FRONTIERS AND CHALLENGES IN LABORATORY ASTROCHEMISTRY

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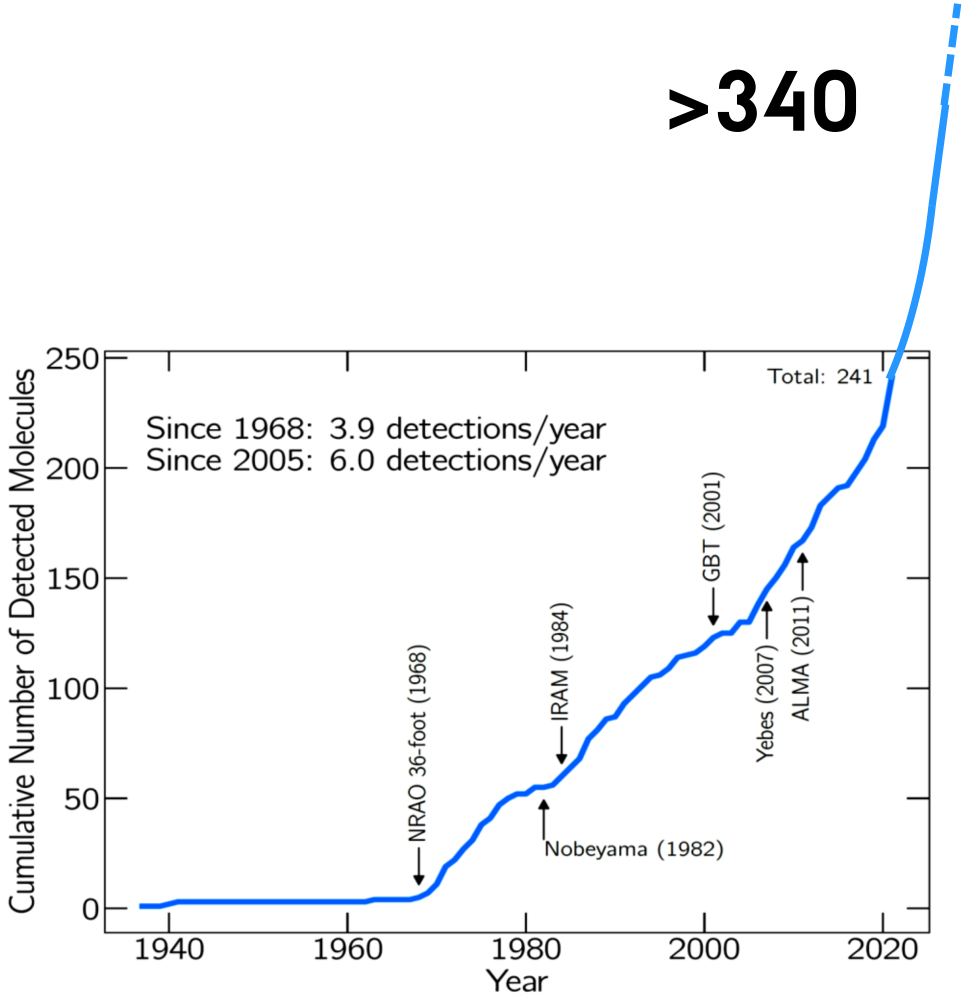
PRESENT & FUTURE OF OBSERVATIONAL ASTRONOMY

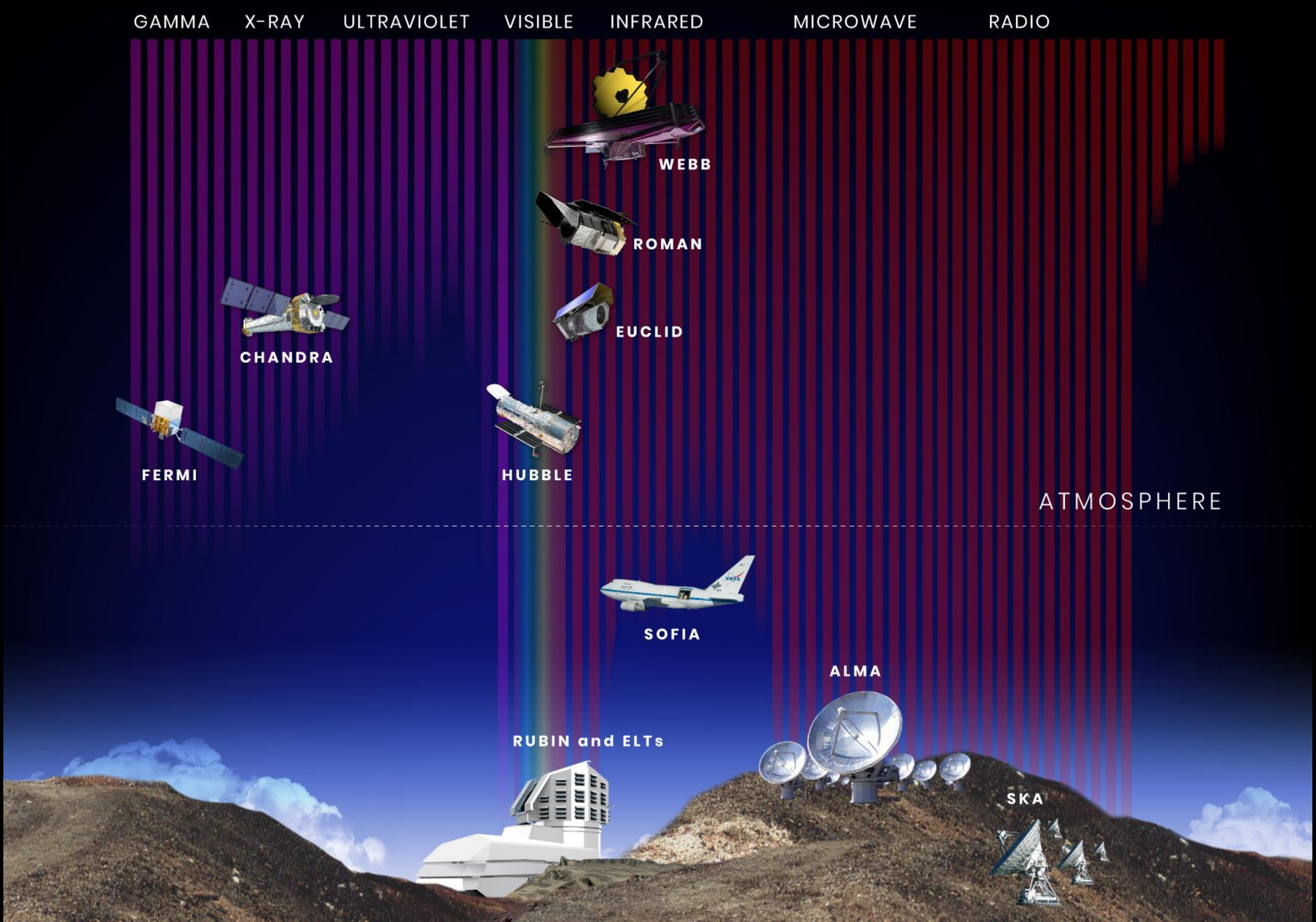
(The CDMS Catalog)

https://cdms.astro.uni-koeln.de/classic/molecules

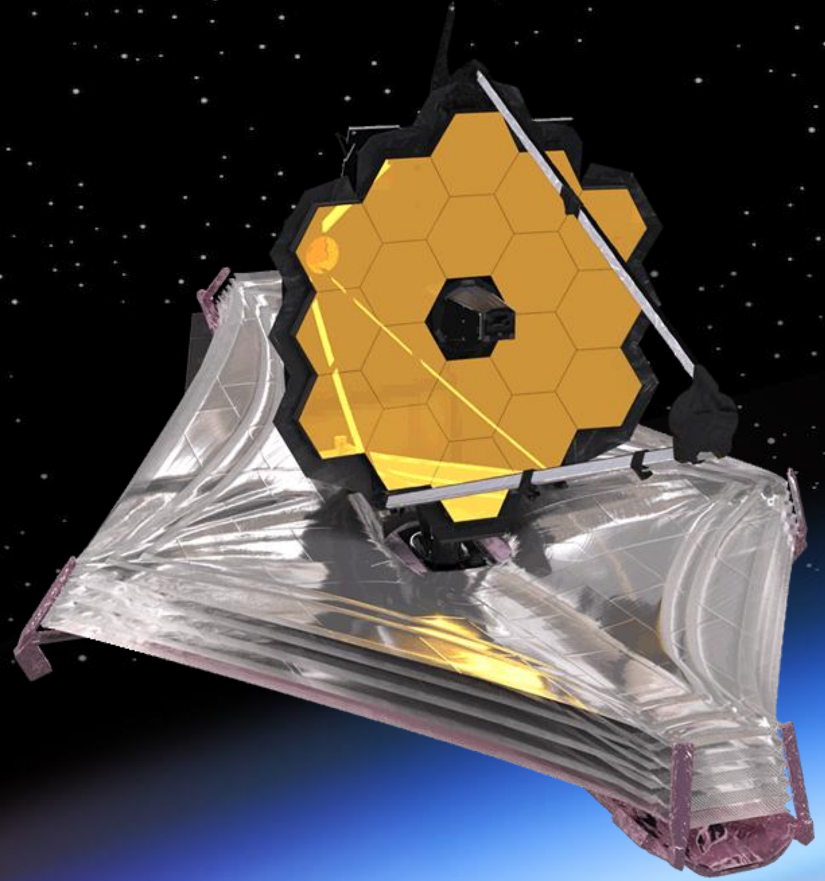


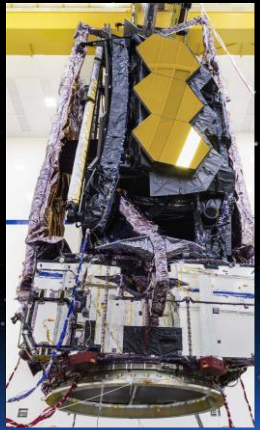
McGuire, *ApJS* (2021)

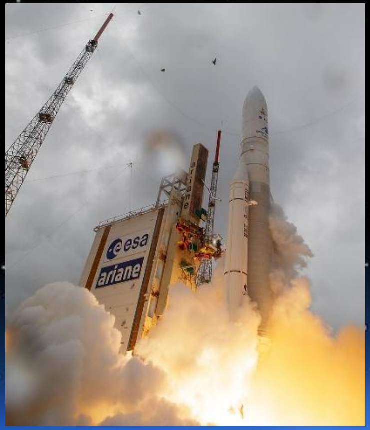
PRESENT & FUTURE OF OBSERVATIONAL ASTRONOMY

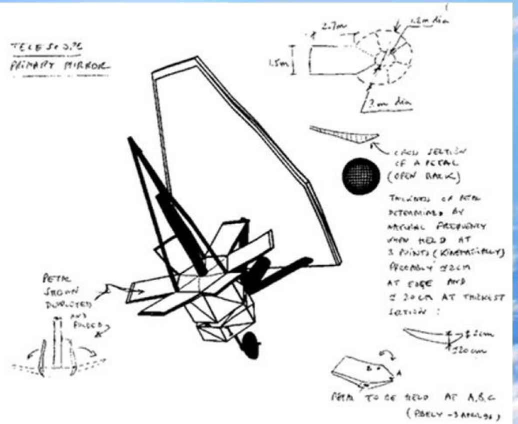


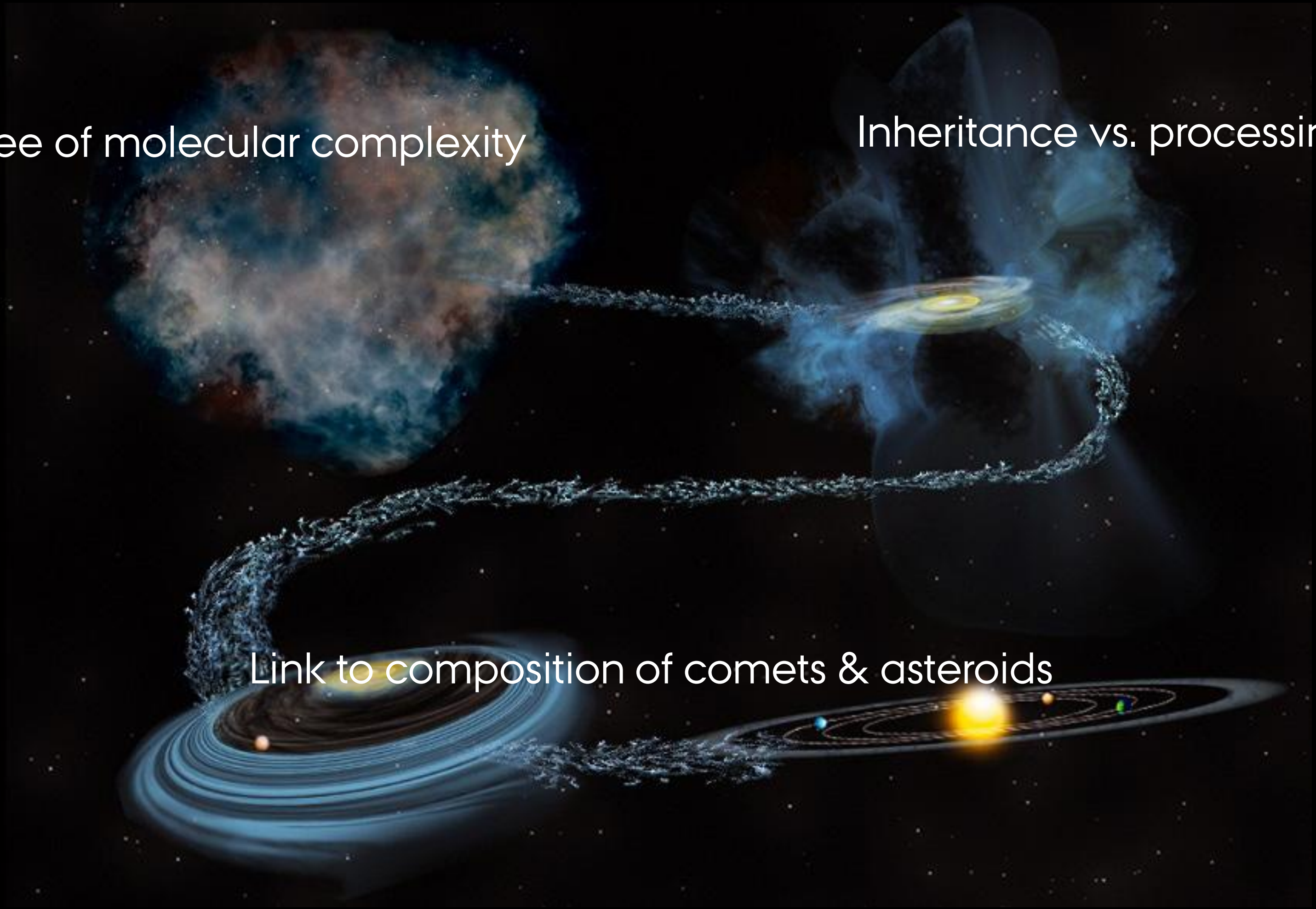
GAMMA
X-RAY
ULTRAVIOLET
VISIBLE
INFRARED
MICROWAVE
RADIO
WEBB
ROMAN
EUCLID
CHANDRA
FERMI
HUBBLE
ATMOSPHERE
SOFIA
ALMA
RUBIN and ELTs
SKA






esa
ariane

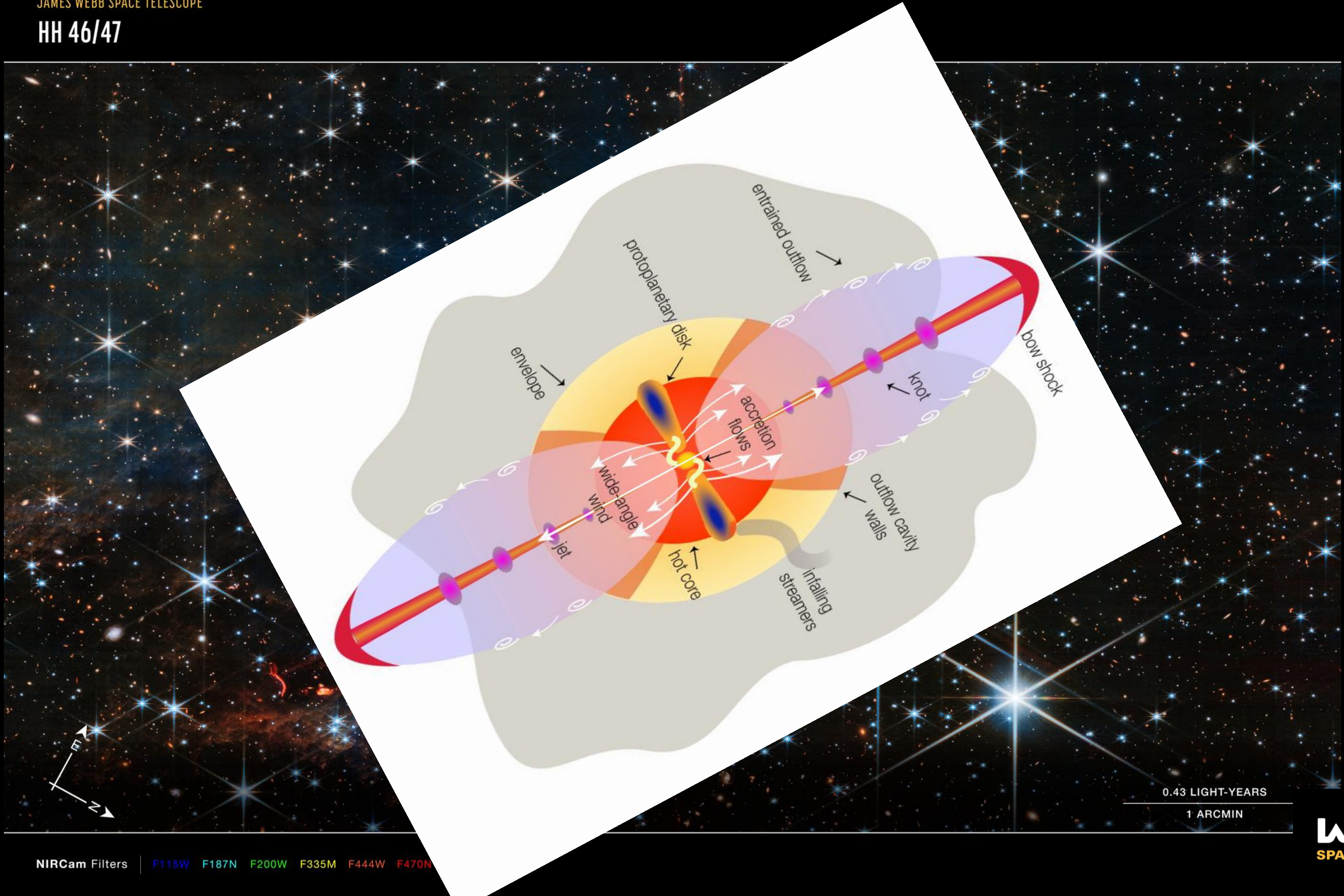

PRIMARY MIRROR
2.7m
1.5m
CROSS SECTION OF A PETAL (OPEN BACK)
THICKNESS OF PETAL DETERMINED BY NATURAL FREQUENCY WHEN HELD AT 3 POINTS (KINEMATICALLY) PROBABLY ≤2CM AT EDGE AND ≤20CM AT THICKEST SECTION :
PETAL SHOWN DUPLICATED AND FOLDED
PETAL TO BE HELD AT A,B,C



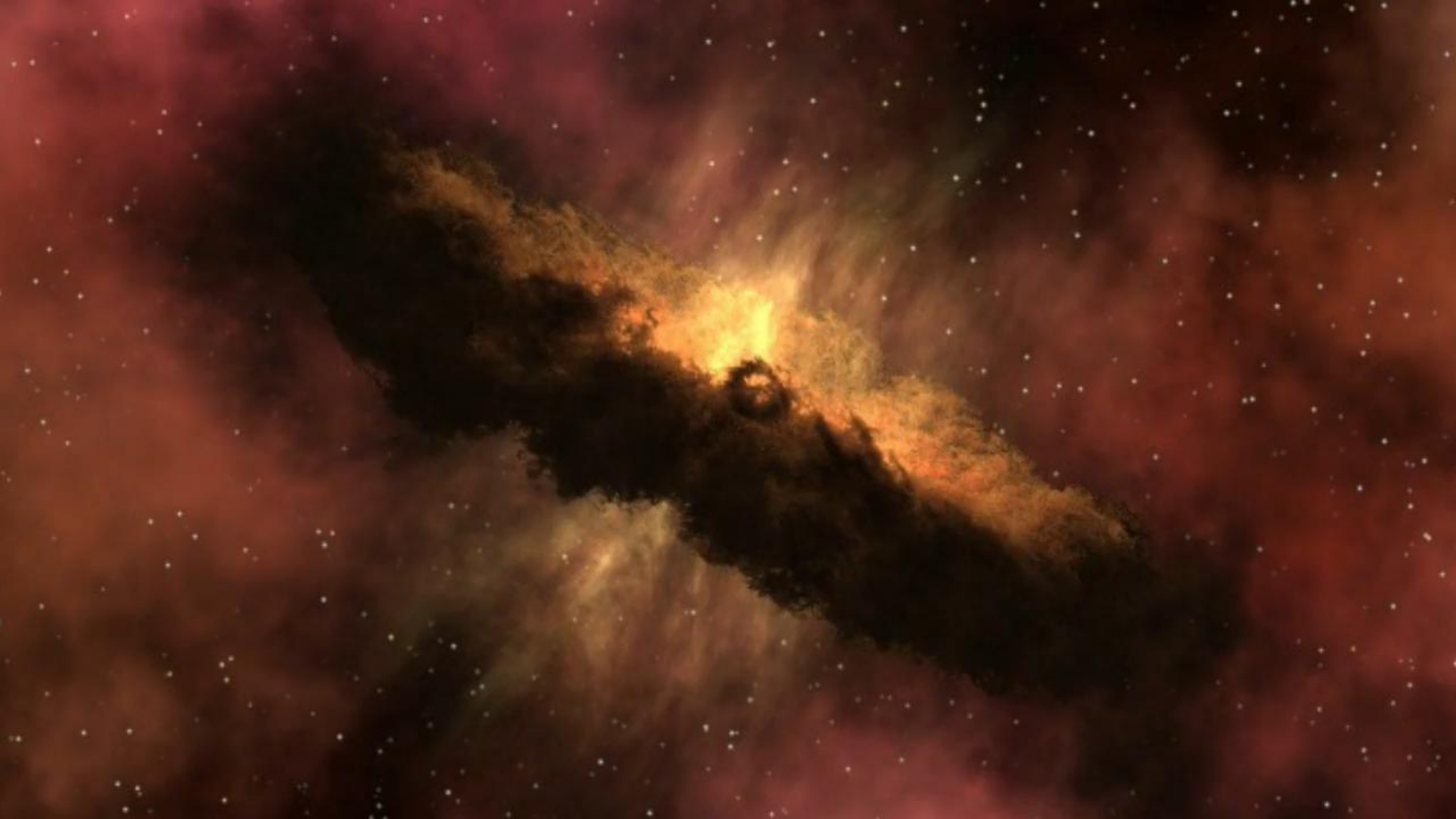
Link to Origin of Life

JAMES WEBB SPACE TELESCOPE

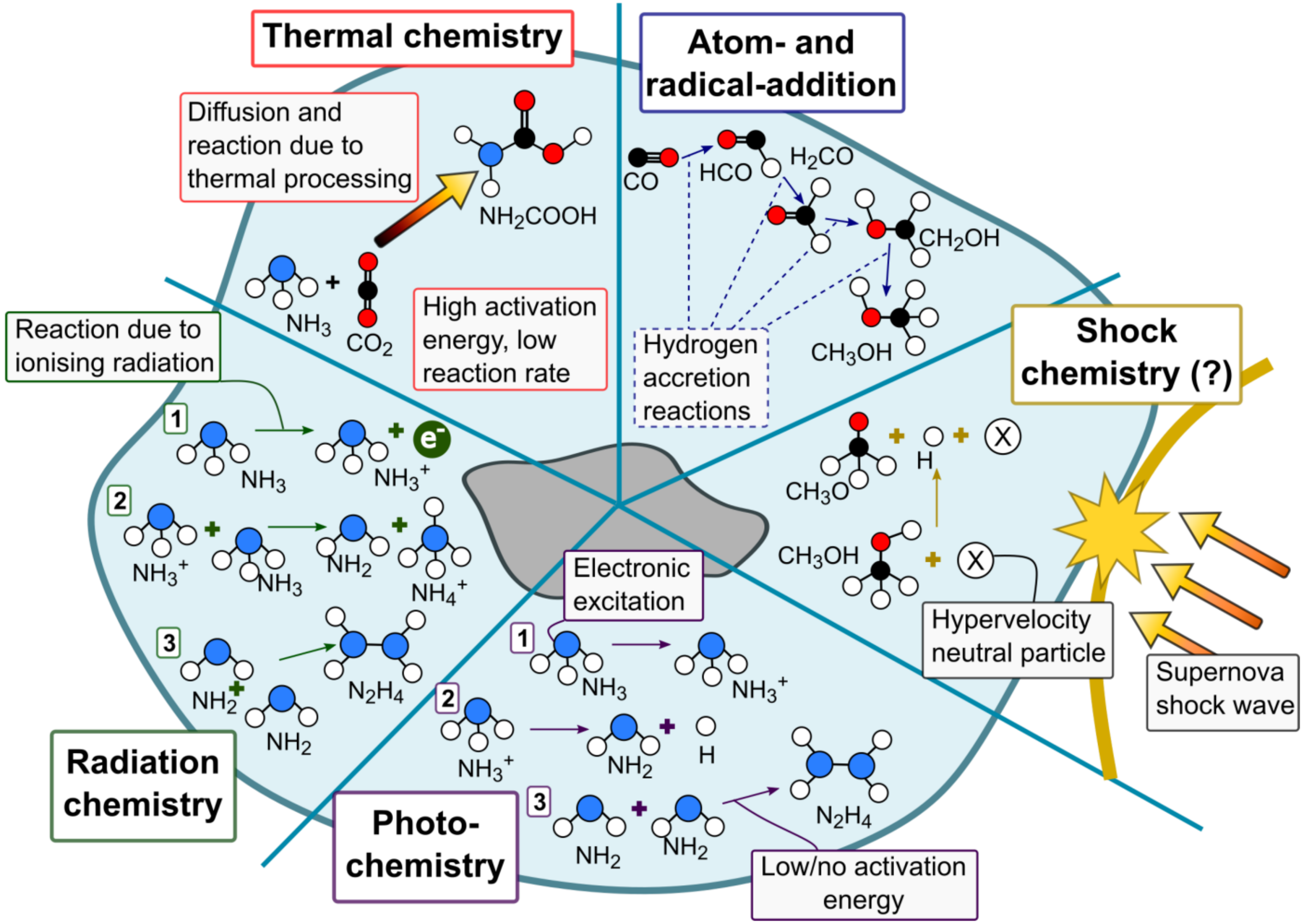
HH 46/47



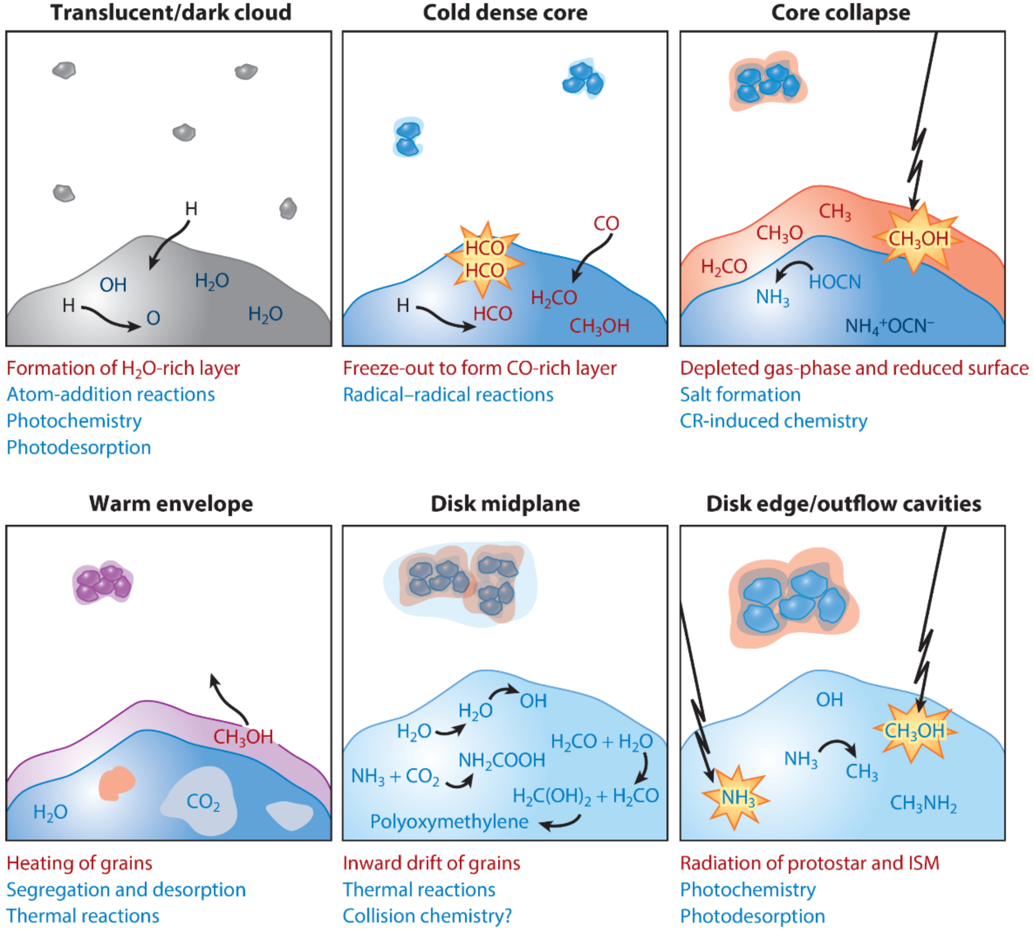
NIRCam Filters F115W F187N F200W F335M F444W F470N

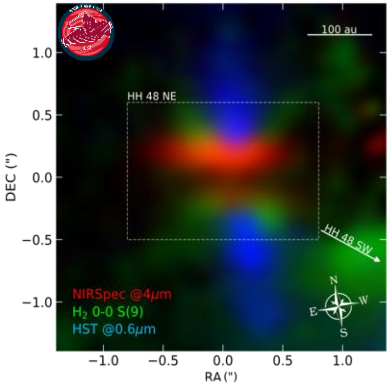


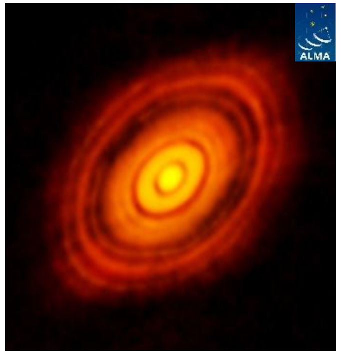
PHYSICS & CHEMISTRY OF ICE GRAINS



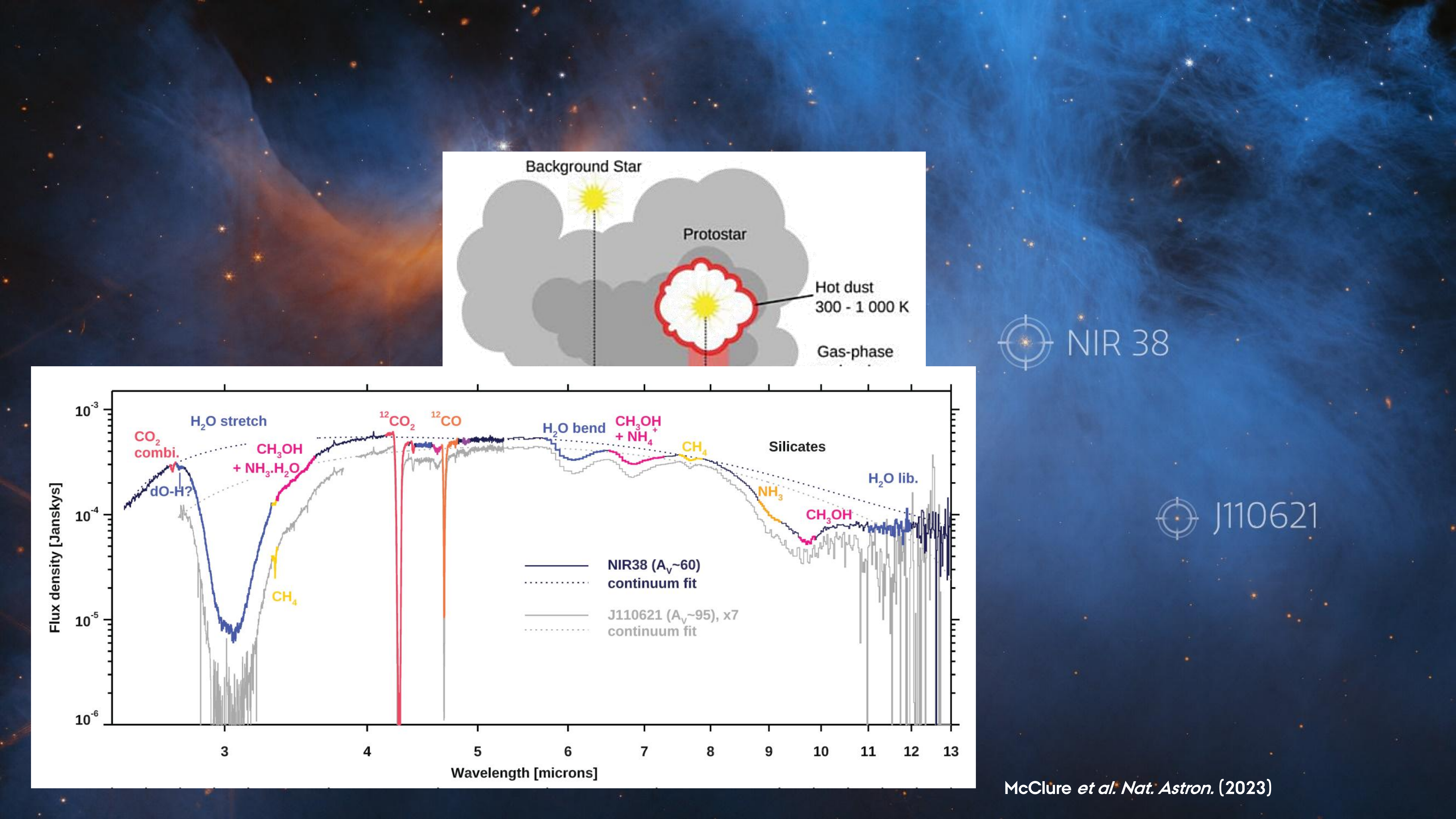
PHYSICS & CHEMISTRY OF ICE GRAINS



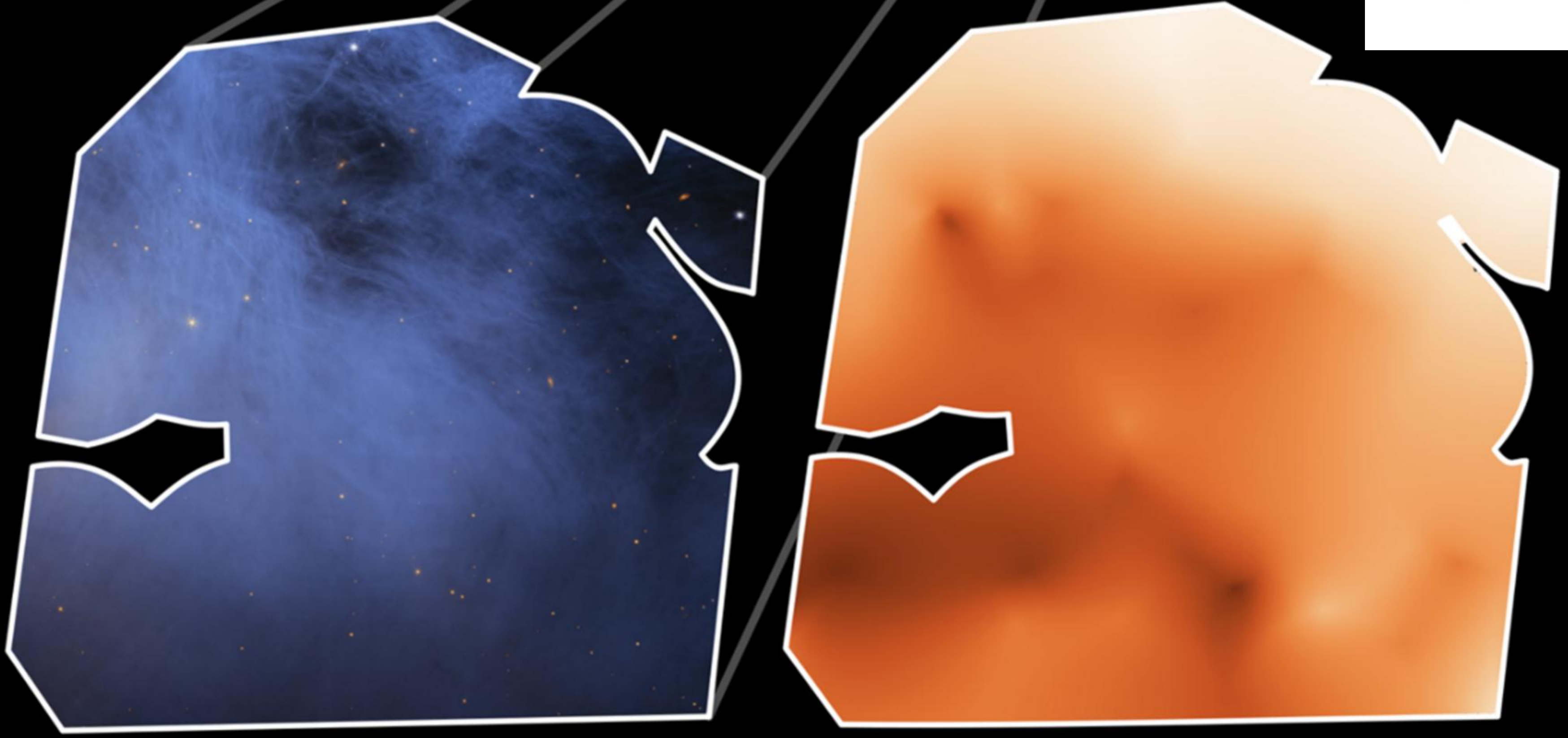




Cuppen, Linnartz & Ioppolo ARAA (2024)

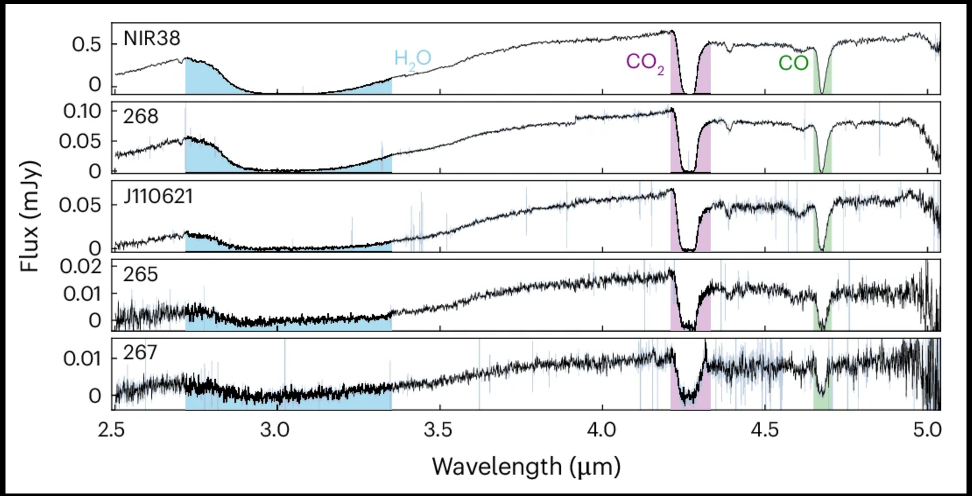


McClure *et al. Nat. Astron.* (2023)



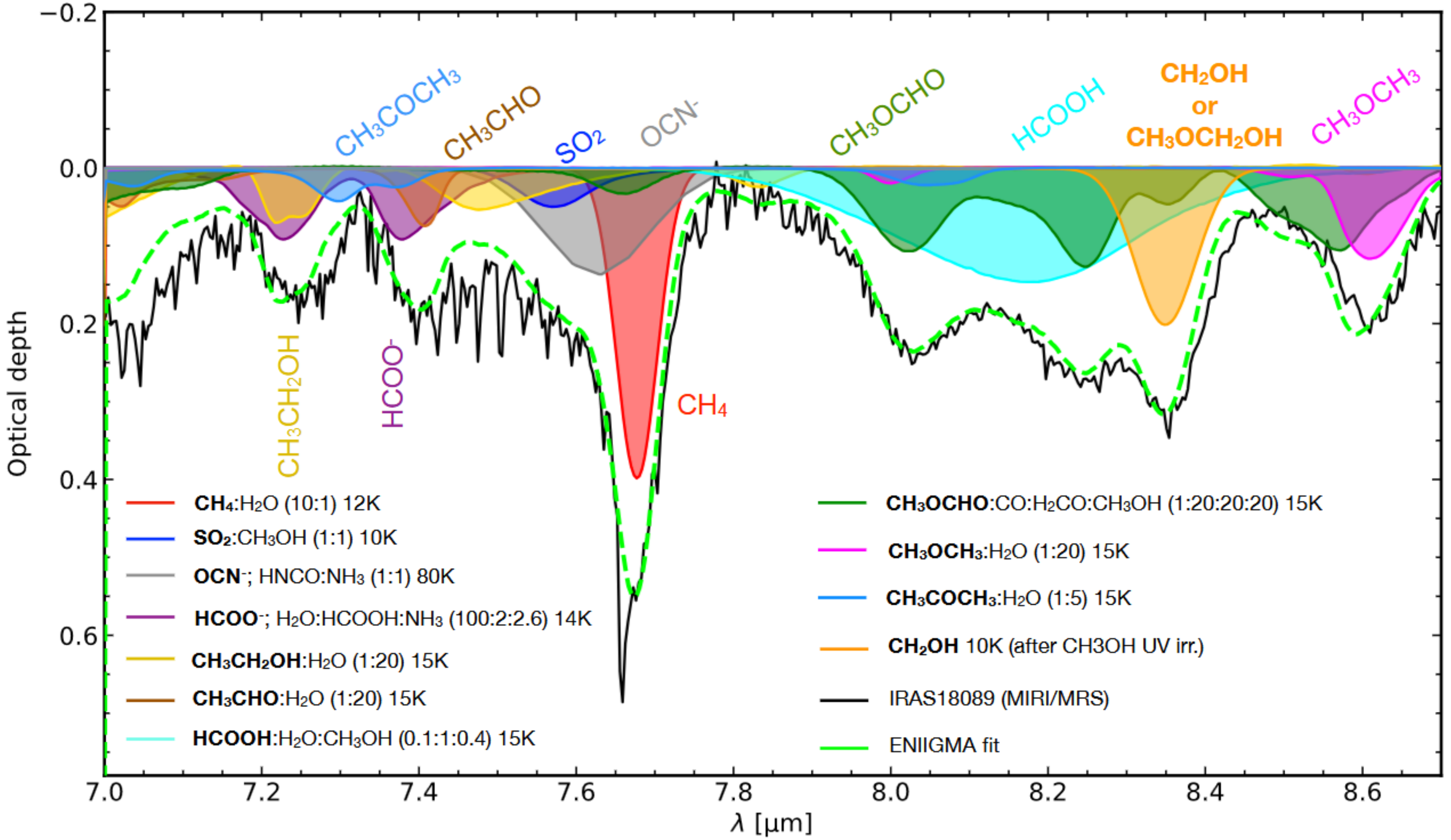
Direct Dust Image

Spectroscopic Ice Map



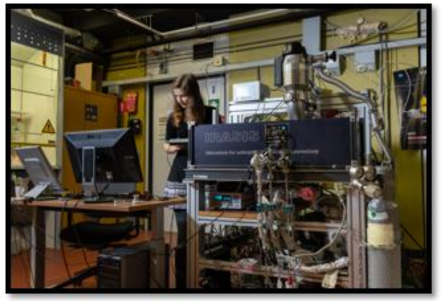
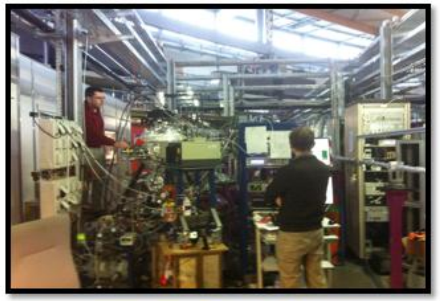
Smith *et al. Nat. Astron.* (2025)

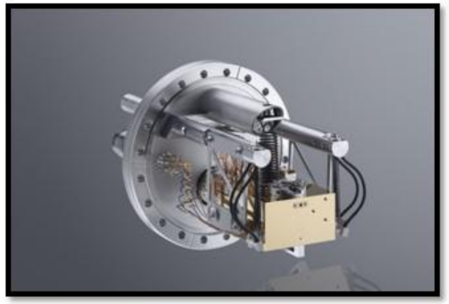
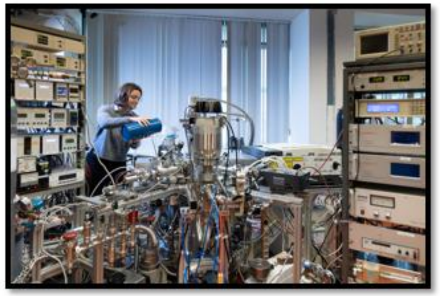
DETECTION OF COMS IN ICES



van Dishoeck *et al.* *A&A* (2025)

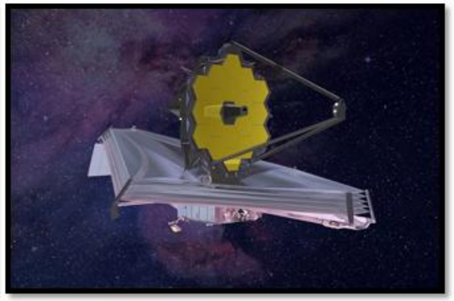
CURRENT STATUS OF LABORATORY INFRASTRUCTURES



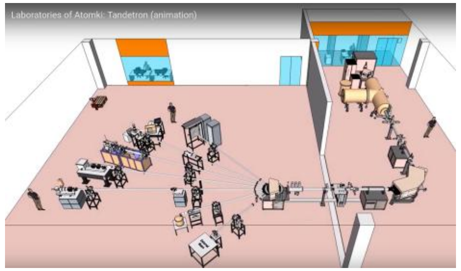


CHALLENGES IN LABORATORY ASTROCHEMISTRY

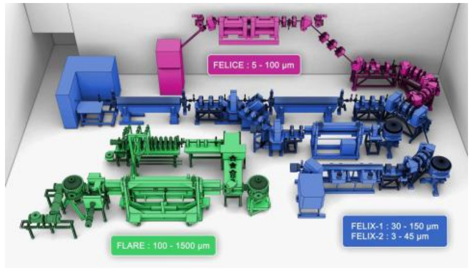
LAB Challenge I:
Generating a (0.1 - 3000 µm) ice database

LAB Challenge II:
Linking Physics and Chemistry of Star Formation



HUN REN atomki

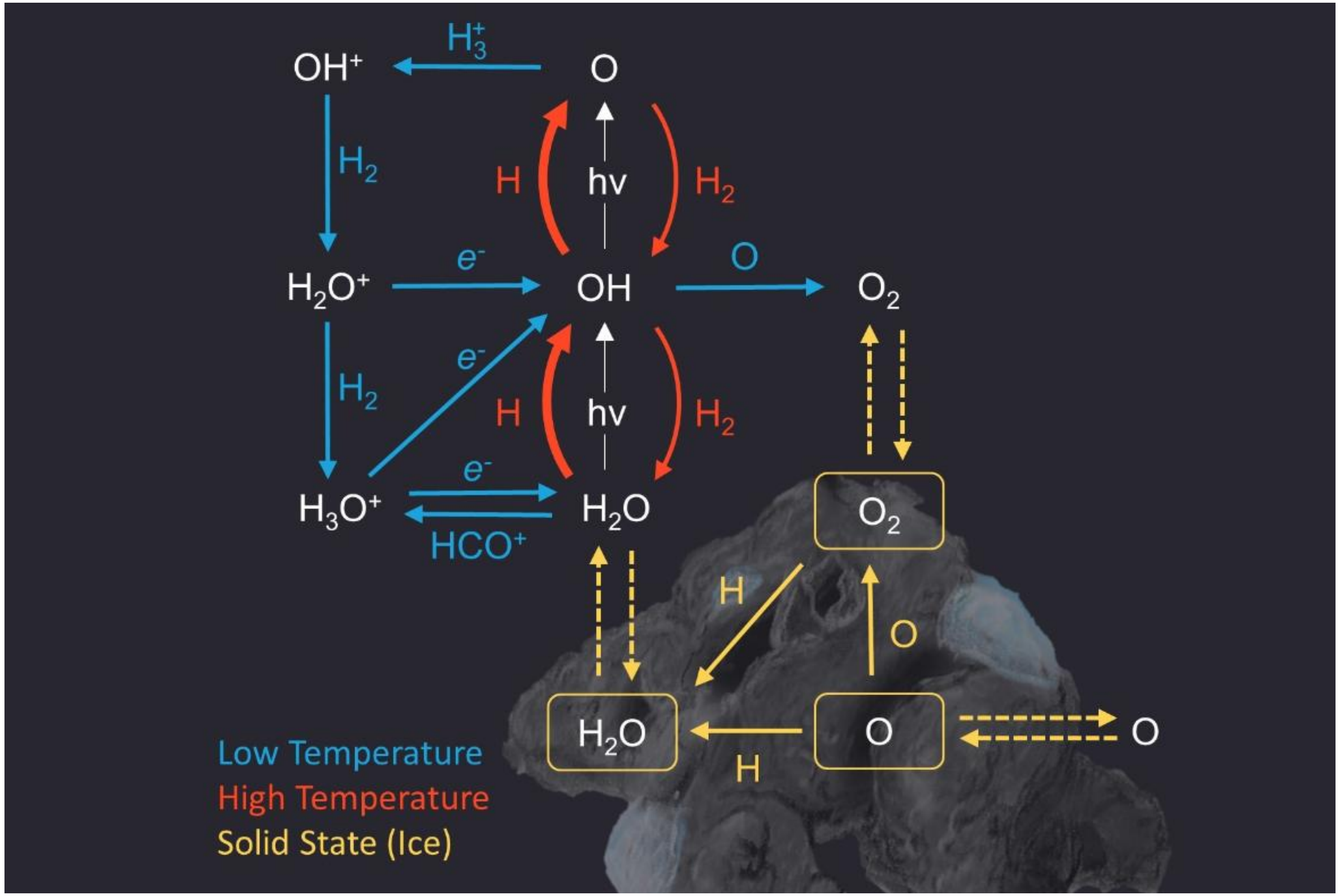
LAB Challenge III:
Formation of the Building Blocks of Life in Space

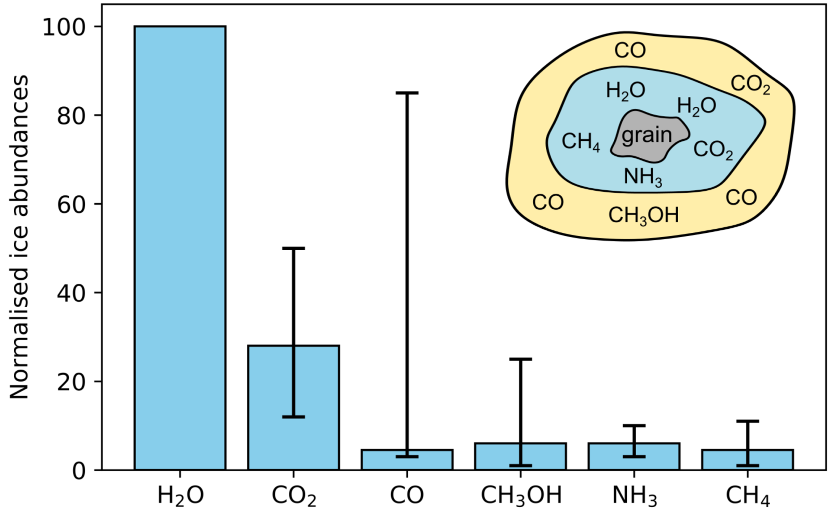


HFML FELIX

DARK CHEMISTRY

Nonenergetic Surface Reactions





Öberg, Chem. Rev. (2016)

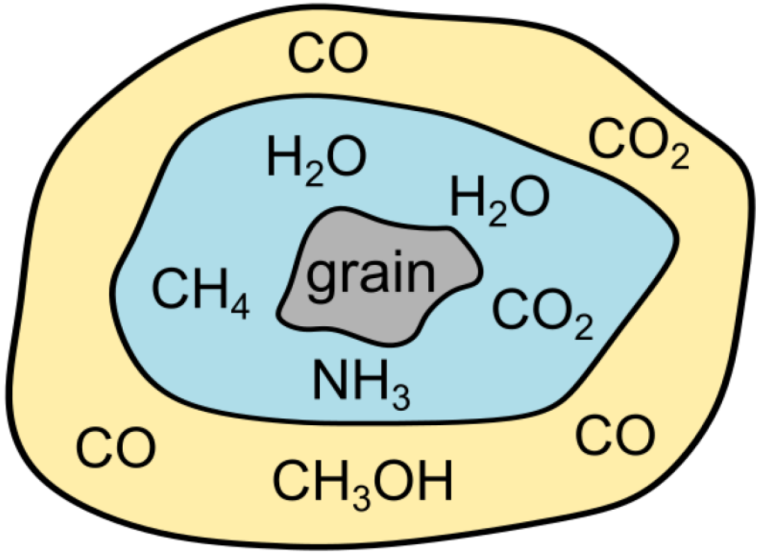
DARK CHEMISTRY

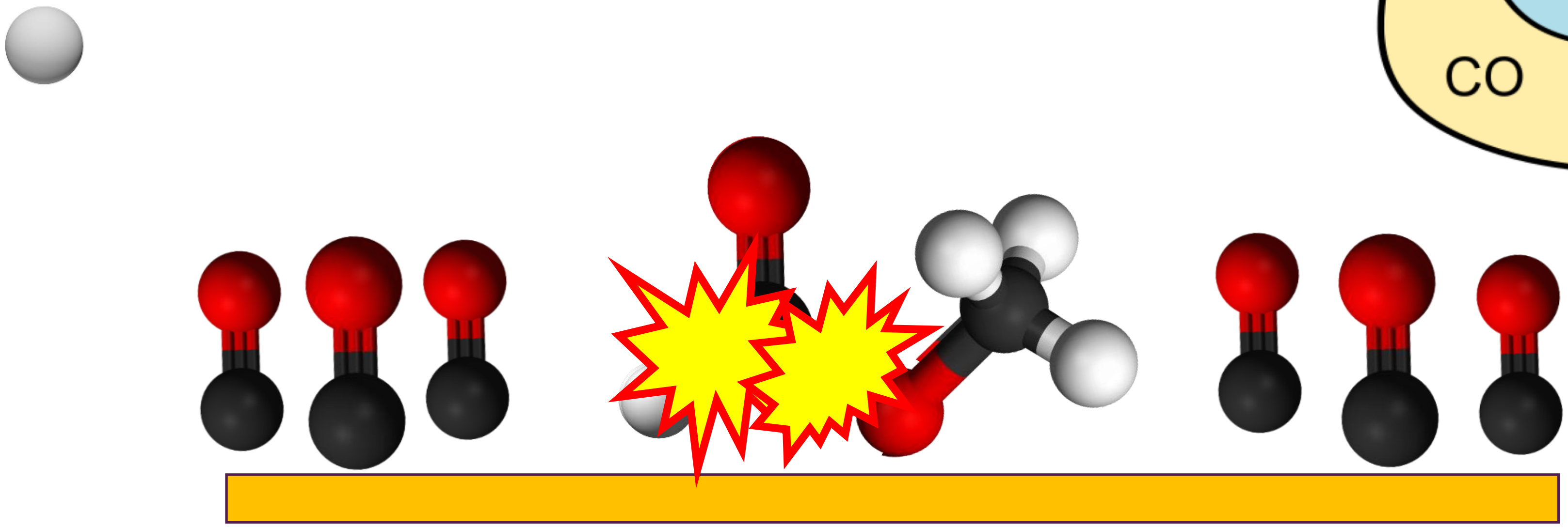
Nonenergetic Surface Reactions

A non-diffusive reaction mechanism at 10 K

Fedoseev *et al., MNRAS* (2015)
Chuang *et al., MNRAS* (2016)
Chuang *et al., MNRAS* (2017)
Fedoseev *et al., ApJ* (2017)
Jin and Garrod, ApJS (2020)

Qasim *et al., A&A* (2019)
Chuang *et al., A&A* (2020)
Qasim *et al., Nat. Astron.* (2020)
Ioppolo *et al., Nat. Astron.* (2021)
Garrod et al., ApJS (2021)

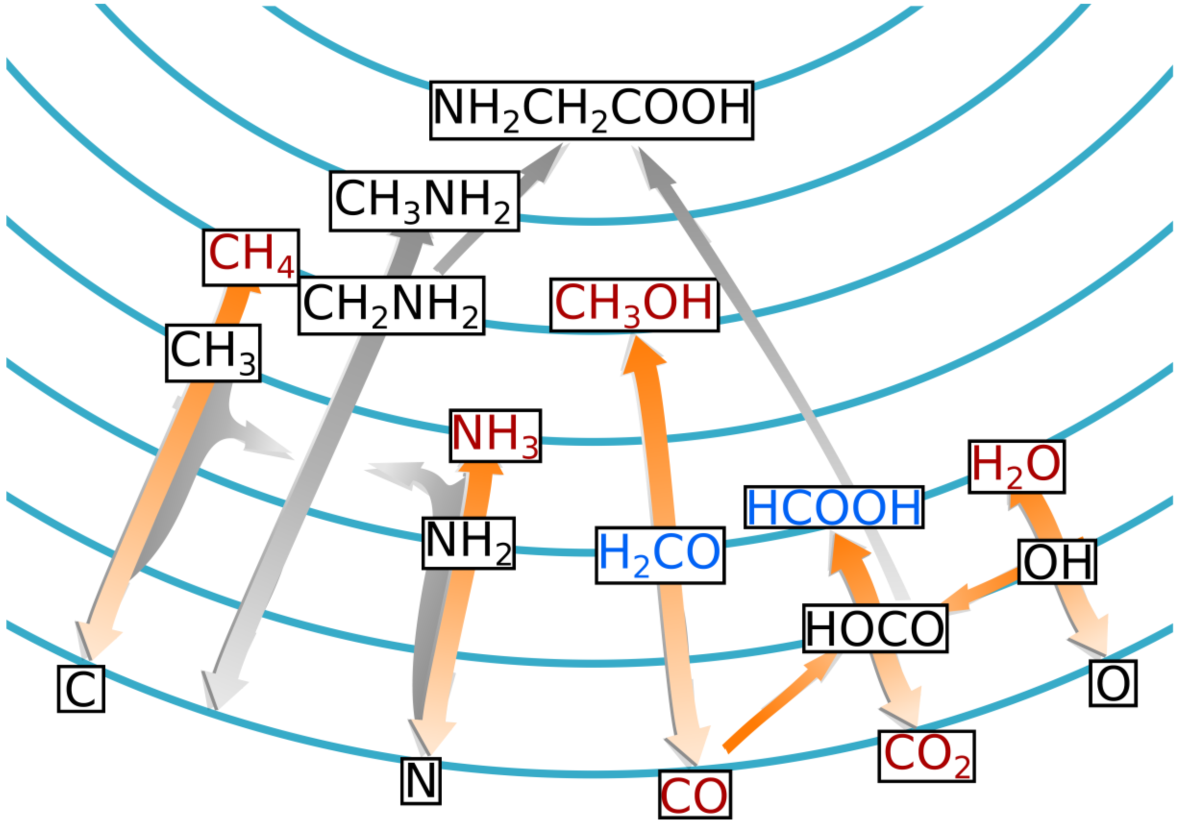


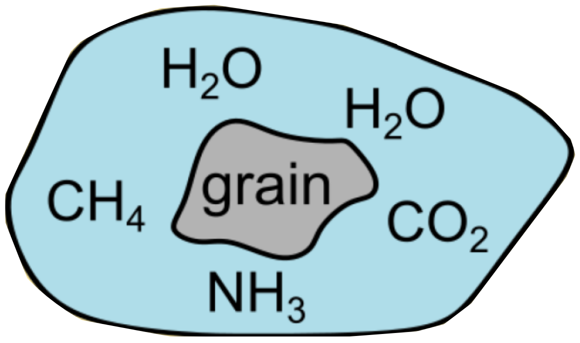


10 K

DARK CHEMISTRY

Nonenergetic Surface Reactions





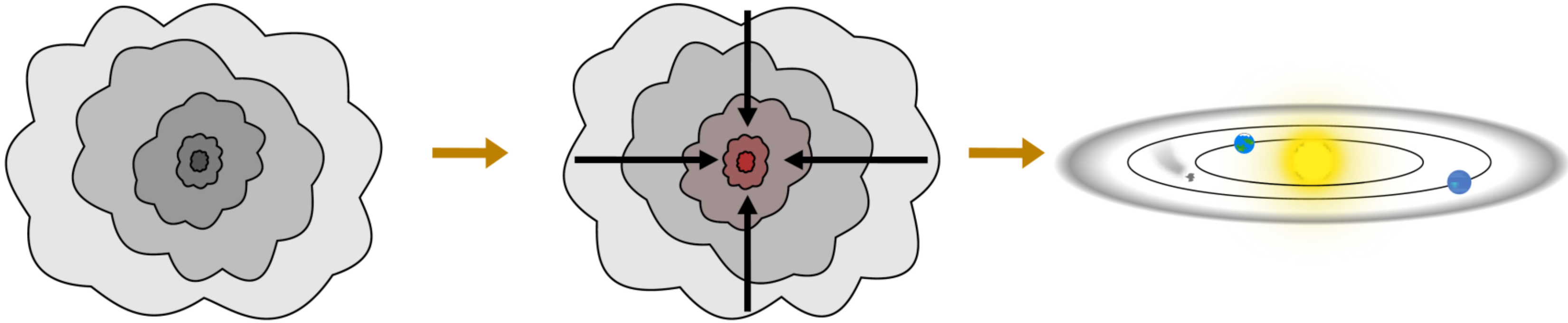
Qasim *et al., Nature Astron.* (2020)
Fedoseev *et al., MNRAS* (2015)
Fuchs *et al., A&A* (2009)

Ioppolo *et al., Nature Astron.* (2021)

Ioppolo *et al., MNRAS* (2011a)
Ioppolo *et al., MNRAS* (2011b)
Ioppolo *et al., ApJ* (2008)

GLYCINE IN SPACE

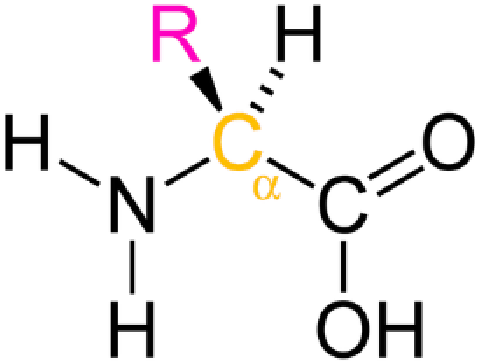
(Non)energetic Surface Reactions

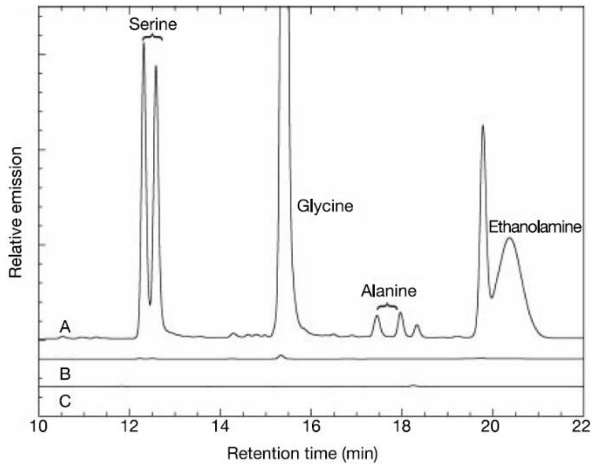


Dense molecular cloud
Non-energetic glycine formation
Ioppolo et al. (2021)

Cloud collapse & Hot core
Energetic amino acid formation

Protostar & Solar system formation
Further processing and inheritance



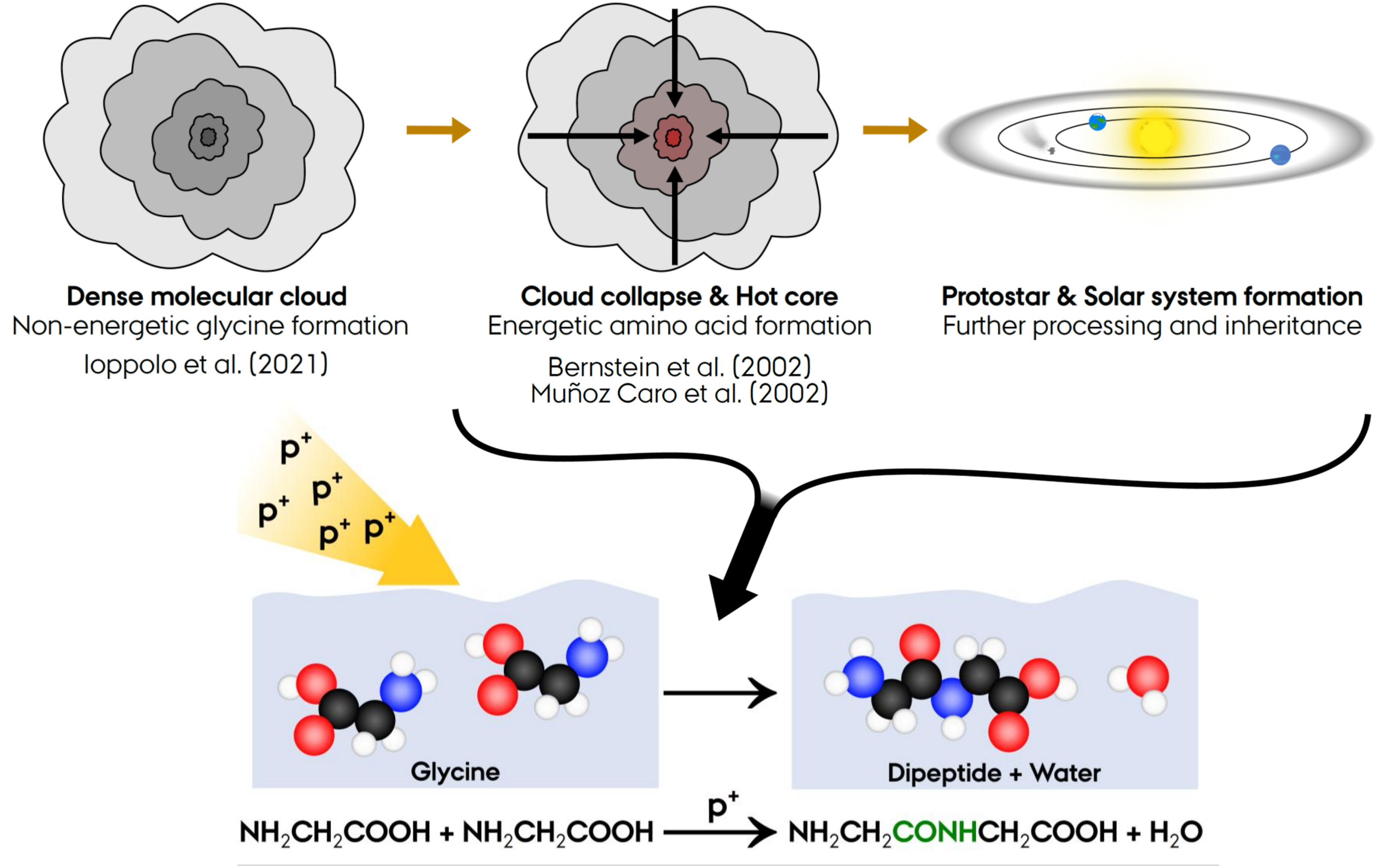


UV photolysis of interstellar ice analogues
$H_2O:CH_3OH:NH_3:HCN = 20:2:1:1$

Bernstein et al., *Nature* (2002)
Muñoz Caro et al., *Nature* (2002)

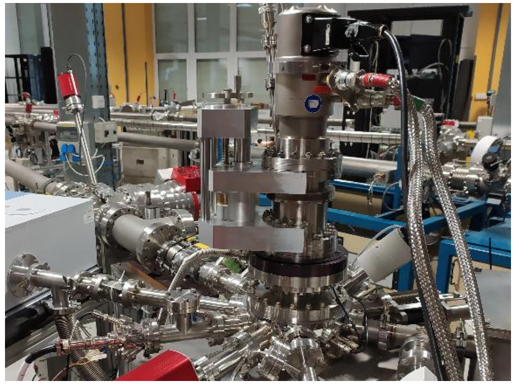
GLYCINE IN SPACE

(Non)energetic Surface Reactions



Hopkinson *et al. Nat. Astron.* (2026)

ENERGETIC PROCESSING OF GLYCINE



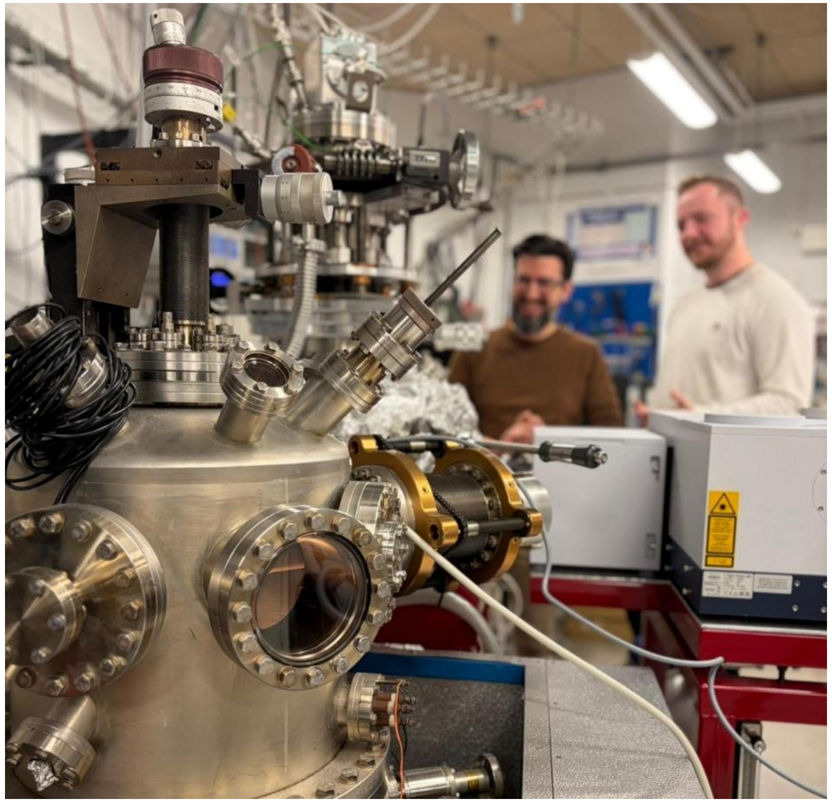
ICA

P < 1x10^{-9} mbar
T_{surf} = 20 - 300 K
E_{ions} = 200 keV – 4 MeV H^+
H^+, He^+, He^{++}, C^+, C^{++}, O^+, O^{++}, S^+, S^{++}
Current = nA - μA

- 2 keV electron gun
- Effusive Cell

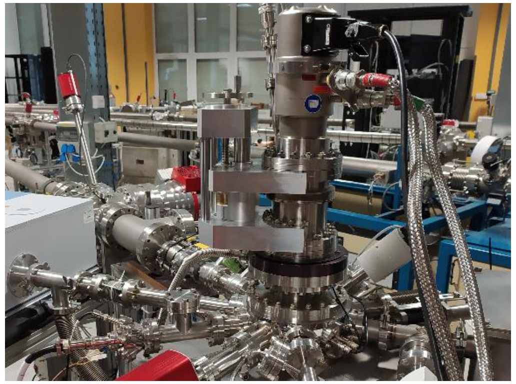
AQUILA

P < 1x10^{-9} mbar
T_{surf} = 20 - 300 K
E_{ions} = 100s eV – 10s keV
Solar Wind: H, He, C, O, Si, Fe, Ni ions
High charge state of ions
Positive/negative ions or molecular ions



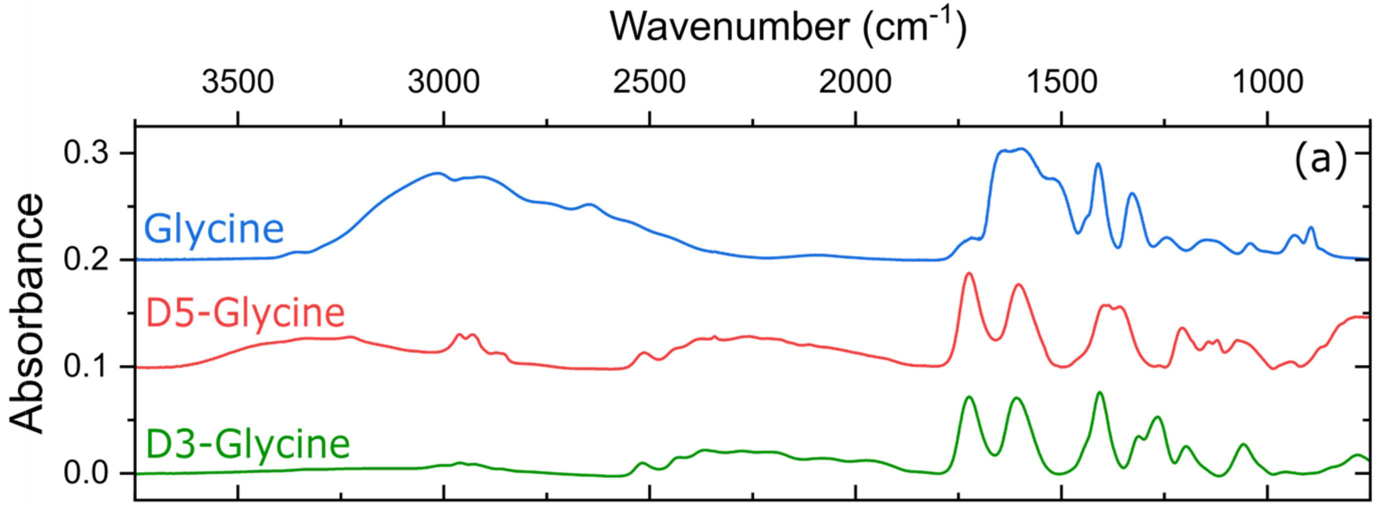
Hopkinson *et al. Nat. Astron.* (2026)

ENERGETIC PROCESSING OF GLYCINE



ICA

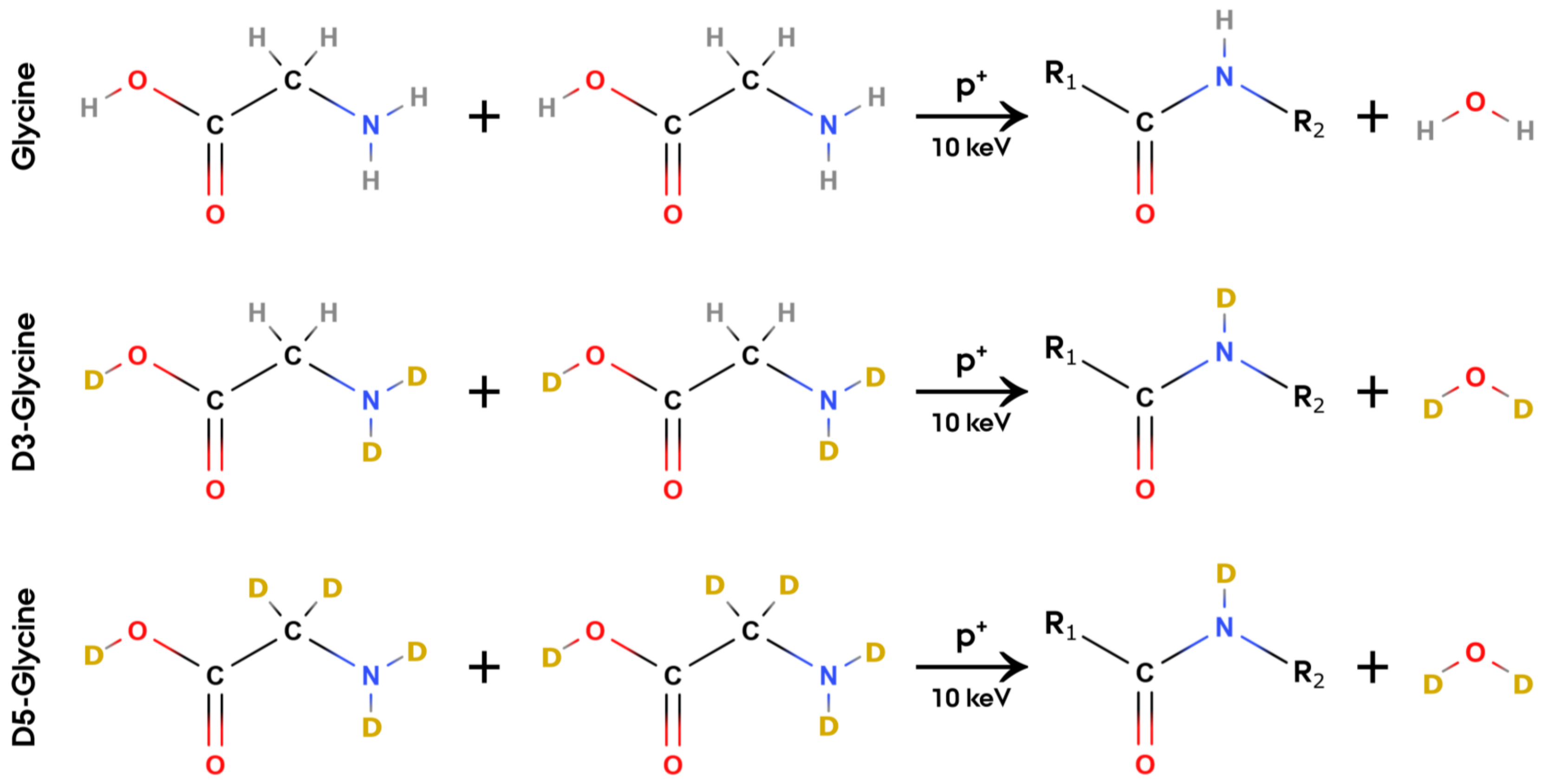
AQUILA



Molecule	Experimental setup	Proton energy
Glycine	AQUILA	10 keV
Fully deuterated D5-Glycine	AQUILA	10 keV
Partially deuterated D3-Glycine	AQUILA	10 keV
Glycine	ICA	1 MeV

Hopkinson *et al. Nat. Astron.* (2026)

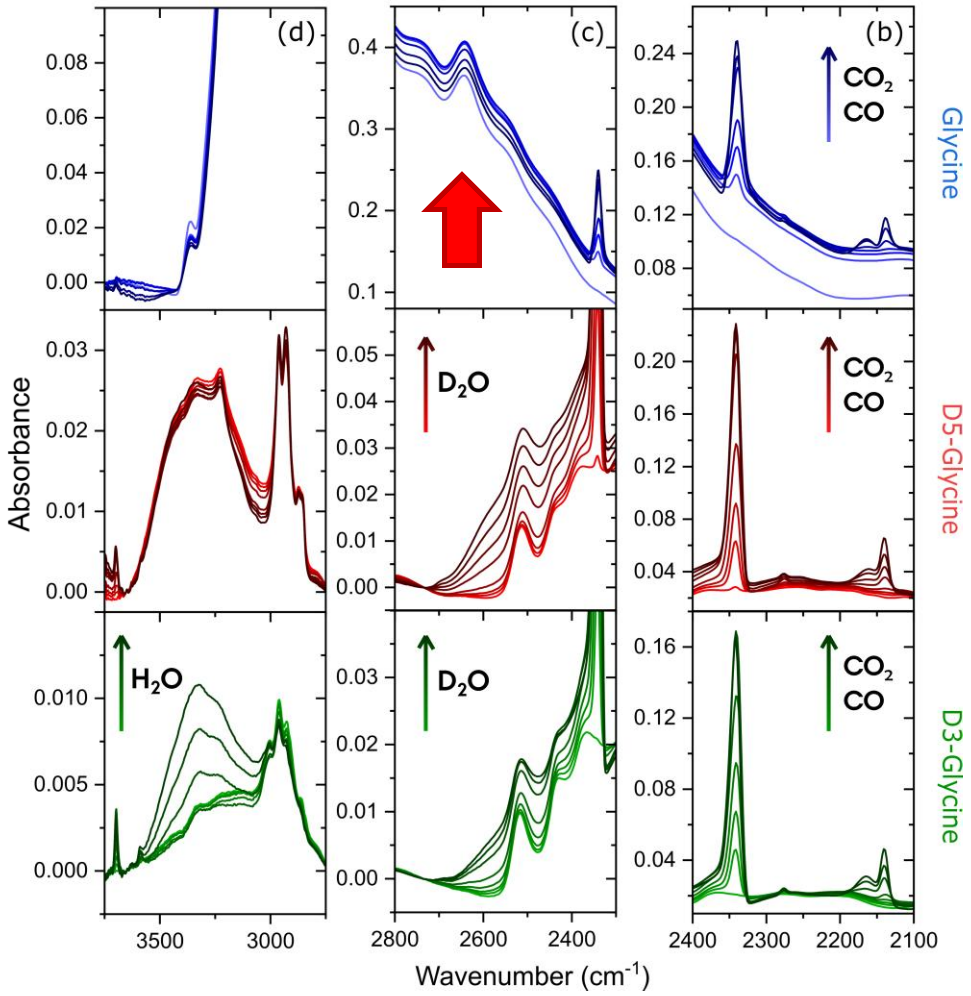
ENERGETIC PROCESSING OF GLYCINE



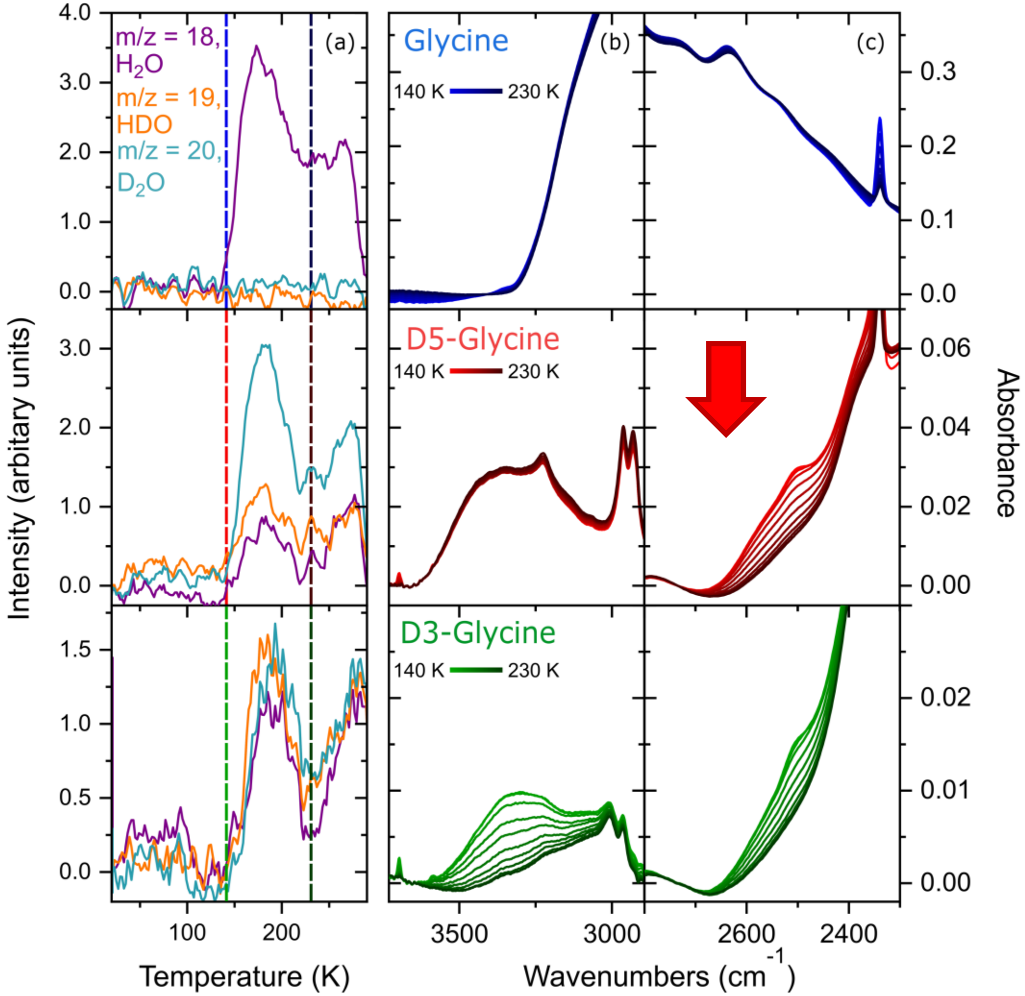
Hopkinson *et al. Nat. Astron.* (2026)

ENERGETIC PROCESSING OF GLYCINE

10 keV irradiation of Gly at 20 K



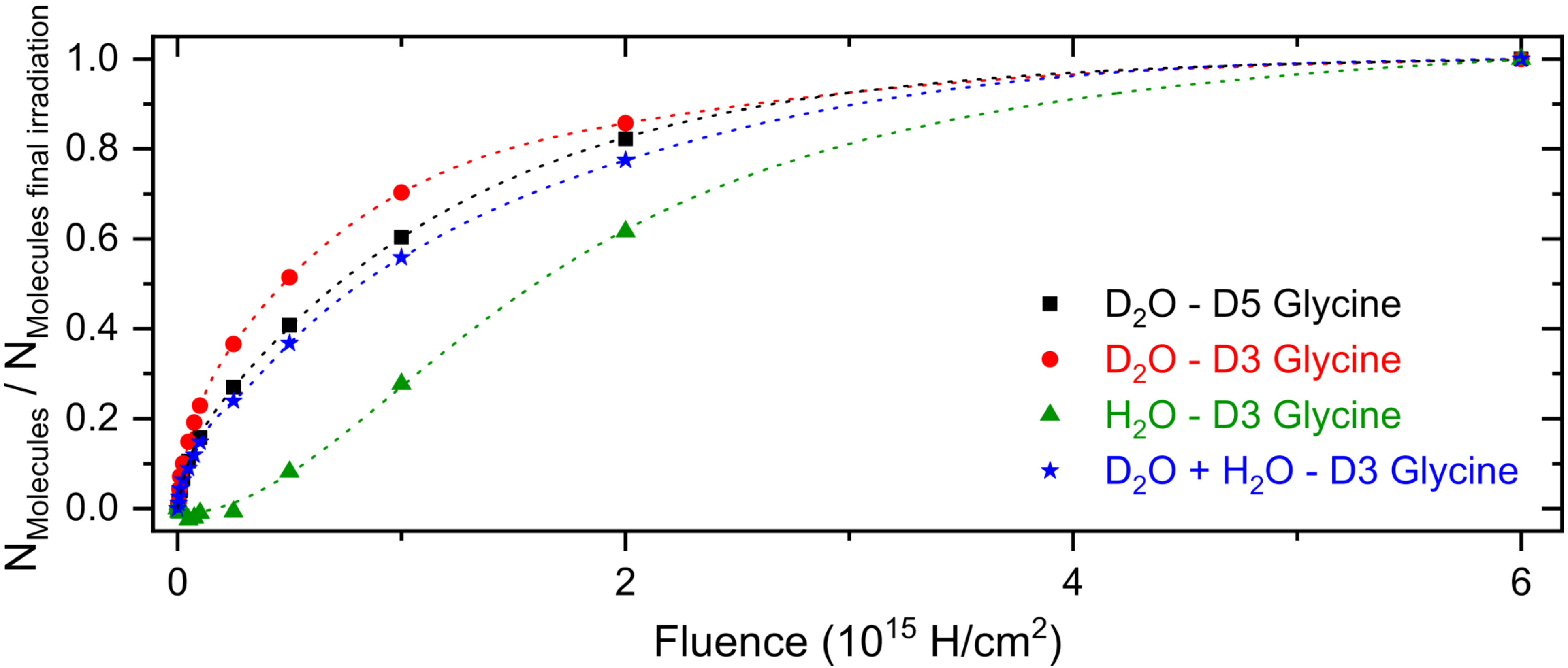
TPD after 10 keV irr of Gly



Hopkinson *et al. Nat. Astron.* (2026)

ENERGETIC PROCESSING OF GLYCINE

Water Formation

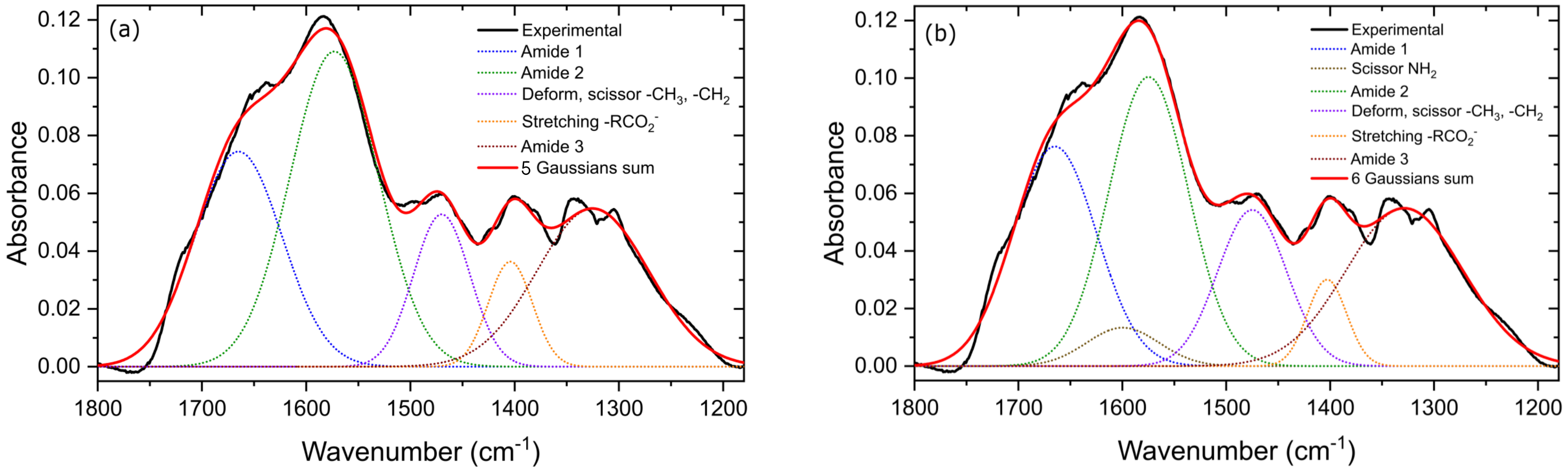


Hopkinson *et al. Nat. Astron.* (2026)

ENERGETIC PROCESSING OF GLYCINE

Formation of Amide Bonds

Residue after 1 MeV irradiation of Gly at 20 K



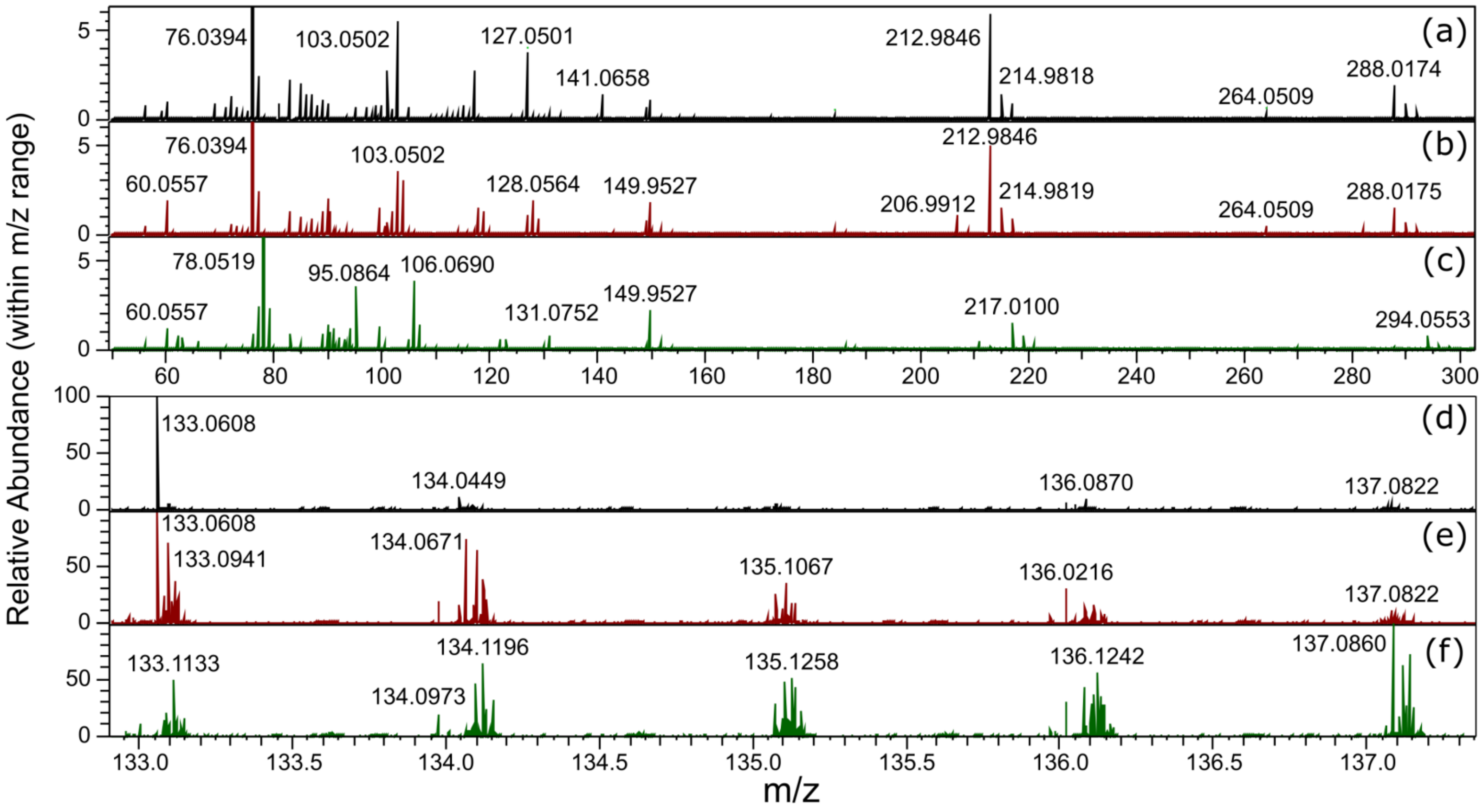
(see Maté et al. 2015)

(see Krasnokutski et al. 2022)

Hopkinson *et al. Nat. Astron.* (2026)

ENERGETIC PROCESSING OF GLYCINE
Electrospray Ionization MS

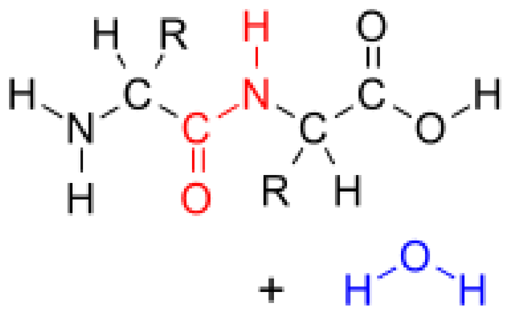
(a) Glycine (b) D3-glycine (c) D5-glycine

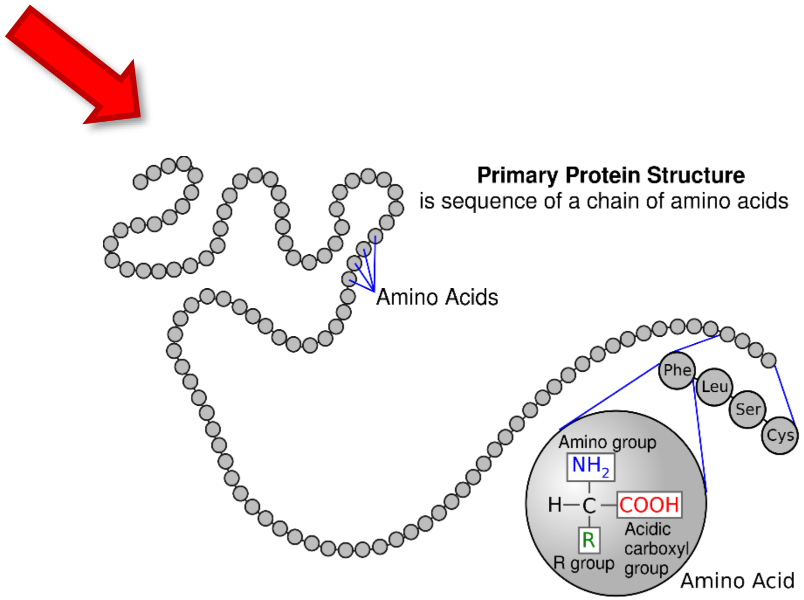


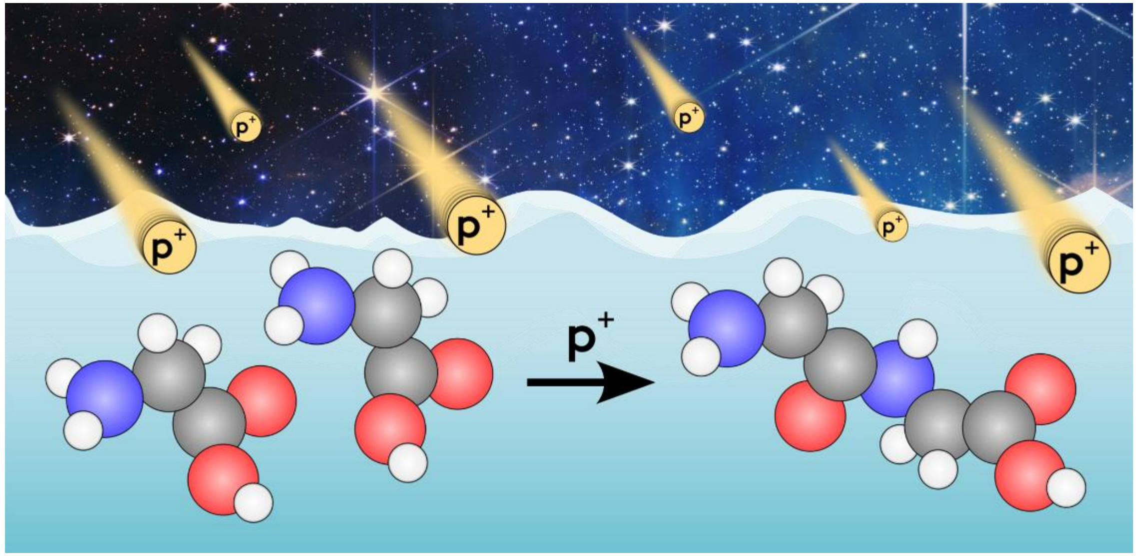
Hopkinson *et al. Nat. Astron.* (2026)

PEPTIDES IN SPACE

The Building Blocks of Proteins







Hopkinson *et al. Nat. Astron.* (2026)

CONCLUSIONS

Simple and complex organic molecules formed on dust grains via Dark Chemistry

UV, CR, electrons, and heat change the physicochemical composition of ice grains

Building blocks of life can survive and evolve during star formation process

Laboratory Astrochemistry needs to strengthen link to Astrobiology

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Astrochemistry
ERC-SyG IRAstro

Danmarks Grundforskningsfond
Danish National Research Foundation

INTERCAT
Center for Interstellar Catalysis

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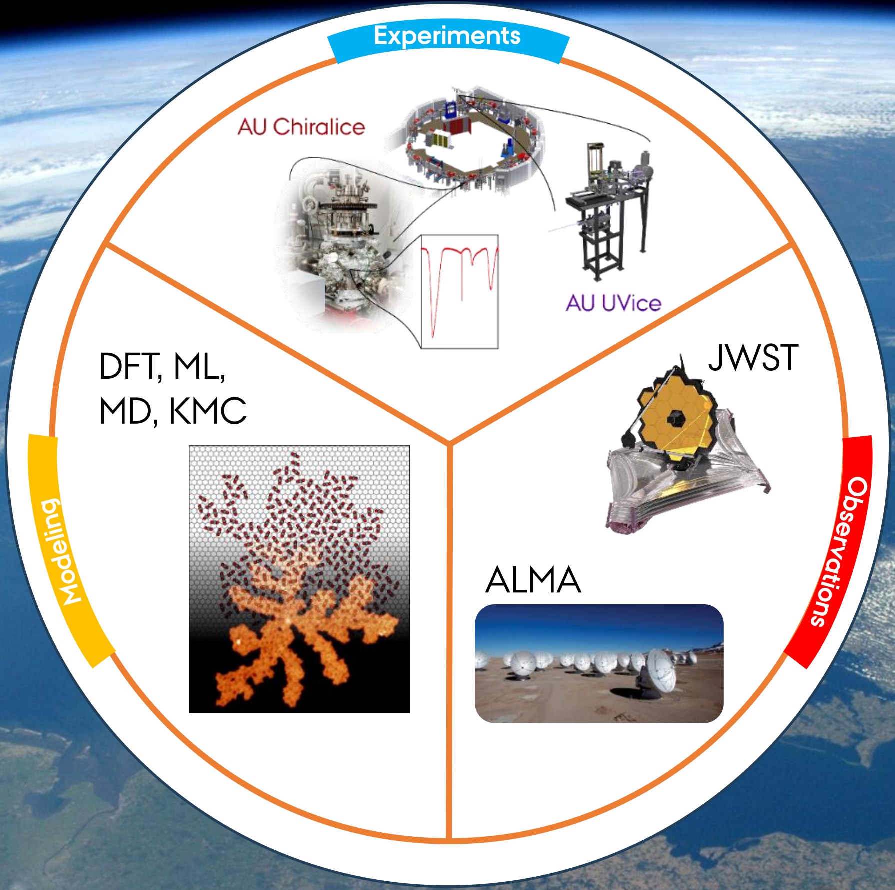
Interstellar Ices

Prof. Bjørk Hammer
Aarhus University
DFT, Machine Learning



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Co-PI Group:
Unique expertise,
Co-supervisors on
specific PhD projects



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Asst. Prof. Melissa McClure
Asst. Prof. Thanja Lamberts
Leiden University

Prof. Herma Cuppen
Radboud University

CNRS Res. Dir.
Cornelia Meinert

THANK YOU