The impact of starspot-crossing events on transmission spectra and the first precise panchromatic spectrum of a starspot with JWST

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Stellar Contamination

How to disentangle the TLSE and the planetary atmosphere?

E.g., **GJ 486b** *[Moran+23]*, **GJ 1132b** *[May+23]*, **TOI 270d** *[Mikal-Evans+23]*, **L98-59c** *[Barclay+23]*, **LHS 1140b** *[Cadieux+24]* and **TRAPPIST-1c** *[Radica+24]*.

Lots of cool work in progress!

- Using multi-planet systems to correct for contamination *[*e.g. **TRAPPIST-1**; *Rathcke+24, JWST-GO-6456 - PI Allen, co-PI Espinoza]*

- Using time-resolved spectroscopy over rotation period to constrain heterogeneous features *[Berardo+25]*

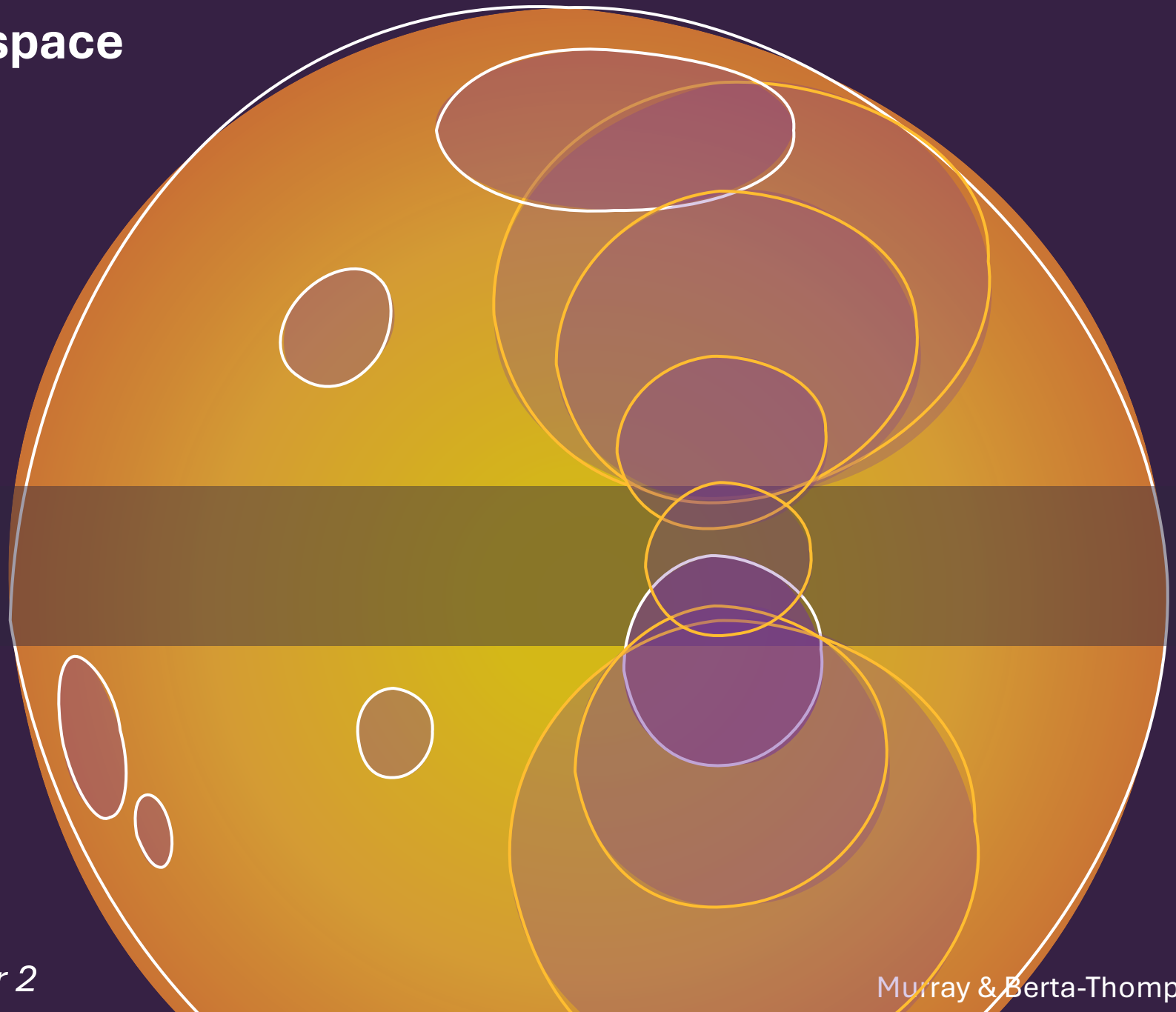
- 3D MHD simulations of cool stars

- Lots more we'll learn this week!

How accurate are our current stellar models?

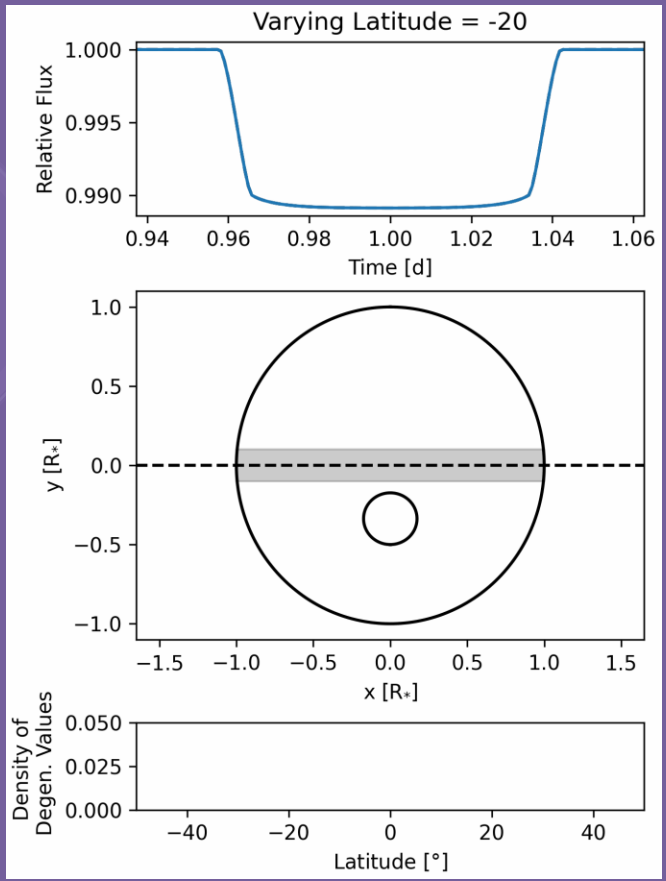
Significant discrepancies between stellar models and with observations *[Rackham & deWit23]*. E.g., **TRAPPIST-1b** *[Lim+23]*

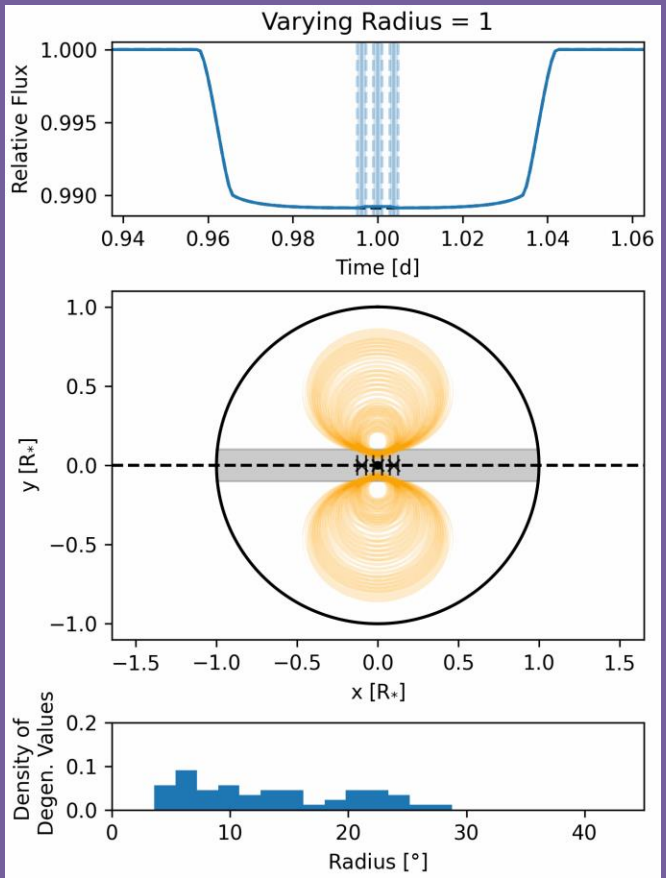
The degeneracy space

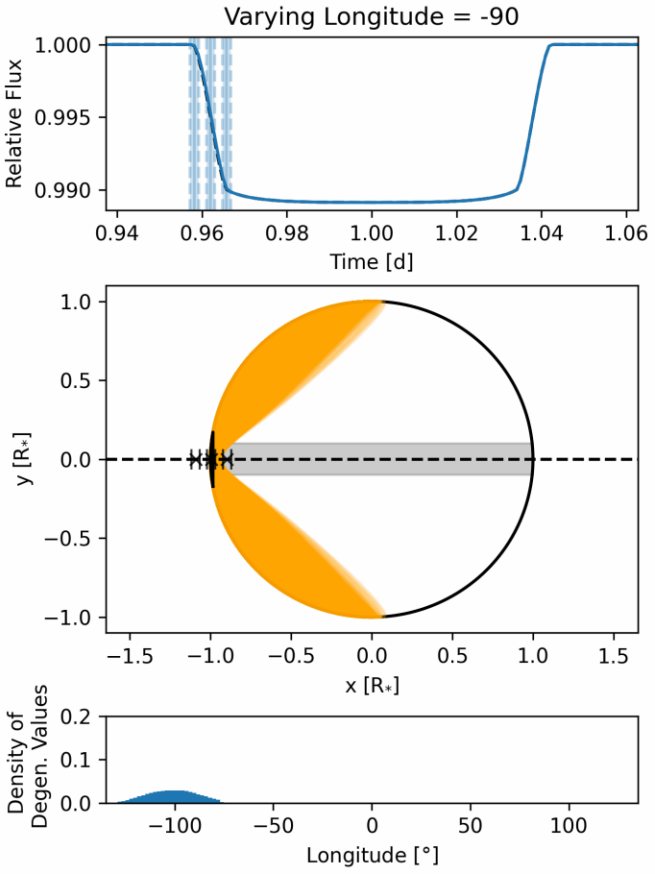


Murray & Berta-Thompson, in prep

The degeneracy space







(assume circular spots, R<45°)

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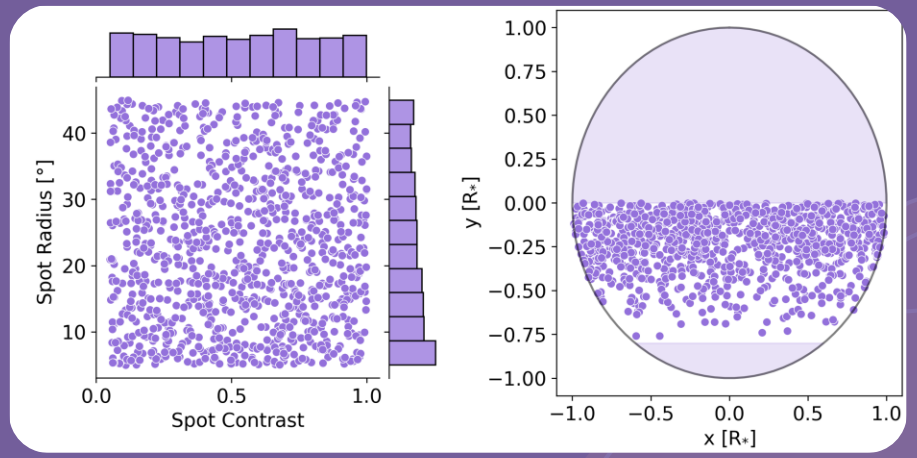
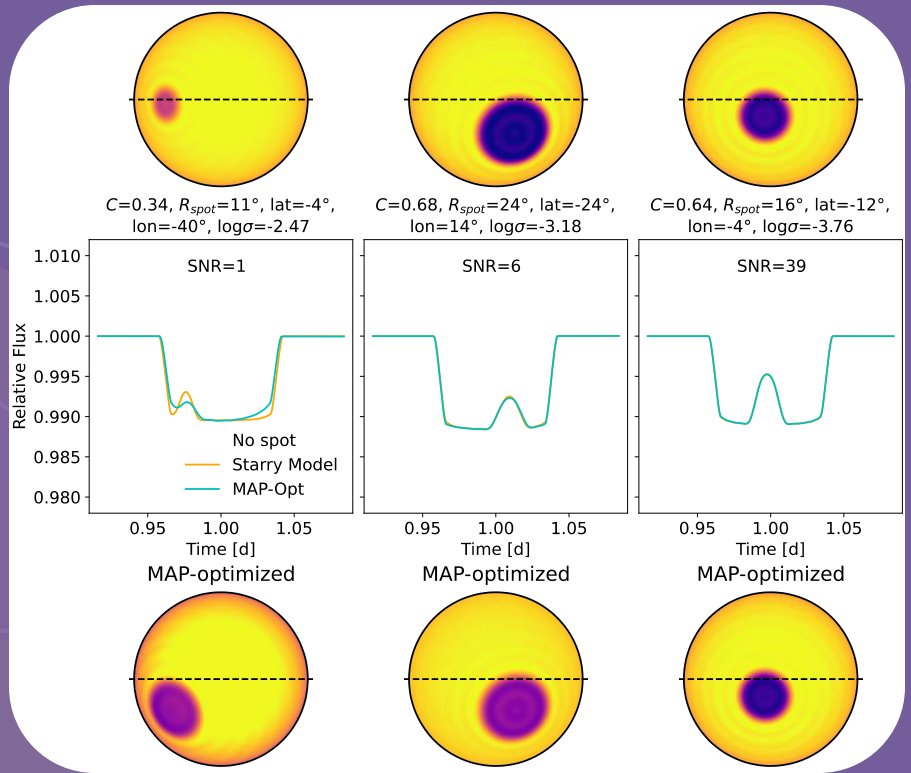
A sample of spot-crossing events

Generate a sample of 1000 spots with spot-crossing events (R_{spot}, φ, λ, C)



Inject into LCs with varying σ (R_p/R_*=0.1)

Recover spot parameters using *starry*



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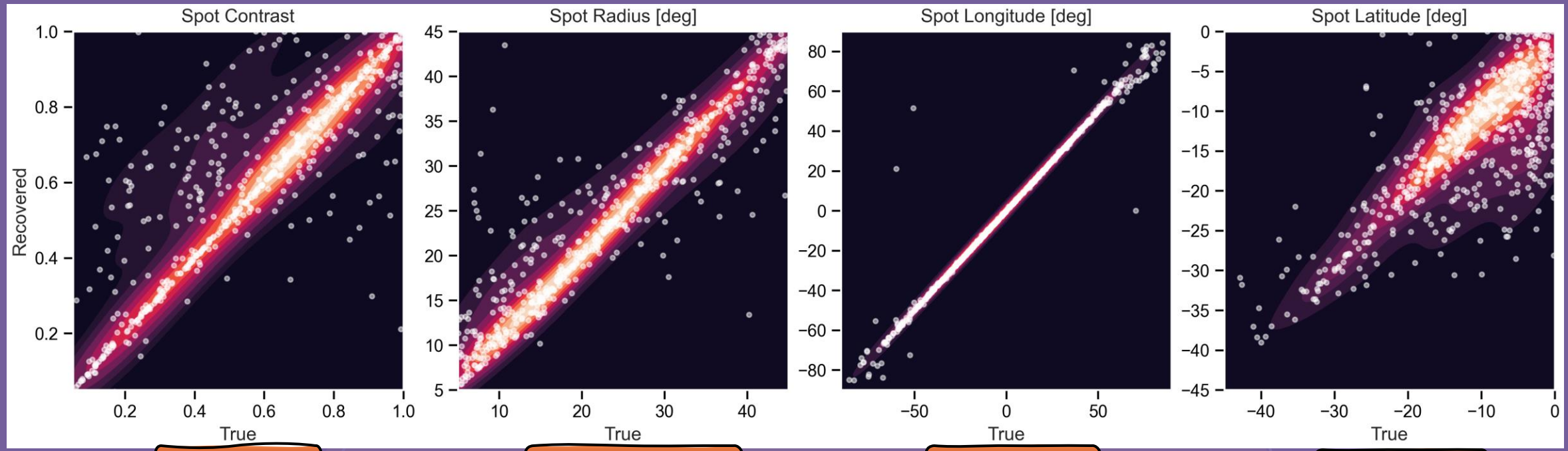
A sample of spot-crossing events

For SNR > 5:



σC = 3%

σR_{spot} = 5%

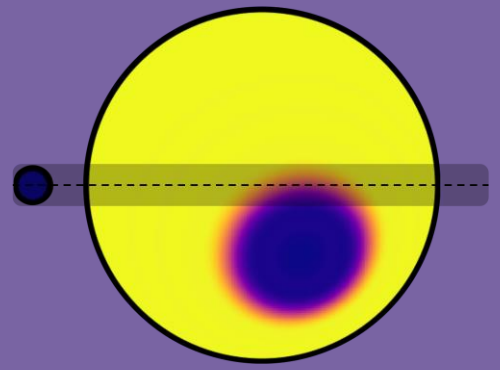
$\sigma \lambda$ = 0.5%

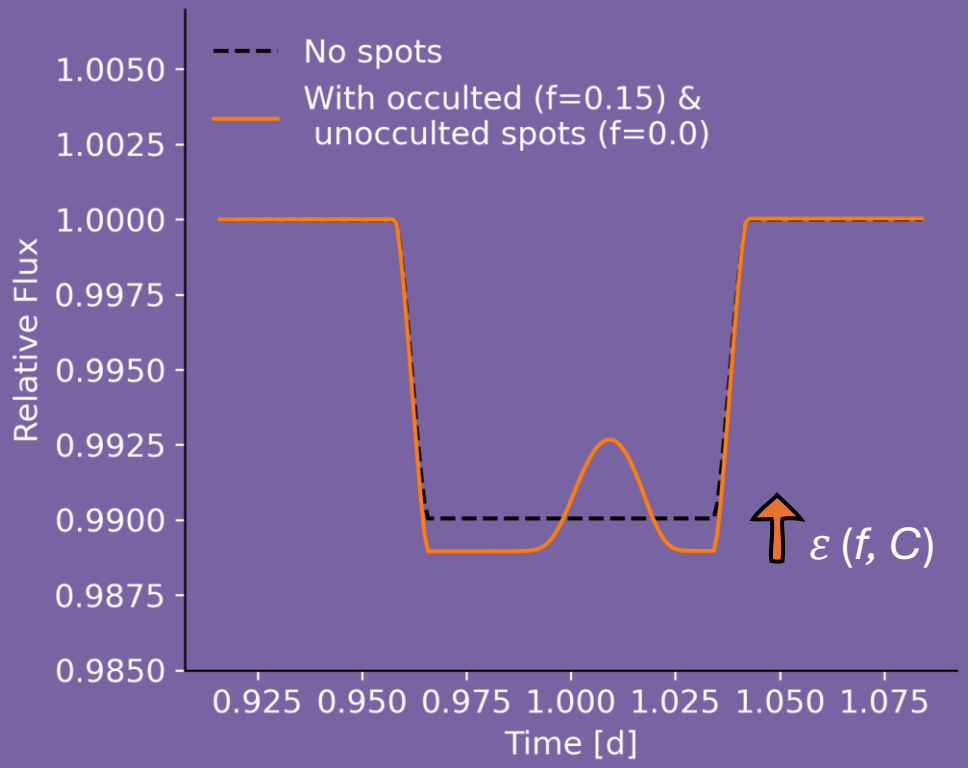
$\sigma \varphi$ = 26%

σR_{planet} = 0.3%

Murray & Berta-Thompson, in prep

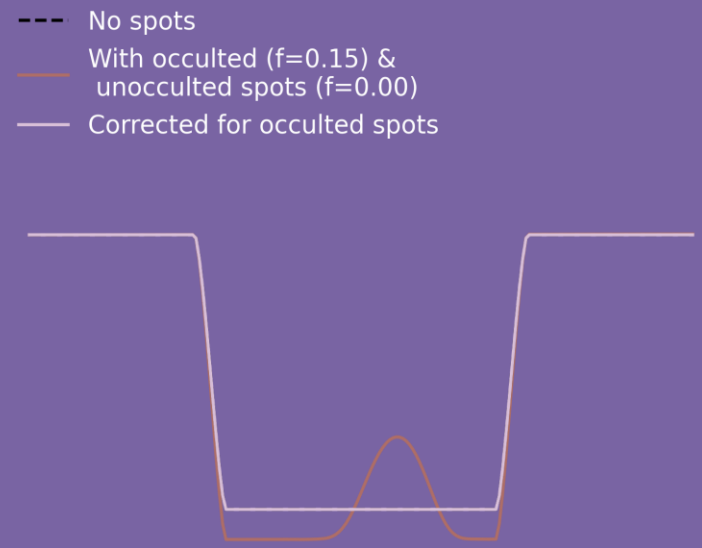
Should you mask or model a spot-crossing event?





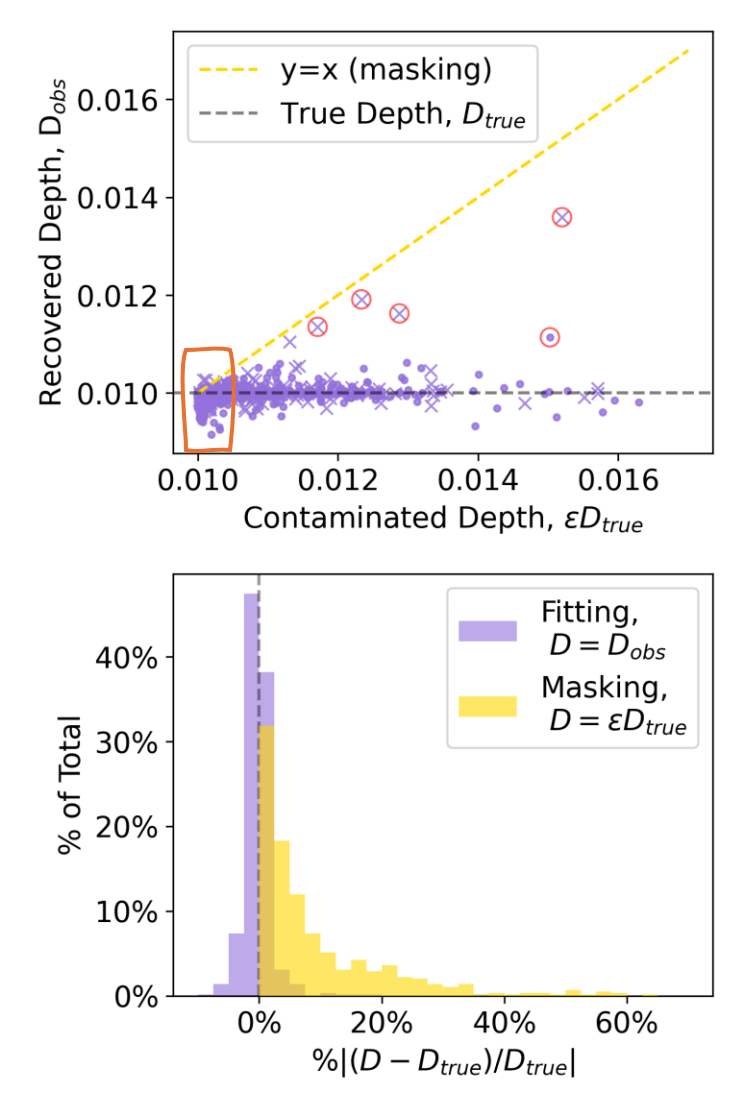
mask?

model?

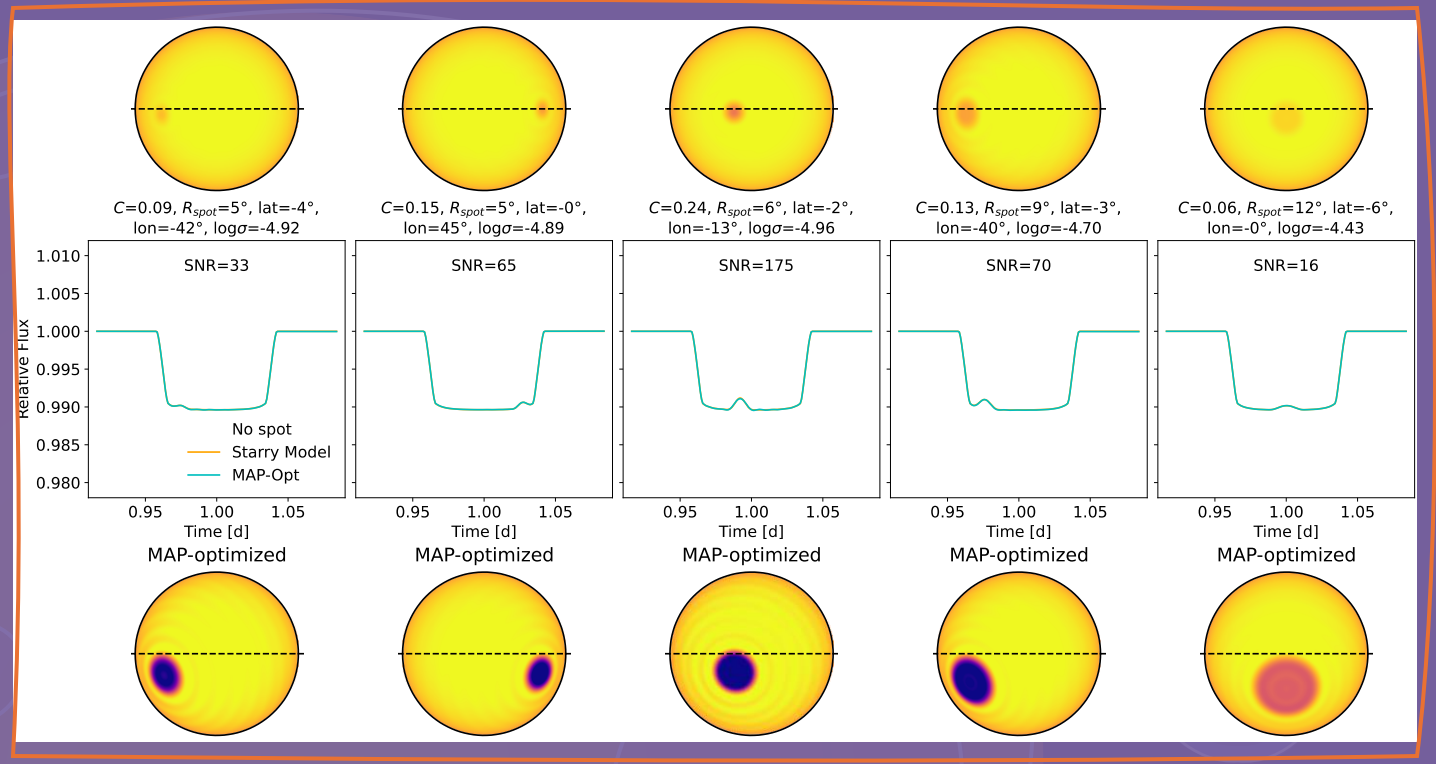


Murray & Berta-Thompson, in prep

Should you mask or model a spot-crossing event?

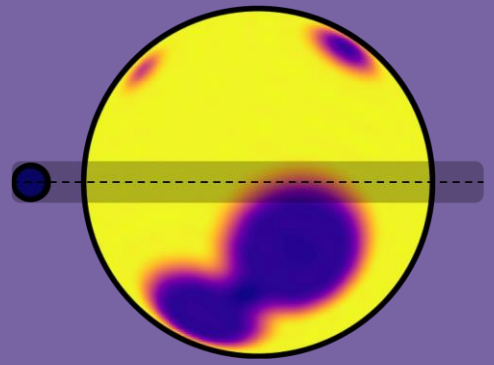


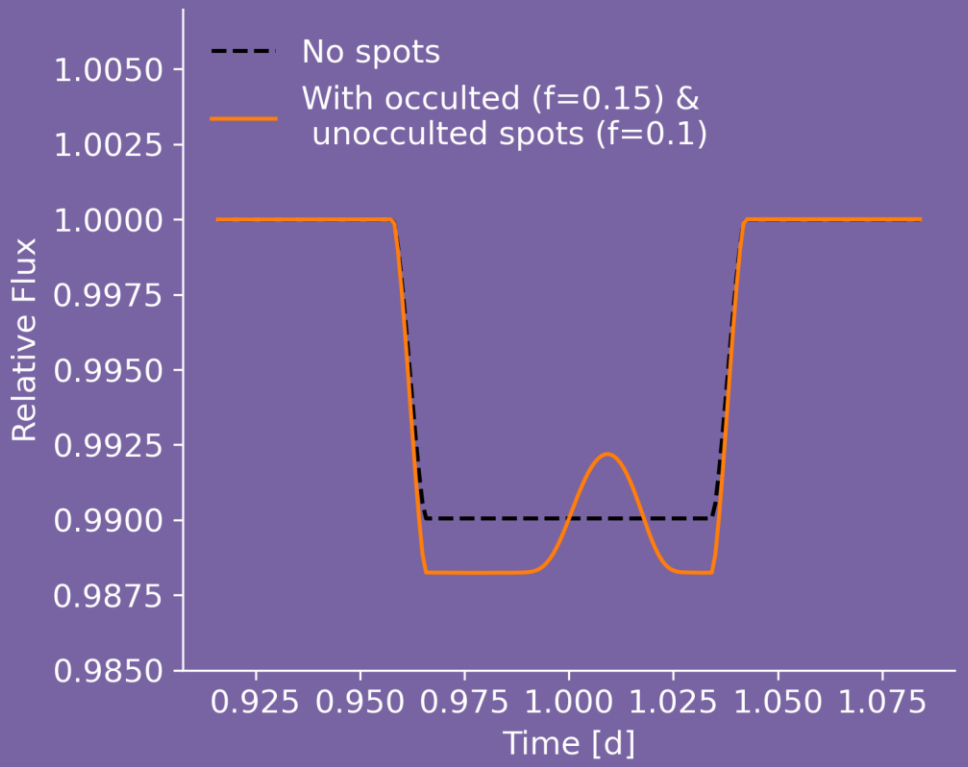
- >95% of SNR>5 cases improved by modeling!
- When $\varepsilon > 3.2\%$ (equiv. $f C_\lambda > 0.03$) fitting for a spot-crossing **always** improved the recovery of the transit depth compared to masking and doesn't rely on stellar models.



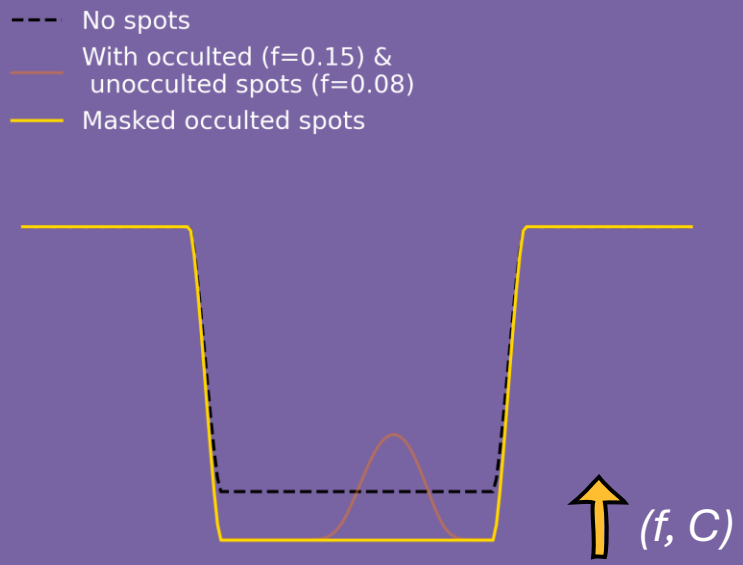
Murray & Berta-Thompson, in prep

What about unocculted starspots?

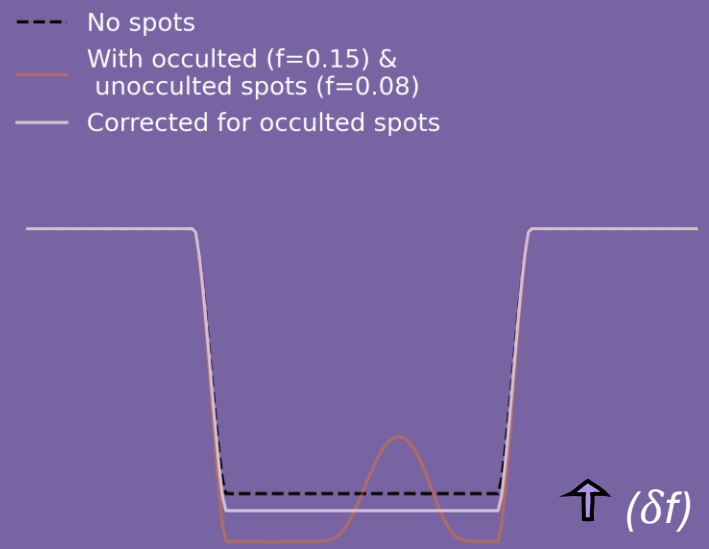




mask?



model?



Murray & Berta-Thompson, in prep

So you have a spot-crossing event...

Should you mask or model?

Model, unless the spot is very small / low contrast.

Can we get informative priors?

The spot-crossing observables can help us to (somewhat) constrain the parameter space.

How do I deal with degeneracies?

Use multiple spot-fitting codes? Model the degeneracy space? Adopt stellar models?

Murray & Berta-Thompson, in prep

The impact of starspot-crossing events on transmission spectra and getting to the first precise panchromatic spectrum of a starspot with JWST

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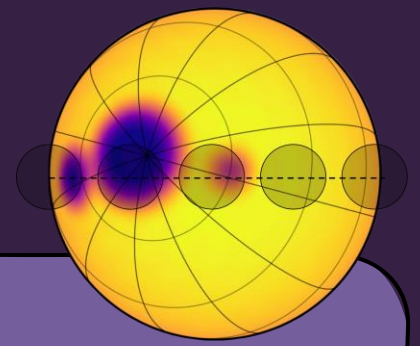
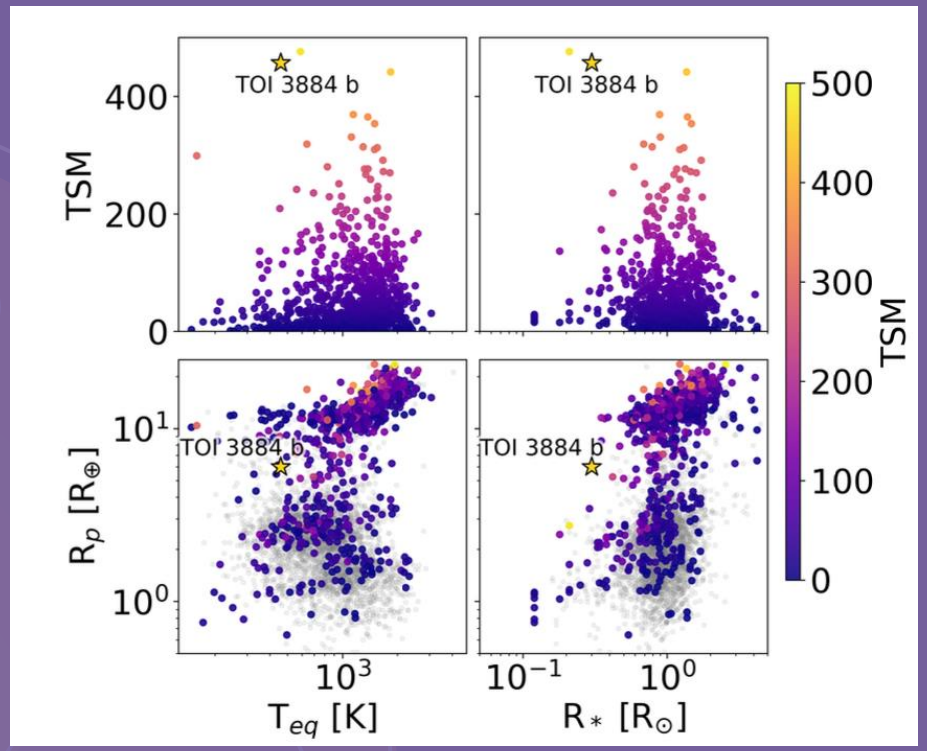
JWST-GO-5863 : Shining a Spot-light on the Atmosphere of a Giant Planet around a Cool Star

PI Catriona Murray

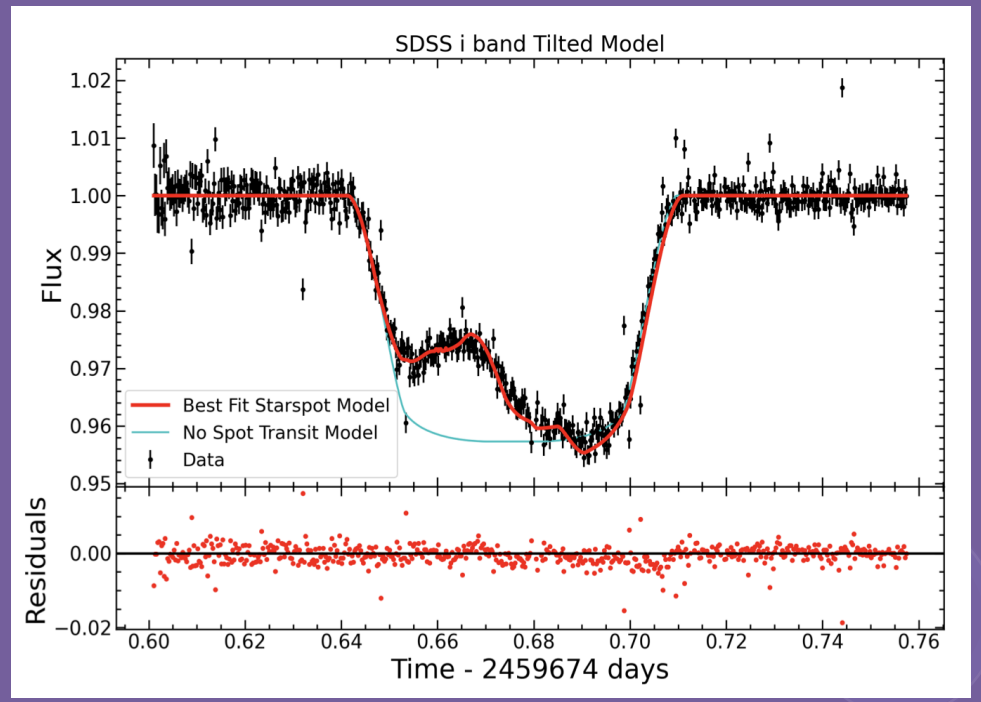


TOI-3884b

TOI-3884b is a uniquely observable super-Neptune transiting an M4



A persistent polar spot complex the planet eclipses every transit



Libby-Roberts+2023

2 NIRISS + 2 NIRSpec G395M

Conclusions

- Spot degeneracies are hard!
  - We can to some extent map the degenerate regions and use these as informative priors
- We ran injection-recovery tests of a large sample of spot-crossings with *starry*
  - We always improve on transit depth recovery (vs masking) with larger/higher contrast spots. Small/low contrast spots are often over-corrected.
  - Despite degeneracies, we recover the longitudes, contrasts and radii well, but as expected, the latitude remains unconstrained.
- JWST-GO-5863 (TOI-3884b)
  - First steps towards a panchromatic empirical spot spectrum.
  - We can compare benchmark stellar contamination mitigation techniques!
  - Lots of challenges! We see lots of flares. We see varying spot structure from transit to transit.

Extra Slides