Solving the Orbit of the Planet-Hosting Binary Tau Bootis: **How did Tau Bootis form?**

Anders Bo Justesen,

Simon Albrecht,

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DET FRIE FORSKNINGSRÅD
DANISH COUNCIL FOR INDEPENDENT RESEARCH

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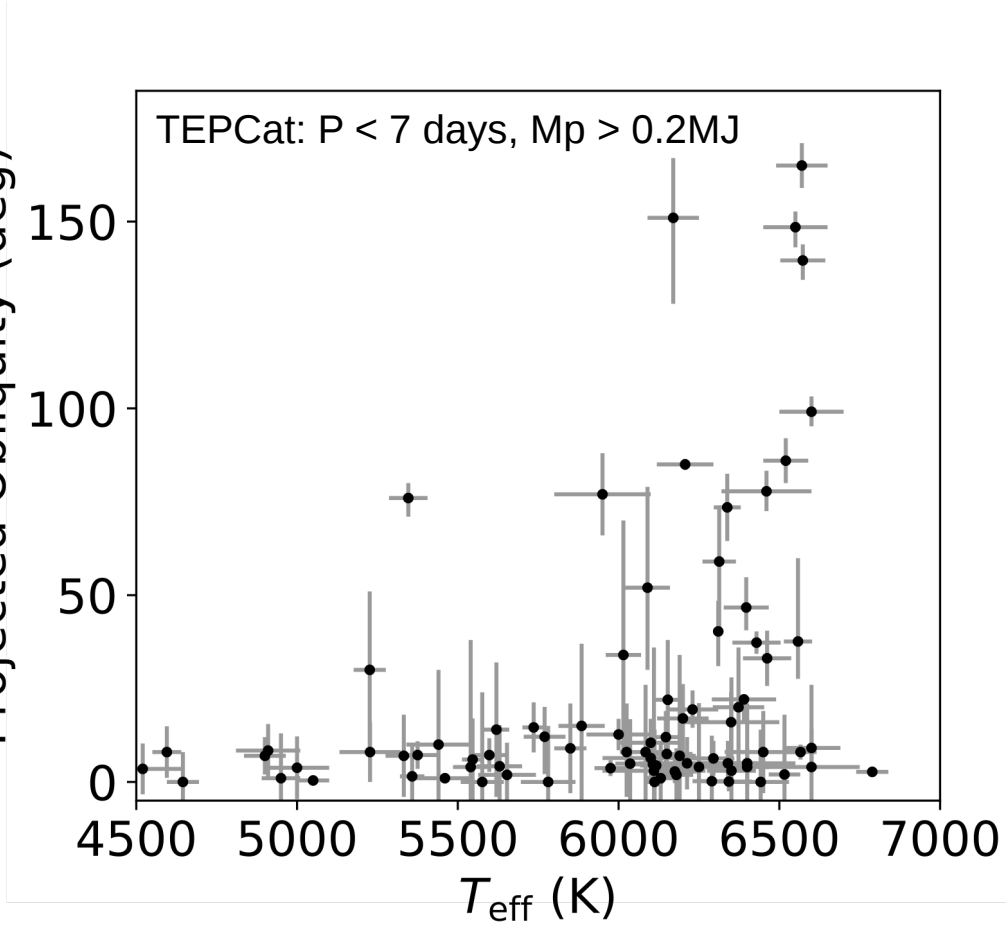
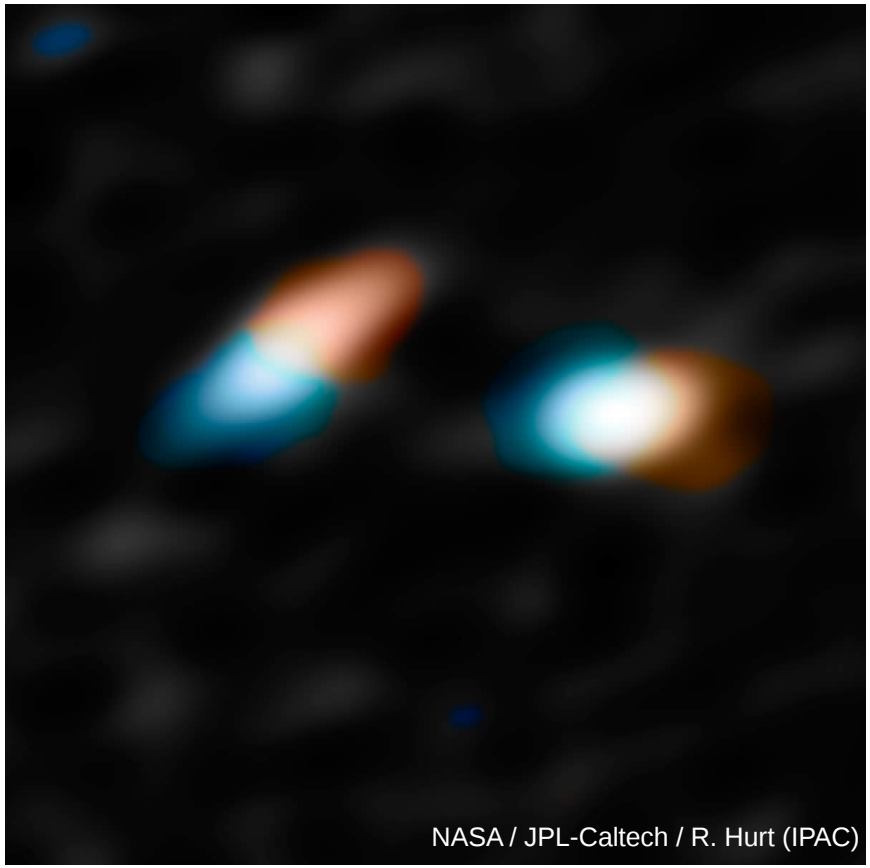
AARHUS UNIVERSITY

Rich dynamics of Hot Jupiters



Winn et al. 2010, Albrecht et al. 2012



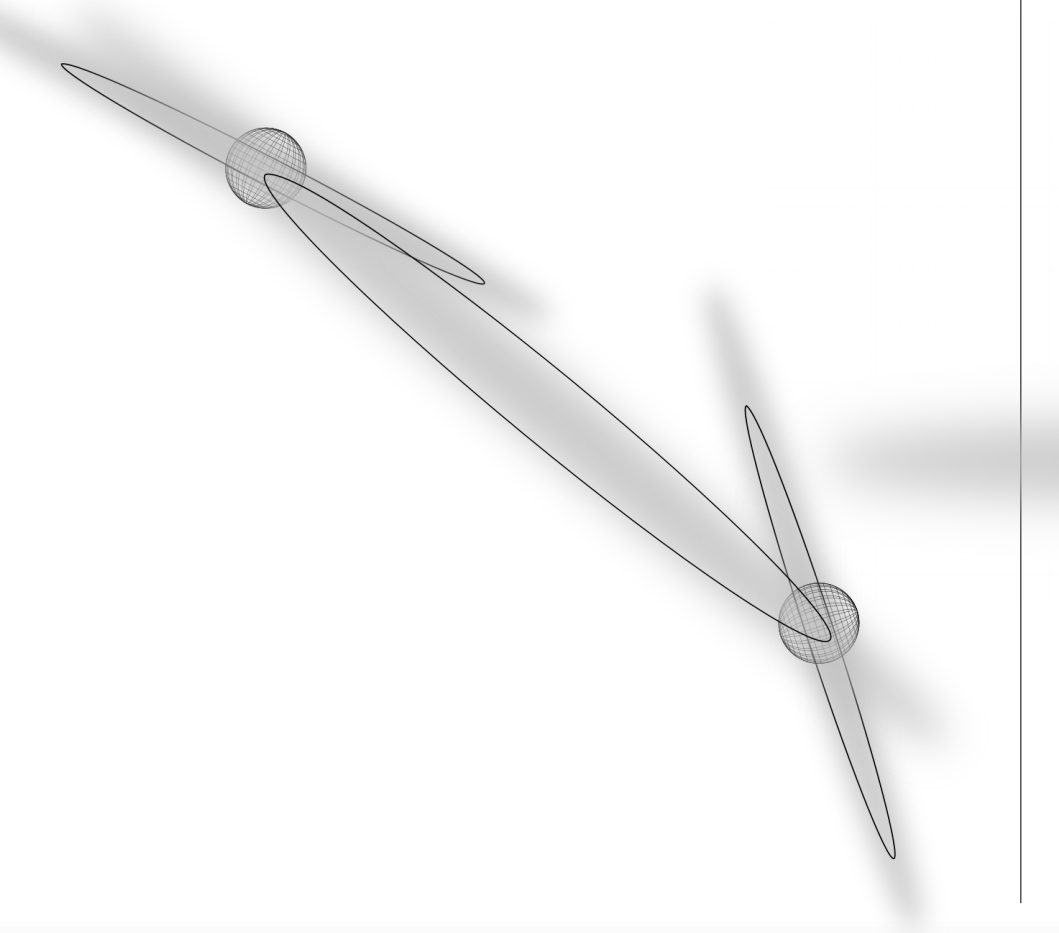
Jensen & Akeson 2014

Formation paths to Hot Jupiters

Disk migration

"Primordial (mis)alignment"

e.g.: Bate 2010, Batygin 2012, Lai 2014, Spalding & Batygin 2015, Zanazzi & Lai 2017



High eccentricity migration

"Late (mis)alignment"

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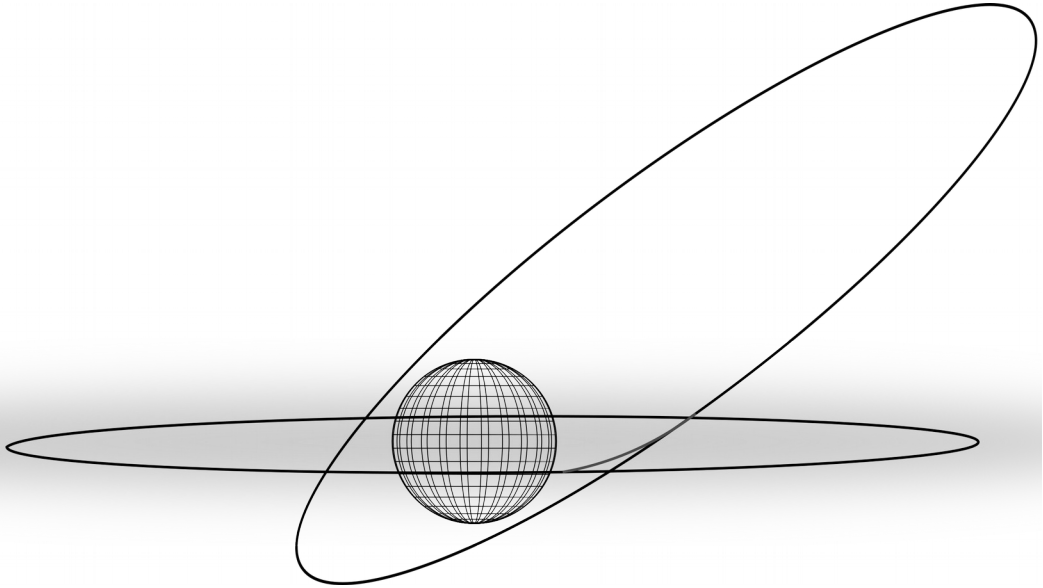

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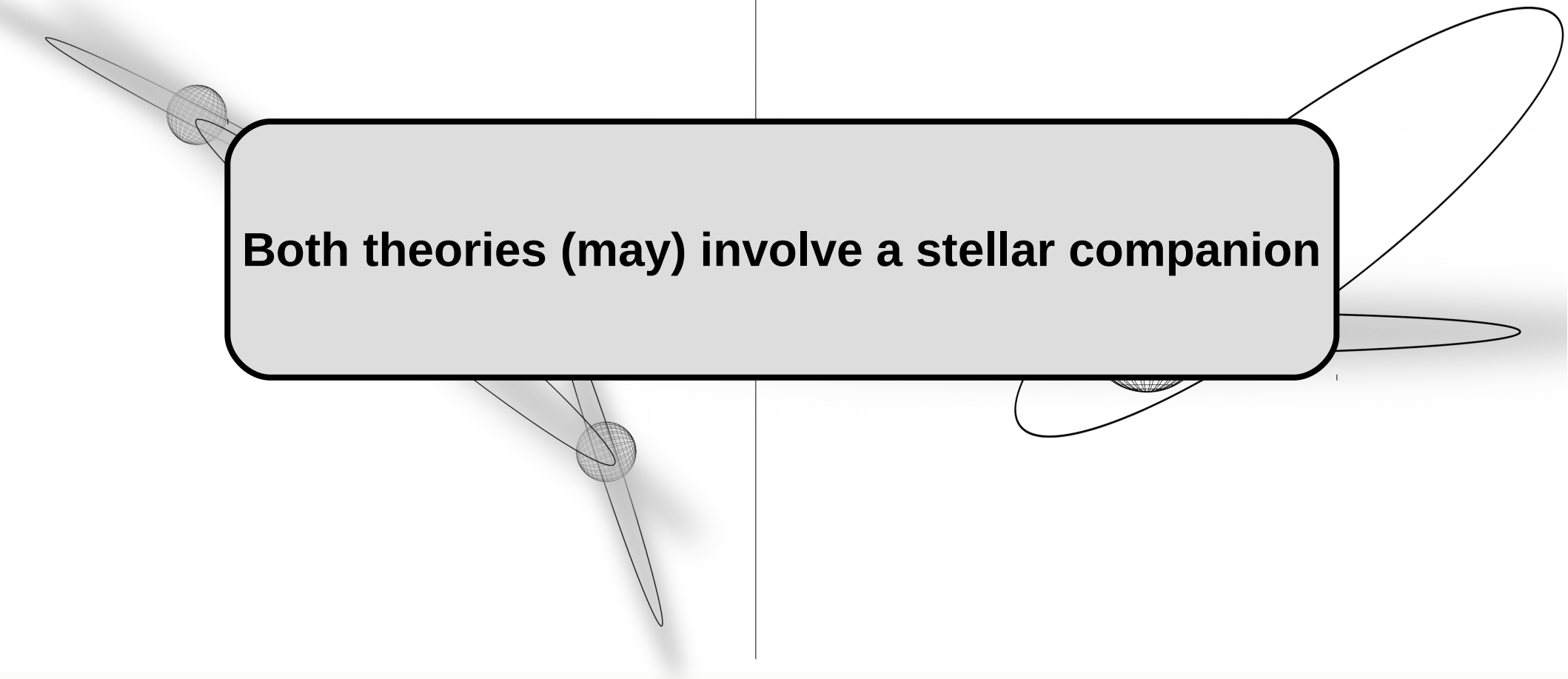

Both theories (may) involve a stellar companion

BOOTES CANES VENATICI, COMA BERENICES, AND
Pl. 10.
DRACO
URSA MAJOR
HERCULES
Phachd
Benetnasch
Asterion
Chara
Cor caroli
el Phekrah
el Acola
Nekkar
Alkalurops
LEO MINOR
E
W
S
CORONA BOREALIS
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MONS MÆNALUS
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QUADRANS MURALIS
V = 4.5

- **AB:** Herschel (1825)
  P > 900 years
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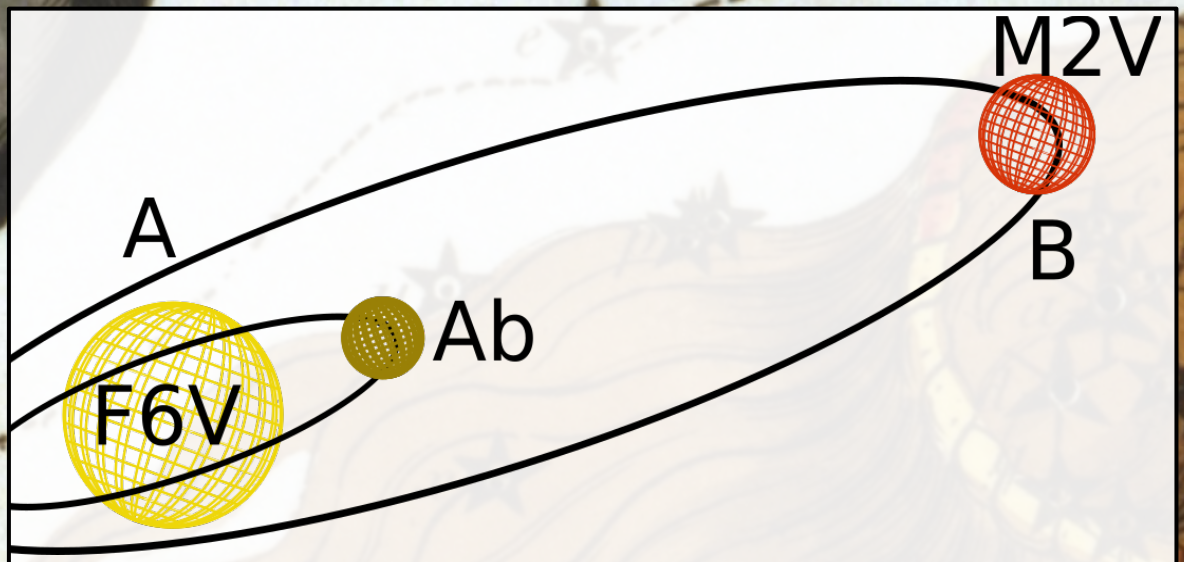

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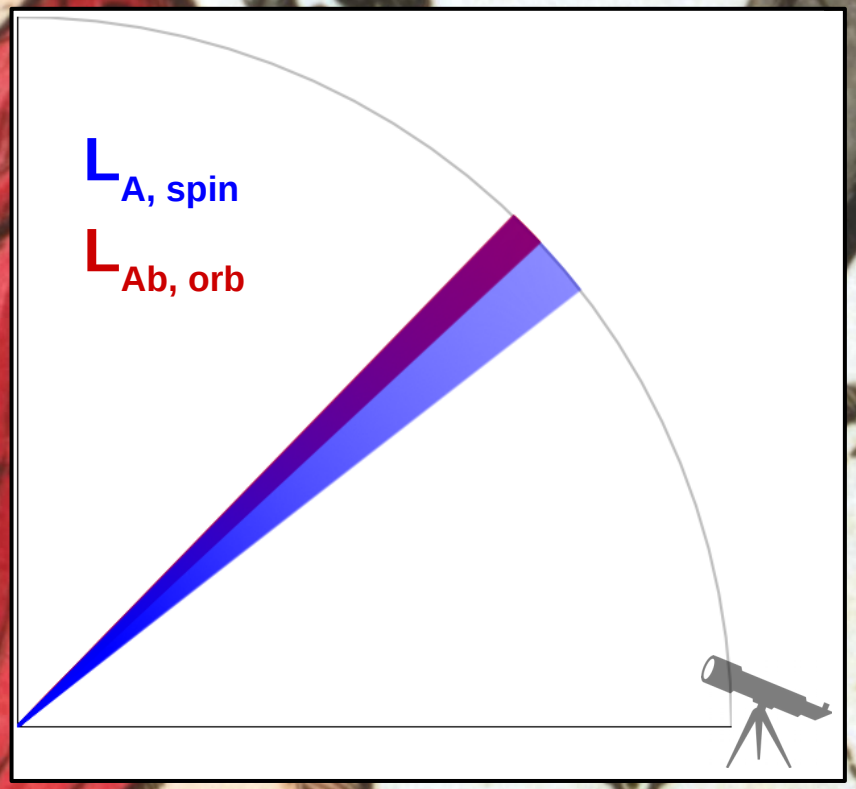

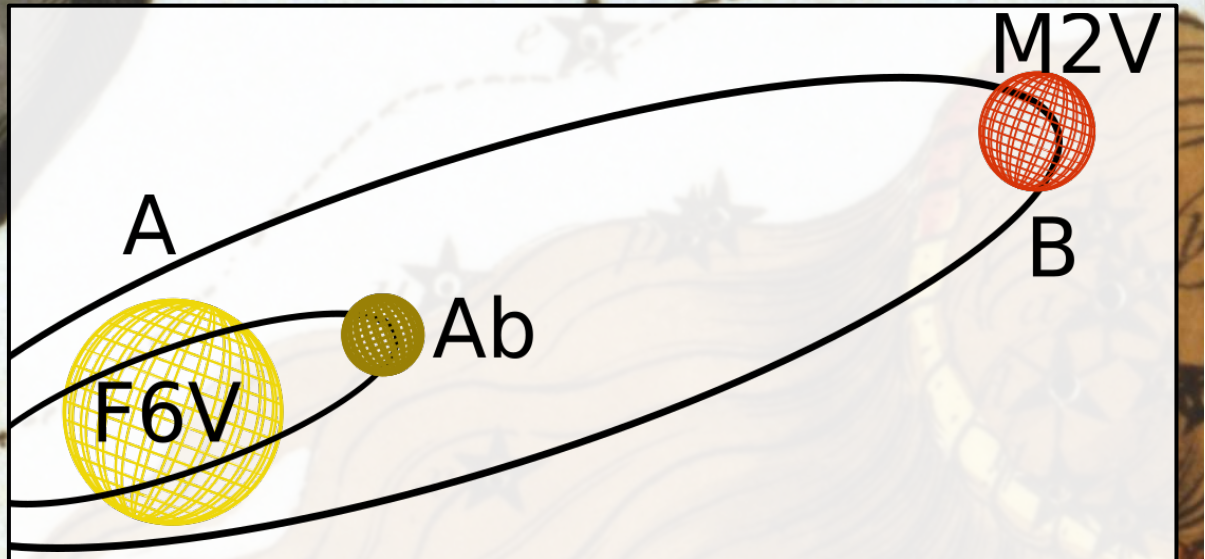

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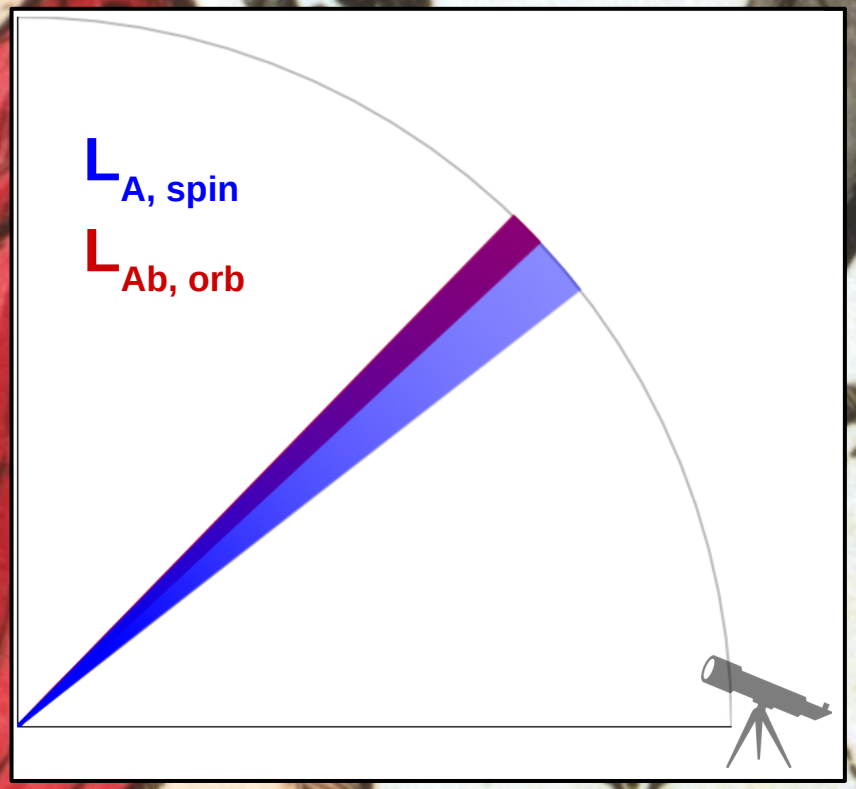

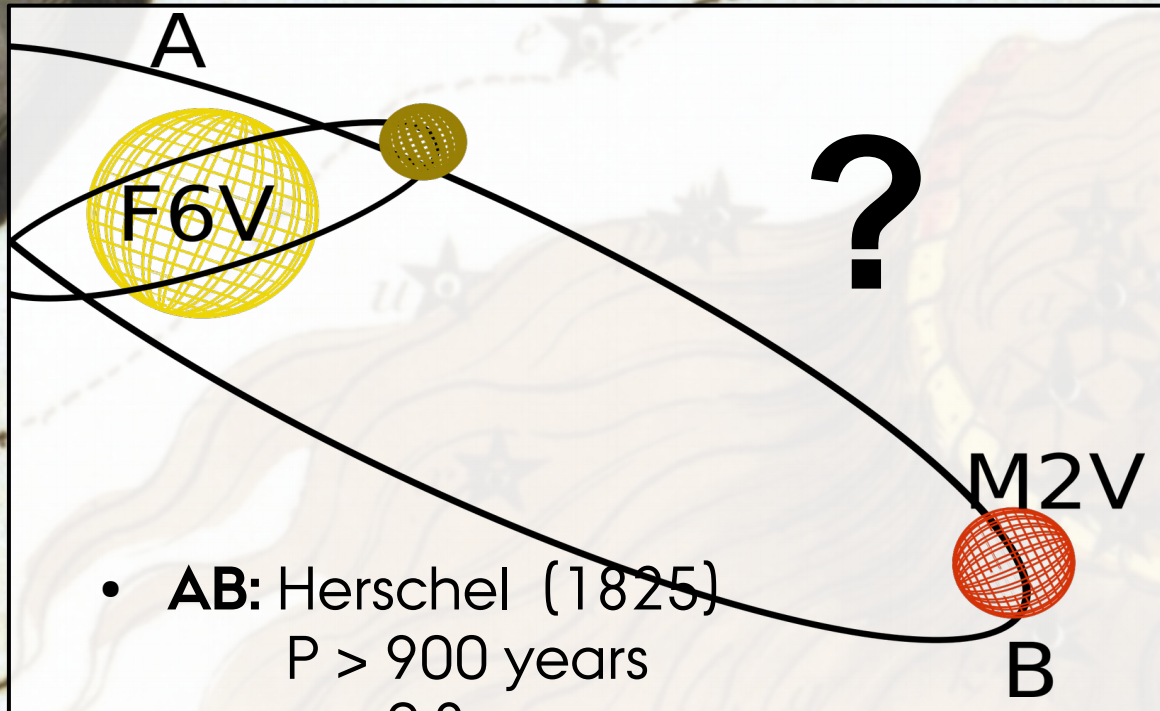

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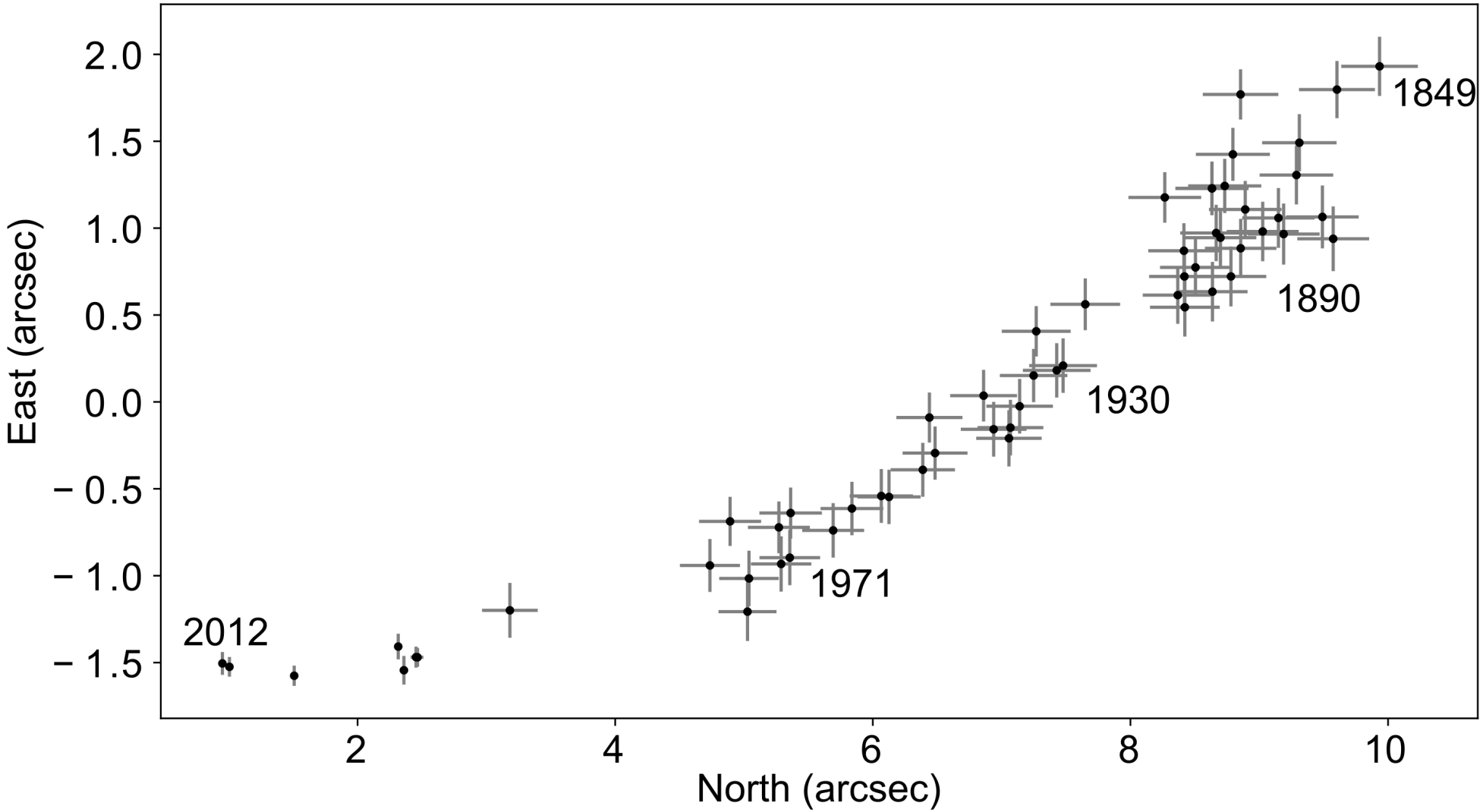
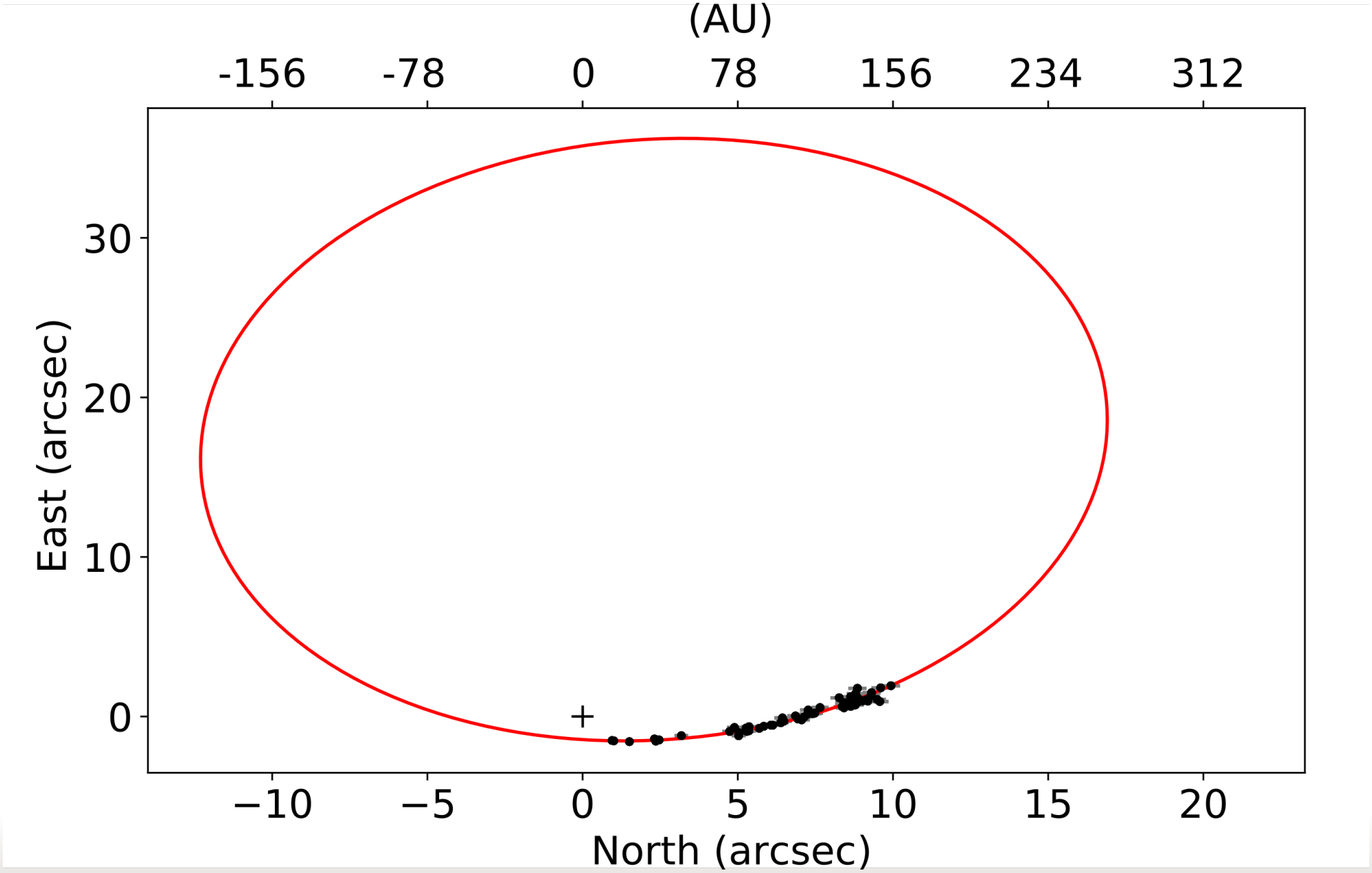
Relative astrometry of tau Boo AB



Washington Double Star Catalog
Position angle and separation, 1849-2012

Astrometric solutions (drawn from posterior)



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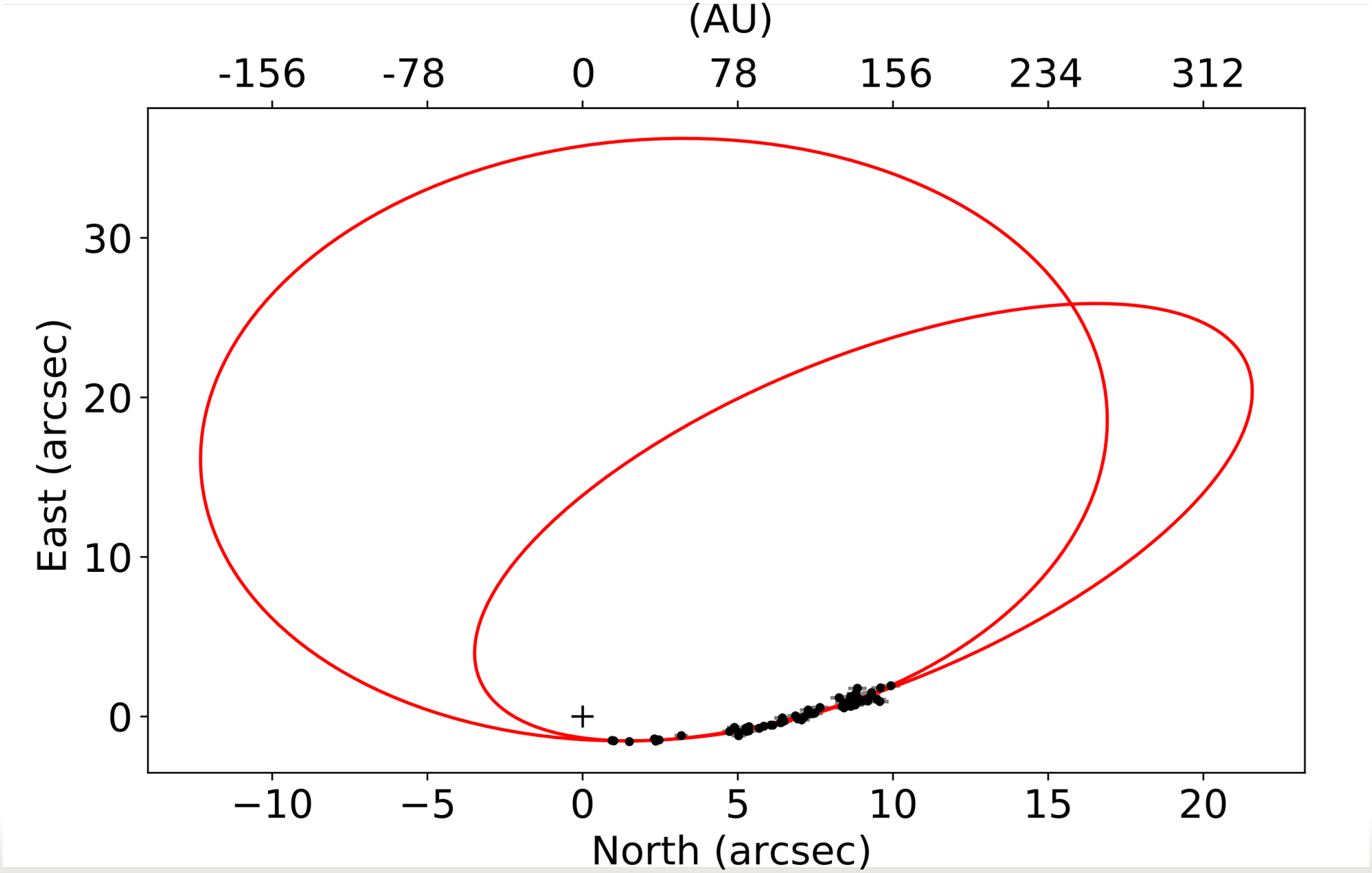

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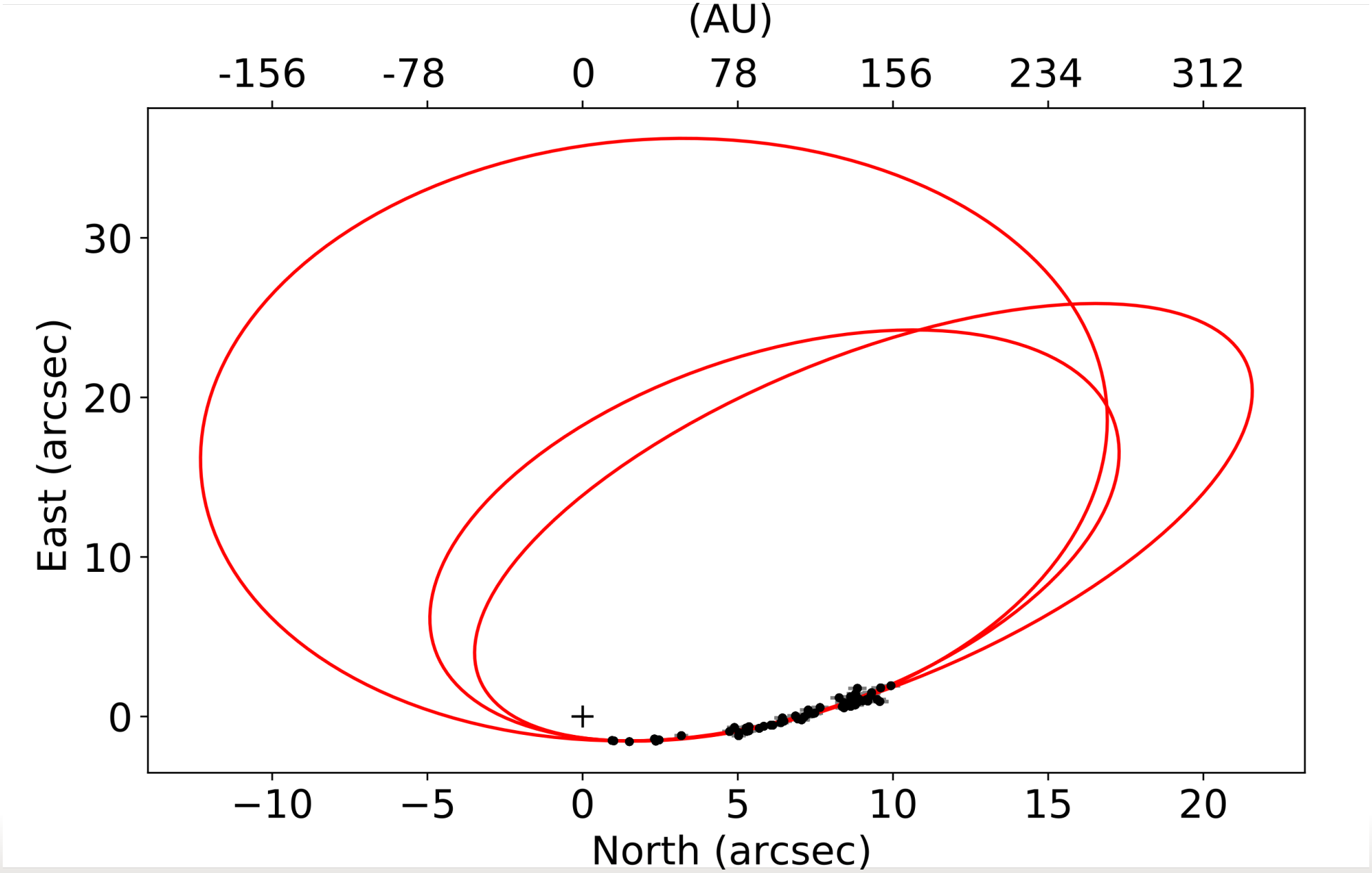

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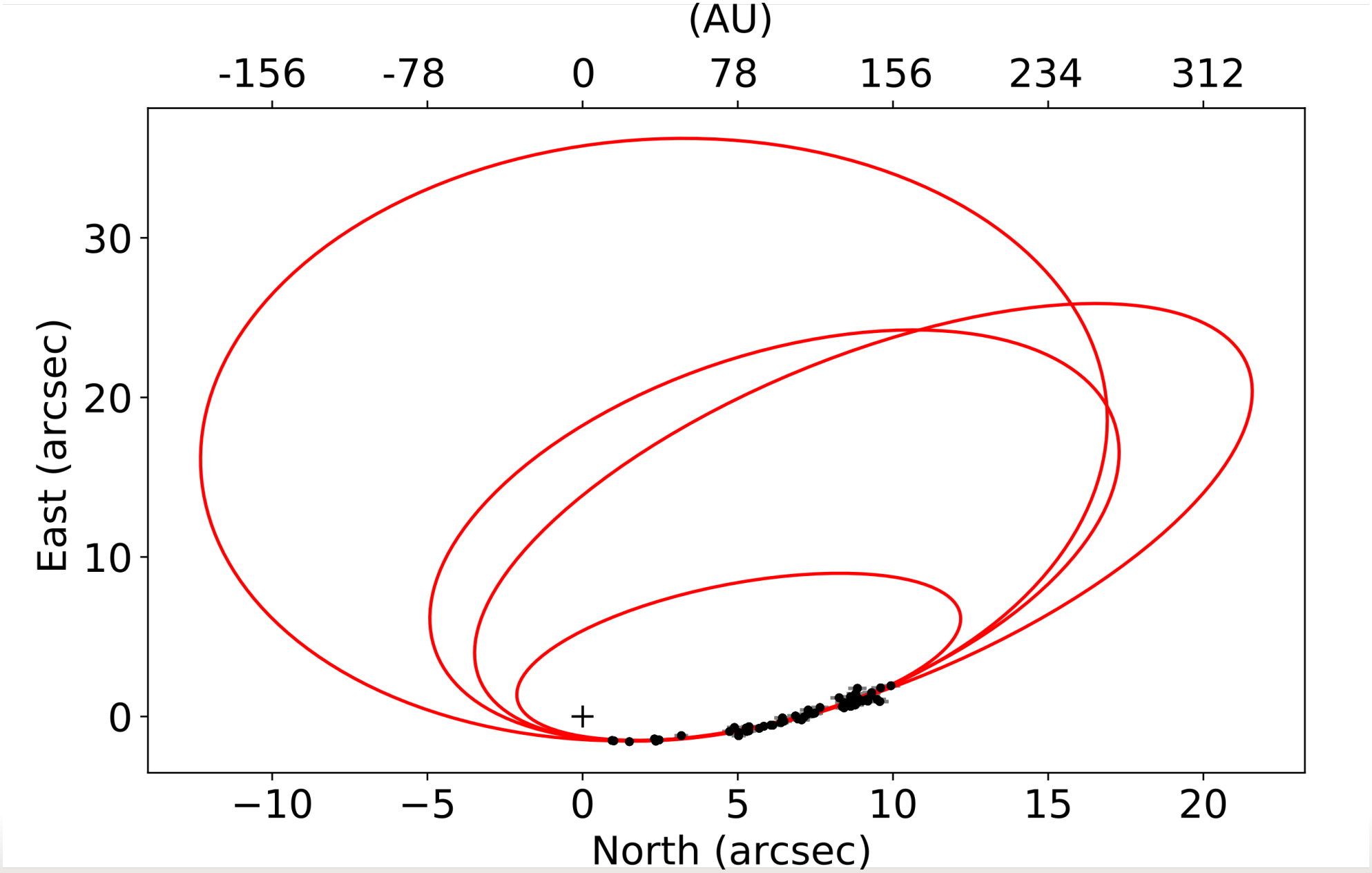

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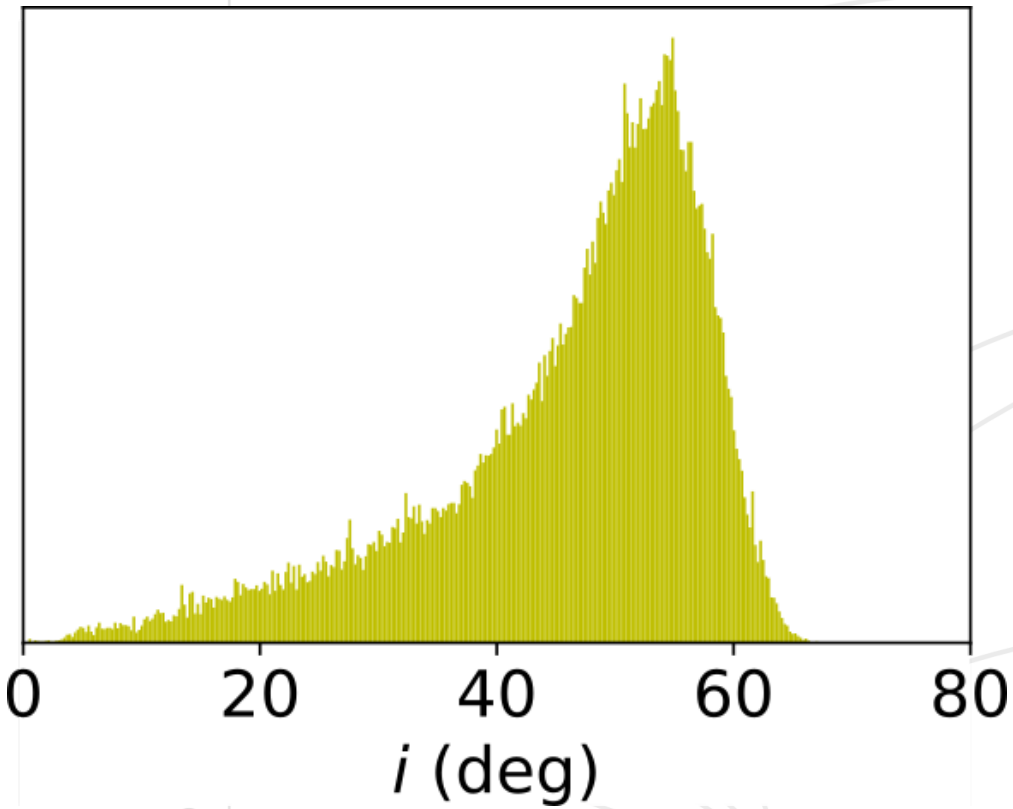
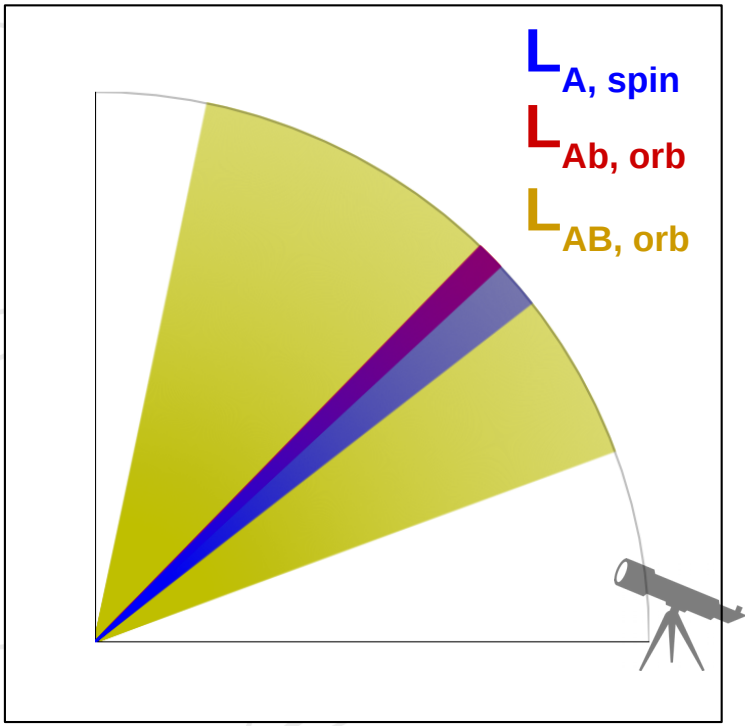
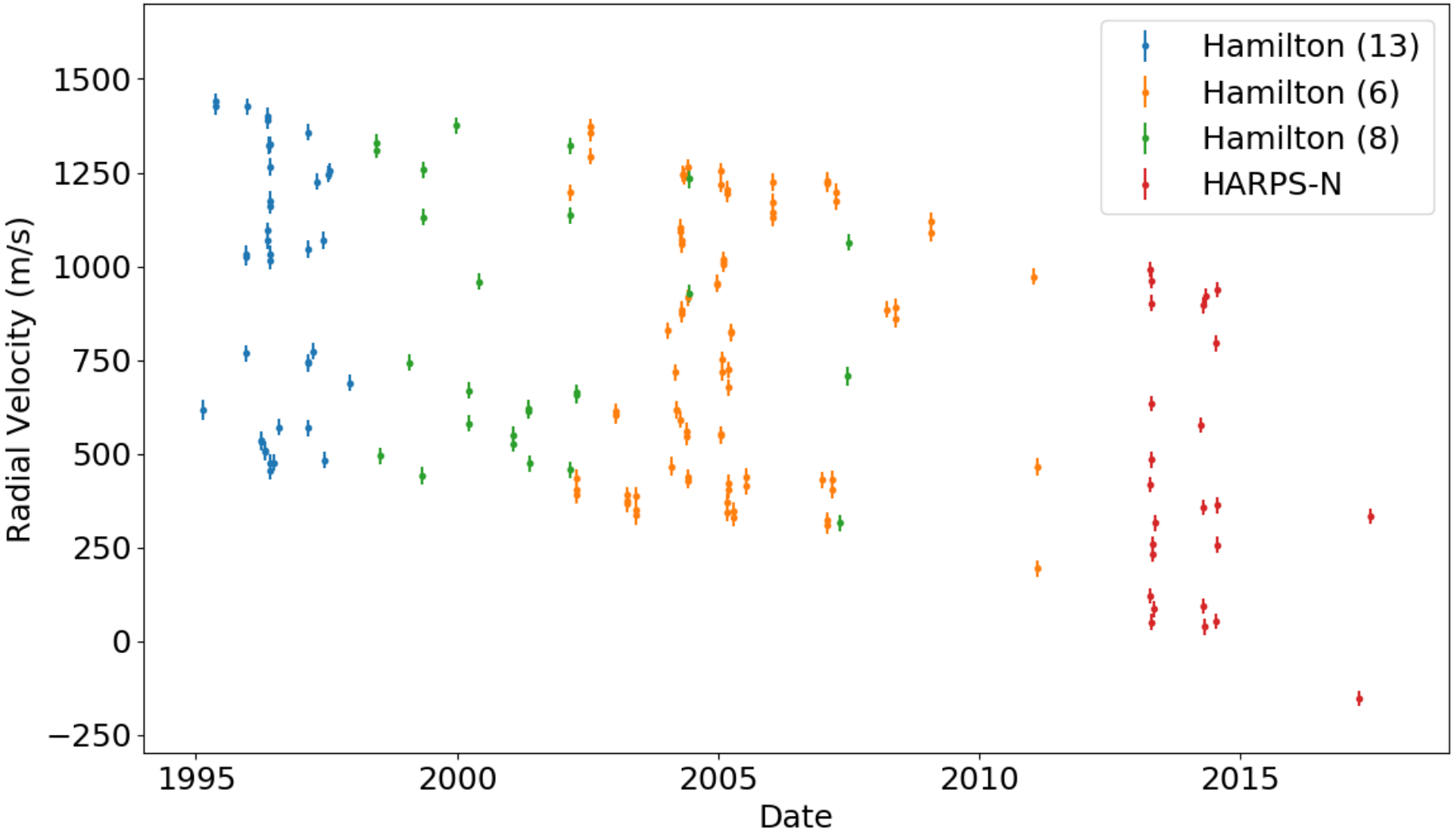




Radial Velocities



- Lick Planet Search program, 1995 – 2007 (Fischer et al. 2014)
- Archival and new TNG/HARPS-N, 2013-2017 (Borsa et al. 2015)

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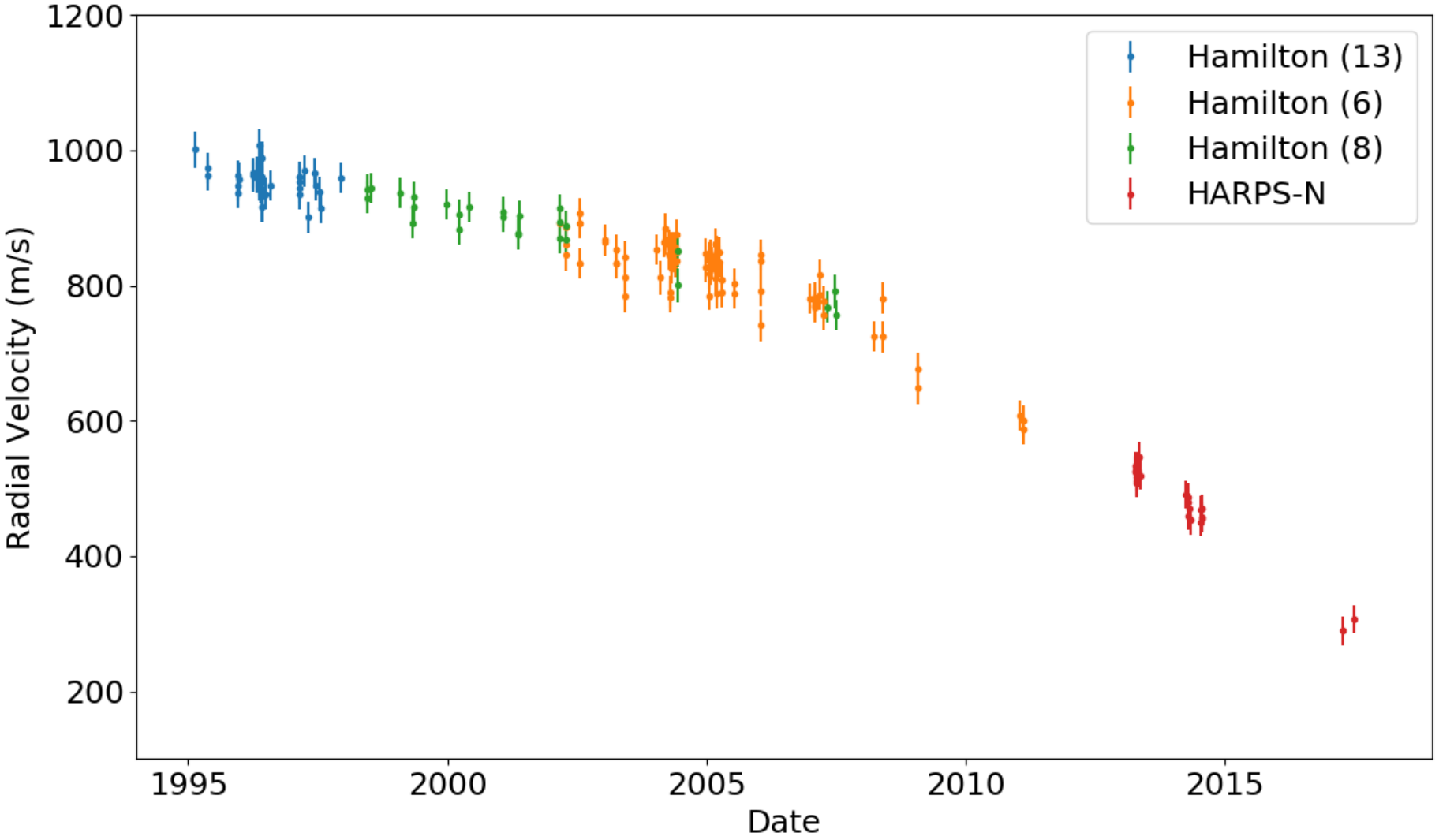

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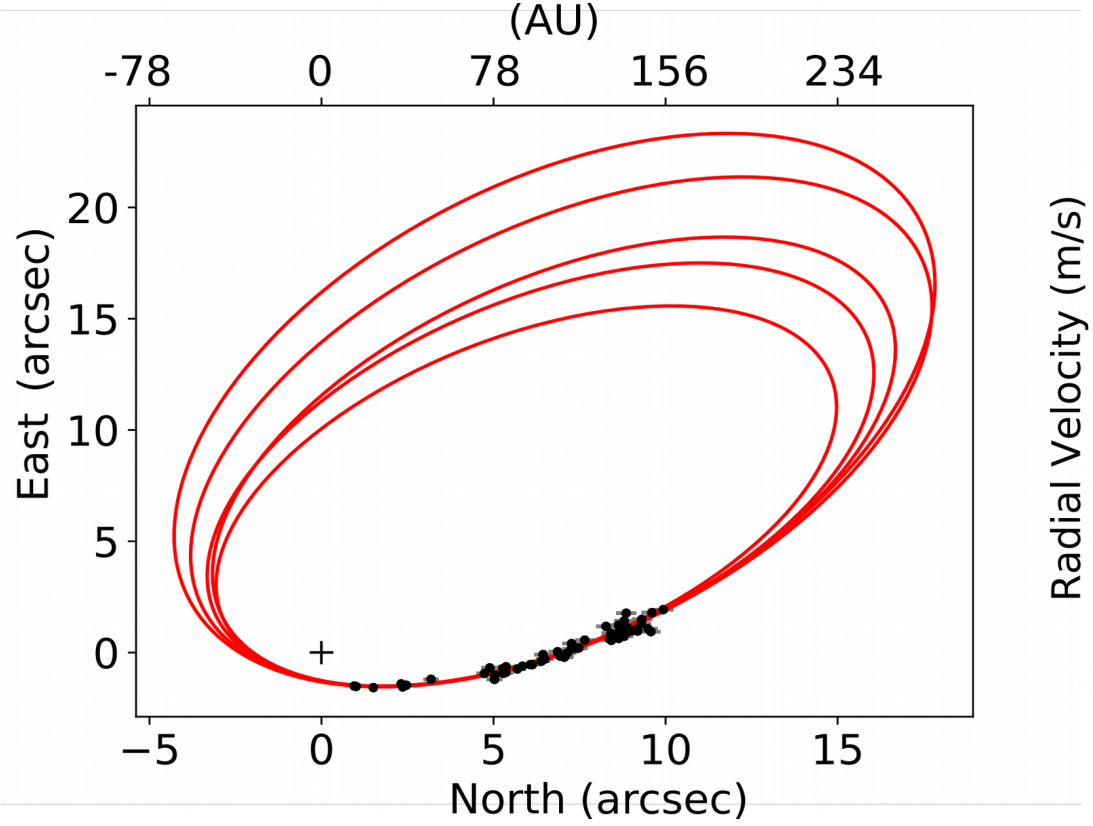
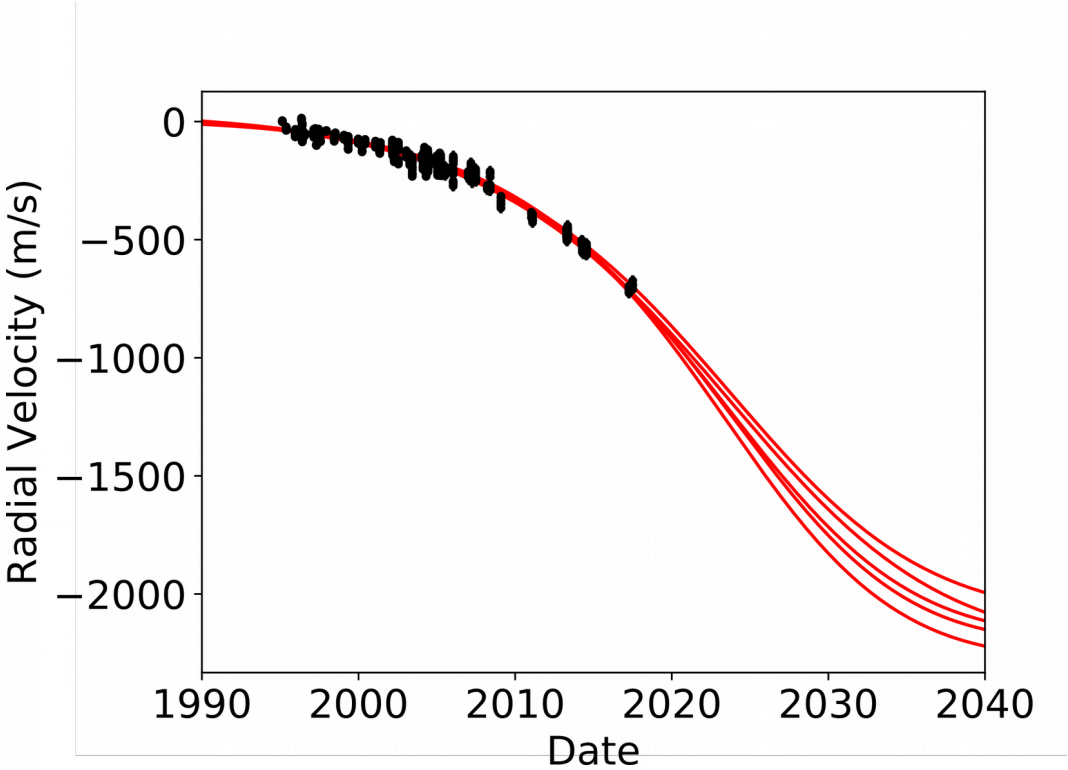
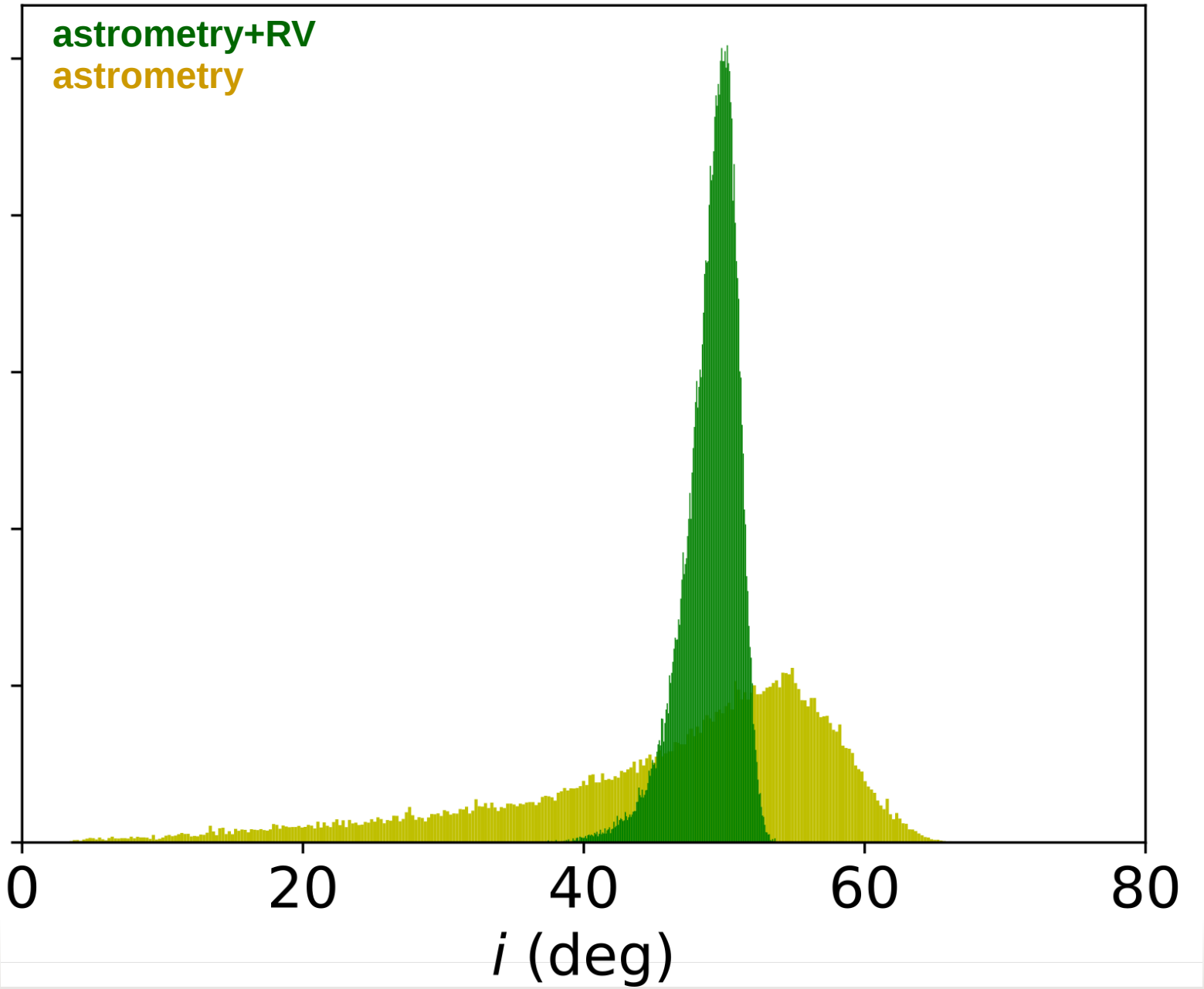
Joint astrometric and RV solutions

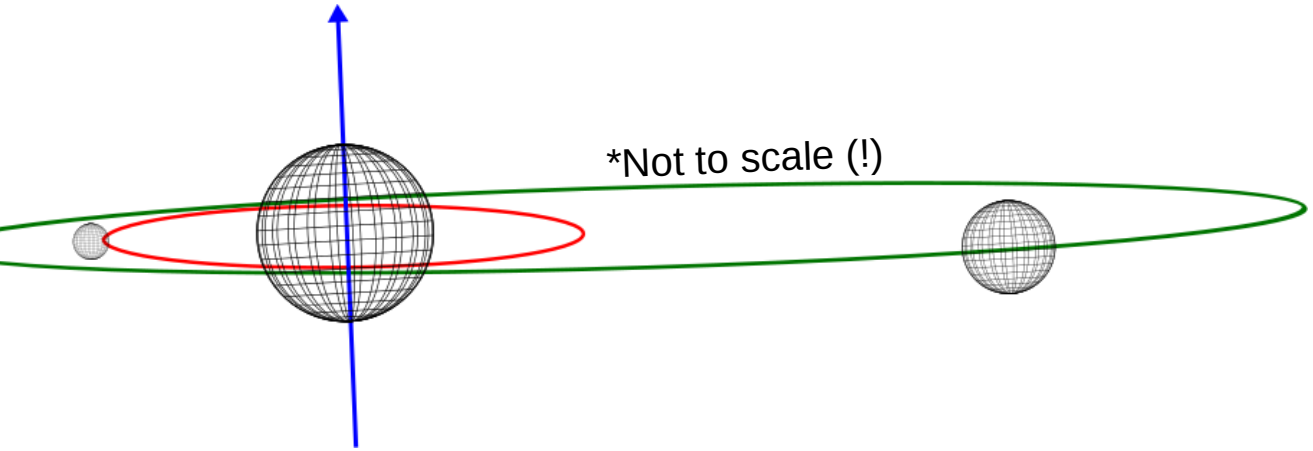


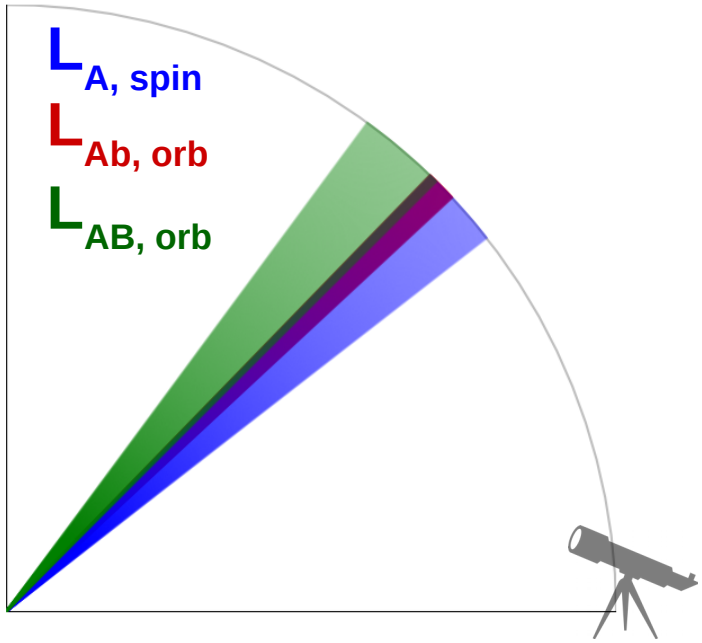


Results from joint MCMC analysis



Clues about formation





- Low mutual orbital inclination
- Spin-orbit alignment

$$i_{\mathrm{A,spin}} = 42 \pm 4 \ \mathrm{deg}$$

$$i_{\mathrm{Ab,orb}} = 44.5 \pm 1.5 \ \mathrm{deg}$$

$$i_{\mathrm{AB,orb}} = 49^{+2}_{-4} \ \mathrm{deg}$$

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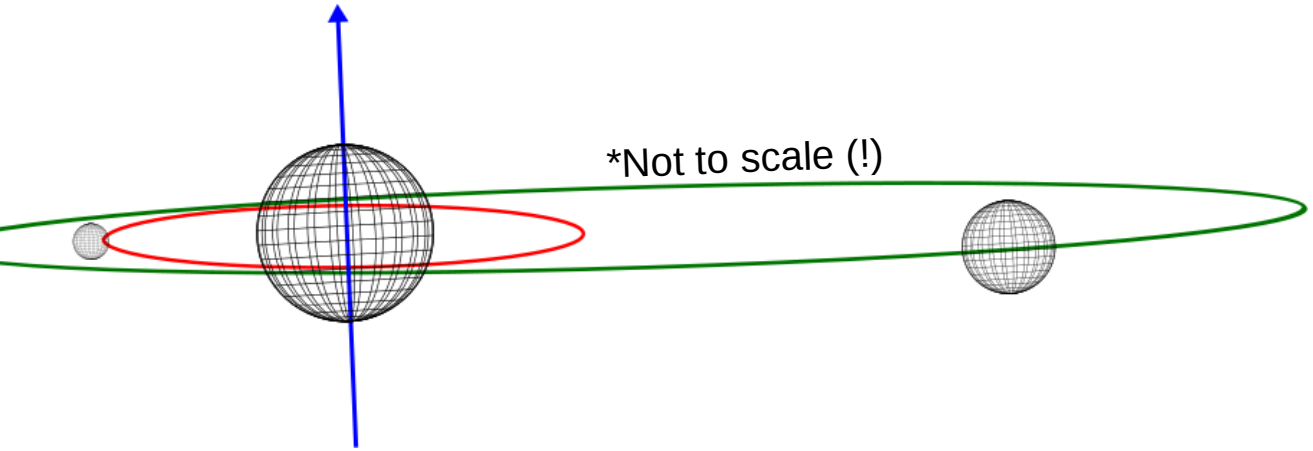

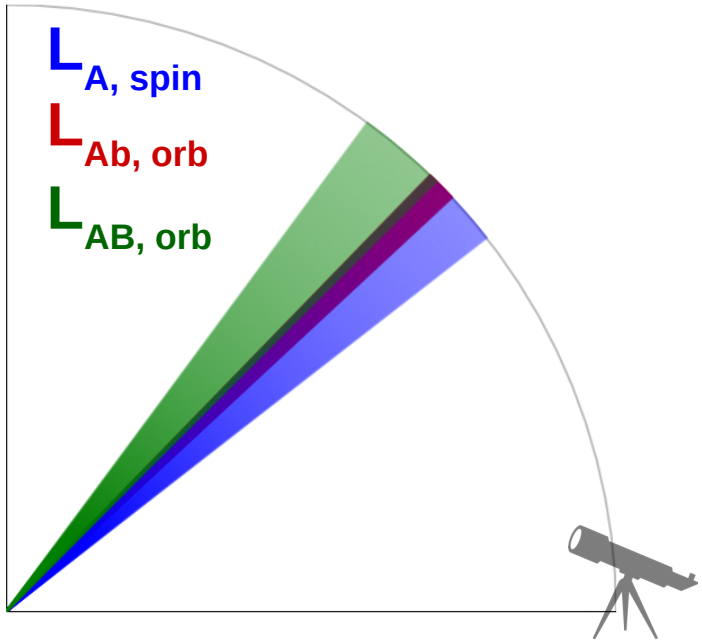

From our inclination measurements

- Tau Boo is a flat, aligned system
- Tau Boo Ab formed via disk migration within primordially aligned disks

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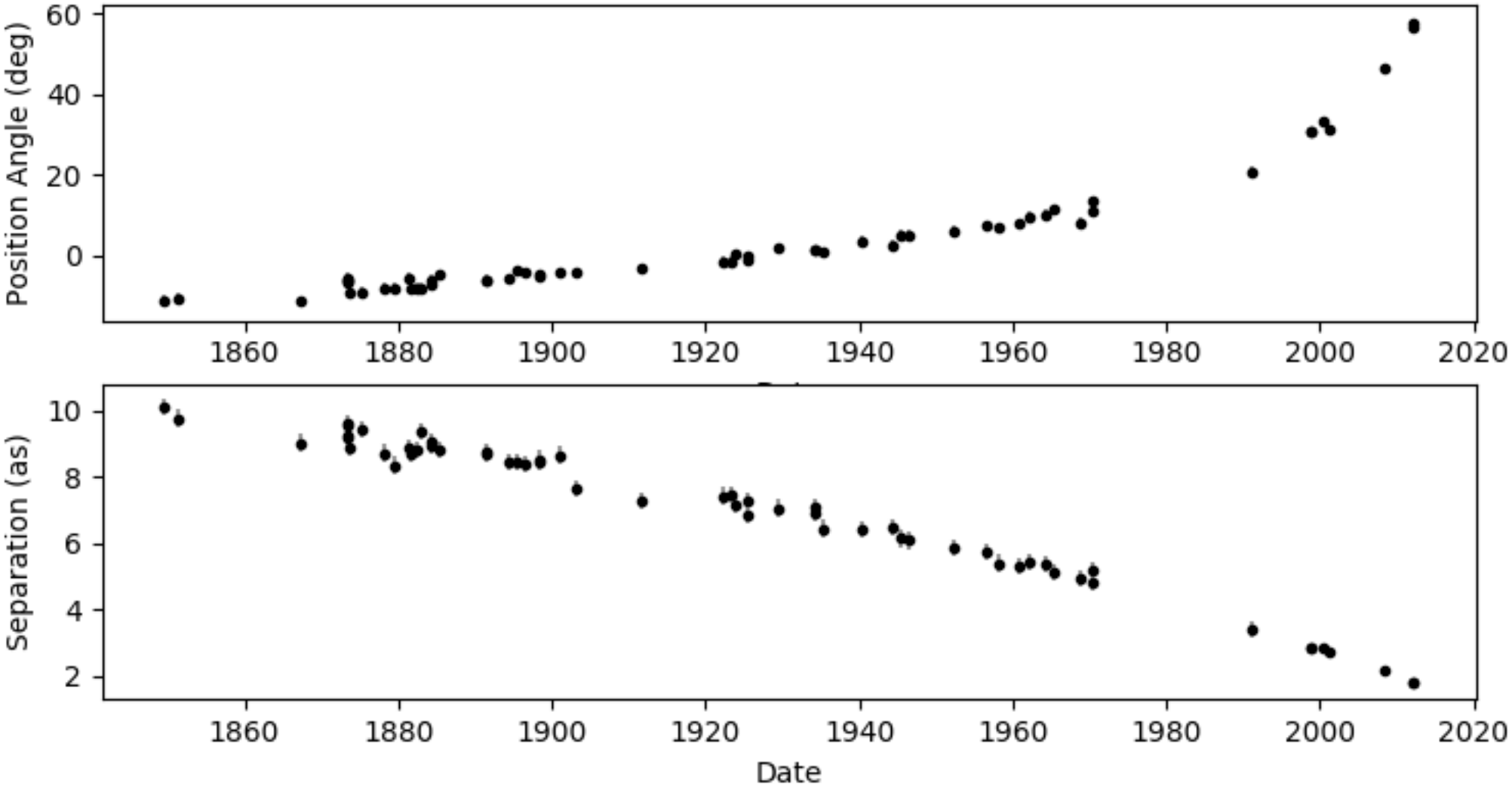
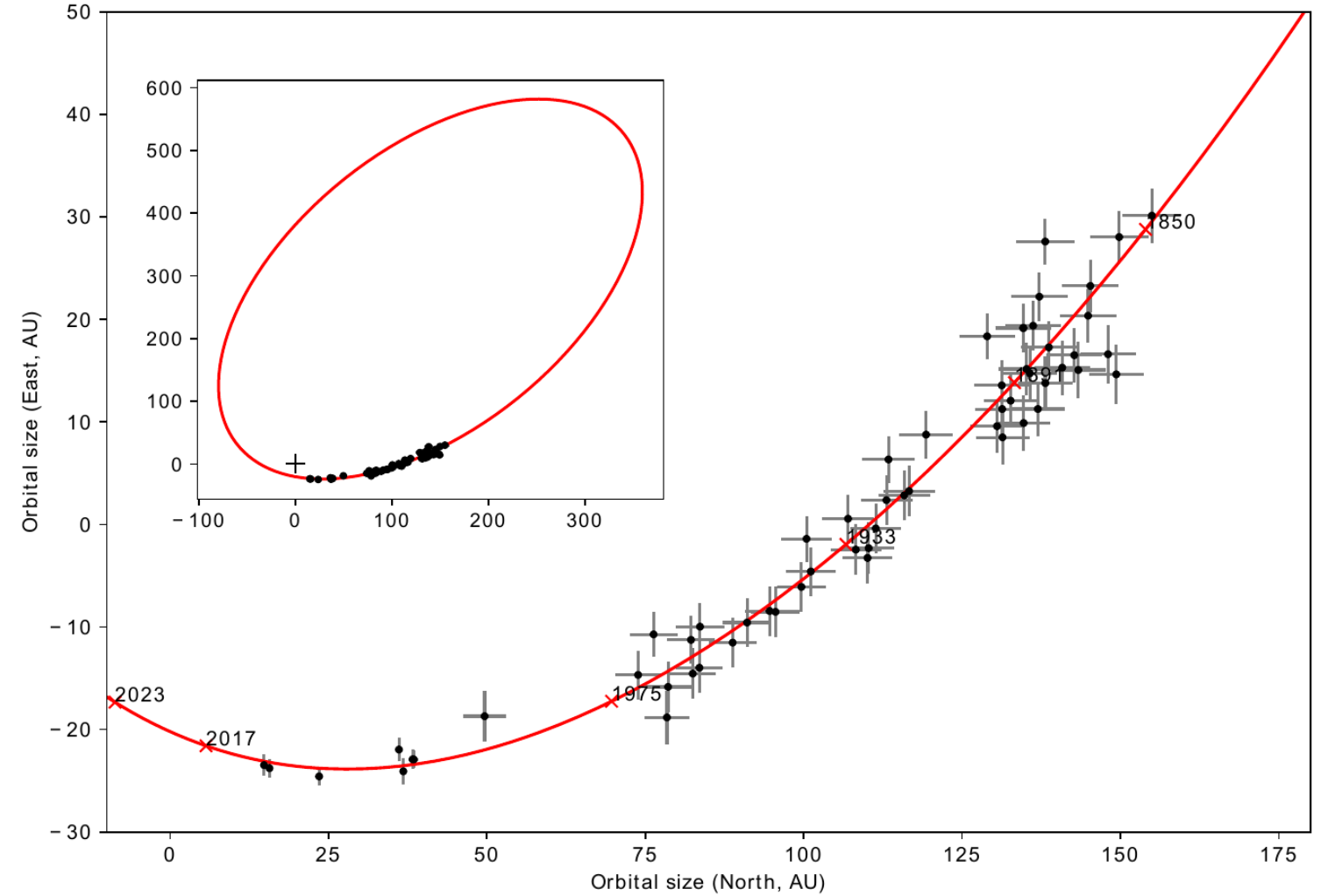
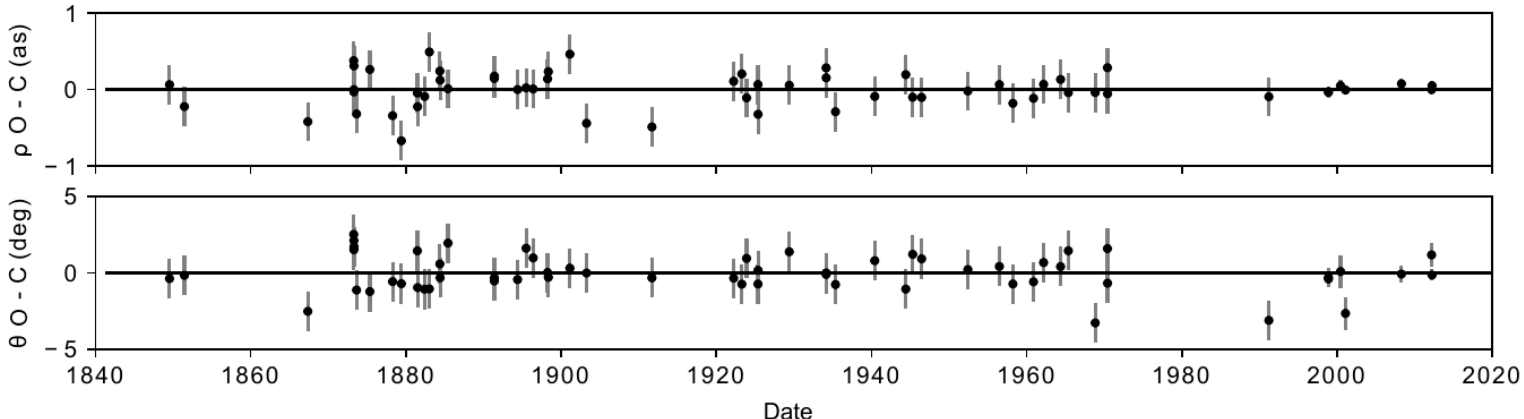
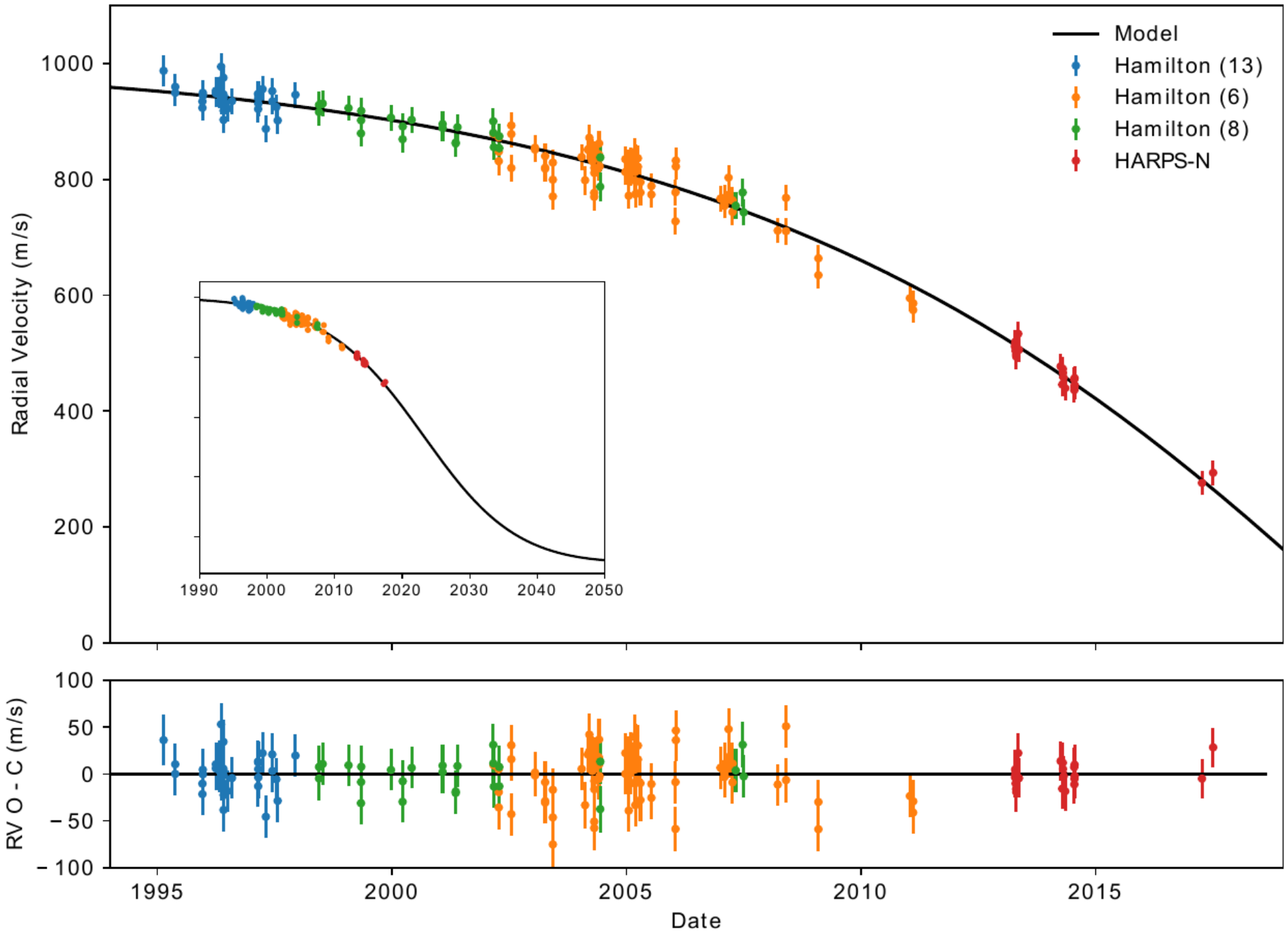
Thank you

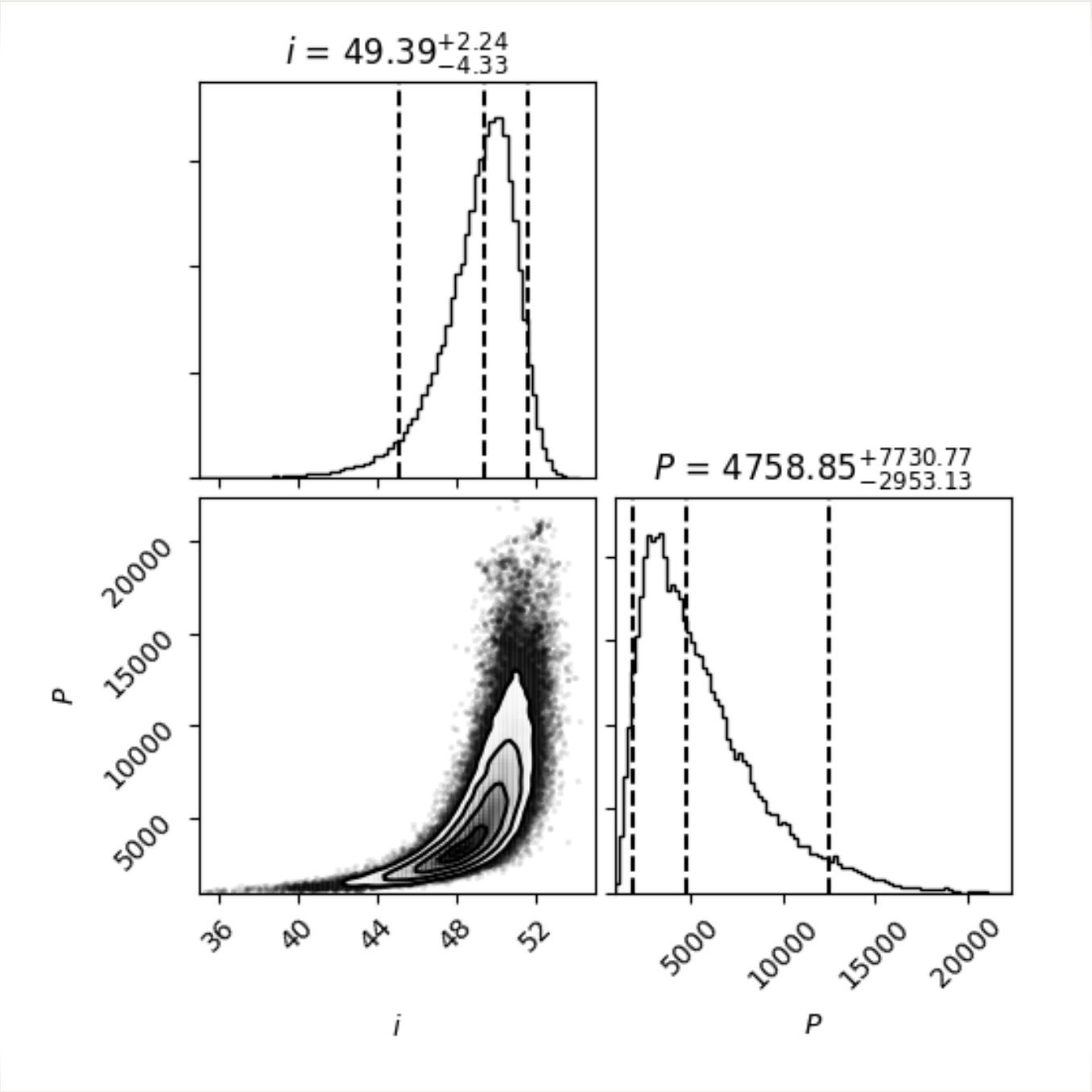
Parameter	Value
P (years)	4800^{+7700}_{-3000}
a (AU)	347^{+312}_{-165}
a^3/P^2 (AU^3/years^2)	$1.85^{+0.06}_{-0.06}$
$M_{\rm A} + M_{\rm B}$ ($M_\odot$)	$1.85^{+0.06}_{-0.06}$
$M_{\rm B}$ ($M_\odot$)	$0.50^{+0.03}_{-0.03}$
T_0	$2024.8^{+2.2}_{-1.2}$
e	$0.92^{+0.04}_{-0.06}$
i (deg)	$49.4^{+2.2}_{-4.3}$


Position Angle (deg)
60
40
20
0
1860
1880
1900
1920
1940
1960
1980
2000
2020
Separation (as)
10
8
6
4
2
1860
1880
1900
1920
1940
1960
1980
2000
2020
Date


Orbital size (East, AU)
Orbital size (North, AU)
2023
2017
1975
1933
1850


ρ O - C (as)
θ O - C (deg)
Date


Model
Hamilton (13)
Hamilton (6)
Hamilton (8)
HARPS-N
Radial Velocity (m/s)
1000
800
600
400
200
0
1990
2000
2010
2020
2030
2040
2050
RV O - C (m/s)
100
50
0
− 50
− 100
1995
2000
2005
2010
2015
Date


$i = 49.39^{+2.24}_{-4.33}$
$P = 4758.85^{+7730.77}_{-2953.13}$
P
20000
15000
10000
5000
36
40
44
48
52
i
5000
10000
15000
20000
P