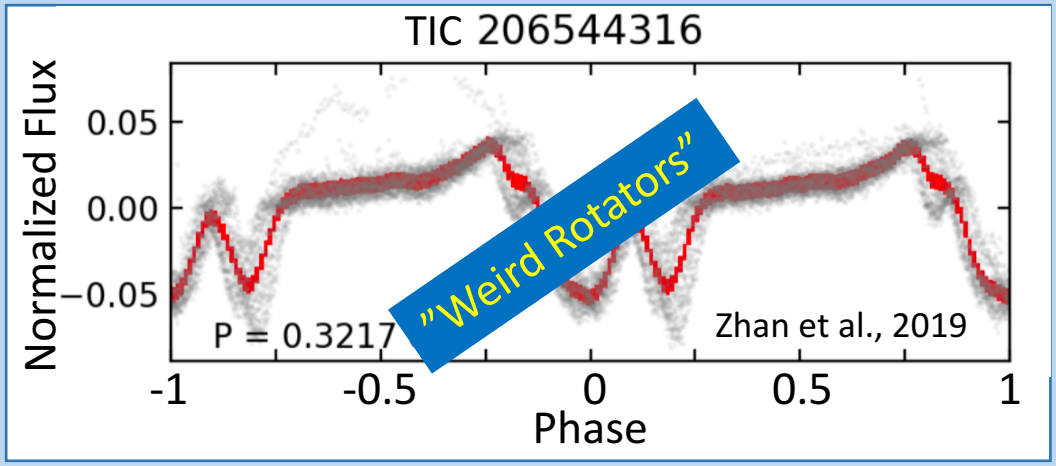
Complex Rotational Modulation of Rapidly Rotating Mdwarfs Observed with TESS



"Weird Rotators"

"Weird Rotators"

"Weird Rotators"

Zhuchang Zhan, MIT

Max Günther, Saul Rappaport, Katalin Oláh, Andrew Mann, Alan M. Levine, Joshua Winn, Fei Dai, George Zhou, Chelsea X. Huang, Luke G. Bouma, Michael J. Ireland and TESS Team.

TESScon1 August 1st, 2019

10 “Weird Rotators” Discovered in Sector 1 & 2 of TESS 2-min Data

Sharp “Dip, Peak, Dip” features

So…
What are they?

Blended stars?

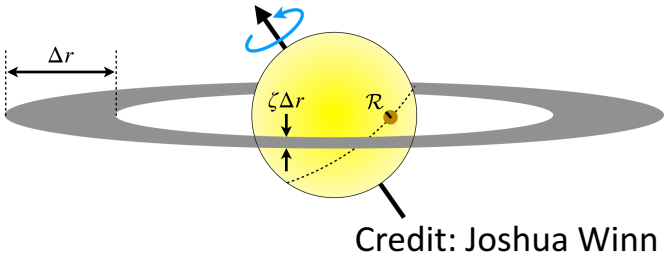
Star spots?

Magnetically trapped dust?

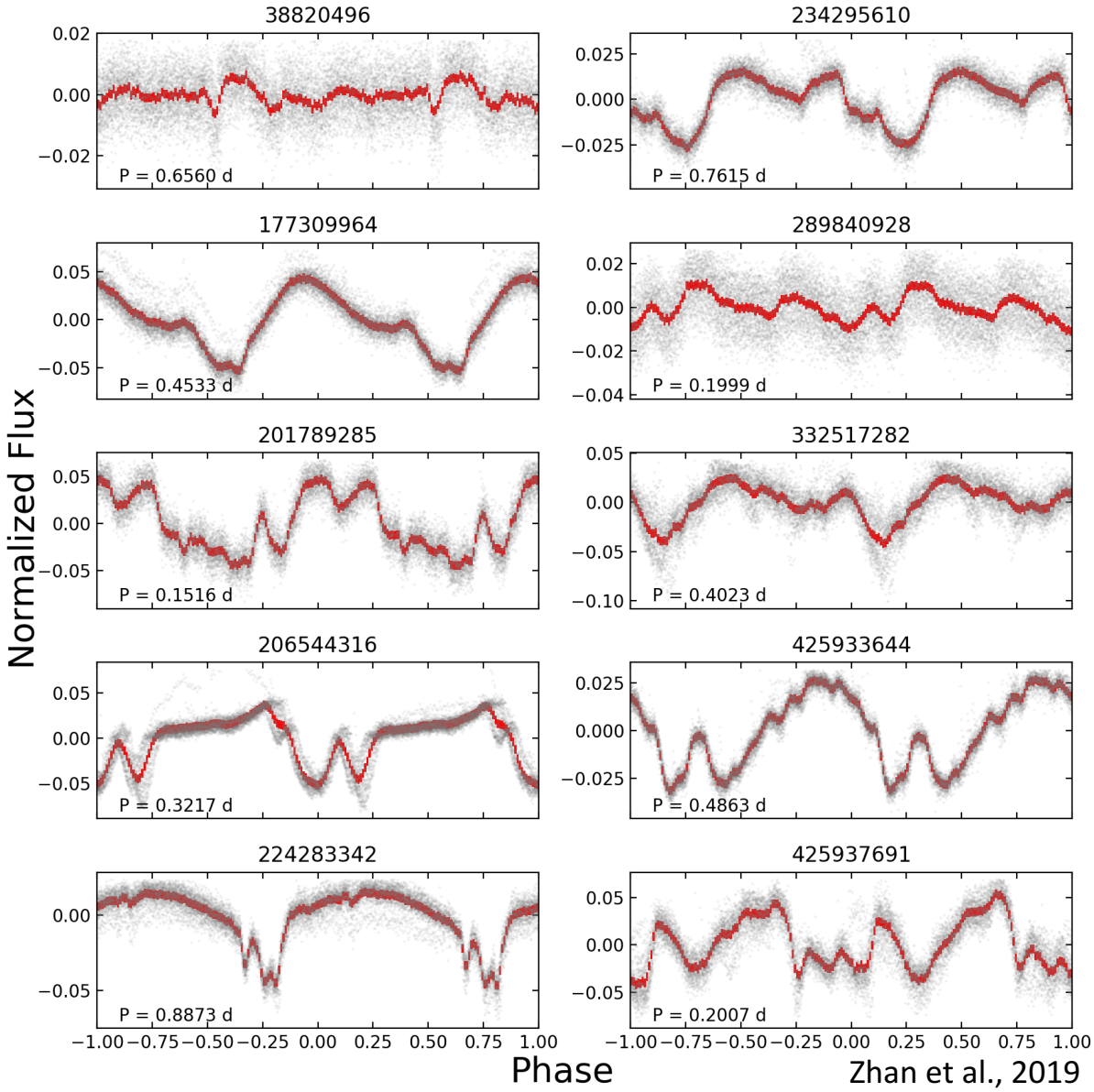
Corotating gas?

Radiation beaming?

Occulting dust rings?



Credit: Joshua Winn



Zhan et al., 2019

The TESS Variable Object of Interest (TVOI) Pipeline

Search for Rapidly Variable Objects Enable by the 2-min Cadence

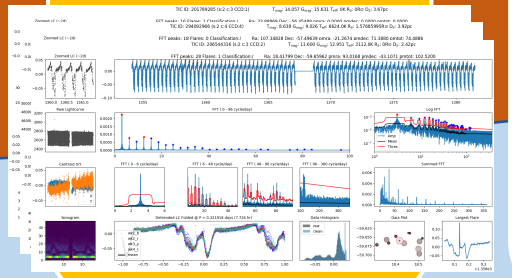
SPOC PDC LC

Detrending
Data
Preprocessing

Fast

Peak
Detection
(Empirical
Threshold)

Data Reports



Vetting

botted

ML <--- Human **Automated Pipeline**

Few “New” Discoveries

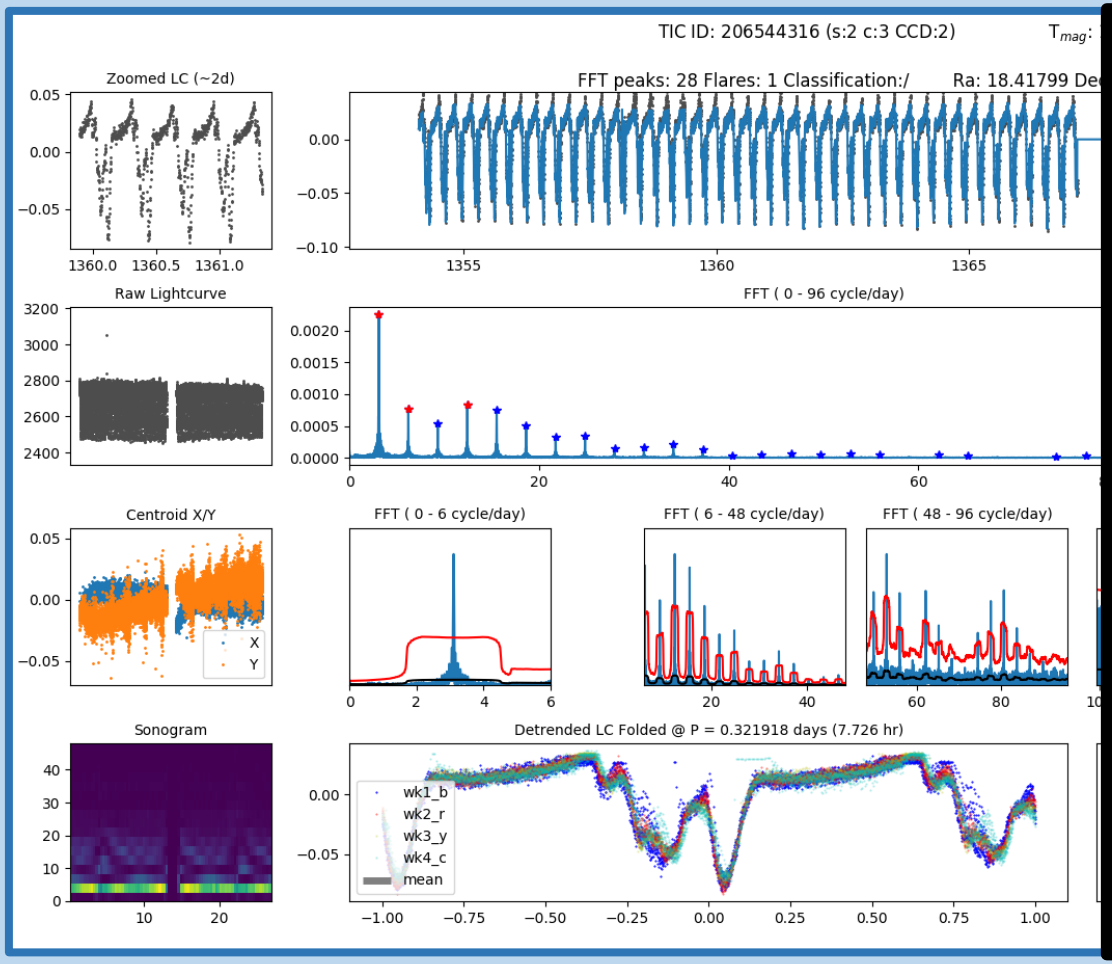
~ 80 Objects (0.5%) for Further Analysis

~ 1600 DV (10%)

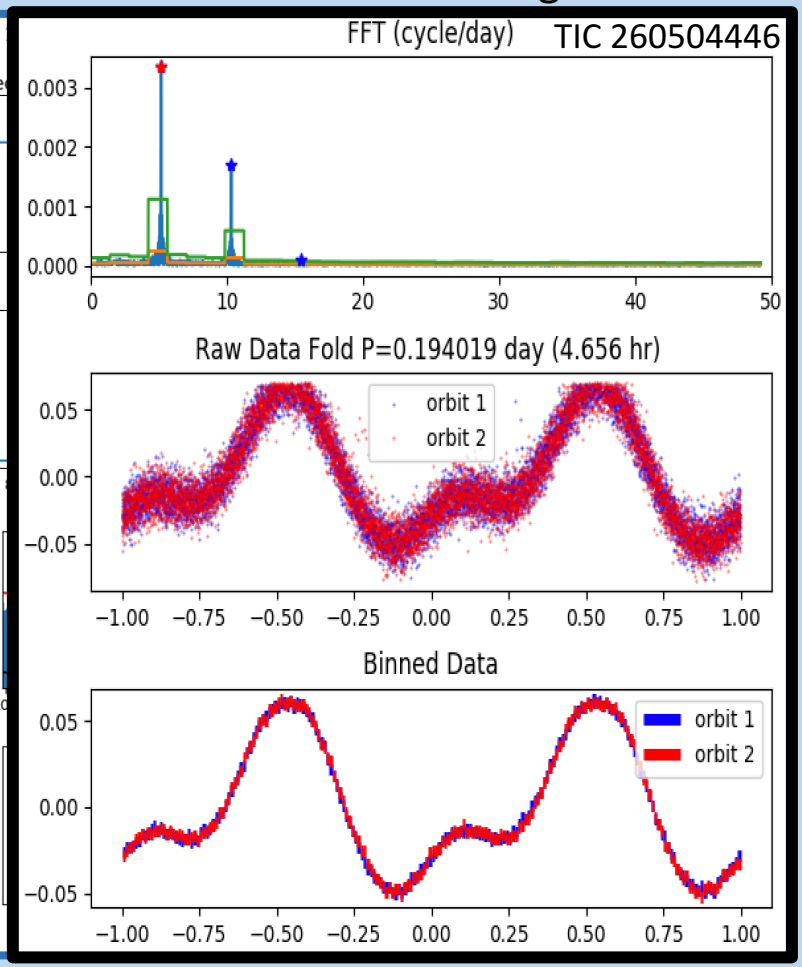
16000 LC/sector

TVOI Data Visualization Report and Discovery of the “Weird Rotators”

https://github.com/azariven/TVOI



“Normal” Fast Rotating Mdwarf



Spectra Follow-up Confirmed “Weird Rotators” are Not Spectroscopic Binaries

- ~~Blended star?~~
- Star spots?
- Magnetically trapped dust?
- Corotating gas?
- Radiation beaming?
- Occulting dust rings?

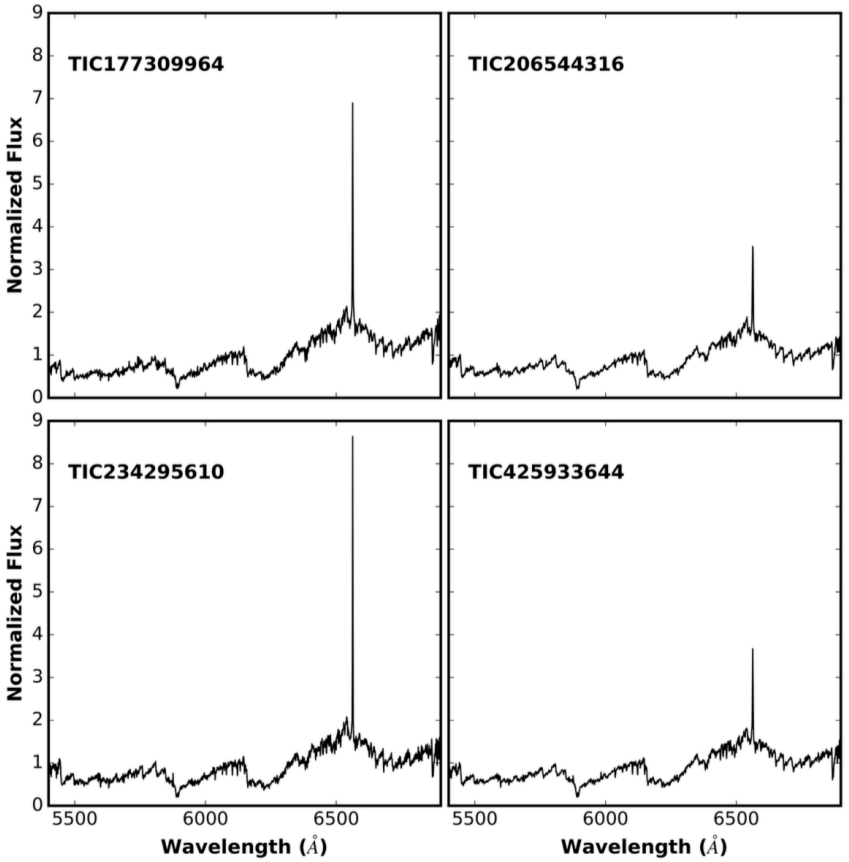
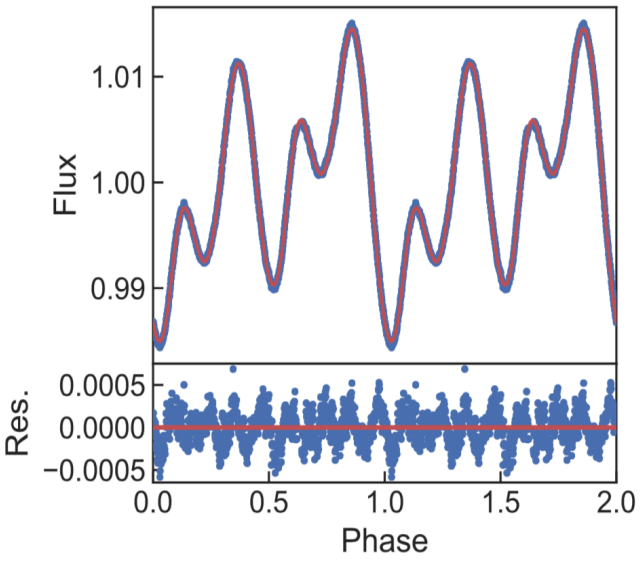
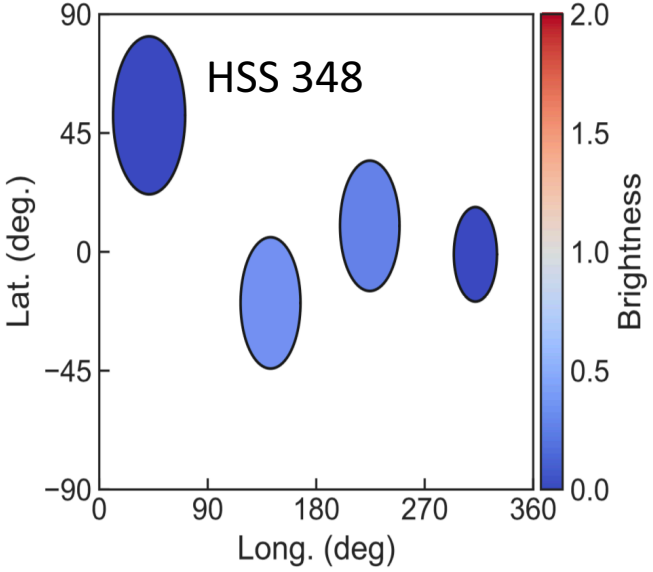


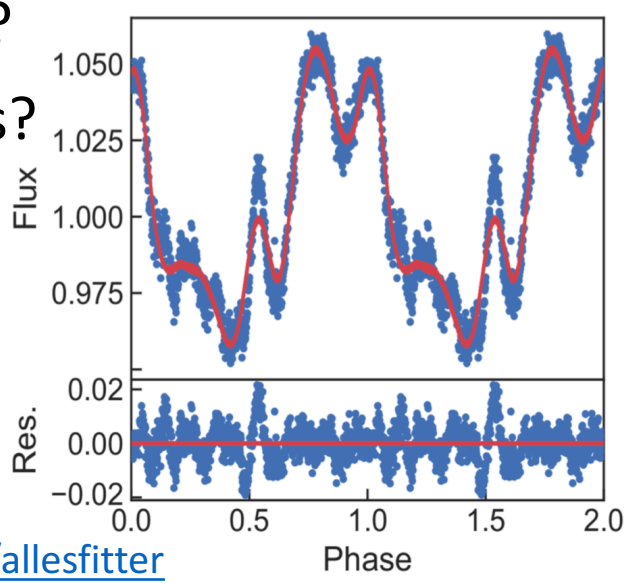
Figure 6. Low resolution spectra for four of the rapidly rotating M-dwarfs obtained with the ANU 2.3-m WiFeS facility. In each spectrum, we see strong Hα emission features at equivalent widths of 4-8 Å, indicative of strong chromospheric activity. We also find no evidence of binarity in any of the spectra. For comparability, each spectrum is normalized by the mean flux between 6000-6200 Å.

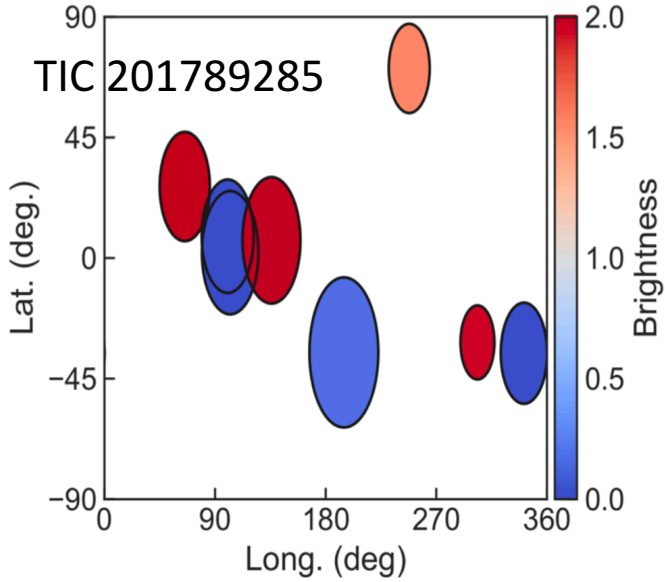
Star Spot Model Nested-Sampling Fit Using ALLESFITTER

- ~~Blended star?~~
- ~~Star spots?~~ (Alone)
- Magnetically trapped dust?
- Corotating gas?
- Radiation beaming?
- Occulting dust rings?





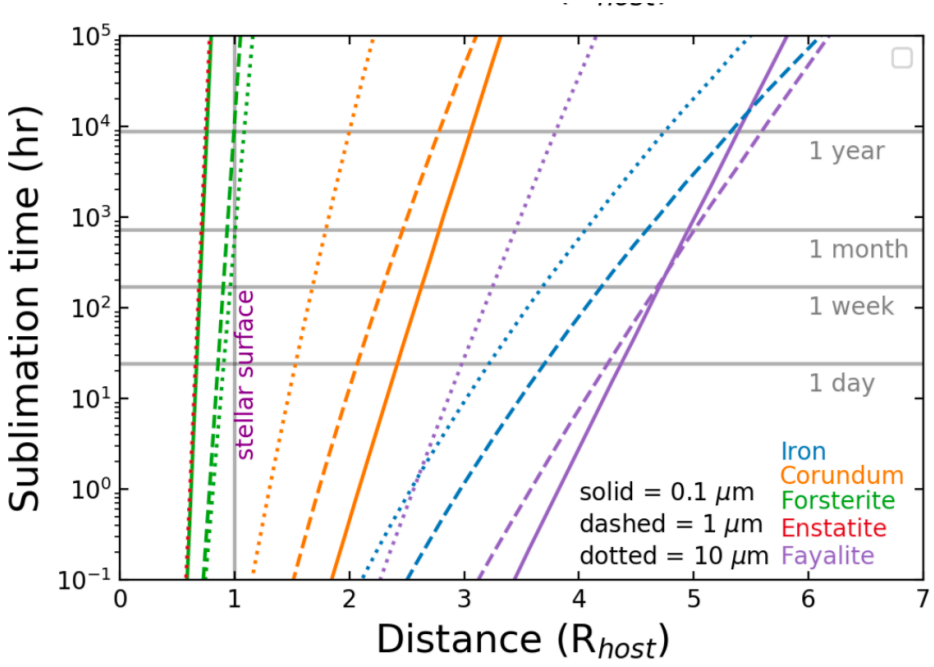


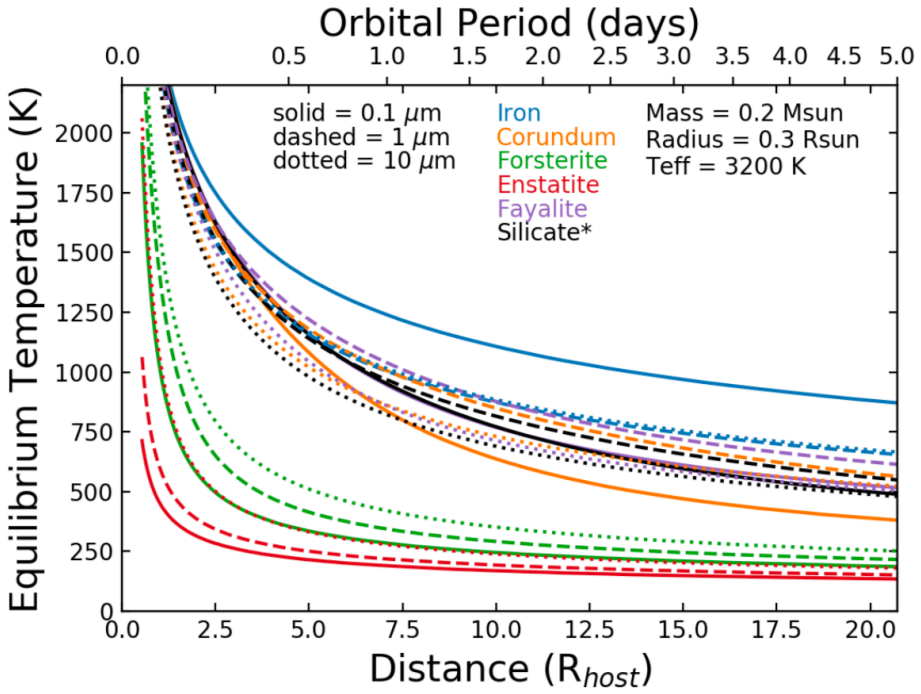


https://github.com/MNGuenther/allesfitter

Dust at Corotation Radius Too Hot to be Sustainable

- ~~Blended star?~~
- ~~Star spots?~~ (Alone)
- ~~Magnetically trapped dust?~~



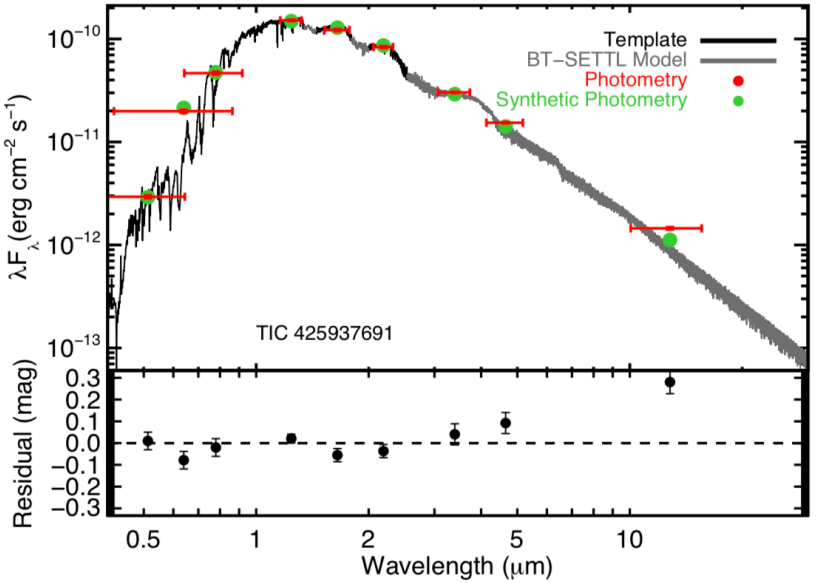


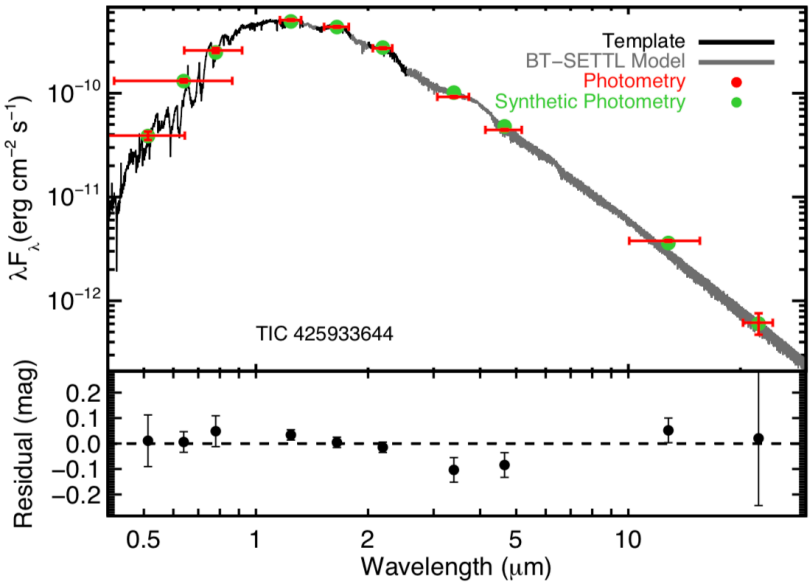
Zhan et al., 2019

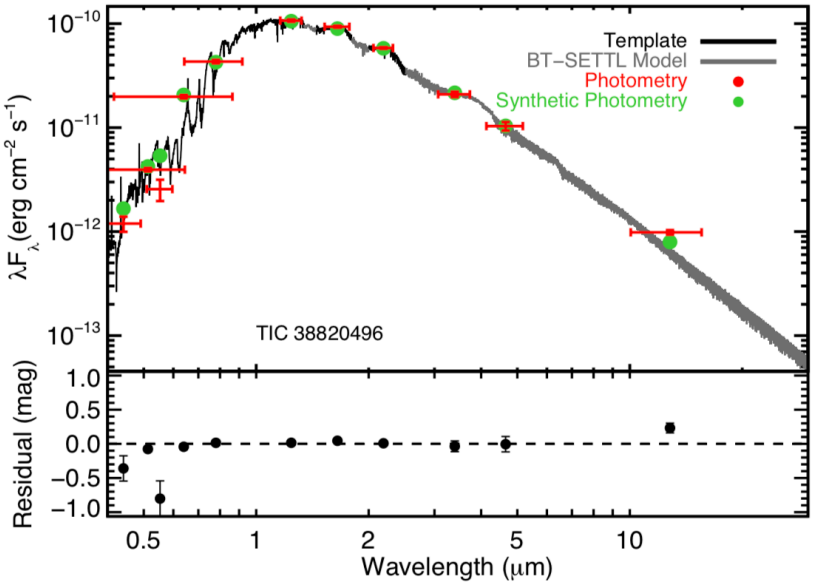
- Corotating gas?
- Radiation beaming?
- Occulting dusty ring?

SED Fit Indicated IR Excess for 3 of 10, Suggesting Presence of Dust

- ~~Blended star?~~
- ~~Star spots?~~ (Alone)
- ~~Magnetically trapped dust?~~
- Corotating gas? (Maybe no)
- Radiation beaming?
- Occulting dust rings?







Radiation Beaming Cannot Explain the Large Flux Modulations

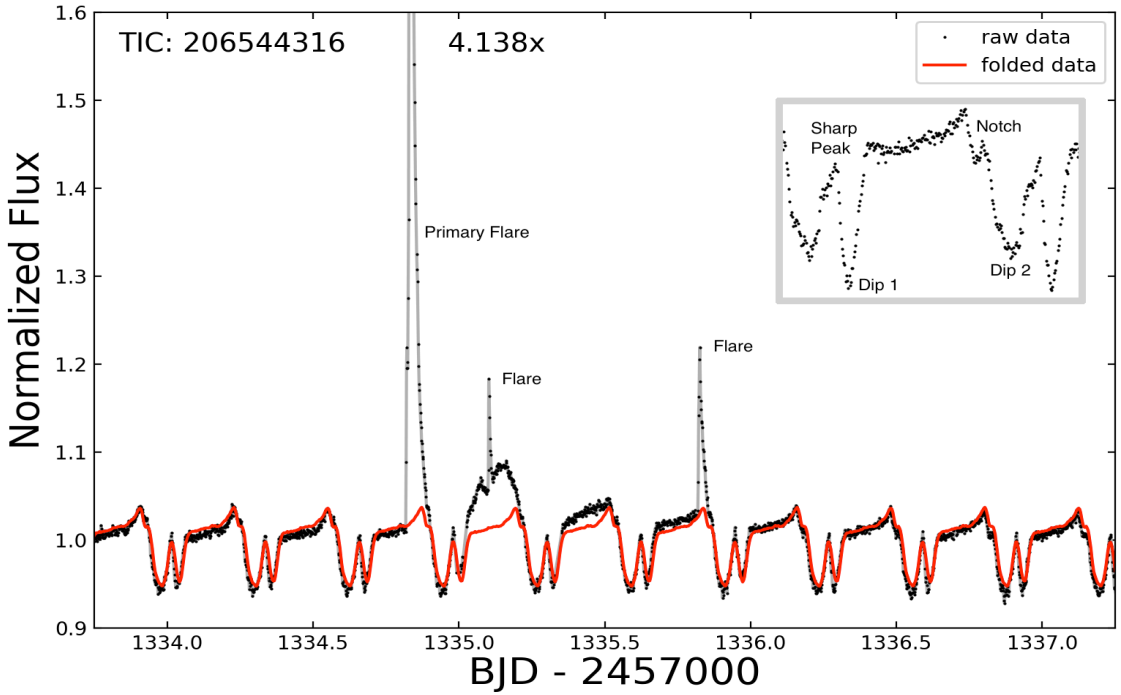
- ~~Blended star?~~
- ~~Star apots?~~ (Alone)
- ~~Magnetically trapped dust?~~ (Too hot)
- Corotating gas? (maybe no)
- ~~Radiation beaming?~~ (~ 10 ppm, too weak. Modulations: ~5%)
- Occulting dusty ring?

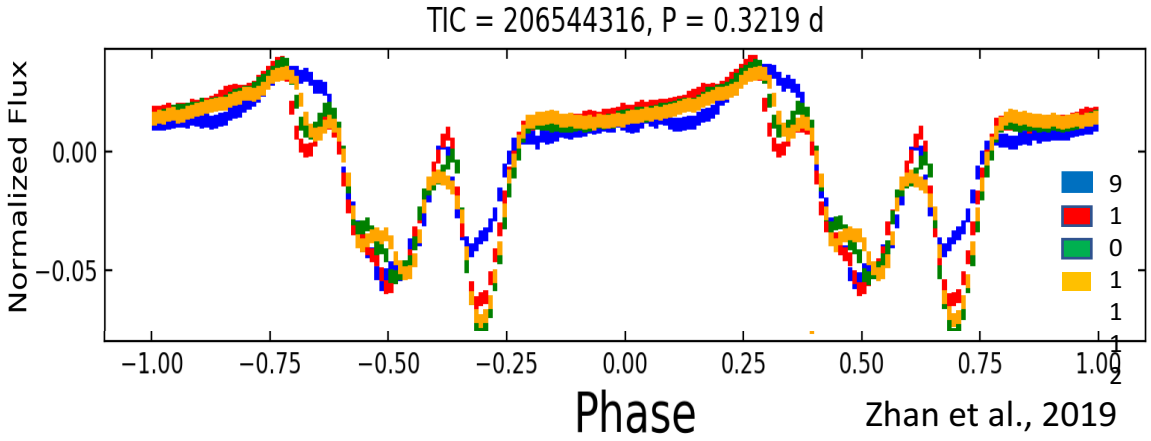
Fortuitous Flaring Events Lasted ~1 day Indicate Modulation is Extrinsic

- ~~Blended star?~~
- ~~Star apots?~~ (Alone)
- ~~Magnetically trapped dust?~~ (Too hot)
- ~~Corotating gas?~~ (modulation is extrinsic)
- ~~Radiation beaming?~~ (~ 10 ppm)

- (Much head scratching later…)

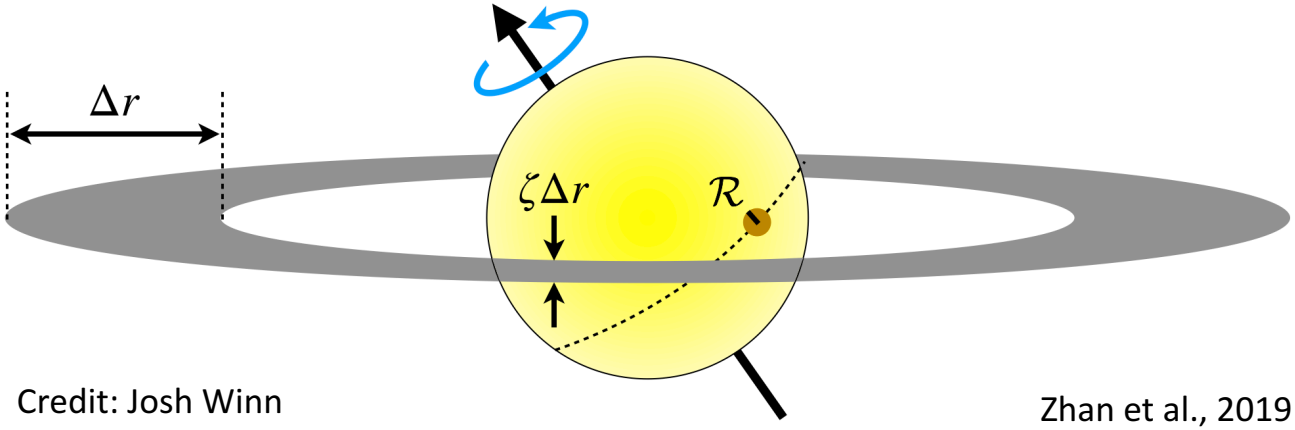
- Occulting dusty ring?





Zhan et al., 2019

Occulting Dust Rings, But Where Does the Dust Come From?



Credit: Josh Winn

Zhan et al., 2019

"Weird Rotators" are young star association members

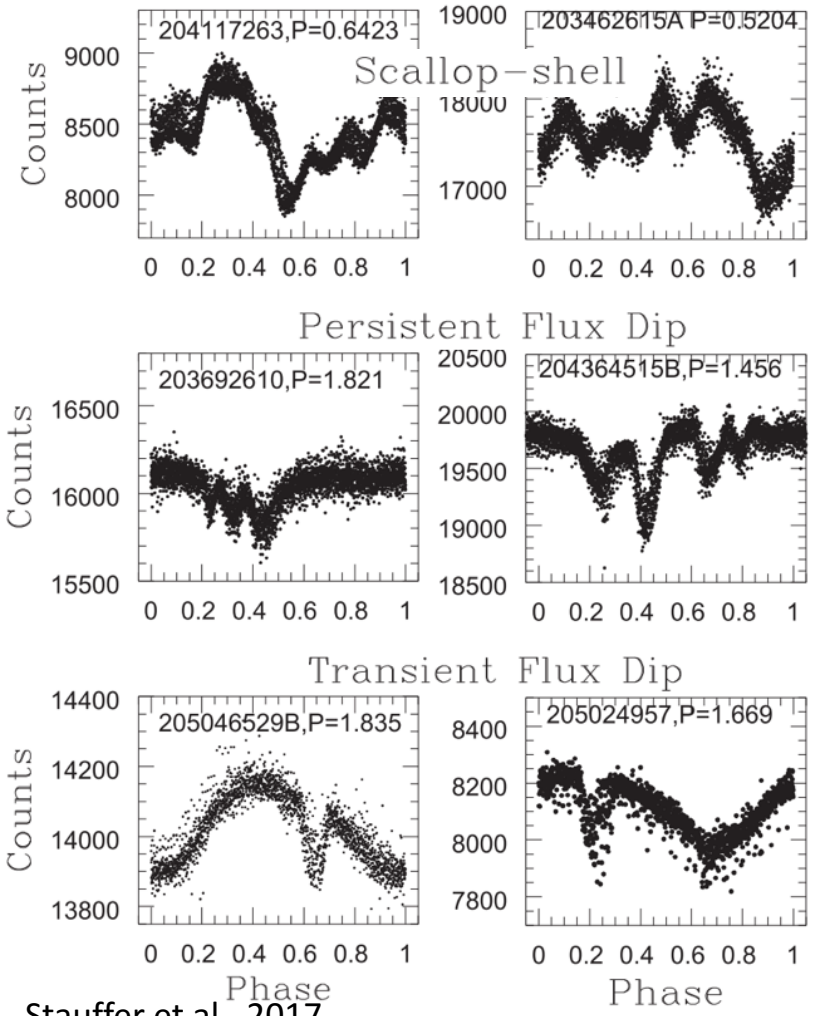
Name	Abbr.	Ave. Dist. [pc]	Age [Myr]
AB Doradus	ABDMG	30^{+20}_{-10}	149^{+51}_{-19}
β Pictoris	βPMG	30^{+20}_{-10}	24 ± 3
Carina	CAR	60 ± 20	45^{+11}_{-7}
Columba	COL	50 ± 20	42^{+6}_{-4}
Tucana Horologium	THA	46^{+8}_{-6}	45 ± 4

Data from Gagné et al. (2018)

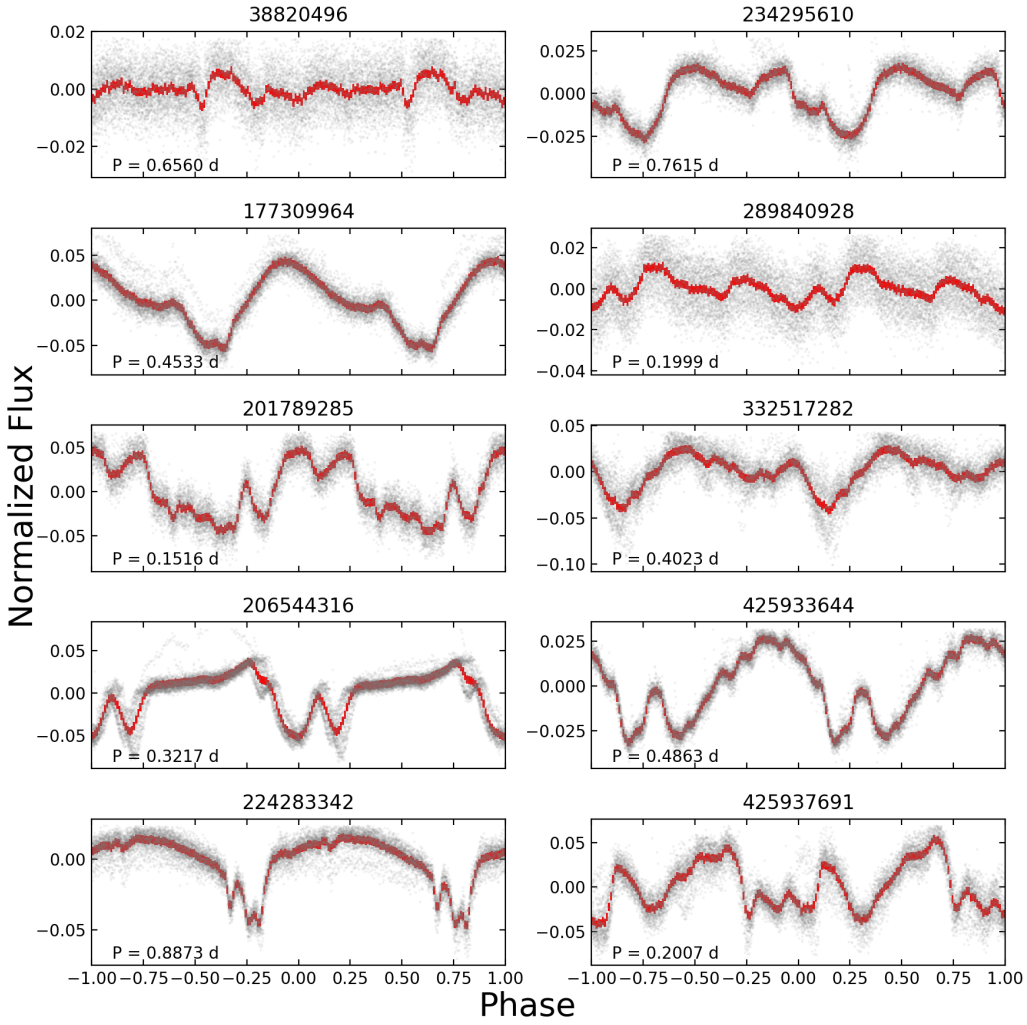
TIC IDs:	T_{eff}	Assoc.
38820496	2987	THA
177309964	3289	CAR
201789285	...	THA/CAR
206544316	3112	ABDMG
224283342	3198	COL
234295610	3082	THA
289840928	3120	BPMG
332517282	3032	ABDMG
425933644	3176	THA
425937691	2733	THA

T_{eff} from TIC 6

“Scallop-shells” (Stauffer et al., 2017) vs “Weird Rotators”



Stauffer et al., 2017



	”Scallop-shell”	“Weird-rotator”	Source	
Distance:	135 pc	45 pc (closer)	(Gaia DR2)	Brown et al. 2018
Age:	5-10Myr	45 Myr (older)	(BANYAN Σ)	Gagné et al. 2018
M_K:	4.9	6.4	(TIC)	Stassun et al. 2018

Summary and Future Prospects

- Summary:
  - 10 “Weird Rotators” in TESS Sector 1 and 2.
  - Modulation display sharp “Dip, Peak, Dip” feature
  - Most plausible explanation: Dusty Ring Model
  - Population different from (Stauffer et al., 2017)
- Unknowns:
  - Alternative, simpler explanation?
  - Where could the dust originate?
  - Are there sub classes of “weird rotators”?
- TESS first year analysis (Zhan, et al. In prep.)
  - 40+ “weird rotator” TVOIs in sector 1 - 13
  - All candidates are in young star associations
- Future Work:
  - Construct dusty ring model
  - Address evolution scenarios
  - Search for more “weird rotators” in FFI, pipeline in development
  - Constrain radius of the rings using multi-band followup observation

Exciting Future Ahead to Solve the Perplexing “Weird Rotators”!

https://github.com/azariven/TVOI

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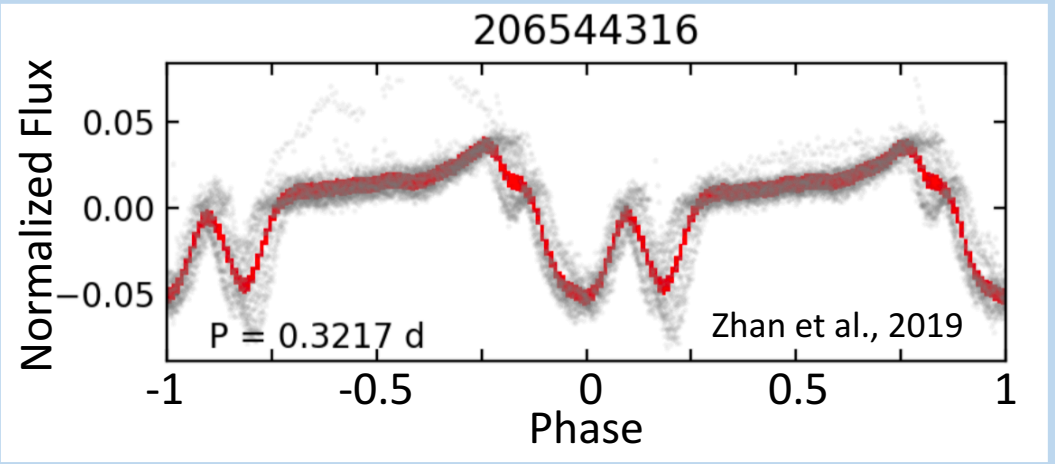
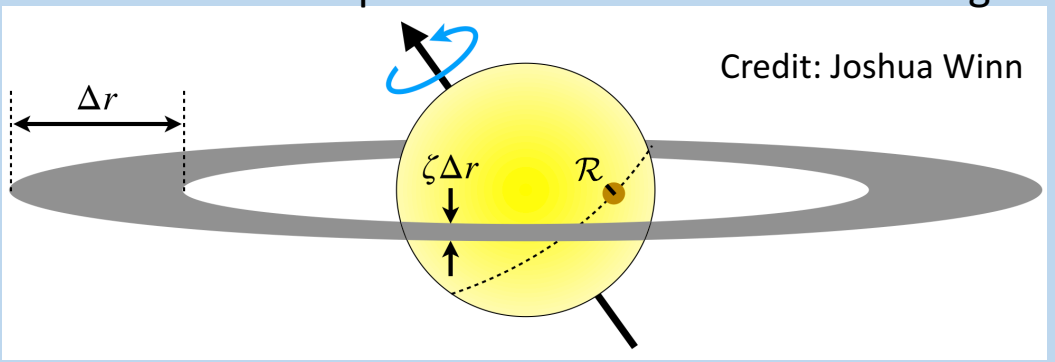
289840928	3120	BPMG
332517282	3032	ABDMG
425933644	3176	THA
425937691	2733	THA

ApJ., 876 (2), 127
Arxiv: 1903.02061



Most Plausible Explanation So far: Small Dust Ring



Complex Rotational Modulation of Rapidly Rotating M-Stars Observed with TESS

Z. Zhan,[1] M. N. Günther,[2,3] S. Rappaport,[2] K. Oláh,[4] A. Mann,[5] A. M. Levine,[2] G. Zhou,[6,7] Chelsea X. Huang,[2,3] L.G. Bouma,[8] M.J. Ireland,[9] G. Ricker,[2] R. Vanderspek,[2] D. Latham,[6] S. Seager,[1,] J. Winn,[8] J. Jenkins,[10] D. A. Caldwell,[11] J. Doty,[2] Z. Essack,[1] G. Furesz,[2] M. E. R. Leidos,[10] J. Rodriguez,[6] P. Rowden,[12] J. C. Smith,[11] K. G. Stassun,[13] and M. Vezie[2]