Wave Propagation and Global Implications of Magnetopause Surface Eigenmodes

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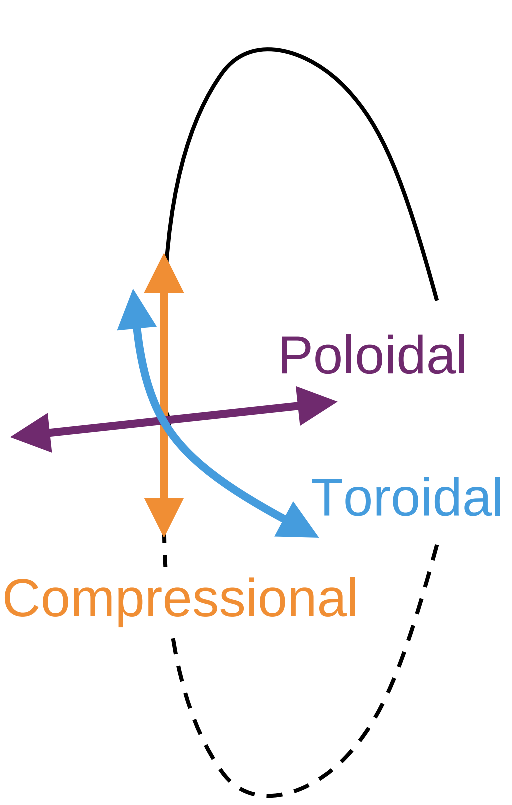
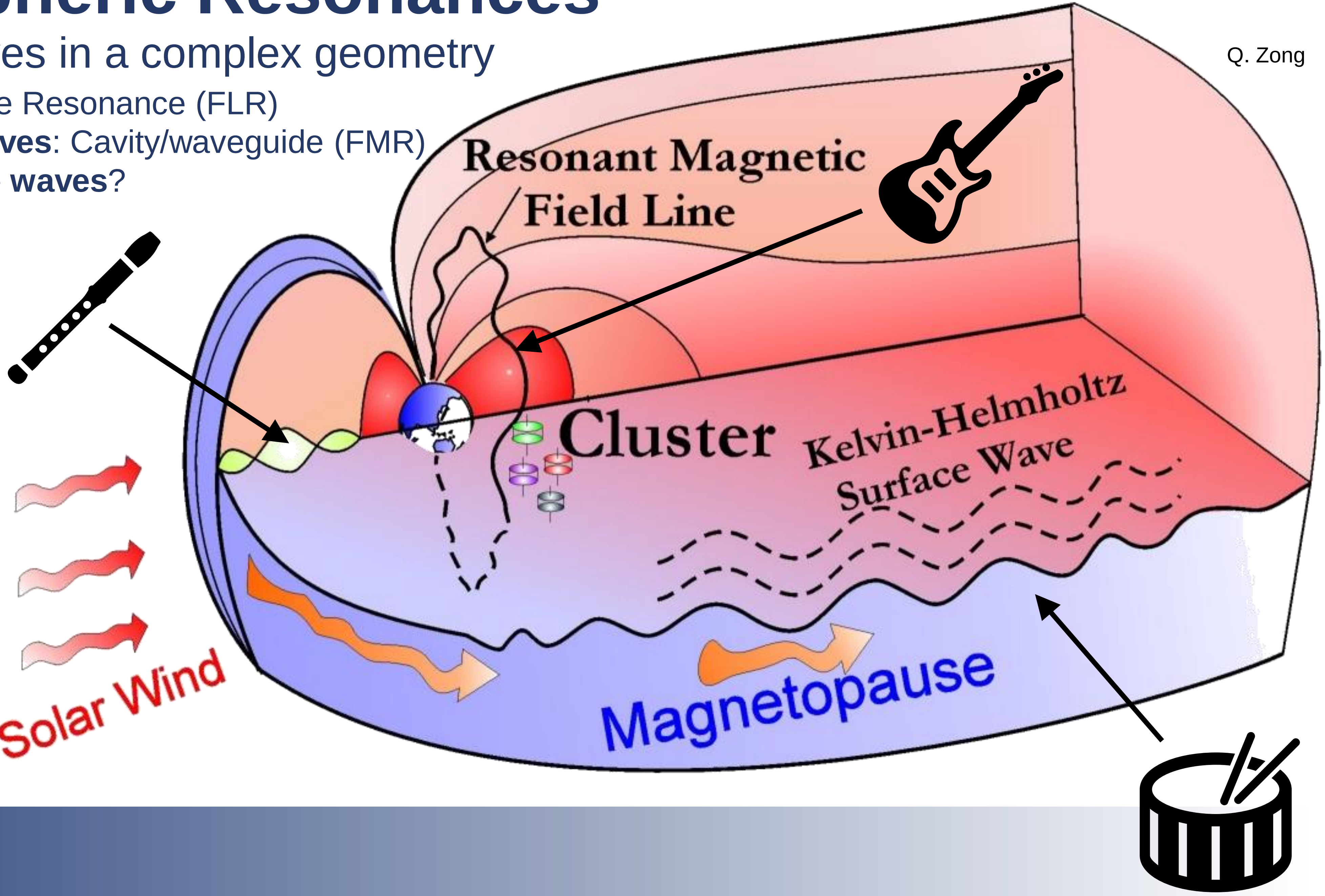
Magnetospheric Resonances

Standing MHD waves in a complex geometry

- **Alfvén waves**: Field Line Resonance (FLR)
- **Fast magnetosonic waves**: Cavity/waveguide (FMR)
- **Magnetopause surface waves**?





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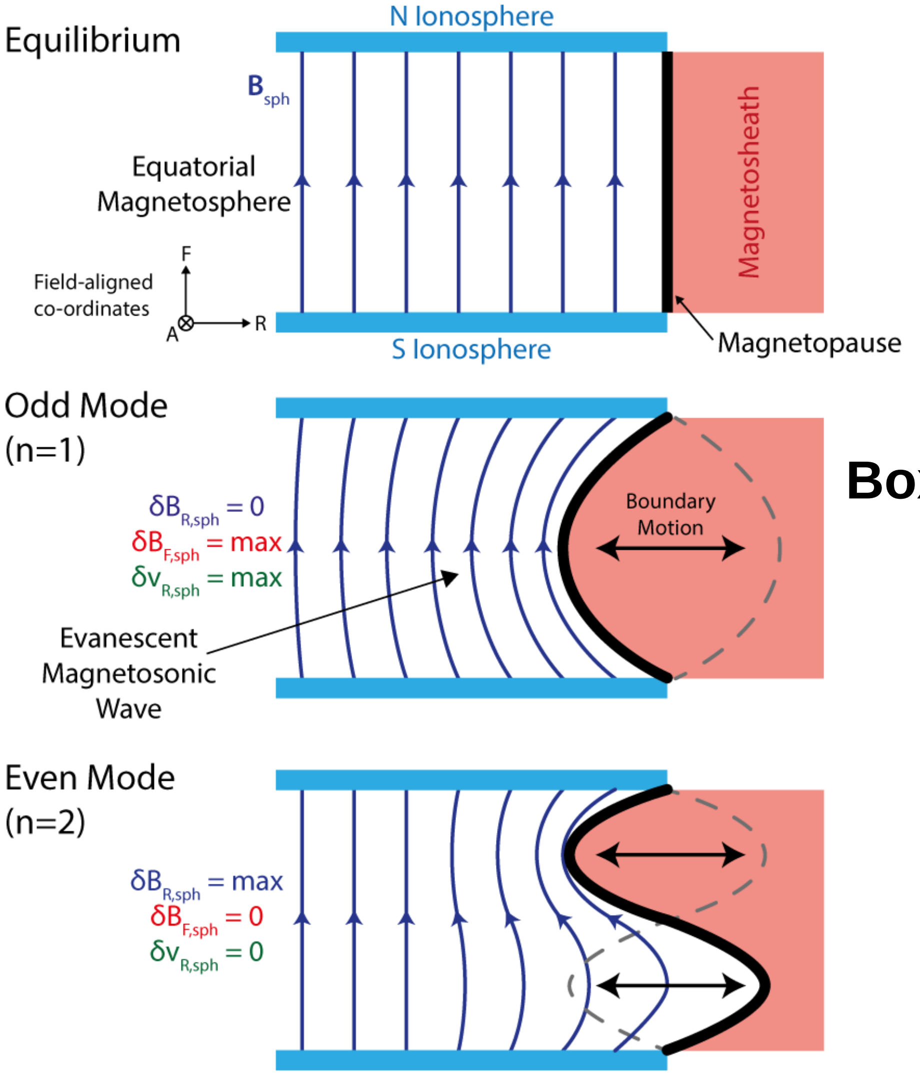
Magnetopause Surface Eigenmode



Natural response of magnetopause surface to impulsive solar wind events due to surface wave reflection by ionosphere

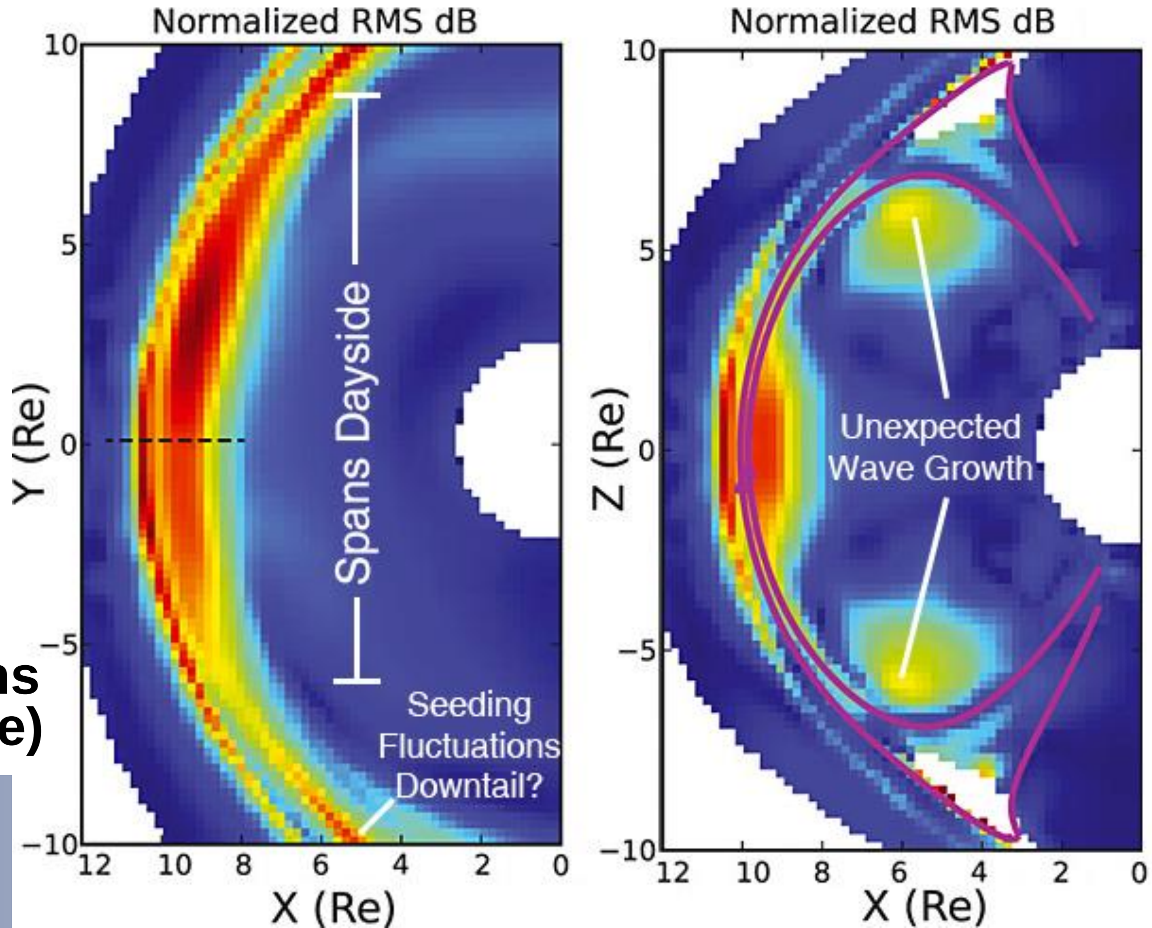
Theory developed in idealised MHD box model magnetospheres

(Chen & Hasegawa, 1974, JGR; Plaschke & Glassmeier, 2011, AG)

Global MHD simulations suggested MSE possible in realistic magnetosphere, but revealed unexplained structure.

(Hartinger+, 2015, GRL)

Box Models



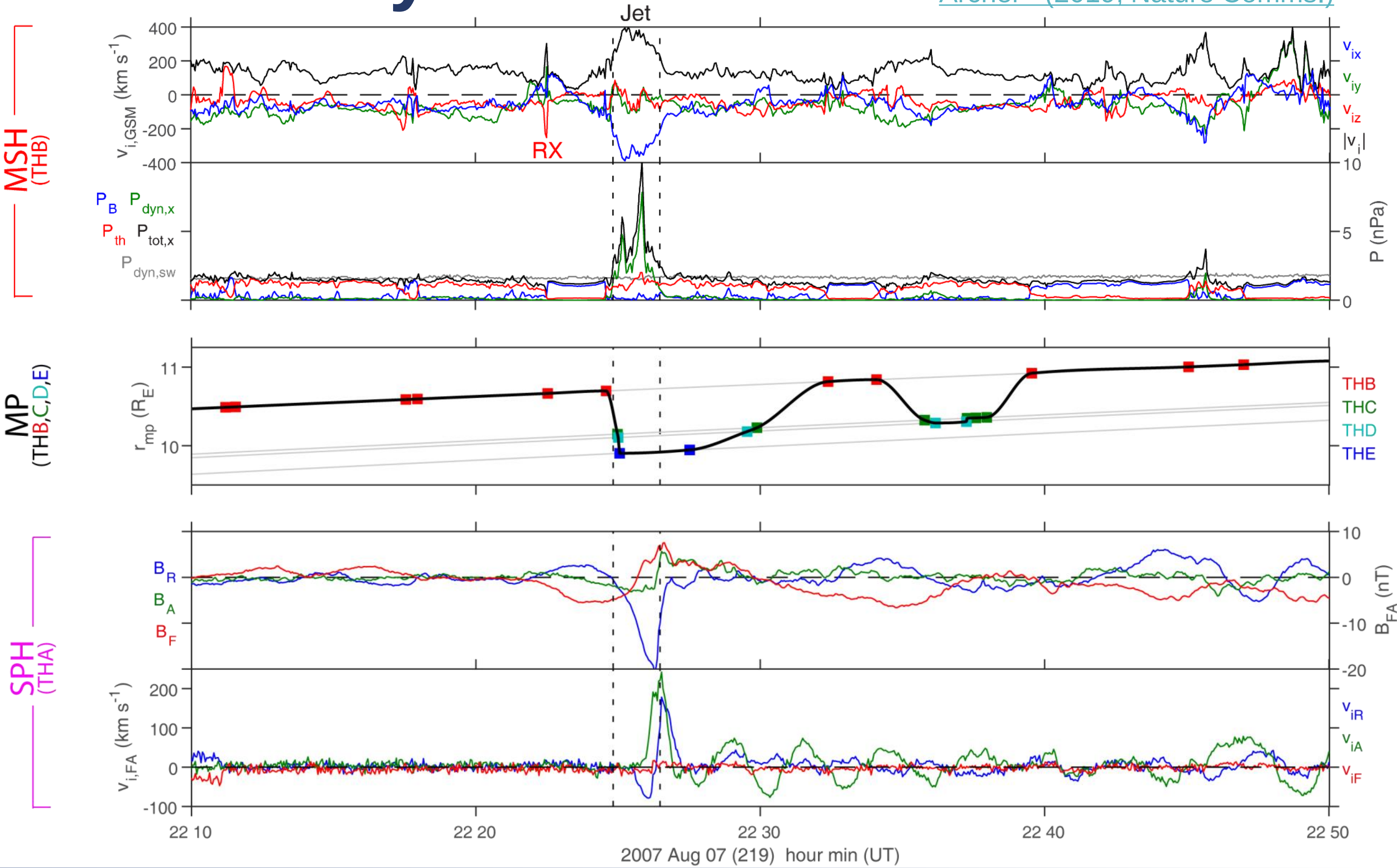
MHD Simulations (n=1 mode)

Observational Discovery

[Archer+ (2019, Nature Comms.)]

Multipoint THEMIS observations of dayside response to isolated magnetosheath jet:

- Broadband impulsive jet upstream of MP
- Narrowband oscillations of MP surface
- Narrowband ULF waves in magnetosphere
- Signatures inconsistent with direct driving, Alfvén / Fast waves / resonances, KH waves, pulsed reconnection
- **Good agreement with predictions for MSE**



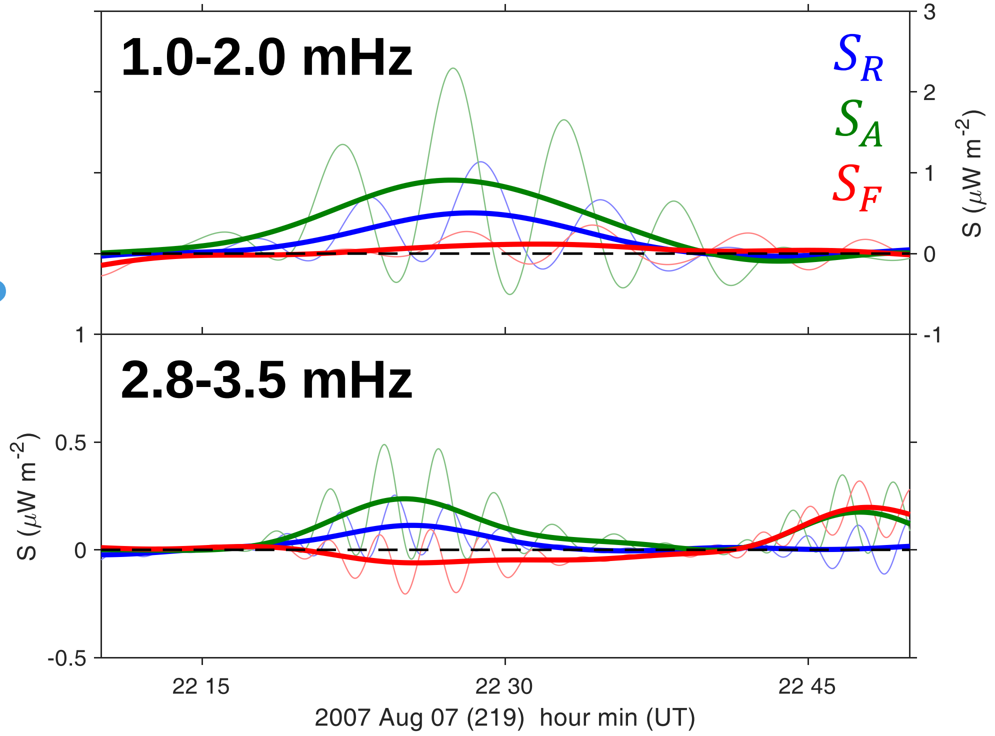
Conundrum

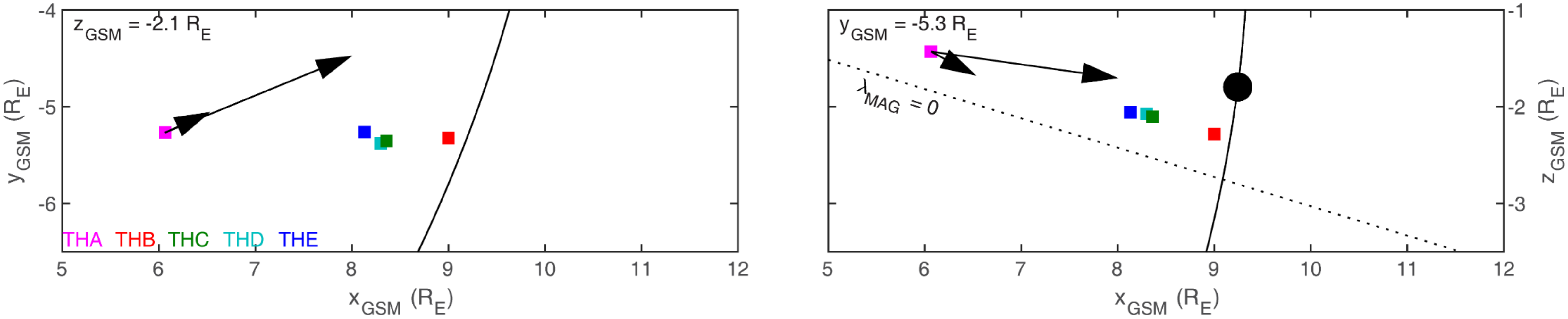
Observations of MSE came from mid-late morning sector BUT magnetosheath flow convects surface waves tailward

How are standing waves possible away from noon?

Time-averaged Poynting vector points towards noon, suggesting surface waves propagate azimuthally against magnetosheath flow

$$\langle \boldsymbol{S} \rangle = \tfrac{1}{2}\Re(\boldsymbol{E} \times \boldsymbol{B}^*)/\mu_0$$
$$= \tfrac{1}{2}\Re([-\delta\boldsymbol{v} \times \boldsymbol{B}_0] \times \delta\boldsymbol{B}^*)/\mu_0$$

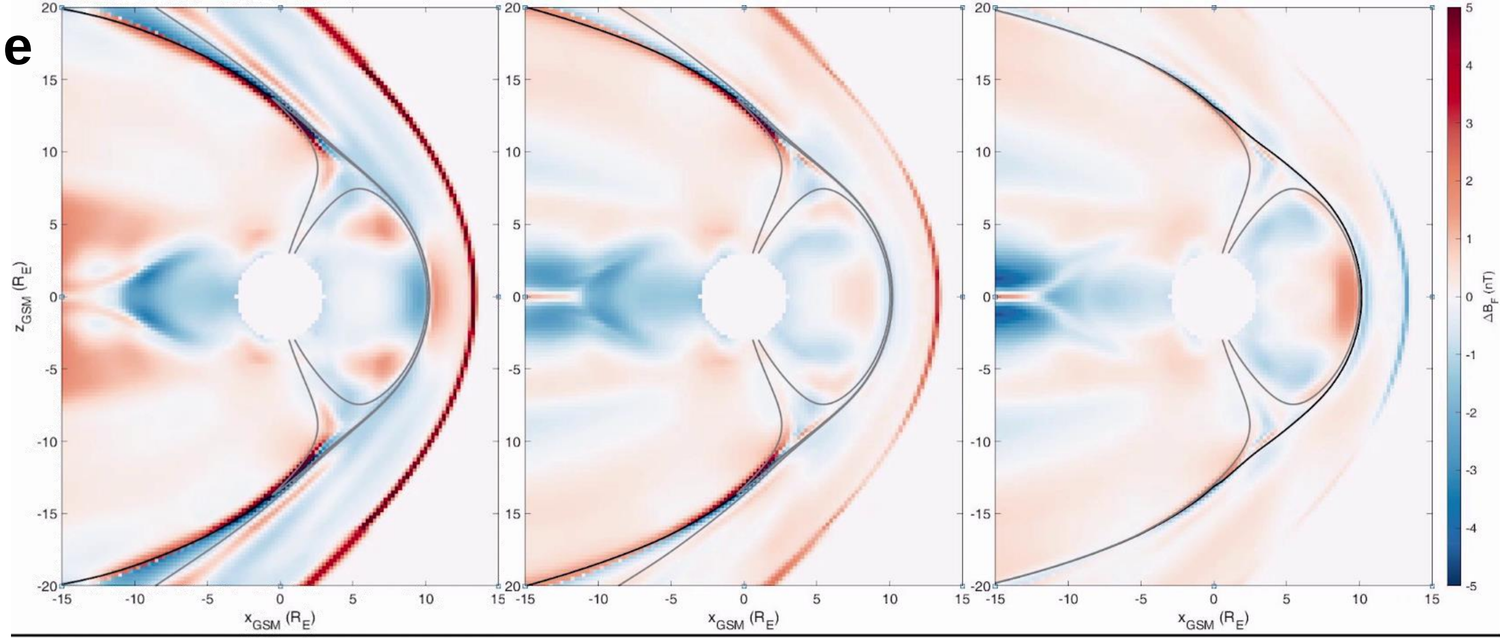




Investigate wave propagation in global MHD simulation

Simulation

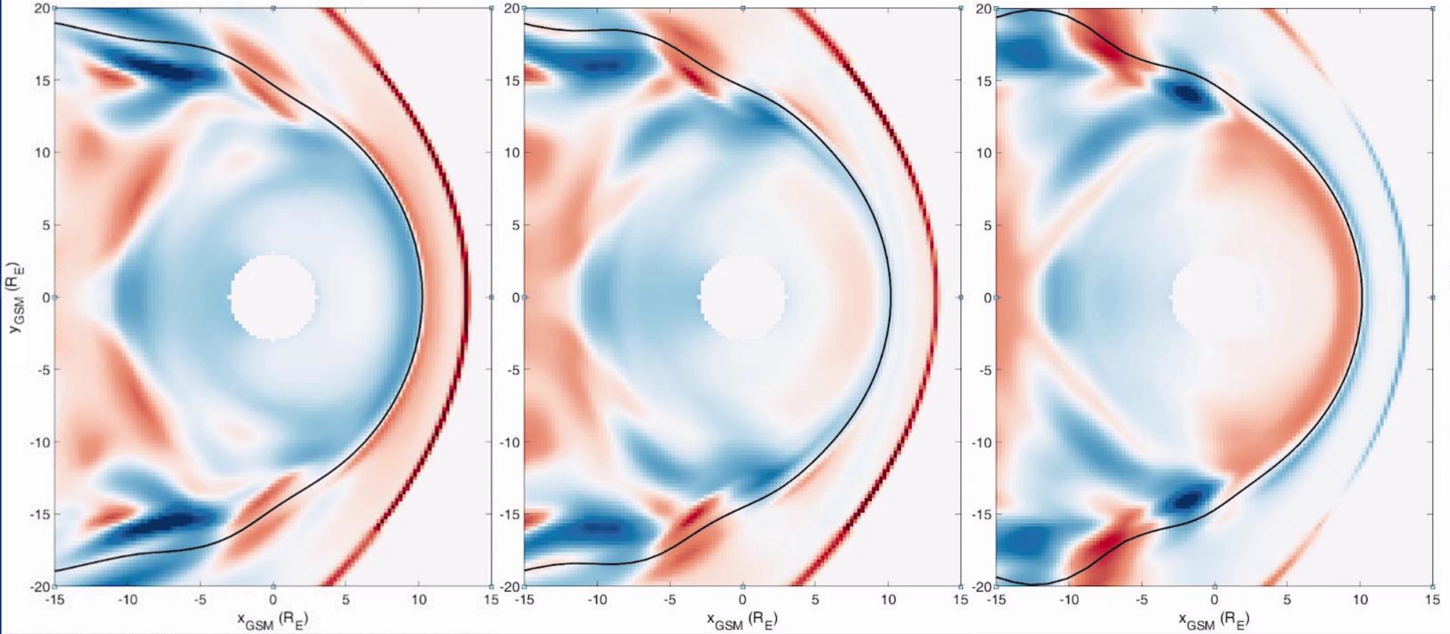
XZ plane



High-res run of SWMF response to pressure pulse under northward IMF

Backgrounds from polynomial fit to start/end of run

MP position ($\pm 0.01 R_E$) as open/closed boundary from field-line tracing using interpolation and bisection



XY plane time→

Frames show $\Delta|\mathbf{B}|$ and MP position at stages during an oscillation period

Apparently standing perturbations span much of dayside

Waves propagating downtail at similar frequency in flanks

Queen Mary University of London

Watch the full video here

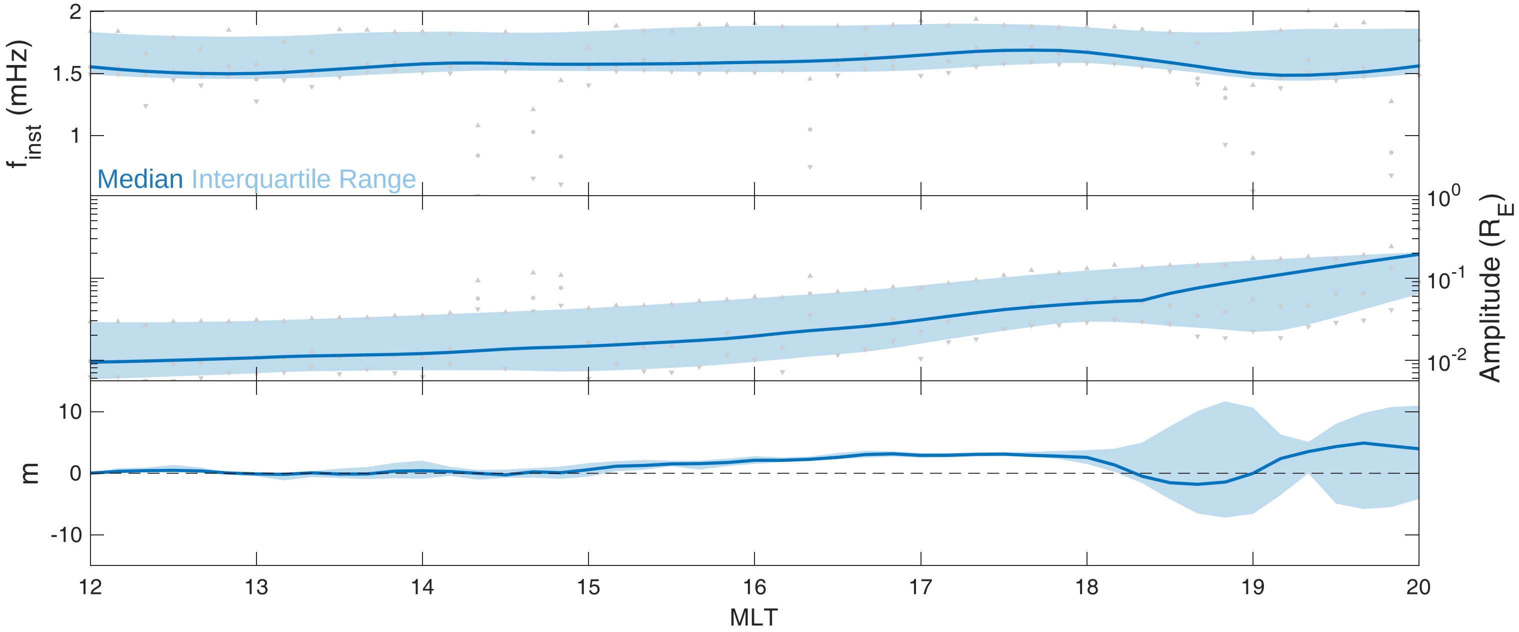
XY plane MP motion

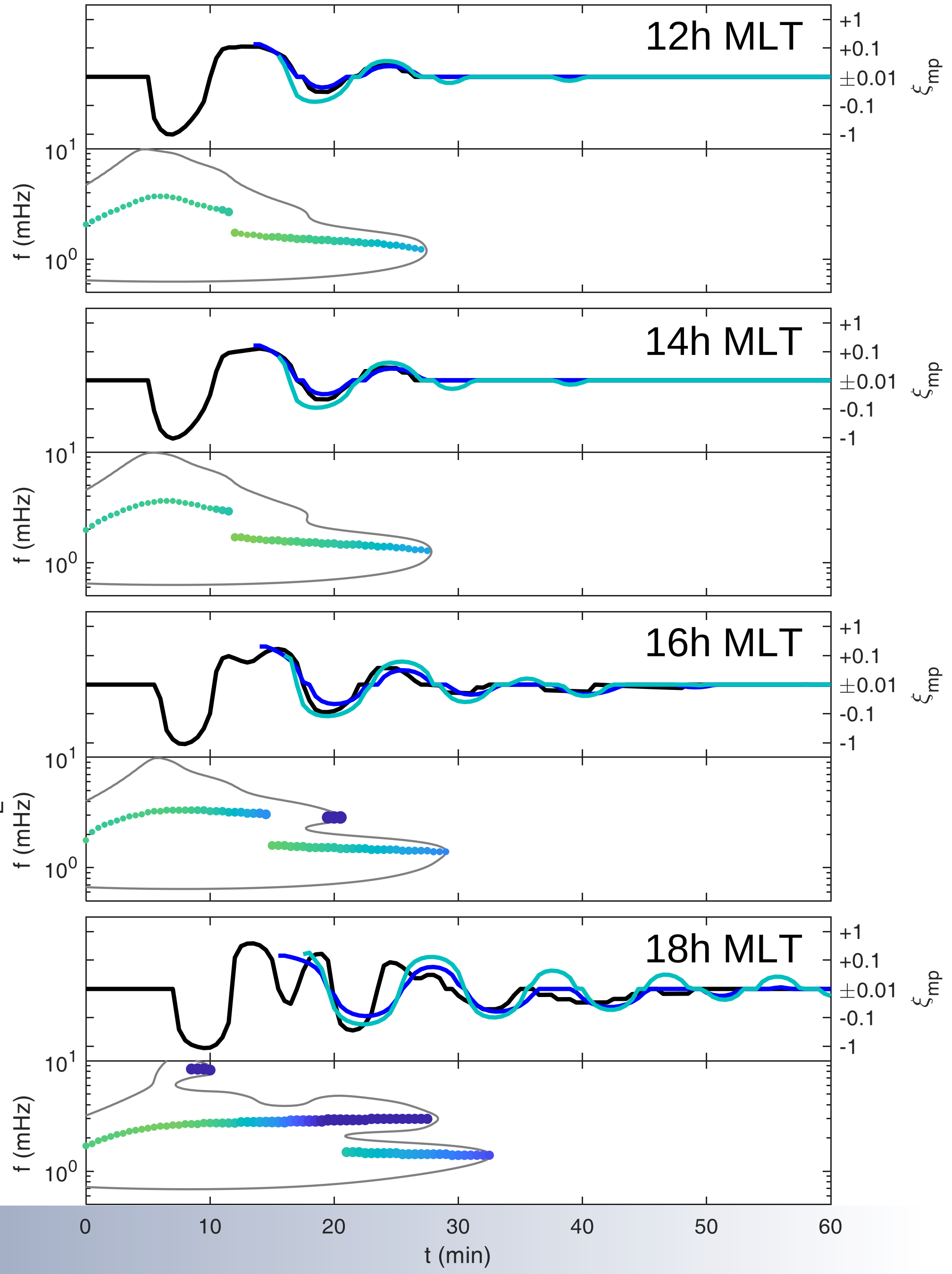
MSE constitute ~1.6mHz signals at all MLT (slight variation)

Kelvin Helmholtz causes growth of new ~3mHz signal **AND** MSE with MSE signal strongest

MSE transitions from azimuthally standing surface waves to propagating at ~15h MLT from wavenumber *m*

Strange behaviour after 18h, physical or processing artifacts?





Time series: Perturbations Lowpass Filter Hilbert Osculating Circle
Wavelets: statistically significant peaks (markers) 95% CI in power (grey)

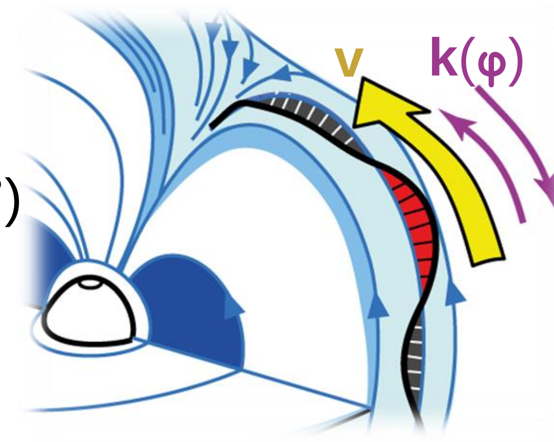
XZ plane MP motion

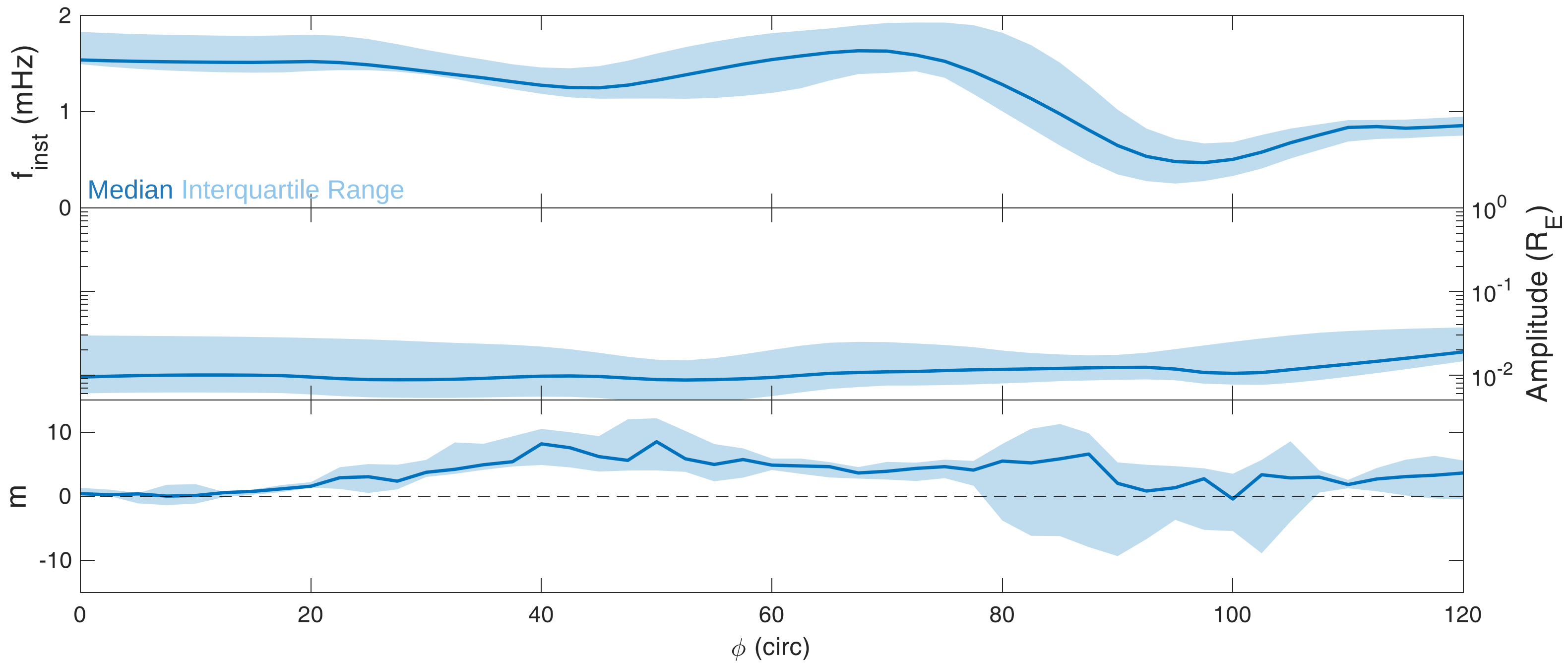
MSE signal present up to cusp region (~75°)

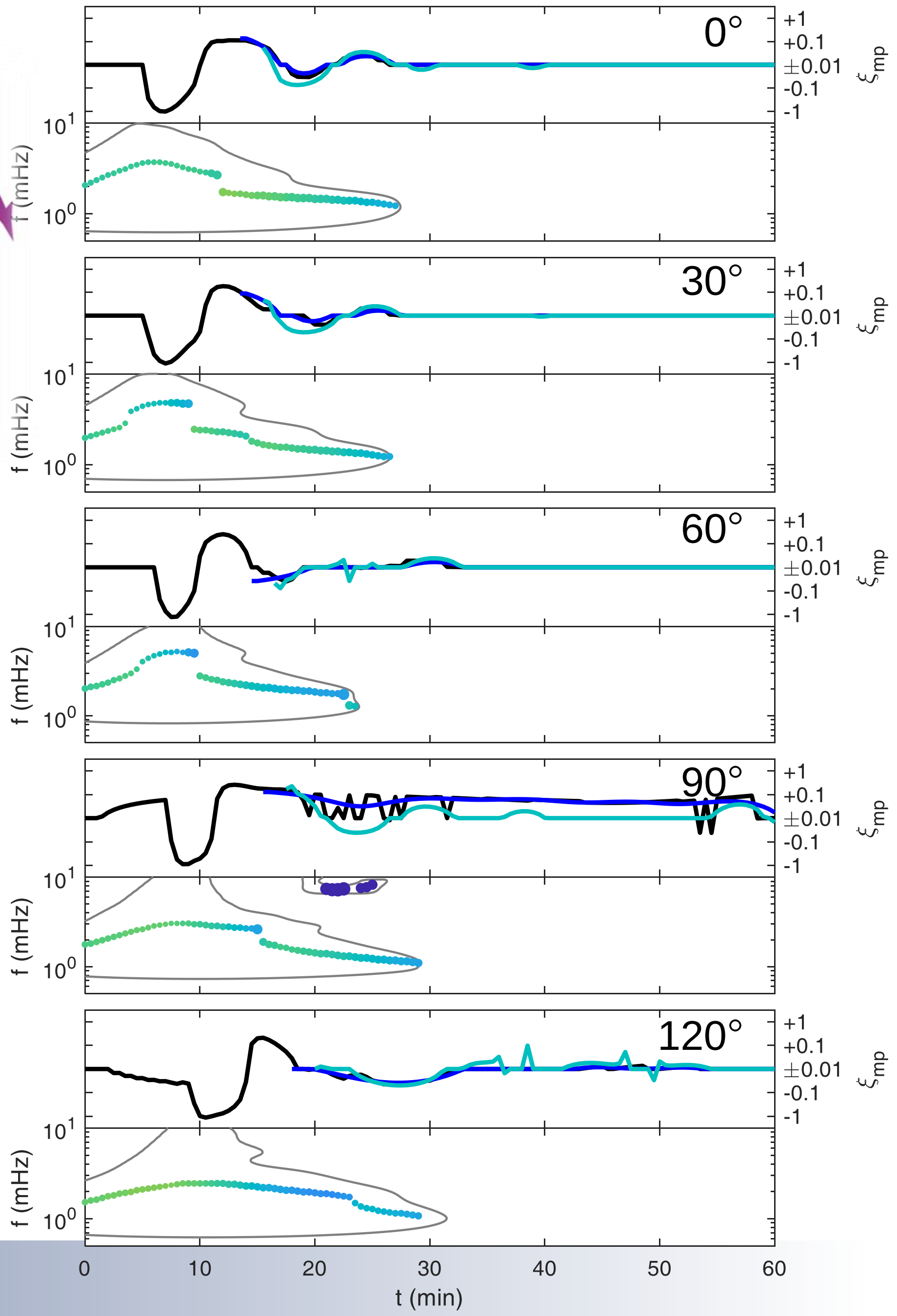
No apparent wave growth with latitude

Mid-latitudes see non-zero wavenumber

MSE not present on nightside high-latitude MP







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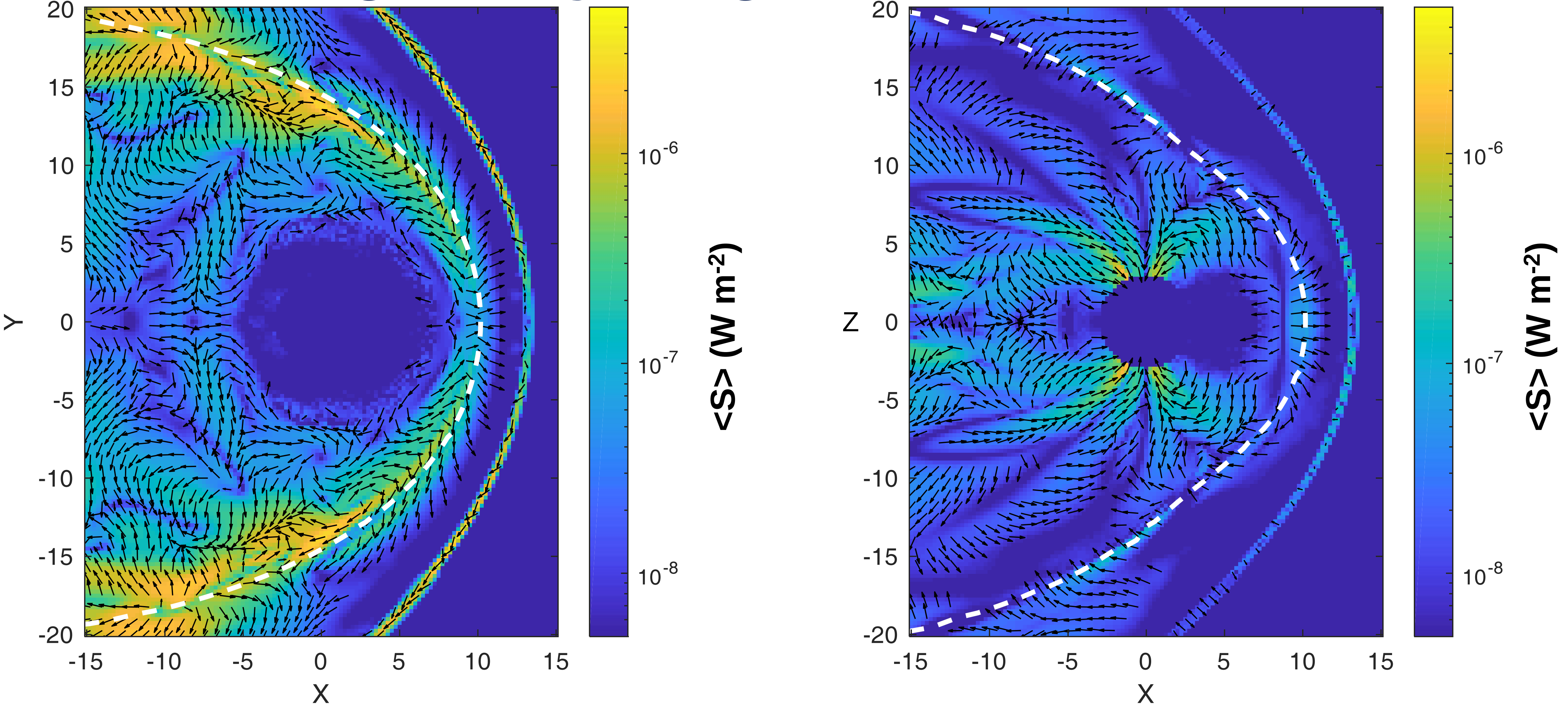
Time-averaged Poynting vector



Colours show magnitude of time-averaged pointing vector during MSE. Arrows give normalised direction.

Direction is consistent with THEMIS observations

Conclusions

Magnetopause Surface Eigenmode (MSE) is resonant response of the magnetospheric boundary to impulsive solar events

Observations and simulations show MSE can occur off-noon where magnetosheath flow should convect surface waves tailward

Preliminary evidence from simulations shows surface waves can stand azimuthally between 9-15h MLT but travel downtail beyond this

Poynting vector from both simulations and observations suggest this is due to surface waves' ability to propagate against the flow, potentially explaining global structure of MSE

Further work will compare with MHD theory