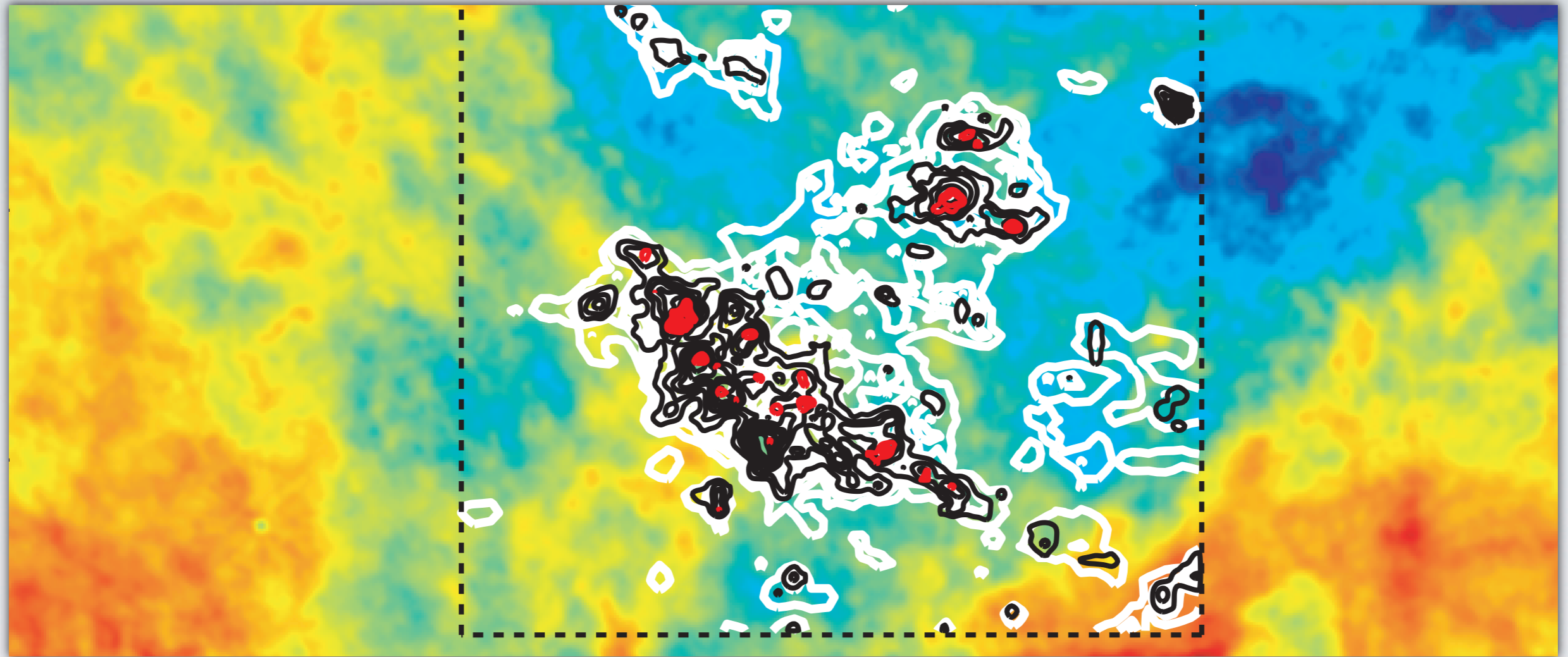


Snapshots in the Life (and Death) of Molecular Clouds

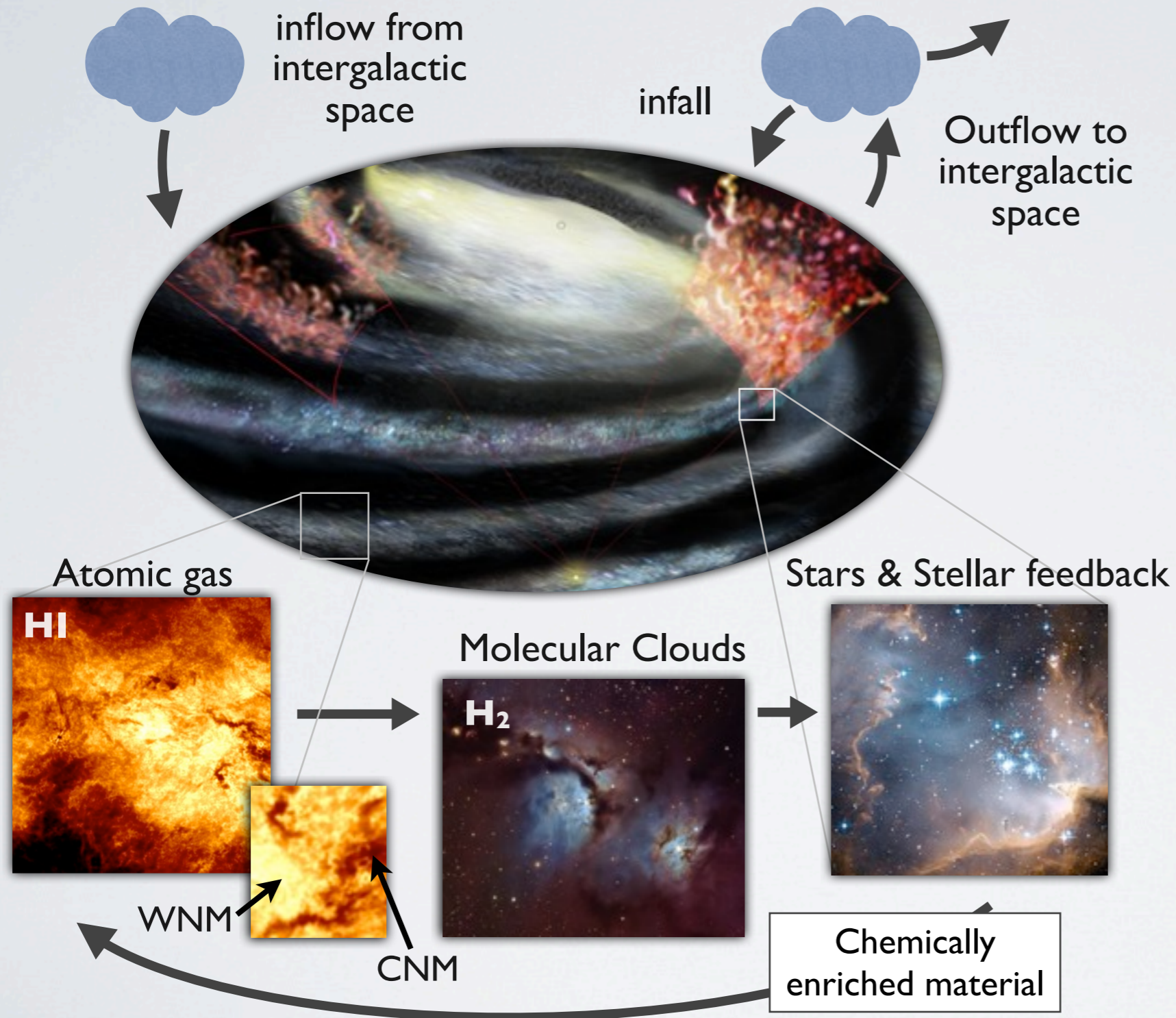


Joanne Dawson

(Macquarie University / CSIRO Astronomy & Space Science)

Mopra Workshop - UNSW - 10th Dec 2015

The Galactic Gas Cycle



From HI to Molecular Clouds

Warm Neutral Medium

$T \sim 8000 \text{ K}$
 $n \sim 0.5 \text{ cm}^{-3}$
 $f > 30\%$



Cold Neutral Medium

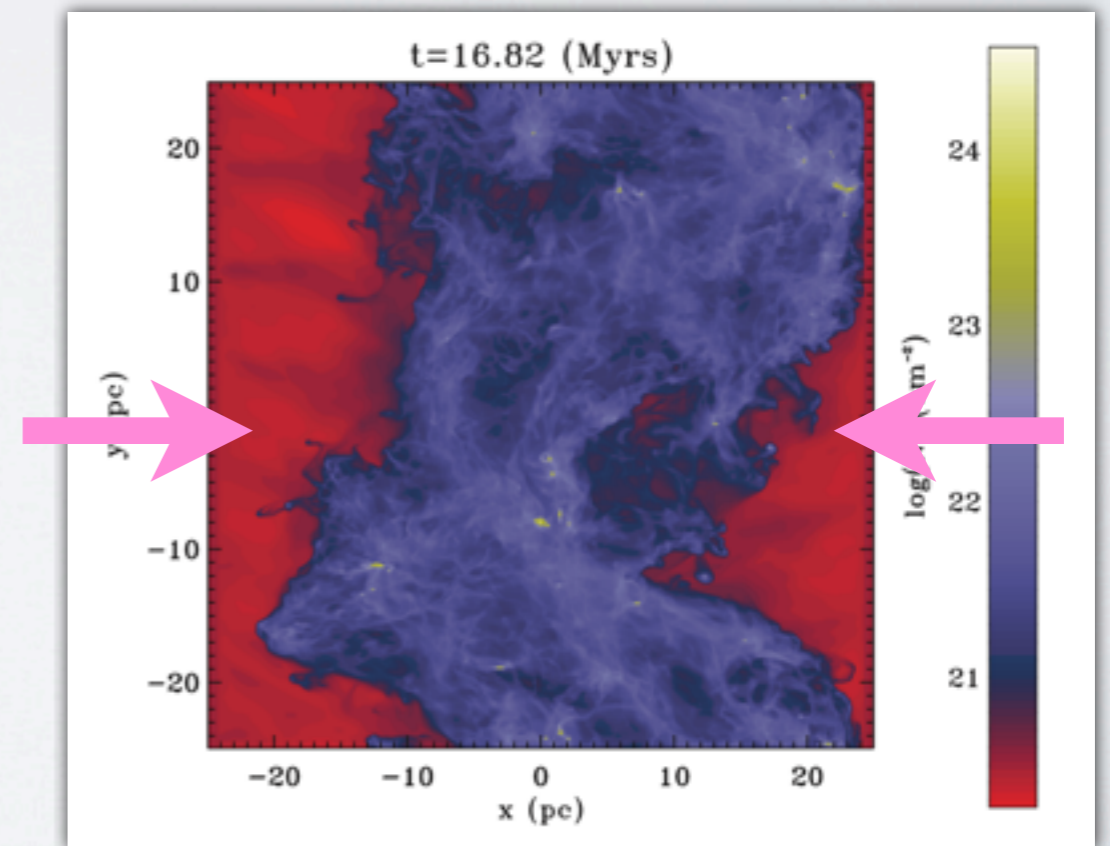
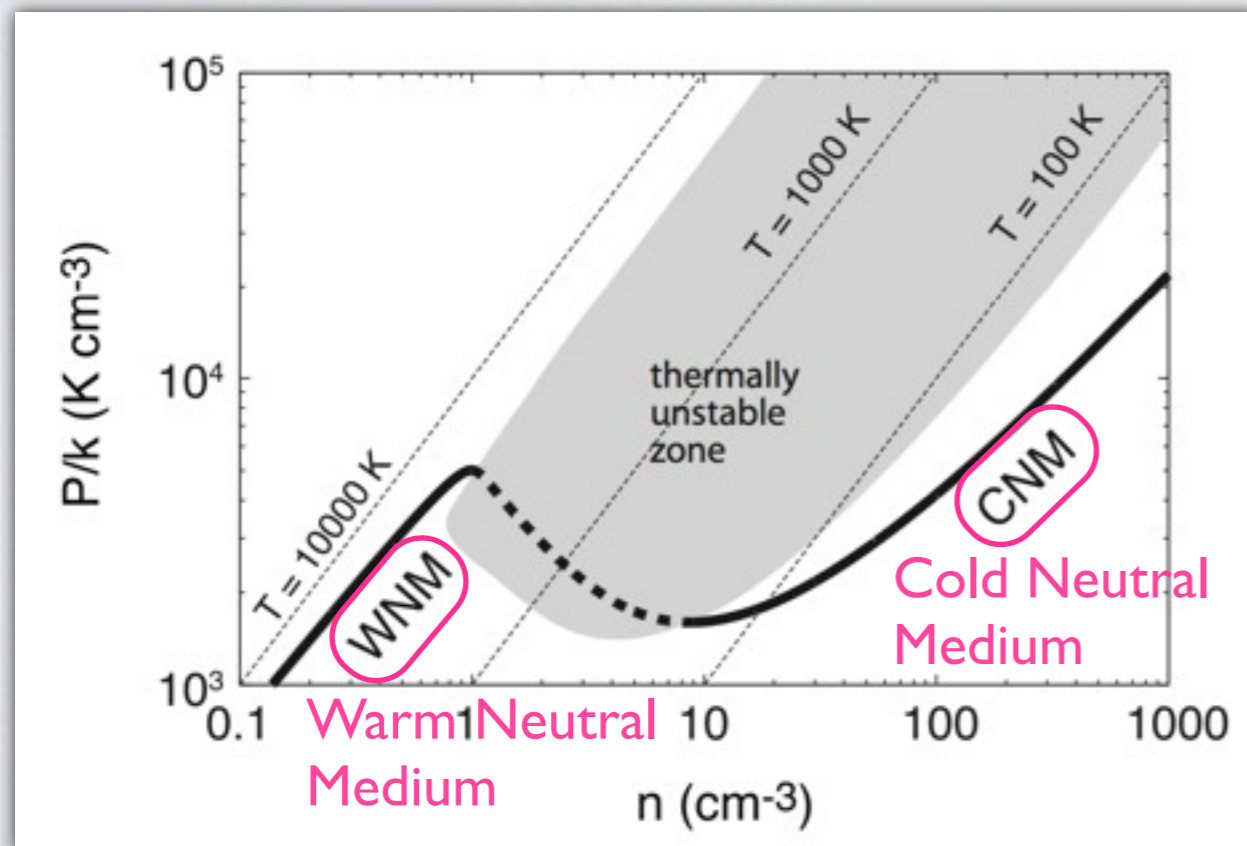
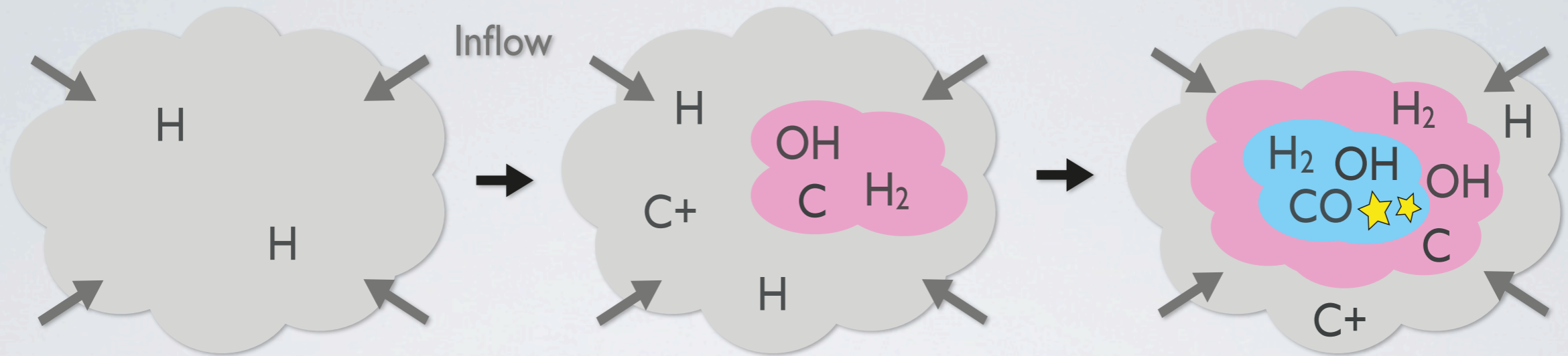
$T \sim 80 \text{ K}$
 $n \sim 50 \text{ cm}^{-3}$
 $f \sim 2 - 4\%$



Molecular Clouds

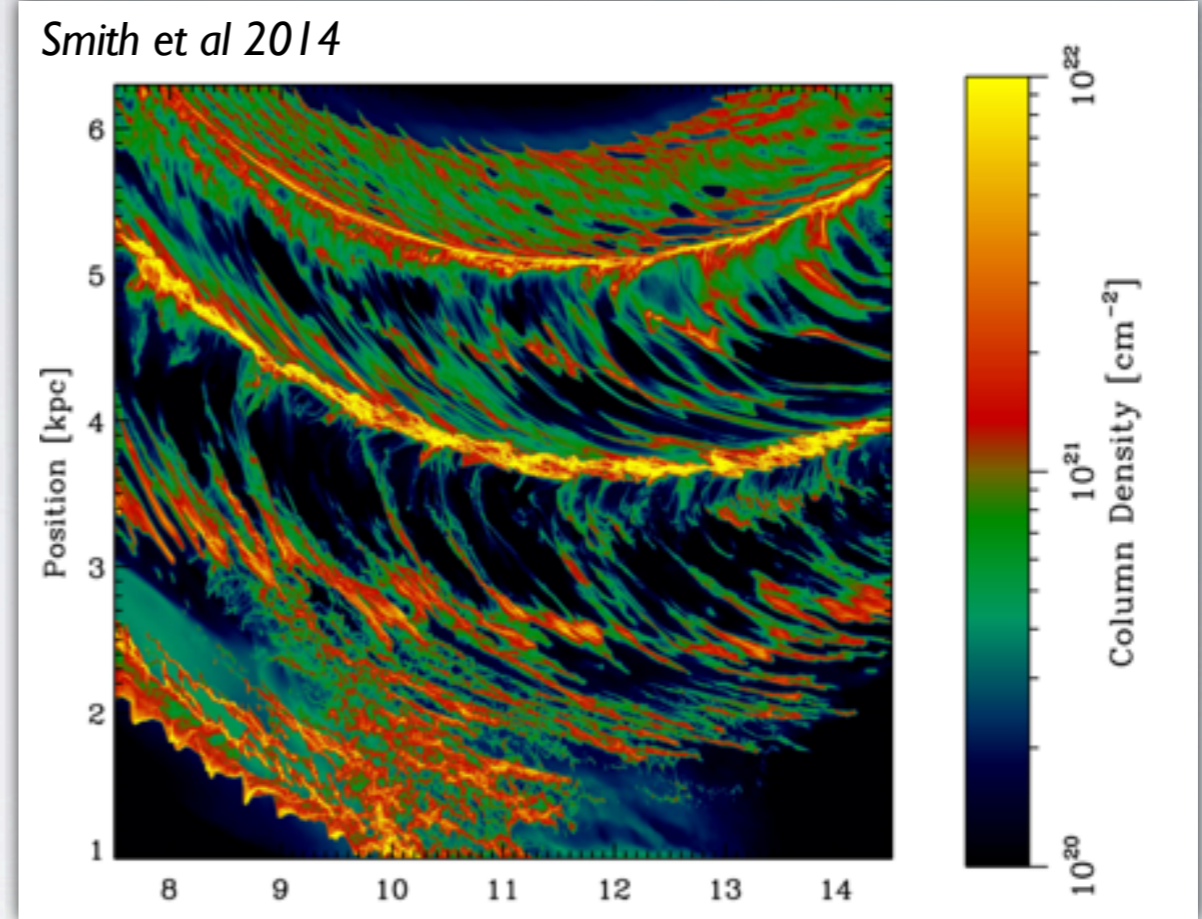
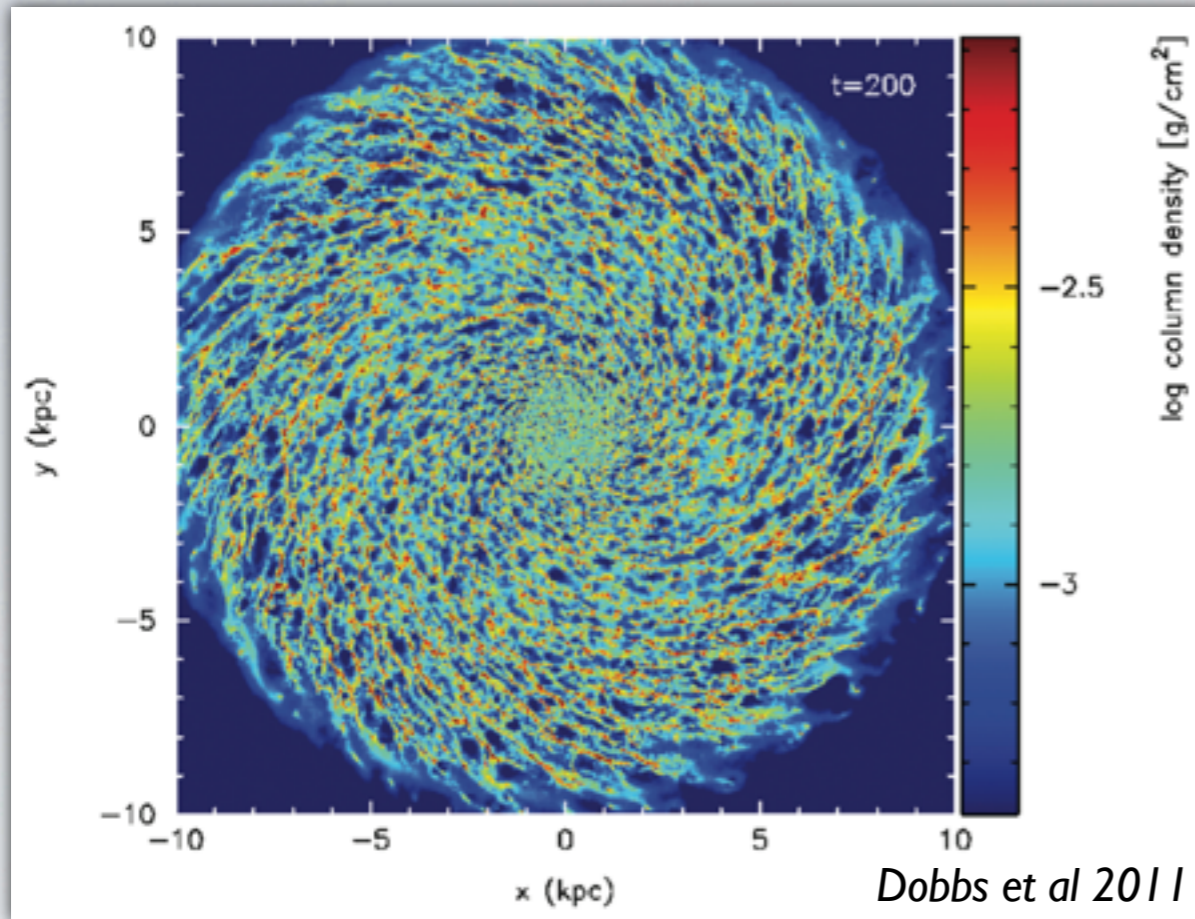
$T \sim 10 \text{ K}$
 $n > 200 \text{ cm}^{-3}$
 $f < 1\%$

Forming Dense (Molecular) Gas

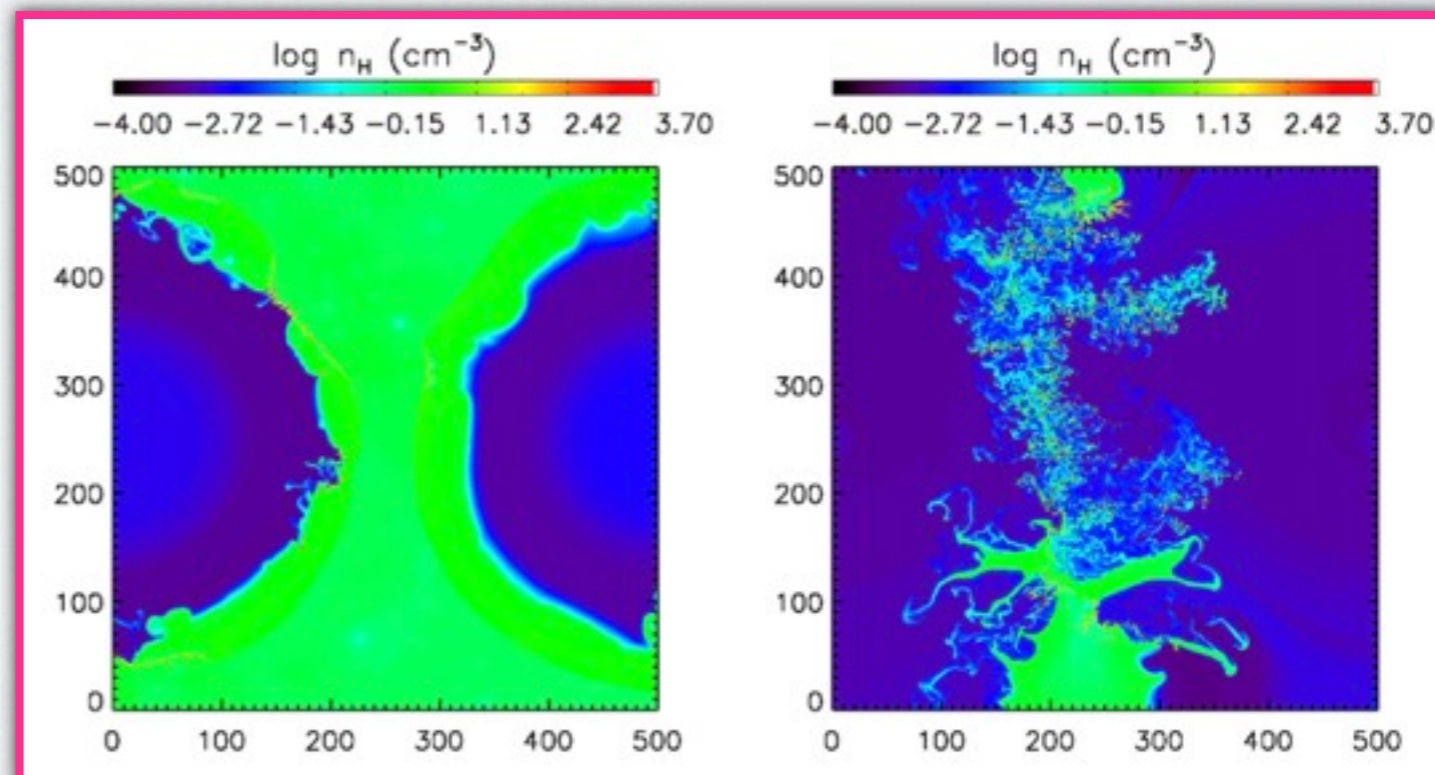


Dense gas formed in colliding WNM flows (Hennebelle 2013)

Astrophysical Drivers of “Colliding Flows”

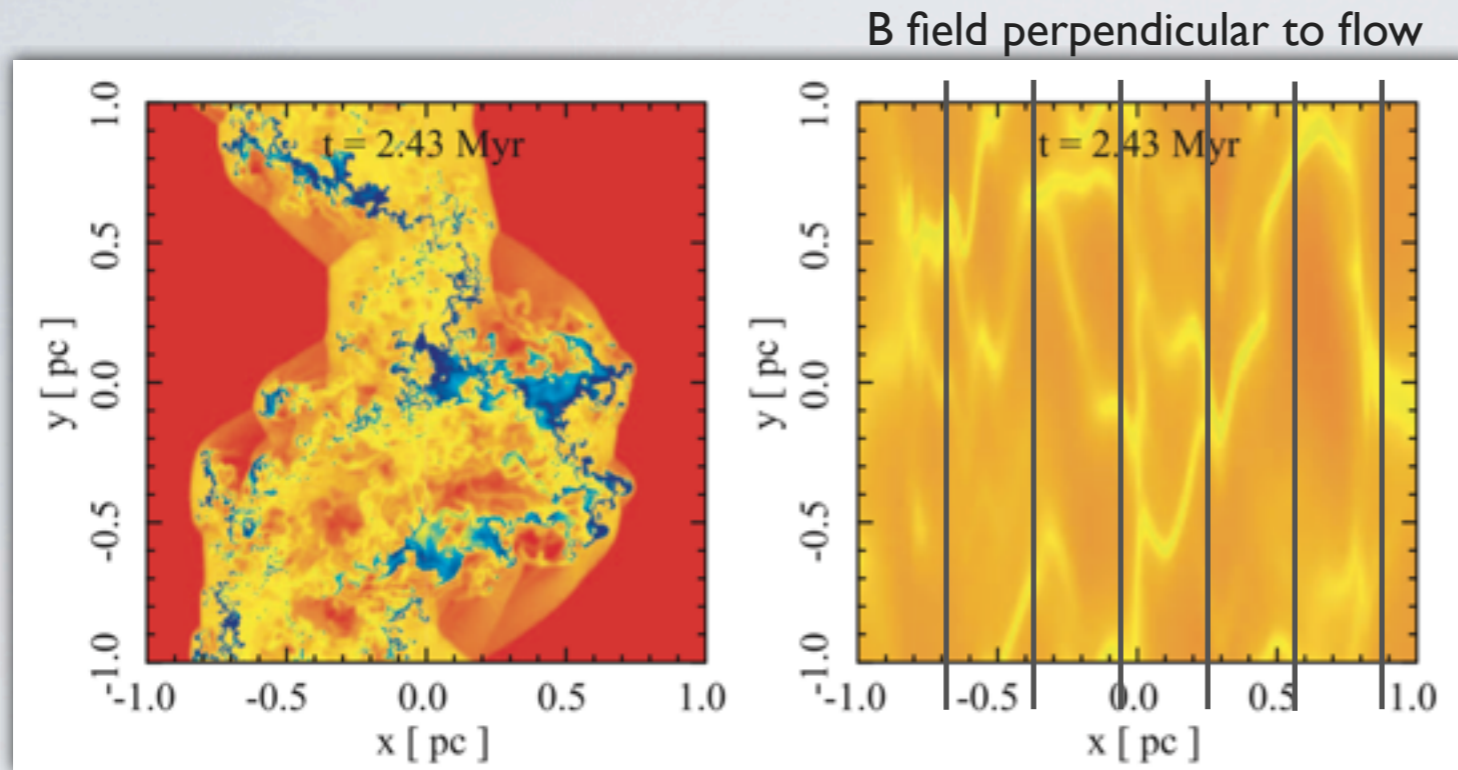


- **Gravitational instabilities**
- **Spiral arms**
- **Large-scale stellar feedback (supershells)**



Ntormousi et al. 2011

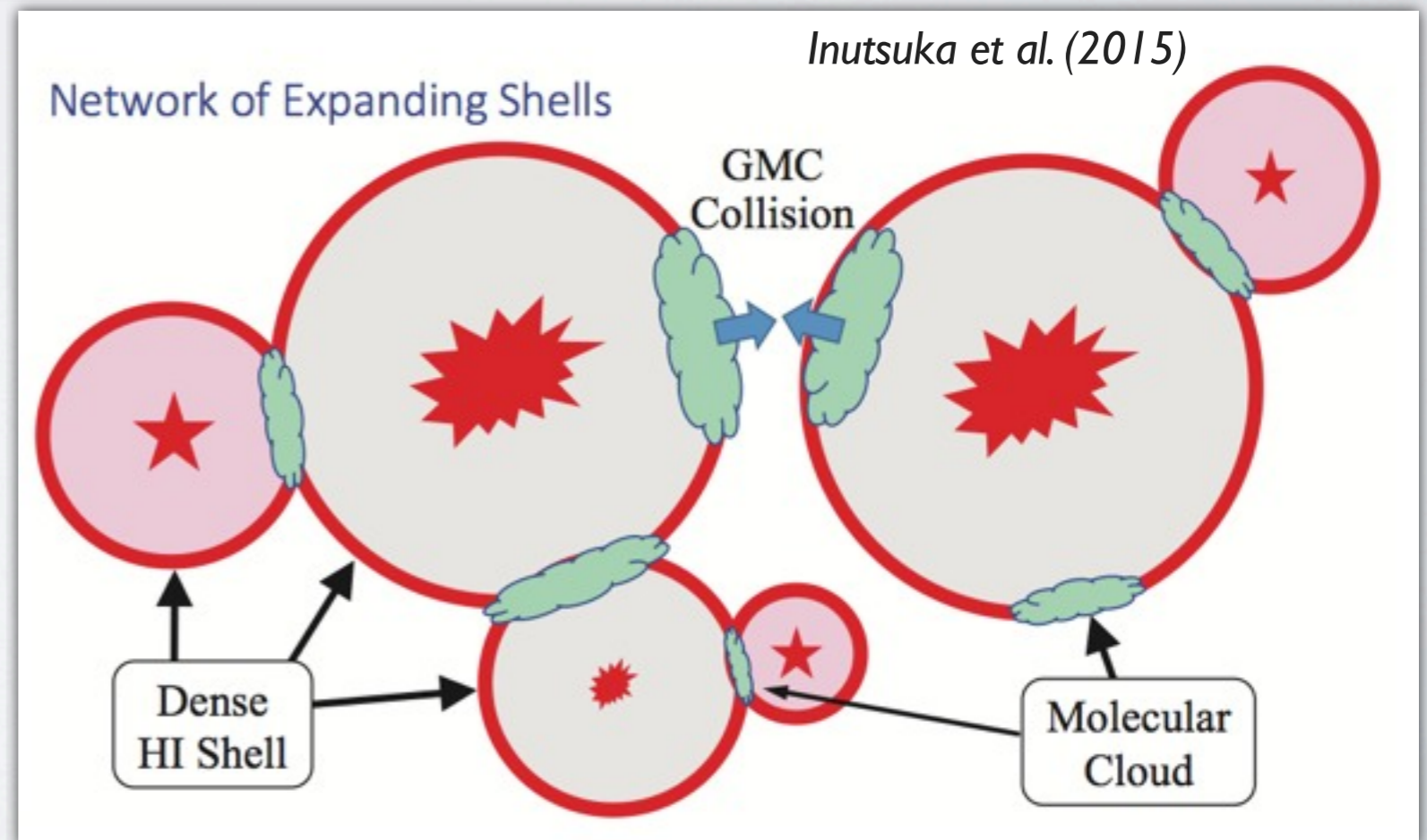
Forming Molecular Clouds In Supershells



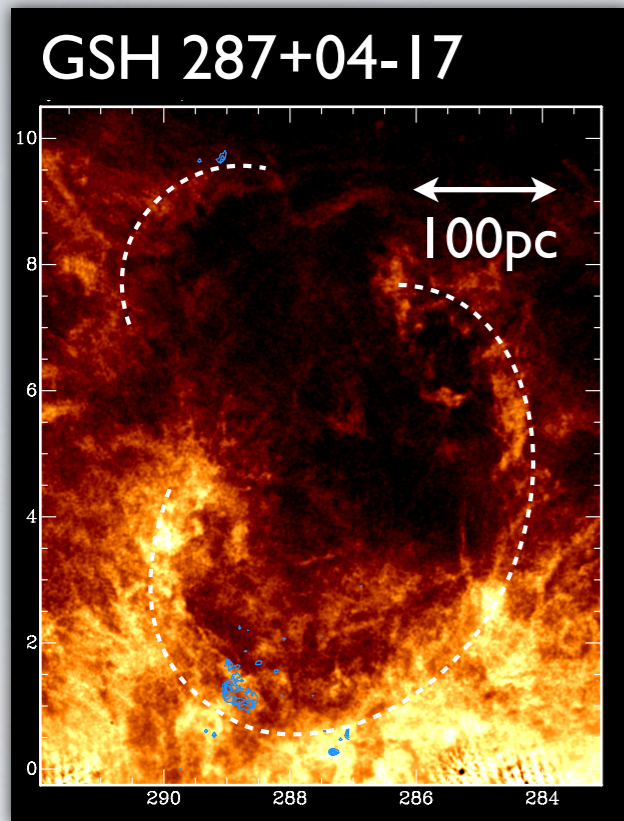
- **Magnetic pressure a problem in colliding flows models**

Inoue & Inutsuka (2008)

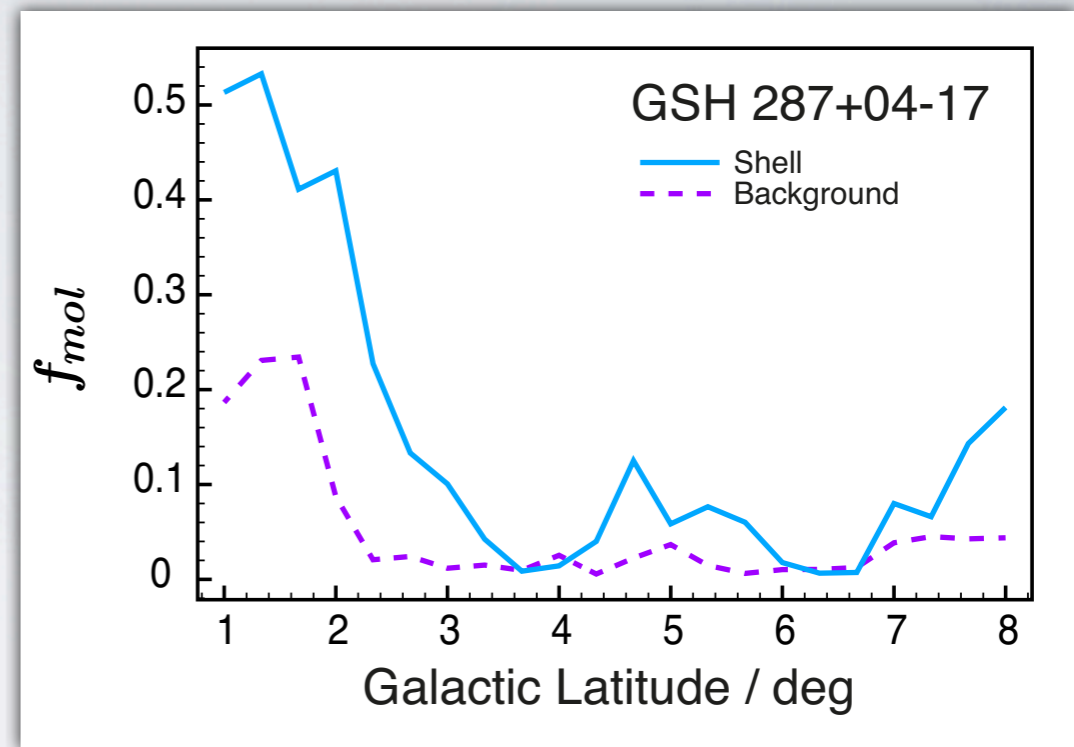
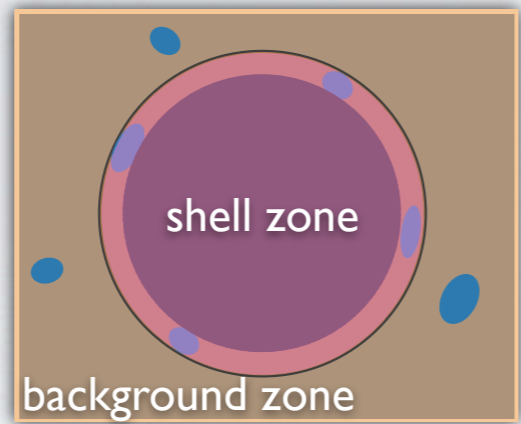
- **Expanding bubbles dominate GMC formation??**
- **Multiple episodes of compression (overlapping shocks)**
- **Magnetic pressure overcome where field fortuitously aligned or where already-dense material is compressed further**



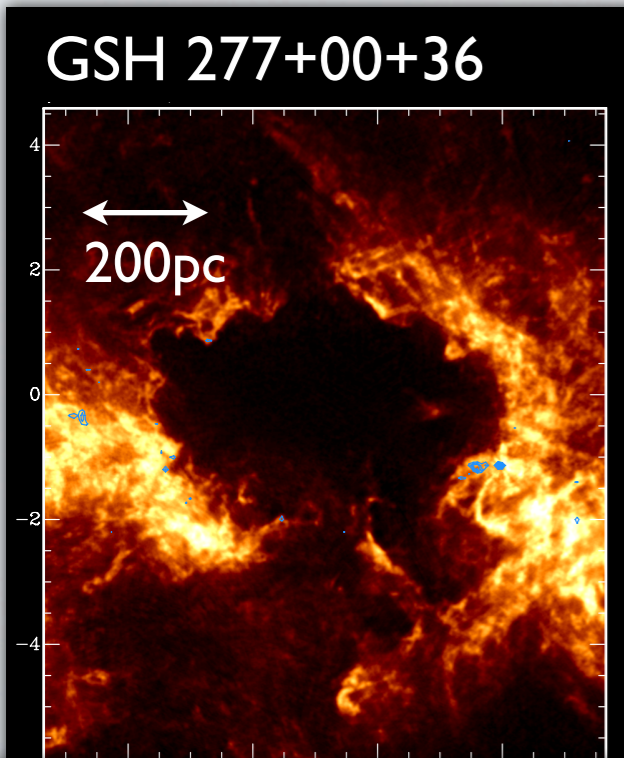
Quantifying Molecular Gas Production



$$\frac{[f_{mol}]_{shell}}{[f_{mol}]_{backgr}} = 3.5 \pm 1.0$$



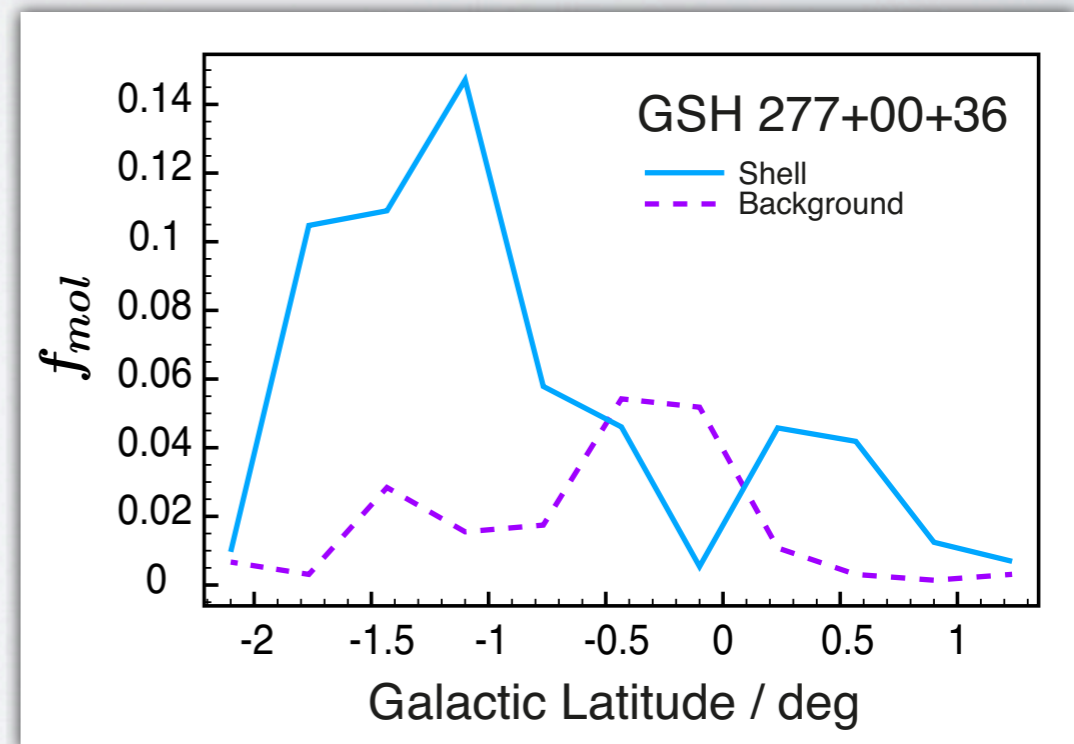
Dawson et al. (2011a)



$$\frac{[f_{mol}]_{shell}}{[f_{mol}]_{backgr}} = 2.0 \pm 0.5$$

“3D” analysis of molecular fraction in shell volumes vs control zones:

Supershell volumes are more molecular

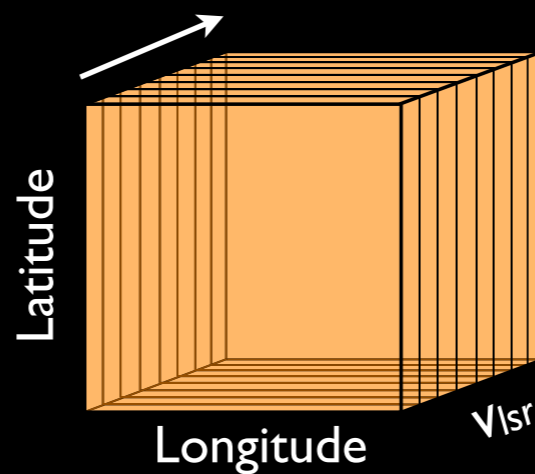
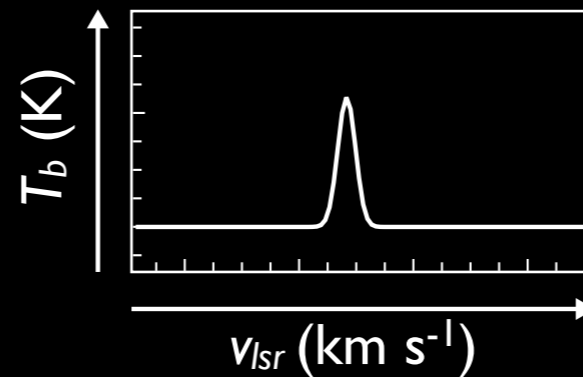
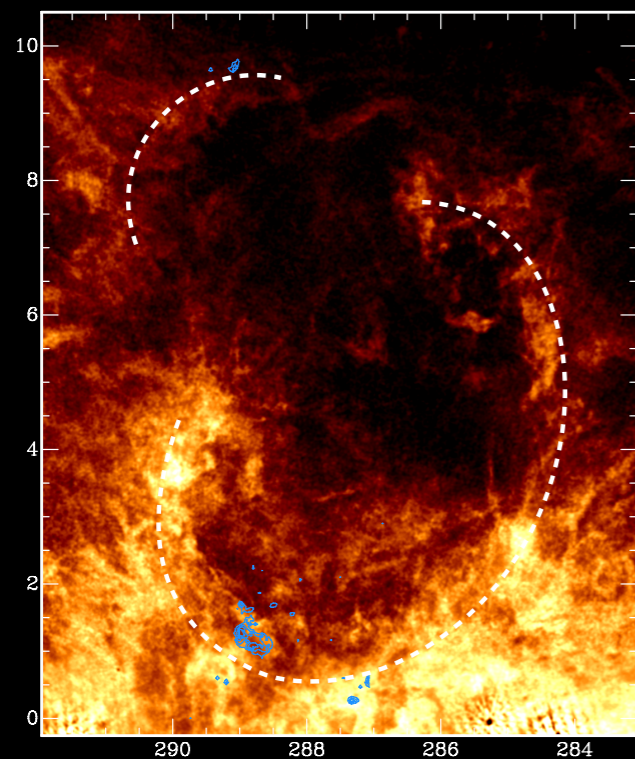


Colour: HI 21cm (ATCA+Parkes)
Contours: $^{12}\text{CO}(J=1-0)$ (NANTEN)

Zooming into Shell Walls

Colour: HI 21cm (ATCA+Parkes)
Contours: $^{12}\text{CO}(J=1-0)$ (NANTEN)

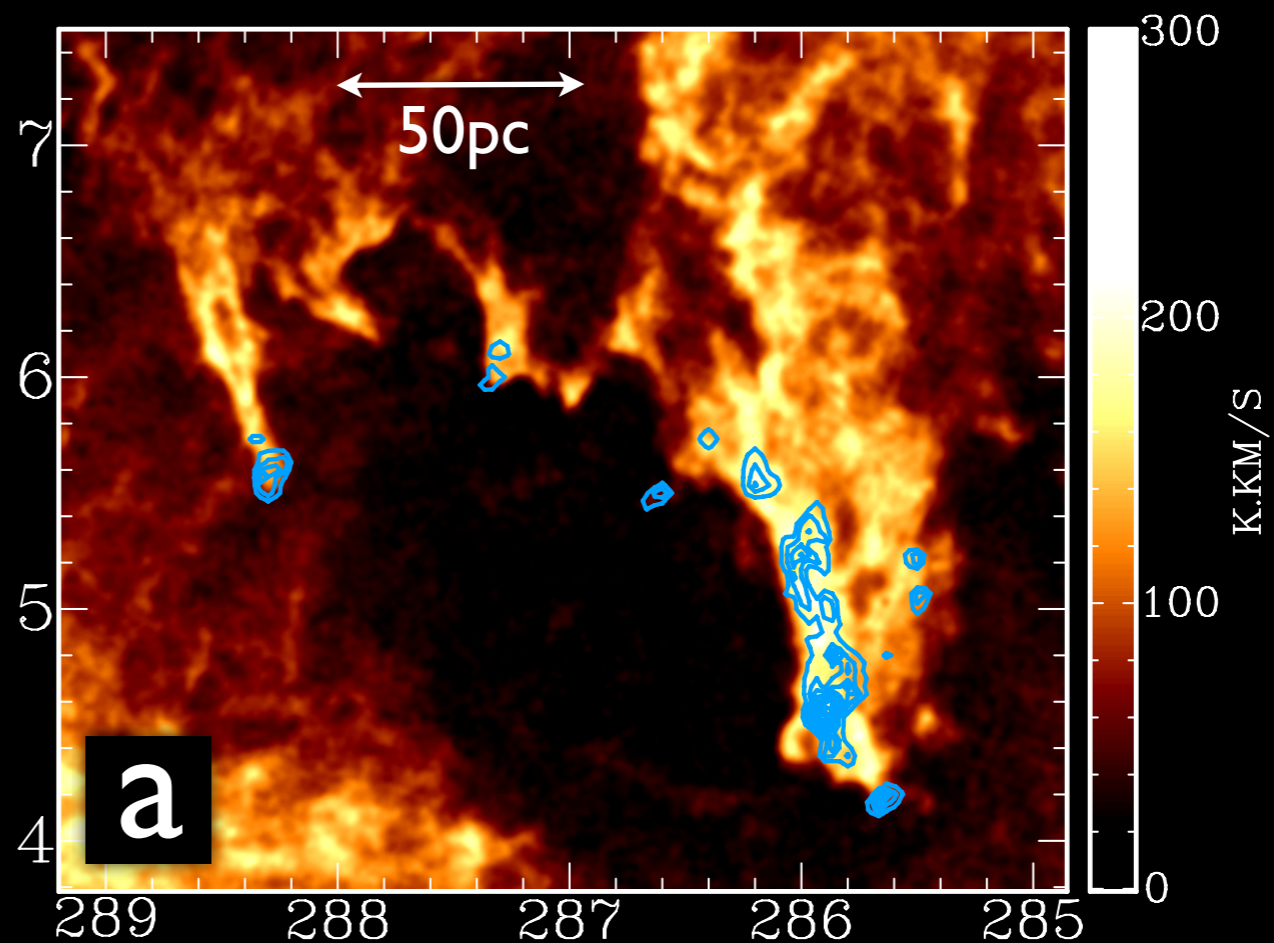
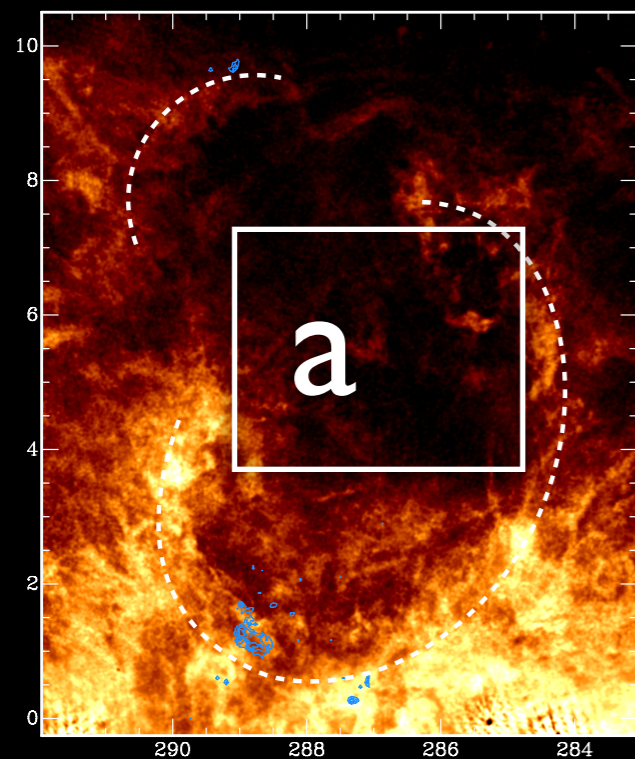
GSH 287+04-17



Zooming into Shell Walls

Colour: HI 21cm (ATCA+Parkes)
Contours: $^{12}\text{CO}(J=1-0)$ (NANTEN)

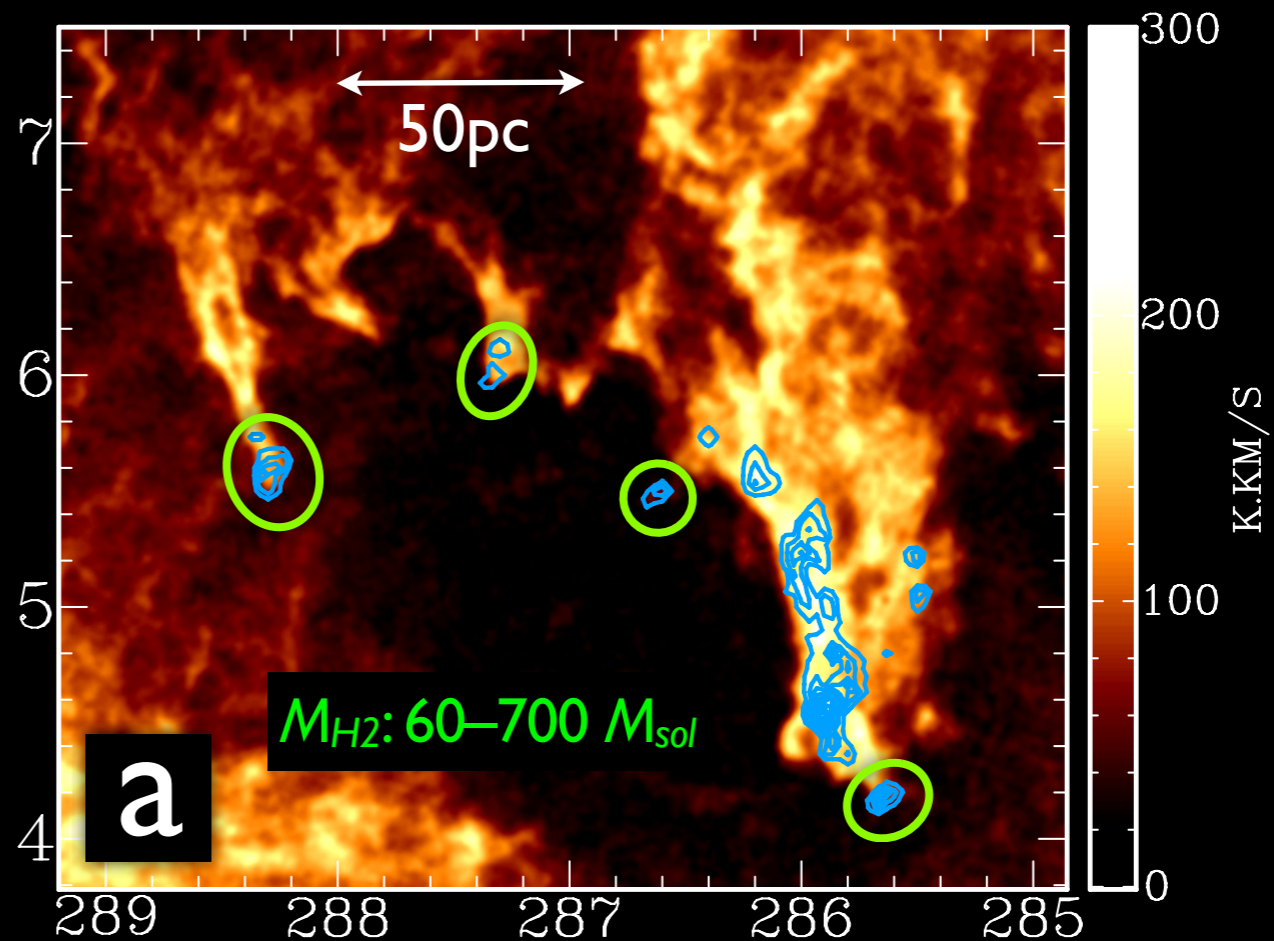
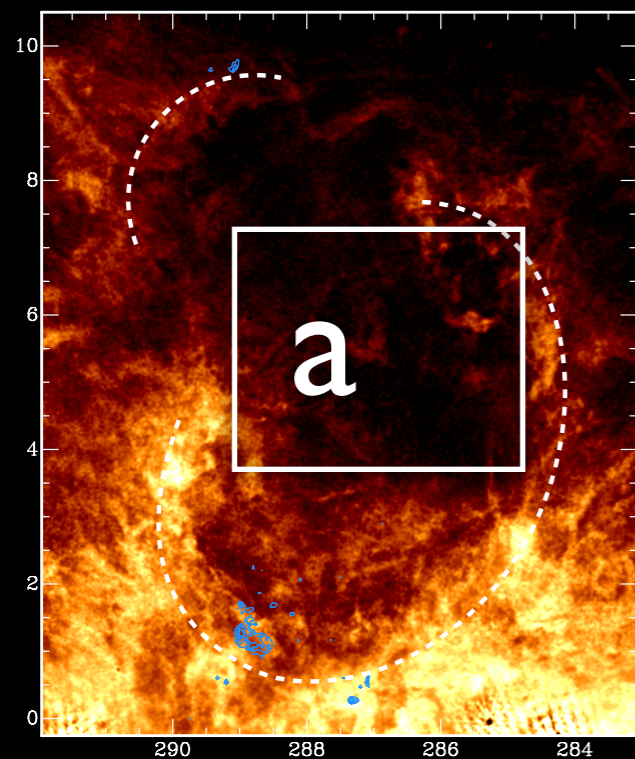
GSH 287+04-17



Zooming into Shell Walls

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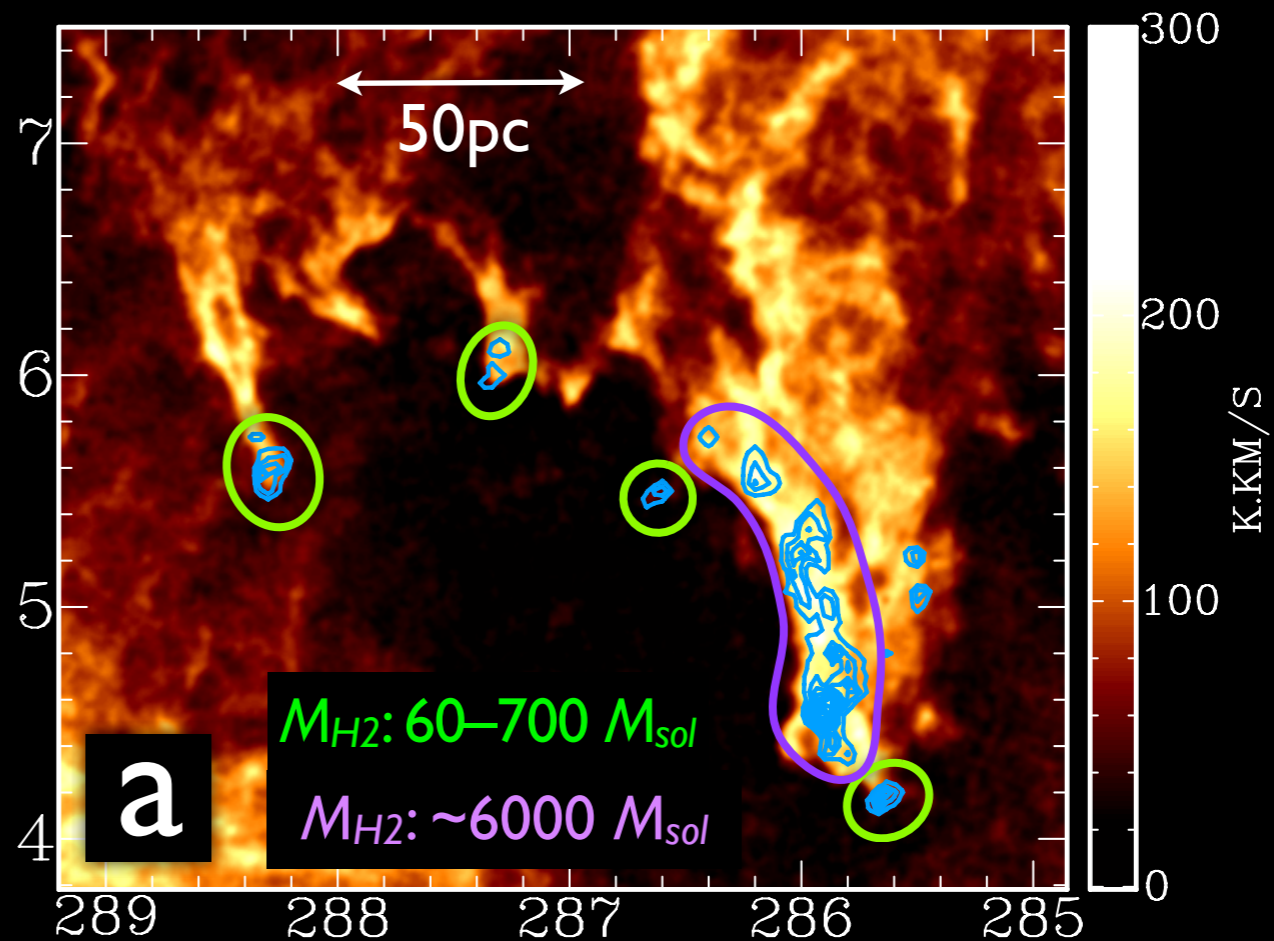
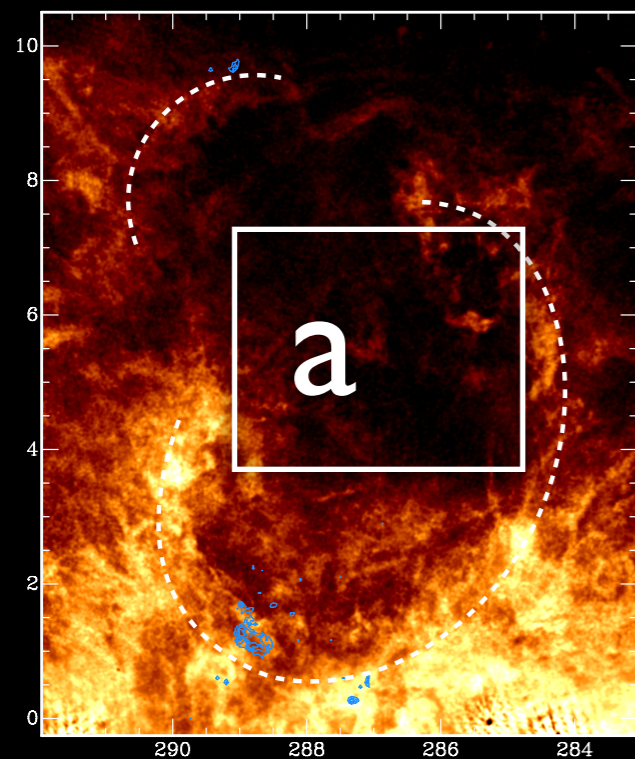
GSH 287+04-17



Zooming into Shell Walls

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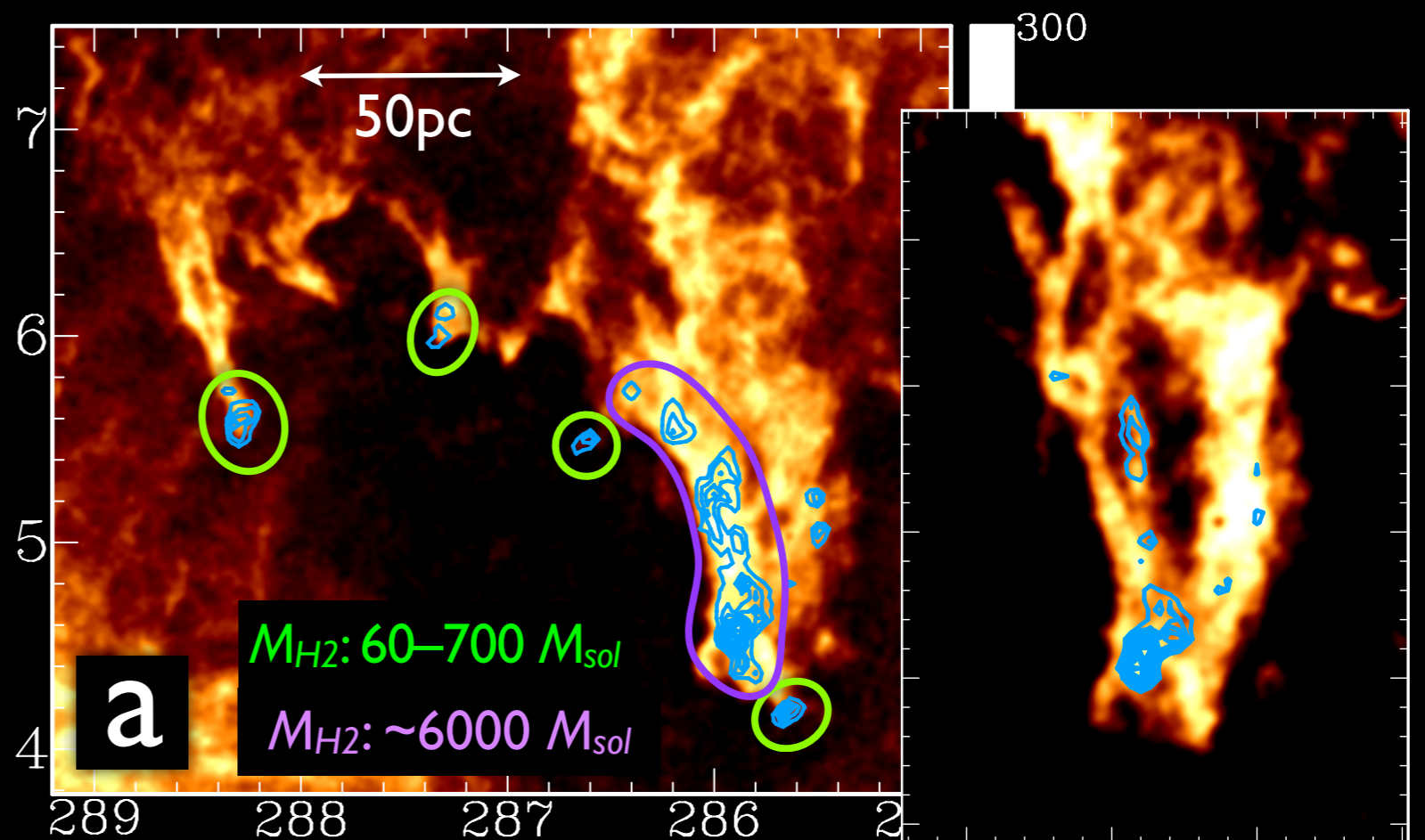
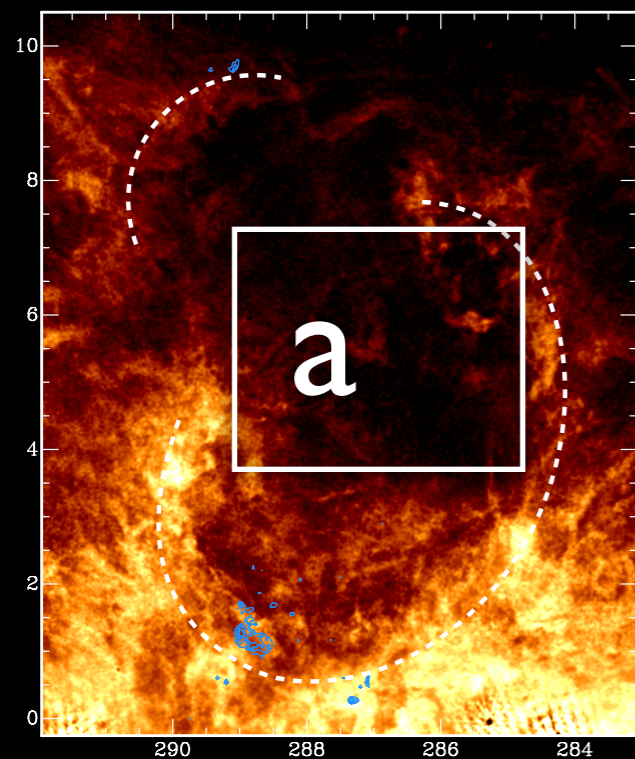
GSH 287+04-17



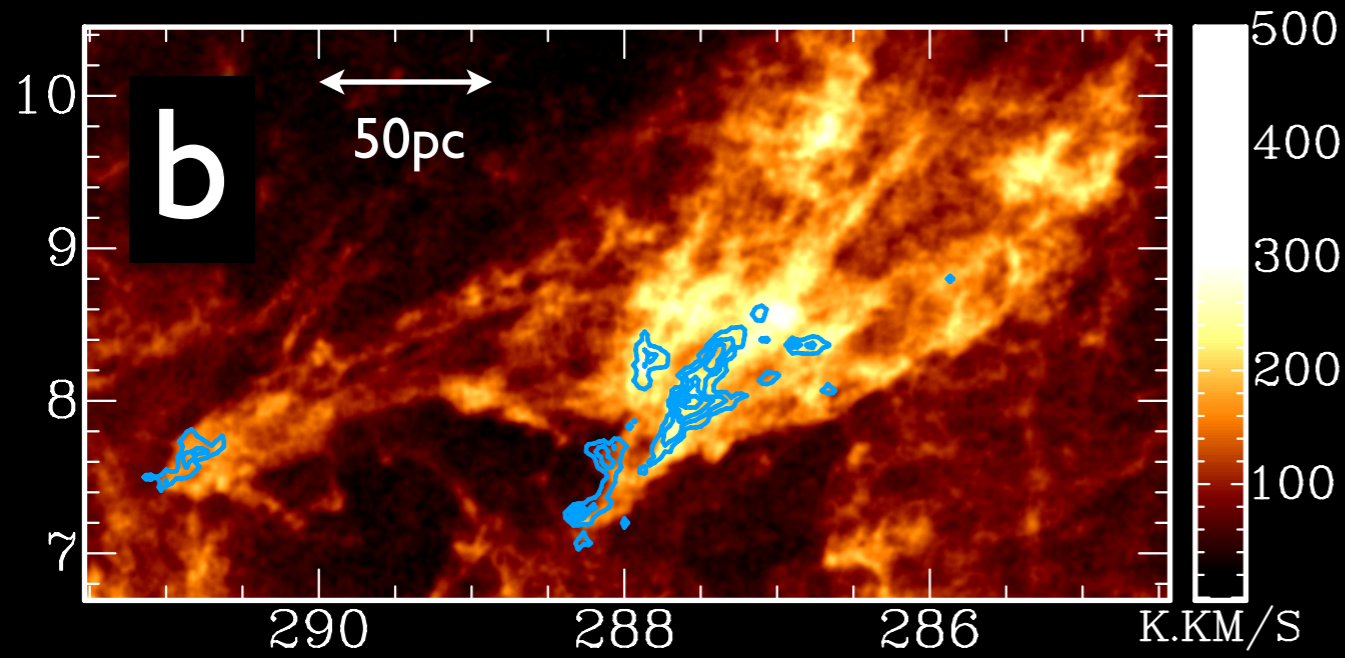
Zooming into Shell Walls

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Contours: $^{12}\text{CO}(J=1-0)$ (NANTEN)

GSH 287+04-17

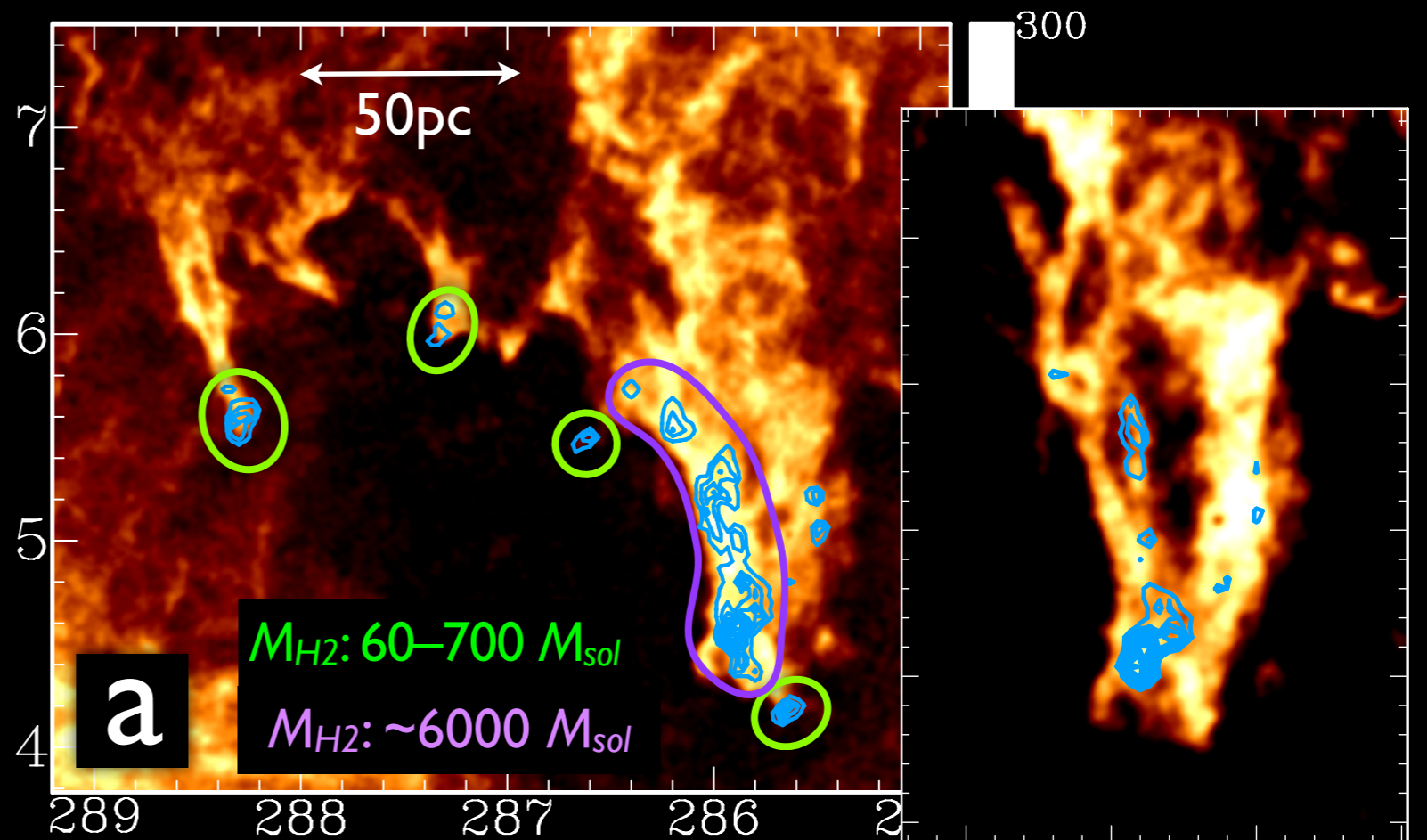
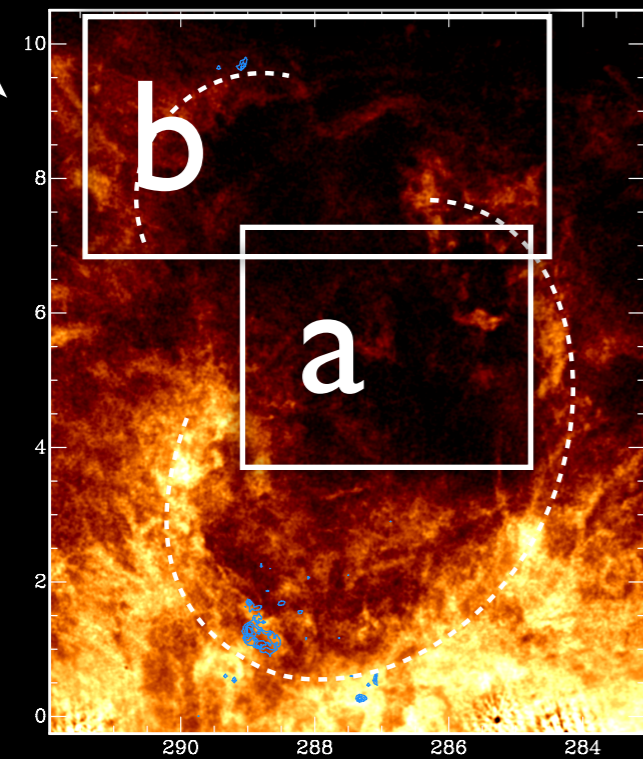


Zooming into Shell Walls

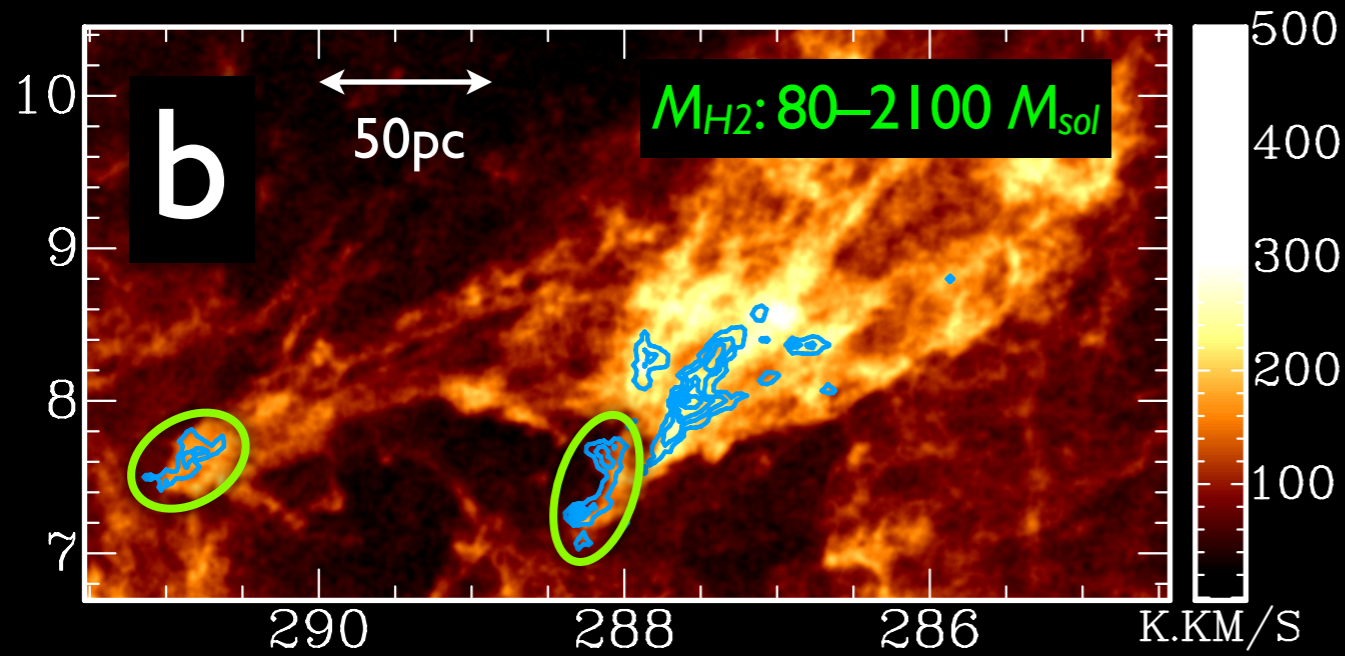


GSH 287+04-17

$z = 450$ pc

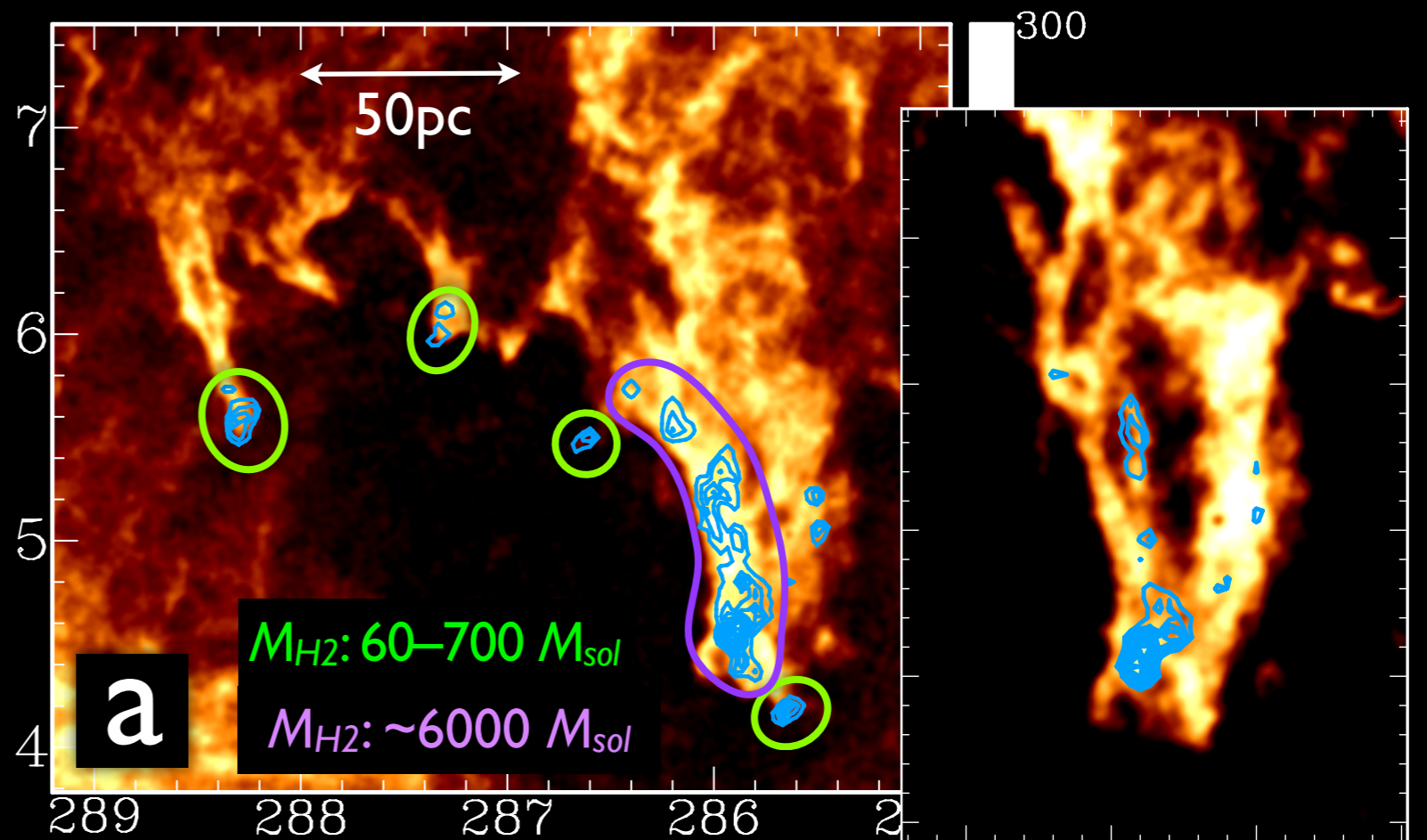
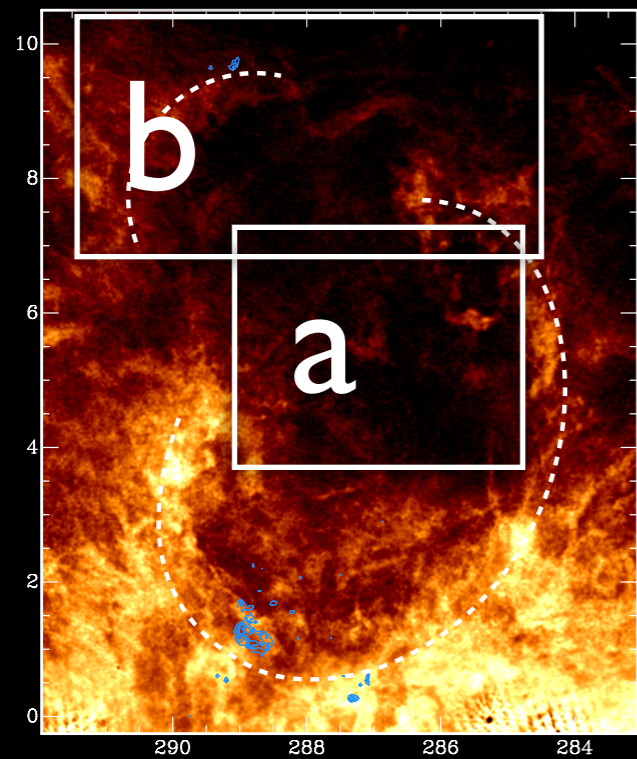


Zooming into Shell Walls

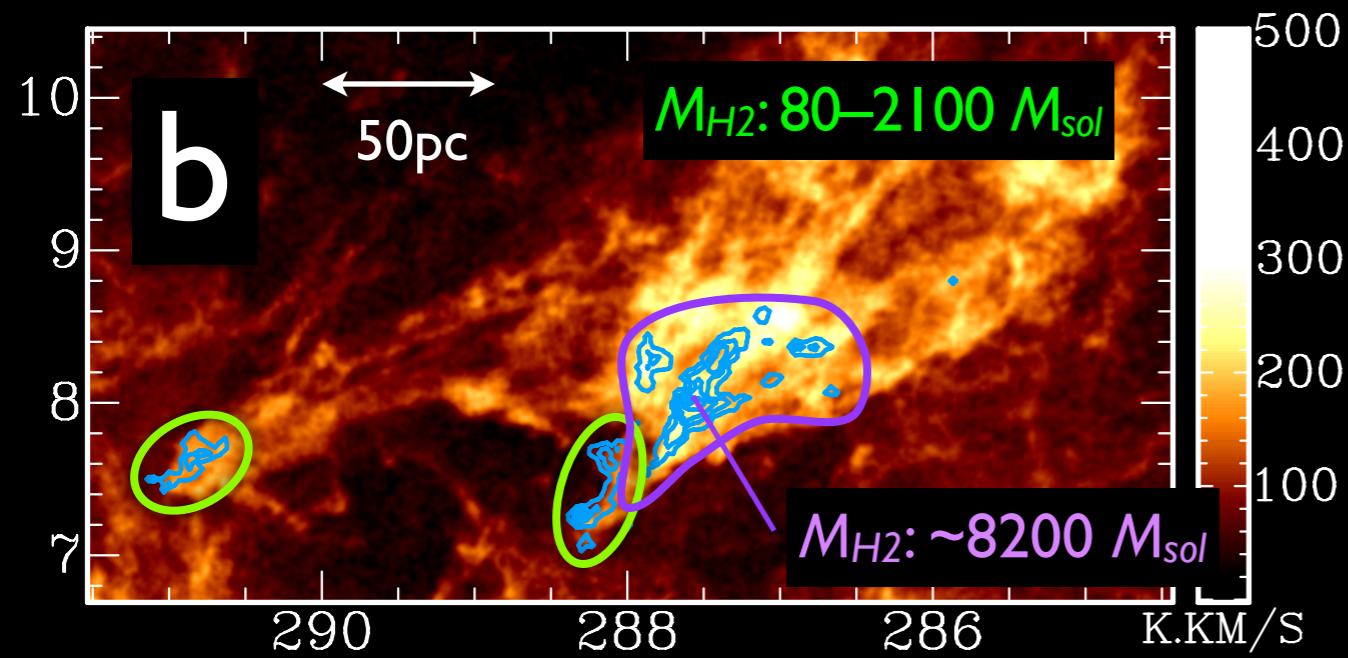


GSH 287+04-17

$z = 450 \text{ pc}$

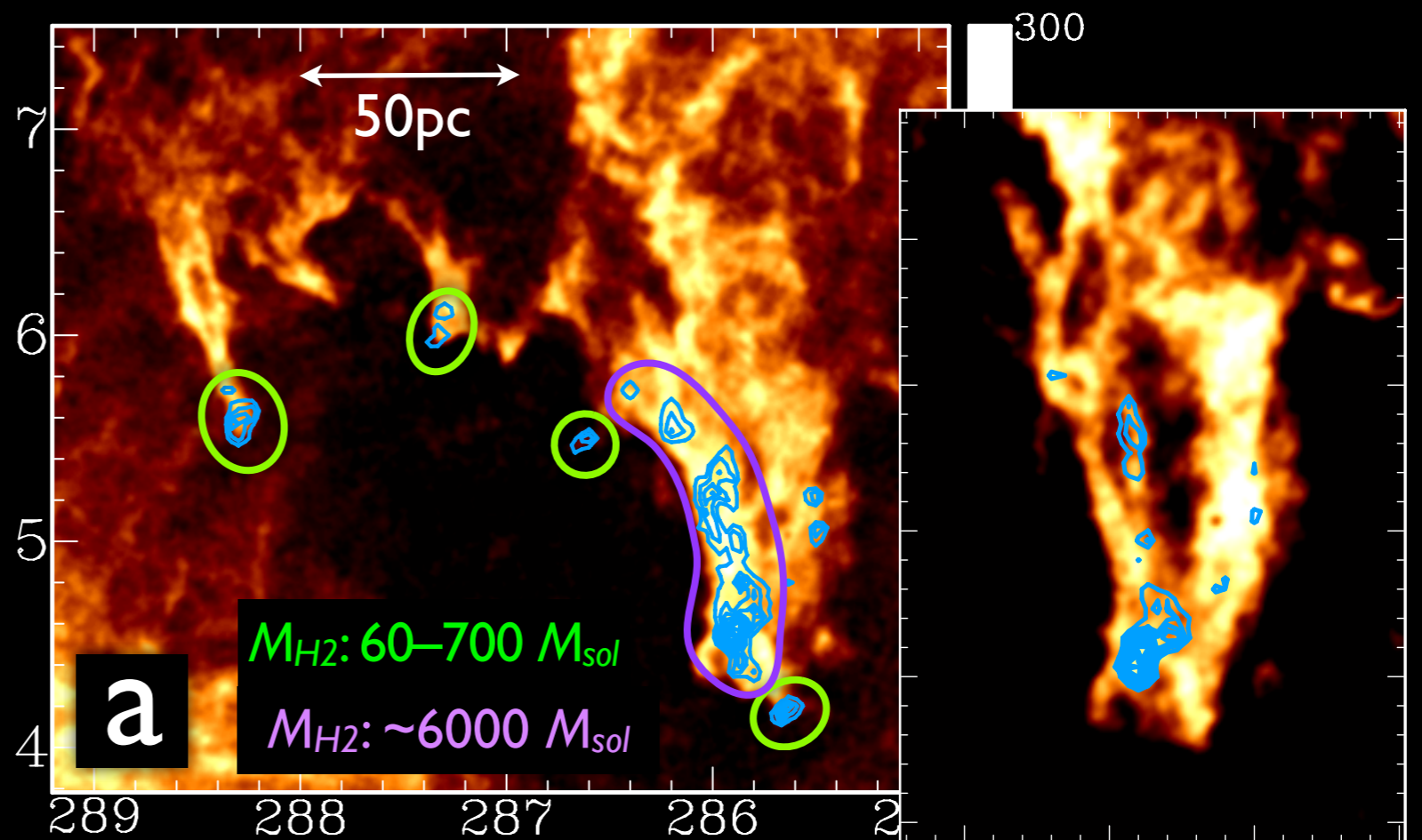
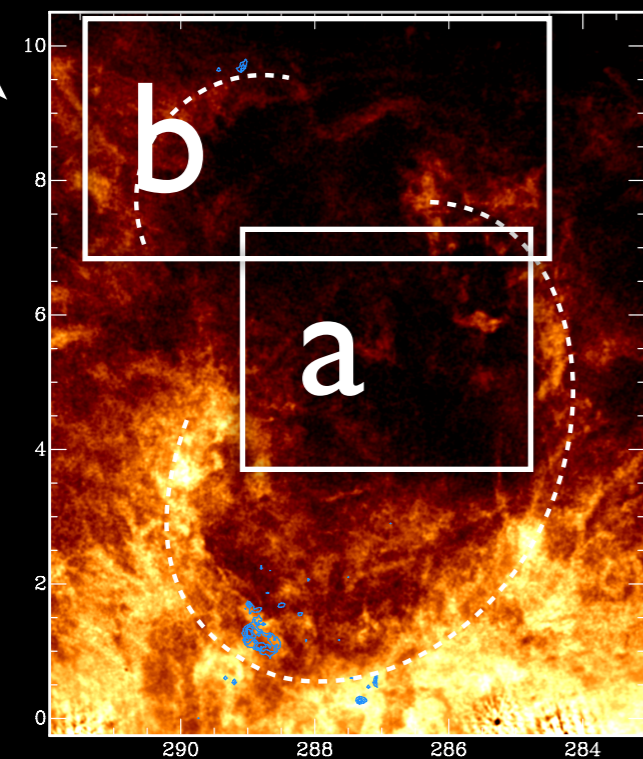


Zooming into Shell Walls

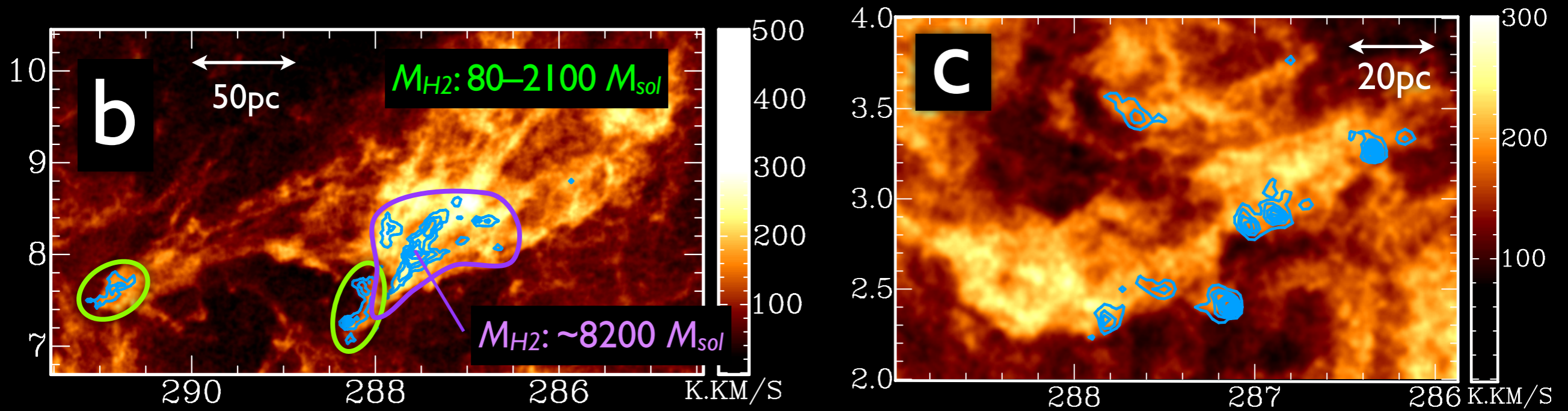


GSH 287+04-17

$z = 450 \text{ pc}$

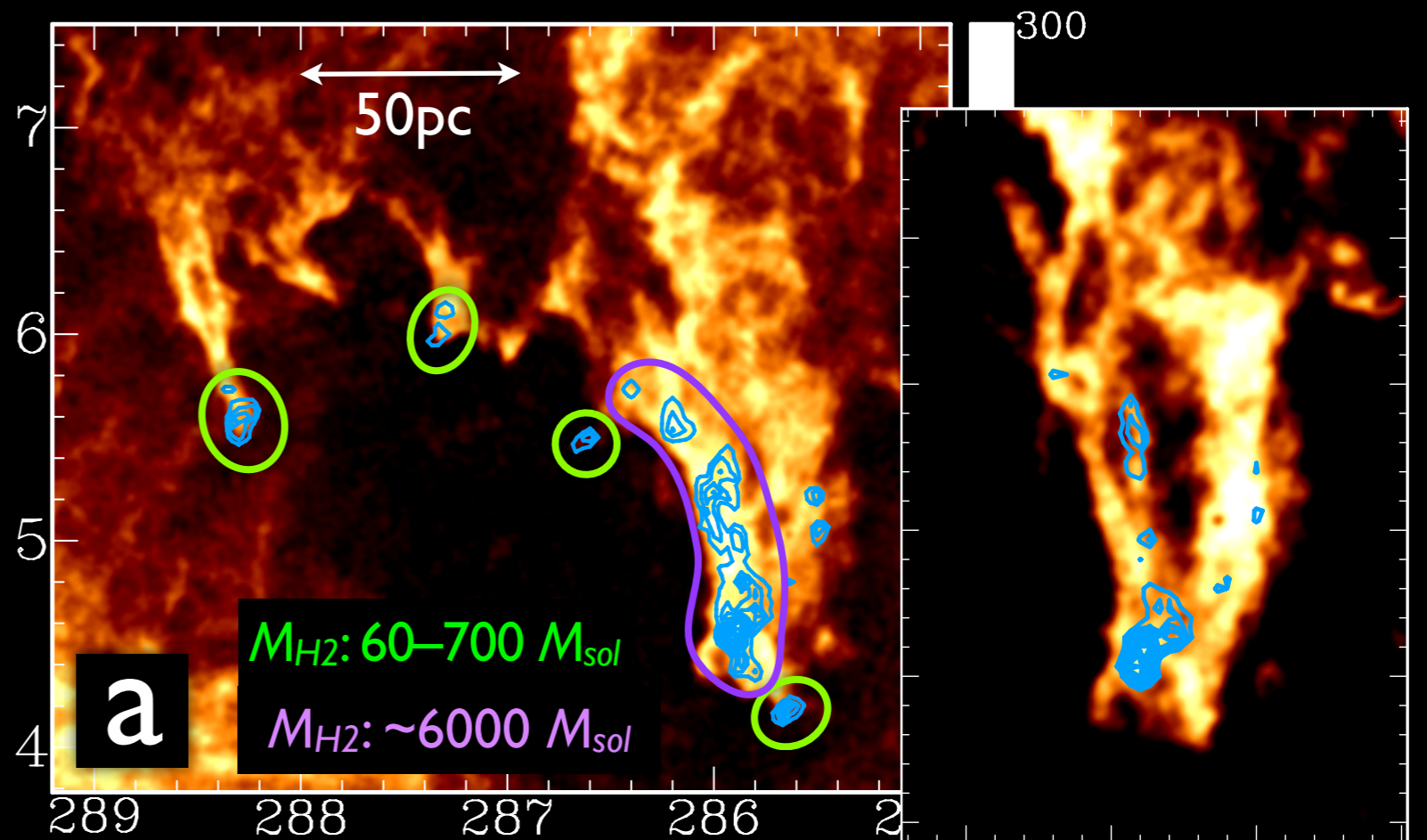
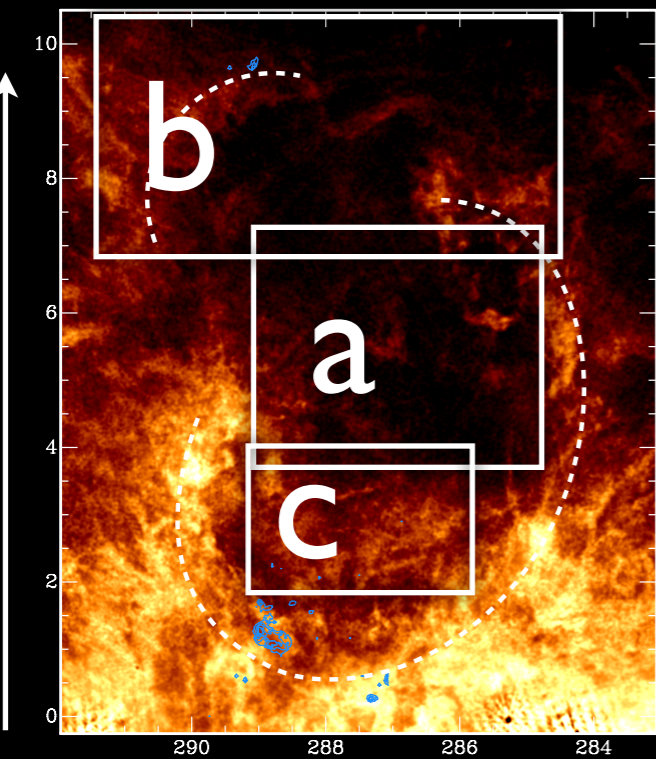


Zooming into Shell Walls



GSH 287+04-17

$z = 450 \text{ pc}$

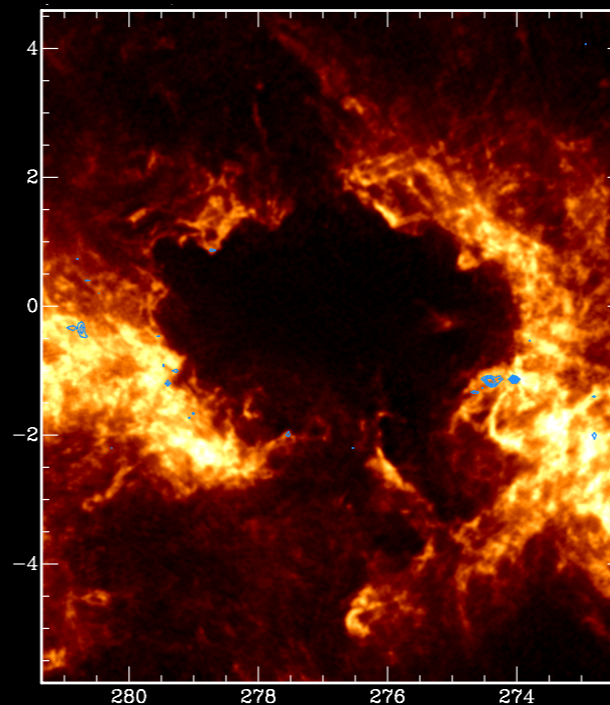


Zooming into Shell Walls

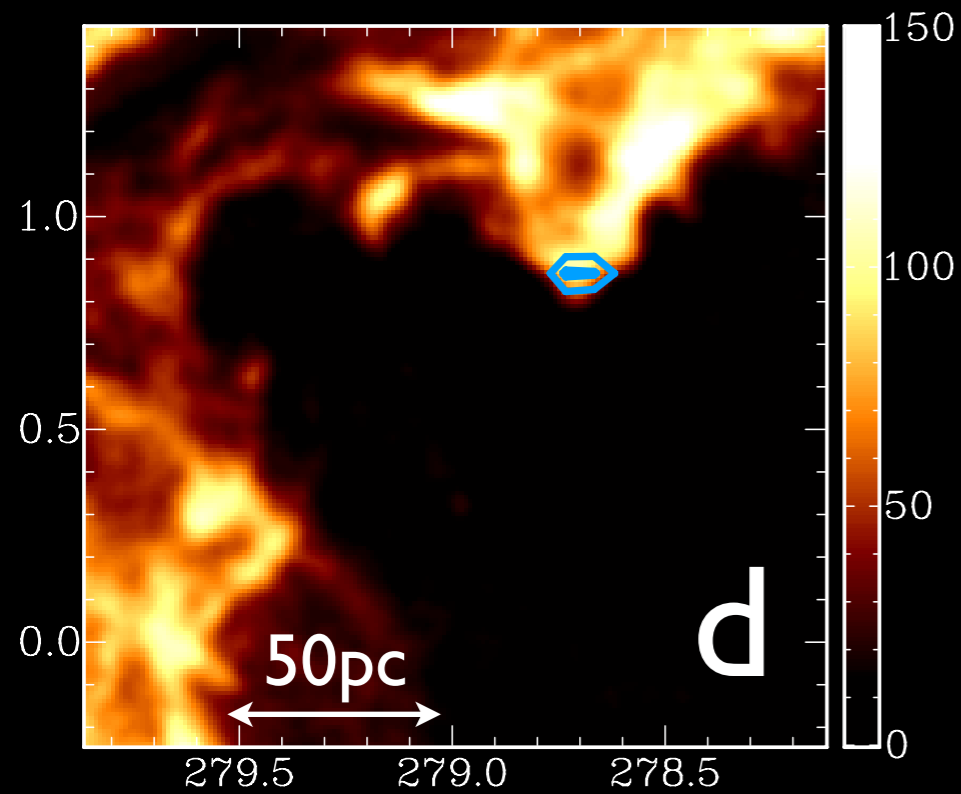
Colour: HI 21 cm (ATCA+Parkes)

Contours: $^{12}\text{CO}(J=1-0)$ (NANTEN)

GSH 277+00+36

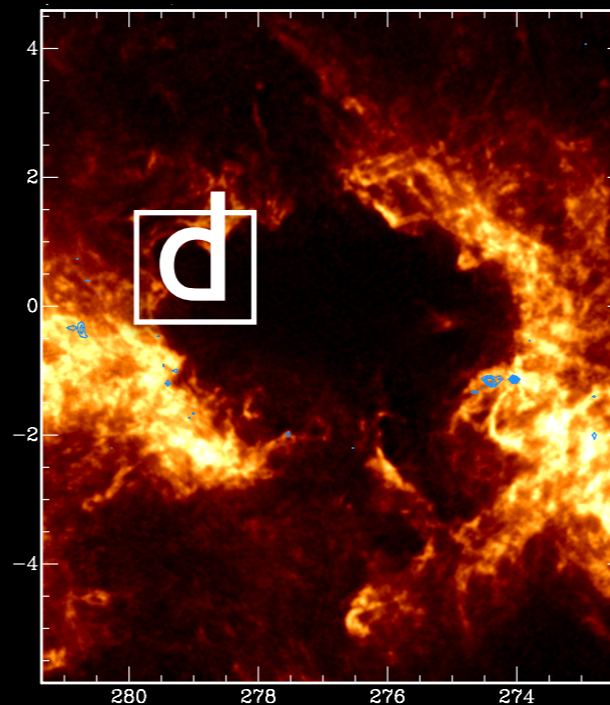


Zooming into Shell Walls

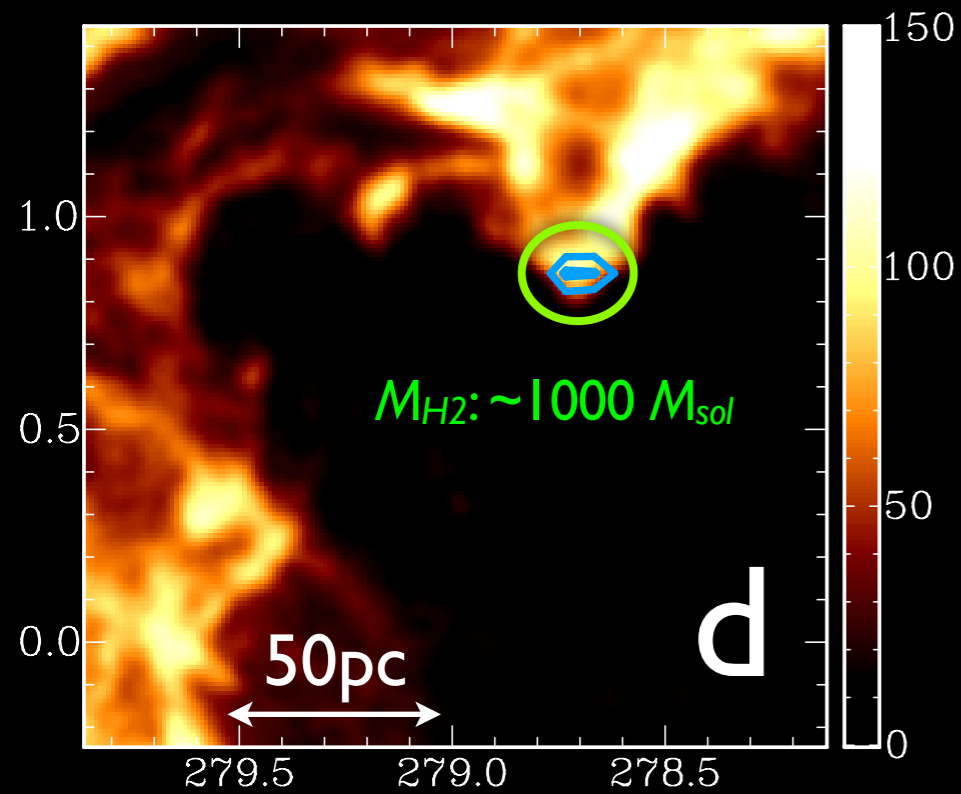


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Contours: $^{12}\text{CO}(J=1-0)$ (NANTEN)

GSH 277+00+36

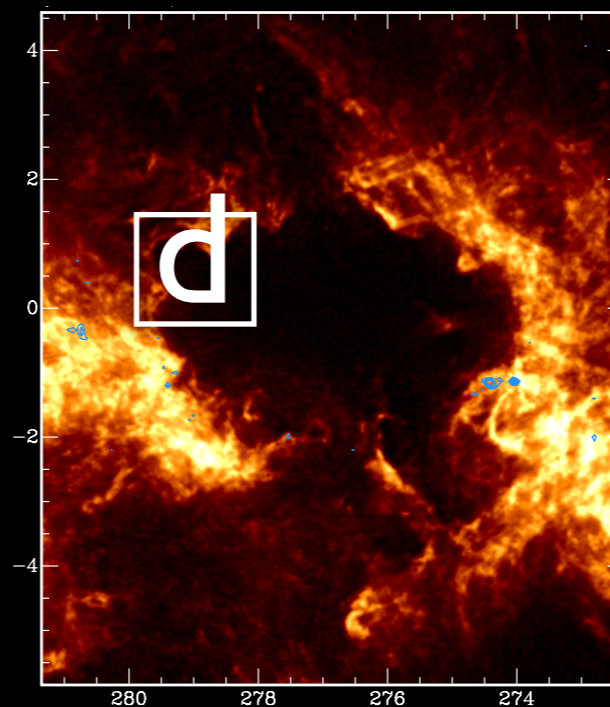


Zooming into Shell Walls

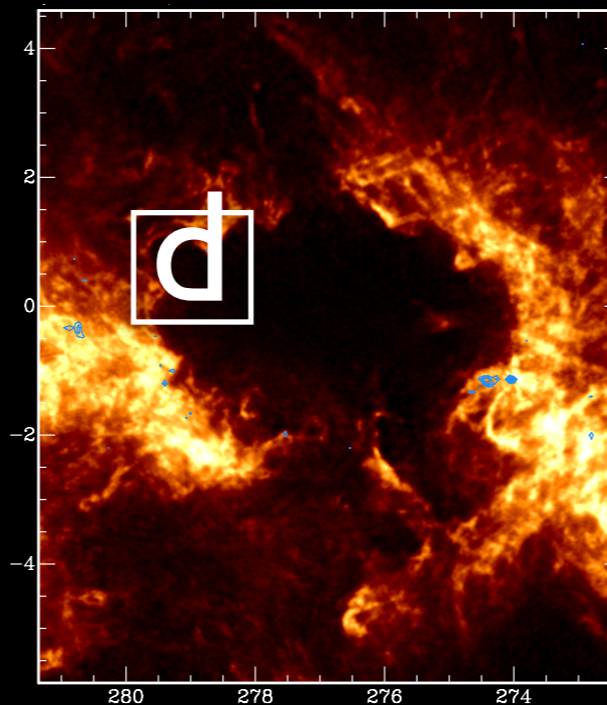
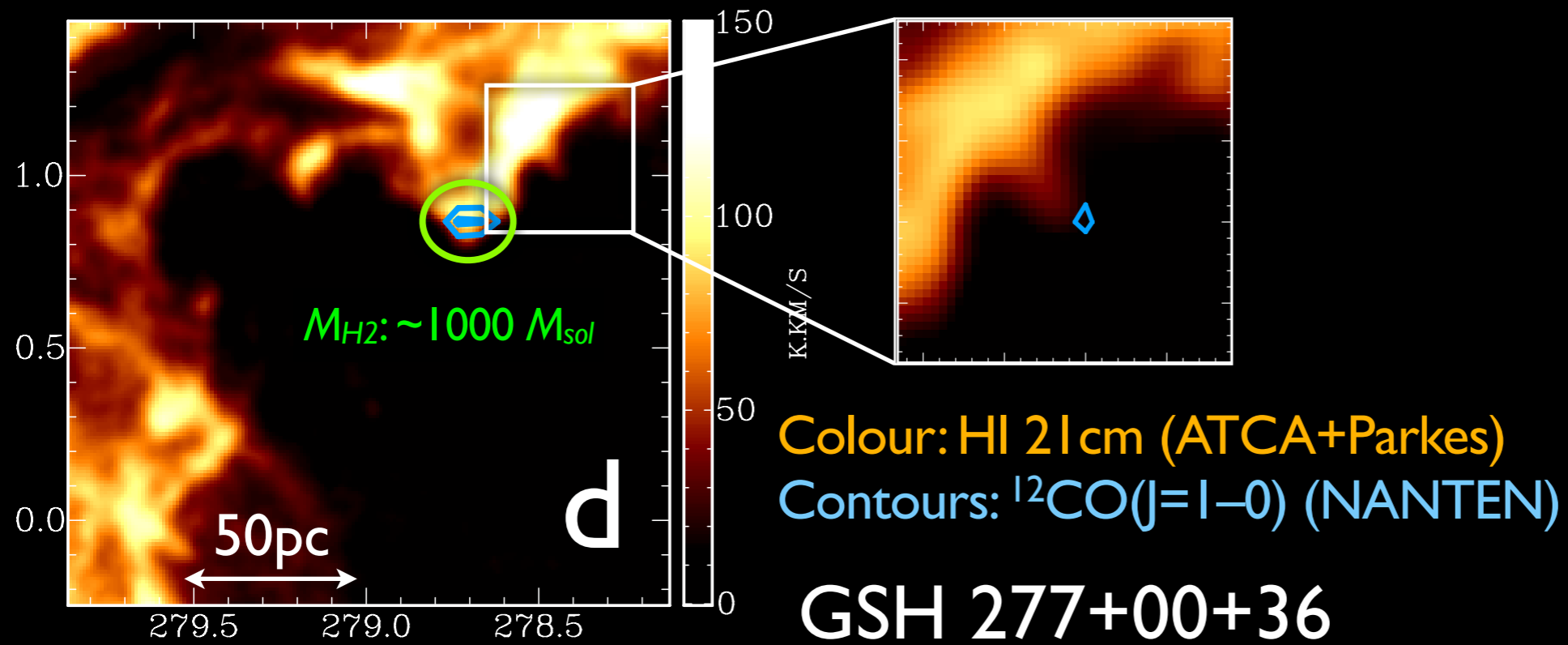


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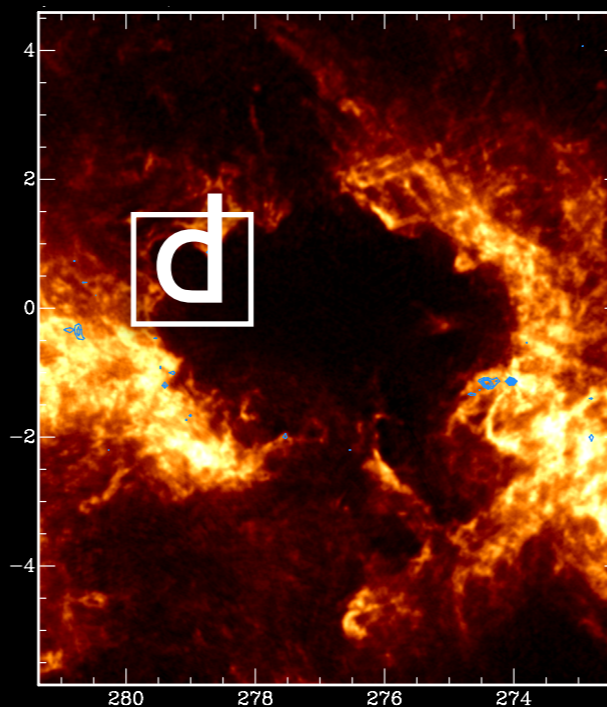
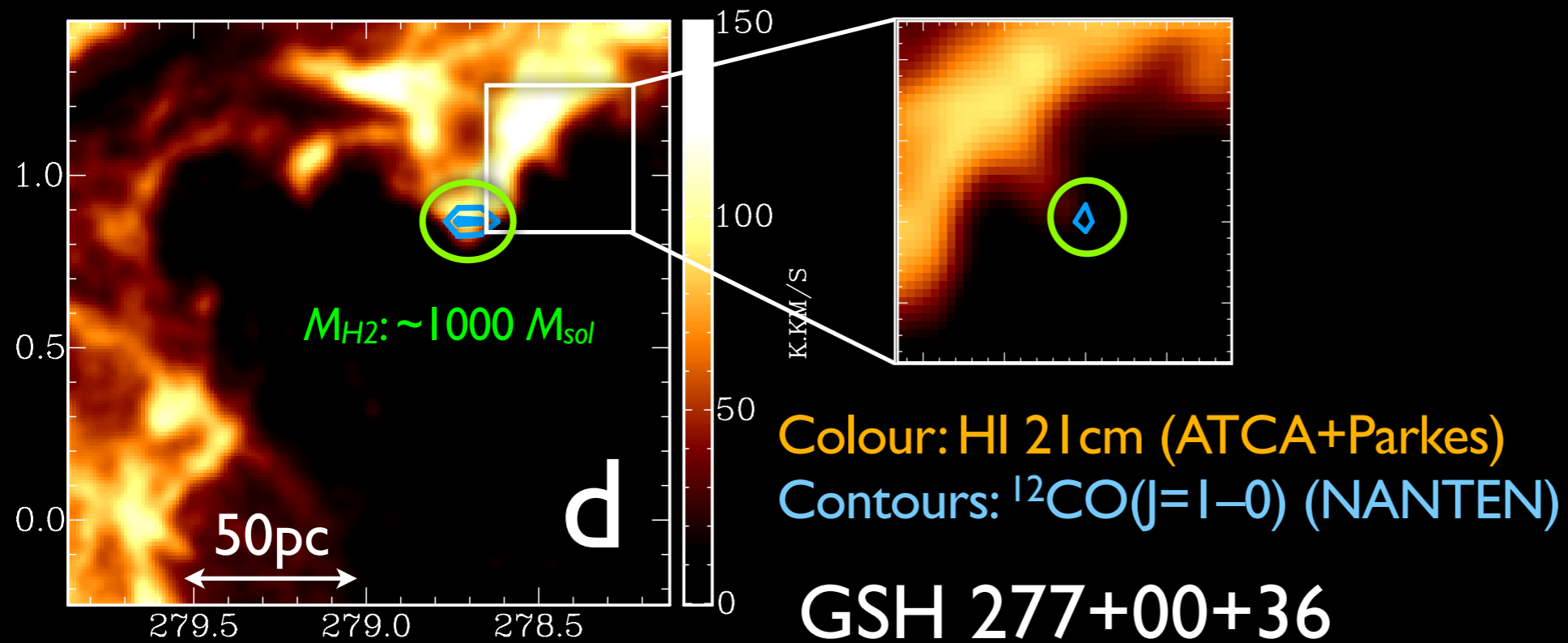
GSH 277+00+36



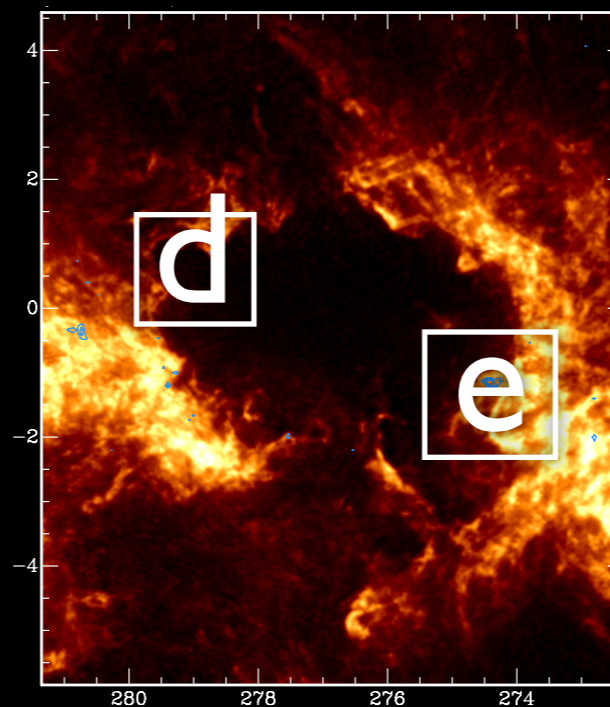
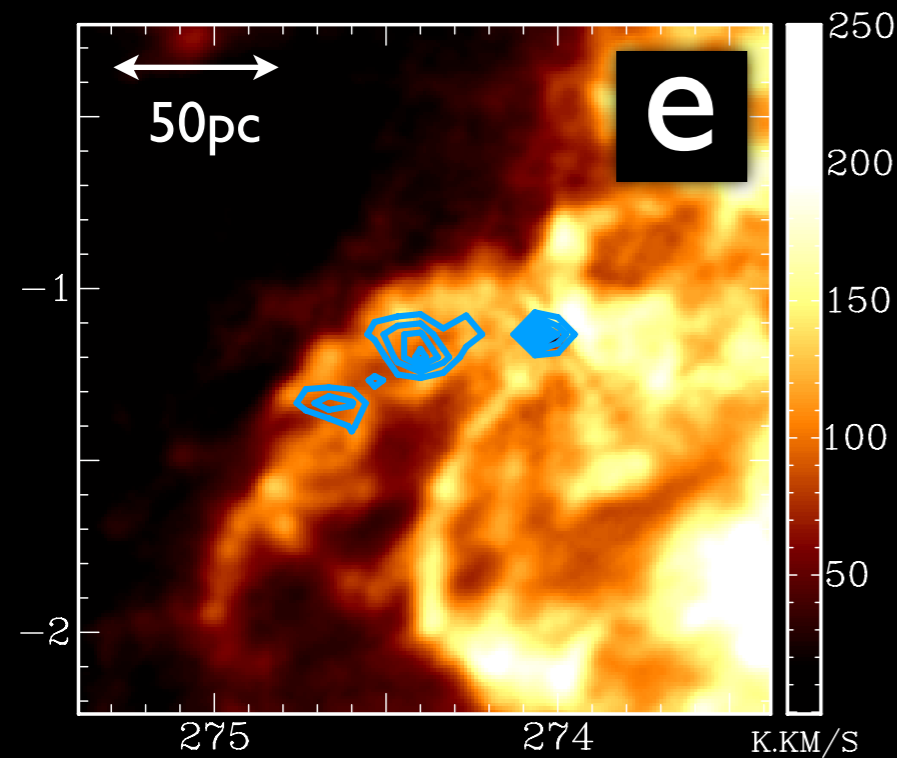
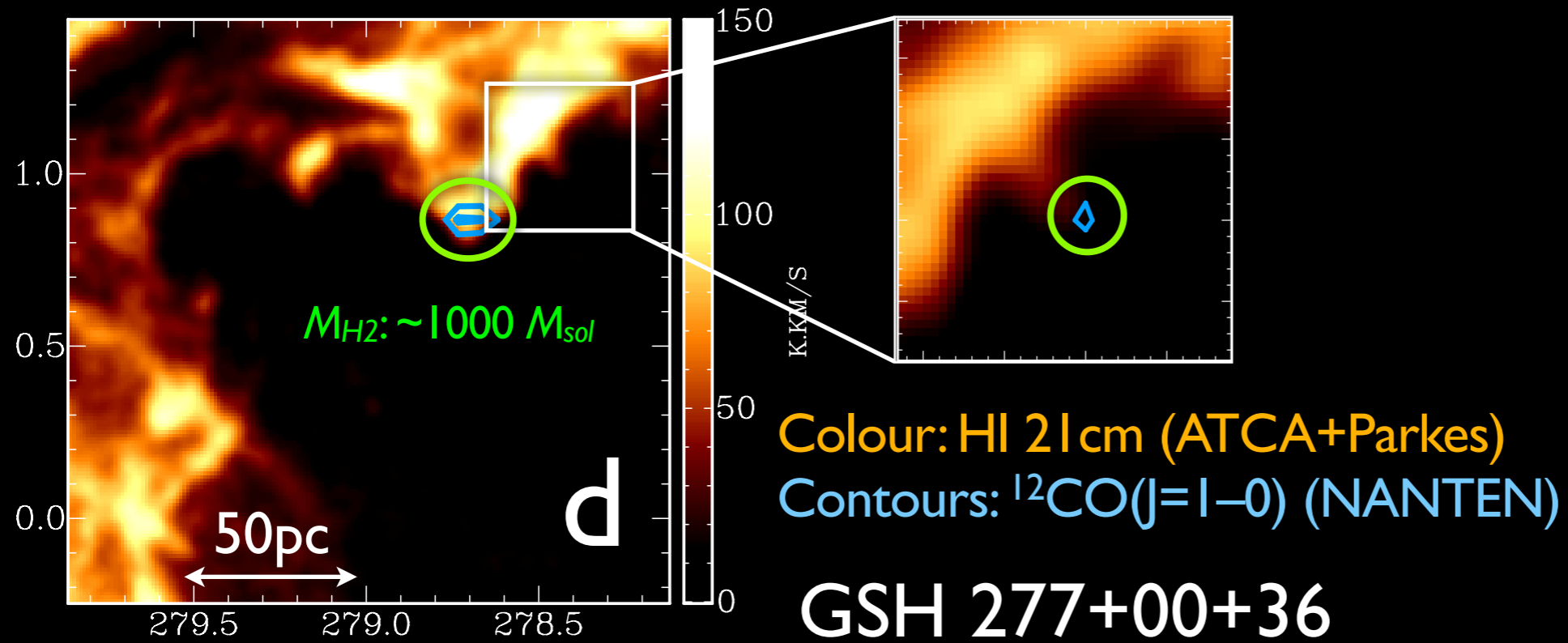
Zooming into Shell Walls



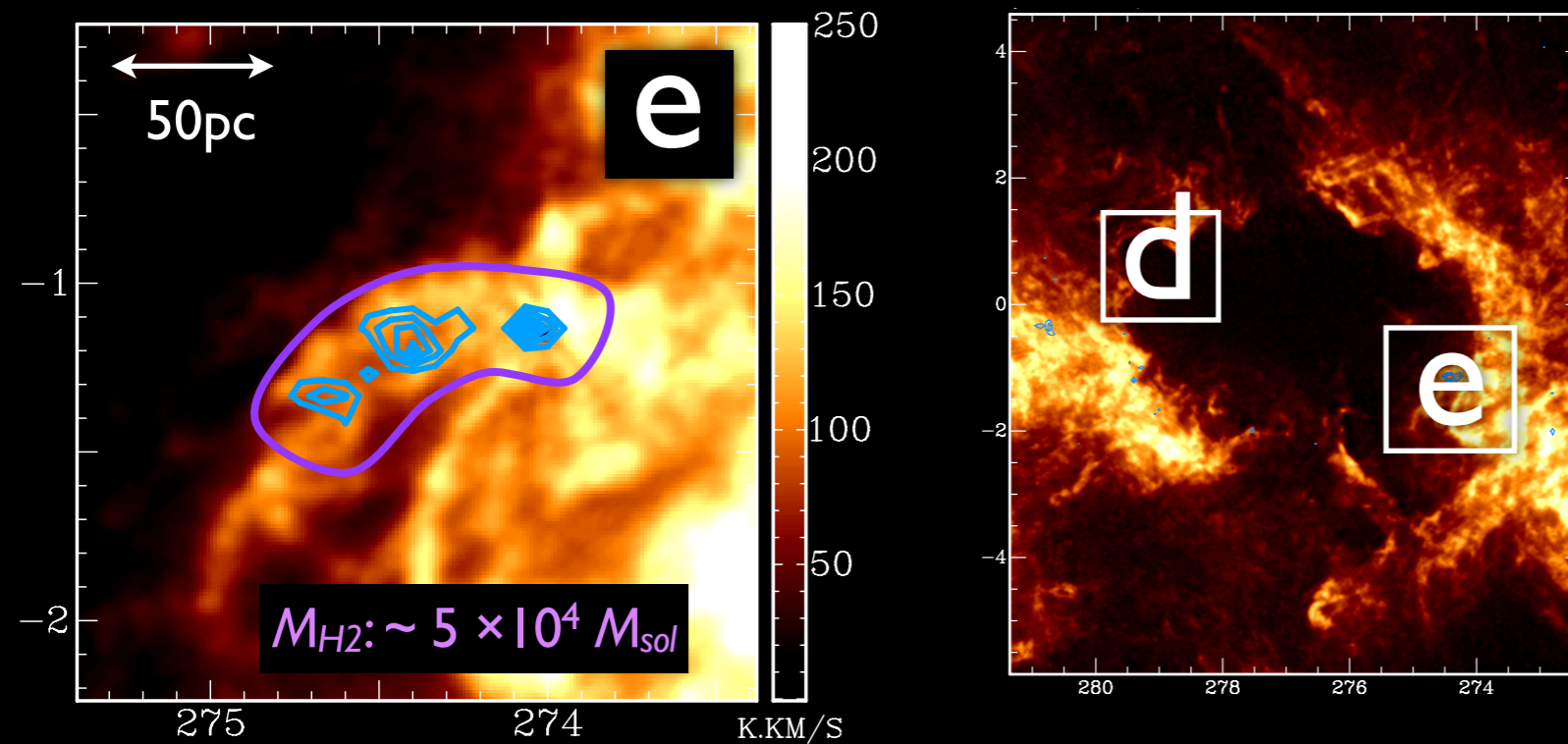
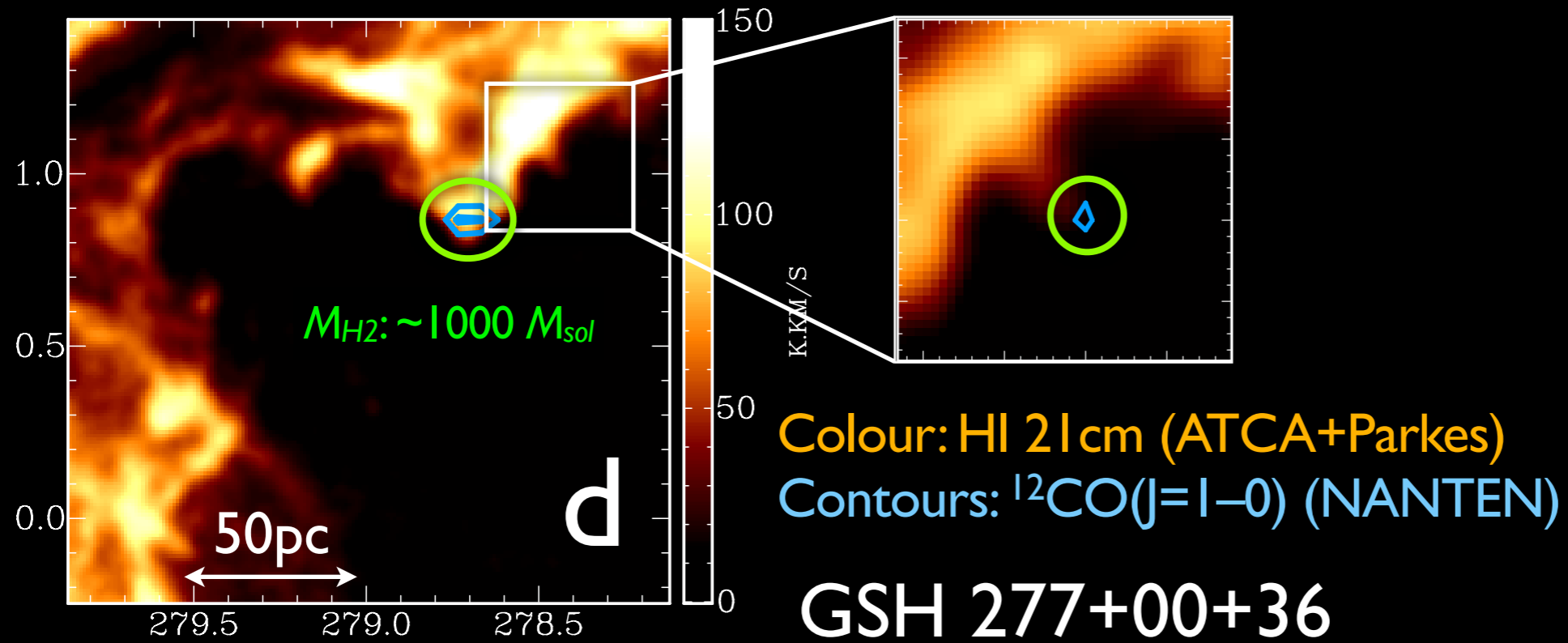
Zooming into Shell Walls



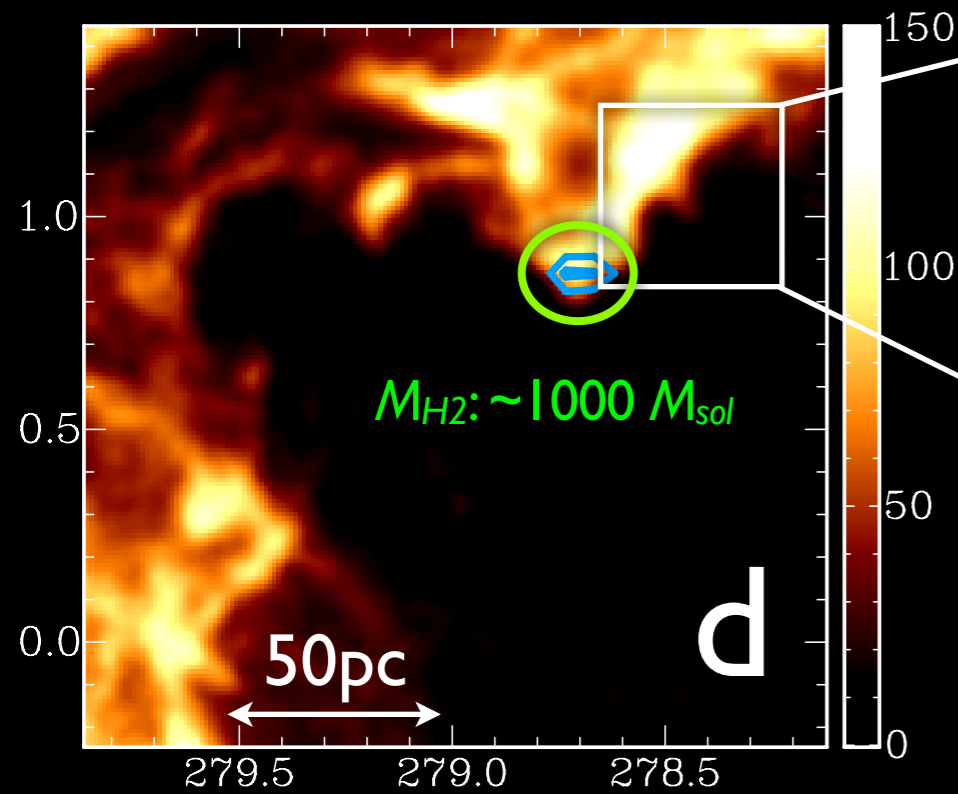
Zooming into Shell Walls



Zooming into Shell Walls

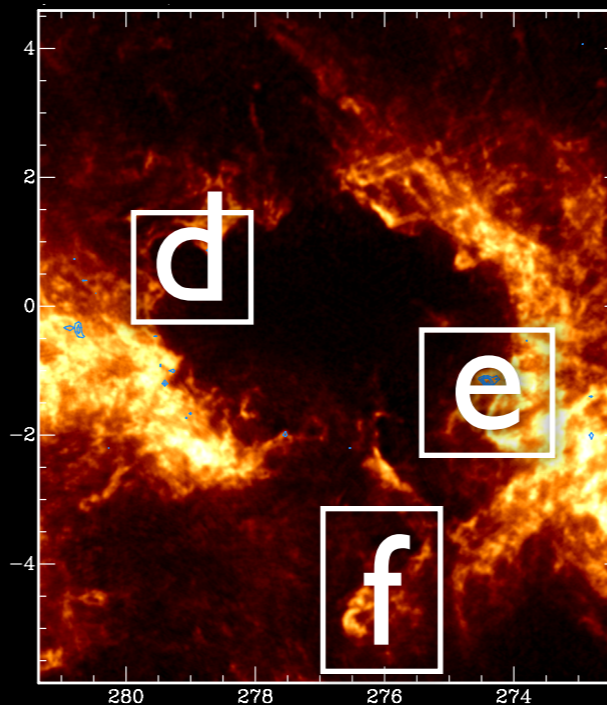
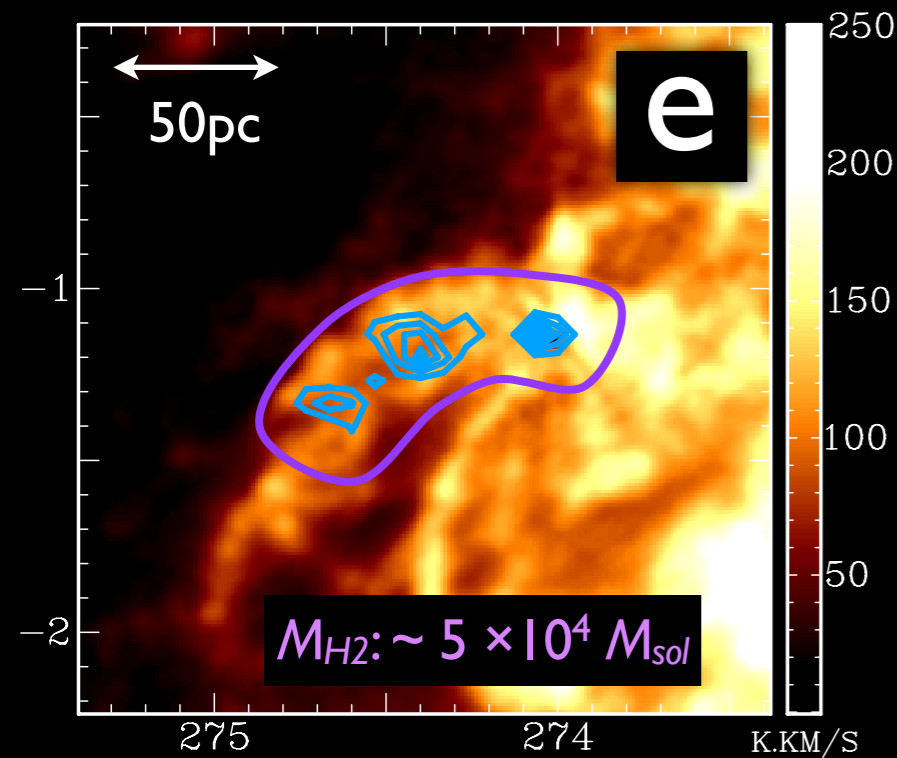


Zooming into Shell Walls

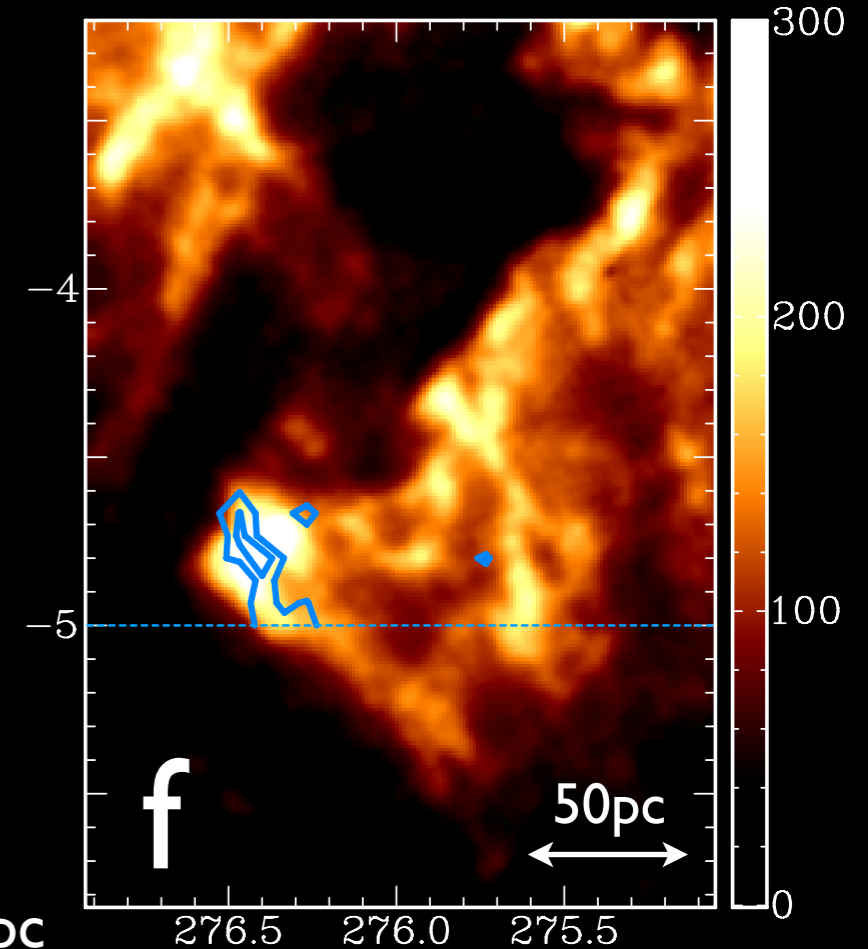


Colour: HI 21cm (ATCA+Parkes)
Contours: $^{12}CO(J=1-0)$ (NANTEN)

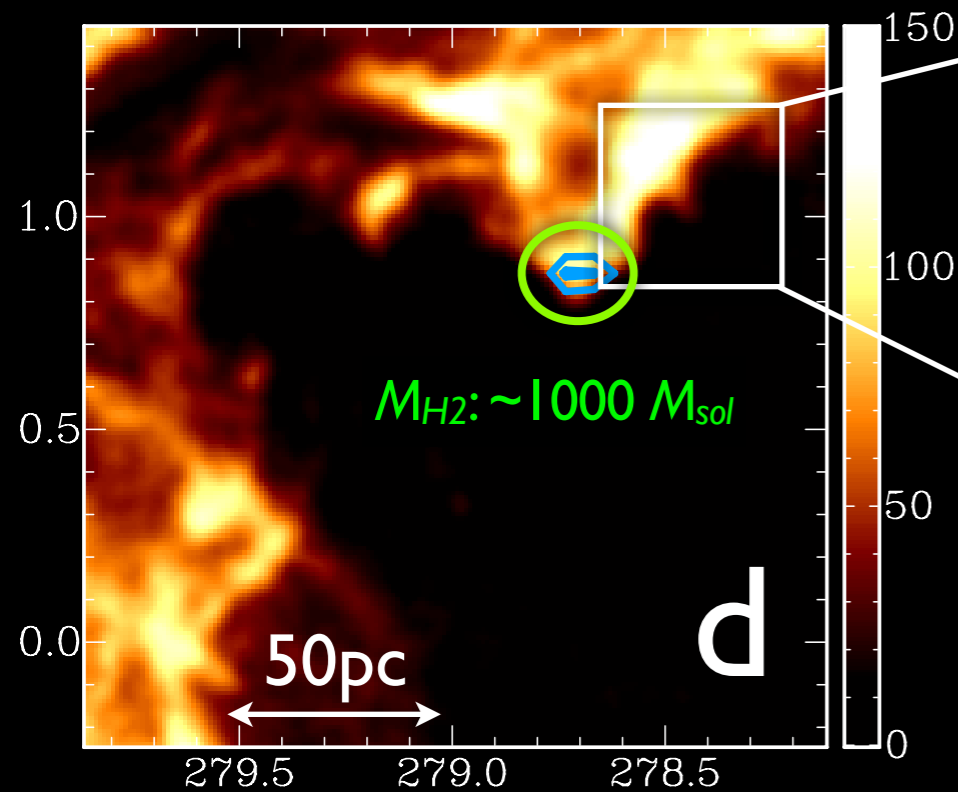
GSH 277+00+36



$z = 450 \text{ pc}$

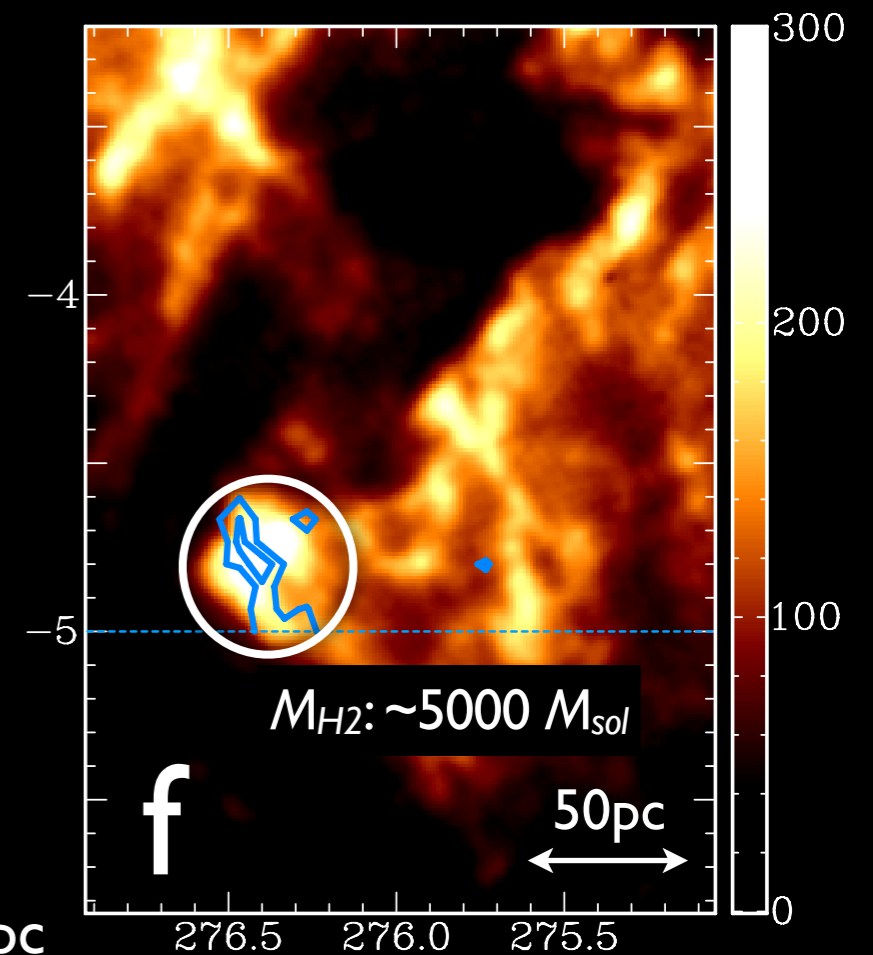
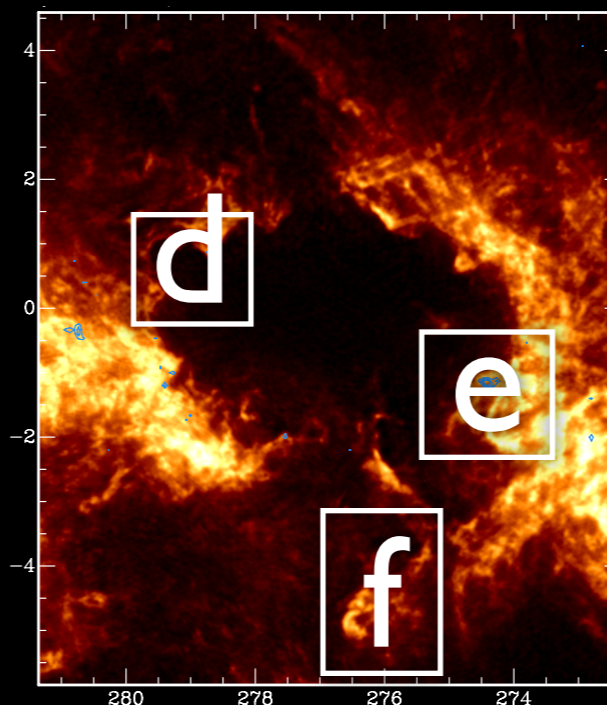
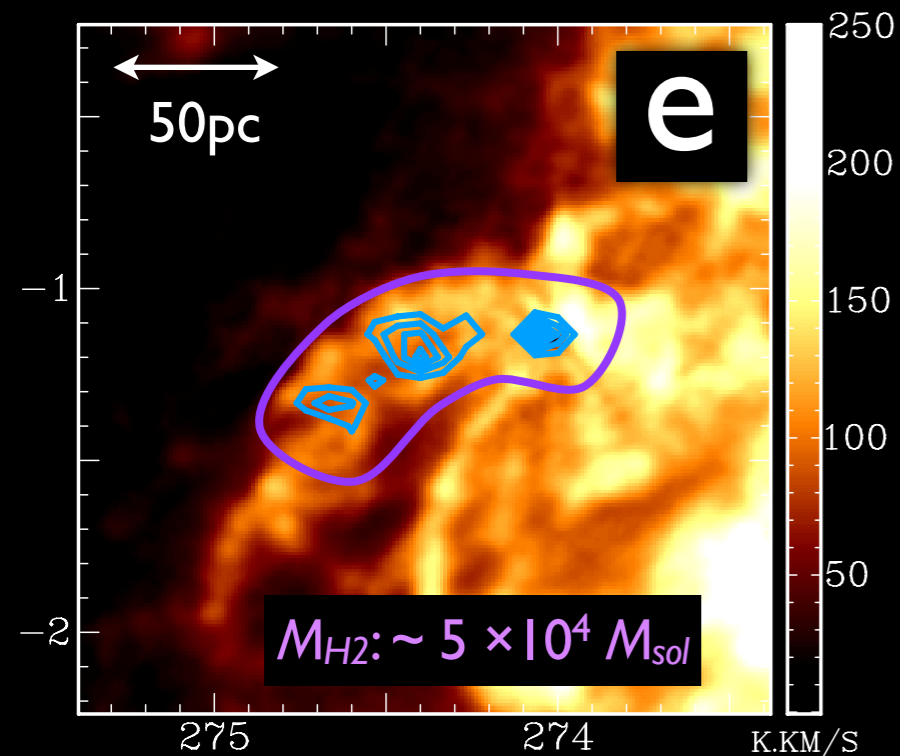


Zooming into Shell Walls

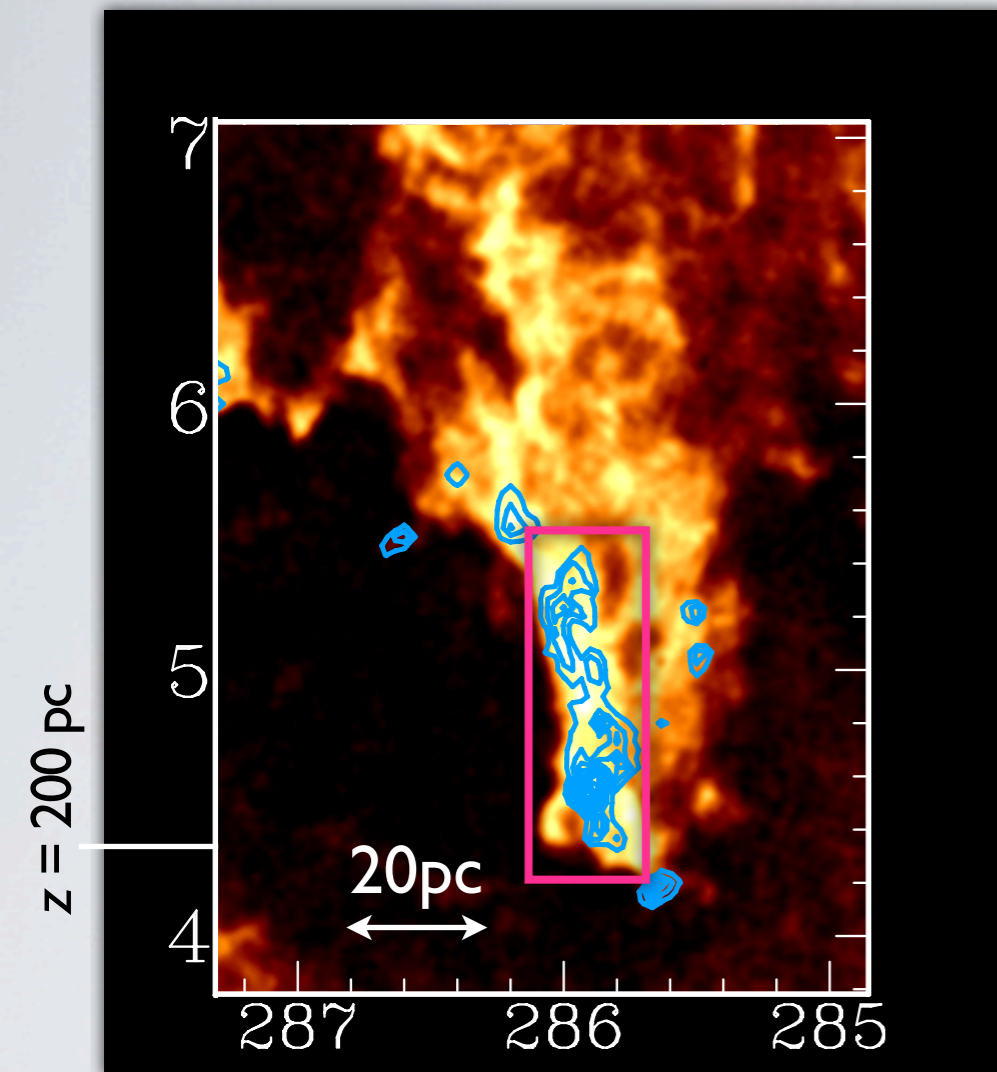


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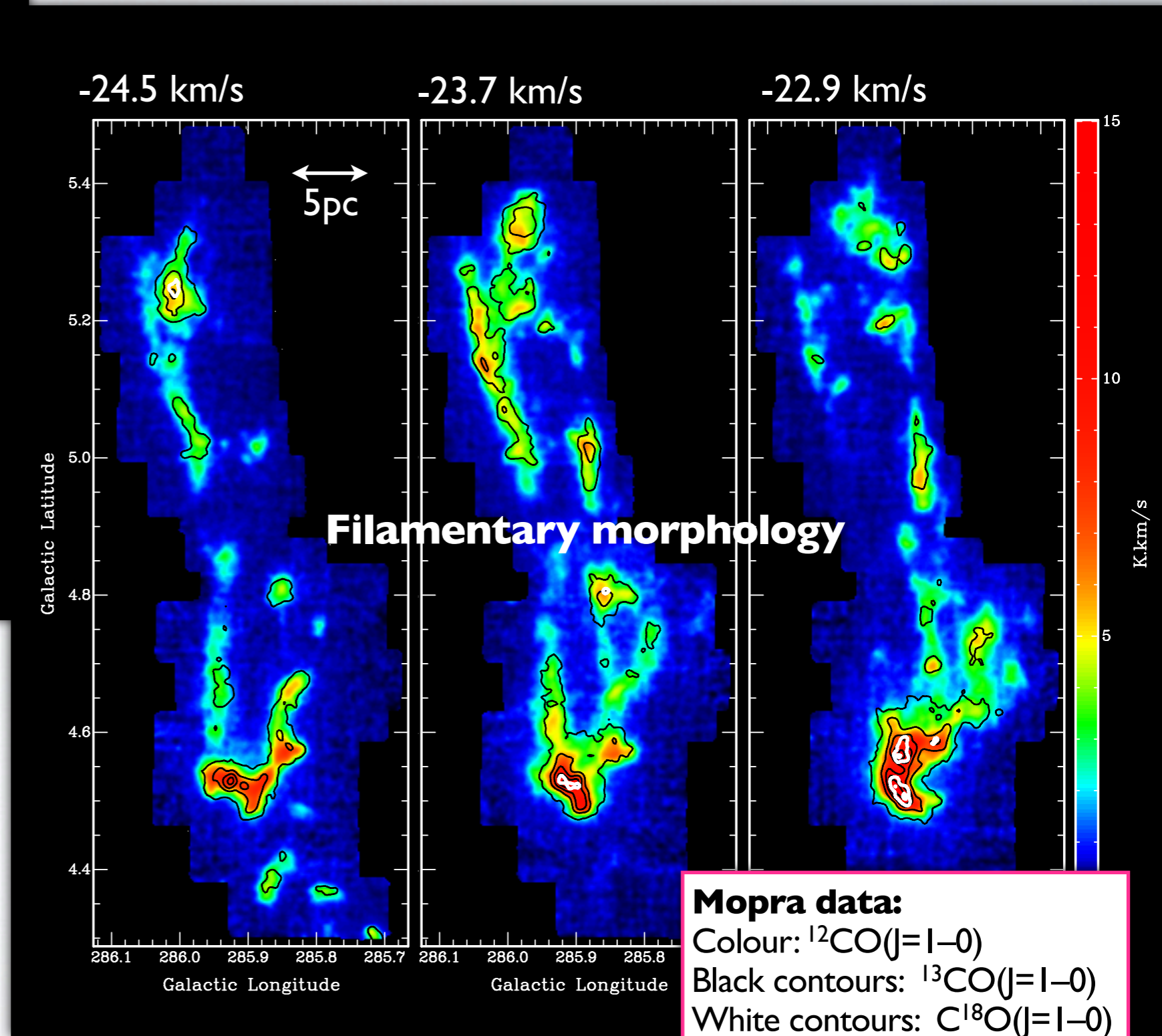
GSH 277+00+36



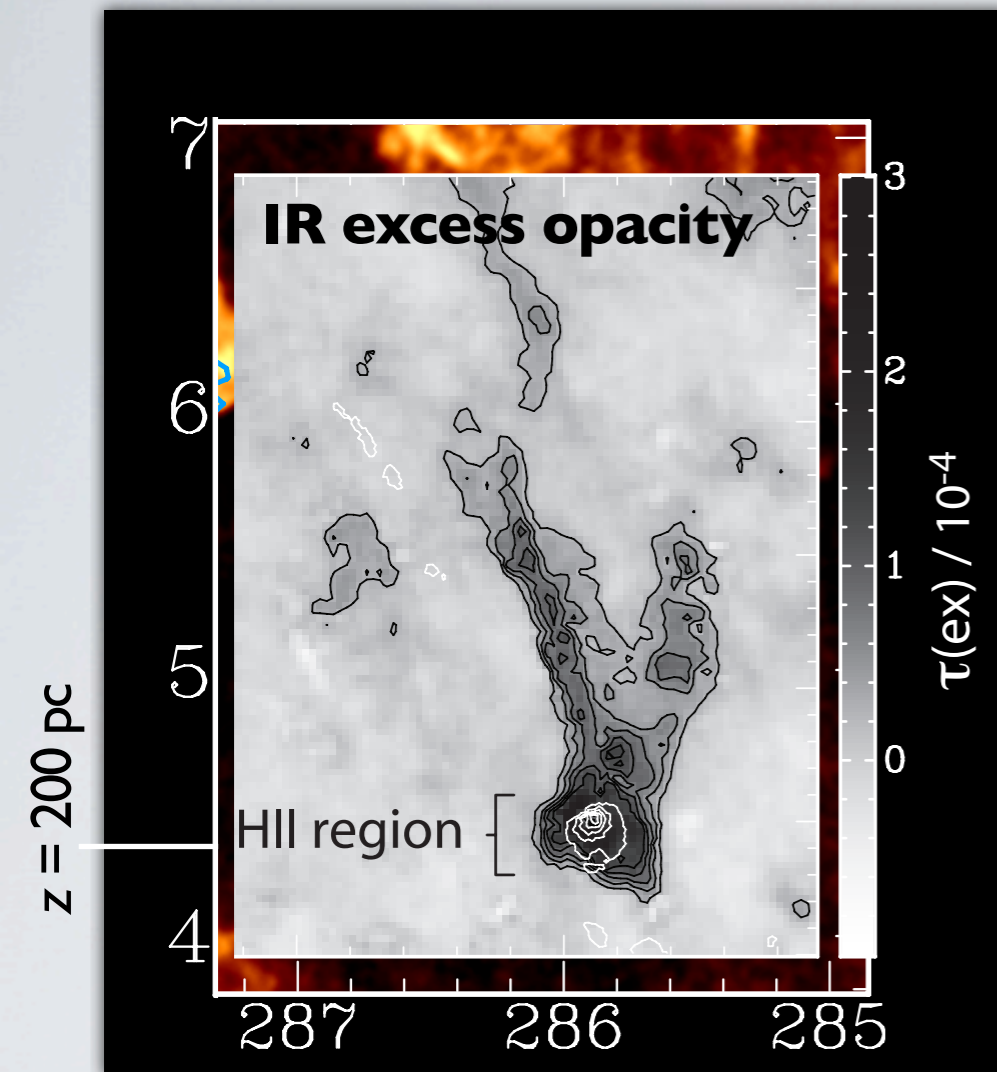
Molecular Cloud (and Star) Formation



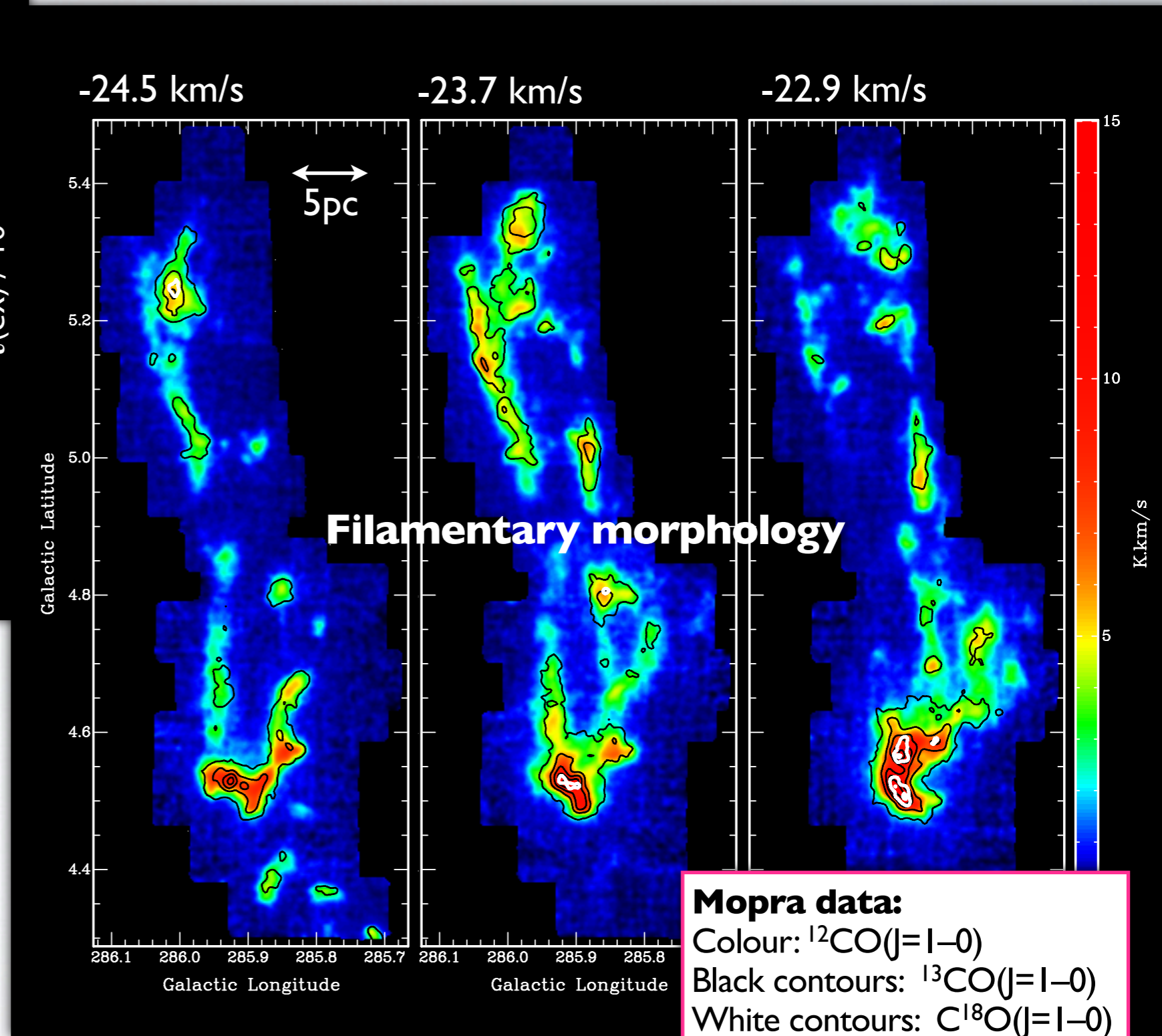
- ~ 50% of material is “dark” ISM
- Sufficient A_v for shielding of CO



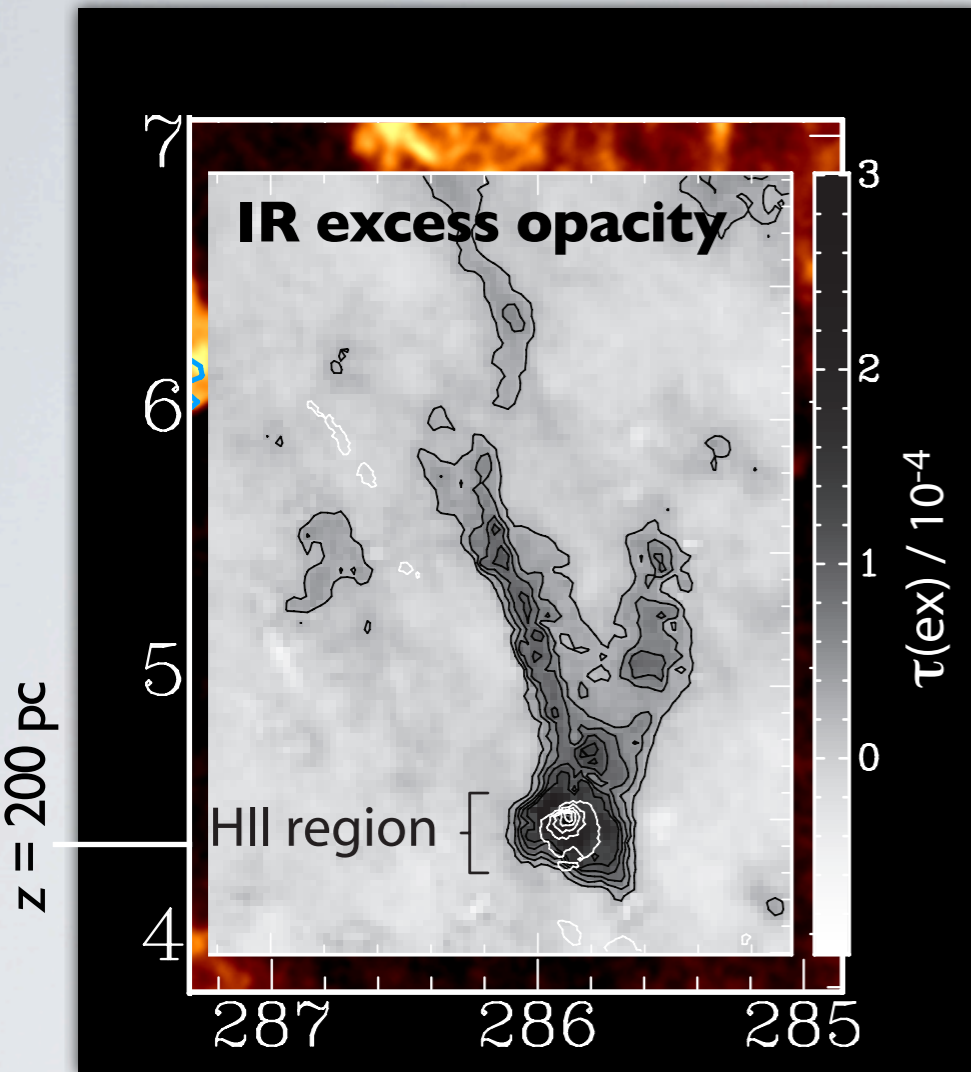
Molecular Cloud (and Star) Formation



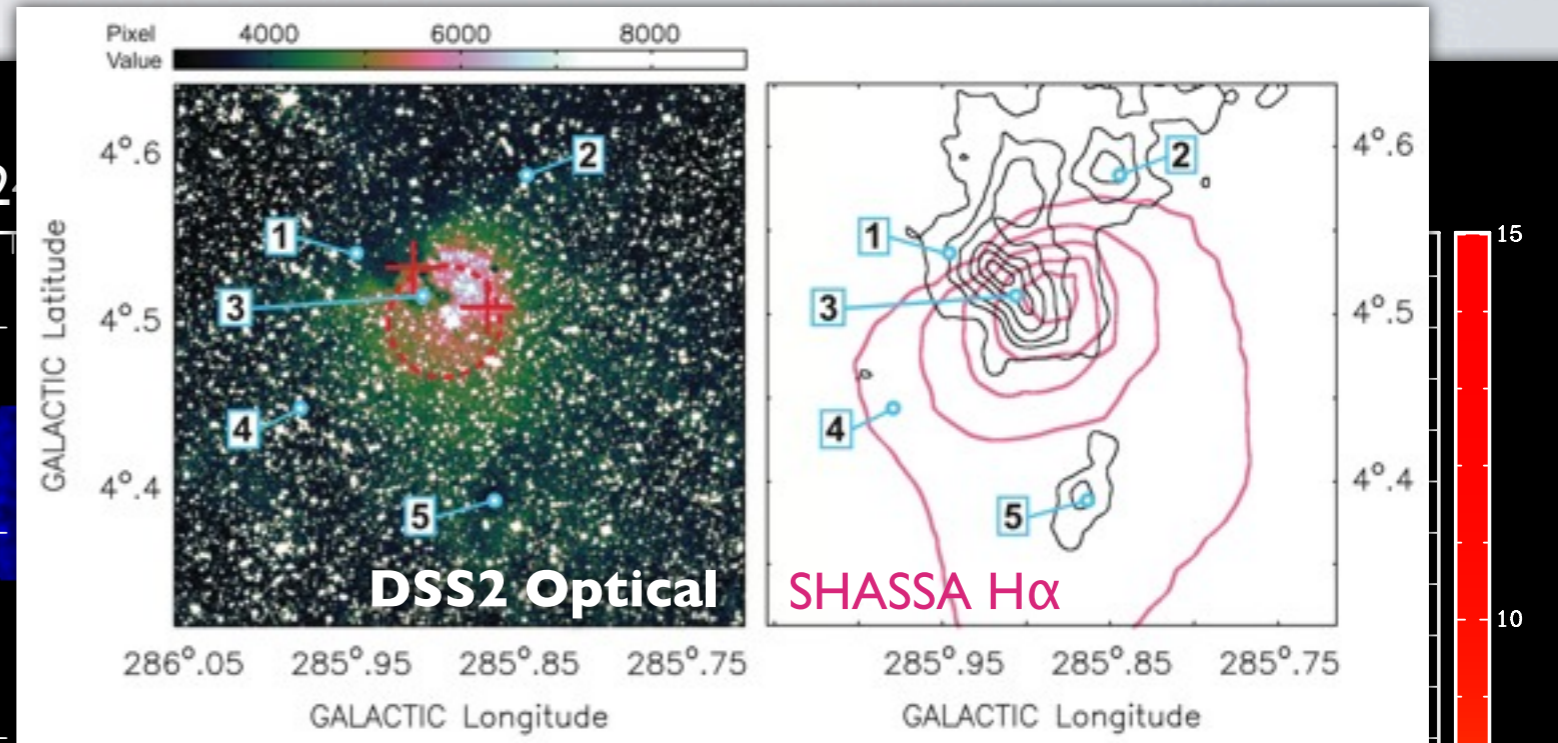
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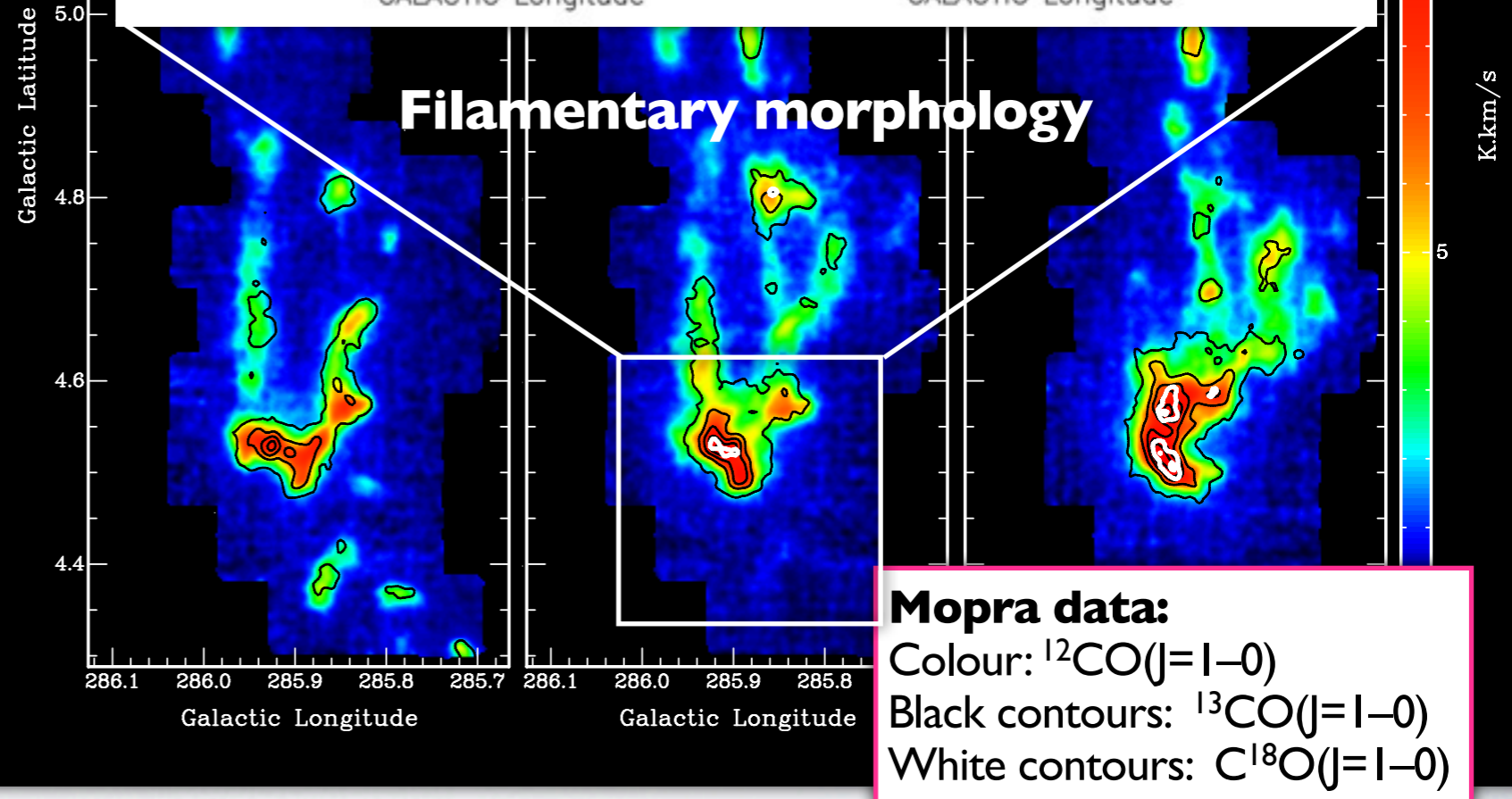
Molecular Cloud (and Star) Formation



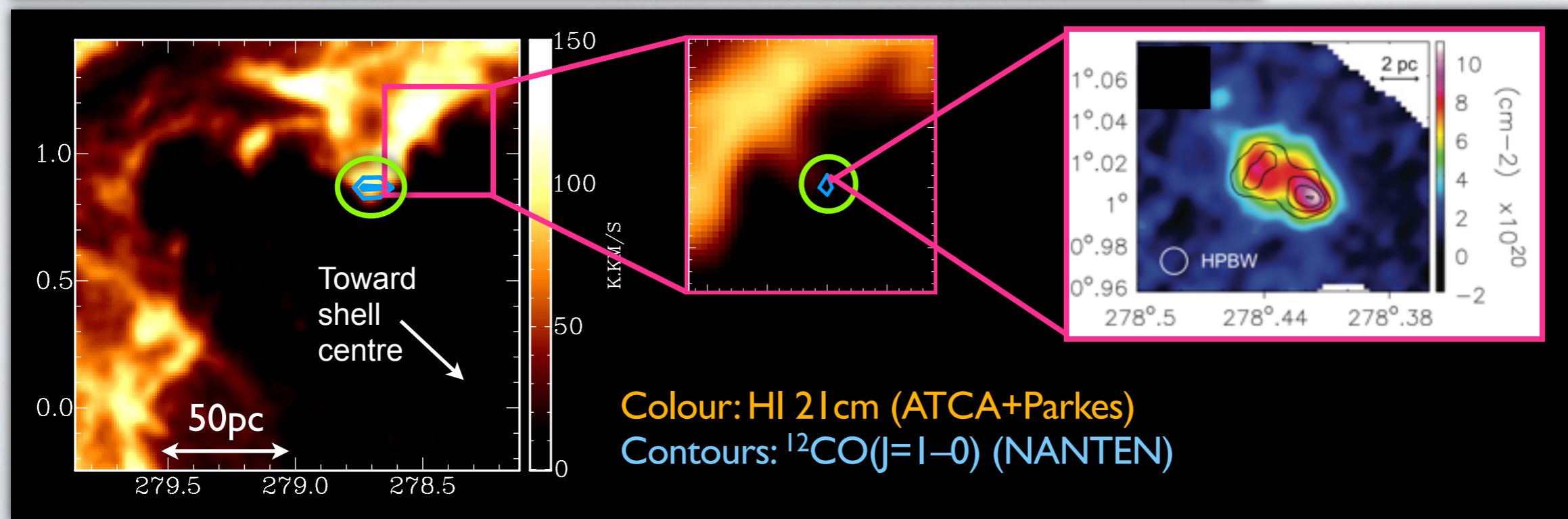
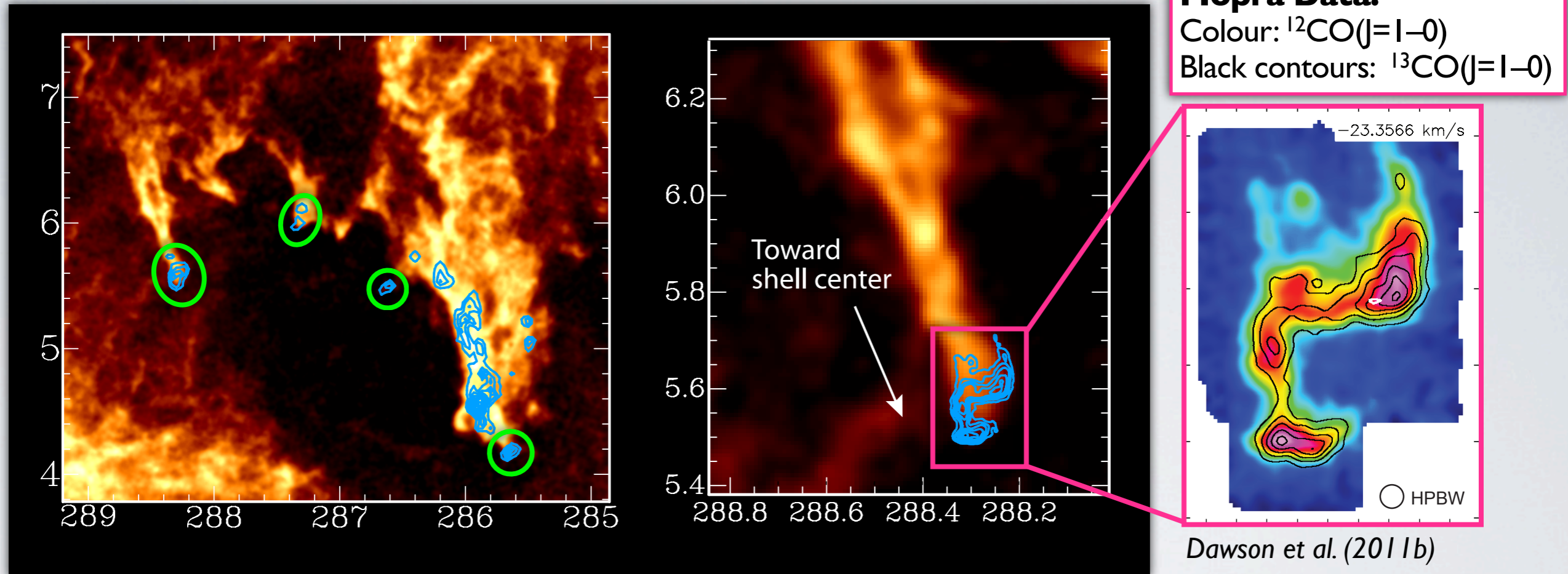
Star formation where filaments join



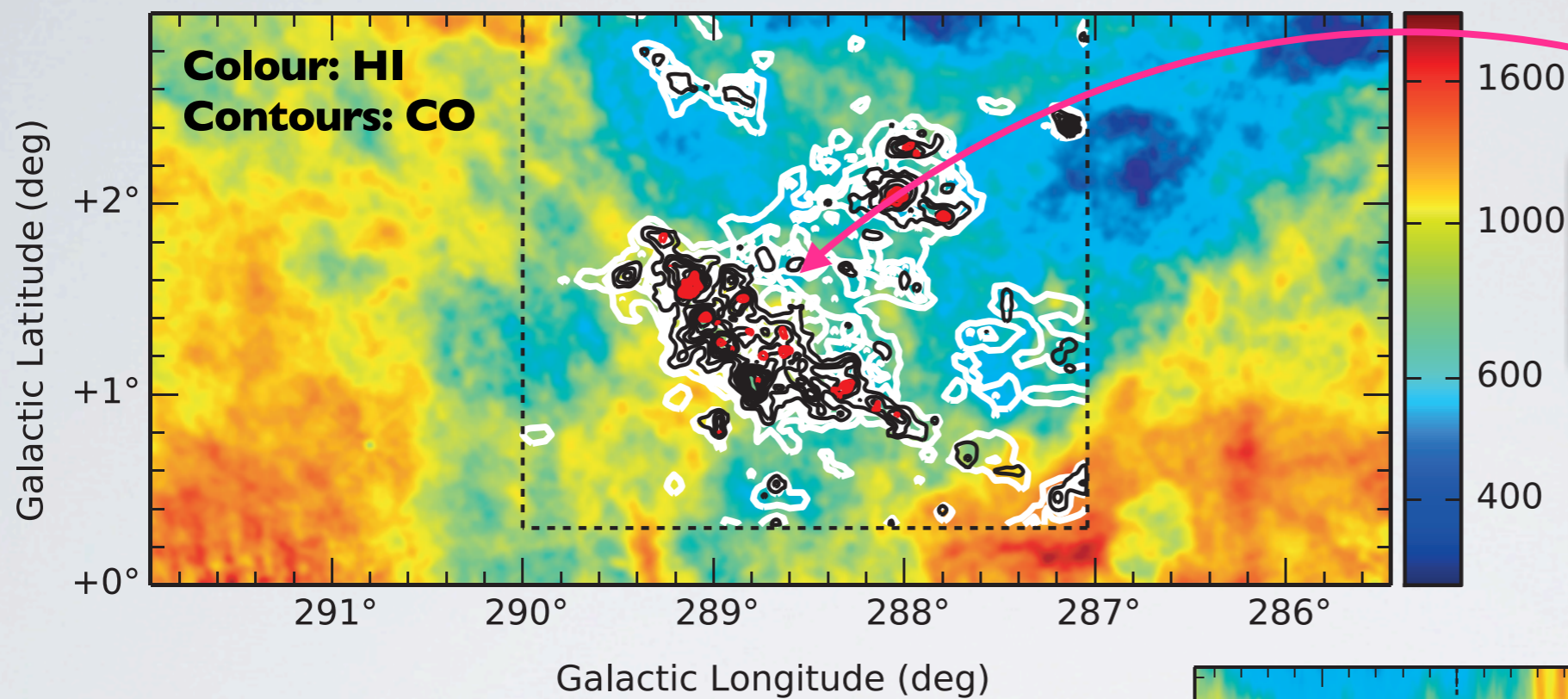
- ~ 50% of material is “dark” ISM
- Sufficient A_v for shielding of CO



Molecular Cloud Destruction



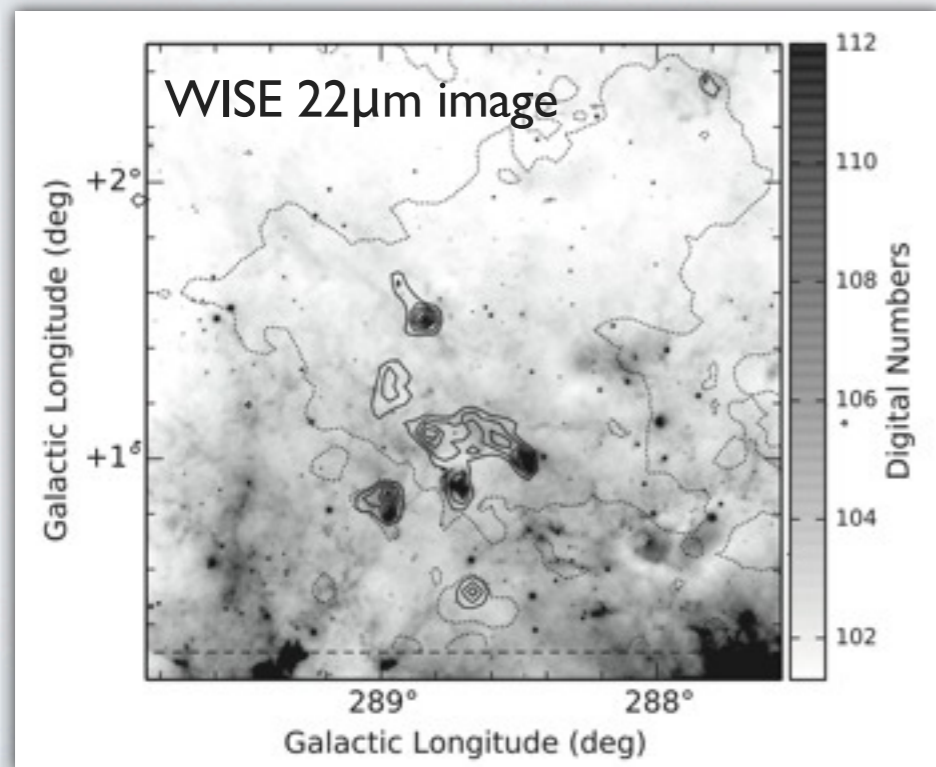
GMC Formation at Supershell Collision Zones



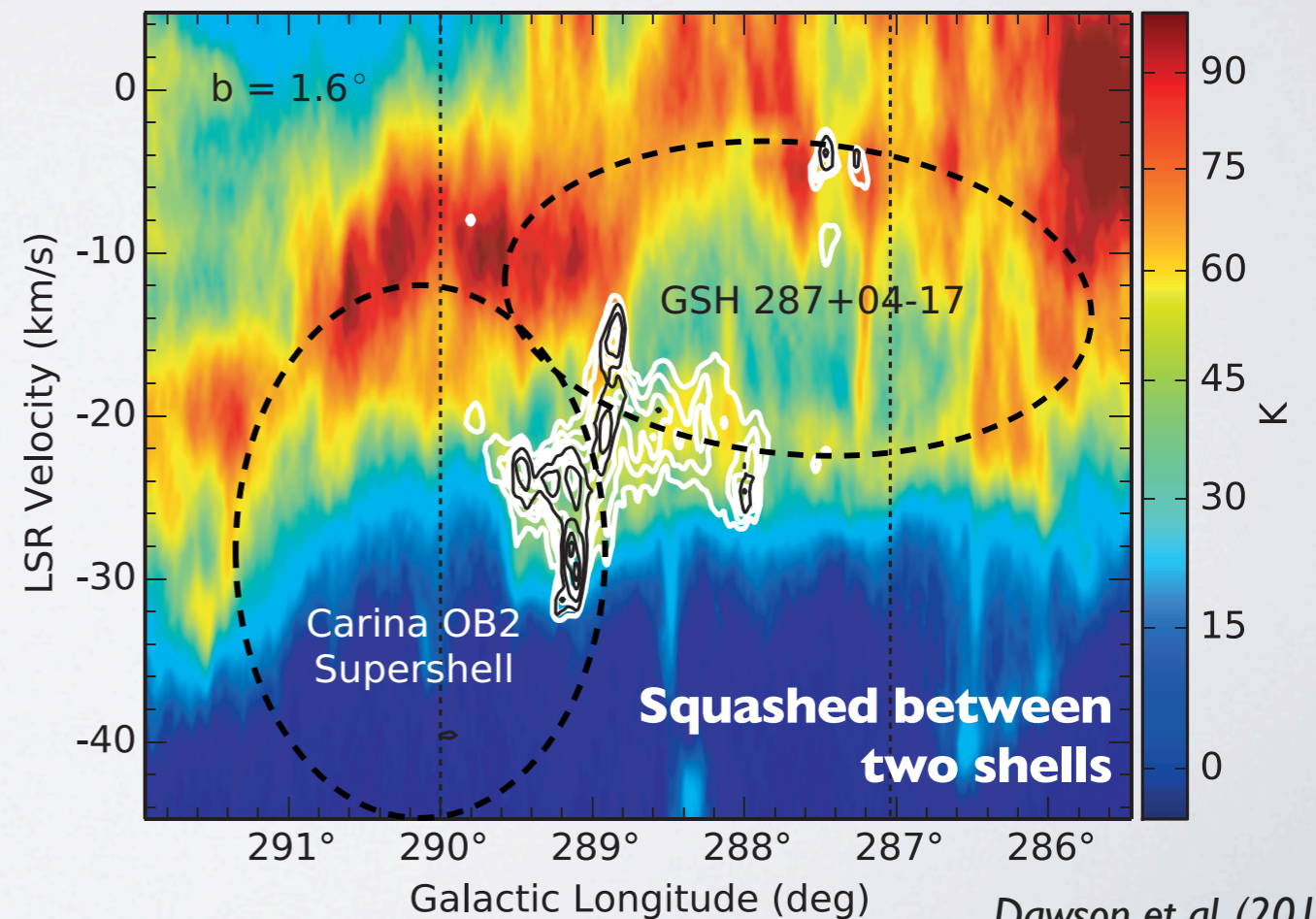
Low $^{13}\text{CO}/^{12}\text{CO}$ ratio \rightarrow
lots of diffuse envelope gas

$^{12}\text{CO}(J=1-0): M(\text{H}_2) \sim 1.7 \times 10^5 M_{\odot}$
 $^{13}\text{CO}(J=1-0): M(\text{H}_2) \sim 3.5 \times 10^4 M_{\odot}$
 $\text{C}^{18}\text{O}(J=1-0): M(\text{H}_2) \sim 0.8 \times 10^4 M_{\odot}$

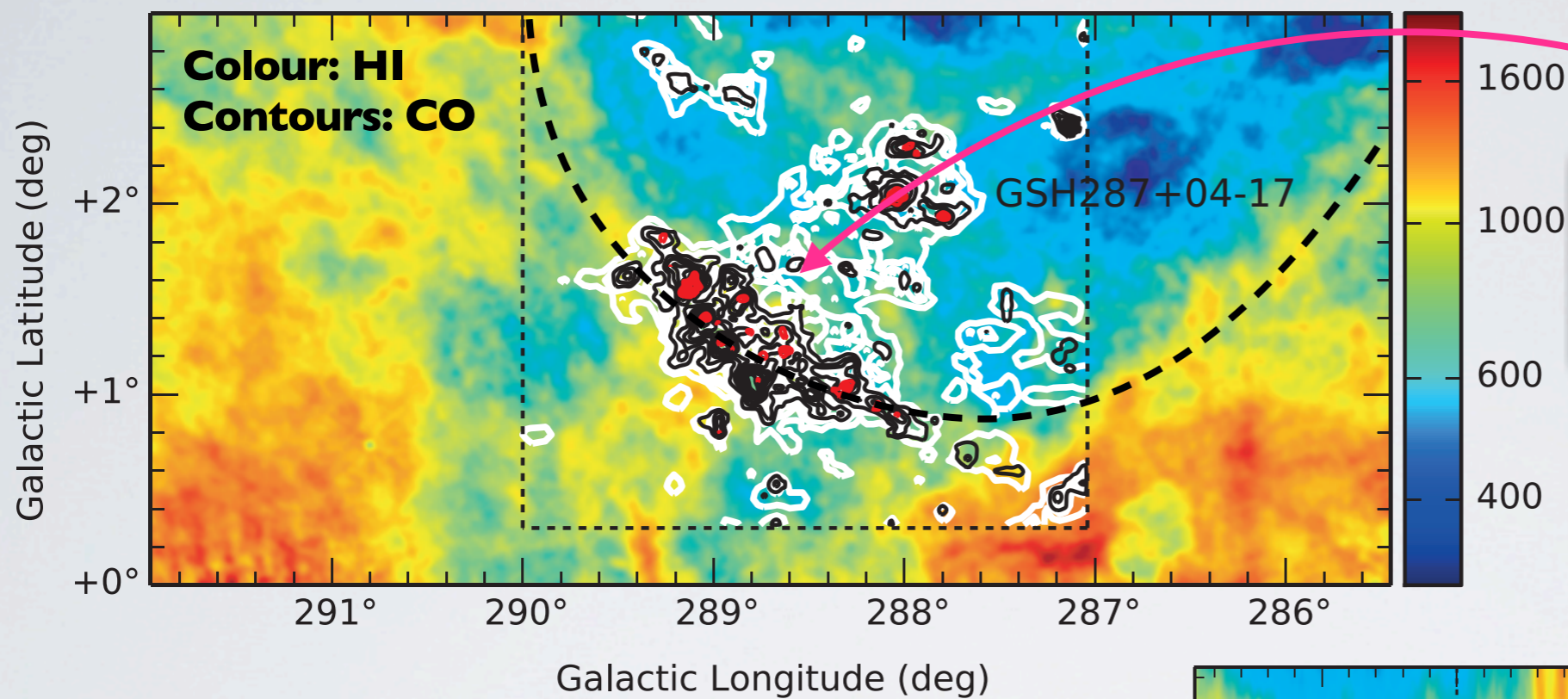
- Low C^{18}O fraction
- $M_{\text{vir}} \gg M_{\text{CO}} \rightarrow$ ram pressure confined?



Low star formation activity



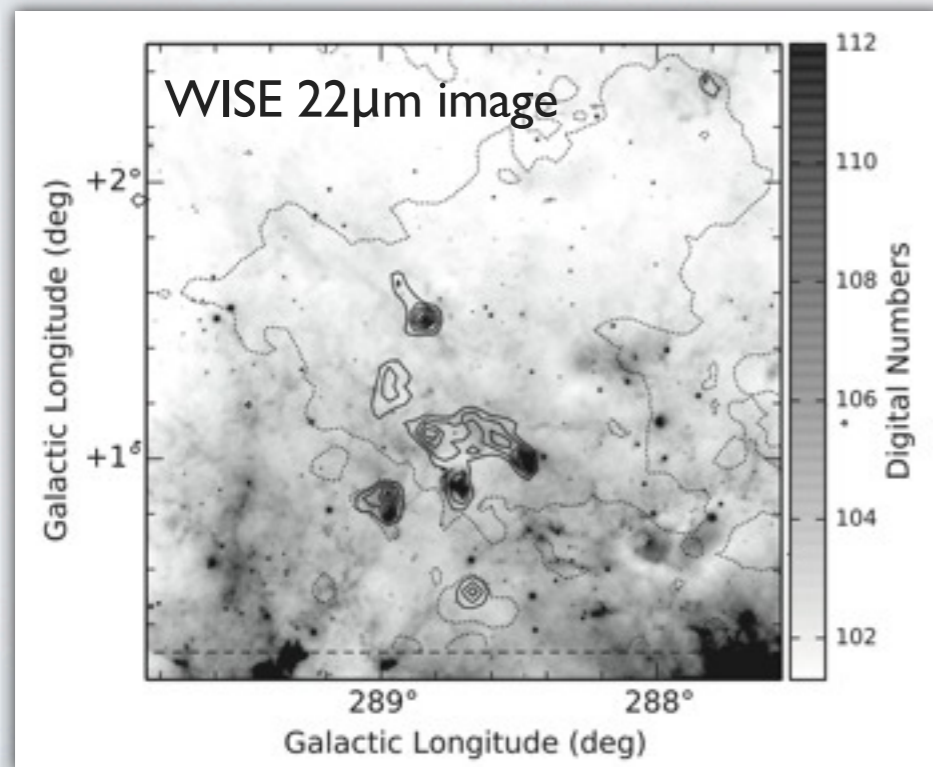
GMC Formation at Supershell Collision Zones



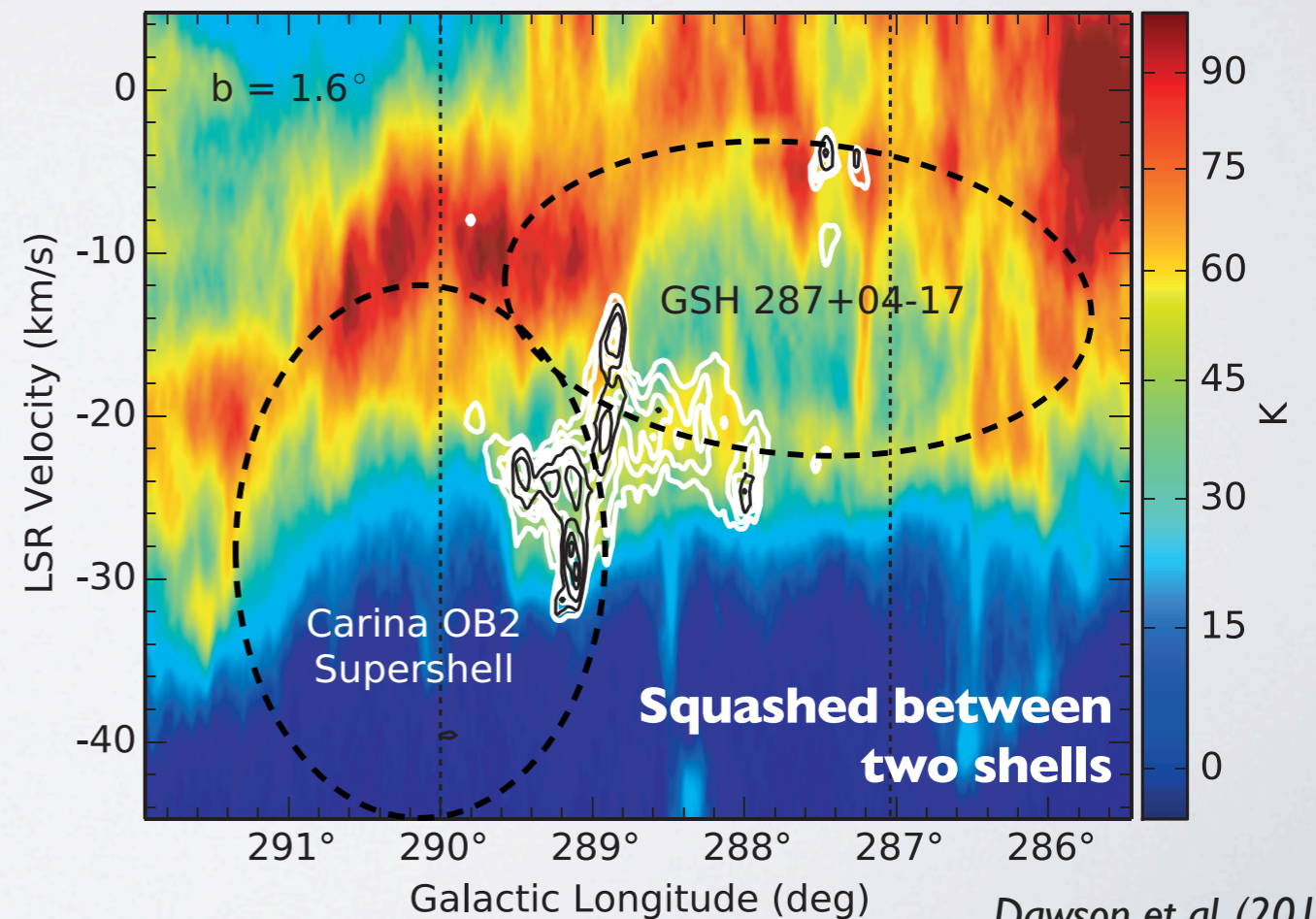
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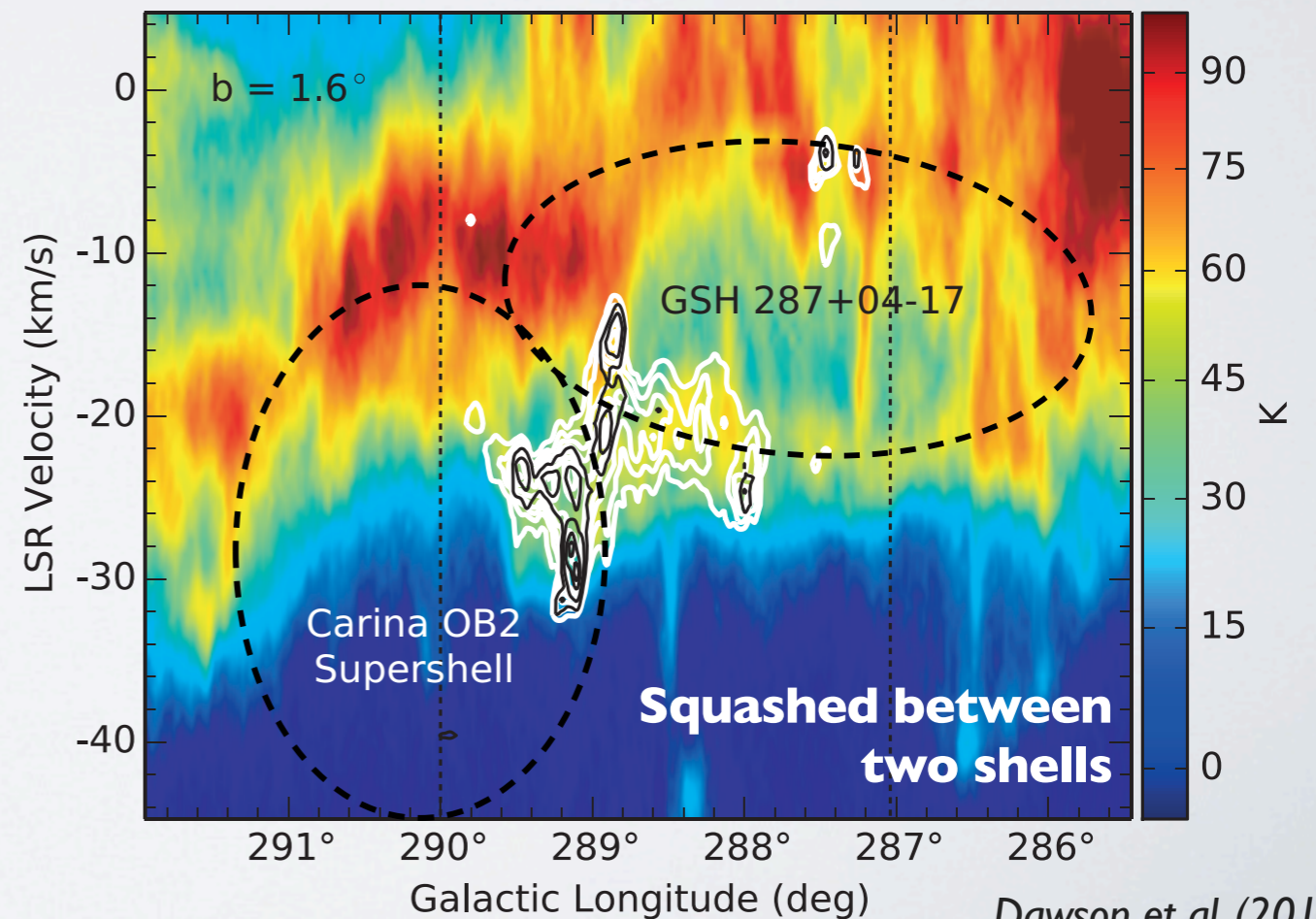
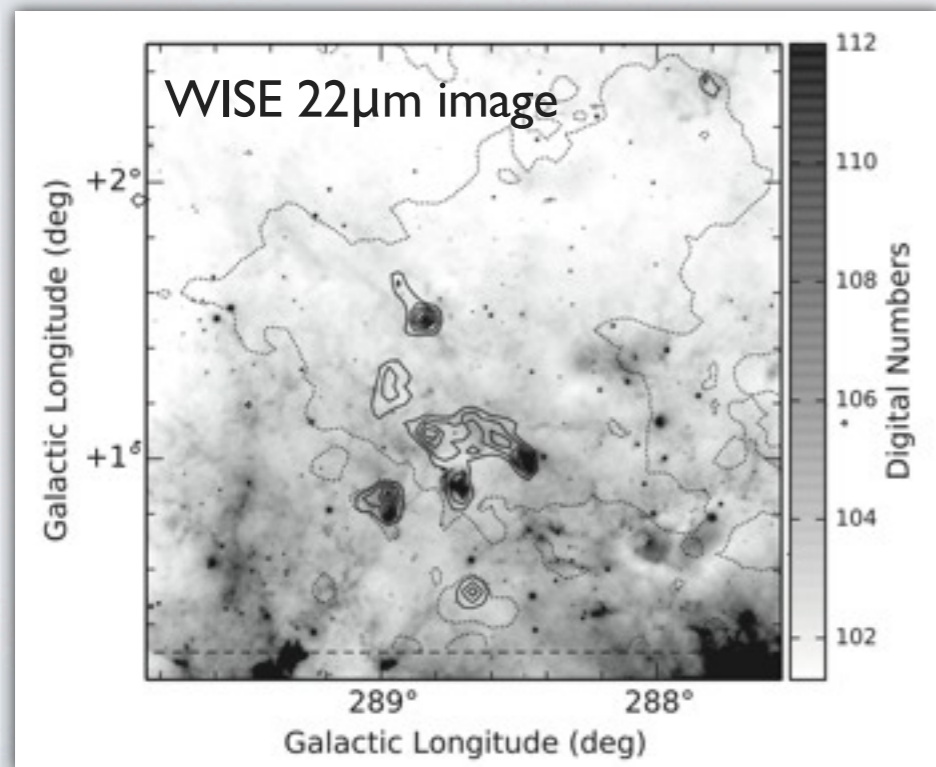
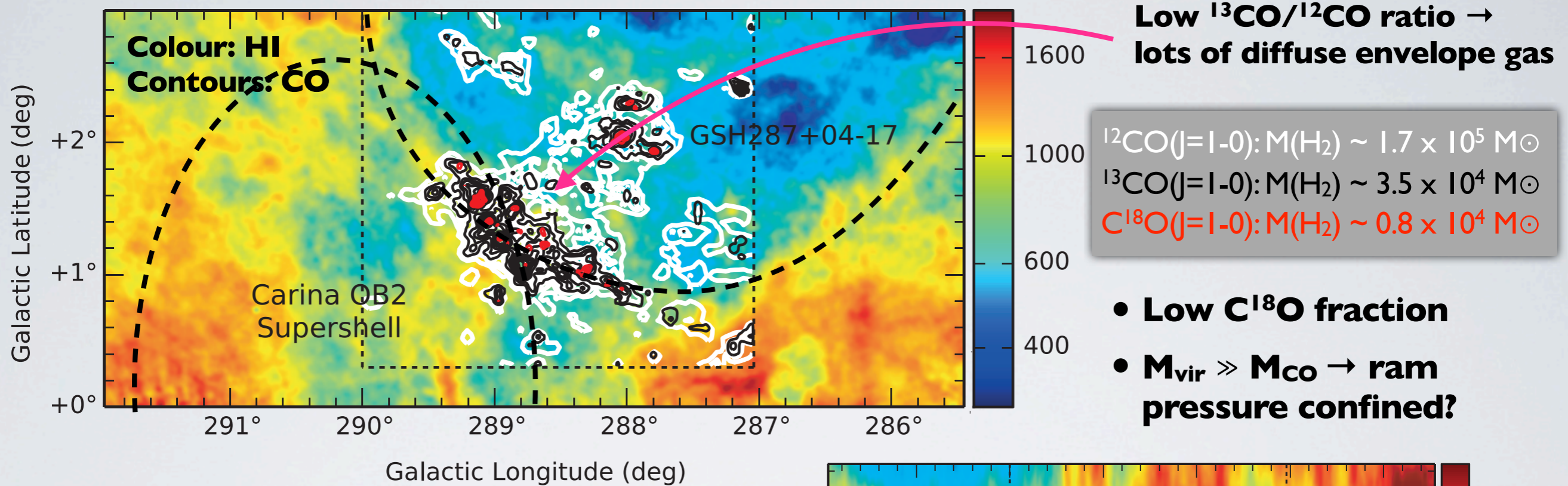
- Low C^{18}O fraction
- $M_{\text{vir}} \gg M_{\text{CO}} \rightarrow$ ram pressure confined?



Low star formation activity

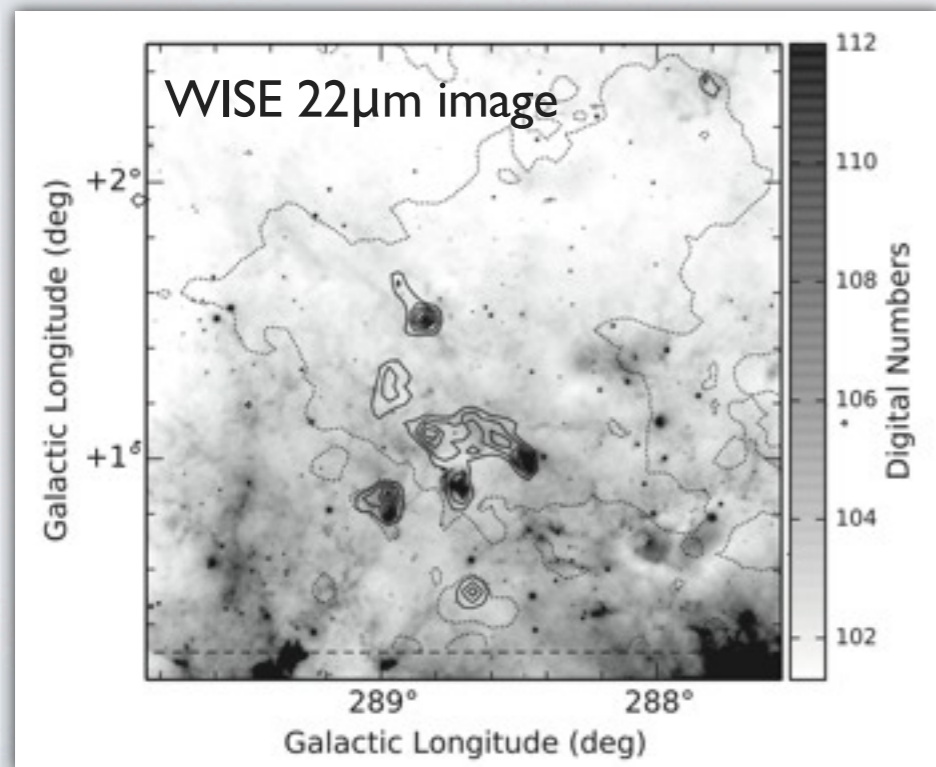
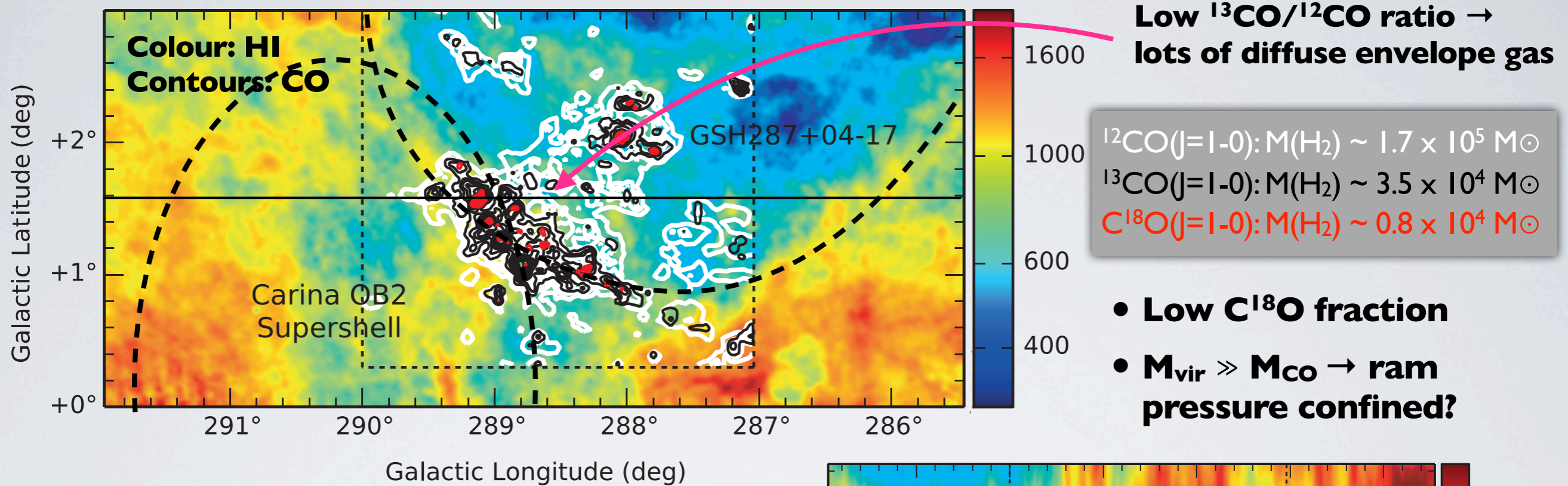


GMC Formation at Supershell Collision Zones

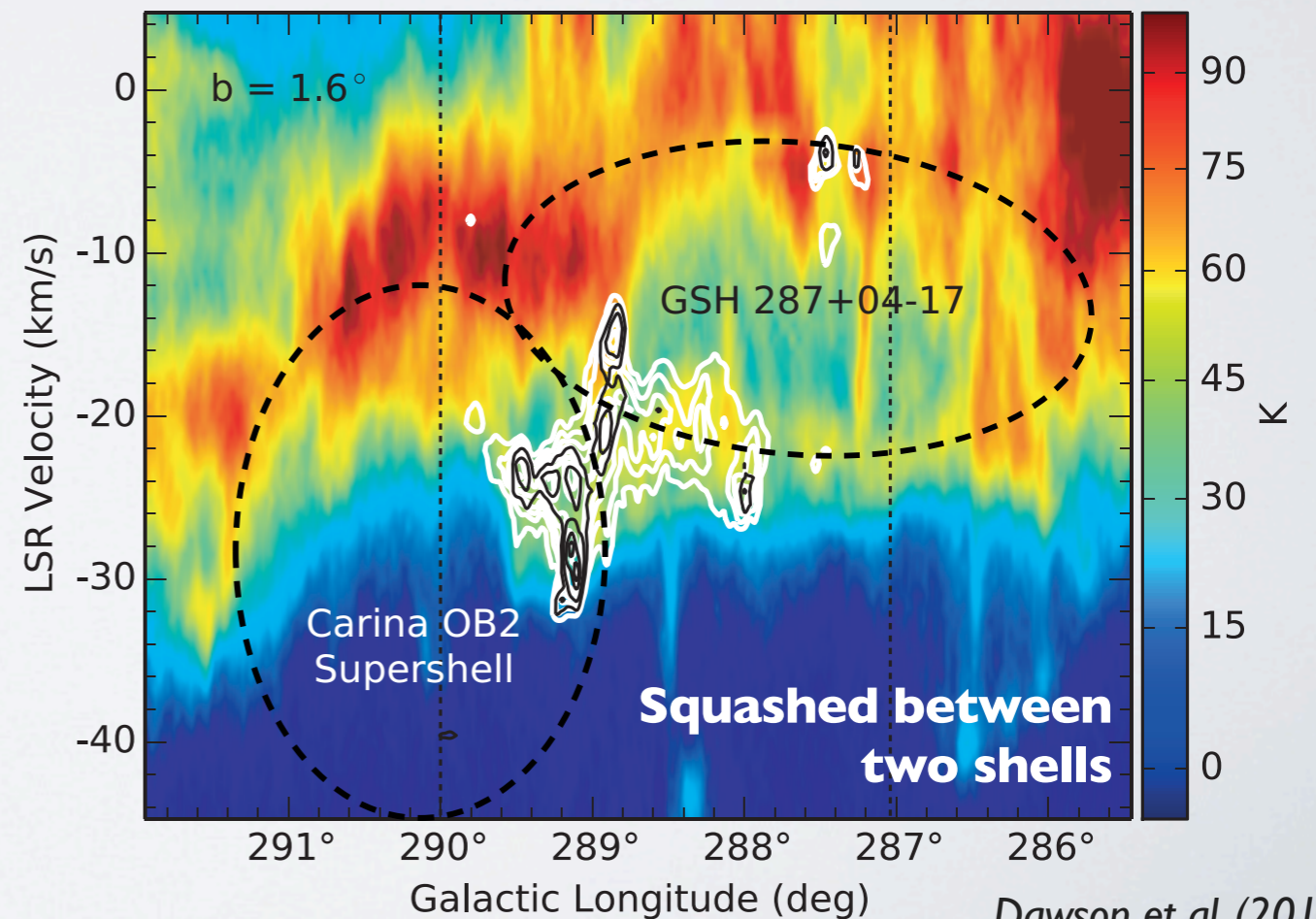


Low star formation activity

GMC Formation at Supershell Collision Zones

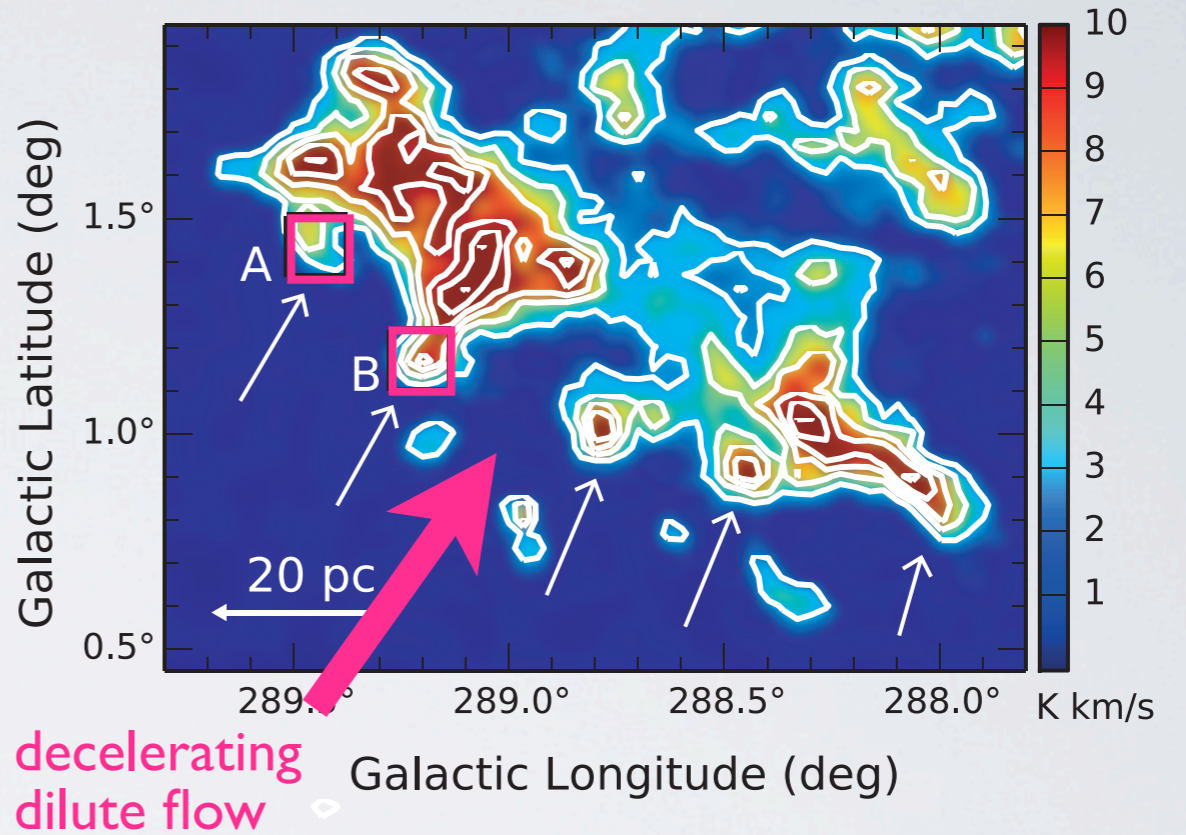
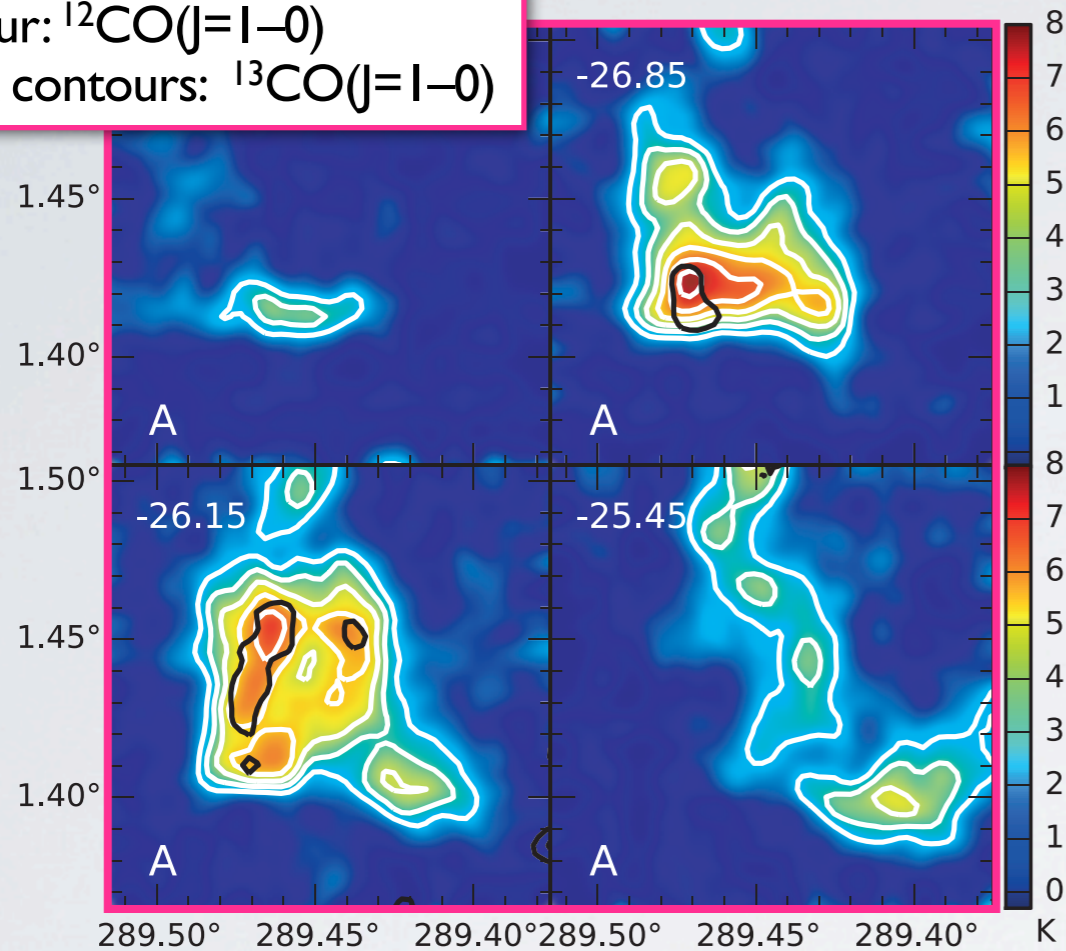


Low star formation activity



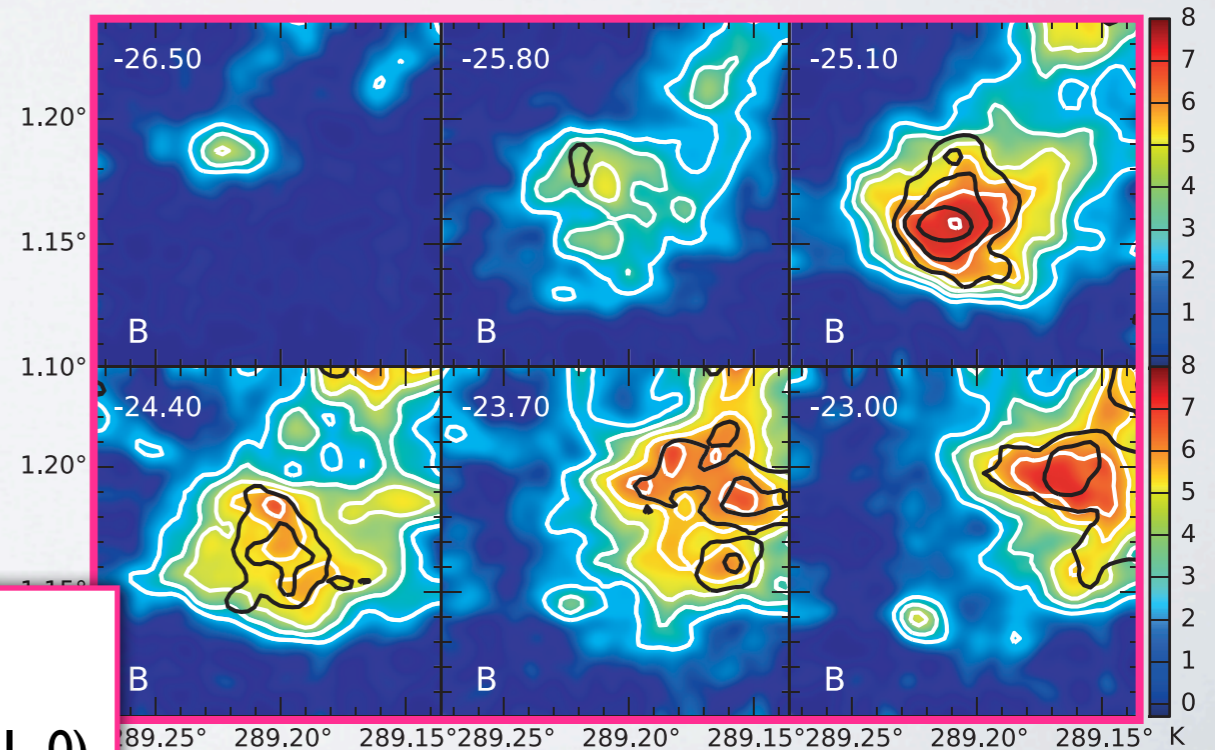
Fluid Instabilities

Mopra data:
 Colour: $^{12}\text{CO}(j=1-0)$
 Black contours: $^{13}\text{CO}(j=1-0)$

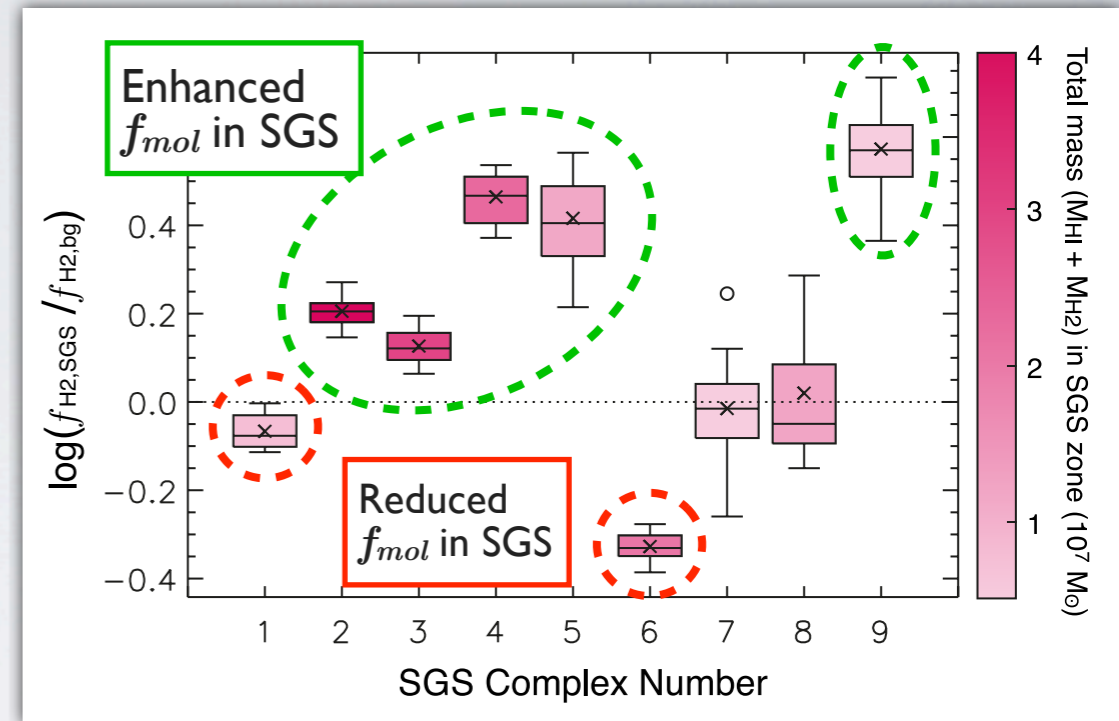
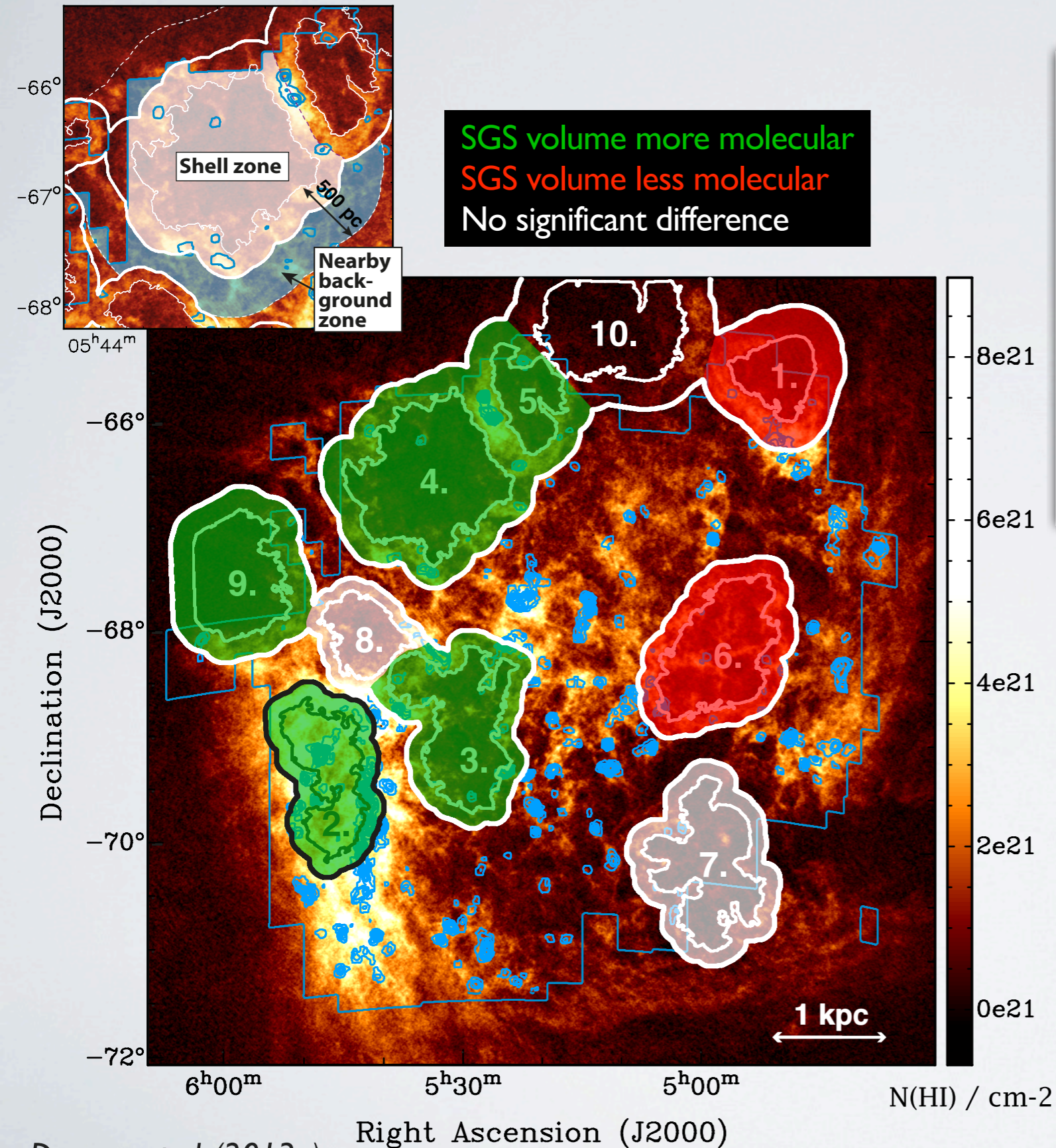


- **Periodic drip-like features**
- **Rayleigh-Taylor instability growth time: ~ 0.3-1.9 Myr**

Mopra data:
 Colour: $^{12}\text{CO}(j=1-0)$
 Black contours: $^{13}\text{CO}(j=1-0)$



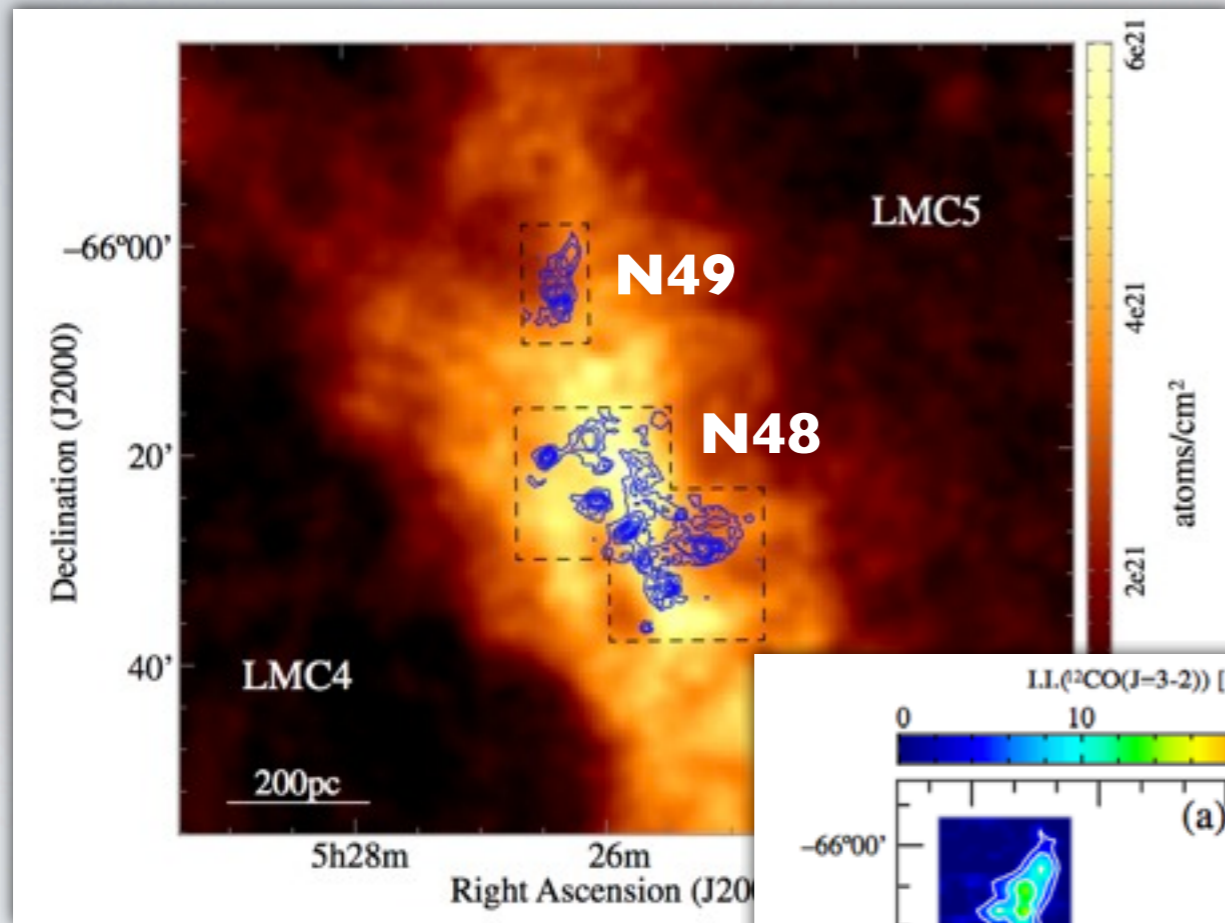
Supergiant Shells in the LMC



Box plot: For each SGS complex compute $[f_{mol}]_{\text{SGS}} / [f_{mol}]_{\text{bg}}$ for range of shell and background zone widths.

- **Supergiant shells drive ~10% of molecular cloud formation?**

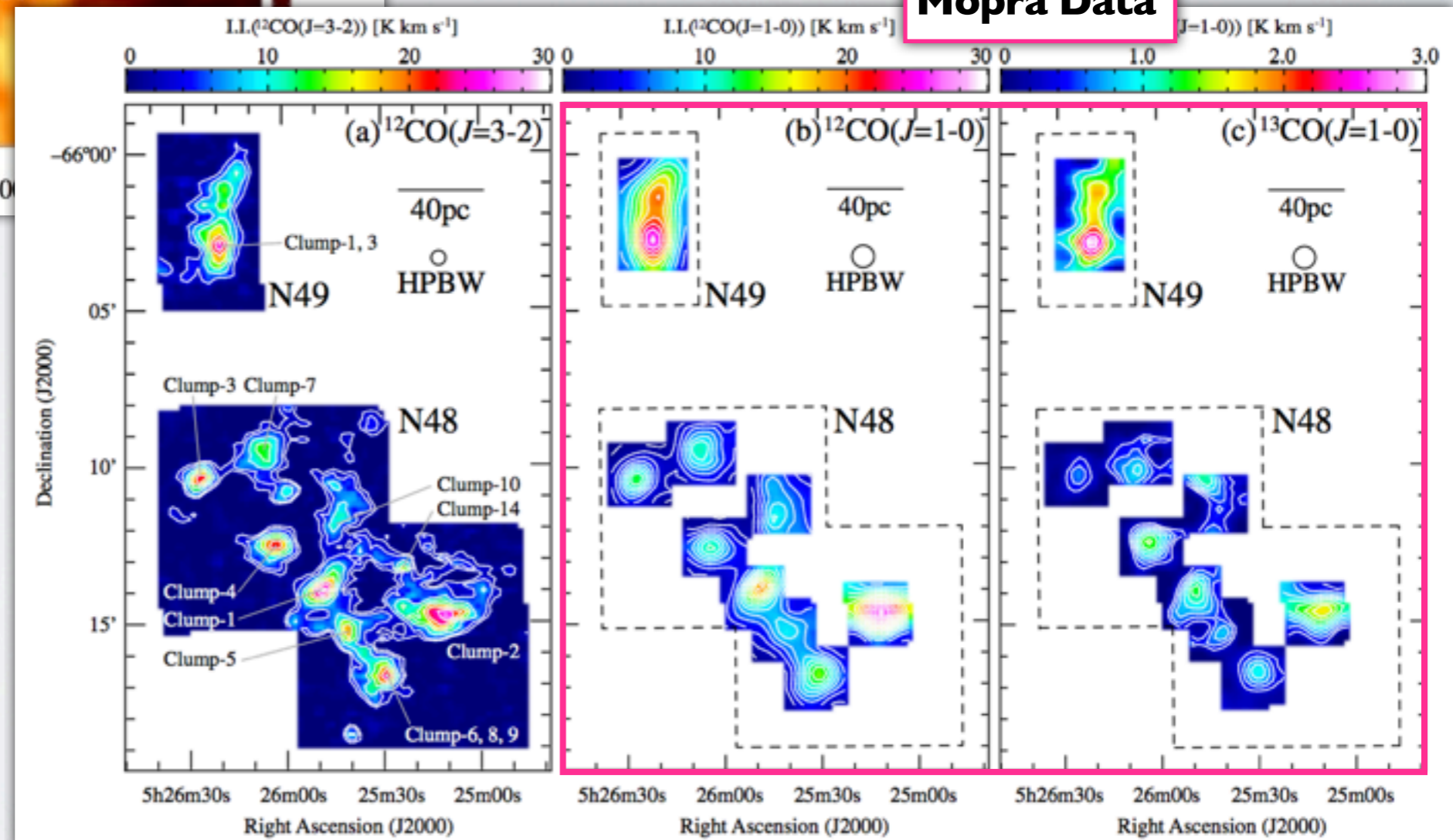
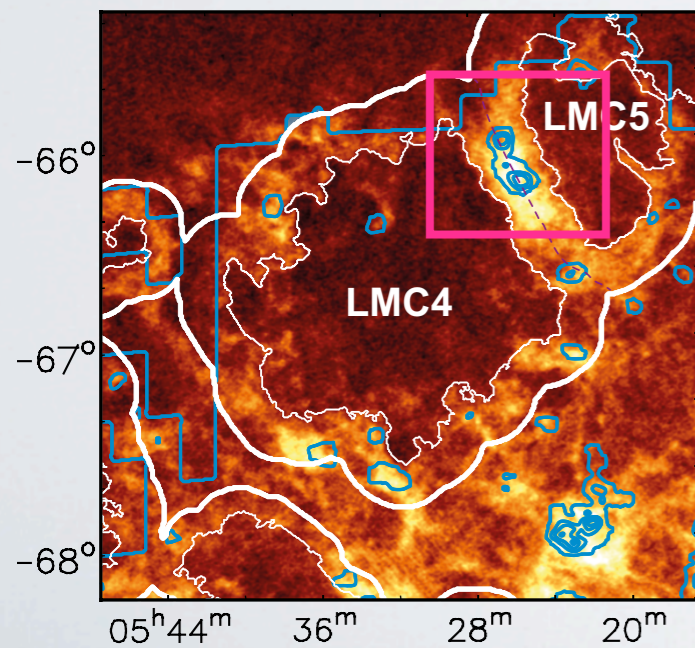
Molecular Clouds at the Interface of LMC4/5



N48 squashed between both shells
N49 only associated with LMC5

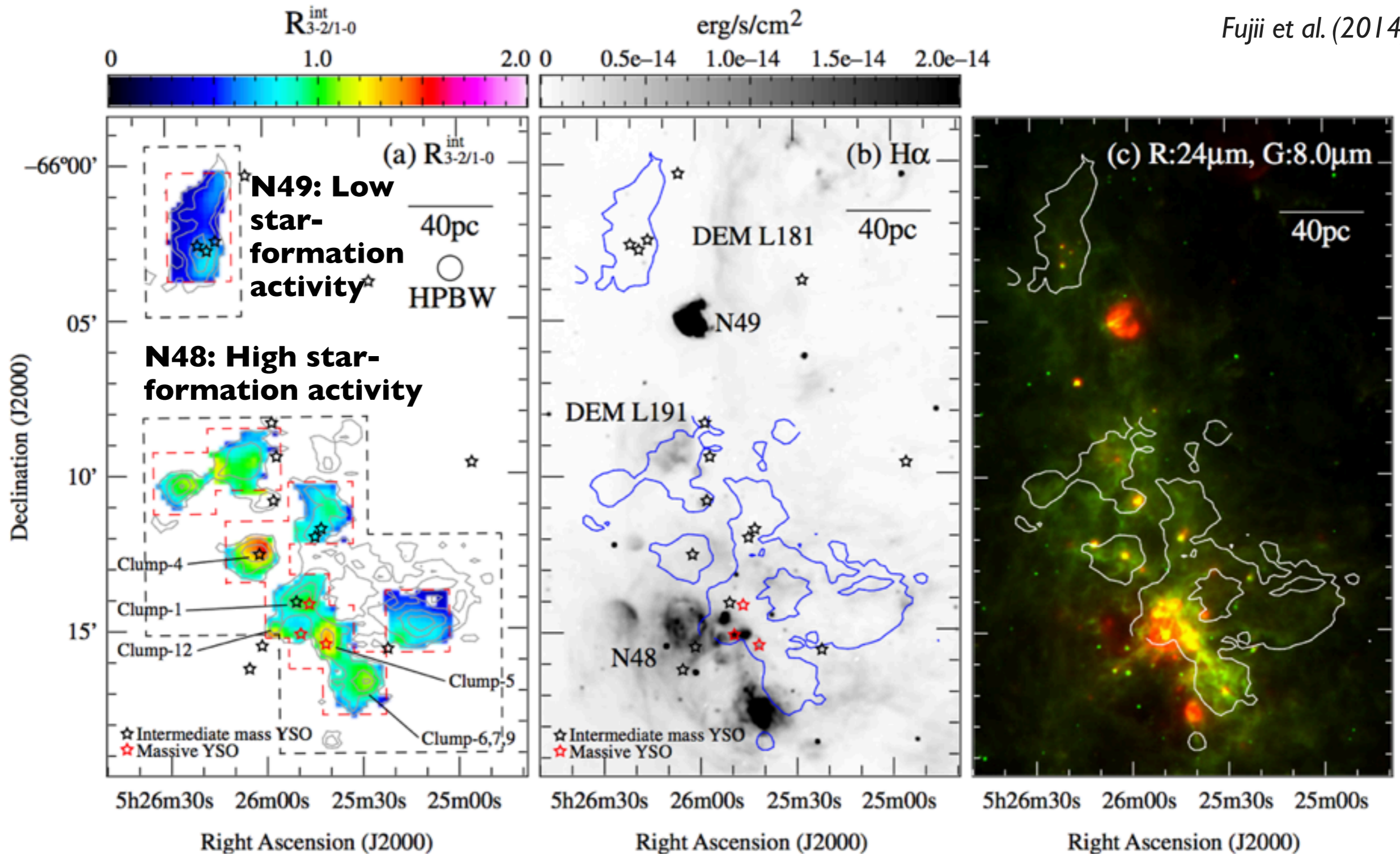
Fujii et al. (2014)

Mopra Data

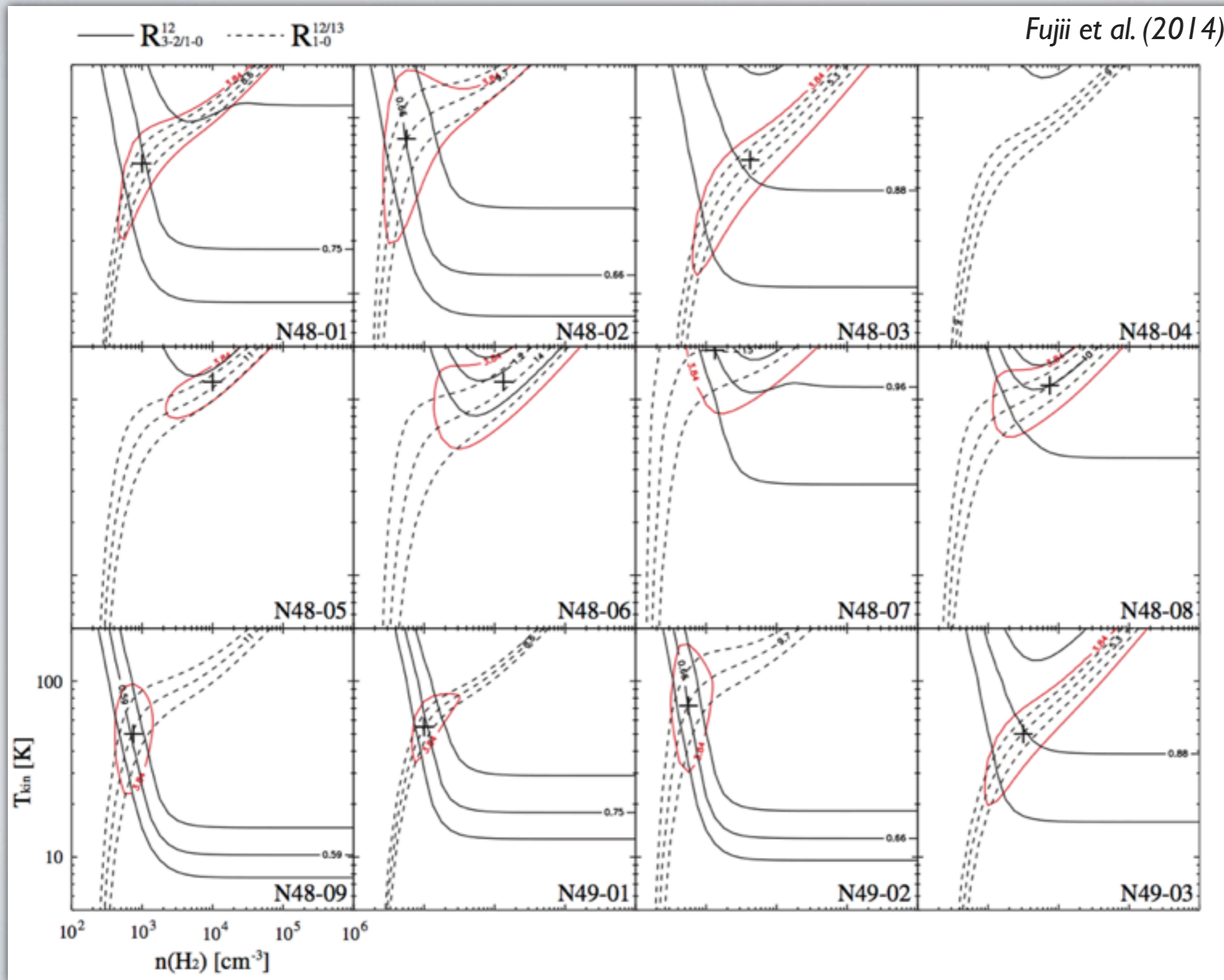


Molecular Clouds at the Interface of LMC4/5

Fujii et al. (2014)



Molecular Clouds at the Interface of LMC4/5

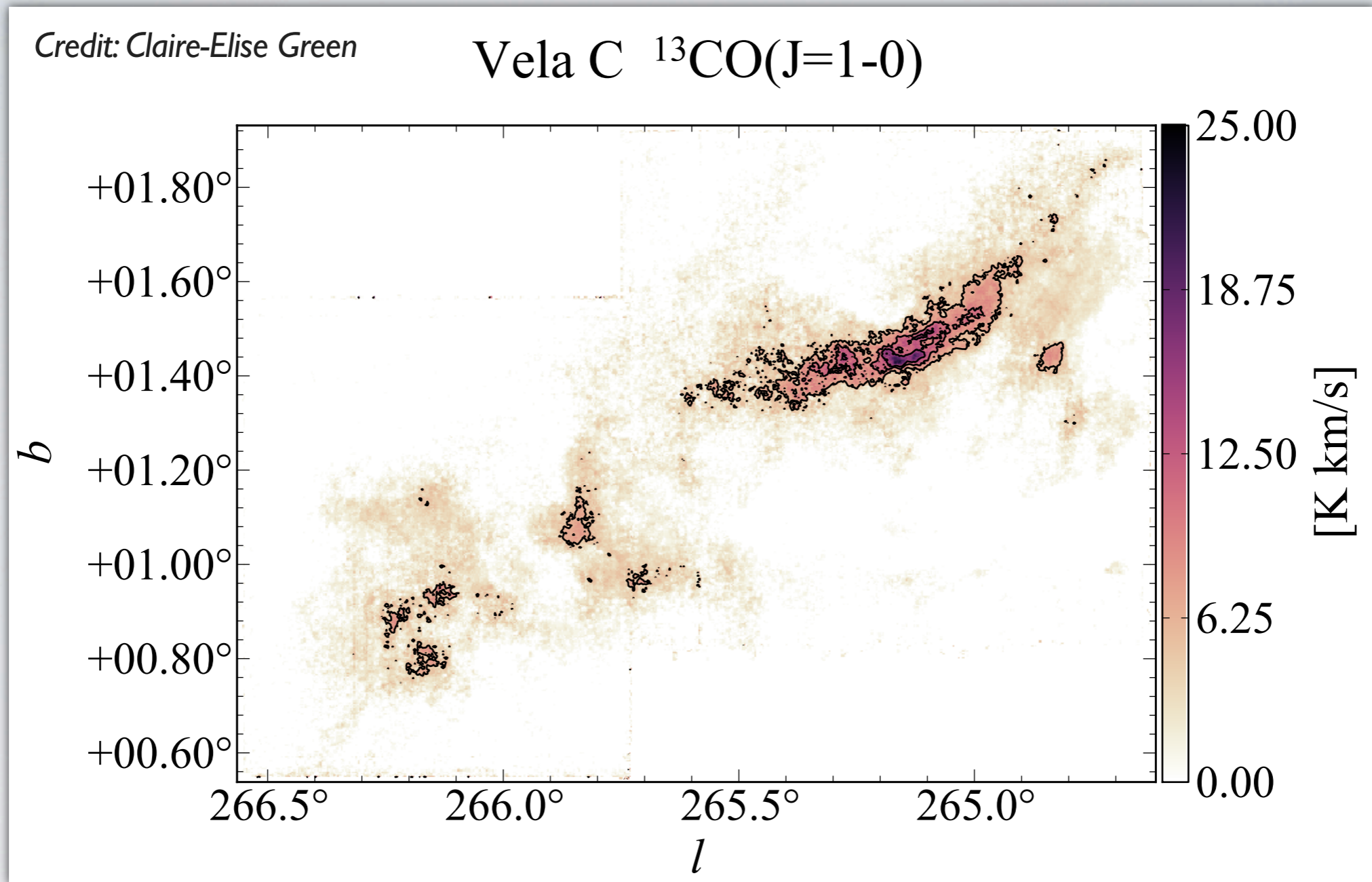


**Mopra gives
CO(J=1-0)**

**ASTE/APEX
give higher J
data**

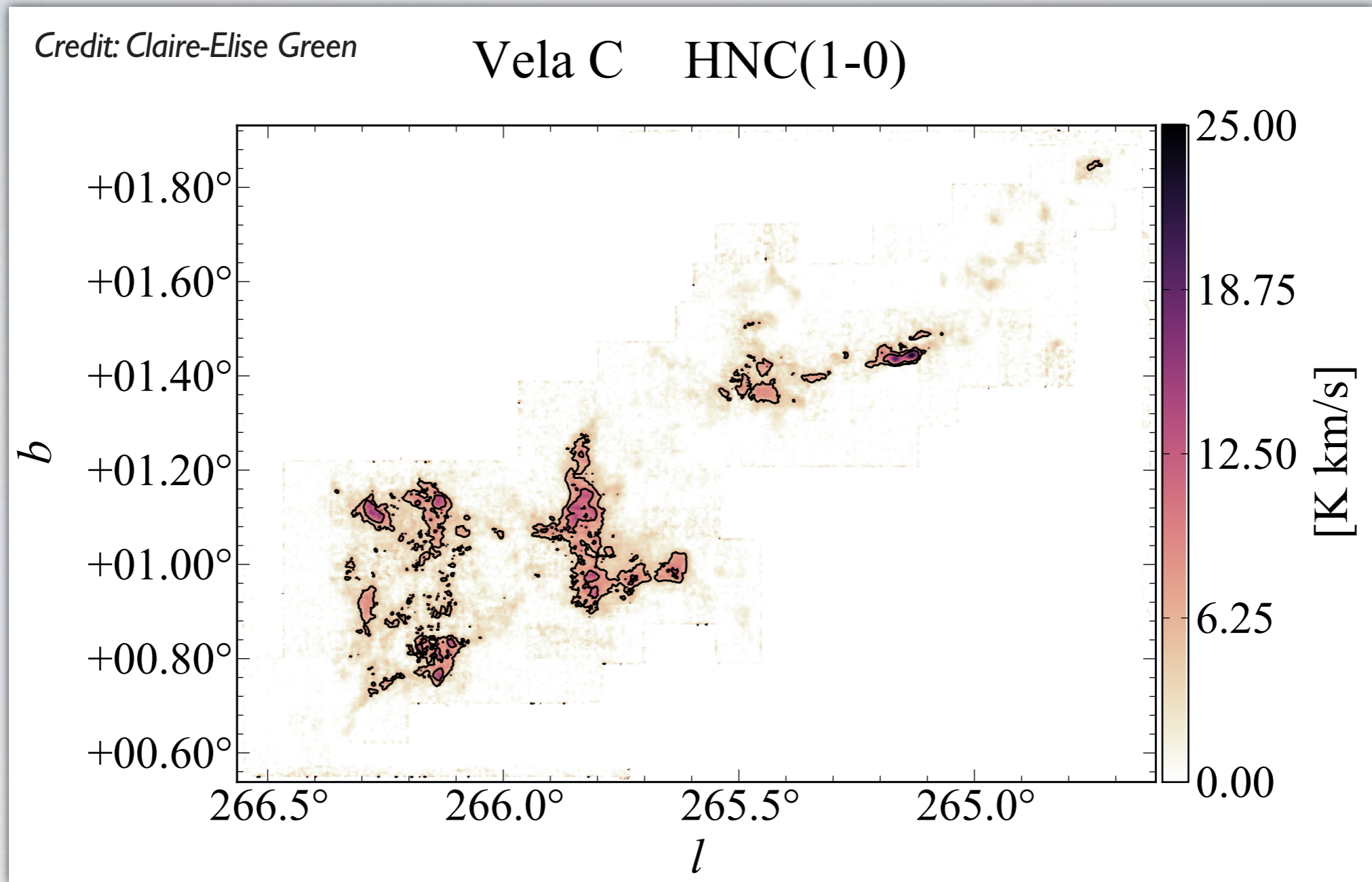
Modelling!

Molecular Filaments with Mopra



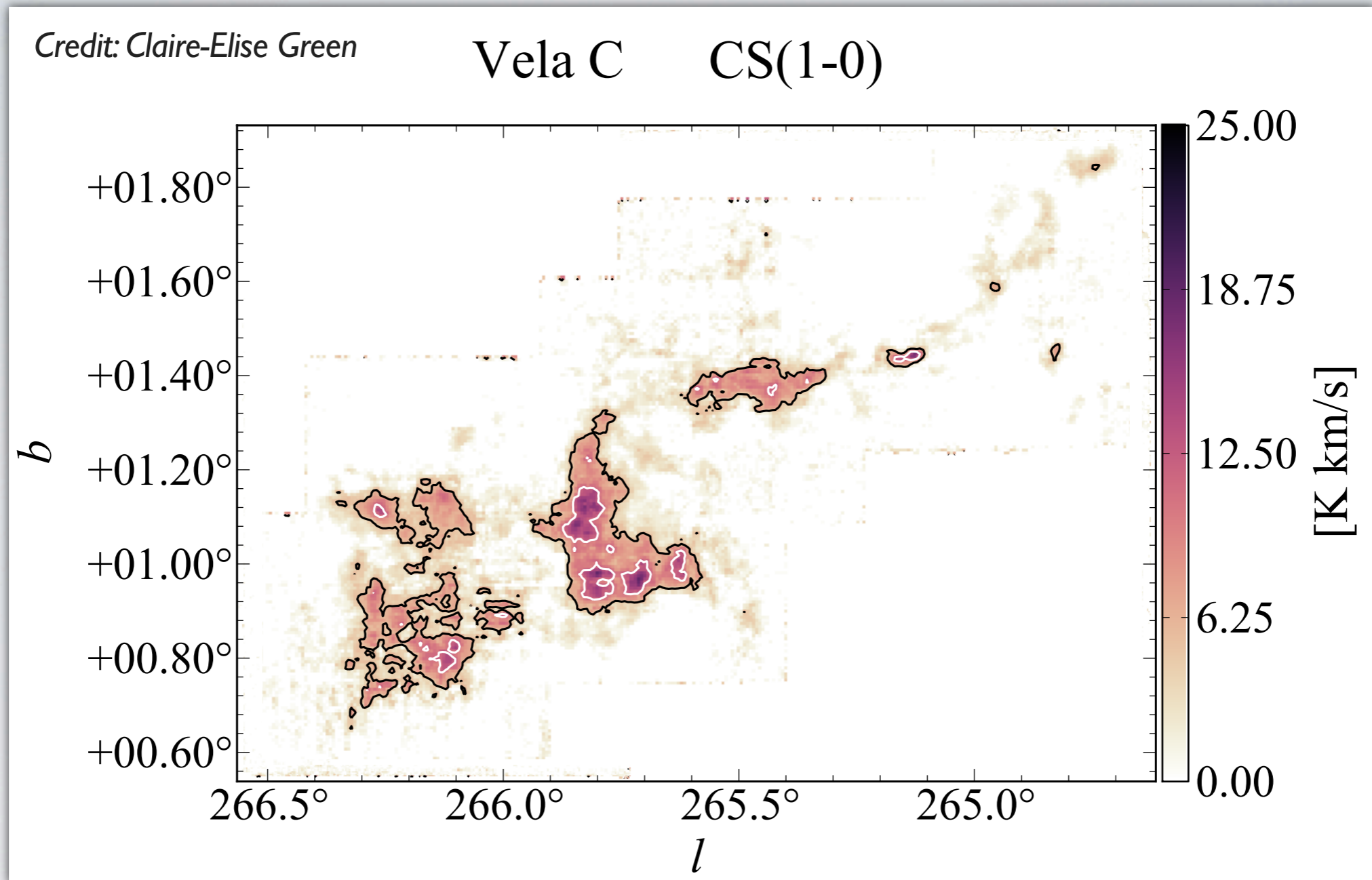
- **Link between filaments and star formation?**
- **Do filaments share common properties?**
- **Role of magnetic fields in filament formation and stability?**
- **Best ways to identify filaments?**

Molecular Filaments with Mopra



- **Link between filaments and star formation?**
- **Do filaments share common properties?**
- **Role of magnetic fields in filament formation and stability?**
- **Best ways to identify filaments?**

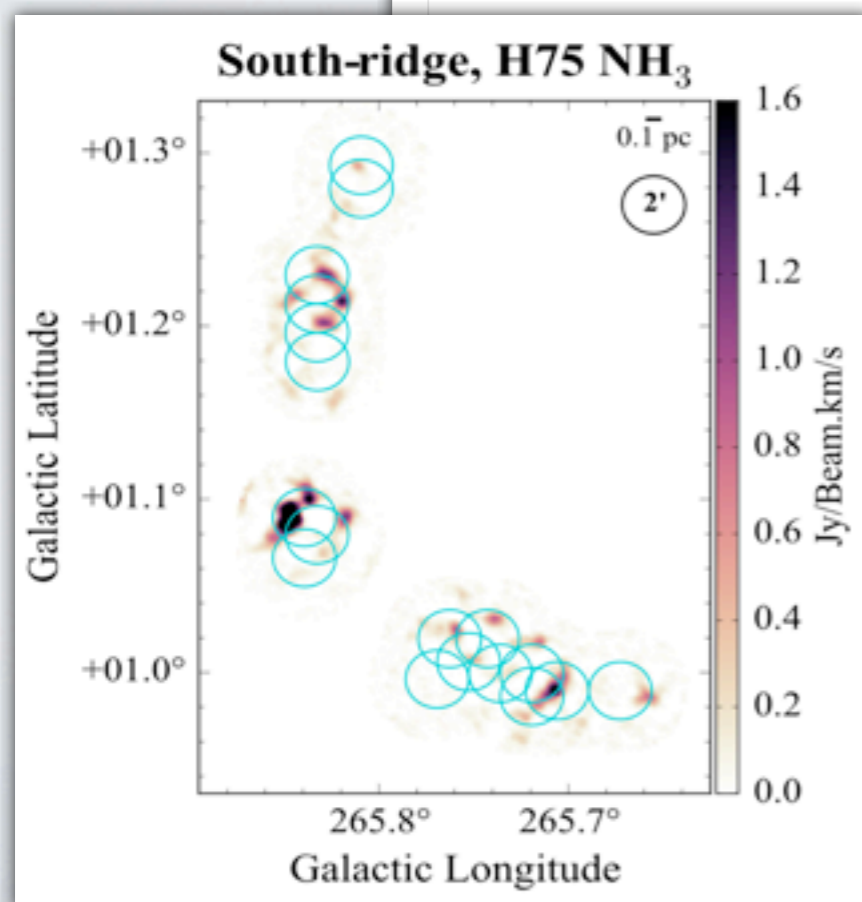
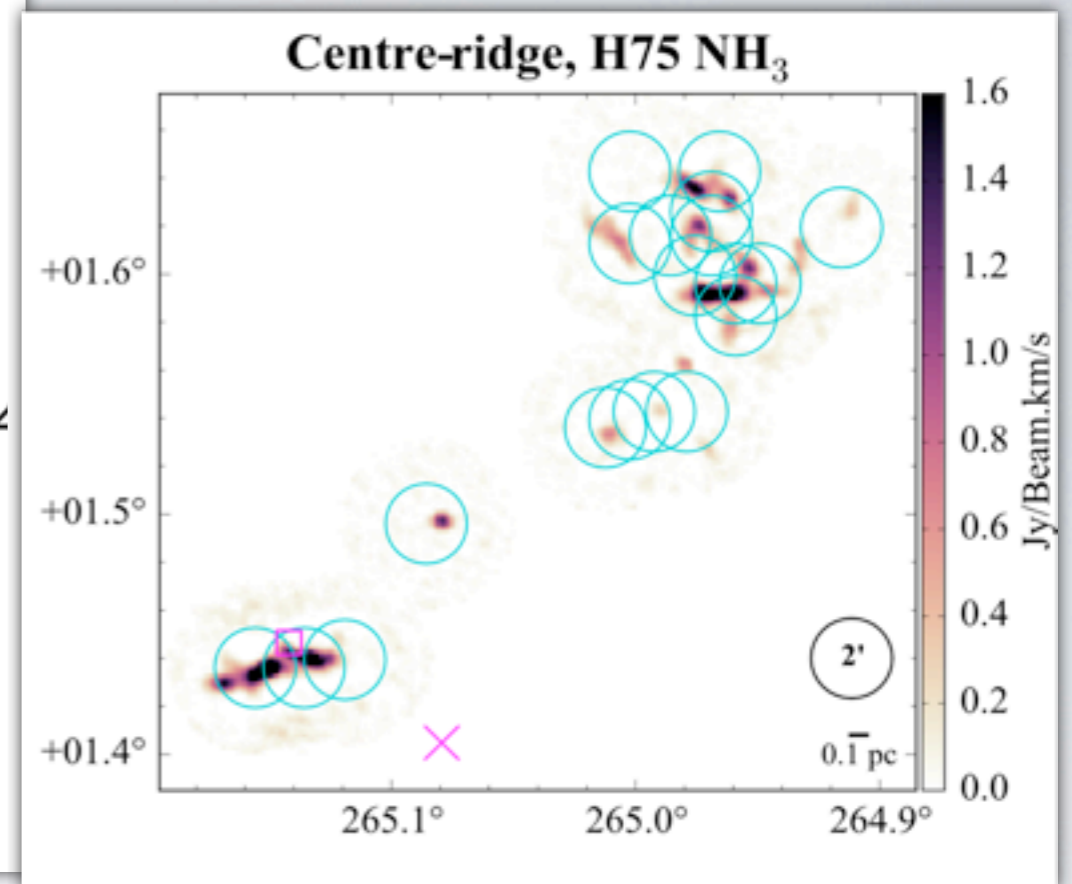
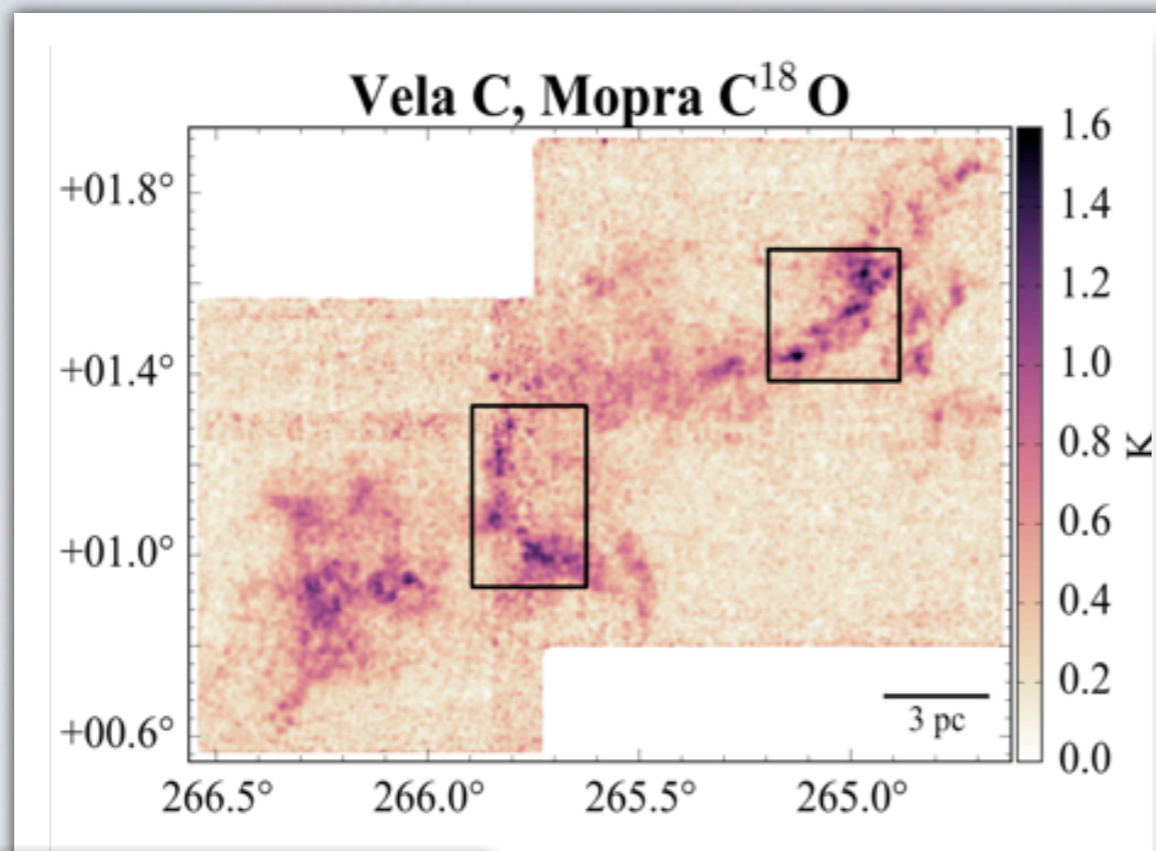
Molecular Filaments with Mopra



- **Link between filaments and star formation?**
- **Do filaments share common properties?**
- **Role of magnetic fields in filament formation and stability?**
- **Best ways to identify filaments?**

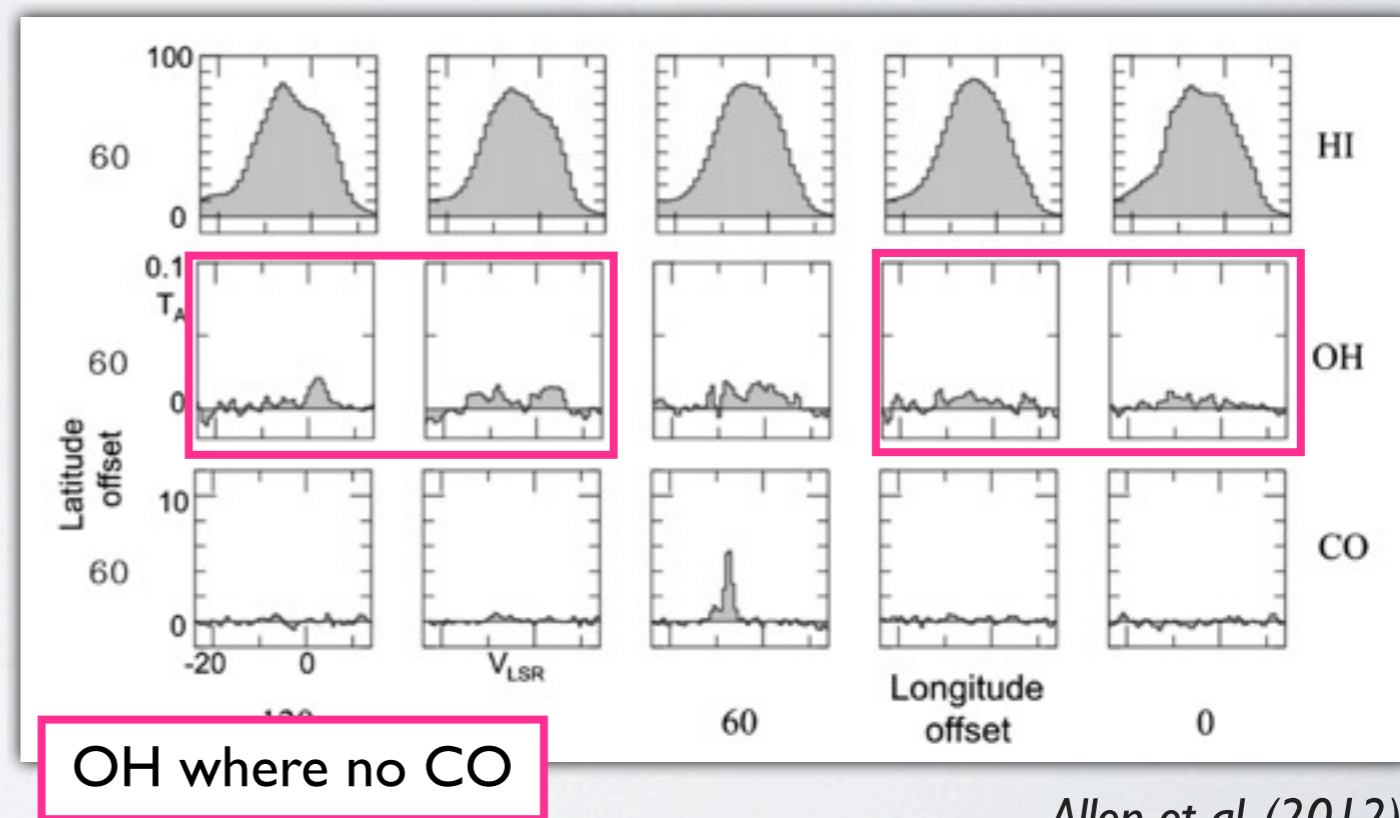
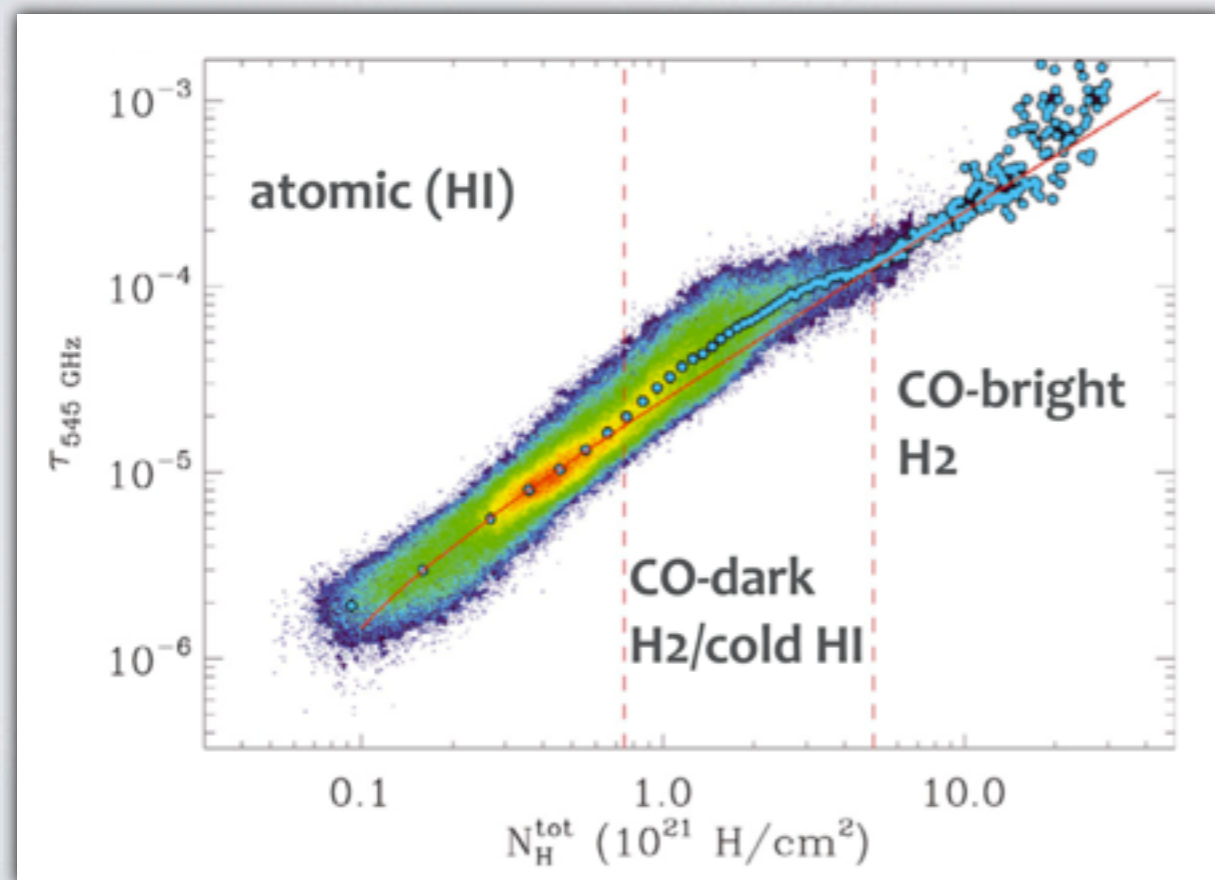
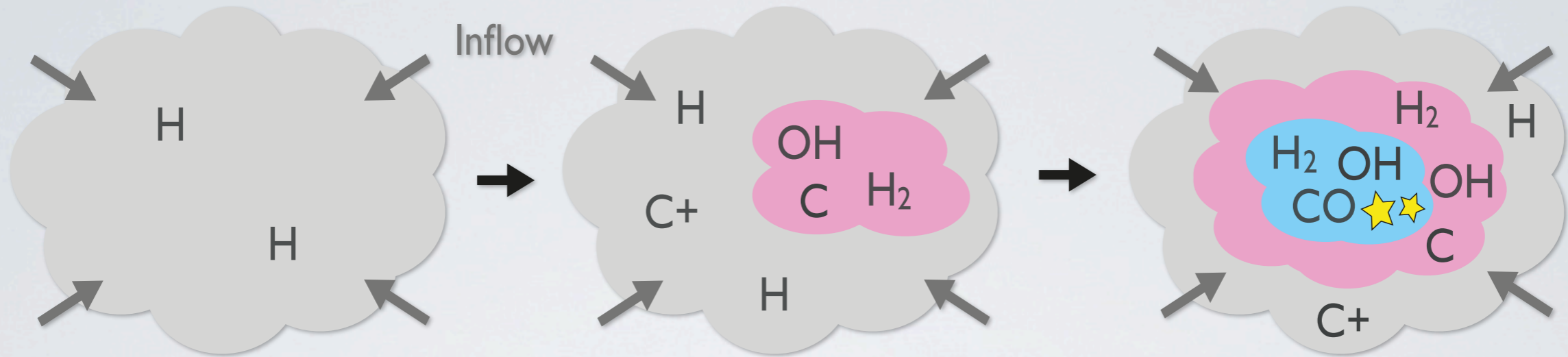
Molecular Filaments with Mopra

Images courtesy
of Claire-Elise
Green



**Mopra can provide single dish data for
combination with ATCA**

SPLASH - Seeking CO-dark H₂

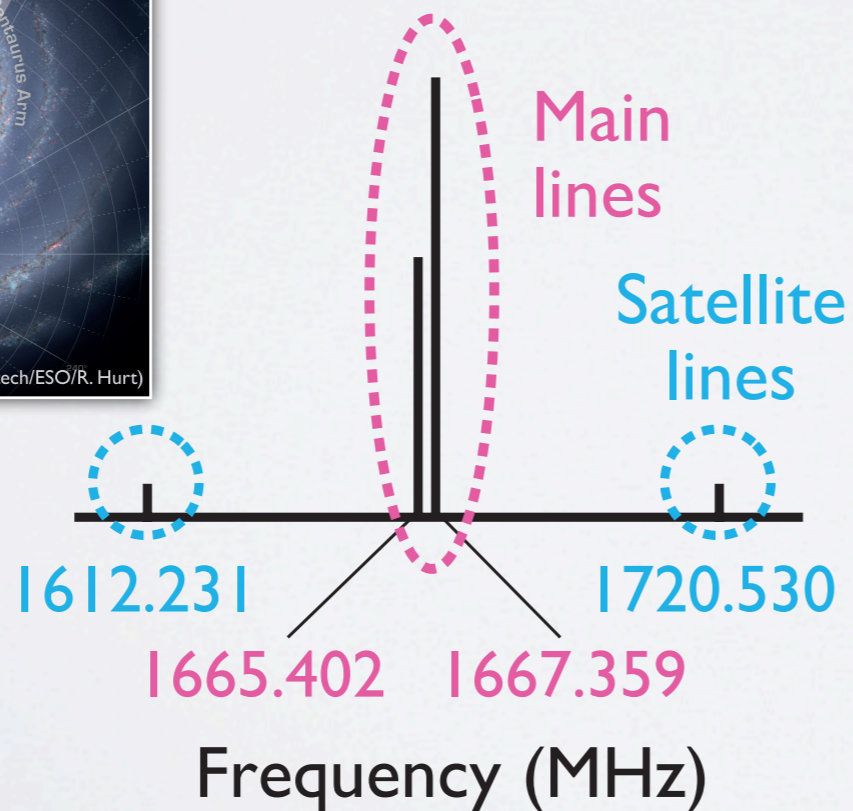
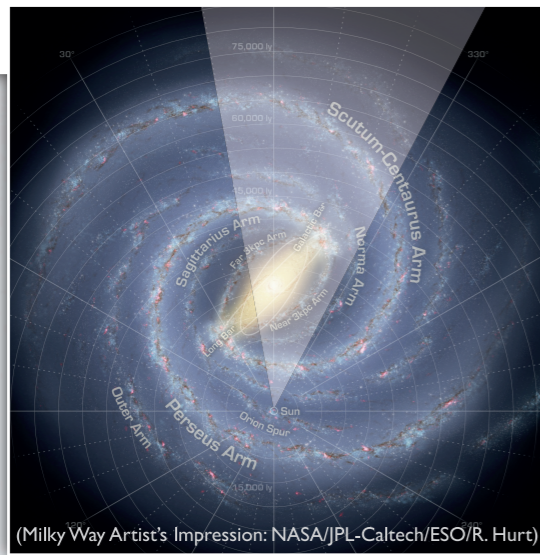
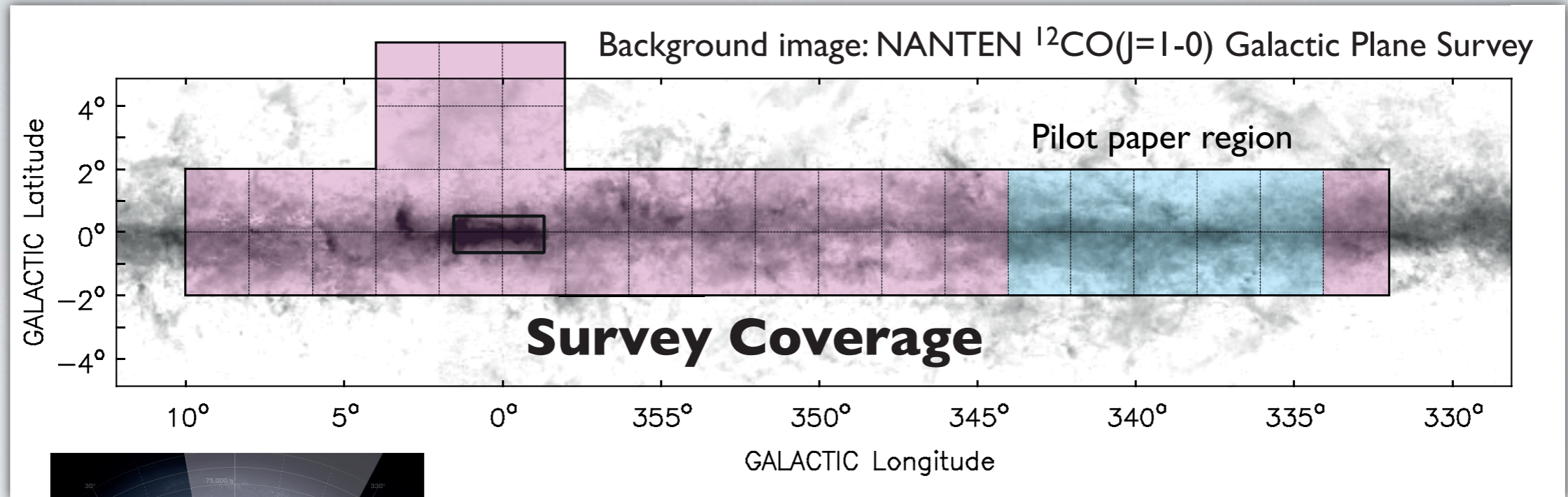


OH where no CO

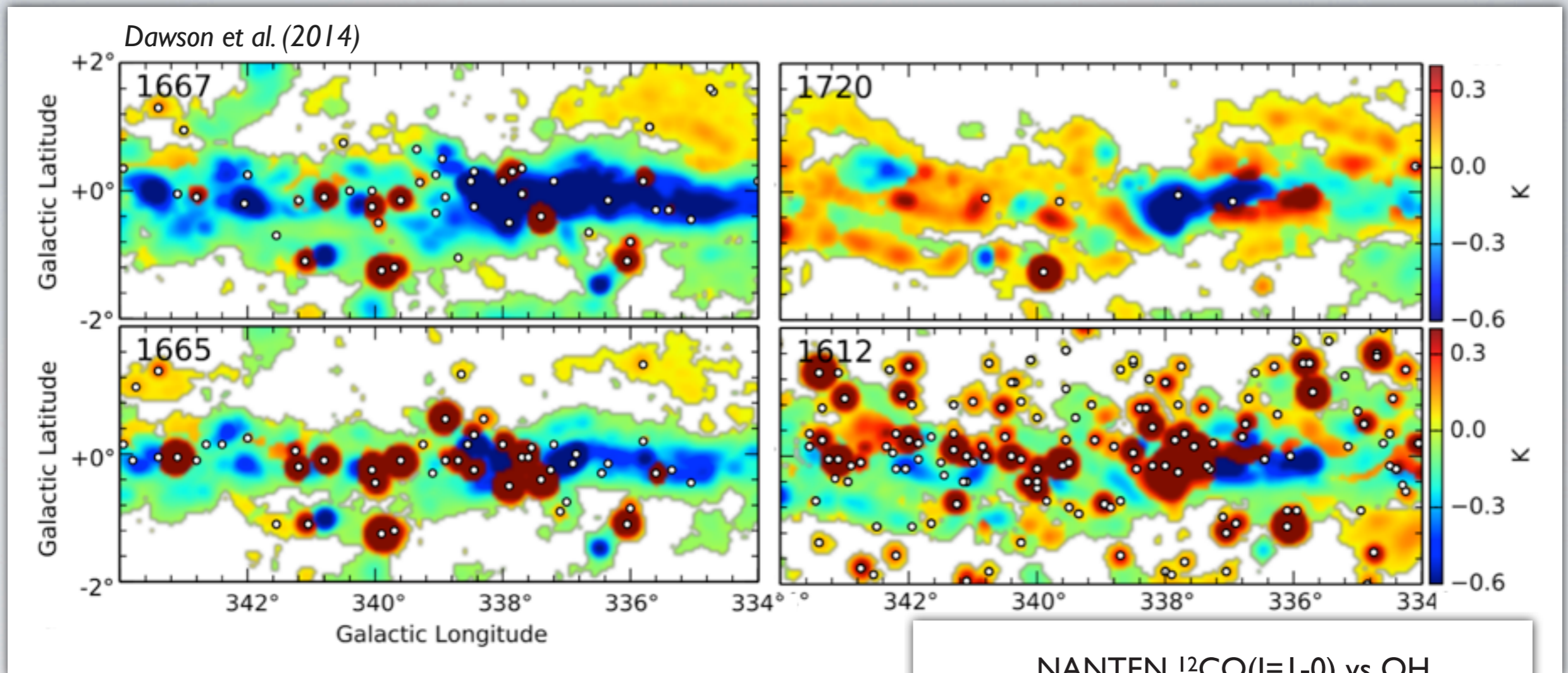
Allen et al. (2012)

SPLASH - Seeking CO-dark H₂

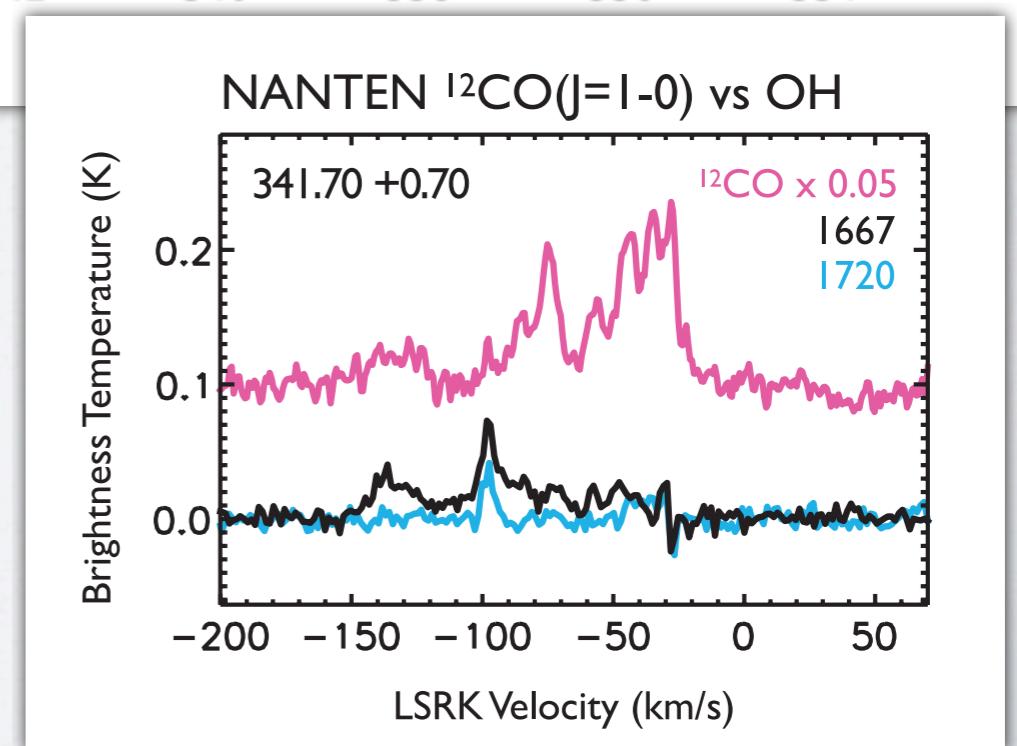
Southern Parkes Large-Area Survey in Hydroxyl



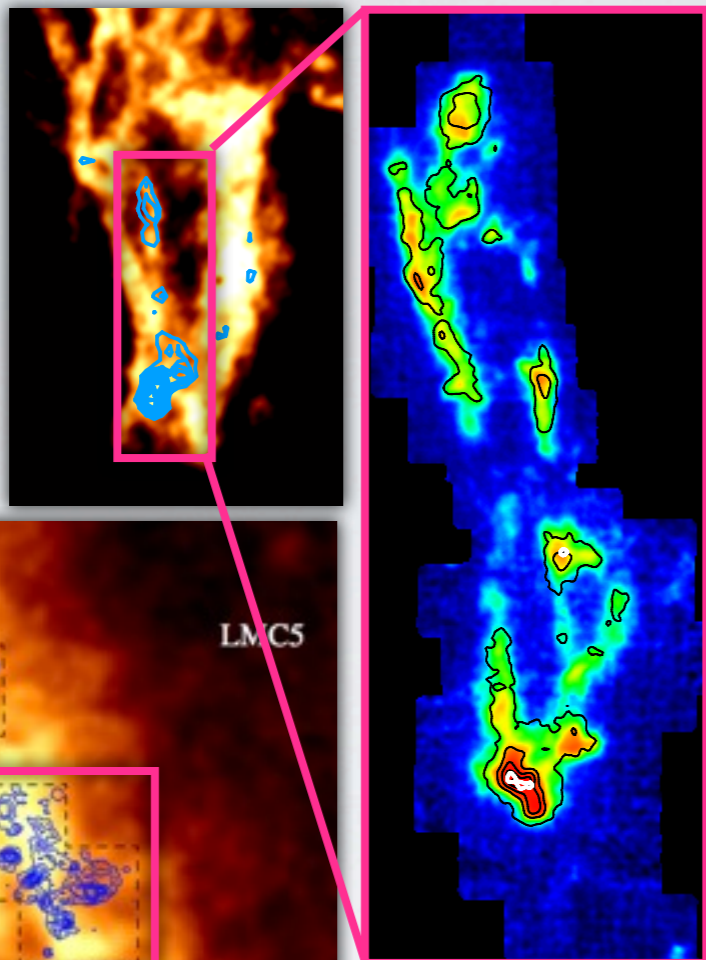
SPLASH - Seeking CO-dark H₂



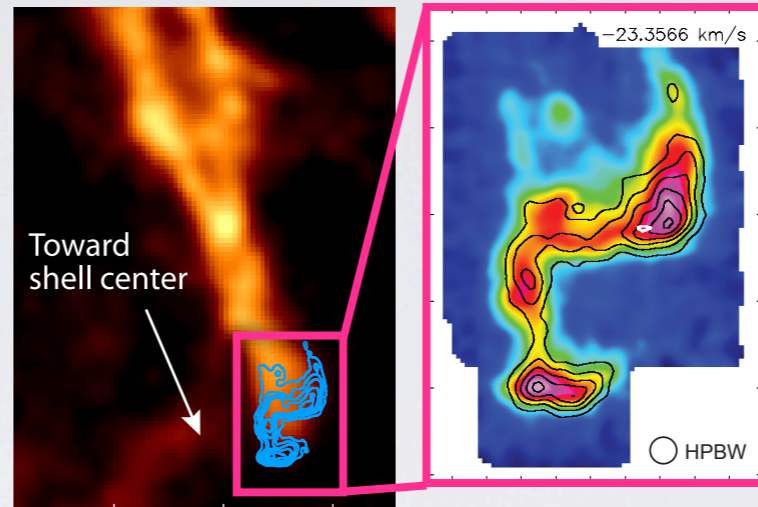
- **Comparison with (multi-line) CO surveys essential!**
- **Mopra surveys: The Mopra Southern Galactic Plane CO Survey, ThrUMMS, etc.**



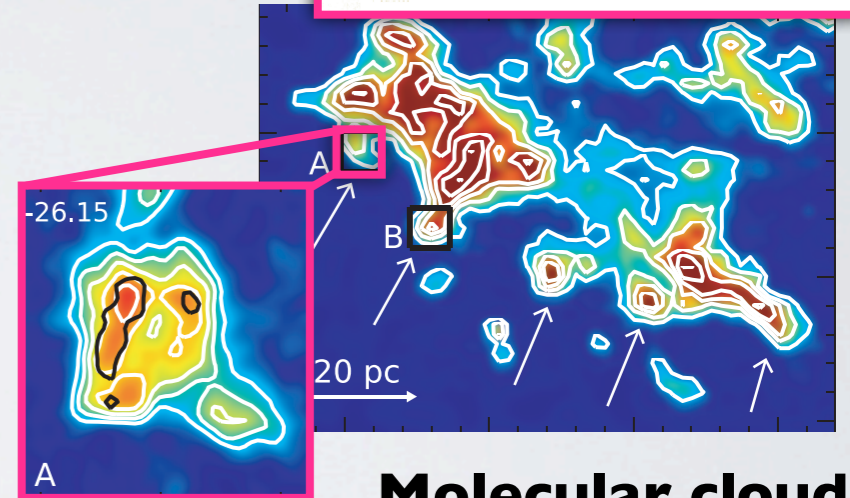
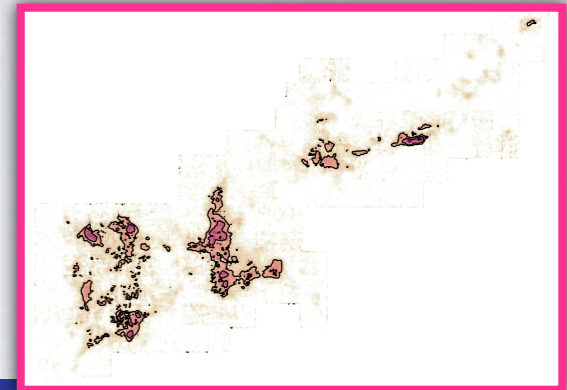
Summary



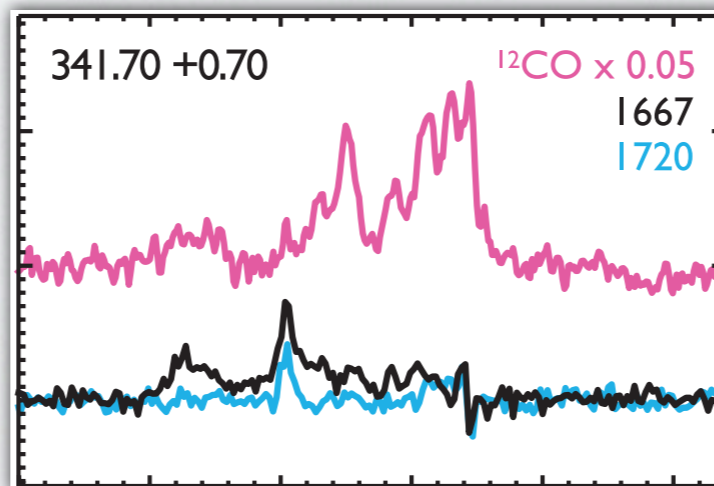
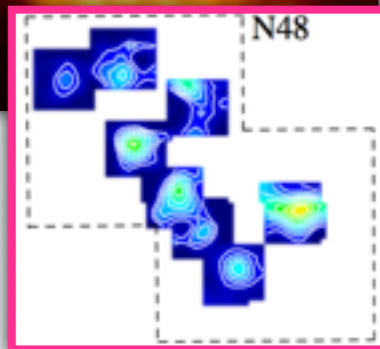
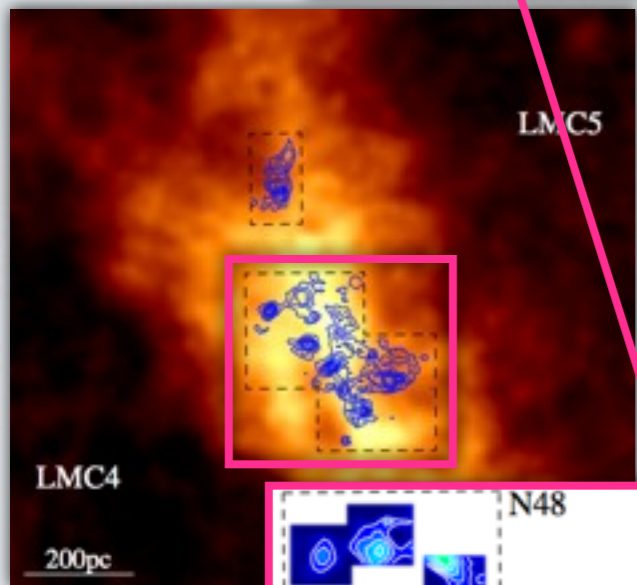
Molecular cloud formation



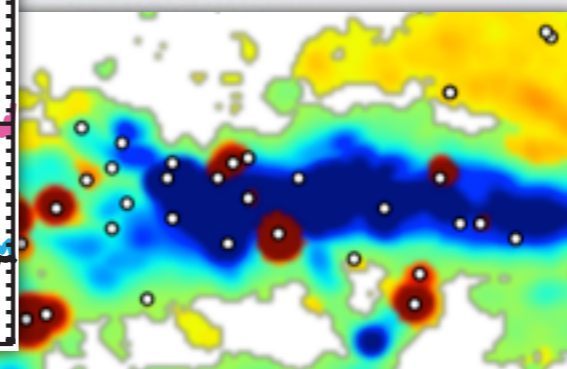
... and destruction



Molecular cloud structure



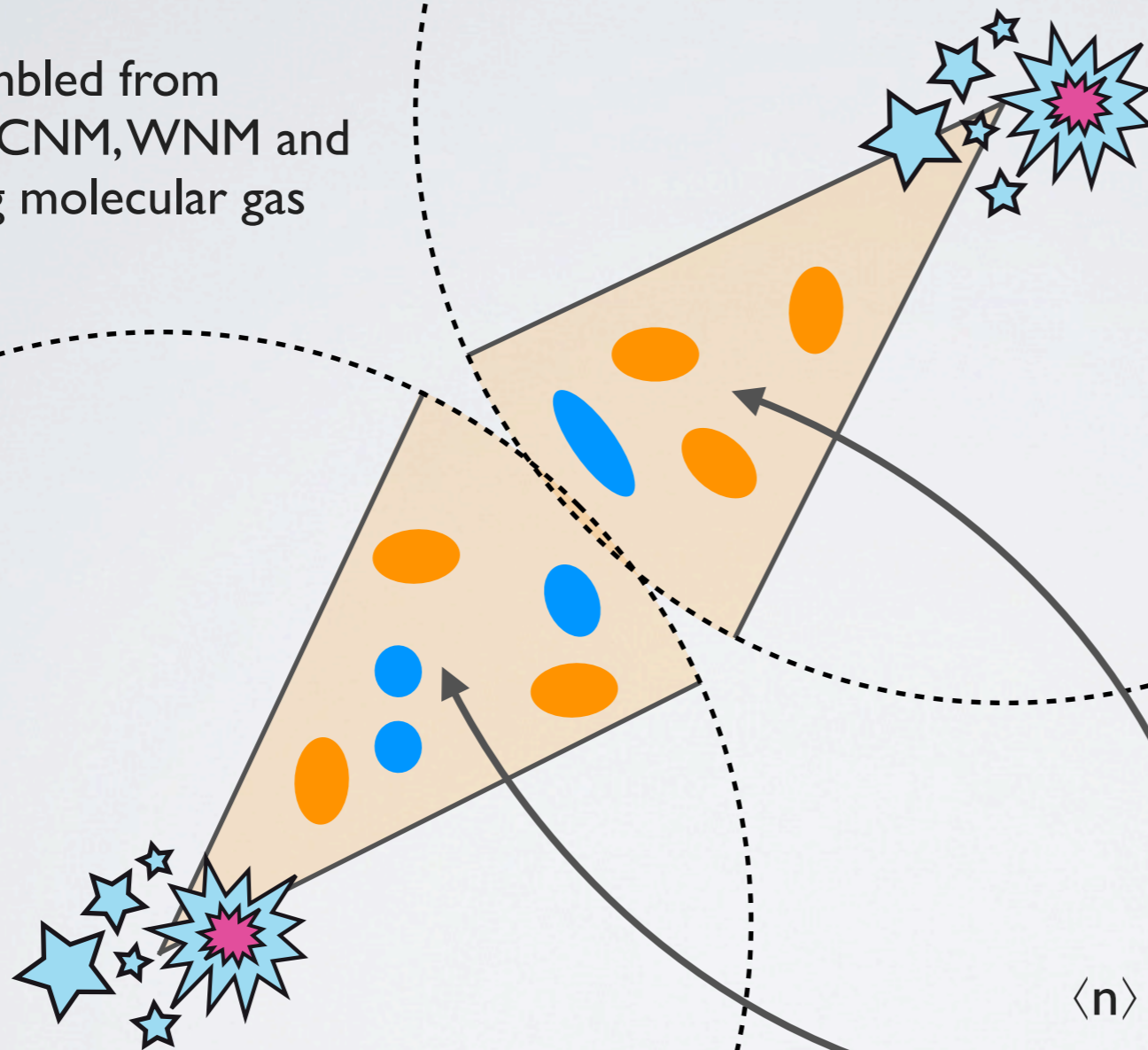
Search for the "dark" ISM?



GMC Formation at Supershell Collision Zones

Favoured Formation Scenario:

GMC assembled from mixture of CNM, WNM and pre-existing molecular gas



$\langle n \rangle \sim 10 \text{ cm}^{-3}$

WNM (0.5 cm^{-3}) + CNM (50 cm^{-3})
+ some molecular gas ($> 200 \text{ cm}^{-3}$)