Horizontal structure and dynamics in Titan’s thermosphere from INMS and Modeling

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The Cassini Ion Neutral Mass Spectrometer Measurements

- Measures ion and neutral gases (1-99 Daltons) in-situ, incl. N\textsubscript{2}, CH\textsubscript{4}, H\textsubscript{2}
- Lowest altitude to-date 950 km
- Primarily northern hemisphere dusk/night conditions
- Analysis of any single flyby tricky: horizontal variations
- Data collected to-date allow determination of horizontal variability
- Form crucial constraint for atmosphere models (all regions)
- Derive temperatures from densities

<table>
<thead>
<tr>
<th>Flyby Name</th>
<th>Flyby Date</th>
<th>C/A Altitude</th>
<th>C/A Latitude</th>
<th>C/A Longitude</th>
<th>C/A LST</th>
<th>C/A SZA</th>
<th>F10.7 cm flux (1 AU)</th>
<th>Titan-Saturn position (SLT)</th>
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<tr>
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<td>Apr 16, 2005</td>
<td>1025</td>
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<td>960</td>
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<td>1.31</td>
<td>106.93</td>
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Empirical model of Titan’s thermosphere

- Define Lat-Alt grid (1000-1600 km)
- Map densities at each altitude versus latitude of measurement
- Fit Legendre polynomials through values
- Determine functions describing vertical change of Legendre amplitudes
- This analytically defines densities in Titan’s thermosphere
- Local time/longitude changes ignored
- Available as IDL routine

Legendre polynomial amplitudes

CH₄ (1200 km)

• Molec fraction

Density (1200 km)

Legendre polynomial amplitudes

P₀

P₂/P₀

P₄/P₀

σ uncertainties

I. Mueller-Wodarg

Titan Aeronomy Meeting

ISSI Bern, August 2007
Validation

- Model captures well some of the observed variability
- Densities vary primarily with latitude and altitude
- Horizontal variations along trajectories are important
- Some flybys (T18, T25) fit poorly: time variability?
Thermospheric temperature structure

- Obtain latitudinal temperature profile in thermosphere from empirical model
- Quasi-isothermal above 1200 km
- Pronounced latitude structure near 1000 km, hot equator
Titan’s thermal structure

- INMS derived temperatures consistent with Voyager UVS
- Opposite latitudinal trends in thermosphere and stratosphere
- Cold polar thermosphere could result from HCN cooling
- Hot polar stratosphere could be dynamical effect: adiabatic heating
- Thermal balance needs to be calculated for entire atmosphere, including dynamical effects

![Temperature vs. Altitude Graph](image)

- INMS: Voyager UVS
- Opposite latitudinal trends
- Cold polar thermosphere
- Hot polar stratosphere
- Thermal balance

Fulchignoni et al. (2005)
S. Vinatier (private comm., 2007)
Dynamics in Titan’s thermosphere

- Use TGCM by Mueller-Wodarg et al. (2000; 2003) to numerically solve momentum equation
  \[
  \frac{\partial \mathbf{U}}{\partial t} + (\mathbf{U} \cdot \nabla) \mathbf{U} = -\frac{1}{\rho} \nabla p - 2\Omega \times \mathbf{U} + \mathbf{U} \times \frac{\left(\mathbf{U} \times \mathbf{a}\right)}{a^2} + \frac{\mu}{\rho} \nabla^2 \mathbf{U}
  \]
- Assume thermal structure from empirical atmosphere model
- Solve coupled continuity equation for inert main gases (N$_2$, CH$_4$)
- Dynamics driven by pressure gradients only
- Steady-state situation assumed
- Wave drag or other momentum sources not considered at present
- Experimented with lower boundary conditions:
  - Co-rotating atmosphere (zero winds) at 960 km
  - Super-rotation by Sicardy et al. (2006) at 960 km
Dynamics in Titan’s thermosphere

In-situ thermal forcing only

Added Sicardy et al. (2006)
super-rotation at 1000 km
Dynamics in Titan’s thermosphere

In-situ thermal forcing only

Added Sicardy et al. (2006) super-rotation at 1000 km
Coupling of dynamics and CH$_4$ distribution

- May treat CH$_4$ as inert in Titan’s thermosphere, so dynamics dominate.
- At most latitudes $V_z << W_{CH4}$, so diffusion dominates and CH$_4$ is in diffusive balance.
- Near 75 N in our simulation $V_z << W_{CH4}$, so diffusive balance no longer holds.
- Opportunity to independently constrain $V_z$?
Some of the open questions

- What is the global circulation pattern in Titan’s thermosphere?
- Is Titan’s thermosphere super-rotating?
- What is the role of waves in depositing momentum?
- How important is vertical coupling in Titan’s atmosphere?
- What is the local time variability in the thermosphere?
- What is the role of dynamics in distributing gases?
- Can we constrain dynamics with measurements of inert gases?
- What determines the energy balance in the thermosphere and below; in particular, what is the role of dynamics (via distribution of HCN and adiabatic processes)?
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<th>Escape flux</th>
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<td>15</td>
<td>$2.05 \times 10^9$ cm$^{-2}$ s$^{-1}$</td>
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<tr>
<td>30</td>
<td>$1.94 \times 10^9$ cm$^{-2}$ s$^{-1}$</td>
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<td>45</td>
<td>$1.94 \times 10^9$ cm$^{-2}$ s$^{-1}$</td>
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<td>60</td>
<td>$2.08 \times 10^9$ cm$^{-2}$ s$^{-1}$</td>
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<td>$2.10 \times 10^9$ cm$^{-2}$ s$^{-1}$</td>
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<td>90</td>
<td>$2.10 \times 10^9$ cm$^{-2}$ s$^{-1}$</td>
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