Stratospheric Spectral Atlases in the Infrared

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Abstract. The spectra for the stratospheric atlases were obtained with the University of Denver Michelson type interferometer balloon-borne spectrometer systems for solar absorption spectra. Prior to 1987, 0.02 cm\(^{-1}\) resolution spectra were available and since then 0.002 cm\(^{-1}\) resolution spectra are used. The atlases provide representative sets of spectra and tables of line positions and identifications. High sun spectra are used for solar lines identifications. Latest editions of these atlases cover selected intervals in the 760–1950 cm\(^{-1}\) and 800–1700 cm\(^{-1}\) regions at 0.02 cm\(^{-1}\) and 0.002 cm\(^{-1}\) resolutions respectively. While the stratospheric atlases will be the main topic, the University of Denver ground-based and laboratory spectra atlases will also be mentioned. A number of spectroscopic studies that developed on the basis of the atlases work will be reviewed, including solar and atmospheric lines. Some ongoing studies and unresolved problems will also be presented.

1. University of Denver Spectral Atlases

A short summary of the atlases work is given in Table 1. The laboratory studies were conducted in support of the atmospheric spectra analysis. Initially, the available solar spectra were collected from Denver (elevation 1.6 km) and the nearby Mt. Evans (elevation 4.3 km) using a 0.06 cm\(^{-1}\) resolution interferometer system. From these data, the 775–1300 cm\(^{-1}\) and 1925–2175 cm\(^{-1}\) regions of the atlas have been completed and published in two volumes (Goldman et al. 1979).

In 1978, the atmospheric spectroscopy group at the University of Denver (DU) started obtaining infrared spectra with a 0.02 cm\(^{-1}\) resolution interferometer system. A large number of spectra have been obtained, including laboratory spectra, ground-based solar spectra, aircraft and balloon-borne solar spectra. The spectra were obtained in selected intervals in the 550–2300 cm\(^{-1}\) region. Many of the laboratory spectra at 0.06 cm\(^{-1}\) and 0.02 cm\(^{-1}\) resolution were published as a CRC handbook (Murray & Goldman 1981).

Numerous 0.02 cm\(^{-1}\) resolution spectra were also obtained from the South Pole, which is a unique site for infrared observations, in December 1978 and in December 1980. Thus, in addition to the continuing stratospheric atlas, work was also started on an Atlas of South Pole IR Solar Spectra (Blatherwick et al. 1982). The first edition of the South Pole Atlas, including the 760–960 cm\(^{-1}\)
Table 1. University of Denver Spectral Atlases.

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Special spectroscopic interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 1980</td>
<td>Grnd-base Denver &amp; Mt. Evans</td>
<td>Stratosph HNO$_3$</td>
</tr>
<tr>
<td></td>
<td>0.06 cm$^{-1}$ resol</td>
<td>Troposph NH$_3$</td>
</tr>
<tr>
<td></td>
<td>0.006 cm$^{-1}$ accur</td>
<td>Solar emiss (covered)</td>
</tr>
<tr>
<td></td>
<td>775–1300, 1925–2175 cm$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Dec. 1983</td>
<td>S. Pole</td>
<td>Stratosph HNO$_3$</td>
</tr>
<tr>
<td></td>
<td>0.02 cm$^{-1}$ resol</td>
<td>Solar OH</td>
</tr>
<tr>
<td></td>
<td>0.002 cm$^{-1}$ accur</td>
<td>Solar emiss</td>
</tr>
<tr>
<td></td>
<td>760–960, 1220–1340 cm$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Sept. 1987</td>
<td>Balloon-Borne</td>
<td>Stratosph CF$_4$, O$_2$, HNO$_3$, ClONO$_2$, Solar emiss</td>
</tr>
<tr>
<td></td>
<td>0.02 cm$^{-1}$ resol</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.002 cm$^{-1}$ accur</td>
<td></td>
</tr>
<tr>
<td></td>
<td>760–1950 cm$^{-1}$ (except 960–1060)</td>
<td></td>
</tr>
<tr>
<td>Oct. 1994</td>
<td>Balloon-Borne</td>
<td>Stratosph COF$_2$, O$_2$, O$_3$ + isot., HNO$_3$, ClONO$_2$</td>
</tr>
<tr>
<td></td>
<td>0.002 cm$^{-1}$ resol</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0002 cm$^{-1}$ accur</td>
<td></td>
</tr>
<tr>
<td>April 1984</td>
<td>Single cell low press, room temp</td>
<td>Over 30 molecules</td>
</tr>
<tr>
<td>Laboratory</td>
<td>0.02 cm$^{-1}$ resol</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.002 cm$^{-1}$ accur</td>
<td></td>
</tr>
<tr>
<td></td>
<td>760–2000 cm$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>Single cell low press, room temp</td>
<td>Over 15 molecules</td>
</tr>
<tr>
<td>Laboratory</td>
<td>0.002 cm$^{-1}$ resol</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0002 cm$^{-1}$ accur</td>
<td></td>
</tr>
<tr>
<td></td>
<td>760–3100 cm$^{-1}$</td>
<td></td>
</tr>
</tbody>
</table>

region, was published in March 1982. In the next large format edition the region 1220–1340 cm$^{-1}$ was added.

The first large format edition of the stratospheric atlas, which included the 760–960 cm$^{-1}$, 1060–1220 cm$^{-1}$, 1550–1660 cm$^{-1}$ and 1830–1950 cm$^{-1}$ regions, was published in January 1982 and also announced in the literature (Goldman et al. 1982). In the stratospheric atlas update of January 1983, the 1220–1340 cm$^{-1}$ region, based on the 10/10/79 and 3/23/81 flights data has been added to the atlas. Further laboratory spectra were obtained at DU and published (Murcray et al. 1984).

For the September 1987 edition the atlas contained 109 frames and covers the entire spectral region from 760 to 1950 cm$^{-1}$, except for the interval 960–
1060 cm\(^{-1}\). The total number of spectral features identified as being genuine exceeded 14,000. In parallel to the atmospheric spectra work, the laboratory spectra were used not only to support the identification and quantification of measured atmospheric features but also for molecular spectroscopy analysis. Numerous scientific publications resulting from the atlas work are listed in that report.

Since 1986 our atmospheric spectroscopy group at DU has been using a new BOMEM interferometer system with a total path difference of 250 cm and an unapodized FWHM resolution of 0.002 cm\(^{-1}\). The system has been modified for balloon-borne measurements of infrared solar spectra and has also been used to obtain several ground-based solar spectra and laboratory spectra. The 0.002 cm\(^{-1}\) resolution exceeds both the previous DU and the ATMOS resolutions, and thus the next sets of DU balloon-borne spectra revealed many new atmospheric features (which are blended on the previous spectra), and have thus become an invaluable source for extending the atlases work and probing the atmospheric trace gases.

Results obtained from the high resolution atlas studies are presented in the preliminary November 1989 and April 1990 editions of the “Atlas of Very High Resolution Stratospheric IR Absorption Spectra,” and subsequent editions, the latest being October 1994 (Goldman et al. 1990–1994). The spectra are now displayed in frames of 2 cm\(^{-1}\) intervals, needed to show the fine details of the spectra. The tabulated line positions were determined using the same line marking computer program employed in our previous atlases. For well resolved lines, line positions have an estimated accuracy of ±0.0002 cm\(^{-1}\) with reference to standard calibration lines of CO\(_2\) and N\(_2\)O.

In the December 1990 edition, the Atlas contained thirty eight frames, covering the intervals 800–810 cm\(^{-1}\), 934–960 cm\(^{-1}\), 992–1002 cm\(^{-1}\), 1220–1230 cm\(^{-1}\) and 1240–1260 cm\(^{-1}\). More than 2400 spectral features in these data have been identified as being genuine telluric or solar absorption features.

Since 1990, our atmospheric spectroscopy group at DU has acquired improved BOMEM and BRUKER 0.002 cm\(^{-1}\) interferometers. These have been employed for the NASA NDSC (Network for the Detection of Stratospheric Change) and other field measurements programs. Data from these systems have been available for complementary studies to the atlas work.

In the April 1993 edition, we have added ten new frames covering the region 1540–1560 cm\(^{-1}\). Data for this new addition were recorded during a balloon flight from Palestine, Texas on June 17, 1991, and from a flight conducted from Ft. Sumner, New Mexico on April 19, 1989. In the October 1994 edition, we have added 25 new frames covering the region 1560–1610 cm\(^{-1}\), thus bringing the total number of spectral features identified as being genuine to over 3500, with less than 50 unidentified lines of absorption greater then 5%. Numerous publications describing findings from the 0.002 cm\(^{-1}\) atlas work are listed in the atlas reports.

Our ongoing laboratory spectra measurements have produced a large number of 0.002 cm\(^{-1}\) spectra in selected spectral regions from 750 to 3000 cm\(^{-1}\). These include CCl\(_4\), CCl\(_2\)F\(_2\), C\(_2\)H\(_6\), CF\(_4\), CHCl\(_3\), CH\(_3\)O, CH\(_3\)Cl, H\(_2\)O\(_2\), HCOOH, HNO\(_3\), NO\(_2\), CF\(_2\)NO\(_2\), COF\(_2\), and COCl\(_2\), which are being prepared for an extended laboratory atlas (Murray et al. 1995). These spectra are used
Figure 1. The 1602–1604 cm\(^{-1}\) frame of the University of Denver 0.002 cm\(^{-1}\) resolution stratospheric atlas, showing the O\(_2\) electric quadrupole triplet near 1603.8 cm\(^{-1}\).

for the identification and quantification of atmospheric spectral features by either complete spectroscopic quantum mechanical analysis or semi-empirical methods. Several spectral regions, which include previously unidentified features of ClONO\(_2\), HNO\(_3\), COF\(_2\), and more, are currently under analysis and will be added to the atlas in the near future.

In what follows, we will present in some detail several of the research topics of current interest that originated on the basis of the atlases work: O\(_2\) Forbidden Lines in (0-1) \(X^3\Sigma^-\), HNO\(_3\) Hot Bands and Intensities, OH Pure Rotation Lines, and Solar Emission IR Lines.
2. \( \text{O}_2 \) Forbidden Lines in \((0-1) \ X^3\Sigma^-_g\)

The first identification and the initial line parameters calculations of the \(eq\) (electric quadrupole) \((0-1)\) vibration-rotation \(\text{O}_2\) lines in \(X^3\Sigma^-_g\) were made on the basis of a peculiar unidentified triplet near 1603.8 cm\(^{-1}\) in DU balloon-borne 0.02 cm\(^{-1}\) resolution spectra (Goldman et al. 1981, Rothman & Goldman 1981). These \(\text{O}_2\) transitions were soon confirmed in laboratory spectra (Reid et al. 1981). Independently, \(eq\) lines in the red system \(X^3\Sigma^+_g(0)\rightarrow b^1\Sigma^+_g(0)\) were observed in the Kitt Peak solar spectrum (Brault 1980). The original \(\text{O}_2\) triplet also appears in the DU 0.02 cm\(^{-1}\) atlas of September 1987. Figure 1 shows the 1602–1604 cm\(^{-1}\) frame in the DU 0.002 cm\(^{-1}\) atlas of October 1994.

The intensive search for the \((0-1)\) \(md\) (magnetic dipole) lines resulted in the first positive identification and line parameters calculations on the basis of both ATMOS and DU solar absorption spectra (Dang-Nhu et al. 1990). For both \(eq\) and \(md\) transitions the intensity calculations were done from Hund’s case \((b)\), and a single magnetic dipole moment was used with the energy eigenvectors for the \(md\) lines. Subsequent line intensity calculations of the \(eq\) lines in intermediate coupling starting from Hund’s case \((a)\) and including vibration-rotation effects on the line intensities showed only minor improvements for a few lines compared to the initial \(eq\) intensity calculations in case \((b)\) (Balasubramanian et al. 1990, 1992).

Improved energy levels constants (Rouille et al. 1992) prompted a new calculation of the line parameters. (Rinsland & Goldman 1992). These results provided improved agreement with DU high resolution (0.002 cm\(^{-1}\)) stratospheric spectra up to all of the high \(J\) values observed. However, an ongoing line intensity problem, mostly due to the \((0-1)\) \(md\) lines persisted. The comparisons of synthetic spectra to the observed spectra show excessive calculated intensity in the QP, QR lines and missing intensity in the QQ lines.

The University of Denver 0.002 cm\(^{-1}\) resolution October 1994 atlas shows a number of frames with \(\text{O}_2\) \(eq\) and \(md\) lines among the other species. The complete identification list is in the Tables volume of the atlas. Figure 2 shows the 1552–1553 cm\(^{-1}\) section from the atlas, along with a theoretical simulation of the atmospheric components, including the \(eq\) and \(md\) \(\text{O}_2\) lines. It demonstrates how the QR and QP \(md\) lines are overcalculated. Additional quantitative spectral fits of the simulations to the observed spectra show how the \(\text{O}_2\) \(md\) QQ lines are undercalculated.

More recently, intermediate coupling intensity calculations starting from Hund’s case \((a)\) were performed for the \(md\) lines with both parallel and perpendicular dipole moments (Balasubramanian et al. 1994, Goldman & Canova 1994). These calculations show significant intensity variation as a function of the ratio of the parallel and perpendicular components, and that an optimal ratio of \(\sim 0.1\) improves the agreement with the observed spectra. This study is in progress.

It is also anticipated that the corresponding electric dipole \(^{16}\text{O}^{18}\text{O}\) lines will be observable in the atmospheric spectra. Line parameters have been generated on the basis of published \(^{16}\text{O}_2\) constants and theoretical isotopic ratio, and a search for these lines is being conducted.
Figure 2. The 1552–1553 cm\(^{-1}\) section from the University of Denver 0.002 cm\(^{-1}\) resolution stratospheric atlas and a simulation of absorption by the individual atmospheric molecular species.
Figure 3. A portion of the HNO$_3$ spectrum from University of Denver 0.002 cm$^{-1}$ resolution laboratory atlas in the 880–888 cm$^{-1}$ region. The $\nu_5+\nu_9-\nu_9$ hot band is indicated with an arrow.

3. HNO$_3$ Hot Bands and Intensities

The stratospheric and laboratory atlases work has contributed significantly to the study of the HNO$_3$ bands. The earlier studies are too numerous to be discussed here. Of particular current interest are the recent and the ongoing studies of the hot bands and of the lines and bands intensities.

In the 25 $\mu$m HNO$_3$ region (dominated by $\nu_9$), the HITRAN 1992 compilation provides line parameters only for the $\nu_9$ band (Goldman & Rinsland 1992). The $\nu_9$ line positions are based on the analysis of high resolution laboratory spectra (Goldman et al. 1988) and the total band intensity is derived from previous low resolution broad band measurements (Goldman et al. 1975). Recent
Table 2. HNO₃ Band Intensities and Hot Bands.

<table>
<thead>
<tr>
<th>HNO₃ bands</th>
<th>GIVER(1984)</th>
<th>GIVER Lab Sum</th>
<th>STP (cm⁻¹ atm⁻¹)</th>
<th>DU(1971)</th>
<th>Lab Sum (cm/mole)</th>
<th>HITRAN 92 w hb</th>
<th>Lab Sum (cm/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ν₅, 2ν₉</td>
<td>692 ± 5%</td>
<td>2.576 E-17</td>
<td></td>
<td>2.597 E-17</td>
<td>2.5700 E-17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ν₃, ν₄</td>
<td>1383 ± 5%</td>
<td>5.148 E-17</td>
<td></td>
<td>5.058 E-17</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ν₂</td>
<td>1530 ± 6.5%</td>
<td>5.695 E-17</td>
<td></td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HNO₃ bands</th>
<th>HITRAN wo hb (cm/mole)</th>
<th>Ratio</th>
<th>LPMA 93 a</th>
<th>LPMA obs+calc hb (cm/mole)</th>
<th>DU93 b Lab Sum (cm/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ν₅, 2ν₉</td>
<td>2.2453 E-17</td>
<td>1.147c</td>
<td>1.382 E-17</td>
<td>2.025 E-17</td>
<td>2.081E-17</td>
</tr>
<tr>
<td>ν₃, ν₄</td>
<td>3.6780 E-17</td>
<td>1.400c</td>
<td>2.848 E-17</td>
<td>3.751 E-17</td>
<td>4.311E-17</td>
</tr>
<tr>
<td>ν₂</td>
<td>4.3810 E-17</td>
<td>1.300</td>
<td></td>
<td></td>
<td>4.402E-17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference</th>
<th>Ratio ν₅/2ν₉</th>
</tr>
</thead>
<tbody>
<tr>
<td>HITRAN (Goldman &amp; Rinsland 1992)</td>
<td>1.281</td>
</tr>
<tr>
<td>Maki &amp; Wells (1992)</td>
<td>1.271</td>
</tr>
<tr>
<td>Perrin et al. (1993a)</td>
<td>1.379</td>
</tr>
</tbody>
</table>

Standing Recommendation: Normalize to Giver, with proper hb correction.

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* LPMA 1993 Lab (published)  
  12 cm cell  
  T = 0 °C, P = 0.5–2.0 Torr hours scans  

b DU 1993 Lab (prelim)  
  1) 100 cm cell  
  T = −30 °C to + 23 °C  
  P = 20–40 micron  
  Not corrected for NO₂, H₂O  
  2) 20 cm cell - not done yet

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Inconsistency exists  
Maki ν₅, 2ν₉ Sum = 2.2104 E-17 cm/molec.

extensive studies of this region at high resolution lead to a revised consistent identification of the hot bands in this region, and line parameters for several of these bands are being generated (Perrin et al. 1994a). New quantitative TDL measurements of individual intensities of ν₉ lines, and a corresponding total band intensity, are in progress (Sirota et al. 1995).

The new hot bands work in the ν₉ region also provided interesting new results for the 11 μm region (dominated by ν₅ and 2ν₉). We have been aware, since 1971, of a weak band in the HNO₃ spectra near 830 cm⁻¹. With the recent work, it became possible to assign this absorption to the 3ν₉-ν₉ Q-branch, and provide quantitative analysis of both laboratory and atmospheric spectra (Perrin...
et al. 1994b). The high resolution laboratory spectra of this region show clearly torsional splitting in the \( v_3 = 3 \) level.

Quantitative analysis of atmospheric spectra of HNO\(_3\) is mostly performed from selected manifolds in the \( \nu_5, 2\nu_9 \) region. The line parameters of these two bands have been improved significantly (Goldman et al. 1994). They show very good agreement with both laboratory and atmospheric spectra, and will be included in the HITRAN 1994 compilation. However, the analysis of the hot bands transitions in this region is still in its early stages.

HITRAN 92 lists two hot bands (Rothman et al. 1992), at 877. cm\(^{-1}\) and at 885. cm\(^{-1}\), assigned as \( \nu_5 + \nu_9 - \nu_9 \) and \( 3\nu_9 - \nu_9 \) respectively. The second band is clearly seen in our laboratory and stratospheric spectra, as a sharp Q-branch centered at 885.425 cm\(^{-1}\). The recent \( \nu_9 \) hot bands work allows to assign it to \( \nu_5 + \nu_9 - \nu_9 \), and provide initial line parameters for quantitative simulations. This work is in progress. Individual transitions from the \( \nu_5 + \nu_9 - \nu_9 \) are not assigned yet, and additional studies are required. Figure 3 shows a portion of the University of Denver 0.002 cm\(^{-1}\) laboratory atlas, with the \( \nu_5 + \nu_9 - \nu_9 \) indicated. For atmospheric applications, it is fortunate that most of the absorption by this band is concentrated in the narrow Q-branch region, with only very weak absorption outside.

Several recent and ongoing studies have been dedicated to a more accurate and consistent determination of the absolute intensity for the HNO\(_3\) bands in the \( \nu_3/\nu_9 \) and \( \nu_5/2\nu_9 \) regions. Table 2 shows several published sets of previous measurements (Goldman et al. 1971, Giver et al. 1984) compared to HITRAN 92. Also included in the table are the more recent LPMA measurements (Perrin et al. 1993b) and the ongoing measurements at DU. As the table shows, the work is not complete, and the standing recommendation is to normalize to Giver et al. (1984), with the proper hot bands correction.

Further improvements are expected from intensity measurements of individual lines in this region, which is in progress.

4. OH Pure Rotation Lines

The first identification of the pure rotation solar OH lines was made from several sets of line quadruplets in the 830–930 cm\(^{-1}\) region, observed in high sun solar spectra obtained during the DU March 1981 balloon flight. The lines were assigned as X \(^2\)II (0–0) and (1–1) OH transitions (Goldman et al. 1981b). Subsequently, more \( \Delta \nu = 0 \) lines in \( v=1,2 \) were identified in the DU March 1981 flight and the DU S. Pole atlas (Goldman et al. 1983a). Figure 4 shows the 920–930 cm\(^{-1}\) interval from the DU September 1987 0.02 cm\(^{-1}\) stratospheric atlas. The emphasis is on the spectral features of stratospheric species in this region, mostly due to CF\(_2\)Cl\(_2\) (CFC-12) and HNO\(_3\). These spectral features are resolved to numerous components at higher resolution, and the detailed identifications are not yet completed for the 0.002 cm\(^{-1}\) resolution stratospheric atlas.

Additional observations and studies of OH and O in the solar photosphere followed, on the basis of the DU spectra (Goldman et al. 1983a), and of the Kitt Peak spectra (Sauval et al. 1984). The later provided \( \Delta \nu = 0 \) lines up to \( v=3 \). Further extension of the identification of the solar pure rotation OH lines...
Figure 4. The 920–930 cm\(^{-1}\) frame of the University of Denver 0.02 cm\(^{-1}\) resolution stratospheric atlas, showing the HNO\(_3\) and CCl\(_2\)F\(_2\) (CFC-12) spectral features overlapping the solar pure rotation OH lines.

were accomplished from the ATMOS solar spectra, with lines up to (4-4) (Geller 1992).

Line parameters for the pure rotation OH lines were generated since their first identification, with the available state of the art spectroscopic constants and assuming a fixed dipole moment function of 1.667 D (Goldman et al. 1983b, and see previous publications cited there). Calculations and experimental electric dipole function (Nelson et al. 1990) lead to a recent update of the line intensities (Goorvitch et al. 1992), still with the old line positions calculations (Goldman et al. 1983b).

The solar OH pure rotation lines observed in the ATMOS spectra, and the recently observed lines in ground based 360–570 cm\(^{-1}\) spectra from the Jungfraujoch (Farmer et al. 1995), were combined with other published OH data sets to generate a new set of molecular constants (Mélen et al. 1995). These latest intensity calculations (Goorvitch et al. 1992) and molecular constants (Mélen et al. 1995), will be next combined to generate a revised line parameters set.
The pure rotation OH lines were also observed in stellar spectra obtained from Kitt Peak (Jennings et al. 1986). More recently, the pure rotation OH lines were observed in the emission spectra of the earth's night time air glow layer at ~100 km (Dodd et al. 1993). Δν=0 lines from ν=0, 1, 2, 3 were observed in these spectra and used to derive column densities.

5. Solar Emission IR Lines

The 12 μm solar emission lines were initially observed in DU 1976 ground-based solar spectra at 811.575 cm⁻¹ and 818.058 cm⁻¹ as two suspicious features, which were whitened out in the DU June 1980 atlas. The features were confirmed by continued investigation of ground-based, aircraft and balloon-borne spectra obtained with different interferometers (Murcray et al. 1981). The same features were also observed, but not reported, in the Kitt Peak spectra (Testerman & Brault 1980, Brault & Noyes 1983).

Subsequently, these features were identified as high Rydberg transitions of Mg I, additional Mg I and Al I lines were identified, and the emission lines were found to be Zeeman-sensitive (Chang & Noyes 1983, and see there for previous publications). More recent and ongoing work with the Kitt Peak and the ATMOS solar spectra have been dedicated to the modeling of line formation, and to the study of both the quiet sun and sunspot penumbra (Deming et al. 1988, Glenar et al. 1988, Chang et al. 1991, Hewagama et al. 1993). These studies provide important results on the solar magnetic fields. Mg I emission lines were also observed in stellar spectra (Jennings et al. 1986), albeit as absorption lines.

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Goldman


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