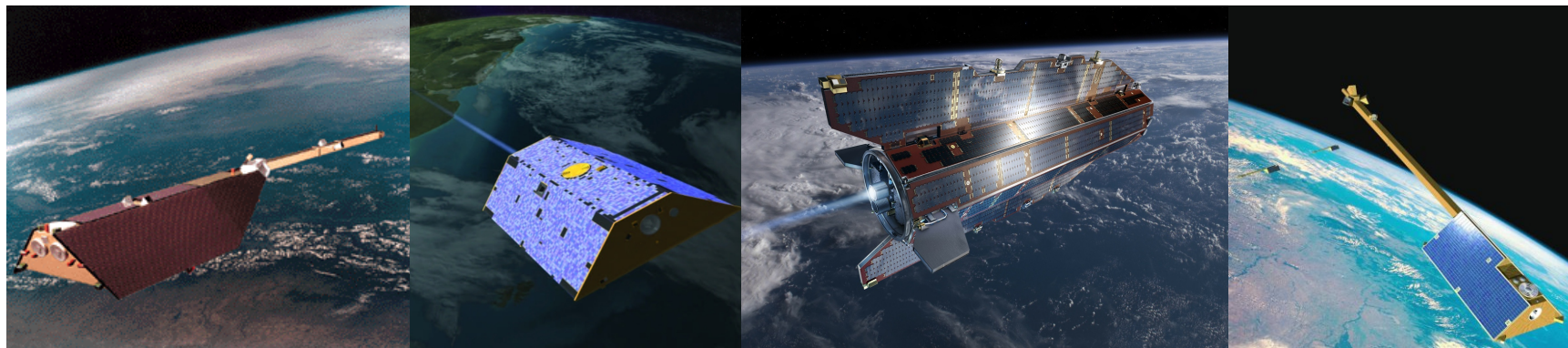


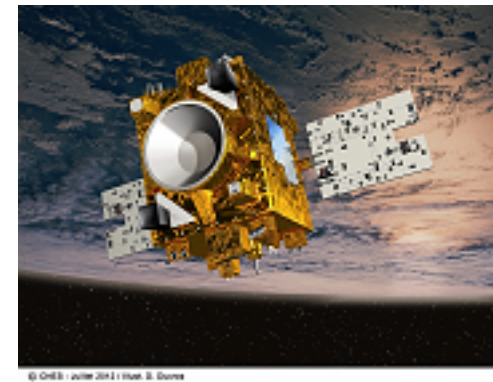
# Retrieval of thermosphere density and wind from space-borne accelerometry – activities at TU Delft

Eelco Doornbos, Pieter Visser

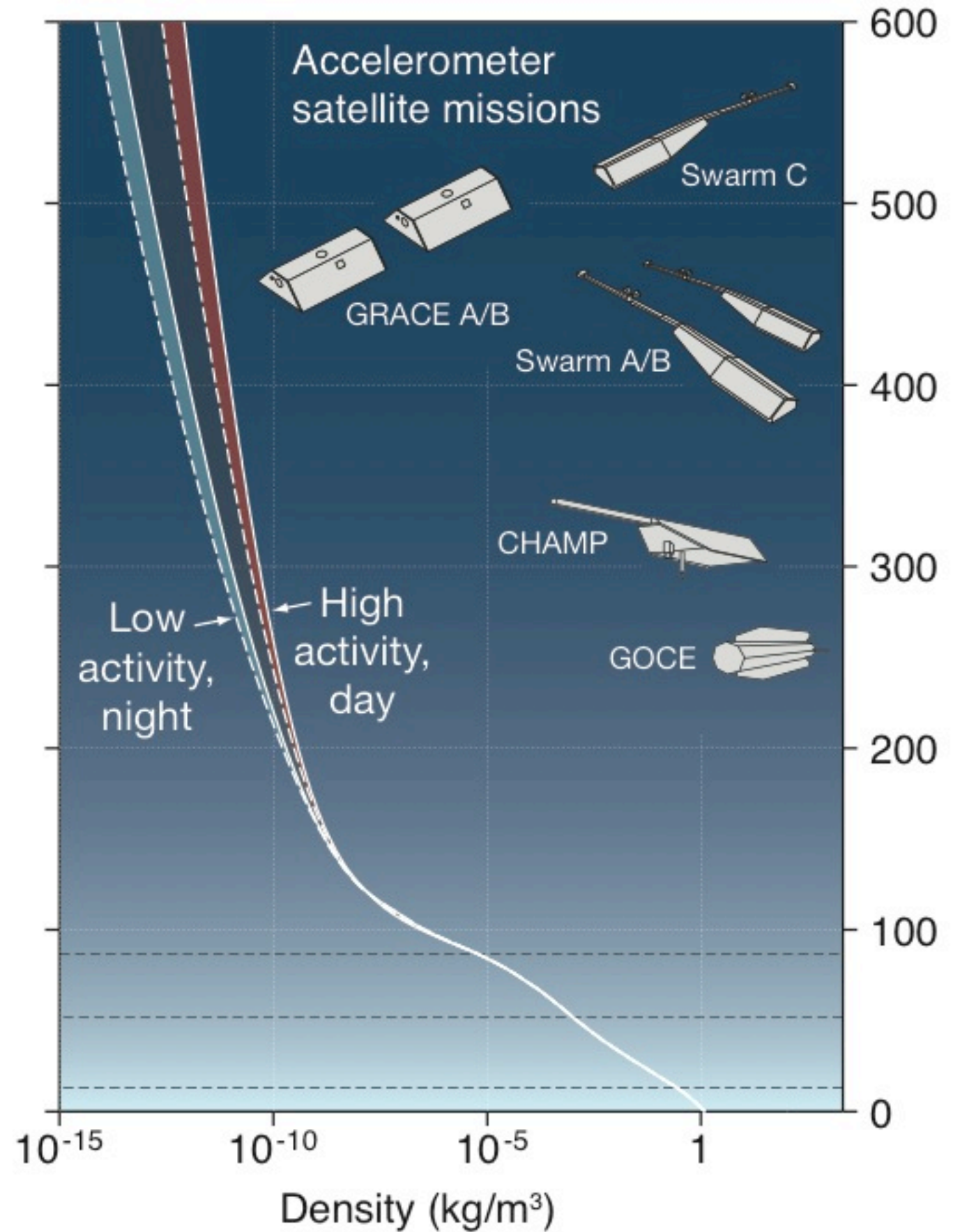
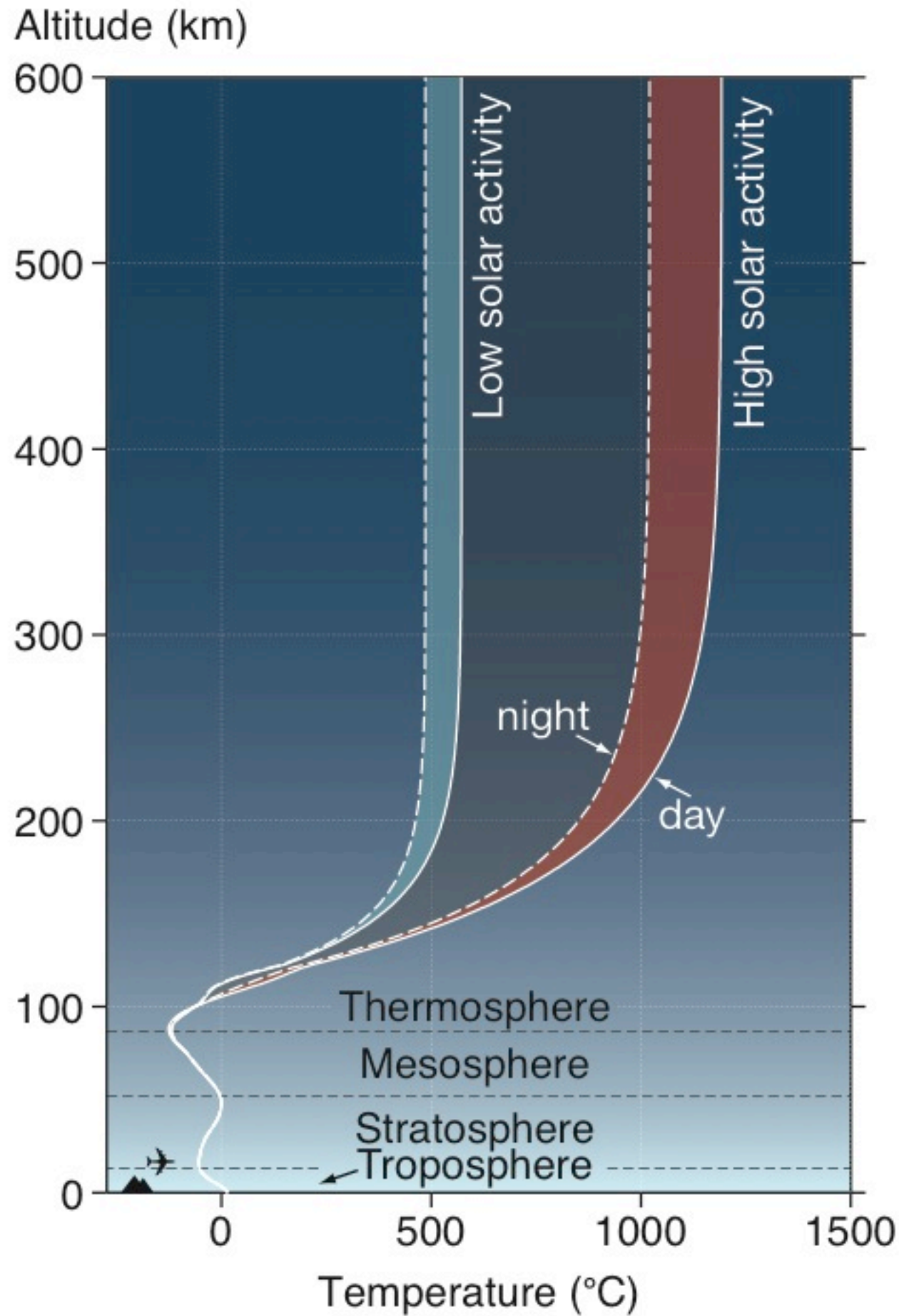
Testing the equivalence principle –  
MICROSCOPE Colloquium III  
3-4 Nov 2014 Palaiseau (France)



← ??? →



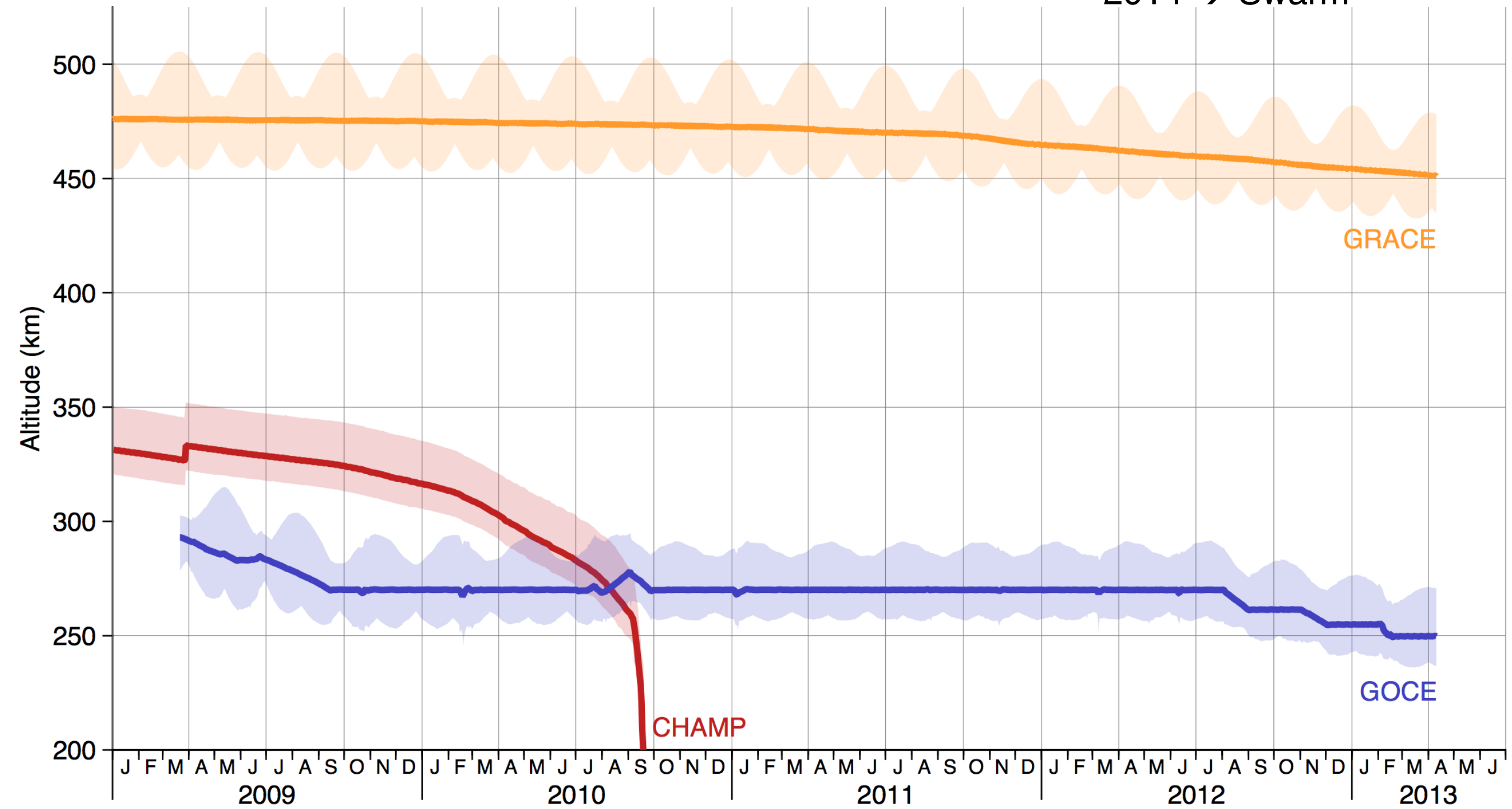
# Microscope: 700 km, sun-synchronous





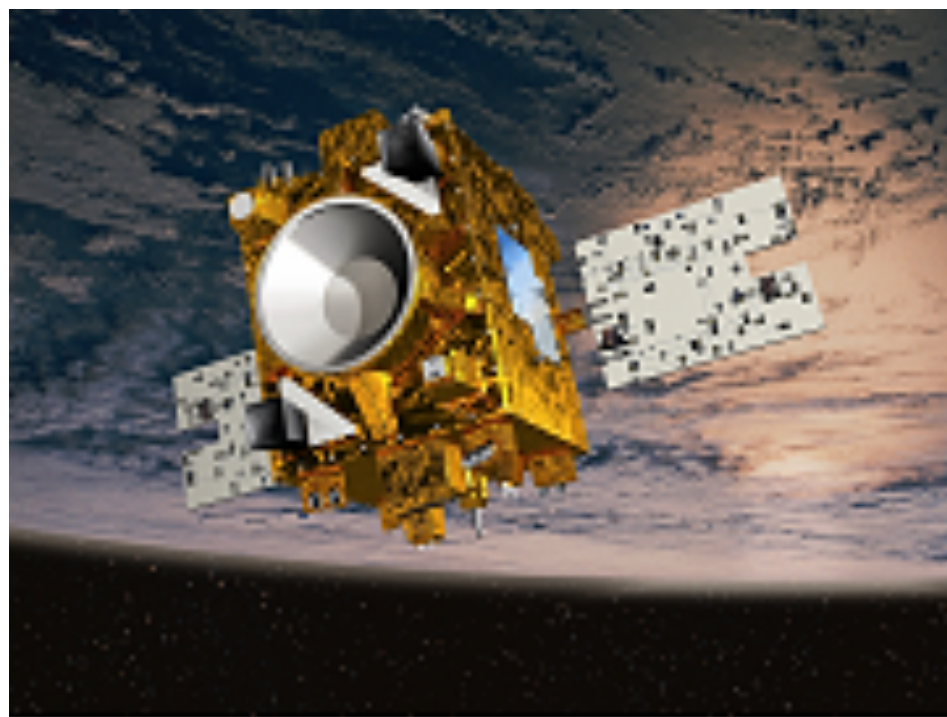
2016 → Microscope

2014 → Swarm



# MICROSCOPE

- Anticipated launch 2016
- Sun-synchronous
- 700 km altitude
- Accelerometers:  $10^{-12}$  m/s<sup>2</sup>
- Drag-free micro-thrusters



© CNRS - juillet 2014 - Hubert B. Duvon

# GOCE

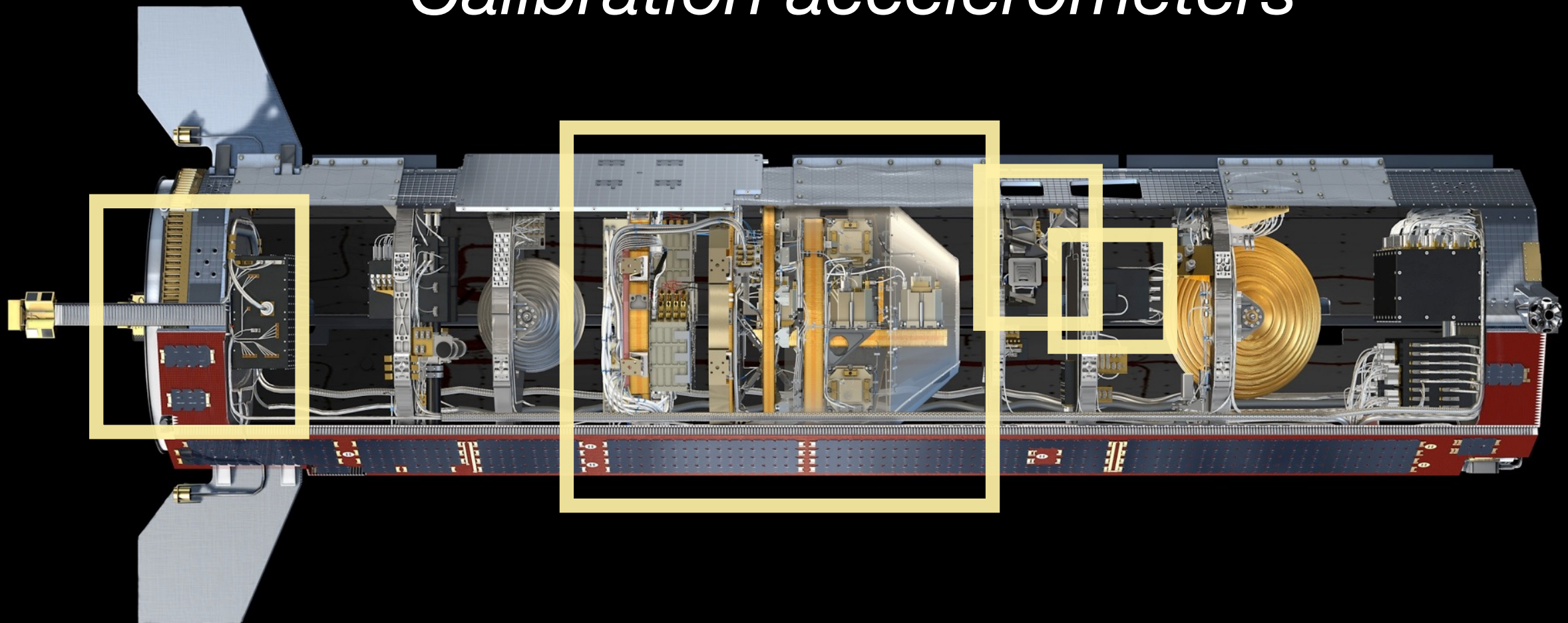
- Operations: 2009-2013
- Sun-synchronous
- 220-250 km altitude
- Accelerometers:  $10^{-12}$  m/s<sup>2</sup>
- Drag-free ion engine





**Gradiometer:** *also non-grav. accelerations*

**GPS receiver:** *orbit determination +  
Calibration accelerometers*

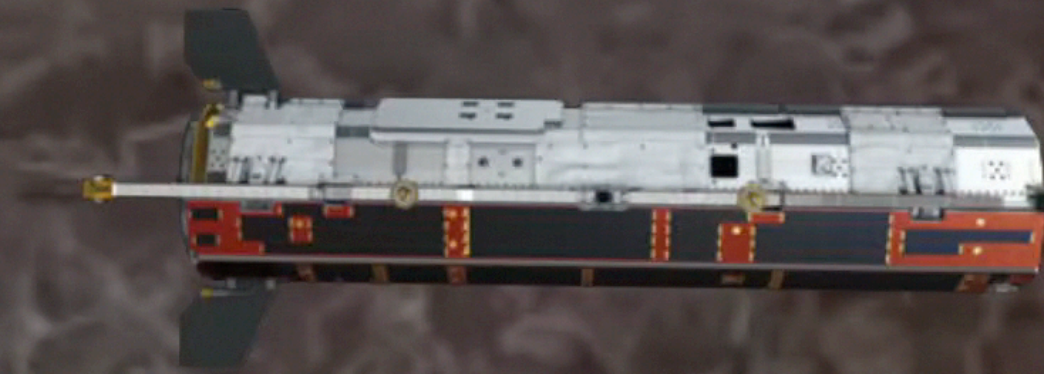


**Star trackers:** *orientation  
satellite/accelerometers*

**Ion engine:** *accelerations through propulsion*



# Velocity of GOCE relative to atmosphere



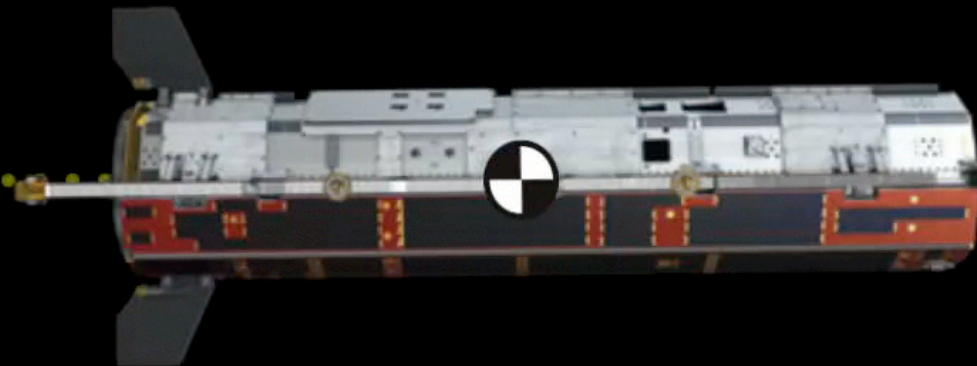
**Orbital velocity:** 7800 m/s

**Rotational velocity atmosphere:** up to 470 m/s

**Wind in the thermosphere:** up to 1000 m/s

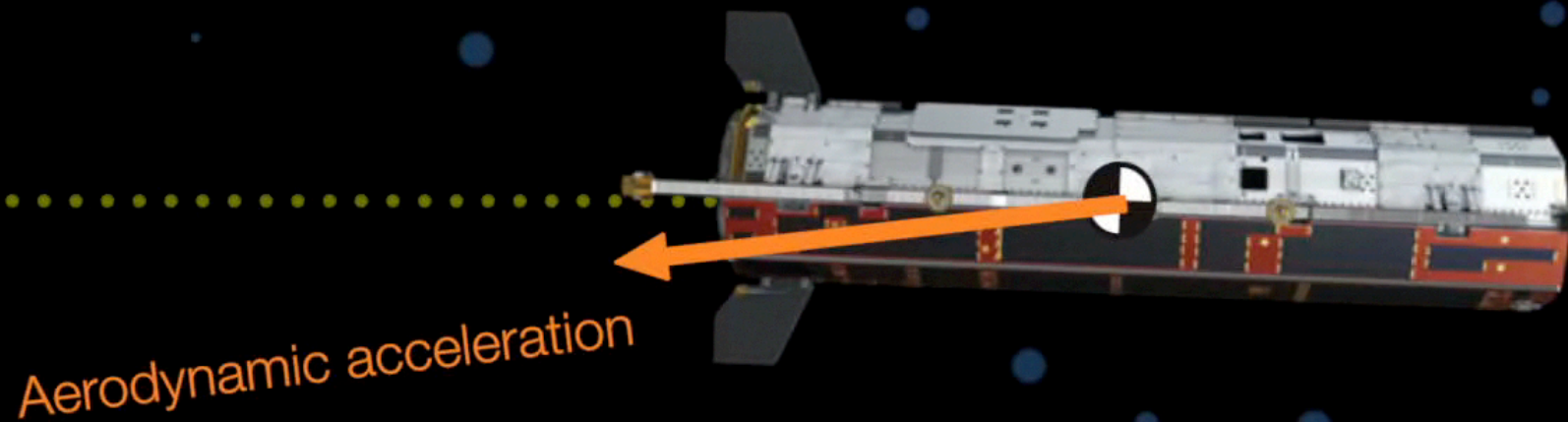


# Dynamics of GOCE: Aerodynamic acceleration



# Dynamics of GOCE

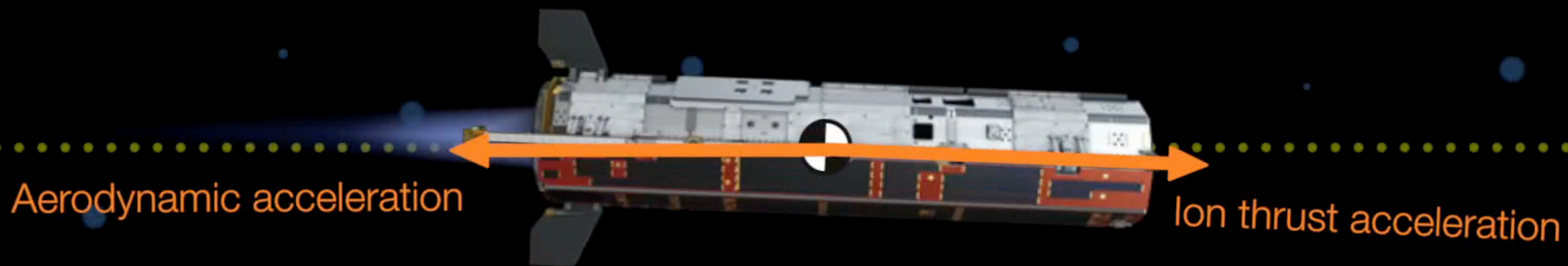
Acceleration provoked by ion engine

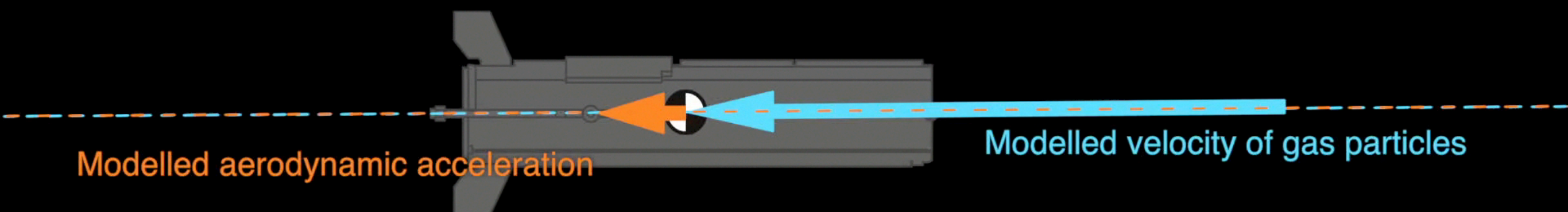




# Dynamics of GOCE

Accelerations caused by radiation pressure





Modelled aerodynamic acceleration

Modelled velocity of gas particles

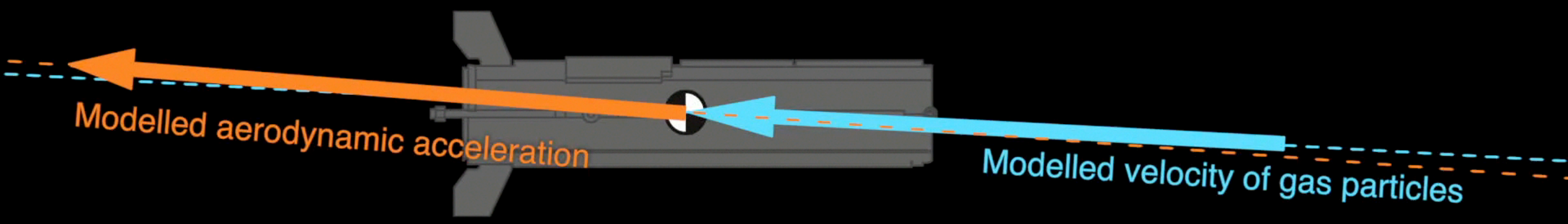
Density of gas particles



0

max



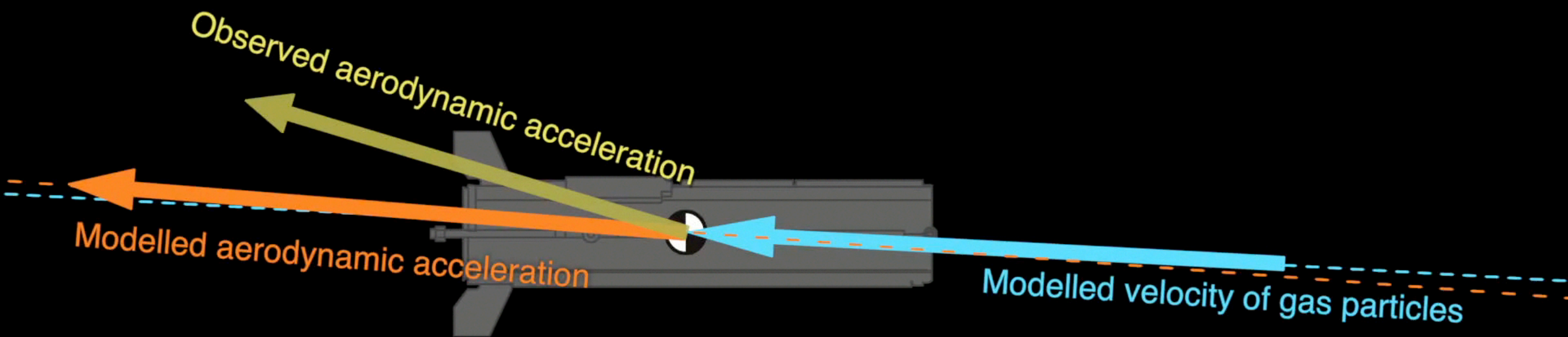


Density of gas particles

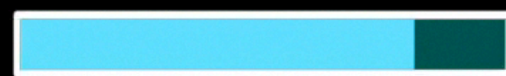


0

max

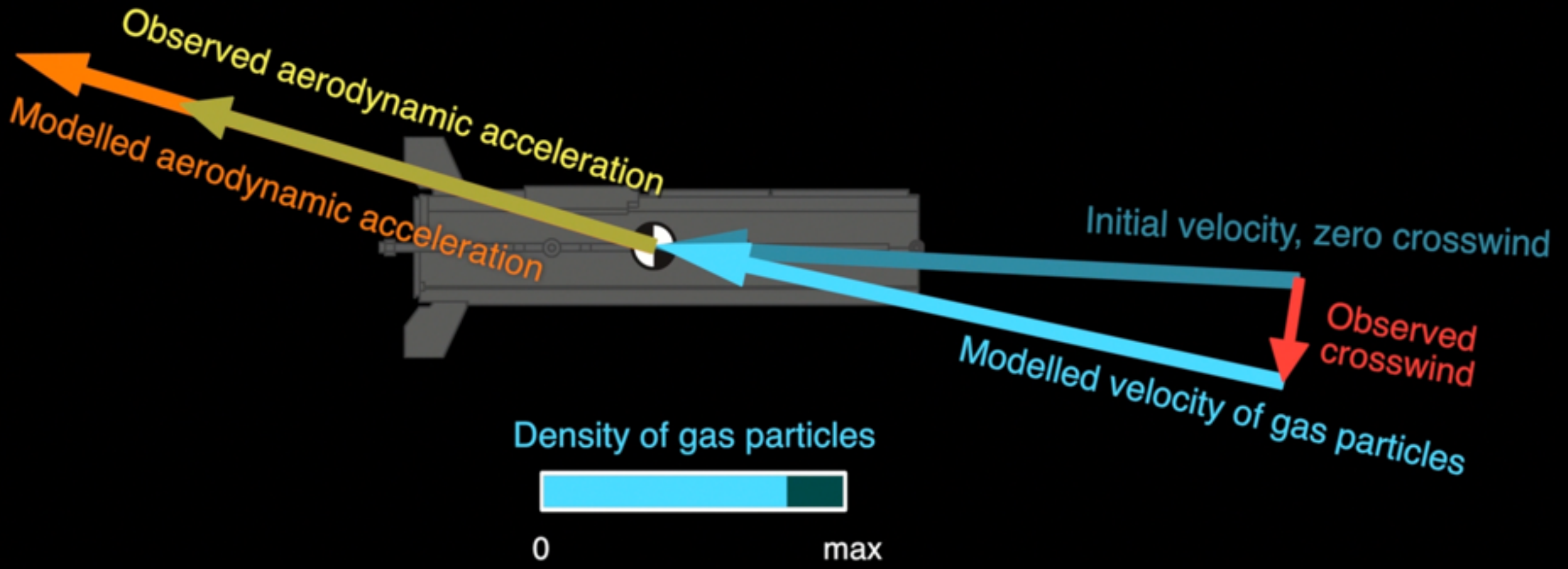


Density of gas particles



0

max



Observed aerodynamic acceleration

Modelled aerodynamic acceleration

Initial velocity, zero crosswind

Observed crosswind

Modelled velocity of gas particles

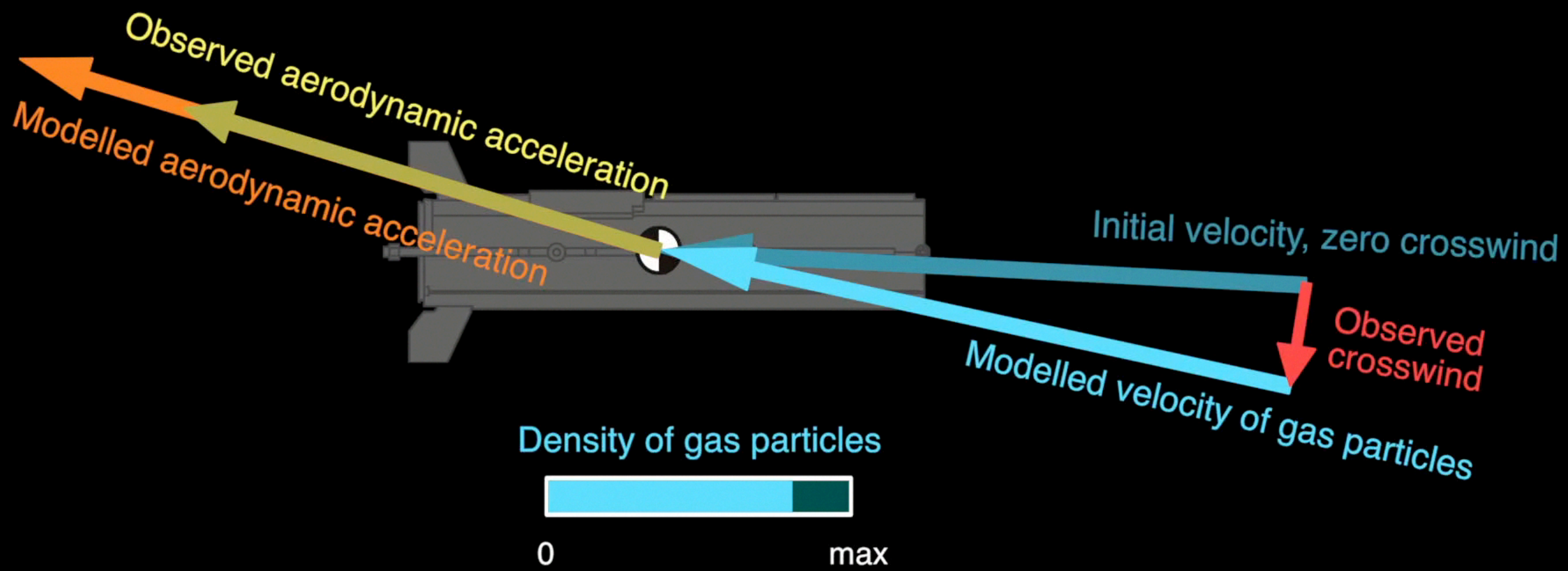
Density of gas particles

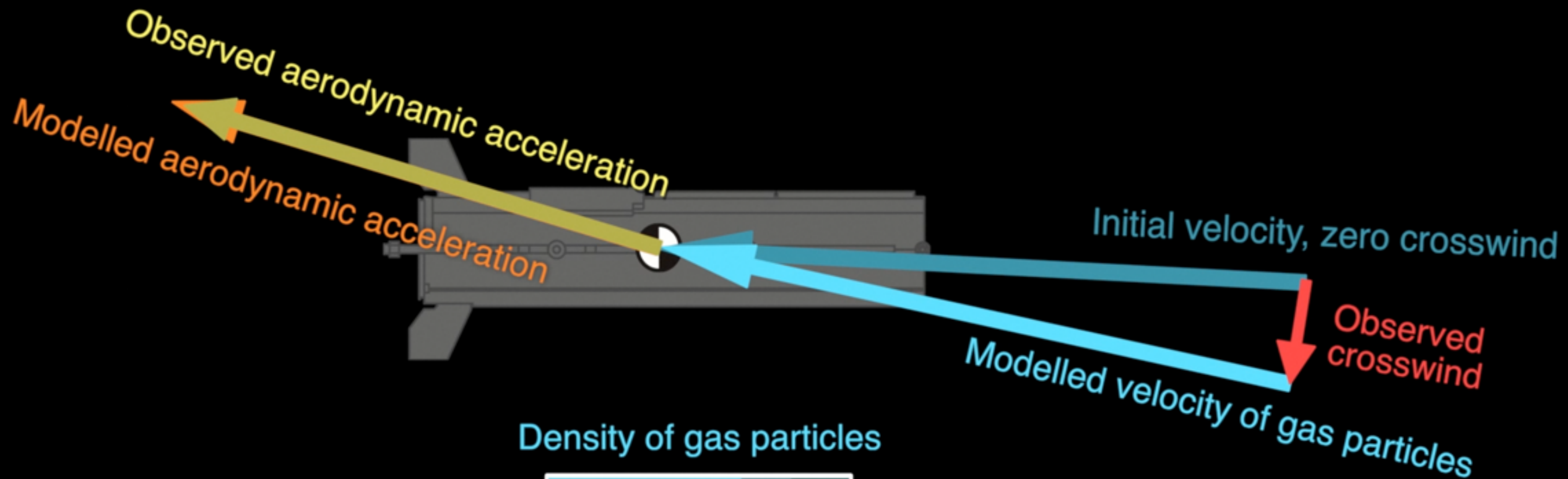


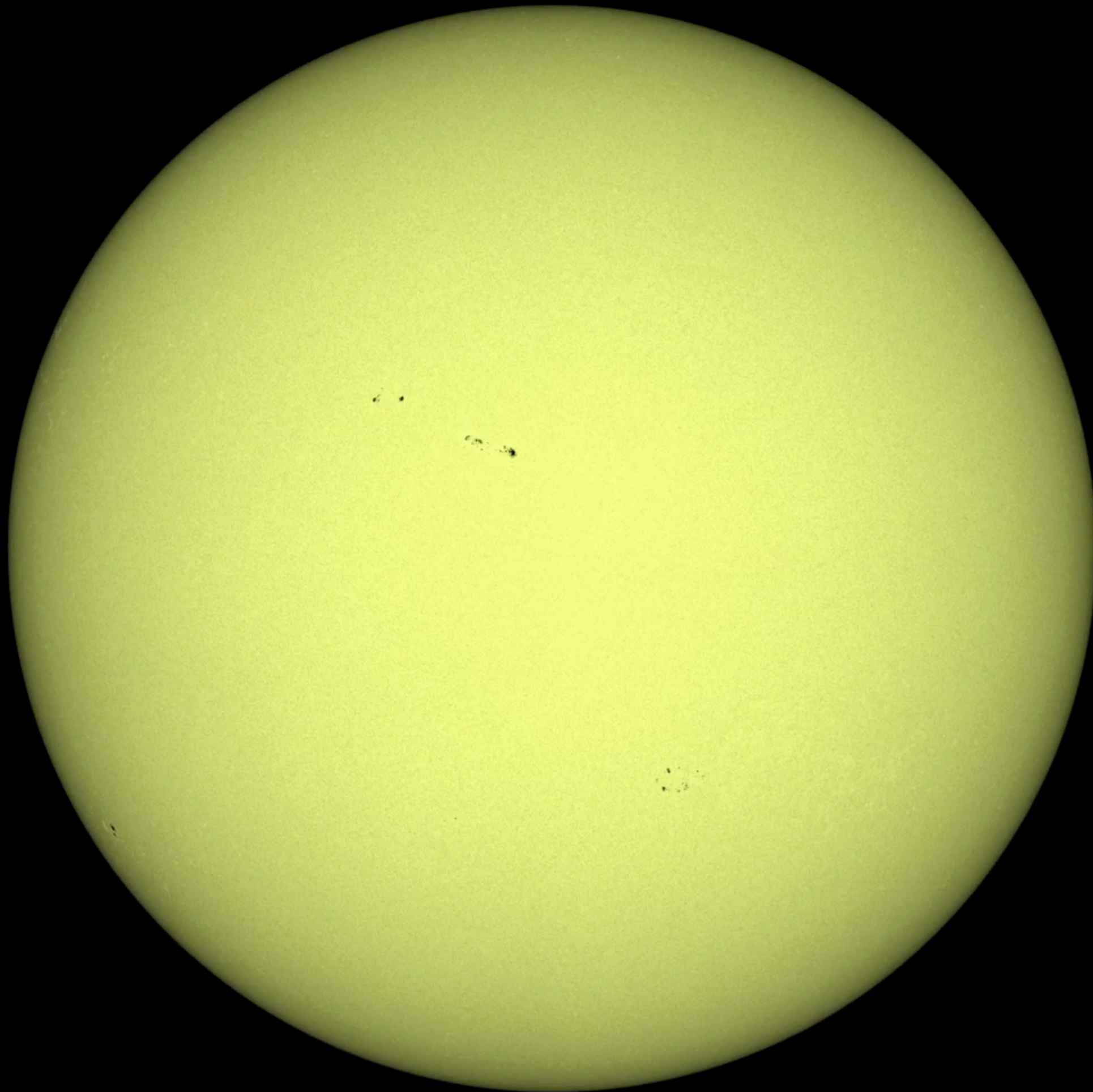
0

max





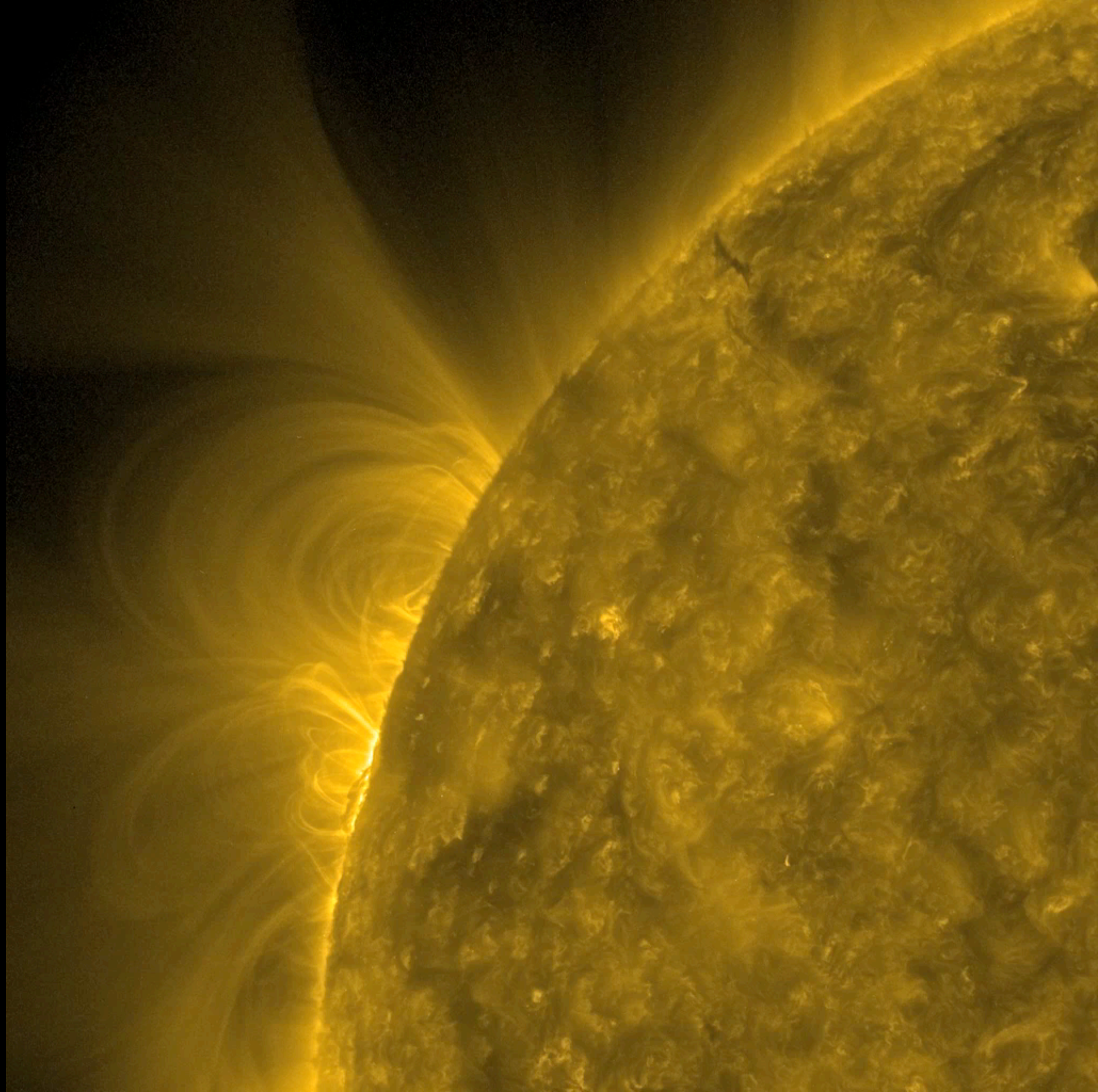








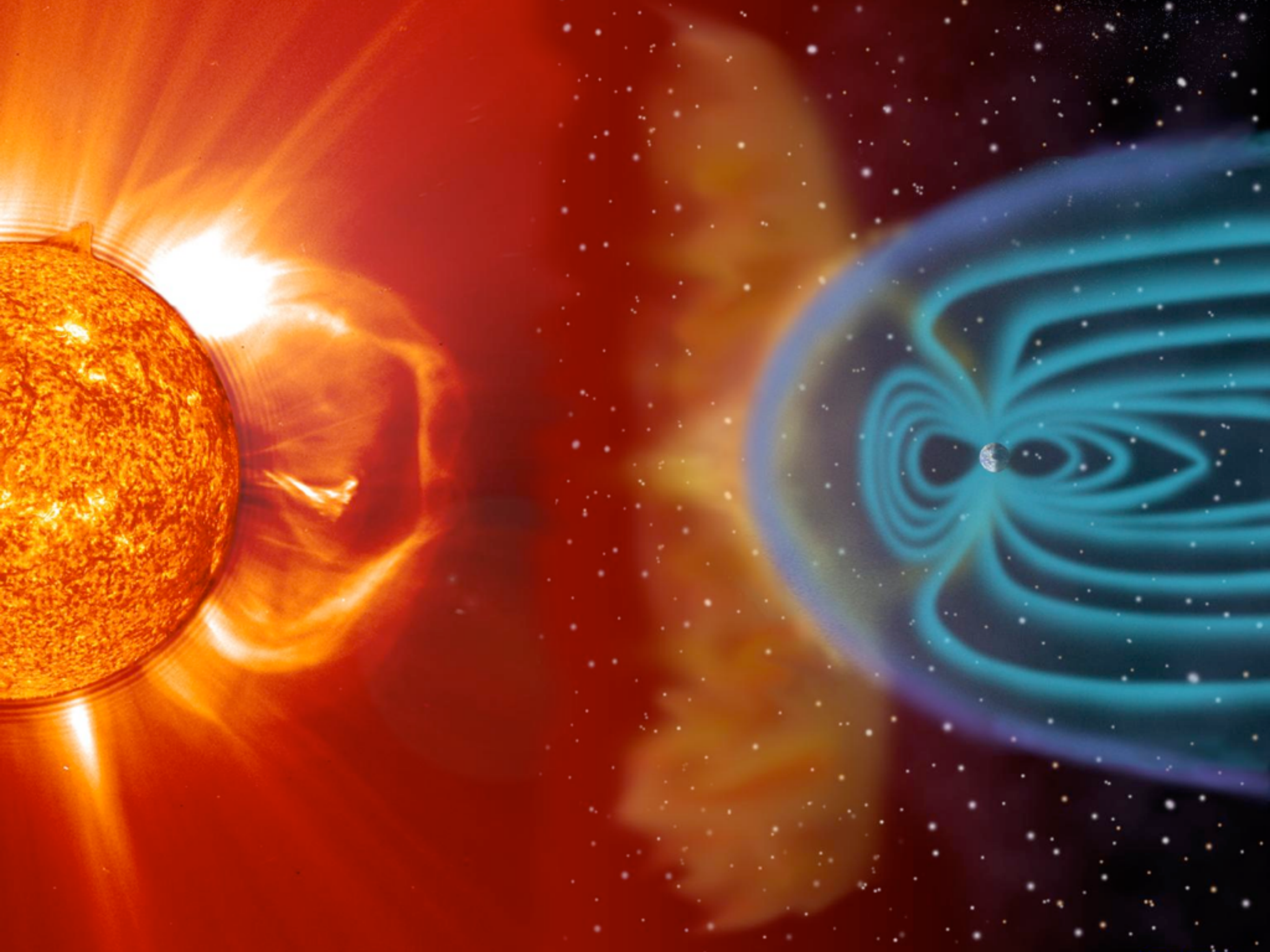















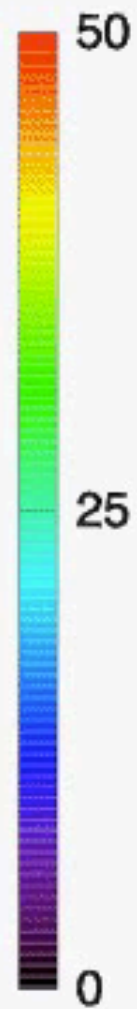
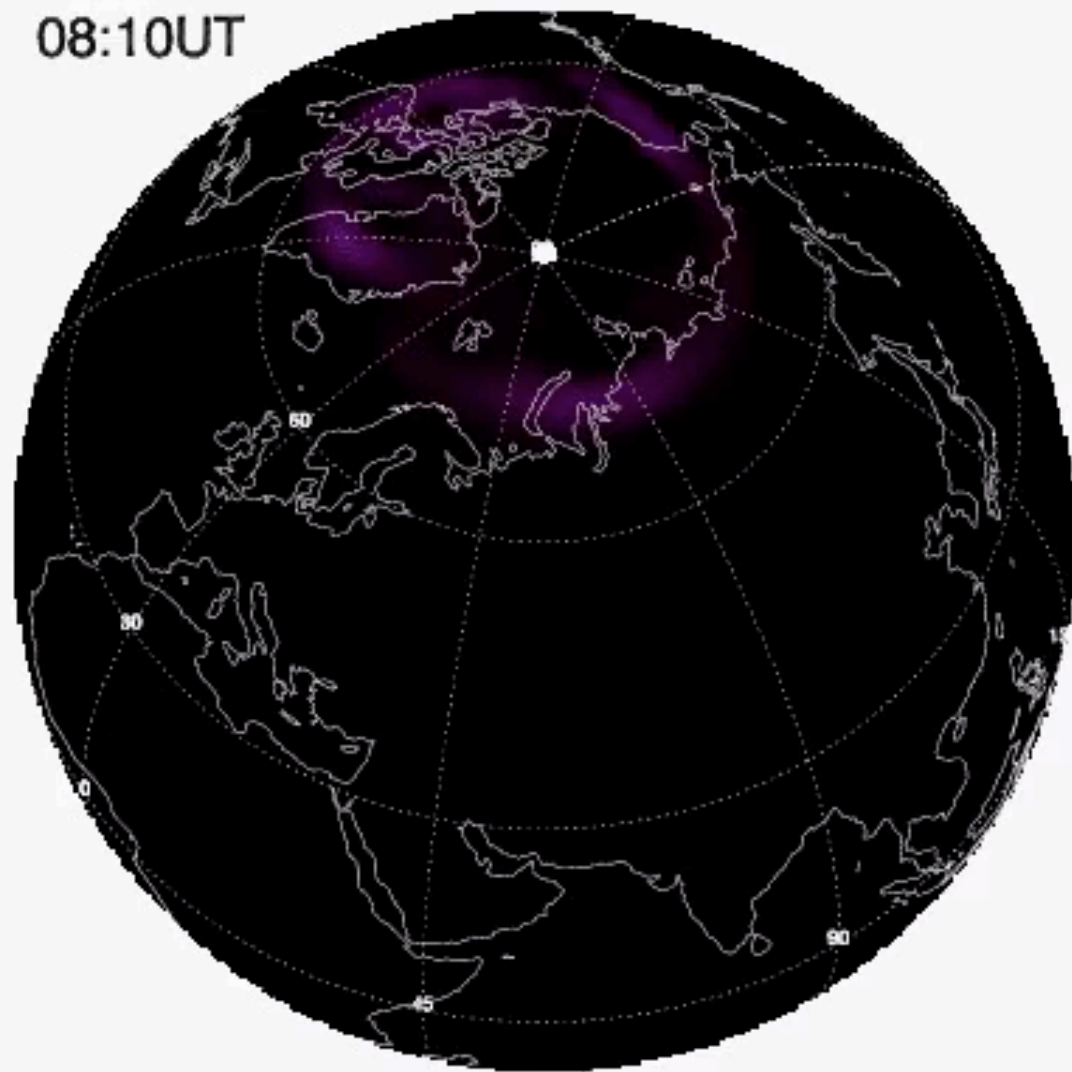


Yellowknife, Canada  
KWON O CHUL



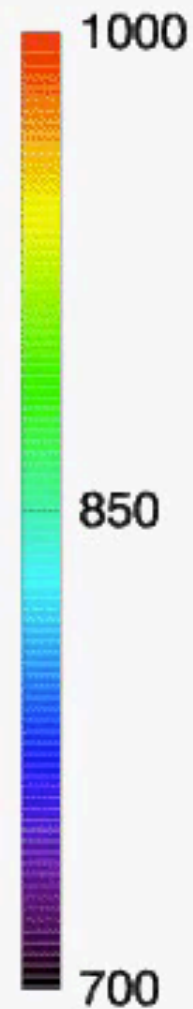
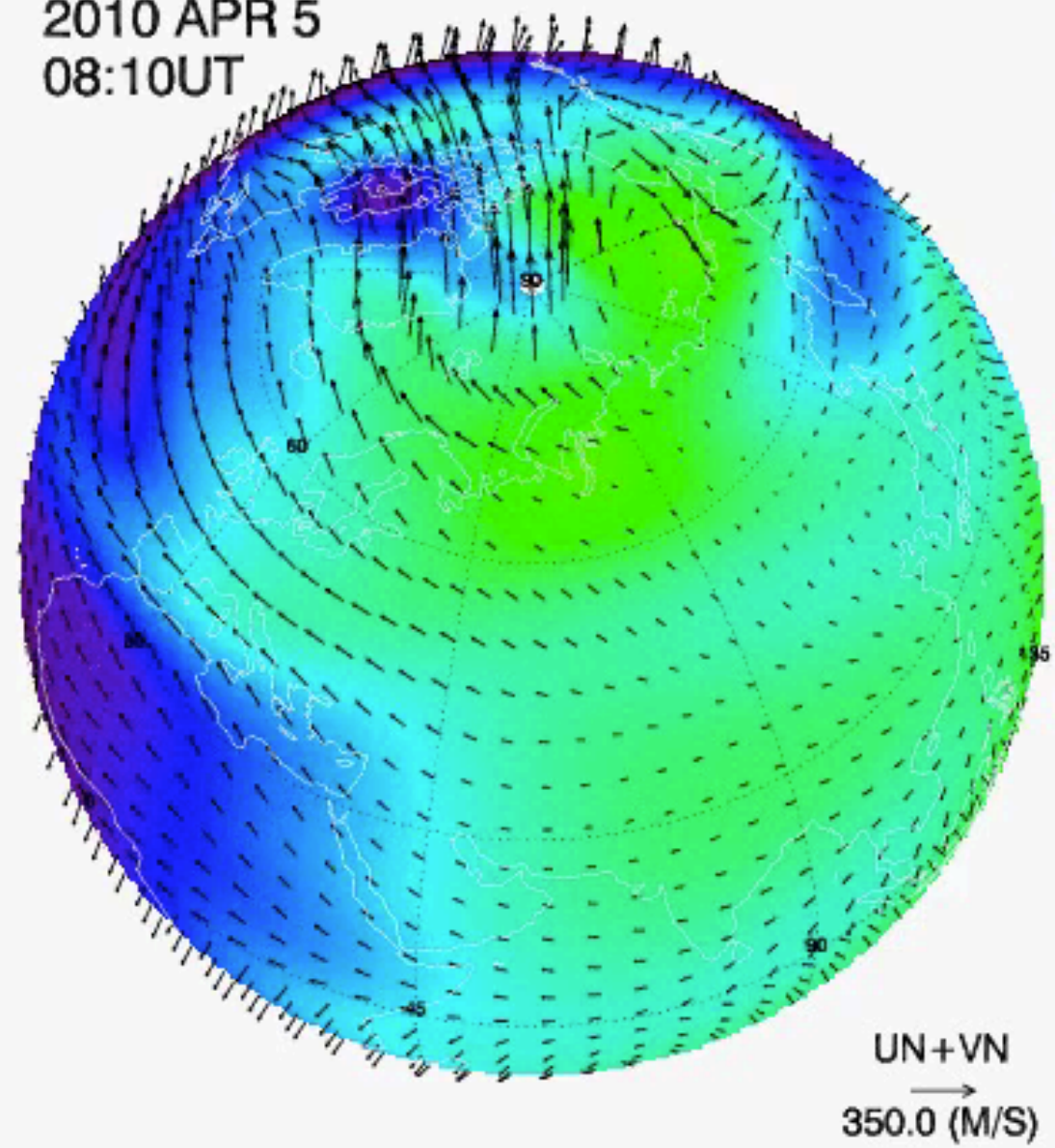
# Joule Heat ( $\text{mW}/\text{m}^2$ )

2010 APR 5  
08:10UT



# Neutral Temperature ( $^{\circ}\text{K}$ ) at 300km

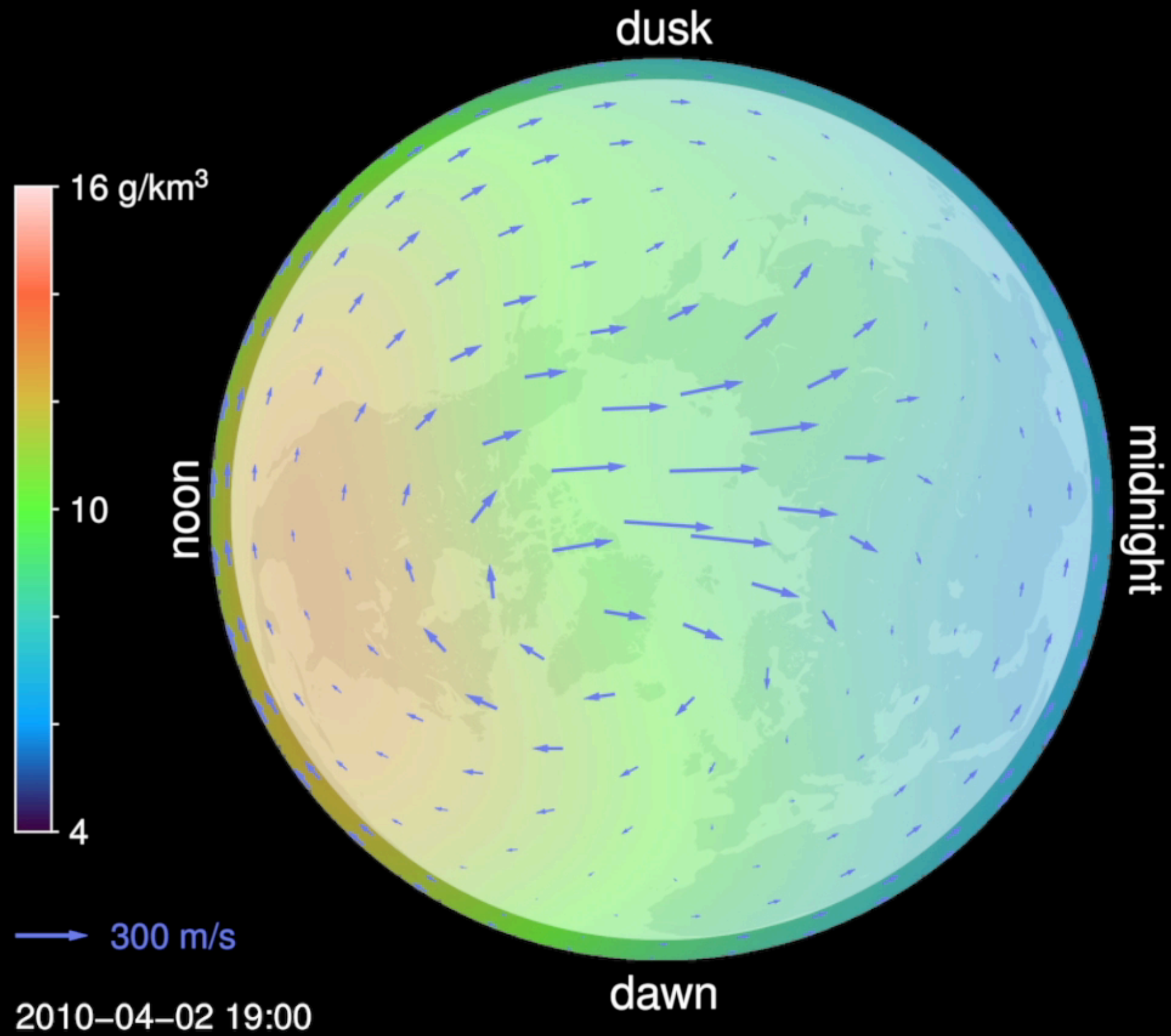
2010 APR 5  
08:10UT



UN+VN  
→  
350.0 (M/S)

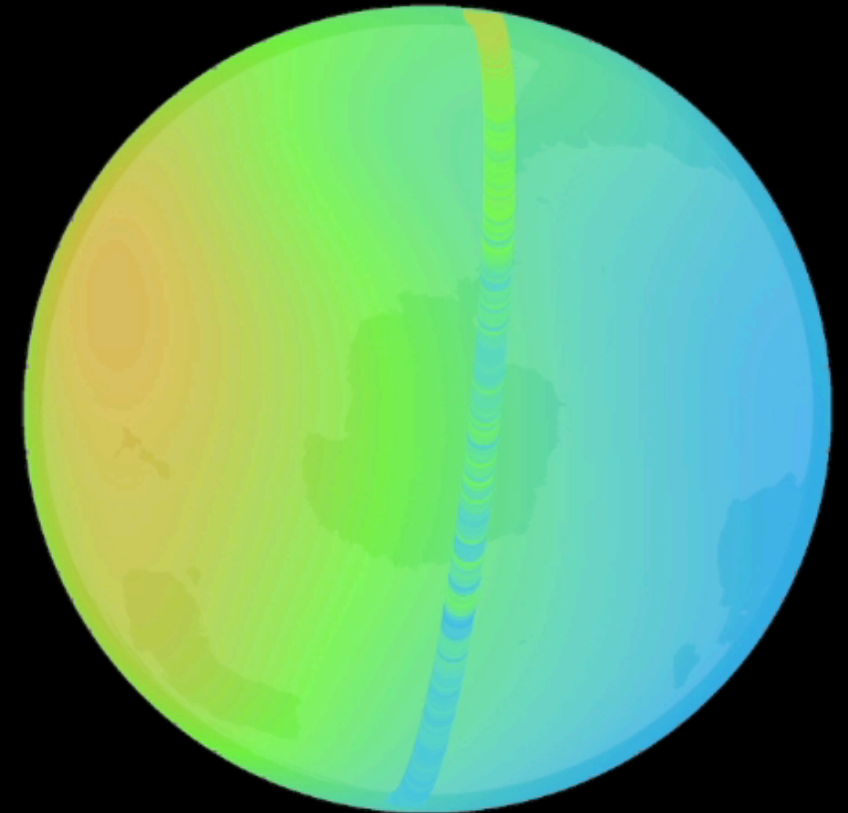
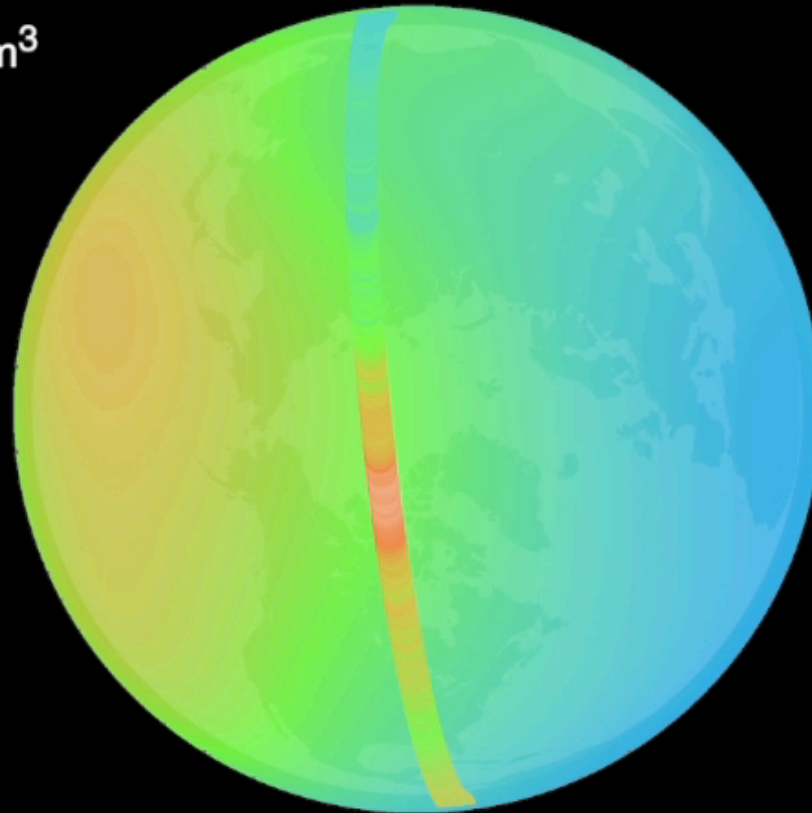
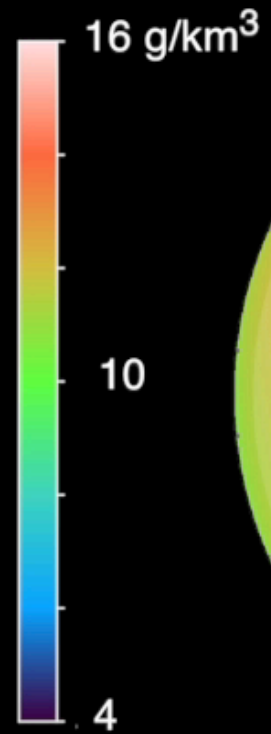






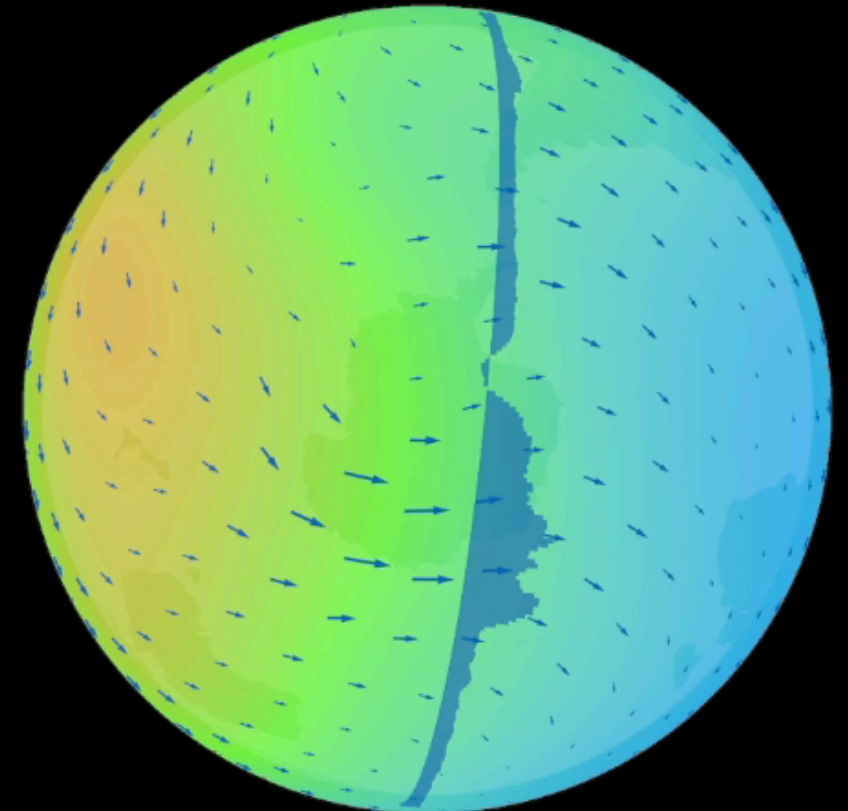
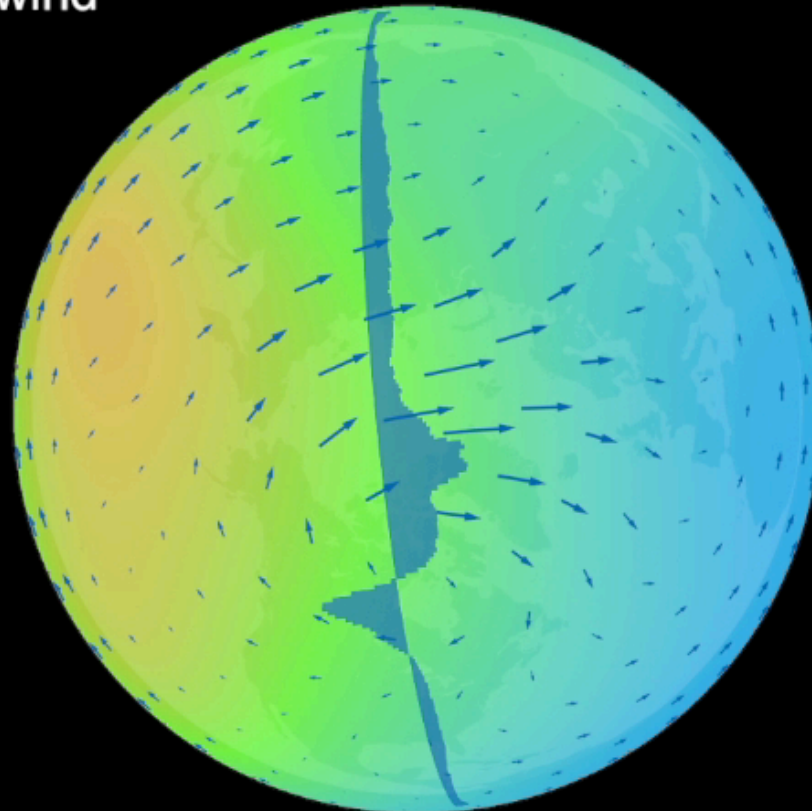


GOCE density / NRLMSISE-00 model density

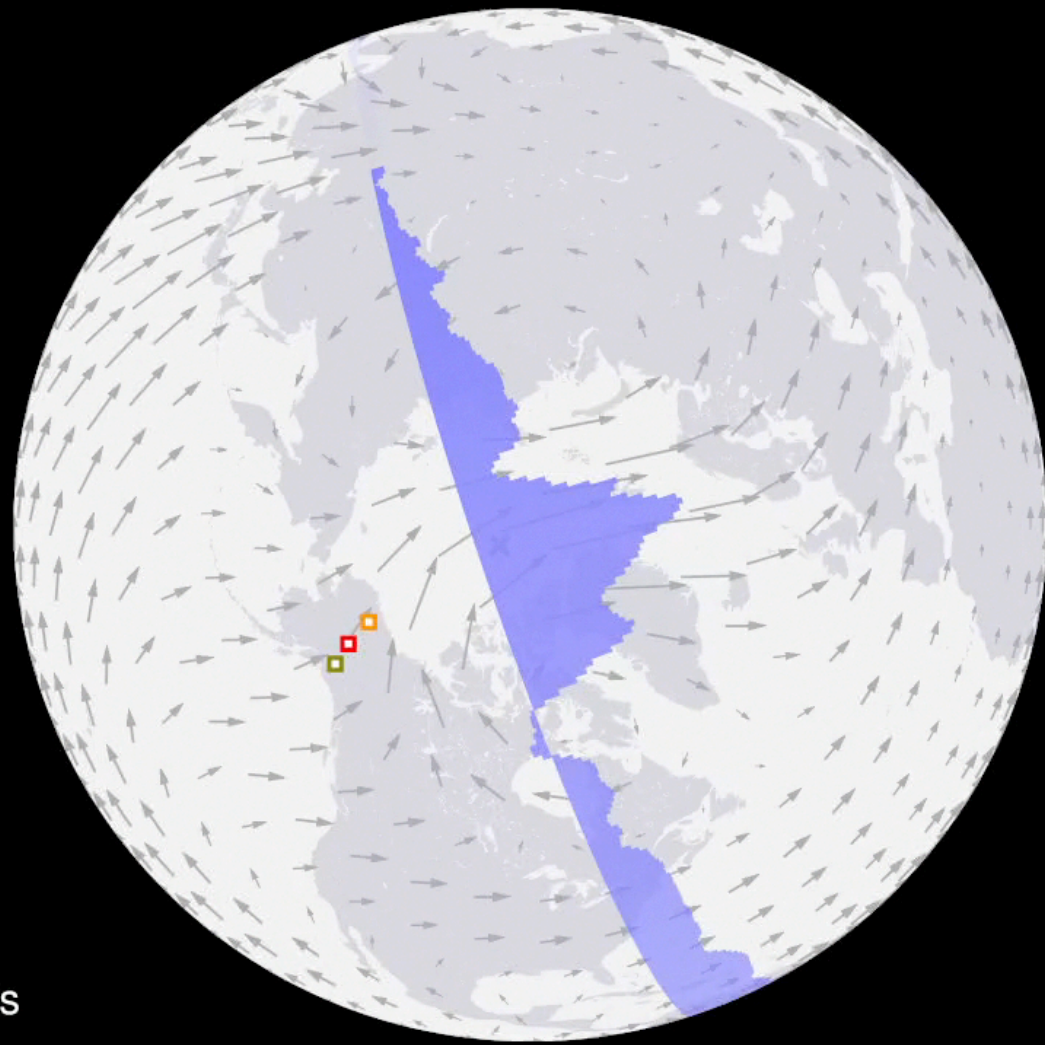


GOCE crosswind / HWM-07 model wind

→ 300 m/s

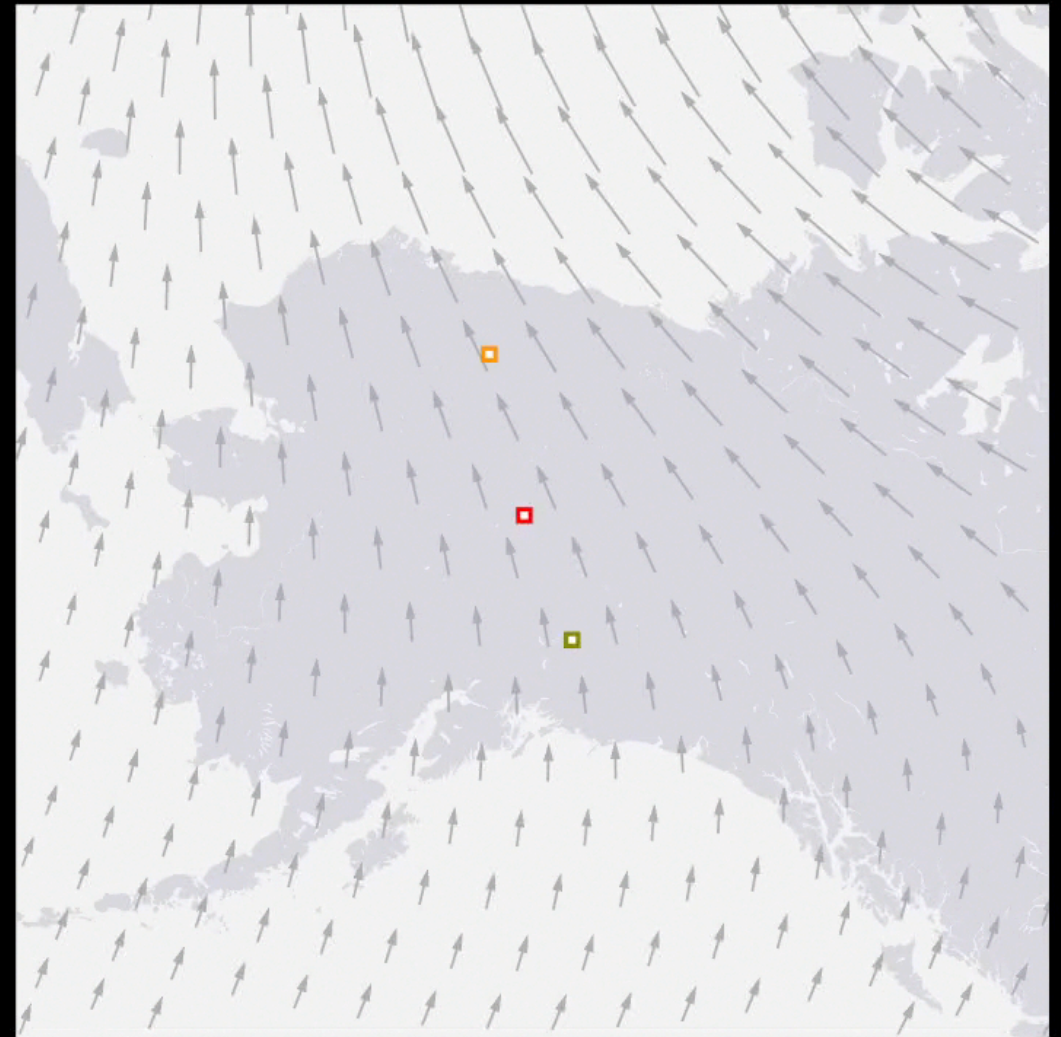


2010-04-03 23:55



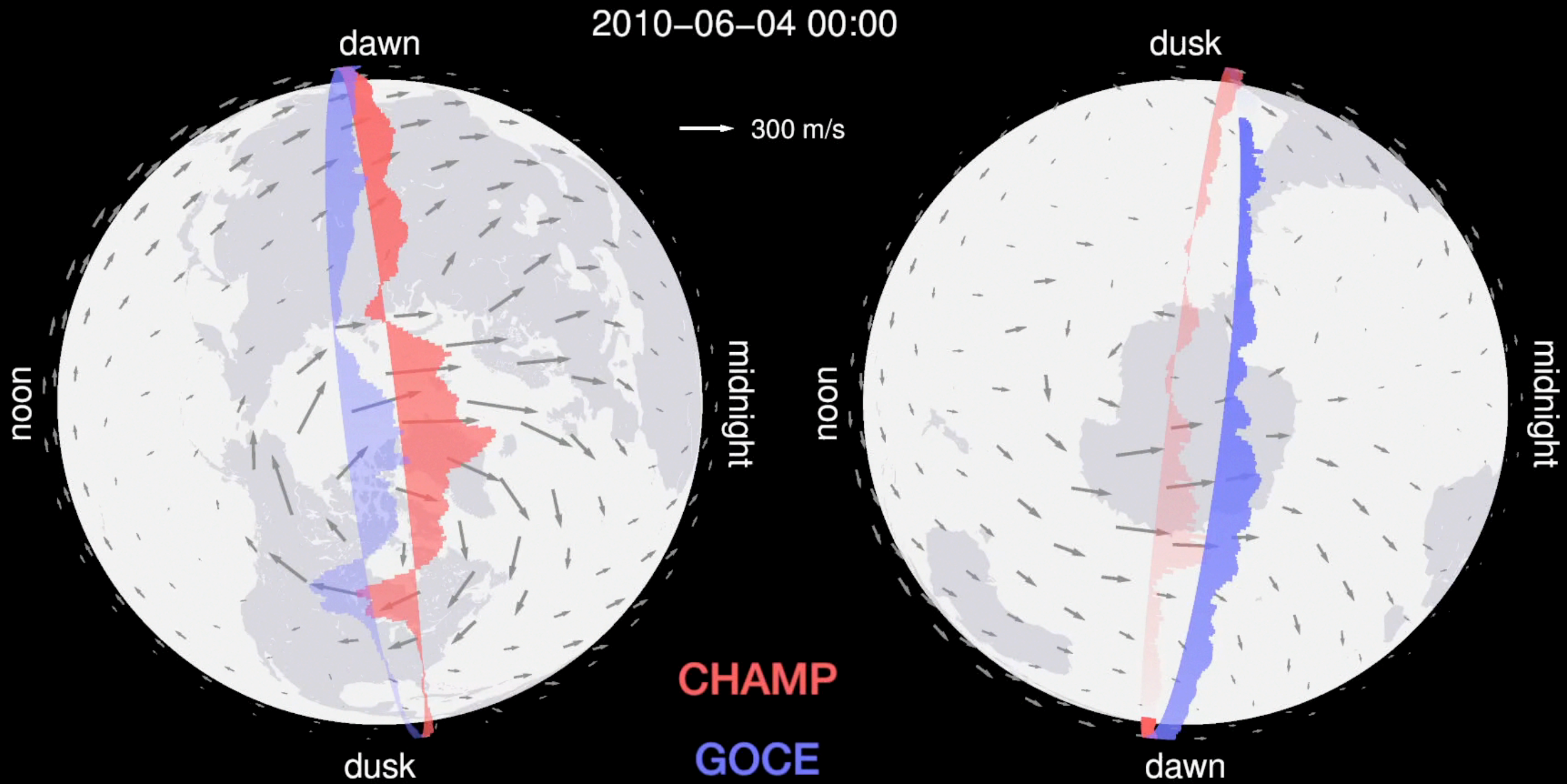
→ 200 m/s

2012-12-21 00:02





# GOCE and CHAMP crosswind comparison





## Tohoku Earthquake

11 March 2011

latitude  $38.32^{\circ}\text{N}$ , longitude  $142.37^{\circ}\text{E}$

magnitude 9.1





GOCE-satelliet. FOTO ESA

# Satelliet hoort beving

De trillingen die de Japanse aardbeving van 11 maart 2011 opwekte, zijn honderden kilometers hoog in de atmosfeer waargenomen. De Tohoku-aardbeving, bekend van de Fukushima-ramp, zond infrageluid met hoge golflengte omhoog en de effecten daarvan werden gesignaleerd door de GOCE-satelliet van de Europese ruimtevaartorganisatie ESA. Ook de zwaartekrachtgolven van de opgewekte tsunami zijn waargenomen. Het is voor het eerst dat dit effect van een aardbeving ook werkelijk in registraties van een satelliet is gevonden. Franse onderzoekers hebben er lang tevergeefs naar gezocht. Nu publiceren zij in *Geophysical Research Letters*. Eerste auteur is Raphael Garcia uit Toulouse.

De GOCE-satelliet, gelanceerd in 2009, is speciaal ontworpen om de zwaartekracht te meten en te variëren van wel 11 procent

een dunne atmosfeerlaag die voornamelijk bestaat uit ionen en vrije elektronen. Op die hoogte wordt nog veel luchtweerstand en dus afremming ondervonden. Die wordt met een permanent werkende ionenmotor overwonnen. De Delftse onderzoeker Eelco Doornbos, co-auteur van het artikel, ontwikkelde een methode om uit de stuwkracht van de ionenmotor en de opgewekte versnelling de dichtheid van de omringende lucht te berekenen. De dichtheid van de ionosfeer vertoont natuurlijke fluctuaties van ongeveer een procent.

Op 11 maart 2011 ontmoette de satelliet het front van de door de beving opgewekte golf infrageluid boven de Stille Oceaan. De versnelingsmeters signaleerden een door het infrageluid opgewekte windsterkte van 130 M/s. Doornbos berekende dat de trillingen van wel 11 procent

10 March 2013 Last updated at 11:20 GMT

Share

## Japan quake 'heard at edge of space'



By Jonathan Amos  
Science correspondent, BBC News

The great Tohoku earthquake in Japan two years ago was so big its effects were even felt at the edge of space.

Scientists say the Magnitude 9.0 tremor on 11 March 2011 sent a ripple of sound through the atmosphere that was picked up by the Goce satellite.



Goce flies lower than any other scientific satellite

The super-sensitive instrumentation was able to detect the disturbance as it passed through the wisps of air still present 255km above the surface.

The observation is reported in the journal *Geophysical Research Letters*.

It has long been recognised that major quakes will generate very low-frequency acoustic waves, or infrasound - a type of deep rumble at frequencies below those discernible to the human ear. But no spacecraft in orbit had the capability to record them, until now.

"We were looking for this signal before with other satellites and haven't seen it before that's because you need an incredibly fine instrument," said Eelco Doornbos of the European Space Agency (ESA).

### Related Stories

- Gravity mapper surfs atmosphere
- Sea sediments tell of past quakes
- What chance of a 'big one' in Tokyo?



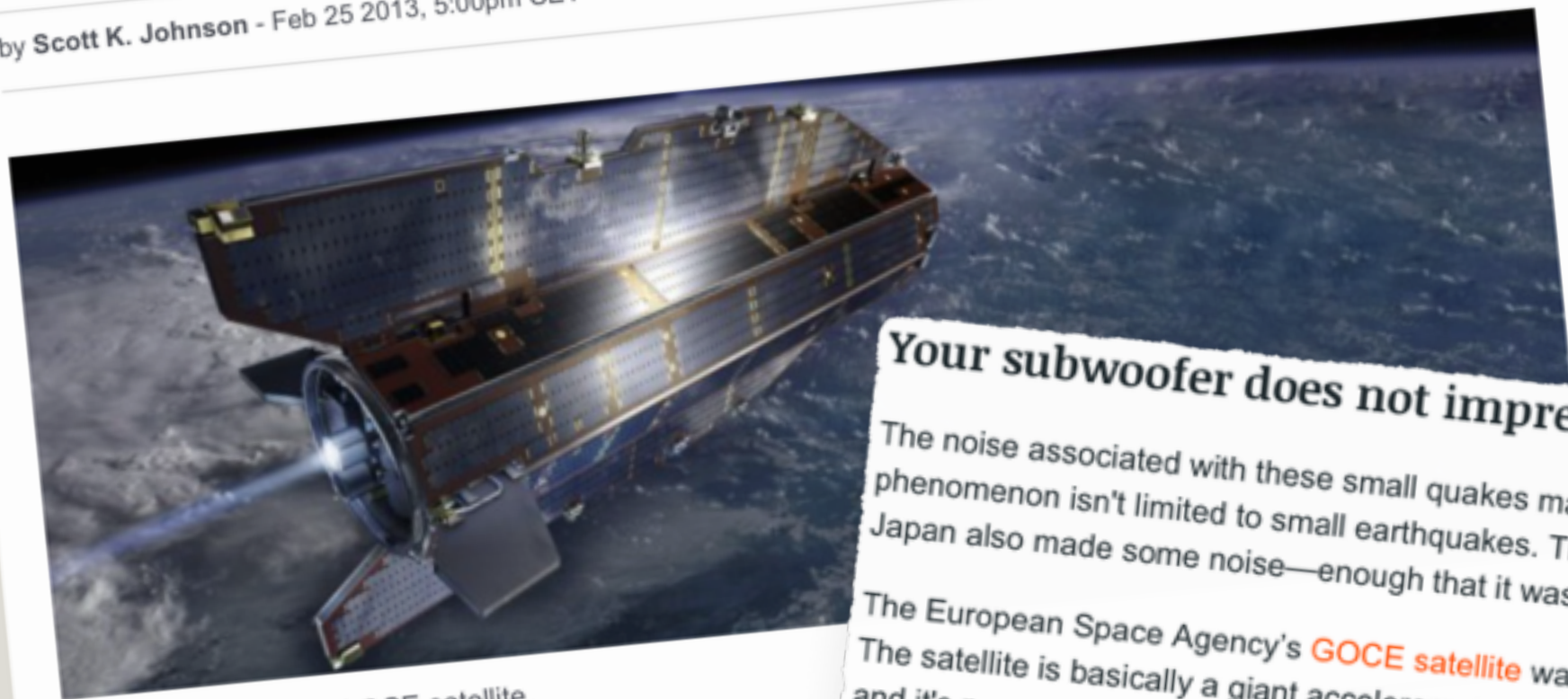
# SCIENTIFIC METHOD / SCIENCE & EXPLORATION

## Earthquakes' booms big enough to be detected from orbit

Satellites listened to the 2011 Japan quake and located fault beneath Spokane.

by Scott K. Johnson - Feb 25 2013, 5:00pm CET

Share Tweet 31



Artist's impression of GOCE satellite.

European Space Agency

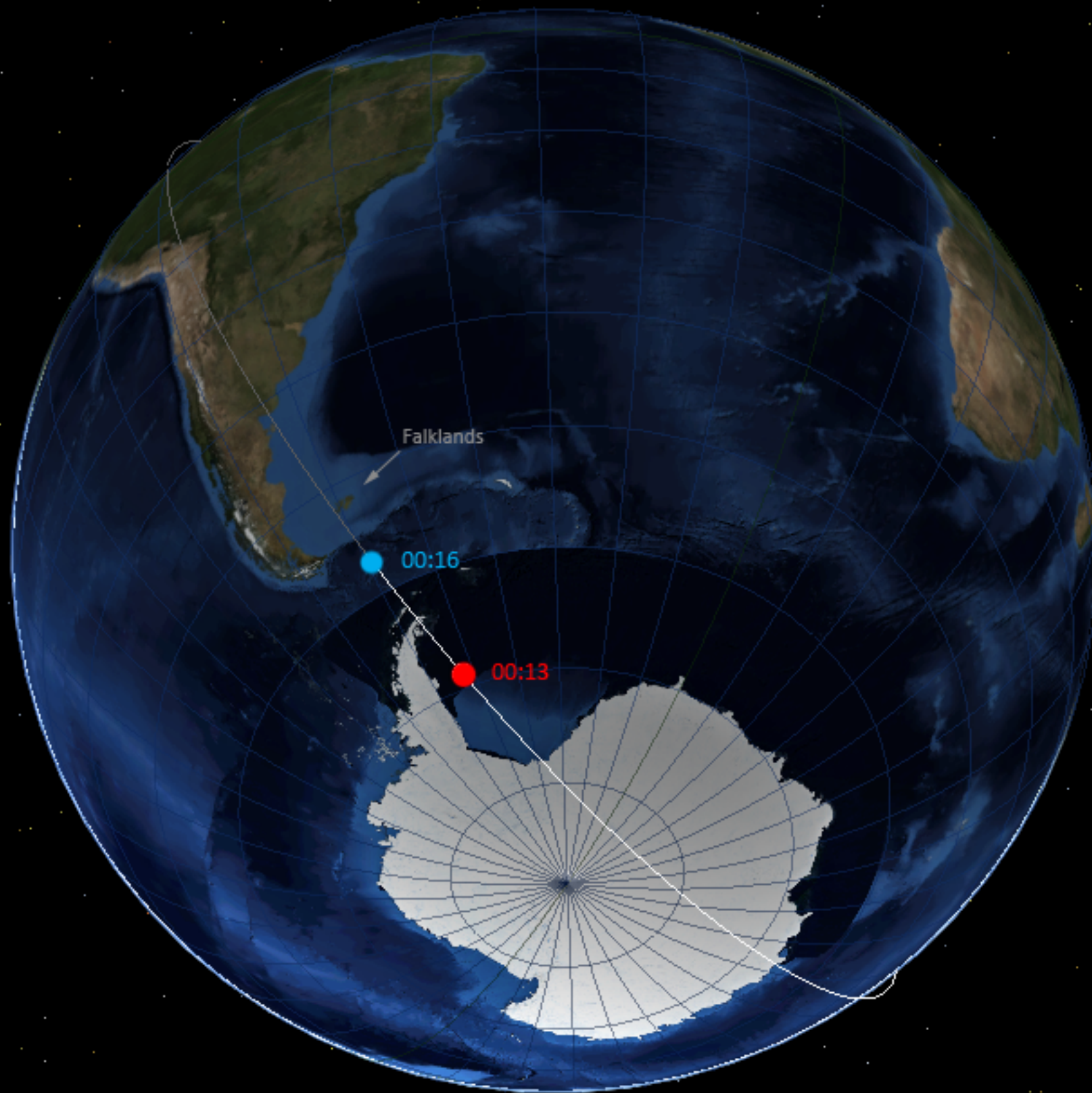
Last year, we reported on some **mysterious booms** small earthquakes. While it was an unusual story, occurrence. Early in the summer of 2001, folks in Spokane, Washington, reported hearing a series of booms. The sounds continued, off and on, for about five months. The booms were picked up by seismometers in the area. (A particularly loud boom occurred exactly one month after the September 11, 2001 terrorist attacks in New York did rattle some

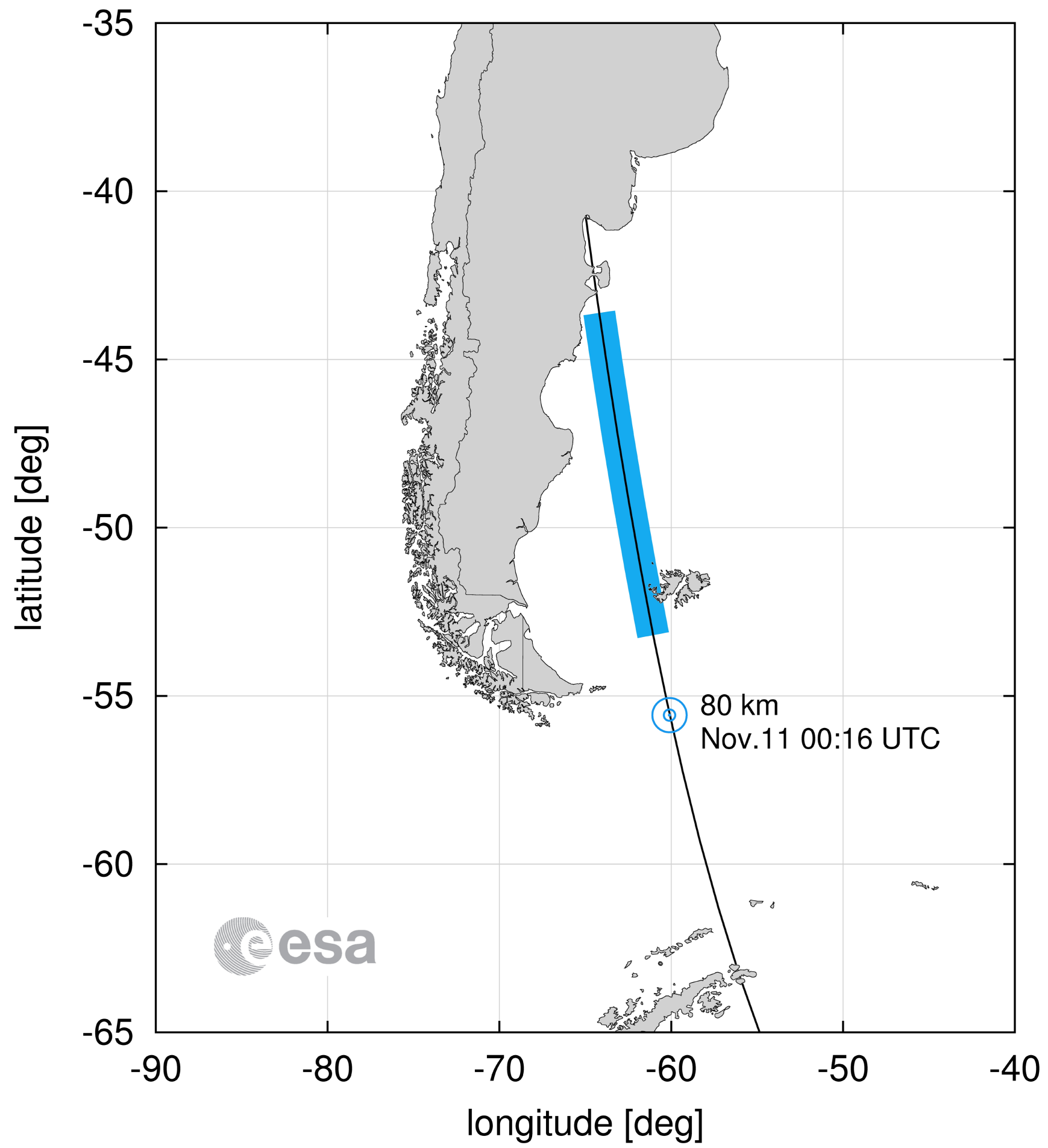
### Your subwoofer does not impress me, mortal

The noise associated with these small quakes may have shaken up local residents, but the phenomenon isn't limited to small earthquakes. The 2011 magnitude 9.0 Tohoku-Oki earthquake in Japan also made some noise—enough that it was detectable from 270 kilometers up.

The European Space Agency's **GOCE satellite** was not designed to be an earthquake eavesdropper. The satellite is basically a giant accelerometer capable of incredibly precise measurements of gravity, and it's normally used to study Earth processes like ocean circulation and melting ice sheets. But a group of researchers from France and the Netherlands decided to examine the satellite's data for any signals related to the massive earthquake in Japan. They weren't looking for changes of the Earth's surface—they were looking for the direct effect of the earthquake's infrasound boom reaching the satellite.









**GOCE re-entry, Nov 11, 2013**

Photo: Bill Charter



# Thermospheric density and winds from CHAMP and GRACE observations

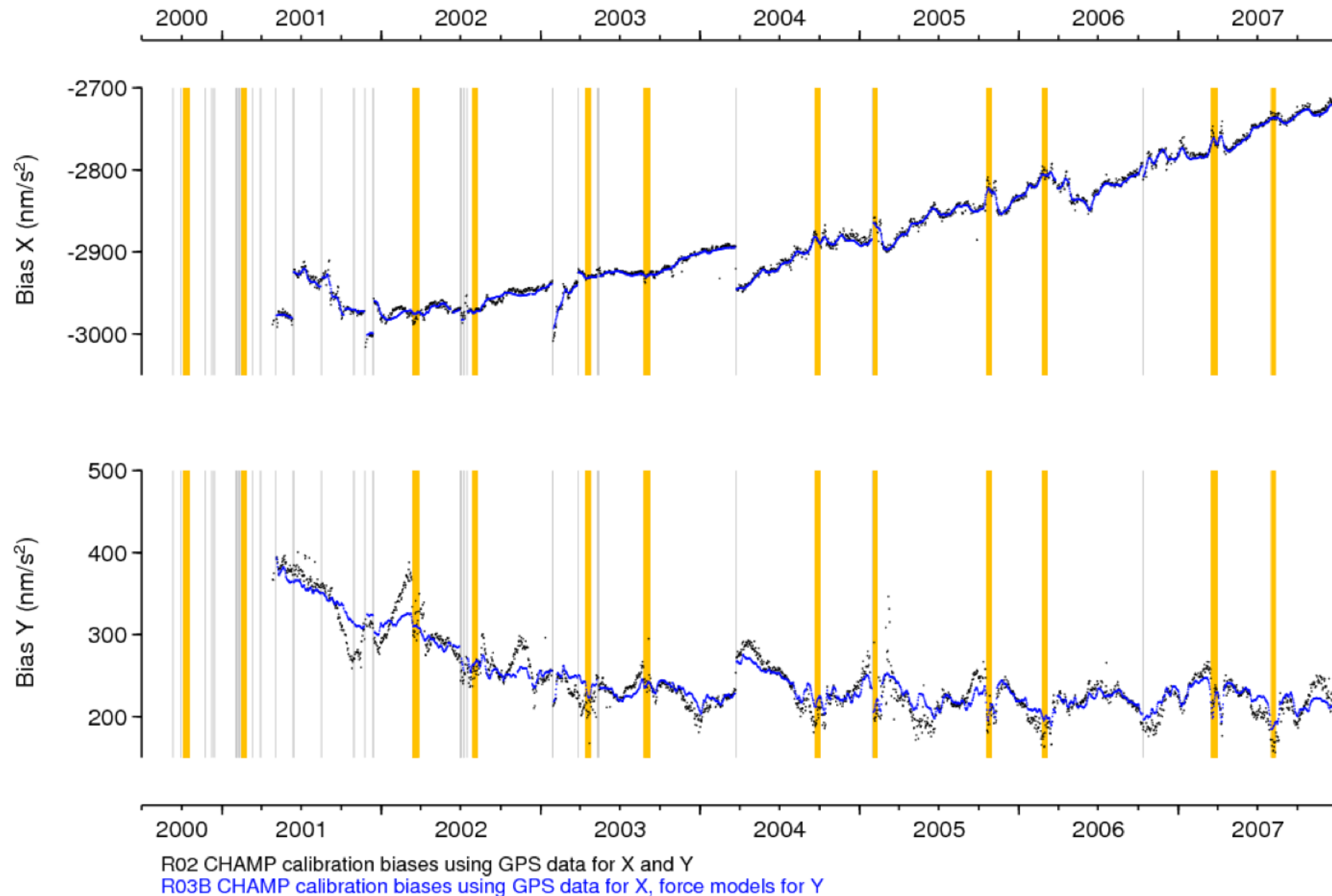
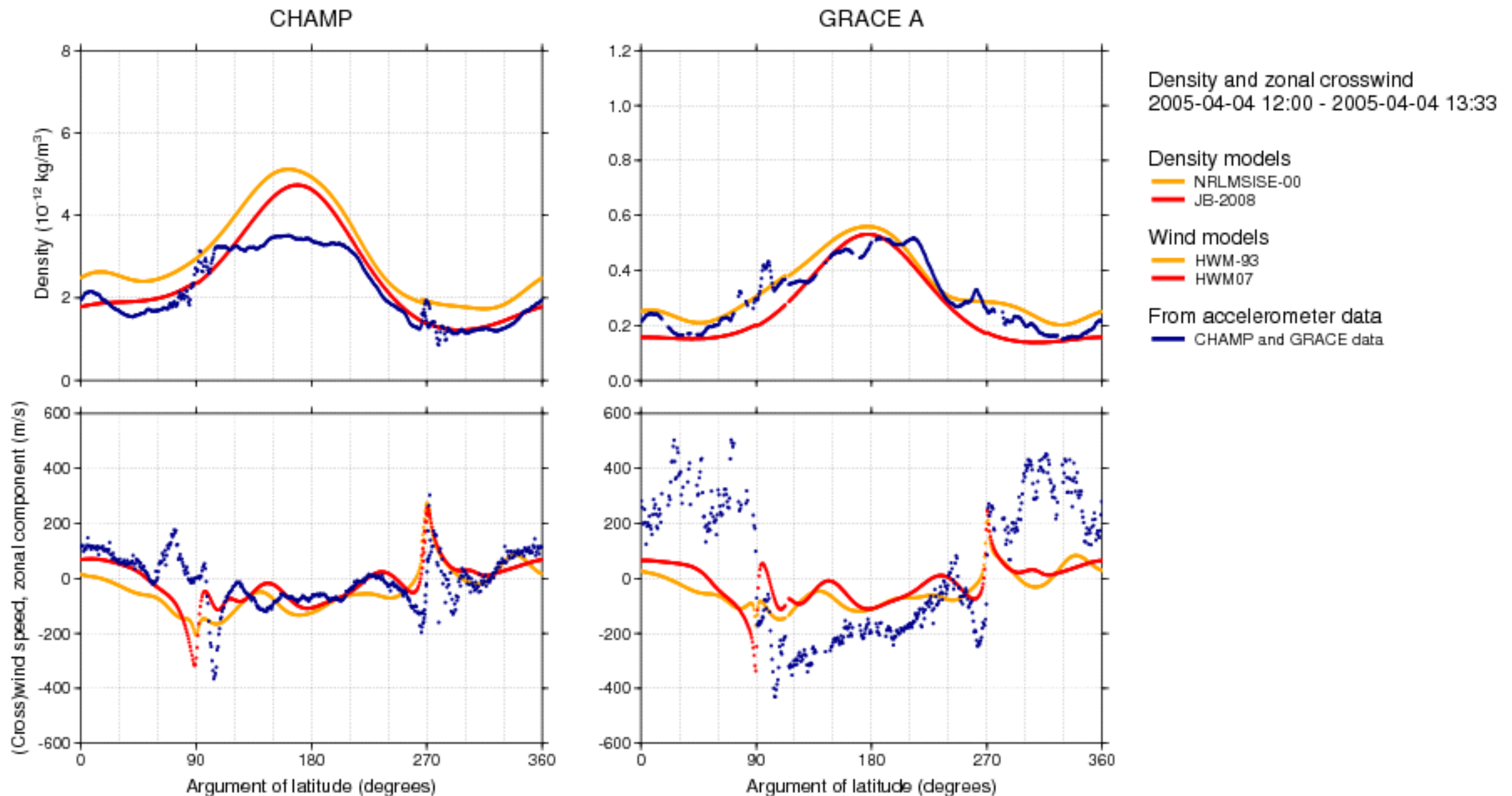


Figure 7.12 Comparison of calibration time series. Vertical grey lines indicate known satellite events, such as resets, software updates and switches of redundant electronics. The yellow/orange areas indicate periods without eclipses.

# Thermospheric density and winds from CHAMP and GRACE observations





# Thermospheric density and winds server TU Delft

The screenshot shows a Mac OS X desktop environment. At the top, the menu bar includes 'Grab', 'File', 'Edit', 'Capture', 'Window', and 'Help'. The system status bar on the right shows the time as 'Fri 10:40', the user 'pnamvisser', and various system icons like volume, network, and battery. The browser window is titled 'Air density models derived from multi-satellite drag observations' and shows the URL 'thermosphere.tudelft.nl/acceldrag/index.php'. The browser's address bar and navigation buttons are visible. The website content includes a navigation menu with 'home', 'data', 'documents', 'literature', and 'links'. The main content area has a 'Welcome' section with a paragraph about the DEOS Thermosphere web server, a 'Website news' section dated 'November 12, 2009' with a sub-section 'Website clean-up' describing a site transformation, and a footer stating 'This site is maintained by Eelco Doornbos'. On the right side of the desktop, a sidebar contains folder icons labeled 'Mavericks', 'DTU-DUT alias', 'Pieter', 'scratch', and 'Setup\_info'. The dock at the bottom contains icons for various applications including Safari, Mail, iPhoto, iMovie, iTunes, and several utility icons.

Grab File Edit Capture Window Help

43% Fri 10:40 pnamvisser

Air density models derived from multi-satellite drag observations

thermosphere.tudelft.nl/acceldrag/index.php

Reader

## Air density models derived from multi-satellite drag observations

home data documents literature links

### Welcome

Welcome to the DEOS Thermosphere web server, providing access to the reports of the ESA study on "Air density models derived from multi-satellite drag observations", and to the accompanying web interface for retrieval of satellite data related to drag and density research.

### Website news

November 12, 2009

#### Website clean-up

The website is undergoing a transformation from an internal website for the ESA project to a website in which data and documentation can be shared with colleagues who were not participants in the ESA project. For this reason, links to the management information of the ESA project has been removed. The data section has been undergoing a major reorganization. Metadata keywords have been added that describe (and control) the data processing. All data is undergoing a reprocessing using this new metadata structure. For a while, older data processing results will still be provided in the "Legacy" data category.

This site is maintained by [Eelco Doornbos](#)



Mavericks



DTU-DUT alias



Pieter



scratch



Setup\_info



# Thermospheric density and winds server TU Delft

Grab File Edit Capture Window Help

Air density models derived from multi-satellite drag observations

thermosphere.tudelft.nl/acceldrag/data.php

home data documents literature links

## Air density models derived from multi-satellite drag observations

### Data products

Those interested in the data available via this web interface are requested to contact Eelco Doornbos ([e.n.doornbos@tudelft.nl](mailto:e.n.doornbos@tudelft.nl)) before first use of the data and when the data is to be used in new scientific investigations or for publications. Any questions and remarks about the data or the website can also be sent to this address.

Click on one of the product names for more details and selection of data fields for downloads. The rightmost two columns indicate the current percentage of data available over the mission lifetime and the date of the most recent available data.

#### Categories

- CHAMP
  - [CH\\_Basic](#)
  - [CH\\_Models](#)
  - [CH\\_Panels](#)
  - [CH\\_Results](#)
- GRACE
  - [GA\\_Basic](#)
  - [GA\\_Models](#)
  - [GA\\_Panels](#)
  - [GB\\_Basic](#)
  - [GB\\_Models](#)
  - [GB\\_Panels](#)
- Legacy
  - [CH\\_PN\\_R02](#)
  - [CH\\_PN\\_R03](#)
  - [GA\\_PN\\_R02](#)
  - [GA\\_PN\\_R03](#)

#### CH\_Basic data products

##### Accelerations

<a href="#">Accel_CH-OG-2-ACC</a>	Linear accelerations, copied from the CH-OG-2-ACC product (uncalibrated).	97.4 %	2010-09-04
<a href="#">Accel_Interpolated</a>	Linear accelerations, copied from the CH-OG-2-ACC product (uncalibrated).	97.4 %	2010-09-04
<a href="#">Accel_Corrections</a>	Linear acceleration corrections, copied from the CH-OG-2-ACC product.	97.4 %	2010-09-04
<a href="#">Accel_CalibrationParameters</a>	Calibration parameters	85.6 %	2010-09-04
<a href="#">Accel_Calibrated</a>	Linear accelerations, calibrated	85.5 %	2010-09-04
<a href="#">Accel_Calibrated_EventsEdited</a>	Calibrated linear accelerations, with data coinciding with satellite events removed	85.4 %	2010-09-04

##### Orbit

<a href="#">Orbit_CH-OG-3-RSO</a>	Earth-fixed cartesian positions and velocities from the Rapid Science Orbits product.	97.8 %	2010-09-04
<a href="#">Orbit_TLE</a>	Earth-fixed cartesian positions and velocities from Two-Line Elements.	100.0 %	2010-09-18
<a href="#">OrbitNumber</a>	Orbit number (measured from first ascending node after launch)	100.0 %	2010-09-18
<a href="#">Orbit_Geo</a>	Geodetic coordinates and other derived parameters from the Rapid Science Orbits.	87.9 %	2010-09-04
<a href="#">Orbit_EquatorLST_TLE</a>	Local solar time at closest equator crossings	87.0 %	2010-05-22
<a href="#">Orbit_Geo_TLE</a>	Geodetic coordinates and other derived parameters from TLEs	89.9 %	2010-09-19
<a href="#">Orbit_Sol</a>	Parameters related to the position of the satellite with respect to the Sun.	86.6 %	2010-09-04
<a href="#">Orbit_Kepler_Osculating</a>	Osculating Kepler elements and related orbit parameters.	87.9 %	2010-09-04
<a href="#">Orbit_Kepler_Mean</a>	Mean Kepler elements and related orbit parameters.	80.6 %	2009-11-08
<a href="#">Orbit_SC_Velocity</a>	Speed of the atmosphere with respect to the spacecraft body-fixed frame due to orbital velocity and corotation of the atmosphere with the Earth.	86.5 %	2010-09-04
<a href="#">Orbit_SC_Velocity_POD</a>	Speed of the atmosphere with respect to the spacecraft body-fixed frame due to orbital velocity and corotation of the atmosphere with the Earth.	87.1 %	2010-09-04

##### Attitude

<a href="#">Quat_CH-OG-2-ACC</a>	Attitude quaternions, from inertial to S/C frame, copied from the CH-OG-2-ACC product	91.2 %	2010-09-04
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