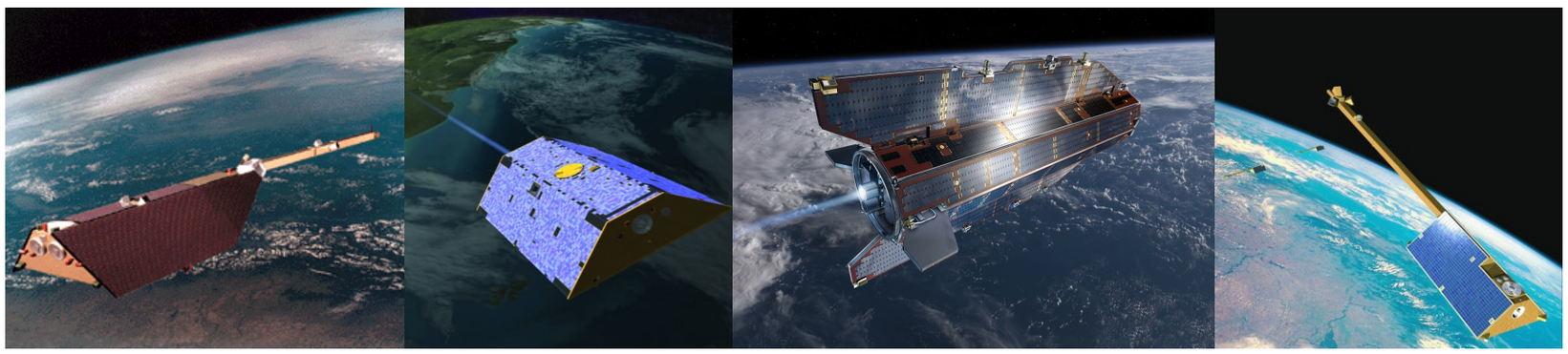
Retrieval of thermosphere density and wind from space-borne accelerometery – activities at TU Delft

Eelco Doornbos, Pieter Visser

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



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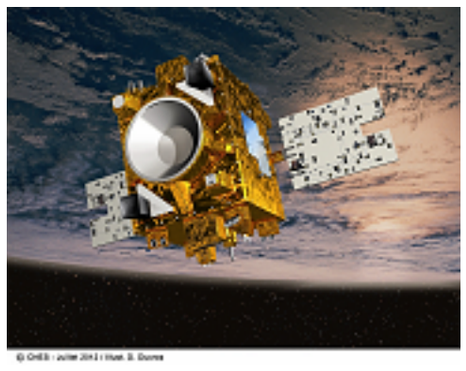
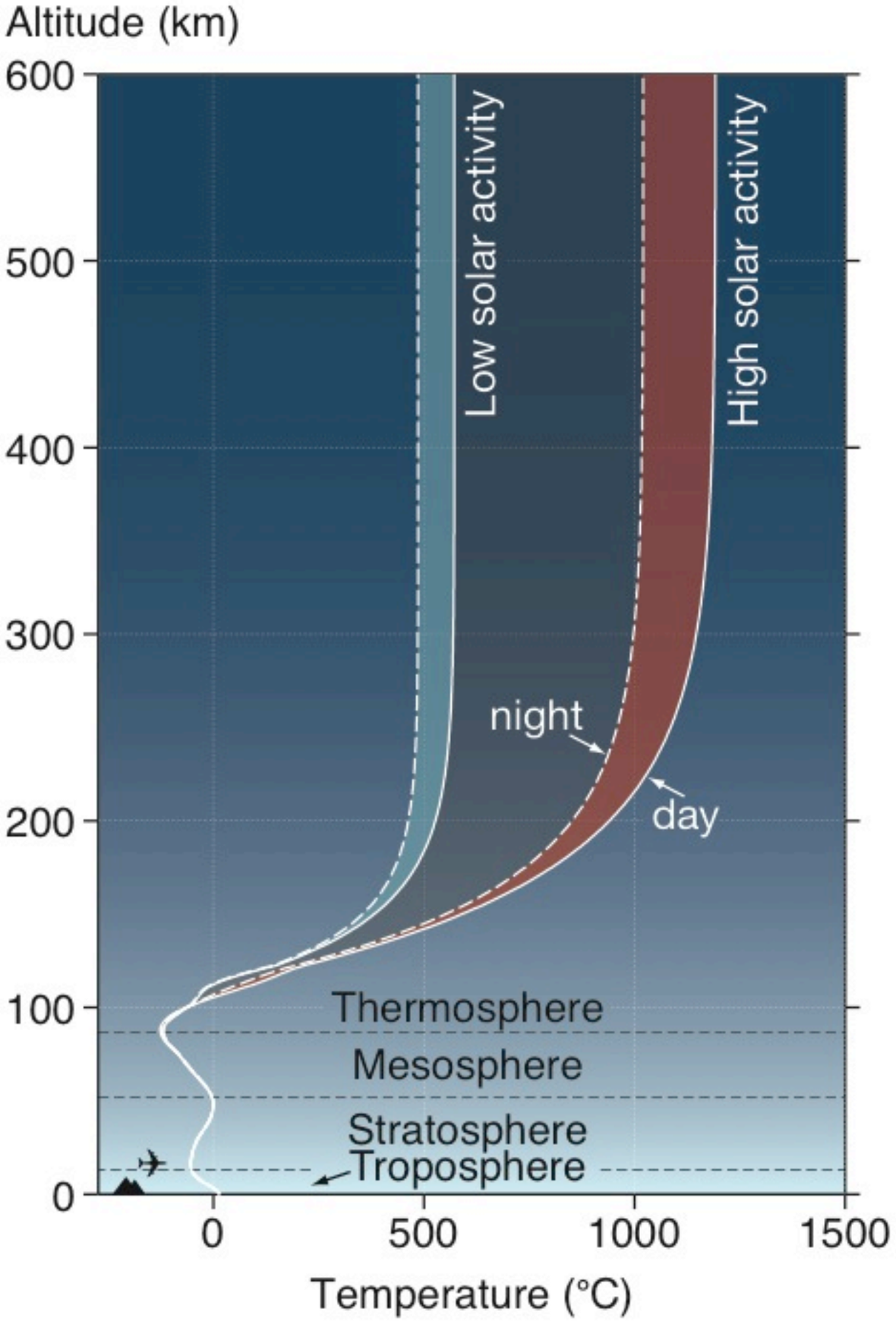
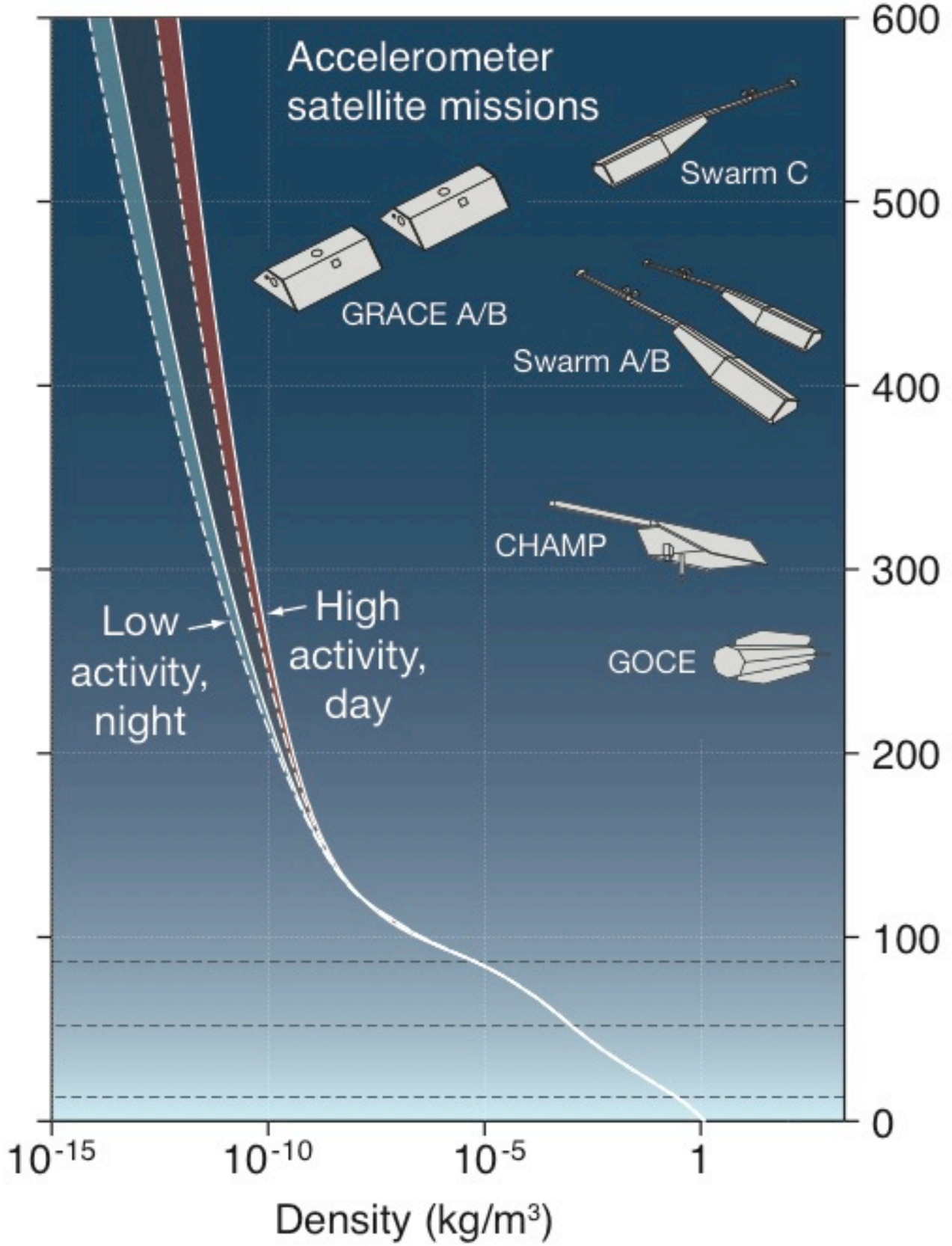


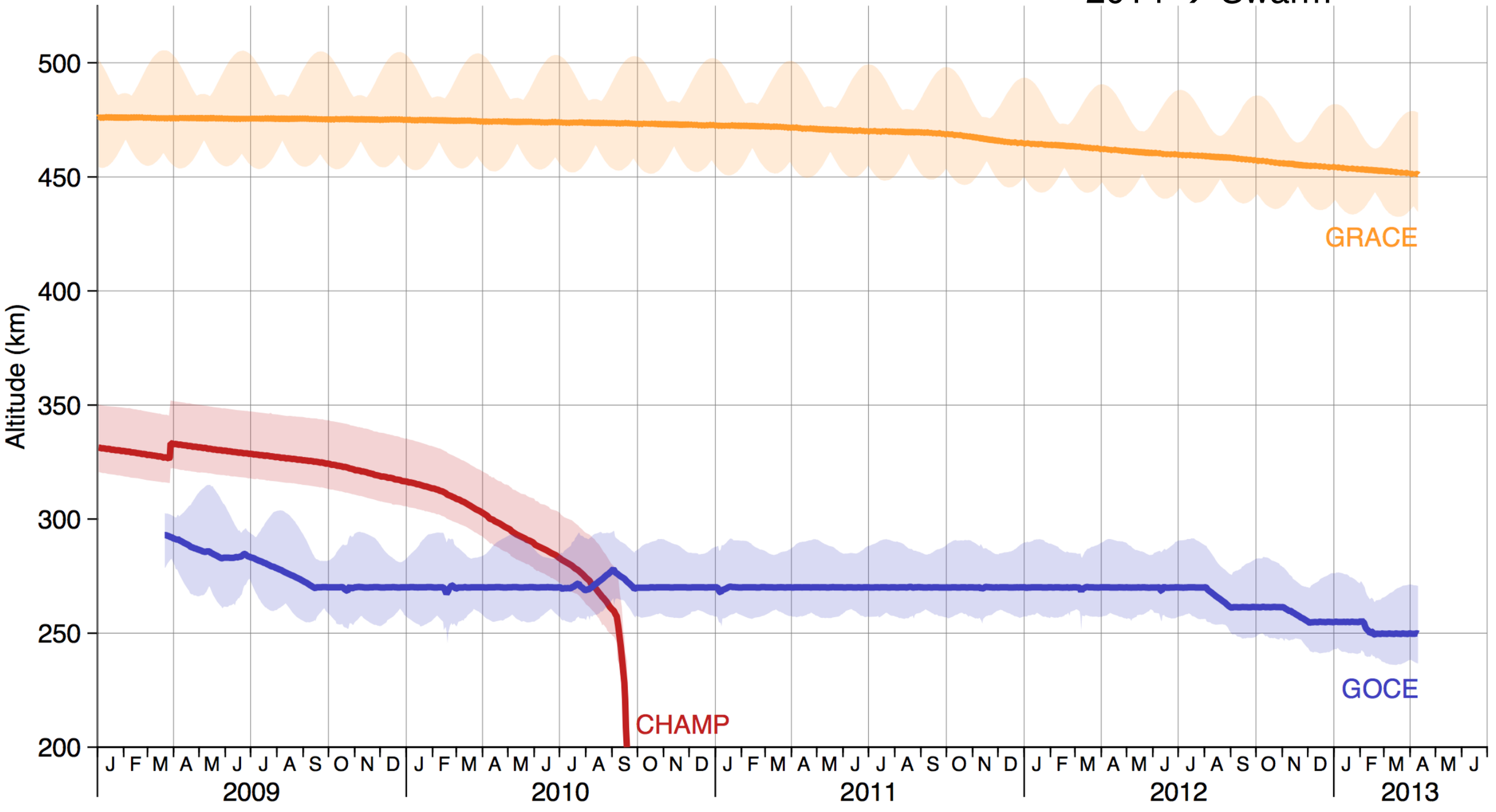
Microscope: 700 km, sun-synchronous





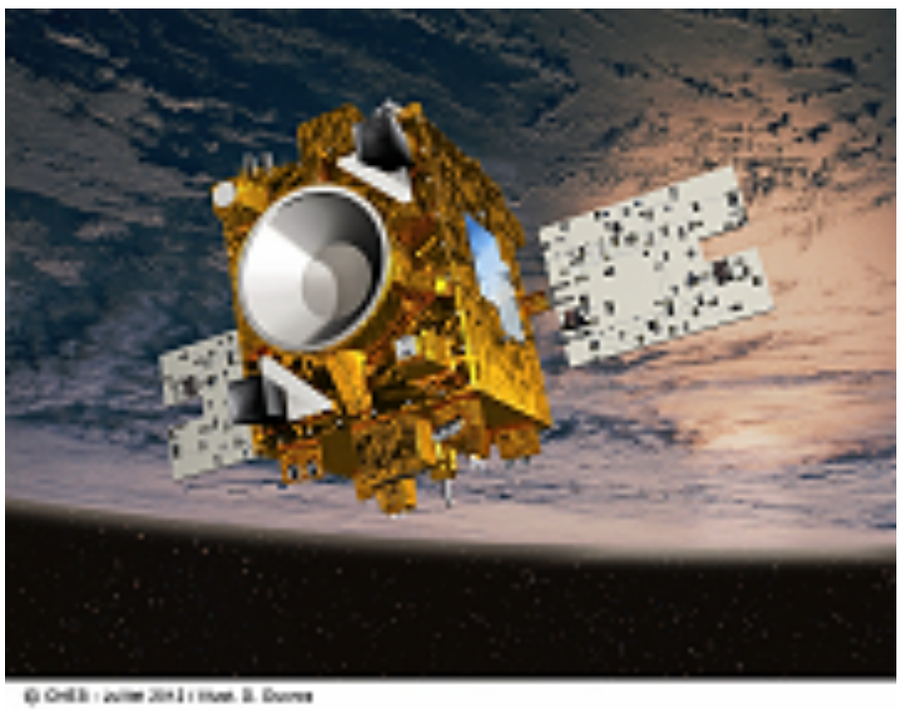
2016 → Microscope

2014 → Swarm



MICROSCOPE

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

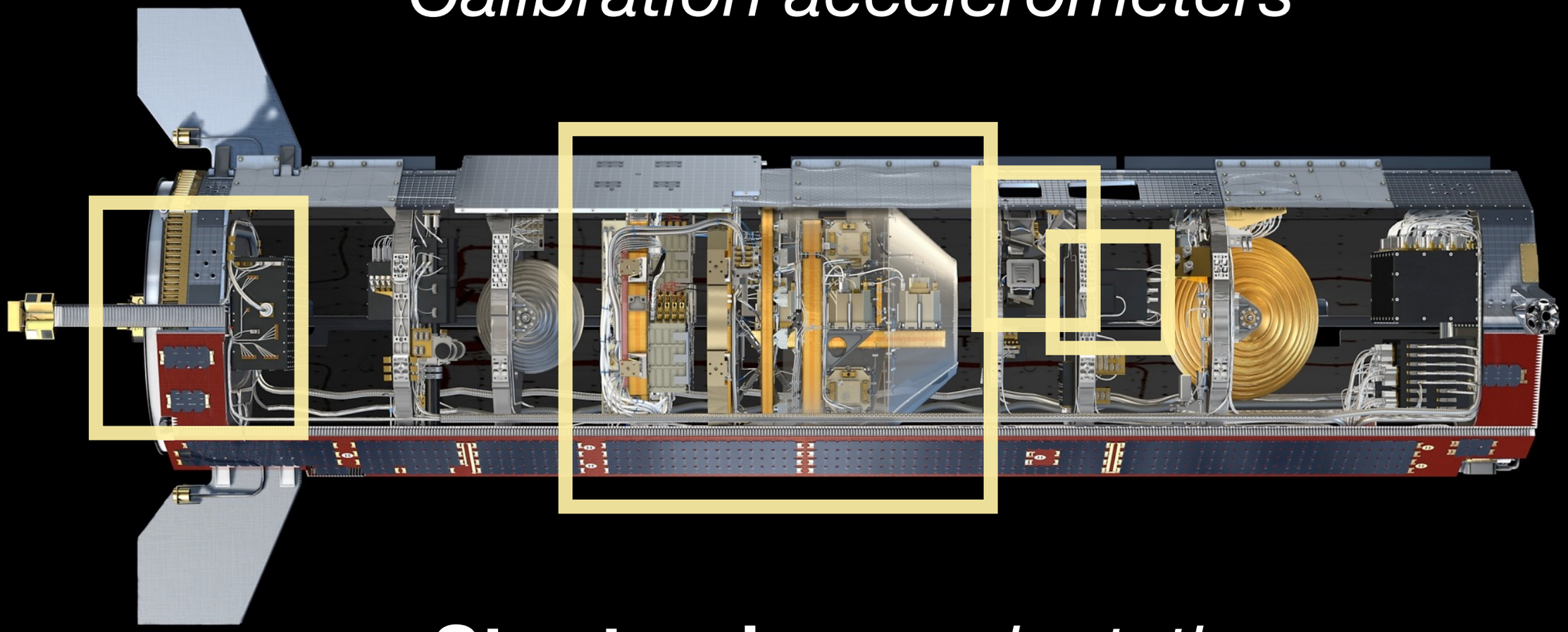


GOCE

- Operations: 2009-2013
- Sun-synchronous
- 220-250 km altitude
- Accelerometers: 10^{-12} m/s^2
- 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*

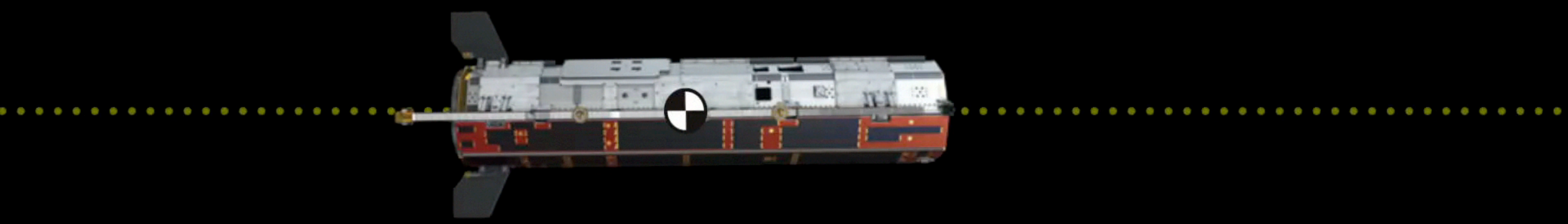
Velocity of GOCE relative to atmosphere

Orbital velocity: 7800 m/s

Rotational velocity atmosphere: up to 470 m/s

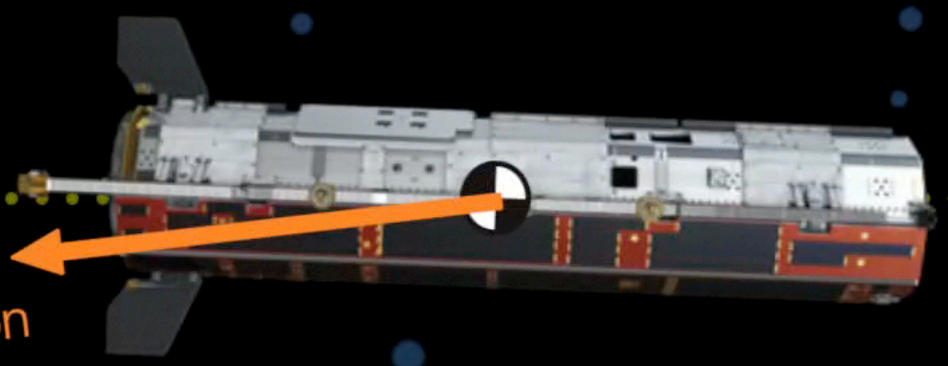
Wind in the thermosphere: up to 1000 m/s

Dynamics of GOCE:
Aerodynamic acceleration



Dynamics of GOCE

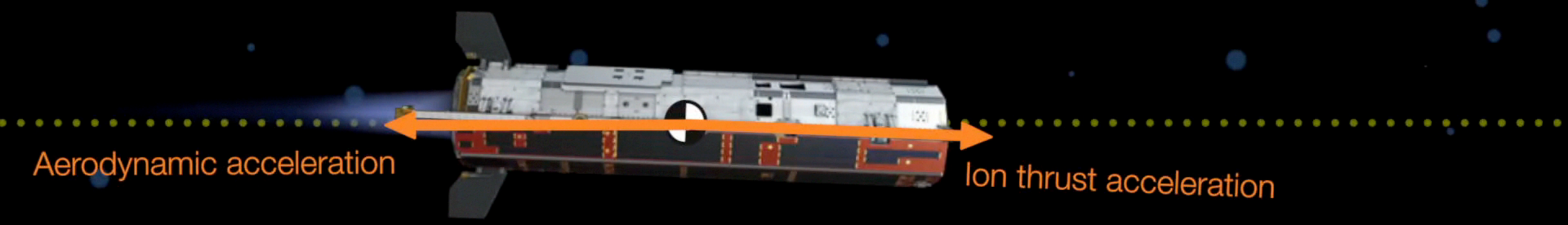
Acceleration provoked by ion engine

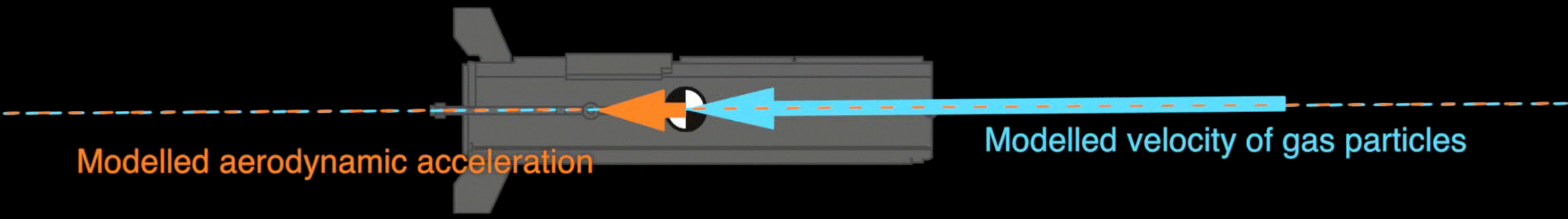


Aerodynamic acceleration

Dynamics of GOCE

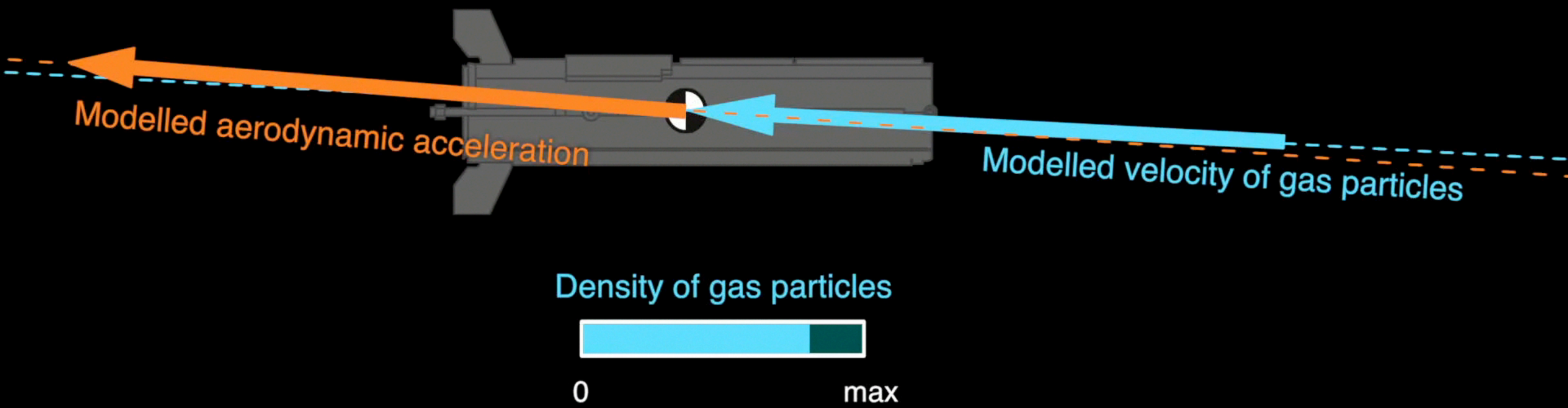
Accelerations caused by radiation pressure





Density of gas particles

0 max


Modelled aerodynamic acceleration
Modelled velocity of gas particles
Density of gas particles
0
max

Observed aerodynamic acceleration

Modelled aerodynamic acceleration

Modelled velocity of gas particles

Density of gas particles

0 max

Observed aerodynamic acceleration

Modelled aerodynamic acceleration

Initial velocity, zero crosswind

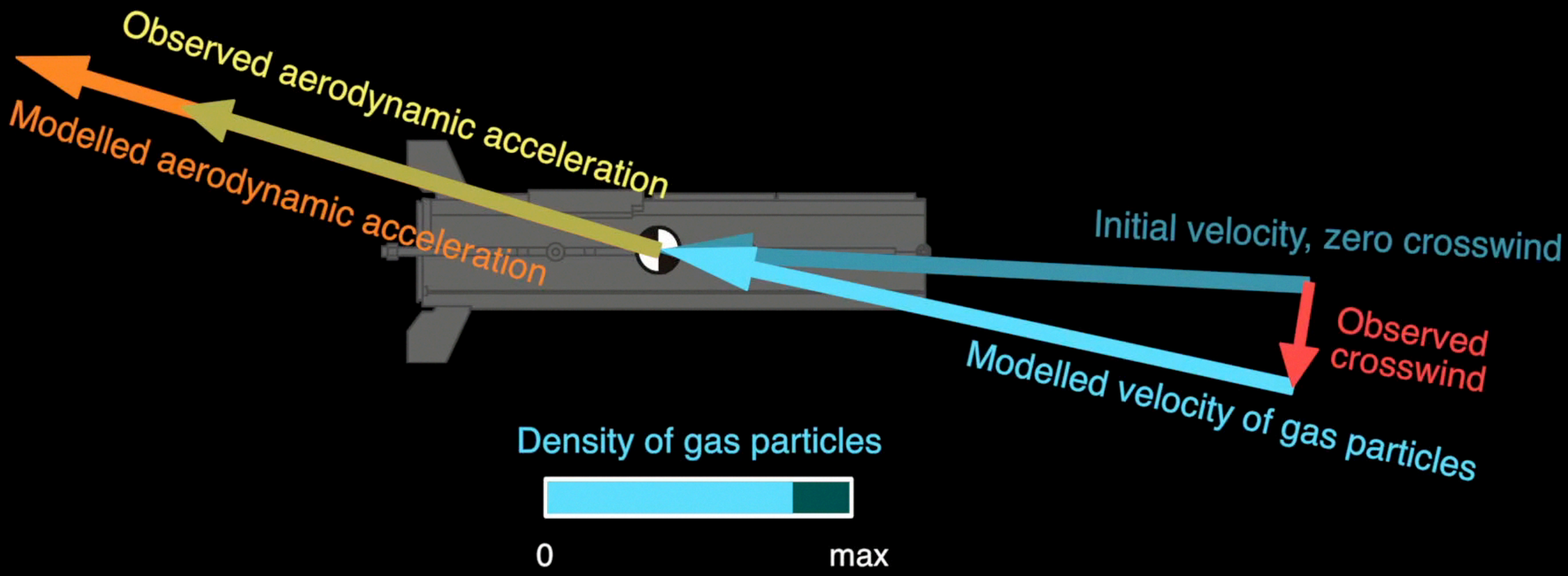
Observed crosswind

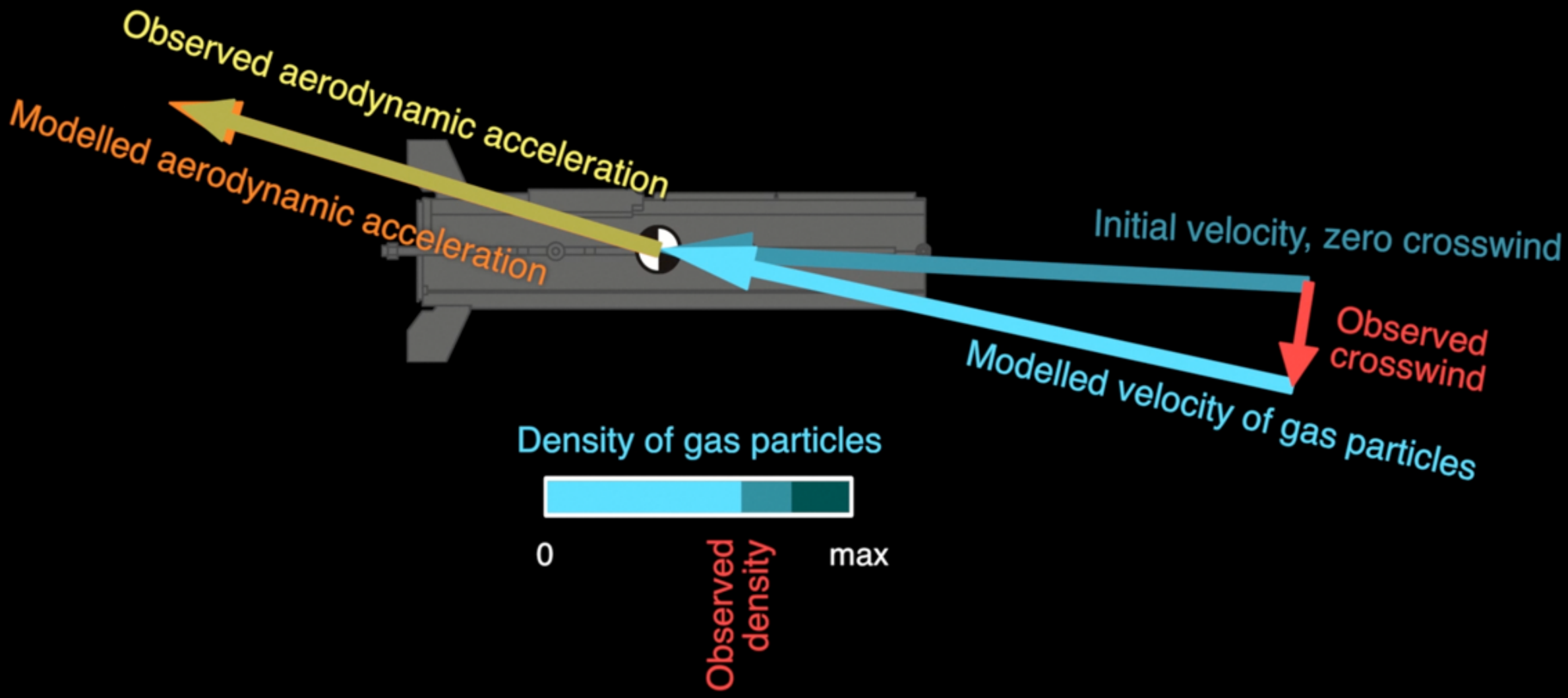
Modelled velocity of gas particles

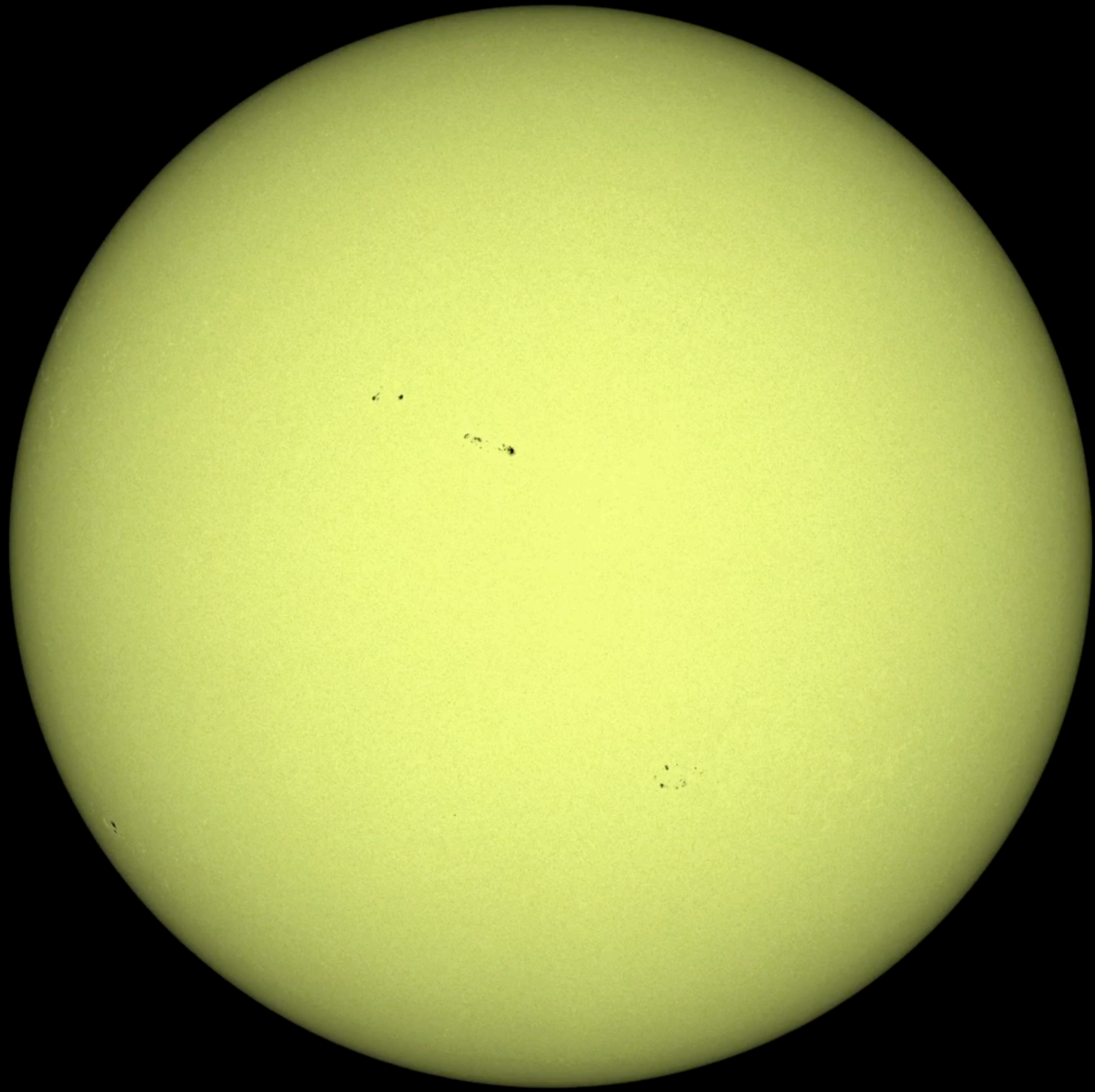
Density of gas particles

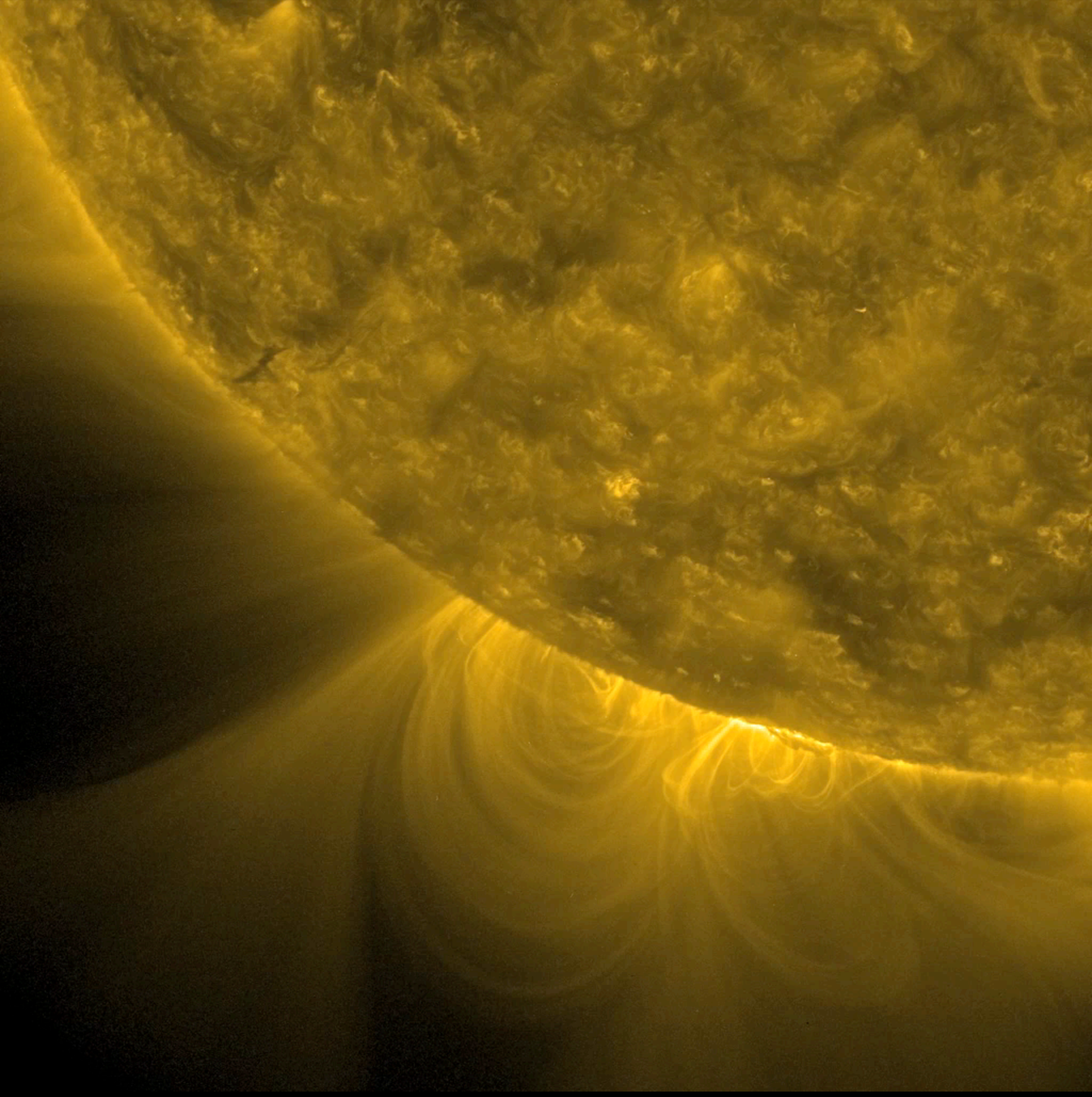
0

max

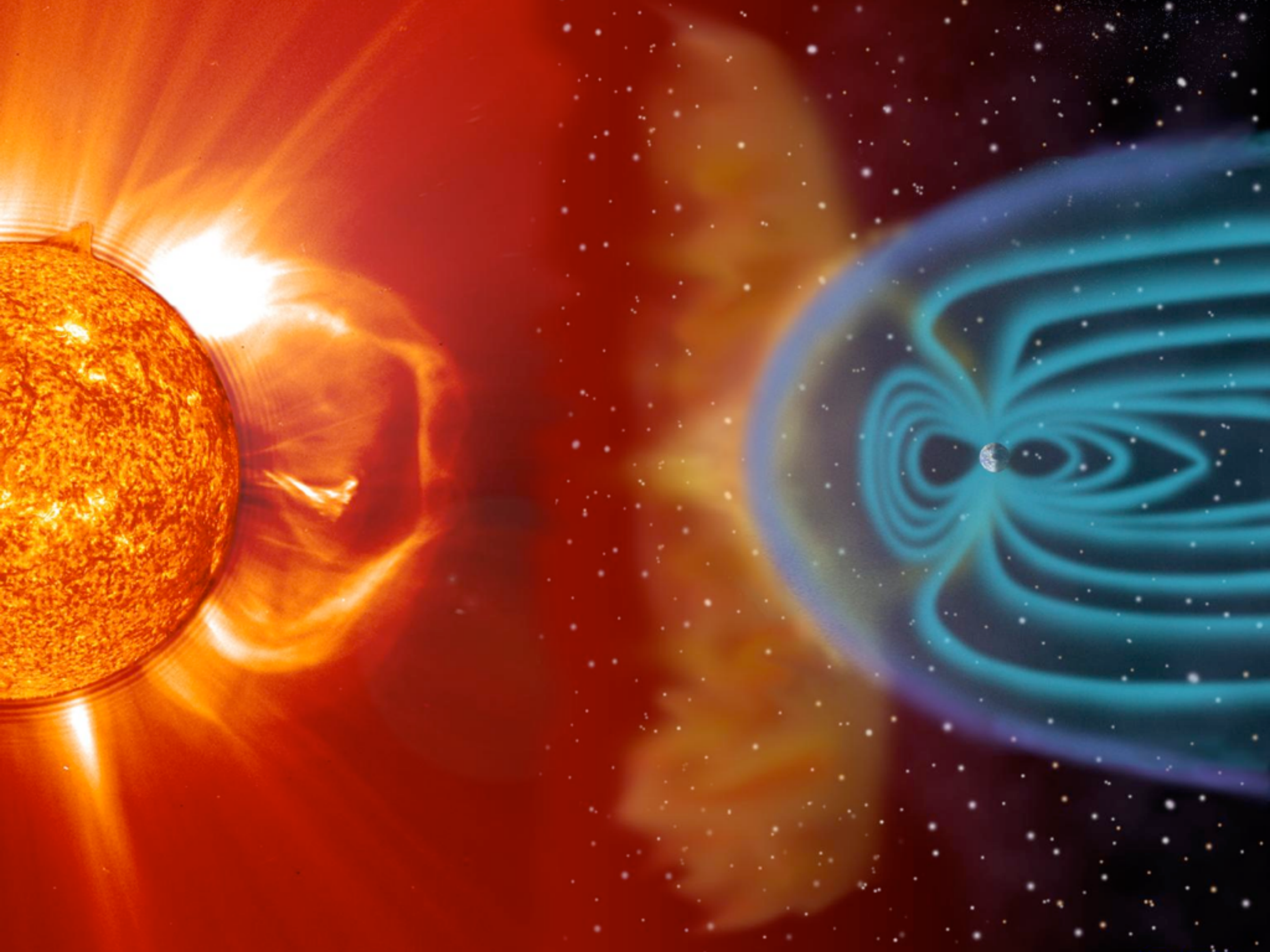

Observed aerodynamic acceleration
Modelled aerodynamic acceleration
Initial velocity, zero crosswind
Observed crosswind
Modelled velocity of gas particles
Density of gas particles
0
max


Observed aerodynamic acceleration
Modelled aerodynamic acceleration
Initial velocity, zero crosswind
Observed crosswind
Modelled velocity of gas particles
Density of gas particles
0
max
Observed density


SDO/HMI Quick-Look Continuum: 2010.11.13_07:53:15_TAI

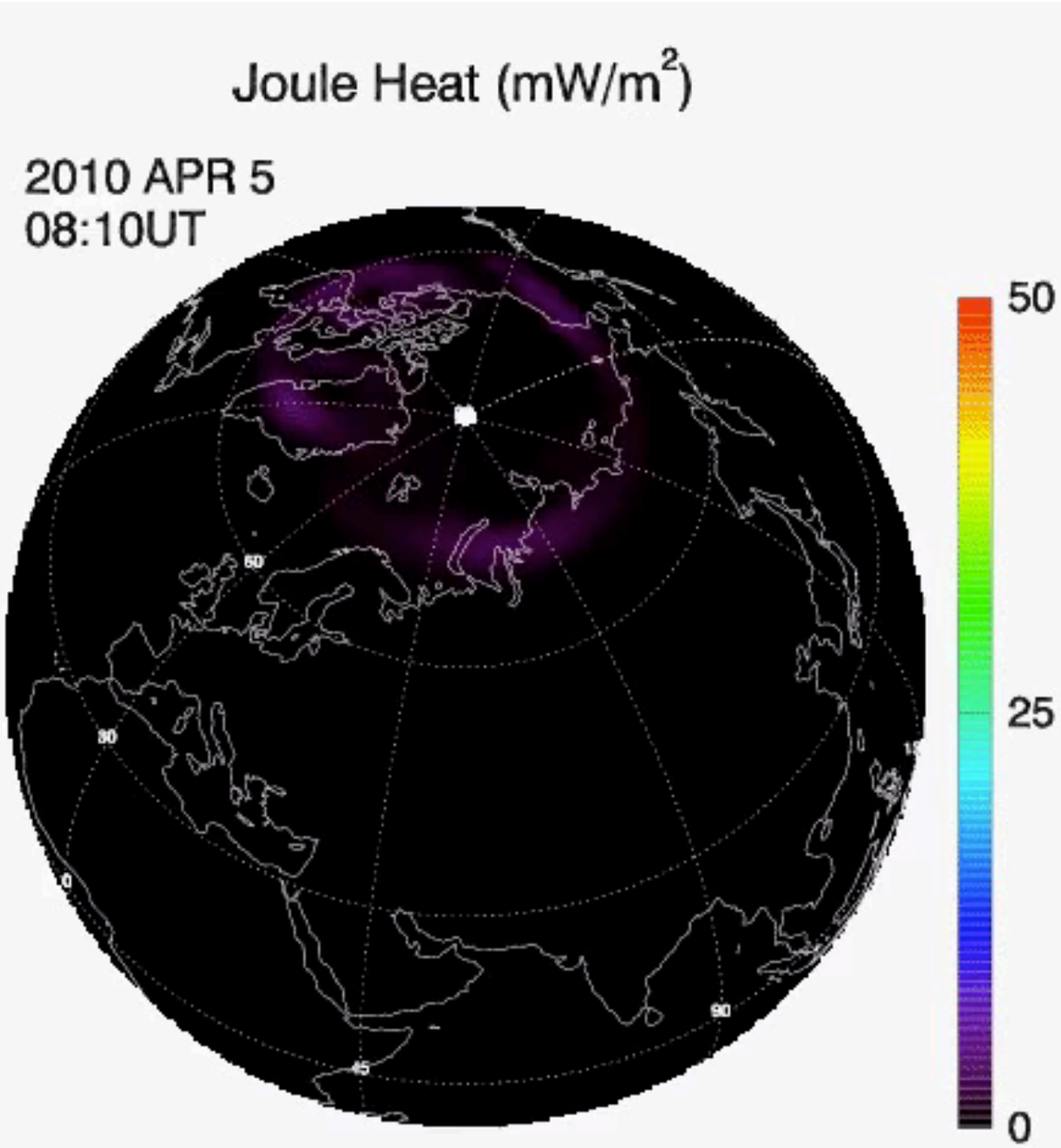



SDO/AIA 304 2011-02-24 07:27:08 UT

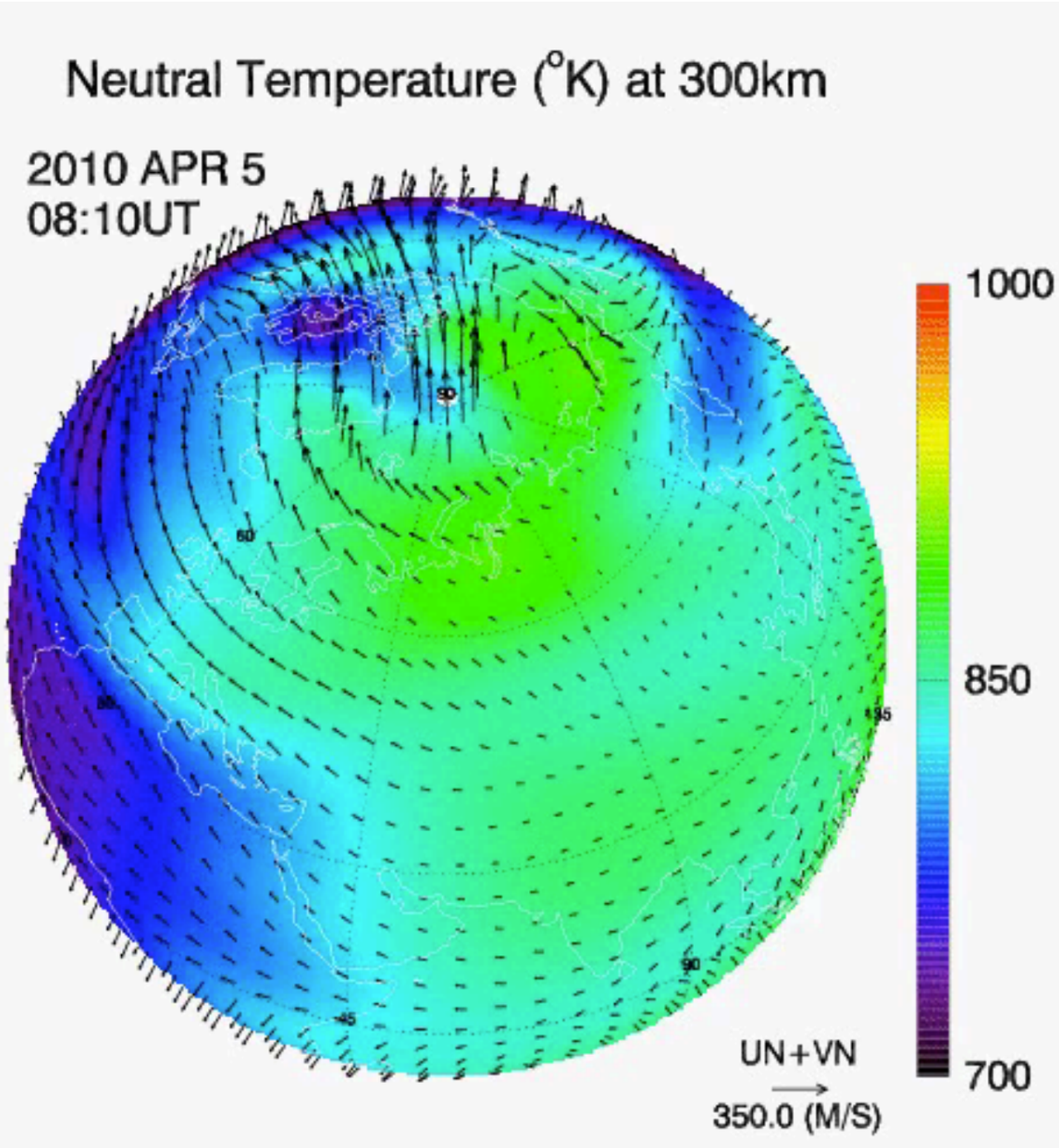


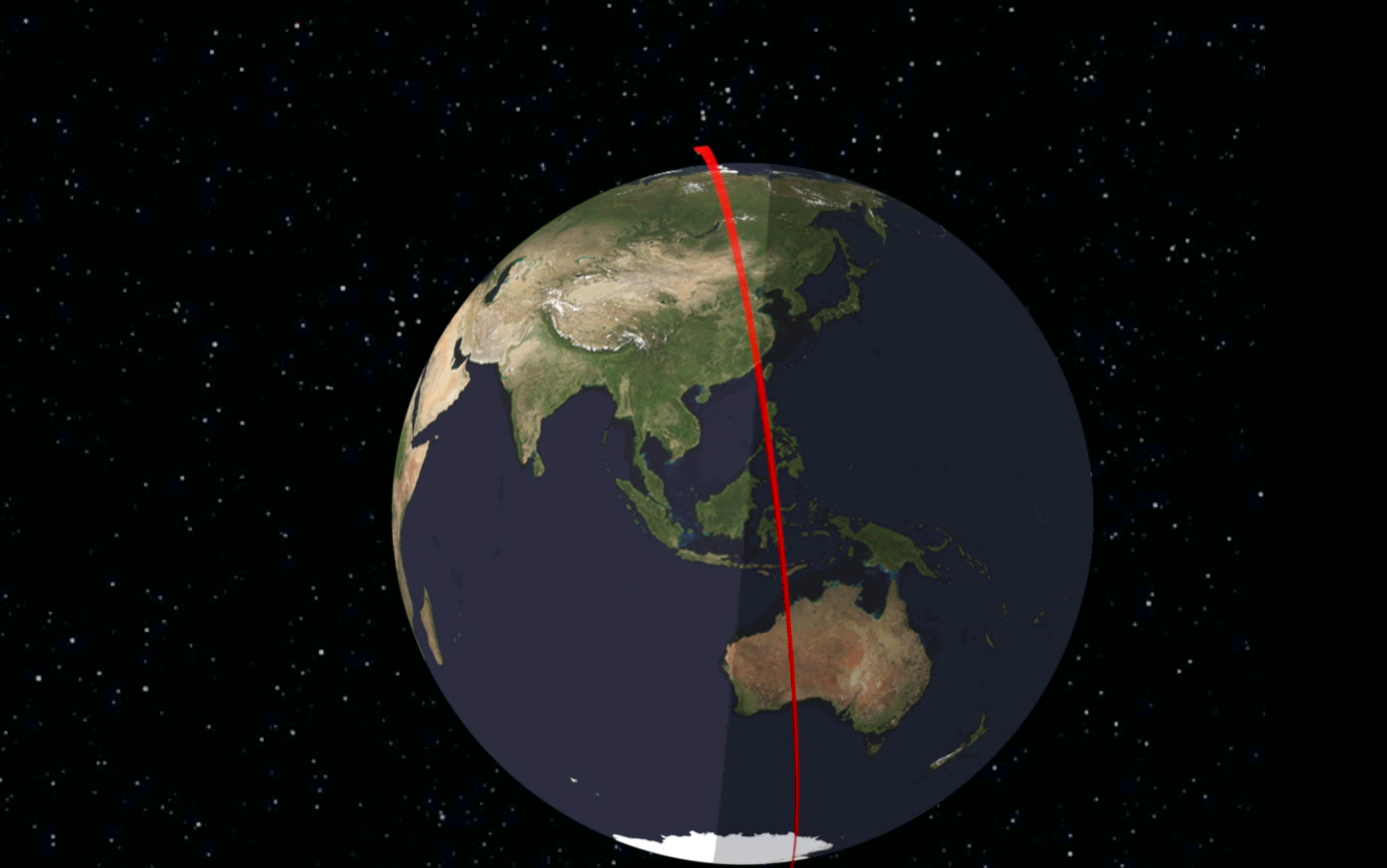

Yellowknife, Cadada
KWON O CHUL

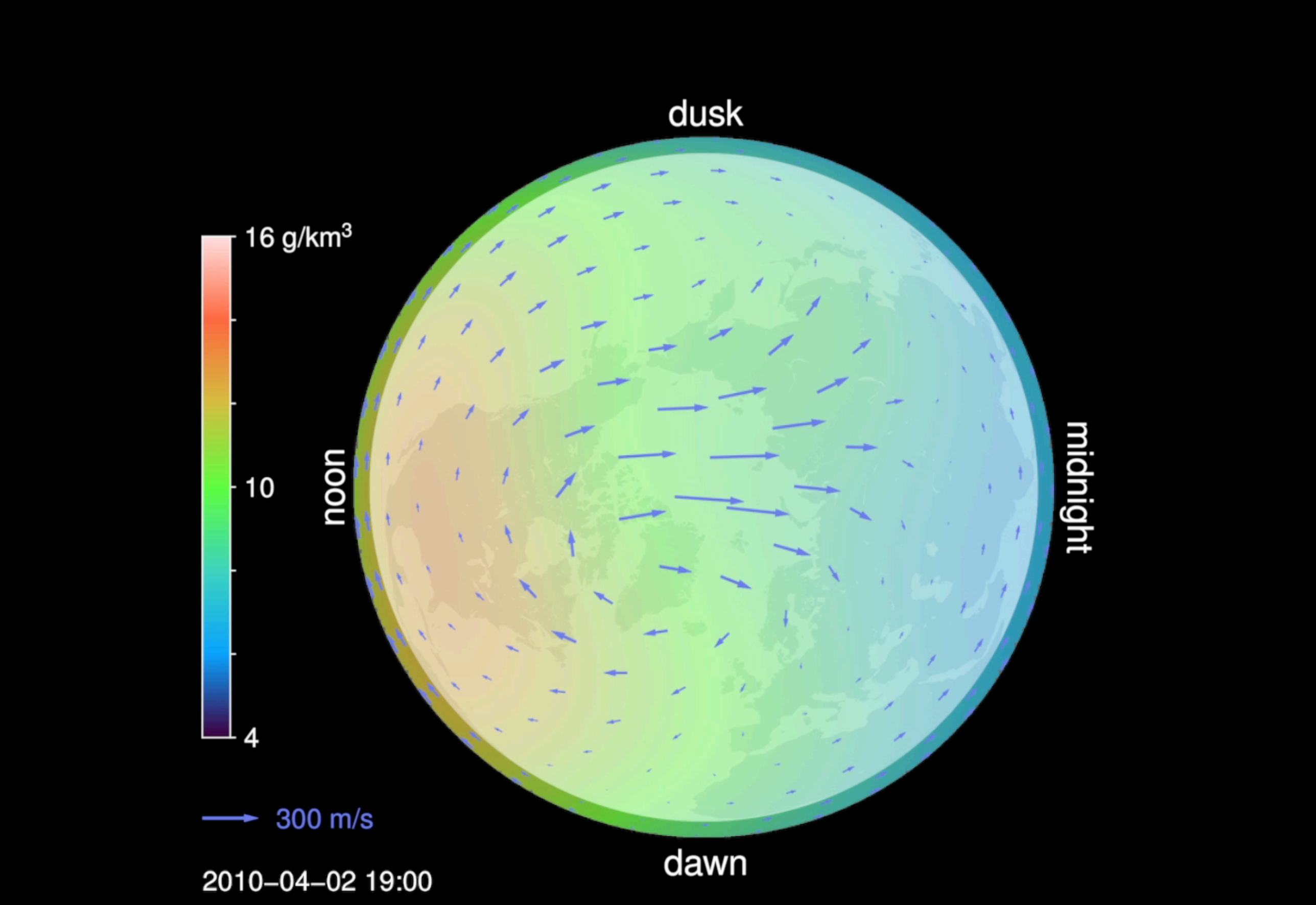
Joule Heat (mW/m^2)



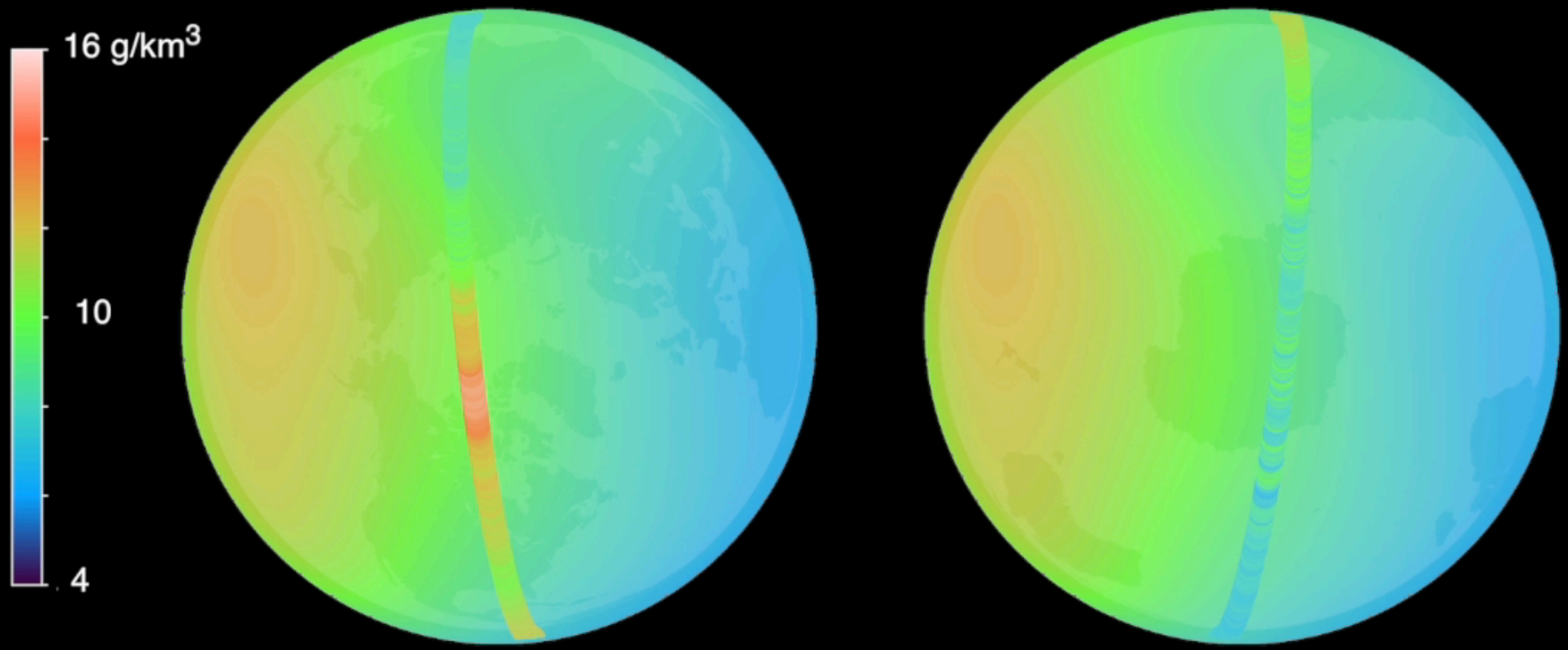
Neutral Temperature (^{o}K) at 300km



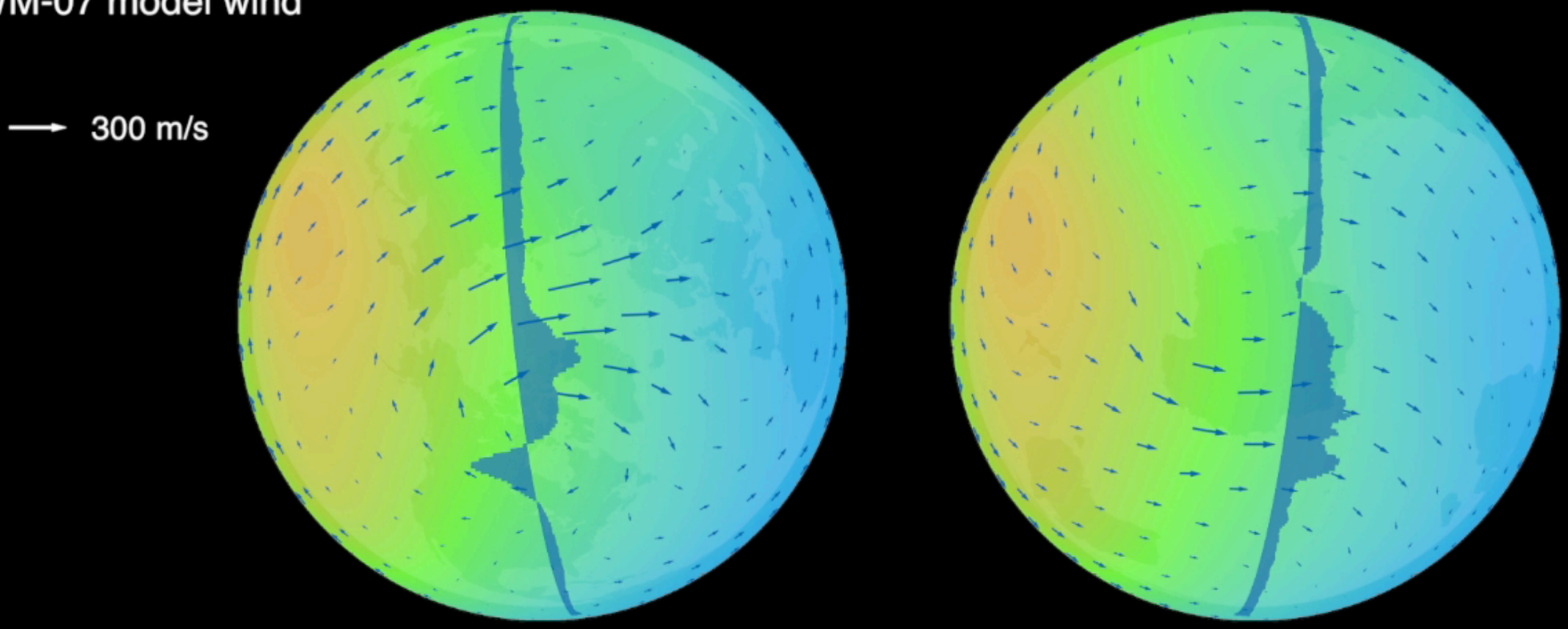



dusk
noon
midnight
dawn
16 g/km3
10
4
300 m/s
2010–04–02 19:00

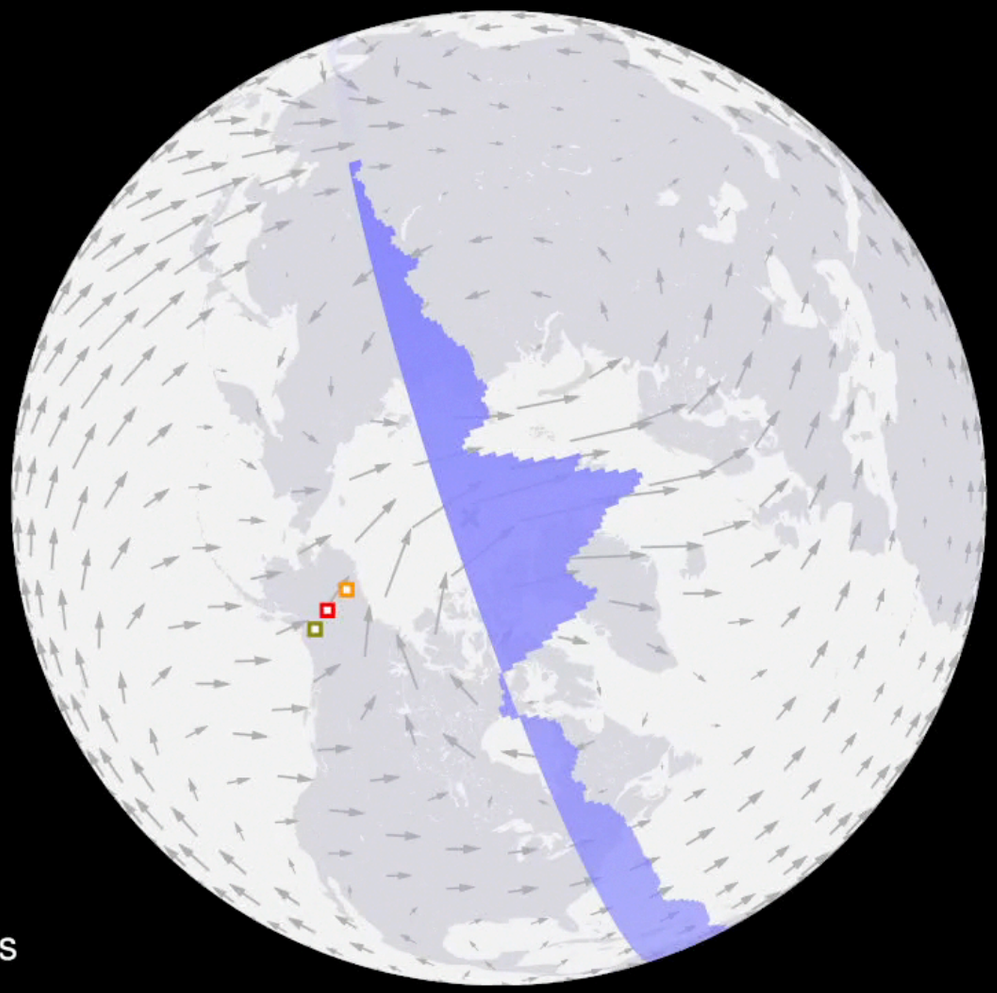
GOCE density / NRLMSISE-00 model density

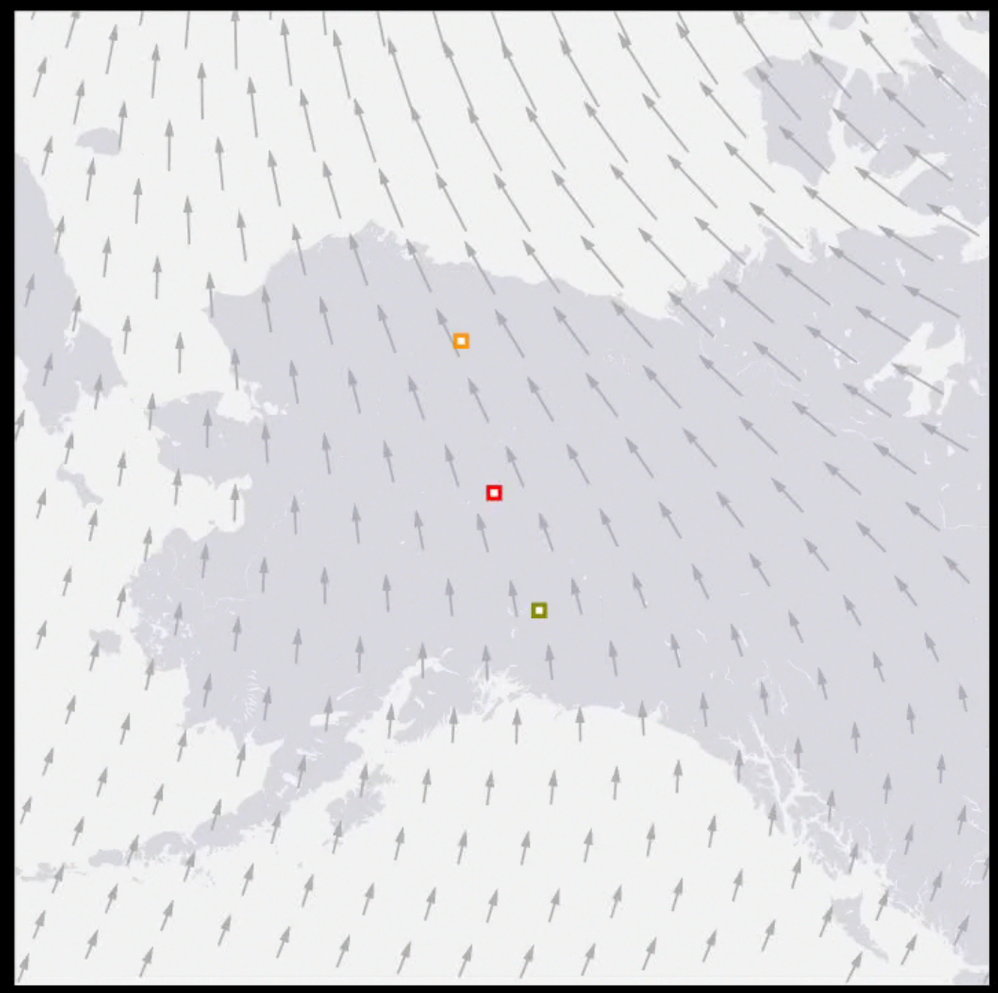


GOCE crosswind / HWM-07 model wind



2010–04–03 23:55

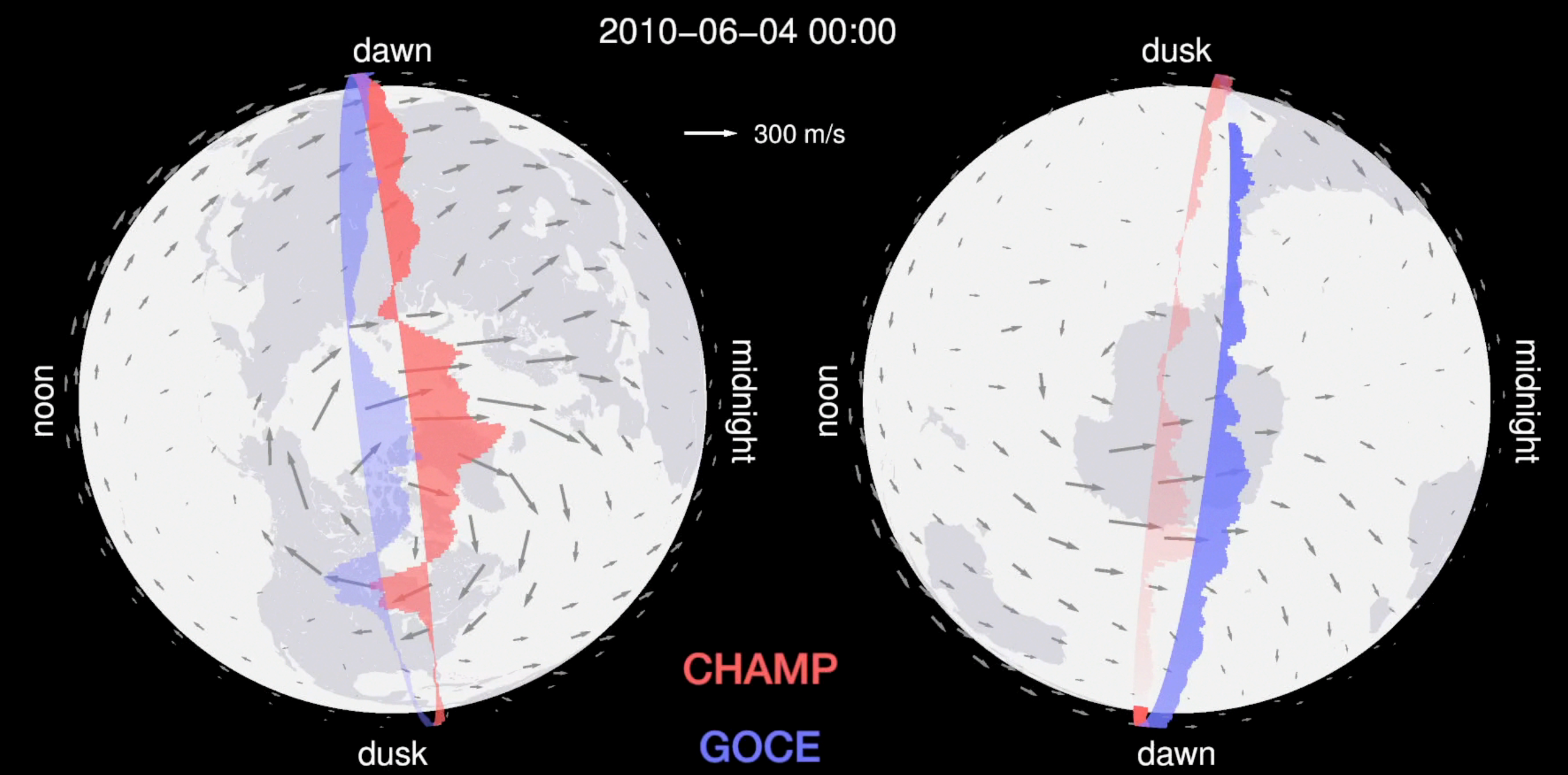




200 m/s

2012–12–21 00:02

GOCE and CHAMP crosswind comparison



Tohoku Earthquake

11 March 2011

latitude 38.32°N, longitude 142.37°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 maart 2009, is speciaal ontworpen

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 versnellingsmeters signaleerden een door het infrageluid opgewekte windsterkte van 130 M/S. Doornbos bere-

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10 March 2013 Last updated at 11:20 GMT

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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.

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

bservation is **reported in the journal Geophysical Research s**.

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

ked for this signal before with other satellites and haven't seen k that's because you need an incredibly fine instrument," said

Goce flies lower than any other scientific satellite

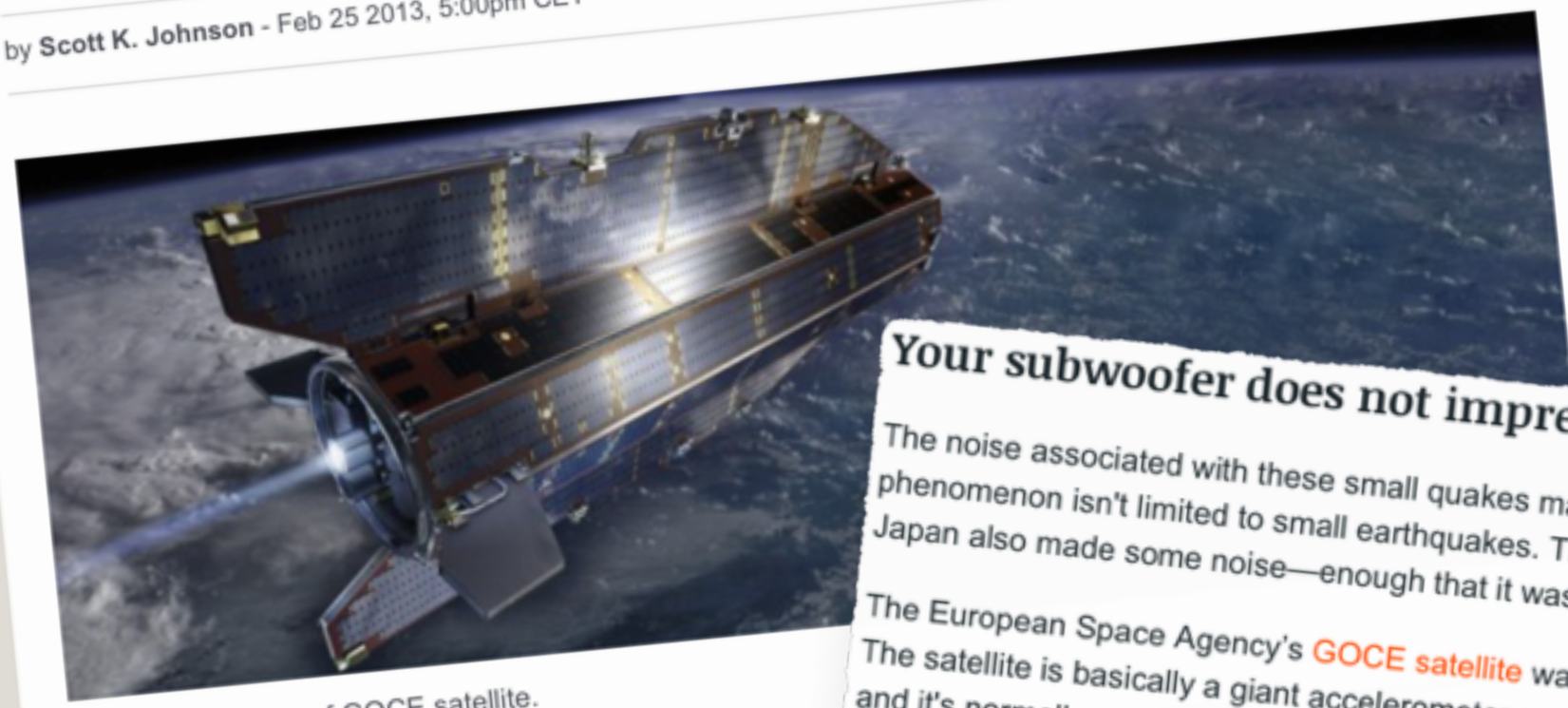
Related Stories

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

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



Artist's impression of GOCE satellite.

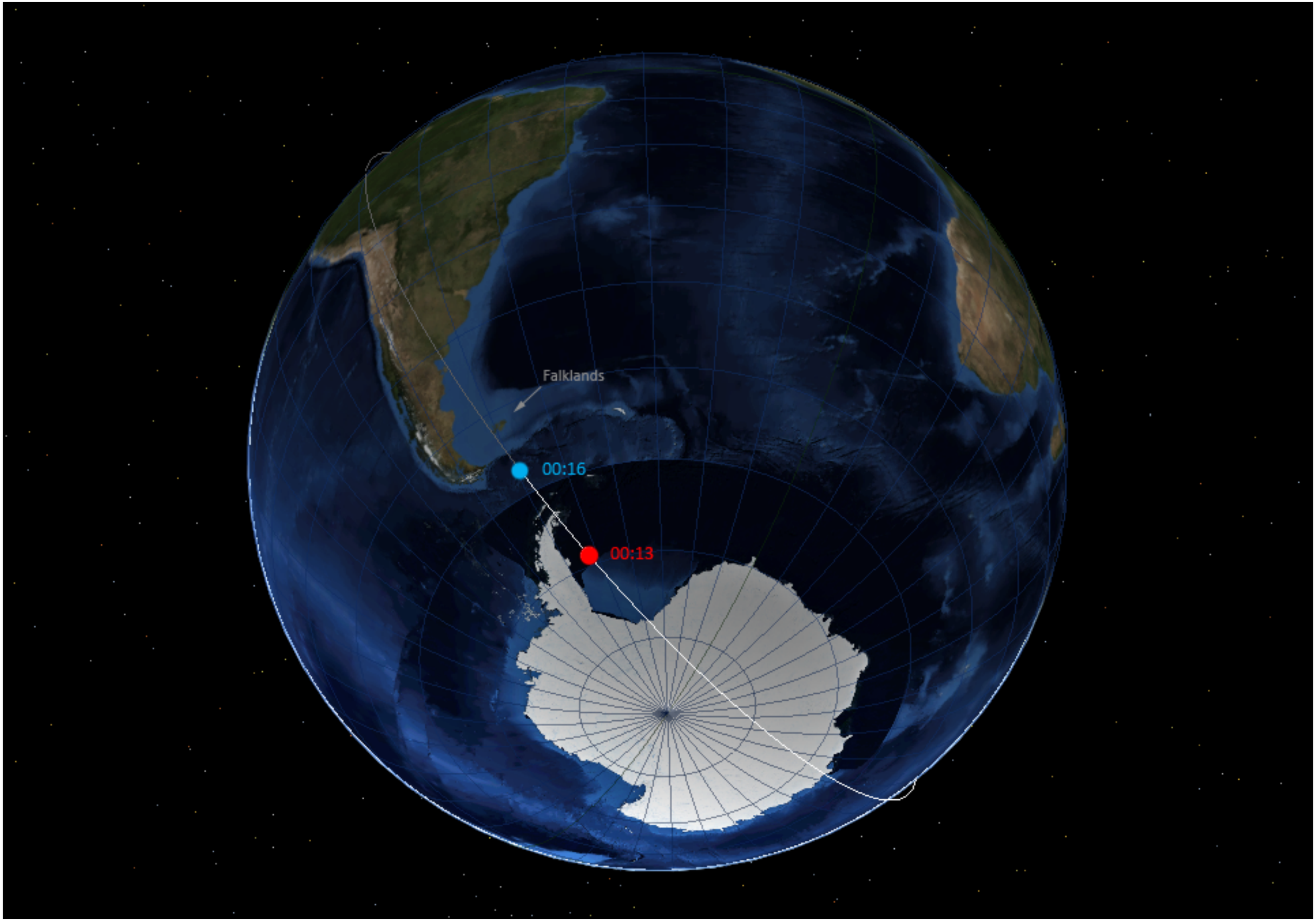
European Space Agency

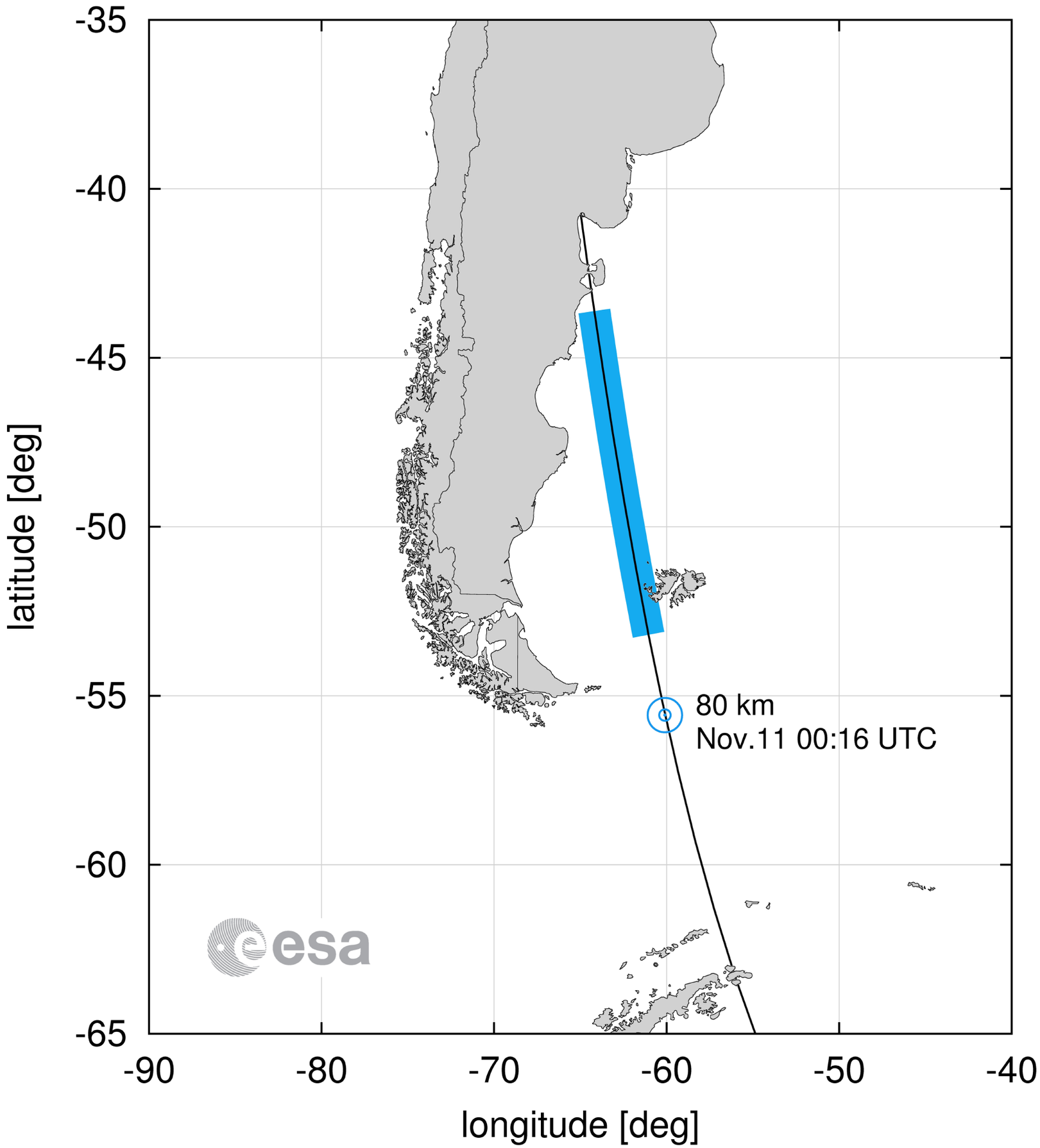
Last year, we reported on some mysterious booms
small earthquakes. While it was an unusual story,
occurrence. Early in the summer of 2001, folks in
booms. The sounds continued, off and on, for about five months.
earthquakes responsible were picked up by seismometers in the area. (A particularly
close 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.


Falklands
00:16
00:13


-35
-40
-45
-50
-55
-60
-65
latitude [deg]
-90
-80
-70
-60
-50
-40
longitude [deg]
80 km
Nov.11 00:16 UTC
esa

GOCE re-entry, Nov 11, 2013

Photo: Bill Charter

Thermospheric density and winds from CHAMP and GRACE observations

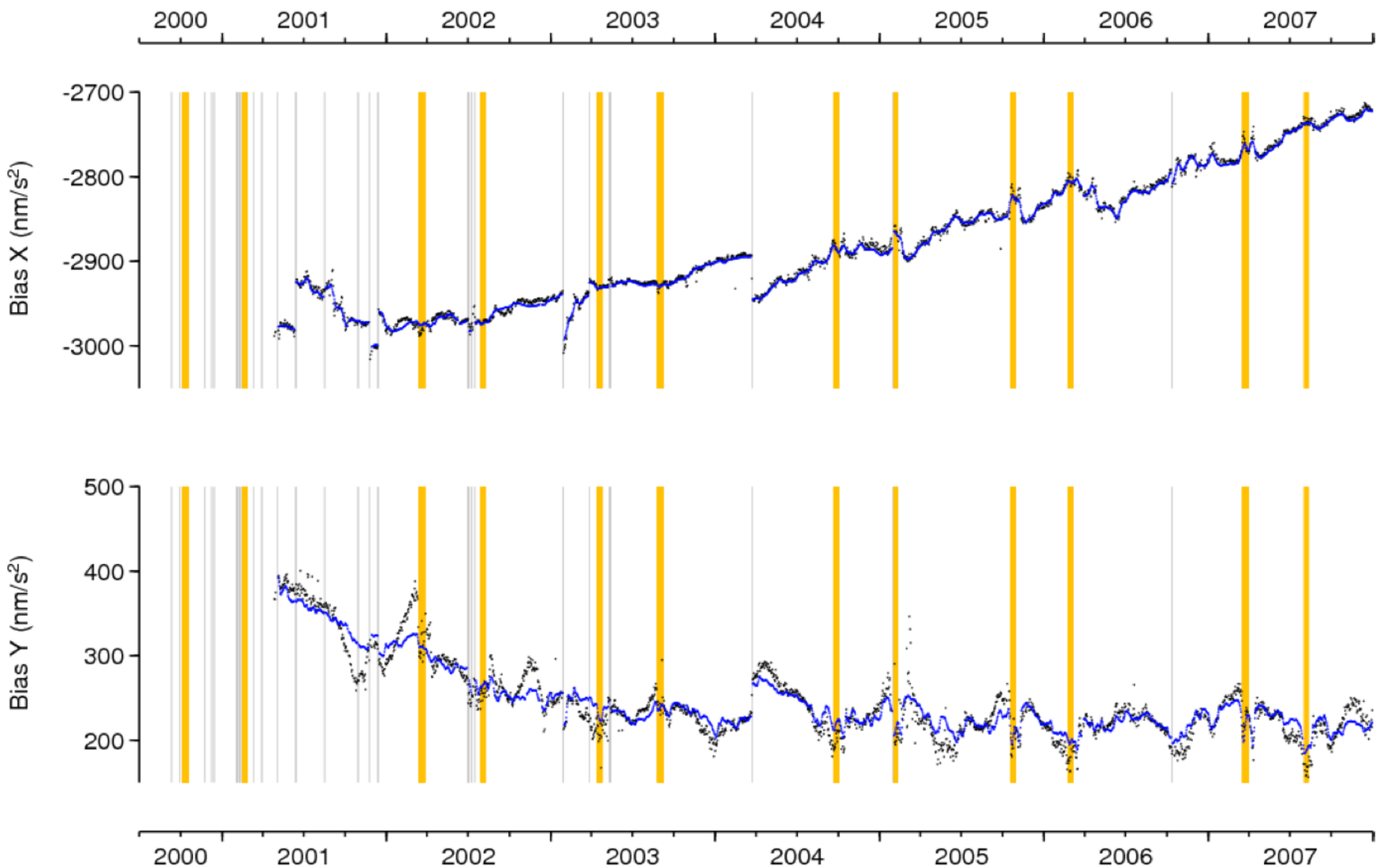
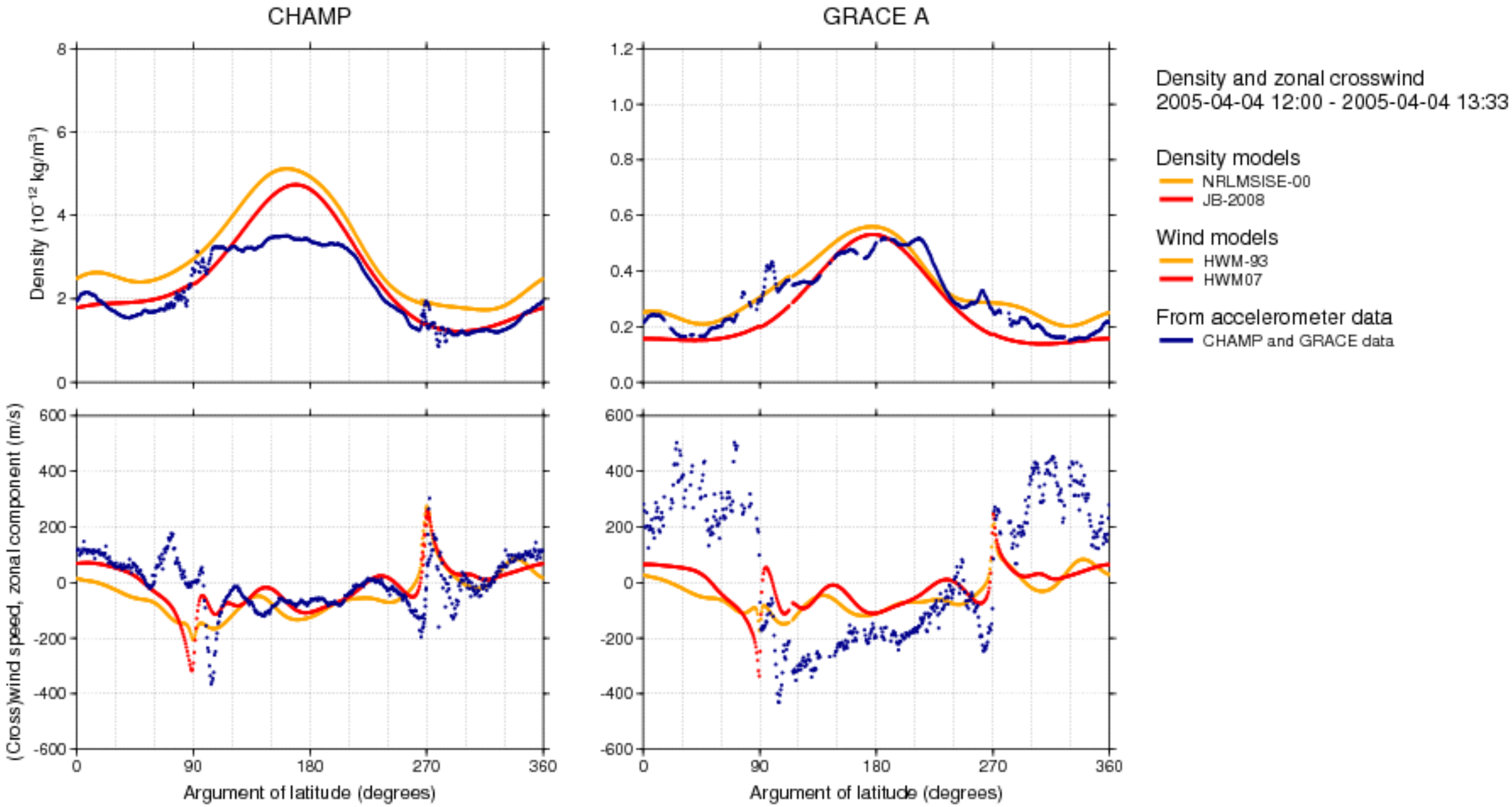
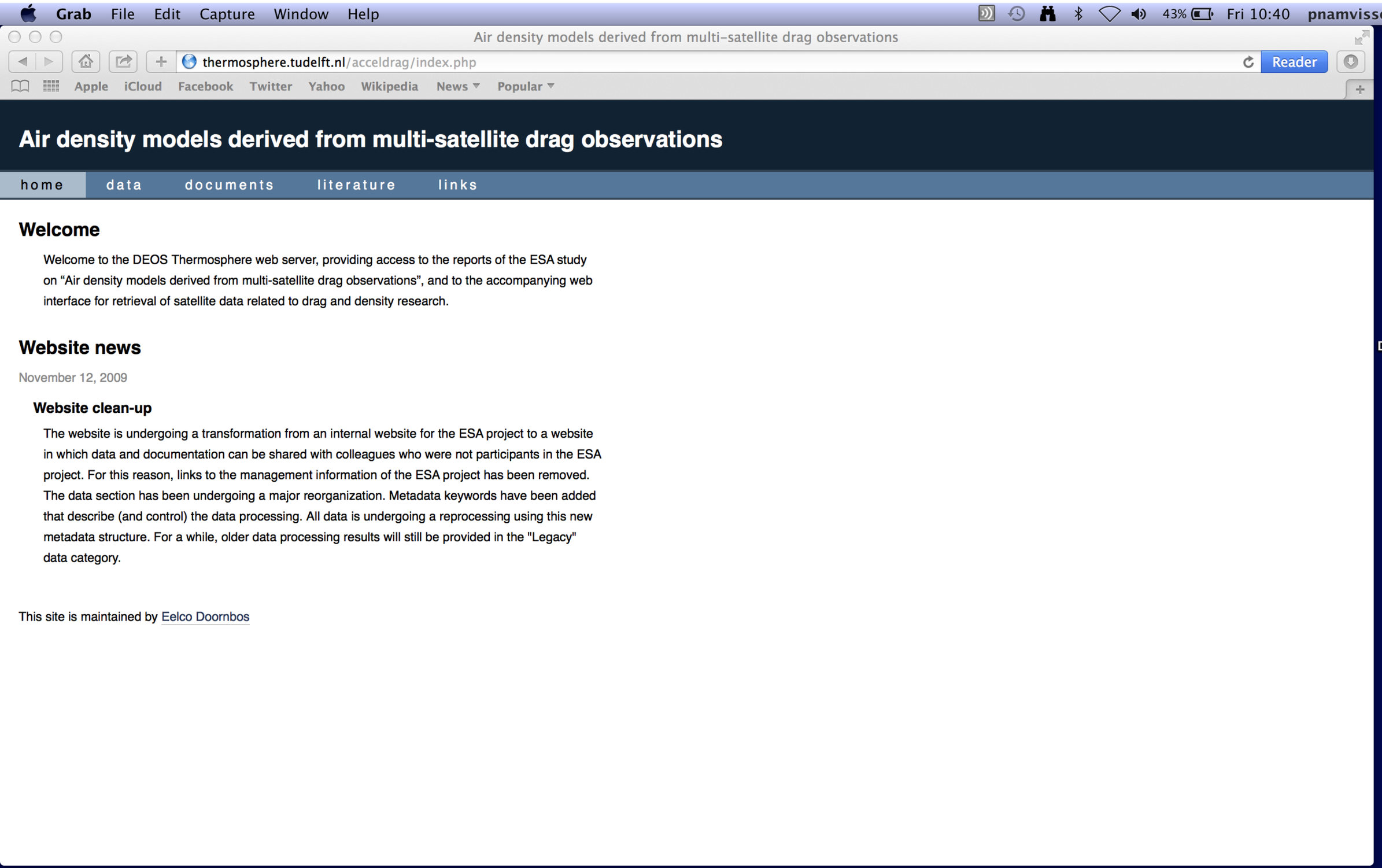


Figure 7.12 Comparison of calibration time series. Vertical grey lines indicate known satellite events, such as resets, software updates and switches of redundant electronics. The yellow/orange areas indicate periods without eclipses.

Thermospheric density and winds from CHAMP and GRACE observations



Thermospheric density and winds server TU Delft



Thermospheric density and winds server TU Delft