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Solar wind interaction with the lunar surface: Observation of energetic neutral atoms on the lunar surface by the Advanced Small Analyzer for Neutrals instrument on the Yutu-2 rover of Chang'E-4

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INTRODUCTION

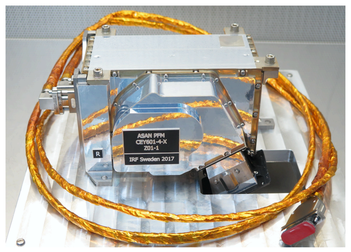
- Remote sensing shows about 1/5th of solar wind protons impinging on the lunar surface are reflected back to space as energetic neutral atoms.
- The **Advanced Small Analyzer for Neutrals (ASAN)** on the Yutu-2 rover of Chang'E-4 is the first instrument measuring energetic neutral atoms directly *in-situ* on the lunar surface.
- ASAN is a single angular pixel instrument with mass and energy resolution and makes use of the mobility of the Yutu-2 rover to investigate different patches of undisturbed lunar regolith under different solar wind illumination conditions and observation angles.
- Chang'E-4 landed on 3 January 2019 in the Von Kármán crater on the lunar farside. ASAN science operations began on January 31, 2019.

INSTRUMENTATION

The Advanced Small Analyzer for Neutrals (ASAN)

- Compact, surface interaction based time-of-flight instrument
- 8th member of the *SWIM family* (*Wieser and Barabash, JGR, 2016*)
- Adapted for operation on Yutu-2 in collaboration between the **Swedish Institute of Space Physics (IRF)** and with the **National Space Science Center, Chinese Academy of Sciences**.

Detects	Energetic neutral atoms (ENA) Positive ions
Energy range	10 eV — 10 keV
Energy resolution	ENA: ΔE/E = 16% - 100% Ions: ΔE/E = 7%
Mass resolution	ENA: H, O, heavier atoms Ions: m/q = 1, 2, 4, 8, 16, >32
Time resolution	4 s
Mass	787 g , w DPU, w/o harness
Bus voltage	28 V (adjustable)
Power	3.4 W (7 W for cover opening)
Dimension	108 * 151 * 100 (mm^3)
Data rate	<1000 bps (CCSDS)
Operation	-25°C ~ +50°C
Actuator	Cover, one-time open
Operation	Continuous, >=1 year



ASAN flight instrument
Wieser et al., SSRv (2020), doi:10.1007/s11214-020-00691-w

OBJECTIVES

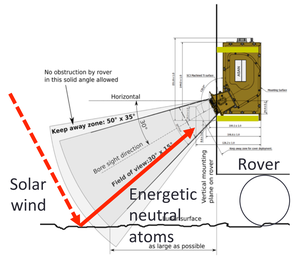
High-level science objectives

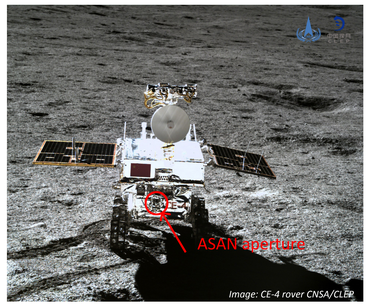
- *What is the microphysics of the solar wind-surface interaction processes?*
- *How is the lunar exosphere formed* and maintained?

Derived measurement objectives

- Determine *in-situ* energy distribution, mass composition and angular emission properties of energetic neutral atoms emitted from the lunar regolith.
- Investigate dependences on solar wind parameters, local time and micro topography.

OBSERVATION GEOMETRY





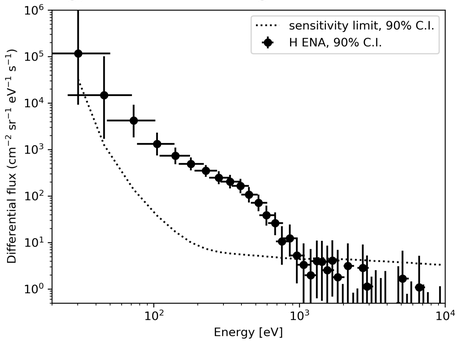
INSTRUMENT STATUS

Status end of January 2020

- ASAN is in excellent health with no visible degradation.
- Typically measurements are performed during local morning and evening due to thermal constraints.
- A total of 49h of data accumulated in 41 individual measurement sessions between January 2019 and January 2020, and counting.

RESULTS

Energy spectrum of energetic neutral atoms emitted from the surface



Average spectrum for energetic neutral hydrogen, January 2019 – September 2019.

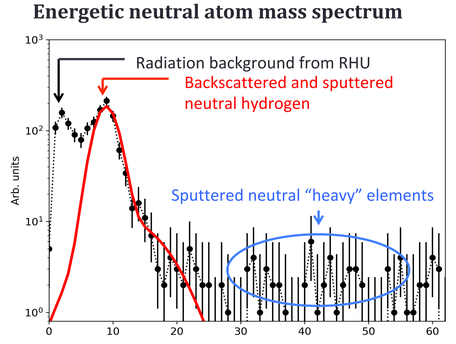
High energy cutoff follows the solar wind proton energy.

Good agreement with Chandrayaan-1/SARA and IBEX.

Low energy part (<100eV) highly variable

(Aibing et al., PSS, 2020)

Energetic neutral atom mass spectrum



Energy-integrated mass spectrum

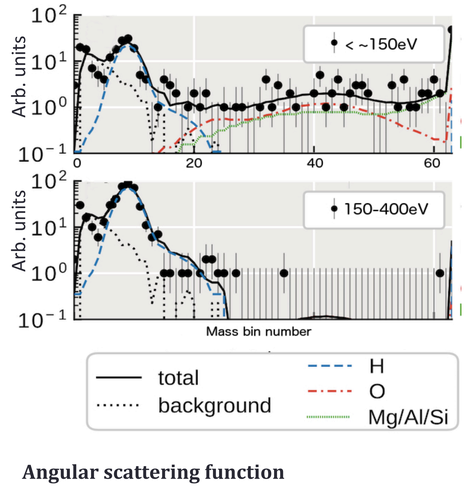
Largest signal is from neutral hydrogen.

Background from Radioisotope Heater Unit (RHU) creates a distinct signature in the mass spectrum.

(Wieser et al. in preparation)

RESULTS (CONT.)

Mass composition with fitted ASAN mass response curves



"Heavy" elements observed at low energies only, confirming their origin from surface sputtering.

Hydrogen mostly originates from backscattering.

Separation of background, oxygen and Si-group elements requires modeling.

Angular scattering function

- Angular scattering profiles appear compatible with models derived from SARA/Chandrayaan-1 measurements (*Vorburger et al., JGR, 2013*).
- More coverage with individual ASAN measurements is needed to constrain these models.
- Removal of solar wind shadowing effects by the rover itself requires modeling.

Estimated lunar hydrogen albedo

The lunar hydrogen albedo for (E>28eV) of the surface at the Von Kármán crater is comparable to large-scale or global averages reported elsewhere, although exact values are somewhat sensitive to the integration methods used:

ASAN (1st May 2019 site):	**0.13 (+0.20/-0.04)**	*Most likely value, median = 0.28*
Chandrayaan-1/SARA:	**0.19 (+0.02/-0.03)**	*(Futaana et al., GRL, 2012)*
IBEX:	**0.11 (+/-0.06)**	*(Saul et al. , PSS, 2013)*

SUMMARY

- **First measurement** of energetic neutral atom emissions directly **on the lunar surface itself**.
- **Energy** spectra for energetic neutral hydrogen agree well with previous remote measurements, although the low energy part < 100eV is highly variable.
- Both **backscattered and sputtered energetic neutral atom components identified**.
- **Hydrogen albedo comparable** with large-scale or global values.