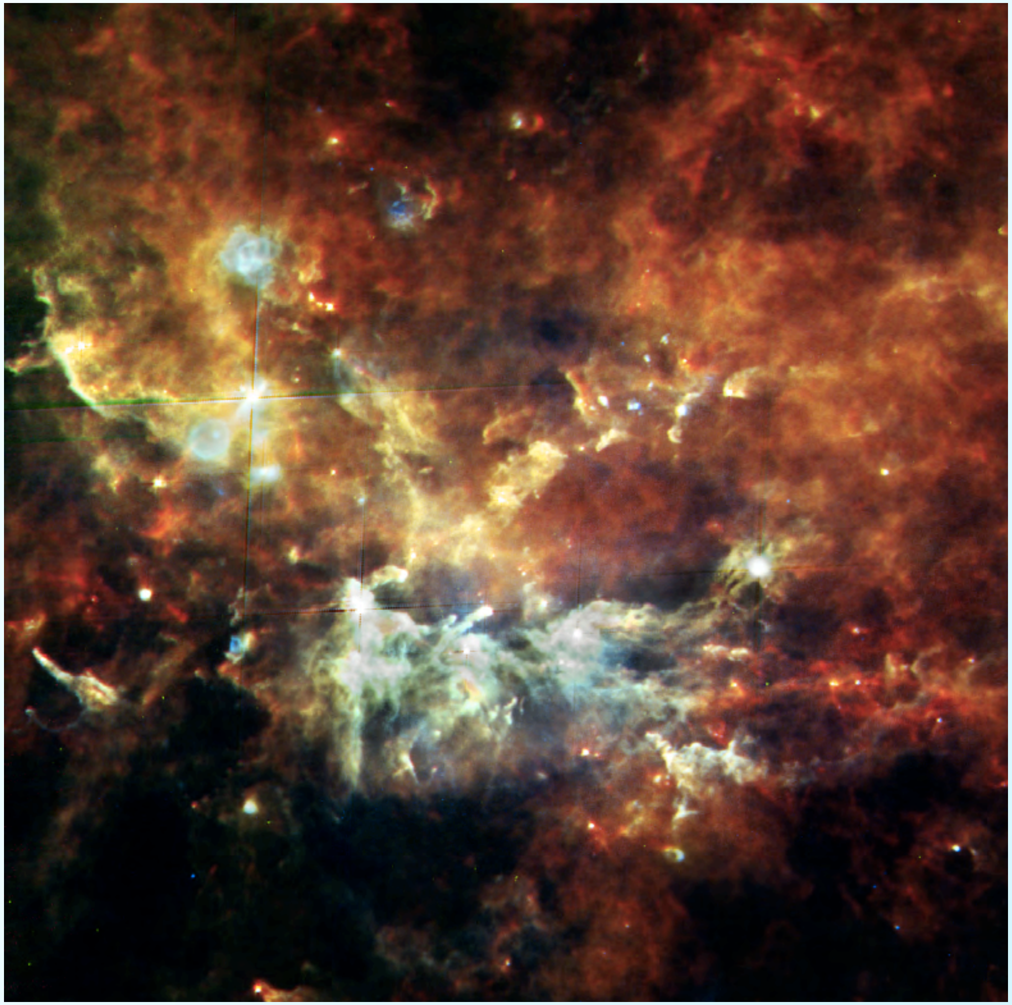
Cloud disruption via ionized feedback: testing simulations by tracing pillar dynamics in Vulpecula



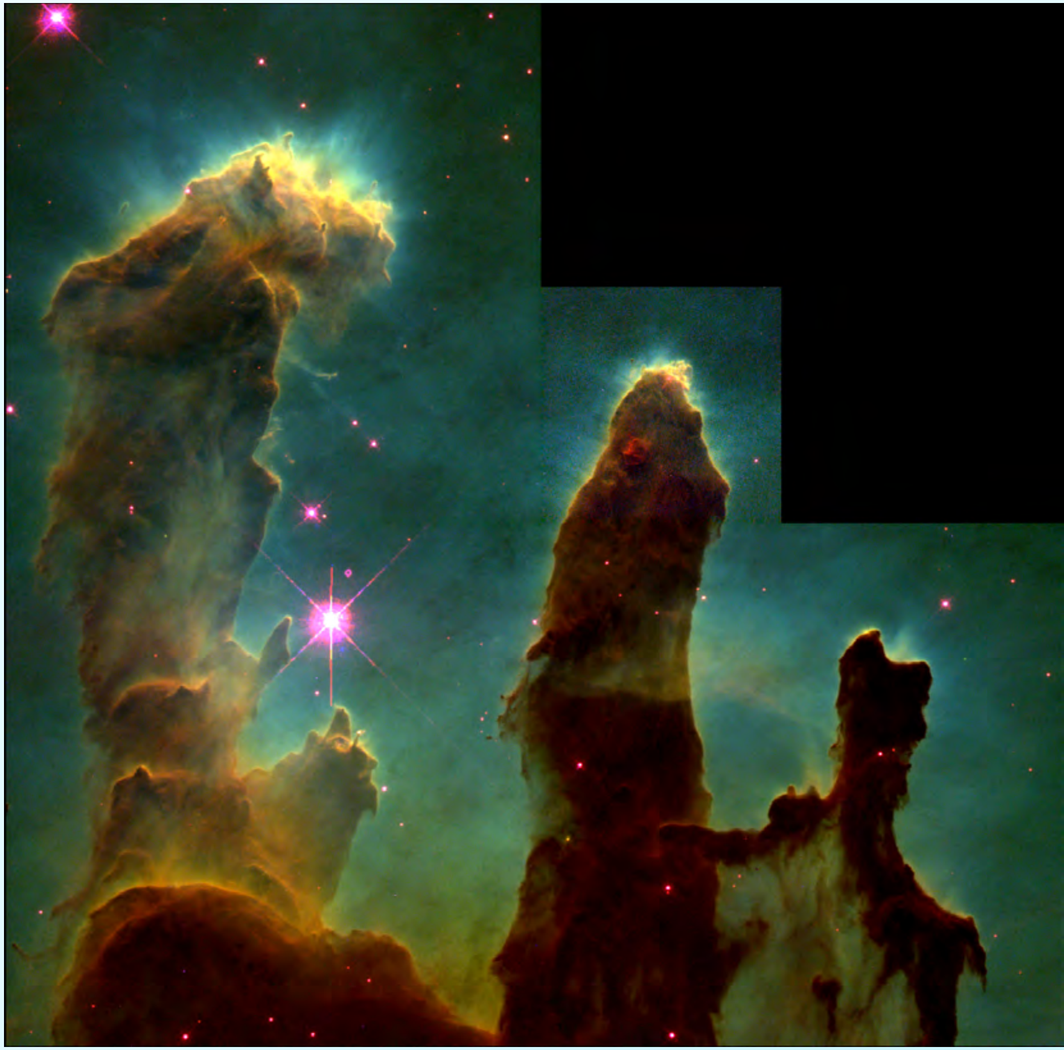
Joseph Mottram

with Pamela Klaassen, Jim Dale & Attila Juhasz

Introduction:
Pillars of Destruction

Pillars: Historical Context

- First discovered in the optical (Minkowski 1949)
- Associated with irradiated molecular clouds
- Multi-wavelength high resolution continuum studies only possible recently



Optical

Image credit: ESA

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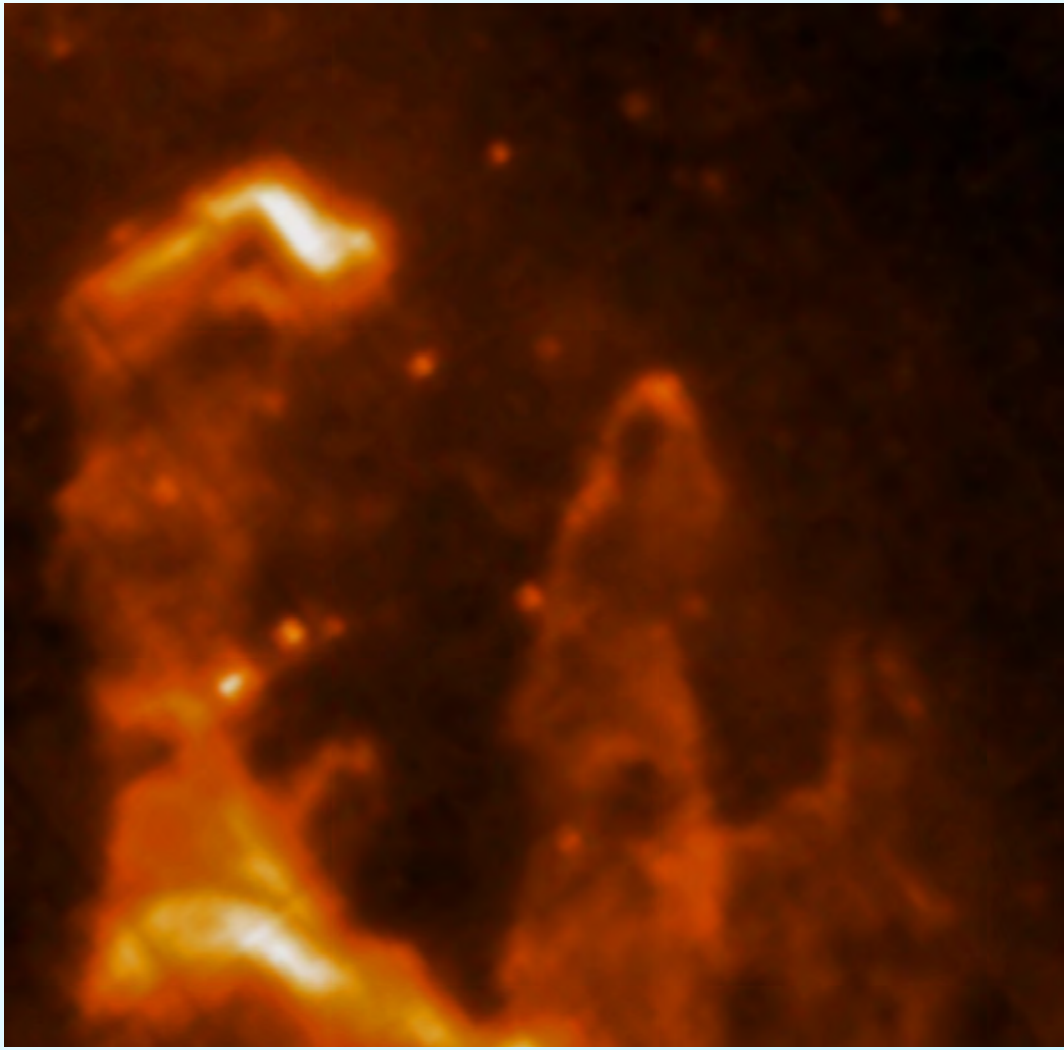


Mid-IR

Image credit: ESA

Pillars: What do they tell us?

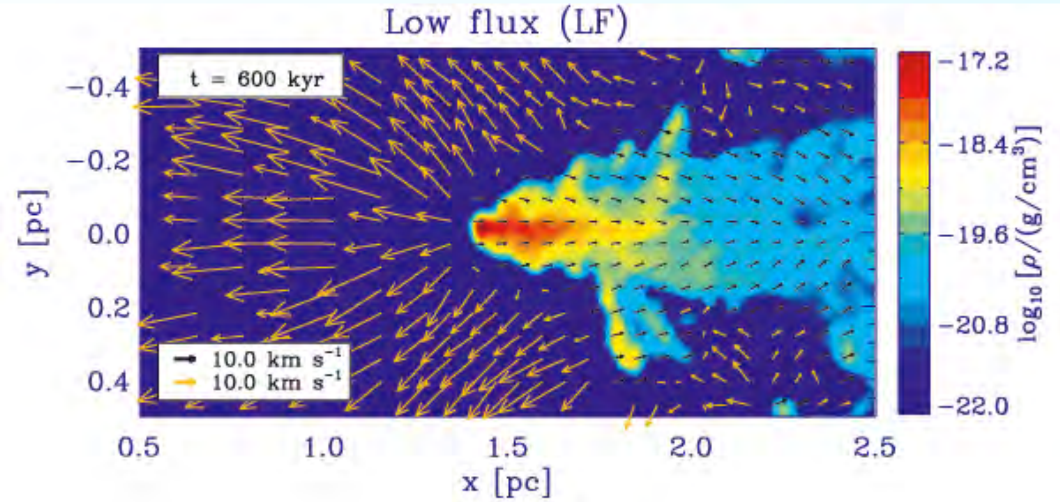
- How and at what rate ionising feedback destroys clouds affects:
  - global and local star formation efficiency
  - evolution of revealed protostars (and their disks)
  - early cluster evolution
  - impact of supernovae and propagation of enriched material

- Pillars are a diagnostic of initial density variations and current feedback conditions

Pillars: Current Models

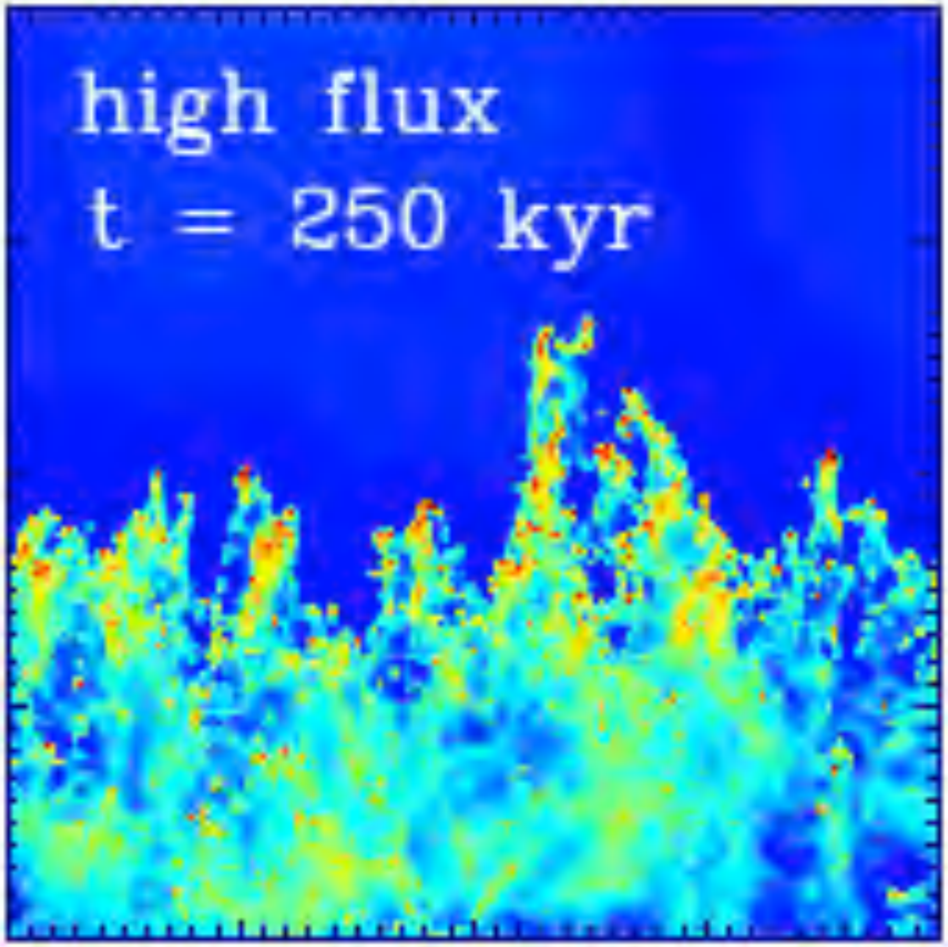
- Starting from different initial conditions, all form pillars which look ok, so shape is not a discriminant
- Predict different kinematics

Pillars: Current Models



- Example 1 (G09):
  - Paper: Gritschneder+ 2009
  - RDI of a Bonnor-Ebert Sphere
  - Global pillar motion relative to cloud: negligible
  - Velocity dispersion: 1-2km/s
  - Internal flows: yes

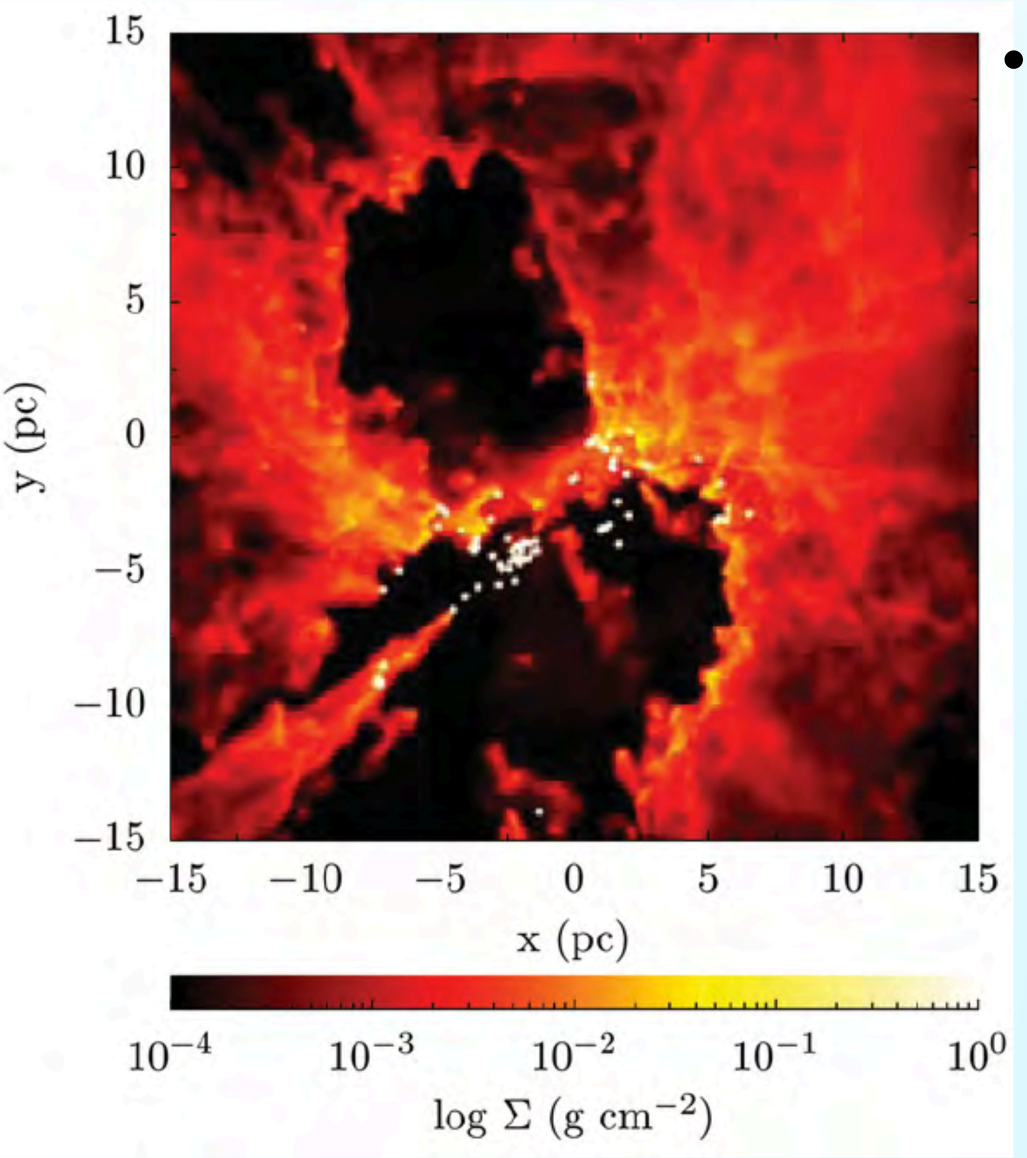
Pillars: Current Models



Colourscale = density

- Example 2 (G10):
  - Paper: Gritschneder+ 2010
  - Planar ionising flux hitting a supersonic medium
  - Global pillar motion relative to cloud: negligible
  - Velocity dispersion: >3 km/s
  - Internal flows: yes

Pillars: Current Models

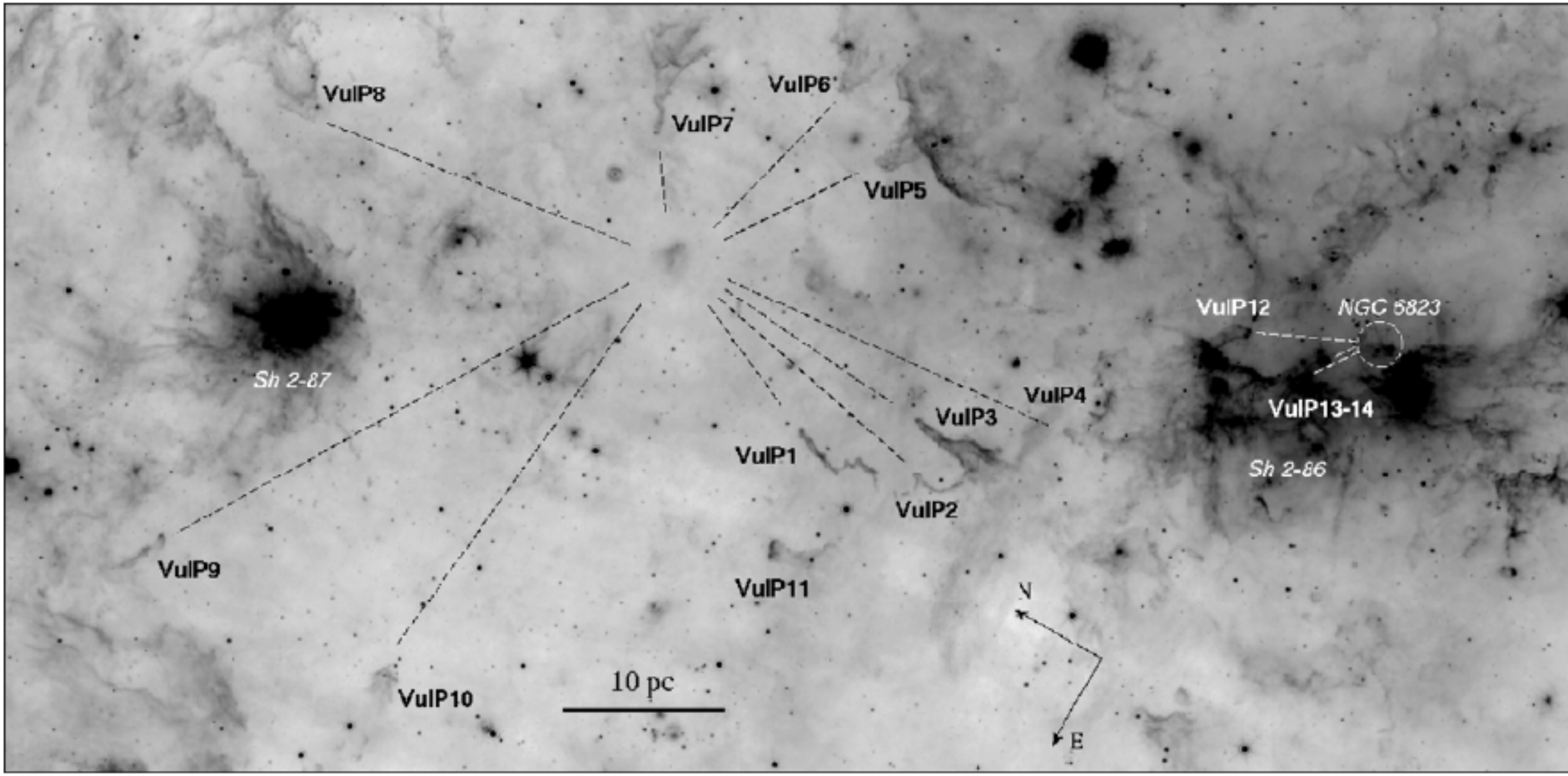


- Example 3 (D12):
  - Paper: Dale+ 2012
  - Ionising cluster inside a filamentary molecular cloud
  - Global pillar motion relative to cloud: 3 km/s
  - Velocity dispersion: ~1 km/s
  - Internal flows: no

Vulpecula:
Ideal for a proof of concept

Vulpecula: The One Minute Guide

Image credit: Billot+, 2010



- Active nearby (2.3 kpc) star formation region
- Many pillars in observations of various surveys

Vulpecula: The One Minute Guide

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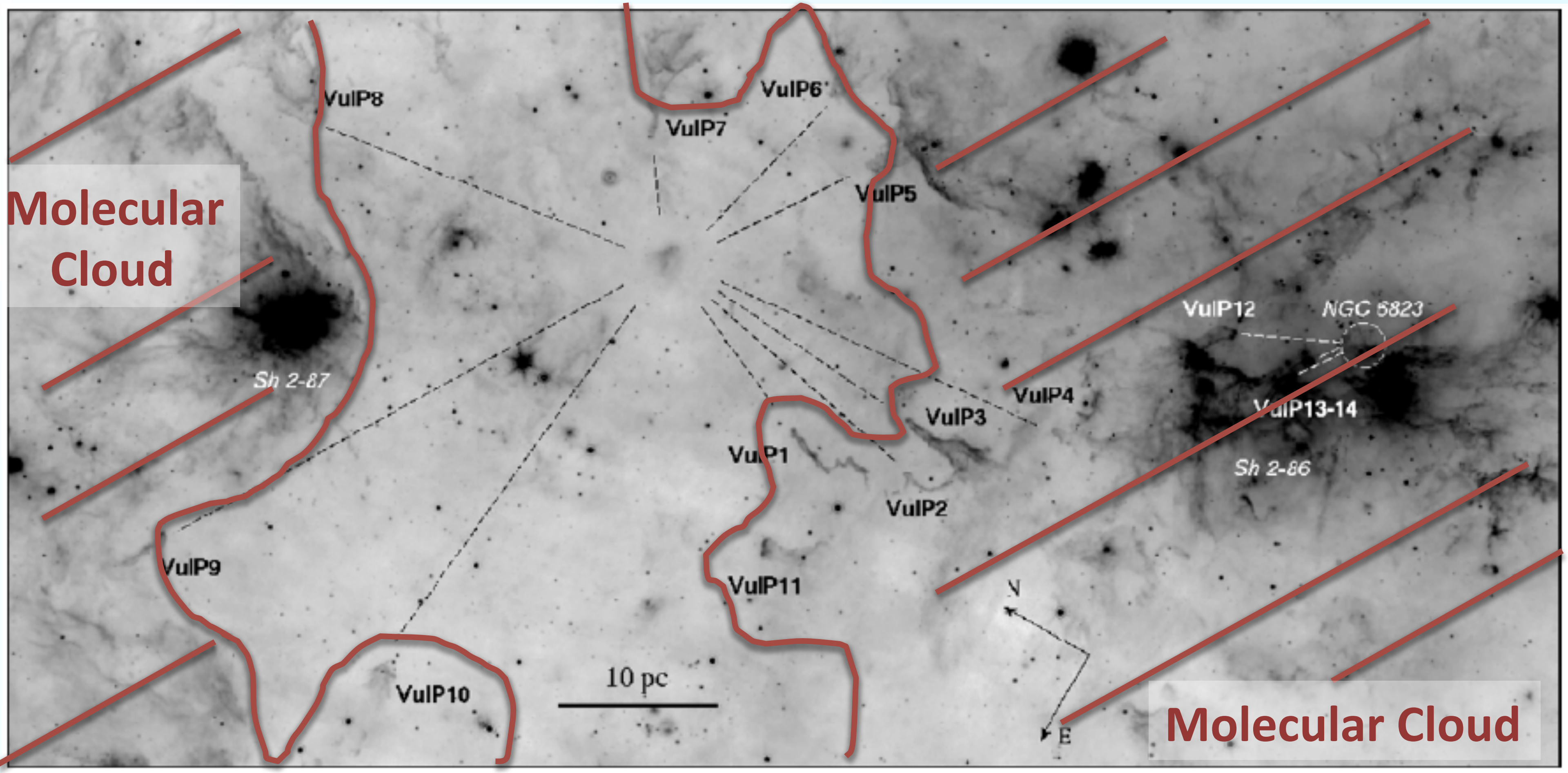

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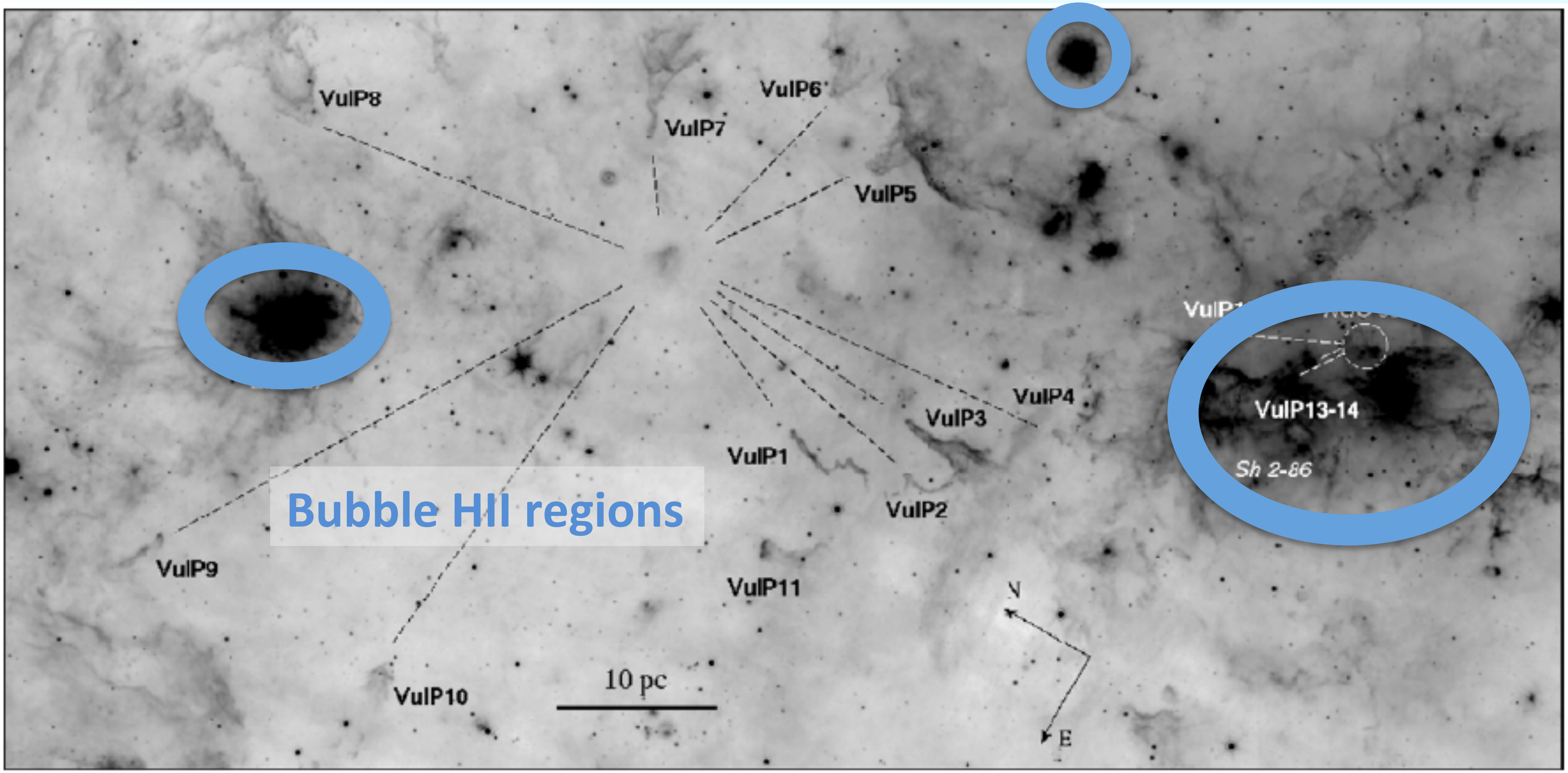

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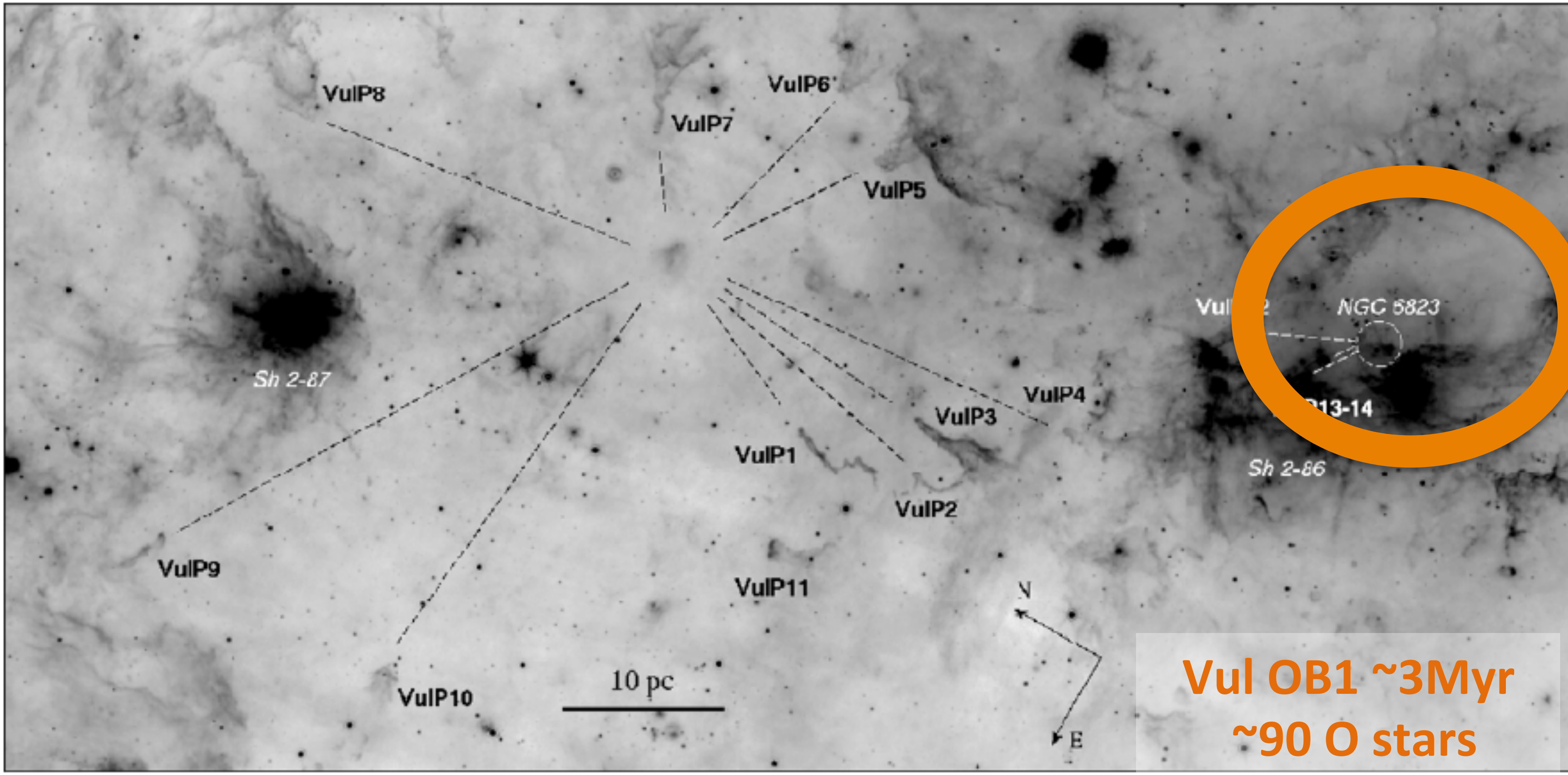

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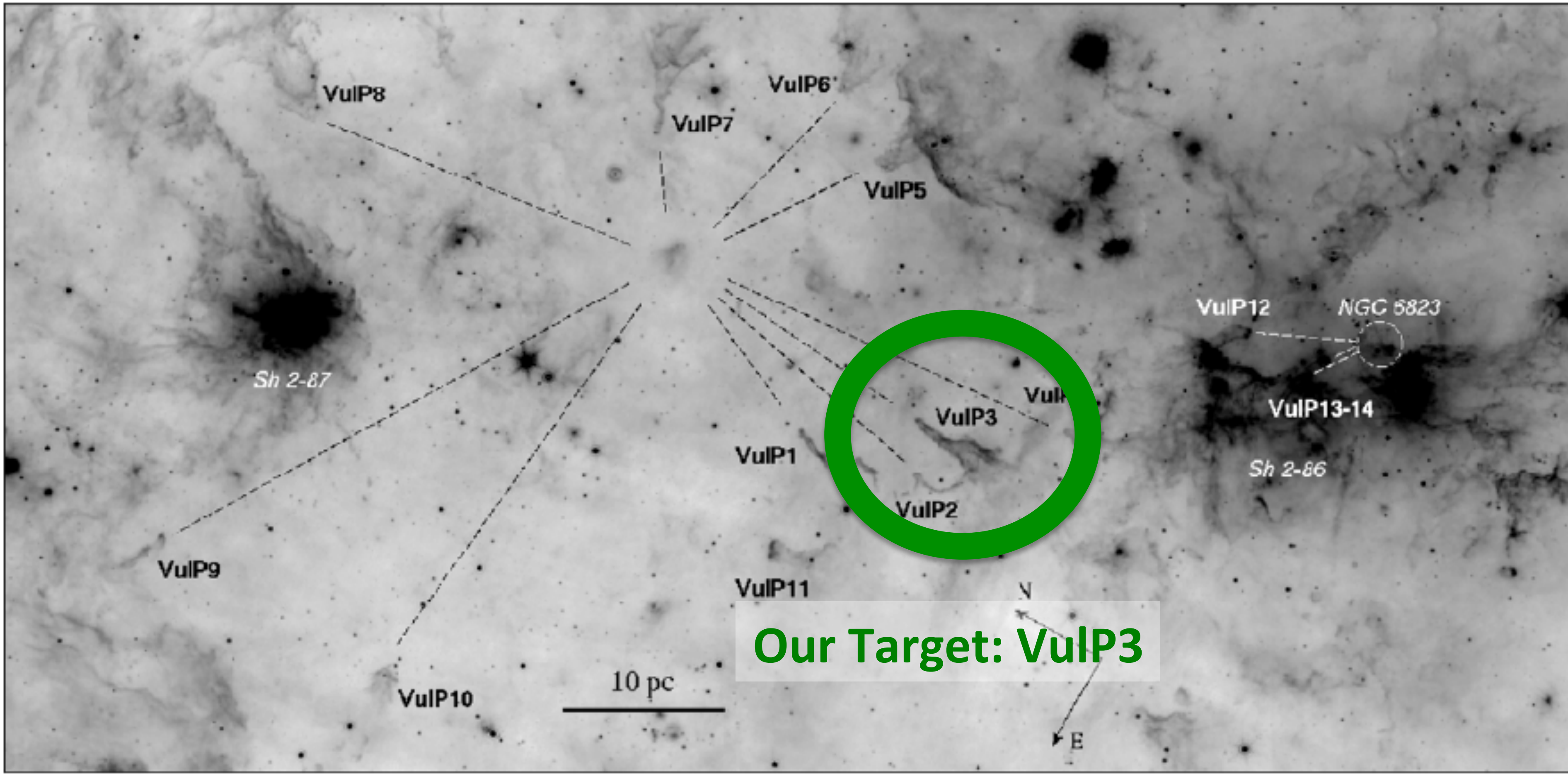

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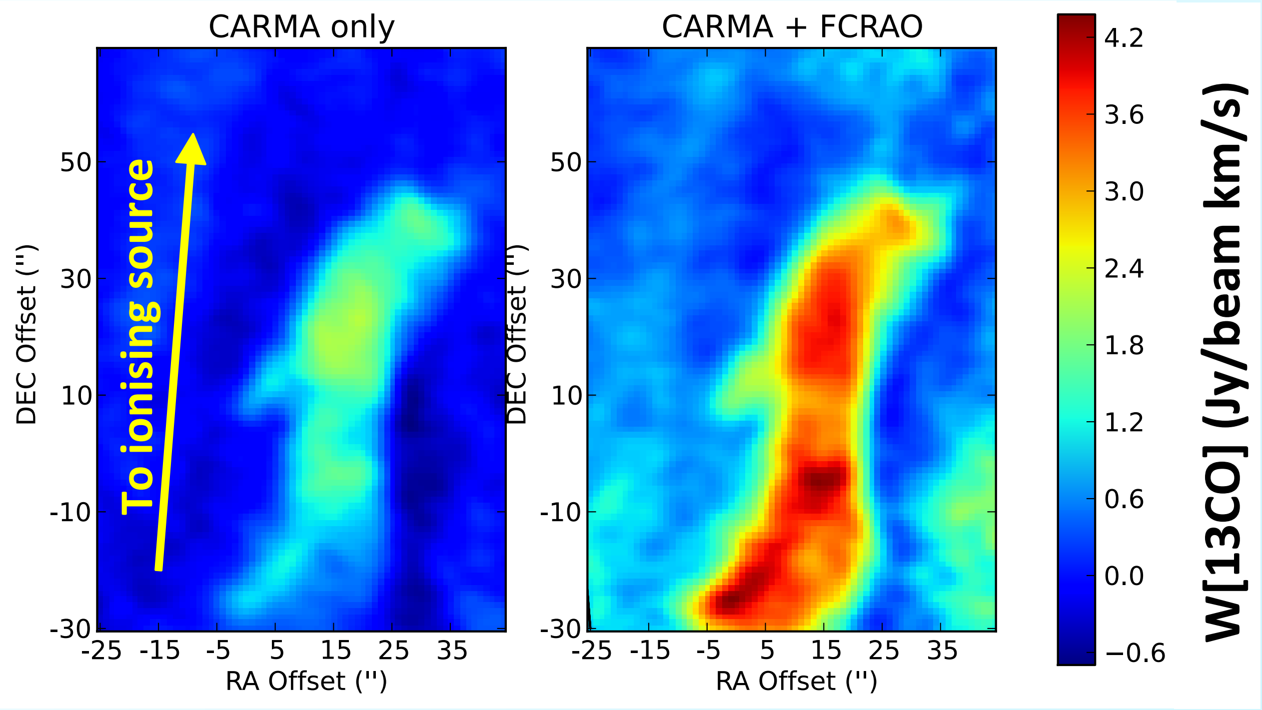
Cloud disruption via ionized feedback: tracing pillar dynamics in Vulpecula

Klaassen, Mottram, Dale & Juhasz, 2014, MNRAS, 441, 656

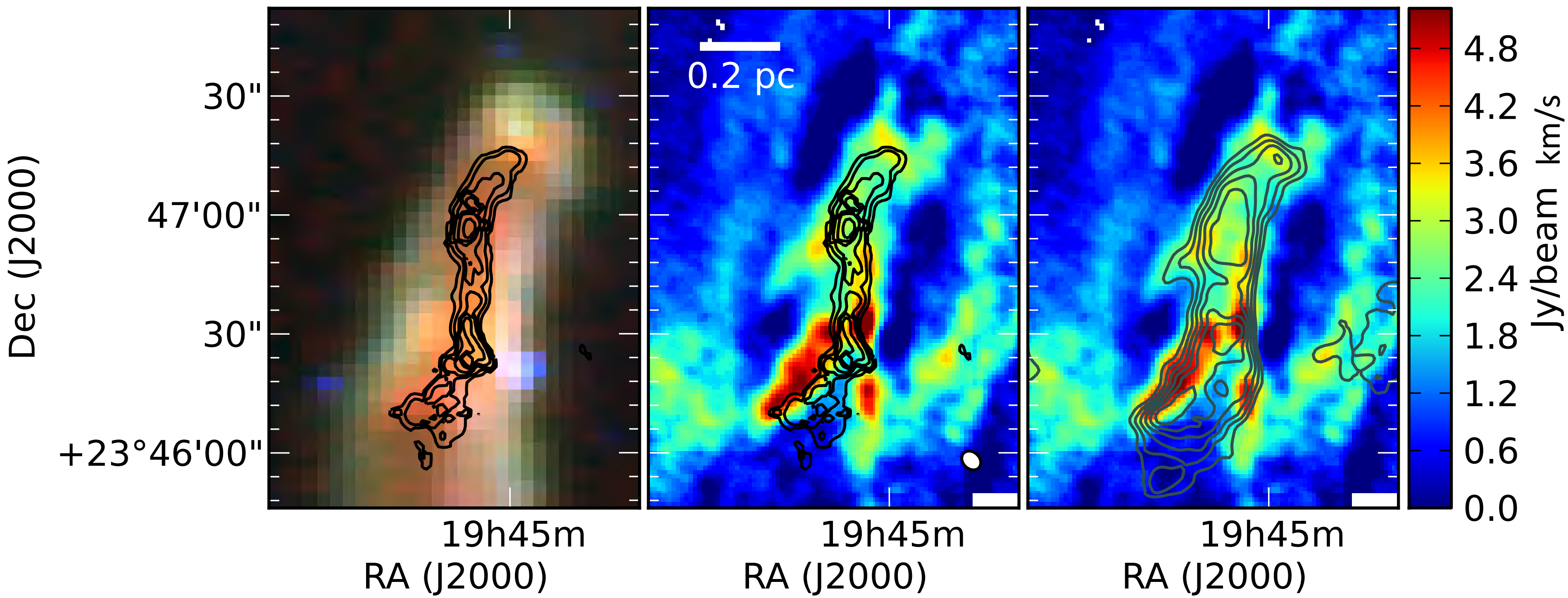
Observations

- Tip of VulP3 from Billot+, 2010 observed with CARMA D-array in ^{12}CO, ^{13}CO and C^{18}O J=1-0
- Data from Exeter FCRAO CO survey (Brunt+, Mottram+, in prep.) used for zero-spacing



Physical Conditions

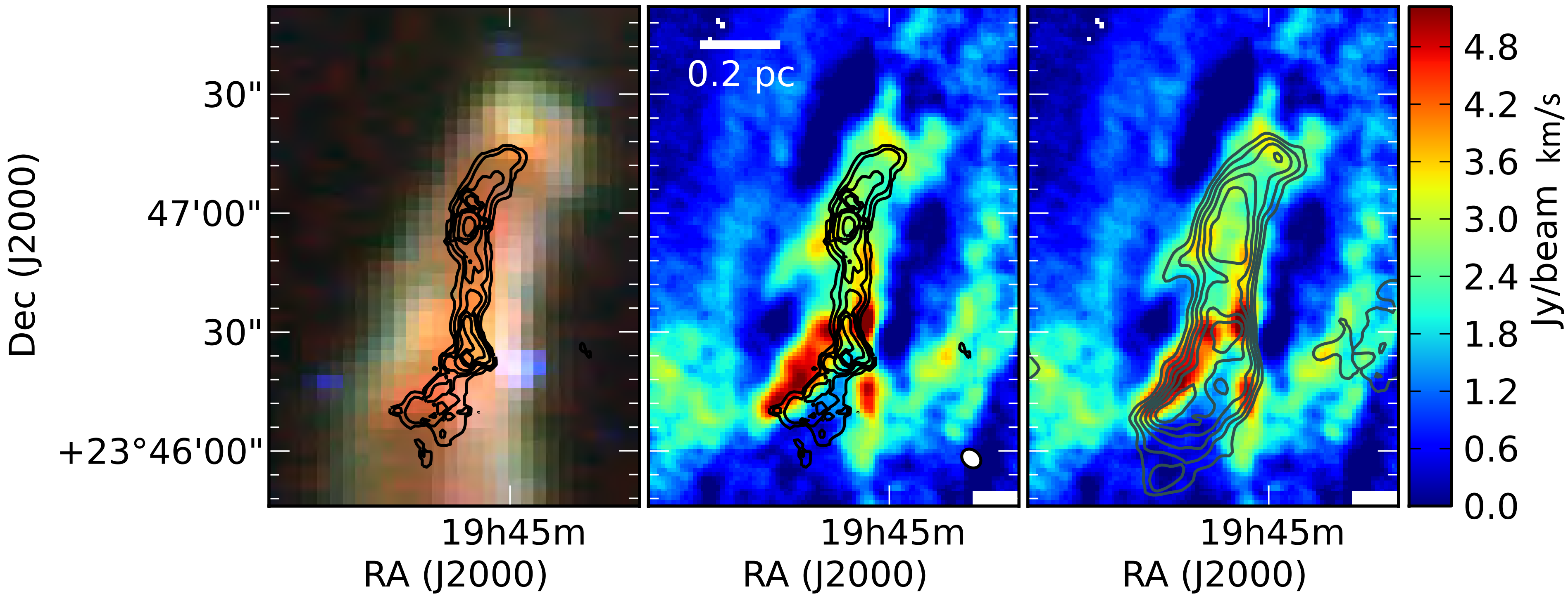
- Mean T_{dust}=18K from greybody fits to Hi-GAL maps
- Mean N[H2] = 8×10^{21} cm^{-3} from ^{13}CO



Image=	8, 24 & 70 micron	W[^{12}CO]	W[^{12}CO]
Contours=	W[C^{18}O]	W[C^{18}O]	W[^{13}CO]

Physical Conditions

- $n \sim 8 \times 10^3$ cm^{-3} assuming pillar is a cylinder
- $M = 94 M_\odot$ from ^{13}CO, $91 M_\odot$ from dust



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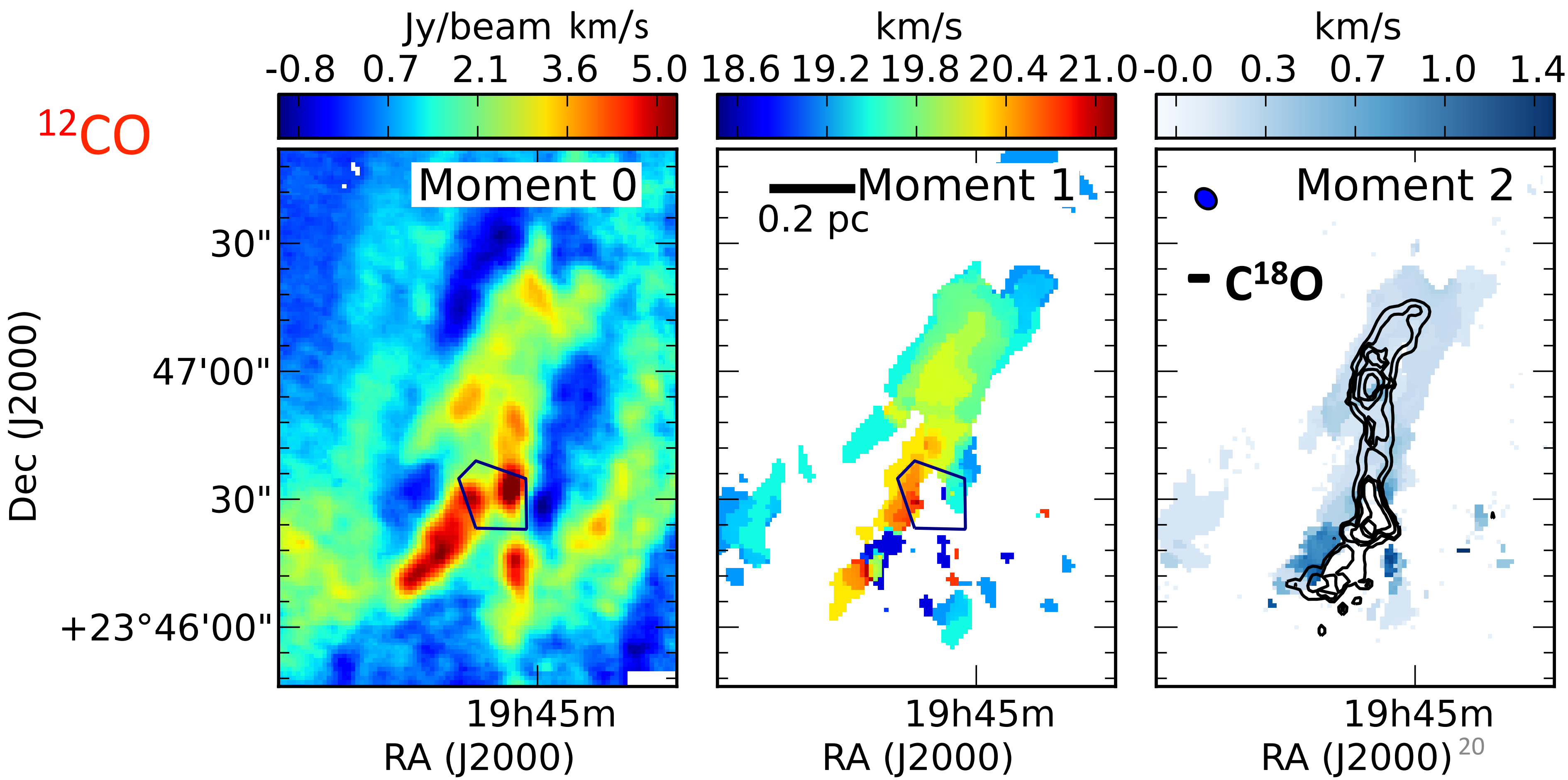
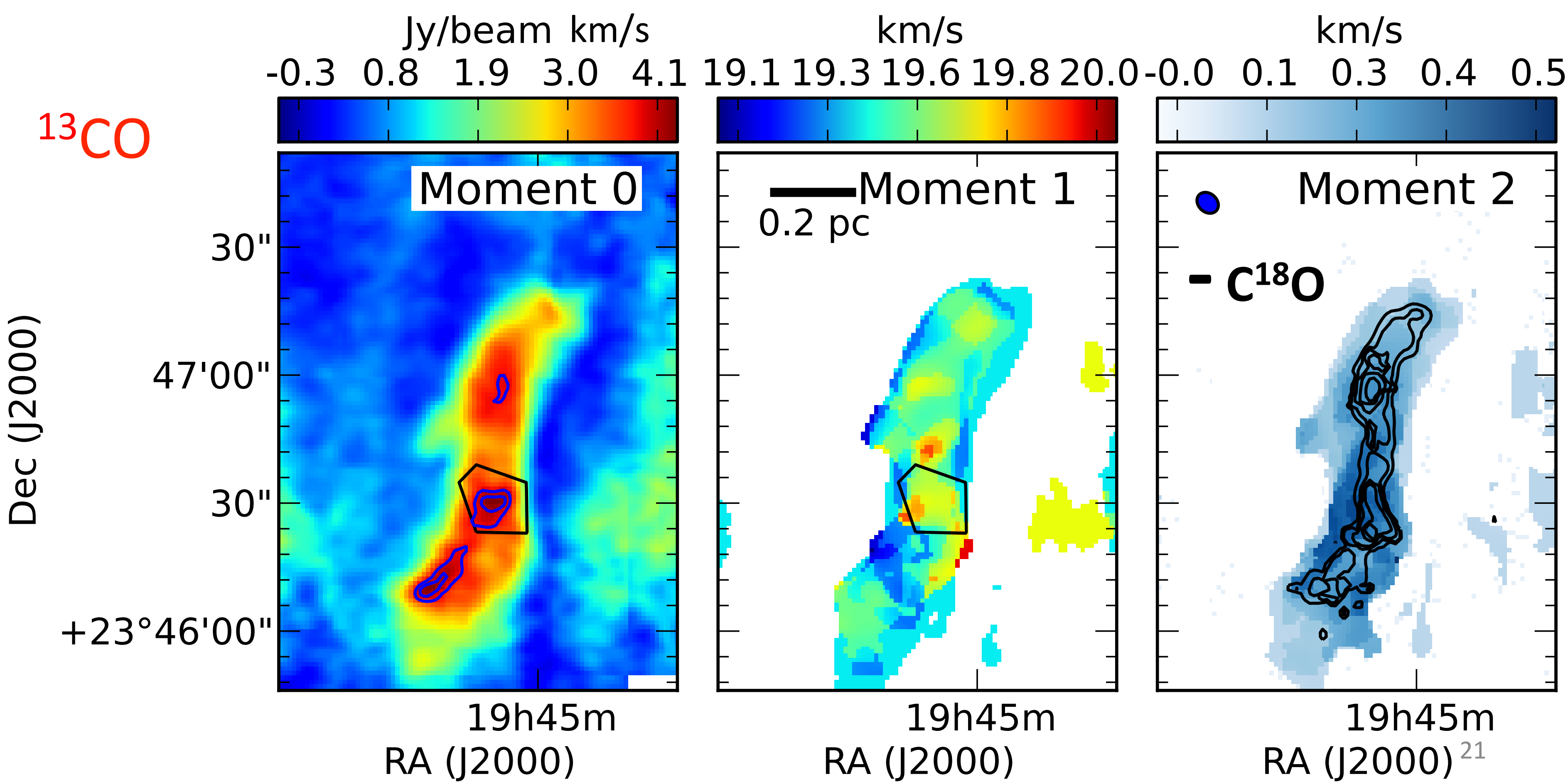
Kinematics

- ^{12}CO traces motions along pillar surface
- Velocity dispersion up to 1.4 km/s



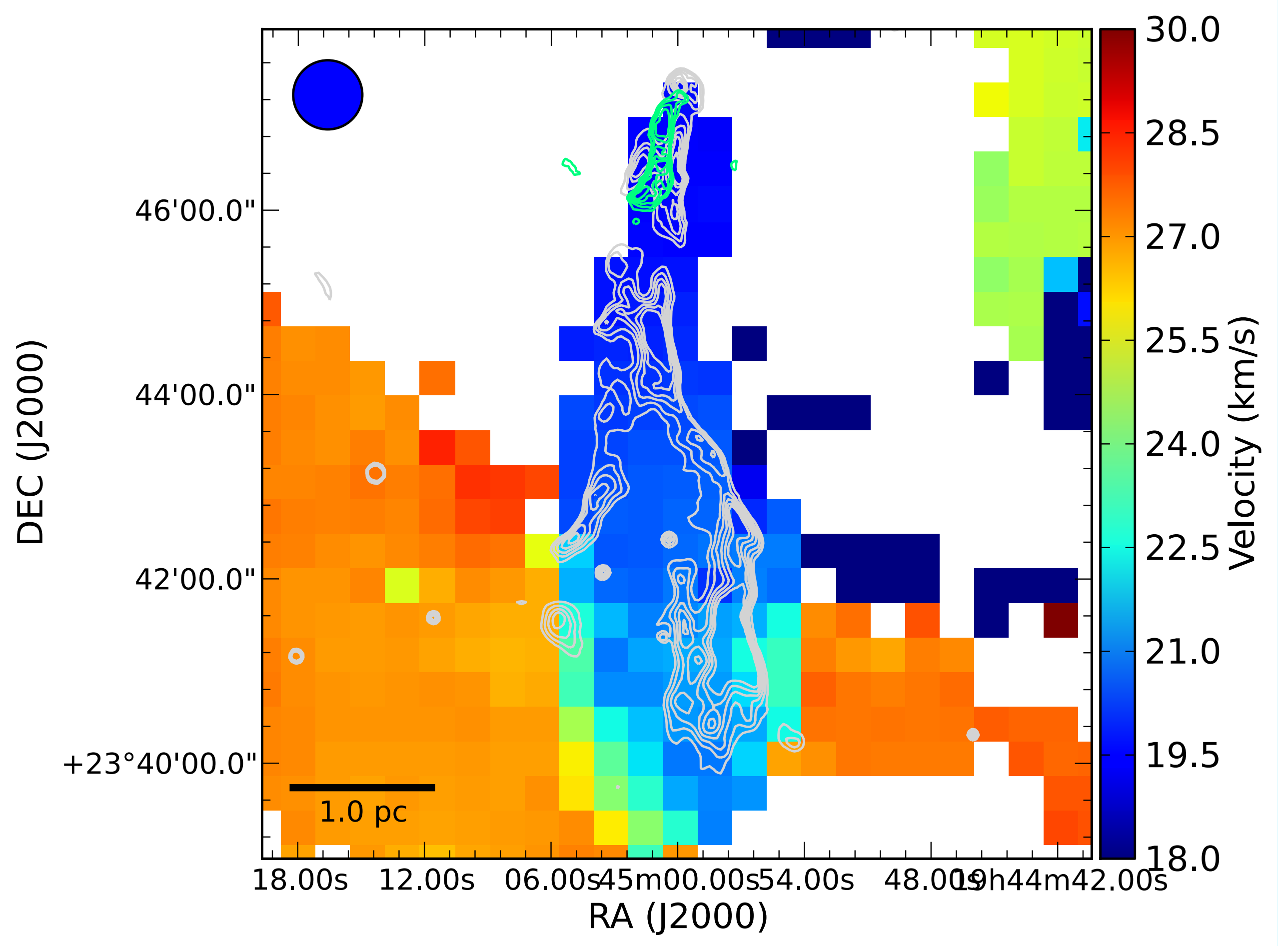
Kinematics

- ^{13}CO & $C^{18}O$ trace pillar core with no internal flows
- Internal velocity dispersion ~0.3-0.5 km/s



Kinematics

- Pillar is offset from nearby cloud and ionising source by ~6km/s



Confronting the Models

Model	Pillar Motion (km/s)	Velocity Dispersion (km/s)	Internal Flows
Obs	6	Internal: 0.3-0.5 Surface: <1.4	Surface only
G09			
G10			
D12			

Confronting the Models

Model	Pillar Motion (km/s)	Velocity Dispersion (km/s)	Internal Flows
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G09	None	1-2	yes
G10	None	>3	yes
D12	3	~1	no

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Obs	6	Internal: 0.3-0.5 Surface: <1.4	Surface only
G09	None	1-2 ✔	yes
G10	None	>3 ✘	yes
D12	3	~1 ✔	no

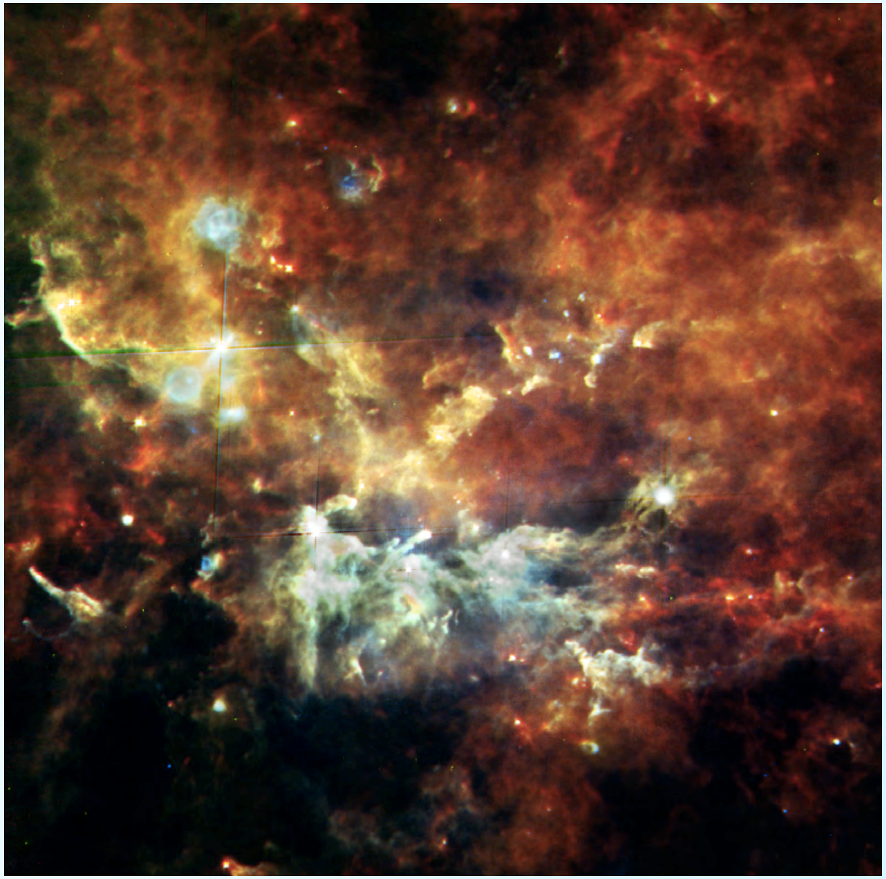
- G10 model ruled out (too large velocity dispersion)
- Not able to distinguish between two others

Conclusions:
A journey of a thousand miles begins with a single step

Conclusions & Next Steps

- The gas kinematics of pillars are an important discriminant between models of ionising feedback
- For a pillar in Vulpecula, we have ruled out one model (G10)
- More likely that pillars are filaments being revealed rather than formed by feedback
- High resolution observations of a larger number of pillars are needed to reveal property distributions, enabling global conclusions -> ALMA

Thank you for your attention. Any questions?



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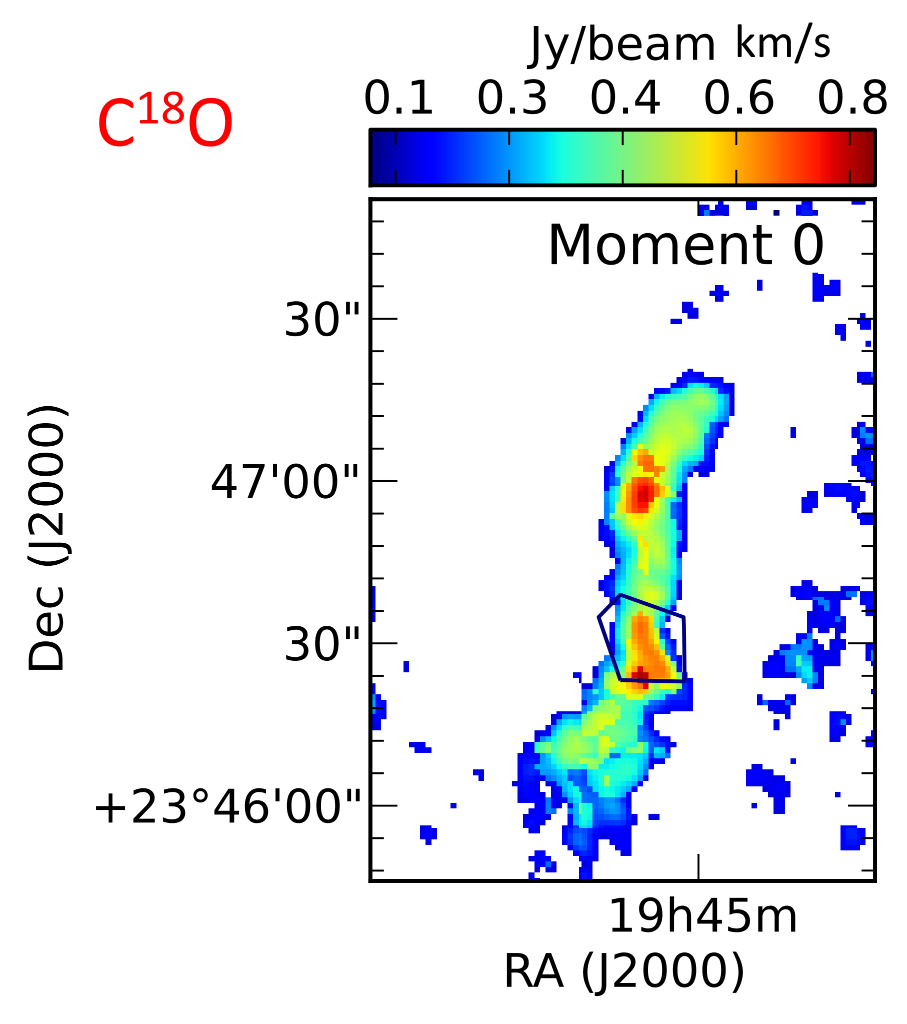
Cores spaced by Jeans Length

- From n~8×10^{-3} cm^{-3}, T=18 K -> Jeans length is 0.3 pc
- Two cores seen in $C^{18}O$ are spaced by ~0.3 pc
- Masses ~15 $M_\odot$ from ^{13}CO (corrected for τ using $C^{18}O$)
- ~30% of mass of pillar is in cores, so overall SFE unlikely to exceed 10%



Rate of cloud destruction

- Assuming constant spherical expansion at 6km/s:
  - Clears 6×10^{-5} pc per year
  - Alternatively, clears $1pc^3$ in 1.6×10^4 yrs
  - Given distance to ionising source of 16pc, suggests that ionisation began ~2.6×10^5 yrs ago
  - This is on the order of the Class 0 or MYSO lifetimes (Evans et al., 2009, Mottram et al., 2011b)
  - Thus, anything more evolved (e.g. Class I/II) must have started forming before onset of ionisation