Mesospheric Temperature Observation Using a Michelson Interferometer

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Abstract

A Michelson interferometer was used to record spectral data of nightglow emissions, and software was written to process the data. The upper mesosphere/lower thermosphere (MLT), approximately 80-105 km above Earth, is a dynamic region of the atmosphere where processes and forces from two layers interact. The MLT is affected by periodic tides, the effects of which can be seen through study of the temperature of the region over time. Due to the altitude of the layer, measurement by long-lived satellite and balloon are impossible, and sounding rockets yield only an instantaneous snapshot. However, with spectral analysis of hydroxyl emissions, remote sensing of temperature over the course of a night is possible. Hydroxyl, found most abundance in this region, exists in a vibrationally excited state (OH*) as well as a ground state (OH). The process which de-excites the OH* to OH results in infrared photon emission. The molecules are in thermodynamic equilibrium with the surrounding atmosphere, so rotational temperature is a reliable measurement of atmospheric temperature. Rotational temperature is calculated using the relationship of photon emission intensity to total upper state angular momentum for a Boltzmann distribution of multiplet rotational levels. To remove noisy data, the spectral data sets are passed through a series of filters before a time vs. temperature graph is created with only valid data. Observations of the 3-1 Meinel band (6400-6700 cm^-1) were made on 5 nights during July 2012 at Center Green Building 1, Boulder, CO in an effort to investigate terdiurnal (thrice-daily) tides at mid-latitudes. An InGaAs detector was used with a Nicolet 6700 spectrometer containing a Michelson interferometer; light entered from a scope attached to the roof. Data collection was limited by malfunctions of the third party software which controls the spectrometer, poor weather conditions, limited ability to align the spectrometer, and the condition of the scope. Variations seen in temperature data from any given night is expected to be approximately 30 K, with an average temperature of 195 K. The valid data collected varied an average of 189.9 K, with an average central point of 271.4 K, and too few valid points were found on all nights to attempt fitting a curve. Error from the spectrometer measurements does not account for the discrepancies. Observations must continue to be taken in hopes of clearer skies, more much work must be done to align the detector of the spectrometer, and additional attention must be given to the scope. Future study also ought to implement a module in the software to calculate total band intensity from the collected spectral data, as time was a constraint this summer.

Hydroxyl

- Appears in most abundance in MLT & is in thermodynamic equilibrium with atmosphere
- Temperature affected by tides and waves
- Excited state from displacement reaction:
  - H+O3 ->OH*+O2+3.3 eV
- IR radiation known as 'Meinel Bands' as de-excitation process takes place
- Ratio of molecules in different states correlated to temperature
- Studied the P1 band
  - Only P1(2), P1(3), and P1(4) used in calculations

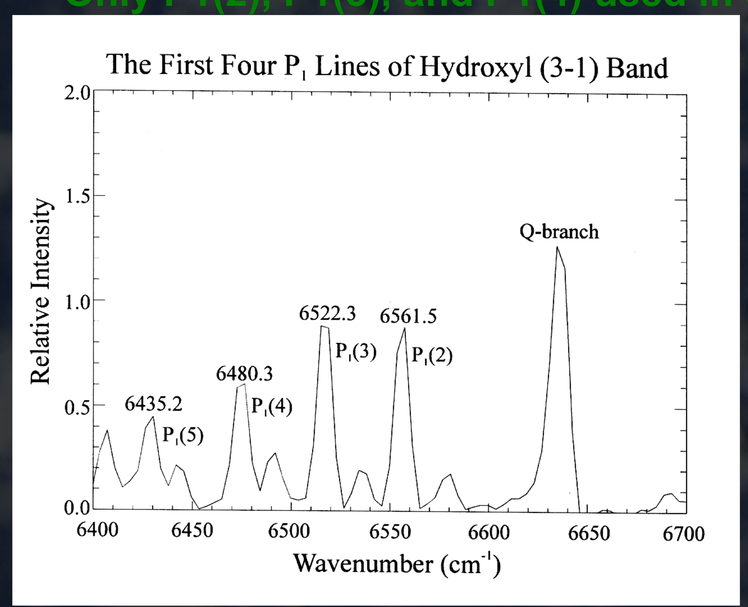
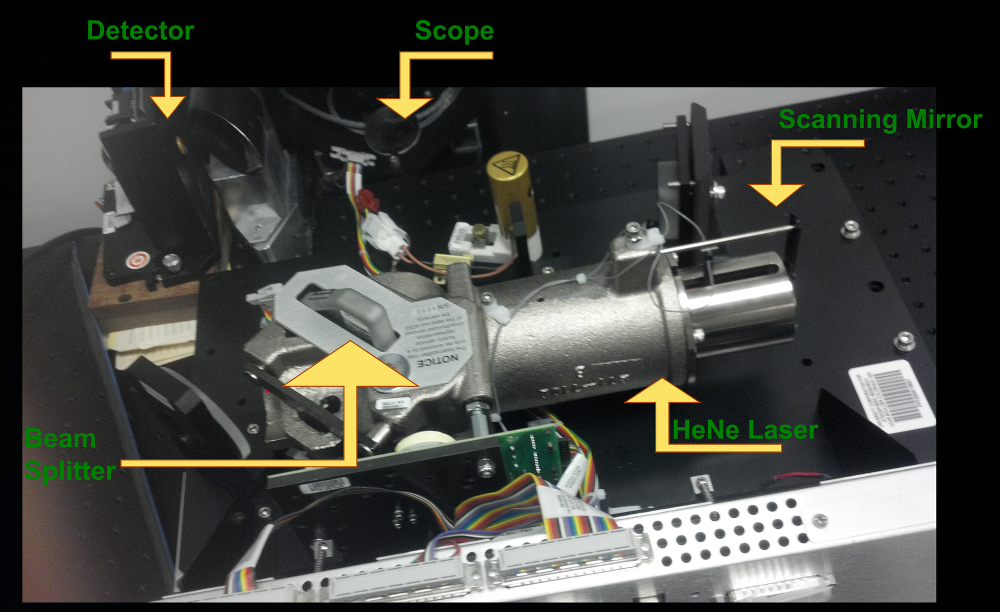


Image Credit: Application of a Michelson Interferometer to Measurements of OH Rotational Temperatures, Won *et al*, Journal of the Korean Physical Society, Vol. 34, No. 4, April 1999, pp. 344~349

The Interferometer



Sky-light is reflected into the instrument from the scope. The beam splitter directs half of the beam a fixed mirror and the other half to the scanning mirror. The scanning mirror moves back and forth at a constant rate; one cycle of the mirror is called a scan. The beams recombine and interfere with each other due to the different path lengths. The recombined beam is reflected by the parabolic mirror by the detector onto the detector, which records the interference pattern (known as interferograms). The relative intensity of each interferogram at different path lengths is related the relative intensity of input light at respective wavelengths. The spectrometer software interprets the interferograms, and calculates relative intensity vs. wavelength.

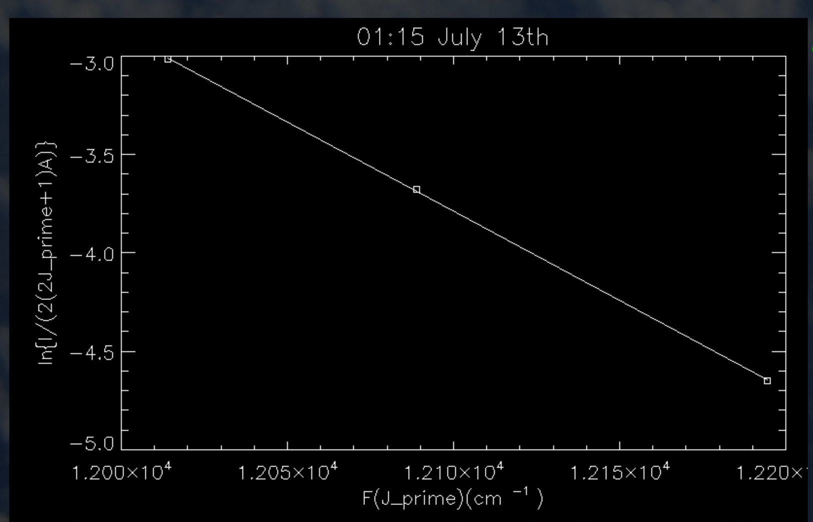
Image Credit: H. LeTourneau

Data Collection

- Collected on 5 nights in July 2012:
  - 9-10, 12-13, 13-14, 18-19, 19-20
- 213 scans co-added per data set
  - Approximately every 5 minutes
- Taken from 10pm to 5am to mitigate solar radiation influence
- Looking for evidence of terdiurdal (thrice daily) tide

Temperature Calculation

- Equations are derived from relationship of photon emission intensity to upper state angular momentum for a Boltzmann distribution of multiplet rotational levels
- For each data set ln(I/(2*A(2*J'+1))) is graphed on y-axis against rotational term values
  - J': Total Upper Angular Momentum (1.5, 2.5, 3.5)
  - A(J'): Einstein Constants (16.74, 20.37, 21.82 s^-1)
  - F(J'): Rotational Term Values (12014.1, 12089.0, 12194.5 cm^-1)
- Linear least squares fit



An example graph; 1:15am, July 13th 2012

T=158.7 K

- T=-100*h*c/(k*slope)
  - H: Planck's Constant
  - C: Speed of Light
  - K: Boltzmann's Constant
- Temperature is graphed over time for all data sets

Data Filtering

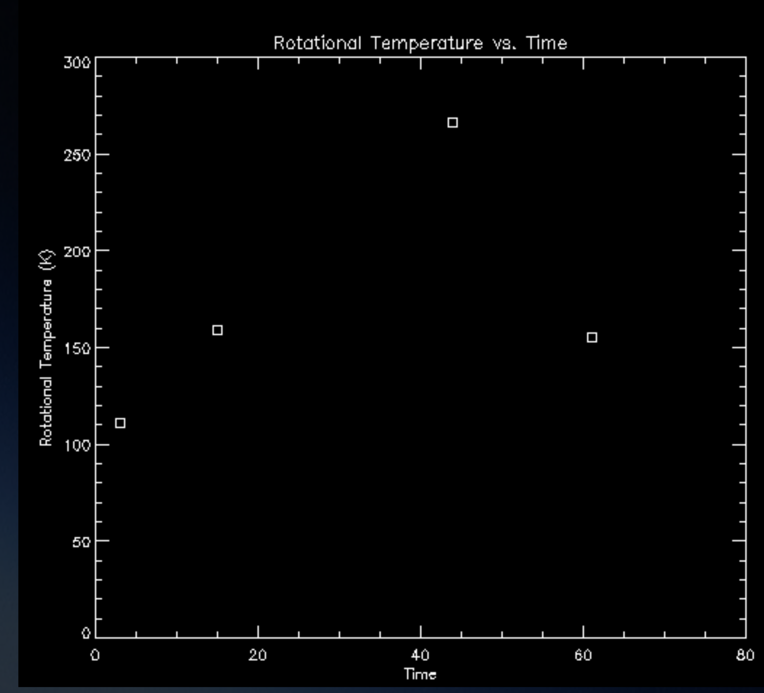
- Most spectral data sets collected weren't accurate due to noise attributed to alignment errors and clouds
- Data was filtered by passing it through a series of tests:
  - Peak intensity must be greater than 0
  - Peak intensity must be greater than 10x average intensity
  - ln(Peak 1)>ln(Peak 2)>ln(Peak 3) must be true for F(J') graph
  - Chi square goodness of fit value for linear fit must be less than .05
- Only valid data was displayed on final graph

Results and Conclusions

Date	Delta T (K)	Average (K)
Jul 09-10	93.44098	350.4082
Jul 12-13	154.9807	172.7274
Jul 13-14	161.4956	403.7898
Jul 18-19	146.4787	192.8737
Jul 19-20	392.6729	235.9299
Average:	189.8138	271.1458

Chart showing change in temperature and average temperature

- Expected delta temperature (nightly high temperature-low) is 30 K
- Expected average temperature is 195 K
- Much more work must be done to refine data collection process and reduce noise
- Too few valid points were found on any night to attempt fitting a wave curve



Temperature vs. Time for July 12th-13th, 2012 as an example of a graph of a typical night.

Time scale: 0=10pm, 80=5am

Future Study

- Collect on more nights in hopes of clear skies
- Improve alignment of detector optics
  - Lab setup was very unstable and prone to de-aligning
- Co-add more scans in hopes of less noise
  - Would result in decreased time resolution

References and Image Credits

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Background Image: Whitworth High Altitude Ballooning