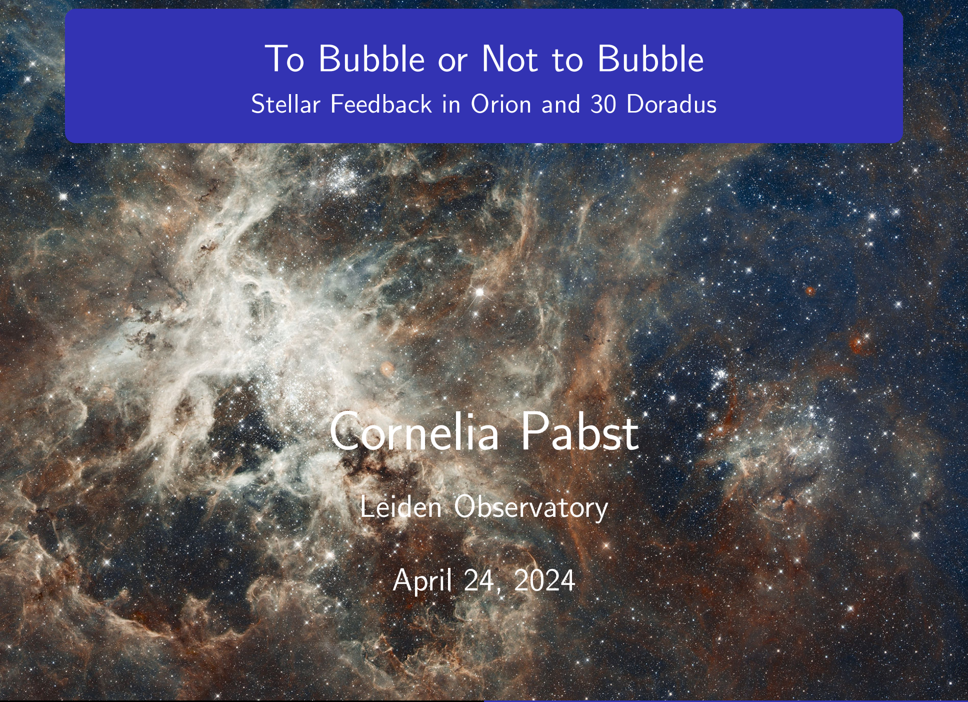

To Bubble or Not to Bubble

Stellar Feedback in Orion and 30 Doradus

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SOFIA
STRATOSPHERIC OBSERVATORY
FOR INFRARED ASTRONOMY

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

Aspects of stellar feedback and star formation

- kinematics and energetics of star-forming regions
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- tracers of star formation in distant galaxies
- regulation of stellar feedback by magnetic fields
- **The Local Truth**: we observe nearby star-forming regions with different characteristics
- but we select bright targets, while large percentage of emission is in faint extended regions

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]*

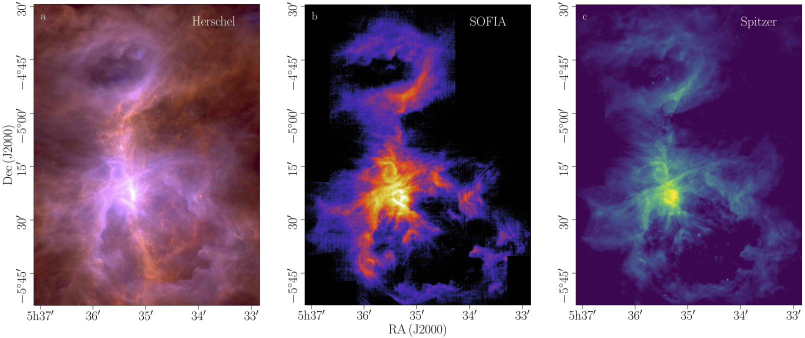


Figure 3: Three infrared images of the Orion Nebula complex (Pabst+2019). a) *Herschel*/PACS and SPIRE dust continuum images (red: SPIRE 250 μm, green: PACS 160 μm, blue: PACS 70 μm). b) Line-integrated [C II] 158 μm emission, observed by the upGREAT instrument onboard SOFIA. c) *Spitzer*/IRAC 8 μm image.

Tracing expanding bubbles: The Veil Shell

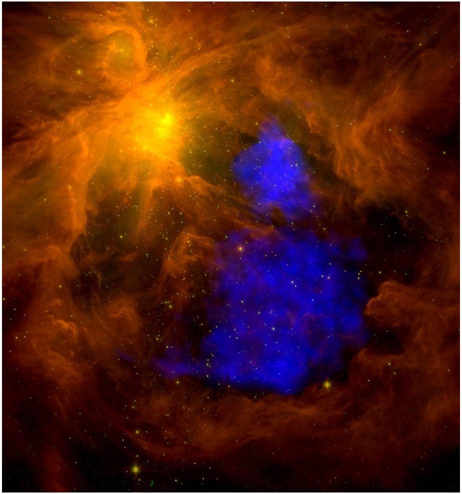


Figure 4: Excess X-ray emission from the cavity of the Orion Nebula (blue). The green and red channels show the *Spitzer*/IRAC 4.5 μm and 5.8 μm emission, respectively (Güdel+2008).

Measuring stellar feedback

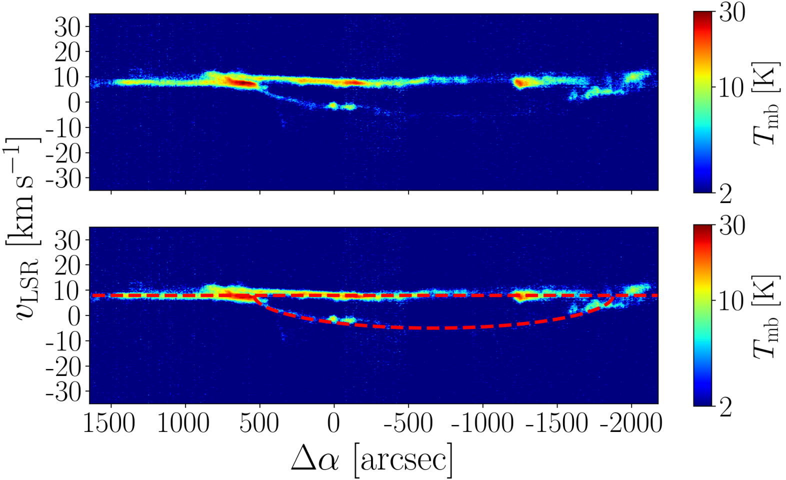


Figure 5: [C II] pv diagram through the Orion Veil shell (Pabst+2019, 2020). The lower panel traces the arc structure for an expansion velocity of 13 $\mathrm{km\,s^{-1}}$ on a background velocity of 8 $\mathrm{km\,s^{-1}}$ (red dashed lines).

The starburst region 30 Doradus

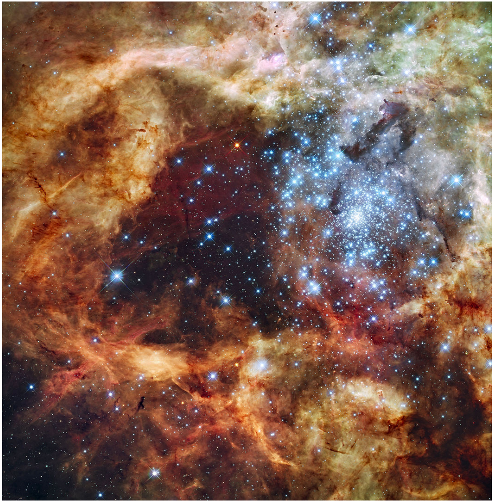


Figure 6: Hubble's view of 30 Dor. Right: close-up of R136 in NGC 2070.

The starburst region 30 Doradus

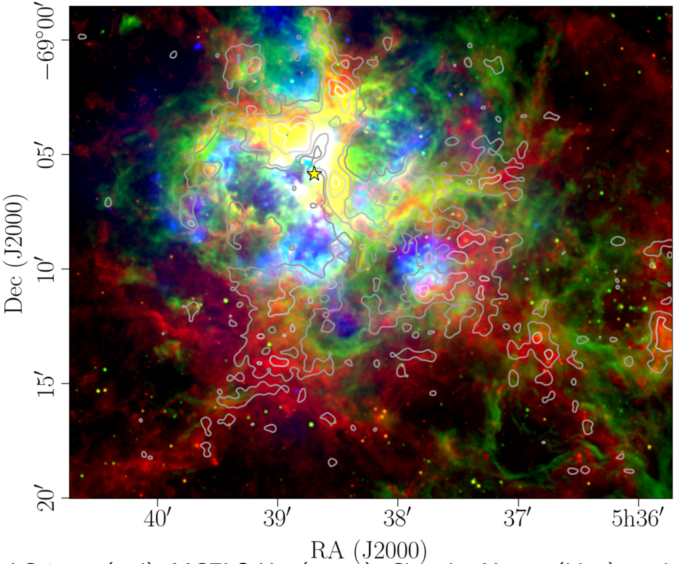
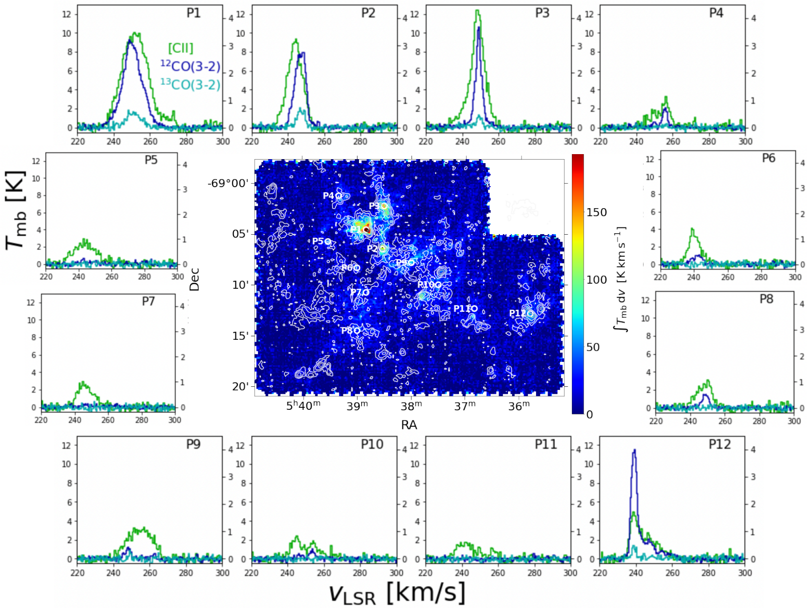


Figure 7: IRAC 8 μm (red), MCELS Hα (green), Chandra X-rays (blue), and [C II] emission (contours).

The starburst region 30 Doradus



Global morphology

- several distinct bubbles/stellar clusters
- X-ray bubbles are outlined by PDR gas
- CO(3-2) emission is more clumpy than [C II] emission
- usually multiple components per line/pixel

Magnetic fields in 30 Dor

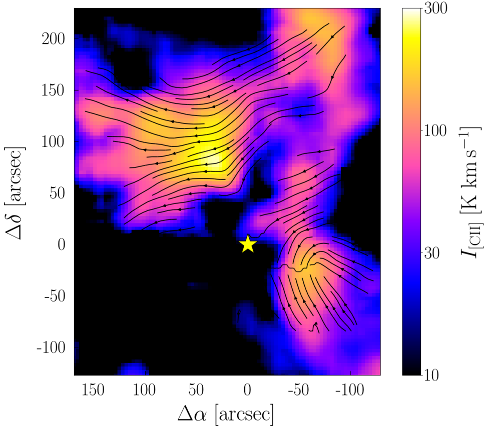


Figure 8: [C II] integrated intensity (upGREAT) with magnetic field lines (HAWC+).

See Tram's talk and paper (2021)

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

Does the magnetic field oppose bubble expansion on larger scales?

Stellar feedback on different scales

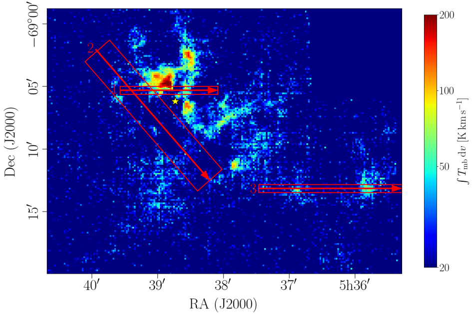


Figure 9: Line-integrated [C II] emission from 30 Dor

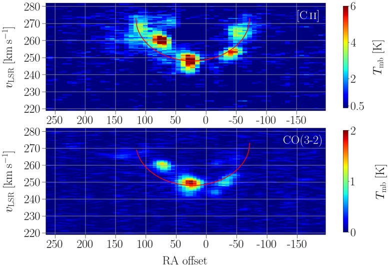


Figure 10: 1: Small-scale bubble

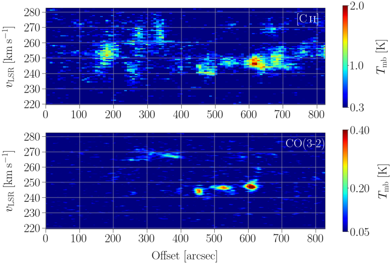


Figure 11: 2: Large-scale feedback

Stellar feedback on different scales

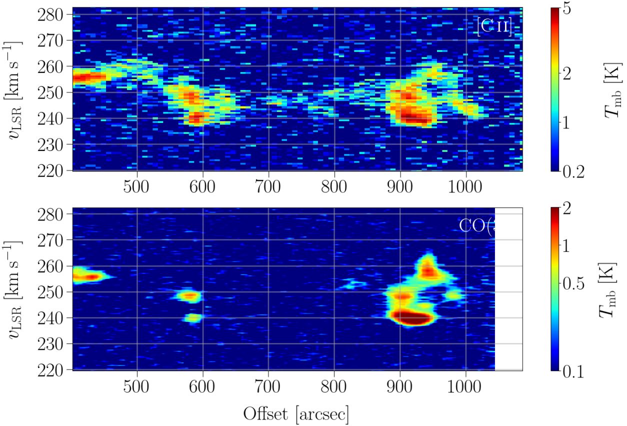


Figure 12: 3: Bubble around single WR star (HD 38029)

Input stellar energy is largely dissipated in smaller structures (see Chu&Kennicutt 1994).

Stellar feedback on different scales

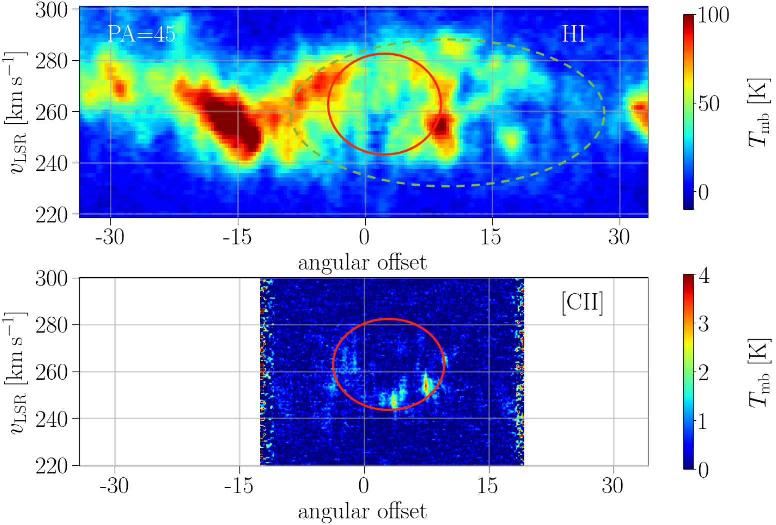


Figure 13: Large HI bubble (Kim+2005)

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 atomic gas mass [$M_\odot$]	1500	$\sim 10^{6}$
kinetic energy of neutral atomic gas [erg]	2×10^{48}	$\sim 10^{51}$
mechanical energy input over lifetime of star(s) [erg]	5×10^{48}	$\sim 10^{53}$
$E_{kin}/(L_w\ t)$	0.5	$\sim 10^{-2}$

Where has all the energy gone?

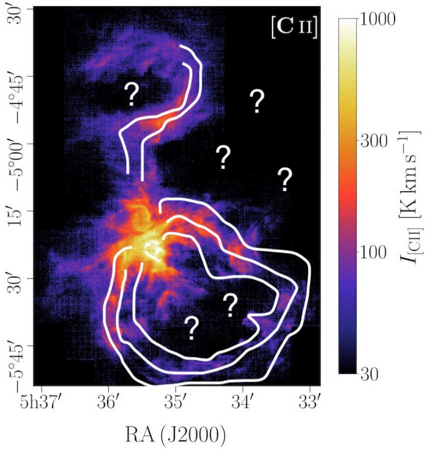
Energetics (continued)

- kinetic and turbulent energy in ionized gas: $\sim 10^{52}\,\mathrm{erg}$
- kinetic energy in large HI shell: $\sim 3 \times 10^{51}\,\mathrm{erg}$

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
- [C II] observations of the Orion Nebula reveal a young expanding spherical bubble
- [C II] observations of 30 Dor show fragmented feedback
- while we do see X-ray bubbles, [C II] emission in shells is very faint: why?
- at upGREAT's angular (and spectral) resolution 30 Dor looks highly turbulent
- each pixel is one Orion
- energy dissipates at smaller (ionized gas) and larger scales (HI halo)
- does R136 heat most of the plasma or do single massive stars heat the plasma locally?