



# ***Detection of prebiotic molecules in UV-photoprocessed interstellar ice analogs***

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- ⑤ Dense Interstellar Medium
- ⑤ Laboratory simulations
- ⑤ Effect of UV irradiation on IS ice analogs
- ⑤ Products of UV-irradiated interstellar ice analogs
- ⑤ Implications for astrobiology

# Dense Clouds



- 🌀 More than  $1000 \text{ atoms cm}^{-3}$
- 🌀 Gas phase molecules and dust particles with ice mantles
- 🌀 Complex chemistry on grain mantles at  $T \geq 10 \text{ K}$  due to:
  - 👁 Surface chemistry
  - 👁 UV and ion irradiation
- 🌀 Star formation
- 🌀 Evolution of dust in ISM  $\Rightarrow$  circumstellar disks  $\Rightarrow$  comets

# *Laboratory simulations*



- 🌀 High vacuum system ( $\sim 10^{-7}$  mbar)
- 🌀 Cold finger cooled to  $\sim 12$  K
- 🌀 Deposition system allows slow condensation of mixtures of gases on the cold finger
- 🌀 Mixture of ices is irradiated with UV lamp
- 🌀 Analysis techniques involve IR spectroscopy, GC, LC, MS

# *Effects of UV irradiation*

- ☉ Photoprocessing of interstellar ice analogs (typically H<sub>2</sub>O, NH<sub>3</sub>, CH<sub>3</sub>OH, CO and CO<sub>2</sub>) produces a refractory organic residue (“yellow stuff”) ⇒ Process could be similar to what occurs in dense medium

# *UV products of IS ice analogs (1)*



## **Dense cloud organic refractory**

(“yellow stuff”)

- **Thermal reactions** of **formaldehyde (H<sub>2</sub>CO)** with itself and other ices take place above 40 to 80 K. Products so obtained are **polyoxymethylene (POM)**, by polymerization, and some POM derivatives when formaldehyde is mixed with H<sub>2</sub>O, CH<sub>3</sub>OH, CO and NH<sub>3</sub>

⇒ Schutte et al. 1993

# UV products of IS ice analogs (2)

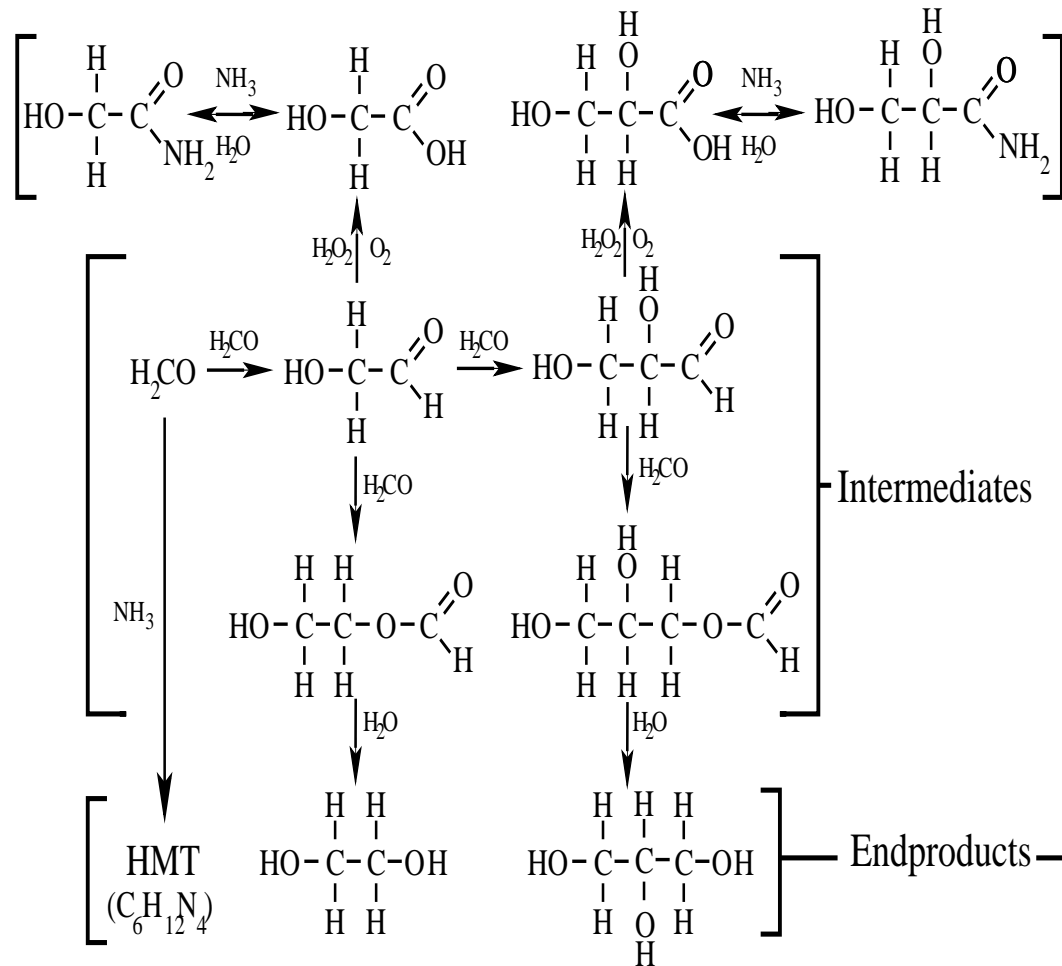


**GC-MS analysis of photolysed CO:NH<sub>3</sub>:H<sub>2</sub>O mixtures:**

- glycolic acid (HOCH<sub>2</sub>CO<sub>2</sub>H)
- glyceric acid (HOCH<sub>2</sub>CH(OH)CO<sub>2</sub>H)
- glycerol (HOCH<sub>2</sub>CH(OH)CH<sub>2</sub>OH)
- glyceramide (HOCH<sub>2</sub>CH(OH)CONH<sub>2</sub>)
- hydroxyacetamide (HOCH<sub>2</sub>CONH<sub>2</sub>)
- oxamide (NH<sub>2</sub>COCONH<sub>2</sub>)
- urea/biuret (NH<sub>2</sub>CONH<sub>2</sub>/NH<sub>2</sub>CONHCONH<sub>2</sub>)
- ethylene glycol (HOCH<sub>2</sub>CH<sub>2</sub>OH)
- glycine (NH<sub>2</sub>CH<sub>2</sub>COOH)
- Carboxylic acid salts, such as (HOCH<sub>2</sub>COO<sup>-</sup>)(NH<sub>4</sub><sup>+</sup>)

⇒ Agarwal et al. 1985, Muñoz Caro et al. 2001

# Formation of carboxylic acids and alcohols





# UV products of IS ice analogs (3)




**Photolyzed H<sub>2</sub>O:NH<sub>3</sub>:CO:CO<sub>2</sub>:CH<sub>3</sub>OH mixture:**

- **Hexamethylenetetramine or HMT (C<sub>6</sub>H<sub>12</sub>N<sub>4</sub>).**  
HMT hydrolyzes under acidic conditions to produce NH<sub>3</sub>, H<sub>2</sub>CO and **amino acids**
- Irradiation of **PAHs covered with water** ice produces polycyclic aliphatic hydrocarbons, aromatic ketones (**quinones**), aromatic alcohols, and aromatic ethers

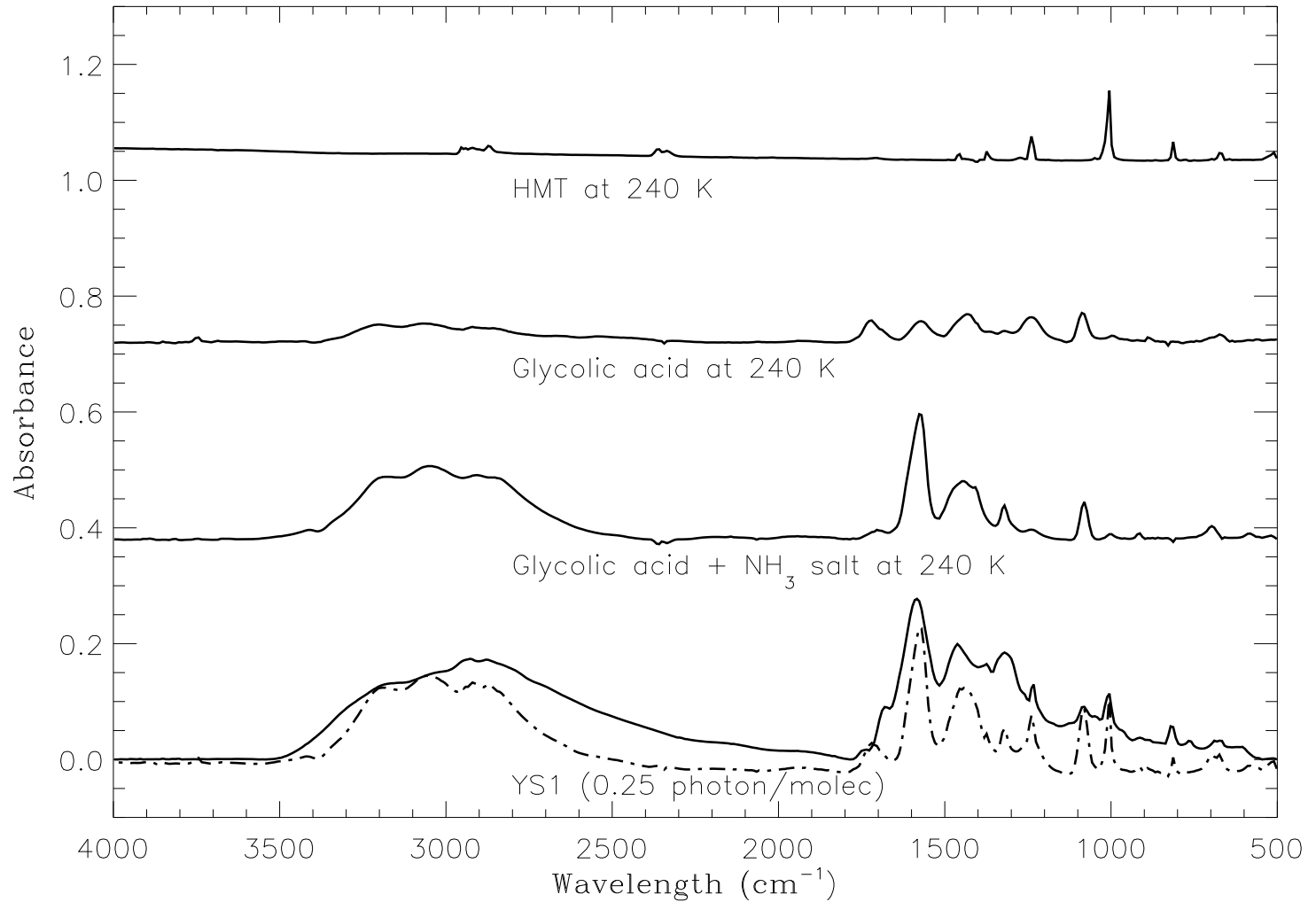
⇒ Bernstein et al. 1995

# *UV products of IS ice analogs (4)*

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- 🌀 Several **HMT derivatives** detected by GC-MS:
    - 👁 methyl-HMT (HMT-CH<sub>3</sub>)
    - 👁 hydroxy-HMT (HMT-OH)
    - 👁 methanyl-HMT (HMT-CH<sub>2</sub>OH)
    - 👁 HMT-amino-aldehyde (HMT-NH-CHO)
    - 👁 methanyl-aldehyde-HMT (HMT-CHOH-CHO)

⇒ Muñoz Caro et al. 2001

# *Fitting the IR spectrum of the organic residue*



# *Implications for astrobiology (1)*

- ☞ **Glycine** and **urea** produced by ice photolysis
- ☞ **Other amino acids** are formed by **acid hydrolysis of HMT**, such as aspartic acid, serine, glutamic acid, proline and alanine  
(Wolman et al. 1971)
- ☞ **Acid hydrolysis of amino acids exposed to UV irradiation** leads to formation of **new amino acids**, e.g.:  
glutamic acid + propionic acid +  $h\nu \rightarrow$  norleucine  
(Ferrari and Cultrera 1961)

## *Implications for astrobiology (2)*



- ⑤ glycerol → phosphoglycerides (membranes)
- ⑤ Isolated droplets develop on aqueous solution of organic residue (Dworkin et al. 2000)
- ⑤ Quinones have similar structure to chlorophyll (Bernstein et al. 2001)
- ⑤ UV induced chemistry on ices goes beyond HMT (HMT-based molecules)