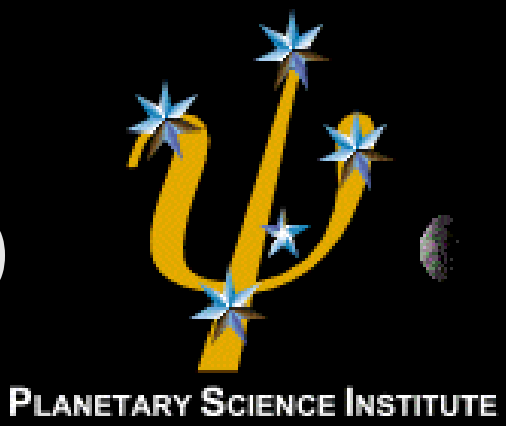
Exoplanets in Reflection and Shadow

Penny D. Sackett
RSAA, Mt Stromlo Observatory

THE AUSTRALIAN NATIONAL UNIVERSITY

Ulyana Dyudina (ANU → Caltech)
PDS (ANU)
Daniel Bayliss (ANU)
Sara Seager (DTM)
Carolyn Porco (Space Science Inst)
Henry Throop (Southwest Research Inst)
Luke Dones (Southwest Research Inst)



ApJ 2004, in press (astro-ph/0406390)

THE AUSTRALIAN NATIONAL UNIVERSITY

Precise, Time-series Photometry

ELT: Lots of photons → possibility for ultra-precise relative photometry

What could we learn about exoplanets with ultra-precise photometry if:

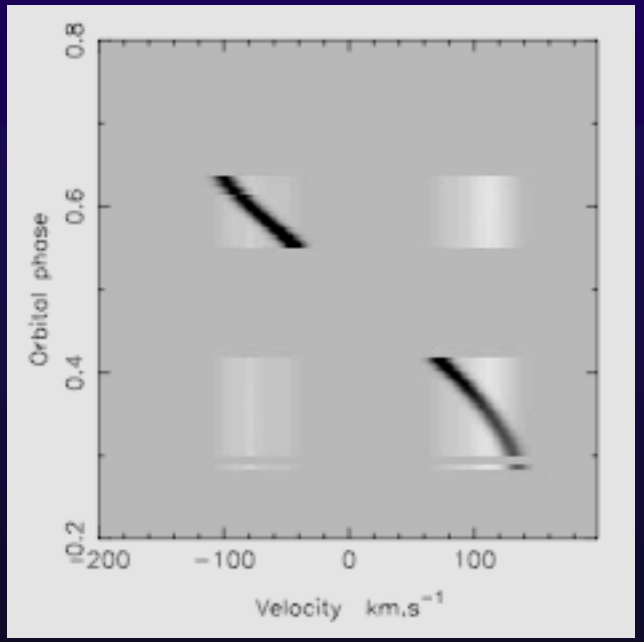
1. adequate time resolution was possible
2. star light could be adequately separated from light associated with the planet (in reflection or

State of Play

Size of modulated signal strongest for planets in orbit with small semi-major axis a.

Searches for modulated reflected light around such planets have yielded:

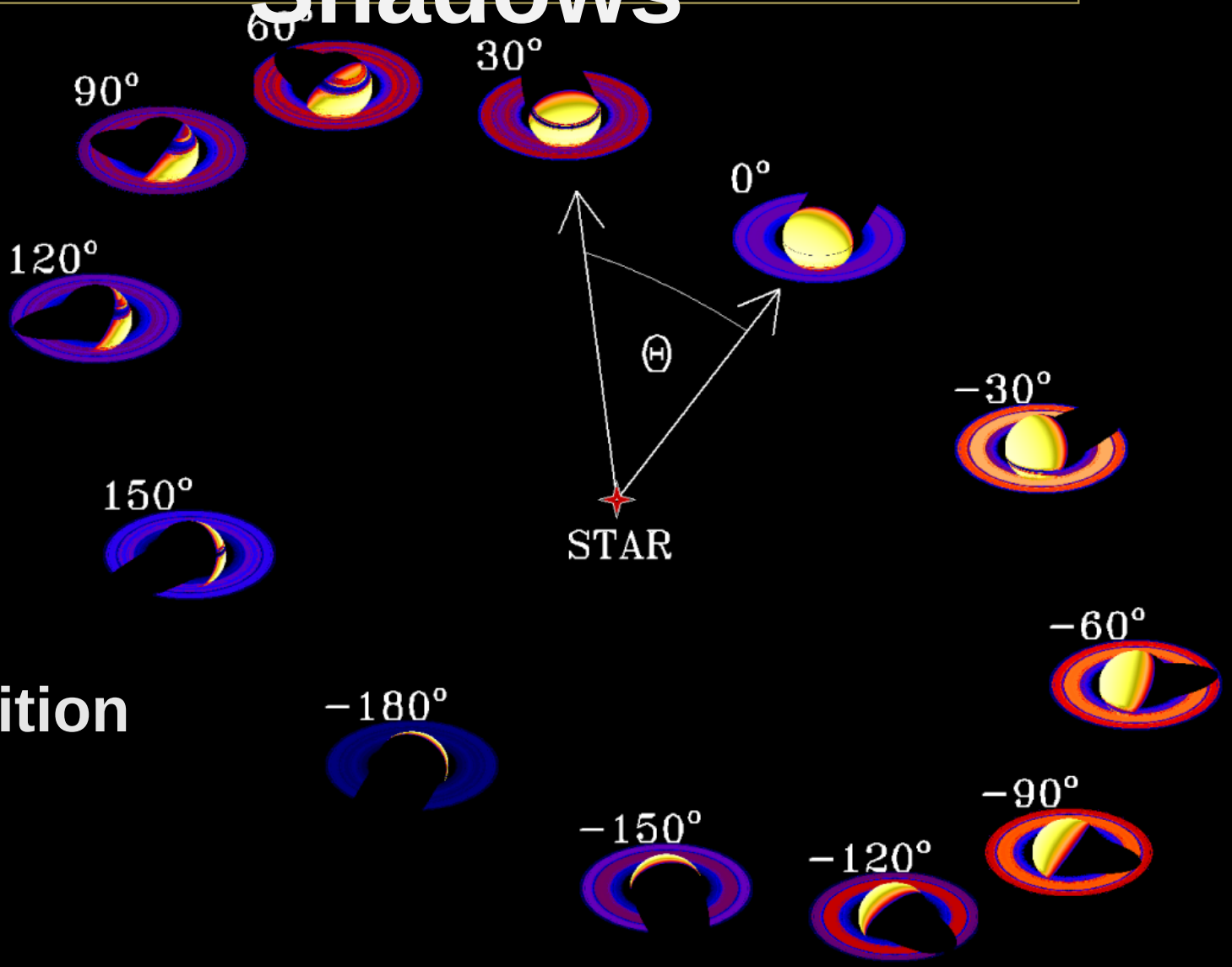
No detections.
Upper limits have placed the albedo of three exoplanets.



Collier Cameron et al 2002, MNRAS

Leigh et al 2003, MNRAS

Reflections and Shadows

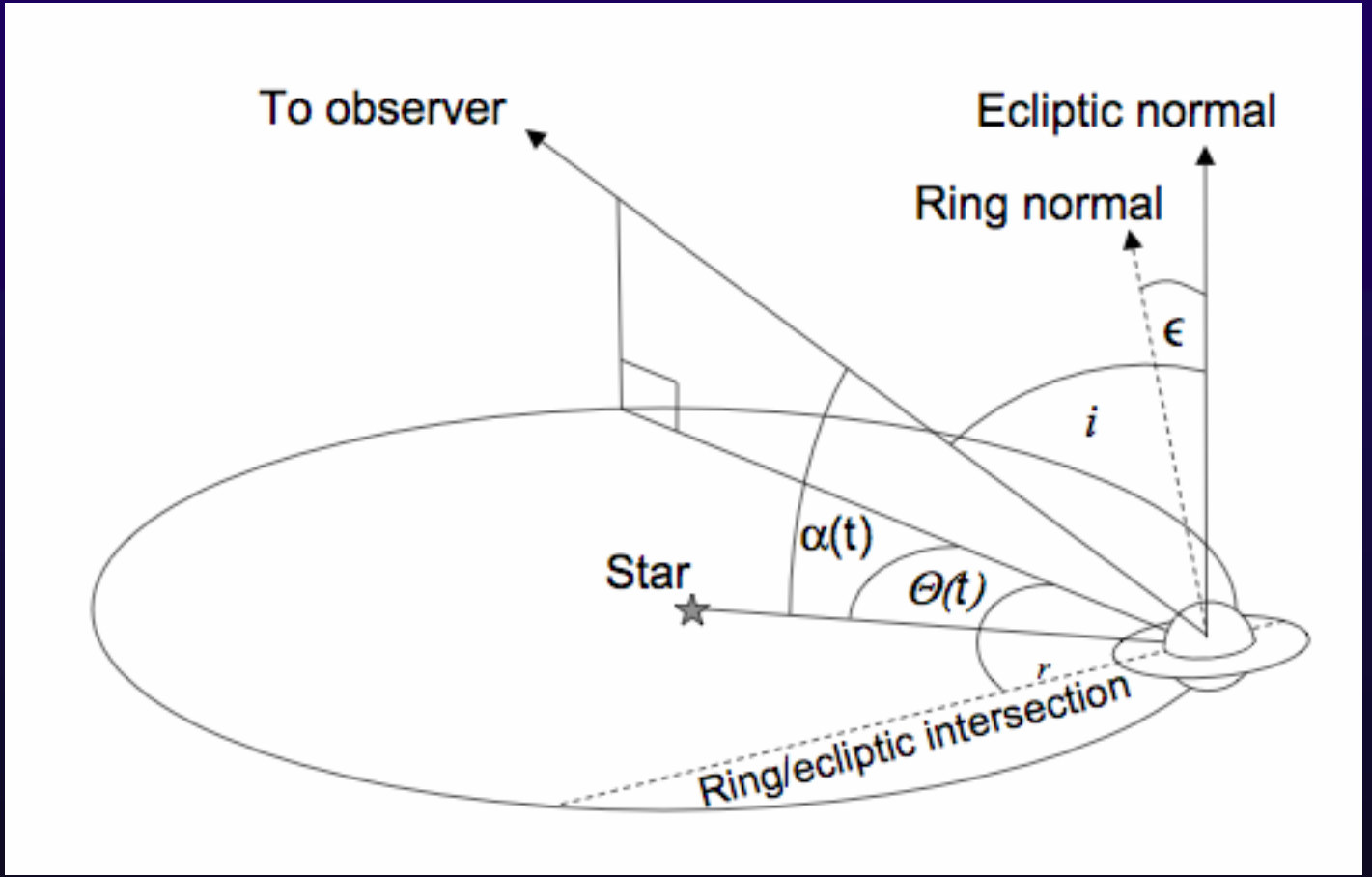


- $\vartheta = 0$

At opposition

THE AUSTRALIAN NATIONAL UNIVERSITY

Basic Geometry



Our Approach

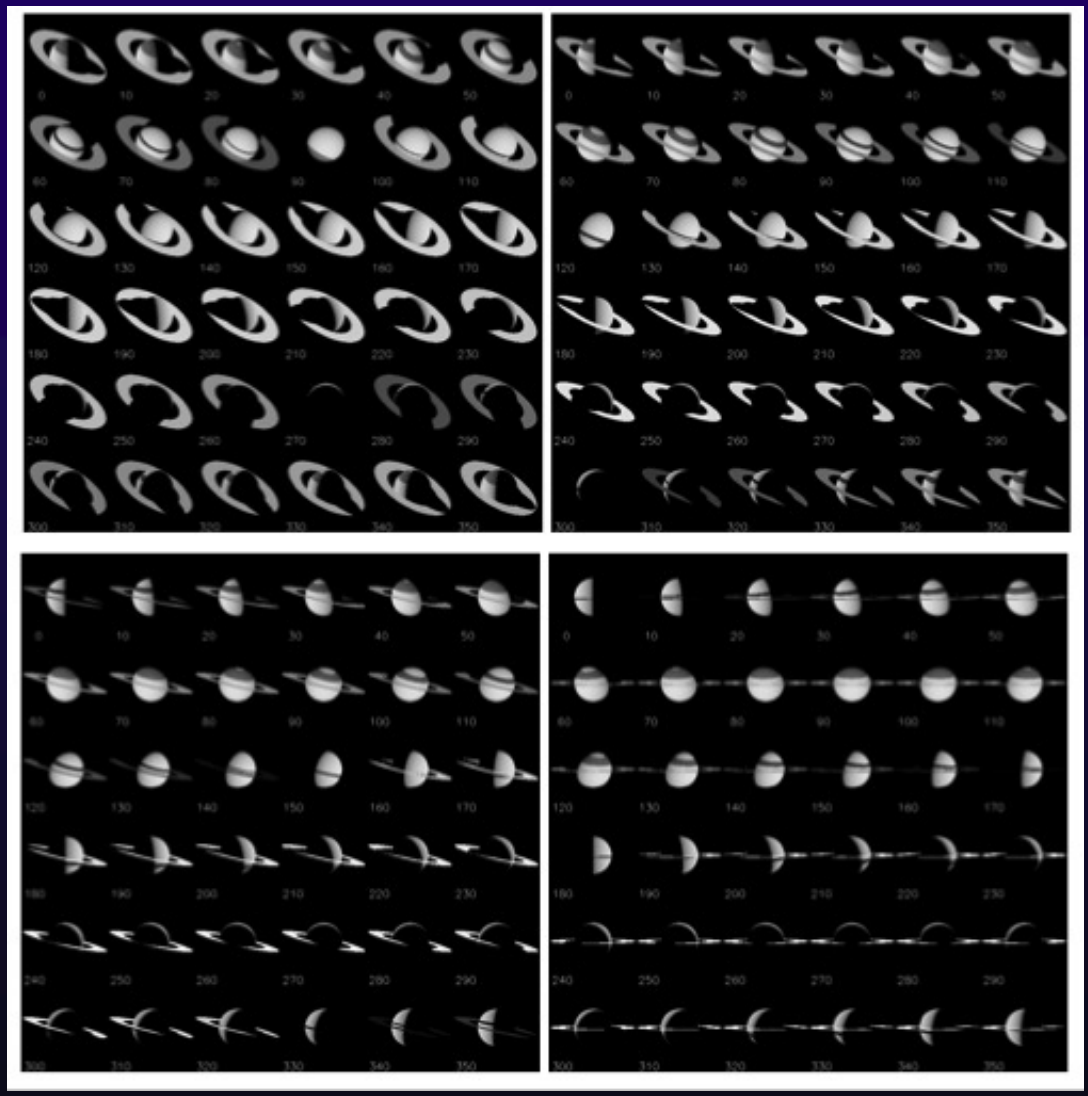
- Use Pioneer- and Voyager-measured *anisotropic* scattering functions of Jupiter, Saturn and its rings at 0.6 - 0.7 micron
- Construct phase light curves. Vary orbital inclination, planet oblateness, ring obliquity, ring viewing angle, orbit size, *orbit eccentricity*, and orbit viewing angle
- Extract detectability (contrast). Compare to Lambertian scattering and ELT capabilities

- Not included: ring size, planetary thermal emission

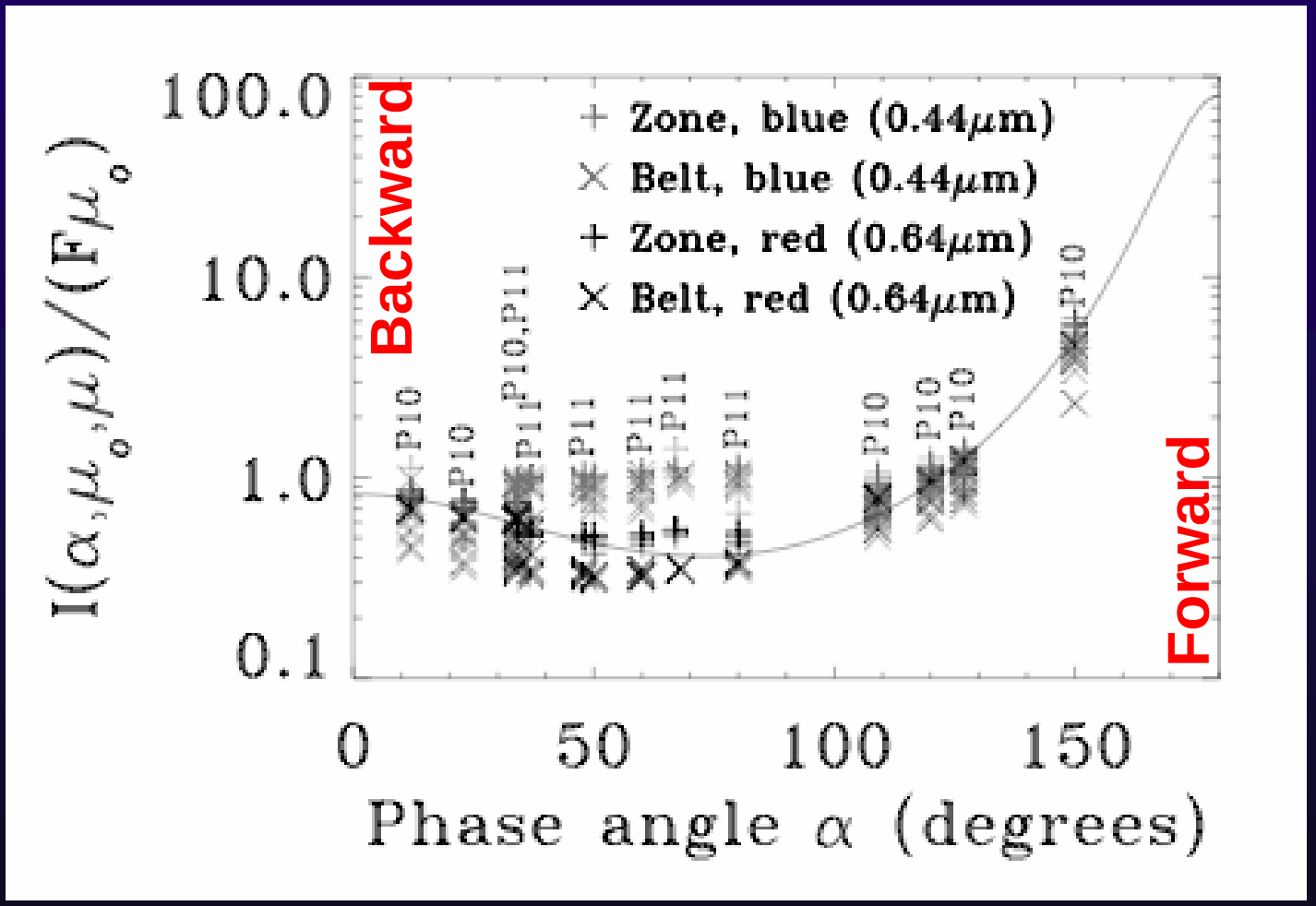
Ring size

Arnold & Schneider 2004,

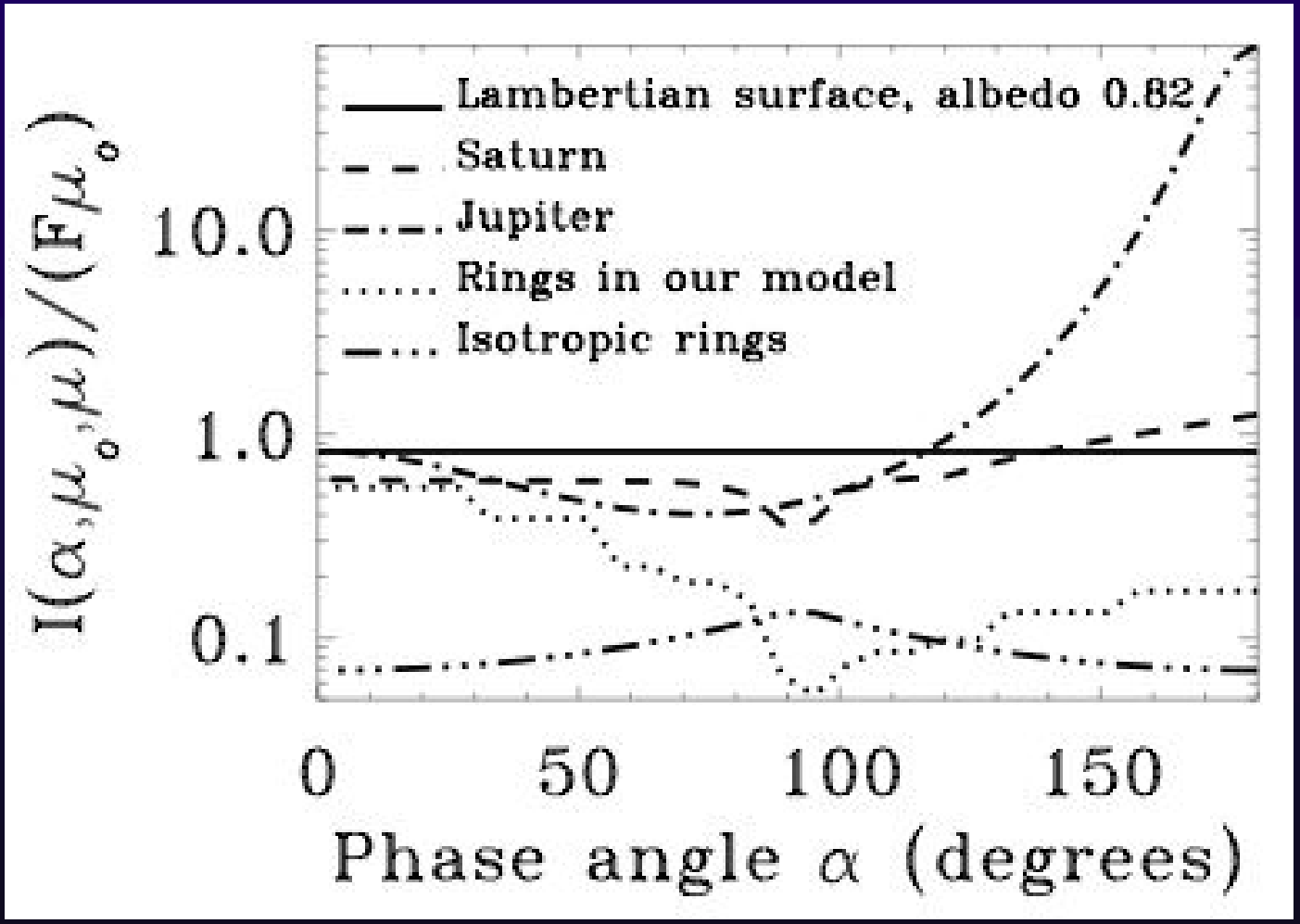
A&A, 420, 1153



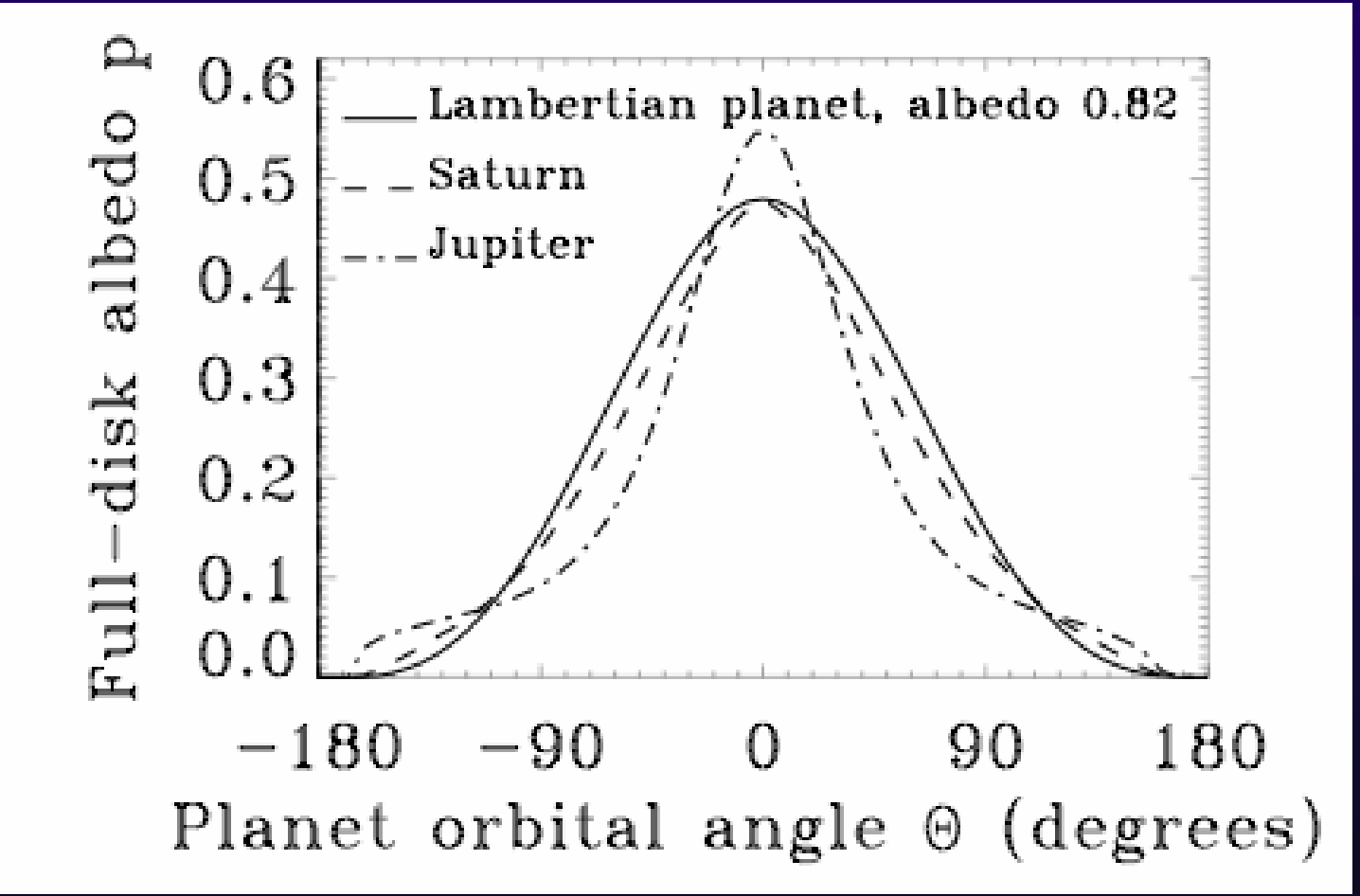
Comparison to Pioneer Data



Model Scattering Properties



Ringless Albedos

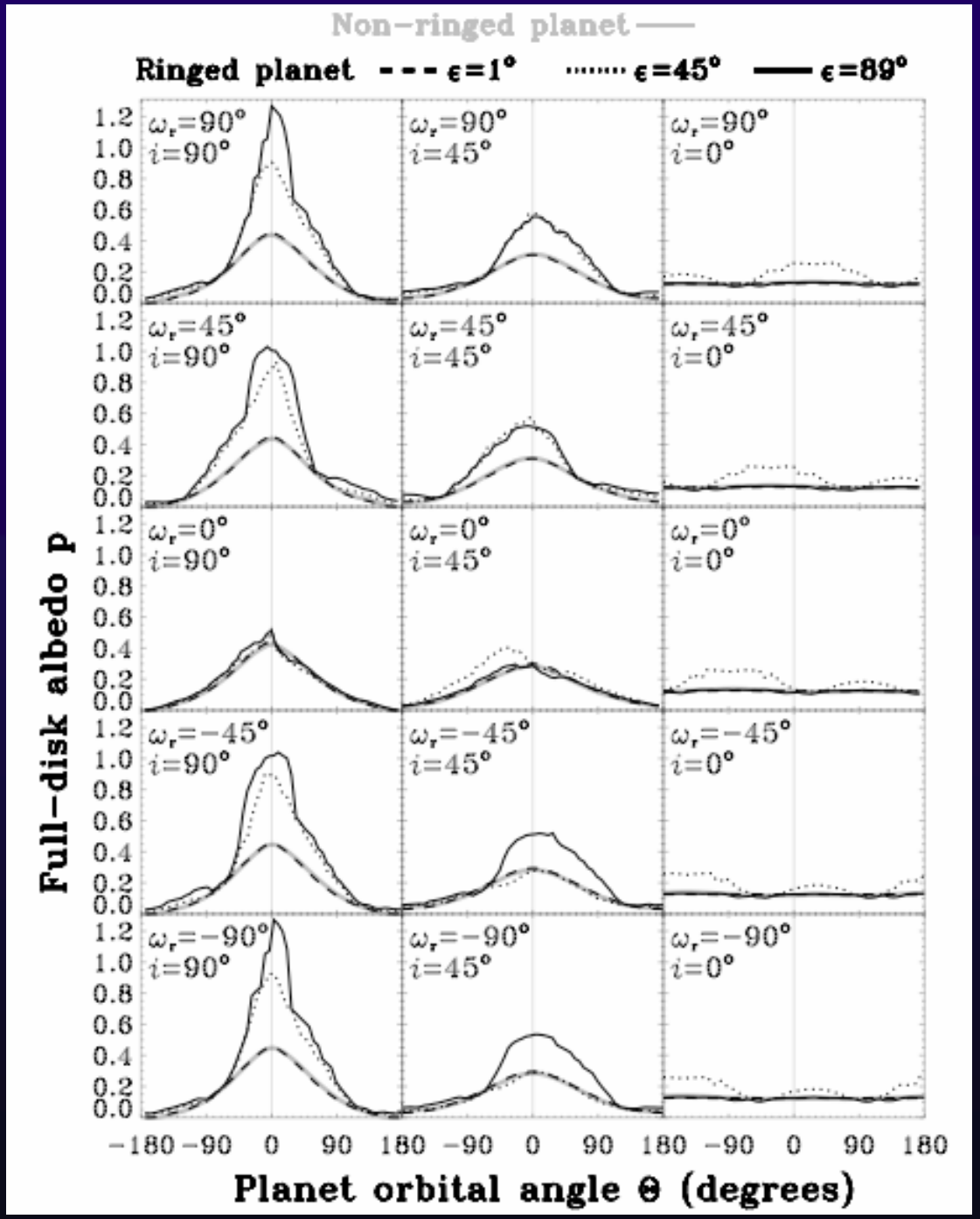


Ring Effects (Edge-on)

45 Degrees Orientation

Top View Orientation

Great Variety in Reflected Light Curves



THE AUSTRALIAN NATIONAL UNIVERSITY

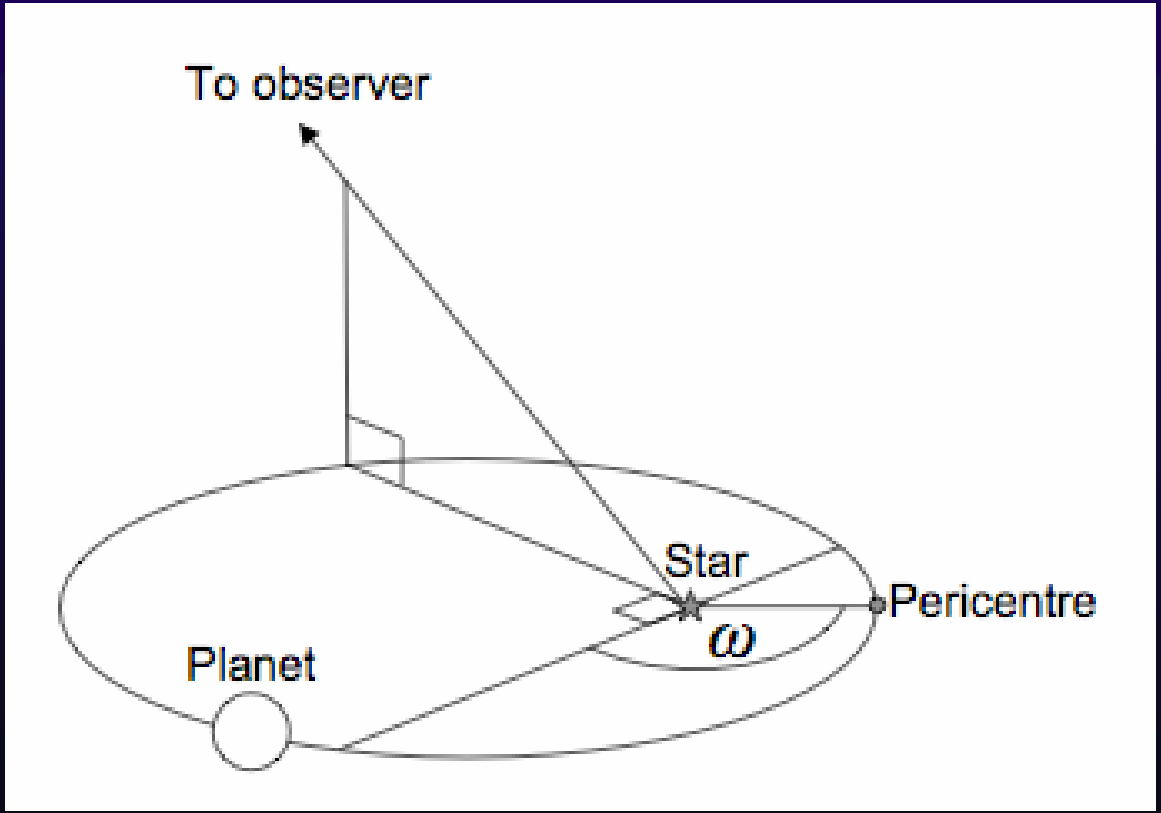
Elliptical Orbits

Observer-Orbit Orientation now Important

Argument of Pericentre ω =

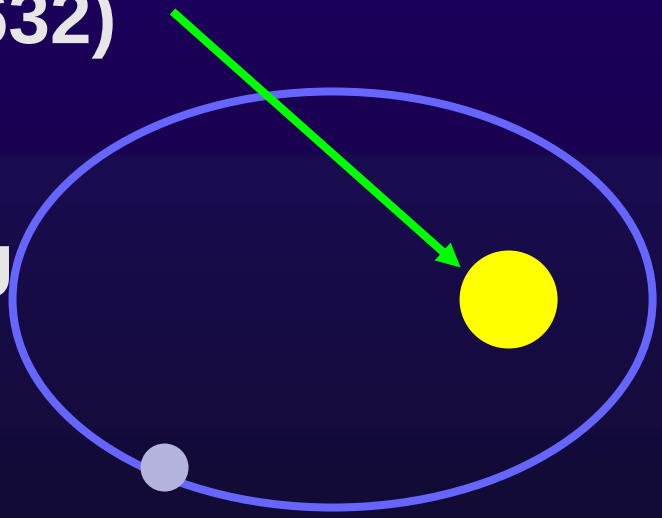
90 deg if viewing from pericentre

-90 deg if viewing from apocentre



Exo Test Case: HD 108147b

Discovered by Pepe, Major et al
(2002, A&A, 388, 632)

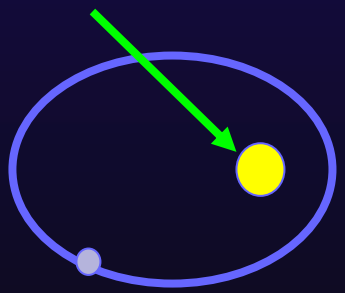


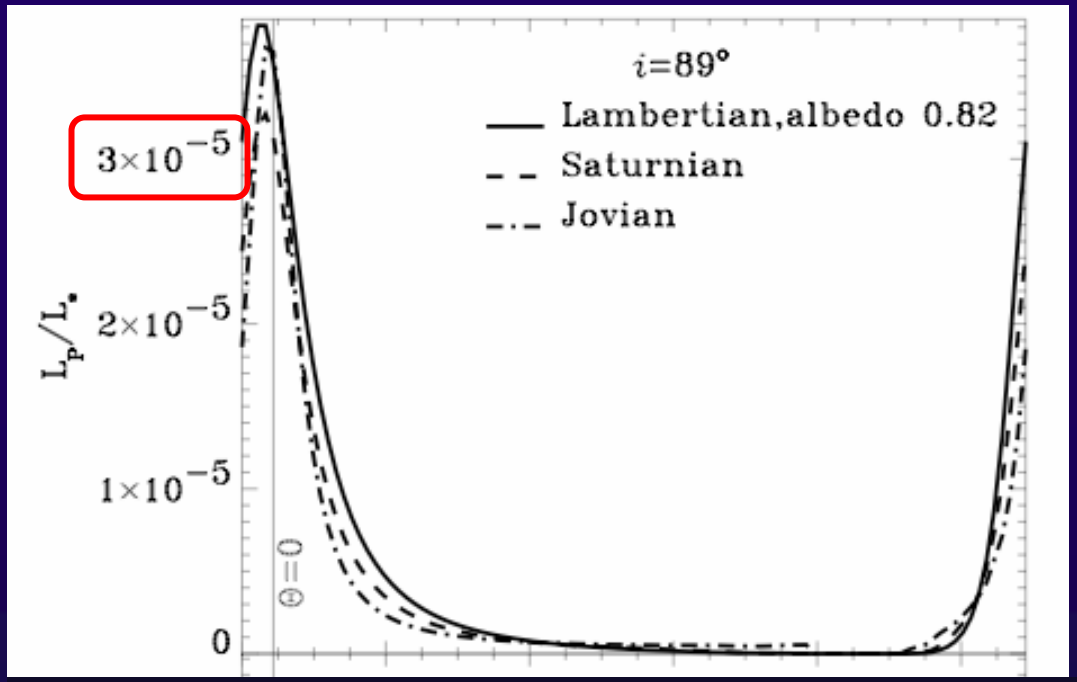
Properties:

- **Semi-major axis = 0.104 AU**
- **Period = 10.9 days**
- **Eccentricity = 0.498**
- **Argument of pericentre = ω = -41°**
- **Inclination = ?**

Worked Example:

HD108147b

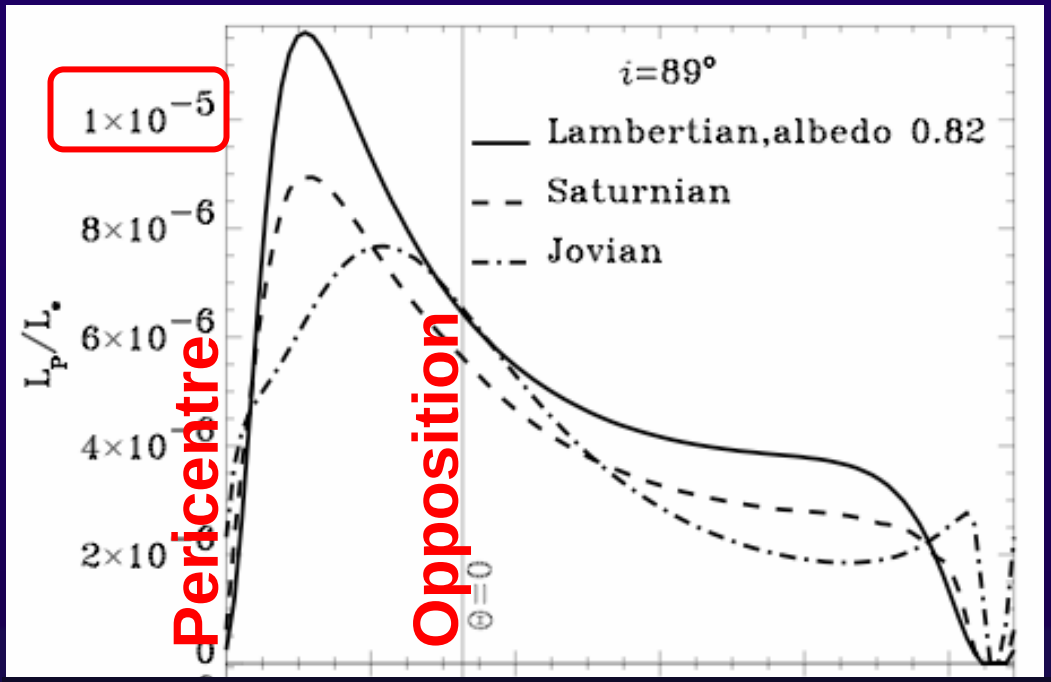




THE AUSTRALIAN NATIONAL UNIVERSITY

HD108147b with different viewing angle

Argument of pericentre = 60 deg, not -41 deg



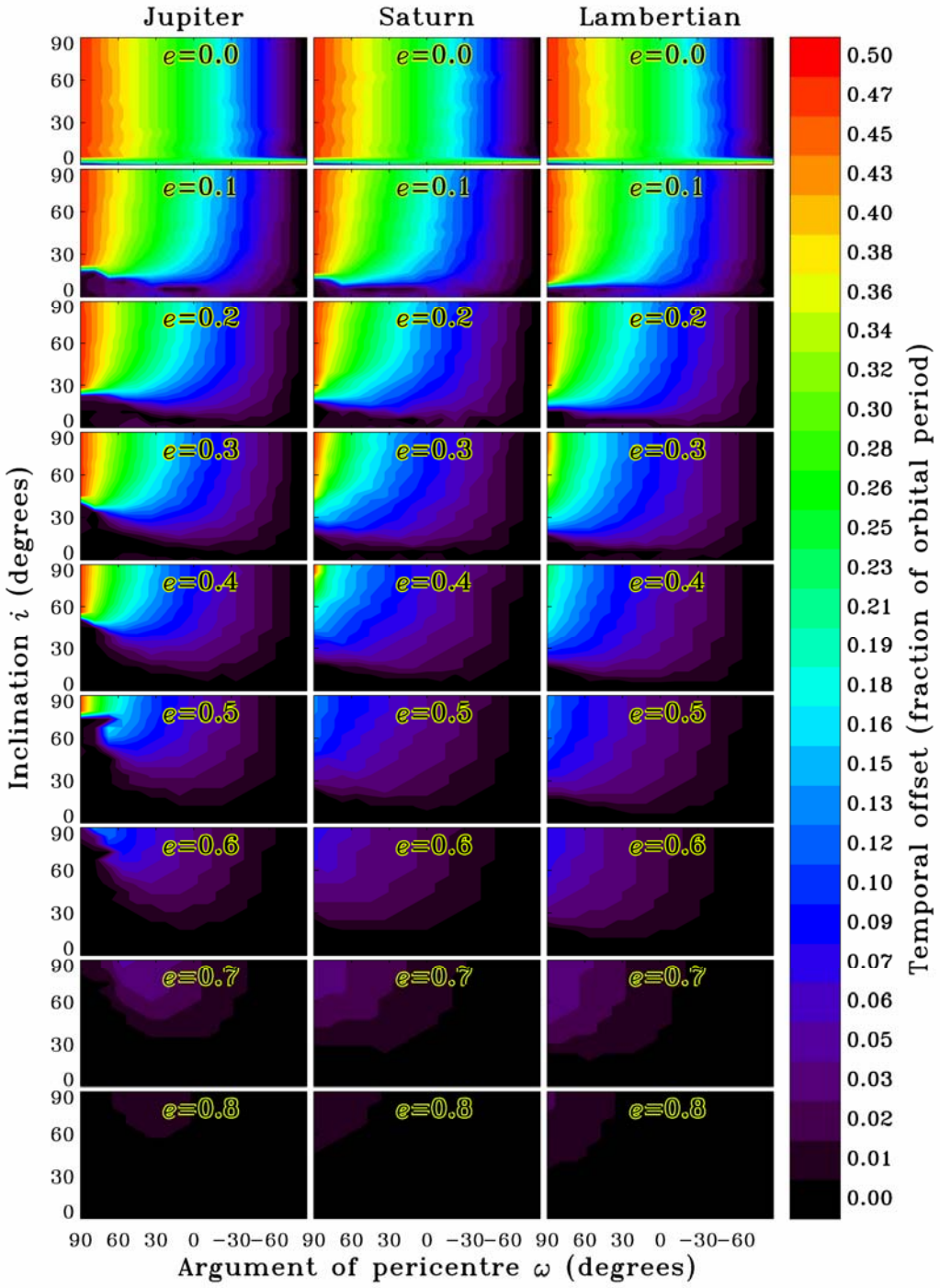
THE AUSTRALIAN NATIONAL UNIVERSITY

Temporal shift is measurable if orbital phase known. How large is shift?

% of Period:

Red	**50%**
Green	**25%**
Blue	**10%**

Can be used to determine inclination

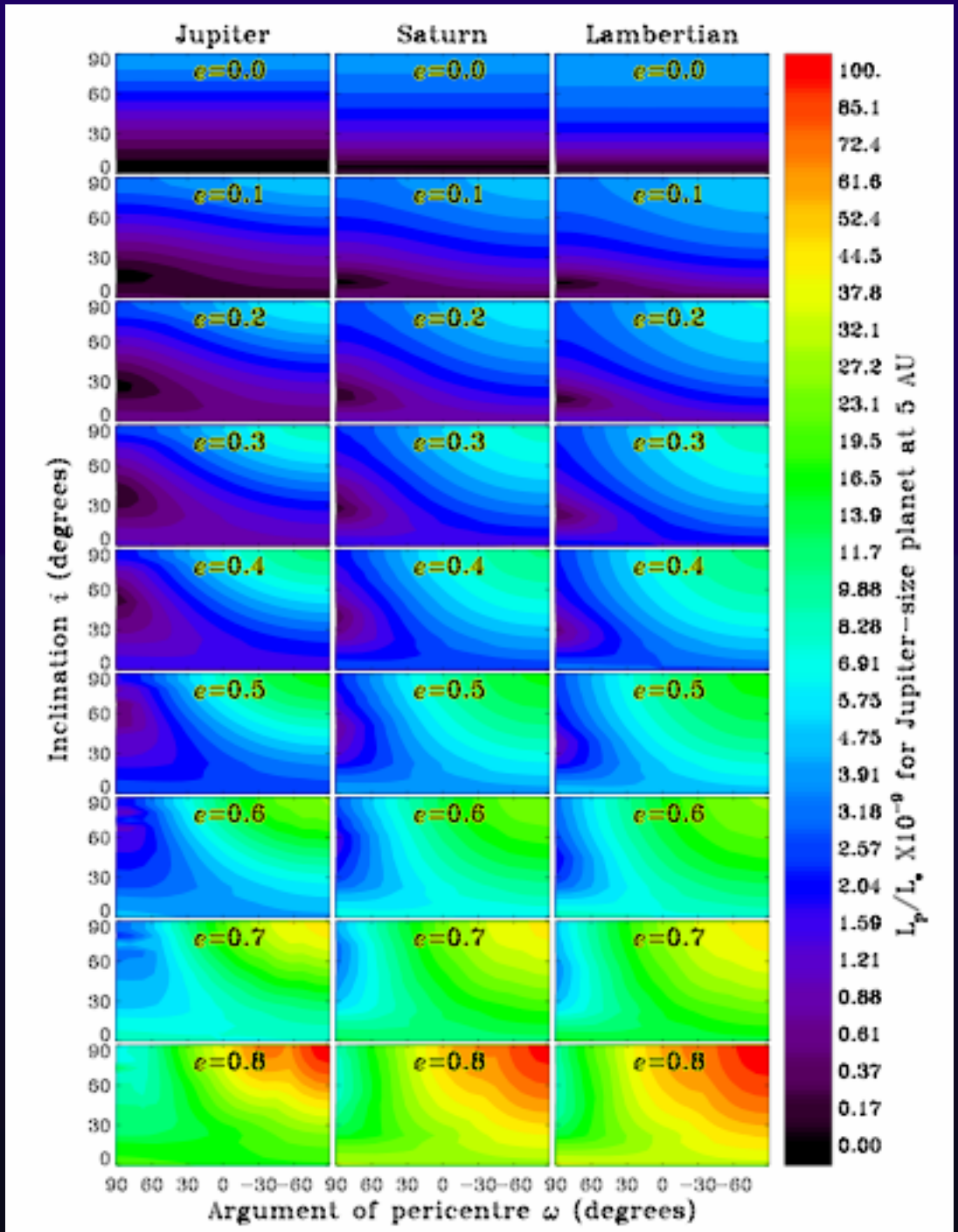


THE AUSTRALIAN NATIONAL UNIVERSITY

Can we detect the effect for, say, Jupiter with a = 5 AU?

Contrast:

Red	10^{-7}
Green	10^{-8}
Blue	10^{-9}



Dyudina, Sackett, Bayliss etal, 2004, ApJ accepted,

astro-ph/0406390

THE AUSTRALIAN NATIONAL UNIVERSITY

Conclusions

With precise photometry (high dynamic range) of 10^5 to 10^9:

- Study planets as distant as 5 AU from solar type stars
- Detect planet morphology (rings)
- Draw inferences atmospheric scattering properties
- Can determine orbital inclination if V_{rad} known
- Difficult systematics at these levels

If contrast can be achieved at relevant distance from host:

- Get orbit automatically
- Get all planets automatically
- Low resolution spectra yield more info RE: atmospheres