Classifying Spacecraft Magnetospheric Region with Ambient Plasma Sensing and Support Vector Machines

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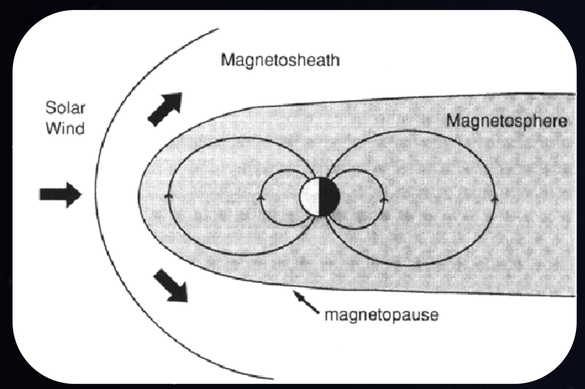
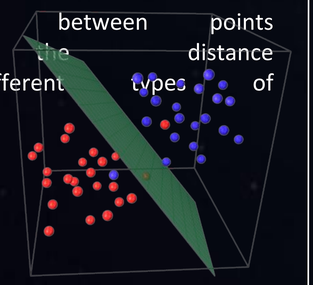
MMS and Regions of Earth's Magnetosphere

- Earth's magnetosphere can be partitioned into separate regions with unique properties
- The Magnetospheric Multiscale Mission (MMS) is a high earth orbit magnetospheric mission
- Flight calibration of MMS's in-situ plasma instrument (FPI) utilizes different plasma in different regions
- Calibration can be automated if we can automatically classify flight region between:
  - Magnetosphere
  - Magnetosheath
  - Solar Wind



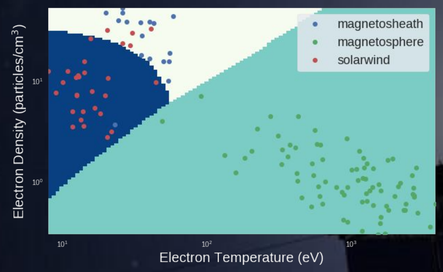
Model to Classify Region

- The Linear-kernel Support Vector Machine (SVM) is a classification model that learns from labeled examples
- Trained using hand-labeled examples from ambient plasma data.
- SVM fits a barrier between points that maximizes the distance Between the different types of points:
  - In 2D, this is a line
  - In 3D, this is a plane
  - In ND, this is a hyperplane



Input Data to Model

- Total dataset size of about 130 labeled points
- Electron and ion particles sensed from ambient plasma environment
- For each of ions and electrons:
  - Number density mean/variance
  - Vx, Vy, Vz, mean/variance
  - Scalar Pressure mean/variance
  - Scalar Temperature mean/variance



Note: Above shows classifier trained with only electron temperature and electron density, in order to plot in 2D. Actual performance is better.

Classification Process

- Algorithm produces a vector of weights over the input parameters for each of the classes.
- Dotted with input:
  - Very positive → likely in category
  - Very negative → unlikely in category
- Vector elements correspond to individual effect of input parameter on classification

Verification

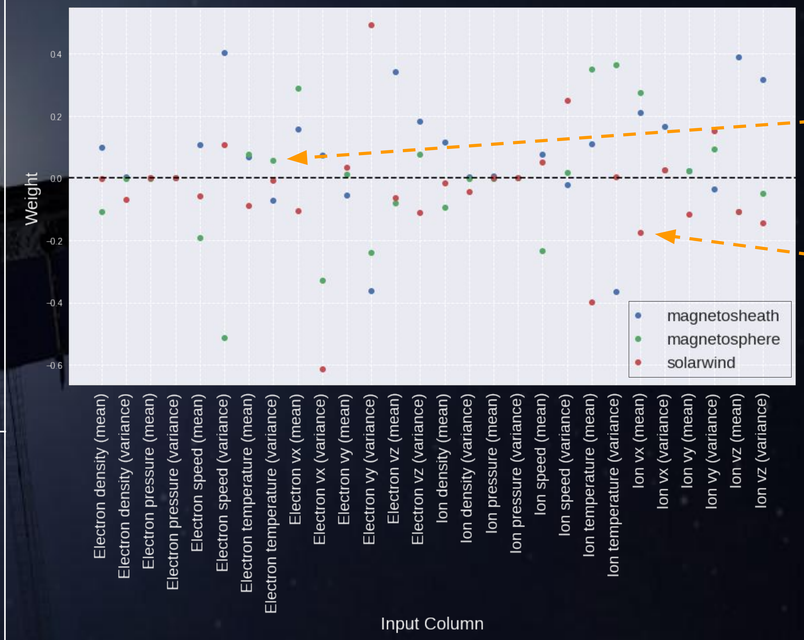
- >99% accuracy over 130 data points
- Validated additionally by hand

	true	pred	class	magnetosheath	magnetosphere	solarwind
10	1	1	magnetosphere	-0.799986	0.799999	-0.799998
7	2	2	solarwind	-5.623818	-5.013491	4.622020
19	1	1	magnetosphere	-294.090267	457.542774	-55.439900
52	0	0	magnetosheath	2.152429	-2.066394	-0.273101
47	1	1	magnetosphere	-14.154829	8.182520	-58.087549
128	1	1	magnetosphere	-33.184505	22.875081	-63.908483
2	1	1	magnetosphere	-316.628934	453.019628	-97.916499
14	1	1	magnetosphere	-219.382074	308.468979	-52.028575
75	2	2	solarwind	-2.994473	-1.170500	1.367496
76	0	0	magnetosheath	1.697446	-0.817595	-4.365473
117	1	1	magnetosphere	2.768682	6.620476	-39.650828
35	2	2	solarwind	-2.584998	-1.803797	0.793560
103	1	1	magnetosphere	-5.244971	18.983811	-56.354430

Input dotted with Weights

Interpreting Model Weights

- Linear SVM weights are interpretable and express how much the input variable is for or against that category
- For general kinds of SVMs (non-linear), weights are not interpretable
- This interpretation agrees with prior knowledge of the magnetospheric physics (see below)
- Weights scale down as natural magnitude of variable scales up, and vice versa



High ion temperature is **++** for magnetosphere, but **--** for magnetosheath and solar wind

High Earth-Facing ion Velocity Component is **++** for solar wind, but **--** for everything else

Conclusion

- A simple linear algorithm and minimal code was able to provide robust predictive powers when paired with the right data
- Provided robust automation where human-in-the-loop was previously required
- Weights learned by algorithm agree with our knowledge of the physics

Acknowledgements

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