Lunar photoemission yields inferred from ARTEMIS measurements

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Introduction & Motivation

- Photoemission yield
  - the number of emitted photoelectrons per incoming photon
  - one of the fundamental properties of solid materials, here lunar surface
  - ***not yet well constrained for photon energies > ~20 eV***

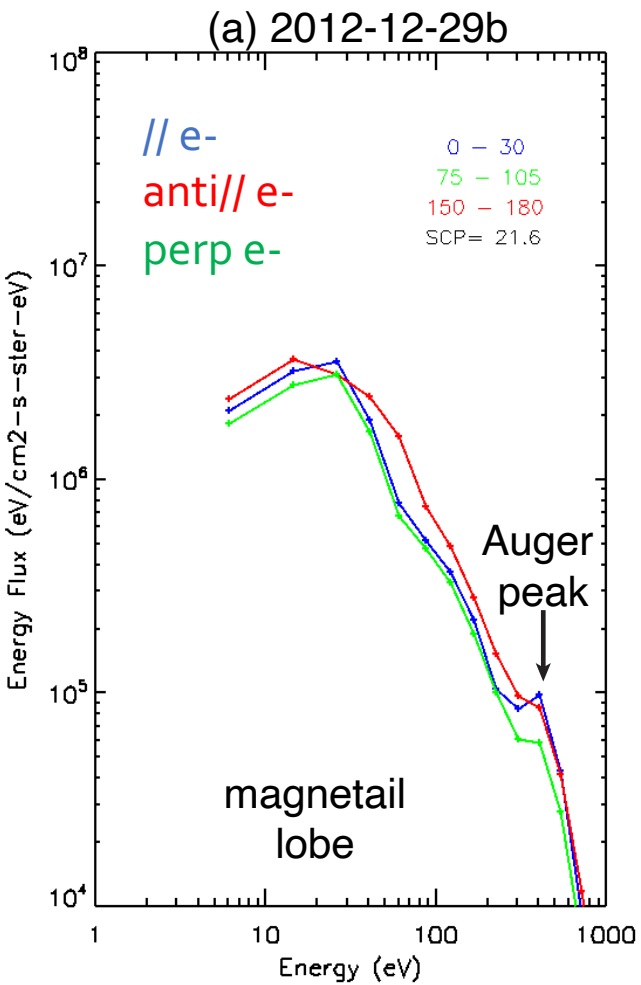
- Important for characterizing lunar surface charging environment
  - Surface potential varying drastically in different plasma environments
  - Solar photon flux variations (solar cycle, solar rotation, solar flares etc)
  - Better surface charging modeling if photoemission yield at high energy available

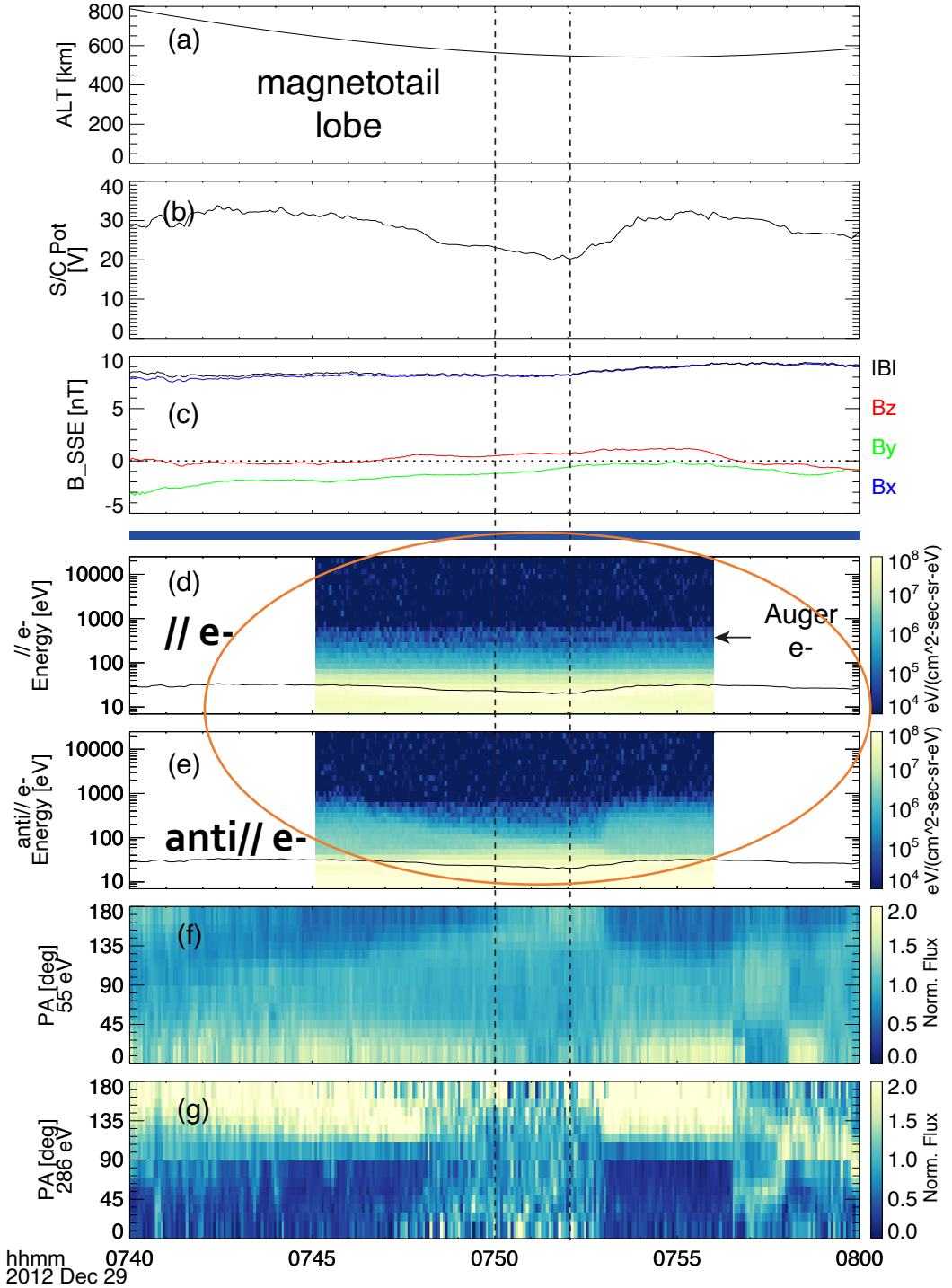
Case Study: Lunar Photoelectrons and Auger Electrons

- <u>Auger e-</u>
  - ionization of inner shell e-
  - peak in flux at fixed energy, ~500 eV for O
  - a unique feature to identify lunar surface photo e- & surface atomic comp.
  - **first report**
- <u>Solving photoemission yield</u>

$$f(\varepsilon)d\varepsilon = \int_W^{\infty} S(E)Y(E)F(\varepsilon,E)dE\, d\varepsilon$$

- f(ε): photo e flux - ARTEMIS data
- S(E): photon flux – FISM2
- F(ε, E): probability function
- *Y(E): photoemission yield*
  - *Matrix inversion → Y(E)*

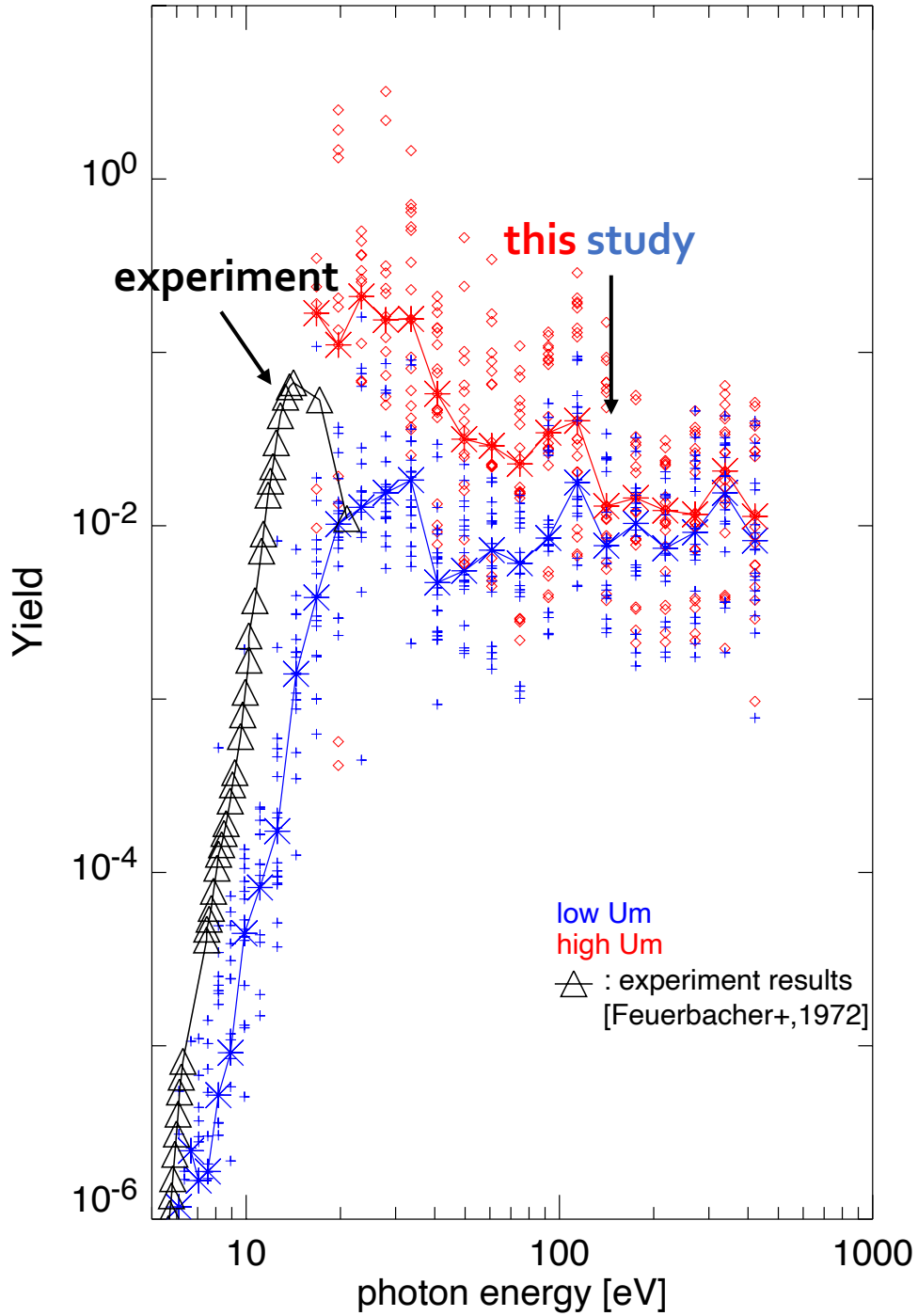




Calculated Yield with PFs in Liter.

- △: experiment results
- +/◇: calculated yields for 5 probability functions (PF) for all 4 selected dates
  - Red: assumed high Um (=lunar surf. potential)
  - Blue: assumed low Um

- This study (red/blue lines):
  - Yield ~ 0.01 for photons > ~30 eV, roughly constant
  - Uncertainty in yield is 1-order of magnitude
  - Unknown Um affects more at low energies
  - **A sensitivity study shows 3-4 orders of magnitude uncertainty in yield because of unknown PFs (assumed in liter.)**



Summary

- We make the first report of oxygen Auger electron observations at the Moon by the ARTEMIS spacecraft

- We infer a lower bound of 10^{-3} in photoemission yield of the lunar surface for photon energies >∼20 eV

- Uncertainties over 3-4 orders of magnitude in yields are found, motivating future experiments on lunar samples for a better understanding

- *Xu, S., Poppe, A. R., Harada, Y., Halekas, J. S., & Chamberlin, P. C. (2021). Lunar photoemission yields inferred from ARTEMIS measurements. Journal of Geophysical Research: Planets, 126, e2020JE006790. https://doi.org/10.1029/2020JE006790*

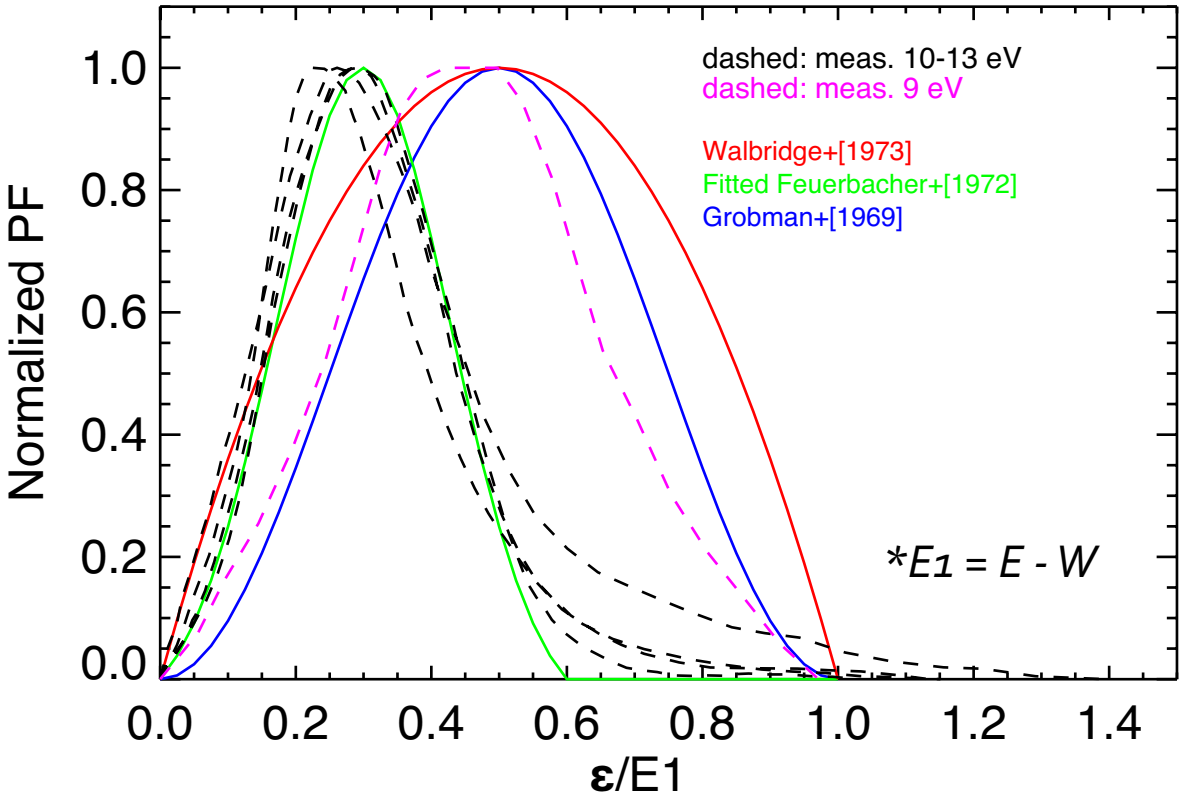
Solving Photoemission Yield

$$f(\varepsilon)d\varepsilon = \int_W^\infty S(E)Y(E)F(\varepsilon,E)dE\ d\varepsilon$$

- E: photon energy
- ε: electron energy
- W: work function ~ 6 eV
- f(ε): photoelectron flux -- ARTEMIS data
- S(E): photon flux – FISM2
- F(ε, E): probability function – assumed in liter.
  - *probability distribution of photo e- flux as a function of ε produced by a photon beam at* E

- *Y(E): photoemission yield*
  - *Matrix inversion →Y(E)*

Various forms of Prob. Func in literature

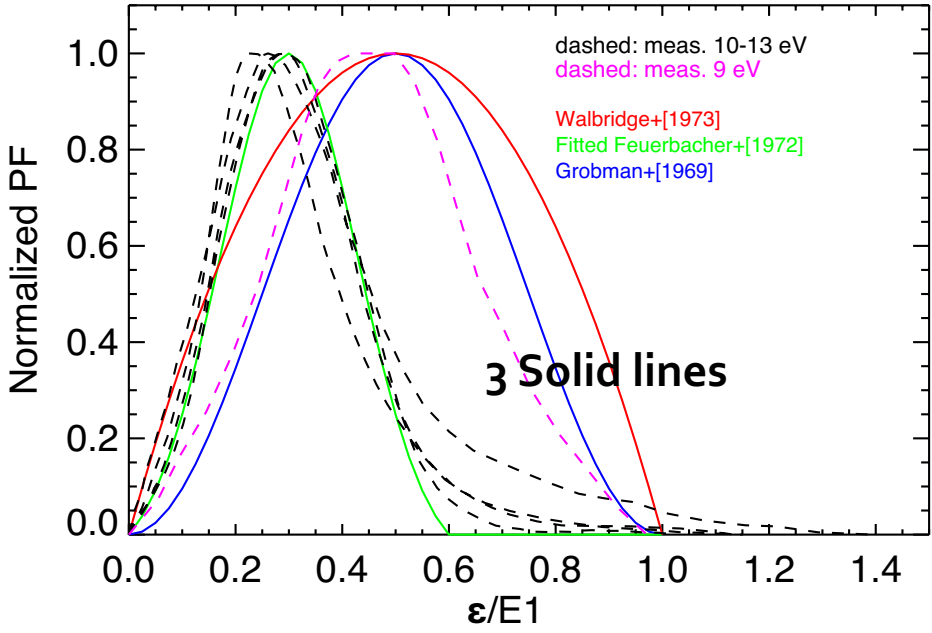


5 Probability Functions

$$F = A_0 \sin(\pi\varepsilon/E_1)^2/E_1;\ (Grobman\ \&Blank,1969);$$

$$F = A_1\varepsilon * (E_1 - \varepsilon)/E_1^3;\ (Reasoner\ \&Burke,1972;Walbridge,1973)$$

$$F = A_2 \left[\exp\left(-\left(\frac{0.3-(\varepsilon/E_1)}{0.182}\right)^2\right) - \exp\left(-\left(\frac{0.3}{0.182}\right)^2\right)\right]$$



- Plus, 2 delta functions
  - δ(ε/E1 = 1): A photon with E1 producing solely photo e- at ε=E1
  - δ(ε/E1 = 0.5): A photon with E1 producing solely photo e- at ε=0.5E1

Sensitivity Study with Delta Func

- Prob Func actually unknown for photon energies > 20 eV

- Sensitivity study with delta functions δ(x), x = ε/E1
  - A photon beam with E (*E1 = E-W*) producing e- at ε only
  - Conceptually, smaller x, smaller ε, more e- produced by a single photon → a higher yield
  - Lower bound of ~0.001 in yield (x = 1)
  - 3-4 orders of magnitude uncertainty in yield
    - Yield for metal (>100 eV) ~ 0.1

- More to uncertainties in yield:
  - **different cases**: a factor of 2-3 uncertainty
  - **unknown in Um**: a factor of few uncertainty for low E1
  - **unknown prob func**: orders of magnitude uncertainty