Measurements of Thermospheric O_2 Density from GOLD

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Overview

The Global-scale Observations of the Limb and Disk (GOLD) instrument, scheduled for launch in 2017, will image the Earth's thermosphere and ionosphere in the far ultraviolet from geostationary orbit. GOLD will measure a number of critical geophysical parameters, including thermospheric temperature and composition, by continuously scanning the Earth's disk and limb 18 hours per day. GOLD will also routinely perform stellar occultation measurements using bright type O and B stars. These provide a direct measurement of the atmospheric slant path transmission profile in the O_2 Schumann Runge continuum, which will be used to retrieve O_2 density profiles between approximately 120 and 250 km altitude. In nominal operational mode GOLD will measure approximately 12-15 occultation events per day. These measurements will occur at latitudes ranging from 65S to 65N at two longitudes, corresponding to the east and west limbs as observed from GOLD's fixed orbit position. Depending on timing and availability each target star can be observed twice daily, in both rising and setting mode. Both daytime and nighttime occultations are possible, which allows for O_2 retrievals over a wide range of local times. Results of detailed retrieval simulations show that the precision and accuracy of the retrieved O_2 density will be 10-20% depending on star brightness. We present a summary of the expected spatial, temporal and local time sampling of the GOLD Level 2 O_2 data products. This data set will shed light on the general morphology of the thermospheric O_2 density profile and its response to geomagnetic disturbances and solar UV variability, and help address the extent to which the O_2 distribution is determined by simple diffusive equilibrium as opposed to chemistry, which can operate on much shorter timescales.

GOLD O_2 Science Objectives

The GOLD O_2 data will be used to address two of the primary GOLD Science Questions:

- How do geomagnetic storms alter the temperature and composition structure of the thermosphere?
- What is the global-scale response of the thermosphere to solar extreme-ultraviolet variability?

Potential quiet-time studies

- Look at deviations from the 10-day mean to get vertical relative variations (changes in scale height, etc.).
- Observe the same star day after day to construct a time series at fixed locations and local time (a 2-week time series has < 1 hour local time change).
- Characterize the O_2 local time variation. Requires observation of multiple stars at similar latitude at one longitude (see plot at bottom right of poster).
- Characterize the O_2 latitudinal variation in each hemisphere.
- Characterize O_2 hemispheric differences at fixed local time.
- Study the relationship between local time variations in O_2 on the limb and O/N_2 on the disk.

Potential storm-time studies

- Look at the latitude gradient during storms. Options are to maximize latitude spread to see average latitude gradient, or focus near the equatorial anomalies to get variations due to these.
- Use multi-day meaurements at the same latitude to get storm time variations of the O_2 profile over a range of local times. Use the disk data to get some idea of the local/time storm time changes that occurred.
- Relate storm-time O_2 profile to what GOLD sees at the same time on the disk.

Potential campaign options

- We have the flexibility to run multi-day campaign modes which maximize occultation measurements.

ID	Name	Type	Magnitude	RA (degree)	DEC (degree)
HD37742	Zet Ori A	B0	1.88	85.1894	-1.94260
HD35468	Gam Ori	B2	1.64	81.2827	6.34980
HD37128	Eps Ori	B0	1.69	84.0532	-1.20190
HD37043	Iot Ori	OE	2.77	83.8580	-5.90990
HD35411	Eta Ori	B1	3.35	81.1191	-2.39710
HD36512	Ups Ori	B3	4.63	82.9825	-7.30140
HD29248	Nu Eri	B2	3.92	69.0795	-3.35240
HD16582	Del Cet	B2	4.07	39.8702	0.328600
HD31237	Pi5 Ori	B3	3.73	73.5626	2.44070
HD30836	Pi4 Ori	B3	3.68	72.8013	5.60510
HD35715	Psi2 Ori	B2	4.60	81.7091	3.09570
HD74280	Eta Hya	B3	4.3	130.806	3.39860
HD34503	Tau Ori	B5	3.59	79.4016	-6.84430
HD30211	Mu Eri	B5	4.00	71.3752	-3.25450
HD37756	HR 1952	B3	4.95	85.2110	-1.12890
HD212571	Pi Aqr	B1	4.64	336.318	1.37730
HD36267	32 Ori	B3	4.20	82.6958	5.94860
HD32249	Psi Eri	B8	4.81	75.3596	-7.17400
HD52918	19 Mon	B3	5.00	105.728	-4.23920
HD36591	HR 1861	B2	5.34	83.1720	-1.59190
HD36695	V* VV Ori	B2	5.34	83.3807	-1.15610
HD177756	Lam Aqi	B9	3.43	286.562	-4.88130
HD426690	HR 2205	B3	5.05	92.9657	-6.55030
HD164284	66 Oph	B3	4.60	270.065	4.36870
HD37490	Ome Ori	B3	4.59	84.7962	4.12140
HD39291	55 Ori	B3	5.34	87.8414	-7.51800
HD37209	HD 37209	B3	5.72	84.1485	-6.06490
HD35299	HR 1781	B3	5.70	80.9259	-0.159700
HD44112	7 Mon	B3	5.25	94.9282	-7.82290
HD217891	Bet Psc	B5	4.52	345.968	3.82020

Table 1. List of 30 potential GOLD target occultation stars. There are ~26 stars with M_V < 5. Some may be excluded as too bright (exceed detector count rate threshold)

GOLD Occultation Implementation

OCCULTATION DATA OVERVIEW

- Frequency: Nominally 10-15 occultations per day, but can be more (we have complete flexibility in planning).
- Measurements made between 03:00 and 21:00 satellite local time (GOLD is in solar safe mode and not operating from 21:00 to 03:00 each night).
- Occultation local times are ~4.5 to 5.5 hours earlier(later) for star rises(sets) and therefore cover full local time range from 00:00 to 24:00 hours.
- Occultation latitudes: 65° S to 65° N.
- Occultation longitudes: 115° to 128.5° W (star sets); 20° to 33.5° E (star rises).
- Retrieval altitude range: 130 – 250 km (depending solar activity/O_2 abundance)
- Retrieval vertical resolution: ≤ 10 km
- O_2 accuracy & precision: ≤ 10 %

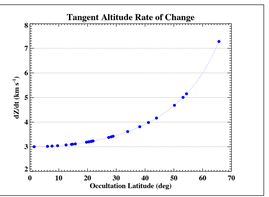
- Occultations are performed using the GOLD OCC slit configuration. The OCC slit is 1-degree wide (E-W) by 10 degrees tall (N-S). Slit width covers ~ 750 km in tangent altitude at the equator.
- Slit is positioned on the limb and held fixed during occultation.
- All stars can be observed in both rising and setting mode and in both sunlit and nighttime conditions.
- Level 1B data has 100 ms time resolution (~0.3 km tangent altitude at equator) and 0.04-nm spectral resolution.
- Level 1C data binned to ~5-km tangent altitude and 1-nm spectral sampling.

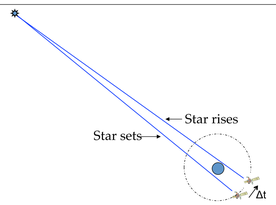
Some occultation timing constants:

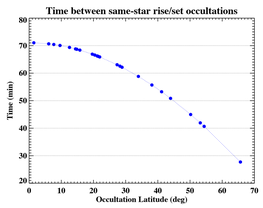
- A star traverses the entire slit in ~4 minutes. Total time required for an occultation event, including scan to position, setup and dwell time, is 5 to 7 minutes.
- Time required to cover the 100-350 km range needed for inversion is ~1.4 minutes, at equator.
- The altitude rate of change during occultation varies with latitude, φ, according to:

$$\frac{dz}{dt} \approx \frac{3}{\cos\varphi}\ \mathrm{km\,s^{-1}}$$

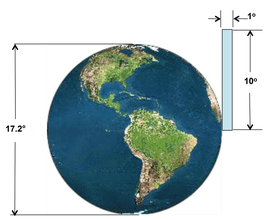
- High-latitude occultations are more smeared out spatially (latitude/longitude) compared to low-latitude occultations.



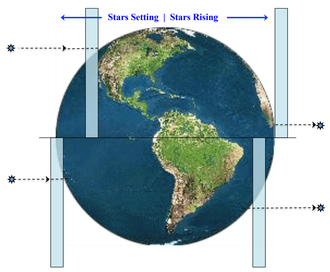




Each star can be observed twice per day, rising on the East limb and setting on the West limb. The time between these two events, Δt, varies between ~30 and 70 minutes depending on occultation latitude.



- Illustration of the geometry of GOLD OCC slit projected onto the disk from satellite orbit. (Note: satellite longitude is wrong in this picture.)
- Slit is 1° wide, covering ~ 750 km on the limb at the equator.



- Illustration of slit placement for occultations on both the East and West limbs and in the Northern and Southern hemispheres.
- The slit will be positioned to ensure the minimum required tangent altitude range (100 – 350 km) is observed at the predicted star latitude.
- There is total flexibility in choosing which, or how many channels view a given occultation event.

O_2 Retrieval Algorithm

O_2 is derived from measurements of stellar occultation in the Shumann Runge continuum. The retrieval algorithm is based on POAM-heritage solar occultation algorithms. It has also been previously used to retrieve thermospheric O_2 profiles from SUSIM/UARS solar occultation measurements and SOLSTICE/SORCE stellar occultation measurements. Retrievals will utilize several 1- to 2-nm spectral channels between 132 and 162 nm, using the spectral dependence of the O_2 absorption cross-section to maximize the O_2 retrieval altitude range.

REFERENCES

Lumpe, J. D., L. E. Floyd, L. C. Herring, S. T. Gibson, and B. R. Lewis (2007), Measurements of thermospheric molecular oxygen from the Solar Ultraviolet Spectral Irradiance Monitor, J. Geophys. Res., 112, D16308, doi:10.1029/2006JD008076.

Lumpe, J. D., L. Floyd, M. Snow, and T. Woods, "Thermospheric Remote Sensing by Occultation: Comparison of SUSIM and SOLSTICE O_2 Measurements", Presented at the Fall 2006 AGU meeting, San Francisco, CA, December 11-15 2006.

Lumpe, J. D., R. M. Bevilacqua, K. W. Hoppel, & C. E. Randall (2002), POAM III retrieval algorithm and error analysis, J. Geophys. Res., *107*(D21), 4575, doi:10.1029/2002JD002137.

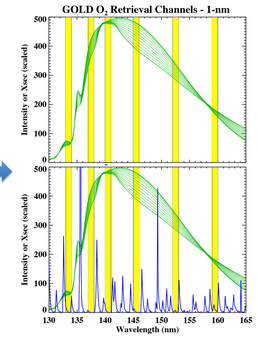
Dayside vs. nightside occultations:

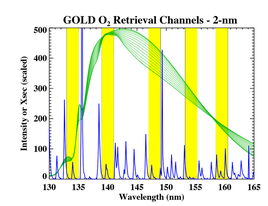
GOLD will measure occultations, and retrieve O_2 density profiles, at all local times. This means some occultations will occur in sunlit conditions. These events have an added complexity compared to the simpler nightime occultations, namely that the measured signal will contain a background due to atmospheric dayglow. This background signal is measured in each slit pixel both before and after the star has passed through the slit, and will be removed in Level 1C processing.

Retrieval Spectral Channel Selection Criteria:

- Full coverage of the O_2 absorption spectrum.
- Avoid known dayglow features (dayside occultations only).

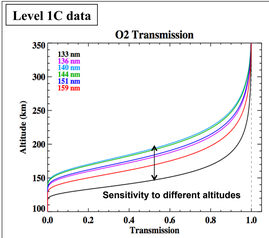
Nominal 1-nm channel selections (yellow bands). Green curves are the O_2 absorption cross section, with multiple curves denoting temperature dependence from 300-1500 K. Blue curve in bottom panel is AURIC dayglow spectrum.



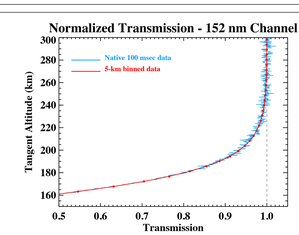


2-nm channels provide higher signal-to-noise but make it harder to avoid dayglow features. Use only if required for signal-to-noise (dimmer stars).

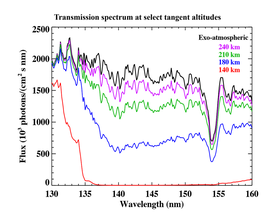
Level 1C data



Different wavelengths, corresponding to different O_2 absorption cross section, are sensitive to different regions of the atmosphere

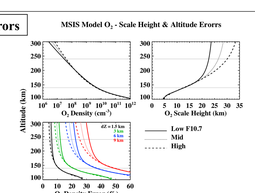


Native vertical resolution of GOLD L1B 100 ms data is ~0.3 km at the equator. The transmission data will be binned to a 5-10 km tangent altitude grid in L1C, reducing measurement noise significantly.

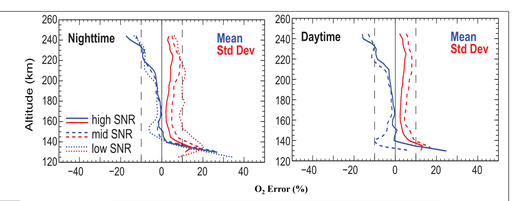


O_2 transmission spectra at various tangent altitude levels

Estimated errors

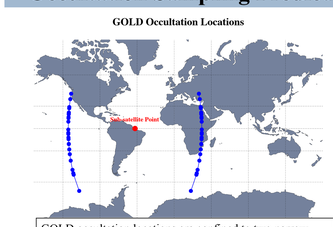


Sensitivity to altitude registration uncertainties.

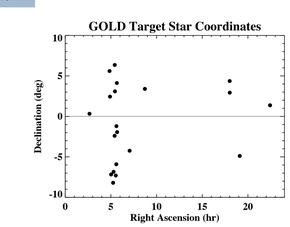


O_2 density retrieval accuracy (blue lines) and precision (red lines).

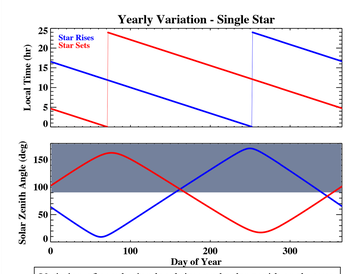
Occultation Sampling Predictions



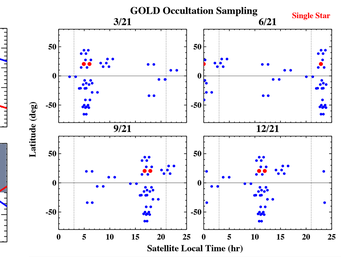
GOLD occultation locations are confined to two narrow longitude strips, corresponding to the East and West limbs as seen from geo.



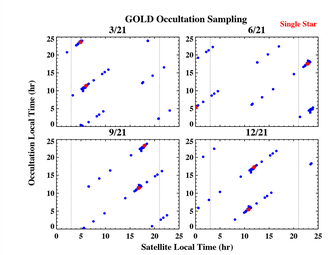
Coordinates of GOLD target stars. Note the clustering in Right Ascension, which leads to clustering in time.



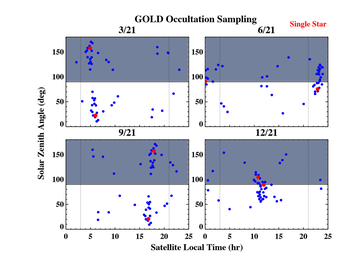
Variation of occultation local time and solar zenith angle over a year for HD35468 (Gam Ori). Each star will sample all local times over a one-year period. Star rise (SR) and star set (SS) events are separated by 9-12 hrs of local time.



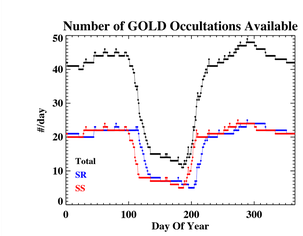
Occultation time/latitude sampling at equinox and solstice. Each star occults at a constant latitude. There are two points for each star, corresponding to SR and SS occultations. Clustering in Right Ascension (see plot above), leads to clustering in event time. Dotted lines denote solar safe mode – events occurring to left or right of these lines (21:00 – 03:00) are not accessible.



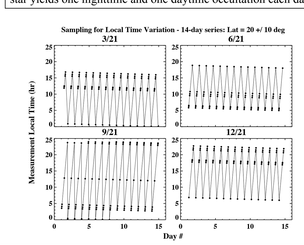
Local time sampling on given days.



Solar zenith angle sampling on given days. Nighttime occultations are denoted by the shaded region. In general each star yields one nighttime and one daytime occultation each day.



Total # of available occultation events per day.



Potential sampling for studying local time variation. 14-day time series at 20° N latitude, 32.5° E longitude. Number of stars used in study = 7.