



GP-B Monthly Report April 2012

This monthly report documents the activities in April, 2012 with focus on progress towards publishing GP-B science and technology papers in *Classical and Quantum Gravity*. Five of these papers are in-work. Co-authored by KACST, NASA, Lockheed Martin, and Stanford personnel, the plan is to complete these first five by August 1, 2012.. Other activities reported below include collection of supporting reference documentation and collaboration status with KACST, Lockheed Martin, NASA, and other potential groups.

A plenary GP-B talk will be given in October at the 2012 Applied Superconductivity Conference by Barry Muhlfelder. GP-B team members will be giving a series of talks at the Marcel Grossmann meeting in Stockholm. A plenary talk by Francis Everitt will be followed by a full session of GP-B contributed talks.

Five papers in-progress:

1) Gravity Probe B Cryogenic Payload: R. Parmley (Lockheed Martin, retired), K. Burns (Lockheed Martin), C.W.F. Everitt, D. Frank (Lockheed Martin), B. Muhlfelder, D. Murray, G. Reynolds (Lockheed Martin), M. Taber, W. Till (MSFC), R. Vassar (Lockheed Martin, retired), KACST personnel.

Abstract: Gravity Probe B mission developed the largest capacity helium flight dewar which provided 17.3 months of cryogenic operations in space. Ground test campaigns and two independent performance models, led by Lockheed Martin and Marshall Space Flight Center, were constructed to ensure that the required hold time of 16 months be met or exceeded. A porous plug device, invented by the GP-B team and subsequently flown on IRAS, COBE, and ISO, successfully constrained the flow of the superfluid cryogen. This paper will present flight performance results and make comparisons with preflight model expectations to inform future space cryogenic systems design.

Work in the past month has focused on Section II. Francis Everitt has consolidated the existing text and has added additional relevant material. The two active and three retired Lockheed Martin team members have provided vital contributions. NASA personnel, involved during on-orbit operations, will add to the paper with thermal modeling analysis. The plan is to have a complete draft of the paper by the end of May. The paper is planned to be finished by the beginning of July.

2) Science Paper: Gravity Probe B test of the precession due to general relativity of gyroscopes in earth polar orbit: C.W.F. Everitt, et al.

Abstract: We report the results of an experiment to measure the geodetic and frame-dragging precessions due to general relativity of gyroscopes in a 640 km polar orbit around Earth. The results are in agreement with general relativity: the geodetic precession predicted by general relativity is -6606.1 milli-arcsec/yr, and the result derived from our measurements is -6601.8 ± 18.3 milli-arcsec/yr; the frame-dragging precession predicted by general relativity is -39.2 milli-arcsec/yr, and the result derived from our measurement is -37.2 ± 7.2 milli-arcsec/yr. This paper

and the accompanying papers in this *Classical and Quantum Gravity* special volume describe in detail the flight instrument configuration, give a detailed description of the data (collected on the ground and during flight) needed for data analysis, describe the data analysis methods used, provide an analysis of systematic error, and provide the derivation of the final results.

In the past month John Conklin has provided the write up on the 2 s filter and Barry Muhlfelder provided a draft of the section on systematic error. General feedback on organization, etc. has been provided by some of the co-authors. John Turneure continues to coordinate this paper and is maintaining the electronic copy. The following contributors are currently working on various sections: John Conklin, Mac Keiser, Barry Muhlfelder, and John Turneure.

3) GP-B Attitude Control: D. DeBra, M. Adams, W. Bencze, J. W. Conklin, J. Kirschenbaum (Lockheed Martin), B. Muhlfelder, M. West (NASA), KACST personnel.

Abstract: We discuss the requirements, design, implementation, and on-orbit performance of the GP-B attitude control system. High precision attitude and roll control, along with a previously described drag-free system, controlled the spacecraft's six degrees of freedom. Novel control features reduced inertially-fixed mispointing to ~ 20 mas. Other techniques allowed the guide star to be locked onto in 1-2 minutes each orbit as the guide star became visible following occultation by the Earth.

Dan DeBra and John Conklin continue to co-lead this paper. During the past month Barry Muhlfelder has provided a description of the telescope. A section by J. Li is underway on spacecraft roll control. Detailed contributions have been provided by B. Muhlfelder, J. Kirschenbaum, J. Conklin, and M. Adams.

4) Gravity Probe B Data Analysis Overview I. A. S. Silbergleit, J. W. Conklin, M. I. Heifetz, G. M. Keiser, J. P. Turneure, P. W. Worden Jr., KACST personnel.

Abstract: We give a detailed description of the analysis of data obtained in the Gravity Probe B Relativity Science mission and its results.

The paper on GP-B data analysis is planned in two parts: Overview I. Coordinate Frames and Analysis Model. (DA I) Overview II. Data to Analyze, Estimation Tools, and Analysis Results. (DA II).

The complete draft of DA I was completed this past month. Sections 6 (S/C pointing), 7 (summary of the models), 2 (introduction), and abstract have been added. It is currently being checked and polished, and I will release revision 5 around mid-May. DA II is underway, with version I to be sent out shortly.

5) GP-B Tracking Telescope: Lipa, Goebel (NASA), Turneure, Wang, KACST personnel.

Abstract: This paper will describe the on-orbit performance of the GP-B Star Tracking Telescope. This system provided star tracking measurement to better than 1 mas and served as the reference sensor for the vehicle's inertial guidance system with a mission average mispointing of < 25 mas. A novel hydroxide catalyzed bonding technique, developed to provide robust and high dimensional stability precision quartz bonds has found application in a wide range of optical systems. The telescope cryogenic optical detection system is comprised of matched pairs of blue-enhanced Si photodiodes coupled to Si JFET amplifiers. The photodiodes and JFET circuits are mounted on a sapphire thermal platform maintained near 72K for optimal noise performance. Flight readout electronics drives the cryogenic detector system in a charge-locked loop reset at a 10 Hz rate. In this paper we describe the flight performance of the system with an emphasis on future lessons learned

for future flight missions.

A rough draft now exists for this paper, and although incomplete, comprises 28 pages. L. Brandt is now reviewing telescope snapshot data acquired on-orbit. This work will support the write up of the on-orbit performance. J. Lipa, S. Wang, L. Brandt, and B. Muhlfelder are involved in this effort.

Two papers to be started by June 1, 2012:

6) GP-B Gyroscope: S. Buchman, C.W.F. Everitt, D. Gill, G. Keiser, F. Marcela, P. Peters (MSFC), J. Hayden, KACST personnel

Abstract: The top level rotor requirement states that the Newtonian drift < 0.1 milli-arc-second per year. To achieve this, the rotor has been manufactured to a sphericity of $2e-7$ and a mass unbalance of $< 20e-9$ m. Rotor lapping and polishing of homosil[™] quartz yields 25 nm P-V rotors. Optical measurement of Homosil gives a mass homogeneity of better than $1e-7$. A uniform niobium deposition maintains the mass unbalance while allowing electrostatic gyroscope suspension and the London Moment readout. The gyroscope housing encases the rotor, and allows electrostatic suspension, charge control, spin up, and readout.

7) GP-B Gyroscope Readout: B. Muhlfelder, B. Clarke, G. Gutt, J. Lockhart, M. Luo, KACST personnel

Abstract: The London Moment SQUID-based readout system provides milli-arc-sec ($\sim 3e-7$ arc-degrees) measurement of gyroscope spin axis orientation in a 5 hour integration time. Active temperature control provides sub-microKelvin SQUID temperature stability at roll frequency, thereby limiting spurious signals caused by temperature variation.

Other activities:

1. Dr. Ken Washington, VP of Lockheed Martin's Advanced Technology Center (ATC) gave a HEPL seminar on April 4, 2012. Discussions were held on the proposed Memorandum of Understanding between Lockheed Martin and Stanford. The intent is to make HEPL the primary party within Stanford.
2. GP-B theses were categorized and reviewed with team members. They are available for use by GP-B co-authors.
3. The GP-B servers were reviewed by S. Eisner and approved for public use.