Diurnal Observations of HCl Altitude Variation in the 70-100 km Mesosphere of Venus

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Short title: DIURNAL HCL IN VENUS MESOSPHERE

Abstract. First submm spectroscopic observations of the 625.9 GHz H^{35}Cl absorption lines of the Venus dayside atmosphere were obtained with the James Clerk Maxwell Telescope (JCMT) on March 2, 2013. These data, which support retrieval of HCl altitude distributions in the Venus mesosphere (70–100 km), are presented here and compared with previously reported JCMT observations of Venus nightside HCl (Sandor and Clancy, 2012). The measured dayside profile agrees with that of the nightside, indicating no diurnal variation is present. More specifically, the nightside spectra revealed a secular decrease of upper mesospheric HCl between observations one month apart, at fixed latitude and local time. The dayside profile reported here presents upper mesospheric abundances that are bracketed by the two previously measured nightside profiles, indicating that if diurnal variation is present, it must be weaker than the secular variations occurring at fixed local time. The previous study, which measured nightside HCl abundances above 85 km to be much smaller than predicted from photochemical modeling, suggested a dynamical explanation for the disagreement wherein nightside downwelling associated with the SubSolar to AntiSolar (SSAS) atmospheric circulation might suppress upper mesospheric abundances predicted purely from photochemistry. However a straightforward prediction from the proposed mechanism is that HCl abundance on the dayside, where the SSAS drives upward rather than downward transport should at least agree with, and perhaps exceed that of the photochemical model. The finding that dayside HCl abundance agrees with that of the nightside, hence also is much smaller than that of the model shows the SSAS hypothesis to be incorrect.

Introduction

Photochemical modeling indicates that HCl should be the primary chlorine reservoir within the Venus atmosphere, where it is expected to be chemically inert (hence roughly constant in mixing ratio) from the ground to the lower thermosphere (eg. Yung and DeMore, 1982; Mills and Allen, 2007; Mills et al., 2007; Krasnopolsky, 2007; 2012; Zhang et al., 2012). Quantitatively, the Yung and DeMore (1982) model predicts HCl abundance to be constant from the ground to 85 km, with a gradual decrease of 20% from 85 to 100 km, and all the later studies are consistent with this result. Each of these models represents the atmosphere in the diurnal mean sense, with photolysis rates fixed at the average of values over local times. Vertical diffusion is considered, while horizontal transport is neglected in all cases. The predicted altitude variation is independent of assumed total atmospheric chlorine, which Yung and DeMore (1982) estimated as 400–800 parts per billion (ppb), bracketing the Connes et al. (1967) first measurement of Venus HCl (600 ± 120 ppb at the 100 hPa (~ 65 km) pressure level). A subsequent reanalysis by Young (1972) found the Connes et al. (1967) spectra to be better fit with a retrieved mixing ratio of 420 ± 70 ppb at 160 hPa (60 km). Subsequent ground-based measurements have been largely consistent with the Young (1972) abundance for altitudes up to 74 km (with exceptions, discussed below), such that more recent modeling studies assume total chlorine of ~ 420 ppb as a model input.

The importance of HCl for understanding the Venus atmosphere follows from its respective roles as the primary reservoir of chlorine, the second largest reservoir (after water) of hydrogen, and its impact on properties of the 40–70 km cloud layer through solution of HCl in liquid water to form hydrochloric acid droplets. Discussion in this work is focused on HCl as a chlorine reservoir. While only weakly reactive itself, HCl underlies atmospheric chlorine chemistry by supporting the presence of highly reactive chlorine species (ClO_x). Young and DeMore (1982) posited ClO_x to be responsible for stabilization of the Venus atmosphere as CO_2 , with O_2 and CO

contributing only trace amounts to the bulk composition. Further, Montmessin et al. (2011) argue their first measurements of Venus O_3 are consistent with ClO_x catalytic destruction of ozone, a process subsequently modeled for the nightside atmosphere by Krasnopolsky (2013). While HCl diurnal variation has not been explicitly modeled, photochemical understanding is that it should be negligible in the Venus mesosphere, where its photochemical lifetime is believed to be longer than the timescale for zonal transport between the dayside and night. The Montmessin et al. (2011) ozone destruction argument, and Krasnopolsky’s (2013) nightside-only model each posit upper mesospheric HCl abundances are smaller on the night than day side based not upon photochemistry, but upon a qualitative dynamical argument that downward transport on the nightside may carry HCl-poor air into the mesosphere from the thermosphere. While the qualitative argument is reasonable, no explicit (quantitative) modeling of the interaction between HCl photochemistry and global transport has been done.

Ground-based measurements of Venus HCl, which are restricted by observational geometry to equatorial and mid-latitudes have largely been consistent with the Young et al. (1972) absolute abundance (420 ± 70 ppb at 60 km). Bezard and de Bergh (1990), and Bezard et al. (2007) determined below-cloud abundances of 500 ± 150 ppb at 15–30 km. Krasnopolsky (2010) retrieved an HCl abundance of 400 ± 30 ppb just above the clouds at 74 km. The Iwagami et al. (2008) observation of 740 ± 60 ppb within the clouds (60–66 km), is an exception to the otherwise broad consistency among observations. The measurements by Connes et al. (1967), Bezard and de Bergh (1990), Bezard et al. (2007), Iwagami et al. (2008) and Krasnopolsky (2010) were each determined with ground based IR observations. Sensitivity to different altitude ranges follows from use of different IR wavelengths.

The first measurements of Venus HCl above 75 km were retrieved from high latitude (74° – 84° North), 70- 100 km observations of the Solar Occultation at InfraRed (SOIR) spectrometer on the European Space Agency’s Venus Express (VEX) orbiter (Vandaele

et al., 2008). Solar occultation geometry is by definition limited to observations at dawn and dusk (local times 6am and 6pm), but has the advantage that (for sufficiently high s/n) each observation has local time, latitude and altitude resolution far superior to that of ground-based measurements. Vandaele et al. (2008) found 70-75 km abundances to be ~ 100 ppb, a factor of four smaller than indicated by ground-based measurements at 74 km and below.

More recently Mahieux et al. (2015) applied a modified, updated retrieval algorithm to a larger set of observations. They incorporated an averaging kernel analysis to identify (and subsequently disregard) parts of each retrieved profile that were overly dependent on the a priori profile, rather than the observation. While Vandaele et al. (2008) retrieved only 3 individual profiles, each over the full altitude range (70-105 km) observed in a single occultation, the Mahieux et al. (2015, their Fig. 3) approach supported retrieval of many partial altitude profiles over a full range of latitudes. They found HCl to be latitude-independent equatorward of 70° , and latitude decreasing (factor of two) from 70° to the pole. The Mahieux et al. (2015) updated analysis indicates HCl abundances increase exponentially with altitude, from 30–60 ppb below 80 km to 800–1100 ppb above 100 km. As described by Mahieux et al. (2015), the SOIR values are much smaller than those of the ground based IR measurements at 74 km and below. They disagree with photochemical model abundances at all altitudes (eg. Yung and DeMore, 1982) and with ground based submm measurements of both the nightside (Sandor and Clancy, 2012) and the dayside (this study) at 70–100 km.

The first measurements of Venus HCl extending above 75 km at lower latitudes ($15^\circ\text{S} - 18^\circ\text{N}$) were retrieved from ground-based submm observations (JCMT[†]) of the 626 GHz H^{35}Cl absorptions obtained on Oct. 23, Nov 7, and Dec 5, 2010 (Sandor and Clancy, 2012). The corresponding 70–95 km altitude-resolved abundance profiles agreed with those of ground-based measurements over the 70–80 km range to which each measurement system is sensitive, but determined mixing ratios at 80–95 km to

be significantly smaller than those predicted from photochemical modeling (discussed above). Sandor and Clancy (2012) suggested the disagreement might be a consequence of global atmospheric transport, which is not considered in the photochemical models. Global circulation in the Venus thermosphere (above 100 km) follows an axisymmetric, SubSolar to AntiSolar (SSAS) pattern (Schubert et al., 1980) wherein air rises on the dayside (most strongly near equatorial noon), and flows horizontally in all directions to the nightside, where it sinks (most strongly near equatorial midnight). While circulation in the mesosphere is predominantly zonal, East to West, the SSAS flow at higher altitudes transports mesospheric air upward into the thermosphere on the dayside, and thermospheric air downward into the upper mesosphere on the nightside. Three of the four 2010 observations were of the nightside near equatorial midnight, and the fourth (at 7am local time) can be interpreted as representative of nightside conditions. Sandor and Clancy (2012) suggested the observed HCl deficit (relative to model) might be due to SSAS transport of HCl-poor lower thermospheric air downward into the nightside upper mesosphere. Descent of HCl-poor air would be a necessary counterpart (at least qualitatively) to the Montmessin et al. (2011) interpretation that their nightside ozone altitude profile measurements were consistent with downward transport of ClO_x -rich lower thermospheric air into the upper mesosphere. The potential significance of this process is supported by Krasnopolsky's (2013) model of the nightside atmosphere, which uses descent of air rich in ClO_x , HO_x , and atomic oxygen to generate ozone profiles, as well as O_2 , OH and NO airglow in agreement with observations. On the dayside however, SSAS vertical transport is upward in this altitude range. If the observed HCl deficit on the nightside is indeed caused by vertical descent, then there should be no deficit on the dayside, where vertical motion is upward. Sandor and Clancy (2012) recommended a measurement of the dayside HCl profile as a test of their proposed mechanism. That dayside measurement is presented in this study. Dates, as well as Venus latitudes and local times of both the day- and night-side HCl observations are

listed in Table 1.

Observations and Data Analysis

A spectrally resolved observation of Venus dayside H^{35}Cl (625.9 GHz) was made on March 2, 2013 with the James Clerk Maxwell Telescope[†] (JCMT), located on Mauna Kea, Hawaii [Matthews, 2003]. Venus presented a sub-Earth latitude of 0.6°N and a sub-Earth local time of 11:30 AM. The relevant HCl spectroscopy, as well as the observational and retrieval methods, are described in detail by Sandor and Clancy (2012). Here those topics are presented in summary form. HCl measurements are sensitive to 70–100 km abundances, with altitude resolution based upon pressure broadening of the absorption. The diffraction-limited 8 arcsec (FWHM) beam was placed at the center of the 9.8 arcsec dayside disc, such that the retrieved abundances correspond to a weighted average over the dayside hemisphere, where weighting is determined by gaussian shape of the beam and by observation of the spherical planet as a two-dimensional projection (disc). Sensitivity is greatest near the disc center (equatorial noon) and lowest near the limb, such that the observation characterizes latitudes roughly $40^\circ\text{S} - 40^\circ\text{N}$, and local times 9am – 2pm.

Spectroscopic line parameters were obtained primarily from the JPL microwave spectroscopy database (Pickett *et al.* [1996]; Poynter *et al.* [1985]). The 625.9 GHz H^{35}Cl absorption is formed by three spectroscopic lines at 625.901, 625.918, and 625.932 GHz, respectively (Cazzoli and Puzzarini, 2004). The pressure broadening coefficient (V_{pres}) is estimated as 3.7 MHz/hPa, where the HITRAN value [Rothman *et al.*, 2009] for broadening by terrestrial air (N_2 and O_2) has been scaled by a factor of 1.4 for application to the Venus CO_2 atmosphere. This factor of 1.4 is based upon the measured air-to- CO_2 increases in collisional broadening coefficients for microwave transitions of CO and H_2O (Varanasi, 1971, 1975; Sagawa *et al.*, 2009). Presence of chlorine as two stable isotopes, ^{35}Cl (75.8%) and ^{37}Cl (24.2%) [Audi *et al.*, 2003], is accounted for in

the retrieval so that total HCl ($\text{H}^{35}\text{Cl} + \text{H}^{37}\text{Cl}$) abundance is reported from observation of the H^{35}Cl transitions. Observations were made with a frequency resolution 488 KHz, and 1000 MHz spectrometer bandwidth, of which the central 900 MHz is useful.

Observations were conducted in beam-switch mode, wherein the telescope pointing rapidly alternates between positions on the planet and 90" off the planet. Subtraction of the off- from on-position spectra removes emission sources (including telluric as well as cosmic microwave background emissions) observed in both positions. It does not remove the signal from Venus, which is found only in the on-position, but also does not remove telluric absorption from the bright Venus continuum. However, that telluric absorption is strongly suppressed by dividing the differenced on-off position spectrum ($\text{Tb}_{\text{on}} - \text{Tb}_{\text{off}}$) by the difference between the spectrally featureless observation of an ambient temperature calibration source within the telescope and the off-position spectrum ($\text{Tb}_{\text{amb}} - \text{Tb}_{\text{off}}$). Fundamentally, this division employs knowledge of the off-position telluric HCl emission to suppress the on-position HCl absorption (P. Friberg, pers. comm. 2012). This data processing algorithm (eqn. 1) is performed internally by JCMT software, and the result stored as the observed spectra. (The on- and off-position spectra are not retained separately.) The doppler-offset telluric absorption would be apparent, with depth 3–4%, if a simple differencing algorithm ($\text{Tb}_{\text{on}} - \text{Tb}_{\text{off}}$) were employed. Signal processing with eqn. 1 suppresses the terrestrial absorption to a level well below the channel-to-channel noise of the data spectra.

$$\frac{[\text{Tb}_{\text{on}} - \text{Tb}_{\text{off}}]}{[\text{Tb}_{\text{amb}} - \text{Tb}_{\text{off}}]} \times J \quad (1)$$

where J is a calibrated flux with units of brightness temperature.

The observed dayside spectrum (thick black line) is presented together with synthetic spectra in figs 1a (full bandwidth) and 1b (central ± 100 MHz). The radiative

transfer procedures employed to generate these synthetic sub-millimeter line absorption spectra are discussed in detail in previous publications (Clancy et al., 2003, 2012). Salient characteristics are thermal emission/absorption (non-scattering), integration over a discrete set of ray paths across the Venus disk (including atmospheric limb paths beyond the solid disk), specification of atmospheric temperature profiles over the key 70-120 km altitude range, and specification of a limb darkened lower boundary continuum brightness associated with 40-70 km CO₂ pressure induced sub-millimeter continuum emission. The corresponding HCl altitude profiles are shown fig 1c. The fig 1a,b synthetic spectral best-fit to the data (red solid lines) differs markedly from that generated from the SOIR measurements (aqua solid lines, Mahieux et al., 2015) at all frequency offsets, corresponding to disagreement between sub-millimeter and SOIR HCl at all altitudes (fig 1c). Note the submm HCl profile disagrees more strongly with the recent SOIR retrieval (aqua solid lines, Mahieux et al., 2015) than it did with the preliminary SOIR values retrieved by Vandaele et al. (2009), which are shown in fig 1c for reference (aqua diamonds). While Sandor and Clancy (2012) suggested a transport mechanism to possibly reconcile the nightside submm HCl with the earlier (Vandaele et al., 2009) SOIR values, neither the SOIR team (Mahieux, pers. comm. 2014, 2016) nor we can explain the conflict between dayside submm HCl and the updated (Mahieux et al., 2015) SOIR abundances. The temperature profile used as an input to the HCl retrieval was itself retrieved from same-day co-located JCMT observations of the 6–5 transitions of ¹²CO (691 GHz) and ¹³CO (660 GHz), such that latitude, local time weighting of the temperature measurement matched that of the HCl data. This JCMT-measured temperature profile was also used to calculate the SOIR synthetic spectra. Hence the SOIR spectrum corresponds to the terminator abundance profile retrieved from SOIR, as it would be seen by JCMT at time/place of the dayside observation. The retrieved submm profile agrees with Krasnopolsky’s (2010) IR measurement of 400 ppb at 74 km, and is consistent with the lower altitude values

of Connes et al. (1967) (420 ppb at 60 km). The best fit spectrum disagrees with that determined from the Yung and DeMore (1982) model HCl profile (dashed purple line) only at offsets smaller ~ 70 MHz corresponding to disagreement between sub-millimeter and model values in the upper mesosphere. Pressure broadening supports HCl retrieval as an altitude profile with vertical resolution corresponding to three layers at 70–75 km, 75–82 km, and 82–95 km. A detailed discussion of sub-millimeter HCl profile retrieval characteristics and error analysis is presented in Sandor and Clancy (2012). The retrieved HCl error envelope spans abundances smaller than those of the Yung and DeMore (1982) model for altitudes 84–100 km.

The observed and model HCl profiles agree below about 82 km, but over 82–95 km the measured HCl abundance decreases much more rapidly with altitude than does model HCl. This is the same basic result determined from previous nightside HCl observations (Sandor and Clancy, 2012), which showed secular variation over a 1-month timescale, but which on all dates indicated upper mesospheric abundances smaller than those of model prediction. Figure 2 (a, b) presents data spectra corresponding to the dayside observation obtained Mar. 2, 2013 (black) centered at equatorial noon, and to two 2010 nightside observations (blue and green, respectively), each centered on equatorial midnight. The synthetic best-fit (red) to the 2013 dayside data is also shown. The blue histogram corresponds to the weighted mean of very similar spectra obtained Oct 23 and Nov 7, 2010, where weighting of the Nov. 7 data was roughly twice that of the Oct. 23 observation, based upon s/n of the respective spectra. The green histogram corresponds to the Dec 5, 2010 observation. The dayside data are consistent with those of the nightside, within the secular variation seen between observations of equatorial midnight, made 1 month apart. The dayside observed spectrum (black) and corresponding best fit spectrum (red) fall between those of the night side observations on Nov 7 (blue) and Dec 5 (green) across the full 900 MHz bandwidth. At line center offsets less than $\sim \pm 30$ MHz, the dayside spectrum agrees very closely with that of the

Nov. 7 nightside observation. For line center offsets $\pm 40\text{--}200$ MHz, the dayside HCl spectrum is intermediate between the two nightside spectra, but is more similar to the Dec 5 than the Nov 7 spectrum. Fig 2c presents abundance profiles retrieved from each of observed spectra presented in fig 2a,b. Retrieved dayside (Mar 2013) HCl abundance profiles agree (within the uncertainties) with the Nov 2010 nightside retrieved profile at all altitudes. Vertical gradients in the dayside profile differ modestly from Nov 2010 HCl gradients above 82 km, falling between HCl profiles for the two 2010 nightside observations (Nov 7 and Dec 5).

Results and Discussion

An HCl abundance profile for the Venus dayside mesosphere was retrieved from sub-millimeter spectroscopic observations centered upon Venus at equatorial noon local time, obtained with the JCMT on March 2, 2013. The measured dayside profile was found to differ from that obtained from Oct 23 and Nov 7, 2010 observations of the nightside by an amount much smaller than the difference between the Oct-Nov and Dec 5, 2010 nightside profiles, where the nightside observations on all three 2010 dates were centered upon equatorial midnight (Sandor and Clancy, 2012). The immediate conclusion is that any HCl diurnal variation is smaller than the secular variation observed at equatorial midnight on a 1-month timescale. This contradicts the Sandor and Clancy (2012) hypothesis that the observation of upper mesospheric HCl abundances much smaller than those of photochemical modeling on the nightside might be explained by vertical descent associated with SSAS circulation in the lower mesosphere. That hypothesis was motivated by knowledge that upper mesospheric CO abundance is greater on the night than dayside specifically because the SSAS pattern drives downward motion on the nightside and upward motion on the dayside (e.g., Bougher et al, 2006; Clancy et al., 2012). It entails a prediction that HCl abundances on the dayside, where vertical motion is upward would agree with or exceed those

predicted from photochemistry alone. The dayside measurement presented here shows the prediction to be incorrect, and therefore the hypothesis to also be incorrect.

The difference between measured and model HCl abundances in the upper mesosphere remains unexplained, but the observed altitude profile, secular variation and absence of diurnal variation provide important constraints for ongoing theoretical modeling. The 82 km altitude above which observed HCl is smaller than that of the models is very close to the 85 km altitude above which observed SO₂ and SO (collectively, SO_x) abundances greatly exceed those of model prediction in observations with the JCMT of the day- and nightsides (Sandor et al., 2007, 2008, 2010), with SPICAV of the terminator (Belyaev et al., 2012), and with ALMA of the dayside (Encrenaz et al., 2015), suggesting the unknown mechanism(s) responsible for the observed HCl deficit (relative to model) may also be responsible for the SO_x surplus (relative to model) observed at very nearly the same altitudes. Further, diurnal observations of SO_x over multiple diurnal cycles have revealed secular variations of total SO_x (SO+SO₂) at least as large as that observed for HCl, and on the same 1-month timescale (Sandor et al., 2010), and no evidence of day-night variation. While simple coincidence cannot be ruled out as an explanation for similarities of the model, data disagreements for (respectively) HCl and SO_x, we believe a relationship between them is more likely than not, either as direct interaction of chlorine with sulfur compounds, or as similarity (perhaps commonality) of the respective explanatory mechanisms for their observed behaviors.

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Captions

Table 1. D is the angular diameter of Venus (arcsec). Phase indicates the fraction of the observed disc that is in sunlight. All observations were of latitudes centered within 10° of the equator. The October 23, November 7, and West-position December 5, 2010 observations were of local times near midnight. The East position observed December 5, 2010 was of the post-dawn dayside, but were interpreted by Sandor and Clancy (2012) as representative of the nightside, as the 7am atmosphere was recently transported from the nightside by the retrograde zonal winds. The first unambiguously dayside observation was obtained on March 2, 2013

Figure 1. Data are the dayside H^{35}Cl spectrum of Venus observed March 2, 2013 (black histogram), presented across the full 900 MHz bandwidth (fig 1a) and for the center 200 MHz (fig 1b). Also shown in figs 1a,b are synthetic spectra corresponding to the best fit to the data (red), the Yung and DeMore (1982) photochemical model altitude profile (dashed purple), and the SOIR profile (solid aqua, Mahieux et al., 2015) retrieved from observations of the terminator at latitudes 30°S – 30°N (light blue). Fig 1c presents the respective corresponding altitude profiles. Previously retrieved SOIR abundances (Vandaele et al., 2009; aqua diamonds) are also shown. (See text discussion.) “K10” represents Krasnopolsky’s (2010) IR measurement at 74 km. For spectral offsets larger than ± 200 MHz the data spectrum (black) and its best fit (red) clearly agree with the synthetic spectrum (dashed purple) corresponding to the HCl altitude profile of the Yung and DeMore (1982) photochemical model, but for offsets $\leq \pm 100$ MHz they just as clearly disagree. Over the central ± 100 MHz the data absorption is more shallow than that corresponding to the model. Additionally, within the central ± 30 MHz offset, over which absorptions corresponding to each of the three respective HCl spectroscopic transitions are resolved, amplitude of the resolved absorptions in the data (black, red) is twice that of the model (dashed purple). Agreement at large, but not small spectral

offsets corresponds to agreement of the measured and model HCl altitude profiles in the lower, but not upper mesosphere (fig 3c). This result for the Venus dayside is identical to that determined from previously nightside observations (Sandor and Clancy, 2012). The submm data (corresponding to the Venus day-, as well as night-side) and SOIR spectra from terminator observations disagree at all offsets, corresponding to disagreement between the respective HCl profiles at all altitudes.

Figure 2. HCl data spectra are shown from observations of the dayside on Mar 2, 2013 (black), and of the nightside on Nov 7, 2010 (blue) and Dec 5, 2010 (green) for bandwidths of 900 MHz (fig 1a) and 200 MHz (fig 1b). The “Nov 7” spectrum represents a weighted average of spectra obtained on Oct 23 and Nov 7, 2010, which were identical within their respective noise envelopes. Corresponding HCl altitude profiles are presented in fig 2c. The Nov 7 data had weighting twice that Dec 5, based upon spectral noise levels. The red synthetic spectrum corresponds to the best fit to the 2013 dayside observation (black). For plot clarity, synthetic fits to the respective (blue, green) nightside observations are not shown here, but were presented by Sandor and Clancy (2012). Fig 2c presents the respective corresponding best-fit altitude profiles. Differences between the nightside (blue, green) spectra correspond to secular variation of HCl abundance profiles observed 1 month apart, each at Venus equatorial midnight. The dayside spectrum (black), as well as its synthetic best-fit (red) lies between the two respective nightside profiles (blue, green) over the entire 900 MHz observed bandwidth, indicating any diurnal variation between day- and night-side HCl altitude profiles must be smaller than the secular variation of HCl on the nightside. Fig 3c shows the retrieved dayside HCl abundances are consistent (with the uncertainties) with those of the Nov 7 nightside. The difference between slopes (decrease with altitude) of the dayside and Nov 7 altitude profiles is marginally significant, but that of the 2013 dayside is intermediate between those of the Nov 7 and Dec 5, 2010 nightside.

Table 1: Observations of HCl in the Venus mesosphere.

Date	Phase	D	Latitude	Local Time
23oct2010	0.016	60''	2S-18N	22:40-23:50
7nov2010	0.036	59''	5S-15N	00:50-02:00
5dec2010 East	0.279	39''	15S-15N	05:50-07:50
5dec2010West	0.279	39''	15S-15N	00:30-02:30
2mar2013	0.994	9.8''	40S-40N	09:00-14:00

Fig 2a: HCl 625.9 GHz spectra, Day & Nightside Data & Synthetic