The Swarm Delta NanoMagSat Project, Latest News

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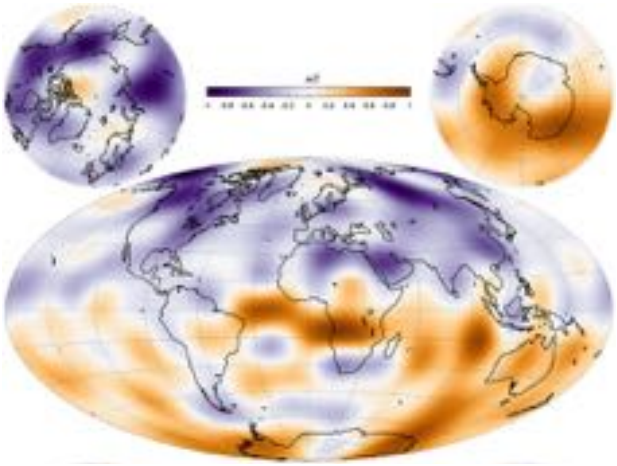
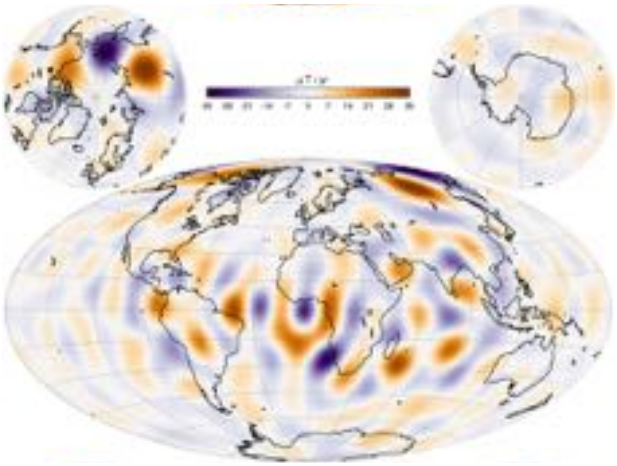
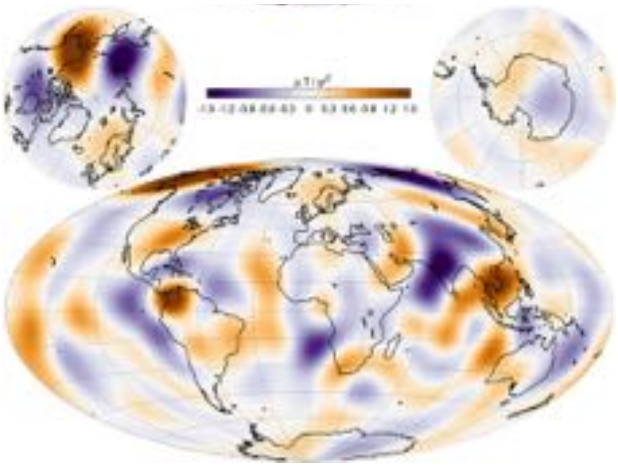
Swarm already makes it possible to follow temporal changes in the core field with high precision



2015 Br Core Field



2015 Br Core Field Variation

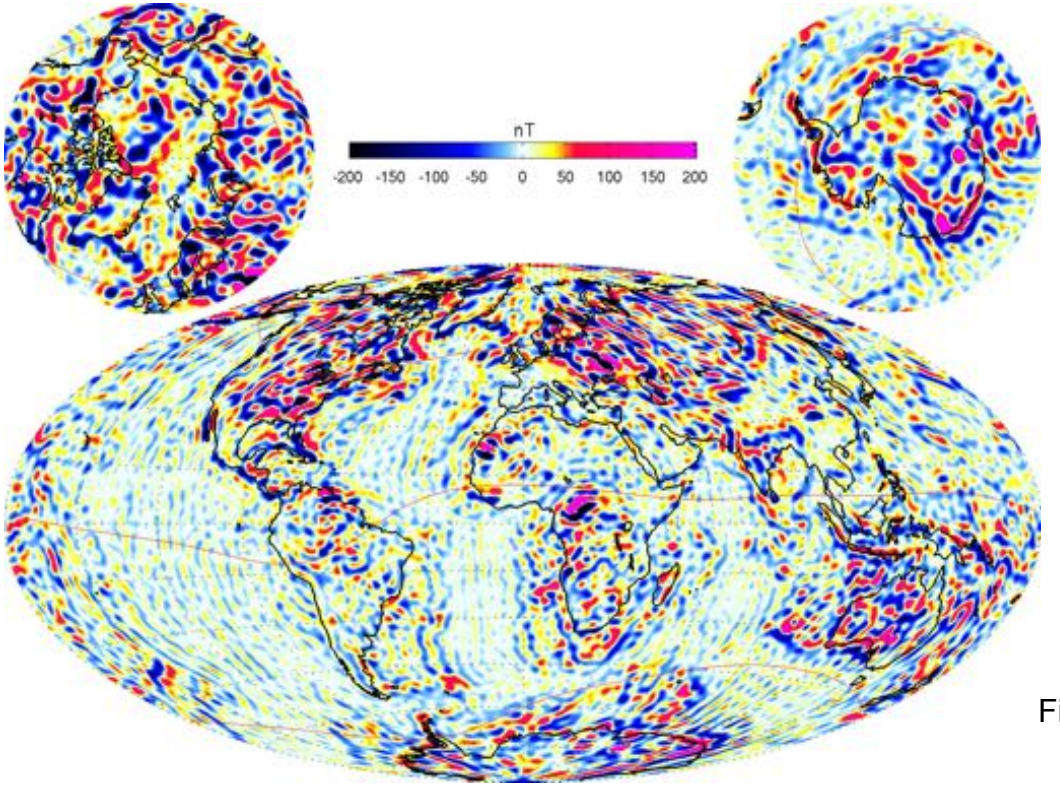


2015 Br Core Field Acceleration

Finlay et al., EPS, 2016

- Core field (radial component, degrees 1-13), Core field variation and acceleration (radial component, degrees 1-16) at the core surface, data from 10 years of Champ data and 2 years of Swarm data
- **Temporal resolution, however, is limited** (B-splines with 6 months knot spacing), **limiting the possibility of studying field "pulses"** (Chulliat et al. GRL, 2010), **and possible fast waves**.

Swarm also makes it possible to improve the lithospheric field recovery thanks to its gradient concept



Finlay et al., EPS, 2016

- Lithospheric field model from CHAOS-6 (radial component, degrees 16-110, at Earth's surface), data from 10 years of Champ data and 2 years of Swarm data.
- More improvement is expected when Swarm Alpha and Charlie will be at lower altitudes. **Note, however, the fairly systematic occurrence of along-track (North-South) bands of apparent signal.**

Swarm also makes it possible to follow temporal changes in the Solar Quiet ionospheric field

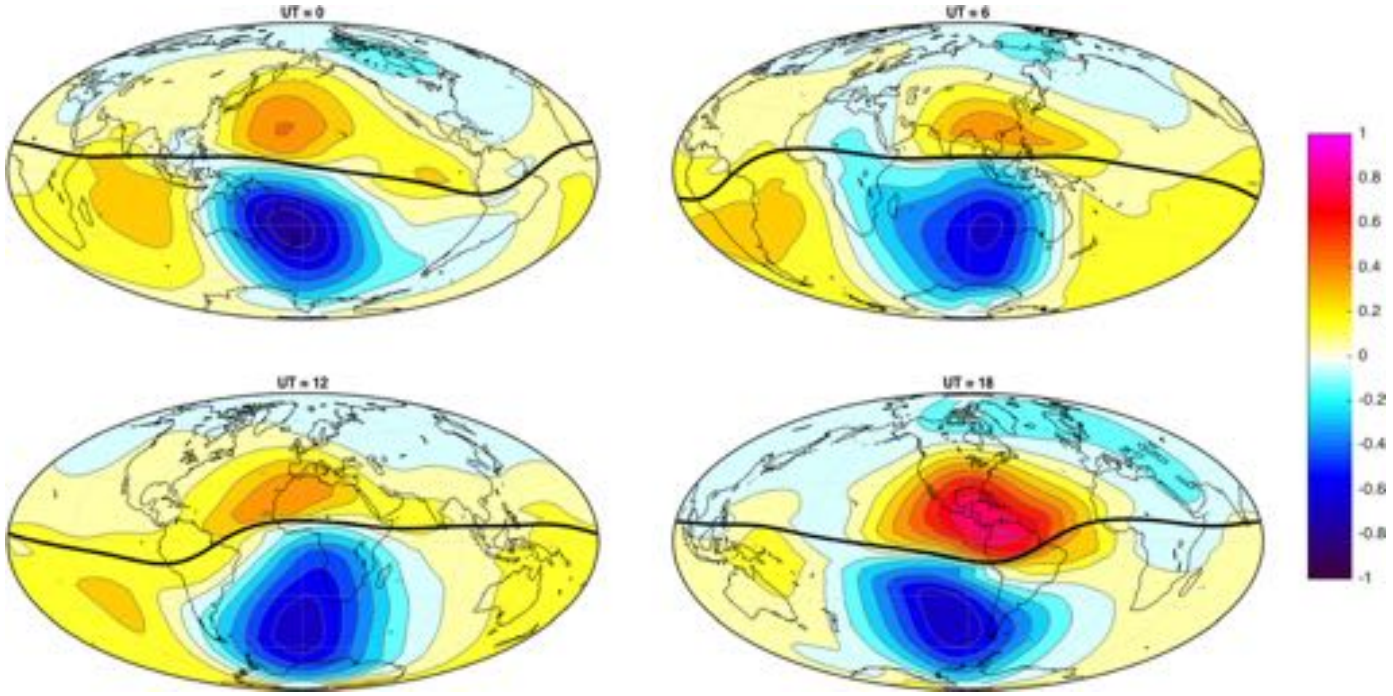
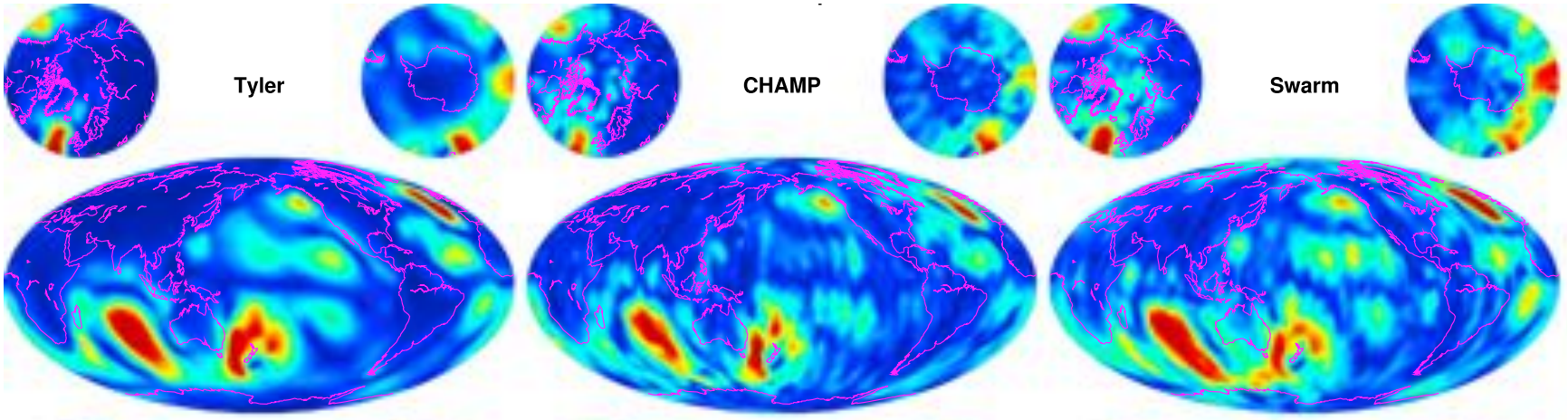


Fig. 8 (Normalized) primary equivalent current function Ψ_1, DIFI-2015b model, for January 1, UT = 0, 6, 12 and 18, and $F_{10.7}$ = 100 SFU. Ψ_1 is normalized by the maximum value for all seasons. A 13.1 kA current flows between the contours. The dip equator is depicted as a *thick black line*

Chulliat et al., EPS, 2016

- This makes it possible to identify interesting new North/South asymmetries.
- **Seasonal variations, however, are limited to three months shortest periodicities, limiting the possibility of studying short-lived events.**

Swarm also makes it possible to follow magnetic tidal signals

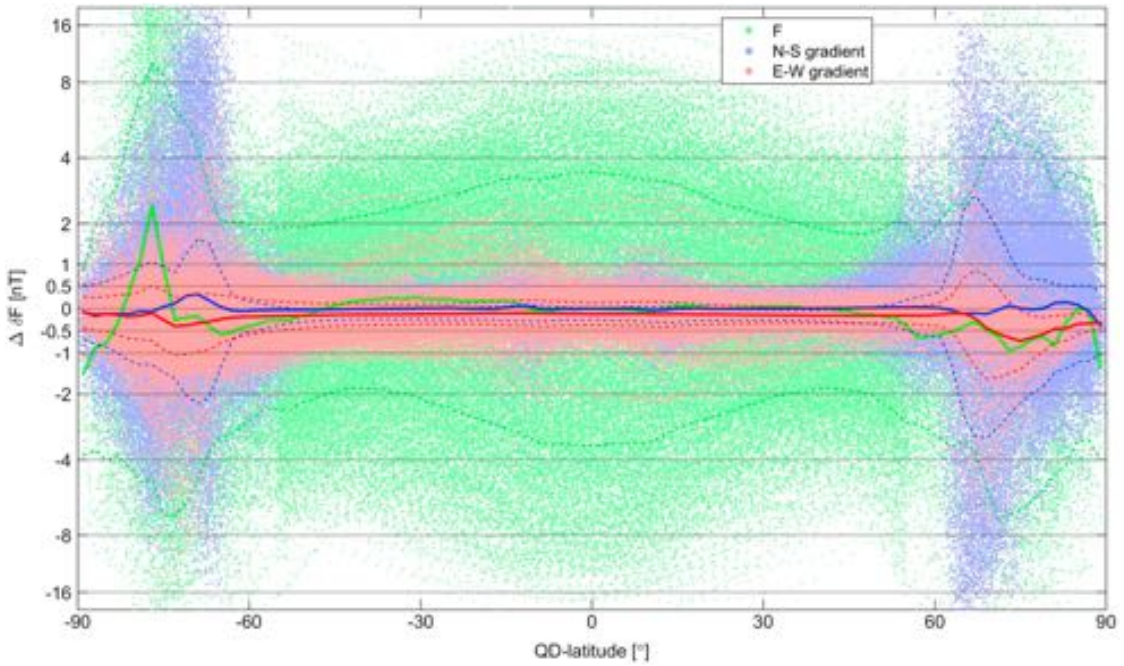


Prediction | Observed by Champ (10 years) | Observed by Swarm (2 years)

Sabaka et al., GRL, 2016

- M2 tidal signals can be detected with only two years of Swarm data (required 10 years of Champ data), providing information about ocean salinity and temperature, as well as info about solid Earth conductivity.
- **But North-South along-track artefacts are also affecting the recovery of this signal**.

Swarm field modelling residuals also provide useful information



Olsen et al., GRL, 2015

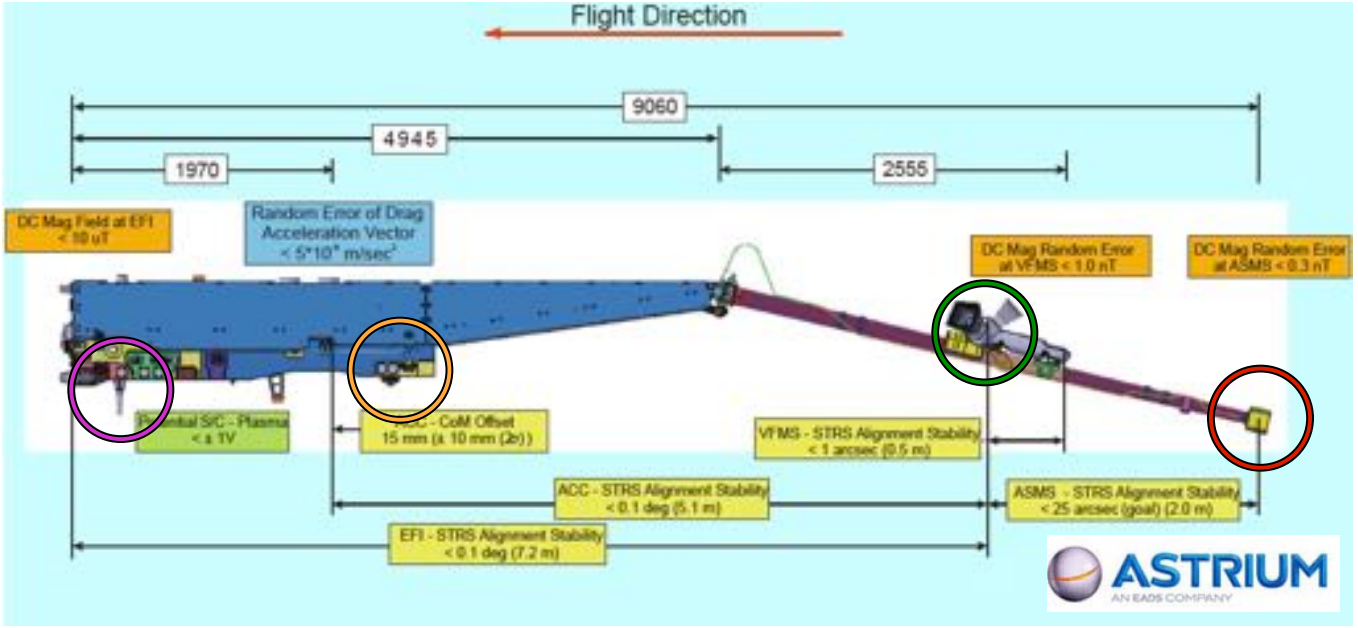
- These are scalar (green) and scalar gradient (blue N-S, red E-W) residuals from the SIFM model, which (in addition to vector data) used scalar data only on the night side, and scalar gradient data on both day and night side, except close to the equator on the day side.
- This revealed the very good agreement of the scalar data on both Alpha and Charlie (with a bias of less than 0.3 nT), but also showed that **even on night quiet times, a lot of geophysical signal is detected by the instruments, which are currently not systematically investigated (contrary to high latitude signals)**

Could the science return of the Swarm mission be improved by just adding a LEO nanosatellite ?

- Swarm has already been proven to be a great success, thanks, in particular, to its constellation/gradient design
- There are weaknesses, however, in the Swarm constellation:
  - Local time separation could still be improved
  - Orbits only cross each other at the poles
  - Signals that are already detected by the instruments cannot yet fully be exploited
- This could potentially be improved thanks to a nanosatellite on a 60° inclined LEO orbit

  -> Swarm Delta/ NanoMagSat

A simplified payload could be used by taking advantage of additional lessons learned from Swarm



Absolute Scalar Magnetometer (CEA/LETI, CNES), 1Hz vector + 250 Hz scalar data

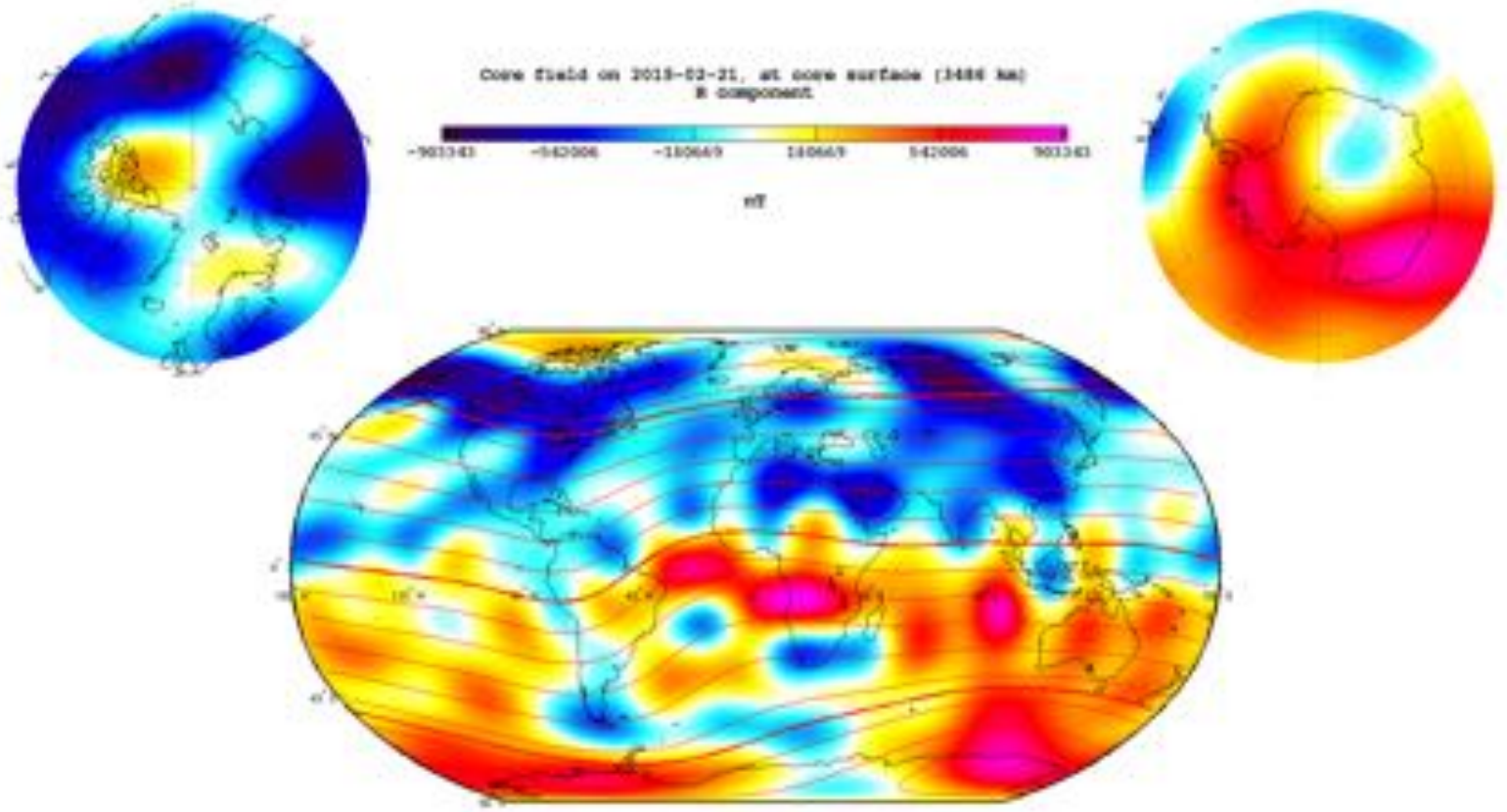
Vector Field Magnetometer and Star Tracker (DTU Space), 50Hz, 1Hz

Accelerometer (VZLU, CZ), 1Hz

Electric Field Inst. (Charge particle imager, UC; Langmuir Probe, Uppsala), 2Hz

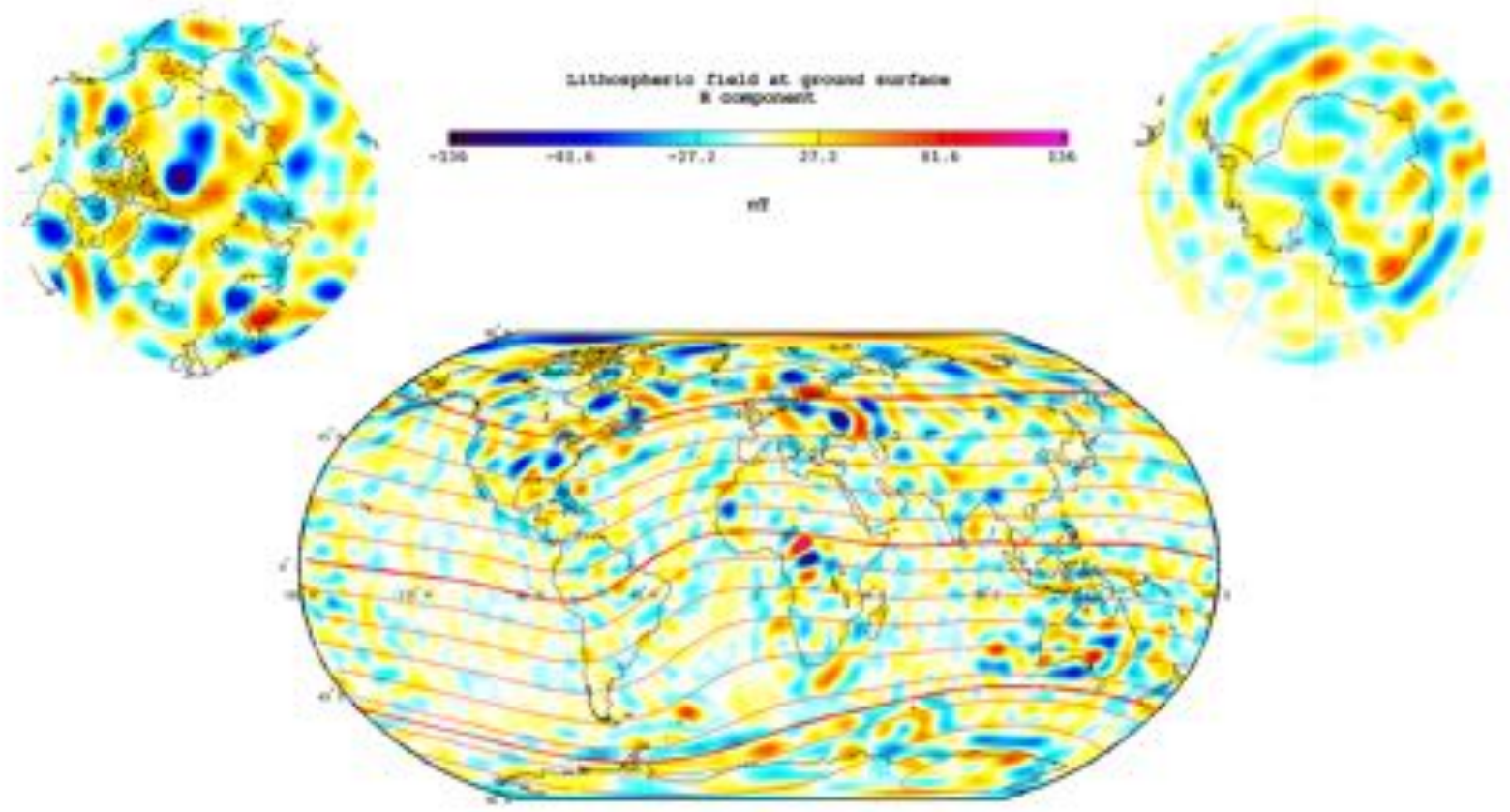
GPSR (Ruag), 1 Hz

ASM-V core field at core surface



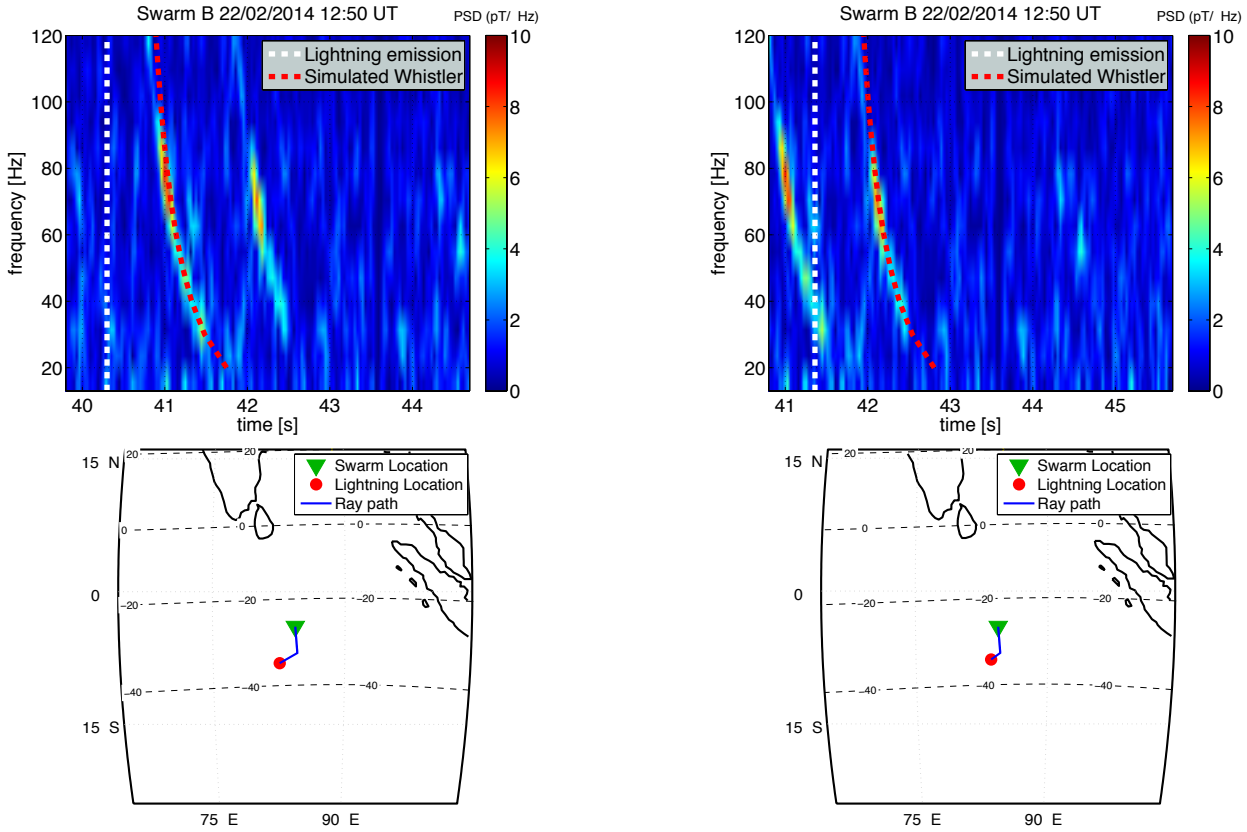
Br component of the core field (n=1-13) model at core surface and central epoch (21/02/2015) built from ASM-V data (with STR information for attitude reconstruction), **recall earlier presentation by Vigneron et al., ID 731, see also Hulot et al. GRL, 2015, DOI: 10.1002/2014GL062700.**

ASM-V lithospheric field at Earth's surface



Br component of the lithospheric field (n=15-45) model at Earth's surface built from ASM-V data (with STR information for attitude reconstruction), **recall earlier presentation by Vigneron et al., ID 731, see also Hulot et al. GRL, 2015, DOI: 10.1002/2014GL062700**.

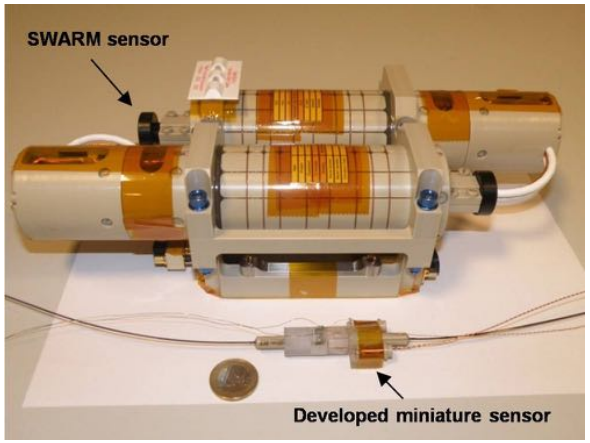
Example of low frequency “whistler” type of signals detected with the ASM burst mode



- **Recall earlier presentation by Coïsson et al., ID 913, session A13,** “A Systematic Investigation of Lightning-Generated Extremely Low Frequency Whistlers Observed during Swarm ASM Burst Mode Sessions”

Progress on the ASM instrument

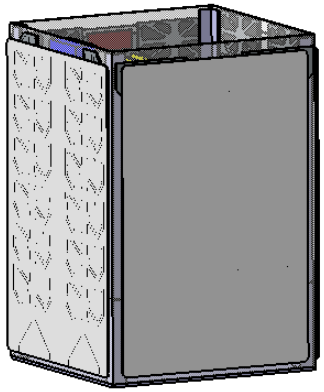
- The instrument is currently being miniaturized (Rutkowski et al., Sensors Actuators, 2014).

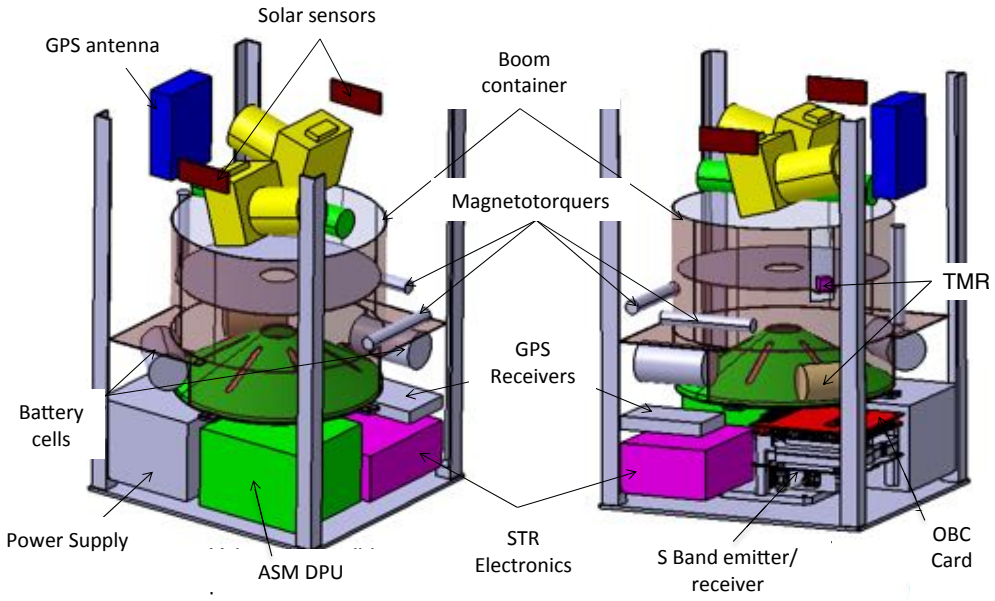


- Issues identified on Swarm (see Léger et al., EPS, 2015; Fratter et al. AA, 2016) are currently being solved (e.g. avoiding using a piezoelectric motor for the polarization, by relying on a polarization crystal).
- Laser source also to be changed (fibre laser to laser diode)
- The instrument could be run in a permanent dual mode so as to simultaneously provide 1Hz scalar + vector data AND up to 400 Hz scalar data, with improved performance.
- **For more details, see next talk by Léger et al., ID1246.**

NanoMagSat current phase 0 design

- **12U Cubesat** (20cmx20cmx30cm) with a 2m boom for the magnetometry payload
- **Miniaturised ASM** magnetometer in **dual vector/burst mode, with two star cameras (STR)**.
- Possibility of **miniaturized VFM or search coils (possibly based on Tunnel Magneto Resistance, TMR)** to also measure high frequency vector field fluctuations (up to 500 Hz or further)
- **Langmuir Probes** (Te, Ne)
- **Dual frequency GPS** (TEC)
- **Little attitude control**: gravitationally stabilized (requirement: spin < 40°/mn swing < 30°/mn to keep bias below 0.2nT)
- **No propulsion**





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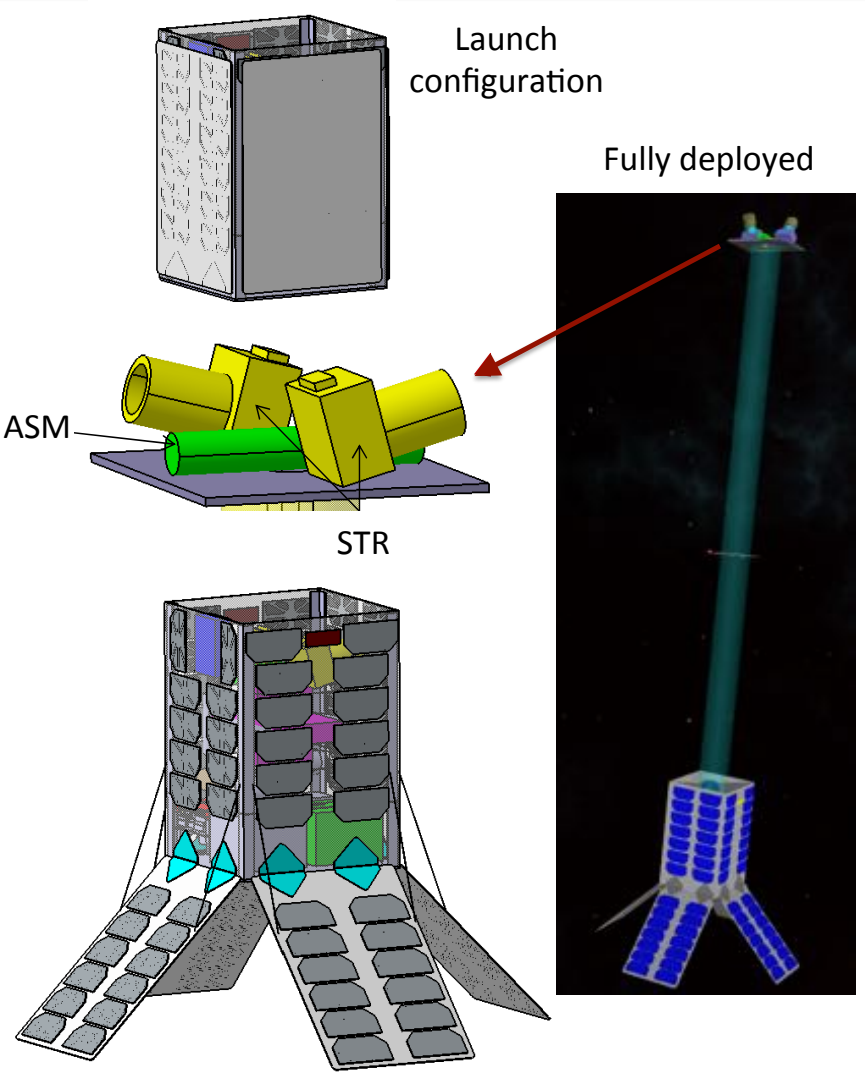
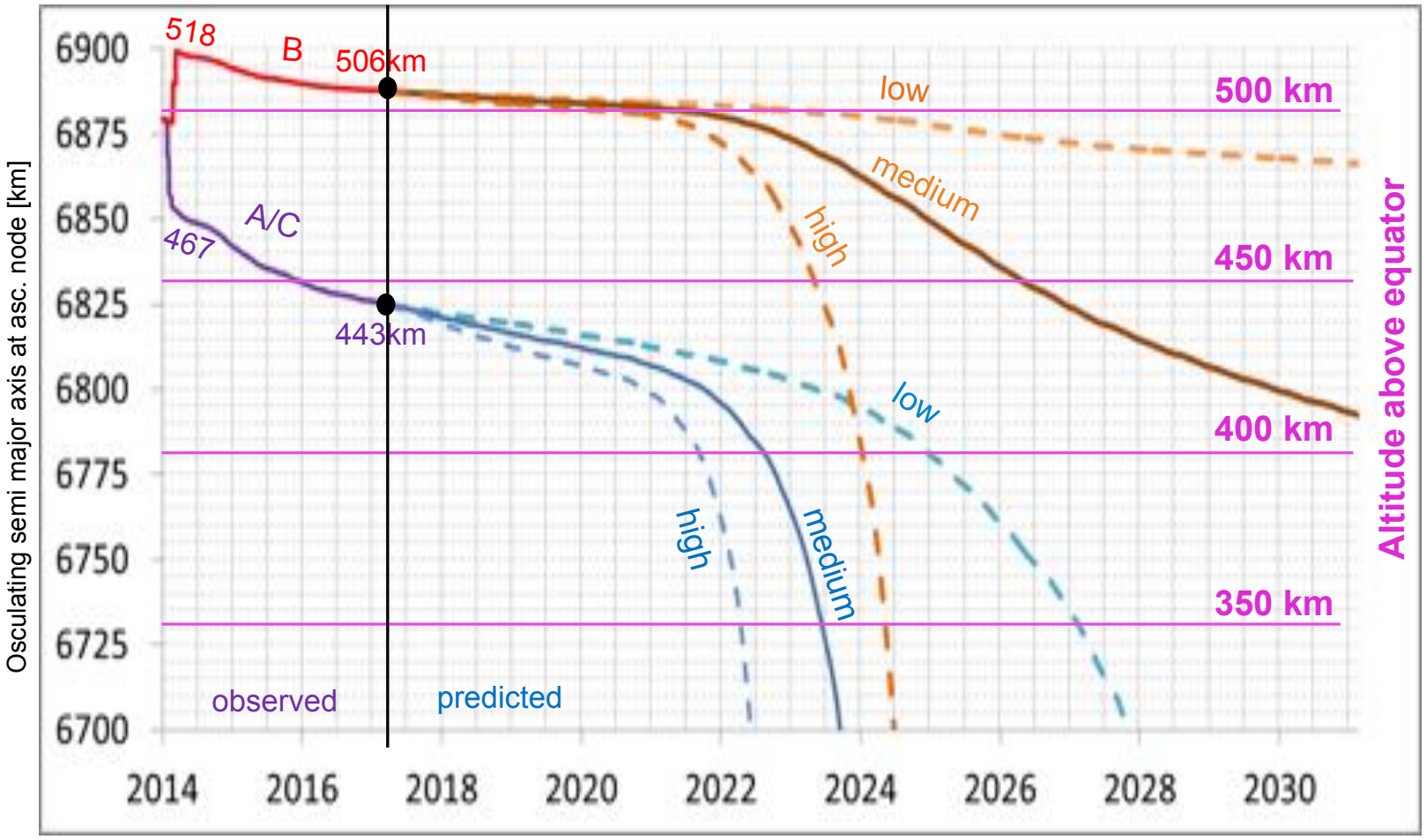
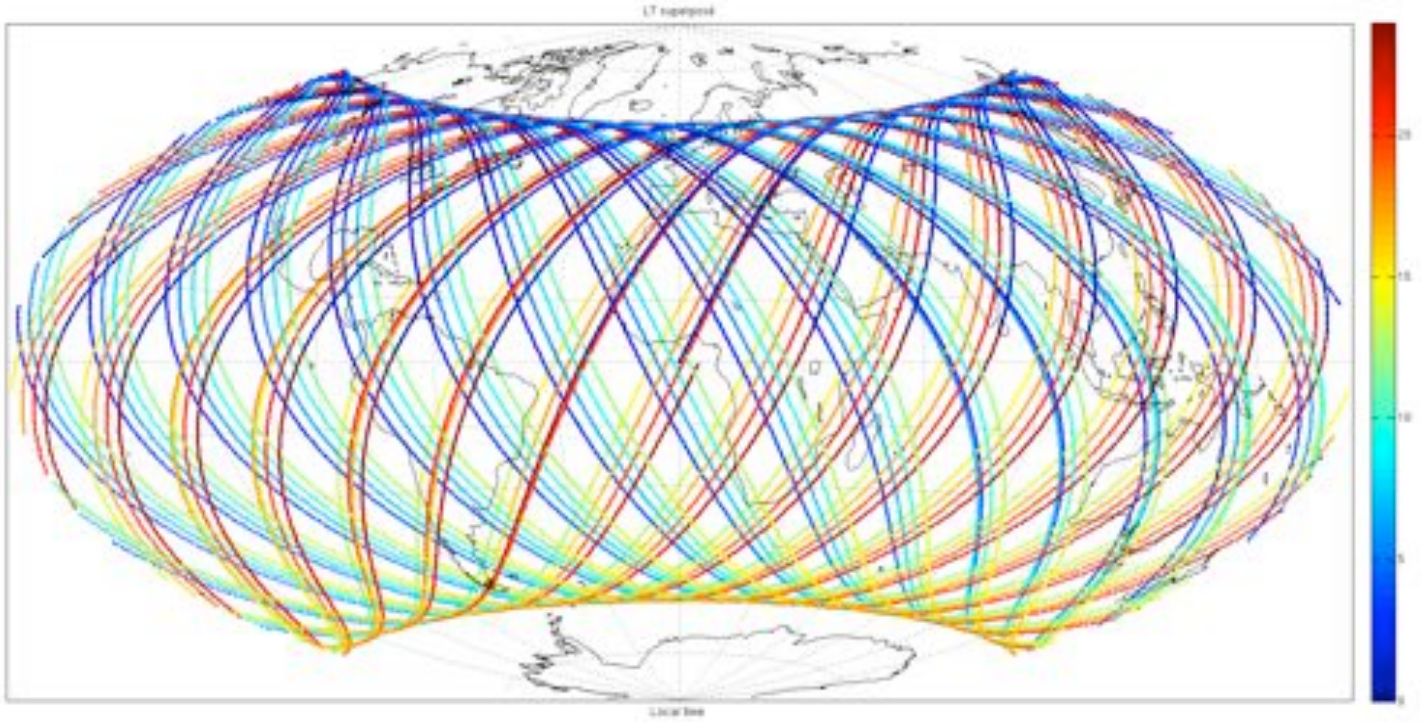


Aiming at a launch before 2021



- Swarm's constellation is complete up to 2023, at least
- Higher Bravo satellite could stay even longer in orbit, likely well beyond 2024

On a (say) 60° inclination LEO orbit, which would provide the missing local times fast



Combined Days 1, 9, 18 and 27 of local time and geographic coverage

Ongoing activities

- A NanoMagSat Phase 0 study within CNES has led to a **technological maturation plan and a number of R&T studies currently under way**
- **An ISSI working group has been organized to run a set of complete end-to-end simulations with the help of the Swarm science community (**and assistance from CNES and ESA, see **http://www.issibern.ch/workinggroups/leo60/**)
  - ✓ A **first workshop has been held in April 2017** (20 participants), tasks have been identified (generation of synthetic orbits and data)
  - ✓ **Synthetic data will be used to test the recovery of signals**
  - ✓ **If you are not currently involved and are interested in participating, please let me know** (gh@ipgp.fr)
  - ✓ **Next workshop is to take place at ISSI Bern in spring 2018** (exact dates to be confirmed in September 2017)