Ion cyclotron waves at the Moon and their connection tothe plasma sheet and the lunar exosphere

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Acknowledgments:
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Tail Environment and Dynamics at Lunar Distances Focus Group
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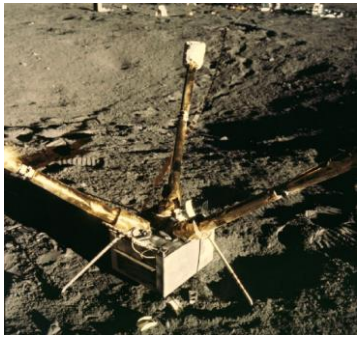
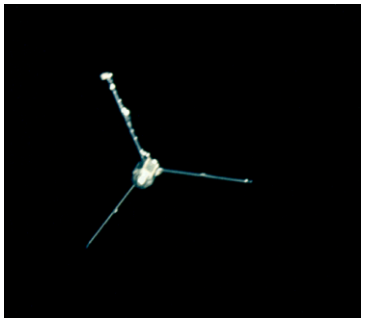
Apollo Magnetic Field Experiments

Lunar Surface Magnetometer (LSM)



Apollo 12
Apollo 15
Apollo 16
(NASA Ames)

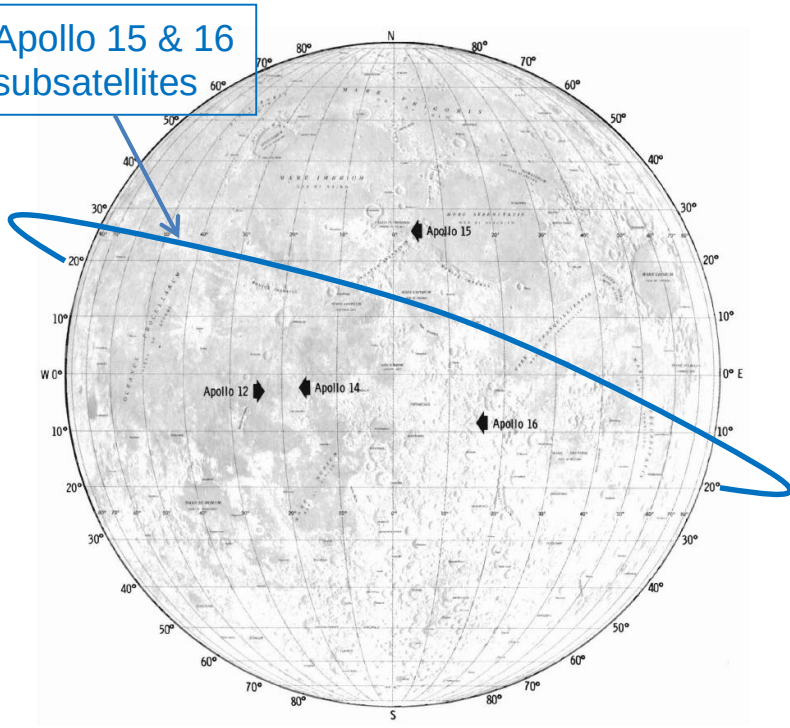
Sub-satellite Biaxial Magnetometer (SBM)

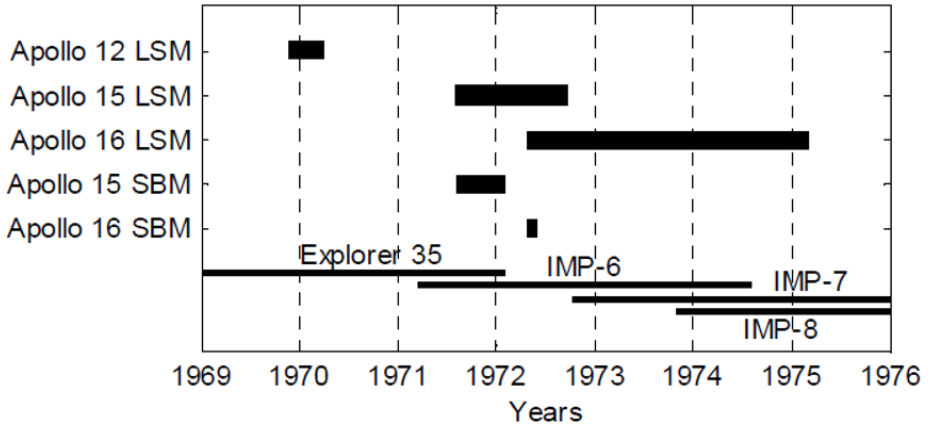


Apollo15
Apollo16
(UCLA)

Lunar Portable Magne-tometer

Apollo 14
Apollo 16
(NASA Ames)

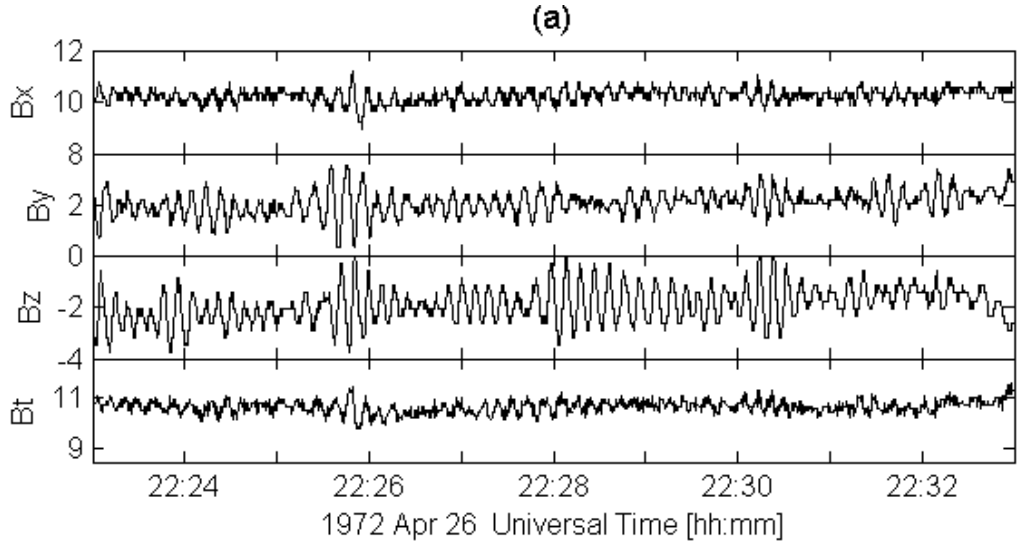


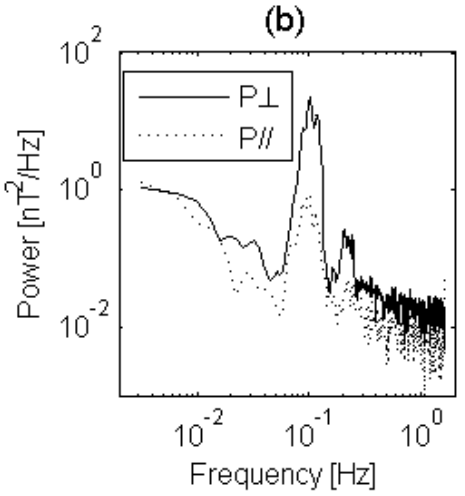


Waves Observed by Apollo 15 LSM: Narroband vs. Broadband

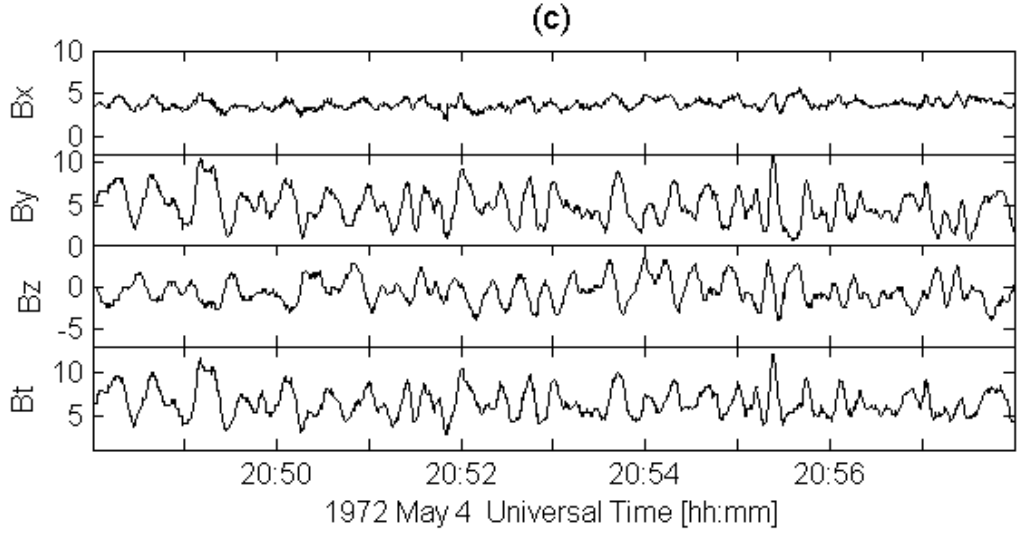
Chi et al. (2013), *PSS.*

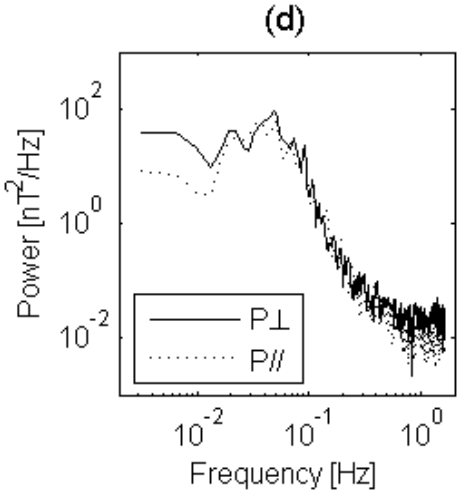
Magnetotail



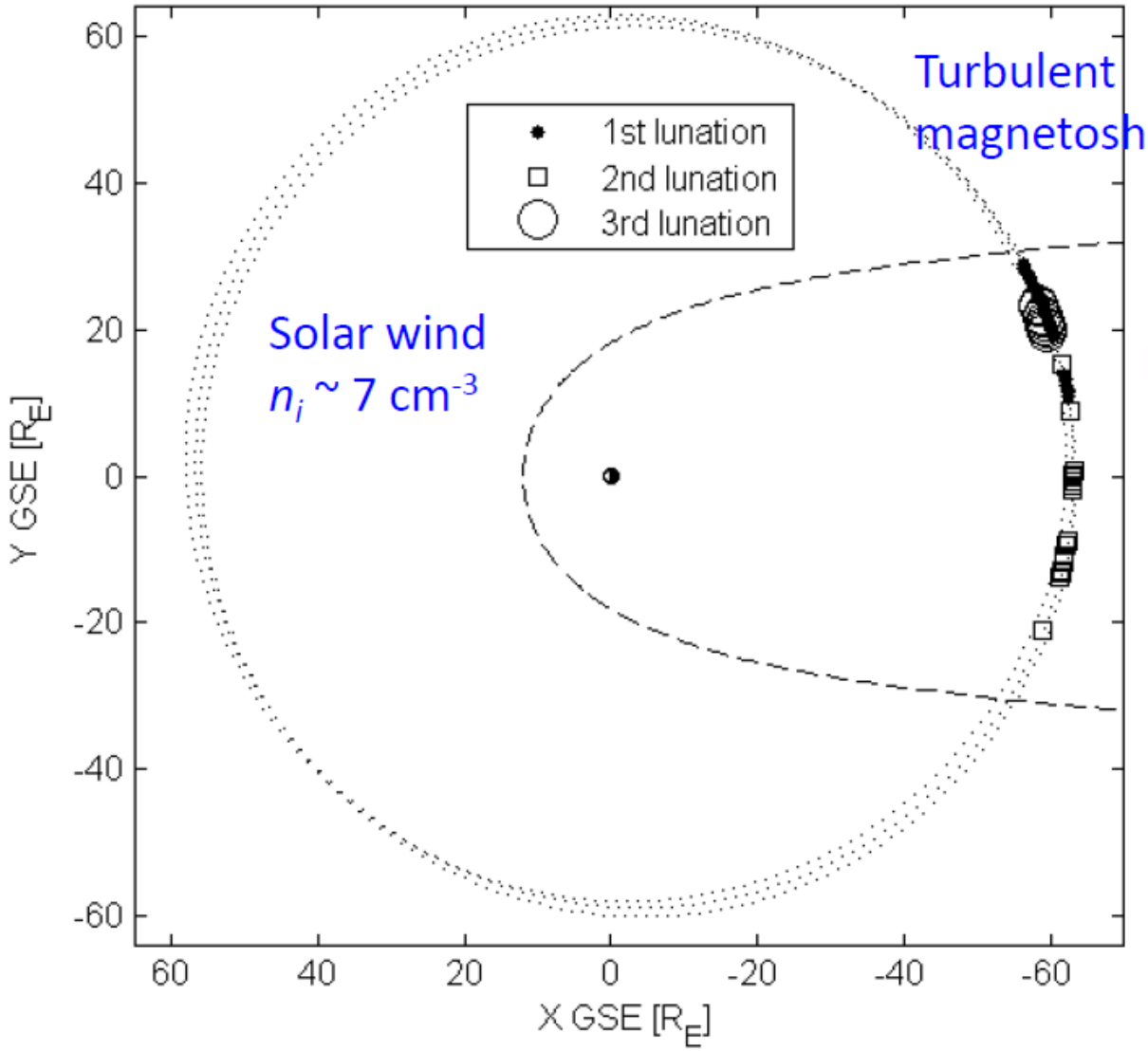


Solar Wind



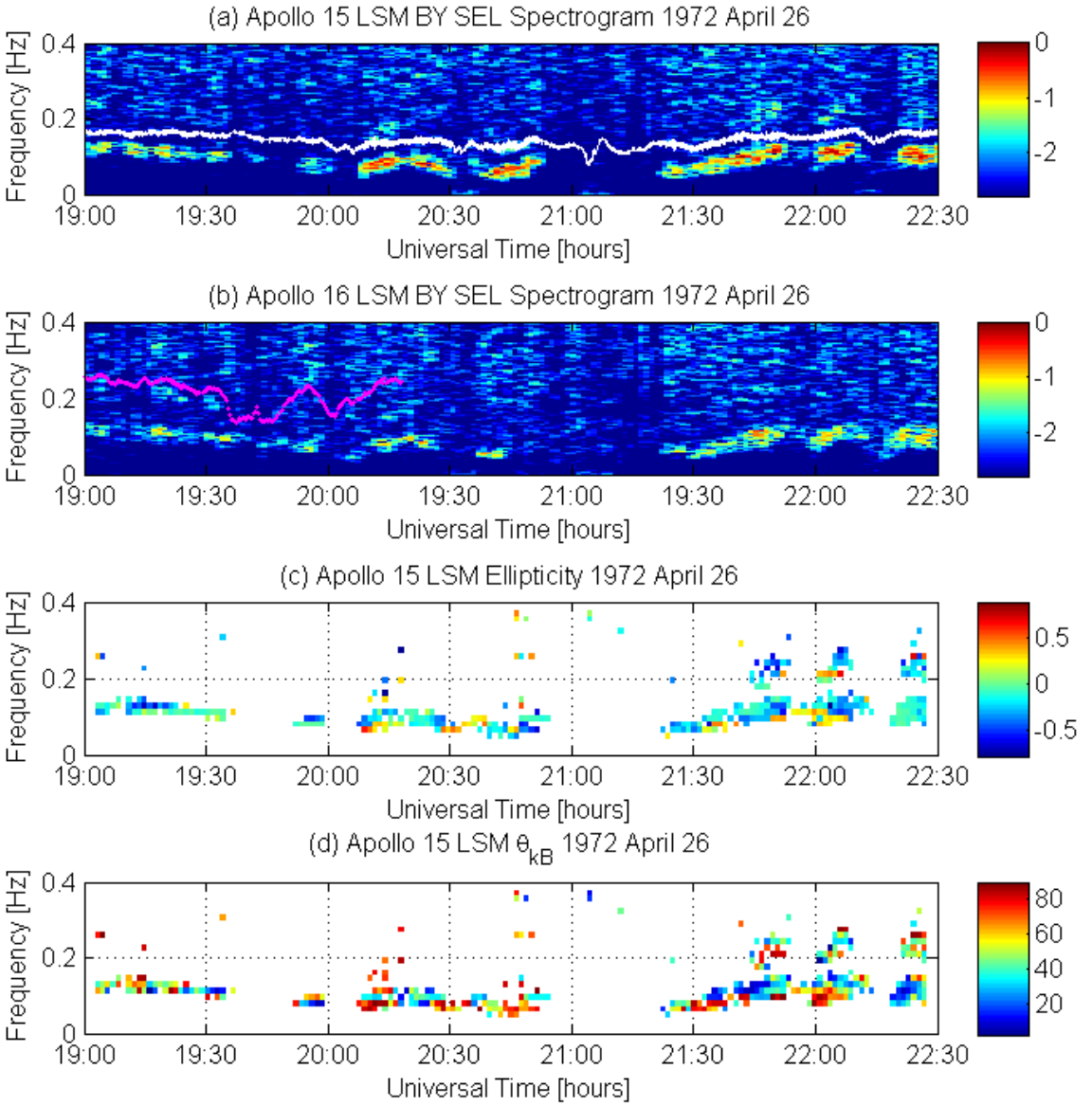


Locations of Narrowband Waves



Wave Amplitude and Polarization

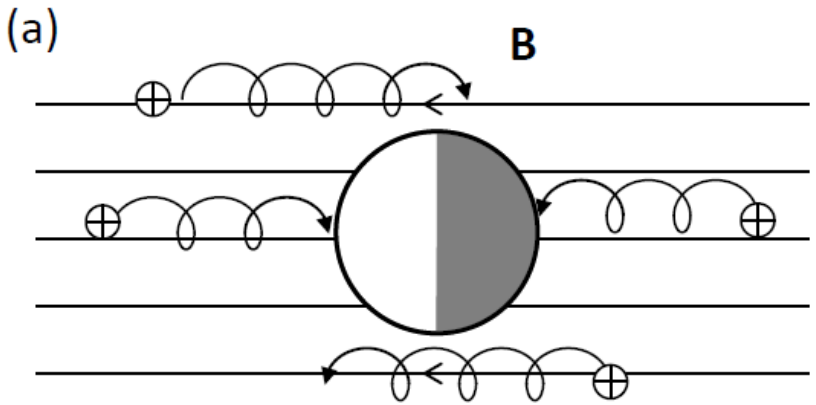
- Every narrow-band wave event was simultaneously observed at both Apollo sites.
- A16 LSM consistently observed lower wave amplitude (1/3 less).
- Second harmonics were sometimes seen at A15 LSM.
- Most waves are left-handed polarized.
- Propagation angles to B can be large.

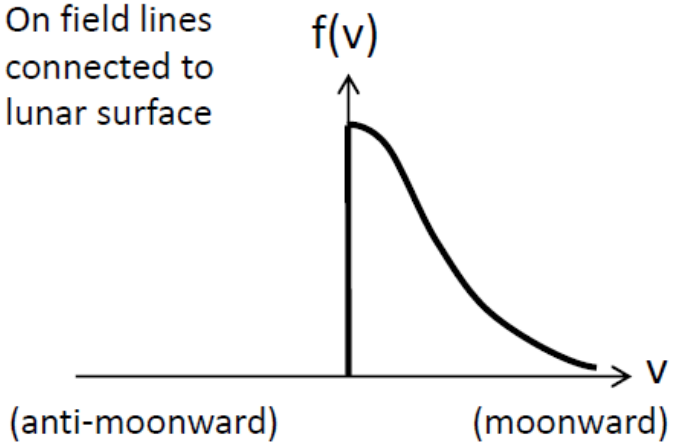


Possible Mechanisms of Wave Excitation at the Moon

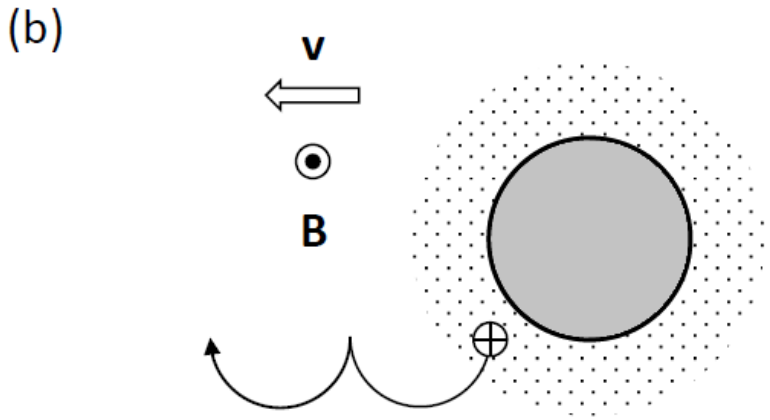
Chi et al. (2013), *PSS.*

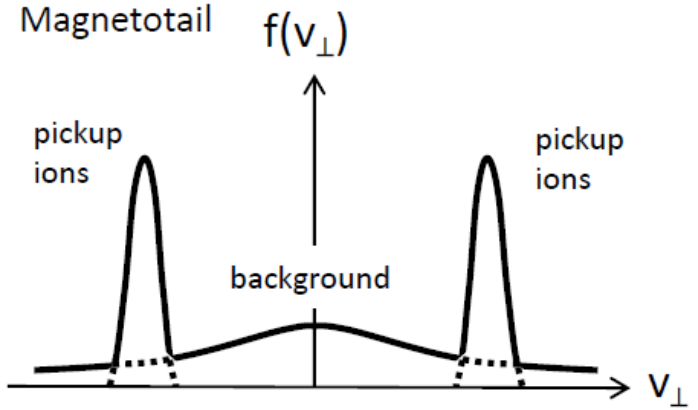
Ion Absorption at the Moon





Pickup Ions



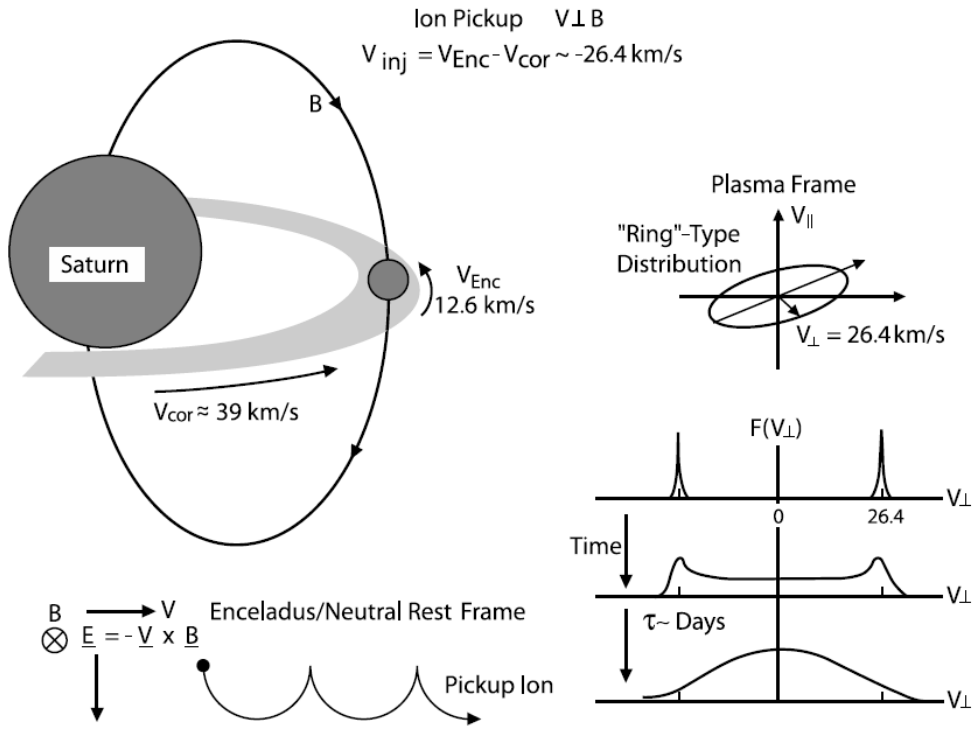


PUI-excited Ion Cyclotron Waves in the Solar System

Ion cyclotron waves associated with pickup ions have been observed in the vicinity of:

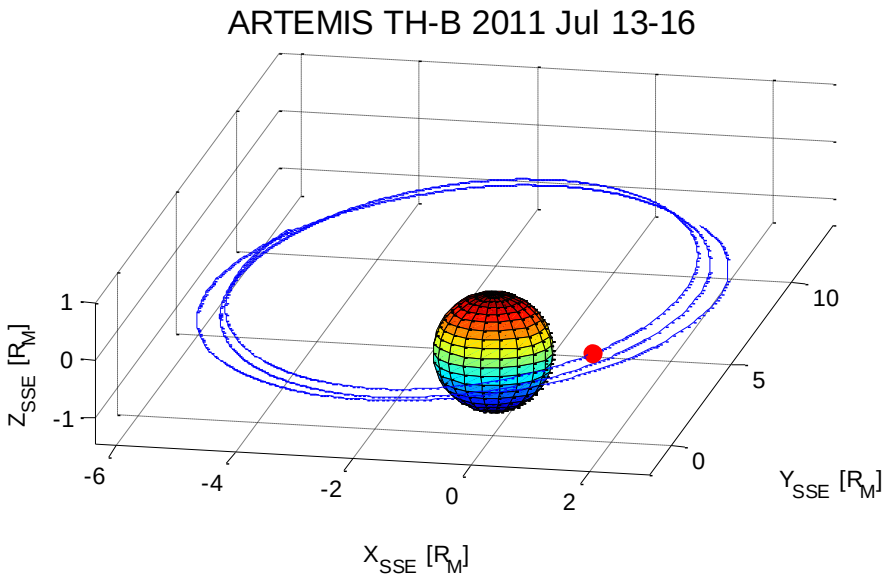
- Mars exosphere
- Venus exosphere
- Neutral torus of Io
- E-ring of Saturn

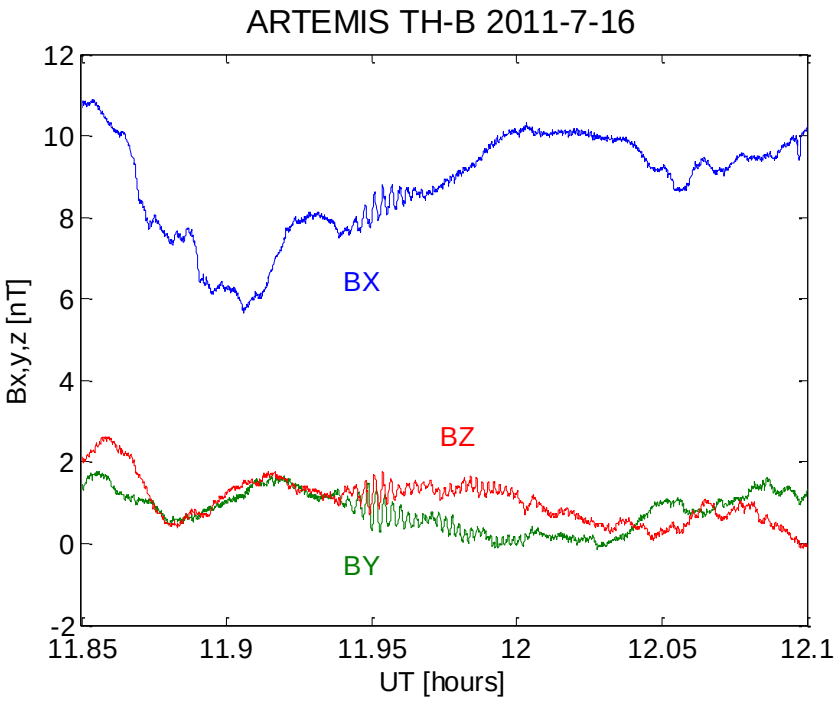
Observation of wave amplitude can be used to estimate the amount of the pick-up ions and atmospheric density.



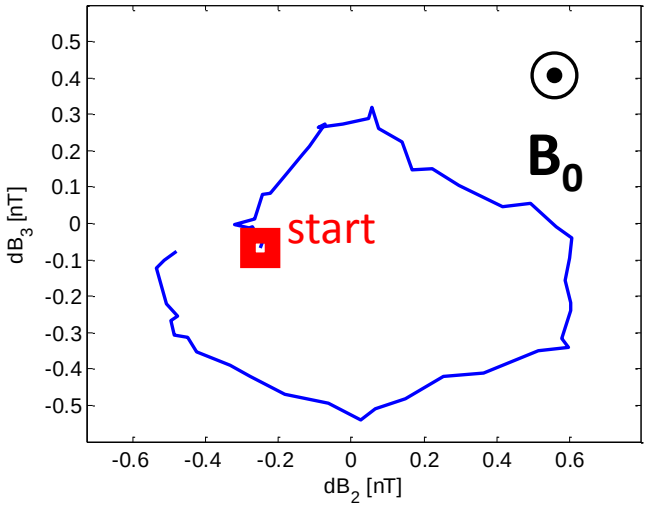
Cowee et al. [2009]

ARTEMIS Observations of ICW: Event 1

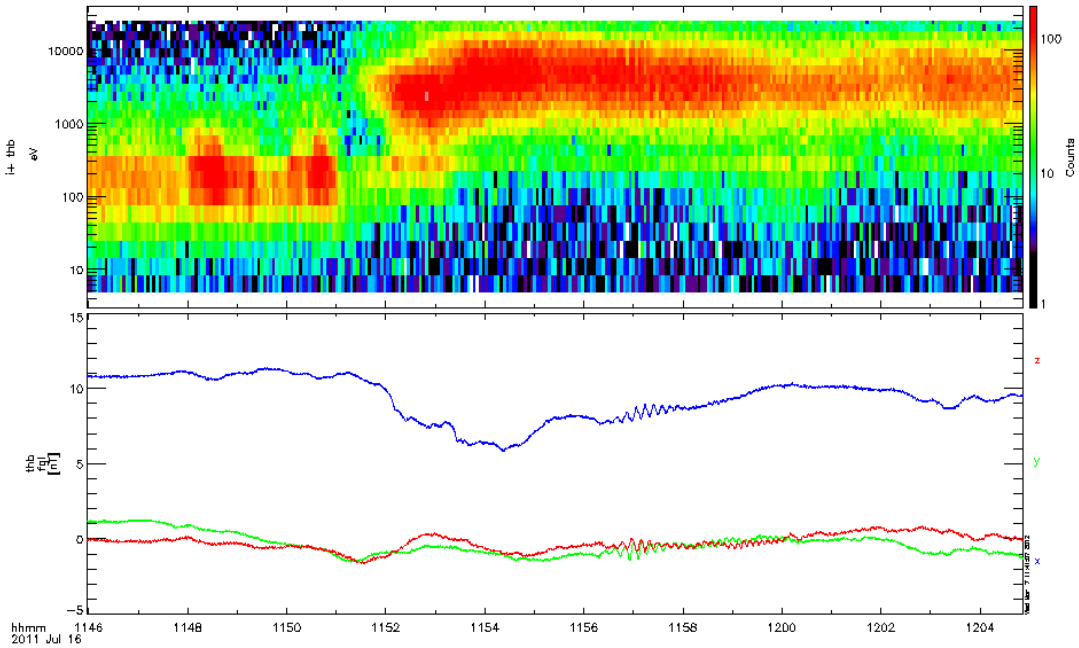


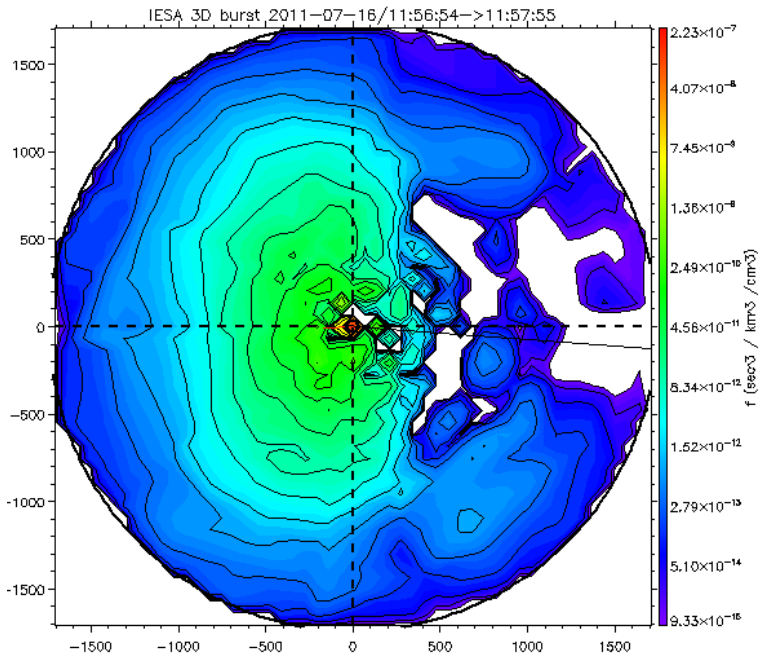


- Lunar spacecraft do not observe ion cyclotron waves as often.
- Several clear wave events were found close to the lunar dayside (highly location-dependent).
- *f* <= *f*cp
- Left-handed, elliptically polarized



Ion Energy/Velocity Distribution during Wave Event

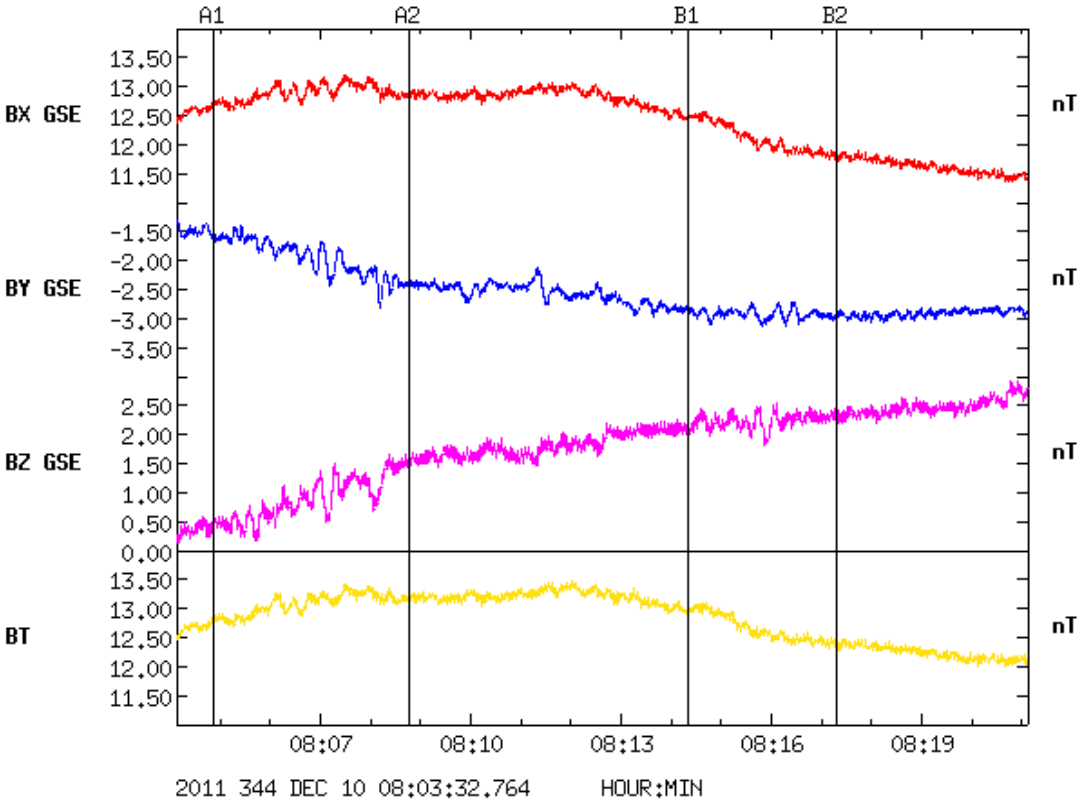


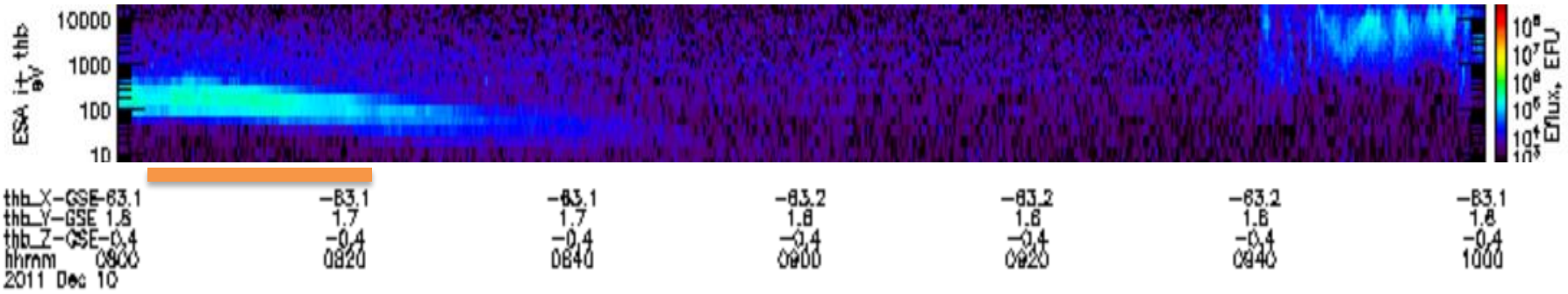


(from Jasper Halekas)

- Magnetic field line connected to the Moon
- Ion temperature ~3 keV (plasma sheet)
- Ion cyclotron wave can be loss-cone driven

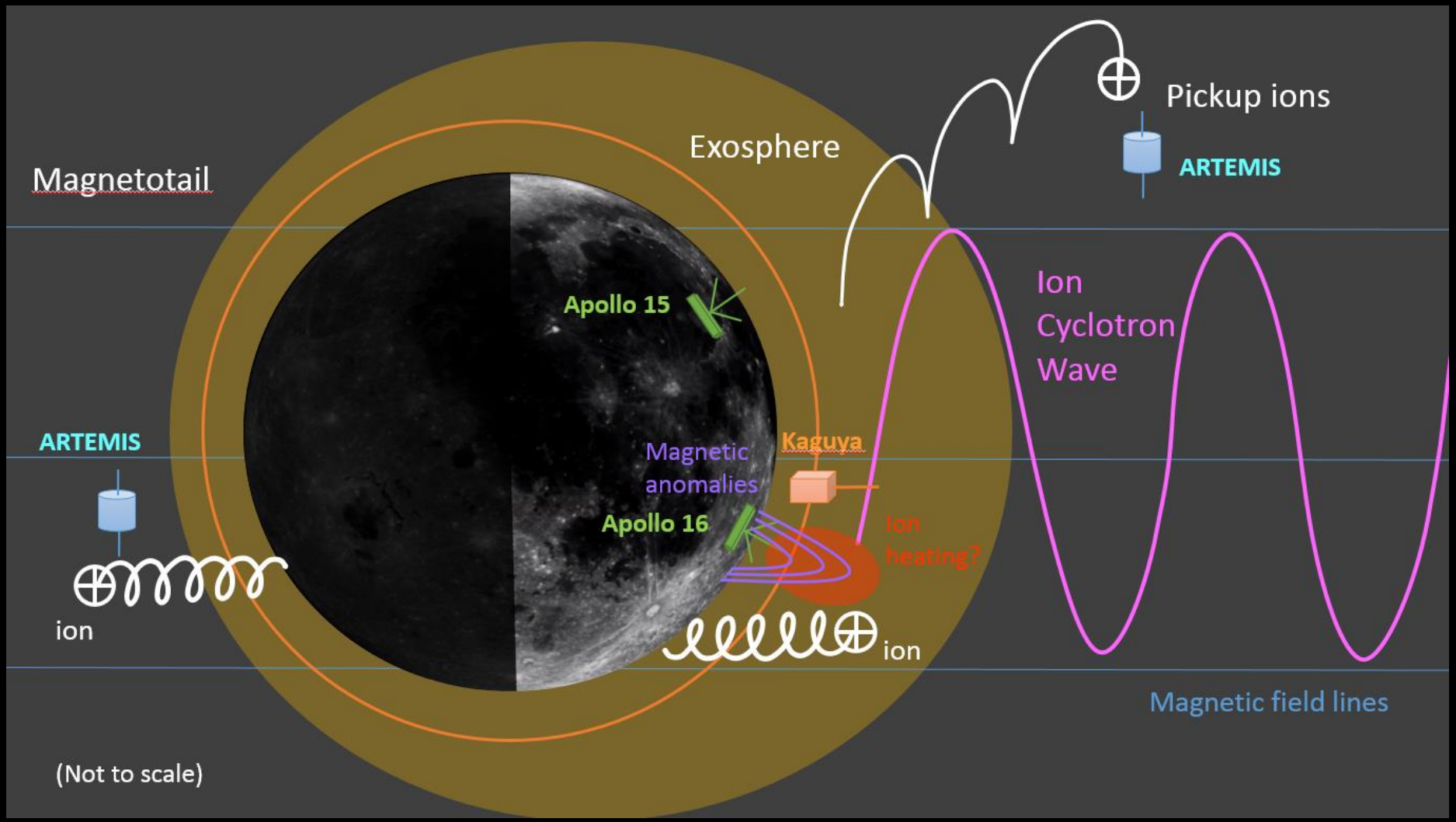
ARTEMIS Observations of ICW: Event 2





- Past observations suggest He as a major species of lunar atmosphere.
- Observation was made by ARTEMIS in the magnetotail and 5.5 lunar radii from the Moon
- Wave properties:
  - f at $f_{c,He+}$
  - Left-handed polarized
  - Field-aligned propagation
- Source particles are to be determined but pickup ions are one of the candidates.

Magnetotail, Lunar Exosphere, ICW



Main Points

- Interest: Understanding the two-way interaction between the Moon (the exosphere) and the magnetotail
- Relevance to FG: The tail environment at lunar distances can be influenced by the presence of the Moon. The Moon can be a dominant particle source in the tenuous magnetotail.
- Suggestions to Future Directions:
  - Identify the generation mechanism(s) of ion cyclotron waves at the Moon (through studying the morphology of ICW and the wave/particle data)
  - If the pickup ions are the source of ICW, the amount of exospheric particles (and their escape) can be estimated by the measurements of ICW.