

The WFIRST CGI Integral Field Spectrograph: Requirements and Performance Predictions

Tyler Groff
NASA Goddard Space Flight Center
8800 Greenbelt Rd
Greenbelt, MD 20771
tyler.d.groff@nasa.gov

Maxime Rizzo
NASA Goddard Space Flight Center
8800 Greenbelt Rd
Greenbelt, MD 20771
maxime.j.rizzo@nasa.gov

Avi Mandell
NASA Goddard Space Flight Center
8800 Greenbelt Rd
Greenbelt, MD 20771
avi.mandell@nasa.gov

Nicholas Nicolaeff
ATA Aerospace
ATA Aerospace Civil 7474 Greenway Center Drive Ste 500
Greenbelt, Maryland 20770
nicholas.m.nicolaeff@nasa.gov

Michael W. McElwain
NASA Goddard Space Flight Center
8800 Greenbelt Rd
Greenbelt, MD 20771
michael.w.mcelwain@nasa.gov

Neil Zimmerman
NASA Goddard Space Flight Center
8800 Greenbelt Rd
Greenbelt, MD 20771
neil.t.zimmerman@nasa.gov

Qian Gong
NASA Goddard Space Flight Center
8800 Greenbelt Rd
Greenbelt, MD 20771
qian.gong-1@nasa.gov

Samuel Gaylin
Genesis Engineering Solutions
4501 Boston Way
Lanham, MD 20706
samuel.gaylin@nasa.gov

Rose Mountcastle
Lentech Inc.
7500 Greenway Center Dr., Suite 505
Greenbelt, MD 20770
rose.m.mountcastle@nasa.gov

Abstract—The WFIRST coronagraphic instrument (CGI) will demonstrate exoplanet spectroscopy using an integral field spectrograph (IFS). The CGI IFS, being designed and built at Goddard Space Flight Center, has a spectral resolution of R50 and is designed to accommodate a 20% bandpass spanning 600-970 nm. The IFS is principally targeting the abundance of Methane features, with the primary coronagraph band being centered around 770nm. Key to the performance estimates are the achievable signal-to-noise (SNR) ratios and the stability of the microspectra over the course of tens and hundreds of hours. As a technology demonstration for CGI, the ability to close a wavefront control loop around the IFS, maintain a stable dark hole, and provide time resolved data that simultaneously spans spatial and spectral dimensions are crucial demonstrations for future observatories. The IFS is optimized both for coronagraphs and science observations with a potential future starshade. We highlight how the long duration observations, and requirements for both starshades and coronagraphs drive the IFS requirements and the calibrations required both on-orbit and on the ground. We also provide further detail on the optomechanical design, its stability based on thermal and structural predictions, anticipated performance, and operations concept of the CGI IFS. The impact of these performance metrics are projected into simulated data products, demonstrating cube extraction of noisy images and the subsequent planet spectrum that can be extracted from them. These demonstrations and performance predictions are key to future missions such as LUVOIR and HabEx, whose principal science case relies on efficient spectroscopy of exoplanets.

TABLE OF CONTENTS

1. INTRODUCTION.....	1
2. EXAMPLE OBSERVING SCENARIO AND STABILITY REQUIREMENTS	2
3. OPTICAL DESIGN	2

4. MECHANICAL DESIGN	3
5. INTERFACES	4
6. THERMAL STABILITY	5
7. JITTER STABILITY	5
8. SUMMARY	6
ACKNOWLEDGMENTS	7
REFERENCES	7
BIOGRAPHY	8

1. INTRODUCTION

The Wide Field Infrared Survey Telescope (WFIRST) coronagraph instrument (CGI) will be the first high contrast imager in space and is a key demonstration for future missions such as the Habitable Exoplanet Surveyor (HabEx) and the Large UV/Optical/IR (LUVOIR) Surveyor[1], [2]. CGI will include a lenslet-based integral field spectrograph (IFS) as one of the two back-end cameras to the coronagraph. The IFS is designed to capture an instantaneous bandpass up to 20% centered anywhere in the range 600 to 970nm. A lenslet-based IFS has the ability to accommodate a large number of spatial samples in a relatively compact design. An IFS, shown schematically in Fig. 1, places a lenslet array at an image plane within the instrument to sample the field and compress the incident light into a grid of spots directly behind the lenslet array. These spots act as the input to a traditional spectrograph that collimates, disperses, and images onto a detector. The spectra are then extracted from a 2-dimensional image and reconstructed into a 3-dimensional data cube (x,y,λ).

The field of view (FOV) of the CGI IFS is ~ 2.1 arcseconds, comparable to the field of view in current ground-based extreme adaptive optics (ExAO) systems such as SCExAO-CHARIS at Subaru[3], [4], GPI at Gemini [5], and SPHERE at the VLT[6]. To provide a clear example of what the

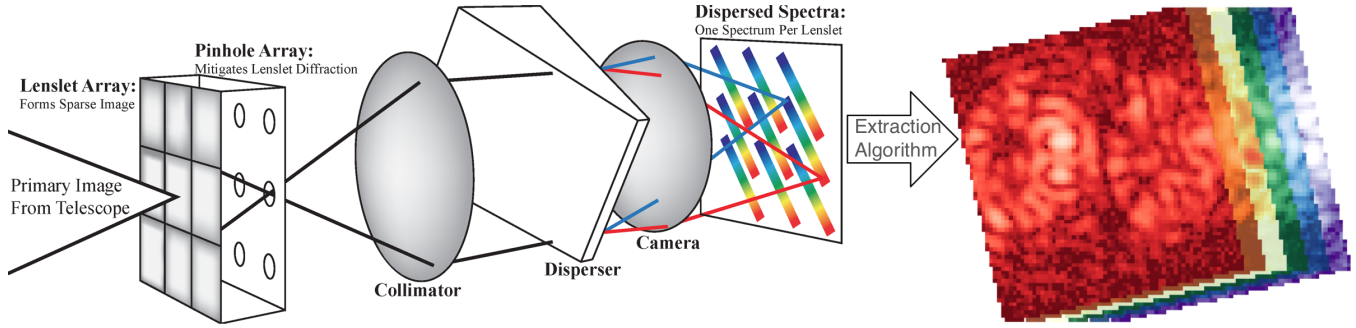


Figure 1. The lenslet array of an IFS Nyquist samples the broadband (18%) image. The spectrograph optics interlace the spectra on the final focal plane, and a data extraction algorithm is used to reconstruct the data cube.

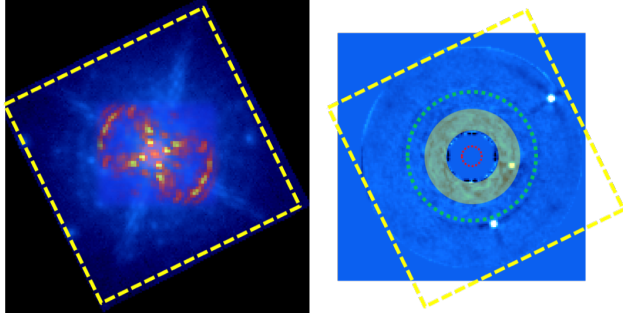


Figure 2. The Shaped Pupil coronagraph (left) and requirements (right) overlaid onto images of M5 and HR8799 taken with SCExAO-CHARIS. The field of view of the CGI IFS is comparable to current state of the art ExAO IFS designs such as GPI and SCExAO-CHARIS. (yellow-dashed) CGI IFS FOV. (green dashed) Coronagraph OWA. (red dashed) Coronagraph IWA. (yellow band) range of requirements definition.

CGI IFS will be able to capture within its field of view, Fig. 2 shows the CGI IFS field of view and coronagraph point spread function (PSF) overlaid onto images of M5 and HR8799 taken with SCExAO-CHARIS. The general performance of the CGI IFS is in family with the state of the art exoplanet IFS specifications being used on ExAO systems today.

2. EXAMPLE OBSERVING SCENARIO AND STABILITY REQUIREMENTS

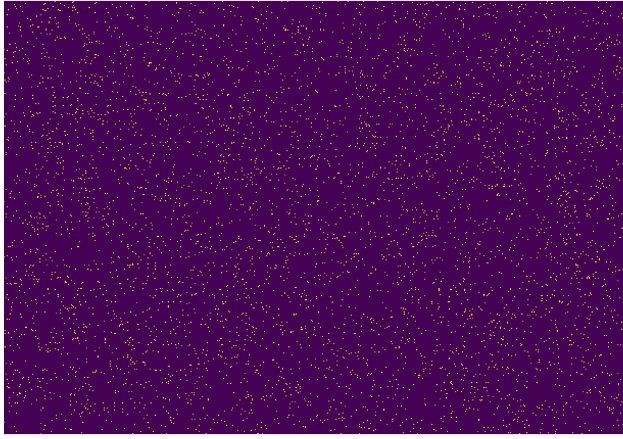
The baseline operations plan for CGI, described fully in Krist et al.[7], is to dig the dark hole and achieve high contrast on a bright ($V_{\text{mag}} \sim 2$) star, then slew to the target ($V_{\text{mag}} \sim 5$) star and execute a series of rolls and chops between the reference and target. The target star is observed in two different roll angles on a 2 hour cadence, while revisiting the reference star every ten hours. Performance predictions and raw contrast sensitivity analysis of these observations are described in Zhou et al.[8]. One example simulation of CGI IFS exposures given input simulations of the speckle field is shown in Fig. 3. For all observations, the final image is a series of ~ 100 second exposures which are co-added to reach the final integration time. The exposure time is set specifically to have an average of ~ 0.1 photons per frame arrive at the detector to support the photon counting mode that the detector is operated in. Thus, the set of frames look like the image shown in Fig. 3(a) and when comparing

Fig. 3(b) to Fig. 3(c) we see that as they are co-added the signal-to-noise ratios (SNR) of the dispersed coronagraphic image will continue to improve. In this context, for the co-adding method to provide the image shown in Fig. 3(c) the IFS optics must remain stable to all disturbances since one cannot simply shift and co-add individual frames in response to drift of the micro-spectra on the detector. The need to be highly stable over the period of hours as the observatory chops between reference and target star is what drives the optical and mechanical design of the CGI IFS. Much of the work to date has been to define global stability requirements for the instrument in response to the jitter environment of CGI due to the reaction wheels, and thermal variation as the spacecraft re-points to the two stars.

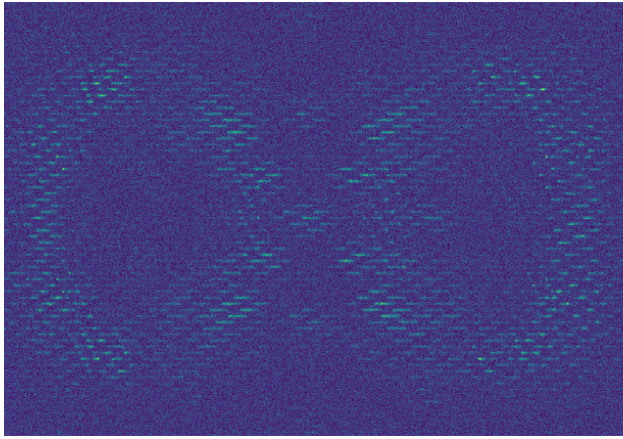
Using image plane motion at the lenslet and detector planes as the parent requirement, we determine the boresight motion as a function of all six degrees of freedom for each optical element using ray tracing software. Making the conservative assumption that their motions are uncorrelated we allocate a tolerance to each element and combine their contributions to bore sight motion via a root sum square (RSS). This allows us to assign larger tolerances to more sensitive degrees of freedom while keeping the RSS boresight stackup below the required net deviation at the lenslet and detector planes. This guides the optical and mechanical design presented in Sec. 3 and Sec. 4, and provides clear performance metrics for the thermal and structural analysis in Sec. 6 and Sec. 7. Eventually the thermal and structural models will be fed back into the optical model for a full stop analysis, and the RSS boresight stackup provides a conservative estimate to judge the performance of the IFS and iterate on the optomechanical design.

3. OPTICAL DESIGN

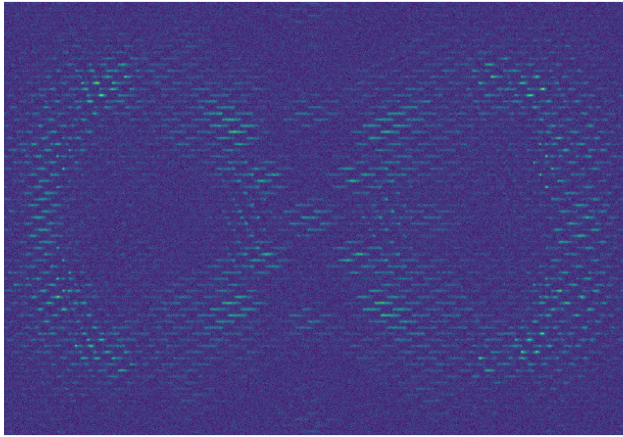
The CGI IFS receives a 5mm collimated beam, and forms an $F/527$ image onto a square-packed lenslet array with a $174 \mu\text{m}$ pitch. The lenslet array and spectrograph relay optics are $F/8$, forming the dispersed image onto a 1024×1024 EMCCD 201 sensor from Teledyne-E2V. Performance predictions and performance estimates of the EMCCD and requirements can be found in Morrissey et al.[9] and Effinger et al.[10] The imaging group shown in Fig. 4 is a reflective off-axis cassegrain design. The first optic is a fold mirror, which only exists for packaging purposes within CGI. The field points shown in Fig. 4 highlight the highly non-telecentric image space at the lenslet array. The spectrograph collimator, prism, and imaging groups shown in Fig. 5 are all refractive elements. The collimator and camera optics



(a)100 sec



(b)1 hour



(c)27 hours

Figure 3. Characteristic dispersed images as a function of total exposure time. The extremely low signal drives a host of strict stability requirements on the IFS.

are all spherical surfaces, and they compensate one another to provide diffraction limited image quality at the final focal plane over the entire field of view. Since the required total bandpass is much less than a full harmonic and there are

large field angles within the spectrograph, the baseline design of the system is refractive. This maintains good image quality at the maximal field points without complicating the packaging with a multi-element reflective system. Something interesting to note is that the FOV of the IFS is nearly a factor of two larger than what the shaped pupil coronagraph provides. The detector size required for an IFS is a function of the interlace chosen for the spectra, the instantaneous bandpass that must be imaged, the spectral resolution, and FOV. For the CGI IFS, we are constrained to a 1024x1024 EMCCD201. Regardless, Fig. 6 shows the detector size required as a function of spectral resolution and FOV for the required bandpass and interlace ratios of the CGI IFS. At R50 and a coronagraphic FOV of ~ 1.1 arcseconds, there is a very healthy margin for the IFS to accommodate the FOV requirements. This alleviates ground-to-orbit alignment variance, which is very important since tip-tilt offsets of the pupil are highly magnified by the F/527 image formed on the lenslet array.

The field of view and bandpass requirements are principally driven by the possibility of a future starshade mission for WFIRST. With the aforementioned margin on FOV, the driving design requirement imposed by the starshade is the 20% instantaneous bandpass. Ultimately, this translates to limiting the efficiency of packing on the detector, which we minimize in order to mitigate the effect of cosmic rays and charge traps on the noise budget for the IFS.

4. MECHANICAL DESIGN

The IFS optomechanics are purpose built first and foremost to meet our tight alignment and stability requirements. The alignment requirements are strict, but are within standard capabilities. However, much like the rest of CGI, stability is paramount. This is particularly true for the IFS, where exposures can take hundreds of hours. A model of the IFS optomechanics is shown in Fig. 7. Much of the precision motion control is accommodated with a set of flexures. All of the mounts are Titanium alloy, and will have a flexure-based mounting scheme onto the carbon fiber CGI bench to accommodate the survival temperature requirements of the system. In all cases, the IFS relies on bench-level alignment in the plane of the optical bench. Tip control is carried internally to the mounts to simplify the alignment. Any height corrections must be done via shims. The lenslet array is mounted in a kinematic housing that allows it to be clocked after the system has been aligned. The prism mount also has clocking capability. We assume that the detector clocking will be controlled by machine tolerance only, so these two degrees of freedom are necessary to correctly orient the micro-spectra on the detector and fine tune the interlacing of the spectra.

The strict stability requirements described in Sec. 2, combined with an effort to reduce cost and schedule risk during the integration and testing of the IFS have motivated a trade study into testing and delivering the IFS to CGI as a single integrated sub-bench, shown in Fig. 9. An architecture where the IFS is developed, tested, and delivered as a pre-aligned subsystem has strong heritage from other coronagraph instruments at major ground observatories. Of these, SCExAO+CHARIS at Subaru[3], [11] and GPI at Gemini-south [12] are the most similar to how the integration and test process will be done for the IFS on CGI. The use of a sub-bench is particularly compelling for the CGI IFS as it must be mounted on the back-side of the optical bench from the rest of the coronagraph optics for packaging purposes.

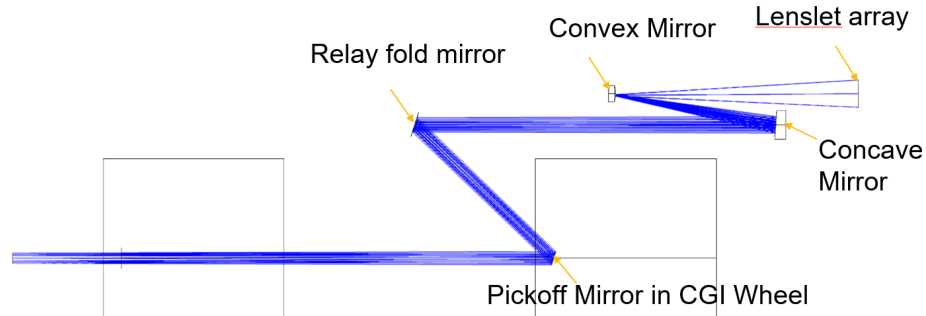


Figure 4. The IFS receives a 5mm collimated beam, and images onto the lenslet array by an off-axis Cassegrain. The ray bundle shown is the chief ray of each field point in the image.

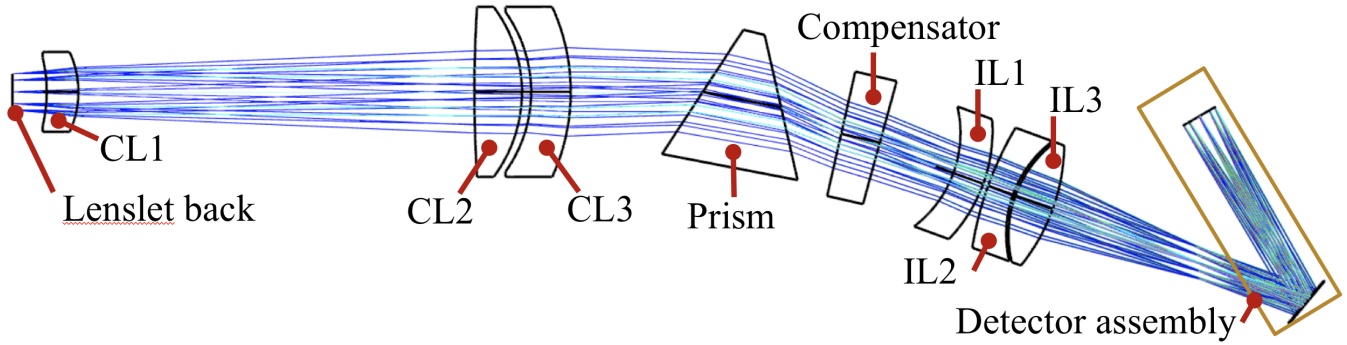


Figure 5. The spectrograph optics after the lenslet array, utilizing a single field corrector and achromat doublet in both the collimator and imaging subassemblies, and a two-element disperser for near-constant spectral resolution.

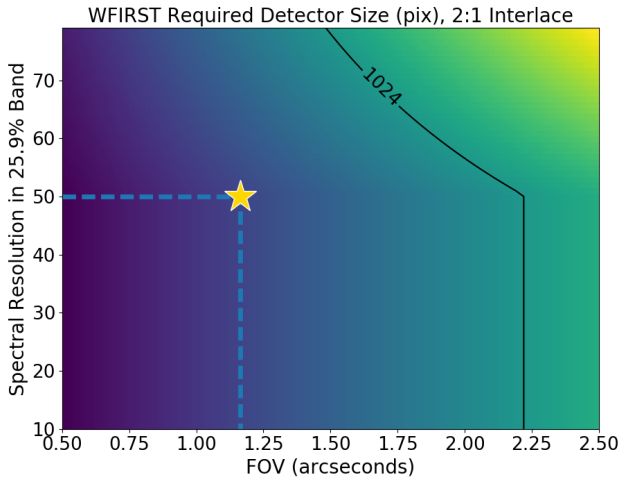


Figure 6. The IFS field of view is approximately a factor of two larger than the coronagraph field of view, providing significant margin against ground-to-orbit misalignment.

5. INTERFACES

Interface control is crucial to the IFS sub-assembly. The IFS must register the input collimated beam, and simultaneously must maintain alignment with the final focal plane. At the front end of the instrument we face the tip-tilt challenges associated with an F/527 beam. At the back end the depth of focus challenges with an F/8 beam challenge our requirements. Below are details on the associated optical and

mechanical interfaces that derive from that.

Optical Interface

There are two primary optical interfaces for the IFS:

- **Coronagraph to IFS**

The direction, position, and orientation of the collimated beam define the final alignment of the imaging mirrors. To alleviate this challenge, we have chosen to provide that group as an aligned sub-assembly.

- **IFS to detector**

The relatively fast F/# of the spectrograph optics and the need to have well characterized lenslet PSFs for the data cube reduction drives requirements on stability, repeatability, and detector flatness. This is compounded by the necessity of a fold mirror before the detector to allow for shielding against cosmic rays.

Mechanical Interface

The baseline design for the relay mirrors is diamond turned aluminum mirrors with a Titanium alloy sub-bench for the three optics, necessitating a flexure-based kinematic mounting to the carbon fiber bench. This produces a long thermal path, but the alignment of the relay assembly will be deterministic and repeatable. Degrees of freedom controlled at the bench interface are X,Z translation and rotation about Y using a removable alignment tool. The range of motion is determined by oversized clearance holes for the bolted interface and assumes the bench interface is raised, lapped titanium pads located at the nominal position of each fastener.

The collimator and imaging mounts support vendor aligned

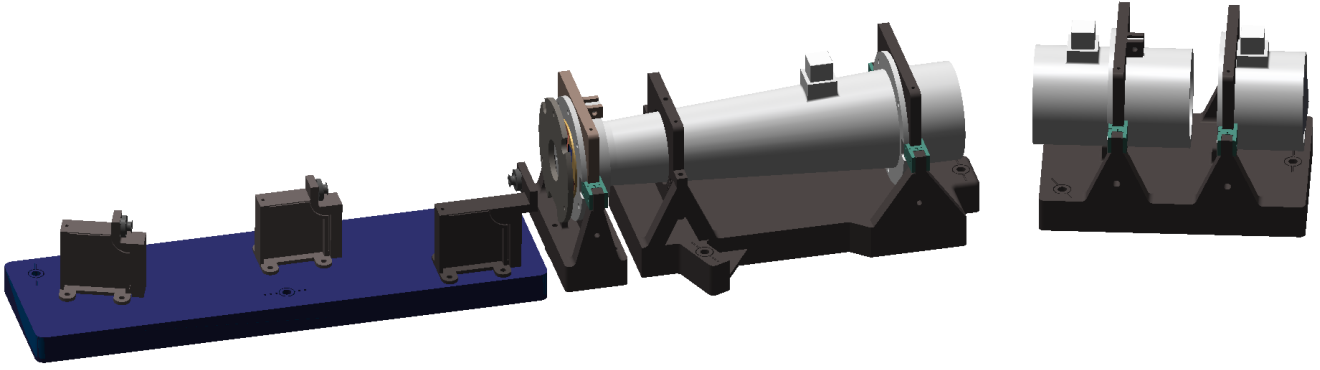


Figure 7. The end-to-end optomechanical layout of the CGI IFS. The optics are put together as major sub-assemblies for the imaging mirror group, the lenslet array, the collimating lens group, prism group, and imaging lens group. This isolates critical internal alignment tolerances from the end-to-end

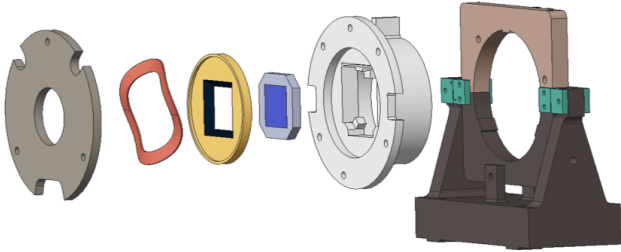


Figure 8. Exploded view of the lenslet array mount, which is held kinematically in the axial direction with a wave washer to define the preload and a radial flexure to control lateral stability of the mount.

lens tubes containing the three collimation optics, with the interface mount made out of Titanium. Translation in the vertical direction and rotation about vertical and optical axes are all uncontrolled within the mount. Degrees of freedom in the plane of the optical bench are controlled at the bench interface using a removable alignment tool. Rotation about the optical axis is unnecessary as the optics are spherical and on-axis. The range of motion is determined by oversized clearance holes for the bolted interface and, like the relay bench, assumes the bench interface is raised, lapped titanium pads located at the nominal position of each fastener.

In all cases these mounts must simultaneously meet requirements on survival temperature, first resonant mode, stability, and repeatability. Survival temperature requirements drive the mounted interface to be flexured, but those flexures will be as stiff as possible to maintain stability and first resonant mode requirements. Since we must be highly repeatable through launch survival temperatures, the flexure designs being considered are made via direct wire electron discharge machining (EDM) into the mount. This eliminates more interfaces and mitigates any issues with creep or stiction, making the bolted interface to the CGI bench highly repeatable through thermal cycles.

6. THERMAL STABILITY

Being near the edge of the bench with two detector assemblies nearby, there is a non-negligible spatial gradient that impacts key modes (such as lenslet clocking stability). The IFS

thermal model is meshed with the rest of the CGI thermal model to understand response to both dynamic variation and physical gradients across the system. With the IFS being highly stabilized and relatively tolerant to wavefront error variation, the principal goal of the modeling is to estimate boresight motion at the lenslet and detector planes over the long periods of time between opportunities to recalibrate the spectrograph. Thermal meshes of the IFS assemblies are shown alongside mechanical models of the IFS optomechanics in Fig. 10. These are integrated into the CGI thermal model to better understand our true environment, but we also track their response to the dynamics of a worst-case slew between reference and target stars to understand maximum deviations of the optics. The temperatures shown in Fig. 11 are, by design, small to maintain stability for all of CGI. To demonstrate compliance with the RSS boresight motion tolerances, the output from the thermal model is mapped onto the structural mesh of the IFS to capture thermally induced stresses (important for survival requirements) and strains. Examples of the structural mesh are shown in Fig. 12 of Sec. 7. It is worth noting that in the case of thermally induced boresight motion the RSS stackup of the optical tolerances is conservative. For example, if the bulk temperature rises by 1K all of the optical mounts and detector housing will expand and contract together and the net alignment as seen by the detector or lenslet array remain largely unchanged. Given that CGI has closed loop thermal control to dynamically stabilize the instrument, variation in physical gradients will be the most significant deviation from common motion changes.

7. JITTER STABILITY

There are no active coolers on the observatory and the only active mechanism during a CGI observation is the fast steering mirror (FSM), which is actively stabilizing the beam within CGI[13]. The only source of jitter for the IFS is from mechanical coupling of the observatory reaction wheels into the CGI bench. CGI maintains a concept of operations that limits the reaction wheel speeds to allow for good FSM correction and to mitigate the energy coupled into the CGI bench post-FSM. For the IFS, we show that in this jitter environment the individual optics remain within their assigned tolerances that guarantee the boresight metric described in Sec. 2. The structural mesh, examples of which are shown in Fig. 12, are used for both the thermal and jitter analysis. To track boresight deviation of each optic a node is placed at the center of each meshed optic and the dynamic response of the optics

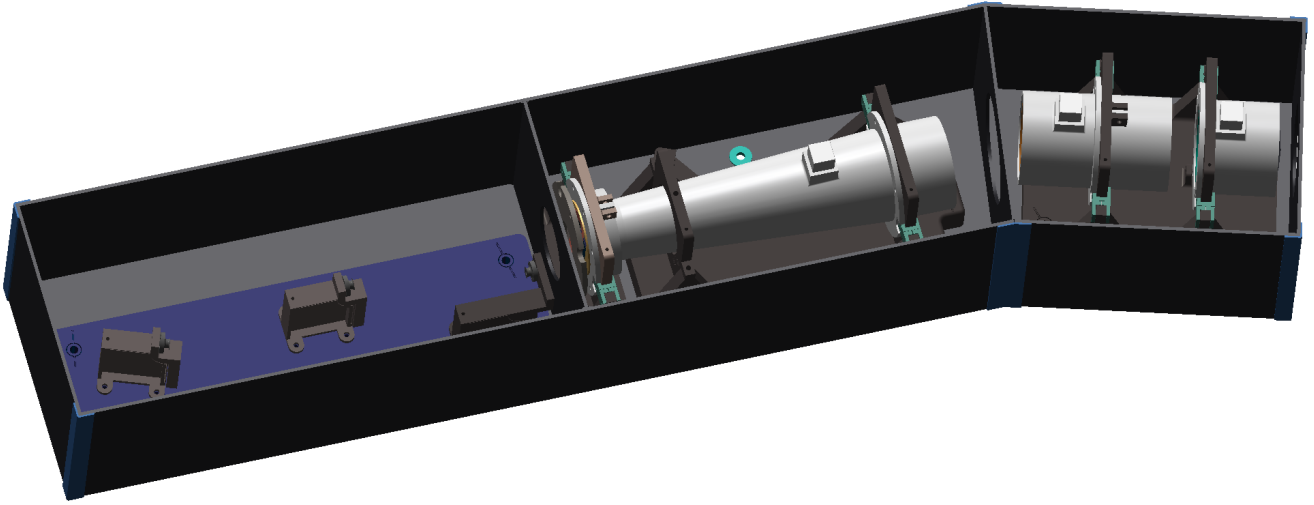


Figure 9. The CGI IFS in a conceptual carbon-fiber sub-bench. The sub-bench allows for a more straightforward verification process of subsystem performance and interfaces. The goal is to reduce complexity and schedule risk during instrument-level integration into CGI.

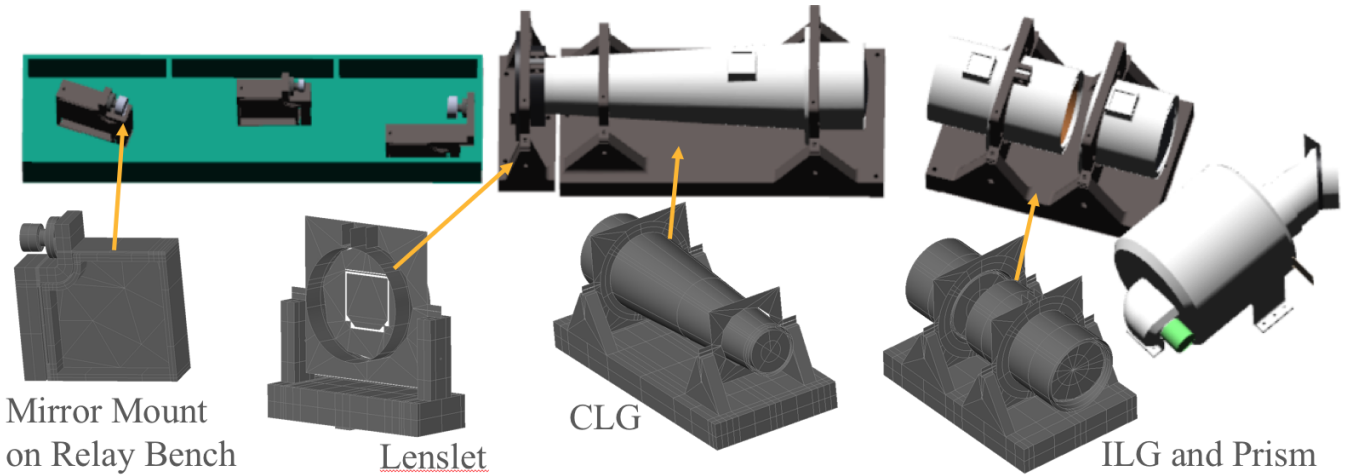


Figure 10.

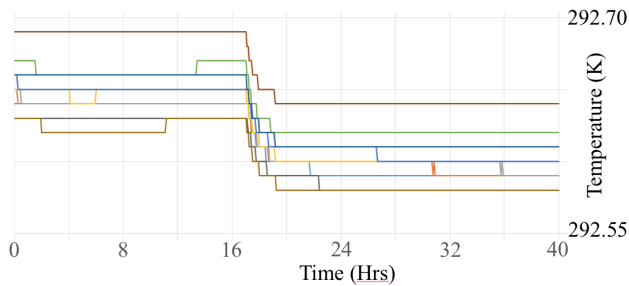


Figure 11. (a) Thermal mesh of the IFS optomechanical sub-assemblies, integrated into the CGI thermal model. (b) Variance of the IFS optical temperatures in what is defined as the worst case telescope slew between target and reference stars

8. SUMMARY

The CGI IFS is designed to provide R50 spectra in 20% bands between 600 and 1000nm. The key challenges in this particular IFS are all related to the very long exposure times in an L2 space environment. Throughput and stability are paramount in a scenario where we must be able to co-add tens of hours of exposure to produce over 2,000 microspectra that achieve $\text{SNR}=10$ at 5×10^{-8} contrast on a $V_{\text{mag}} = 5$ star. Additionally, we must close the wavefront control loop with the IFS, which imposes stability and accuracy requirements that must be calibrated and maintained during on-orbit operations to achieve such high contrast in the first place. The on-orbit operations concept, supporting optical tolerances, and performance predictions are used to demonstrate that the IFS can in fact meet these stringent requirements and achieve the highest contrast spectral measurements of exoplanets ever taken.

and their mounts are computed. Unlike the thermal case, the RSS approach to setting the tolerance is likely much closer to reality since we are less likely to see significant modal coupling between mounts and the detector housing.

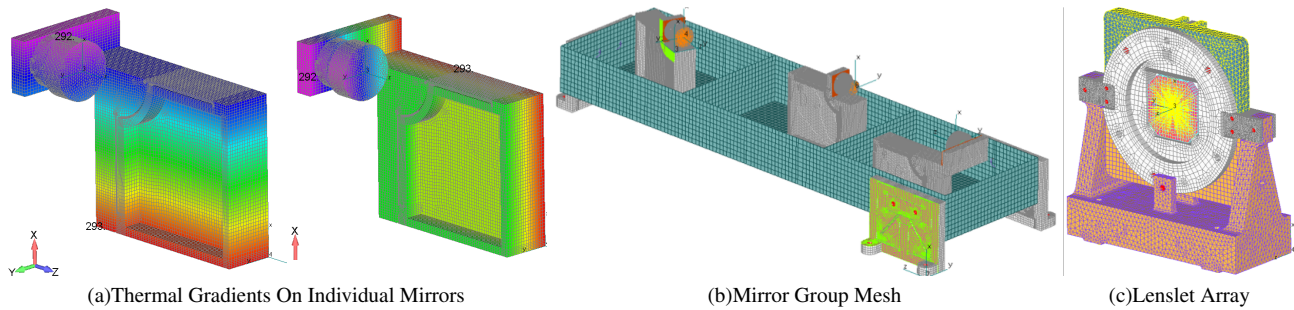


Figure 12. Structural mesh of some key elements of the IFS. These are used to evaluate first resonant modes, stability to thermal variance and jitter, as well as survival through launch.

ACKNOWLEDGMENTS

This research was carried out at Goddard Space Flight Center and the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

CHARIS was built and commissioned under a Grant-in-Aid for Scientific Research on Innovative Areas from MEXT of the Japanese government (Number 23103002).

REFERENCES

- [1] B. Mennesson, J. Debes, E. Douglas, B. Nemati, C. Stark, N. Kasdin, B. Macintosh, M. Turnbull, M. Rizzo, A. Roberge, N. Zimmerman, K. Cahoy, J. Krist, V. Bailey, J. Trauger, J. Rhodes, L. Moustakas, M. Frerking, F. Zhao, I. Poberezhskiy, and R. Demers, "The wfIRST coronagraph instrument: a major step in the exploration of sun-like planetary systems via direct imaging," in *Proc. SPIE*, vol. 10698, 2018, p. 106982I.
- [2] R. Demers, "Review and update of wfIRST coronagraph instrument design and technology," in *Proc. SPIE*, vol. 10698, 2018, p. 106982J.
- [3] N. Jovanovic, O. Guyon, J. Lozi, T. Currie, J. Hagelberg, B. Norris, G. Singh, P. Pathak, D. Doughty, S. Goebel, J. Males, J. Kuhn, E. Serabyn, P. Tuthill, G. Schworer, F. Martinache, T. Kudo, H. Kawahara, T. Kotani, M. Ireland, T. Feger, A. Rains, J. Bento, C. Schwab, D. Coutts, N. Cvetojevic, S. Gross, A. Ariola, T. Lagarde, N. Kasdin, T. Groff, B. Mazin, Y. Minowa, N. Takato, M. Tamura, H. Takami, and M. Hayashi, "The scexao high contrast imager: transitioning from commissioning to science," in *Proc. SPIE*, vol. 9909, 2016, p. 99090W.
- [4] T. Groff, J. Chilcote, N. Kasdin, M. Galvin, C. Loomis, M. Carr, T. Brandt, G. Knapp, M. Limbach, O. Guyon, N. Jovanovic, M. McElwain, N. Takato, and M. Hayashi, "Laboratory testing and performance verification of the charis integral field spectrograph," in *Proc. SPIE*, vol. 9908, 2016, p. 99080O.
- [5] J. E. Larkin, J. K. Chilcote, T. Aliado, B. J. Bauman, G. Brims, J. M. Canfield, A. Cardwell, D. Dillon, R. Doyon, J. Dunn *et al.*, "The integral field spectrograph for the gemini planet imager," in *Proc. SPIE*, vol. 9147, 2014, p. 91471K.
- [6] J. Beuzit, M. Feldt, K. Dohlen, D. Mouillet, P. Puget, F. Wildi, L. Abe, J. Antichi, A. Baruffolo, P. Baudoz *et al.*, "Sphere: a planet finder instrument for the vlt," in *Proc. SPIE*, vol. 7014, 2008, p. 41.
- [7] J. Krist, R. Effinger, B. Kern, M. Mandic, J. McGuire, D. Moody, P. Morrissey, I. Poberezhskiy, A. Riggs, N. Saini, E. Sidick, H. Tang, and J. Trauger, "WfIRST coronagraph flight performance modeling," in *Proc. SPIE*, vol. 10698, 2018, p. 106982K.
- [8] H. Zhou, J. Krist, E. Cady, and I. Poberezhskiy, "High accuracy coronagraph flight wfc model for wfIRST-cgi raw contrast sensitivity analysis," in *Proc. SPIE*, vol. 10698, 2018, p. 106982M.
- [9] P. Morrissey, L. Harding, M. Bottom, R. Demers, R. Effinger, D. Nieraeth, L. Hovland, Y. Muruyama, B. Nemati, N. Bush, D. Hall, R. Burgon, and A. Holland, "Photon counting emccd developments for the wfIRST coronagraph," in *Proc. SPIE*, vol. 10709, 2018, p. 107090B.
- [10] R. Effinger, B. Nemati, M. Rizzo, P. Morrissey, L. Harding, M. Bottom, D. Pontrelli, R. Demers, N. Bush, D. Hall, R. Burgon, and A. Holland, "WfIRST coronagraph detector trap modeling results and requirements," in *Proc. SPIE*, vol. 10709, 2018, p. 1070917.
- [11] T. Groff, J. Chilcote, T. Brandt, N. Kasdin, M. Galvin, C. Loomis, M. Rizzo, G. Knapp, O. Guyon, N. Jovanovic, J. Lozi, T. Currie, N. Takato, and M. Hayashi, "First light of the CHARIS high-contrast integral-field spectrograph," in *Proc. SPIE*, vol. 10400, 2017, p. 1040016.
- [12] B. A. Macintosh, A. Anthony, J. Atwood, B. Bauman, A. Cardwell, K. Caputa, J. Chilcote, R. J. De Rosa, D. Dillon, R. Doyon *et al.*, "The gemini planet imager: first light and commissioning," in *Proc. SPIE*, vol. 9148, 2014, p. 91480J.
- [13] F. Shi, B. Seo, E. Cady, B. Kern, R. Lam, D. Marx, K. Patterson, C. Prada, J. Shaw, C. Shelton, J. Shields, H. Tang, and T. Truong, "WfIRST low order wavefront sensing and control dynamic testbed performance under the flight like photon flux," in *Proc. SPIE*, vol. 10698, 2018, p. 106982O.

BIOGRAPHY



Tyler Groff received his PhD from Princeton University in 2012. He is the lead engineer for the IFS in the WFIRST CGI. His interest is in instrumentation to directly image and characterize exoplanets. He focuses on focal plane wavefront control, coronagraph instrument design, and integral field spectroscopy for ground and space telescopes.



Neil Zimmerman is a scientist at Goddard specializing in exoplanet imaging. He researches nearby stars and their planetary systems, and technologies for new instruments. He is on the project science team for WFIRST, contributing to CGI and its IFS. He also works on coronagraph studies and data simulations for future mission concepts.



Maxime Rizzo received his M.S. in Aerospace Systems Engineering from ISAE-SUPAERO in France in 2010, and his Ph.D. in Astronomy from the University of Maryland, College Park in 2016. He is an instrument systems engineer at NASA GSFC for WFIRST. His interests are in space-borne instrumentation for astronomy and other disciplines.



Qian Gong is an optical engineer at NASA Goddard Space Flight Center. She is the optical designer for the prototype and flight IFS designs for WFIRST CGI. She is also the lead optical designer for the coronagraph instruments for the LUVOIR instrument concept study.



Avi Mandell is a scientist in Planetary Systems at Goddard; his research focuses on the characterization of extrasolar planets and the formation and evolution of planetary systems, understanding factors that determine habitability and what the characteristics of these planets will be.



Michael W. McElwain is an exoplanet scientist and instrumentalist in the Astrophysics Laboratory at NASA Goddard. His current research focuses on the discovery and characterization of exoplanets and circumstellar disks with both direct imaging and radial velocity techniques.



Samuel Gaylin is a mechanical engineer at Genesis Engineering Solutions. He is the optomechanics designer for the IFS on WFIRST CGI.



Nick Nicolaeff earned his BSME from Polytechnic Institute of New York University in 1984. He has over 30 years of experience in optomechanical design/analysis at several major aerospace companies, including space telescopes, star trackers, and electronic packaging for space applications. He is the lead structural analyst for the WFIRST Focal Plane Assembly and the CGI IFS.

Rose Mountcastle received her MS from Embry-Riddle in 2007. She has over 10 years of experience in thermal analysis, design and test. She previously worked on optical and particle sensing instruments and geostationary spacecraft. Currently she provides analysis support for the WFIRST Payload and CGI IFS.