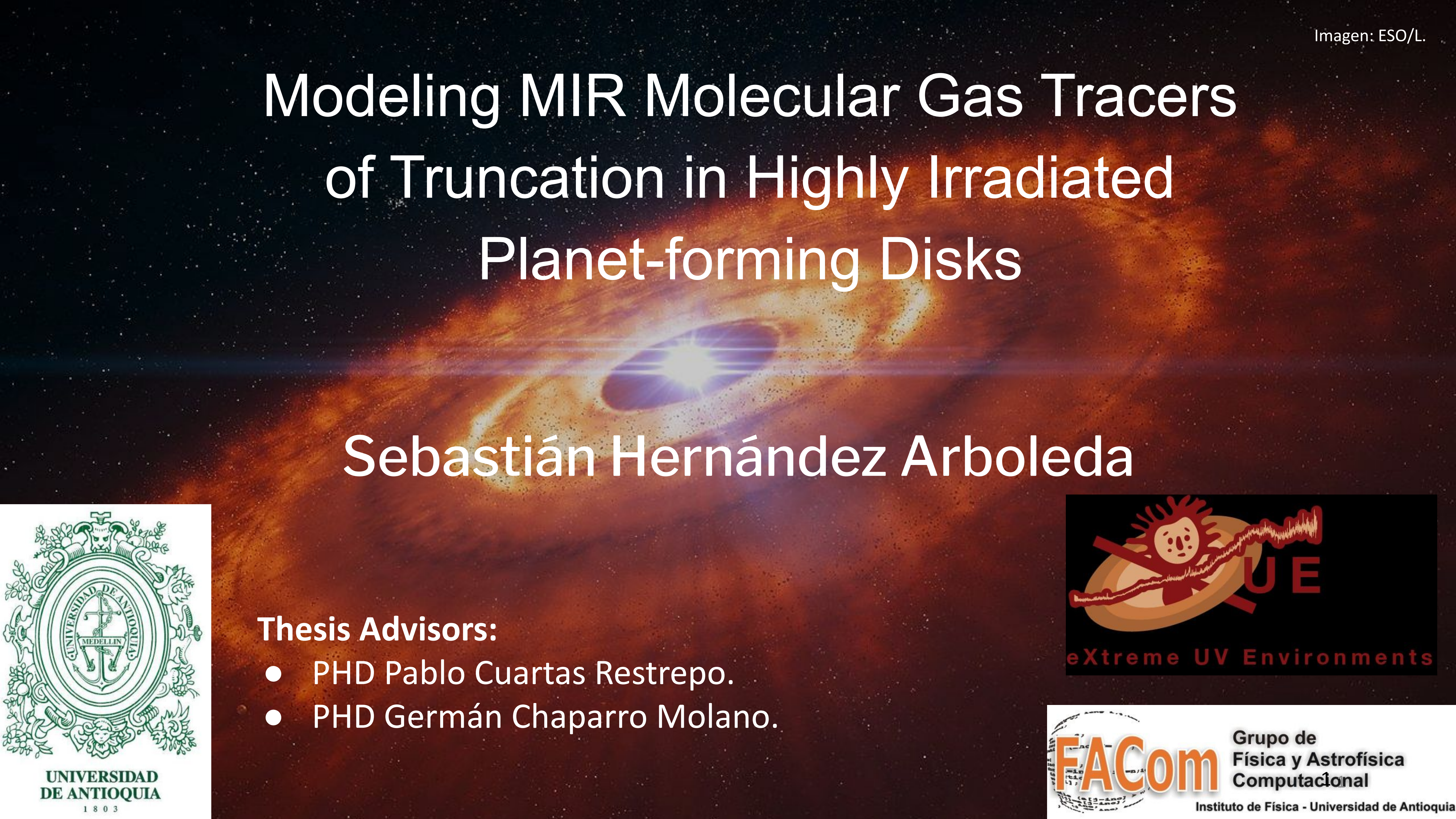
Imagen: ESO/L.

Modeling MIR Molecular Gas Tracers of Truncation in Highly Irradiated Planet-forming Disks

Sebastián Hernández Arboleda

Thesis Advisors:
- PHD Pablo Cuartas Restrepo.
- PHD Germán Chaparro Molano.

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eXtreme UV Environments

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Grupo de
Física y Astrofísica
Computacional
Instituto de Física - Universidad de Antioquia

Imagen: ESO/L.

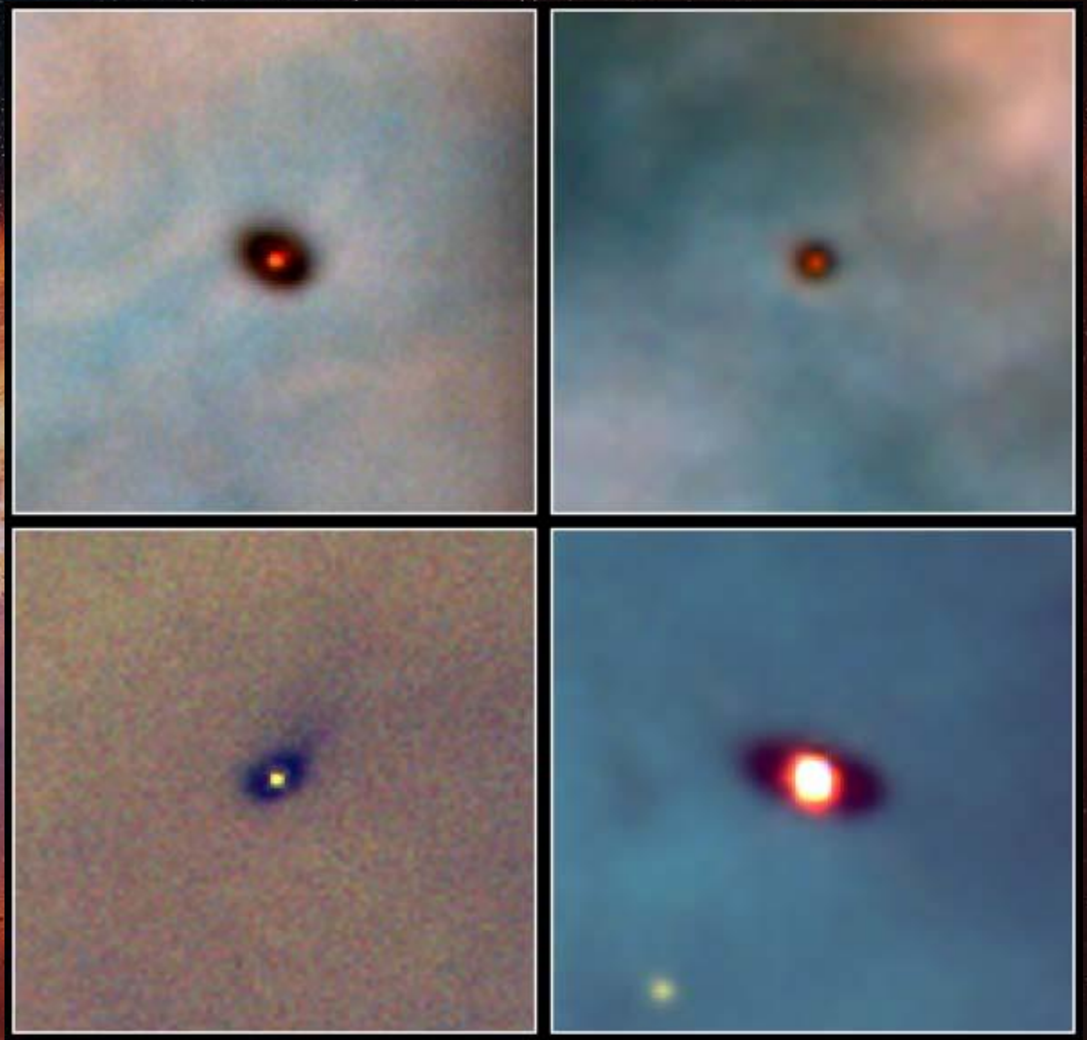
Introduction

Part 1: Context:

- Planet-forming disks.
- Xue Consortium.
- First Observational results.

Part 2: Our research:

- Parametric models.
- Results.
- Preliminary conclusions.

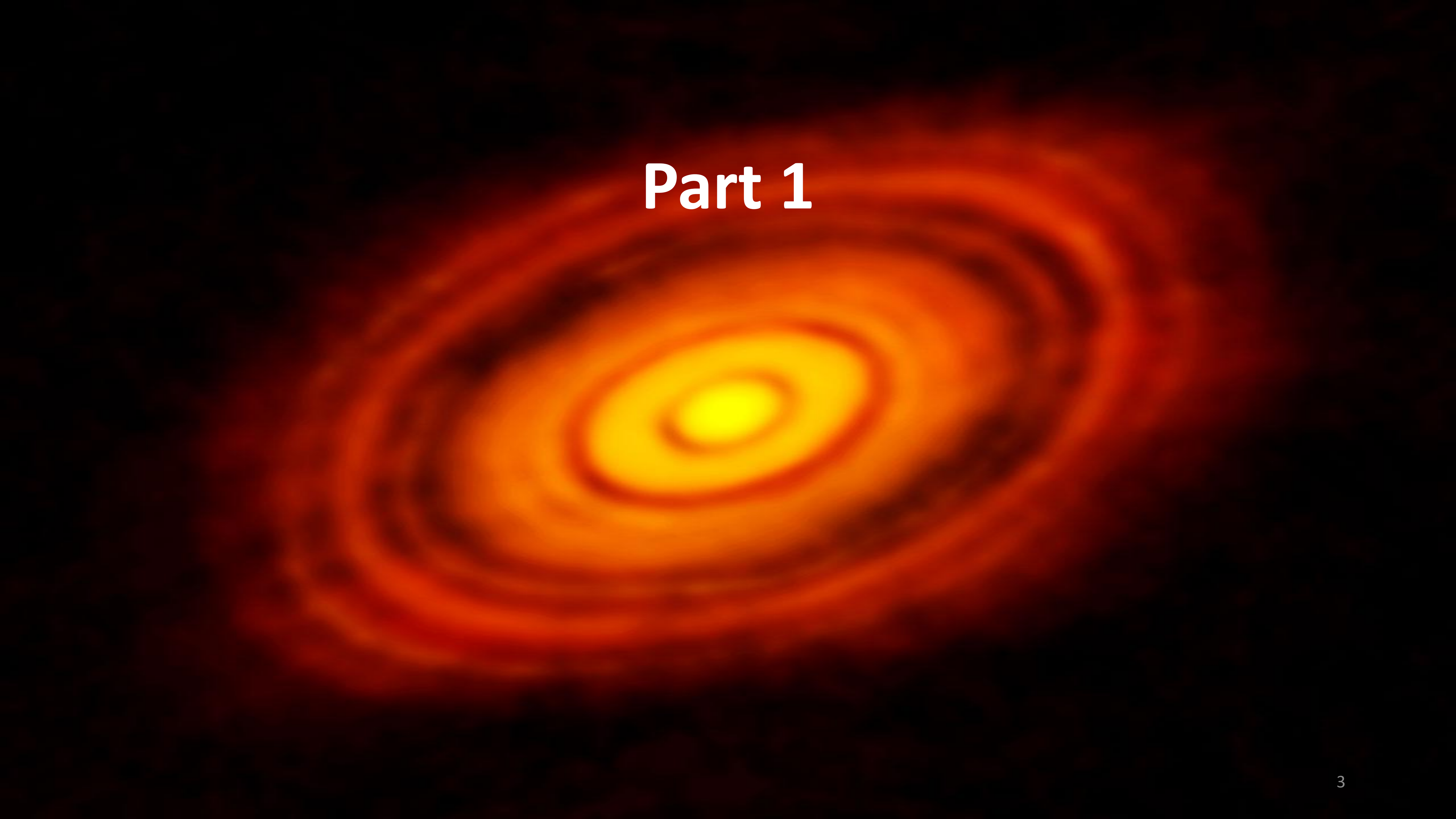


Protoplanetary Disks
Orion Nebula

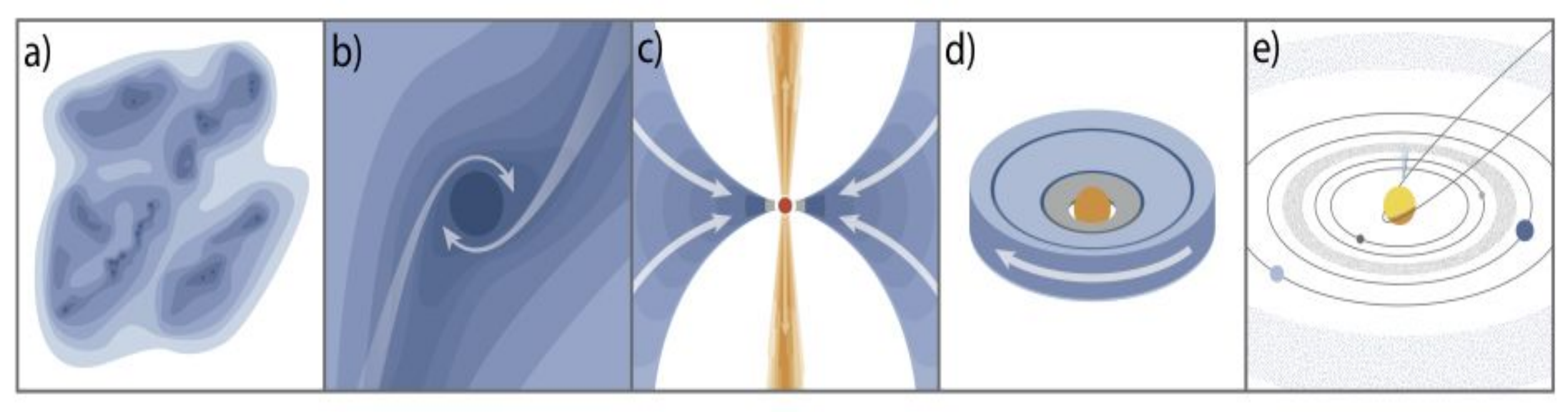
HST • WFPC2

PRC95-45b • ST ScI OPO • November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

Part 1



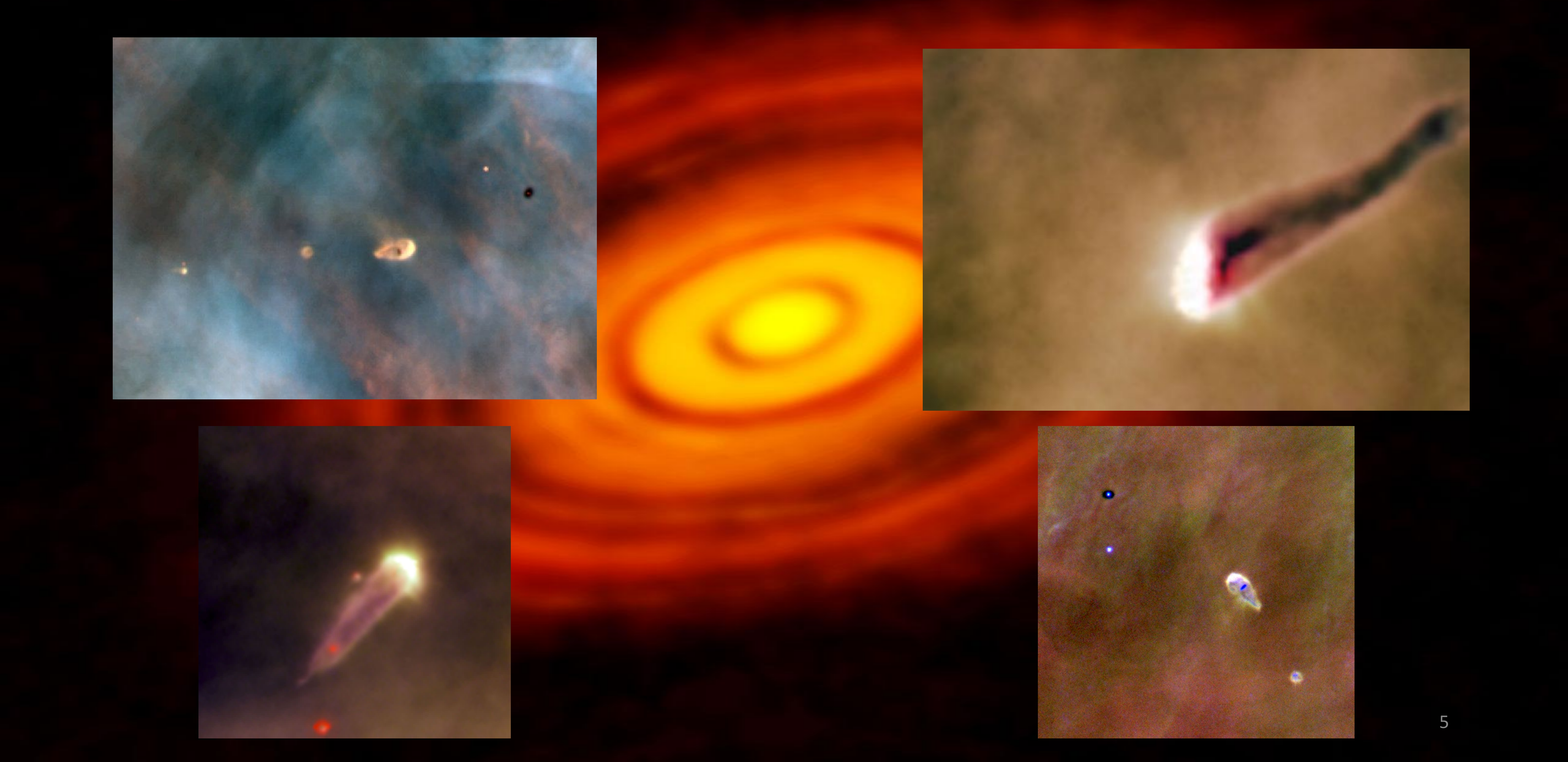
FROM MOLECULAR CLOUDS TO STARS



Öberg, K. I., & Bergin, E. A. (2021)

A. **Dense nuclei in molecular clouds.**
B. **Gravitationally collapse.**
C. **The center begins to heat up, forming a protostar. Disc formation and ejection of material.**
D. **Pre-main sequence star accompanied by an accretion disk.**
E. **Formation of planets.**

Proplyds.



XUE Consortium - James Webb Space Telescope (JWST) program.

HST - NGC 6357

J
Jueves

La Autoridad Nacional de Licencias Ambientales decidió archivar la solicitud para la ampliación de la autopista Norte que hizo la Concesión Ruta Bogotá Norte. La obra iría de la calle 191 a la 245 y tendría una inversión de $1,59 billones. / Bogotá p. 9

Indicadores económicos

PETRÓLEO BRENT (Barril)		US$78,54 0,37%
DÓLAR EN CASAS DE CAMBIO (Promedio)		
COMPRA $3.707 -0,16%	VENTA $3.890 -0,18%	
DTF		12,35%

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Señales para otra Tierra

Un equipo liderado por la astrónoma colombiana María Claudia Ramírez encontró en un punto hostil de una galaxia lejana condiciones favorables para la formación de planetas similares a la Tierra. Incluso algunos elementos que conocemos que son básicos para la vida, como agua y dióxido de carbono. / Vivir p. 14

Un equipo de científicos colombianos estudió la región interna del disco XUE-1, cuyo nombre hace honor al dios del Sol en la cultura muisca. / NASA - Instituto Max Planck

Maria Claudia Ramirez-Tannuz

UE

eXtreme UV Environments

XUE Consortium - James Webb Space Telescope (JWST) program.

The Astrophysical Journal Letters, 958:L30 (14pp), 2023 December 1
https://doi.org/10.3847/2041-8213/ad03f8

XUE: Molecular Inventory in the Inner Region of an Extremely Irradiated Protoplanetary Disk

María Claudia Ramírez-Tannus[1], Arjan Bik[2], Lars Cuijpers[3], Rens Waters[3,4], Christiane Göppl[5], Thomas Henning[1], Inga Kamp[6], Thomas Preibisch[5], Konstantin V. Getman[7], Germán Chaparro[8], Pablo Cuartas-Restrepo[8], Alex de Koter[9,10], Eric D. Feigelson[7,11], Sierra L. Grant[12], Thomas J. Haworth[13], Sebastián Hernández[8], Michael A. Kuhn[14], Giulia Perotti[1], Matthew S. Povich[15], Megan Reiter[16], Veronica Roccatagliata[17,18,19], Elena Sabbi[20], Benoît Tabone[21], Andrew J. Winter[22,23], Anna F. McLeod[24,25], Roy van Boekel[1], and Sierk E. van Terwisga[1]

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Among many others…..

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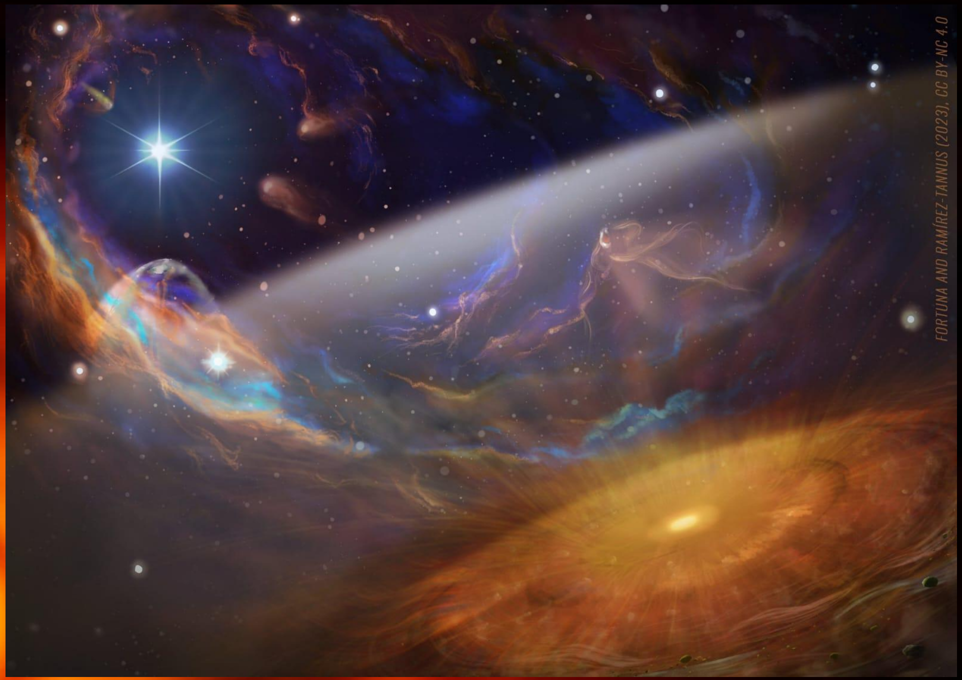
Observations.

- XUE targets 15 disks in three areas of NGC 6357, which hosts numerous massive OB stars, including some of the most massive stars in our Galaxy.
- XUE 1 was observed on 2022 August 3 as part of the XUE project in Cycle 1 (GO-1759; Ramirez-Tannus et al. 2021) with the MIRI MRS.


FORTUNA AND RAMÍREZ-TANNUS (2023), CC BY-NC 4.0

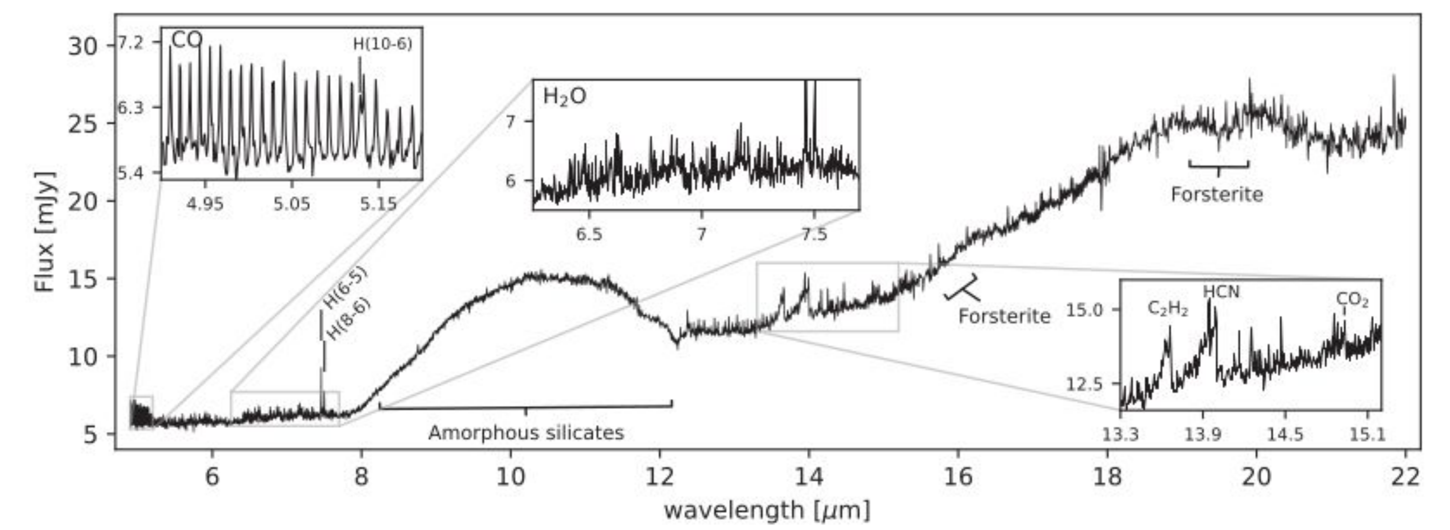


Figure 1. MIRI MRS spectrum of XUE 1. The most prominent dust features are labeled. The insets show the *P*-branch transitions of the CO rovibrational fundamental band, the water emission around 7 μm, and the 13–15 μm region featuring C_2H_2, HCN, and $^{12}CO_2$.

Ramirez-Tannuz et al 2023.

Results.

- Detection of abundant water, CO, 12CO2, HCN, and C2H2 in the inner few au of XUE 1.
- Discussion: Is Xue1 disk truncated or fUV radiation shielded (extinction)?

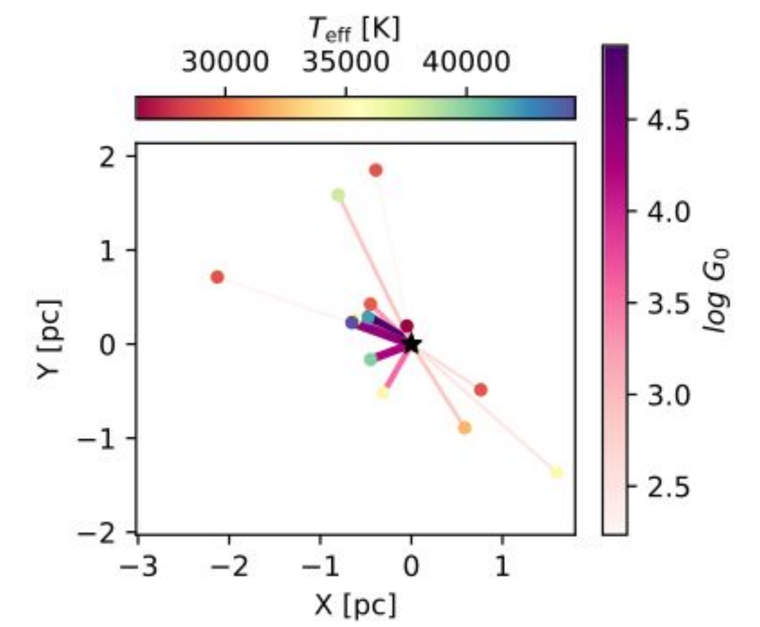


Figure 5. Top: extinction A_K for a sample of stars in Pis24, shown in colors. The position of XUE 1 in this diagram is indicated with a star. The O stars from the bottom panel are indicated with magenta borders. Bottom: radiation field toward XUE 1. The lines show the 2D distance from the massive stars to XUE 1 (indicated with the black star), and the colors of the circles show their temperature. The FUV radiation felt by XUE 1 from each massive star is shown by the color and width of the lines.

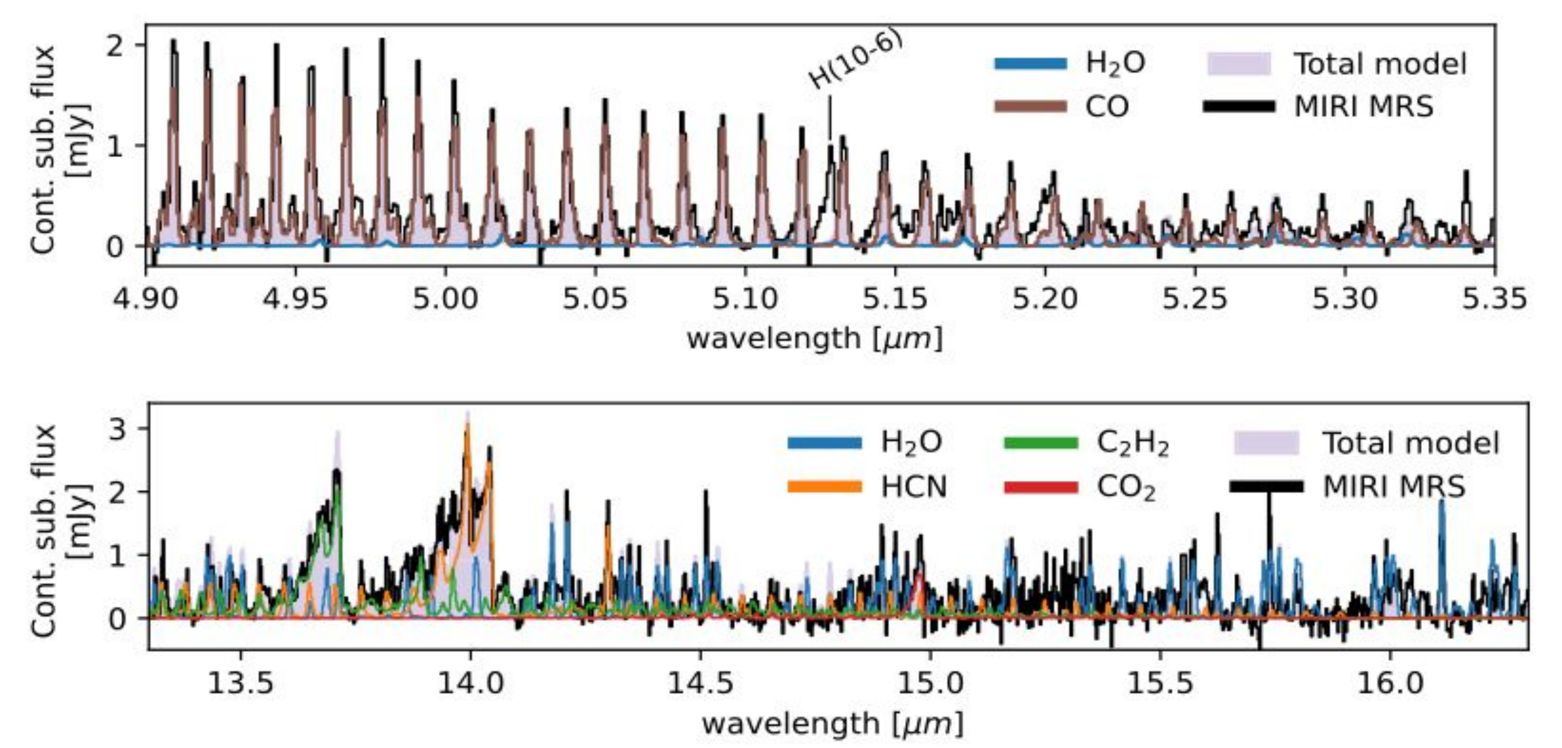
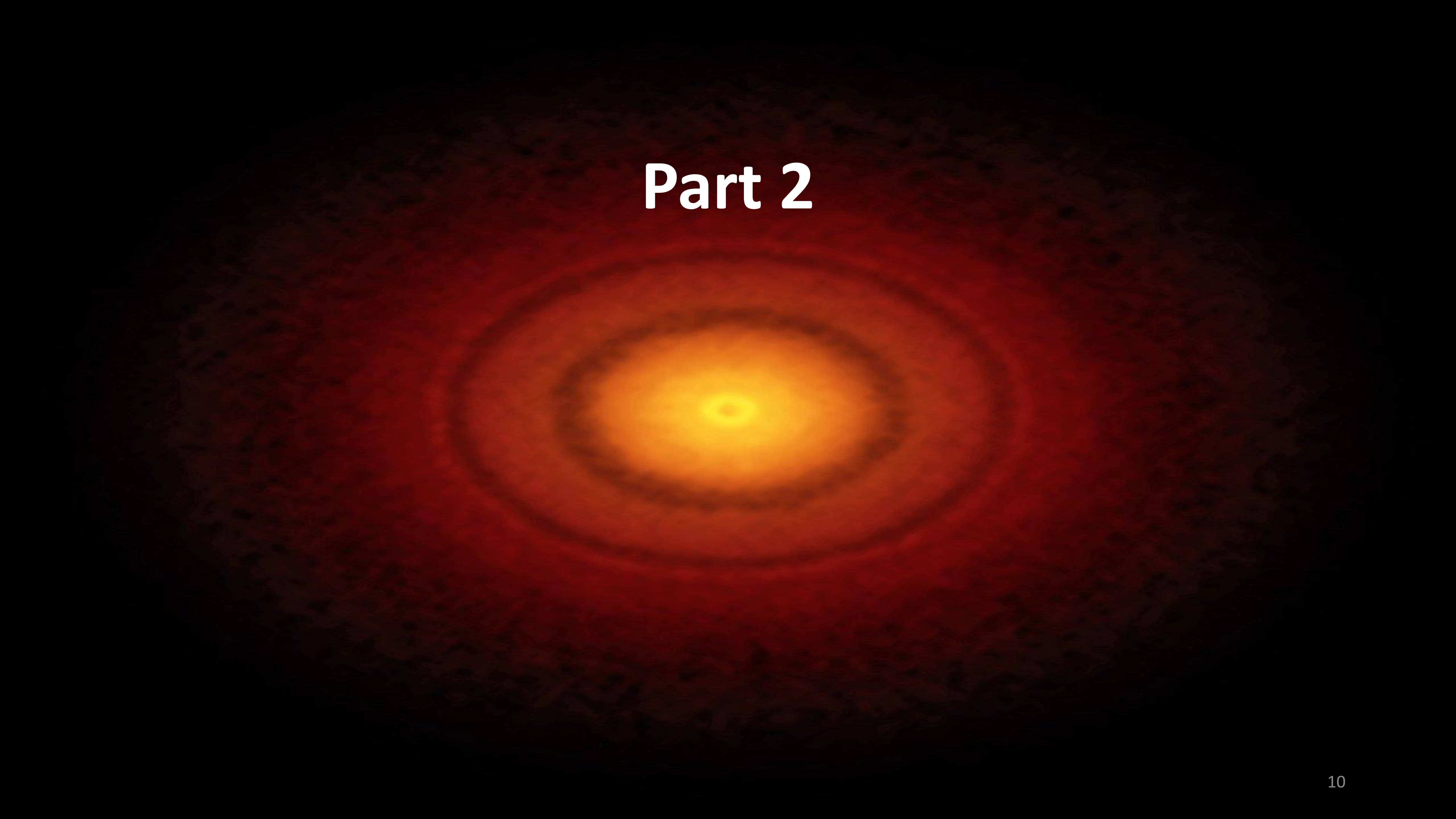


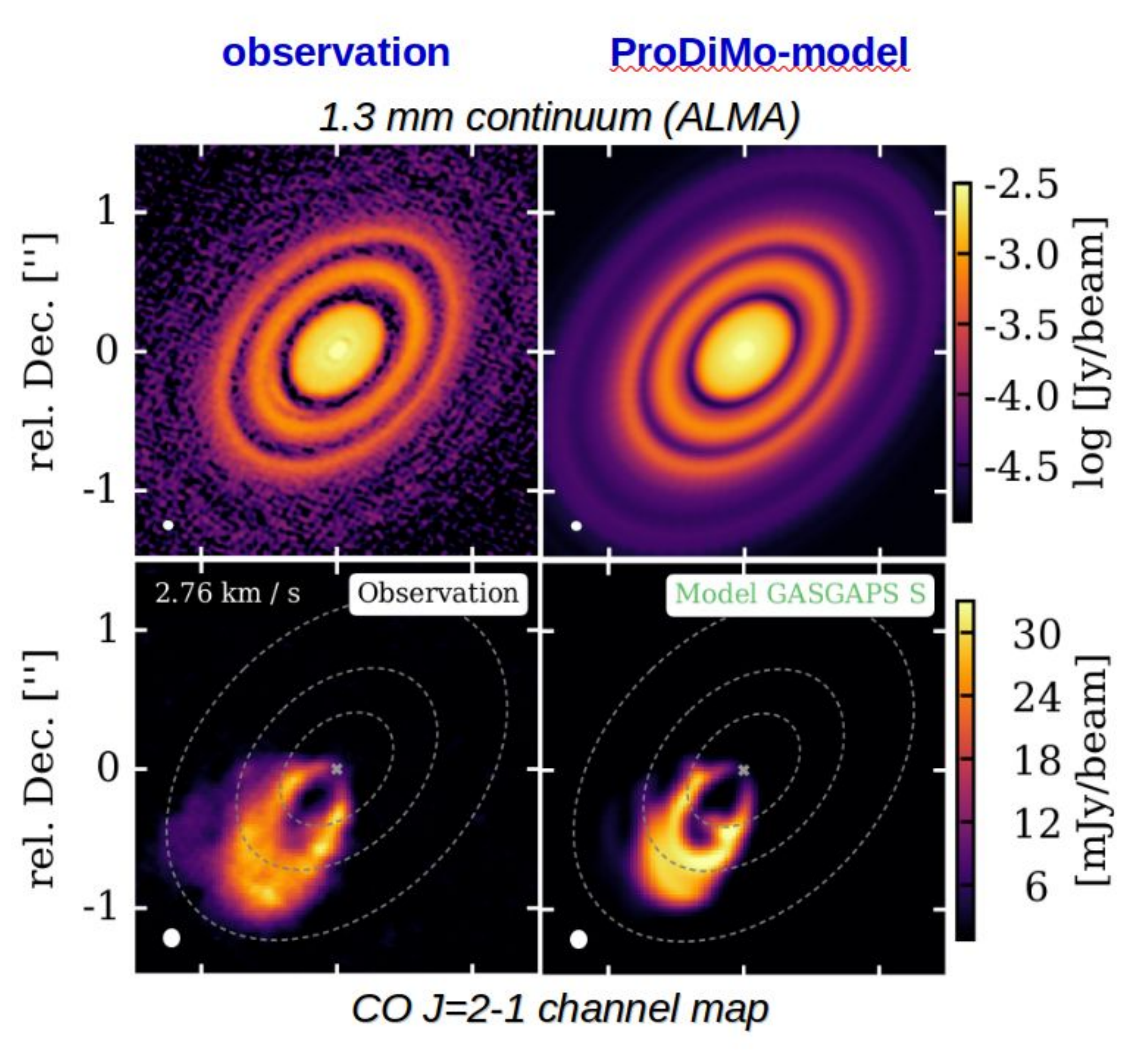
Figure 3. Continuum-subtracted MIRI spectrum of XUE 1 (black) with the best-fit slab models. Molecules are shown with colors, and the purple shaded area shows the total model spectrum. Top: region between 4.9 and 5.35 μm including CO (brown) and H_2O (blue). Bottom: region between 13 and 16 μm including H_2O (blue), C_2H_2 (green), HCN (orange), and $^{12}CO_2$ (red).

Ramirez-Tannuz et al 2023.

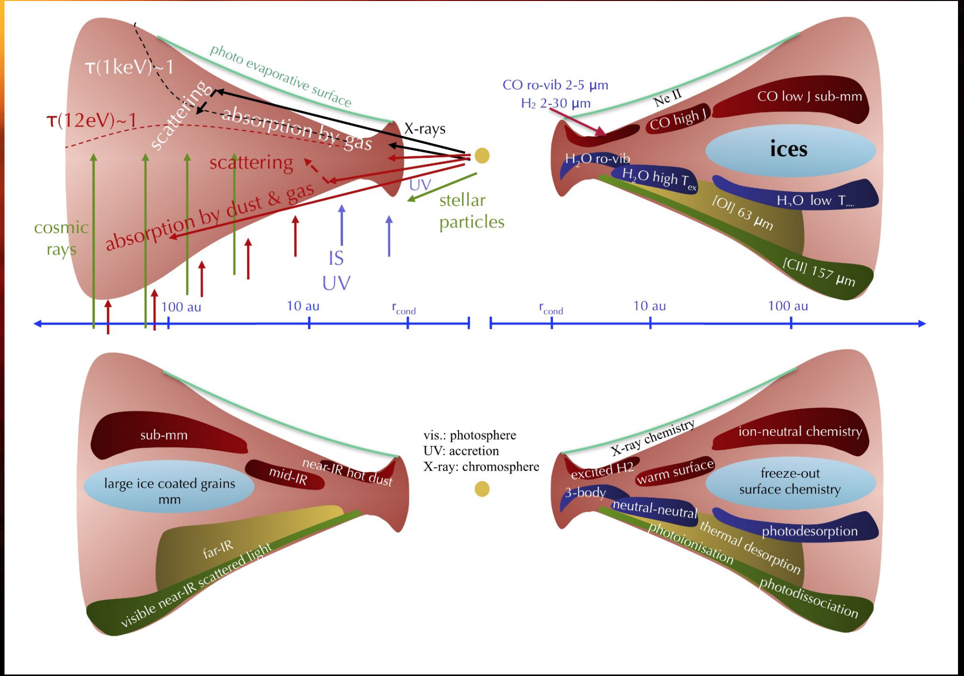
Part 2



PRODIMO (PROtoplanetary DIsk MOdel)

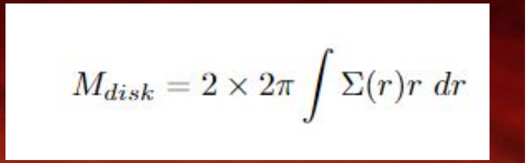


- CO ro-vibrational emission lines.
- Simulates gas phases, X-ray and UV-photochemistry, ice formation, gas heating and cooling balance, disk structure, and radiative transfer.

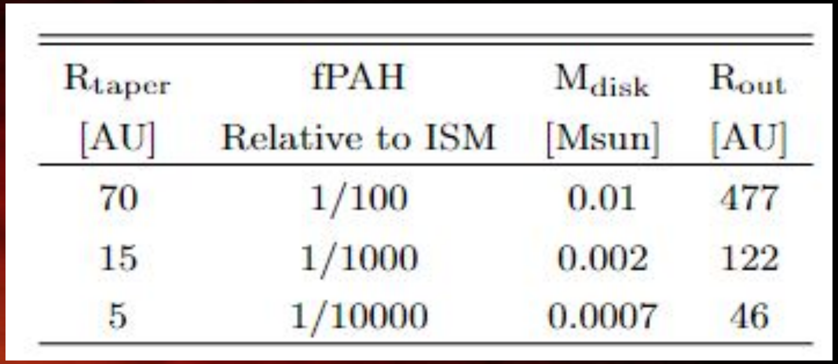


Parameter space and fiducial model.

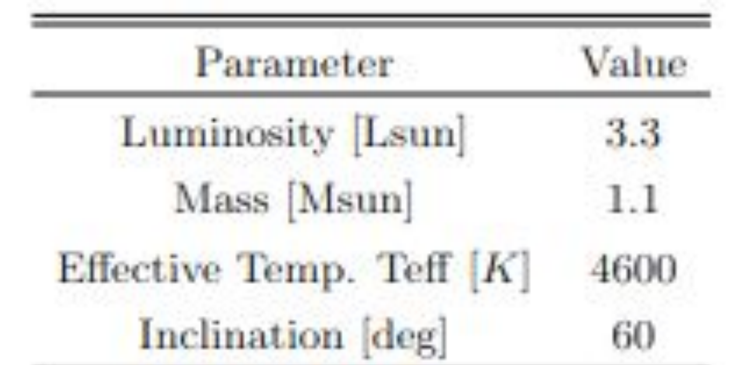
- Two sets of hydrostatic models, one isolated and the other one highly externally irradiated.
- Then one more iteration to set the same structure and mass distribution.



$$M_{disk} = 2 \times 2\pi \int \Sigma(r) r \, dr$$



R_{taper} [AU]	fPAH Relative to ISM	M_{disk} [Msun]	R_{out} [AU]
70	1/100	0.01	477
15	1/1000	0.002	122
5	1/10000	0.0007	46



Parameter	Value
Luminosity [Lsun]	3.3
Mass [Msun]	1.1
Effective Temp. Teff [K]	4600
Inclination [deg]	60

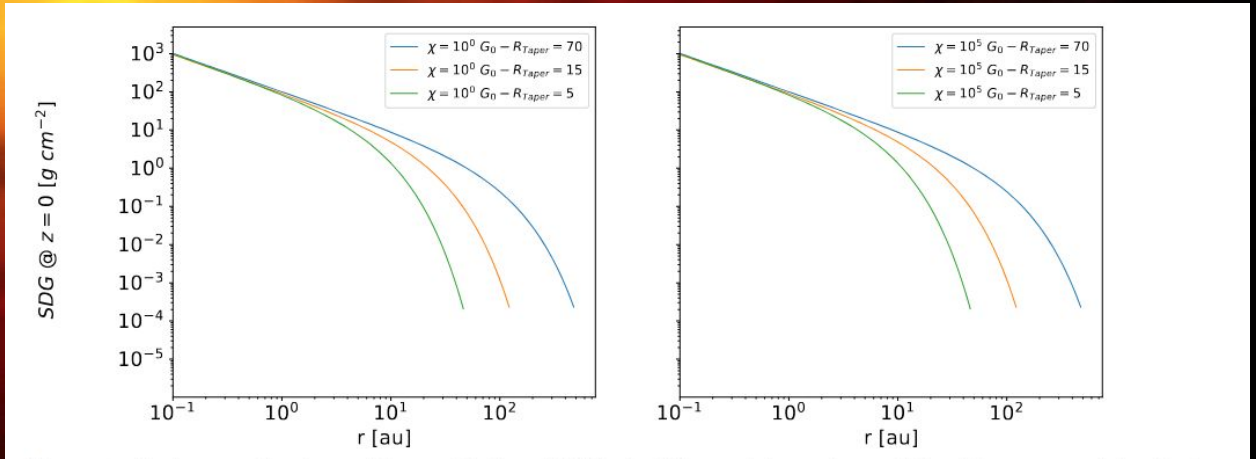
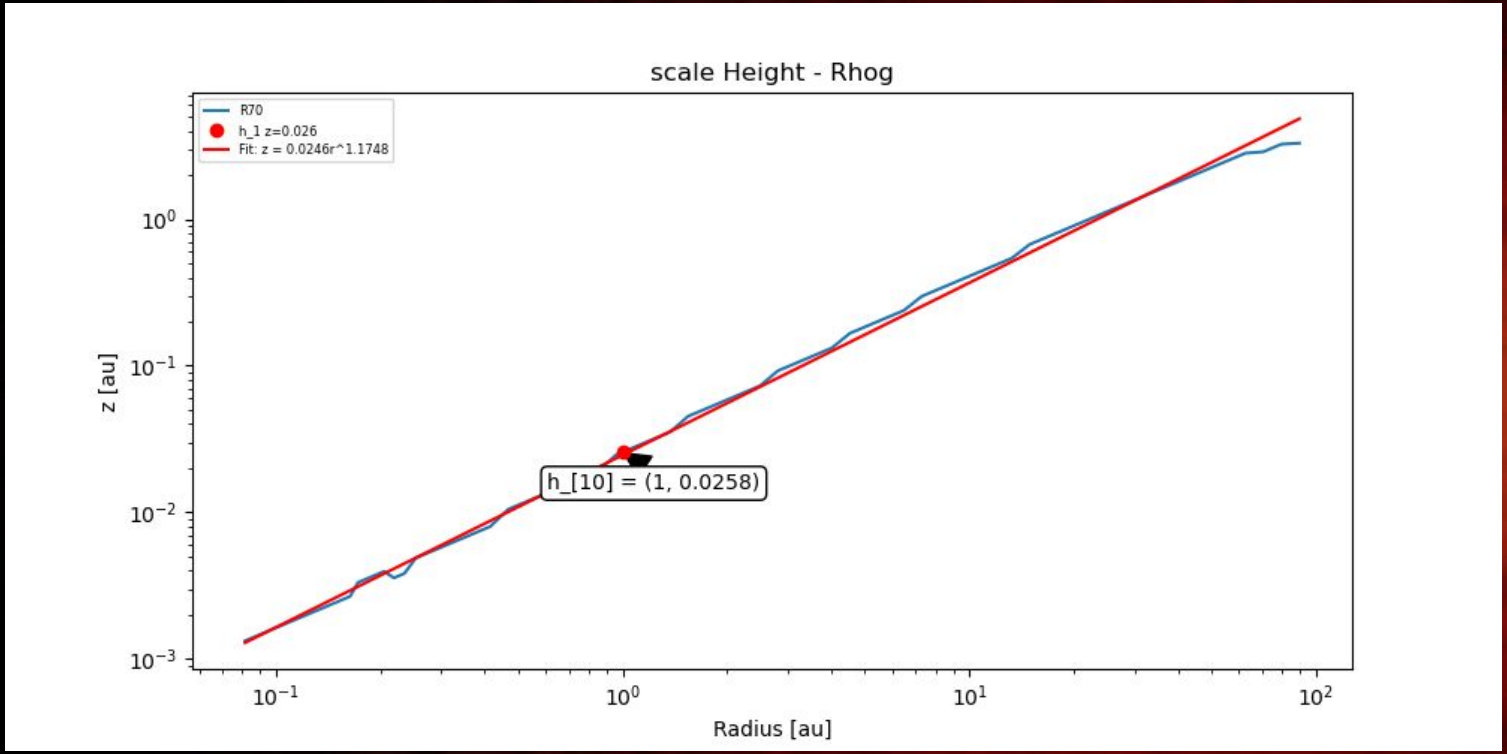
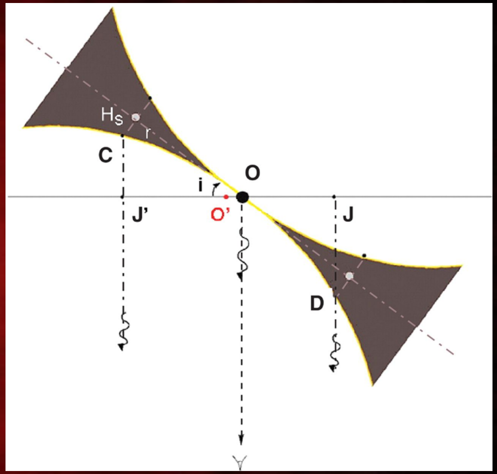


Figure 1: Surface gas density profile at mid-plane (SDG), the left panel shows the models without external irradiation ($\chi = 10^0\ G_0$) and the right panel extreme irradiated planet-forming disks ($\chi = 10^5\ G_0$).

Parameter space and fiducial model.





- Same scale height at 1 AU and β (flaring index) for all models.

Parameterized models.

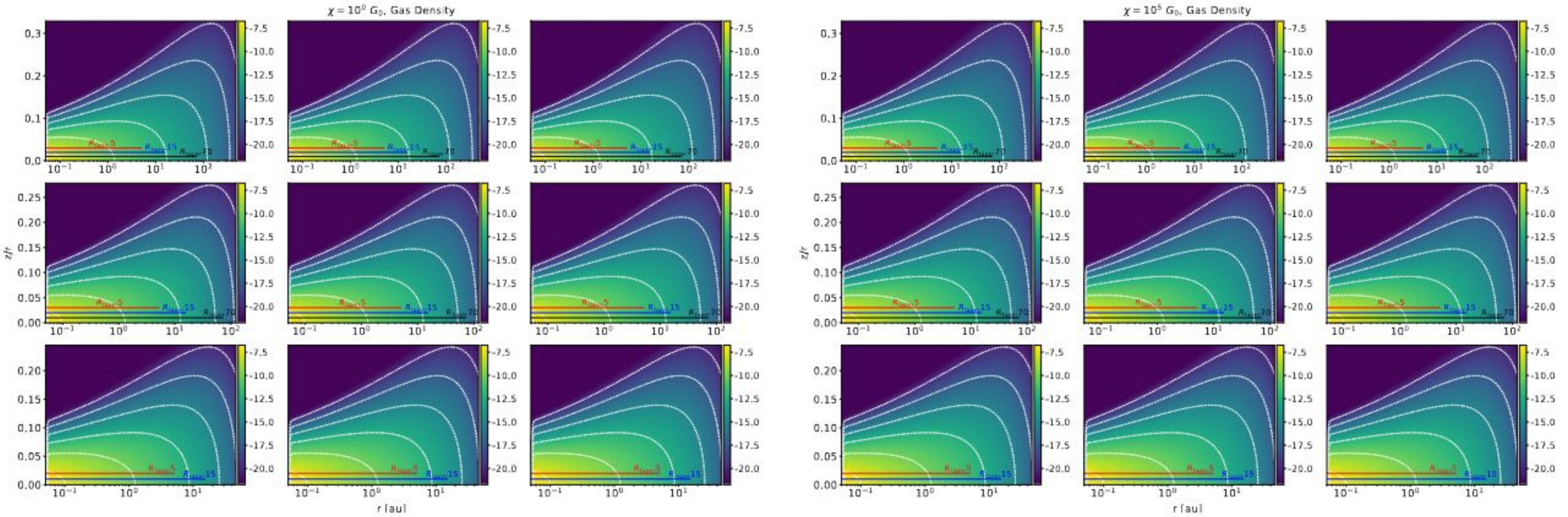
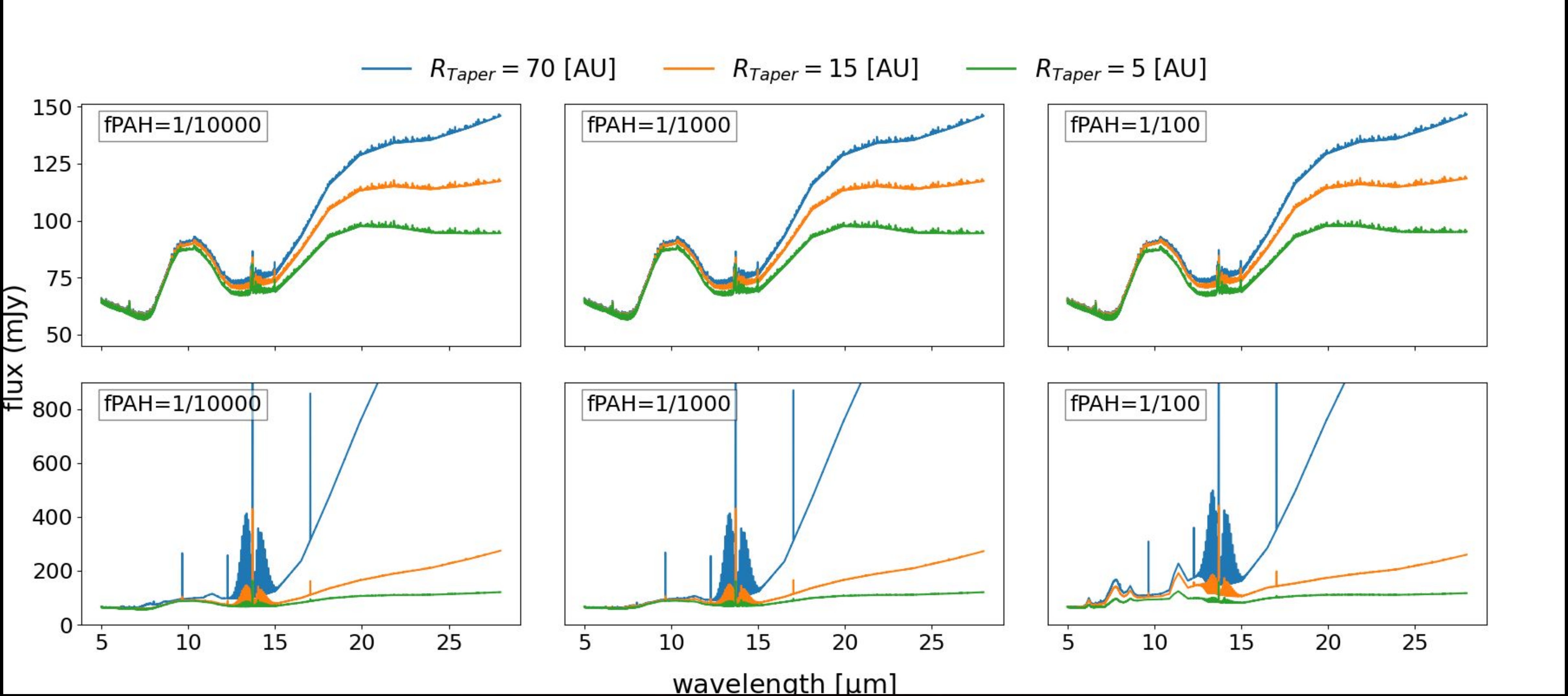
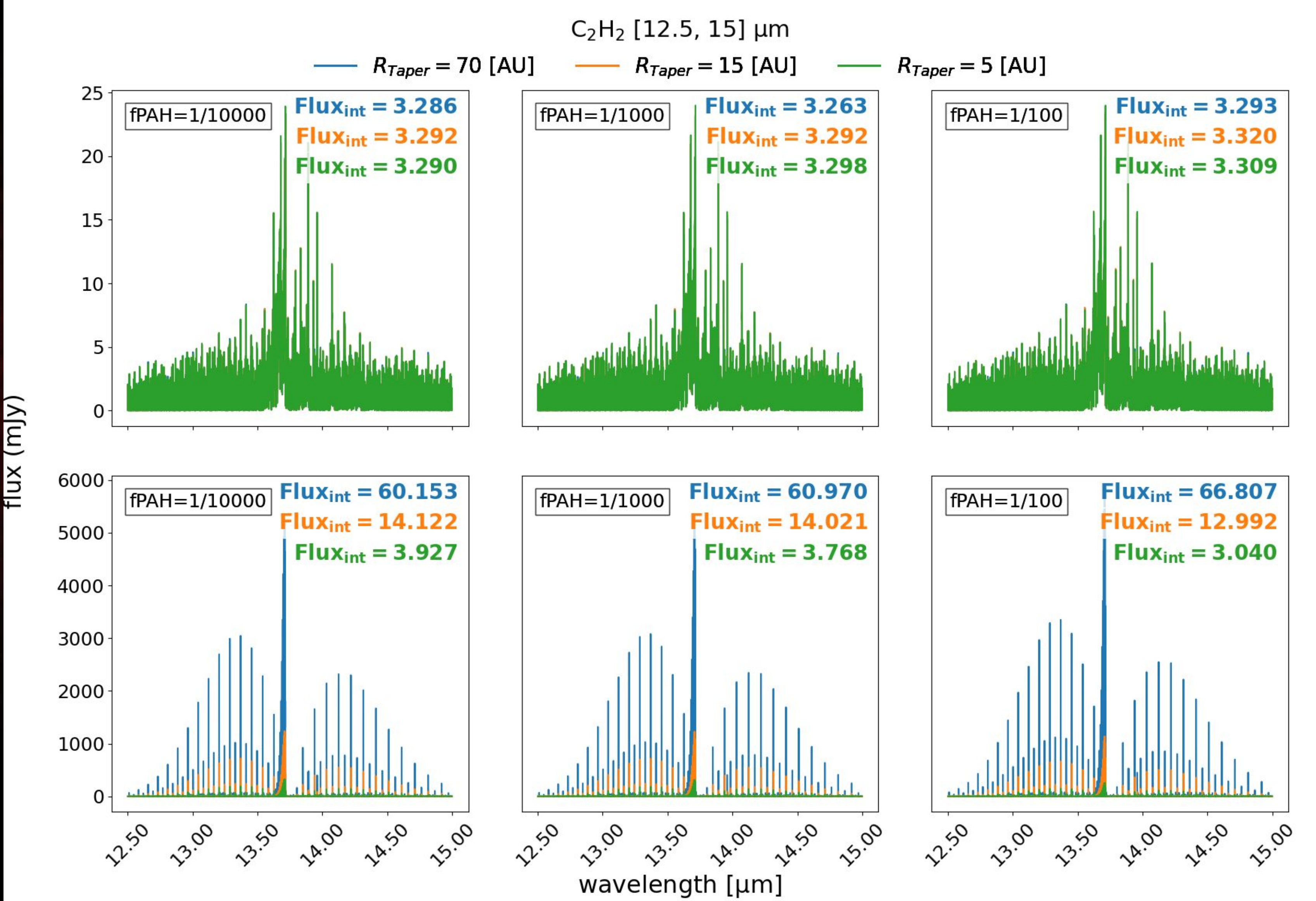


Figure 26: Gas density contour for all sets of models.

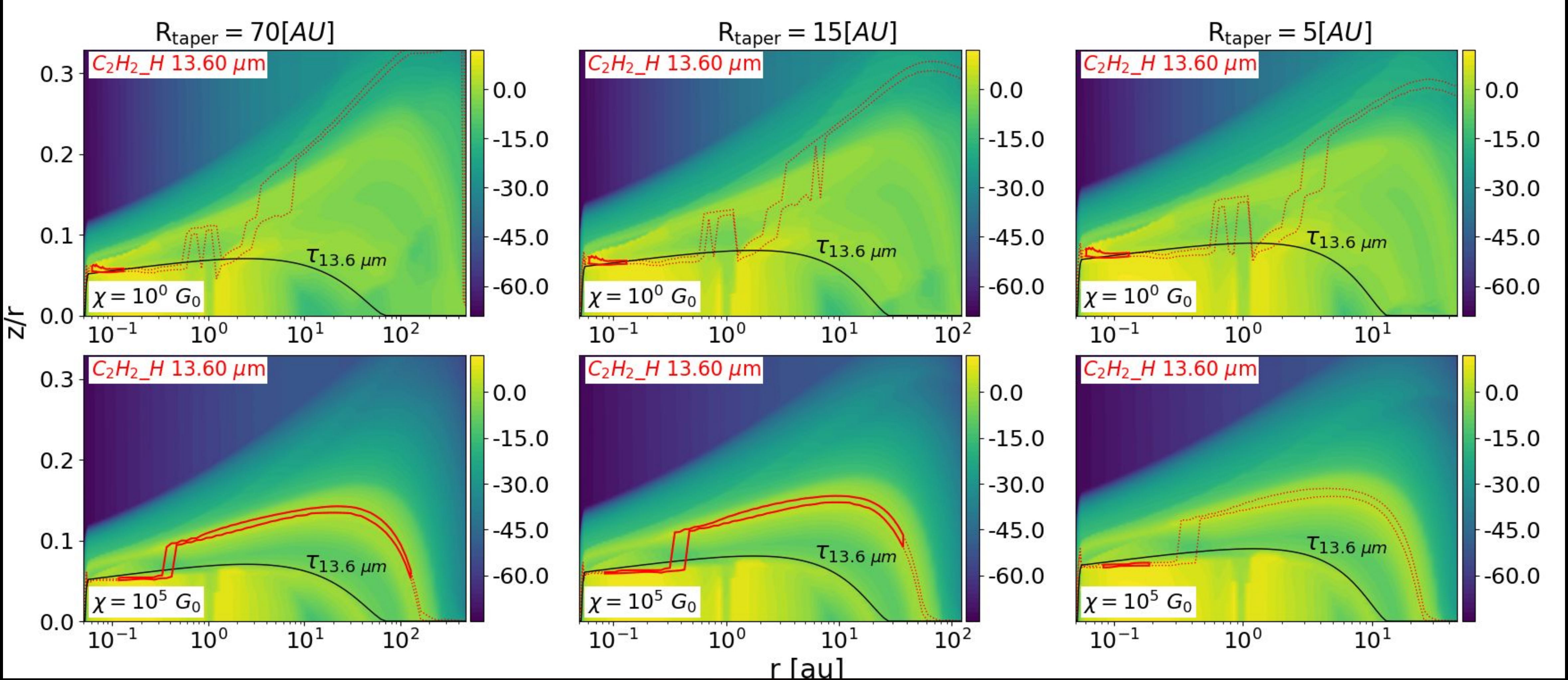
Synthetic spectra



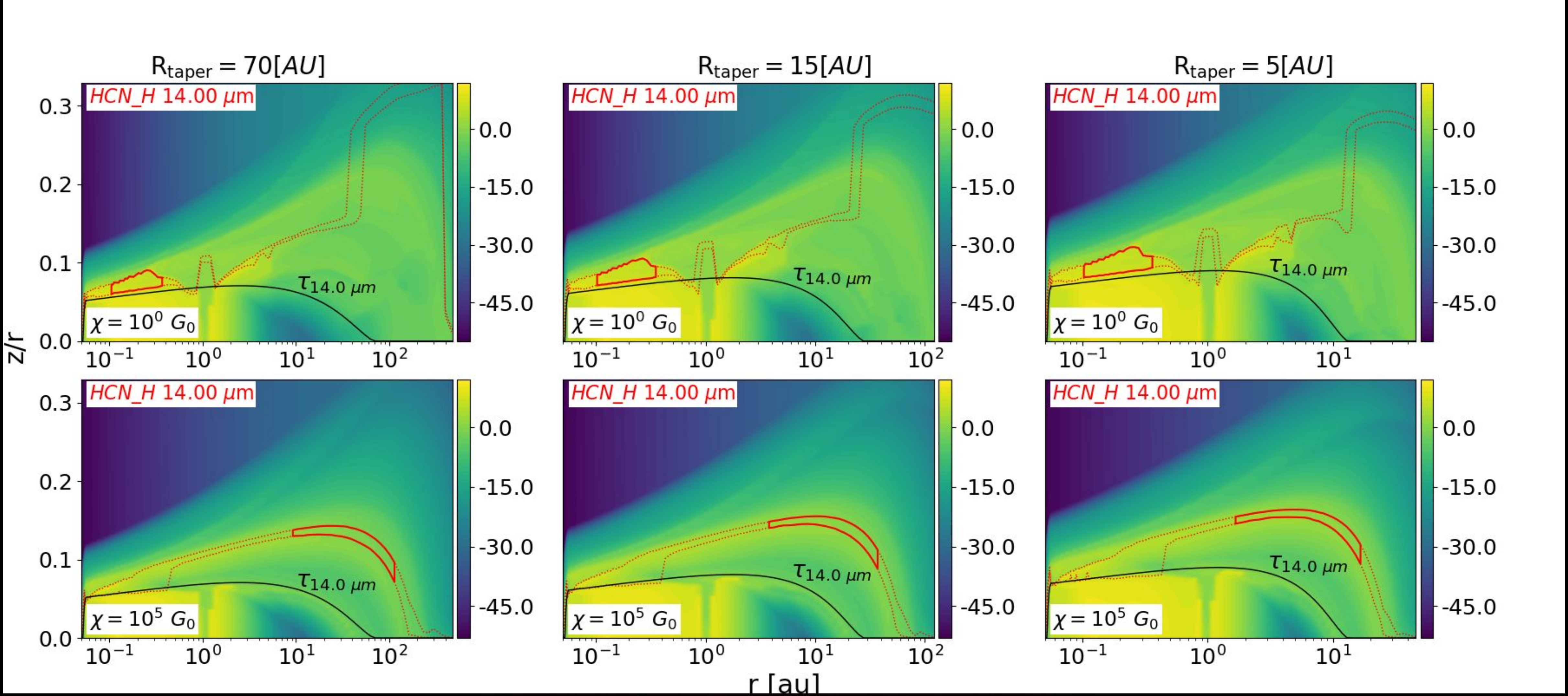
C2H2 Spectra (12.5-15 µm)



C2H2 emission region.

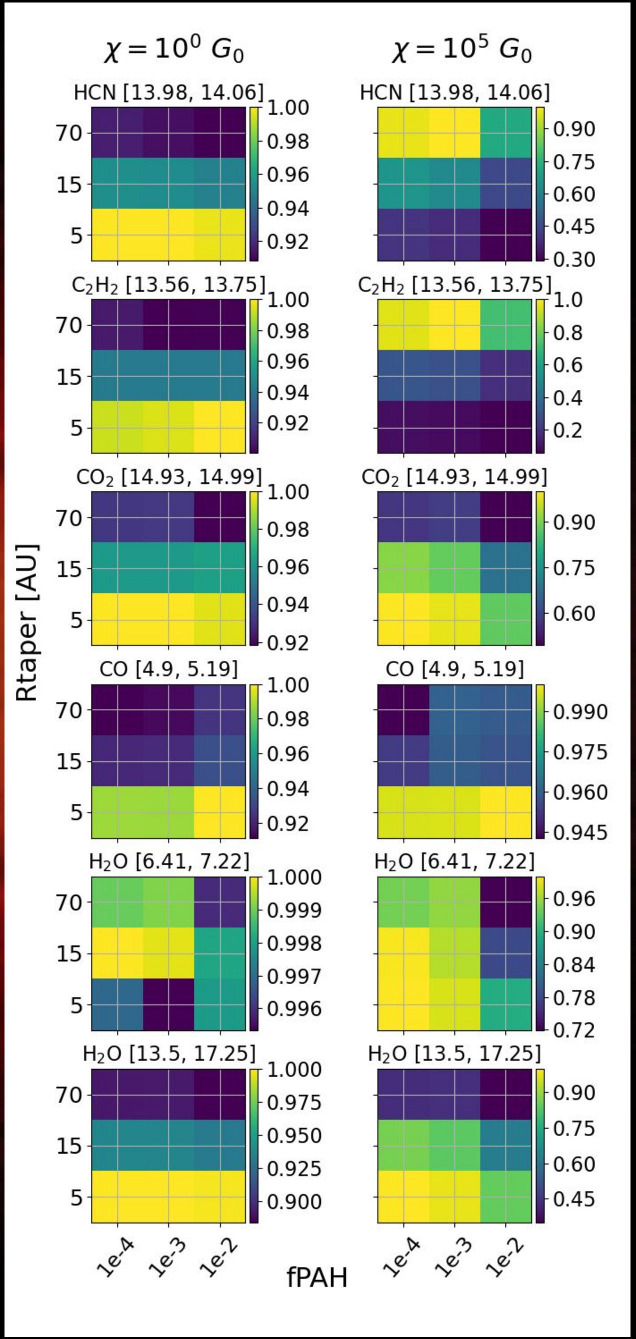


HCN emission region.

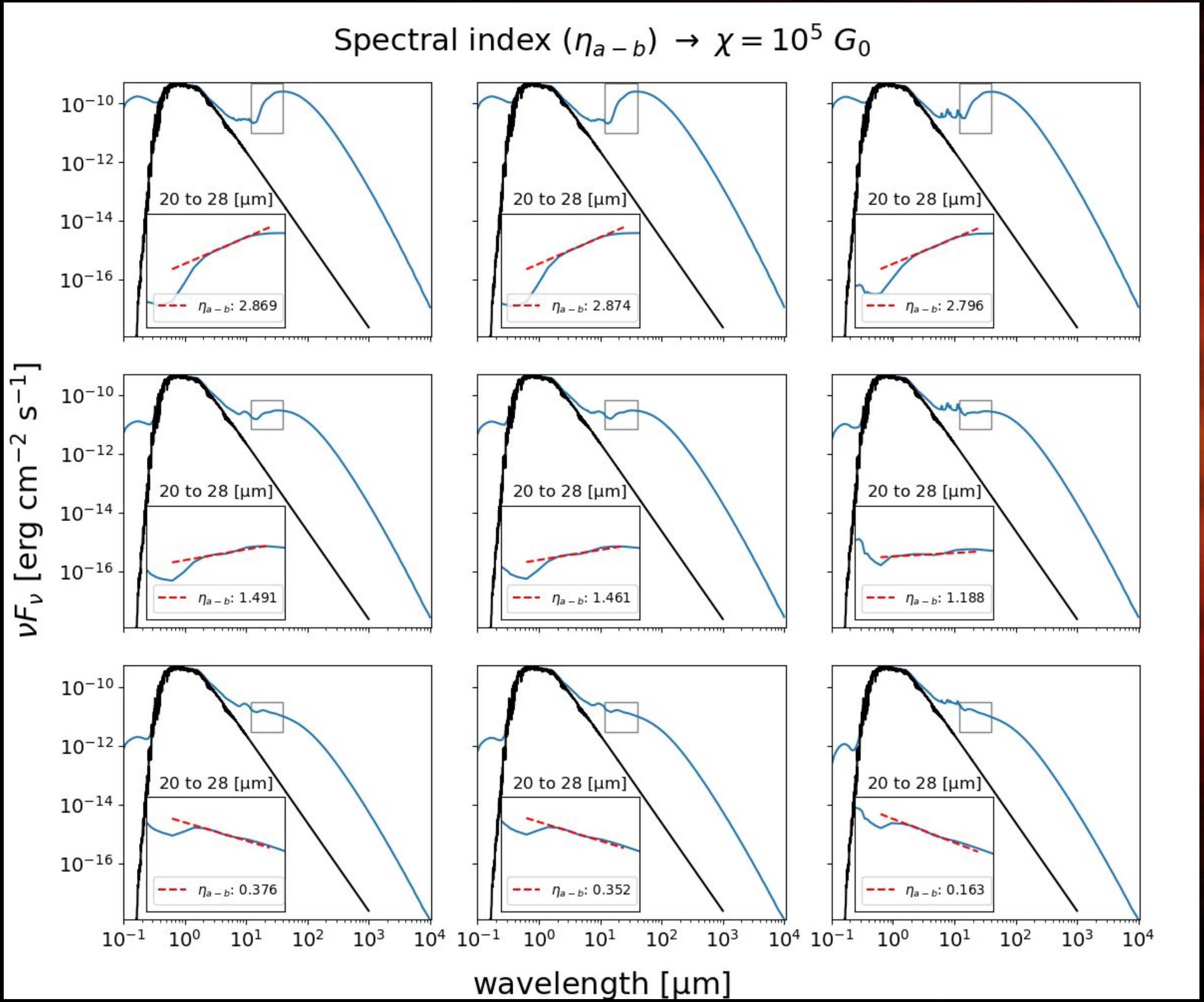


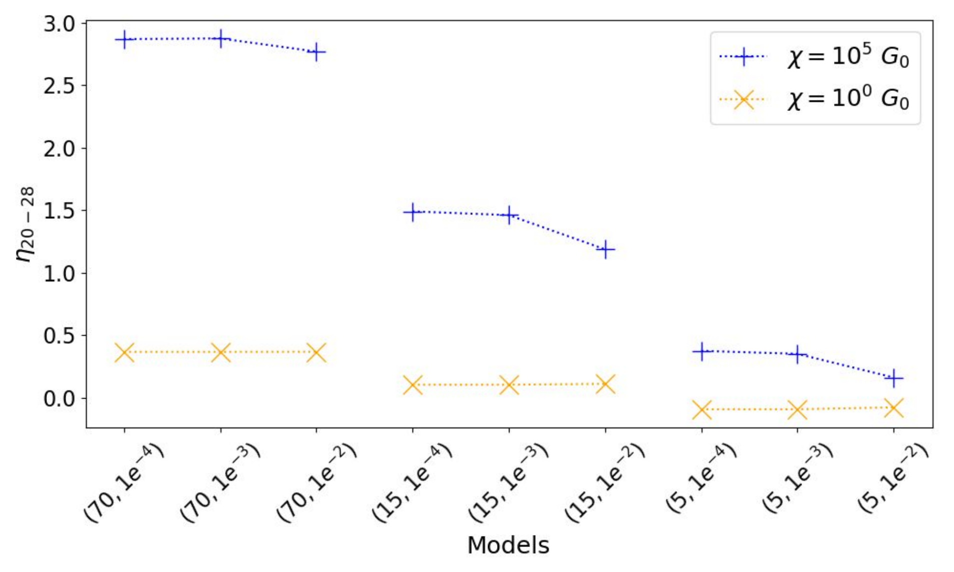
Line flux/continuum ratio.

- HCN and C2H2 present 70% and 80% of reduction between truncation radii for highly externally irradiated models. Nearly 25% and 20% of reduction between PAHs fraction for the same truncation radii.
- The line flux/continuum ratio has a significant effect from our parameter space for all species. the CO is the only species that not present any relevant effect.
- For isolated models, the PAHs fraction parameter has no relevant impact; meanwhile, the truncation radii could impact the line flux/continuum ratio by nearly 10%.



SED


Spectral index (η_{a-b}) → $\chi = 10^5\ G_0$
νF_ν [erg cm^{-2} s^{-1}]
10^{-10}
10^{-12}
10^{-14}
10^{-16}
20 to 28 [μm]
η_{a-b}: 2.869
η_{a-b}: 2.874
η_{a-b}: 2.796
η_{a-b}: 1.491
η_{a-b}: 1.461
η_{a-b}: 1.188
η_{a-b}: 0.376
η_{a-b}: 0.352
η_{a-b}: 0.163
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
wavelength [μm]


η_{20-28}
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$\chi = 10^5\ G_0$
$\chi = 10^0\ G_0$
(70, 1e^{-4})
(70, 1e^{-3})
(70, 1e^{-2})
(15, 1e^{-4})
(15, 1e^{-3})
(15, 1e^{-2})
(5, 1e^{-4})
(5, 1e^{-3})
(5, 1e^{-2})
Models

Some preliminary conclusions and discussion.

- Some species, like HCN and C2H2, have an extreme impact from our parameter space. They show a reduction in the integrated flux when the disk is truncated and externally irradiated. They also show a reduction in the integrated flux when the fraction of PAHs is increased.
- Regarding the XUE 1 observations, and assuming that we don't have a big extinction between us, our results show that the disk could be truncated. More models are needed to sweep the parameter space of external irradiation and complete our understanding of how some molecular species flux in the disk is affected by external UV irradiation.
- We need to estimate the photoevaporated gas flux to gain a clearer understanding of how disk truncation and the PAHs fraction affect the disk's structure in hostile environments (in progress).
- We need more observations to disentangle the hypothesis that the near material is creating a great extinction between us or even shielding the disk from UV radiation.
- Our parameter space also affects the spectral index between 20 and 28 microns; we show a reduction through the truncation radios and when the PAHs fraction is increased. This tool could be used to characterize this kind of object. More models must be performed to complete the parameter space of external irradiation fields.

ONC proplyds: setting the stage for planet formation in the most typical environment

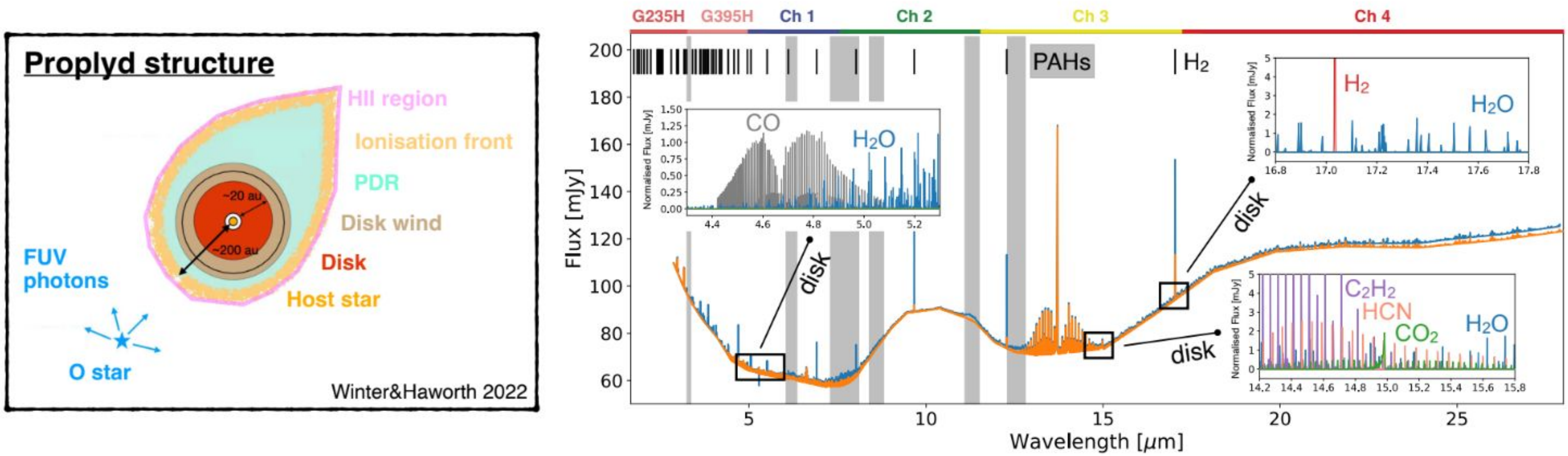
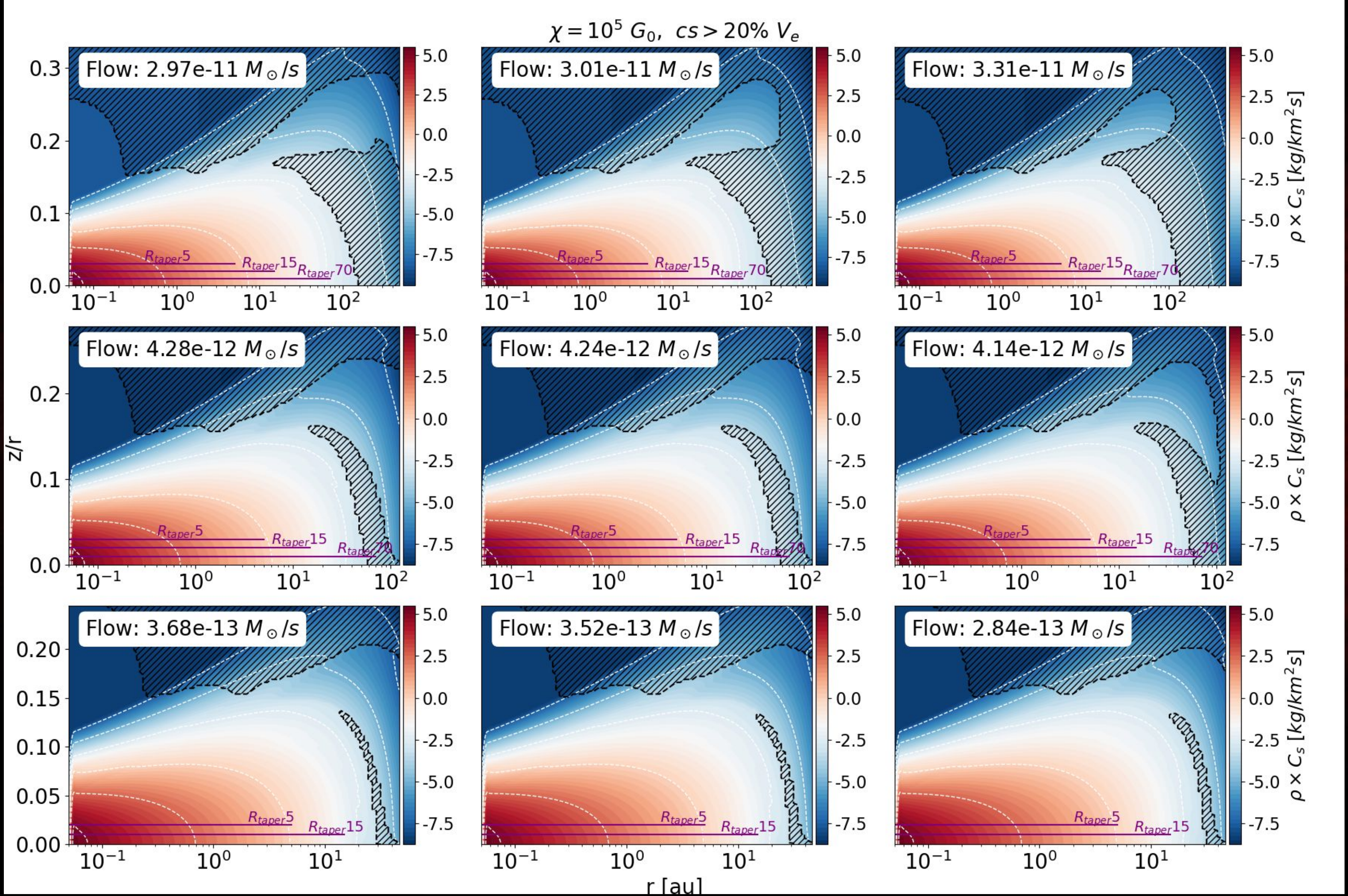
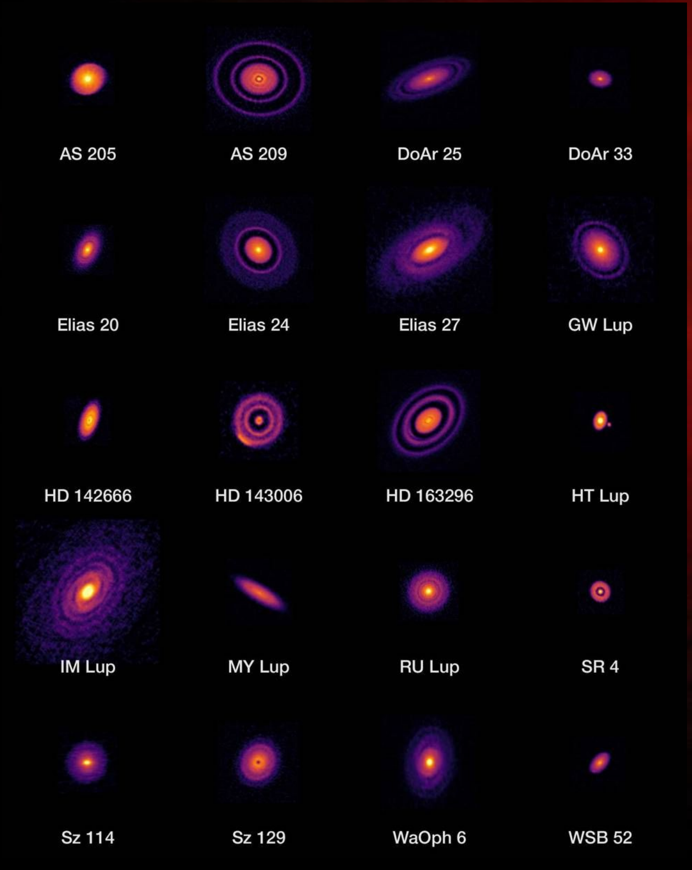


Figure 2: *Representative structure of an ONC proplyd, and the expected ProDiMo irradiated disk emission (in orange and insets) versus disk+Meudon PDR model [38] (in blue) for* 10^4 G_0.

Photoevaporation rate



Thanks!!!


AS 205
AS 209
DoAr 25
DoAr 33
Elias 20
Elias 24
Elias 27
GW Lup
HD 142666
HD 143006
HD 163296
HT Lup
IM Lup
MY Lup
RU Lup
SR 4
Sz 114
Sz 129
WaOph 6
WSB 52