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# Birth and evolution of magnetosheath mirror modes as seen by the global hybrid-Vlasov simulation Vlasiator

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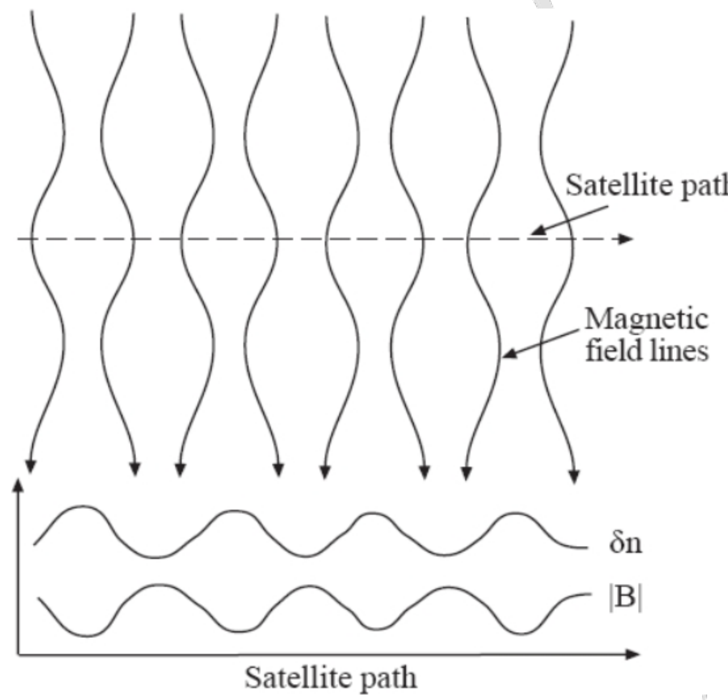
# Outline

- Mirror modes
- Vlasiator
- Mirror modes in Vlasiator
- Comparison with THEMIS observations
- Conclusions

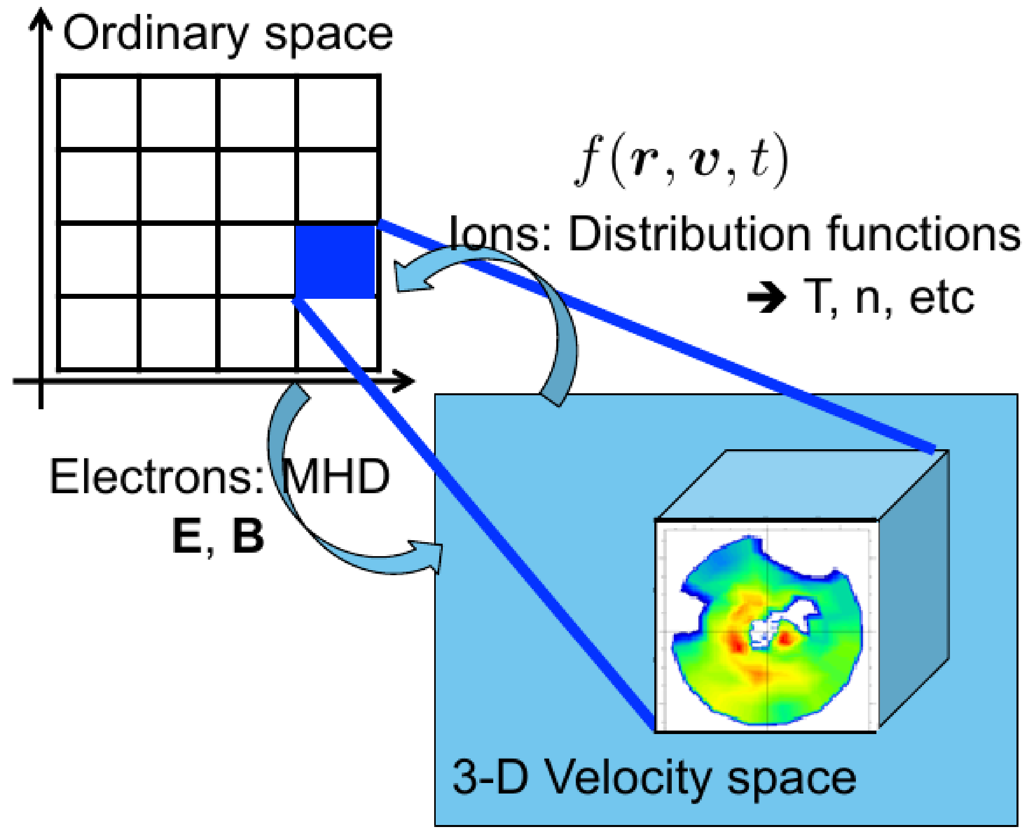
# Mirror modes

- Physical properties:
  - Large amplitude, low frequency waves
  - Anti-correlation between magnetic field strength and plasma density
  - Arise from temperature anisotropy in region fulfilling the condition:
    - $T_{\perp}/T_{||} > 1+1/\beta_{\perp}$ (Hasegawa, 1969)
  - Almost linearly polarized
- Criteria for observations:
  - Variance matrix eigenvalues fulfill:
    - $\lambda_{max}/\lambda_{int} \gg \lambda_{int}/\lambda_{min} \sim 1$ (Wilson III et al, 2009)
    - $\lambda_{max}/\lambda_{int} > 1.5$ and $\lambda_{min}/\lambda_{int} > 0.3$ (Soucek et al, 2008)
  - Angle between ambient magnetic field and maximum variance direction less than 30° (Soucek et al, 2008)
  - Amplitude with respect to background > 10%



# Vlasiator scheme in a nutshell

- Compute EM-fields in ordinary space
- Each ordinary space cell contains a 3D velocity space
- In velocity space, propagate distribution function with Vlasov equation
  - Couple back to ordinary space to compute EM-fields



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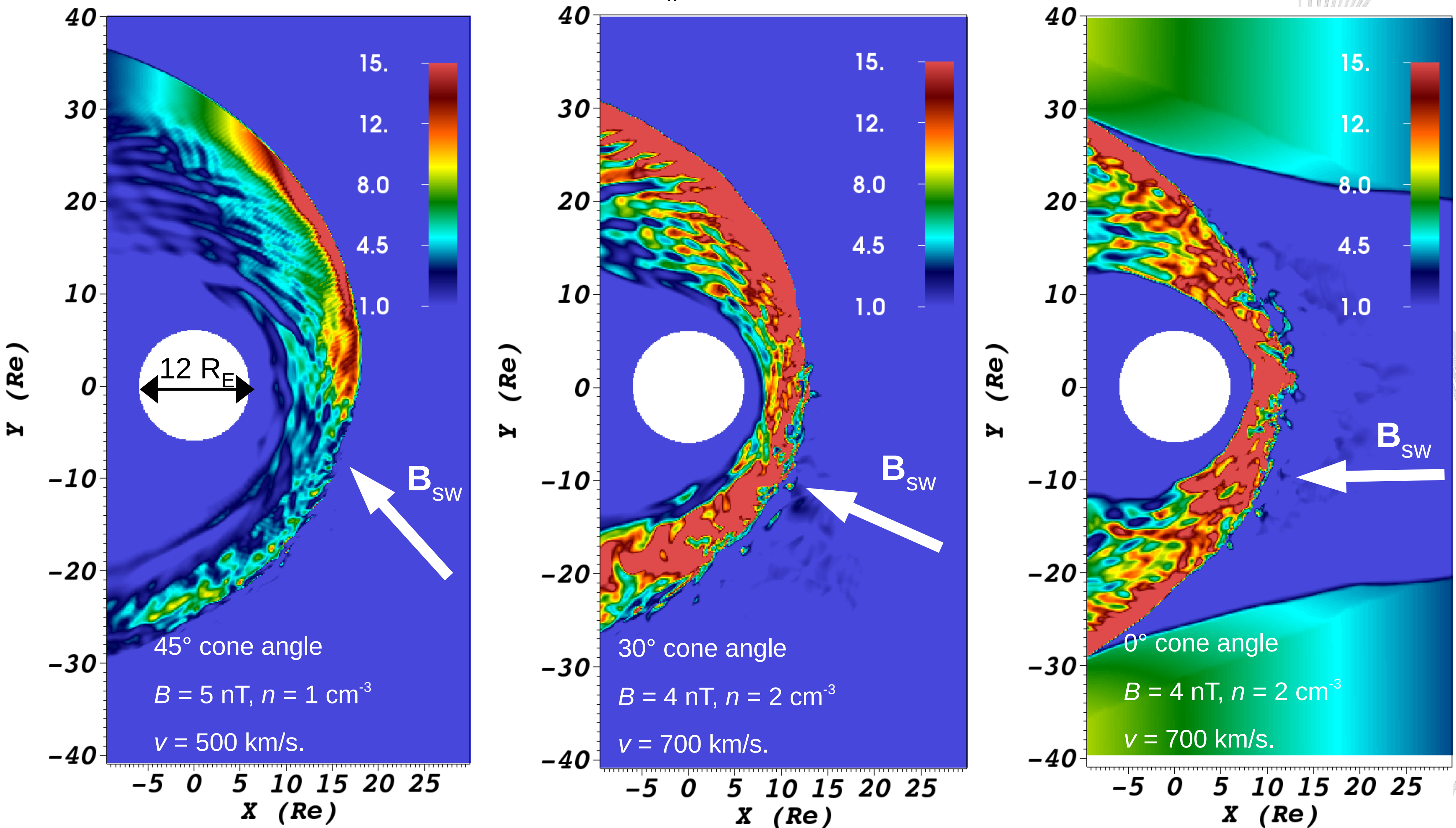
# Runs

Color: mirror instability condition $\beta_\perp (T_\perp/T_{||}-1) > 1$ at t = 1000 s



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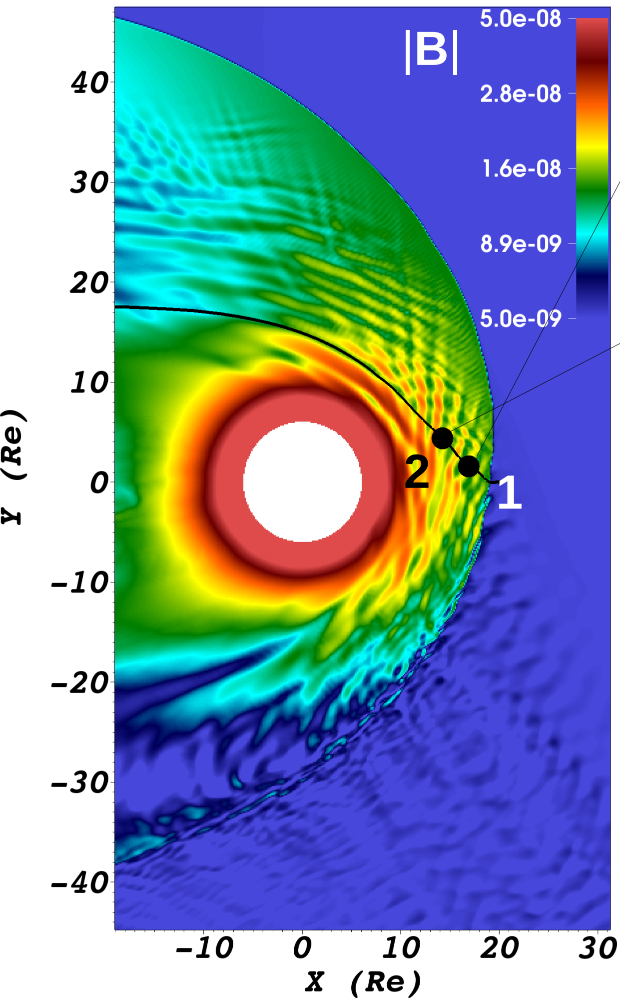
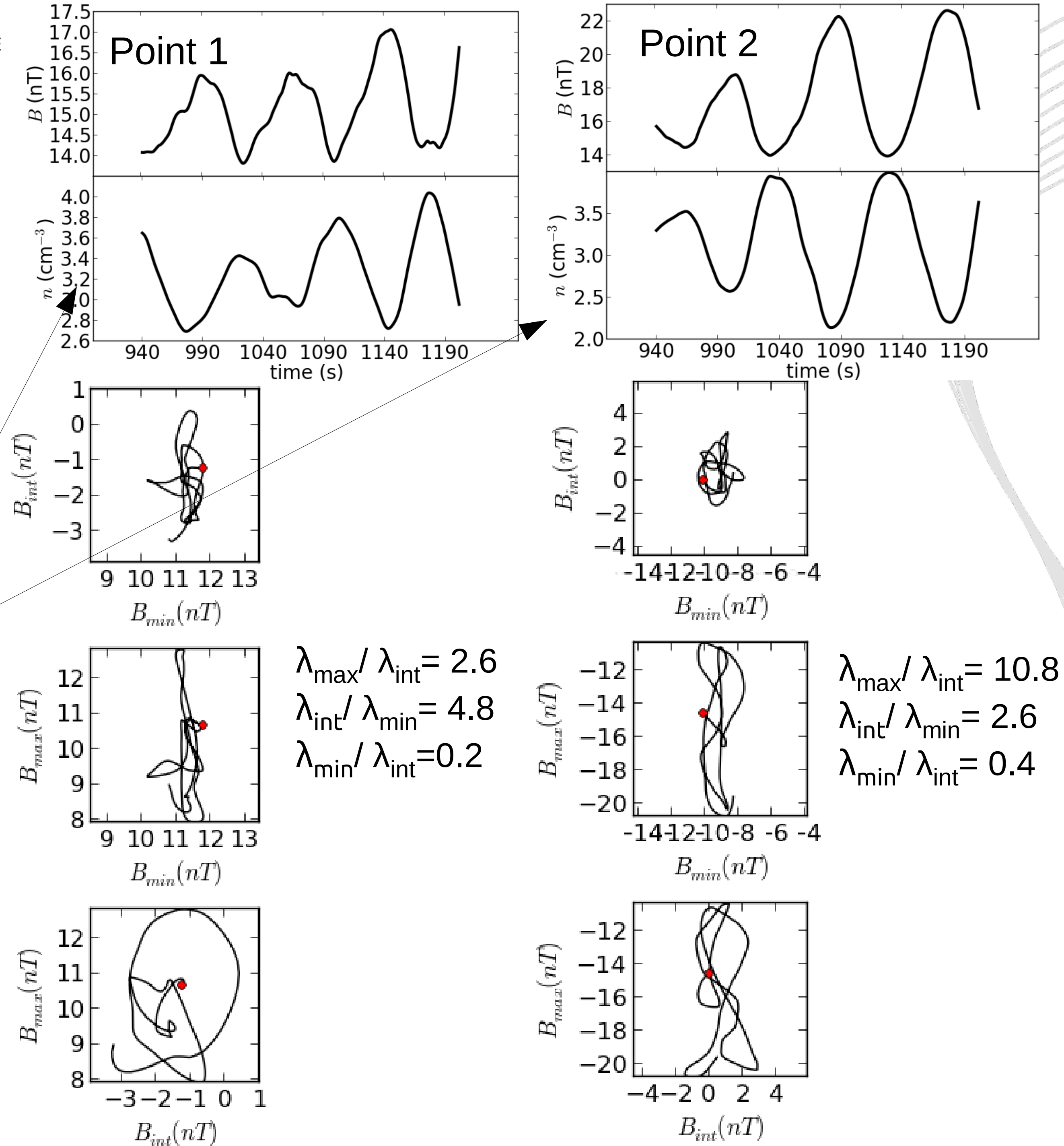
# Wave analysis




Point 1:

$\lambda_{max}/\lambda_{int} = 2.6$

$\lambda_{int}/\lambda_{min} = 4.8$

$\lambda_{min}/\lambda_{int} = 0.2$

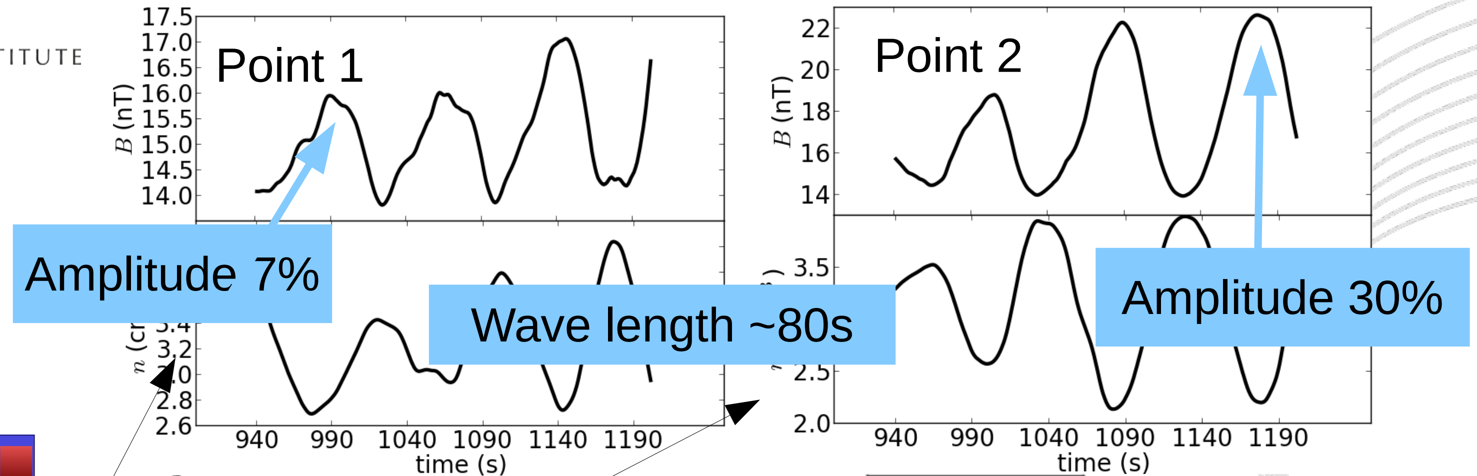
Point 2:

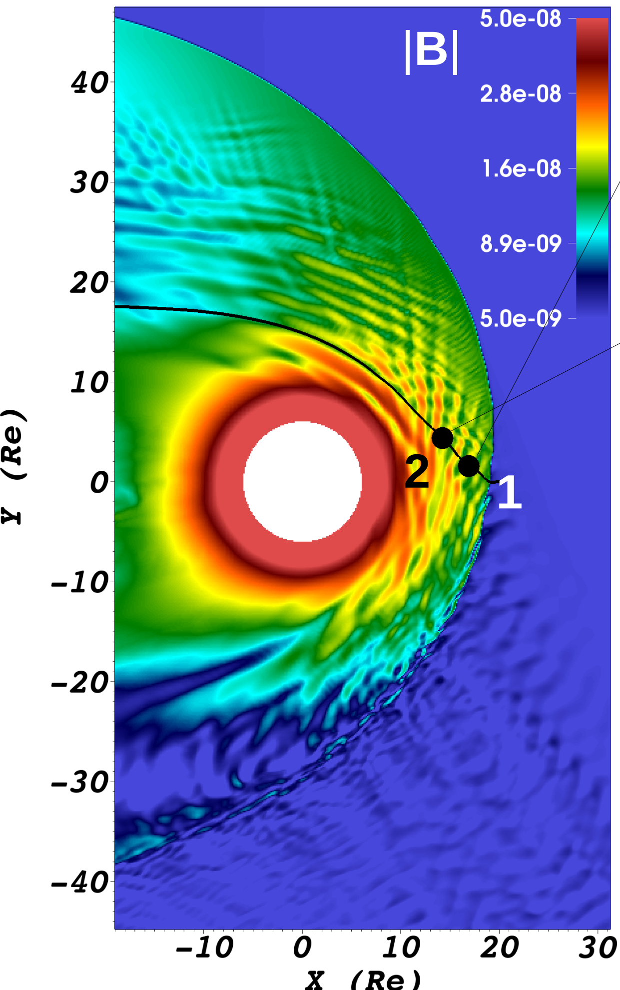
$\lambda_{max}/\lambda_{int} = 10.8$

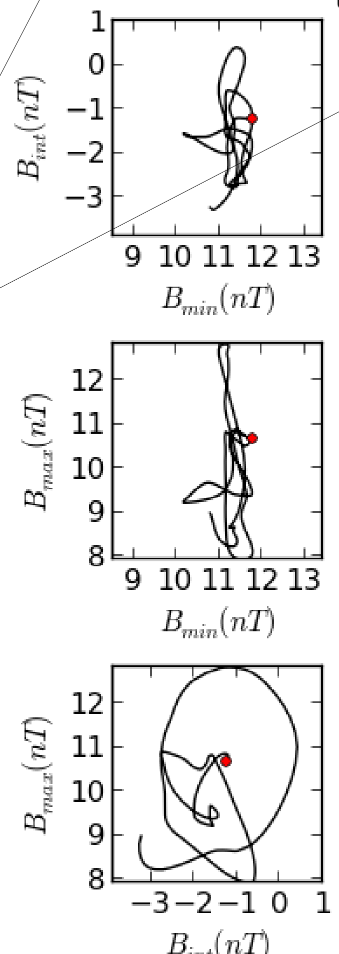
$\lambda_{int}/\lambda_{min} = 2.6$

$\lambda_{min}/\lambda_{int} = 0.4$

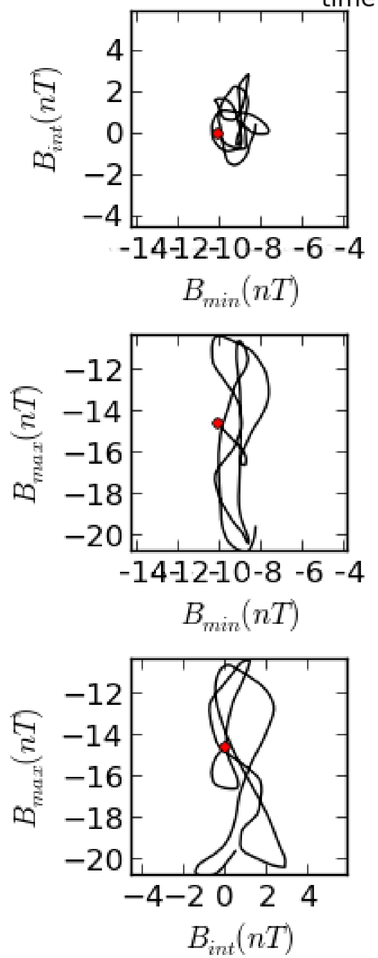
# Wave analysis




$\lambda_{max}/\lambda_{int}$= 2.6
$\lambda_{int}/\lambda_{min}$= 4.8
$\lambda_{min}/\lambda_{int}$=0.2




$\lambda_{max}/\lambda_{int}$= 10.8
$\lambda_{int}/\lambda_{min}$= 2.6
$\lambda_{min}/\lambda_{int}$= 0.4

Criteria:
$\lambda_{max}/\lambda_{int} \gg \lambda_{int}/\lambda_{min} \sim 1$
$\lambda_{max}/\lambda_{int} > 1.5$
$\lambda_{min}/\lambda_{int} > 0.3$

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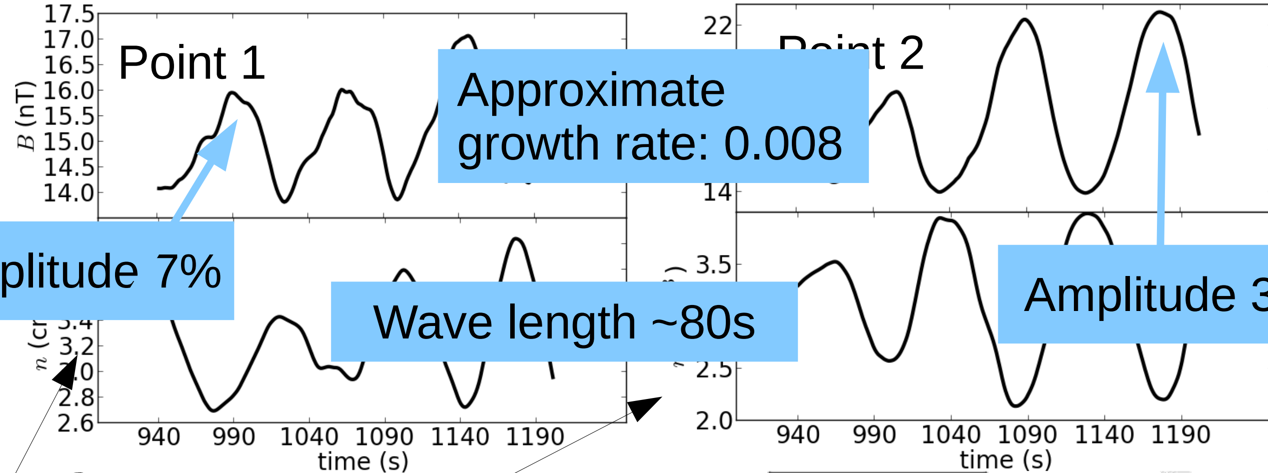
# Wave analysis

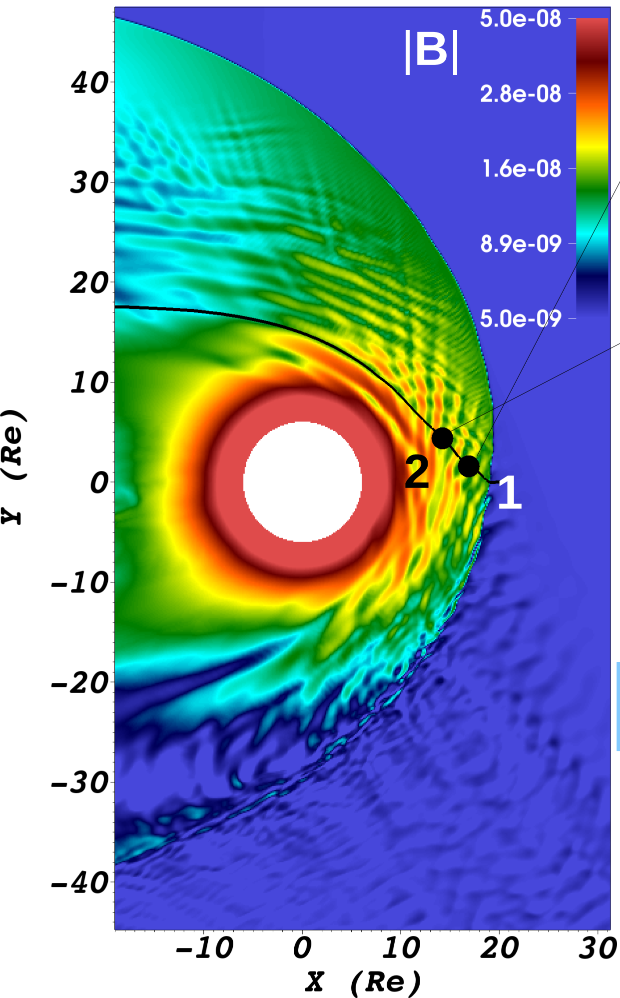


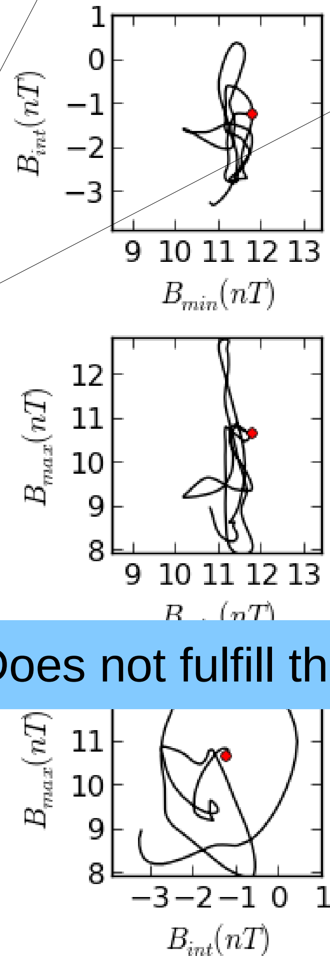

Approximate growth rate: 0.008

Amplitude 7%

Wave length ~80s

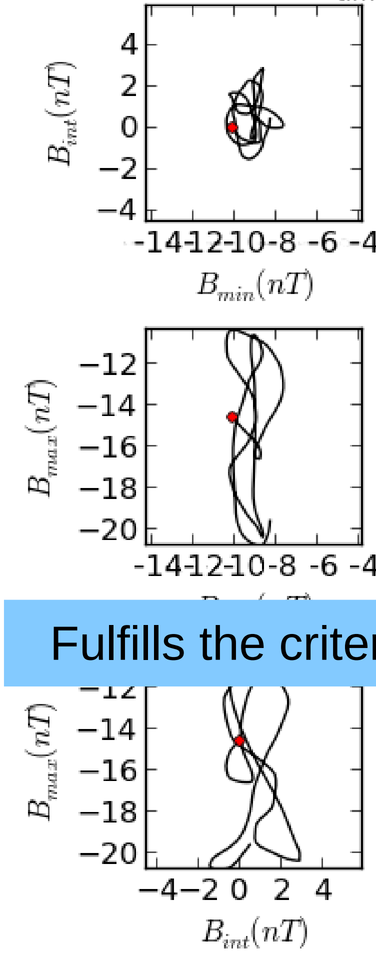
Amplitude 30%




$\lambda_{max}/\lambda_{int}$= 2.6
$\lambda_{int}/\lambda_{min}$= 4.8
$\lambda_{min}/\lambda_{int}$=0.2

Does not fulfill the criteria




$\lambda_{max}/\lambda_{int}$= 10.8
$\lambda_{int}/\lambda_{min}$= 2.6
$\lambda_{min}/\lambda_{int}$= 0.4

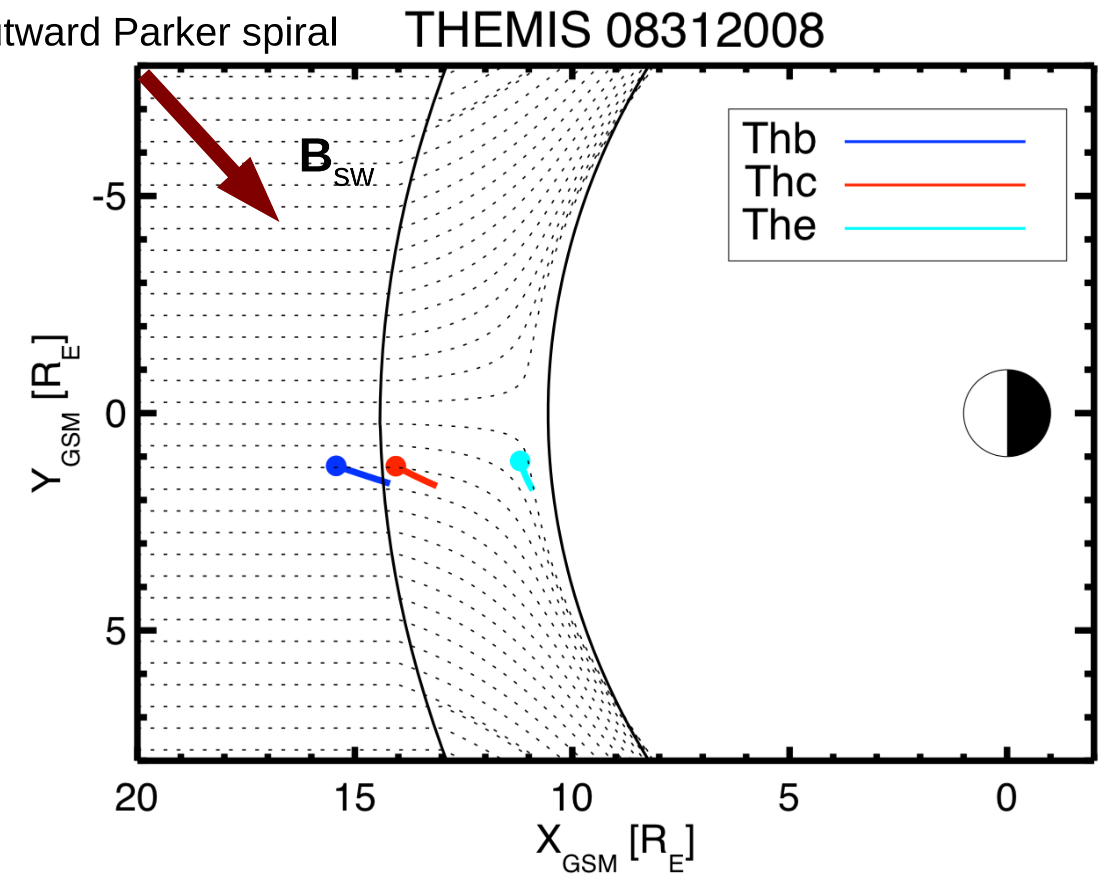
Fulfills the criteria

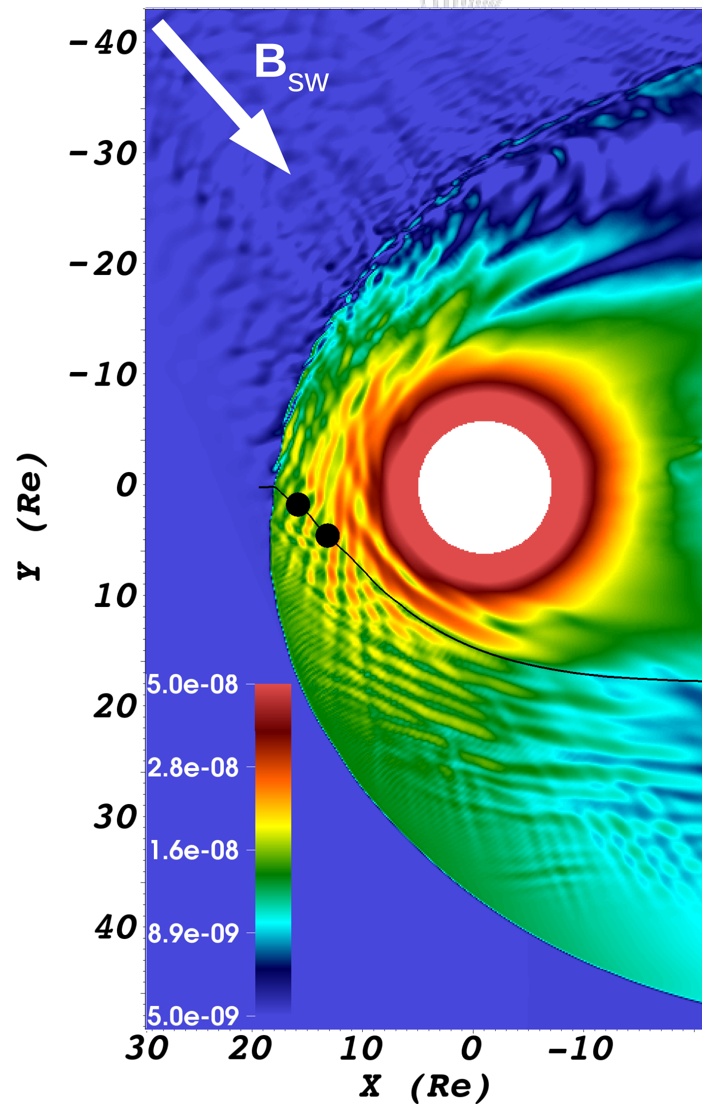
Criteria:
$\lambda_{max}/\lambda_{int} \gg \lambda_{int}/\lambda_{min} \sim 1$
$\lambda_{max}/\lambda_{int} > 1.5$
$\lambda_{min}/\lambda_{int} > 0.3$

# Observations

**Themis B in solar wind**
**Themis C in magnetosheath behind bow shock**
**Themis E in magnetosheath close to magnetopause**

Outward Parker spiral



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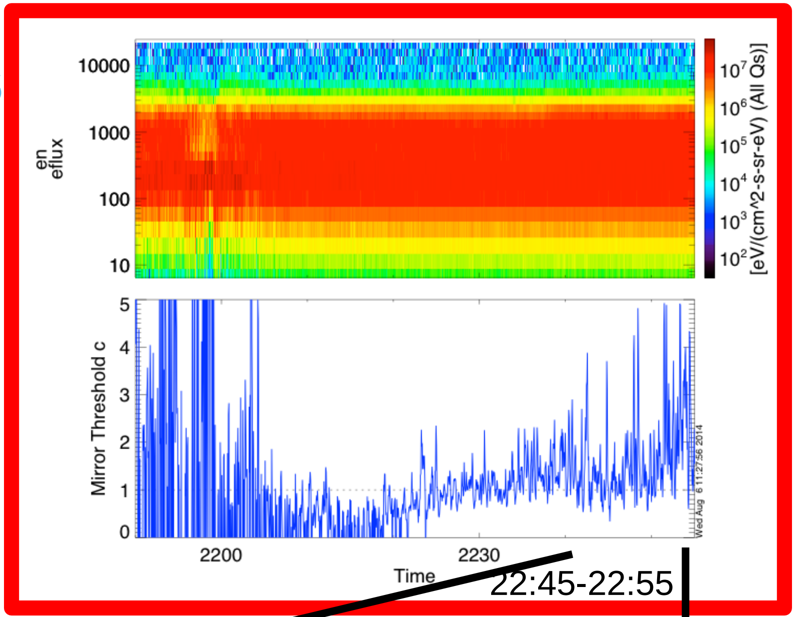
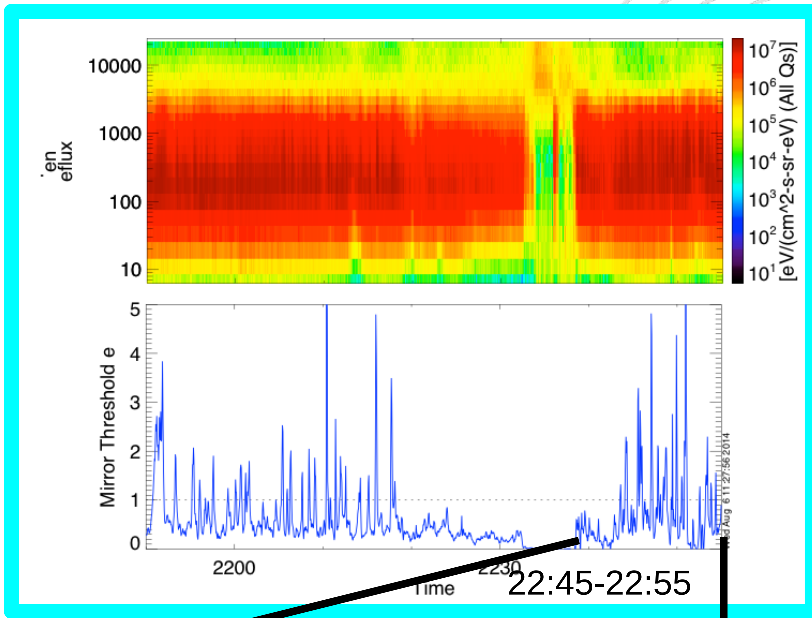
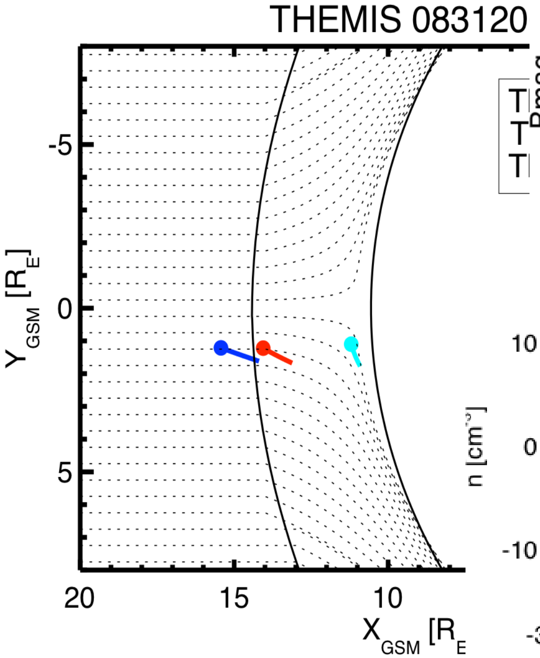
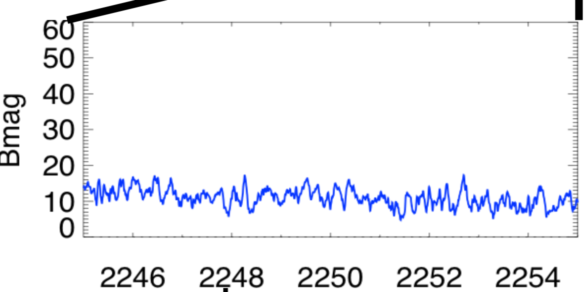
# Mirror modes in THEMIS observations

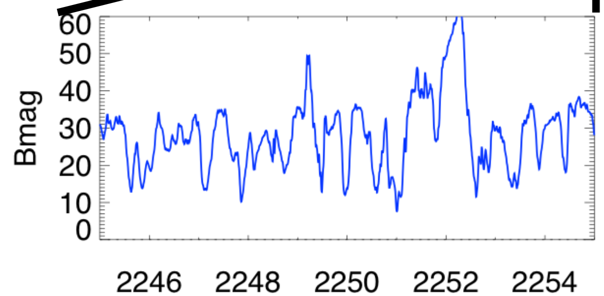
Approximate growth rate: ~0.003

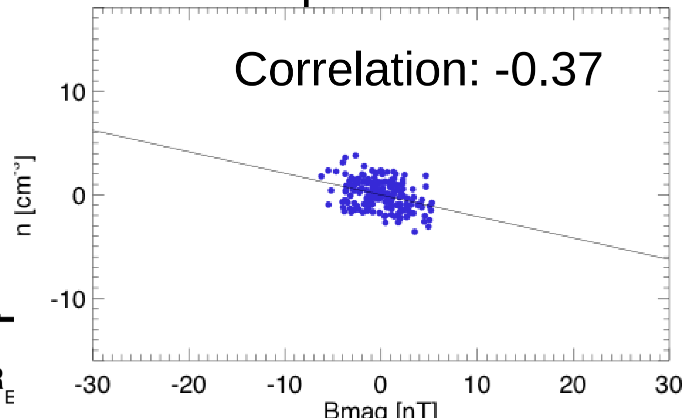


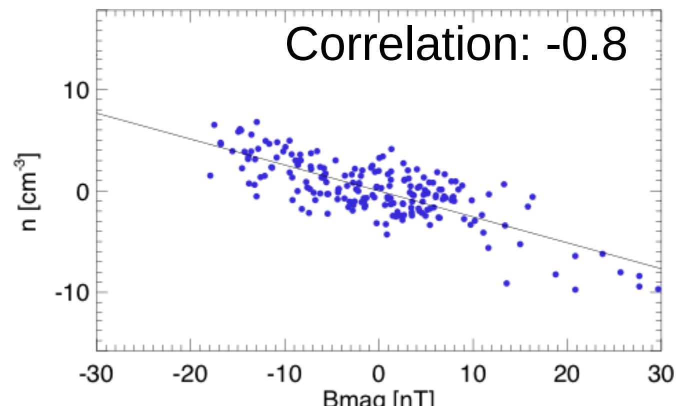



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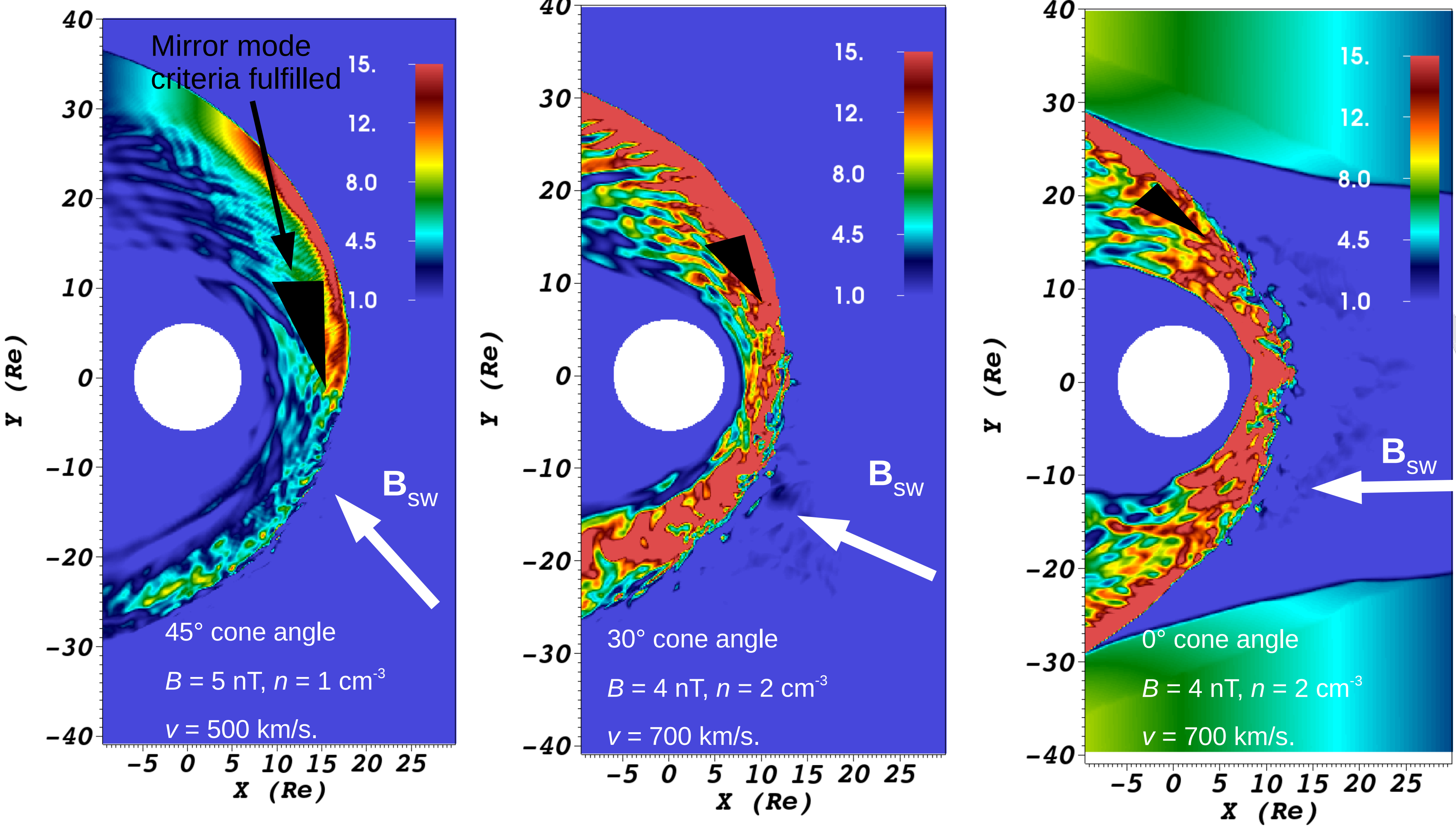
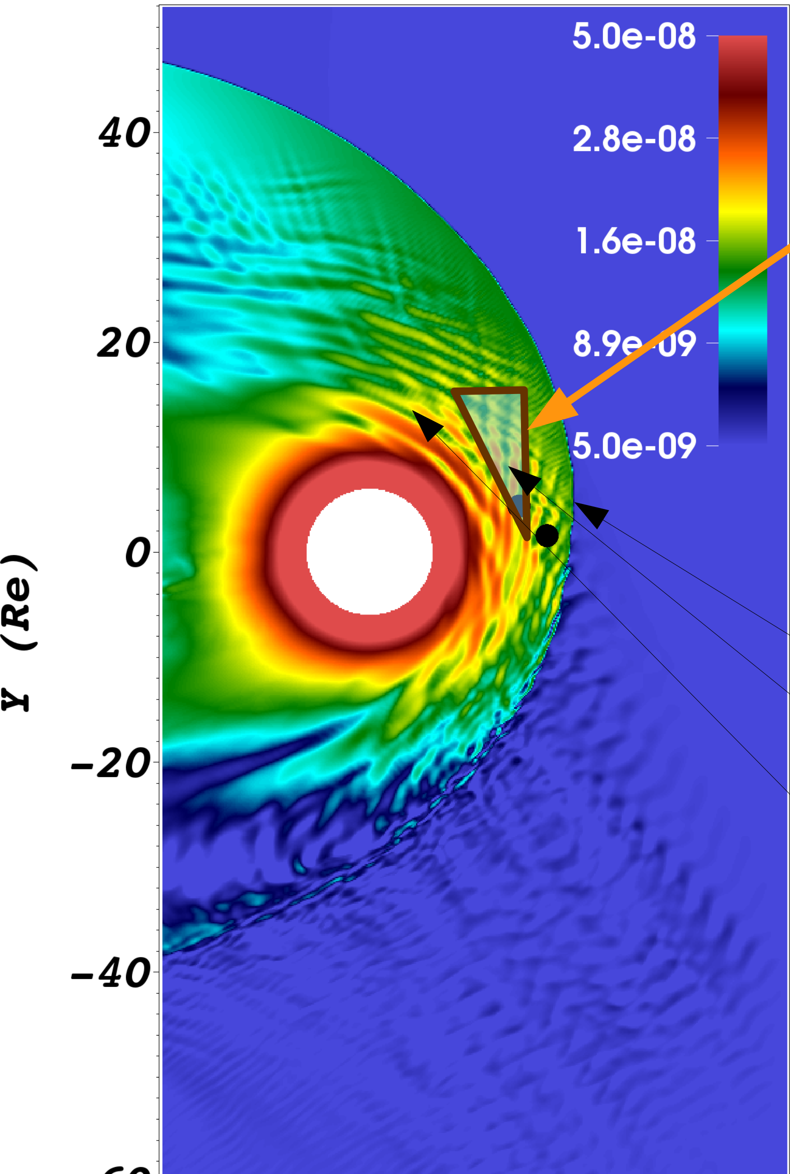
# Wave location and IMF cone angle

Color: mirror instability condition $\beta_\perp (T_\perp/T_{||}-1) > 1$ at t = 1000 s



# Conclusions




- 3 runs analyzed (45°, 30°, 0°)
- Vlasiator fluctuations fulfill observational criteria:
  - Linear polarization
  - Amplitude
  - Anti-correlation between B and n
- Vlasiator results in quantitative agreement with THEMIS observations
- Wave evolution:
  - Formation near the ULF wave boundary
  - Linear polarization further away from bow shock
  - Elliptical polarization further in flanks

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# Thank you for your attention!

**vlasiator.fmi.fi**