Results of precise magnetic calibrations at the facilities of IG, CAS

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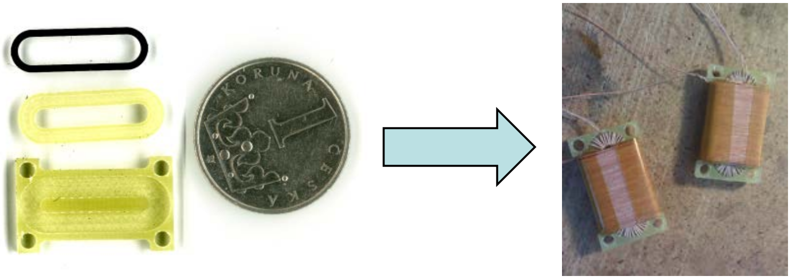
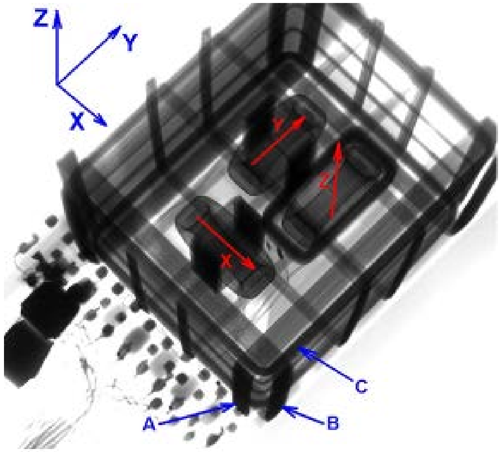
“MAGLAB”

MAGLAB @ CTU FEE competence

- **Fluxgate sensors & magnetometers**
  - FGS: low noise vectorial mg. field sensors
  - Magnetic materials selection and treatment
  - Sensor construction & characterization
  - Magnetometer construction & calibration



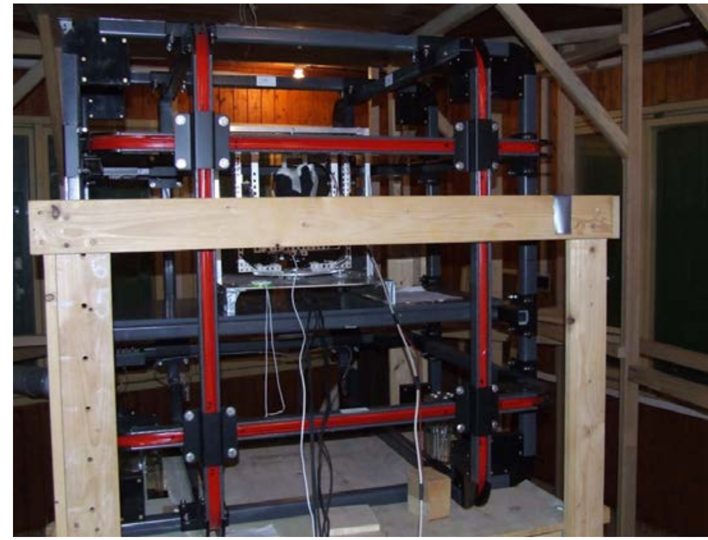


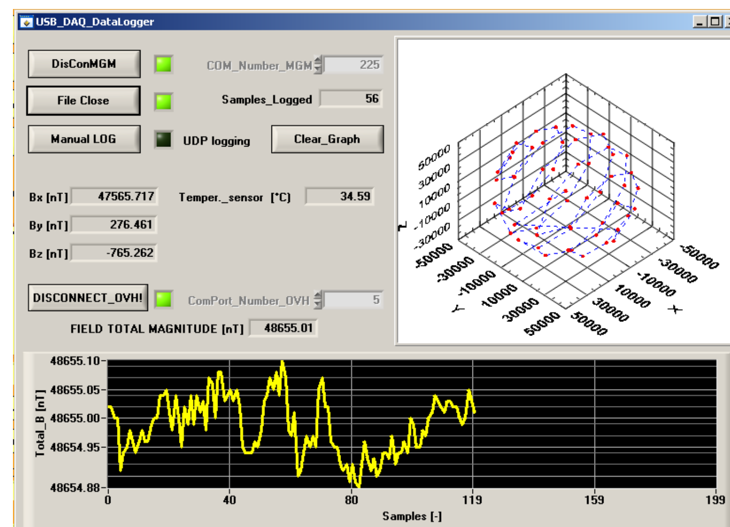
- **Induction coils** 10 Hz – 100 kHz
- **Custom electronics** for commercial sensors (Hall, AMR, GMR..)

Petrucha, Azpurua, Janosek; IEEE Trans. Instrum. Meas. - 2015

Magnetometer calibration

- **Triaxial sensor heads**
  - 9 parameters (gain, offset, orthogonality error)
- **Vectorial calibration**
  - Pre-defined field generated in calibrated coils
  - OL - precise control of coil current or CL - precise sensor
  - Direct measurements or non-linear optimization
- **Scalar calibration**
  - Homogeneous (Earth's) magnetic field
  - Scalar value is monitored (Overhauser, PPM)
  - Sensor is rotated to cover all possible directions with respect to Earth's field vector
  - Non-linear optimization (fitting) of the parameters (vector scalar value should match the scalar value measured with OVH)

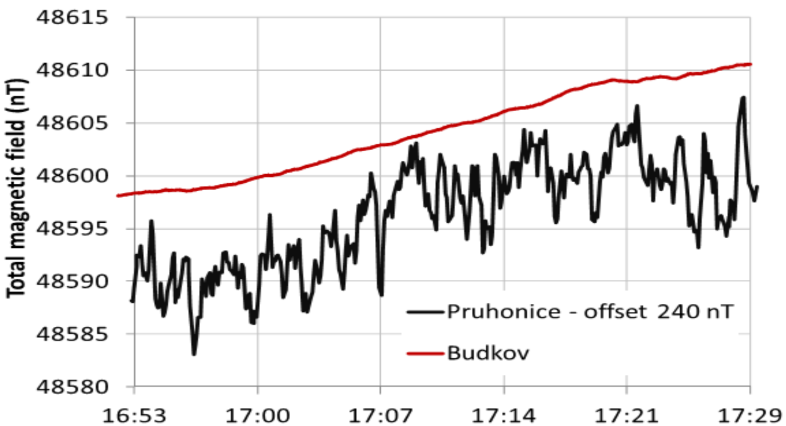




Calibrations at GFU facilities

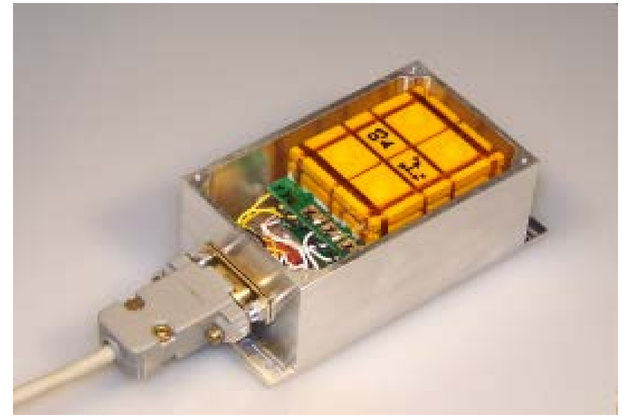
- **Long-term collaboration with IG CAS**
- **Vectorial calibrations**
  - At Pruhonice ex-observatory.
    - Triaxial calibrating coils X CMI national flux density standard
    - Results > 400 ppm (gain) – ambient noise (subway, railway).
    - *Zikmund, Janosek et al., IEEE Trans. Instrum. Meas. 2015*

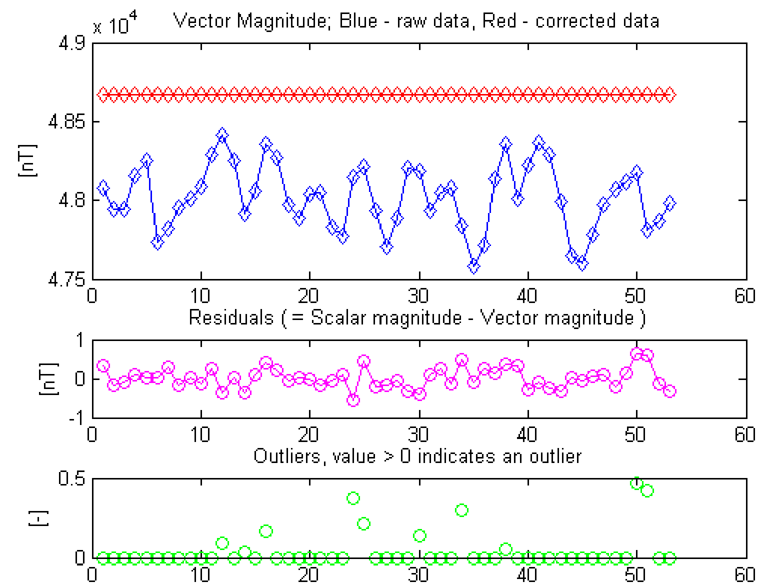
- **Scalar calibrations**
  - **At BDV observatory**
    - Homogeneity ~ 5nT/m in the absolute pavilion
    - 2 OVH scalar mags available @ BDV
    - Calibration during quiet periods - BDV forecasts
    - Possibility of long-term on-site calibrations
    - Results : up to 10 ppm STDEV (gain)



Scalar calibrations ctd.

- Residual obtained from the vectorial sensor triplet after calibration $R = B_{OVH} - |B_{VEC}|$
- The minimum obtained at BDV facility with our best sensors – vectorially compensated - was **0.2 - 0.3 nT_{rms}**
- This corresponds to uncertainty of estimation:
  - Gain factors **±10 ppm**
  - Offsets **±1.5 nT** offsets
  - Orthogonality **± 3 arc-sec**
- Important for ***moving sensor*** applications
  - Mine hunting, archaelogy, geology mapping etc.
  - Much higher sample rates than with any OVH or PPM
- Non-INTERMAGNET repeat stations – possibility to integrate variometer and total field measurement in one instrument.





CTU variometer - long-term and noise measurements

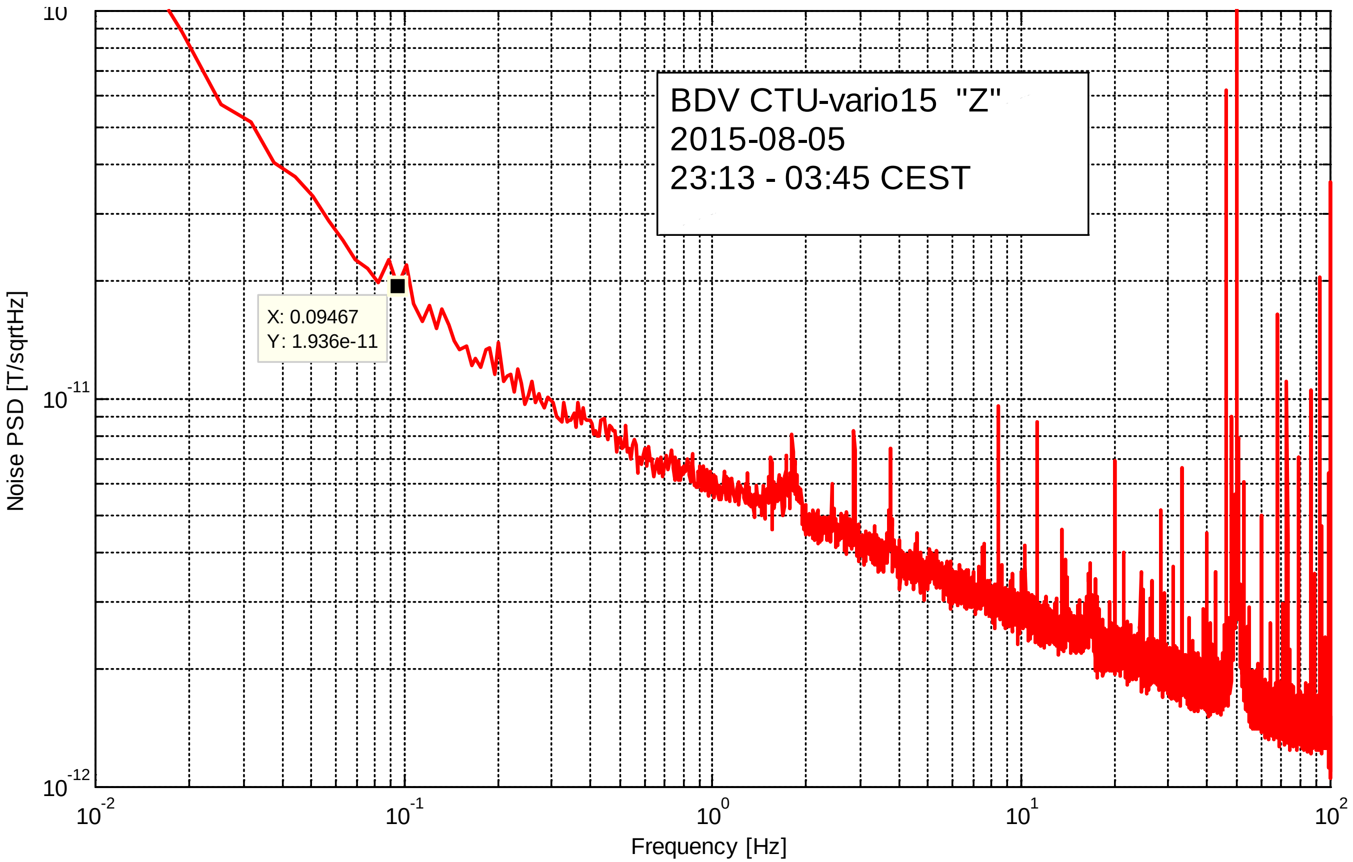
- CTU variometer uses low-noise sensors and low noise offset feedback
  - Race-track sensors, 5 pT / √Hz @ 1 Hz
- 2 pcs installed at NOA Athens
- 1 piece test at IG CAS for a variation station

- BDV measurements:

  – **Long-term measurement** to prove **stability** of the sensors (offset and gain)

  – **Noise measurement** during night periods
    - Motivation: upcoming INTERMAGNET standard requiring low noise instruments.
    - difficult to measure in shielded chambers - size and offset field creation

Noise measurement results



Even at BDV, ambient noise is lowest in the night.

2300-0345 CEST data used for noise evaluation of the variometer

0.1Hz ~ 20pT/√Hz

1Hz ~ 6pT/√Hz

Foreseen Intermagnet standard - 0.1Hz - 10pT/√Hz

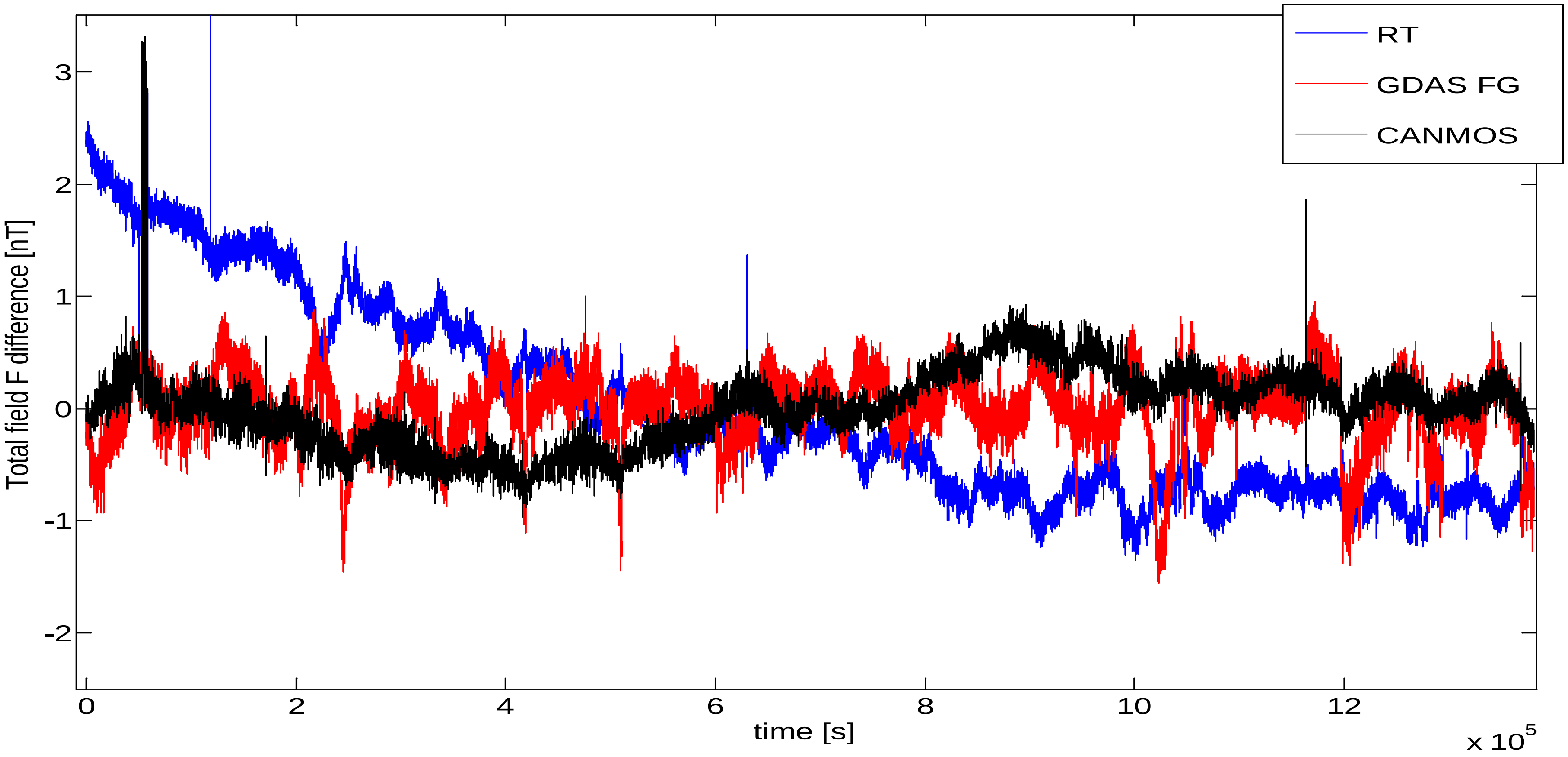
Make more measurements or move to a large shielded room (PTB Berlin)

Variometer long-term stability

- December 2015, 16 days burn-in, no temperature control (unheated absolute building)
- Calculated total (blue) compared to observatory devices: GDAS (red), CANMOS (black)
- Differences from OVH PPM readings plotted:

  Burn-in of feedback sense resistors during first 10 days

  Lower noise than CANMOS, far better than GDAS.



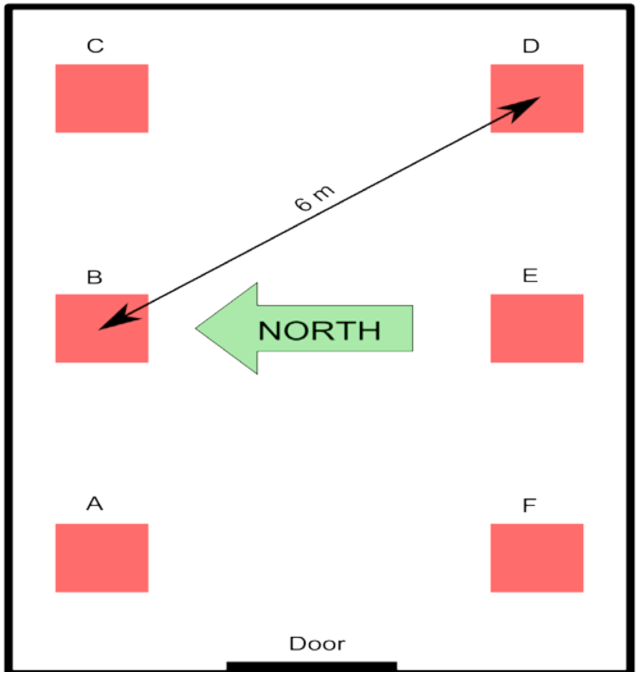
APMP Overhauser magnetometer comparison

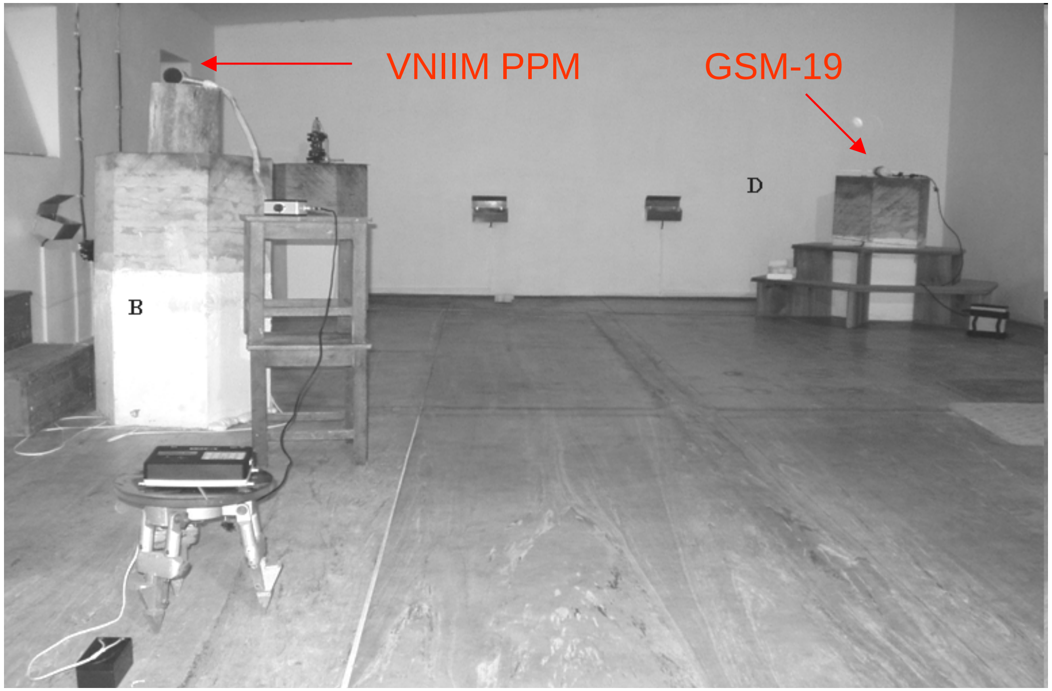
- 2014, Metrological task led by *VNIIM, St. Petersburg*
- 10 Metrology and Geophysical institutes over the world

- Motivation – estimate the uncertainty achievable with widely used Overhauser PPM magnetometers
  - VNIIM – facility with He-Cs MFD standard, 0.3-1 ppm STDEV
  - VNIIM provided a travel standard to be checked at Earth's field levels

- IG CAS, CTU and Czech Metrological Institute participated together
  - Earth's field with low magnetic gradient and disturbances
  - 2 OVH PPM's (GEM GSM-19) from CTU and IG

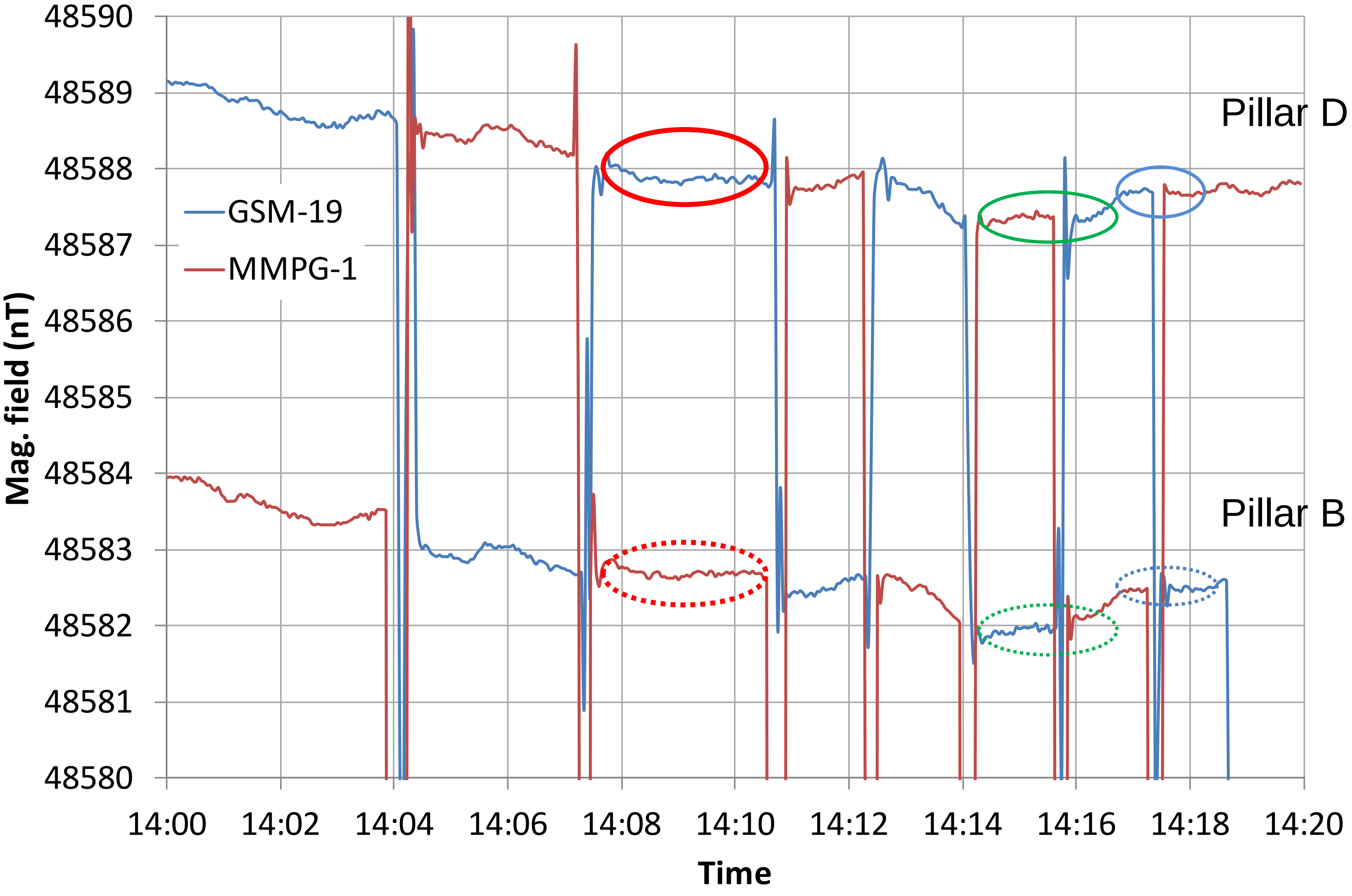
The comparison procedure





- The 3 instruments swapped : B x D (magnetic gradient ~ 6 nT)
- Total field logged (instrument time synchronized)
- Equation with MFD gradient, instrument difference and “true field”
- Mutual differences + standard deviation were established
  - *Ulvr, Zikmund, Kupec et al., Journal of Elec. Eng. 2015*

The procedure contd.



Comparison results

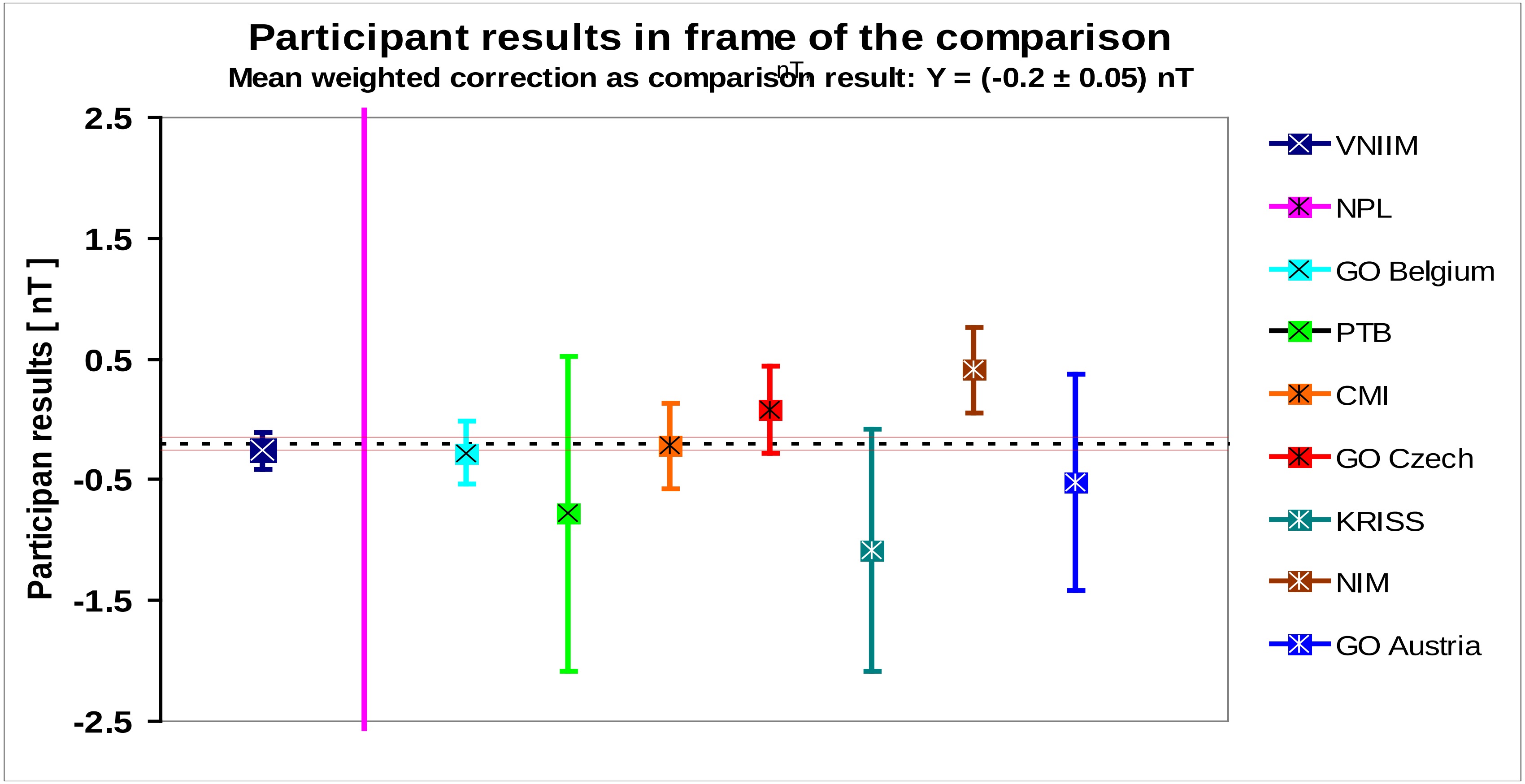
$$\Delta_{CTU-VNIIM} = (-0.17 \pm 0.36)\ \mathrm{nT}$$

$$\Delta_{IGCAS-VNIIM} = (-0.47 \pm 0.36)\ \mathrm{nT}$$

$$\Delta_{CTU-IGCAS} = (0.30 \pm 0.36)\ \mathrm{nT}$$

The results are third best in among the participants as for the uncertainty and estimated value.

(after VNIIM and RMI - Dourbes with *He/Cs or potassium-magnetometer closed-loop coil system)*



Summary

- The BDV observatory and the facilities find intensive use during research tasks performed by CTU and IG CAS
- The results achieved are quite encouraging
- I really appreciate our good relationships and look forward for more nice results published together ☺

Thank you for your attention.