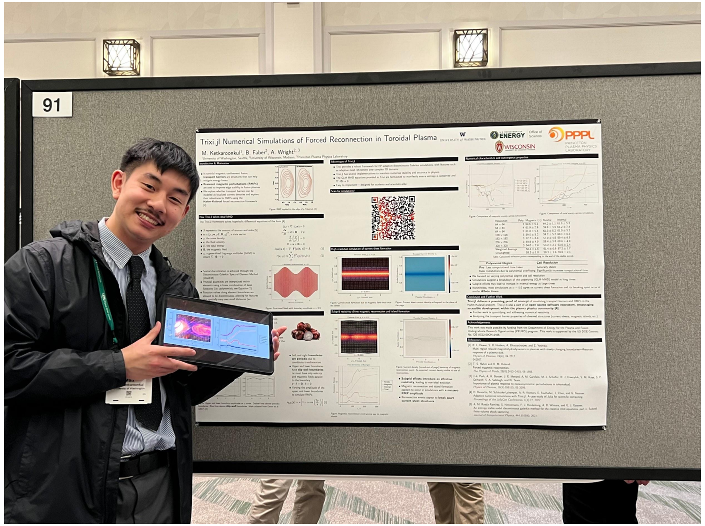
2024 GSS Flash Talks 1 (7/30/24)
Madelyn Cassens
Brian Behrens
Estêvão Gomes
Matt Ketkaroonkul
Michael Richardson
David Martinez
Alexandra Lachmann
Annika Zettl
Enrique Rojas
Augusto G-Guerrero
Mason Haberle
Ajay Krishnan

PPPL Flash Talk

Matt Ketkaroonkul

A little about me

- UofWA alum
- SULI/PFURO alum
- Going to UCLA
- Outreach w/ Computational Research Access NEtwork (CRANE)
    - Teaching computational plasma physics to underrepresented students
    - **We have collab'ed with the PPPL!**
- I like to read, hike, crochet, video games



CRANE

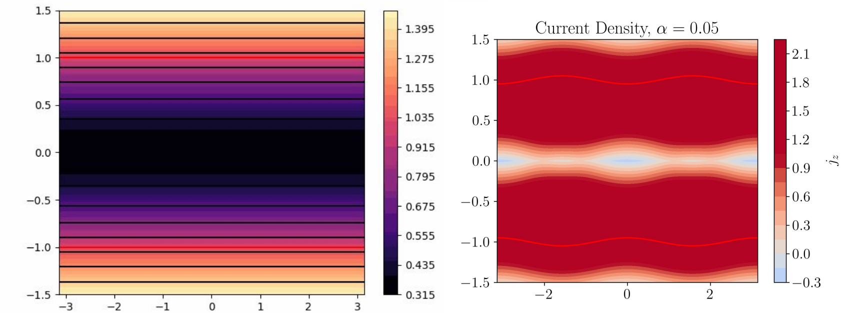
COMPUTATIONAL RESEARCH ACCESS NETWORK

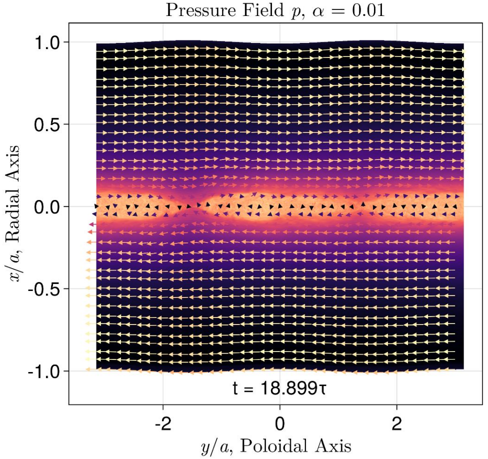
Research Interests & Experience

- Remote work w/ Prof. Adelle Wright's group @ UW Madison
- MHD Theory and Simulation

Research, continued

- Localized currents evolution
  - In response to magnetic field perturbations
  - Alfvén, resistive timescales
  - Magnetic island structures
  - Reconnection events
- Investigating non-linear, higher order solutions of magnetic field
  - Inspired by the work of Prof. Dewar [a]
- Hope to learn more about math behind stellarators this week!





[a] Dewar et al. (2017), Hahm and Kulsrud (1985)

Ongoing Design of Doppler Reflectometry for use on the Helically Symmetric eXperiment (HSX)

Michael Richardson[1], Xiang Han[1], K.M. Likin[1], H. O. M. Hillebrecht[1], T. Gallenberger[1], C. Seyfert[1], N. Maruschenko[2], P. Aleynikov[2], B. Geiger[1], B. Knowles[1], R. Wagner[1] and the HSX team

[1]HSX Plasma Lab, University of Wisconsin-Madison
[2]Max-Planck Institute for Plasma Physics – Greifswald

This work was funded by the Department of Energy (DoE) under grant number DE-FG02-93ER54222

Outline

- Doppler Reflectometry, the **H**elically **S**ymmetric e**X**periment, and you
- Design Constraints to the system
- Rotatable Mirror design
- Additional Planned Upgrades to the Reflectometry System
- Conclusions

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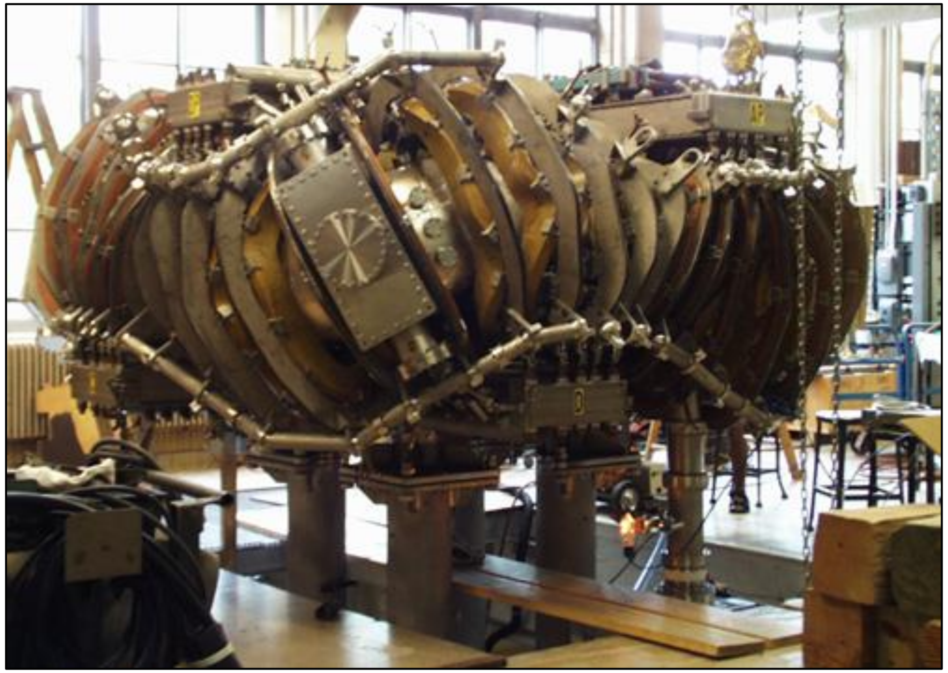
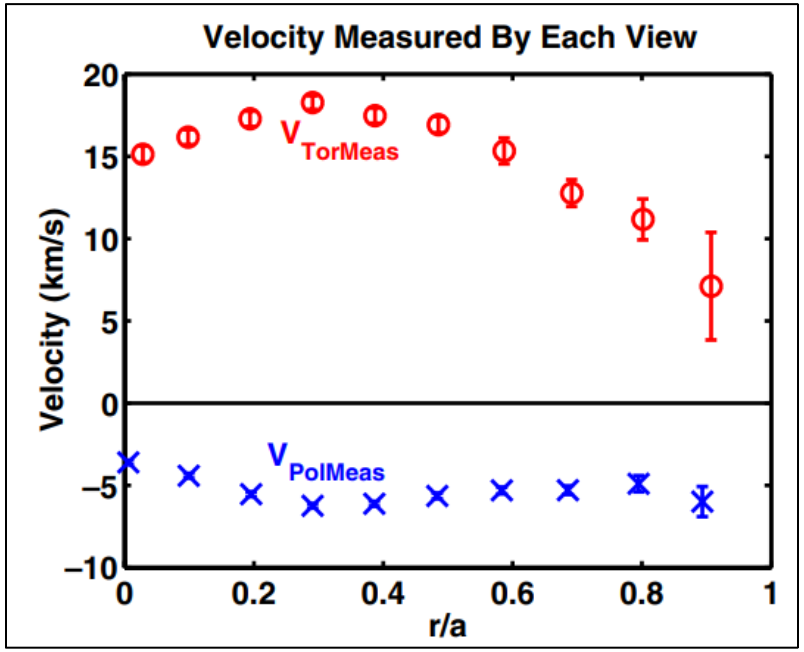
HSX Important Parameters

- HSX:
  - Major radius: 1.2 m
  - Minor radius: 0.12 m
  - Shot time: 50 ms
  - Peak densities $\sim 0.8\ e19\ m^{-3}$ (1 T)
  - B on axis = 1 T
    - Can operate at 0.5 T
    - Upgrade to achieve 1.25 T in progress
  - Fluctuation measurements are of interest in HSX
    - Compare to CHERS measurements of velocities in HSX

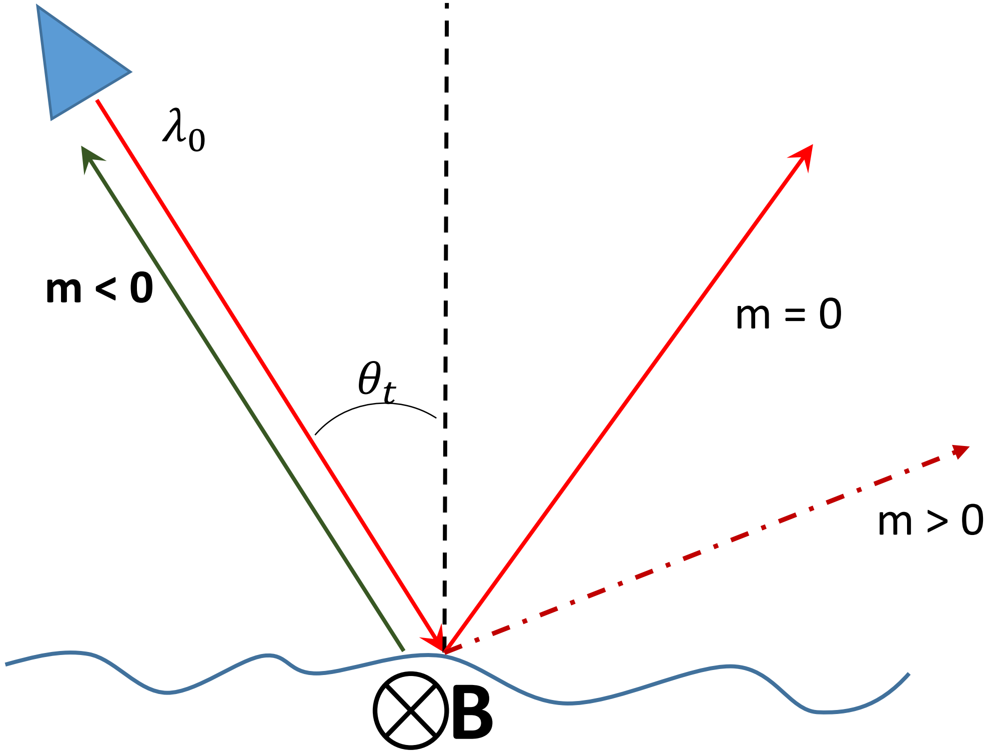




A. Briesemeister Plasma Phys. Control. Fusion (2013)

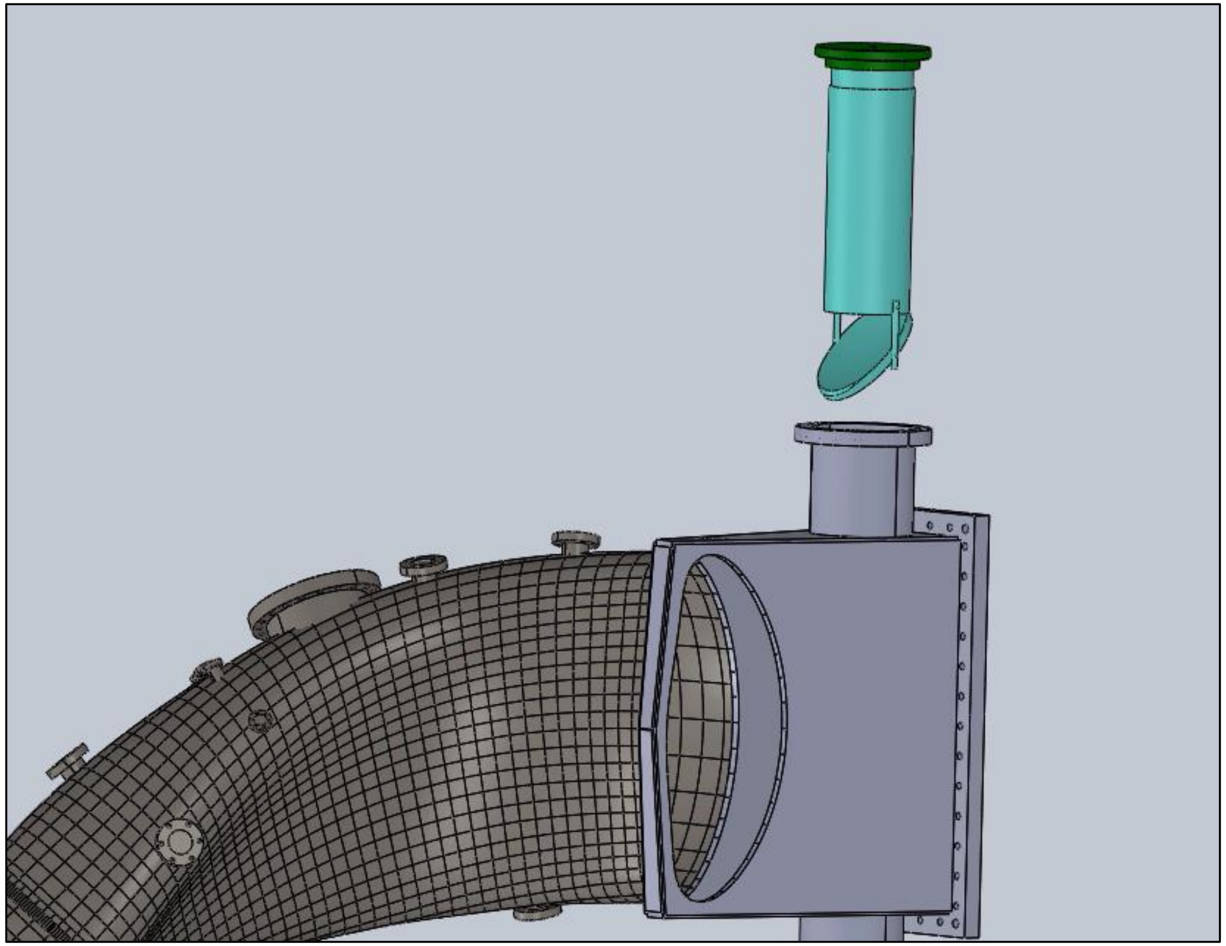
Doppler Reflectometry, Why and How?

- Technique for approaching density fluctuation analysis.
- A microwave is tilted (poloidally) w.r.t. the incident plasma surface
  - (oriented either with E || B for O-mode, or E ⊥ B for X-mode)
- Uses the Bragg condition at -1st order to obtain fluctuation wavenumber
  - $k = 2k_0 \sin(\theta_t)$
- Doppler shift in beam can be used to estimate rotation velocity $\vec{u}$
  - $\omega_D = \vec{u} \cdot \vec{k} \approx u_\perp k_\perp$



Current HSX Reflectometry System

- Current Setup has been described in detail in the previous talk
- Key parameters to keep in mind
  - – Monostatic antenna
  - – Operable in either O or X-mode orientation
    - Requires machine up-to-air to rotate antenna system
  - – Switch-controlled VCO sources operable between **14.5 – 25.5 GHz**
  - – Digitizer with **8 Msa/s** digitization
  - – Installed in HSX box port A alongside Interferometry diagnostic



Outline

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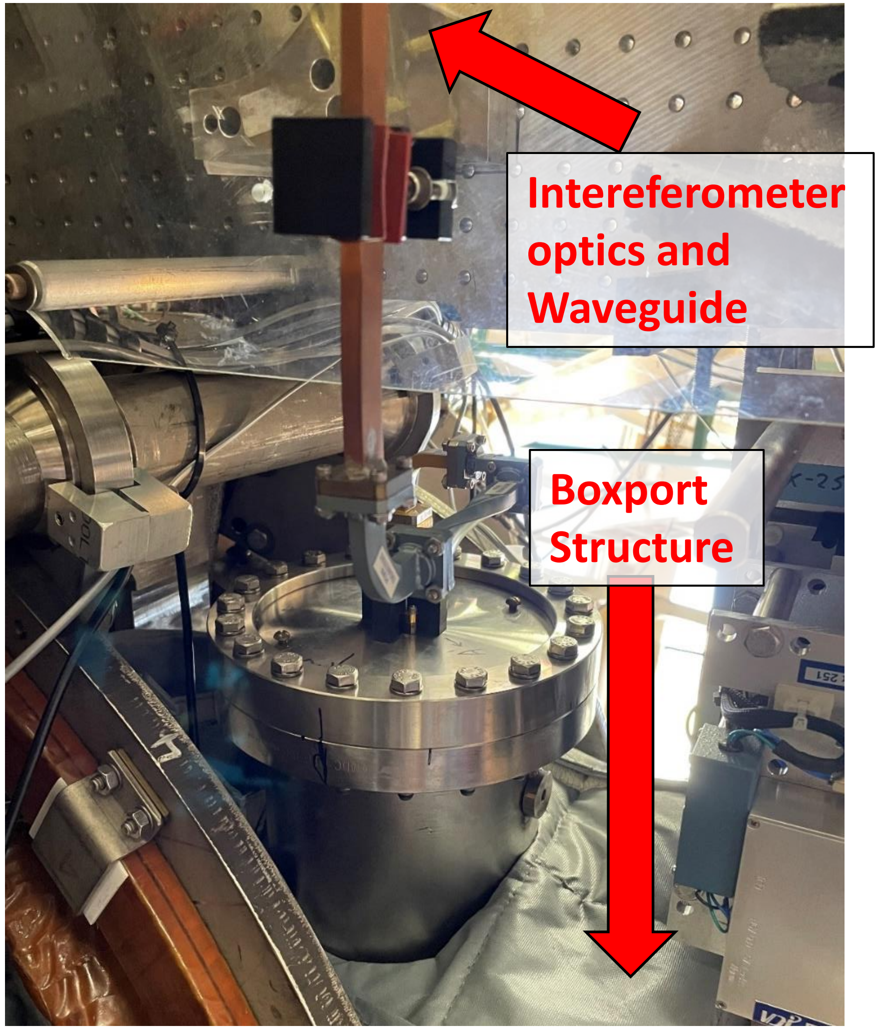
System Requirements

- Tilting of mirror requires control of the structure within vacuum
- As little impact on beam pattern as possible
- Access to the system is currently limited by space within the boxport
  - Reflectometry shares a boxport with Interferometry…
  - Current motor designs share flange with antenna/mirror support structure



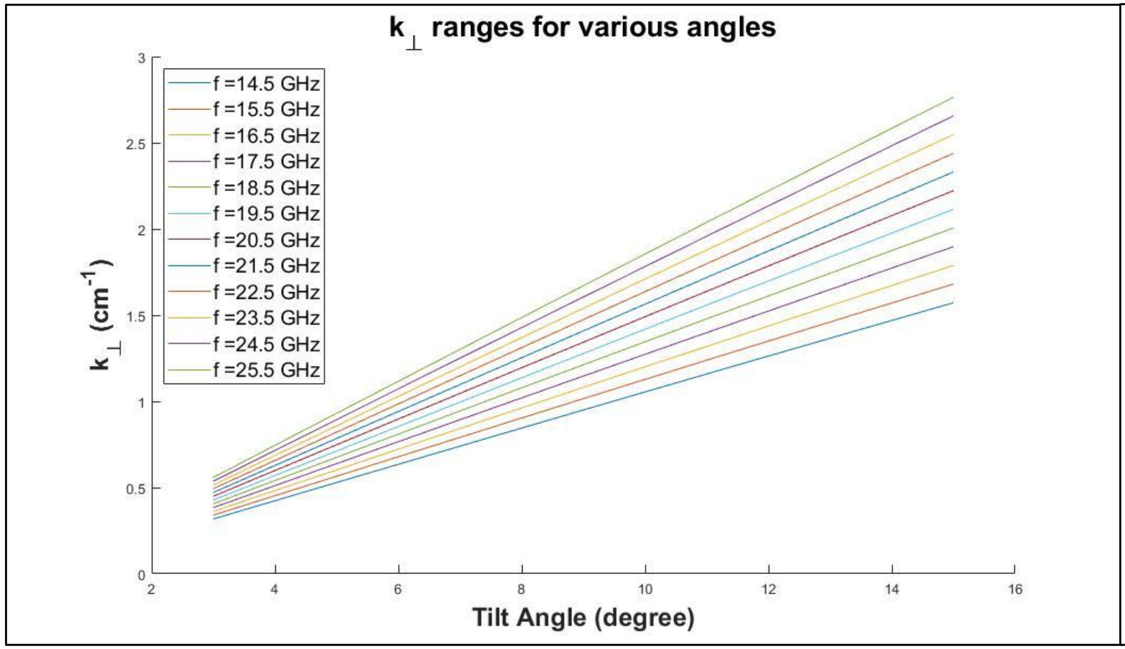
System Design Goals

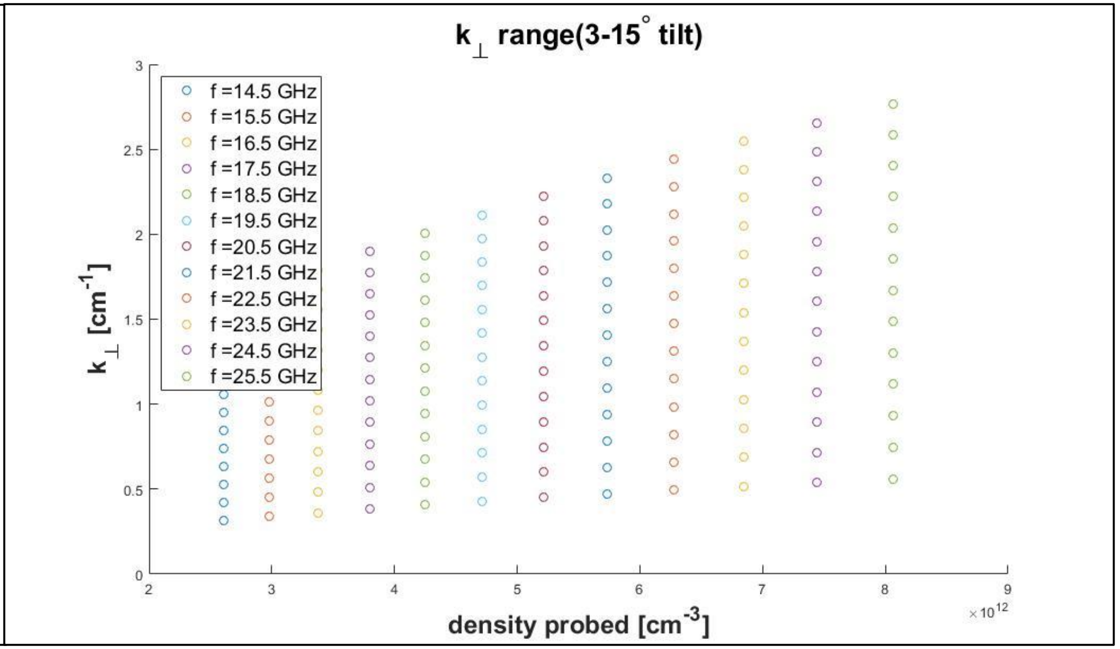
- Tilt Resolution
  - Want to rotate up to 15 degrees with good precision for $k_\perp$
- Controllability between shots
  - Remote motor control preferable
  - 8 minute inter-shot time
- Flexibility between O and X mode
  - Allows for ability to measure density range expected in 0.5, 1, and 1.25 T regimes
    - Currently, X-mode scans 0.5 T plasma better, O-mode scans 1 T better
    - While not yet implemented, 1.25 T is predicted to increase density by a factor of ∼3x
- Ability to continue operation as profile/stepped frequency device when needed

Estimated Parameter Range ($k_\perp$)

- Initial k-range estimated for 15 degree rotation
  - Ray-Tracing will provide more accurate incidence angle ranges (ongoing)

QHS 1T estimates	Core (r/a = 0)	Mid-radius (r/a ~ 0.4)	Edge (r/a ~ 0.8)
$n_e\ (m^{-3})$	8 e18	3 e18	1 e18
$\rho_s\ (cm)$	0.592	0.323	0.131
$k_\perp \rho_s$ est. range	< 1.48 (O), < 0.88 (X)	< 0.5 (O), N/A (X)	Not (yet) accessible by either orientation





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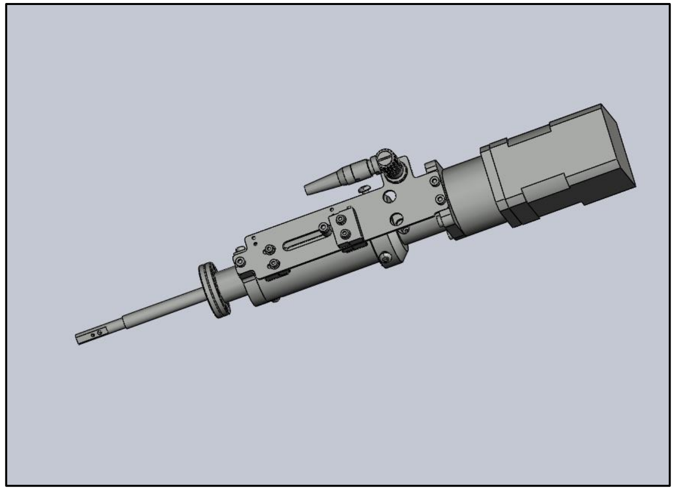
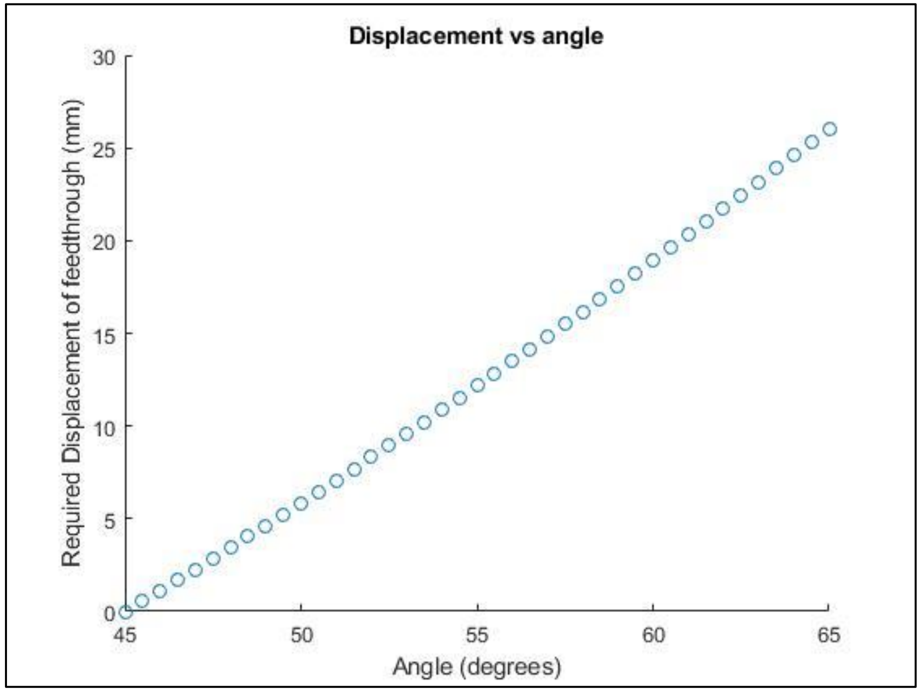
Rotatable Mirror Design

- Uses linear feedthrough to control mirror position with motor to 1 μm precision (1)
  - Corresponds to 0.001 Degree precision
  - Neutral 45° position of mirror can be one extreme of the stepper for ease of standard profile or stepped-frequency operation
  - With a modest 25 mm stroke feedthrough, 19 degrees of tilt can be achieved.
  - Calibration curve estimated from geometry of actuation setup
    - In-lab calibration necessary before installation

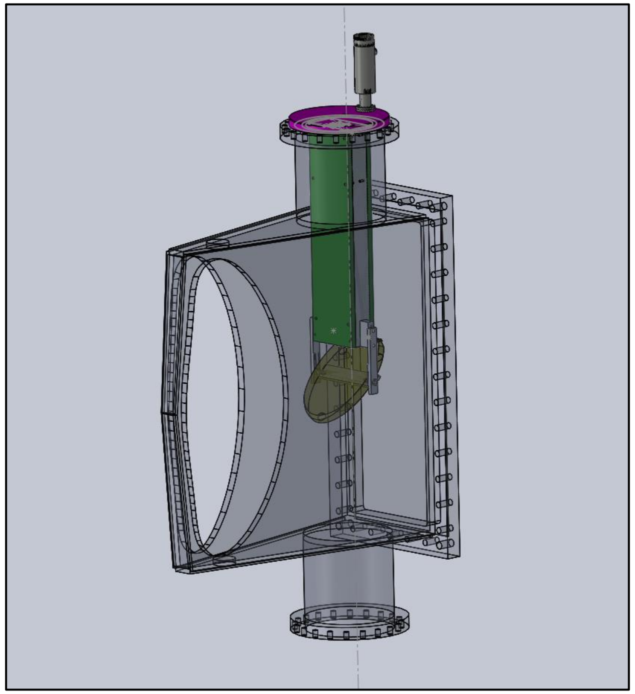


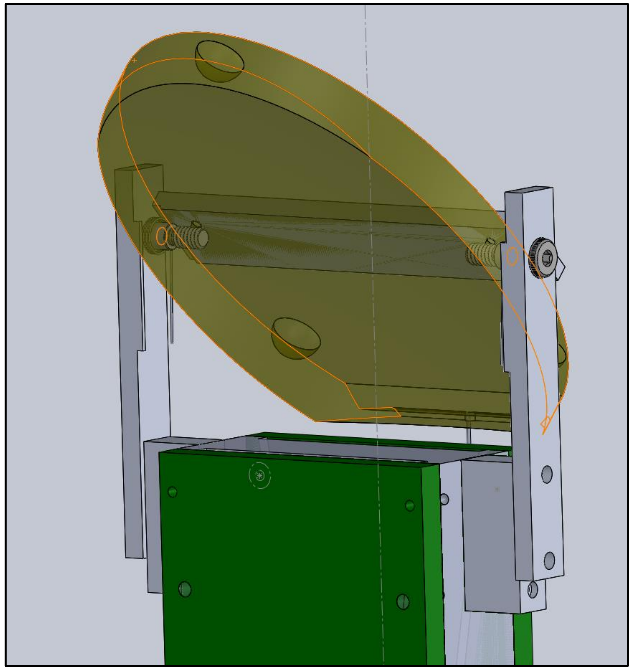


Kurt J. Lesker, Linear Bellows Drive, 25 mm stroke

Rotatable Mirror Design

- Current Design removes cylindrical support structure
  - Mirror is supported by a new antenna block, and tilted by a torsion spring at the pivot
- Currently shown in X-mode orientation, supports for O-mode operation are feasible, retaining the flexibility of the original device.





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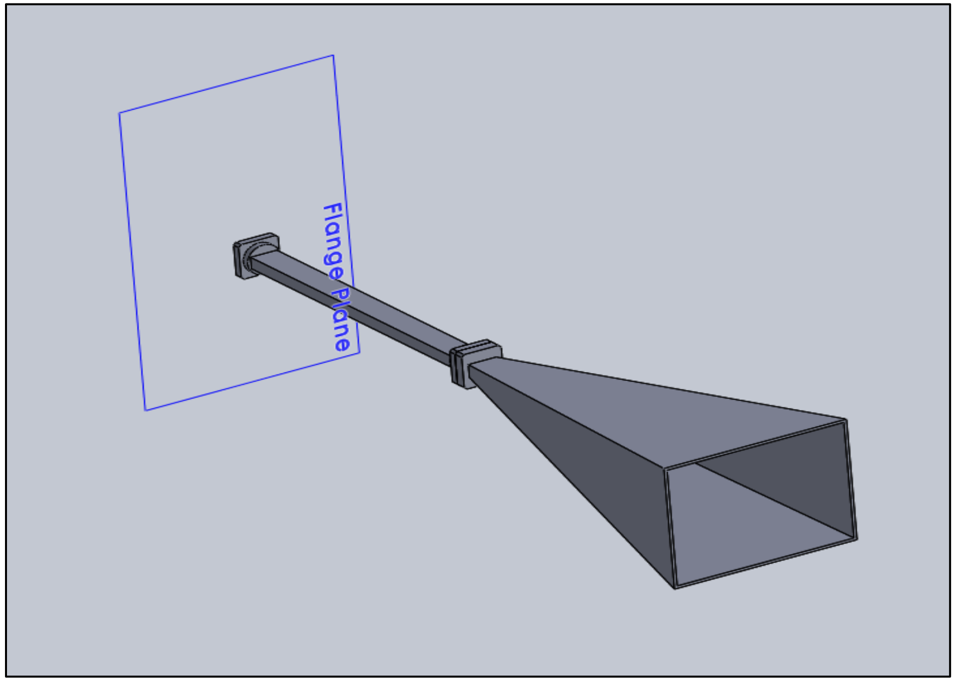
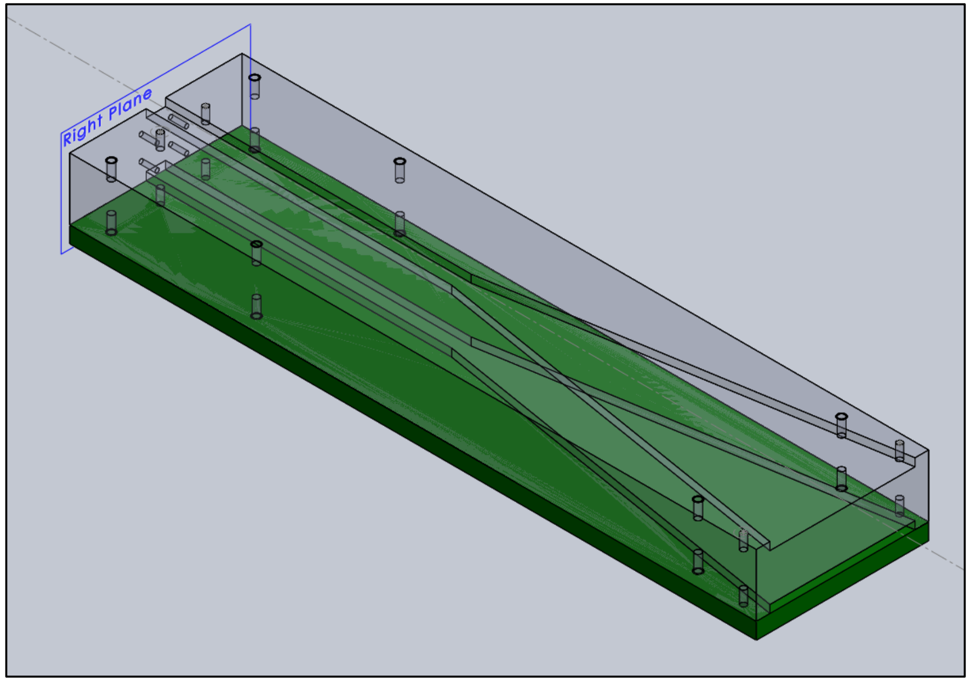
Bistatic Antenna Setup

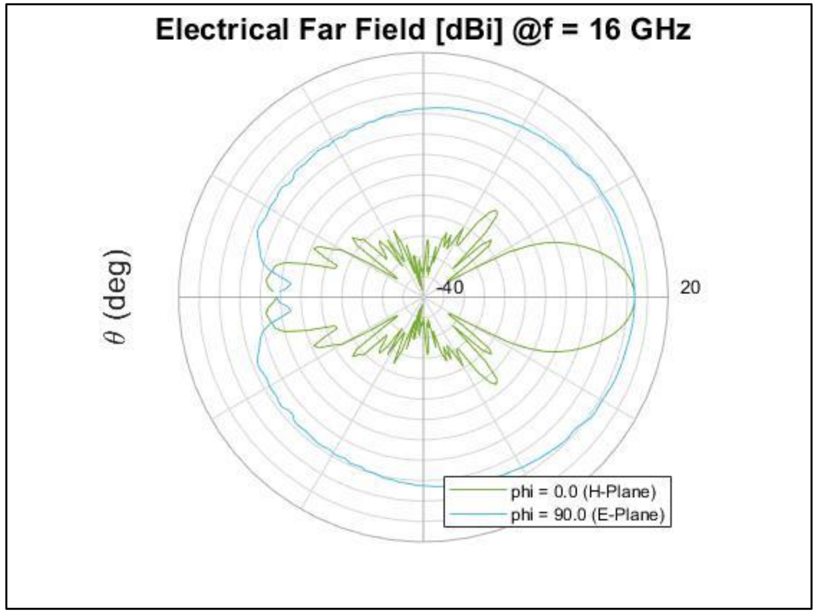
- Investigating Bistatic antenna solution for the reflectometer.
  - Two H-plane sectoral antennae placed 30mm apart rather than one horn antenna
  - Should improve the signal-to-noise ratio of the device
  - Initial design (lower right)

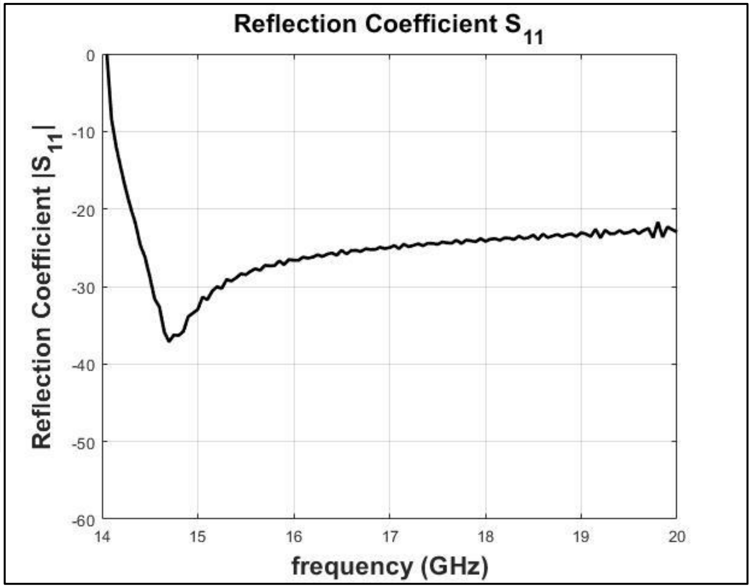


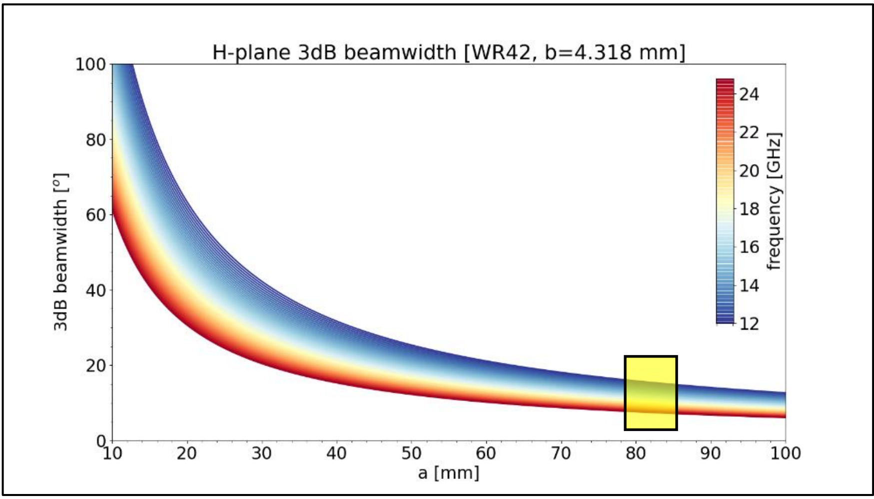


Bistatic Antenna Setup (Beam Simulations)

- Investigating Bistatic antenna solution for the reflectometer.
  - Sectoral antenna beam pattern and directivity simulated using openEMS software
  - Antenna width at mouth slightly reduced (85 mm -> 80 mm)
    - 3dB Beamwidth estimated not to change significantly because of this







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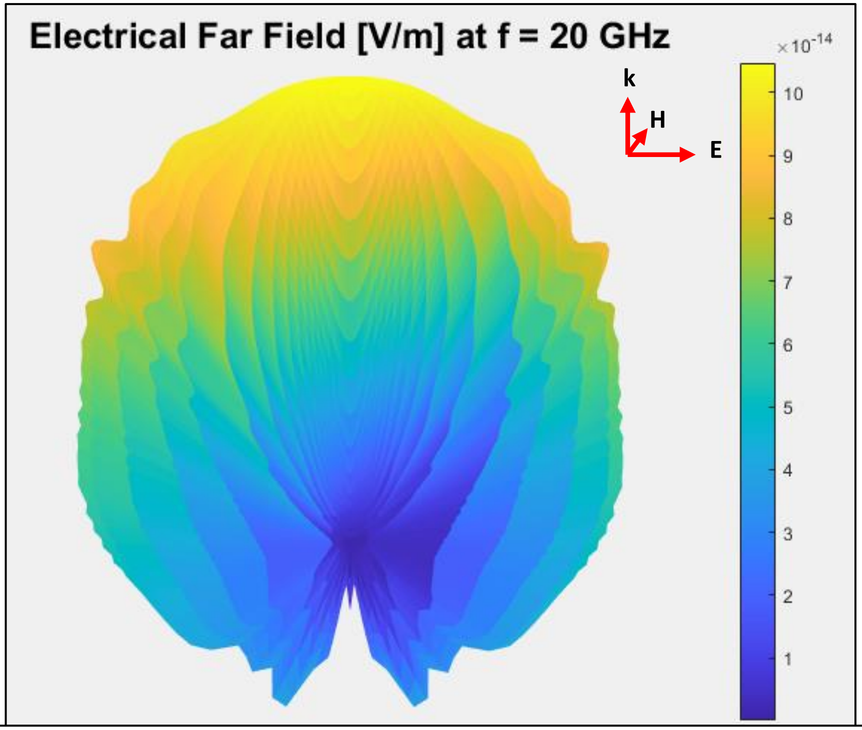
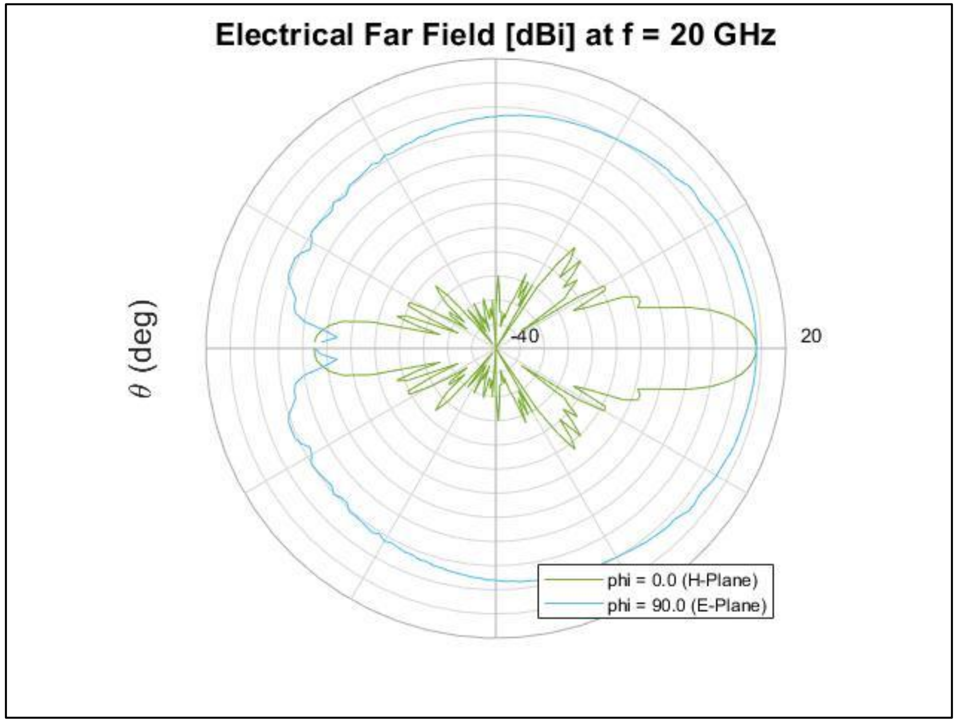
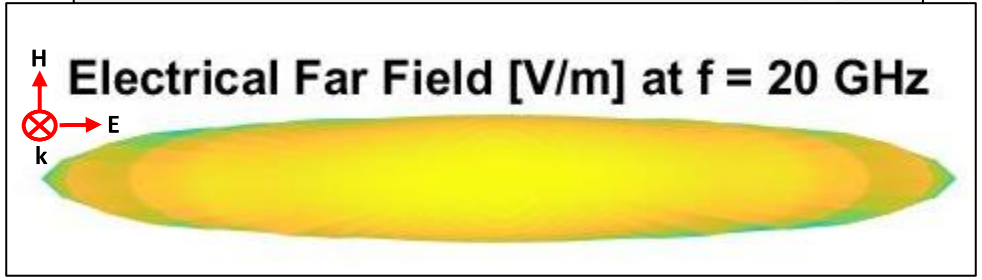
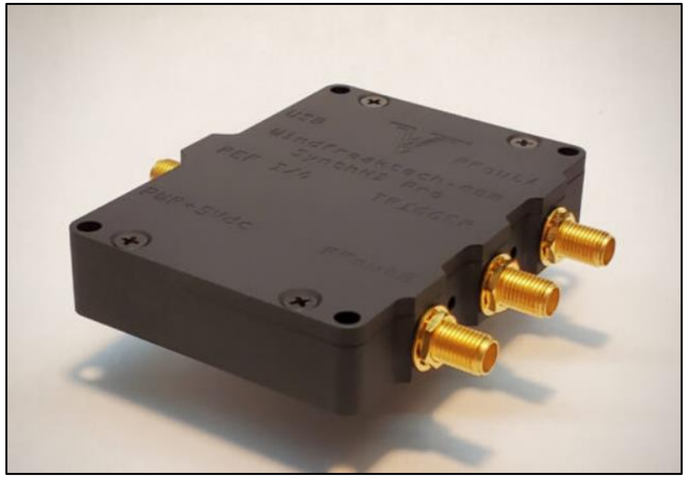


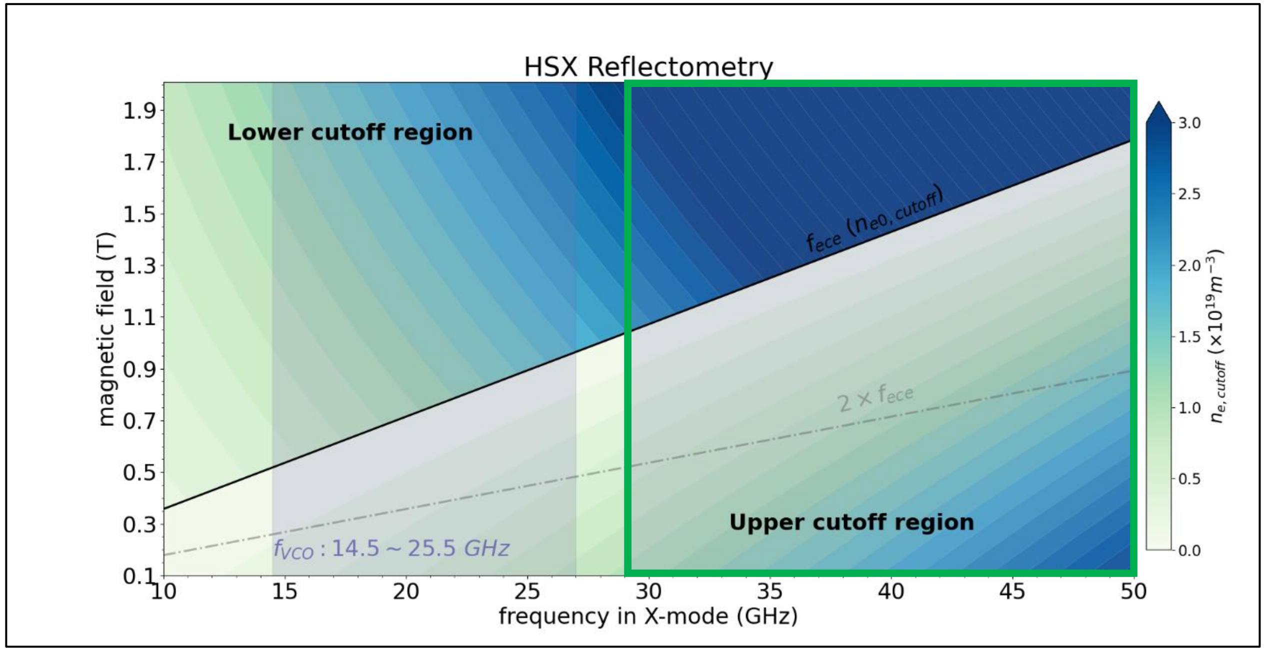




Frequency Sources, Frequency Doubling

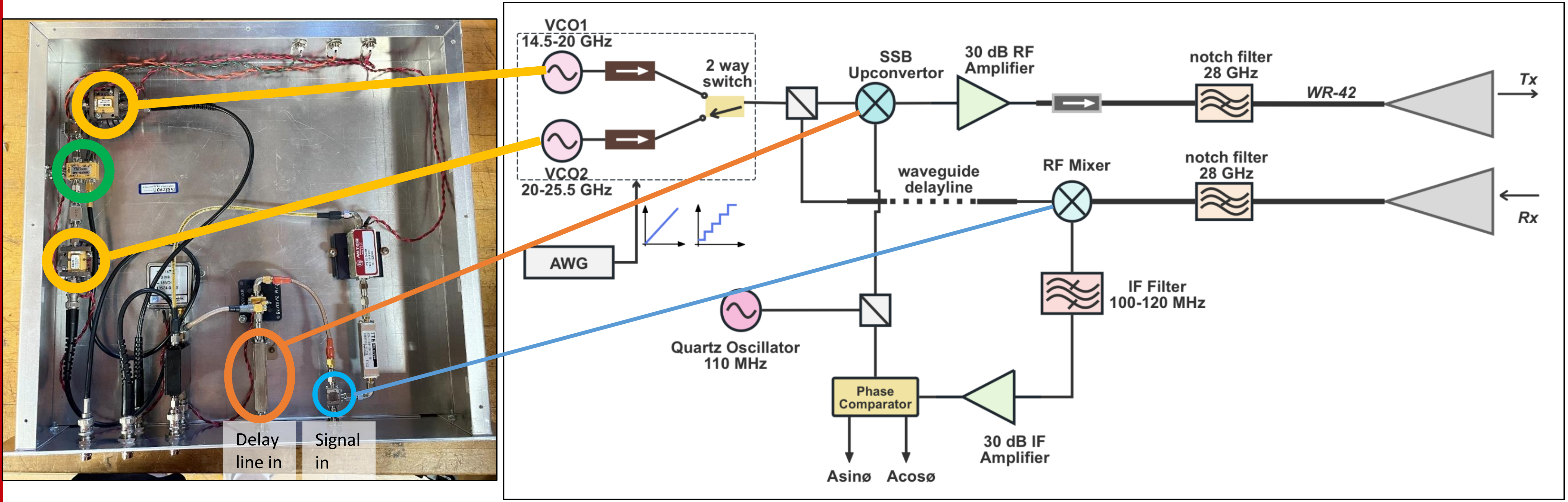
- Current setup employs two VCOs that can scan between 13-25.5 GHz (Waveguide cutoff limits operation below 14.5 GHz)
- Two current avenues for upgraded operation
  - Invest in new low-noise Frequency source capable of 10MHz – 25 GHz operation (such as a SynthHD Pro signal generator)
  - A Frequency doubler to allow for higher frequency band operation in upgraded 1.25 T plasmas
    - Accessible range -> 14.5 ~ 50 GHz
  - Improved density range:
    - $\mathrm{n_e} < 2.5 \times 10^{19}\ m^{-3}$ (X-mode)
    - $2.7 \times 10^{18} < n_e < 3.1 \times 10^{19}\ m^{-3}$ (O-mode)





Microwave setup

- **SSB** upconverter output previously added noise before mixing with returning signal, reducing the achievable SNR
- Reroutes waveguide-delayed signal directly to **RF mixer**
- Addition of frequency doubler may require new mixer in the future



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Summary & Conclusions

- Design of a Doppler Reflectometer is underway for installation on HSX
- A Rotatable Mirror is being designed for control and access within a single flange
  - The new design will preserve the flexibility of the previous system while giving access to new regimes of measurements
- Initial estimates of key parameters have been made
  - Modelling in the near future will lend specificity to parameter space
- Upgrades to the antenna and microwave system are also in consideration
- We are happy to hear feedback and advice on how to best continue and execute this project!

David Martinez-del-Rio

Converse KAM

WARWICK

University of Warwick

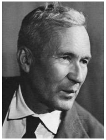
Mathematics Institute

Robert MacKay

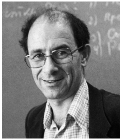
Nikos Kallinikos

KAM Theory

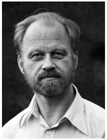
Goal: Provide sufficient conditions for the existence of invariant tori of given class in Hamiltonian systems.



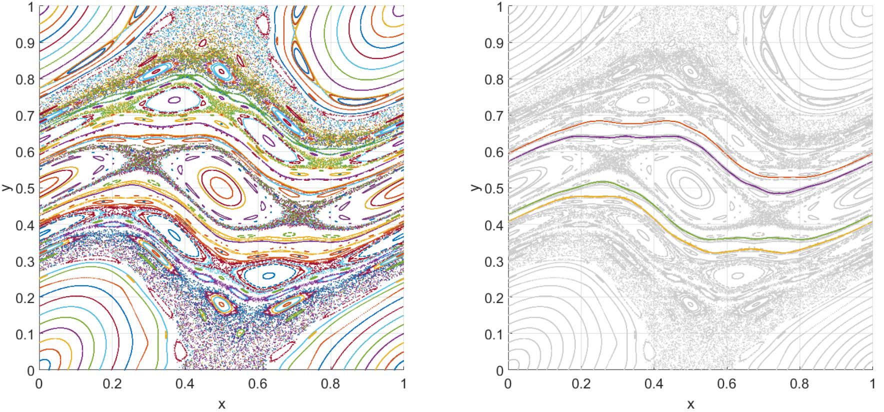
Kolomogorov
(1903-1987)



Arnold
(1937-2010)



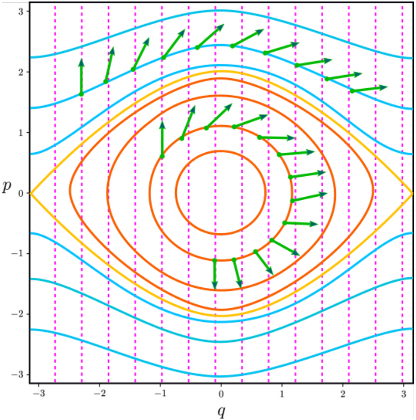
Moser
(1928-1999)



Converse KAM

Goal: determine regions through which no invariant tori of given class pass.

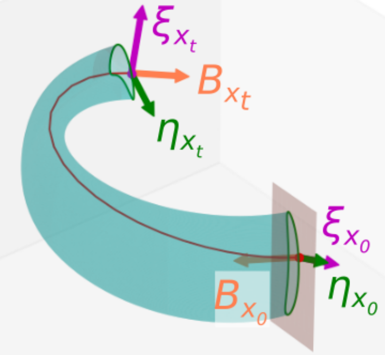
- Herman (1983).
- Mather (1984).
- MacKay & Percival (1985).
- MacKay, Meiss, Stark (1989).
- MacKay (1989).
- White (2012).
- MacKay (2018).
- Duignan, Meiss (2021).
- Kallinikos, MacKay, Syndercombe (2022).
- Kallinikos, MacKay, **DM** (2023).

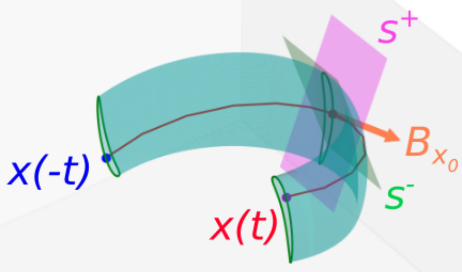


Converse KAM formulations

Direct formulation[1]

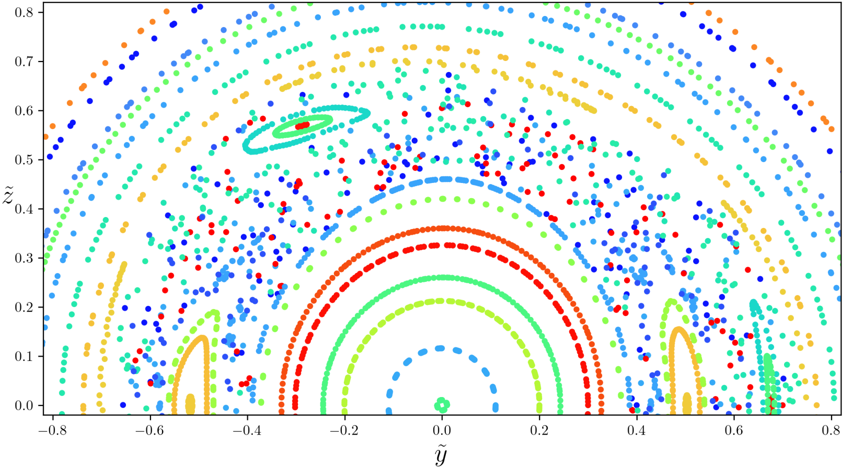
Conefield formulation[2]



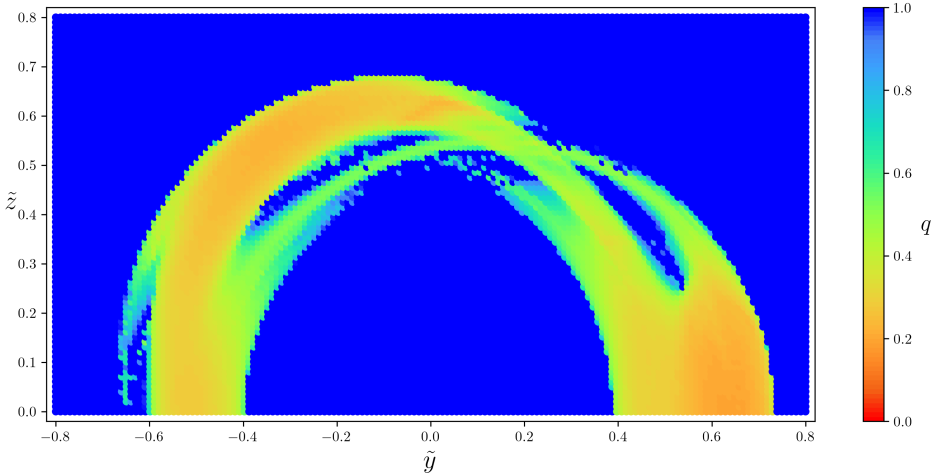


[1] N Kallinikos, RS MacKay, **DM** 2023 *PPCF* **65** 095021.
[2] RS MacKay, **DM** *In preparation.*

Converse KAM results



Converse KAM results



Goal: Apply Weighted Birkhoff Averaging (WBA) to gauge energetic particles interaction with electromagnetic perturbations.

Motivation:

- In the case of multiple Alfven waves or perturbation to QS, Poincare maps are higher dimensional and are difficult to interpret.
- Looking for alternatives to Poincare plots
  - The accuracy of & relative time to WBA convergence distinguishes between integrable and chaotic flows.

Conditions we are evaluating:

- Varying strength of field
- Varying initial conditions of a passing EP (s, chi coordinates) for overlapping islands

Looking for distinctions in periodic, quasi-periodic, and chaotic behavior

$$WBA(p_\zeta) = \frac{1}{T}\int_0^T Ce^{-\frac{1}{\frac{t}{T}(1-\frac{t}{T})}} p_\zeta(t)\, dt$$

Evaluated guiding center motion in simple magnetic field with a varying perturbation:

$$B = B_0(1 + \bar{\eta} r \cos(\theta - N\zeta)) \\ + B_{0z}\cos(m\theta - Nn\zeta)$$

Calculated the WBA of EP momentum across many convergence times, and calculate the digit accuracy

$$\text{digit accuracy}_T(p) \equiv -\log_{10}\frac{|WBA(p)\,(t_{T/2}) - WBA(p)\,(t_T)|}{\frac{1}{2}\,|WBA(p)\,(t_{T/2})| + |WBA(p)\,(t_T)|}$$

as a measure of integrability. [1]

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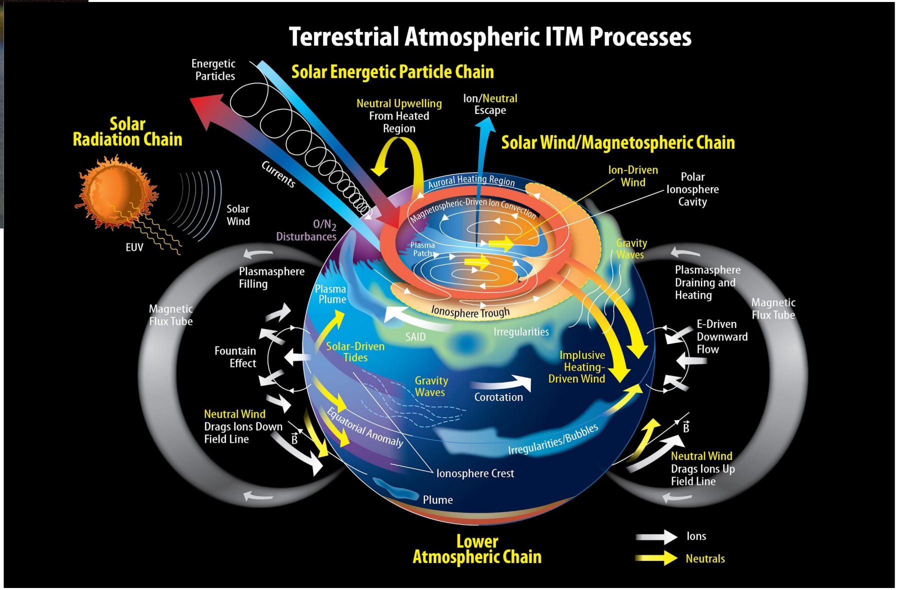
[1] Duignan, Meiss. Distinguishing between regular…, *Physica D: Nonlinear Phenomena*, 2023

Introduction.



Introduction.

PONTIFICIA
UNIVERSIDAD
CATÓLICA
DEL PERÚ

. Undergrad.

Radio Observatorio de
JICAMARCA
Radio Observatory

. Research assistant.

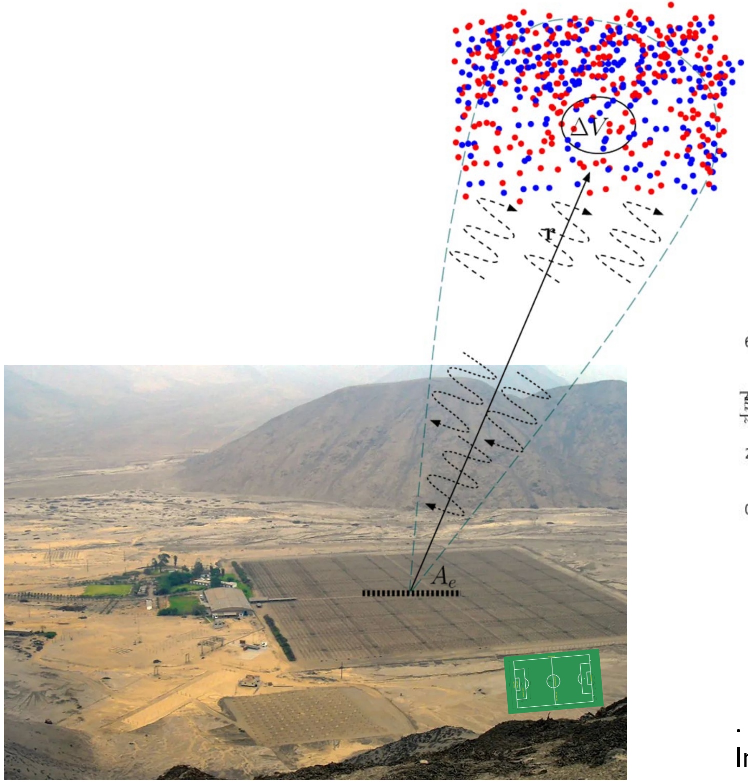
Cornell University

. PhD/Postdoc.

MIT
HAYSTACK
OBSERVATORY

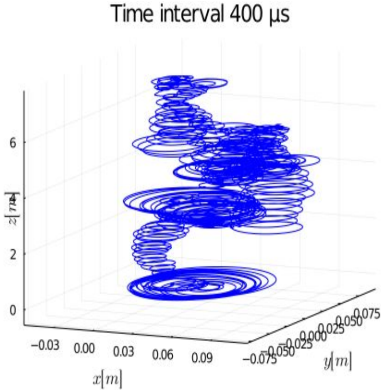
. Research Scientist.

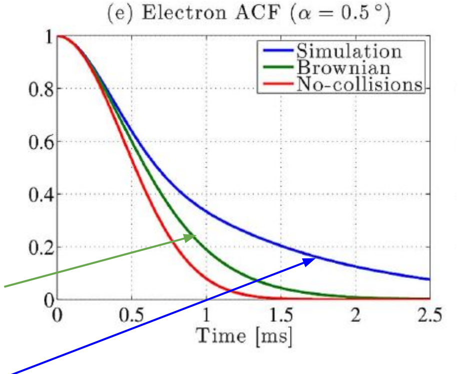
Collective Thomson Scattering and Coulomb collisions.



. Jicamarca Radio Observatory has a very large radar that can detect electron fluctuations in space.

. We have a model for those fluctuations, so we can estimate the local state of the plasma by fitting parameters **but starts failing as we get close to perpendicular to B.**





Takes milliseconds

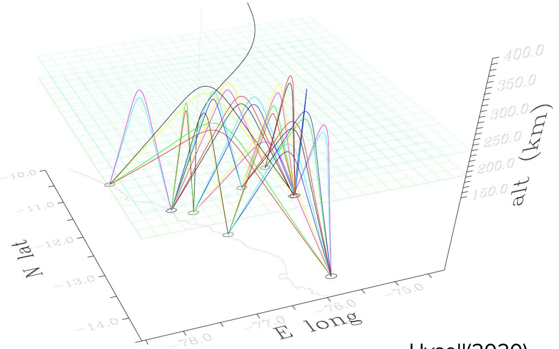
Takes hours

. We can simulate the correct statistics but its very computationally intensive. Instead, we are **building a surrogate model.**

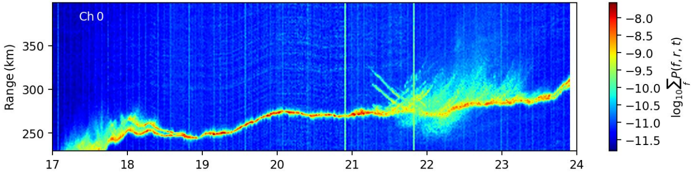
Ionospheric refraction tomography.

. Measure ray variables at receiver and try to fit ionospheric parameters.

. Several Transmitter/Receiver links were installed.



Hysell(2020)



. Example of what receivers see.

. Simulate variables measured at receivers.

$$\dot{\boldsymbol{r}} = -\left(\frac{\partial H}{\partial \omega}\right)^{-1}\frac{\partial H}{\partial \boldsymbol{k}}$$

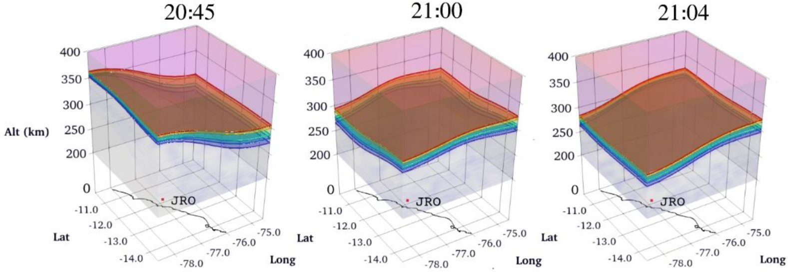
$$\dot{\boldsymbol{k}} = \left(\frac{\partial H}{\partial \omega}\right)^{-1}\frac{\partial H}{\partial \boldsymbol{r}}$$

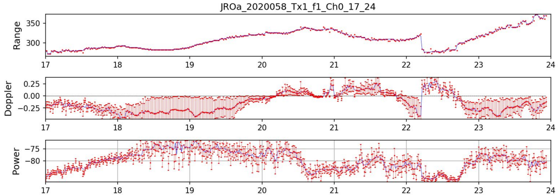
$$\dot{\omega} = \left(\frac{\partial H}{\partial \omega}\right)^{-1}\frac{\partial H}{\partial t}$$

$$\dot{P} = -\frac{c}{\omega}\left(\frac{\partial H}{\partial \omega}\right)^{-1}\boldsymbol{k}\cdot\frac{\partial H}{\partial \boldsymbol{k}}$$

. Compare with model on a loop.

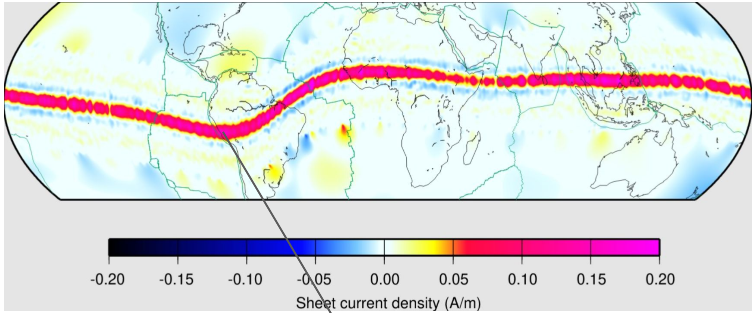
. We repeat until variables fit the data:



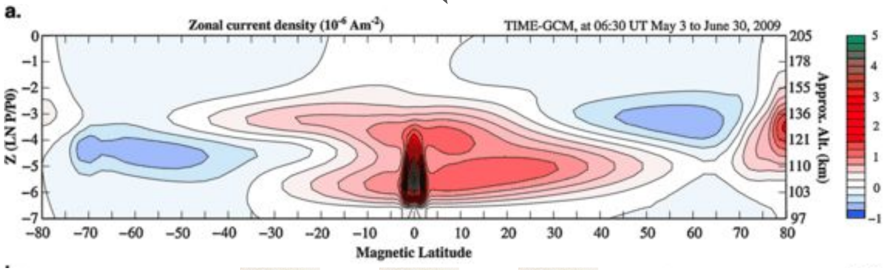


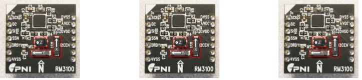
. We preprocess the data and isolate ray-tracing variables

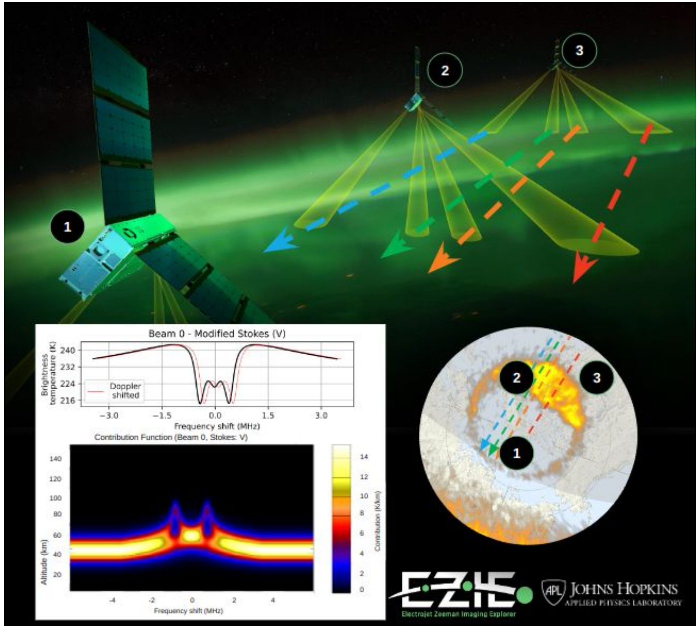
Measuring current sheets in space.

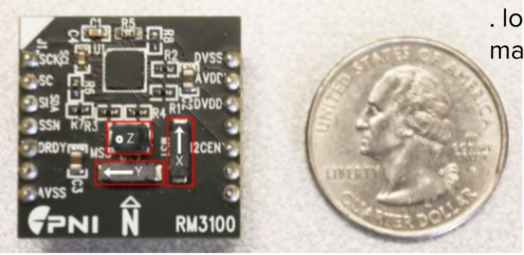


. transverse cut.









. low-cost magnetometers.

. Low-cost magnetometers make possible to think about larger networks, but **what is the optimal sensor configuration?**

Thanks!

Global Stellarator Optimization

Mason Haberle

- 4th year PhD student at NYU
- Background in theoretical fluids, turbulence theory, and convex integration
- Working on global stage 1 stellarator optimization
    - Using global methods to find new minima: pdfo, turbo
    - Combining local and global methods
    - Future: optimizing for nonlinear quantities like plasma turbulence