AST 301
Introduction to Astronomy

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Topics for this week

- Area and volume
- Finding extrasolar planets
  - Imaging
  - Astrometric technique
  - Doppler technique
  - Transit technique
- What is found
  - Masses
  - Orbits
  - Densities and compositions
- Formation of extrasolar planets

Correction to homework

multiply that number by 4200 to convert it to Joules.
e) Your answer to part d should come out to less than the energy you radiate in a day. Where might the rest of the energy you radiate come from? Hint: the answer is similar to the explanation of why the greenhouse effect makes the surface of the Earth warm enough that it radiates more infrared radiation than the amount of visible sunlight it absorbs.

Groups of four

Get together in groups of four.

Pick a discussion leader and a scribe.

Put your names on a sheet of paper.

As a group, come up with a definition of the word area.

If you have a definition for area, next try for a definition of volume.

Area of a triangle

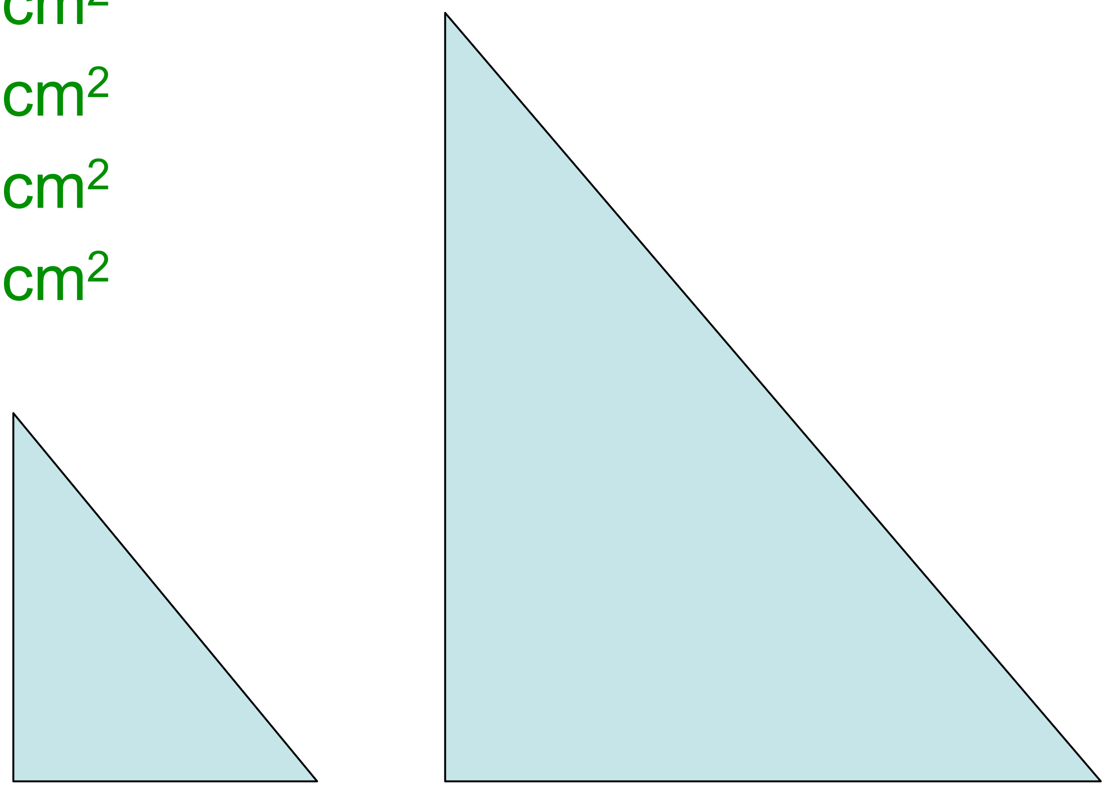
The triangle on the left has sides of length 3 cm, 4 cm, and 5 cm. Its area is 6 cm^2. The triangle on the right has sides of length 6 cm, 8 cm, and 10 cm. What is its area?

A. 12 cm^2

B. 24 cm^2

C. 48 cm^2

D. 60 cm^2



Equilateral triangle

An equilateral triangle with sides of length 3.72 cm has an area of 6 cm^2. What is the area of an equilateral triangle with sides of length 7.44 cm?

A. 9.72 cm^2

B. 12.00 cm^2

C. 14.88 cm^2

D. 24.00 cm^2

Surface area of a solid object

What is the surface area of a cube with a width of 2 cm?

A. 4 cm^2

B. 12 cm^2

C. 16 cm^2

D. 24 cm^2

Surface area of a cube

What is the surface area of a cube with a width of 2 cm?

A. 4 cm^2

B. 12 cm^2

C. 16 cm^2

D. 24 cm^2

A cube has 6 square faces, so its surface area is 6 times the area of each face. The area of a square is w^2.

$6 \times 2^2 = 6 \times 4 = 24$

It turns out that the surface area of a sphere is 4 times the area of a circle with the same radius or diameter.

Surface area of a sphere

A sphere with a diameter of 1 cm has a surface area of 3.14 cm^2. What is the surface area of a sphere with a diameter of 100 cm?

A. 31.4 cm^2

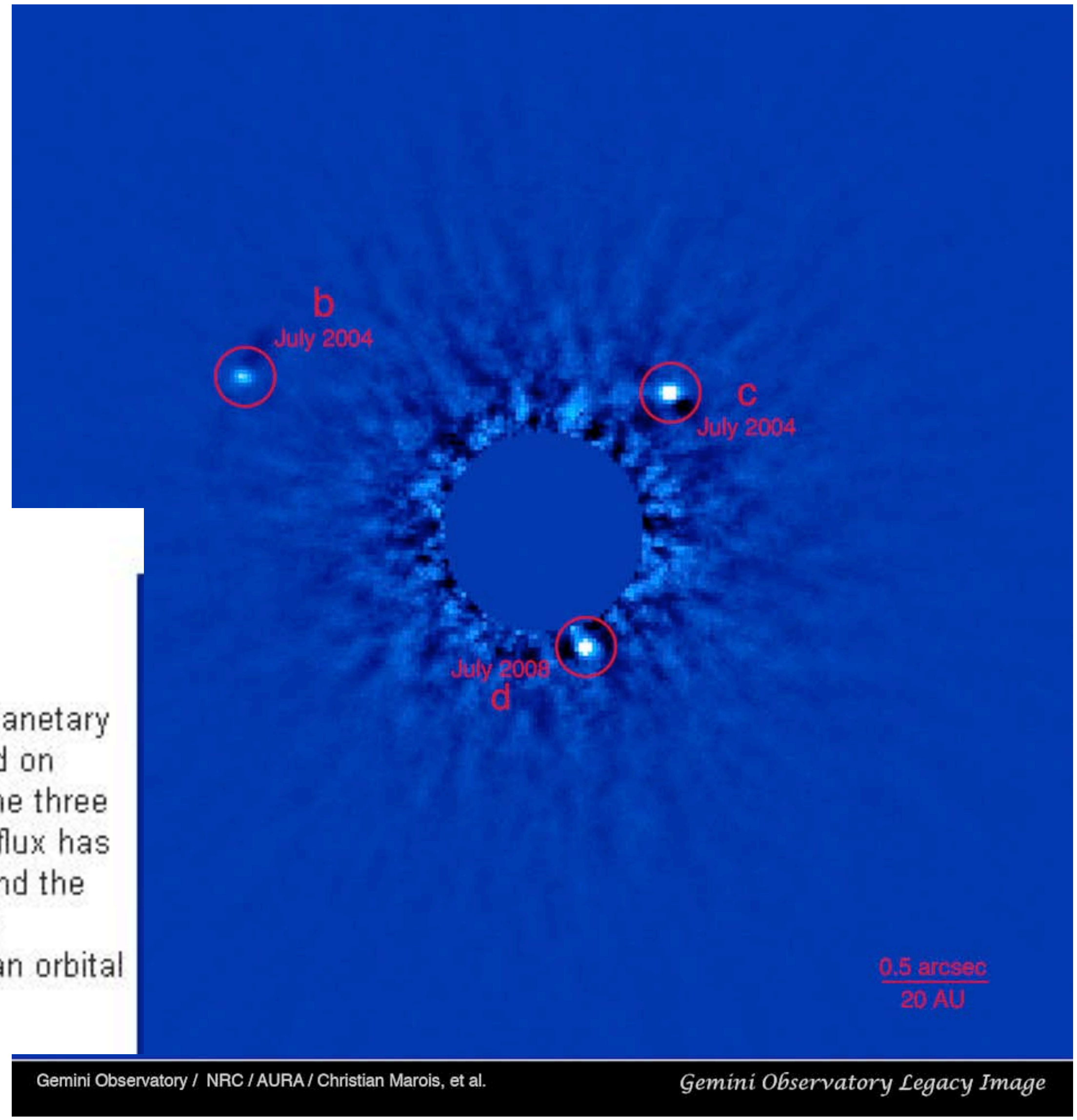
B. 314 cm^2

C. 3140 cm^2

D. 31400 cm^2

Extrasolar planets

Two years ago a picture was taken of three planets orbiting around a star.



Planetary "First Family"

Date: 05/11/2010
Credit: Gemini Observatory

A K-band (2.2microns) AO image of the HR 8799 planetary system made using Gemini/Altair/NIRI and acquired on September 5, 2008 (North is up and East is left). The three planets are designated with red circles. The stellar flux has been subtracted using ADI (**see text for details**) and the central saturated region is masked out. Multiepoch observations have shown counterclockwise Keplerian orbital motion for all three planets.

Why did it take so long?

The nearest star to the Sun is 280,000 AU away.

If we scale the Sun to the size of a basketball, 1 AU would be 100 feet, and Jupiter would be a golf ball 500 feet from the basketball.

On this scale, the nearest star would be 280,000 x 100 feet = 5000 miles away.

We'd need a good camera to separate Jupiter from the Sun in out picture, but astronomers have good cameras.

The real problem is that Jupiter is much fainter than the Sun.

Can we figure out how much fainter?

Where does the light we see from Jupiter originate?

How bright is Jupiter?

If all of the sunlight that hits Jupiter bounces off of it, we can figure out how bright it is compared to the Sun by asking what fraction of the Sun's light hits Jupiter.

When sunlight gets to Jupiter, it has spread out over the surface of an imaginary sphere 5 AU in radius.

Jupiter's radius is 1/2000 AU, or 1/10,000 of 5 AU.

How does Jupiter's area compare to the area of a sphere with 10,000 times larger radius?

How bright is Jupiter?

How does Jupiter's area compare to the area of a sphere with 10,000 times larger radius?

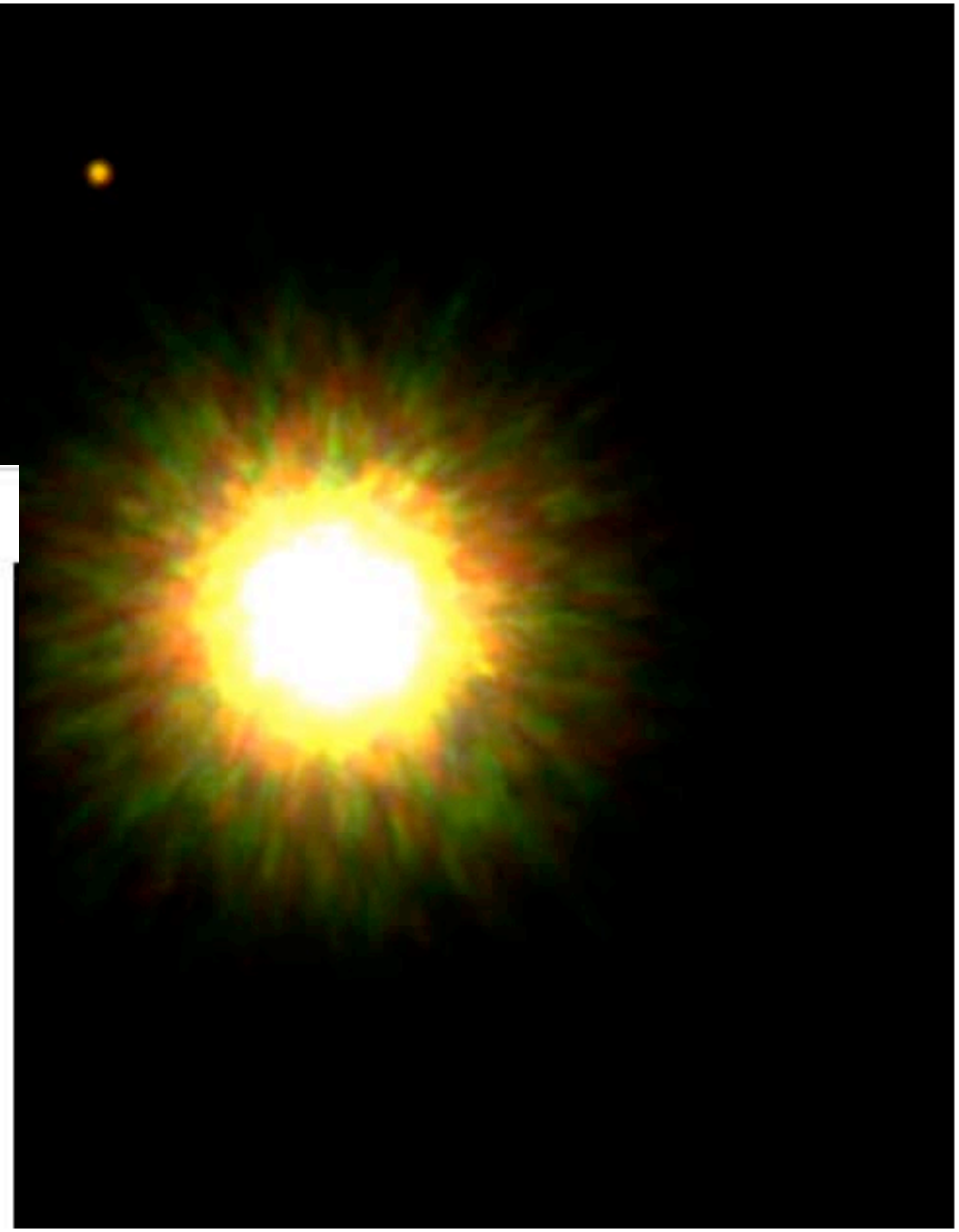
It is 10,000 x 10,000 = 100,000,000 times smaller.

And since only the face of Jupiter that the sunlight hits counts, only 1/400,000,000 of the Sun's light hits Jupiter.

So even if all of this light bounces off of Jupiter, it would appear 400,000,000 times fainter than the Sun.

Why wasn't there a star 400,000,000 times brighter than the planets in the picture I showed?

A possible planet and its star



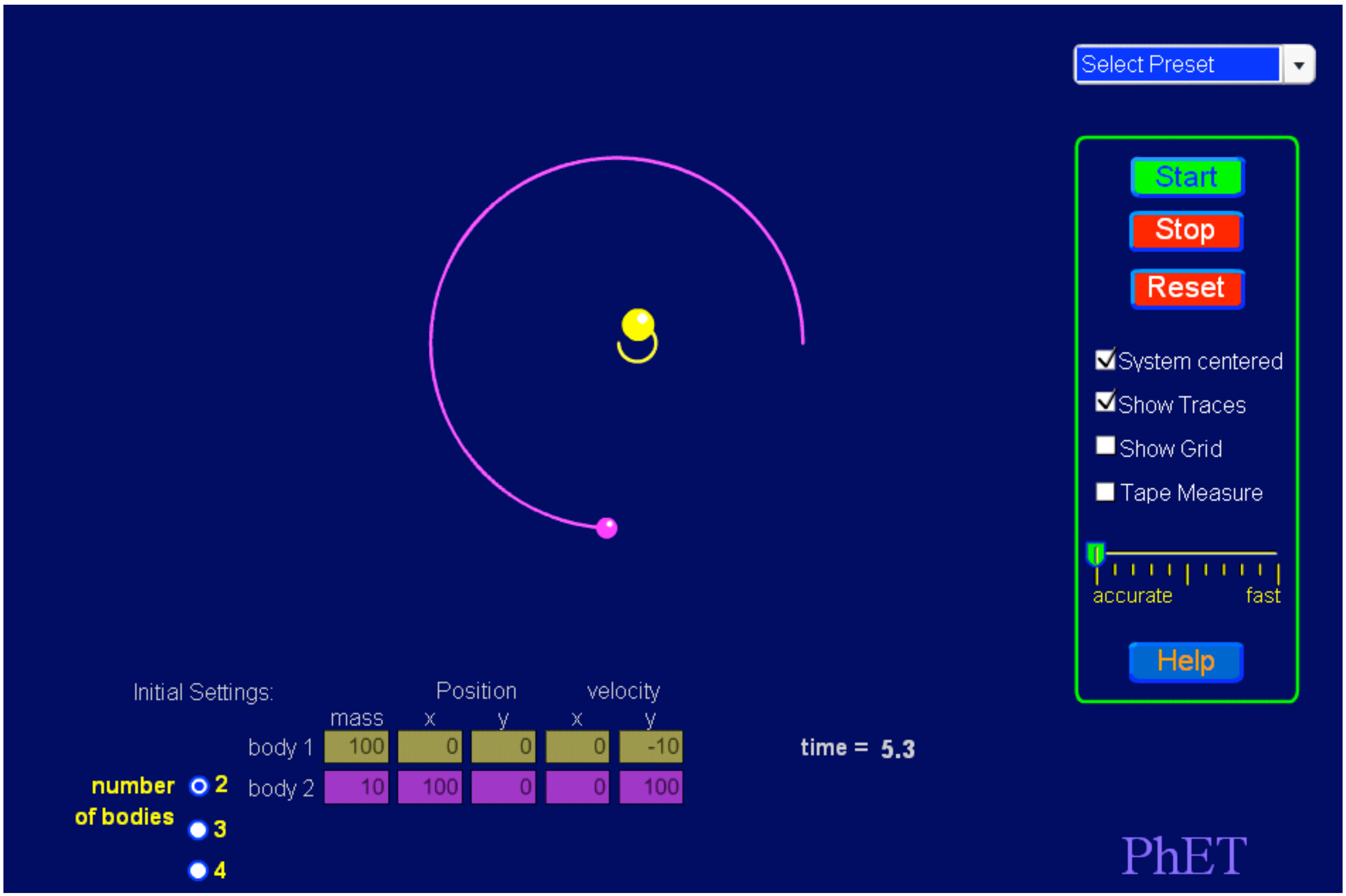
First Picture of Likely Planet around Sun-like Star

Date: 09/15/2008
Credit: Gemini Observatory

Gemini adaptive optics image of 1RSX J160929.1-210524 and its likely ~8 Jupiter-mass companion. This image is a composite of J-, H- and K-band near-infrared images. All images obtained with the Gemini Altair adaptive optics system and the Near-Infrared Imager (NIRI) on the Gemini North telescope.

Indirect evidence for extrasolar planets

If you ran My Solar System with a massive planet, you may have noticed that the Sun moved. Why did it move?



The motion of the Sun

If Jupiter were the only planet in the solar system, the Sun and Jupiter would both orbit around their ‘center of mass’.

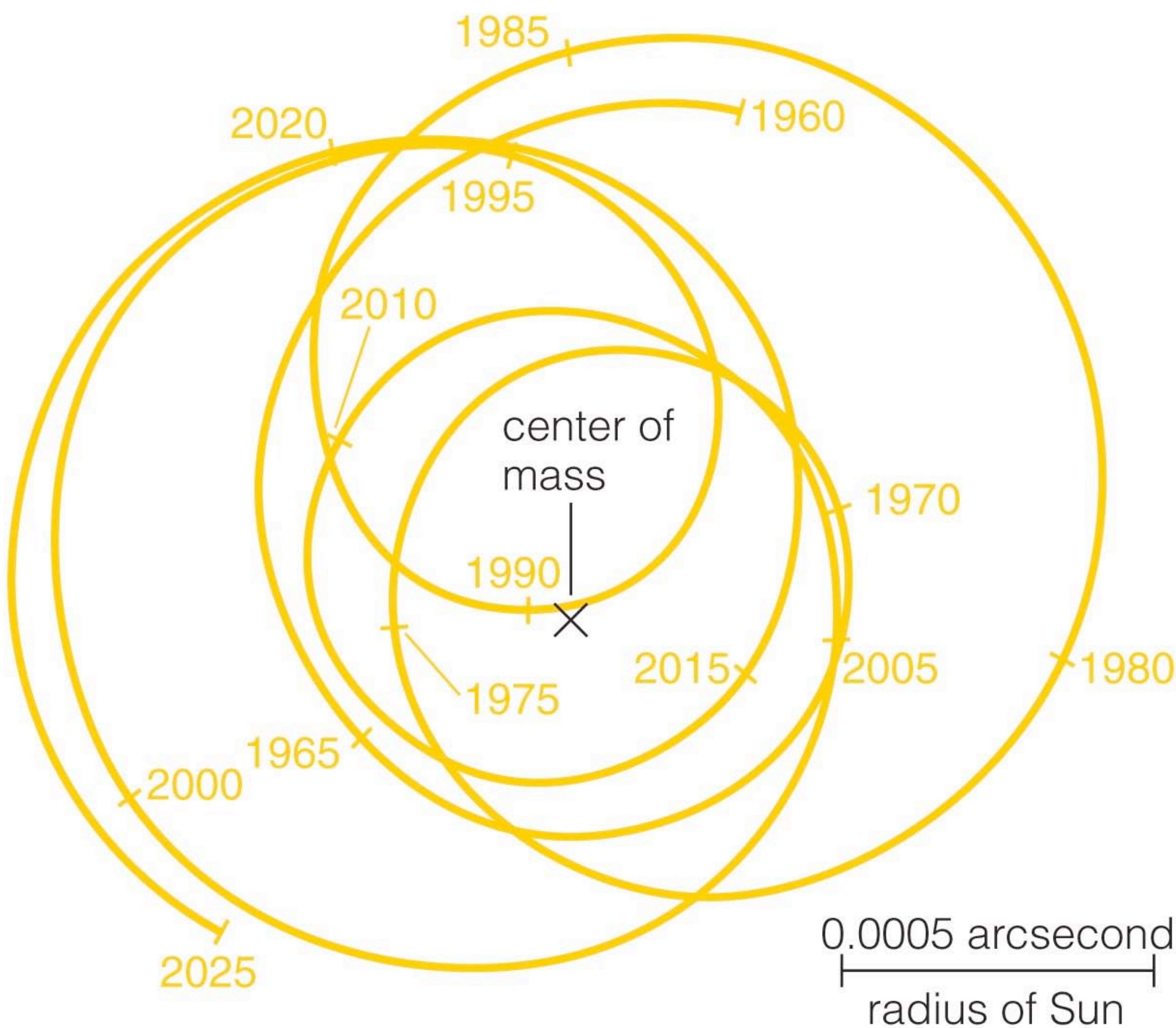
Since Jupiter’s mass is 1/1000 the Sun’s mass, the center of mass is 1/1000 of the way from the center of the Sun to the center of Jupiter. That is near the surface of the Sun.

If we took a picture of the solar system from a nearby star, we’d probably only notice the Sun, but maybe if we took a series of pictures we could tell that the Sun is moving.

It would be like seeing a basketball 5000 miles away move by its diameter.

How long would it take it to move that far?

Motion of the Sun as seen from 10 light-years



The Astrophysical Journal, 715:1203–1220, 2010 June 1 doi:10.1088/0004-637X/715/2/1203

NEW OBSERVATIONAL CONSTRAINTS ON THE υ ANDROMEDAE SYSTEM WITH DATA FROM THE *HUBBLE SPACE TELESCOPE* AND HOBBY-EBERLY TELESCOPE*

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Received 2009 October 14; accepted 2010 April 8; published 2010 May 7

ABSTRACT

We have used high-cadence radial velocity (RV) measurements from the Hobby-Eberly Telescope with existing velocities from the Lick, Elodie, Harlan J. Smith, and Whipple 60″ telescopes combined with astrometric data from the *Hubble Space Telescope* Fine Guidance Sensors to refine the orbital parameters and determine the orbital inclinations and position angles of the ascending node of components υ And A c and d. With these inclinations and using $M_* = 1.31 M_\odot$ as a primary mass, we determine the actual masses of two of the companions: υ And A c is $13.98^{+2.3}_{-5.3}$ $M_{\rm JUP}$, and υ And A d is $10.25^{+0.7}_{-3.3}$ $M_{\rm JUP}$. These measurements represent the first astrometric determination of mutual inclination between objects in an extrasolar planetary system, which we find to be $29\overset{\circ}{.}9 \pm 1^\circ$. The combined RV measurements also reveal a long-period trend indicating a fourth planet in the system. We investigate the dynamic stability of this system and analyze regions of stability, which suggest a probable mass of υ And A b. Finally, our parallaxes confirm that υ And B is a stellar companion of υ And A.

Key words: astrometry – planetary systems – planets and satellites: dynamical evolution and stability – planets and satellites: fundamental parameters

Online-only material: color figures, machine-readable table

1. INTRODUCTION

υ Andromedae (υ And) is a sunlike F8 V star that is

and suggested that for parameters supported by the observations the system experienced chaotic evolution. They also concluded that *N*-body interactions alone could not have boosted υ And

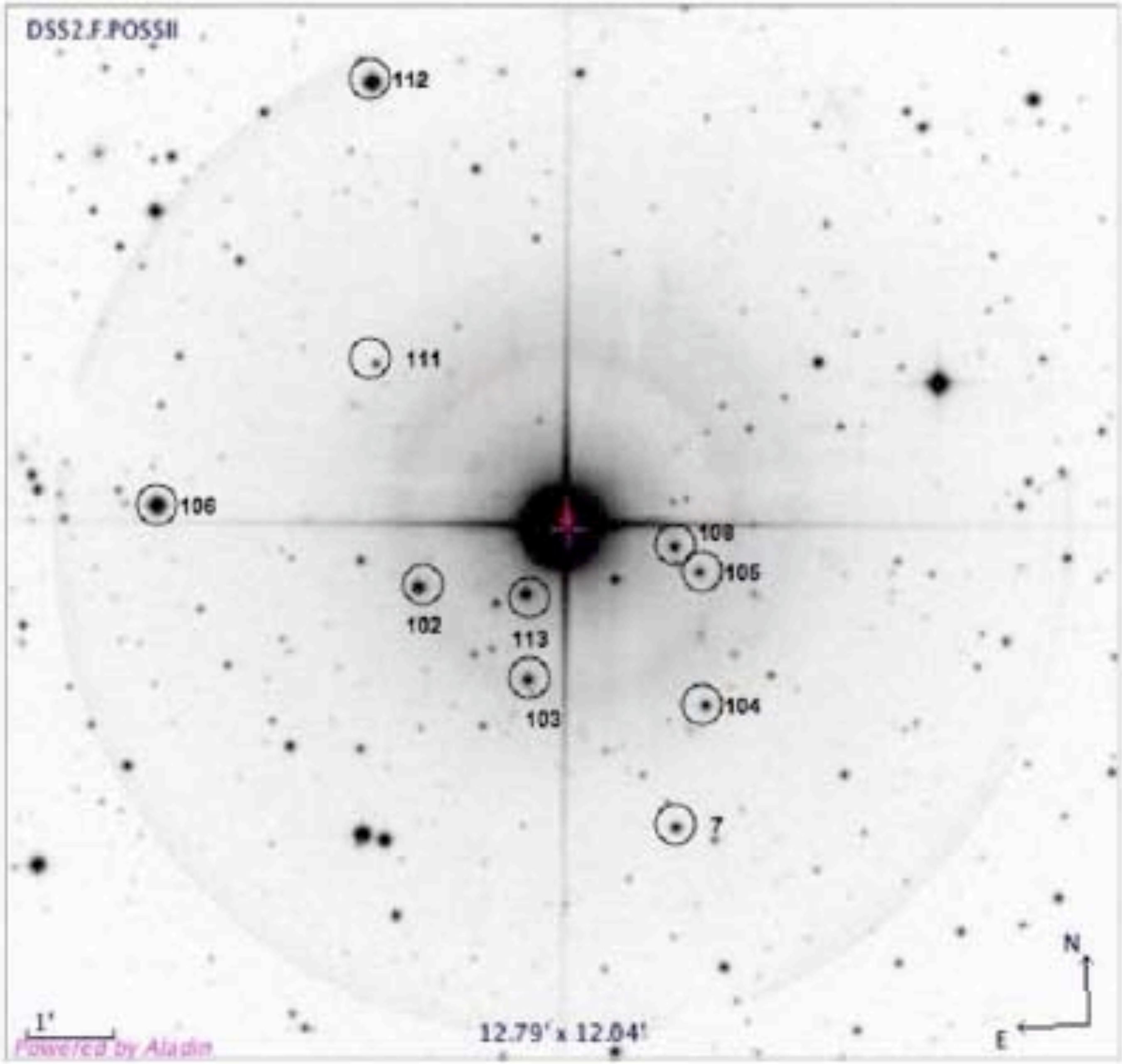


Figure 2. υ And field with astrometric reference stars marked. Reference star 113 is υ And B. The box is 15′ across.

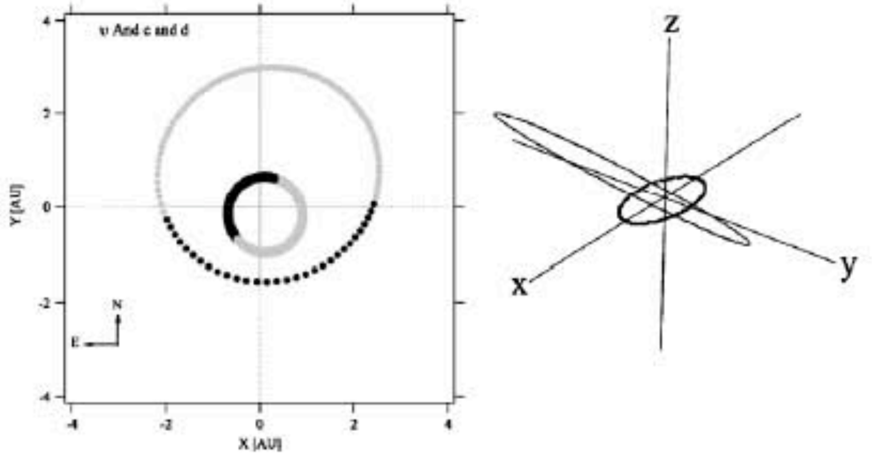
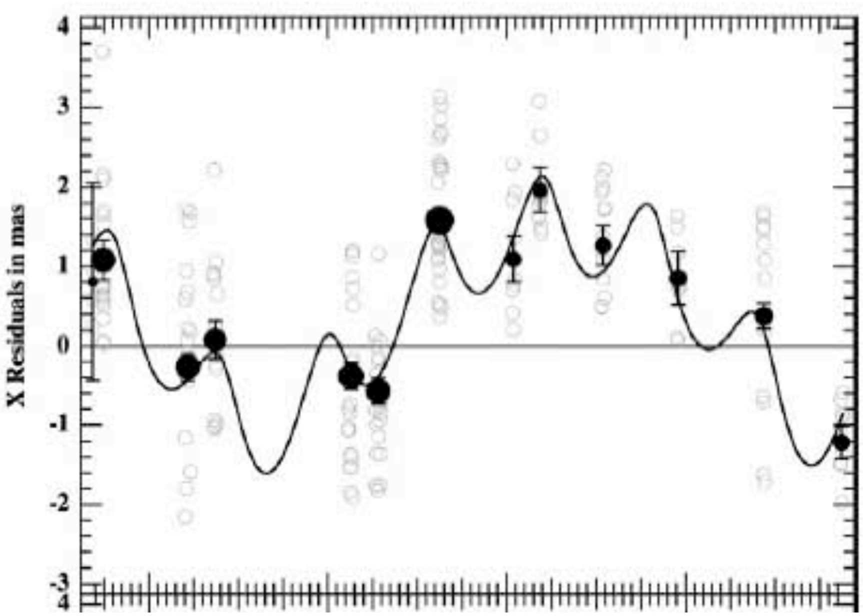


Figure 8. Left: orbits of υ And c and d on the sky. Darker segments of the orbits indicate out of plane, lighter behind plane of sky. Trace size is proportional to the masses of the companions. Right: perspective view of the orbits of components c and d projected on orthogonal axes.



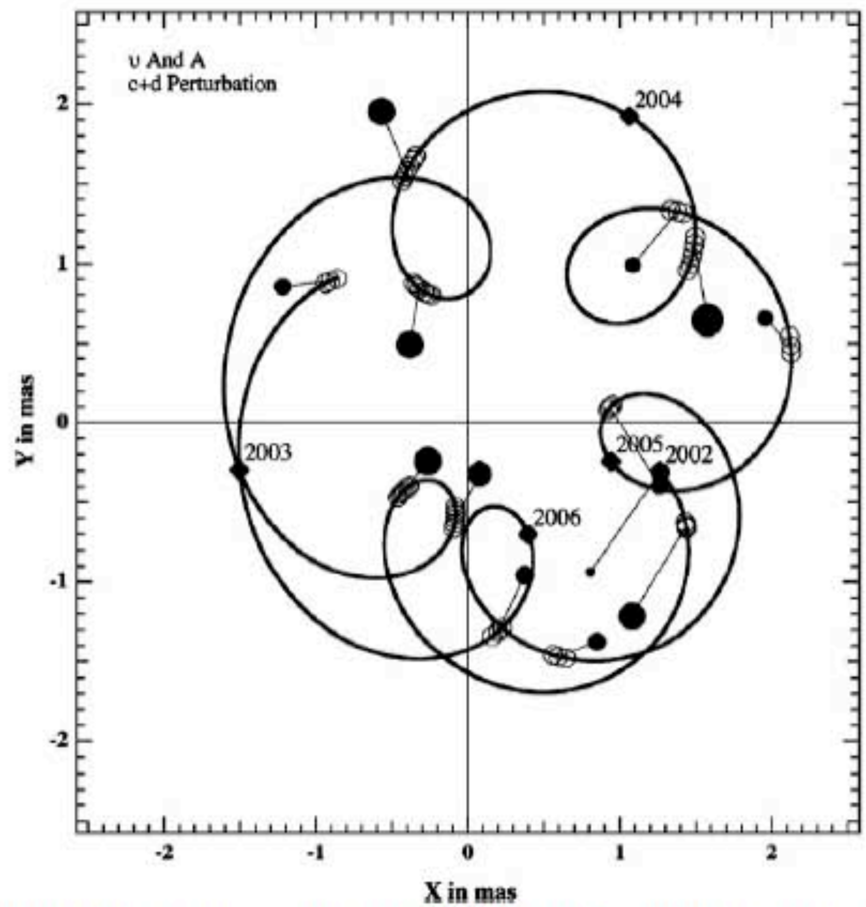


Figure 10. Astrometric reflex motion of υ And due to υ And c and d. The astrometric orbit is shown by the dark line. Open circles show times of observations, dark filled circles are normal points made from the υ And residuals to an astrometric fit of the target and reference frame stars of scale, lateral color, cross filter, parallax, and proper motion of multiple observations (light open circles) at each epoch. Normal point size is proportional to the number of individual measurements that formed the normal point. Solid line shows the combined astrometric motion of υ And c and d from the elements in Table 13.