The Formation of Titan's Atmosphere

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The origin and evolution of Titan

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1.1 Introduction

Although Titan is similar in terms of mass and size to Jupiter's moons Ganymede and Callisto, it is different in that it is the only one harboring a massive atmosphere. Moreover, unlike the Jovian system, which is populated with four large moons, Titan is the only large moon around Saturn. The other Saturnian moons are much smaller and have an average density at least 25 percent less than Titan's uncompressed density and much below the density expected for a solar composition (Johnson and Lunine, 2005), although with a large variation from satellite to satellite. Both Jupiter's and Saturn's moon systems are thought to have formed in a disk around the growing giant planet. However, the difference in architecture between the two systems probably reflects different disk characteristics and evolution (e.g., Sasaki et al., 2010), and, in the case of Saturn, possibly the catastrophic loss of one or more Titan-sized moons (Canup, 2010). Moreover, the presence of a massive atmosphere on Titan, as well as the emission of gases from Enceladus' active south polar region (Waite et al., 2009), suggest that the primordial building blocks that comprise the Saturnian system were probably more volatile-rich than those of Jupiter.

The composition of the present-day atmosphere ... Mass Spectrometer (GCMS) on *Huygens* (Niemann et al., 2005, 2010) suggests that nitrogen was brought to Titan not in the form of N_2, but rather in the form of NH_3 (Owen, 1982). The argument goes as follows: Ar and N_2 have similar volatility and affinity with water ice. Thus, if the primary carrier of Titan's N_2 was molecular nitrogen itself, the Ar/N_2 ratio on Titan should be within an order of magnitude of the solar composition ratio of about 0.1 (Lunine and Stevenson, 1985), which is about 500,000 times larger than the observed ratio. This indicates that nitrogen has been brought in the form of easily condensable compounds, most likely ammonia, which then has been converted in situ by impact-driven chemistry (McKay et al., 1988; Sekine et al., 2011; Ishimaru et al., 2011) or by photochemistry (Atreya et al., 1978). As will be further discussed in this chapter, both conversion processes required restrictive conditions to occur, and therefore dictated specific evolutionary scenarios for Titan.

Photochemical processes are also known to lead to an irreversible destruction of methane, implying that a source of replenishment must exist to explain its few percent abundance (vertically averaged) in the atmosphere. In the absence of such a replenishment, the atmospheric methane should disappear over a timescale of several tens of millions of years. Before the *Cassini-*

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FORMATION AND EVOLUTION OF TITAN'S ATMOSPHERE

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Abstract. The origin and evolution of Titan's enigmatic atmosphere is reviewed. Starting with the present-day volatile inventory, the question of what was the original composition on Titan and how a satellite of similar size to other Galilean moons managed to acquire and hold on to the required material is discussed. In particular the possible sources and sinks of the main mother molecules (nitrogen, methane and oxygen) are investigated in view of the most recent models and laboratory experiments. The answers expected to be provided by the instruments aboard the Cassini-Huygens mission to some of the most prominent current questions regarding Titan's atmosphere are defined.

Keywords: Satellites; Titan; atmospheres; Solar System; infrared; space missions

1. Introduction

Titan's atmosphere is a mystery to this day. In this year of the arrival of the Cassini-Huygens mission in the Saturnian system, one of the questions that scientists will try to answer from the data gathered by the spacecraft and the probe will be : why does Titan have an atmosphere, while other similarly large satellites (and planets for that matter, like more massive Mars) do not and where does this atmosphere come from. Indeed, it is curious to observe that Jupiter's large moons Ganymede and Callisto, although of comparable mass and size to Titan, having also formed in the outer solar system, proved unable to retain a gaseous envelope of any significant size.

This is just one question related to Titan's atmosphere. Another has to do with its origin, how it was formed and maintained. Yet a third one relates to the chemical composition and the inventory of such a major gas envelope.

The subject of the origin of Titan's atmosphere has been extensively addressed

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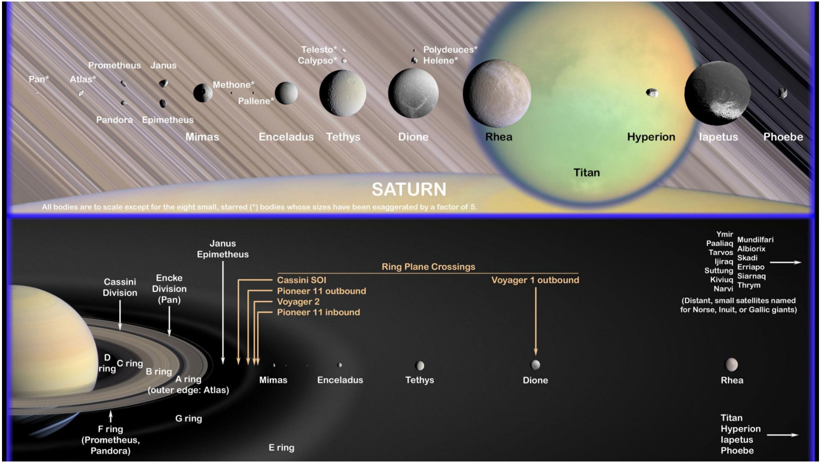
Saturn’s Satellites



Saturn’s satellites

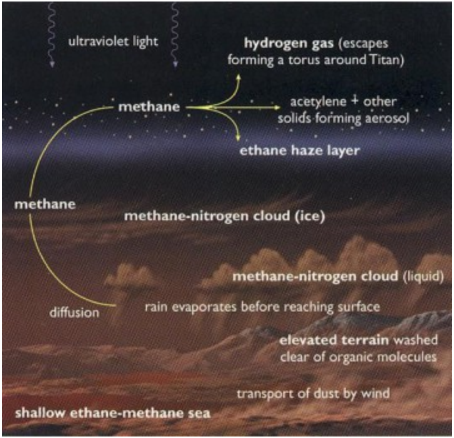
Titan Through Time

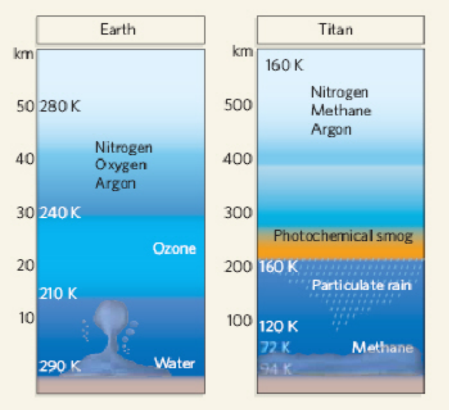
Entry, descent, and landing of Huygens (Jan. 14, 2005)

- Discovered by Christianus Huygens, 1655;
- Ground-based:
  1. Atmospheric limb darkening (Comas Solas,1908);
  2. CH_4 detected (Gerard Kuiper, 1944);
- Voyager 1 (1980);
- Ground-based and Earth-bound observatories(HST[a],ISO[b]) 1990s;
- Cassini arrives at Saturn on 30 June 2004;
- Huygens lands on Titan 14 January 2005.

[a] HST: Hubble Space Telescope;
[b] ISO: Infrared Space Observatory

Titan and Earth





- Help us understand early chemical evolution in the primordial atmosphere on Earth.

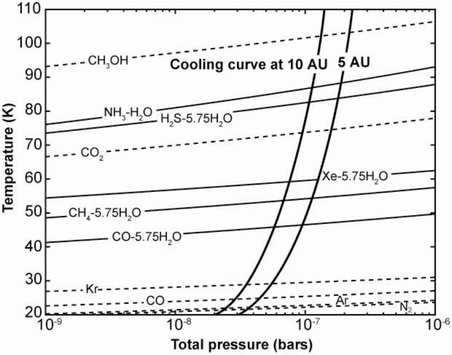
Composition of Titan's Atmosphere

- Titan is similar to Jupiter's moons: Ganymede and Callisto;

- Why does Titan have an atmosphere?
- How it was formed and maintained?

Common (official) name	Formula	Amount (in stratosphere unless otherwise indicated)
Nitrogen	N_2	95% near surface
		=98%
Methane	CH_4	4.9% at surface near equator
		1.4% in lower stratosphere
		=2% at =1000 km
Hydrogen	H_2	0.1–0.2% in lower atmosphere
		=0.4% at =1000 km
Argon	Ar^{40}	43 parts per million (ppm)
	Ar^{36}	28 parts per billion (ppb)
Ethane	C_2H_6	=20 ppm
Carbon monoxide	CO	=45 ppm
Acetylene (ethyne)	C_2H_2	3.3 ppm
		19 ppm at =1000 km
Propane	C_3H_8	700 ppb
Hydrogen cyanide	HCN	800 ppb in winter stratosphere
		=100 ppb in summer stratosphere
Ethylene (ethene)	C_2H_4	160 ppb
Carbon dioxide	CO_2	15 ppb
Methyl acetylene (propyne)	C_3H_4	10 ppb
Acetonitrile	CH_3CN	a few ppb
Cyanoacetylene	HC_3N	>5 ppb in winter stratosphere
		<1 ppb in summer stratosphere
Methyl acetylene	CH_3C_2H	5 ppb
Cyanogen	C_2N_2	5 ppb
Water vapor	H_2O	8 ppb
Diacetylene (buta-1,3-diyne)	C_4H_2	1.5 ppb (slightly higher in winter)
Benzene	C_6H_6	1.4 ppb at winter pole, <0.5 ppb elsew

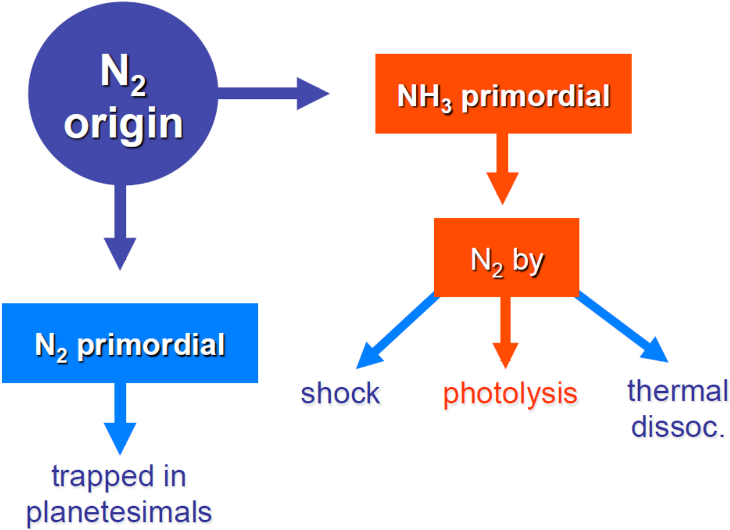
The Formation of Titan’s Atmosphere



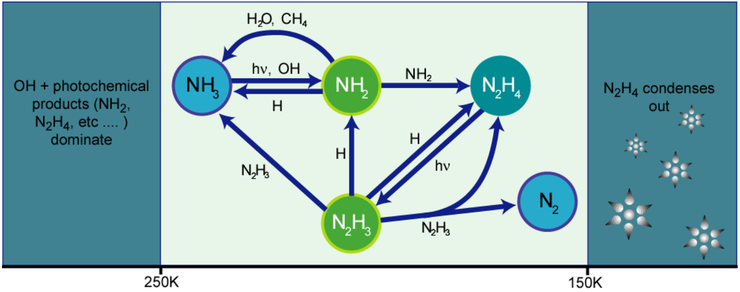
Several ways obtained atmosphere:

- By capturing it from the solar nebula or from an unfractionated proto-Saturnian nebula;
- By outgassing of the accreted material;
- Volatile contributions from impacting comets.

The Origin of Nitrogen And Methane



The Origin of Nitrogen And Methane

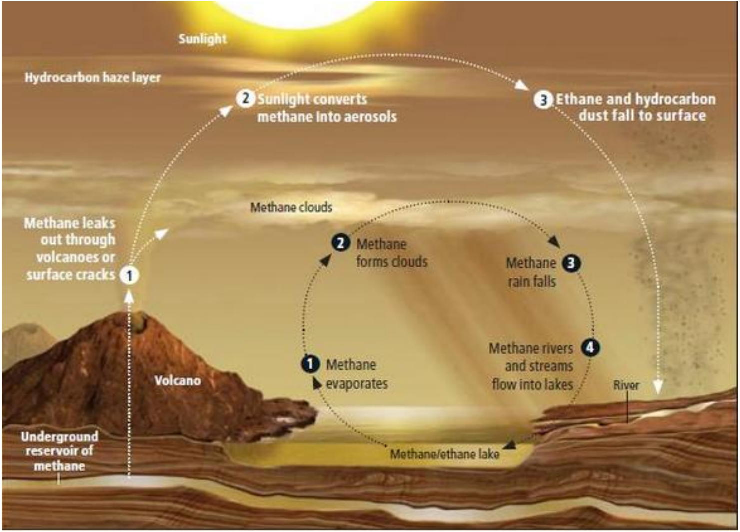


N_2 from NH_3 on Primordial Titan

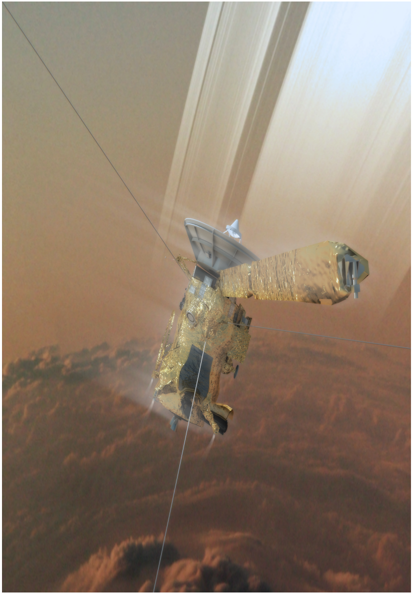
Potential Sources of Methane in Titan:

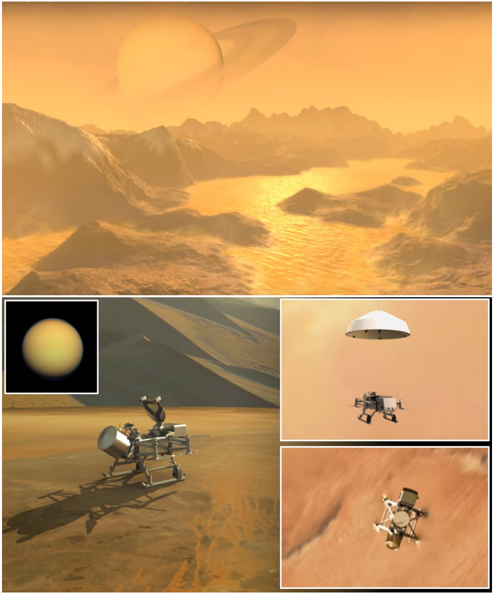
- Produced from the gas phase conversion of CO and CO_2 in an initially warm and dense Saturn's subnebula;
- Produced from serpentinization reactions(i.e. interaction between water and rock) in the interior of Titan;
- Originating from the solar nebula.

The Cycle of Methane in Titan’s



Further Research





Thanks!