GP-B Monthly Report
January 2012

This monthly report, the first in a series, documents the status of the GP-B plan to publish a set of 24 papers in a 600 page special volume of *Classical and Quantum Gravity*. The current effort is focused on four papers. Three additional papers will be started by April 1, 2012. The plan is complete a total of five papers by July 1, 2012 with at least 5 KACST, 2 NASA, and 4 Lockheed Martin co-authors. Other activities reported below include collection of supporting reference documentation and collaboration status with KACST, Lockheed Martin, NASA, and other potential groups.

<u>Four papers in-progress</u>:

1) Gravity Probe B Cryogenic Payload: B. Muhlfelder, K. Burns (Lockheed Martin), C.W.F. Everitt, D. Frank (Lockheed Martin), D. Murray, R. Parmley (Lockheed Martin, retired), 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.

This group has been holding regular meetings to review status and to maintain forward momentum. The two active and three retired Lockheed Martin team members have provided vital contributions. NASA personnel were involved during on-orbit operations and will be involved in the paper with thermal modeling analysis. The plan is to have a complete rough draft of the paper by mid-March, and a polished draft by end of April. The paper will 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 ± 18.3milli-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.

The following contributors are currently working on various sections of the paper: John Conklin, Mac Keiser, Barry Muhlfelder, and John Turneaure. John Turneaure is coordinating the effort on this paper and will maintain the electronic copy of the paper. The next meeting of this group to discuss the progress on the various sections of the paper will be held Monday, February 6.

3) GP-B Attitude Control: D. DeBra, M. Adams, W. Bencze, J. W. Conklin, L. Herman (consultant), J. Kirschenbaum (Lockheed Martin), 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.

A detailed outline has been developed and writing is underway. Dan DeBra and John Conklin are co-leading the work.

4) Gravity Probe B Data Analysis Overview I. A. S. Silbergleit, J. W. Conklin, M. I. Heifetz, G. M. Keiser, J. P. Turneaure, 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).

Paper DA I is well under way. In January revision 3 of the paper was released to all the co-authors, containing 60 – 70% of all the material that needs to be included. By means of a painful tedious word by word editing its length did not grow much, although, in particular, a large appendix on the theoretical model for TFM and polhode variations of the SQUID scale factor has been added. Since then an essential progress was made towards revision 4, which should hopefully be finished in March. This revision will contain, not counting a very brief introduction and summary, all but one of the planned sections, including the voluminous and complicated appendix with the full theoretical description of patch effect torques.

As for DA II, its structure has been determined, along with an understanding of required specific topics. Writing assignments have been made. One appendix has been completed. DA II is led by M. Heifetz.

Three papers to be started by April 1, 2012:

5) GP-B Tracking Telescope: Lipa, Goebel (NASA), Turneaure, 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.

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 (~ 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.

<u>Other activities:</u>

1. The team located 92 GP-B related Ph.D. theses and documented our findings in the attached spreadsheet. Approximately 80 of these theses, retrieved from off-campus storage, are now maintained in the Physics/Astrophysics Bldg. Hamoud Aljibreen, Barry Muhlfelder, and David Cuffy have begun cross checking the theses with additional hardcopy and on-line sources (e.g. Stanford Socrates, Proquest) and will complete this effort in February.

2. Met with Dr. Ken Washington, VP of Lockheed Martin's Advanced Technology Center (ATC) on January 17. Agreed to expand Memorandum of Understanding between Lockheed Martin and Stanford to include HEPL and GP-B. Dr. Washington also agreed to give a Spring Quarter HEPL seminar at Stanford.

3. Documents added to Stanford webpage to support the writing of technology papers.