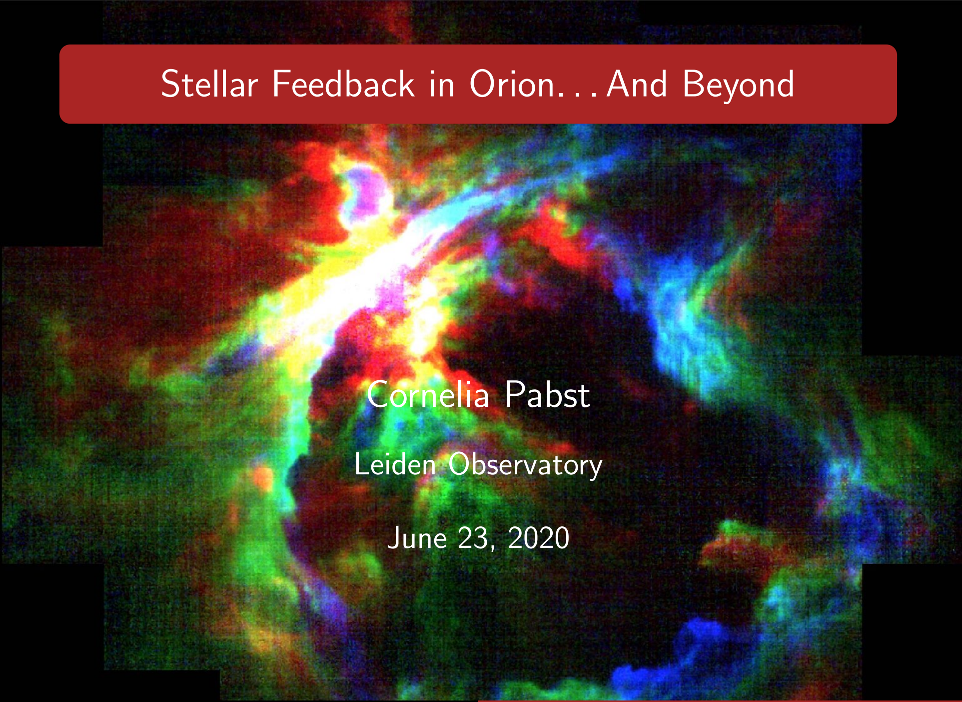
Stellar Feedback in Orion. . . And Beyond



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June 23, 2020

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

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- kinematics and energetics of star-forming regions
  ⇒ **SOFIA/upGREAT**
- heating and cooling of the ISM
  ⇒ **SOFIA/upGREAT+HIRMES+FORCAST and JWST**
- transmittance of turbulence into molecular clouds and the dilute ISM
  ⇒ **SOFIA/upGREAT+HIRMES+EXES and ALMA**
- tracers of star formation in distant galaxies
  ⇒ **SOFIA/upGREAT+HIRMES+FIFI-LS**
- regulation of stellar feedback by magnetic fields
  ⇒ **SOFIA/HAWC+**

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

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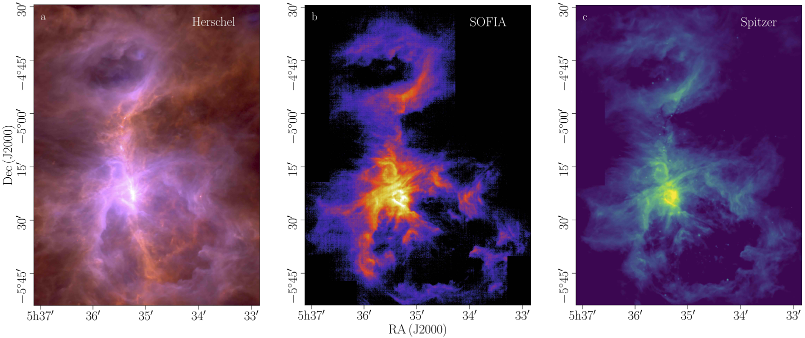


Figure 1: Three infrared images of the Orion Nebula complex (Pabst+2019). a) *Herschel*/PACS and SPIRE dust continuum images (red: SPIRE 250 μm, green: PACS 160 μm, blue: PACS 70 μm). b) Line-integrated [C II] 158 μm emission, observed by the upGREAT instrument onboard SOFIA. c) *Spitzer*/IRAC 8 μm image.

Measuring stellar feedback

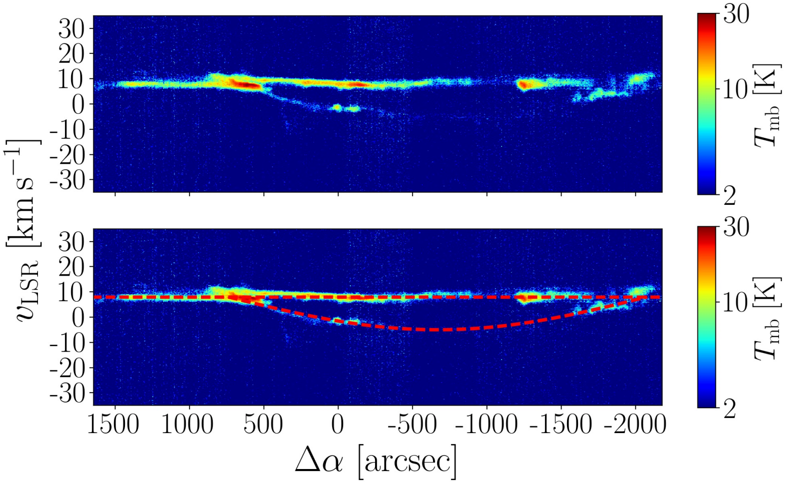


Figure 2: [C II] pv diagram through the Orion Veil shell (Pabst+2019, Pabst+2020). The lower panel traces the arc structure for an expansion velocity of 13 $\mathrm{km\,s^{-1}}$ on a background velocity of 8 $\mathrm{km\,s^{-1}}$ (red dashed lines).

Turbulence and hydrodynamic instabilities

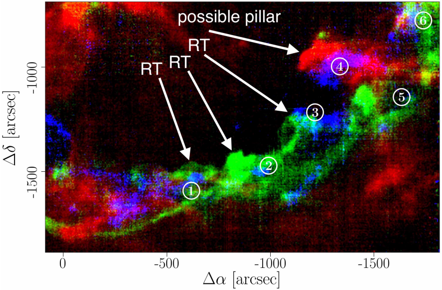
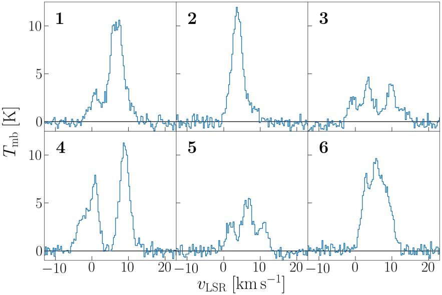


Figure 3: Three-color image of [C II] velocity channels of the southern Veil shell (Pabst+2020). Blue: $v_{\rm LSR} = 0\text{-}2\,\rm km\,s^{-1}$, green: $v_{\rm LSR} = 4\text{-}6\,\rm km\,s^{-1}$, red: $v_{\rm LSR} = 8\text{-}10\,\rm km\,s^{-1}$. The spectra were extracted towards the areas indicated by the numbered circles.

Figure 4: [C II] spectra towards the Veil shell. Each spectrum is averaged over a circle with a radius of 40″. Each spectrum consists of multiple line components, which is characteristic of thermodynamic instabilities.



Filaments and molecular globules in Orion

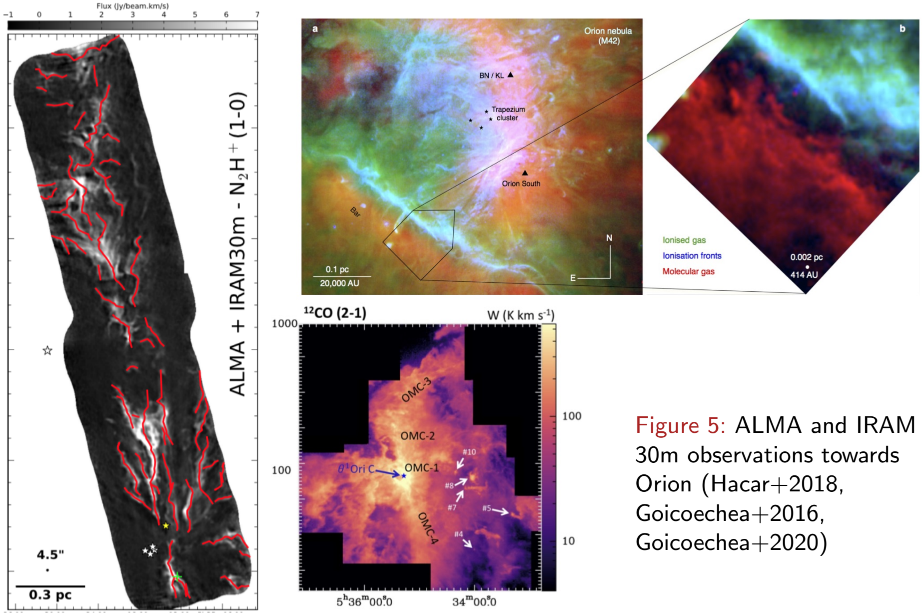
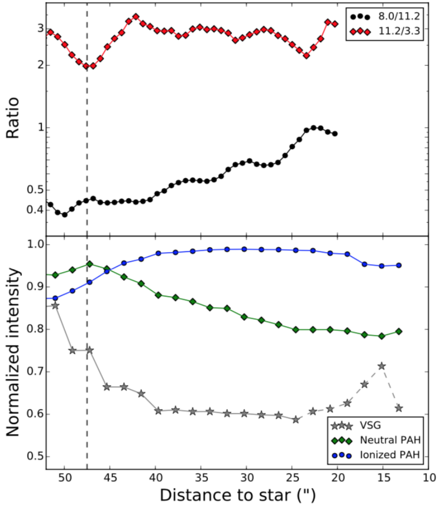


Figure 5: ALMA and IRAM 30m observations towards Orion (Hacar+2018, Goicoechea+2016, Goicoechea+2020)

Heating and cooling: efficiency and PAH properties

Figure 6: PAH properties in NGC 7023 (Croiset+2016)



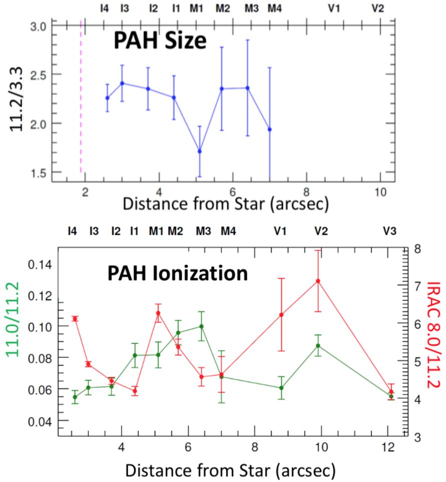
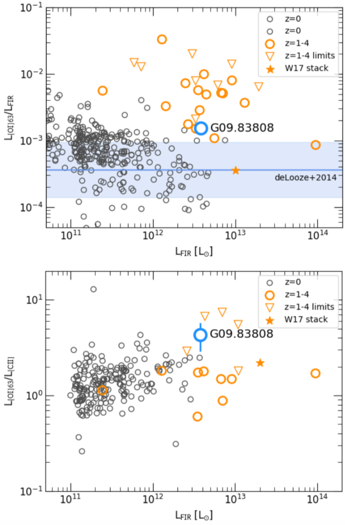


Figure 7: PAH properties in Orion (Knight+submitted, cf. Boersma+2012)



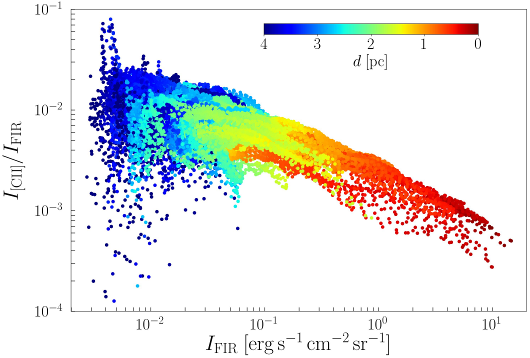
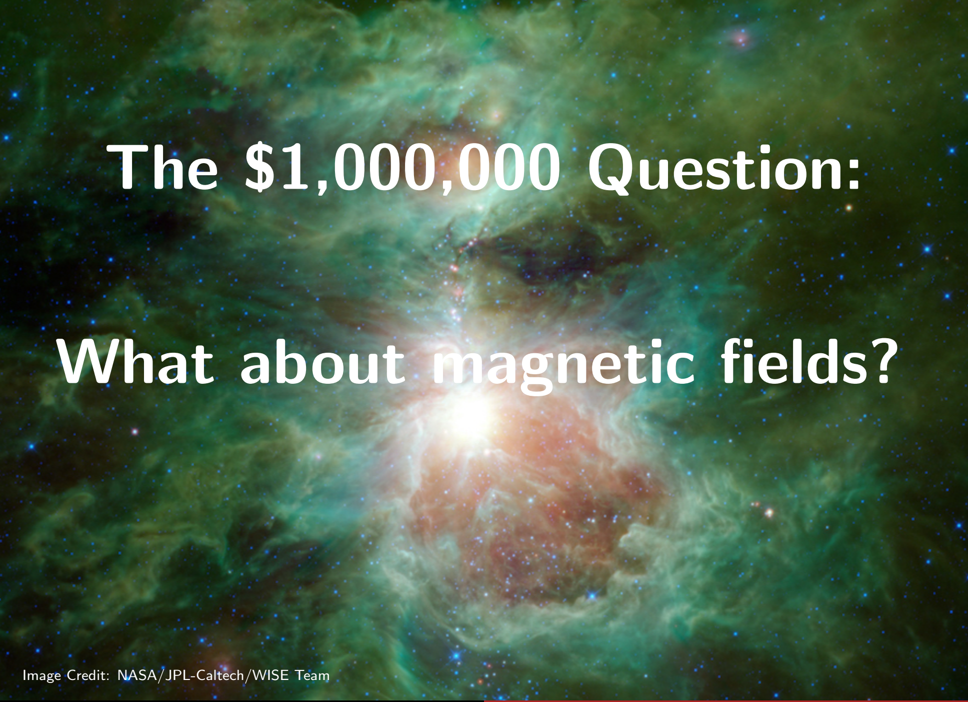


Figure 8: [O I] 63 μm and [C II] 158 μm as tracers of star formation (and local conditions).
Left: Rybak+2020 for $z \sim 6$ dusty star-forming galaxy, *right*: Pabst+in prep. for Orion Nebula.



The $1,000,000 Question:

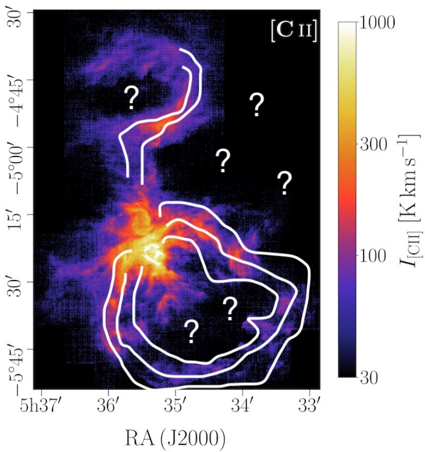
What about magnetic fields?

Image Credit: NASA/JPL-Caltech/WISE Team

Magnetic Orion

Figure 9: Magnetic field lines in OMC1 (APOD, Chuss+2019).

Figure 10: Magnetic field lines in the Veil?



Summary

- [C II] map of Orion is an incredibly rich data set, many as yet unexplored features
- need to map large regions at high spectral and spatial resolution efficiently
- a HIRMES-like instrument could provide this for the [O I], [O III] and [N II] FIR lines
- SOFIA can map the two most important FIR cooling lines of the ISM at high spectral and angular resolution
- SOFIA can quantify stellar feedback (ongoing: FEEDBACK C+ Legacy Program)
- SOFIA observations help constrain physical conditions in the ISM
- SOFIA can map PAH properties within a large FoV
- SOFIA helps understand the role magnetic fields play in regulating star formation
- SOFIA provides the "local truth" for star-formation tracers in the distant universe