Astrochemistry and compositions of planetary systems

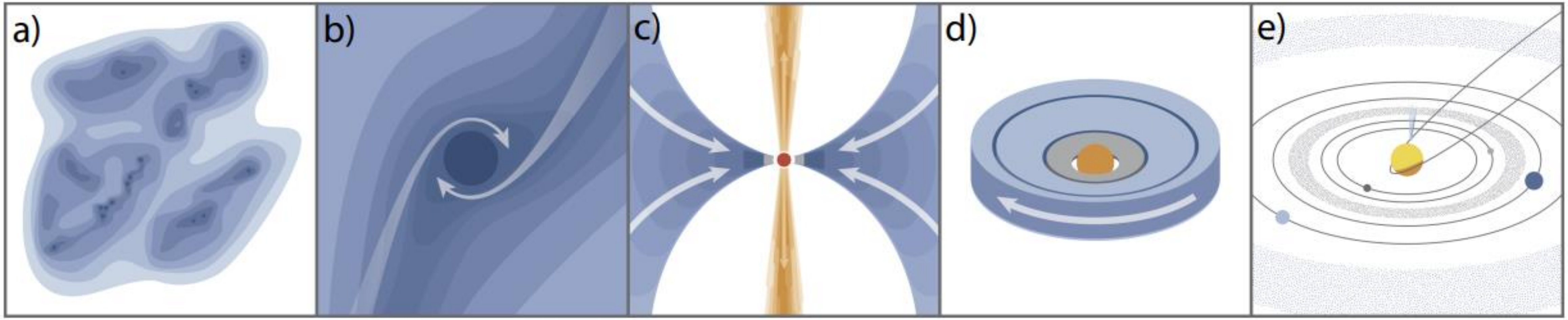
Daniel Ziegler 21.11.2023

Outline:

1. Formation of stars and Planetary systems
2. Most important chemical reactions
3. Chemistry of molecular Clouds
4. Protostellar stage
5. Chemistry of Protoplanetary disks
   - 5.1 Snowlines
   - 5.2 Organics
6. Summary

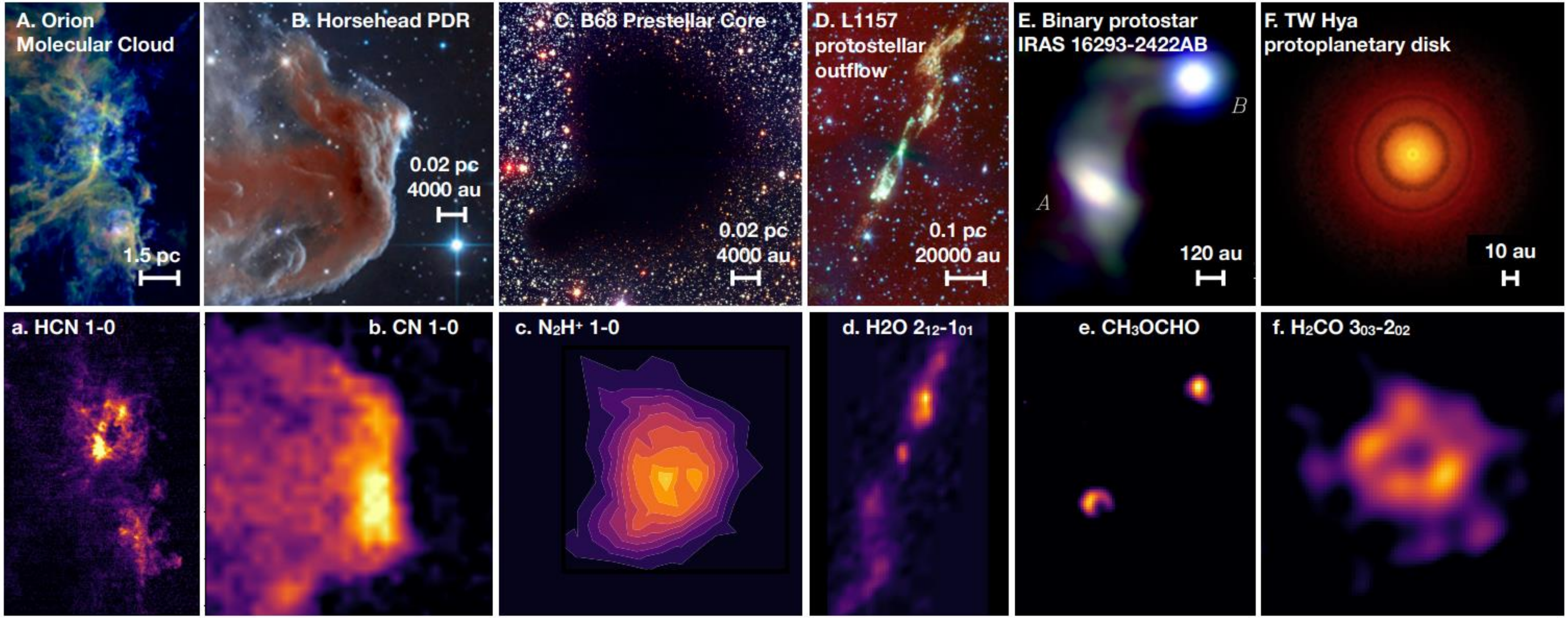
Formation of stars and Planetary systems

Formation of stars and Planetary systems



Öberg and Bergin (2020) doi:10.48550/arXiv.2010.03529

Chemical structures of different stages of star and planet formation



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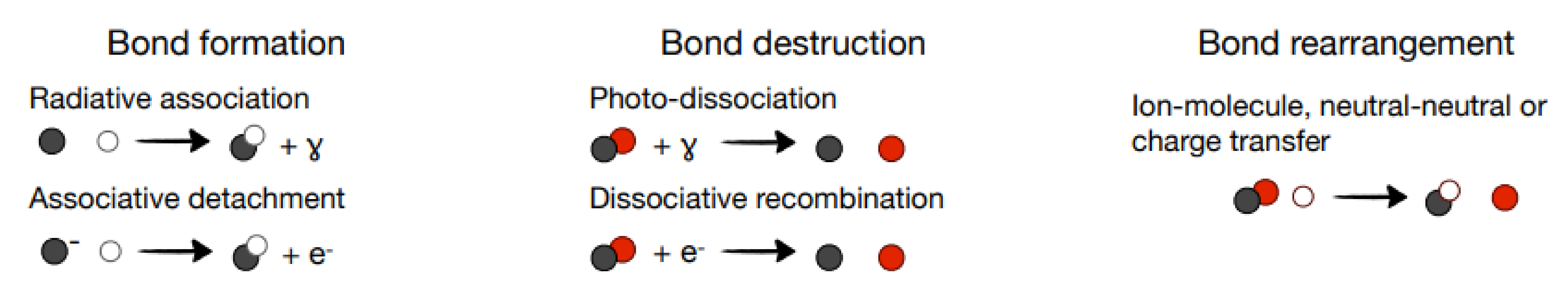
Most important chemical reactions

Gas phase chemistry



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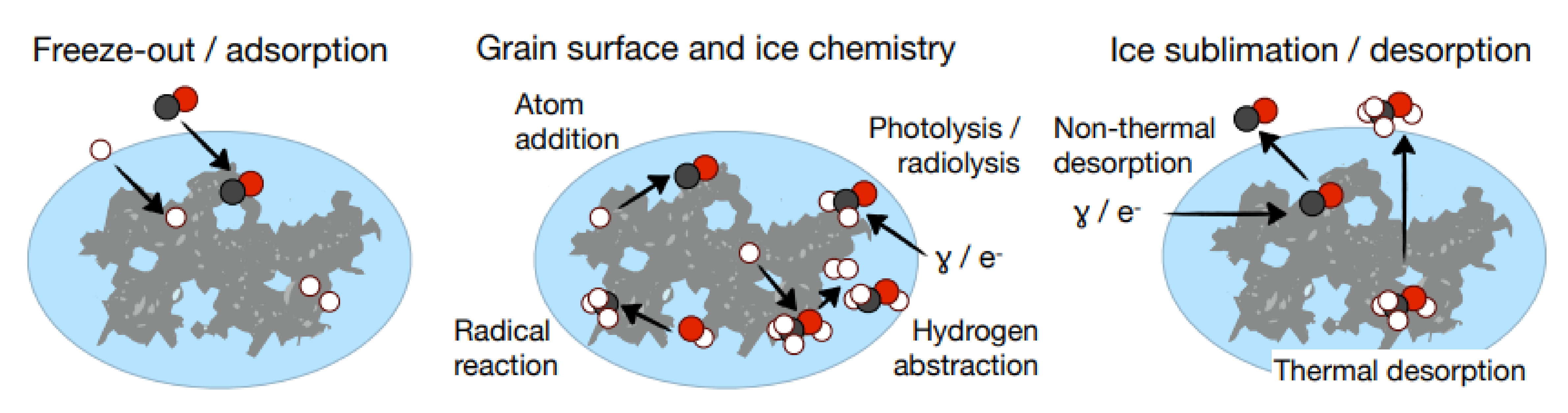
Grain-surface and ice processes



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Classification of volatiles

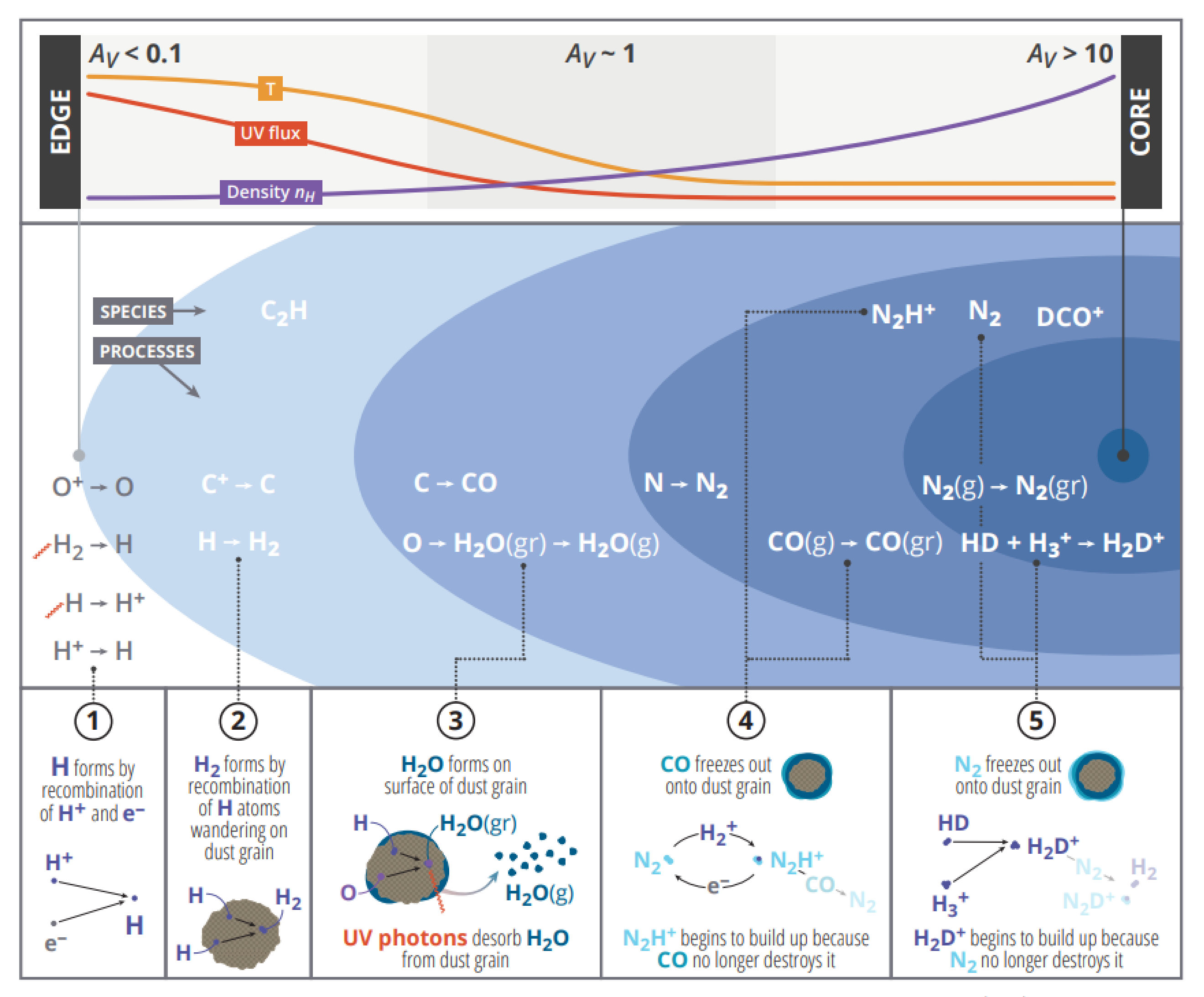
- Hypervolatiles: CH_4, CO and N_2
- Volatiles: H_2O, CH_3OH, CO_2 and NH_3
- Refractories: silicates and carbonaceous grains

Chemistry of molecular Clouds

Chemical structure of molecular clouds

- Radiation field
- Gas temperature
- Dust temperature
- Gas density

Chemical structure of molecular clouds



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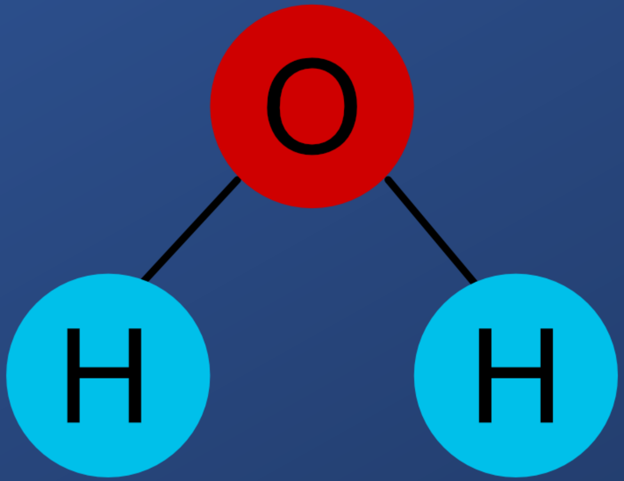
The major molecules

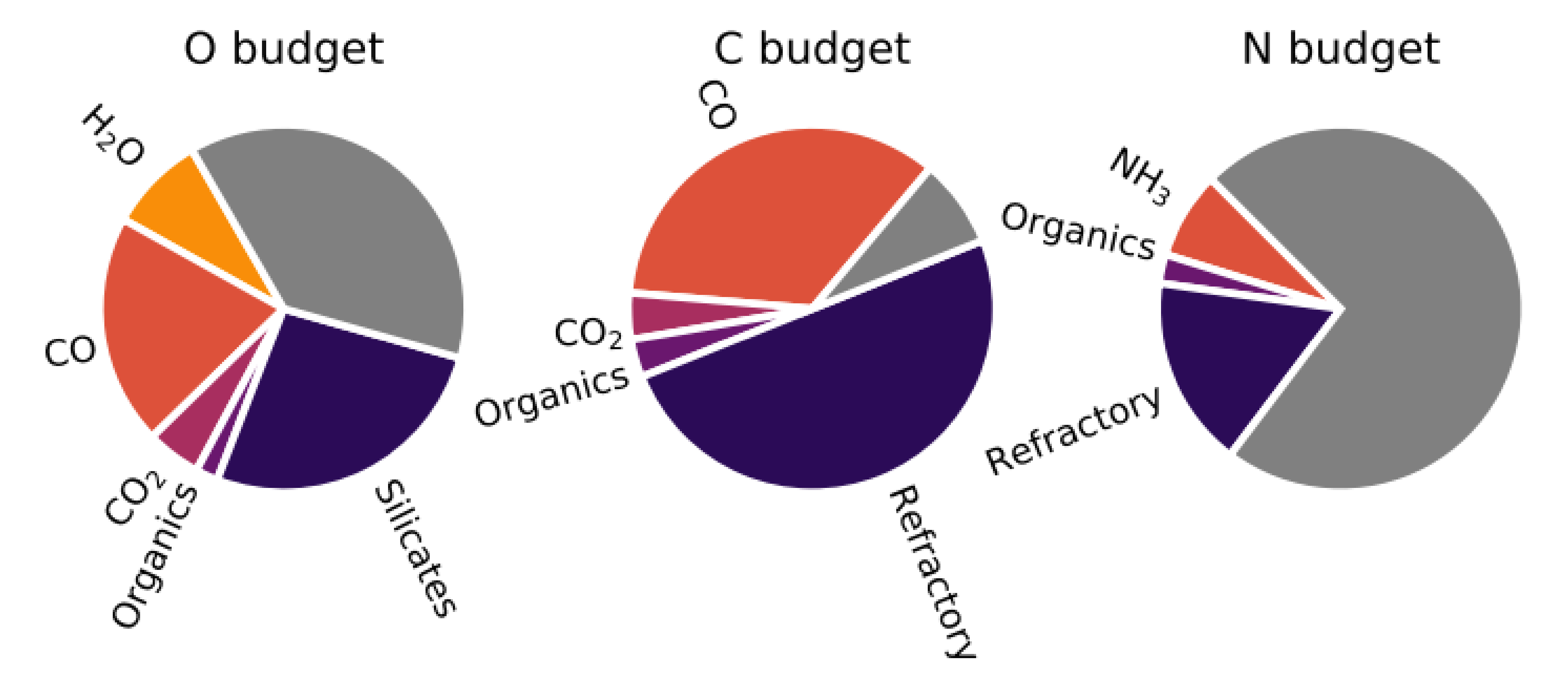
H_2O



CO

N_2

O/C/N budgets



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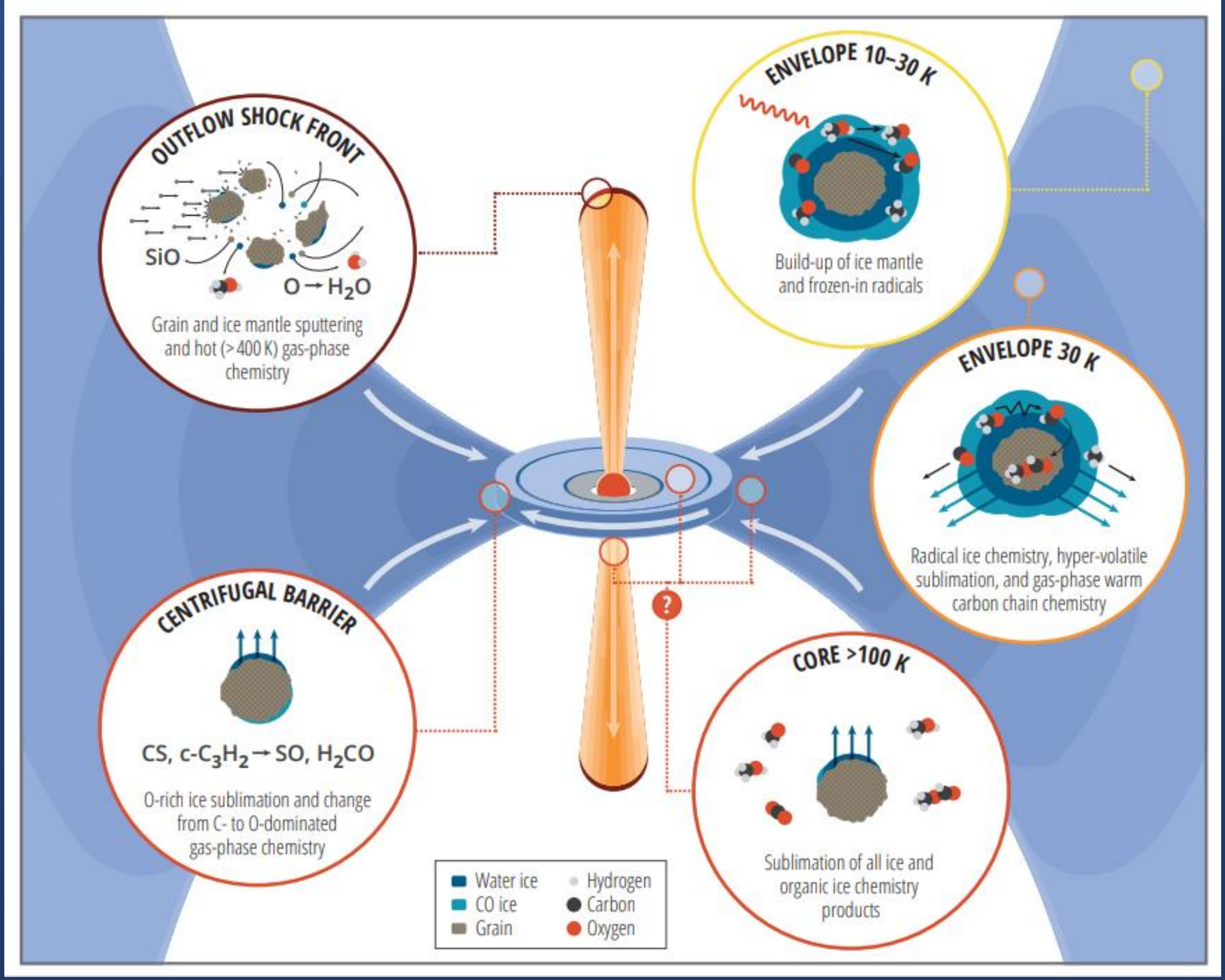
Organic reservoir

- First generation of organic molecules
- Formed through gas-phase and ice-phase chemistry
- Most common organic molecules: CH_3OH and CH_4
- Some gas-phase reactions to form HCN and unsaturated organics
- Some complex organic molecules

Protostellar stage

Chemical structure of Solar-type protostars



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Chemical structure of Solar-type protostars

- 25-30K : Most volatile ice constituents begin to sublimate
- → Warm carbon chain chemistry
- Ice chemistry for more complex organic material
- 100-200K: We get hot corinos

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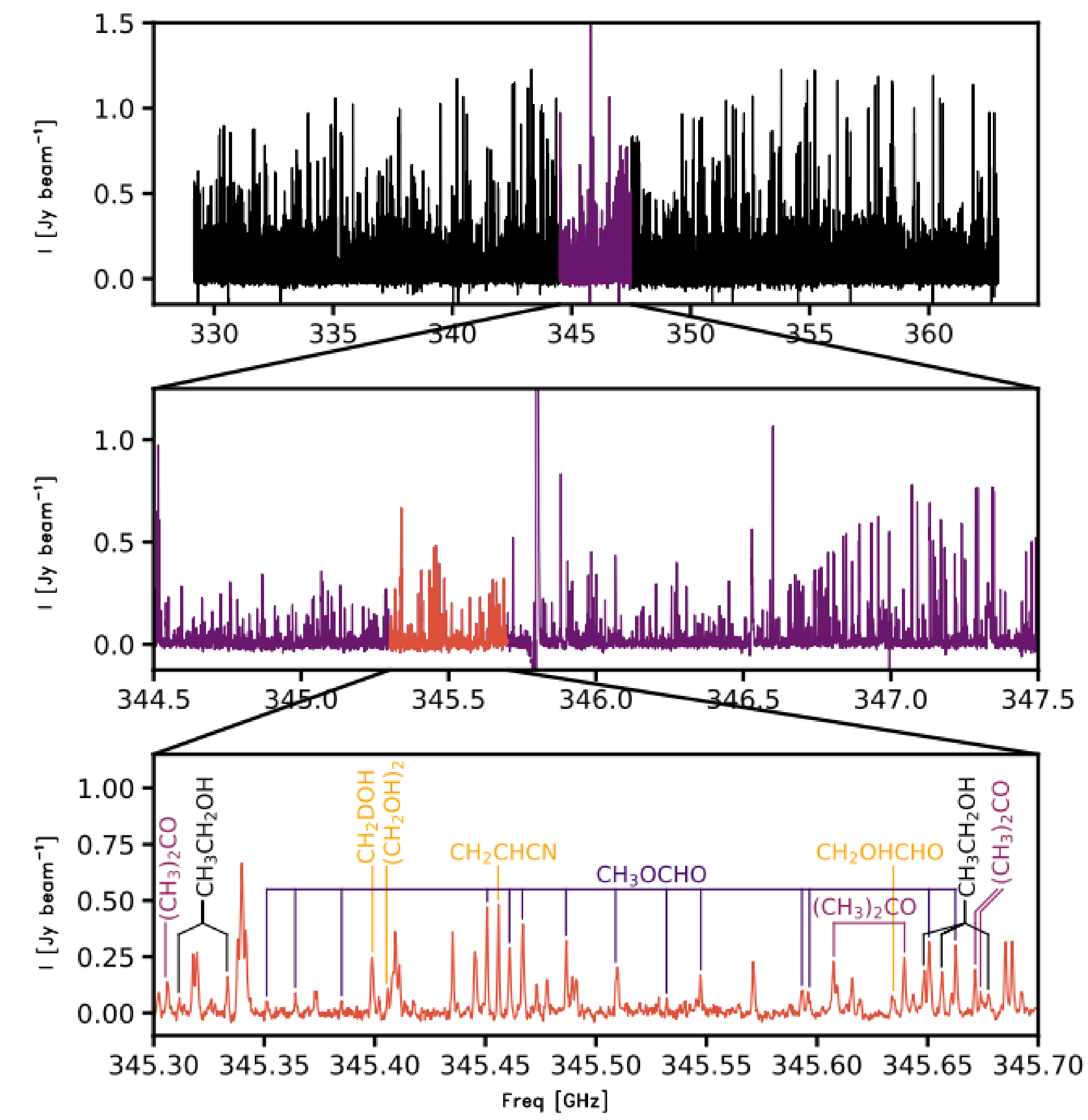

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- Chemistry mainly takes place in icy grain mantles

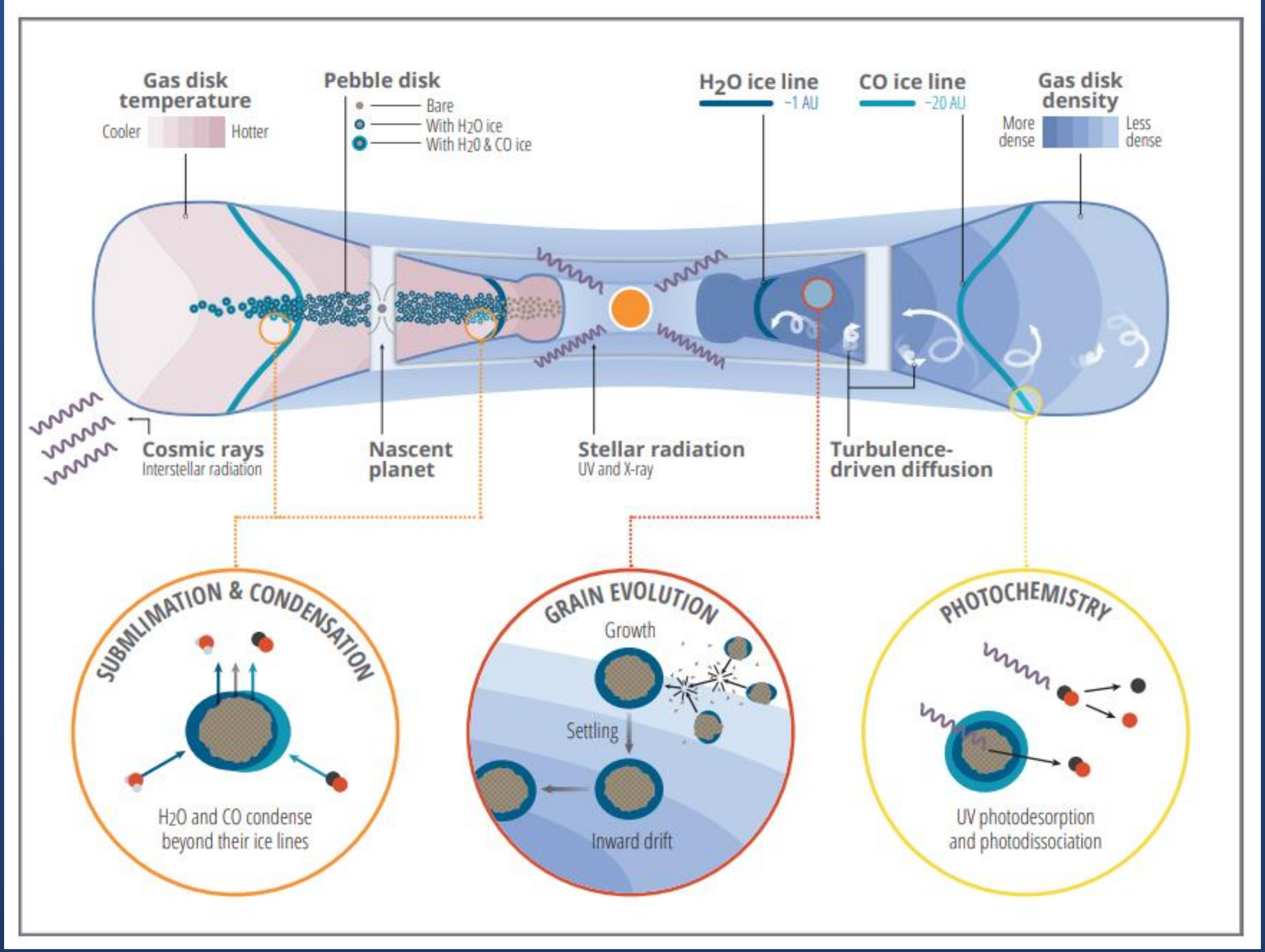
- Main elemental carriers at this stage remain the same

Chemistry of Protoplanetary disks

Protoplanetary disk chemistry and planet formation

- Time dependent radial and vertical distrubution of molecules
- Division of molecules between gas and solids
- Snowlines
- Grain compositions
- Grain fragmentaition
- Coagulation properties
- → Pebble size distribution → Planetesimal and planet growth

Protoplanetary disk chemistry and planet formation



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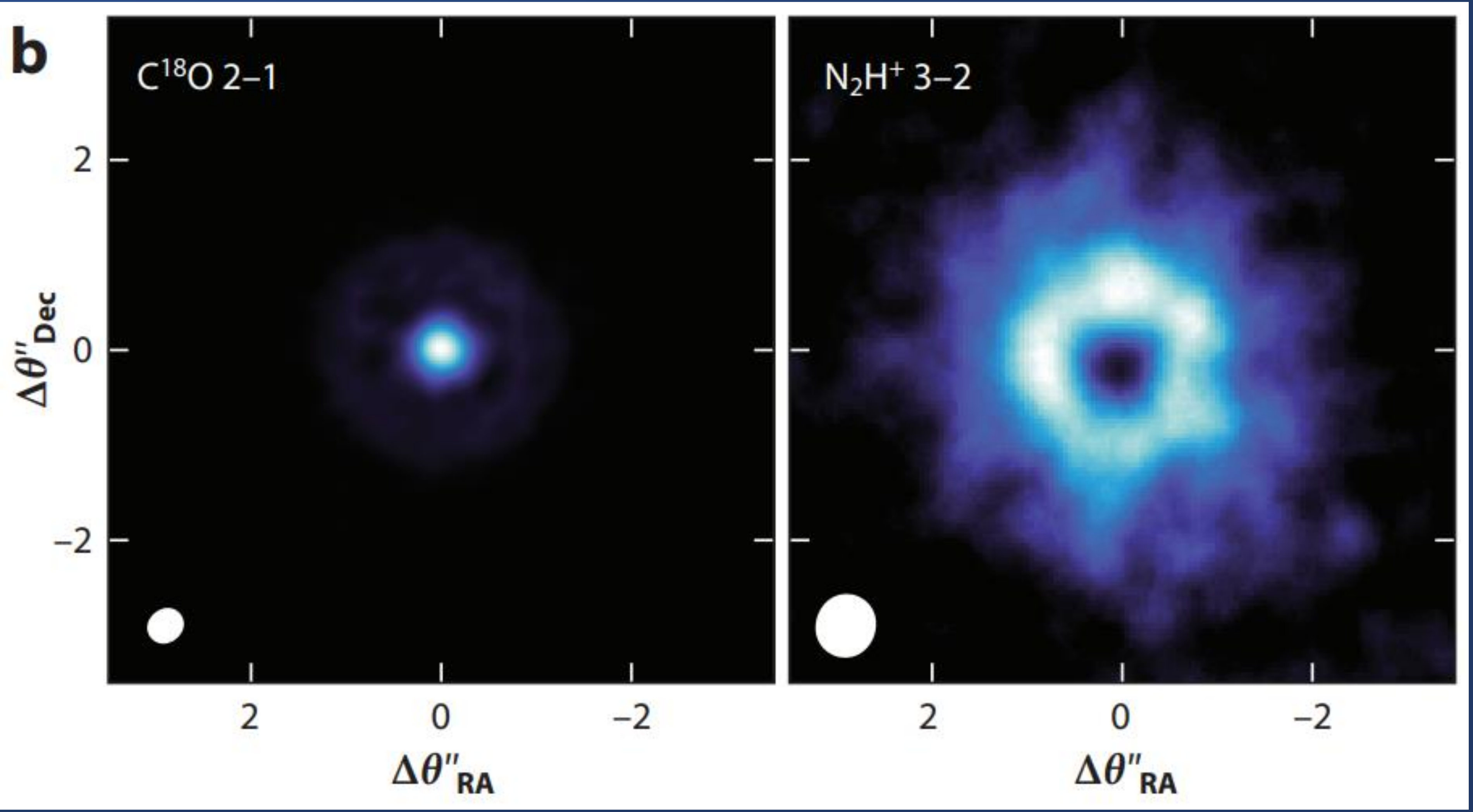
Snowlines

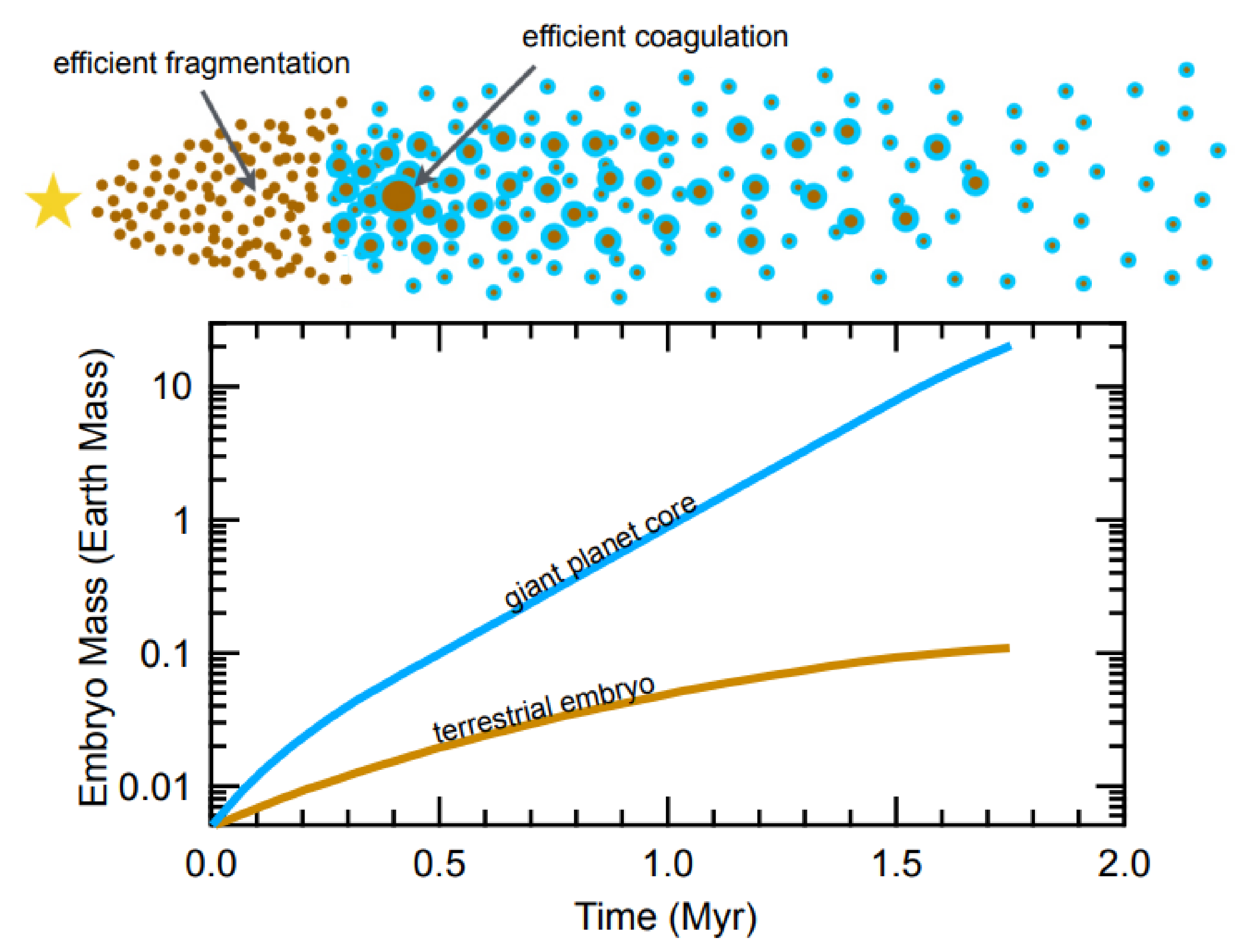
- Determine the elemental content of solids and gas at different disk locations
- Surface density increases
- Diffusive flows → Increasing column density of solids→ Larger particles
- Properties changes across snowlines
- Localized regions of enhanced pressure

Snowlines



Öberg et al. (2023) https://www.annualreviews.org/doi/pdf/10.1146/annurev-astro-022823-040820

Growth of planets



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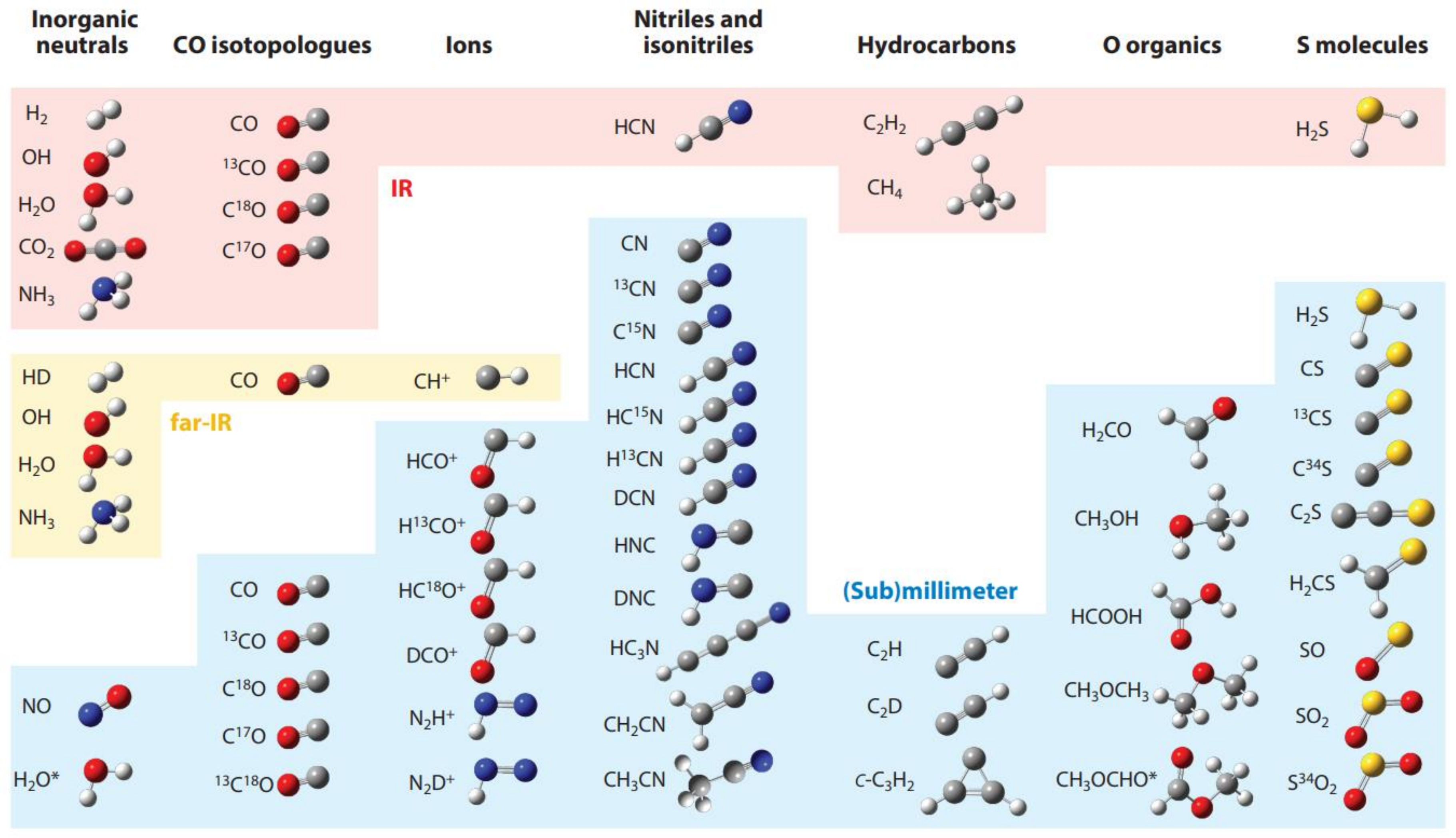
Disk organic chemistry



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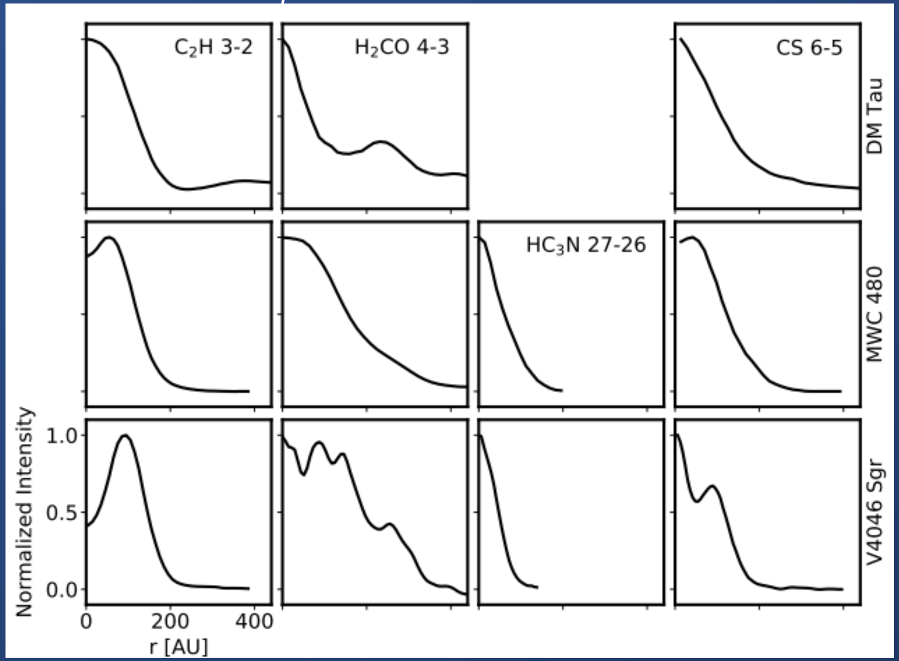
Disk organic chemistry

- Small organic molecules in the inner disk atmosphere



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- → Planetesimal organic compositions will strongly depend on both where and around which star the planetesimals formed.

Delivery of water and organics to temperate planets

- Three theories for the origin of water on a dry world:

1. In situ
2. Snowline evolution
3. Dynamical supply

Summary

- Most abundant volatile elements: C, O, N
- In cloud cores: gas phase formation shifts to grain surface
- Most important molecules: CO, N_2, H_2O
- Organic feed-stock molecules are formed in cold cloud regions
- Snowlines play an important role in planet formation
- Unclear delivery of water and organics to temperate planets

Sources:

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