GP-B Monthly Report
June 2012

This monthly report documents activities in June, focusing on progress towards publishing GP-B science and technology papers in *Classical and Quantum Gravity*. Five papers are in-work. Co-authored by KACST, NASA, Lockheed Martin, and Stanford personnel, the plan is begin work on a second set of papers after the first five near completion. Majid Al-meshari is coordinating the KACST paper writing effort. Other activities reported below include collection of supporting reference documentation and collaboration status with KACST, Lockheed Martin, NASA, and other potential groups.

Team members will be giving a series of eight talks in a special session dedicated to GP-B at the Marcel Grossmann meeting in Stockholm July 1-7, 2012. The talks will cover the technology and science underlying the Program. See Table below. In addition, Francis Everitt will give 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.

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

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

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 June has focused on Sections IV, V,VII, and IX.

1. Updates to Probe Development - Gary Reynolds provided a significant update to the Probe Components portion of Section IV. Gary estimates that the probe components rough draft is now 70% complete. He plans to complete the probe components rough draft for the next meeting. Windows 1 – 4 (Section IV) - Richard Vassar reports that the rough draft is complete. This work will be incorporated into the probe components portion of Section IV.
Updates to System Thermal Model (Section V) - Kevin Burns provided a revised version of System Thermal Model but he still has work to do to complete the rough draft of his section. The thermal analysis model is now up and running again so Kevin can look at some of the differences between the predictions and on-orbit actuals. He is working with a goal to complete the rough draft for the next meeting. Updates to On-Orbit Operational Experience and Performance (Section VII) - Dave Murray and Barry Muhlfelder are working on getting photos and graphics from the GP-B server. Dave Frank provided some of the missing data for the COBE, IRAS, and Spitzer cyrostats for the Table in performance comparison to other SFHe Cryrostats (Section IX).

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.

Mac Keiser, Barry Muhlfelder, John Conklin, and John Turneaure agreed to modify the paper as follows:

5. Analysis of Spin Frequency Data
5.1 Determination of Polhode Period
5.2 History of Gyroscope Spin Speed
5.2 Trapped Flux Mapping
5.2.1 Methods
5.2.1 Results
5.2.1. Trapped Flux Distribution
5.2.2 Difference in Moments of Inertia
5.2.3Polhode Path and Polhode Phase
5.2.3 Variation in Low Frequency Scale Factor
6. Short-Term Analysis of Roll Frequency Data
6.1 Matching of Gyroscope at Telescope Scale Factors
6.1.1 Time History and Comparison of Redundant Telescope Scale Factors
6.1.2 Orientation of Telescope Axes Relative to Gyroscope Readout Loops
6.2 Gyroscope Orientation Determination, Readout Scale Factor, Roll Phase Offset for Individual Orbits
6.2.1. Time History of Apparent Gyroscope Orientation Relative to Guide Star
Not Including effects of Annual Aberration, Deflection of Light, GS Motion
6.2.2 Time History of True Gyroscope Orientation Relative to Guide Star
Effects of Annual Aberration, Deflection of Light, GS Motion Removed
6.2.3 Time History of Gyroscope Scale Factors
6.2.3 Time History and Comparison of Roll Phase Offsets
6.2.5 Time History of Injected Calibration Signal
6.3 Analysis of Post-Science Calibration Phase Data

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. 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. 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 with one more quick review required before submission to *CQG*.

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. J. Lipa, S. Wang, L. Brandt, and B. Muhlfelder are involved in this effort.

Two papers to be started by August 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 (~ 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. Much effort this past month was focused on preparing for the GP-B MG-13 talks.