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Can an Astronaut on Mars distinguish Earth from its Moon?

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Math Required: Simple math and algebra.

Background: Some day an astronaut will stand on Mars and look back at Earth. As Alfred, Lord Tennyson wrote

Venus, Hesper,
Were we native to that splendour or in Mars
We would see the globe we groan in,
  fairest of their evening stars
Could we dream of wars and carnage,
  craft and madness lust and spite
Roaring London, raving Paris,
  in that peaceful point of light?
Would we not, when gazing heavenward,
  at a star so silver-fair
Yearn, and clasp the hands, and murmur:
  Would to God that we were there?

But what exactly will one see from Mars? An observer on Earth needs a powerful telescope to see the tiny moons of Mars, Phobos and Deimos, but our own moon is much larger, and orbits at a greater distance. Could the unaided eye of an observer on Mars tell apart the Earth and its moon, at their greatest separation?

One might ask a similar question about the four big moons of Jupiter, discovered by Galileo. They are about as big as our own moon. Could an observer on Earth distinguish any of them from their planet?

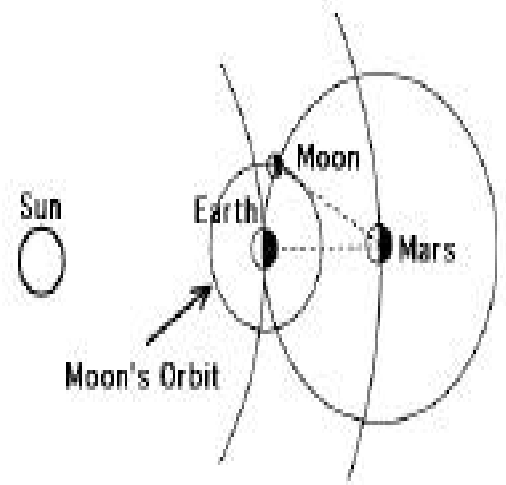
The visible disks of the sun or moon have a width of about 30' (30 minutes of arc; 60 minutes of arc equal one degree, or $60' = 1^0$). A person with sharp eyesight can tell apart ("resolve") objects at a distance of 1-2 minutes of arc: that was the accuracy of the best measurements before telescopes were introduced, made by Tycho Brahe around 1595 (See http://www-spof.gsfc.nasa.gov/stargaze/Skeplaws.htm).

Needed Information: The average distance of Mars from the Sun is 1.52 astronomical units (AU), where 1 AU, about 150,000,000 kilometers, is the mean Earth-Sun distance. Actually, since the orbit of Mars is elliptical, it comes within 1.4 AU of the Sun, but we will ignore that and assume circular orbits, making the closest distance equal to 0.52 AU. The average distance of our moon from Earth is 385,000 kilometers, about 30 Earth diameters.

Jupiter's average distance from the Sun is 5.2 AU and the distances of its moons, in millions of kilometers, are:

Io	0.4214
Europa	0.67
Ganymede	1.07
Callisto	1.88

Solution: Suppose Earth and Moon are seen from Mars when Earth and Mars are at their closest distance, 0.52 AU. Draw a circle around Mars with a radius representing 0.52 AU (Figure 1); you might represent Mars by M, the Earth by E and the Moon by L (Luna).



The Moon will be **somewhere** on a smaller circle around the Earth, representing its orbit. That orbit will intersect the bigger circle at **two points**, and when the Moon is at one of them, an observer on Mars will see it at its greatest separation from Earth.

Do you remember the formula for the circumference of a circle?
The formula for the full length C of a circle of radius R (its "circumference") is

$$C = 2\pi R$$

where the Greek letter π ("pi", the Greek equivalent to our "p") is a number close to 3.14159... It is a fundamental number in mathematics--you cannot write down its value exactly, the decimal figures go on and one without a pattern. For many calculations, the simple approximation 22/7 is good enough; a closer one is 355/113.

What would be the circumference of the big circle?

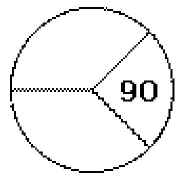
$2 \times 3.1416 \times 0.52 \times 150{,}000{,}000 = 490{,}100{,}000$ km.

How do you calculate the lenth of part of the circle--of a "circular arc" between the end of two radii?

If we draw from the center of a circle a number of radii (the plural of "radius"), they will divide it into curved sections ("circular arcs"), each proportional in length to the angle between the radii reaching its ends (drawing below). The sum of all angles around the center is 360^0 and the length of the entire circle is $2\pi R$, so the length of an arc corresponding to an angle x is

$$\text{arc} = 2\pi R\ (x / 360)$$

For instance, in the drawing below, the arc cut off by the 90^0 angle has a length $2\pi R\ (90 / 360) = 2\pi R\ (1/4)$ or one quarter of the length of the circle. (The other two arcs, resting on angles of 135^0, each equal to 3/8 of the circle.)



How many kilometers would be the length of ***one minute of arc*** *on the circle around Mars?*

That circle contains 360 × 60 = 21 600 minutes of arc. The length of a circular arc corresponding to **one minute of arc** is therefore

$$(490{,}100{,}000) / 21{,}600 = 22690 \text{ km}$$

How many minutes of arc are contained in the mean distance between the Earth and the Moon, which is 385,000 km?

385,000 / 22,690 = 16.96 or about 17.

True, the Earth-Moon distance is measured along a straight line, and here we are comparing it to a small circular arc which is curved. However, this is such a small part of the circle (less than 1/1000, same as 25 miles compared to the circumference of the Earth) that the difference in length between it and a straight line is slight enough to be ignored.

The Earth-Moon distance then covers about 17' (17 minutes of arc), and thus the Moon should be easily visible from Mars; this distance is about the same as the visible radius of the Moon, seen from Earth. Of course, in actuality, when the Earth and Moon are closest to Mars, the astronaut must look in the direction of the Sun, and both the Earth and its satellite would be invisible against the Sun's glare. If the Earth were viewed at quadrature, where exactly half of the Earth and half of the Moon are illuminated as seen from Mars, then both the Earth and Moon would be out of the Sun's glare. In this case, the Earth-Moon distance would only cover about 7.7 minutes of arc – still large enough for the eye to resolve

With Jupiter we need a circle centered on Earth and passing through that planet and one of its moons. Its radius is now not 0.52 AU but 4.2 AU.

What is the circumference?

2 × 3.1416 × 4.2 × 150,000,000 = 3,958,000,000 km.

What is the length of one minute of arc on that circle?

3,958,000,000 / 21,600 = 183,000 km

The separations between Jupiter and its moons are therefore 2.3, 3.7, 5.85 and 10.3 minutes of arc. That would suggest the eye might be able to distinguish at least the outer one or two, but you are not likely to succeed in doing so. The glare of Jupiter is too bright! In fact, as seen from Earth it is the brightest planet after Venus. It has about 10 times the diameter of Earth.

Besides that, the moons of Jupiter are rather dim. They are about as big as our moon, but compared to the Earth's moon viewed from Mars, they are 8 times more distant (4.2 AU compared to 0.52 AU). If they were equally brightly lit, they would be 64 times dimmer. But they are not: being about 5 times more distant from the Sun than our Moon, the sunlight they receive is 25 times weaker. So you are looking for objects about 1600 times dimmer!

Additional Tidbits:

-- The fact the Earth and Moon can be distinguished from Mars was part of a science fiction story by Isaac Asimov.

-- In April 2001, the Odyssey spacecraft was launched on an unmanned mission to continue the mapping of Mars. It's expected to arrive in late October of 2001. A recent image from Odyssey, looking back at the Earth and moon from about 5 million km, presents an interesting contrast in distance and size between the Earth and its lone satellite (see http://themis.asu.edu/latest.html).