Yanbo Pan
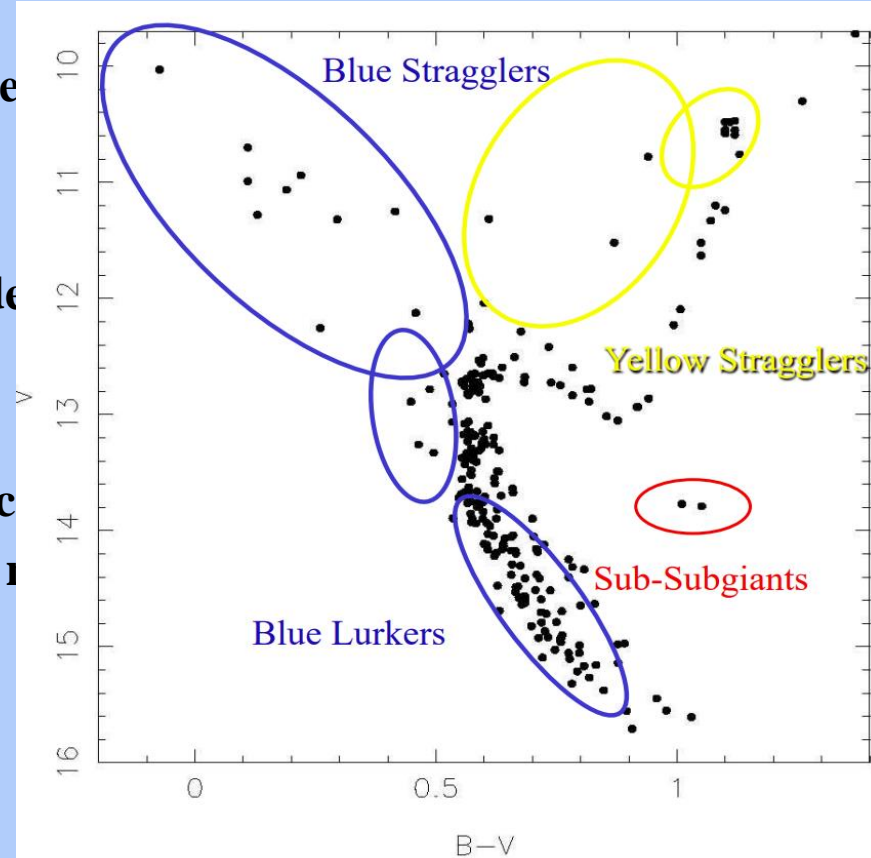Collaborator: Robert Mathieu, Evan Linck, Don Dixon
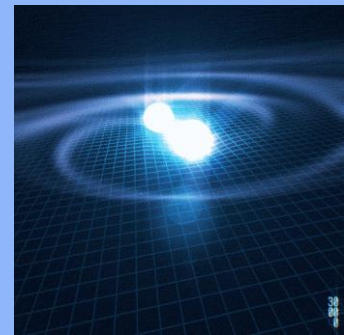
The WIYN Open Cluster Survey

- 100,000+ radial velocities (σ = 0.4 km/s) we[...]
  over 30+ years.

- However, 25% of stars could not be well de[...]
  evolutionary track.

- Instead, binary stars (i.e. blue stragglers) c[...]
  mass transfer, stellar collision, and stellar r[...]

Example RVD

| recno	WOCS	XID	RAJ2000	DEJ2000	_tab1_5	Tel	RVel1	RVel2	RVel3
1	1001	S1024	08 51 22.91	+11 48 49.40	45784.8376	TD	10.6	56.86	--
2	1001	S1024	08 51 22.91	+11 48 49.40	45807.6793	TD	-31.66	101.01	--
3	1001	S1024	08 51 22.91	+11 48 49.40	46065.0463	MD	-30.25	99.1	--
4	1001	S1024	08 51 22.91	+11 48 49.40	46072.0582	TD	-27.84	94.82	--
5	1001	S1024	08 51 22.91	+11 48 49.40	46125.8883	TD	93.85	-32.79	--

theJoker

"A custom Monte Carlo sampler for *sp[...]* body systems that can produce posterio[...] likelihood function is poorly behaved ([...]
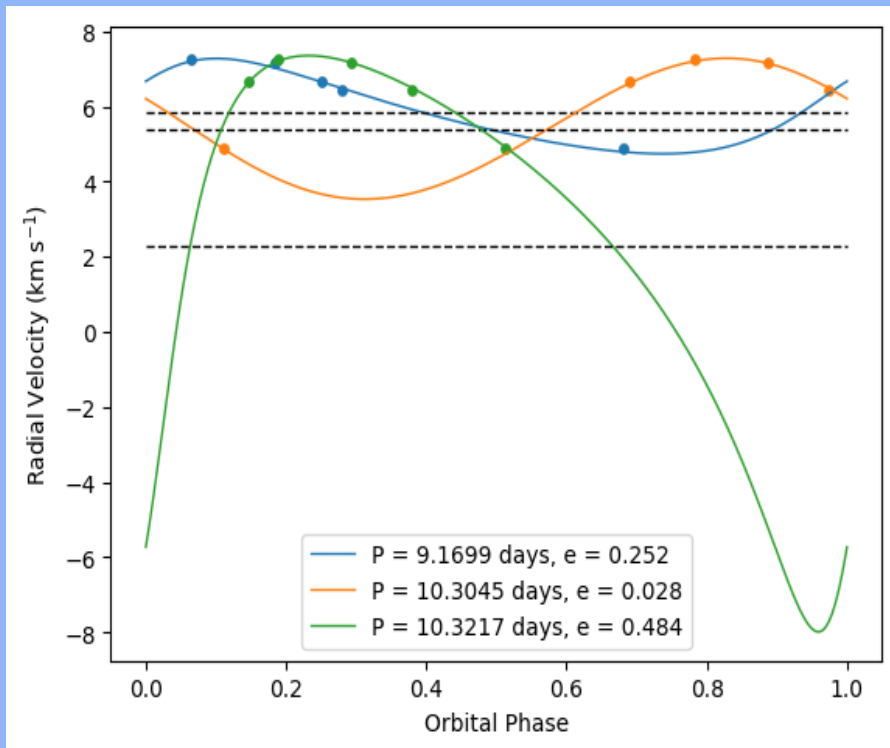
Rejection Sampleing on linear paramet[...]
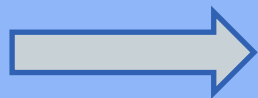
Monte Carlo Sampler re[...]

The Joker [YO-ker] /ˈjoʊkər/
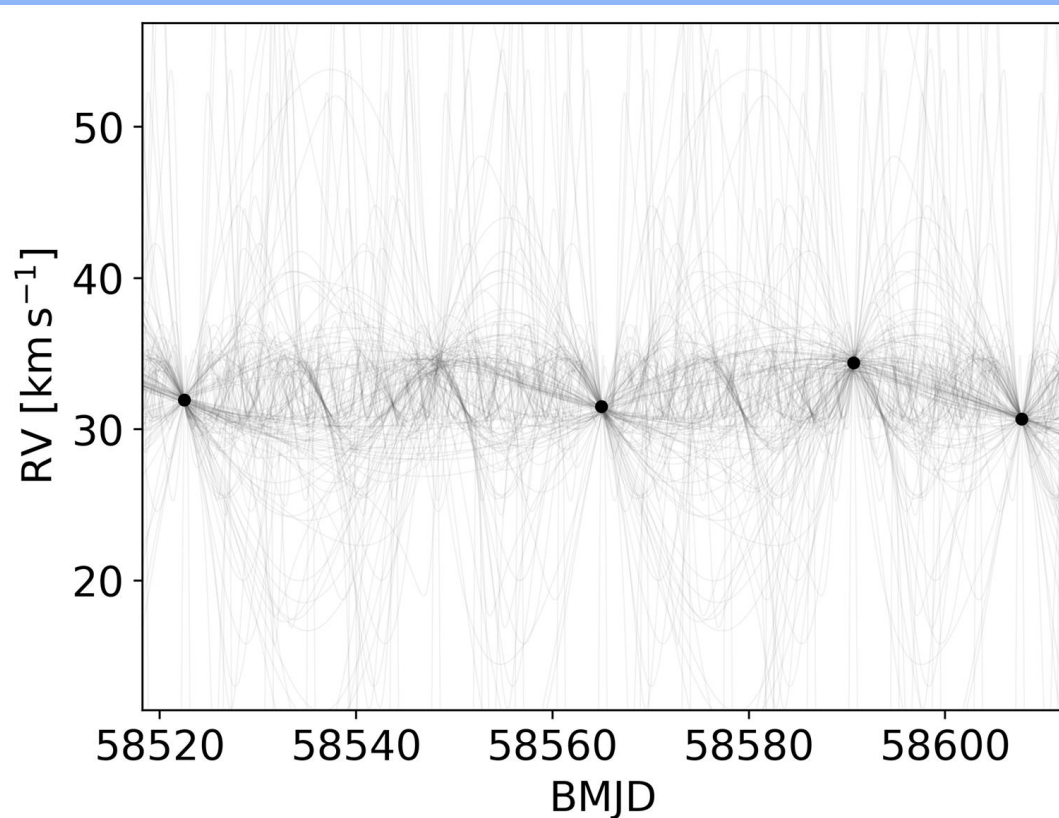
Example theJoker orbits (with only 5 RVD)

Rejection Sampling and MCMC
Star 7004 P:529.9 days e: 0.103
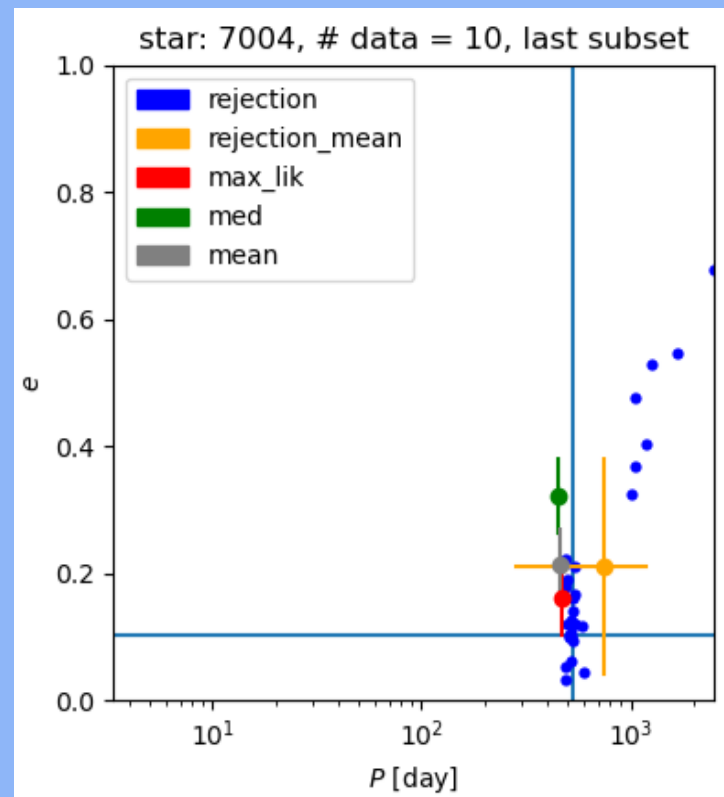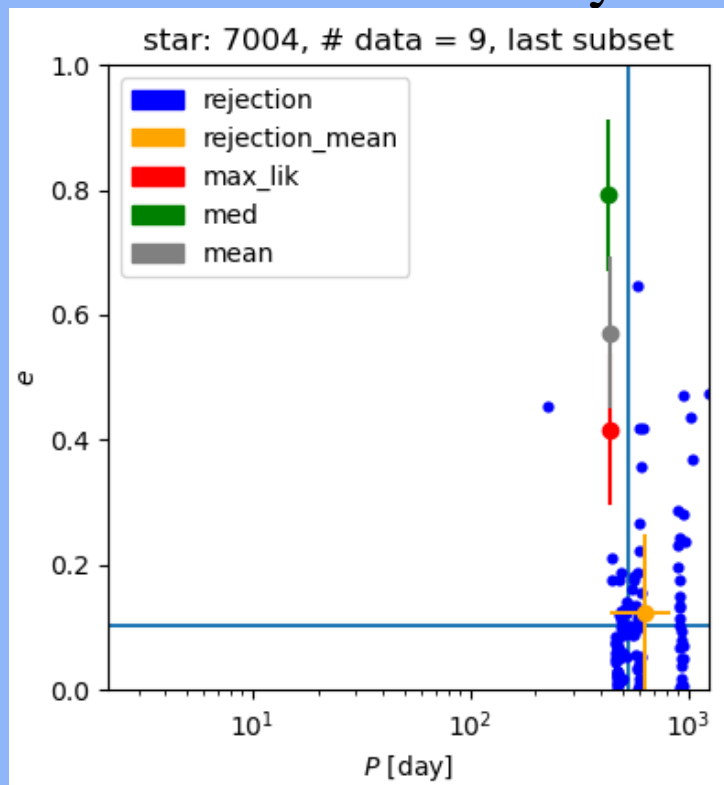
Significance to Future Observing (WIYN/NEID data)

3-4 data points offer no constraints on orbit from either rejection sampler or mcmc

5-7 data points let the rejection sampler constrain possible orbits; mcmc still performs poorly

8-10 data points are required for the rejection sampler to find unimodal (in period) solutions. The mcmc starts to converge with the rejection sampler in

Only for low-period (<1000 days) and low-eccentricity (<0.5) binary
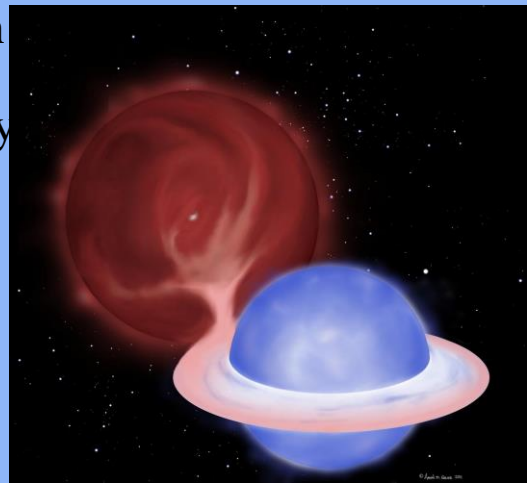
Example theJoker orbits (with only 5 RVD)
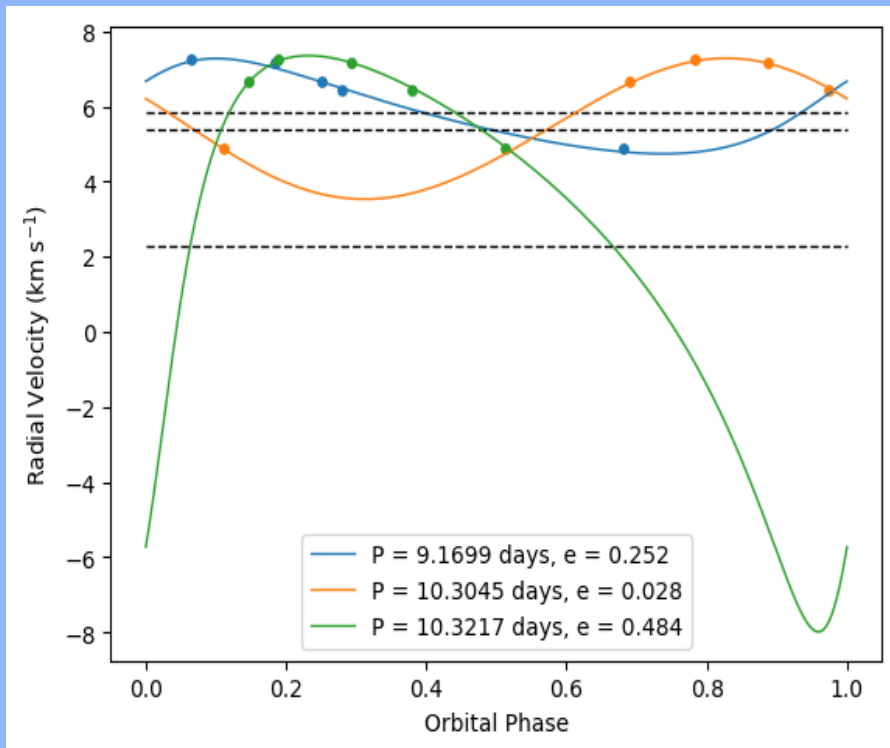
theJoker Design

TheJoker was originally envisioned to estimate orbital parameters with only a few (3 - 4) radial velocity measurements in the APOGEE dataset.

Over the summer, we apply theJoker on single-lined binaries within the NGC 188 (Geller et al., 2009) and M67 (Geller et al., 2021), where we have at least 10+ observations for each binaries system.

By the design, theJoker was not meant to find orbital parameters to the publishable precision. However, it is meant to find a sample of *close* orbit candidates with less than 12 RV measurements, comparing to direct integration.

Publishable Precision

Table 5. Orbital Parameters for M67 Single-Lined Binaries

ID	XID	P (days)	Orbital Cycles	γ (km s^{-1})	K (km s^{-1})	e	ω (deg)	$T_\circ$ (HJD-2400000 d)	$a \sin i$ (10^6 km)	$f(m)$ (M$_\odot$)	σ (km s^{-1})	N
1005	S1250	4422	2.8	33.64	2.59	0.529	81	47587	133	4.8×10^{-3}	0.44	111
		$\pm$ 17		$\pm$ 0.05	$\pm$ 0.08	$\pm$ 0.023	$\pm$ 3	$\pm$ 20	$\pm$ 5	$\pm 0.5\times10^{-3}$		
1015	S1237	698.56	23.9	33.58	5.02	0.087	260	46574	48.0	9.1×10^{-3}	0.44	75
		$\pm$ 0.24		$\pm$ 0.06	$\pm$ 0.07	$\pm$ 0.015	$\pm$ 10	$\pm$ 19	$\pm$ 0.7	$\pm 0.4\times10^{-3}$		
1033	S721	6350	2.5	34.53	0.98	0.54	266	46860	71	3.6×10^{-4}	0.41	89
		$\pm$ 220		$\pm$ 0.06	$\pm$ 0.09	$\pm$ 0.07	$\pm$ 10	$\pm$ 220	$\pm$ 8	$\pm 1.1\times10^{-4}$		
2002	S1040	42.8251	382.4	33.00	8.47	0.016	80	45539	4.99	2.70×10^{-3}	0.54	60
		$\pm$ 0.0010		$\pm$ 0.07	$\pm$ 0.10	$\pm$ 0.012	$\pm$ 50	$\pm$ 5	$\pm$ 0.06	$\pm 0.10\times10^{-3}$		
2008	S1072	1513	10.8	32.70	2.57	0.30	158	46889	51	2.3×10^{-3}	1.05	71
		$\pm$ 7		$\pm$ 0.13	$\pm$ 0.19	$\pm$ 0.07	$\pm$ 14	$\pm$ 52	$\pm$ 4	$\pm 0.5\times10^{-3}$		
2014	S1221	6475	2.5	32.85	5.71	0.037	320	52500	508	1.25×10^{-1}	0.44	110
		$\pm$ 16		$\pm$ 0.05	$\pm$ 0.07	$\pm$ 0.011	$\pm$ 19	$\pm$ 300	$\pm$ 6	$\pm 0.05\times10^{-1}$		
2016	S1224W	12.4424	558.5	33.48	22.06	0.025	246	48115.7	3.77	1.38×10^{-2}	1.02	44
		$\pm$ 0.0005		$\pm$ 0.17	$\pm$ 0.25	$\pm$ 0.010	$\pm$ 25	$\pm$ 0.8	$\pm$ 0.04	$\pm 0.05\times10^{-2}$		

Reference:

Geller, A. M., Mathieu, R. D., Harris, H. C., & McClure, R. D. (2009). Wiyn Open Cluster Study. XXXVI. spectroscopic binary orbits in NGC 188. The Astronomical Journal, 137(4), 3743–3760. https://doi.org/10.1088/0004-6256/137/4/3743

Geller, A. M., Mathieu, R. D., Latham, D. W., Pollack, M., Torres, G., & Leiner, E. M. (2021). Stellar radial velocities in the Old Open Cluster M67 (NGC 2682). II. the spectroscopic binary population. The Astronomical Journal, 161(4), 190. https://doi.org/10.3847/1538-3881/abdd23

Price-Whelan, A. M., Hogg, D. W., Foreman-Mackey, D., & Rix, H.-W. (2017). the joker:a custom Monte Carlo sampler for binary-star and exoplanet radial velocity data. The Astrophysical Journal, 837(1), 20. https://doi.org/10.3847/1538-4357/aa5e50

- Thanks for listening!
- Any Questions?
- panpi@umich.edu

Notes on theJoker

Multimodal solutions do not mean bad estimate of orbit. Sometimes, unimodal could be more deviate from the "true" solution.

When both unimodal and multimodal are away from the "true" solution, multimodal could be more informative on possible orbits and RVD.

Longer period (>300 days) and higher eccentricity systems require more observations (12+). The MCMC seems to perform better than the rejection sampler for higher eccentricity systems with at least 10 observations.