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Field retermination of APOGEE Spectrograph MTP fiber connectors

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ABSTRACT

We discuss the field retermination of high-fiber count MTP fiber connectors used with the APOGEE spectrograph at Apache Point Observatory (APO) in 2021. We address lessons-learned, wear-analysis of removed MTPs, and throughput of the fiber train with the newly terminated fibers in SDSS-V. For the past decade the spectrograph at APO, as part of multiple incarnations of the Sloan Digital Sky Survey (SDSS), has relied upon rapid changes of ten MTP connectors, each containing 30 terminated fibers, and all contained within a custom gang connector system. These rapid changes enable the iterative plugging of the gang connector into multiple cartridges with different plug plates to observe various survey fields throughout the night. While robotic Focal Plane Systems have been developed for SDSS-V to replace plug plates, which will minimize the fiber connector cycles, we nonetheless reterminated the most heavily used MTP connectors. The connector cycles had far exceeded manufacturer lifetimes and the overall system throughput was degrading.

Keywords: Fiber Optics, Near-Infrared, Spectroscopy, Fiber Connectors, MTP

1. INTRODUCTION

High fiber-count MTP connectors from US Conec[1] are a critical technology for the two Apache Point Observatory Galactic Evolution Experiment (APOGEE) spectrographs[2] used for the APOGEE-1 and -2 surveys[3] as part of the Sloan Digital Sky Survey (SDSS)-III[4] and SDSS–IV.[5] The spectrographs are currently in use for the Milky Way Mapper Survey in SDSS-V.[6] The fiber-fed, high-resolution ($\lambda/\Delta\lambda \sim 22{,}500$), near-infrared (1.5 – 1.7 µm) spectrographs are capable of observing 300 objects at once when coupled with the wide field of view 2.5-m Sloan Foundation Telescope[7] at Apache Point Observatory (APO), New Mexico, USA, and the 2.5-m du Pont Telescope[8] at Las Campanas Observatory (LCO) in Chile.

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In the ten years between commissioning in 2011 and retermination in 2021, the most heavily used MTP connectors sustained >17,000 cycles, over 34 times the 500 cycles that US Conec typically uses for product durability testing.[9] These cycles supported the collection of over ~2,000,000 stellar spectra[10] for the APOGEE-1 and APOGEE-2 surveys using the northern version of the instrument at APO. They also supported the first year of SDSS-V operations.

In the APOGEE-1 and -2 surveys, multiple fields on the sky were observed throughout the night, each for about one hour. For each field, a custom aluminum fiber plug plate with holes drilled at precise locations corresponding to the known positions of stars in the sky was placed at the focal plane of the telescope. These plug plates were secured within cartridges that attached to the bottom of the telescope. Multiple cartridges were prepared in advance, loaded with different plug plates, to allow rapid cartridge changes throughout the night. During the daytime, each cartridge was manually prepared by plugging 300 discrete fibers into the various holes in the plates (Figure 1).

The fibers collected and transmitted stellar light observed with the telescope to a female "gang connector" port at the bottom of the cartridge. The port contained a set of ten MTP connectors (configured with guide pin holes) in which the 300 fibers within the cartridge terminated. A complementary male gang connector pin contained ten MTP connectors (configured with guide pins) that were the termination of the 300 fibers emanating from the spectrographs. Figure 2 shows the gang connectors assemblies. The iterative plugging and unplugging of the gang connector system as each cartridge was changed allowed the observation of up to ~2000 objects per night.

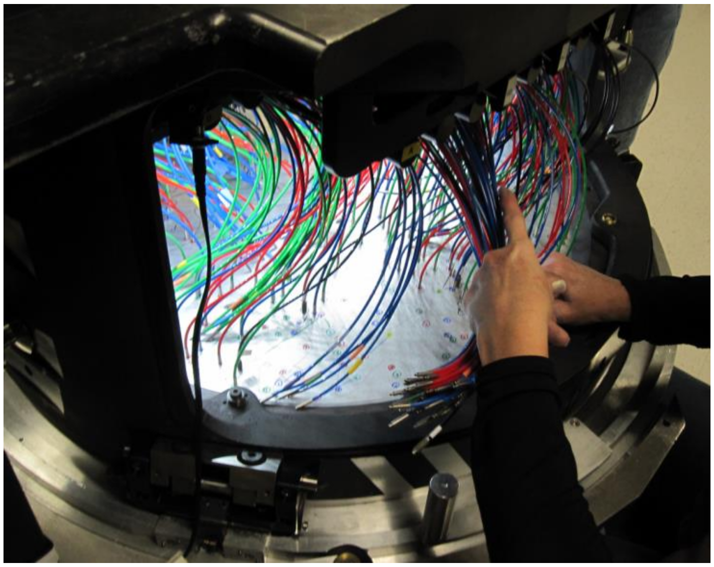


Figure 1: Discrete fibers are being plugged by hand into a custom aluminum fiber plug plate that is secured within a cartridge (turned upside down in the picture to allow plugging). The cartridge gets mounted to the bottom of the telescope such that the plug plate is positioned at the telescope focal plane for observation of a specific field on the sky.

Over the last few years of the APOGEE-2 survey throughput degradation for multiple connectors on different cartridges at APO became apparent, as shown in Figure 3. Some of the discrete changes in throughput performance are understood. For instance, in September 2017, approximately day 2200, maintenance was done on the MTP connections in the field. A rodent had chewed through the entire set of 30 fibers associated with MTP 5. The break, located at the base of the telescope, was repaired by installing an extra pair of MTP connectors at the break. All subsequent observations for that set of 30 fibers suffered an additional ~20% throughput loss. MTP 10 at the male gang connector was also replaced to recover a broken fiber. All spring pushes on the male gang connector MTPs were removed and two-part spring push parts were installed instead. Sometimes throughput degradation was caused by problems with the complementary female MTP connectors in specific cartridges (signified by specific colors in Figure 3), some of which were subsequently resolved.

Since the instruments are critical for the success of the ongoing Milky Way Mapper survey in SDSS-V, we conducted a field retermination of the MTP connectors at APO to address the apparent end of life issues of the original connectors. (The analogous connectors at LCO have only been in service since 2017 and have not shown this degradation so far.) Specifically, the twelve (10 + 2 spare) MTPs associated with the male gang connector were reterminated as were twelve (10 + 2 spare) MTPs that are part of the most heavily used calibration port. (The original MTPs associated with the female plug plate cartridge gang connector ports were decommissioned since a new robotic Focal Plane System (FPS)[11,12] for the telescope, which include new MTP terminations, was commissioned during the summer 2022 for SDSS-V.) We also installed new gang connector mechanical assemblies.

The retermination, led by Dan Rocheleau (Fiber Optics Center; New Bedford, MA), required 9 days effort distributed across three individual trips to the telescope. Nearly all of the equipment used for the retermination had to be supplied by FOC and transported to the site as the observatory is not equipped to undertake such a major fiber connectorization project. The project was supported by Computer Crafts, Inc. (Hawthorne, NJ). They kindly shared lessons-learned and specific polishing procedures based upon their experience fabricating tributary fiber assemblies[13] that included MTP connectors for the FPS mentioned above.

In Section 2 we provide specifics of the fiber and MTP system. Section 3 discusses the field retermination and Section 4 provides initial results after the retermination. Section 5 provides analysis of the removed MTP hardware. In Section 6 we conclude with lessons learned.

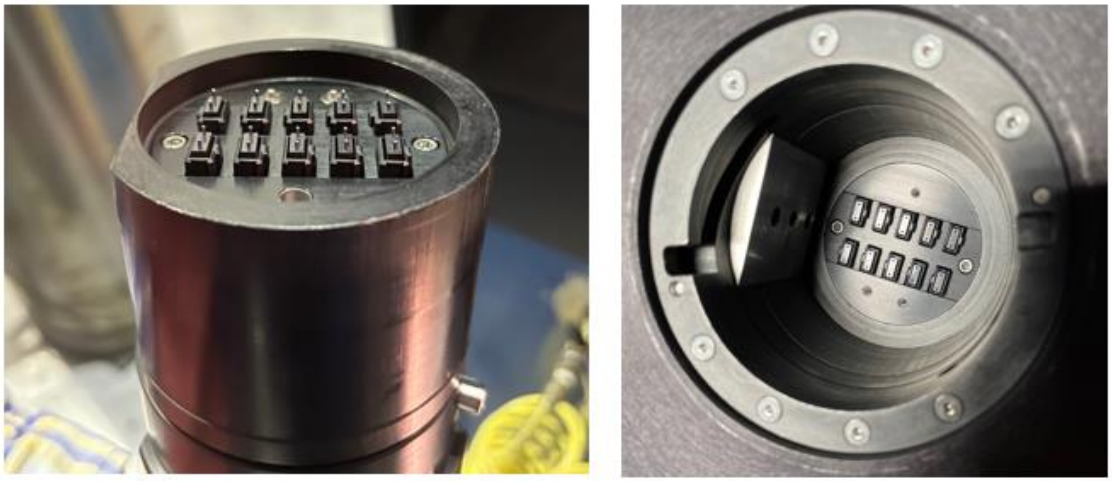


Figure 2: (Left) The male gang connector with ten MTPs configured with guide pins. (Right) The complementary female gang connector port.

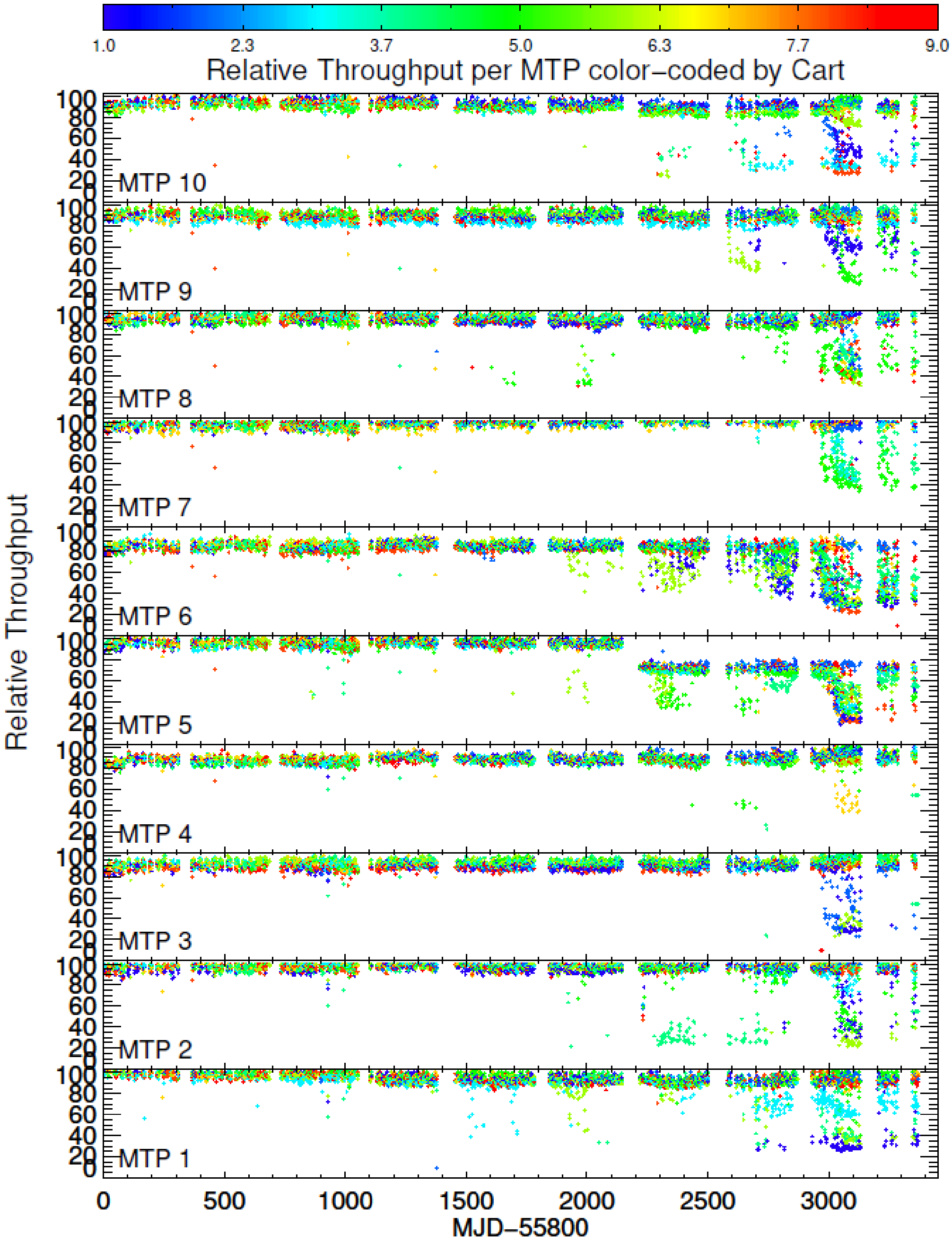


Figure 3: Relative throughput over the ~ 3500 days of use of the MTP connectors before retermination. Data is color-coded by cartridge – each cartridge had a separate female gang connector with a set of ten MTP connectors (configured with guide pin holes).

2. FIBER & MTP SYSTEM

To ensure maximum sensitivity, the APOGEE fiber train must efficiently transmit the near-infrared light collected by the telescope to the instrument located about 45 meters away in an adjacent building. The light enters the fiber tips located at the telescope focal plane and exits at the fiber tips arranged side-by-side in v-groove blocks inside the instrument. Thirty fibers are contained within each v-groove block and ten v-groove blocks mount along a curve at the pseudo-slit (Figure 4). Each fiber tip at the pseudo-slit is an object of the spectrograph and the instrument optics reimage the fiber

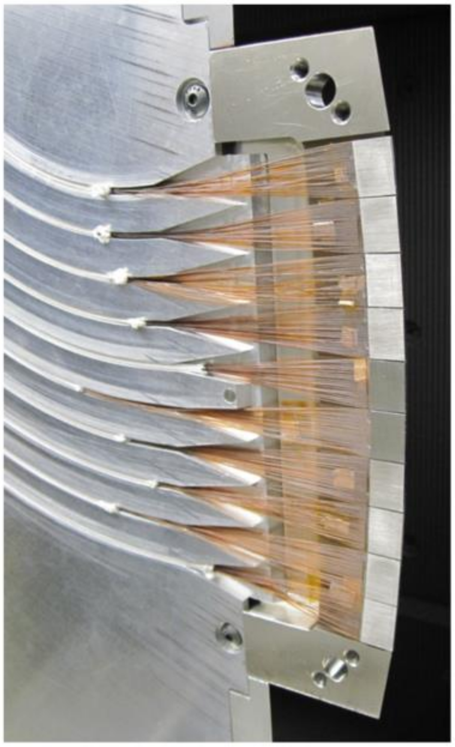


Figure 4: The pseudo-slit within the instrument that lines up the ten v-groove blocks, each containing 30 fibers, that are connected to the MTP connectors at the gang connector system.

tips onto the three near-infrared detectors placed side-by-side at the instrument focus. A dispersing optic at the pupil of the spectrograph creates the spectrum recorded by the detectors.

The MTP connections at the bottom of each cartridge are the only connectors in the fiber train. To penetrate the cryostat wall we designed custom fiber feedthroughs. The fibers, enscapsulated within epoxy, penetrate without break while the epoxy provides a hermetic seal to enable instrument evacuation to support internal cooling to cryogenic temperatures with LN_2.

We use Molex (Polymicro) low-OH FIP120170190 circular core multi-mode fiber. The core size is 120 µm diameter, the cladding is 170 µm diameter, and the polyimide buffer is 190 µm diameter. The core size was chosen such that each fiber subtends approximately 2 arcsec on the sky imaged at the focal plane of the telescope.

Back in 2009, US Conec created a custom high fiber-count ferrule mold for the APOGEE project. The ferrules manufactured using this mold, made of glass-filled Polyphenylene Sulfide (PPS) thermoplastic, can accept 32 fibers in a 4 x 8 array of fiber holes. Each row has eight holes on 325 µm centers. Each row is spaced 325 µm apart. The fiber holes are 195 µm diameter.

MTP connectors rely upon fiber-fiber contact to provide low-loss connections for all fibers[1]. In addition to the use of polishing processes that promote fiber tip protrusion and appropriate end-face geometries, the connector systems include springs to force the fiber tips into contact. Figure 5 provides an exploded view of the MTP connector system. We have always specified use of 20 N springs given the high-fiber count of our ferrules. Recent testing by US Conec has further substantiated the necessity of the 20 N springs for this connector.[14]

The fibers are epoxied into the MTP ferrules using Masterbond EP21LV room-temperature cure epoxy using a 2 – 3 days cure time. It is important to note that the polyimide coating is not stripped from the fiber prior to termination. Room temperature cure epoxy minimizes stress on the fibers — mechanical stress leads to Focal Ratio Degradation (FRD), the angular spreading of light that can lead to lost light in finite-sized downstream optics.[15]

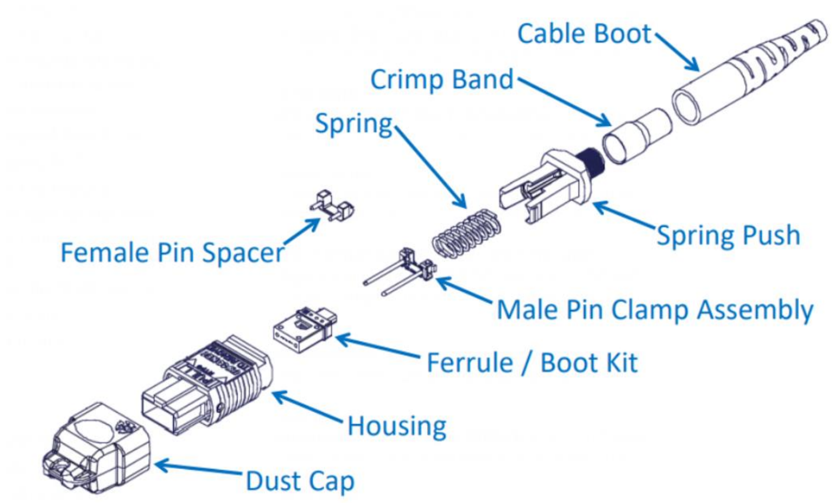


Figure 5: An exploded view of an MTP connector from US Conec Application Engineering Note (AEN-2019).

3. FIELD RETERMINATION

Field retermination took place one level below the telescope in a space known as the lower enclosure (Figure 6). It has an annular floor plan that surrounds the cone bearing which supports the telescope above. While it is environmentally controlled and kept clean, the lower enclosure does not meet any clean room standards. A supply of > 60 psi compressed air was available for use with the polishing machine.

3.1 Equipment & Supplies

High fiber-count MTP connectors require heavy-duty automatic polishing machines to produce the necessary polishing forces. We used a Domaille Engineering Automatic Polishing Machine Model HDC-5320 with a chuck capable of polishing 12 MTP ferrules simultaneously. Another important piece of equipment was an automated interferometer to measure surface topography to verify endface geometries met our goals (see Section 3.4 below). Table 1 lists the major equipment used for the retermination.

As part of the retermination project, we worked with US Conec to create "kits" with known components to standardize future MTP component orders. Table 2 provides the list of US Conec parts used for the retermination. In Figure 5, the ferrule is shown with the ferrule-boot already installed in the rear of the ferrule. It is important to note that a ferrule-boot is not available that fits the 32-fiber ferrule part number 22997. Thus we used a ferrule-boot designed for 48-fiber ferrules. The front of the ferrule-boot was trimmed to enable insertion into the back of the ferrule. Figure 6 shows how a ferrule-boot was trimmed by Computer Crafts while fabricating tributary fiber assemblies.

The main purpose of the ferrule-boot is to prevent epoxy from wicking backwards along the fiber since the back opening where the fibers feed into the ferrule is relatively large, both for moldability purposes and to accommodate multiple rows of fibers. Without the boot there would be a large opening through which epoxy can wick backwards along the fibers, making the fibers behind the connector more conducive to breaking. Flexible UV-cured adhesive, applied to the fibers within the ferrule-boot prior to filling the ferrule with epoxy, played a critical role in preventing the epoxy from wicking between fibers. The ferrule-boot was essentially a confinement area in which to inject the flexible UV-cured adhesive to serve as an epoxy dam between the 30 fibers exiting the boot. A secondary benefit is the ferrule-boot holds the fibers straight as they exit the ferrule. This helps the fiber survive handling and fiber movement since any force along the fiber is axial. It also provides a softer material that helps keep the fibers away from the harder ferrule edge if pulled at 90 degrees

Table 1: Equipment used during the field retermination.

Equipment	**Specifics**
Optical Fiber Connector Polishing Machine	Domaille Engineering Model HDC-5320 with chuck PFA-MT-EZ-12
Imager	Dimension Easy Check 400X microscope viewer with integrated 8 inch LCD display and MTP adapter
Epoxy Stub Cutter	Phenix Fibersect.multi
Vacuum Pump Kit for MTP	US Conec MTA-021
Interferometer	DORC ZX-1 micro Array+
Black Body Calibrator	Omega Model BB702

Table 2: Parts and kits from US Conec

Description	**Part Number**
Kit, MTP Connector, Female, Multimode, 4.5 mm Round Cable, High Spring Force, Black, Custom	23119
Kit, MTP Connector, Male, Multimode, 4.5 mm Round Cable, High Spring Force, Black, Custom	23120
Ferrule, 32 Fiber, Multimode, PPS, 4 x 8 x 195 µm diameter	22997
Boot, Ferrule, MT, 48F	16361

The MTP ferrule listed in Table 2 is the part number for ferrules manufactured using an updated mold that has a tighter angular tolerance on the fiber holes relative to the normal of the ferrule face. During testing of the original MTP ferrules (part number 12773) for the Prime Focus Spectrograph project[16] on the Subaru Telescope, it was found that the ferrules have fiber holes with mean tilts of 0.58 deg; ferrules with the new part number have tilts < 0.2 deg. Use of this improved ferrule could increase throughput by 3 % or more across MTP connections.[1]

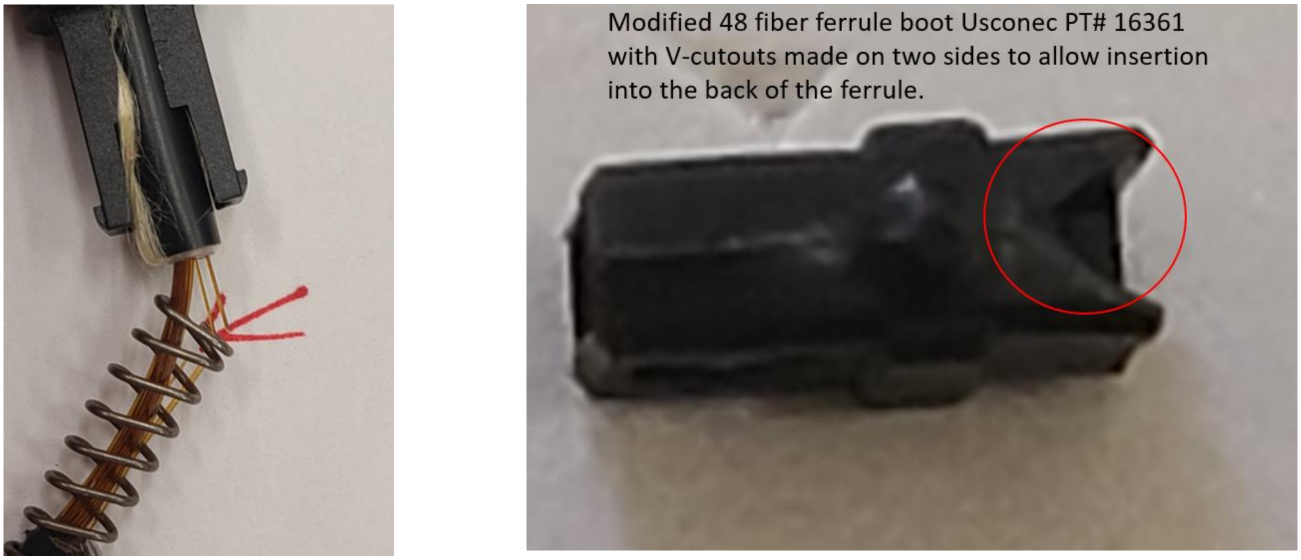


Figure 6: (Left) Two broken fibers behind the connector near the spring. (Right) A 48-fiber ferrule-boot modified for use with the 32-fiber connectors used for APOGEE. Both pictures courtesy of Computer Crafts.

3.2 Fiber Mapping

As mentioned above, the fiber assembly that connects the pseudo-slit, inside the instrument, with the MTPs at the male gang connector, runs without break. Hence, it was our intention to retain the one-to-one correspondence between specific fibers and the corresponding holes within the various MTP ferrules. This was desirable so that we did not have to remap the correspondence after retermination. We had to abandon this plan and accept a completely new, random, reordering of the fibers within the MTPs when it was found that some of the old MTP connectors had significant epoxy buildup behind the connectors. This buildup prevented the simple identification of a fiber's position in the 4 x 8 array relative to the back of the MTP connector.

3.3 Checking Fiber Continuity

We checked for broken fibers multiple times throughout the retermination process. As the instrument was cryogenically cooled and operational during retermination of the 12 MTP connectors on the male gang connector, we could not access ends of the fiber within the instrument at the pseudo-slit to visually check throughput. So we checked fiber health by illuminating fibers, singly or in groups or full MTP connectors, with the output of an Omega Black Body Calibrator set to 130 – 140 ˚C. This temperature range provided ample counts in exposures with the instrument's near-infrared arrays. While this method required coordination with personnel in the control room of the observatory to command the observations, a similar coordination effort would have been required even if we had access to the ends of the fibers since the instrument resides in a different building.

3.4 Extra Two Fibers

While the MTP connectors have a capacity of 32 fibers, only 30 fibers are connected between the MTP ferrules and v-groove blocks at the pseudo-slit within the instrument. The two remaining fibers, by convention placed in the two corners of the ferrule closest to the epoxy window, only run to the vicinity of the v-groove blocks but are not terminated. The purpose of populating the extra two fibers in the MTP was to provide a complete set of fibers and avoid the complication of asymmetric fiber loading on the polishing process. The bookkeeping involved with accounting for these two unused fibers added extra difficulty during retermination – after cutting off the old MTP connector, these two unused fibers had to be identified by iteratively determining which two of the 32 fibers did not illuminate the instrument. The presence of broken fibers further complicated the process.

3.5 Crimp Ring

Outside of the instrument, the sets of 32 loose fibers that run between the MTPs of the male gang connector and the cryostat wall are contained within Tyco Electronics cable with a PVC jacketing with nominal outer diameter of 3.8 mm. Over ten years ago when the original MTP connectors were installed crimp rings designed for a nominal 4.5 mm round cable were used as US Conec did not offer crimp rings for a nominal 4.0 mm cable. While US Conec now offers the 4.0 mm crimp ring, for historical reasons, we chose to continue use of crimp rings designed for 4.5 mm round cable.

3.6 Bare Fiber Breakage

Anecdotally, the polyimide buffer coating with annular thickness of 10 µm surrounding the fiber core and clad seemed fragile as compared to traditional fibers used for telecommunications for which much of the equipment and procedures were developed. While difficult to be definitive, it seemed susceptible to breaks when nicked with hard objects such as the spring or dust of abrasive material. Steps when bare fibers were exposed required special care and handling – the majority of the fiber breaks were directly related to the loading and unloading of the ferrules into the polishing fixture. Figure 6 shows such broken fibers that occurred during fabrication of tributary fiber assemblies by Computer Crafts.

3.7 Procedures

After equipment set-up, the retermination work consisted of old connector disassembly, old ferrule inspection, new connector installation, new ferrule epoxying (followed by 2-3 days of curing), new ferrule polishing, sample testing with the interferometer, and new connector final assembly. Interspersed between the steps were checks of throughput with the black body calibrator to monitor for unintended fiber breakage. Below are specific notes about some major steps:

<u>New Ferrule Installation</u>

This step was straightforward but time consuming since the fibers were loose and not ribbonized. We made no attempt to ribbonize fibers into groups of eight for the four different rows of the MTP. The need to identify the two extra fibers, as described in Section 3.4, also required extra care. The fibers were epoxied into the ferrule-boot using Delo Photobond AD494 UV-cure adhesive instead of the Masterbond EP21LV room-temperature cure epoxy used for epoxying the fibers into the ferrule. While use of a fast-curing UV-cure epoxy probably adds mechanical stress and hence FRD, its use was expedient for this field retermination. Figure 7 shows installation of fibers into the ferrules and Figure 8 shows a group of ferrules ready for epoxying.

<u>New Ferrule Epoxy</u>

While a utility vacuum pump and bell jar were used to degas the MasterBond EP21LV, the recommended method for degassing this particular epoxy is to use a centrifuge for 2-3 min at 1000 - 2000 rpm.[**] After filling the ferrule epoxy well, we used US Conec's vacuum pump kit with a special tip for the front of the MTP ferrule to create suction and "pull" some epoxy along the fiber holes from the well to the front of the ferrule. As settling occurred the well was refilled. A small bead of epoxy was placed at the front of the ferrule.

<u>New Ferrule Polishing</u>

Ferrule faces were polished flat (not angled) in sets of 12 at a time using the Domaille Engineering APM polisher (Figure 9) following the procedures developed by Computer Crafts listed in Figure 10.

[**] MasterBond, Private Communication, July, 2022.

Figure 7: Installing fibers within ferrules with the aid of a high-magnification digital microscope. The pigtail of fibers that normally extends up to the telescope and terminates in the male gang connector has been retracted and is seen draped against the wall that surrounds the cone bearing supporting the telescope so the connectors can be replaced on the workbench.

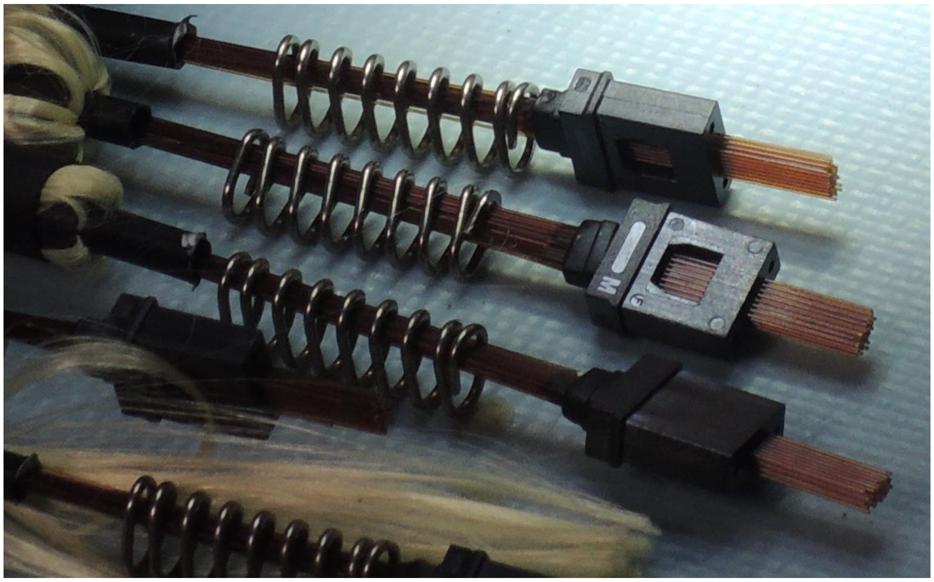


Figure 8: MTP ferrules ready for expoxying with MasterBond EP21LV epoxy.

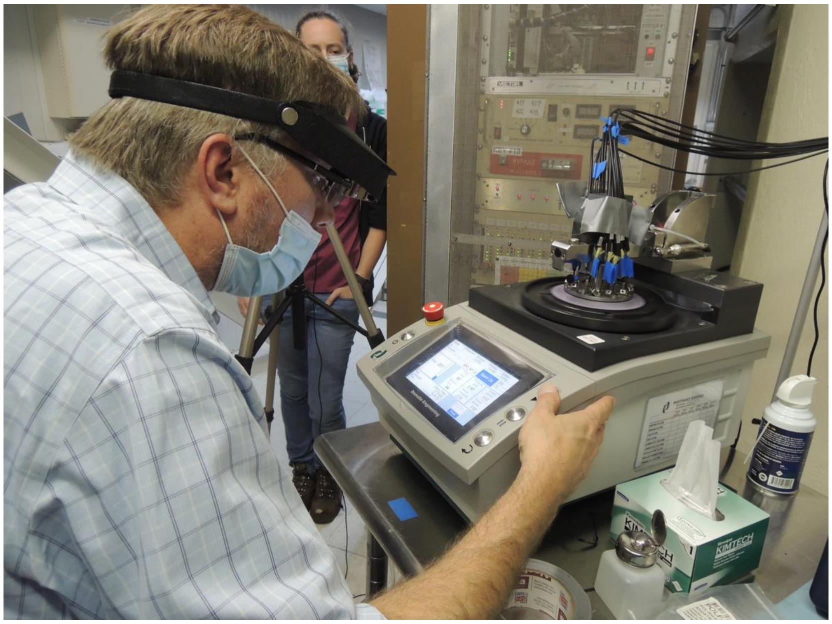
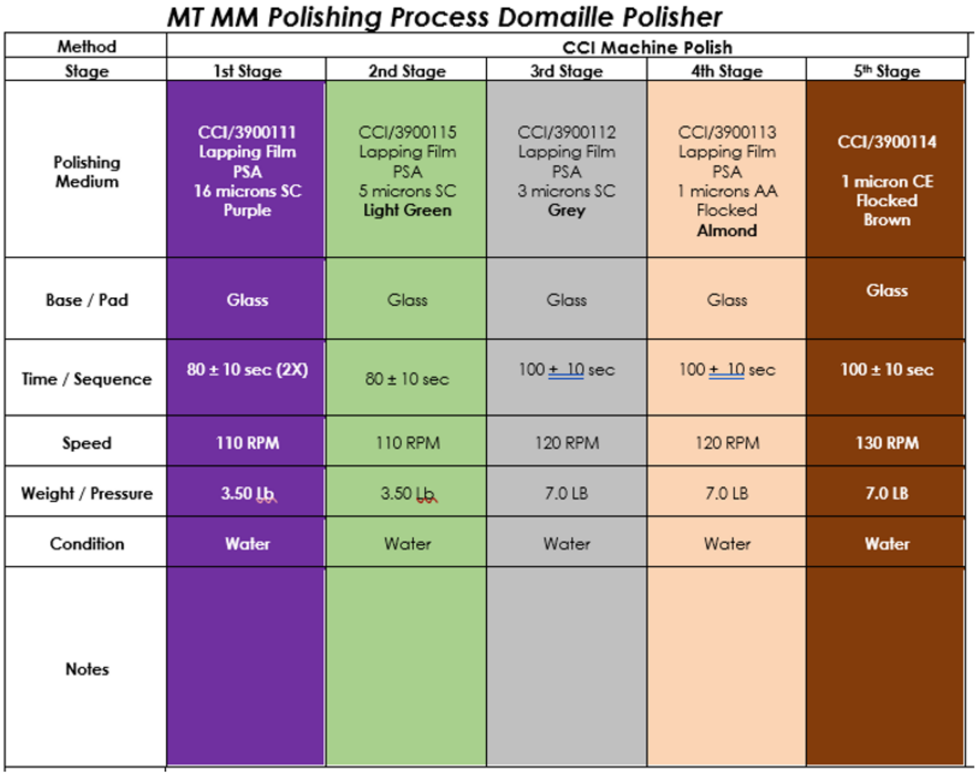


Figure 9: A set of 12 MTP ferrules are polished with the automated polishing machine.



MT MM Polishing Process Domaille Polisher

Method	CCI Machine Polish				
Stage	1st Stage	2nd Stage	3rd Stage	4th Stage	5th Stage
Polishing Medium	CCI/3900111 Lapping Film PSA 16 microns SC Purple	CCI/3900115 Lapping Film PSA 5 microns SC Light Green	CCI/3900112 Lapping Film PSA 3 microns SC Grey	CCI/3900113 Lapping Film PSA 1 microns AA Flocked Almond	CCI/3900114 1 micron CE Flocked Brown
Base / Pad	Glass	Glass	Glass	Glass	Glass
Time / Sequence	80 ± 10 sec (2X)	80 ± 10 sec	100 ± 10 sec	100 ± 10 sec	100 ± 10 sec
Speed	110 RPM	110 RPM	120 RPM	120 RPM	130 RPM
Weight / Pressure	3.50 Lb	3.50 Lb	7.0 LB	7.0 LB	7.0 LB
Condition	Water	Water	Water	Water	Water
Notes					

Figure 10: The Computer Crafts polishing process used for the retermination. “Water” refers to deionized, distilled water.

3.8 Inspection & Testing

It was beyond the scope of the project to have specific endface geometry and testing requirements. First, retermination in the field is difficult. Second, the APOGEE 32-fiber MTP ferrules have not been rigorously tested to determine how the endface geometry specifications should differ from those for standard multi-fiber MTP ferrules. Our goal was to attain endface geometries that were in rough compliance with the International Electrotechnical Commission (IEC) standards for multi-fiber MTP connectors[17]. Table 3 provides interferometric measurements for a set of reterminated MTP connectors. While fiber tip radius was not measured, experience with standard MT connectors and 125 µm fiber, using the same polishing films and similar process, suggests that meeting the fiber tip radius “spec” of >1 mm would not be a problem. Figure 11 shows an image of the array of polished fibers provided by the interferometer.

Table 3: Endface geometry measured with the DORC ZX-1 micro Array+ interferometer for a set of reterminated MTPs.

	Radii of Curvature		Tilt		Coplanarity	Fiber Height		Core Dip	
MTP	Long (mm)	Short (mm)	Long (deg)	Short (deg)	Minus (nm)	Average (µm)	Std. Dev. (µm)	Average (µm)	Std. Dev. (µm)
1	2427	549	0.048	0.087	83	2060	42	-99	14
2	3603	525	0.273	0.180	69	1900	88	-87	13
3	2234	532	0.097	0.149	107	1930	60	-100	17
4	3090	522	0.128	0.149	100	1980	73	-92	13
5	2595	594	0.022	0.069	80	1956	88	-99	16
6	3886	565	0.049	0.140	116	1927	111	-90	12
7	1099	561	0.088	0.289	277	2148	164	-102	16
8	2249	552	0.072	0.146	90	1992	50	-102	15
9	2744	523	0.429	0.180	133	1919	58	-84	9
10	2248	564	0.128	0.167	112	1944	52	-77	15
11	4315	500	0.102	0.119	107	1825	130	-79	11
12	2143	567	0.074	0.086	115	2187	71	-72	6

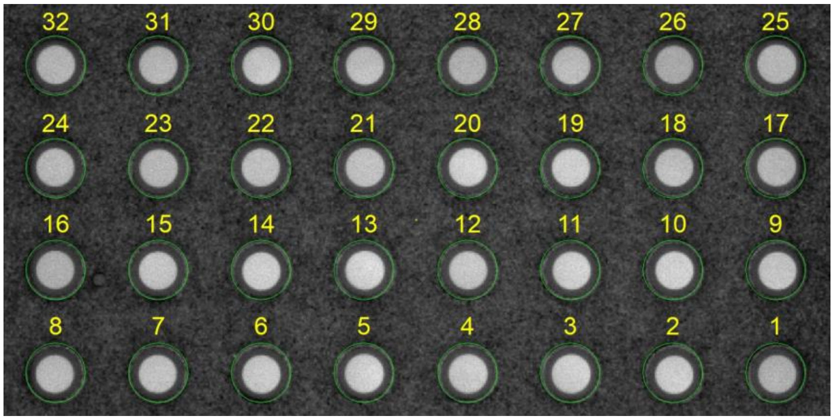


Figure 11: Fiber tips of a polished MTP as imaged by the DORC interferometer as part of an automated check of surface topography.

4. RESULTS

Neither the Sloan Foundation Telescope nor APOGEE instrument system is equipped with light sources for absolute calibration. Instead, stars with known brightness provide absolute calibration for astronomical research. Unfortunately, use of stellar observations means that only total system throughput, i.e. telescope and instrument in series, is measurable. In addition to this MTP retermination project, other modifications were made to the telescope during summer 2021 that impacted throughput, including installation of a new 3-element corrector[18] and installation of the FPS. Thus teasing out relative contributions to total throughput changes is not definitive and relies upon understanding likely changes based on sub-system testing prior to installation, vendor specifications, etc.

Fortunately, total system throughput measured during the past six months of observing, after retermination and after other telescope modifications were made, has improved such that we can confidently say MTP retermination was successful — at least a 10% overall throughput improvement relative to typical throughput observed before the last few years of degradation, can be attributed to retermination. This increase likely comes from two contributions. The first is a 7% throughput increase by achieving fiber-fiber contact, thus eliminating Fresnel reflection losses at two fiber surfaces. The second is reduction or elimination of other losses, possibly from use of the ferrules (part number 22997) with improved fiber hole angular tolerance and possibly reduced FRD due to repeatable and tested retermination and polishing procedures.

5. ANALYSIS OF REMOVED HARDWARE

5.1 MTP Connectors

After removal, visual inspection of the old MTP ferrules revealed the following:

- Fiber tips appeared to be polished flat, not domed.
- Fiber tips did not show the damage one would normally expect with the fiber-fiber contact of hundreds of matings, let alone thousands.
- Most ferrules did not have ferrule-boots on the back of the ferrules. (In fairness, Computer Crafts use of the 48-fiber ferrule-boot was innovative in that a 32-fiber ferrule-boot is not available for these ferrules.)
- Epoxy had wicked along the fibers behind the ferrules.

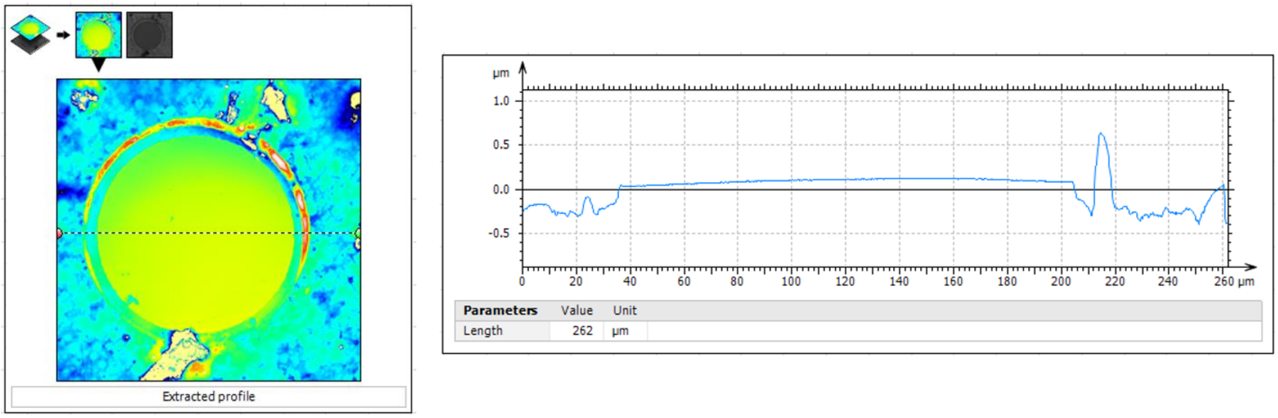
The old connectors were also sent to US Conec so the ferrule endfaces could be inspected with their interferometers and high magnification microscopes. Their findings included:

- Inconsistent endface geometry. Many had very small radii across the ferrule faces when one would normally expect much flatter endfaces.
- There was almost no protrusion of the fibers above the ferrule surface – fibers should normally protrude about 1 – 2 µm above the ferrule end face.

One fiber was scanned at high magnification. As shown in Figure 12, the fiber tip is flush with the ferrule and epoxy protrudes above both, a condition which would impede fiber-fiber mating.

Individual parts that make up the MTP connector, besides the ferrule, were inspected by US Conec to see how they survived the heavy use at the telescope. Some wear and damage to the entrance of the guide pin holes was noted in keeping with expectations for lots of use. There were a few ferrules that had broken shoulders on the molded portion from repeated mating/demating beyond the normal life-cycle. (US Conec had occasionally seen this before and concluded that unless the break is catastrophic the ferrule often continues to function as expected.) Otherwise, there was no significant wear or damage to any of the components nor anything else of concern. In fact, they looked better than expected.

These results were not surprising – first article testing of the original assemblies had suggested that fiber-fiber contact was not being achieved and there were additional small losses at the junctions.[2]



Parameters	Value	Unit
Length	262	µm

Figure 12: Profile of a fiber tip from an originally polished MTP ferrule measured by US Conec.

5.2 Gang Connector Hardware

The retired gang connector hardware was inspected for excessive wear. The system relies upon tight radial clearances between the outside diameter (OD) of the male gang connector and features that define the inside diameter (ID) of the female gang connector port to locate the MTP connectors with sufficient accuracy and repeatability to allow the ten MTPs with guide pins to correctly align with the MTPs with guide pin holes. The male gang connector OD could be readily measured and there was wear of < 0.001”. Unfortunately, we did not have the proper equipment available to accurately measure the inside diameter features. In general, the hardware had held up quite well given that they were designed for 10,000 cycles and in fact were used for over 17,000 cycles. Aside from aluminum blocks in which individual MTP connectors are mounted, the assemblies are fabricated from polycarbonate.

6. LESSONS LEARNED

Field retermination of the MTPs at the telescope was a difficult, stressful, and time-consuming task. In contrast to the typical manufacture of fiber assemblies in a lab or vendor production space where necessary equipment is readily available and both ends of the assembly are available for straightforward testing, neither of these advantages were available.

For this project, we never gave serious thought to removing the entire fiber train from the telescope and instrument to allow retermination at a vendor or lab. We had assumed that removal of the fiber assemblies from cable trays and from the instrument a more time consuming and risky endeavor than field retermination of the MTP ends. If future reterminations are necessary, given this experience, removal and repair must be considered.

For future instruments, this project highlighted the importance of adopting a fiber assembly design that includes a "consumable" fiber assembly that can be readily removed and sent to a vendor or other lab for either retermination or replacement. The APOGEE design, with the aim of reducing the number of connectors to maximize throughput, had the fiber run straight through a special hermetic seal in the cryostat wall without fiber break. Unfortunately, the efficiencies gained by eliminating a connector were lost (until now) at the remaining connector that was improperly polished. Two properly polished junctions would likely have had the same or better throughput and would have allowed the convenience of the design described above.

When just reterminating one end, we found it was essentially impossible to retain "fiber mapping". We also found that far less time was necessary for remapping the one-to-one correspondence between MTP fiber holes and fiber location on the detector arrays inside the instrument than would have been necessary to try to retain the "fiber mapping".

In hindsight, it is clear that the polishing procedures used for the original MTP connectors were not suitable for producing fiber tip protrusion upon which the MTP connectors rely. Quality control was also poor. Interferometric testing of all connectors should have been required.

Since the MTP ferrules have now been properly polished, with the requisite fiber protrusion to ensure fiber-to-fiber contact, we can expect decreased longevity compared to the original terminations as a trade-off for the improved optical performance and connector mating.

In addition to degraded throughput, improper and inconsistent polishing likely made connector cleaning more difficult. It is important to note that APO is located in the Sacramento Mountains overlooking White Sands National Park, the world's largest deposit of gypsum. The dusty environment makes effective connector cleaning, to the maximum extent allowed by telescope operations, very important for the long-term health of the fiber system.

Aside from the lack of fiber tip protrusion and inconsistent polishing, no "smoking guns" were found that were the direct cause of the degradation of throughput over the ten years of connector use. It was likely a combination of normal wear and tear and accumulation of scratches over time on the connector faces, exacerbated by the difficulty in cleaning and the dusty environment.

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