Image guider subsystem analysis for the GHAPS project

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INTRODUCTION

The Gondola for High-Altitude Planetary Science (GHAPS) project is a balloon-borne astronomical observatory designed to operate in the UV, Visible, and near-mid IR spectral region.

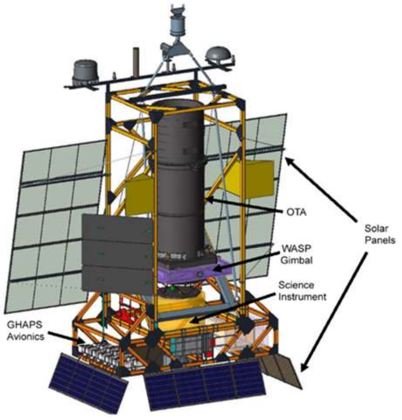


Figure 1. GHAPS Gondola Assembly Design.

GHAPS Key Features:

1) One Meter Ritchey-Chrétien (RC) near-diffraction limited performance (vis.) with 450 arc sec. field-of-view (FOV).
2) Better than 1 arc sec. pointing accuracy using Wallops Arc Second Pointing System (WASP)
3) Float altitude between 30 and 40 km. (above 99.5% of the atmosphere) with up to 100 days mission durations.
4) Science Instrument (SI) payloads that can be interchanged between missions.

GHAPS will utilize the WASP pointing system which combines the information from multiple sensors, including a high precision star tracker which is primarily responsible for achieving the desired pointing accuracy of 1 arc sec. or better.

First order analysis of GHAPS OTA and WASP Star Tracker revealed a potential shift of OTA line-of-sight (LOS) with respect to Star Tracker LOS that depends on the OTA elevation angle and thermal environment.

Analysis objectives:

1) Determine worst case long term (bias) pointing error.
2) Determine if additional hardware is needed to reduce this bias error so as to comply with GHAPS goals.
3) If additional hardware is needed, determine the best implementation for GHAPS.

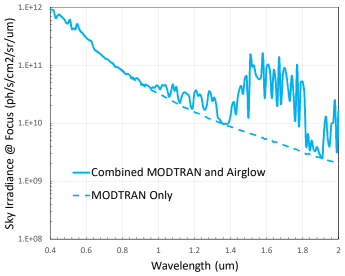
ANALYSIS

Primary and secondary mirror deflections (de-space and tip/tilt) were determined from a Finite Element Model (FEM) analysis of the OTA. Values were then converted into LOS changes per the sensitives from the OTA optical model. Worst case bias LOS error range between **6 arc sec. to more than 30 arc sec**. depending on the conditions and observation time.

A number of operational and pre-flight calibration solutions were considered to remove the pointing bias error from the system, but all were considered too costly or could not achieve 1 arc sec. performance. **Additional hardware to correct bias pointing error at float altitude is required,** namely some form of a Facility Guider Subsystem (FGS).

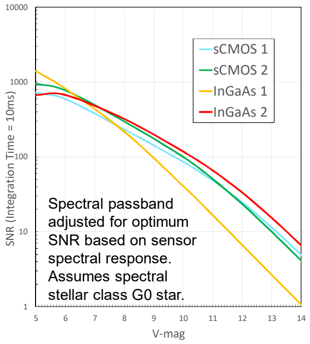
Photometric model:

1) Sky background at 30km – daytime and nightime, included airglow estimate (Figure 1).
2) Telescope model - Idealized F/14 RC, conservative PSF.
3) Star Radiance – Idealized spectral radiance.
4) Image Sensors – High resolution from Visible to Mid IR, including sCMOS, DD-CCD, InGaAs, InSb, MCT, eAPD, etc.



Sky background radiance calculated from combination of MODTRAN and an estimate of airglow from SABER instrument data aboard NASA TIMED satellite.

Figure 2. Daytime Sky Background Radiance at 30km.

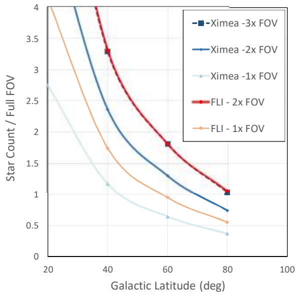


Spectral passband adjusted for optimum SNR based on sensor spectral response. Assumes spectral stellar class G0 star.

Star image Signal to Noise Ratio (SNR) for best performing image sensors. Assuming minimum SNR of 10, best performer is TE cooled InGaAs (V_{mag}=13.5) Slightly better than sCMOS (V_{mag}=13.2) Other Mid-IR sensors candidates (MCT, e-APD, InSb) were eliminated due to need for cryo-cooling.

Figure 3. Image Performance Comparison, Worst Case Daytime.

RESULTS



Estimated Facility Guide Subsystem performance using candidate sCMOS sensors and available OTA FOV, outside of the Science FOV. Some configurations use multiple sensors to cover maximum available FOV. Best configuration yields at least 1 star over 98% of sky and 2 stars over 80% of sky.

Figure 3. Predicted FGS Star Count Performance, 2 sec. Integration

Physical implementation of a bias correction subsystem could be a GHAPS facility provide function or be incorporated into the SI package. Analysis was performed to estimate FGS measurement errors and compare them with a similarly capable SI-based system. The results are summarized in the Table 1 below.

Table 1. FGS vs SI-based Guider Comparison Summary

	Facility Guider Subsystem (FGS)	Science Instrument (SI-based) Guider	Comment
SWAP (size, weight, and power)	Worse. (FGS Camera Cold Plate)	Better (Cooling built into SI)	No need for additional cooling lines in SI-based system.
Daytime star performance	1 star over 98% of sky 2 stars over 80% of sky	Equal or better	SI-based systems should have more FOV available than FGS.
Bias Offset Measurement Accuracy.	Good	Better	SI Guider will have significantly lower uncorrectable bias offset.
Cost	Highest	Equal or lower (Regardless, SI will have to have this functionality to meet science jitter pointing requirements)	Optimization of SI Guider should allow for possibility of lower cost components. (subsequent SIs may have increased cost due to guider mandatory inclusion)
Operations Impact	Minimal with auto LIS	Minimal with auto LIS (Potentially lower with FSM within SI)	Both systems impact con-ops when FOV contains only 1 star.
Schedule Impact Risk	Good (GHAPS will have Bias, pointing, and PSF functional checkouts without need for SI.	Worse (GHAPS relies on SI for functional checkouts of Bias, Pointing, and PSF.)	Risk can be mitigated by designing functionally equivalent GSE that can be used earlier in A I &T flow. Additional cost though.

CONCLUSIONS

There is an understandable desire to divorce the bias detection capability from the SI, so that the GHAPS system is completely self-sufficient in terms of pointing correction. SI-based systems will inherently have lower sensitivities to deflection, and are the best implementation from an engineering and performance standpoint.

REFERENCES

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