Astro 121, Spring 2014
Week 9 (March 27)

Topic: Adaptive optics and the atmosphere

Break: Jamie

Last week we took it for granted that seeing could be a limiting factor when observing from the ground. This week, we'll understand in more detail why seeing happens in the first place, and some techniques to correct for it.

Reading for next week on adaptive optics. Definitely read/look at things in the first four bullets, and if you need more detail on something, go to the next two.

- Bradt, *Astronomy Methods*, pp. 119–128. The basic ideas of adaptive optics, but without a lot of detail. Some good diagrams illustrating out-of-phase wavefronts. (This is not yet on reserve yet in Cornell but I'll put a copy in the lab.)

- Chromey, Sections 6.5 and 6.6 (adaptive optics and large telescopes). It would be a good idea to first review Section 5.4.2 (on seeing) which was in last week's reading.

- To see some nice examples of AO images and AO systems, look through the PDF of the notes for the first lecture in Claire Max's Adaptive Optics course at UC Santa Cruz: http://www.ucolick.org/~max/289/. Also see the links to some movies, just to the right of the lecture 1 notes link.

- Though they are unrelated to astronomy, check out the following cool AO links:

    - Using an AO wavefront sensor to measuring aberrations in the human eye: http://www.cvs.rochester.edu/williamslab/r_wavefront.html

    - An AO-corrected movie of blood flow through capillaries in the eye, showing *individual blood cells* flowing: http://www.ucolick.org/~max/289/Lectures/Lecture1/BloodFlow1.mov

- Optionally, for a more technical overview, see McLean, *Electronic Imaging in Astronomy,* Sections 2.3–2.5.

- Also optional, if you want to go deeper: *Adaptive Optics in Astronomy*, edited by F. Roddier. Read pp. 9–21 for a somewhat more detailed explanation of the various equations than McLean gives. Also see Chapter 14 for a discussion of the practicalities of actually observing with an AO system.

Important concepts and problems:

1. Briefly define the following terms in writing, and be prepared to explain them in your own words in seminar:

   a) Strehl ratio.

   b) Coherence length or Fried parameter r_0.

   c) Coherence time.

   d) Isoplanatic patch.

2. Scintillation: explain the reasoning behind Chromey's statements on p. 141 that concave wavefront distortion will make an object appear brighter, and a convex wavefront distortion will make an object appear fainter.

3. Why is AO being used primarily at near-infrared wavelengths? What is it about IR that makes AO inherently easier than doing it at optical wavelengths?

4. Draw a picture of distorted wavefronts (similar to the diagrams in Bradt) and use it to explain the idea of tip/tilt correction. What part of the wavefront distortion is taken out by a tip/tilt system?

5. The number of actuators needed for AO control of a mirror of diameter D is roughly $(D/r_0)^2$. Give a physical explanation for why this is so.

6. Derive an expression giving the approximate physical distance that AO mirror actuators must be able to travel in order to properly correct the wavefront, if the overall wavefront tip and tilt are already corrected. Evaluate your expression for $\lambda = 2.2$ μm.

7. Give an order-of-magnitude derivation of Chromey's equation for the Greenwood time delay. That is, don't worry about the leading coefficient, but give a physical explanation of the dependence on the different variables.

8. As above, give an order-of-magnitude derivation of Chromey's equation 6.10, for the size of the seeing disk.

9. Let's consider the properties of our own observing site for the Peter van de Kamp Observatory, and what implications they would have for installing an AO system.

   a. Our typical seeing is 3" FWHM at 500 nm. Assuming that all of this is due to turbulence in the atmosphere, not in the dome, what is the Fried parameter for our site?

   b. If the turbulent layer in the atmosphere blows across the telescope at an average velocity $\langle v \rangle$ = 10 m/s, what response time would be necessary for our AO system?

10. Why must AO guide stars be bright? If possible, try to roughly fill in the variables in a statement like the following: "they must be bright enough to deliver S/N of X in time Y," and explain why.

11. What are the strengths and weaknesses of using natural guide stars vs. laser guide stars? (Check out the nice picture of the Lick Observatory laser guide star setup next to my lab door.)