Astro 500 Problem Set #3

Use definitions and numbers given in the class notes or provided here.

1. Compare the prime-focus aberrations for a spherical and parabolic mirror for a modern, fast, wide-field telescope, considering these formulae for aberrations (β in radians) as a function of wavelength (λ), beam speed (*f*-ratio), and off-axis angle (θ):

$$\beta_{\text{diffraction}} = 1.22\,\lambda / D$$
$$\beta_{\text{spherical}} = [\,128\,(f/D)^3\,]^{-1}$$
$$\beta_{\text{coma}}\ \text{(parabola)} = 3\,\theta / [\,16\,(f/D)^2\,]$$
$$\beta_{\text{astigmatism}}\ \text{(parabola)} = \theta^2 / [\,2\,(f/D)\,]$$

(a) At what off-axis angle, θ, does the astigmatism or coma of a parabolic mirror become as large as the spherical aberration of spherical mirror? Express the angle(s), in units of degrees, as a function of *f*-ratio. Which aberration (astigmatism or coma) more quickly matches the amplitude of spherical aberration with field angle?

(b) Based on this calculation, if you were considering building a telescope with a 4 degree of view (θ = 2 deg), assuming you knew you needed a prime-focus corrector but wanted to minimize the corrections, would you choose a spherical or parabolic primary? What *f*-ratio would make the dominant aberrations of a spherical and parabolic mirror equal at the edge of the field?

2. SALT's primary has a spherical figure with radius of curvature R = 26.165m.

(a) Calculate the diameter of the circle of least confusion (in mm and arcsec).

(b) For a parabolic mirror of the same entrance aperture and focal length as SALT's primary, compare the above to the coma and astigmatism at 8 arcmin from the field center.

(c) At what wavelength does diffraction from each 1m SALT mirror segment become equal to the circle of least confusion of the entire primary?

Surface	*c*	Space (mm)	Glass	a_2	a_4	a_6	a_8	*k*	Clear Diam.
1......................	−8.889E−5	0.0	−Air			3.81E−22	−1.52E−29	−1.285	2500
2......................	−1.390E−4	−3644.46	Air			1.79E−19		−11.97	1080
3......................		3619.91	FQ	2.321E−5	−1.173E−10	−7.87E−17	1.59E−22		722
4......................		12.0	Air						721
5......................	−4.307E−4	672.64	FQ						657
6......................		10.00	Air	−7.747E−5	−4.123E−10	−6.53E−15	5.23E−20		656
7......................		86.61	Air						653

NOTES.—The second column is curvature, and the second to last column is the conic constant. See text for details.

3. Conics are categorized by constants k such that: $k = 0$ (sphere,) $k = -1$ (parabola), $k < -1$ (hyperbola), $-1 < k < 0$ (oblate ellipse), $k > 0$ (prolate ellipse). The above table gives the optical prescription for a telescope. In the second to last column is the conic constant k. The first two lines give the primary and secondary mirror surface prescriptions. In the family of 2-mirror telescope designs, what would kind of telescope would this be considered?

4. Derive the equation for the back focal-distance of *any* two-mirror telescope. This is the distance between the center of the focal surface and center of the surface of the primary mirror. Indicate what equation(s) you start with, how you set up the problem, and your steps to the solution. You may find it helpful drawing, and suitably labeling, a figure.

5. The telescope described in the above table has the primary mirror at the 1^{st} surface, the secondary mirror at the 2^{nd} surface, and the final (Cassegrain) focus at the 7^{th} surface. Given this telescope has an effective *f*-ratio of 5 at the Cassegrain focus, find the following quantities:

(a) the focal length of the primary mirror;
(b) the focal scale at prime focus;
(c) the focal-length of the secondary mirror; and
(d) the location of the exit pupil with respect to the Cassegrain focus.

Pay attention to the sign of these quantities. Do they make sense?

6. Here you compare SALTICAM (SALT's prime-focus imager) to Dragonfly (Problem Set 2).

The survey speed of a telescope can be estimated by the product of the collecting area of the telescope (A), the solid angle it can see on sky (Ω), and the system efficiency (ε): $A \times \Omega \times \varepsilon$. The effective collecting area, $A \times \varepsilon$, is the collecting area (in m^2) for the equivalent system with no losses of any kind, although here we will ignore the atmosphere. Assume you are observing in a wavelength range in the *V*-band with a filter transmission of 90%.

(a) Calculate the survey speed of SALT relative to Dragonfly. For Dragonfly, see problem 1 in Homework Set 2. For SALT and SALTICAM use the numbers from problem 3 in Homework Set 2 for the telescope and corrector, but replace SALTICAM for RSS, where SALTICAM has 8 air-glass surfaces, each coated to transmit 99% of the light at 550nm, a CCD with a quantum efficiency of 85% at 550 nm.
(b) How many SALTICAM pixels would you need to bin (given as a real number) to match the Dragonfly sampling? For Dragonfly, see problem 1 in Homework Set 2. For SALTICAM, the camera optics speed up the prime focus beam from f/4.2 to f/1.9. The CCD has 15μm pixels.
(c) Using scaling arguments from your calculation of Dragonfly in the previous problem set, what is the required exposure time to remain sky-limited with SALTICAM assuming the same sky brightness and no binning of CCD pixels? SALTICAM has a read-noise of 2.5e- rms.
(d) Assuming SALTICAM is binned to yield super-pixels covering identical solid angle as for Dragonfly, and again using scaling arguments, what is the narrowest bandpass ($\Delta \lambda / \lambda$) that could be used with SALTICAM for a single, sky-limited exposure over a one hour exposure?