Upper Limits for the Abundance of Lunar Exospheric Dust

from Clementine Star Tracker Limb Measurements

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2012 Lunar Science Forum

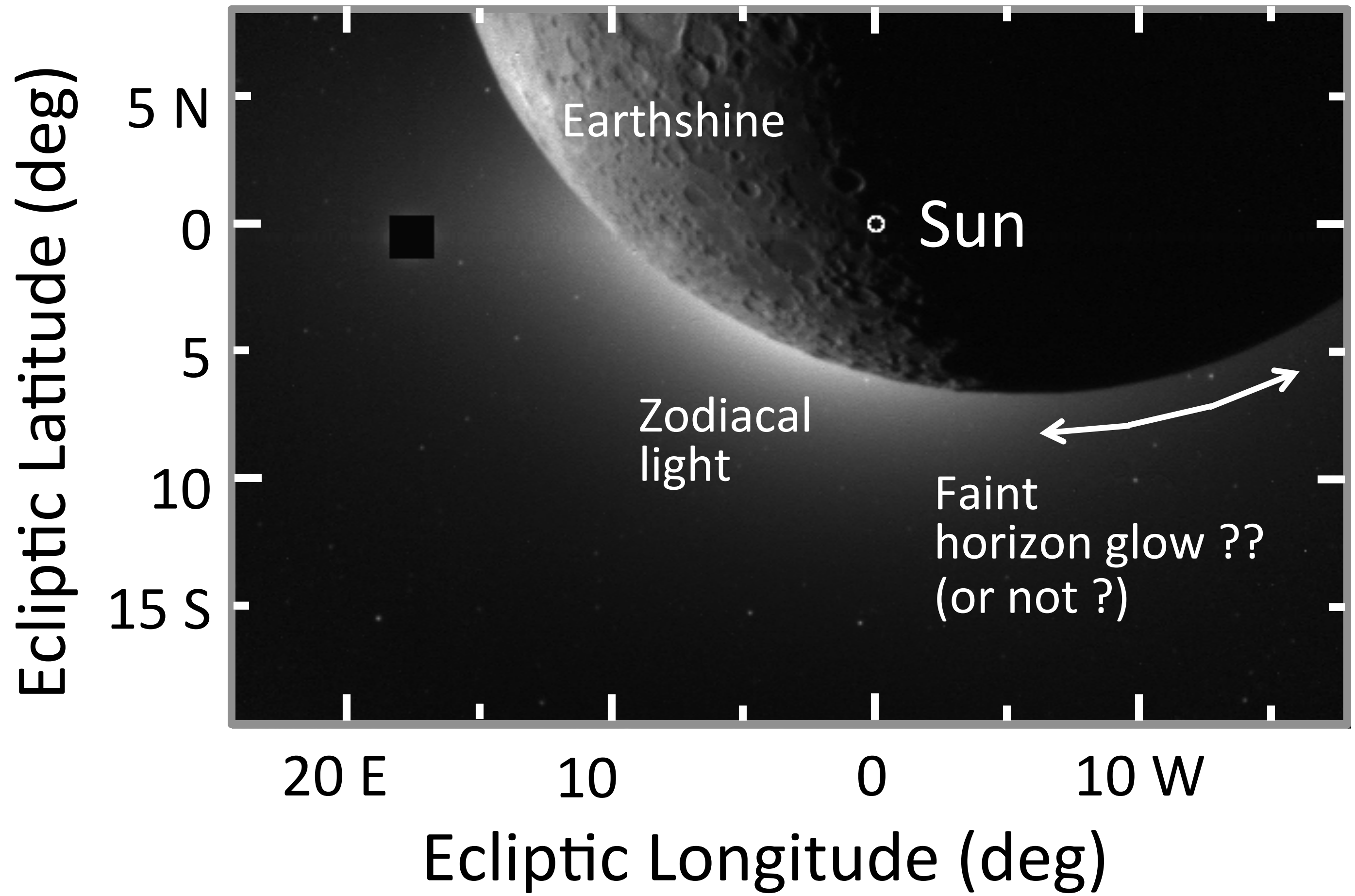
The high altitude dust exosphere . .

Sporadic observations exist, but confident detection has been elusive

Searches and apparent detections

- ❑ Visual observations/sketches) of horizon glow (HG) by **Apollo 17** astronauts (McCoy, Zook, Criswell; ‘74, ’91)
- ❑ Uplooking photometry from the surface by **Lunokhod-2** lander (Severny et al. ‘75). Detected VIS and UV signals.
- ❑ Conspicuous excess light in calibrated, **Apollo 15** coronal photographs at orbital sunset (McCoy ’76). Reanalyzed by Glenar et al. 2011.
- ❑ 1994 **Clementine** star tracker measurements (weak but tentative HG detected; Zook et al. ‘95) **this talk**
- ❑ **Luna 19** radio occultation measurements show high electron concentrations (attributed to “dust electrons”; Stubbs et al. ‘11)
- ❑ Recent limb searches by **LRO/LAMP.** Ongoing. No detection as of July ‘12.
- ❑ Next year: **LADEE mission**. UVS and LDEX searches for exospheric dust

Sample Star Tracker Image – Orbit 193



Zook et al., LPS 26, '95:
"a very dim LHG, at about 10^{-13} B_o brightness, and with a scale height of 10-20 km has been observed with the star tracker camera . . .
This finding is still somewhat uncertain . . .

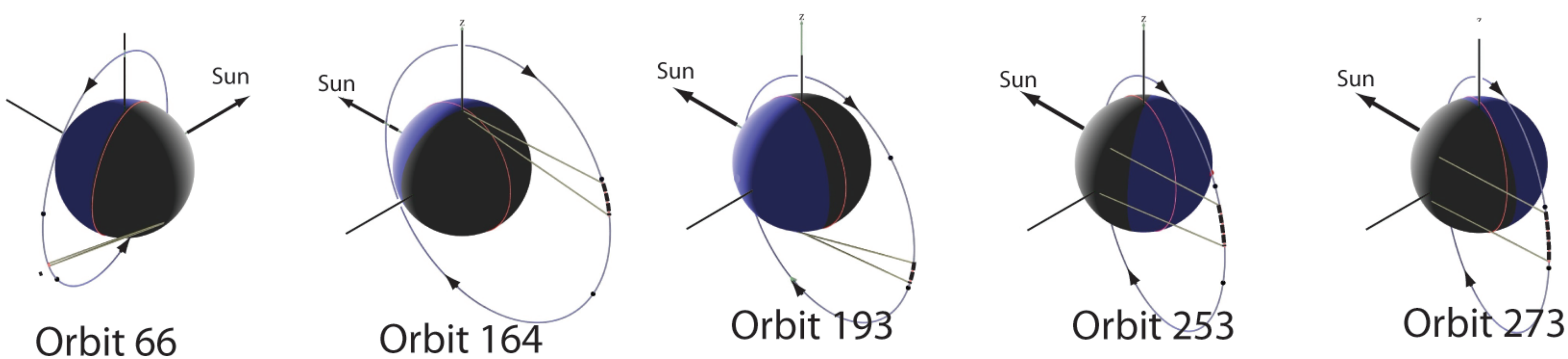
Clementine Measurements

- Two-month surface mapping mission at small (-30 to +30) solar phase angles

- Portions of 25 orbits allocated for horizon-glow searches using navigational star trackers. Spacecraft in shadow, look for forward-scattered sunlight from high altitude dust.

- Star tracker image sequences are photometrically calibrated (Hahn '02). *Two limitations: Low spatial-resolution at limb (~10 km) and 8-bit digitization, partly mitigated using multiple integration times.*

- We examine five sequences with Earth-dark limb, and small solar elongation angle (low dust illumination altitude).

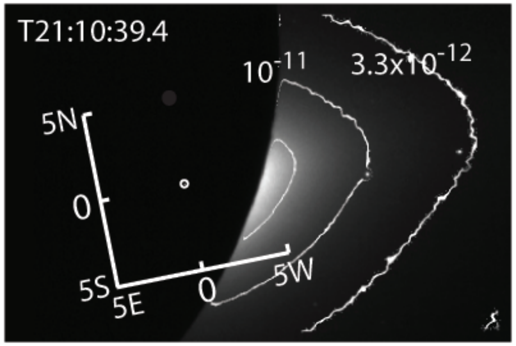


Sample Images from each series . . .

- ❑ Axes: Ecliptic coordinates
- ❑ Brightness contours in units of mean solar disk brightness (B_{Sun})

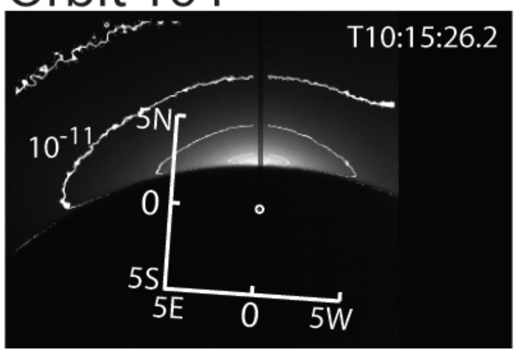
Surface Sunrise

Orbit 66

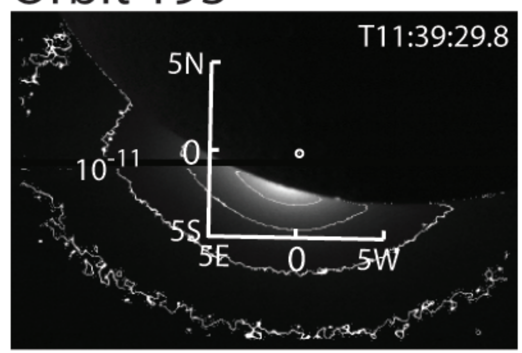


High Latitude

Orbit 164

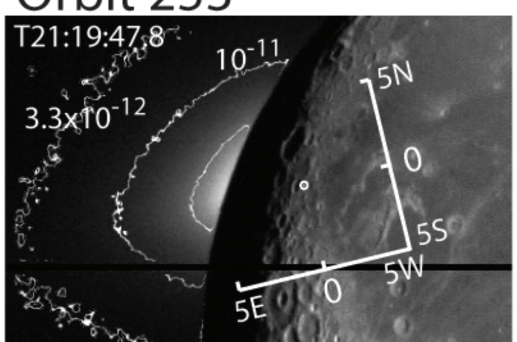


Orbit 193

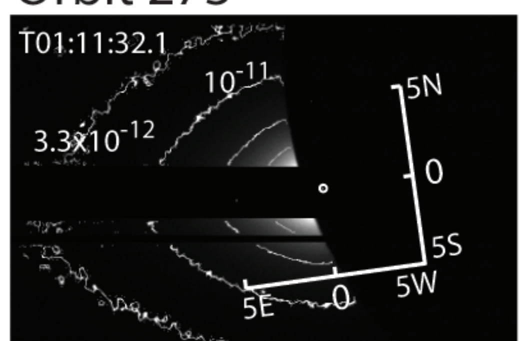


Surface Sunset

Orbit 253



Orbit 273



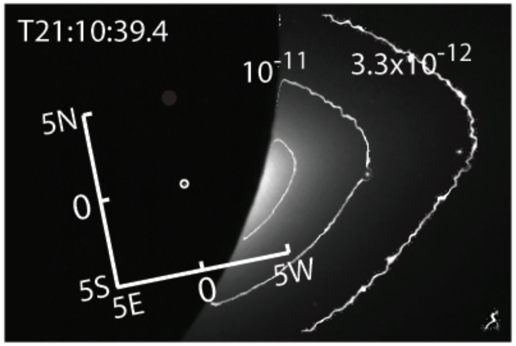
Sample Images from each series . . .

- Axes: Ecliptic coordinates
- Brightness contours in units of mean solar disk brightness (B_{Sun})

Need to subtract an independent Zodiacal light measurement !

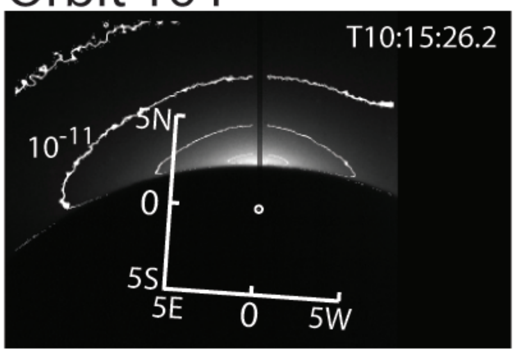
Surface Sunrise

Orbit 66

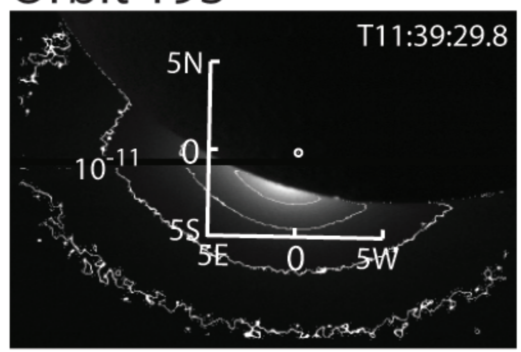


High Latitude

Orbit 164

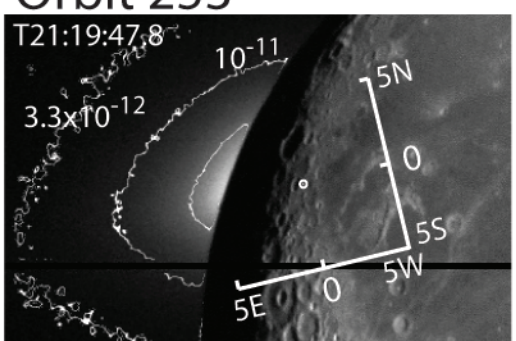


Orbit 193

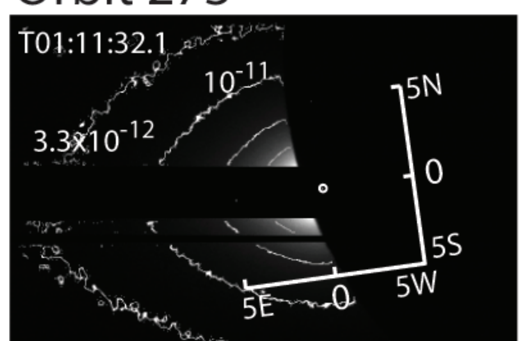


Surface Sunset

Orbit 253



Orbit 273

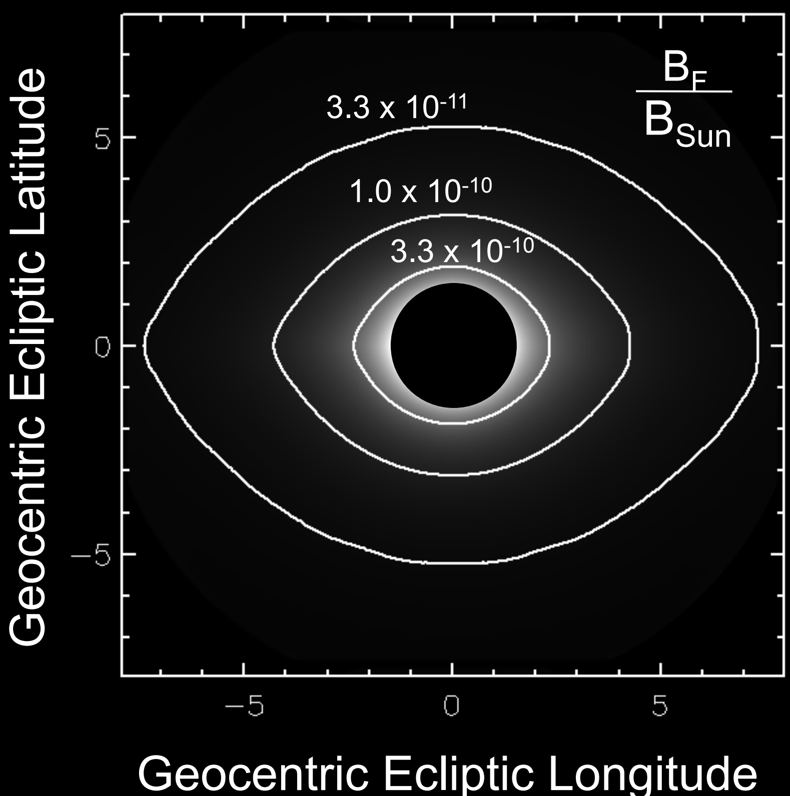


Inner Coronal-Zodiacal Light
(Feb-Apr, 2005 Image Series: SOHO/LASCO Wide-Field Coronagraph)

F (dust) corona

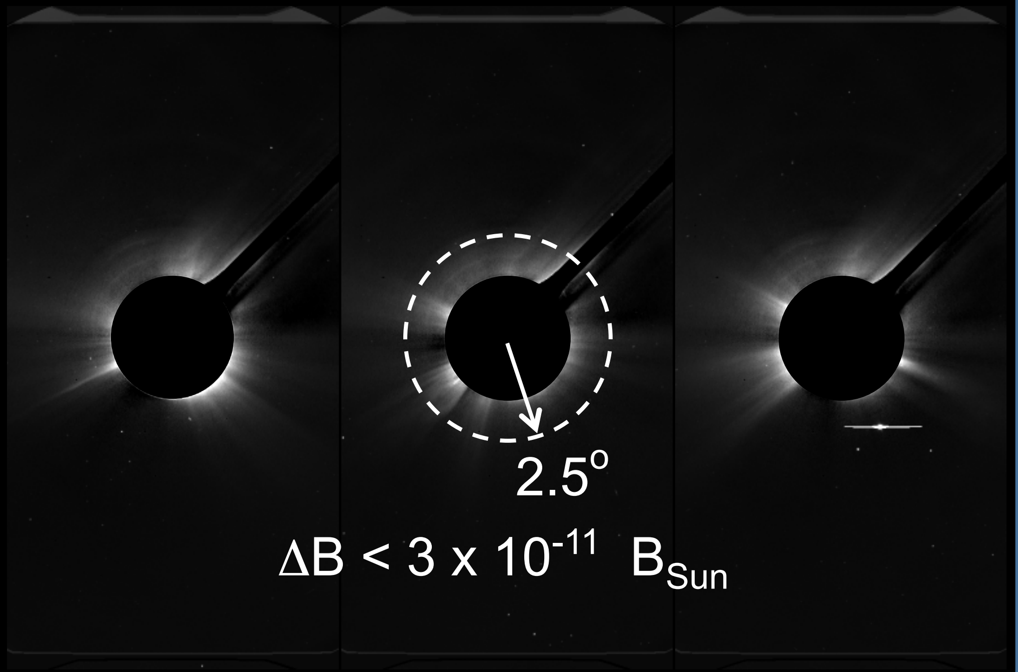
Image series: j= 1, 2, 3, . . .

$F_{x,y} = \min_j \{image_{x,y,j}\}$

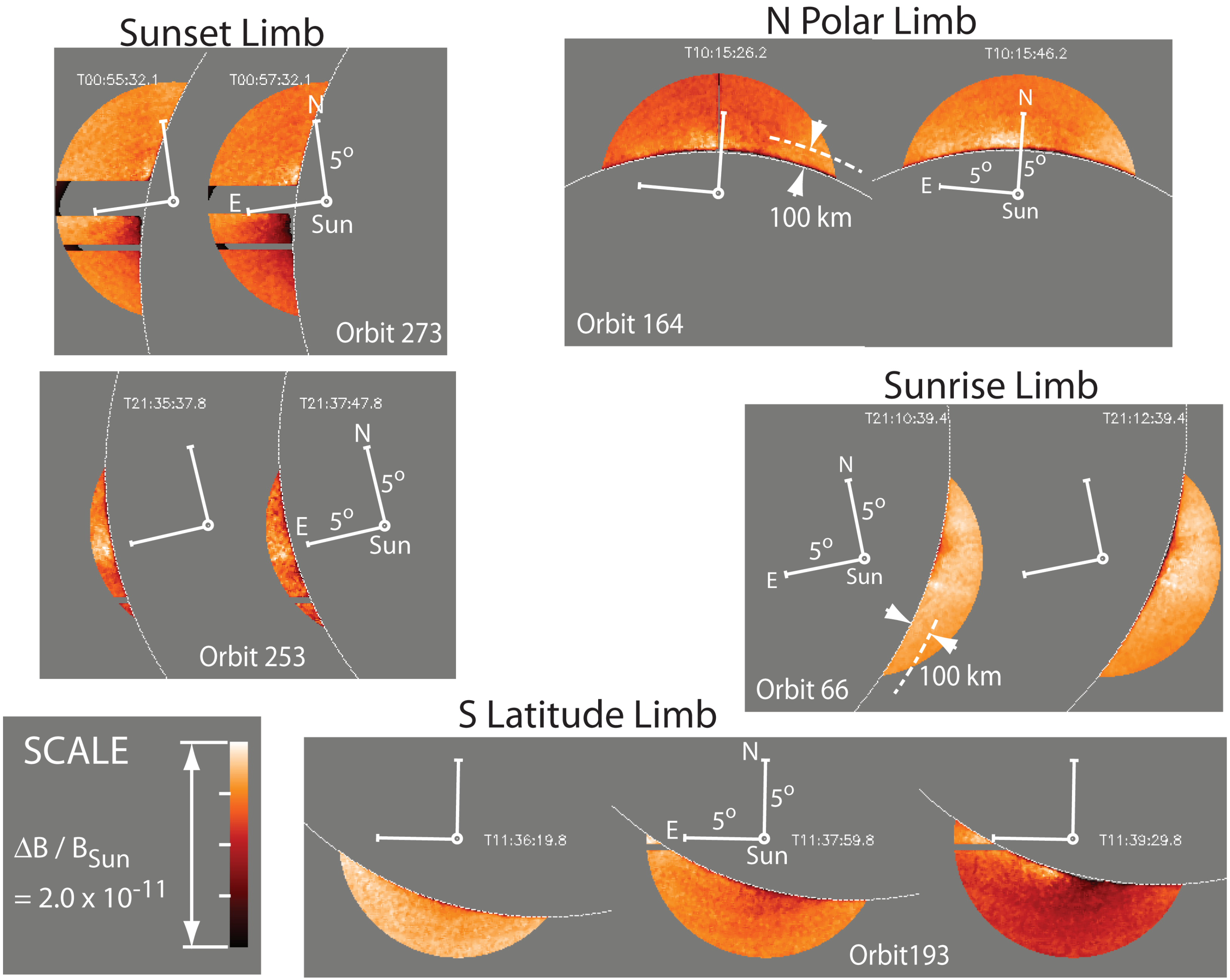


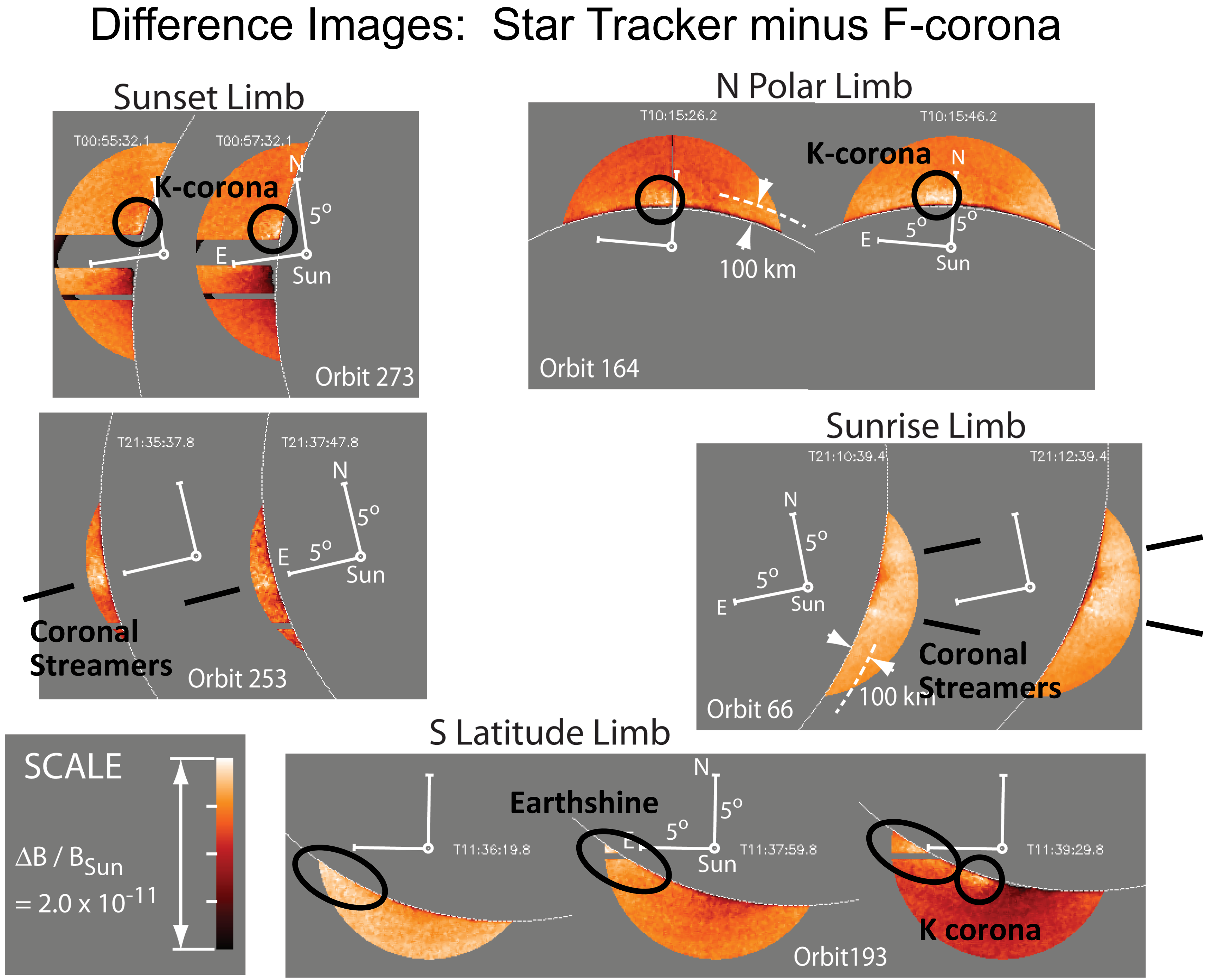
Time-Variable K-corona & streamer structure

(sample images – Fcorona)



Difference Images: Star Tracker minus F-corona




Difference Images: Star Tracker minus F-corona
Sunset Limb
T00:55:32.1
T00:57:32.1
K-corona
N
5°
E
Sun
Orbit 273
N Polar Limb
T10:15:26.2
T10:15:46.2
K-corona
100 km
Orbit 164
T21:35:37.8
T21:37:47.8
Coronal Streamers
Orbit 253
Sunrise Limb
T21:10:39.4
T21:12:39.4
Coronal Streamers
100 km
Orbit 66
SCALE
ΔB / B_Sun = 2.0 x 10^-11
S Latitude Limb
Earthshine
T11:36:19.8
T11:37:59.8
T11:39:29.8
K corona
Orbit193

Dust Detection Limits

Measured pixel-to-pixel brightness fluctuations ("granulation noise"):

$$B_{fluct} \approx 3 \times 10^{-12} \; B_{Sun}$$

What is the dust line-of-sight upper limit ?:

Solar elongation angle (scattering angle) at limb: 2.3^{o} - 6.2^{o}

Dust illumination altitude: 1 – 3 km

} *Star tracker observing geometry*

Per-grain radiance: (1 grain cm^{-2})

$B_{grain} = 6 \times 10^{-15} \; B_{Sun}$

} ***Parameters**:*
0.1 μm radius grains
Mie theory
VIS wavelengths
Small angle scattering

Raise threshold by factor of ~ 2: Optical blur is ~ 10 km at limb (1 to 2 x H_{dust})

Line-of-sight dust concentration ($2 \; B_{fluct} / B_{grain}$) : ***< 1000 grains cm^{-2}***

Summary & Conclusions

- Star tracker images are examined from 5 favorable limb sequences (Earth-dark limb and small solar elongation angle).

- No detection of horizon glow down to "a few" x 10^{-12} B_{Sun}
  (Equivalent to < 1000, r=0.1 μm grains cm^{-2})

- This limit is far smaller than excess brightness observed in Apollo 15 coronal photography , of ~ 5 x 10^{-11} to 10^{-9} B_{Sun} (McCoy '76), used as basis for exo-dust models (McCoy, '76; Glenar et al. '11, Stubbs et al. 12)

- Possibilities to consider:
  - Solar-cycle dependence of UV photoemission from surface (*but F10.7 flux, a UV proxy, was not much different during these two missions; (C)60-90 , (A)113*).
  - Active meteoroid streams (Southern Delta Aquarids & Perseids) during Apollo 15
  - Topography may exert a strong influence
  - Possible calibration error or stray light in the Apollo 15 measurements

- Dust dilemma should be resolved by LADEE UVS and LDEX measurements next year