Exploration of the Saturn System by the Cassini Mission: Observations with the Cassini Infrared Spectrometer

Mian Abbas
NASA – Marshall Space Flight Center
Collaborators

- Andre LeClair: NASA-MSFC
- Elizabeth Woodard: UAH
- CIRS - Science Team
- (NASA/GSFC; JPL; OXFORD UNIV;
- Meudon Obs. & Univ. of Paris, France)


• Introduction to the **Cassini mission**, and Cassini mission objectives

• **Cassini spacecraft, instruments, launch, and orbit insertion**

• **Saturn, Rings, & Satellites**, Titan

• **Composite Infrared Spectrometer (CIRS)**

• **Infrared observations of Saturn and Titan**
The Cassini mission, named after of the 17th century Italian/French astronomer, Giovanni Domenico Cassini, is a joint NASA-ESA mission, launched on October 17, 1997 for exploration of the Saturn system.

- Successful insertion in Saturn’s orbit for a four year orbital tour occurred on July 1, 2004.

- The French Huygens-Probe with six instruments, was programmed for a soft landing on Titan. Successful landing on Titan’s surface occurred in January 2005.
The Cassini Mission General Objectives

- Exploration of the Saturn system for investigations of the origin, formation, & evolution of the solar system.

- The solar system is believed to be formed in a gravitationally collapsing giant interstellar cloud of gas and dust, or proto-solar nebula, with the proto-sun formed at the core and the planets in the surrounding disc.

- Two current models of formation are:
  - (a) Core accretion model: agglomeration of dust grains into pebbles, to rocks, to planetesimals, and to the formation of planets in a gaseous disc.
  - (b) Gravitational instability model where the planets are formed directly at various distances from the sun in a proto-stellar disc.

- None of the two models provide satisfactory explanation of the observations.
The Cassini Mission Specific Objectives

• Measure atmospheric thermal structure, gas abundances & isotopic ratios for Saturn system.

• Measure wind speeds and cloud structure.

• Obtain data for better understanding of the structure and formation of the interior.

• Investigations Saturn’s rings and its satellites.

• Study Saturn’s Magnetosphere & ionosphere, and interactions with the magnetic field.
Cassini Spacecraft
Spacecraft Characteristics

- The Cassini spacecraft orbiter carries 12 instruments.
- The Huygens Probe contained 6 instruments.
- The spacecraft weights about 5000 kg, about the size of an empty school bus, and is 6.8 m (~22 ft) high.
- Three Radioisotope Thermoelectric Generators (RTGs) provide the electric power.
- Sequence commands received via 4-m diameter high gain antenna on the Orbiter’s central computer.
- Attitude control maintained by a dedicated computer which continually propagates up to 50 vectors to a variety of objects (e.g., Sun, Earth, Saturn and its satellites). The computer commands the reaction wheels to point Cassini to the desired direction.
- Data stored on 2 solid state recorders (SSRs) during the tour.
Spacecraft Characteristics (cont’d)

- **Power at Saturn:** ~ 660 W
- **Data Storage:** 4 Gbits
- **Pointing Accuracy:** 2.0 mrad; Pointing stability 0.036 mrad ( ~ 5 sec)
- **Number of Engineering Computers:** 26
- **Transmitter Power:** 19 W (RF): Transmitter Freq : Xband
- **Data rate at Saturn:** 140 KB/s
- **Main Engine Thrust:** 445 N

**The Huygens Probe**
- The Probe was designed as a fully instrumented robotic laboratory designed to enter Titan’s atmosphere using a heat shield and a series of parachutes.
- **Scientific measurements made during descent,** with 30 min at the surface of Titan.
Optical and Microwave Remote Sensing Instruments

- **Composite Infrared Spectrometer (CIRS):** Temperature & composition of surfaces & atmospheres in the Saturn system.
- **Visual and Infrared Mapping Spectrometer (VIMS):** Spectral mapping to study composition & structure or surfaces, atmospheres, & rings.
- **Imaging Science Subsystems (ISS):** Multispectral imaging of Saturn, Titan, rings, & the icy satellites to observe their properties.
- **Ultraviolet Imaging Spectrograph (UVIS):** Spectra & low resolution imaging of atmospheres, & rings for structure, chemistry and composition.
- **Cassini Radar (RADAR):** Radar imaging, altimetry, & backscatter of Titan's surface.
- **Radio Science Subsystem (RSS):** Study of atmospheric & ring structure, gravity fields, & waves.
Cassini Orbiter Instruments

FIELDS, PARTICLES, AND WAVES INSTRUMENTS:

**Cosmic Dust Analyzer (CDA):** In-situ study of ice & dust grains in the Saturn system.

**Ion and Neutral Mass Spectrometer (INMS):** In-situ compositions of neutral & charged particles in the Saturn magnetosphere.

**Cassini Plasma Spectrometer (CAPS):** In-situ study of plasma within & near Saturn's magnetic field of atmospheres, & rings for structure, composition.

**Radio & Plasma Wave Science (RPWS):** Study of plasma waves, radio emissions, and dust in the Saturn system.

**Dual Technique Magnetometer (MAG):** Study of Saturn's magnetic field & interactions in the solar wind.

**Magnetospheretic Imaging Instrument (MIMI):** Global magnetospheretic imaging & in-situ measurements of Saturn’s magnetosphere & solar wind interaction.
Huygens Probe Instruments

**Probe Science Payload Instrumentation:**

**Huygens Atmospheric Structure Instrument (HASI)**
A suite of sensors to measure the physical and electrical properties of Titan's atmosphere.

**Doppler Wind Experiment (DWE)**
Radio signals to deduce wind speeds on Titan

**Descent Imager/Spectral Radiometer (DISR)**
Imaging and spectral observations of Titan's surface and atmospheric hazes.

**Aerosol Collector and Pyrolyser (ACP)**
Chemical composition of Titan's aerosols. composition analysis.

**Surface-Science Package (SSP)**
A number of sensors designed to determine the physical properties of Titan's surface.

**Gas Chromatograph & Mass Spectrometer (GCMS)**
The Cassini Launch on Oct. 17, 1997, Cape Canaveral
The Cassini Launch on Oct. 17, 1997, Cape Canaveral
Venus-Venus-Earth-Jupiter: Gravity Assist
A View of VENUS obtained by Magellan

Ganymede
Cassini/Infrared Jupiter Observations

- Global Temperature Maps
  - Observations of dynamical processes on Jupiter

- Global distribution of gas abundances
  - $^{14}\text{NH}_3$, $^{15}\text{NH}_3$, \(\text{PH}_3\), \(\text{C}_2\text{H}_6\), \(\text{C}_2\text{H}_2\)
  - Complex hydrocarbons
Saturn’s Orbit Insertion

Spacecraft turns away from Earth for SOI activities
June 30 6:11pm PDT

Ascending ring-plane crossing
7:11pm PDT

SOI burn 7:36 - 9:12pm PDT

Spacecraft passes behind rings, planet
9:54 - 10:44pm PDT

Descending ring-plane crossing
10:58pm PDT

Spacecraft returns to Earth-point
Playback of SOI data begins
July 1 12:00am PDT

Cassini Saturn Orbit Insertion
View from Earth
Saturn’s Rings
Some Physical Parameters of Saturn

- **Mean Distance from Sun**: 9.6 AU
  
  1.4 billion km (~ 0.9 billion miles)

- **Diameter**: 120,660 km (Equator)
  107,629 km (Polar)

- **Mass (Earth = 1)**: 95.2

- **Gravity (Earth = 1)**: 1.06

- **Density (Earth = 5.52)**: 0.69 g/cm³ (Water = 1.0)

- **Orbital Period**: 29.4 years

- **Rotation Period**: 10 h 40 m

- **Orbital Inclination**: 2.5°
Saturn’s Atmospheric Thermal Structure and Composition

- Temperature: 135 K at 1 bar; 82 K at tropopause (60 mbar)
- Composition: H₂ (~ 88%), He (~ 12%), CH₄, NH₃, PH₃, C₂H₂, C₂H₆, CO, CO₂, H₂O, plus other trace gases.
- Cloud layers of: Water cloud at the bottom, Ammonia at the top, and NH₄SH in the middle troposphere, theorized.
## Saturn’s Rings

<table>
<thead>
<tr>
<th>Name</th>
<th>Inner Radius (Rs)</th>
<th>Width (km)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Ring</td>
<td>1.1</td>
<td>7500</td>
<td>?</td>
</tr>
<tr>
<td>C-Ring (inner)</td>
<td>1.235</td>
<td>17,500</td>
<td>1x10^{18}</td>
</tr>
<tr>
<td>B-Ring</td>
<td>1.524-1.947</td>
<td>25,500</td>
<td>3x10^{19}</td>
</tr>
<tr>
<td>Cassini Division</td>
<td>1.985 (center)</td>
<td>4800</td>
<td></td>
</tr>
<tr>
<td>A-Ring</td>
<td>2.023-2.267</td>
<td>14,600</td>
<td>6x10^{18}</td>
</tr>
<tr>
<td>F-Ring</td>
<td>2.3267</td>
<td>30-500</td>
<td>?</td>
</tr>
<tr>
<td>G-Ring</td>
<td>2.8</td>
<td>8000</td>
<td>1x10^{7} (?)</td>
</tr>
<tr>
<td>E-Ring</td>
<td>3.0 - 8.0</td>
<td>300,000</td>
<td>?</td>
</tr>
</tbody>
</table>
Ring Science Objectives

• Study the **shape and structure of the rings and the processes** responsible for the ring structure (gravitational, viscous, erosional, and electromagnetic).

• Map the **chemical makeup and the size distribution** of ring material.

• Investigate the **relationship between the rings and the moons of Saturn**, including moons contained within the ring system.

• Determine the **distribution of dust and meteoroids** in the vicinity of the rings.

• Study **interactions between the rings and Saturn's magnetosphere, ionosphere, and atmosphere**.
Saturn Science Objectives

• Global mapping of atmospheric thermal structure, gas abundances, and isotopic ratios to provide observational constraints for the formation and evolution of Saturn and Titan.

• Measure wind speeds and directions across the planet.

• Observe long-term variations in the cloud features and processes.

• Collect data for better understanding of the interior of the planet.

• Study the day-to-night variations of Saturn's ionosphere and determine its degree of interaction with the magnetic field.
## Satellites of Saturn

<table>
<thead>
<tr>
<th>Name</th>
<th>Diameter (km)</th>
<th>Distance (R$_{\text{S}}$)</th>
<th>Discoverer</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan</td>
<td>20</td>
<td>2.2</td>
<td>Showalter</td>
<td>1980</td>
</tr>
<tr>
<td>Atlas</td>
<td>28</td>
<td>2.3</td>
<td>Terrile</td>
<td>1980</td>
</tr>
<tr>
<td>Prometheus</td>
<td>92</td>
<td>2.3</td>
<td>Collins</td>
<td>1980</td>
</tr>
<tr>
<td>Pandora</td>
<td>92</td>
<td>2.4</td>
<td>Collins</td>
<td>1980</td>
</tr>
<tr>
<td>Epimetheus</td>
<td>114</td>
<td>2.5</td>
<td>Walker</td>
<td>1980</td>
</tr>
<tr>
<td>Janus</td>
<td>178</td>
<td>2.5</td>
<td>Dollfus</td>
<td>1966</td>
</tr>
<tr>
<td>Mimas</td>
<td>392</td>
<td>3.1</td>
<td>Herschel</td>
<td>1789</td>
</tr>
<tr>
<td>Enceladus</td>
<td>520</td>
<td>4.0</td>
<td>Herschel</td>
<td>1789</td>
</tr>
<tr>
<td>Tethys</td>
<td>1060</td>
<td>4.9</td>
<td>Cassini</td>
<td>1684</td>
</tr>
<tr>
<td>Name</td>
<td>Diameter (km)</td>
<td>Distance (R$_s$)</td>
<td>Discoverer</td>
<td>Date</td>
</tr>
<tr>
<td>------------</td>
<td>---------------</td>
<td>-----------------</td>
<td>--------------</td>
<td>--------</td>
</tr>
<tr>
<td>Telesto</td>
<td>30</td>
<td>4.9</td>
<td>Reitsema</td>
<td>1980</td>
</tr>
<tr>
<td>Calypso</td>
<td>26</td>
<td>4.9</td>
<td>Pascu</td>
<td>1980</td>
</tr>
<tr>
<td>Dione</td>
<td>1120</td>
<td>6.3</td>
<td>Cassini</td>
<td>1684</td>
</tr>
<tr>
<td>Helene</td>
<td>32</td>
<td>6.3</td>
<td>Laques</td>
<td>1980</td>
</tr>
<tr>
<td>Rhea</td>
<td>1530</td>
<td>8.8</td>
<td>Cassini</td>
<td>1672</td>
</tr>
<tr>
<td>Titan</td>
<td>5146</td>
<td>20.4</td>
<td>Huygens</td>
<td>1655</td>
</tr>
<tr>
<td>Hyperion</td>
<td>286</td>
<td>24.7</td>
<td>Bond</td>
<td>1848</td>
</tr>
<tr>
<td>Iapetus</td>
<td>1460</td>
<td>59.4</td>
<td>Cassini</td>
<td>1671</td>
</tr>
<tr>
<td>Phoebe</td>
<td>220</td>
<td>216</td>
<td>Pickering</td>
<td>1898</td>
</tr>
</tbody>
</table>
Saturn’s Moon – IAPETUS

D = 1460 km; R = 59.4 Rs
Saturn’s Moon - Tethys
Objectives for the Icy Satellites

• Determine the **general characteristics and geological histories** of the icy satellites.

• Determine the processes that change the **surface and near-surface of the icy satellites**, and determine the **makeup and distribution of surface materials**, especially the **dark material**.

• Provide observational constraints on the **internal structure and makeup of the moons**.

• Investigate **interaction of the icy satellites** with the **magnetosphere and the ring system**.
Near IR image of Titan, with the dark and the bright reds representing the presence of pure water ice, simple hydrocarbons, respectively.
Near IR view of Titan by VIMS with the yellow, blue and white colors indicating presence of hydrocarbons, ice, and methane clouds, respectively.
Titan’s Atmospheric Thermal Structure and Composition

- **Temperature**: 92 K at surface (1.5 bar)
  72 K at tropopause (150 mbar)
- **Gases**: $N_2$ (~ 95%), $H_2$, Ar, $CH_4$, $C_2H_2$, $C_2H_4$, $C_2H_6$, $C_3H_4$, $C_3H_8$, $C_4H_2$, HCN, $HC_3N$, CO, $CO_2$, $H_2O$, complex hydrocarbons
- **Haze, Clouds**: $CH_4$, Hydrocarbons
Titan Science Objectives

- Global distribution of atmospheric gas abundances and isotopic ratios, provide information for better understanding of the formation and evolution of Titan’s atmosphere.
- Search for more complex organic molecules. Study photochemical models, the formation and composition of aerosols, and clouds.
- Measure winds and global temperatures and the seasonal effects.
- Determine whether the surface is liquid or solid, and determine the shape and composition of the surface.
- Collect data to determine the internal structure of Titan.
- Investigate the upper atmosphere and ionosphere of Titan and their roles as sources of neutral and ionized material in the magnetosphere of Saturn.
Cassini Infrared Observations with the Composite Infrared Spectrometer (CIRS)
**CIRS Instrument Characteristics**

<table>
<thead>
<tr>
<th></th>
<th>Far-IR</th>
<th>Mid-IR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Telescope diameter (cm)</strong></td>
<td>50.8</td>
<td></td>
</tr>
<tr>
<td><strong>Interferometers</strong></td>
<td>Polarizing</td>
<td>Michelson</td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spectral range (cm(^{-1}))</strong></td>
<td>10—600</td>
<td>600—1400</td>
</tr>
<tr>
<td><strong>Spectral range ((\mu m))</strong></td>
<td>17—1000</td>
<td>7—17</td>
</tr>
<tr>
<td><strong>Spectral resolution (cm(^{-1}))</strong></td>
<td>0.5—15.5</td>
<td>0.5—15.5</td>
</tr>
<tr>
<td><strong>Integration time (s)</strong></td>
<td>2—50</td>
<td>2—50</td>
</tr>
<tr>
<td><strong>Focal planes</strong></td>
<td>Fp1</td>
<td>Fp3</td>
</tr>
<tr>
<td><strong>Spectral range (cm(^{-1}))</strong></td>
<td>10—600</td>
<td>600—1100</td>
</tr>
<tr>
<td><strong>Detectors</strong></td>
<td>Thermopile</td>
<td>PC HgCdTe</td>
</tr>
<tr>
<td><strong>Pixels</strong></td>
<td>2(^a)</td>
<td>1 \times 10</td>
</tr>
<tr>
<td><strong>Pixel FOV (mrad)</strong></td>
<td>3.9</td>
<td>0.273</td>
</tr>
<tr>
<td><strong>Peak D(^*) (cm Hz(^{1/2}) W(^{-1}))</strong></td>
<td>(4 \times 10^{9})</td>
<td>(2 \times 10^{10})</td>
</tr>
<tr>
<td><strong>Data telemetry rate (kbs)</strong></td>
<td>2 and 4</td>
<td></td>
</tr>
<tr>
<td><strong>Instrument temperature (K)</strong></td>
<td>170</td>
<td></td>
</tr>
<tr>
<td><strong>Focal planes 3 and 4 Temperature (K)</strong></td>
<td>75—90</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Single FOV, two polarizations.
CIRS Infrared Spectrum of Saturn
FIR Spectrum of Titan
Titan’s Composition Retrievals from Infrared Spectra
Analytical Techniques for Retrieval of Atmospheric Thermal Structure & Composition

- **Radiative Transfer Models (Forward solutions of the Radiative Transfer Equation (RTE))**
  - Provide synthetic spectra for known values of: model atmosphere with known parameters (thermal structure, gas distributions, cloud opacity etc.), instrument characteristics, and modes of observation.

- **Retrieval Programs (Inverse solutions of the RTE)**
  - Calculate the atmospheric parameters (temperatures, gas distributions, isotopic ratios, cloud opacity, pointing directions, etc.) by comparison with the synthetic spectra and employing non-linear least-squares iterative techniques.
Radiative Transfer Model

Observed radiance:

\[ I_v(\theta) = \varepsilon_{vs} \tau_{vs} B_v(T_s) - \int_{ps}^{pt} B_v(T) \ C_v(\theta, p, T, n_i) \ d\ln p \]

Transmittance:

\[ t_n = \exp \left( \int \frac{\hat{o} \hat{\alpha}}{k_n(p, T)} \ du_i \right) \]

Contribution Functions:

\[ C_v = B_v(T) \ \frac{\partial \tau_v}{\partial \ln p} \]

\[ C_v = \frac{\partial B_v}{\partial T} \cdot \frac{\partial \tau_v}{\partial \ln p} \]

\[ C_v = \frac{\partial \tau_v}{\partial \ln u_i} \cdot \frac{\partial B_v}{\partial \ln p} \]
Relaxation Equations:

- Assuming an initial guess model atmosphere, radiances are calculated for the selected frequencies and compared with the observed values.

- The atmospheric parameters (T, gas mixing ratios) are corrected at the peaks of the contributions functions (CFs) till the rms differences approach the noise level.

- The regions above and below the CFs are scaled appropriately.

\[
I_i^n = I(q^n)
\]

\[
r_i^n = I_i^o - I_i^n
\]

\[
\sigma^n = \sqrt{\frac{1}{m} \sum_{i=1}^{m} (r_i^n)^2}
\]

\[
q^n = q^{n-1} + \frac{\sum_{i=1}^{m} \left( r_i^{n-1} a_i^{n-1} \right)}{\sum_{i=1}^{m} \left( a_i^{n-1} \right)^2}
\]

\[
a_i^n = \left( \frac{\partial I(q; \nu_i)}{\partial q} \right)_{q=q^n}
\]
Titan Temperature Retrieval

Combined limb and nadir temperature retrieval of Titan Tb observations at $-13^\circ$ latitude.
Titan Model Atmosphere

- **Composition:**
  - $\text{N}_2 \sim 95.6 - 98.1\%$
  - $\text{CH}_4 \sim 4.4 - 1.6\%$
  - $\text{H}_2 \sim 0.1\%$
  - $\text{C}_2\text{H}_2, \text{C}_2\text{H}_4, \text{C}_2\text{H}_6, \text{C}_3\text{H}_4, \text{C}_3\text{H}_8, \text{C}_4\text{H}_2, \text{C}_6\text{H}_6$
  - HCN, HC$_3$N
  - CO, CO$_2$, H$_2$O
Titan Composition Retrieval: C$_2$H$_2$

Mean C$_2$H$_2$ mixing ratio at 3 mbar in each latitude bin retrieved from T0, Tb, and T3 nadir observations.
Titan Composition Retrieval: C2H6

Mean C2H6 uniform mixing ratio in each latitude bin retrieved from T0, Tb, and T3 nadir observations. Run with HT04 data. Test run with GS03 data retrieves 1.6e-5 in southern hemisphere.
Titan Composition Retrieval: HCN

Mean HCN uniform mixing ratio in each latitude bin retrieved from T0, Tb, and T3 nadir observations.
Titan Composition Retrieval: CO2

Mean CO2 uniform mixing ratio in each latitude bin retrieved from T0, Tb, and T3 nadir observations.
Titan Composition Retrieval: Comparison Spectra

- Intensity (W/cm² ster cm⁻¹)
- Frequency (cm⁻¹)

- Titan
- -45° Latitude
- Res: 2.8 cm⁻¹

- CO₂
- HCN
- C₂H₂
CH$_3$D Retrievals and D/H Ratio

- **Data:** T0, Tb, T3 nadir observations at 0.5 cm$^{-1}$ res, for 10° latitude bins centered at (T0: -60.6, -58.1); (Tb: -3.4, 4.3, 15.3); (T3: -23.0, -16.5)
- **Spectral isolated CH$_3$D lines used:** 1130.75, 1143.50, 1156.00 cm$^{-1}$
- **Temperature profile retrieved from nadir observations at 2.8 cm$^{-1}$ res. Provides good fit with the 0.5 cm$^{-1}$ data in the 1300 cm$^{-1}$ region.**
- **Continuum level is fitted with aerosol next to each frequency. The CH$_3$D abundance is retrieved to find the best fit of the three lines together.**
- **Retrieved CH$_3$D mean mixing ratio** = 1.30 × 10$^{-5}$
  - CH$_3$D/CH$_4$ ratio = (8.14 ± 2.2) × 10$^{-4}$
  - Mean D/H ratio = (2.04 ± 0.55) × 10$^{-4}$
- **Comparison with**
  - Athena Coustenis: D/H: (1.17$^{+0.16}_{-0.21}$) × 10$^{-4}$
  - Huygens D/H: (2.3 ± 0.5) × 10$^{-4}$
Titan Comparison Spectra: CH3D

Titan
+4° Latitude
Tb observations
Res: 0.53 cm⁻¹

Intensity (W/cm² ster cm⁻¹)

Frequency (cm⁻¹)

1120 1125 1130 1135 1140 1145 1150 1155 1160 1165 1170

1130.75 1143.5 1156.0

Observed
Retrieved
Saturn Infrared Spectra: CO2

Saturn: Nadir View
s58.128SA.C001: FP3
Lat: -53.65
Res = 0.5 cm\(^{-1}\)

CO2
C2H2
C2H2
CO2
CO2
Saturn IR Observed and Synthetic Spectra:

Saturn Nadir View: s18.021SA.C003
Lat = 14.69°; EA = 67.32°
Res= 0.53 cm⁻¹
Retrieved Saturn CO2 Mixing Ratio Profile

Saturn CO₂ Retrieved & Model Distributions

Moses, Model profile

Cassini: Limb Obs.

Cassini: Mean Nadir Obs.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>$Q_v \text{ (CO}_2\text{)}$</th>
<th>$N \text{ (CO}_2\text{)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Value of Atmos. Pressure @ 1 mb</td>
<td>4.74E-10</td>
<td>2.14E+14</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.52E-10</td>
<td>5.74E+13</td>
</tr>
<tr>
<td>Standard Deviation of Mean</td>
<td>5.10E-12</td>
<td>2.21E+12</td>
</tr>
<tr>
<td>Mean Value of Atmos. Pressure @ 10 mb</td>
<td>1.05E-10</td>
<td>6.30E+14</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.19E-11</td>
<td>1.56E+14</td>
</tr>
<tr>
<td>Standard Deviation of Mean</td>
<td>1.10E-12</td>
<td>5.77E+12</td>
</tr>
</tbody>
</table>
Thank You!