Annie Jump Cannon (1863-1941)

- Graduated from Wellesley College 1884
- Likely discoverer of the still enigmatic spectral diffuse interstellar bands (DIB) (~ 1918)
- Stellar classification: “OBAFGKM”
- Classified 350,000 stars
- Became a “special student” of astronomy at Radcliffe College (1894)
- First woman to receive an honorary degree from Oxford (1925)
Formation of Secondary Electrons in Cosmic Ices and Dust Grains

- Secondary electron cascade (0-20 eV)
- Thin (~100 ML) ice layers (10 K)
- Cosmic ray $10^7$-$10^{20}$ eV

Bare silicate or carbonaceous interstellar dust grain
 Importance of Low-Energy Electrons

1 MeV particle $\rightarrow$ 100,000 low-energy electrons

C. Arumainayagam et al., *Surface Science Reports* 65 (2010) 1–44.
Electron-induced Dissociation Mechanisms

Electron Impact Excitation

Electron Attachment

Electron Impact Ionization

not possible for photons

AB + e− → AB* + e−

> 3 eV

Electron Impact Excitation

> 15 eV

Electron Attachment

< 15 eV

AB* + e− → A* + B

A+ + B−

AB + energy

A* + B

A+ + B−

AB− + energy

A* + B−

AB− + energy

A* + B++

Dipolar Dissociation

Autodetachment

Dissociative Electron Attachment

Associative Attachment

Fragmentation

> 10 eV

AB++ + 2e−
Electron-induced Dissociation Mechanisms
Breaking a 3.5 eV Bond with a 0 eV Electron

Threshold Energy: \[ \Delta H_o (B^-) = D(A - B) - EA(B) \]

C. Arumainayagam et al., Surface Science Reports 65 (2010) 1–44.
Photon-Induced Dissociation

Threshold Energy: \[ \Delta E = D_o (A - B) + AEE(B) \]
Photon-Induced Dissociation

Three Scenarios for Photon-Induced Dissociation

- **Bound Upper State**
  - Potential Energy vs Internuclear Distance
  - $A+B^*$
  - $D_0$
  - $\Delta E$

- **Unbound Upper State**
  - Potential Energy vs Internuclear Distance
  - $\Delta E$
  - $D_0$
  - Atomic Excitation Energy (B)
  - Excited State
  - Ground State

- **Predissociation**
  - Potential Energy vs Internuclear Distance
  - $\Delta E$
  - $A+B^*$
  - $D_0$
  - Atomic Excitation Energy (B)
UV light formation within dark, dense molecular clouds

- Cosmic Ray $10^7$-$10^{20}$ eV
- Low-energy (< 20 eV) electrons
- UV light 3-12 eV
- Icy interstellar dust grain
Formation of Secondary Electrons in Cosmic Ices and Dust Grains

- Secondary electron cascade (0-20 eV)
- Thin (~100 ML) ice layers (10 K)
- Cosmic ray $10^7$-$10^{20}$ eV
- Bare silicaceous or carbonaceous interstellar dust grain
UHV Chamber at Wellesley College
Temperature-Programmed Desorption (TPD)

\[ R = kN = A \frac{-E_a}{RT} N \]

Figures: http://www.chem.qmul.ac.uk/surfaces/scc/scat5_6.htm
Temperature Programmed Desorption
How to Identify Desorption Peaks

Figures: http://www.chem.qmul.ac.uk/surfaces/scc/scat5_6.htm
Extremely Bright < 8 eV Photon Source: Laser-Driven Plasma: EQ 1500

Spectral Radiance of 30W D2, 75W Xe, EQ99 and EQ1500 - Log

Wavelength [nm]

Spectral Radiance [mW/mm²/Å/nm/sr]
UV Absorption Spectrum of Condensed Ammonia

Mean Free Path Calculation for a 7 eV Photon

\[
\lambda = \frac{1}{n\sigma} = \frac{1}{(\text{number of molecules per cm}^3)(\text{photon absorption cross section in cm}^2)} = \frac{1}{\left(\frac{\text{density in g/cm}^3}{\text{molar mass in g/mole}}\right)(\text{number of molecules per mole})(\text{photon absorption cross section in cm}^2)} = \frac{1}{\left(\frac{0.68 \text{ g/cm}^3}{17 \text{ g/mole}}\right)(6.02 \times 10^{23} /\text{mole})(2 \times 10^{-18} \text{ cm}^2)} = 0.2 \text{ microns}
\]

Most, if not all, of the ice mantle surrounding dust grains will be susceptible to photochemistry.
Low-energy electron-induced radiolysis in cosmic ices

radical formation

excitation

radical-radical reactions

NH$_3$*

H•, •NH$_2$

N$_2$H$_4$

low-energy electrons

cosmic ray
A general method for the inclusion of radiation chemistry in astrochemical models

Christopher N. Shingledecker and Eric Herbst
December 2017: Identification of Methoxy methanol in the ISM [~10 quadrillion miles away]

Black: Overall microwave spectrum of NGC 6334I
Red: Simulated rotational spectrum of methoxymethanol
Green: Simulations of species that are major contributors to the overall spectrum