Hydrogen at the Lunar Terminator

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Livengood *et al.* (2015). Moonshine: Diurnally varying hydration through natural distillation on the Moon, detected by the Lunar Exploration Neutron Detector (LEND). *Icarus* **255**, 100–115, doi: 10.1016/j.icarus.2015.04.004.

LEND
Lunar
Exploration
Neutron
Detector

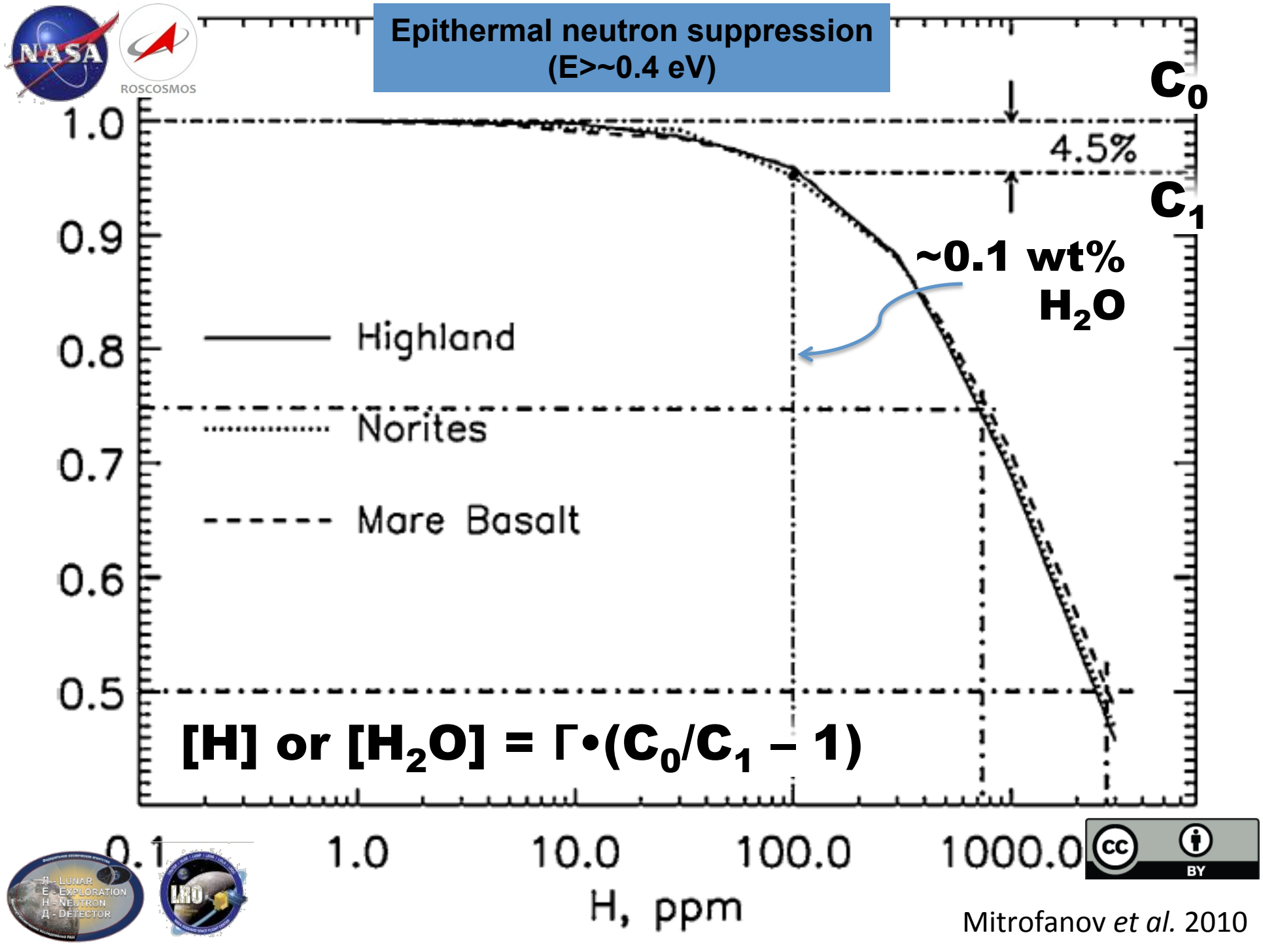
Poly

STN

SHE

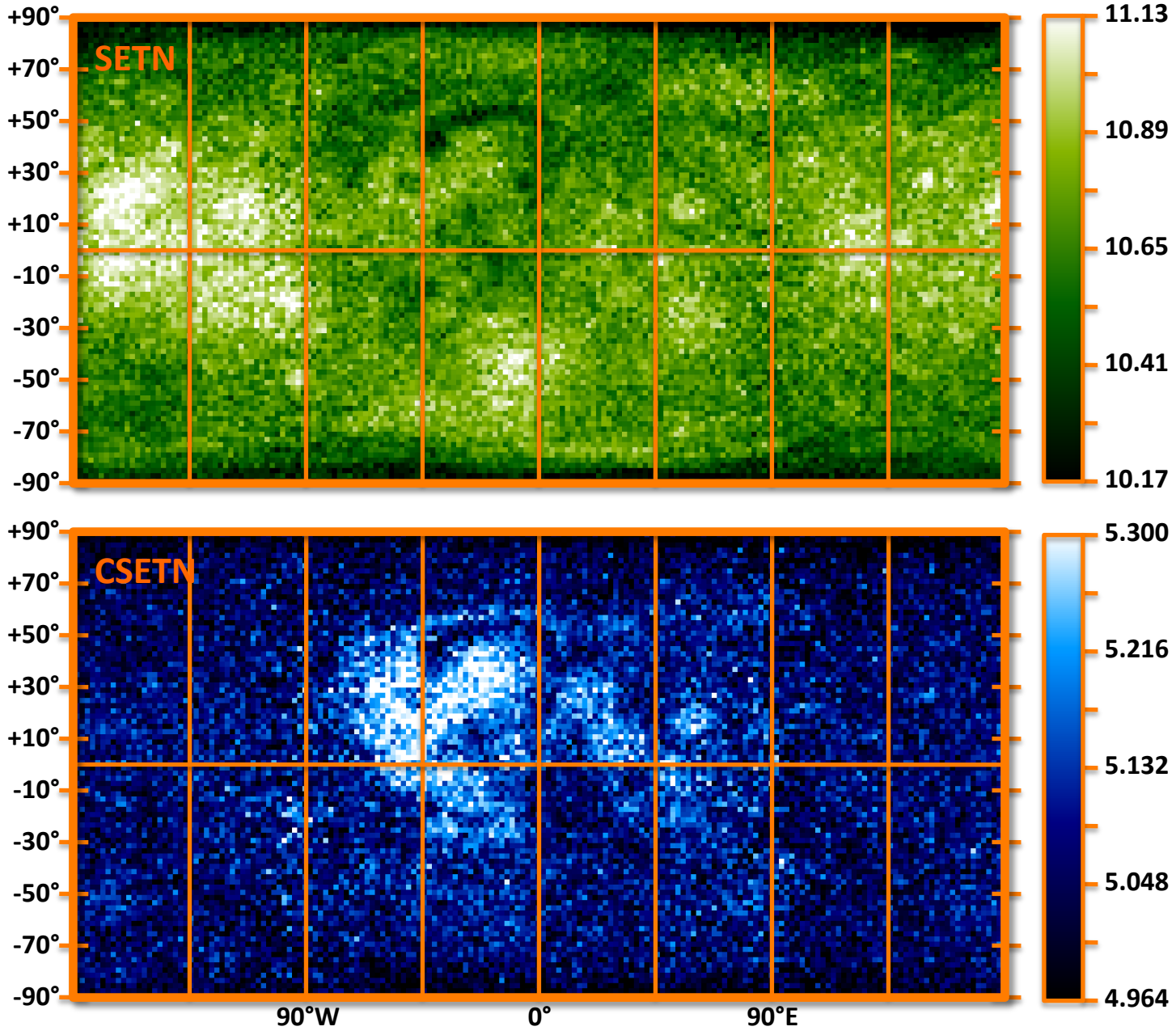
STN

Mod
and



Mitrofanov *et al.* 2010

Cylindrical maps of Lunar Neutron Flux

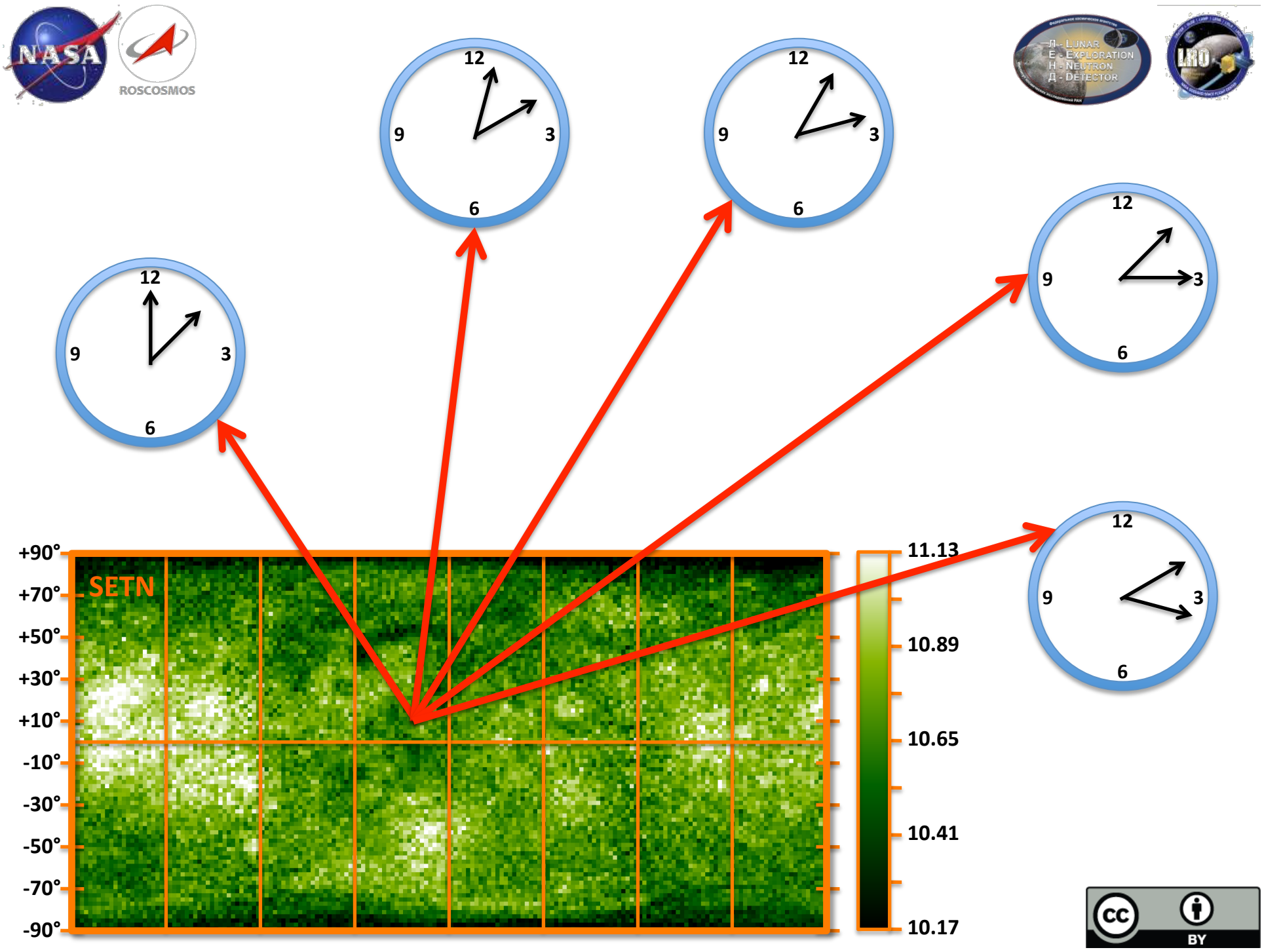


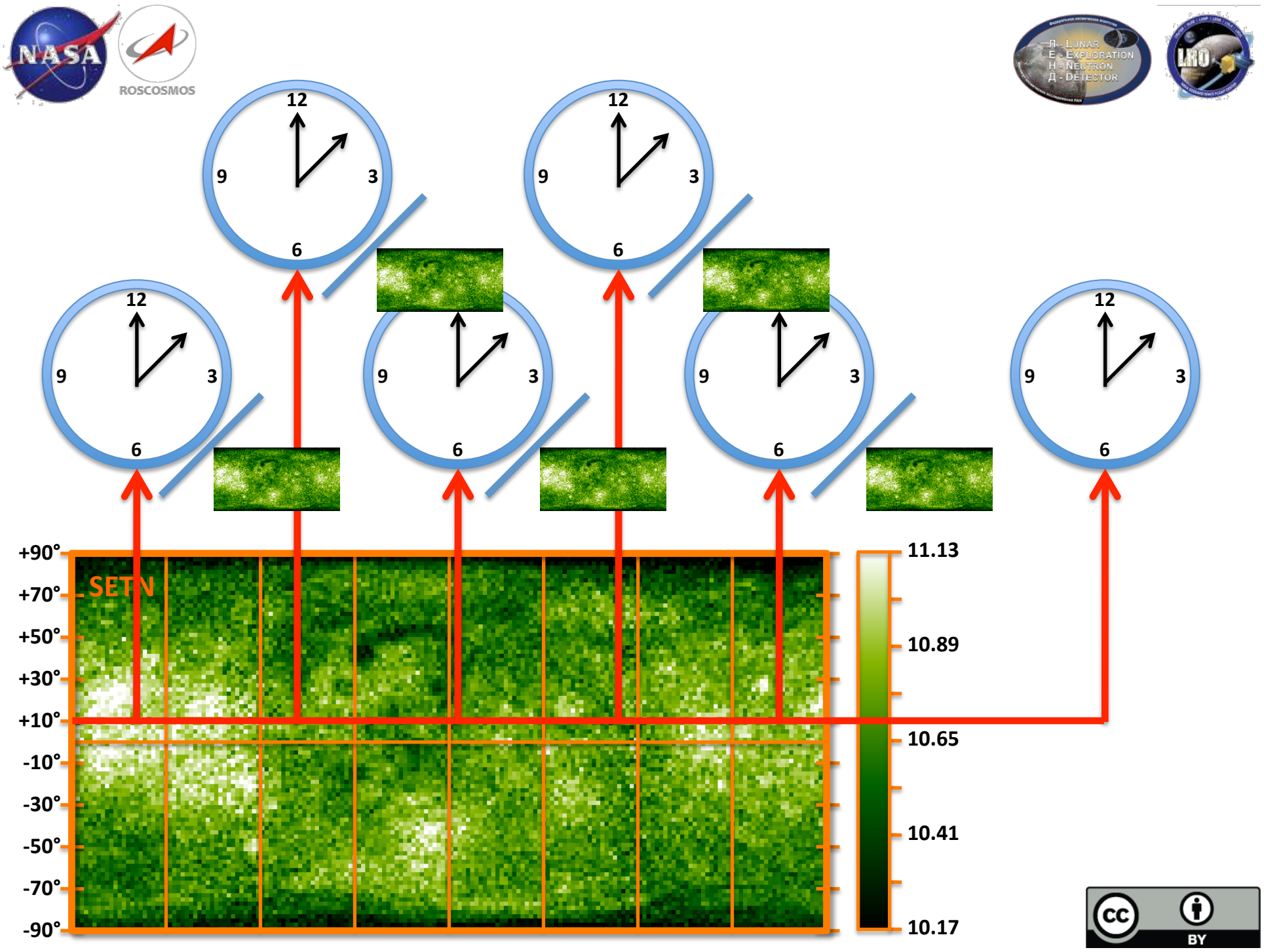
Uncollimated Epithermal = E>0.4 eV

Collimated Epithermal = E>0.4 eV

+

Out-of-collimation component at higher energy


NASA
ROSCOSMOS
Л - LUNAR
Е - EXPLORATION
Н - NEUTRON
Д - DETECTOR
LRO
12
3
6
9
SETN
+90°
+70°
+50°
+30°
+10°
-10°
-30°
-50°
-70°
-90°
11.13
10.89
10.65
10.41
10.17
CC
BY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LRO
12
3
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SETN
+90°
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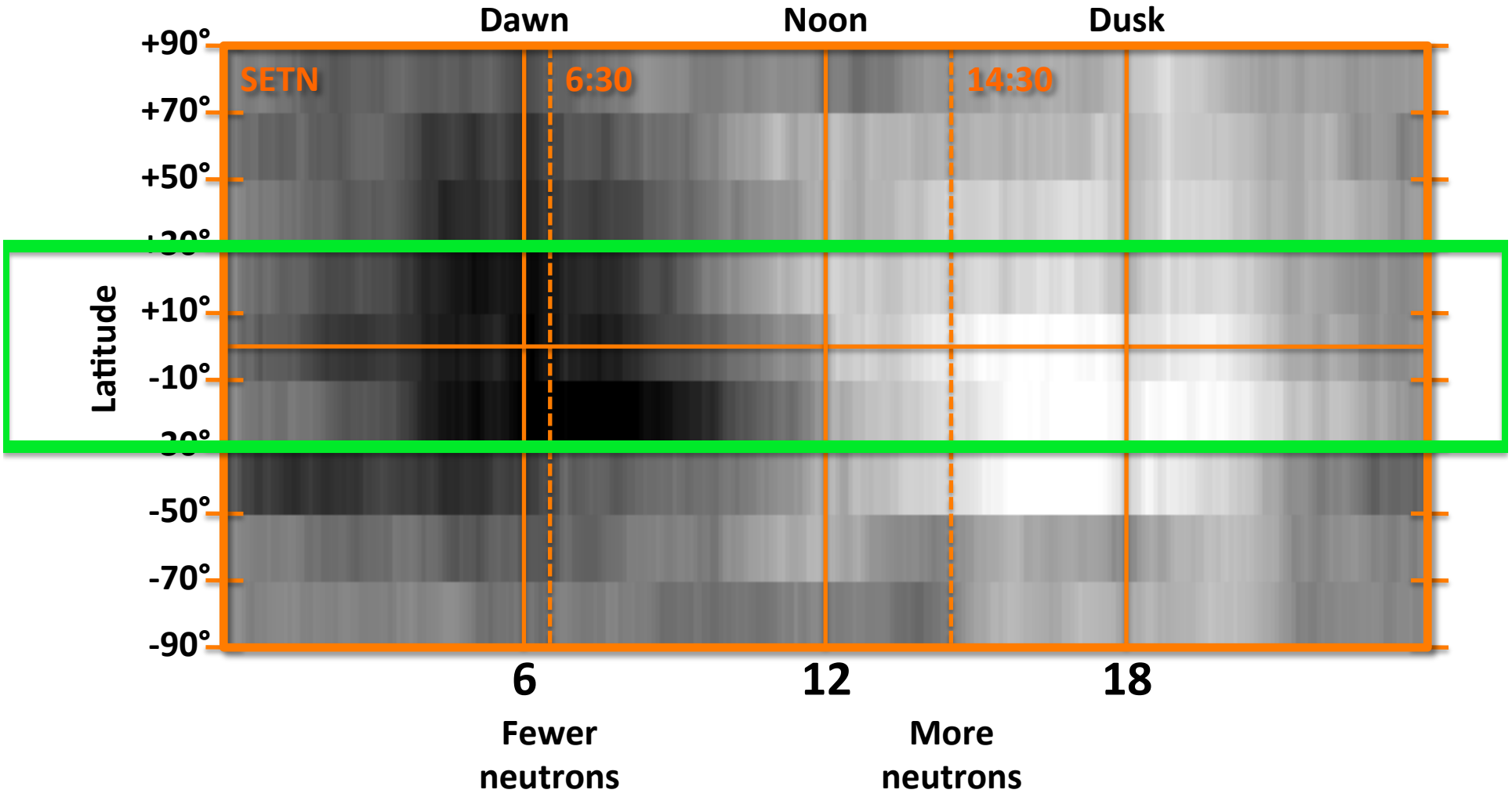
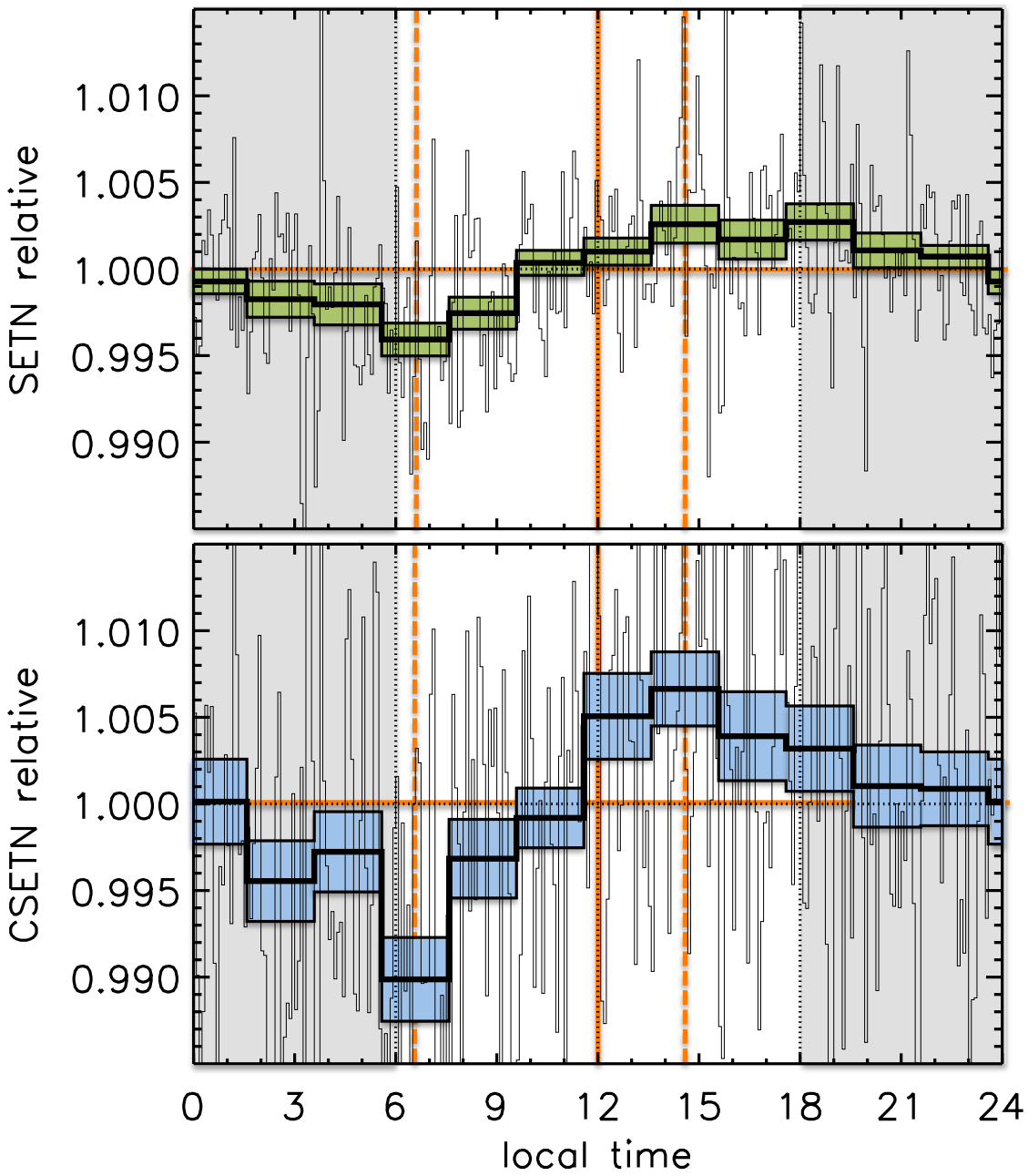
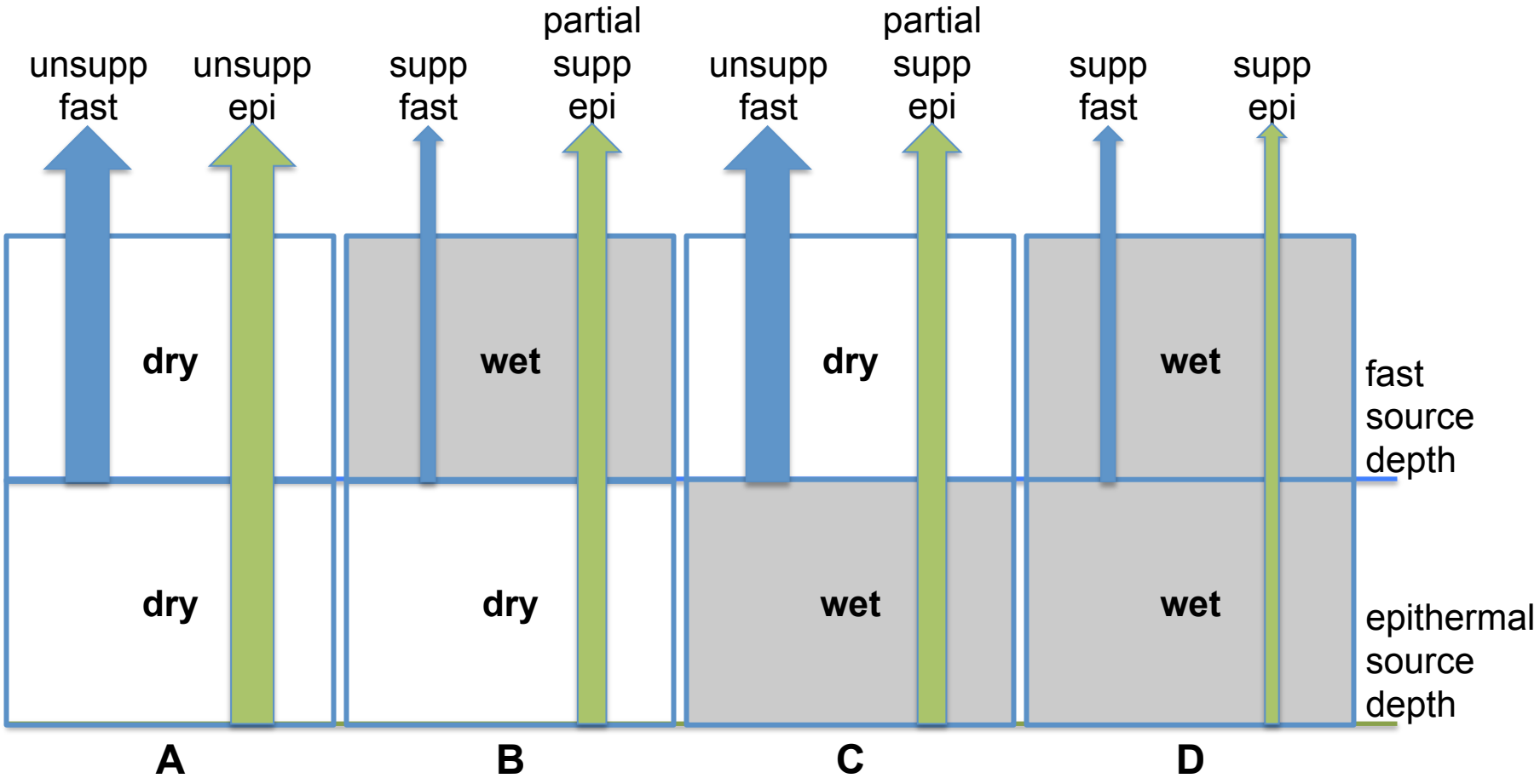
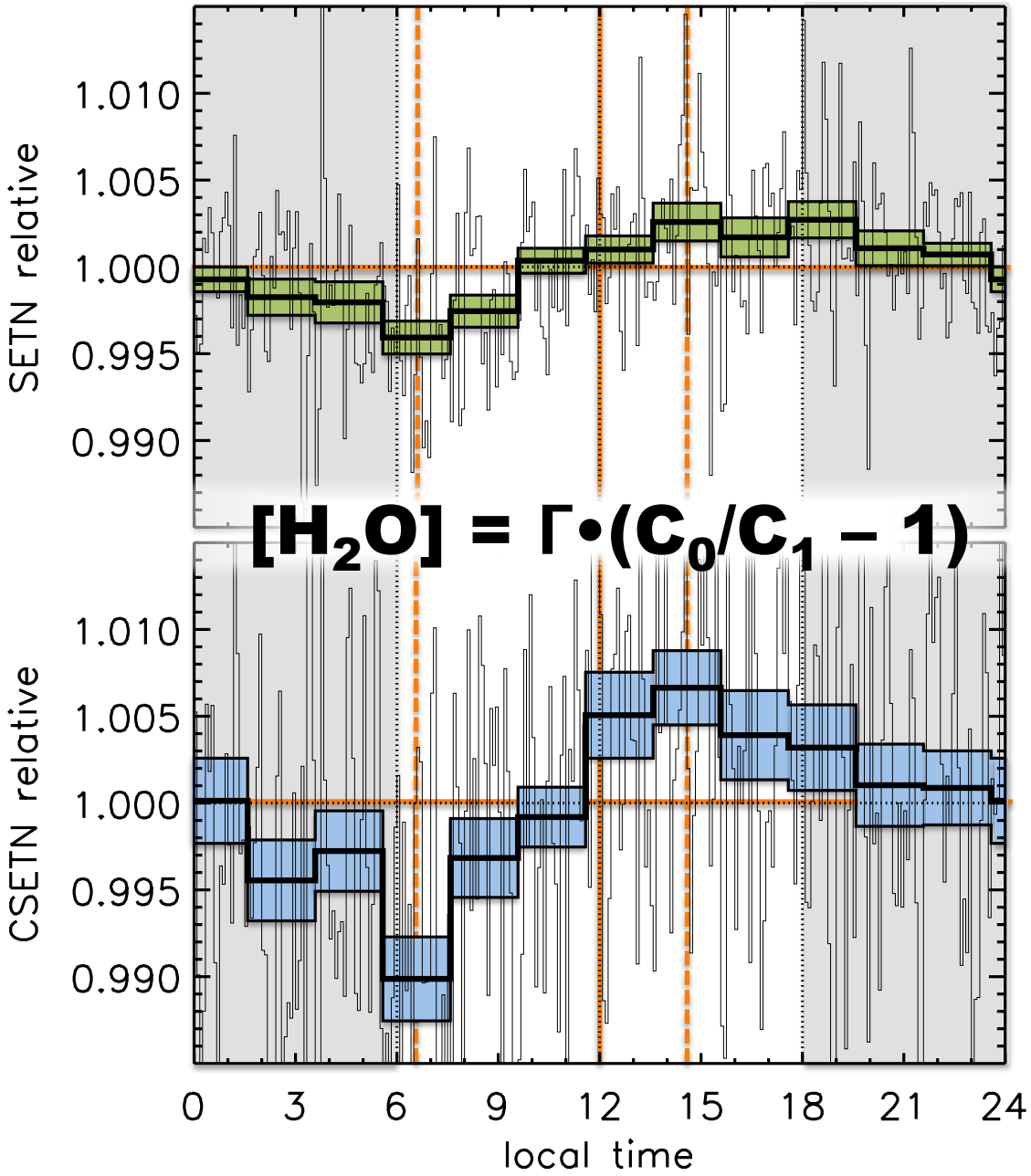
+30°
+10°
-10°
-30°
-50°
-70°
-90°
11.13
10.89
10.65
10.41
10.17
BY

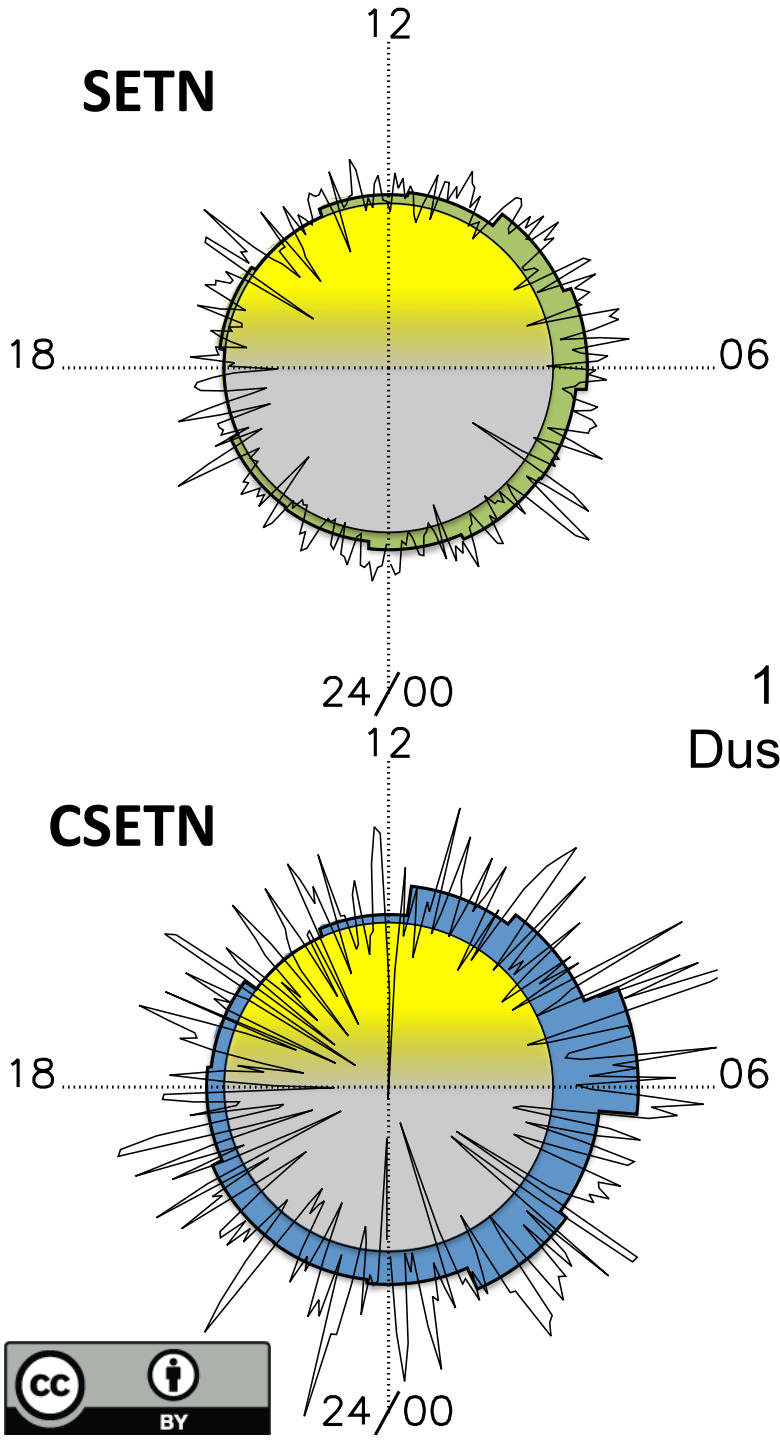
SETN

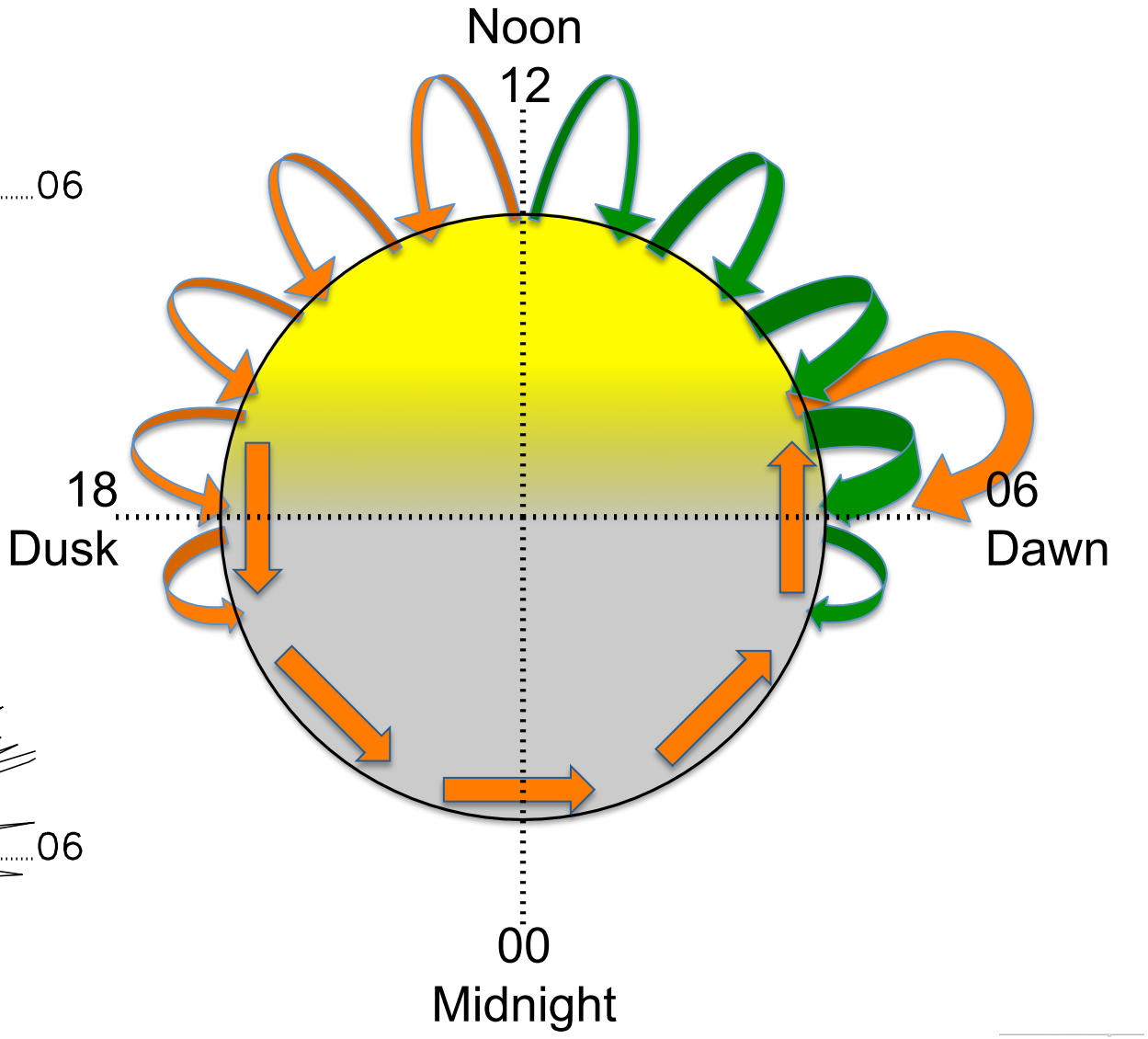

Dawn
Noon
Dusk
SETN
6:30
14:30
+90°
+70°
+50°
+10°
-10°
-50°
-70°
-90°
Latitude
6
12
18
Fewer neutrons
More neutrons

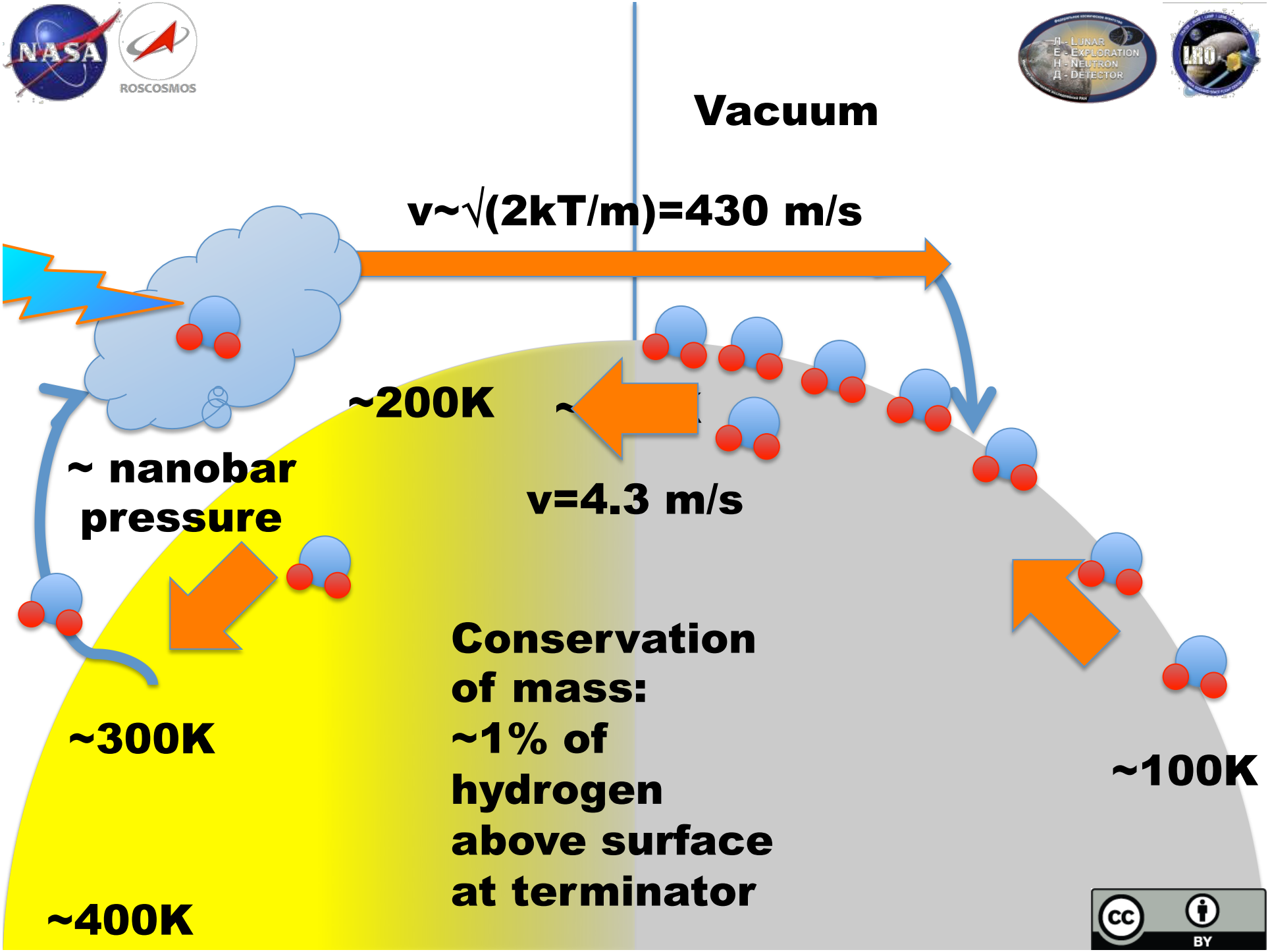

SETN relative
1.010
1.005
1.000
0.995
0.990
CSETN relative
1.010
1.005
1.000
0.995
0.990
0
3
6
9
12
15
18
21
24
local time

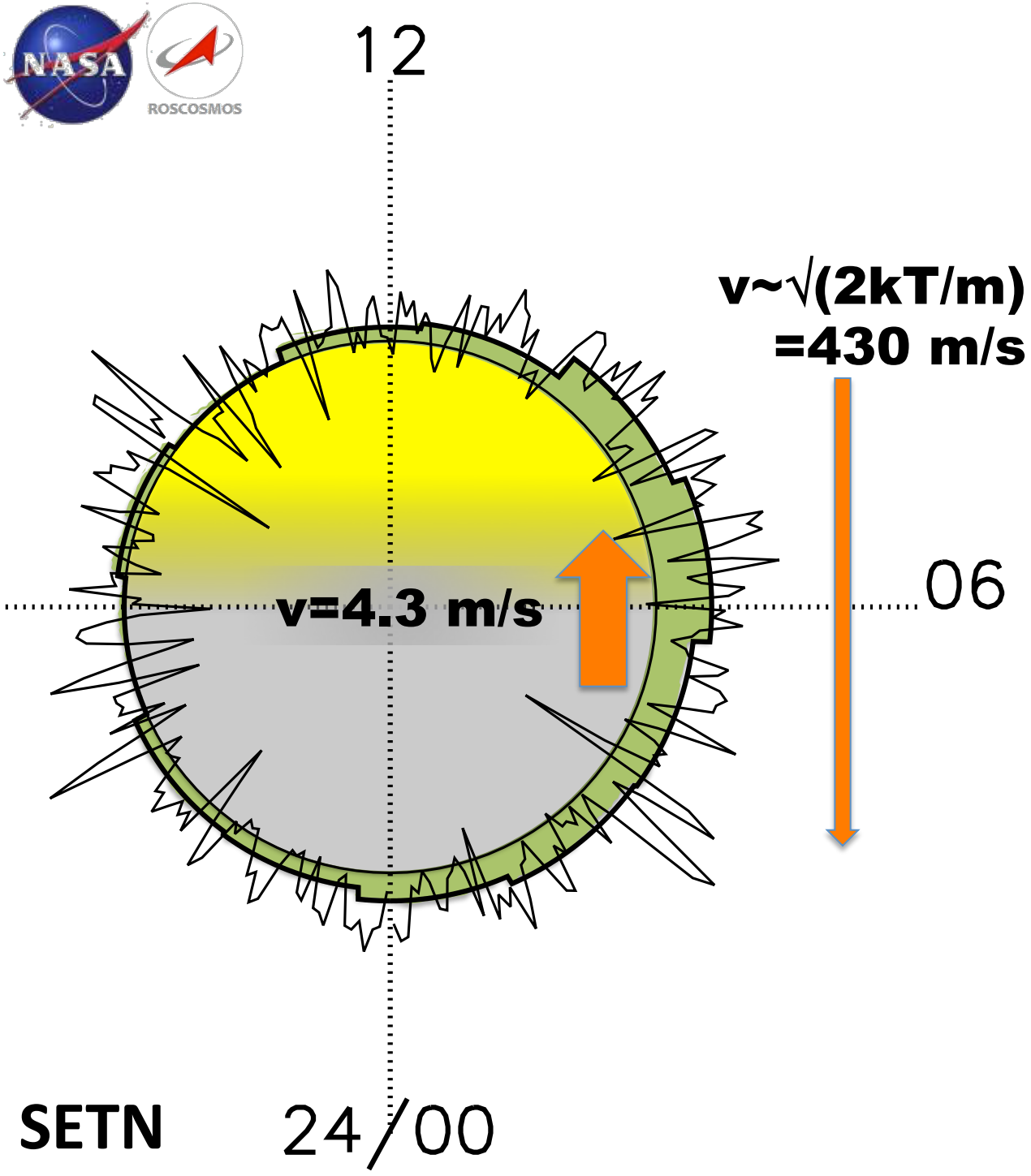

unsupp fast
unsupp epi
supp fast
partial supp epi
unsupp fast
partial supp epi
supp fast
supp epi
dry
wet
dry
wet
dry
wet
dry
wet
fast source depth
epithermal source depth
A
B
C
D


SETN relative
1.010
1.005
1.000
0.995
0.990
[H2O] = Γ•(C0/C1 – 1)
CSETN relative
1.010
1.005
1.000
0.995
0.990
0
3
6
9
12
15
18
21
24
local time


SETN
12
18
06
24/00
CSETN
12
18
06
24/00


Noon
12
18
Dusk
06
Dawn
00
Midnight

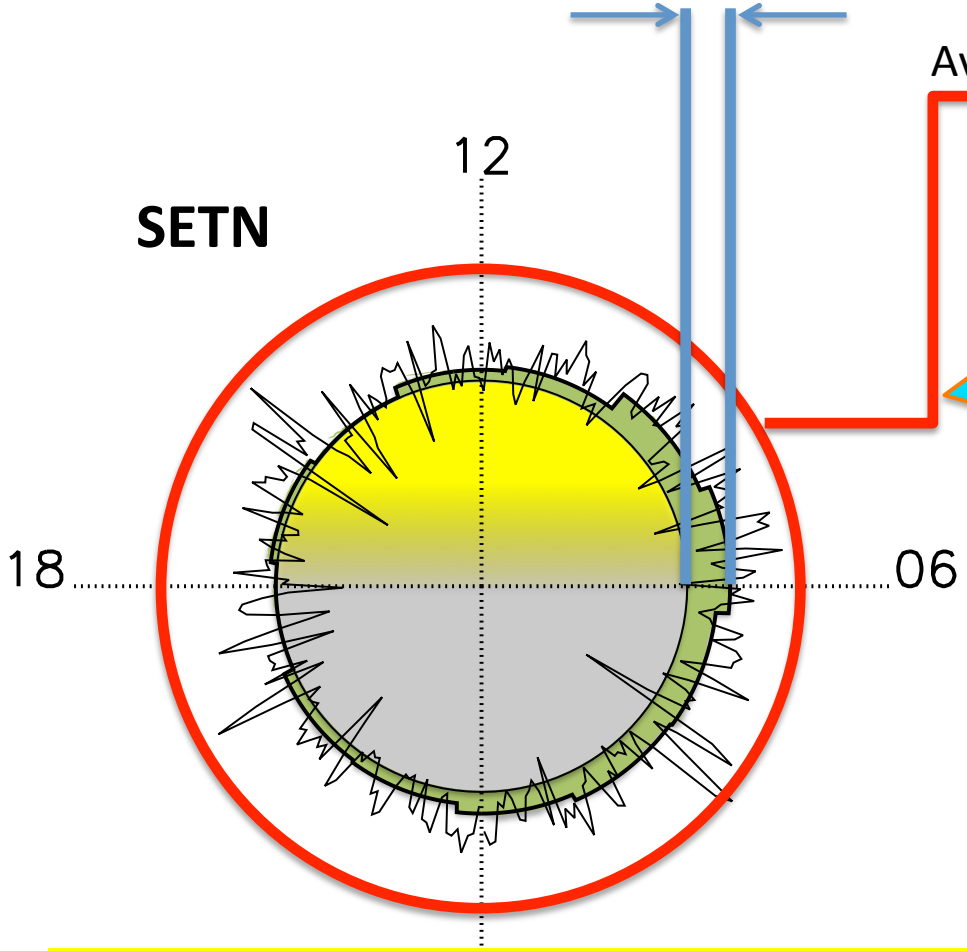

Vacuum
v~√(2kT/m)=430 m/s
~200K
~
~ nanobar pressure
v=4.3 m/s
~300K
Conservation of mass: ~1% of hydrogen above surface at terminator
~100K
~400K



Conservation of mass: ~1% of hydrogen above surface at terminator

$[H_2O]$ = 0.013±0.002 wt% WEH
= 187±33 ml/m^2
= (6.3±1.1)×10^{20} $[H_2O]$/cm^2

Avg $[H_2O]$ = (2.3±0.3)×10^{20} $[H_2O]$/cm^2



~99% sequestered at dawn terminator (conservation of mass), extends lifetime by ~100×
Lifetime ~ 10^5 sec × 100 = 10^7 sec

Photodestruction rate
= 2.3×10^{20} / 10^7
= 2×10^{13} $[H_2O]$/cm^2/sec

Solar wind, ~10^8 $[H_2O]$/cm^2/sec

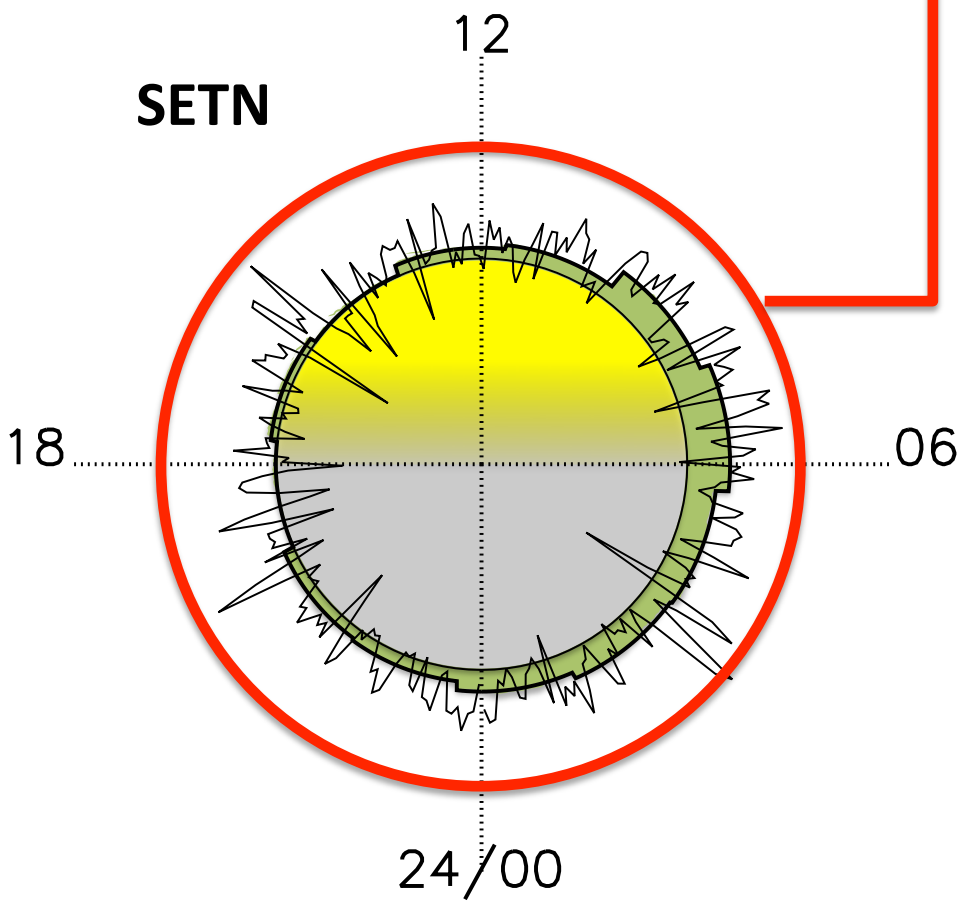
Micrometeoroids, <10^8 $[H_2O]$/cm^2/sec

Known exogenous sources too small by 5 orders of magnitude. Diurnally varying hydration must be indigenous.

Problem with outgassing primordial inventory

Resupply rate = Photodestruction rate = 2×10^{13} $[H_2O]/cm^2/sec$

= ~20 Earth total oceans over 4.5 Gyr.



Outgassing 20 Earth oceans of primordial water = absurd, implausible.

Lifetime extenders:

- ×2 – half of Moon not in Sun
- ×? – self-shielding
- ×? – recycling within collisional atmosphere

Alternative Estimates for Diurnally Variable Atmosphere/Water

- Apollo 17 Lunar Atmosphere Composition Experiment
  Estimated post-dawn density at surface ~10^7 mol/cm^3
  Integrated column = 6×10^{13} mol/cm^2 (200 K H_2O)
  Lifetime = 10^5 sec (no shielding)
  Photodestruction rate ~ 10^9 [H_2O]/cm^2/sec
  Solar wind supply is 1 order of magnitude too small.

- Near-IR Reflectance at 2.8 µm
  Minimum thickness = 1.4 µm monolayer
  Estimated average ~0.1 wt% [H_2O] = 7×10^{15} [H_2O]/cm^2
  Lifetime = 10^7 sec (assume shielding)
  Photodestruction rate ~ 10^9 [H_2O]/cm^2/sec
  Solar wind supply is 1 order of magnitude too small, with favorable assumptions.
  If monolayer is 1 mm thick, solar wind is 3-4 O too small.

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- Water at dawn peak = ~190 ml/m^2
- Water is mobile – intercept it above surface for "moisture farming".
- Equilibrium water density requires resupply from above (exogenous) or below (indigenous).
- Resupply rate is far too great for solar wind – only source not currently ruled out is indigenous.
- Definitive test requires equatorial landed mission; stick a probe in the ground, measure gas aboveground


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