Reaching Pluto, and the End of an Era of Planetary Exploration

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OUT THERE

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As long as scientists can keep prying nickels from the clenched fists of legislators, probes will keep popping off to Mars every couple of years. NASA now has plans to send a spacecraft to Jupiter's moon Europa, which has a salty ocean underneath its ice, and may get around to flying a probe through the geysers spurting from the Saturnian moon Enceladus someday to sniff for organic materials. My personal favorite is the idea to send a boat to float around on the methane seas and lakes of Titan, Saturn's biggest moon.

The discovery of one microbe anywhere out there that was not our own would be the greatest scientific event of the age.

Table 1a. Compounds Identified on Titan: Atmosphere[a]

Compound	Location and Abundance
	Major and Minor Gases (in Decreasing Abundanc
Nitrogen, N_2	95% near surface 98+% in stratosphere ~97% near 1000 km
Methane, CH_4	~5% near surface 1.4% in stratosphere ~2% above 1000 km
Hydrogen, H_2	~0.1% in lower atmosphere 0.4% above 1000 km
Argon, Ar	43×10^{-6} in stratosphere (^{40}Ar) 0.28×10^{-6} in stratosphere (^{36}Ar)
	Hydrocarbons[c] *(in Decreasing Abundance)*
Ethane, C_2H_6	$10 - 20 \times 10^{-6}$ in stratosphere $8 - 20 \times 10^{-6}$ near 1000 km 120×10^{-6} above 1000 km
Monodeuterated Methane, CH_3D	~7.5×10^{-6} in stratosphere
Acetylene, C_2H_2	$3 - 4 \times 10^{-6}$ in stratosphere $200 - 260 \times 10^{-6}$ near 1000 km ~190×10^{-6} above 1000 km
Propane, C_3H_8	$0.5 - 0.8 \times 10^{-6}$ in stratosphere $<5 \times 10^{-6}$ above 1000 km
Ethylene, C_2H_4	$0.1 - 0.2 \times 10^{-6}$ in stratosphere $680 - 1000 \times 10^{-6}$ near 1000km $200 - 500 \times 10^{-6}$ above 1000 km
Propene, C_3H_6 (propylene)	$1.5 - 4 \times 10^{-6}$ near 1000 km
~~2-~~Propyne, C_3H_4 (methylacetylene)	$5 - 20 \times 10^{-9}$ in stratosphere 40×10^{-9} in stratosphere $7 - 12 \times 10^{-6}$ near 1000 km 4×10^{-6} above 1000 km

~~2-~~Propyne, C_3H_4 (methylacetylene)	$5 - 20 \times 10^{-9}$ in stratosphere 40×10^{-9} in stratosphere $7 - 12 \times 10^{-6}$ near 1000 km 4×10^{-6} above 1000 km
1,3-Butadiyne, C_4H_2 (diacetylene)	$1 - 15 \times 10^{-9}$ in stratosphere 40×10^{-9} in stratosphere $2 - 6 \times 10^{-6}$ near 1000 km 0.5×10^{-6} above 1000 km
Benzene, C_6H_6	up to 3×10^{-9} in stratosphere; $\sim 0.3 \times 10^{-9}$ everywhere else $1 - 5 \times 10^{-6}$ near 1000 km $<5 \times 10^{-6}$ above 1000 km
Monodeuterated Acetylene, C_2HD	1.3×10^{-9} atmosphere average
Toluene, $C_6H_5CH_3$ (methylbenzene)	$<1 \times 10^{-6}$ *inferred* near 1000 km
Naphthalene, $C_{10}H_8$	$<1 \times 10^{-6}$ *inferred* near 1000 km
	Nitriles[c] *(in Decreasing Abundance)*
Hydrogen Cyanide, HCN	$50 - 800 \times 10^{-9}$ in stratosphere $<5 \times 10^{-6}$ above 1000 km
Cyanoacetylene, HC_3N	$0.1 - 25 \times 10^{-9}$ in stratosphere $<5 \times 10^{-6}$ near 1000 km
Acetonitrile, CH_3CN (methyl cyanide)	"a few ppb" in upper atmosphere
Acrylonitrile, C_2H_3CN (~~ethyl~~ cyanide) vinyl	$<2 \times 10^{-9}$ in stratosphere (estimate *inferred* from data)

Cyanogen, C_2N_2	5×10^{-9} in stratosphere $2 - 6 \times 10^{-6}$ above 1000 km 55×10^{-12} in stratosphere
Dicyanoacetylene, C_4N_2	0.4×10^{-9} *inferred* at 90 km
Propionitrile, C_2H_5CN	$<2 \times 10^{-9}$ in stratosphere
Cyanodiacetylene, HC_5~~C~~N	$<0.4 \times 10^{-9}$ in stratosphere

Isomer of methyl acetylene CH2CHCH2

	Oxidized Species and Others (in Decreasing Abundance)
Carbon Monoxide, CO	$\sim 47 \times 10^{-6}$ in stratosphere
Carbon Dioxide, CO_2	$\sim 15 \times 10^{-9}$ in stratosphere
Water, H_2O	$<0.9 \times 10^{-9}$ in stratosphere 8×10^{-9} near 1000 km
Ammonia, NH_3	trace component of haze aerosols

Methyl Cyanide C2H5CN

Table 1b. Compounds Identified on Titan: Surface[a]

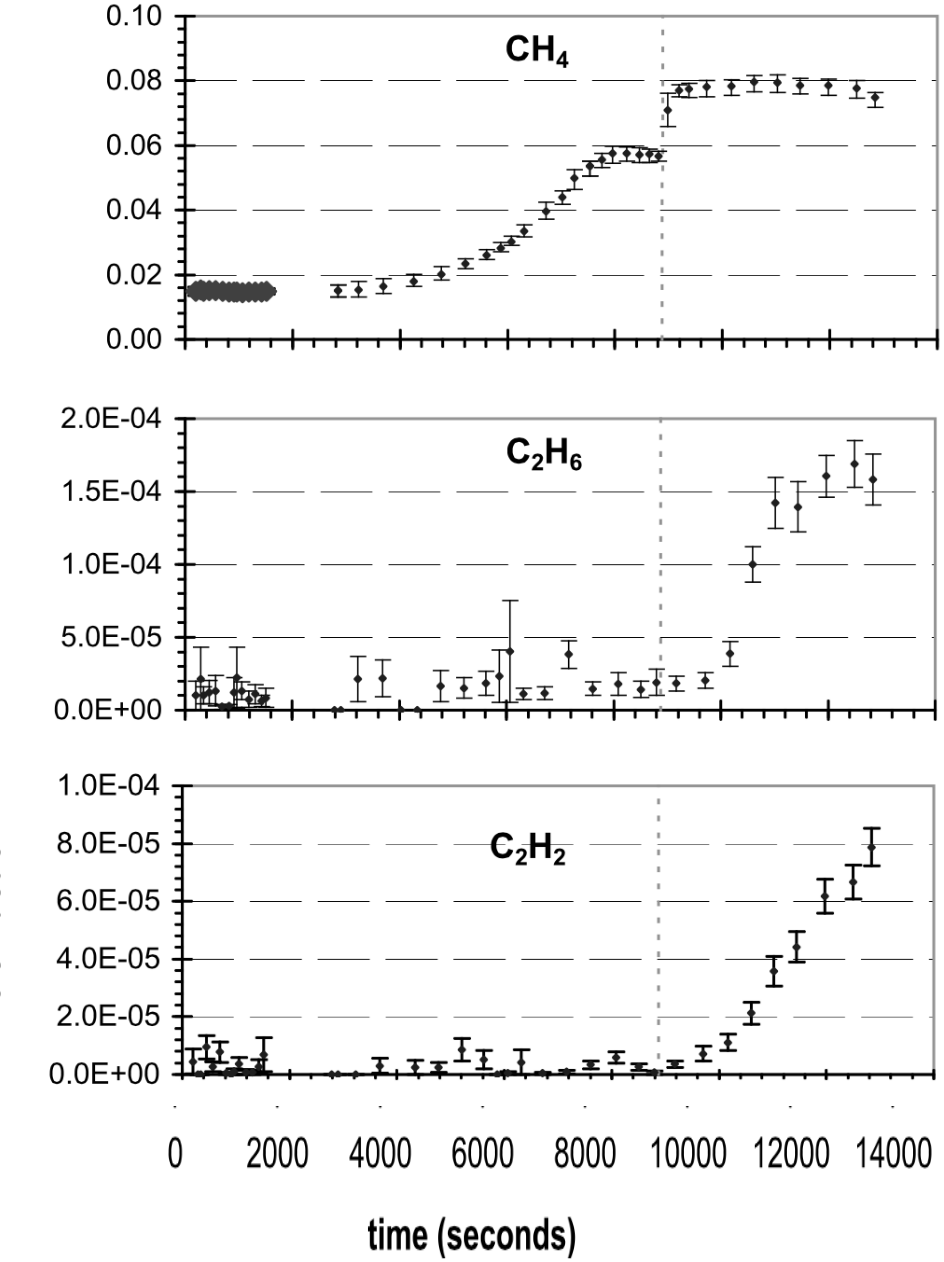
Compound	Location Including Spectral Basis	Methods of Detection Including Author's "Confidence"[b]	Group and Year
		Major Hydrocarbons and Nitrile Condensates	
Methane, CH_4	Huygens Landing Site	GCMS (firm)	*Niemann et al.* [2005]
	Select locations in 'dark' terrain	VIMS (probable, from absorption feature.)	This study
Ethane, C_2H_6	Huygens Landing Site	GCMS (firm)	*Niemann et al.* [2005]
	Ontario Lacus	VIMS (firm)	*Brown et al.* [2008]
	Select locations in 'dark' terrain	VIMS (probable, from absorption feature.)	This study
Benzene, C_6H_6	Huygens Landing Site	GCMS (tentative)	*Niemann et al.* [2005]
	Select locations in 'dark' terrain, especially Fensal/Aztlan	VIMS (definite, from absorption feature.)	This study
Cyanoacetylene, HC_3N	Select locations in 'bright' terrain	VIMS (possible)	This study
Toluene, C_7H_8	Select locations in 'dark' terrain	VIMS (possible but not definitive)	This study
Cyanogen, C_2N_2	Huygens Landing Site	GCMS (tentative)	*Niemann et al.* [2005]
Acetonitrile, CH_3CN	Select locations in 'dark' terrain	VIMS (possible but not definitive)	This study

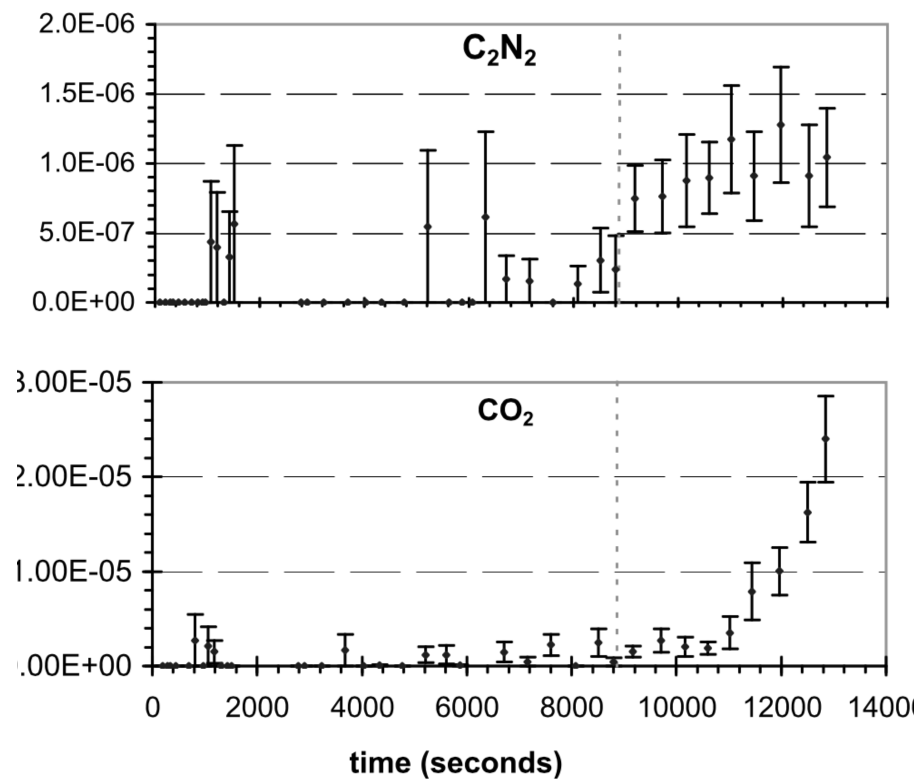
Oxidized and Other Species, includin

Water, H_2O	Extensively exposed	UKIRT and IRTF
	Disk-averaged surface spectra	ISO
	~25% leading hemisphere; 12 – 15% trailing hemisphere	ESO – ISAAC
	Huygens Landing Site	DISR (inconclusive)
	Huygens Landing Site	VIMS, Cassini
	Huygens Landing Site	DISR recalibrated
	'Dark features', eg. Adiri, Quivira where κ ~ 2.8	RADAR scatterometry ('compatible' with water ice)
	1 of 2 'averaged' surface terrains	RADAR radiometry

Carbon Dioxide, CO_2	Huygens Landing Site 5-μm bright Tui Regio region	GCMS (tentative) VIMS
	2.74 μm abs. in surface spectra	ISO
	Disk-averaged dielectric constant $\kappa \sim 1.75 - 2.50$	RADAR reflectivity
Ammonia, NH_3	Select locations in 'dark terrain'	VIMS (could contribute to slope)
	Select bright areas	VIMS (could contribute to slope)
'Yellow Tholin'	Huygens Landing Site	DISR (to fit red slope in the visible)
Neutral Absorber	Huygens Landing Site	DISR (to fit blue slope from 0.83 to 1.42 μm)
'Dark Tholin' (Tholin 4 of Cruikshank, 1991)	Disk-averaged surface spectra	UKIRT and IRTF (to fit blue slope > 1.5 μm)

GCMS surface





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