Capabilities and Challenges in the Remote Sensing of Titan’s Atmosphere from (near) Earth

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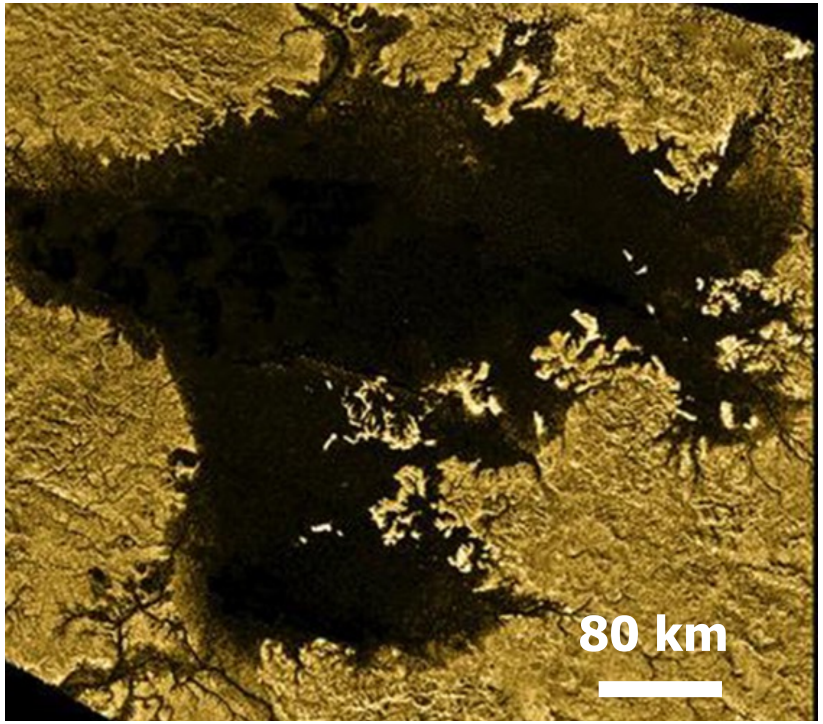
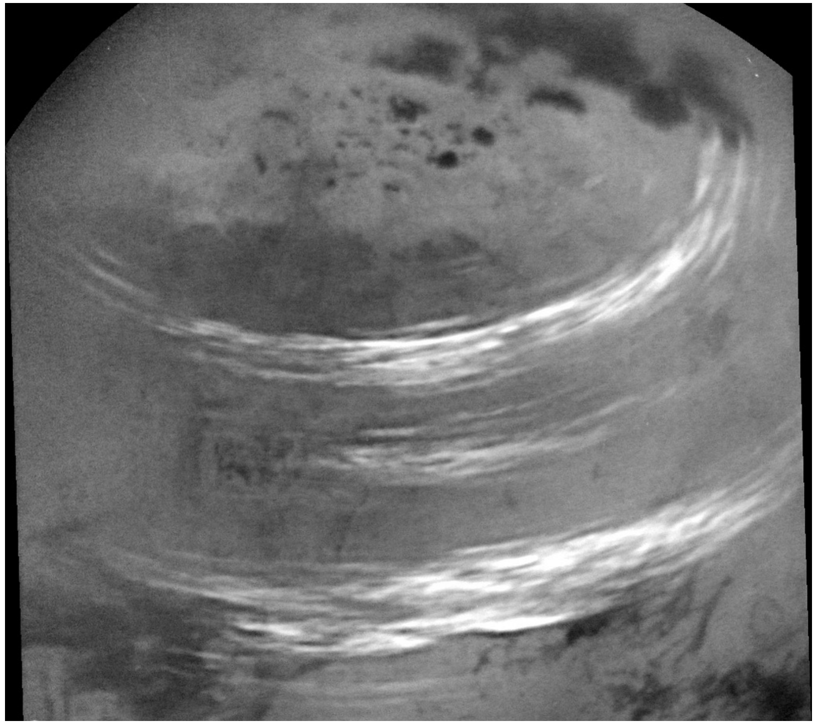
9th Chianti Topics International Focus Workshop on Atmospheres
“Current challenges in the remote sensing of planetary atmospheres”

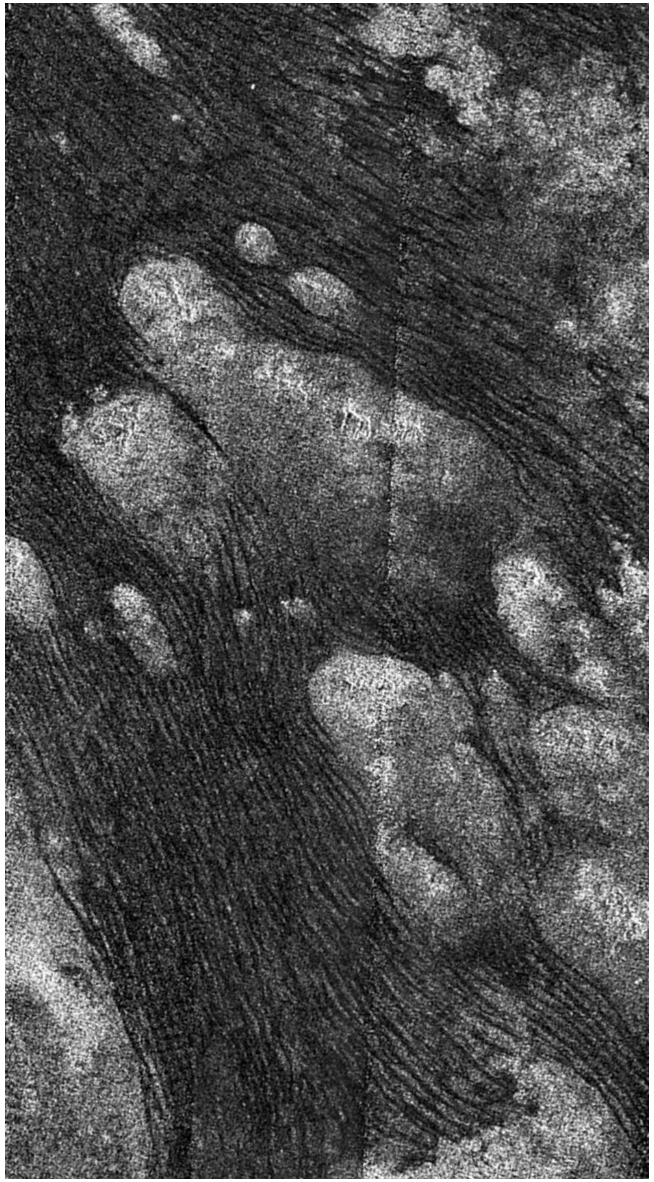
In this ~~Poster~~ Talk

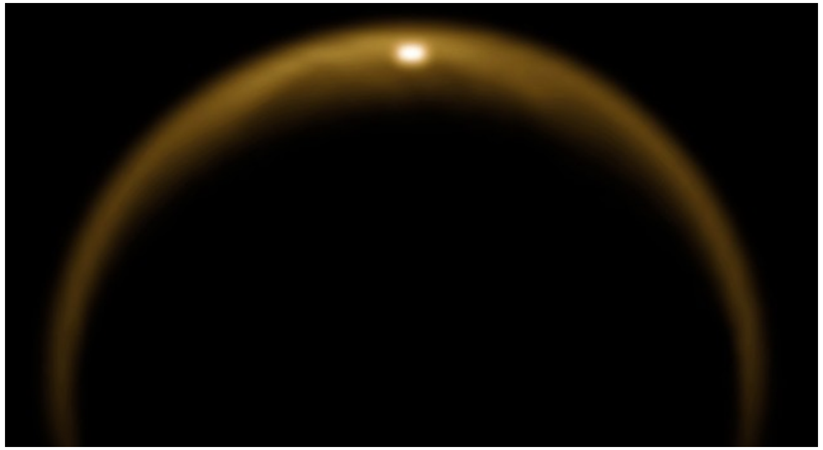
1. All About Titan
2. Recent Work Measuring Titan's Composition and Dynamics from Earth
3. Paths Forward
4. Needs from the Community

Titan has Many Similarities to Earth









~95% N_2, 4% CH_4, with an active CH_4-based hydrological cycle

Earth: 78% N_2, 21% O_2

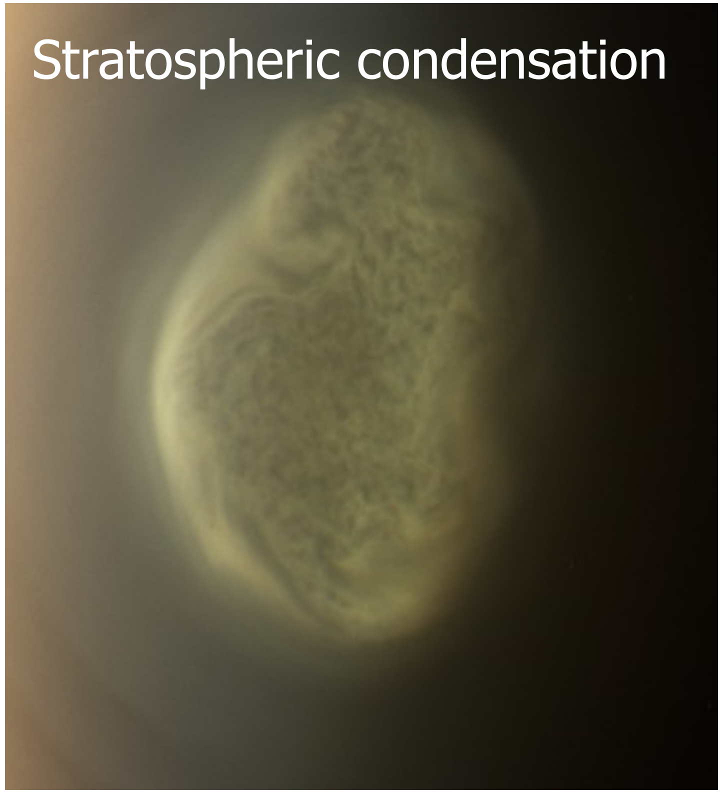
Surface aeolian features, dunes

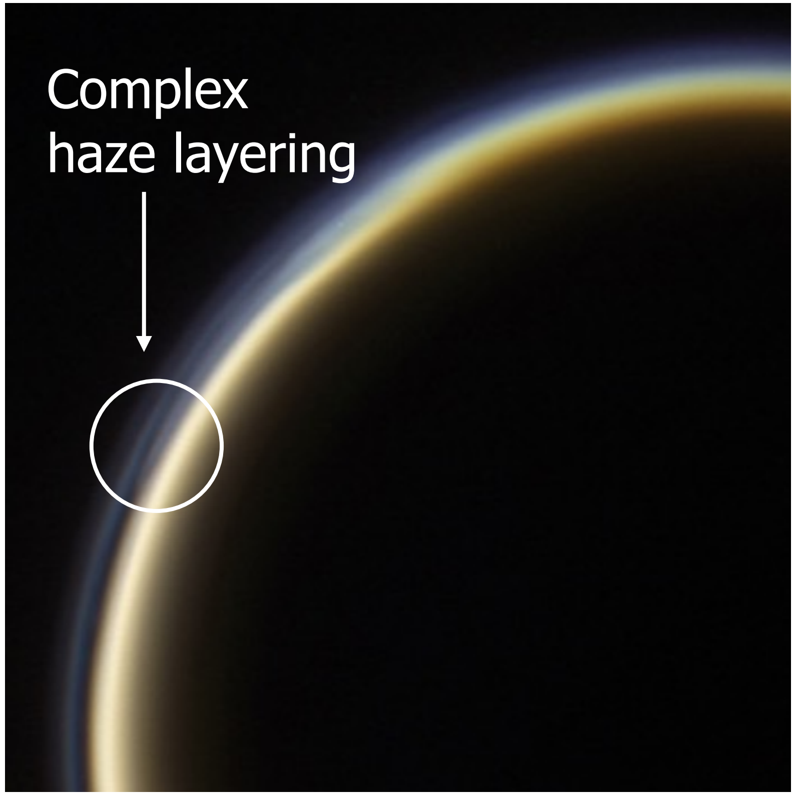
Atmospheric Structure is Driven by Chemistry

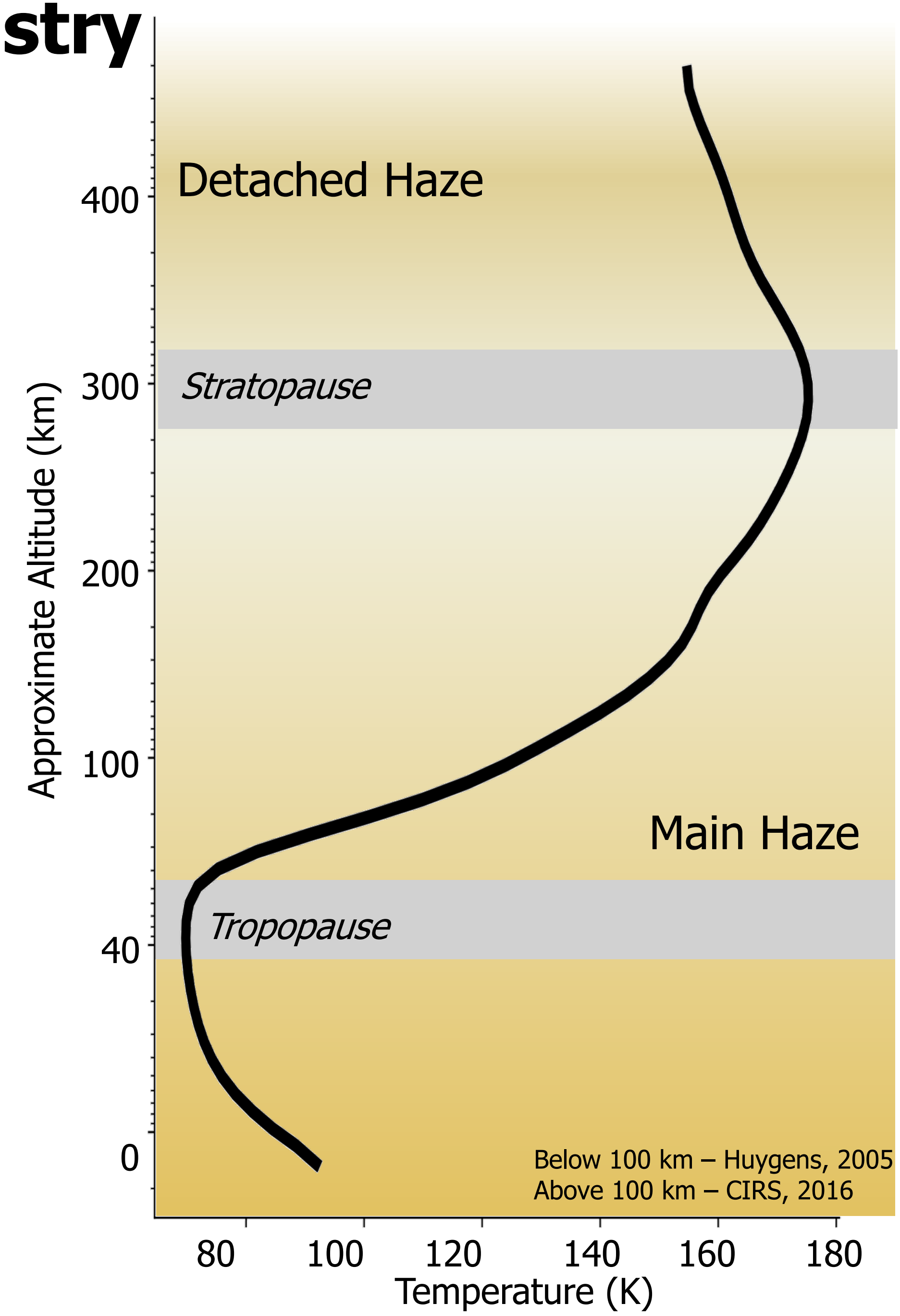
Destruction of N_2, CH_4 leads to complex photochemistry

Trace molecules → large haze particles → dune material

Solar heating of haze leads to Earth-like vertical structure (troposphere, stratosphere, mesosphere)

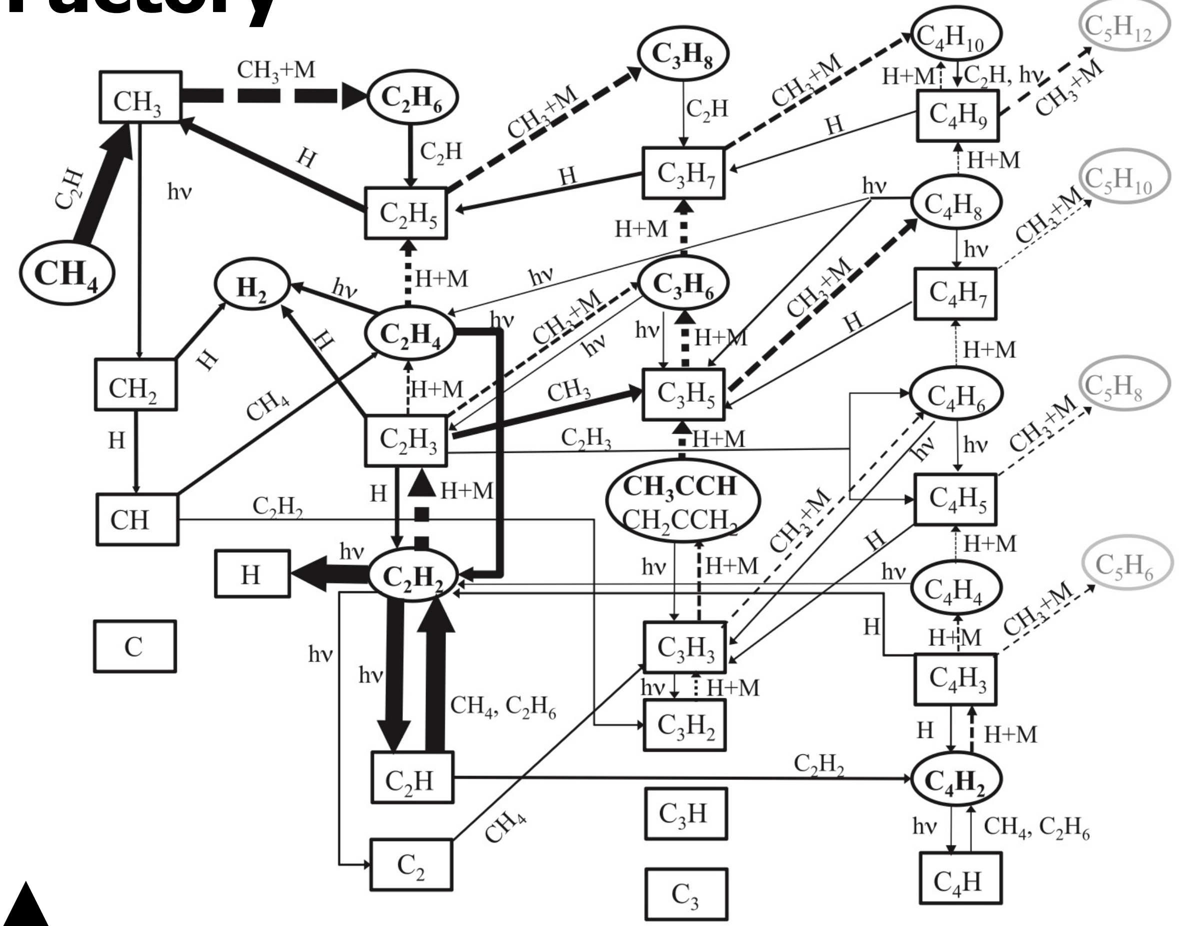






Titan's Atmosphere is a Chemical Factory

Atoms	Hydrogen and Hydrocarbons		Nitrogen Compounds		Oxygen Compounds	
2	H_2		N_2		CO	
3			HCN	HNC	H_2O	CO_2
4	C_2H_2		C_2N_2			
5	CH_4	C_3H_2	HC_3N			
6	C_2H_4	C_4H_2	CH_3CN			
7	CH_3CCH	CH_2CCH_2	C_2H_3CN			
8	C_2H_6		C_3H_3CN			
9	C_3H_6		C_2H_5CN			
10+	C_3H_8	C_6H_6				



Web of production and destruction pathways from Dobrijevic et al. 2016, Icar

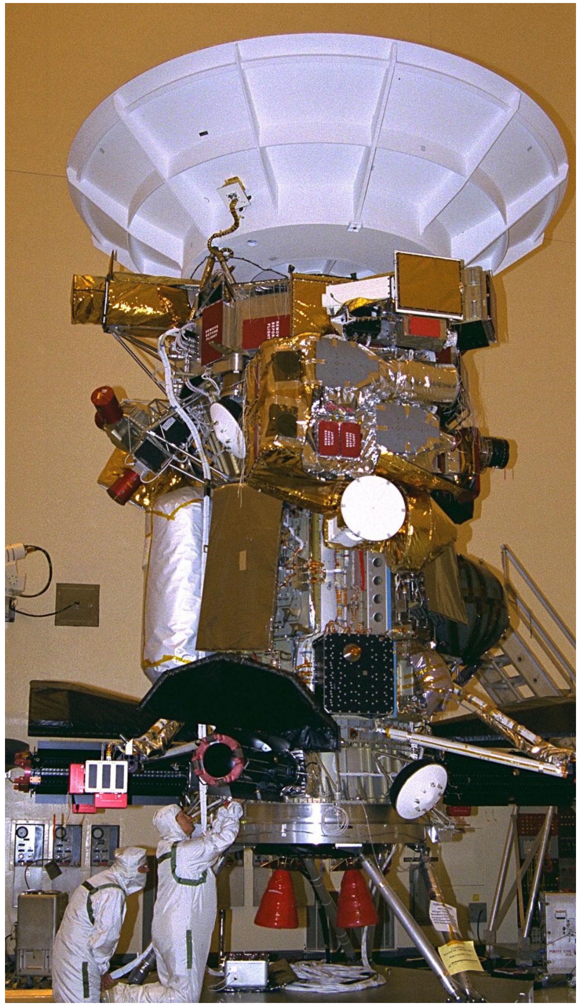
Molecules currently known to exist in Titan's atmosphere, from Nixon 2024, ACS ESC

Titan Undergoes Seasonal Changes over its 29.5 Earth-year Year

Cassini Mission to Saturn

2004 – 2017

~½ Titan year



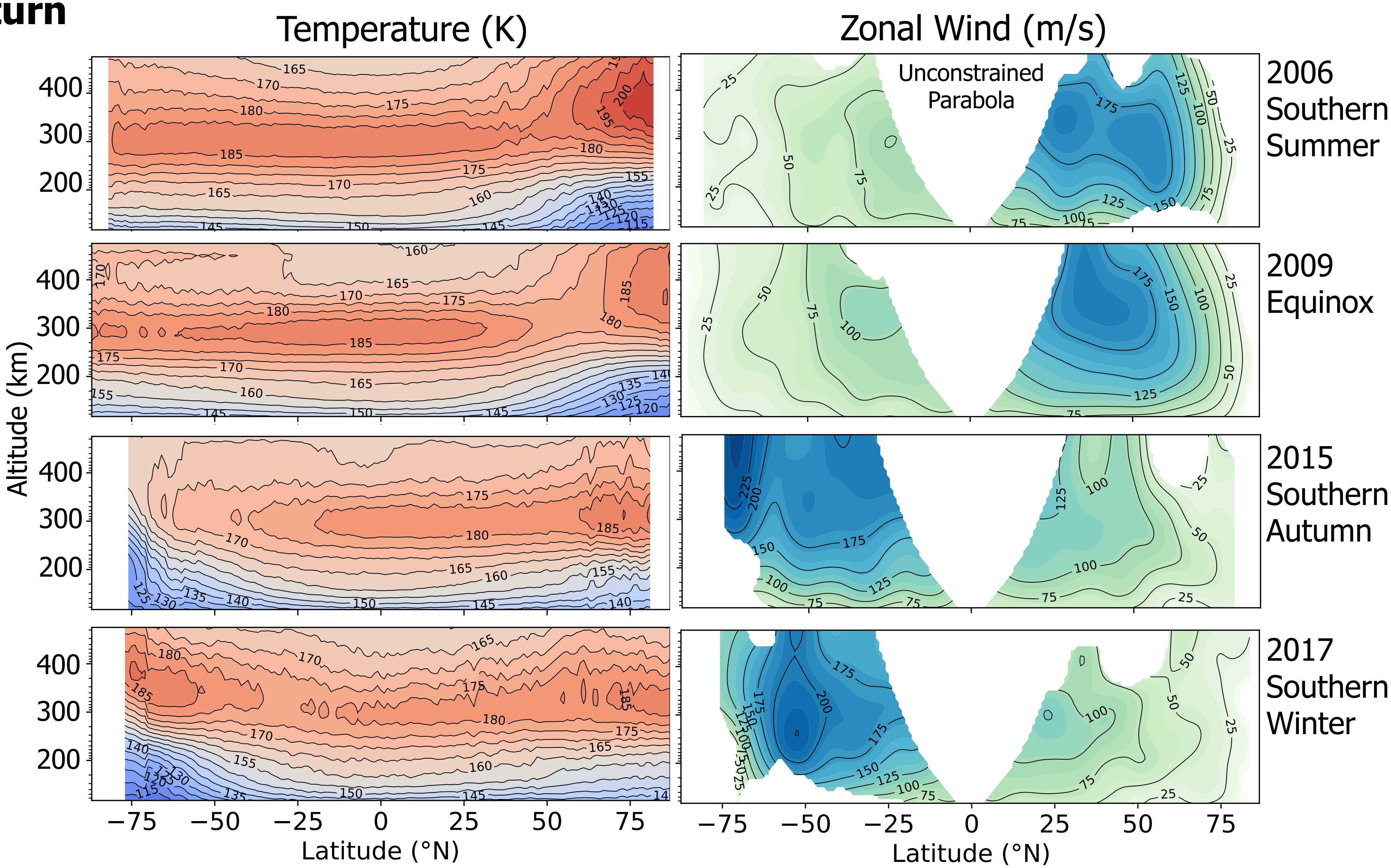
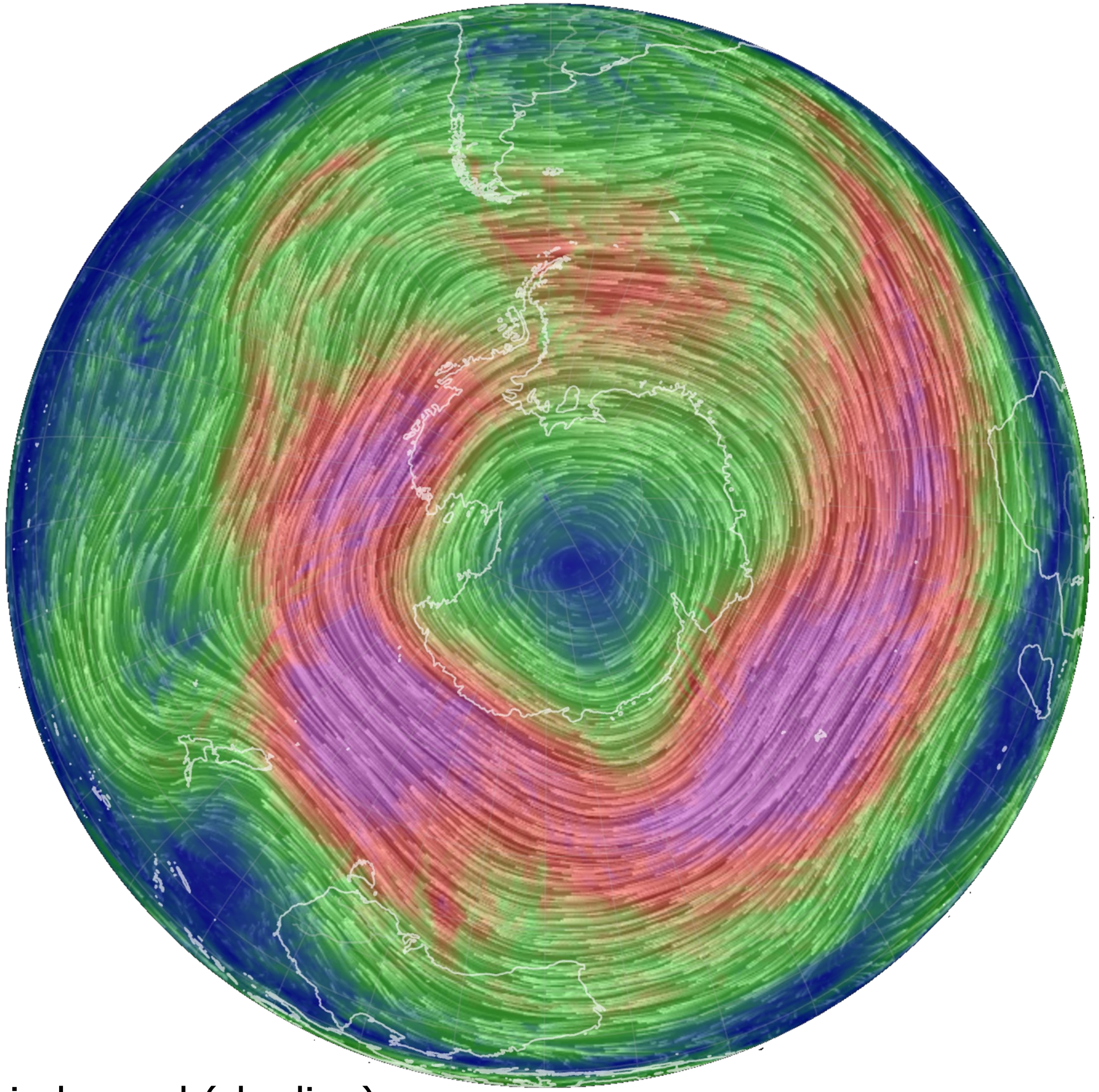


Image: Public domain from NASA/Cassini

Data from Wright et al. 2025, PSJ

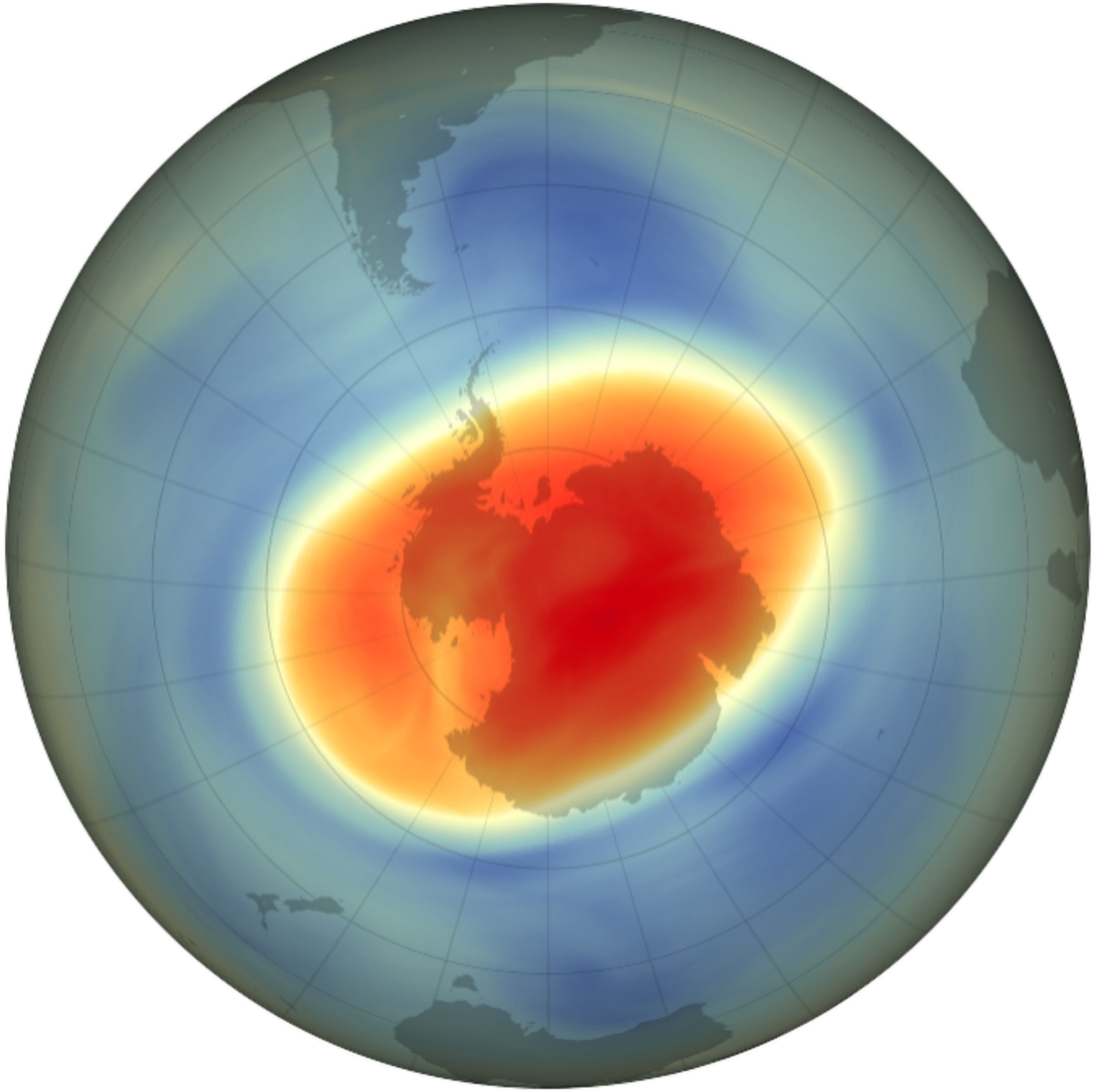
On Earth, the Stratospheric Polar Vortex Sequesters Air

Earth's stratospheric polar vortex



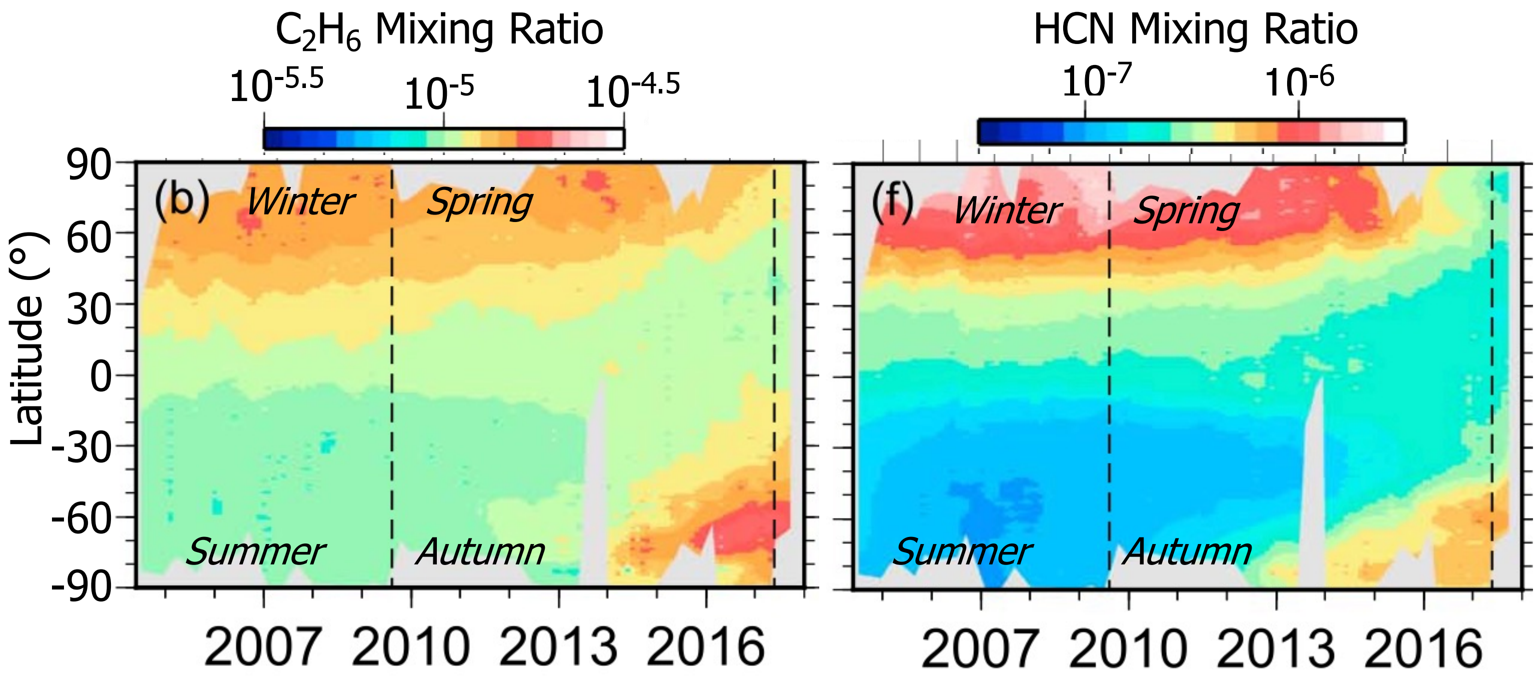
18 km wind speed (shading)
and direction (arrows)

Ozone depletion in Earth's SPV

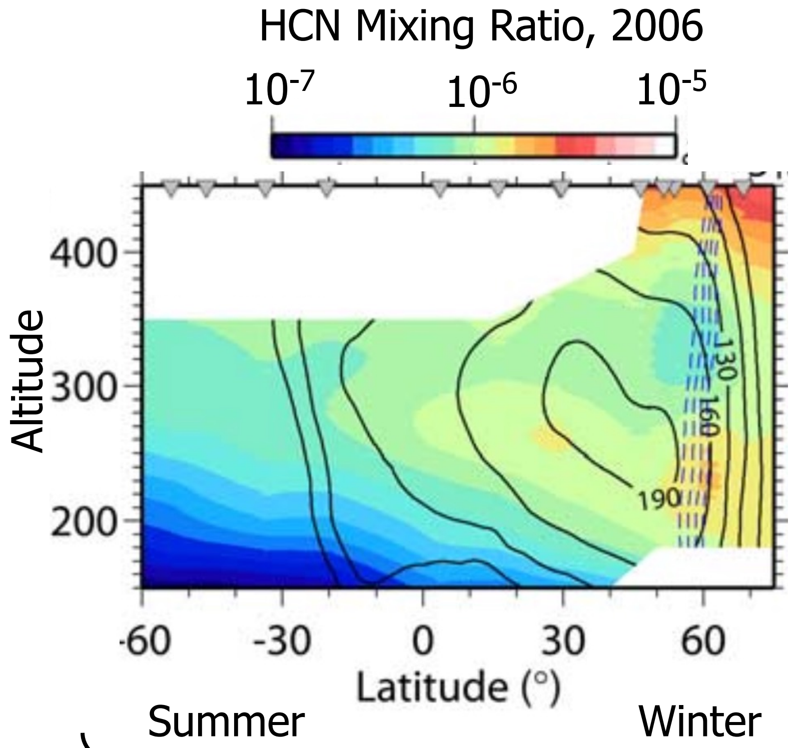


Red = Depleted
Blue = Normal

Titan's Circulation Drives the Distribution of Trace Species



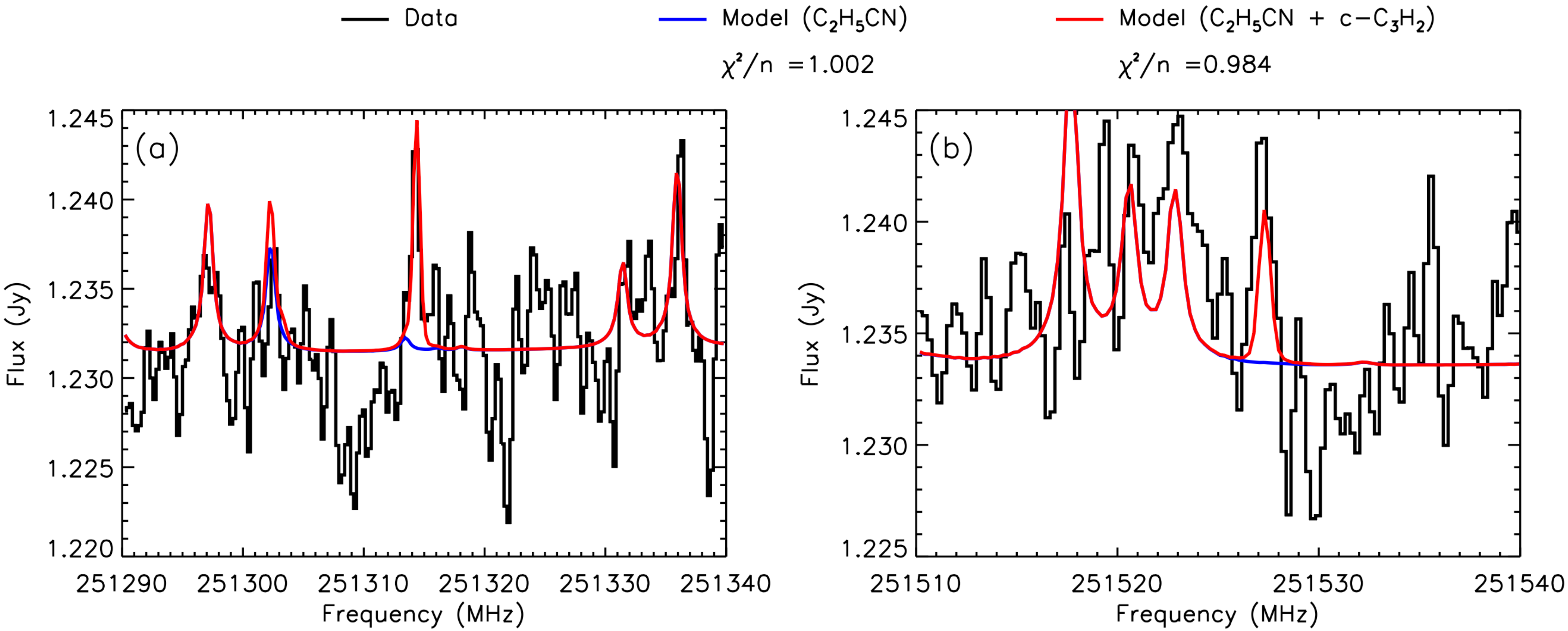
Measurements near 150 km in the stratosphere over the duration of the Cassini mission

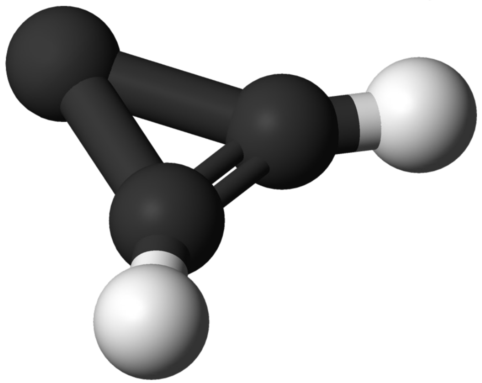


Cross-section of HCN Mixing Ratio in mid northern winter

Vertical Data from Teanby et al. 2008, JGR
Horizontal from Teanby et al. 2019, JGR: Planets

Recent Work: Measurement of $c\text{-}C_3H_2$ with ALMA



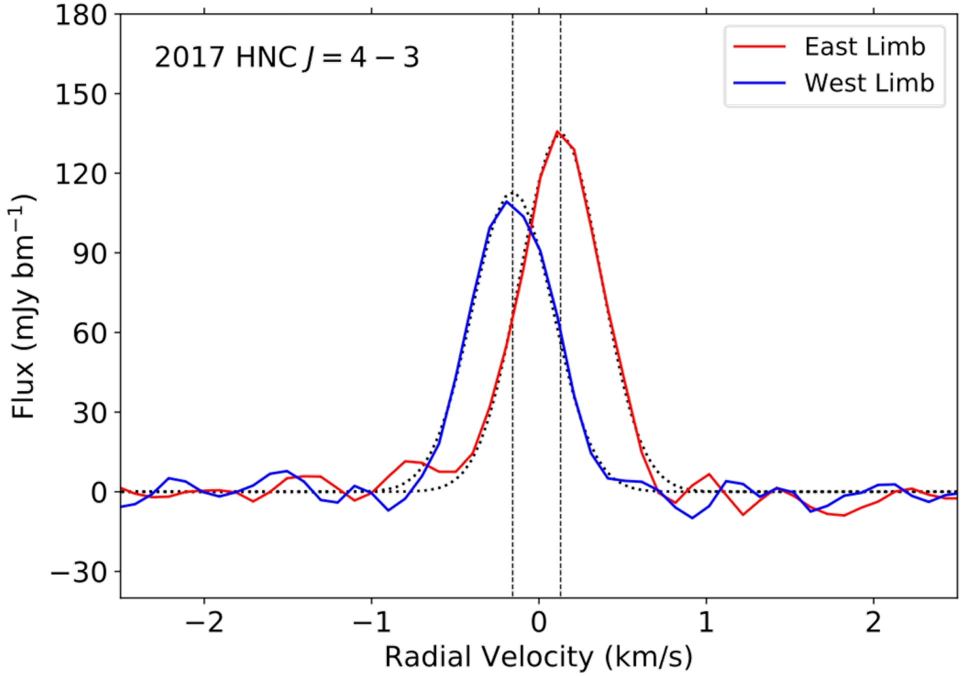


0.50 +/- 0.14 ppb above 350 km

Measurement of $c\text{-}C_3H_2$ provides insight to intermediate products of Titan's photochemistry

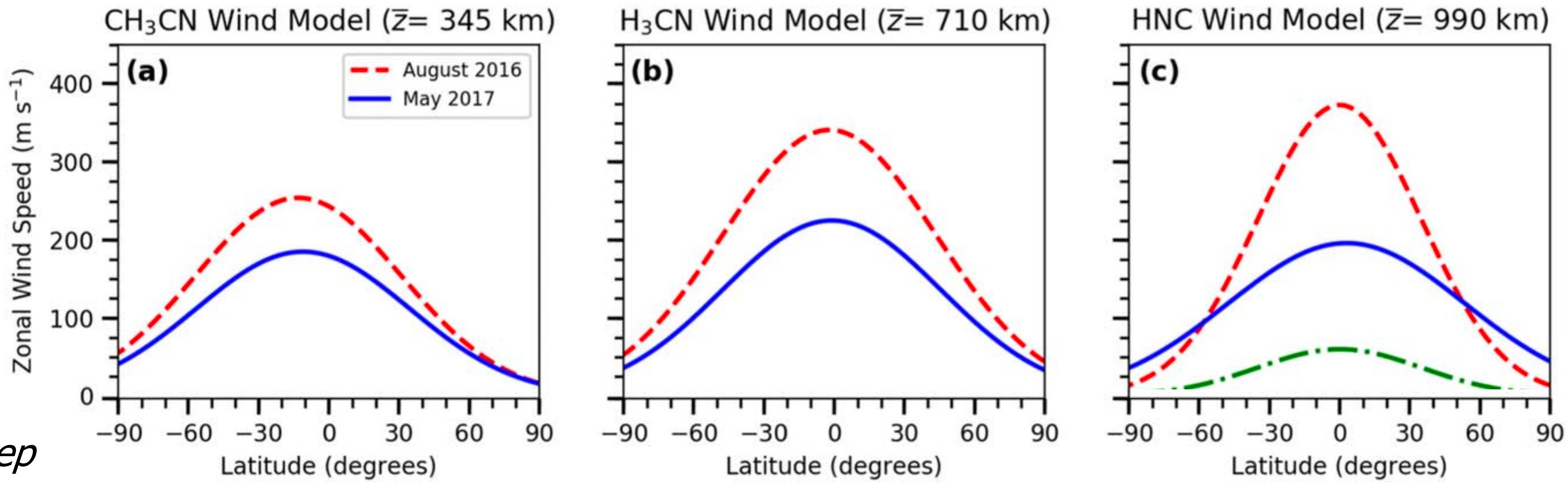
Figure adapted from Nixon et al. 2020, ApJ

Recent Work: Measuring middle atmospheric winds with ALMA



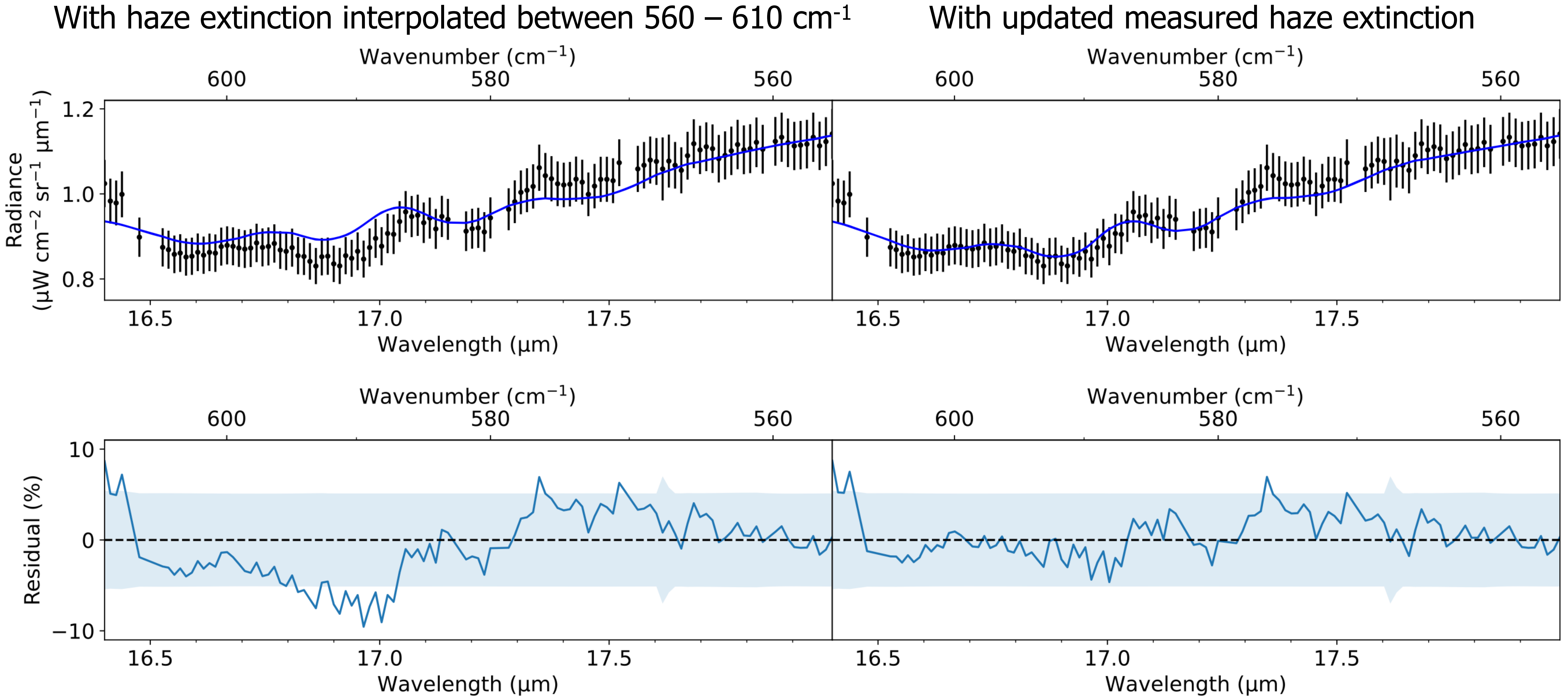
High spectral resolution observations from ALMA of the doppler shifts of emission lines can directly measure winds in Titan's upper stratosphere, mesosphere, and thermosphere (~350 km and above)

Continued monitoring of winds with ALMA allows for seasonal-scale study of Titan's dynamics after the Cassini era



Data from
Cordiner et al. 2020, ApJL
New paper currently in prep

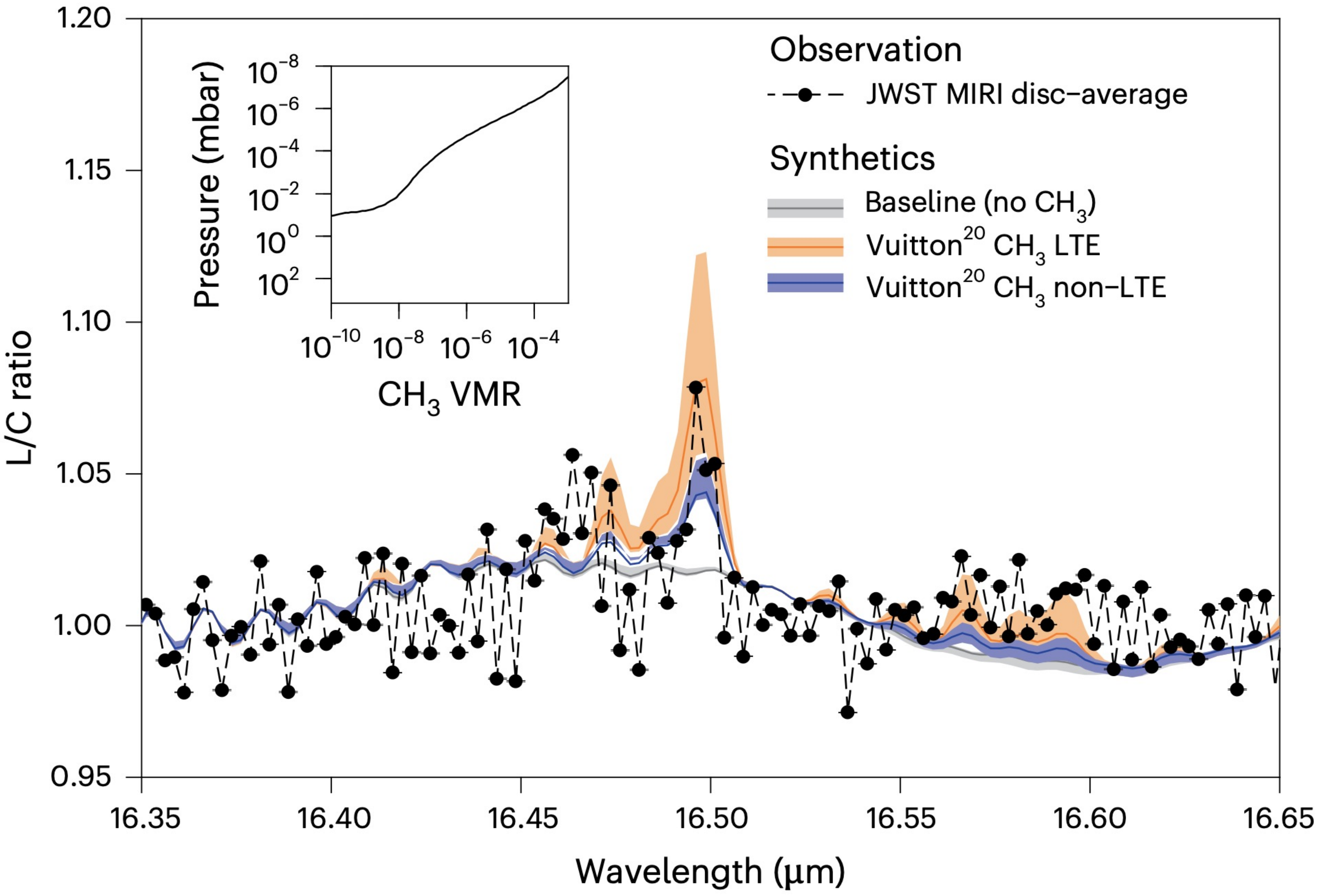
Recent Work: Haze extinction cross-section spectra from Spitzer

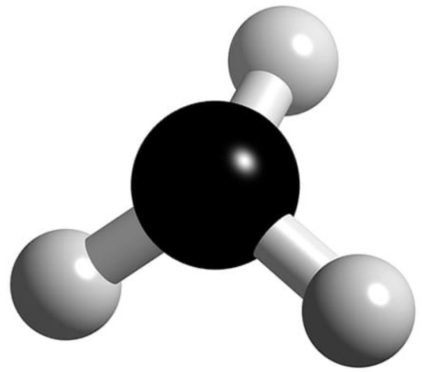


Measurement of aerosol spectrum in this range adds to a broader understanding of Titan aerosols and improves studies of other species in this region

Figure from Coy et al. 2023, PSJ

Recent Work: Detection of CH_3 with JWST MIRI





CH_3 is one of the main sources of C_2H_6 in the upper atmosphere

Detection of CH_3 provides insight to key intermediate product of Titan's photochemistry

Figure from Nixon et al. 2025, NatAstro

Recent Work: Monitoring Tropospheric Clouds with JWST

Clouds reveal locations of high relative humidity, possibly produced by:

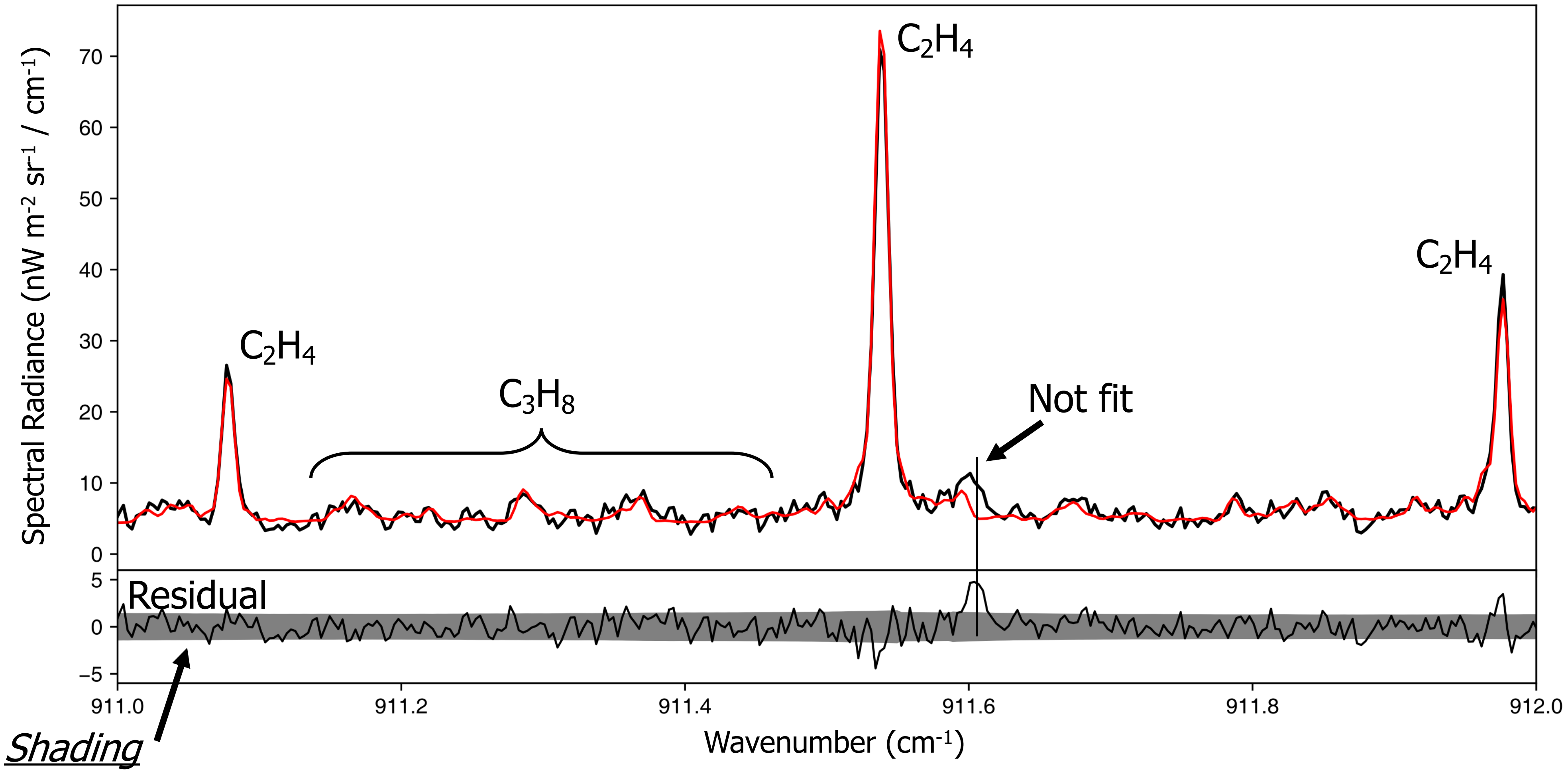
ascending motion
wave activity
radiative cooling

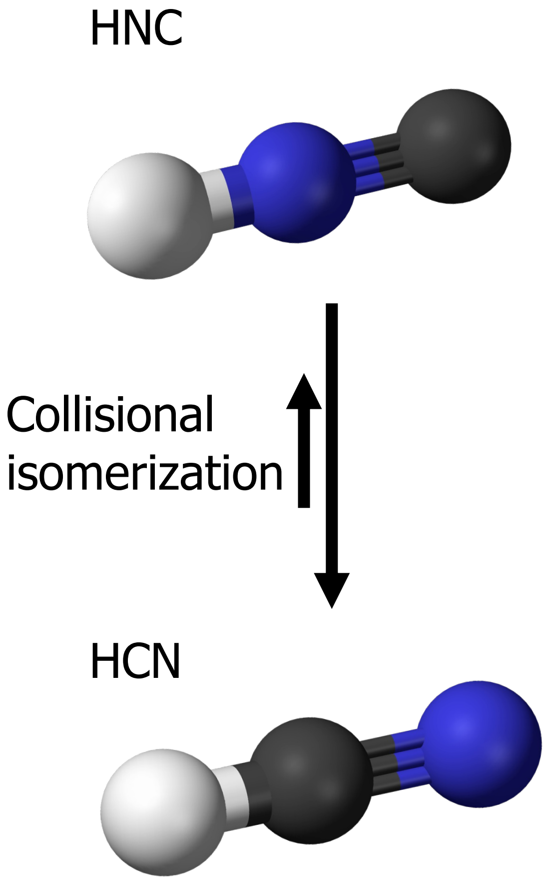
Not necessarily tracking the winds!

Identification of clouds in Titan's troposphere with JWST reveals how energy, methane is transported through the atmosphere

Nixon et al. 2025, NatAstro

Current Work: Measurement of Stratospheric HNC from IRTF





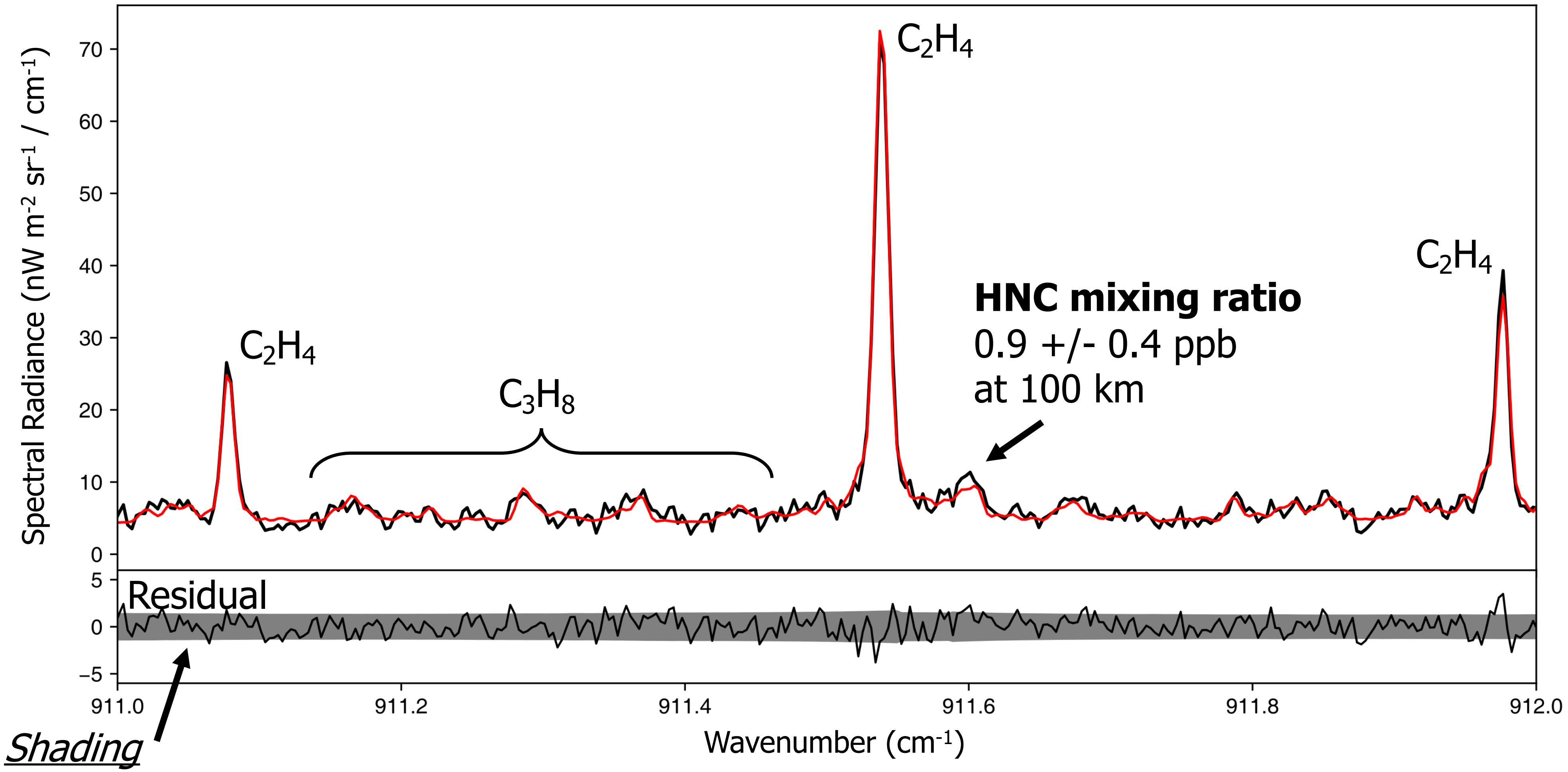
Shading
1σ envelope

Data from TEXES on IRTF, R ~ 70,000

Δν ~ 0.013 cm^{-1}

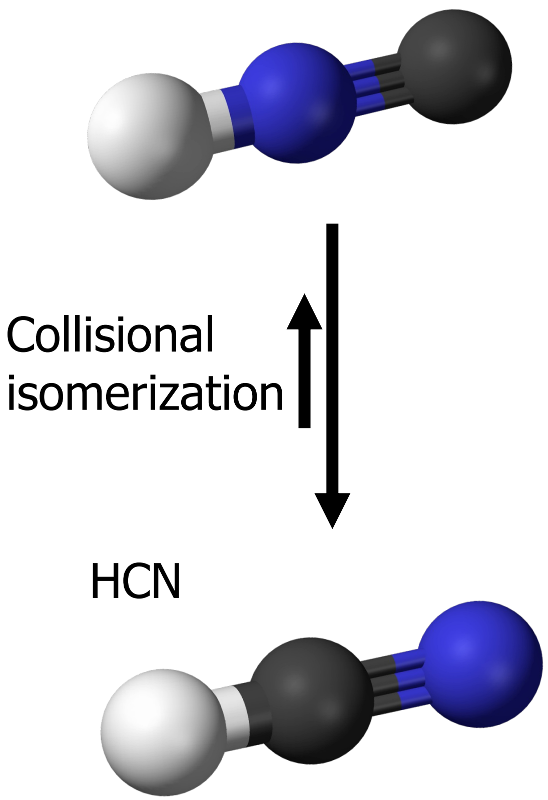
Lombardo et al. in prep for PSJ

Current Work: Measurement of Stratospheric HNC from IRTF



Shading
1σ envelope

HNC



HCN

Data from TEXES on IRTF, R ~ 70,000

Δν ~ 0.013 cm^{-1}

Lombardo et al. in prep for PSJ

Provides a Strong Constraint to Stratospheric Chemical Models

The main loss pathway of HNC in the stratosphere is the collisional isomerization to HCN

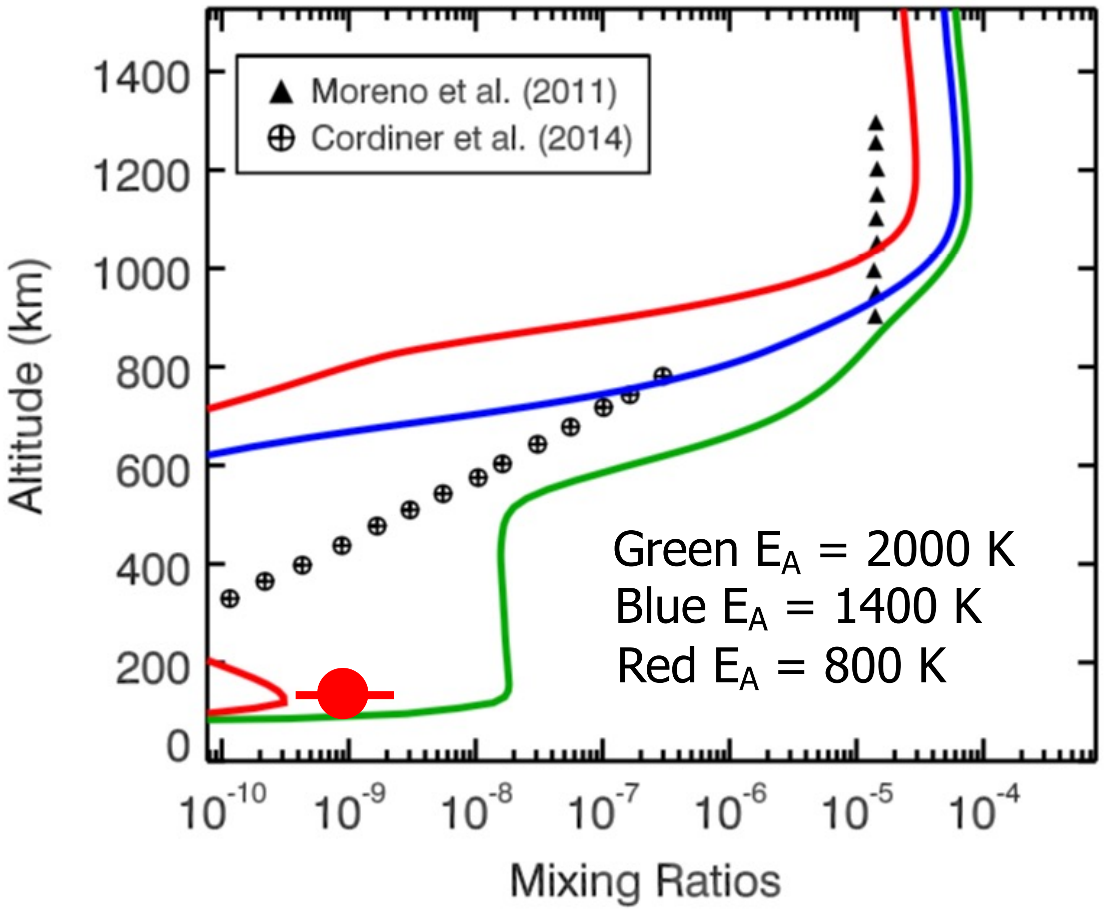
$$H + HNC \rightarrow HCN + H$$

The Activation Energy (E_A) of the reaction in literature ranges from 800 K to 2000 K

The simulated abundance of HNC is very sensitive to the value of the activation energy

Our measurements suggest $E_A \approx$ 800K

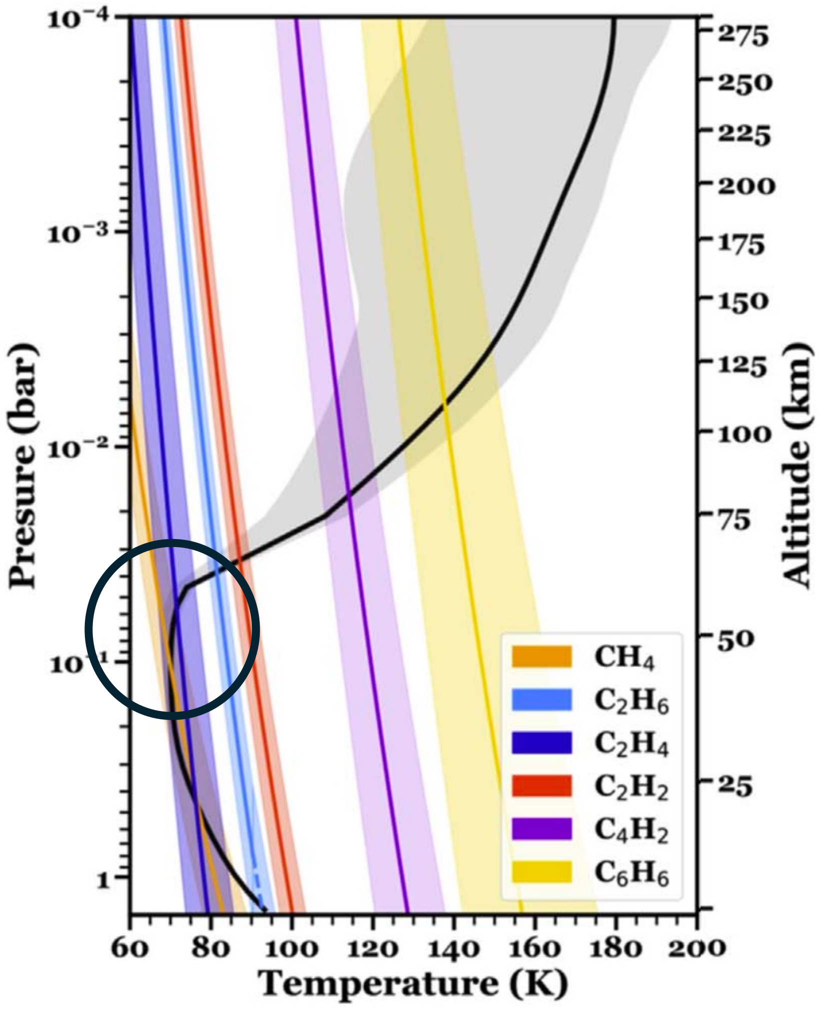
Willacy, et al., 2016

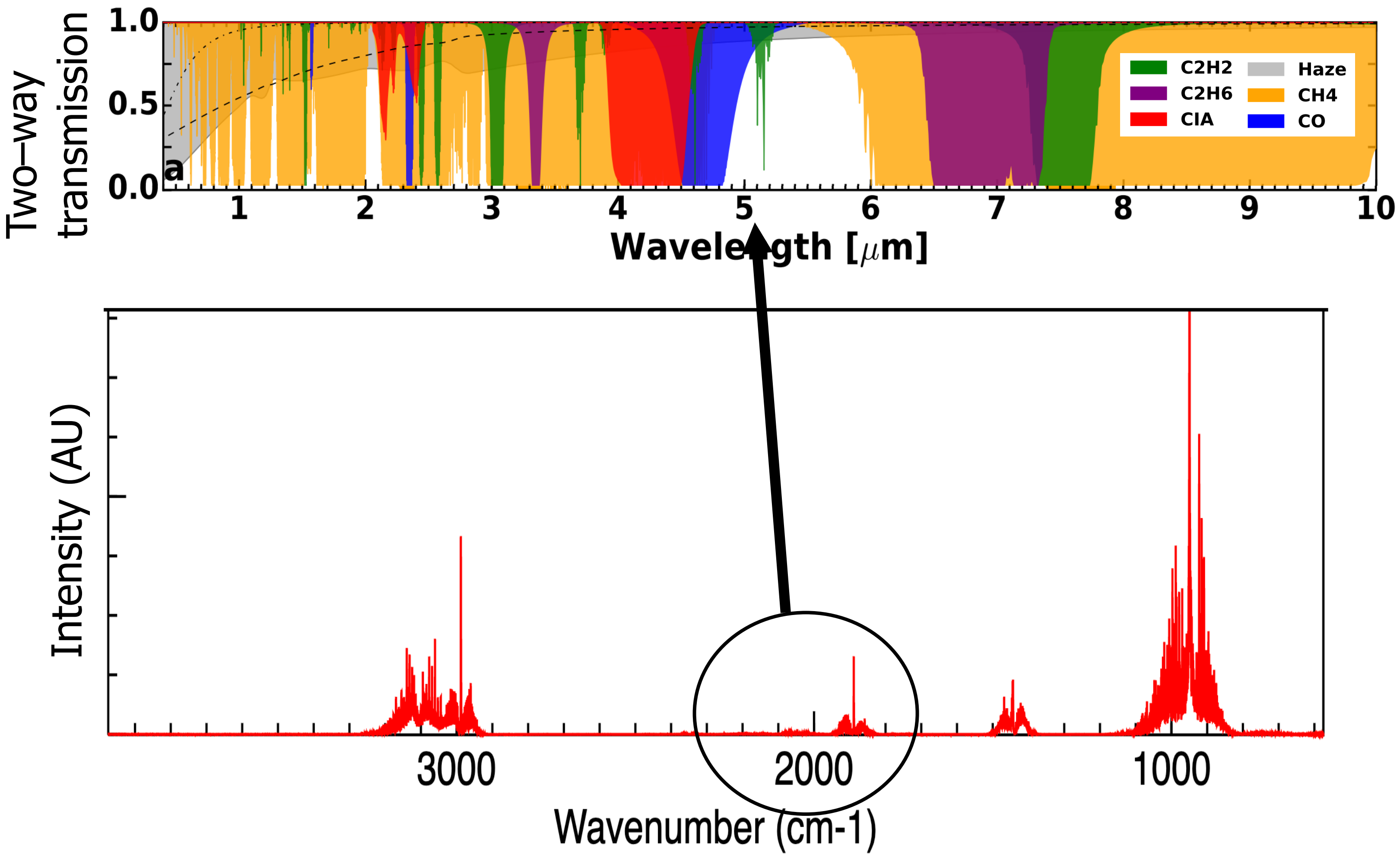


First measurement of stratospheric HNC pinpoints isomerization E_A and HCN destruction pathway

Lombardo et al. in prep for PSJ

Paths Forward: Probing tropospheric C_2H_4





C_2H_4 only condenses a small amount above the tropopause – could have near-stratospheric levels (VMR ~10^{-8}) in the troposphere

Overtone of v_7 band (?) is the only feature in a clear spectral window

Figure adapted from Yu et al. 2023, ApJSS

Atmospheric transmission from Corlies et al. 2020

Needs from the Community

High spectral resolution lab measurements of large molecules ($>C_3$) at **<u>Titan temperatures, pressures</u>**

~150 K, ~10 Pa

High spectral resolution instruments to resolve intermediate chemical species

TEXES ($\Delta\nu \sim 0.012$ cm^{-1})

ALMA ($\Delta f = 976$ kHz)

Time on telescopes large enough to spatially resolve Titan across wavelengths

Titan diameter ~0.7″
need 0.14″ for meaningful data

What we can Offer

Validation of lab spectra

Testing instruments on a bright, well-studied target

Data from a unique Earth-like world

Always looking for new collaborations!

Email
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Grazie per l'attenzione!