

# IMPACTS OF **STELLAR** **HETEROGENEITIES** ON **HIGH-RESOLUTION** TRANSMISSION SPECTROSCOPY

FOR M DWARFS

IN THE NEAR-INFRARED

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Baptiste Klein | Suzanne Aigrain



UNIVERSITY OF  
**OXFORD**

CENTER FOR

**ASTROPHYSICS**

HARVARD & SMITHSONIAN

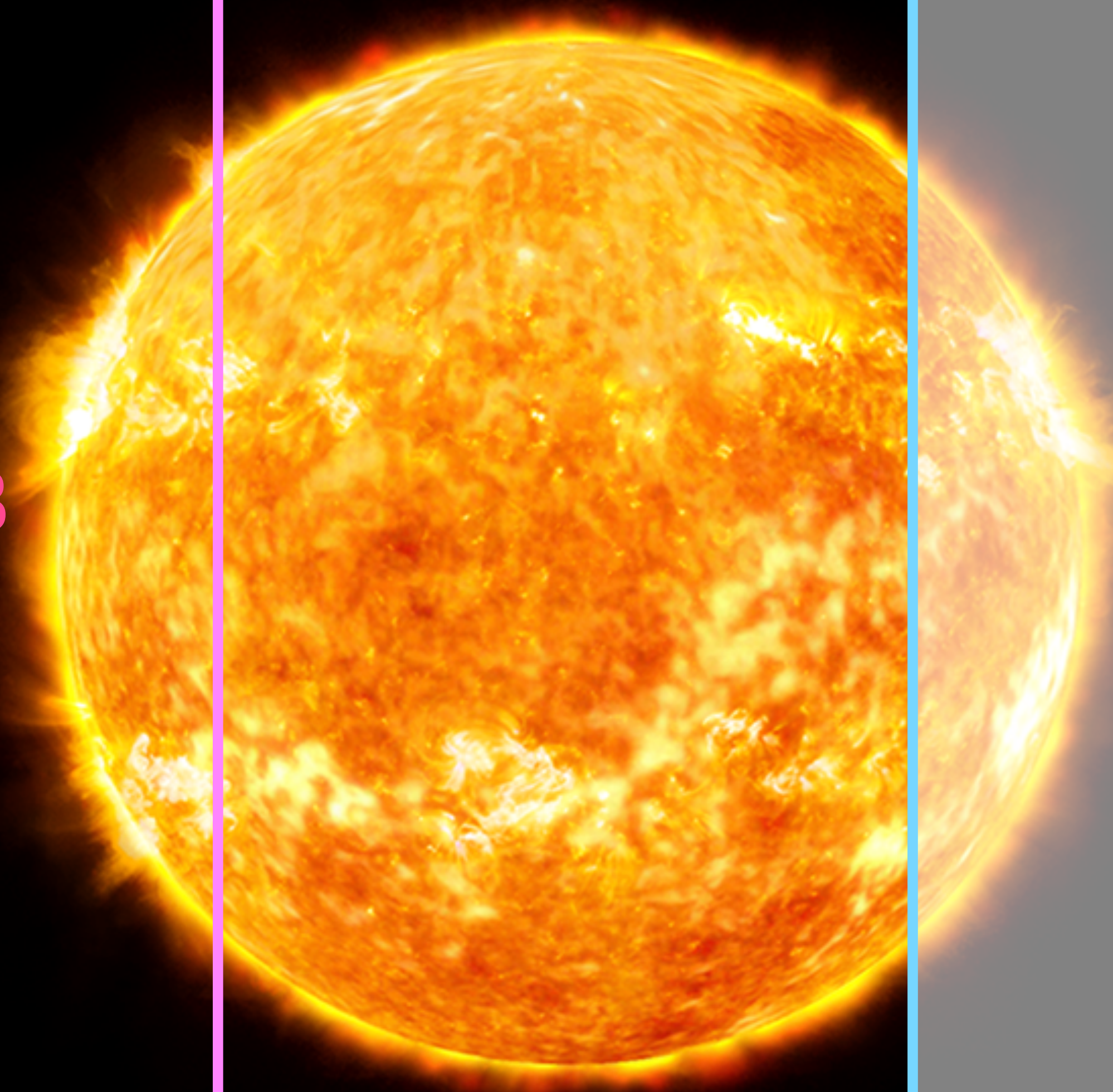


# TRANSIT INDUCED

**ROTATION**

**CENTRE-TO-LIMB  
VARIATION**

**PHOTOSPHERIC  
FEATURES**



# INTRINSIC

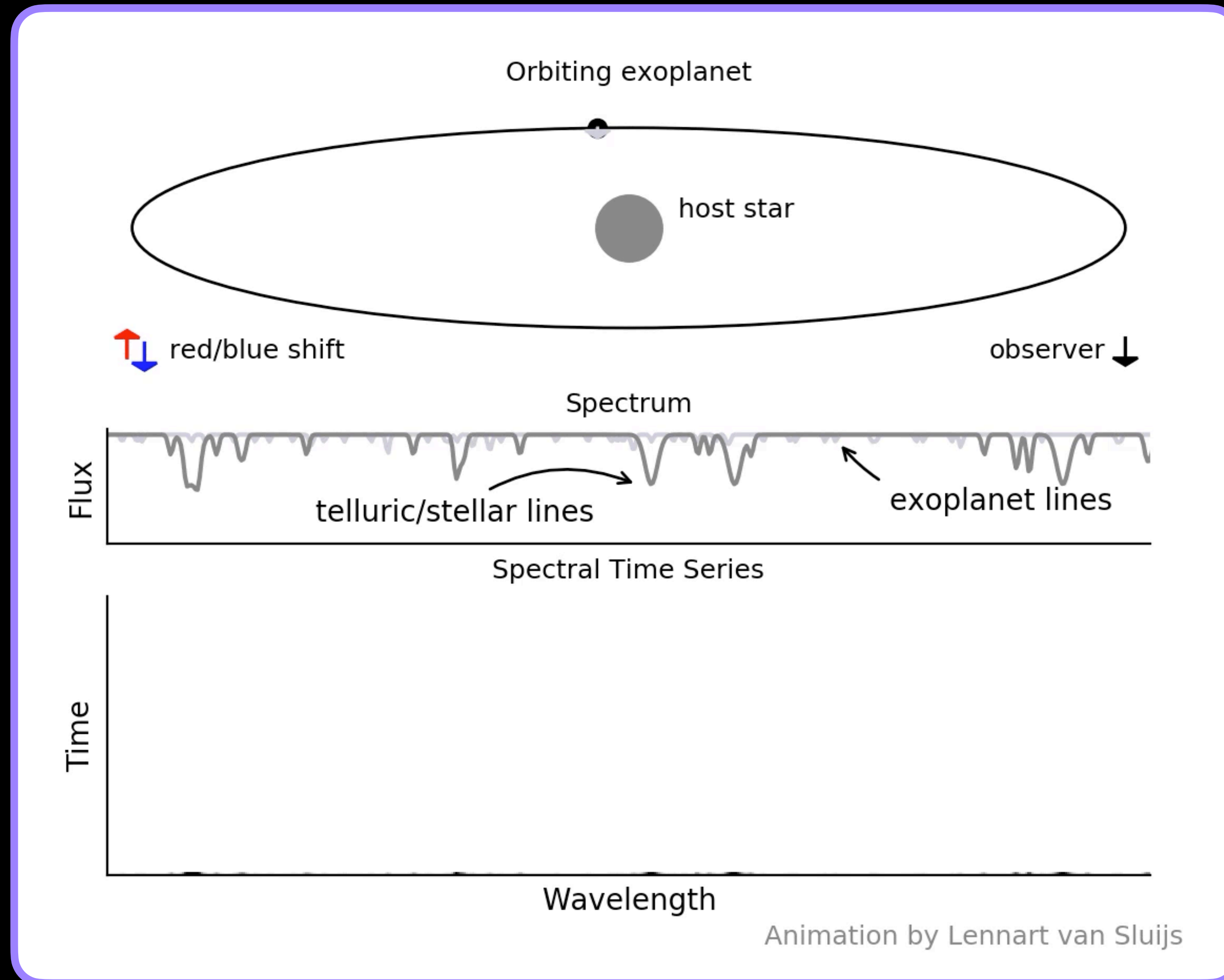
**CONVECTIVE  
BLUESHIFT**

**GRANULATION**

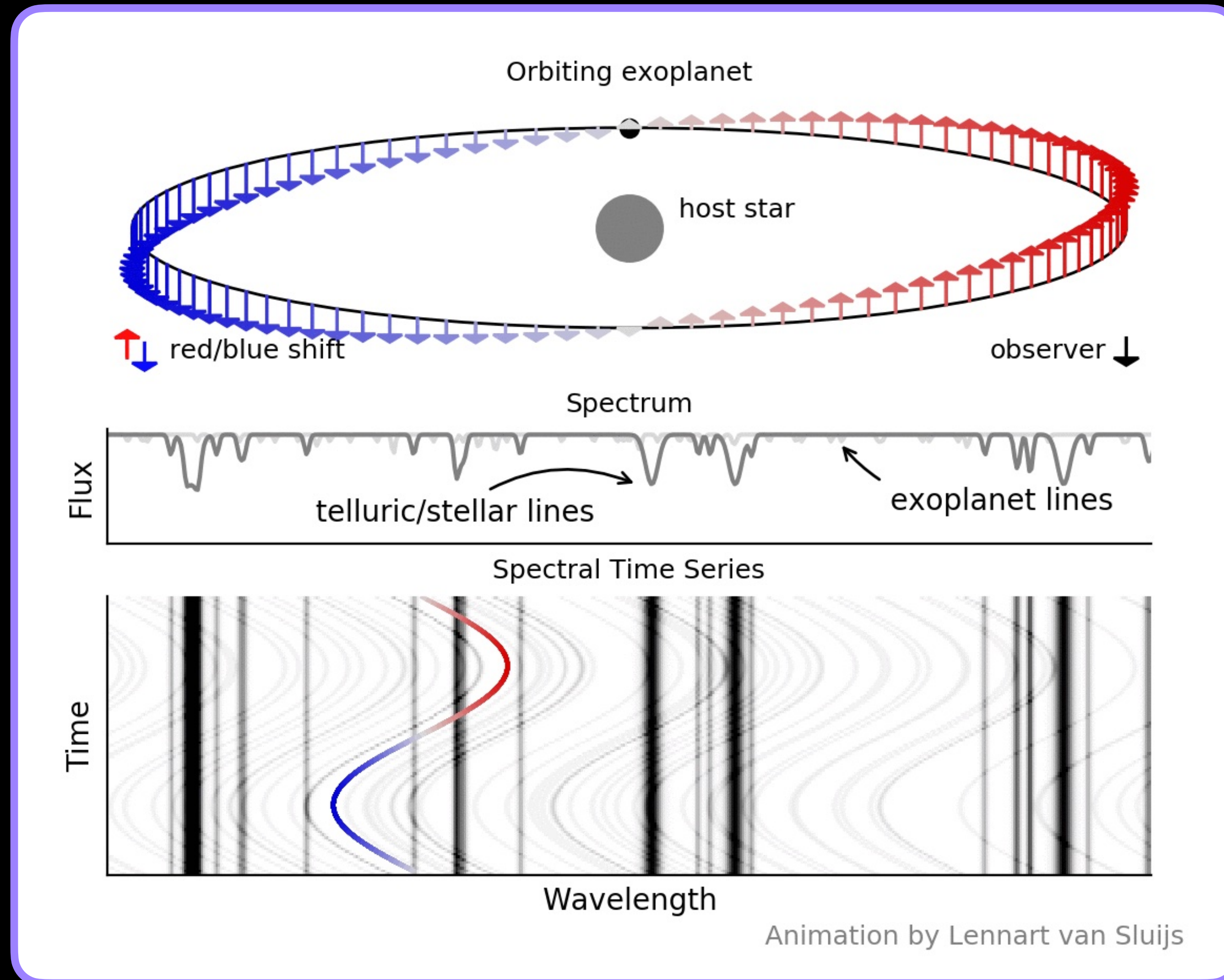
**FLARES**

**OSCILLATIONS**

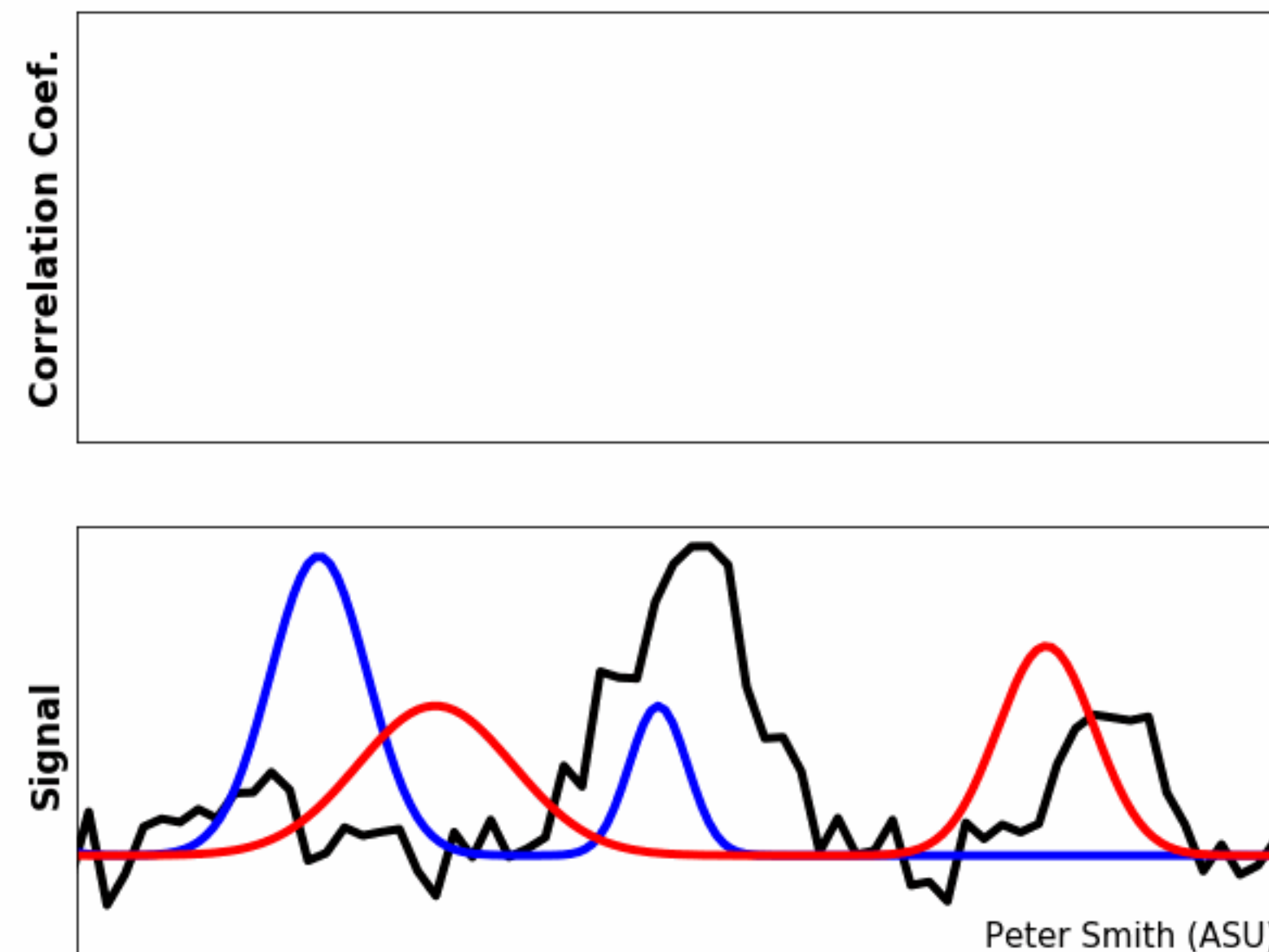
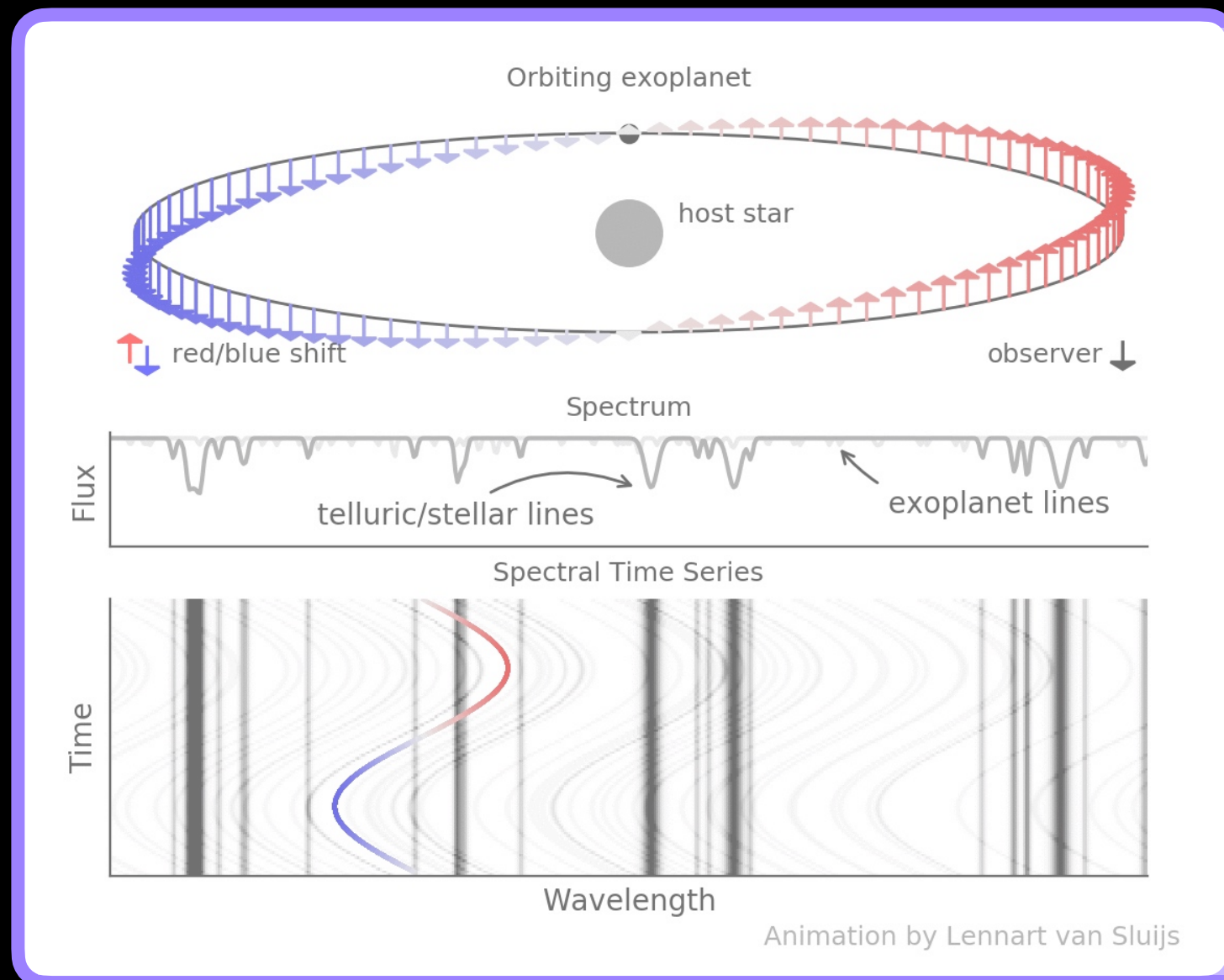
# HIGH-RESOLUTION SPECTROSCOPY



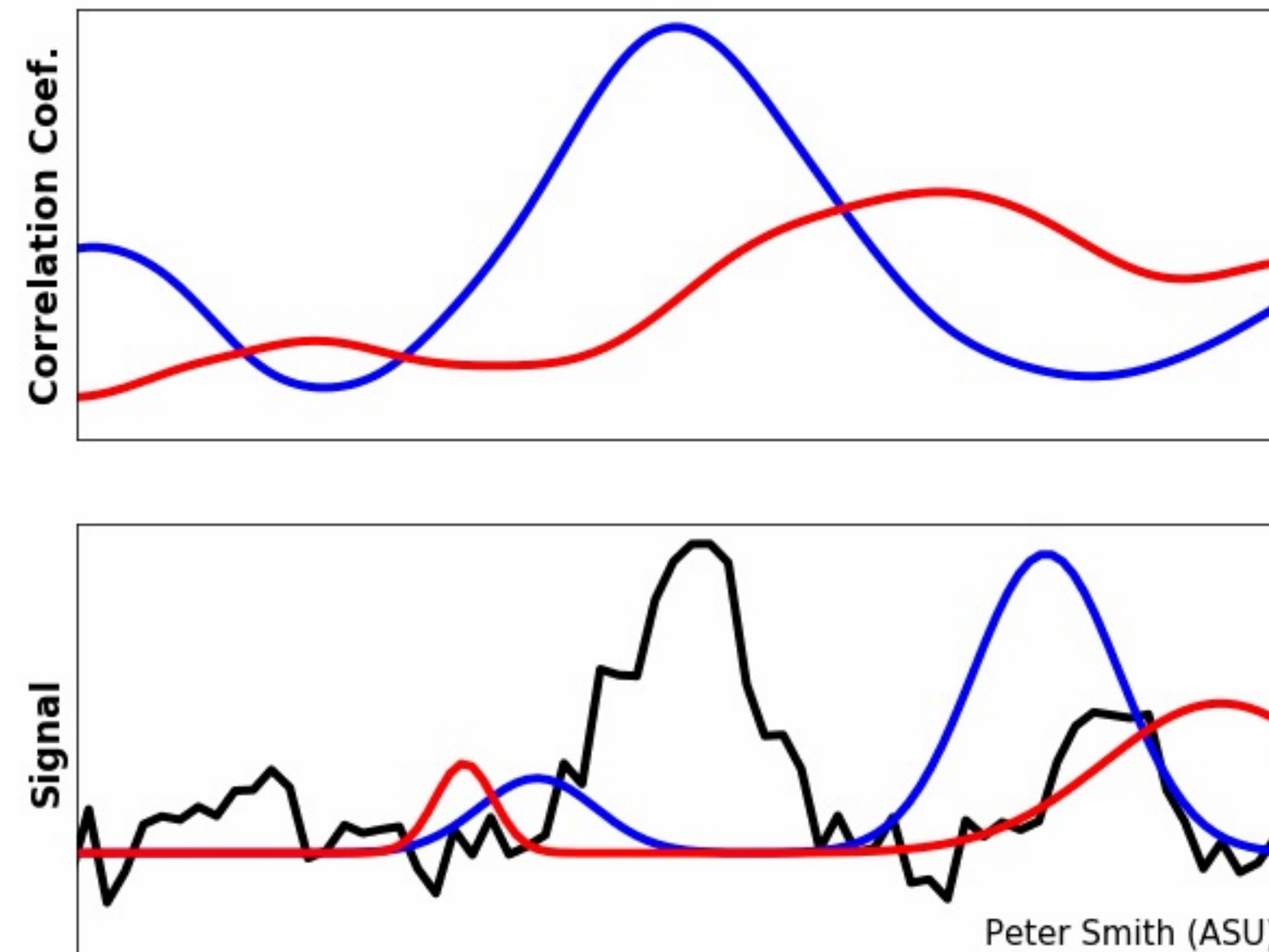
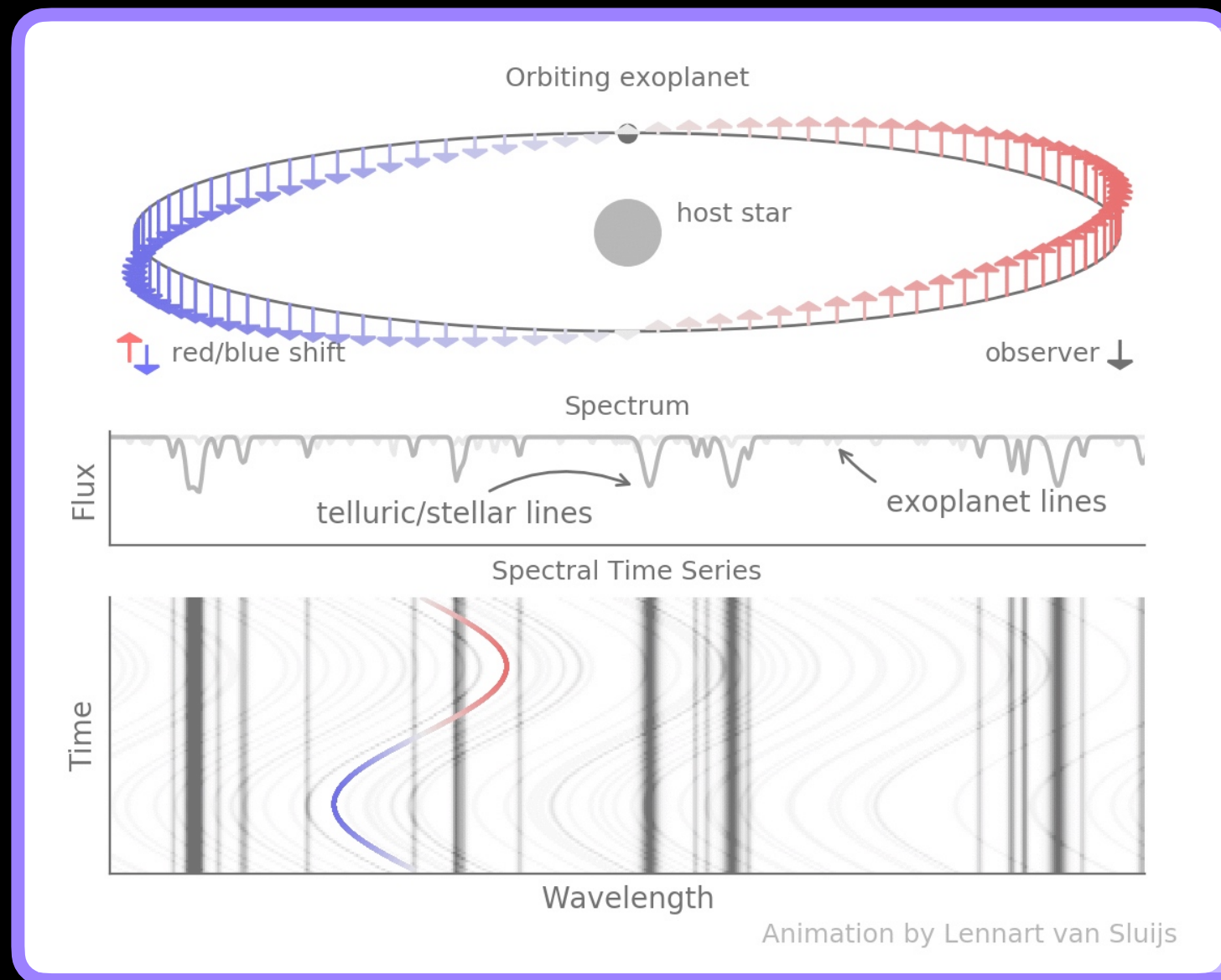
# HIGH-RESOLUTION SPECTROSCOPY



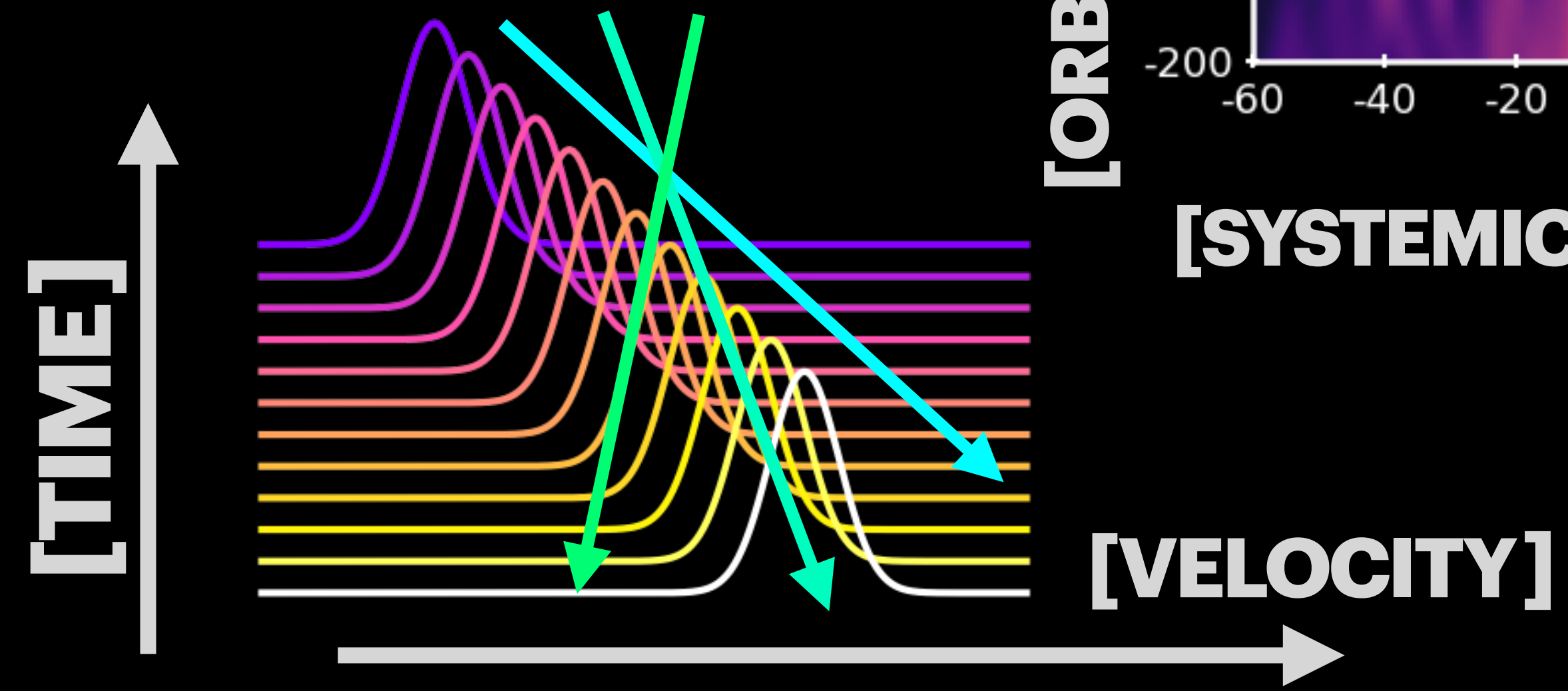
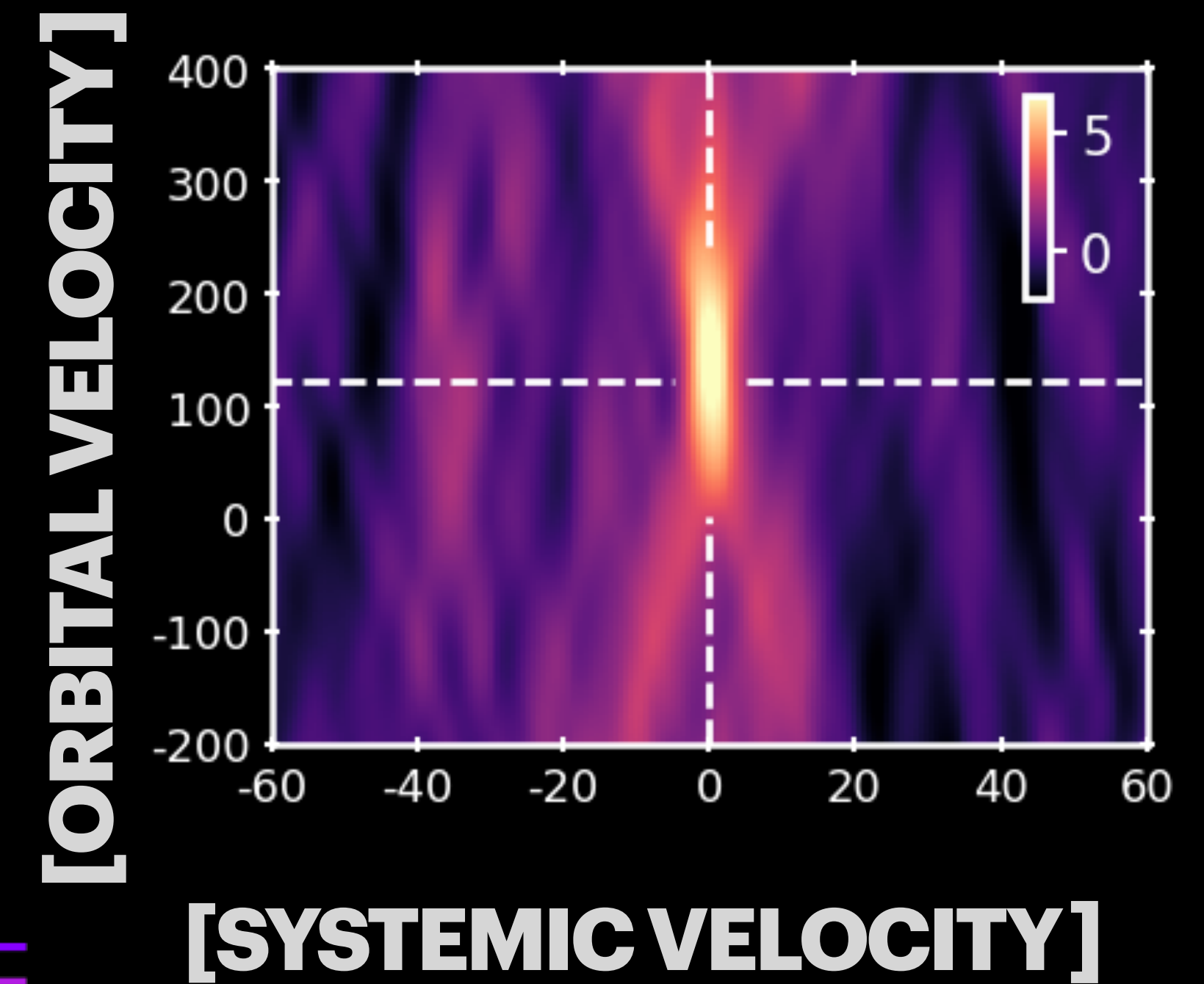
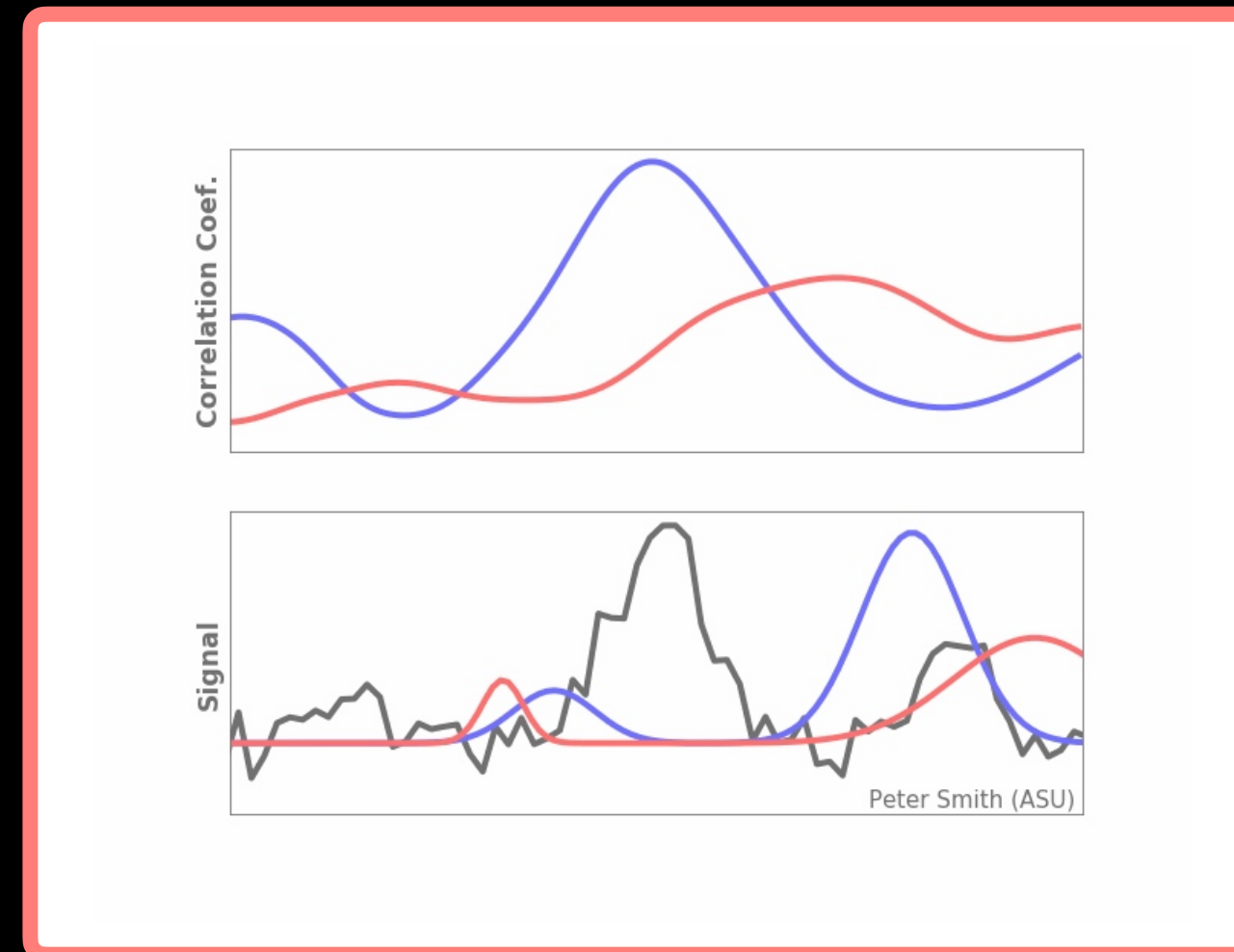
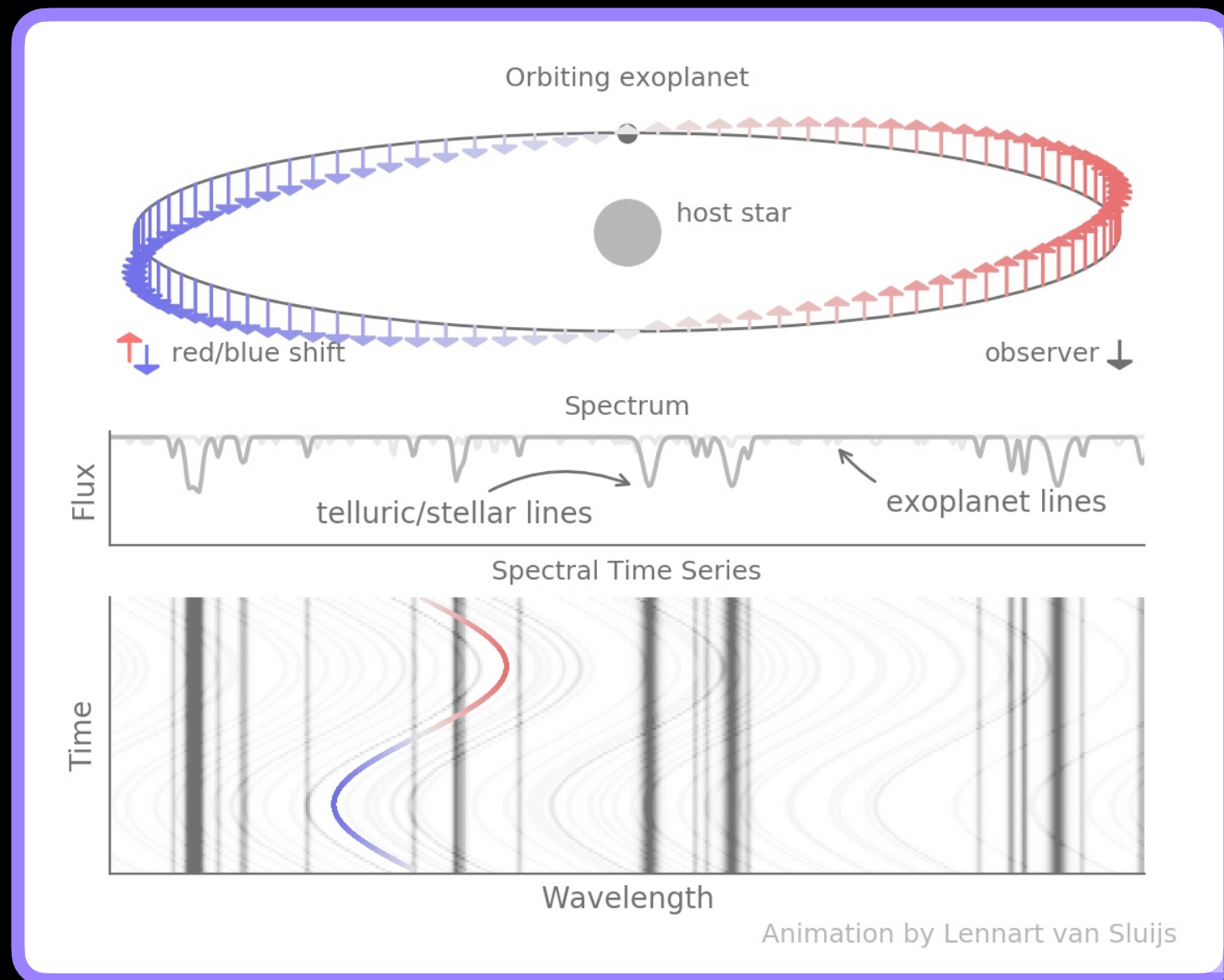
# HIGH-RESOLUTION CROSS-CORRELATION SPECTROSCOPY



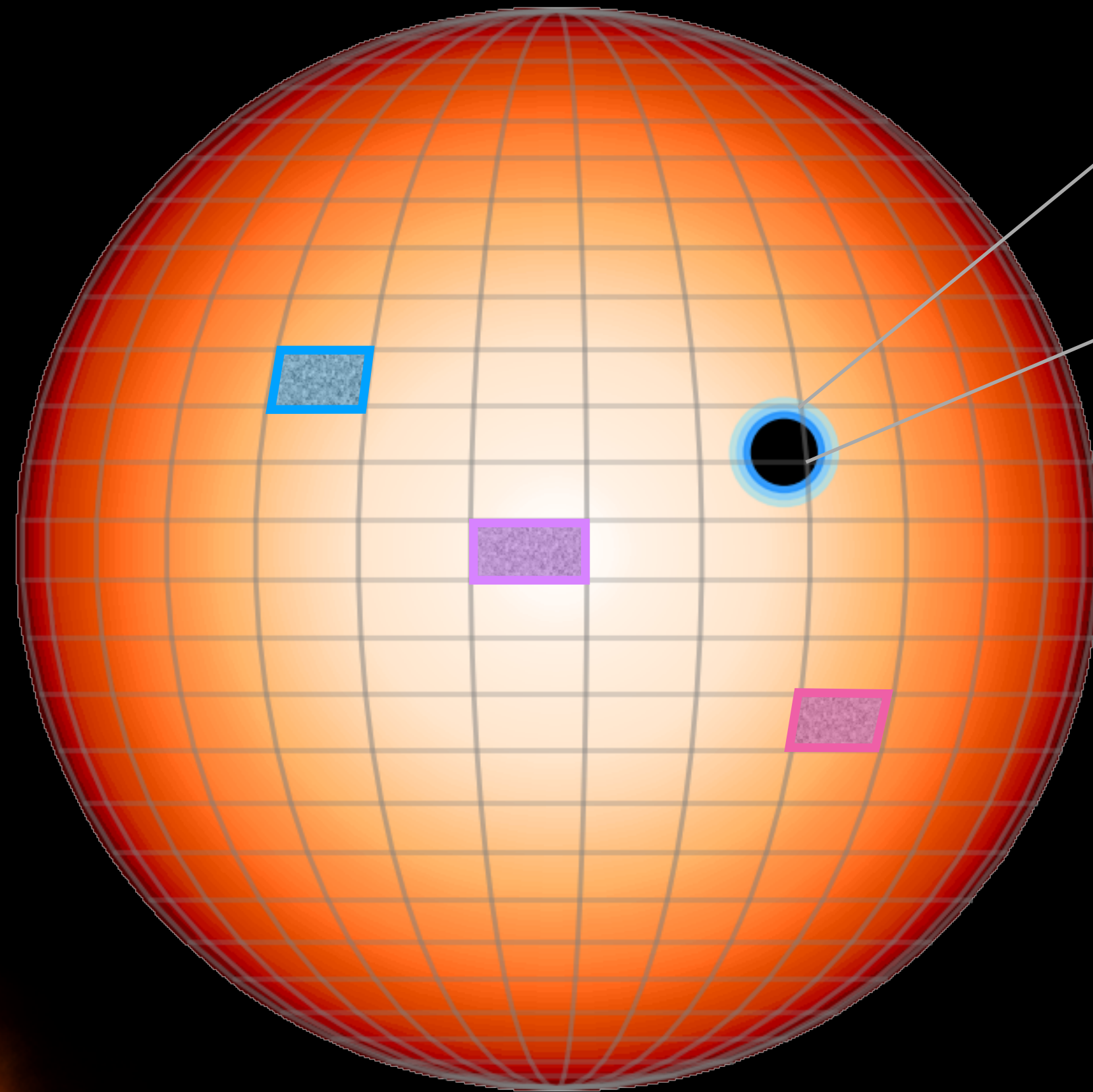
# HIGH-RESOLUTION CROSS-CORRELATION SPECTROSCOPY



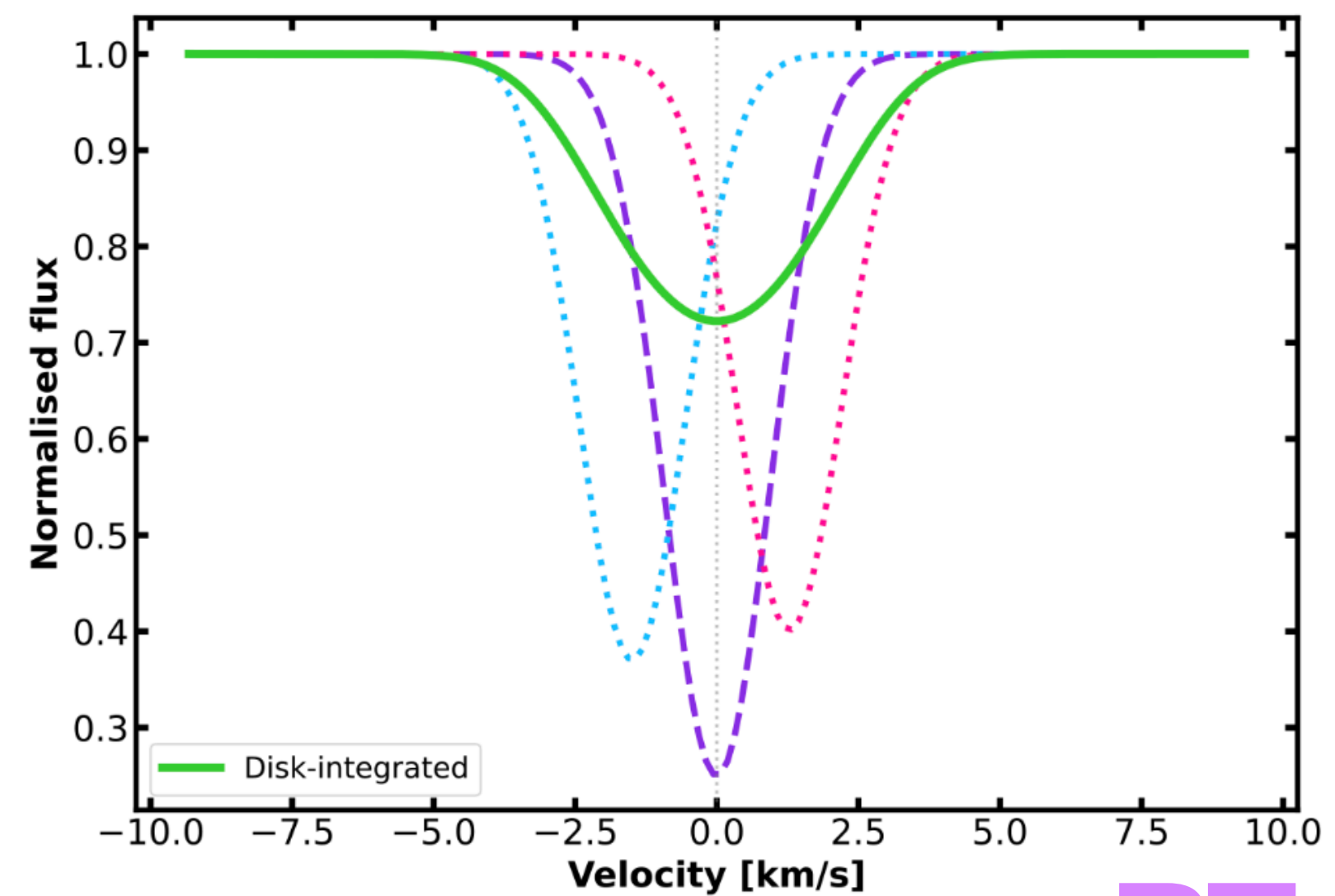
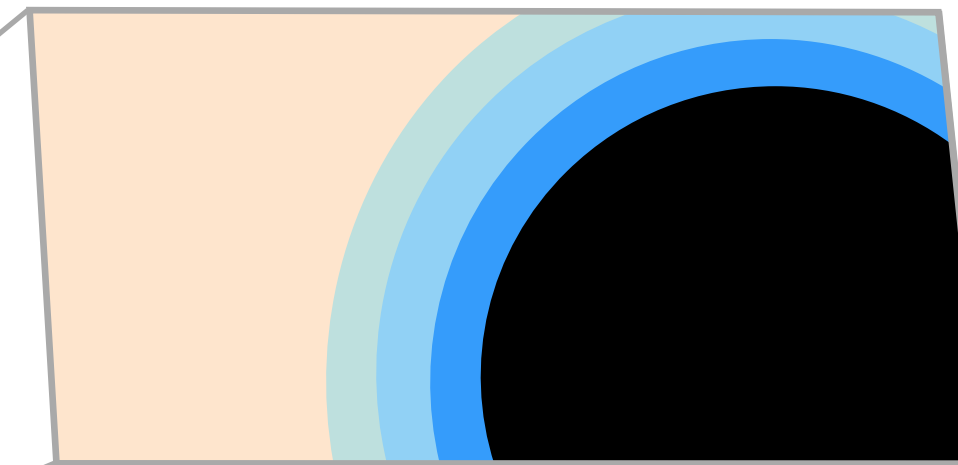
# HIGH-RESOLUTION CROSS-CORRELATION SPECTROSCOPY



# A FORWARD MODEL [MEECH+IN PREP]



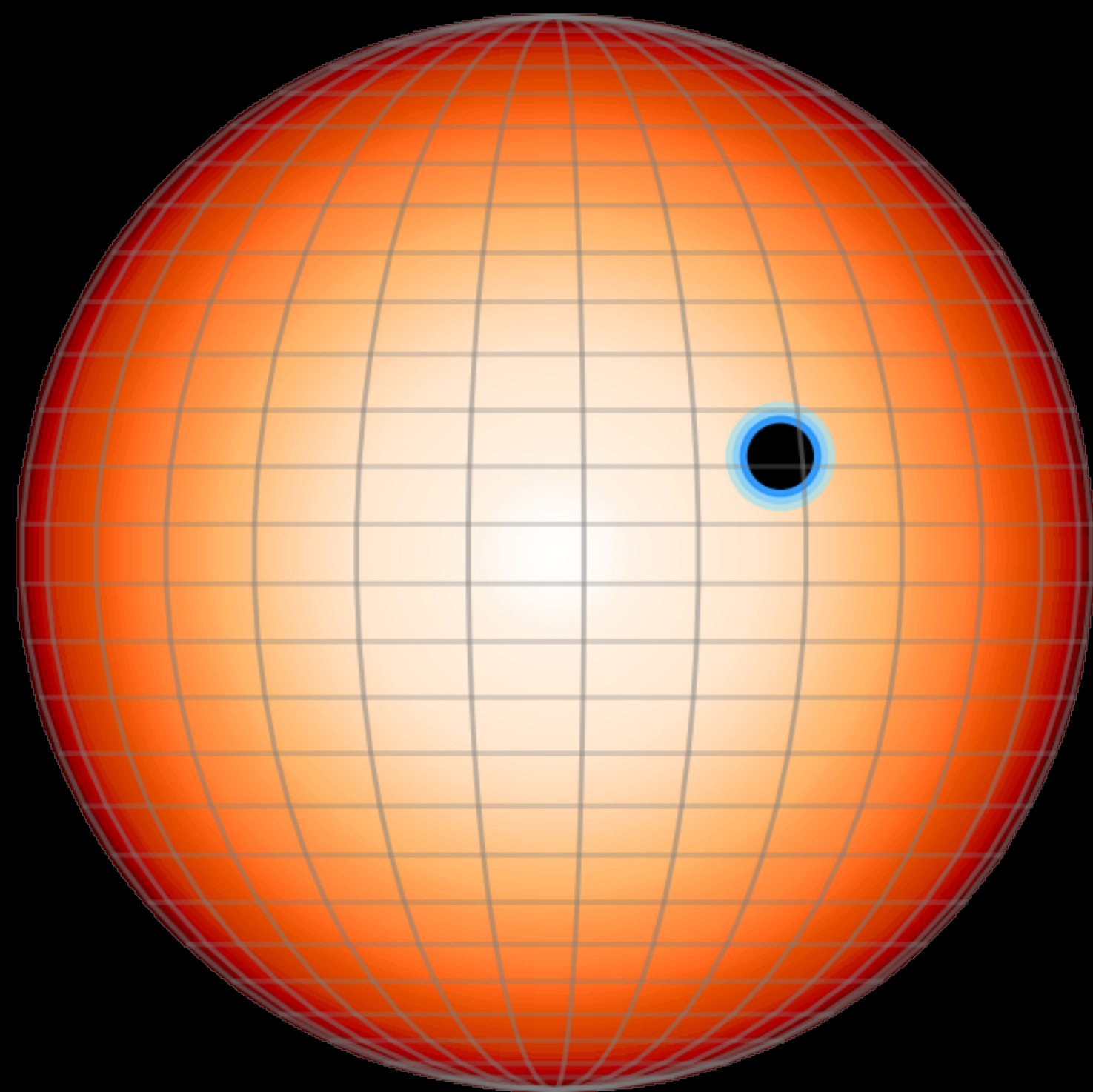
**PETITRADTRANS**



**BT-SETTL**



# MODEL SETUP [MEECH+INPREP]



## 1/ SPECTRA

BT-Settl (1D) for photosphere, solar metallicity  
Cooler BT-Settl for spots, with same gravity  
PetitRADTRANS for H<sub>2</sub>O planetary atmosphere

## 2/ BANDPASS

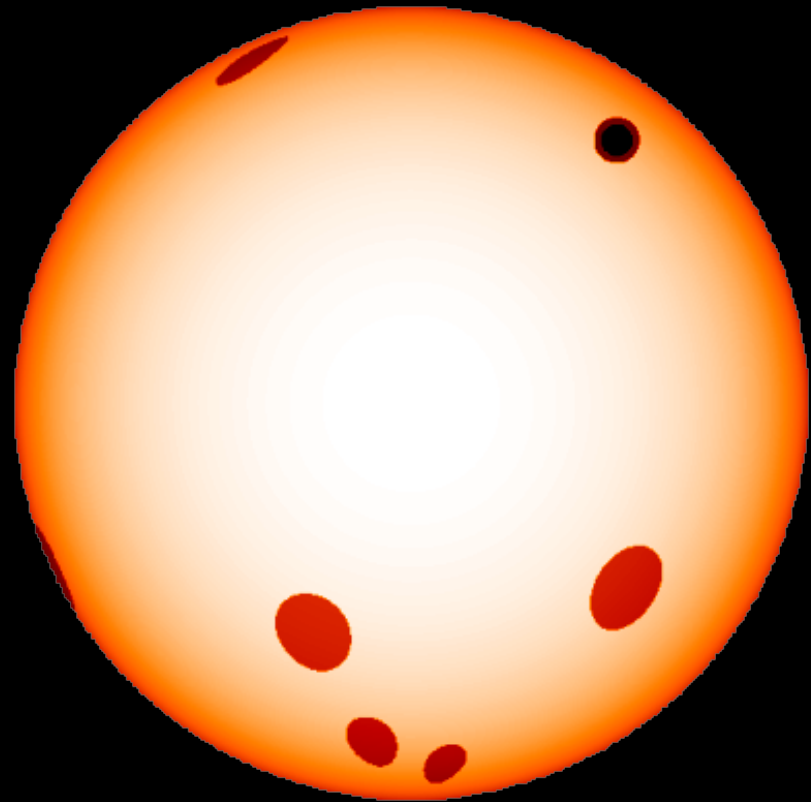
CRIRES wavelength region 1.9–2.4 microns  
Resolution R=140k

## 3/ SNR

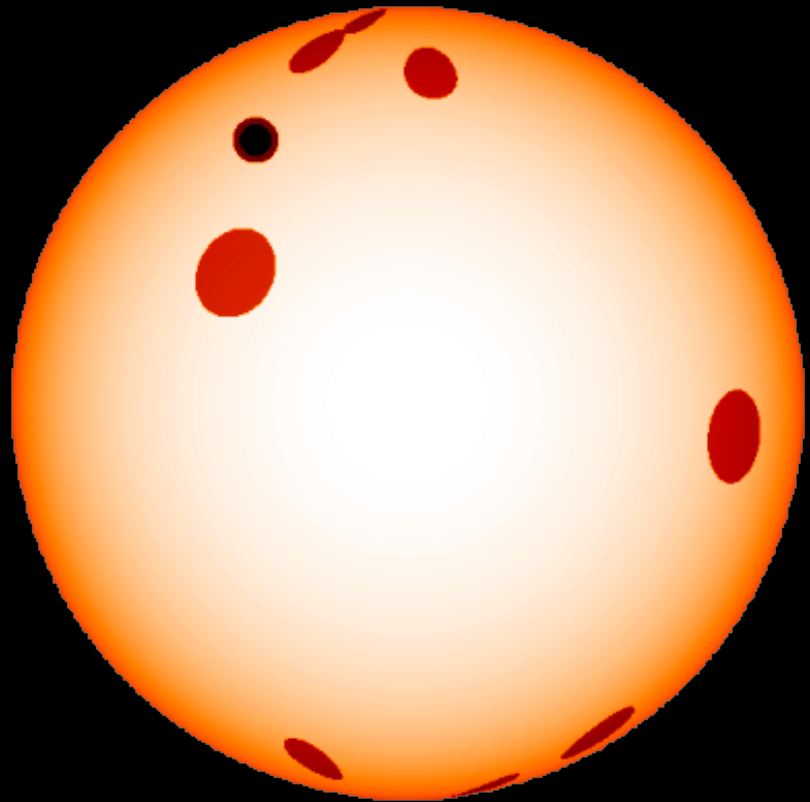
Signal-to-noise of 100 to meet 5-sigma  
reference detection threshold

# M-DWARF FAMILY

[MEECH+IN PREP]



[M0V]



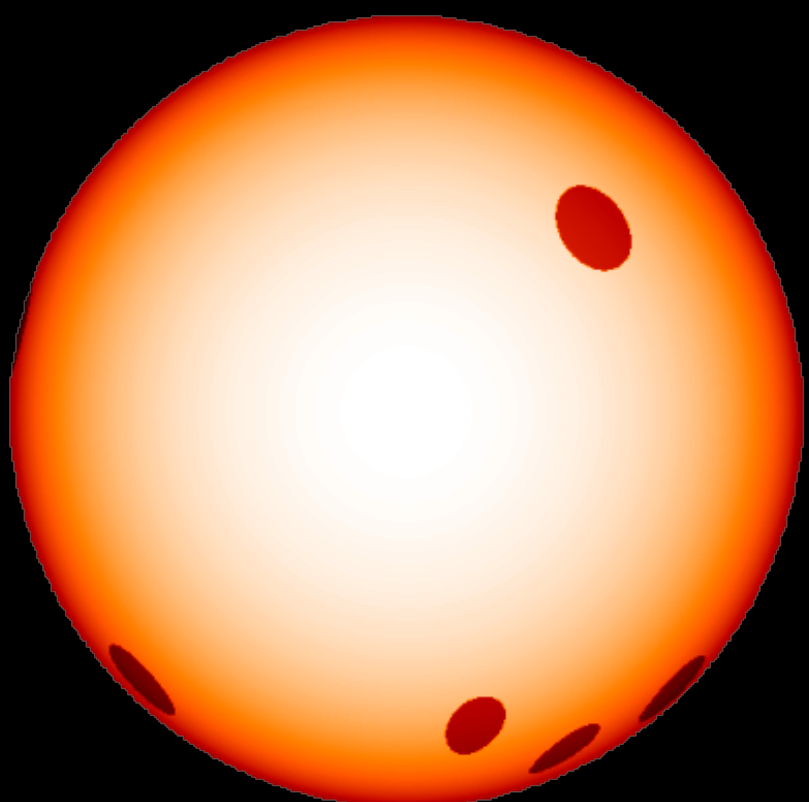
[M1V]



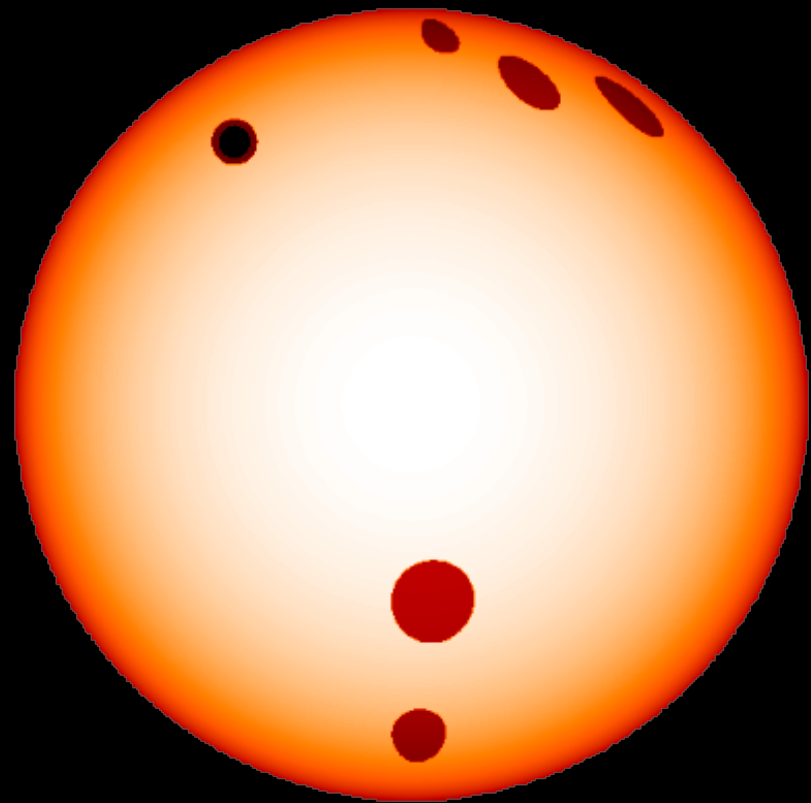
[M2V]



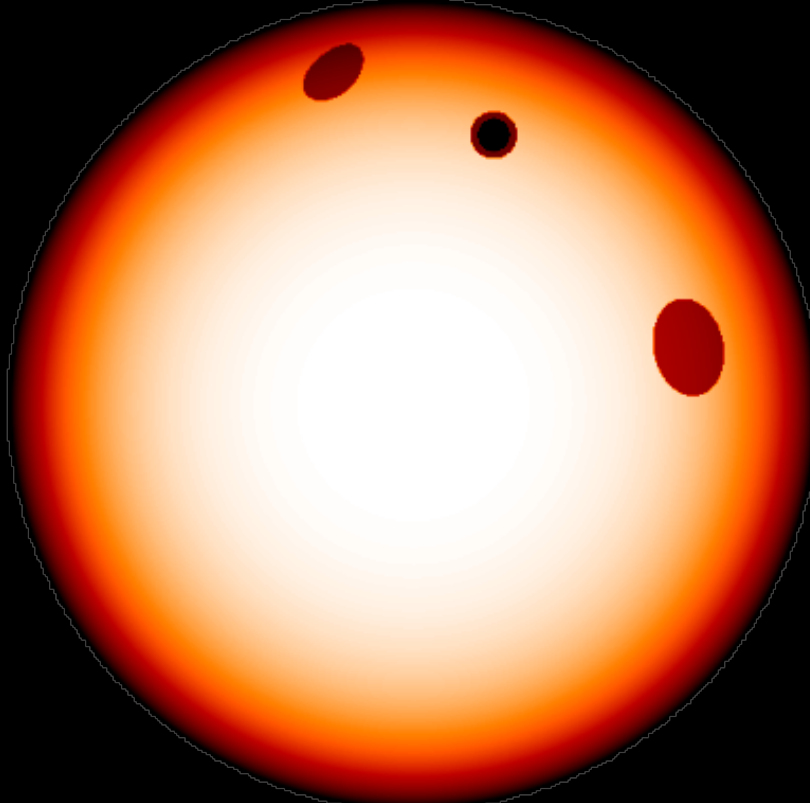
[M3V]



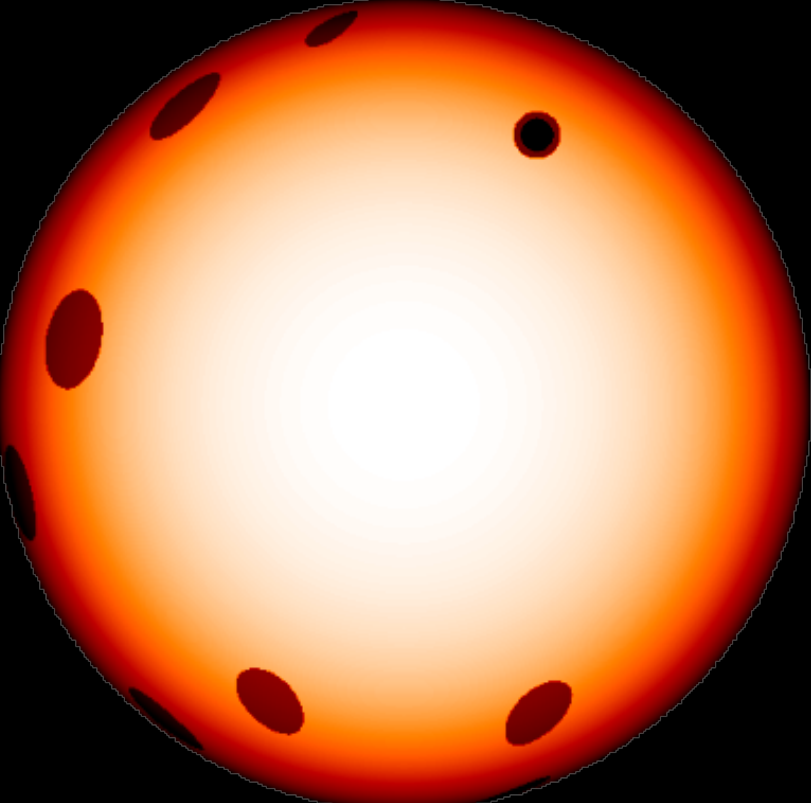
[M4V]



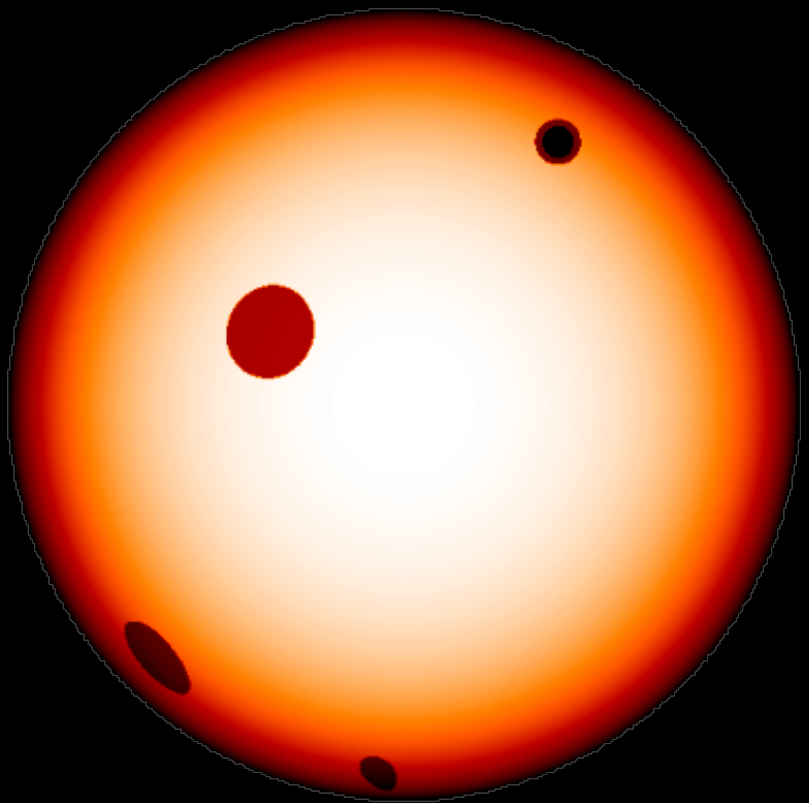
[M5V]



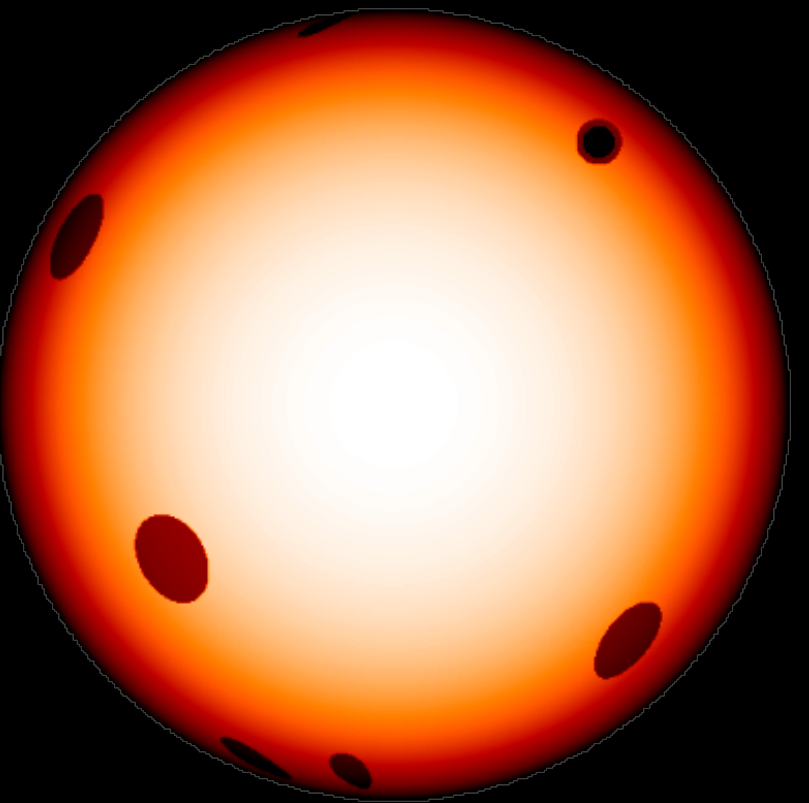
[M6V]



[M7V]

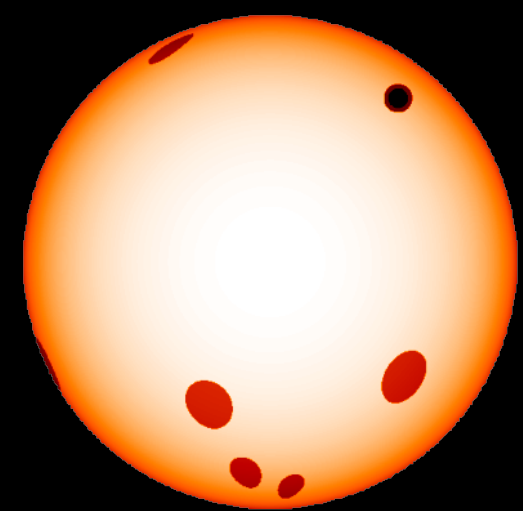


[M8V]

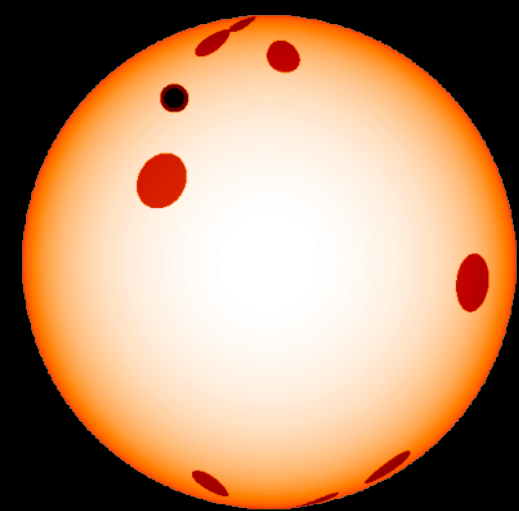


[M9V]

# M-DWARF SPOTS



[M0V]



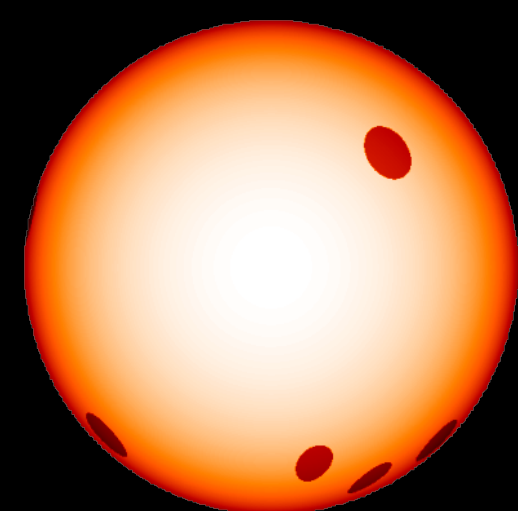
[M1V]



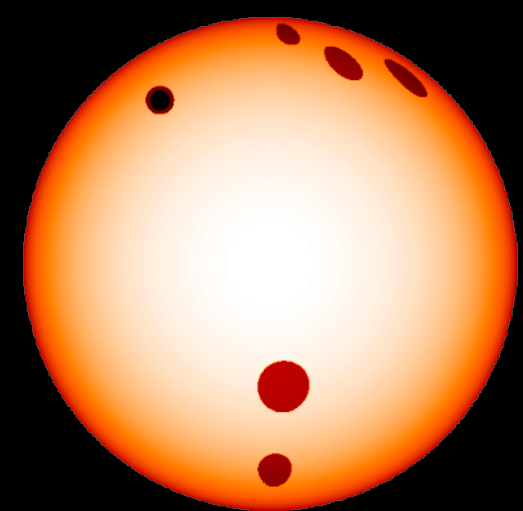
[M2V]



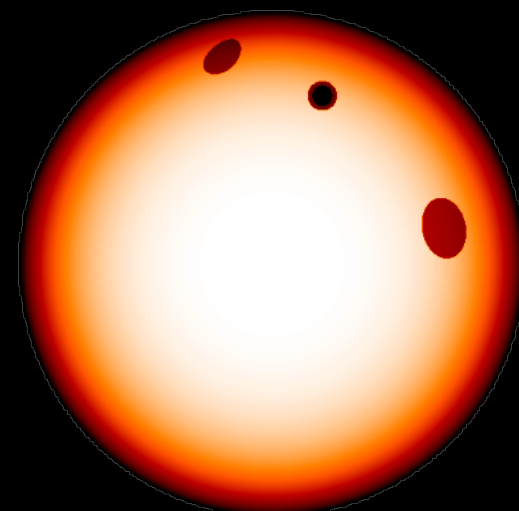
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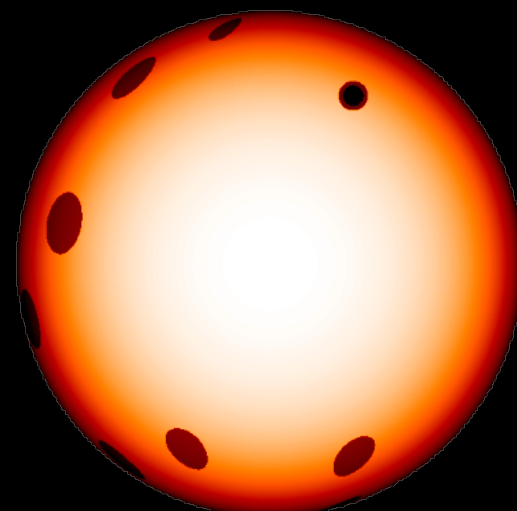
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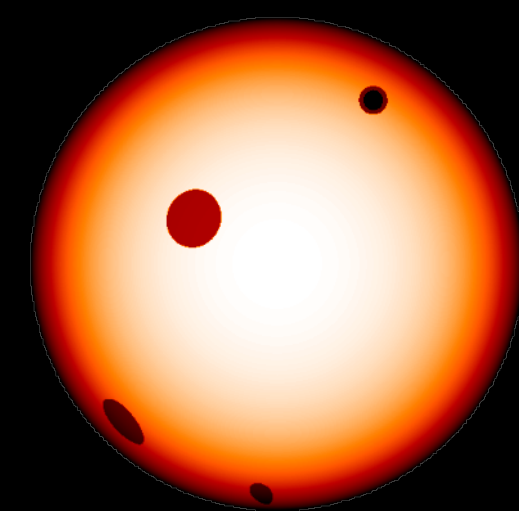
[M5V]



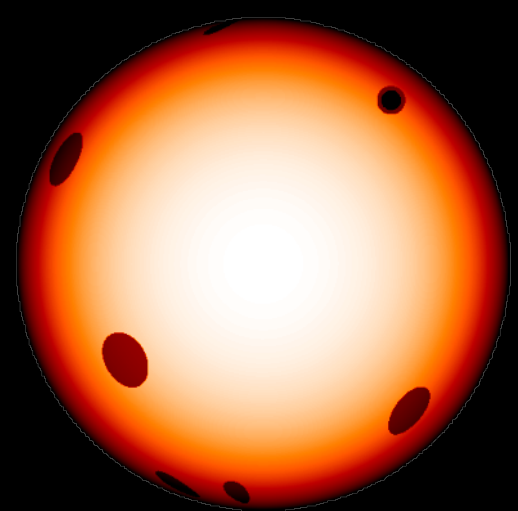
[M6V]



[M7V]



[M8V]



[M9V]

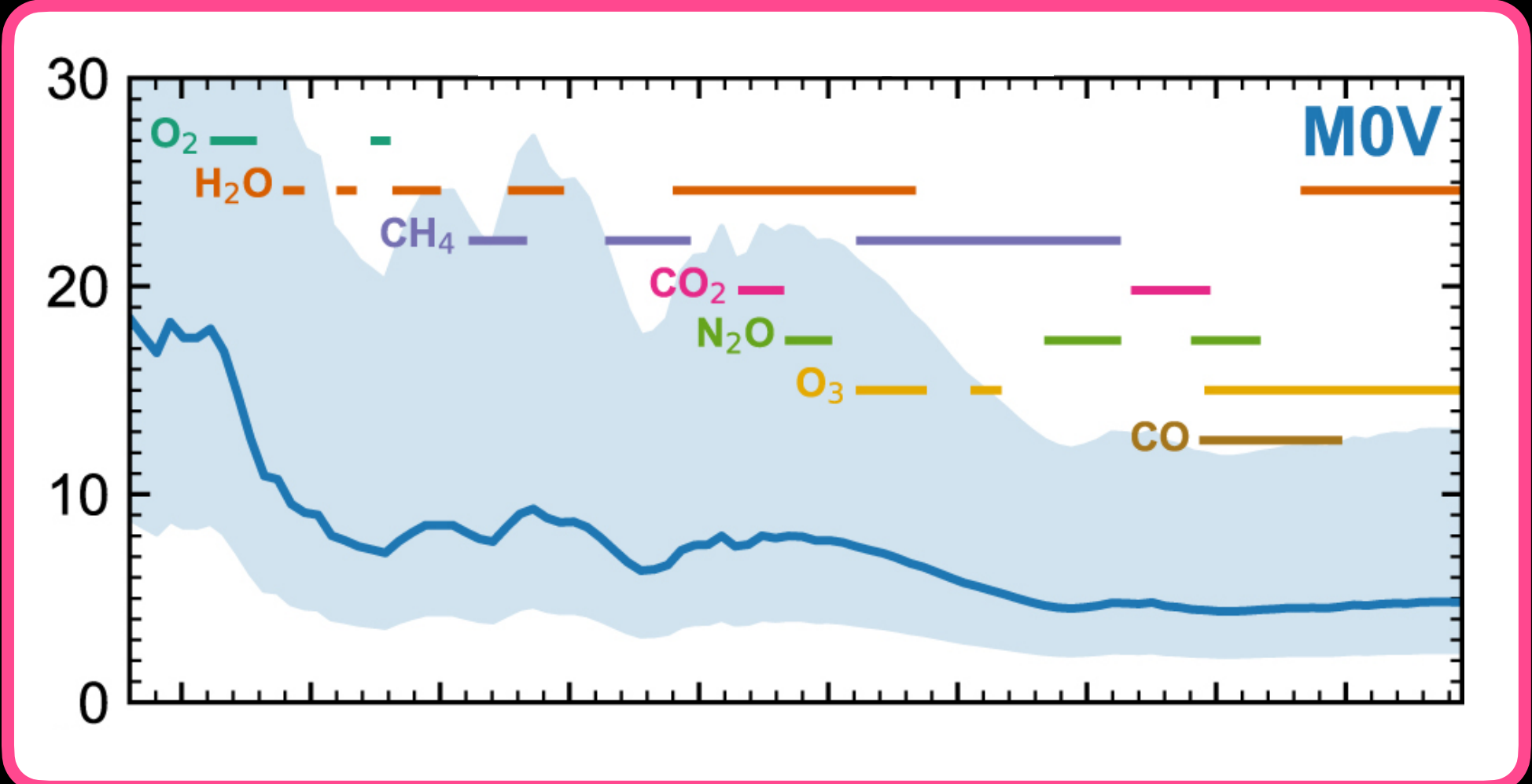
**TWO TYPES OF SPOTS:**

**1/ GIANT**

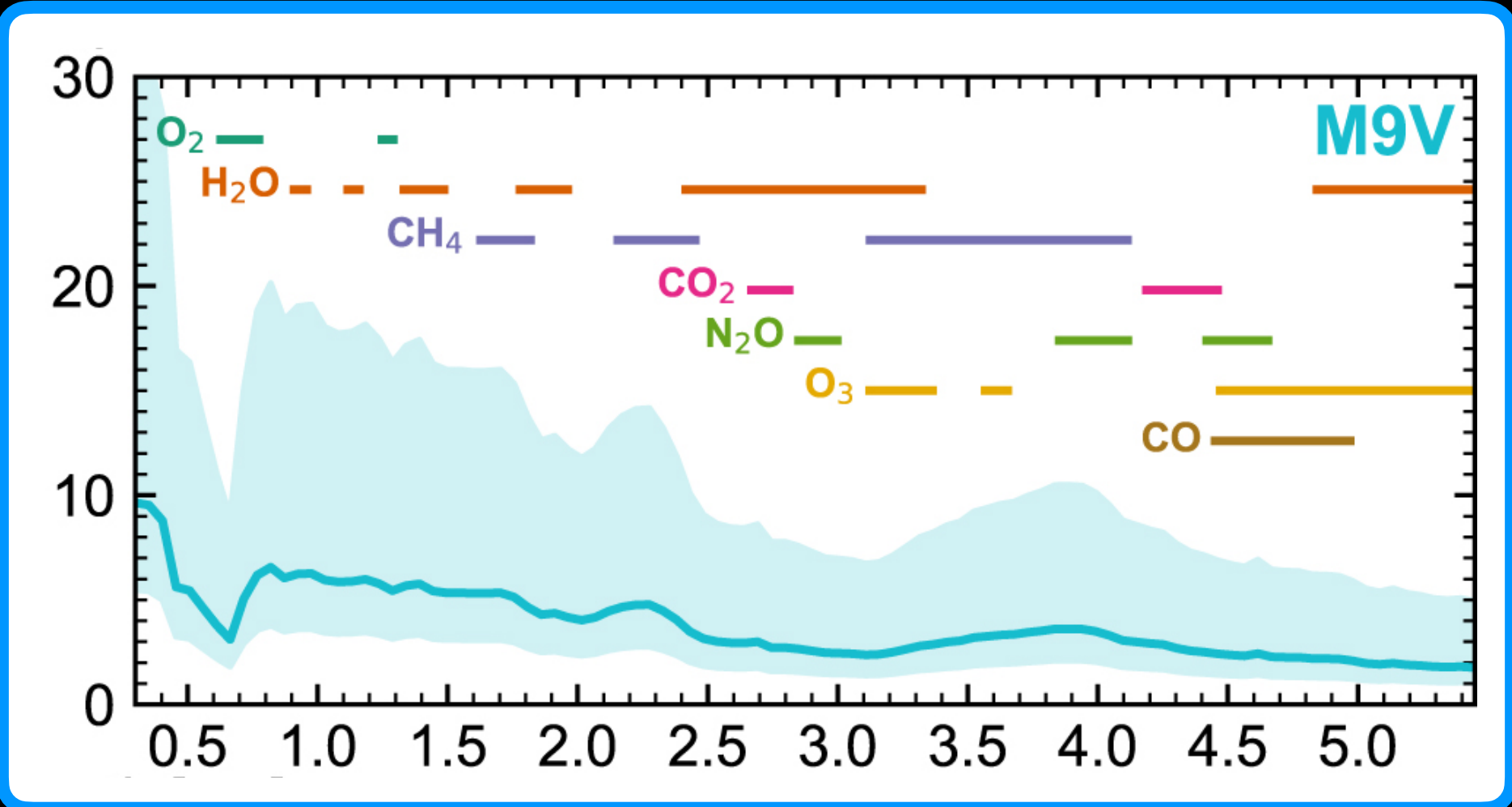
**2/ SOLAR-LIKE**

[RACKHAM+2018]

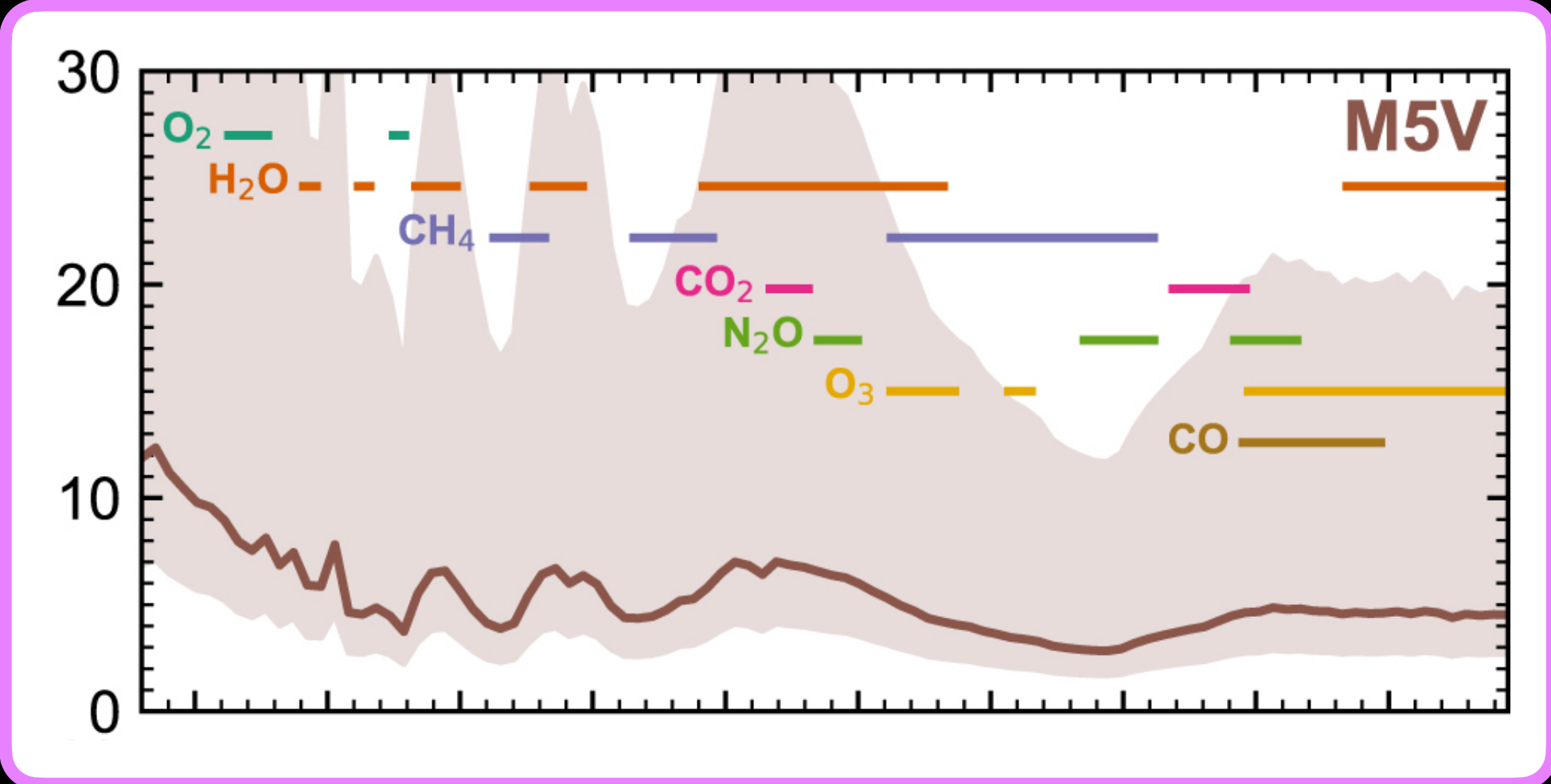
# UNOCCULTED SPOTS SOLAR-LIKE



[M0V]



[M9V]

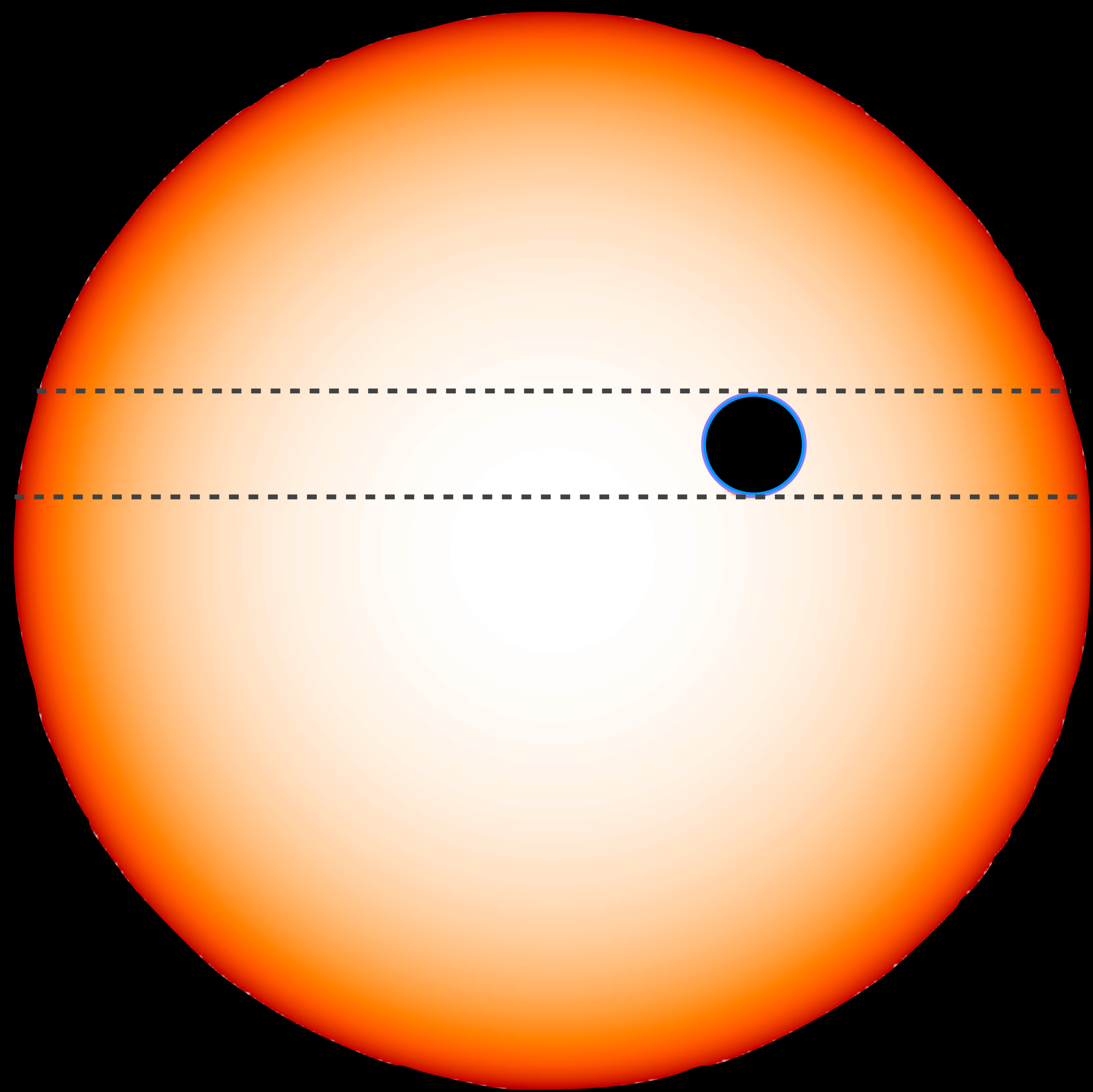


[M5V]

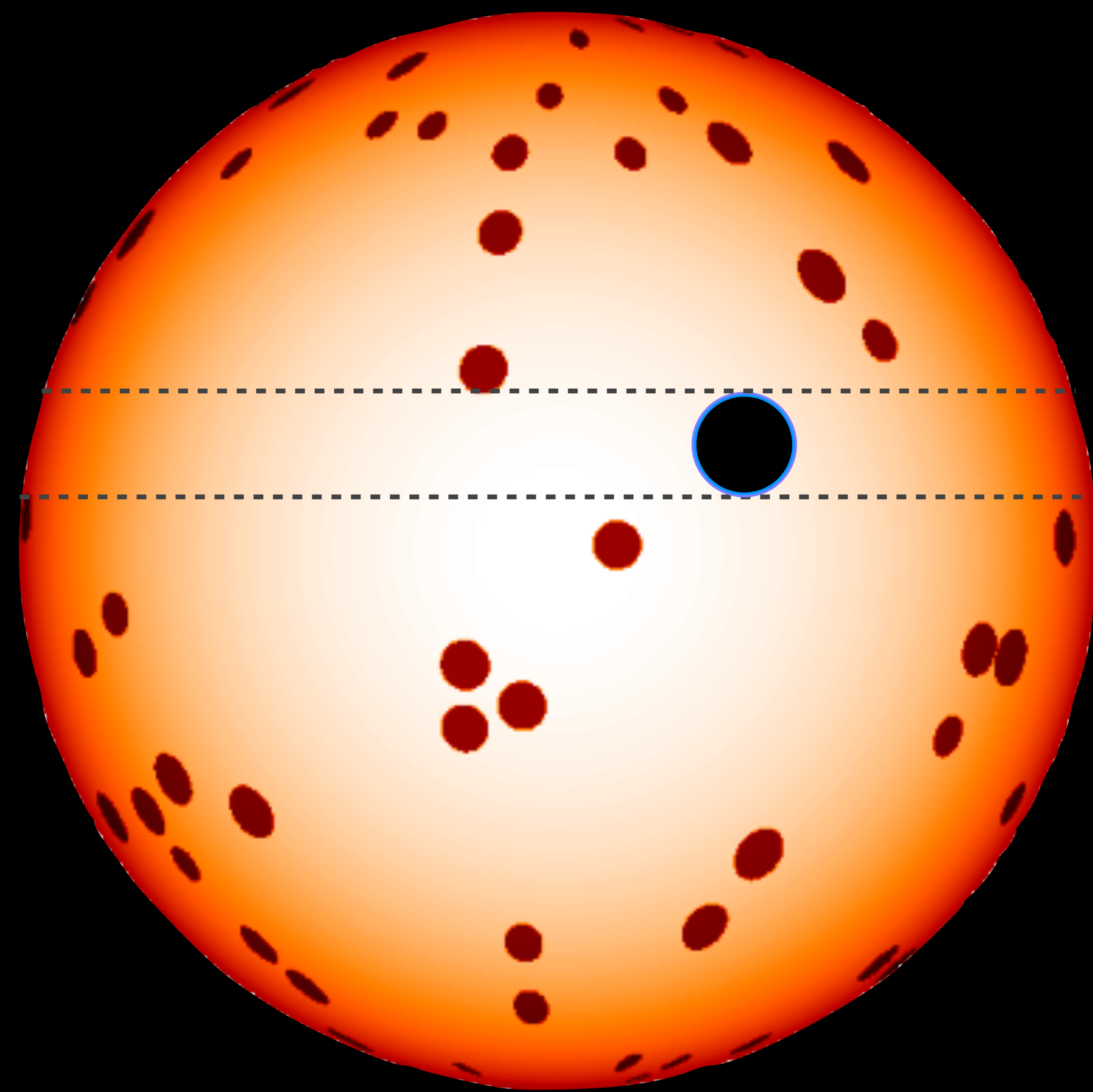
[RACKHAM+2018]



# UNOCCULTED SPOTS [MEECH+INPREP]



[REFERENCE]



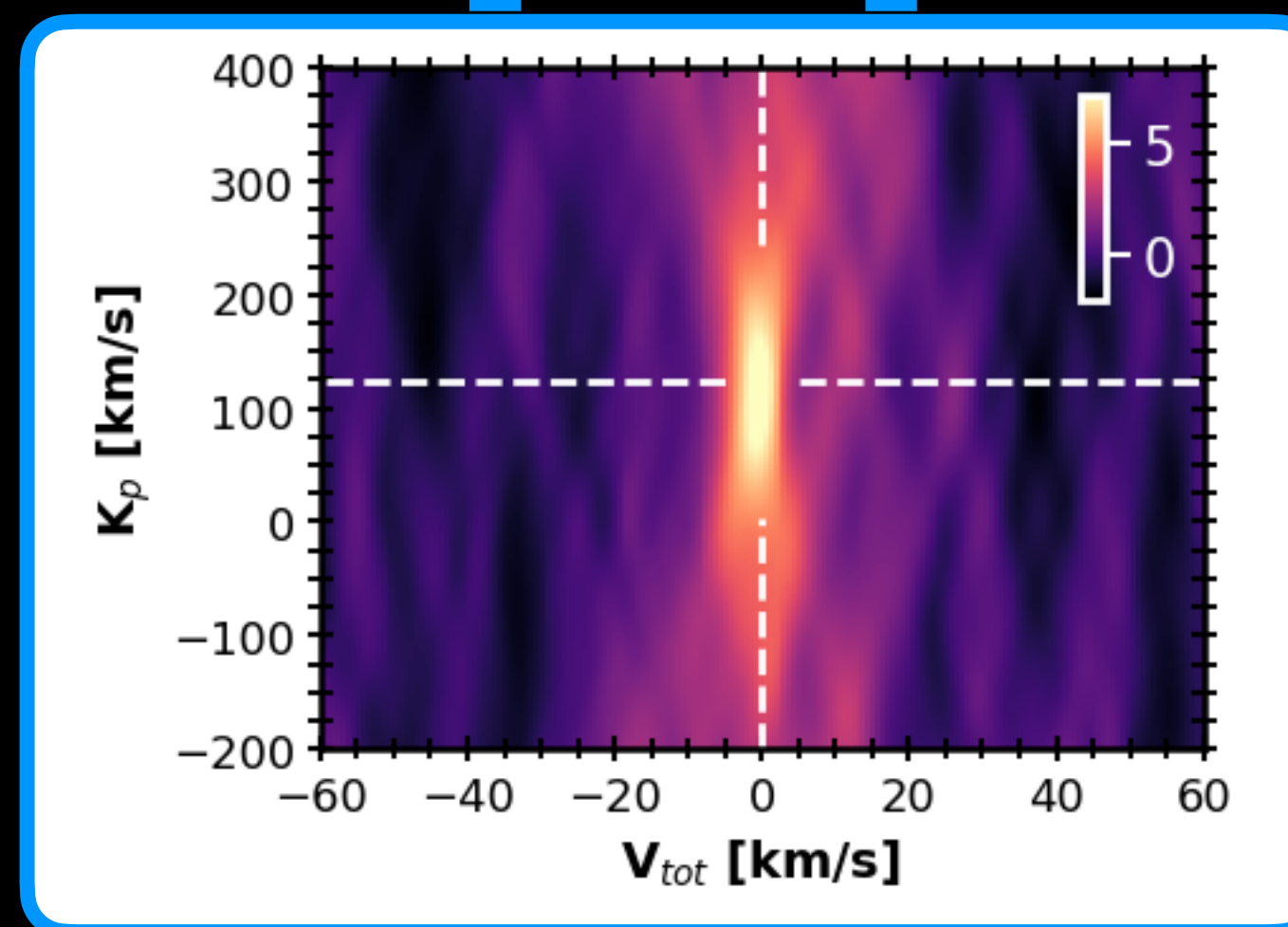
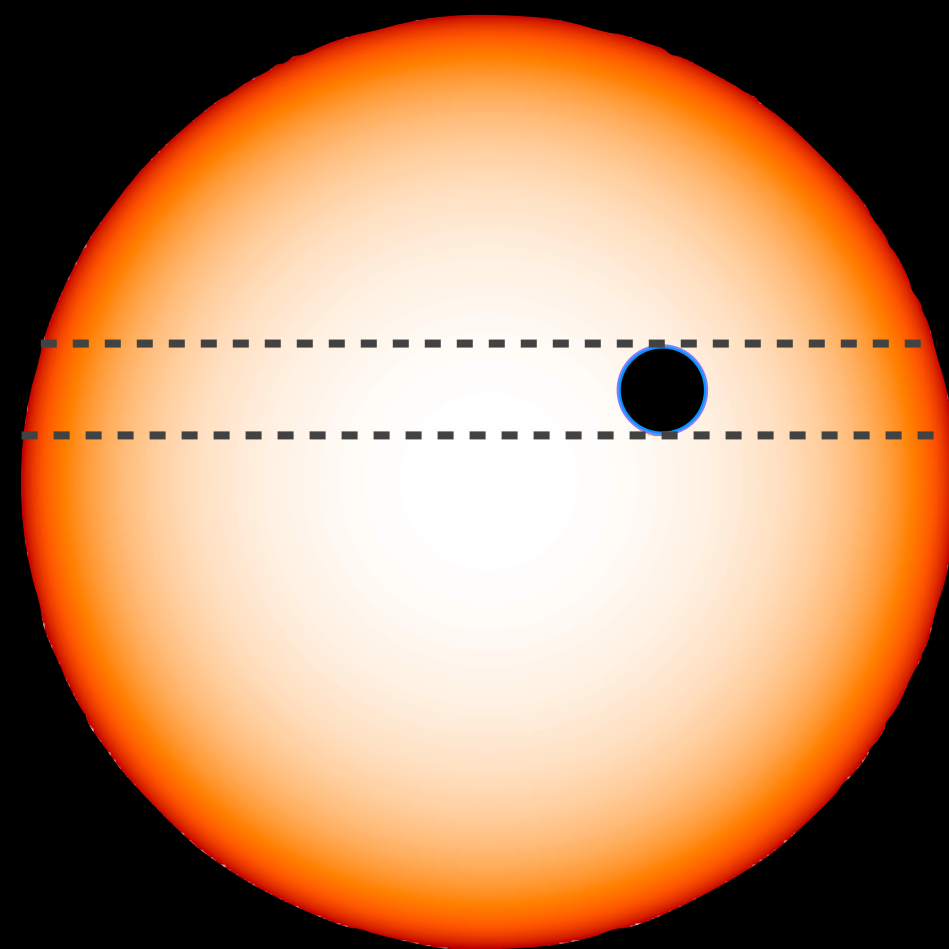
[SPOTTED STAR]



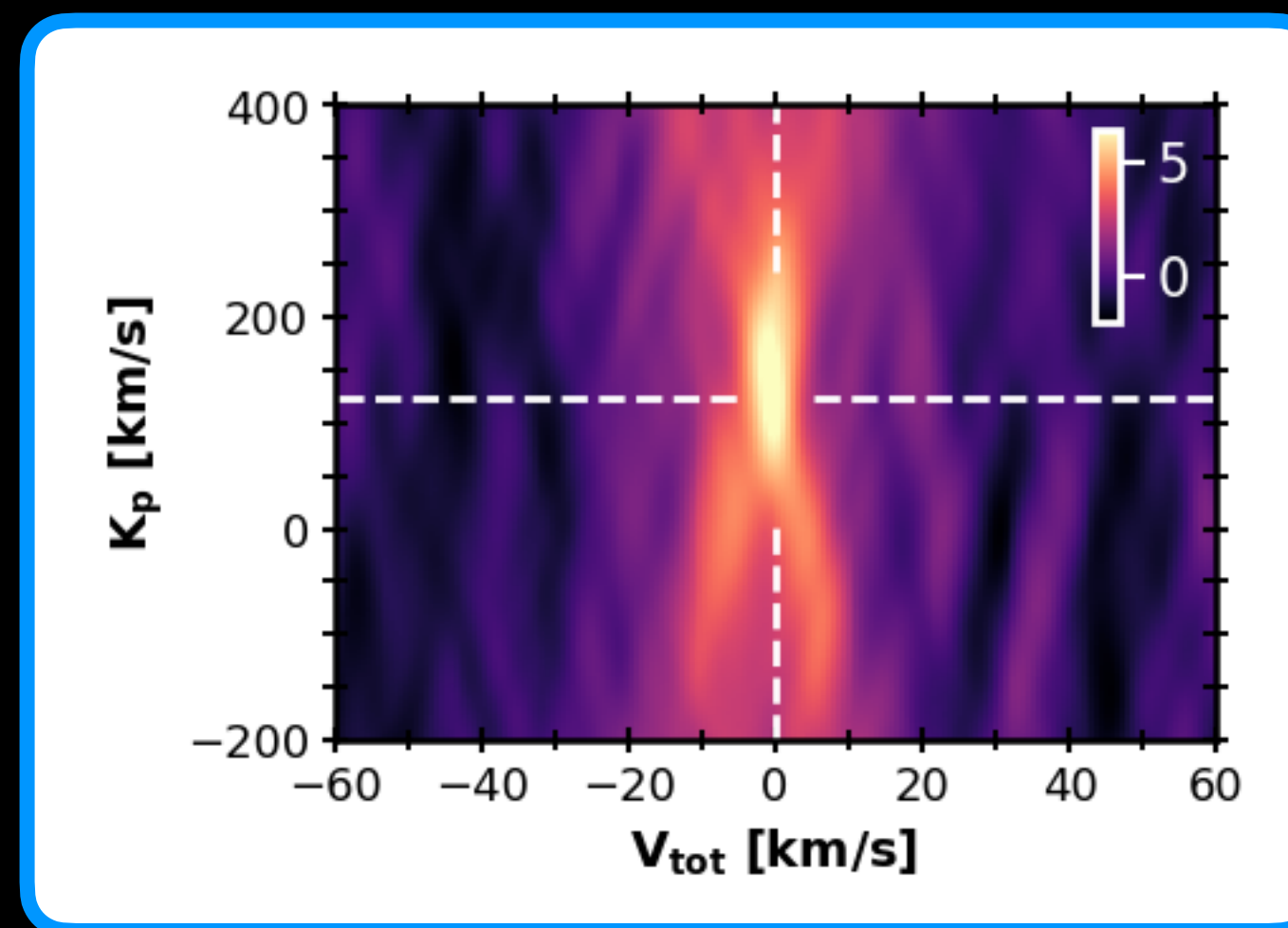
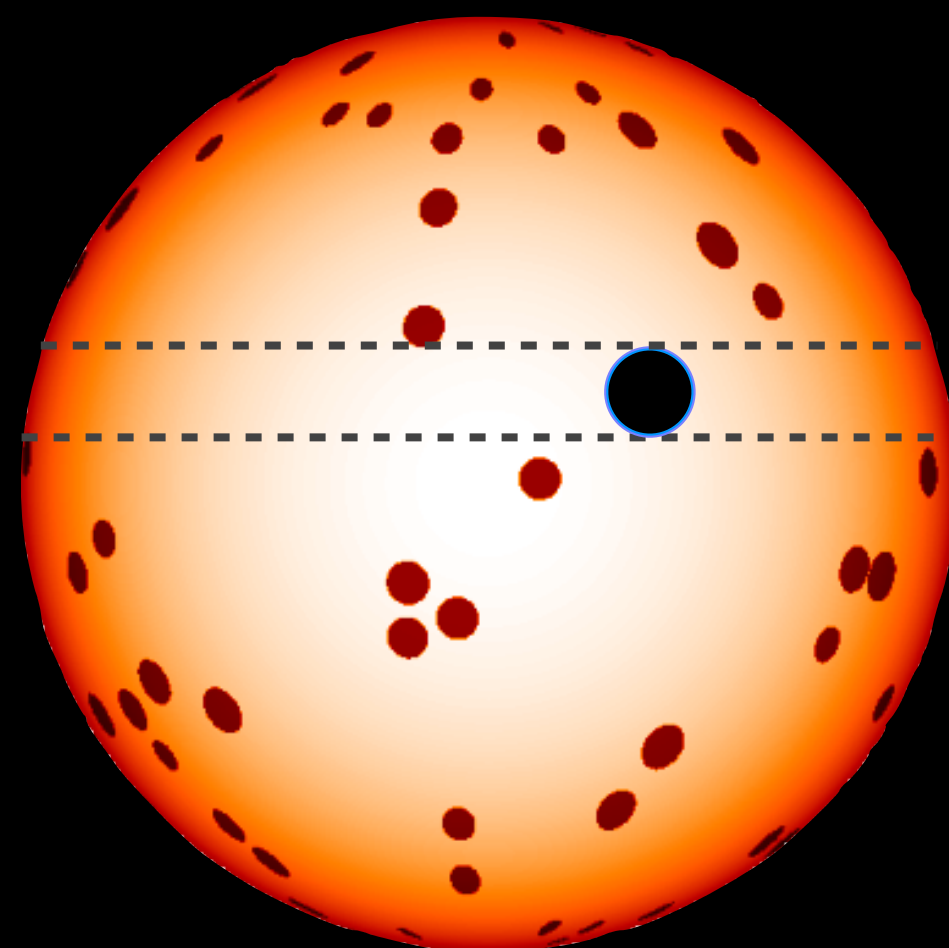
# UNOCCULTED SPOTS [MEECH+IN PREP]

[H<sub>2</sub>O]

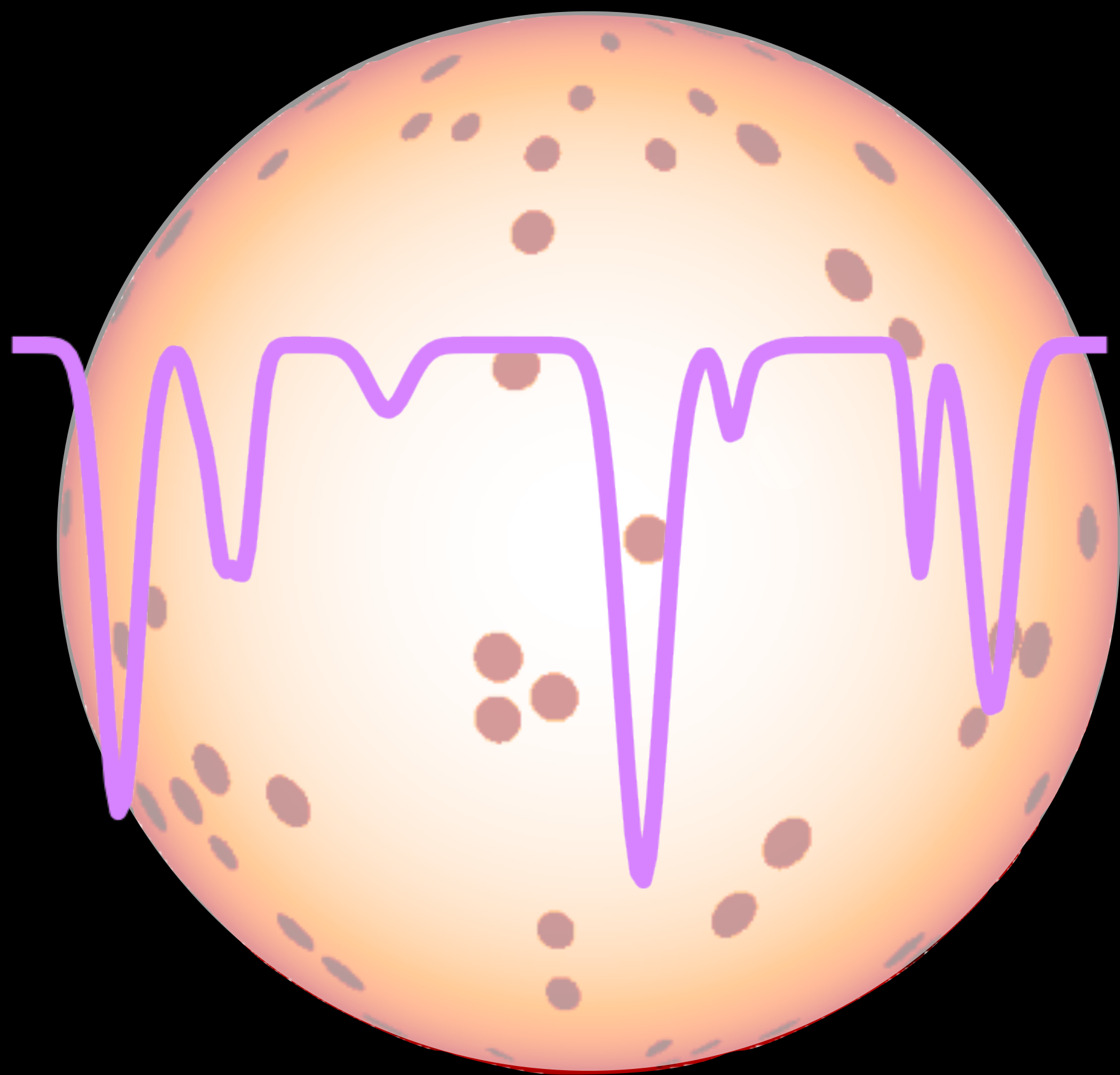
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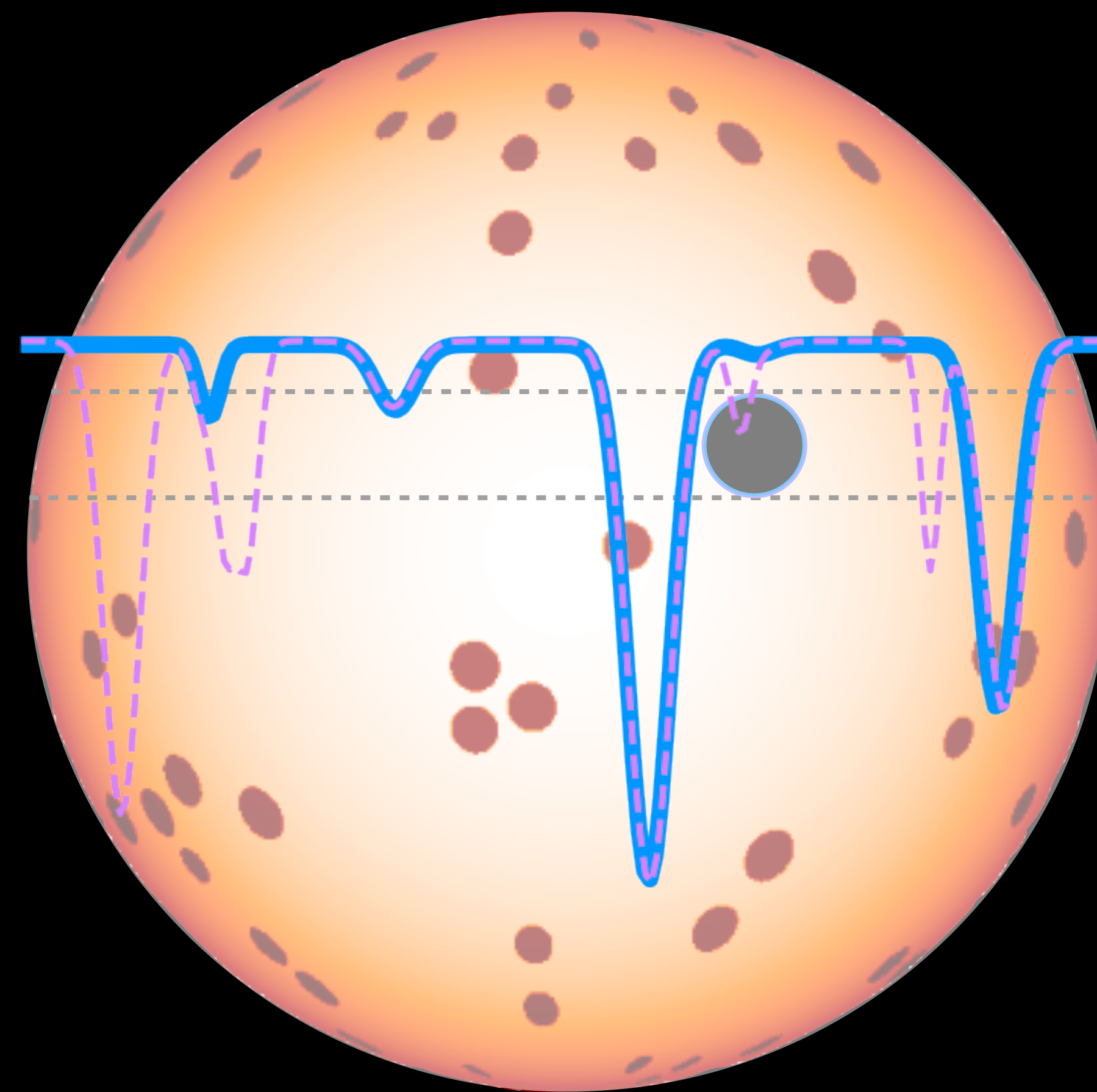
[SPOTTED STAR]



# UNOCCULTED SPOTS



[OUT-OF-TRANSIT]

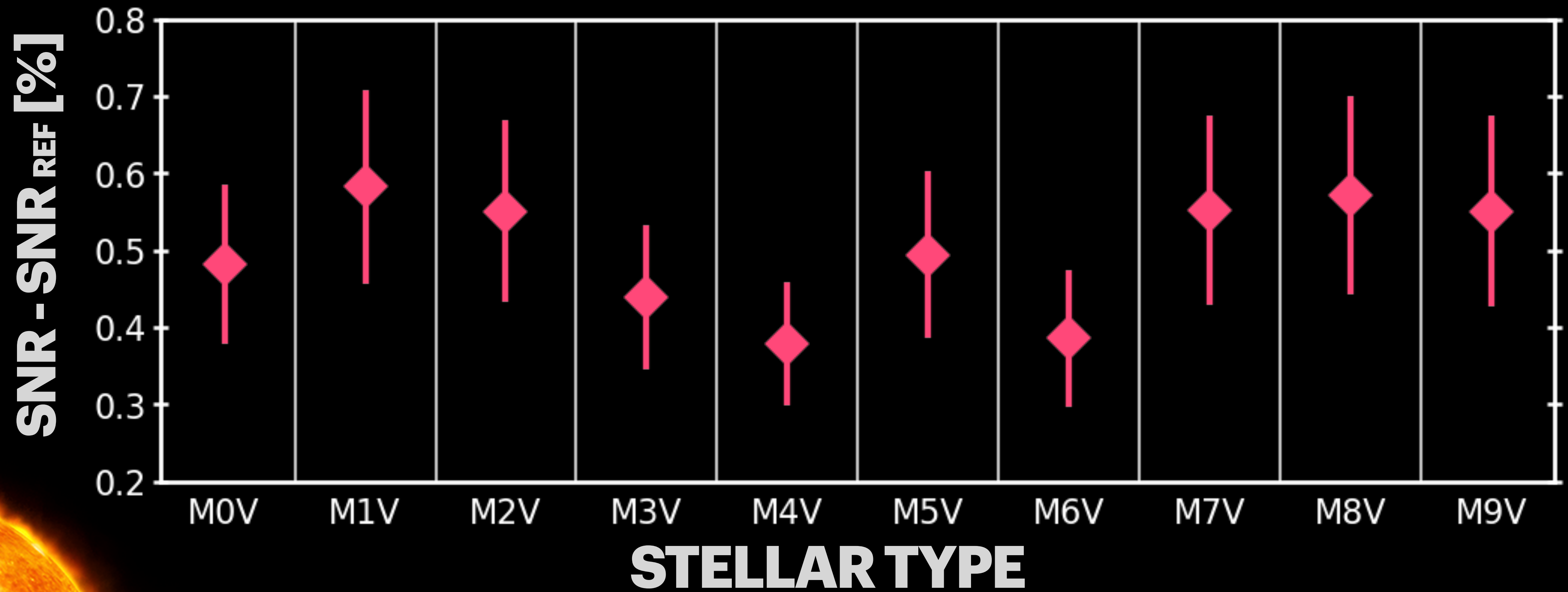


[IN-TRANSIT]



# UNOCCULTED SPOTS [MEECH+IN PREP]

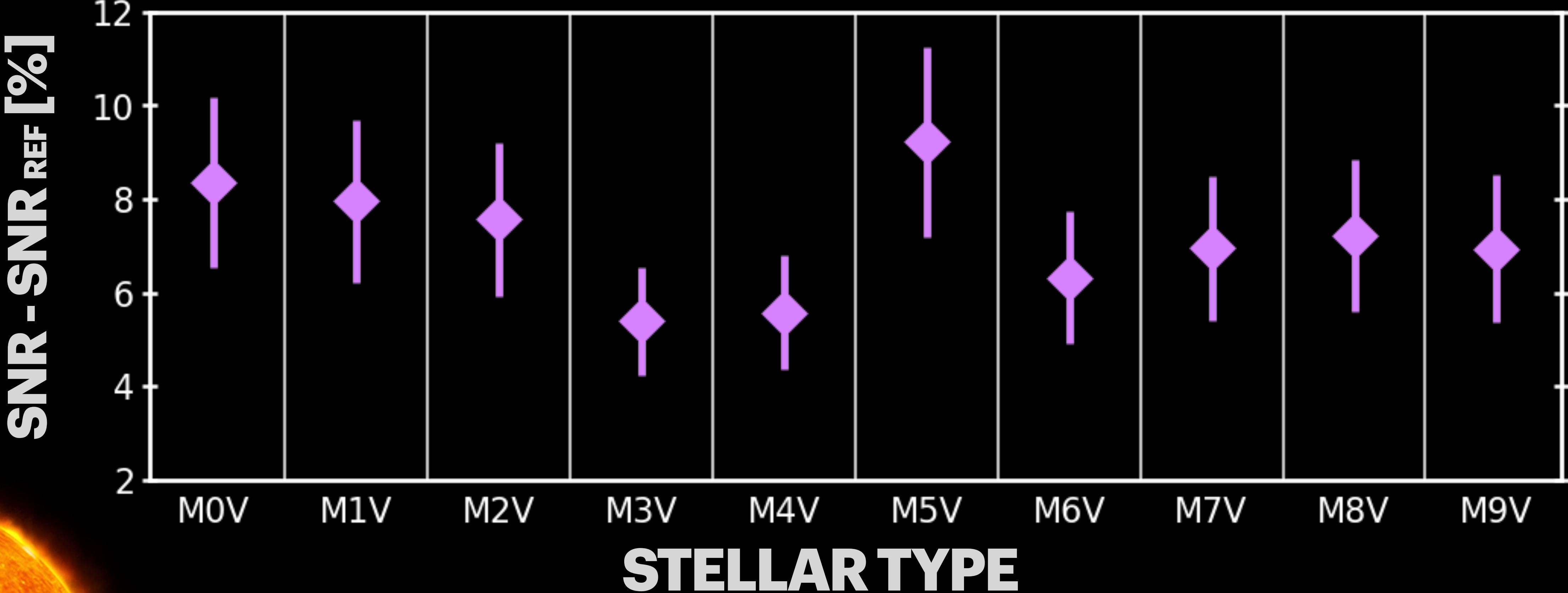
GIANT SPOTS



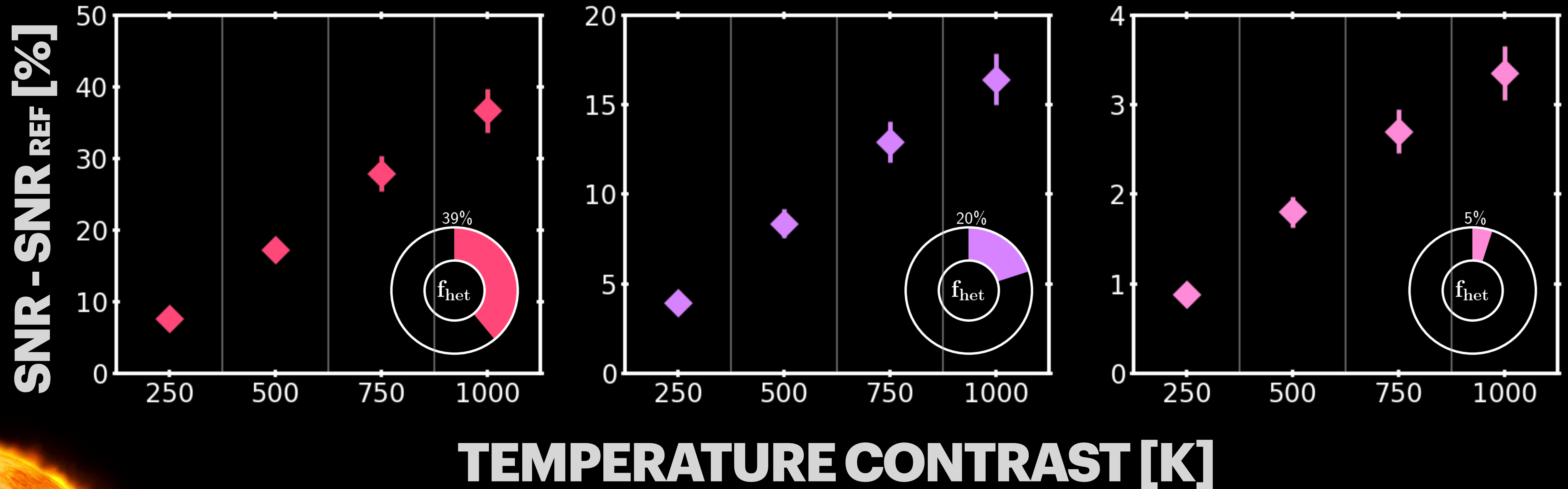


# UNOCCULTED SPOTS [MEECH+IN PREP]

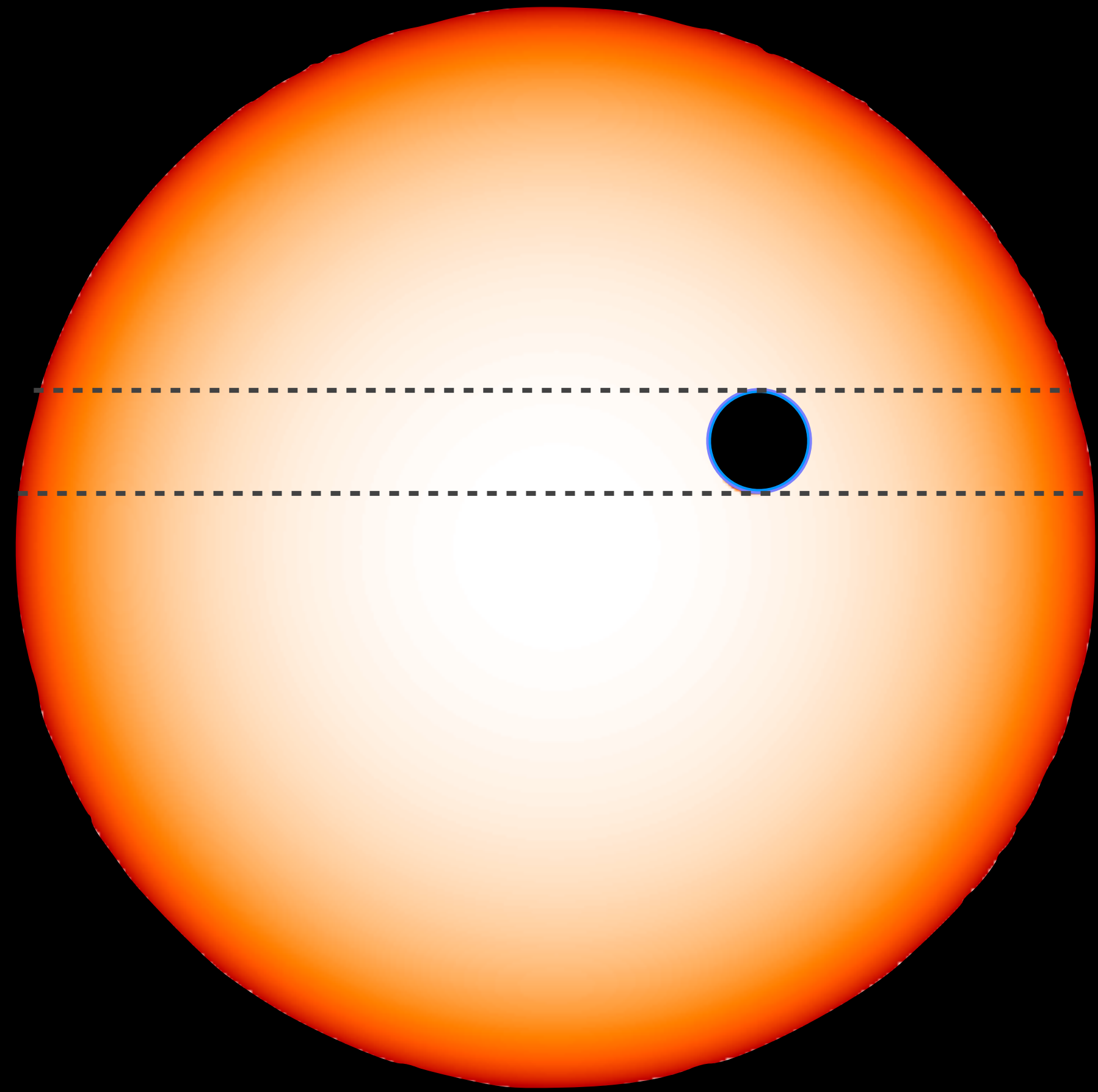
## SOLAR-LIKE SPOTS



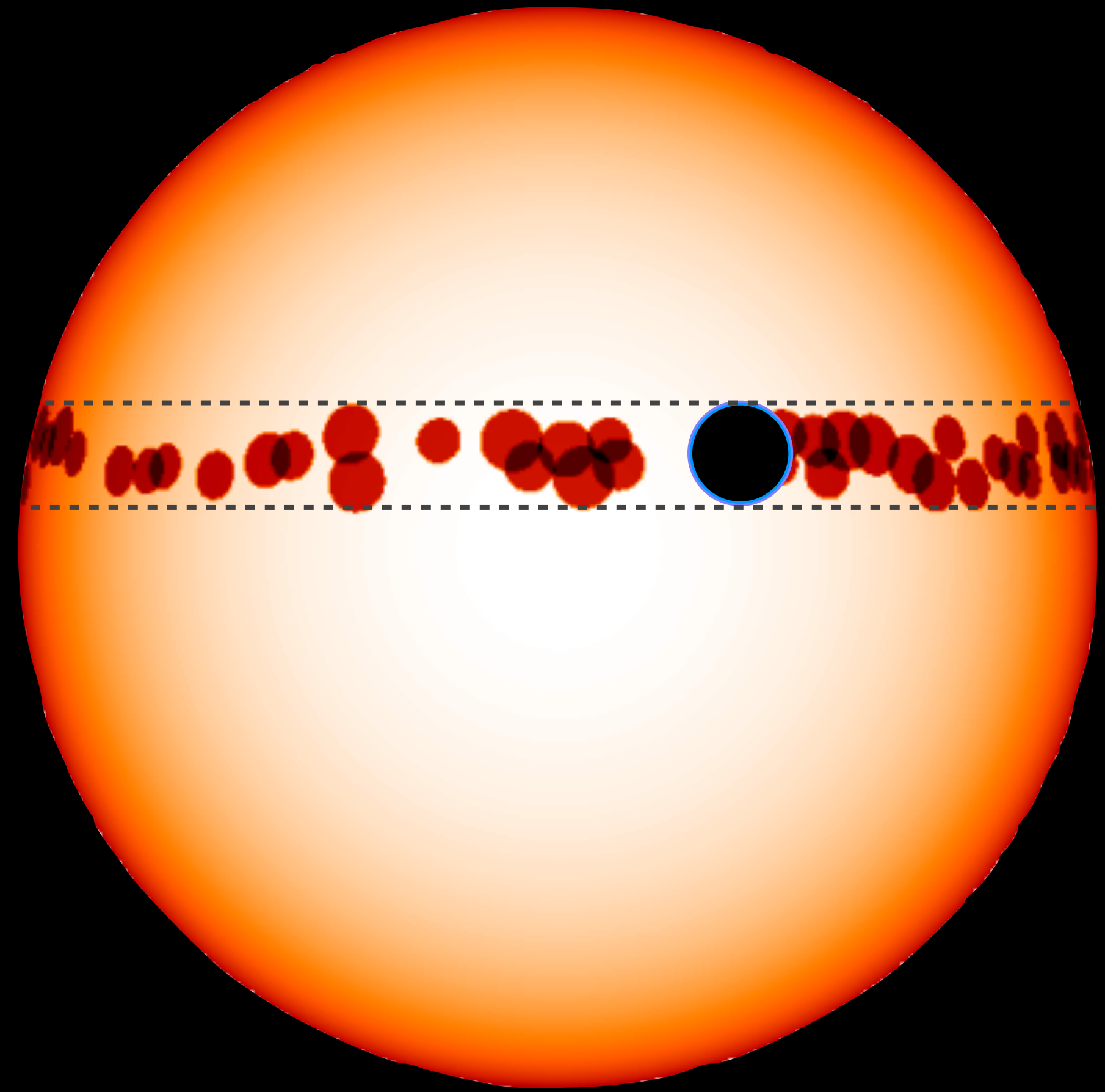
# UNOCCULTED SPOTS [AUMIC]



# OCCULTED SPOTS [MEECH+IN PREP]



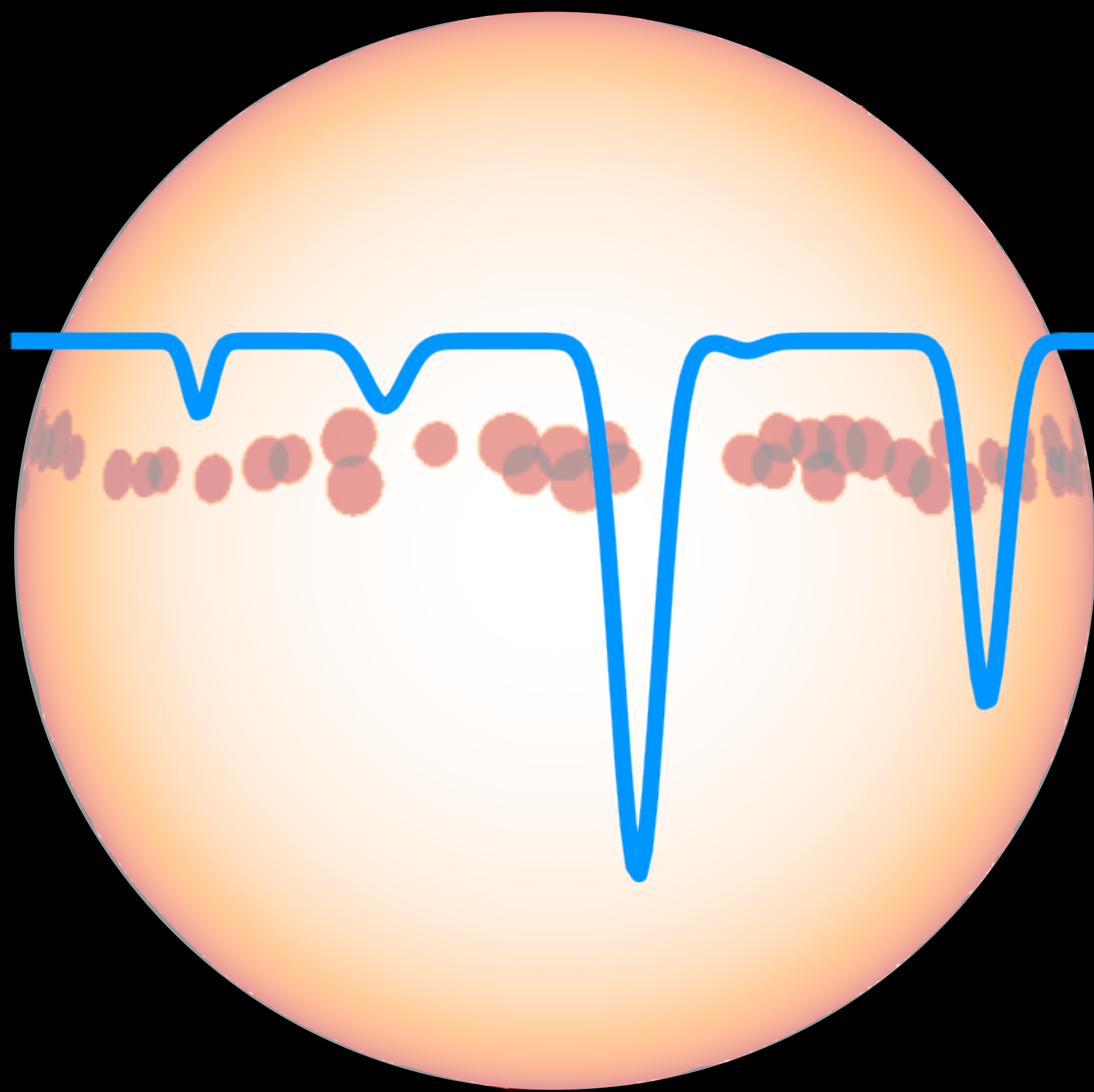
[BASELINE REFERENCE]



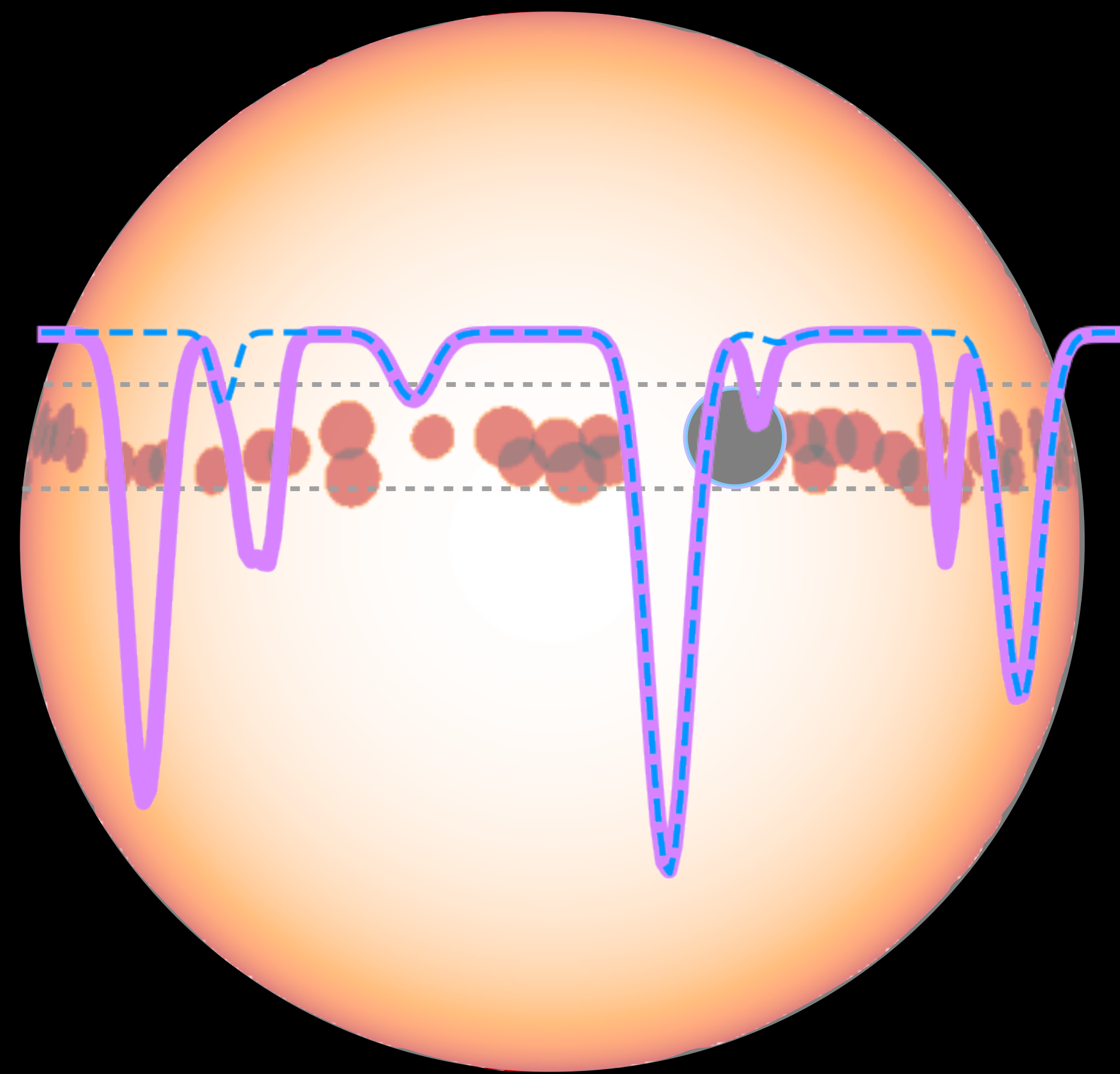
[SPOTTED STAR]



# OCCULTED SPOTS



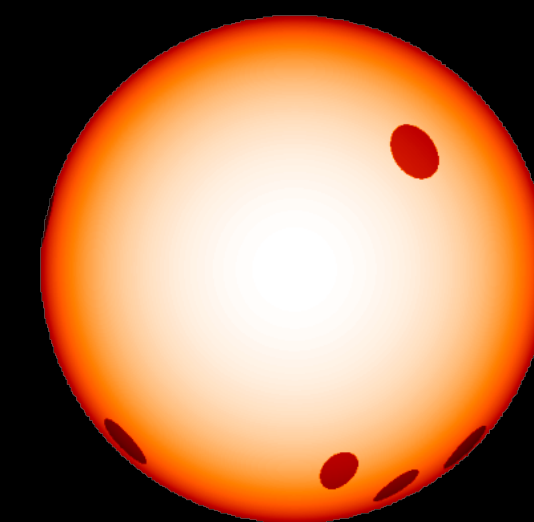
[OUT-OF-TRANSIT]



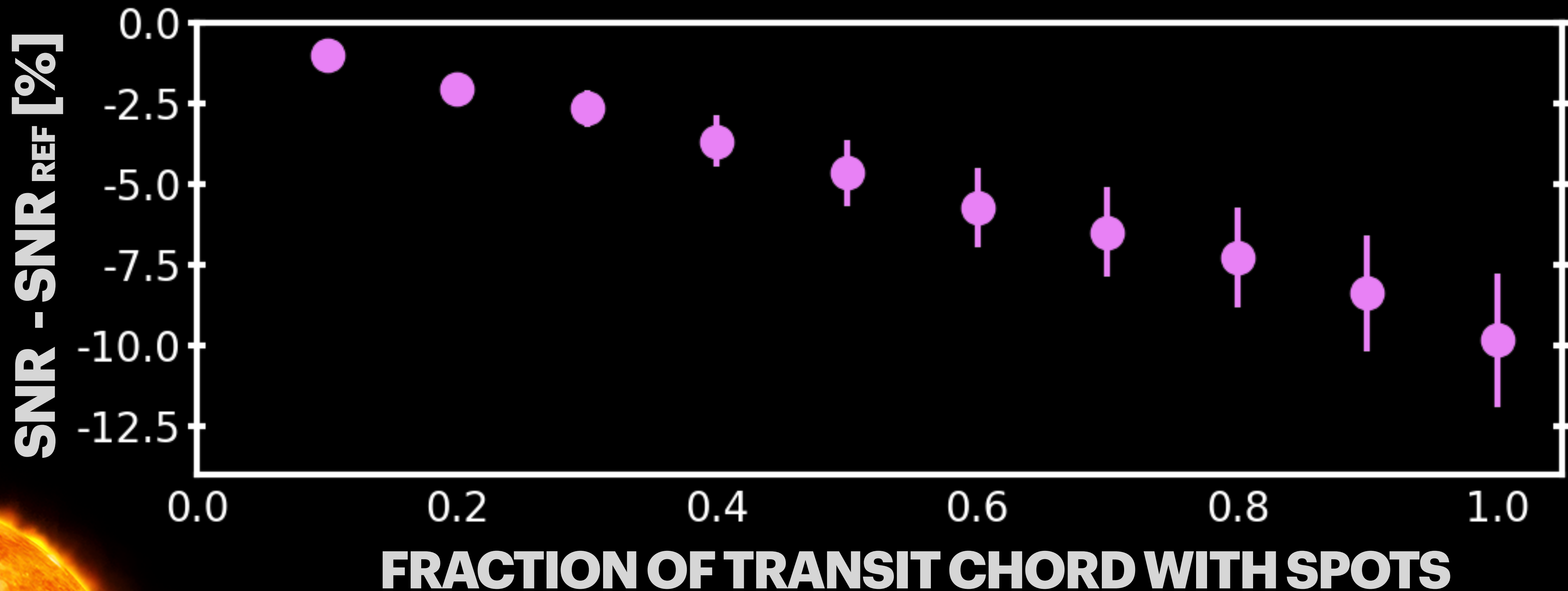
[IN-TRANSIT]



# OCCULTED SPOTS [MEECH+IN PREP]

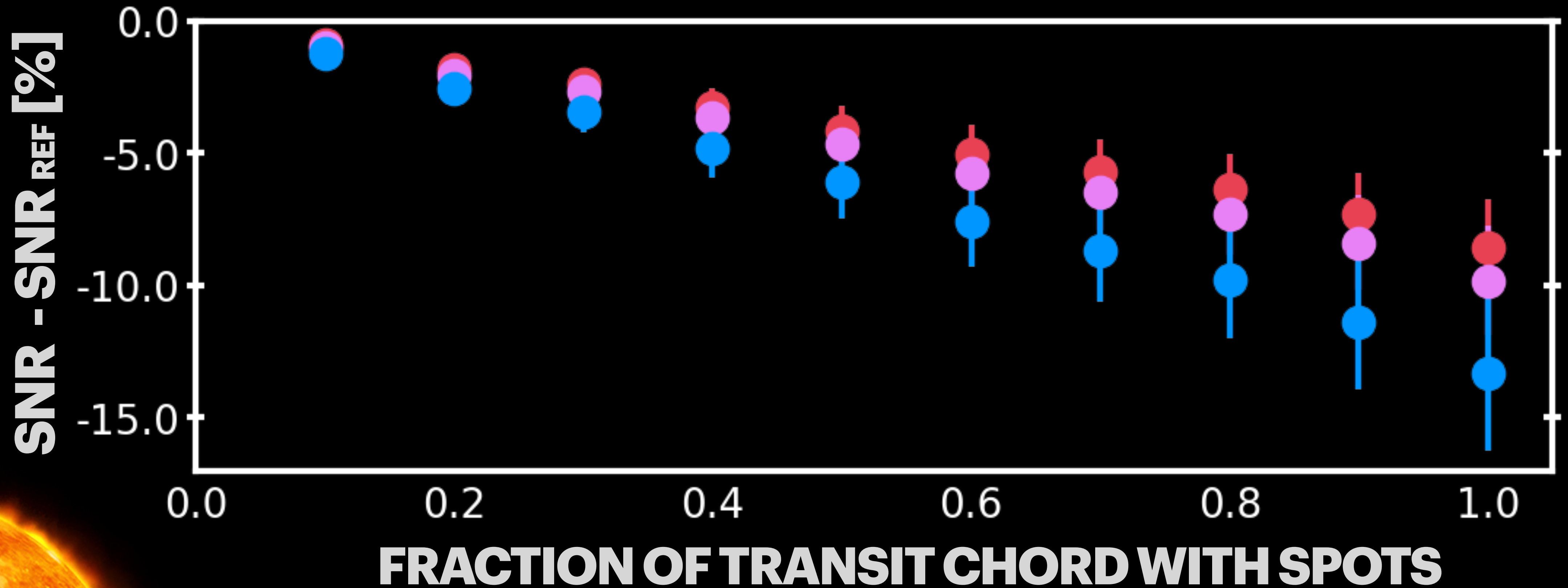


[M4V]



# OCCULTED SPOTS [MEECH+IN PREP]

[M1V]  
[M4V]  
[M9V]



# TAKEAWAYS

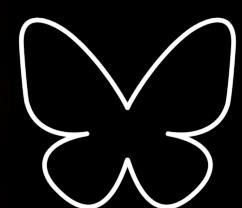
## UNOCCULTED SPOTS

If these contain sought species, they may artificially boost cross-correlation detection significance

This is only significant with high filling factors

## OCCULTED SPOTS

Can potentially obscure atmospheric detections using high-resolution cross-correlation spectroscopy, depending on signal-to-noise



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