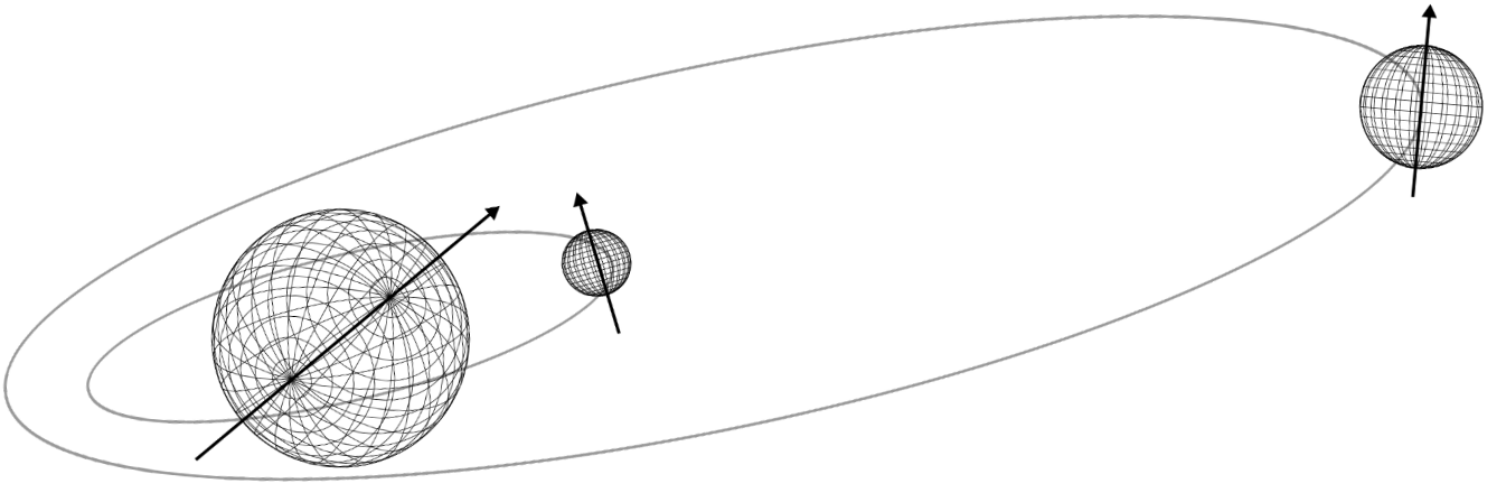
Obliquities and implications for binaries and exoplanets



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(Tushar Sanjay Shrotriya)

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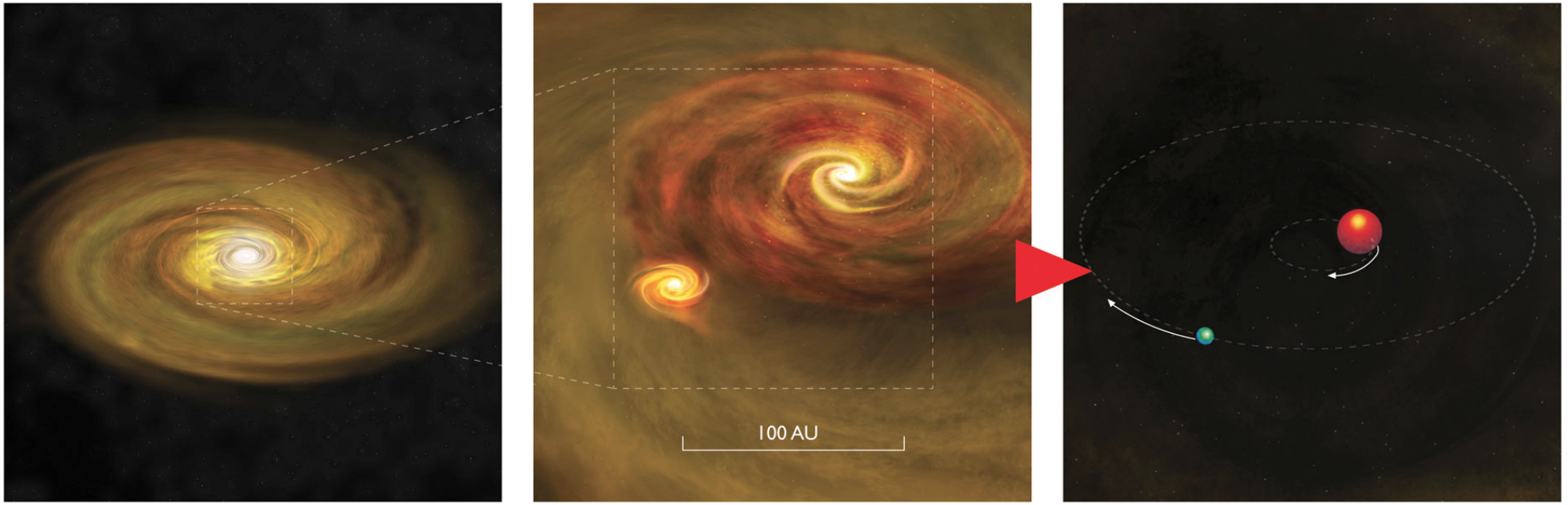
DET FRIE FORSKNINGSRÅD
DANISH COUNCIL FOR INDEPENDENT RESEARCH

STELLAR ASTROPHYSICS CENTRE

AARHUS UNIVERSITY

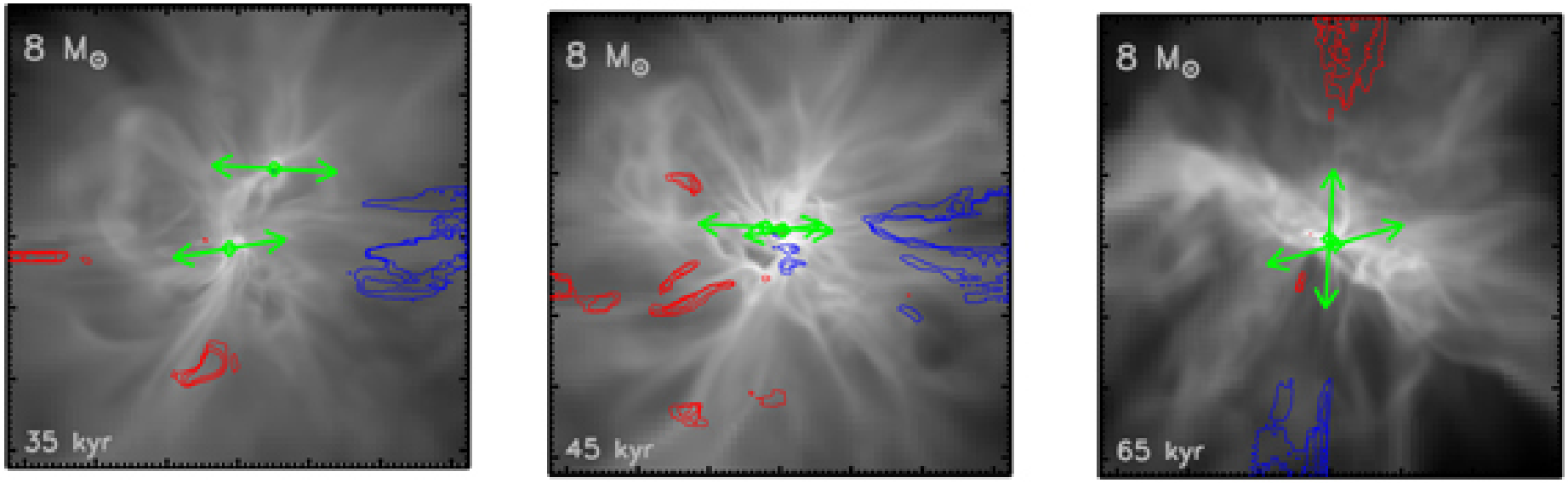
How do binary stars and planetary systems form?

Disk Fragmentation: Primordial Alignment



Credit: Bill Saxton, NRAO/AUI/NSF (2013)

Turbulent Fragmentation: Primordial Misalignemnt



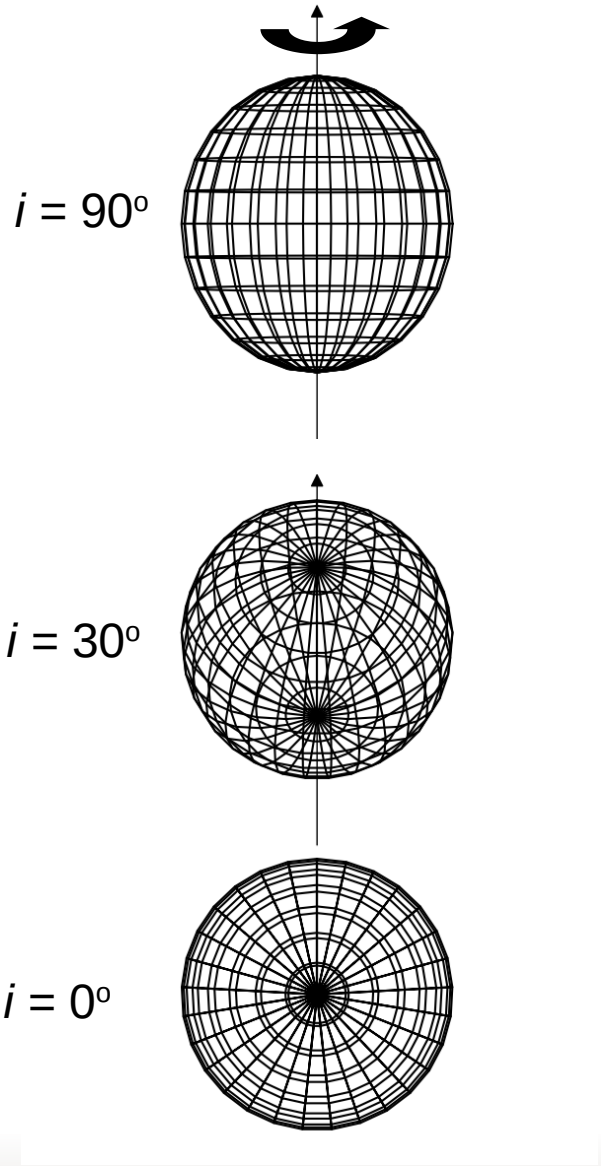
Offner et al. (2016)

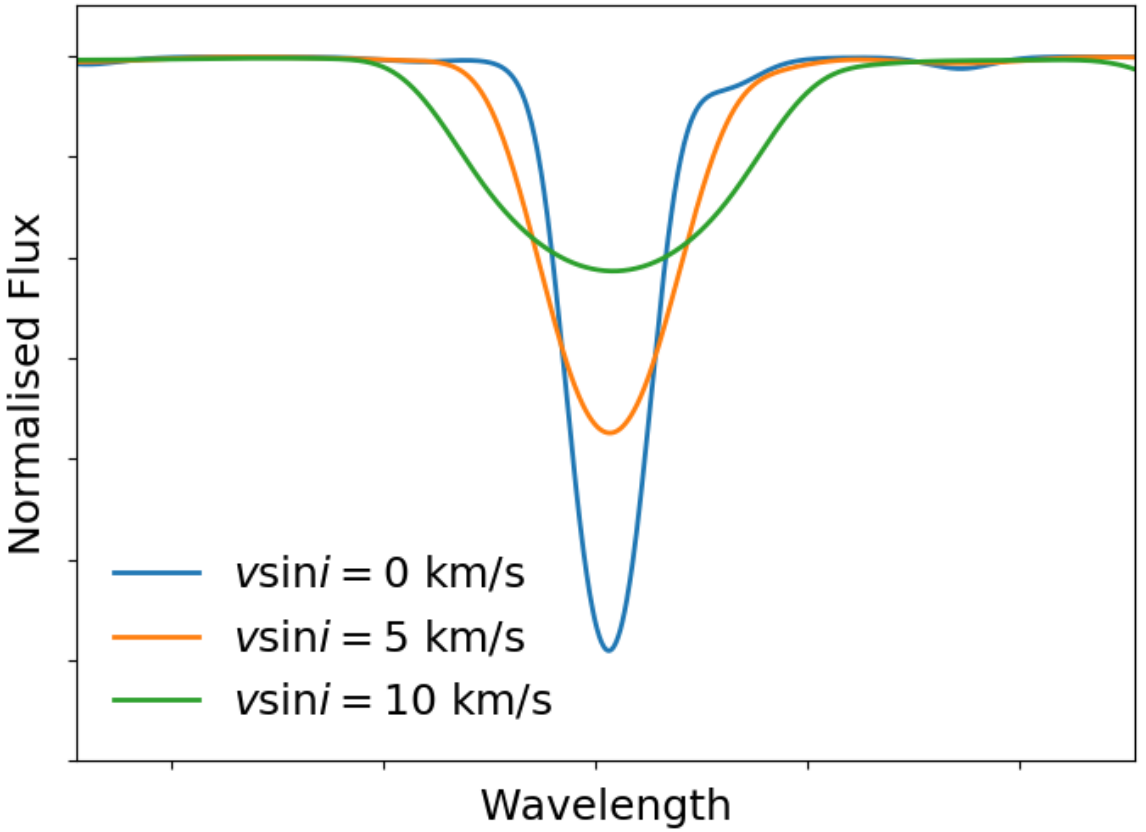
Are binary stars often spin-orbit aligned?

Planet formation: Effect of inclined companion

- Tilt the protoplanetary disk (Misaligned multi-planet systems)
- Kozai-Lidov oscillations (Highly eccentric and inclined planets, Hot Jupiters?)
- Truncate protoplanetary disk (prohibit planet formation?)

The *v*sin*i* method





The *v*sin*i* method

Combine *v*sin*i* with radius R_* and rotation period $P_{\rm rot}$:

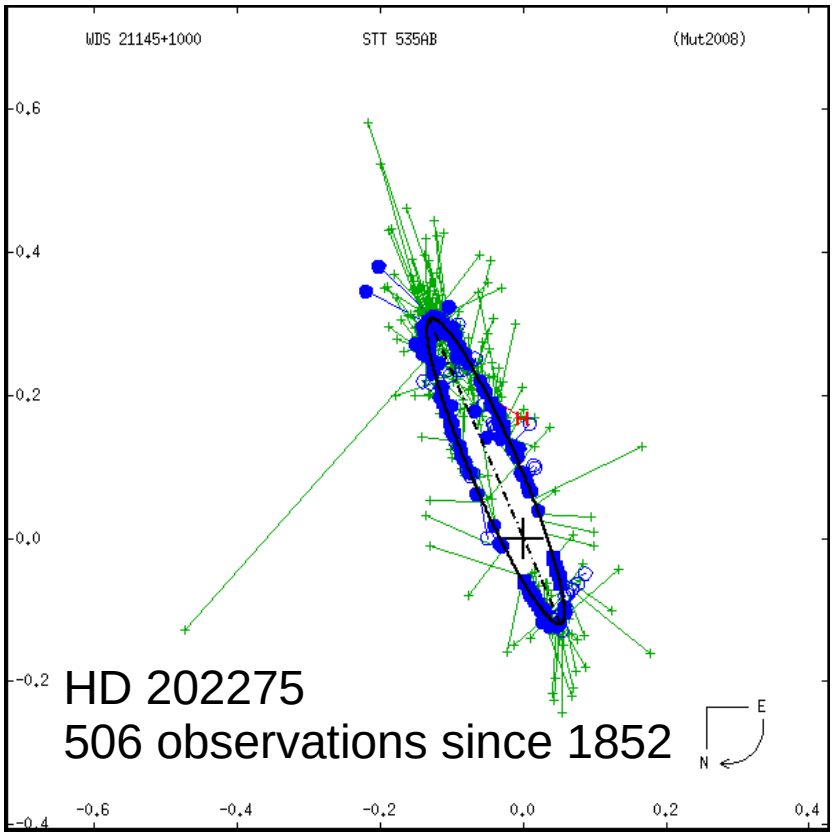
$$\sin i = \frac{v \sin i \cdot P_{\rm rot}}{2\pi R_*}$$

- **Efficient** and **independent** of orbital parameters
- Only sensitive to **strong** misalignment
- Requires estimate of **stellar rotation period**
  Photometry, spectroscopy,
  activity indicators, gyrochronology

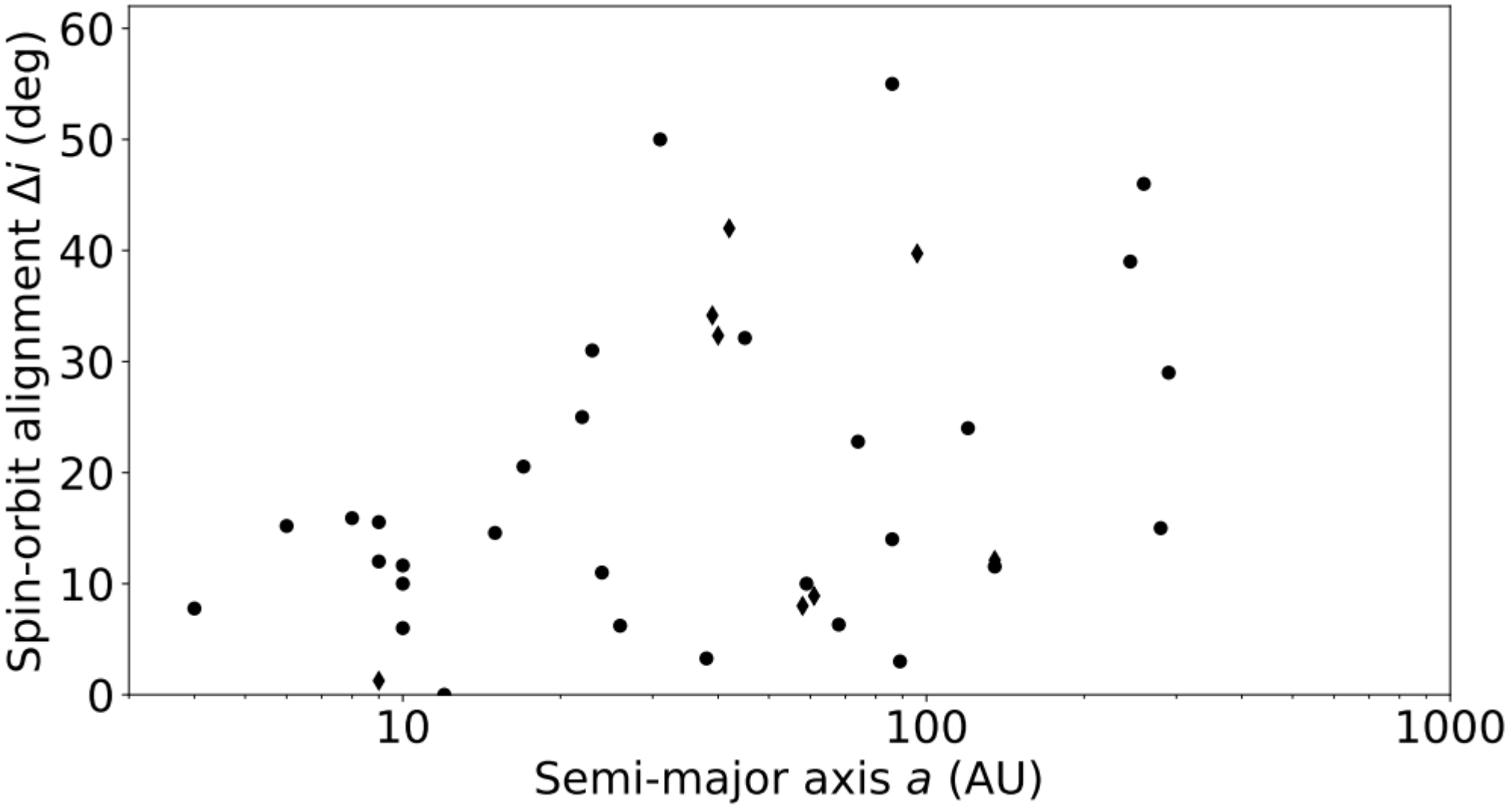
Projected Spin-orbit Alignment

- Orbital inclination from astrometric and spectrosocpic orbits

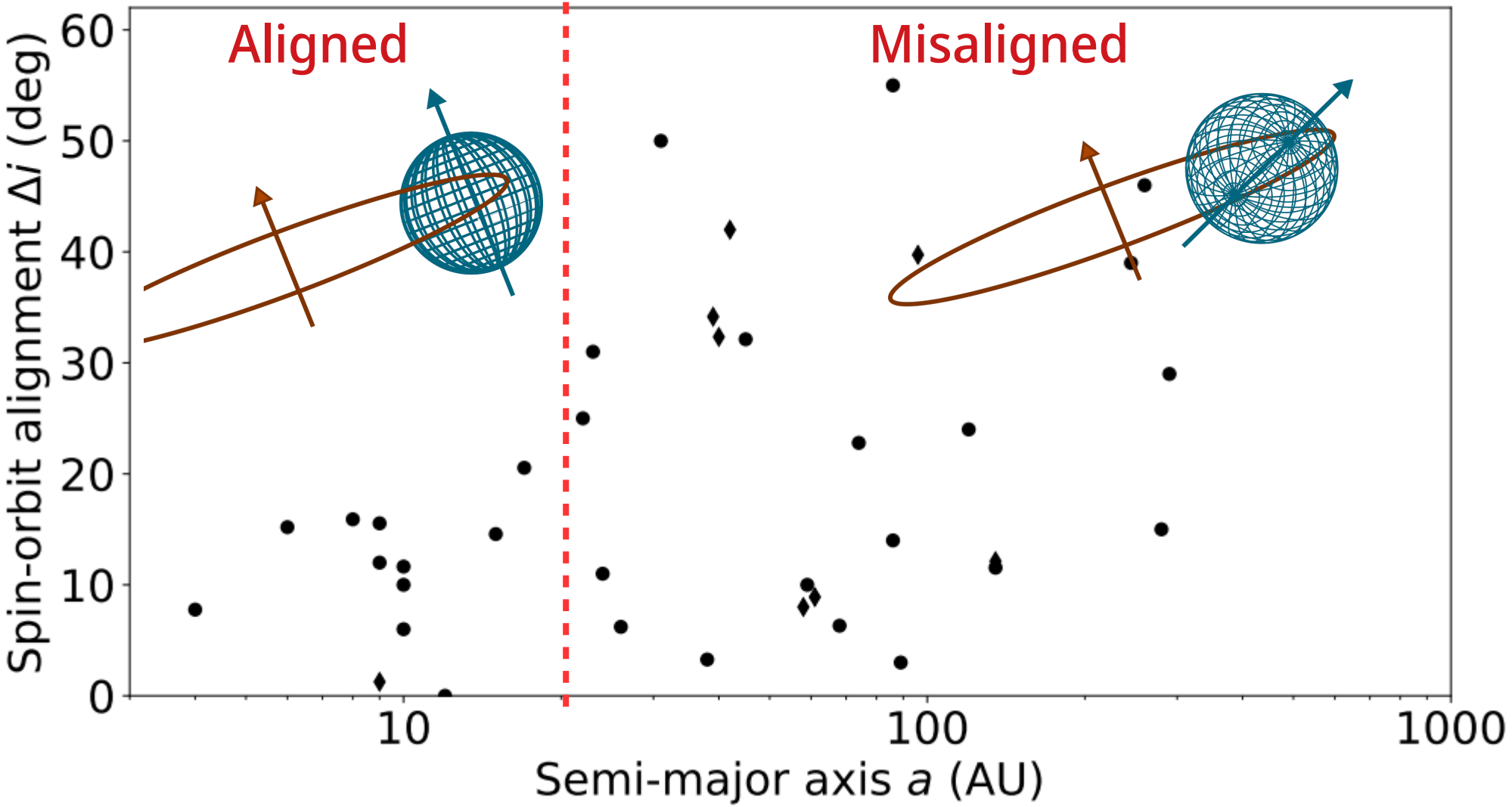
$$\Delta i = |i_{\rm orb} - i_*|$$



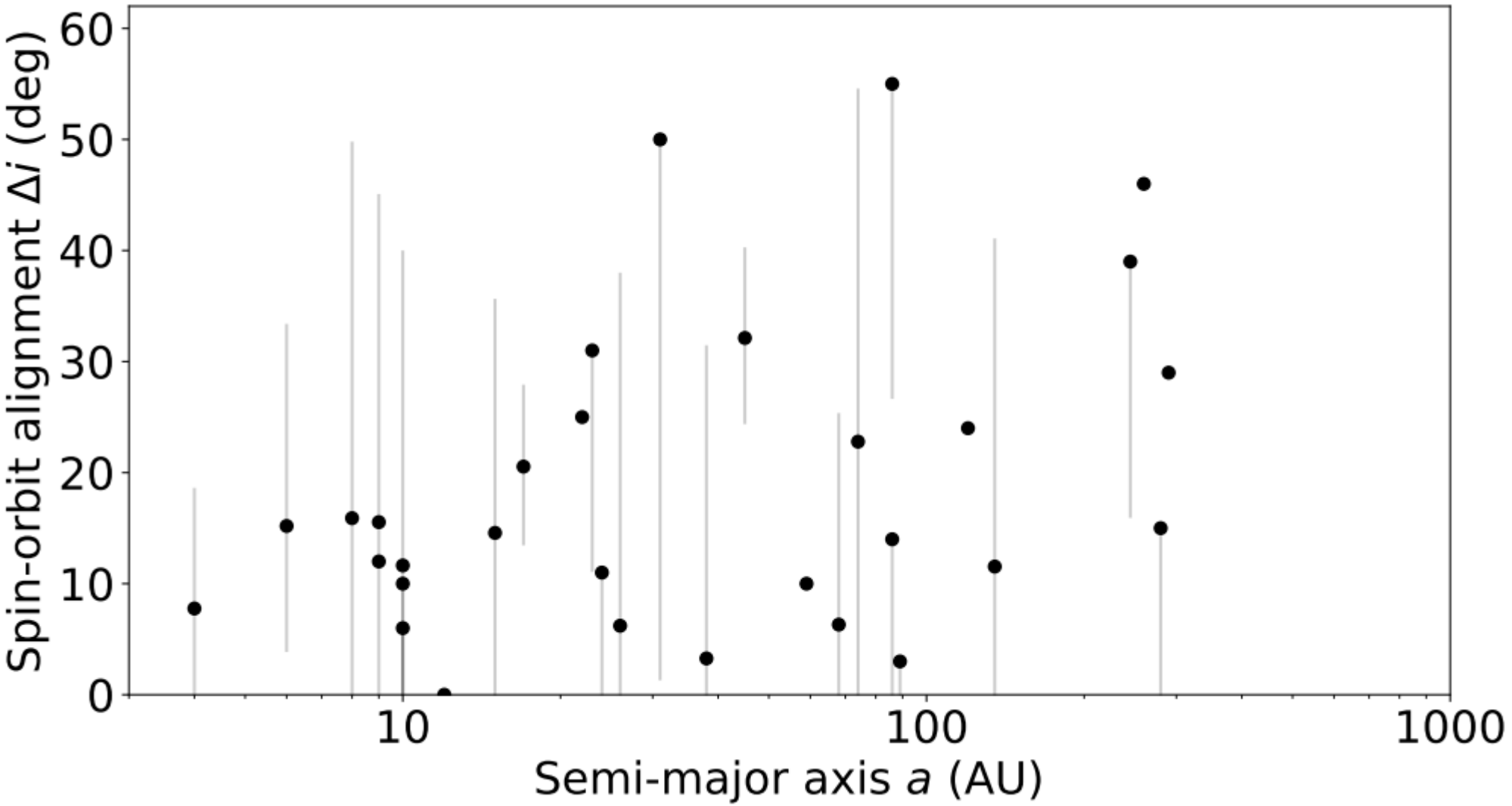
Hale (1994)


Spin-orbit alignment Δi (deg)
0
10
20
30
40
50
60
10
100
1000
Semi-major axis a (AU)

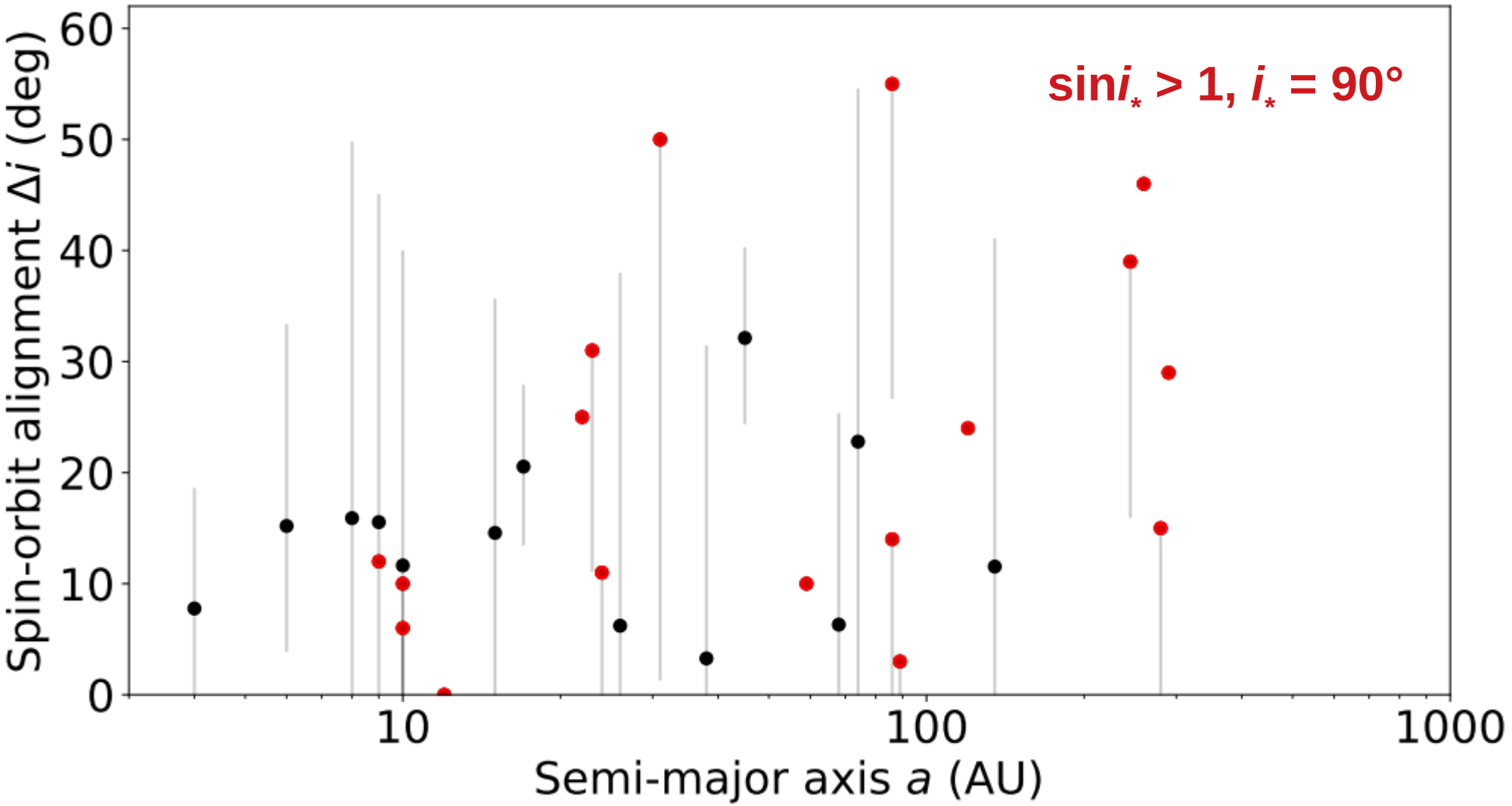
Hale (1994)


Aligned
Misaligned
Spin-orbit alignment Δi (deg)
0
10
20
30
40
50
60
10
100
1000
Semi-major axis a (AU)

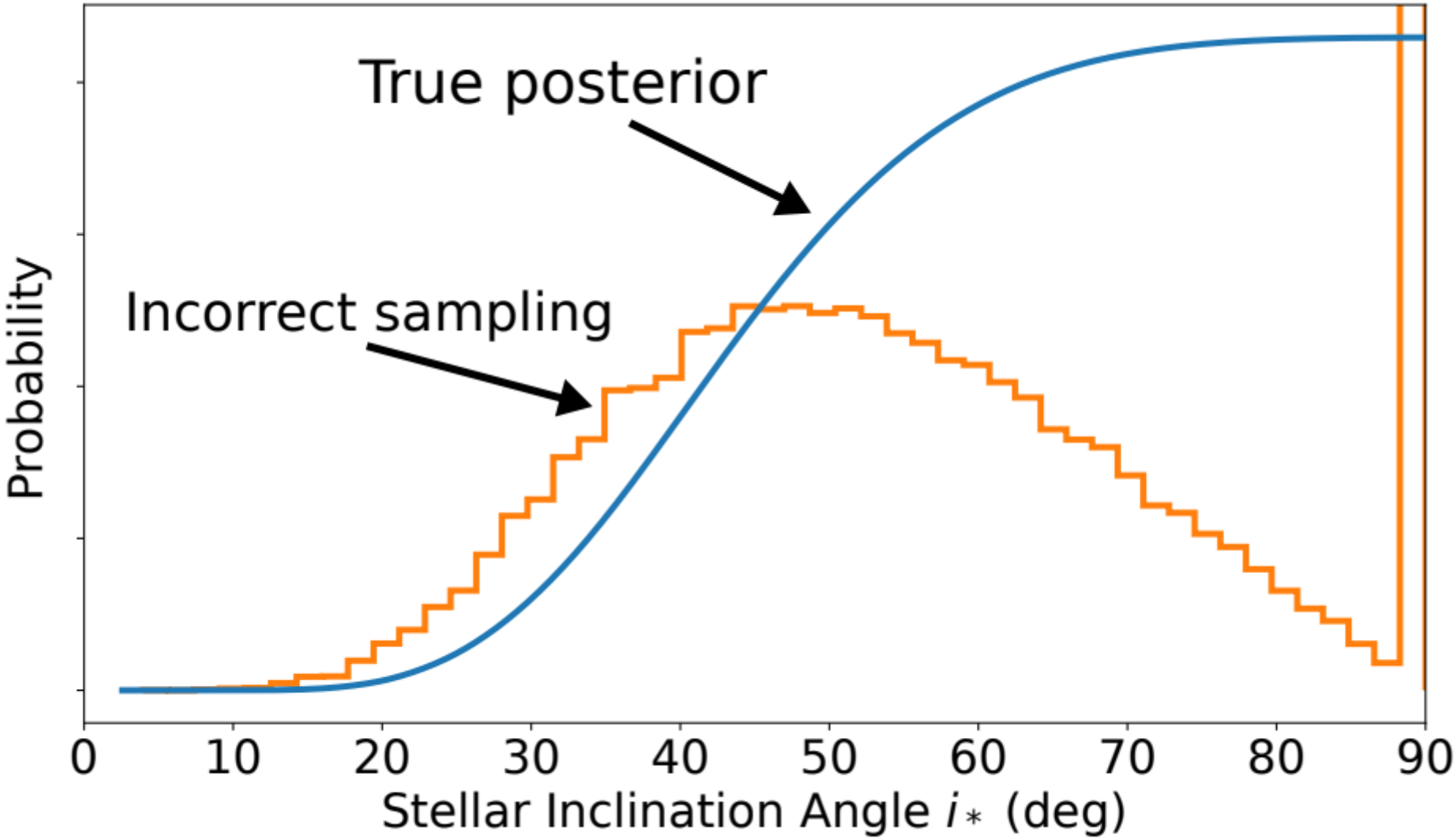
Hale (1994)


Spin-orbit alignment Δi (deg)
0
10
20
30
40
50
60
10
100
1000
Semi-major axis a (AU)

Hale (1994)

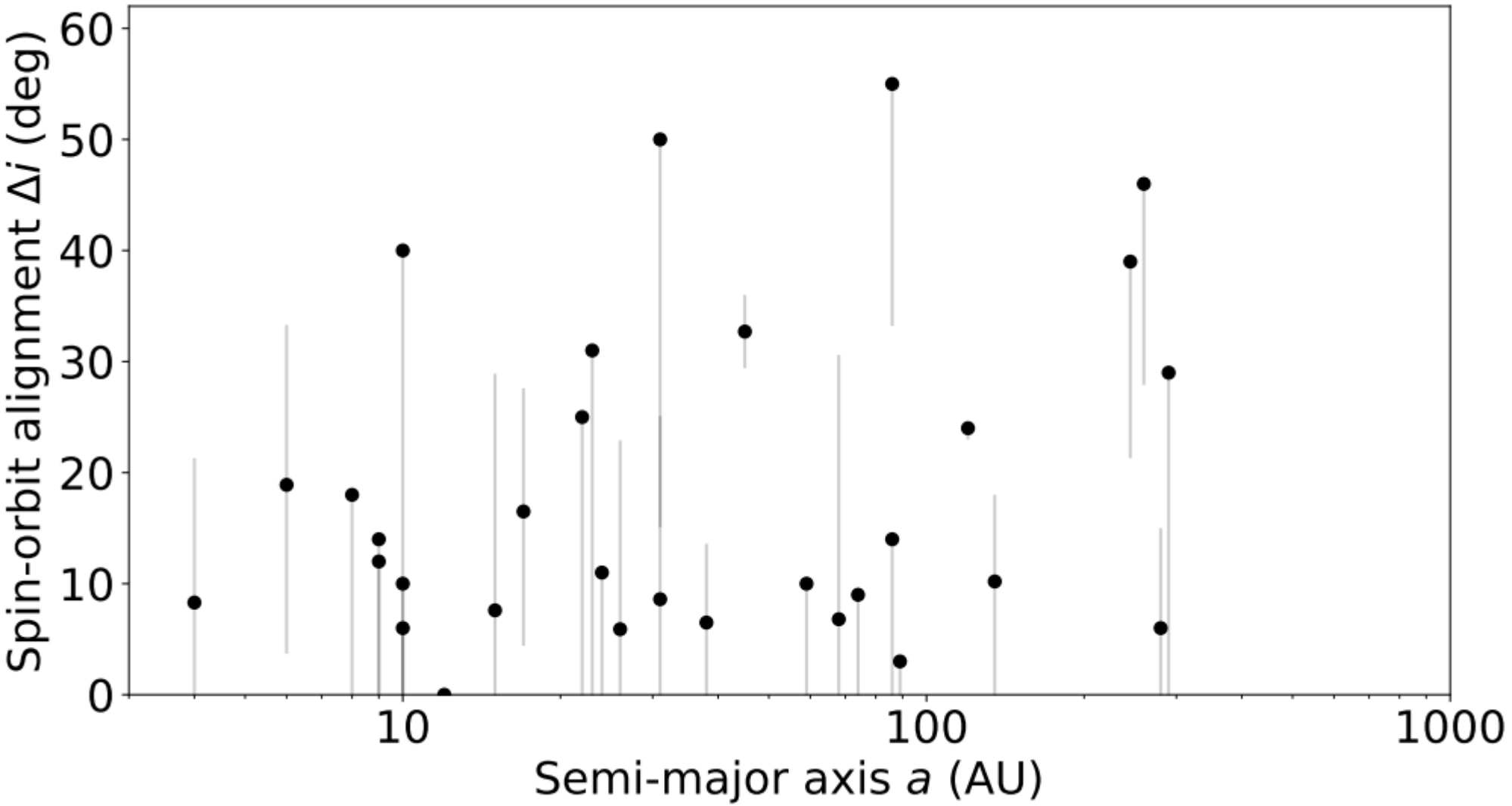

sini_* > 1, i_* = 90°
Spin-orbit alignment Δi (deg)
0
10
20
30
40
50
60
10
100
1000
Semi-major axis a (AU)

Dealing with sin*i* > 1

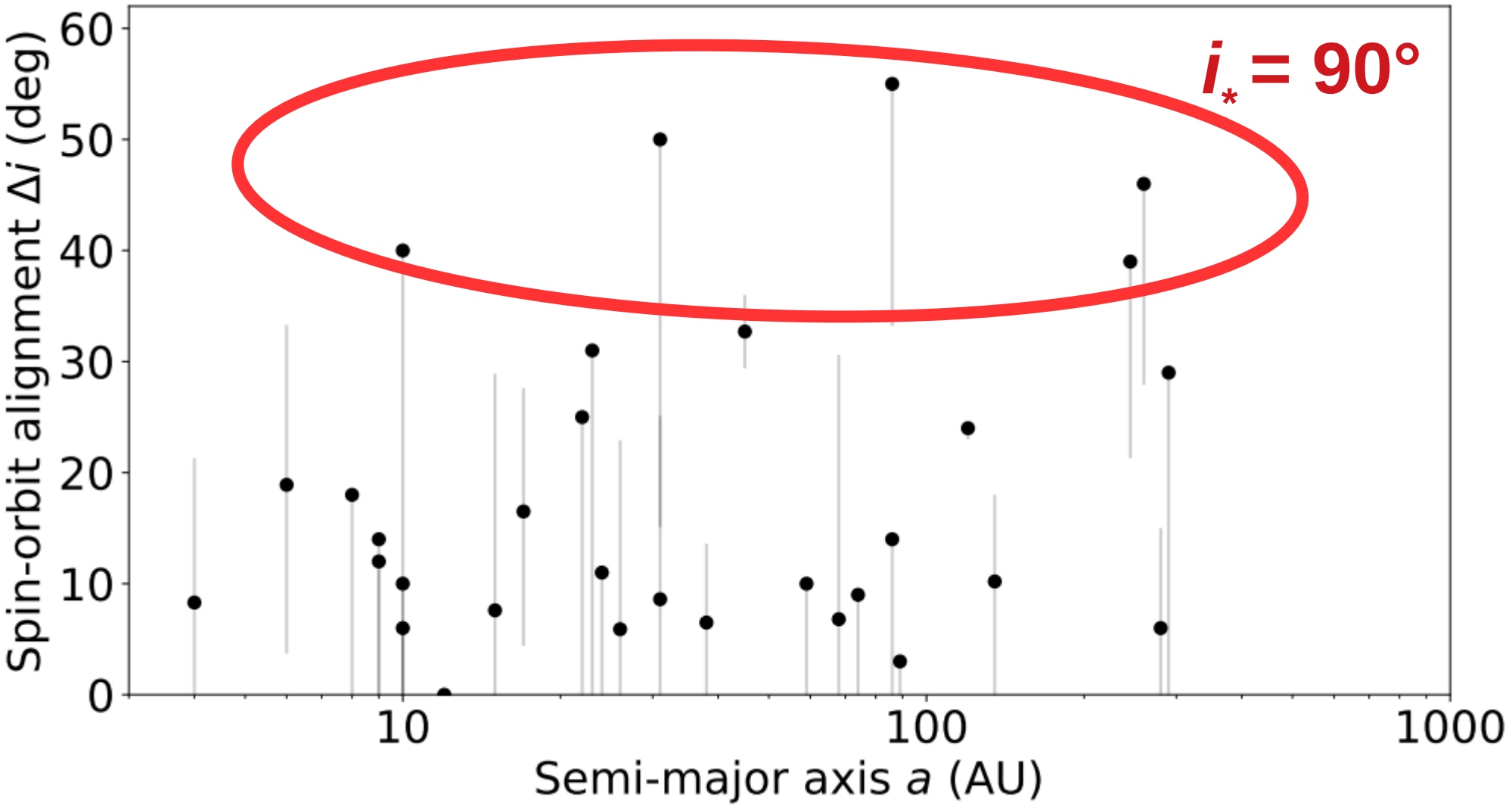


Adapted from Morton & Winn 2014

Hale (1994) data, Bayesian reanalysis

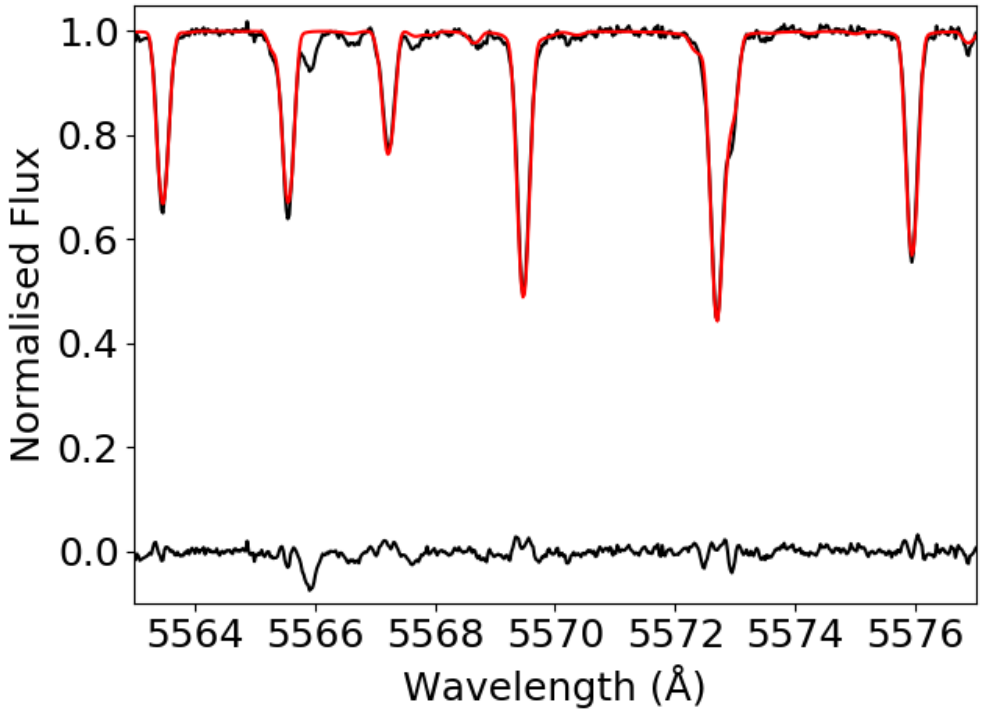


Hale (1994) data, Bayesian reanalysis



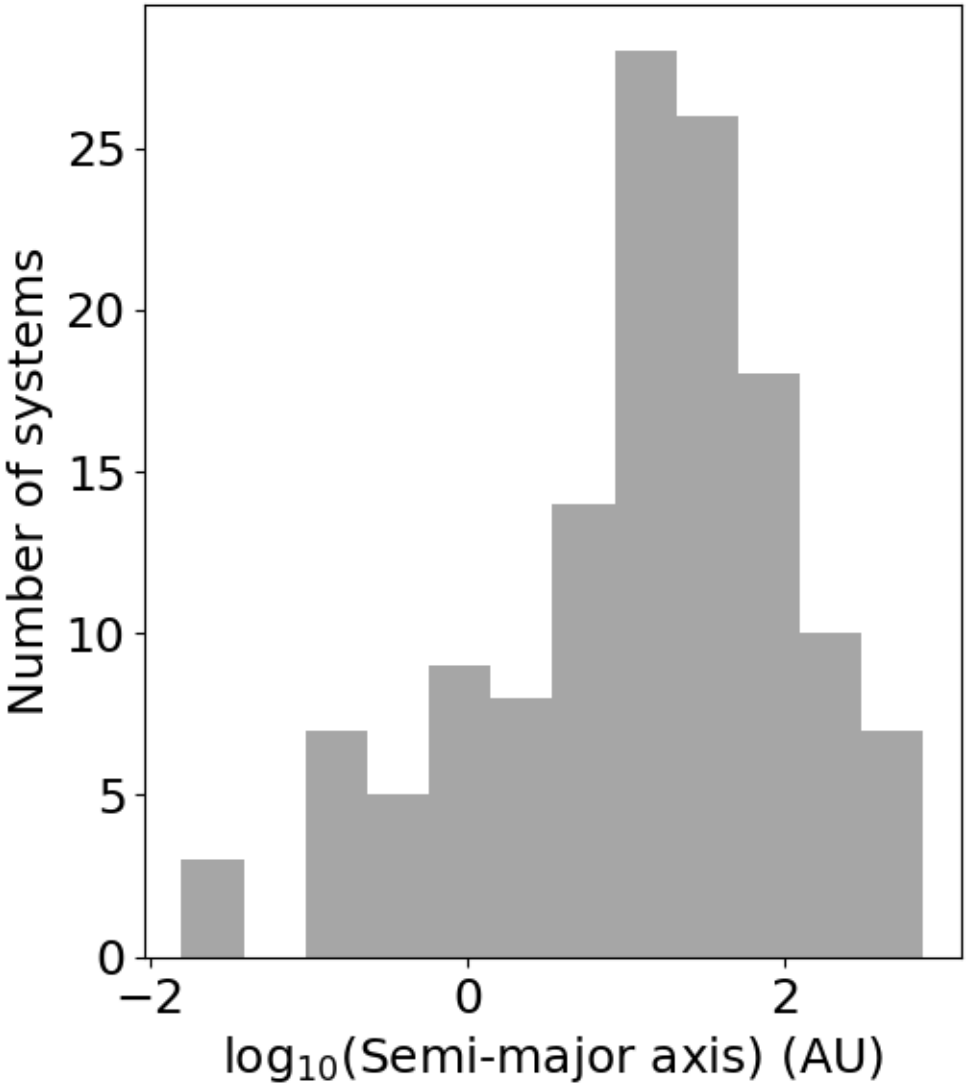
The SONG Binary Sample

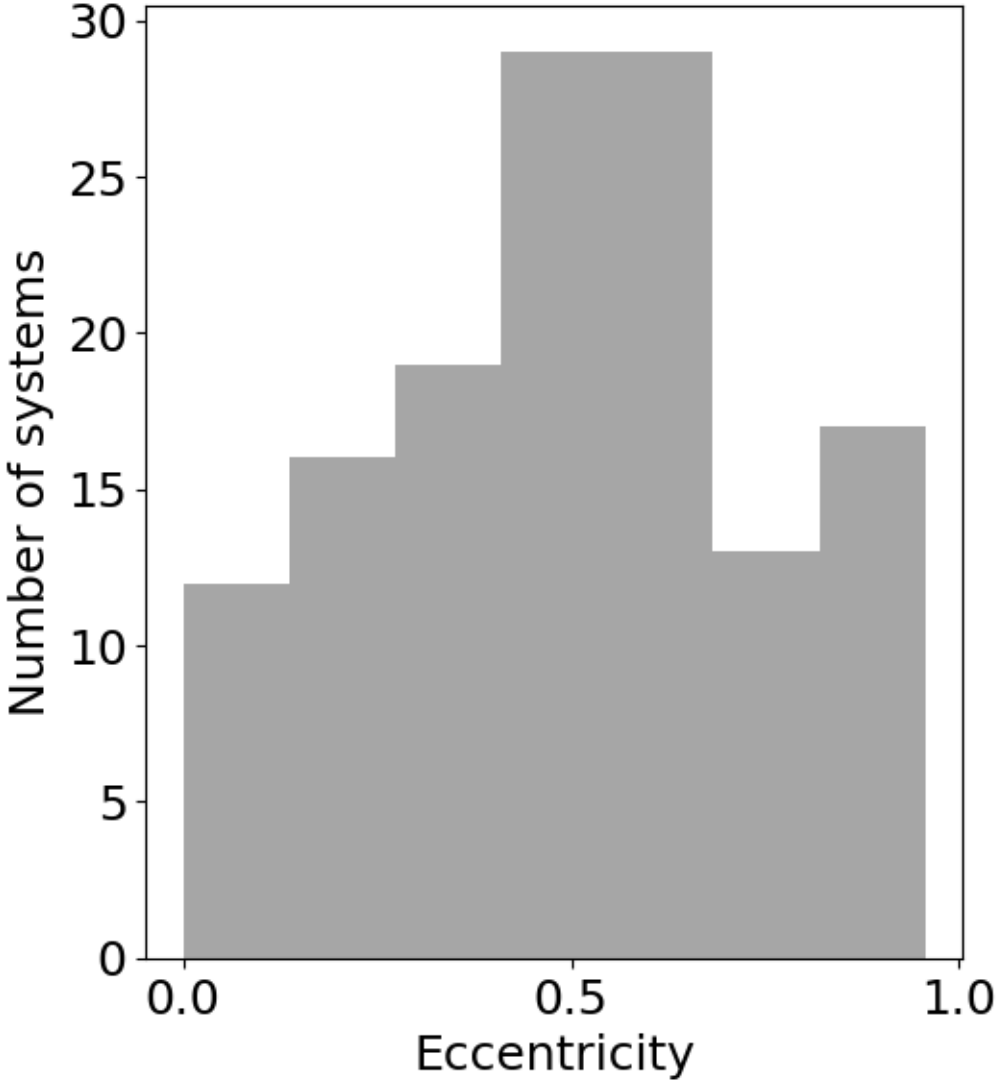
- Bright binaries with known orbits
- High Resolution
- Ideal for filler observations
- Consistent analysis
  (resolution, instrumental profile, treatment of macroturbulence, etc.)



The SONG Binary Sample

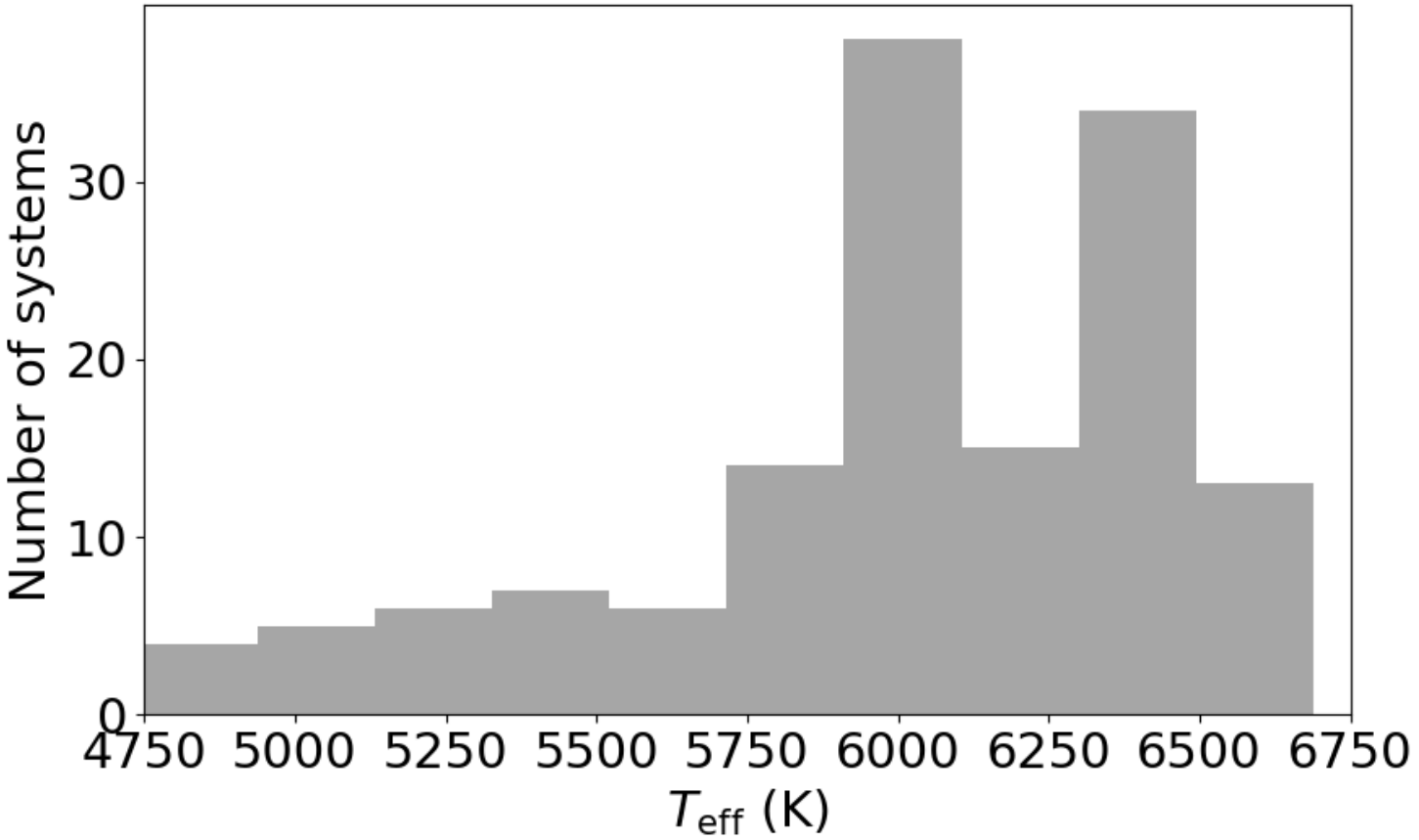
- **148 stars** in binary or multiple systems





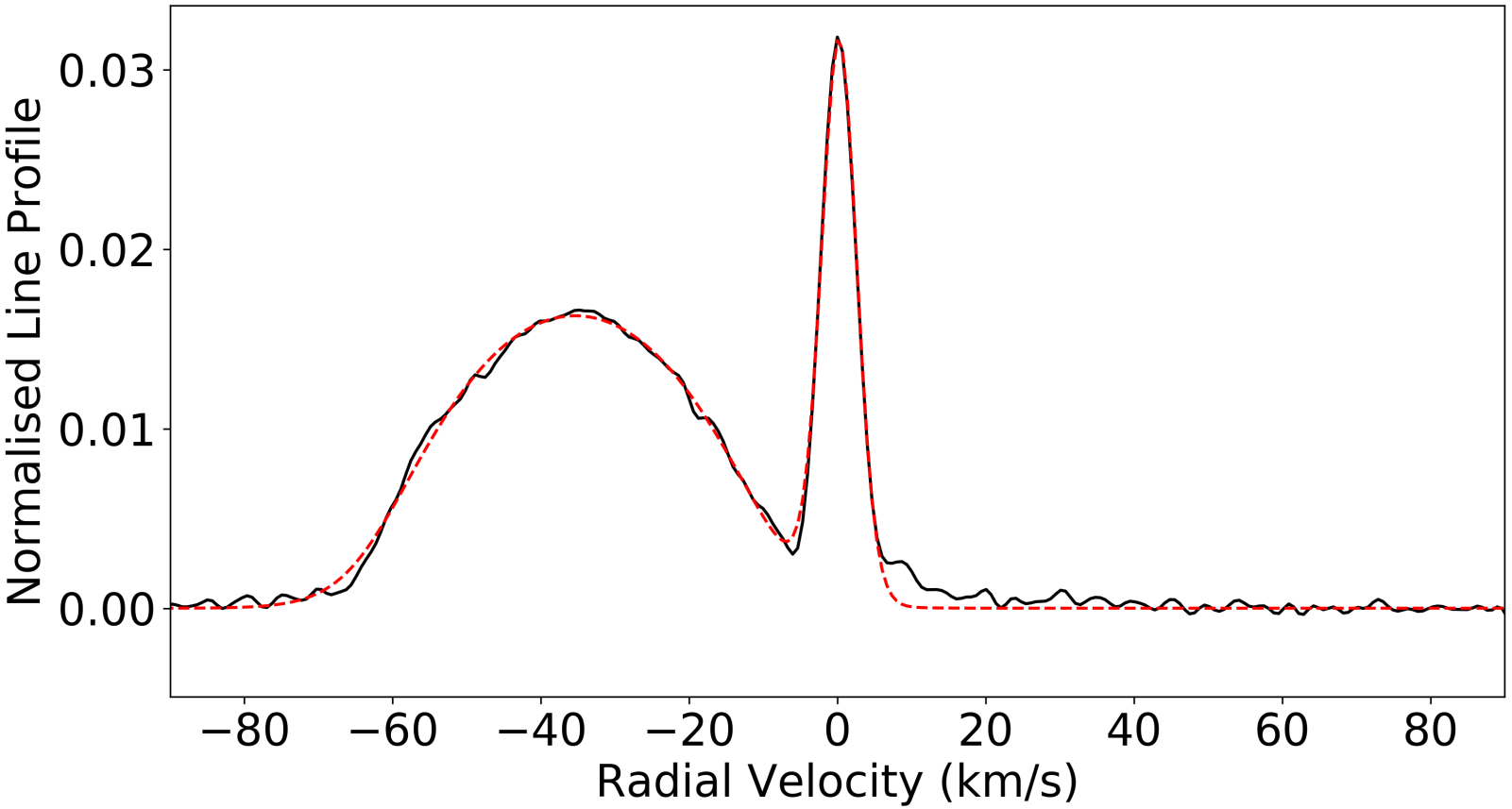
The SONG Binary Sample

- Larger fraction of hotter stars with faster expected rotation

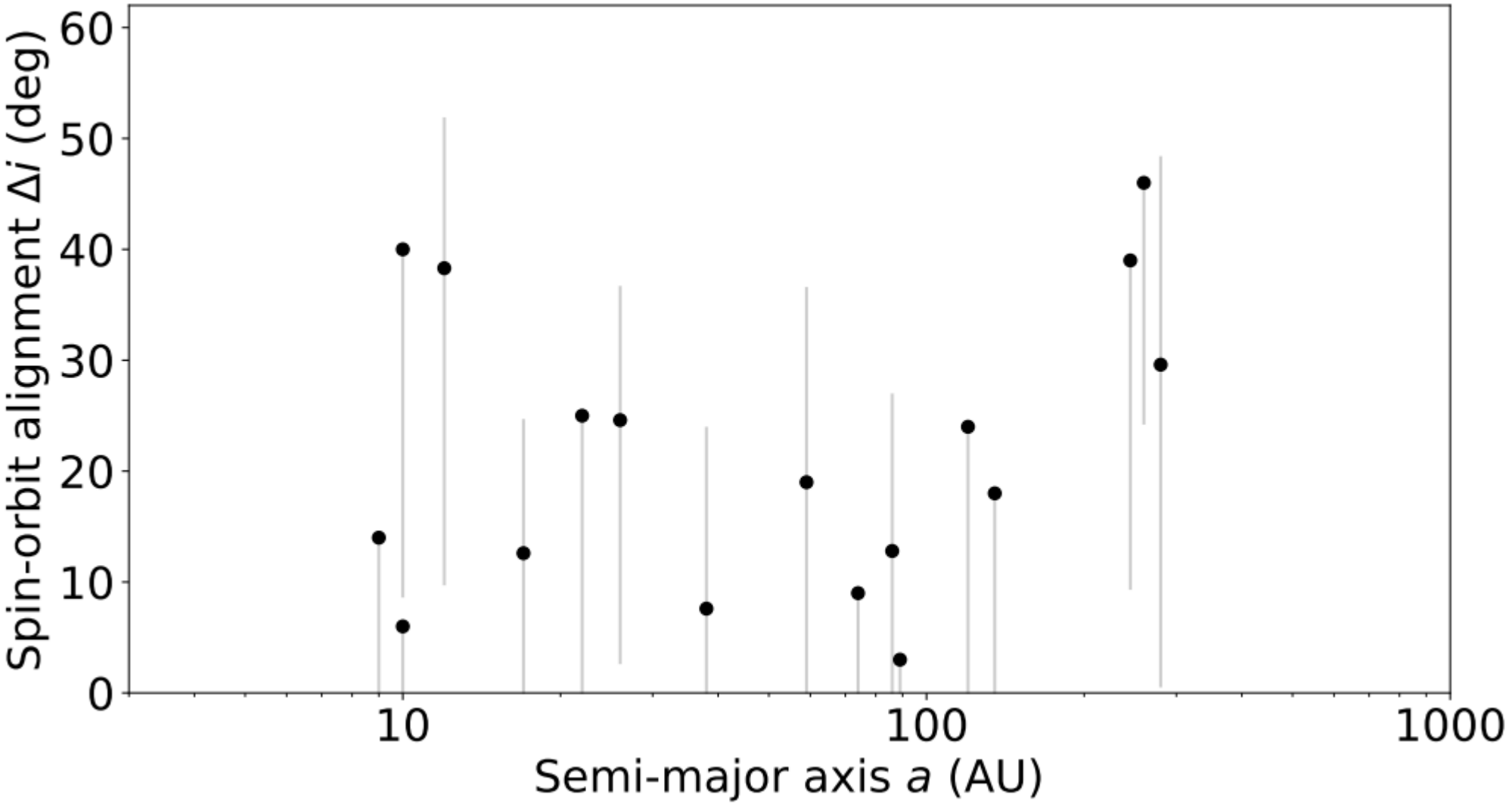


The SONG Binary Sample

- Double-lined binaries: spin-spin alignment



Preliminary SONG analysis



Take away points

- Spin-orbit (mis)alignment important for binary and planet formation
- Large sample of binary stars observed
- Uniform data and analysis approach
- Difference between close and wide binaries not as obvious as suggested?