

Problem Set 1

1 AE, Dst, Kp

Obtain and plot the AE [1min resolution] and Dst [1hr resolution] indices directly from their official site, WDC-C in Kyoto, and Kp [3hr resolution] index from its official site, GFZ Potsdam, the entire month of March 2015. Download ASCII and plot using your own tools which are not SPEDAS. Note it's easier to download in IAGA-2002 format for AE and Dst and to use the ftp directory download for kp.

1.1 AE and Dst indices

[a] In a short paragraph explain: What is AE index, and Dst index, and how are they derived? How did you download and plot? Show some lines of the ascii data.

The AE index (Auroral Electrojet index) and Dst index (Disturbance Storm-Time index) are geomagnetic indices used to measure different aspects of Earth's magnetic activity. The AE index quantifies the intensity of auroral electrojets, currents flowing in the auroral regions, and is derived from horizontal magnetic field variations measured by magnetometers distributed around the auroral zone. It provides insight into substorm activity and is calculated using the difference between maximum and minimum horizontal components recorded at these stations. The Dst index, on the other hand, measures the intensity of the ring current, a system of charged particles trapped in Earth's magnetosphere. It is derived from the average horizontal magnetic field variations observed by low-latitude magnetometers. The Dst index is commonly used to assess geomagnetic storms, with negative values indicating stronger disturbances.

We can use julia to download and plot the AE and Dst indices directly from their official site, WDC-C in Kyoto.

- <https://wdc.kugi.kyoto-u.ac.jp/aeasy/index.html>
- <https://wdc.kugi.kyoto-u.ac.jp/dstae/index.html> / http://wdc.kugi.kyoto-u.ac.jp/dst_final/201503

```
dir = "docs/courses/epss261/homework"
if isdir(dir)
    cd(dir)
    Pkg.activate(".")
    Pkg.resolve()
    Pkg.instantiate()
end
```

```

using DataDeps
using Dates
using CairoMakie, SpacePhysicsMakie
using DimensionalData
using CSV, DataFrames

```

First we register and download the data dependencies using the DataDeps package.

```

using CSV, DelimitedFiles
using TimeSeries

register(DataDep("AE Index",
"""
    Dataset: AE Index
    Website: https://wdc.kugi.kyoto-u.ac.jp/aeasy/index.html
    """,
    "https://wdc.kugi.kyoto-u.ac.jp///aeasy///wwwtmp/WWW_aeasy04087001.dat"
))

register(DataDep("Dst Index",
"""
    Dataset: Dst Index
    Website: https://wdc.kugi.kyoto-u.ac.jp/dstae/index.html
    """,
    "https://wdc.kugi.kyoto-u.ac.jp///dstae///wwwtmp/WWW_dstae04096902.dat"
))

# Step 1: Download data
ae_file = readdir(datadep"AE Index", join=true)[1]
dst_file = readdir(datadep"Dst Index", join=true)[1]

```

The data is downloaded as text files in IAGA-2002 format. Sample data looks like this:

DATE	TIME	DOY	AE	AU	AL	AO	
2015-03-01	00:00:00.000	060	245.00	122.00	-123.00	-1.00	
2015-03-01	00:01:00.000	060	253.00	125.00	-128.00	-2.00	
2015-03-01	00:02:00.000	060	235.00	122.00	-113.00	5.00	
2015-03-01	00:03:00.000	060	225.00	120.00	-105.00	8.00	

DATE	TIME	DOY	DST	
2015-03-01	00:00:00.000	060	-34.00	
2015-03-01	01:00:00.000	060	-44.00	

```

2015-03-01 02:00:00.000 060      -30.00
2015-03-01 03:00:00.000 060      -31.00

```

Since the above url is not persistent, we use `CDAWeb.jl` to download the data.

```

using CDAWeb

start_time = "2015-03-01T00:00:00"
end_time = "2015-03-31T23:59:59"

dataset = CDAWeb.get_data("OMNI2_H0_MRG1HR", start_time, end_time; clip=true)
ae_data = dataset["AE"] |> DimArray
dst_data = dataset["DST"] |> DimArray

```

```

Precompiling packages...
  9507.0 ms  ✓ CDFDatasets → CDFDatasetsSpacePhysicsMakieExt
  1 dependency successfully precompiled in 11 seconds. 316 already
precompiled.

```

```

744-element DimArray{Int32, 1} DST
|----- dims
|
1   ↓ Ti Sampled{CommonDataFormat.Epoch} [2015-03-01T00:00:00, ...,
2015-03-31T23:00:00] ForwardOrdered Irregular Points
|----- metadata
|
CommonDataModel.Attributes{CDFDatasets.ConcatCDFVariable{Int32, 1,
DiskArrays.ConcatDiskArray{Int32, 1,
Vector{CommonDataFormat.CDFVariable{Int32, 1, CommonDataFormat.rVDR{Int64}},
CommonDataFormat.CDFDataset{CommonDataFormat.NoCompression, Int64}}}},
DiskArrays.GridChunks{1, Tuple{DiskArrays.RegularChunks}},
DiskArrays.Chunked{DiskArrays.SubRanges{DiskArrays.NoStepRange}}}, Nothing}}
with 14 entries:
  "FILLVAL"      => Int32[99999]
  "FIELDNAM"     => "Dst Index (1-h)"
  "VALIDMAX"     => Int32[500]
  "SCALEMAX"     => Int32[500]
  "CATDESC"       => "Dst - 1-hour Dst index, from WDC Kyoto"
  "VALIDMIN"     => Int32[-800]
  "DISPLAY_TYPE"  => "time_series"
  "UNITS"         => "nT"
  "DEPEND_0"      => "Epoch"
  "BIN_LOCATION"  => "0.0"
  "FORMAT"        => "I5"
  "VAR_TYPE"      => "data"
  "SCALEMIN"      => Int32[-800]

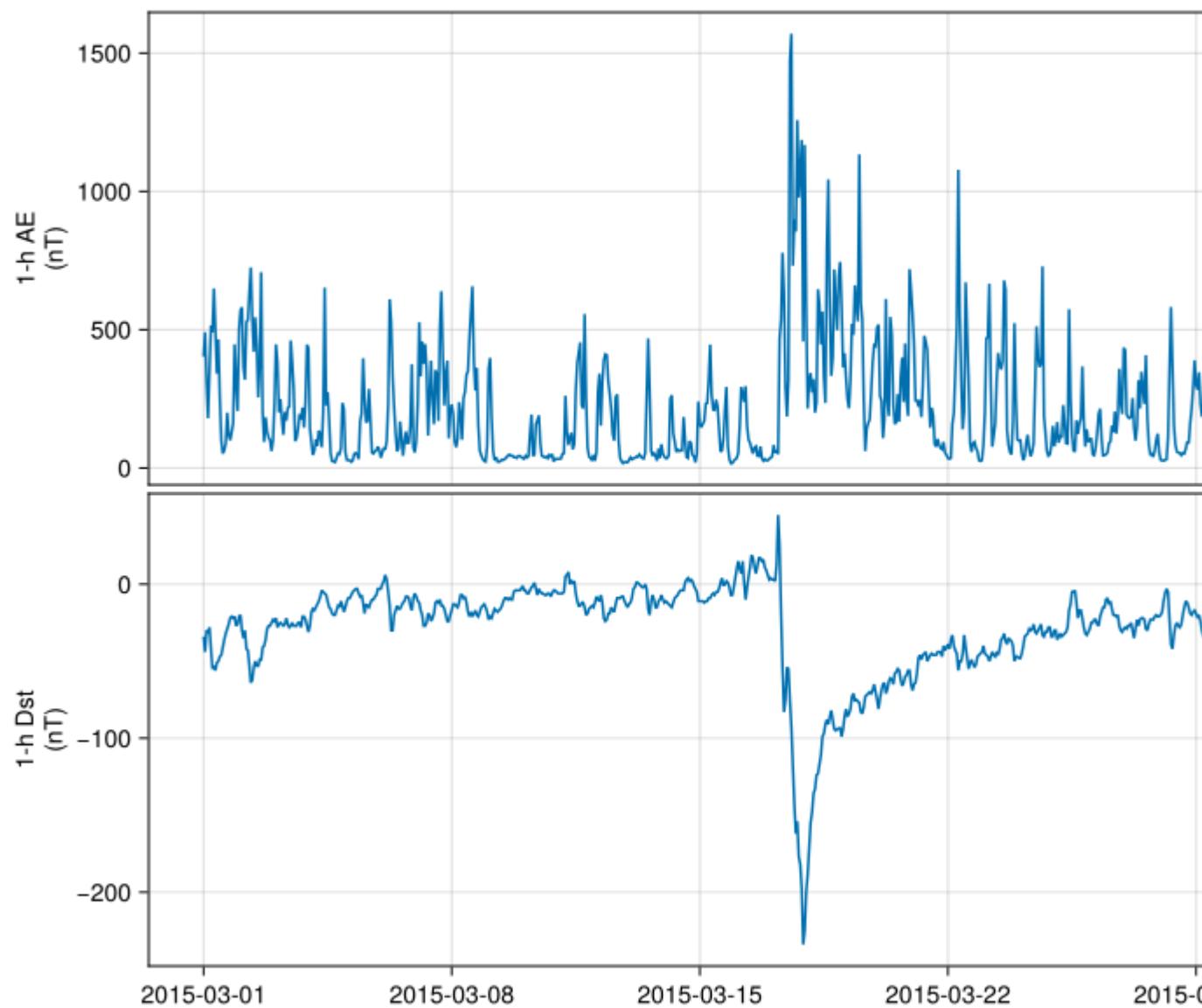
```

```
"LABLAXIS"      => "1-h Dst"
```

```
: [?]
```

Plot the data using CairoMakie.

```
f = tplot([ae_data, dst_data])
```



1.2 Kp index

In a second paragraph do the same as above but for Kp. What is Kp index? And how is it derived?

The Kp index is a global geomagnetic activity index that quantifies disturbances in Earth's magnetic field caused by solar activity. Kp is calculated from the K values or the geomagnetic recordings of 13 mid-latitude geomagnetic observatories.

```
using SpaceWeather

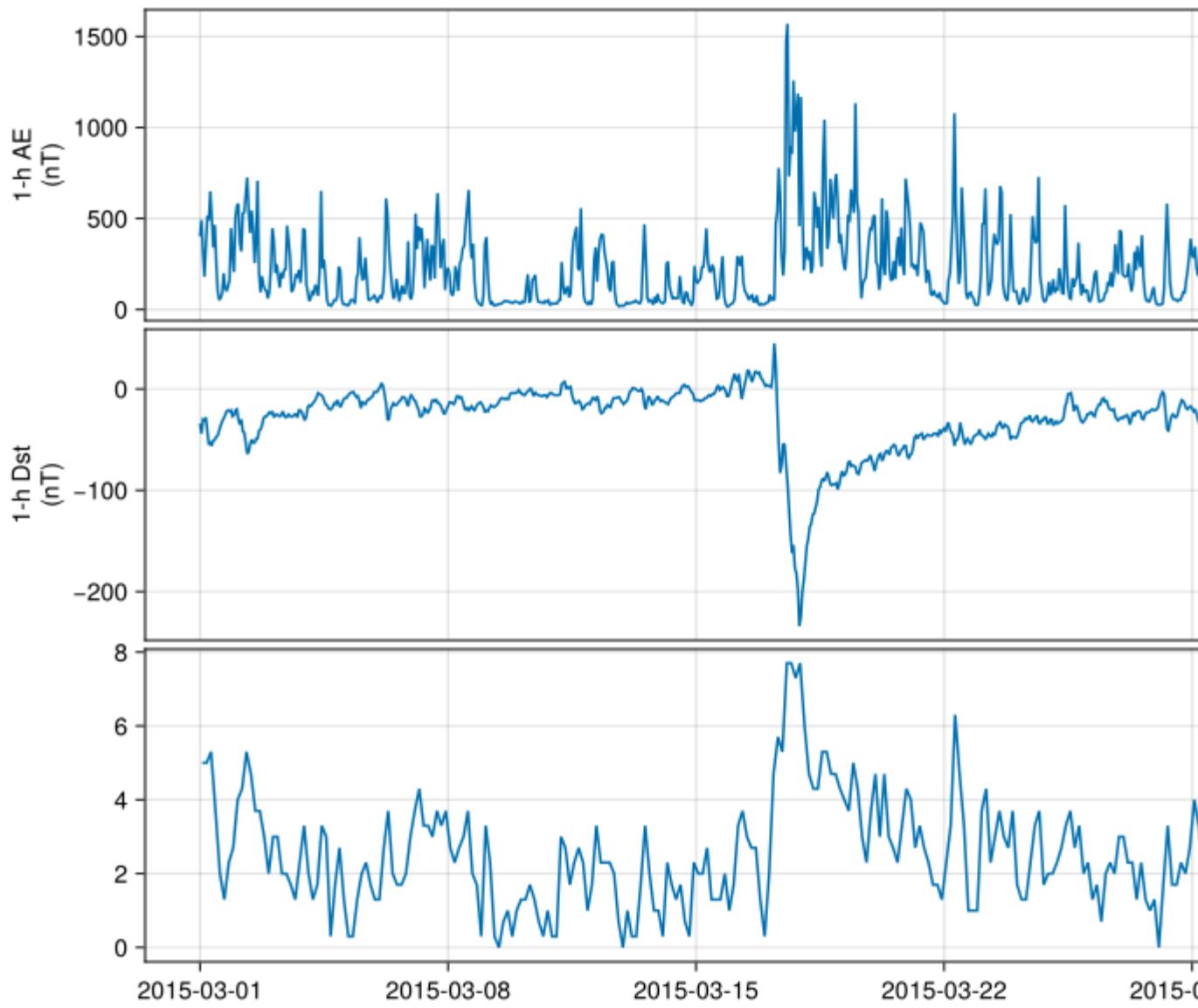
kp_data = SpaceWeather.Kp(start_time, end_time)

1-dimensional KeyedArray(NamedDimsArray(...)) with keys:
↳ time ∈ 248-element StepRange{Dates.DateTime,...}
And data, 248-element reshape(adjoint(::Matrix{Union{Missing, Float64}}), 248)
with eltype Union{Missing, Float64}:
    DateTime("2015-03-01T01:30:00")      5.0
    DateTime("2015-03-01T04:30:00")      5.0
    DateTime("2015-03-01T07:30:00")      5.3
    DateTime("2015-03-01T10:30:00")      3.7
    DateTime("2015-03-01T13:30:00")      2.0
    DateTime("2015-03-01T16:30:00")      1.3
    DateTime("2015-03-01T19:30:00")      2.3
    DateTime("2015-03-01T22:30:00")      2.7
    :
    DateTime("2015-03-31T04:30:00")      0.7
    DateTime("2015-03-31T07:30:00")      2.3
    DateTime("2015-03-31T10:30:00")      2.3
    DateTime("2015-03-31T13:30:00")      3.0
    DateTime("2015-03-31T16:30:00")      3.0
    DateTime("2015-03-31T19:30:00")      2.7
    DateTime("2015-03-31T22:30:00")      2.0
```

1.3 Plot

[c] Plot all 3 indices in a single plot with common time, UT in usual units [2015-03-01 00:00]. If you cannot plot in this format, simply plot in decimal day or decimal hour.

```
f = tplot([ae_data, dst_data, identity.(kp_data)])
```



2 Galileo Magnetometer PDS

Obtain and plot the Galileo magnetometer flyby #8 data of Ganymede from the Planetary Data System (PDS). This is the NASA data repository of Planetary missions, the counterpart of SPDF (Space Physics Data Facility) used for Heliophysics missions. Note that planetary magnetospheric quantities are stored in both. UCLA is the central “node” for PDS with Prof. Walker the PI of that program. Use your own tools such as Excel (but not SPEDAS) to do this (you are welcome to use SPLASH if on Windows (download it from PDS)).

2.1 Coordinate system

In a short paragraph explain: What is the coordinate system and how did you download and plot?

Dataset about Galileo (<https://pds-ppi.igpp.ucla.edu/mission/Galileo>) flyby of Ganymede is available in the Planetary Data System (PDS) <https://pds-ppi.igpp.ucla.edu/collection/urn:nasa:pds:galileo-mag-jup-calibrated:data-highres-ganymede> [1]. Galileo calibrated MAG high-resolution magnetic field and trajectory data from the Ganymede 8 orbit Ganymede flyby cover 1997-05-07T15:36:00 to 1997-05-07T16:22:00.

The dataset contains data in the following coordinate systems:

- Ganymede Phi-Omega (GPHIO) coordinates https://pds-ppi.igpp.ucla.edu/item/urn:nasa:pds:galileo-mag-jup-calibrated:data-highres-ganymede:orb08_gan_gphio::1.0 [1].
- Ganymede-centered ‘planetocentric’ right-handed (GSPRH) coordinates https://pds-ppi.igpp.ucla.edu/item/urn:nasa:pds:galileo-mag-jup-calibrated:data-highres-ganymede:orb08_gan_gsphr::1.0
- Despun Spacecraft (IRC) coordinates https://pds-ppi.igpp.ucla.edu/item/urn:nasa:pds:galileo-mag-jup-calibrated:data-highres-ganymede:orb08_gan_irc::1.0
- System III [1965] (SYS3) coordinates https://pds-ppi.igpp.ucla.edu/item/urn:nasa:pds:galileo-mag-jup-calibrated:data-highres-ganymede:orb08_gan_sys3::1.0

The data is downloaded as CSV format, read and plot using Julia.

```
register(DataDep("ORB08_GAN_GPHIO",
  """
  Dataset: ORB08_GAN_GPHIO
  Website: https://pds-ppi.igpp.ucla.edu/mission/Galileo
  """,
  "https://pds-ppi.igpp.ucla.edu/ditdos/write?id=urn:nasa:pds:galileo-mag-jup-calibrated:data-highres-ganymede:orb08\_gan\_gphio::1.1&f=csv"
))

GAN_file = readdir(datadep"ORB08_GAN_GPHIO", join=true)[1]

data = CSV.File(GAN_file) |> DataFrame
```

Row	SPACE-CRAFT	BX	BY	BZ	B-FIELD MAGNITUDE	X	Y	Z
	CRAFT							
	EVENT							
	TIME							
	Date	Float64	Float64	Float64	Float64	Float64	Float64	Float64
1	1997-05-07T15:36:13.2504			-85.24		89.23	-1.57456	-3.67635
								0.6489

Row	SPACE-CRAFT	BX	BY	BZ	B-FIELD	X	Y	Z
	EVENT TIME				MAGNITUDE			
	Date	Time						
			Float64	Float64	Float64	Float64	Float64	Float64
2	1997-05-07T15:38:38	.467	-25.16	-85.22	89.25	-1.57452	-3.67527	0.64893
3	1997-05-07T15:38:45	.800	-25.09	-85.24	89.25	-1.57448	-3.6742	0.64897
4	1997-05-07T15:38:44	.133	-25.08	-85.27	89.28	-1.57445	-3.67313	0.649
5	1997-05-07T15:36:56	.467	-25.16	-85.19	89.23	-1.57441	-3.67206	0.64904
6	1997-05-07T15:38:46	.800	-25.18	-85.18	89.23	-1.57437	-3.67098	0.64907
7	1997-05-07T15:36:56	.133	-25.2	-85.18	89.25	-1.57434	-3.66991	0.64911
8	1997-05-07T15:38:47	.467	-25.04	-85.12	89.13	-1.5743	-3.66884	0.64914
9	1997-05-07T15:38:47	.800	-25.04	-85.17	89.17	-1.57426	-3.66777	0.64918
10	1997-05-07T15:38:48	.133	-25.3	-85.06	89.14	-1.57423	-3.66669	0.64921
11	1997-05-07T15:38:39	.467	-25.27	-85.0	89.08	-1.57419	-3.66562	0.64925
12	1997-05-07T15:38:38	.800	-25.01	-85.09	89.09	-1.57415	-3.66455	0.64928
13	1997-05-07T15:38:39	.133	-24.98	-85.12	89.11	-1.57411	-3.66348	0.64932
:	:	:	:	:	:	:	:	:
8176	1997-05-07T16:20:20	.132	17.76	-86.47	88.93	-1.00607	5.14564	0.79636
8177	1997-05-07T16:20:20	.465	17.67	-86.62	89.06	-1.00598	5.1467	0.79637
8178	1997-05-07T16:20:20	.799	17.63	-86.69	89.14	-1.00589	5.14777	0.79637
8179	1997-05-07T16:20:21	.132	17.59	-86.88	89.32	-1.00579	5.14884	0.79638
8180	1997-05-07T16:20:21	.465	17.93	-86.6	89.1	-1.0057	5.1499	0.79638
8181	1997-05-07T16:20:21	.799	17.63	-86.44	88.9	-1.00561	5.15097	0.79639
8182	1997-05-07T16:22:02	.132	17.53	-86.46	88.9	-1.00551	5.15204	0.79639
8183	1997-05-07T16:20:22	.465	17.45	-86.38	88.81	-1.00542	5.1531	0.7964
8184	1997-05-07T16:22:02	.799	17.35	-86.41	88.82	-1.00533	5.15417	0.7964
8185	1997-05-07T16:22:03	.132	17.39	-86.42	88.84	-1.00523	5.15524	0.79641
8186	1997-05-07T16:22:23	.465	17.37	-86.27	88.71	-1.00514	5.1563	0.79641
8187	1997-05-07T16:22:23	.465	17.37	-86.27	88.71	-1.00514	5.1563	0.79641

2.2 Plot

Plot XYZ components and magnitude of the field in four panels. Use a 5th panel in the same plot to show all four traces with different colors, say: Blue, Green, Red, Black for X,Y,Z,T.

```
# Create the plot with multiple panels
fig = Figure(; size=(600, 600))

time = data."SPACECRAFT EVENT TIME"

# Panel for BX
ax1 = Axis(fig[1, 1], title="BX Component", xlabel="Time", ylabel="BX (nT)")
lines!(ax1, time, data[!, "BX"], color=:blue)

# Panel for BY
ax2 = Axis(fig[2, 1], title="BY Component", xlabel="Time", ylabel="BY (nT)")
lines!(ax2, time, data[!, "BY"], color=:green)

# Panel for BZ
ax3 = Axis(fig[3, 1], title="BZ Component", xlabel="Time", ylabel="BZ (nT)")
lines!(ax3, time, data[!, "BZ"], color=:red)

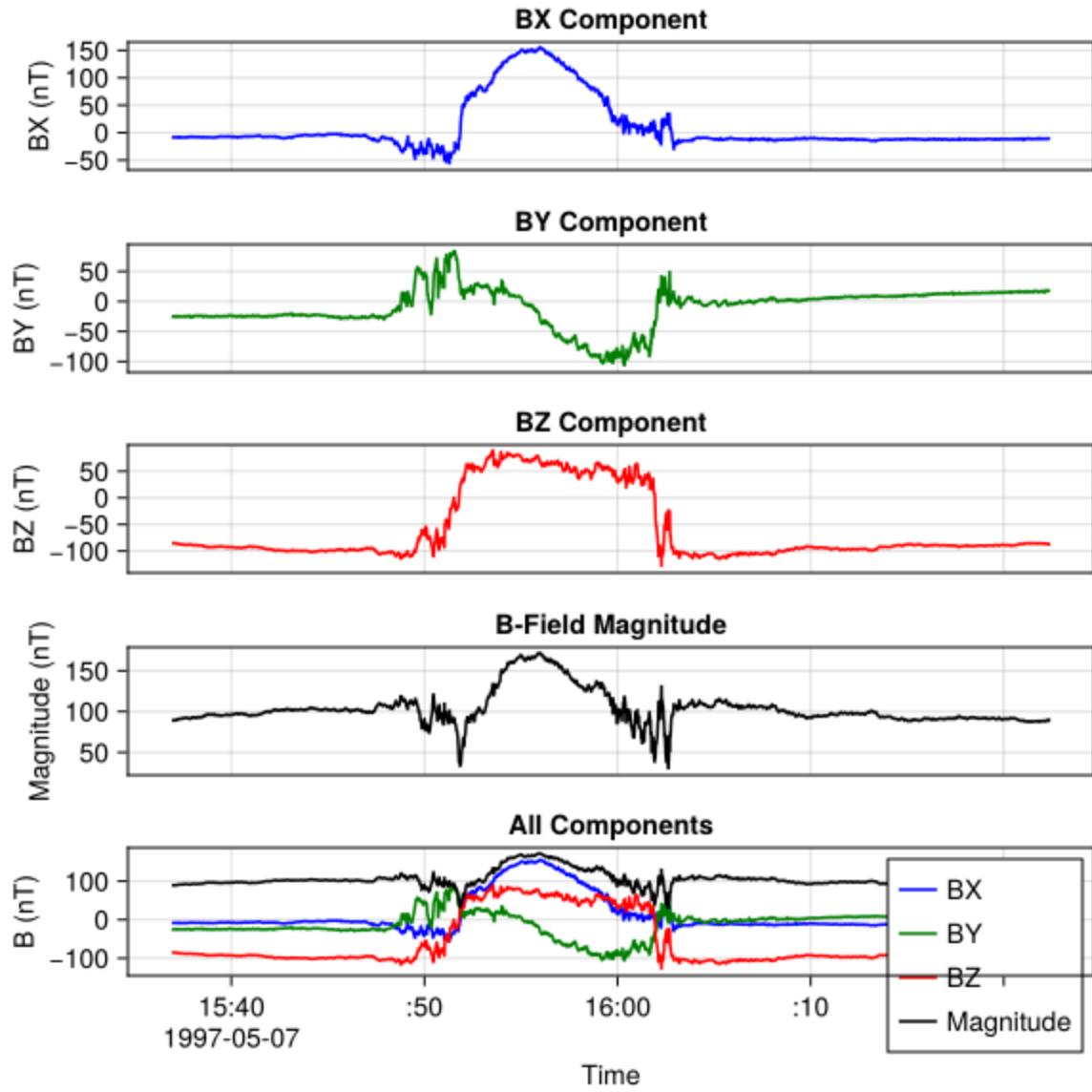
# Panel for B-FIELD MAGNITUDE
ax4 = Axis(fig[4, 1], title="B-Field Magnitude", xlabel="Time",
ylabel="Magnitude (nT)")
lines!(ax4, time, data[!, "B-FIELD MAGNITUDE"], color=:black)

# Panel for all traces
ax5 = Axis(fig[5, 1], title="All Components", xlabel="Time", ylabel="B (nT))
lines!(ax5, time, data[!, "BX"], color=:blue, label="BX")
lines!(ax5, time, data[!, "BY"], color=:green, label="BY")
lines!(ax5, time, data[!, "BZ"], color=:red, label="BZ")
lines!(ax5, time, data[!, "B-FIELD MAGNITUDE"], color=:black,
label="Magnitude")

for ax in [ax1, ax2, ax3, ax4]
    hidexdecorations!(ax, grid=false)
end

linkxaxes!(ax1, ax2, ax3, ax4, ax5)
axislegend(ax5)

fig
```



3 Voyager 2 Heliospheric termination shock

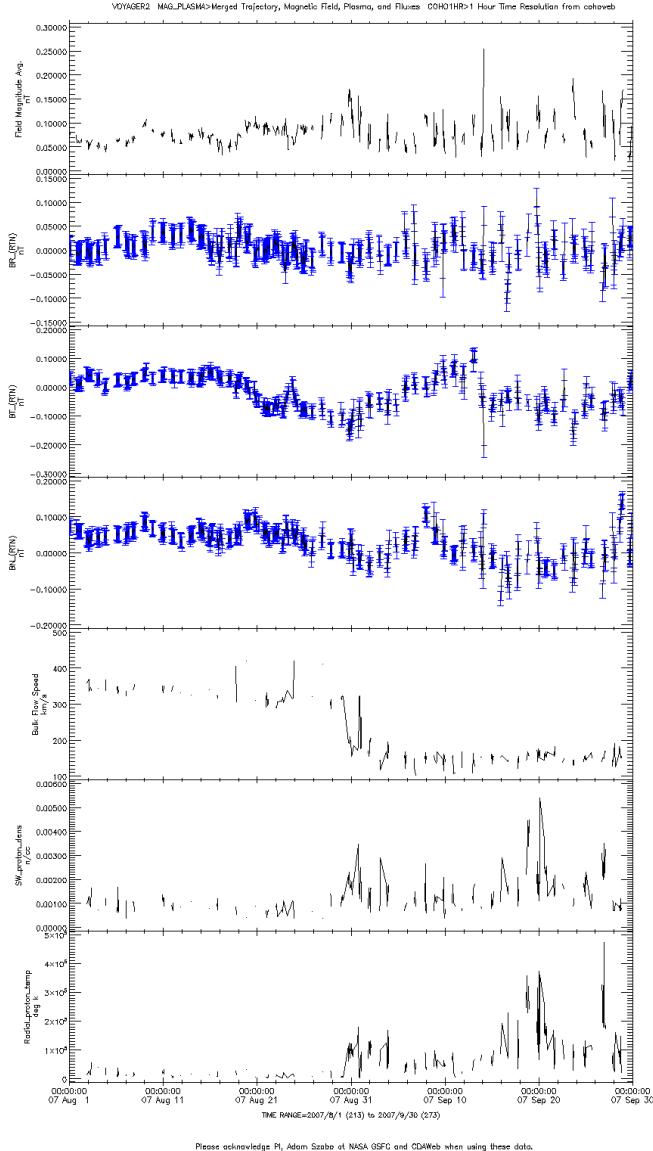
Voyager 2 crossed the Heliospheric termination shock and entered the heliosheath in Aug. 2007.

3.1 Plot and analysis

- [a] Plot the shock crossing in CDAWeb using their own plotting resources. In particular plot the total and RTN components of the magnetic field, flow speed, proton density N, and

temperature T. In a short paragraph explain: what is the RTN system and how did you create the plot? In a second paragraph explain if the changes in the above parameters are consistent with shock crossings.

The RTN (Radial-Tangential-Normal) coordinate system is a heliocentric coordinate system used to describe the position in relation to the Sun fixed at a spacecraft (or the planet): The R axis is directed radially away from the Sun, the T axis is the cross product of the solar rotation axis and the R axis, and the N axis is the cross product of R and T.



We utilize the combined COHOWeb dataset (VOYAGER2_COHO1HR_MERGED_MAG_PLASMA, https://cdaweb.gsfc.nasa.gov/mis/NotesV.html#VOYAGER2_COHO1HR_MERGED_MAG_PLASMA) [2]. The plot was generated using

“CDAWeb Data Explorer” by selecting the “Plot Data” option and choosing the appropriate data variable. We select time range from 2007/08/01 00:00:00.000 to 2007/09/30 00:00:00.000.

Around the end of August 31, we observe a significant decrease in bulk flow velocity accompanied by increases in proton density and temperature, corresponding to the shock crossing. Additionally, the magnetic field exhibits a slight increase. These changes are consistent with shock crossings, as shocks typically cause reductions in downstream flow velocity and simultaneous enhancements in plasma density, temperature, and magnetic field strength.

[b] What is the change in pressure, including dynamic pressure, across the shock (assume the crossing is along the shock normal)? To do this also ignore the electron thermal pressure (just use ion thermal pressure) and plot the quantity: $N^*V^2 + Pt$, where Pt is the sum of magnetic and thermal pressures. Do this using your own tools (not SPEDAS) after downloading the data from SPDF.

```
using CDAWeb
using SpaceDataModel: setmeta
using Unitful
using Unitful: μ₀, k, mp

t₀ = "2007-08-01"
t₁ = "2007-09-30"
dataset = CDAWeb.get_data("VOYAGER2_COHO1HR_MERGED_MAG_PLASMA", t₀, t₁)
N = DimArray(dataset["protonDensity"]) * u"cm⁻³"
V = DimArray(dataset["V"]) * u"km/s"
B = DimArray(dataset["ABS_B"]) * u"nT"
T = DimArray(dataset["protonTemp"]) * u"K"
```

```
↳ 1464-element DimArray{Unitful.Quantity{Float32, Ⓜ, Unitful.FreeUnits{(K,), Ⓜ, nothing}}, 1}
|----- dims
|
|   ↓ Ti Sampled{CommonDataFormat.Epoch} [2007-08-01T00:00:00, ...,
2007-09-30T23:00:00] ForwardOrdered Irregular Points
|----- metadata
|
|   CommonDataModel.Attributes{CDFDatasets.ConcatCDFVariable{Float32, 1,
DiskArrays.ConcatDiskArray{Float32, 1,
Vector{CommonDataFormat.CDFVariable{Float32, 1, CommonDataFormat.VDR{Int64}},
CommonDataFormat.CDFDataset{CommonDataFormat.NoCompression, Int64}}}},
DiskArrays.GridChunks{1, Tuple{DiskArrays.IrregularChunks}},
DiskArrays.Chunked{DiskArrays.SubRanges{DiskArrays.NoStepRange}}}, Nothing}}
with 11 entries:
  "FILLVAL"      => Float32[-1.0f31]
  "FIELDNAM"     => "Proton temperature"
```

```

"VALIDMAX"      => Float32[1.0f7]
"CATDESC"       => "Proton Temperature (calculated from thermal speed width
T=...
"VALIDMIN"      => Float32[0.0]
"DISPLAY_TYPE"  => "time_series"
"UNITS"         => "deg k"
"DEPEND_0"       => "Epoch"
"FORMAT"         => "f9.0"
"VAR_TYPE"       => "data"
"LABLAXIS"       => "Radial_proton_temp"

```

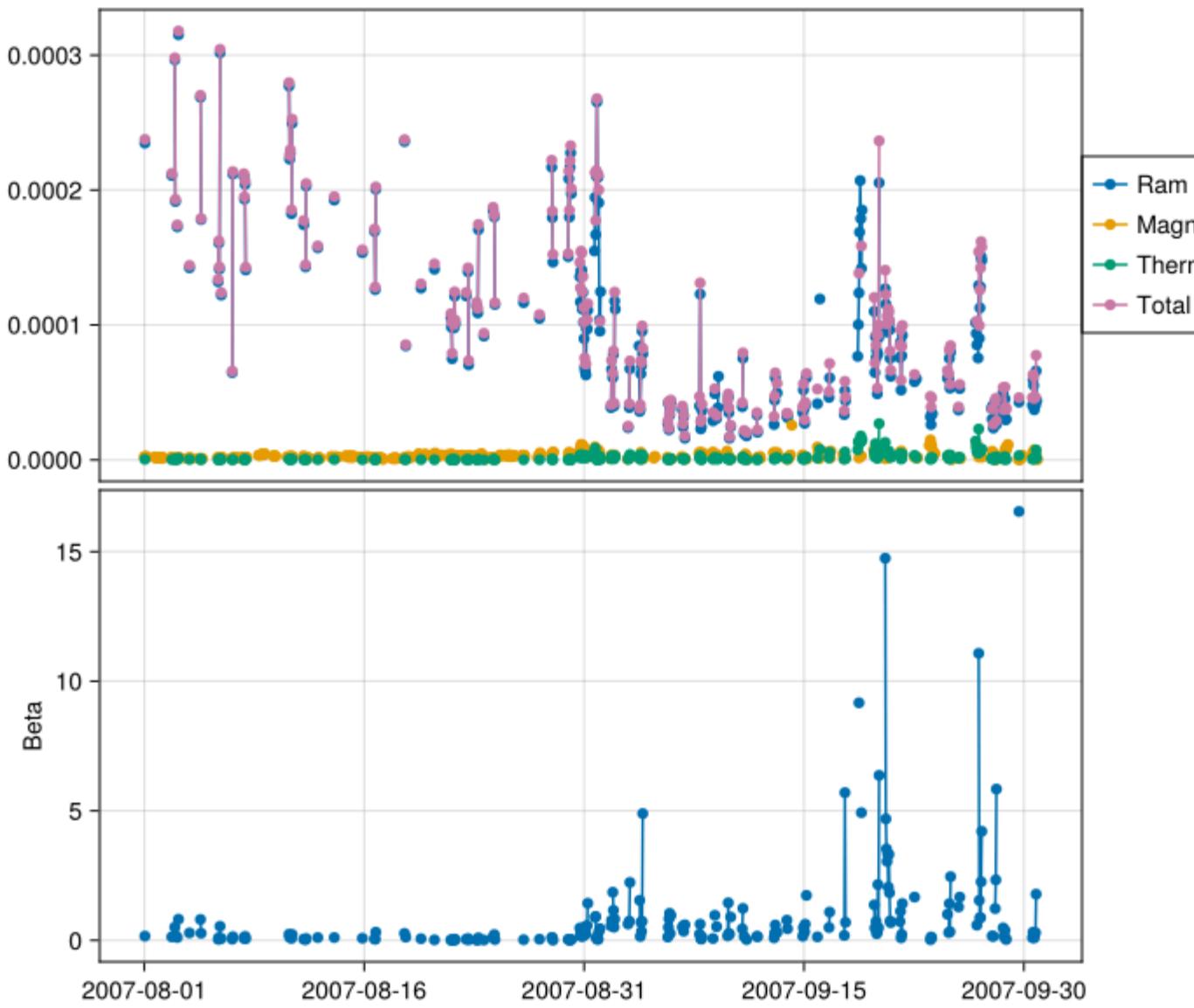
⋮ ?

```

# Calculate the pressure
pB = @. B^2 / μθ / 2 / 1u"nPa" |> NoUnits
pT = @. k * N * T / u"nPa" |> NoUnits
pRam = @. mp * N * V^2 / u"nPa" |> NoUnits
beta = pT ./ pB

pB = setmeta(pB, "LABEL_PTR_1" => "Magnetic Pressure")
pT = setmeta(pT, "LABEL_PTR_1" => "Thermal Pressure")
pRam = setmeta(pRam, "LABEL_PTR_1" => "Ram Pressure")
pressure = setmeta(pRam .+ pB .+ pT, "LABEL_PTR_1" => "Total Pressure")
beta = setmeta(beta, "UNITS" => "", "LABLAXIS" => "Beta")
tplot([[pRam, pB, pT, pressure], beta]; plottype=ScatterLines)

```



4 Archived code

Parsing the data into TimeSeries using DelimitedFiles and TimeSeries.

```
function load_ae_data(filename)
    meta = Dict(
        "unit" => "nT",
        "label" => "AE Index"
    )

    # Skip the header lines (first 14 lines)
```

```

data, header = readdlm(filename, skipstart=14, header=true)

# Convert date and time columns to DateTime
datetime = DateTime.(data[:, 1] .* "T" .* data[:, 2])

TimeArray(datetime, data[:, 4:7], header[4:7], meta)
end

function load_dst_data(filename)
    meta = Dict(
        "unit" => "nT",
        "label" => "Dst Index"
    )

    # Skip the header lines (first 17 lines)
    data, header = readdlm(filename, skipstart=17, header=true)

    # Convert date and time columns to DateTime
    datetime = DateTime.(data[:, 1] .* "T" .* data[:, 2])

    TimeArray(datetime, data[:, 4:4], header[4:4], meta)
end

ae_data = load_ae_data(ae_file)
dst_data = load_dst_data(dst_file)

```

Using a web service client to load the data (<https://kp.gfz-potsdam.de/en/data>) from json format into the TimeArray.

```

using JSON3

"""
Download 'Kp', 'ap', 'Ap', 'Cp', 'C9', 'Hp30', 'Hp60', 'ap30', 'ap60', 'SN',
'Fobs' or 'Fadj' index data from kp.gfz-potsdam.de

# Notes
- 'start_time' and 'end_time': date format 'YYYY-MM-DDThh:mm:ss'
"""

function load_Kp_data(start_time, end_time, index=:Kp)
    url = "https://kp.gfz-potsdam.de/app/json/?start=$(start_time)Z&end=$(end_
time)Z&index=$(index)"
    data = JSON3.read(download(url))
    datetime = DateTime.(data[:datetime], "yyyy-mm-ddTHH:MM:SSZ")
    TimeArray(datetime, Float64.(data[index]), [index], Dict("unit" => "",
"label" => string(index)))
end

```

```
kp_data = load_Kp_data(start_time, end_time)
```

Using a web service client to load the data (https://cdaweb.gsfc.nasa.gov/misc/NotesV.html#VOYAGER2_COH01HR_MERGED_MAG_PLASMA) from csv format.

```
using Unitful
using Unitful: μ₀, k, mp

register(DataDep("VOYAGER2_COH01HR_MERGED_MAG_PLASMA",
"""
    Dataset: VOYAGER2_COH01HR_MERGED_MAG_PLASMA
    Website: https://cdaweb.gsfc.nasa.gov/misc/NotesV.html#VOYAGER2_COH01HR_
MERGED_MAG_PLASMA
""",
"https://cdaweb.gsfc.nasa.gov/tmp/cweb_B6vad1PhkF/VOYAGER2_COH01HR_MERGED_
MAG_PLASMA_1663093.csv"
))

# Read the CSV file
VIM_file = readdir(datadep"VOYAGER2_COH01HR_MERGED_MAG_PLASMA", join=true)[1]
data = CSV.File(VIM_file; comment="#" ) |> DataFrame

allowmissing!(data)
data[!, "time"] = DateTime.(data."EPOCH_yyyy-mm-ddThh:mm:ss.sssZ", "yyyy-mm-
ddTHH:MM:SS.sssZ")
for c ∈ eachcol(data)
    replace!(c, -1.0e31 => missing)
end
dropmissing!(data)

N = data[!, "SW_PROTON_DENS_n/cc"] * u"cm^-3"
V = data[!, "BULK_FLOW_SPEED_km/s"] * u"km/s"
B = data[!, "FIELD_MAGNITUDE_AVG._nT"] * u"nT"
T = data[!, "RADIAL_PROTON_TEMP_deg_k"] * u"K"
```

Bibliography

- [1] K. Kivelson M.G., “Galileo Jupiter MAG Highres Ganymede Data 1997-05-07.” 2022.
- [2] N. F. Ness, J. D. Richardson, L. F. Burlaga, and N. E. Papitashvili, “Voyager 2 Hourly Merged Magnetic Field and Plasma Data.” NASA Space Physics Data Facility, 2023. doi: 10.48322/VE5T-HF15.