Stratospheric composition of Titan from Cassini/CIRS observations

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For the CIRS Team
Since July 2, 2004: T0-T10 flybys
FP1, FP3 and FP4 spectra
high resolution apodized (0.53 cm\(^{-1}\)) or medium resolution (2.5 cm\(^{-1}\))
Covering Titan’s disk
Cassini-CIRS Ta at Titan

Titan North from Ta Flyby  Resolution 1.7 cm\(^{-1}\)

![Graph showing spectral lines for various compounds such as CH\(_4\), C\(_2\)H\(_2\), C\(_2\)N\(_2\), C\(_3\)H\(_4\), H\(_2\), C\(_4\)H\(_2\), C\(_2\)H\(_6\), HC\(_3\)N, C\(_3\)H\(_4\), and CH\(_3\)D.]
Coustenis et al., 2006; subm
b) TB 5° S

Coustenis et al., 2006; subm
c) T4 55° N

Coustenis et al., 2006; subm
**T3 latitude dependence:** abrupt change around 60°
- C$_4$H$_2$ increases faster than C$_3$H$_4$
- HC$_3$N and C$_6$H$_6$ appear, CO$_2$ and C$_3$H$_8$ drop
- at higher lat than 60°N, HCN and C$_2$H$_2$ drop slightly
Meridional variations of Titan’s minor constituents

Coustenis et al., 2006; subm
Meridional variations of Titan’s minor constituents

![Graph showing variations of minor constituents across different latitudes.](image-url)

Coustenis et al., 2006; subm
Volume mixing ratio

Cassini CIRS (2004)
(early N. winter)

Voyager IRIS (1980):
Coustenis & Bézard (1995)
(early N. spring)
Hadley circulation in Titan GCMs

Tokano and Neubauer (2005)

Grieger et al. (2004)

Zhu and Strobel (2005)

Rannou et al. (2006)
Titan/T0: Comparison of emission observed by CIRS FP4 and model

Model

lat=50-70°S

Radiance (W sr⁻¹ cm⁻² cm⁻¹)

Wavenumber (cm⁻¹)

CH₃D

D/H = 1.2 ± 0.2 \times 10^{-4}
Titan/T0: Comparison of emission observed with CIRS FP3 and model

Model
lat=50-70°S

Radiance (W sr\(^{-1}\) cm\(^{-2}\)/cm\(^{-1}\))
Wavenumber (cm\(^{-1}\))

C\(_2\)H\(_2\)
HCN
C\(_3\)H\(_8\)
CO\(_2\)
C\(_3\)H\(_4\)
C\(_4\)H\(_2\)
C2H2 vertical distributions at Titan's equator

- C2H2 (model Lebonnois)
- cst
- Lara*0.9 (Lara et al. 1996)
- ISO*0.65 Coustenis et al. (2003)

Pressure (mbar)

Mixing ratio

- Hot bands
- Q-branch
- isotope

C2H2 = 3 \times 10^{-5}
Constant profile
Lebonnois et al.

Z-increasing profile
Lara et al. 1996
Differences at 5°S 96RTI with varying C2H2

- **Diff cst**
- **Diff Lara**

Q-branch

Difference in radiance

Wavenumber (cm⁻¹)
Photochemical models

Chemical reaction scheme in the gas phase by Coll et al., 1995
Benzene and HC$_3$N on Titan

**Context:**
- Benzene has been discovered in the stratospheres of the giant planets Jupiter and Saturn with ISO (Bézard et al., 2002) but not in Uranus and Neptune. Nothing appeared in the V1/IRIS data at 674 cm$^{-1}$ at the resolution of 4.3 cm$^{-1}$.
- Benzene was expected in Titan’s atmosphere with a formation dominated by propargyl recombination through (Wilson et al., 2002):
  $$
  \begin{align*}
  2(CH_4 + h\nu \rightarrow ^1CH_2+H_2) \\
  2(C_2H_2 + ^1CH_2 \rightarrow C_3H_3+H) \\
  C_2H_2 + C_2H_2 \rightarrow [n-1]C_6H_6 \\
  2C_2H_2 + CH_4 \rightarrow C_6H_6 + 2H + H_2
  \end{align*}
  $$

ISO saw the C$_6$H$_6$ emission feature at 674 cm$^{-1}$ where the $\nu_4$ band occurs. The abundance derived was $4\pm3$ $10^{-10}$ at the 9-mbar region (Coustenis et al., 2003). ISO also observed HC$_3$N in emission at mid-latitudes at 663 cm$^{-1}$ ($5\pm3$ $10^{-10}$ at 9-mbar).

CIRS finds C$_6$H$_6$ $1.4\pm0.5$ $10^{-9}$ at 60° N and < 5 $10^{-10}$ elsewhere.

HC$_3$N varies from some $10^{-10}$ up to $5$ $10^{-9}$ at 60°N
Solid Benzene on Titan?

- Titan Limb 0-90 South
- Lab Solid Benzene 145 K
- Lab Solid Benzene 50 K

Solid C₆H₆?
Table 1. Some organics, as yet unobserved on Titan in the thermal IR, but potentially observable with CIRS and their deduced upper limits in Titan’s atmosphere from previous observations.

<table>
<thead>
<tr>
<th>Studied Compounds</th>
<th>Strongest signatures</th>
<th>Upper limit of mean mixing ratio in Titan’s stratosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency (cm⁻¹)</td>
<td>Band strength at 300 K (cm² atm⁻¹)</td>
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<tr>
<td>Hydrocarbons</td>
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<td>CH₃CCH₂</td>
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<td>65</td>
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<td>C₄H₄</td>
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<td>C₆H₂</td>
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<td>C₄H₂</td>
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<td>Nitriles</td>
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<tr>
<td>CH₃CN</td>
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<td>CH₃CHCN</td>
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<td>CH₃CH₂CN</td>
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<tr>
<td>CH₃CH₂CH₂CN</td>
<td>728/742</td>
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<tr>
<td>(CH₃)₂CHCN</td>
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<td>Δ CN</td>
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<tr>
<td>CH₃CHCHCN</td>
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<td>CH₃CHCH₂CN</td>
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<td>CH₂C(CH₃)CN</td>
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<td>NCCHCHCN (trans)</td>
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<td>Other N organics</td>
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<td>CH₃N₃</td>
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</table>

† Feature not yet observed. CH₃CN detected in millimeter observations (l), with a derived mole fraction 1.5×10⁻⁹ at 1 mbar.

*From Flasar et al., 2004*
Cassini/CIRS: what to do next

**Work in progress:**

- evolution of the N-S asymmetry and meridional variations
  
  be fun to see if we find similar results as Voyager in 4 years from now (will be almost a full Titan year since 1980)

GET MORE DATA AT HIGH LATITUDES

- interpretation: dynamics, seasonal effects, GCM

- New atmospheric species: benzene, allene, higher hydrocarbons (C6H2….) and nitriles (HC5N….)

  -> Highest degree of chemical complexity

- Isotopes: D/H, 14N/15N, 12C/13C

  -> Titan’s formation and evolution

- Vertical profiles for species with intense lines
  
  - (C2H2, C2H6, etc….)

  -> photochemical models