ASTR 1020: Stars & Galaxies
April 30, 2008

- **Next class: Review for Final & Wrap-up.**
- Final Exam: **May 5, 4:30 – 7:00 pm; Chapters: 1.1-1.2, 4.1-4.4, 5, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23.**

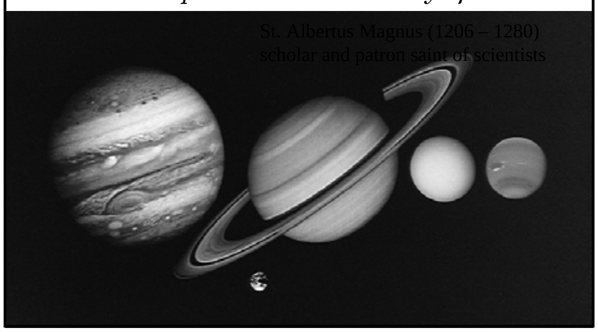
The New Worlds Observer:

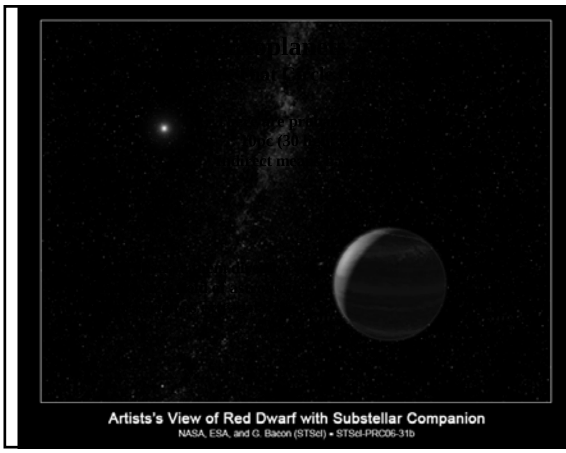
Looking for the Next Earth Using External Occulters

Phil Oakley
University of Colorado
April 30th, 2008

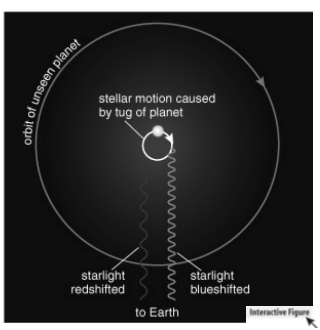
Do there exist many worlds, or is there but a single world? This is one of the most noble and exalted questions in the study of Nature.

St. Albertus Magnus (1206 – 1280)
scholar and patron saint of scientists



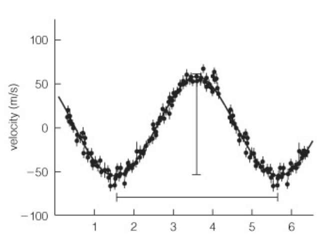


Detecting ExoPlanets: Doppler Technique



- Measuring a star's Doppler shift can tell us its motion toward and away from us.
- Current techniques can measure motions as small as 1 m/s (walking speed!).
- Newton's version of Kepler's 3rd Law allows us to estimate mass.

First Extrasolar Planet



- Doppler shifts of star 51 Pegasi indirectly reveal a planet with 4-day orbital period
- Short period means small orbital distance
- First extrasolar planet discovered orbiting a "regular" star (1995)

Clicker Question

Suppose you found a star with the same mass as the Sun moving back and forth with a period of 16 months—what could you conclude?

A. It has a planet orbiting at less than 1 AU.
B. It has a planet orbiting at greater than 1 AU.
C. It has a planet orbiting at exactly 1 AU.
D. It has a planet, but we do not have enough information to know its orbital distance.

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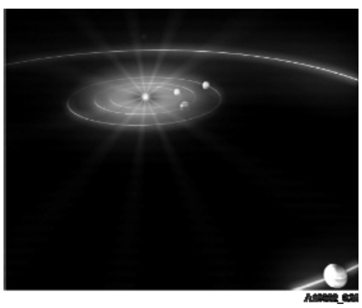
Direct Imaging is What We Want



Can We Ever Map Extra-Solar Systems In This Manner?

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Why Hasn't This Been Done?

- An Earth-like planet is 10 billion (10,000,000,000) times fainter than its host star.
- The planet is only 0.1 arcsecond (0.000027 degrees) away from the host star.
- Must be done above the Earth's atmosphere
- Mirror's must be smooth to perfection

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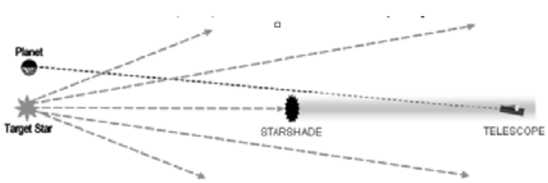
New Worlds Observer Diagram



- Telescope big enough to collect enough light from planet
  - 4 meter diameter mirror
- Occulter big enough to block star
  - 50 meter diameter starshade
- Telescope far enough back to still see the Earth-like planet
  - 50,000 kilometers

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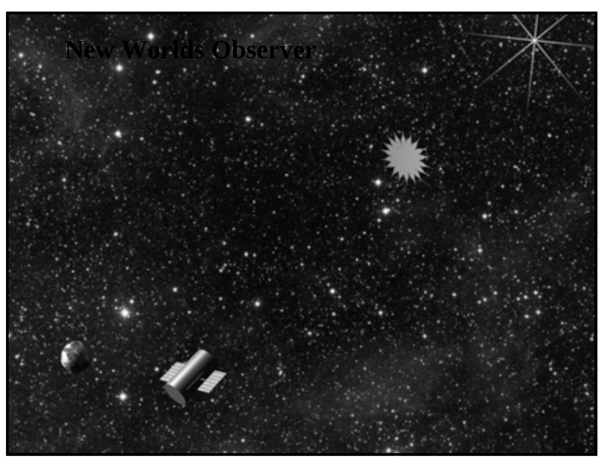
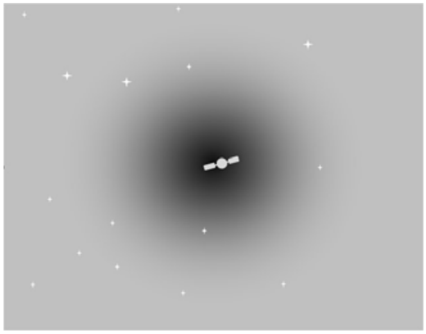


Fly the Telescope into the Shadow



The Obstacle

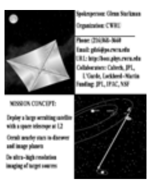
DIFFRACTION

Despite What They Tell You in Sixth Grade
Light Does Not Move In Straight Lines

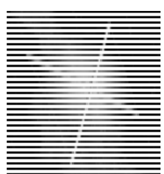
Occulters

- Several previous programs have looked at occulters
- Used simple geometric shapes
  - Achieved only a factor of 100 suppression (need 10 billion)

http://umbras.org/

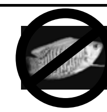


BOSS

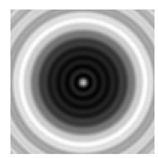


Starkman (TRW ca 2000)

Extinguishing Poisson's Spot



- Occulters can actually concentrate light!



- Need an occulter shape that casts a near perfect shadow for the telescope

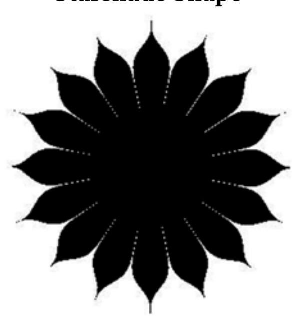
Fresnel Approximation

$$E = \frac{E_0 e^{ikF} e^{\frac{iks^2}{2F}}}{i\lambda F} \int_0^\infty e^{\frac{ik\rho^2}{2F}} \rho \int_0^{2\pi} A(\theta,\rho) e^{\frac{ik\rho s\cos\theta}{F}} d\theta d\rho$$

Then, if circularly symmetric:

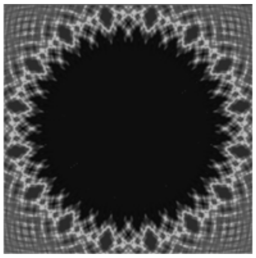
$$E = \frac{E_0 k e^{ikF} e^{\frac{iks^2}{2F}}}{iF} \int_0^\infty e^{\frac{ik\rho^2}{2F}} A(\rho) J_0\left(\frac{k\rho s}{F}\right) \rho d\rho$$

Starshade Shape

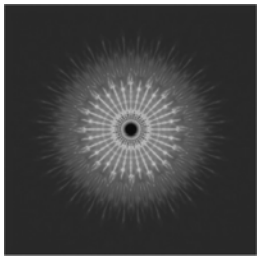


Petal shape causes diffracted light to cancel out

Shadow of 16 Petal Mask



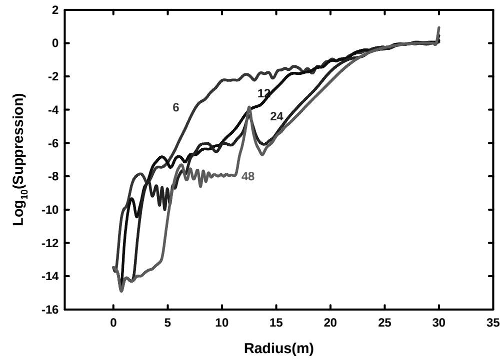
Linear



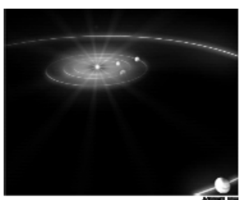
Log

Petal Profiles

Effect of Petal Number



Simulated Solar System

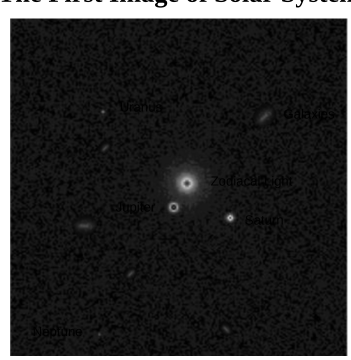


http://newworlds.colorado.edu/downloads/NWO.htm

New World Observer Architecture

- 4m Telescope Diameter Breakpoint
- Two Starshades – one small and fast
- Very Powerful Scientifically
- Cost comparable to other missions

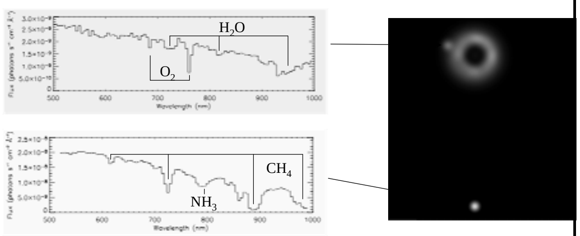
The First Image of Solar System



10 arcseconds

Spectroscopy

- ☞ Spectroscopy will distinguish terrestrial atmospheres from Jovian with modeling



S. Seager

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It should be possible to detect oceans and continents!

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Challenges for New Worlds Observer

- ☞ Deployment of 50m shade to an accuracy of milli-meters
- ☞ Flying the starshade and telescope in formation
- ☞ Fuel usage, retargetting time
- ☞ Stray Light – particularly from our Sun

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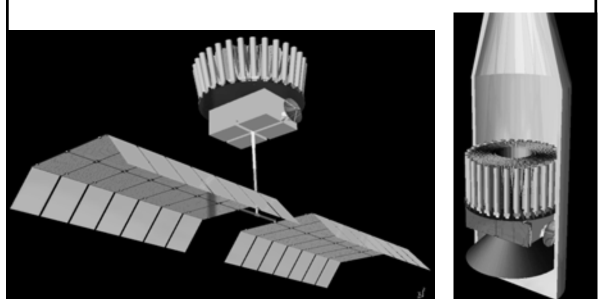

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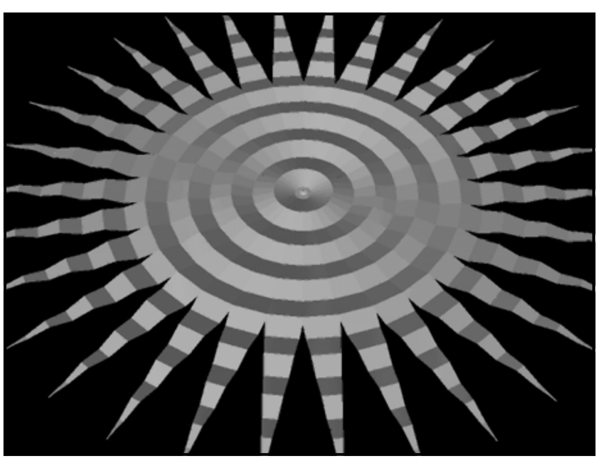
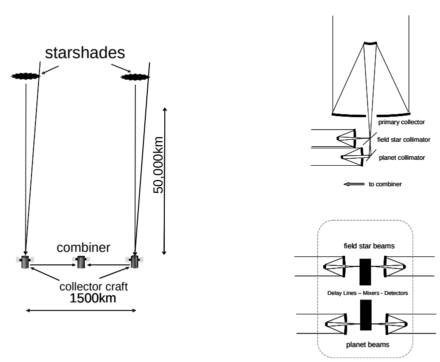


NWI Concept



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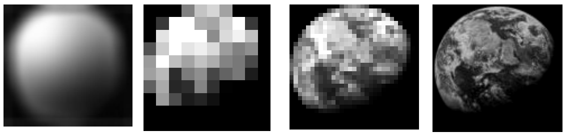
TRUE PLANET IMAGING



3000 km | 1000 km | 300 km | 100 km

Earth Viewed at Improving Resolution

Conclusion