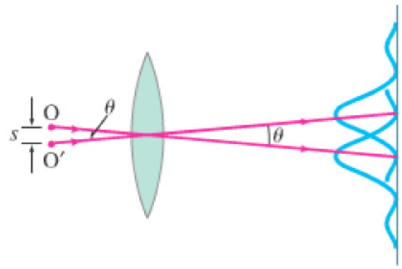

FIGURE 25–30 The *Rayleigh criterion*. Two images are just resolvable when the center of the diffraction peak of one is directly over the first minimum in the diffraction pattern of the other. The two point objects O and O′ subtend an angle θ at the lens; only one ray (it passes through the center of the lens) is drawn for each object, to indicate the center of the diffraction pattern of its image.

EXAMPLE 25–10 **Hubble Space Telescope.** The Hubble Space Telescope (HST) is a reflecting telescope that was placed in orbit above the Earth's atmosphere, so its resolution would not be limited by turbulence in the atmosphere (Fig. 25–31). Its objective diameter is 2.4 m. For visible light, say $\lambda = 550\,\text{nm}$, estimate the improvement in resolution the Hubble offers over Earth-bound telescopes, which are limited in resolution by movement of the Earth's atmosphere to about half an arc second. (Each degree is divided into 60 minutes each containing 60 seconds, so $1^\circ = 3600$ arc seconds.)

APPROACH Angular resolution for the Hubble is given (in radians) by Eq. 25–7. The resolution for Earth telescopes is given, and we first convert it to radians so we can compare.

SOLUTION Earth-bound telescopes are limited to an angular resolution of

$$\theta = \tfrac{1}{2}\left(\frac{1}{3600}\right)^{\circ}\left(\frac{2\pi\ \text{rad}}{360^\circ}\right) = 2.4 \times 10^{-6}\ \text{rad}.$$

The Hubble, on the other hand, is limited by diffraction (Eq. 25–7) which for $\lambda = 550\,\text{nm}$ is

$$\theta = \frac{1.22\lambda}{D} = \frac{1.22(550 \times 10^{-9}\ \text{m})}{2.4\ \text{m}} = 2.8 \times 10^{-7}\ \text{rad},$$

thus giving almost ten times better resolution $(2.4 \times 10^{-6}\ \text{rad}/2.8 \times 10^{-7}\ \text{rad} \approx 9\times)$.

NOTE The Hubble can also observe radiation in the near ultraviolet (wavelengths as small as 115 nm) and infrared (wavelengths as long as 1 mm), which are ranges of the spectrum blocked by the atmosphere. The sensor is a CCD, as in a camera (see Section 25–1), with a pixel count of 16 MP.

FIGURE 25–31 Hubble Space Telescope, with Earth in the background. The flat orange panels are solar cells that collect energy from the Sun.

EXAMPLE 25–11 **ESTIMATE** **Eye resolution.** You are in an airplane at an altitude of 10,000 m. If you look down at the ground, estimate the minimum separation s between objects that you could distinguish. Consider only diffraction, and assume your pupil is about 3.0 mm in diameter and $\lambda = 550\,\text{nm}$.

PHYSICS APPLIED

How well the eye can see

APPROACH We use the Rayleigh criterion, Eq. 25–7, to estimate θ. The separation s of objects equals their distance away, $L = 10^4\,\text{m}$, times θ (in radians) as θ is small, so $s = L\theta$.

SOLUTION In Eq. 25–7, we set $D = 3.0\,\text{mm}$ for the opening of the eye:

$$s = L\theta = L\frac{1.22\lambda}{D}$$

$$= \frac{(10^4\ \text{m})(1.22)(550 \times 10^{-9}\ \text{m})}{3.0 \times 10^{-3}\ \text{m}} = 2.2\ \text{m}.$$

EXERCISE D Someone claims a spy satellite camera can see 3-cm-high newspaper headlines from an altitude of 100 km. If diffraction were the only limitation ($\lambda = 550\,\text{nm}$), use Eq. 25–7 to determine what diameter lens the camera would have.