Design of a Novel Laser Metrology Scheme for the Palomar Adaptive Optics System

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Abstract. We describe the design of a novel scheme for monitoring the effects of flexure in the adaptive optics system for the Palomar 200" telescope, now nearing completion at JPL. Uncorrected flexure can cause substantial blurring of the time-integrated point-spread function, or loss of throughput when a small slit is used in spectroscopic mode. These effects are particularly serious in the non-common paths downstream from the dichroic, where the science and wavefront-sensing beams have separated: flexure-induced tips and tilts of these optical elements will not be corrected by the normal closed-loop operation of the adaptive optics system's fast-steering (tip/tilt) mirror. Our proposed metrology scheme uses a single visible laser to probe both of the non-common paths and monitor the difference between them. Signals derived from our metrology scheme are incorporated quite easily in the wavefront sensor as small amendments to the centroid offsets stored for each subaperture in the Shack-Hartmann lenslet array.

1. Introduction: Adaptive Optics

With recent technological advances, it has become feasible to implement real-time corrections in hardware that compensate for wavefront distortions induced by the turbulent atmosphere, as first proposed by Babcock (1953). A number of groups are working to build such adaptive optics systems for large astronomical telescopes, and some have already made astrophysical observations of real value. The promise of this approach is very great, particularly when combined with the new generation of large ground-based apertures.

At Palomar, an adaptive optics system for the 200" telescope is now being built at the Jet Propulsion Lab (Dekany 1996; Dekany *et al.* 1998). The system is expected to be commissioned early in 1999; it will substantially enhance the performance of a telescope that remains one of the world's largest. The essential nature of the performance improvement is a dramatic reduction in the scale of the point-spread function, which unfortunately implies that mechanical flexures in the optical train have a proportionately larger effect. The measurement and compensation of these flexures form the subject of this paper.

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2. The AO Design for the Palomar 200" Telescope

In most respects the general design of the Palomar adaptive optics system is fairly standard. The deformable mirror has 349 electrostrictive PMN actuators, and 241 of these map onto the telescope pupil. Each actuator has a mechanical travel of $\sim$5 μm, giving twice that amount of total amplitude in wavefront correction capability. Wavefront sensing is done at visible wavelengths to derive corrections that are applied to a near-infrared science beam; the two beams are separated at a dichroic that in our system is infrared-transmitting. The wavefront sensor is of the Shack-Hartmann type, with a 16×16 lenslet array mapped onto the diameter of the telescope primary.

To facilitate guide star acquisition, the dichroic is motorized to allow slow rotations about both axes, and works in tandem with a second motorized "steering mirror" (SSM2) to direct guide star light from any of a reasonably broad range of field positions into the wavefront sensor camera at the correct angle of incidence. The guide star image is first directed, though, onto the central 4"-square reflecting silvered patch of the "field stop", an otherwise transparent substrate permitting the field around the guide star to be imaged by an "acquisition" camera positioned behind the transparent substrate.

Some additional components are located between the field stop and the WFS camera (an atmospheric dispersion compensator, the lenslet array, and some associated optics), but these are mounted on the same optical breadboard as the camera, making a mechanically rigid sub-assembly.

3. Flexure in the "Non-Common" Paths

Flexure in optical elements upstream of the dichroic will affect the beam reaching the wavefront sensor in the same way as it will the beam reaching the science camera, and so the errors induced (largely image motion) will be tracked and corrected automatically while the adaptive optics loop is closed. However, flexure is more problematic in the dichroic or the optical elements further downstream, where the infrared science beam and the visible sense beam are separate. Changing flexure in the science "non-common path" during a long integration will degrade the effective point-spread function in an imaging mode, or move the infrared beam right off the spectrograph entrance slit in a spectroscopic mode, but will go undetected by the wavefront sensor. Conversely, beam deflection due to changing flexure in the visible sense beam will cause invalid corrections to be made by the fast-steering mirror, with the same deleterious effects.

One might tabulate non-common path flexure as a function of telescope pointing, as is commonly done to map flexure of instruments mounted at the Cassegrain focus. Then, to the extent that the tabulated values do not change with temperature or over time (indeed, over a fairly long time, to avoid the bother and lost telescope time of constant remeasurement), they could be applied as a calibration to later observations. This approach is somewhat laborious, and would require calibration at about 50 positions to cover the sky to 60° away from zenith with a $\sim$15° grid spacing. A more elegant real-time technique is presented in the next section.

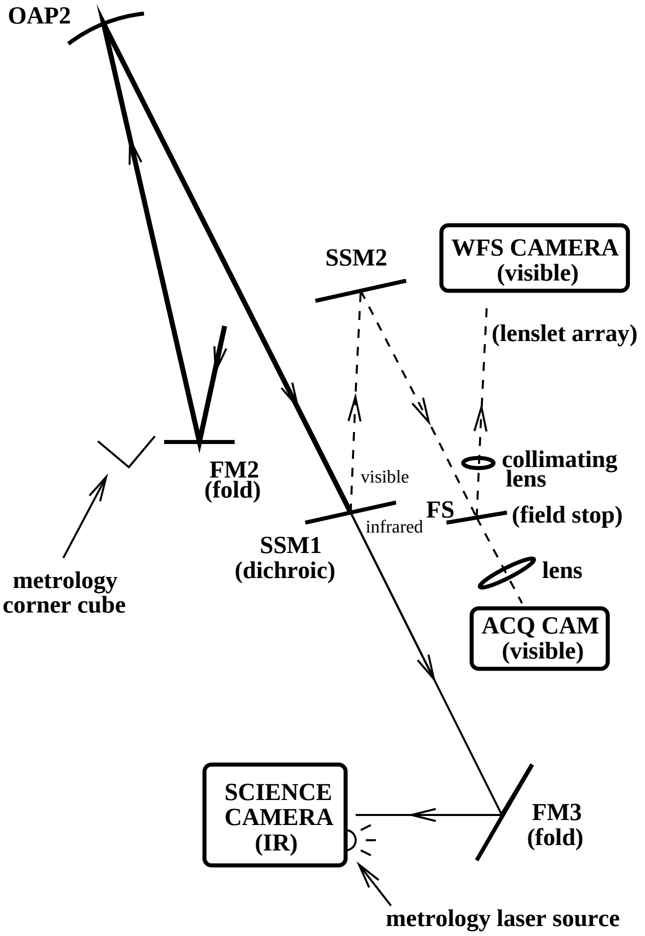

Figure 1. Position of the laser metrology components (corner cube and laser source) with respect to the standard AO components. The lighter solid line and the dashed line indicate the "non-common paths," downstream of the dichroic, of the science and wavefront-sense beams.

4. Laser Metrology for the Palomar 200" AO System

Our scheme for measuring the effects of flexure in the non-common paths is presented in Figure 1, which is drawn roughly to scale. Preceding the fold mirror FM2, but not shown, are the deformable mirror, the fast-steering mirror that applies fast tip-tilt correction, and the off-axis paraboloid, OAP1, that collimates the f/15.7 telescope beam for these active mirrors. The paraboloid OAP2 converts the collimated beam into an f/15.7 converging beam that focuses on the science camera and the field stop (for the infrared and visible paths).

The key metrology elements are a quasi-isotropic laser source mounted rigidly in the focal plane of the science camera, at a fixed position with respect to the science slit or imaging field center, and a corner cube near FM2, where the off-axis paraboloid OAP2 has collimated the laser metrology beam. These metrology components are shown schematically and are not to scale.

It is fairly easy to see that, if there were no dichroic, the metrology beam would be retroreflected to focus again on its source, regardless of flexure anywhere in the system. The dichroic will actually transmit only about 5% of the (visible) laser light to the corner cube, and on the return will send most of that to the acquisition camera. There, as can be seen with some thought, the metrology spot provides a reference conjugate to the laser source, and hence, up to a fixed offset, to the field center of the science camera itself, that now correctly incorporates the effects of flexure in both non-common paths. The metrology spot may effectively be used by the wavefront-sensor subsystem, which is built to be rigidly fixed with respect to the nearby acquisition camera; this reference spot is to be taken as a fiducial for the position of the visible wavefront-sensing beam (the image of the guide star). That is, to track and correct for flexure, the AO system should now steer the guide star to remain fixed with respect to the metrology laser spot, rather than fixed on the detector of the WFS camera.

It is quite straightforward to implement simple additive supplements to the wavefront-sensor sub-aperture centroid offsets that incorporate this flexure-compensation information. The laser metrology scheme then corrects for tips, tilts, and translations of FM3, SSM1, and SSM2, which should be the dominant non-common path flexures...larger, eg., than flexures of elements mounted on the wavefront sensor optical breadboard (between the FS and the WFS camera), or of the laser-emitting optical fiber with respect to the slit or image center in the science camera focal plane. Also corrected are motions transverse to their respective beams of the science camera or wavefront sensor optical breadboard as a whole with respect to the rest of the adaptive optics system.

In practice, the metrology beam will probably be imaged in a separate, dedicated camera located in the vicinity of the acquisition camera. The metrology spot crosses the plane of the field stop (FS), a 1:1 conjugate of the science camera focal plane, at a substantial distance (~ 1.75 inches) from the AO beam field center, and should thus clear the lens system preceding the acquisition camera. The spot is launched by a 50-μm-diameter fiber, spot motions are expected to be 2 or 3 μm for typical flexures in some of the large optical mounts in the non-common path, and the metrology camera has pixels measuring 11×13 μm; hence it appears desirable to magnify the metrology beam by a factor of about five. We are currently finalizing the optical design, but it appears best to achieve this magnification with a negatively-powered lens positioned slightly upstream of the field stop, and a metrology camera to one side of the acquisition camera.

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References

Babcock, H. W. 1953, PASP, 65, 229

Dekany, R. G. 1996, in Adaptive Optics, OSA Technical Digest Series, 13, 40

Dekany, R. G., Brack, G., Palmer, D., Wallace, J. K., & Oppenheimer, B. R. 1998, in Astronomical Telescopes and Instrumentation, PSPIE, 3353, in press