Etalon Imaging of Mid-Thermosphere Winds

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Introduction

Little data exists on the wind velocity characteristics of the upper atmosphere. The Split-Field Etalon Doppler Imager (SEDI) is designed to measure the velocities of neutral winds in the thermosphere by Doppler imaging of the 630 nm atomic oxygen "red line" glow that occurs in the altitude range 250 and 350 km.

Instrument Concept Summary

The thermosphere scene is imaged through a Fabry-Perot etalon with the etalon centered in a collimated part of the beam. An optical filter restricts the focal plane illumination to a narrow band around the O(3P) red line. The resulting image at the focal plane is a product of the red line scene above the earth limb multiplied by the multi-ring interferogram of the etalon. Spatially localized estimates of the red-line Doppler shift (i.e. the radial component of the neutral wind) are obtained from radial phase shifts in the interferogram fringes. Using two objective lenses, SEDI creates a split field image, simultaneously observing forward and aft scenes for triangulation of wind vectors.

Observation Methods

- Solar radiation is absorbed and reemitted by chemical elements in the upper atmosphere at discrete wavelengths.
- The mission studies the mid-thermosphere region where the red line glow is emitted by atomic oxygen.
- Interferometry is used to precisely measure shifts in wavelengths. One order (the spacing between adjacent interferogram fringes) corresponds to λ/2 = 20 nm. A radial component of 10 m/s causes a Doppler shift of 20 fm - i.e. a fraction of a pixel. Precise fringe phasing is obtained by image processing over multiple fringes and many image pixels.
- Note: fore and aft velocity offsets due to the orbital speed must be backed out before wind triangulation.

SEDI Instrument

Built as a proof of concept bench test model at the Space Dynamics Laboratory, the Split-Field Etalon Doppler Imager (SEDI) was adapted as the science instrument for RLAGS. The table shows the anticipated performance of SEDI as a CubeSat payload.

Calibration vs. Red Line

The difference between the red-line and calibration interferograms (170 orders) is manageable because the atomic line wavelengths are known very precisely: red-line rest wavelength 630.03 nm; calibration source: 633.43 nm.

Results

- The payload rotation rate was much lower than predicted.
- Azimuthal sampling range was only 200 deg.
- Flight duration was morning (daylight).

Lessons and Recommendations:

- Successful thermocast test of integrated payload -40C and 10 mbar to simulate anticipated flight conditions. Load: icescrine in a dry-ice bath.
- Red-line interferograms are visible above the daylight background. Use of a polarizer is contraindicated.
- The onboard neon calibration source was bright and stable.
- Balloon rotation is much slower than predicted from prior balloon missions. Longer exposures are possible.
- Bands of stray light were observed in some images. A baffles is needed behind the field splitter.
- The calibration interferogram has a residual phase offset, likely due to the small fit of calibration illumination relative to the red-line image. This offset can be measured on the ground using a single-mode HeNe laser as a surrogate source.

Payload Design

- Attitude determination for the SEDI instrument was provided by a sun camera, a star camera and an IMU.
- A thermal control system stabilizes the temperature of the etalon cavity. An integral TEC stabilizes the Trius SX9 CCD imager.
- Interferogram phasing is obtained by image processing over multiple fringes and many image pixels.

Science Requirements

- High sampling rate: 10 measurements per hour
- Attitude and location knowledge (from GPS)
- Instrument attitude knowledge <1° from sun/star sensors.
- Onboard interferogram calibration: neon glow lamp, single line; illuminates the entire FPA through the etalon from inside SEDI.
- SEDI FOV - up through thermosphere, baffling to block stray light.
- Rayleigh background reduction. A polarizer over one view that rotates with solar orientation to minimize the background radiance.
- Temperature control. Maintain SEDI structures and etalon to ±1°C. ULE spacer in the etalon minimize temperature dependence.
- Bandpass filters centered at 630 nm; FWHM ~ 2 nm.

The Scientific Research Balloon

At 36 kilometers, the instrument is above 98% of the atmosphere. This altitude provides excellent viewing conditions for red line airglow observations.

On-Float Interferogram

- 240 s integration time.
- Well defined high contrast fringes on non-polarizer FOV
- Fringes significantly less defined on the FOV with the polarizer.
- Stray light bands can be seen on both side, indicating need for internal baffling.

Interferogram Processing

- Image processing establishes the precise center of the interferogram.
- Pixel rati are scaled quadratically to equalize the fringe spacing field.
- Amplitude equalization corrects for vignetting and snare nonuniformity.
- Aggregate multiple fringes (above).
- Evaluate the sampled weighting fringe phase.

The Scientific Research Balloon

The Scientific Research Balloon (RLAGS) is a small high altitude balloon that allows up to 7 days of continuous free flight. It is designed for scientific experiments and a variety of practical applications. The balloon is carried by a transportable container and is launched from a fixed launch site.

RLAGS Balloon Experiment

RLAGS is an acronym for the Scientific Research Balloon. It is a high altitude scientific balloon experiment that provides an opportunity to study various aspects of the upper atmosphere.

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