Extensions to the **HITRAN** broadening parameters & Future Plans for **HITEMP**

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HARVARD-SMITSONIAN
CENTER FOR ASTROPHYSICS

ExoMol Conference: Spectroscopy of Exoplanets

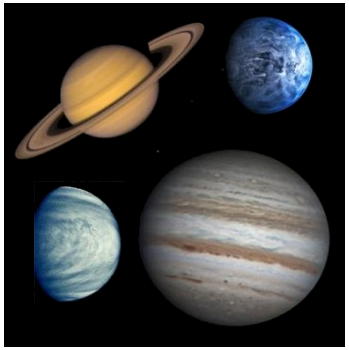
Cumberland Lodge, Windsor, UK

Monday 9th July, 2018

Overview

Brief introduction to the HITRAN2016 database

- Downloading data
- HAPI
- Additional parameters



Outline of latest additions for foreign broadening parameters

- Of relevance to planetary/exoplanetary atmospheres
- H_2, He, CO_2, H_2O broadening

The future of HITEMP

- Of relevance to exoplanet observations
- Proposed summary for data to be collected
- Example for N_2O

Current HITRAN Database

Journal of Quantitative Spectroscopy & Radiative Transfer 203 (2017) 3–69

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Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

The HITRAN2016 molecular spectroscopic database

I.E. Gordon [a,*], L.S. Rothman [a], C. Hill [a,b], R.V. Kochanov [a,c], Y. Tan [a], P.F. Bernath [d], M. Birk [e], V. Boudon [f], A. Campargue [g], K.V. Chance [a], B.J. Drouin [h], J.-M. Flaud [i], R.R. Gamache [j], J.T. Hodges [k], D. Jacquemart [l], V.I. Perevalov [m], A. Perrin [n], K.P. Shine [o], M.-A.H. Smith [p], J. Tennyson [b], G.C. Toon [h], H. Tran [n], V.G. Tyuterev [q], A. Barbe [q], A.G. Császár [r,rr], V.M. Devi [s], T. Furtenbacher [r], J.J. Harrison [t,tt,ttt], J.-M. Hartmann [n], A. Jolly [i], T.J. Johnson [u], T. Karman [a,v], I. Kleiner [i], A.A. Kyuberis [a,w], J. Loos [e], O.M. Lyulin [m], S.T. Massie [x], S.N. Mikhailenko [m], N. Moazzen-Ahmadi [y], H.S.P. Müller [z], O.V. Naumenko [m], A.V. Nikitin [m], O.L. Polyansky [b,w], M. Rey [q], M. Rotger [q], S.W. Sharpe [u], K. Sung [h], E. Starikova [m], S.A. Tashkun [m], J. Vander Auwera [aa], G. Wagner [e], J. Wilzewski [a,e], P. Wcisło [bb], S. Yu [h], E.J. Zak [b]

54 authors from **30** laboratories worldwide

67 pages, almost **650** references

The HITRAN community is **much larger** than the author list!

Credit: Y. Tan

Brief overview of HITRAN

Credit: Y. Tan

- **Line-by-line (high precision) :** HITRAN2016 molecules (49 molecules)

Species (isotopologues) in line-by-line portion of HITRAN						
H_2O (6)	NO (3)	**HCl (4)**	N_2 (2)	COF2 (2)	NO^+ (1)	C_4H_2 (1)
CO_2 (10)	SO_2 (2)	HBr (4)	HCN (3)	SF_6 (1)	HOBr (2)	HC_3N (1)
O_3 (5)	NO_2 (1)	HI (2)	CH_3Cl (2)	H_2S (3)	C_2H_4 (2)	**H_2 (2)**
N_2O (5)	NH_3 (2)	ClO (2)	H_2O_2 (1)	HCOOH (1)	CH_3OH (1)	CS (4)
CO (6)	HNO_3 (2)	OCS (5)	C_2H_2 (3)	HO_2 (1)	CH_3Br (2)	SO_3 (1)
CH_4 (4)	OH (3)	H_2CO (3)	C_2H_6 (2)	O (1)	CH_3CN (1)	**C_2N_2 (1)**
O_2 (3)	**HF (2)**	HOCl (2)	PH_3 (1)	$ClONO_2$ (2)	CF_4 (1)	**$COCl_2$(2)**

- **Absorption cross sections : (~320 molecules, with ~2000 experimental cross sections!)**
  - Primarily from the PNNL database [1] and the Hodnebrog review [2].
- **HAPI (the HITRAN Application Programming Interface) [3]**
  - A free open source Python module (library) for working with HITRAN data.
- **Aerosol Properties**
- **Collision-Induced Absorption (CIA)**

[1] S. Sharpe, et al., (2004), *App. Spectrosc.* 58, 1452.
[2] Ø. Hodnebrog, et al. (2013), *Rev. Geophys.* 51, 300.
[3] R. V. Kochanov, et al. (2016), *JQSRT* 177, 15.

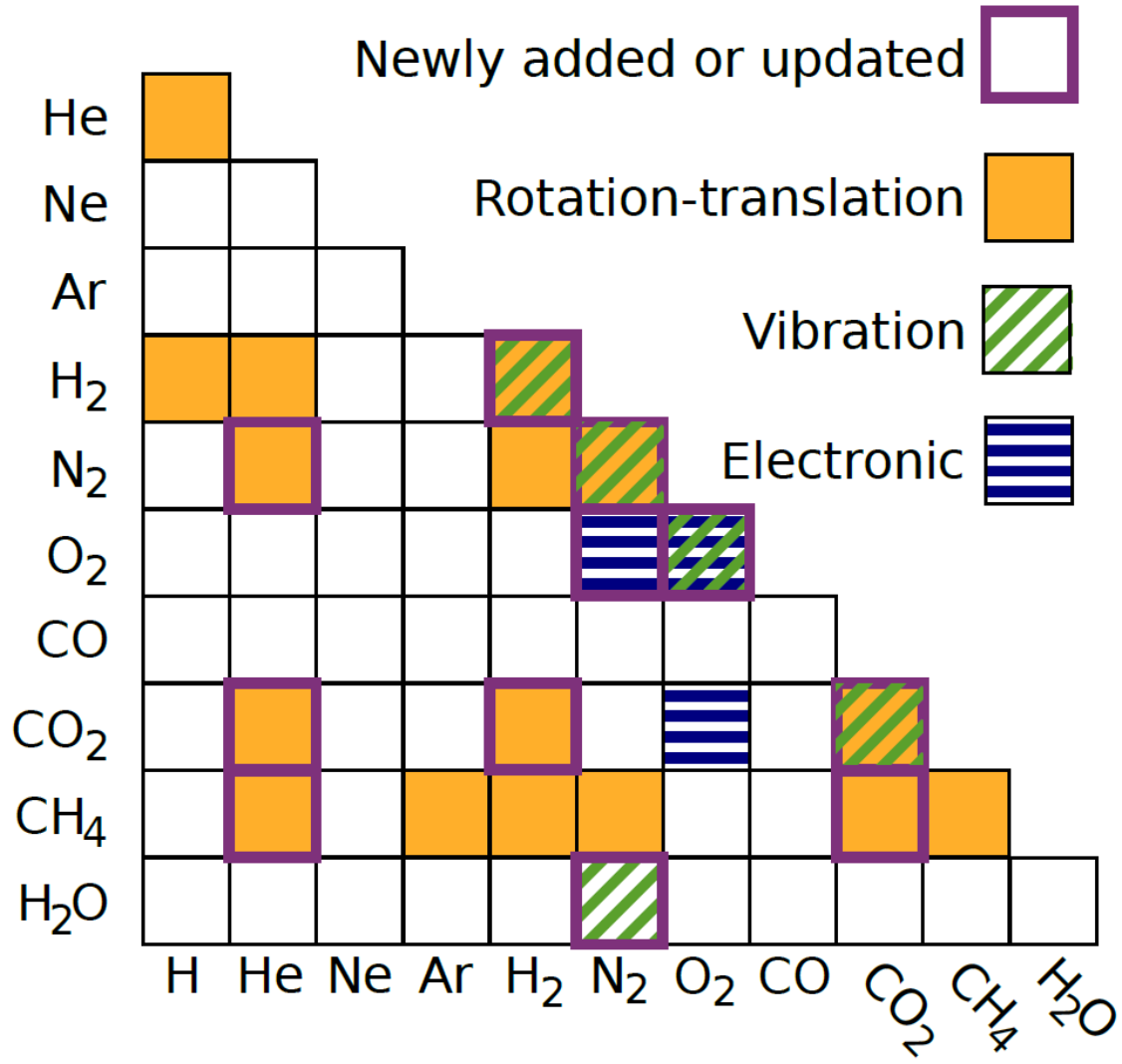
Brief overview of HITRAN

Credit: Y. Tan

- Line-by-line (hig

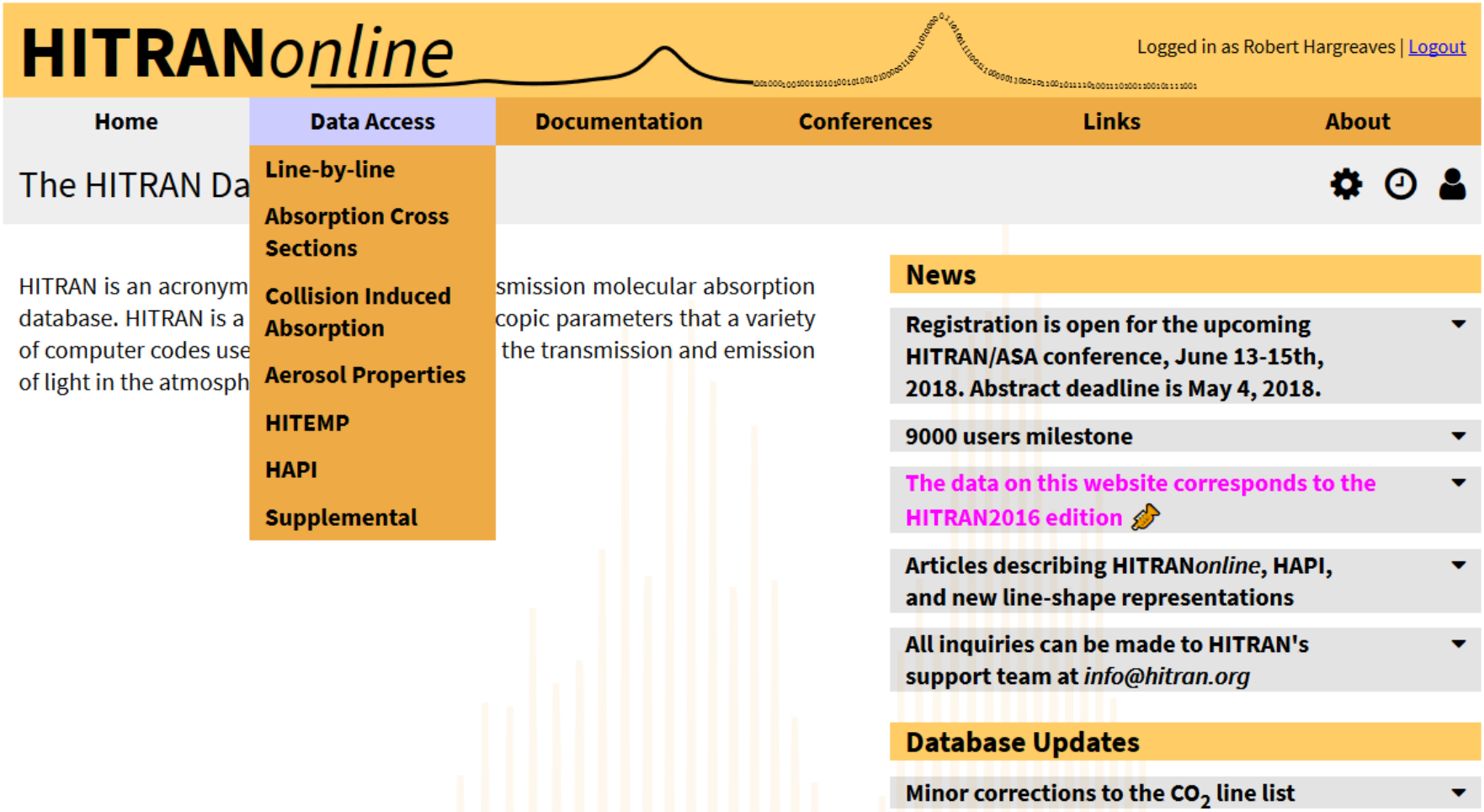
Spec		AN	
H_2O (6)	NO (3		C_4H_2 (1)
CO_2 (10)	SO_2 (2		HC_3N (1)
O_3 (5)	NO_2 (		H_2 (2)
N_2O (5)	NH_3 (2	1)	CS (4)
CO (6	HNO_3 (	)	SO_3 (1)
CH_4 (4	OH (3	1)	C_2N_2 (1)
O_2 (3	HF (2)		$COCl_2$(2)

- Ab rption cros cross sections!)
  - rimarily from
- HA (the HITRA
  - free open
- Ae sol Properl
- **Collision-Induced Absorption (CIA)**



[1] S. Sharpe, et al., (2004), *App. Spectrosc.* 58, 1452.
[2] Ø. Hodnebrog, et al. (2013), *Rev. Geophys.* 51, 300.
[3] R. V. Kochanov, et al. (2016), *JQSRT* 177, 15.

Accessing HITRAN*online*



Credit: Y. Tan

www.hitran.org

[1] C. Hill, et al., *JQSRT* 177, 4 (2016)

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Credit: I. Gordon

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Line-by-Line Search

1. Select Molecules

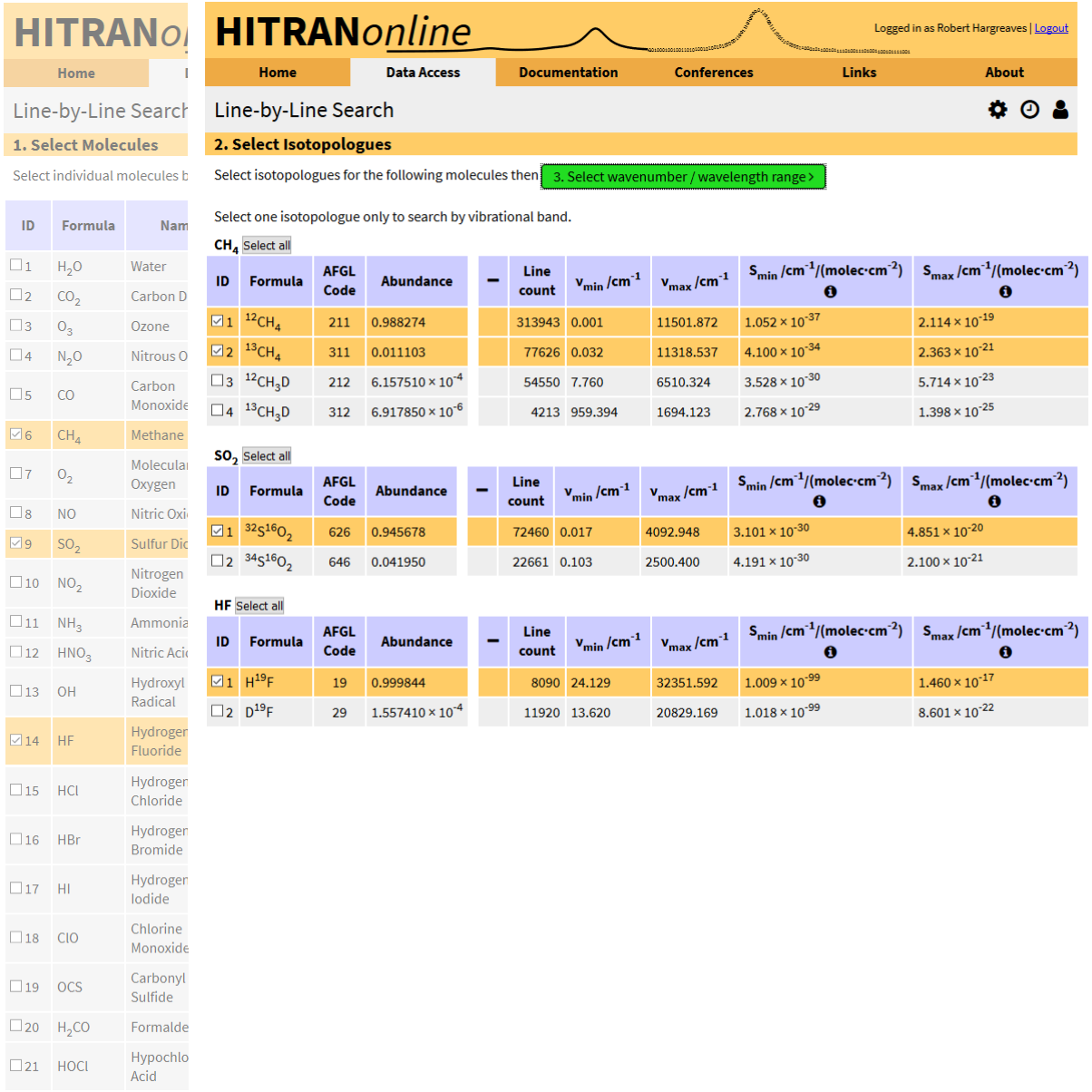
Select individual molecules below or Select all Select first 7 then: 2. Select Isotopologues >

ID	Formula	Name	Line count	ν_{min} /cm^{-1}	ν_{max} /cm^{-1}	S_{min} /cm^{-1}/(molec·cm^{-2})	S_{max} /cm^{-1}/(molec·cm^{-2})	Overview spectrum
☐1	H_2O	Water	304225	8.400×10^{-5}	25710.825	1.055×10^{-39}	2.662×10^{-18}	
☐2	CO_2	Carbon Dioxide	559874	0.757	14075.298	5.937×10^{-36}	3.542×10^{-18}	
☐3	O_3	Ozone	449570	0.026	6996.681	1.498×10^{-31}	4.059×10^{-20}	
☐4	N_2O	Nitrous Oxide	160287	0.791	10363.675	1.000×10^{-29}	1.004×10^{-18}	
☐5	CO	Carbon Monoxide	5381	3.402	14477.377	1.013×10^{-45}	4.556×10^{-19}	
☑6	CH_4	Methane	450332	0.001	11501.872	1.052×10^{-37}	2.114×10^{-19}	
☐7	O_2	Molecular Oxygen	14085	6.440×10^{-7}	17272.060	1.960×10^{-54}	8.797×10^{-24}	
☐8	NO	Nitric Oxide	105079	1.000×10^{-6}	9273.214	1.451×10^{-95}	2.322×10^{-20}	
☑9	SO_2	Sulfur Dioxide	95121	0.017	4092.948	3.101×10^{-30}	4.851×10^{-20}	
☐10	NO_2	Nitrogen Dioxide	104223	0.498	3074.153	4.240×10^{-28}	1.302×10^{-19}	
☐11	NH_3	Ammonia	67148	0.058	10348.719	2.115×10^{-39}	5.493×10^{-19}	
☐12	HNO_3	Nitric Acid	1008972	0.007	1769.982	3.246×10^{-29}	3.198×10^{-20}	
☐13	OH	Hydroxyl Radical	33058	0.003	35874.955	8.504×10^{-84}	6.449×10^{-17}	
☑14	HF	Hydrogen Fluoride	20010	13.620	32351.592	1.009×10^{-99}	1.460×10^{-17}	
☐15	HCl	Hydrogen Chloride	53252	5.342	20231.245	1.003×10^{-99}	5.038×10^{-19}	
☐16	HBr	Hydrogen Bromide	8980	7.656	16033.492	3.148×10^{-71}	1.214×10^{-19}	
☐17	HI	Hydrogen Iodide	4751	5.888	13907.689	9.342×10^{-64}	3.420×10^{-20}	
☐18	ClO	Chlorine Monoxide	11501	0.015	1207.639	5.944×10^{-30}	3.196×10^{-21}	
☐19	OCS	Carbonyl Sulfide	33030	0.396	7821.109	3.000×10^{-28}	1.248×10^{-18}	
☐20	H_2CO	Formaldehyde	44601	1.000×10^{-6}	3099.958	4.441×10^{-39}	7.436×10^{-20}	
☐21	HOCl	Hypochlorous Acid	16276	1.081	3799.682	1.720×10^{-24}	3.360×10^{-20}	

C. Hill, et al., *JQSRT* 177, 4 (2016).

Accessing HITRAN*online*

Credit: I. Gordon



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Line-by-Line Search

1. Select Molecules

Select individual molecules b

ID	Formula	Nam
1	H_2O	Water
2	CO_2	Carbon D
3	O_3	Ozone
4	N_2O	Nitrous O
5	CO	Carbon Monoxide
6	CH_4	Methane
7	O_2	Molecular Oxygen
8	NO	Nitric Oxi
9	SO_2	Sulfur Dio
10	NO_2	Nitrogen Dioxide
11	NH_3	Ammonia
12	HNO_3	Nitric Aci
13	OH	Hydroxyl Radical
14	HF	Hydrogen Fluoride
15	HCl	Hydrogen Chloride
16	HBr	Hydrogen Bromide
17	HI	Hydrogen Iodide
18	ClO	Chlorine Monoxide
19	OCS	Carbonyl Sulfide
20	H_2CO	Formalde
21	HOCl	Hypochlo Acid

2. Select Isotopologues

Select isotopologues for the following molecules then 3. Select wavenumber / wavelength range ›

Select one isotopologue only to search by vibrational band.

CH_4 Select all

ID	Formula	AFGL Code	Abundance	–	Line count	ν_{min} /cm^{-1}	ν_{max} /cm^{-1}	S_{min} /cm^{-1}/(molec·cm^{-2})	S_{max} /cm^{-1}/(molec·cm^{-2})
☑ 1	$^{12}CH_4$	211	0.988274		313943	0.001	11501.872	1.052×10^{-37}	2.114×10^{-19}
☑ 2	$^{13}CH_4$	311	0.011103		77626	0.032	11318.537	4.100×10^{-34}	2.363×10^{-21}
☐ 3	$^{12}CH_3D$	212	6.157510×10^{-4}		54550	7.760	6510.324	3.528×10^{-30}	5.714×10^{-23}
☐ 4	$^{13}CH_3D$	312	6.917850×10^{-6}		4213	959.394	1694.123	2.768×10^{-29}	1.398×10^{-25}

SO_2 Select all

ID	Formula	AFGL Code	Abundance	–	Line count	ν_{min} /cm^{-1}	ν_{max} /cm^{-1}	S_{min} /cm^{-1}/(molec·cm^{-2})	S_{max} /cm^{-1}/(molec·cm^{-2})
☑ 1	$^{32}S^{16}O_2$	626	0.945678		72460	0.017	4092.948	3.101×10^{-30}	4.851×10^{-20}
☐ 2	$^{34}S^{16}O_2$	646	0.041950		22661	0.103	2500.400	4.191×10^{-30}	2.100×10^{-21}

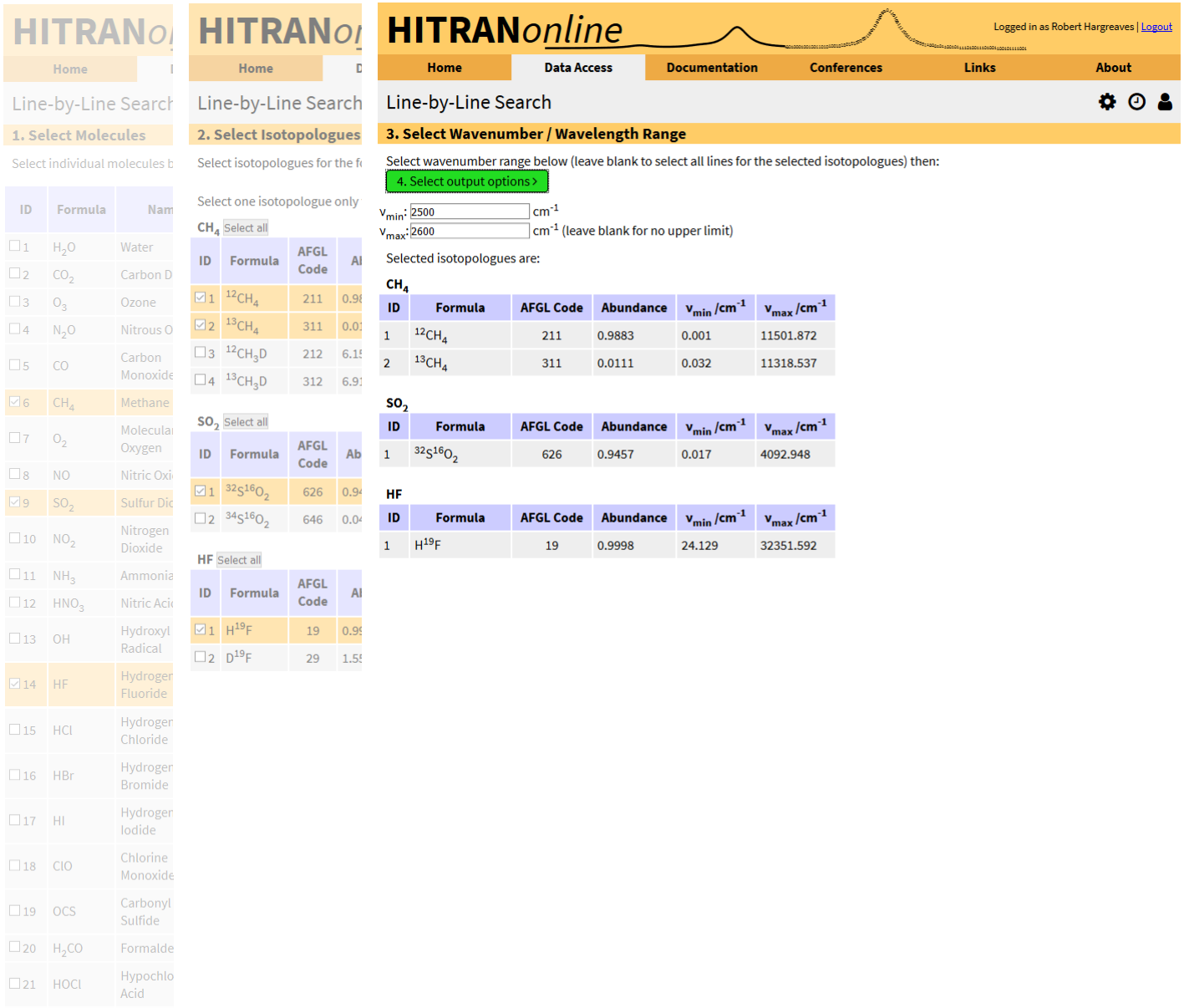
HF Select all

ID	Formula	AFGL Code	Abundance	–	Line count	ν_{min} /cm^{-1}	ν_{max} /cm^{-1}	S_{min} /cm^{-1}/(molec·cm^{-2})	S_{max} /cm^{-1}/(molec·cm^{-2})
☑ 1	$H^{19}F$	19	0.999844		8090	24.129	32351.592	1.009×10^{-99}	1.460×10^{-17}
☐ 2	$D^{19}F$	29	1.557410×10^{-4}		11920	13.620	20829.169	1.018×10^{-99}	8.601×10^{-22}

C. Hill, et al., *JQSRT* 177, 4 (2016).

Accessing HITRAN*online*

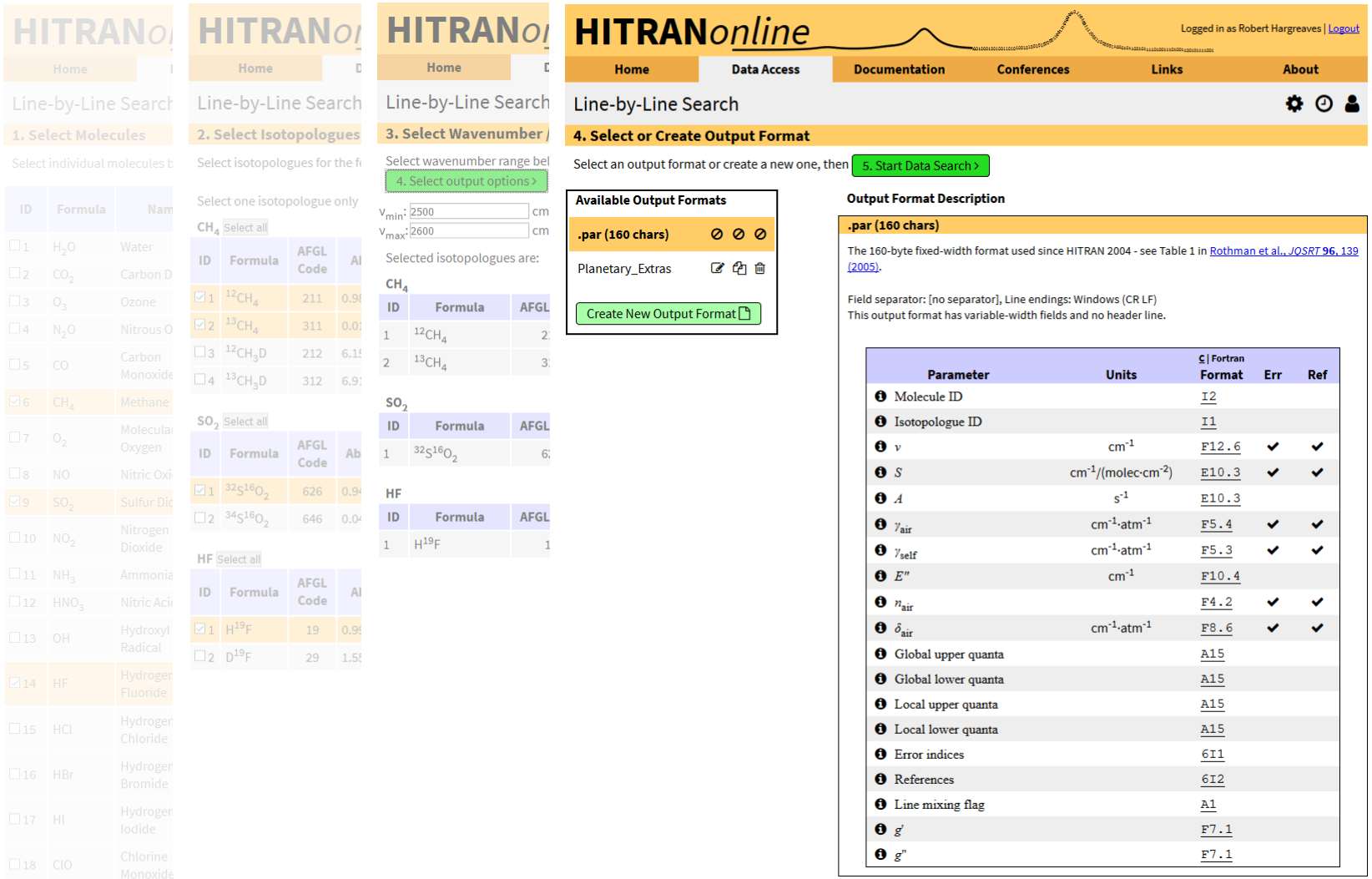
Credit: I. Gordon



C. Hill, et al., *JQSRT* 177, 4 (2016).

Accessing HITRAN*online*

Credit: I. Gordon



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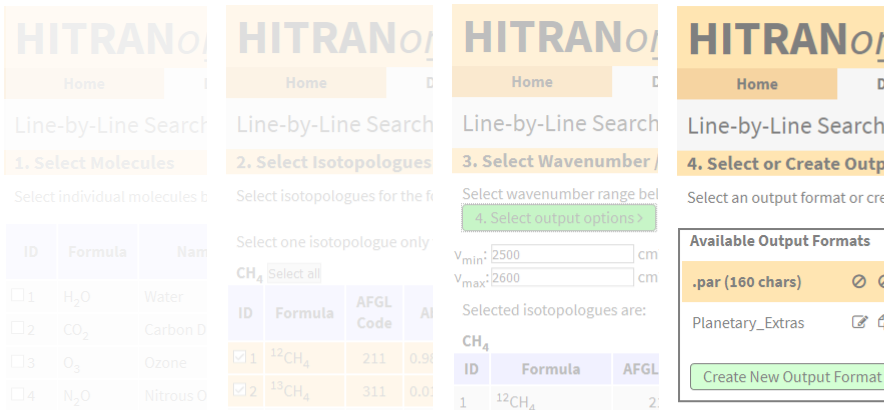
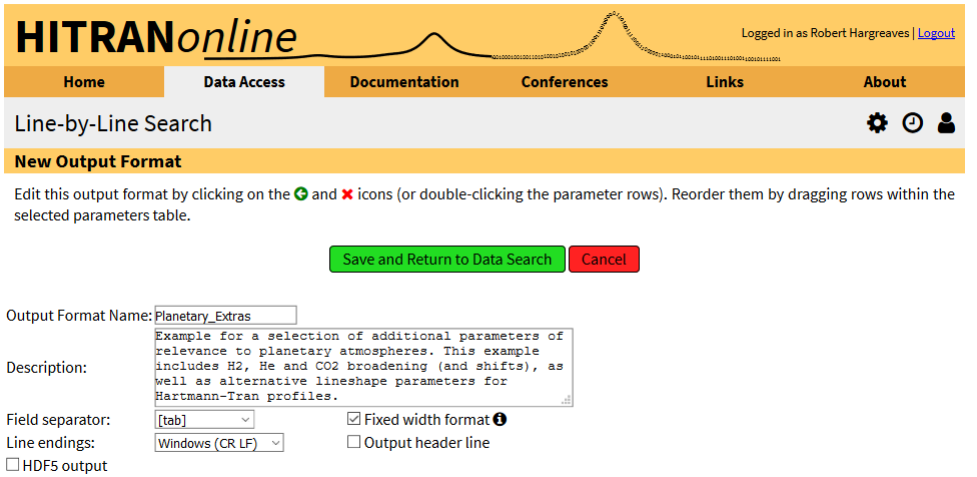
Accessing HITRANonline

Credit: I. Gordon





New Output Format

Parameter	Units	C | Fortran Format	Err	Ref
Molecule ID		I2		
Isotopologue ID		I1		
ν	cm^{-1}	F12.6		
S	$cm^{-1}/(molec \cdot cm^{-2})$	E10.3		
γ_{H2}	$cm^{-1} \cdot atm^{-1}$	F6.4		
n_{H2}		F7.4		
δ_{H2}	$cm^{-1} \cdot atm^{-1}$	F9.6		
γ_{He}	$cm^{-1} \cdot atm^{-1}$	F6.4		
δ_{He}	$cm^{-1} \cdot atm^{-1}$	F9.6		
γ_{CO2}	$cm^{-1} \cdot atm^{-1}$	F6.4		
n_{CO2}		F7.4		
$\delta_{HT\_0\_self}(296)$	$cm^{-1} \cdot atm^{-1}$	F9.6		
$\delta'_{HT\_0\_self}(296)$	$cm^{-1} \cdot atm^{-1} \cdot K^{-1}$	F9.6		
$\gamma_{HT\_0\_self}(296)$	$cm^{-1} \cdot atm^{-1}$	F6.4		
$n_{HT\_0\_self}(296)$		F7.4		
$\delta_{HT\_2\_self}(296)$	$cm^{-1} \cdot atm^{-1}$	F9.6		
$\gamma_{HT\_2\_self}(296)$	$cm^{-1} \cdot atm^{-1}$	F6.4		
κ_{HT_self}		F7.4		
ν_{HT_self}	$cm^{-1} \cdot atm^{-1}$	F7.4		
η_{HT_self}		F7.4		

Available Parameters

Parameter
Global isotopologue ID
A
γ_{air}
γ_{self}
n_{air}
δ_{air}
E''
g'
g''
δ'_{air}

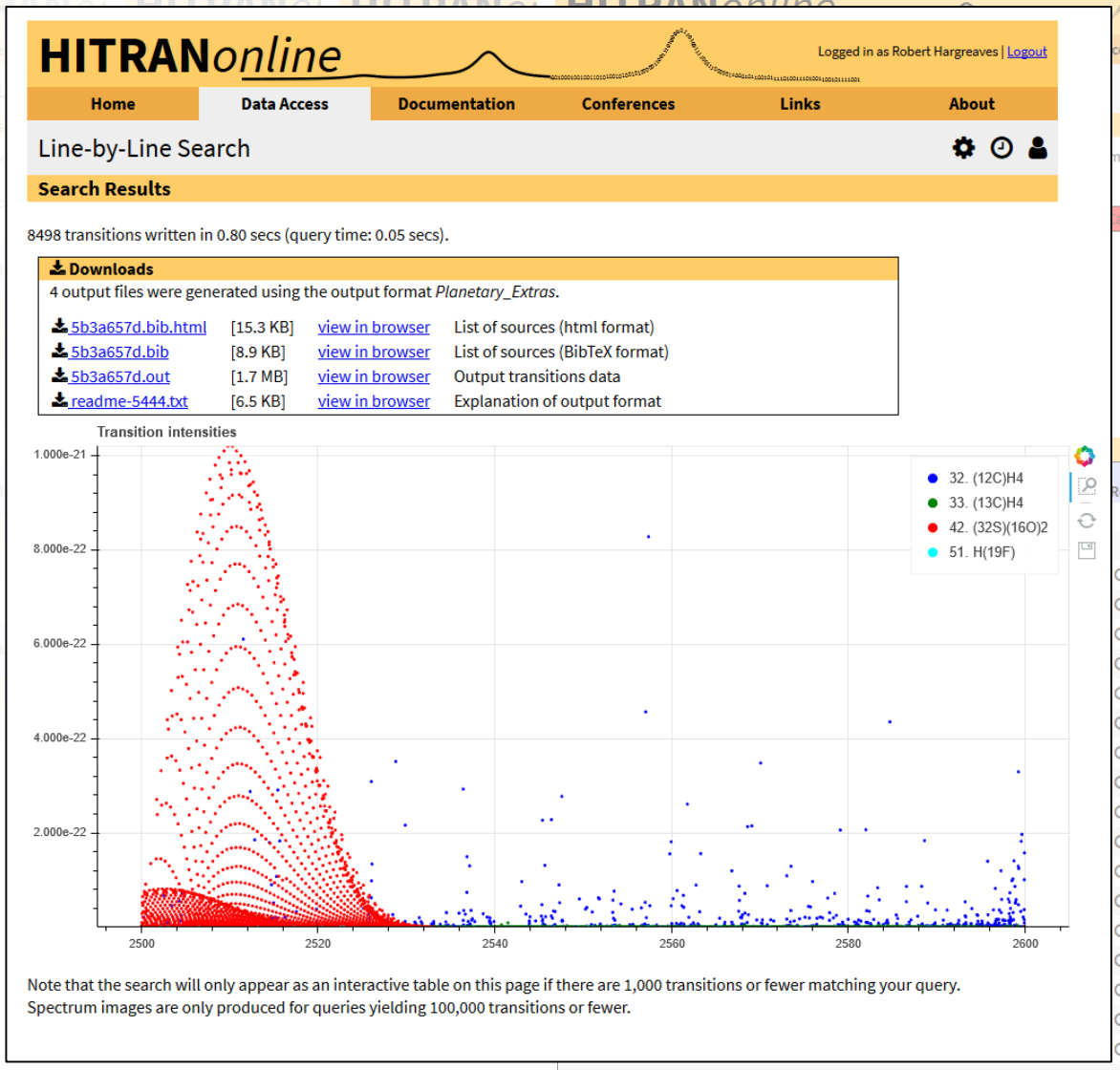
Grouped Parameters

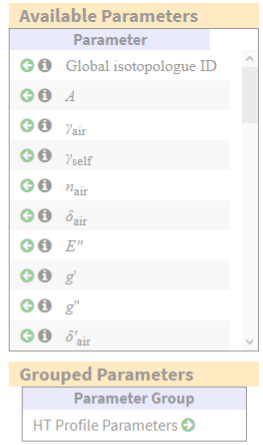
Parameter Group
HT Profile Parameters

C. Hill, et al., *JQSRT* 177, 4 (2016).

Accessing HITRAN*online*

Credit: I. Gordon





C. Hill, et al., *JQSRT* 177, 4 (2016).

Accessing HITRAN with HAPI

- **HAPI (the HITRAN Application Programming Interface) [1]**
  - A free open source Python module (library) which provides a set of tools for working with structured spectroscopic data from different sources.

```
# Import HAPI functions for downloading the data:
from hapi import *

# Fetch the CH4 data for the main isotopologue, in the 2500-2600 wavenumber range:
fetch('ch4',6,1,2500,2600)

# Select the lines with and intnensity greater than 1.0x10e-21 cm/molecule:
select('ch4', DestinationTableName='ch4_strong', Conditions=('>','sw', 1e-21))

# Calculate absortption coefficeient:
nu_coeff= abscoef('ch4_strong')

# Repeat the fetching for other molecles and isotopologues in previous example:
fetch('ch4',6,2,2500,2600)
fetch('so2',9,1,2500,2600)
fetch('hf',14,2,2500,2600)

# Print a list of unique IDs:
getHelp(ISO_ID)

# Fetch the CH4 data for the two strongest isotopologues, in the 2500-2600
# wavenumber range, including the additional broadening parameters:
fetch_by_ids('ch4', [32,33], 2500, 2600, ParameterGroups=['160-char'], Parameters[
        'gamma_H2', 'delta_H2', 'gamma_He', 'delta_H2', 'gamma_CO2', 'delta_CO2', ... ])
```

Import HAPI library

Easy command to download data

Tools for working with the data

Embedded help (and tutorials)

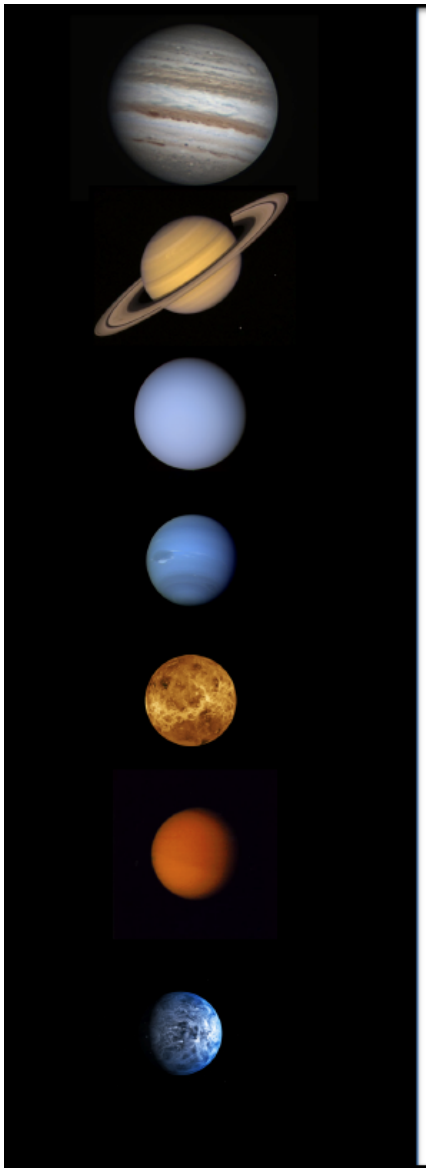
Many more options to include additional parameters, filtering etc.

www.hitran.org/hapi/

[1] R. V. Kochanov, et al. (2016), *JQSRT* 177, 15.

Broadening, temperature dependence & pressure shifts in planetary atmospheres

Credit: I. Gordon



Jupiter: H_2, He, CH_4, **C_2H_2**, C_2H_6, C_2H_4, H_2O, C_4H_2, C_6H_6, HD, C_3H_4, NH_3, PH_3, **CO**, GeH_4, AsH_3, CO_2, ...

Saturn: H_2, He, CH_4, **C_2H_2**, C_2H_6, C_3H_4, CH_3, H_2S, H_2O, C_3H_8, NH_3, SiH4, PH_3 , **CO**, GeH_4, AsH_3, CO_2, ...

Uranus: H_2, He, CH_4, C_3H_4, C_4H_2, C_2H_6, **C_2H_2**, **CO**, H_2S, ...

Neptune: H_2, He, CH_4, C_2H_4, **C_2H_2**, C_3H_4, CH_3, C_6H_6, ...

Venus: CO_2 , N_2, **SO_2**, H_2SO_4, **CO**, O, N_2, O_3, **HCl**, **HF**, Ne, H_2S, **OCS**, H, H_2, He, H_2O, O_2, Cl, ClO, ClO_2, COCl , ...

Titan: N_2, CH_4, Ar, C_2H_6, C_3H_8, H_2O, **CO**, CO_2, CH_3D, CH_3, C_2H_4, NH_3, HCN, C_2N_2, HC_3N, CH_3CN, C_4H_2, **C_2H_2**...

HD 189733b: H_2, H_2O, O, CH_4, **CO**, ...

HITRAN contains **self-** and **air-** broadening parameters for all line-by-line molecules

Foreign broadening gas

Gas being broadened

Broadening, temperature dependence & pressure shifts in planetary atmospheres

- A consequence of dominant gases in planetary atmospheres
- **PART 1:** This work has recently expanded for H_2, He and CO_2

Molecule	Parameter	Perturbed by H_2	Perturbed by He	Perturbed by CO_2
SO_2	γ	2	2	1
	n	1	1	0
	δ	0	0	0
NH_3	γ	3	3	2–3
	n	2–3	1	0
	δ	2–3	2–3	2
HF	γ	1	1	1–2
	n	0	1	0
	δ	0	1	1
HCl	γ	1	1–2	1–2
	n	1	0	0
	δ	1	1–2	1–2
OCS	γ	1	1	1–2
	n	0	0	0
	δ	0	0	0
C_2H_2	γ	3	3	1
	n	1	1	0
	δ	1	1–2	0–1

γ = Broadening coefficient (Lorentz)

n = Temperature dependence:

$$\gamma(T) = \gamma(T_{ref}) \cdot \left(\frac{T_{ref}}{T} \right)^n$$

δ = Pressure shifts

0 = No data available

1 = Few data available

2 = Some measurements available allowing semi-empirical extrapolations

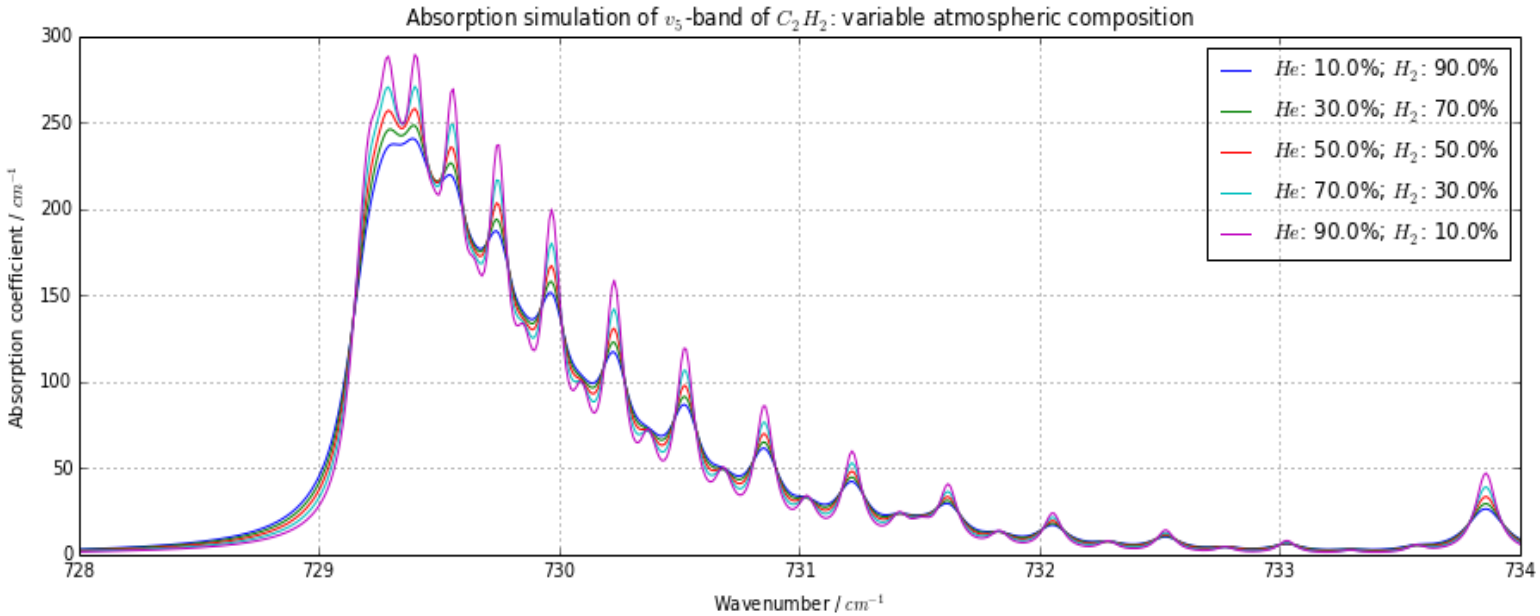
3 = Relatively complete set of measurements and/or calculations available at least at room temperature

[1] J. S. Wilzewski, et al. (2016), *JQSRT* 168, 193.

Broadening calculations with HAPI

- Example of modelling the C_2H_2 ν_5 band absorption in a He+H_2 atmosphere

```
alphas = [0.1, 0.3, 0.5, 0.7, 0.9]
leg = []
for alpha in alphas:
    He_frac = alpha; H2_frac = 1-alpha
    nu,coef = absorptionCoefficient_Voigt(SourceTables='c2h2_v5', WavenumberRange=[727.,735.],
                                          Diluent={'He':He_frac,'H2':H2_frac},HITRAN_units=False)
    plot(nu,coef)
    leg.append('$He$: %.1f%%; $H_2$: %.1f%%'%(He_frac*100,H2_frac*100))
title('Absorption simulation of $v_5$ band of $C_2H_2$: variable atmospheric composition')
xlabel('Wavenumber / $cm^{-1}$'); ylabel('Absorption coefficient / $cm^{-1}$')
xlim(728,734); grid(True); legend(leg)
```



Credit: I. Gordon

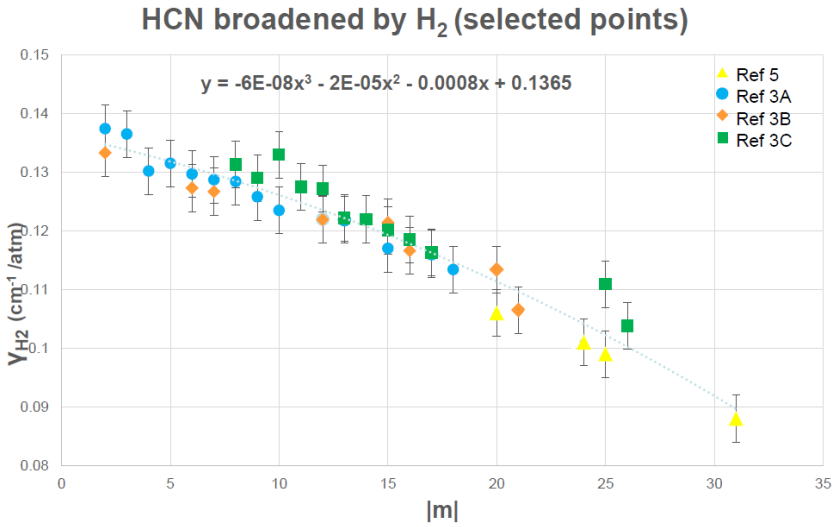
See: "H_2, He, and CO_2 line-broadening coefficients, pressure shifts and temperature-dependence exponents for the HITRAN database. Part 1: SO_2, NH_3, HF, HCl, OCS and C_2H_2"
J. S. Wilzewski, et al. (2016), *JQSRT* 168, 193.

Broadening, temperature dependence & pressure shifts in planetary atmospheres

Credit: S. Samuels

- **PART 2:** This work has recently expanded for H_2, He and CO_2
  - Includes line broadening coefficients (γ), temperature dependence exponents (n) and pressure shifts (δ)
  - CO_2, N_2O, OH, H_2CO, HCN, H_2S

Molecule	Parameter	Perturbed by H_2	Perturbed by He	Perturbed by CO_2
HCN	γ	3	2	0
	n	1	1	0
	δ	1	1	0
CO_2	γ	1	1	3
	n	1	1	3
	δ	0	1	3
N_2O	γ	0	1 or 2	1 or 2
	n	0	1	1
	δ	0	1 or2	0
H_2CO	γ	2	2	0
	n	0	0	0
	δ	1	0	0
H_2S	γ	1	2	2
	n	0	0	0
	δ	0	0	0



0 = no data available
1 = few data available
2 = some measurements available allowing semi-empirical extrapolations
3 = relatively complete set of measurements and/or calculations available at least at room temperature

- "H_2, He and CO_2 Line-Broadening Coefficients for Molecules in the HITRAN Database. Part II: CO_2, N_2O, H_2CO, HCN, H_2S, OH"

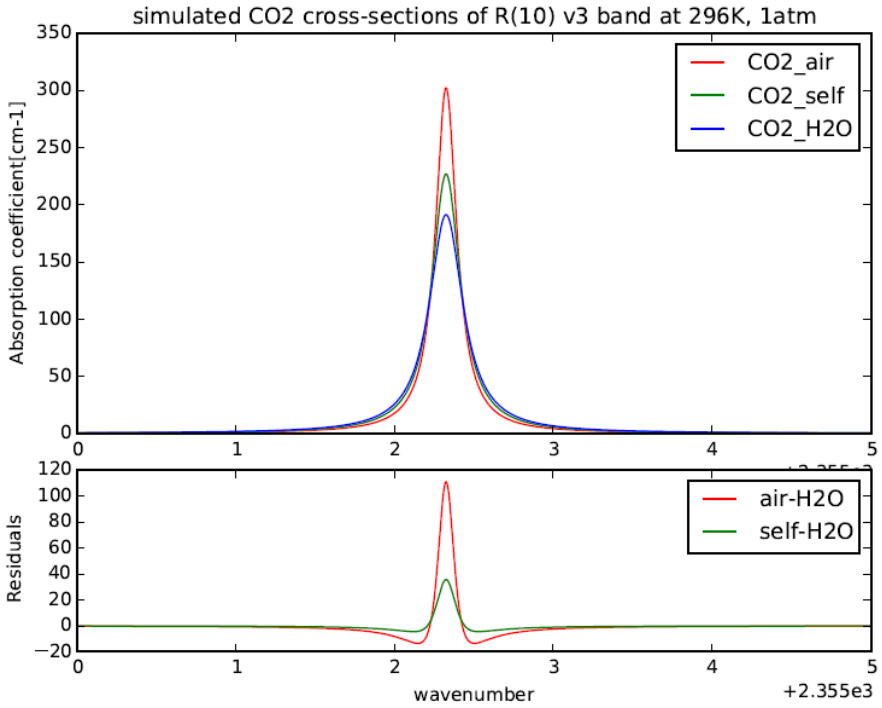
  S. Samuels, Y. Tan, R. V. Kochanov, L. S. Rothman, I. E., Gordon, *in preparation*

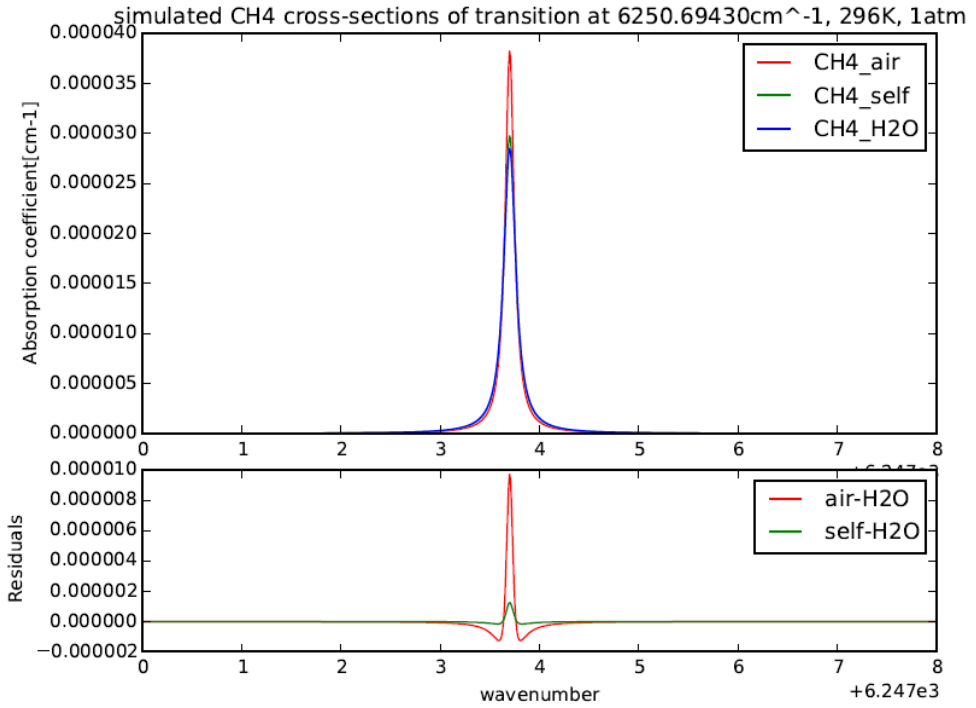
What about water?

Credit: Y. Tan

- Water vapor is a very **efficient** broadening gas
  - Compared to N_2 and O_2
- For the Earth's lower atmosphere water vapor is **highly variable**
- Some rocky exoplanets have been predicted to have **"steamy" atmospheres**

Simulated effect of water broadening of CO_2 and CH_4





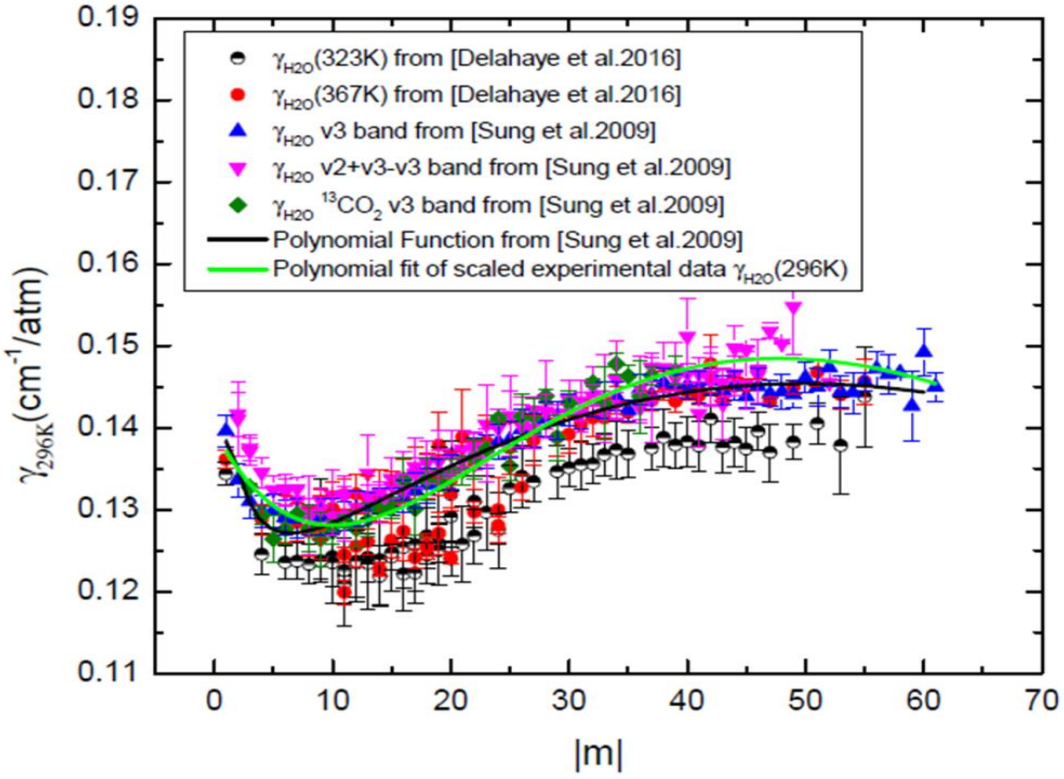
What about water?

Credit: Y. Tan

- H_2O broadening coefficients of CO_2, O_2, CH_4, CO, NH_3, N_2O and H_2S
- Example for CO_2:

Polynomial function in the quantum index m:

$$\gamma(m) = c_0 + c_1 \cdot m + c_2 \cdot m^2 + c_3 \cdot m^3 + c_4 \cdot m^4 + c_5 \cdot m^5$$



Molecule \ Parameter	γ	n
CO_2	3	3
O_2	3	2
CH_4	1	0
CO	2	2
NH_3	1	0
N_2O	1	0
H_2S	1	0

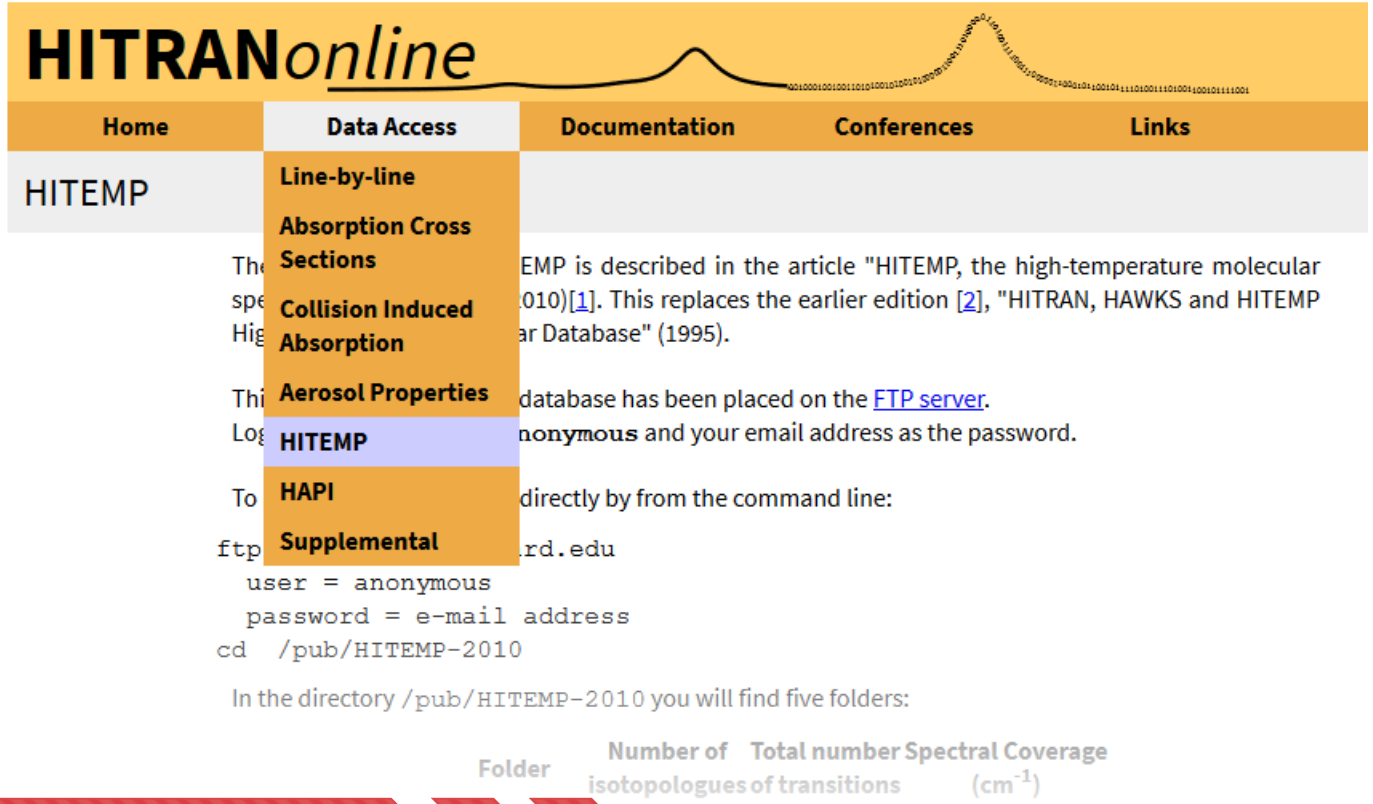
Data Availability in **Table**:

- **0** = No data available;
- **1** = Few data available, new HITRAN file contains mostly averages;
- **2** = Some measurements available, allowing semi-classical extrapolations;
- **3**= Relatively complete set of measurements or calculations available - at least for room temperature.

Y. Tan, I. E., Gordon, R. V. Kochanov, L. S. Rothman, *in preparation*

Current HITEMP

- **Hi**gh-**Temp**erature Molecular Spectroscopic Database
  - L.S. Rothman, I.E. Gordon, R.J. Barber, H. Dothe, R.R. Gamache, A. Goldman, V. Perevalov, S.A. Tashkun, and J. Tennyson, *J. Quant. Spectrosc. Rad. Transf.* **111,** 2139-2150 (2010)



www.hitran.org/hitemp/

Current HITEMP

- Line-by-line data is at 296 K like HITRAN
- Currently only five molecules:

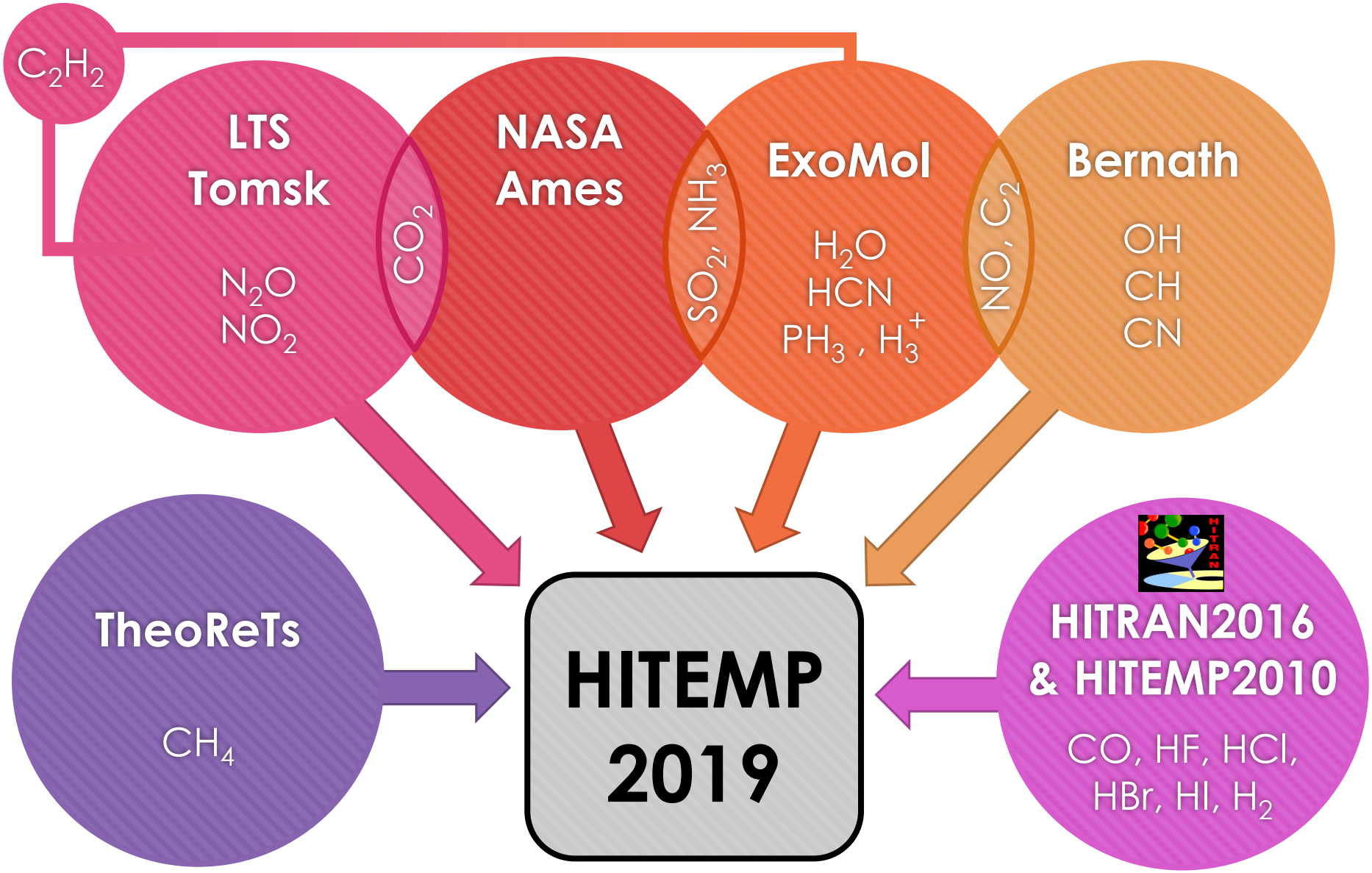
Molecule	Spectral Coverage (cm^{-1})	Number of Isotopologues	Number of Transitions
H_2O	0 – 30,000	6*	111,241,164
CO_2	5 – 12,785	7	11,193,608
NO	0 – 9,274	3*	115,610
CO	0 – 8,465	6	113,631
OH	0 – 19,268	3*	41,557

*only principal isotopologue

- **HITRAN2016** data for HF, HCl, HBr, HI and H_2
  - Also suitable for 1000's of Kelvin
  - **TIPS** up to 9000 K for some molecules
- Line parameters in HITEMP will be consistent with HITRAN
  - Where possible

www.hitran.org/hitemp/

Proposed data for HITEMP



N_2O for HITEMP

- Available **NOSD-1000** from LTS Tomsk group:

Journal of Quantitative Spectroscopy & Radiative Transfer 177 (2016) 43–48

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

NOSD-1000, the high-temperature nitrous oxide spectroscopic databank

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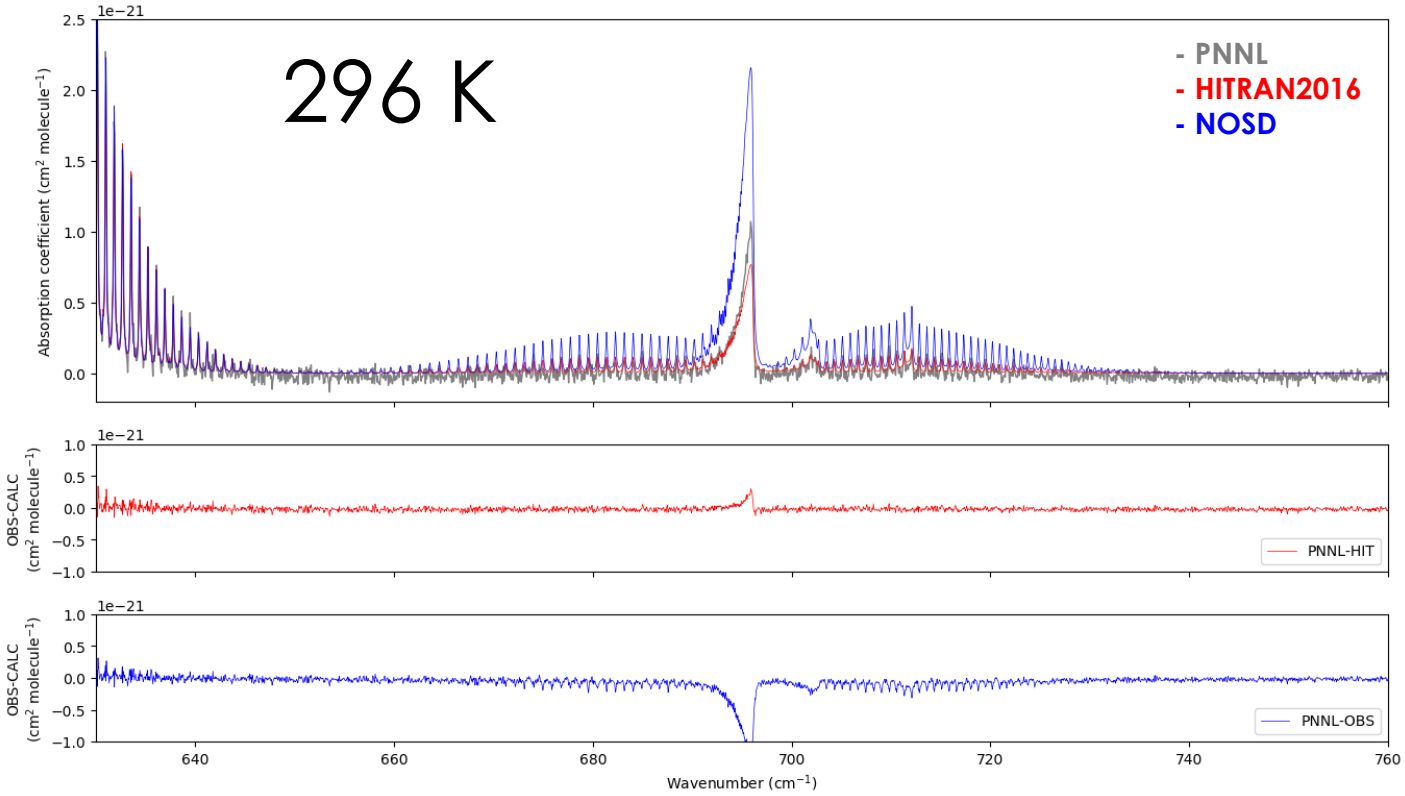
N_2O comparisons to PNNL at 296K (1000-0110)

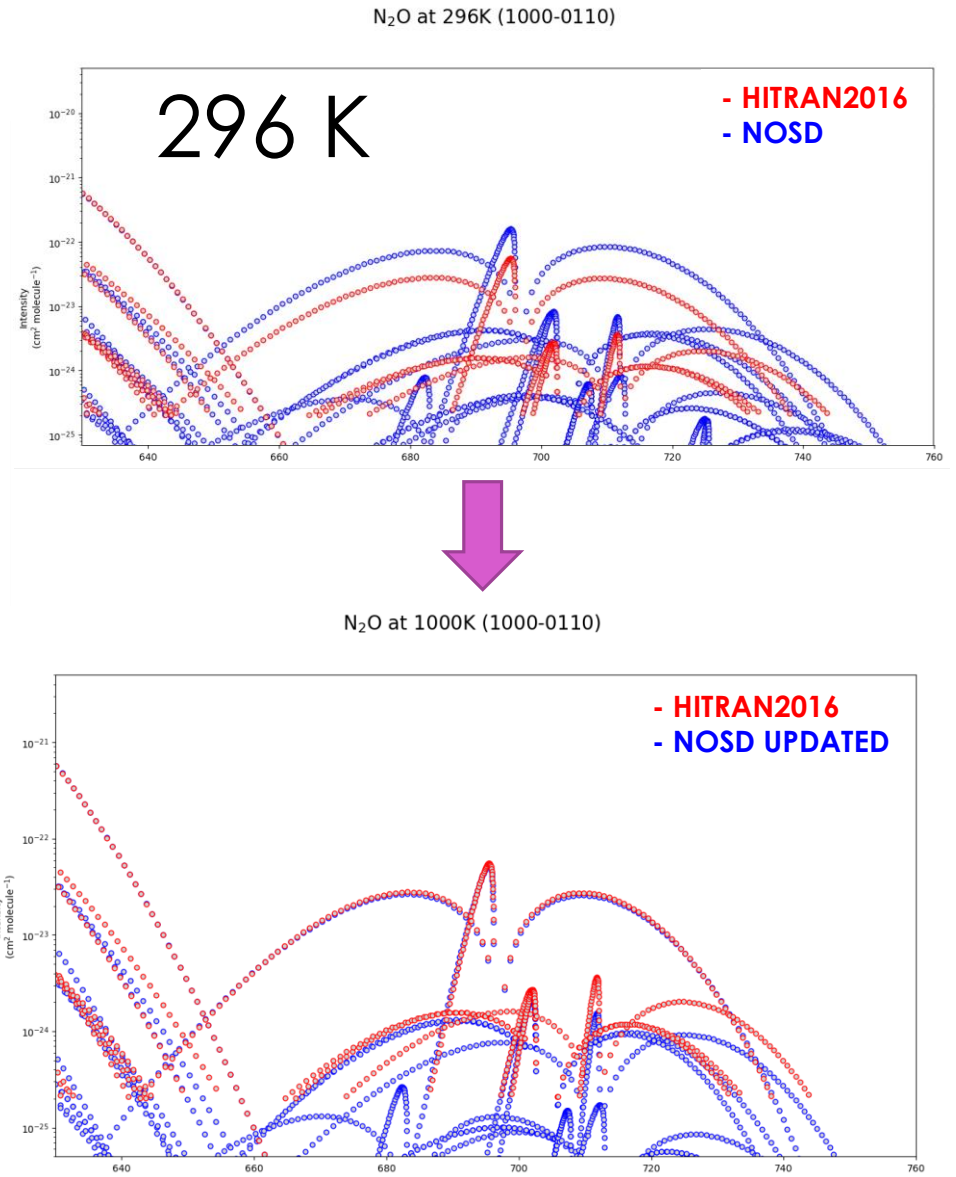


- Noticeable differences
  - PNNL
  - HITRAN2016
- Band intensity was corrected

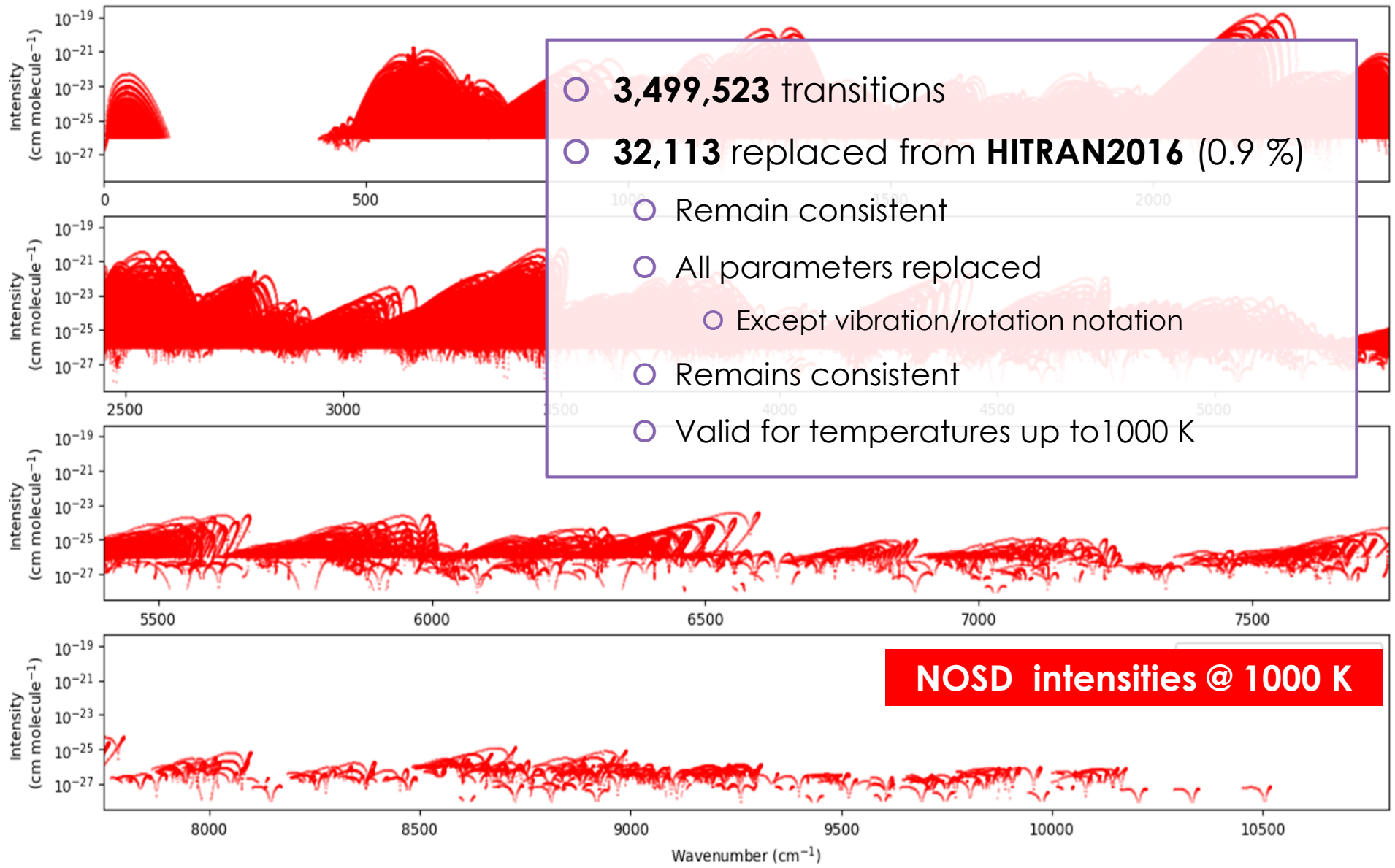
N_2O for HITEMP

- Recalculated by S. A. Tashkun
  - @ 296 K
  - @ 500 K
  - @ 1000 K

- Updated line list for HITEMP
  - >1.0x10^{-26} cm molecule^{-1}
  - At all temperatures
  - HITRAN replacements



N_2O overview for HITEMP

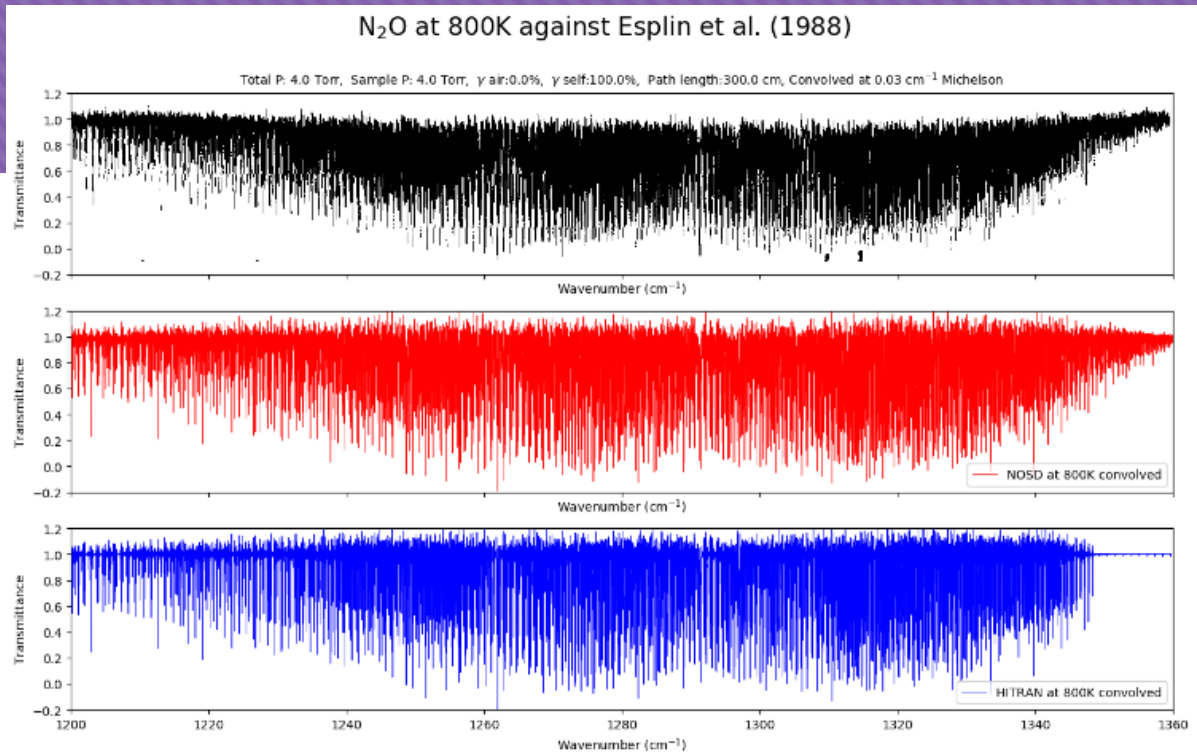


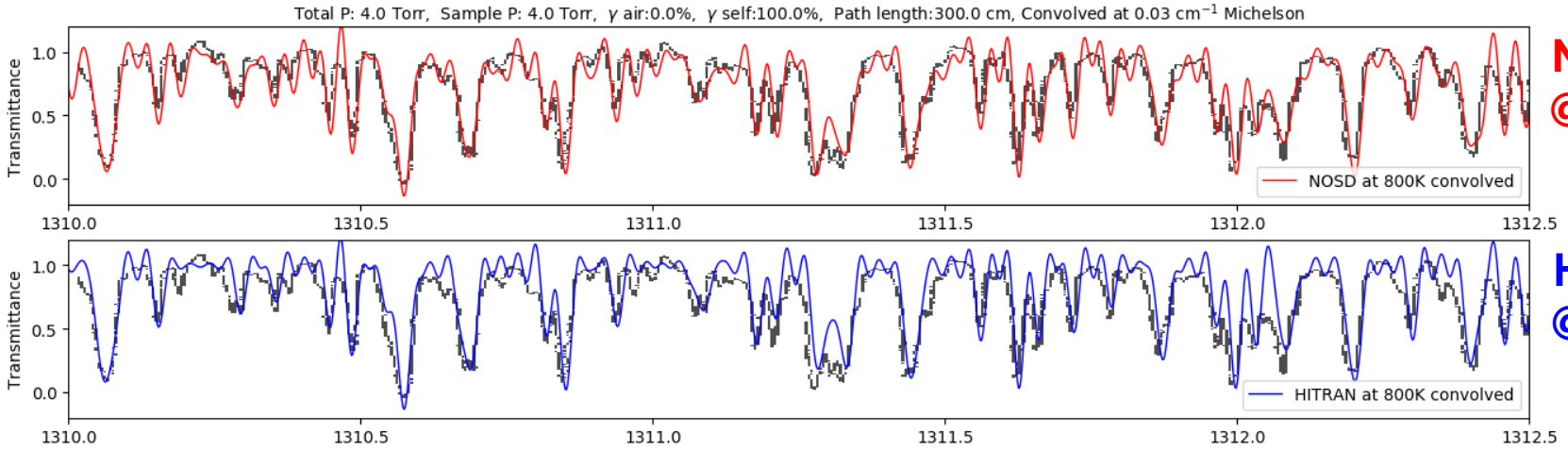
- **3,499,523** transitions
- **32,113** replaced from **HITRAN2016** (0.9 %)
  - Remain consistent
  - All parameters replaced
    - Except vibration/rotation notation
  - Remains consistent
  - Valid for temperatures up to1000 K

NOSD intensities @ 1000 K

800 K

- High temperature comparison
  - **M. P. Esplin et al. *Mikrochim. Acta* 2, 403 (1988)**
- Calculated using HAPI tools
  - R. V. Kochanov et al. *JQSRT* 177, 15 (2016)





NOSD @ 800 K

HITRAN @ 800 K

Summary

- **HITRAN freely available online**
  - Line-by-line data and cross sections available (among other information)
  - HAPI Python libraries to download
    - Easy to work with HITRAN data
  - Broadening, temperature dependence and shifts parameters are being updated for **foreign broadeners relevant to planets/exoplanets**
    - Numerous molecules

- **Work towards the next HITEMP update underway!**
  - Expected… 2019
    - Some molecules easier to validate than others
  - More high temperature measurements needed for validation
  - Data will be relevant for hot exoplanets
  - Further molecules will be added in secondary update

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