PICTURE Science Traceability Matrix for a Titan Orbiter Mission

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ABSTRACT

Within the methane windows of Saturn's largest moon, Titan, lies a wealth of information that was just out of reach from Cassini's VIMS instrument. VIMS was limited by its spectral resolution, making definitive identification of trace gasses is Titan's atmosphere and surface impossible. We identify five of the most important Titan science questions that a high spectral resolution near-infrared spectrometer instrument hasto answer and present them in this report. We follow the NASA Science Traceability Matrix design flow to present these questions.

Keywords: Titan — Science Traceability — Near-Infrared Astronomy — Planetary Science

1. INTRODUCTION

1.1. *Titan*

Saturn's largest moon, Titan, is an important target for scientific inquiry. Data from the Cassini-Hyugens missions answered many long standing questions about the large moon, but ushered in many more questions about the intricacies of Titan's surface and atmosphere.

Cassini was the last space mission to Titan, executing 54 flybys of Titan from 2004 to 2017. On board Cassini was the Visible and Infrared Mapping Spectrometer (VIMS), a near infrared spectrometer with a maximum resolution of 270. At the time VIMS resolution was considered high and was able to observe Titan at 100 times the resolution of previous spectrometers. Much was learned from Cassini VIMS data, but higher resolution data is needed to distinguish between molecules in Titan's atmosphere and surface.

The James Webb Space Telescope (JWST) instrument NIRSPec will observe Titan in late 2022 at a maximum resolution of 2700. This data has the potential to answer some questions outlined in Section 3. Data from JWST will be helpful in constraining atmospheric components but JWST NIRSpec lacks the spatial resolution of a space mission NIR spectrometer and will not be able to clearly resolve differences between adjacent surface components.

1.2. *PICTURE*

The Photonic Integrated Circuit TUned for Reconnaissance and Exploration (PICTURE) instrument is a near infrared (NIR) spectrometer currently being developed at Goddard Space Flight Center. PICTURE aims to revolutionize spectrometer design with Photonic Integrated Circuits (PICS). PICS allows PICTURE to be lightweight, efficient, and have a high resolving power of 15000. PICTURE will have an operational window between 1 and 5 µm to observe well into the NIR range. If PICTURE visits Titan, it will observe features similar to those observed by Cassini's VIMS instrument but at a much higher resolution (PICTURE: 15000, VIMS: 270) allowing scientists to identify trace gas and surface components. A comparison of resolutions between Cassini VIMS, JWST NIRSpec, and PICTURE is presented in Figure 1 in the 4.5 to 5µm range of a standard Titan configuration.

PICTURE is in the NASA Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) planetary instrument development stage at a flight readiness of TRL3. It is hoped that PICTURE can be placed on the Titan orbiter mission tentatively planned for New Frontiers 6 launched in the 2030's (National Academies of Sciences & Medicine (2022)).

2. METHODS

We used the NASA Planetary Spectrum Generator (PSG) and Docker to simulate the spectra of trace amounts of atmospheric gasses and surface components to see what PICTURE will be able to observe on Titan. We set the PSG

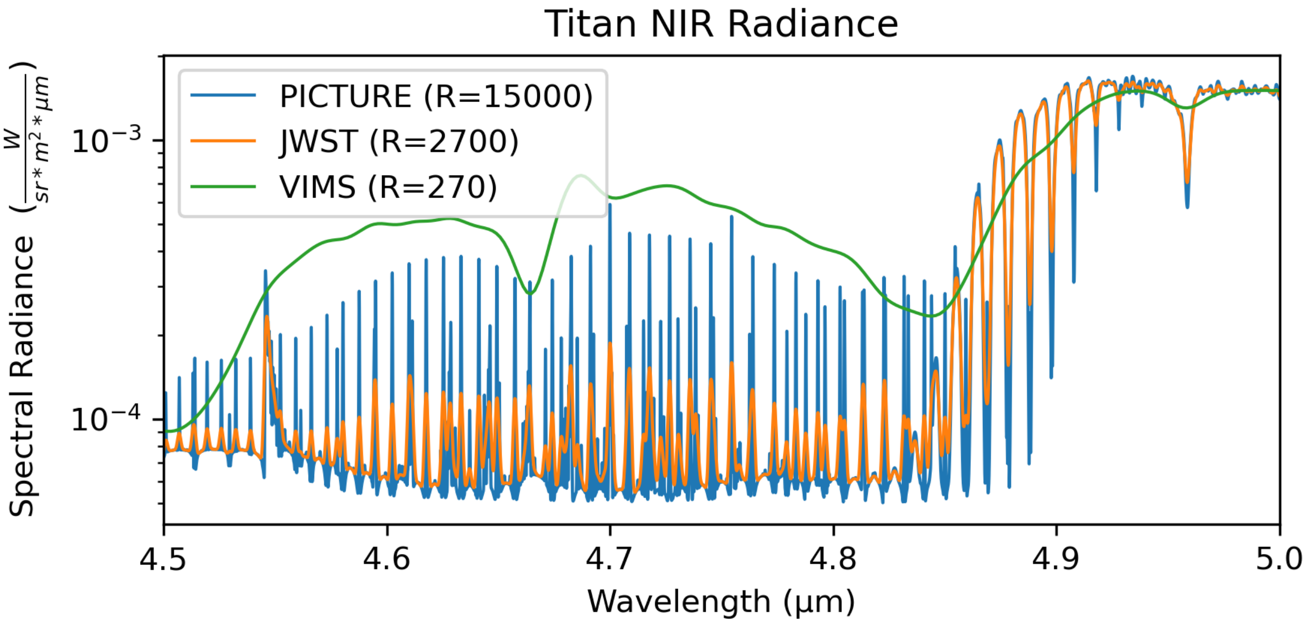


Figure 1: Comparison of PICTURE, Cassini VIMS, and James Webb NIRSpec resolution on 4.5-5µm region of Titan's spectra. Simulated with PSG.

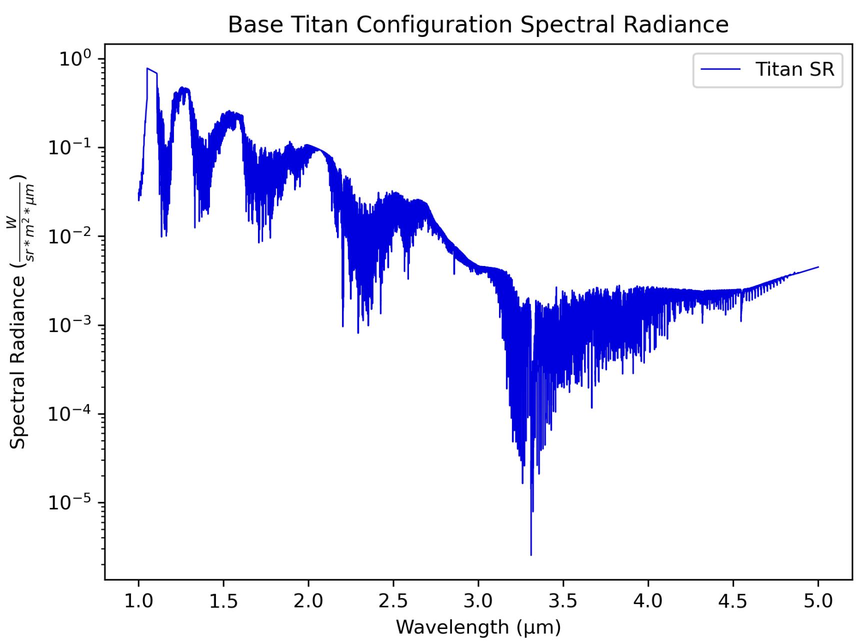


Figure 2: Basic Titan model spectral radiance over a 1-5µm region

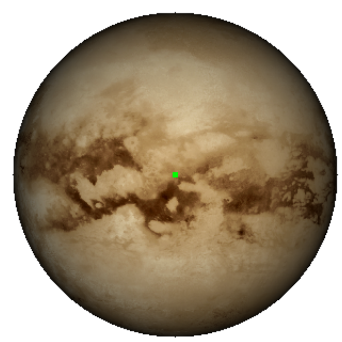


Figure 3: The green dot represents the simulated view of the instrument's observing geometry from PSG.

resolution to 15000 and a wavelength range from 1-5µm, and choose a nadir observing geometry of 0 longitude, 0 latitude, 90°observation angle, 0°incidence angle, 0°solar azimuth, 180°phase angle, and observe from 10,000km from the moon. Simulated observing geometry can be seen in Figure 3. Using PSG we create a standard Titan model with an atmosphere of 96% N_2, and a scalar abundance of CH_4 (vertical profile of CH_4 can be obtained using the Titan PSG object), a surface of the Titan_USGS_Planet_Surface, and a Khare_Titan_Haze aerosol composition with a radius of 0.201µm. The spectral properties for Titan's surface and Haze are shown in Figure 4. Due to PSG simulation limits

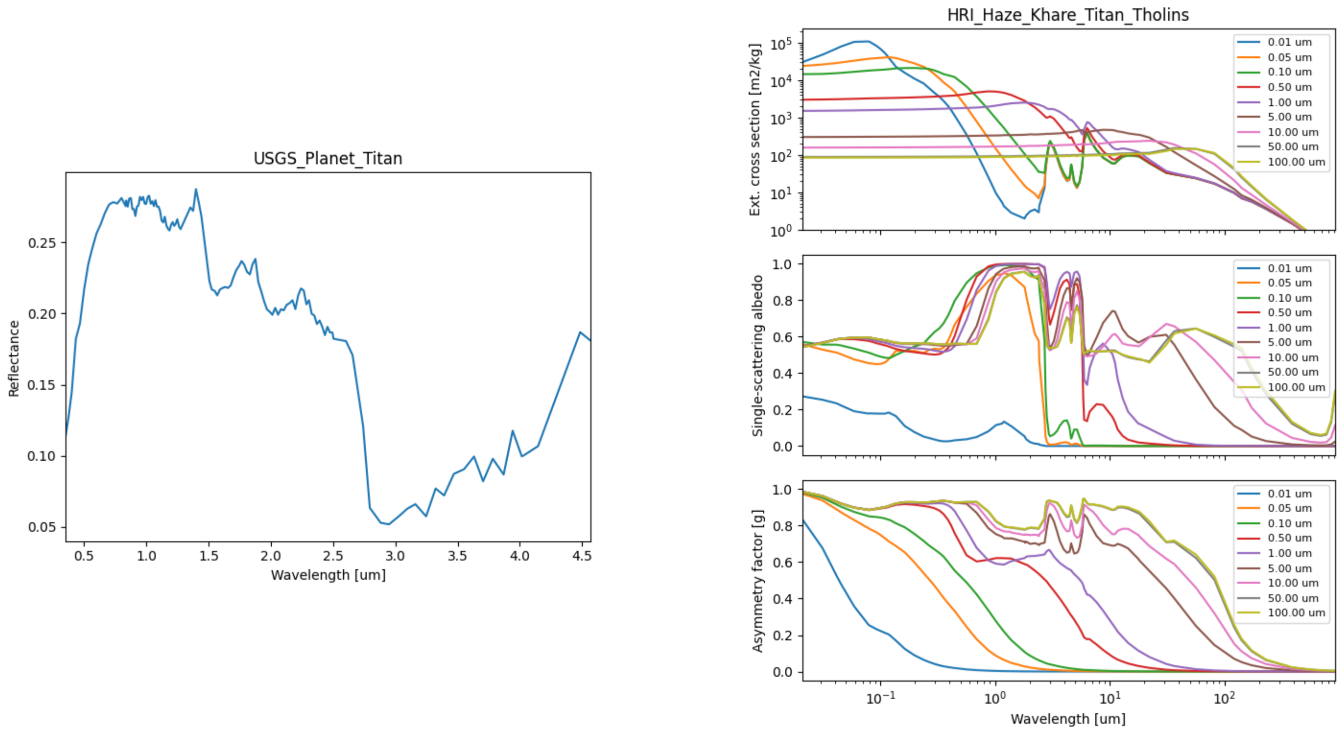


Figure 4: Titan USGS Planet Surface reflectance (left) and HRI Haze Khare Titan Tholins optical properties (right).

the complexity of the standard Titan atmosphere and surface was limited. The standard Titan model configuration was built off of recommendations from Titan researcher Conor Nixon and literature.

To find the spectral contribution for each molecule we test, we add the desired molecule to the basic Titan model in the desired quantity. Added molecules and quantities are shown in Table 1.. We run PSG with the base Titan configuration (Figure 2) and the added molecule. Then we take the difference between the simulated spectral radiance and the basic configuration spectral radiance and plot the difference to see where the molecule is absorbing or emitting.

Data, instructions on how to use PSG and Docker, and plotting functions can be found at https://github.com/EmmaLitzer/NASA_PSG.

3. SCIENCE TRACEABILITY

In order for any science mission to be successful, the goals and requirements for the mission must be clearly understood. This can be accomplished with the use of a science traceability matrix (STM). The purpose of the science traceability matrix is to provide a structured and logical overview of the goals of a mission and mission instruments. The STM sets up a logical flow from high level science questions to the science objectives, observed features, measurement objectives, and instrument requirements. Missions can be maximally efficient by taking instrument requirements and goal priority into account when designing observing schedules and instruments that will be implemented on the spacecraft.

NASA requires an STM in instrument and mission proposals. In this case, this STM covers the science justifications for sending the PICTURE NIR spectrometer on a spacecraft designed to orbit Titan. Science goals were collected from Titan literature and measurement requirements were simulated in the Planetary Spectrum Generator (PSG) when possible.

Science objectives and measurement requirements were taken from Titan literature and from PSG models but some subjectivity was required in choosing wavelength ranges. Supporting evidence is cited in figures and literature below.

We aim to identify Titan topics of interest and wavelength windows that maximize future scientific data from PICTURE using the STM.

The STM is organized into 5 overarching questions:

1. What is Titan's surface composed of?

Gas	Amount	Lakes	Amount	Ices	Amount
$H_{2[CKTB/LBLN]}$	10 ppmv	Ch_4 Amorphous$_{[OPTIC]}$	20%	CO_2 AMES$_{[OPTIC]}$	20%
$C_2H_{2[CKTB/LBLN]}$	10 ppmv	CH_4 Liquid$_{[OPTIC]}$	20%	CO_2 CRISM$_{[REFL]}$	20%
$C_2H_{2[CKTB/LBLN]}$	10 ppmv	C_2H_6 Amorphous$_{[OPTIC]}$	20%	H_2O AMES$_{[REFL]}$	20%
$C_2H_{6[CKTB/LBLN]}$	10 ppmv	C_2H_6 Metastable$_{[OPTIC]}$	20%	H_2O CRISM$_{[REFL]}$	20%
$C_3H_{8[LBLN]}$	10 ppmv		20%	H_2O and CH_4 AMES$_{[OPTIC]}$	20%
$C_4H_{2[LBLN]}$	10 ppmv		20%	CH_4 GSFC$_{[OPTIC]}$	20%
$C_6H_{6[LBLN]}$	10 ppmv		20%	CH_4 II-I Ice Liquid$_{[ALPH]}$	20%
$HCN_{[CKTB/LBLN]}$	10 ppmv		20%	NH_3 GSFC$_{[OPTIC]}$	20%
$HNC_{[LBLN]}$	10 ppmv		20%		20%
$HC_3N_{[LBLN]}$	10 ppmv		20%		20%
$CH_3CN_{[LBLN]}$	10 ppmv		20%		20%
$C_2H_5CN_{[LBLN]freq}$	10 ppmv		20%		20%
$C_2N_{2[LBLN]}$	10 ppmv		20%		20%
$NH_{3[CKTB/LBLN]}$	10 ppmv		20%		20%
$CO_{[CKTB/LBLN]}$	10 ppmv		20%		20%
$CO_{2[CKTB/LBLN]}$	10 ppmv		20%		20%
$H_2O_{[CKTB/LBLN]}$	10 ppmv		20%		20%
$CO_{2[CKTB/LBLN]}$	10 ppmv				20%
$N_{2[CKTB/LBLN]}$	10 ppmv				
$CH_{4[CKTB/LBLN]}$	10 ppmv				
$CH_3CCH_{[LBLN]}$	10 ppmv				
$CH_3OH_{[LBLN]}$	10 ppmv				

Table 1: Molecules simulated in PSG.

2. Where does Titan's oxygen supply come from?
3. What is the composition of Titan's atmosphere?
4. How does Titan's haze develop and move?
5. Do active cryovolcanoes exist on Titan's surface?

These questions were chosen due to their impact on our understanding of Titan and our ability to observe them from an orbiter with the PICTURE instrument in the 1 to 5µm range. The STM is presented in Figure 5

ref #	Science Goal	Science Objective	Observed Feature	Measurement Objective	Measurement Requirement
1.1	Does Titan show signs of habitibility?	Do molecules exist in TItan's lakes that can spontaneously form cell membranes?	Polar molecules (Vinly Cyanide: C2H3N)	Lake componds, NIR	Sensitive NIR spectroscopy in 1-3um and 4.5-5um range
1.11		Are there energy synthesis pathways for organisms to breakdown moloecules? (similar to ATP synthesis)	Molecules with double and triple bonds	Surface and lake compounds. Photochemical pathways	Sensitive spectroscopy in the 1-3um and 4.5-5um range
1.2	What is the morphology of lakes on Titan?	What percentage of Titan surface is liquid?	Lake surface	Imaging	
1.21		What is the density of lakes and how does it vary by latitude?	Lake surface	Imaging	
1.22		How does lake depth vary with latitude?	Lake depth	RADAR/SAR, altimetry, bathymetry	NIR lake bottom reflectance
1.3	What are the main components of Titan's lakes?	What is the ethane abundance in Titan's lakes?	C2H6	Ethane, NIR	Sensitive spectroscopy in the 4.5-5um range
1.31		What is the methane abundance in Titan's lakes?	CH4	Methane, NIR	Sensitive spectroscopy in the 4.5-5um range
1.32		What is the abundance of hydrocarbons and nitriles in Titan's lakes?	HCN, C2H6, N2	Lake componds, NIR	Sensitive NIR spectroscopy
1.33		What is the organic abundance in Titan's lakes?	C2H2, O, aerosols	Lake componds, NIR	Sensitive NIR spectroscopy
1.34		Do water clathrates exist in Titan's lakes?	H2O	Lake componds, NIR	Sensitive NIR spectroscopy
1.35		Are noble gasses dissolved in Titan's lakes or in clathrates?	Kr, Ar, Xe	Lake componds, NIR	Sensitive NIR spectroscopy
1.36		How does lake composition very by latitude and region?	CH4, N2, C2H6	RADAR/SAR, altimetry, bathymetry	Imaging, hyperspectral imaging
1.4	What is the vertical profile of Titan's liquid surface?	How does molecule abundance vary with depth?	CH4, C2H6, N2, C2H2, O	RADAR/SAR, altimetry, bathymetry	Imaging, hyperspectral imaging
1.5	What are the photochemical pathways to obtain surface components from atmospheric components?	What molecules deposit to the surface from the atmosphere?	Vertical profiles of organic molecules	Occultation	NIR occultation of atmosphere. See atmosphere section for distinguishing spectar
1.51	What is the composition of Titan's dunes?	What is the organic composition of Titan's dunes?	Organic molecules	C2H6, C2H2, CH4	NIR spectroscopy at 0.94-5μm
1.52		Does exposed water-ice exist in Titan's dunes?	Water-ice	Water ice	Sensitive NIR spectroscopy in 2-2.2um, 2.6-3.2um, and 4.5-5um range
2.1	Does exposed water-ice exist on Titan's surface?	Does pristine exposed water-ice exist on Titan's surface?	Water ice exposed on mountian peaks	Water ice, NH3 ice	NIR spectroscopy at 1-3μm, 1.9μm, 3.29μm
2.11		Does impure exposed water-ice exist on Titan's surface?	Water ice exposed on mountian peaks	Water ice, NH3 ice	NIR spectroscopy at 1-3μm, 1.9μm, 3.29μm
2.12		What imputities are common in Titan's exposed water-ice?	Water ice exposed on mountian peaks	Water ice, NH3 ice	NIR spectroscopy at 1-3μm, 1.9μm, 3.29μm
2.2	Do cryovolcanos outgass?	What is the composition of cryovolcano outgass fog?	Gas composition vertical profiles	Fog, CH4	Nadir occultation NIR spectroscopy
2.3	What is Titan's cryovolcano distribution?	What is Titan's cryovolcano count?	Cryovolcano identification	Bright features, water ice, hyperspectral imaging	Imaging, hyperspectral imaging
2.31		How does the density of cryovolcanos change with latitude?	Cryovolcano identification	Bright features, water ice, hyperspectral imaging	Imaging, hyperspectral imaging
3.1	Is Titan's oxygen supply endogenic or exogenic?	Does Titan's oxygen supply come from micrometeorite abalation or from an outside source?	Oxygen vertical profile	Oxygen	NIR occultation, High resolution sensitive NIR spectroscopy at 4.2-5um
3.2	Does Titan's oxygen supply come from Enceledus?	Does Enceledus's oxygen plumes supply Titan's oxygen?	Enceledus plumes, oxygen vertical profile	Oxygen	NIR occultation, High resolution sensitive NIR spectroscopy at 4.2-5um
3.3	Does oxygen deposit from Titan's atmosphere in complex molecules?	What oxygen molecules are present in Titan's lower atmosphere and surface?	Oxygen at low altitudes, oxygen at surface	Oxygen, complex oxygen molecules	NIR occultation, High resolution sensitive NIR spectroscopy at 4.2-5um
4.1	What is TItan's atmospheric composition?	What is the abundance of atmospheric molecules?	Molecule abundance, vertical profiles	CH4, N2, CO, C2H2, C2H6, CH3OH, HCN, C8H7N, C6H6, C10H8, C12H11	Sensitive and high resolution NIR spectroscopy. See Atmospheric section for wavelength ranges.
4.11		What is the vertical profile of Tian's atmospheric molecules?	Molecule abundance, vertical profiles	CH4, N2, CO, C2H2, C2H6, CH3OH, HCN, C8H7N, C6H6, C10H8, C12H12	NIR occultation, Sensitive and high resolution NIR spectroscopy. See Atmospheric section for wavelength ranges.
4.2	What is the isotope makeup of Titan's atmosphere?	What is the abundance of isotopes in Titan's atmosphere?	Isotope abundance, vertical profile	CO, CH4, N, CO2	Sensitive high resolution NIR spectroscopy at 4-5um (CO) and 3.02-3.2um (CH4)
4.21		What is the vertical profile of isotopes in Titan's atmosphere?	Isotope abundance, vertical profile	CO, CH4, N, CO3	Occultation, Sensitive high resolution NIR spectroscopy at 4-5um (CO) and 3.02-3.2um (CH4)
4.3	What is the noble gas composition in Titan's upper atmosphere?	What is the abundance of noble gasses in Titan's upper atmosphere?	Nobel gas abundance	Ar, Ne, Kr, Xe	High resolution NIR spectroscopy in the 1-3um range
4.4	How does Titan's CH4 mixing ratio vary?	How does Titan's CH4 mixing ratio vary by latitude?	CH4 abundance	CH4	NIR spectroscopy at 3.05-3.2μm
4.5	What atmospheric constituant causes absorber NIR features?	What PAH is causing the UnE NIR features?	UnE (3.28um)	PAH	NIR spectroscopy at 3.28um
5.1	What is Titan's haze composed of?	What is the abundance of haze particles?	Haze molecule abundance	HCN and other aerosols	NIR spectrsocopy at 1-3um
5.2	What are the physical characteristics of Titan's haze?	What is the distribution of aerosols in Titan's main haze layer?	Tholins	Imaging, vertical profiles	NIR spectroscopy vertical profiles
5.21		What is the fractal dimension of haze particles?	Tholins	Spectroscopy, occultation	NIR spectroscopy
5.22		What is the size of Titan's haze particles?	Tholins	Spectroscopy, occultation	NIR spectroscopy at 1-3um
5.3	How does Titan's haze change with latitude, altitude, and time?	How does Titan's haze develop and move?	Titan's haze (temporal changes)	Multiple haze measurements over the course of a season	Visible to MIR spectroscopy at .439μm, .889μm, ..673μm, .953μm and 1-3um.

Figure 5: Science Traceability Matrix for a orbiter mission to Titan with the PICTURE instrument.

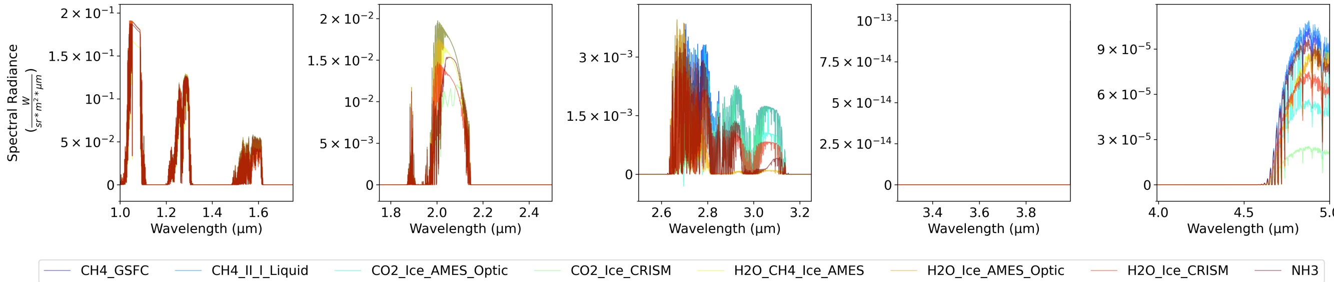


Figure 6: Difference between Titan's CH_4 and N_2 atmosphere with Titan surface and 80% Titan surface + 20% surface ice.

3.1. *What is Titan's surface composed of?*[1]

3.1.1. *Solid Surface*

Observing Titan's solid surface can reveal photochemical pathways of atmospheric molecules that we cannot observe in Titan's atmosphere. Areas of interest include cryovolcanos and dunes. PICTURE will be capable of observing potential cryovolcanic sites as discussed in Section 3.2 but may not be capable of observing intricacies of Titan's dune fields.

PICTURE will be able to distinguish between different surface ices. Figure 6 and Figure 7 demonstrates the differences between different ice components. To observe ices that make up 20% of the observed surface, high resolution and high sensitivity $5 * 10^{-3} \frac{W}{sr*m^2*m}$ for the 1.8-2.2µm range, $5 * 10^{-4} \frac{W}{sr*m^2*m}$ for the 2.6-3.2µm range, and $1 * 10^{-5} \frac{W}{sr*m^2*m}$ is needed in the 4.5-5µm range.

3.1.2. *Liquid Surface*

Looking into Titan's liquid surface in the NIR can reveal the surface composition of Titan's lakes and seas. The composition of methane and ethane in Titan's lakes can give us a clue to Titan's meteorological cycle. More data on Titan's lakes will also help answer questions about the discrepancy between northern lake composition (mostly methane) and the southern lake composition (equal parts methane and ethane).

Using PSG to simulate different lake components, we found that to observe the difference between 20% ethane and methane, PICTURE must be able to distinguish between $3 * 10^{-5} \frac{W}{sr*m^2*m}$. Figure 8 and Figure 9 show these results.

The depth profiles could also answer questions about Titan's interior liquid surface and if there is liquid exchange between the surface and subsurface, although it is questionable if PICTURE will be able to look deep into Titan's lakes

3.2. *Do cryovolcanoes exist on Titan's surface?*[2]

Data from Cassini VIMS has identified potential cryovolcano sites from flow-like features and bright patches of ice, although nothing has been confirmed. Titan's elusive cryovolcanos are though to erupt volatiles such as water, methane, and ammonia which will deposit pure water-ice and ammonia ice on Titan's surface. Ammonia is not expected to exist in large quantities on the surface of Titan and definitive defections of ammonia ice would be a strong indicator that cryovolcanos are erupting material that exists beneath the surface of Titan.

It is also possible that cryovolcanos are supplying Titan's atmosphere with methane. Titan's methane atmosphere would not exist as it is today without a mechanism replenishing atmospheric methane lost in photochemical reactions. Without this resupply, Titan's methane atmosphere would have been broken down in 10 Myr.

PICTURE can find cryovolcanos by looking for patches of water-ice and ammonia ice through the hyperspectral imaging technique. PICTURE will also be capable of observing methane fog and vertical profiles of the atmosphere above a potential cryovolcano.

Cryovolcanos could be an opening to mix complex chemicals that exist on Titan's surface with mixtures in the (proposed) subsurface liquid ocean. This could offer an opportunity for life to form. Looking for cryovolcanic regions also offers a unique window into the composition of Titan's subsurface.

[1] Questions on Titan's surface are identified in reference number 1 in the STM.

[2] Questions on Titan's cryovolcanos are identified in reference number 2 in the STM.

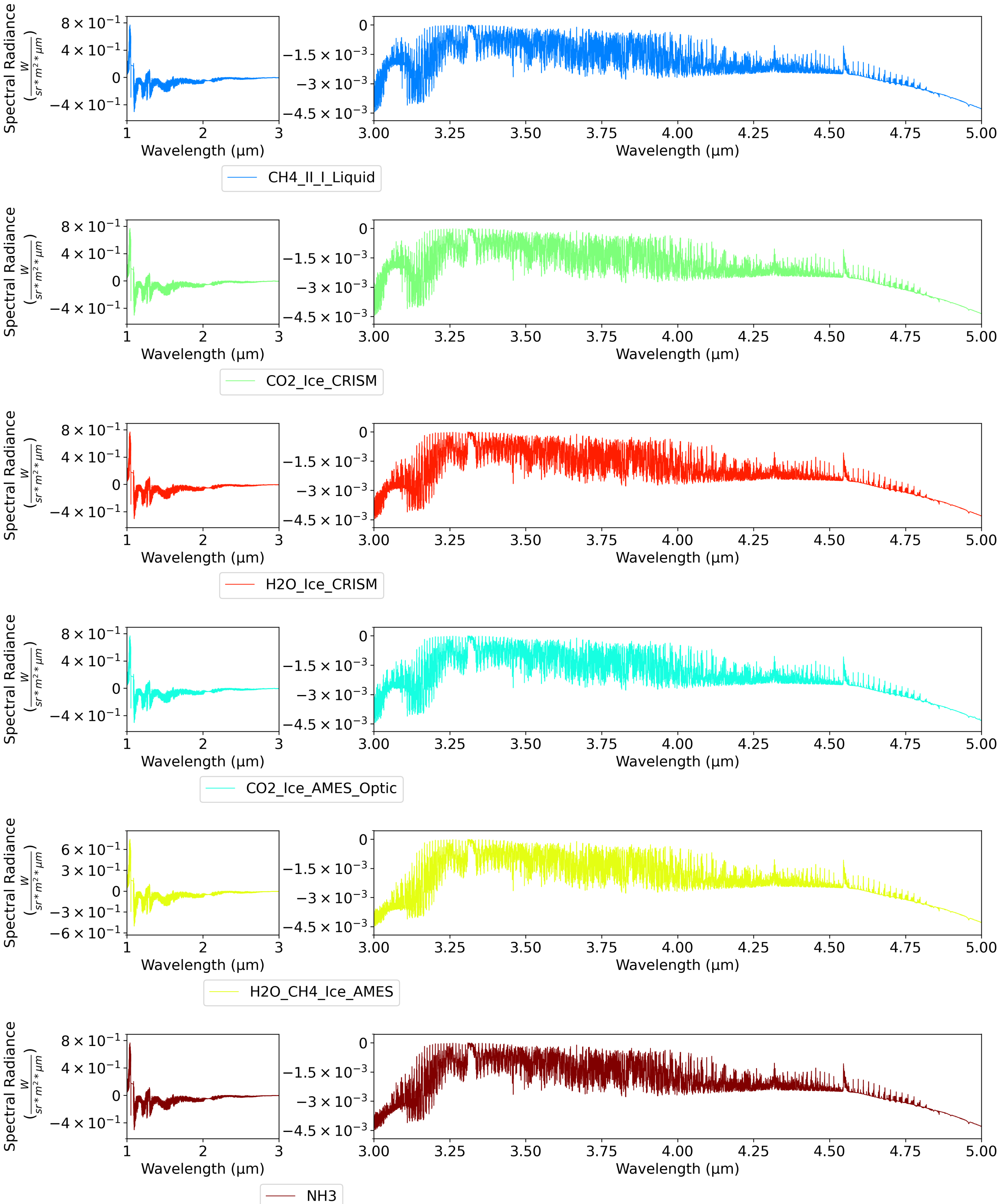


Figure 7: Individual ice components simulated with PSG. Difference between Titan's CH_4 and N_2 atmosphere and 100% Titan surface and 80% Titan surface and 20% surface ices.

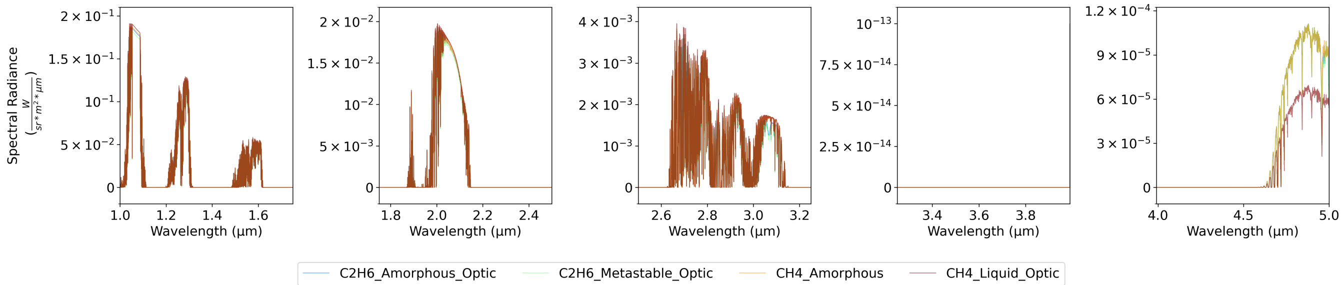


Figure 8: Difference between Titan's CH_4 and N_2 atmosphere with Titan surface and 80% Titan surface + 20% surface lake.

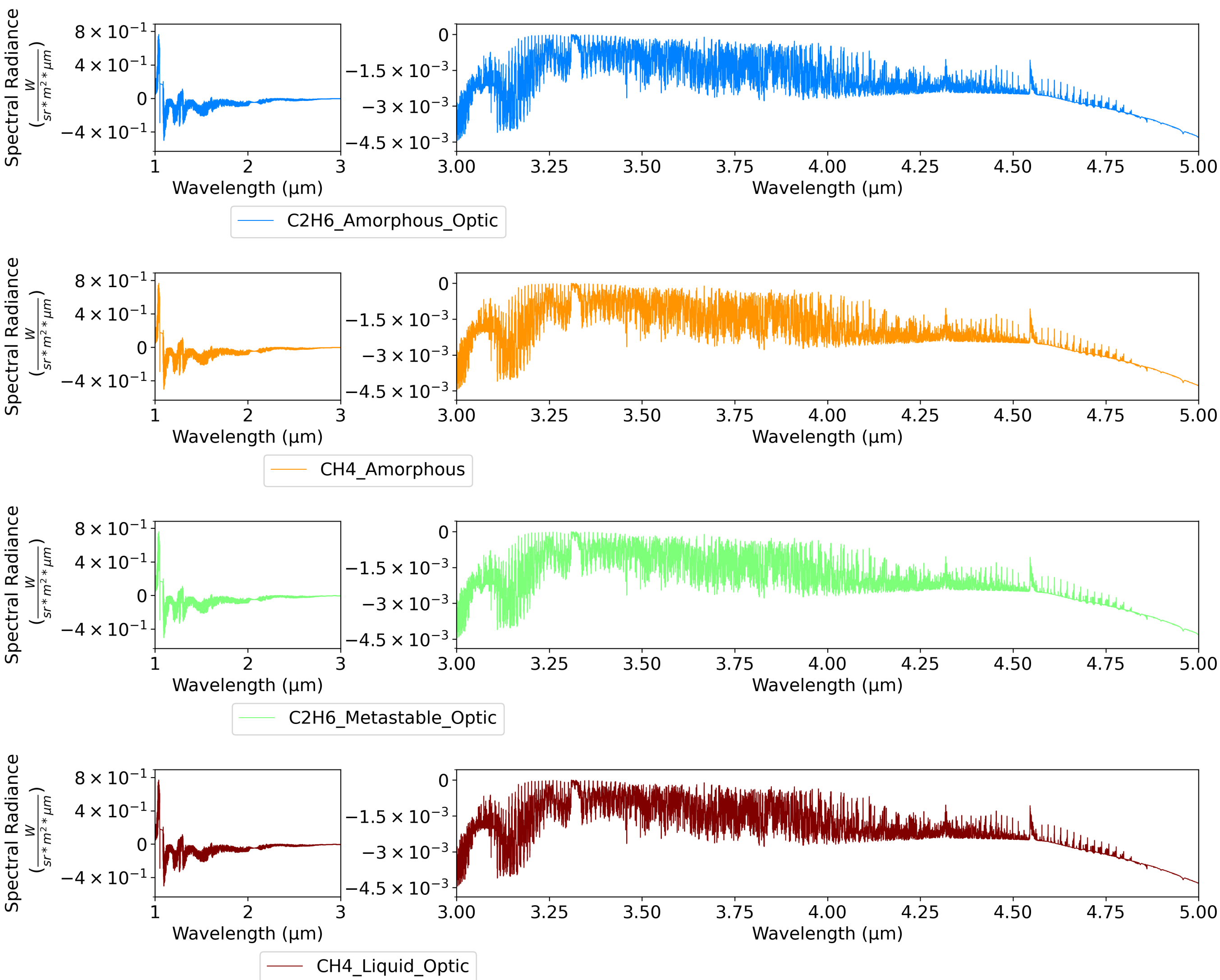


Figure 9: Individual ice components simulated with PSG. Difference between Titan's CH_4 and N_2 atmosphere and 100% Titan surface and 80% Titan surface and 20% surface lakes.

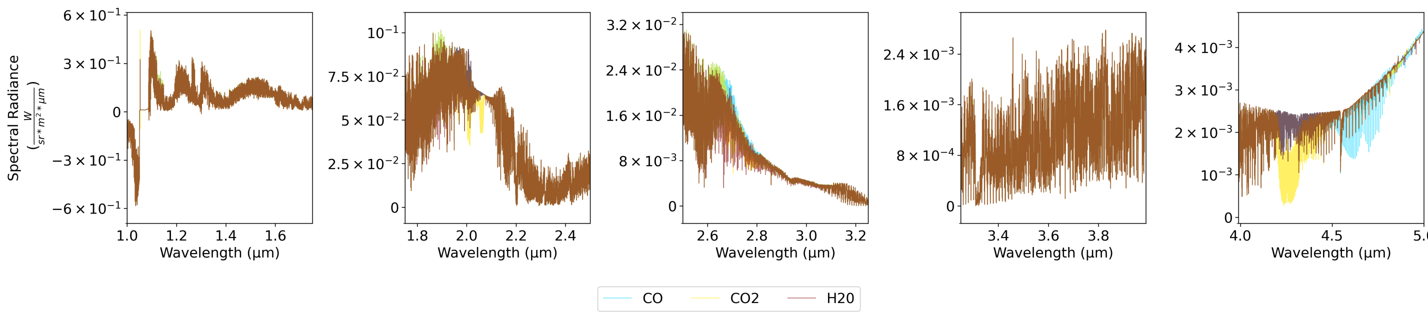


Figure 10: Difference between Titan's basic atmosphere and 10 ppmv of oxygen bearing gasses (H_2O, CO, CO_2).

Identification of cryovolcanic activity on Titan will aid in our understanding of Titan's sub-surface oceans, Titan's geology, and the nature of Titan's methane atmosphere making them a key target for a NIR instrument aboard a Titan orbiter.

To simulate what wavelengths we can observe cryovolcanic material, we simulate Titan with water-ice, methane and water-ice, and ammonia ice. The results can be seen in Section 3.1.2 in Figure 7.

3.3. *Where does Titan's oxygen supply come from?*[3]

Based on oxygen abundance in Titan's atmosphere, it is possible that Titan's oxygen supply comes from and external source such as Enceledus or from micrometeorite ablation instead of from an internal source on Titan. Of the two external theories, the Enceledus oxygen source is more likely due to the discrepancies in the nobel gas composition that would accompany the micrometeorite ablation theory (Moreno et al. (2012)).

Measuring at the vertical profiles of Titan's atmospheric oxygen bearing molecules can reveal the source of Titan's oxygen supply. Lara et al. (2014) looks further into expected vertical profiles based on the internal oxygen theory and the external (Enceledus and micrometeorite ablation) theories behind Titan's oxygen. Lara et al. (2014) concludes that an Enceledus oxygen source can explain the CO_2/H_2O vertical profiles (with an additional H_2O loss component to Titan's haze). Lara et al. (2014) also concludes that micrometeorite ablation of a comet impact approximately 275 Mya could explain CO_2 stratospheric excess but is not likely considering Titan's impact rate.

We use PSG to simulate oxygen molecules in Titan's atmosphere at 10 ppmv. Individual molecule spectra difference can be seen in Figure **??** and a comparison of the oxygen molecule spectra difference can be seen in Figure 10. Our results show that a high resolution spectrometer is needed to observe the maximal difference in oxygen bearing species in the 4-5m range.

3.4. *What is the composition of Titan's atmosphere?*[4]

PICTURE's NIR range is sensitive to a variety of molecules in Titan's atmosphere. Using PICTURE we can further constrain the mole fraction of molecules in Titan's atmosphere beyond what Cassini VIMS was capable of. We use the atmospheric molecules summarized in the table in Hörst (2017).

Due to the methane in Titan's atmosphere, there are limited wavelength windows that we can see into. Using PSG to simulate expected spectra allows as to see where in the regions between the methane windows molecules can be distinguished.

[3] Questions on Titan's oxygen supply are identified in reference number 3 in the STM.

[4] Questions on Titan's atmosphere are identified in reference number 4 in the STM.

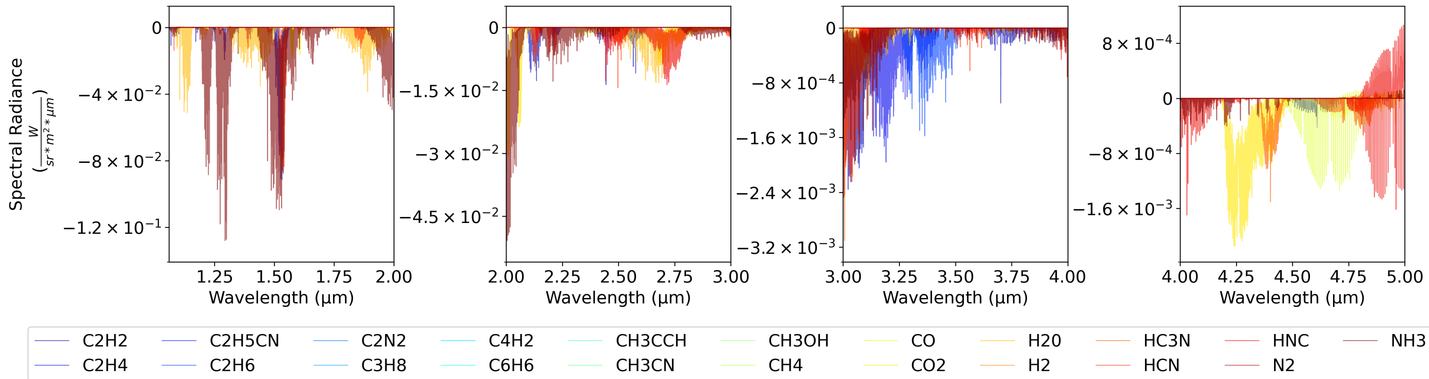
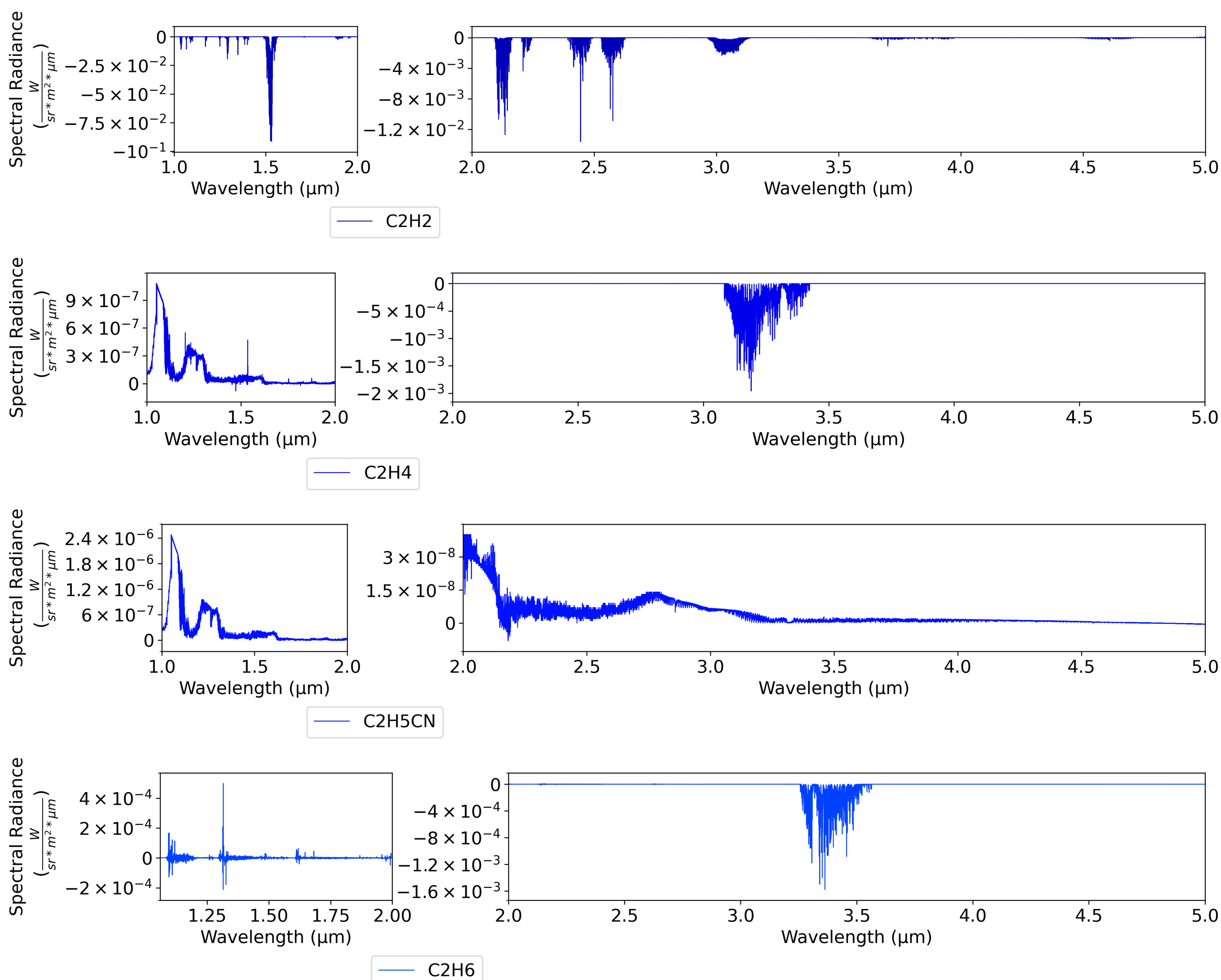
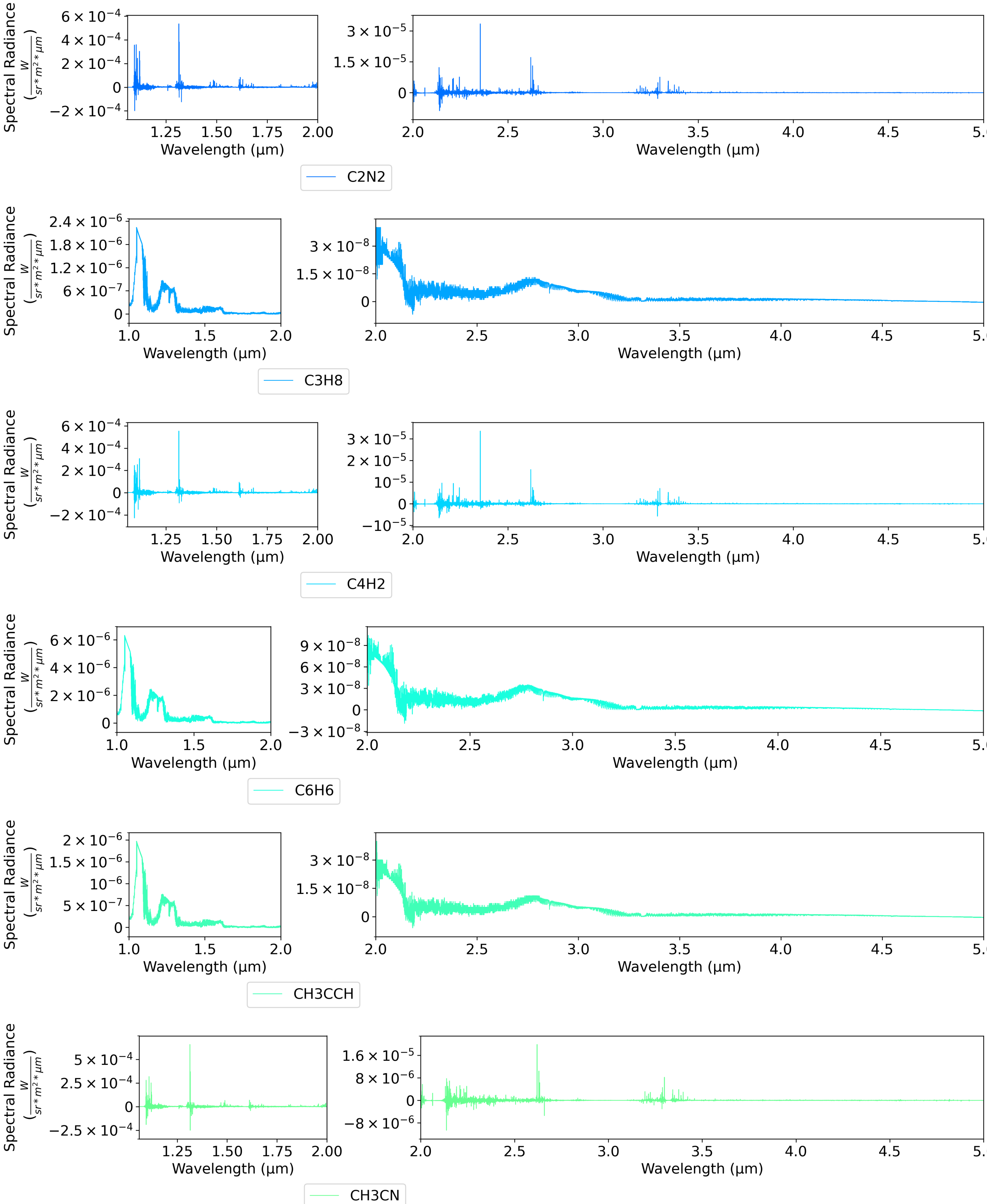
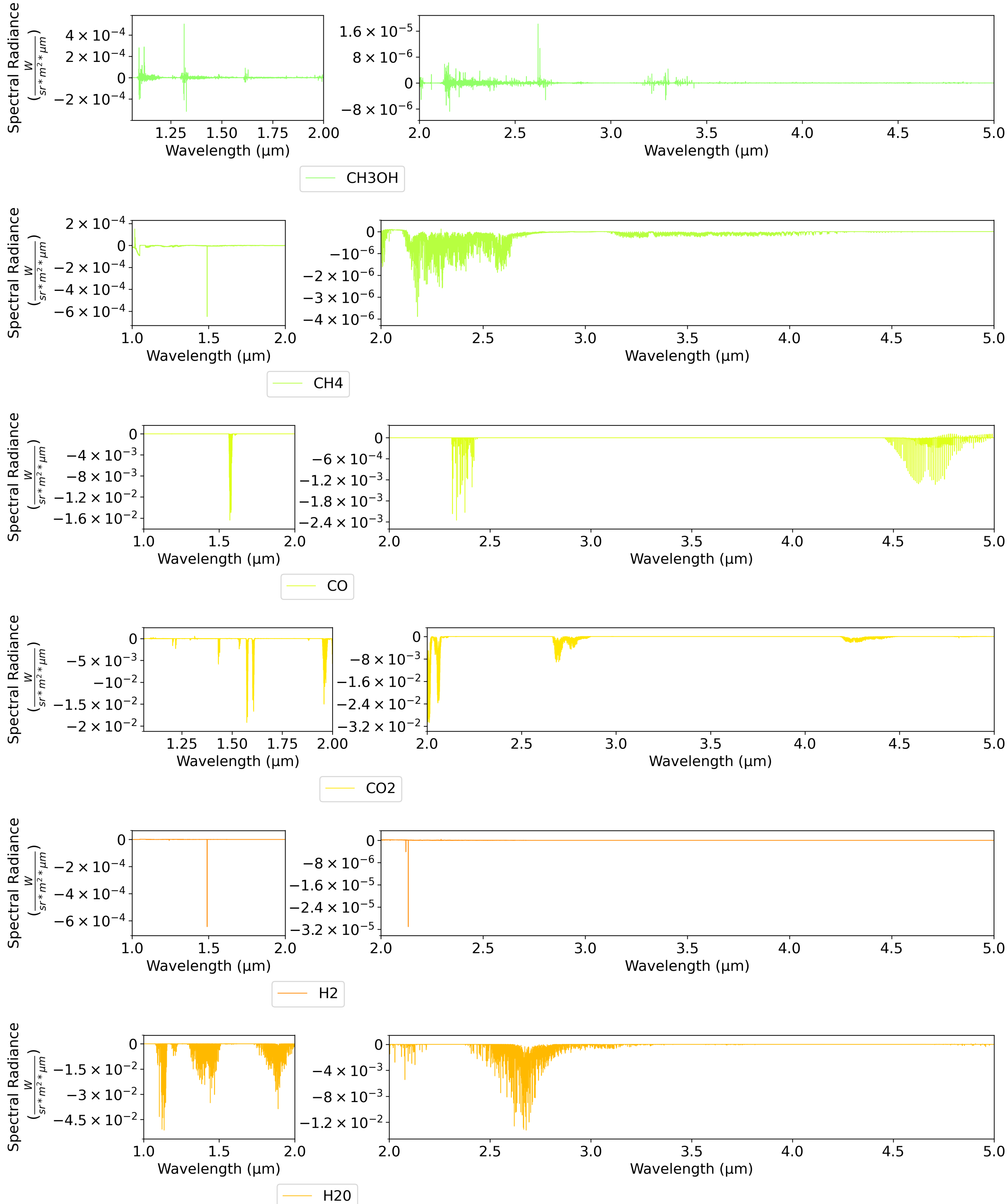


Figure 11: Difference between Titan's CH_4 and N_2 atmosphere and 10 ppmv of trace gasses




Spectral Radiance
$(\frac{W}{sr*m^2*\mu m})$
Wavelength (μm)
C2N2
C3H8
C4H2
C6H6
CH3CCH
CH3CN


Spectral Radiance
Wavelength (μm)
CH3OH
CH4
CO
CO2
H2
H20

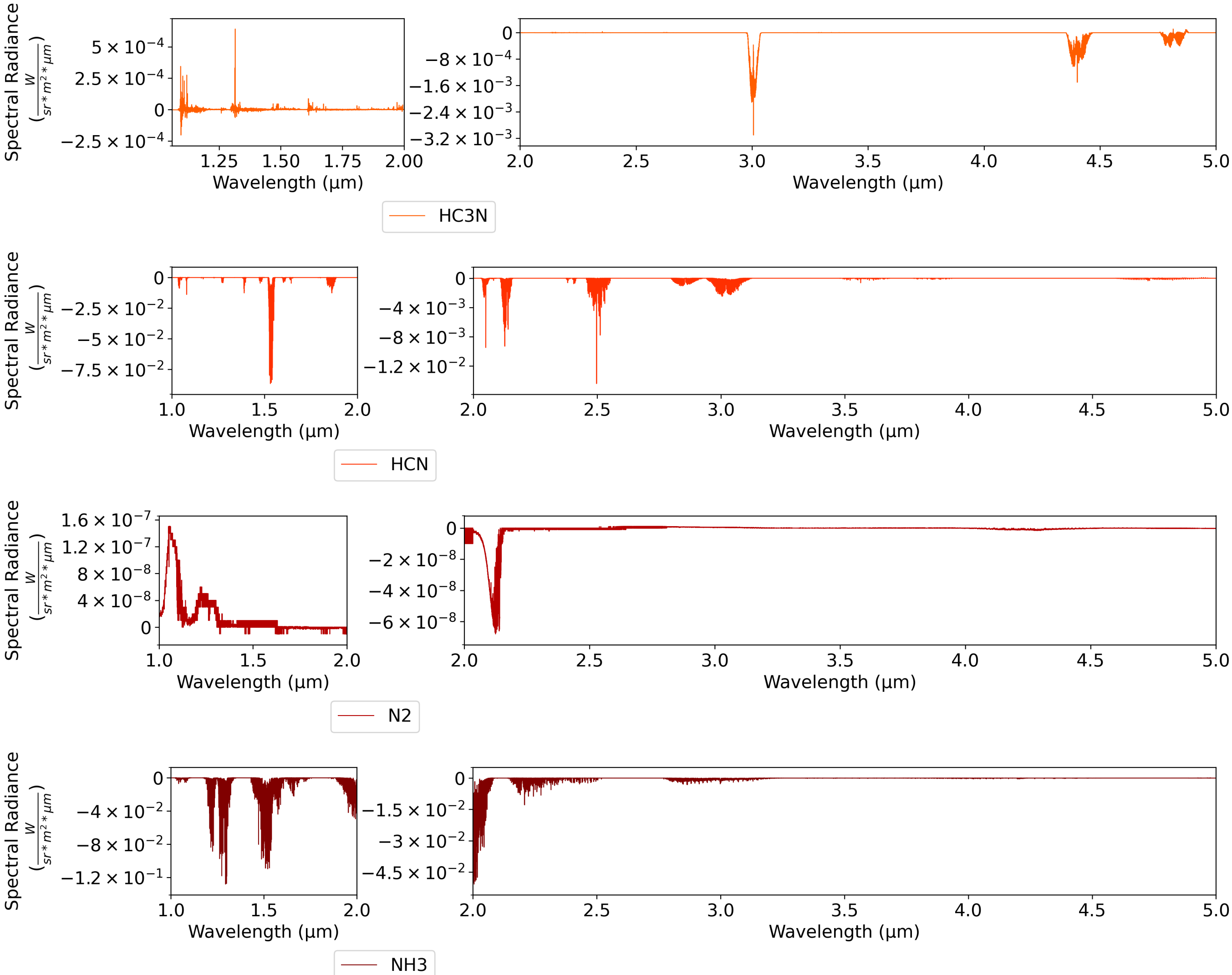


Figure 12: Individual atmospheric components simulated with PSG. Difference between Titan's CH_4 and N_2 atmosphere and 10 ppmv of trace gasses

3.4.1. *Isotopes*

Atmospheric isotopes ratios can reveal the nature of Titan's atmosphere. Isotopic ratios of carbon $^{12}C/^{13}C$ and oxygen $^{16}O/^{18}O$ and $^{16}O/^{17}O$ in molecules of CO, CH_4, C_2H_2, C_2H_6, HCN, and other abundant molecules can point us towards the origins and evolution of the atmosphere. Carbon isotopic ratios can hint towards cryovolcanic outgassing of CH_4. Oxygen isotopic ratios can reveal if Enceledus is enriching Titan's atmosphere with oxygen or if Titan's oxygen source is internal (see Section 3.3). Difference abundances of CO and CH_4 are simulated using PSG. Results are shown in Figure 13.

3.5. *How does Titan's haze develop and move?*[5]

Data from Hubble has shown Titan's haze shift from north to south polar regions over Titan's 29 Earth year cycle. PICTURE will be able to sample the NIR bright lower 500 km of the 1000 km haze that circulates in the troposphere to the upper stratosphere.

[5] Questions on Titan's haze are identified in reference number 5 in the STM.

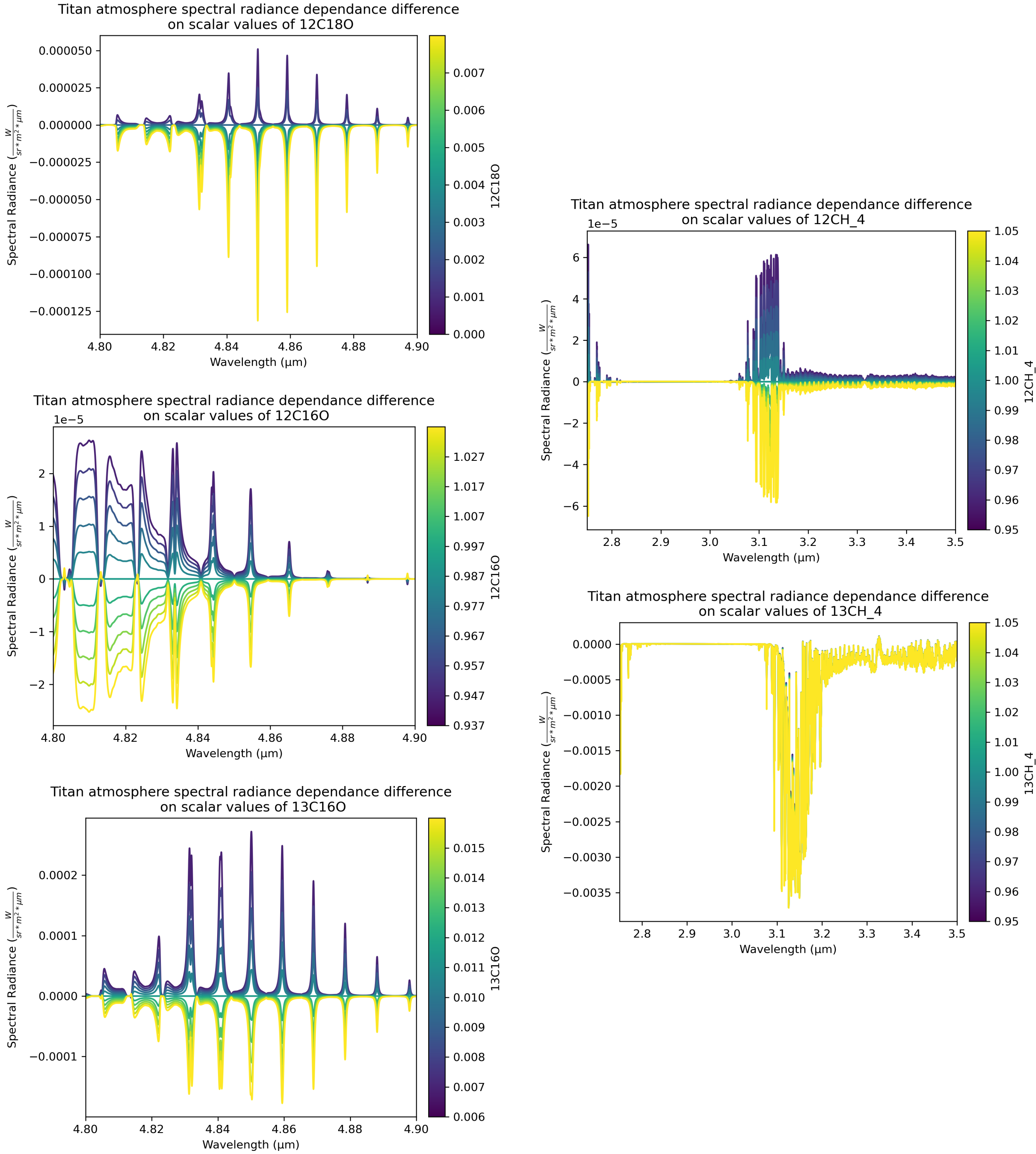


Figure 13: Trace isotope difference with Titan's atmosphere. CO (left), CH_4 (right)

Looking at Titan's haze with PICTURE over a long period of time (10-13 years or aboout half of a Titan year) would establish how the haze develops and moves and how this is affected by Titan's seasons. PICTURE will also be able to constrain haze aerosol composition, size, and possibly vertical profile. This will aid in our understanding of

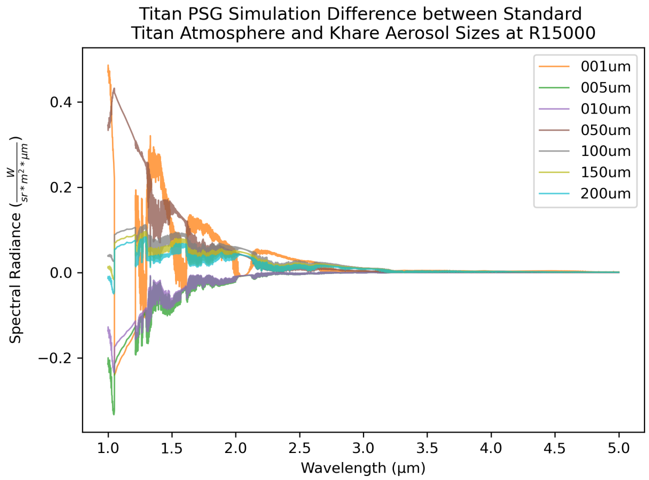


Figure 14: Spectral radiance of the difference between Titan's Khare tholin haze based on particle radius and the basic Titan model spectral radiance.

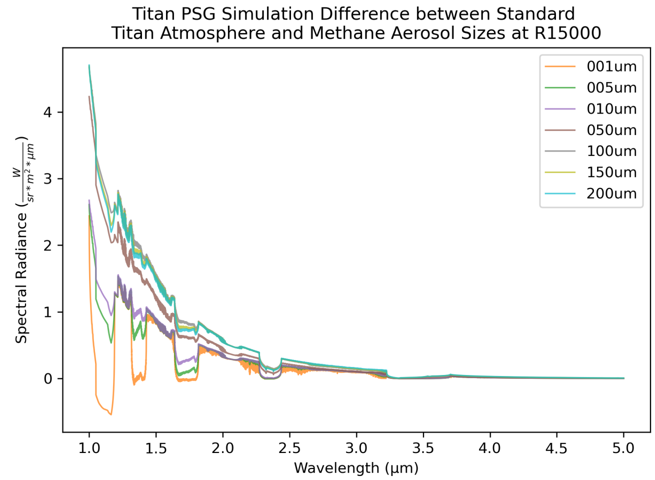


Figure 15: Spectral radiance of the difference between Titan's Martonchik methane ice aerosol based on particle radius and the basic Titan model spectral radiance.

Titan's atmospheric dynamics and our understanding of haze science. We may also be able to apply the data from Titan's haze in our understanding of the early, hazy, Earth.

Comparing haze data to experimentally derived laboratory analogs 'tholins' we can learn more about the chemical evolution of Titan's haze and atmosphere. Some derived tholins have shown exciting characteristics (amino acids) that point towards habitable conditions on Titan (Khare et al. (1986)). Higher resolution haze data will constrain the haze composition and allow us to create tholins of higher similarity to Titan's aerosols.

Using PSG we can simulate what different aerosols look like. In Figure 14 and Figure 15 the differences between two different laboratory made tholins (Khare and Martonchik tholins) can be seen. We can also measure the difference in spectral radiance between tholin sizes. To measure a difference of .05um, a NIR spectrometer sensitivity greater than 1 $\frac{W}{sr*m^2*m}$ is needed. The sensitivity required for the instrument goes up as particle size increases.

4. CONCLUSION

PICTURE and PICS technology will revolutionize the field of spectroscopy in astronomy. If PICTURE were included on a Titan orbiter mission, it has a great potential to answer key questions about Titan's atmosphere and surface that we are not capable of answering with Cassini VIMS data (low resolution) and James Webb Space Telescope (low spacial resolution).

PICTURE will be especially capable of observing trace gasses as well as carbon and oxygen isotopes in Titan's atmosphere - answering questions about the nature and origin of Titan's atmosphere, oxygen, and haze. PICTURE will also be helpful in determining whether Titan has any active cryovolcanos by looking for exposed surface ice. Finally, PICTURE will be able to identify and analyze the surface composition of Titan's lakes - answering questions about Titan's meteorological cycle. Answering these questions will also aid in determining Titan's habitability and could offer an insight into the early Earth and planetary atmosphere evolution.

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Software: Planetary Spectrum Generator (Villanueva et al. 2018)

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