Simultaneous multi-wavelength observations of comets with CRIRES+ and TRAPPIST

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ESO Belgian Day 2022
December 8, 2022

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Comets: a key to the early Solar System chemistry

Comets are remnants of the Solar System formation

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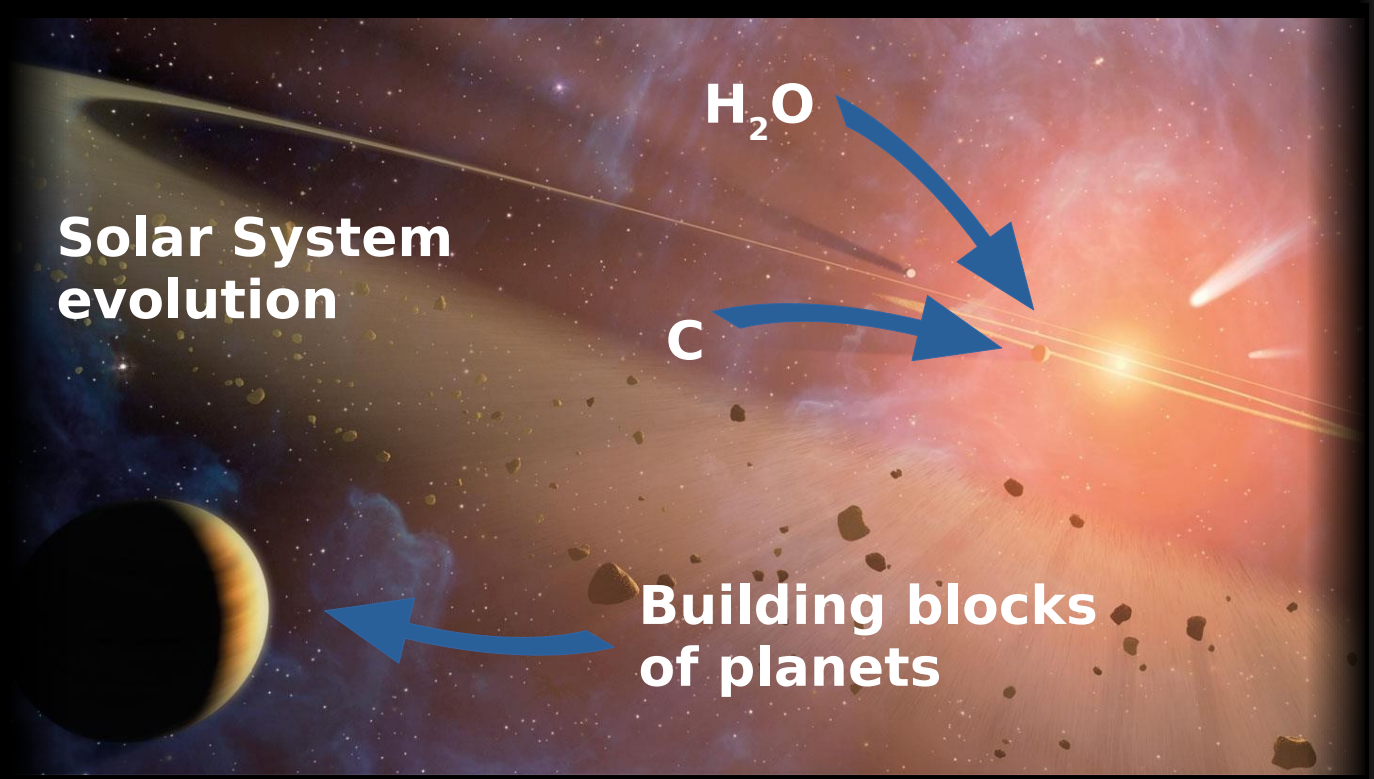
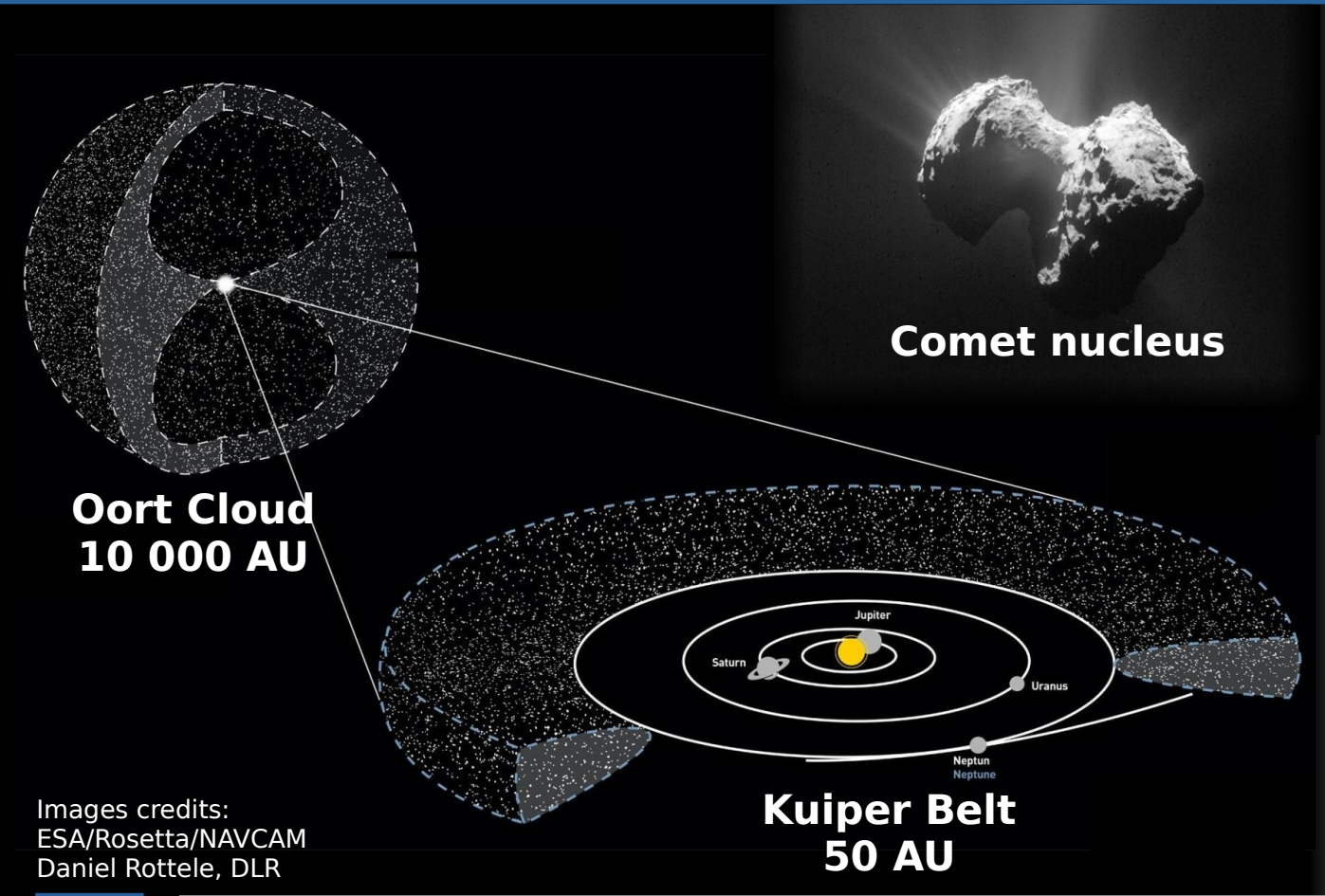


Comets are remnants of the Solar System formation

→ **Evolution history of the Solar System**

→ Astrobiology: **Earth's water and organics**

Comets in the Solar System



Images credits:
ESA/Rosetta/NAVCAM
Daniel Rottele, DLR

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Kuiper Belt
→ Ecliptic plane
→ Short period comets
Oort Cloud
→ Isotropic inclination
→ Long period comets

Dynamical vs chemical classification?

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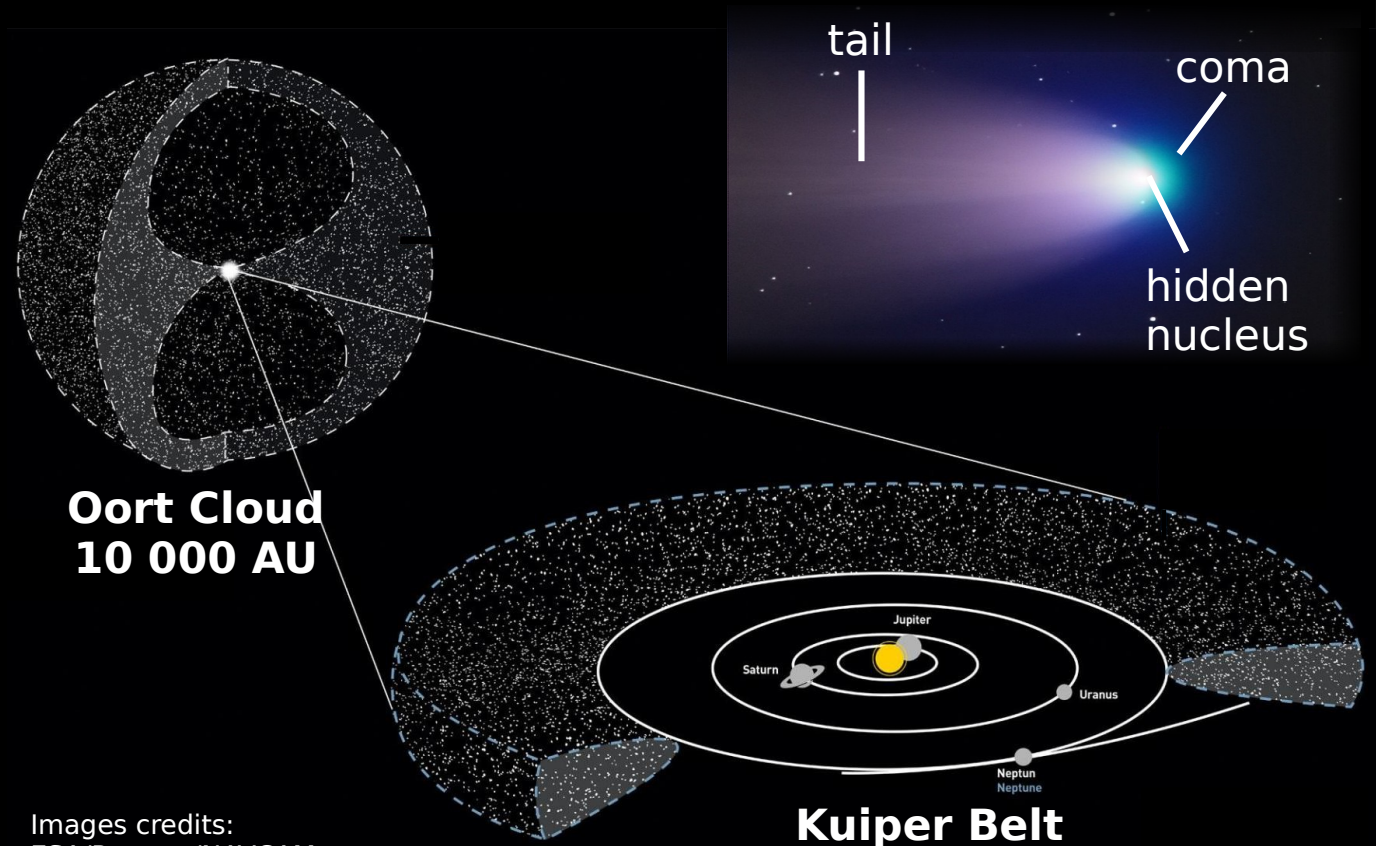

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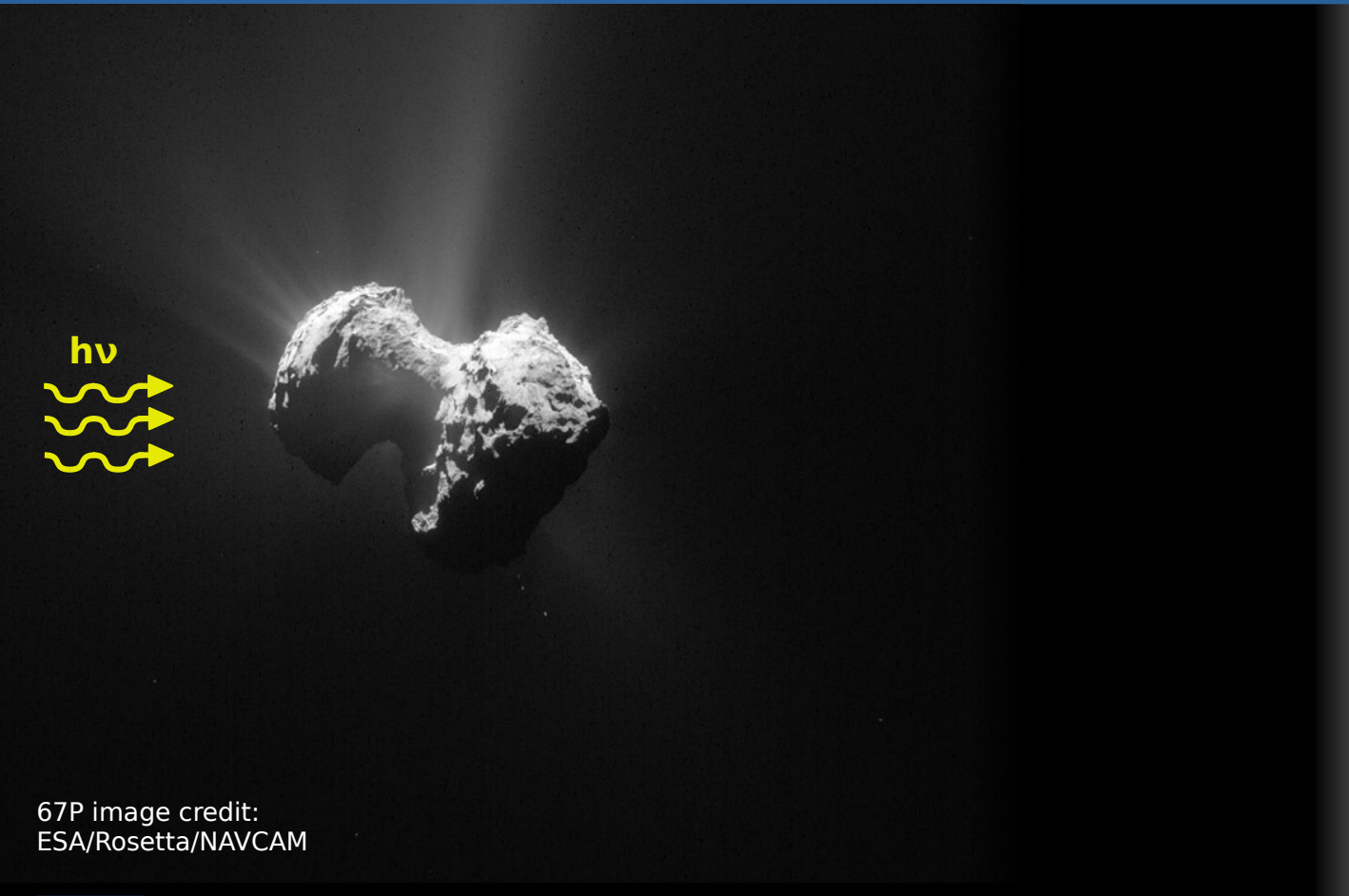
Coma composition related to nucleus composition

Formation of the gaseous coma



67P image credit:
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Comet nucleus difficult to observe directly

→ study of the **coma**

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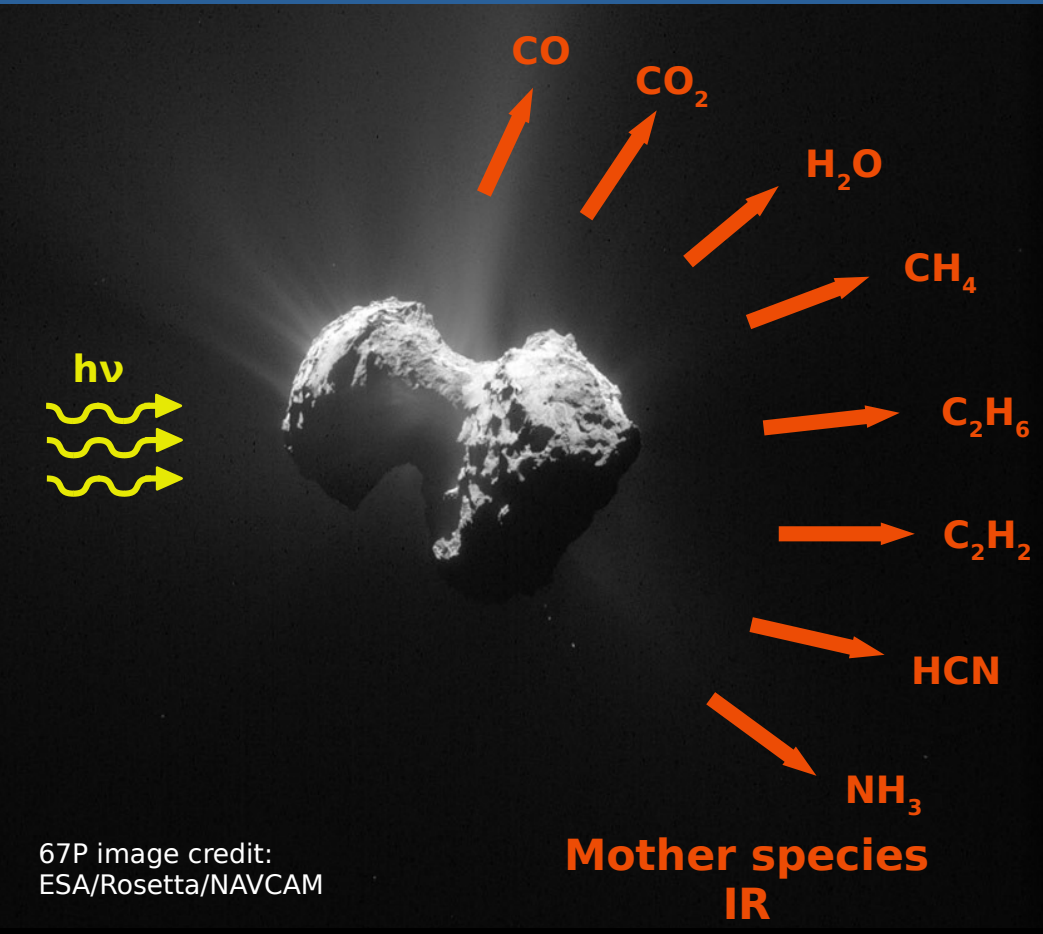

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sublimates from the nucleus
→ fluorescence in the **IR**

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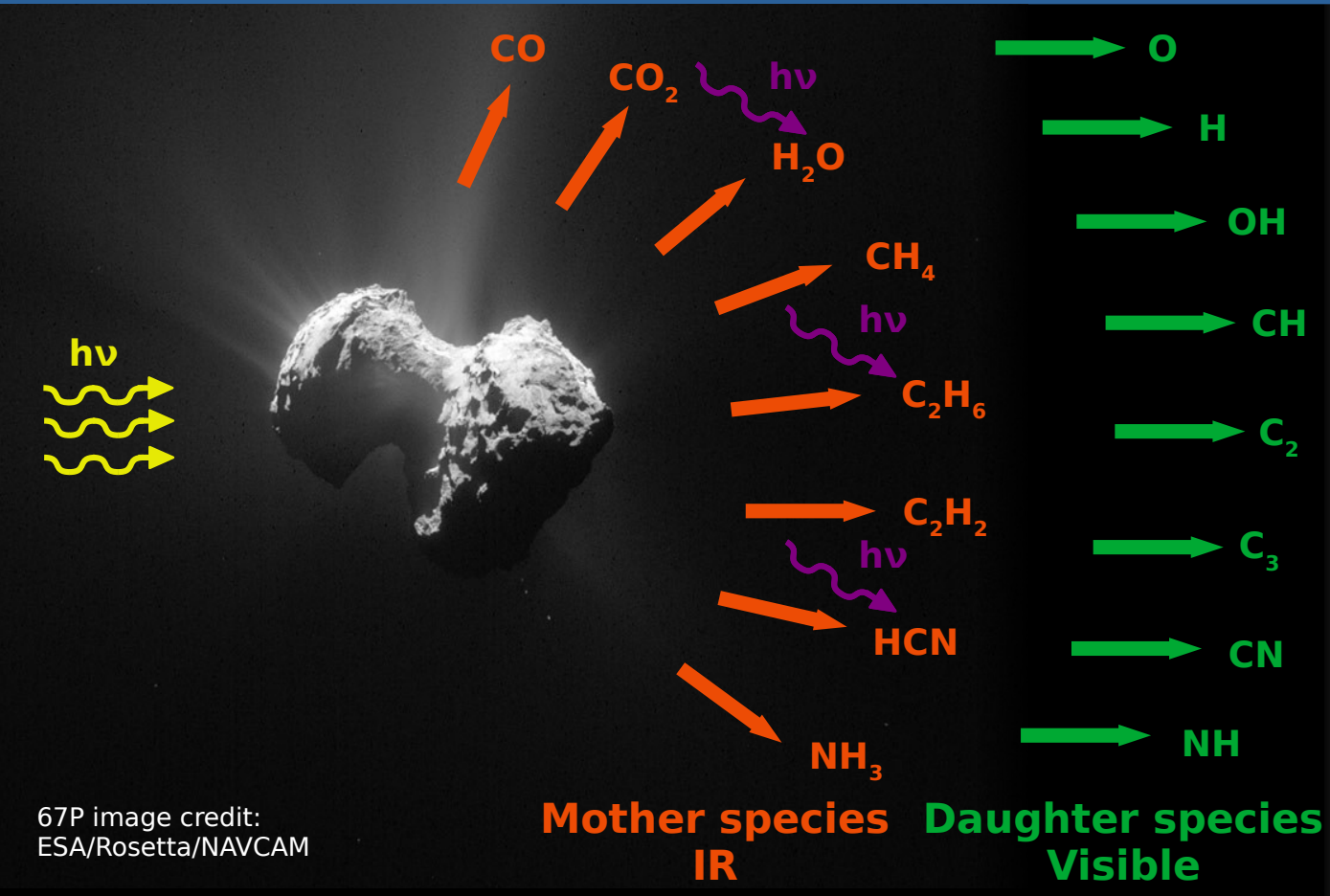

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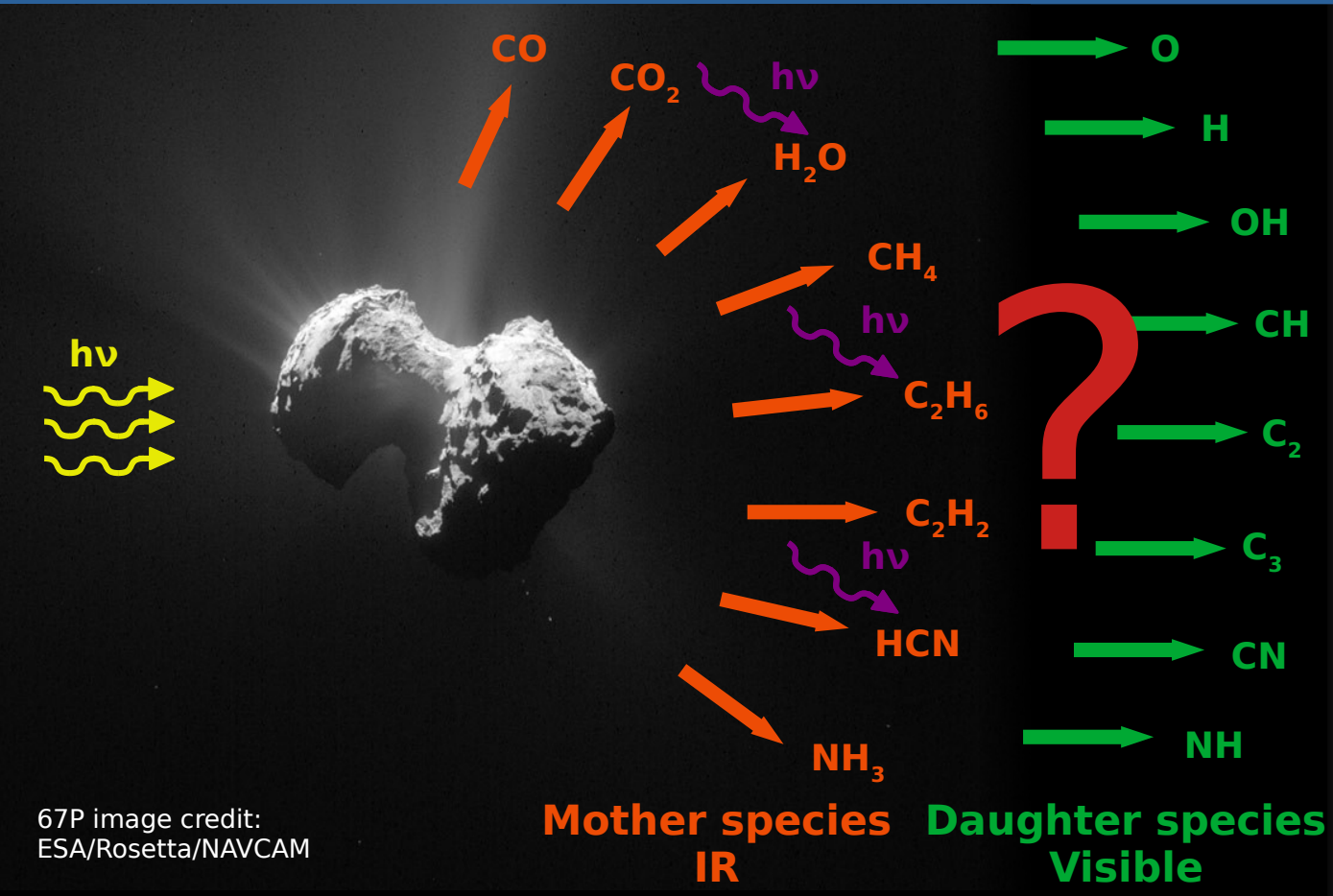

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→ no unified taxonomy !

Simultaneous multi-wavelength study of comet's volatiles

- Variability in cometary activity → Essential to the understand the coma chemistry
- Simultaneous observations never done before! → **Towards a unified IR + Visible taxonomy**

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High resolution IR spectroscopy: mother species

New CRIRES+ at the Very Large Telescope (ESO Chile)

→ Echelle spectrometer, near-infrared (0.95-5.3 µm):
H_2O, HDO, HCN, CO, CH_4, C_2H_2, C_2H_6, NH_3, CH_3OH, ...
→ Resolving power reaching 100 000

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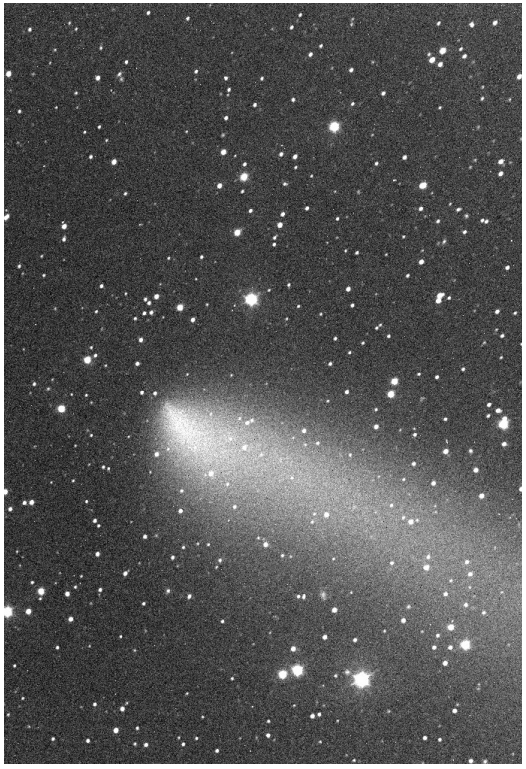
nUV-Vis photometry: daughter species

TRAPPIST-South
La Silla Observatory, Chile

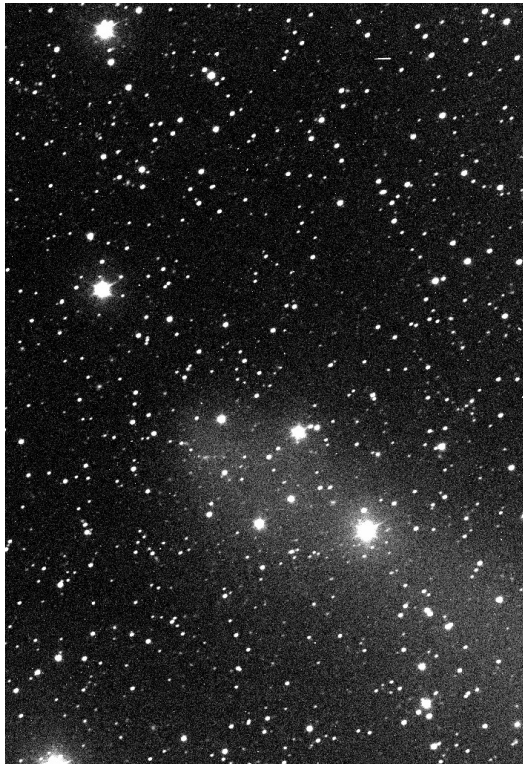
TRAPPIST-North
Oukaimeden, Morocco

→ Narrow-band comet filters (Farnham et al., 2000):
OH, CN, C_2, C_3, NH, CO^+, H_2O^+, dust
→ Dense long term surveys

C/2021 A1 (Leonard)



2022-03-08 (R)

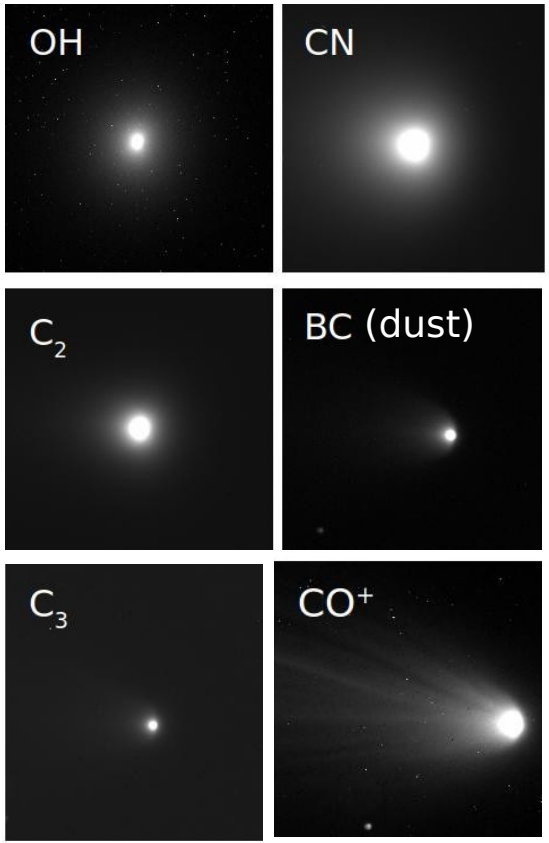


2022-04-08 (R)

- Discovered on January 3, 2021
- Long period Oort Cloud comet
- Perihelion on January 3, 2022
  - $m_v \sim 3$
  - Heliocentric distance = 0.62 au
  - Relative velocity = 68 km/s
- Very active close to perihelion
  → multiple outbursts
- Disintegrated after perihelion

TRAPPIST	28 nights December 2021 to January 2022
CRIRES+	3 nights 28/12/2021 31/12/2021 03/01/2021

Comet C/2021 A1 with TRAPPIST: daughter species



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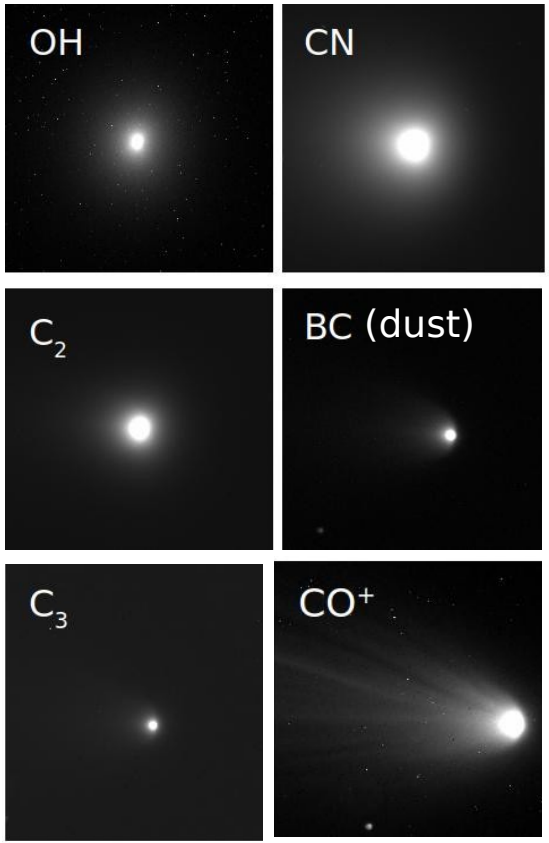

Haser Model (Haser 1957)

- Spherical nucleus
- Constant radial velocity (ejection speed)
- One step photodissociation process with first order kinetic
- Only one mother molecule per daughter species

$$n(r) = \frac{Q}{4\pi v r^2} \frac{\beta_0}{\beta_1 - \beta_0} (e^{-\beta_0 r} - e^{-\beta_1 r})$$

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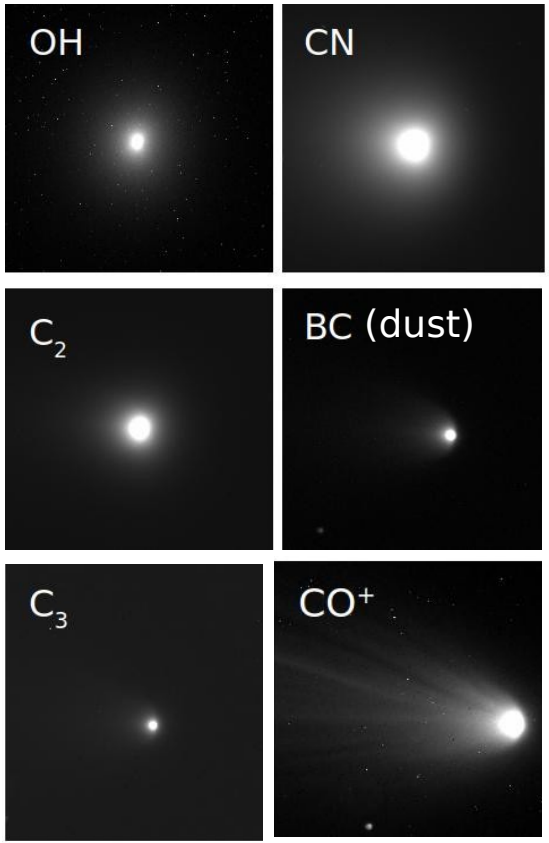

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Related to the **measured flux** by a fluorescence model

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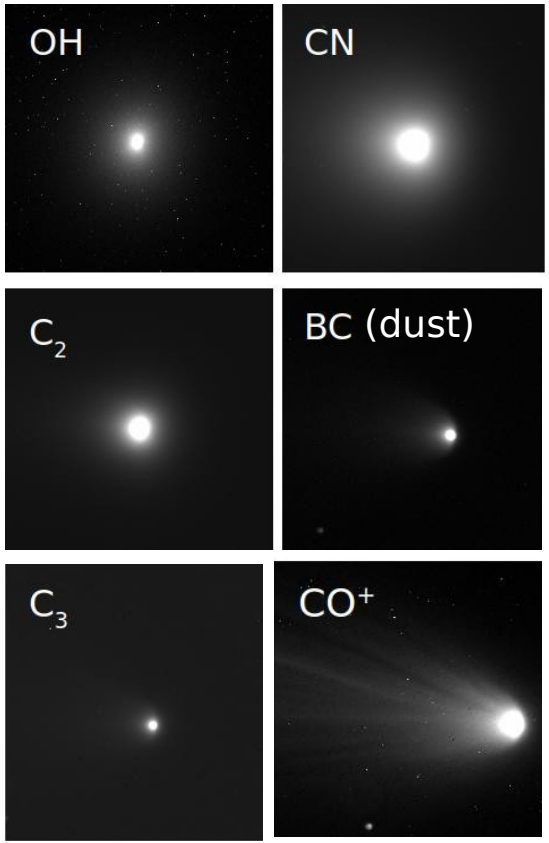

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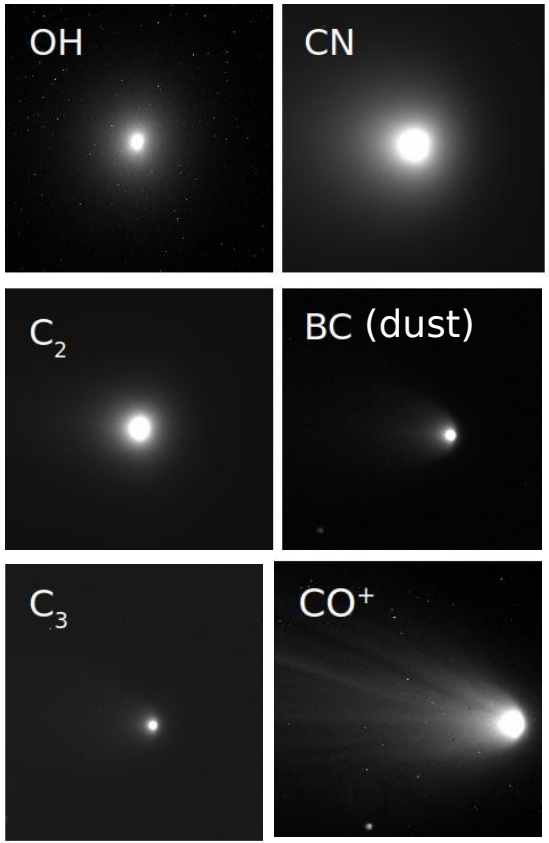

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Daughter species scale length

Mother species scale length

Empirical

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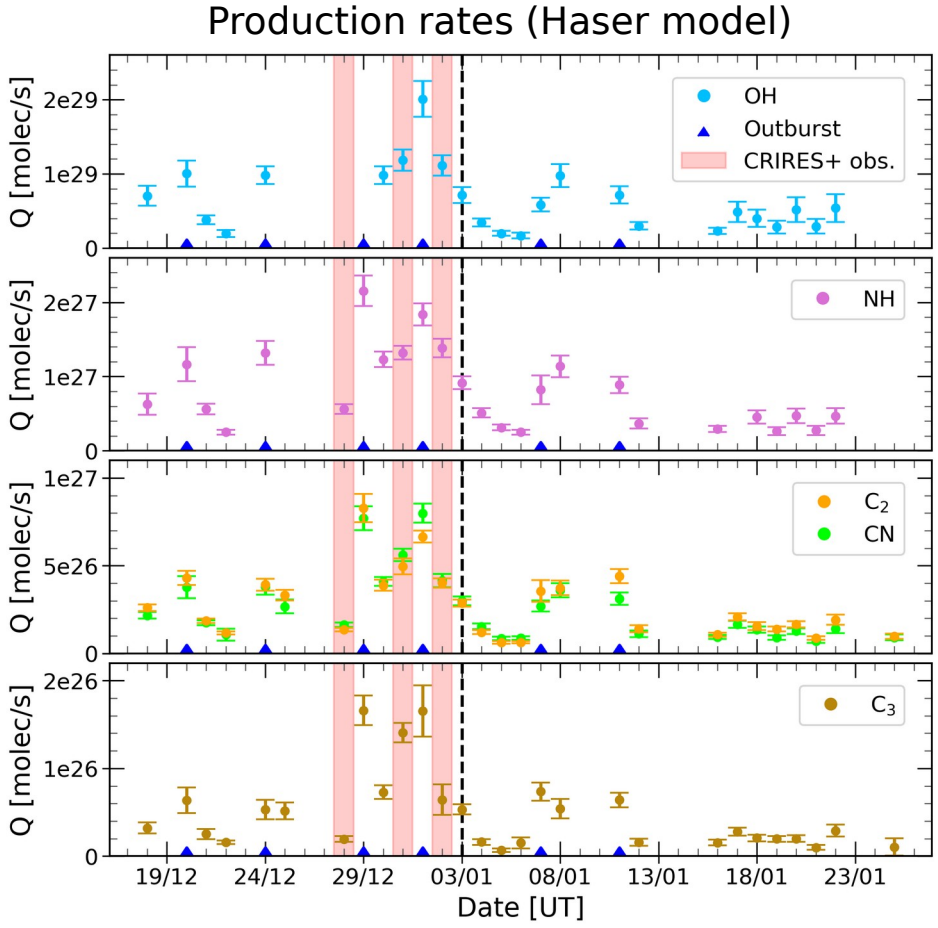

- Dense monitoring around perihelion

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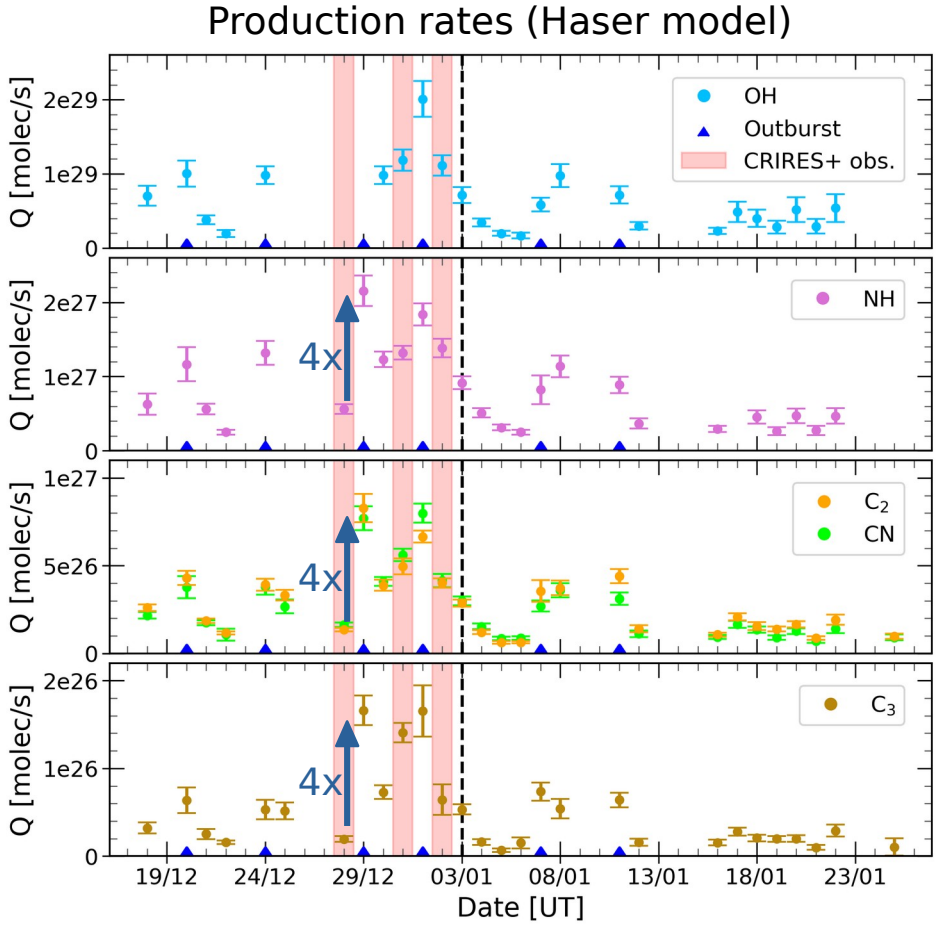

- Dense monitoring around perihelion
- High variability of cometary activity → need for **simultaneity**

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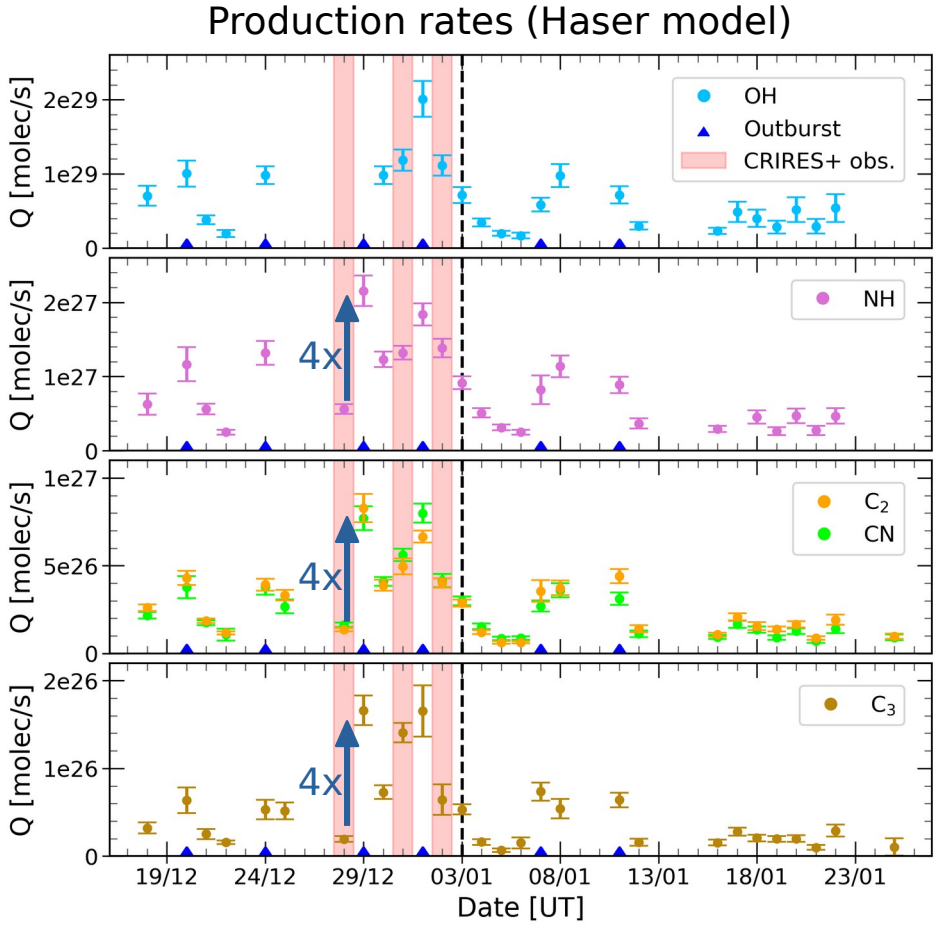

- Dense monitoring around perihelion
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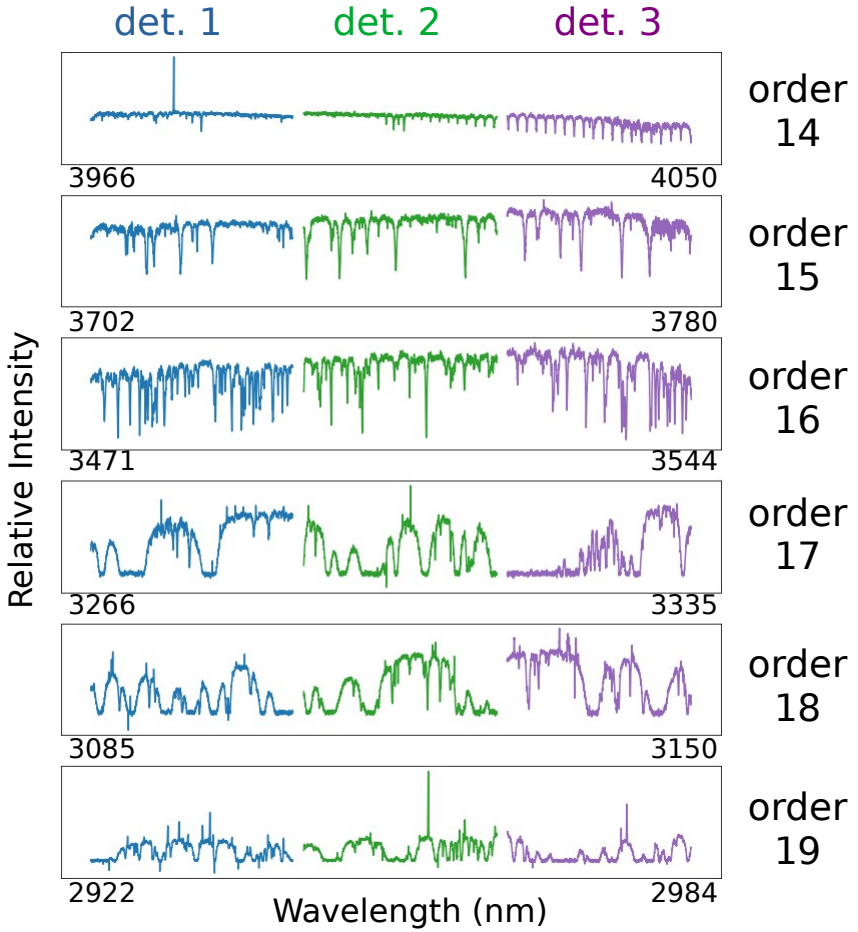
- 3 common nights with CRIRES+: first CRIRES+ observations of a comet!

Comet C/2021 A1 with CRIRES+: mother species

L3302 setting: 2922.62 to 4049.66 nm
→ CH_4, H_2O, OH*, C_2H_6, CH_3OH, H_2CO, NH_3

Data reduction with **PISCO** (master thesis):

- Image stacking and **spectral extraction**



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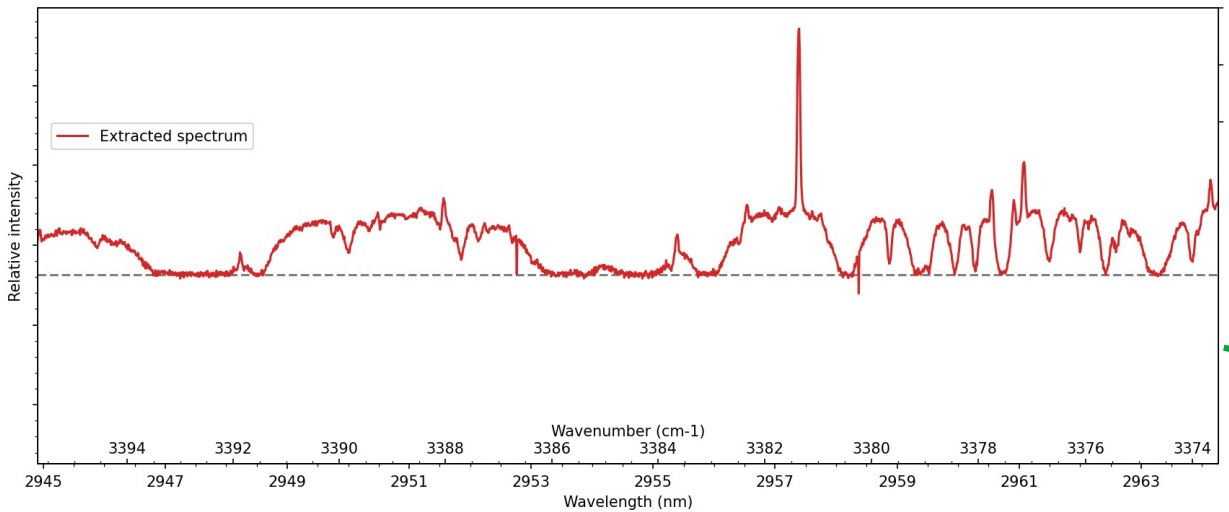

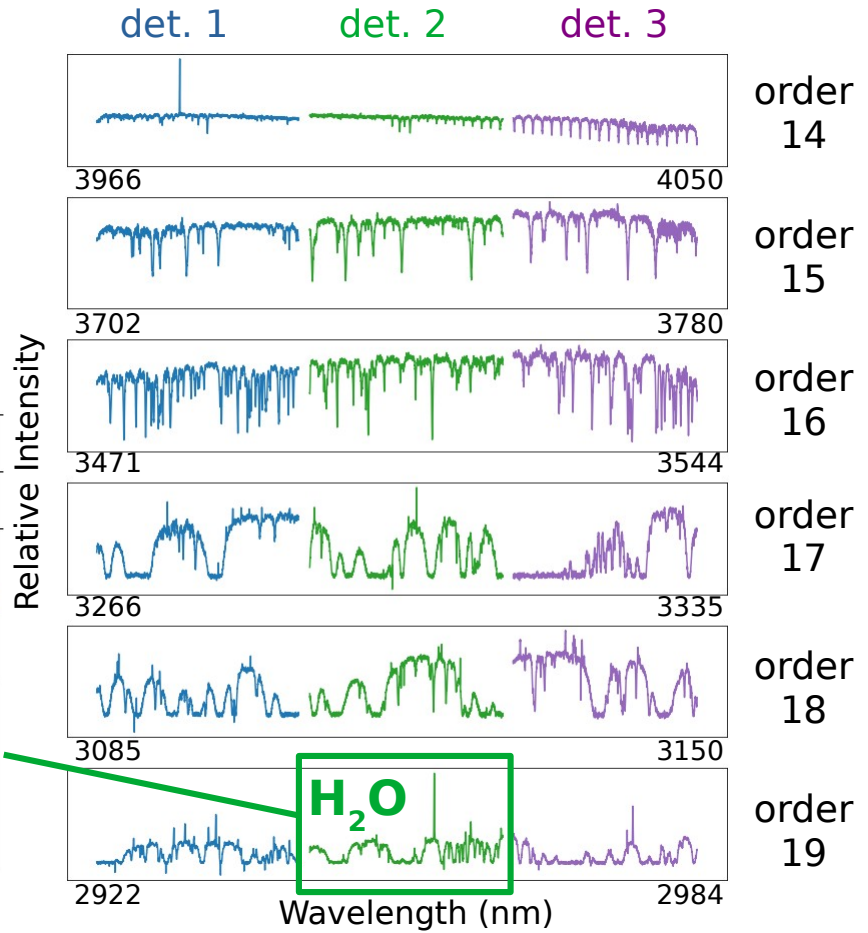

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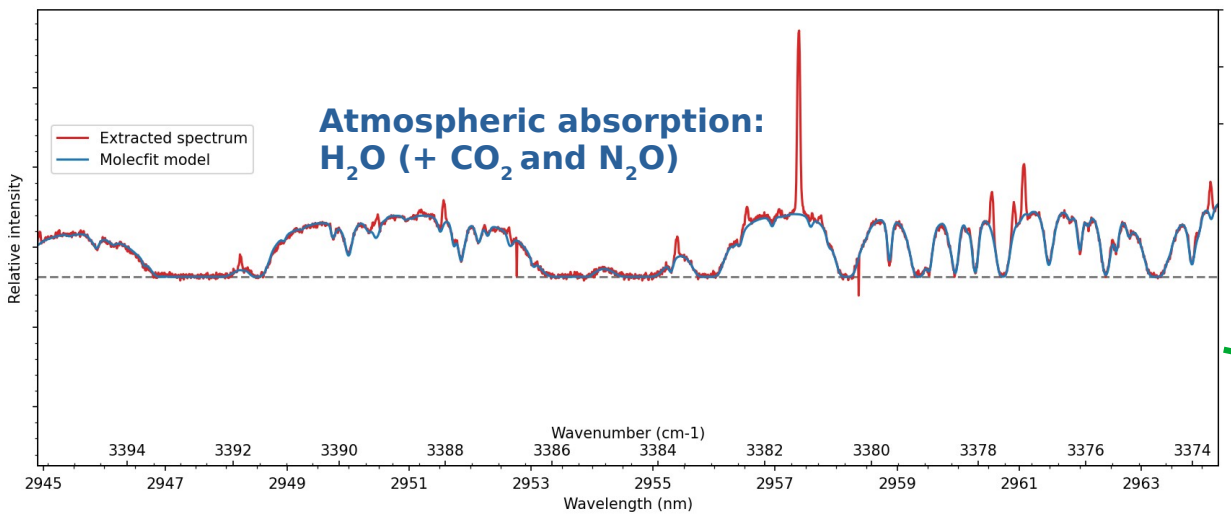

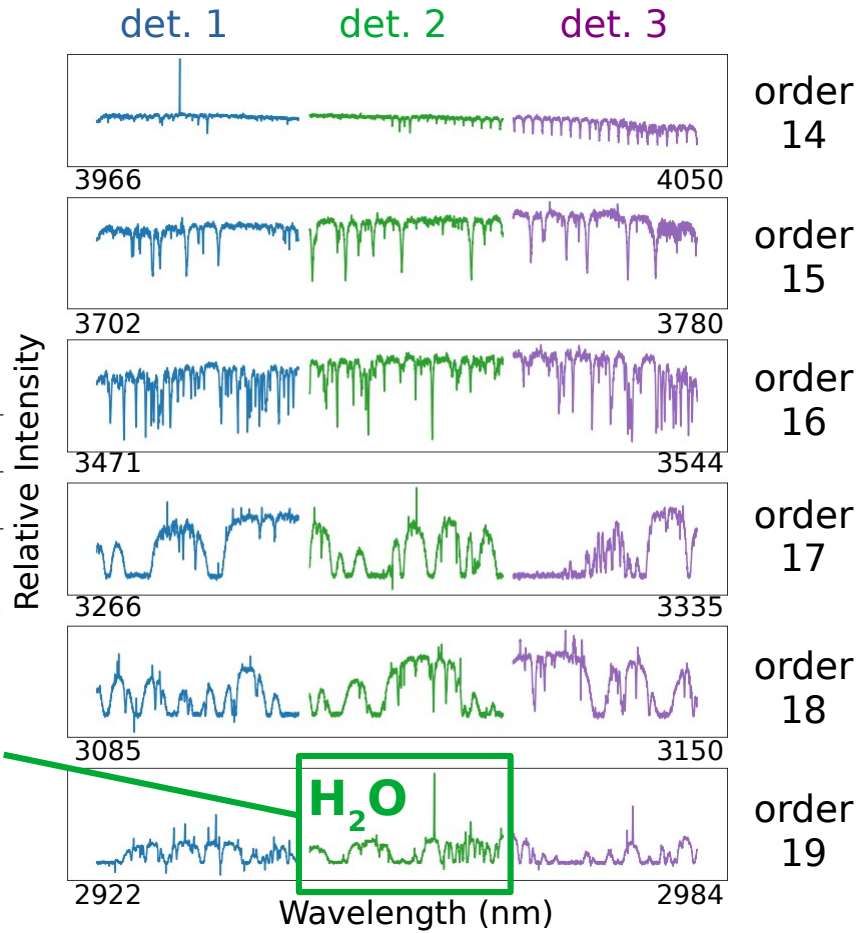

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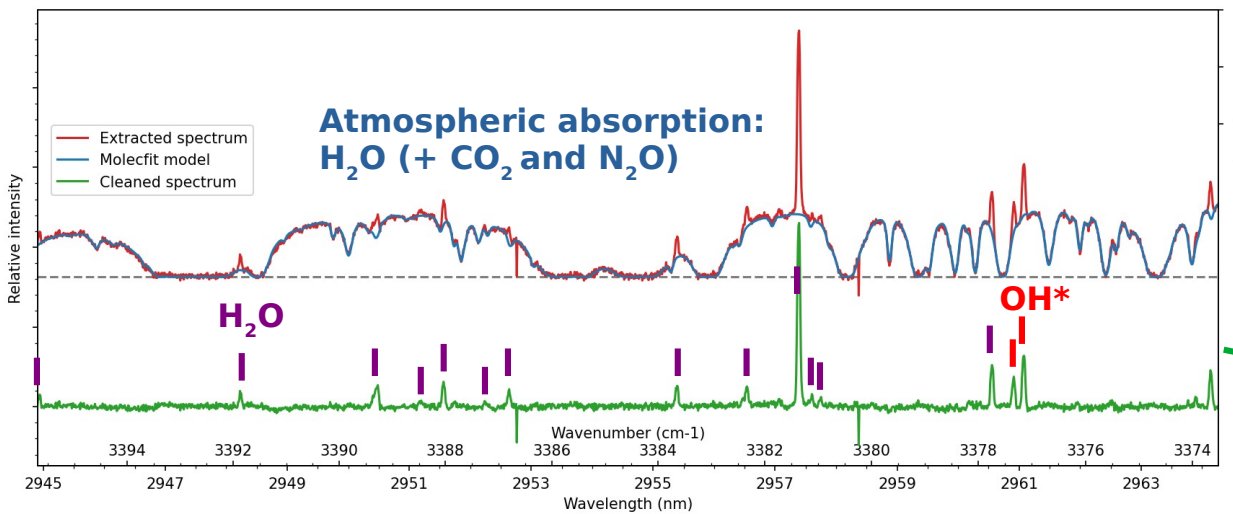

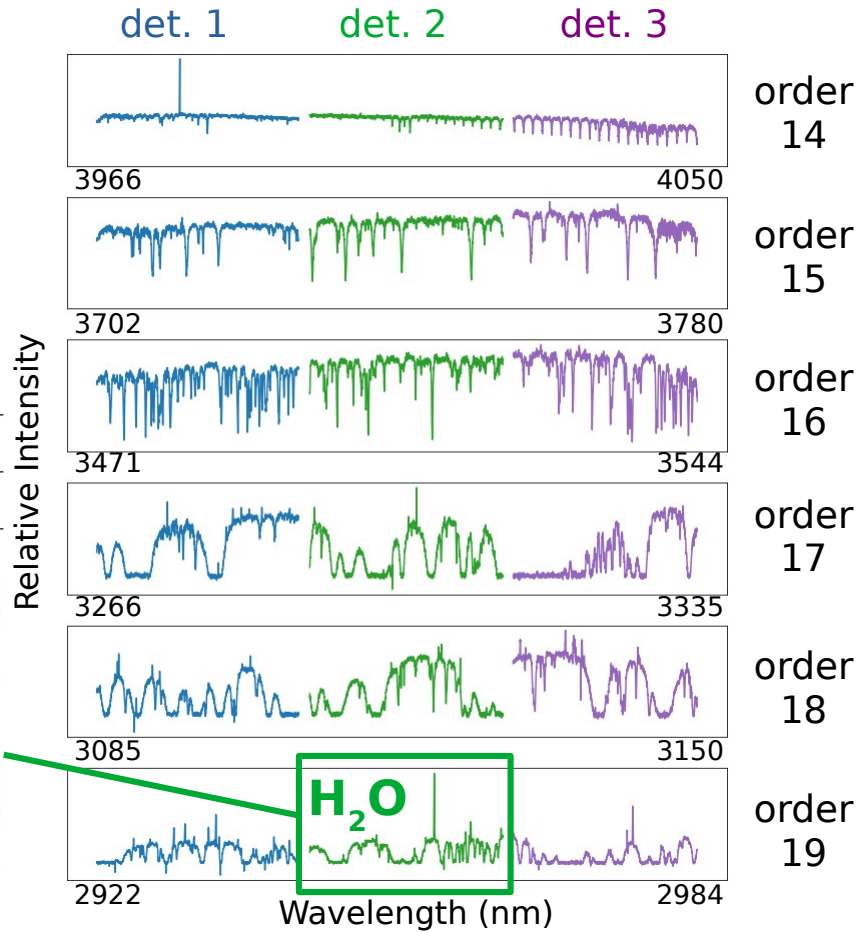

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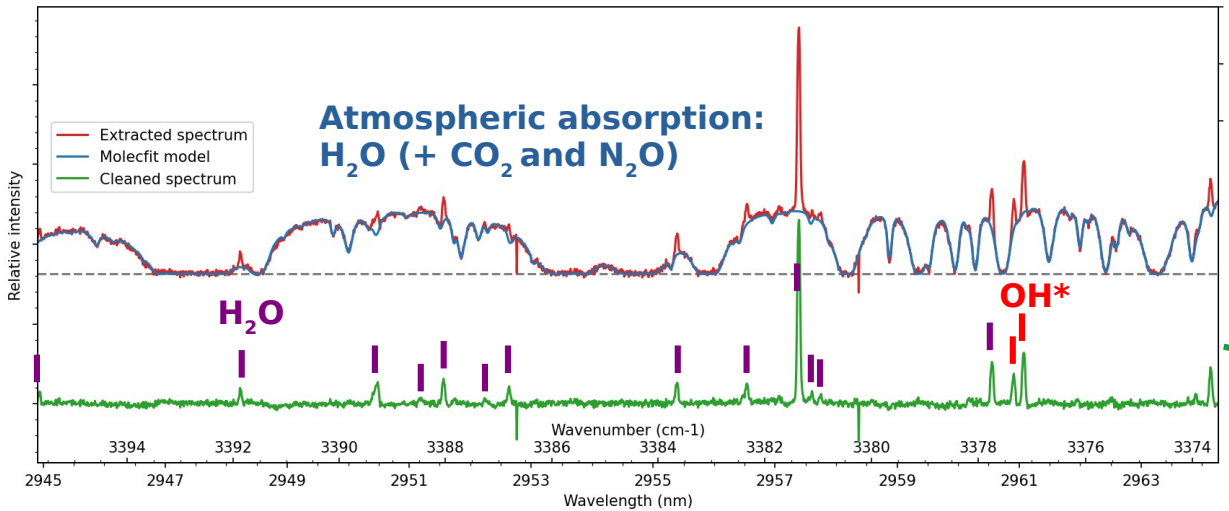
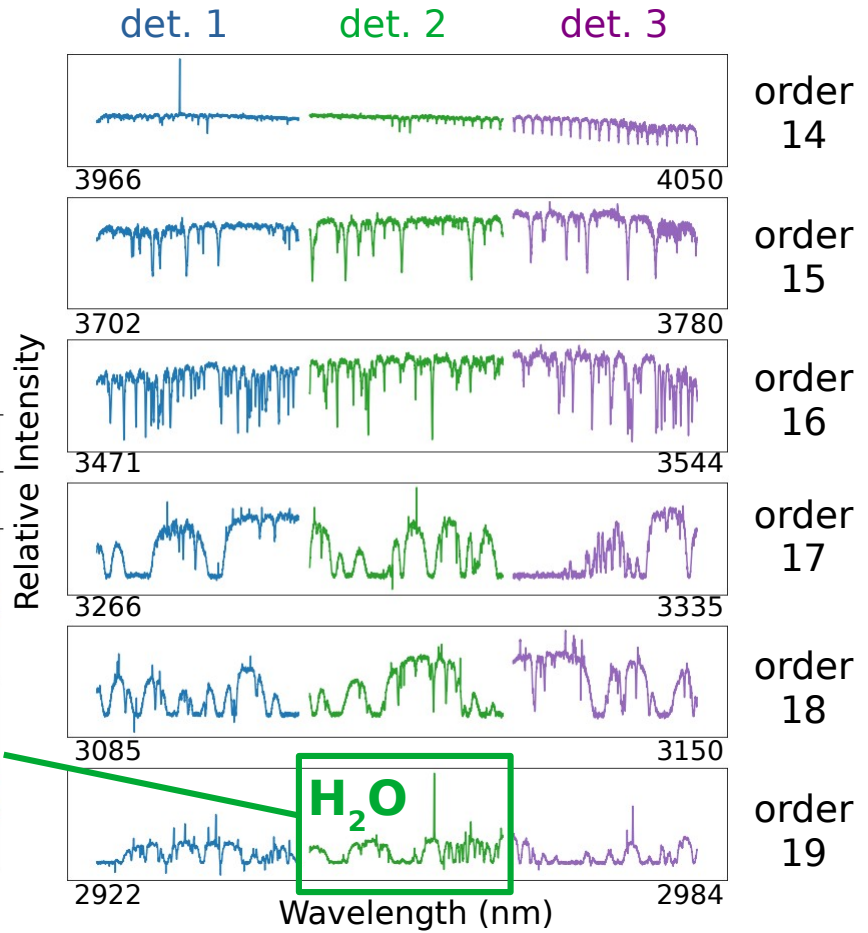
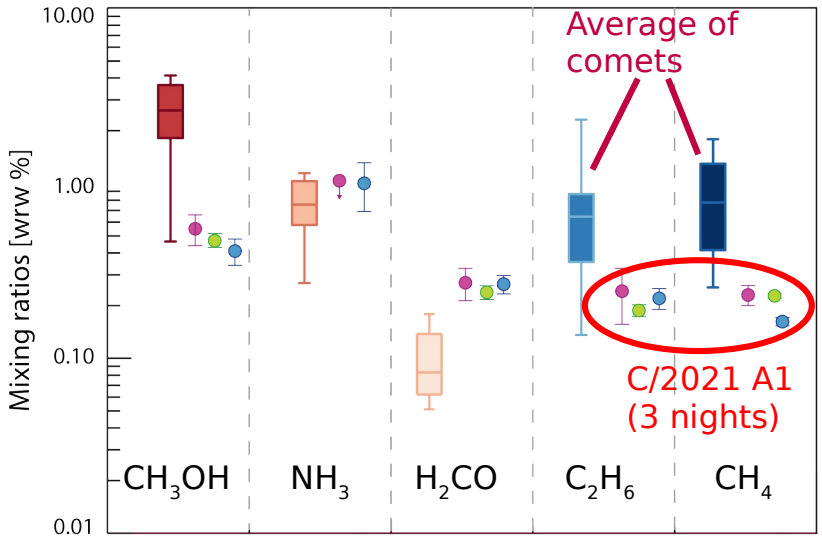
- **Production rates** calculation with fluorescence models (Villanueva et al., 2018)





Comet classifications comparison

C/2021 A1 in the IR classification



→ *Organic depleted* according to IR classification by Lippi et al., 2021

Lippi, Vander Donckt et al., in prep.

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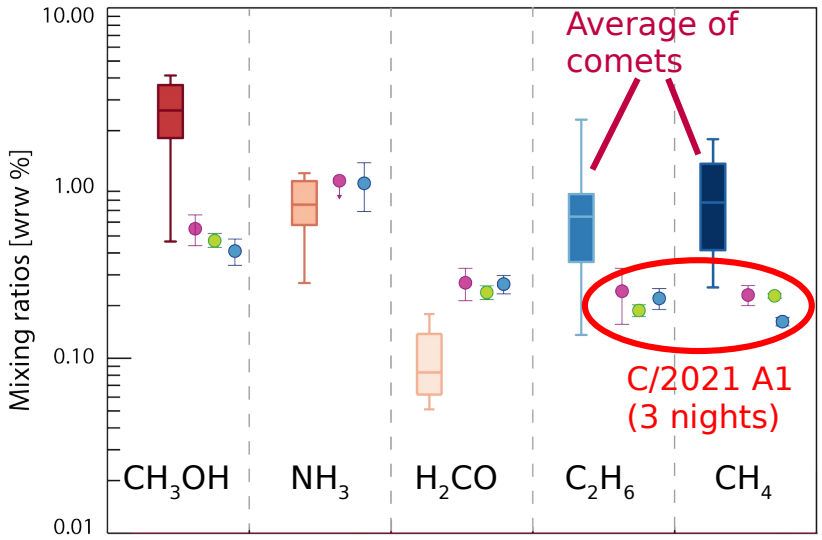

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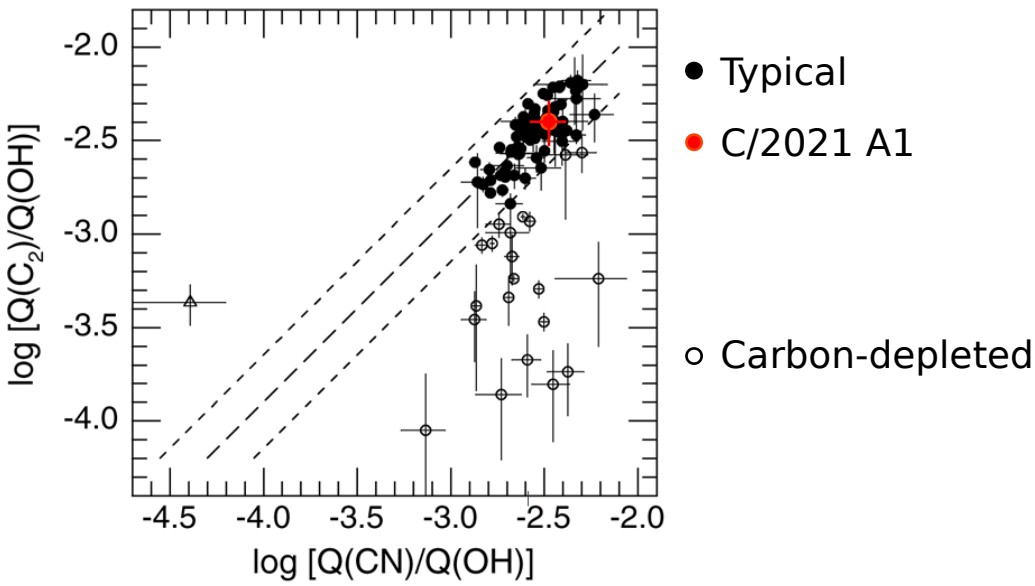

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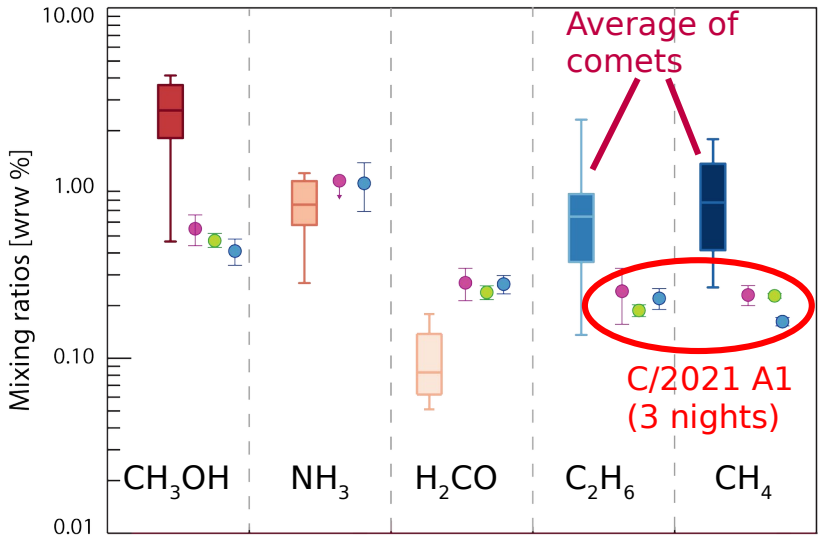

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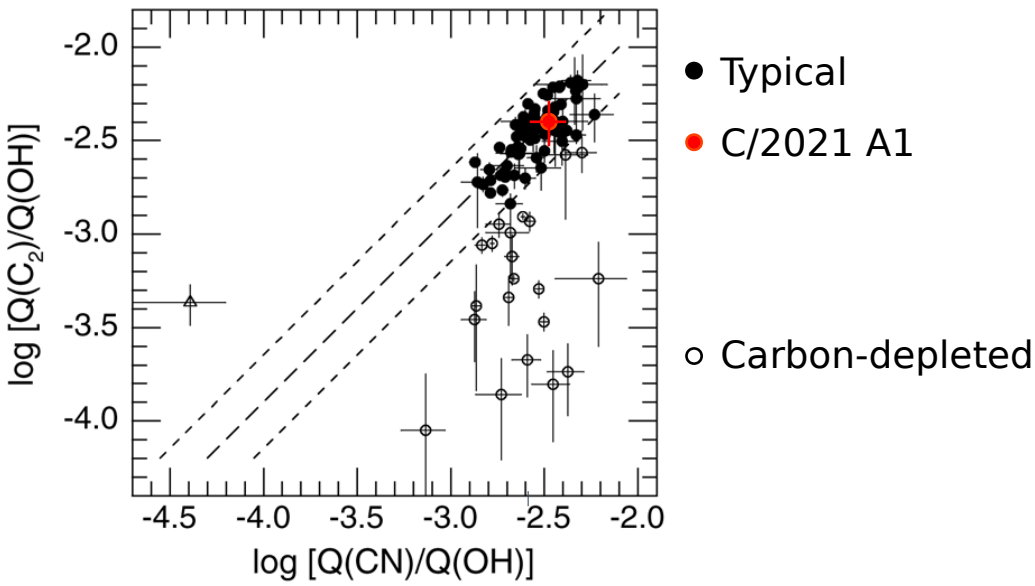

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→ need for a **simultaneous approach**

A bright future for the IR spectroscopy of comets

- CRIRES+ on the ESO Very Large Telescope (2021)
- James Webb Space Telescope (2022)

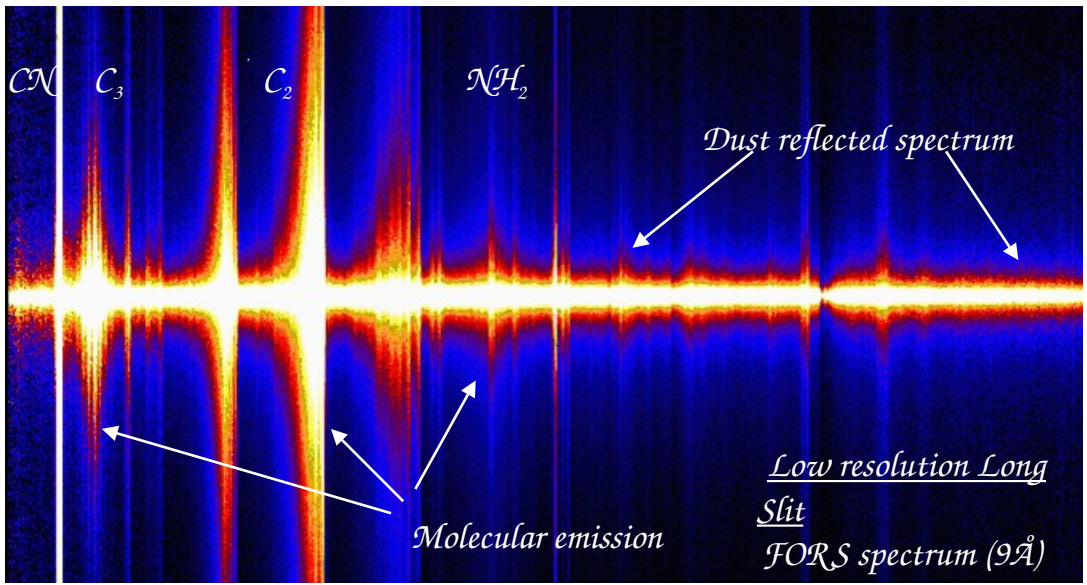
  → Abundance of CO_2 ices
- METIS on the ESO Extremely Large Telescope (2027)

  → Origin of water on Earth (HDO/H2O isotopic ratios in a large sample of comets)
- Support for ESA Comet Interceptor mission (2029)

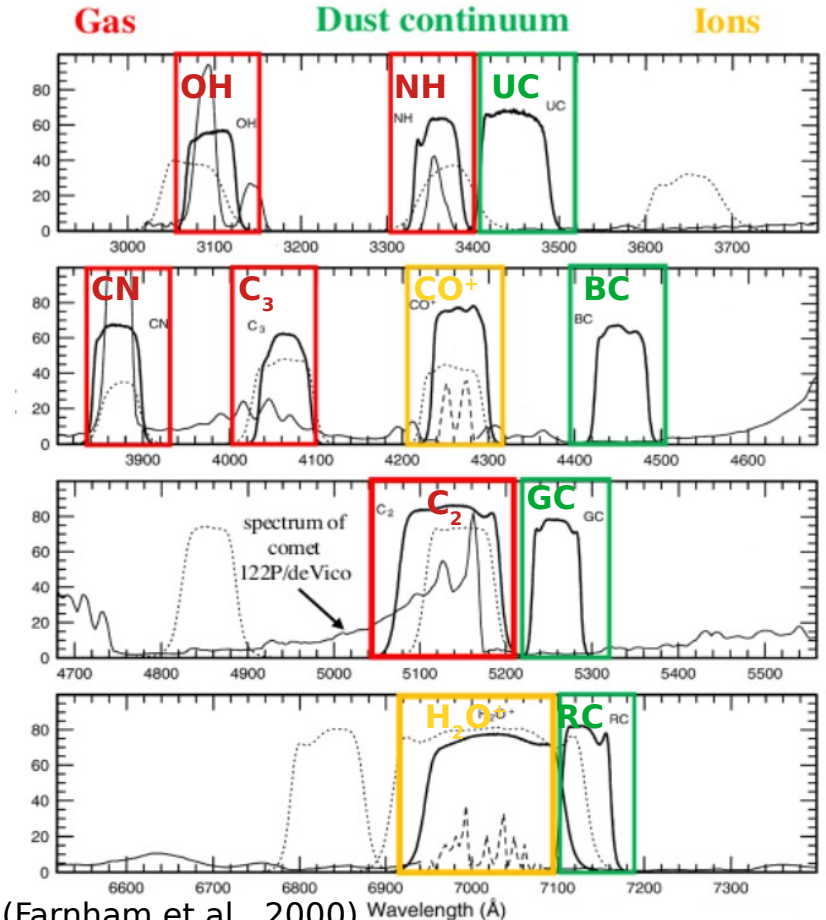
Need for an IR expertise of comets in Europe!

TRAPPIST cometary narrow-band filters

- 0.6m telescopes
- Johnson/Cousins B, V, R and I filters
- HB narrow band filters (Farnham et al., 2000)

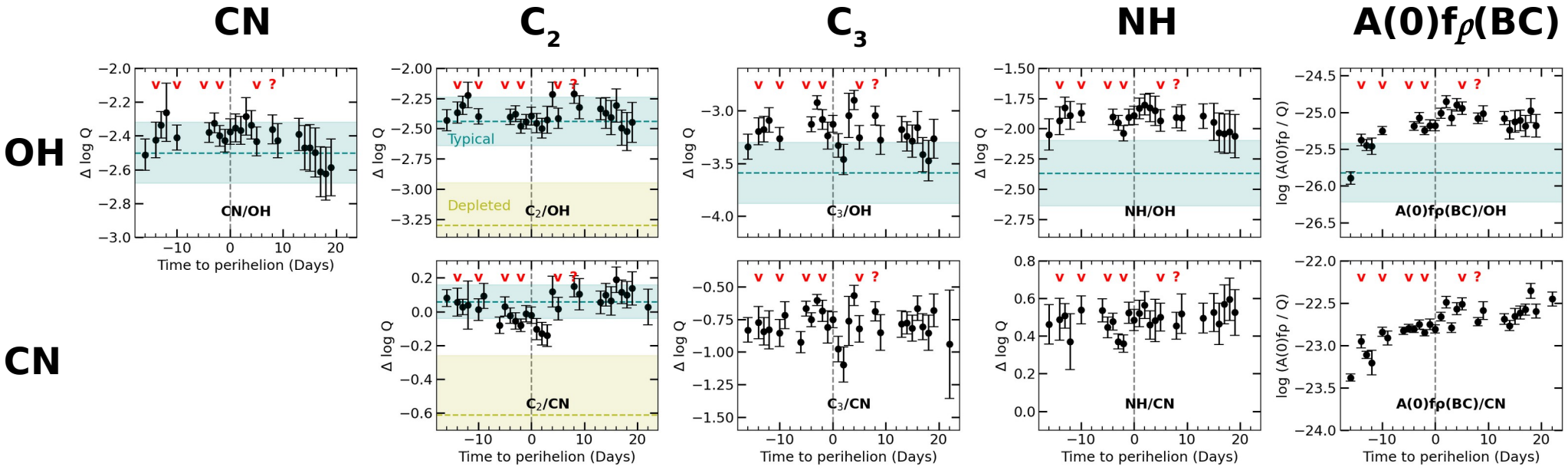


(Jehin et al., 2002)



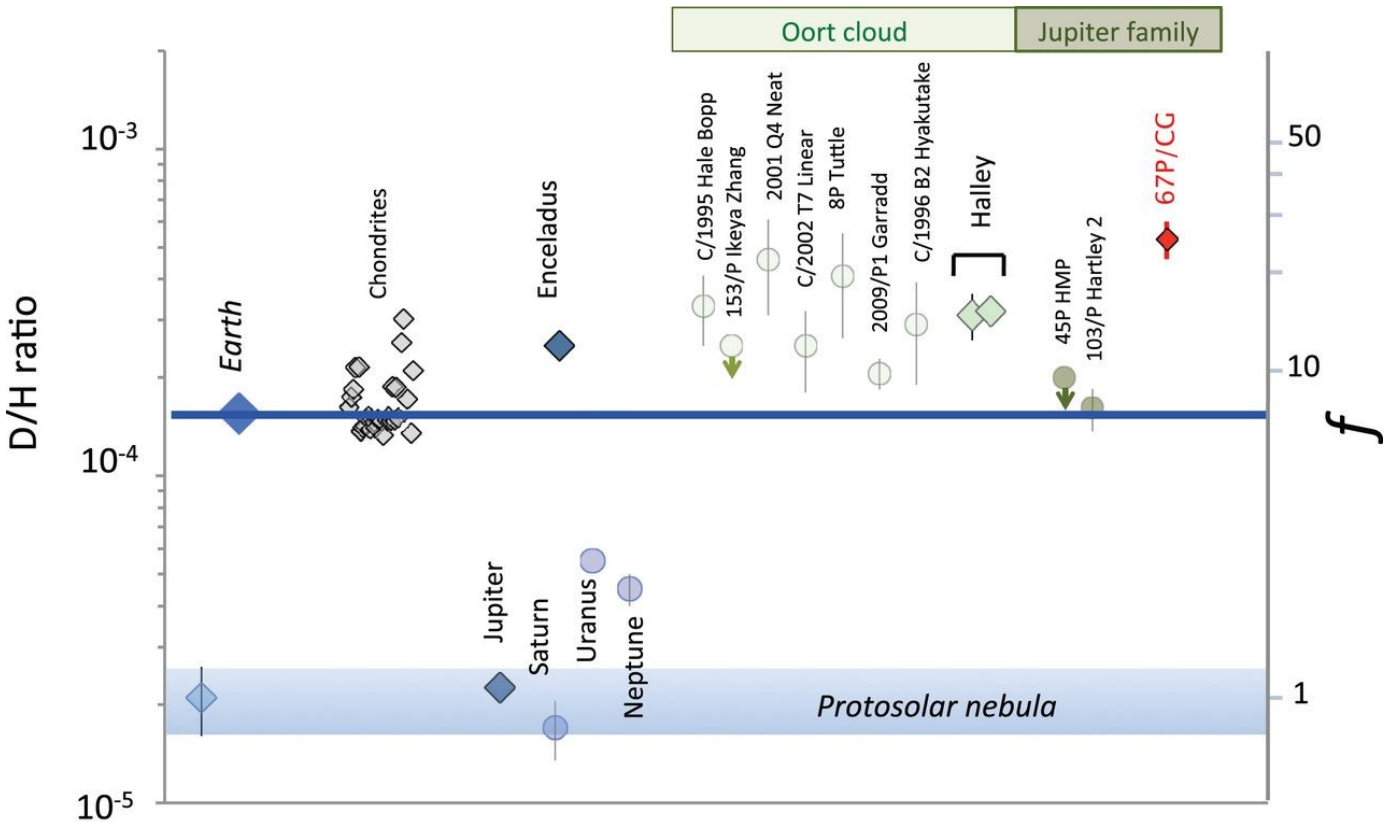
(Farnham et al., 2000)

TRAPPIST abundance ratios



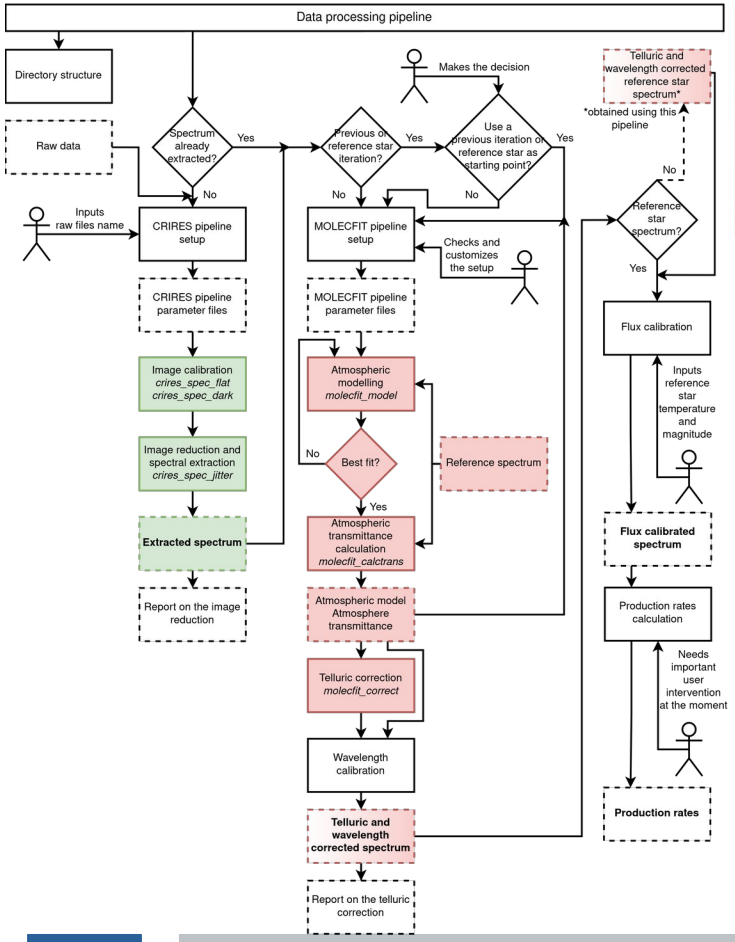
- Typical comet according to A'Hearn et al., 1995 classification
- Dust to gas ratio increasing at perihelion
- Abundance ratio and outburst activity uncorrelated

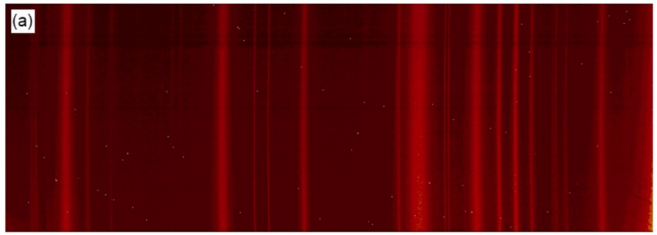
HDO/H_2O in comets

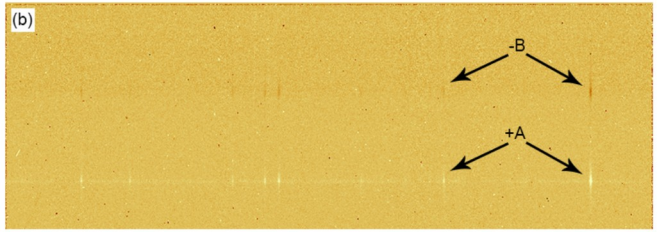


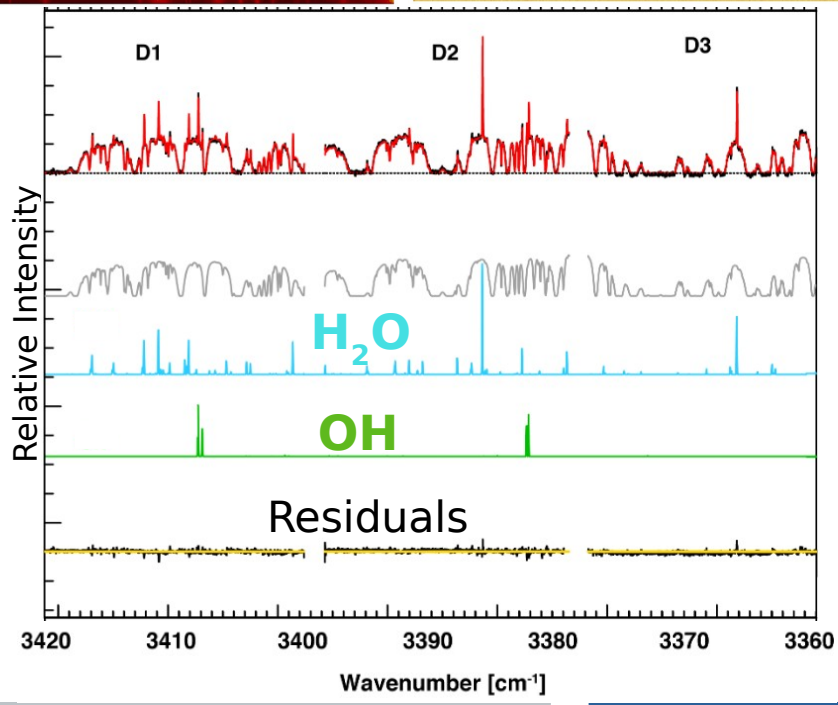
(Altwegg et al., 2014)

Pipeline for the Infrared Spectroscopy of COmets

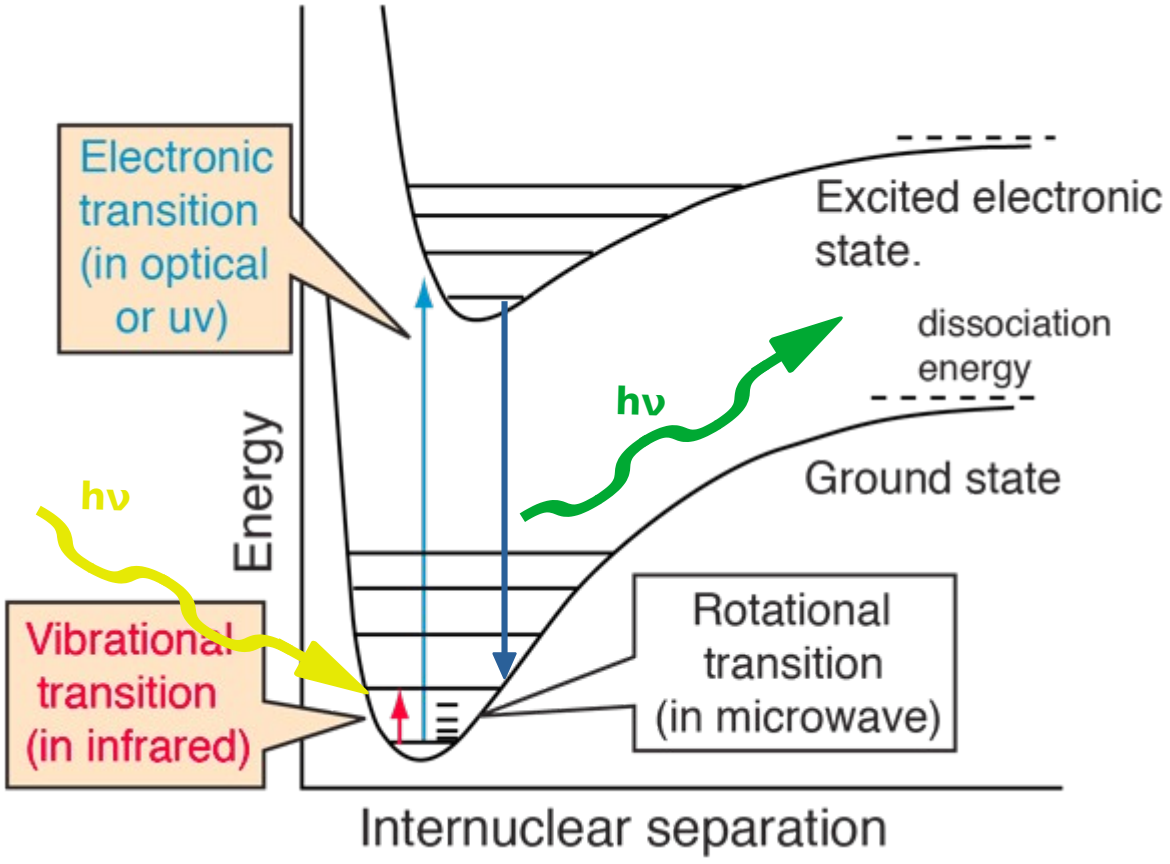








Resonance fluorescence



Example of reactions in the coma gas phase

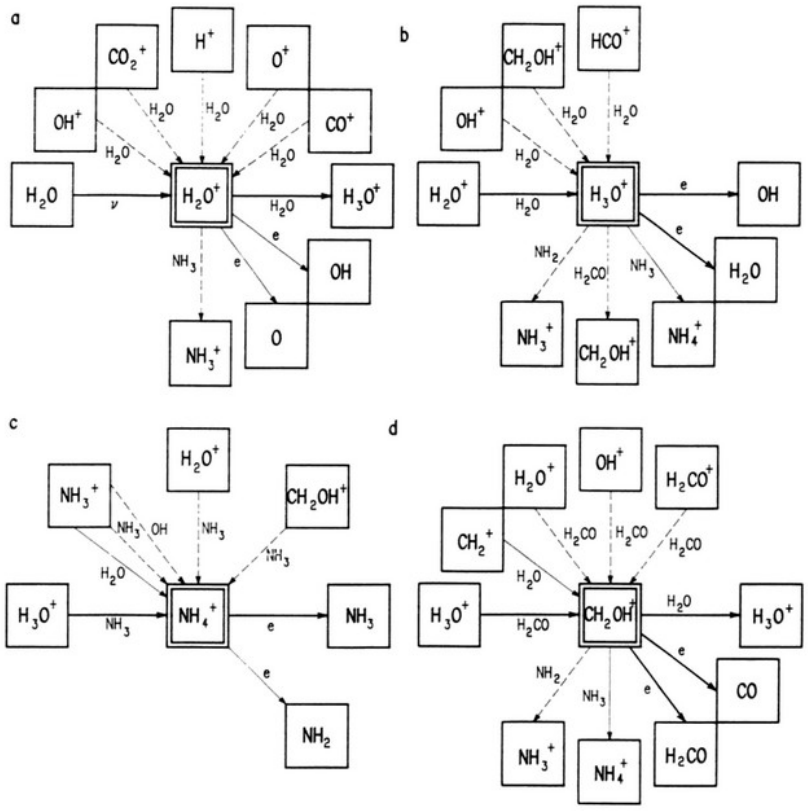


Fig. 7. Major reactions to form: (a) H_2O^+, (b) H_3O^+, (c) NH_4^+, and (d) CH_2OH^+. Symbols next to the arrows indicate the reactants, ν indicates photodissociation or photoionization, and e indicates electron dissociative recombination.

(Newburn et al., 1989)

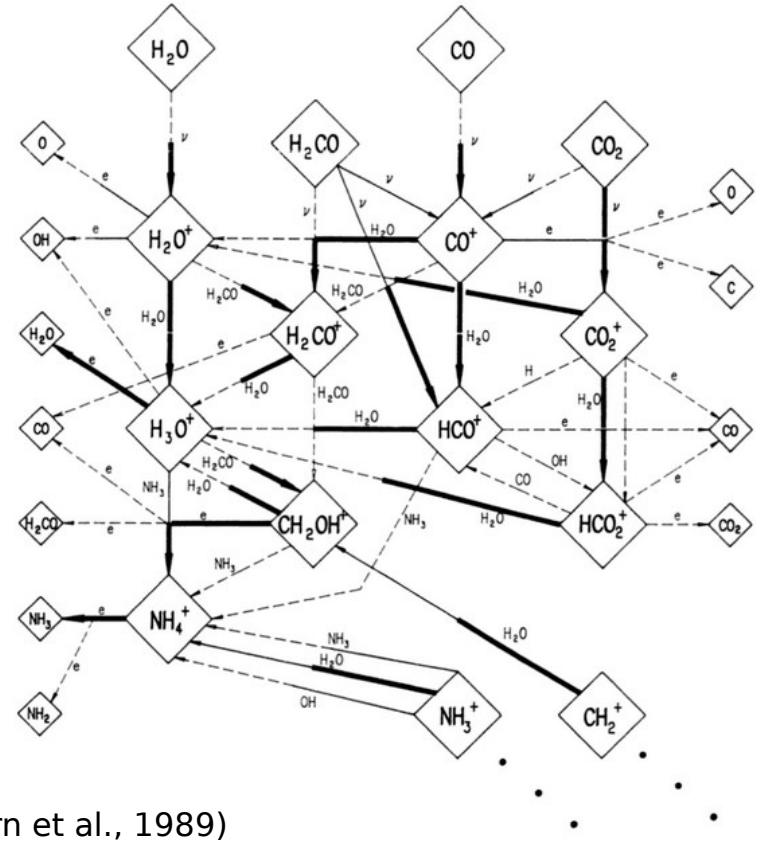


Fig. 8. Relationship of the reactions of Fig. 7. Symbols have the same meaning as in Fig. 7.