

# GP-B EXPERIMENT ERROR: A WORK IN PROGRESS



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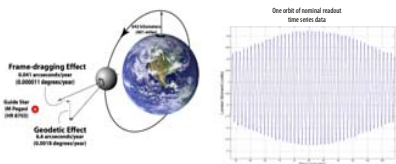
## Overview

Experiment error status:  $1\sigma$  limit: 100 marcsec/yr

Pre-launch expectation: Three main error sources

- Torque induced gyro drift ~ 0.1 marcsec/yr
- Gyro mass & shape tightly controlled
- Support force minimized with drag free
- Magnetic forces, gas damping controlled
- Gyro readout errors ~ 0.1 marcsec/yr
- d: SQUIDS to reduce stochastic error
- Thermal & magnetic control to limit systematics
- Guide star proper motion error ~ 0.1 marcsec/yr
- SAO VLBI provides precision measurements
- Total pre-launch error:  $\leq 0.5$  marcsec/yr

### Experiment Concept



## Post-launch Findings

Most systems met pre-launch plan:

- Gyro shape, mass properties < ground limit
- Gyro position stability met spec
- Drag free control system worked properly
- SQUID sensor met spec (3 out of 4 systems)
- Telescope readout met spec
- Magnetic forces, gas damping controlled
- Data timing accuracy to 0.002 seconds
- Roll phase uncertainty met spec
- Magnetic fields met spec (achieved 3  $\mu$ G)
- Minimal gyro gas damping:  $\tau_{\text{gyro spin-down}} \sim 26,400$  yr
- Orbit determination met spec

Gyroscope



SQUID



Telescope



Above give error  $\leq 0.5$  marcsec/yr

- Two requirements were not met: Gyro torques, Gyro readout EMI effects

## Quantifying the Error

Sensitivity Analysis

- Intentionally degrade data for one parameter
- Perform full mission analysis with degraded data
- Compare degraded relativity result to original
- Difference provides experiment error for parameter

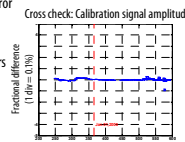
Gyro to gyro consistency

- Consistency increases confidence in result
- Combining consistent results decreases error

- Internal cross checks build confidence
- Stability of measured reference parameters

Error tree to track/organize effort

Definition: The residual relativity uncertainty associated with the modeling of a systematic effect is the systematic error of that effect.



## Gyro Torques (I)

Misalignment torque: Torque proportional to angle subtended by SV roll axis and gyro spin axis

Cause: Interaction of patch fields on rotor and casing

Induced drift rate ~ 0.1 to 1.0 arcsec/yr

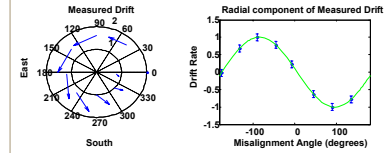
Require > 99% removal for  $10^3$  arcsec/yr

Misalignment torque: direction is known

- Mitigation: phase sensitive detection
- measure relativity in orthogonal direction

Error in resulting mitigated drift:

- Uncertainty in torque direction: gives 4 marcsec/yr
- Mitigation: phase sensitive detection
- Changing amplitudes of misalignment, torque coefficient



## Current Limits on Experiment Error

Error Source	Current Error (marcsec/yr)	Mitigation
Current error including resonance observation	100	Improved modeling
EMI effects	5	Data grading & noise removal
Misalignment patch-effect torque	4*	Improved misalignment model
Polhode frequency error (Cg)	2.5	Trapped flux mapping.
Roll phase uncertainty	< 1	None required
Other known torques	< 1	None required
Telescope nonlinearity	< 1	None required
Time tagging uncertainty	< 1	None required
SQUID thermal sensitivity	< 1	None required
SRE circuit issues (multi)	< 1	None required
Guide star proper motion	< 1	None required

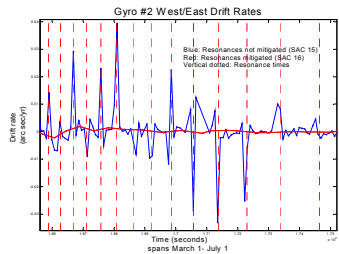
\* contribution from misalignment uncertainty only

## Gyro Torques (II)

Resonance-correlated observation

Cause may be related to patch effect fields

Observation present when  $f_{\text{roll}} = N f_{\text{polhode}}$  where N is an integer



Impact on experiment error 100 marcsec/yr

Error obtained by performing sensitivity tests when the resonance width is varied

- Some of above error may be due to data selection process
- Non-roll averaged patch torque
- Other torques: Support dependent & indep. < 1 marcsec/yr

## Gyroscope Readout

Investigated the following effects:

- Space vehicle EMI
- Turned off offending EMI emitter
- Prior to turn off gives 5 marcsec/yr error impact
- Polhode frequency sensitivity
- Determined polhode frequency to ~ 0.01%
- Gives 2.5 marcsec/yr error impact

Readout to readout coupling

Gyro-gyro coupling < 0.04%

Gives < 1 marcsec/yr error impact

Thermal sensitivity

1-2% of data removed to mitigate effect

Preferred A/D codes

Effect < 1 code out in 16 bit converter

Dynamic range

No science data limited by system dynamic range

Also evaluated:

Signal aliasing, open loop gain limitations, gyro position sensitivity

Current readout impact on experiment error ~ 5 marcsec/yr

Readout EMI Signature

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## Telescope, Roll Phase, Timing

Telescope: Provides vehicle inertial pointing information

Telescope uncertainty causes relativity error

0.5% scale factor uncertainty

3% nonlinear term uncertainty

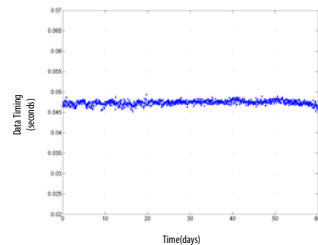
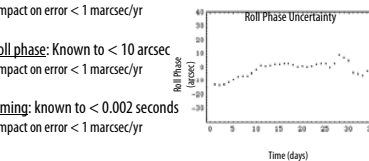
Impact on error < 1 marcsec/yr

Roll phase: Known to < 10 arcsec

Impact on error < 1 marcsec/yr

Timing: known to < 0.002 seconds

Impact on error < 1 marcsec/yr



## Next Steps

Driving Down Experiment Error

Improved resonance and non-roll averaged torque modeling

More complete removal of EMI from data

Update misalignment analysis

Continue investigation of systematic effects

Use flux mapping to reduce scale factor error and increase integration durations

Pre-launch single integration of t duration mission

$$\delta\Omega_{\text{single}} \propto t^{-3/2}$$

Current status: N sub-mission length integrations

$$\delta\Omega_{\text{multiple}} \propto N \delta\Omega_{\text{single}}$$

Confident of significant reduction in experiment error from current 50-100 marcsec/yr value

