STARK BROADENING OF HIGH ORDER RADIO RECOMBINATION LINES TOWARDS THE ORION NEBULA: AGREEMENT BETWEEN MEASUREMENTS AND THEORY

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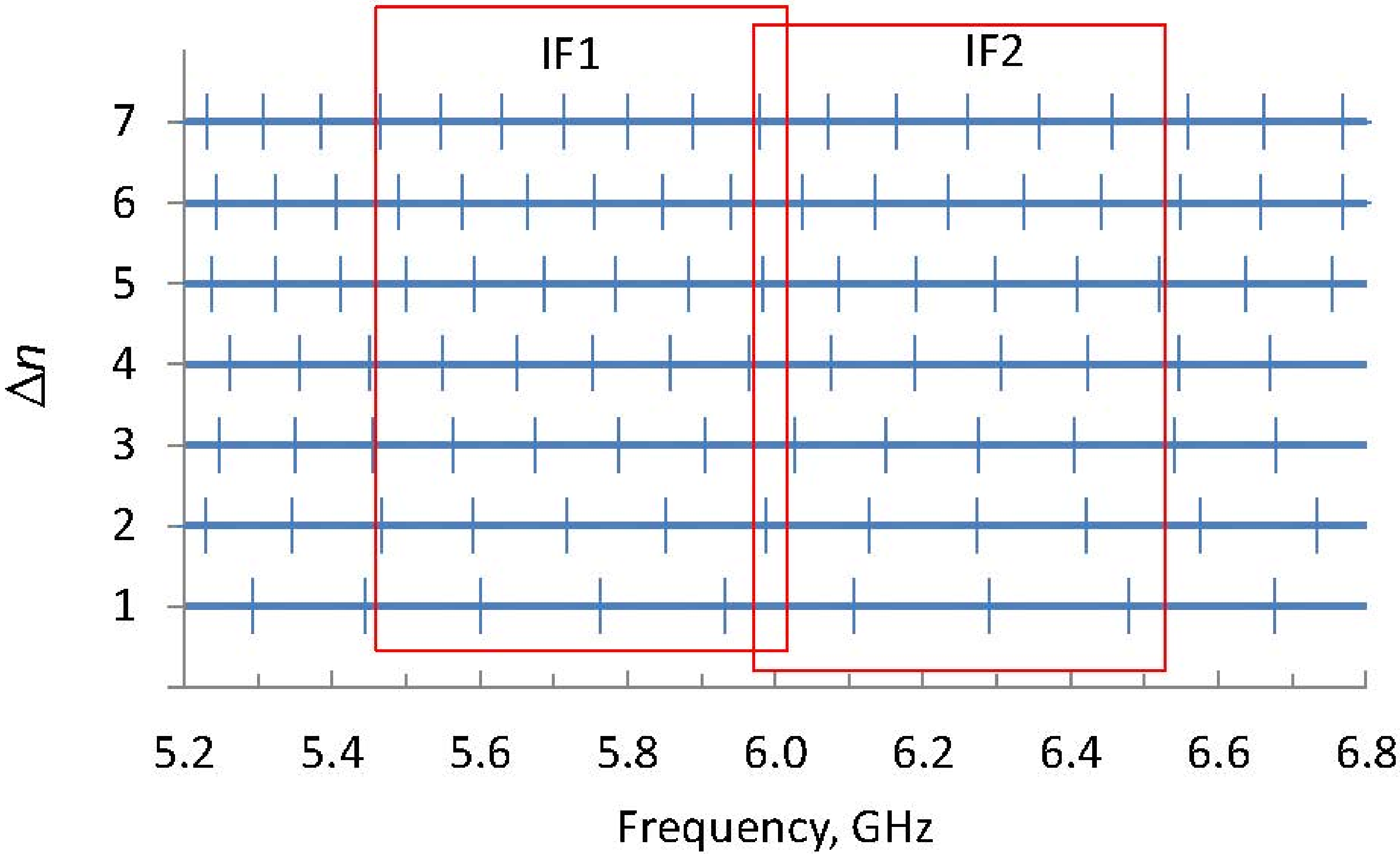
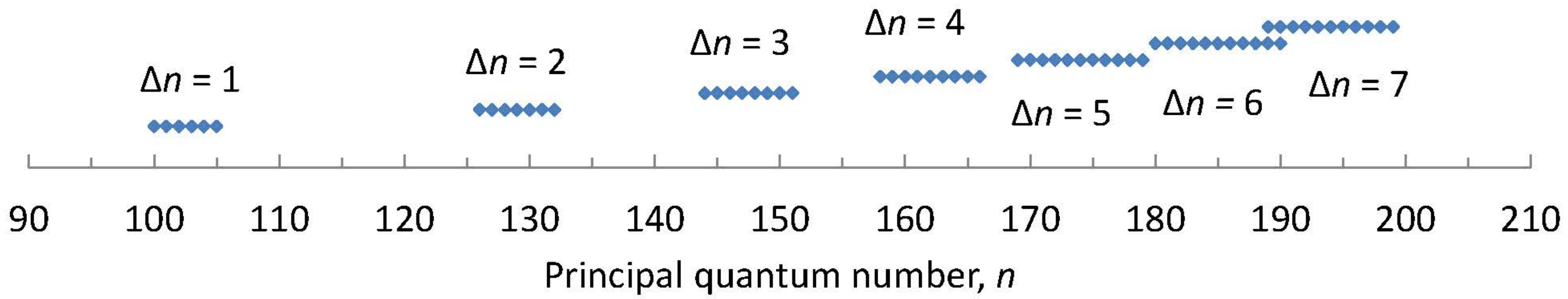
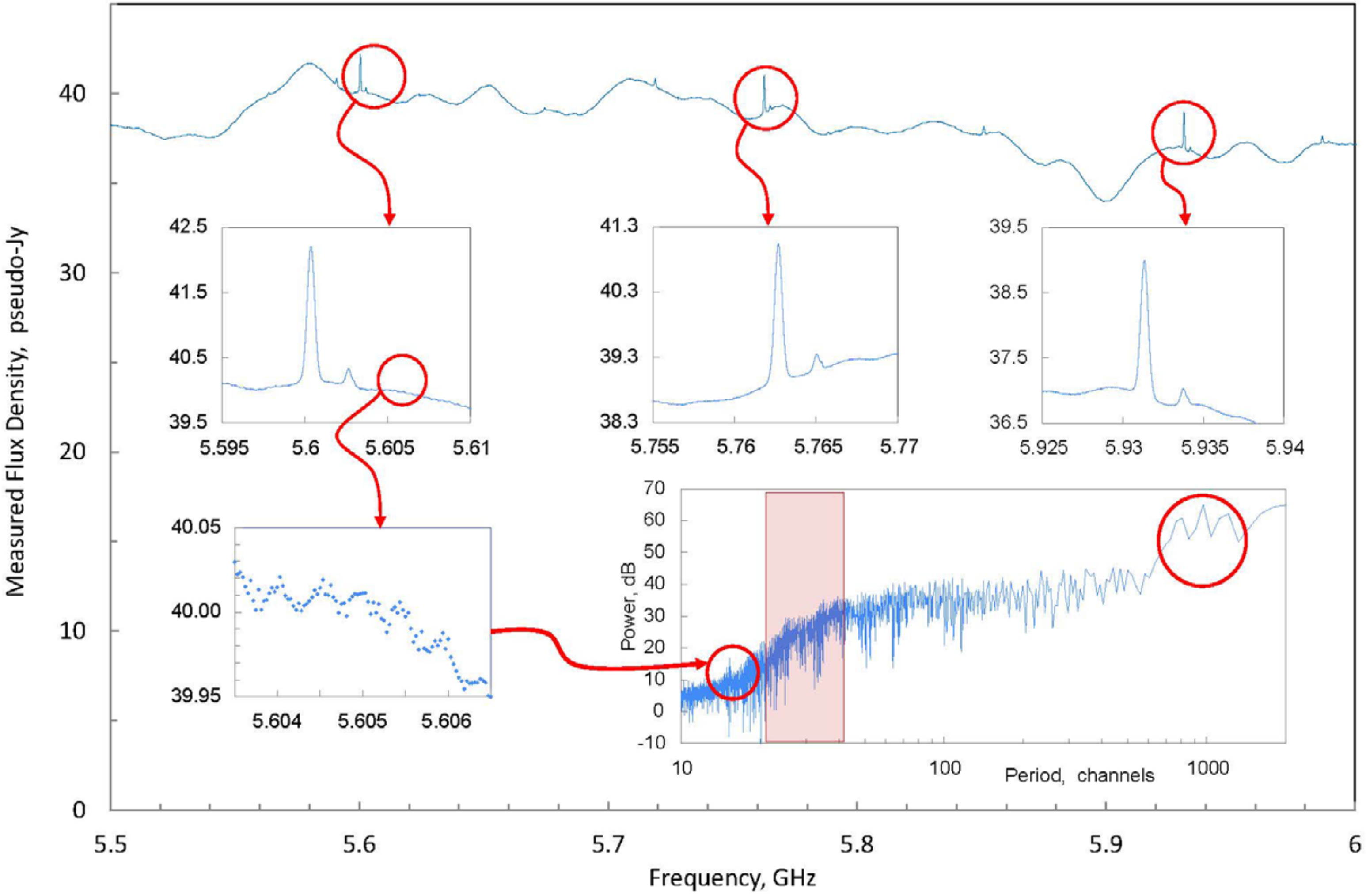
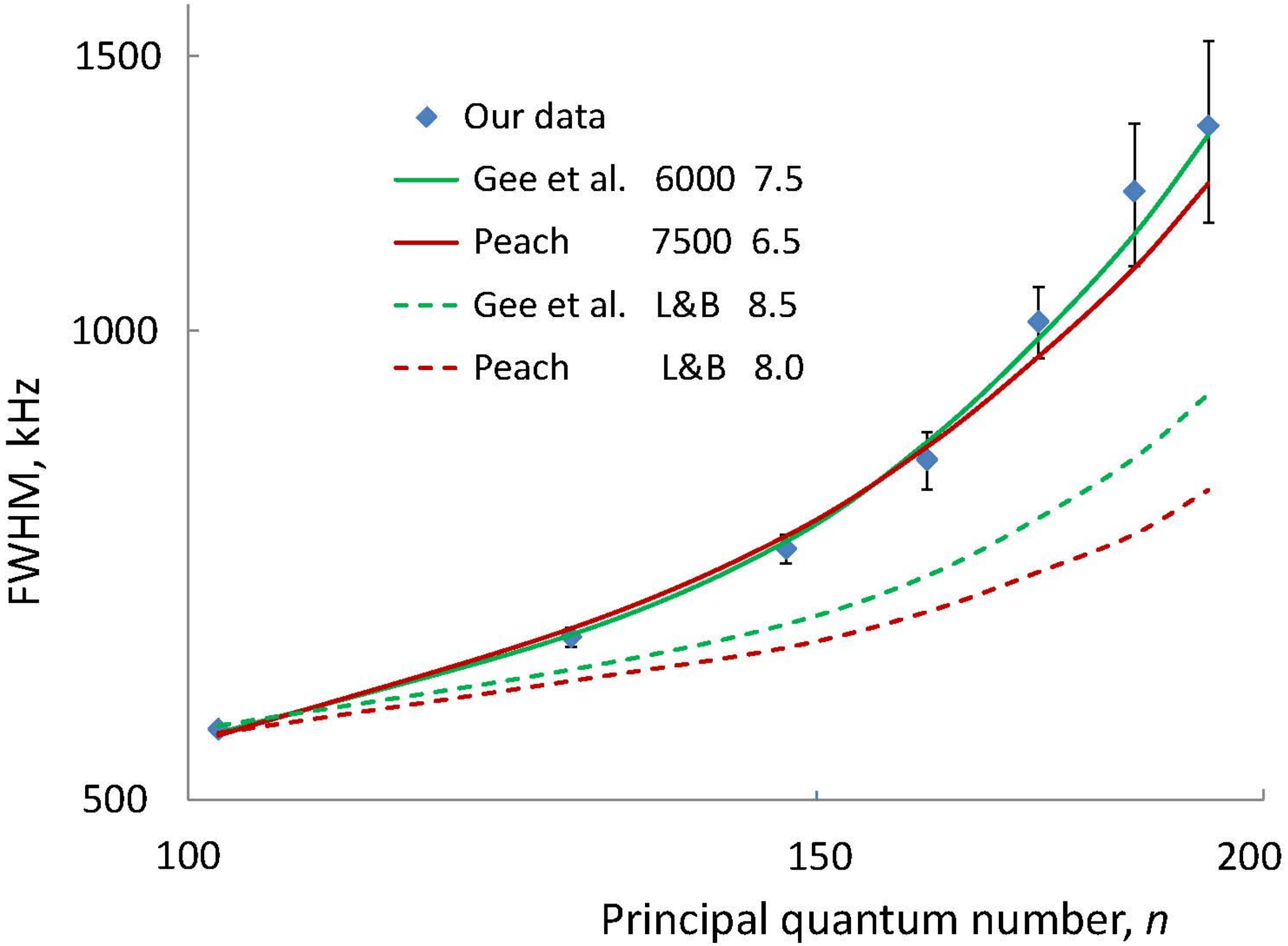

IF1
IF2
7
6
5
4
3
2
1
Δn
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
Frequency, GHz

Δn	1	2	3	4	5	6	7
Range of n	100-105	126-132	144-151	158-166	169-179	180-190	189-199
# of stacked lines	6	7	8	9	11	11	11
FWHM, kHz	555 ± 4	636 ± 9	724 ± 15	826 ± 35	1013 ± 54	1228 ± 128	1352 ± 180


Δn = 1
Δn = 2
Δn = 3
Δn = 4
Δn = 5
Δn = 6
Δn = 7
90
100
110
120
130
140
150
160
170
180
190
200
210
Principal quantum number, n



Measured Flux Density, pseudo-Jy
Frequency, GHz
40
30
20
10
0
5.5
5.6
5.7
5.8
5.9
6
42.5
41.5
40.5
39.5
5.595
5.6
5.605
5.61
41.3
40.3
39.3
38.3
5.755
5.76
5.765
5.77
39.5
38.5
37.5
36.5
5.925
5.93
5.935
5.94
40.05
40.00
39.95
5.604
5.605
5.606
Power, dB
Period, channels
70
60
50
40
30
20
10
0
-10
10
100
1000

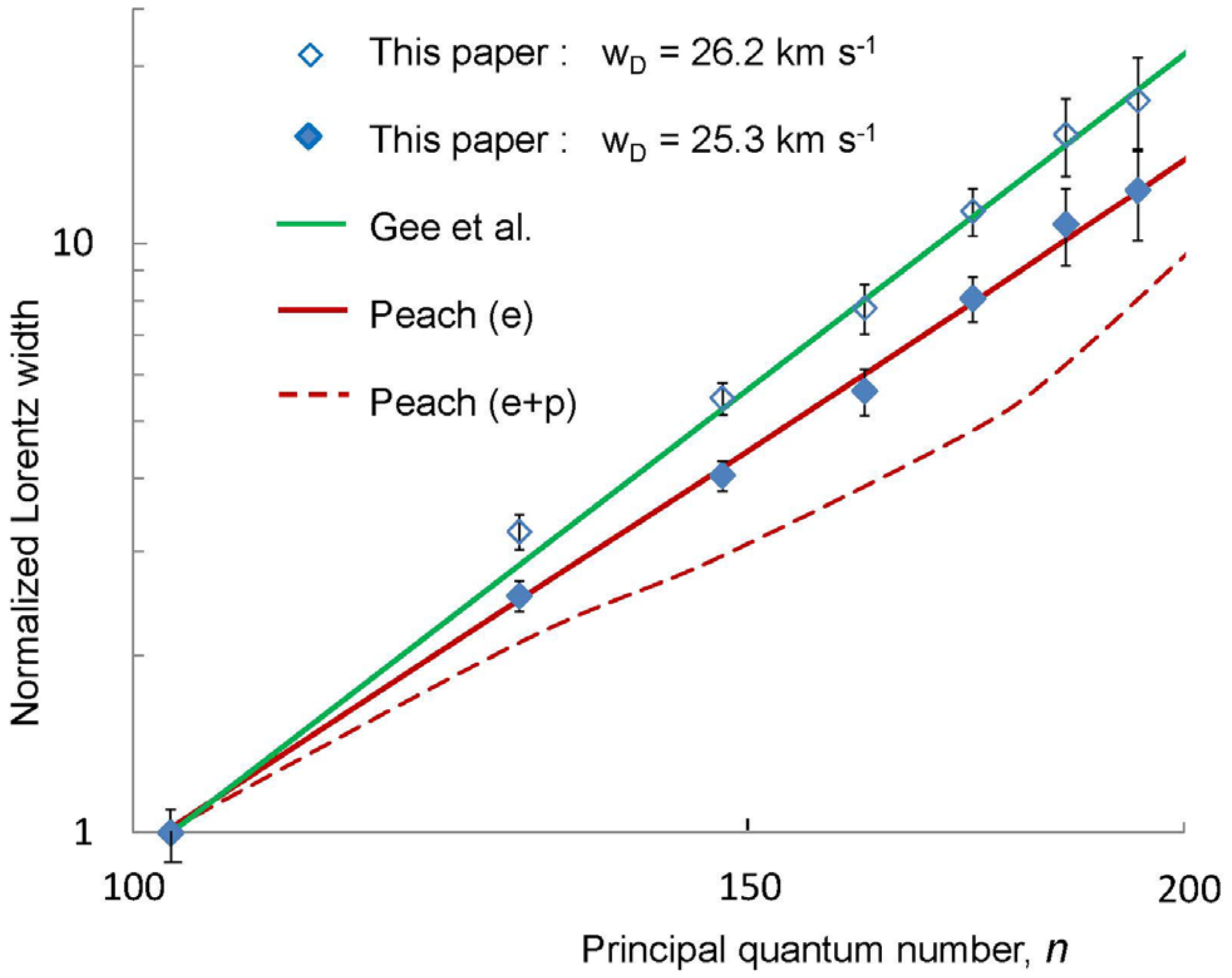


1500
1000
500
100
150
200
FWHM, kHz
Principal quantum number, *n*
Our data
Gee et al. 6000 7.5
Peach 7500 6.5
Gee et al. L&B 8.5
Peach L&B 8.0

To extract Lorentz widths w_L (FWHM) from the observed high order RRL profiles, we use the approximate formula of Kielkopf [1973] presented by Smirnov [1985] as

$$w_L = 7.786\, w_V \left[1 - \sqrt{1 - 0.240\ \left(1 - (w_D/w_V)^2\right)}\right], \tag{2}$$

where w_V is the Voigt width (FWHM) of the spectral line determined by the line fitting procedure and w_D is the Doppler width (FWHM). Given the Lockman and Brown [1975]



This paper : w_D = 26.2 km s^{-1}
This paper : w_D = 25.3 km s^{-1}
Gee et al.
Peach (e)
Peach (e+p)
Normalized Lorentz width
10
1
100
150
200
Principal quantum number, *n*

In the electron impact broadening theory (Griem [1967]),

$$w_L \propto n^4 \ln\left(\frac{\rho_{\max}}{\rho_{\min}}\right) \propto n^\beta, \tag{3}$$

where $\rho_{\max}$ and $\rho_{\min}$ are maximum and minimum impact (cut-off) parameters (radii). The minimum cut-off radius is typically chosen as

$$\rho_{\min} = \sqrt{\frac{5}{6}}\frac{n^2\hbar}{mv_e} \tag{4}$$

There are different approaches with respect to the choice of the maximum cut-off radius $\rho_{\max}$ leading to different dependences of the electron impact width on n. If

$$\rho_{\max} = \frac{v_e}{\omega_{n,\,n\pm1}} \propto n^3 \tag{5}$$

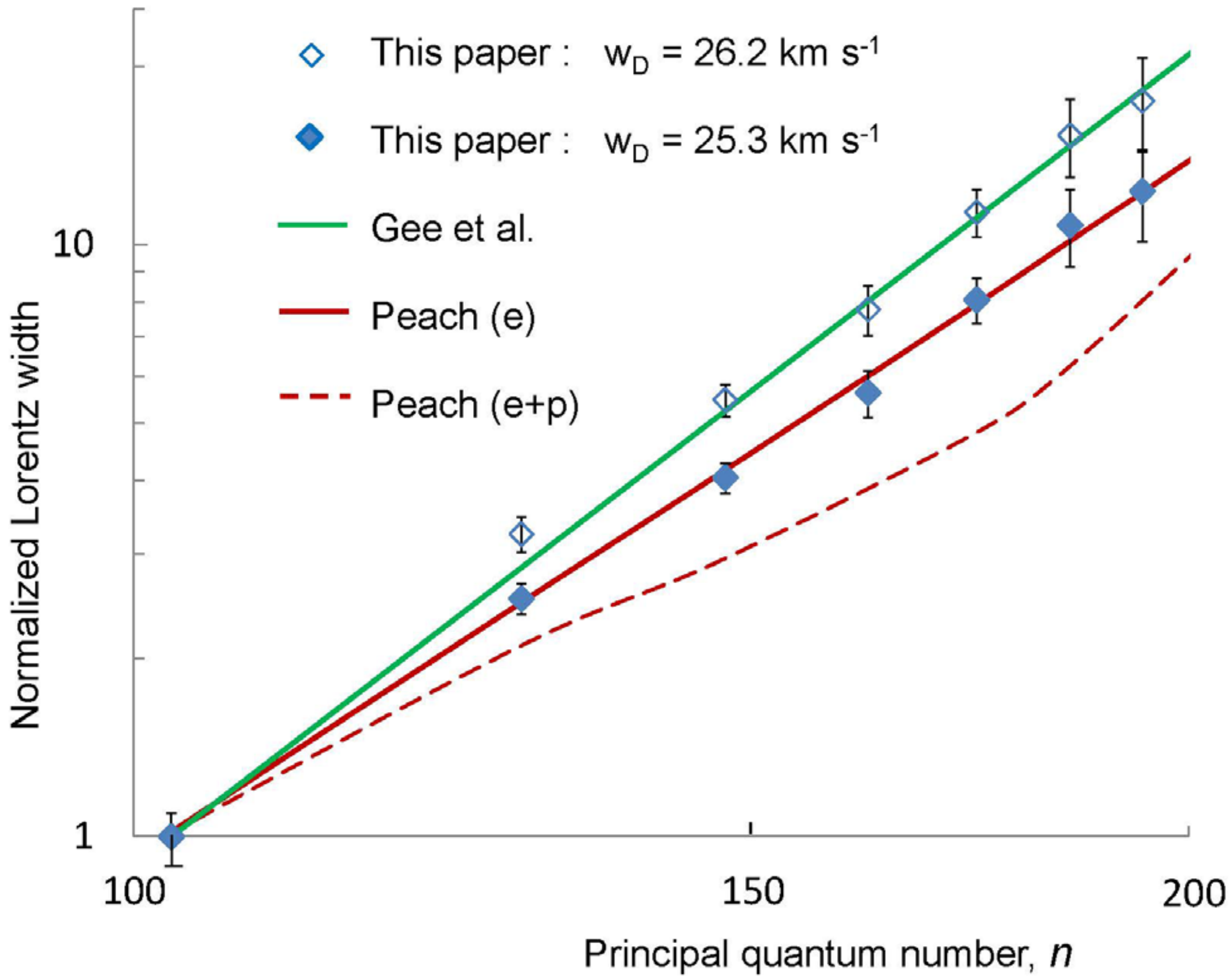
(Griem [1967]), where $\omega_{n,\,n\pm1} = 2\pi\nu_{n,\,n\pm1}$ is the angular frequency of transition $n \rightarrow n \pm 1$, substitution of (4) and (5) into (3) results in $\rho_{\max}/\rho_{\min} \propto n$ and $\beta > 4$. For a typical HII region electron temperature of $T_e = 10^4$ K Equation (3) predicts

$$w_L \propto n^{4.4} \tag{6}$$

If the Debye radius is used instead as the maximum cut-off parameter, then

$$\rho_{\max} = R_D = \sqrt{\frac{kT_e}{8\pi N_e e^2}}$$

This gives $\rho_{\max}/\rho_{\min} \propto n^{-2}$ and $\beta < 4$. For a typical HII region electron density of $N_e = 10^4$ cm^{-3}, Equation (3) predicts $w_L \propto n^{3.97}$ (Peach [2014]). Watson [2006] provides a theoretical expression for electron impact widths valid for $n \leq 70$. His proposed formula for $n > 70$ (Equations (16) and (17) in Watson [2006]) results in $w_L \propto n^{3.97}$, consistent with theoretical results of Peach [2014].[1]



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Peach (e)
Peach (e+p)
Normalized Lorentz width
10
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Principal quantum number, n

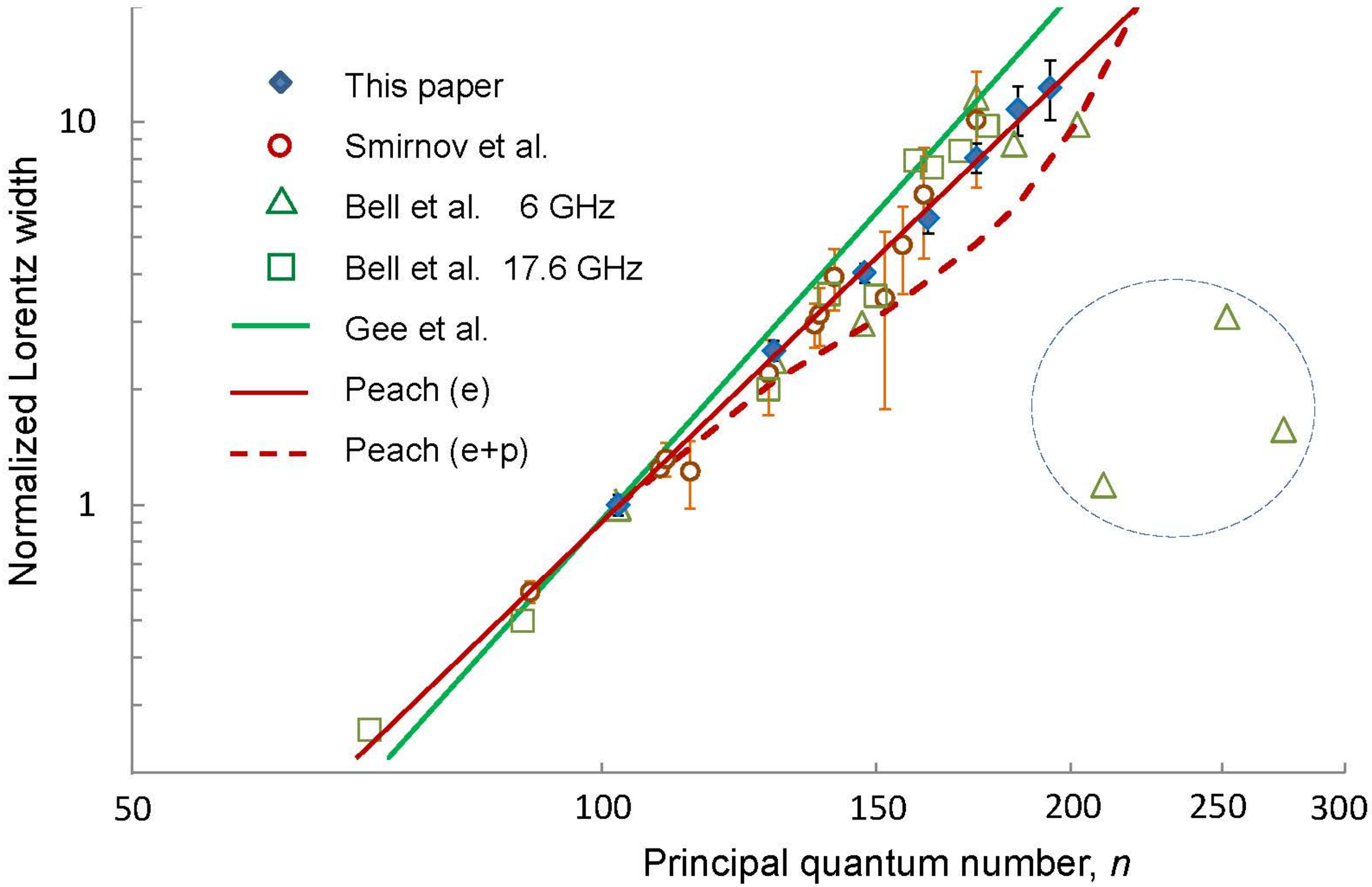
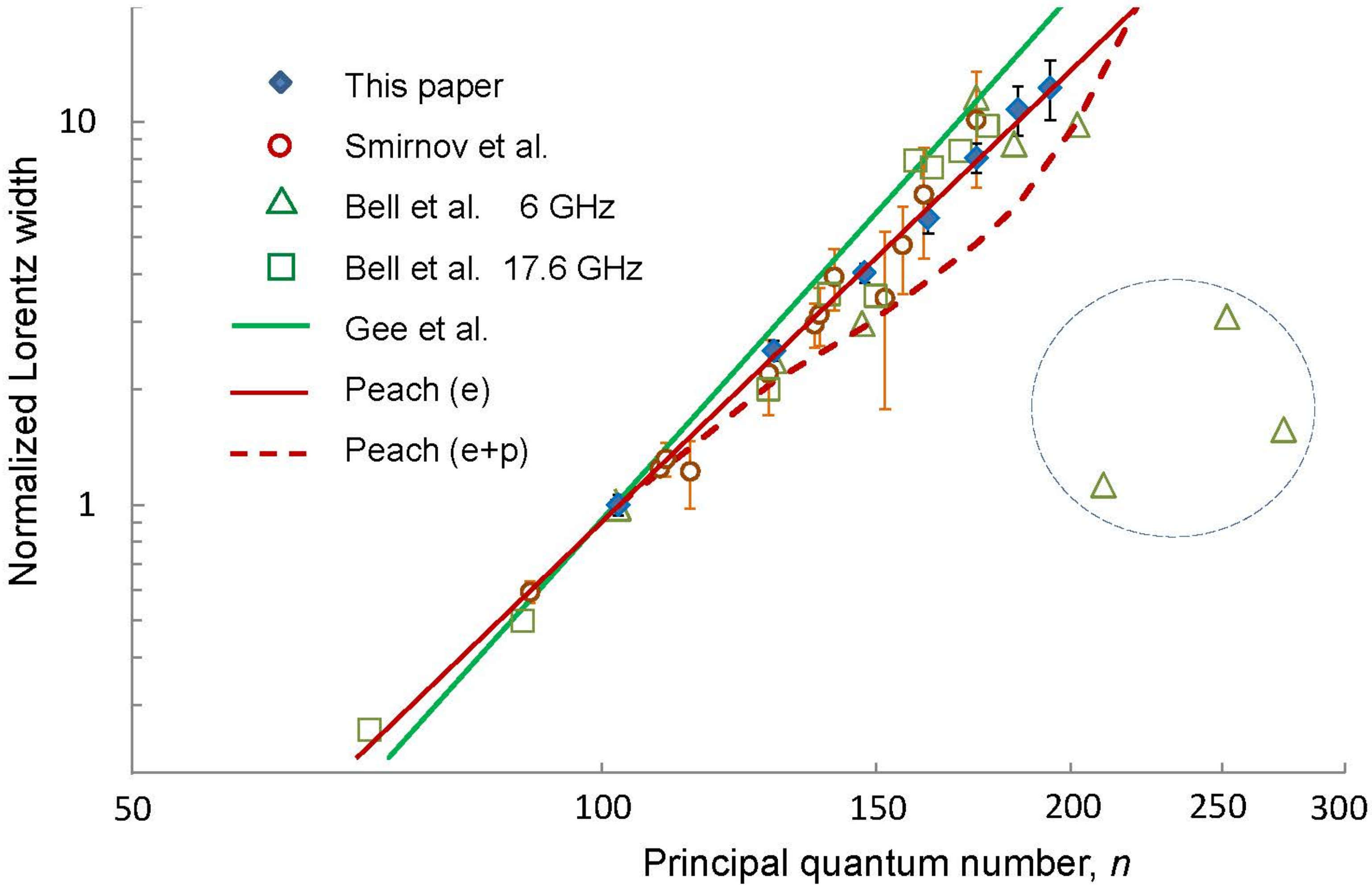

This paper
Smirnov et al.
Bell et al. 6 GHz
Bell et al. 17.6 GHz
Gee et al.
Peach (e)
Peach (e+p)
Normalized Lorentz width
10
1
50
100
150
200
250
300
Principal quantum number, n

Table 2: Doppler widths and the exponent β computed for five sets of high order RRL observations.

Frequency, GHz	Range of Δn	Range of n_{low}	Doppler width, km s^{-1}	β	Reference
5	1–4	109–174	26.0 ± 0.25	3.86 ± 0.16	Smirnov et al. [1984]
5.5–6.5	1–7	100–199	25.35	3.97 ± 0.08	This paper
6	1–6	102–194	25.8	3.97 ± 0.54	Bell et al. [2011]
9	1–6	90–161	25.2 ± 0.5	4.15 ± 0.22	Smirnov et al. [1984]
17.6	1–17	71–177	24.0	3.97 ± 0.18	Bell et al. [2011]



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Thank you!