The PDR Toolbox

Marc Pound
co-I: Mark Wolfire

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pdrtpy.readthedocs.io
Pound & Wolfire, 2023, AJ, 165, 25

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- SOFIA *FEEDBACK* Legacy Program feedback.astro.umd.edu
- JWST-ERS *PDRs4All* program pdrs4all.org

image: Orion Bar PDR credit: NASA/JWST, PDRS4All

What is the PDR Toolbox and Why should you use it?

What?

- An open source Python toolkit for discovering the physical properties of PDR gas.
- User-friendly analysis of observations of PDRs from JWST, SOFIA, GUSTO, ALMA, Herschel, and many more.
- Pre-computed **models** of PDR emission and various **tools** to explore models & fit observations to them.
- Tutorial jupyter notebooks
- Easy to install: `pip install pdrtpy`

Why?

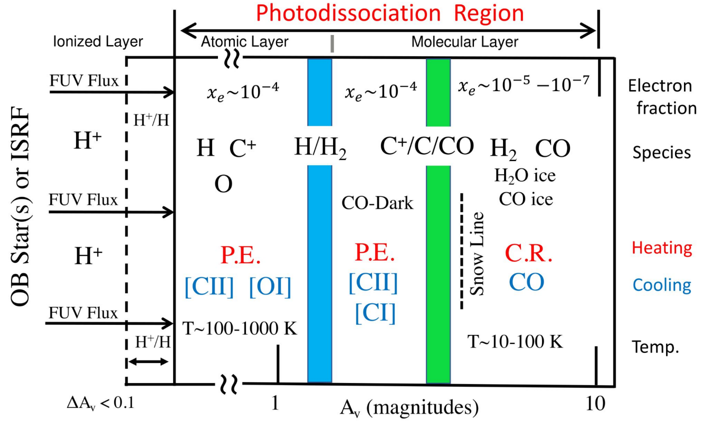
- PDRs are the signposts of **radiative feedback** in star-forming regions
- Throughout the ISM, UV radiation plays a critical role in heating, cooling, and chemistry of the gas phase.

Most of the non-stellar baryons in galaxies are in PDRs

The Models

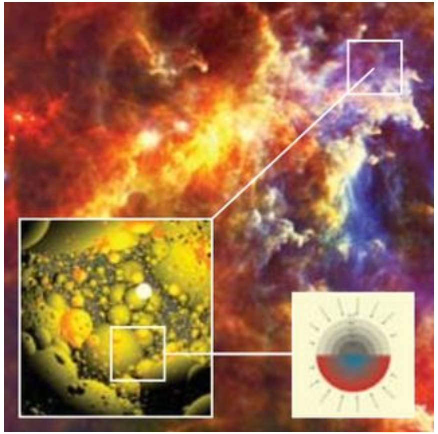
Wolfire/Kaufman

- Kaufman+2006; many updates since 2020 - “WK2020”
- plane-parallel geometry, directional FUV illumination
- face-on emergent intensity (edge-on and angles coming soon!)
- Z = 0.2 (SMC), 0.5 (LMC), 1.0, 3.0
- [C II], C I, [O I], H_2, CO, ^{13}CO, [Fe II], [S I], FIR continuum
- New species computed upon request!



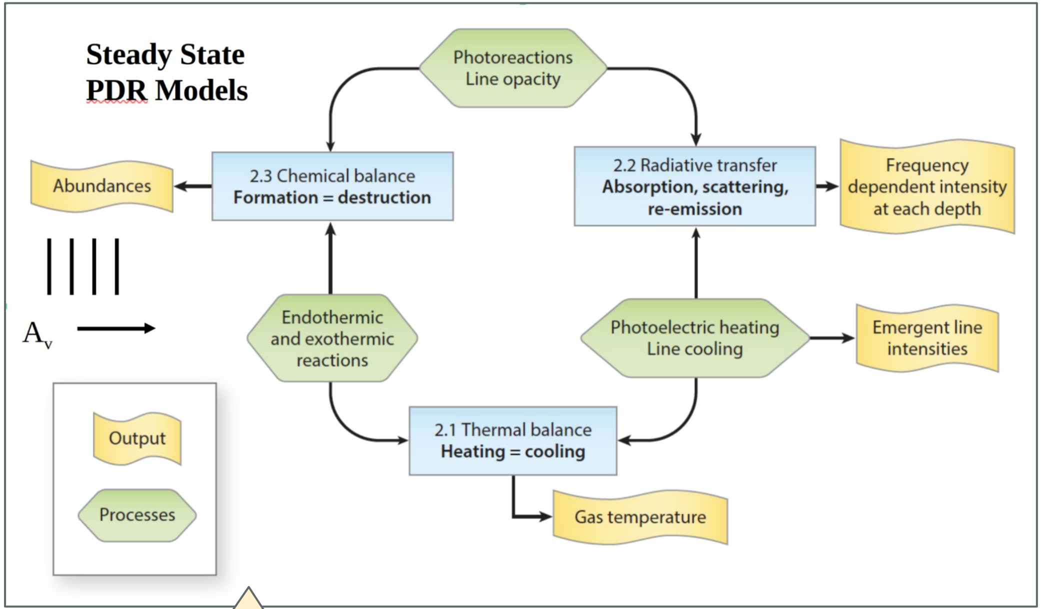
KOSMA-Tau

- Röllig & Ossenkopf-Okada 2022
- spherical geometry, isotropic FUV illumination
- clumpy PDRs approximated by ensemble of spherical masses
- Z=1
- [C II], C I, [O I], H_2, CO, FIR continuum



Comparable physics & chemistry in both

What's in the models?



Wolfire, Vallini, & Chevance ARAA 2022

Mark W. does this part

The models files are intensity ratios or intensities as a function of H nucleon density *n* and external radiation field G_0

n range: $10 - 10^7$ cm^{-3}
G_0 range: $0.1 - 10^7$ Habing

(1 Habing = 1.6×10^{-3} erg s^{-1} cm^{-2})

Stored as FITS files (also available outside the Toolbox)

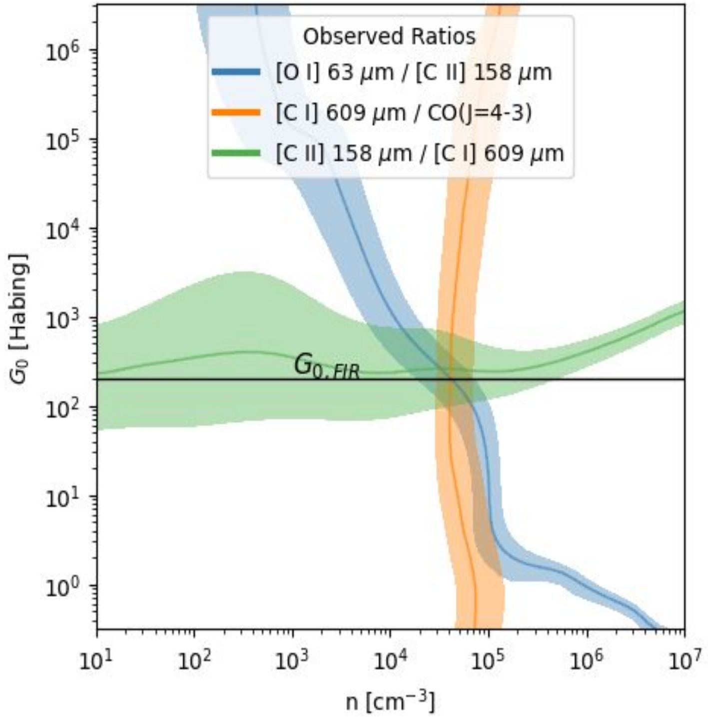
The Tools

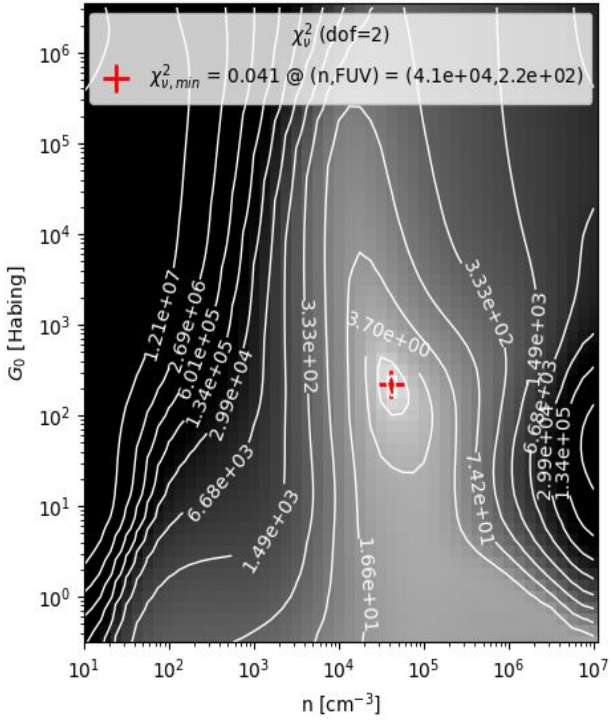
The Tools

Marc P. does this part

Determining n and G_0 from observations

LineRatioFit: From your observed intensities, LSQ fitted n, G_0 with errors, overlay plots, χ^2 map

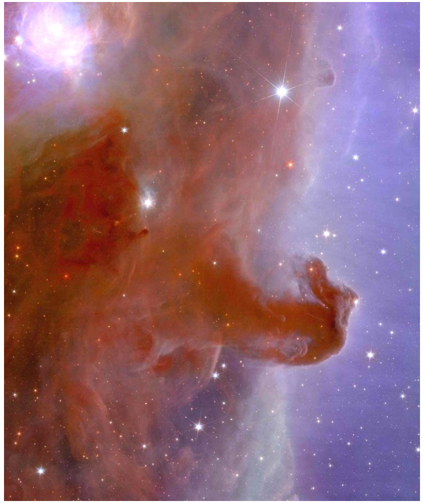


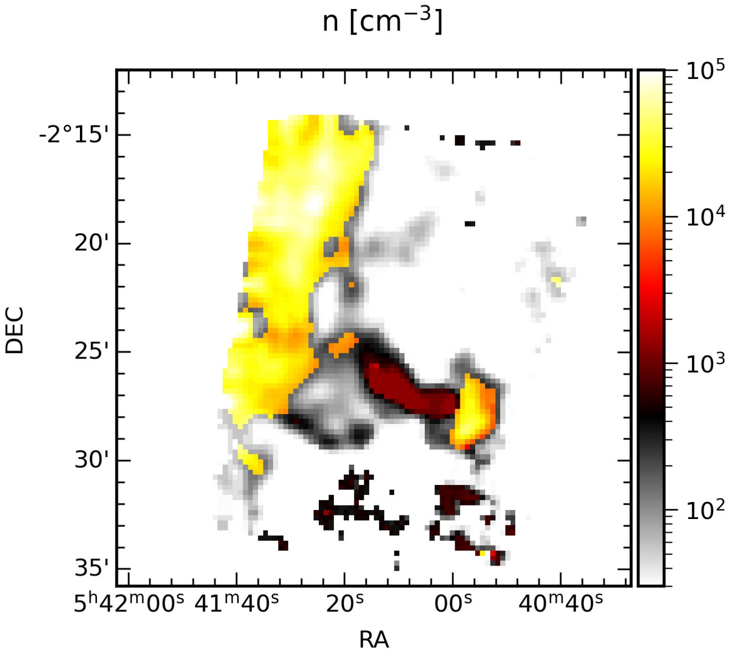


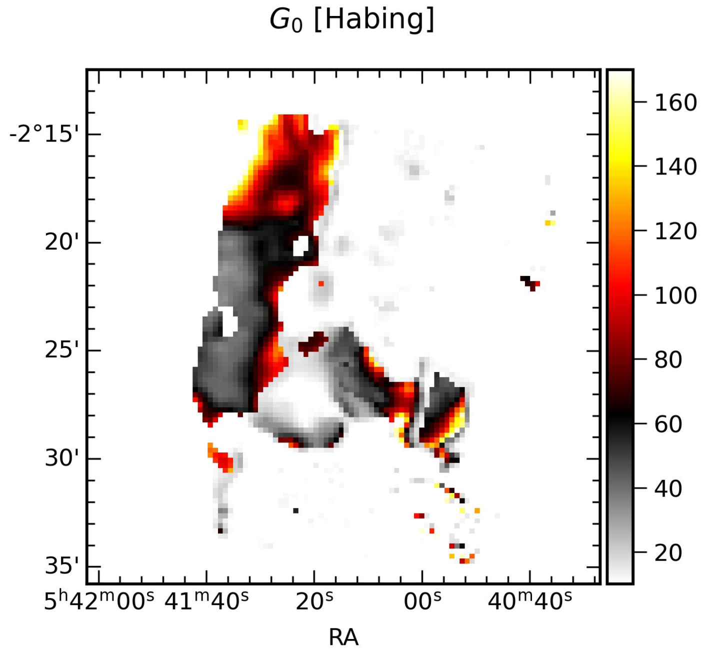
MCMC fitting & corner plots also possible

Determining n and G_0 from observations: Maps!

Input FITS images of intensities w/errors, get n, G_0 maps and per pixel fit statistics



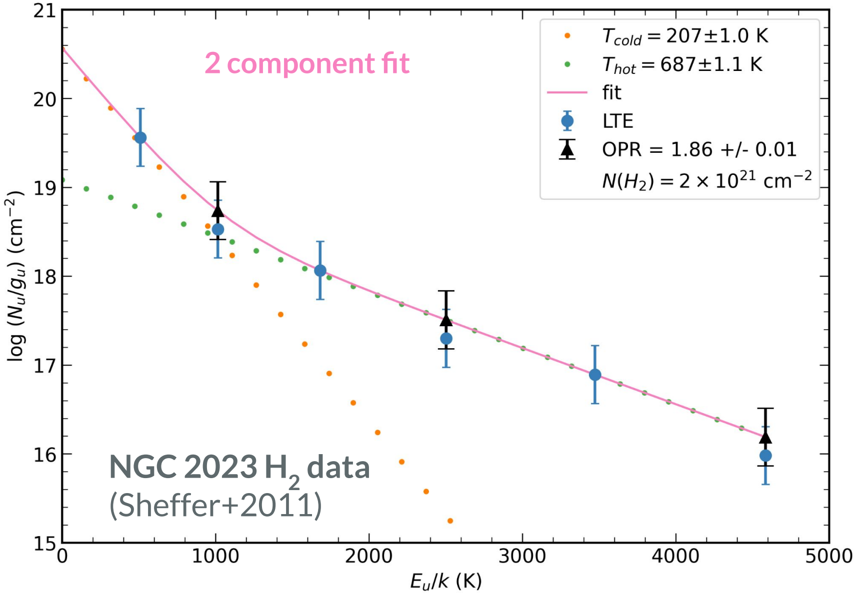


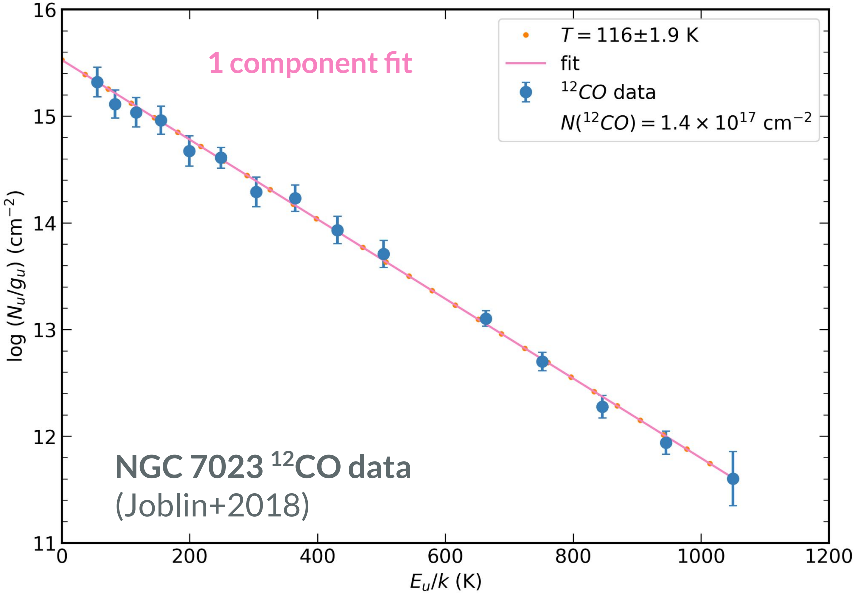


Derived from Horsehead data from Pabst+2017 (Thanks, Cornelia!)

Excitation Diagram Fitting

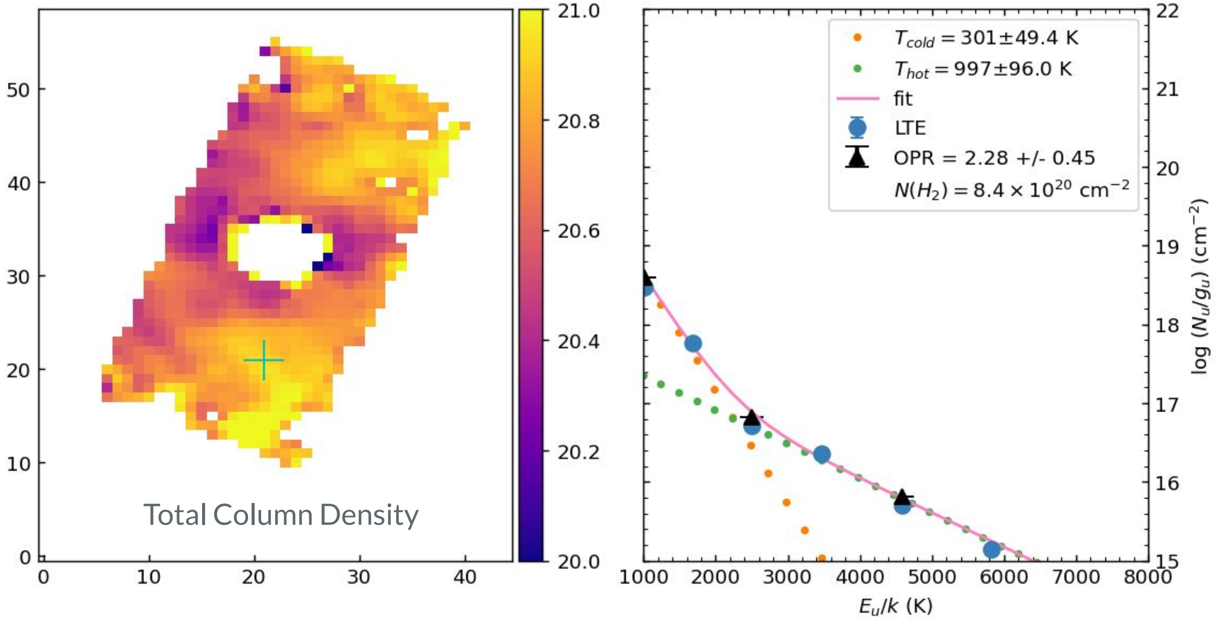
ExcitationFit: Excitation diagram fitting - H_2, CO, ^{13}CO. (More molecules coming)
Solves for temperatures and column densities, and optionally, ortho-para ratio, and A_v





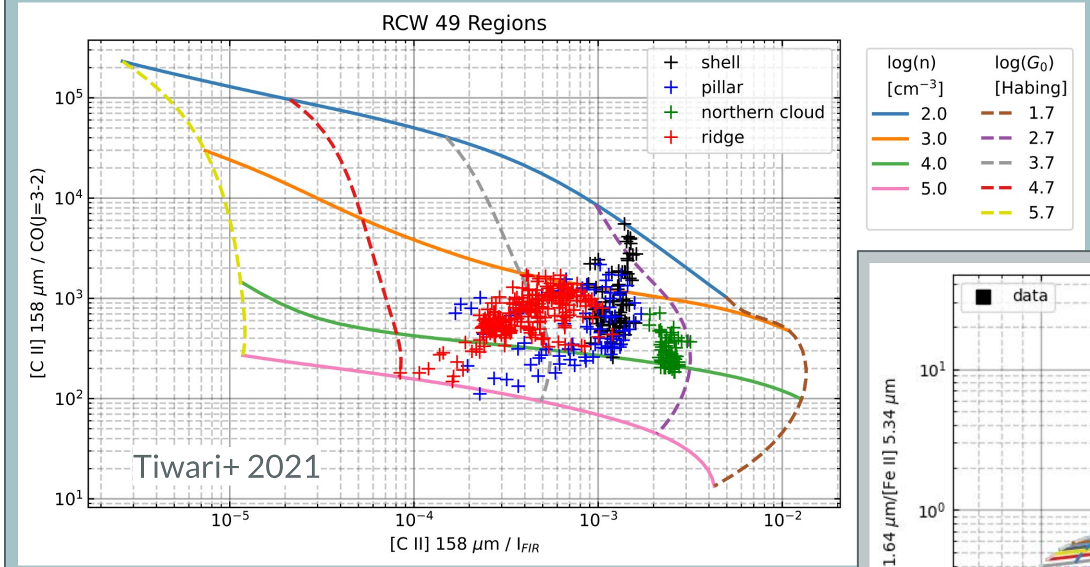
Excitation Diagram Fitting: Maps!

Interactively view fitted quantities. Click on any pixel and see its excitation diagram



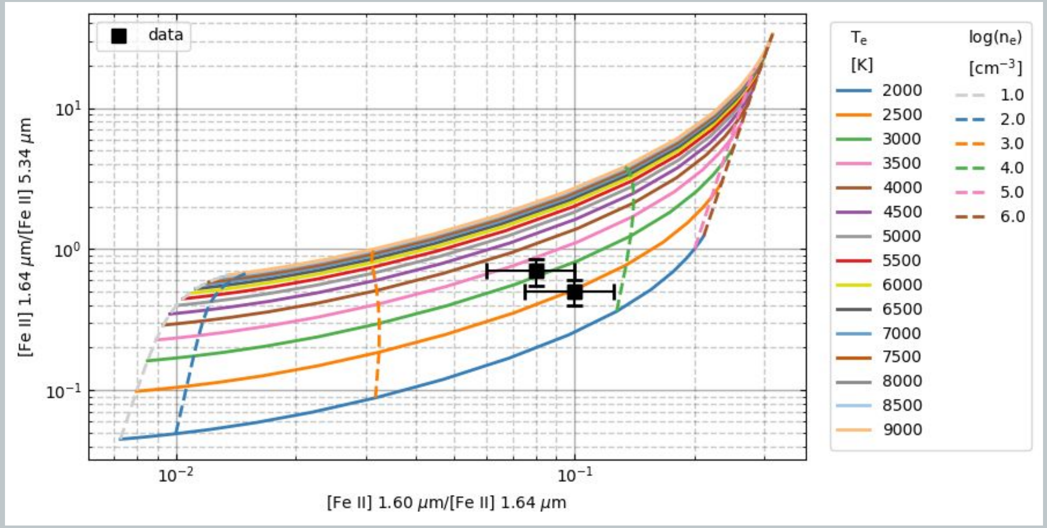
JWST H_2 data of the Centaurus A galaxy (Evangelista+, in prep)

Phase space diagrams: plot data in model space



PDR gas: n, G_0 as a function of line intensity ratio

Ionized gas: n_e, T_e as a function of line intensity ratio



Model enhancements:

- Multiple viewing angles - edge-on, 75, 60, 45, 30, 15 degrees (WK models only)
- More metallicities for dwarf galaxies, high-z galaxies, and galactic nuclei (Z=0.1 to 5)
- Deuterium chemistry for protostellar disk evolution (D/H ratio); HD at 112 μm has 4x lower energy than H_2
- More spectral lines (request your favorite!)

Tool enhancements:

- Regularization in image-based fitting — more robust solutions when observations are limited or of low S/N
- Excitation fitting - more molecules and fitting multiple v-levels simultaneously
- New tools for cross-comparison between different model sets

John in 1989 on the Kuiper Airborne Observatory.

We were flying our 490 GHz receiver.

Observing CI -- **A PDR LINE!**


THE END