Laboratory Studies in Support of Planetary Missions -- Titan

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NASA Ames Research Center

OPAG May 1-2, 2007

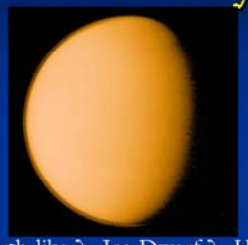
Premise

- *Cassini* and *Huygens* data on Titan require supporting lab work for full interpretation
- Planning for any future mission to Titan will benefit from laboratory studies undertaken over next decade
- Large investments have been made in laboratory installations, but operating funds are lacking

Goal of this Presentation

- A recommendation from OPAG to NASA in support of funding for Titan-directed lab studies is needed.
- Beyond support for current data, new techniques for *in situ* sampling and analysis on Titan must be developed.
  - Atmospheric gas and aerosols
  - Surface chemistry, wet and dry
  - Emphasis on organic chemistry

Titan's complexity requires laboratory research in several areas



[Earth-like ? Ice-Dwarf ? Habitable ?]

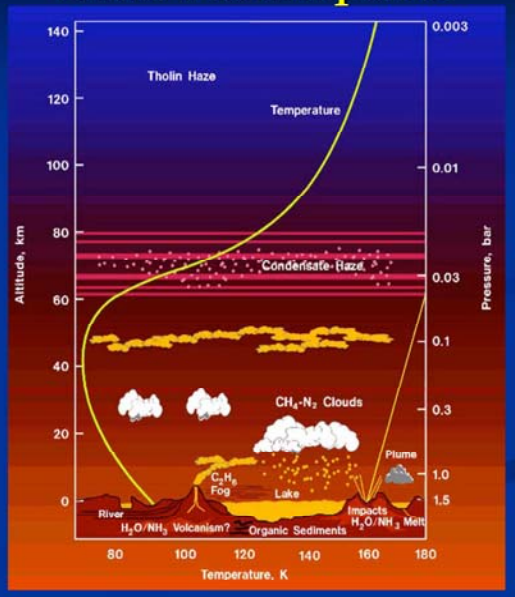
[Bird ? Reptile ? Mammal ?]

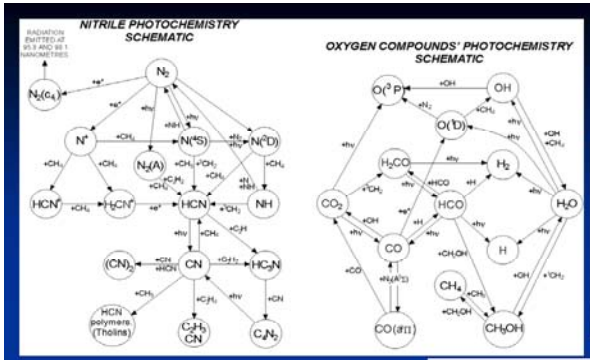
- Atmospheric chemistry
  - Ionosphere
  - Middle and lower atmospheres
  - Gases and aerosols
- Surface chemistry
  - Surface-atmosphere interactions
  - Mixed ices
  - Ice-aerosol interactions
- Astrobiology
  - (all of the above)
- Geology
  - Cryovolcanism
  - Impacts and other structures in ice
  - Dune formation

TITAN's ATMOSPHERE

Constituent	Mixing ratio
N_2	~ 0.98
Ar	<0.07
CH_4	~ 0.018
H_2	1.1×10^{-3}
C_2H_6	2.0×10^{-5}
CO	3.2×10^{-5}
	$5\text{-}7\times10^{-5}$
CH_3D	1.1×10^{-5}
D/H	8.7×10^{-6}
C_2H_2	5.5×10^{-6}
HC_3N	3.0×10^{-7}
C_3H_8	2.0×10^{-7}
C_2H_4	1.2×10^{-7}
CO_2	2.0×10^{-8}
C_3H_4	1.2×10^{-8}
H_2O	8.0×10^{-9}
C_4H_2	2.0×10^{-9}
CH_3CN	1.5×10^{-9}
C_6H_6	4.0×10^{-10}
C_3H_4	$<2.0\times10^{-9}$
C_2N_2	$<1.0\times10^{-9}$
C_4N_2	

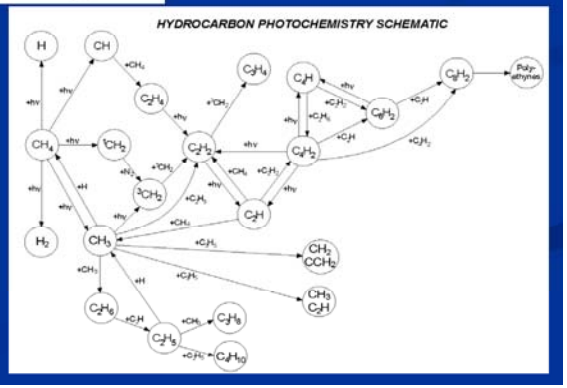
The complexity of Titan's atmosphere





Atmosphere

Laboratory studies are needed to provide fundamental data to enable modeling.



Rate constants & branching ratios

Photochemistry
Neutral – Neutral
Ion - Neutral

Ionization ReactionRate at 1 AU, Solar Minimum, Optically Thin Conditions

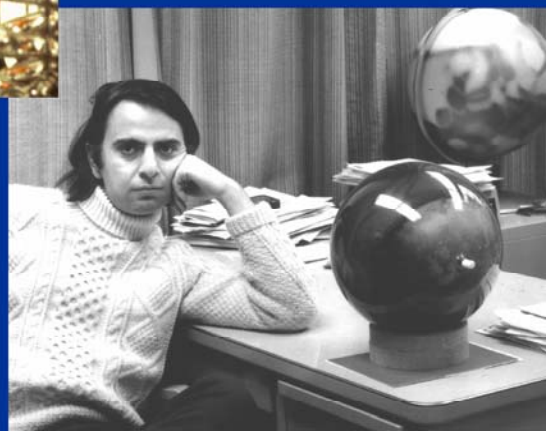
H2O + hν --> H2O+ + e-	k = 3.3 x 10-7 s-1
C3H2 + hν --> C3H2+ + e-	k = 5.5 x 10-7 s-1
C3H4 + hν --> C3H4+ + e-	k = 5.5 x 10-7 s-1
C3H4 + hν --> C3H2+ + H2 + e-	k = 2.0 x 10-7 s-1
C3H6 + hν --> C3H6+ + e-	k = 5.5 x 10-7 s-1
C3H6 + hν --> C3H4+ + H2 + e-	k = 2.0 x 10-7 s-1
C3H6 + hν --> C3H2+ + 2H2 + e-	k = 0.1 x 10-7 s-1
C3H8 + hν --> C3H6+ + H2 + e-	k = 2.0 x 10-7 s-1
C3H8 + hν --> C3H4+ + 2H2 + e-	k = 0.1 x 10-7 s-1
C4H2 + hν --> C4H2+ + e-	k = 2.0 x 10-7 s-1

Keller, Anacich, Cravens

Aerosols

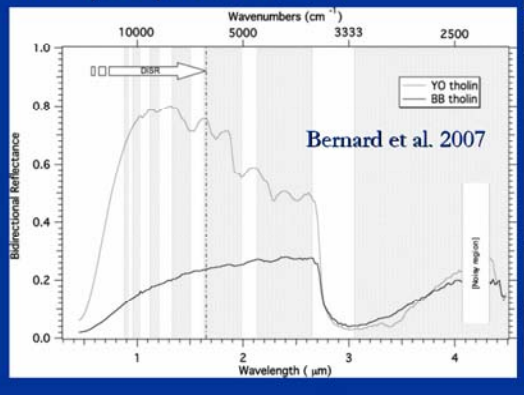
Tholins made at Cornell to simulate Titan's aerosol

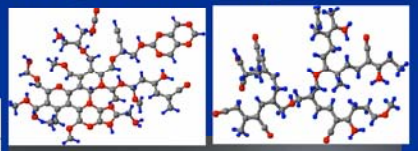
Energy deposition in mixtures of simple reducing gases produces complex refractory solid material

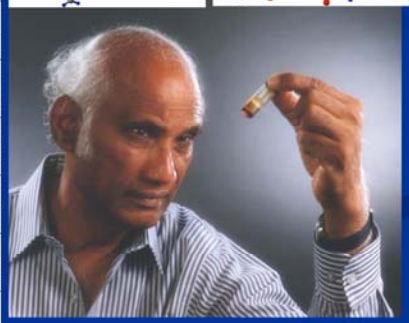


Tholin Studies

- Formation
- Optical properties (refractive indices)
- Role of tholins in maintaining CH_4 mixing ratio in atmosphere
- Structure
- Hydrolysis of tholins







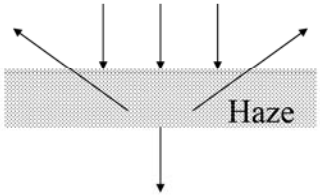
B. N. Khare

Complex refractive indices (optical constants)

Complex refractive index : $m = n + i\,k$

Atmospheric haze

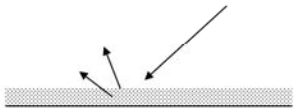
Radiative transfer



Thermal structure

Surface material

Surface Reflectance

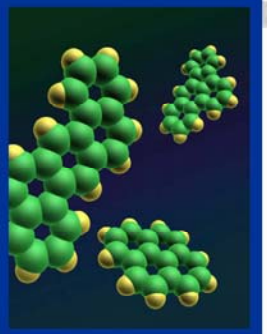


Identification of organic material?

Systematic study of n & k for various tholins as a function of experimental parameters

Astrobiology

- The irradiation of aromatic hydrocarbons in H_2O ice produces molecules of biological significance.

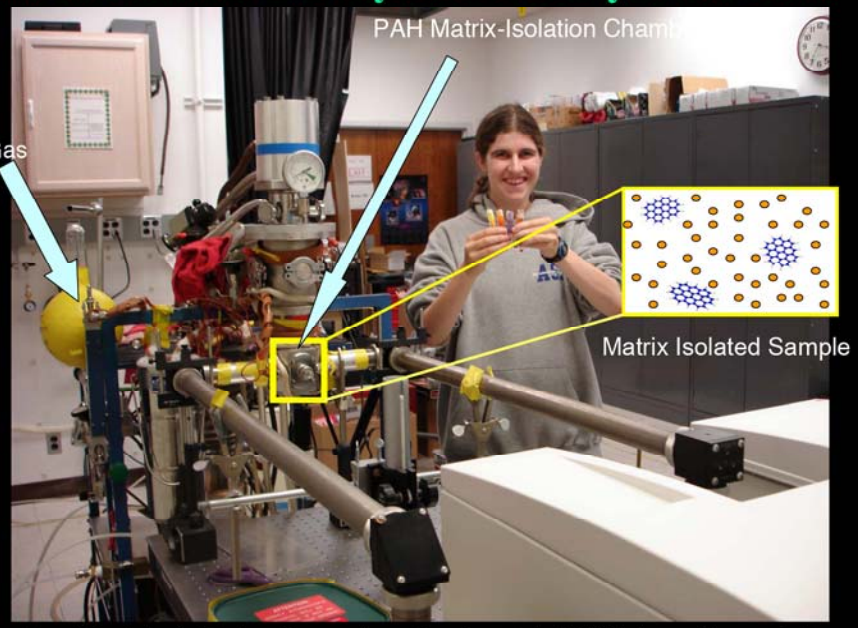


REPORTS

UV Irradiation of Polycyclic Aromatic Hydrocarbons in Ices: Production of Alcohols, Quinones, and Ethers

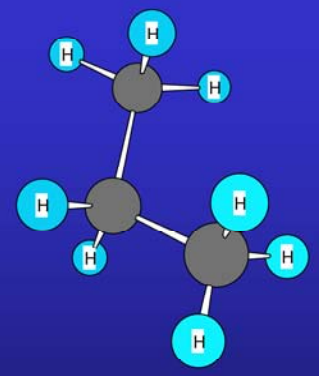
Max P. Bernstein,[1,2*] Scott A. Sandford,[1] Louis J. Allamandola,[1] J. Seb Gillette,[3] Simon J. Clemett,[3] Richard N. Zare[3]

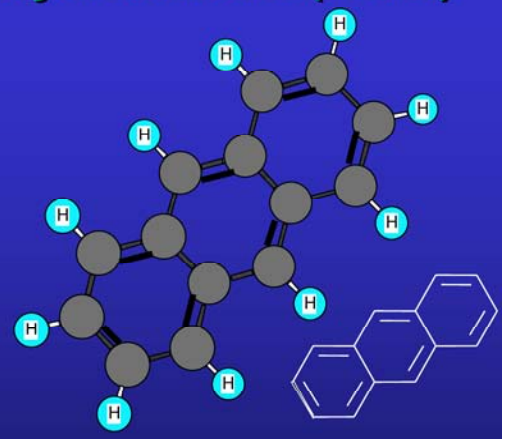
Matrix isolation of Polyaromatic Hydrocarbons



Andrew Mattioda & Lindsay Rutter, Astrochemistry Lab, NASA Ames Research Center

Polycyclic Aromatic Hydrocarbons (PAHs)





Aliphatic Carbon Molecule

Propane

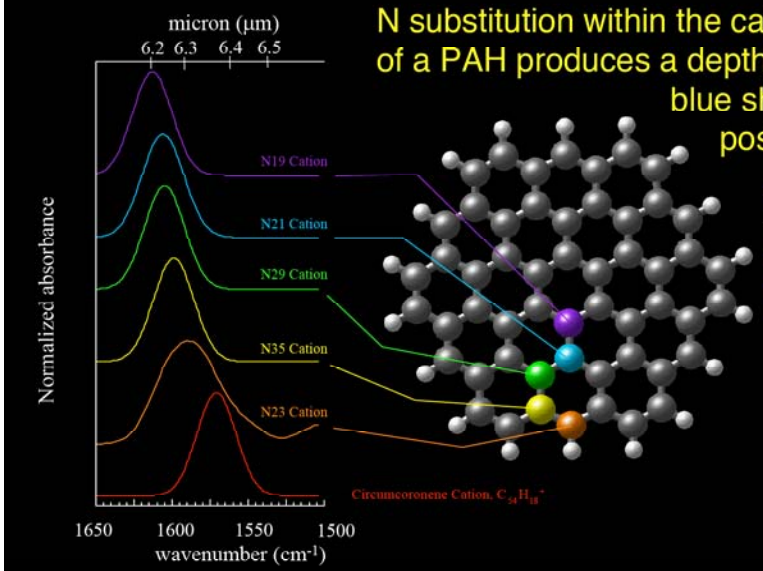
C_3H_8

PAH

Anthracene

$C_{14}H_{10}$

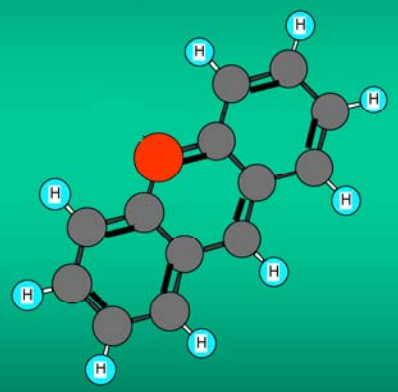
"Endoskeletal" Polycyclic Aromatic Nitrogen Heterocycles, PANHs



N substitution within the carbon skeleton of a PAH produces a depth-dependant blue shift in the position of the dominant CC stretching feature near 6.2 μm.

Astrobiological Significance

Inserting a nitrogen in a PAH …



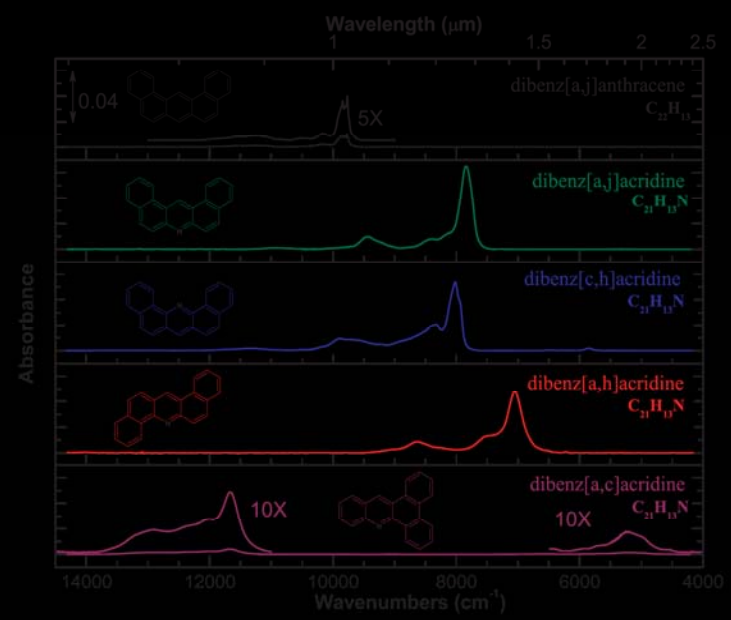
Anthracene ($C_{14}H_{10}$)

↓

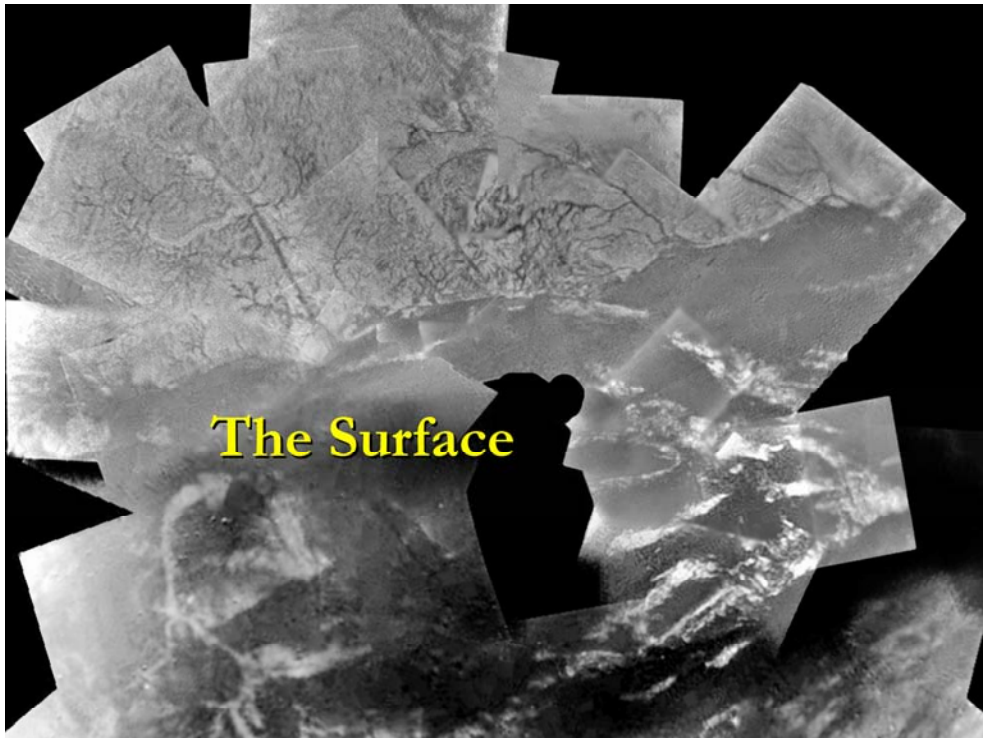
Acridine ($C_{13}H_9N$)

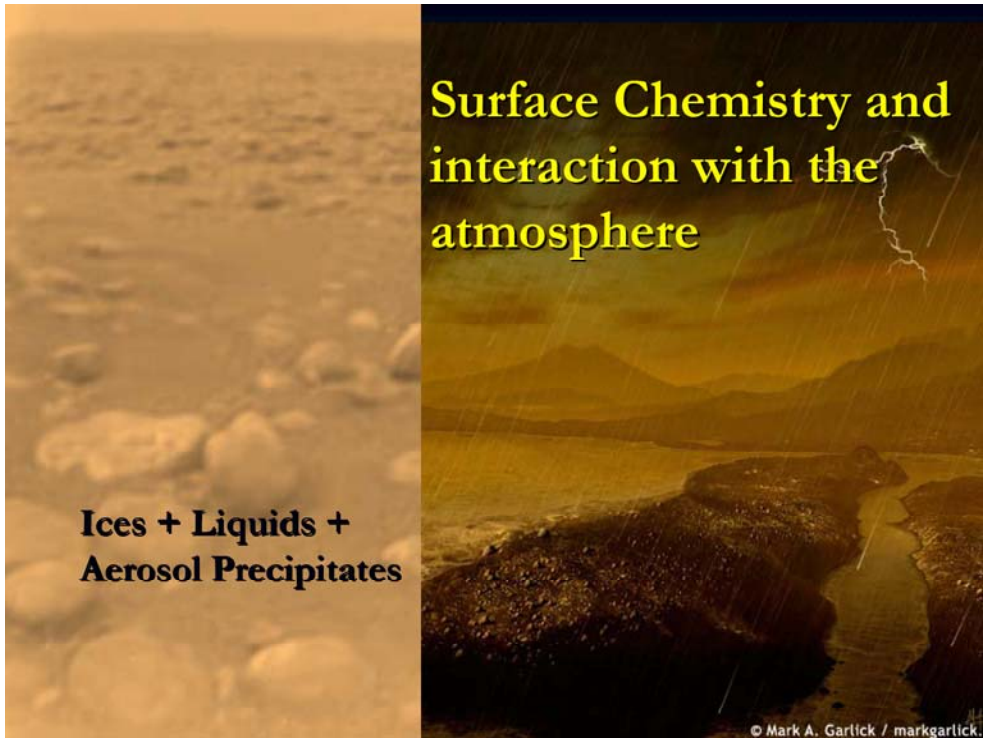
creates a Polycyclic Aromatic Nitrogen Heterocycle (PANH)

Influence of Nitrogen on the PAH NIR transitions.

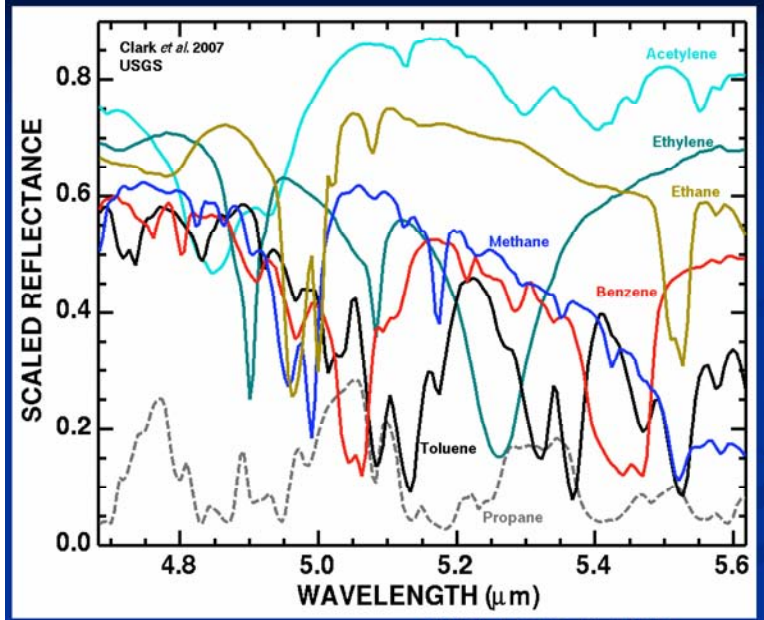


Andrew L. Mattioda, Lindsay Rutter , John Parkhill, Martin Head-Gordon, Timothy J. Lee and Louis J. Allamandola, ApJ 2007 (submitted)



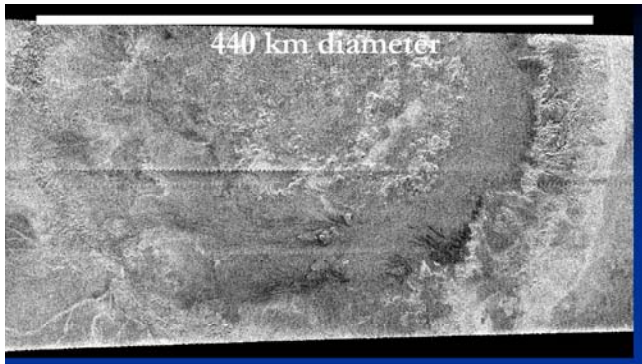


The complexity of Titan's icy surface

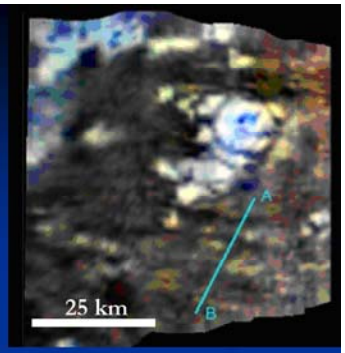


Reflectance spectra of organic ices

R.N. Clark & J. Curchin, USGS

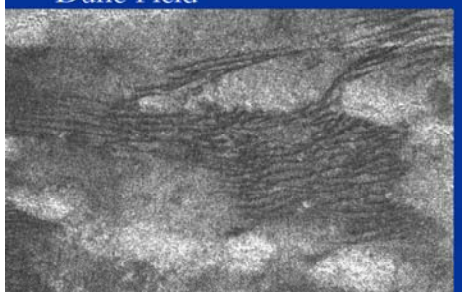


Impact Crater



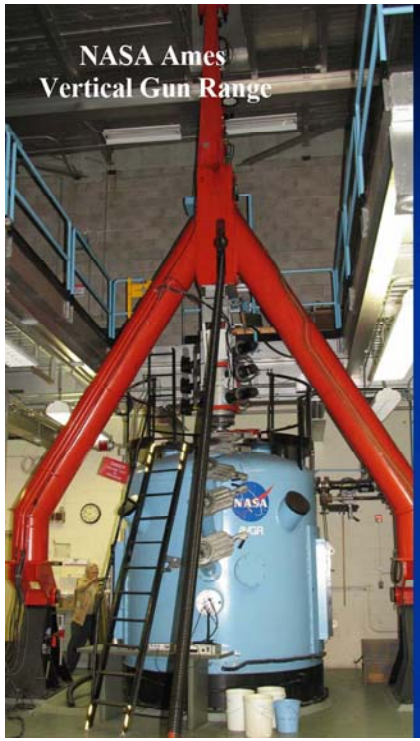
Cryovolcanic Extrusion ?

Dune Field

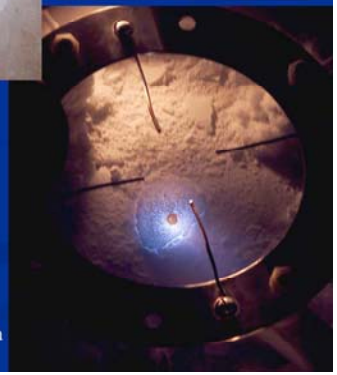


Geology

- Cryovolcanism (role of NH_3, if any)
- Impact cratering
- Dune field formation



Ice-Impact Studies of Organic Synthesis



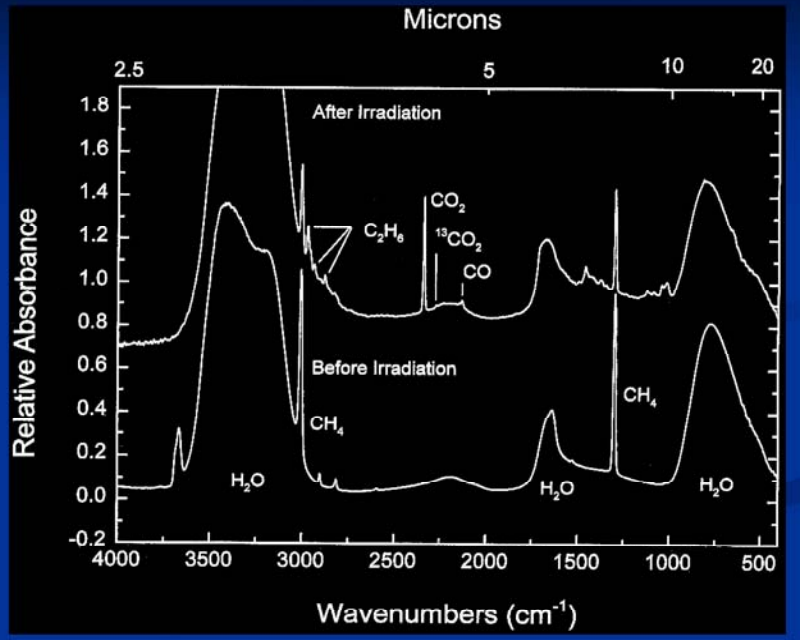
~6 km/sec impacts in ices generate shock and electrical impulses that may initiate organic chemical reactions.

J. Borucki, D. Cruikshank, B. N. Khare, M. P. Bernstein

Irradiation of ices produces new species

Ion irradiation of H_2O + CH_4

Moore & Hudson, 1998



Some titles from an NSF-sponsored Titan laboratory workshop (Honolulu, Feb. 5-7, 2007) - I

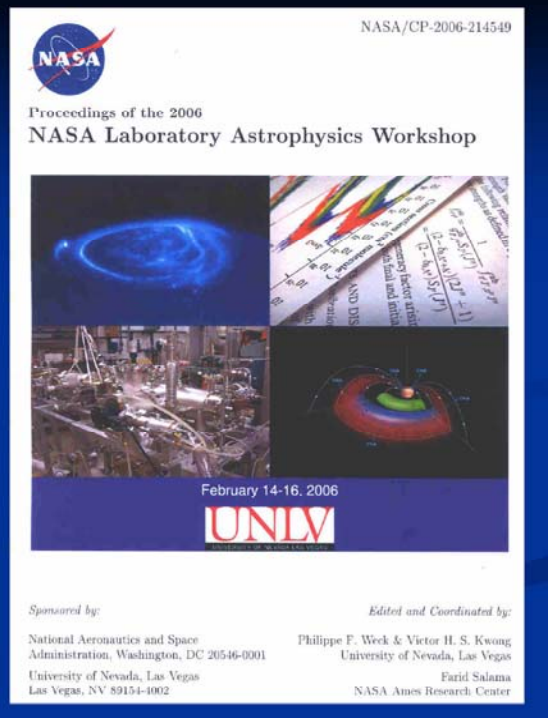
- C_2H reactions: Low-temp. kinetics and product detection (S. R. Leone)
- Photolysis of simulated Titan atmospheres with HCN and CO: Complex refractive index of haze analogs (B. Tran et al.
- Formation of carbon aerosols in Titan's atmosphere (F. Salama et al.)
- Rate constants of neutral-neutral reactions in Titan's atmosphere (C. Berteloite et al.
- Bimolecular reactions of radicals with unsaturated hydrocarbons—buildup of aerosols (Y. Guo et al.)
- Ion imaging of hydrocarbon growth by photochemistry (A. G. Suits et al.)
- Tholin influence on CH4 mixing ratio in the atmosphere (B. N. Khare et al.)

Some titles from an NSF-sponsored Titan laboratory workshop (Honolulu, Feb. 5-7, 2007) - II

- Role of photoionization in forming complex organic molecules in Titan's upper atmosphere (H. Imanaka et al.)
- Spectroscopy of Titan tholins (E. Quirico et al.)
- Cryogenic IR reflectance spectroscopy of organic ices (J. Curchin et al.)
- Formation of 5-Carbon-atom molecules in Titan's atmosphere (F. Goulay & S. R. Leone)
- New lab. Studies of titan's ionospheric chemistry (R. Thissen et al.)
- Spectroscopy of hydrocarbon radicals in gas phase and cryogenic matrices (Zhang, X. et al.)
- Kinetic measurements of hydrolysis of tholins: Implications for prebiotic chemistry on Titan (C. D. Neish et al.)

Proceedings of the most recent NASA Laboratory Astrophysics Workshop

February 14-16, 2006



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NASA Ames Research Center

NASA's Laboratory Astrophysics Program

- ROSES solicitation
- Lab astro is a sub-element of APRA (Astronomy and Physics Research and Analysis Program
- In FY 2006, 33 investigations funded for total of ~$3.8 million
  - 4 infrared
  - 9 supporting interstellar medium studies
  - 5 sub-millimeter spectroscopy
  - 8 UV/optical atomic processes
  - 2 UV/optical molecular and dust formation processes
  - 5 X-ray mission supporting investigations

Information from Hashima Hasan, NASA HQ

Proposal to the American Astronomical Society for a Working Group on Laboratory Astrophysics & Astrochemistry

- Steering Committee consisting of
  - Paul Goldsmith (JPL)
  - Steve Federman (U Toledo) - Chair.
  - Farid Salama (Ames Res. Center)
  - Daniel Savin (U Colombia)
- AAS Council has given its initial encouragement of this effort
- Cruikshank has encouraged Consolmagno (DPS Chair) to support this effort, with some kind of DPS participation

The End