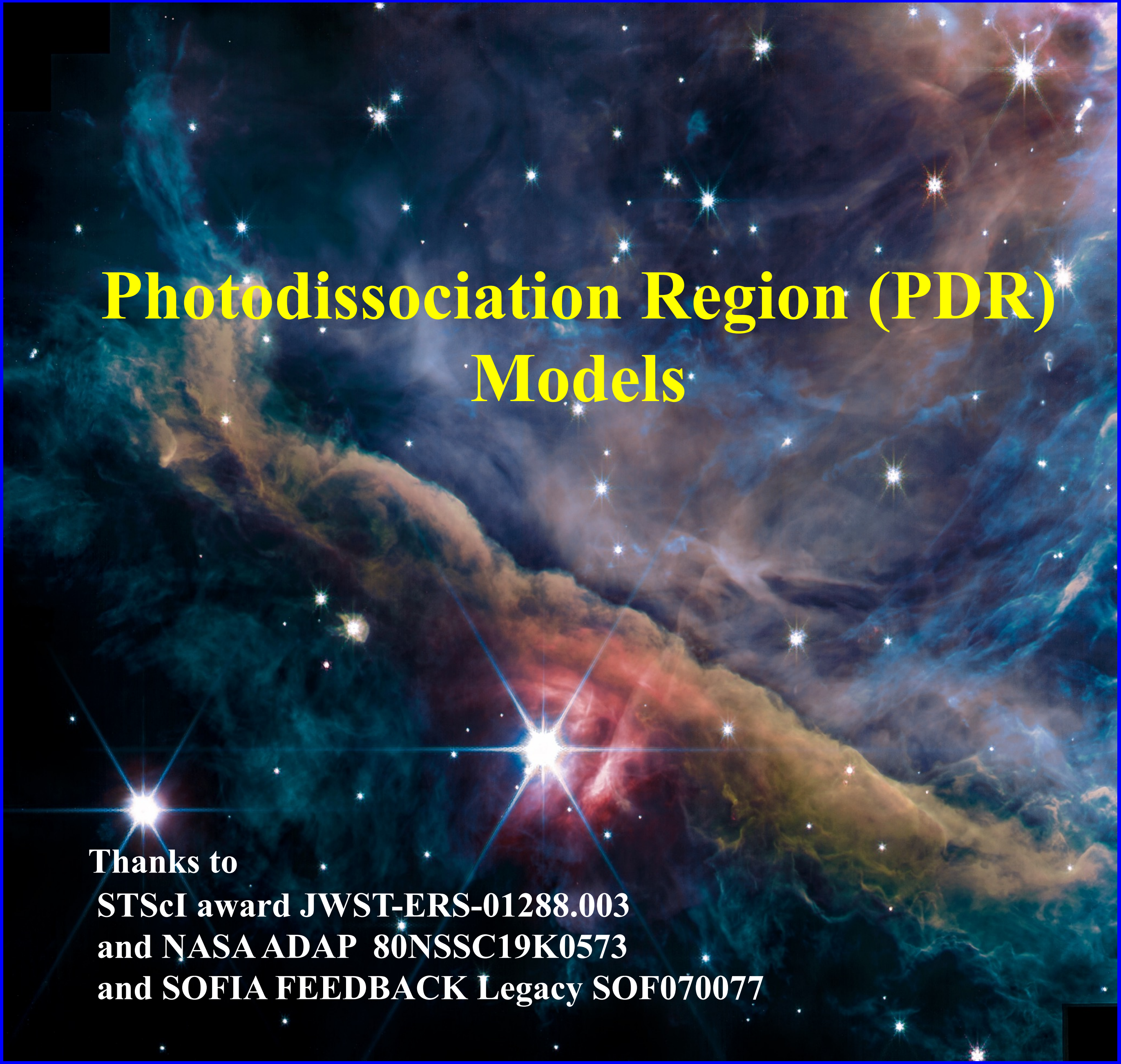
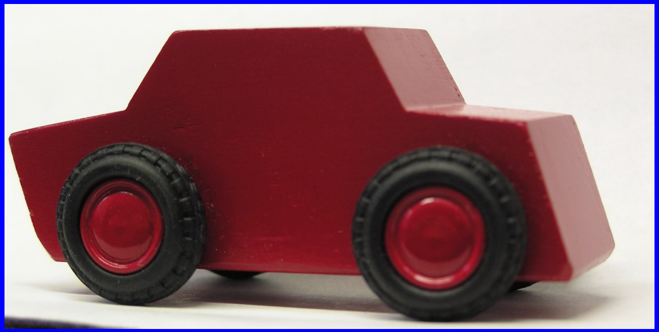
Photodissociation Region (PDR) Models



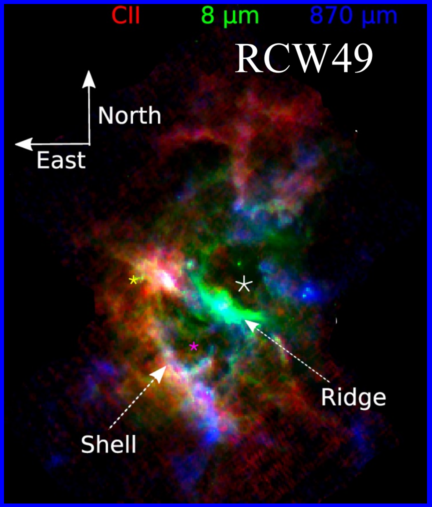
Thanks to
STScI award JWST-ERS-01288.003
and NASA ADAP 80NSSC19K0573
and SOFIA FEEDBACK Legacy SOF070077

STARS

CARS

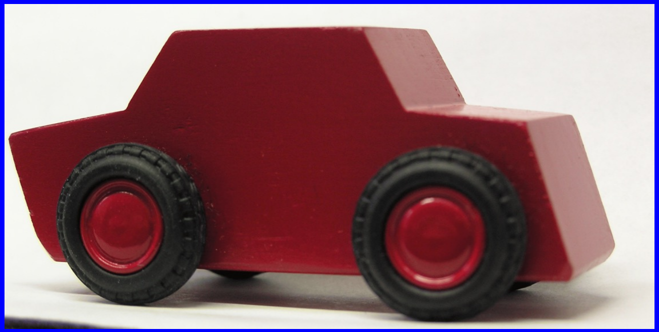


and PDRs

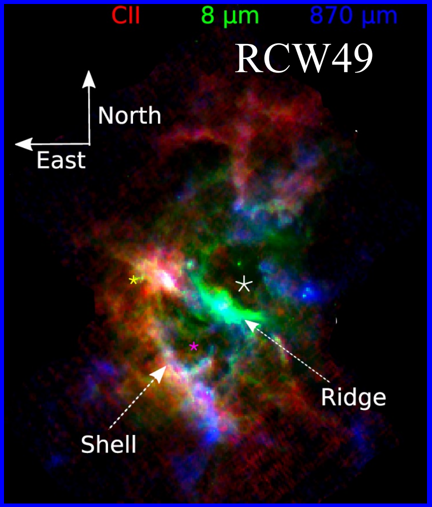


Introduction to PDRs: - What are they?
Where are they found?

CARS



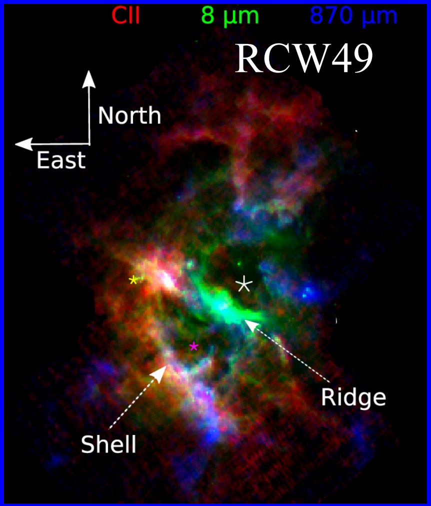
and PDRs



Introduction to PDRs: - What are they?
Where are they found?

Structure and Chemistry, Heating Processes, Cooling Processes and Dominant Cooling Lines, Gas Line Diagnostics

and PDRs



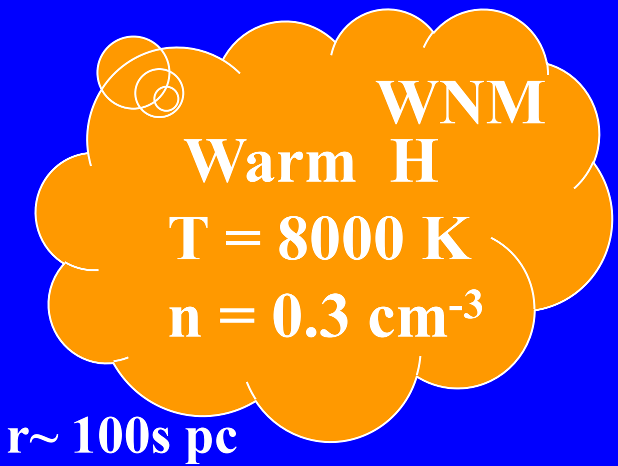
Introduction to PDRs: - What are they?
Where are they found?

Structure and Chemistry, Heating Processes,
Cooling Processes and Dominant Cooling Lines,
Gas Line Diagnostics

PDR Models and Comparison to Observations
Geometry, Metallicity, Self-Absorption

PDR: PhotoDissociation Region

Gas phase in which UV radiation plays a role in the heating and/or chemistry



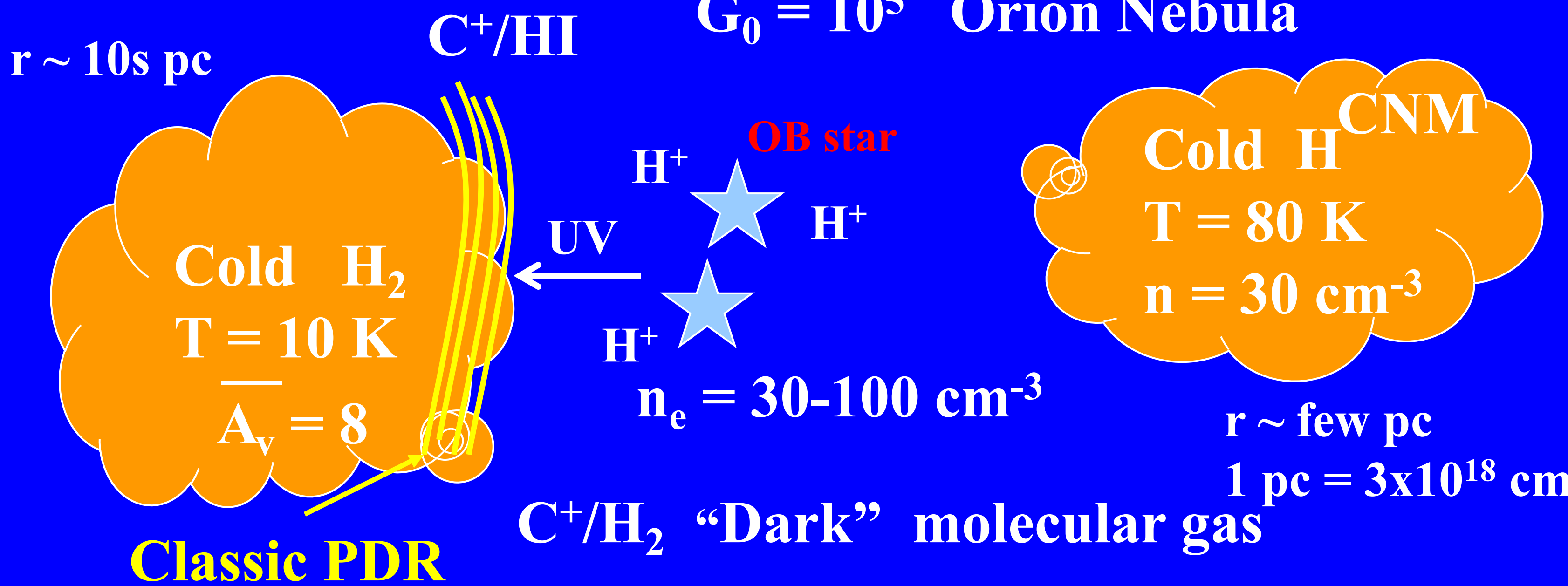
UV: 6 eV – 13.6 eV

G_0 = 1 Interstellar field

1.6×10^{-3} erg cm^{-2} s^{-1}

10^8 ph cm^{-2} s^{-1}

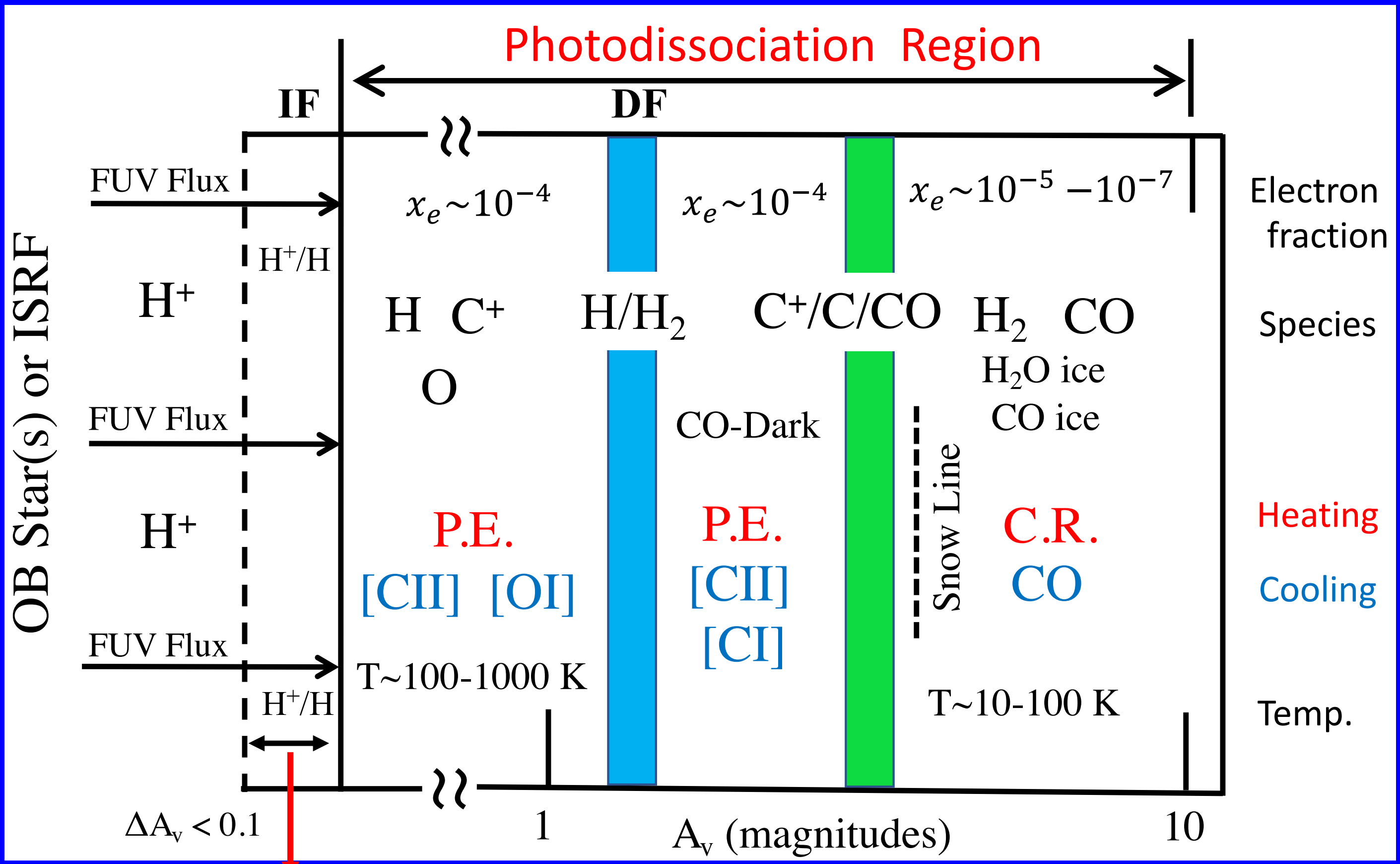
$G_0 = 10^5$ Orion Nebula



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


JWST
PDRs4All ERS
The inner Orion Nebula seen with JWST
Towards Trapezium cluster
Young star inside globule
Protostar
Young star with disk inside its cocoon
Cocoon
Disk
Orbit of Neptune
Protostellar Disk
+ Outflow
Orion Bar
θ² Orionis A
Filaments
Evolved Star + Shells
Credits : NASA / ESA / CSA / PDRs4All team S. Fuenmayor

Wolfire, Vallini, Chevance, ARAA, 2022



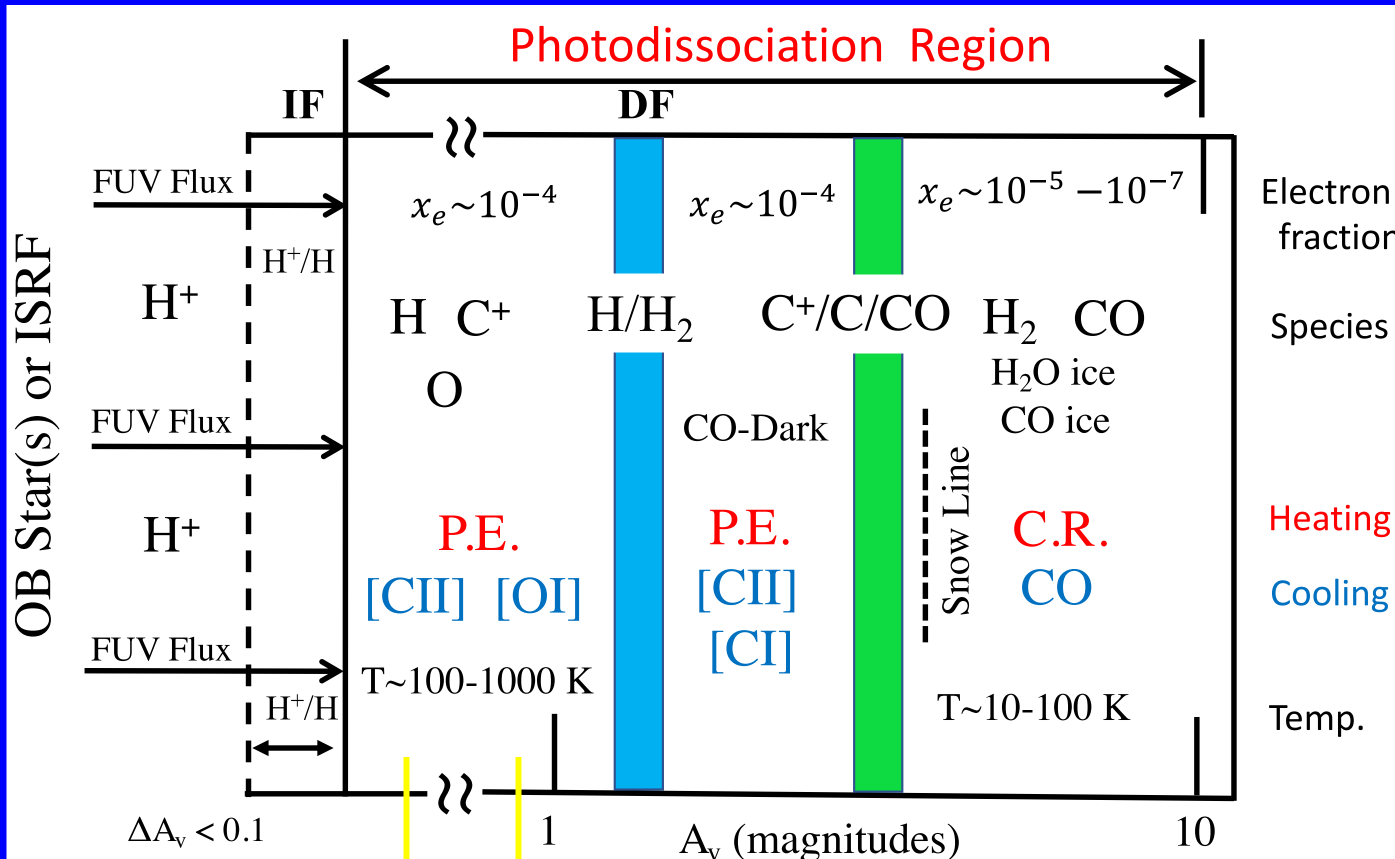
Diagnostics: HI, He — Spitzer, JWST

[SiII], [FeII], [SIV], — Spitzer, JWST

[NeII], [ArIII], [SIII[— Spitzer, JWST

Optical Lines — HST, VLT

Wolfire, Vallini, Chevance, ARAA, 2022



Diagnostics: C^+ 158 μm — Herschel, SOFIA

O 63 μm, 145 μm — Herschel, SOFIA

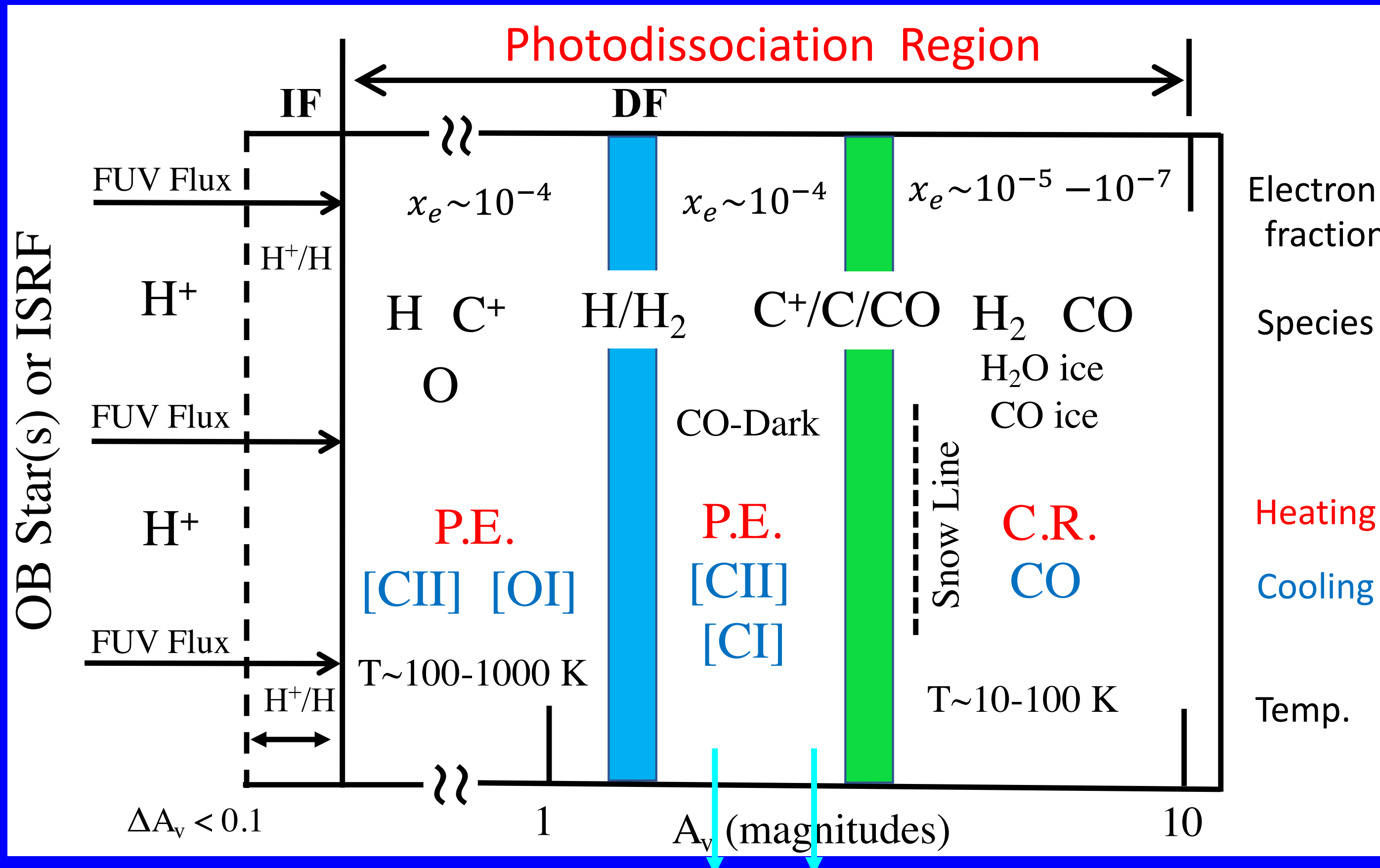
Si^+ 35 μm, Fe^+ 26 μm — Spitzer, JWST

Dust Continuum — Herschel, SOFIA, JWST

PAH 3.3, 6.2, 7.7, 8.6 — Spitzer, JWST

11.2 μm — Spitzer, JWST

Wolfire, Vallini, Chevance, ARAA, 2022



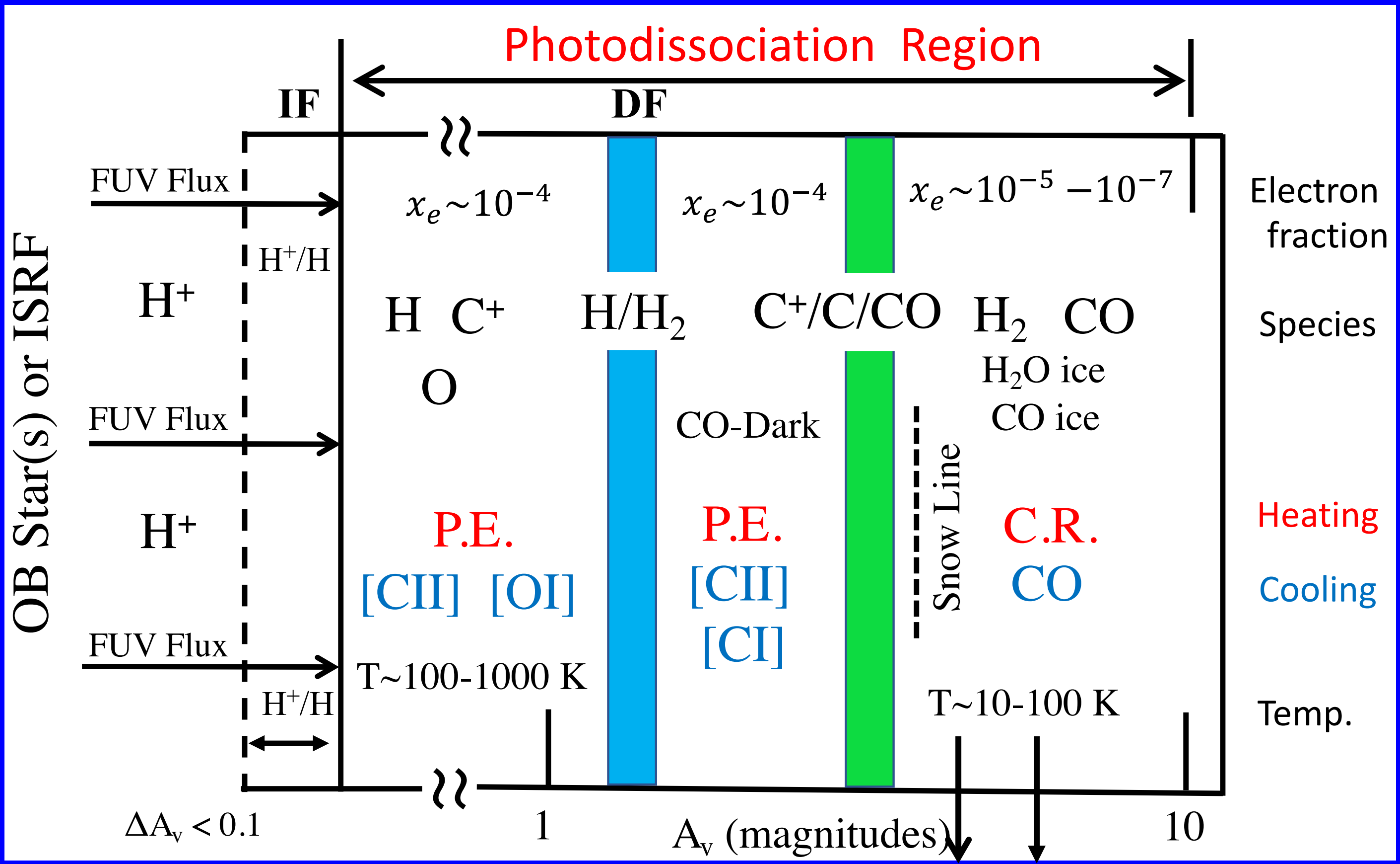
Diagnostics: C^+ 158 µm, OI 63 µm — **Herschel, SOFIA**

C 609 µm, 370 µm — **Herschel, Alma**

H_2 0-0 S(2) 12.3 µm — **Spitzer, JWST**

H_2O, H_2O^+, OH^+ — **Herschel, SOFIA**

Wolfire, Vallini, Chevance, ARAA, 2022



Diagnostics: High –J CO Herschel , ALMA, SOFIA

Low –J CO ALMA

POLYCYCLIC AROMATIC HYDROCARBONS AND THE UNIDENTIFIED INFRARED EMISSION BANDS: AUTO EXHAUST ALONG THE MILKY WAY!

L. J. ALLAMANDOLA[1] AND A. G. G. M. TIELENS
Space Science Division, NASA/Ames Research Center
AND
J. R. BARKER
Department of Chemical Kinetics, SRI International

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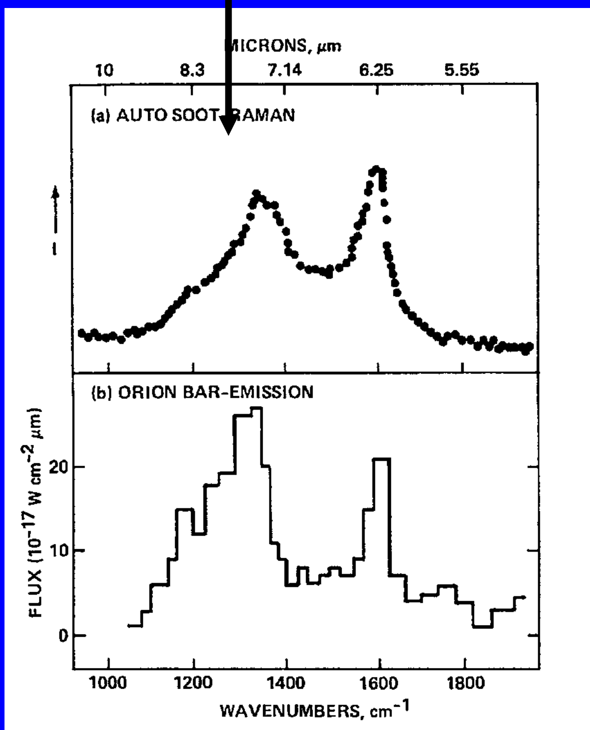
1985 ApJ



PAHs: 1)Dominate the photoelectric heating
Bakes+ 1994, Weingartner+ 2001, Berné+ 2022

2)Govern the electron fraction
e.g., Hollenbach+ 2012, Shaw+ 2021

3)Might be sites of H_2 formation
Tielens 2021, Wolfire+ 2022

Grain Photoelectric Effect

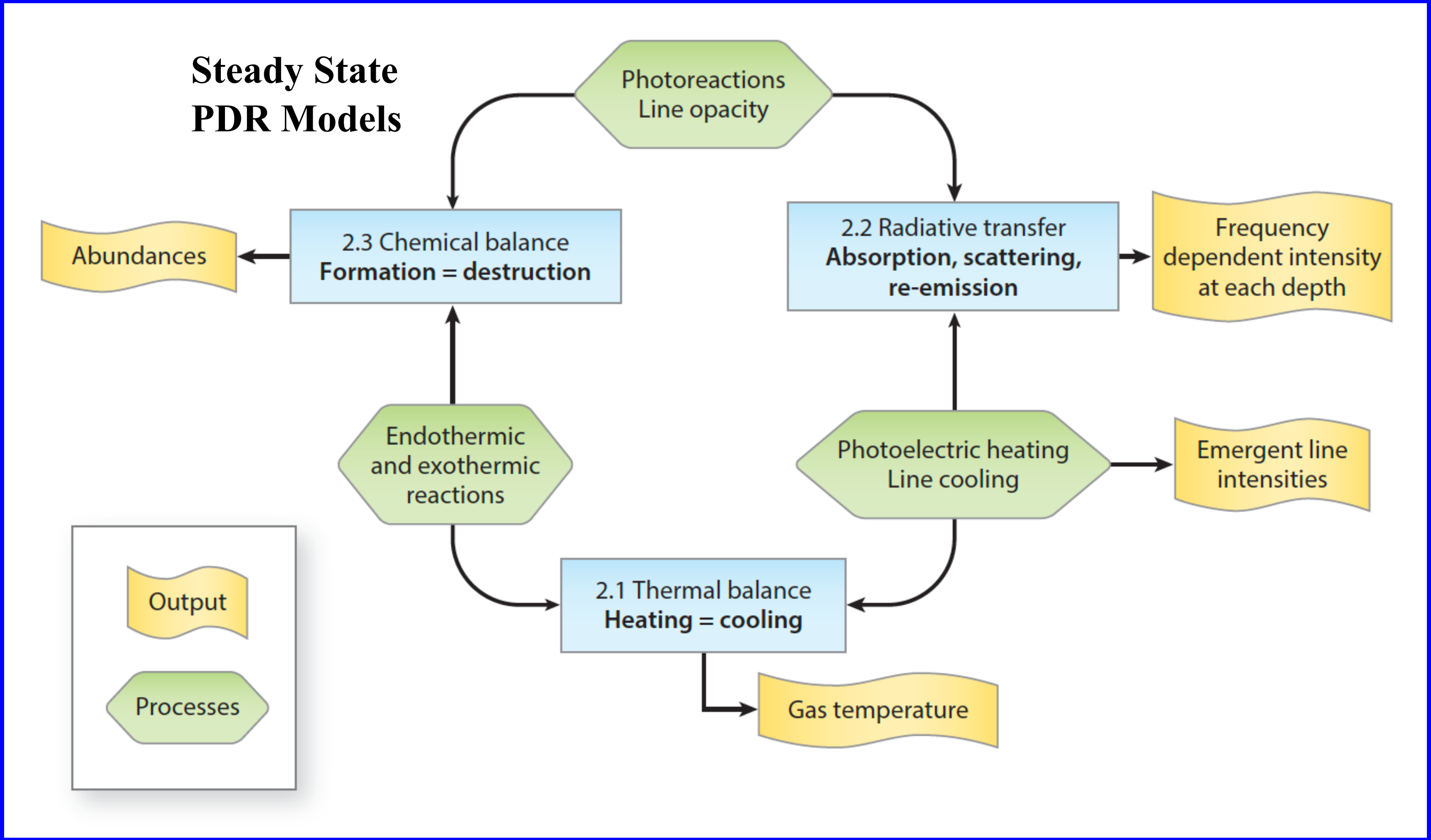
↑

Stellar Photons → PAHs → PDRs

↓

Auto Exhaust

Wolfire, Vallini, Chevance, ARAA, 2022



Codes:

UMD: Tielens & Hollenbach 1985, Wolfire et al. 2010, Neufeld & Wolfire 2016

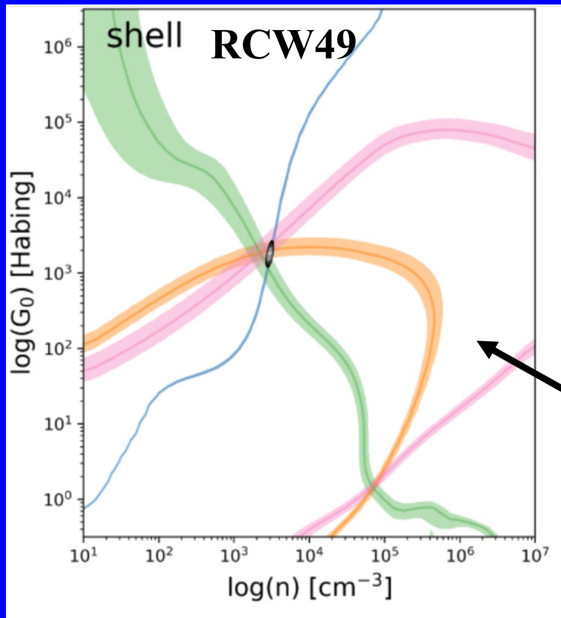
Meudon Code: Le Petit, et al. 2006, Bron et al. 2014, Bron et al. 2021 (ismdb.obspm.fr)

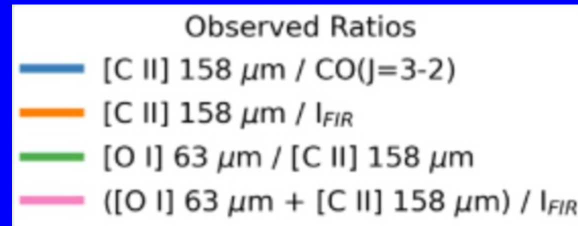
KOSMA-Tau: Röllig et al. 2016, Röllig et al. 2013, Röllig & Ossenkopf-Okada 2022

Cloudy: Shaw et al. 2005, Ferland et al. 2013, 2017, Shaw et al. 2022

UCL-PDR: Bell et al. 2006, Priestley et al. 2017, Holdship, et al. 2017

Tiwari, Wolfire, Pound et al. 2022

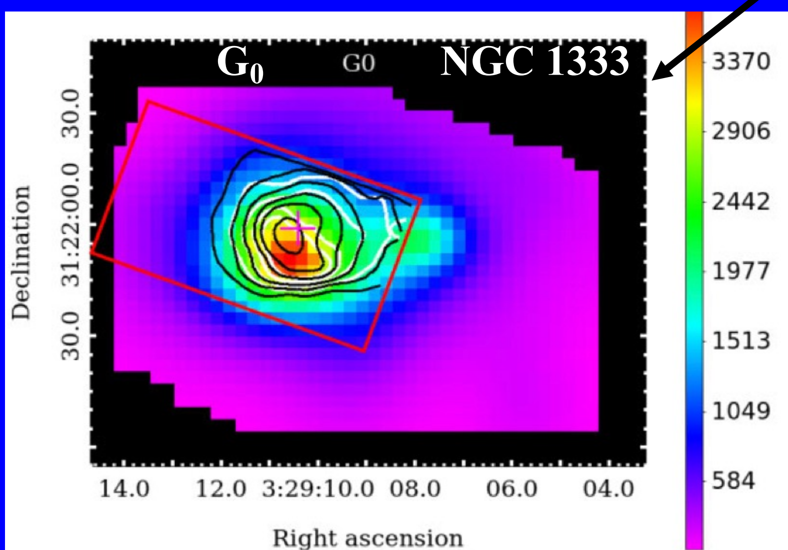


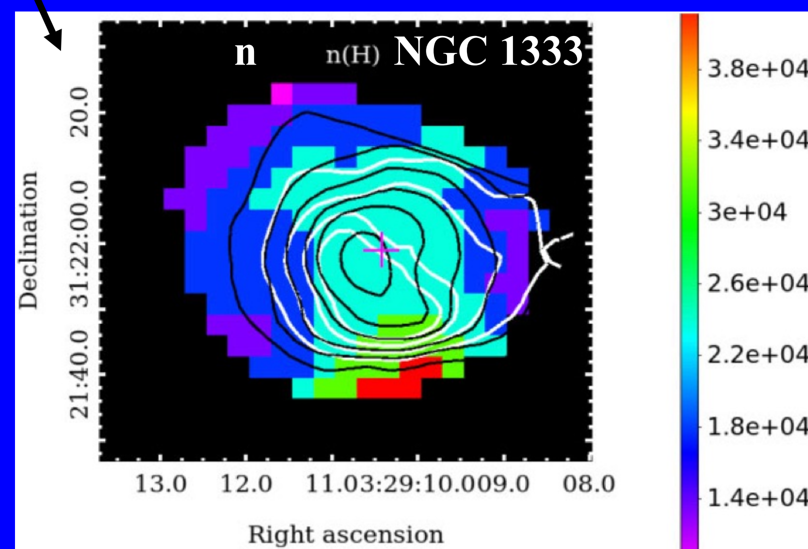


PDR Toolbox: dustem.astro.umd.edu

Fit for Single Position

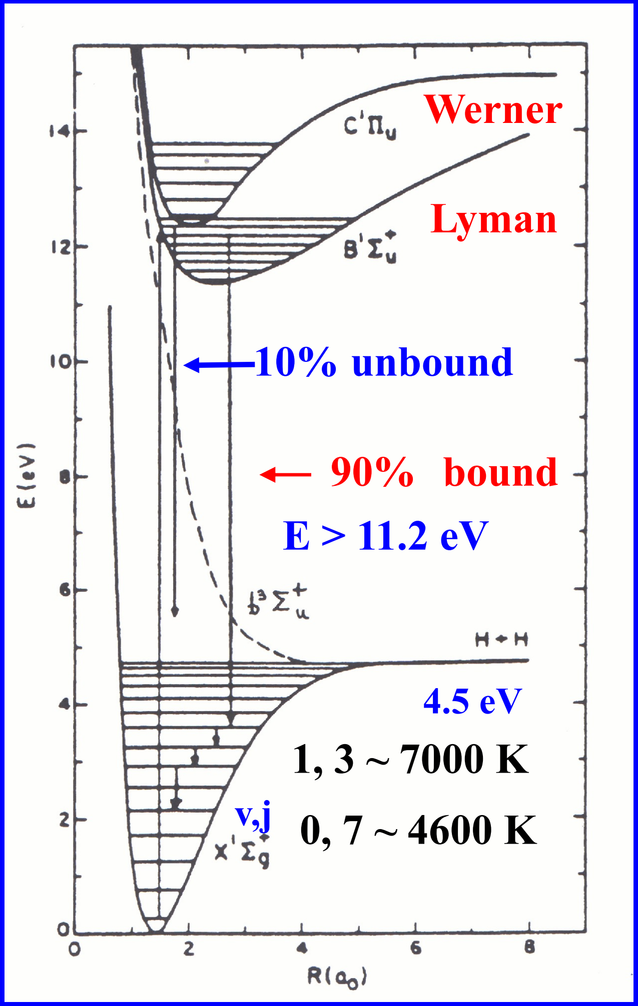
Fits for Line Maps



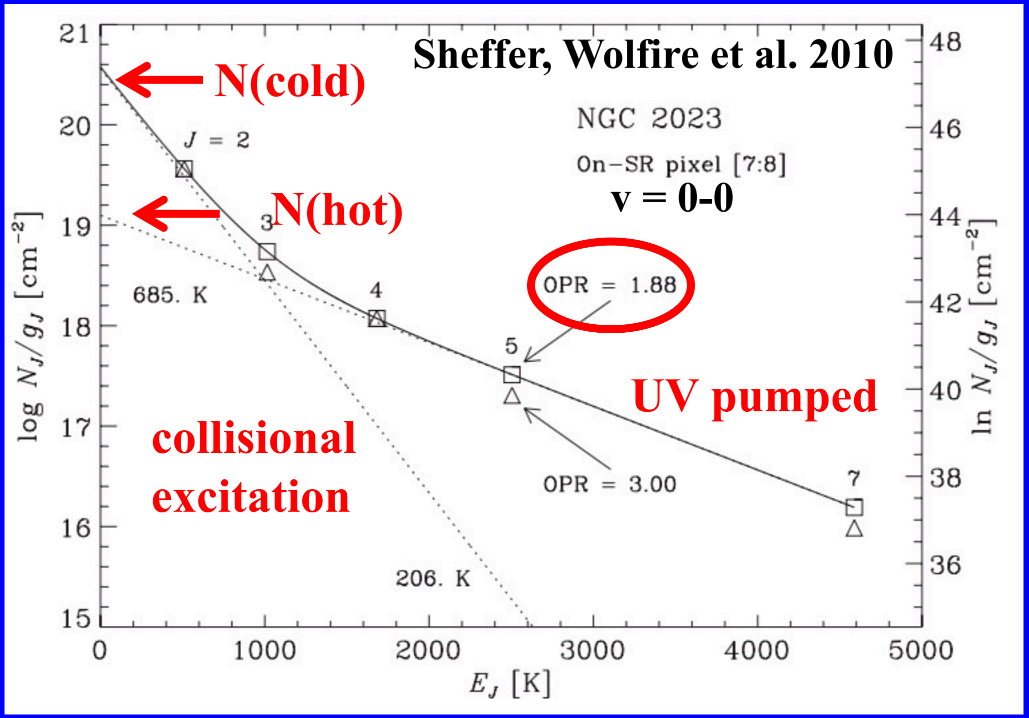


Knight, Peeters, et al. 2022

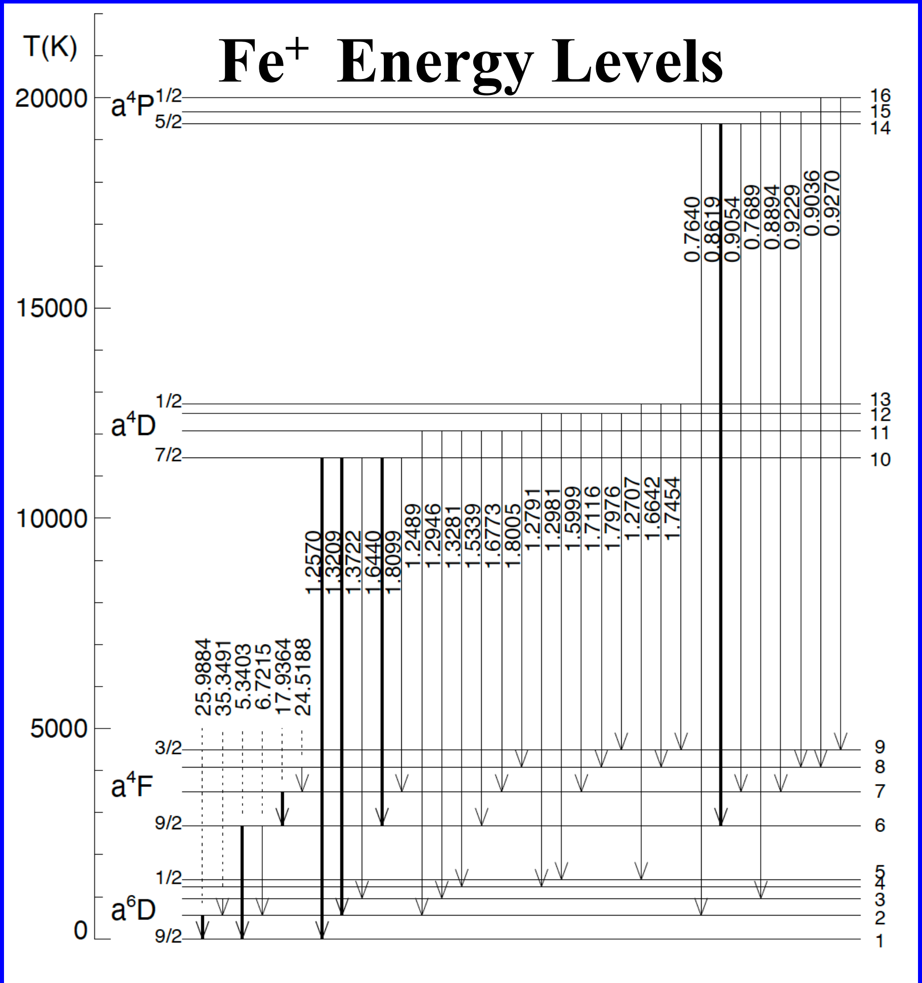
H_2 Energy Levels



H_2 Excitation Diagram

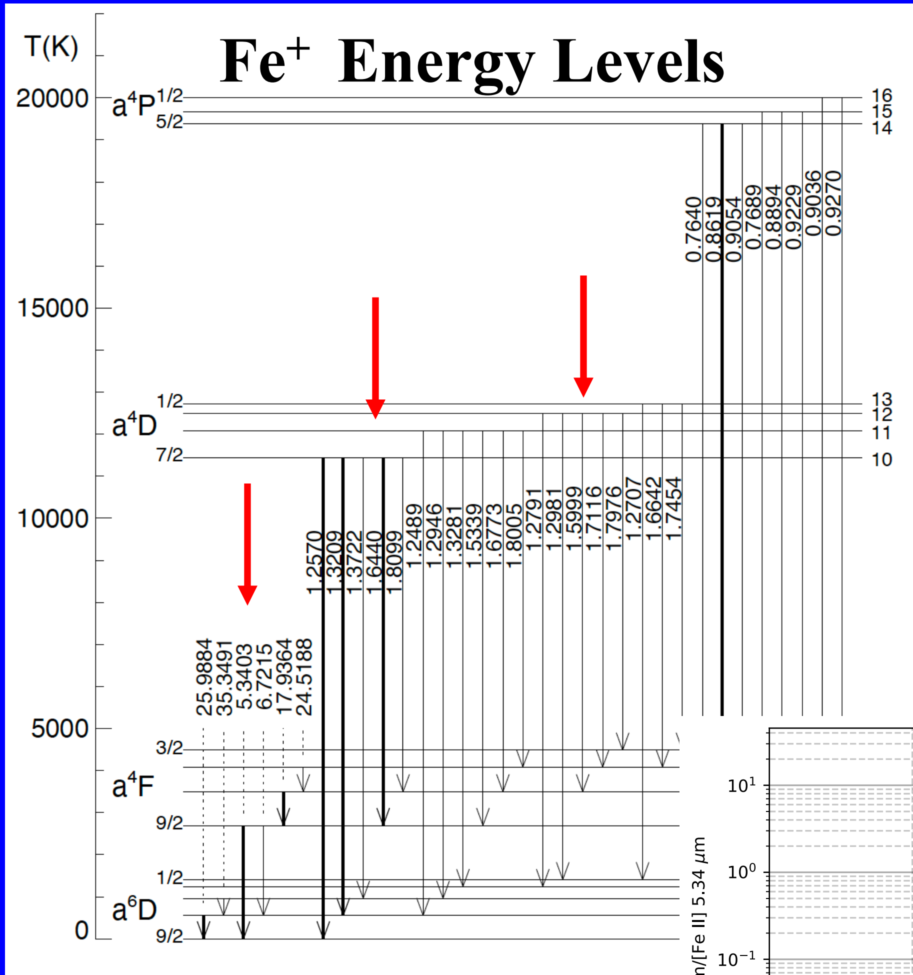


Trondheim, Norway



HII Region Diagnostics

[FeII], [ArIII], [ArV]



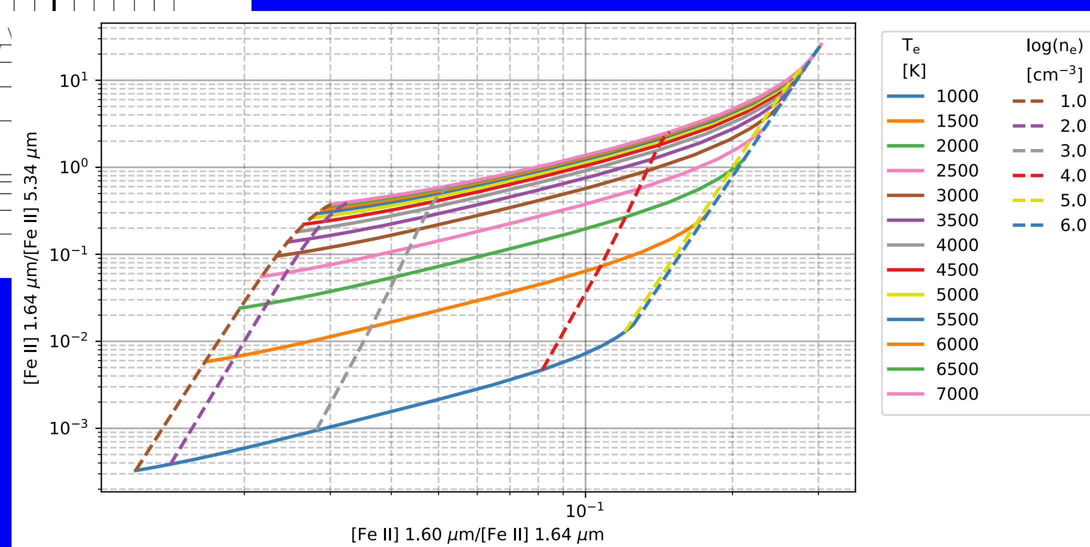
HII Region Diagnostics

[FeII], [ArIII], [ArV]

Volume emissivities from (modified) CHIANTI

Note: A values and collision strengths are uncertain and will be updated following more observations.

Phase Space Plot



[FeII] 1.64/[FeII] 5.34 ⟶ T_e

[FeII] 1.60/[FeII] 1.64 ⟶ n_e

Effects of Geometry

Not all sources are face-on!

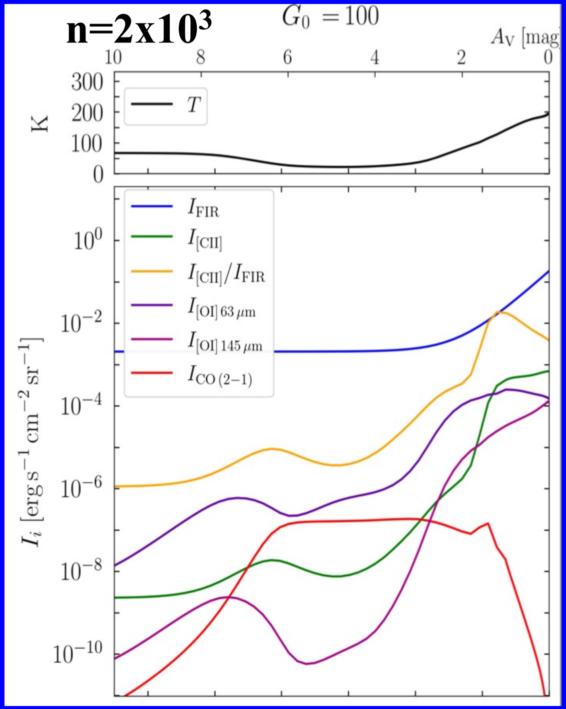
For edge-on sources:

Optically thin lines increase by geometrical factor e.g., H_2, [OI] 145

Optically thick or marginally thick increase by a factor of a few e.g., [OI] 63µm, [CII]

Intensities vary across the source

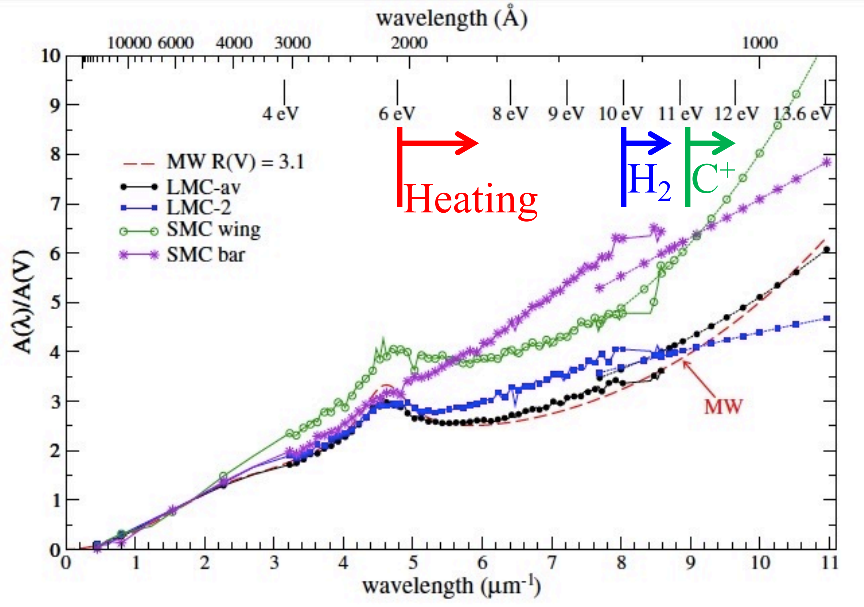
Habart et al. 2023



Pabst et al. 2017, 2022

Effects of Metallicity/Grain Properties

Extinction Curves



A_v conversion to N(H)

$$\mathrm{MW}: A_V = \frac{N(H)}{1.9\mathrm{x}10^{21}\,\mathrm{cm}^{-2}}$$

$$\mathrm{LMC2}: A_v = \frac{N(H)}{7.0\mathrm{x}10^{21}\,\mathrm{cm}^{-2}}$$

$$\mathrm{SMC\text{-}bar}: A_V = \frac{N(H)}{1.3\mathrm{x}10^{22}\,\mathrm{cm}^{-2}}$$

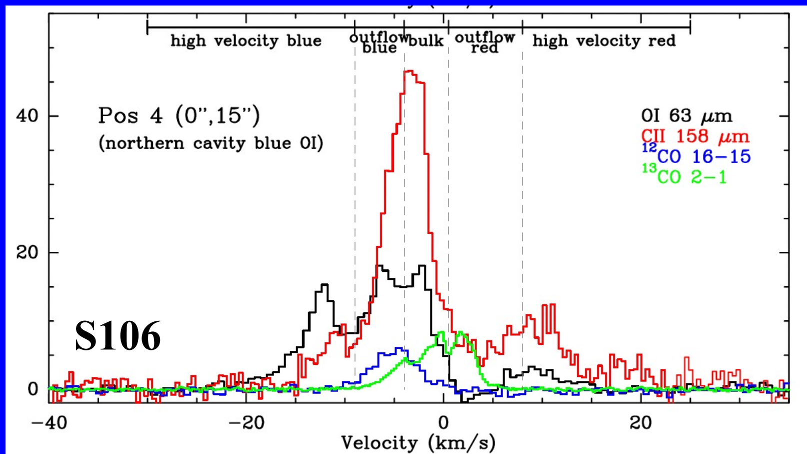
Gas Phase Abundances

LMC ~ 1/2 Milky Way
SMC ~ 1/5 Milky Way

Incident Radiation Field Hardness

Hot Star – more UV
Cool Star – less UV

Self Absorption



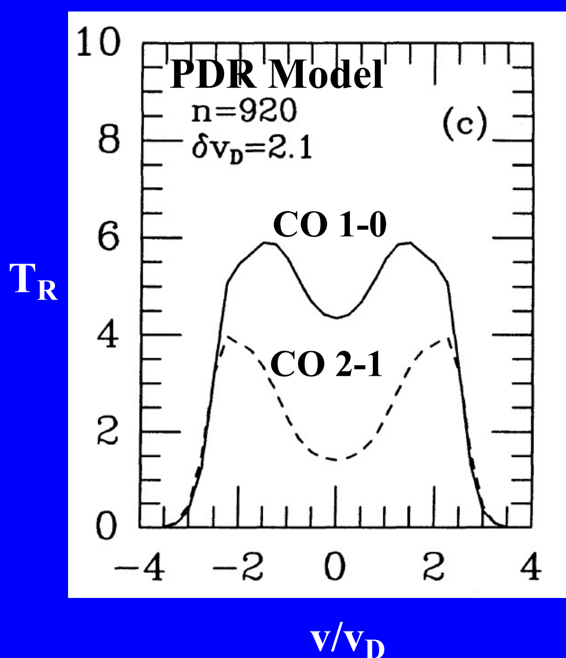
Schneider et al. 2018

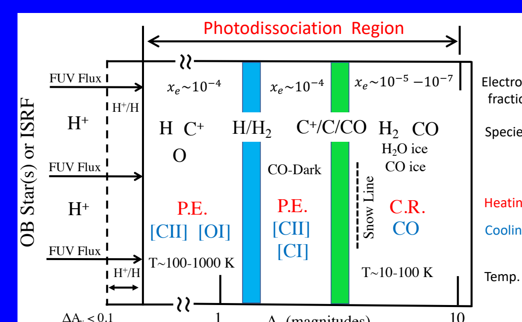
[OI] 63 µm self-absorption

PDR Models account for optically thick lines (self-absorbed or not)!

[OI] 145 µm/[OI] 63 µm > 0.1 not a single face-on PDR. Could be FOREGROUND absorption.

Wolfire et al. 1993

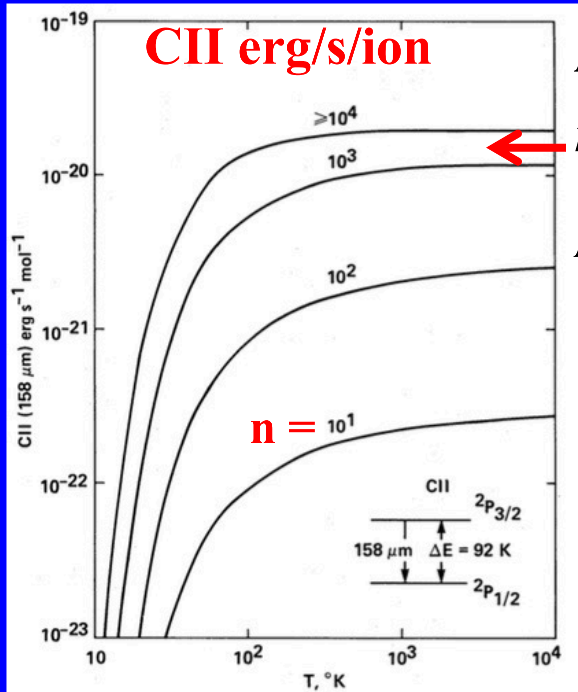




Typically an increase in [OI] 63µm of 2-4 is required.

Schneider et al. 2018, Goldsmith 2021

Tielens & Hollenbach 1985



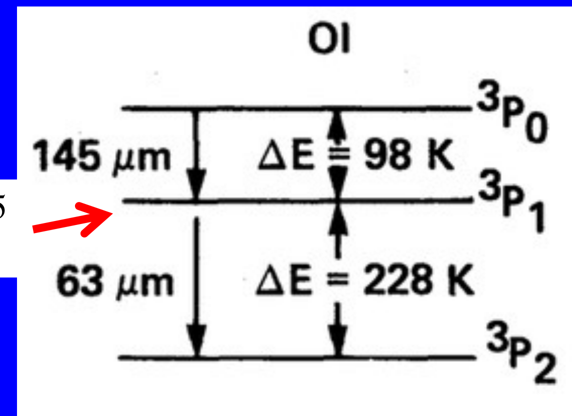
$\Lambda \propto n$ (erg s^{-1} cm^{-3})

$n_{cr} = A_{ul} / \gamma_{ul}$

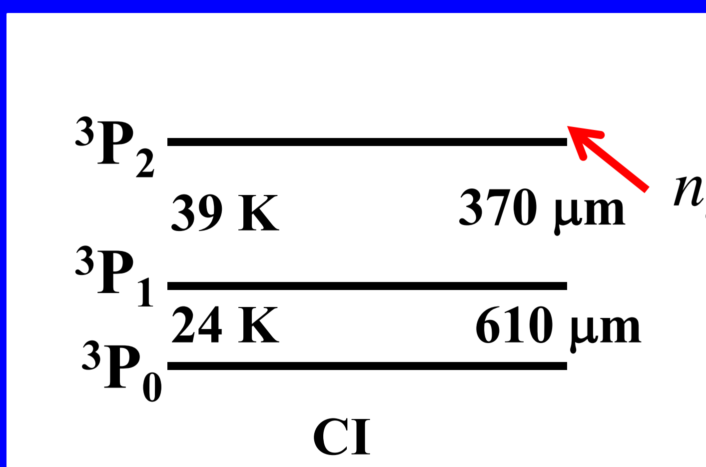
$\Lambda \propto n^2$ (erg s^{-1} cm^{-3})

Tielens & Hollenbach 1985

$n_{cr} \approx 5\text{x}10^5$



See also Goldsmith et al. 2012



$n_{cr} \approx 3000$