# Ion irradiation of N2O Simulated Astrophysical Ice (SAI)

## Relevance to the ISM and trans-Neptunian Objects

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INTERNATIONAL SYMPOSIUM AND WORKSHOP ON ASTROCHEMISTRY

Understanding extraterrestrial molecular complexity through experiments and observations

# THE SAI CULTURE

**Culture: The customs and beliefs, art, way of life and social organization of a particular country or group. (Oxford Dictionary)**

**XXI Century**

→

**Rush**

**Lack of Time**


↙

**Padronization**

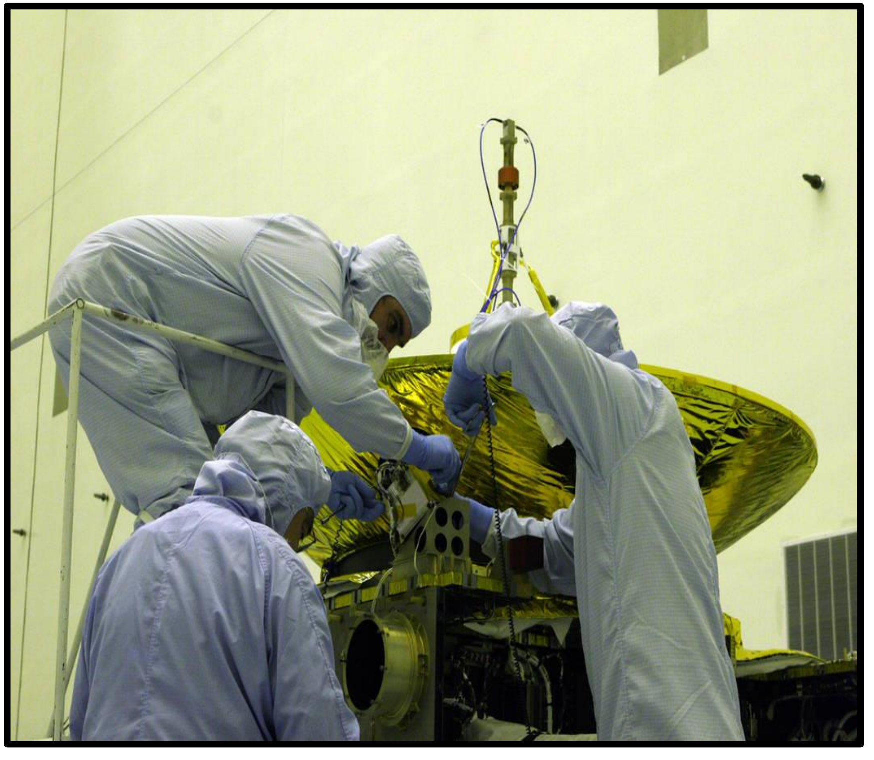
↘

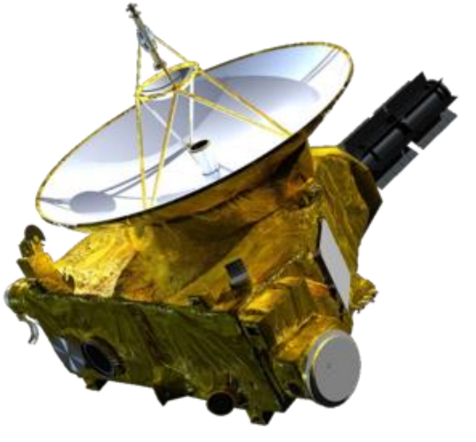
**SAI**

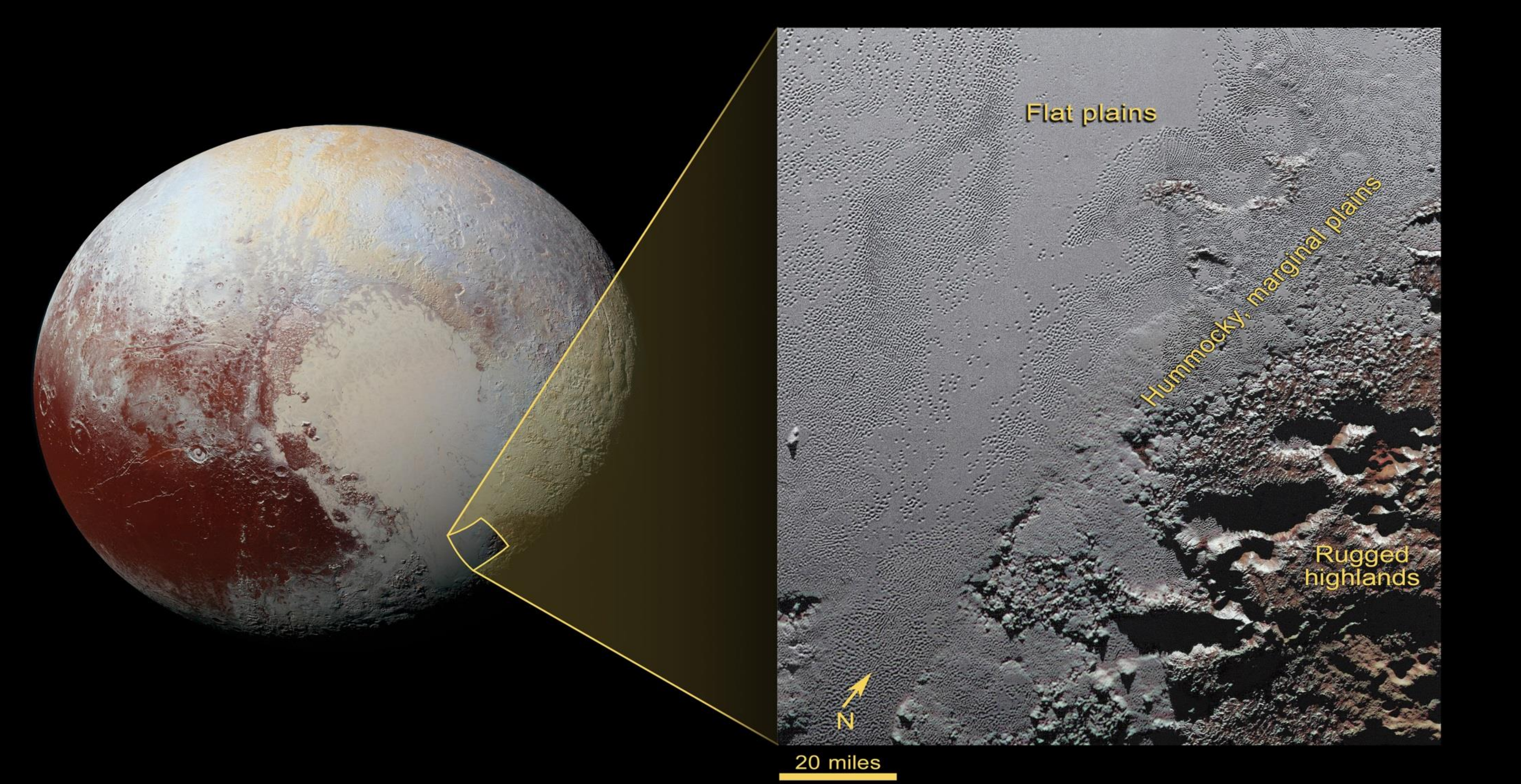
**Simulated Astrophysical Ice**

# Motivation: The New Horizons Mission

- **Launched by NASA on 19 January of 2006.**
- **Runned 4,8x$10^9$ Km until Pluto.**
- **Met Pluto on July 14 of 2015.**
- **Collected about 64Gb of Data.**
- **It will take about 5 months plus to collect all data on Earth.**
- **Revealed that Pluto has an Atmosphere rich in $N_2$ with $H_2O$, $CH_4$ and CO frozen on surface.**
- **Left Pluto on January 2016 and went further to study the KBO's**



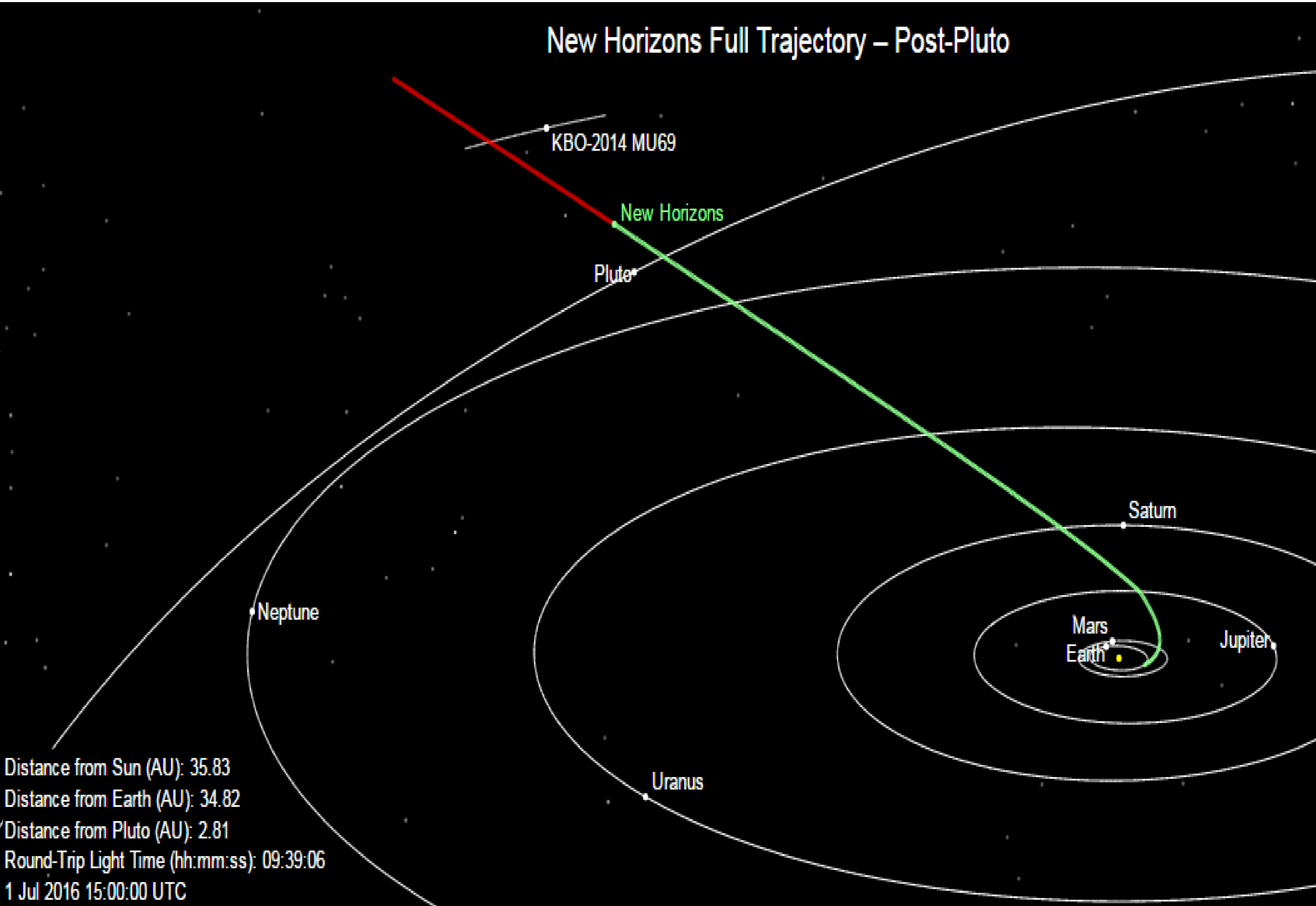




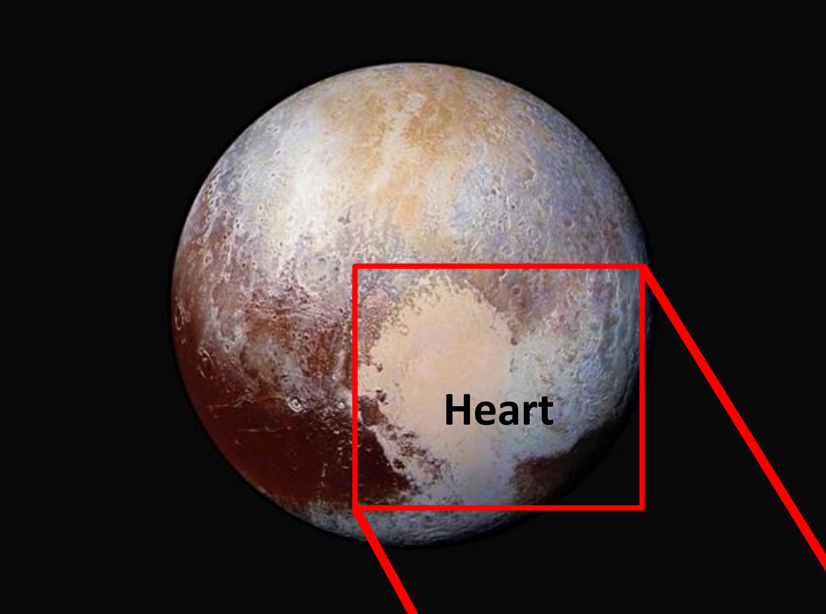

**PLUTO**
**DWARTH PLANET**
**(2006)**
**D = 2.372 Km**

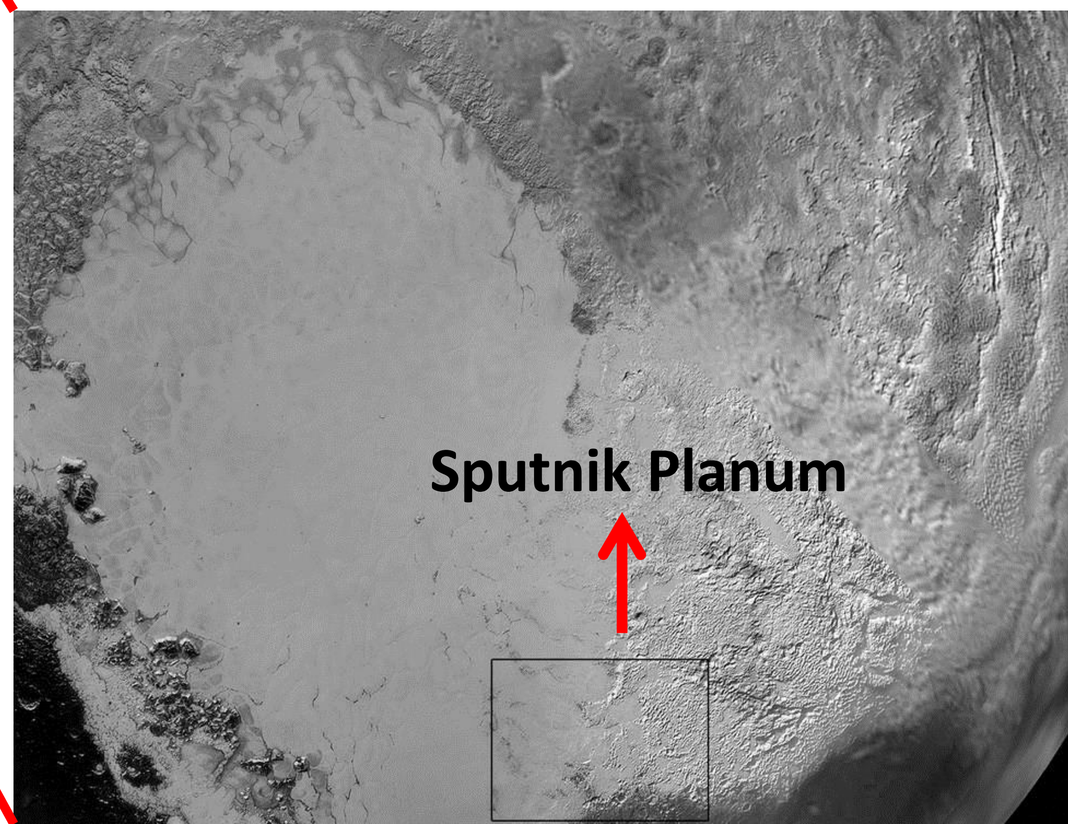
**CHARON**
**LARGEST MOON**
**D = 1207 Km**

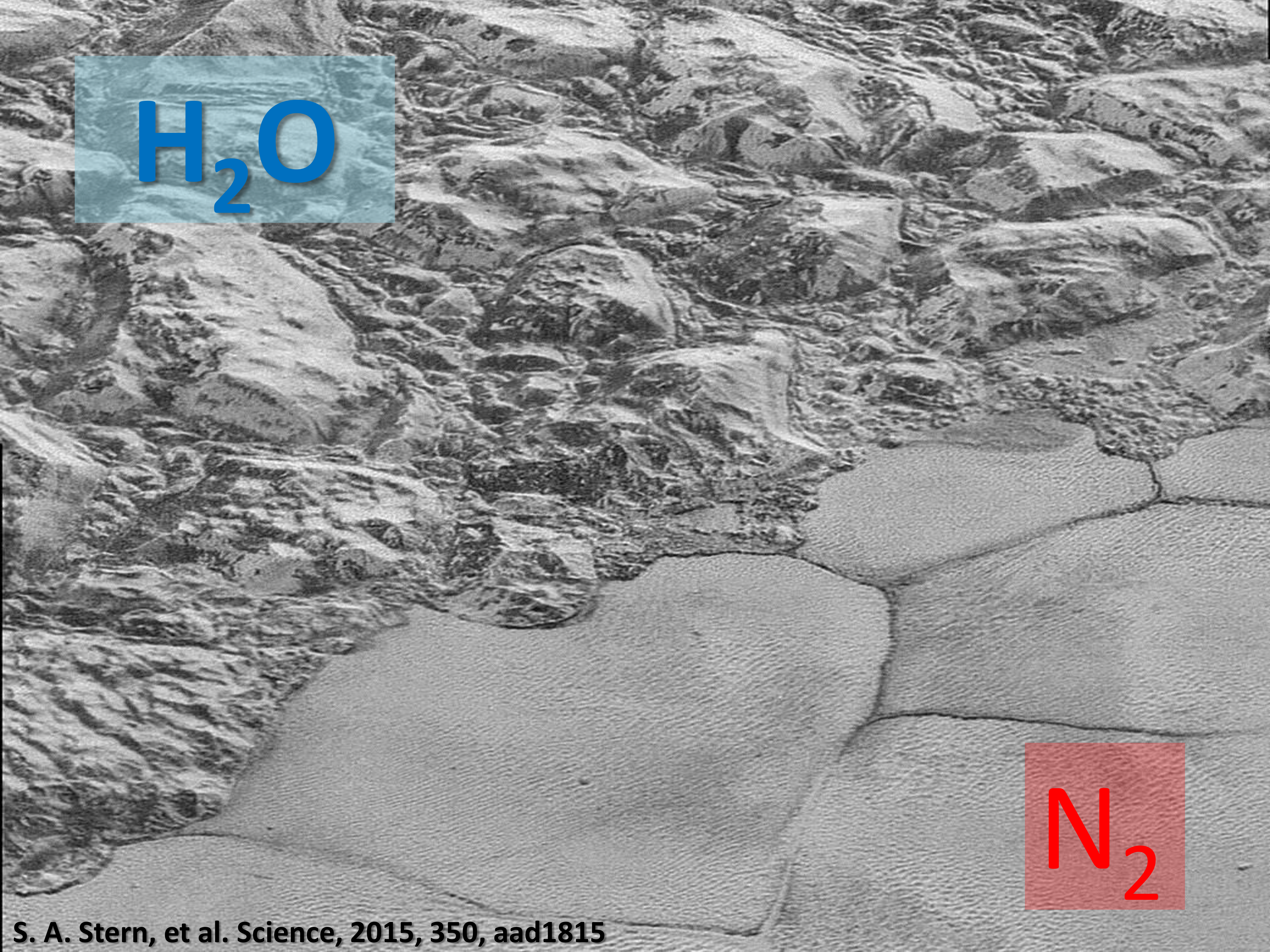
# Where is New Horizons Now?



*a) S. A. Stern, et al. Science, 2015, 350, aad1815.*





$H_2O$
$N_2$
S. A. Stern, et al. Science, 2015, 350, aad1815

# The Van de Graaff Laboratory

## (VDG -PUC-Rio)




**(1) VDG Accelerator**

**(2) $90^0$ Magnet**

**(3)Control Room**

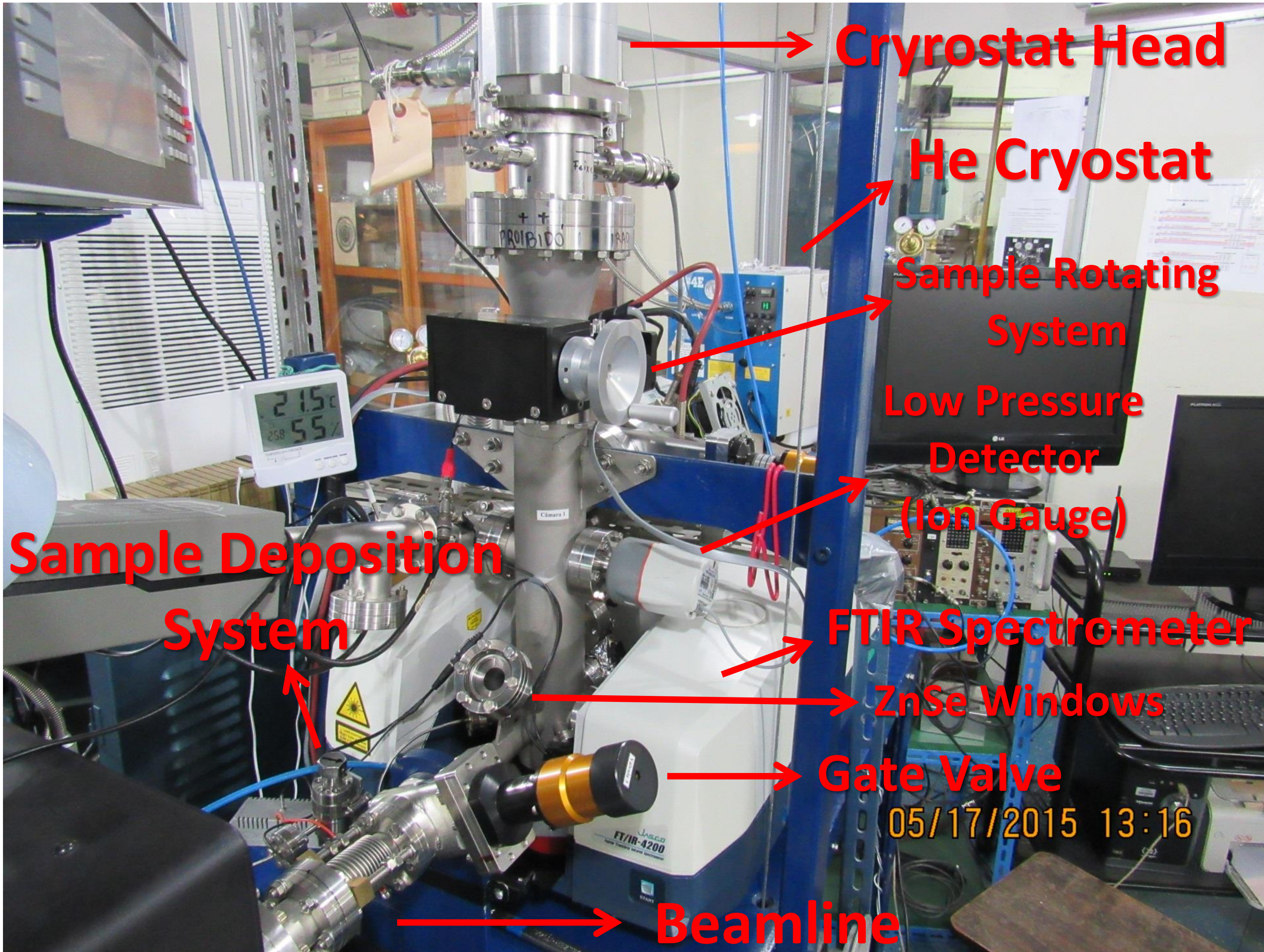
https://www.youtube.com/watch?v=qXktiWlmW7k

$H^+$, $He^+$, $C^+$, $N^+$ , $N_2^+$, $O^+$, $Ar^+$ Beams

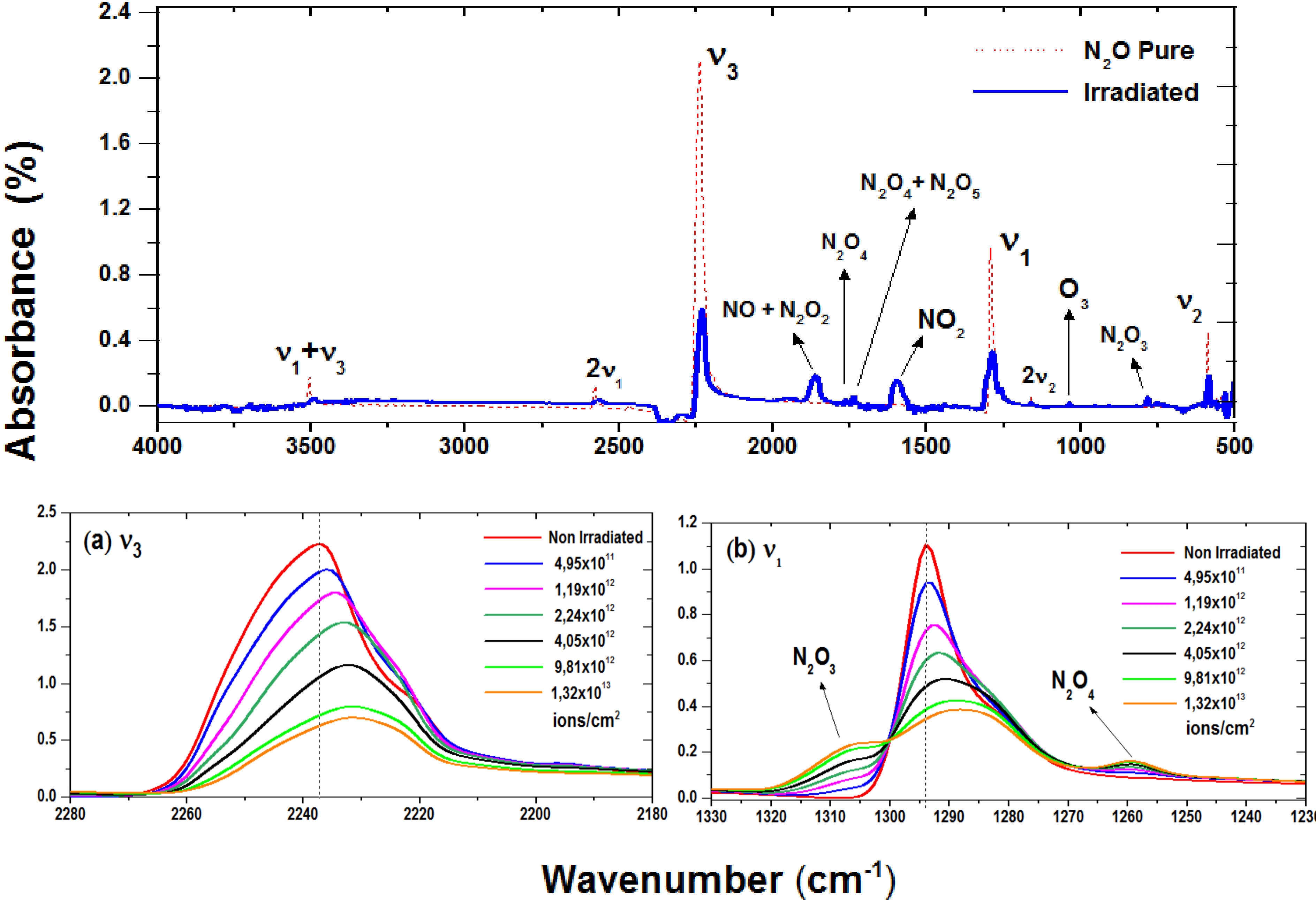
(0.5 - 4 MeV )

# VDG Experimental Station

# FTIR Beamline UHV Chamber Overview



# Results and Discussion



# Results and Discussion

$$N_0 = \frac{1}{A_\nu} \int \tau_\nu \, d\nu$$

| Peak Position[b] ($cm^{-1}$) | Peak Position[c,d] ($cm^{-1}$) | Peak Area | Assignments | Band Strength $A_\nu$ (x $10^{-17}$ cm $molecules^{-1}$) |
|---|---|---|---|---|
| 3508 | 3509[c] 3499[d] | 1.91 | $\nu_1 + \nu_3$ | 0.13[a] |
| 2580 | 2581[c] 2575[d] | 2.34 | $2\nu_1$ | 0.16[a] 0.15[b] |
| 2468 | 2469[c] 2466[d] | 0.33 | $\nu_1 + 2\nu_2$ | 0.02[a] |
| 2237 | 2239[c] 2235[d] | 82.5 | $\nu_3$ | 5.69[b] |
| 1294 | 1295[c] 1291[d] | 17.0 | $\nu_1$ | 1.17[a] 1.07[b] |
| 1164 | 1166[c] 1167[d] | 0.4 | $2\nu_2$ | 0.03[a] |
| 588 | 588[d] | 4.31 | $\nu_2$ | 0.30[a] |

*[b] This work. [c] Fulvio et al. (16K) . [d] Lapinski et al. (10K) [12]*

# Results and Discussion

| Wavenumber ($cm^{-1}$) | Mode | Molecule |
| --- | --- | --- |
| 1863 | NO Monomer Stretch[e,f,g] | NO* |
| 1836 | (A') NO Stretch[h] | $N_2O_3$ |
| 1765 | ON-NO Antisymetric Strech[g] | $N_2O_2$ |
| 1738 | ($B_{2u}$) NO Stretch[i]/ (A) Antisymetric NO Stretch[j] | $N_2O_4$/$N_2O_5$ |
| 1710 | (B) Antisymetric NO Stretch[h,j] | $N_2O_5$ |
| 1260 | ($B_{3u}$) NO Strech[i] | $N_2O_4$ |
| 1613 | Antisymetric strech[k] | $NO_2$ |
| 1038 | Antisymetric stretch[k] | $O_3$ |
| 1593 | $NO_2$ Antisymetric stretch[L] | $N_2O_3$ |
| 1307 | $NO_2$ Symetric stretch[L] | $N_2O_3$ |
| 784 | Deformation of $NO_2$ Group[L] | $N_2O_3$ |

**$N_2O$ Ice Irradiation → $N_xO_y$ (x = 1-2 and y = 1-5) oxides and $O_3$**

*In ice phase, NO is arranged in $(NO)_2$ units which has a different structure from the dimer $N_2O_2$ (Reference d).

[e] Fateley, Bent and Crawford Jr. (1959), [f] Varetti and Pimentel (1971), [g] Krim, (1998), [h] Stirling et al. (1994), [i] Wiener and Nixon, (1957), [j] Hisatsune, Devlin and Wada (1962), [k] Shimanouchi (1977), [L] Nour, Chen and Laane (1983).

# Ice Thickness Measurement

$$N_0 = \frac{1}{A_v}\int \tau_v \, dv$$

$$L_{ice} = \frac{N_0 M}{\rho A} \times 10^4$$

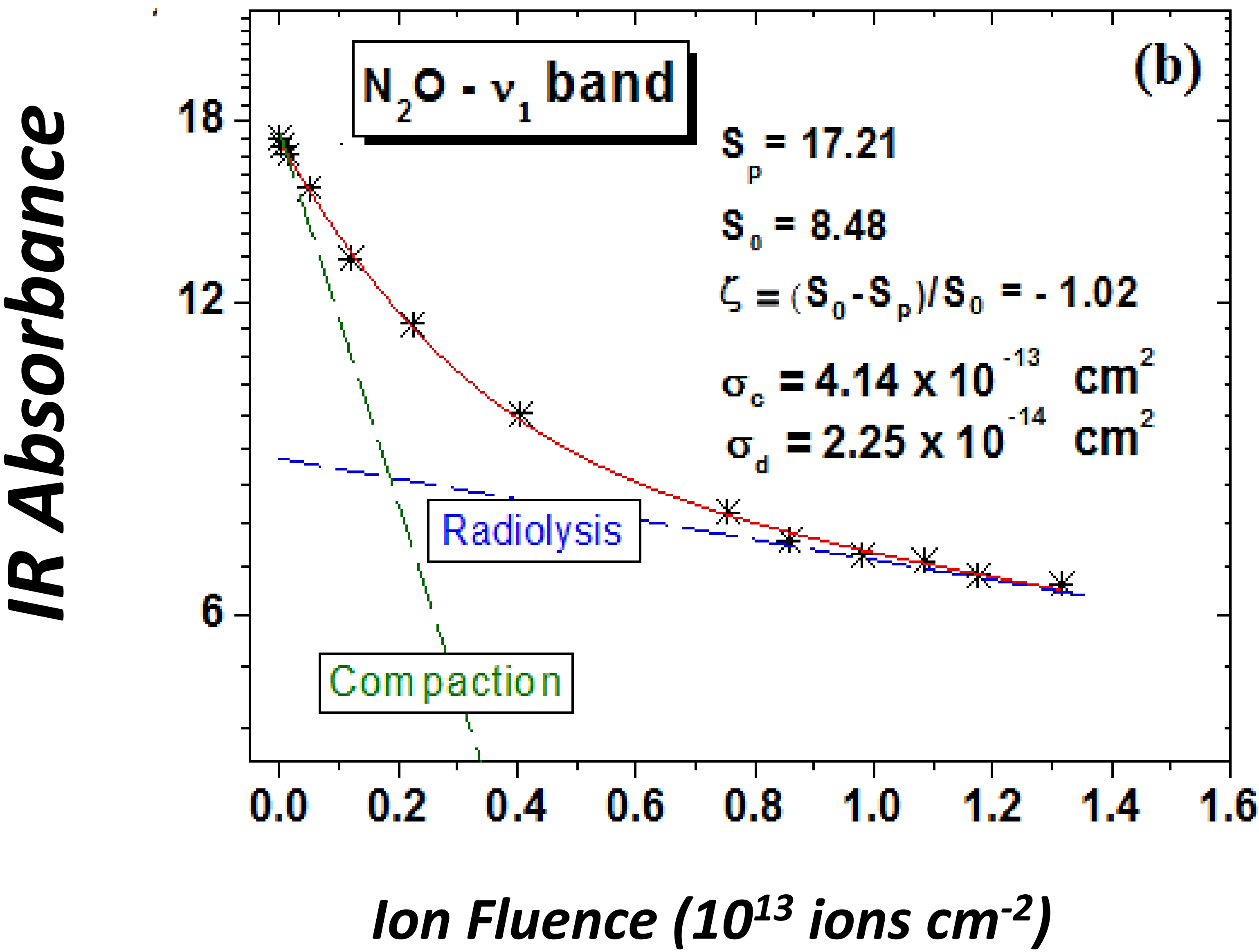
M = 44.01 g/mol    $\rho_{N2O\ solid}$ = 1.16 g/cm$^3$

$N_0$ = 3.34x10$^{18}$ molecules/cm$^2$

$L_{ice}$ = 2.1 µm

# Ice Radiolysis X Ice Compaction

## "A MeV Ion Tale"



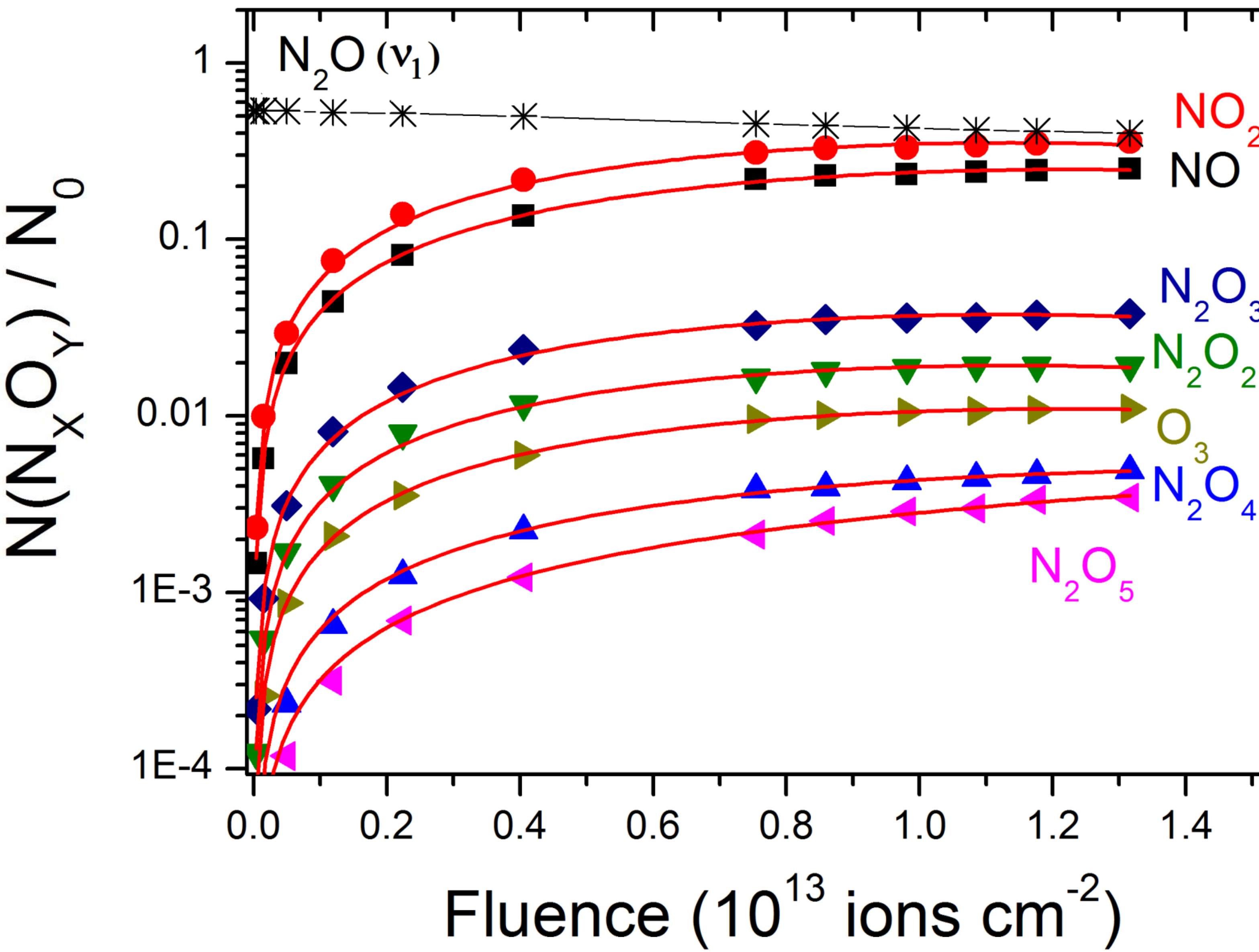
# Destruction and Compaction Cross Sections

$$S(F) = S_0 e^{(-\sigma_d F)} - S_0 \zeta e^{-(\sigma_c + \sigma_d)F}$$

"Ice Porosity"
$\zeta = (S_0 - S_P)/S_0$

| Mode | Feature ($cm^{-1}$) | $S_p$ | $S_0$ | $\zeta$ | $\sigma_c$ ($10^{-13}$ $cm^2$) | $\sigma_d$ ($10^{-13}$ $cm^2$) |
|---|---|---|---|---|---|---|
| $v_1 + v_3$ | 3508 | 1.90 | 0.45 | -3.39 | 4.73 | 0.26 |
| $2v_1$ | 2580 | 2.27 | 0.76 | -1.98 | 1.88 | 0.24 |
| $v_1 + 2v_2$ | 2468 | 0.11 | 0.12 | -0.04 | 2.48 | 0.25 |
| $v_3$ | 2237 | 84.9 | 20.1 | -3.22 | 3.78 | 0.27 |
| $v_1$ | 1294 | 17.2 | 8.48 | -1.02 | 4.14 | 0.23 |
| $2v_2$ | 1164 | 0.37 | 0.25 | -2.45 | 6.76 | 0.26 |
| $v_2$ | 588 | 4.11 | 1.59 | -1.58 | 2.85 | 0.25 |

# Results and Discussion



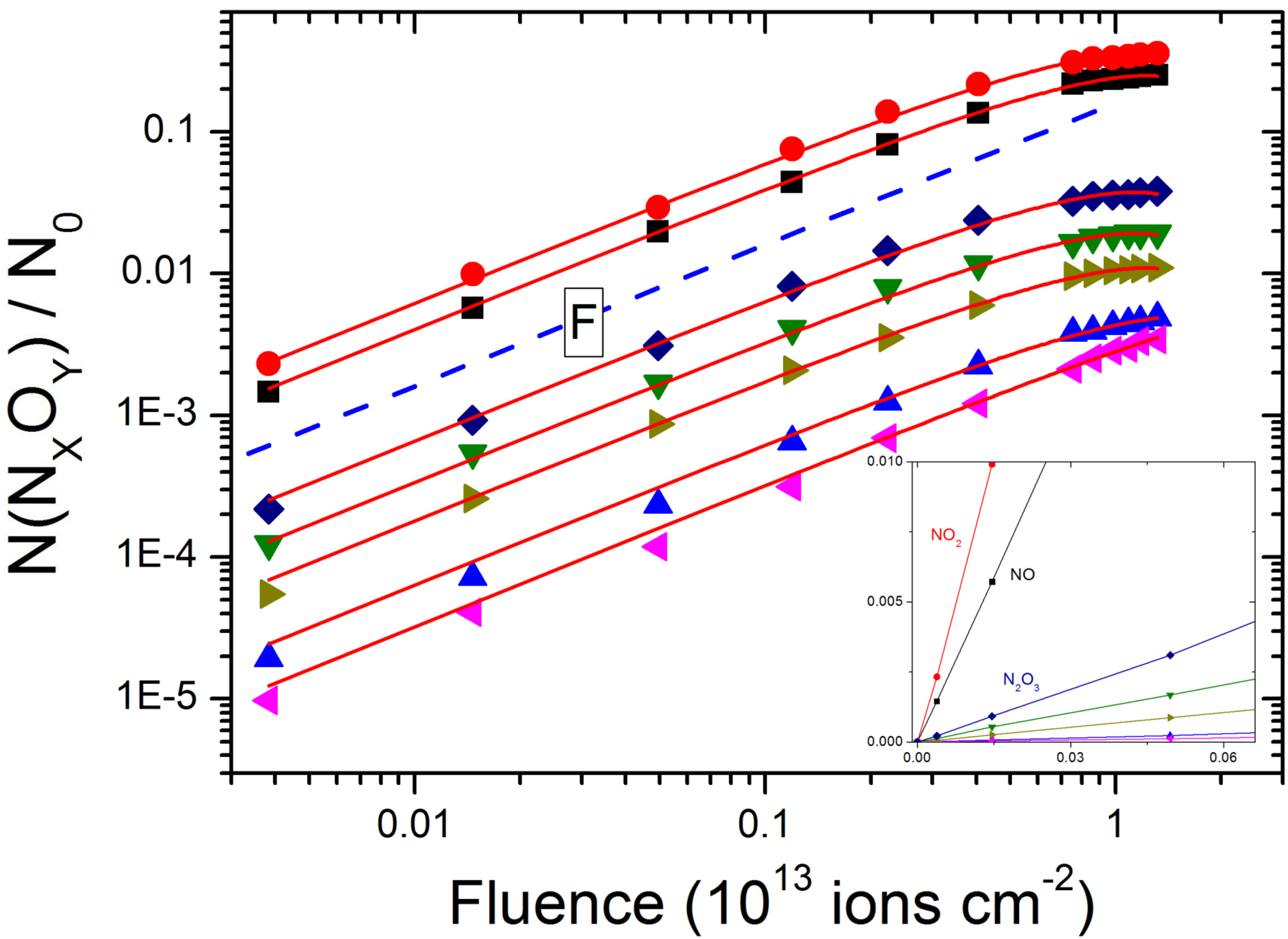
# Formation and Destruction Cross Sections
# "Daughter Species"

$$N_i(F) \approx N_0 \frac{\sigma_{f,i}}{\sigma_d - \sigma_{d,i}} [\exp(-\sigma_{d,i} F) - \exp(-\sigma_d F)]$$

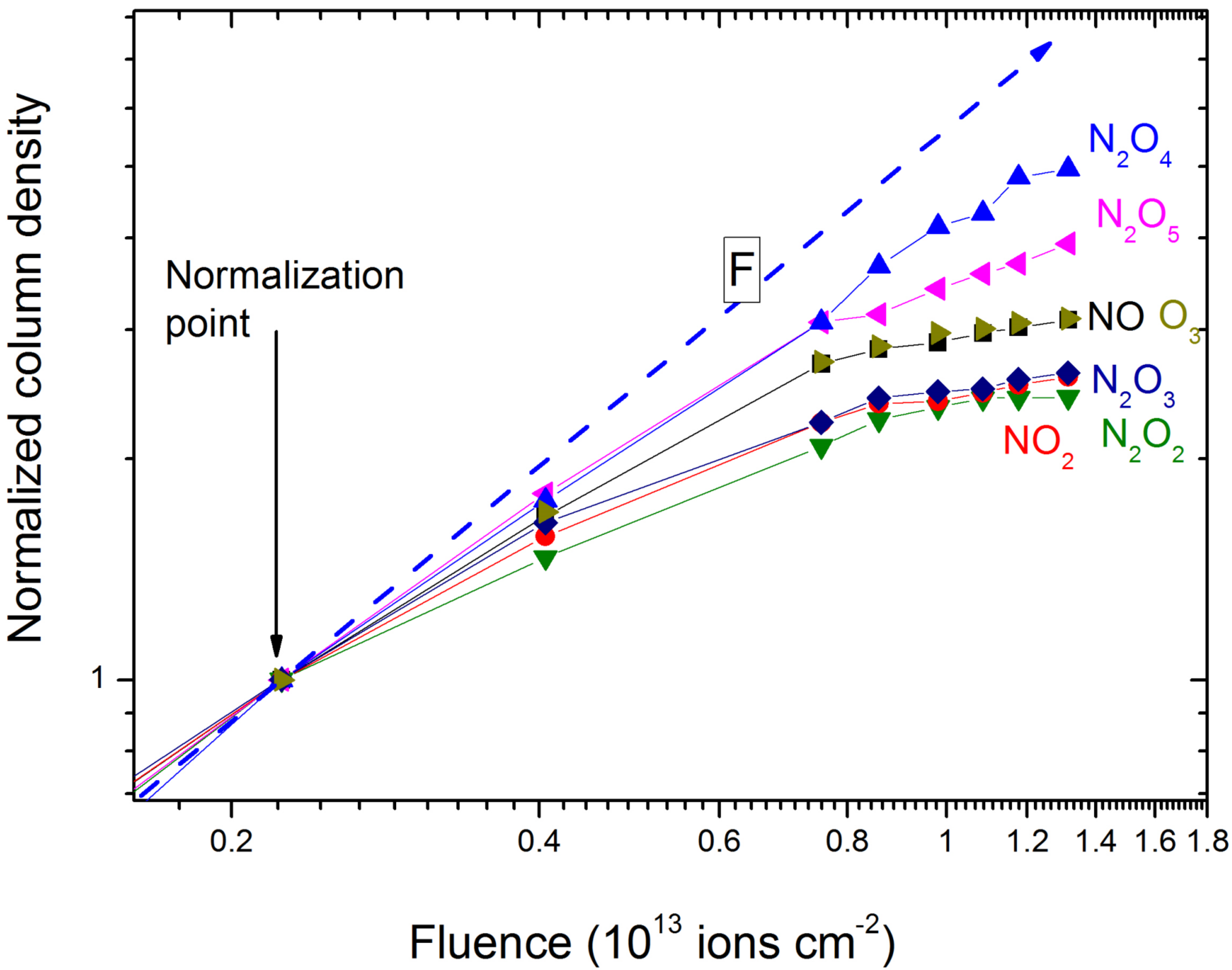
| Daughter Species | Vibration Mode ($cm^{-1}$) | Band Str. $A_v$ ( $10^{-17}$ cm molec.$^{-1}$)* | $N(F)_{end}$ ($10^{16}$ molec. $cm^{-2}$) | $\sigma_{f,i}$ ($10^{-14}$ $cm^2$) | $\sigma^{eff}$ ($10^{-14}$ $cm^2$) | $\sigma_{d,i}$ ( $10^{-14}$ $cm^2$) |
|---|---|---|---|---|---|---|
| NO | 1863 | 0.7 | 86.5 | 0.96 | 8.12 | 5.87 |
| $NO_2$ | 1613 | 6.3 | 123.4 | 2.09 | 8.79 | 6.49 |
| $N_2O_2$ | 1764 | 15.0 | 6.6 | 0.34 | 8.78 | 6.53 |
| $N_2O_3$ | 1836 | 6.4 | 13.1 | 0.63 | 8.85 | 6.59 |
| $N_2O_4$ | 1260 | 8.5 | 1.7 | 0.03 | 2.56 | 0.31 |
| $N_2O_5$ | 1710 | 3.8 | 1.2 | 0.06 | 3.19 | 0.94 |
| $O_3$ | 1038 | 1.4 | 3.8 | 0.18 | 8.23 | 5.98 |

*Jamieson et al. (Reference 3)

# Low Fluence Region



# High Fluence Region



# PHYSICAL CHEMISTRY ASPECTS

**Main Dissociation**

$$N_2O \xrightarrow{^{14}N^+} N_2 + O \quad (1)$$

$$N_2O \xrightarrow{^{14}N^+} N + NO \quad (2)$$

**Hot Plasma Reactions**

$$O + O \rightarrow O_2 \quad (3)$$

$$O + O_2 \rightarrow O_3 \quad (4)$$

$$N + O \rightarrow NO \quad (5)$$

$$N + O_2 \rightarrow NO_2 \quad (6)$$

$$N + NO_2 \rightarrow 2NO \quad (7)^n$$

$$NO_2 + O \rightarrow NO + O_2 \quad (8)^n$$

*$^n$Spealman and Rodebush (1935)*

# HOW ICE CHEMISTRY OCCURS?

**COLDER REGIONS**

$NO + O \rightarrow NO_2$ (OK) (9)
$N_2O + O \rightarrow N_2O_2$ (OK) (10)
$N_2O + O_2 \rightarrow N_2O_3$ (OK) (11)
$N_2O + O_3 \rightarrow N_2O_4$ (WRONG) (12)
$N_2O + 2O_2 \rightarrow N_2O_5$ (WRONG) (13)
$N_2O + O_3 + O \rightarrow N_2O_5$ (Very Very WRONG) (14)

$2NO_2 \rightarrow N_2O_4$ (MORE LIKELY) (15)
$2NO_2 + O \rightarrow N_2O_5$ (MORE LIKELY) (16)
(Inner Track Reactions)

ICARUS_2016_69 | Original V0 | Research paper

# Cosmic Ray Impact on N2O astrophysical ice analogs: Implications to Nitrogen Interstellar Chemistry and trans-Neptunian Objects.

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## Abstract

Nitrous oxide, N2O, is found in the interstellar medium associated with dense molecular clouds and its abundance is explained by active chemistry occurring on N2 rich ice surfaces of dust grains. Since solid N2O presents stronger features in the infrared spectra than solid N2, it is believed that N2O can be used as a tracer to indirectly determine solid N2 abundances in the Solar System as well as in molecular clouds. In particular, the N2O tracer method could be used for the analysis of the recent data acquired by the NASA New Horizons mission. Since cosmic rays are one of the main ionizing agents in space, the aim of this work is to experimentally simulate the effects of cosmic ray impact on N2O ice by irradiating N2O astrophysical ice analog at 10 K with 1.5 MeV N+ beam. The induced chemical modifications in the ice matrix were monitored by Fourier Transform Infrared Spectroscopy. Analyzing the absorbance evolution of all the vibration modes of N2O in ice phase, the destruction cross section of the N2O molecule and the formation cross sections of its radiolysis products, namely the NxOy (x = 1-2 and y = 1-5) oxides and the ozone (O3), were determined. NO2 and NO are the most abundant products. The O/O2 production ratio inside the ion beam track in the ice is estimated. The effects of ice radiolysis and of the ice compaction due to the MeV ion beam irradiation could be analyzed distinctly. A new method for determining the spatial distribution of the daughter molecules inside the projectile track in the ice is proposed and applied for the N2O ice. The current data may be helpful for a better understanding of the nitrogen chemistry in the interstellar medium.

## Keywords

Ice; FTIR; Cosmic Rays; MeV Ion Beam; trans-Neptunian Objects

# Conclusions

- ✓ The Relative band strengths for all $N_2O$ FTIR Bands found were determined.
- ✓ The most abundant oxide produced was $NO_2$ followed by NO, $N_2O_3$, $N_2O_2$, $O_3$, $N_2O_4$ and $N_2O_5$.
- ✓ We were able to separate the ice compaction and the ice radiolysis effects and determine the destruction cross sections $\sigma_d$ and compaction cross sections $\sigma_c$ for all $N_2O$ vibration modes.
- ✓ The compounds produced by $^{14}N^+$ ion irradiation are the same as the ones produced by 1 keV electrons (Prof. Nigel Mason's Work)[o] However the dynamics of production revealed to be completely different.
- ✓ The formation cross sections, $\sigma_{f,i}$, as well as the destruction cross sections, $\sigma_{d,i}$, for the compounds produced by solid $N_2O$ radiolysis were determined.
- ✓ These data may also be helpful for future astronomical investigations beyond Neptune's orbit and also for a better understanding of interstellar nitrogen chemistry.

[O] *B.Sivaraman, et al. Chem. Phys. Lett., 2008, 460, 108-111.*

# “You don’t really know Brazil until you know Rio de Janeiro”

**(Seu Jorge)**

# OBRIGADO!

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