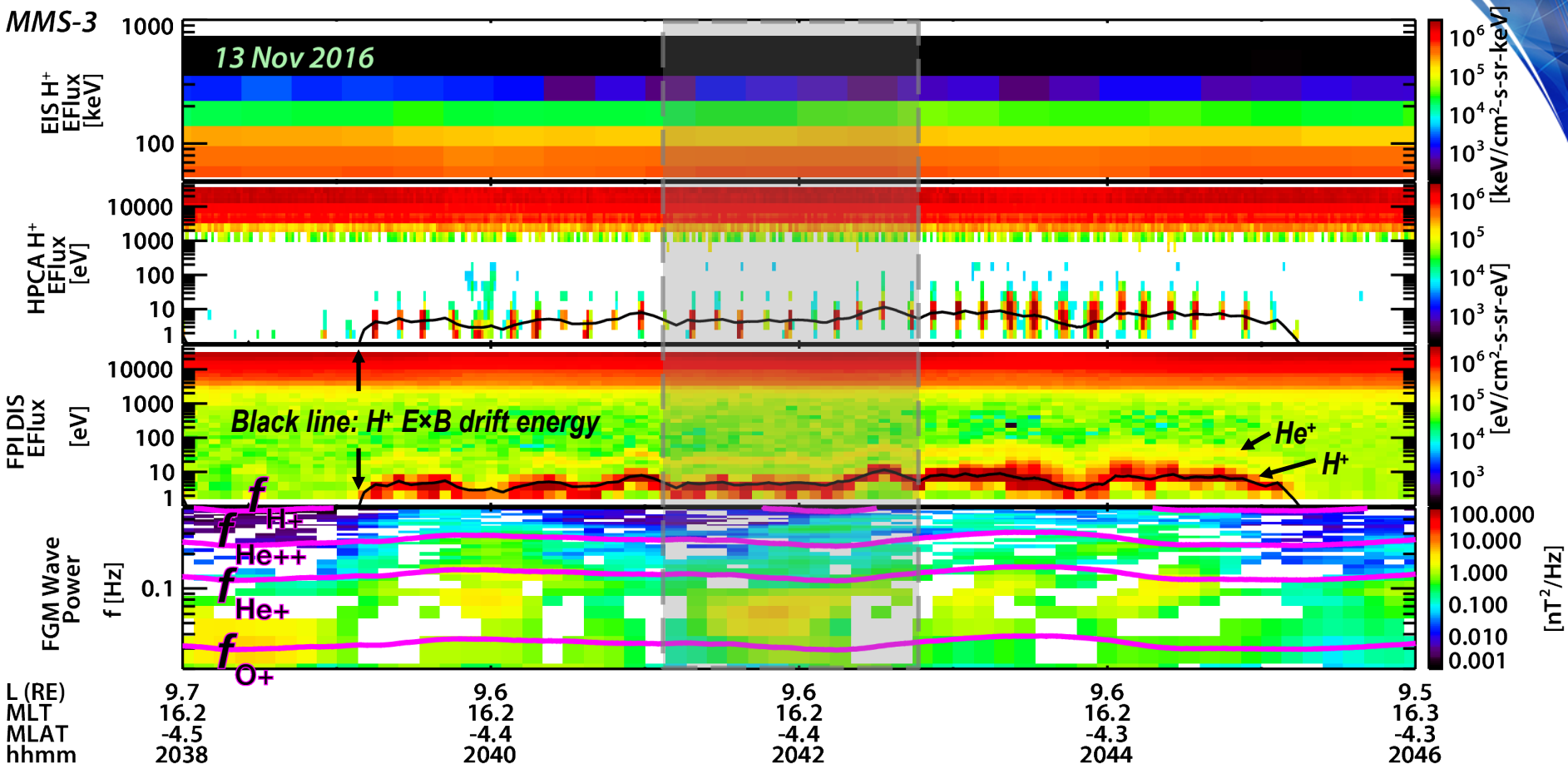
Direct measurements of cold plasma composition, EMIC waves, and implications for inner magnetosphere dynamics

Justin Lee (justin.h.lee@aero.org), Drew Turner, Sarah Vines, Sergio Toledo-Redondo, Robert Allen, Sam Bingham

- Bulk plasma flows (convection/ULF waves) sometimes accelerate the cold plasma core so that it can be directly measured by plasma sensors
  - *MMS and other existing mission (THEMIS, Cluster, RBSP) satellites charge positive in sunlight, so cold (0.1 to few eV) ions are not measurable most of the time*
  - *There have been times when full cold ion distributions were measured by MMS*
  - *Such times should hold clues to improve understanding of cold ions and their effects on EMIC waves*



Ion concentrations calculated from HPCA data

Cold $H^+/He^+/O^+$: 0.976/0.024/<0.001

Hot $H^+/He^+/O^+/He^{++}$: 0.945/0.002/0.047/0.006

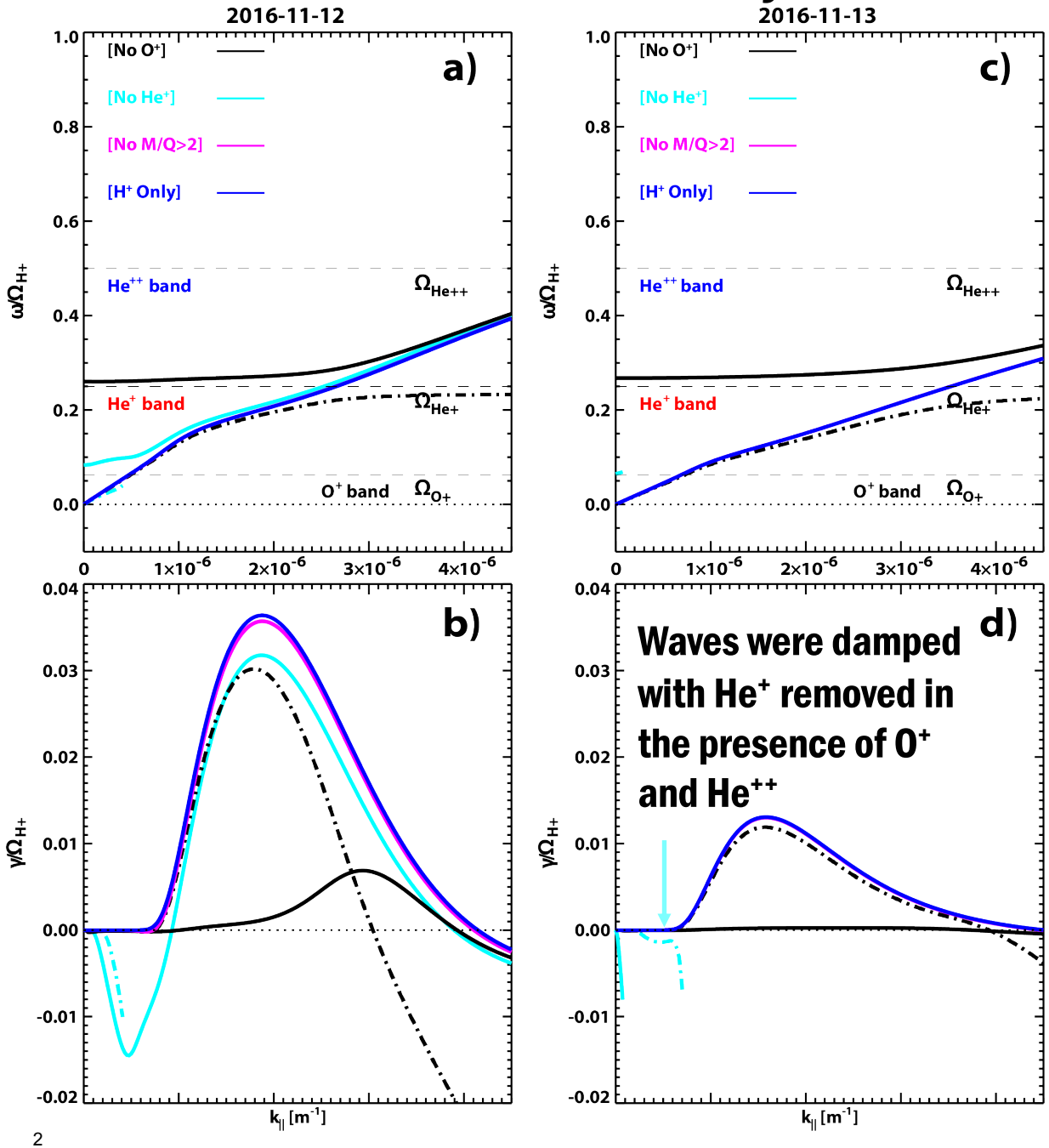
Lee and Angelopoulos 2014: doi.org/10.1002/2013JA019305

Lee+ 2019: doi.org/10.1029/2019GL085182

Linear theory proxy suggested the full interval was unstable to EMIC waves. Full dispersion relation solutions using MMS HCPA+EIS cold and hot ion measurements painted a more complex picture, with moderate growth below f_{He+} modulated by Pc5 ULF waves.

Collective influence of the heavy ions on wave growth

Modeling performed using WHAMP:
github.com/irfu/WHAMP



Removal of heavy ion components for each Event to investigate overall effects of heavy ion presence on wave growth

- In most cases, the growth rate was always slower in the presence of heavy ions in comparison to the "No M/Q>2" and "H^+ Only" cases
- Event 2 wave growth showed a dependence on He^+ component presence when O^+ (mostly hot) and He^{++} were also present
  - *Cold He^+ appeared necessary for wave growth*
- The range of unstable $k_{||}$ was always narrower when heavy ions were present
  - *Radiation belt electron scattering dependent on $k_{||}$ (e.g. Chen+ JGR 2013), with larger $k_{||}$ leading to scattering at lower (100s keV) electron energies*
  - *Consideration of cold and hot heavy ions is needed to understand impacts of EMIC waves on inner magnetosphere dynamics*
- Lee+ JGR 2020 (under review)

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- MMS event studies showing increased growth rate associated with higher concentration of cold vs. hot heavy ions
- But increased damping of EMIC waves at low $k_{||}$ was suggested during an event with increased hot O^+ presence
  - *Relation of $k_{||}$ to minimum energy of electrons resonant with EMIC waves (Chen+ JGR 2013)*
  - *Increased hot O^+ concentration was seen in interval nearer a geomagnetic storm's main phase (consistent with previous observations by Kistler+ JGR 2006, 2016)*
- MMS event studies suggest cold and hot ion composition measurements are needed to quantitatively investigate EMIC wave growth

- What are the associated impacts of cold and hot heavy ions on EMIC wave generation and ensuing wave-particle interactions in the inner magnetosphere?
  - *ASPOC operation, FPI, and HPCA measurements to characterize the cold and hot plasma properties*
    - Are more frequent measurements near or within 6 R_E possible?
  - *FIELDS measurements to characterize the waves and derive total plasma density*
  - *Applications of measurements to linear theory to derive predictions for particles subject to EMIC wave effects*
  - *LEO satellites may be able to observe particle precipitation*

MMS observatories could be applied to investigate inner magnetosphere dynamics associated with EMIC waves.