

**FORMATION OF NUCLEOBASES FROM THE UV PHOTO-IRRADIATION OF PYRIMIDINE IN ASTROPHYSICAL ICE ANALOGS.** S. N. Milam<sup>1,2</sup>, M. Nuevo<sup>1</sup>, S. A. Sandford<sup>1</sup>, J. E. Elsila<sup>3</sup>, and J. P. Dworkin<sup>3</sup>, <sup>1</sup>NASA Ames Research Center, Mail Stop 245-6, Moffett Field, CA 94035, USA (e-mail: stefanie.n.milam@nasa.gov), <sup>2</sup>SETI Institute, 515 N Whisman Rd, Mountain View, CA 94043, USA, <sup>3</sup>NASA Goddard Space Flight Center, Code 691.0, Greenbelt, MD 20771, USA.

**Introduction:** Astrochemistry laboratory simulations have shown that complex organic molecules including compounds of astrobiological interest can be formed under interstellar/circumstellar conditions from the vacuum UV irradiation of astrophysical ice analogs containing H<sub>2</sub>O, CO, CO<sub>2</sub>, CH<sub>3</sub>OH, NH<sub>3</sub>, etc. Of all prebiotic compounds, the formation of amino acids under such experimental conditions has been the most extensively studied [1–3]. Although the presence of amino acids in the interstellar medium (ISM) has yet to be confirmed [4,5], they have been detected in meteorites [6,7], indicating that biomolecules and/or their precursors can be formed under extraterrestrial, abiotic conditions. Nucleobases, the building blocks of DNA and RNA, as well as other *N*-heterocycles, have also been detected in meteorites [8,9], but like amino acids, they have yet to be observed in the ISM [10]. In this work, we present an experimental study of the formation of pyrimidine-based compounds from the UV photo-irradiation of pyrimidine in ice mixtures containing H<sub>2</sub>O, NH<sub>3</sub>, and/or CH<sub>3</sub>OH at low temperature and pressure.

**Experimental:** Pyrimidine (C<sub>4</sub>H<sub>4</sub>N<sub>2</sub>), the carbonaceous backbone for 3 biological nucleobases (cytosine, thymine, and uracil), was mixed with ice mixtures containing H<sub>2</sub>O, NH<sub>3</sub>, and/or CH<sub>3</sub>OH, and UV irradiated at 20–30 K in order to simulate astrophysical conditions. The UV photons were provided by a discharge H<sub>2</sub> lamp emitting mainly Lyman  $\alpha$  (121.6 nm) photons and a continuum centered around 160 nm. After irradiation at low temperature, the samples were warmed up to room temperature and analyzed by two independent and complementary chromatography techniques, namely, high-performance liquid chromatography (HPLC), and gas chromatography coupled with mass spectroscopy (GC-MS). Photolyzed ice mixtures were also measured in situ by mid-infrared spectroscopy to study the photostability of pyrimidine and its photo-products in the various ice mixtures.

**Results and discussion:** Both HPLC and GC-MS data showed that the UV irradiation of pyrimidine mixed with H<sub>2</sub>O and/or NH<sub>3</sub> ices lead to the formation of a large variety of compounds where hydroxyl/keto (–OH/=O) and amino (–NH<sub>2</sub>) groups are added to the pyrimidine base structure. Among all photo-products

identified in the samples, the presence of the nucleobases uracil [11] and cytosine [12] has been confirmed by both HPLC and GC-MS. When CH<sub>3</sub>OH is present in the starting ice mixtures, the addition to the pyrimidic ring of functional groups such as methyl (–CH<sub>3</sub>), methoxy (–OCH<sub>3</sub>), and/or –CH<sub>2</sub>OH groups is expected, and has yet to be confirmed by on-going experiments. The photo-stability and survival of pyrimidine and its photo-products, from the astrophysical environments where they are likely to be formed to their delivery to telluric planets, as well as the formation pathways of the nucleobases and other pyrimidine derivatives will also be discussed.

**References:** [1] Bernstein M. P. et al. (2002) *Nature*, 416, 401–403. [2] Muñoz Caro G. M. et al. (2002) *Nature*, 416, 403–406. [3] Nuevo M. et al. (2008) *Orig. Life Evol. Biosph.*, 38, 37–56. [4] Kuan Y.-J. et al. (2003) *Astrophys. J.*, 593, 848–867. [5] Snyder L. E. et al. (2005) *Astrophys. J.*, 619, 914–930. [6] Engel M. H. & Macko S. A. (1997) *Nature*, 389, 265–268. [7] Cronin J. R. & Pizzarello S. (1999) *Adv. Space Res.*, 23, 293–299. [8] van der Velden W. & Schwartz A. (1977) *Geochim. Cosmochim. Acta*, 41, 961–968. [9] Stoks P. & Schwartz A. (1979) *Nature*, 282, 709–710. [10] Charnley S. B. et al. (2005) *Adv. Space Res.*, 36, 137–145. [11] Nuevo M. et al. (2009) *Astrobiology*, 9, 683–695. [12] Milam S. N. et al., in preparation.