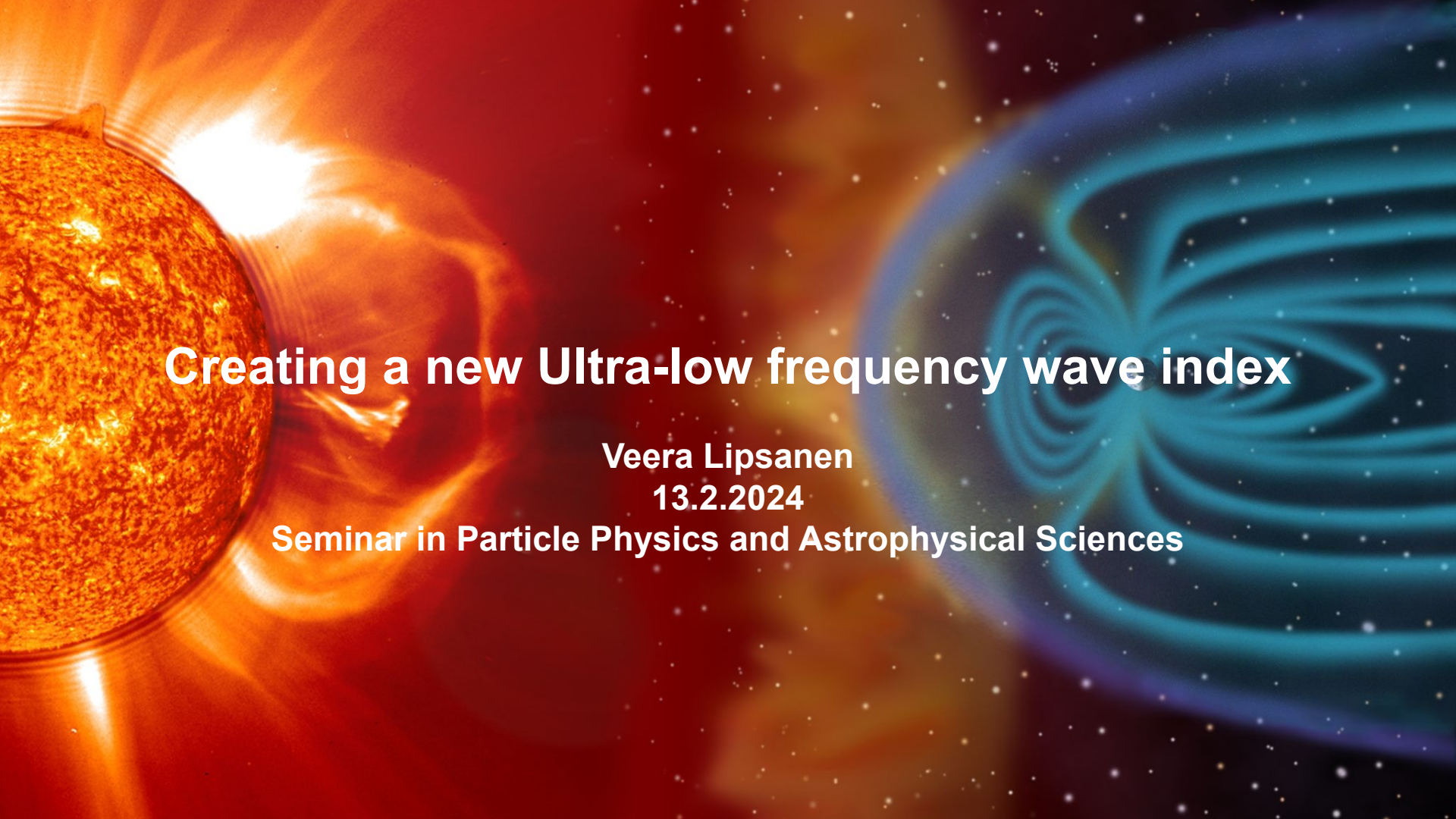

Creating a new Ultra-low frequency wave index

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13.2.2024

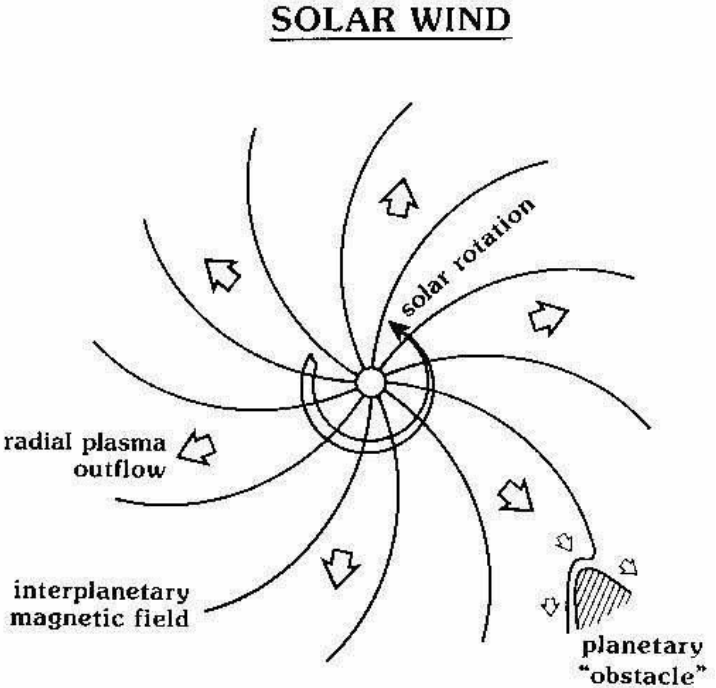
Seminar in Particle Physics and Astrophysical Sciences

Outline

1. Background
    a. Solar wind
    b. Magnetosphere
    c. Magnetic local time
    d. ULF waves
2. Creating a ULF wave index
3. How the index can be used
4. Future studies

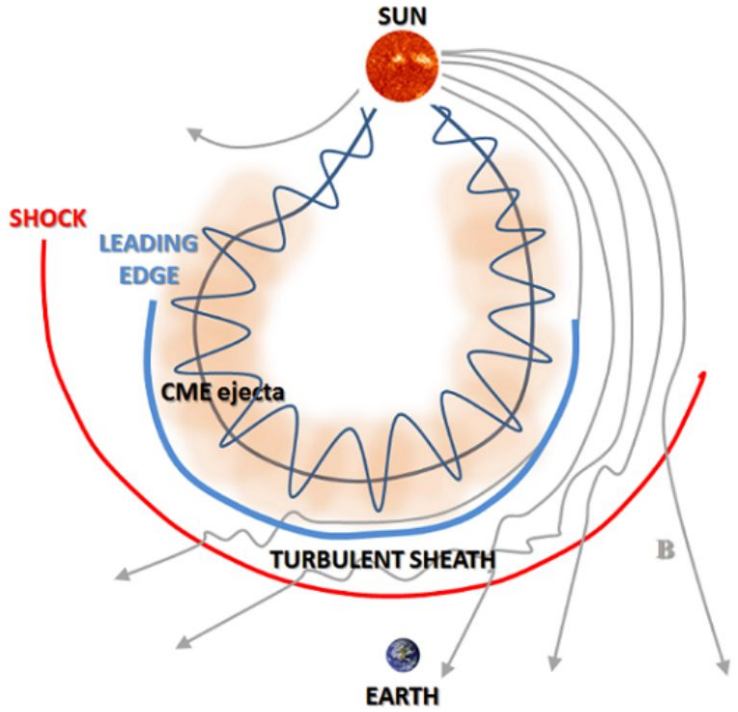
Solar Wind

- Constant outflow of plasma from the Sun
- Drags out magnetic field and forms the interplanetary magnetic field (IMF)
  - rotation of the Sun causes the IMF to twist
- Divided into
  - slow (300-500 km/s) and dense wind
  - fast (500-800 km/s) and tenuous wind



Interplanetary coronal mass ejections (ICMEs)

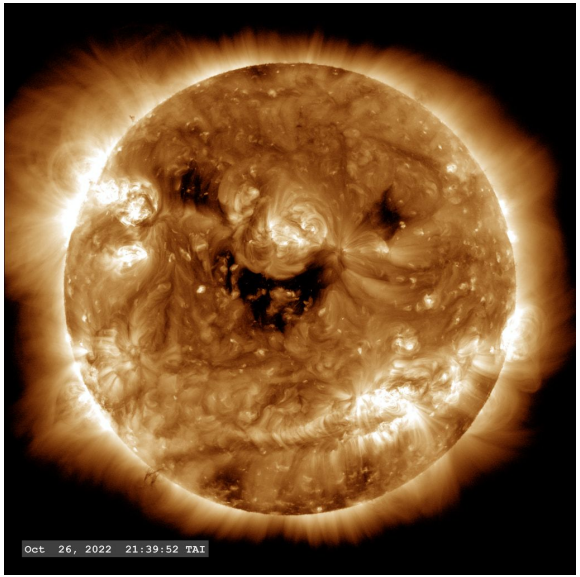
- Massive eruptions of plasma
- Can cause intense geomagnetic storms
- Ejecta:
  - magnetic field changes smoothly
  - if fast enough can create a sheath region
- Sheath:
  - turbulent plasma
  - magnetic field field variations
  - enhanced magnetic field

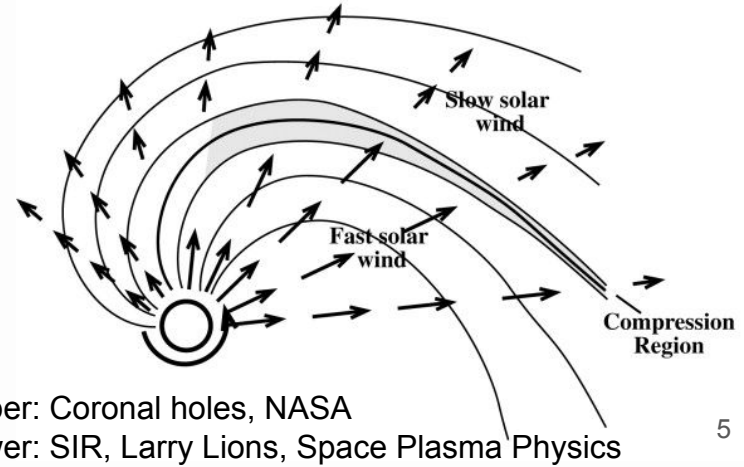


ICME structure, Kilpua et. al (2017)

High Speed Streams (HSSs)

- Extended periods of fast solar wind
  - originate from large regions of open magnetic fields
- Fast wind can catch slower flow ahead
  - stream interaction region (SIR) is formed
  - particle density and IMF strength are increased
- Can cause geomagnetic storms
  - not as strong as ICMEs





Upper: Coronal holes, NASA
Lower: SIR, Larry Lions, Space Plasma Physics

Geomagnetic storms

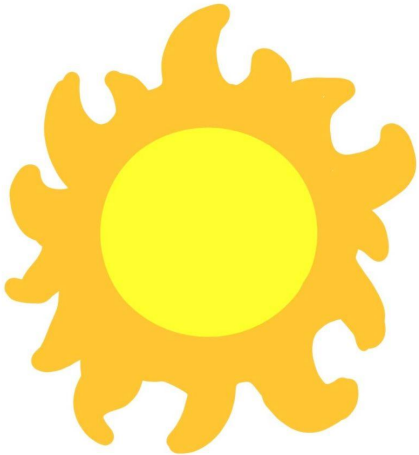
- A disturbance or change in the magnetosphere
  - can last several days
- SYM-H index
  - indicator for geomagnetic activity
  - negative value means weakened magnetic field

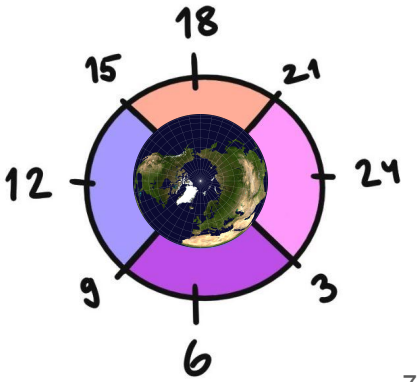
Substorms

- Energy release from the magnetotail into the ionosphere caused by a disturbance in the magnetosphere
  - last for a few hours
- AE index
  - indicator for substorm activity
  - measure of magnetic activity in the auroral zone

Magnetic local time

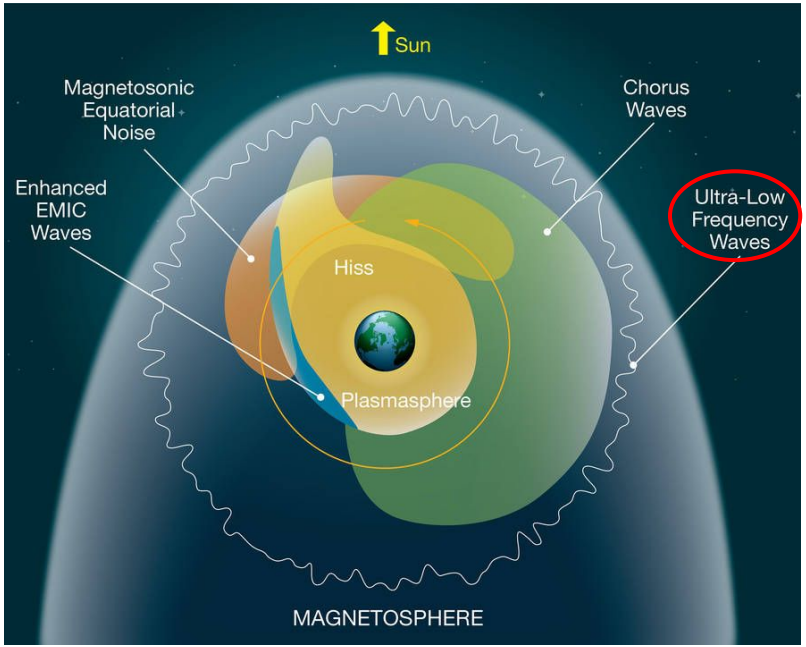
- Parameter used to organize data with respect to the position of the Sun
  - a 24-hour clock around Earth
  - MLT=12 (noon) always points directly at the Sun
- Divided into four sections:
  - **Day (9-15 MLT)**
  - **Dusk (15-21 MLT)**
  - **Night (21-3 MLT)**
  - **Dawn (3-9 MLT)**





Ultra-low frequency (ULF) waves

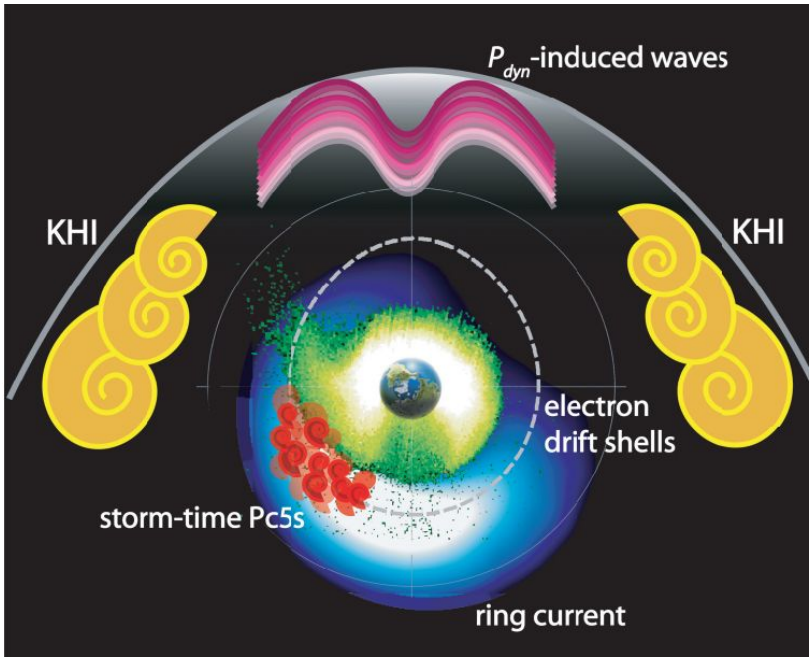
- Pulsations of Earth's magnetosphere
  - frequencies in 2-5000 MHz range
- Pc5 (2-7 mHz) ULF waves are of special interest
  - period comparable to drift period of energetic electrons in radiation belts → acceleration
  - can change electron fluxes
- Energy transfer between solar wind and magnetosphere



Different plasma waves in Earth's magnetosphere, NASA

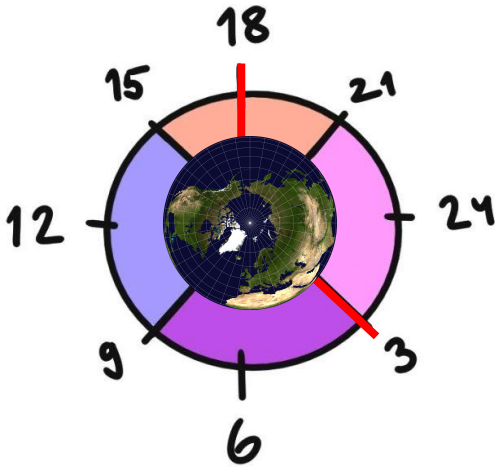
ULF wave generation and distribution

- Fluctuation of dynamic pressure in solar wind
  - mostly on the dayside
- HSSs can drive Kelvin-Helmholtz instabilities
  - occur at dawn and dusk
- Dawn-dusk asymmetry: pc5 more prominent on dawnside
- Substorm activity
  - nightside



A pre-existing “global” ULF wave index: T_{GR}

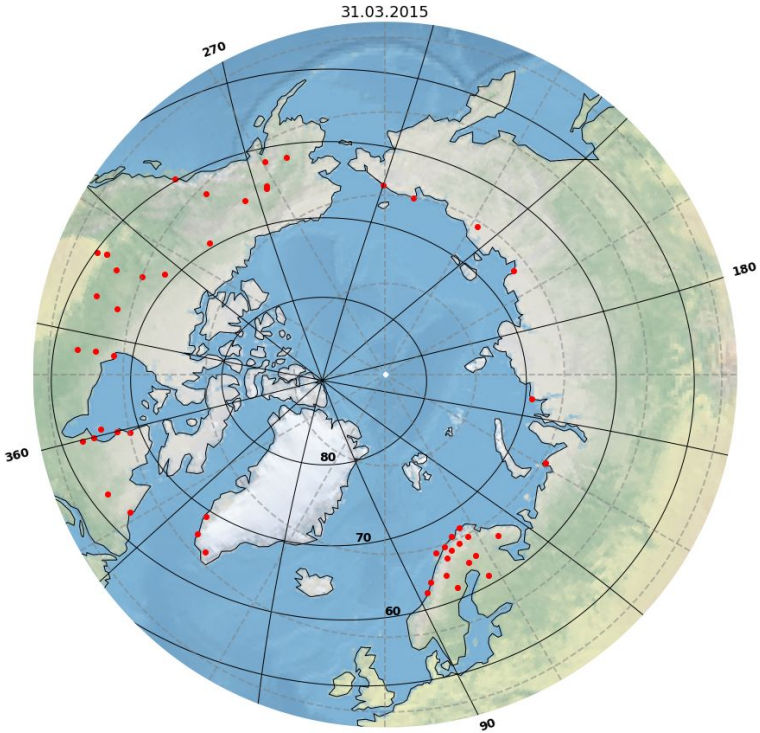
- Created by Kozyreva et.al (2006)
  - 1-hour resolution
  - magnetic latitudes of 60-70°
  - no MLT-dependence
- Stations are selected from 3-18 MLT
  - nightside is fully omitted
  - cross-correlation for 00–24 and 03–18 MLT sectors i high
- Only the station with the peak power is selected



Creating a MLT dependent groundbased ULF wave index

Magnetometer data

- SuperMAG offers data from nearly 600 magnetometers
  - offers 1-min and 1-sec resolution data
  - data is in the same coordinate system
- Magnetometers between magnetic latitudes of 60-70°
  - peak ULF intensity
- Small problem: only a few magnetometers in northern Russia



Red dots are stations between 60-70 MLAT.

Preparation of data

- Take data from the needed time interval
  - for my thesis I used only small intervals
  - if time interval is longer than few days the data has to be divided into shorter intervals
- Data has to be inspected first
  - if there is a data gap longer than 40 minutes, that station is left out
  - shorter data gaps can be interpolated

Wavelet transform

- Decomposes a time series into time and frequency space
  - variations of power within a time series can be studied
  - translate and dilate a chosen wavelet function
- Python module PyCWT
  - routines for wavelet analysis using fast fourier transform
- Takes a long time for a long time series

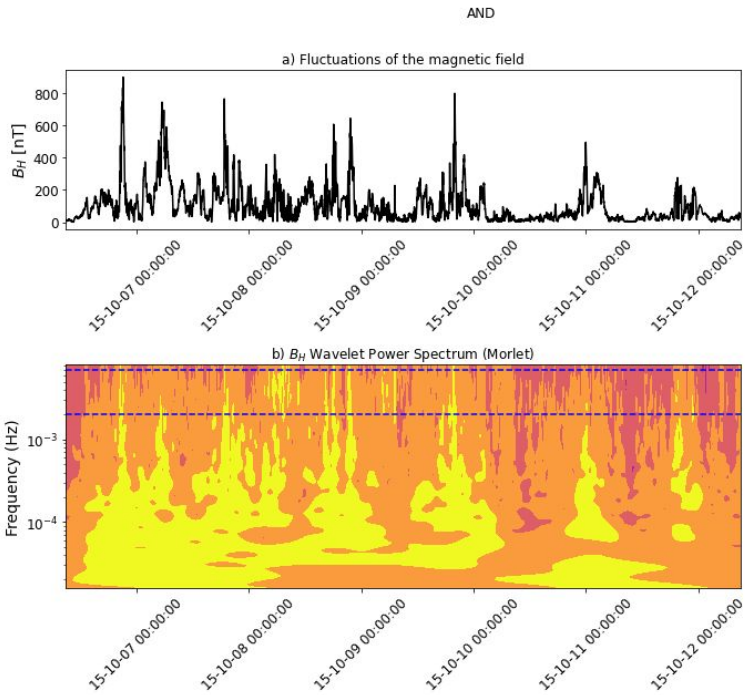
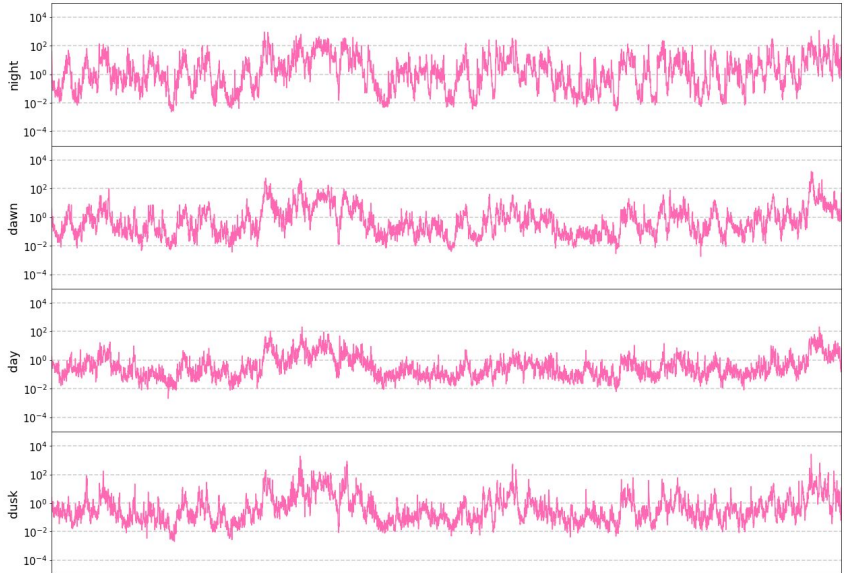


Figure: Upper panel has magnetic field, lower panel wavelet power

Finishing touches

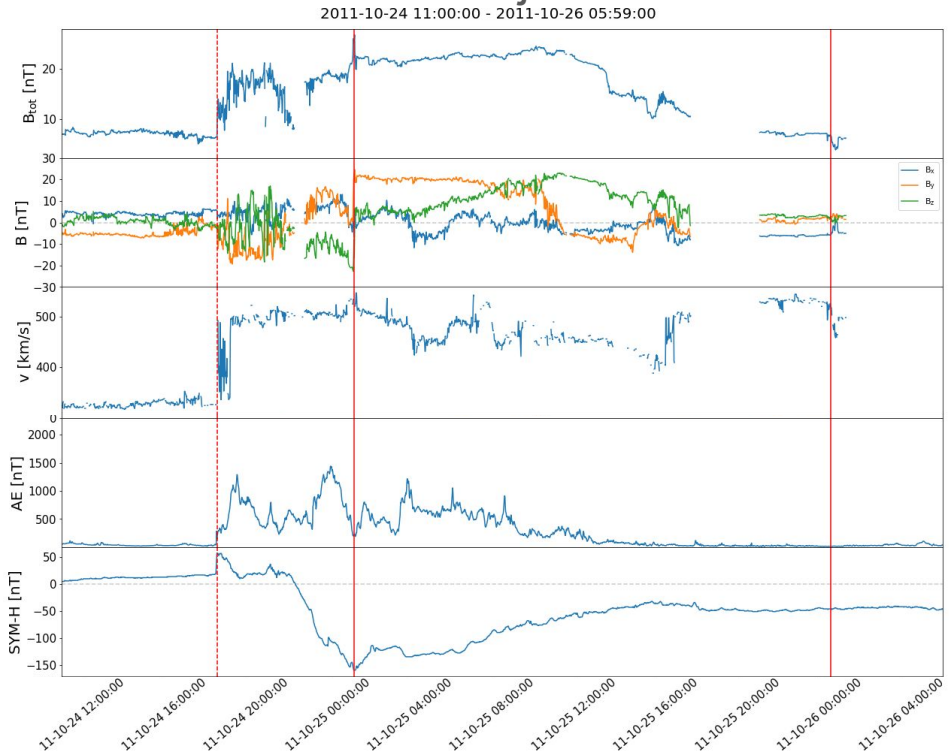
- Take an average power over the pc5 frequencies
- Divide the power into the four MLT sectors
  - each minute the stations are divided and the ULF power is averaged across stations
- In the end we should have four different ULF indices with 1-minute resolution



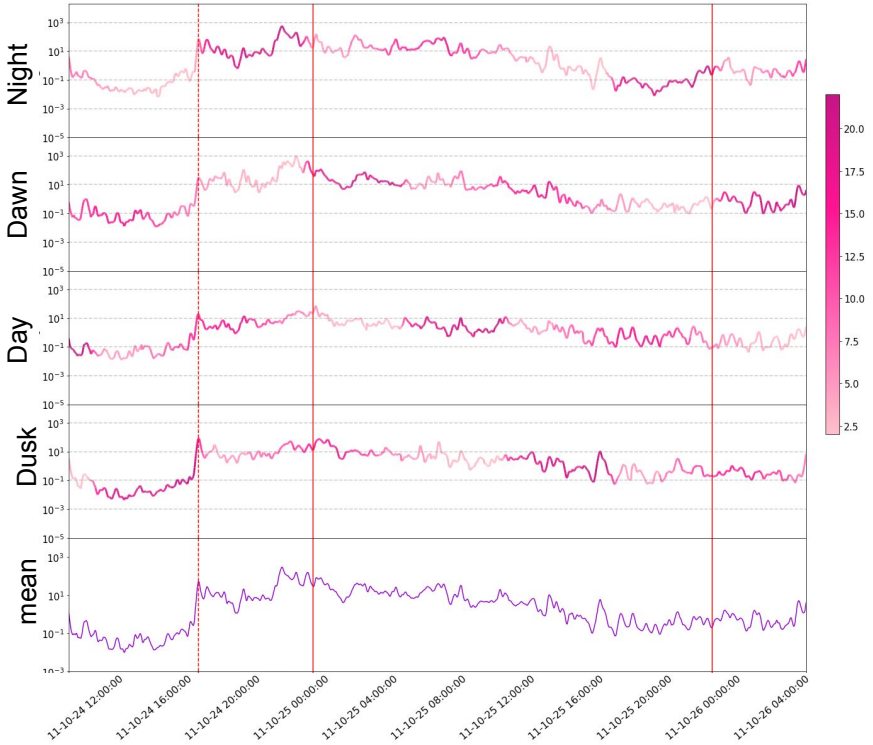
How the index can be used

ICME 24.10.2011

sheath ejecta



solar wind data



ULF index

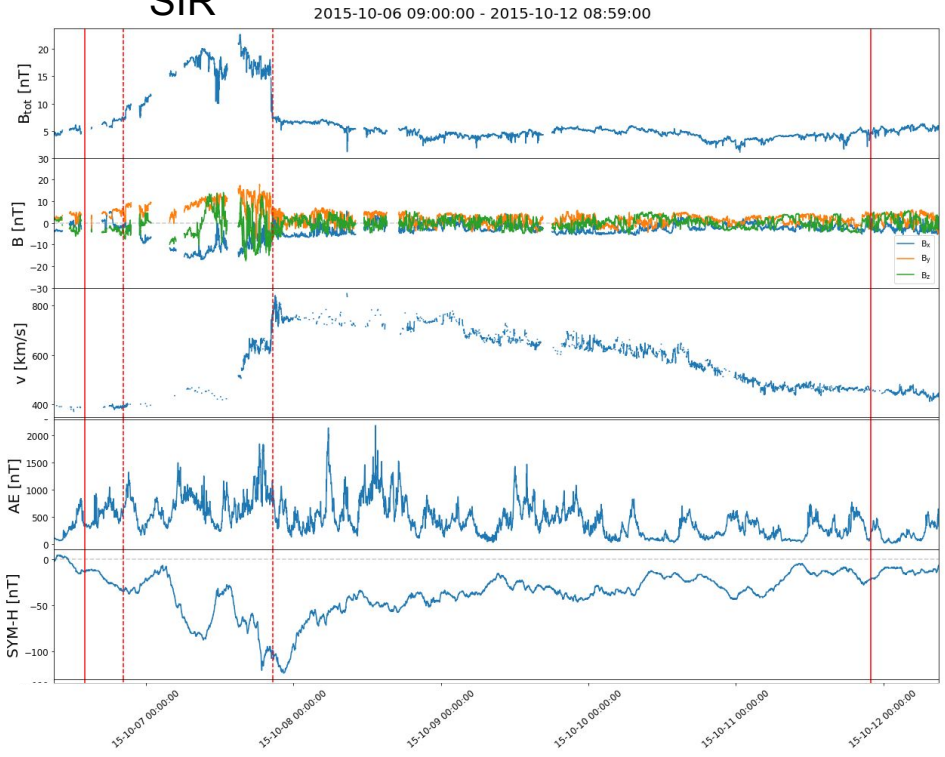
sheath

ejecta

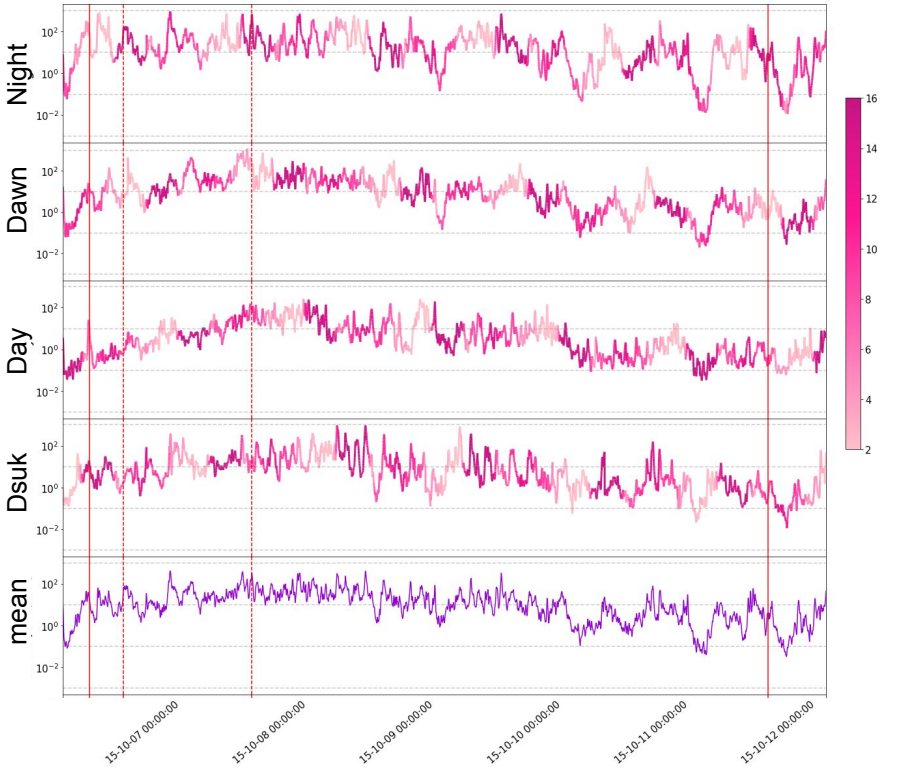
- During sheath region AE index and dawn have high correlation, but during ejecta AE index correlates best with nightside
- z-component of IMF correlates better in sheath region
- Dawn-dusk asymmetry

HSS 6.10.2015

SIR



solar wind data



ULF index

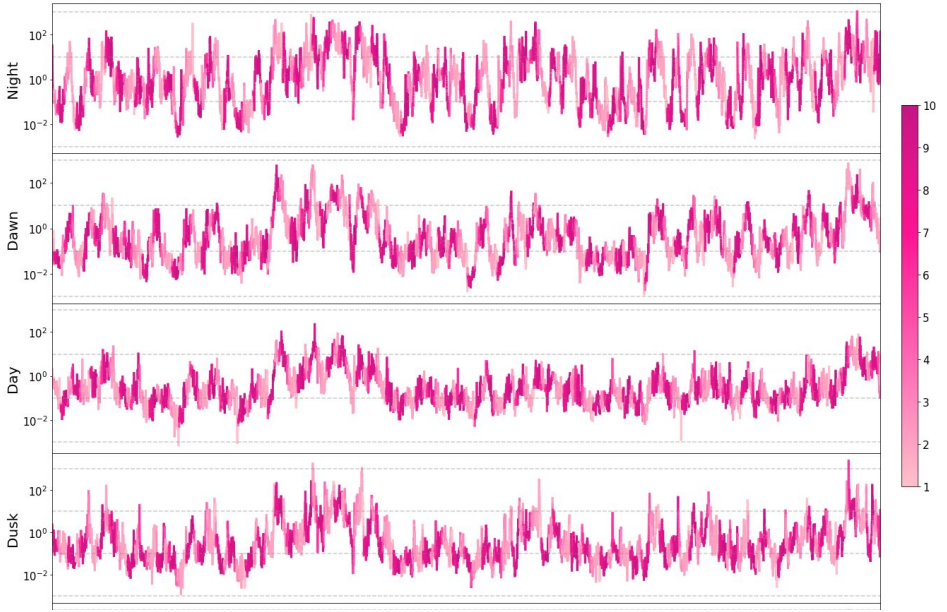
SIR

HSS after SIR

- After SIR, AE index and nightside have the highest correlation
- During SIR velocity has high correlation with day and dawn, after SIR correlation decreases
- Dawn-dusk asymmetry

Future studies

- Create a yearly index
  - How activity of the Sun affects
- Study non-linear dependencies
- Study phenomena that have smaller time-scales
  - Foreshock transients



Summary

- ULF waves are generated around the Earth by different mechanisms
- Previous ULF wave index was not global or MLT-dependent
- New created index is global and MLT-dependent
  - can be used to study where wavepower is coming from
- Results show that wavepower differs in MLT sectors

Thank you!