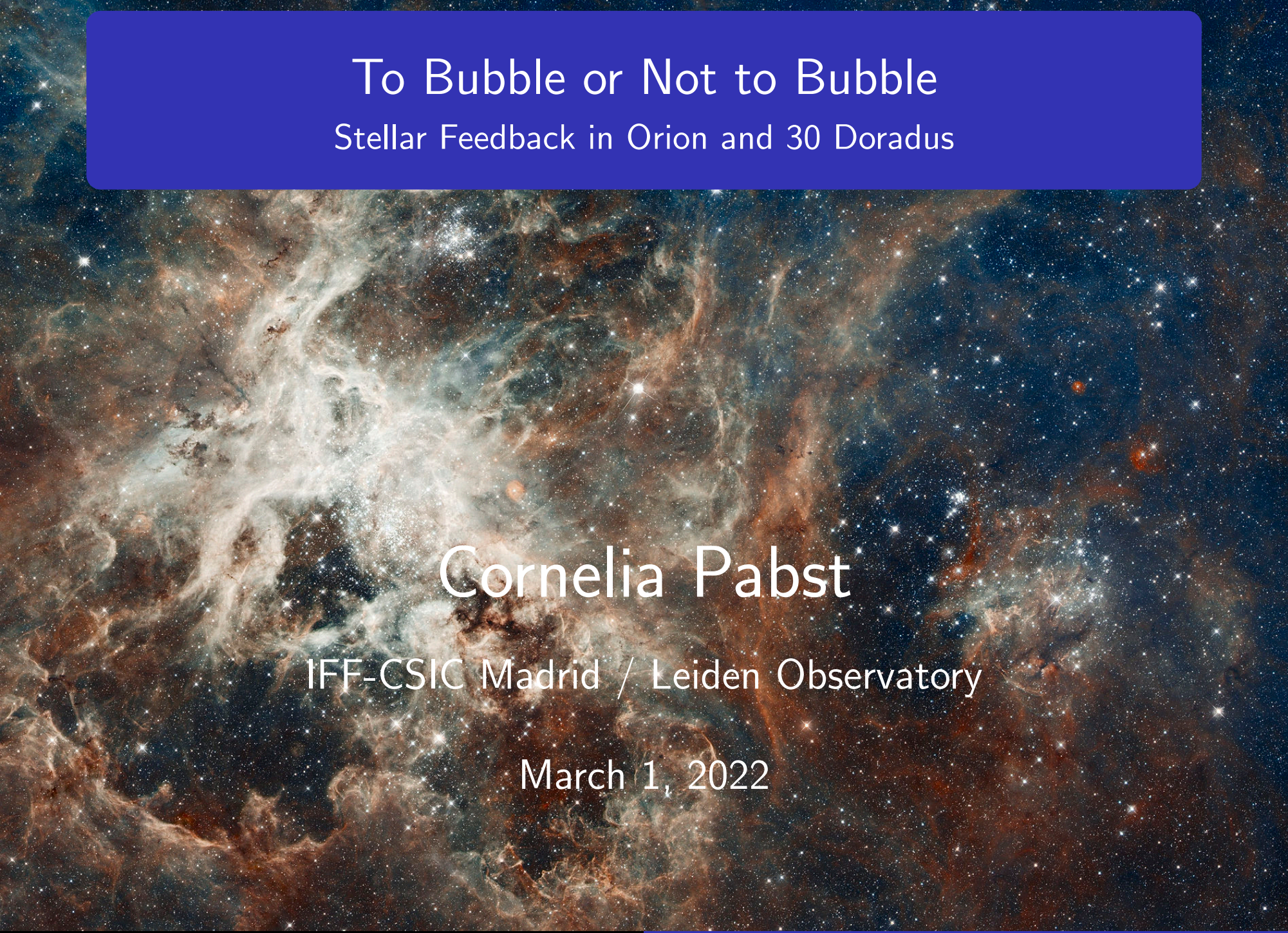
To Bubble or Not to Bubble

Stellar Feedback in Orion and 30 Doradus



Cornelia Pabst

IFF-CSIC Madrid / Leiden Observatory

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SOFIA
STRATOSPHERIC OBSERVATORY
FOR INFRARED ASTRONOMY

Outline

Aspects of stellar feedback and star formation:

- kinematics and energetics of star-forming regions
- heating and cooling of the ISM
- transmittance of turbulence into molecular clouds and the dilute ISM
- tracers of star formation in distant galaxies
- regulation of stellar feedback by magnetic fields

Orion versus the Tarantula

Figure 1: 1 O7V star, less than 1 Myr old

Figure 2: 300 O stars and 17 WR stars, 1-2 Myr old

Disruption of the Orion molecular core 1 by wind from the massive star θ^1 Orionis C

C. Pabst[1], R. Higgins[2], J. R. Goicoechea[3], D. Teyssier[4], O. Berne[5], E. Chambers[6], M. Wolfire[7], S. T. Suri[2], R. Guesten[8], J. Stutzki[2], U. U. Graf[2], C. Risacher[8,9] & A. G. G. M. Tielens[1]*

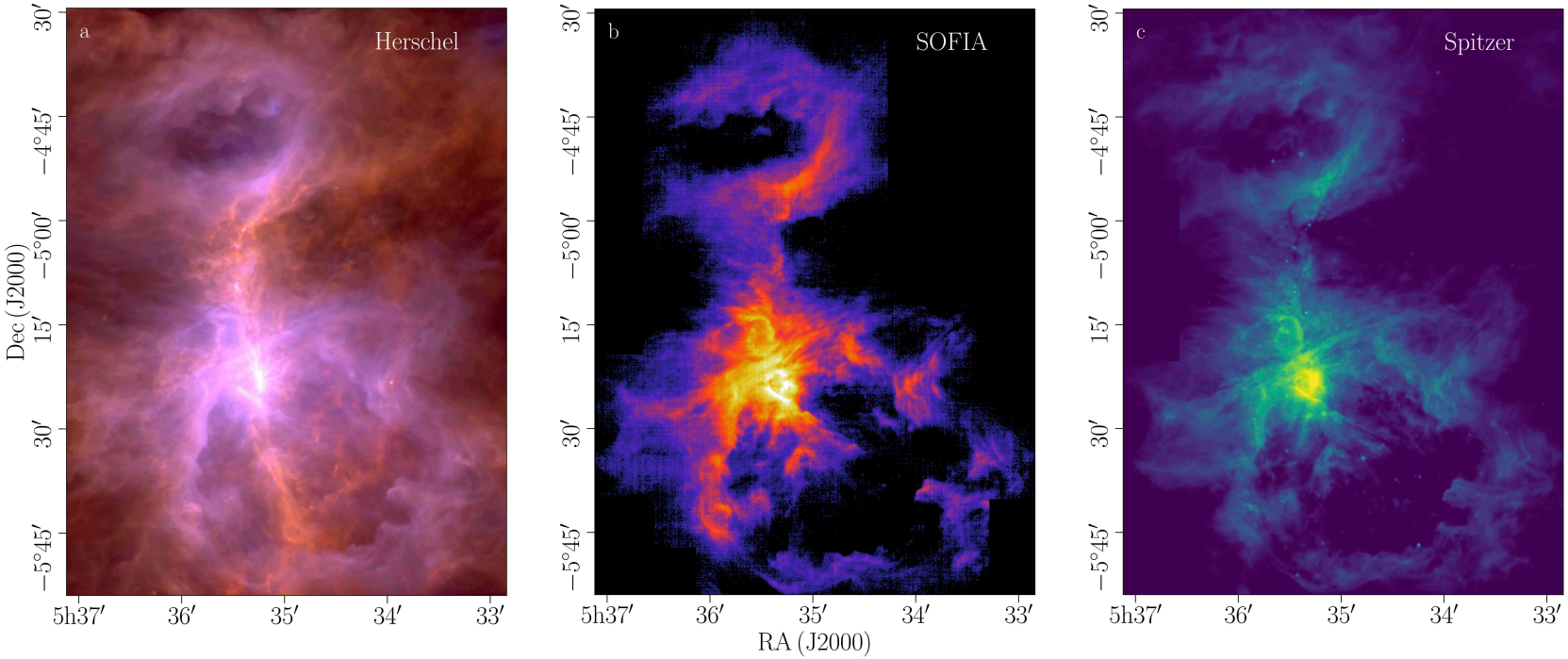


Figure 3: Three infrared images of the Orion Nebula complex (Pabst+2019). a) *Herschel*/PACS and SPIRE dust continuum images (red: SPIRE 250 μm, green: PACS 160 μm, blue: PACS 70 μm). b) Line-integrated [C II] 158 μm emission, observed by the upGREAT instrument onboard SOFIA. c) *Spitzer*/IRAC 8 μm image.

Measuring stellar feedback

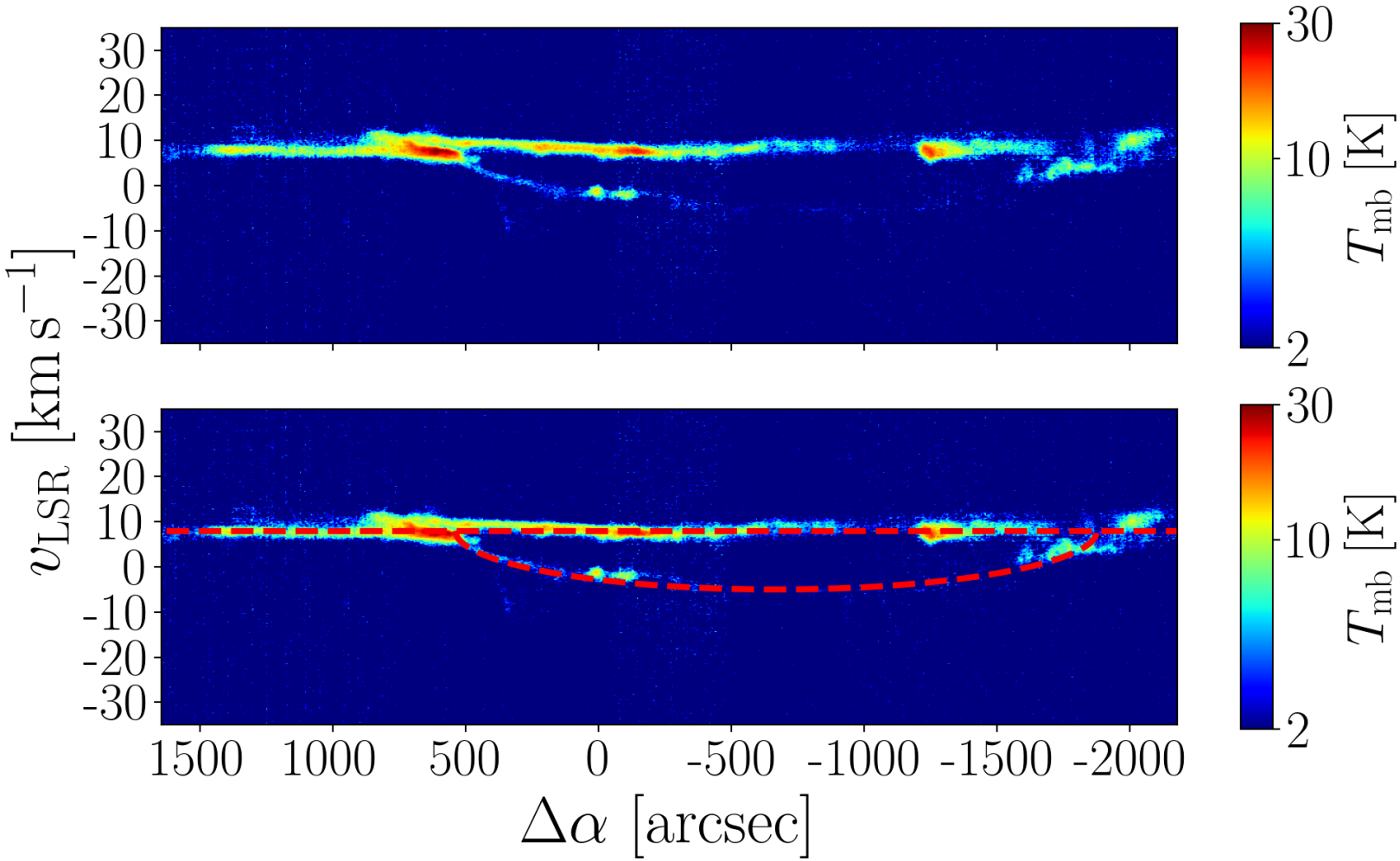


Figure 4: [C II] pv diagram through the Orion Veil shell (Pabst+2019, 2020). The lower panel traces the arc structure for an expansion velocity of 13 $\mathrm{km\,s^{-1}}$ on a background velocity of 8 $\mathrm{km\,s^{-1}}$ (red dashed lines).

The starburst region 30 Doradus

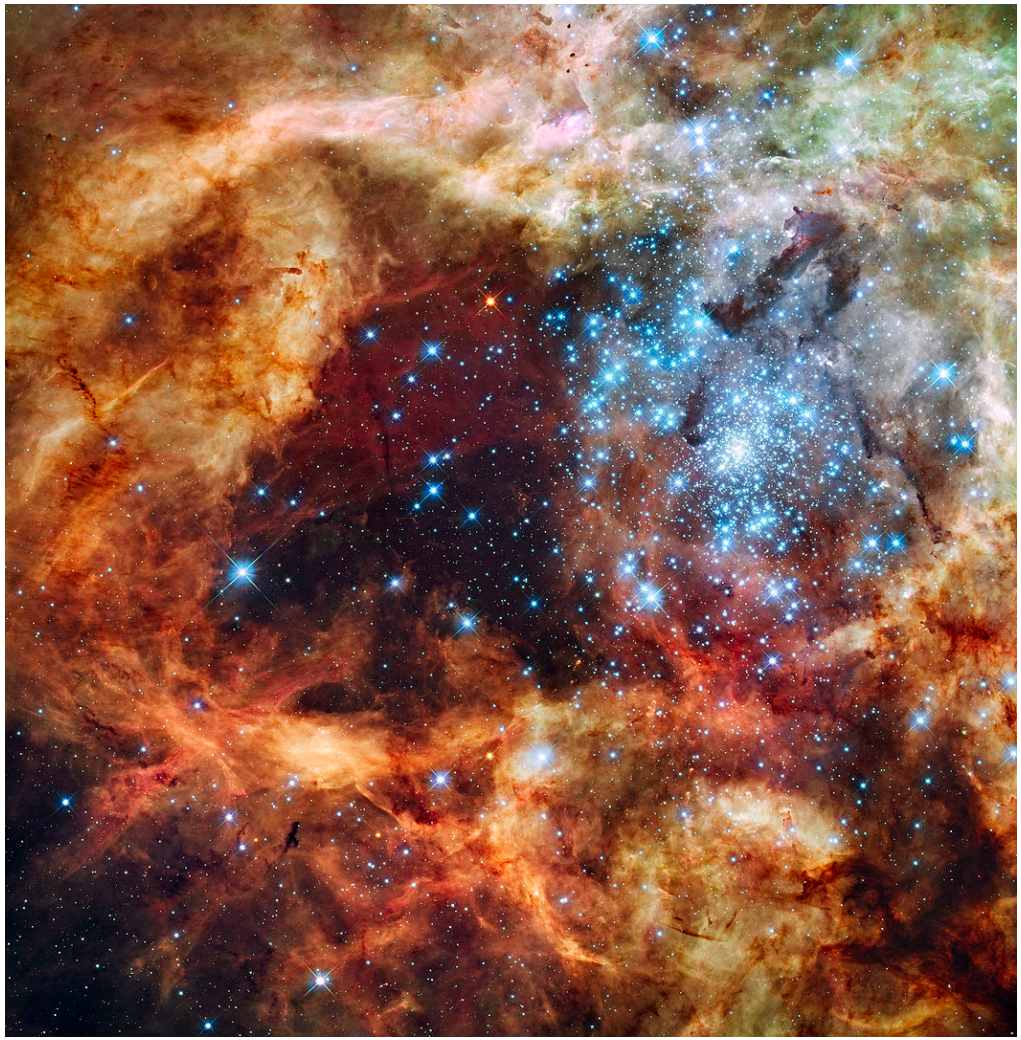


Figure 5: Hubble's view of 30 Dor.
Right: close-up of R136 in NGC 2070.

The starburst region 30 Doradus

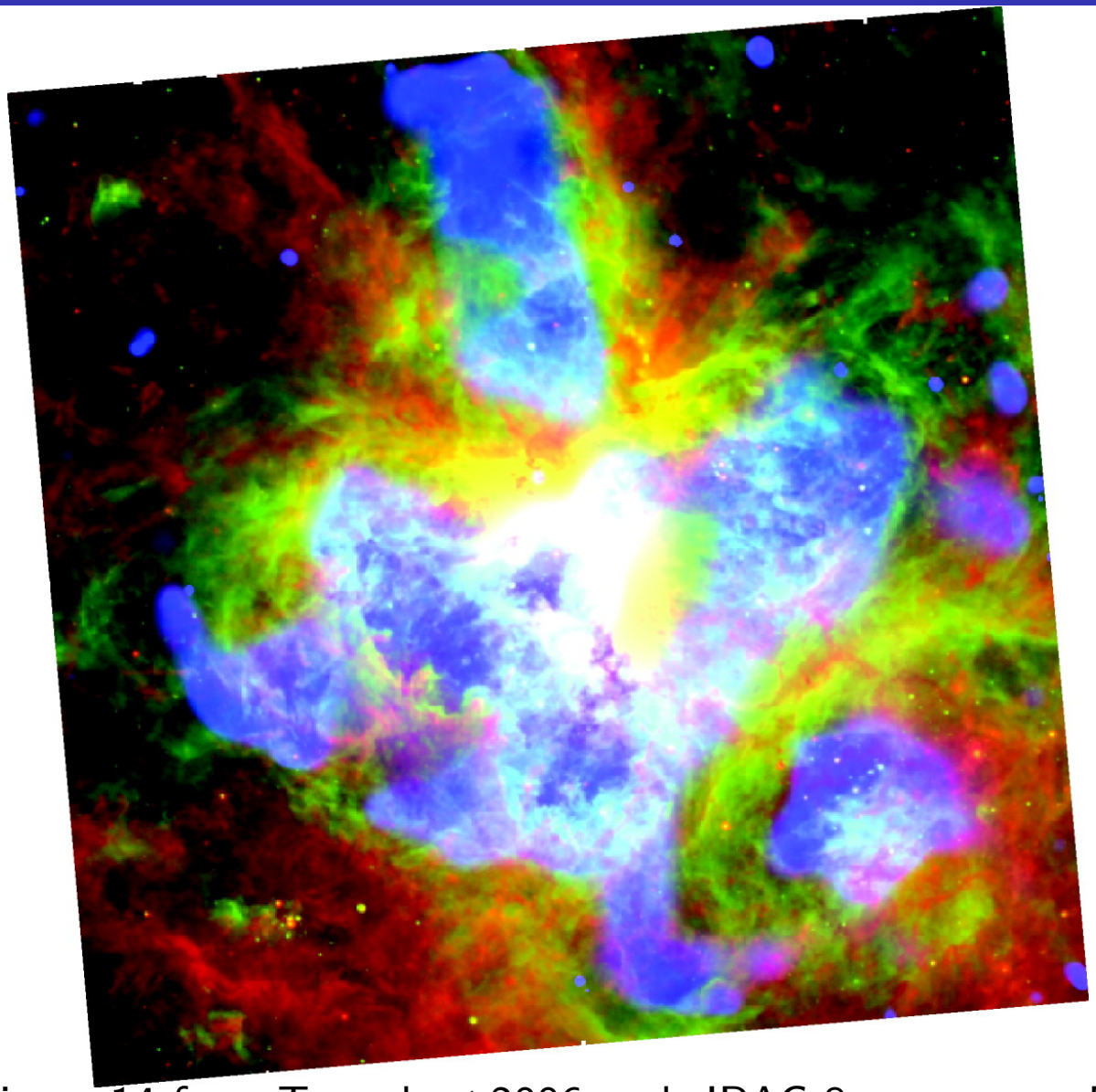


Figure 6: Figure 14 from Townsley+2006; red: IRAC 8 μm, green: MCELS Hα, blue: Chandra X-rays.

The starburst region 30 Doradus

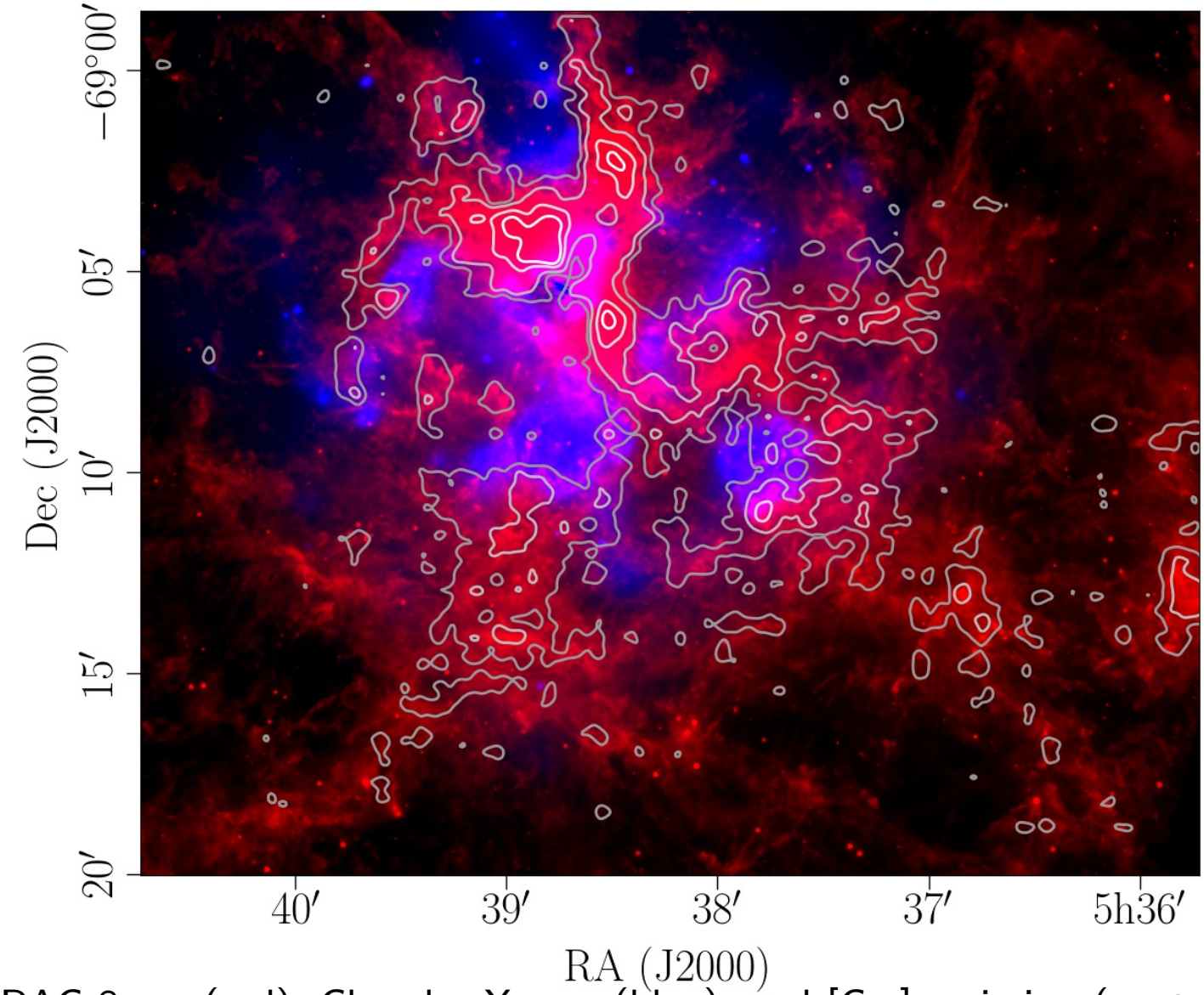


Figure 7: IRAC 8 μm (red), Chandra X-rays (blue), and [C II] emission (contours). [C II] pv diagrams reveal several expanding bubbles (Pabst+in prep.).

Magnetic fields in 30 Doradus

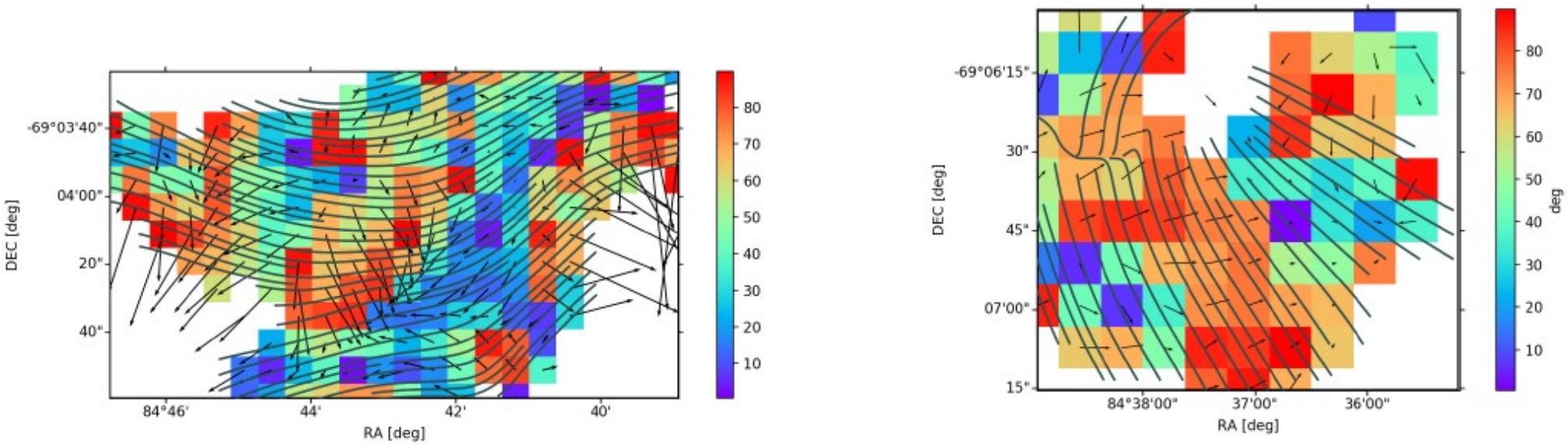
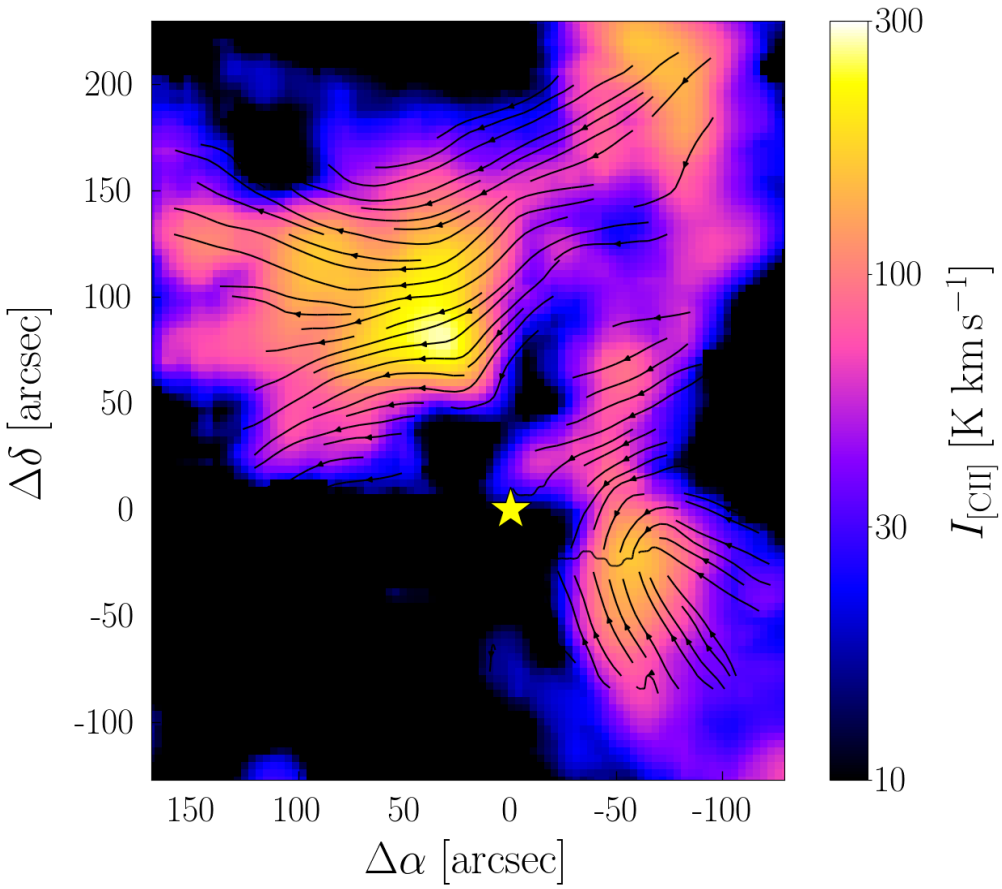


Figure 8: Relative orientation of magnetic field lines and the gradient of the velocity map (arrows. 90 degrees means perpendicular, 0 degrees means parallel.

Magnetic fields in 30 Doradus



Davis-Chandrasekhar-Fermi:
$B_\perp \sim 400\,\mu\mathrm{G}$

Figure 9: [C II] integrated intensity (upGREAT) with magnetic field lines (HAWC+).

Stellar feedback on different scales

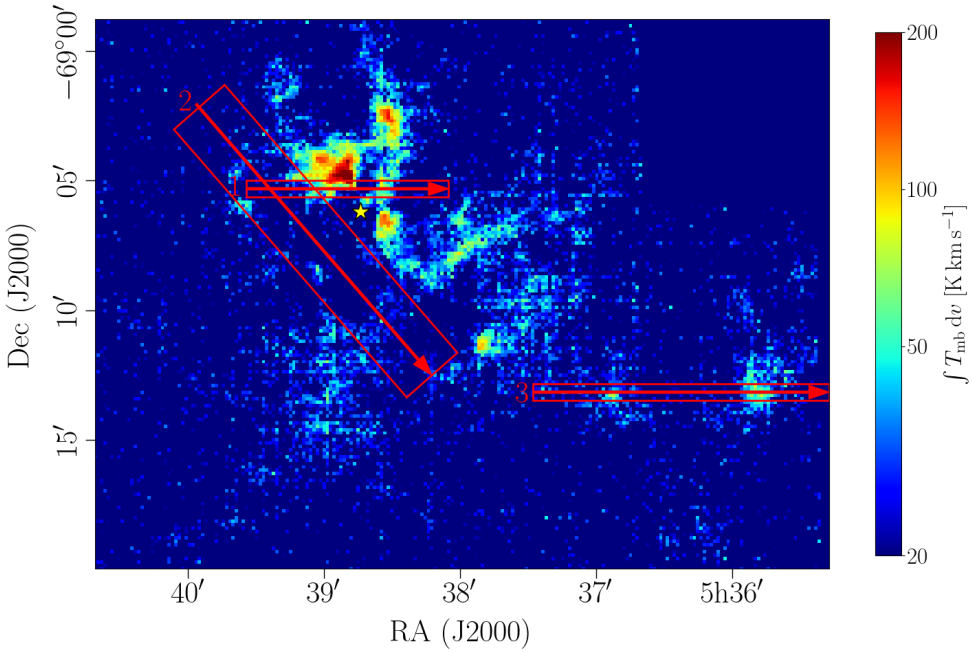


Figure 10: Line-integrated [CII] emission from 30 Doradus

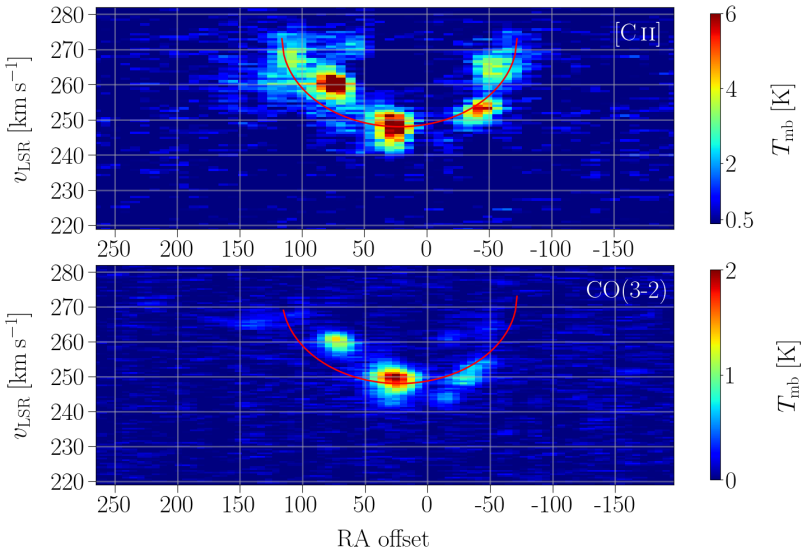


Figure 11: 1: Small-scale bubble

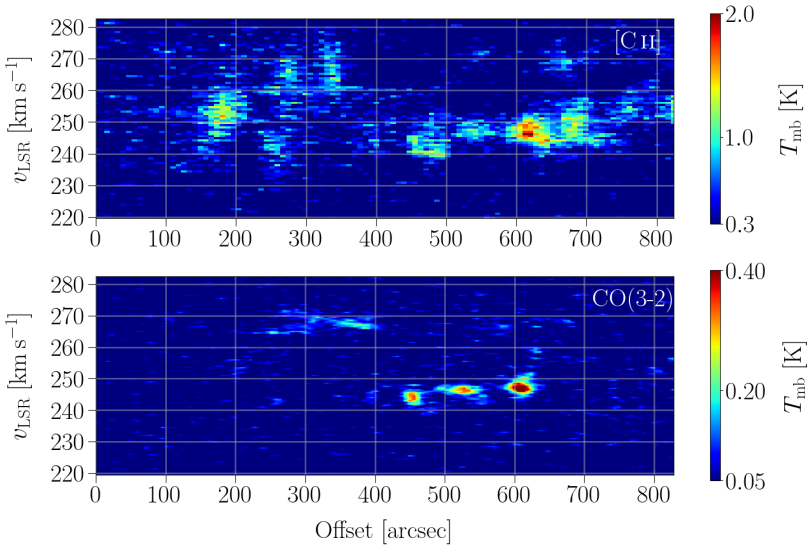


Figure 12: 2: Large-scale feedback

Stellar feedback on different scales

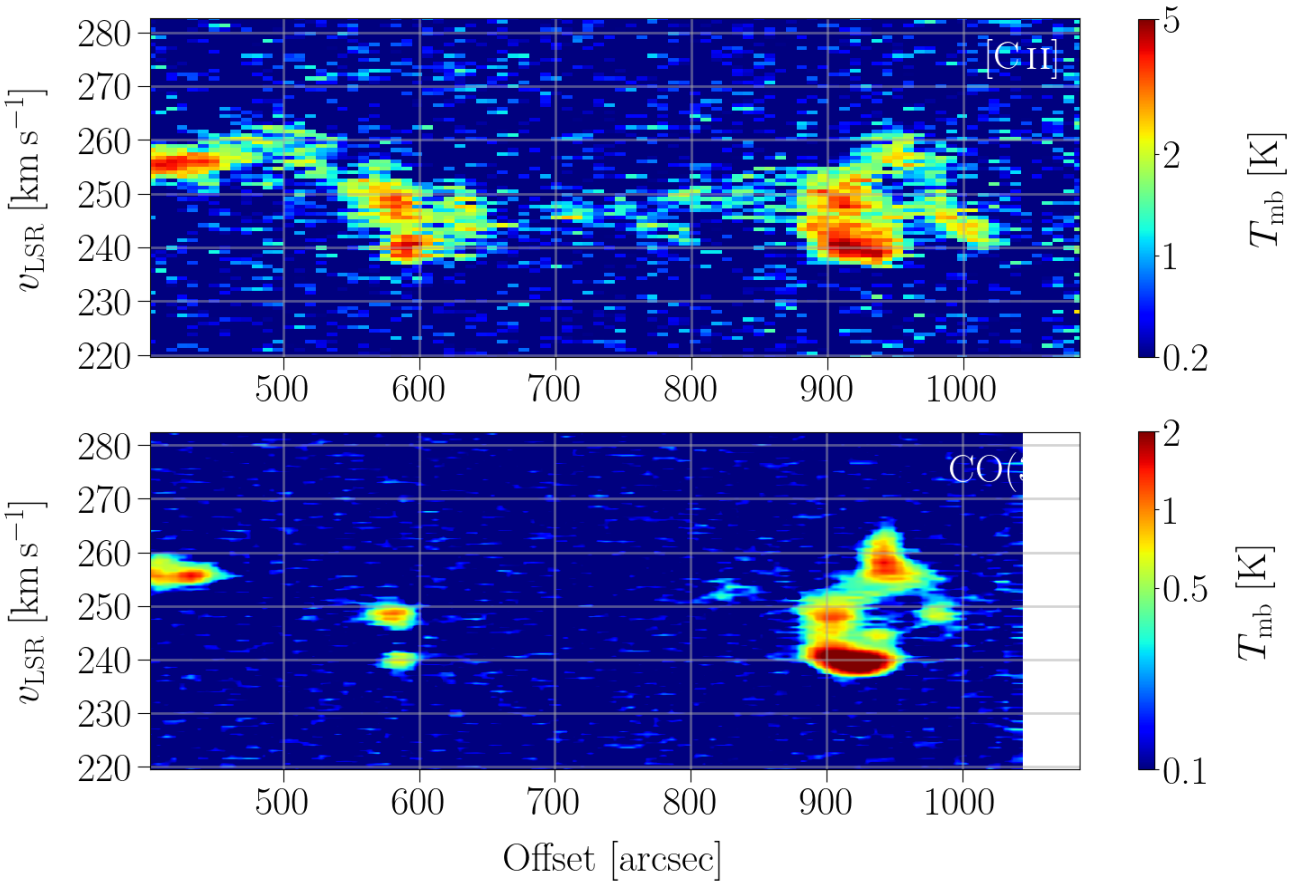


Figure 13: 3: Bubble around single WR star (HD 38029)

Single massive stars in 30 Doradus have large recognizably expanding bubbles, but R136 does not

Energetics

	Orion	30 Dor
age [Myr]	0.2	1-2
wind luminosity [erg s^{-1}]	8×10^{35}	2×10^{39}
thermal energy of hot plasma [erg]	10^{47}	10^{52}
neutral gas mass [$M_\odot$]	1500	~10^5
kinetic energy of neutral gas [erg]	2×10^{48}	~10^{50}
mechanical energy input over lifetime of star(s) [erg]	5×10^{48}	~10^{53}
$E_{kin}/(L_w\ t)$	0.5	~10^{-3}

Where has all the energy gone?

Pressures

Source		NGC 1977	M43	RCW 120	Veil Shell	RCW 49	30 Dor
Plasma	thermal	-	-	7	10	49	18
HII	thermal	8	80	4	8	49	5 turbulent: 24
PDR	radiation	0.8	30	1.3	1	26	4
	thermal	9	10	10	3	12	5
	turbulent	0.8	8	60	10	59	960
	magnetic	?	?	?	20	?	1600

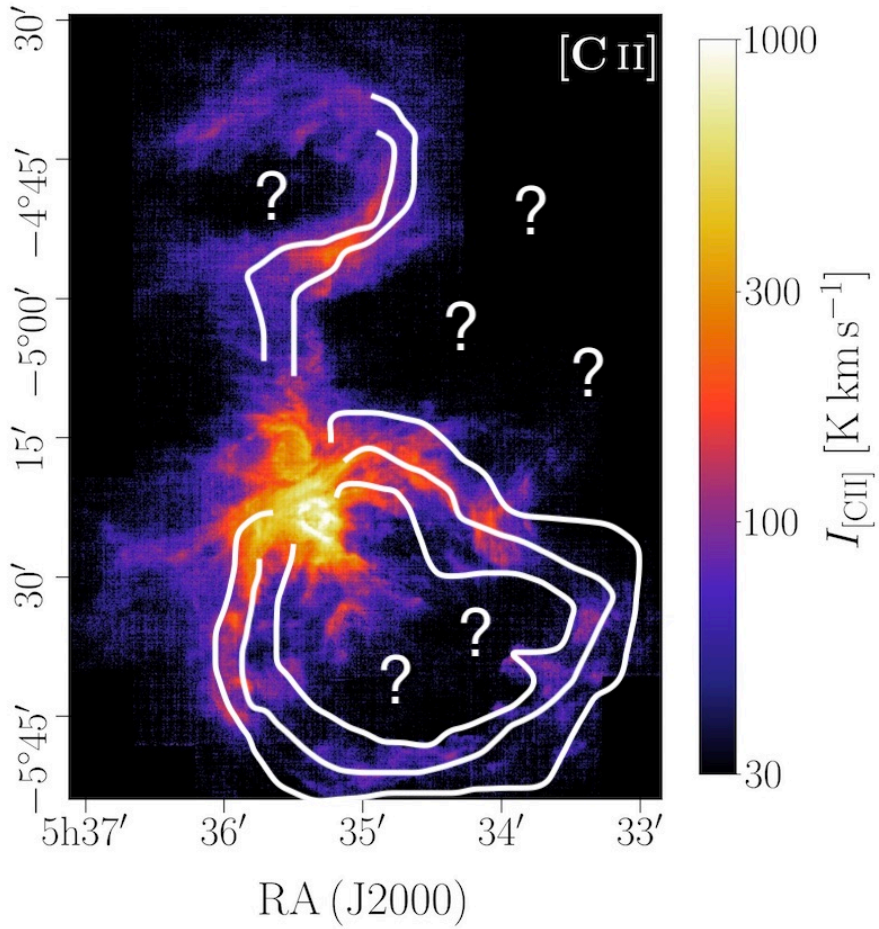
in $10^5\,\mathrm{K\,cm^{-3}}$

(Pabst+2019, 2020; Luisi+2021; Tiwari+2021; Cheng+2021; Chu&Kennicutt 1994)

Magnetic Orion

Figure 14: Magnetic field lines in OMC1 (APOD, Chuss+2019).

Figure 15: Magnetic field lines in the Veil?



Conclusions

- [C II] map of Orion is an incredibly rich data set, many as yet unexplored features
- To explore stellar feedback we need to map large regions at high spectral and spatial resolution efficiently
- [C II] observations of the Orion Nebula reveal a young expanding spherical bubble
- [C II] observations of 30 Doradus show fragmented feedback
- no efficiently driven bubbles around R136, but bubbles around single WR stars