Photometric studies of light scattering above the lunar terminator
J.E. McCoy

… and other evidence of light scattering effects

Presented by
Addie Dove
Lunar Science Seminar
March 30, 2010

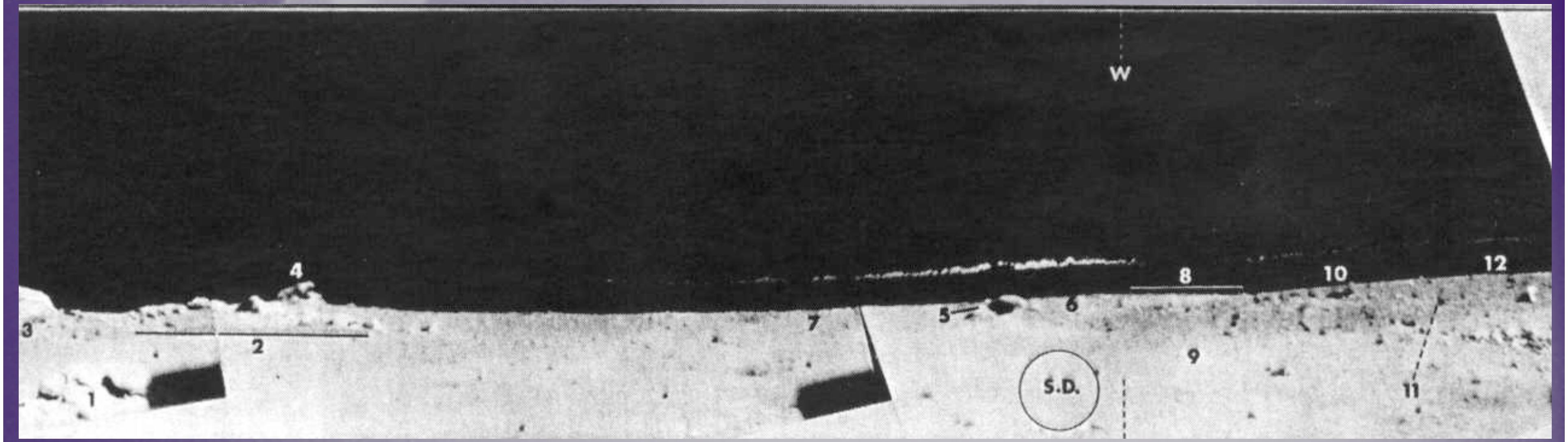
Outline

- Looking from the ground up:
  - Lunar Horizon Glow
  - Higher altitude light scattering observations
- Detecting dust particle movement
- What can we learn from the observations and data?
- Seriously - it's been 30 years.

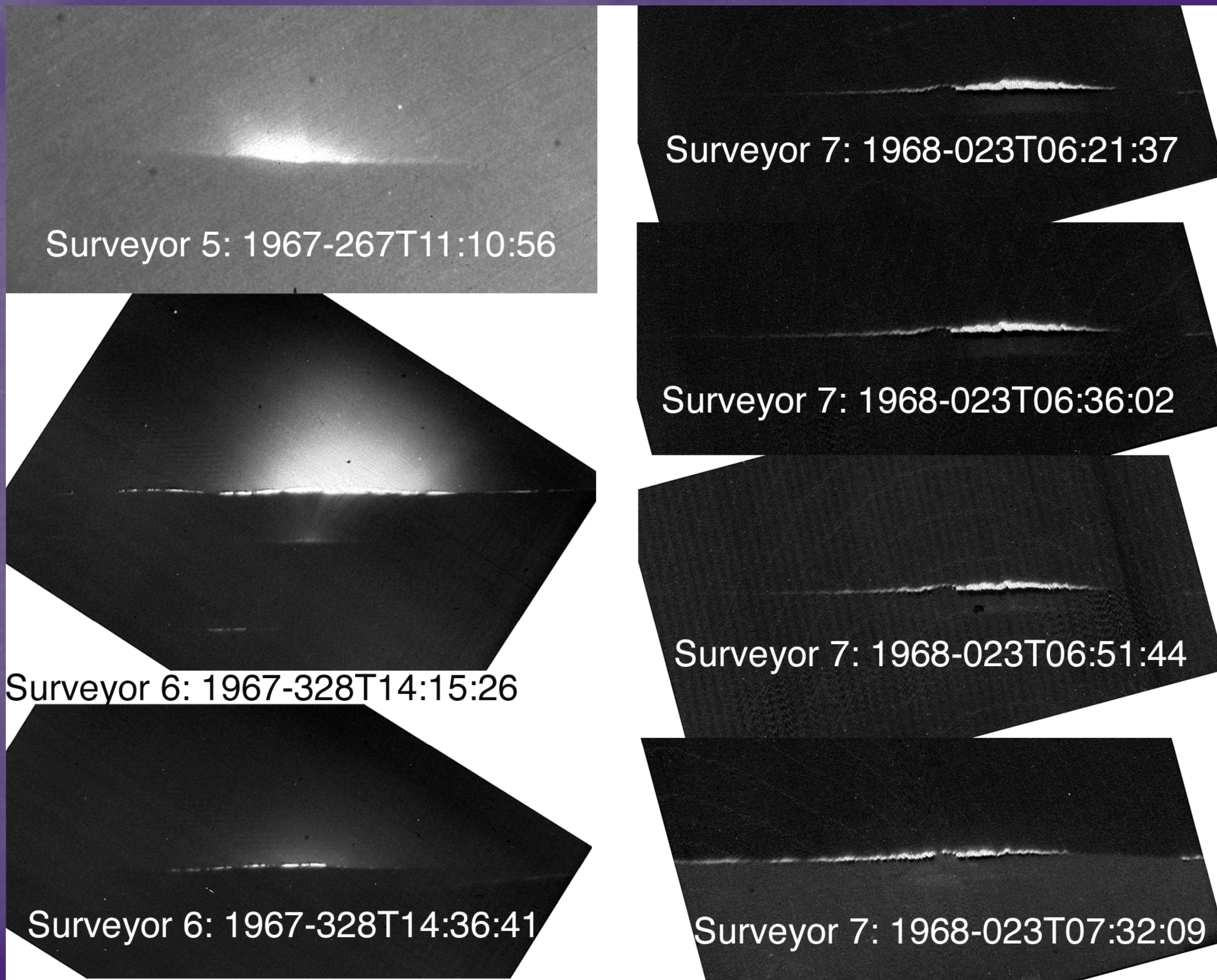
  What are we going to do about this?

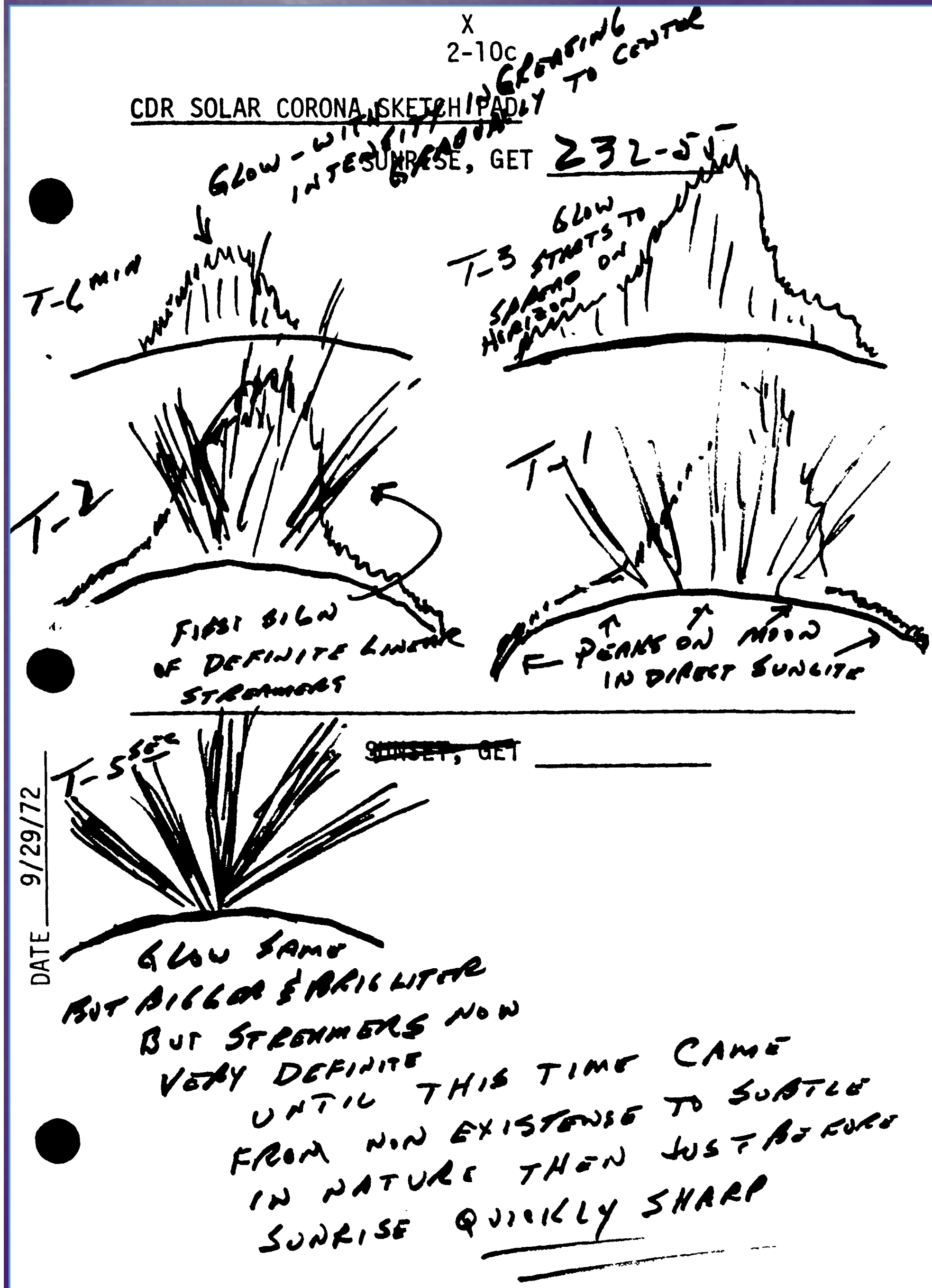
OBSERVATIONS

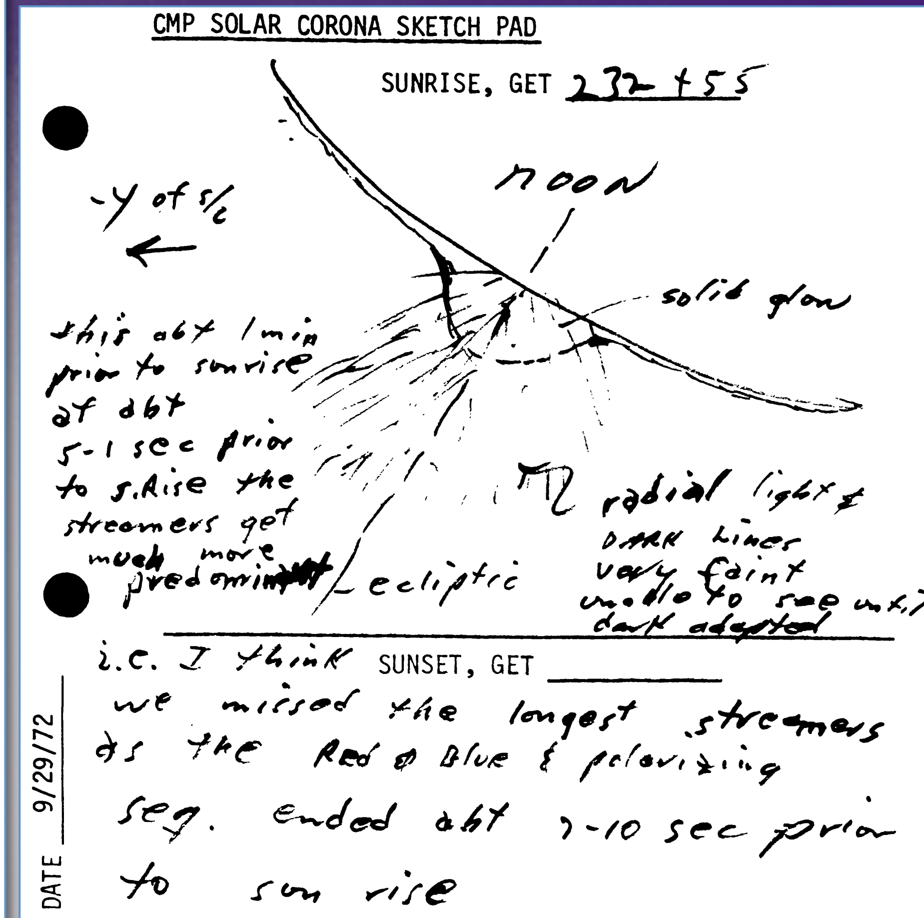
Surveyor Composite Image



Lunar Horizon Glow

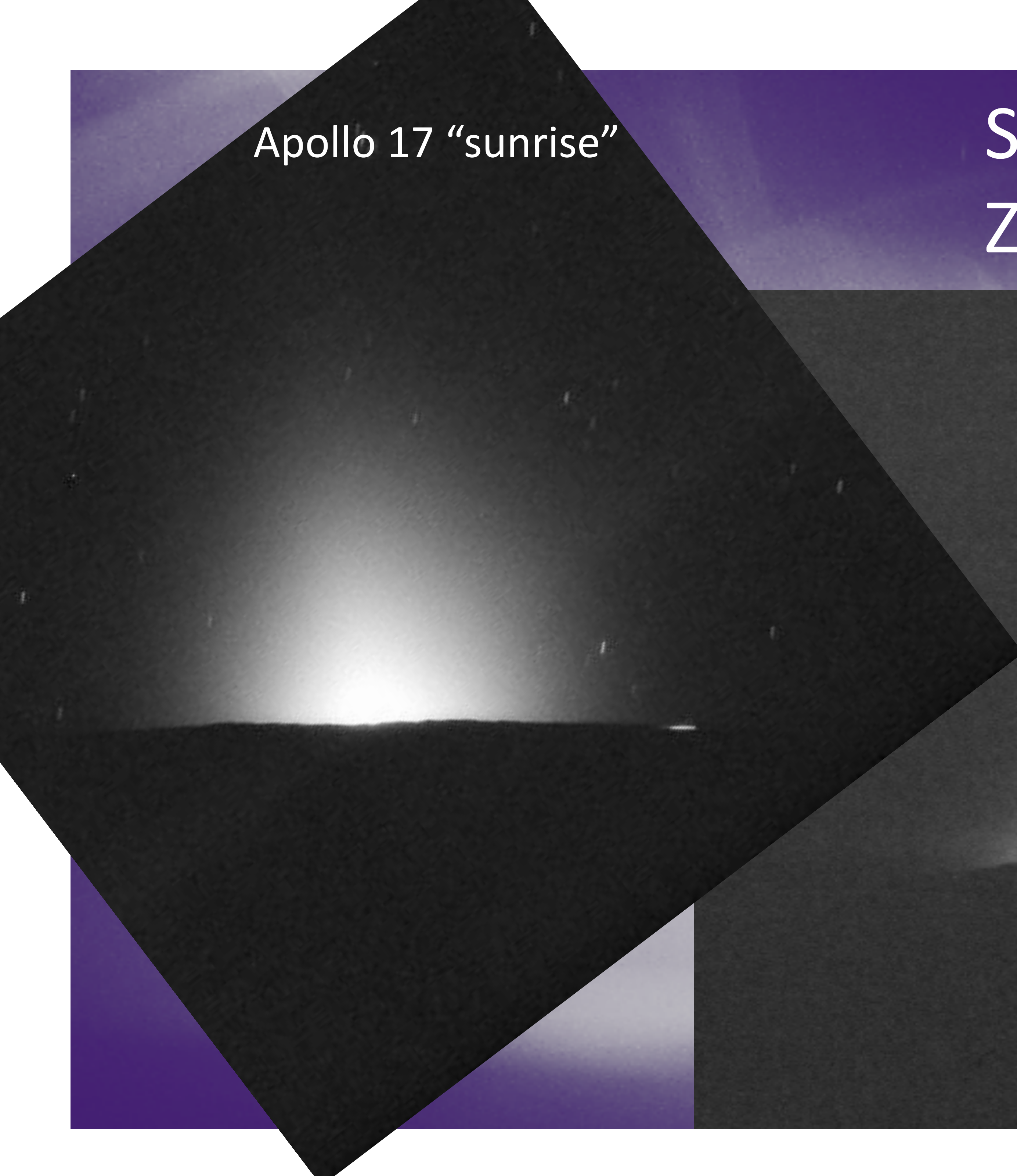


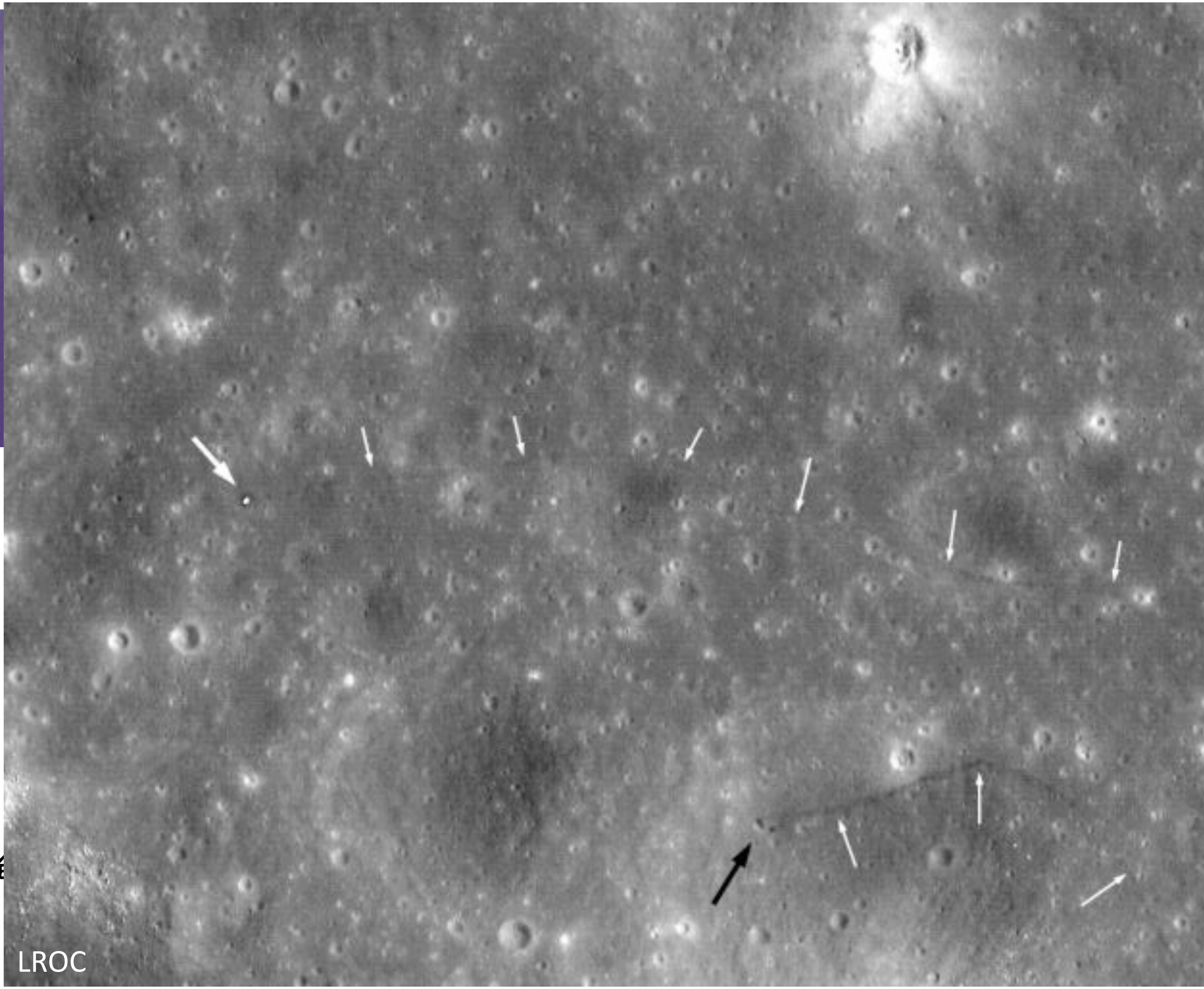




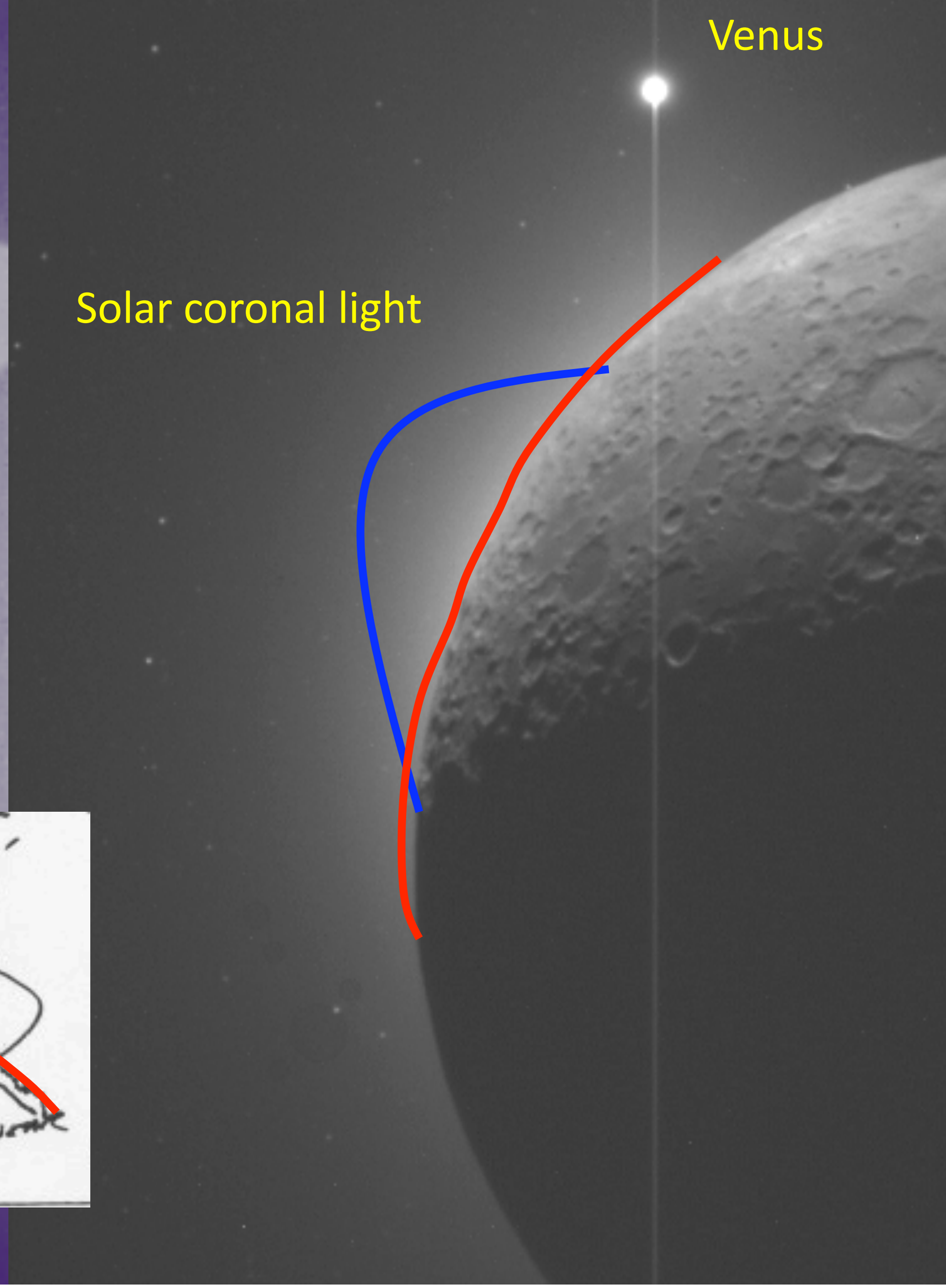
Solar Corona Sketch Pads
Apollo 17 Astronauts
Cernan and Evans

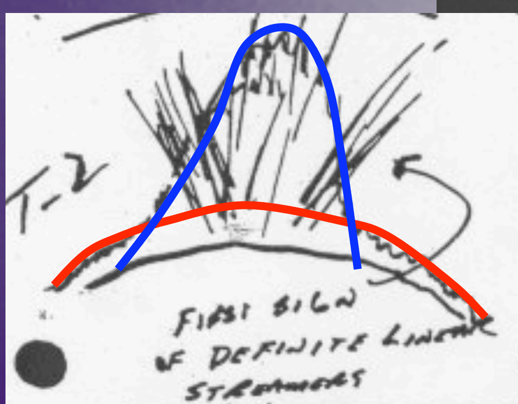
Solar Corona/ Zodiacal Light



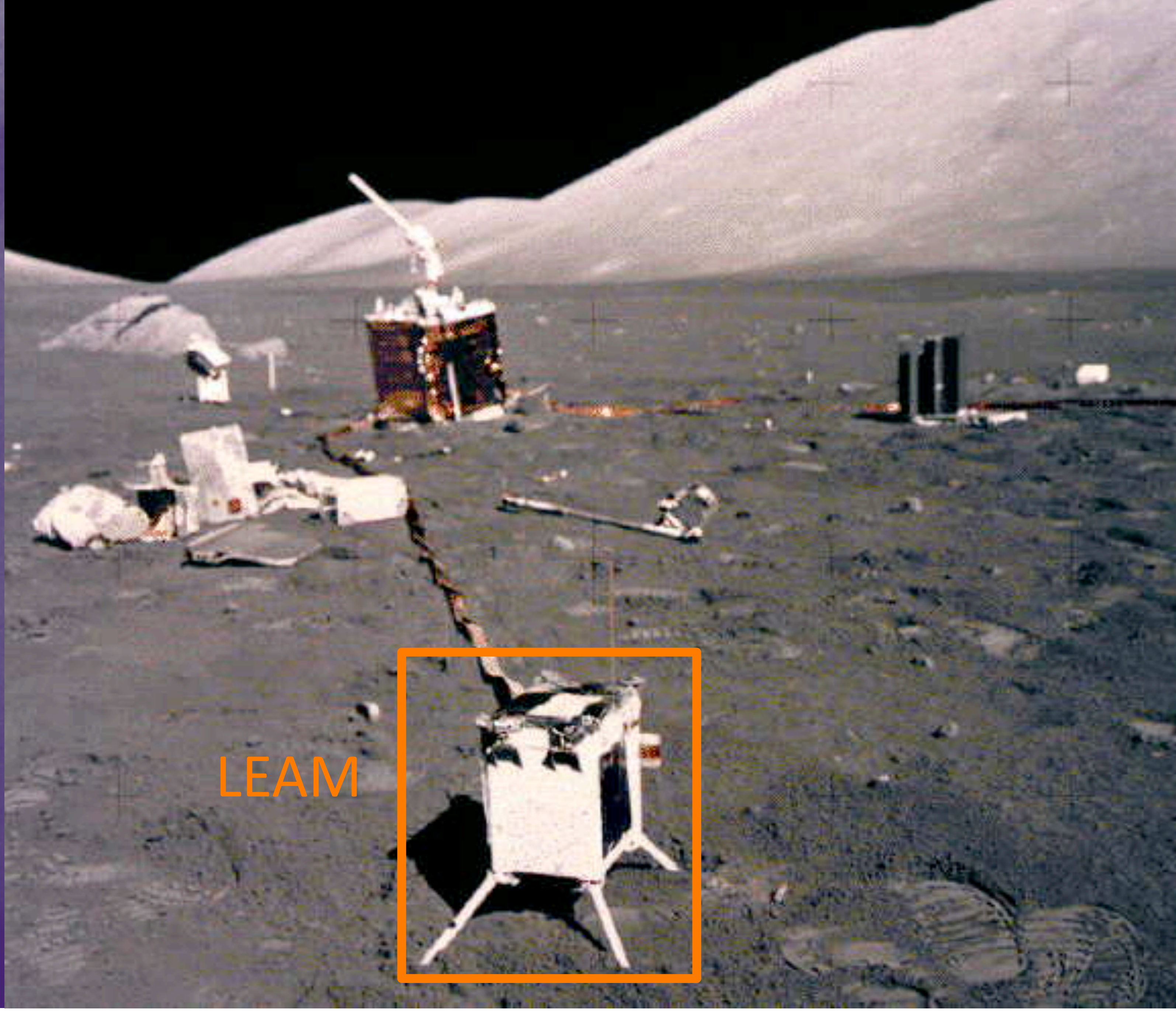

LROC

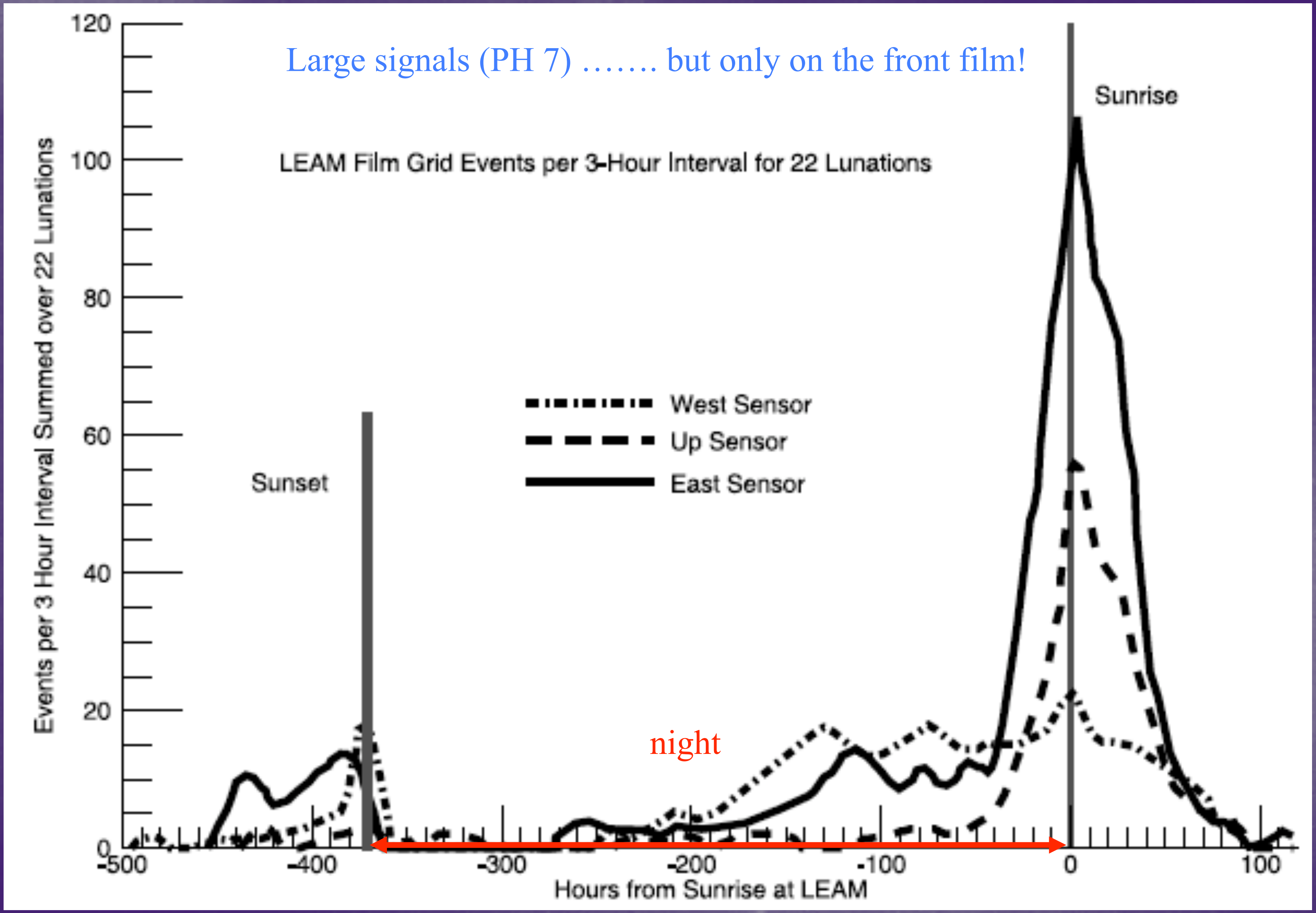
Clementine


Venus
Solar coronal light
surface illuminated by earthshine


T-2
FIRST SIGN OF DEFINITE LINEAR STREAMERS

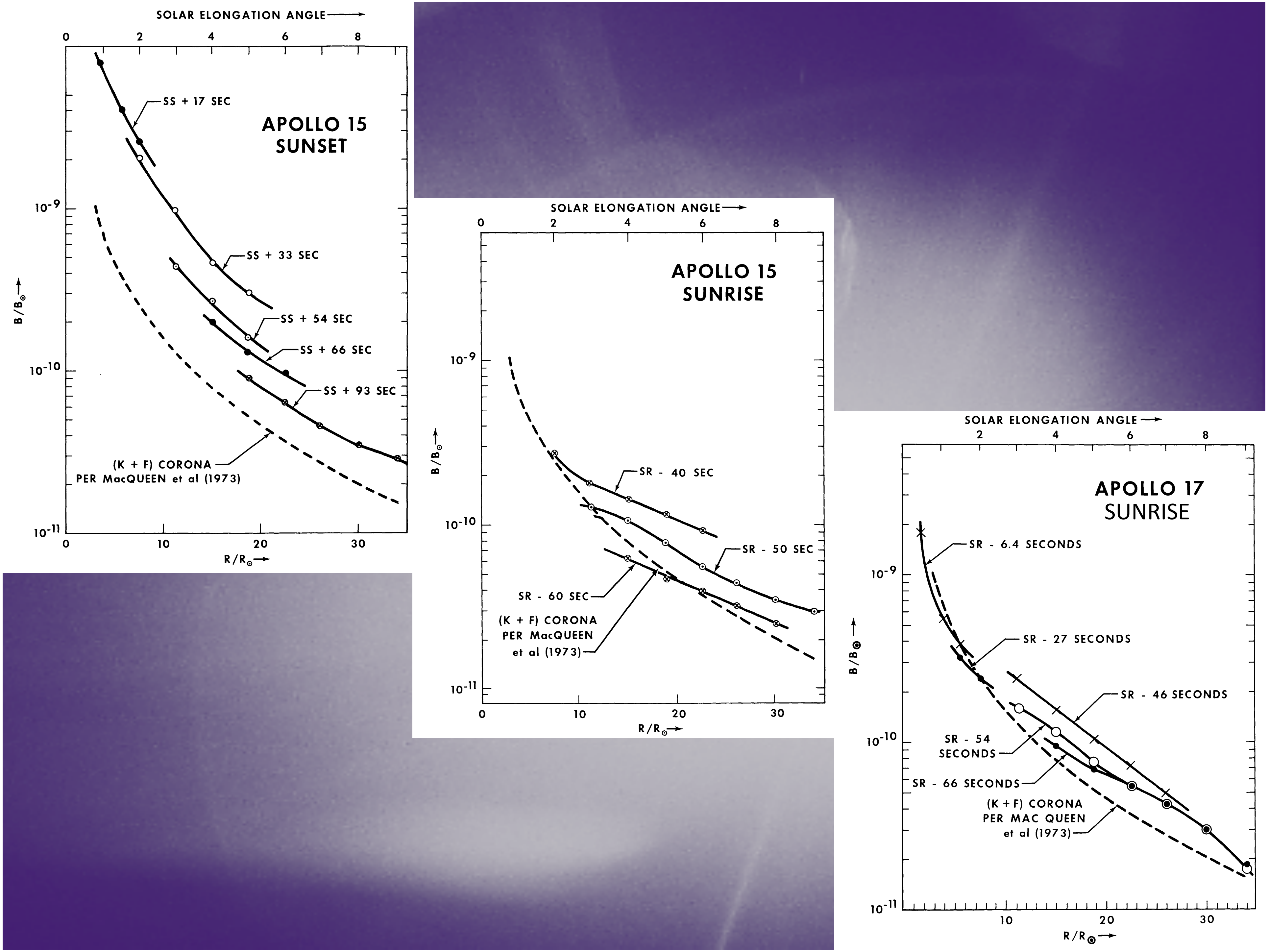
Apollo 17 Lunar Surface Experiment Package

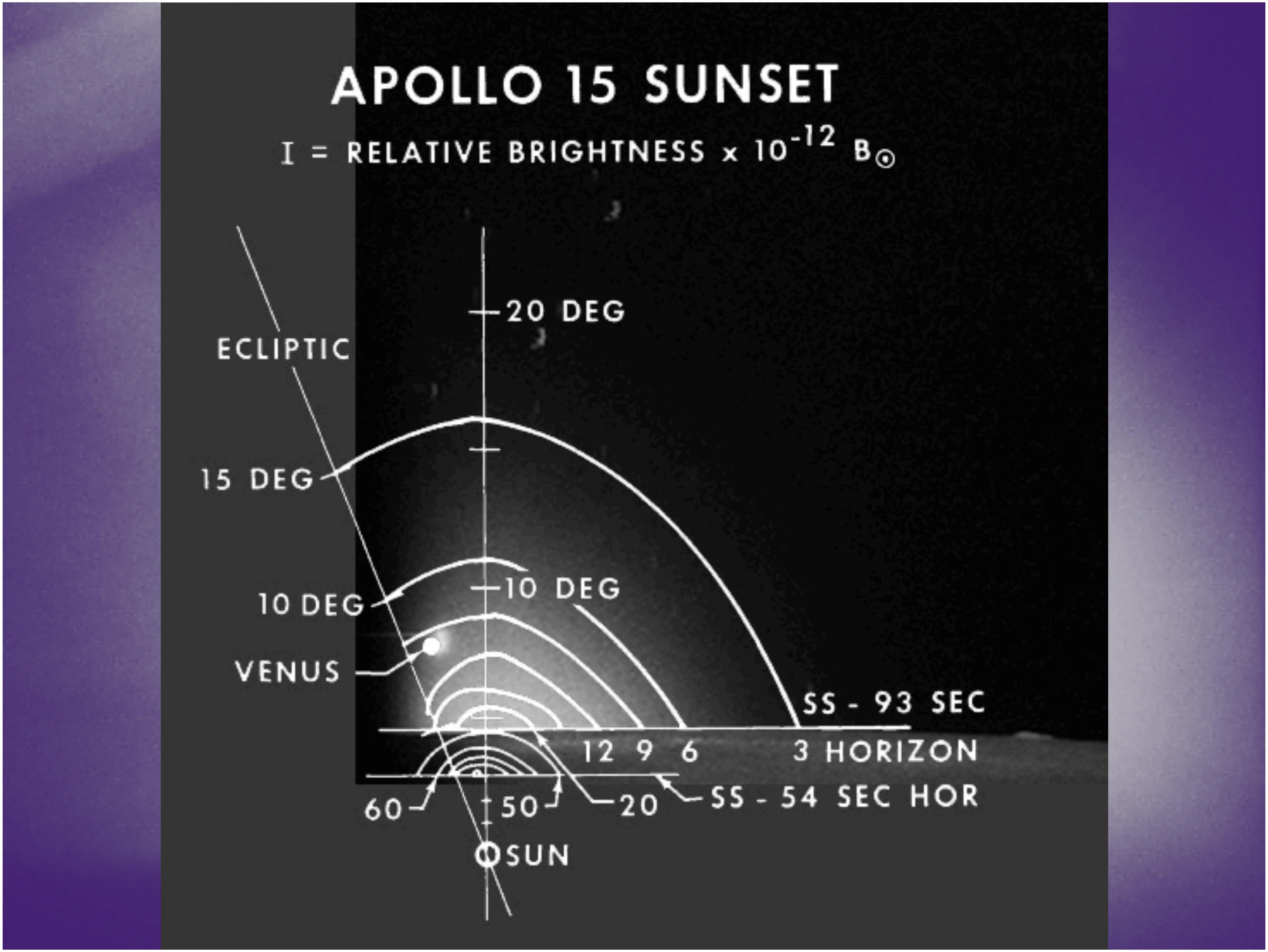




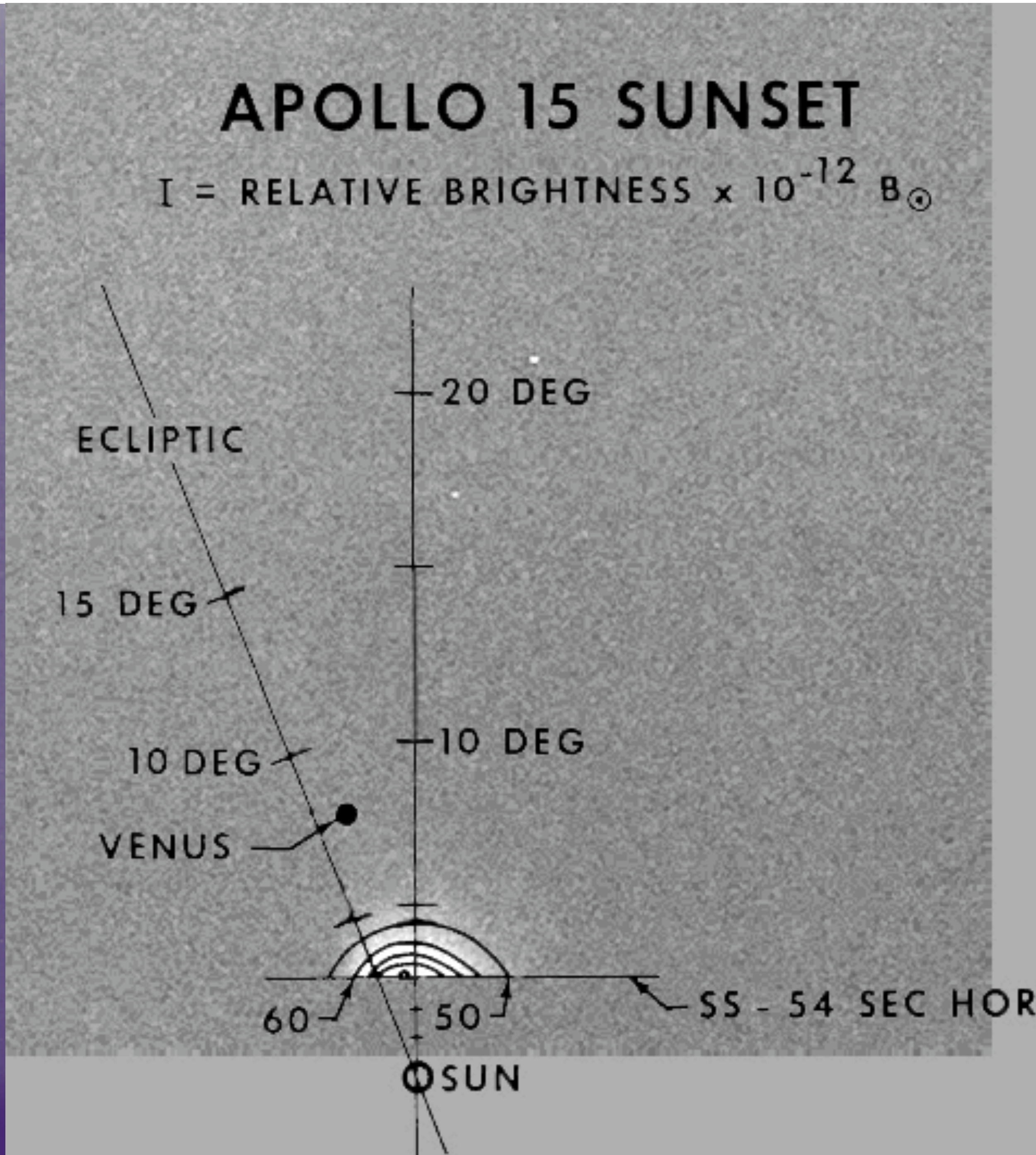
Large signals (PH 7) ……. but only on the front film!
LEAM Film Grid Events per 3-Hour Interval for 22 Lunations
Sunrise
Sunset
West Sensor
Up Sensor
East Sensor
night
Events per 3 Hour Interval Summed over 22 Lunations
Hours from Sunrise at LEAM
120
100
80
60
40
20
0
-500
-400
-300
-200
-100
0
100

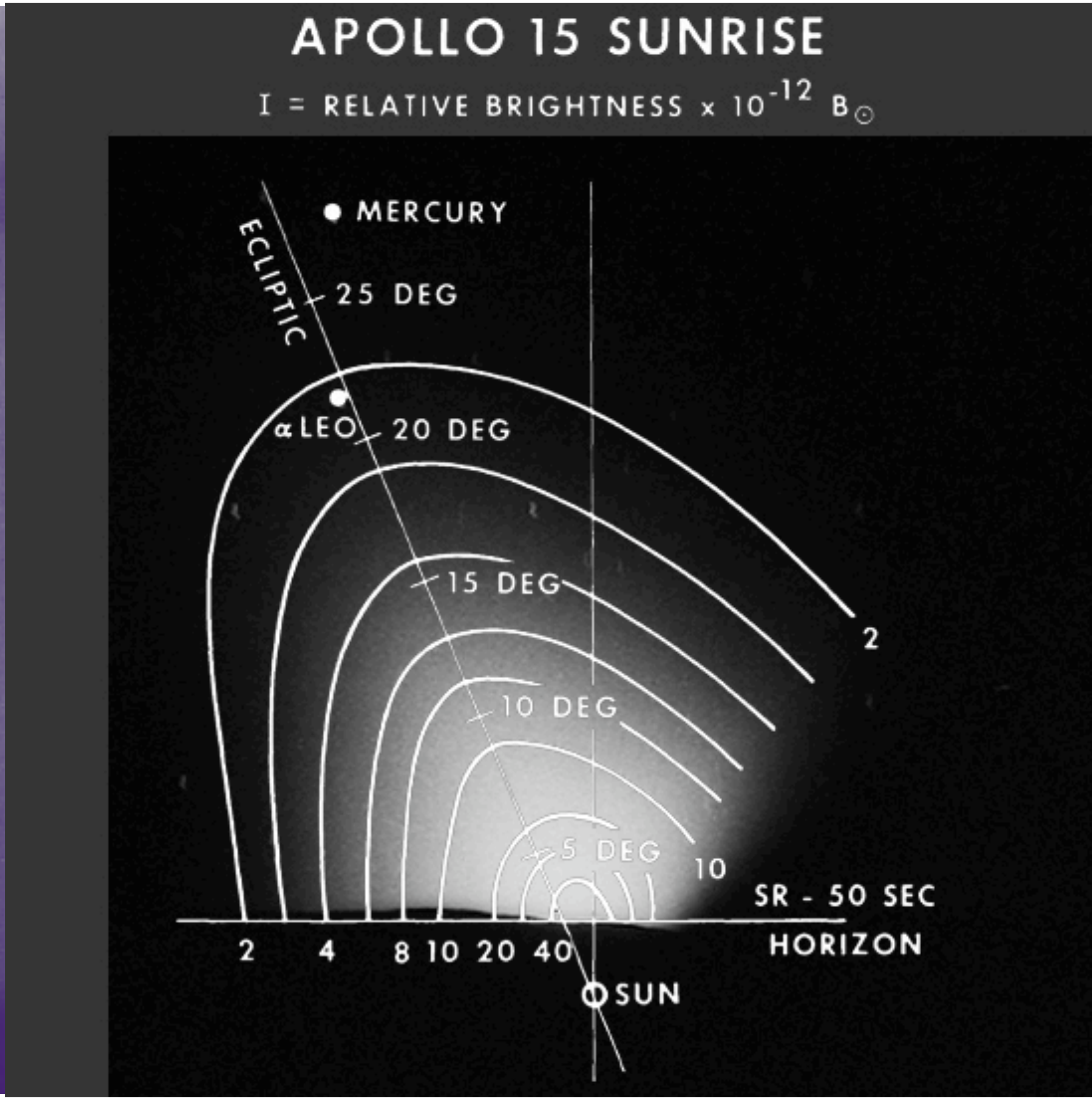
Data (Image) Analysis

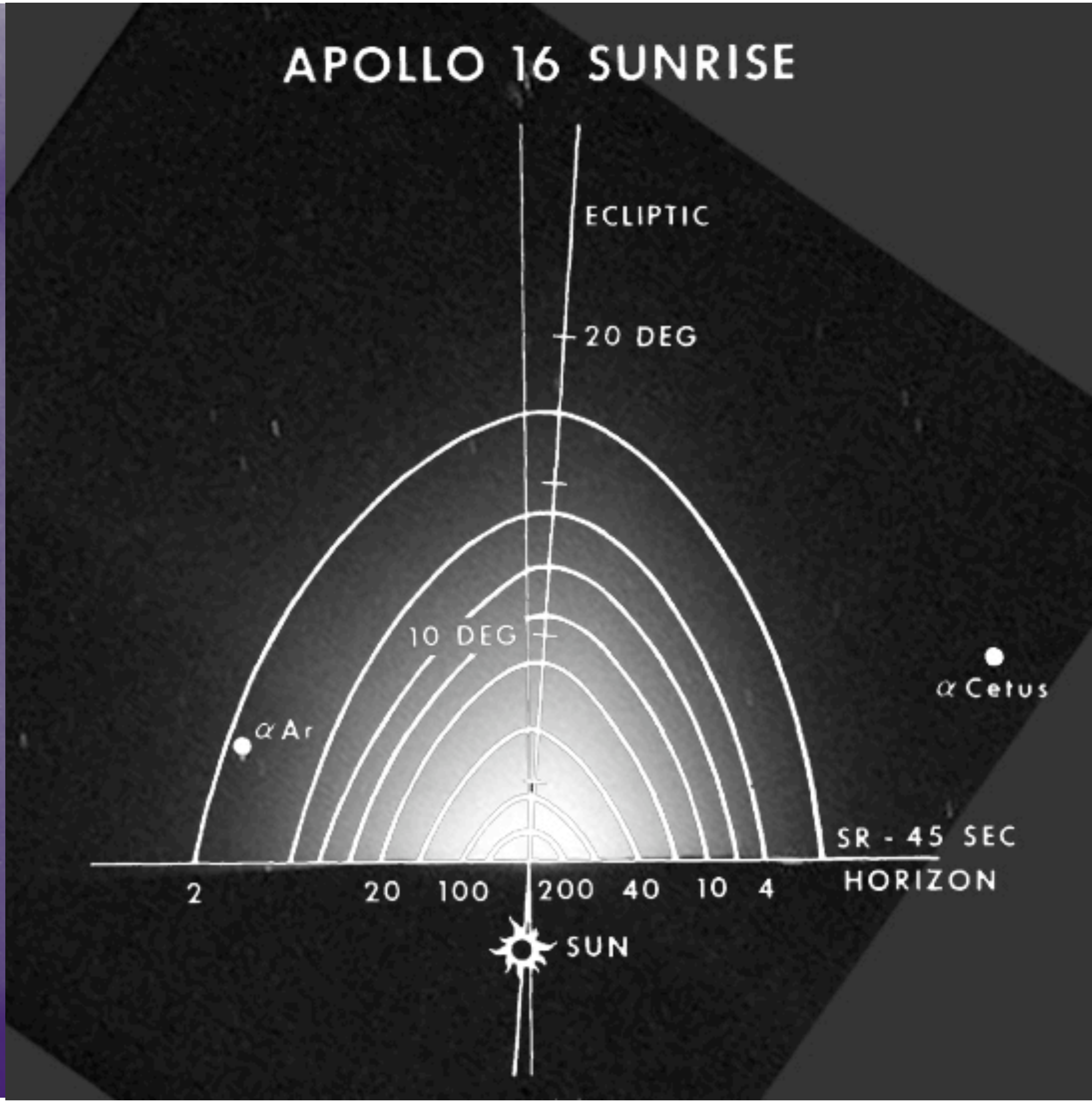

SOLAR ELONGATION ANGLE
APOLLO 15
SUNSET
SS + 17 SEC
SS + 33 SEC
SS + 54 SEC
SS + 66 SEC
SS + 93 SEC
(K + F) CORONA
PER MacQUEEN et al (1973)
B/B⊙
R/R⊙
SOLAR ELONGATION ANGLE
APOLLO 15
SUNRISE
SR - 40 SEC
SR - 50 SEC
SR - 60 SEC
(K + F) CORONA
PER MacQUEEN
et al (1973)
B/B⊙
R/R⊙
SOLAR ELONGATION ANGLE
APOLLO 17
SUNRISE
SR - 6.4 SECONDS
SR - 27 SECONDS
SR - 46 SECONDS
SR - 54
SECONDS
SR - 66 SECONDS
(K + F) CORONA
PER MAC QUEEN
et al (1973)
B/B⊙
R/R⊙

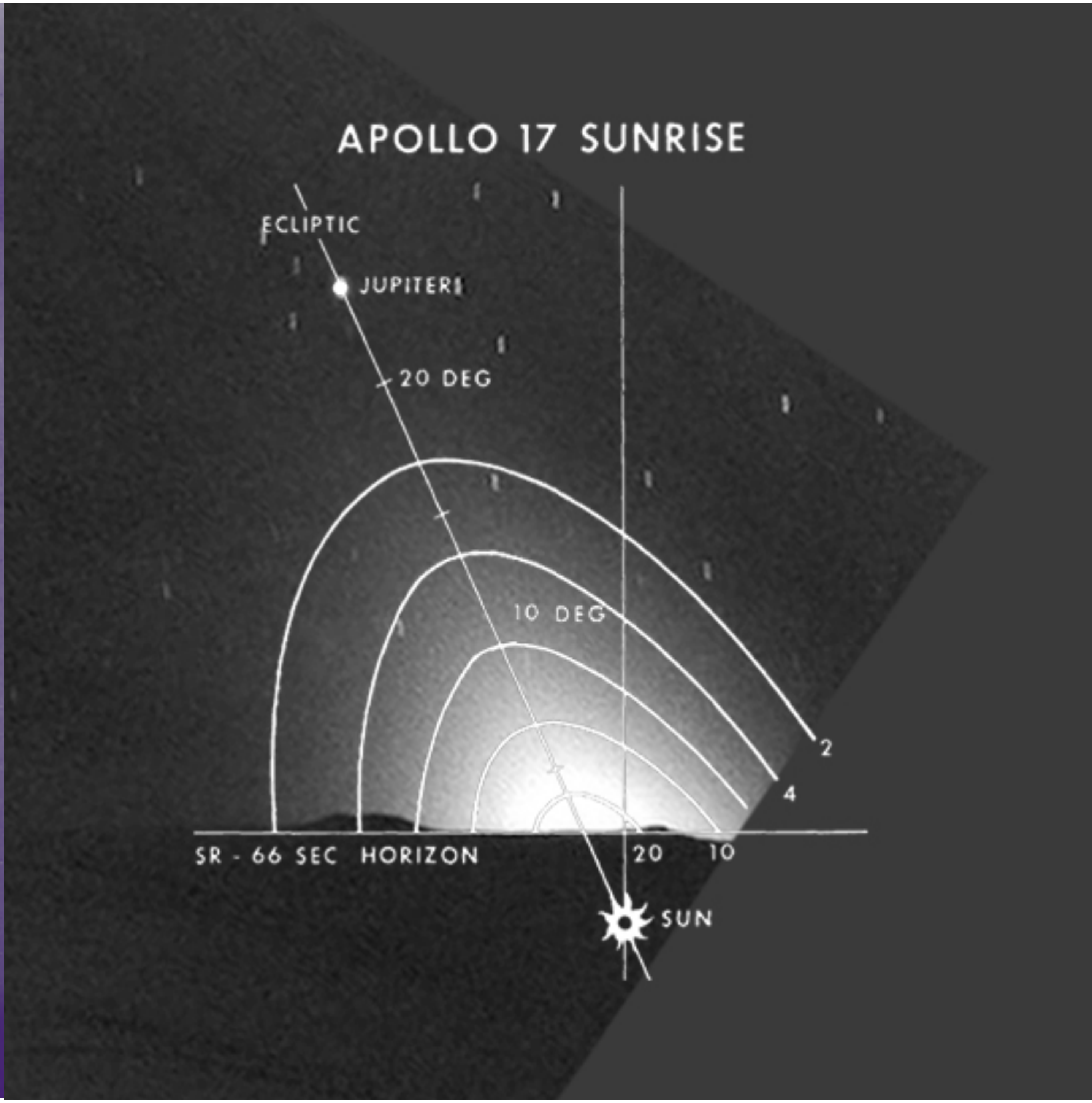


APOLLO 15 SUNSET
I = RELATIVE BRIGHTNESS x 10-12 B☉
ECLIPTIC
20 DEG
15 DEG
10 DEG
10 DEG
VENUS
SS - 93 SEC
12 9 6
3 HORIZON
60
50
20
SS - 54 SEC HOR
SUN


APOLLO 15 SUNSET
I = RELATIVE BRIGHTNESS x 10-12 B⊙
ECLIPTIC
20 DEG
15 DEG
10 DEG
10 DEG
VENUS
60
50
SS - 54 SEC HOR
SUN

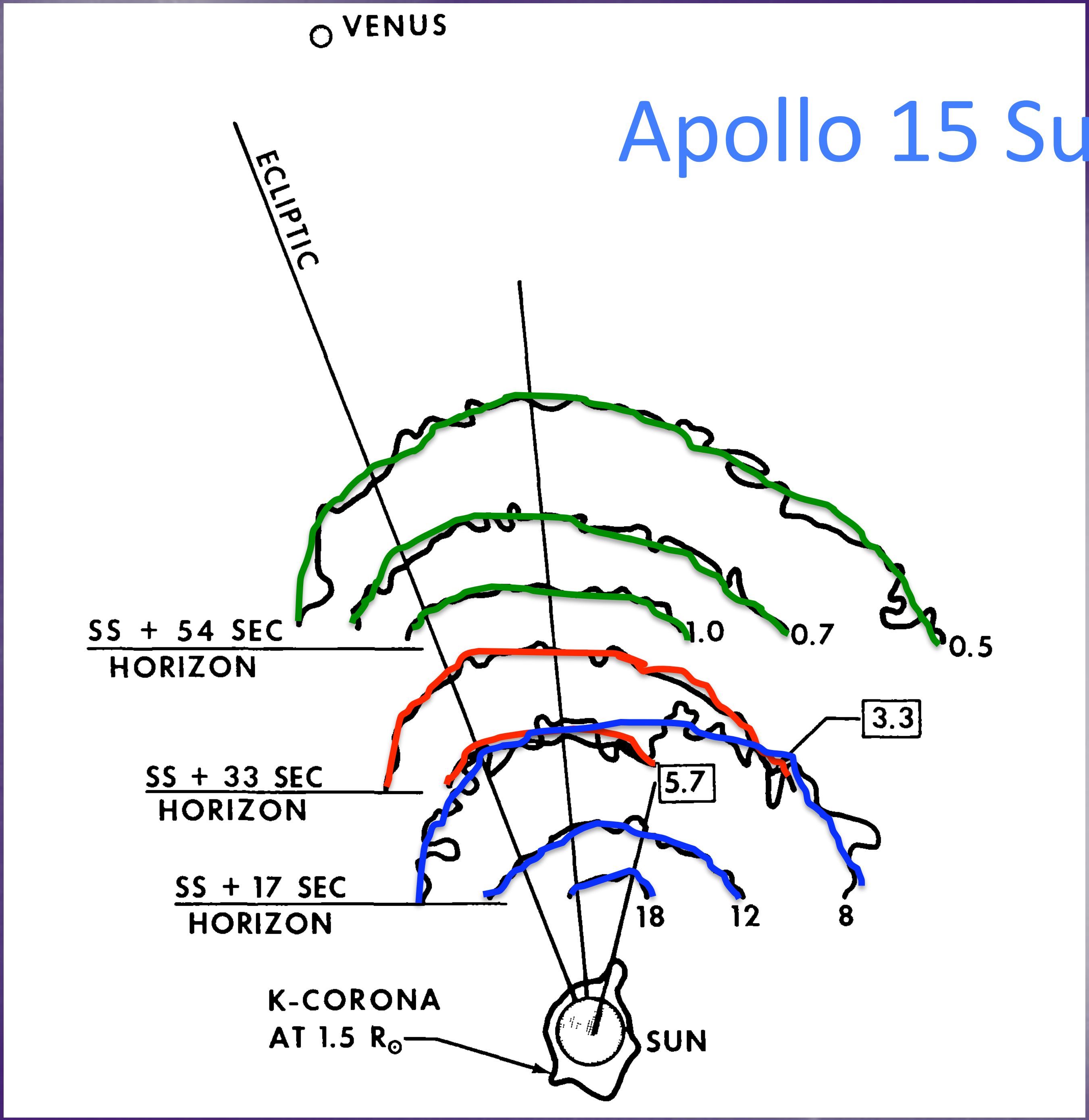

APOLLO 15 SUNRISE
I = RELATIVE BRIGHTNESS x 10^-12 B⊙
MERCURY
ECLIPTIC
25 DEG
αLEO
20 DEG
15 DEG
10 DEG
5 DEG
2
10
SR - 50 SEC
HORIZON
2
4
8 10 20 40
SUN


APOLLO 16 SUNRISE
ECLIPTIC
20 DEG
10 DEG
α Ar
α Cetus
SR - 45 SEC
HORIZON
2
20
100
200
40
10
4
SUN



APOLLO 17 SUNRISE
ECLIPTIC
JUPITER
20 DEG
10 DEG
2
4
SR - 66 SEC
HORIZON
20
10
SUN

Apollo 15 Sunset



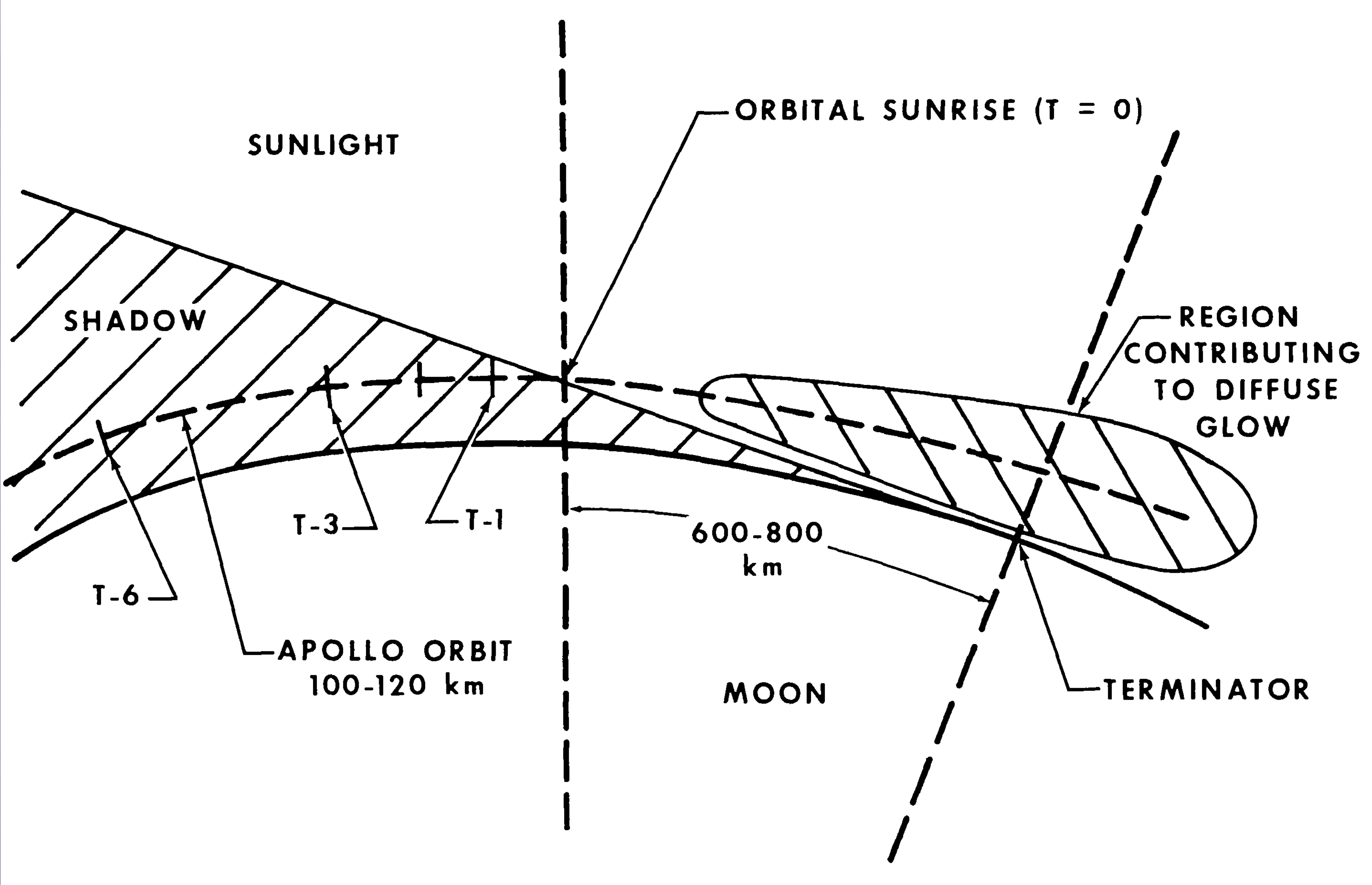
Excess is NOT due to …

- Solar corona streamers
- Lunar atmosphere/exosphere contribution
- Co-orbital spacecraft debris
- Micrometeorite production

So, what IS* causing the excess brightness?

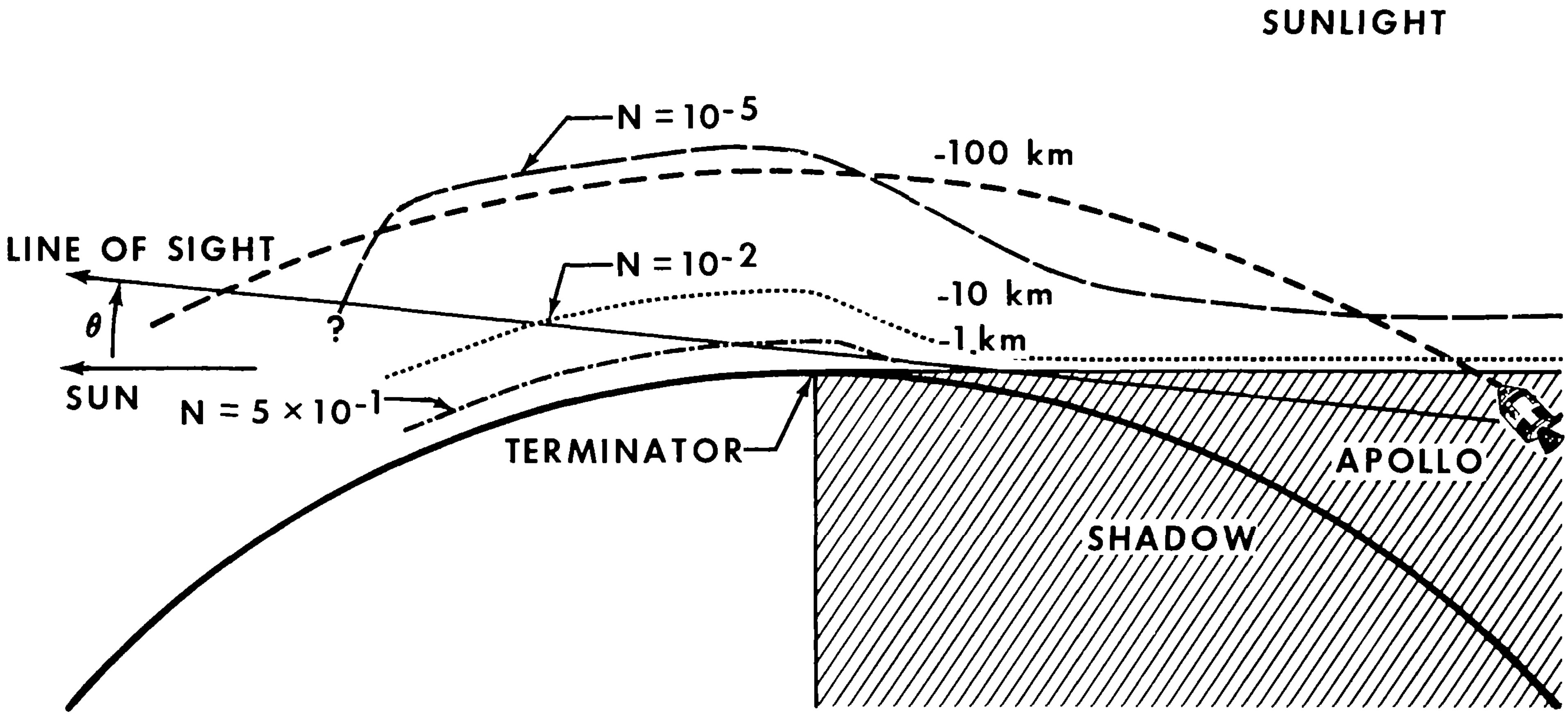
*probably

Model “0”



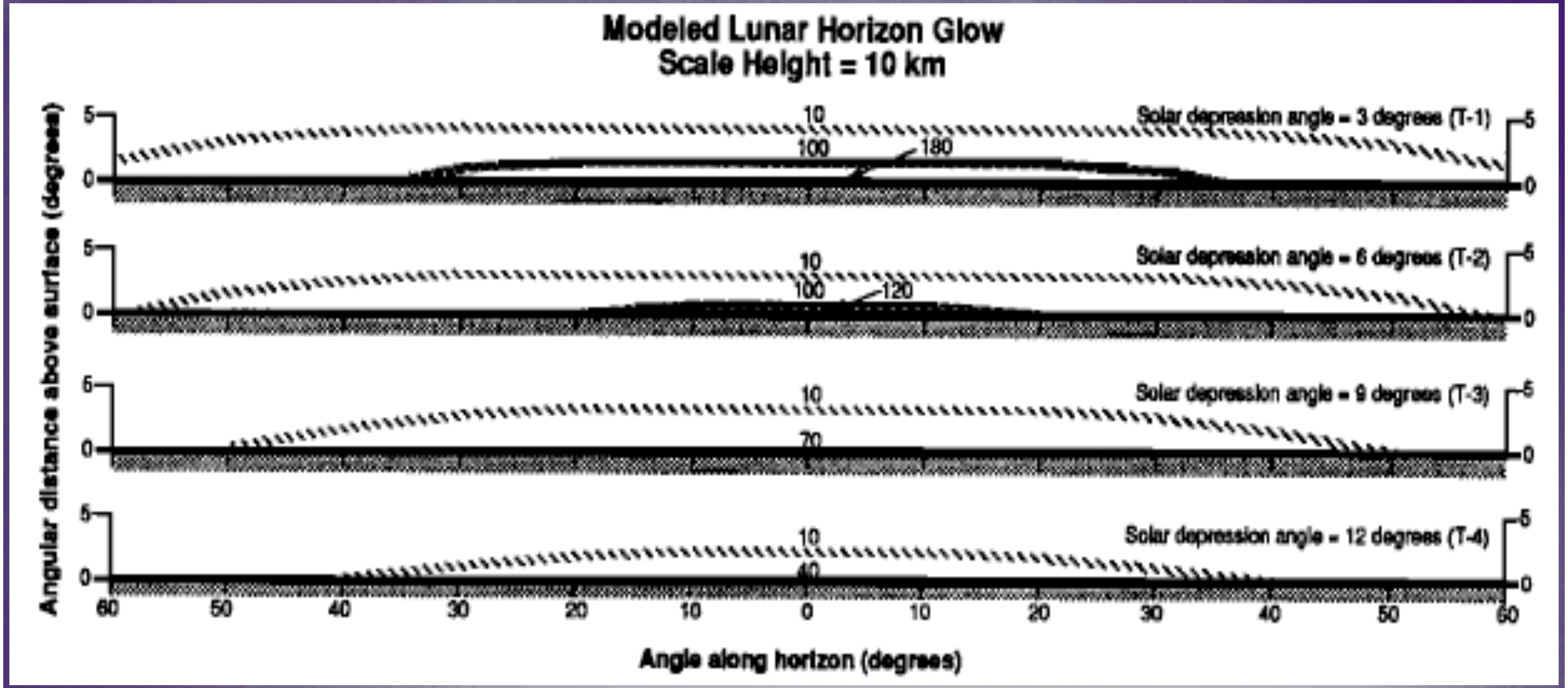
ORBITAL SUNRISE (T = 0)
SUNLIGHT
SHADOW
REGION CONTRIBUTING TO DIFFUSE GLOW
T-3
T-1
600-800 km
T-6
APOLLO ORBIT 100-120 km
MOON
TERMINATOR

Observations



$$N_c = \langle Nd \rangle = \frac{B(\theta)}{F(a,\theta)\pi a^2 E}$$

A more detailed model

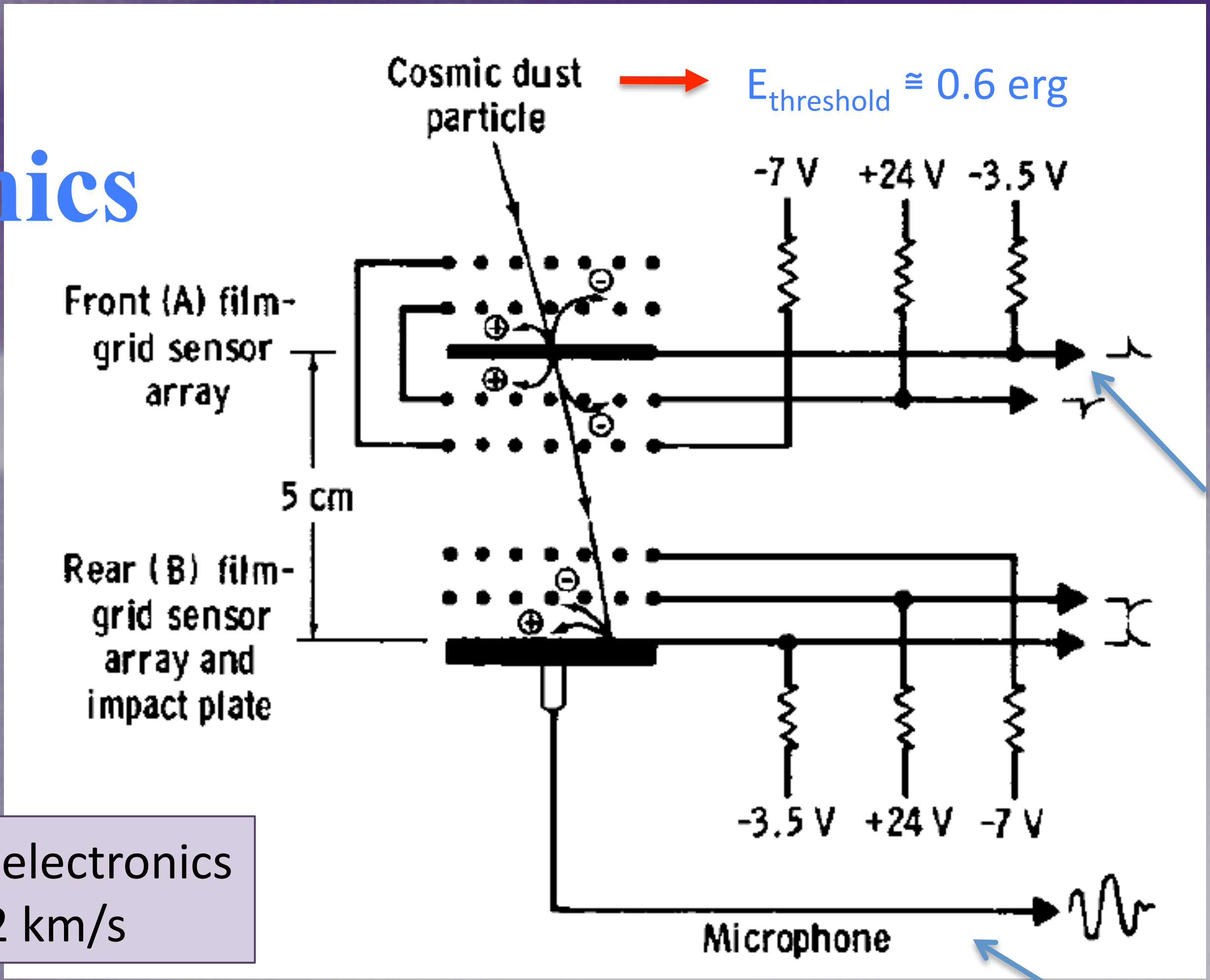


Zook and McCoy (1991)

$$N \sim e^{-H/H_s}$$

H_s = 5 – 20 km

LEAM electronics



$\sim m v_d^{2.6}$

$\sim m v_d$

$\tau \approx \frac{5cm}{v_d}$

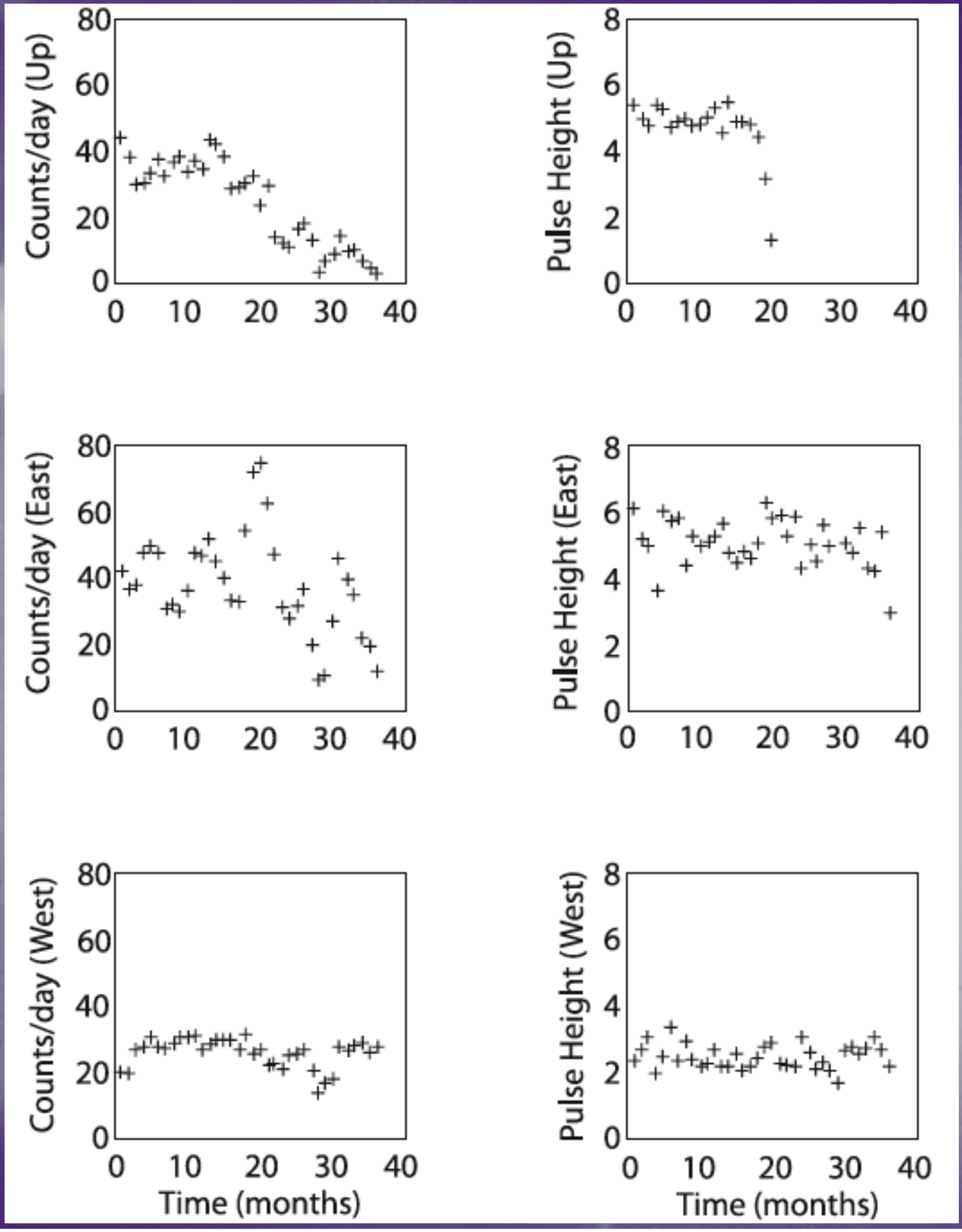
Time of Flight electronics
$2 < v < 72$ km/s

Pre-flight calibration:
0.1 – 10 μm iron spheres
$4 < v_d < 40$ km/s

1 – 4 PHA
signal duration < 1 μs

Pulse Height Analysis (PHA) range: 0 to 7

Monthly Impact Rates — Average Pulse Heights



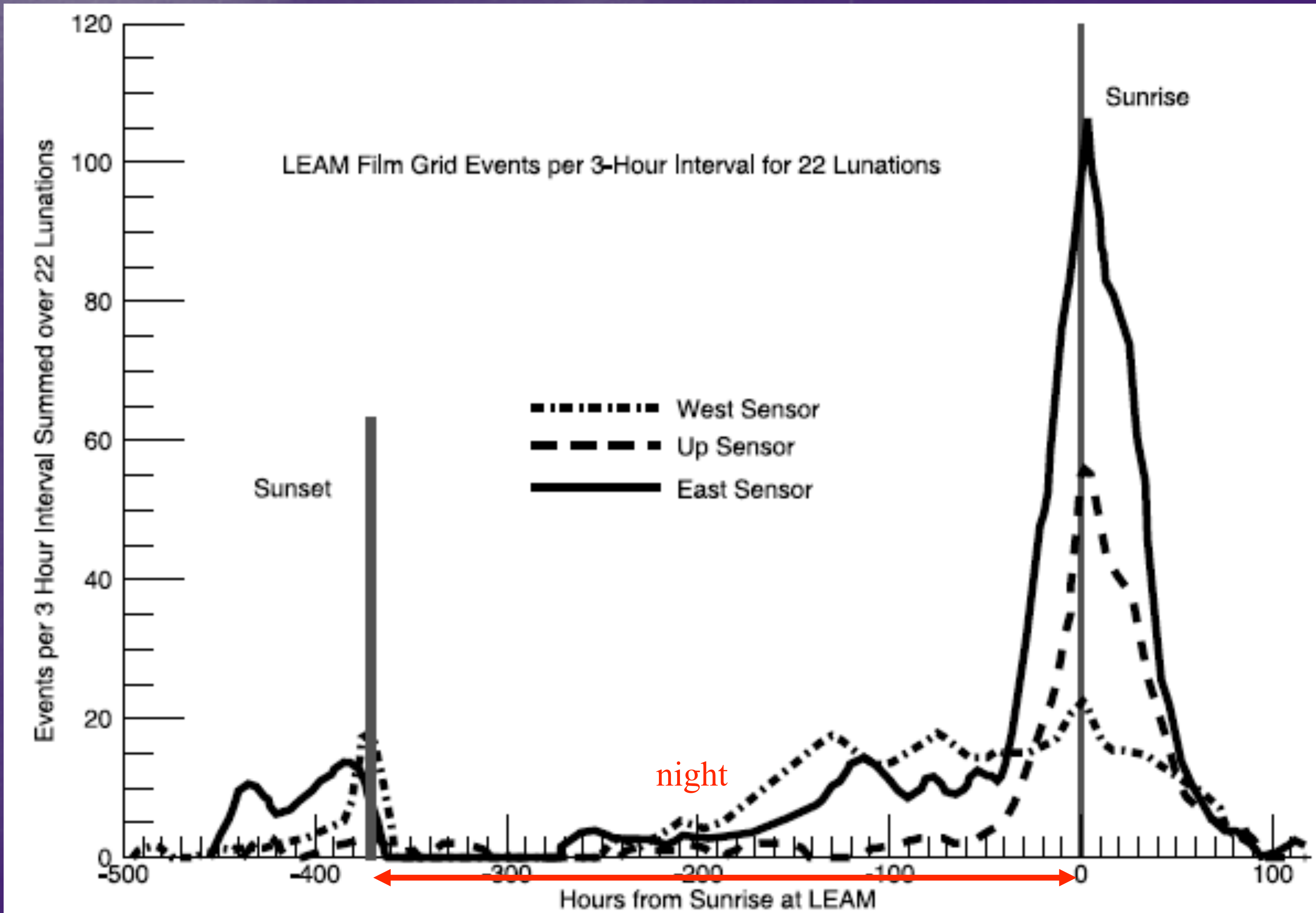
UP: Decline w/ time
covered by dust?

EAST: Highest rates

WEST: No front sensor

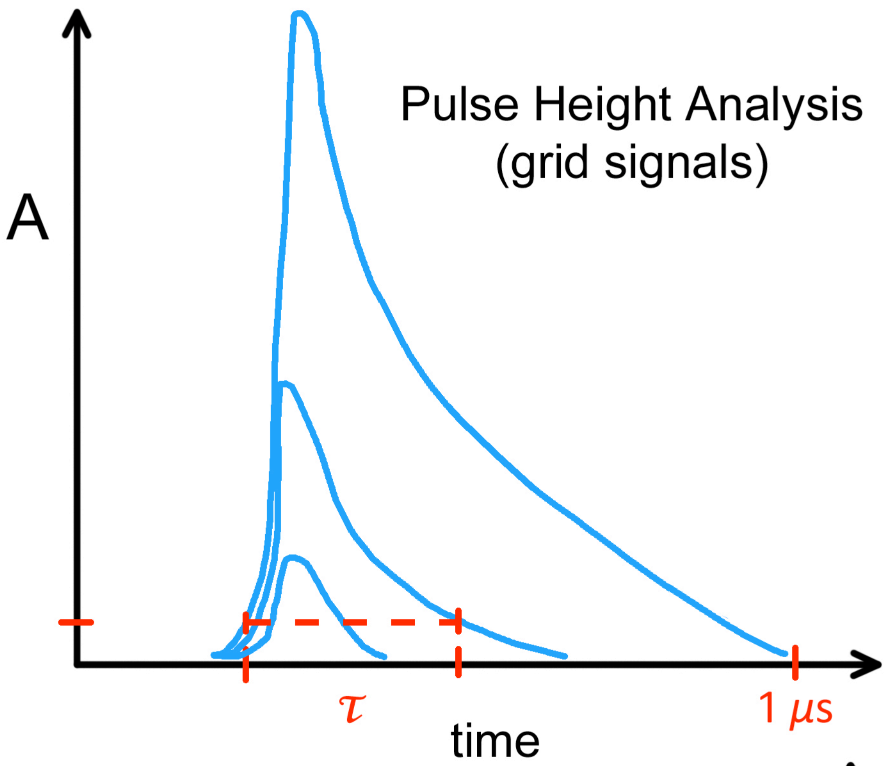
Colwell *et al* (2007)

Large signals (PHA 7) ……. but only on the front film!



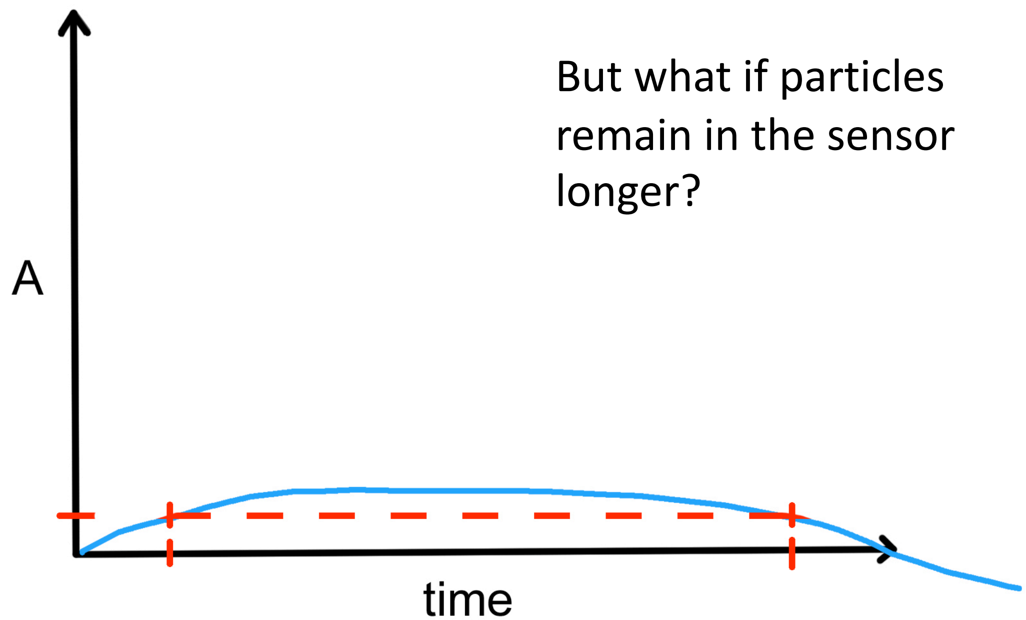
Berg *et al.* (1976)

Pulse Height Analysis (grid signals)

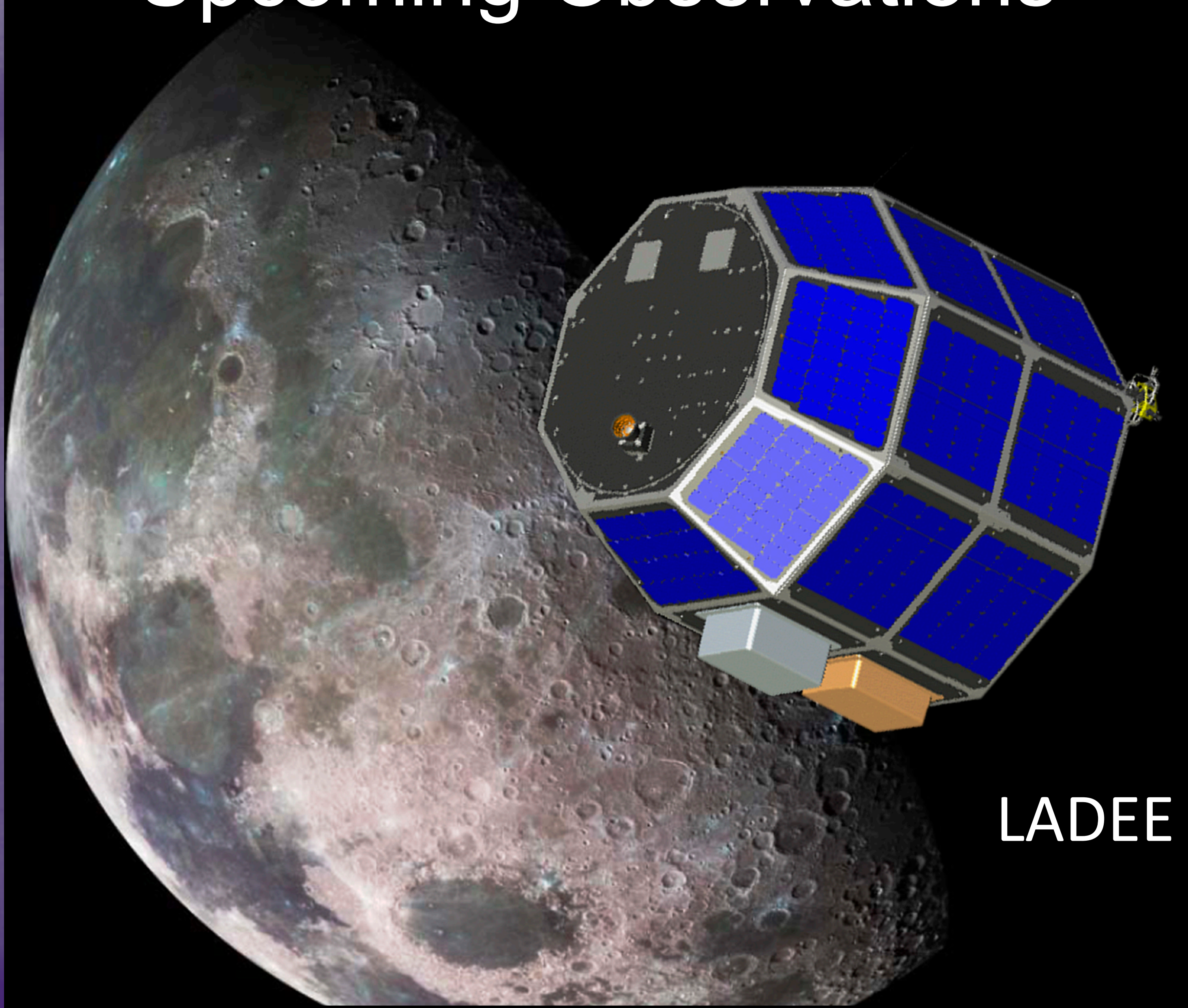


duration ~ amplitude

But what if particles remain in the sensor longer?

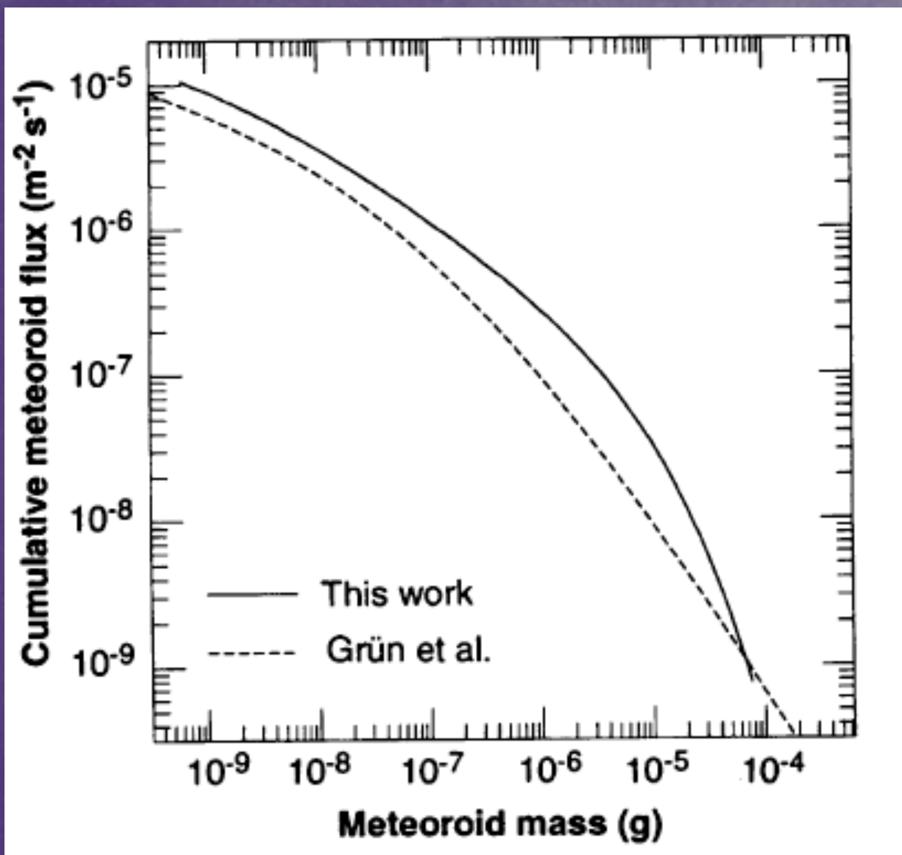


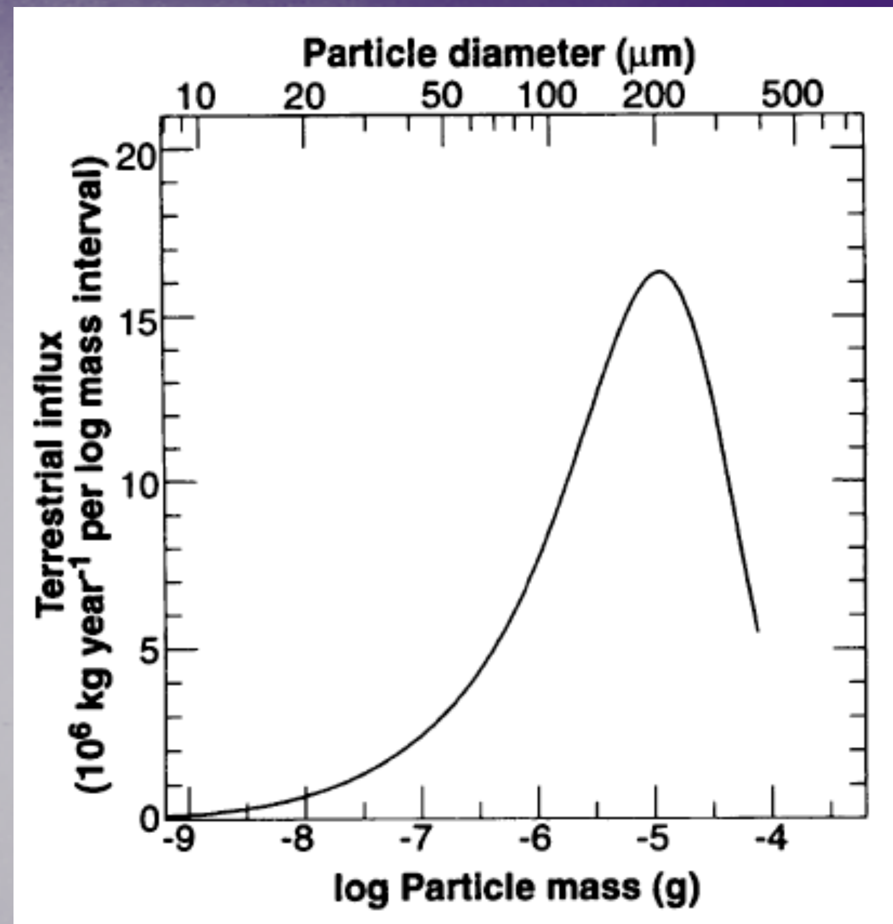
Upcoming Observations



Lunar Atmosphere and Dust Environment Explorer

Interplanetary Dust Bombardment



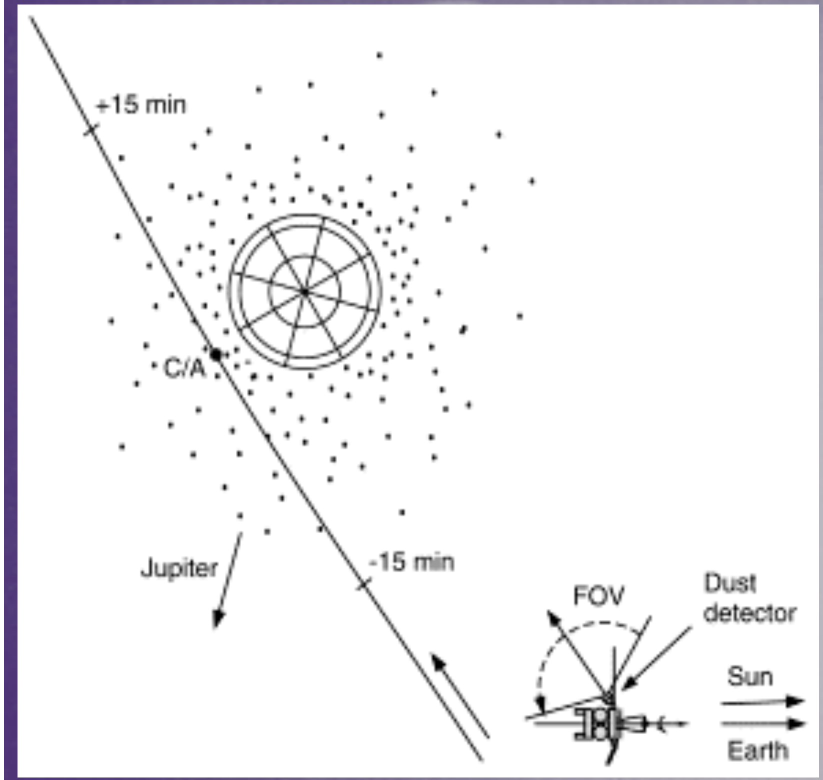


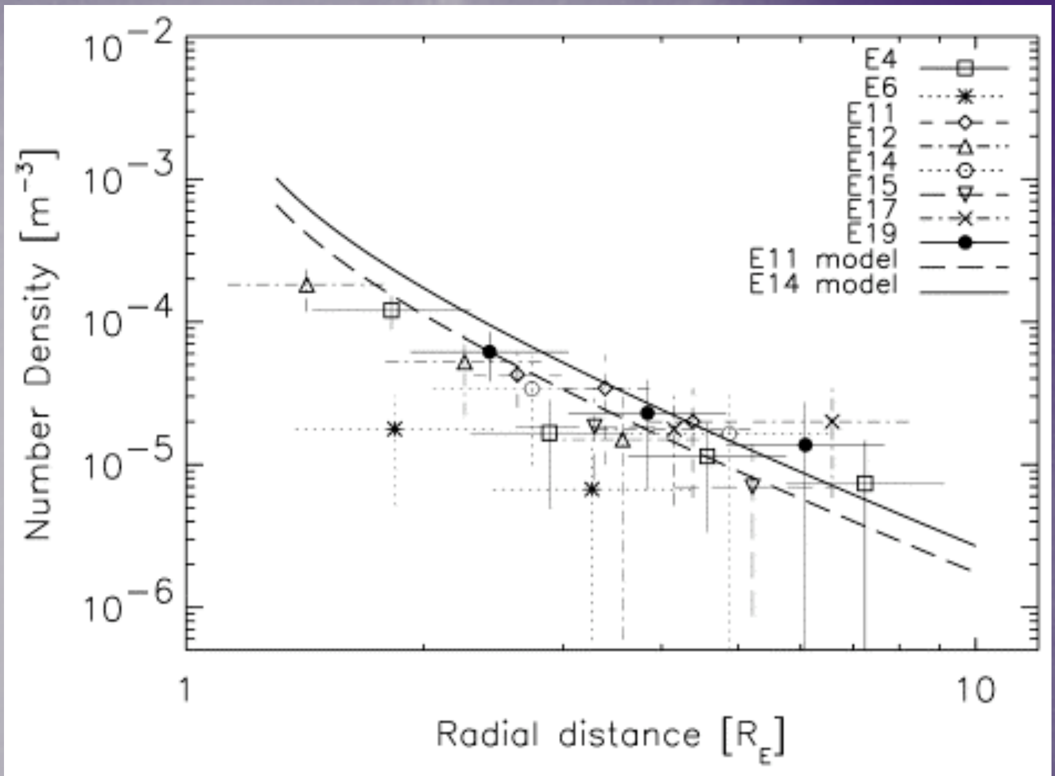
Love and Brownlee, 1993

100 ton/day @ Earth → 5 ton/day @ Moon

Secondary Ejecta

Galileo @ Europa

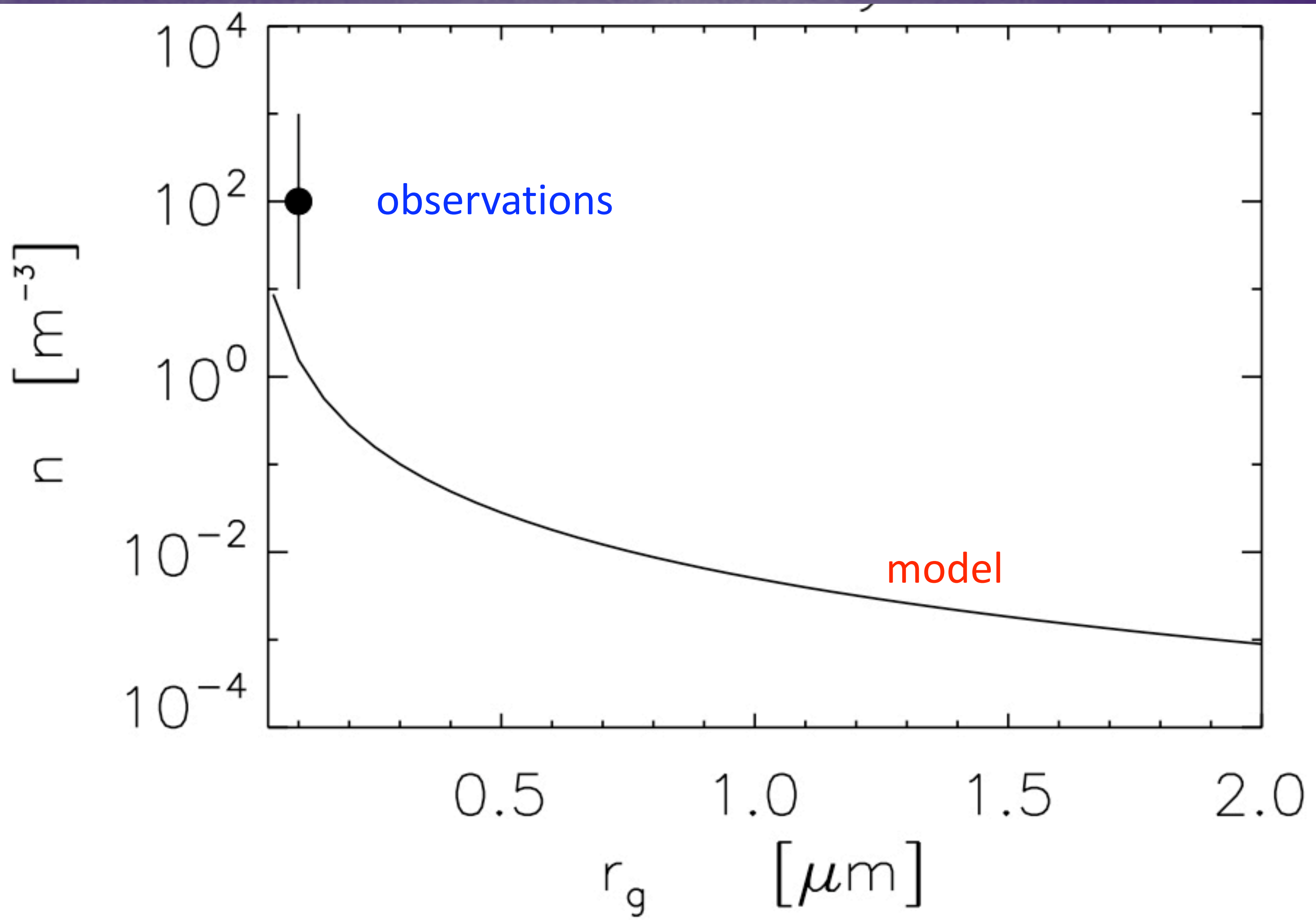




Kruger et al, 2003

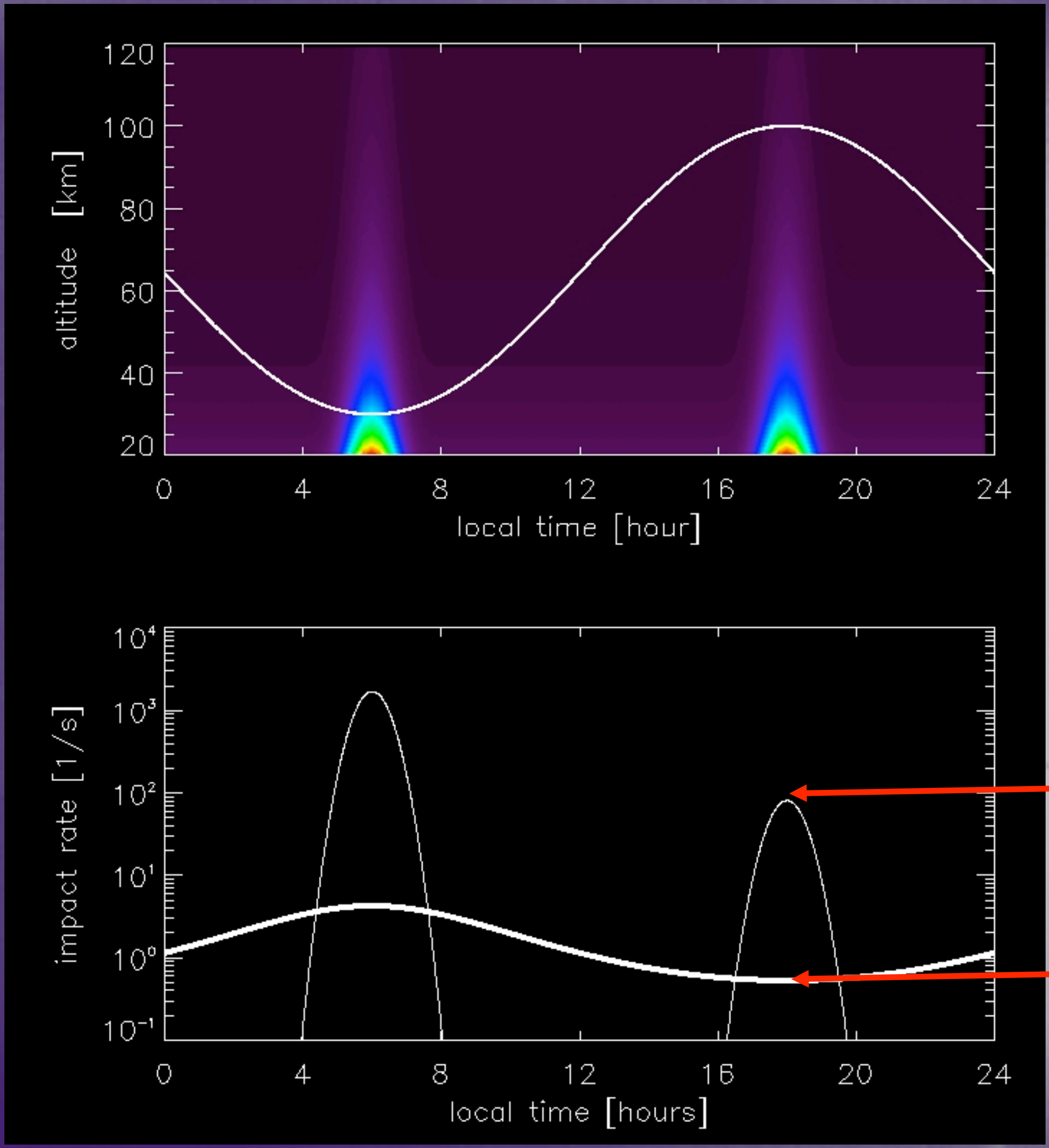
Parameters: yield, ejecta mass and velocity distributions

Lunar Ejecta



h = 50 km

Expected Impact Rates



30 x 100 km orbit

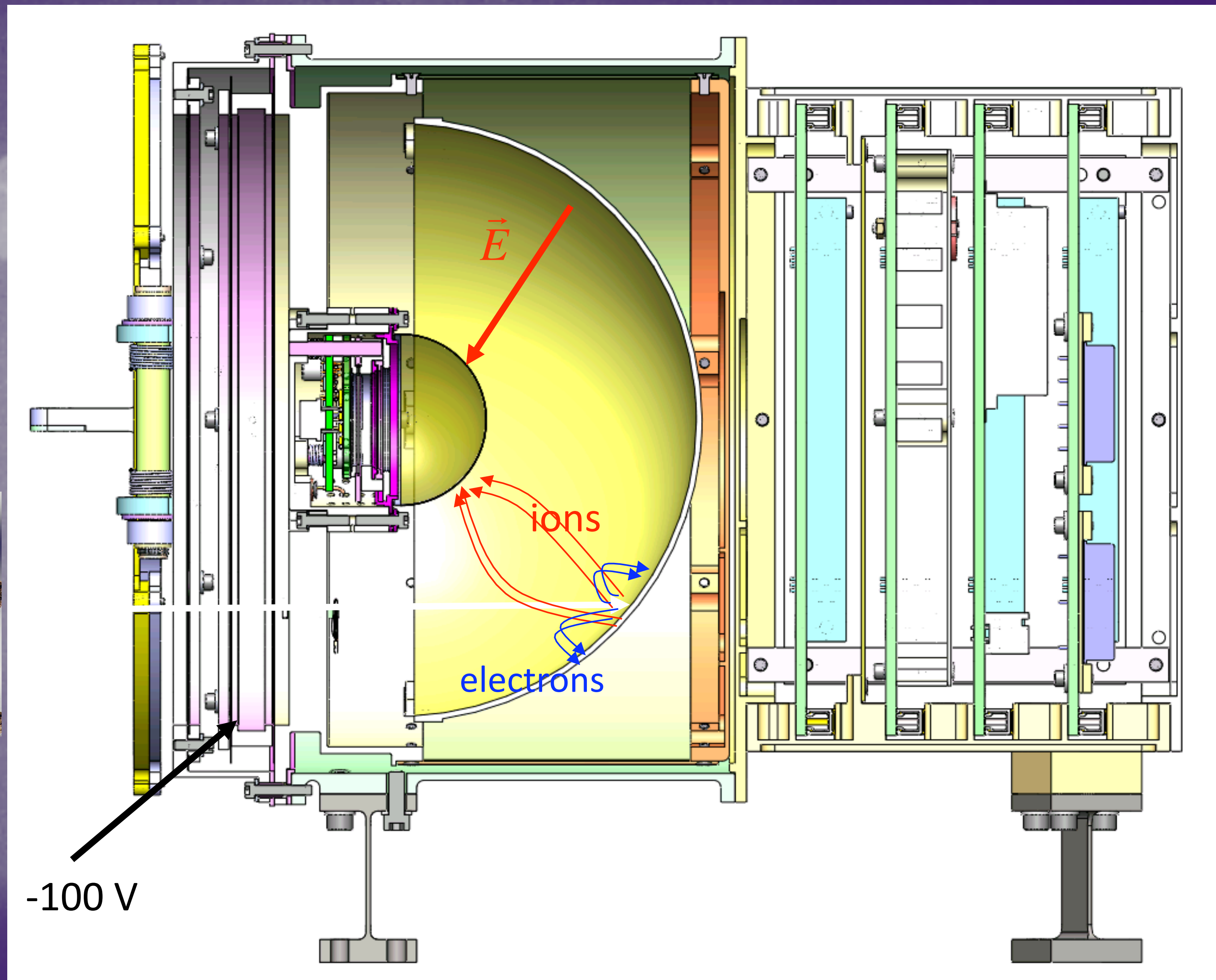
Pericenter over the morning terminator

$A = 100\ cm^2$

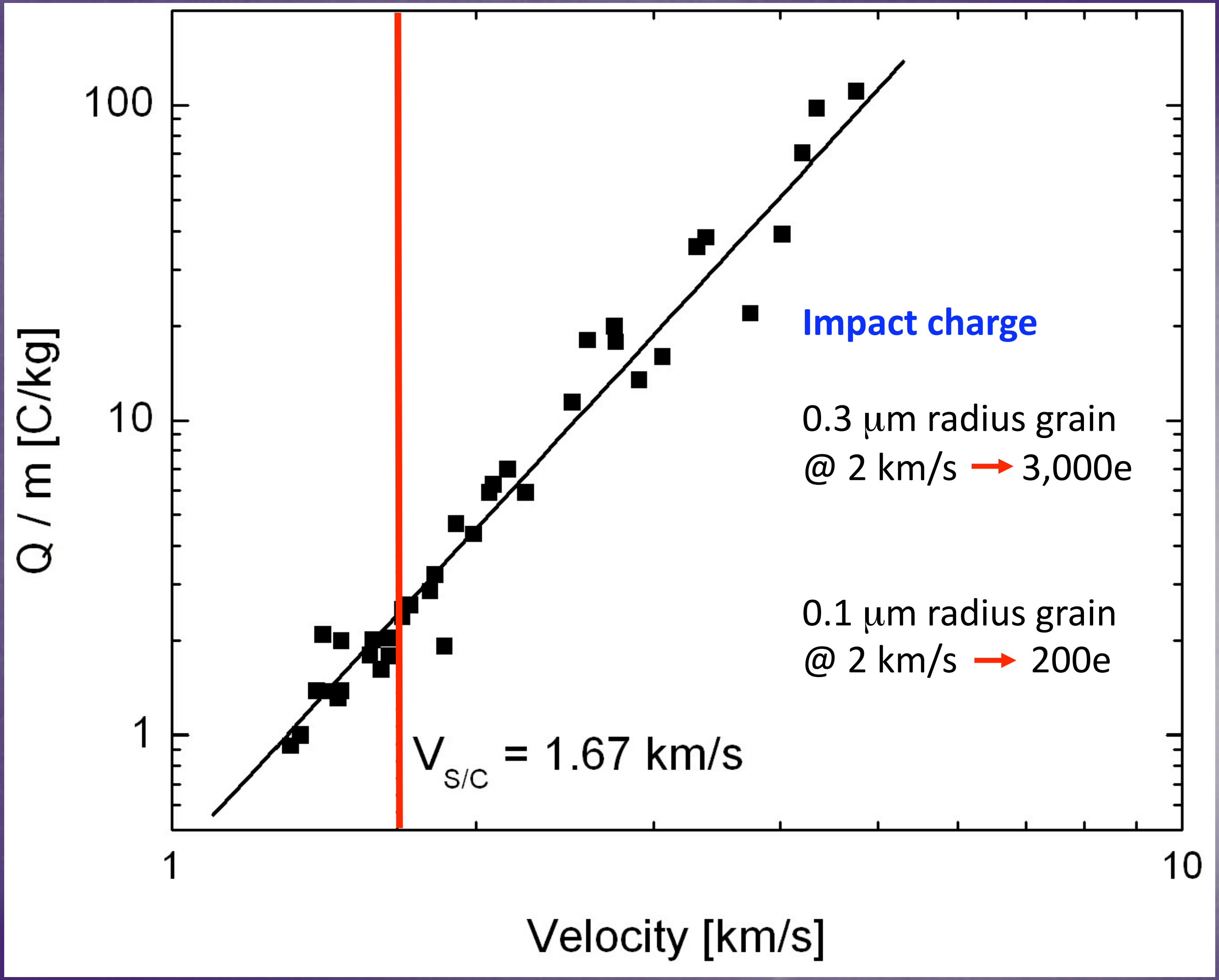
≤ 0.3 µm

> 0.3 µm

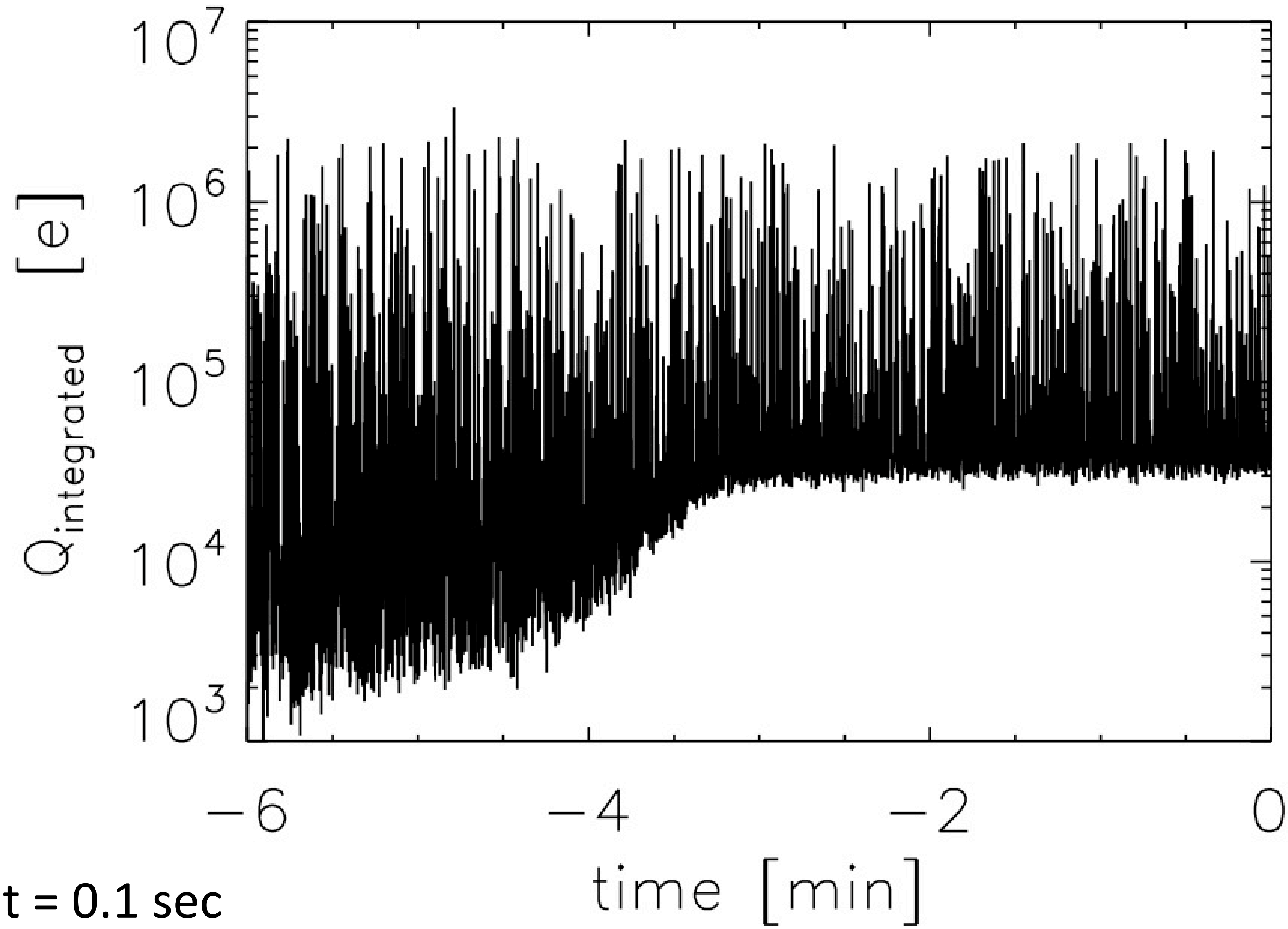
LDEX Instrument



Impact Charge

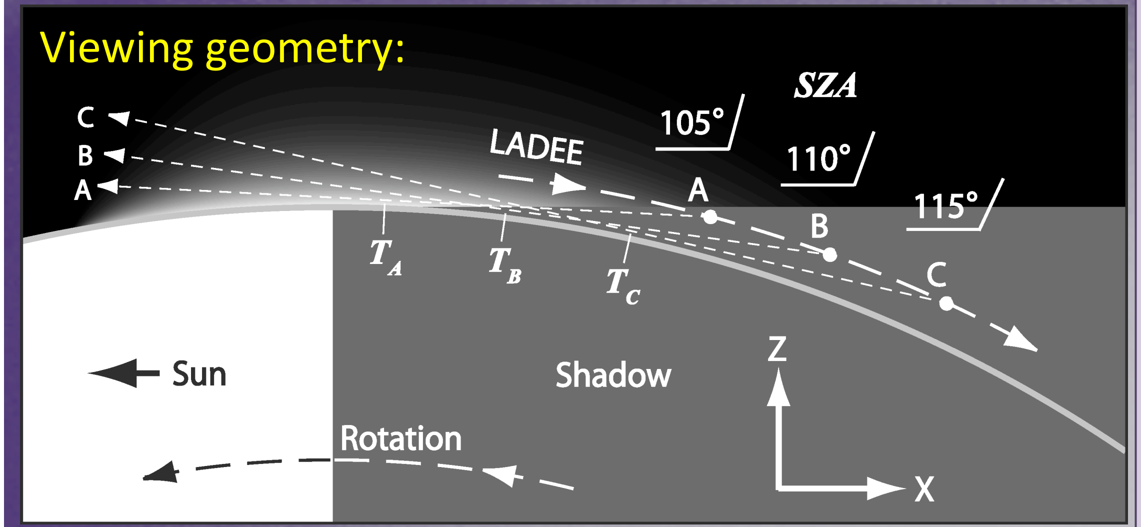


Expected Signal



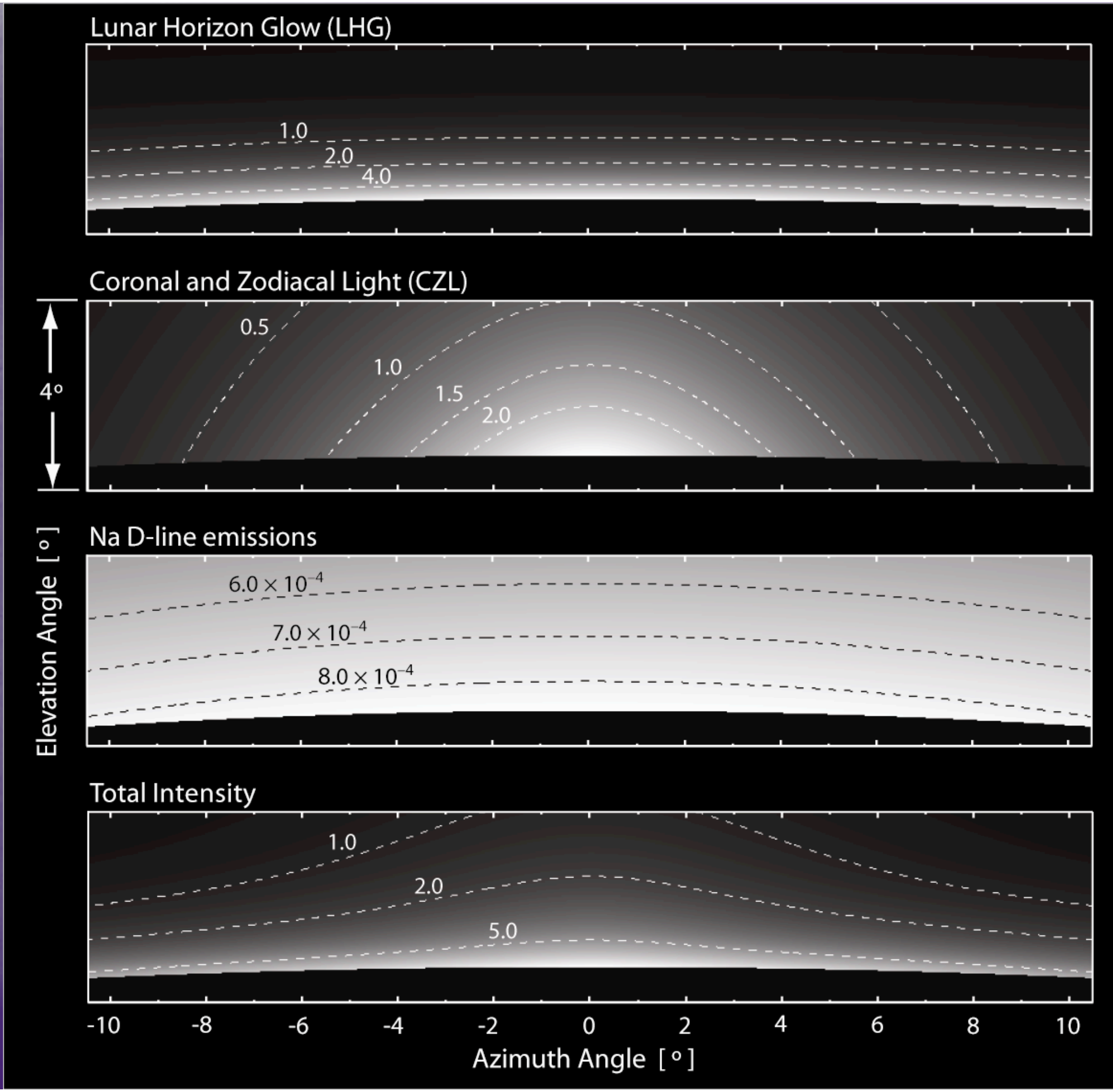
dt = 0.1 sec

Ultraviolet Spectrometer (LCROSS heritage)



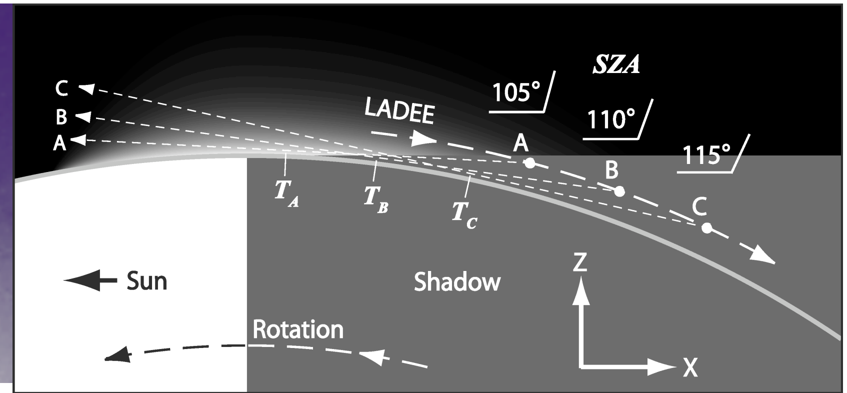
- Make predictions for limb observations w/ UVS and star tracker cameras
- Will look for
  - LHG
  - emission lines from exospheric gases
  - background CZL

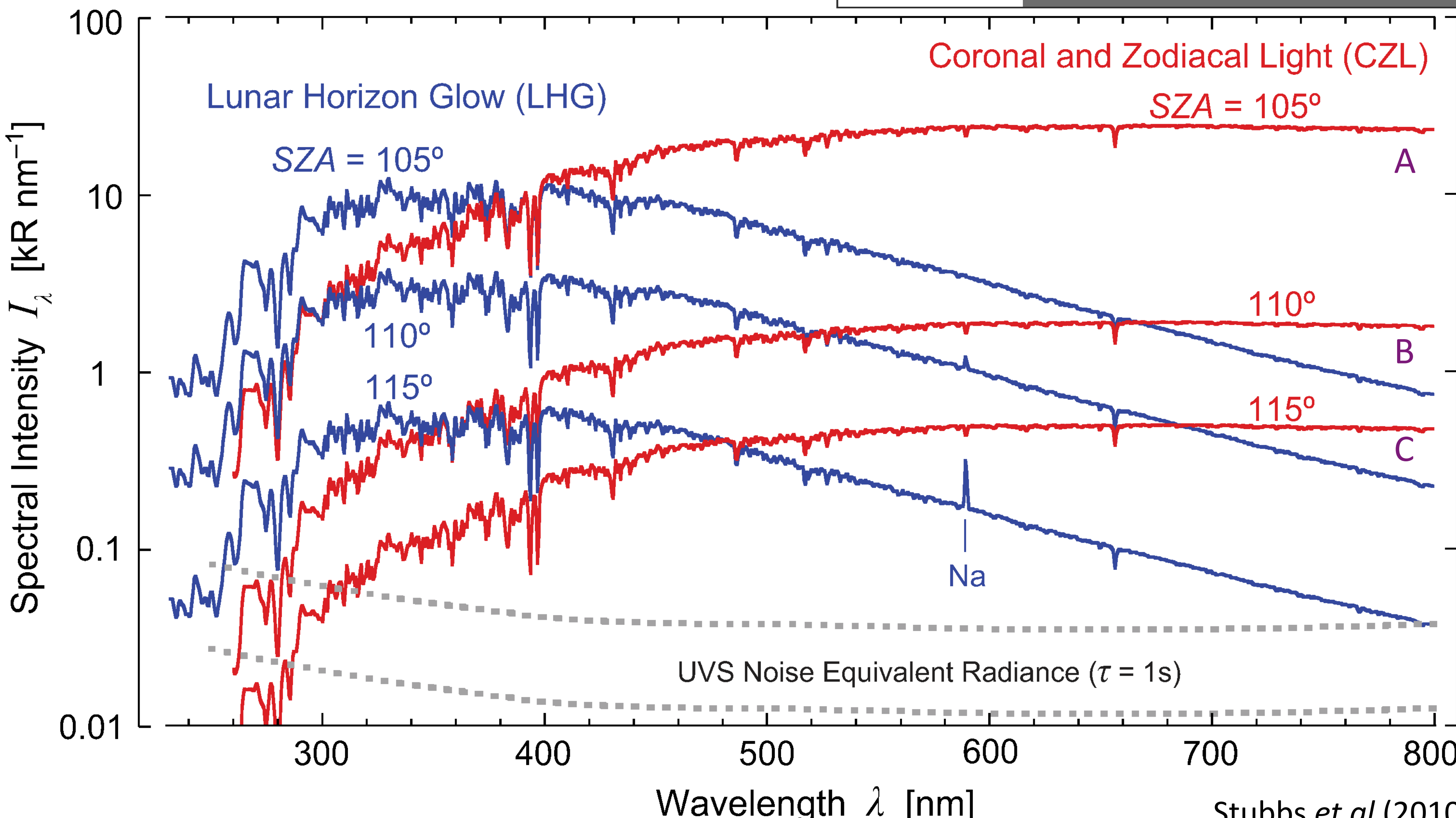
Field of View:	1.0° circular
Spectral coverage:	231.6-825.9 nm / 1044 pixels
Effective resolution:	0.70 nm
Spectral sampling:	0.54 nm
Sensitivity (kR/nm):	0.056 (λ=423 nm), 0.028 (λ=589 nm)
Operating modes:	Limb or solar occultation



Stubbs *et al.* (2010)

Expected spectral signals





Stubbs *et al* (2010)