First Observations from the Winds Cross-Track Instrument on the Dynamo 2 Mission

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Key Takeaways

The Dynamo 2 Campaign launched July 2021 to study the global dynamo current

On board was the **Winds Cross-Track instrument**, which **measures the neutral wind vector frequently and accurately**

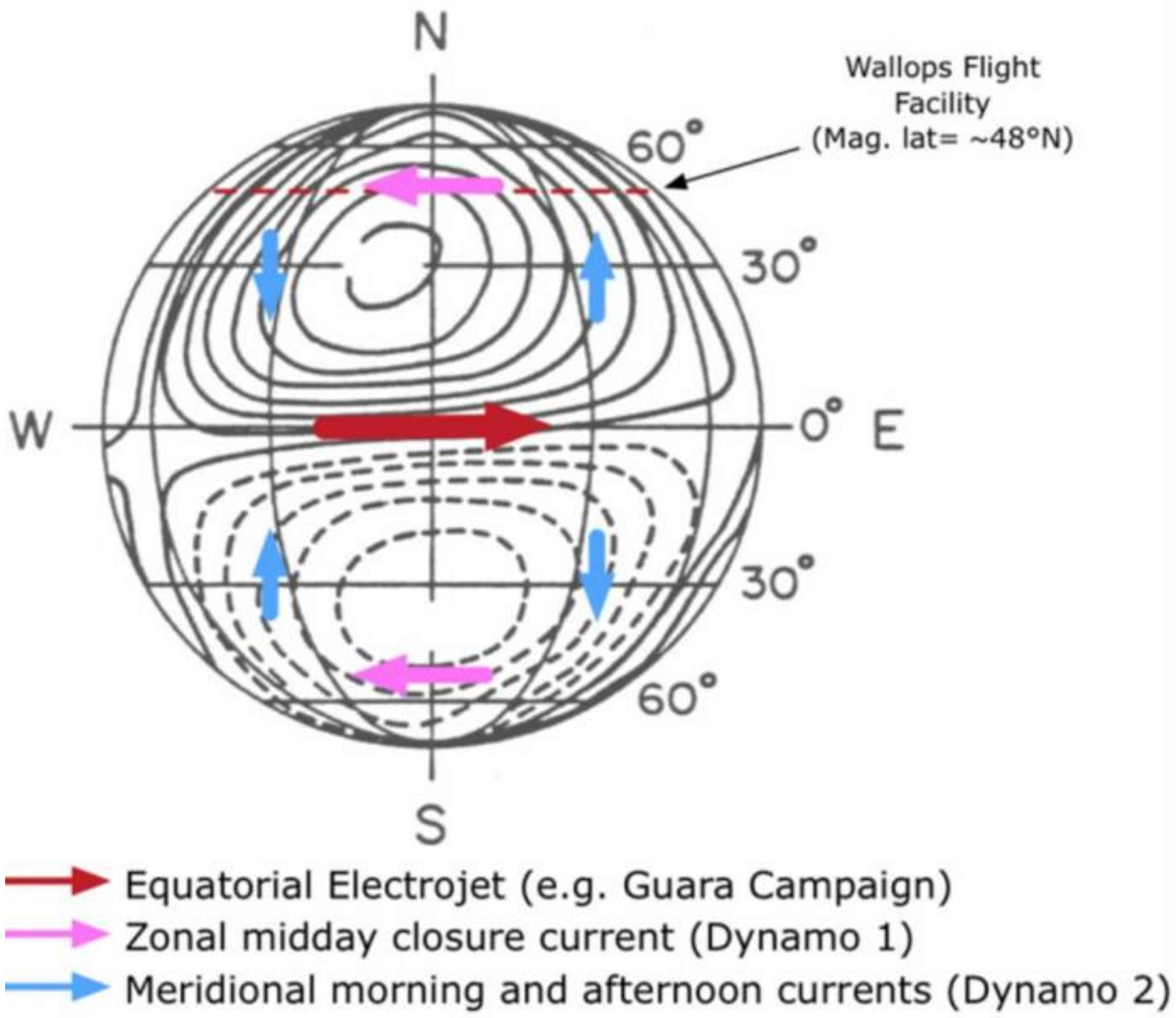
Initial, preliminary results are promising and show wind speeds ~50-150 m/s between altitudes 110-130 km

Global Dynamo

- Solar heating and gravitation tides generate neutral winds
- Wind drives unmagnetized electrons across field lines
  →Generates Currents
- Dynamo Equation

$$\vec{J} = \overline{\sigma}(\vec{E} + \vec{U} \times \vec{B})$$

- Strongest between ~80-135 km

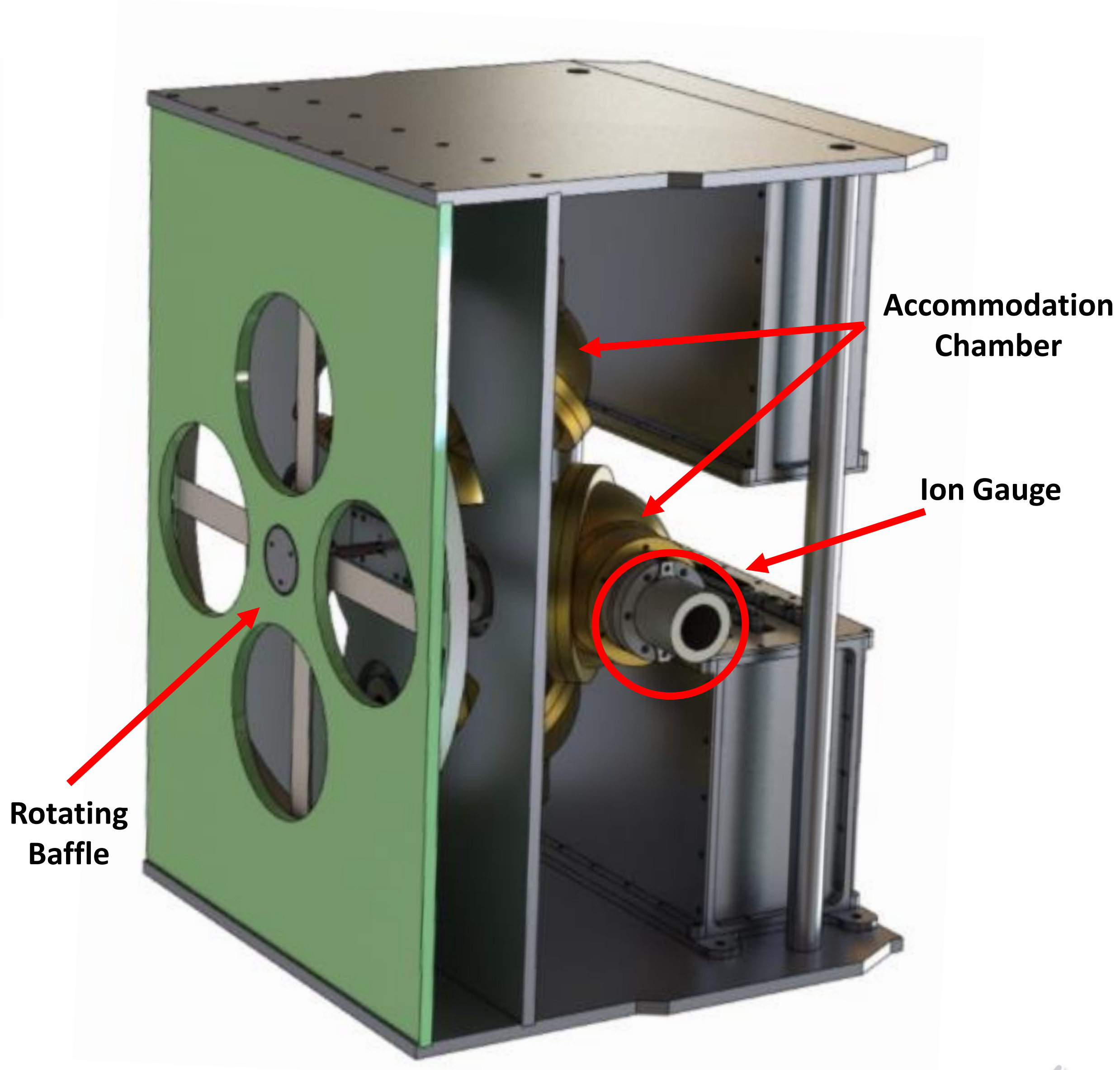


Dynamo 2 Campaign

- Investigate meridional currents and characterize the Dynamo equation as a function of altitude
  - Driven primarily by imposed electric fields, large neutral winds, or both?
- Obtain accurate, vector **neutral wind profiles** of the daytime E-region
- Two identical rockets were launched separately in July 2021 from Wallops Flight Facility
- Instruments include: Electric field probes, magnetometers, Langmuir Probes, Ionization Gauges, **Winds Cross-Track** and In-Track, and Ion Mass Spectrometer

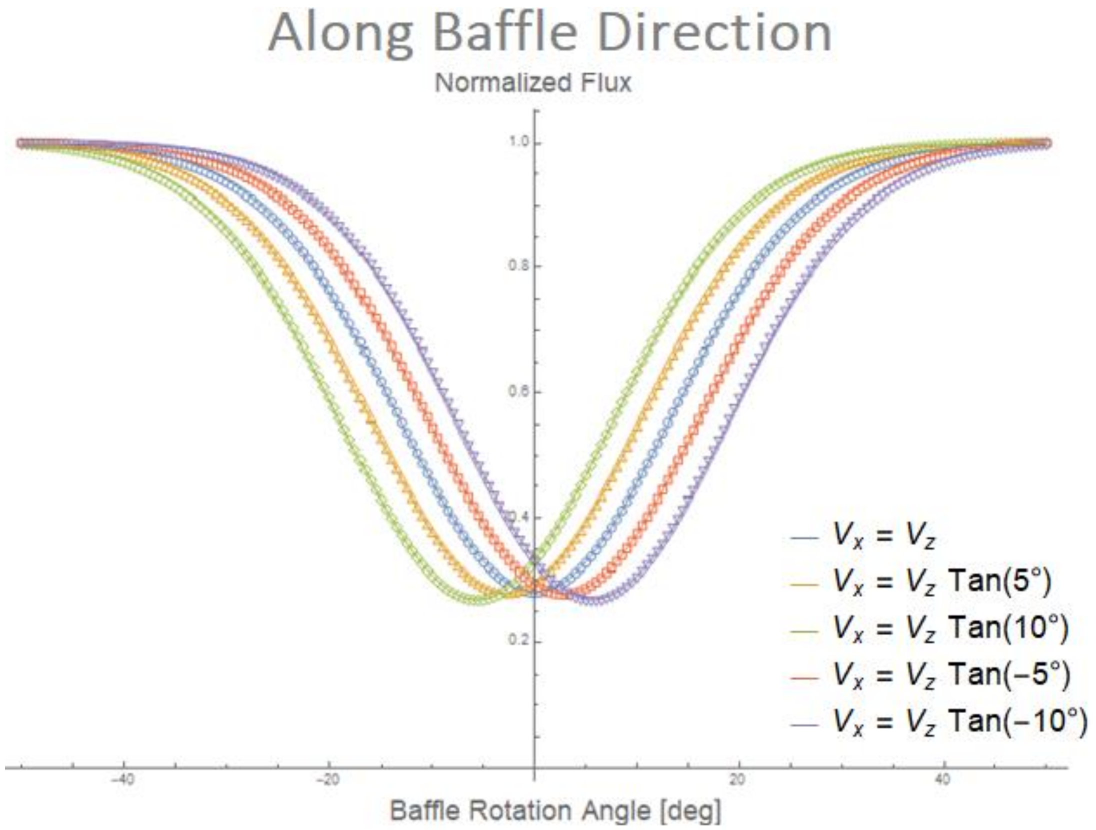
Winds Cross-Track Instrument

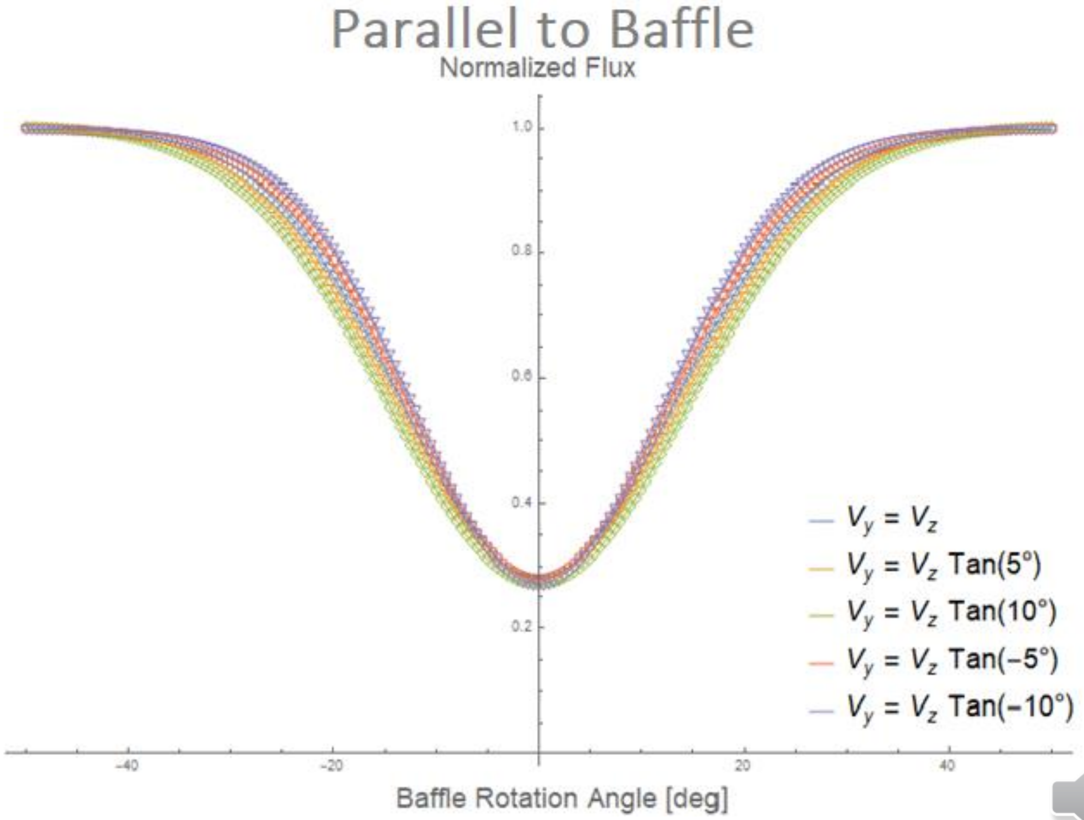
- Goal: Measure the **cross-track** (perpendicular to ramming direction) **neutral wind vector** components, **thermal velocity** of ambient gas, and **mean molecular mass**
- Incoming flux is rammed into the instrument and modulated by a rotating baffle, forming a wake
- When gas impacts the accommodation chamber, the gas obtains the known temperature of the chamber
- 4 Ionization gauges, oriented in 90° increments, measure how the density changes as a function of baffle rotation at 1000 samples per second
- **Neutral wind sampled 8 times per second**



Model Response to Neutral Winds

- The **displacement of the wake** indicates a **neutral wind vector component along the baffle rotation direction**
- The component parallel to the baffle is more difficult to measure, thus why the apertures are oriented in 90° increments

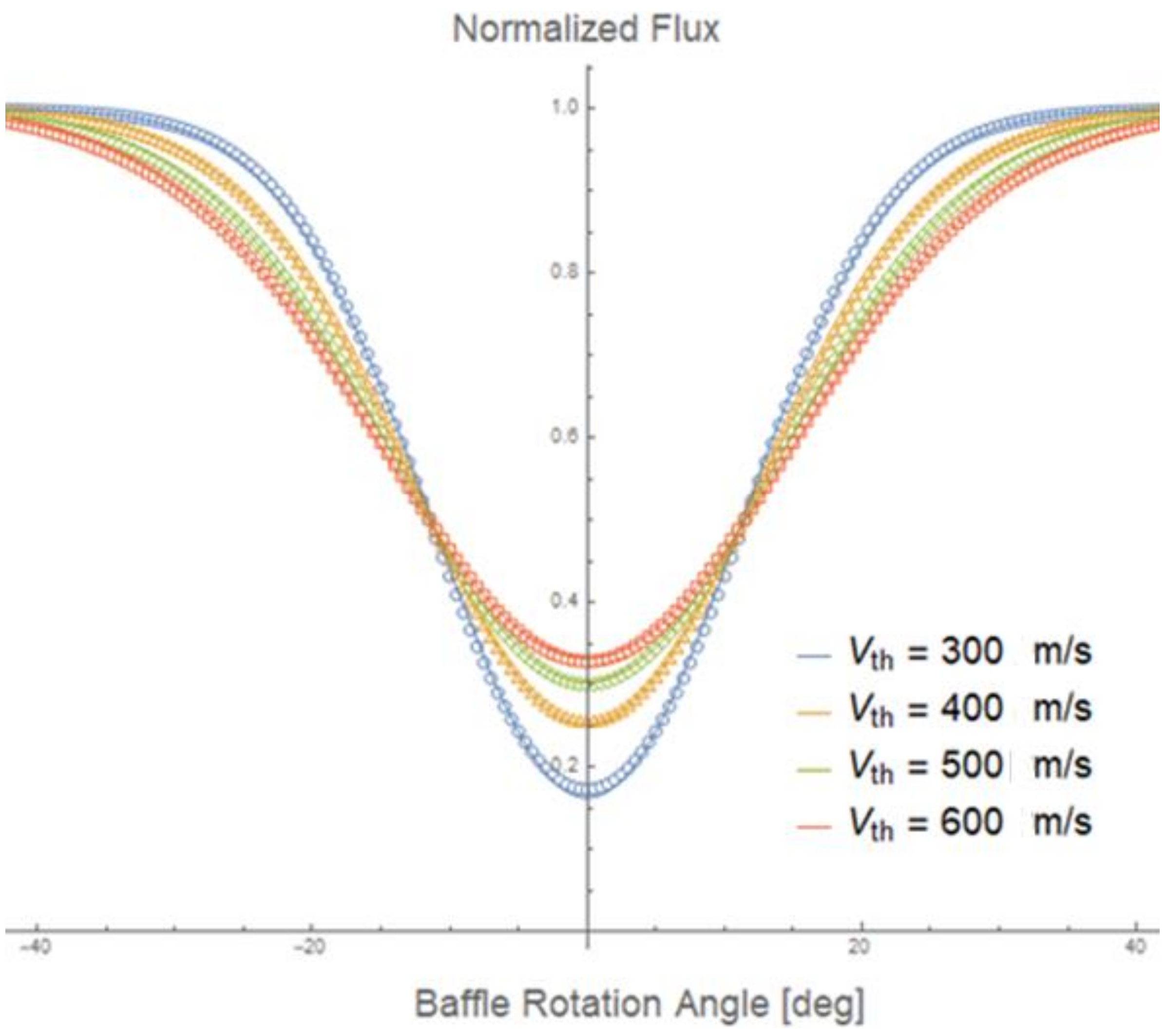




Response to changing neutral wind vectors as a function baffle rotation angle for velocities expected for Dynamo 2

Model Response to Thermal Velocity

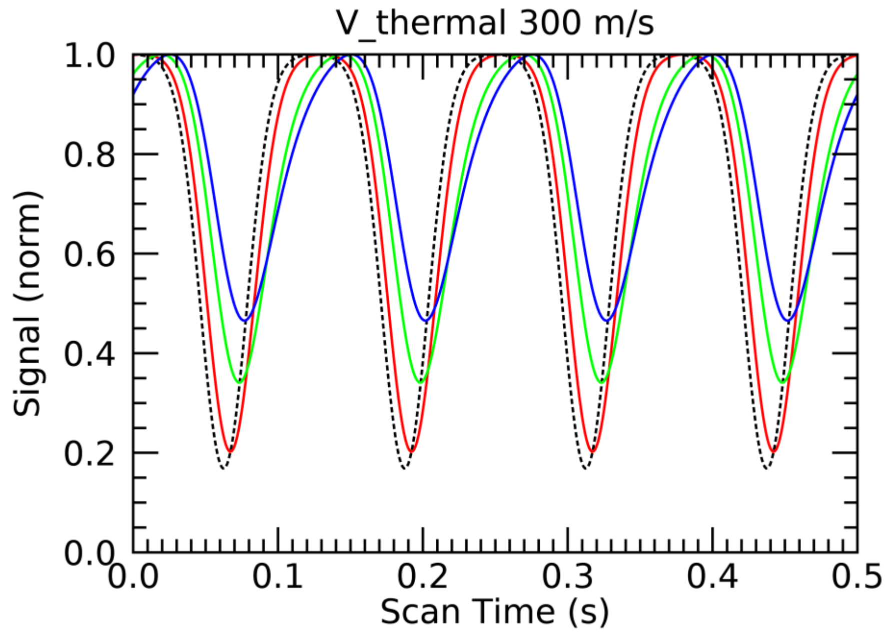
- The response of the WCT to a variety of gas parameters was modeled
- For **increasing thermal velocity, the width of the wake increases**



Response to changing thermal velocity as a function baffle rotation angle for velocities expected for Dynamo 2

Accommodation Chamber Time Constant

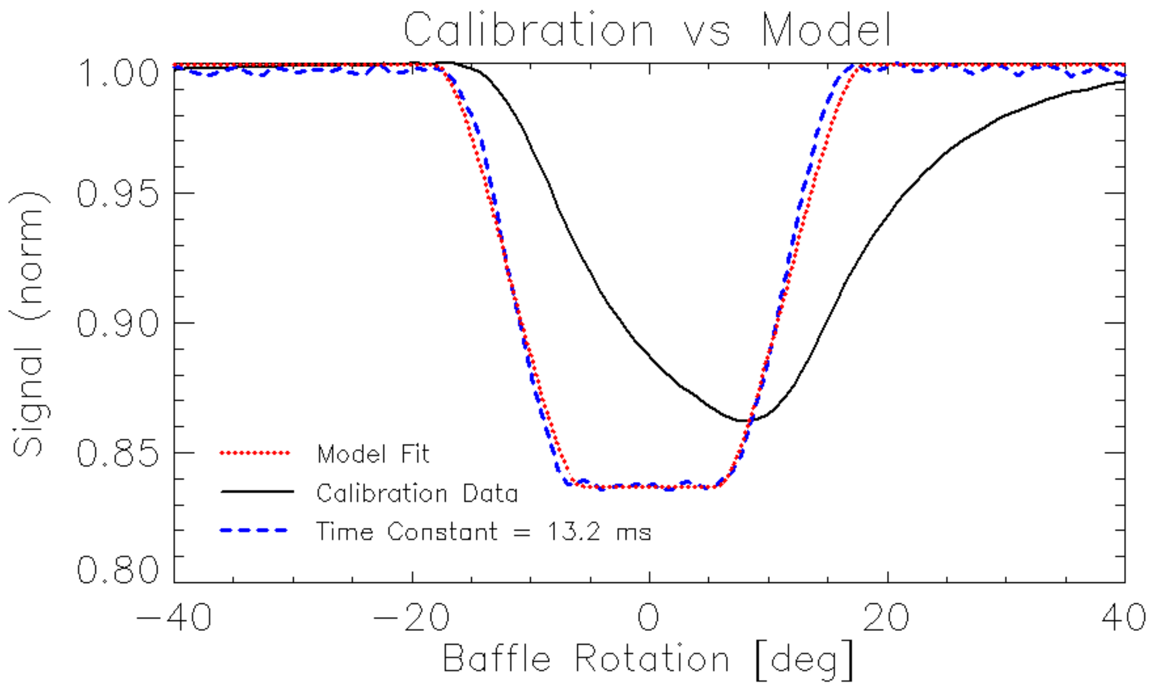
- The incoming flux rammed into the accommodation chamber must balance the outgoing flux
- The measured wake thus has a delayed response to the incoming flux as it takes some time for the gas to exit the chamber
- This time constant is proportional to the thermal velocity
- **Combine with the independently measured thermal velocity to get temperature and mean molecular mass of the ambient gas**



Modeled response to for different time constants: 5 ms (red), 15 ms (green), and 25 ms (blue)

Application of Time Constant

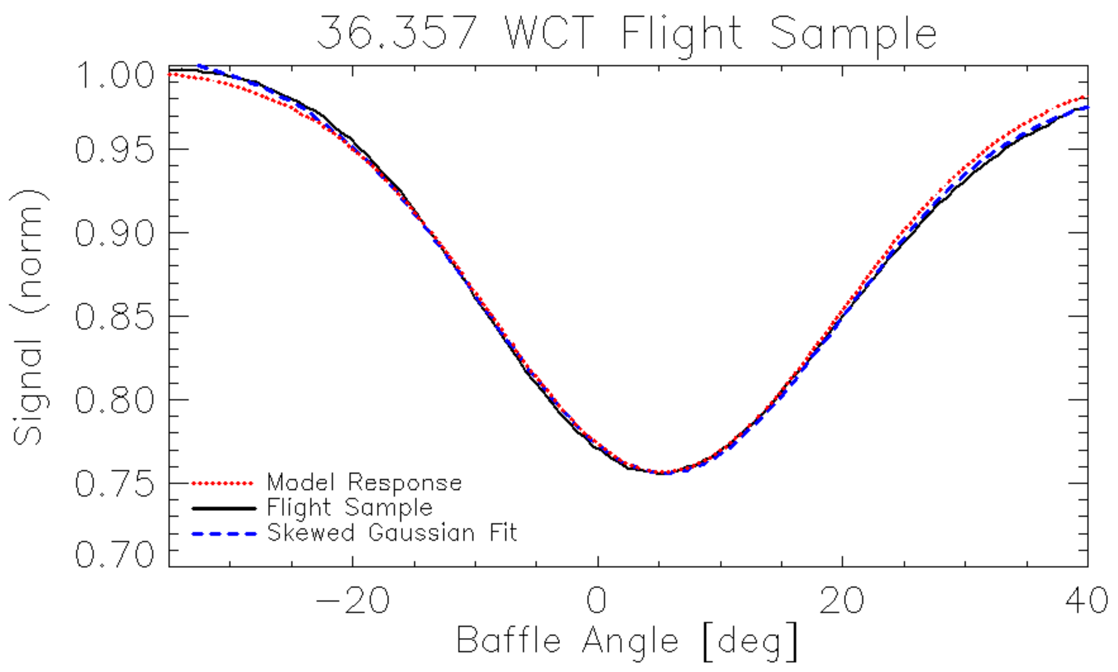
- Laboratory calibration data utilizing supersonic molecular beam
  - Such beams are cold (few K), thus the “blockish” wake
- Time constant selected which best symmetrizes the signal about its minimum
  - At normal incidence, signal is well-fit by a gaussian, i.e., it is symmetric
- Best fit **time constant was 13.2±0.1 ms**, which corresponds to a **mean molecular mass of ~28.3±0.5 amu → N2**!
- Similar results for finding Ar molecular mass
- The adjusted signal matched well with the modeled incoming flux



Calibration Data for N2 at Normal Incidence

Turning Flight Signals into Gas Parameters

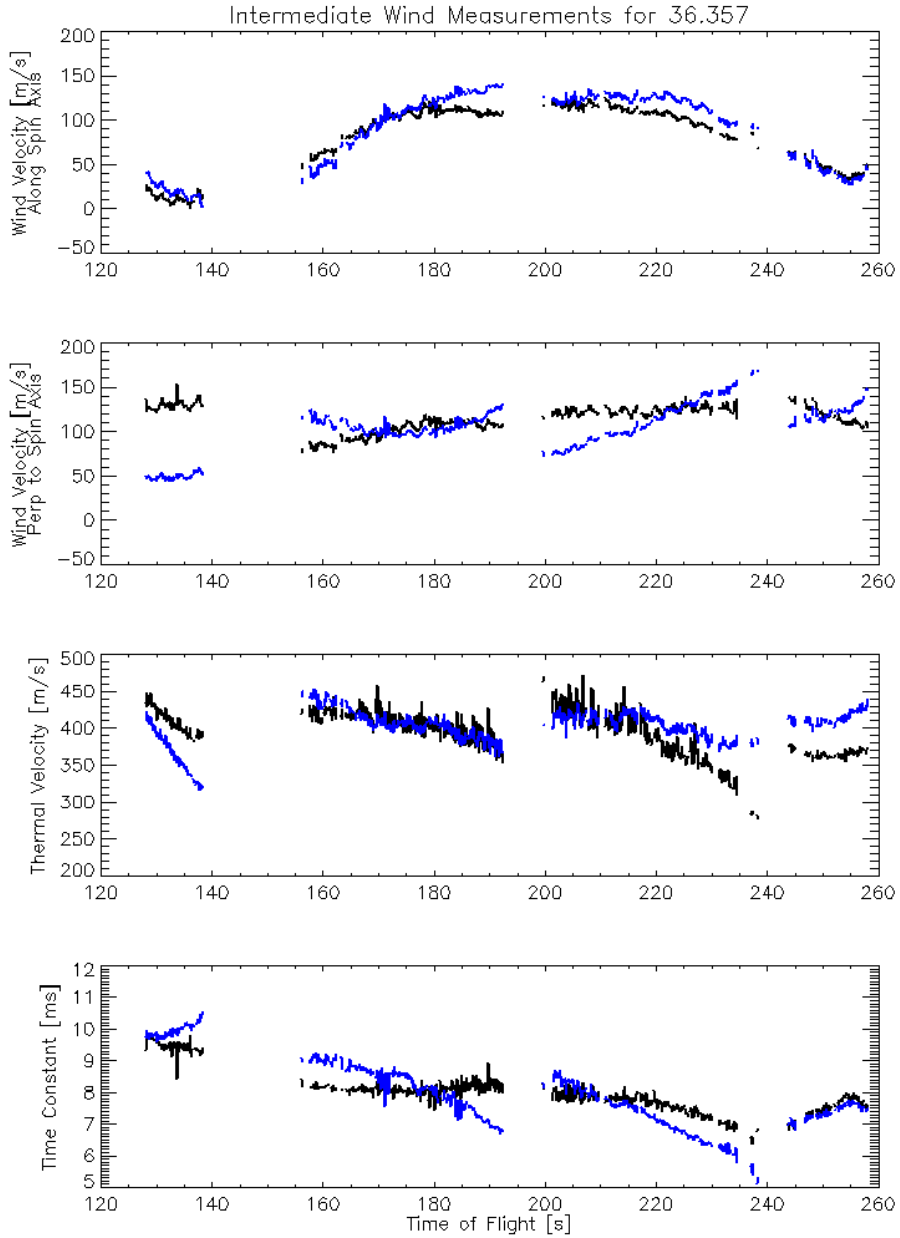
- A skewed Gaussian is fit to each sample
- Broadly speaking:
  - Displacement → wind along baffle rotation
  - Width of wake → thermal velocity
  - Skewness of wake → time constant of instrument and high wind vector angle
    - → mean molecular mass
    - → temperature
- Fit parameters are then compared against a catalog of known, modeled signals
  - Closest match inverts the measured fit into gas parameters
- Note each gas parameter affects each fit parameter to some extent



WCT Sample from Flight 36.357

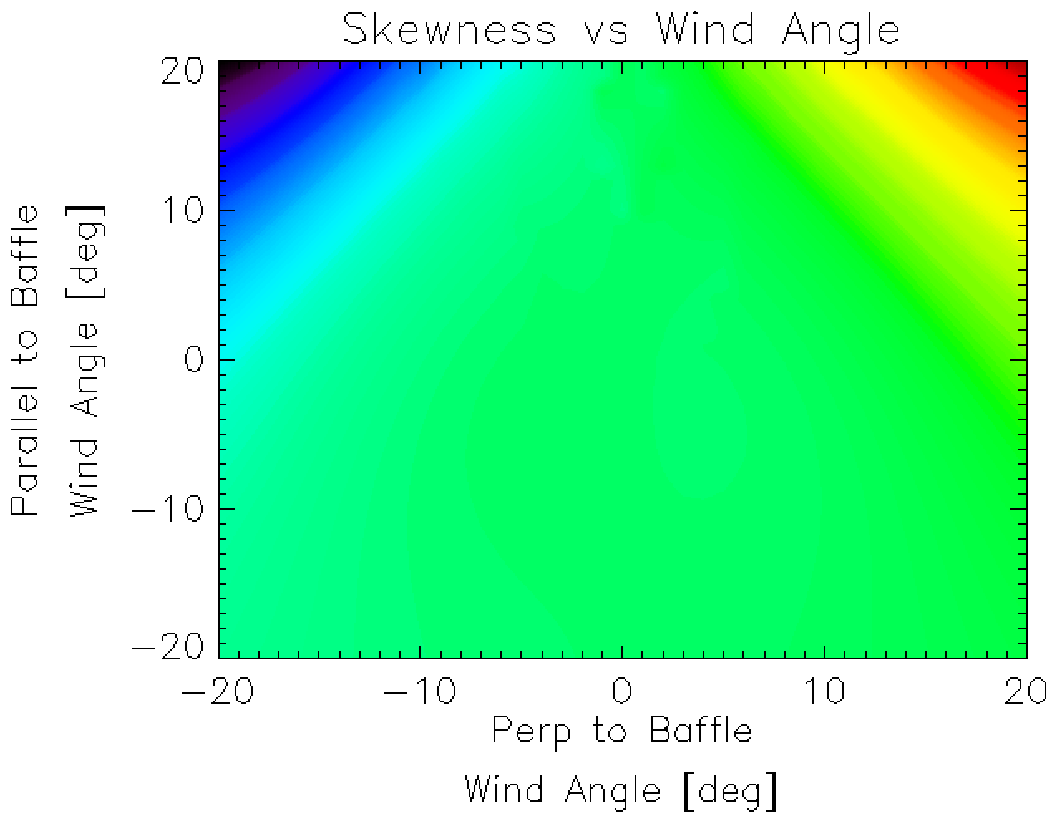
Intermediate Results

- Status of WCT measurements from Dynamo 2
- As expected, winds in the range of 50-150 m/s are observed at altitudes between 110-130 km
- An accurate In-Track component is required to turn the WCT measurements into accurate wind and thermal velocity measurements
- Data in the gaps needs further work, measurements complicated by high angles of attack or ACS maneuvers
- Thermal velocity and time constant measurements require further work



Road Ahead

- The current conversion from fit to gas parameters assumes that skewness is dependent solely on the time constant
- However, at high wind angles (+/-15°), skewness caused by the high-angles becomes comparable to chamber-caused skew
- Separating the high-angle and chamber-caused skews is the next step
- Accounting for effects of scale height and more accurate rotation rates are further steps

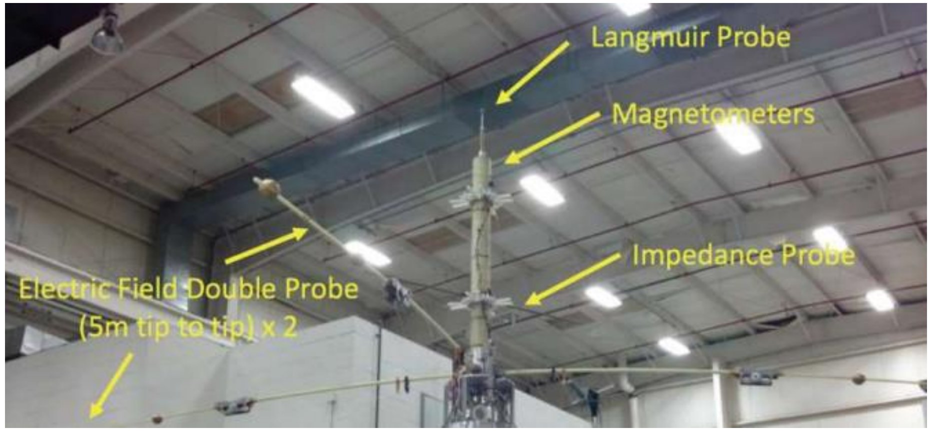


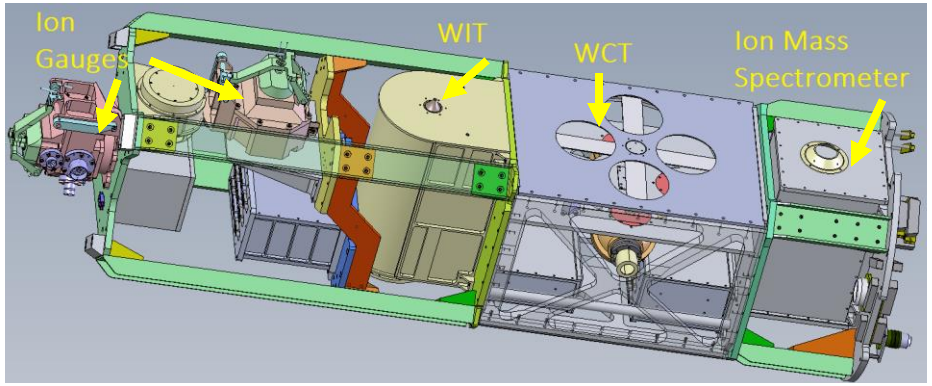
Summary

The Dynamo 2 Campaign launched July 2021 to study the global dynamo current

On board was the **Winds Cross-Track instrument**, which **measures the neutral wind vector frequently and accurately** using a rotating baffle

Initial results are promising, though further work is required to fully utilize and understand the *in situ* wind measurements



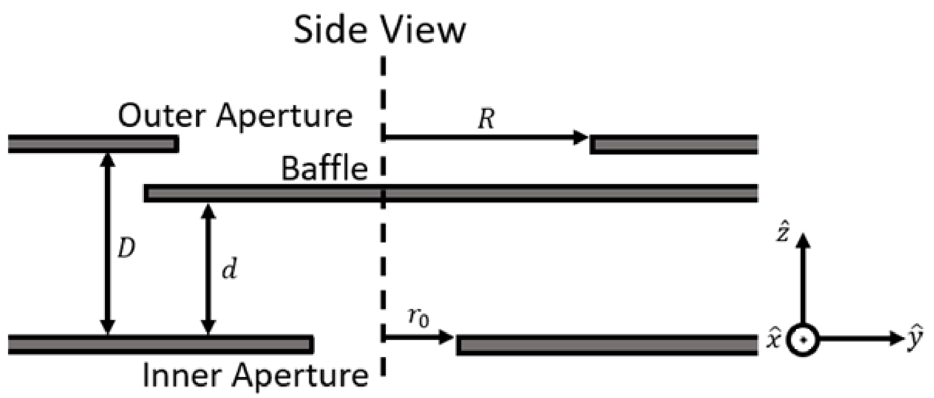


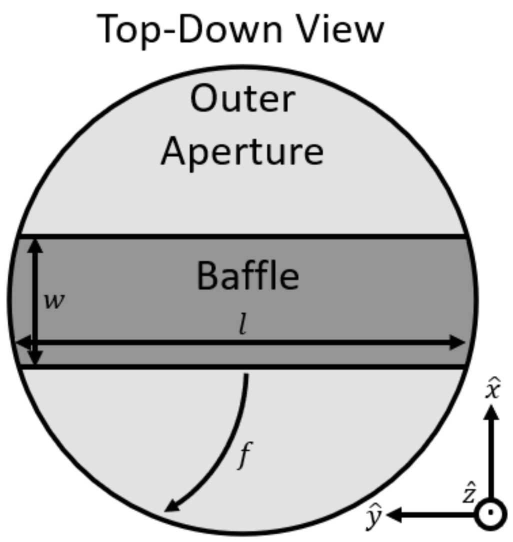
Dynamo 2 Instrumentation

- DC Electric Field Probes (E-field)
- Vector Magnetometer (B-field)
- Langmuir Probes (plasma density)
- Ionization Gauges (neutral density)
- **Wind Cross-Track** and In-Track (**neutral wind vector**)
- Ion Mass Spectrometer (plasma composition)

WCT Design

- The WCT has 4 apertures, each with an accommodation chamber and ionization gauge, oriented in 90° increments
- A baffle rotates above the apertures at a rate of 2 Hz, leading to a **fast 8 samples per second**
- A optical sensor measures the rotation rate of the baffle
- **Ion gauges measure the chamber density at 1000 samples per second** (around 0.72° of rotation per sample)





Limitations and Room for Improvement

- The rotation rate of the baffle influences how much time is available for the incoming and outgoing flux to balance
  - Primarily impacts the neutral wind velocity and time constant measurements
  - Currently sampled at a rate of 1 kHz
  - Increased time resolution can yet be gleaned from extra words in telemetry file
- The catalog of model responses can be expanded for larger wind angles and thermal velocities
- The model can be improved by including back-scattering of the outgoing gas on the baffle (likely a minor factor)