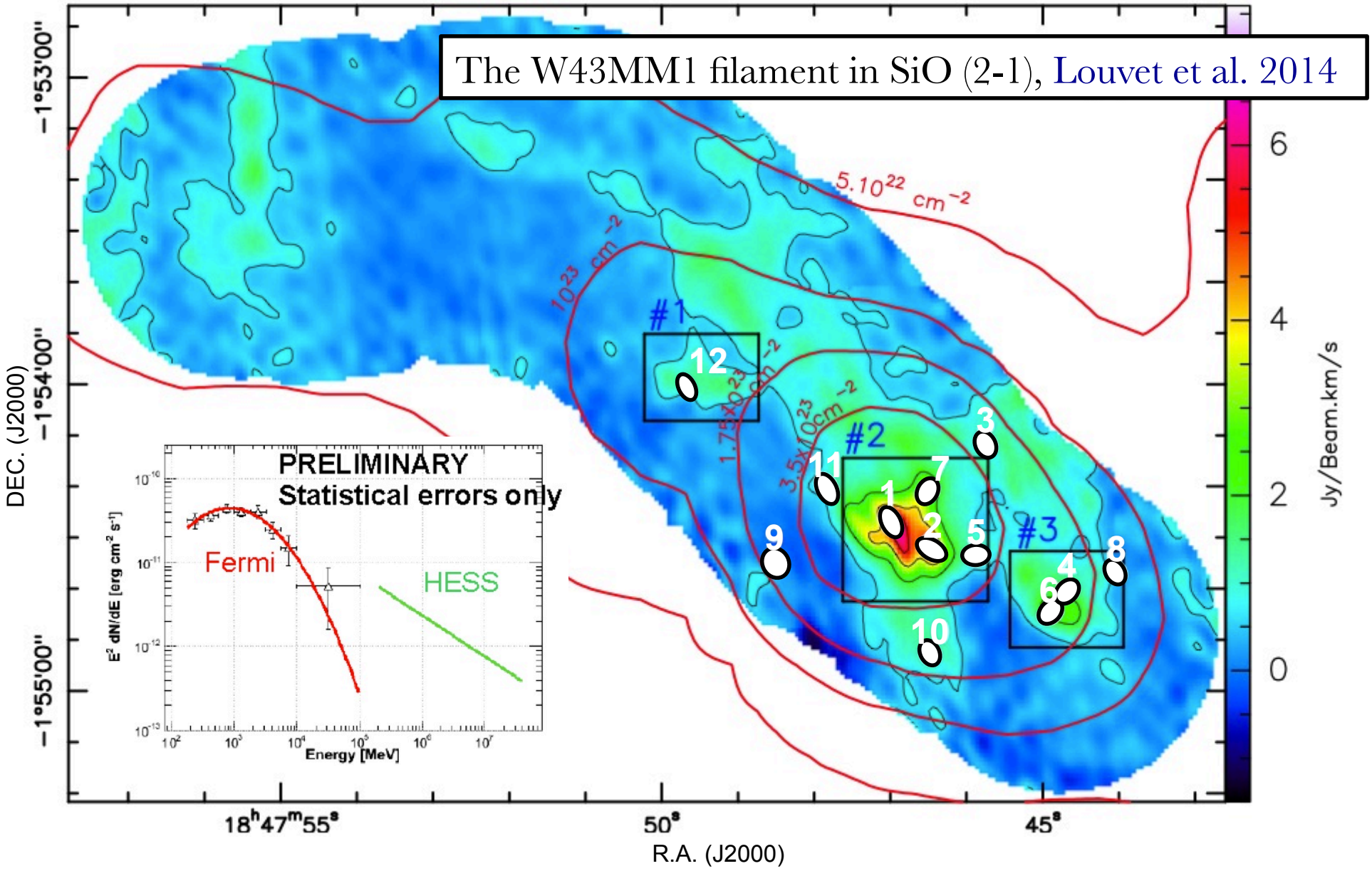
Nguyen-Luong et al. 2013, Motte et al. 2014

Ubiquity of CR-related questions in shocked regions



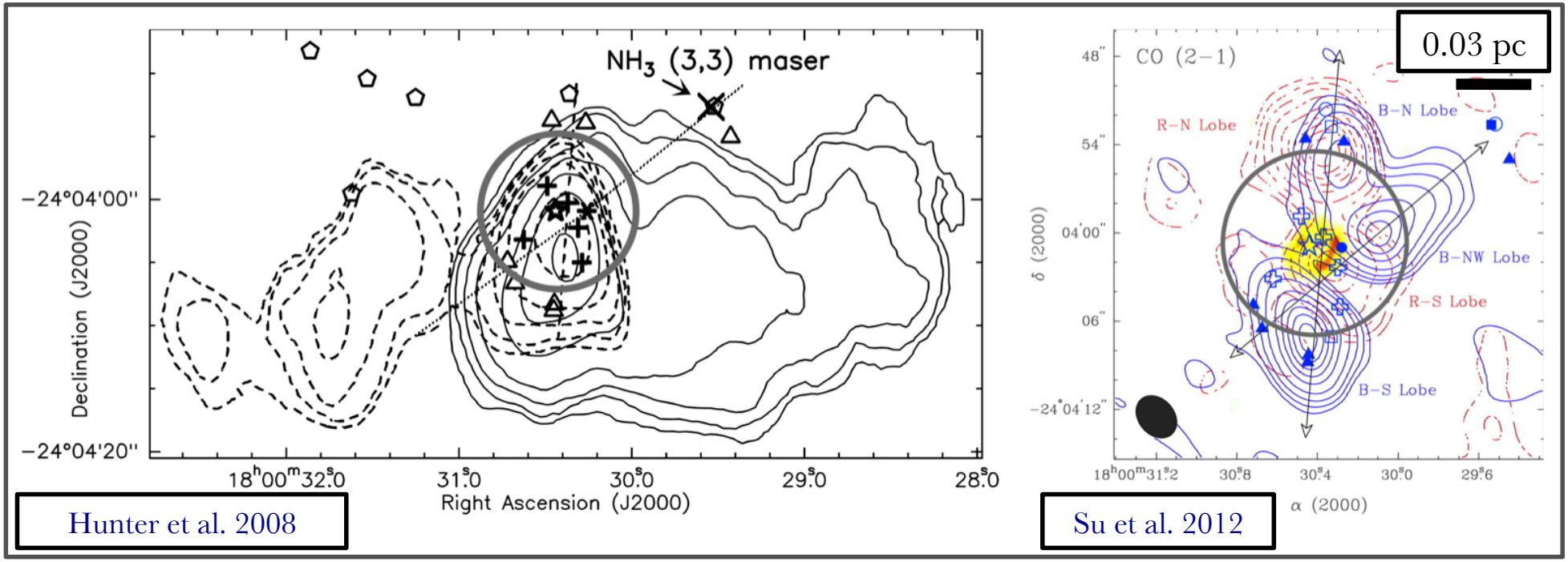
Nguyen-Luong et al. 2013, Motte et al. 2014

Ubiquity of CR-related questions in shocked regions

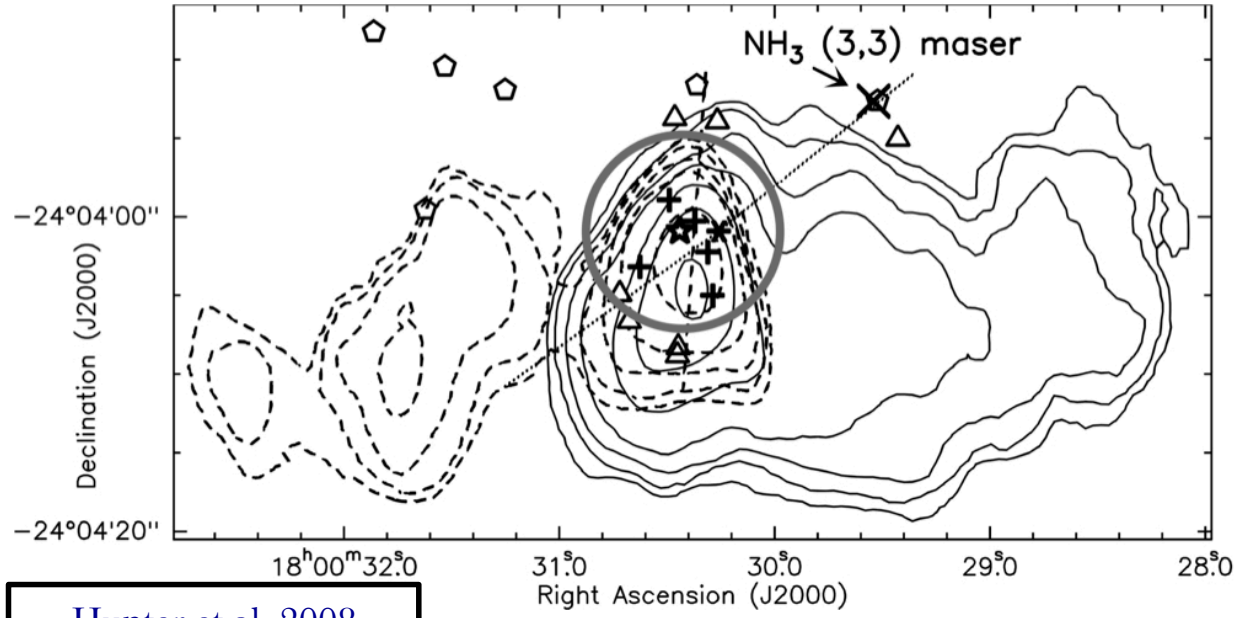


Nguyen-Luong et al. 2013, Motte et al. 2014

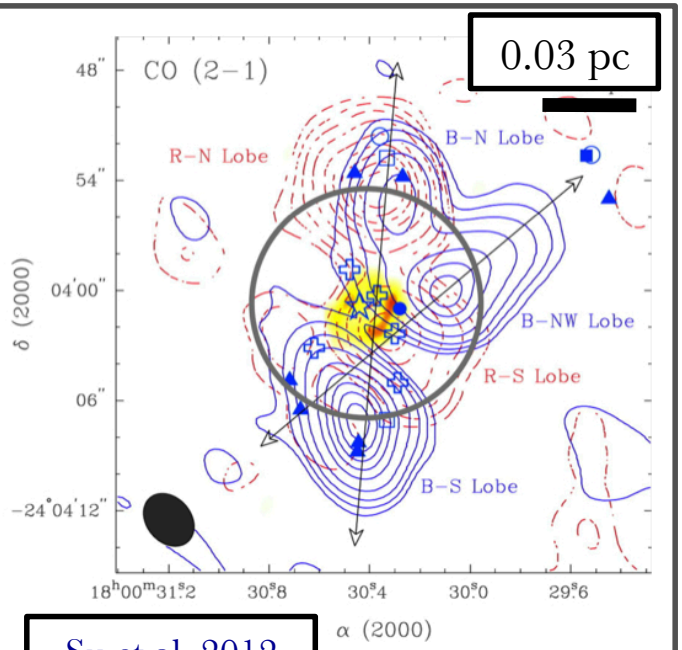
Ubiquity of CR-related questions in shocked regions



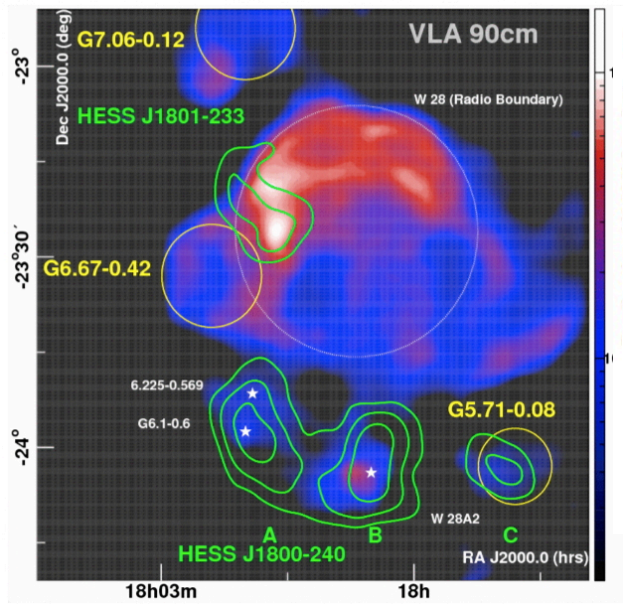
Ubiquity of CR-related questions in shocked regions

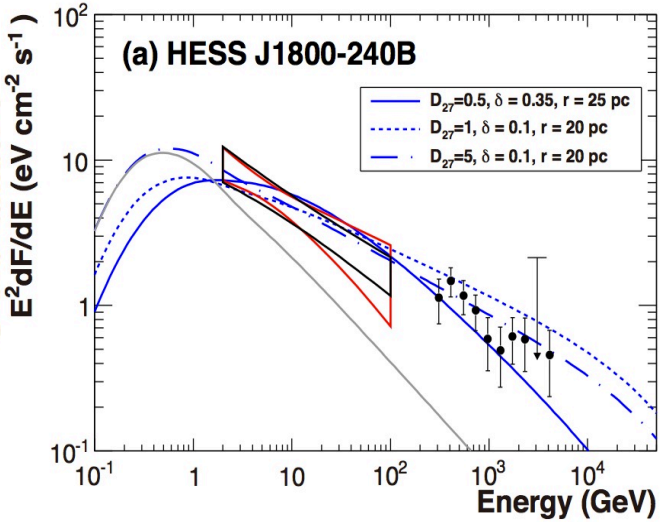


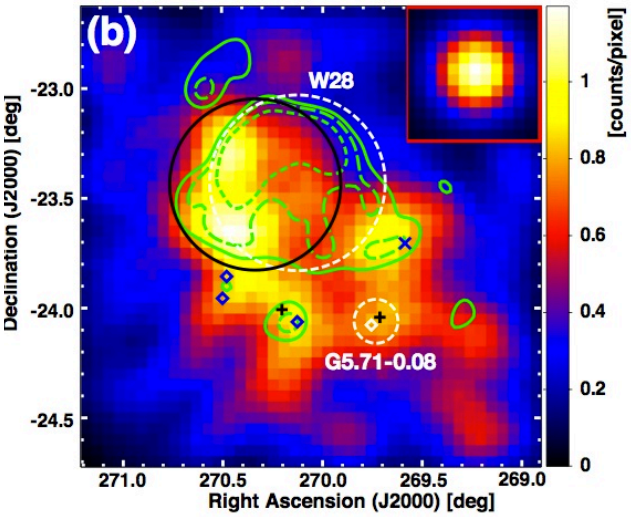
Hunter et al. 2008



Su et al. 2012







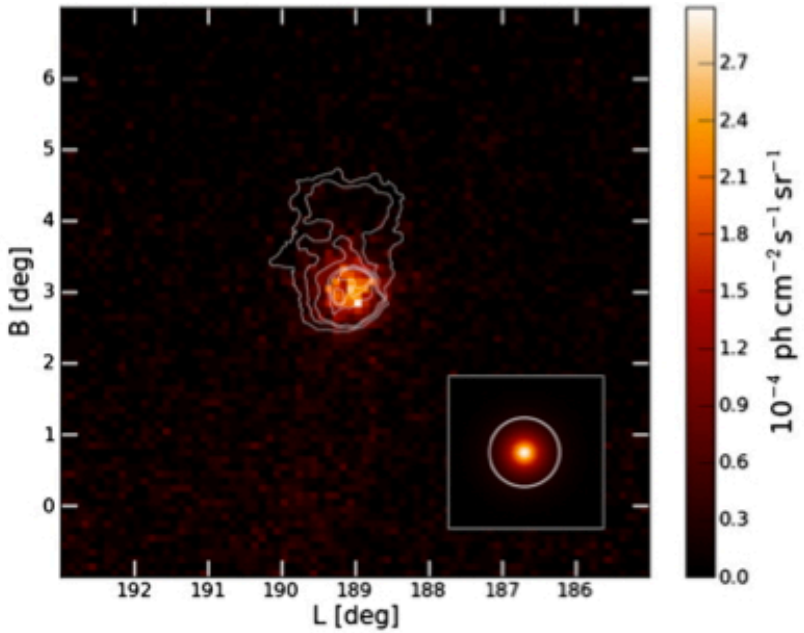
Aharonian et al. 2008, Hanabata et al. 2014

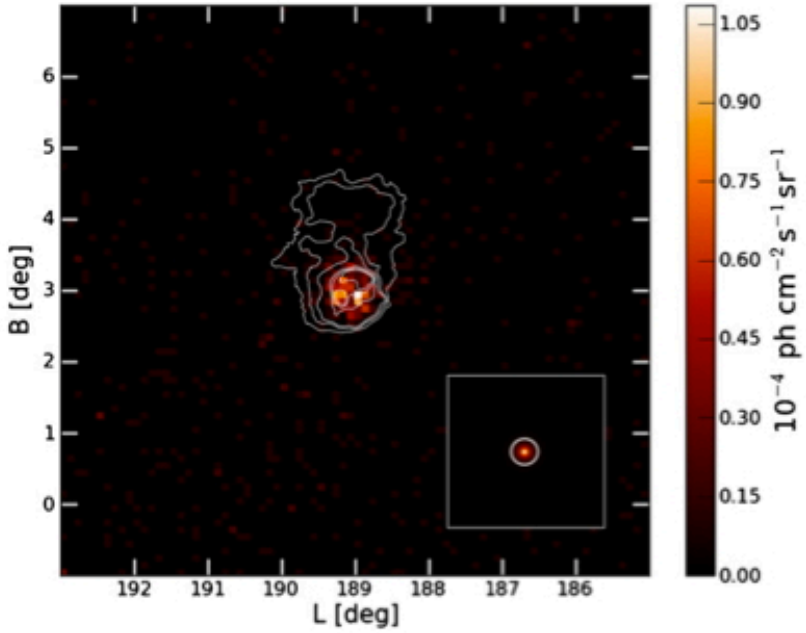
Announcement

S08 workshop at SF2A 2016 week, 15-17th June, Lyon
'Cosmic Rays and the Interstellar Medium'
Abstract can still be submitted !

Thanks for your attention !

L'étude des rayons cosmiques dans IC 443 (1)

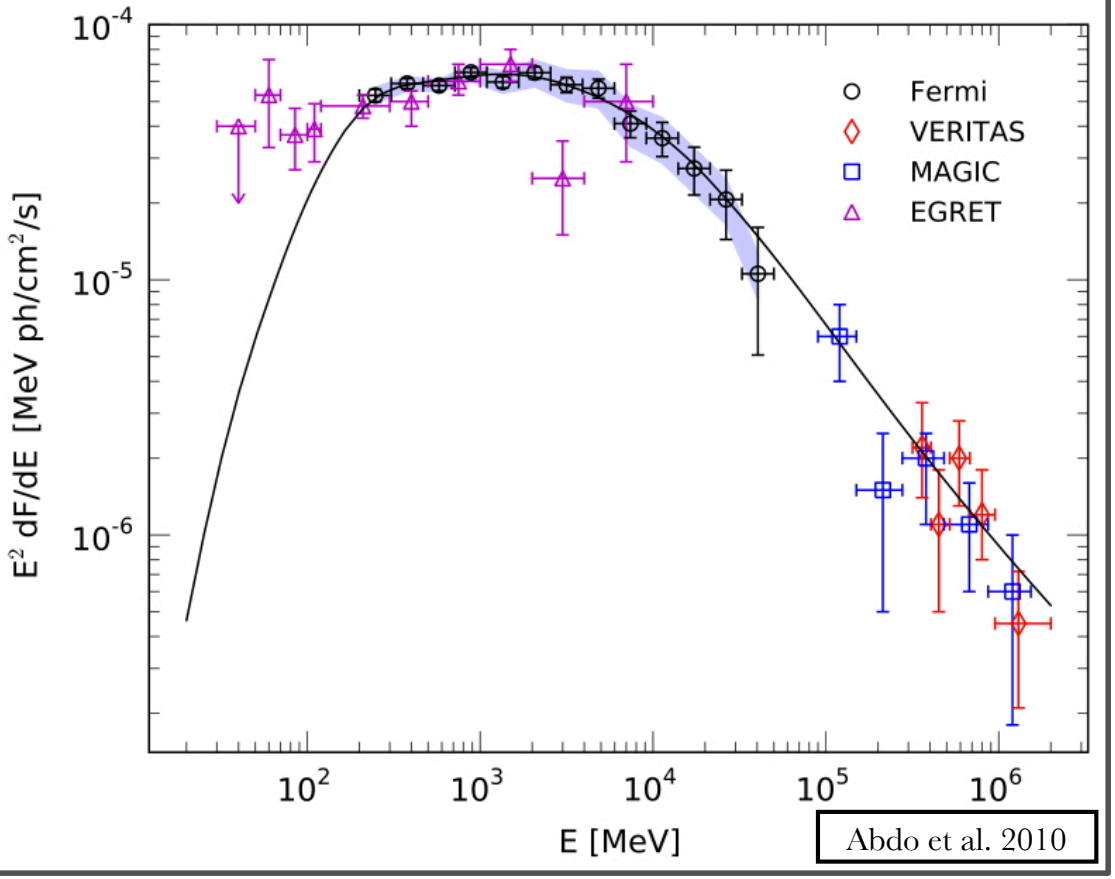




- Fermi: gamma-ray space telescope

20 MeV - 300 GeV

  - IC 443 1-5 GeV
  - IC 443 5-50 GeV
  - Combined with data from EGRET, MAGIC, VERITAS



Abdo et al. 2010

L'étude des rayons cosmiques dans IC 443 (2)

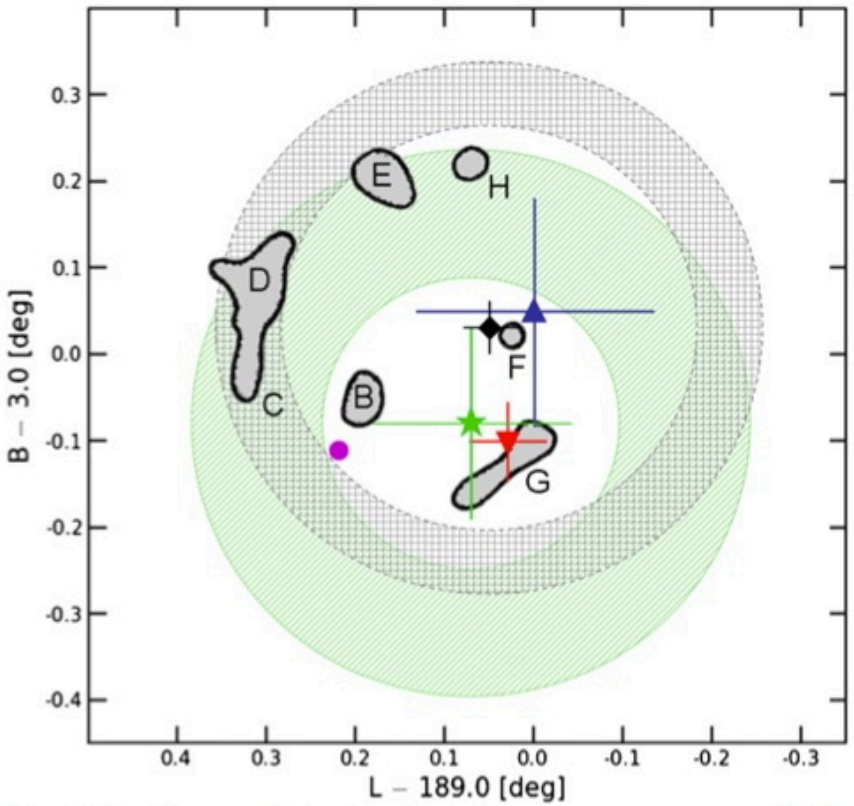
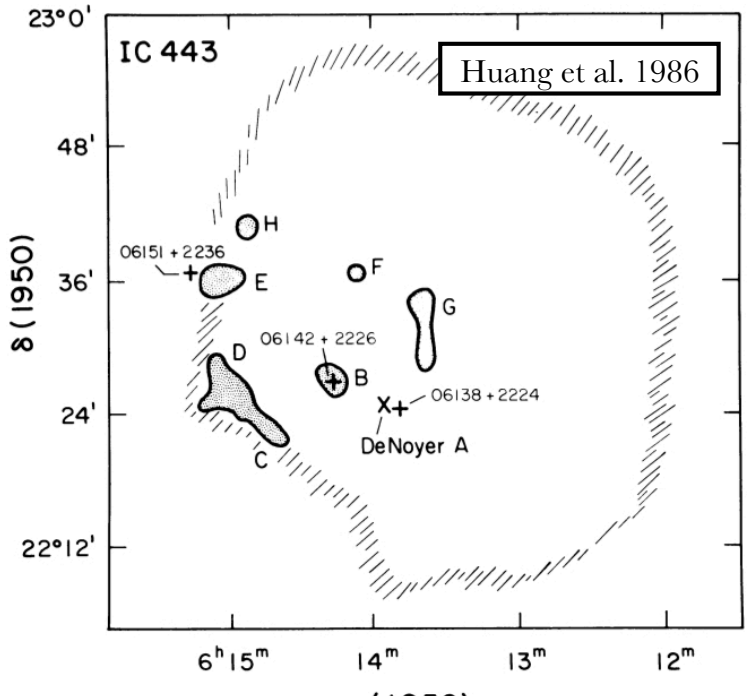
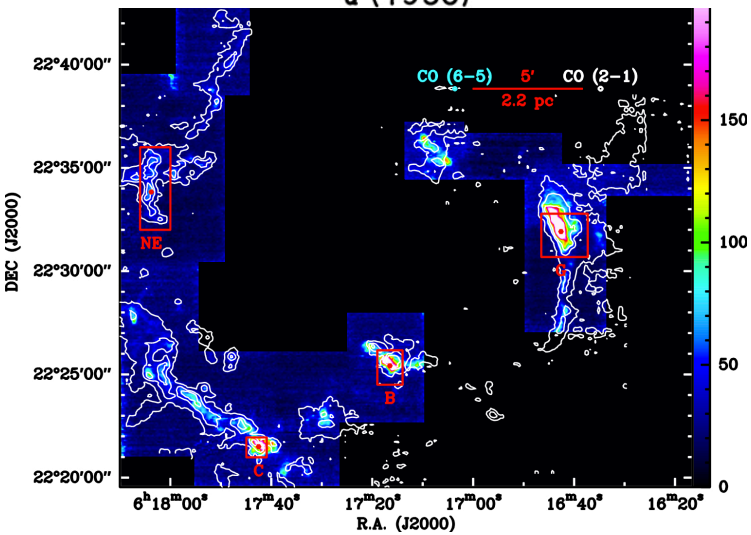


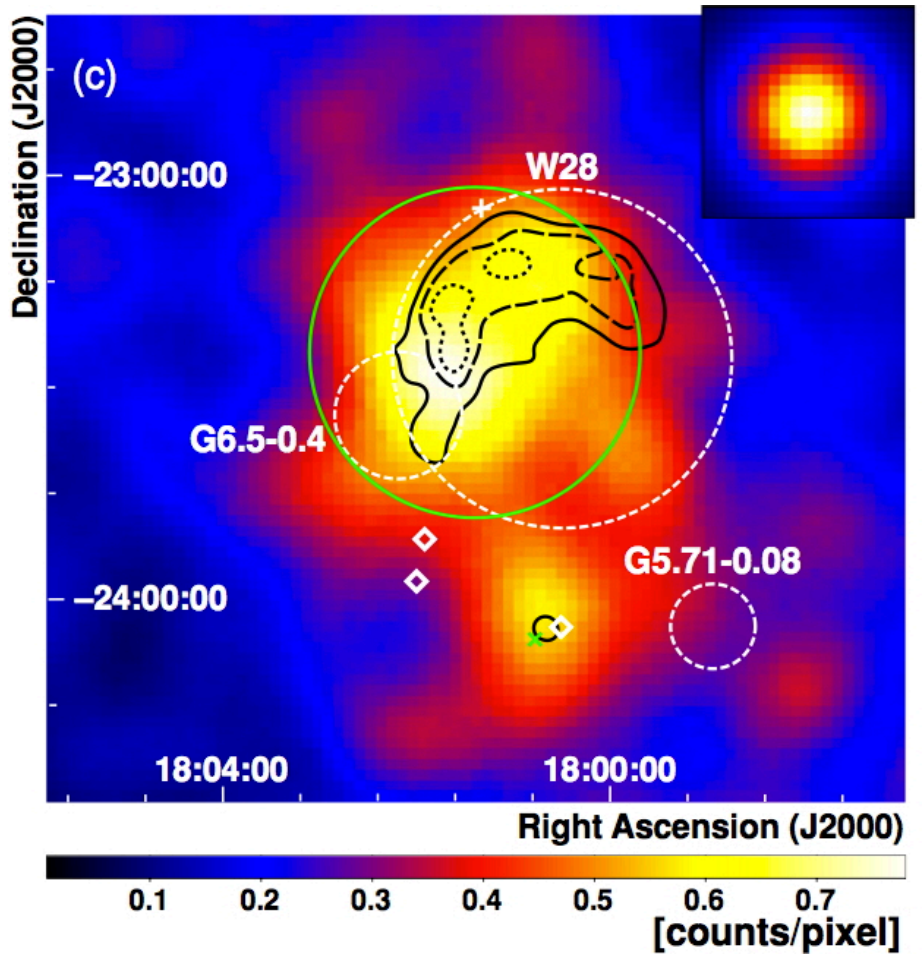
Figure 5. Locations and extensions of the four gamma-ray sources: *EGRET* centroid (△), *MAGIC* centroid (▽), *VERITAS* centroid (star), and *Fermi* LAT centroid (◇). The respective localization errors as tabulated in Table 5 are shown as crosses. Best-fit spatial extensions of the *Fermi* (cross-hatched band) and *VERITAS* (striped green band) sources are drawn as rings with radii of $\theta_{68}^{\rm ext}$ and widths of $\pm 1\sigma$ error. The PWN location is shown as a dot. Contours are the locations and shapes of the local shocked molecular clouds taken from Huang et al. (1986).

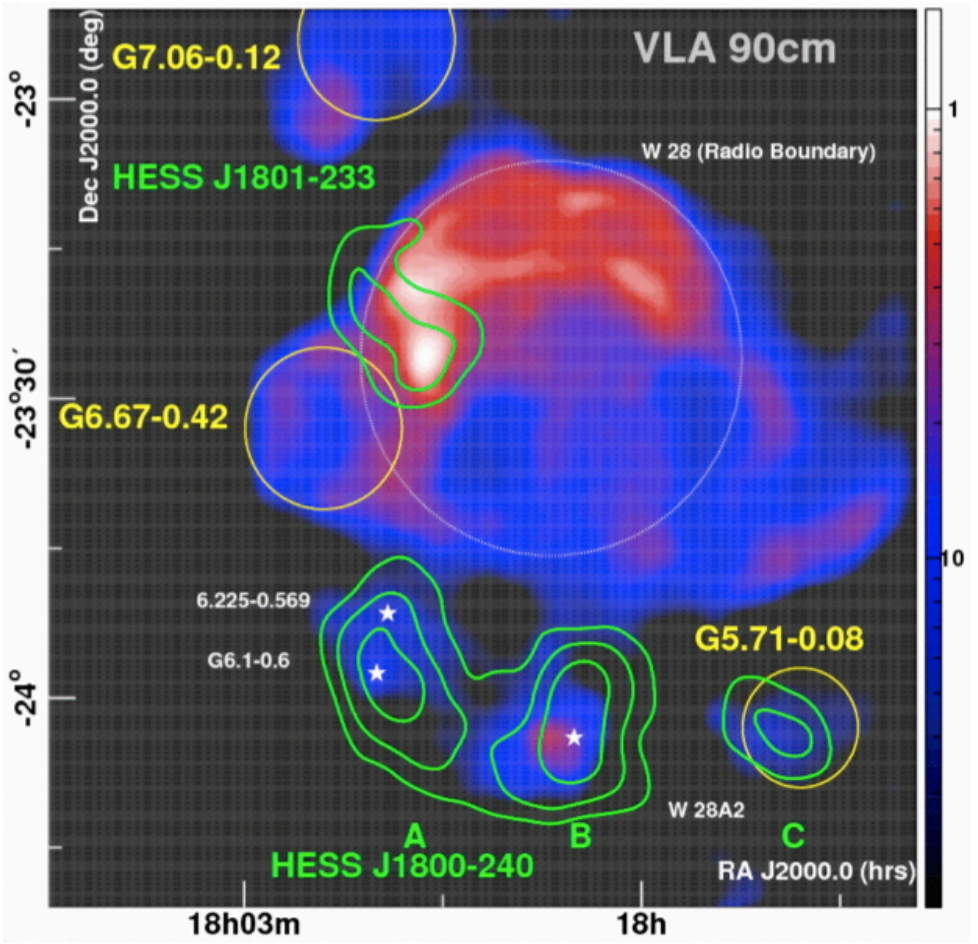




Abdo et al. 2010

G5.89 – 0.39 : rayonnement gamma (1)





- The Fermi-lat count map

2-10 GeV with 0.2° resolution

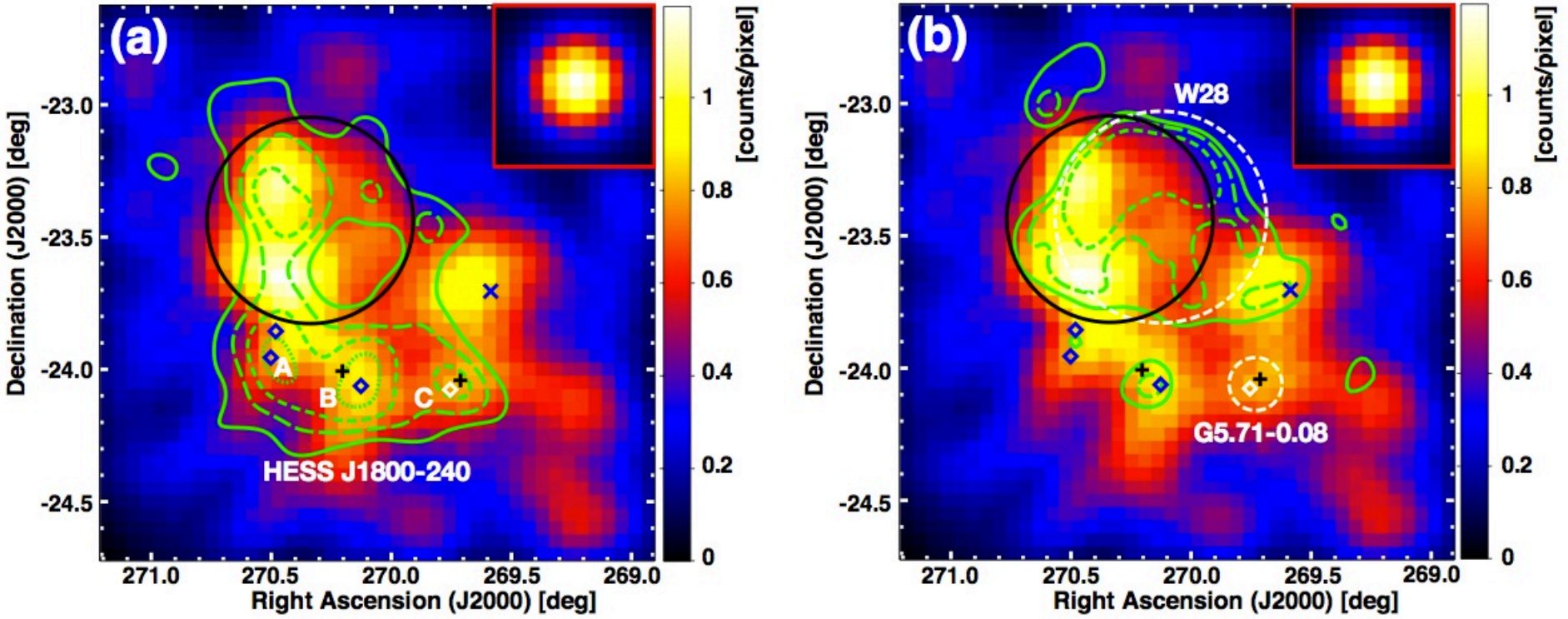
Abdo et al. 2010

- The HESS count map

Above 320 GeV with 5-6’ resolution

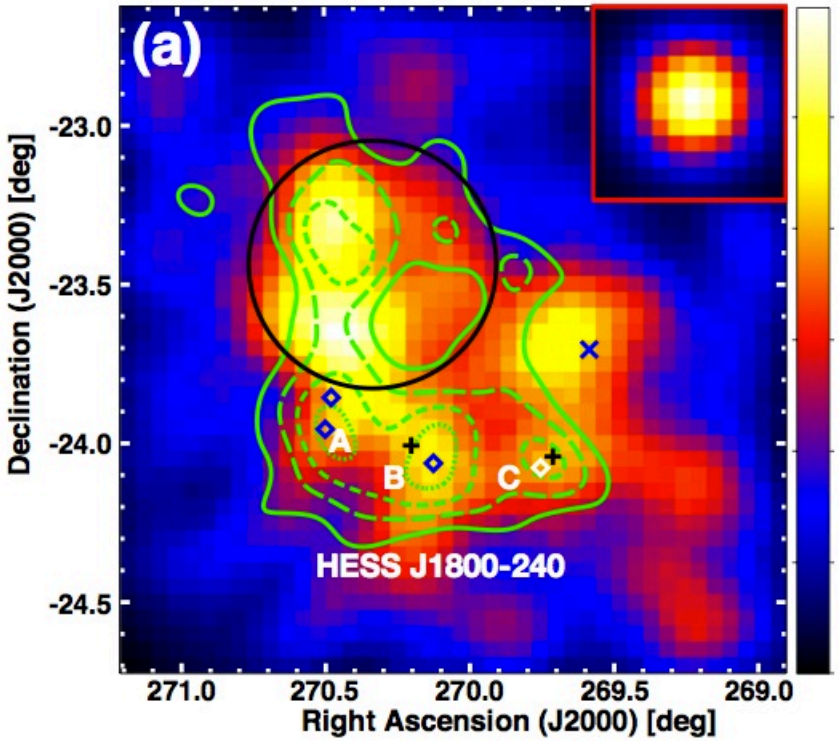
Aharonian et al. 2008

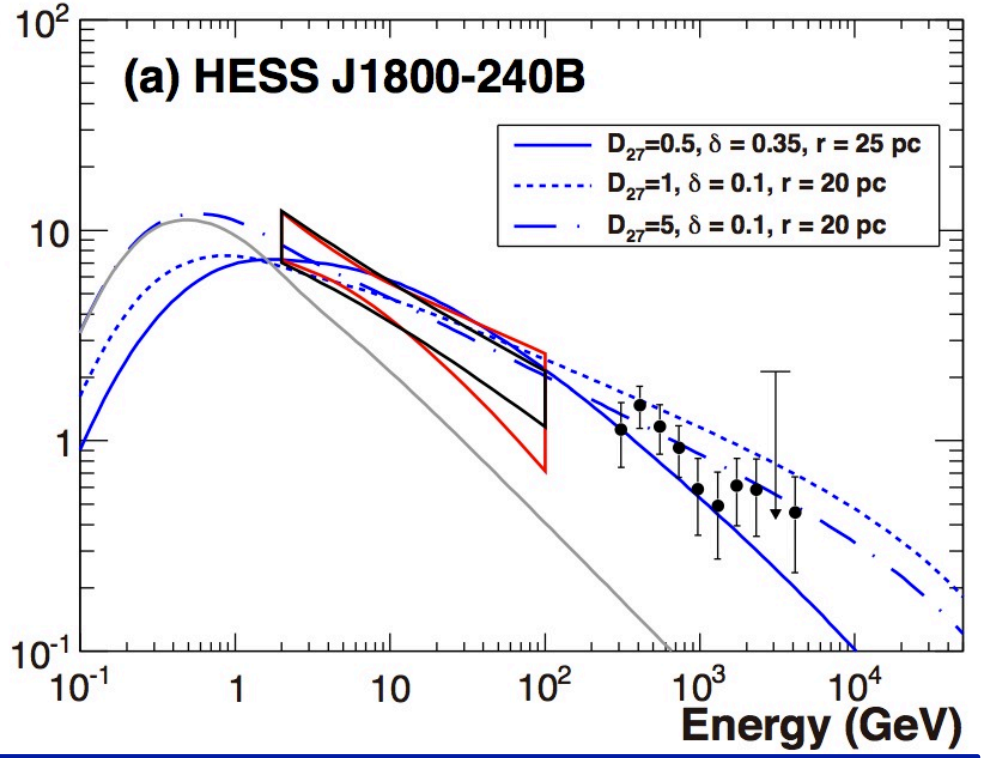
G5.89 – 0.39 : rayonnement gamma (2)



Hanabata et al. 2014

G5.89 – 0.39 : rayonnement gamma (3)



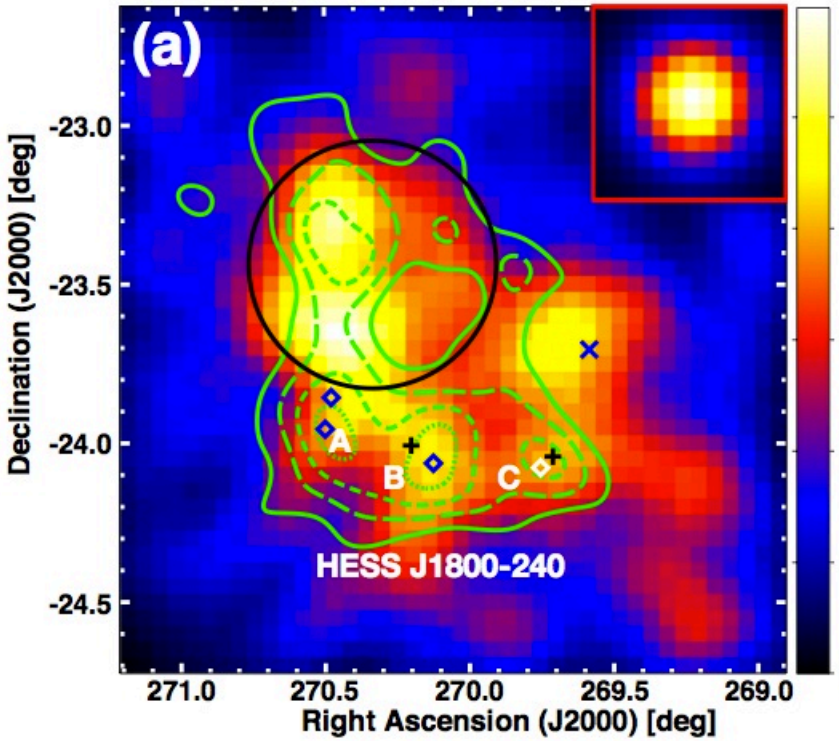


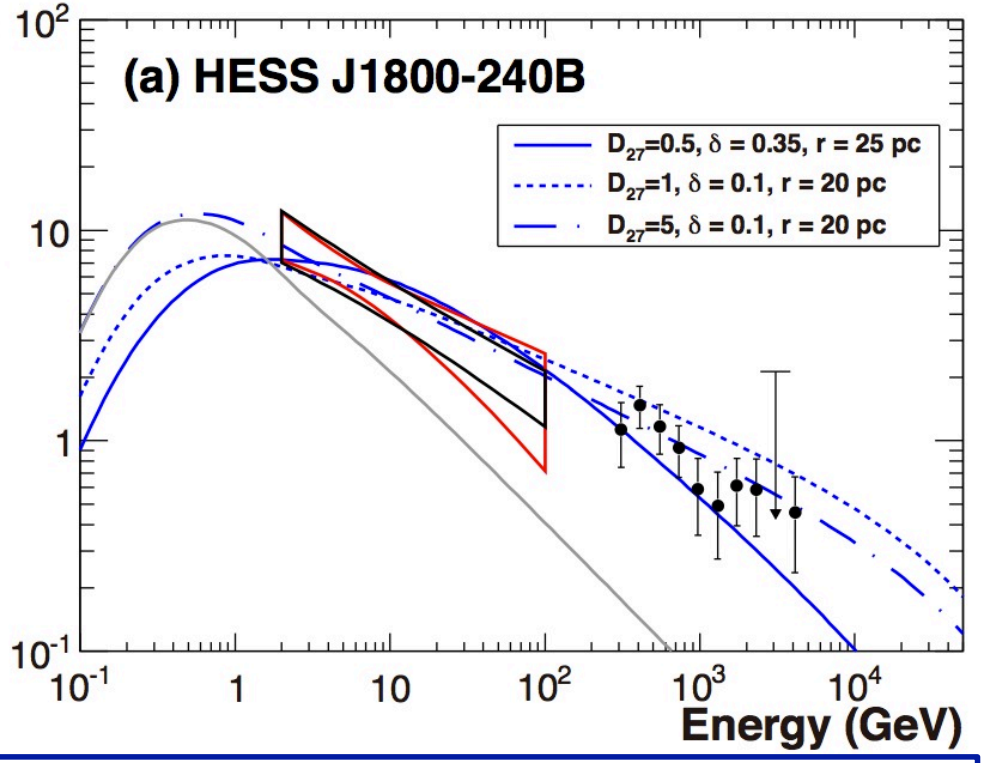
- HESS points
- 68% confidence range of LAT
- upper limit of the γ-ray emission

produced by the sea of Galactic CRs in the same CR-illuminated cloud

Hanabata et al. 2014

G5.89 – 0.39 : rayonnement gamma (3)

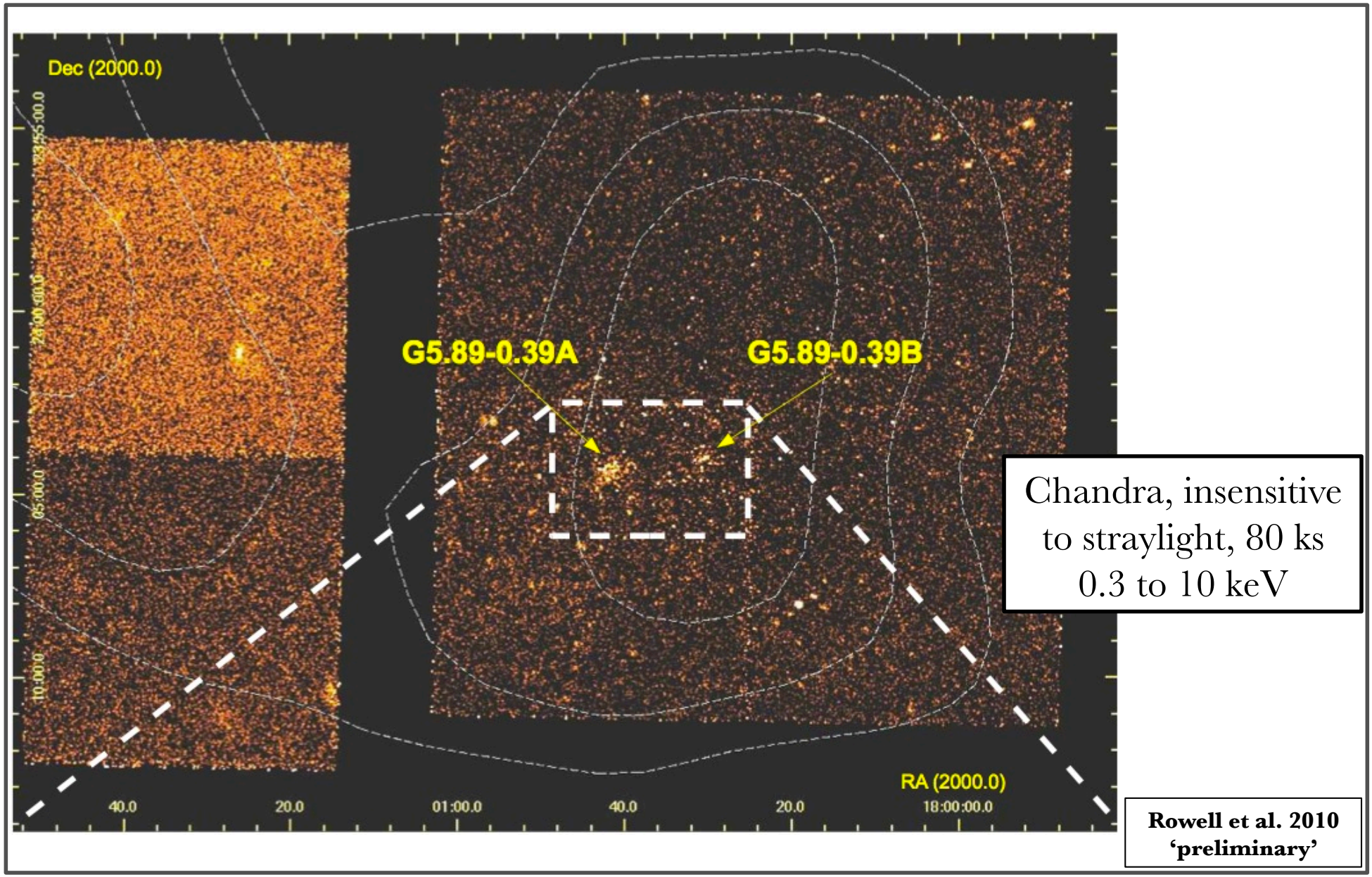




'There is no model for multi-TeV particle acceleration in such HII regions'

Hanabata et al. 2014

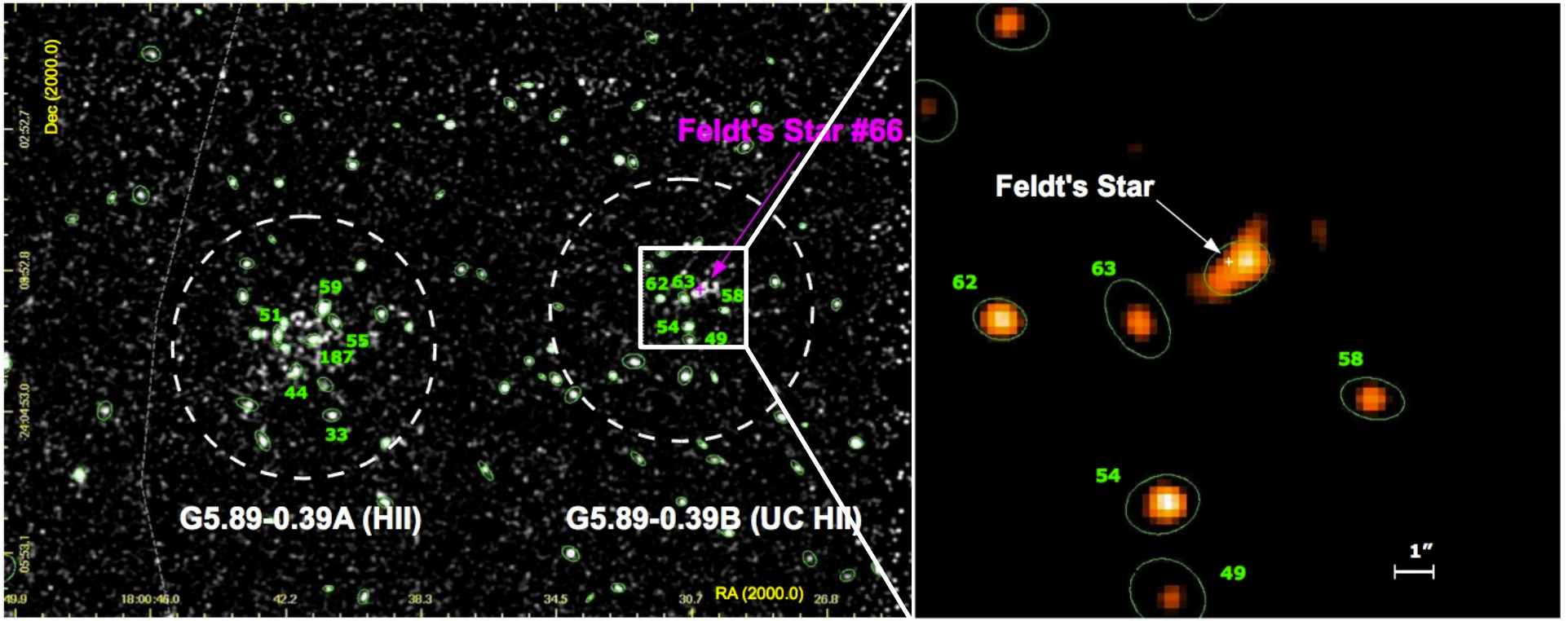
G5.89 – 0.39 : rayonnement X (1)



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

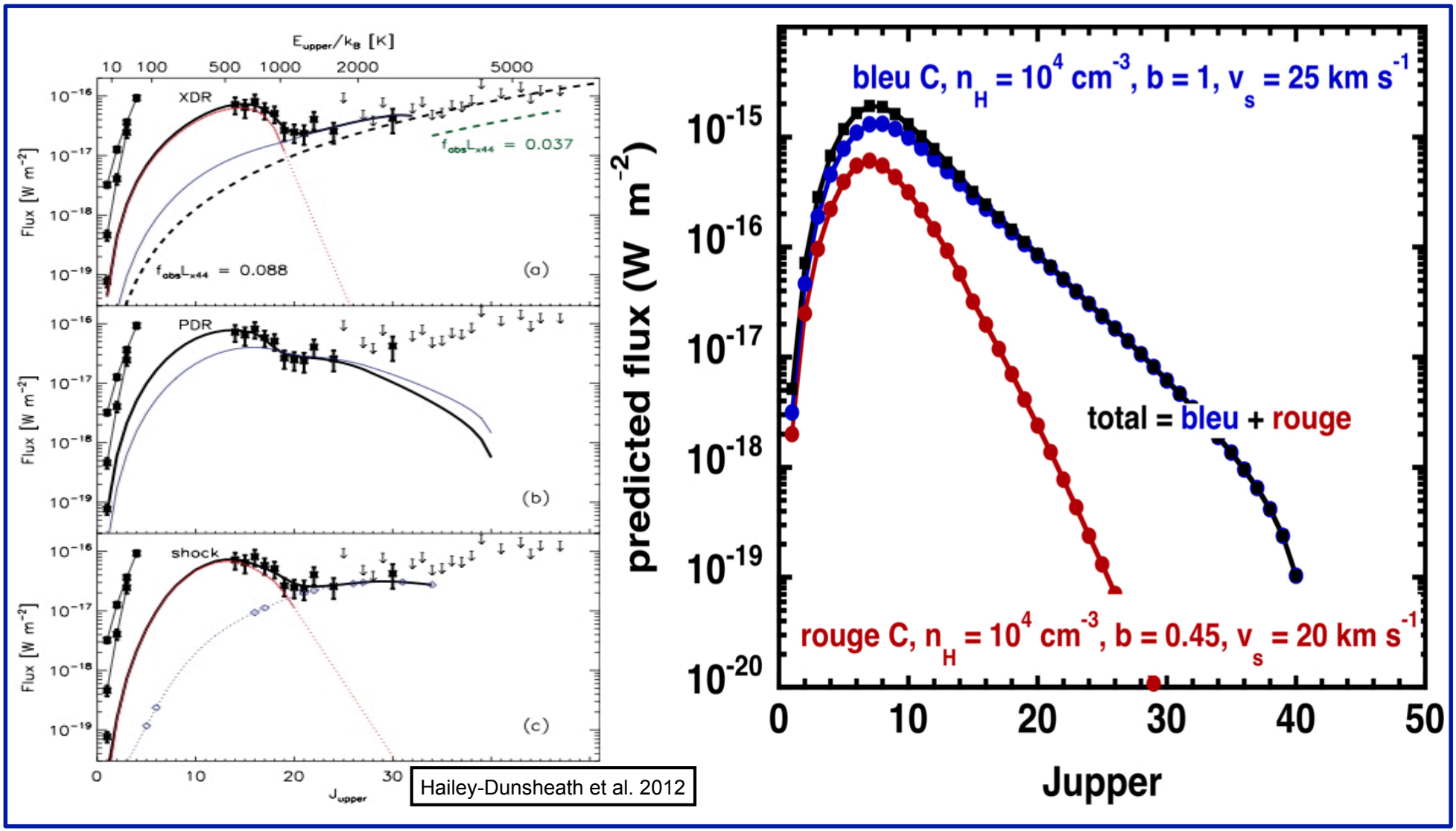
Rowell et al. 2010 'preliminary'

G5.89 – 0.39 : rayonnement X (2)



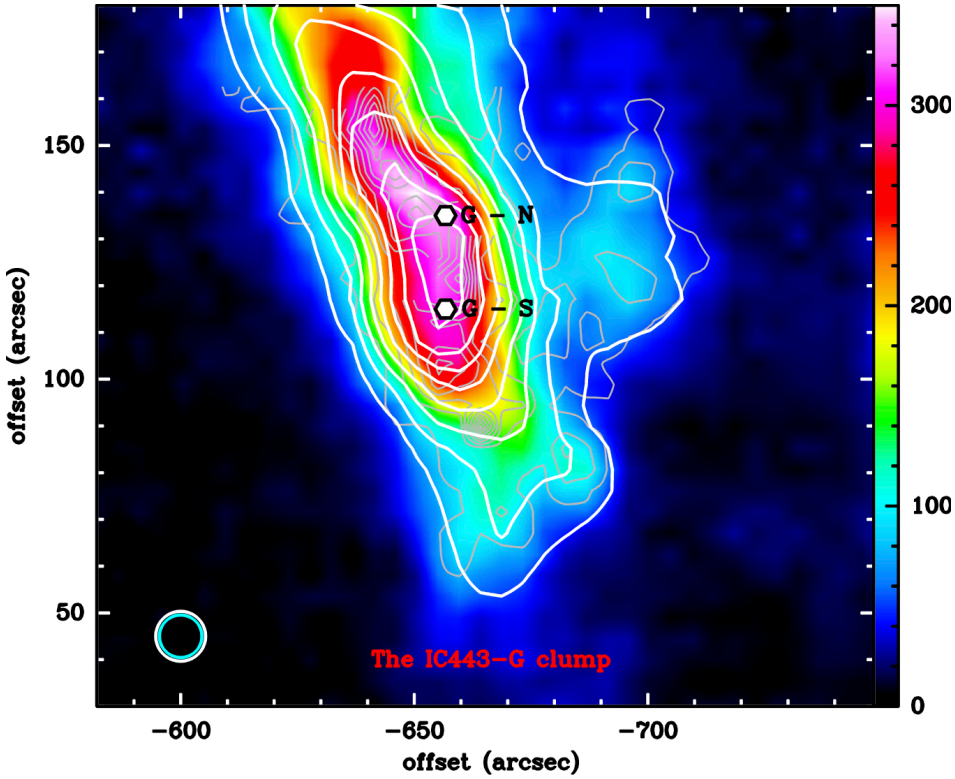
Rowell et al. 2010
'preliminary'

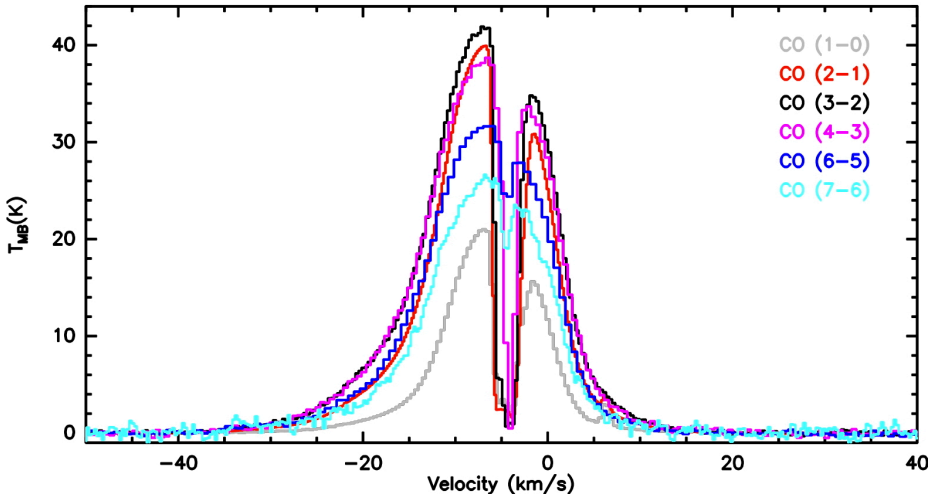
W28 : chocs et contribution à l'échelle d'une galaxie

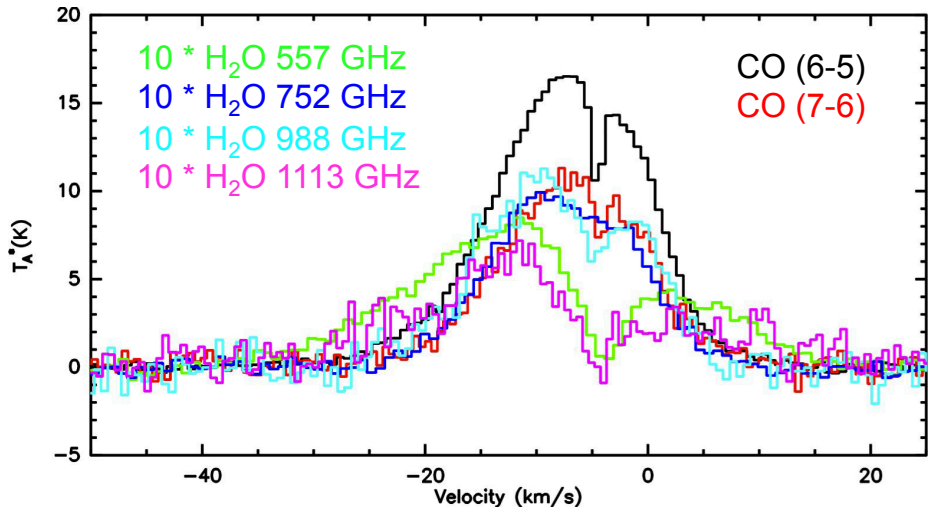


Hailey-Dunsheath et al. 2012

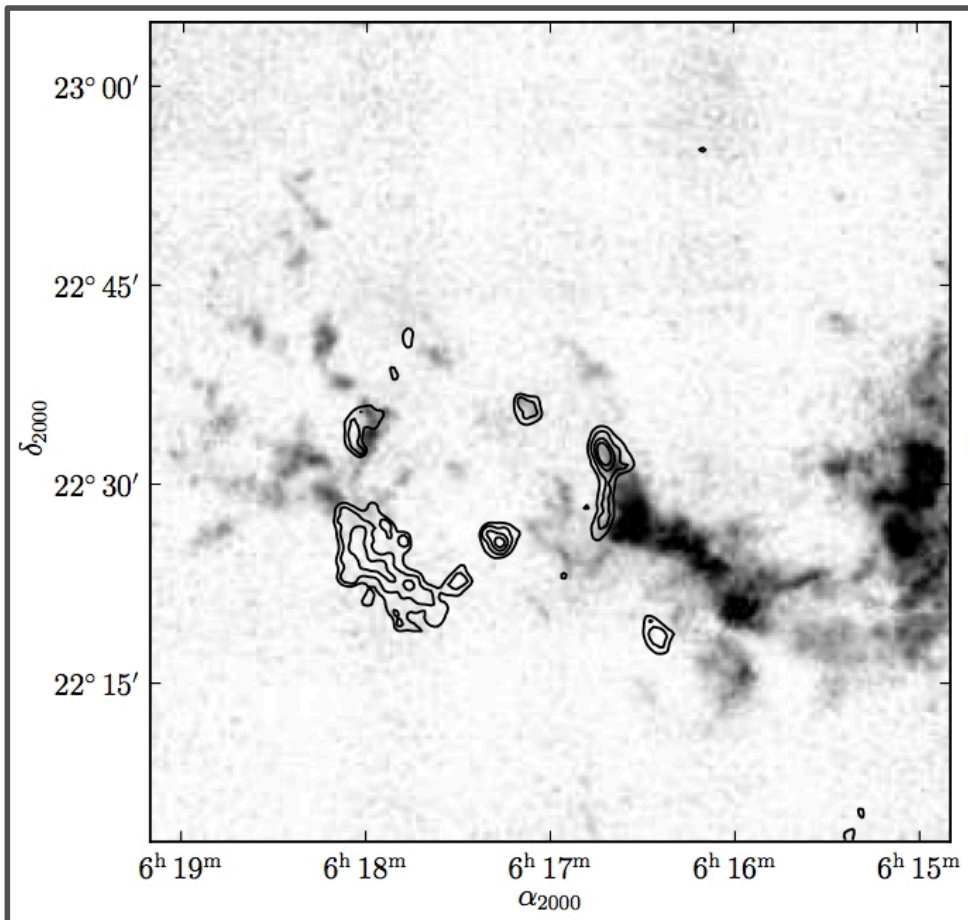
IC 443G : projets en cours



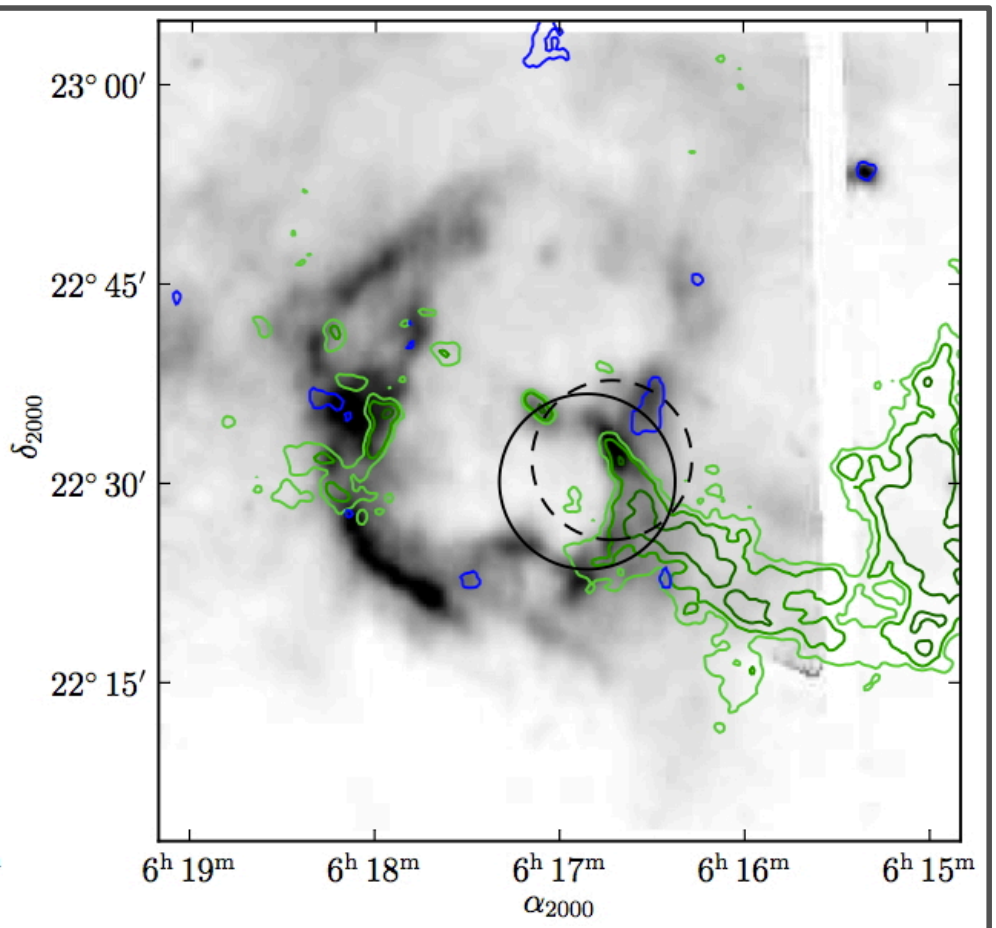




IC 443 : la formation stellaire



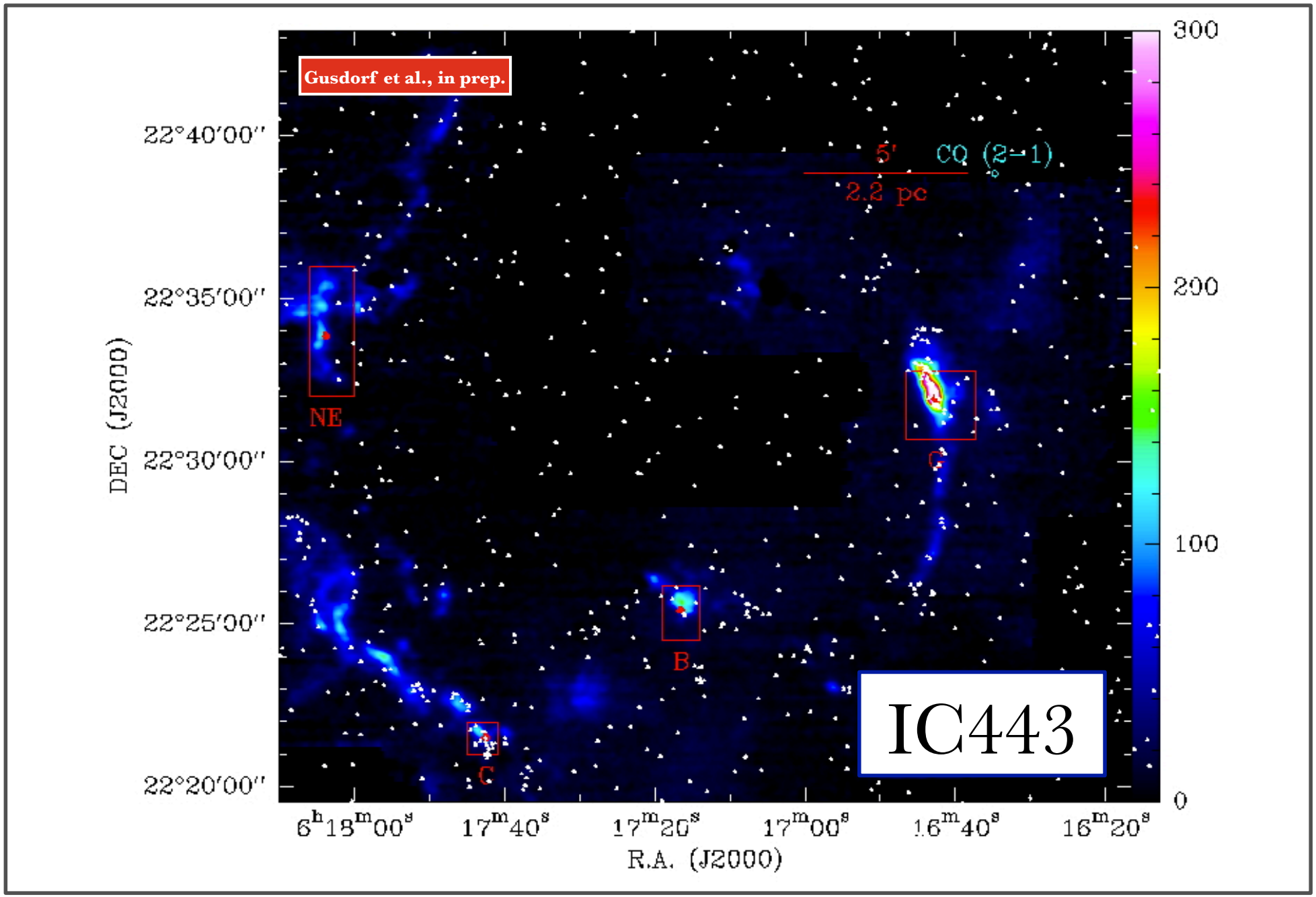
Lee et al. 2012



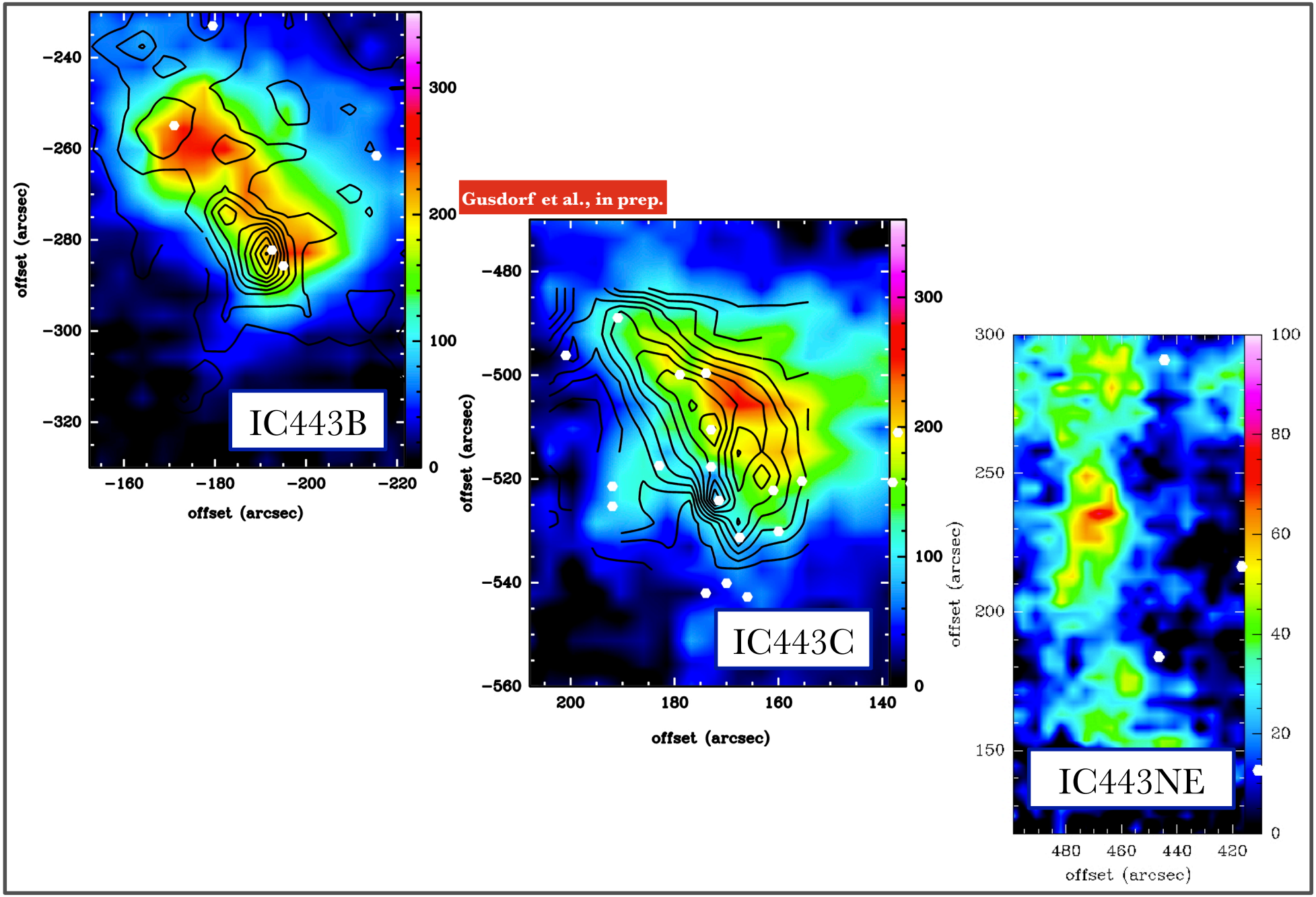
- Nuages ambiants en CO à 5 km/s (image de fond) et HCO^+ integre sur tout le profil de vitesse (contours)

- image 90 µm AKARI (image de fond) et nuage ambiant en CO à 5km/s (contours verts)

IC 443 : la formation stellaire



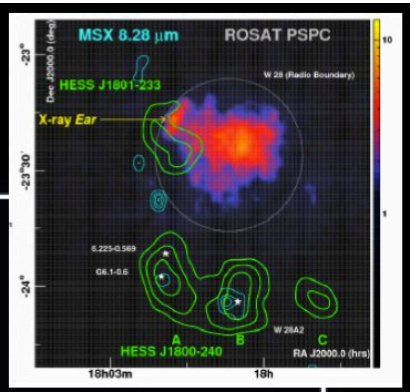
IC 443 : la formation stellaire



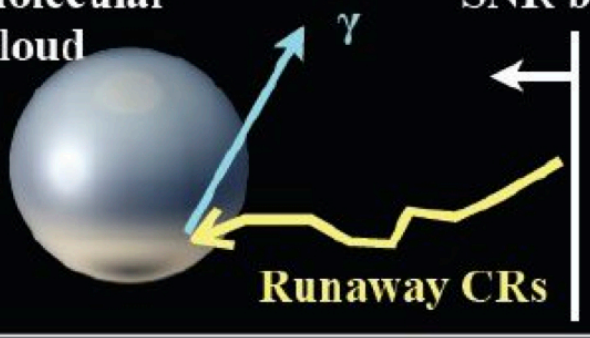
Mécanisme de rayonnement gamma dans les SNRs âgés

Two main scenarii proposed

See Talk by S. Gabici



« Aharonian & Atoyan » type Scenario:

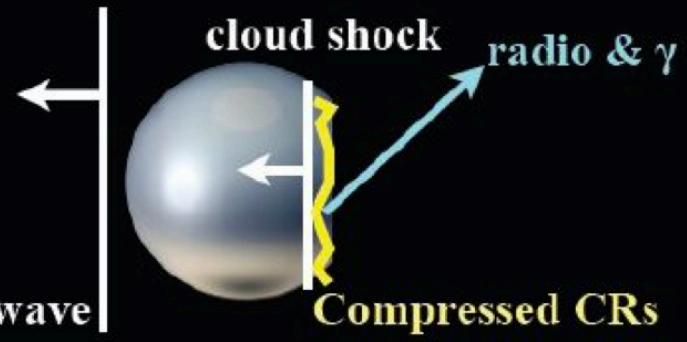


CRs escaping from SNR and colliding with nearby MCs

e.g., Gabici+09, Fujita+10, Ohira+10

« Uchiyama+10 » type Scenario:

relying on Blandford & Cowie 82
see also Bykov+00



radio/γ-ray coming radiatively compressed zone behind "cloud shock"