## THE THEODOLITE: SAFETY ISSUES AND PROPER PROCEDURES

Astronomers need to measure angles to accuracies of order an arcsecond or better. It is exceedingly difficult to measure angles to this accuracy. The Sun and Moon are half degree in diameter: this is 30 arcminutes, or 1800 arcseconds.

A *theodolite* can measure angles to arcsecond accuracy *if* it has not been damaged by improper handling and if it is used correctly. We will use theodolites to measure the elevation angle of some stars (the elevation angle is the angular distance above the horizon, where "horizon" is defined by the local direction of gravity). We will use these measurements to measure Campbell Hall, the circumference of the Earth, and the refraction of the atmosphere.

The accuracy of a theodolite comes at a great price: a theodolite costs about as much as a new car.

### 1. Proper Handling.

*1.1. Transport*: Theodolites are universally used in constructing dams and bridges, which are often built in remote, nearly inaccessible areas where they must be transported over rough terrain. However, the instruments are *delicate*. The instruction book specifies how a theodolite should be packed onto a horse or mule (sometimes denoted by the term "undergraduate") so that it will not be damaged, and also how it should be transported in a 4-wheel drive vehicle. *We will observe the same precautions.*

A direct quote: "...the best way to transport the instrument...is on one's lap (**always** in an upright position) or, at least, to wrap it up well in blankets and stand it in such a way that it cannot suffer any hard knocks or shocks." We like to think our freeways are smooth, but they are not: there are thousands of little tiny jerks per mile, and the centrifugal force on a curve can easily topple an upright instrument unless it is secured. And we won't dare comment about Berkeley streets! Thus, we have **Rule Number 1**: in a car, either carry the instrument *on your lap* or strap it into a passenger seat with a *seat belt* so that it is *absolutely secure*.

*1.2. Unpacking*: If the internal bearings are damaged the instruments will not provide accurate results. They can be damaged by dirt; by jolts; and by being stressed by too much weight. For these reasons, it is *the simple act of removing the instrument from its case and mounting it on the tripod* which is the most risky. So follow this simple procedure:

**1.** Before doing anything else, set up the tripod so that is ready to receive the theodolite. The tops of some tripods have a triangular cover, which must be removed before the tripod can receive the theodolite.

**2.** Before opening the case, place it on a flat surface such that, if you accidentally drop the instrument, it cannot fall more than a few inches. For example, the ground if it is clean, the seat or floor of a car, the hood of a car if it is big and flat.

**3.** After opening the case, rotate the case such that the brand name "WILD" faces you; see the illustration on the back of this page.

**4.** Loosen the three securing screws (the *black* knurled knobs on the bottom of the case) and pull back the slides.

**5.** Grasp the theodolite with *two hands*: the *left hand* supporting the *base* and the *right hand* on the *right-hand upright*, which is the vertical pillar just above where it says "WILD". Lift the instrument, walk over to the tripod, and secure the theodolite to the tripod with the screw in the center of the triangle.

### 2. Using the theodolite.

The theodolite rotates around two "circles". The "horizontal circle" lies in the horizontal plane,

and therefore has a vertical axis; it is also called the "azimuth circle". The "vertical circle" lies in the vertical plane, and therefore has a horizontal axis; it is also called the "altitude circle".

For each circle there are two important knobs. The "clamping knob" locks the instrument: when loose, you can point the telescope easily by hand and when clamped, you cannot. The other is a "tangent screw" which allows a fine adjustment—a vernier adjustment—after you have gotten close to the right position and tightened the clamping knob.

It is easy to recognize the *clamping knobs* because they are inclined with respect to the symmetry axes. The clamping knob for the vertical circle, number 11 on the illustration, is tilted downward from the horizontal. The clamping knob for the horizontal circle is not visible on the illustration because it is on the back; it sticks out in a cockeyed direction towards the left if you are facing it.

The tangent screws are numbers 8 and 24 for the vertical and horizontal circles, respectively.

*There are two possibilities for damage.* One is tightening a clamping knob *too strongly.* It doesn't require much force—use your thumb and a single finger and turn it just slightly more than gently. The other is trying to turn the theodolite by hand after the clamping knob has been tightened.

**3. Packing up after use.**

*First*, rotate the telescope so that it is vertical and pointing downwards. Then tighten the clamping knobs for both the horizontal and vertical circles.

*Then* follow the procedure for unpacking, but in reverse order.