Searching for lunar horizon glow with the lunar orbiter laser altimeter (LOLA)

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Lunar Horizon Glow

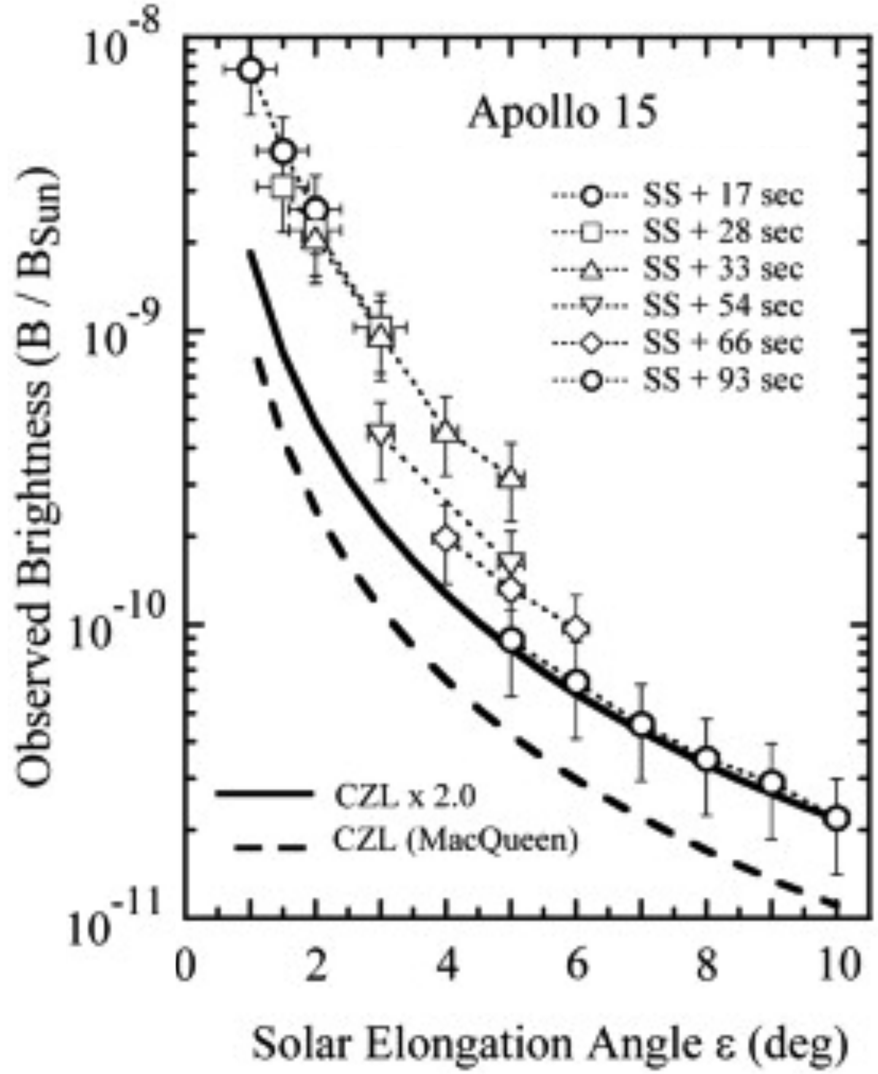
- Surveyor landers, Lunokhod-2 lander, Apollo 17 astronaut sketches (Rennilson & Criswell 1974, Severnyi et al. 1975, McCoy & Criswell 1974, Zook & McCoy 1991)

==> Electrostatic levitation, dynamic lofting (Stubbs et al. 2006, Farrell et al. 2007)

- Apollo 15 photographs at dawn: LHG extending ~30 km above horizon, N~10^3-10^5 cm^{-2} for grain r = 0.1 μm (McCoy 1976, Glenar et al. 2011)

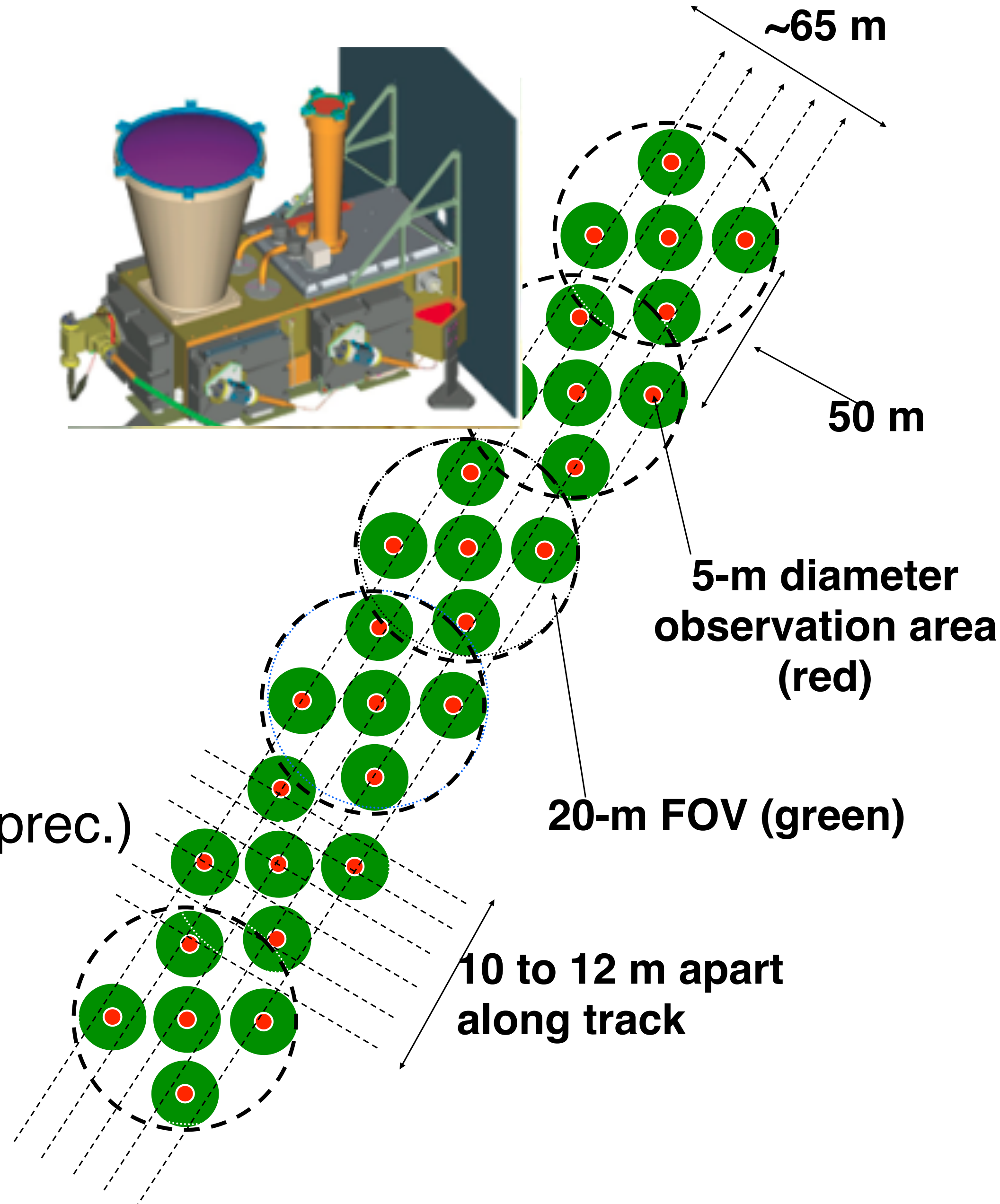
==> Meteor stream impact ejecta could initiate a saltation-like cascade process

- Recent searches with Clementine Star Trackers, LRO/LAMP, and LADEE/LDEX gave limits on dust density ~100x lower than A15 (Glenar et al. 2014, Feldman et al. 2014, Szalay & Horányi 2015, Horányi et al. 2015)



Glenar et al. (2011)

Lunar Orbiter
Laser Altimeter (LOLA)



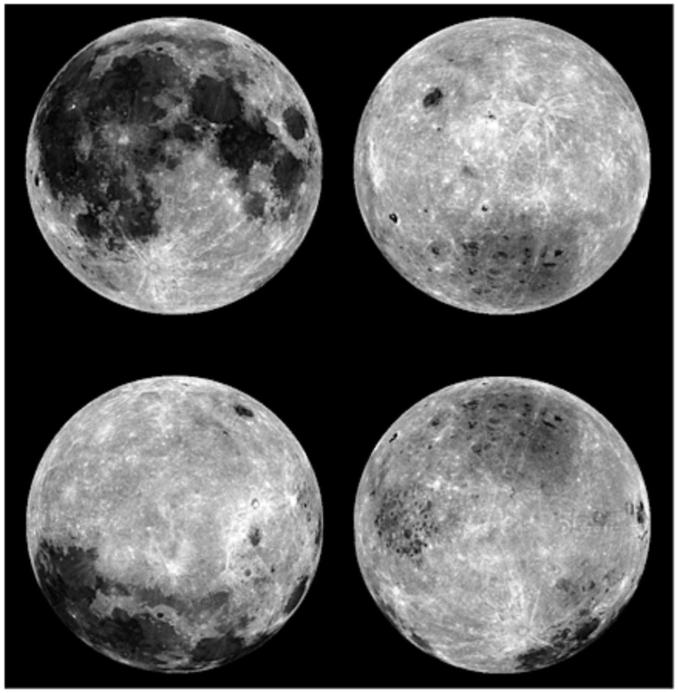
- 5-beam time-of-flight laser altimeter onboard the Lunar Reconnaissance Orbiter (LRO)

- 28 Hz laser, 140 measurements/sec

- Each shot provides:
  - up to 5 ranges to surface (10 cm prec.)
  - footprint-scale surface roughness
  - footprint-scale slope
  - 1064-nm reflectance of surface

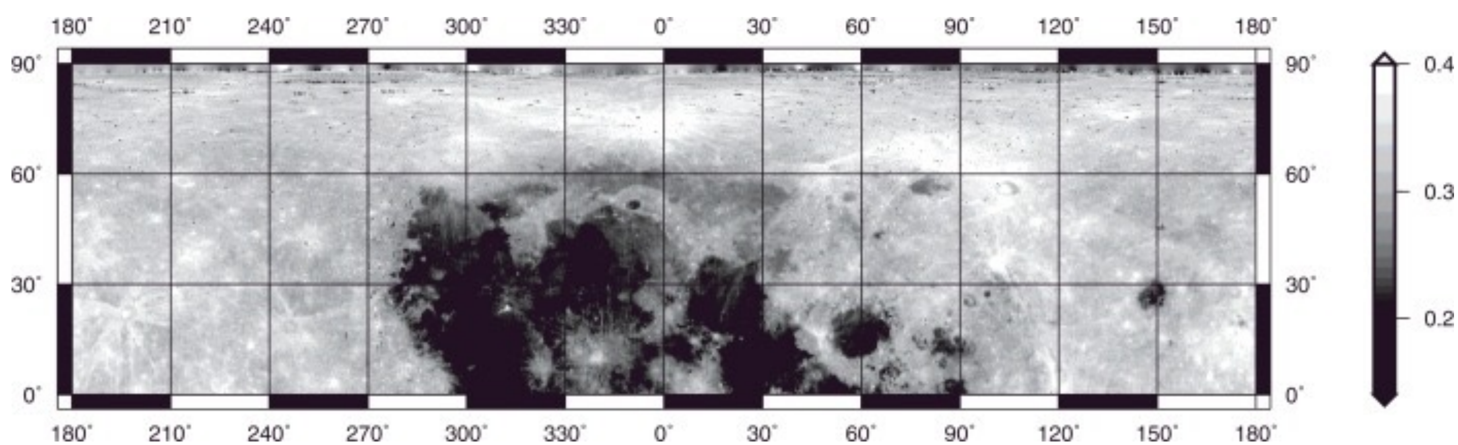
- Detectors: 5 fiber optically-coupled avalanche photodiodes

LOLA has two radiometric modes:

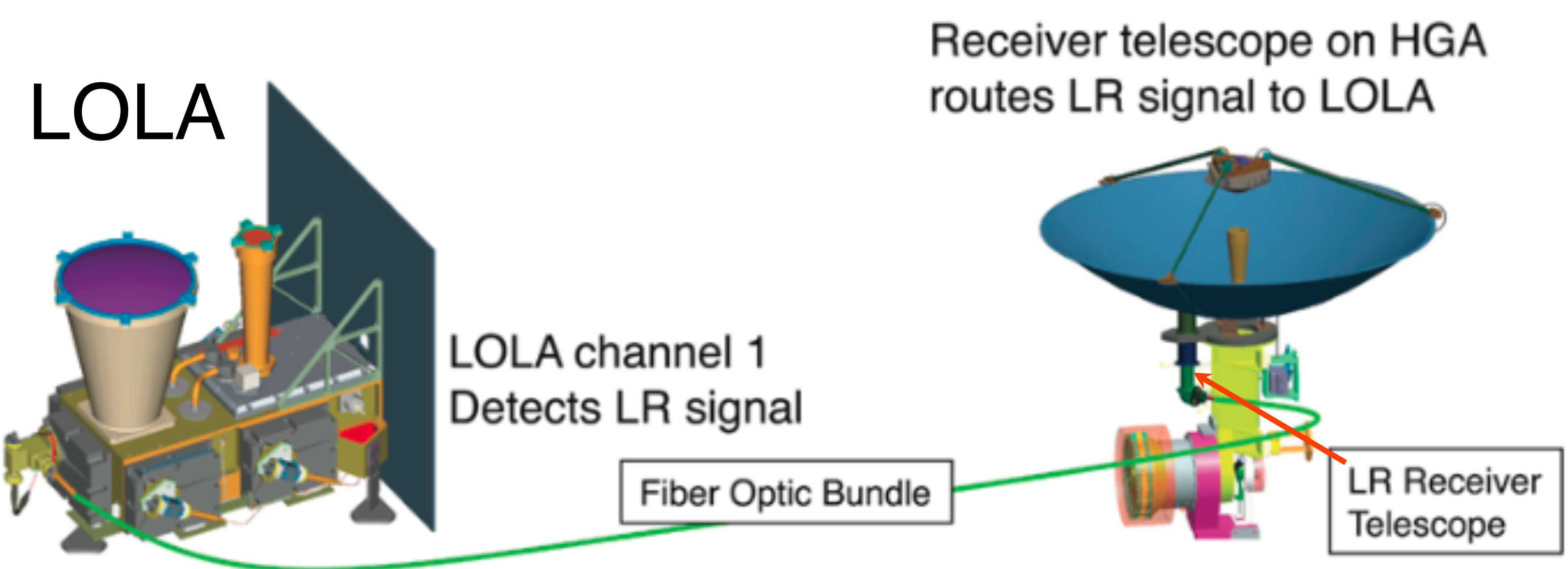


(1) Active radiometry:
LOLA laser is the light source.
1064-nm normal albedo
Lemelin et al. (2016)

(2) Passive radiometry:
Sun is the light source.
1064-nm phase function
Barker et al. (2016)

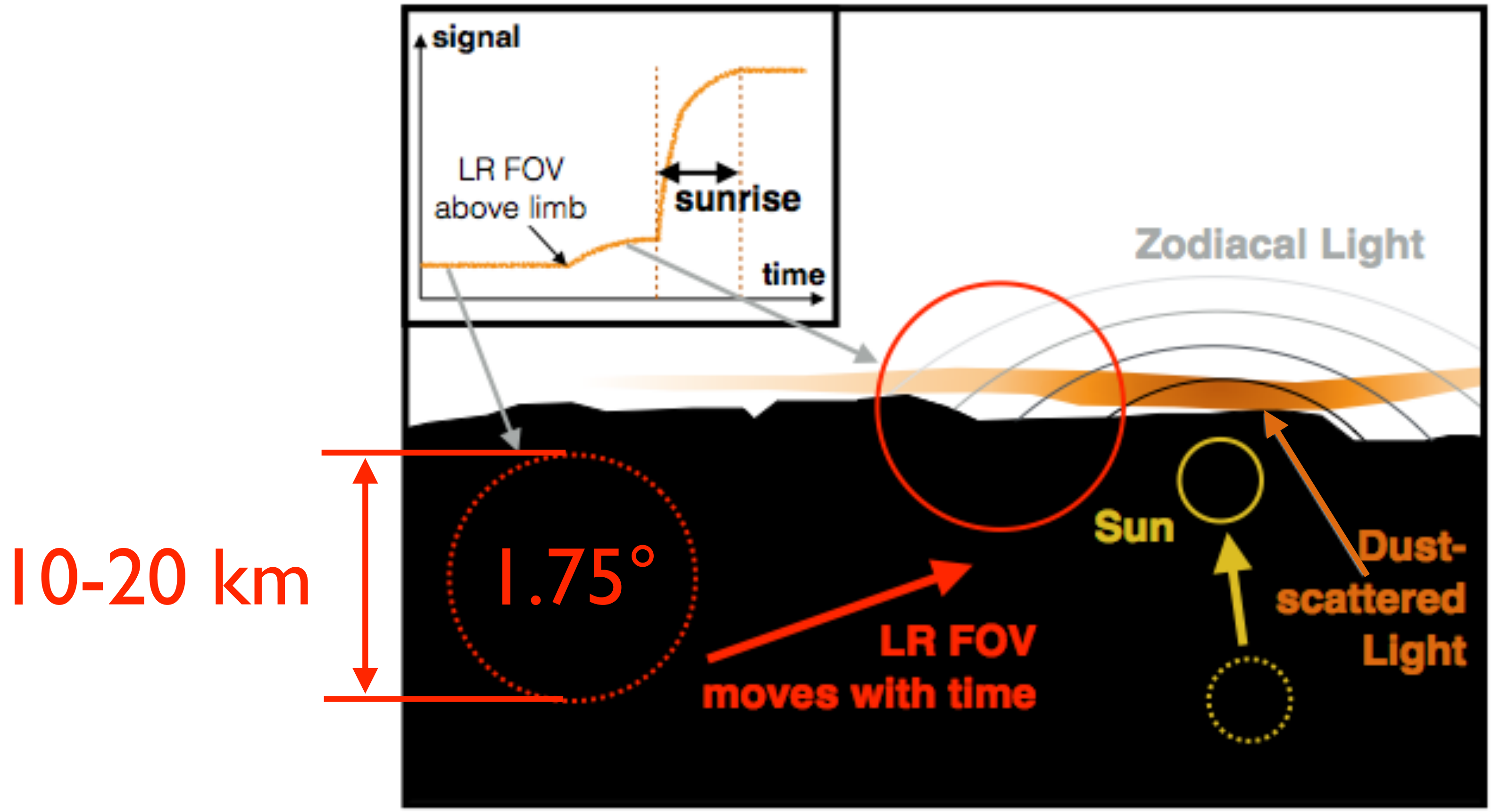


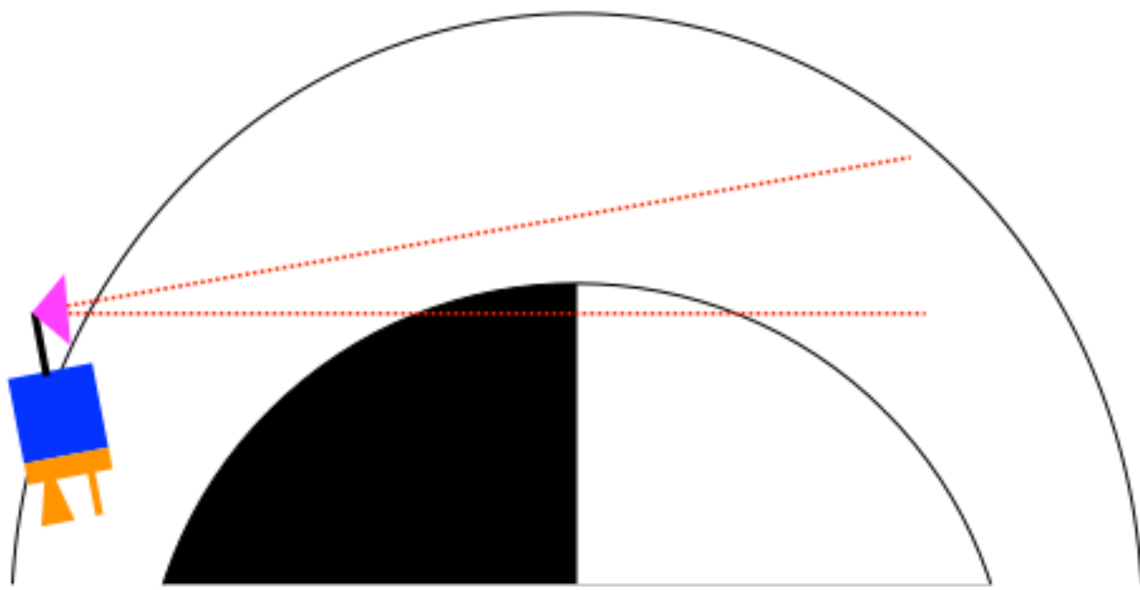
LOLA Laser Ranging (LR) System



532 nm +/- 0.15 nm

Zuber et al. (2010)

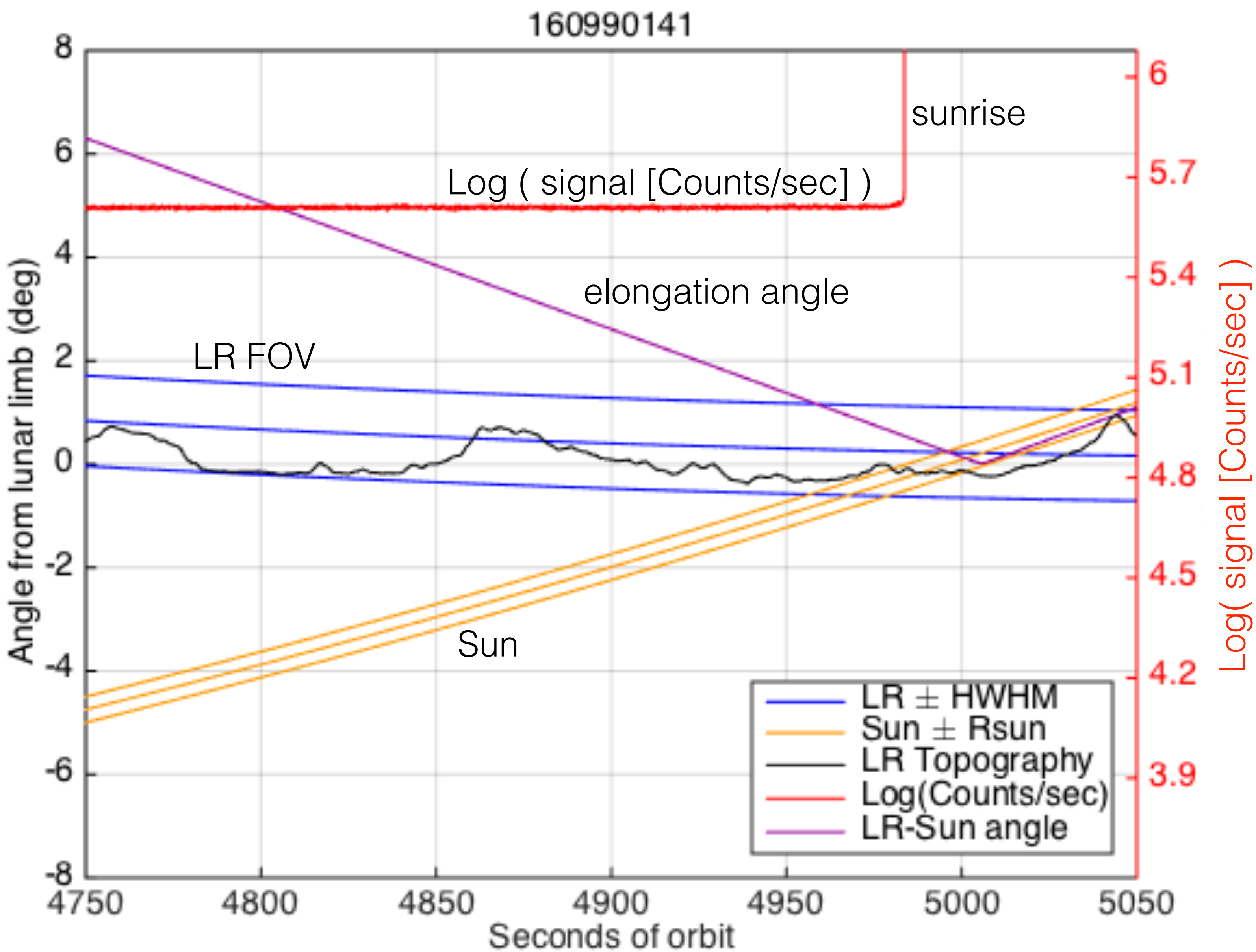




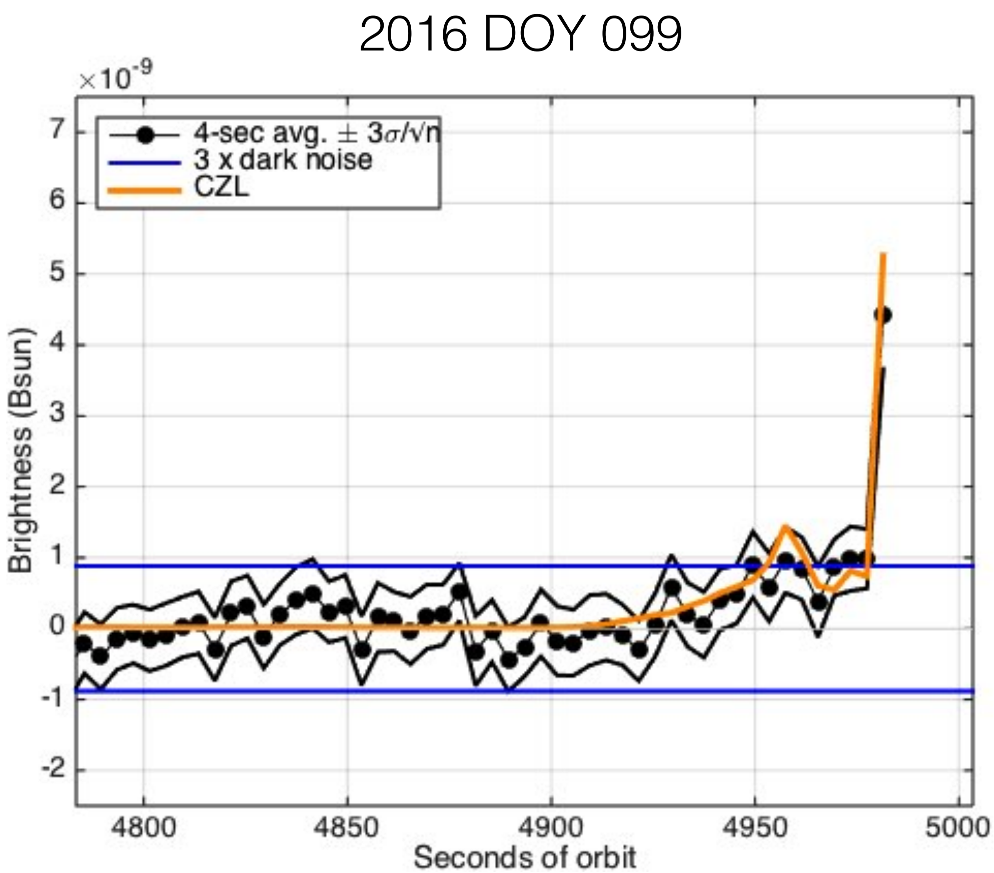
LOLA-LR can withstand direct sunlight and observe arbitrarily close to the Sun without damaging itself or any of the other instruments.

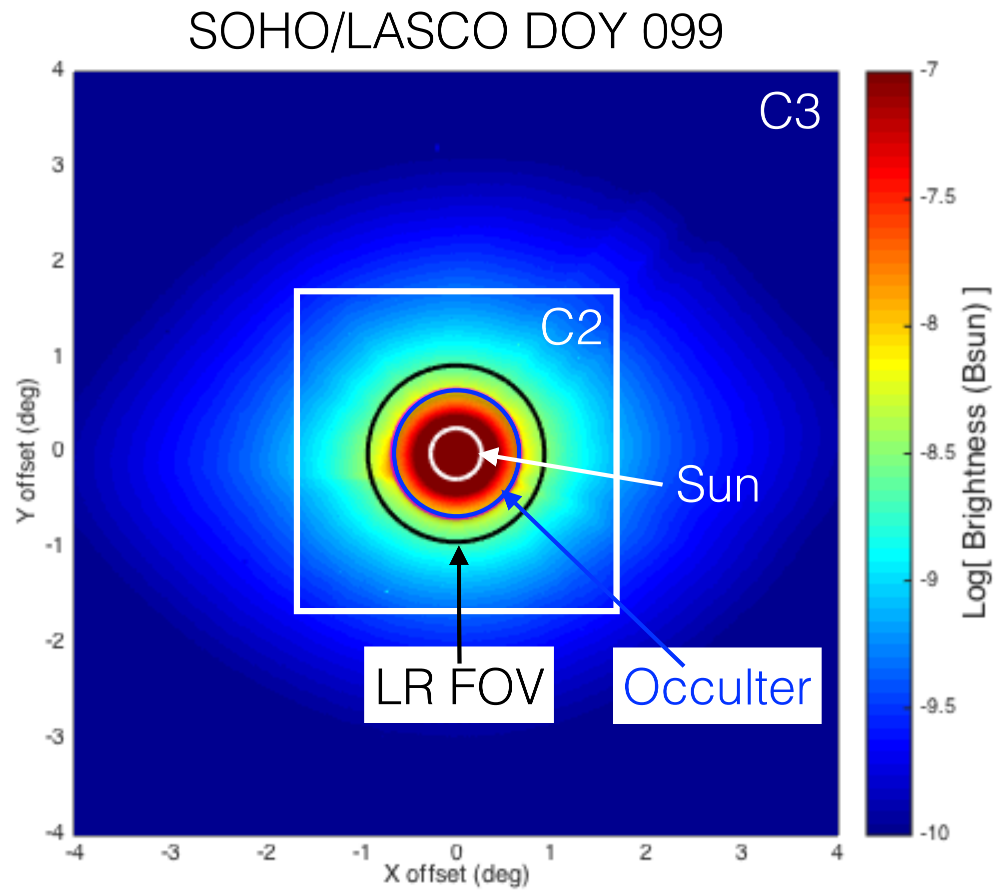
2016 DOY 99

Beta: 63



Coronal & Zodiacal Light (CZL)

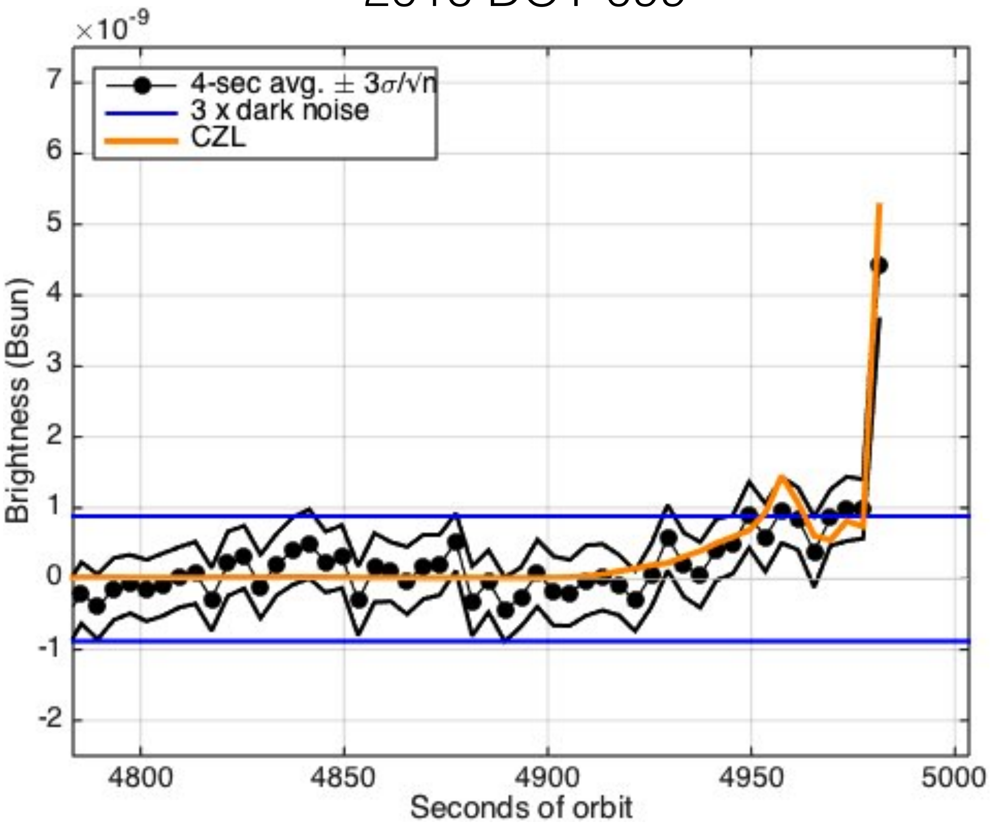


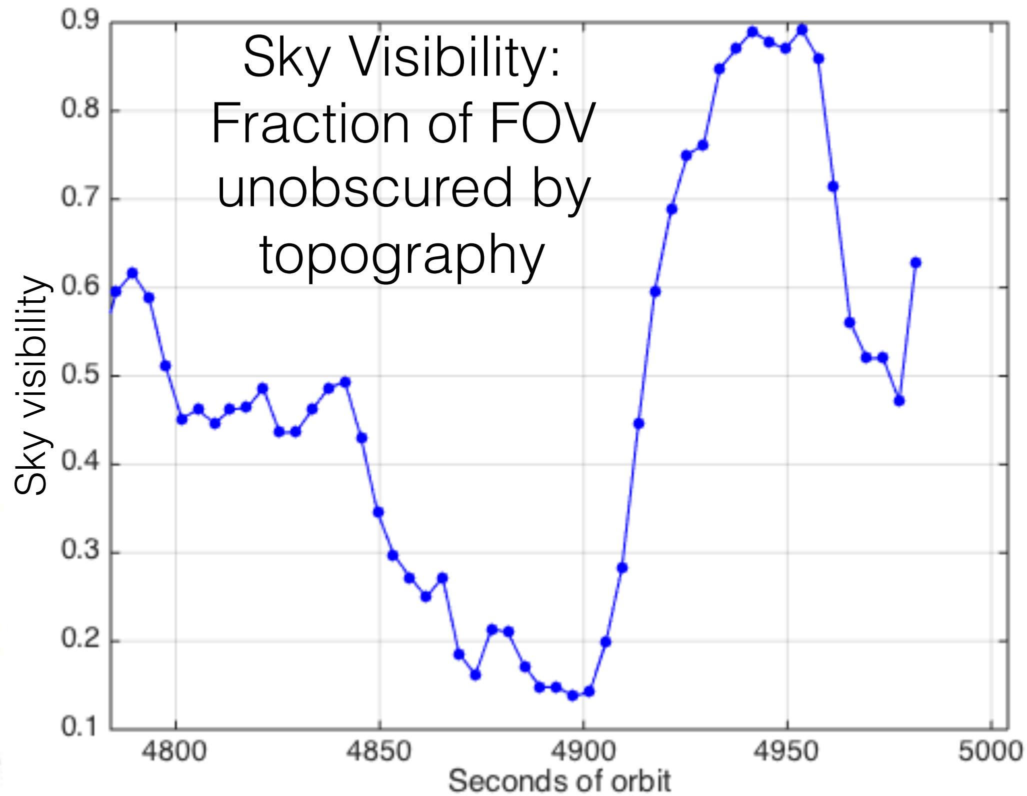


The photometric calibration is achieved by fitting the data from this particular scan to a semi-empirical CZL model, shown by the orange line and based on LASCO images from the same day. The same scale factor is then used for the other scans.

It is important to model the sky visibility within the LR FOV.

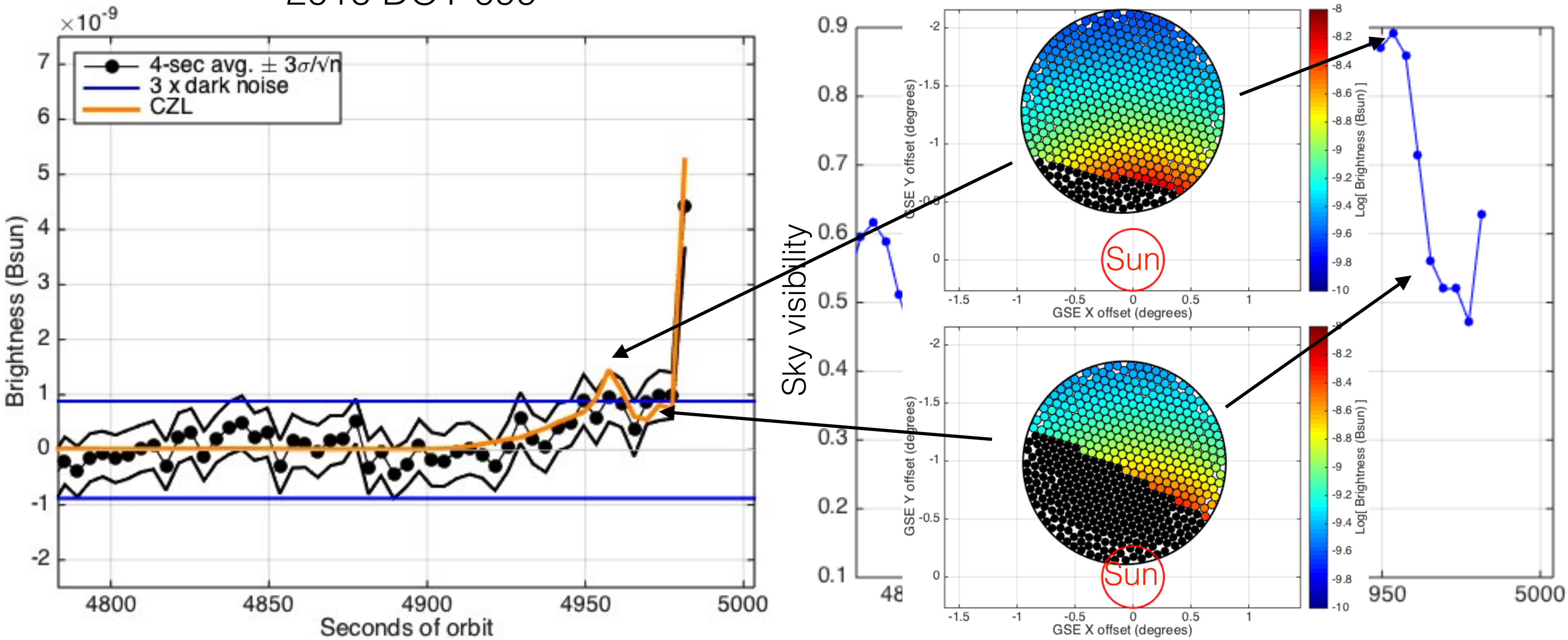
2016 DOY 099





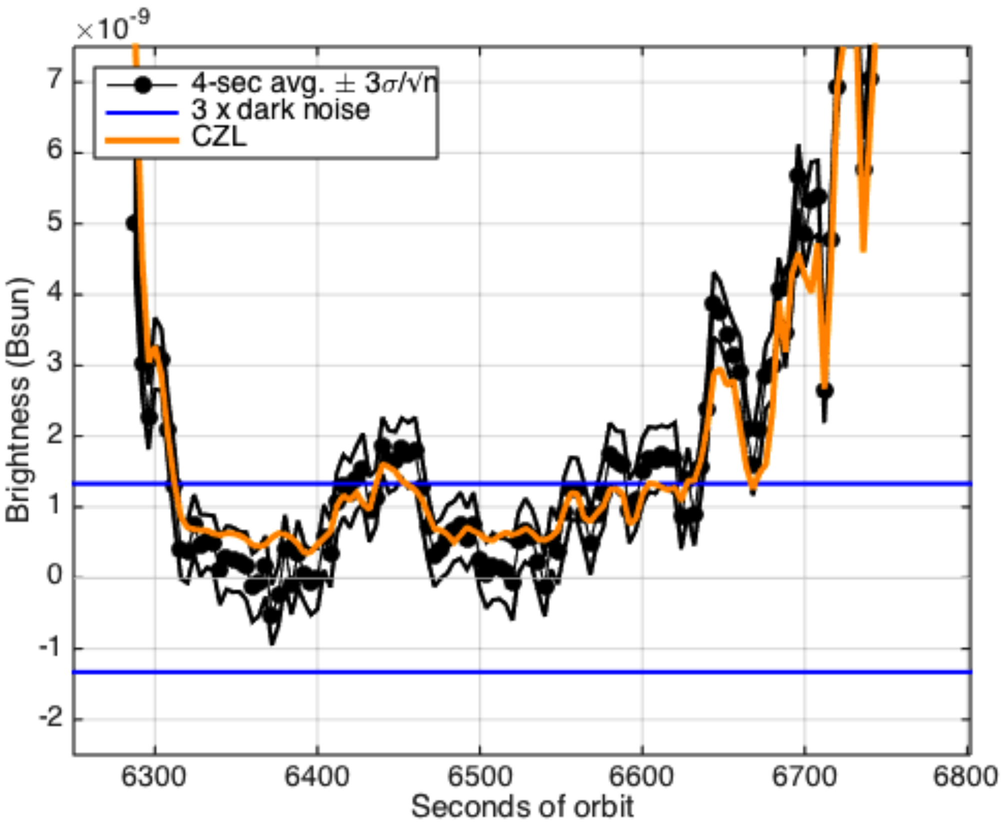
To calculate the sky visibility, sub-sample the FOV with 500 sightlines.

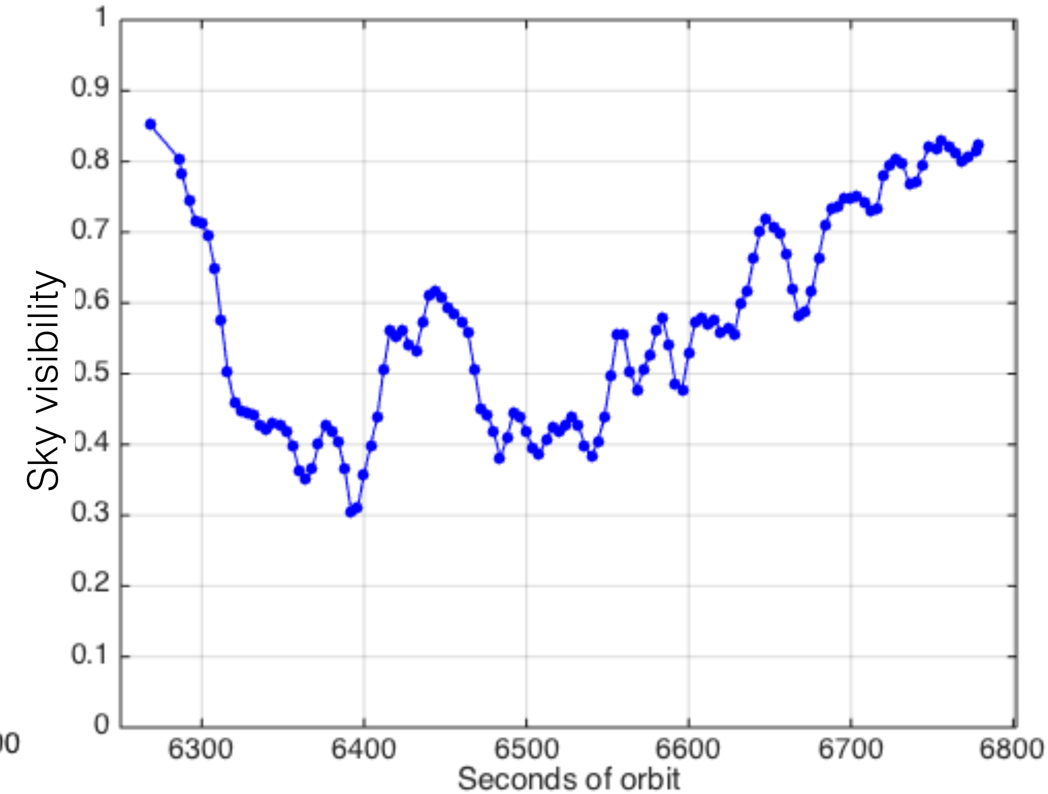
2016 DOY 099



Another example: 2016 DOY 142

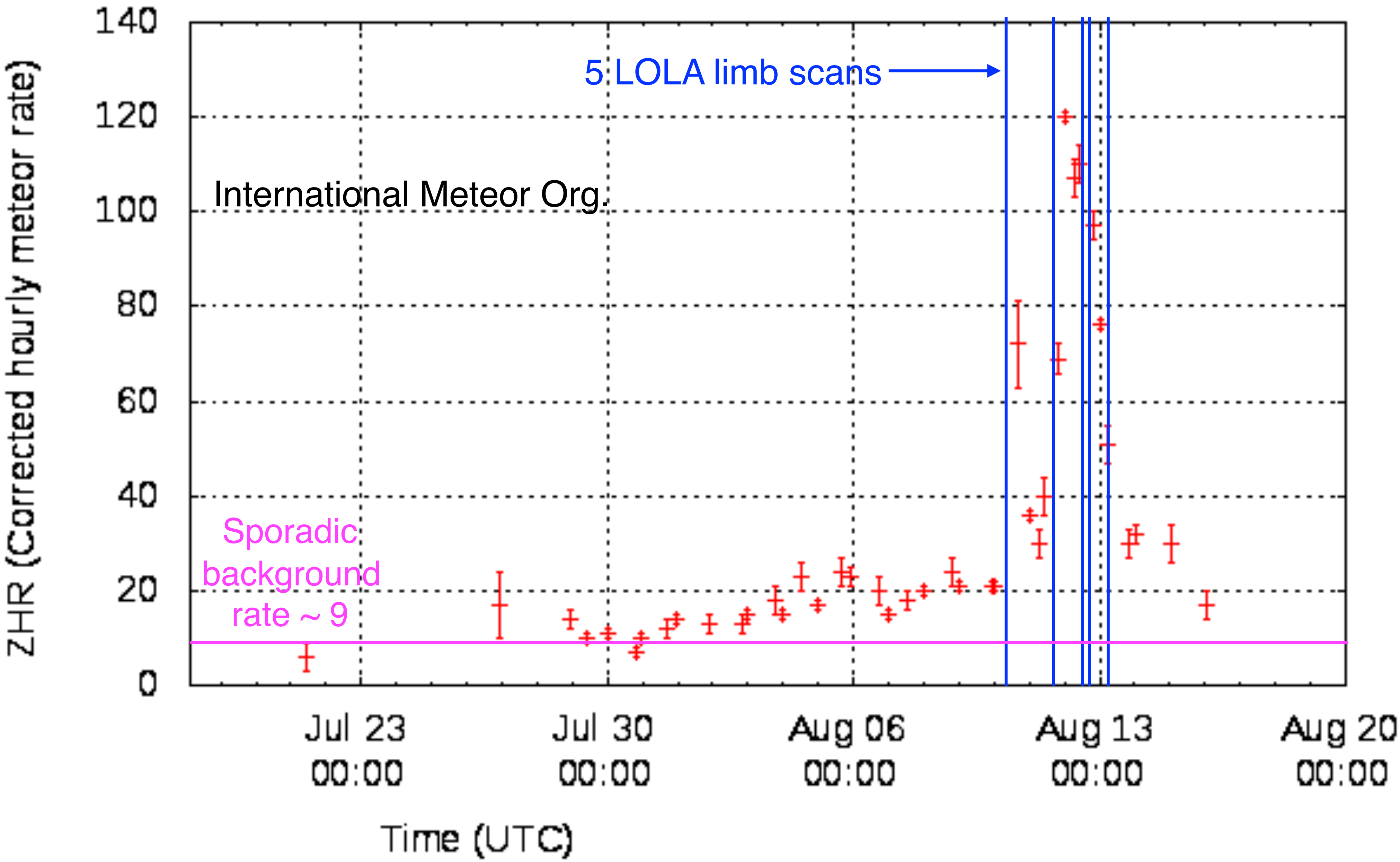
Beta: 72





Elongation fixed at ~0.7°.
Fluctuations in the signal are well correlated with the sky visibility.

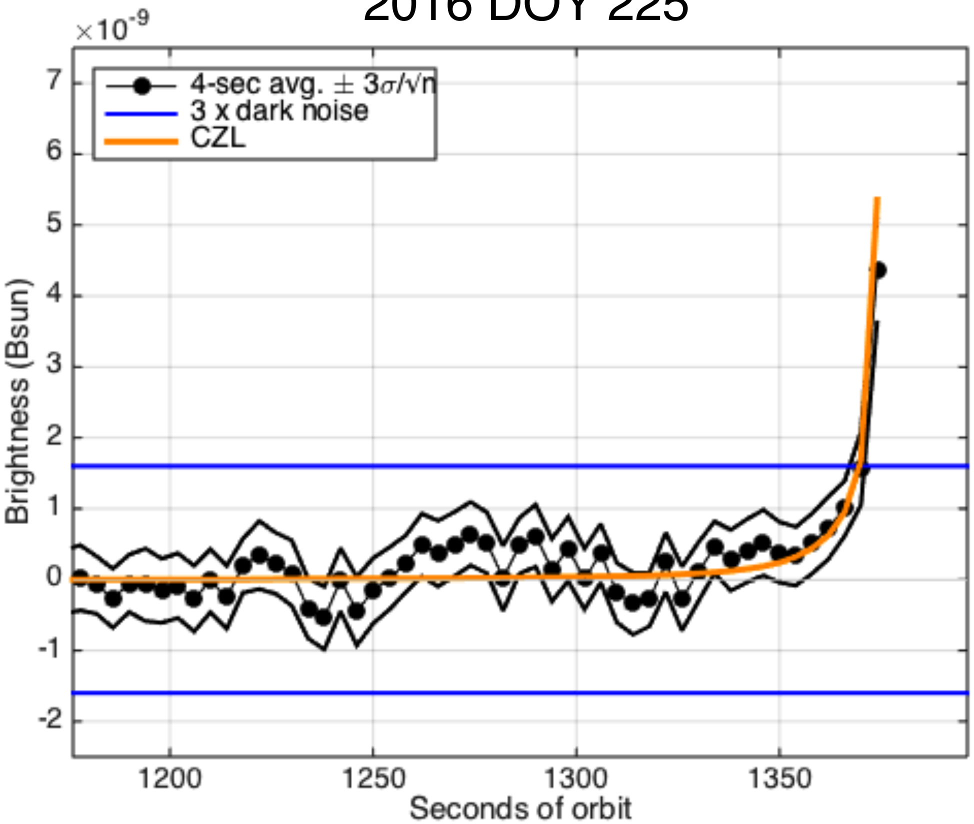
2016 Perseid Meteor Stream Observations

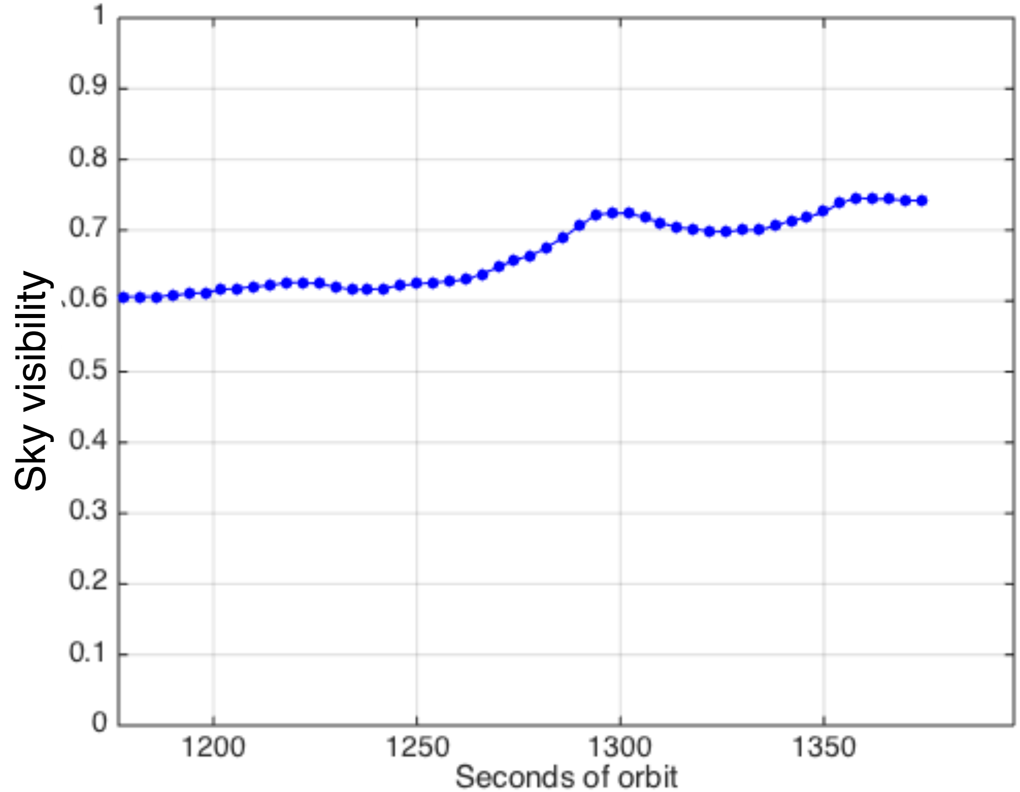


Perseids Limb Scan

Beta: 10°

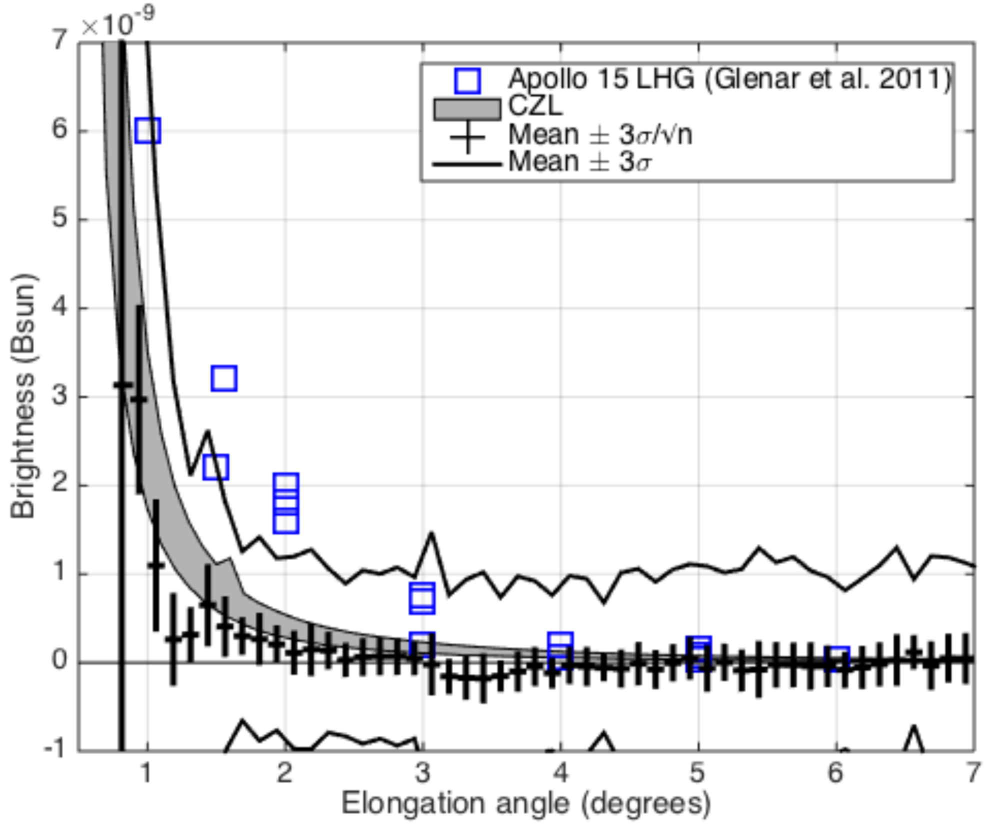
2016 DOY 225

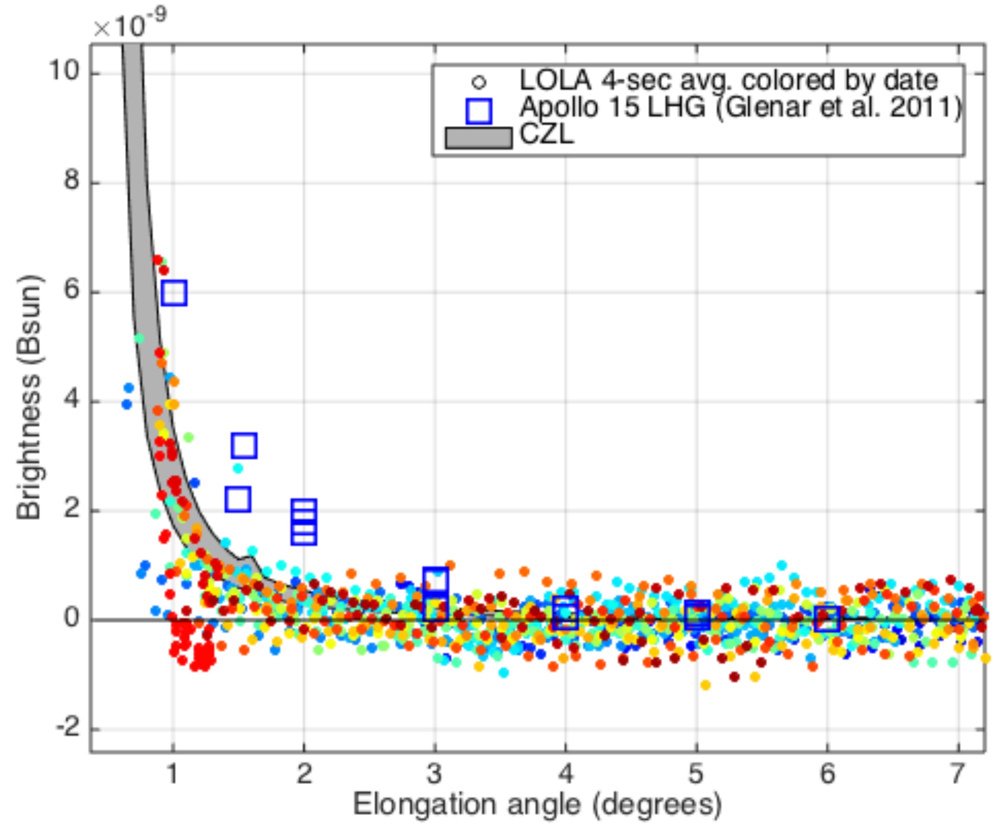




All 5 Perseid limb scans show similar behavior, as do 2 Leonids, 2 Geminids, 3 Quadrantids.

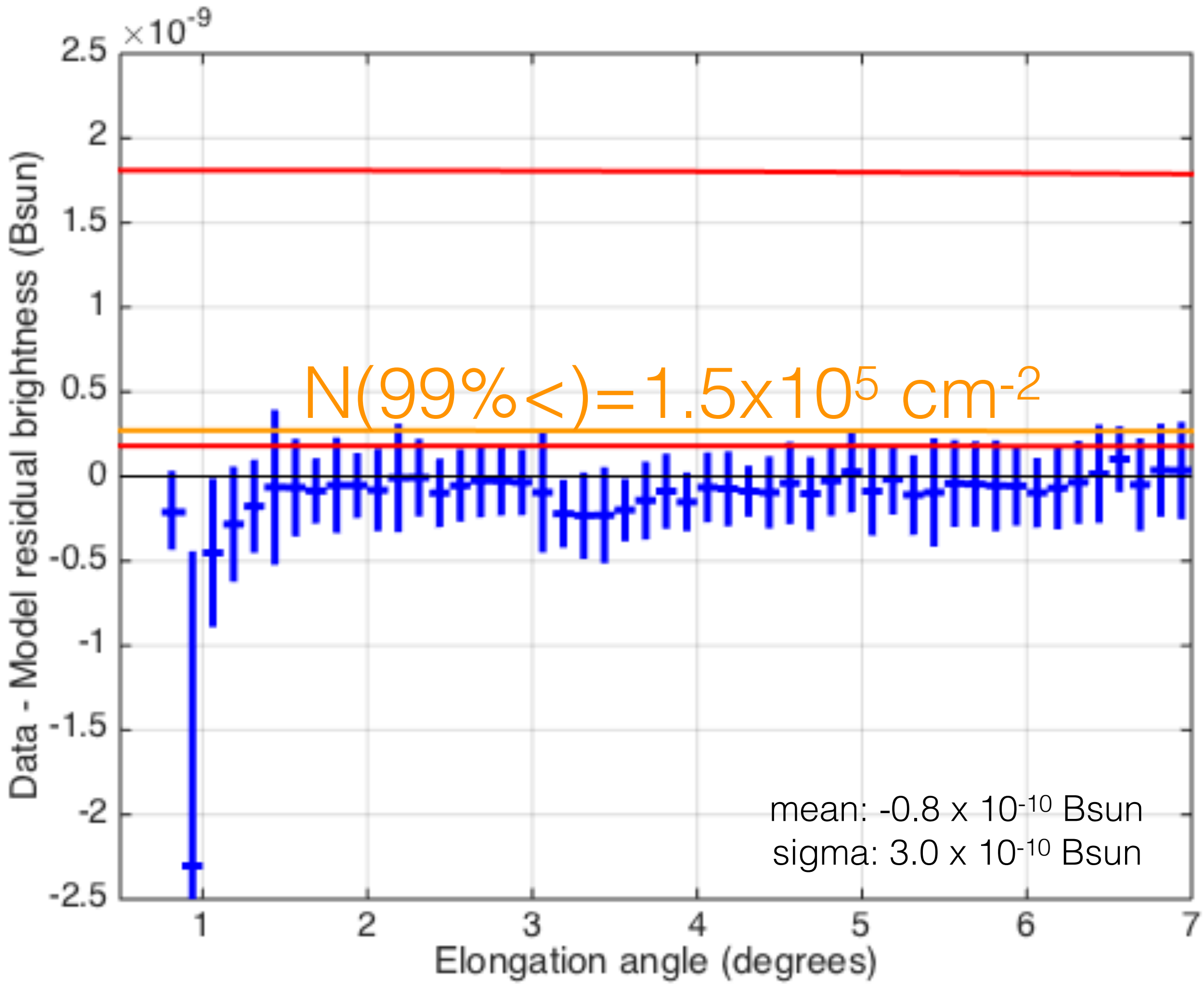
As of Jan. 03, 2017,
33 total
(21 dawn, 12 dusk,
12 stream)





Optimal elongation ≲ 3°

Data - CZL residuals



r=0.1 μm

N=10^6 cm^{-2}

N=10^5 cm^{-2}

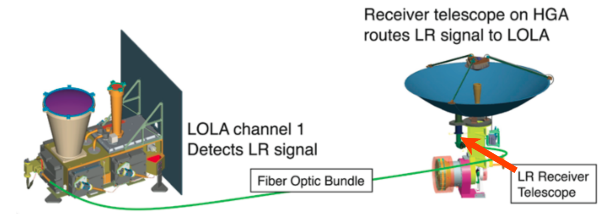
No significant difference if split by dawn/dusk or stream/no-stream

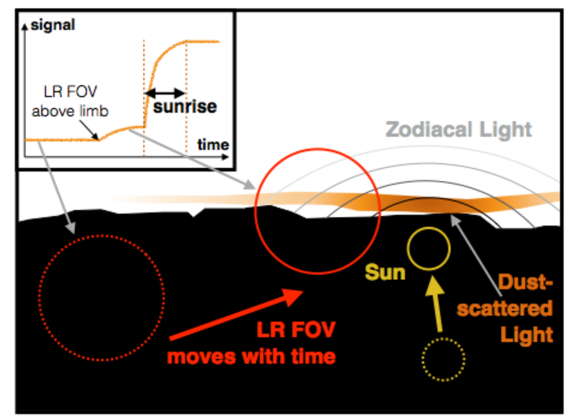
N ~ 100x lower for r = 0.3 μm

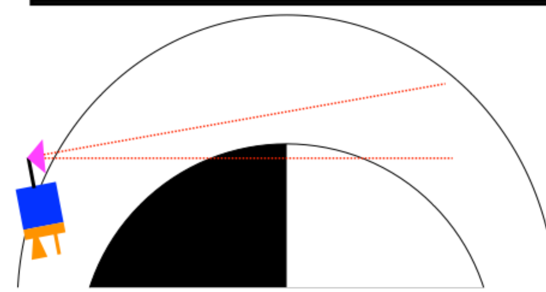
Summary: LOLA Search for LHG

- Advantages of a LOLA LHG search:
  - Can observe arbitrarily close to the Sun
  - Long time baseline & regular sampling including meteor streams
  - Focus on altitudes < 20 km

- 33 sunrise limb scans conducted so far
  - 12 during streams
- Routine detection of CZL at elong. angle ≲ 2°
- Could detect an Apollo 15-like LHG out to ~3°
- No clear evidence yet of an A15-like LHG
- Preliminary upper limit on N ~ 10^5 cm^{-2}







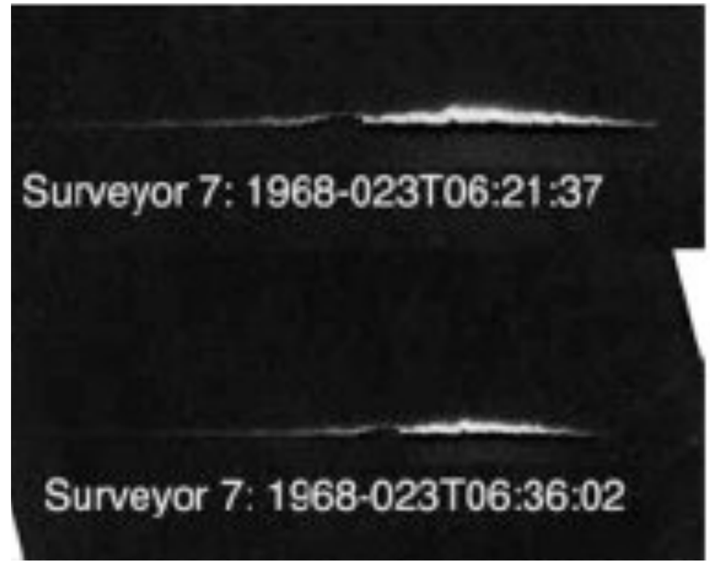
The End

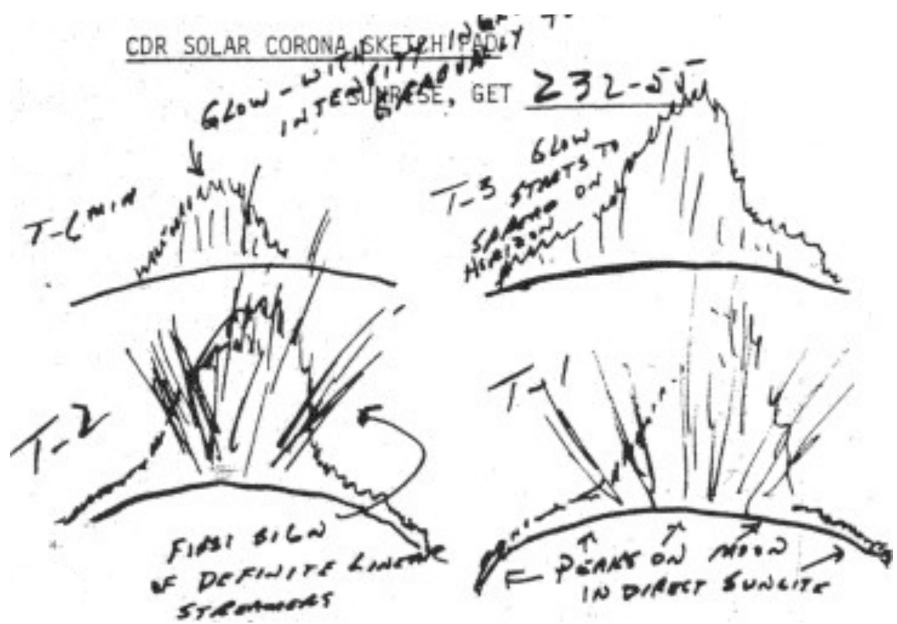
Backups

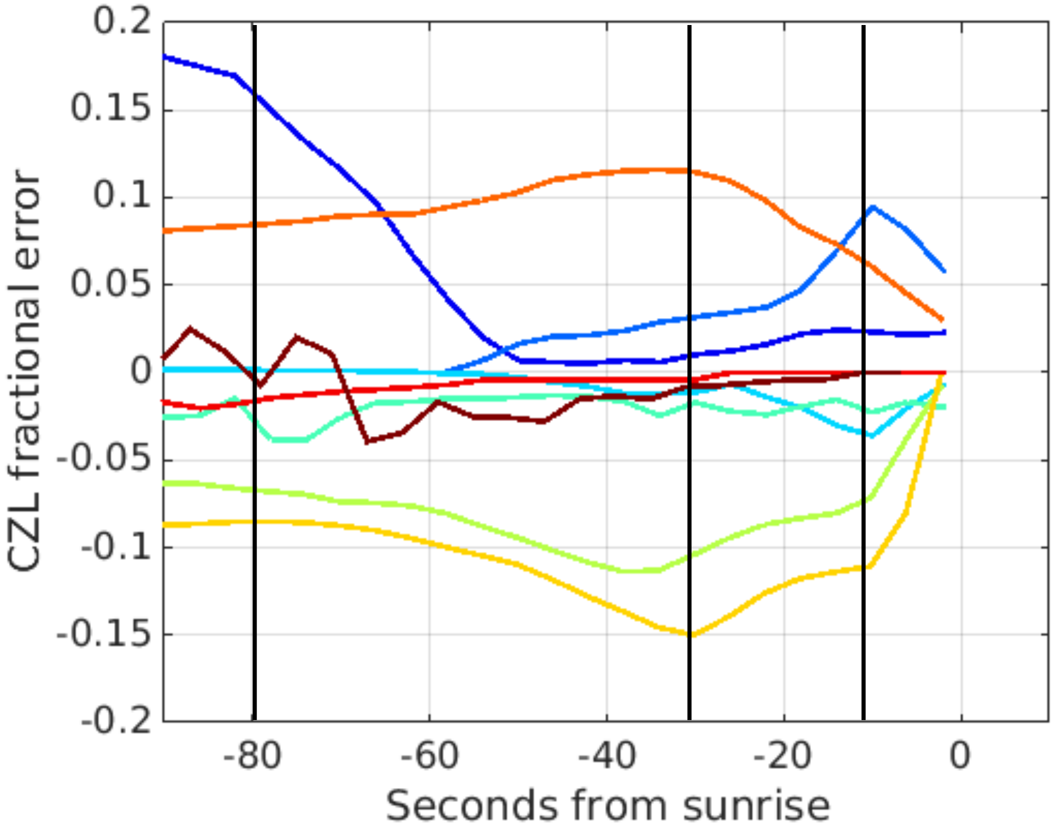
Lunar Horizon Glow

- LHG: Excess sky brightness before sunrise or after sunset.
- Usually interpreted as scattered sunlight from exospheric dust grains.
- The properties of the LHG (i.e., brightness, dimensions, when & where it occurs) depend on the dust grain characteristics and transport mechanisms.

    ==> Surface science & exploration

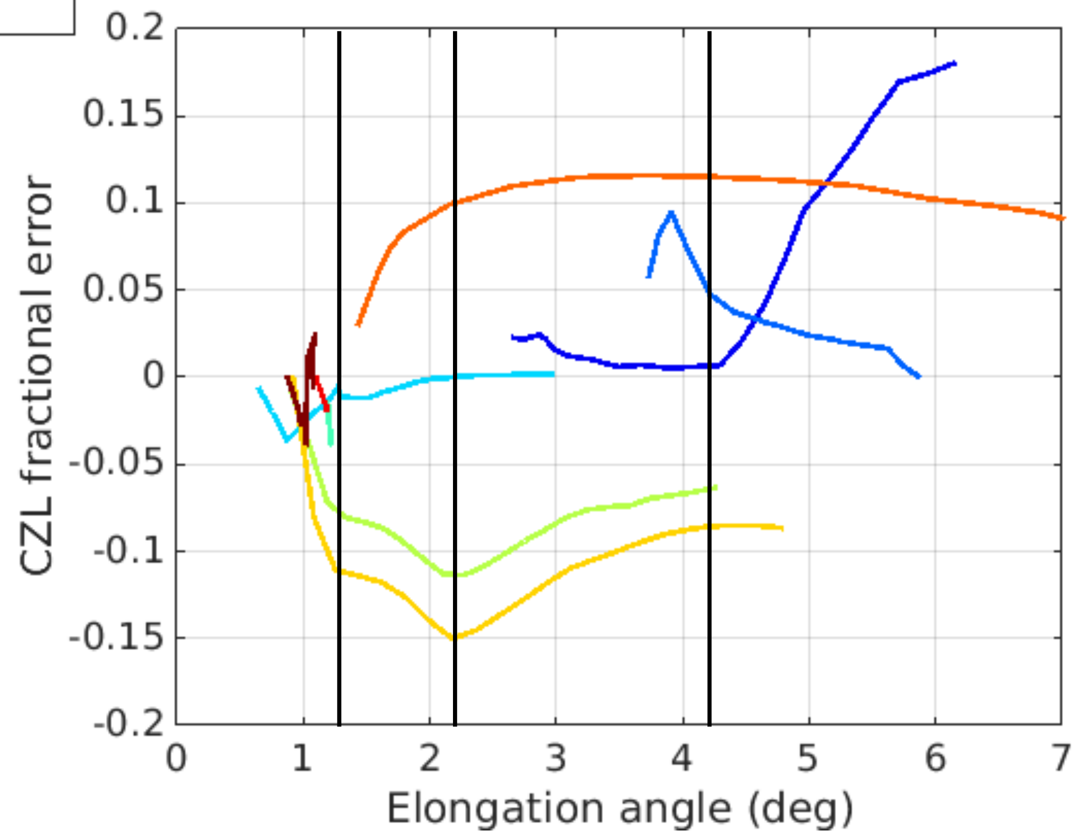




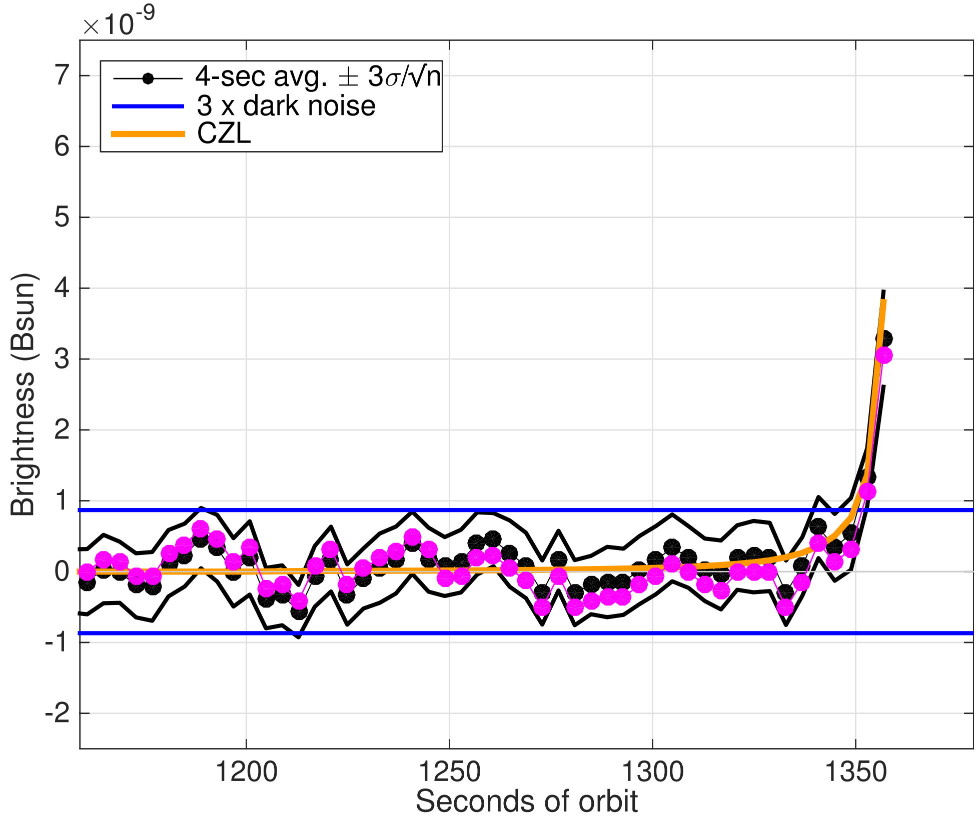


LASCO CZL on different dates

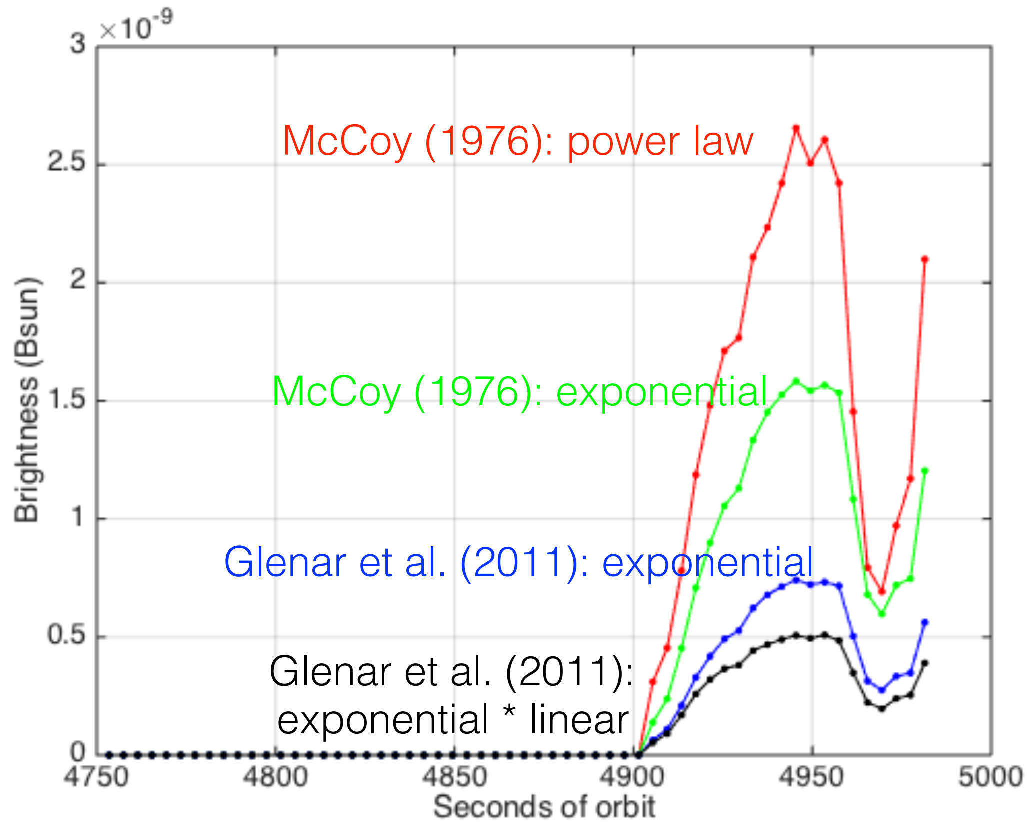
DOY XXX - DOY 099
DOY 014
DOY 061
DOY 092
DOY 142
DOY 182
DOY 226
DOY 280
DOY 284
DOY 321



Temperature dependence

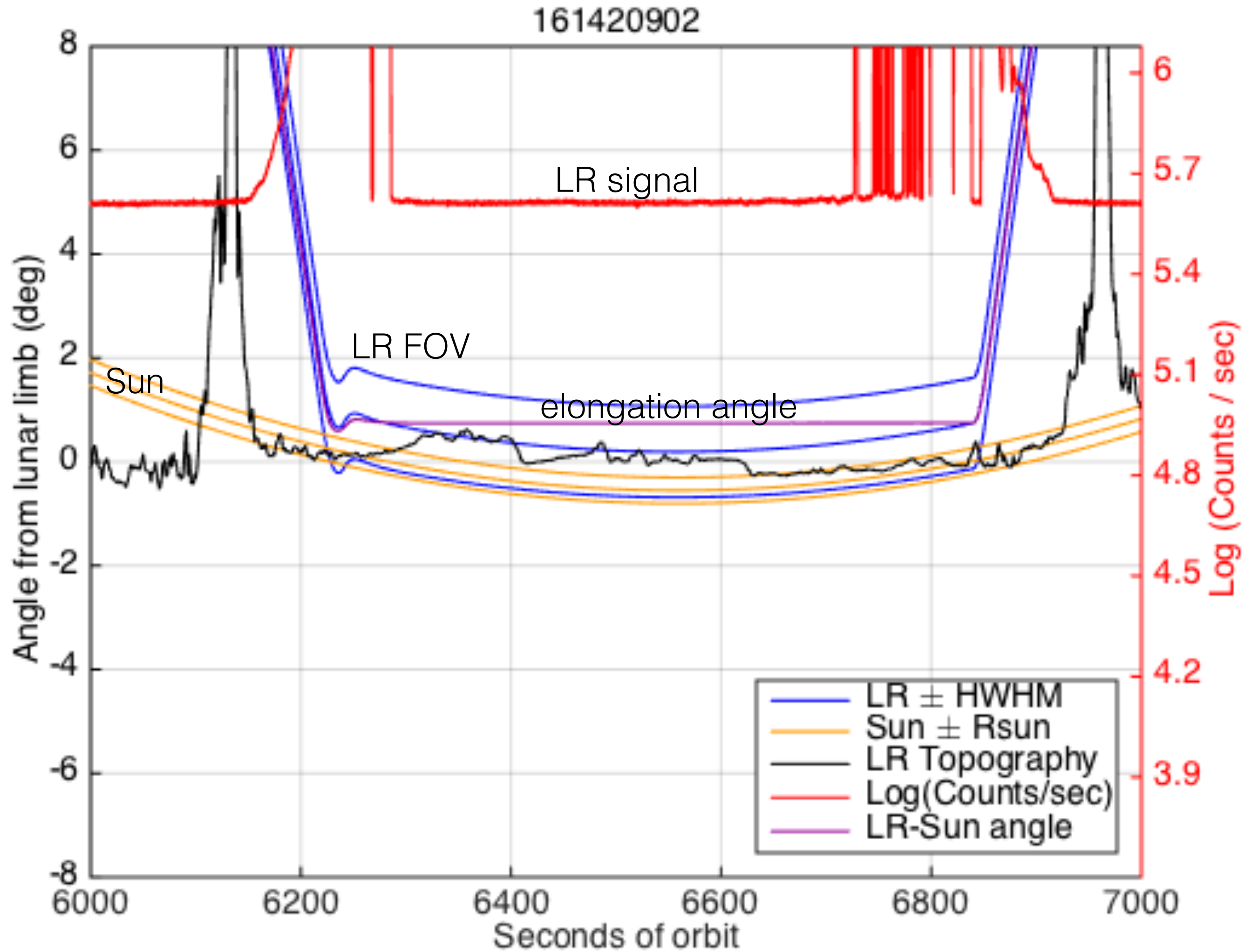


Different dust density models:

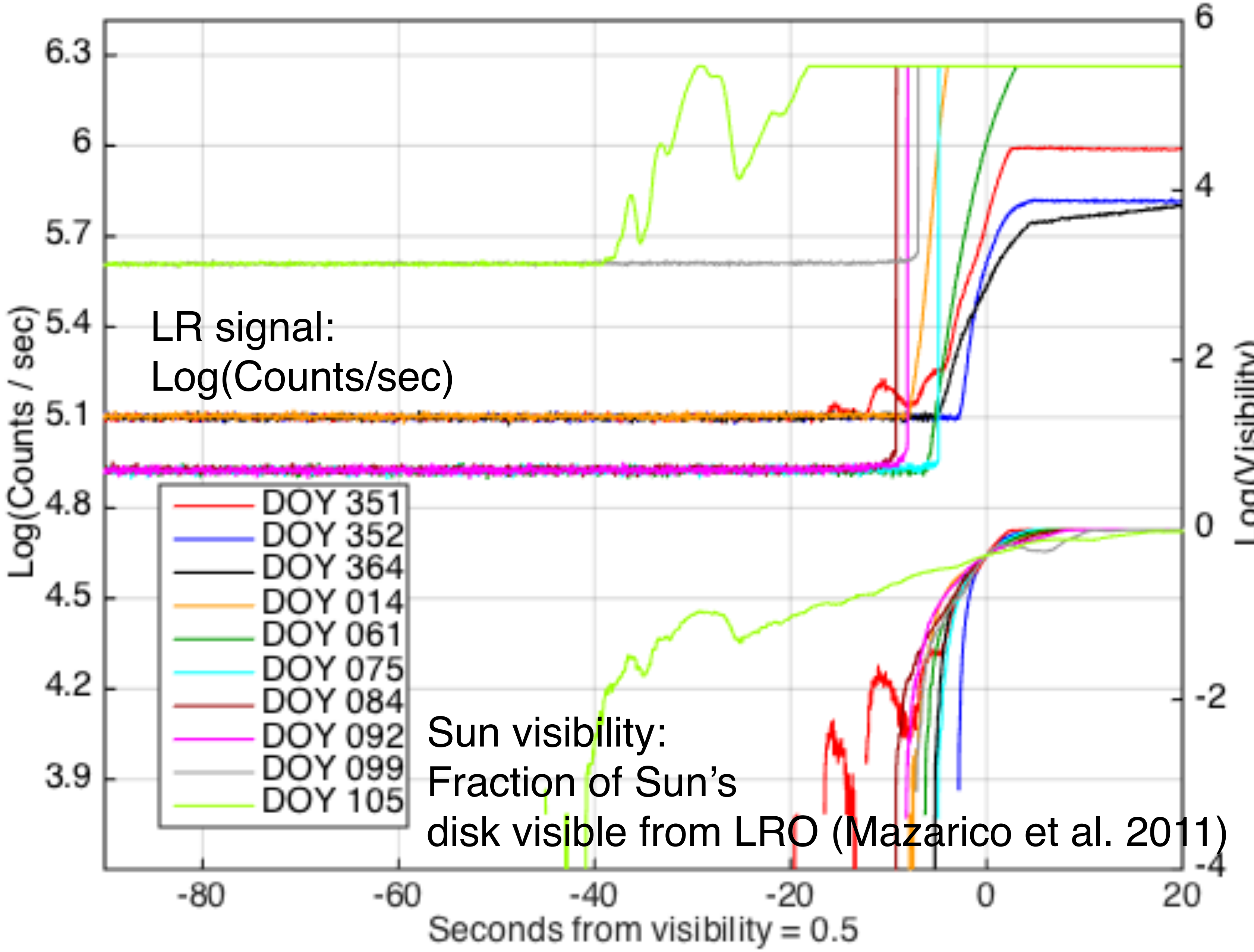


Another example: 2016 DOY 142

Beta: 72



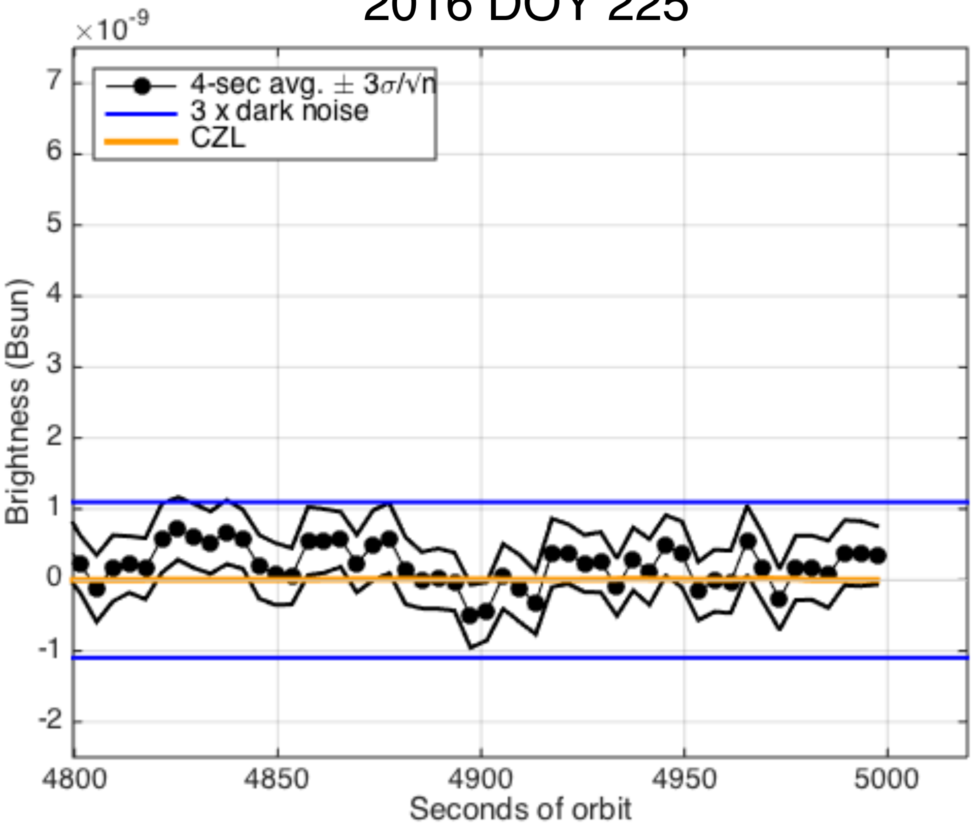
Illumination Modeling

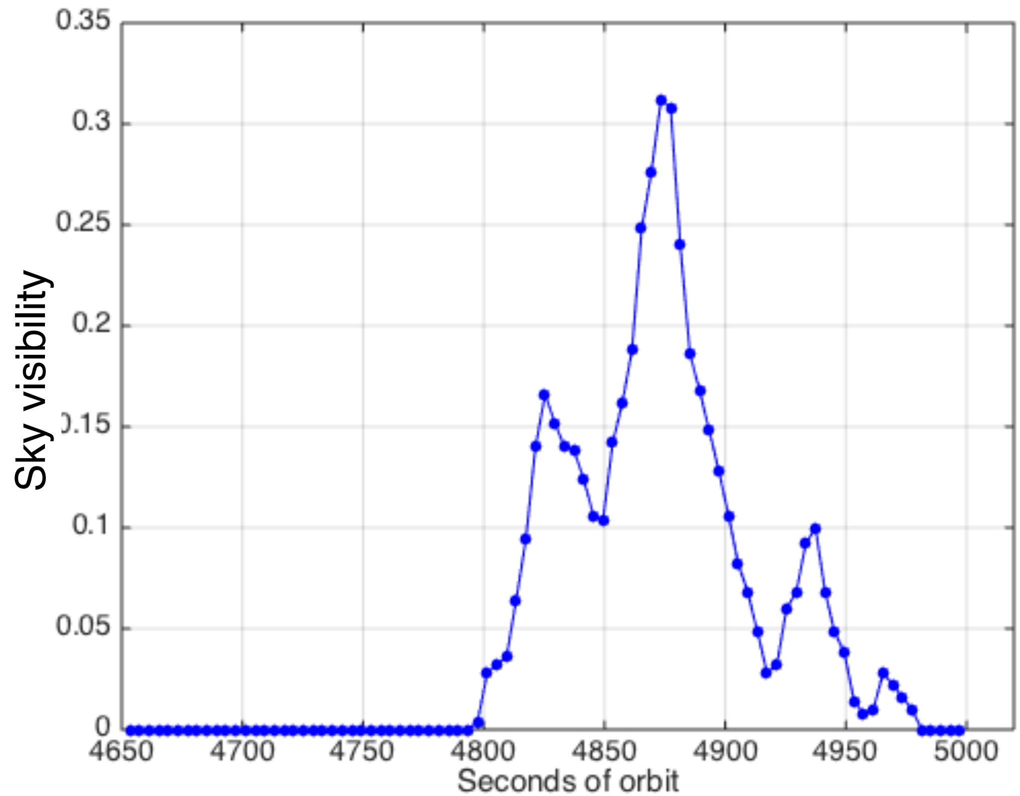


Geminids Limb Scan

Beta: 42°

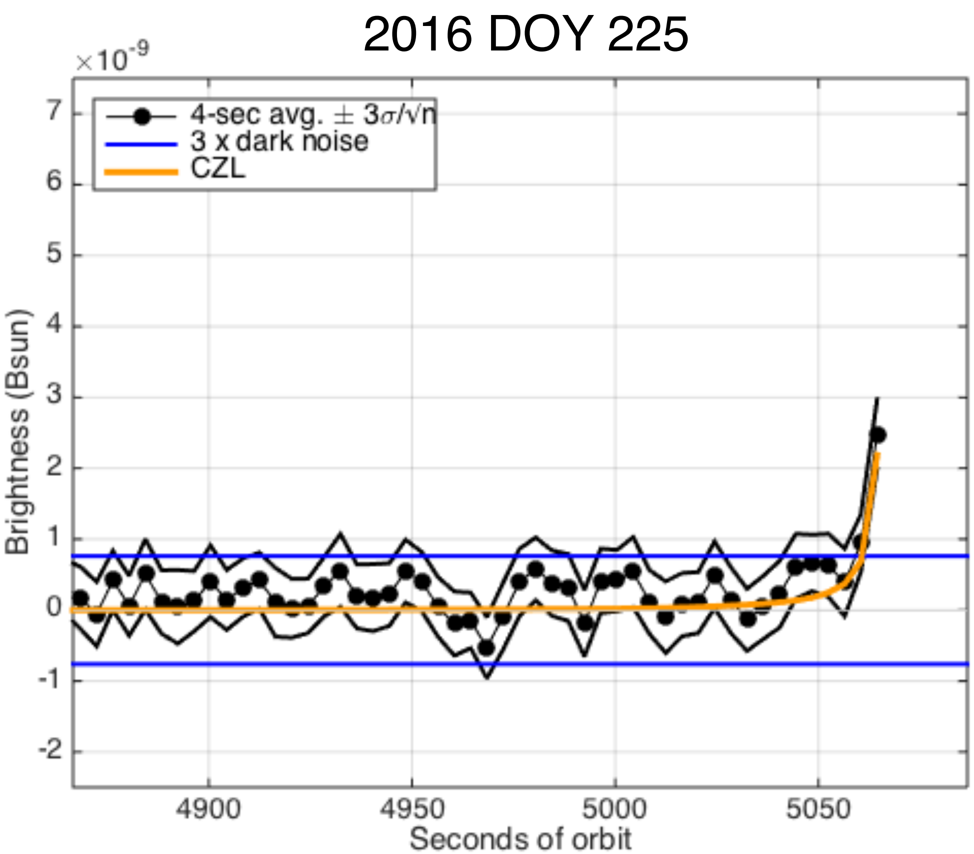
2016 DOY 225

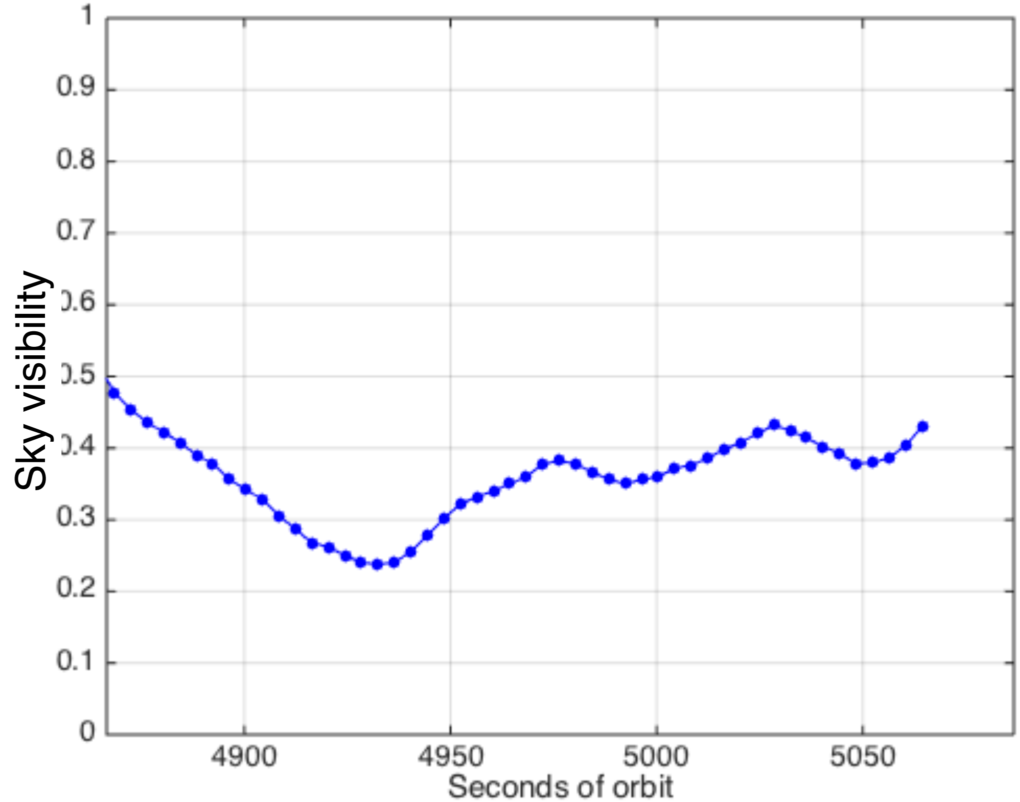




Quadrantids Limb Scan

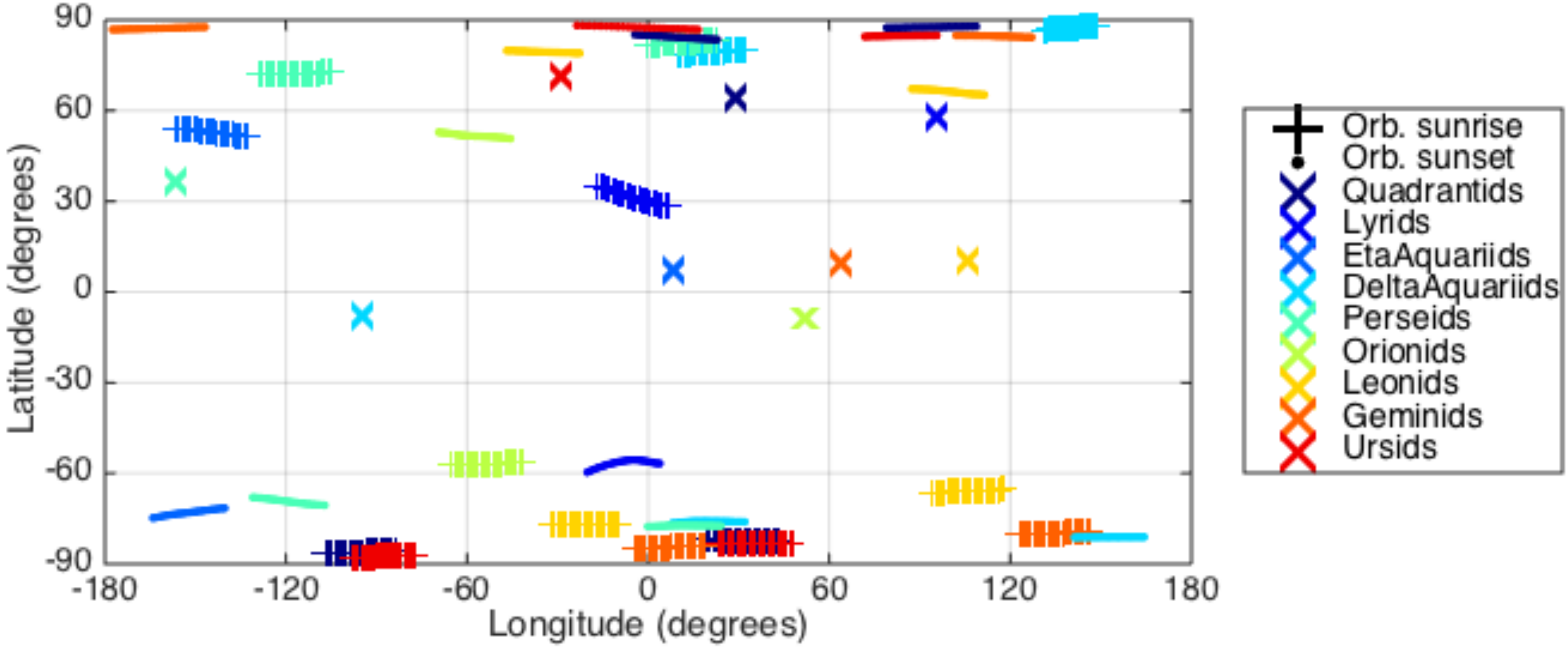
Beta: 21°

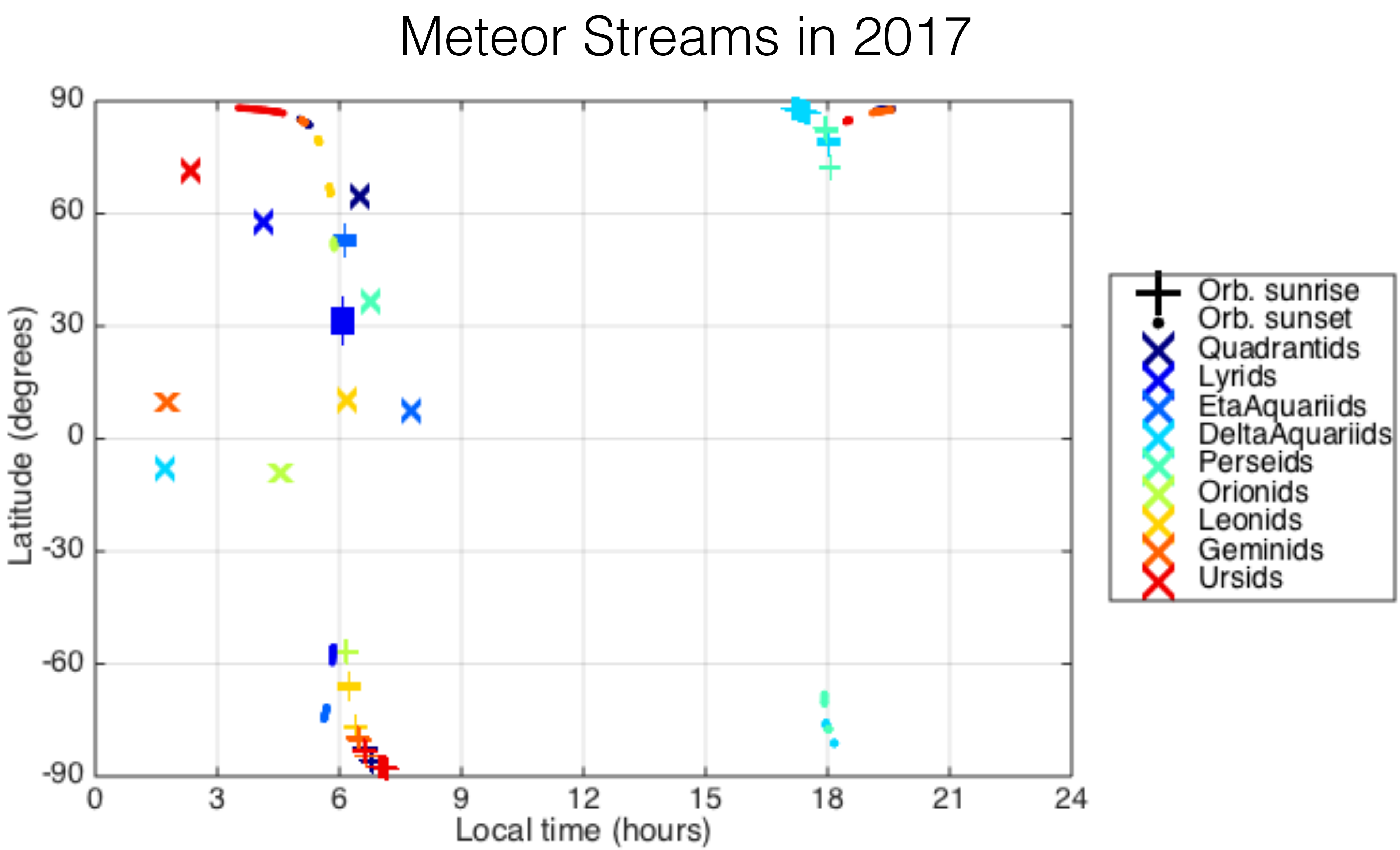




	RA (deg)	DEC (deg)	Radiant long.	Radiant lat.	Horizon long.	Horizon lat.	Local time
2016 PER	48	58	351	37	150	89	dusk
2016 LEO	152	22	243	10	237	-40	dawn
2016 GEM	112	33	213	10	300	-75	dawn
2017 QUA	230	49	30	64	30	-83	dawn

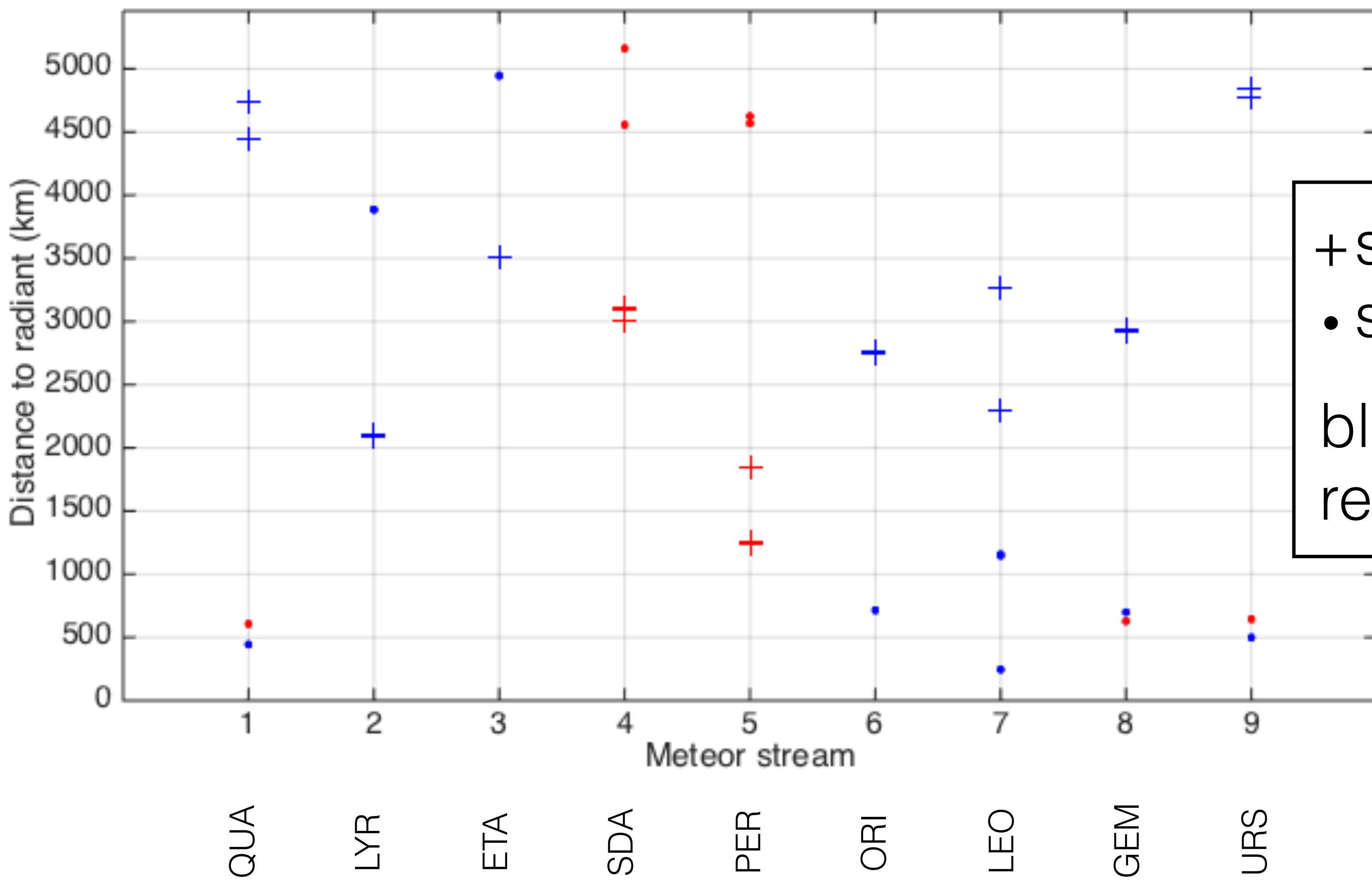
Meteor Streams in 2017





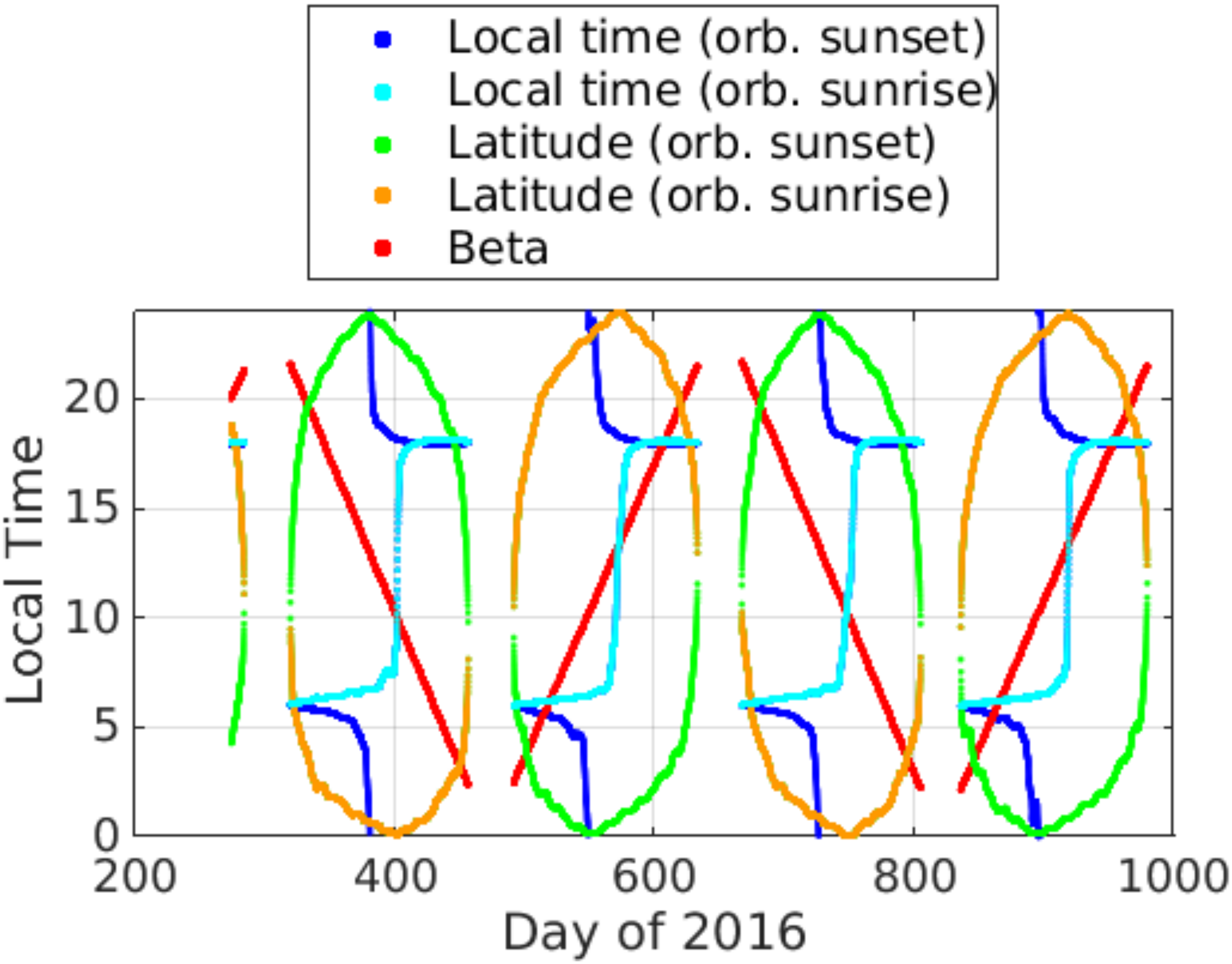
Meteor Streams in 2017
Latitude (degrees)
90
60
30
0
-30
-60
-90
0
3
6
9
12
15
18
21
24
Local time (hours)
Orb. sunrise
Orb. sunset
Quadrantids
Lyrids
EtaAquariids
DeltaAquariids
Perseids
Orionids
Leonids
Geminids
Ursids

LRO is sometimes closer to stream radiant at orbital sunset than at sunrise



+ sunrise
• sunset

blue: dawn
red: dusk


Local time (orb. sunset)
Local time (orb. sunrise)
Latitude (orb. sunset)
Latitude (orb. sunrise)
Beta
Local Time
0
5
10
15
20
200
400
600
800
1000
Day of 2016