

Orbital & Physical
Characterization
of TNO binaries

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Outline

- Known systems, a quick overview
- Orbits of resolved (visual) TNBs
 - Methods
 - Orbital parameters: the (true) orbit
 - Physical parameters: Mass – density
- Prospects

TNB observations

• Instruments

- Ground (AO/LGS, Magellan, Keck, CFHT, etc.)
- Space (HST)

• Numbers

- about 30 Centaurs and TNBs or TN systems, mostly from HST (4/5)
- about 12 with some orbital data (incl. Pluto and Centaurs)

• Data

- relative position
- relative magnitude (sometimes ambiguous)

Orbit determination

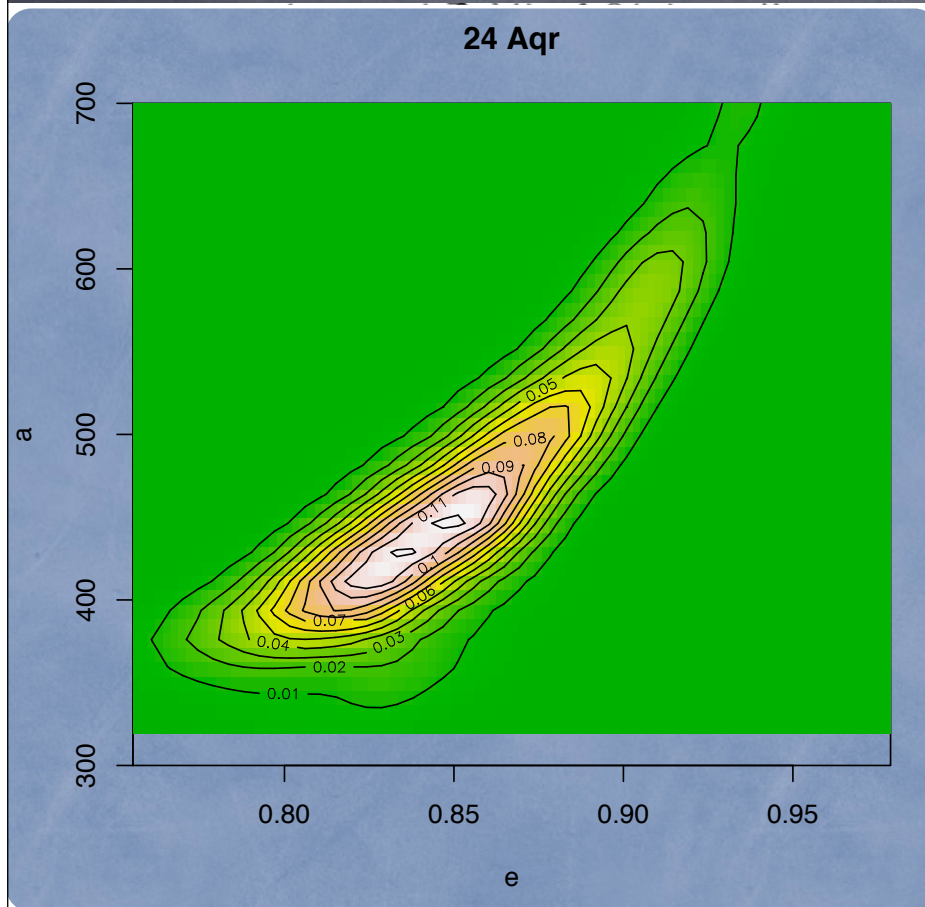
- Get the 7 parameters for the true (Keplerian or osculating) orbit
- Different methods → solution(s) **and** confidence region
 - already applied to MBBs and Trojans
 - GLS or LLS
 - statistical inversion, adapted to scarce and sparse data

New Method

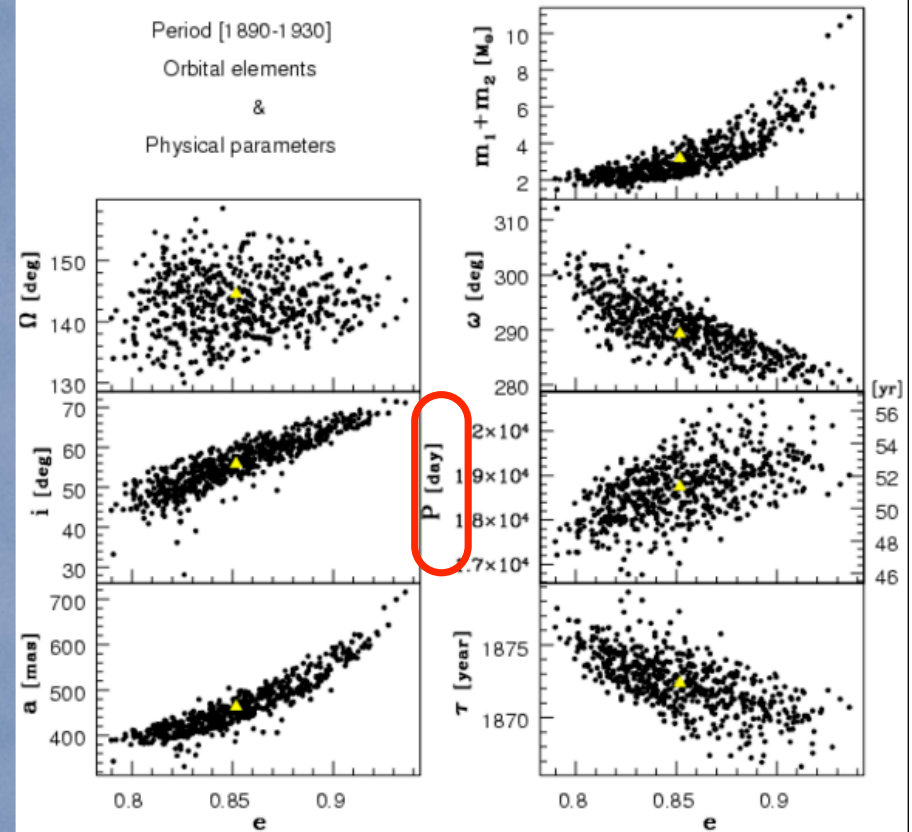
Hestroffer & Vachier 2005

- Based on Thiele Innes + Monte-Carlo
 - scan for only one parameter: the period P
=> it's fast
 - get the number density and the p.d.f.
=> solutions + confidence regions
- Well adapted to the case of TNBs with few observational data

24 Aquarii (R. Aitken)

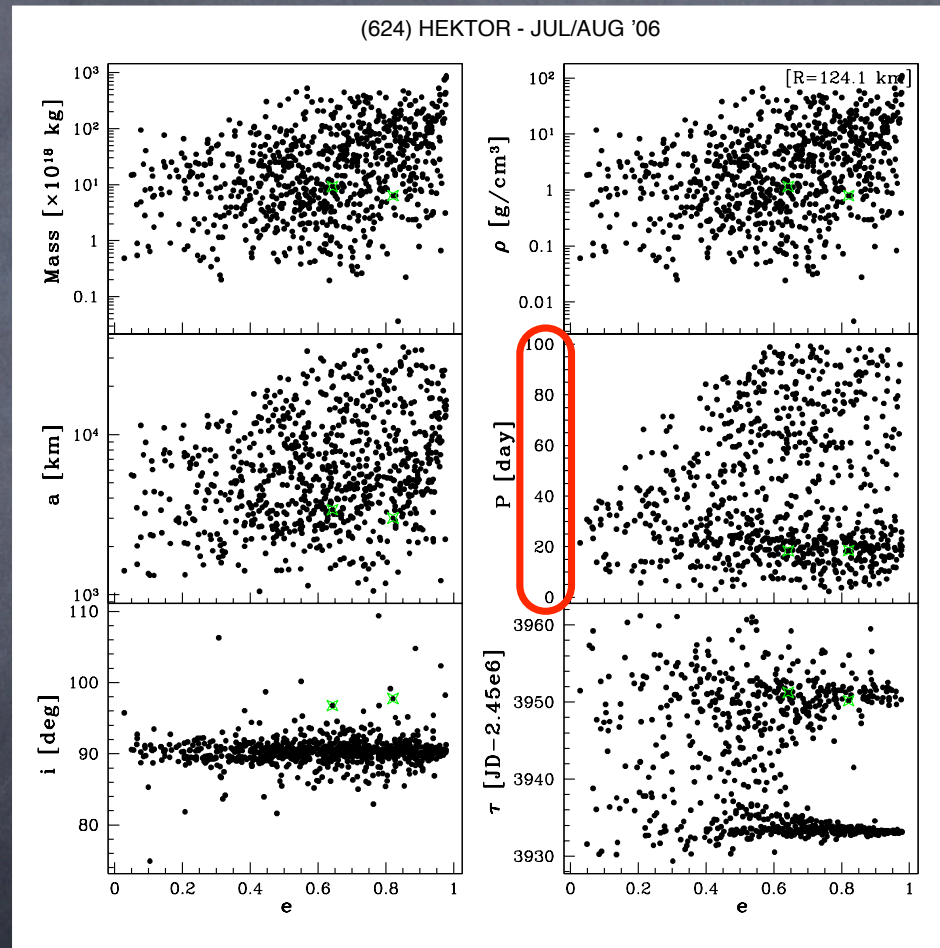


Visual binary 24 Aquarii

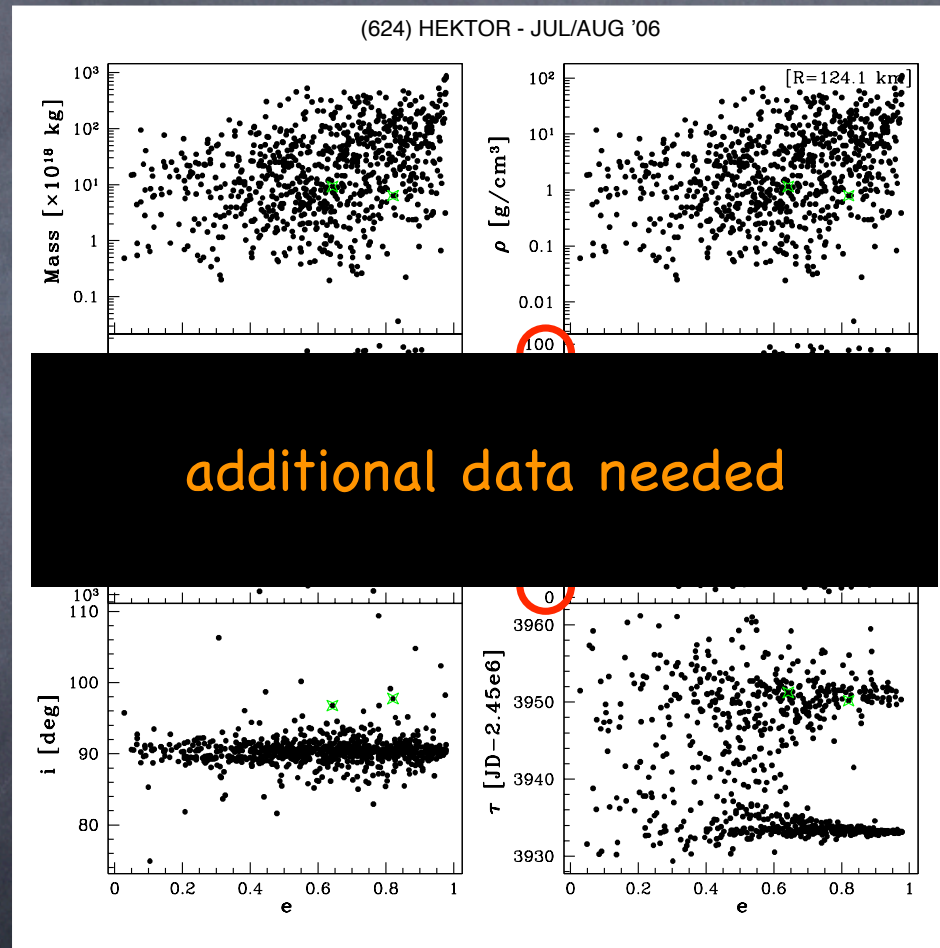


Trojan: 624 Hektor

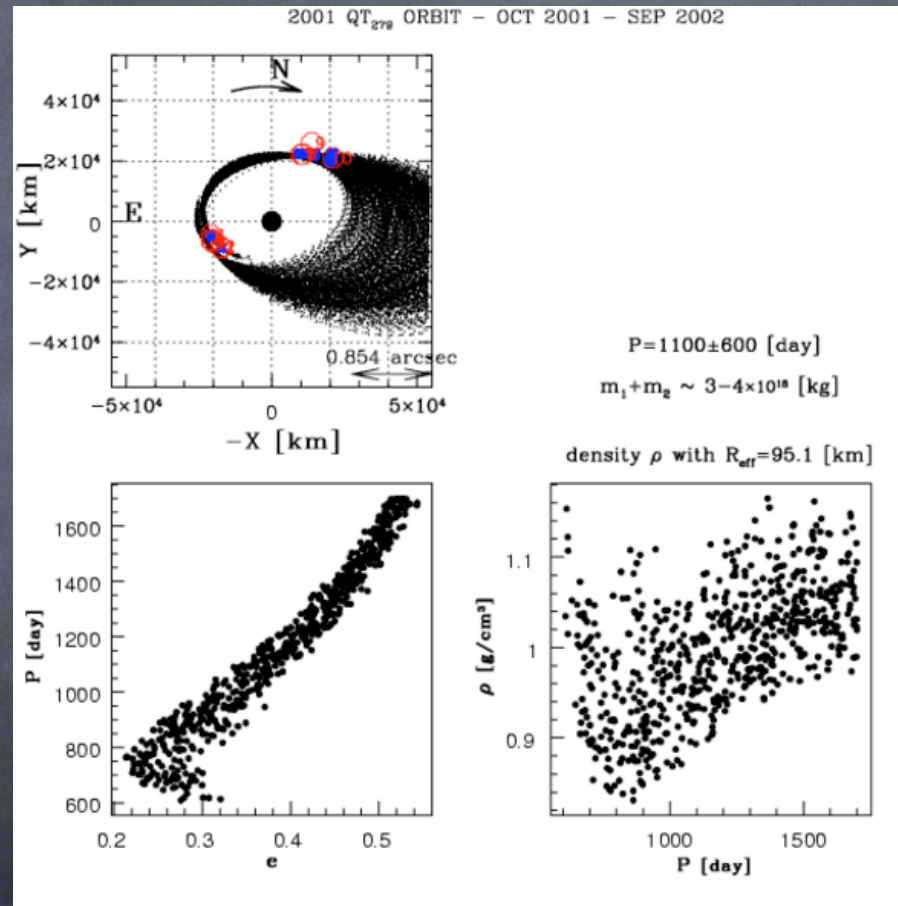
Marchis et al. 2006



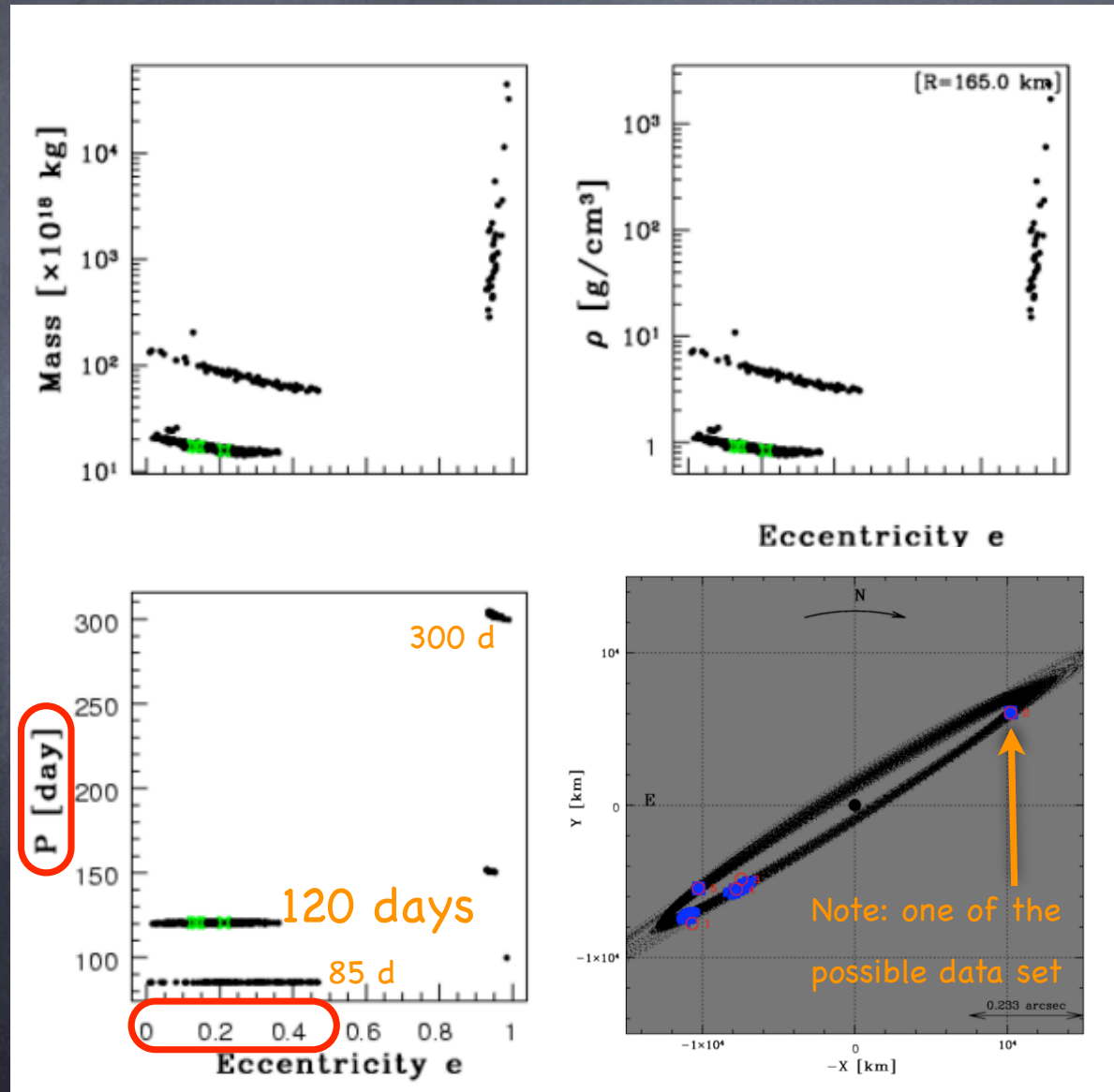
Trojan: 624 Hektor



2001 QT₂₉₇ (Osip et al. 2003)



2003 QY₉₀ (Kern & Elliot 2006)



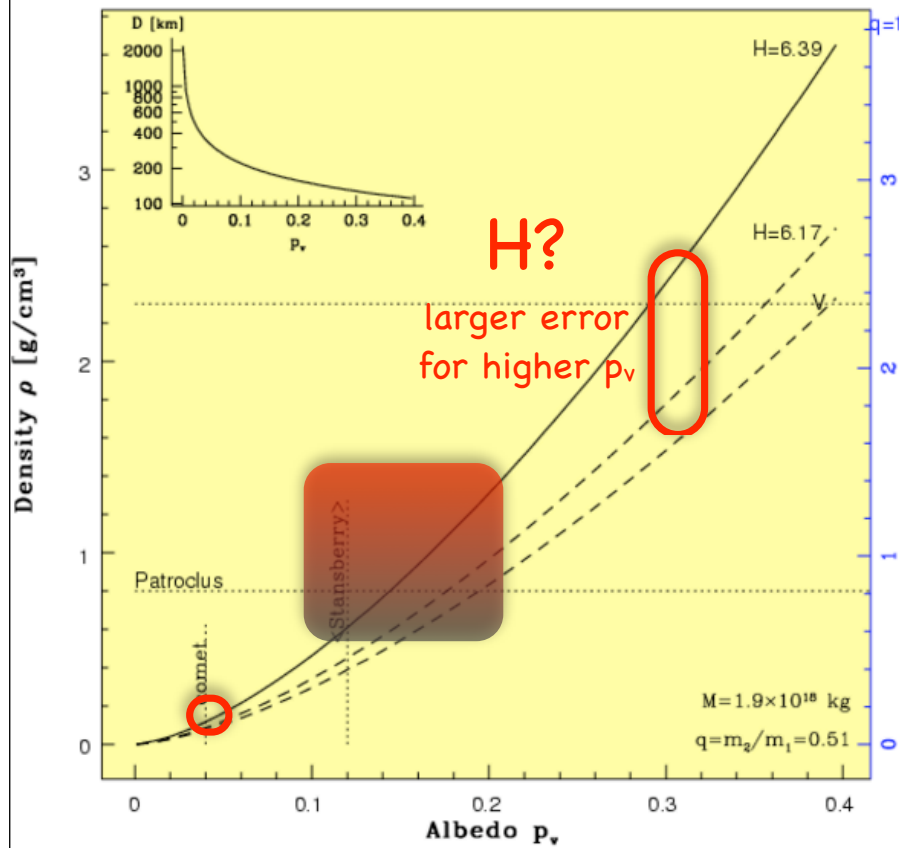
Physical parameters

- The total mass M_1+M_2
 - $q=M_2/M_1$
 - can be estimated from flux/size ratio, or $\ll 1$
(bias in mass due to J_2)
- The bulk density $\rho=M/V$
 - relation (ρ, H, p_v)
 - or model dependent (not only for binaries)

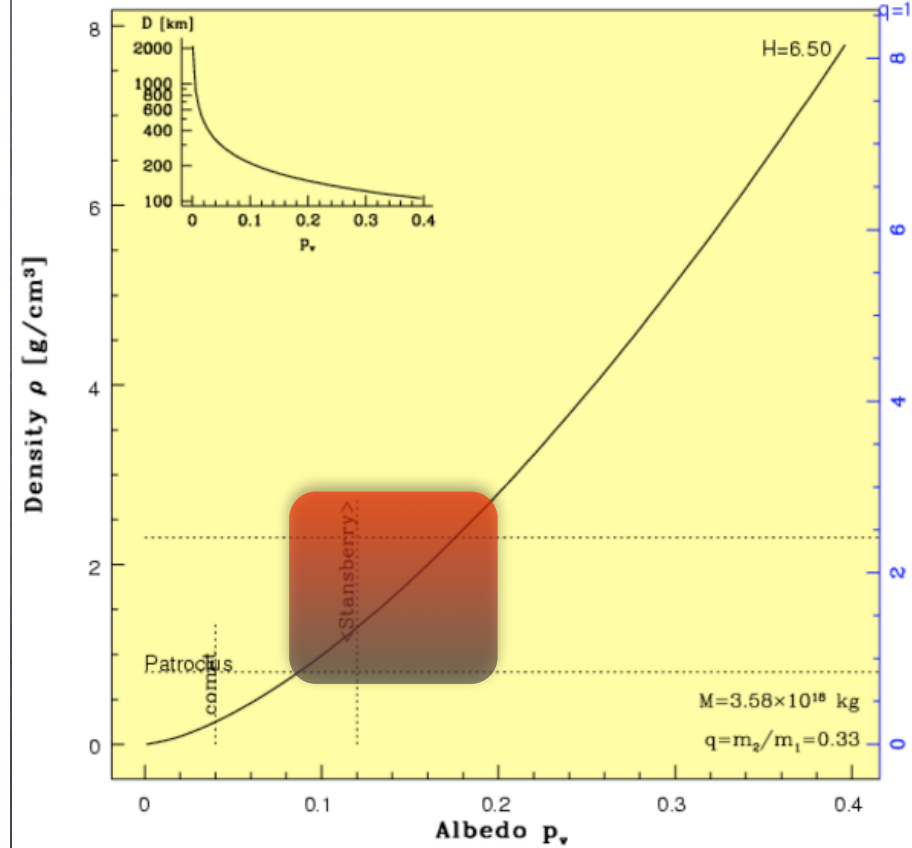
Bulk density

$$\rho = f(M, q, H, p_v)$$

2003 QY₉₀



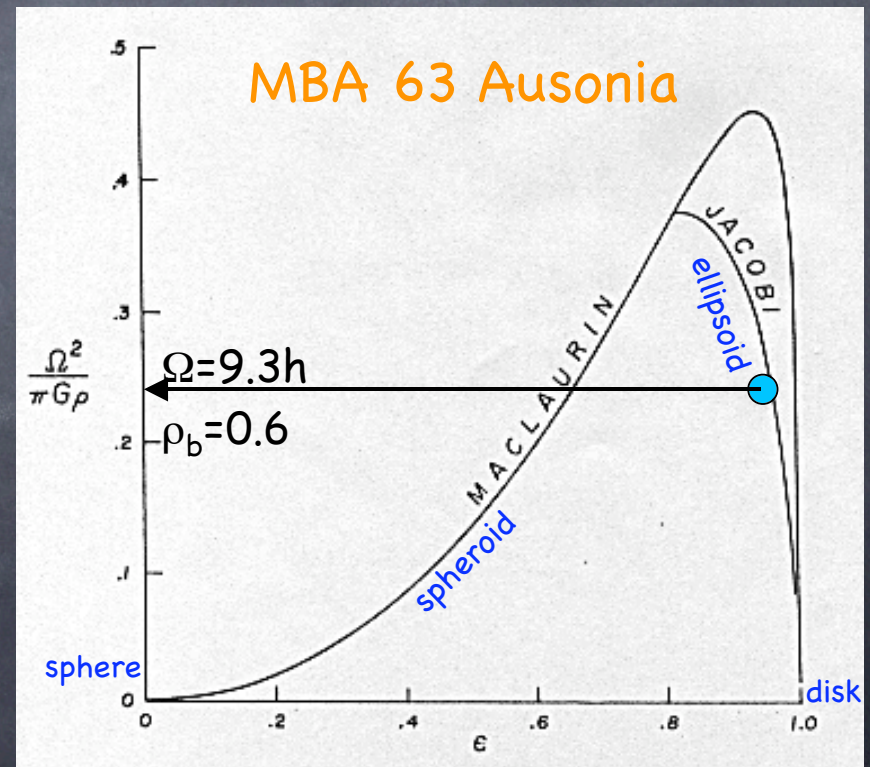
2001 QT₂₉₇



Bulk density

- Figures for hydrostatic equilibrium
e.g. Varuna (Jewitt & Sheppard 2002, 2004)

- Not only for binaries, needs the shape a:b:c
- Model dependent
 - validity? if small rub.piles
 - compressibility? if large



Orbital parameters

- Eccentricity, Period, a (a/R), etc.

- Inclination, 2 poles ambiguity

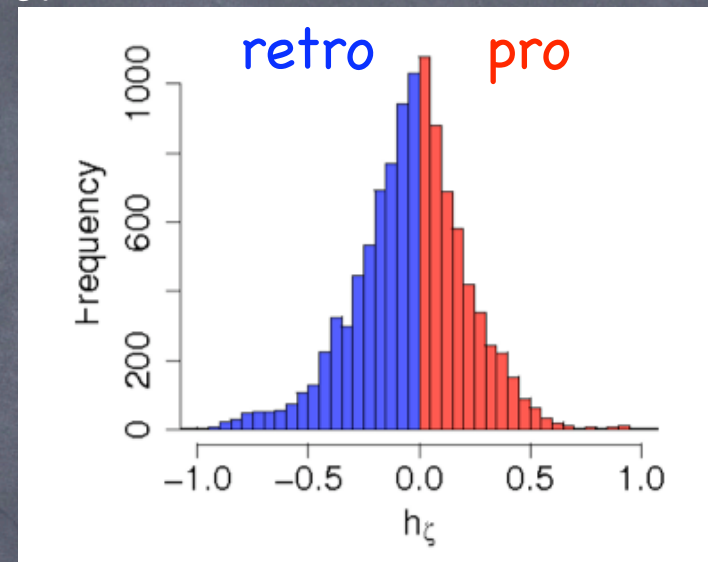
- Tests of formation models (CAC)
(prograde – retrograde)

- *Lee, Astakhov and Farrelly 2007*

- Prediction of mutual phenomena
(extremely rare events)

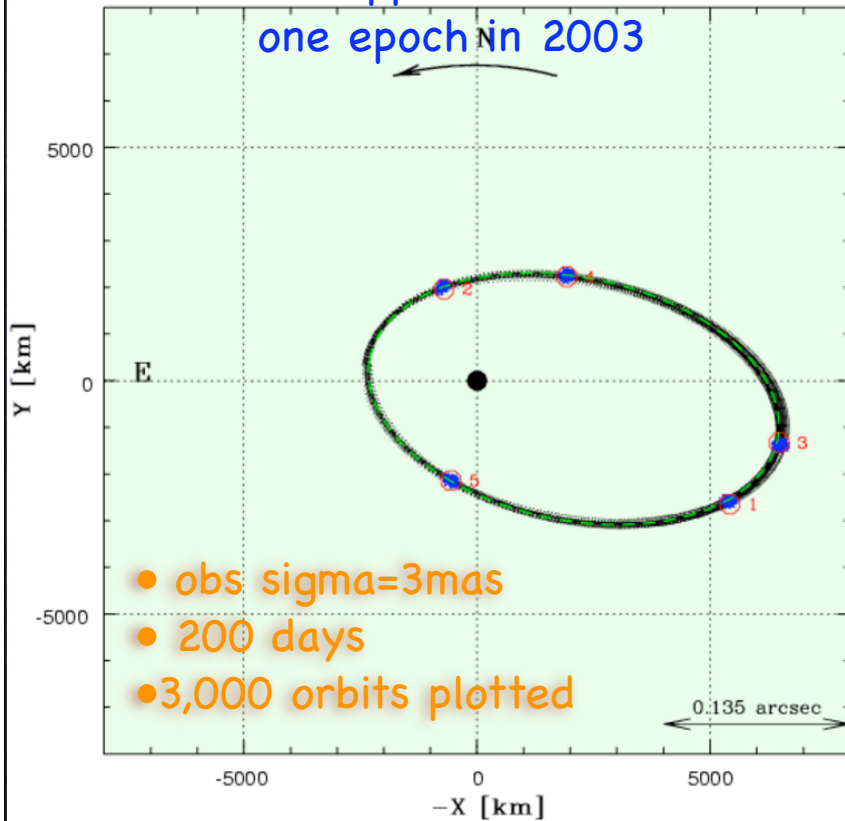
- occultation: sizes, etc. (sim Pluto-Charon late '80s)

- eclipses: thermal inertia

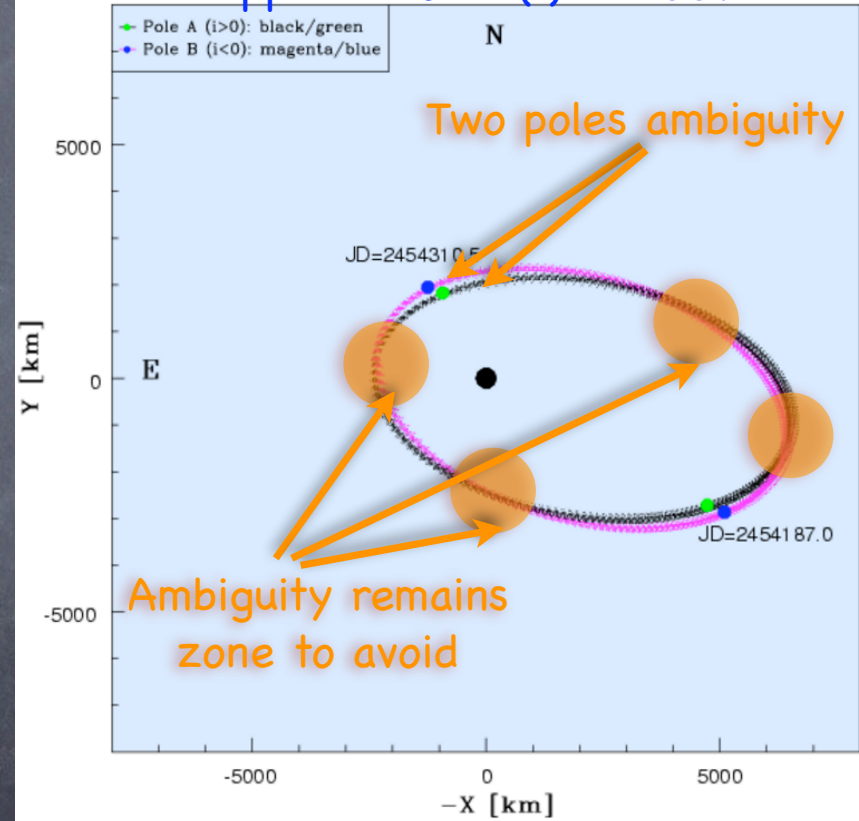


1999 RZ₂₅₃ (Noll et al. 2004)

Initial apparent orbit at one epoch in 2003

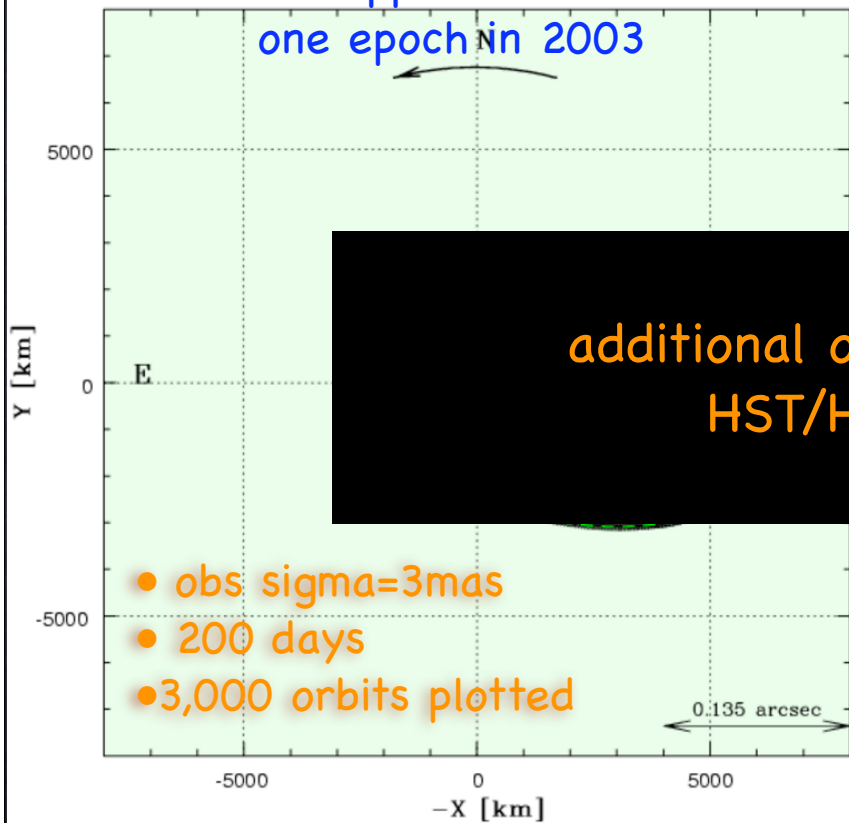


Apparent orbit(s) in 2007

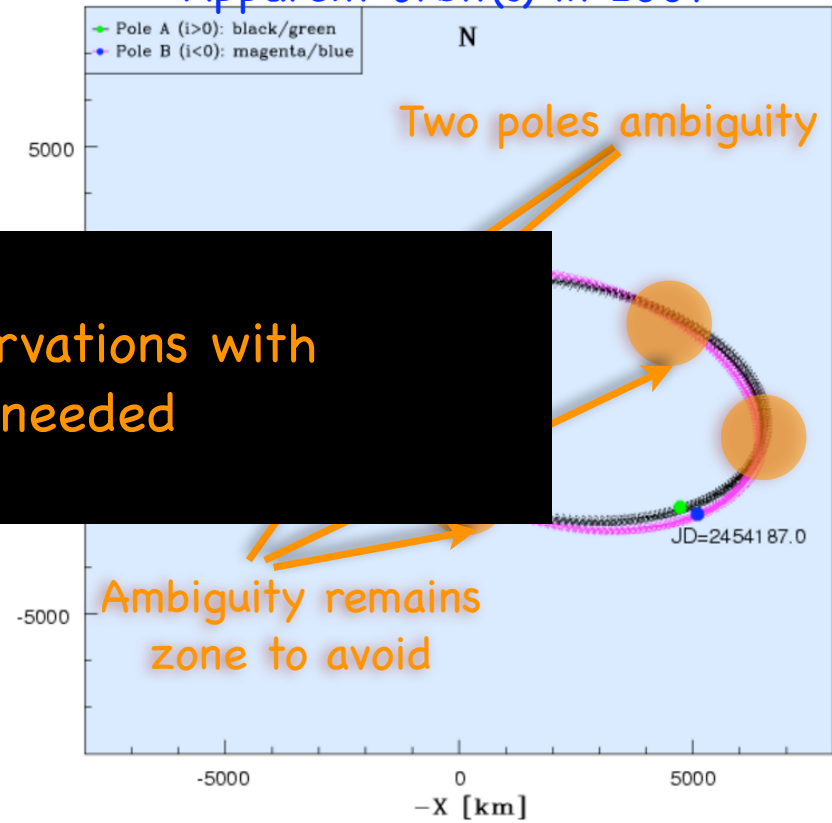


1999 RZ₂₅₃ (Noll et al. 2004)

Initial apparent orbit at one epoch in 2003

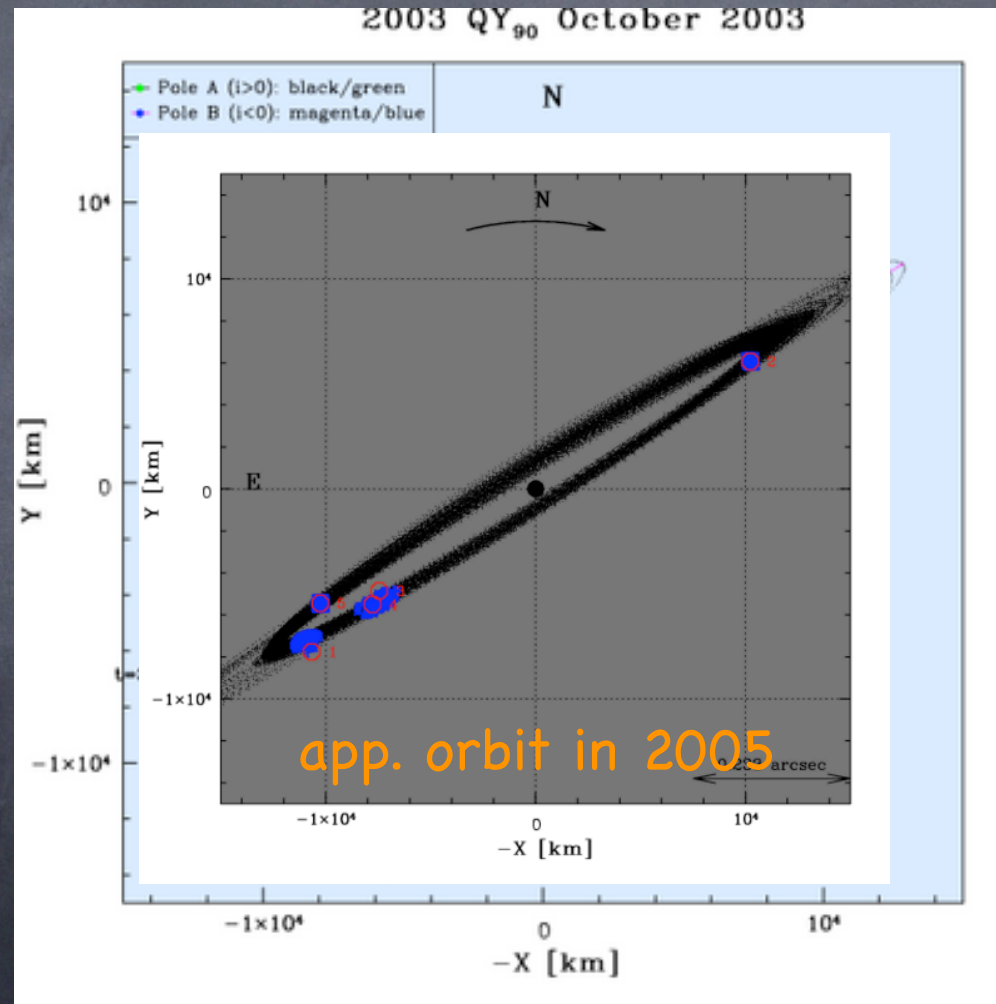


Apparent orbit(s) in 2007

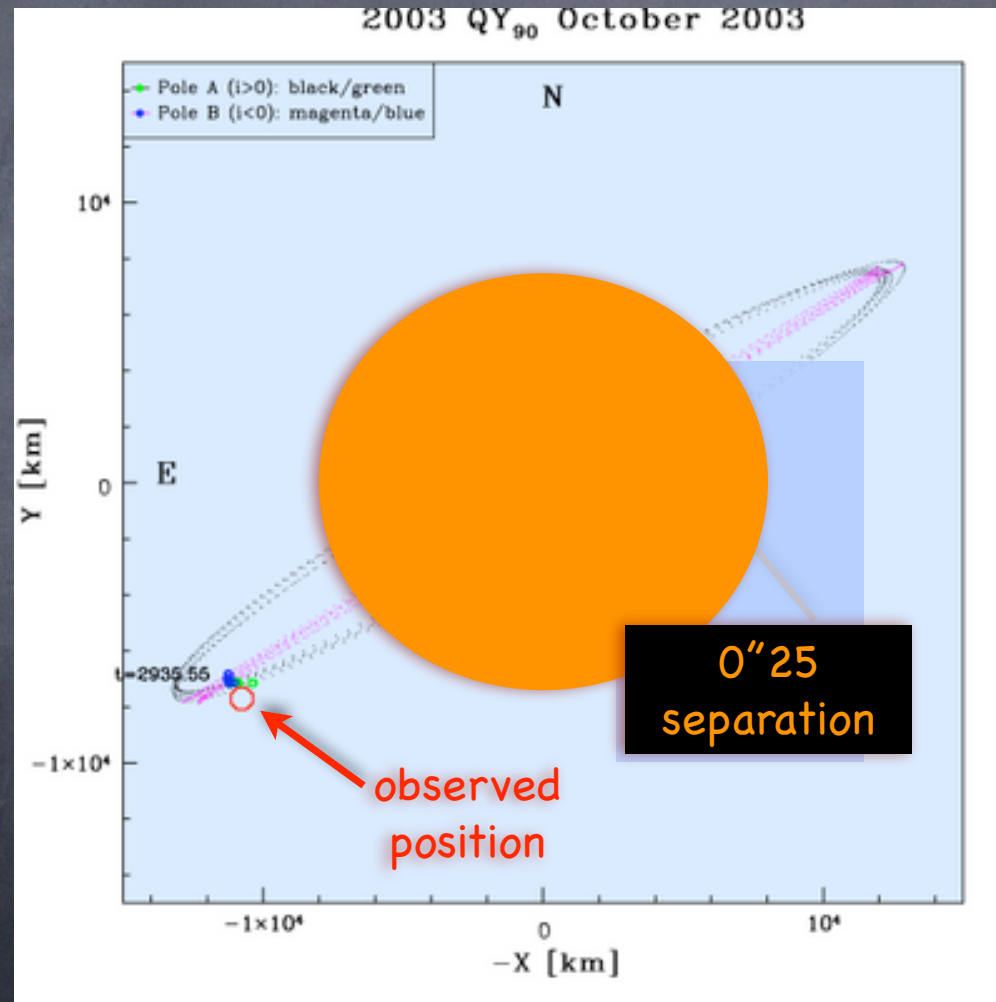


additional observations with HST/HRC needed

2003 QY₉₀ (Kern & Elliot 2006)

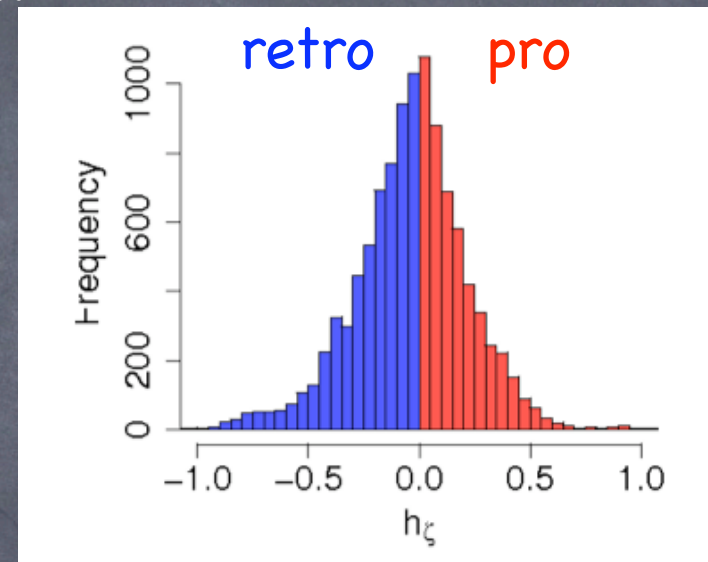


2003 QY₉₀ (Kern & Elliot 2006)



Orbital parameters

- Eccentricity, Period, a (a/R), etc.
- Inclination, 2 poles ambiguity
 - Tests of formation models (CAC) (prograde – retrograde)
Lee, Astakhov and Farrelly 2007
 - Prediction of mutual phenomena (extremely rare events, 2/250 years)
 - occultation: sizes, individual info. (sim Pluto–Charon late '80s)
 - eclipses: thermal inertia (e.g. Patroclus, [M. Müller et al.](#))

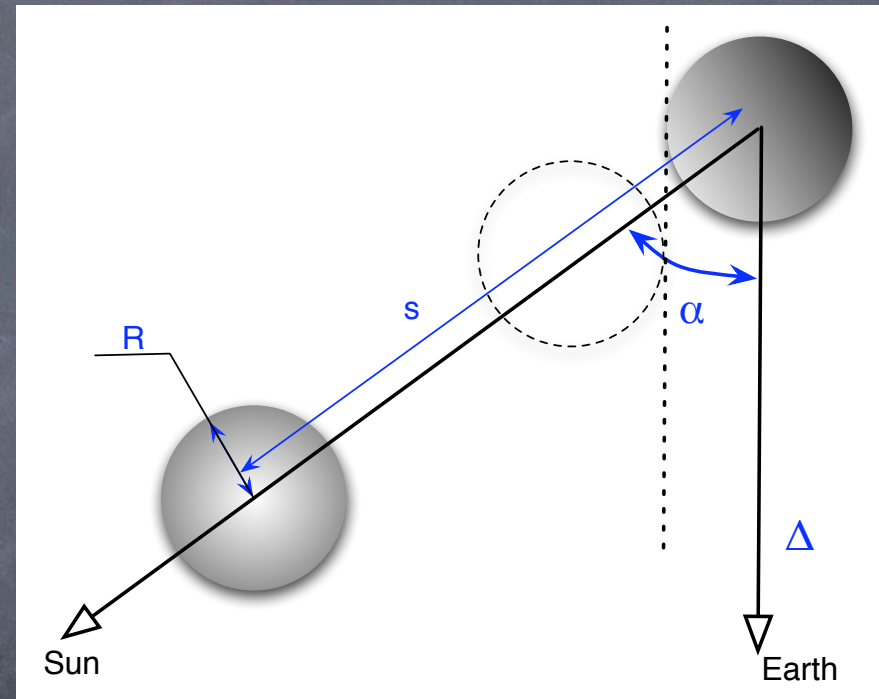


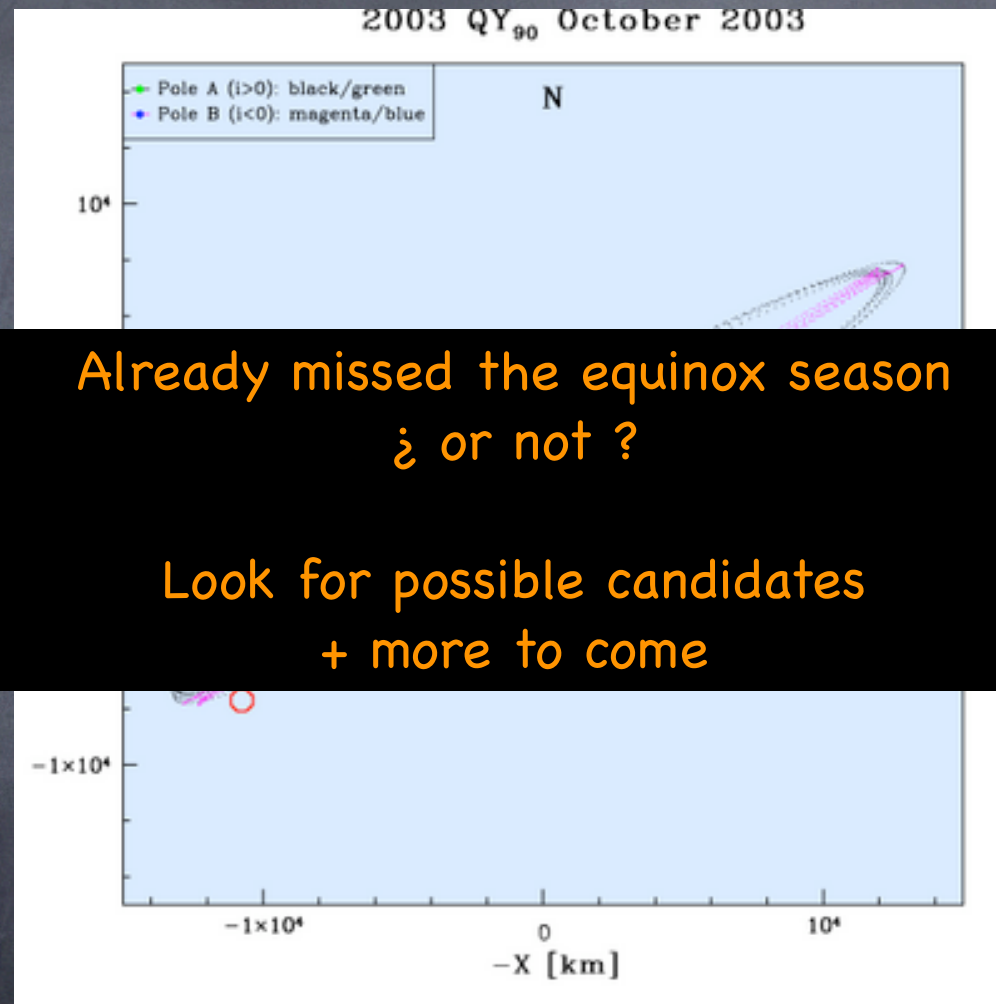
Eclipse

- Phase angle is small
 $\alpha \approx 1^\circ$
- To see the shadowed surface (cooling/heating)

$$\Delta \leq \frac{a(1-e)}{2R} \leq \frac{s}{2R} \approx 10 - 150 \text{ AU}$$

- If no shadow, however asymmetric slopes at immersion and emersion





Already missed the equinox season
¿ or not ?

Look for possible candidates
+ more to come

Oblateness perturbations

- Effect of J_2 ($-C_{20}$)

combined $J_2 \approx J_{2,\text{prim}} + (R/a)^2 J_{2,\text{sec}}$

Periodic + **Secular** effects

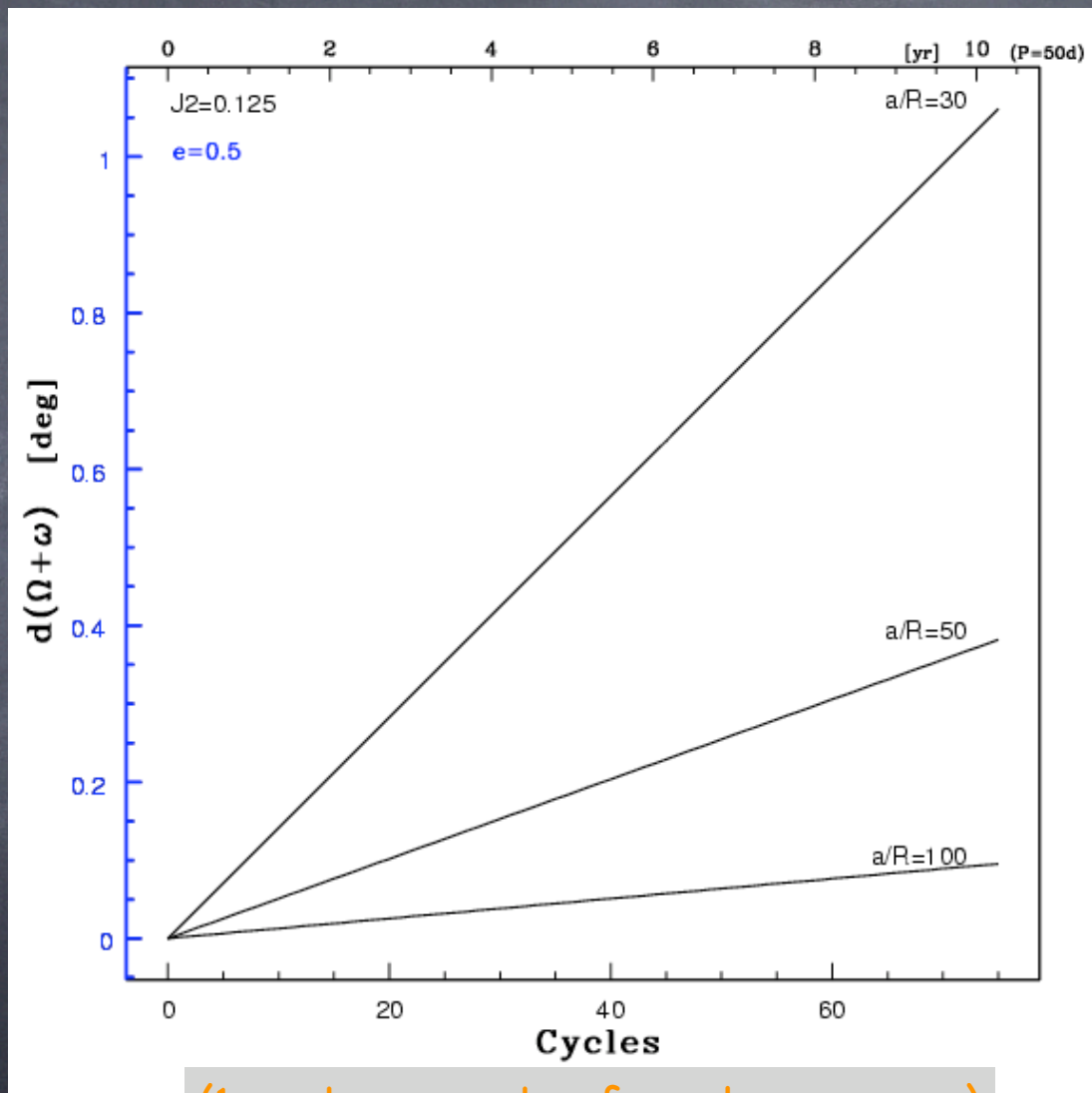
- Equatorial and circular orbit little sensitive

$e \cdot d\omega, \sin(I) \cdot d\Omega$

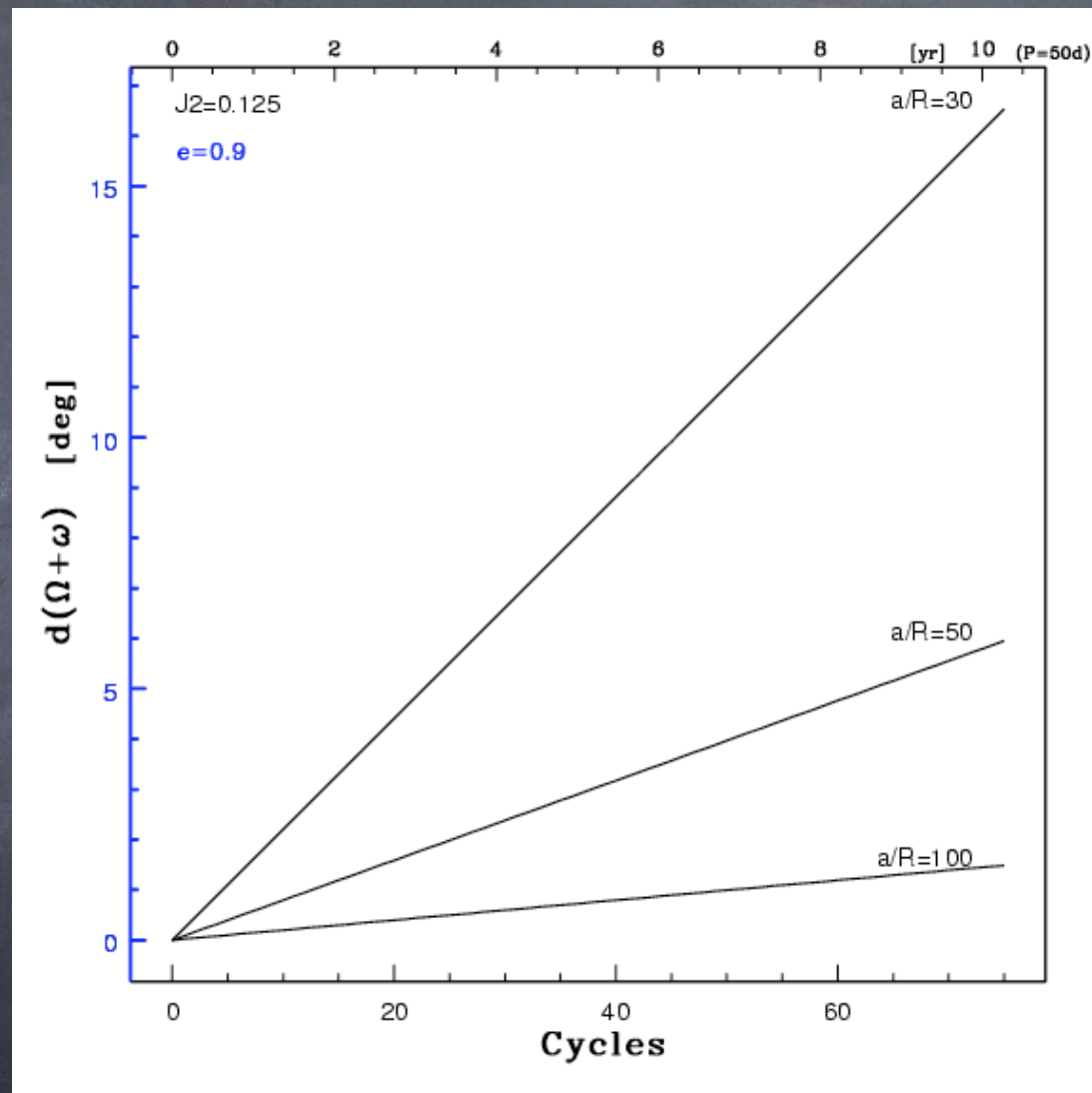
- Eccentric orbits (case $I=0$)

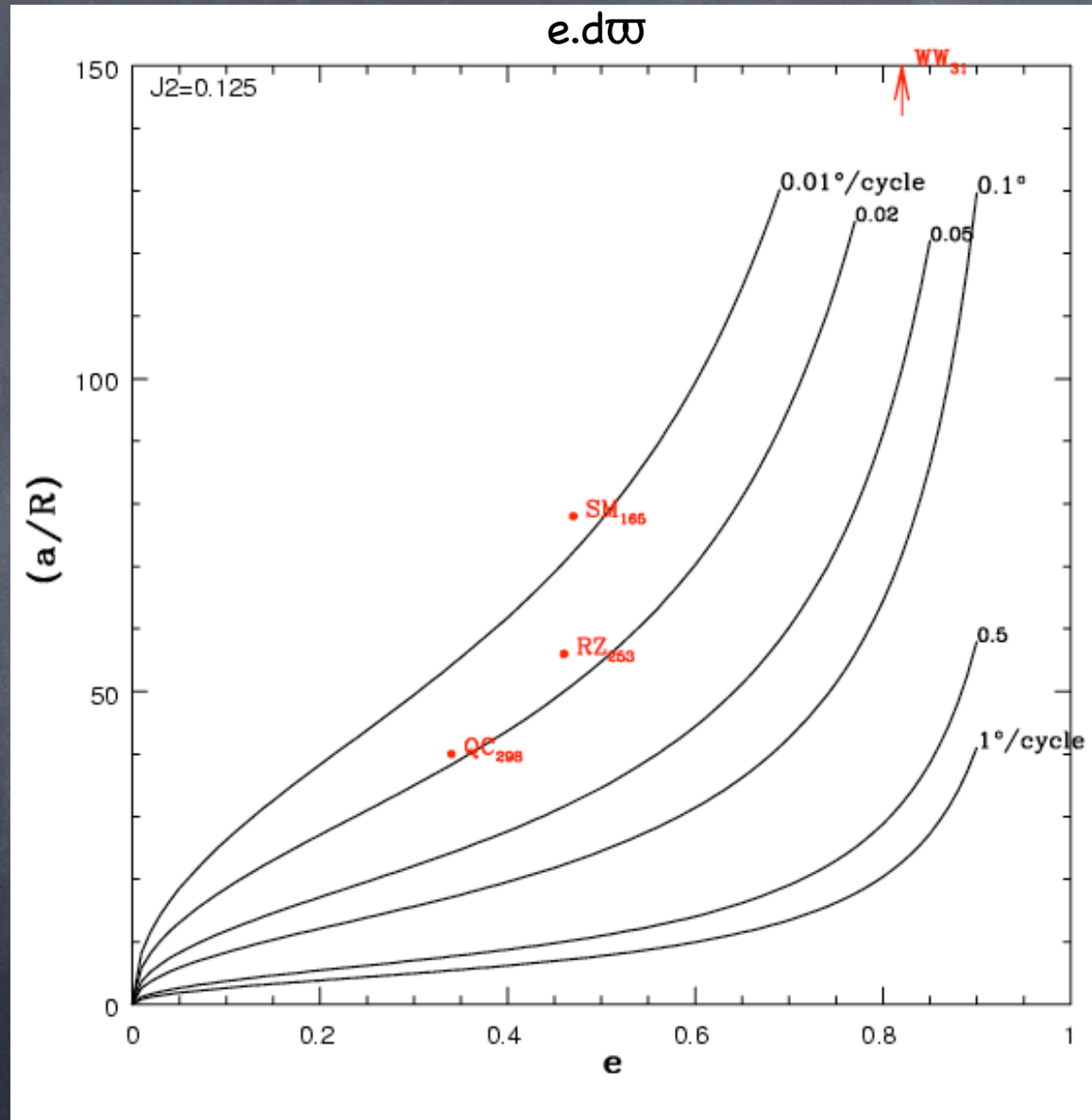
- $d\omega/dt = 3\pi J_2 (R/a)^2 (1-e^2)^{-2}$ (**rad/cycle**)

- $J_2 \approx 0.1-0.15, R/a \approx 10-300, e \approx 0-0.8$



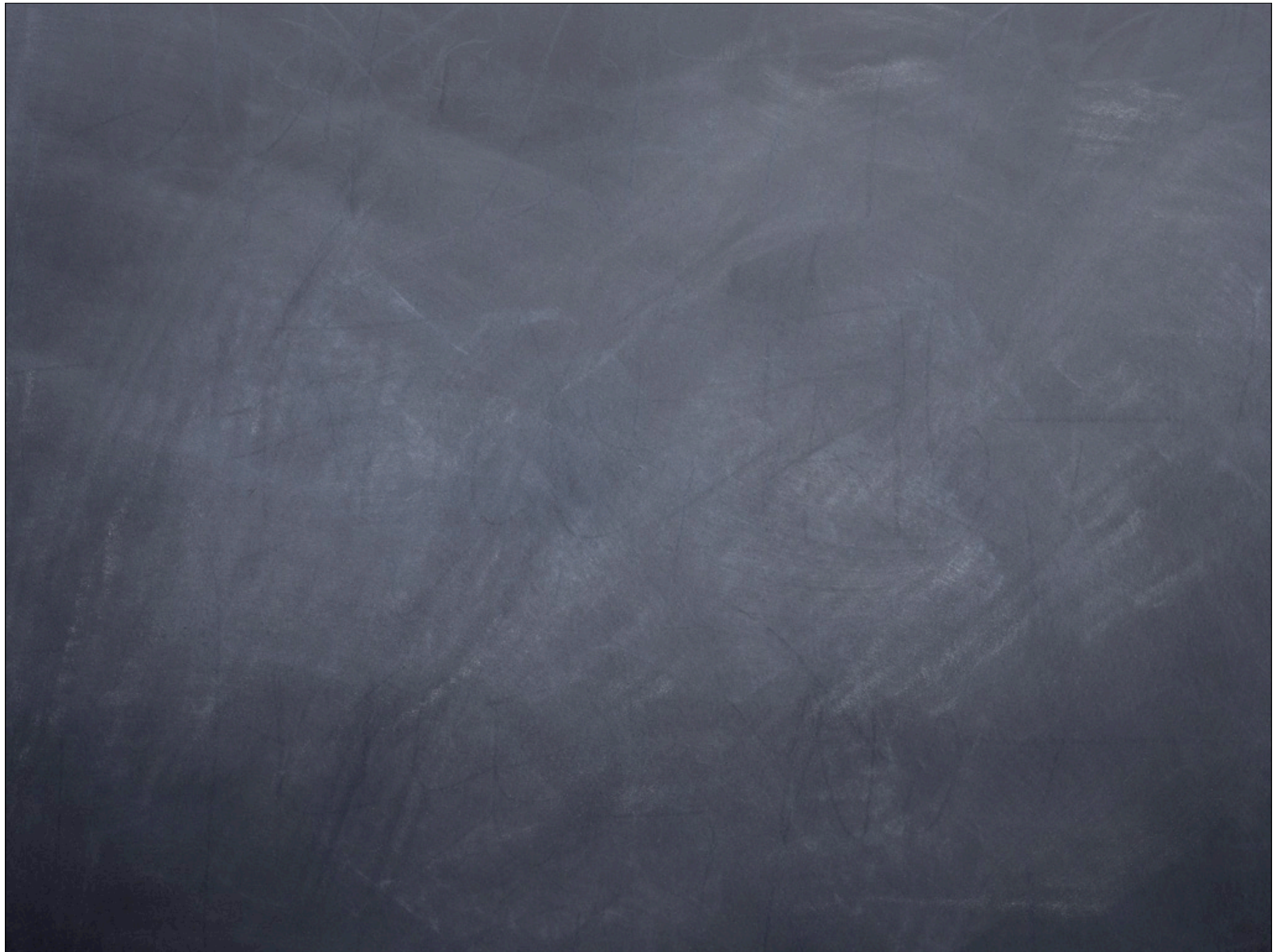
(1 cycle = couple of weeks or years)



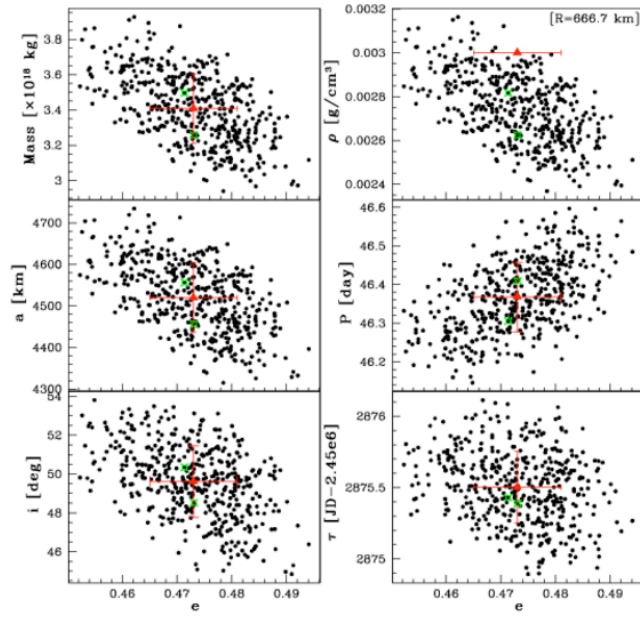


Summary

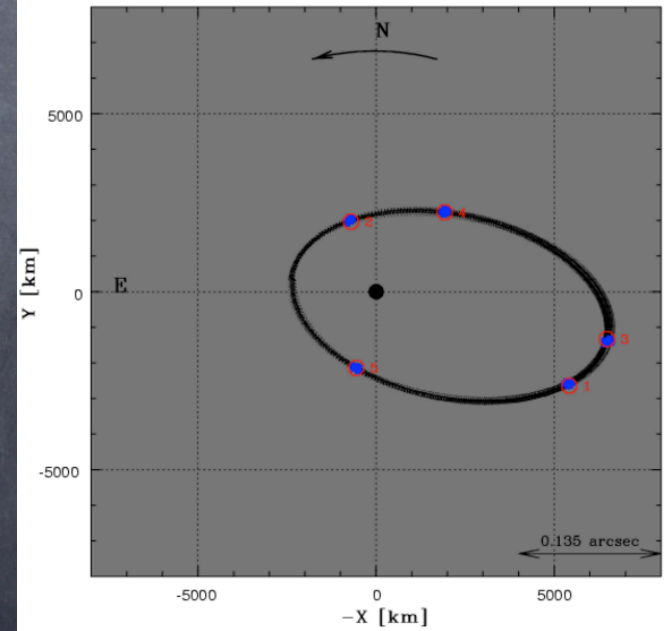
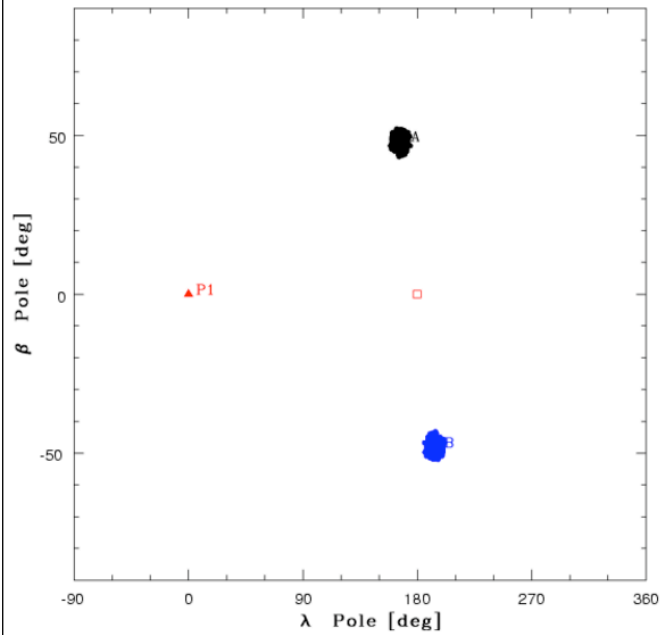
- Binary is cool.....at least for total mass
- HST/HRC is —high sensitivity & accuracy
- Bulk density is —what can be inside?
- Monitor orbits for
 - (unambiguous) orbital pole.....formation and phenomena
 - precession



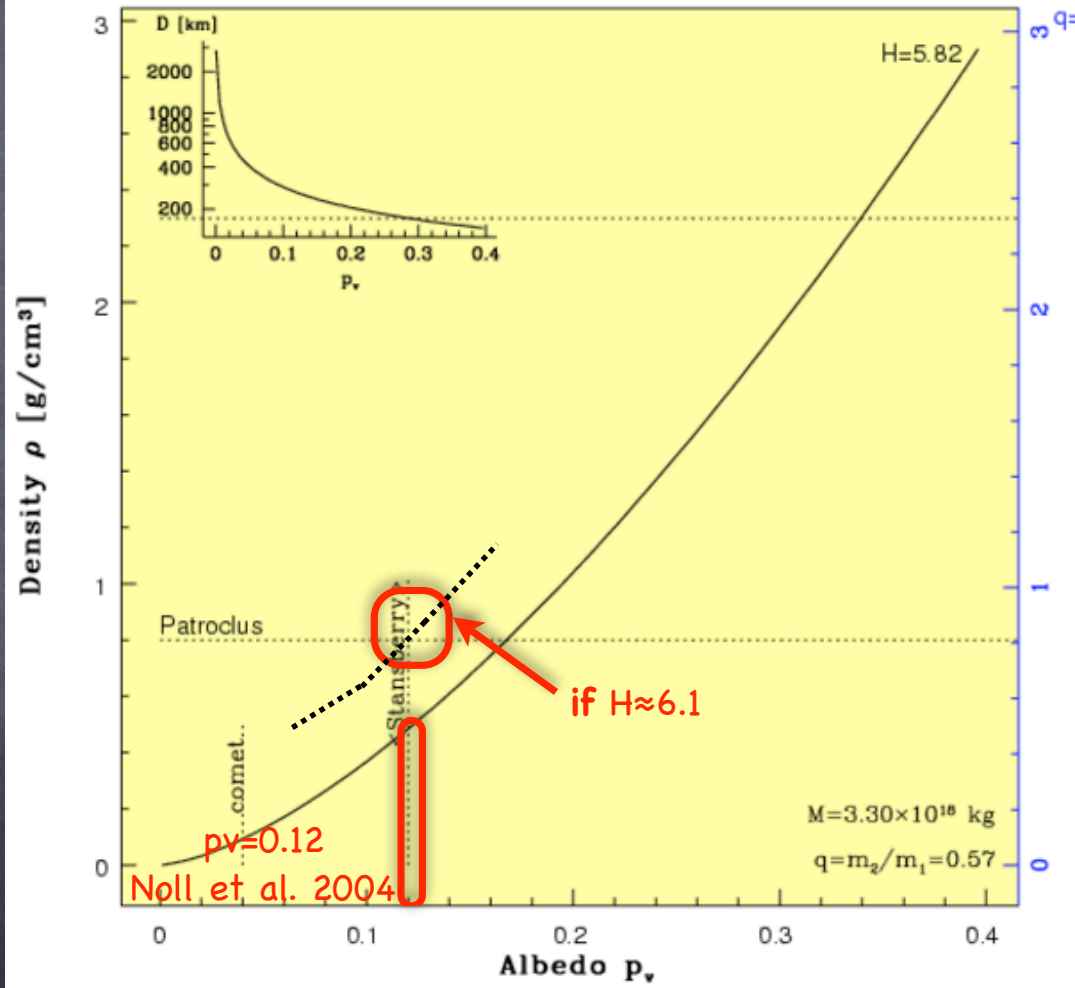
1999 RZ₂₅₃ (Noll et al 2004)



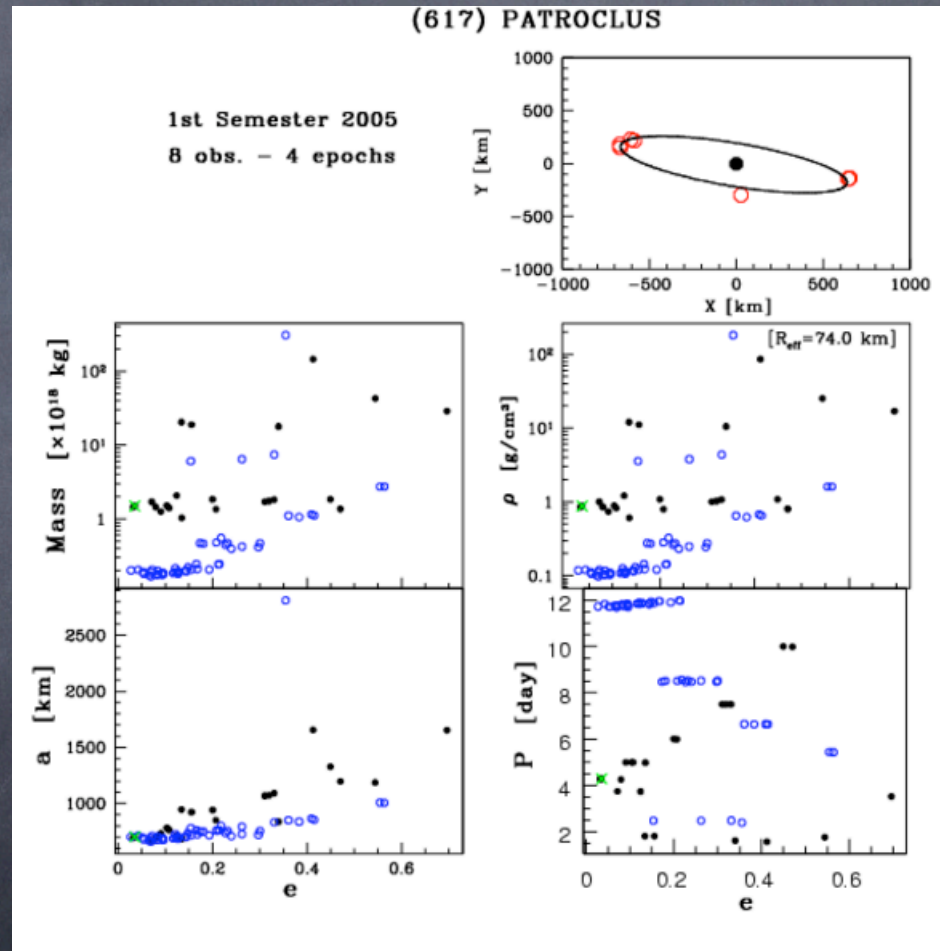
POLE ECLIPTIC J2000



1999 RZ₂₅₃



Trojan: 617 Patroclus



before Marchis et al. 2006

