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In-orbit operation of a compact torsion-bar gravitational wave detector: SWIMμν

Wataru Kokuyama*, Masaki Ando[C], Shigenori Moriwaki[A], Koji Ishidoshiro, Kakeru Takahashi, Akito Araya[B], Yoichi Aso, Takeshi Takashima[D], Kazuhiro Nakazawa, Tadayuki Takahashi[D], Motohide Kokubun[D], Tetsuo Yoshimitsu[D], Hirokazu Odaka[D], Takayuki Yuasa, Takehiko Ishikawa[D], Teruaki Enoto, Keiko Kokeyama[E], Shin-ichiro Sakai[D], Shuichi Sato[F], Akiteru Takamori[B], Kimio Tsubono, Tomoaki Toda[D], Tatusaki Hashimoto[D]

Department of Physics, The University of Tokyo , Department of Advanced Materials Science, The University of Tokyo [A], Earthquake Research Institute, The University of Tokyo [B], Kyoto University [C], Institute of Space and Astronautical Sciences, Japan Aerospace Exploration Agency [D], National Astronomical Observatory of Japan [E], Department of System Control Engineering, Hosei University [F]

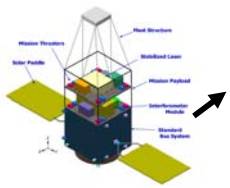
*e-mail: kokuyama@granite.phys.s.u-tokyo.ac.jp

Abstract

SWIMμν is a tiny (3.5kg-weight) gravitational wave detector, which was successfully launched in January 2009. It is a torsion-bar type gravitational wave detector with two floating aluminum bars (50g each). Main objectives of this project are to gain experiences with a space mission for future detectors such as DECIGO Pathfinder and to observe gravitational waves in orbit as the first space-based gravitational wave detector. We have successfully operated the detector for more than a year, engaging detector characterization and observational run.

1. DECIGO roadmap and SWIMμν

SWIMμν (2009)

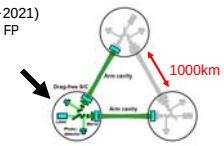


DECIGO Pathfinder (~2015)

- Single FP cavity in LEO
- GW & earth gravity observation

Talks by M.Ando, S.Sato, & Y.Michimura
Poster by A.Shoda

Pre-DECIGO (~2021)
- Inter-satellite FP
- GW detection



DECIGO (~2027)

- Four constellations
- Frequent GW detection

Talk by S.Kawamura
Poster by N.Seto

Tiny GW sensor on a small satellite before DPF: SWIMμν
Cheaper & faster technology demonstration

2. SDS-1/SWIM

- SWIM: one of the four main missions of SDS-1
(Small Demonstration Satellite-1, a JAXA's piggyback satellite)
- Comprises SWIMμν and SpaceCube2 (Space-qualified computer)
- Demonstrate SpaceWire-based DAQ framework in space

Launch photo on January 23, 2009

Photo of SDS-1
70x70x70cm, 100kg, 670km SSO
Spin/3-Axes attitude control

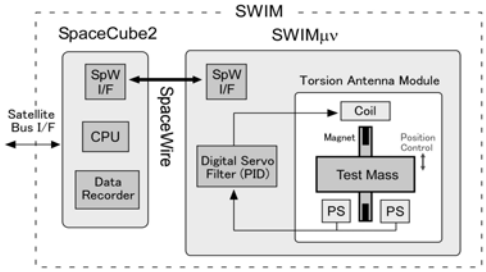
3. SWIMμν

Torsion-type GW detector

Mission Objectives:
(i) Observe GWs in orbit for the first time
(ii) Gain experiences for future space GW detectors
(iii) Evaluate the satellite's vibration level

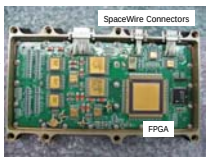
Photo of SWIMmn

- 3.5kg, 3W Power
- 120 x 180 x 220mm
- Design Sensitivity:
~10^{-6} rad/Hz$^{1/2}$ at 0.1-1Hz
(limited by electronics-noise)
- Same feedback system as DPF



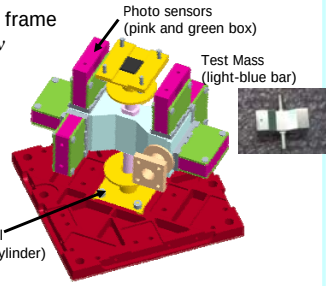
Test mass: Controlled to be not contacted with the frame
DAQ realized by SpaceCube2 and FPGA on SWIMμν

SpaceCube2



Digital electronics board

SpaceWire



Structural view of torsion antenna module
(excluding aluminum frame)

Digital position control
6 Photosensors
↓ Displacement signal
A/D converters
↓
Digital PID Filters on FPGA
↓
D/A converters
↓ Feedback signal
4 Coil-magnet actuators

→ Similar to test mass control loop of DPF
(electrostatic sensors / actuators)

- **Test Mass:**
50g, Aluminum, 4 magnet attached for actuators
- **Photo Sensors:**
Infrared LED and PDs
Relative displacement measurement
- **Coils:** Attached to the frame
- **Environmental monitor**
On-Chip Gyros and Accelerometers

4. Results

Operation:
- Only 2-5 days/month
- Feb. 2009~
- ~16MB of data (total)

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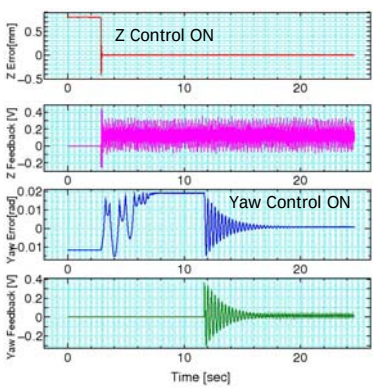
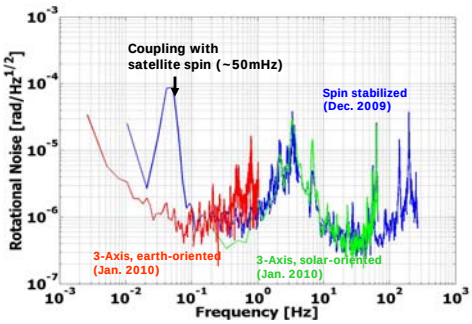
- Successful test mass control (Total ~ 7 hours)
- Noise spectrum of the sensor measured
- Clock synchronization with GPS (6-digits accuracy)
- GW observation run

Successful test mass position control



Vertical & rotational lock of test mass

Detector Characterization



- 10^{-6} rad/Hz$^{1/2}$ residual noise level at 0.1-1Hz
- SWIMmn clearly detects satellite motion
- Calibration run (Openloop TF measurement) finished, now analysis ongoing

Observation & data analysis

Although SWIMmn has 10-digits worse sensitivity than DPF,...

1) GWs from the Galactic Center
- Main target for DPF observations
- SWIMμν can be oriented at GC.
Done!

2) Coincident observation with ground-based torsion-bar antenna at U.Tokyo / Kyoto U.
- Detector in low-earth orbit moves around the earth in every 100min.

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Interesting analysis?
(If there is, it can be applied to DPF.)

More operations and data analysis (Detector diagnosis, vibration measurement, GW observation, etc.) ongoing/planned