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Design development of a deployable tertiary mirror for Keck

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ABSTRACT

The University of California Observatories will design and construct a deployable tertiary mirror (named K1DM3) for the Keck 1 telescope, which will complement technical and scientific advances in the area of time-domain astronomy. The K1DM3 device will enable astronomers to swap between any of the foci on Keck 1 in under 2 minutes, both to monitor varying sources (e.g. stars orbiting the Galactic center) and catch rapidly fading sources (e.g. supernovae, flares, gamma-ray bursts). In this paper, we report on the design development during our in-progress Preliminary Design phase. The design consists of a passive wiffle tree axial support system and a diaphragm lateral support system with a 5 arcminute field-of-view mirror. The mirror assembly is inserted into the light path with an actuation system and it relies on a kinematic mechanism for achieving repeatable, precise positioning. This project, funded by an NSF MRI grant, aspires to complete by the end of 2016.

Keywords: Time domain, Keck telescope, tertiary mirror

1. INTRODUCTION

A major thrust of astronomy in the 21st century is to study, observationally and with theoretical inquiry, time-variable phenomena in the night sky. This area is broadly referred to as time domain astronomy (TDA) and its high scientific priority was established by the Astro2010 report (National Research Council, 2010). Their highest recommendation for large telescope ground-based observing, for example, is to build the Large Synoptic Survey Telescope (LSST). In advance of that ambitious project, several projects are using wide-field cameras to image large areas of the sky at high cadence. This includes the partially NSF-sponsored Palomar Transient Factory (PTF) and the Pan-STARRS surveys which repeatedly image the full northern sky, finding hundreds of new transient phenomena on every clear night. These surveys are discovering *thousands* of supernovae, immense samples of asteroids and near-Earth objects, variable stars of diverse nature, flaring phenomena, and other exotic sources. These advances in TDA observing at optical wavelengths follow decades of TDA science performed at higher energies from space. Indeed, the first astronomical sources detected with γ-rays were themselves transient phenomena: the so-called γ-ray bursts (GRBs; Klebesadal et al., 1973). Satellites like NASA's *Swift* and *Fermi* monitor $\approx\pi$ steradians of the sky, scanning for transient and variable high-energy events.

The focus of most previous and on-going TDA projects has been wide-field imaging of the sky in search of rare and new classes of events. To fully explore and exploit the astrophysics of newly discovered sources, however, one must establish the redshift and/or the type of object responsible. Optical and infrared wavelengths remain the most powerful and efficient passbands to perform the required spectroscopy. This is the primary role of large, ground-based observatories in TDA science. Recognizing their value, several 8 m-class observatories have established very effective observing strategies (generally at great expense) to perform such science. Both the Gemini and European Southern Observatories (ESO) designed their largest telescopes with systems that could rapidly feed any of the available foci. Furthermore, they designed queue operations to enable rapid responses to targets-of-opportunity (ToOs) and programs that repeatedly observe a source for short intervals at high cadence. Successes of this model include time-resolved spectroscopy of varying absorption lines from a GRB afterglow on minute time-scales (Vreeswijk et al., 2007) and high-cadence monitoring of the Galactic center to recover high fidelity orbital parameters (e.g. Gillessen et al., 2011).

The W.M. Keck Observatory (WMKO) boasts twin 10-m telescopes, currently the largest aperture, fully-operational optical/IR telescopes. Over the course of the past ~20 years, we have successfully instrumented each telescope with high-throughput imagers and spectrometers spanning wavelengths from the atmospheric cutoff to several microns. The Keck I (K1) telescope hosts the Nasmyth-mounted HIRES spectrograph (Vogt et al., 1994), one of the primary tools for obtaining high-resolution visible wavelength spectra from TDA observations. K1 also hosts the Nasmyth-mounted Keck I adaptive optics (AO) system with a recently commissioned laser guide star (LGS) system (Chin et al., 2012) and now hosts the near-IR integral field spectrograph OSIRIS (Larkin et al., 2006), a key tool for synoptic observations of the

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Galactic center. Two K1 instruments are used at Cassegrain: the LRIS multi-object visible wavelength spectrograph (Oke et al., 1995) and the near-IR multi-object spectrograph and imager MOSFIRE (McLean et al., 2012). This is a unique instrument suite, especially within the U.S. community: the HIRES spectrometer is the only echelle spectrometer on a large aperture telescope in the northern hemisphere; LRIS provides extremely sensitive spectroscopy especially at blue (< 4000 Å) and red (> 8000 Å) wavelengths, and MOSFIRE represents a unique capability for multi-slit, near-IR spectroscopy in the northern hemisphere.

Presently, K1 cannot switch rapidly between instruments at Nasmyth or auxiliary bent Cassegrain foci (at least 1 hour) and a swap between Nasmyth and Cassegrain focal stations requires the installation (or removal) of the tertiary mirror module. Thus, in practice, this limits any TDA investigation to a single instrument on a given night. Furthermore, it is essentially impossible to design an observing campaign to study a set of objects at high cadence (e.g., relatively short observations every night). The proposed K1 deployable tertiary (K1DM3) will directly address these shortcomings, enabling WMKO to fully and vigorously participate in TDA science with its unique set of K1 instruments. As the driving paradigm in observational astronomy shifts from a passive, static sky to one that displays dramatic changes on a nightly basis, it is critical to enhance our technical capabilities in this arena.

We proposed successfully to the National Science Foundation (NSF) Major Research Instrumentation (MRI) Program in 2013 for funding of the K1DM3 project. We received the full award requested and the total project budget ($2.1M USD) incudes a 30% cost-share from WMKO, the UC Observatories, and the University of California Santa Cruz. The project entered its Preliminary Design phase in October 2013 and expects to complete this phase in Summer 2014. This paper presents a report on the current system design (see http://k1dm3.ucolick/org for updates).

2. SCIENCE MOTIVATIONS

The K1DM3 device will enable several avenues of TDA science. A more comprehensive discussion of test cases and the science enabled were presented in our first SPIE paper on K1DM3 (Prochaska et al., 2012). Here, we briefly summarize a few primary science-drivers and refer the interested reader to our previous publication.

Targets of Opportunity (ToOs): There is an extremely valuable (and growing) set of astrophysical phenomena that appear and then disappear on time-scales of hours to days. These transient events include the deaths of massive stars, the flares from tidally disrupted stars, and the chirps of merging compact objects. These sources are random both in time and position on the sky and therefore require one to interrupt any planned observations to capture their fleeting light. Therefore, one needs the flexibility to match the proper instrumentation with the event to fully reap the science.

Prime examples of ToO events to be studied with K1DM3 include: (1) gamma-ray bursts (GRBs) – explosive events of extremely bright high-energy emission, generally discovered with dedicated satellite missions. In addition to the high-energy emission, most GRBs exhibit 'afterglows' that radiate throughout the electromagnetic (EM) spectrum, including the optical and near-IR pass-bands. Imaging and spectroscopy of these events establish the GRB energetics and refeine their location on the sky (e.g. to establish the nature of their host galaxies). Absorption-line spectroscopy of the afterglow yields measurements of the gas and dust properties local to the progenitor and also any material that intervenes in the line of sight. The most distant events offer a probe of HI reionization through analysis of the HI Lya transition; (2) Tidal Disruption Flares (TDFs) – Transient emission at primarily UV and optical wavelengths from the (putative) disruption of a star by a super-massive black hole. Ongoing optical and high-energy experiments and future radio observations are predicted to discover 10 to 100 such events per year, each fading on timescales of days to weeks (e.g. Strubbe & Quataert, 2009). Follow-up observations with the suite of K1 instruments would precisely establish the position of the source and provide spectral diagnostics of the emission, elucidating the demography of local MBHs (Rees, 1988); (3) Gravitational Waves (GWs) – Advances in GW detectors have poised that community for the discovery of tens (perhaps hundreds) of extragalactic events driven by the merger of massive, compact objects (e.g. colliding black holes). To fully leverage a GW event, one must localize the event and establish the distance to the source. This will likely require the discovery of a EM counterpart to the transient GW event.

Cadence Observing: For many variable sources – in luminosity, position, color -- there is tremendous scientific value in taking a series of observations across a modest time-scale (days to months). Areas of cadence TDA science that will greatly benefit from K1DM3 include: (1) observations of the stars orbiting the Galactic center. In particular in 2018, the brightest star (S0-2) known to orbit the ~10^6 solar mass MBH at the Galactic center will reach pericenter (Ghez et al., 2008). With an orbital period of a mere 16 years, S0-2 is the fastest freely-falling object observable to date in the universe. Since measurements around periapse are also most valuable to constrain the Keplerian parameters of the

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(osculating) orbit, covering S0-2 with many high-quality observations at this time will improve empirical constraints on the properties of the black hole and our galaxy (e.g. our Sun's distance to the Galactic center) by at least a factor of ~5; (2) exo-planet research, e.g. high-cadence radial velocity (RV) measurements scheduled to confirm promising candidates, perform the Rossiter-McLaughlin experiment, and mitigate aliasing due to the lunar synoditc frequency; (3) monitoring of variability in SNe spectroscopy (e.g. Simon et al., 2009).

Other impacts: In addition to TDA science, the commissioning of K1DM3 will provide increased capability to observe time-critical events (e.g. in coordination with other facilities), allow more efficient scheduling of science on Keck 1, and offer the option to match science programs to current/changing weather conditions. Although a full-time queue is unlikely to be implemented at WMKO, we expect K1DM3 to provide much greater observing efficiency

3. PROJECT OVERVIEW

3.1 Requirements

At the start of Preliminary Design (October 2013), the K1DM3 generated a comprehensive Requirements Document describing the functionality and technical requirements for the project. These include performance, optical, mechanical, and implementation requirements for the new tertiary mirror system within the Keck 1 telescope. This document will specify all aspects of the project – materials, handling, shipping, integration within the Keck 1 telescope control system, etc. The Requirements Document is guiding our work in the Preliminary Design (PD) phase but is also considered a living document that may evolve as we complete PD. A full description of the document is beyond the scope of this paper, but we highlight several areas which are fundamental to the design and/or which we consider particularly challenging for the project.

Performance Requirements: There are two primary configurations for the K1DM3 mirror – (1) deployed, when the mirror is inserted into the optical path to re-direct light from M2 to one of the Nasmyth or bent-Cassegrain foci; and (2) retracted, when the mirror is removed from the optical path so that the beam from M2 travels to the Cassegrain focus.

The primary performance requirements for K1DM3 when deployed are:

- Provide a 5 arcminute field-of-view (FOV) to each of the Nasmyth foci. The current Keck 1 instruments at Nasmyth are OSIRIS behind the AO system and the HIRES echelle spectrometer. Each of these currently requires a FOV of less than 2 arcminutes. The requirement of 5 arcminutes was determined by the anticipated maximum FOV (approximately 4 arcminute diameter) that would be required if a second, offset, guiding channel was added to the HIRES instrument.
- Provide a optical surface that contributes less than 0.054 arcseconds image degradation for 80% enclosed energy. This translates to a 57 nm RMS surface error and a 1.68e-6 radian slope error (RMS) measured across any 476 mm diameter on the mirror.
- Provide a reflective surface with greater than 90% reflectivity for optical and near-IR wavelengths (300-2500 nm).

The primary performance requirements for K1DM3 when retracted are:

- Avoid vignetting either of the FOV's of the Cassegrain instruments including their guide cameras. It is a goal to achieve this requirement by retracting the mirror to a fixed location, but it may need to be achieved by rotating the mirror with the instrument during observations.
- Minimize vignetting of the primary mirror.

Mechanical Requirements: A primary objective of the K1DM3 device is to enable fast swapping between the various instruments on the Keck 1 telescope. This drives several aspects of the mechanical design. The requirement for deployment/retraction is to complete this process in less than 120 seconds. We expect that deployment/retraction will be performed at the same elevation to facilitate a higher precision of repeatability. To enable fast swapping between the foci on the elevation ring, we require a rotation slew speed of 2 degrees per second.

The other key mechanical requirements relate to the in-beam (deployed) positioning of K1DM3 as regards accuracy, stability, and repeatability. The project has carefully considered these requirements as they affect the image quality and observing performance of the instruments at the Nasmyth and bent-Cass foci. There are several types of misalignment,

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including image displacement, distortion, and rotation. For reference, a tilt of the mirror (from its nominal position of 45 degrees) of 11.5 arcseconds leads to a 1 arcsecond offset of the image at the focal plane. This corresponds to a misalignment of the tertiary by approximately 50 microns. The project recognizes that many aspects of misalignment may be mitigated by M1 and M2 (e.g. repointing the telescope, adjusting the M2 focus). Nevertheless, we strive to minimize the impact of K1DM3 misalignment. The current requirement is to achieve a tip-tilt accuracy of 2.8 arcseconds and less than 0.181 mm decenter from the telescope optical and elevation axes. We have determined that achieving these requirements will insure that the pupil image in the current AO system is repositioned to a small fraction of the required precision for placement of the pupil image on the AO system's defomable mirror. Ongoing work will determine the impacts of misalignment on spectra obtained with the HIRES spectrometer, e.g. motions of the pupil on the dispersing elements.

The repeatability requirements match those for accuracy. We cannot accommodate a system that would require frequent (or even occasional) realignment of the device. Regarding stability, the chief requirement is that the K1DM3 device will contribute less than 10% to the image quality assuming 0.4 arcsecond seeing. This translates to a stability of 29 microns along the optical and elevation axes or 0.25 arcseconds in tip and tilt. It will be a challenge to design a sufficiently stiff system to meet these stability requirements under all vibrational modes.

Other notable requirements: A few additional requirements are worth listing here:

- The system cannot dissipate more than 5 Watts of heat above the primary mirror when operated.
- The total mass of the system will be less than 1000 kg.
- The module must be installed from the base of the tertiary tower and will be mounted onto the existing kinematic mounts, without adjustment of the tower mount points (i.e. to allow replacement of the existing tertiary tower).

3.2 Timeline

The K1DM3 project was funded in late August 2013 by the NSF MRI program and the Preliminary Design phase began October 2013. As proposed, we envision a 38 month project with commissioning completed by the end of 2016. Our first major milestone was a mid-term review during Preliminary Design, held April 17, 2013 at UC Observatories. The team presented on its design work and received critical feedback on the baseline design. Our next major milestone is the Preliminary Design Review, currently planned for late July 2013. If achieved, this would maintain the project on its 38-month timeline. The Detailed Design phase is planned to take 17 months, followed by a 9 month fabrication phase. Figure 1 presents the top-level Gantt chart for the K1DM3 project.

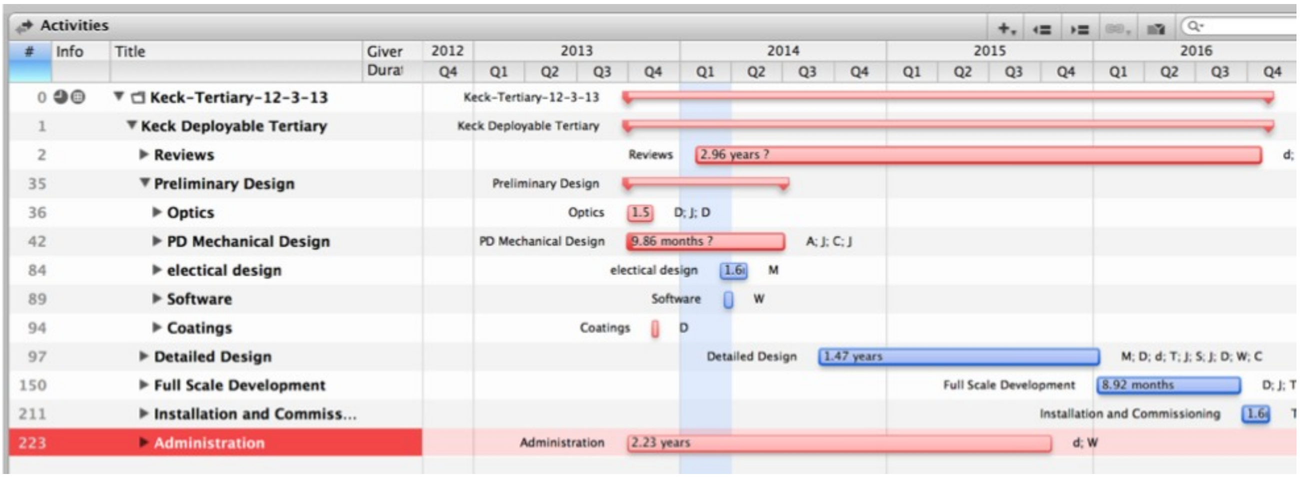

Figure 1. Top-level Gantt chart and work breakdown structure for the K1DM3 project highlighting the major milestones for the project.

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4. MIRROR DESIGN

4.1 Material

In our opinion, the highest quality material for a flat optic is the Clearceram-Z glass from Ohara. This is the preferred material. Alternatively, Zerodur standard will meet the requirements.

4.2 Dimensions

The optical beam of the Keck 1 telescope is defined by the pupil (1.46 m diameter at 17.448 m above the primary) and the focal plane (0.2176 m for a 5 arcminute FOV, located 2.5 m below the primary). The intersection of a plane (the K1DM3 mirror) with the cone defined by the pupil and focal plane is an ellipse. Simple geometry yields the dimensions of this ellipse: a major axis 2a=881.1 mm and a minor axis 2b=623.0 mm. The center of this ellipse must be offset 13.7 mm in the plane of the mirror from the optical axis. These calculations were verified by a full Zemax model of the Keck 1 telescope that includes the new K1DM3 device. Figure 2 compares the mirrors from K1DM3 and the current tertiary system.

We selected a thickness of 50 mm as a compromise between weight and stiffness and, more importantly, to accommodate a lateral-restraint center hole which must be drilled past the centerline. A thinner mirror would result in greater surface deformation and slope error, higher stress, and greater risk of failure. The current mirror design weighs 54.5 kg.

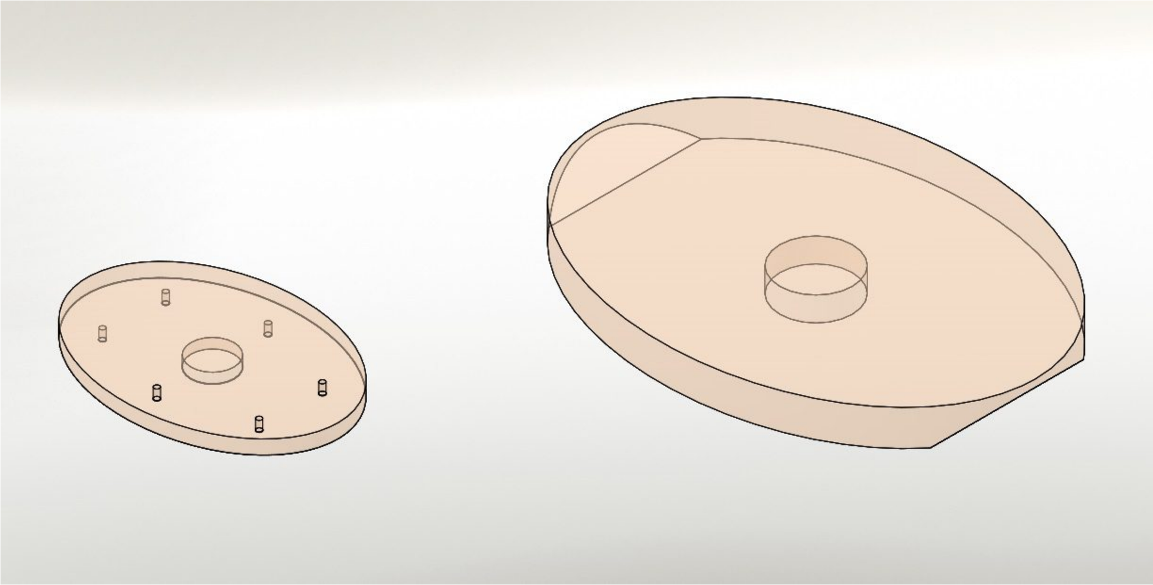

Figure 2. This schematic compares the dimensions of the planned mirror for K1DM3 (left) with the current tertiary mirror on the Keck 1 telescope. The former provides a 5 arcminute FOV with an ellipsoid having major axis 2a=881 mm and minor axis 2b=623 mm. The current tertiary system provides a 20 arcminute FOV using a mirror nearly twice the size along each axis.

4.3 Surface and Coating

As noted in our description of the requirements, the requirements on surface error are 57 nm of RMS error and a slope of 1.68e-6 radians (RMS). We further specify a roughness of less than 2 nm. It is believed that these can be achieved with standard polishing by the mirror manufacturer.

Given the requirement of high reflectivity from the atmospheric cut-off through the visible (HIRES), and into the near IR (AO), bare aluminum is the only viable choice for the mirror coating.

4.4 Mirror Support

The mirror will be supported by a wiffle tree system, similar in spirit to the support system for the current tertiary. The current design consists of 6 axial rods – two along the minor axis and an additional support in each quadrant of the

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ellipse -- that support the mirror normal to its midplane (or surface). A finite element analysis (FEA) of this configuration which assumed attaching the axial supports to the insides of holes on the back of the mirror is shown in Figure 3. Following our recent midterm review, we have been developing a new design which attaches the axial supports to pads glued to the back of the mirror, thereby avoiding the drilling of 6 axial support holes. Our FEA indicates that the performance of this support configuration has similar deflections as the previous and we are very likely to proceed without drilling axial support holes.

The mirror is supported in the lateral direction by a strut glued to a central, 150 mm diameter hole drilled 36 mm into the glass. This provides excellent performance in regards to RMS and slope deflections. We are also studying whether we achieve comparable performance by attaching to pads glued to the back of the mirror.

We examined deflections of the mirror due to changes in temperature and the mis-match in CTE between the mirror support system and the glass. We find that the worst case of these influences result in surface deformations in the order of 0.5 nm RMS and 2 nm peak-to-valley.

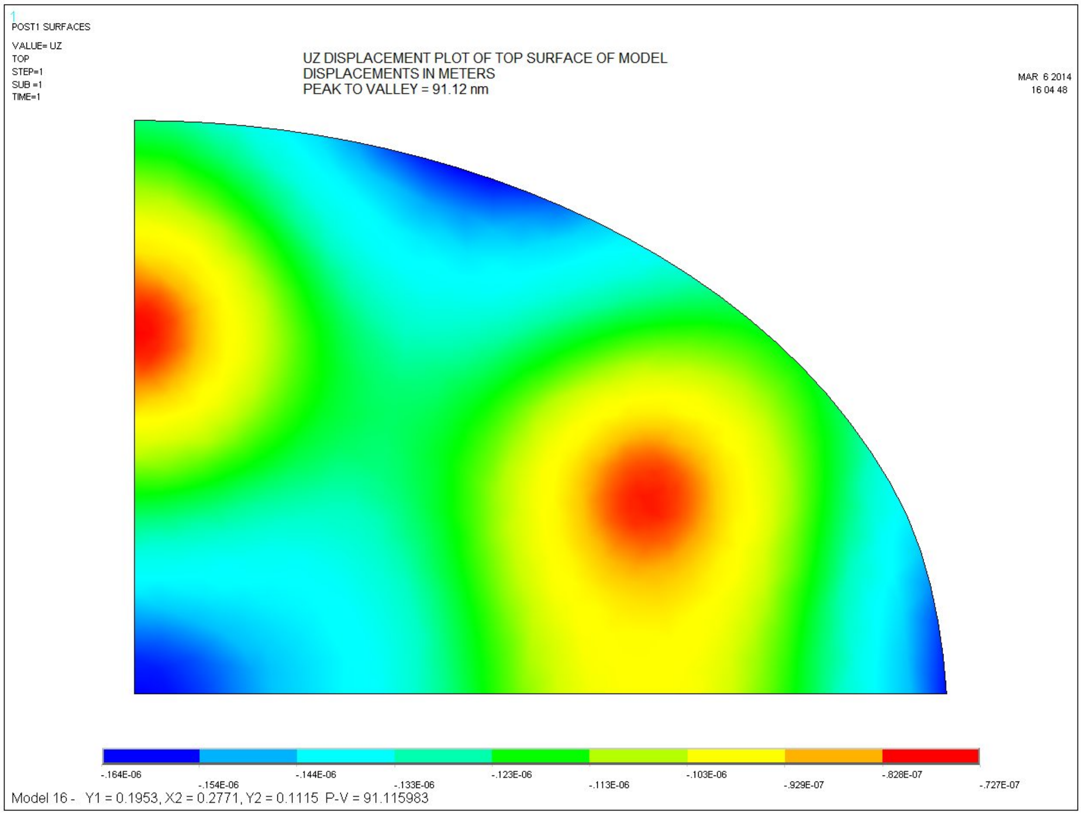

Figure 3. This color contour map shows the deflections of the FEA for full gravity load perpendicular to the surface with a 6 point axial support. The support locations are at the center of the two red regions. At these locations the vertical deflections were constrained to be zero. The peak to valley deflection is approximately 91 nm.

4.5 Wiffle Tree

The axial and lateral support system will be integrated into a wiffle tree that is attached to the deployment/retraction mechanism of K1DM3. At present, we have only developed a conceptual design based on the existing wiffle tree of M3 on the Keck 1 telescope. We present this concept in Figure 4 but note that it is subject to significant modifications during PD.

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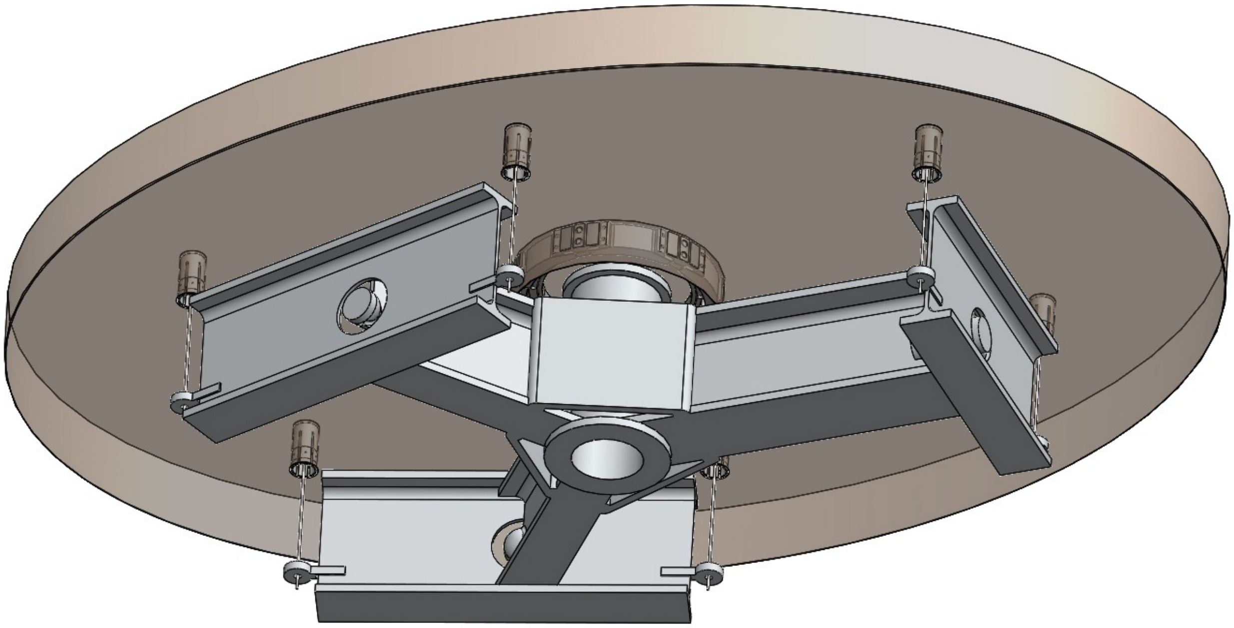

Figure 4. Conceptual design of the wiffle tree support for K1DM3. The figure shows the 6 axial supports and lateral support. These are contained within a wiffle tree using three struts.

5. DEPLOYMENT/RETRACTION SYSTEM

5.1 Deployed

The K1DM3 mirror and its supports will be deployed into position with a ball-screw linear actuator which has a maximum stroke length of approximately 610 mm and a maximum dynamic load of 6800 N. Figure 5 shows a diagram of the mirror when deployed; the linear actuator is located at the base of the support system.

The mirror and wiffle tree support are attached to a “swing arm” comprised of a steel that has a coefficient of thermal expansion matched to both the tertiary tower structure and rotation bearings. There are three spherical/v-groove interfaces that make up the kinematic coupling. These interfaces reside at the periphery of the swing arm, out of the Cassegrain instruments’ FOVs when retracted. The kinematic coupling is used to position the K1DM3 mirror accurately with a high degree of repeatability. The v-grooves are supported by three bipod struts which are attached to the drum that rotates K1DM3. The kinematic-coupling manufacturer’s specifications report better than 1 micron repeatability in lab conditions. The plane of the bidpod struts lean outward to maintain a perpendicular orientation to the v-groove axes. This orientation reduces bending stress in the bipod while staying out of the FOV.

We have performed a FEA of the deformation of the swing arm under gravity for a range of orientations. Our current design of the swing arm uses a 3x6 inch, one-quarter inch wall tube that is light-weighted and reinforced. We estimate that this arm has a 5.5 arcsecond differential displacement when comparing the displacements at Zenith and 45 degrees elevation (considered to be near the maximum angle for science observations). This exceeds the current requirement of 2.8 arcseconds and present a significant design challenge at that we hope to overcome.

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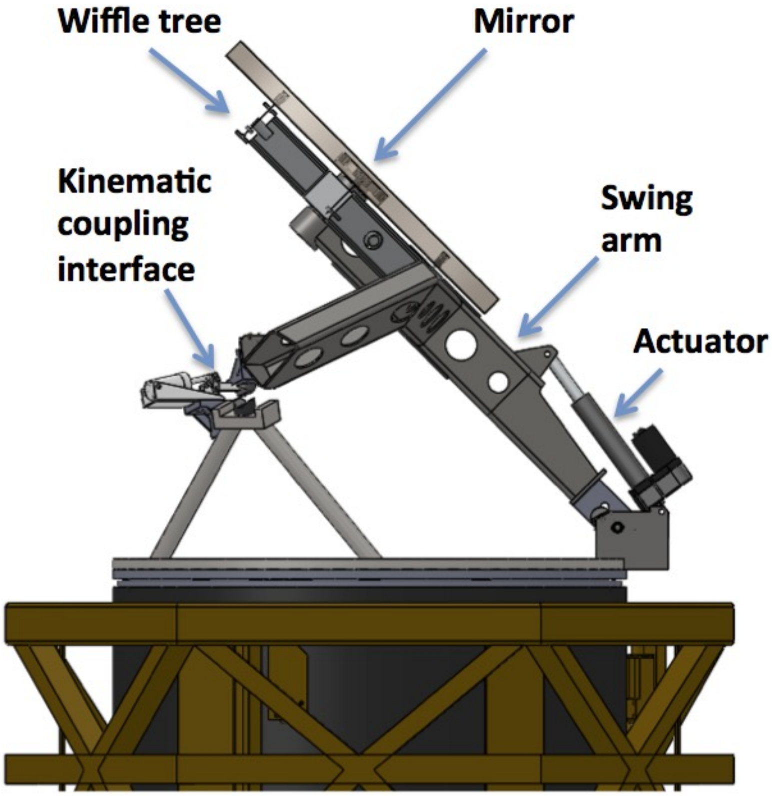

Figure 5. Side-view of K1DM3 when deployed. The system juts out above the tertiary tower of Keck 1 (brown struts at bottom) and rotates on a "drum" consisting of two bearings. This diagram shows one of three bipod struts (gray) which hold kinematic coupling for accurate and repeatable positioning. The mirror and its swing-arm support are deployed and retracted with the linear actuator shown on the lower right.

5.2 Retracted

The K1DM3 mirror and support will be retracted by the same linear actuator system. When retracted, the primary requirement is that the mirror and swing-arm avoid vignetting the fields of view of the Cassegrain instruments. This also includes the bipod struts and the drum which holds and rotates the device. With Zemax modeling, we have determined the areas that must be avoided to prevent vignetting the LRIS and MOSFIRE instruments. Figure 6 shows the footprint of the off-axis LRIS instrument – both its science and guide cameras – at an elevation of 5m above the primary. We performed a similar calculation for the MOSFIRE instrument, finding that this on-axis instrument is generally less constraining.

All aspects of our design for K1DM3 need to take into consideration these footprints – the mirror and its support system, the kinematic mounts, the bearing, the actuation system, electronics, etc. Figure 7 shows two views of K1DM3 when retracted. These demonstrate that the current design avoids vignetting the footprint of the LRIS instrument. We have verified that the footprint for MOSFIRE is also unvignetted. One notes in the top-view, however, that the mirror does extend beyond the profile of the tertiary tower and may therefore slightly vignette the primary mirror. Full analysis of this issue is underway.

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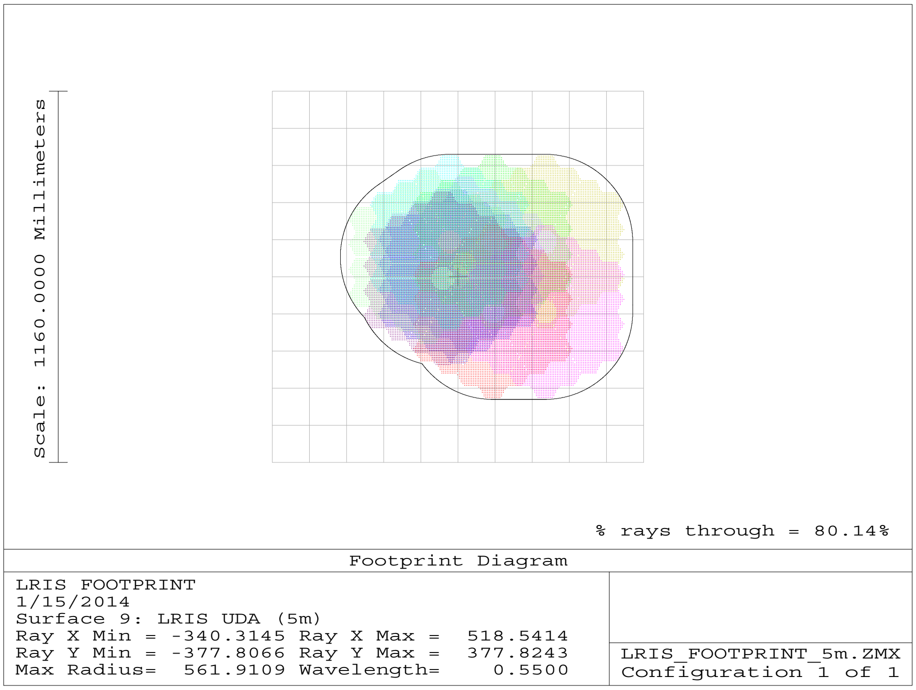

```
% rays through = 80.14%
Footprint Diagram
LRIS FOOTPRINT
1/15/2014
Surface 9: LRIS UDA (5m)
Ray X Min = -340.3145 Ray X Max =  518.5414
Ray Y Min = -377.8066 Ray Y Max =  377.8243
Max Radius=  561.9109 Wavelength=    0.5500
LRIS_FOOTPRINT_5m.ZMX
Configuration 1 of 1
```

Figure 6. Zemax calculation of the footprint of the LRIS science and guide cameras at an elevation of 5 m above the primary mirror. A series of similar calculations were performed to establish the area which must be avoided by K1DM3 when retracted to avoid vignetting the LRIS instrument. A similar calculation was performed for the MOSFIRE instrument.

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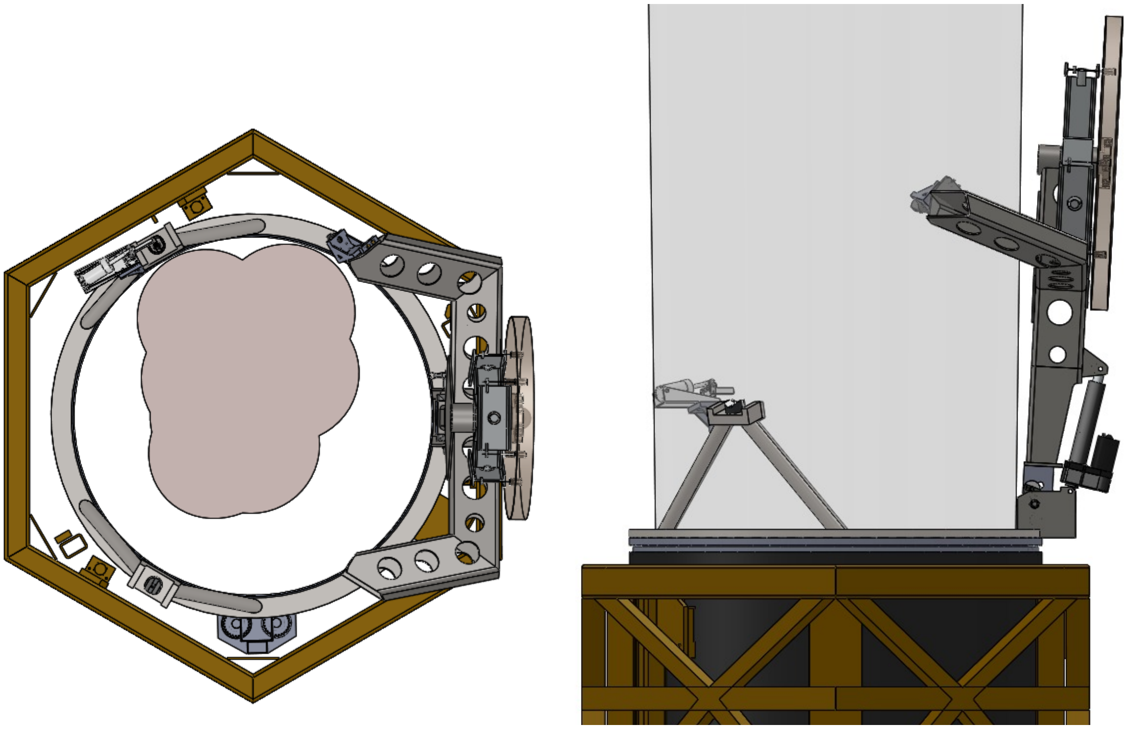

Figure 7. (left) Top-view of the K1DM3 device when retracted. The mirror and its support system barely intersect the inner diameter of the drum system which, as designed, avoid the LRIS footprint as shown. It is possible, however, that the device will slightly vignette the primary mirror or rays between M1 and M2. This is currently under research. (right) Image on the right is a side-view of K1DM3 when retracted. The grey 'beam' indicates the extremity of the FOV for LRIS, which we are required to avoid. It is evident that the current design meets this requirement.

6. MISCELLANEOUS

6.1 Electronics and Controls

The electronics for K1DM3 will need to control three main subsystems: (1) precise rotation of the device; (2) deployment/retraction of the mechanism via a linear actuator; (3) clamping of the device into the kinematic couplings. The rotation and deployment/retraction stages will employ brakes for safety in the event of power loss while movingcp and to hold position when the motors are off.

A key requirement for the control system is that we dissipate less than 5 Watts of power during observations (this may be relaxed during reconfiguration of the mechanism). Presently, we only require the rotation of K1DM3 for deployment/retraction. The system will need an Ethernet connection and we will access to 120 Vac for a 24 Vdc power supply in a box below the primary mirror.

We plan to employ a low power National Instruments RIO (2.4 Watts) to monitor rotation and control power to two Galil DMCs (DMC1, DMC2). DMC1 will be used to rotate the module with the same encoder as the RIO. It will be located on the stationary structure and powered as needed. The DMC2 will located on the rotating structure and will be powered when needed for deployment and retraction. This DMC2 will have electrical contacts at only 0 and 180 degree positions. This means that we will not have positive feedback that K1DM3 is retracted/deployed when DMC2 is off. We are performing tests of this design, i.e. verifying the tolerance for alignment to provide Ethernet and power at fixed orientations. We are also considering an alternative system that would use cable wraps and therefore offer continuous power and network connectivity.

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6.2 Alignment Plan

The project has developed a preliminary Alignment Plan whose goal it to replicate the alignment of the existing tertiary so that the instruments at the Nasmyth foci do not need re-alignment, and so that K1DM3 and the existing tertiary module may be used interchangeably if ever needed. We believe the existing tertiary is well-aligned, so that replicating its alignment will require only small adjustments to an ideal alignment of K1DM3. The plan consists of an initial alignment at UCO, followed by a final alignment at WMKO.

For the initial alignment, the primary goal is to verify that K1DM3 redirects light from the optical axis (defined as the rotational axis of K1DM3) to 45 degrees along the elevation axis. The initial alignment to define the rotation axis and align the mirror at 45 degrees will utilize a 45-90-45 degree prism with respect to the rotation axis. A high quality prism can be obtained with better than 1 arcsecond accuracy. We will also utilize a D-275 collimating telescope with a CCD camera to measure positions. The first stage will be to establish the rotational axis of K1DM3 by attaching jigs to the end of the module with K1DM3 retracted. By rotating the module, one can identity the axis of rotation. One then aligns the collimating telescope along this axis. One then deploys the mirror with the 45-degree prism attached and oriented with the surfaces orthogonal to the minor/major axes of the mirror. The kinematic mounts of the device are adjusted until the prism reflects the image straight back to the collimating telescope.

For final alignment, our current plan envisions constructing a mount that replicates the kinematic interfaces on the tertiary tower for mounting the mirror system. This mount would be placed on the floor of the Keck 1 dome. The existing tertiary system would be attached and its positioning would be precisely characterized with a collimating telescope. It would be then be replaced by K1DM3 and we would adjust the module kinematics until the mirror was positioned identically (within tolerances) to the current system. The advantages of this approach include avoiding the challenges of measuring positioning from the Nasmyth foci and the much greater ease of adjusting the module kinematics off the tertiary tower.

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REFERENCES

[1] National Research Council, [New Worlds, New Horizons in Astronomy and Astrophysics], National Academies Press, New York, NY (2010).

[2] Klebesadel, R.W., Strong, I.B., and Olson, R.A. ApJL, 182, L85 (1973).

[3] Vreeswijk, P. M., Ledoux, C., Smette, A.; Ellison, S. L., Jaunsen, A. O., Andersen, M. I., Fruchter, A. S., Fynbo, J. P. U., Hjorth, J., Kaufer, A., Møller, P., Petitjean, P., Savaglio, S., and Wijers, R. A. M. J., “Rapid-response mode VLT/UVES spectroscopy of GRB 060418. Conclusive evidence for UV pumping from the time evolution of Fe II and Ni II excited- and metastable-level populations”, A&A, 468, 83 (2007).

[4] Gillessen, S., Genzel, R., Fritz, T. K., Quataert, E., Alig, C., Burkert, A., Cuadra, J., Eisenhauer, F., Pfuhl, O., Dodds-Eden, K., Gammie, C. F., and Ott, T., “A gas cloud on its way towards the super-massive black hole in the Galactic Centre”, Nature, 481, 51 (2012).

[5] Vogt, S. S., Allen, S. L., Bigelow, B. C., Bresee, L., Brown, B., Cantrall, T., Conrad, A., Couture, M., Delaney, C., Epps, H. W., Hilyard, D., Hilyard, D. F., Horn, E., Jern, N., Kanto, D., Keane, M. J., Kibrick, R. I., Lewis, J. W., Osborne, J., Pardeilhan, G. H., Pfister, T., Ricketts, T., Robinson, L. B., Stover, R. J., Tucker, D., Ward, J., and Wei, M. Z., “HIRES: the high-resolution the high-resolution echelle spectrometer on the Keck 10-m telescope”, Proc. SPIE 2198, 362 (1994).

[6] Chin, J.C.Y., Wizinowich, P., Campbell, R., Chock, L., Cooper, A., James, E., Lyke, J., Mastromarino, J., Martin, O., Medeiros, D., Neyman C., Panteleev, S., Stalcup, T., Tucker, P., Wetherell, E., van Dam, M., “Keck I laser guide star adaptive optics system”, Proc. SPIE 8447, 4 (2012).

[7] Larkin, J., Barczys, M., Krabbe, A., Adkins, S., Aliado, T., Amico, P., Brims, G., Campbell, R., Canfield, J., Gasaway, T., Honey, A., Iserlohe, C., Johnson, C., Kress, E., LaFreniere, D., Lyke, J., Magnone, K., Magnone, N.,

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McElwain, M., Moon, J., Quirrenbach, A., Skulason, G., Song, I., Spencer, M., Weiss, J., and Wright, S., "OSIRIS: a diffraction limited integral field spectrograph for Keck", Proc. SPIE 6269, 42 (2006).

[8] Oke, J. B., Cohen, J. G., Carr, M., Cromer, J., Dingizian, A., Harris, F. H., Labrecque, S., Lucinio, R., Schaal, W., Epps, H., and Miller, J, "The Keck Low-Resolution Imaging Spectrometer", PASP, 107, 375 (1995).

[9] McLean, I. S., Steidel, C. C., Epps, H., Matthews, K., Adkins, S., Konidaris, N., Weber, B., Aliado, T., Brims, G., Canfield, J., Cromer, J., Fucik, J., Kulas, K., Mace, G., Magnone, K., Rodriguez, H., Wang, E., and Weiss, J., "Design and development of MOSFIRE: the multi-object spectrometer for infrared exploration at the Keck Observatory", Proc. SPIE 7735, 47 (2010).

[10] Prochaska, J.X., Christoph, P., Cabak, G., Cowley, D.J., Nelson, J., "Keck 1 deployable tertiary mirror (K1DM3)", Proc. SPIE 8444, 4 (2012).

[11] Strubbe,, L.E., Quataert, E., "Optical flares from the tidal disruption of stars by massive black holes," Monthly Notices of the Royal Astronomical Society, Volume 400, Issue 4, pp. 2070-2084 (2009).

[12] Rees, M.J., "Tidal disruption of stars by black holes of 10 to the 6th-10 to the 8th solar masses in nearby galaxies," Nature (ISSN 0028-0836), vol. 333, June 9, 1988, p. 523-528.

[13] Ghez, A. M., Salim, S., Weinberg, N. N., Lu, J. R., Do, T., Dunn, J. K., Matthews, K., Morris, M. R., Yelda, S., Becklin, E. E., Kremenek, T., Milosavljevic, M., and Naiman, J., "Measuring Distance and Properties of the Milky Way's Central Supermassive Black Hole with Stellar Orbits", Astrophysical Journal, 689, 1044–1062 (2008).

[14] Simon, J. D., Gal-Yam, A., Gnat, O., Quimby, R. M., Ganeshalingam, M., Silverman, J. M., Blondin, S., Li, W., Filippenko, A. V., Wheeler, J. C., Kirshner, R. P., Patat, F., Nugent, P., Foley, R. J., Vogt, S. S., Butler, R. P., Peek, K. M. G., Rosolowsky, E., Herczeg, G. J., Sauer, D. N., and Mazzali, P. A. (2009). Variable Sodium Absorption in a Low-extinction Type Ia Supernova. Astrophysical Journal, 702:1157–1170.

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