New Measurements of Spin-Orbit Angles in Planetary and Binary Star Systems

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The Planet Finder Spectrograph

Magellan Clay 6.5 m Telescope

Planet Finder Spectrograph

PFS team:
Paul Butler, Jeff Crane, Steve Shectman, Ian Thompson
WASP-7: hot misaligned

- Period = 4.9 days;
- \( M_{\text{Planet}} = 0.9 M_{\text{Jupiter}} \)
Challenges: Low SNR

What we would expect if $v \sin i_* \approx 0 \text{ km s}^{-1}$?

- no RM signal
- no proj. obliquity preferred

Diagram:
- Excluded values
- Allowed values

$v \sin i$

proj. obliquity [deg]

-90 0 90
Challenges: Low SNR

What we would expect if $v \sin i_\star \approx 0 \text{ km s}^{-1}$?

$\Rightarrow$ no RM signal
$\Rightarrow$ no proj. obliquity preferred

Mock data without RM signal
Challenges: Low SNR

Need to isolate RM signal

- subtract systemic velocity $\rightarrow$ offset
- subtract orbital RVs ($K_*$) $\rightarrow$ slope

$\Rightarrow$ high-pass filter

and

0° or 180°

90° or −90°

high frequency

low frequency
Challenges: Low SNR

Need to isolate RM signal

- subtract systemic velocity $\rightarrow$ offset
- subtract orbital RVs ($K_*$) $\rightarrow$ slope

$\Rightarrow$ high-pass filter
Challenges: Low SNR

Need to isolate RM signal

- subtract systemic velocity → **offset**
- subtract orbital RVs ($K_*$) → **slope**

⇒ high-pass filter
WASP-2: misaligned?

proj. obliquity: $153^\circ_{11}^{+11}_{-15}$ degrees

WASP-2: misaligned?
WASP-2: fit to mock data without RM effect
WASP-2: new observations

RV scatter during transit and out of transit similar
⇒ no RM effect measured
⇒ obliquity is undetermined
Projected Obliquity: new measurements added

Tidal forces seem to be important
Projected Obliquity

- **Radiative Envelope**
- **Convective Envelope**

Tidal forces ⇒ also the eccentricity should be affected
systems with **low eccentricities** can have **high obliquities**
Orbital Eccentricity

- Circular Orbit
- Low Eccentricity
- High Eccentricity

exoplanet systems: $\tau_{\text{circ}} < \tau_{\text{align}}$

double star systems: $\tau_{\text{circ}} > \tau_{\text{sync}}$
Orbital Eccentricity

- Circular Orbit
- Low Eccentricity
- High Eccentricity

Mass of the secondary exoplanet systems: \( L_{\text{rotation}} : L_{\text{orbit}} \approx 1:1 \)
Mass of the secondary double star systems: \( L_{\text{rotation}} : L_{\text{orbit}} \approx 1:1000 \)
Obliquity and eccentricity function of mass ratio?

- Circular Orbit
- Low Eccentricity
- High Eccentricity

See also Johnson et al. (2009), Hébrard et al. (2010, 2011)
Orbital eccentricity

formulas from Zahn (1977)
Evidence for tidal forces

1) tidal forces are important
2) originally wide distribution in obliquity and eccentricity
What about close binary stars?

- The RM effect was first measured in binary systems (1924), but only a few quantitative RM results.
- Formation of close binaries still not completely understood.

Let’s take the Rossiter-McLaughlin effect back to its roots.
BANANA Survey

**Binaries Are Not Always Neatly Aligned**

Early type stars (young & radiative envelope)  
↓

“primordial” obliquities
BANANA Survey


(Hamilton spectrograph 0.6 m)
BANANA Survey


(SOPHIE OHP)
BANANA Survey


(SOPHIE OHP)
$\alpha$ CrB: primary aligned $\beta_p = 2 \pm 4^\circ$

(Hamilton spectrograph 0.6 m)
- $\alpha$ CrB: aligned – Maybe short period, circular systems?
CV Velorum: primary misaligned $\beta_p = -42 \pm 10^\circ$

- Short period (6.9 days);
- Circular orbit ($e = 0$)

(FEROS 2,2 m)
Conclusions

**exoplanets:**
- Tidal forces are important
- Wide distribution in obliquities and eccentricities

**stellar binaries:**
- Misalignment might be common
- Alignment seems not to be a simple function of period or eccentricity