ESTIMATING THE SHAPES AND SPINS OF ASTEROIDS FROM GAIA DR3 PHOTOMETRY

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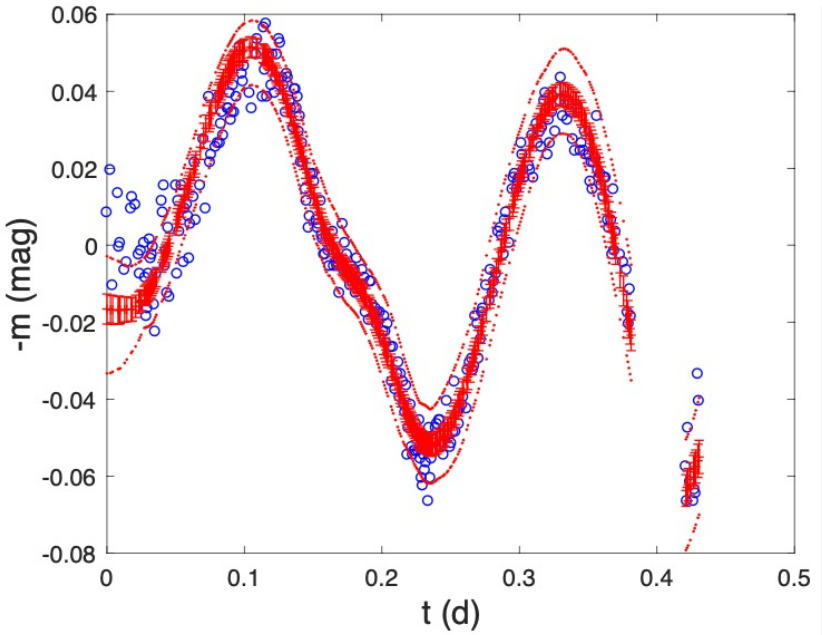
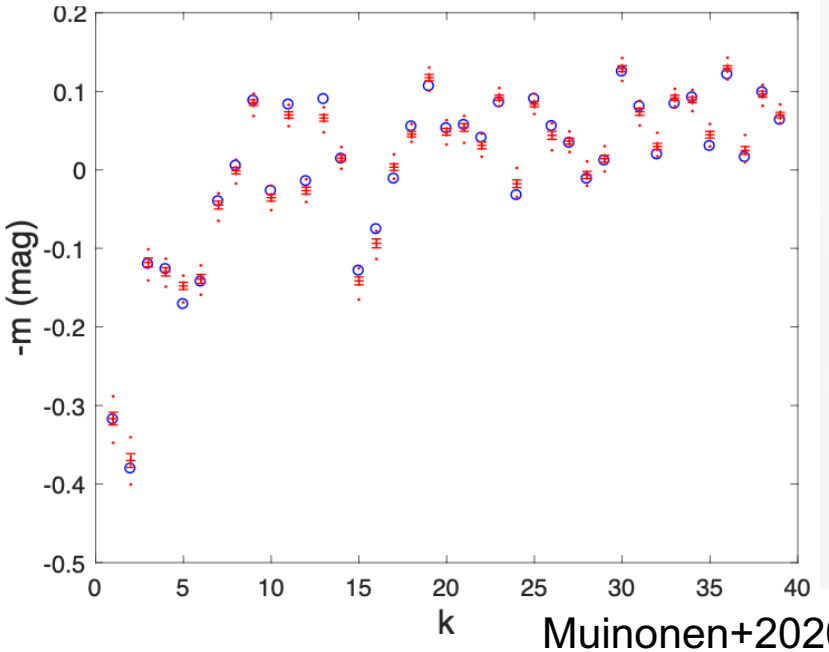
PHOTOMETRIC INVERSION

- brightness variation as an asteroid rotates provides information about its shape
- traditionally, dense lightcurves are used (*top right*)
- multiple lightcurves at different viewing aspects can be *inverted* into a best-fit shape model
  - assuming a convex shape gives stable solution(s)
- adoption of accurate sparse photometry has been demonstrated to be useful (*bottom right*)





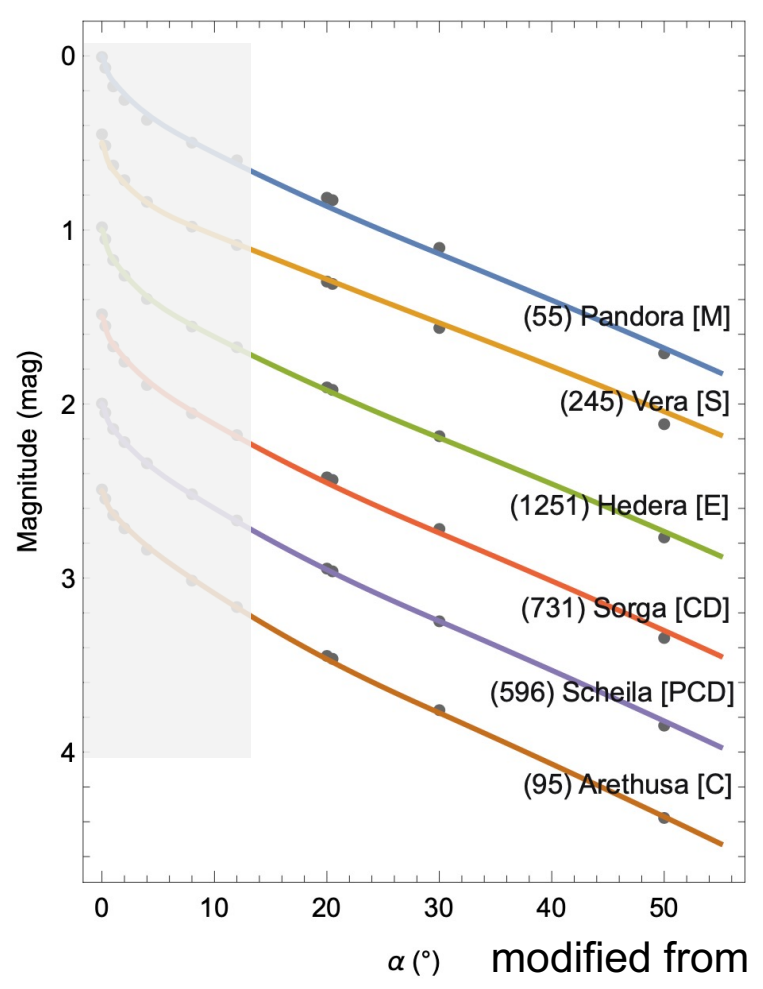
Muinonen+2020

Gaia Data Release 3 (GDR3)

- sparse in time *absolute* photometry for 150,000+ asteroids spanning 34 months (Tanga+2022)

- serendipitous observations of asteroids typically occur at solar phase angles, $\alpha > 15^{o}$
  - linear phase function is appropriate
  - no opposition effect (greyed out area)

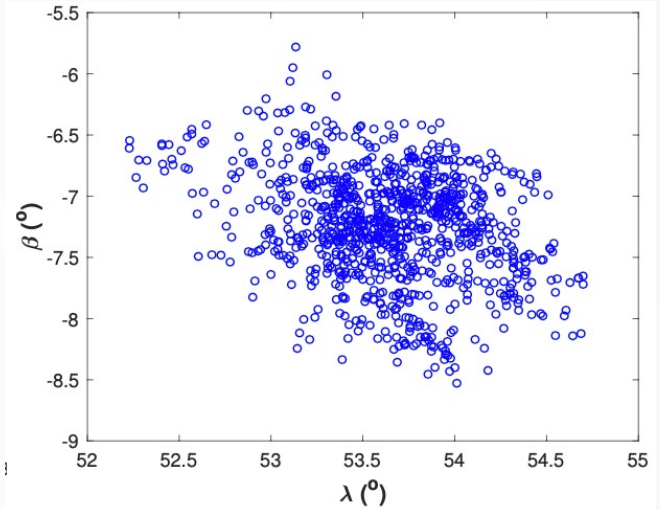
- we use asteroids with at least 25 *Gaia* transits
  - mostly main-belt asteroids

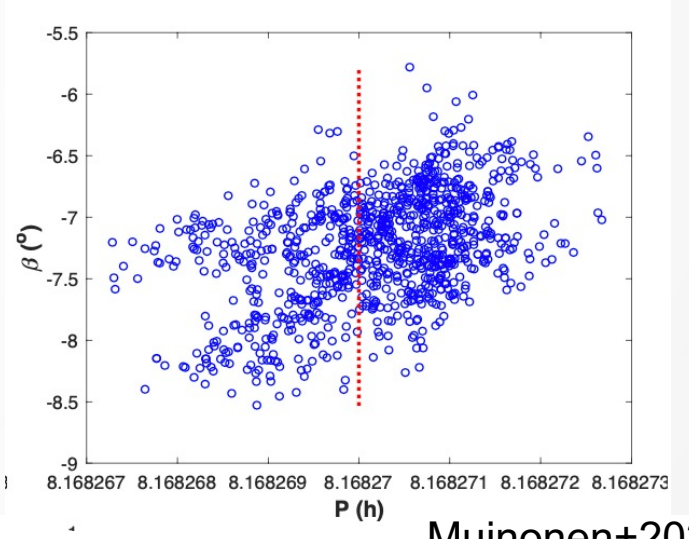


modified from Martikainen+2021

Inversion Procedure Characteristics

- rotation period, spin axis (latitude & longitude), linear photometric slope, two shape assummptions:
  1. triaxial ellipsoid shape (**EI**)
     - b/a and c/a ratios
  2. convex shape (**CXI**)
     - described by Gaussian surface density
     - maximum of four degrees in spherical harmonic function
- use MCMC to account for observational (random) and systematic (model) uncertainties (Muinonen+2020)
- N = 22,812 asteroids considered

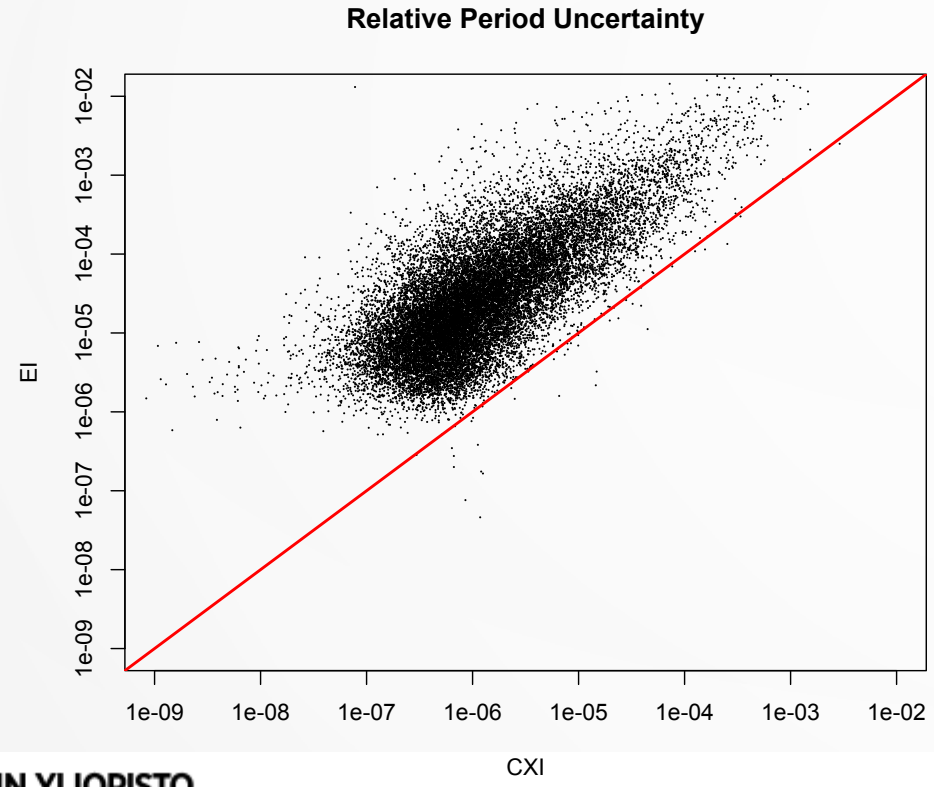




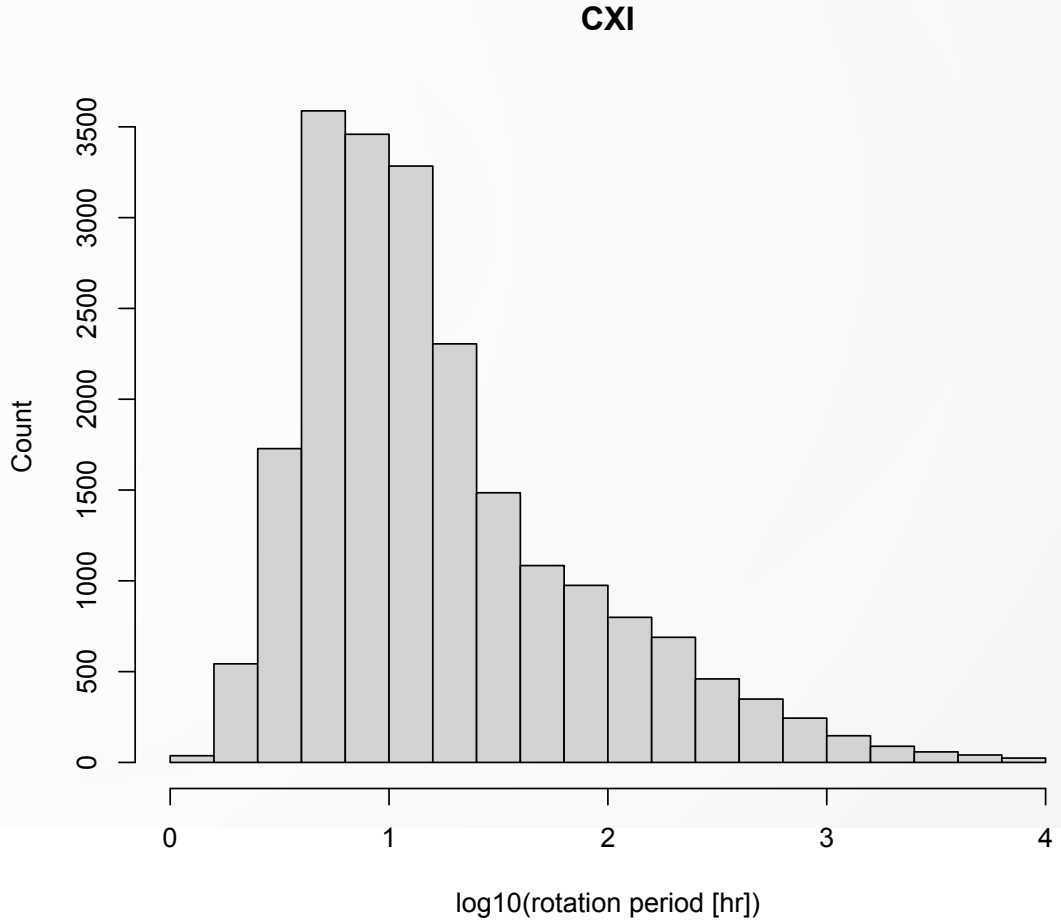
Muinonen+2020

Rotation Periods

- relative rotation period uncertainties using convex shapes are, on average, lower by an order of magnitude

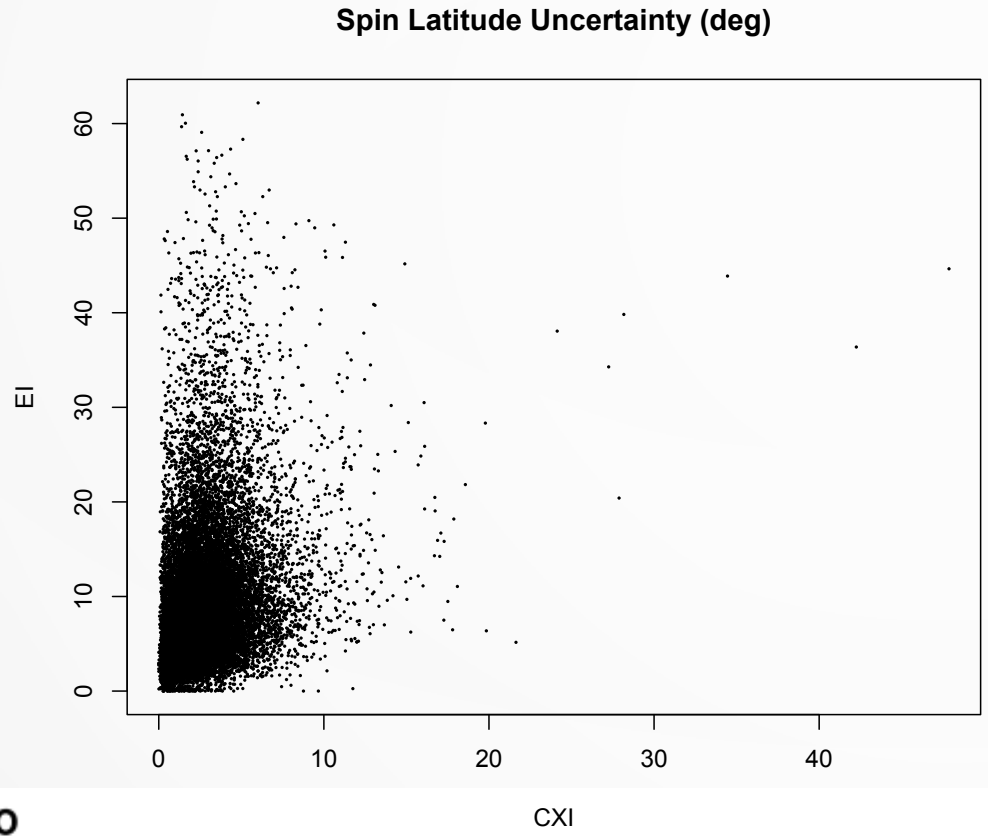


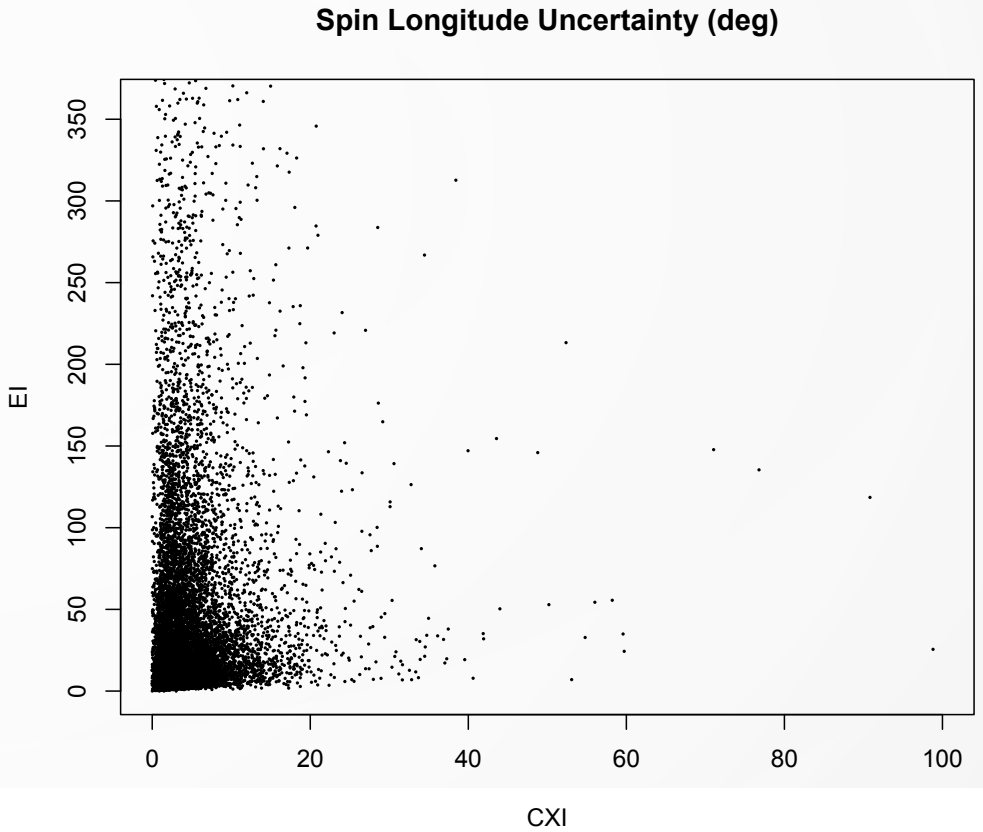
- we find a significant number of slow rotators (P_{rot} > 100 hr)
- tumbling (non-principal axis rotation) is very likely
- some fraction could be binaries with long orbital periods



Spin Axes
(ecliptic coordinates)

- CXI spin axis uncertainties are much smaller than EI
- best-fit solutions for CXI and EI mostly agree





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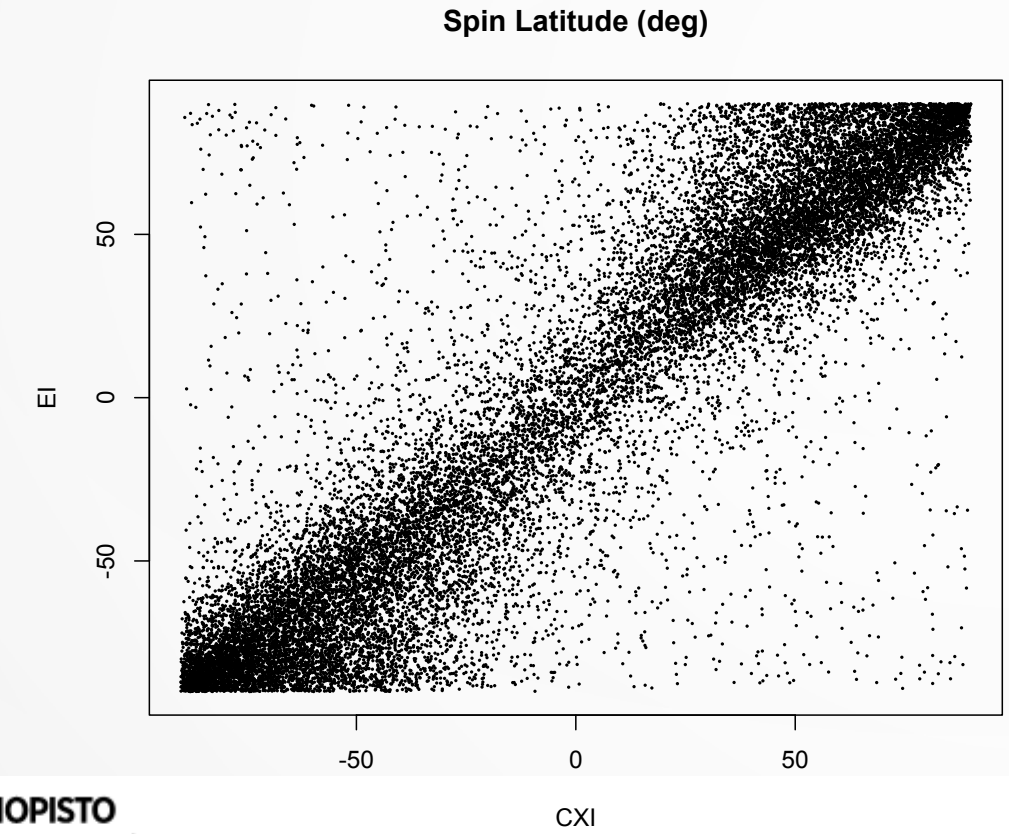
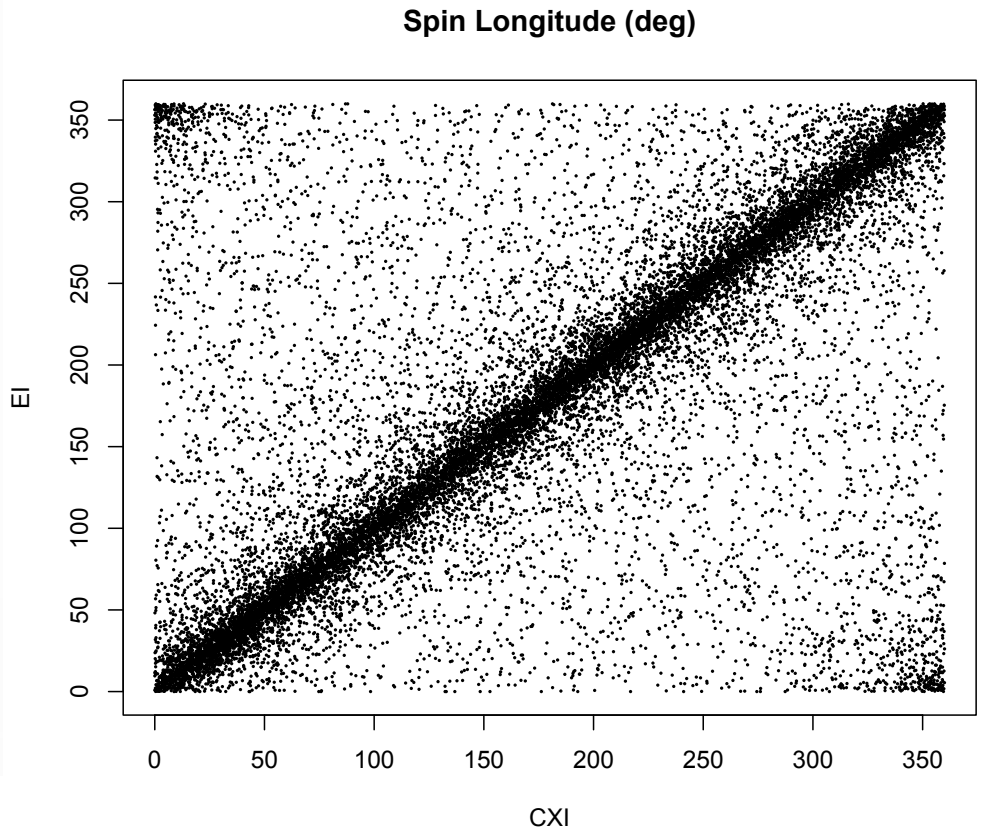
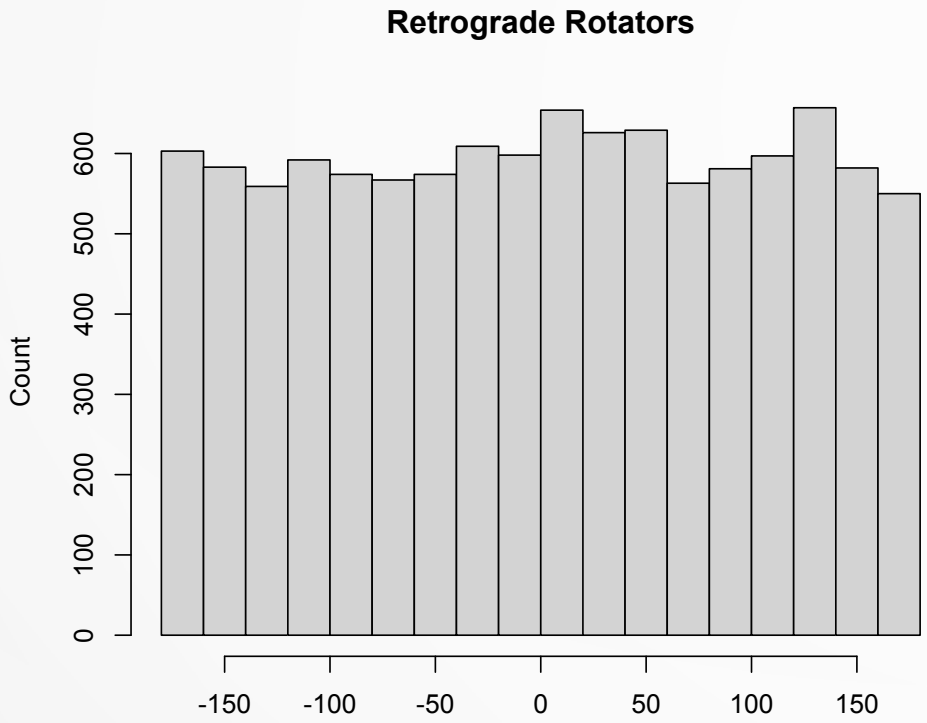
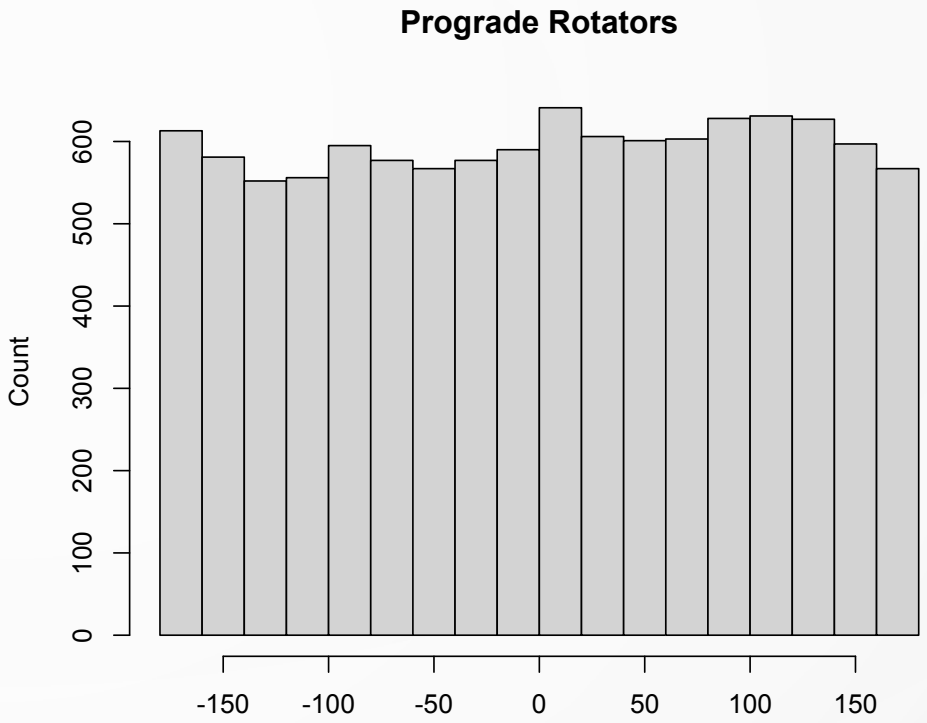




Ellipsoid Spin Axes

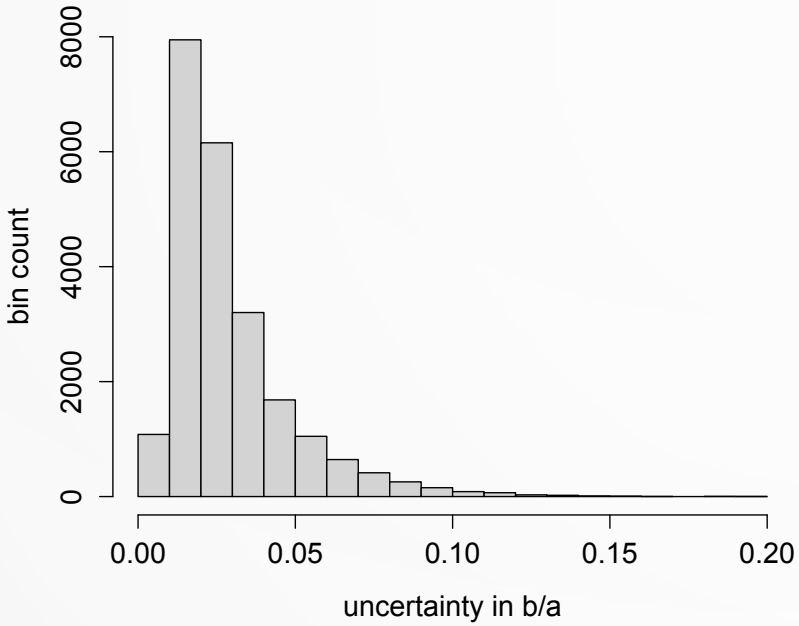
- non-uniform spin axis longitudes for retrograde spins only
- similar features seen by Cibulková+2016

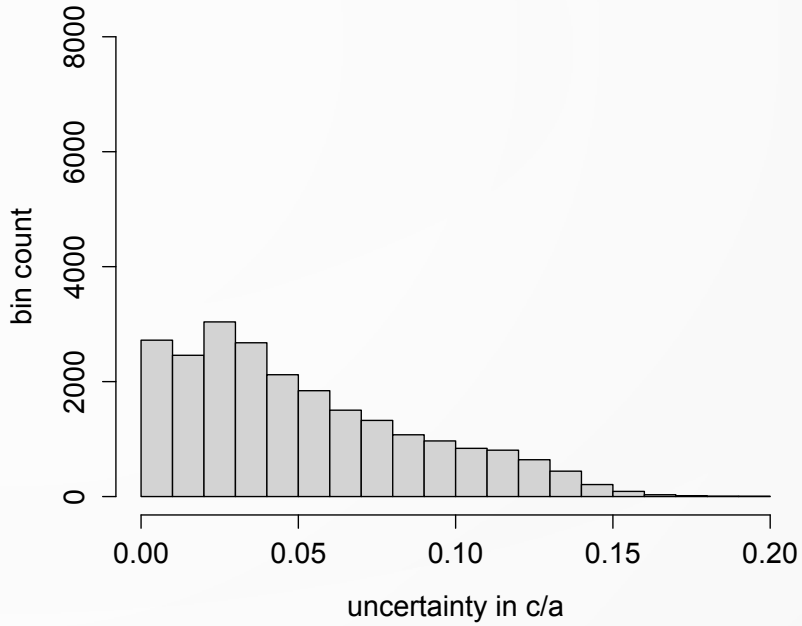




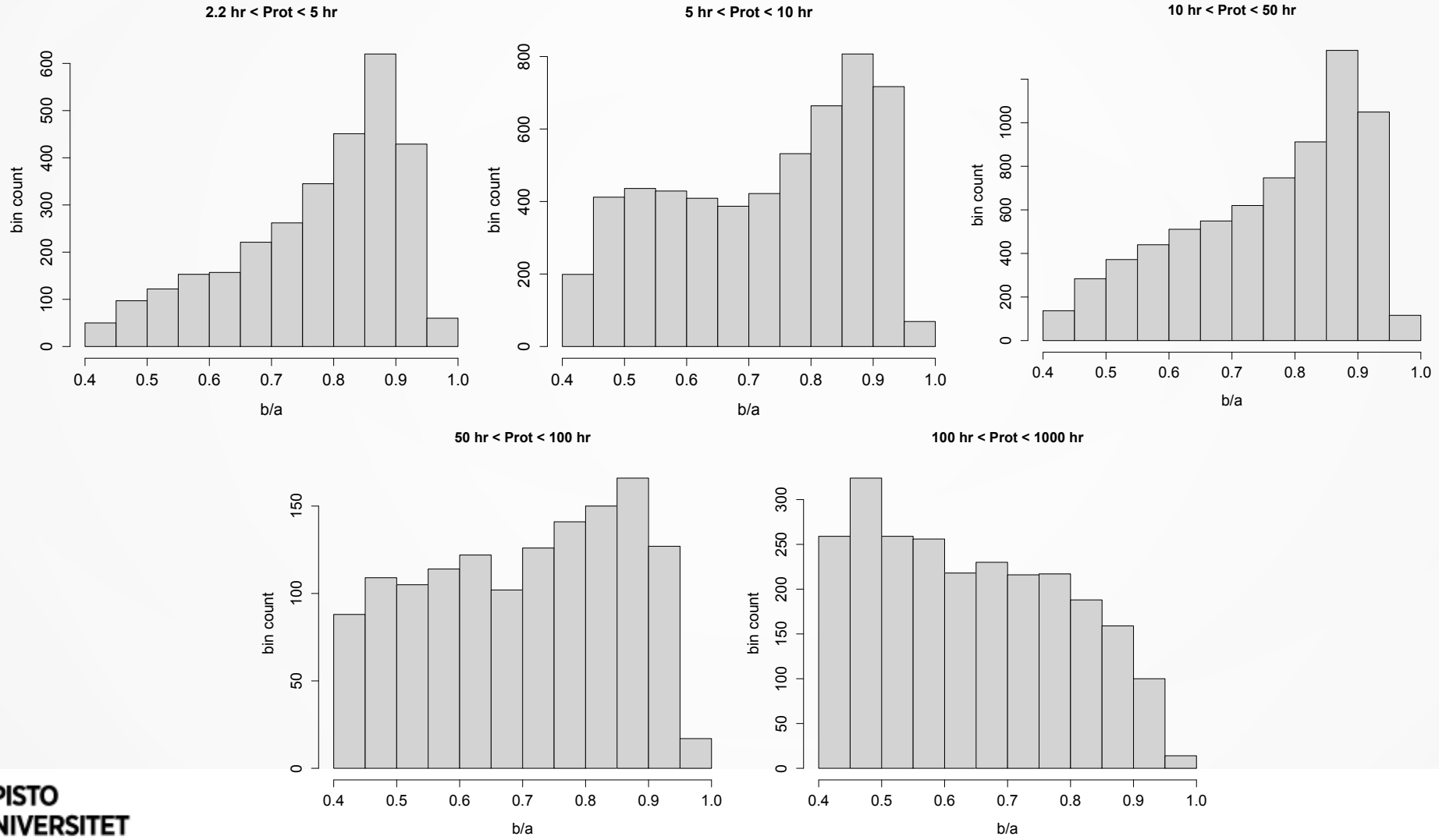
Ellipsoid Shapes

- better constraints on a/b, compared to c/a
  - c/a estimation requires changes in viewing aspect across observations

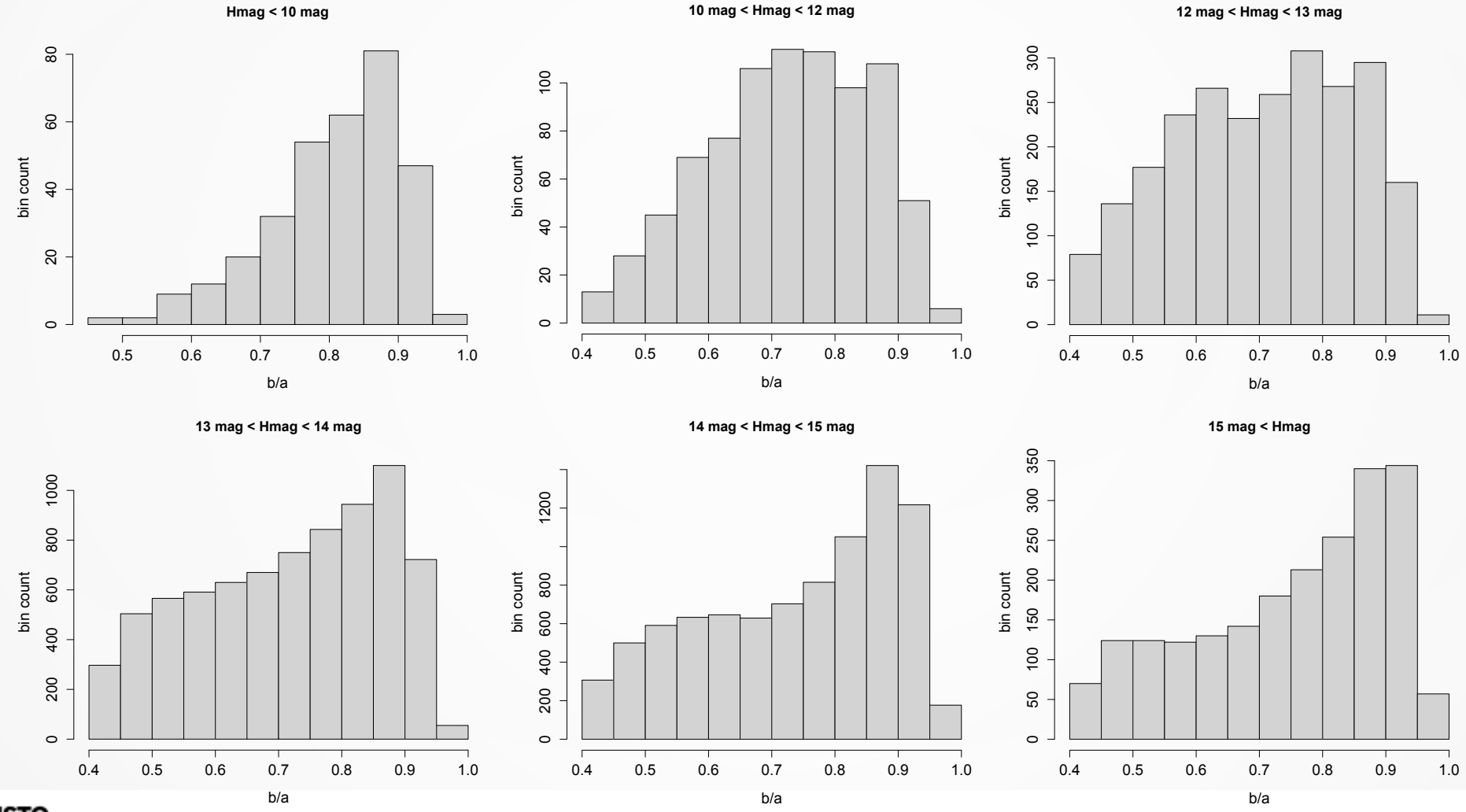




Variation in Shape: Rotation Period

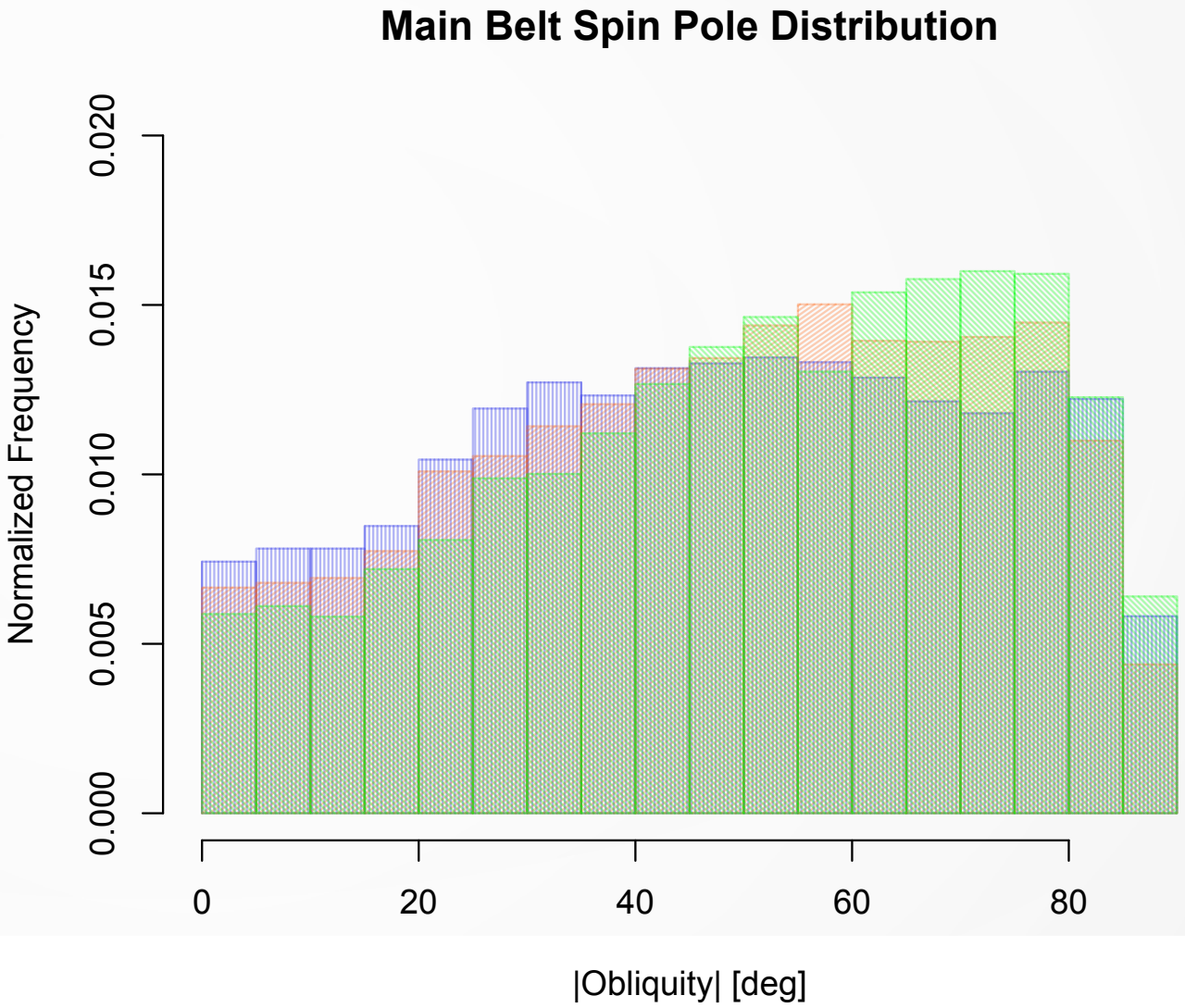


VARIATION IN SHAPE: ABSOLUTE MAGNITUDE



Spin Properties in the Main Belt

- spin obliquity = 90 when orthogonal to asteroid orbital plane
- outer main-belt asteroid spins are ailgned more orthogonally to their orbits than middle and inner main-belt asteroids
- thermal torques (Y.O.R.P.) could be the cause

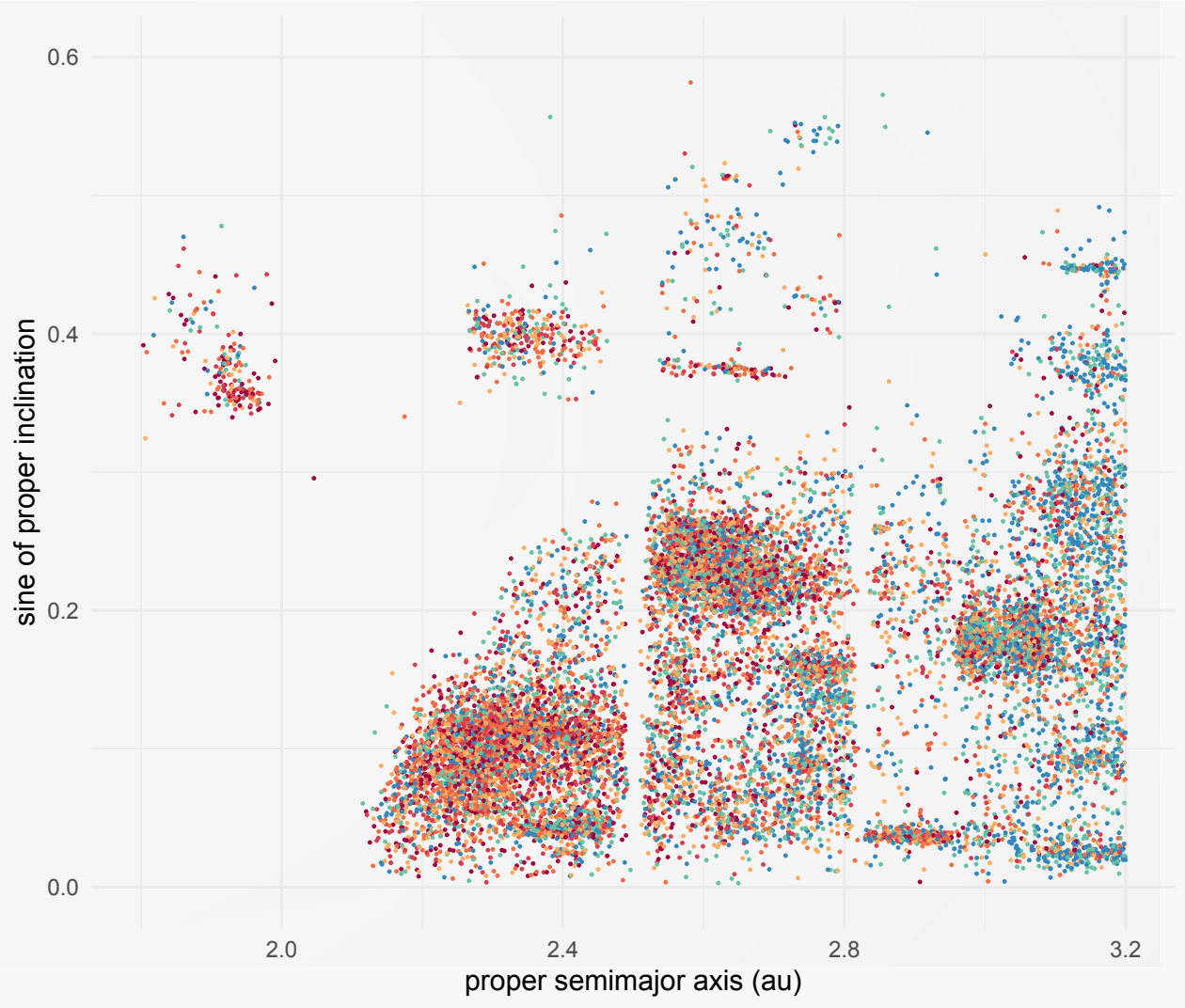


Photometric Slopes

- change in brightness with solar phase angle varies with taxonomic class
- best-fit *linear* slopes (βs) using ellipsoid shapes for Main Belt + Hungaria asteroids
  - shallow ~ inner MB+H, steep ~ outer MB

Tholen class	β_S (mag rad^{-1})
E	1.36
S/M	1.60
C	2.16
P	2.09
D	2.11

- we will combine these slopes with *Gaia* spectra to classify thousands of asteroids in DR3



SUMMARY

- Inversion of *Gaia* DR3 photometry can provide reliable estimates of:
  - rotation period (particularly, slow rotators)
  - spin axis latitude, longitude
  - elongation of shape (e.g. b/a of a triaxial ellipsoid)
  - linear photometric slope

- publication being prepared… all results will be freely available to all