The application of a fluxgate magnetometer for Mars space environment exploration in CHINA

Jindong Wang, Bin Zhou, Xin Zhang, Hua Zhao

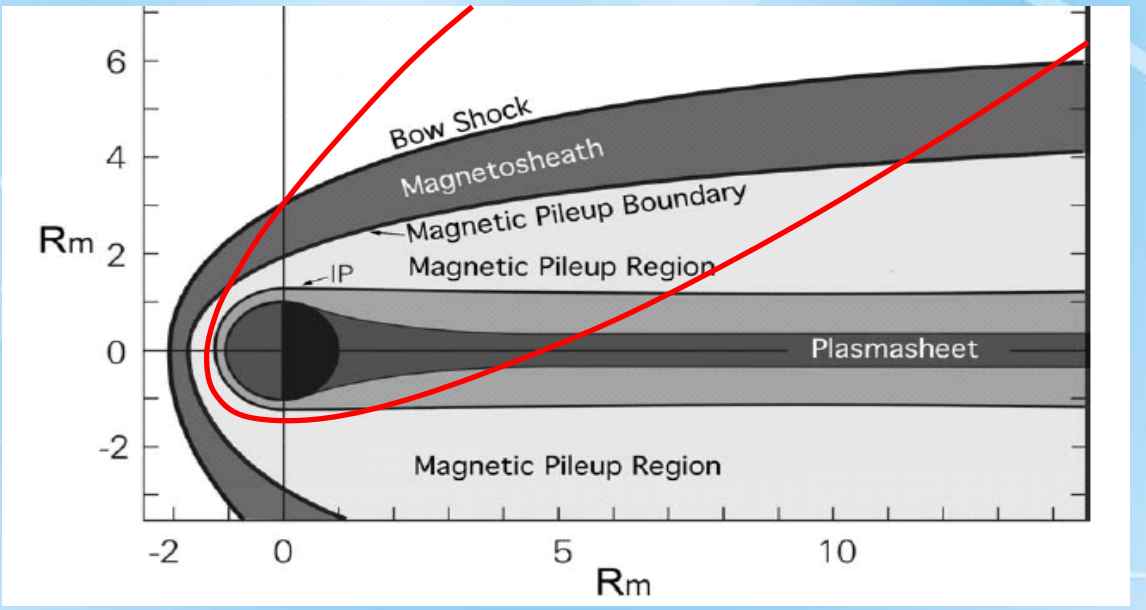
Center for Space Science and Applied Research, Chinese Academy of Science, Beijing, China

contents

- Magnetic field of Martian Space Environment
- Introduction of the fluxgate magnetometer (FGM)
- Calibration & EM tests
- Spacecraft residual magnetic field
- Summary

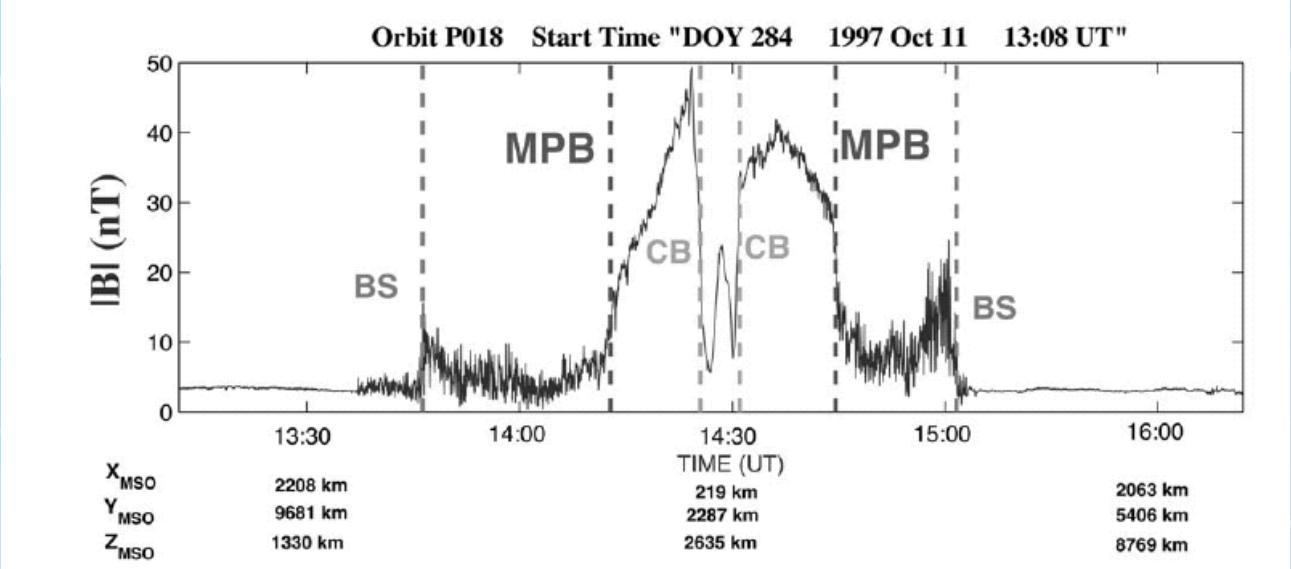
Orbit & Martian space environment

- orbit： elliptical, periapsis (nearest point) 800km， apoapsis (furthest point) 76,000km, period 72hours.
- “YH-1” orbiter will pass through bow shock, magnetosheath, magnetic pileup boundary, magnetic pileup region, and magnetic tail.



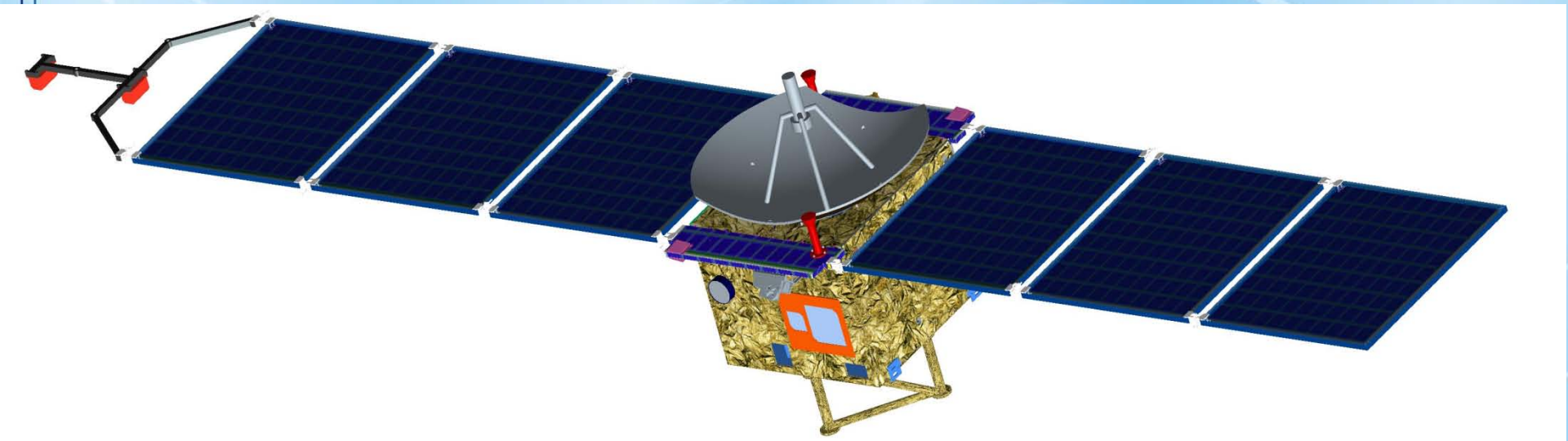
Martian magnetic field

- Mars lacks an appreciable global magnetic field (<0.5 nT equatorial surface field)
- Based on the Mars Global Surveyor (MGS), magnetic field at 800km altitude is dominated by external fields arising from the interaction of the solar wind with Mars.
- This external field is highly variable, ranging from a few nT to as much as (rarely) ~100 nT.

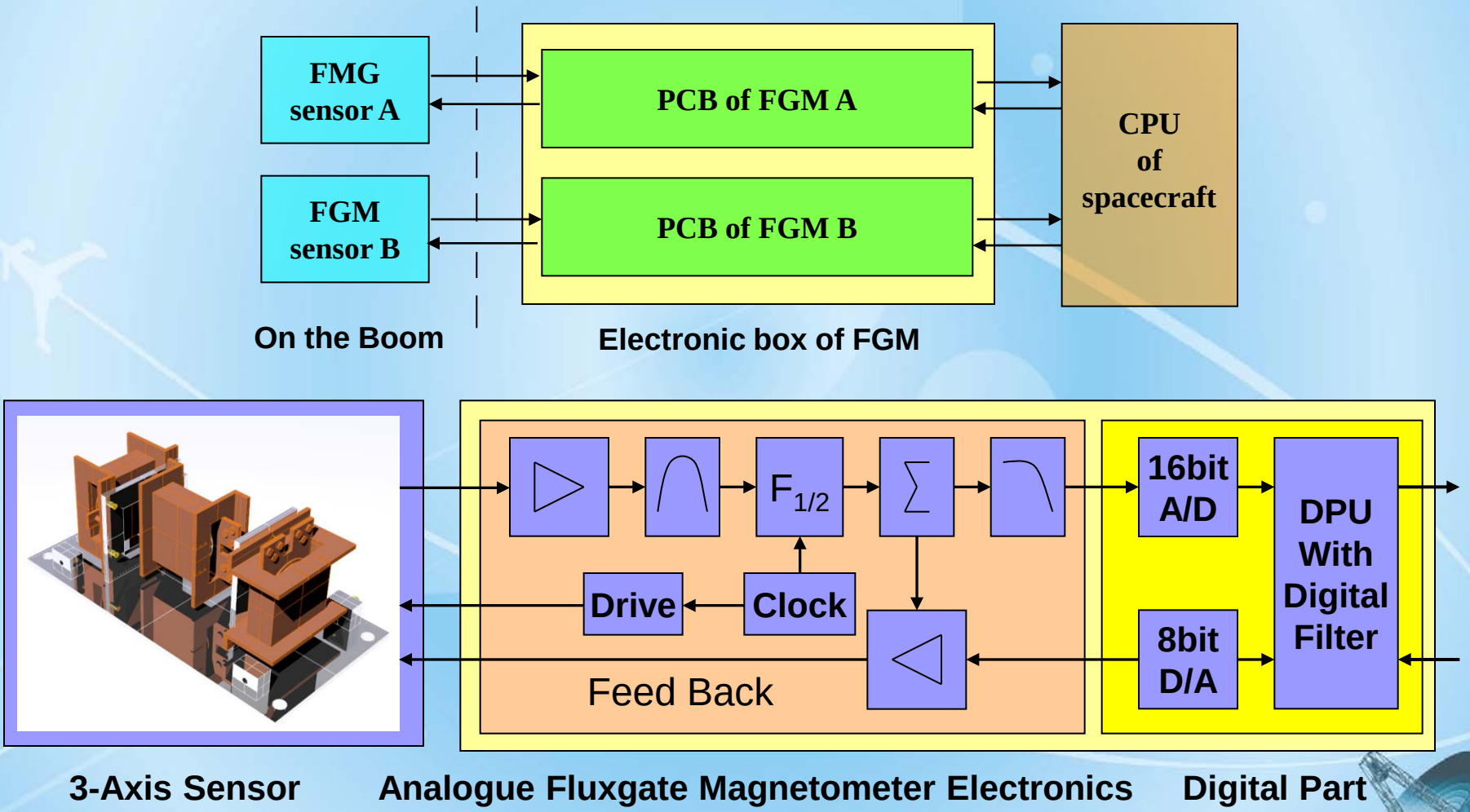


Design parameters

- Measurement range: ±256nT
- Resolution: 0.01nT
- Noise: <0.01nT/√Hz@1Hz
- Operating temperature range：-120~+70 ℃
- Mass: <2.5kg

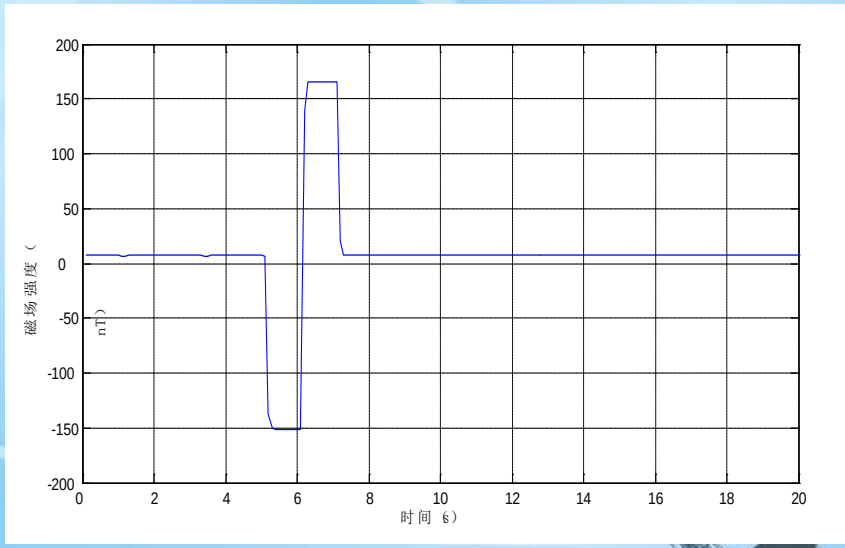


Block diagram of FGM



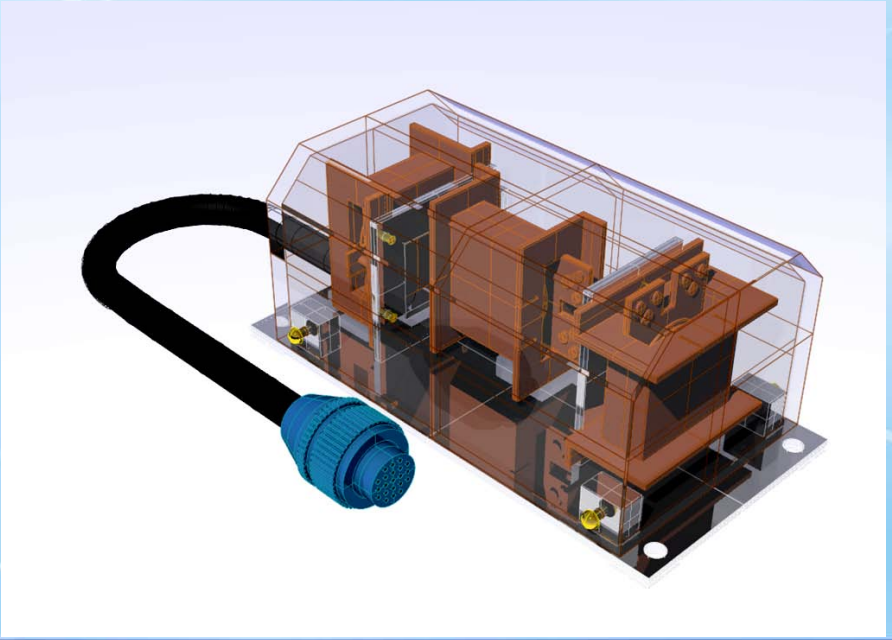
Operating modes

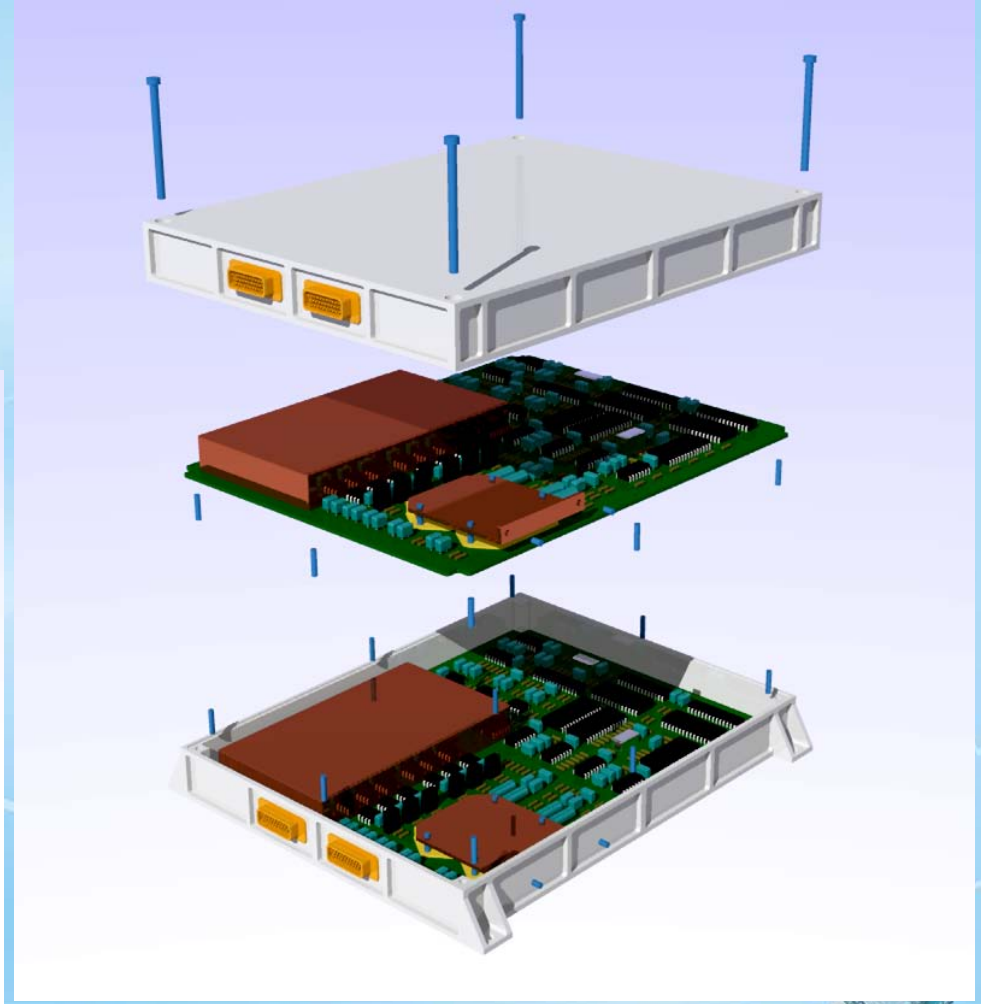
- Default mode
  - Acquires vector magnetic field measurements up to 10 samples/s in orbit;
  - Measurement range: -256~+256nT, resolution 0.01nT
- Compensation mode
  - Only used in ground testing;
  - Measurement range: +/-65000nT
- Self-calibration mode
  - Every time starting FGM
  - Self-calibration every 18 hours



Instrument design

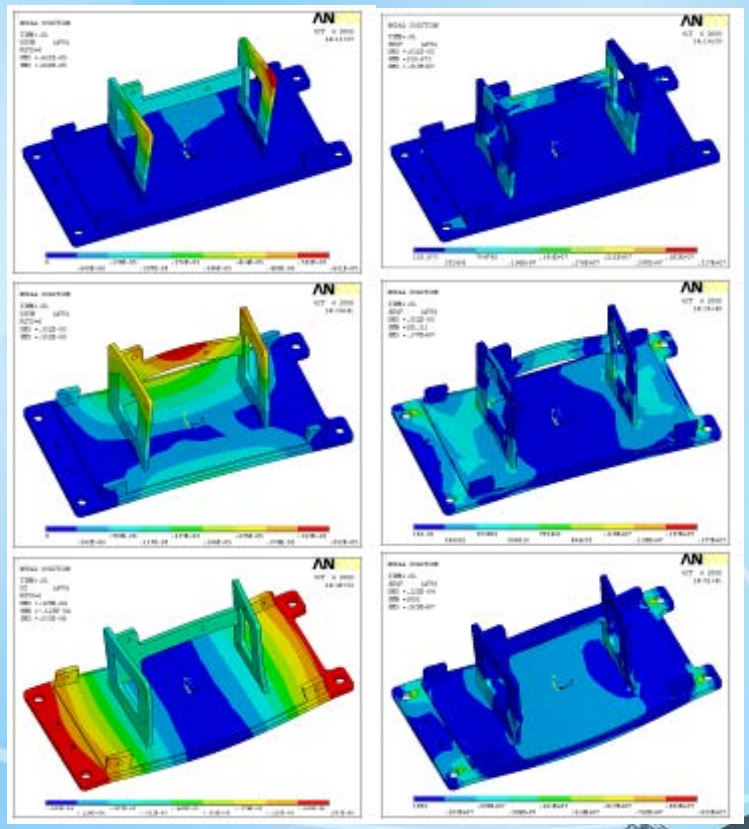
- Integrate 3 fluxgate sensors into a small casing;
- Can be divided into two independent instruments.





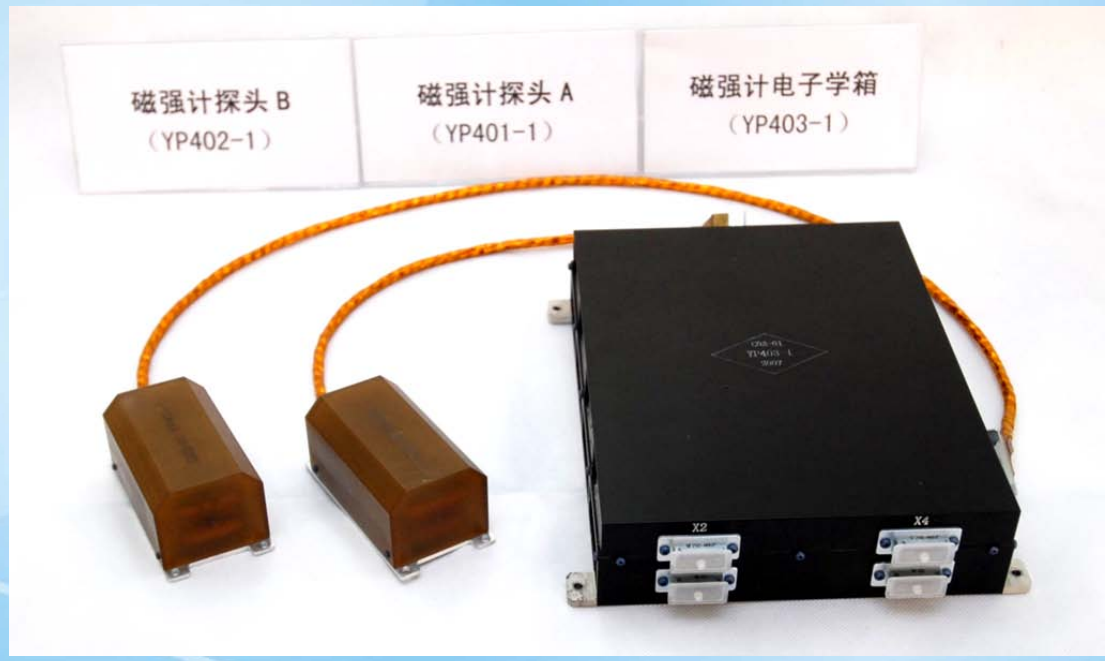
Simulation of structure stress

20℃	15g acceleration		
	X	Y	Z
Max stress (MPa)	3.17	1.77	9.26
Displacement (μm)	6.21	0.353	12.5
-180℃	15g acceleration		
	X	Y	Z
Max stress (MPa)	8.18	3.79	15.2
Displacement (μm)	12.6	2.16	21.3
75℃	15g acceleration		
	X	Y	Z
Max stress (MPa)	7.62	2.28	13.2
Displacement (μm)	9.34	1.15	18.4



Performance

- Measurement range
  - -256nT~+256nT
  - -65000nT~+65000nT
- Resolution
  - 0.01nT
- Noise
  - <0.01nT/√Hz@1Hz
- Sample rate
  - 10 Hz
- Mass
  - 2.5kg
- Power consumption
  - 6W



YH-1 FGM, flight model

Calibration & Test

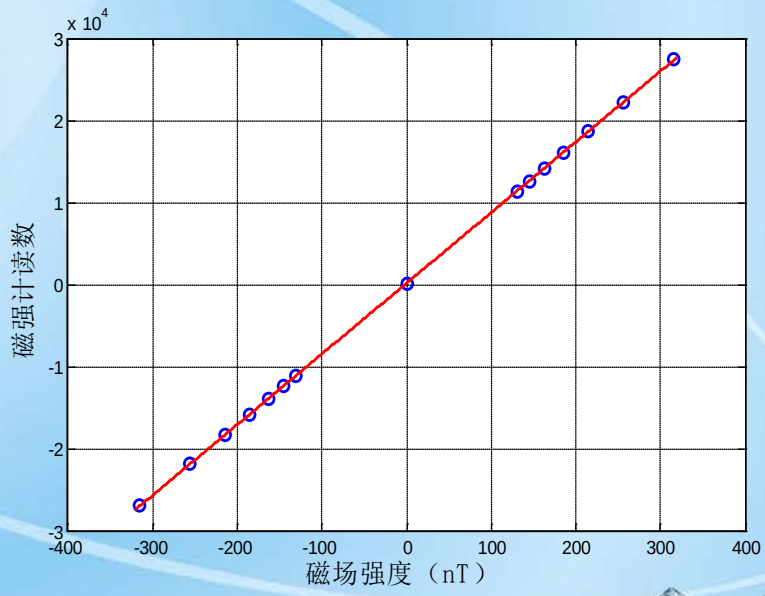
- Linearity and resolution
- Noise
- Stability
- Thermal stability

Linearity and resolution

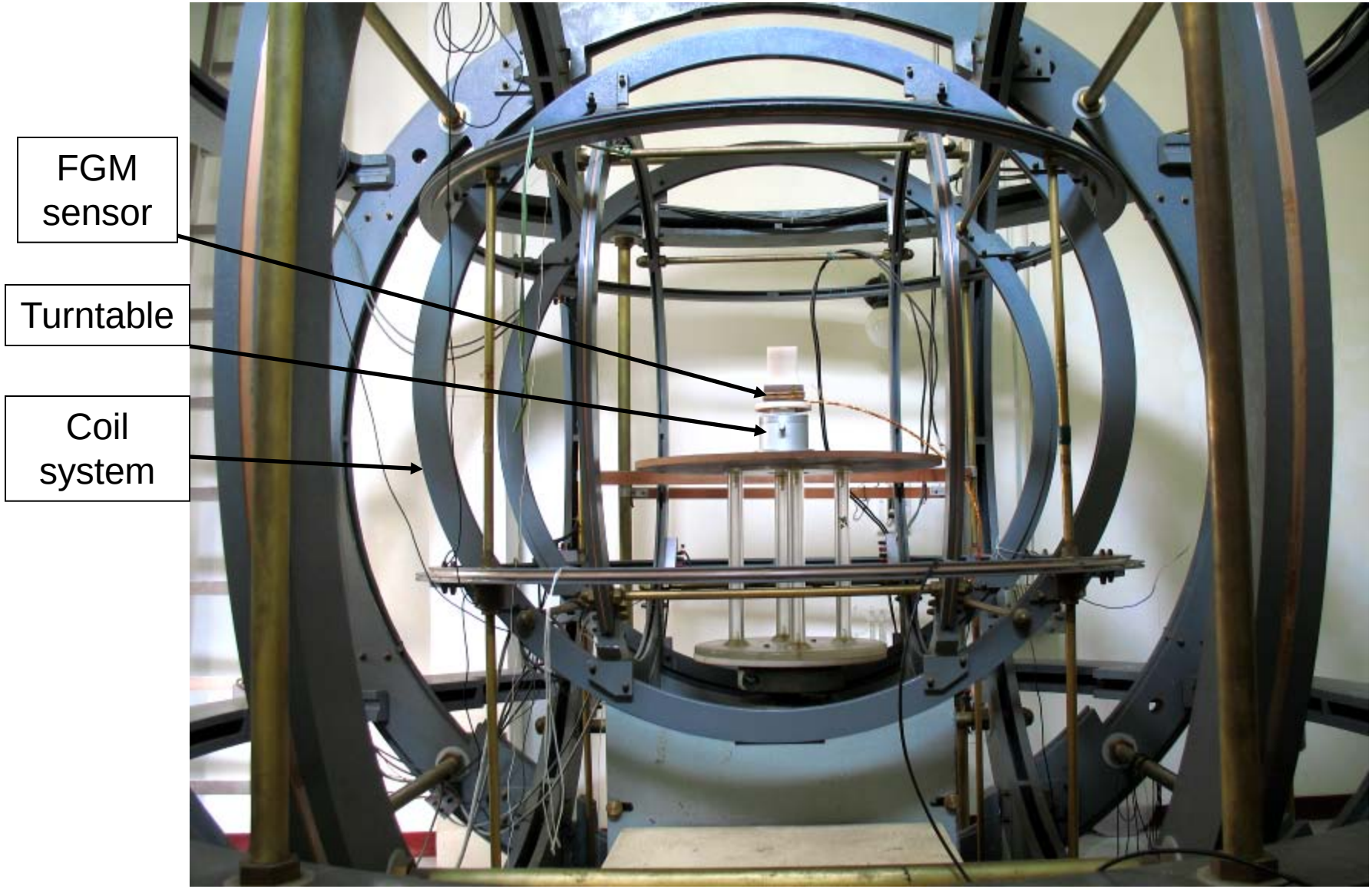
- Laboratory for calibration:
  - National Institute of Metrology, Beijing, China;
  - 3-axis criterion coil system; magnetic clean and thermostatic test room.

	Linearity (%)	Range (nT)	Sensitivity (nT)
X	0.041	>±256	0.098
Y	0.031	>±256	0.097
Z	0.116	>±256	0.099

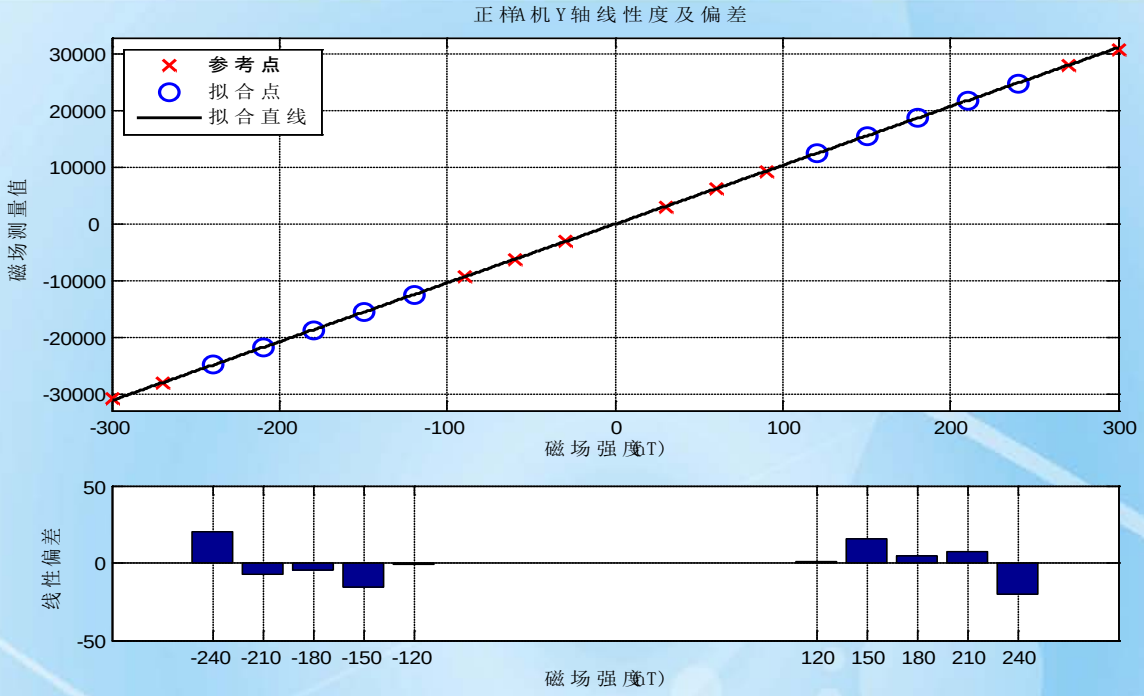
Linearity, sensitivity and resolution of FGM A



Linearity of FGM A, axis X



Calibration for FGM sensor——National Institute of Metrology, Beijing, China

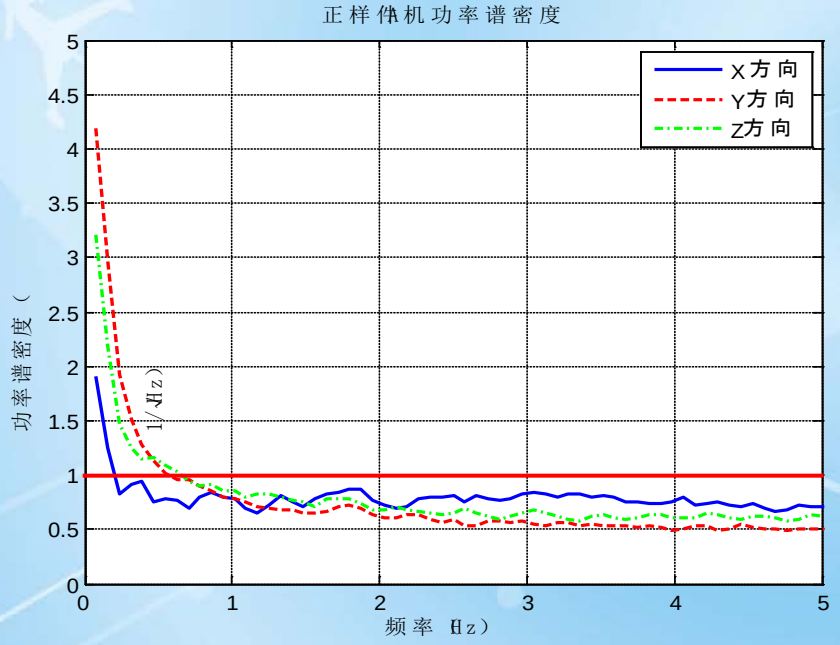


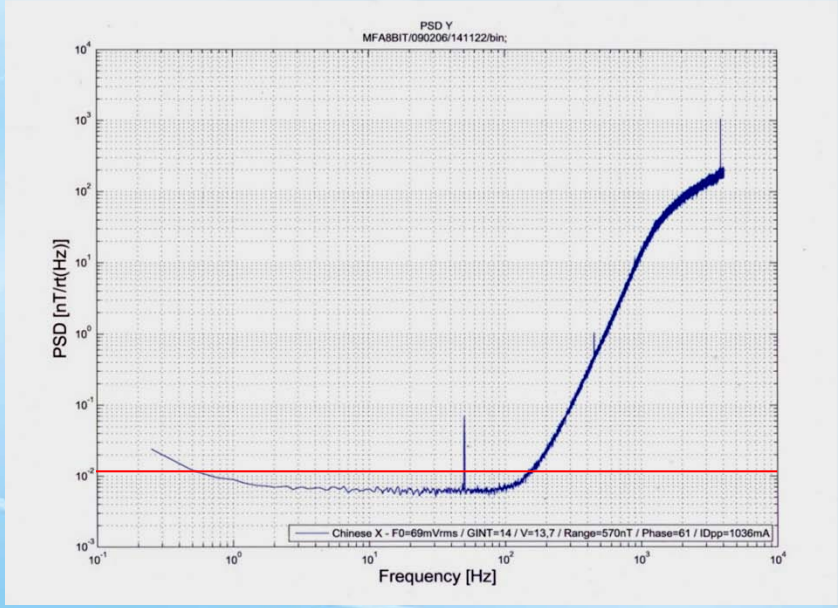
	Axis	Sensitivity（1/nT）	Resolution （nT/1）	Linearity（%）
A	X	101.58	0.0098	0.041
	Y	103.32	0.0097	0.031
	Z	103.80	0.0098	0.116
B	X	103.06	0.0097	0.052
	Y	104.19	0.0096	0.083
	Z	101.23	0.0099	0.045

Linearity, sensitivity and resolution of FGM, flight mode

Noise

- Laboratory for noise test
  - Ming-Tombs Geomagnetic Station, Institute of Geology and Geophysics, China Academy of Sciences, Beijing, China
  - Space Research Institute, Austrian Academy of Sciences, Graz, Austria





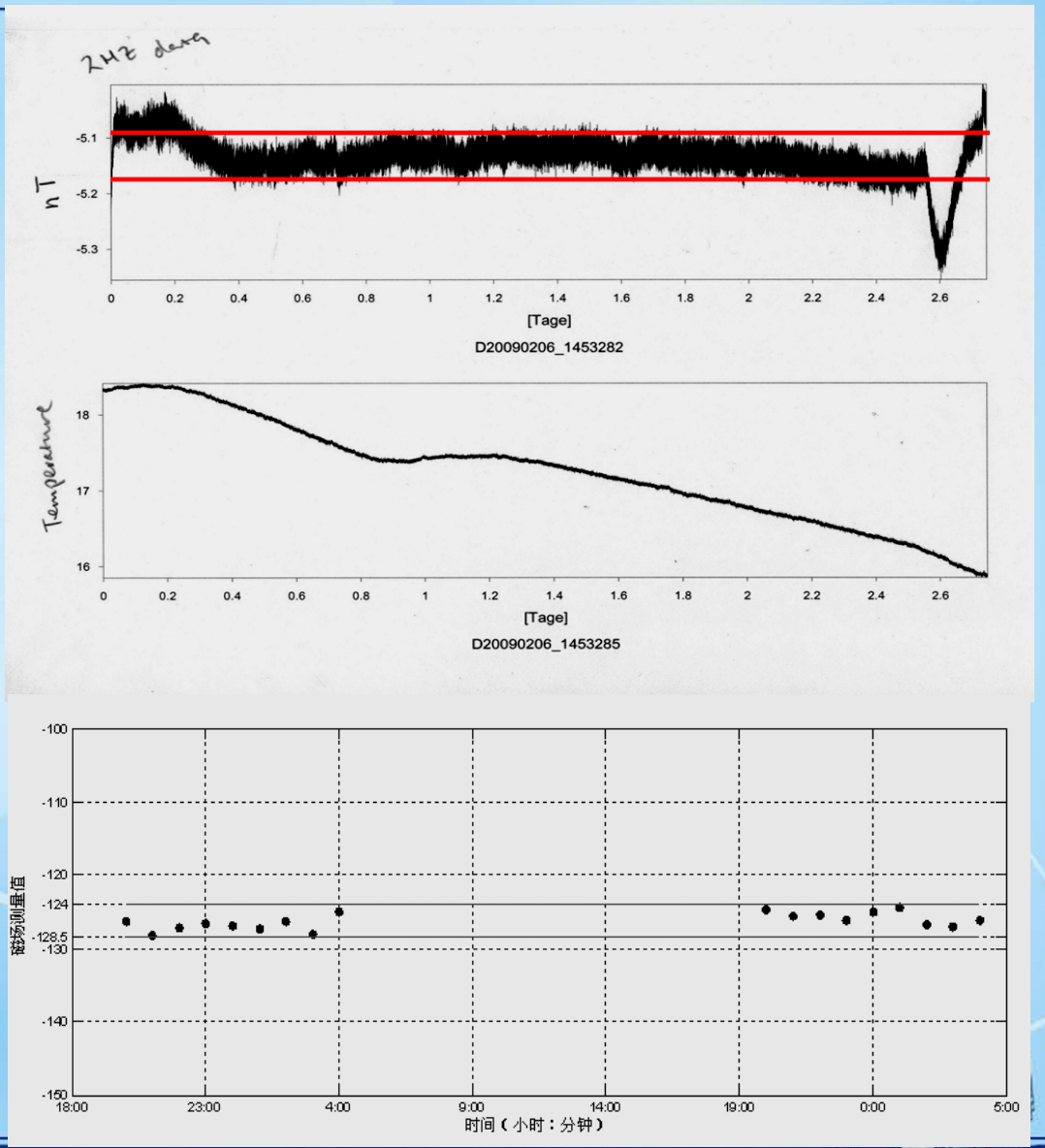
PSD noise of FGM sensor, CAS, Beijng & IWF, Graz

Stability

- Laboratory for stability test
  - CSSAR, Beijing, China
  - Space Research Institute, Austrian Academy of Sciences, Graz, Austria

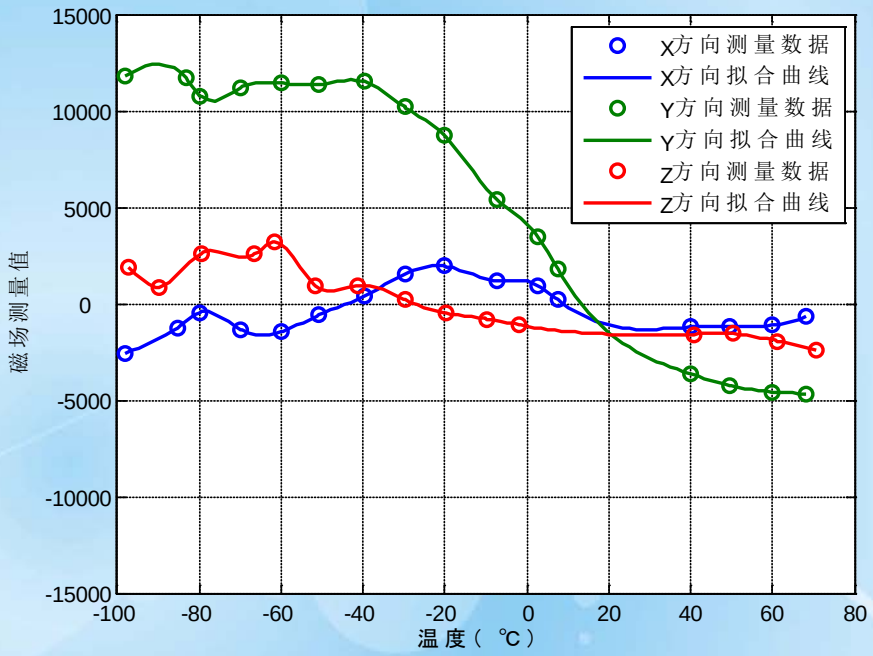
FGM	Axis	stability （nT/24hours）
A	X	0.035
	Y	0.116
	Z	0.096
B	X	0.057
	Y	0.105
	Z	0.110

Stability of FGM, flight mode



Thermal stability

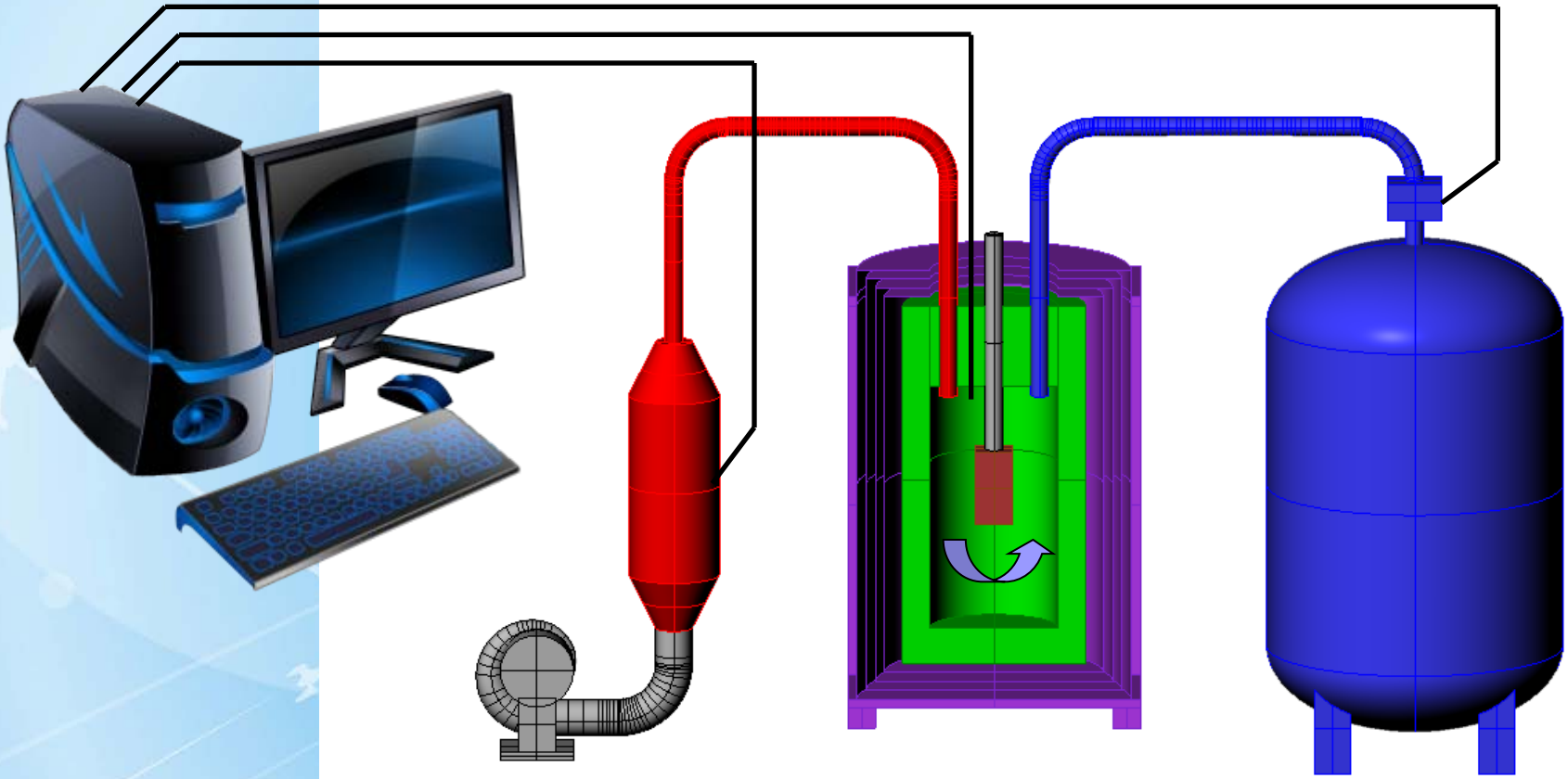
- During eclipses, temperature of FGM sensors could drop to about -210℃;
- Temperature drift must be calibrated so that we could fix the data measured in orbit.



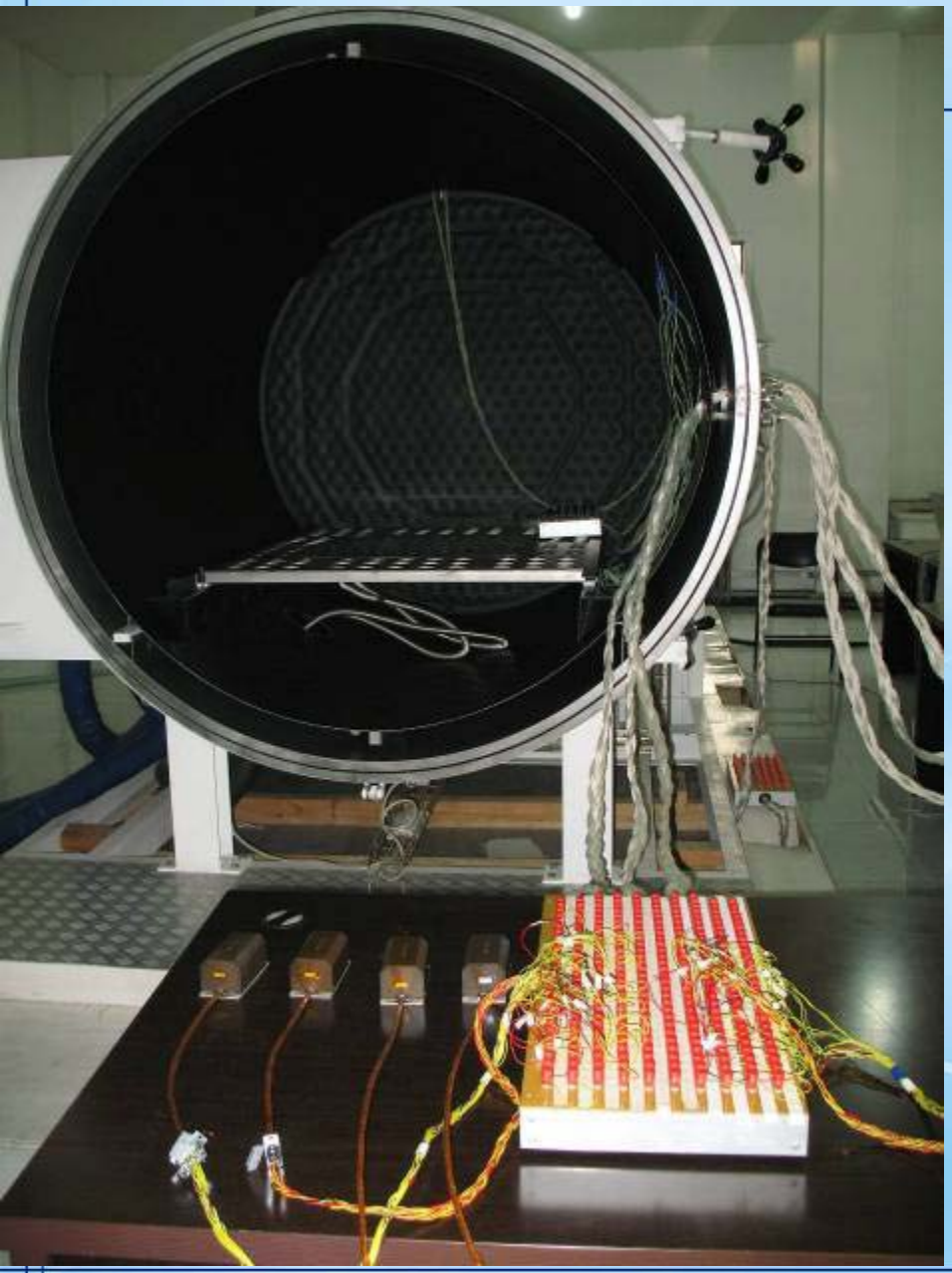
Temperature（℃）		-80	-60	-40	64
Axis Y, FGM A flight mode	Measurement	13276	13253	13238	13279
	Error	0.11%	0.06%	0.18%	0.13%

Sensitivity VS Temperature

Thermal test devices



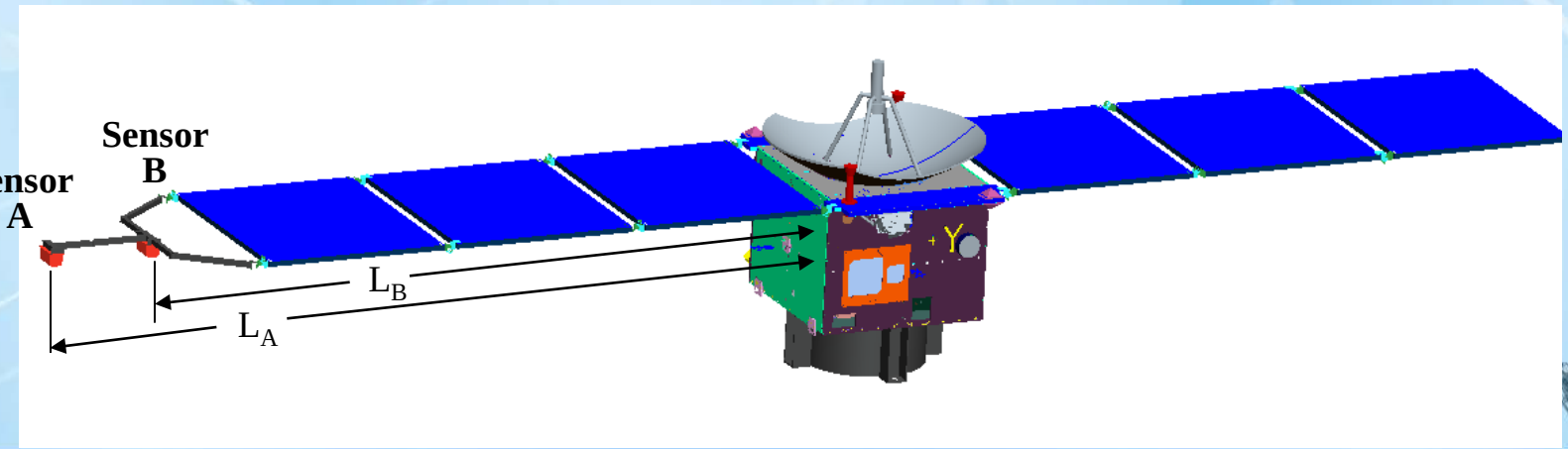
Block diagram of thermal test equipment



Spacecraft residual magnetic field

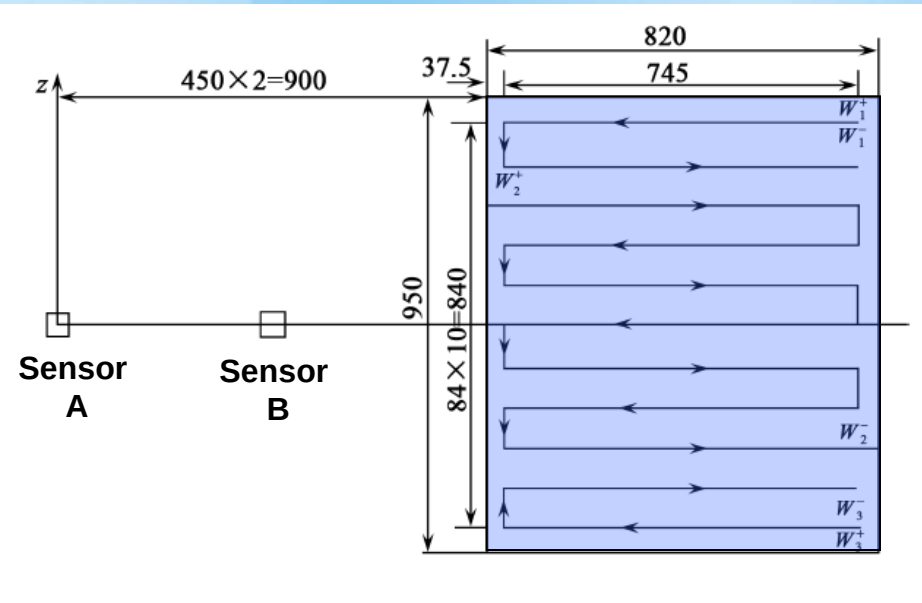
- In case of limited boom length, the spacecraft residual magnetic field could be simplified as a dipole;
- Use gradient magnetic data by two sensors, we can eliminate the influence of residual magnetic field of the spacecraft;
- Multi-pole magnetic field can be ignored because it weaken by 5-th power of distance.

$$B_M = \frac{L_A^3 B_A - L_B^3 B_B}{L_A^3 - L_B^3}$$



Current of Solar Wing

- Current on the solar wing generates electromagnetic interference;
- An analyses model was established in order to remove these interference;
- Typical case：
  - W1=W3=0.2A
  - W2=0.1A，
- Result:
  - 1.97nT at Sensor A
  - 8.38nT at Sensor B



Summary

- Time and Space Resolution
  - Time resolution: 0.1s
  - Space resolution: better than 0.3 km

    The speed of YH-1 spacecraft is about 3km/s at perimartian (nearest point), so in most case space resolution will be better than 0.3 km.
- Performance

Performances	Design specifications	Measured indicators
Range	-256nT～256nT	-270~270nT
Resolution	0.01nT	0.0099nT
PSD noise	0.01nT/$\sqrt{Hz}$ @1Hz	$0.008nT/\sqrt{Hz}$ @1Hz
RMS noise	<0.1nT	<0.03nT
Accuracy	<0.125nT	<0.09nT

Thank you