GP-B Monthly Report
July 2012

This monthly report documents activities in July, focusing on progress towards publishing GP-B science and technology papers in *Classical and Quantum Gravity*. There has been significant progress in the first set of papers. Co-authored by KACST, NASA, Lockheed Martin, and Stanford personnel, the plan is begin work on a second set of papers after the first set nears completion. Majid Al-meshari is coordinating the KACST contribution. Other activities reported below include information on conference talks given by team members and the collaboration status with KACST, Lockheed Martin, NASA, and other potential groups.

A series of eight talks were given in a special session dedicated to GP-B at the Marcel Grossmann (MG) meeting in Stockholm July 1-7, 2012. Roy Kerr, of Kerr metric fame, gave a short informal talk on relativity. Subsequent talks by the GP-B team, detailed the technology and data analysis underlying the Program. See Table below. In addition to the special session, Francis Everitt gave a plenary presentation overviewing Fundamental Physics in Space, a talk on the Satellite Test of the Equivalence Principle (STEP), and a historical talk on Maxwell. Of special interest, Roy Kerr gave a plenary talk on the theoretical significance of GP-B.

Speaker (in presentation order)	Topic
Barry Muhlfelder	Overview and SIA
Richard Parmley	Cryogenic payload
Alex Silbergleit	Data analysis I
John Conklin	Data analysis II
Majid Al-meshari	Data analysis III
Bill Bencze	Control systems
Gaylord Green	Lessons learned
Francis Everitt	Closing Comment

There were two significant side discussions at MG-13. Francis Everitt and Barry Muhlfelder met with Majid Almeshari to discuss the GP-B KACST-Stanford collaboration. Point of contacts have been identified at Stanford. KACST is in the process of identifying personnel to join the project. At MG-13, Francis Everitt and Barry Muhlfelder also met with Adam Day, publisher at *CQG*. We discussed the overall status of the special volume. The *CQG* staff at has been monitoring GP-B's progress by review of this Monthly Report.

GP-B continues to receive wide recognition in the engineering and scientific communities. Barry Muhlfelder will give the lead Plenary talk at the upcoming Applied Superconductivity Conference in Portland Oregon, Oct. 8. There are expected to be approximately 1500 participants.

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, retired), 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.

The team has now nearly completed a draft of this entire paper. Work in July has focused on Sections II, IV,VI, and VII. Francis Everitt has updated Section II. An abbreviated version of the previous Section VI (Vacuum Model) is now incorporated into Section II. Section IV (Probe), along with the newly renumbered Section VI (Ground Performance) are now nearly complete. Section VII (On-orbit Performance) has been reworked with improved text and additional technical material. Kevin Burns has revived the LM computer-based thermal analysis model in an effort to understand the higher than expected measured, on-orbit skin temperature of the spacecraft. This analysis is important to understand the GP-B helium lifetime and to help predict the lifetime of future cryogenic missions. Section IX (Conclusion) is in-work, with completion expected this coming month.

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.

John Conklin, Mac Keiser, Barry Muhlfelder, and John Turneaure continue to work on this paper. John Turneaure has developed a numerical truth model to further strengthen our confidence in the misalignment torque model. Starting with the spherical harmonic "truth" expansion, he has retained terms up to order 1500 (this maximum value derives from the physical understanding of patches). Next, a Fourier expansion, with reduced order, is constructed and used to estimate the patch-induced drift. This estimated drift is within ~ 2 marcsec/yr of truth.

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 with a push in this last month to advance all sections of the paper. John will continue to work this paper as he transitions to University of Florida, Gainesville.

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).

This paper is in near final form for submission to CQG. Alex Silbergleit has just completed pohode calculations based on the formula for the asymptotic polhode period. The bottom line is that TFM and Dolphin's data on Delta I/ I are consistent. An interesting estimate of the time to reach the asymptotic position is also obtained (finite in the presence of spin-down torque).

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.

Work continues towards completion of a rough draft. Varun Cherukuri, an undergraduate student, worked on the telescope paper this summer and provided the following outline of the paper.

Two papers to be started by August 31, 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 (~ 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.