Initial Measurements of Thermospheric O_2 Density Profiles from GOLD

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Overview

The Global-scale Observations of the Limb and Disk (GOLD) instrument was launched January 25 2018 onboard the SES-14 commercial communications satellite. The GOLD nominal mission plan calls for two years of science operations beginning in October 2018. From its location in geostationary orbit at 47.5° W longitude GOLD will image the Earth's thermosphere and ionosphere in the far ultraviolet (132 – 162 nm), measuring a number of critical geophysical parameters by continuously scanning the Earth's disk and limb 18 hours per day.

GOLD also performs stellar occultation measurements using bright type O and B stars, which are used to retrieve O_2 density profiles between 120 and 240 km altitude. Approximately 10 to 12 occultations per day will be obtained at latitudes ranging from 60°S to 50°N and two fixed longitudes, 33° E and 128° W, corresponding to the east and west limbs as observed from GOLD's fixed orbit position. Both daytime and nighttime occultations are possible, providing O_2 retrievals over a complete range of local times. We present here preliminary O_2 density retrievals from the first month of GOLD occultation measurements. The spatial, temporal and local time sampling of this initial GOLD Level 2 O_2 data set are summarized along with a discussion of data quality, retrieval errors and plans for validation studies. In this first look at the GOLD O_2 data we have concentrated primarily on the retrievals from nighttime occultations, as some aspects of the atmospheric background removal are still being tested for the daytime data.

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

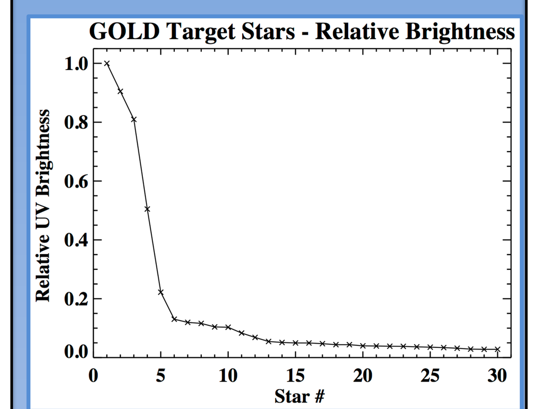
- Look at deviations from the 10-day mean to get vertical relative variations (changes in scale height, etc.).
- Observe the same star day after day to construct a time series at fixed locations and local time (a 2-week time series has < 1 hour local time change).
- Characterize the O_2 local time variation. Requires observation of multiple stars at similar latitude at one longitude.
- 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 measurements 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
HD42690	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 stars potentially used for GOLD occultations. 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.**
- **Local time coverage: complete range from 00:00 to 24:00 hours.**
- **Latitude coverage: 60° S to 50° N.**
- **Longitude coverage: 120° - 128.5° W (star sets); 25° - 34° 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) and 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 ~0.9 km tangent altitude and 0.12 nm spectral sampling.**

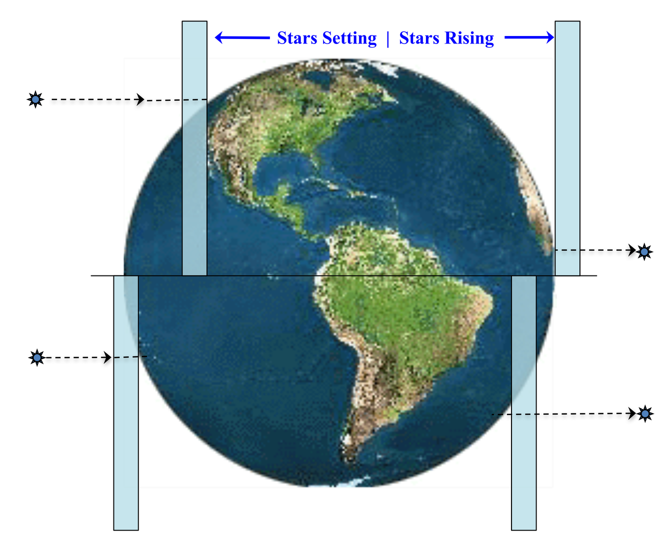
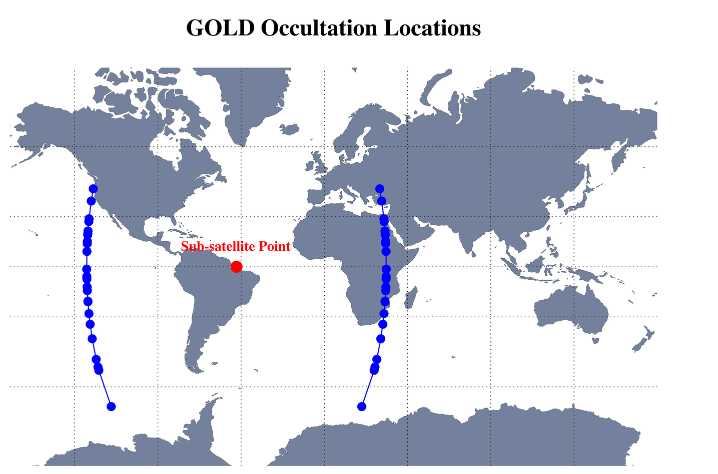
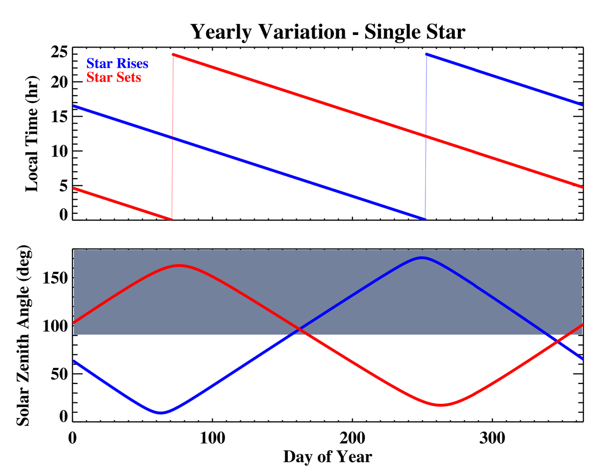


Illustration of slit placement for occultations on both the East and West limbs and in the Northern and Southern hemispheres.

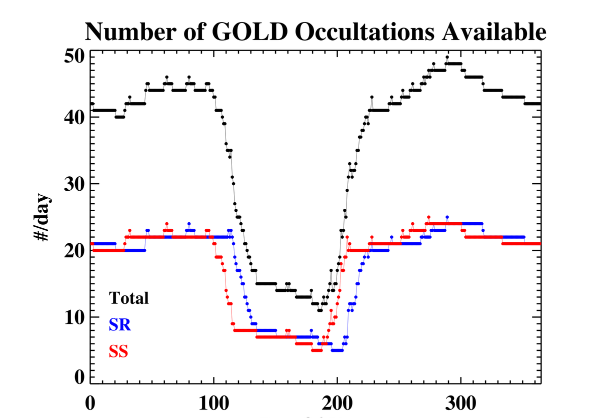


GOLD occultation locations are confined to two narrow longitude strips, corresponding to the East and West limbs as seen from geostationary orbit.

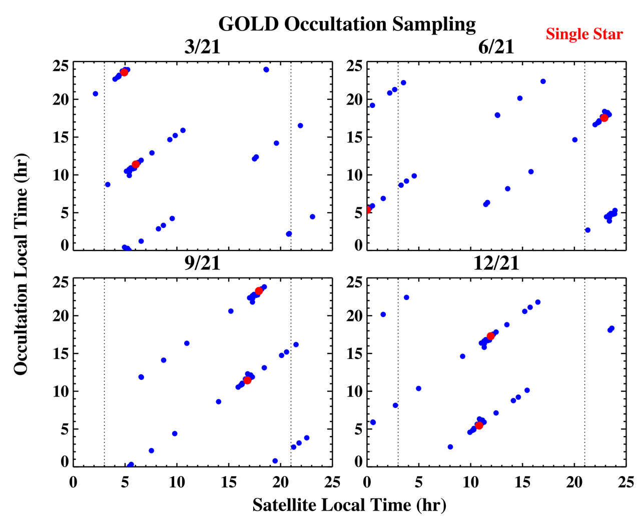
Occultation Sampling Predictions



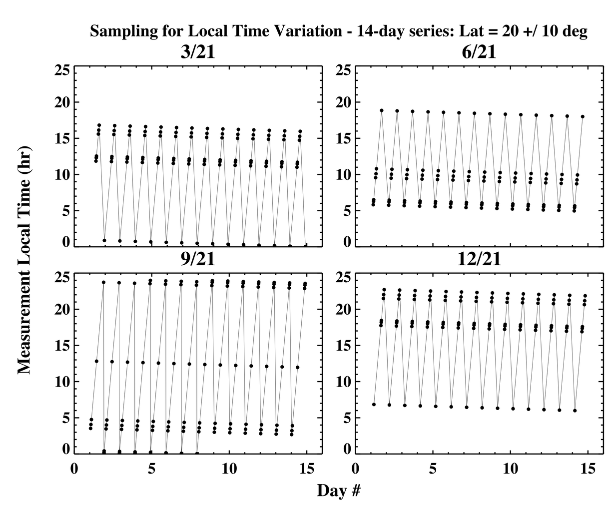
Variation of occultation local time and solar zenith angle over a year for HD35468 (Gam Ori). Each star will sample all local times over a one-year period. Star rise (SR) and star set (SS) events are separated by 9-12 hrs of local time.



Total # of available occultation events per day. Seasonal variation is caused by clustering of target stars in right ascension (see Table 1).



Predicted local time sampling on given days.



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.

O_2 Retrieval Algorithm

O_2 is derived from measurements of stellar occultation in the Shumann Runge continuum. The retrieval algorithm is based on heritage algorithms from the POAM series of multi-channel stratospheric solar occultation missions. 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 combine several 1- to 2-nm spectral channels between 132 and 162 nm, utilizing the spectral dependence of the O_2 absorption cross-section to maximize the O_2 retrieval altitude range. A non-linear optimal estimation algorithm is used to retrieve the O_2 density profile from the multi-spectral slant path transmission spectra.

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.

Daytime vs. nighttime occultations:

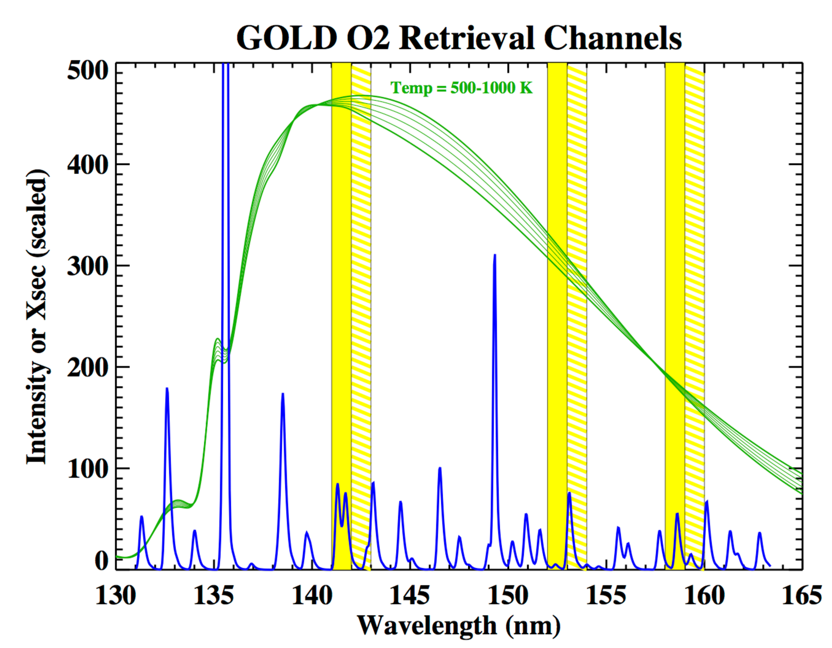
GOLD will measure occultations, and retrieve O_2 density profiles, at all local times. This means some occultations will occur in sunlit conditions. These events have an added complexity compared to the simpler nighttime occultations, namely that the measured signal will contain a background due to atmospheric 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.

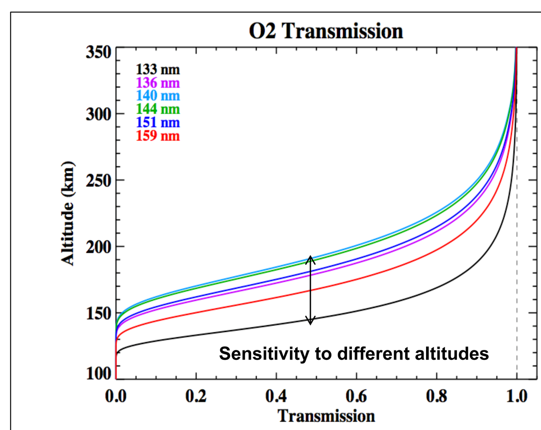
Retrieval Spectral Channel Selection Criteria:

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

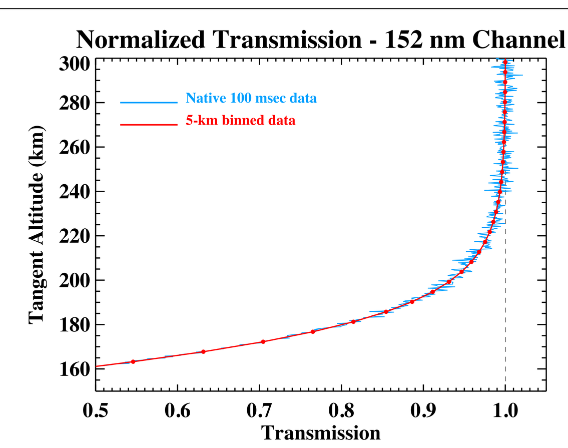
Retrieval spectral channel selections are represented by yellow bands. Green curves are the O_2 absorption cross section, with multiple curves denoting temperature dependence from 500-1000 K. Blue curve is simulated AURIC dayglow spectrum (arbitrary units).

Spectral binning of input L1C data is completely flexible. Nominal 1-nm channels will be used for brighter stars. 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).

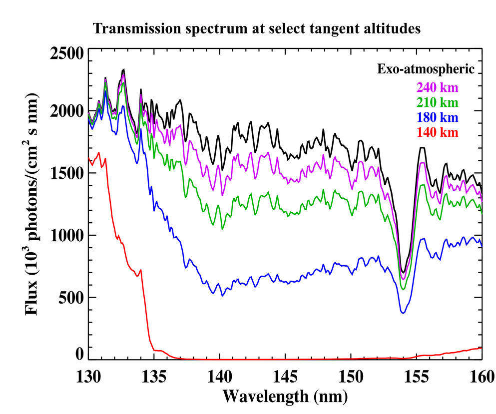




Different wavelengths, corresponding to different O_2 absorption cross section, are sensitive to different regions of the atmosphere

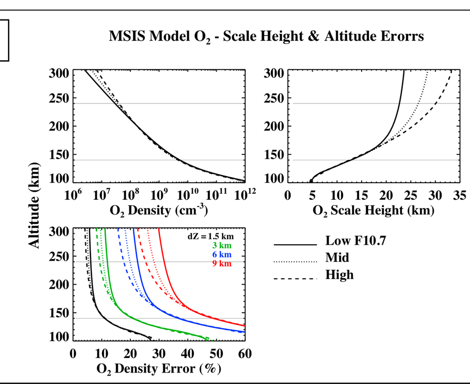


Native vertical resolution of GOLD L1B 100 ms data is ~0.3 km at the equator. The transmission data will be binned to a 5-10 km tangent altitude grid in L1C, reducing measurement noise significantly.

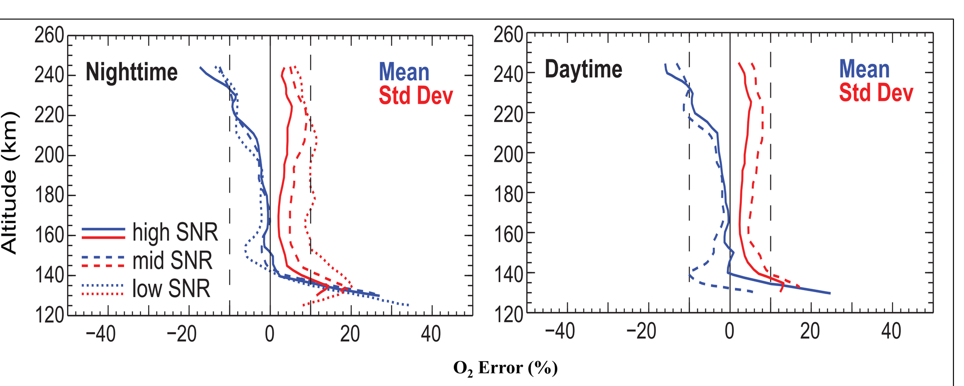


O_2 transmission spectra at various tangent altitude levels

Estimated errors



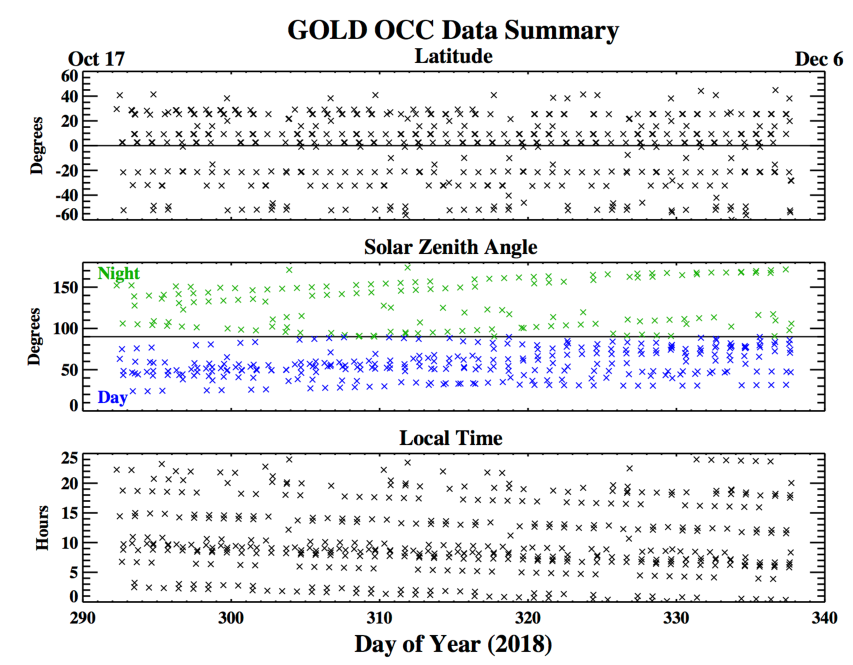
Sensitivity to altitude registration uncertainties.



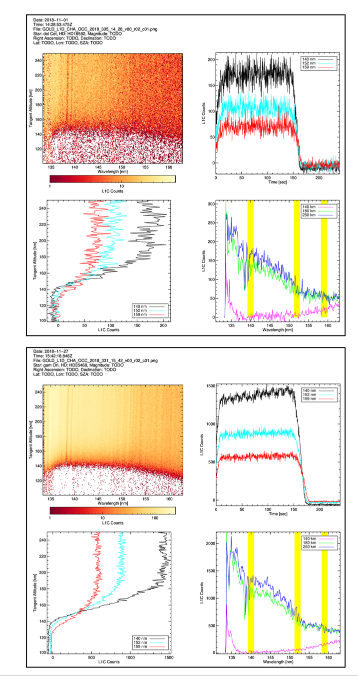
O_2 density retrieval accuracy (blue lines) and precision (red lines).

Preliminary GOLD O_2 Data

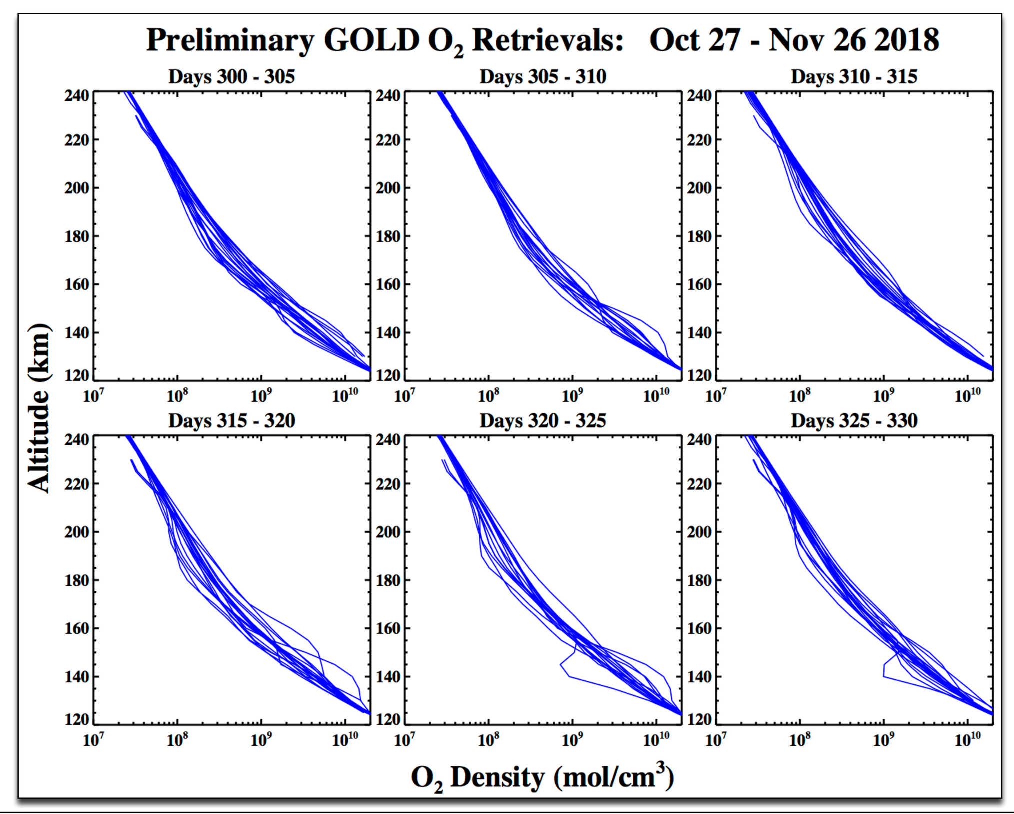
GOLD began making routine occultation measurements on October 19. Since that time nominal operations have provided 10 occultations per day, using 26 of the 30 primary stars in the GOLD target star list (Table 1). The three brightest stars in the list have not yet been observed, pending analysis to ensure they do not saturate the detector due to high count rates. Currently, each occultation event is observed simultaneously by both GOLD channels.



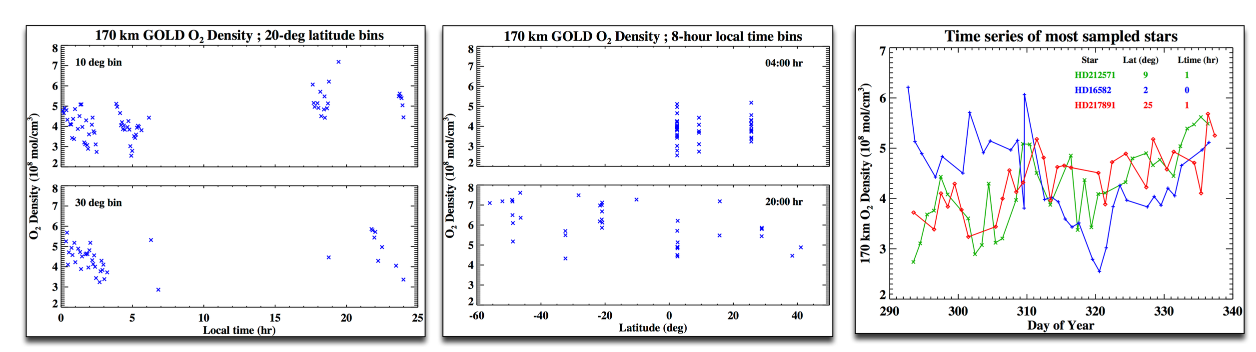
Summary of occultation sampling to date – latitude, solar zenith angle (day/night) and local time.



Sample GOLD L1D OCC images, produced from the L1C file for every occultation event. Top – star #8 on the GOLD list (dim). Bottom – star #2 on the GOLD list (bright).



Representative sample of retrieved O_2 density profiles in 5-day increments. Channel A nighttime occultations only are shown here for simplicity (approximately 5 per day). Significant variability is observed in each day.



Sample plots of O_2 density at 170 km (data from nighttime occultations only). Left – local time dependence in two latitude bins. Middle – latitude dependence in two local time bins. Right – time series of data from the 3 most-sampled stars.