Charter and Activities of the SIRTF In-Orbit Checkout Focus Integrated Products Team and Optical Performance of the CTA

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ABSTRACT

The NASA Space Infrared Telescope Facility (SIRTF) contains an 85 cm cryogenically cooled beryllium Ritchey-Chretien telescope. This Cryogenic Telescope Assembly (CTA) will operate at about 5 K. Once in orbit, the telescope may be focused by moving the secondary mirror using a cryogenic focus mechanism to vary the separation between the primary and secondary mirrors. The risk of failure of the motor is unknown but is believed to be non-negligible. It is therefore desirable to evaluate and achieve best focus with a minimum number of motor activations. The SIRTF Project has charged an Integrated Products Team (IPT) with conducting this activity. We describe a strategy to determine the initial mirror spacing by quantitatively evaluating the shapes of the images formed by the telescope using the Infrared Array Camera (IRAC) and other science instruments (SI's). We show that this information can be used to predict the direction and magnitude of the secondary mirror move that will result in the telescope best focus. The tools used to evaluate focus position and optical quality of the in orbit CTA have been qualified during the ground-based BRUTUS test are here described. Future activities of the IPT to meet IOC objectives are summarized.

Keywords: Space Infrared Telescope Facility (SIRTF), In-Orbit Checkout (IOC), Integrated Products Team (IPT), Infrared Array Camera (IRAC), focus, Cryogenic Telescope Assembly (CTA)

1. INTRODUCTION

NASA's Space Infrared (IR) Telescope Facility (SIRTF) will collect IR light from astrophysical sources to study the creation of the universe, the formation and evolution of primitive galaxies, the genesis of stellar systems that form planets, and the creation and dispersal in the ejecta of dying stars of the elements that are the building blocks of the planets and biological life. The heart of SIRTF is an 85-cm cryogenically cooled beryllium Ritchey-Chretien telescope. The Cryogenic Telescope Assembly (CTA) houses the cryogenic telescope, the He dewar, and the science instruments. The telescope will operate at temperatures as low as 5.5 K. Fulfillment of the SIRTF science objectives requires that the focal plane images delivered by the CTA meet a Level-One-Requirement (LOR) of diffraction limited performance at 6.5 μm ($\lambda/14 = 0.464$ μm RMS wave-front error). Once in orbit, the CTA can be focused by moving the secondary mirror using a cryogenic focus mechanism. The failure risk for the very first IOC focus motor move, though believed to be small, is feared to be non-negligible. A failure of the secondary mirror focus mechanism could become a single-point failure in the SIRTF mission's ability to meet its science objectives. Therefore, it is desirable to determine from the initial images obtained during In-Orbit Check-Out (IOC) whether the telescope is in an acceptable focus condition or not without resorting to a conventional focus sweep. If the telescope is not at best focus then we wish to the determine the magnitude and direction of the secondary mirror move that will result in best focus from analysis of the initial images alone. Our objective is to achieve the best focus with a minimum number of focus mechanism actuations. A SIRTF IOC Focus Integrated Products Team (IPT) has been established to address these issues and to develop an IOC focus activity plan that will meet these objectives. In this paper we describe a strategy used to determine the initial IOC focus condition of the CTA by quantitatively evaluating the shapes of the images formed by the telescope using the Infrared Array Camera (IRAC) and the other Science Instruments (SI's). We show that this information can be use to predict the direction and magnitude of the minimum number of secondary mirror moves that will result in best focus. Prior to launch, the assembled CTA was subjected to an optical auto-collimation test. This end-to-end optical test was conducted by Ball Aerospace Technology Corporation (BATC) at 5.5 K in a chamber called "BRUTUS". We refer to this

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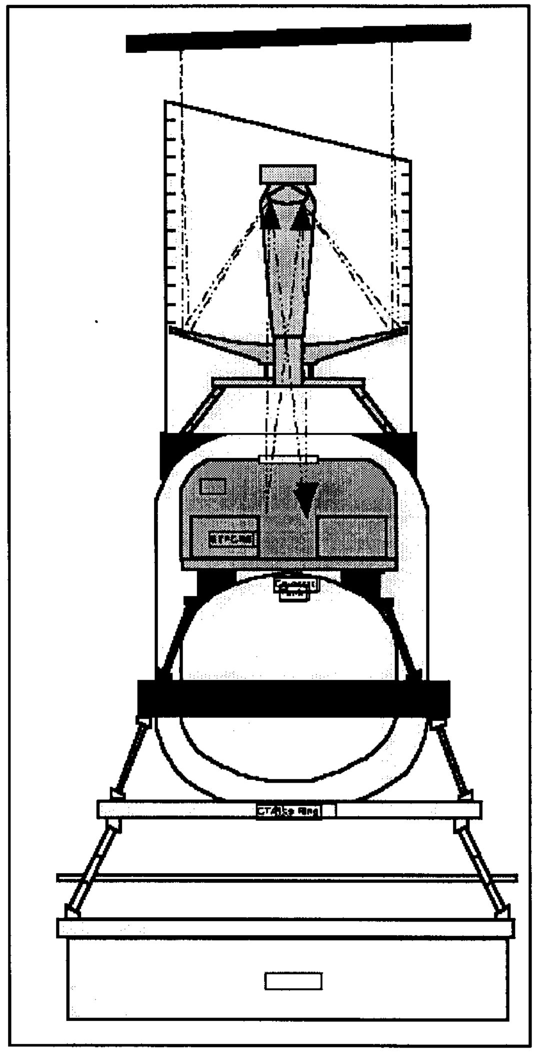

Figure 1: Schematic view of the double pass BRUTUS autocollimation test. The light from the focal plane Short Infrared IR glower (called the SWIR) is collimated by the CTA telescope, reflected by the OSCAR flat, and directed to the IRAC, IRS, and PCRS instruments which form an image of the artificial star IR glower. The illumination from the IR glowers must traverse a semi transparent window which is located in the Aperture Door Mechanism (ADM). The ADM is integral to the "Warm Launch" (WL) concept. In the W L concept the telescope is attached external to the dewar vacuum vessel. The WL concept allows for a substantially smaller dewar which weighs less. The hermetic ADM which is located on the vacuum vessel surface is deployed during IOC. During integration and testing the ADM is not deployed to prevent contaminants from condensing on the optical surfaces of the Science Instruments (SI's) due to the extreme temperature gradients that exist in the test chamber. To mitigate ground hold thermal parasitics the ADM window is coated to reflect radiation beyond about 5.3 μm. Only IRAC channels 1-3 and IRS short-low modes could be used for CTA image performance evaluation during the BRUTUS Test. Image courtesy of J. Schwenker and BATC.

this activity as the "BRUTUS Test". In this test we have evaluated the optical performance of CTA in auto-collimation, validated our IOC focus analysis tools, and set the secondary mirror position to the expected in-flight best focus position. In the BRUTUS test, an IR glower (the Short Wavelength Infrared, or SWIR source) which is located in the SIRTF focal plane is viewed by the IRAC and IRS science instruments by reflection from an articulated mirror flat, called OSCAR, which is suspended over the CTA aperture (see Figure 1). During the BRUTUS test, the OSCAR auto-collimation flat is held at cryogenic temperatures. The OSCAR mechanical suspension is articulated so that the image of the IR glower can be directed to the desired position on the SI focal plane. We describe several tools that have been developed to evaluate the "best-focus " optical performance of the CTA using SI data gathered during the BRUTUS Test and outline the post-BRUTUS activities that must follow to prepare theses tools for the IOC focus activity.

2. SIRTF IOC FOCUS IPT CHARTER

The SIRTF IOC Focus IPT has been charged with the responsibility of evaluating the optical performance of the CTA from data acquired during the BRUTUS Test, conducting a focus verification activity during the BRUTUS Test, recommending the pre-launch focus setting of the secondary mirror focus mechanism, determining the state of the CTA focus during IOC, and supervising any focus moves that may be required during IOC. These activities include the definition of the software and hardware required to support the BRUTUS and IOC Focus activities, the identification of personnel/hardware/software resources required to support these activities, the development of analysis tools and "success criteria" for evaluating BRUTUS/IOC focus data, and the presentation of the results of IOC focus image analysis to the SIRTF Team with the objective of recommending potential focus adjustments.

3. IOC FOCUS IPT ORGANIZATION AND OPERATION

The IOC Focus IPT is led by R. D. Gehrz (Principal) and E. A. Romana (Deputy Principal). It is composed of representatives from the various teams that must participate in the evaluation of CTA optical performance and the setting of CTA focus. These teams include the SI's (IRAC, IRS, and MIPS), PCRS, BATC, LMMS, the SSC, JPL and the SWG. Most of the work is reviewed during weekly 2-hour telecons where materials are presented to participants using an IP address that can be accessed through the Internet and discussion is conducted on a toll-free voice line. The plan of work is reviewed on each telecon, and action items are assigned as required. Teams work the action items independently between telecons. Results are presented at each telecon. The Principals interact with teams as required to track the progress of assigned tasks. Periodic face-to-face "table top" reviews of the work are conducted at BATC and JPL, and the IPT members participate as required in on-site activities at BATC and SSC/JPL during the BRUTUS/IOC activities.

During its operating lifetime and by the conclusion of the IOC activity, the Focus IPT is expected to have produced the following deliverables to the SIRTF Project: 1) requirements for the Brutus Test Plan including a test sequence and script; 2) an IOC Focus Confirmation and Adjustment Plan containing a description of the operational strategy (including confirmation methods, targets, data acquisition and commanding approach, success criteria, decision points, decision process, IOC time-line, test approaches, and personnel roles and responsibility during IOC; 3) IOC image libraries and software algorithms for evaluating the state of CTA focus and predicting the magnitude and direction of required focus adjustments; 4) IOC activity sequence design ; 5) a model of the wavefront performance of the CTA based upon JPL and BRUTUS test data; and 6) a document describing potential contingency situations and plans for dealing with them.

4. CONCEPTUAL APPROACH TO FOCUSING THE SIRTF CTA DURING IOC

Because of the perceived high risk of failure of the cryogenic motor that moves the secondary mirror, and because such a failure would cause a "single-point" degradation of undetermined but potentially large magnitude in the scientific potential of SIRTF, the project desires to determine the state of the CTA IOC focus in a passive way and to optimize focus, if

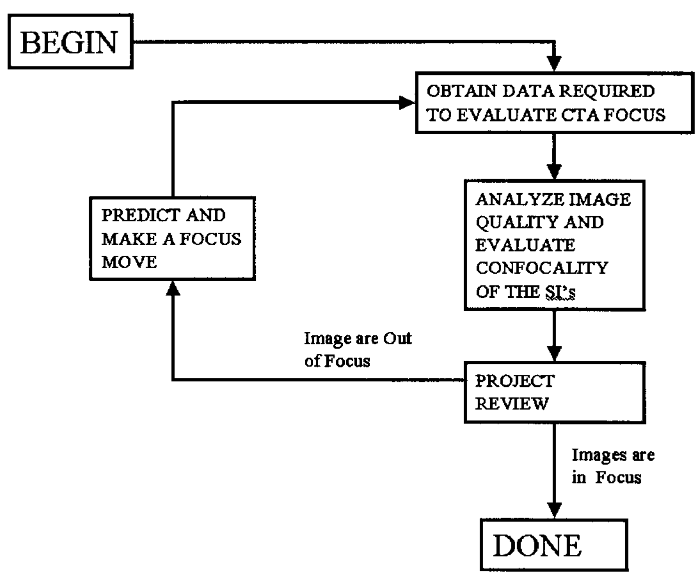

Figure 2 The conceptual SIRTF IOC Focus Decision Tree. Each focus move is preceded by a passive evaluation of data to determine the state of the focus.

necessary, with minimum risk. The Focus IPT has developed a conceptual strategy for doing this as shown in Figure 2. Upon orbit, and once the CTA has come into thermal equilibrium, image data sufficient to establish the state of the CTA focus will be gathered by the SI's and PCRS. The centerpiece of this plan, as described below, is to use IRAC images of a bright star imaged on 9 and 25 positions of the four IRAC channels to determine whether the CTA focus meets the level one mission requirement of diffraction limited performance at $\lambda = 6.5$ µm. If the telescope is not in focus, an evaluation of the image data will be conducted using a variety of methods to predict the direction and magnitude of the secondary mirror move that must be made to achieve the level one requirement. The results of this evaluation will be submitted to the project for review, and the IPT will conduct a focus move if so directed. Following the move, the data collection -image evaluation -project review sequence will be repeated as necessary until the level one requirement has been met. We have determined that the actual conduct of each focus move will depend upon several conditions. If a refocus activity is required on-orbit, the initial mirror mechanism activation will be a small move designed to ascertain that the mirror moves in the desired direction and that the images behave as predicted by the libraries generated from the optical model. Should the outcome of this initial move be successful, another move will be made to converge to best focus. This final move will be accomplished in one step if the move is smaller than 2 Depth of Focus Units (DFU's), and several steps if the required move is greater than 2 DFU. Several contingencies have been identified that would require a radical departure from the low-risk plan. These include the possibility that the images produced by the CTA are not consistent with the optical model, the failure of one or more SI's, and problems with the secondary mirror mechanism.

5. TOOLS TO EVALUATE CTA OPTICAL PERFORMANCE, FOCUS POSITION, AND SI CONFOCALITY

The Focus IPT has spent considerable effort over the past year and a half to find optimum ways of verifying that the CTA has met its level one optical performance criterion of diffraction limited performance at $\lambda = 6.5$ µm (464 nm RMS wave-front error). In this effort, we have conducted extensive reviews of BATC HeNe interferrometric test data obtained during CTA optical components and sub-assemblies testing, JPL Cryogenic Test Chamber data, and BRUTUS auto-collimation test data. One complicating factor is that the images from the IRAC instrument, which is intended to be an area survey instrument, are under-sampled with respect to the Point Spread Function (PSF). The 1.2 arcsecond SIRTF pixels are 13% larger than the Rayleigh Criterion ($\theta_{min} = 1.22\lambda/D = 1.07$ arcseconds at 3.6 µm, the shortest wavelength at which SIRTF operates). This results in highly "pixelated" images as illustrated in the BRUTUS focus sweep shown in Figure 3. We describe below several criteria that can be used to evaluate image quality and SI confocalty, and we show that it is possible to use these criteria to focus the CTA with a minimum number of focus movements despite the highly pixelated nature of the IRAC images.

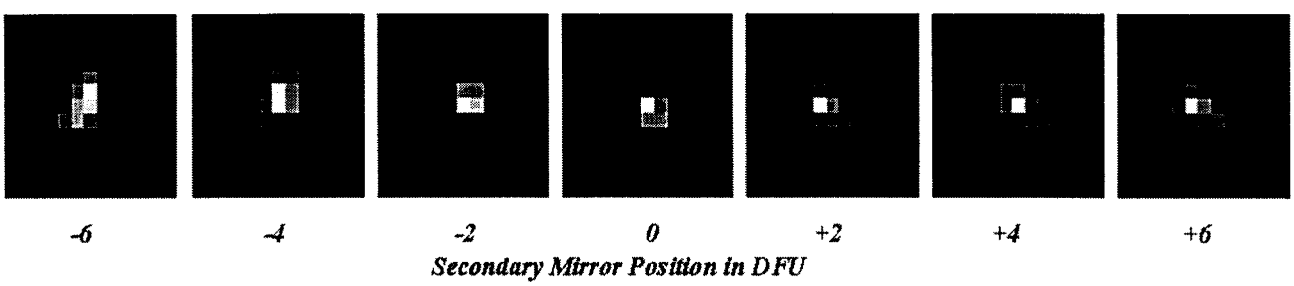

Figure 3: IRAC channel 1 BRUTUS focus sweep showing actual data collected with 1.2 arcsecond pixels. In the BRUTUS autocollimation double pass test the telescope aberrations are doubled, but diffraction remains unaffected. At best focus, the light is concentrated on the minimum number of pixels. The image shape reveals which side of focus the secondary mirror is for out of focus images. Courtesy of W. Hoffman and the IRAC Team.

5. 1 The noise pixel (N_P) success criterion

BRUTUS and IOC image quality can be quantified by computing the Noise Pixel (N_P) criterion for the PSF. N_P is a direct measure of light concentration, and is straight forward to determine for under-sampled images as compared to quantities such as Encircled Energy (EE) or Strehl ratio. After E.L. Wright[1], we define the noise pixel criterion N_P by the quantity:

$$N_P = \frac{\left(\sum_1^J n(j)\right)^2}{\sum_1^J n(j)^2}, \qquad (1)$$

where $n(j)$ is the number of counts in the jth pixel. It can be seen that N_P is minimized as the light becomes concentrated on the smallest possible number of pixels. For example, an image with all the energy in one pixel has $N_P = 1$ while a uniform PSF with all the energy in n pixels has $N_P = n$. The effects of spatial under-sampling are illustrated in Figure 4. Several interesting asymptotic behaviors of N_P occur in the limits where the pixel size is either much smaller than or larger than the PSF. In the limit when the pixels are very small compared to the PSF, N_P increases quadratically with increasing wavelength because the number of pixels flooded with signal is proportional to the area of the PSF. When the pixels become very large compared to the PSF so that all of the signal can be contained within a single pixel, N_P converges asymptotically to 1, 2, or 4 depending upon whether the PSF falls squarely on the middle of one pixel, on the edge of two adjoining pixels, or at a corner where 4 pixels join. To evaluate N_P effectively for pixelated images such as those produced by IRAC, one must "dither" the telescope about by sub-pixel sized amounts in order to find the minimum N_P value when the centroid of the PSF is at the center of a pixel. Astronomical integration time scales linearly with N_P in the photon noise or Background Limited Incident Power (BLIP) regimes.

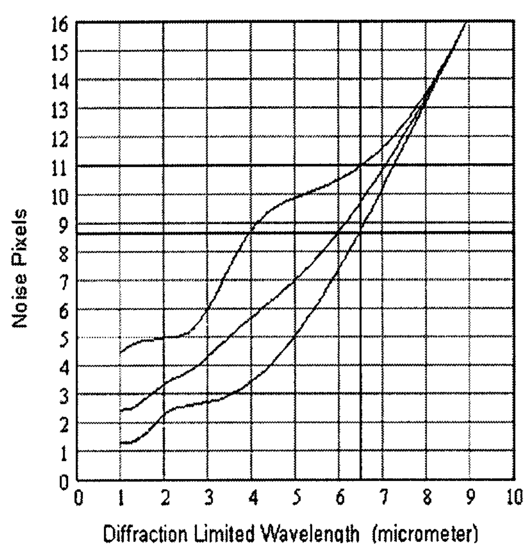

Figure 4: IOC noise pixels (N_P) in the PSF of the ideal SIRTF Telescope plotted as a function of wavelength for the IRAC instrument which has 1.2 arcsecond pixels. The Telescope PSF was placed at the center of a 100 by 100 pixel box for the N_P calculation. Each curve is for the PSF centered at a different representative pixel location or pixel phase. The Telescope model used has linear central obscuration ratio of 0.3765 but no spider vanes. Note that the N_P function becomes parabolic at long wavelengths as the pixel size becomes much smaller than the diffraction limit of the CTA ($\lambda_{Diff} = 1.22(\lambda/D) = 1.92$ arcseconds at 6.5 μm or 1.60 pixels) and that the value of N_P converges asymptotically to the values of 1, 2, and 4 when the pixel size is $\geq 1.22(\lambda/D)$. The reason for the quantized convergence at short wavelengths is discussed in the text. It is interesting to note that for wavelengths beyond 8.5 microns the N_P of point sources is invariant with respect to pixel phase.

5. 2 Evaluating N_p Focus Position Using Focus Diversity

W. Hoffmann of the IRAC Team has developed a method we call "focus diversity" that can be used to establish the CTA focus condition from an evaluation of a set of multiple images of a bright star placed at 9 and 25 selected field positions on all four IRAC arrays. All images are taken at the same secondary mirror position. These images can be used to determine whether the telescope is optimally focused, and if it is not, how far and in what direction the secondary mirror should be moved to achieve best focus. The technique makes use of the fact that the telescope focal surface has field curvature, which varies quadratically across the telescope field of view (FOV) as illustrated in Figures 5 and 6. In effect, images at selected field locations are equivalent to a conventional secondary mirror displacement focus sweep.

Figure 5 shows how the Noise Pixels values obtained during the BRUTUS test, for nine field positions in each of the three IRAC channels that were able to view the IR test glower, for seven discrete focus position settings spaced 2DFUappart. IRAC channel four was blocked by the transmission characteristics of the Aperture Door Mechanism (ADM) window (see Figure 1) In this plot the N_P value obtained for each of the nine field position is shifted horizontally by small amount that corresponds to the focus shift due to the curvature of field in that channel at that field location. In this figure the continuous quadratic curve is the best focus prediction from the optical model.

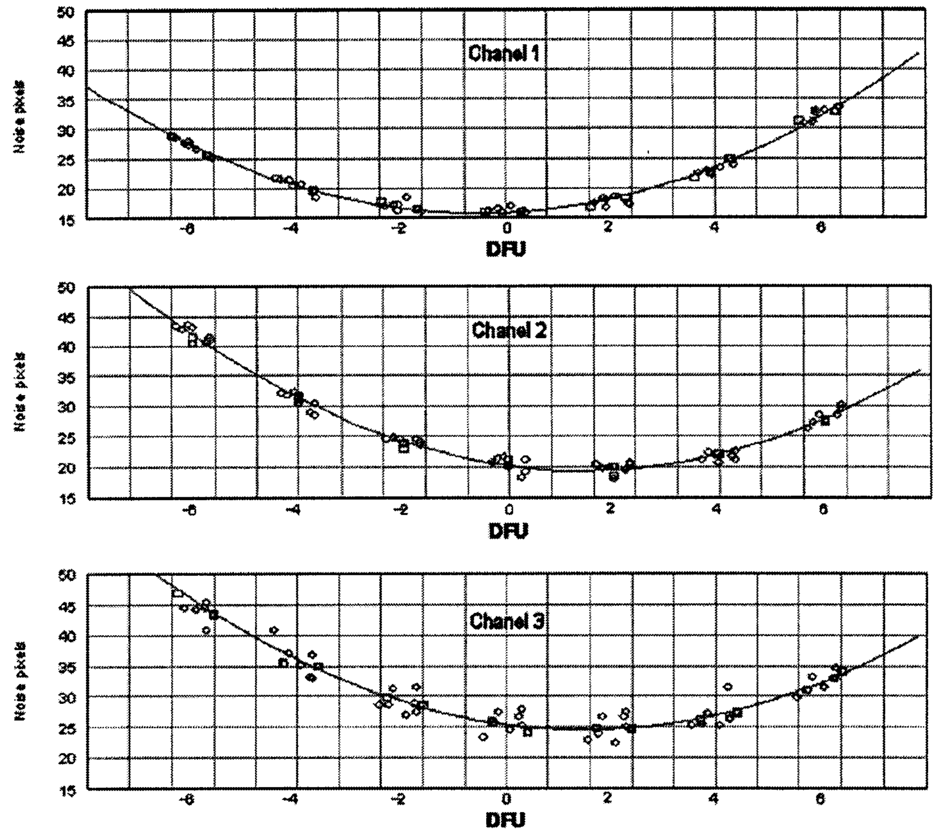

Figure 5: Noise pixel plots plotted as a function of secondary mirror position ind DFU's at nine focal-plane positions for IRAC channels 1, 2, and 3 from BRUTUS data. Curves are bets-fit parabolas. Best focus position and focus sign can be determined from individual out of focus images as described in the text. Courtesy of W. Hoffman and the IRAC Team.

With out resorting to a conventional focus sweep, the magnitude and direction to of the secondary mirror move that will achieve best focus can be predicted from the slope of the field N_P values obtained in this plots.

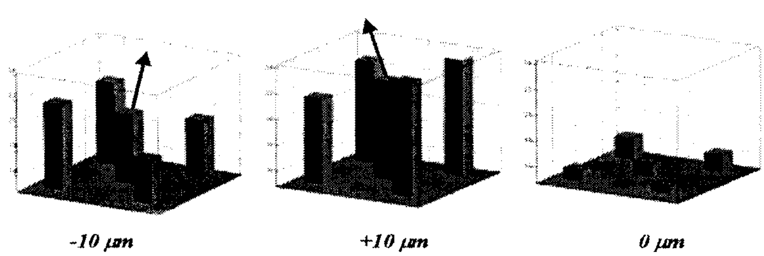

Figure 6: Noise Pixels across the IRAC FOV show unambiguously by the direction of the focal plane curvature whether the CTA is inside or outside the nominal focus position. The three data cubes from left to right show BRUTUS data for the secondary mirror positioned 10 μm inside, 10 μm outside, and at best focus. Red vectors show the normal to the best-fit focal surface at the center of the array. Image courtesy of W. Hoffman and the IRAC Team.

Figure 6 shows how the parabolic focal plane curvature varies quadratically and monotonically on each side of the "best - focus" position over the FOV. The direction and angle with respect to the "normal" at the center of the FOV for a given separation of the primary and secondary mirrors indicates which way and how far to move the secondary mirror to achieve CTA "best focus". Our analysis shows that the accuracy of this technique is about 0.25 DFU during IOC with the 3.5 μm IRAC channel

5.3 Evaluating Focus Position Using the CTA Optical Model

W. Hoffmann has developed a software package to compare the IOC image of a point source with a library of out of focus images that has been generated using the CTA optical model. This process is reminiscent of the "blink"method of comparing two plates of the same portion of the sky taken at two different epochs. The comparison of the sky image and the model is performed by cross correlation and by a normalized subtraction method. Both methods yield similar results. For these comparison to be successful the centroid of the sky and model images must coincide precisely. Since the centroid of the sky image is not known exactly a priori, the software searches for the best centroid fit by re-binning the model images which are stored in the data base in pixels that are 5 times smaller than the actual IRAC pixels.

Although we can demonstrate that focus position can be precisely determined by comparison with a model library of focus slew images, the method relies on the accuracy of the optical model itself. In particular the higher order Zernike term discrepancies bias the results. Since the method of Focus Diversity, explained above, rely simply on the low order curvature of field or Petzval sum, and on the well understood relative focus position offsets or confocality between instrument modules; we have chosen Focus Diversity as the primary IOC focus position evaluation tool.

5. 4 The depth of focus unit (DFU) as a success criterion

The IPT has adopted the depth of focus unit (DFU) to evaluate the confocality of the SI's and to determine when the CTA is within the acceptable operating range of the "ideal" best focus position. Following the arguments given by Born and Wolf[1], we can define the DFU as:

$$DFU = F^2 \lambda \tag{2}$$

where F is the focal ratio of the telescope and λ is the wavelength at which the depth of focus is being evaluated. As noted by Born and Wolf[2], the ususal definition of acceptable optical performance is defined as a loss in intensity of about 20% at the center of the image, or a Strehl[3,4] of 0.8. This condition occurs at a distance of 2.058 DFU on either side of the best focus position (where the Strehl is unity). The SIRTF Project has adopted the more stringent requirement that the intensity loss shall be no greater than 10% (Strehl = 0.9) for any SI for the CTA to be considered in adequate focus and confocality. This condition is met for focus settings within ± 1 DFU of the best focus position for IRAC channel one as we discuss in Section 6 below.

6. OPTICAL PERFORMANCE OF THE CTA

We have evaluated the optical performance of the SIRTF CTA from HeNe interferograms obtained by BATC during the CTA assembly tests at JPL and from IRAC images of the SWIR glower acquired during the BRUTUS Test . Although the optical components that comprise the CTA assembly were individually verified for optical performance, the SIRTF Project decided, nevertheless, to test the completed CTA as an end-to-end assembly optical auto-collimation in the BRUTUS test chamber as described above. The CTA was tested in optical auto-collimation in the BRUTUS test chamber as described above. Unlike optical component or subassembly testing where one can resort to interferogram measurements of the optical wavefront, the CTA "end to end" test must by necessity use the IR science instruments as the detector or imaging device. In the BRUTUS Test, the SI's deliver rather intensity image measurement. A further complicating factor was that the IRAC instrument used for the BRUTUS CTA characterization is a survey instrument whose pixel scale is not well suited for over sampling the PSF.

To overcome these challenges, Eric Mentzell of the IRAC Team, using software routines developed by C.J. Burrows[5], successfully implemented "Phase Retrieval" of the intensity images to obtain the actual optical wavefront of the exit pupil. Because the technique of Phase Retrieval reconstructs the optical wavefront from a series of out of focus images, the challenge of the relatively large pixel scale was entirely overcome. The phase retrieved exit pupil wavefront has proven very useful to verify the accuracy of the formal optical model constructed from the individually tested optical elements.

Wavefront, microns rms

Field point	Measured	Mar '02 Model
0	0.239	0.240
1	0.410	0.418
2	0.254	0.264
3	0.281	0.270
4	0.441	0.433
5	0.350	0.313
6	0.240	0.235
7	0.239	0.242
8	0.352	0.369

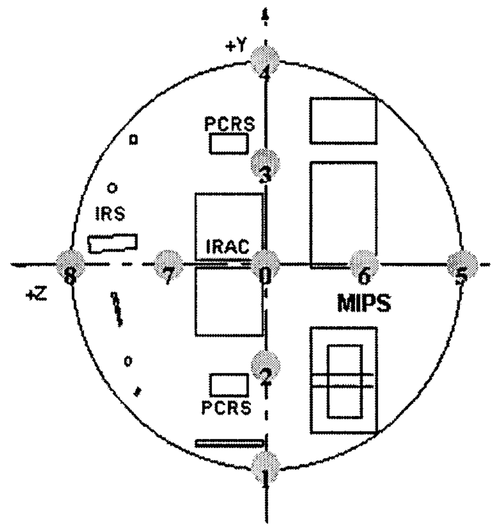

Figure 7: Optical performance for the in orbit SIRTF telescope at representative field locations. Shown are the measured and predicted values for the optical wavefront error in micrometer rms. The Measured column contains the values that result from a model that is derived from Phase Retrieval exit pupil wavefront measurements obtained with the IRAC instrument. The Mar'02 Model column are the values predicted from the "component" model. The component model is constructed from measurements of all optical subassemblies. All field locations show some margin with respect to the level one specification of 464 nanometer wavefront error RMS. Figure courtesy of J. Schwenker and BATC.

7. DETERMINING CONFOCALITY OF THE SI's, SETTING THE LAUNCH FOCUS POSITION, AND EVALUATING THE PROBABILITY OF REQUIRING A FOCUS MOVE DURING IOC

The Project would prefer to take the position that it is risky and therefore undesirable to move the secondary mirror unless a move is absolutely necessary to meet the level one requirements for SI confocality and CTA diffraction limited performance at 6.5 μm. Figure 8 summarizes the current state of the SIRTF CTA SI's with respect to confocality, the final setting of the launch focus position, and the evaluation of the probability that a focus move will be required during IOC.

With respect to confocality, the level one requirement is that the CTA should not have to be refocused for individual observing campaigns with different SI modules to meet the level one optical performance. The challenge of achieving instrument confocality during IOC lies in testing the focus status of instrument modules that span a wavelength range from the near to the far IR. Early in the design phase of SIRTF, it was decided to adopt a "bolt and go"strategy. In this strategy every SI places an external fiducial mark on the outer envelope of the instrument. This fiducial bears a known offset distance with respect to the to detector focal plane. During module integration in to the CTA instrument cavity, each module is adjusted for confocality with respect to these external fiducial marks. Figure 8 summarizes the achieved confocality for the as-built CTA. The vertical bars represent a range of ± 1 DFU (about 10% signal loss) about the best focus position as determined from theodolite measurements of the fiducial markers. The large open circles show the best focus positions of the IRAC Channels 1, 2, and 3 and the IRS Short-Low slit as determined from observing images of the SWIR glower during the two independent runs of the BRUTUS test. It is evident that the internal focality dispersion within IRAC itself is large enough that t the achievement of level one confocality for these four channels requires that the CTA focus must end up lying with +1.0 DFU and -0.4 DFU of the best focus for the IRAC Channel one.

During the BRUTUS Test activity, the CTA focus was set to the IRAC "compromise" best focus position (see the dashed line). At this position, the average deviation of the four IRAC channels from best focus is minimized, although IRS Short-Low is at the extreme value of the level one confocality requirement. Note that the length of the DFU bars in Figure 8 is proportional to λ (see equation 2),so that all of the other SI module that operate at $\lambda \geq 6$ μm are comfortably within their optimal optical performance requirements for this setting.

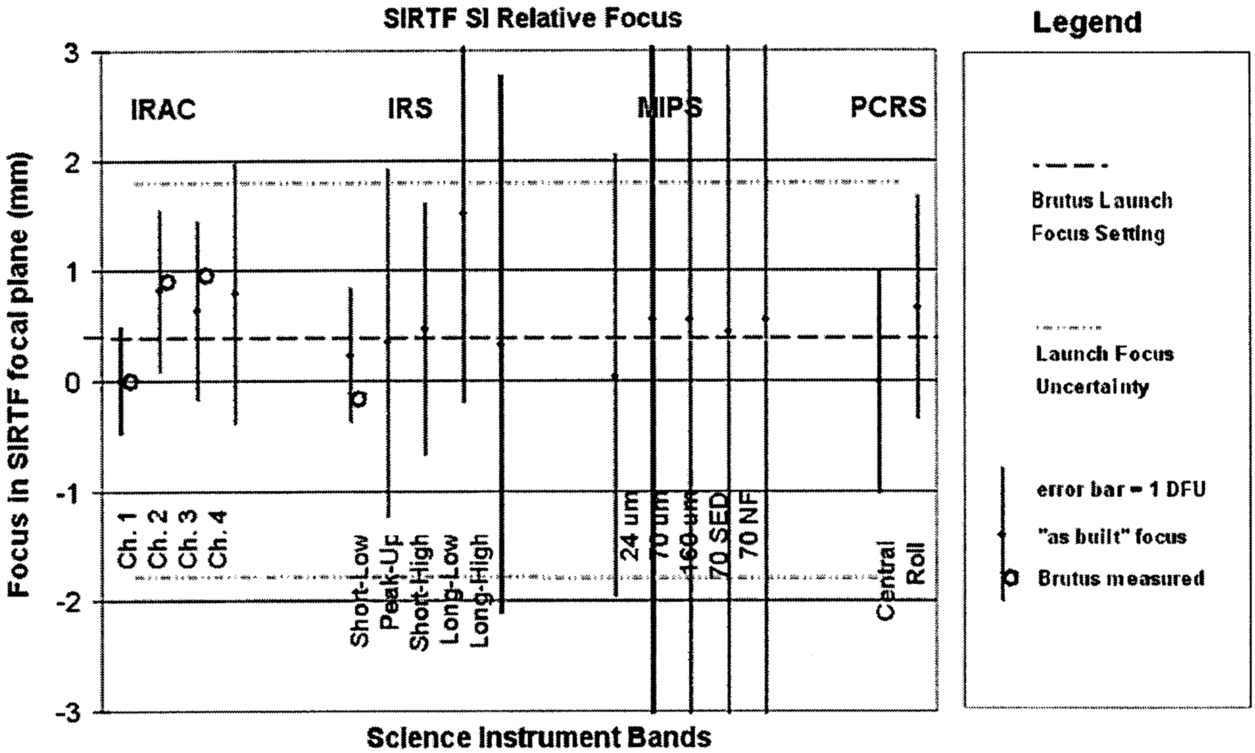

Figure 8: Confocality of the Science instrument Modules. The vertical axis is focal distance in mm at prime focus. Each vertical bar indicates the acceptable focus range or depth of focus of a particular Science Instrument Module. Depth of focus scales linearly with wavelength. The dot at the center of each vertical bar represents the instrument external Fiducial Mark as explained in the text. The vertical position of each bar is determined from the external fiducial mark theodolite measurements carried out to verify the confocality achieved at the conclusion of the SI CTA instrument integration. The open circles in the short wavelength modules are the result of the optical focus position determinations that were conducted during the BRUTUS test. The long wave IR channels were not available for measurement in the BRUTUS test as described in the text. The horizontal doted line in the vicinity of +0.2mm focus is the "Launch Focus" or the position to which the pre launch telescope has been set. The horizontal lines in the vicinity of +/- 1.8 mm focus represent the high confidence band in which we expect to find the initial the fight telescope. This apparently large focus expectation band is due to uncertainty in the integrated coefficient of thermal expansion. It is likely that the IOC CTA telescope will require an initial focus move.

The Focus IPT has tried to evaluate the likelihood that an IOC focus move will be necessary to meet the level one optical requirements. During the testing of the optical components required for the BRUTUS Test, it was discovered that the OSCAR flat develops a convex radius of curvature of about 3 km when its temperature is lowered to 5.5K where it is operated during BRUTUS. CTA variations within the fused silica blank is the most likely source of this effect. The focal plane focus shift of about 30 mm caused by this OSCAR "power" term must be accounted for in setting the final CTA focus position for launch. Seven cryogenic cycles were performed on OSCAR during the test program, and result of these showed that the radius was consistent within a 3σ upper limit of about $\pm$ 1.8 mm (the dash-dotted lines shown in Figure 8). Since the best focus condition for the IRAC and IRS channels has a tolerance of approximately $\pm$ 0.5mm (0.83σ with respect to the certainty with which the radius of curvature of OSCAR is known), it would appear that the likelihood that the focus will have to be reset during IOC is high.

8. POST-BRUTUS PREPARATIONS FOR THE IOC FOCUS ACTIVITY

The IOC IPT will spend the period until 1 January, 2003 preparing for the IOC focus activity that will follow the anticipated 9 January, 2003 launch of SIRTF. During this period, the most important tasks will be to use several models of the CTA to generate image libraries for the four IRAC channels that can be used to evaluate the state of the focus of the CTA by passive inspection. We will carry two models into IOC; these are the March 2002 phase retrieval model developed by E. Mentzell from BRUTUS focus sweep data, and the July 02 model assembled by J. Schwenker from the interferrometric surface map data obtained by R. Brown and D. Chaney of BATC during component and assembly tests of the CTA using the JPL Cryogenic Optical Test Chamber. These models differ somewhat because of the various errors involved in the testing and analysis techniques. In the event of a complete failure of either model to accurately describe the images observed on orbit, our contingency plan is to focus the CTA by minimizing the nosie pixel criterion empirically with a small number of experimental and minimal secondary mirror moves . The other major pre-launch activities are to finalize the focus object selection, test the analysis hardware/software tools and focus activity sequences, and identify Principals and Deputies for each critical activity.

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