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The ISP will measure the intensity of incident starlight after it has been attenuated by the atmosphere and dispersed using a diffraction grating. The dispersed and attenuated light will be focused on a CCD (Charge Coupled Device) detector. The spectral resolution of the data collected by the CCD will be 5 nm with a total wavelength range of 400 nm ranging over the Chappuis band from 400 to 800 nm. The CCD detector readout will be sent to the on-board data compression system which will take incoming data from both the GPS and the detector and pass all of the information to the telemetry system which will transmit the data to a receiving system on the ground.

The Attitude Video Camera is an optical camera which has a wider field of view than the optical system and is used to determine the pointing direction of the optical system. This camera transmits the images it receives down to the data processing equipment on the ground on a separate frequency.

The first section below describes the methods which will be used to acquire and analyse the optical data. The instrumentation used is described in more detail in section 1.5.2. Section 1.5.3 describes the resolution and confidence which are expected to be obtained for the ozone concentration profile. Last the zeroth level data processing and ground-based validation which will be discussed.

1.5.1 Description of Experimental Methods

The NITEOWL experiment is going to measure ozone concentrations using stellar occultation. The decent of the rocket through the atmosphere and its rotation allow various stars to be viewed. Because the methods applied do not depend on tracking any particular star, or on the position of the sun or moon, measurements may be at any local time during the night. The data from the ISP is aquired at a rate of one frame per second. In each frame several stars will be visible, however the SNR required to do accurate inversion will only be achieved by stars of magnitude x or brighter. Each star provides a line of sight through the atmosphere. The combination of all the lines of sight seen as the rocket falls is necessary to perform tomographic analysis.

The initial measurement of each star will be used as a benchmark for all subsequent measurements of that star. This allows self-calibration of the ISP. Using the ratio of the initial intensity, which will be the least attenuated signal from a given star, and the intensity measured viewing the same star along a different line of sight with greater absorption the ozone column amount may be calculated. Using the column amounts one can use a simple onion peeling technique to determine the vertical ozone profile. The expected resolution of such a vertical profile is 1 km. This resolution is determined by the number of stars which provide information pertaining to a each altitude. Tomographic methods will be employed to improve the ozone profile by providing a horizontal component to the result. The expected resolution of such a profile is 1 km vertically, and 100 km geographically. This resolution is based on the number of lines of sight through a given volume.

1.5.2 Instruments

The starlight from a field of view which subtends 15 degrees horizontally and 7.5 degrees vertically will be imaged by the optical system on the CCD detector. This starlight is assumed to be emitted by point sources and to arrive at the entrance to the optical system collimated. The first element in the optical system is a transmission grating which diperses the collimated light which is incident from the stars in the field of view. This dispersed light is then focused on the CCD detector by an objective lens. These two elements have been chosen such that the dispersion of the incoming

light by the transmission grating allows the objective lens to project an image onto the CCD detector such that 5 nm of the spectrum covers a single pixel of the CCD detector.

The Global Positioning System is to be provided by Bristol Aerospace as an integrated portion of the Orion rocket telemetry system. This system should allow tracking of the experiment with a precision of up to 100 m.

The attitude video camera will be a camera with a CCD detector with a wide enough field of view and a high enough sensitivity that one can be assured of enough stars being in the field of view at all times to be able to determine the pointing direction of the optical system. This type of system has been used on both the GEMINI and OEDIPUS-C missions.

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1.5.3 Expected Performance

From an apogee of 80 km, the NiteOwl instrument will scan the horizon, viewing stars as it falls through the mesosphere. The instrument will image unocculted stars of magnitude 3.0 or brighter with a minimum signal to noise ratio of 100:1 while rotating at a rate of 6° per second or less. The visual acuity will be 5 nm in the spectral domain and 1 min of arc in the spatial domain.

It has been determined that zeniths are available over Churchill whose corresponding horizons contain no stellar gaps larger than 12% of the azimuthal range for third magnitude stars and brighter. This is based on the star database supplied by the Finnish Meteorological Institute for the GOMOS project.

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Ozonesonde performance ???

1.5.4 Analysis and Ground-based validation

Two data components are transmitted to the ground base. The largest data component is the compressed imaging spectrophotometer (ISP) and GPS data at 1628 Mhz. These will be decompressed losslessly and stored with the time data for later tomographic analysis. The other data component will be the attitude video camera (AVC) image received at 2.0 Mhz.

The AVC data with time data will first be decoded frame by frame to determine the direction in which the ISP was looking at each moment. This technique has already been demonstrated successfully in Frank Harris' GEMINI project with the NRC. The process involves computing centroids of the brightest regions in the frame, joining the centroids, computing the combination of angles, and matching these angles with a database of known star geometry. From these, the look ...

Next, the ISP images will be processed to obtain the species responsible for stellar occultation and the corresponding column densities. The first step is to remove the blurring caused by ISP movement during optical integration. This blurring will be primarily perpendicular to the spectral data. Therefore, adjacent spectra can be shifted and summed to compensate for ISP movement. This is accomplished by referring to the angular deflections obtained over time from the AVC results. This summation process will simultaneously intensify the spectra obtained and cause random noise present on each spectrum to cancel itself.

The cleaned up and intensified stellar spectrum will be compared with the unocculted spectrum for the star obtained before the line of sight crossed into the atmosphere below 40 km altitude. The ratio of these spectra will yield a wavelength-dependent transfer function which may be decomposed into its constituent parts based on the known transfer functions of the dominant atmospheric species above 10 km altitude: O_3, NO_3, and NO_2. The weights of these component transfer functions will correspond to the constituent column densities of these species.

Each ozone column density furnishes a single linear equation linking the ozone concentrations in each of the regions through which the starlight passed. The accumulation of all such equations represents a linear system awaiting solution by a known tomographic algorithm for the ozone distribution in the vicinity of the instrument's trajectory. Because the deviation of the columns from the horizontal is very slight, the information about the vertical ozone distribution will be much richer than for geographic distribution. Correspondingly, the vertical resolution of (expected to be +/- 1 km) will be much better than the geographical resolution (+/- 100 km).

2 Science Team

2.1 Members of the Science Team

Dr. D. P. Steele (Senior Research Scientist and Adjunct Professor of Physics and Engineering Physics, University of Saskatchewan) is the Principal Investigator of the NITEOWL Team. His areas of specialization and expertise are upper atmospheric physics and optical imaging of atmospheric emissions to derive atmospheric state parameters.

Dr. H. S. Caplan (Professor and Head of Physics and Engineering Physics, University of Saskatchewan) has extensive experience in science administration and project management.

Dr. A. V. Koustov (Assistant Professor of Physics and Engineering Physics, University of Saskatchewan) has expertise in geophysical application of ground-based and satellite measurements to study the structure of the Earth's atmosphere and ionosphere.

Dr. A. I. Smolyakov (Assistant Professor of Physics and Engineering Physics, University of Saskatchewan) has extensive theoretical expertise in the analysis of random processes in plasma environments including neutral turbulence and dynamics of non-linear processes in fluid-like media.

Dr. R. J. Bolton (Professor of Electrical Engineering and Associate Member in Computer Science, University of Saskatchewan) has expertise in VLSI circuit design, pattern recognition techniques, digital circuit design, computer systems and electrical systems integration. He also has experience in the analysis of attitude video camera and on-board CCD data.

Dr. H. C. Wood (Professor and Head of Electrical Engineering and Associate Member in Agricultural and Bioresource Engineering, University of Saskatchewan) has extensive expertise in the development of instrumentation for optical atmospheric studies.

Dr. J. D. Bugg (Associate Professor of Mechanical Engineering, University of Saskatchewan) has expertise in numerical modelling and experimental investigations of thermal/fluid systems.

Dr. A. T. Dolovich (Associate Professor of Mechanical Engineering, University of Saskatchewan) has expertise in the development of tomographic methods for optical measurement and non-destructive testing.

Dr. C. E. Soteros (Associate Professor of Mathematics and Statistics, University of Saskatchewan) has extensive expertise in large scale computation.

Dr. R. Srinivasan (Associate Professor of Mathematics and Statistics, University of Saskatchewan; consultant with AT&T Bell Labs) has extensive expertise in noise modeling, data compression techniques, and inversion algorithms.

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Mr. E. V. Ivanov (Senior Research Engineer, SCI-TEC Instruments Inc., Saskatoon) has expertise in optical system design and construction, and balloon-borne optical measurements of stratospheric ozone.

Dr. J. E. Johnston (Senior Research Scientist, SCI-TEC Instruments Inc., Saskatoon) has expertise in both ground-based and space-borne spectroscopy and interferometry applied to chemical composition measurements of the troposphere, stratosphere, and mesosphere.

Mr. D. J. Sniezek (Vice President of Research, Development, and Engineering, SCI-TEC Instruments Inc., Saskatoon) has extensive experience in project management and the development and engineering of optical equipment for atmospheric ozone monitoring.

2.2 Responsibility and Level of Effort

Team Member	Responsibility	Level of Effort
D. P. Steele	Project co-ordination, mission planning and data analysis	160 hr/month
H. S. Caplan	Project management	5 hr/month
A. V. Koustov	Instrument calibration and data storage	20 hr/month
A. I. Smolyakov	Mission simulation	20 hr/month
R. J. Bolton	Electrical design	25 hr/month
H. C. Wood	Design consultation	5 hr/month
J. D. Bugg	Mechanical and thermal design	15 hr/month
A. T. Dolovich	Development of tomographic analysis technique	15 hr/month
C. E. Soteros	Inverse problem	15 hr/month
R. Srinivasan	Image reconstruction	15 hr/month
E. V. Ivanov	Optical instrument fabrication and testing	15 hr/month
J. E. Johnston	Optical instrument specification and design	30 hr/month
D. J. Sniezek	Management of instrument development	5 hr/month

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3 NITEOWL in the Canadian and International Context

Various efforts have been made to determine profiles of the atmospheric constituents. Canadian missions include the ground-based Stellar Brewer as well as the ODIN and MOPITT satellite projects. The Stellar Brewer project measures the total ozone column from atmospheric absorption of solar ultraviolet radiation using four channels from 310-320 nm. They plan to extend the operation of this instrument to include a stellar source in order to monitor ozone in the high Arctic during the polar night. The commitment to furthering the understanding of ozone trends is shown by the Canadian involvement in missions such as ODIN and MOPITT.

Onboard Nimbus 7, the TOMS instrument provided nearly fifteen years of reliable, global ozone maps. This coverage is still being provided today by other TOMS instruments which highlights the international interest in monitoring global ozone trends. Unlike TOMS, which uses individual spectral signatures to measure ozone, HALOE identifies absorption features within selected spectral bands through a solar occultation technique. HALOE is another instrument which is aimed to obtain ????. All of these missions exclude the polar night.

In order to provide ozone coverage during the polar night, the GOMOS project was initiated. GOMOS will perform stellar occultation measurements to study ozone, similar to the NiteOwl project, but at a much higher cost which may partially be attributed to the number of targeted species and the necessary spectral resolution. In an attempt to reduce costs while still realizing similar GOMOS science objectives, the COALA study is intended to make complementary nighttime or validation measurements for other missions. Although the NiteOwl objectives also include nighttime ozone retrieval, we plan to provide similar science results at a reduced cost from a Canadian perspective.

It is our intention to provide a Canadian polar night ozone measurement by tomographic technique. A key element for quality tomographic results is redundant measurements. These would be of the same atmospheric cell taken from different vantage points during descent and improved by multiple lines-of-sight provided by the various stars in our field of view. Presently, this is accomplished by making observations over multiple passes of the same area. Our technique is to have the payload rotate as it descends, thereby getting multiple looks through the same cells, each from a different angle. This allows the required redundancy to be achieved in one pass. In addition, the broad ozone absorption feature of the Chappuis band (450 - 750 nm) does not place heavy restraints on the spectral resolution of our instrument. This may affect the number of recoverable species but will reduce the cost of the mission.

4 Required Theoretical and Modelling Support

During the Phase A study, at least three modeling exercises will provide important data to the mission. These will deal with simulations of: the kinematics of the payload during descent, the

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spectral inversion problem and the tomographic inversion problem. Support for these studies will come from existing research funding from sources such as NSERC.

*** questions here: If theoretical and modeling means not funded by CSA SPP program, does that mean the kinematic and detailed tomographic simulation should go in another section? They are pretty central to the whole endeavor and I think they should be funded.****

*This project requires high altitude deployment of a controlled-spin parachute. The local dynamics of the payload (attitude fluctuations) under the influence of atmospheric turbulence has not been modeled to date. There exist statistical models for various upper atmospheric conditions, and the modelling required for NiteOwl will incorporate these to simulate the local payload dynamics during descent.

So far absorption data has been generated using expected constituents of the atmosphere and current data on the corresponding absorption bands. Remaining to be done is the addition of noise to these data, with subsequent inversion to analyze the sensitivity of the process to random and systematic noise.

There are variety of tomographic algorithms available for reconstruction of the ozone distribution from the column density data. A comparison of these as well as a search for alternative techniques to bridge the gaps in the horizontal star distribution would permit the choice of optimal tomographic inversion techniques for our particular mission.

*Tomographic simulation has already been done for small sectors of the horizon having more than one star in them. These have been useful for setting the current expected resolutions for tomographic reconstruction. However, a more detailed simulation needs to be done. This simulation would use the actual star distribution during actual launch windows and include the change in the star positions during the hour or so flight time. In addition, the expected local payload dynamics from the first modelling study could be included. This would provide a much stronger point of reference in establishing appropriateness of the top level science requirements.

5 Required Support Measurements

The chemical ozonesonde will provide one means of ozone validation by *in situ* measurements. The vertical resolution of the ozonesonde is comparable to the ISP at 0.5-1 km, and the detector provides sufficient sensitivity for accurate measurements of ozone in the stratosphere. In addition, a Brewer instrument will be used to determine column ozone density by means of moonlit measurements. The Lunar Brewer requires only that the image is formed on a slit which provides for measurements of different phases of the moon with equal intensity. The tracking requirements become more stringent with smaller phases of the moon, but these can be accommodated. In order to use the Lunar Brewer within the same night as the mission, the moon must be at a sufficient height

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for at least one hour. The optimal launch windows, corresponding to the presence of the moon (and no sun) with later blackout conditions for the NiteOwl mission, are *****.

Support measurements may be found in satellite measurements (e.g. GOME, TOMS) that correspond to the Churchill region within a reasonable time frame. However, it is more likely that this mission will obtain vertical ozone profile validation from either the ground-based Brewer in Umkher mode or an ozonesonde which may be flown separately from the NiteOwl payload. The ozonesonde is preferred due to its higher spatial and temporal resolution in the vertical profile.

In order to determine other trace species concentrations, it is required that temperature or pressure be measured. Although the inversion technique could also provide some measure of these parameters, several species are extremely sensitive to photolysis rate dependent on the temperature. With this requirement on the precision of the temperature survey, it is best to provide a definite means of measurement. A thermistor will allow the measurement of temperature in a simple, effective and reliable way that would not place significant burden on the cost or payload weight of the mission.

6 Data Analysis and Publication Plan

TBD - JAS, MAW with input from ATD, DPS, and others

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