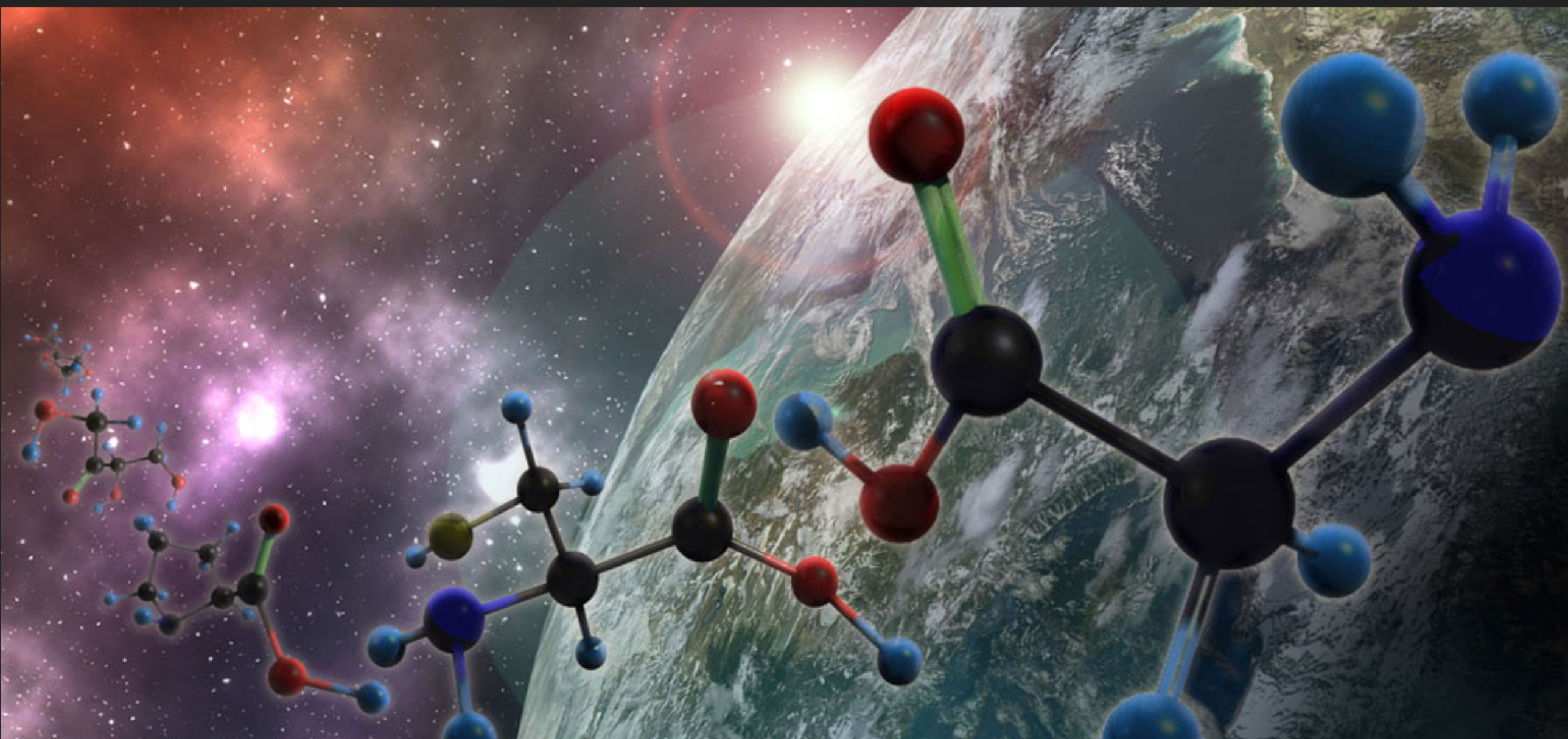
INTRODUCTION

STEFANO BOVINO

UNIVERSIDAD DE CONCEPCION



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HTTP://THEORY-STARFORMATION-GROUP.CL/SBOVINO/

HOW THE COURSE IS ORGANIZED

Classes

@ Wednesdays: 17:15-19:00

@ Thursday: 14:15-15:00

https://forms.gle/NAwbn8TpLcXckAGY6

Link to the form

@http://stf.astroapoyo.cl/surveys.html

QUICK SURVEY: TEST YOUR ASTROCHEMISTRY KNOWLEDGE

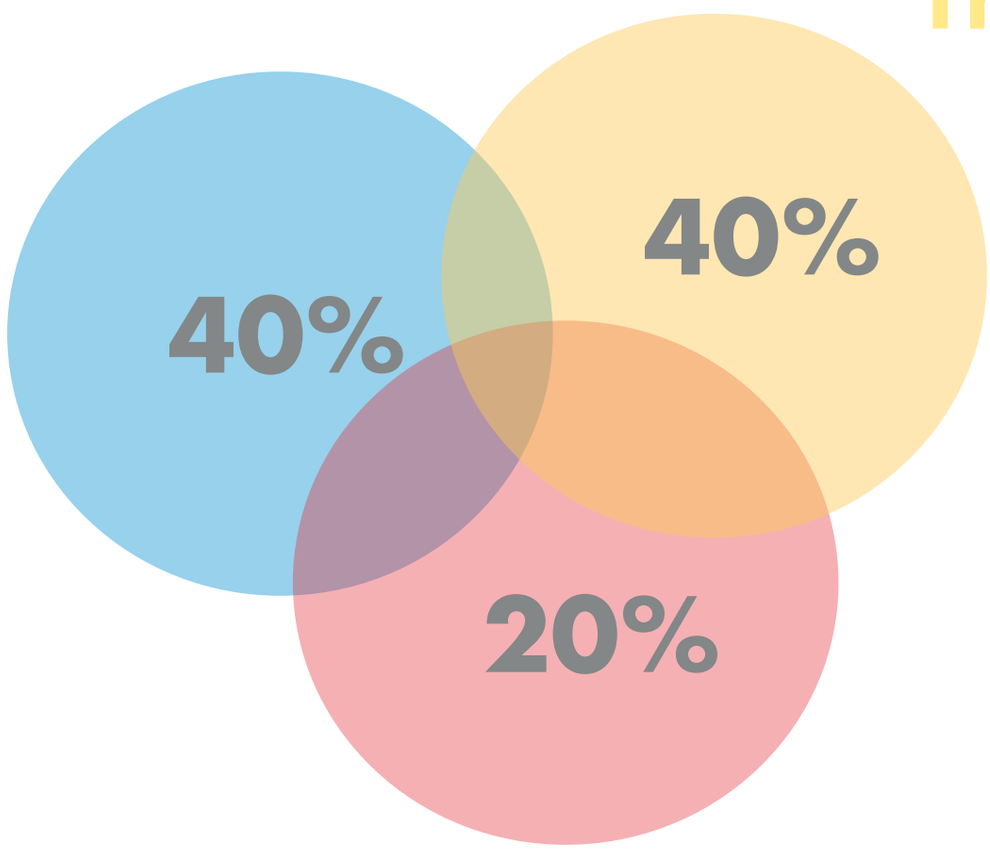
https://s.surveyplanet.com/qtoix7ov

- **Syllabus** (compact version):
  - Basic Introduction on Astrochemistry and the ISM
  - Radiative and collisional processes
  - Gas-Phase Chemistry
  - Photochemistry and Cosmic-rays induced chemistry
  - Grain Surface Reactions (Dust physics)
  - Thermal processes: cooling & heating
  - Chemical Kinetics and Modeling in Astrophysics
  - Introduction to Computational astrochemistry

EVALUATION:

Theoretical exam

Team work



Computational work

EVALUATION: TEAM WORK

Split in groups (max 3 students per group)

Pick up a molecule of interest:

CO, H_2O, HCN, NH_3, H_2D^+, HCO^+, DCO^+

N_2H^+, CH_3OH, H_3^+, H_2, H_2CO, …

Prepare a report and a short oral presentation

Build a small network which describes the molecule of interest
(how to do in future classes)

EVALUATION: WRITTEN EXAM

At the end of the semester

Topics: theoretical aspects discussed in class

EVALUATION: COMPUTATIONAL WORK

Practical classes and homework

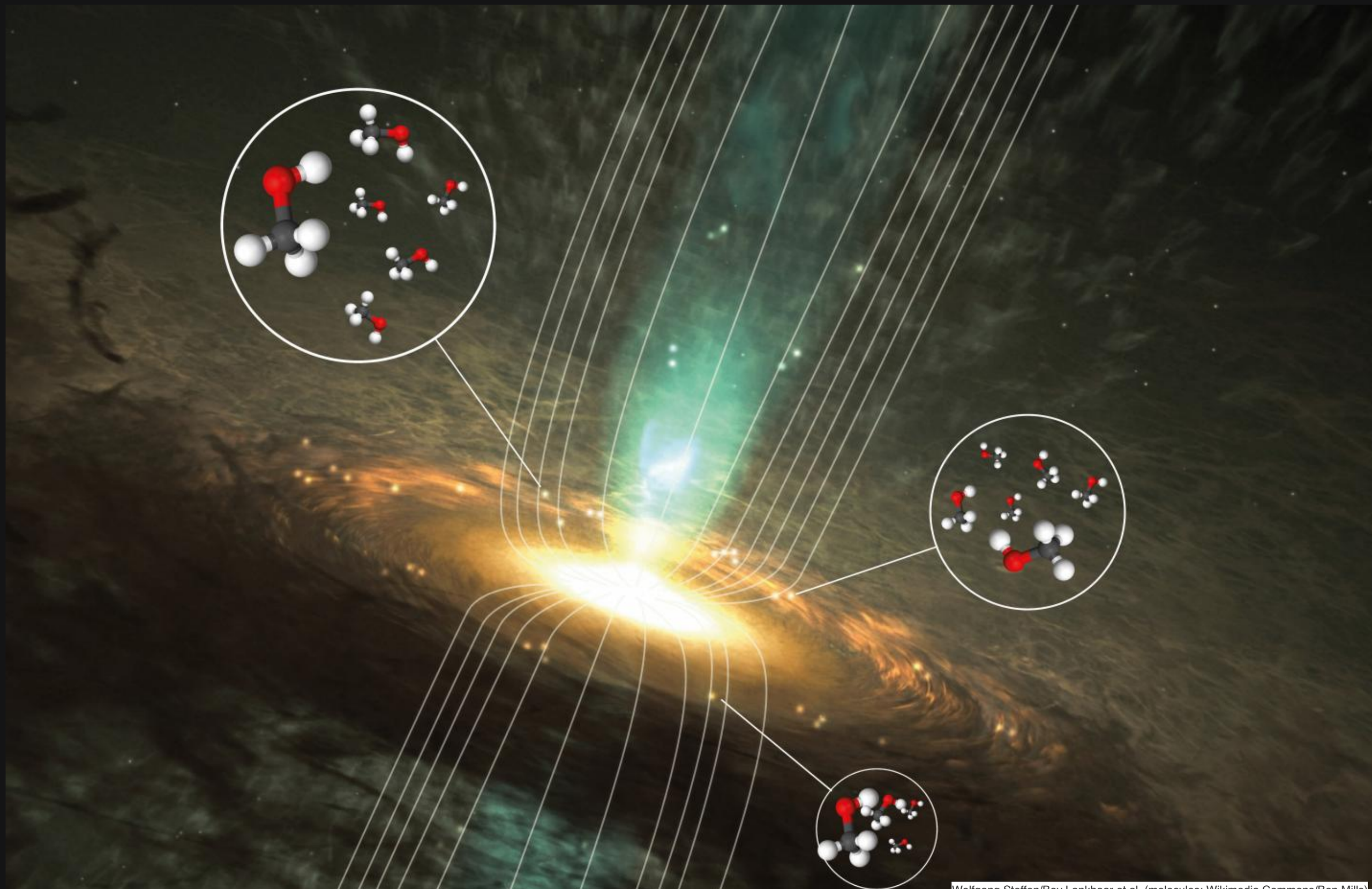
TOOLS WE WILL USE

- Bigbam (a simple python code for astrochemistry)
- Krome (fortran code for astrochemistry in hydrodynamics)

MATERIAL: THESE LECTURE SLIDES FIRST

- Introduction to Astrochemistry, S. Yamamoto, 2017
- Dynamical Astrochemistry, D. Williams+, 2018
- The Chemistry of Cosmic Dust, D. Williams+, 2016
- Molecular Collisions in the Interstellar Medium, D. Flower, 2005
- Observational Astronomy, D. Williams+, 2013
- The Physics and Chemistry of the Interstellar Medium, A. Tielens, 2005
- The Interstellar Medium, J. Lequeux, 2005
- Faraday Discussion on Astrochemistry, E. Van Dishoeck, 2014

WHAT IS ASTROCHEMISTRY?



Wolfgang Steffen/Boy Lankhaar et al. (molecules: Wikimedia Commons/Ben Mills)

THE STUDY OF THE FORMATION, DESTRUCTION, AND EXCITATION OF MOLECULES IN ASTRONOMICAL ENVIRONMENTS AND THEIR INFLUENCE ON THE STRUCTURE, DYNAMICS, AND EVOLUTION OF ASTRONOMICAL OBJECTS

Alex Dalgarno (2008)

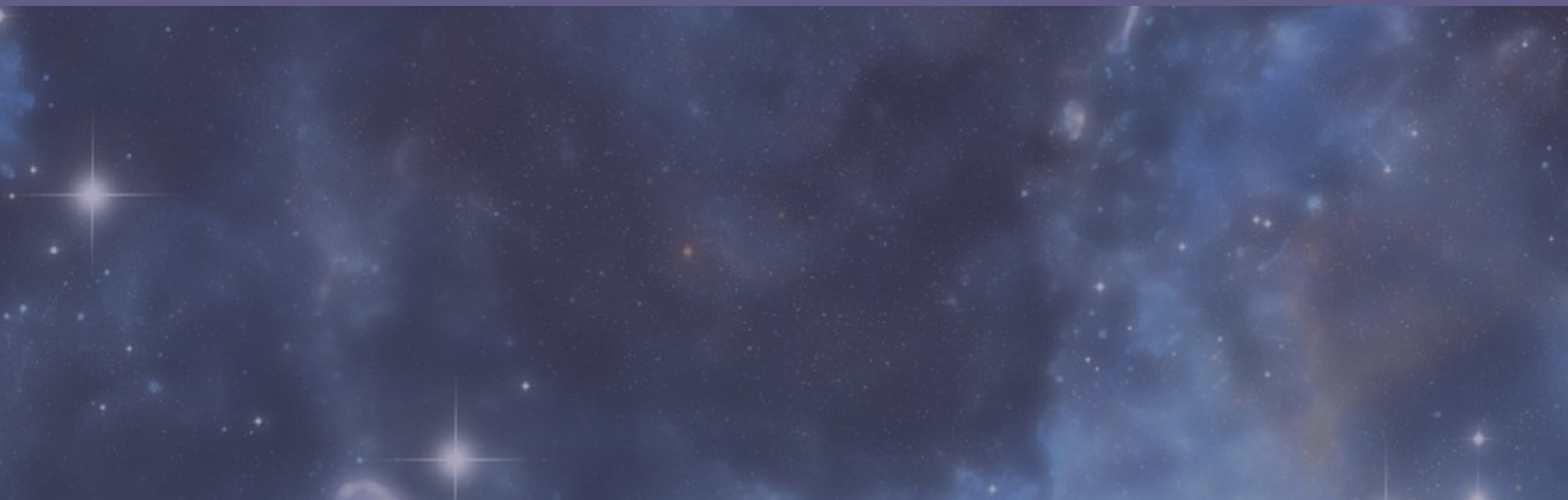
BLENDING OF ASTRONOMY AND CHEMISTRY IN WHICH EACH AREA ENRICHES THE OTHER IN A MUTUALLY STIMULATING INTERACTION

Alex Dalgarno (2008)

THE STUDY OF THE CHEMICAL NETWORKS THAT ARE BELIEVED TO LEAD TO THE FORMATION OF INTERSTELLAR MOLECULES

David Williams (2017)

THE STUDY OF HOW MOLECULES AND CHEMICAL PROCESSES AFFECT THE DYNAMICS OF GALAXIES, STARS AND PLANETS FORMATION!



Astrochemistry: the study of molecules in spaces

where they are

how they got there

what they are doing

Astrochemistry: the study of molecules in spaces

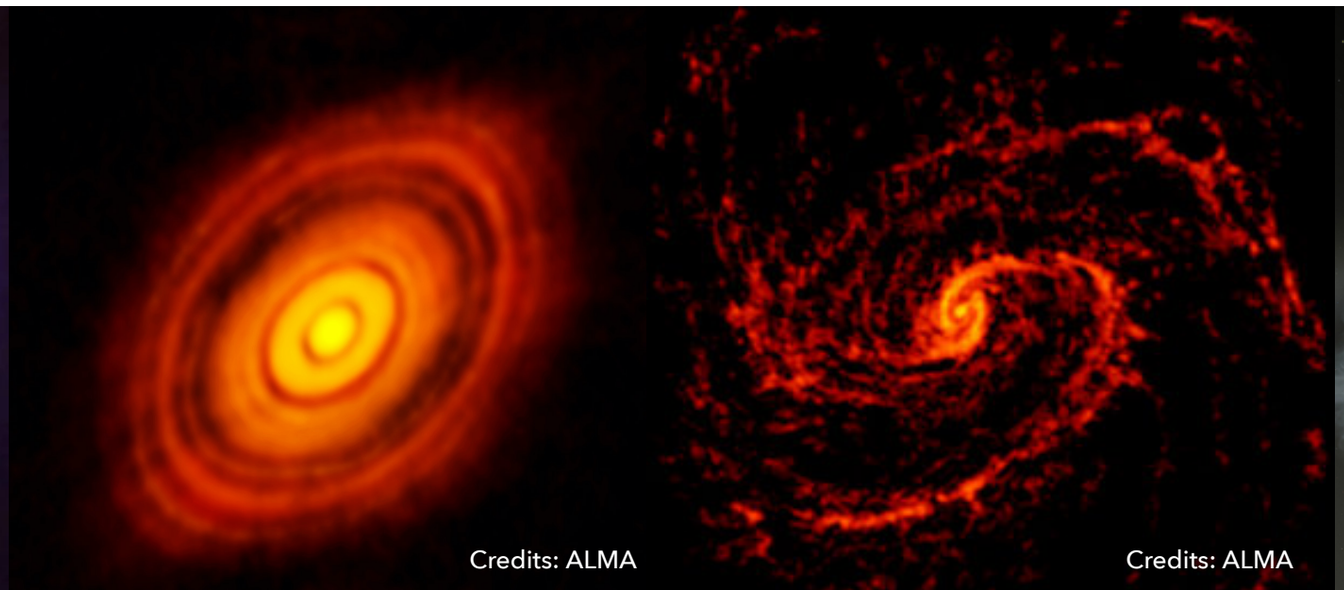
where they are, how they got there, and what they are doing

Where

Everywhere in space:

from evolved stars to PPD, galaxies, and comets!


Credits: ALMA


Credits: ALMA

Credits: ALMA


Credits: NASA/SOFIA

Astrochemistry: the study of molecules in spaces

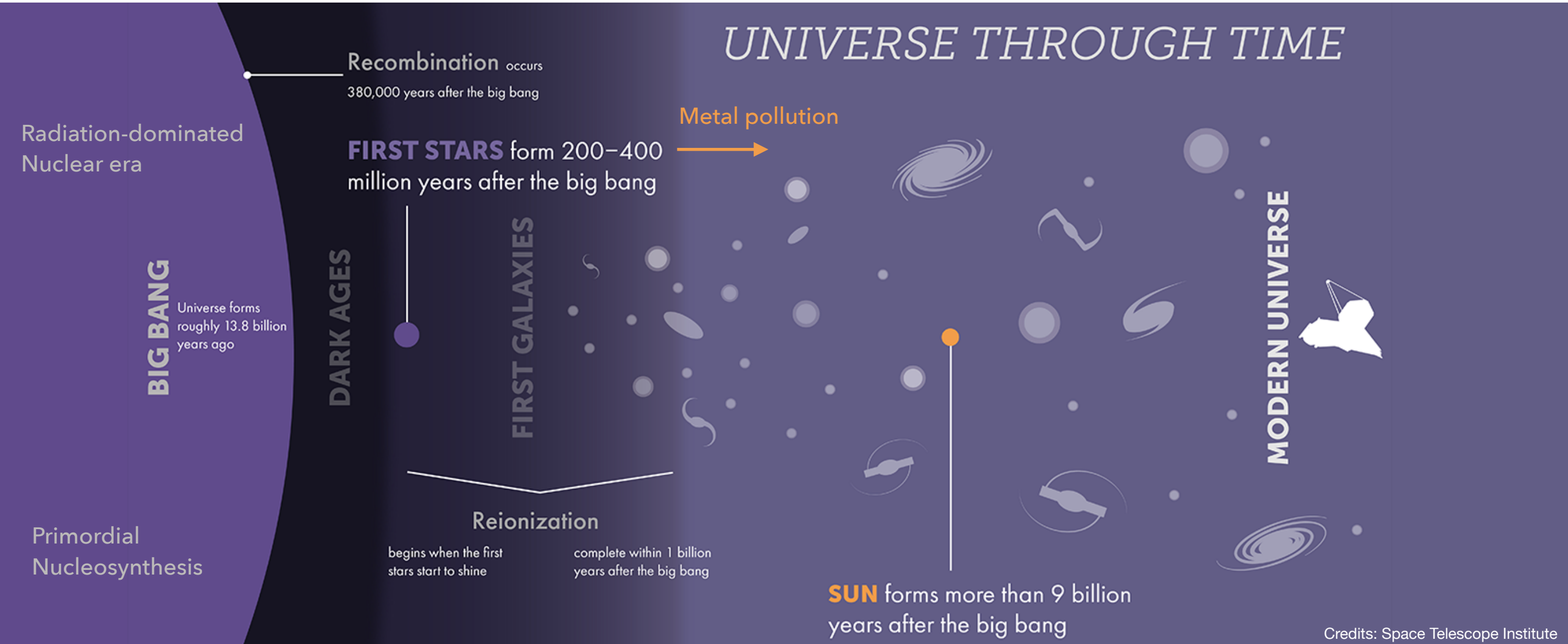
where they are, how they got there, and what they are doing

How

A story started 13.8 billion years ago

H and **He** were formed within 20 minutes after the Big Bang (**primordial nucleosynthesis**)

Death of the first stars polluted the medium with ***metals***
(in Astronomy *everything heavier than He*)

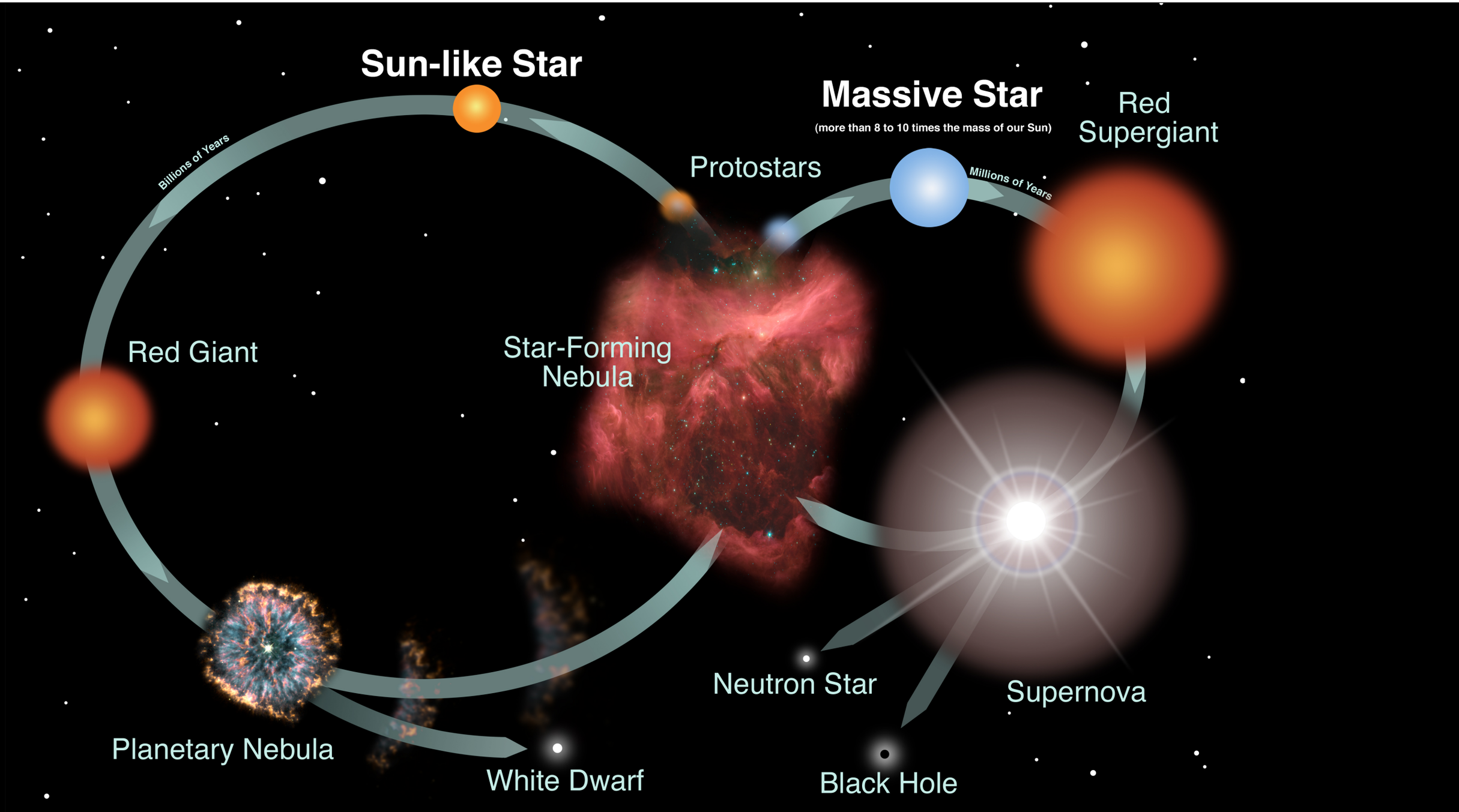


Credits: Space Telescope Institute

Astrochemistry: the study of molecules in spaces

where they are, how they got there, and what they are doing

How



Astrochemistry: the study of molecules in spaces

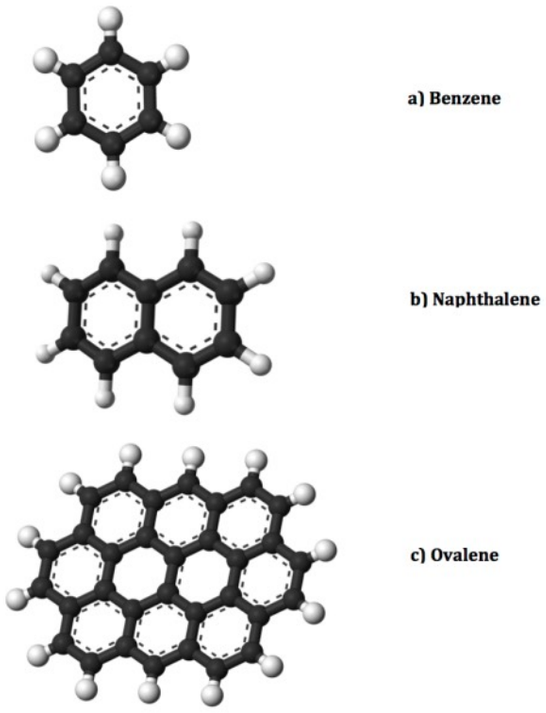
where they are, how they got there, and what they are doing

What

They do exactly what molecules on Earth are doing: forming, interacting, begin destroyed.

The **difference**: molecules in space are exposed to ***extreme conditions***

Example: PAH (byproducts of combustion found in vehicle exhaust) are thought to form in the outflows of post-AGB stars at temperatures around 1100 K



What

Most of the molecules form at 10 K, extremely cold environment.

Density in space is much lower

	Earth	Mars	Moon	Europa	Enceladus	Space
Mean Temperature (°C) (range)	15 [6.73] (-89.2 to 56.7) [6.110]	-63 (-89 to -31)[6.74]	-20 (-178 to 117) [6.75]	-183 (-227 to -177) [6.4]	-203[6.82]	-270 in deep space[6.33] (-157 to 121 at LEO) [6.76]
Pressure (Pa) (range)	1.01×10^5 (8.7×10^4 to 1.09×10^5) [6.73]	636 (400 to 870)[6.74]	3×10^{-16} [6.75]	no data	no data	1.460×10^{16} [6.39]
Atmospheric composition (%) by volume	N_2 78.08 O_2 20.95 Ar 0.93 CO_2 0.04 [6.73]	CO_2 95.32 N_2 2.70 Ar 1.6 O_2 0.13 [6.74]	^4He 25.8 ^{20}Ne 25.8 H_2 22.6 ^{40}Ar 1.3 [6.75]	no data	no data	no data
Cosmic radiation	3 mGy/y[6.11]	76 mGy/yr[6.45]	no data	no data	no data	500mGy/h [6.15]

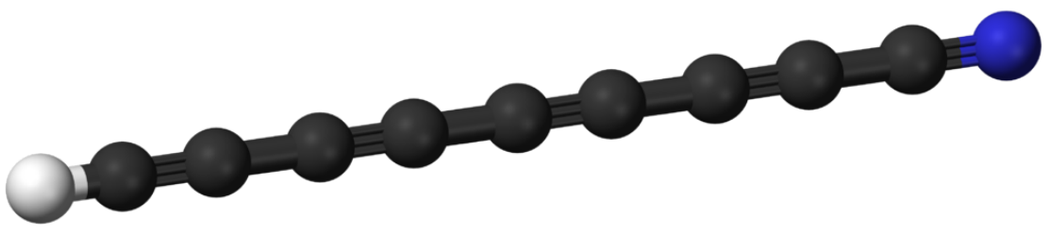
WHY

Give us a glimpse at a primitive molecular word

Chemical archeology in space

Molecules not found on Earth

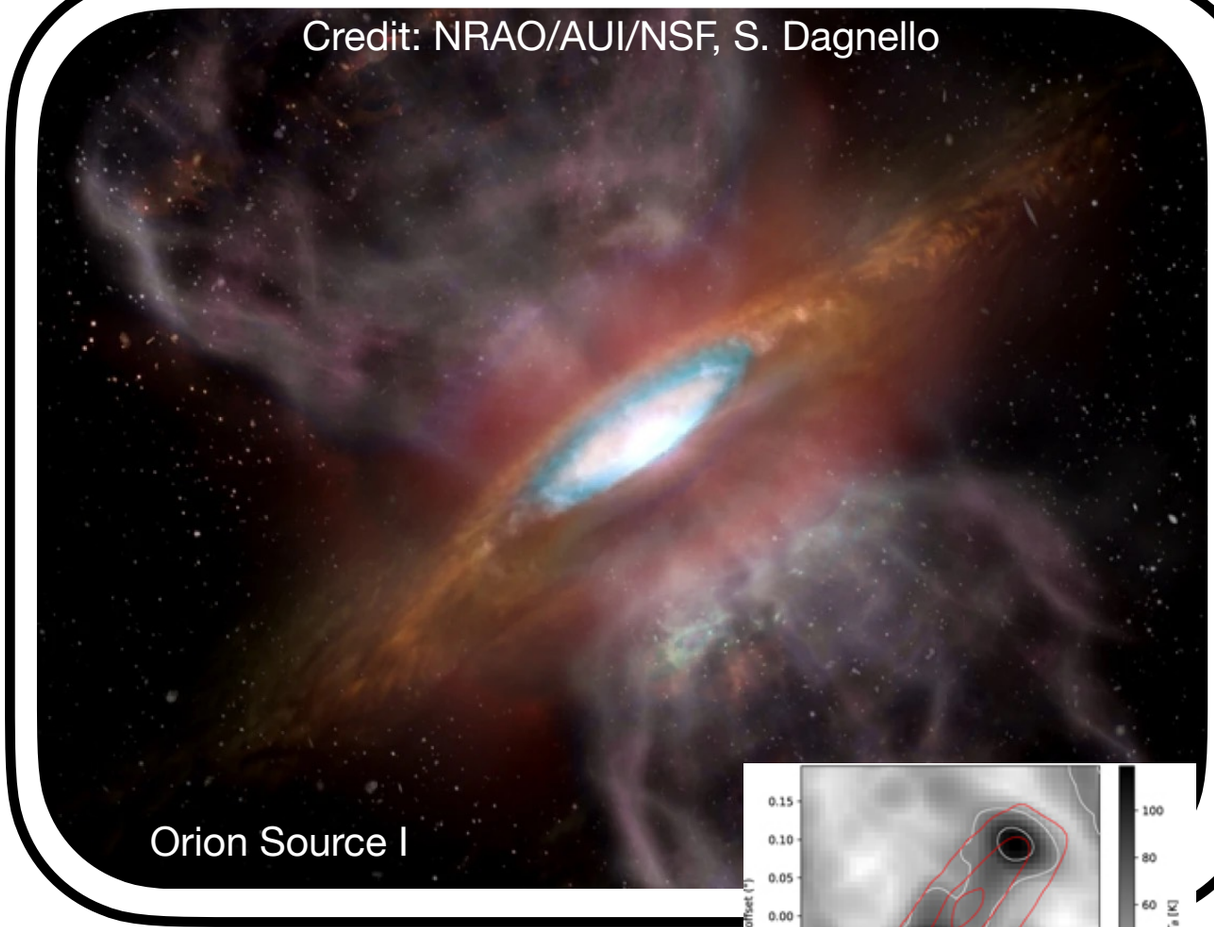
Cyanopollynes: Long unsaturated carbon-chains



Hydrogen
Nitrogen
Carbon

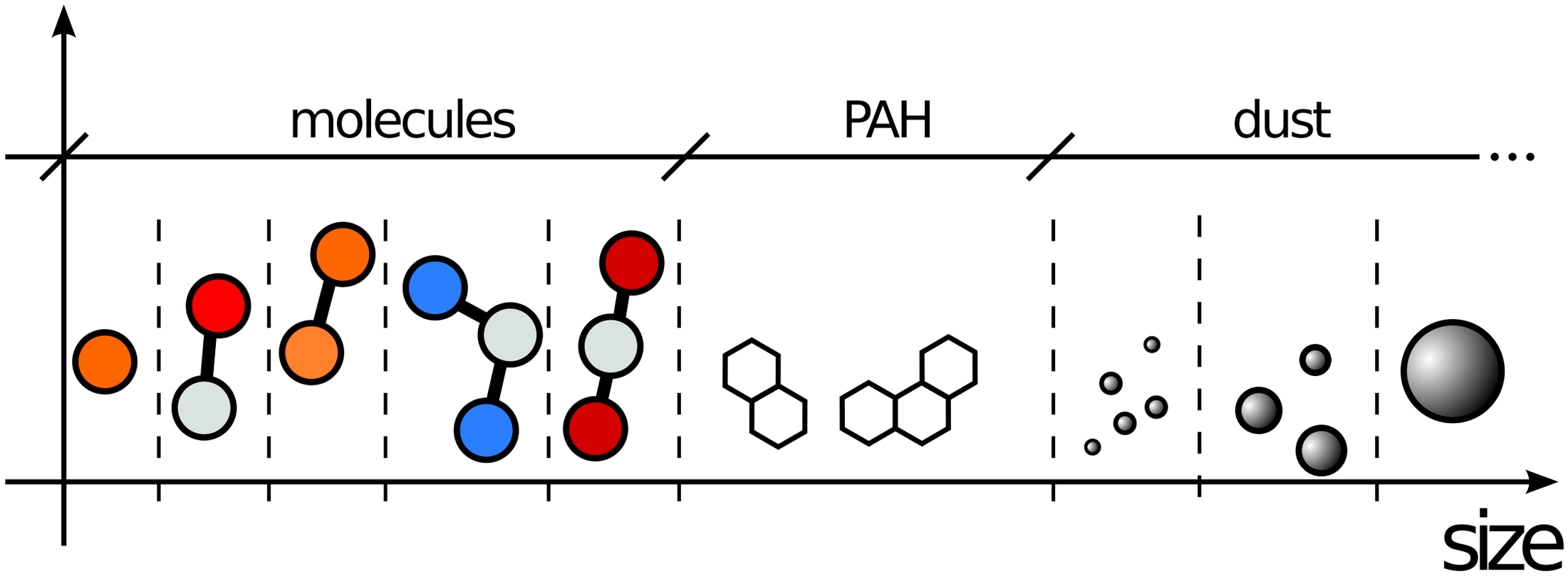
HC_9N

Common compounds on Earth e.g. NaCl



- Molecules as **diagnostic** of the physical conditions of the environments where they reside (T, density, velocity)
- History / **evolution** of various objects (e.g. ratios among tracers)
- Where **exoplanets** formed (comparison between atmospheric composition and modeled profiles of PPDs)
- Molecules regulates the cooling: **star-formation**

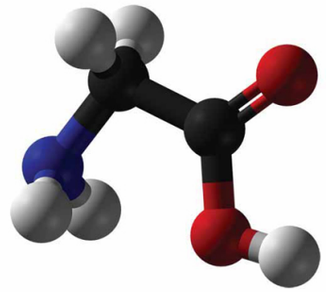
MOLECULAR ASTROPHYSICS

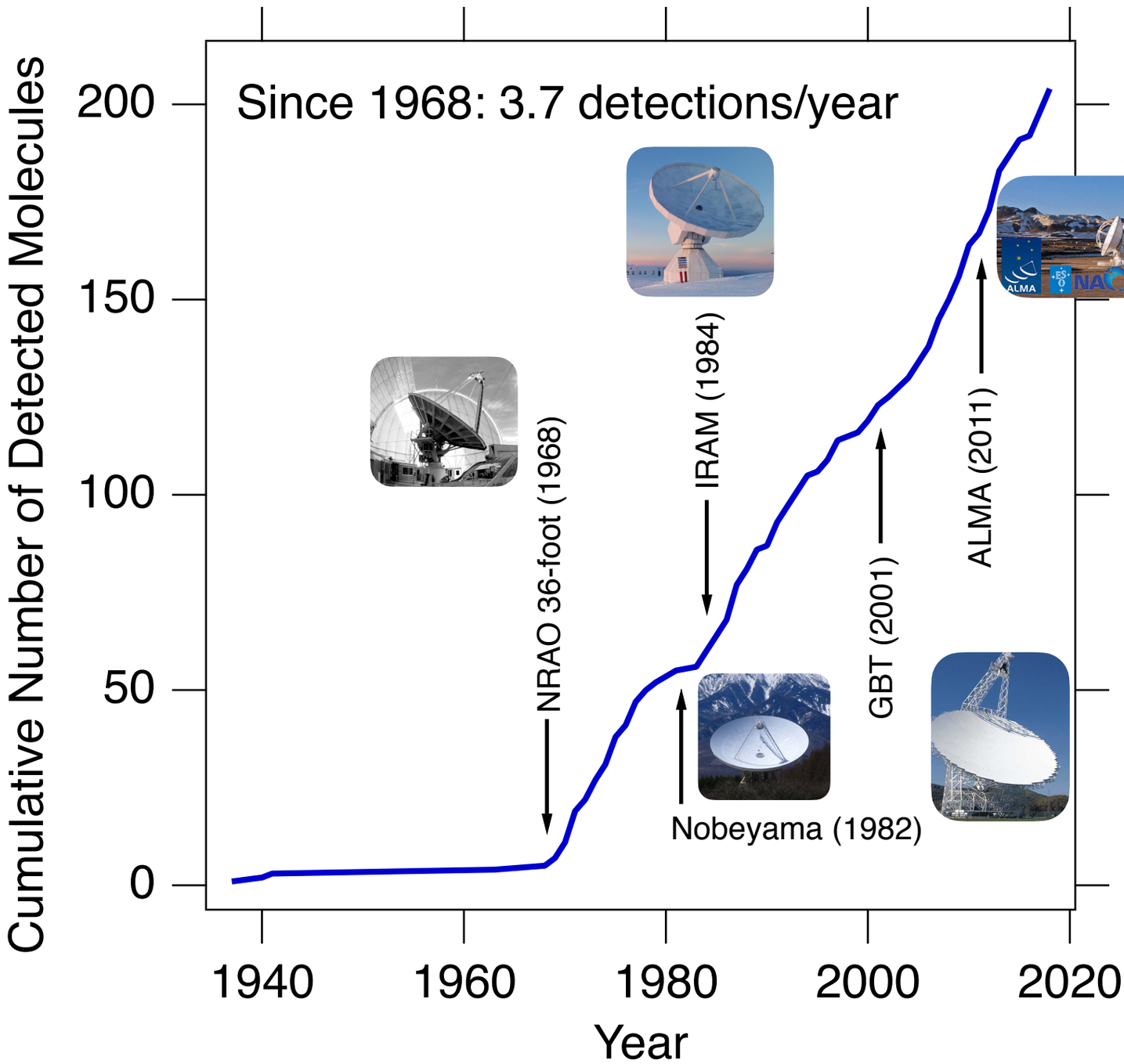


Molecules have been observed throughout the Universe:

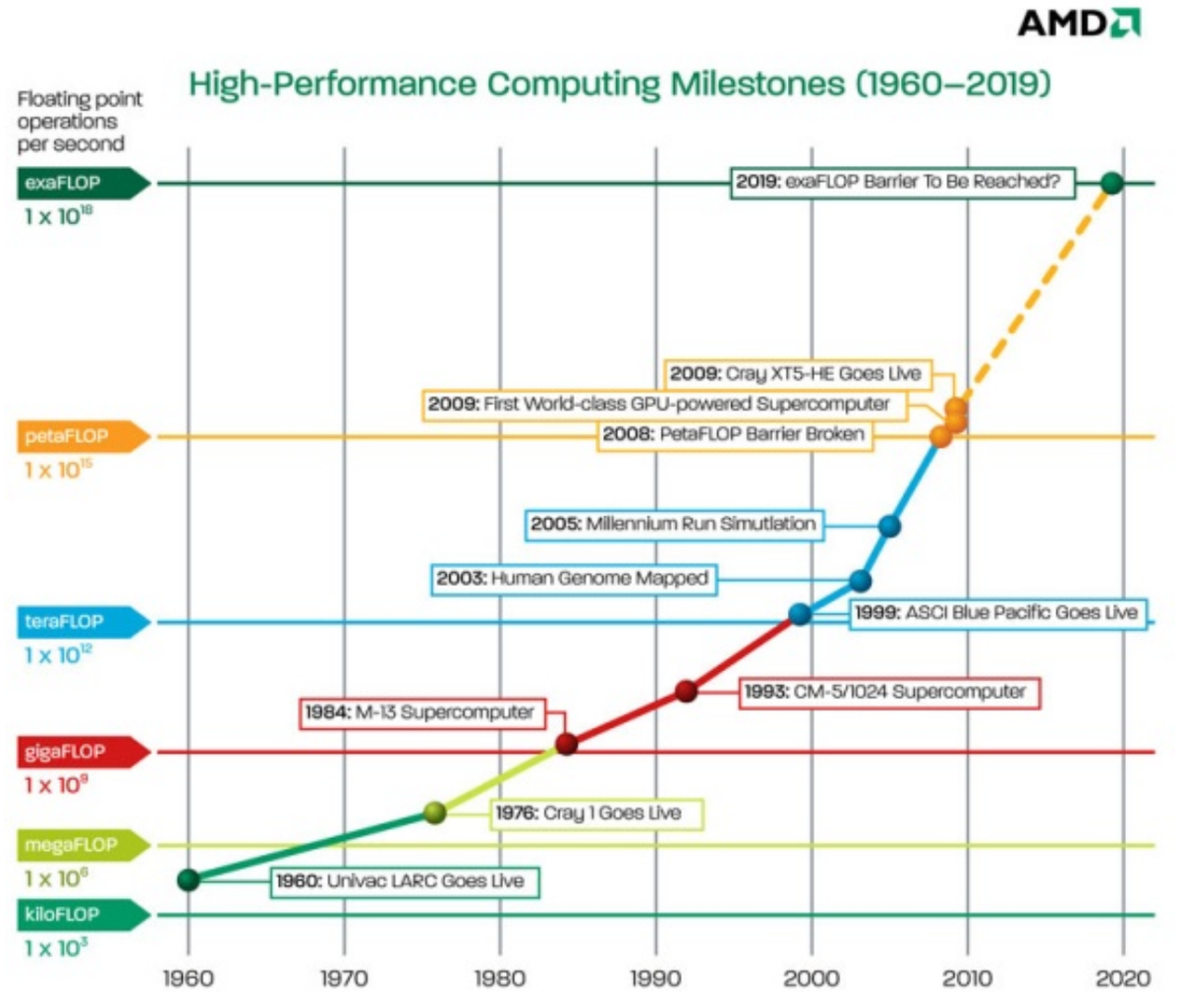
- Molecular clouds, evolved stars, planetary nebulae, protoplanetary disks, planetary atmospheres, comets etc.
- Chemistry responds to physical conditions: Temperature, radiation, density…

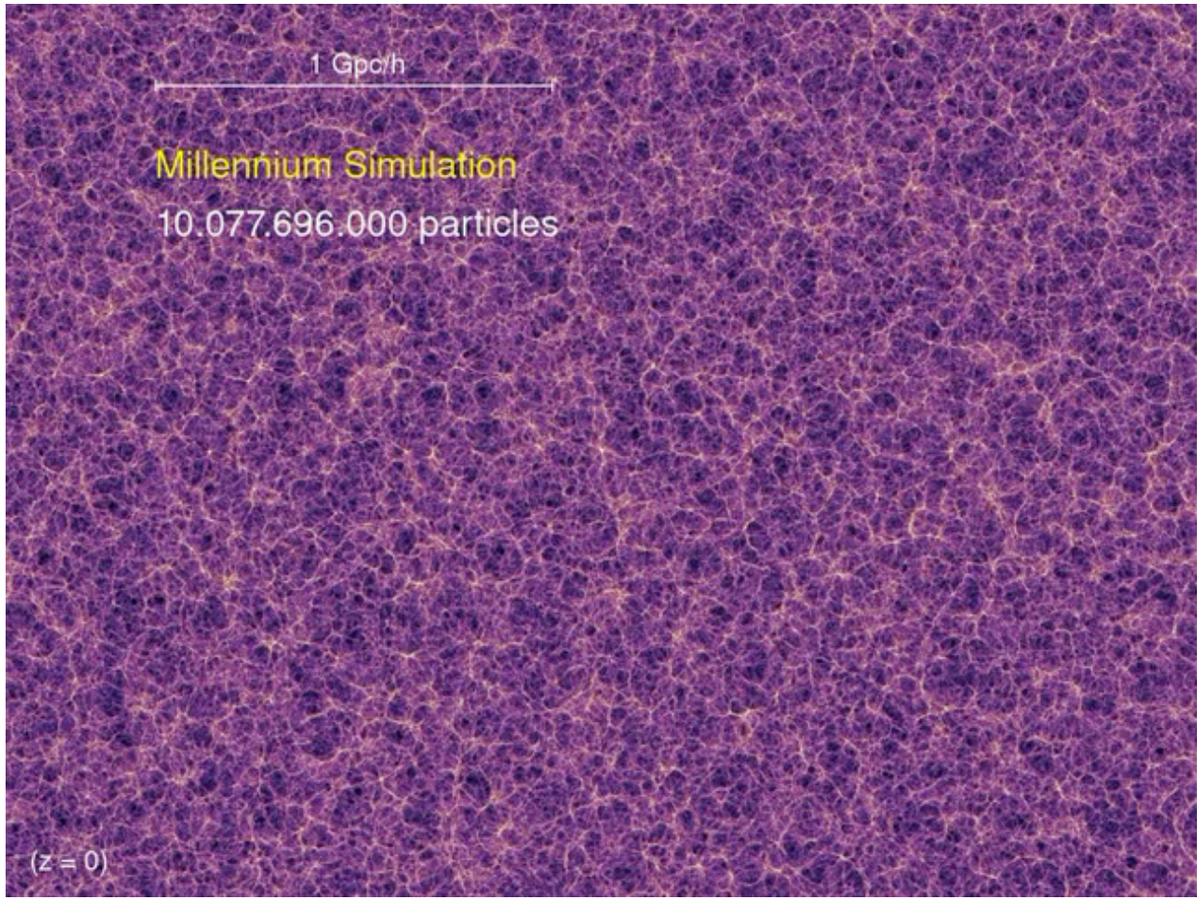
MOLECULAR ASTROPHYSICS





McGuire, 2020





ASTROCHEMISTRY QUESTIONS

1. What are chemical processes leading to formation and destruction of molecules?
2. What causes chemical diversity?
3. How well are basic molecular processes known from experiments or theory?
4. How can molecules be used as physical and chemical diagnostic of physical structure?
5. How do molecules in spaces relate to life as we know it (astrobiology)?
6. To which extent are interstellar-chemistry products preserved into planetary systems ?

Laboratory Astrochemistry

Quantum Chemistry

Computational Astrophysics

Observational Astronomy

Spectra, Collisional Coefficients, Atomic/Molecular Data

Chemical Modeling, Simulations, Interpretation of Observations

BASICS

- Astrochemistry field evolved over the years together with the technological development (computing + observatories)
- Astrochemistry is the study of the chemical processes under ISM conditions
- It is an incredible powerful tool to interpret observations and provide hints on the physics of the observed regions

- **Spectroscopy**
- **Molecular physics**
- **Chemical kinetics**
- **Surface science**
- **Quantum chemistry**
- **Astronomy**
- **Numerics**
- **Biology**