Gas signatures of Herbig Ae/Be disks probed with Herschel SPIRE spectroscopy

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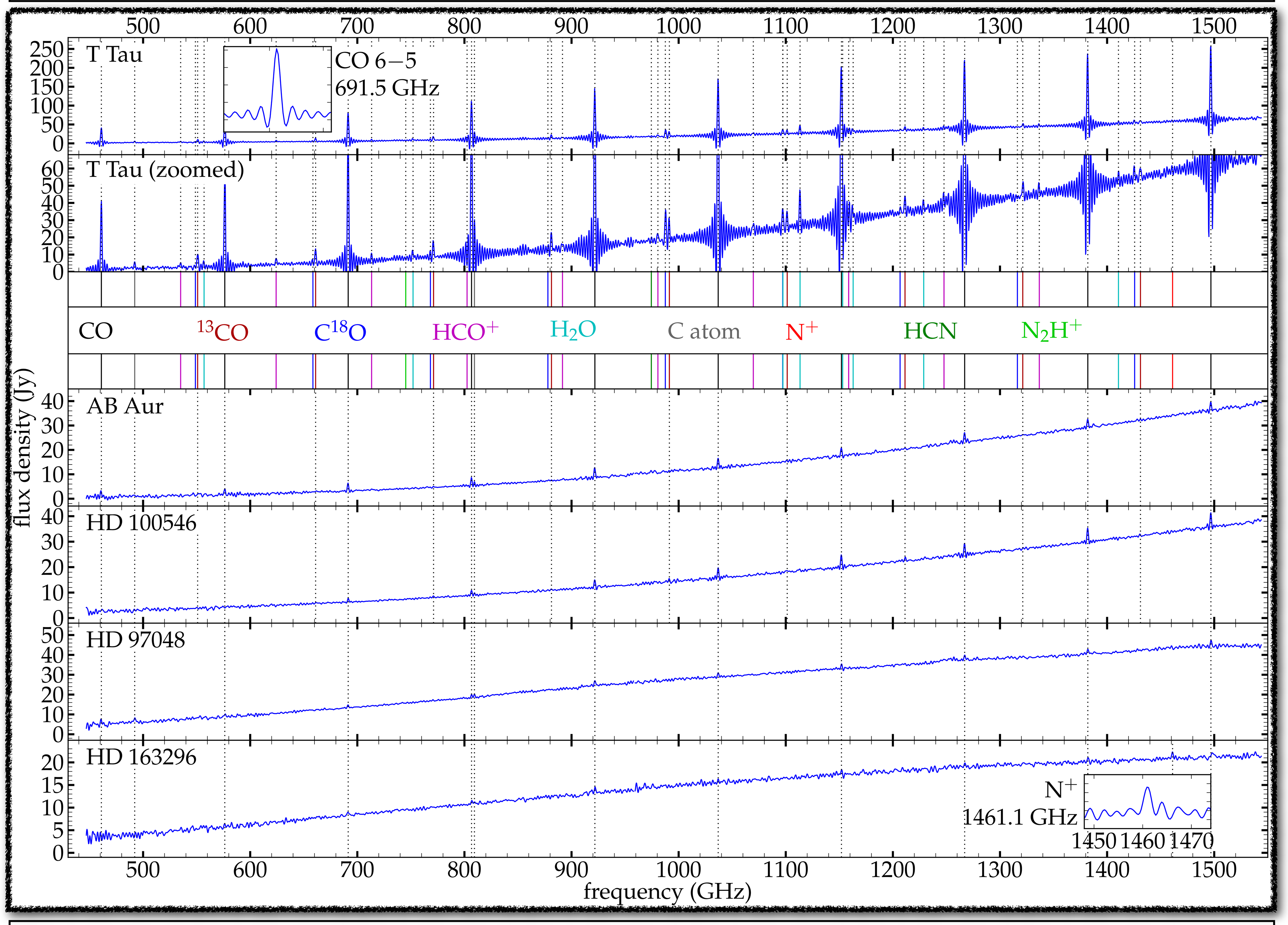
Overview

Herbig Ae/Be objects, like their lower mass counterparts T Tauri stars, are seen to form a stable circumstellar disk which is initially gas-rich and could ultimately form a planetary system. We study gas in a sample of young Herbig disks: **AB Aur, HD100546, HD97048, HD163296, T Tau, HD142527, HD144432, RY Tau, HD104237, HD36112, HD169142, HD100453 and TW Hya**. Of these, the first five show detectable line signal identified as, e.g., CO, H_2O, neutral C or N^+.



Observations and data processing

Spectra of the sample of objects were obtained with the SPIRE FTS instrument onboard *Herschel*, in a 16-hour SPIRE guaranteed time project (P.I. Göran Olofsson). The disks are point-like, relative to the angular resolution of SPIRE FTS: 42”–17” in the frequency range 460–1540 GHz. At a spectral resolution of 1.2 GHz ($R \sim 300$–1400), lines from these objects are spectrally unresolved. Data processing is done with the HIPE 9 pipeline, followed by subtraction of a median background signal obtained from the off-center detectors.

The processed spectrum of T Tau shows a jump in intensity between the two SPIRE FTS bands, characteristic of extended emission. Its spectrum above has been ‘corrected’ for a spatial extent of 17” (Makiwa et al. 2013; Wu et al. 2013), a size which is only realistic for an envelope, not a disk.

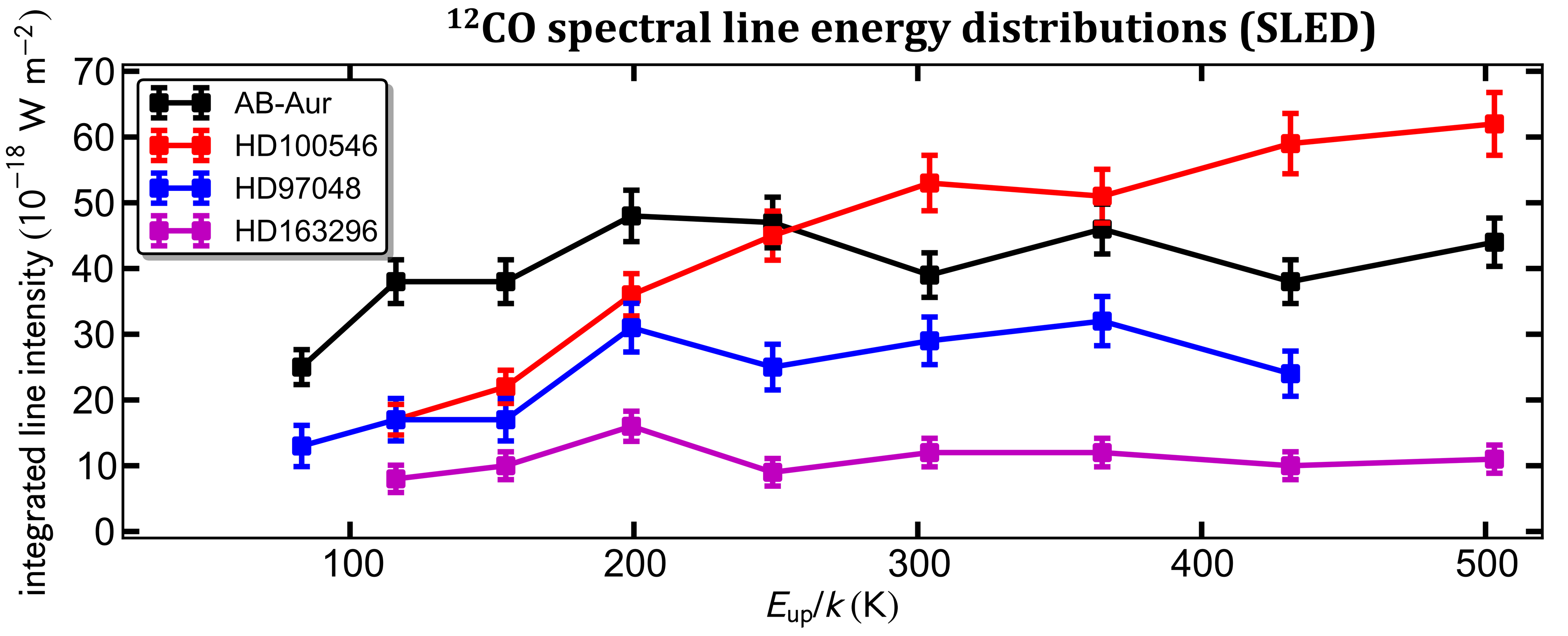
Results

The figure above shows the SPIRE spectra of the five targets in our sample that display detectable spectral line signal, listed in detail in the table on the right. Line parameters are derived using a dedicated Fourier Transform line fitter tool developed at the University of Lethbridge*, which simultaneously fits a continuum component and a set of Sinc shaped line profiles (see inset in top panel) with a known instrumental linewidth. The other eight targets only show continuum.

Interpretation and analysis plans

- The **N^+ line in HD 163296** is 10^4–10^5 times brighter than what is predicted by current irradiated disk models (e.g., Aresu et al. 2011), even when invoking X-ray luminosities much higher than appropriate for HD 163296. Since N^+ is also detected in all off-center detectors up to 1’ away from the star, we hypothesize that *an external source is responsible for ionizing nitrogen both in the disk/jet of HD 163296 and in the surrounding gaseous medium.*
- It is evident from the SPIRE FTS spectra toward the center of the T Tau system and those from off-center detectors that the continuum and CO lines originate in an extended remnant envelope rather than in the disk. This is likely also the case for the **cold H_2O vapor**.
- In contrast to T Tau, the **^{12}CO lines** in the other four targets are likely to originate in the protoplanetary disks. Where measured, ^{12}CO/^{13}CO line ratios are as low as ~3–10, indicating optical depths of ~5–20 for the ^{12}CO lines.
- *analysis plan*: characterize warm gas in Herbig protoplanetary disks using CO 4–3 to 13–12 lines ($E_{up} \sim 50$–500 K). Of the four disks listed below, HD 100546 appears to harbor the warmest gas, with its SLED (below) rising across the entire energy range, a trend known to continue into even higher CO transitions observed with *Herschel* PACS (Bruderer et al. 2012).

^{12}CO spectral line energy distributions (SLED)



line transition	E_{up}/k [K]	frequency [GHz] (b)	line flux [10^{-18} W m^{-2}] (error in brackets)				
			T Tau	AB Aur	HD 100546	HD 97048	HD 163296
CO 4–3	**55**	**461.0**	**448 (5)**	**35 (2)**	**-**	**37 (3)**	**-**
(unknown)	-	478.3	-	12 (2)	-	-	-
C $^3P_1$–$^3P_0$	24	492.2	35 (5)	-	-	26 (3)	-
(unknown)	-	503.2	-	-	10 (2)	-	-
HCO^+ 6–5	90	535.1	26 (5)	-	-	-	-
$C^{18}O$ 5–4	79	548.8	12 (5)	-	-	-	-
^{13}CO 5–4	79	550.9	91 (5)	-	-	-	-
H_2O 1_{10}–1_{01}	61	556.9	28 (5)	-	-	-	-
(unknown)	-	560.1	-	-	−12 (2)	-	-
(unknown)(d)	-	565.8	-	-	−11 (2)	-	-
CO 5–4	**83**	**576.3**	**599 (5)**	**25 (2)**	**-**	**13 (3)**	**-**
HCO^+ 7–6	120	624.2	34 (5)	-	-	-	-
(unknown)	-	633.4	-	-	-	-	9 (2)
$C^{18}O$ 6–5	111	658.6	7 (5)	-	-	-	-
^{13}CO 6–5	111	661.1	85 (5)	-	-	-	-
CO 6–5	**116**	**691.5**	**740 (5)**	**38 (2)**	**17 (2)**	**17 (3)**	**8 (2)**
HCO^+ 8–7	154	713.3	22 (5)	-	-	-	-
N_2H^+ 8–7	161	745.2	7 (5)	-	-	-	-
H_2O 2_{11}–2_{02}	137	752.0	47 (5)	-	-	-	-
$C^{18}O$ 7–6	147	768.3	18 (5)	-	-	-	-
^{13}CO 7–6	148	771.2	100 (5)	6 (2)	7 (2)	-	-
HCO^+ 9–8	193	802.5	39 (5)	-	-	-	-
CO 7–6	**155**	**806.7**	**1141 (5)**	**38 (2)**	**22 (2)**	**17 (3)**	**10 (2)**
C $^3P_2$–$^3P_1$	62	809.3	93 (5)	14 (2)	8 (2)	17 (3)	5 (2)
^{13}CO 8–7	190	881.3	90 (5)	-	-	-	-
HCO^+ 10–9	235	891.6	39 (5)	-	-	-	-
CO 8–7	**199**	**921.8**	**1531 (5)**	**48 (2)**	**36 (2)**	**31 (3)**	**16 (2)**
(unknown)	-	925.9	-	-	9 (2)	-	-
HCN 11–10	281	974.5	10 (4)	11 (2)	-	-	-
(unknown)	-	978.1	-	10 (2)	-	14 (3)	-
HCO^+ 11–10	282	980.6	37 (4)	-	-	-	-
$C^{18}O$ 9–8 (a)	237	987.6	133 (4)	-	-	-	-
^{13}CO 9–8	238	991.3	75 (4)	5 (2)	14 (2)	-	-
CO 9–8	**249**	**1036.9**	**1106 (4)**	**47 (2)**	**45 (2)**	**25 (3)**	**9 (2)**
HCO^+ 12–11	334	1069.7	38 (4)	-	-	-	-
$C^{18}O$ 10–9 (a)	290	1097.2	87 (4)	-	-	-	-
^{13}CO 10–9	291	1101.3	61 (4)	-	-	-	-
H_2O 1_{11}–0_{00}	53	1113.3	132 (4)	-	-	-	-
CO 10–9	**304**	**1152.0**	**1202 (4)**	**39 (2)**	**53 (2)**	**29 (3)**	**12 (2)**
H_2O 3_{12}–2_{21}	249	1153.1	124 (4)	-	-	-	-
HCO^+ 13–12 (a)	389	1158.7	39 (4)	-	-	-	-
H_2O 3_{21}–3_{12}	305	1162.9	51 (4)	-	-	-	-
(unknown)	-	1184.0	-	9 (2)	-	−7 (3)	-
^{13}CO 11–10	349	1211.3	50 (4)	-	14 (2)	-	-
H_2O 2_{20}–2_{11}	196	1228.8	22 (4)	-	-	-	-
HCO^+ 14–13	449	1247.7	43 (4)	-	-	-	-
(unknown)	-	1249.0	36 (4)	-	-	-	-
(unknown)(c)	-	1251.0	48 (4)	-	-	-	-
(unknown)	-	1253.6	-	17 (2)	-	-	-
(unknown)	-	1257.0	-	14 (2)	-	25 (3)	-
CO 11–10	**365**	**1267.0**	**1225 (4)**	**46 (2)**	**51 (2)**	**32 (3)**	**12 (2)**
^{13}CO 12–11	412	1321.3	53 (4)	-	-	-	-
HCO^+ 15–14	513	1336.7	30 (4)	-	-	-	-
CO 12–11	**431**	**1382.0**	**1224 (4)**	**38 (2)**	**59 (2)**	**24 (3)**	**10 (2)**
(unknown)	-	1383.3	42 (4)	-	-	-	-
H_2O 5_{23}–5_{14} ?	642	1410.6	20 (4)	-	-	-	-
$C^{18}O$ 13–12	479	1425.7	31 (4)	-	-	-	-
^{13}CO 13–12	481	1431.2	44 (4)	-	-	-	-
N^+ $^3P_1$–$^3P_0$	70	1461.1	-	-	-	-	17 (2)
CO 13–12	**503**	**1496.9**	**1262 (4)**	**44 (2)**	**62 (2)**	**41 (3)**	**11 (2)**

(a) For T Tau: may be blended with H_2O line.
(b) Rest frequency (from JPL, Pickett et al. 1998, except N^+ from SLAIM) for identified lines; observed frequency for unidentified lines.
(c) Possibly H_2O^+ or H_3O^+ near 1250.9 GHz, but both at E_{up}~1400 K.
(d) Possibly CN (N=6–5) in absorption.

References:
- Aresu et al., 2011, A&A 526, A163
- Bruderer et al., 2012, A&A 541, A91
- Makiwa et al., 2013, Applied Optics, 52 (16), 3864
- Pickett et al., 1998, J. Quant. Spec. Radiat. Transf., 60, 883
- Wu et al., 2013, accepted by A&A

(*) The FT Fitter tool is available at www.uleth.ca/phy/naylor/index.php?page=ftfitter

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