VIS-NIR POPULATION ANALYSIS OF 20 EXOPLANETS WITH HST

Evidence for Stellar Contamination

Arianna Saba

A. Thompson, K. H. Yip, S. Ma, A. Tsiaras, A. Al-Refaie, G. Tinetti

University College London (UK)

arianna.saba.20@ucl.ac.uk

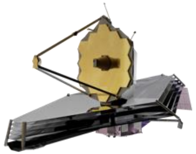
Know Thy Star, Know Thy Planet 2

A recipe for large scale population studies

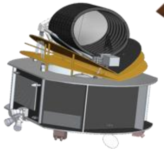
1. Exoplanet spectra should be simultaneously recorded across the broadest possible wavelength range to mitigate the difficulties of observations taken at different epochs.
   - Active stellar host
   - Atmospheric variability

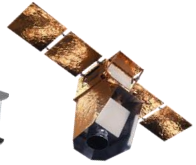
2. Planetary atmospheres should be observed by a single instrument or by combining multiple well calibrated instruments mounted on the same telescope.
   - Instrumental offsets

→ JWST



Ariel, Twinkle





HST

3. A single pipeline to analyse homogeneously all data sets, minimising biases.

→ Iraclis

4. Robust statistical tools should be adopted to allow quantitative comparisons and data interpretation.

→ TauREx 3.1

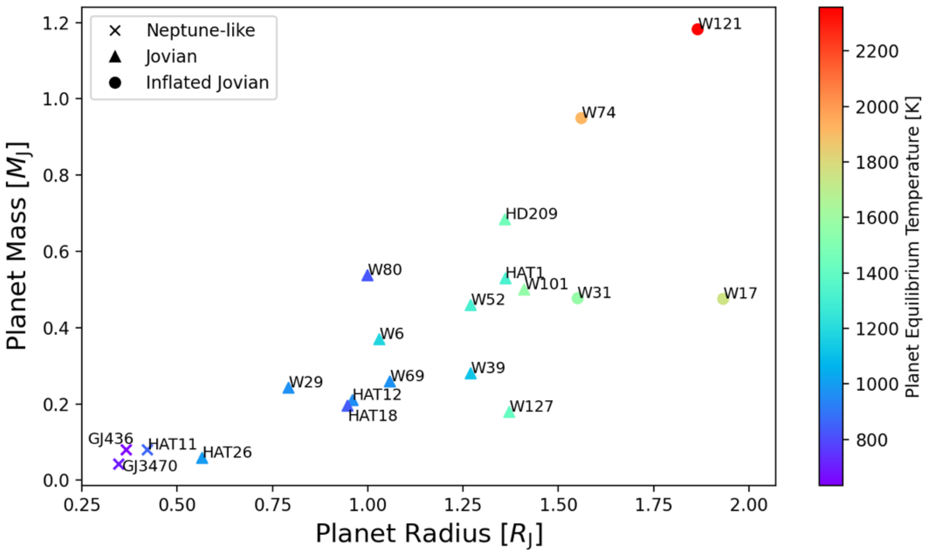
The sample of planets and stellar hosts

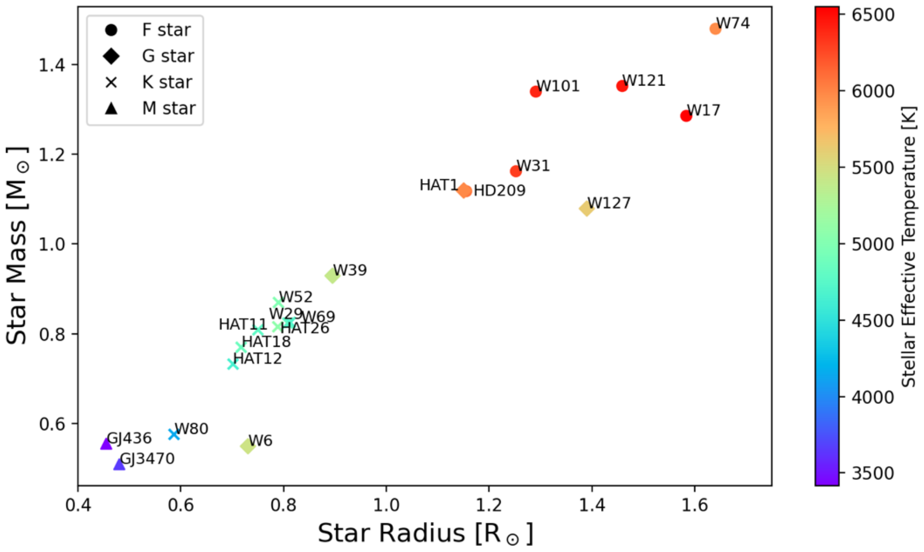
Research Approach:

- Combine repeated observations from publicly available HST data sets.
- Sample: 20 different exoplanets around various stellar types.

Objectives:

- Determine the origin of distinct spectral signatures.
- Analyse the impact of stellar contamination, leveraging the optical coverage from STIS.





Data analysis and spectral modelling

Data Analysis:

- Analysed 16 WFC3 and over 50 STIS archival data sets using Iraclis (Tsiaras et al. 2016a).
- Included 24 WFC3 data sets previously presented by Tsiaras et al. (2018) and Edwards et al. (2022).
- White and spectral light curves were modelled with the PyLightcurve package.

Results:

- Multiple optical spectra for each planet.

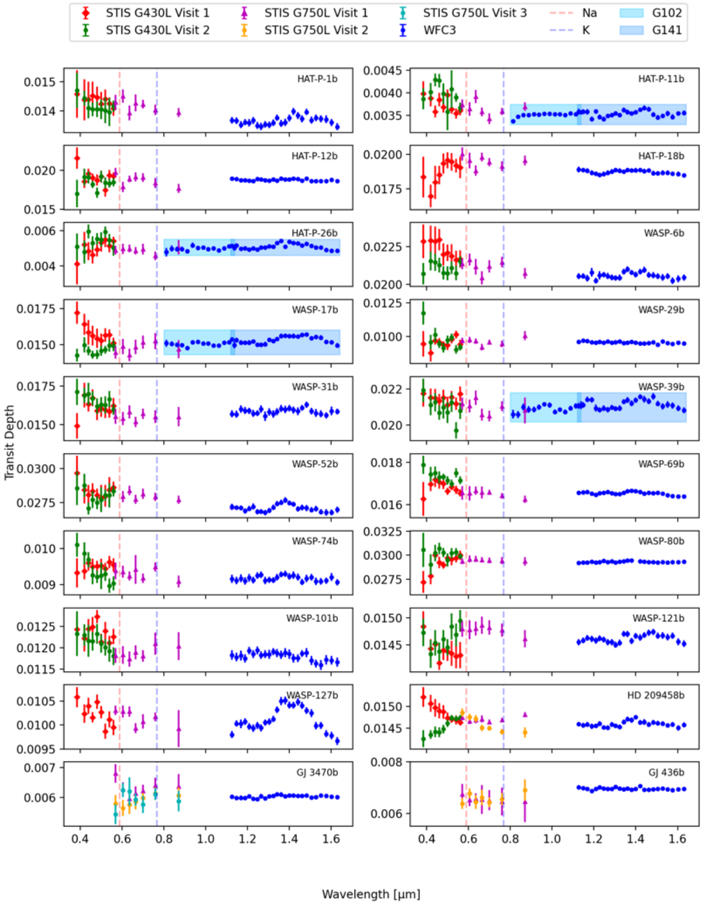
Modelling Approach:

- Handled divergent STIS spectra with the Bayesian retrieval framework TauREx 3.1 (Al-Refaie et al. 2021, 2022).
- Modelled different combinations of data sets as separate spectral scenarios for each planet.

Progressive retrieval complexity:

❖ Base model: primary atmosphere with H_2O as the sole absorber.

❖ Added features: grey clouds, alkali metals, stellar activity (ASteRa, Thompson et al. 2024).



Bayes factor $\ln(B_{S\text{-}B})$

Model Preference from a Bayesian perspective:

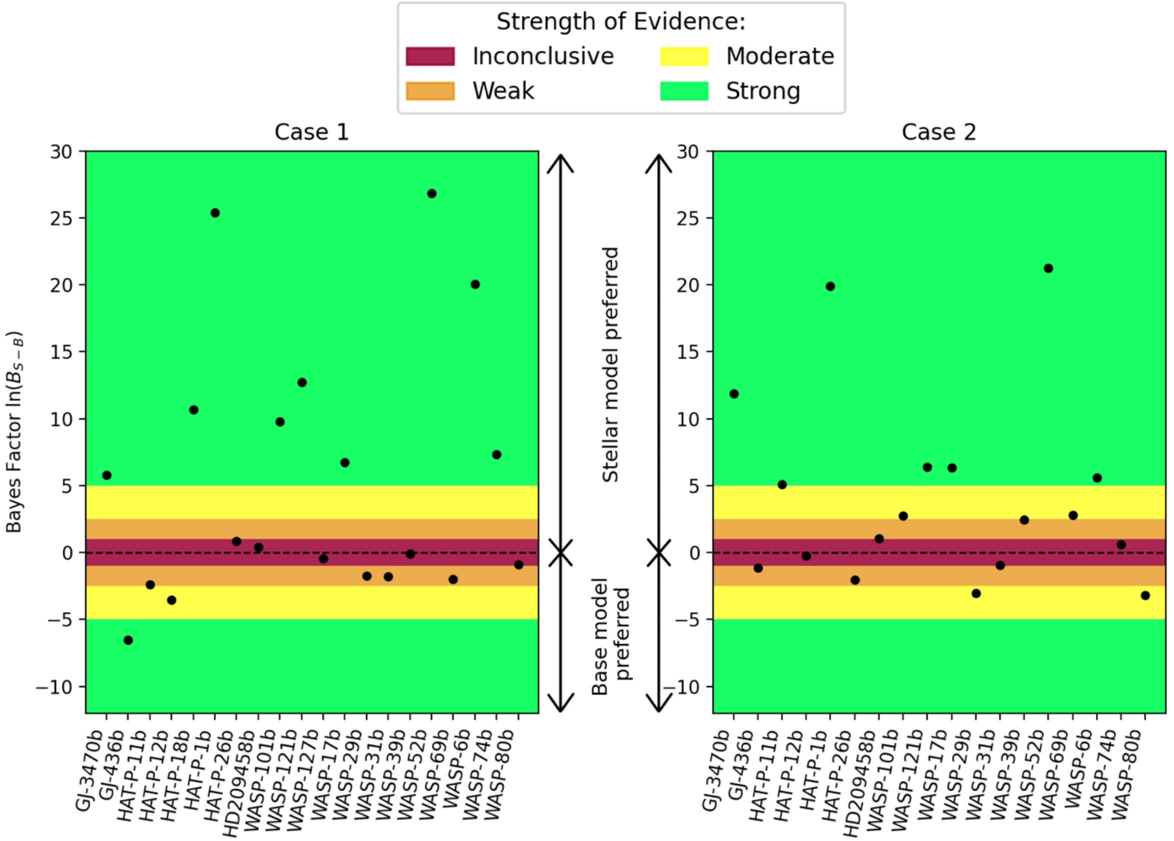
- Bayes factor is defined as the ratio of stellar contamination model evidence to quiet star model evidence given the observed data.

Strength of Evidence:

- Colour-coded according to the Jeffreys' scale (Jeffreys 1998; Trotta 2008).
- Active star model statistically penalised for its increased complexity but still favoured for many planets.

Key Findings:

- Nearly half of the targets exhibit a strong preference for the active star model.
- Only one planet strongly favours the quiet star model ($\ln(B) < -5$).
- Highlights the importance of accounting for unocculted stellar spots and faculae in optical spectral retrievals.



Stellar Activity Distance metric (*SAD*)

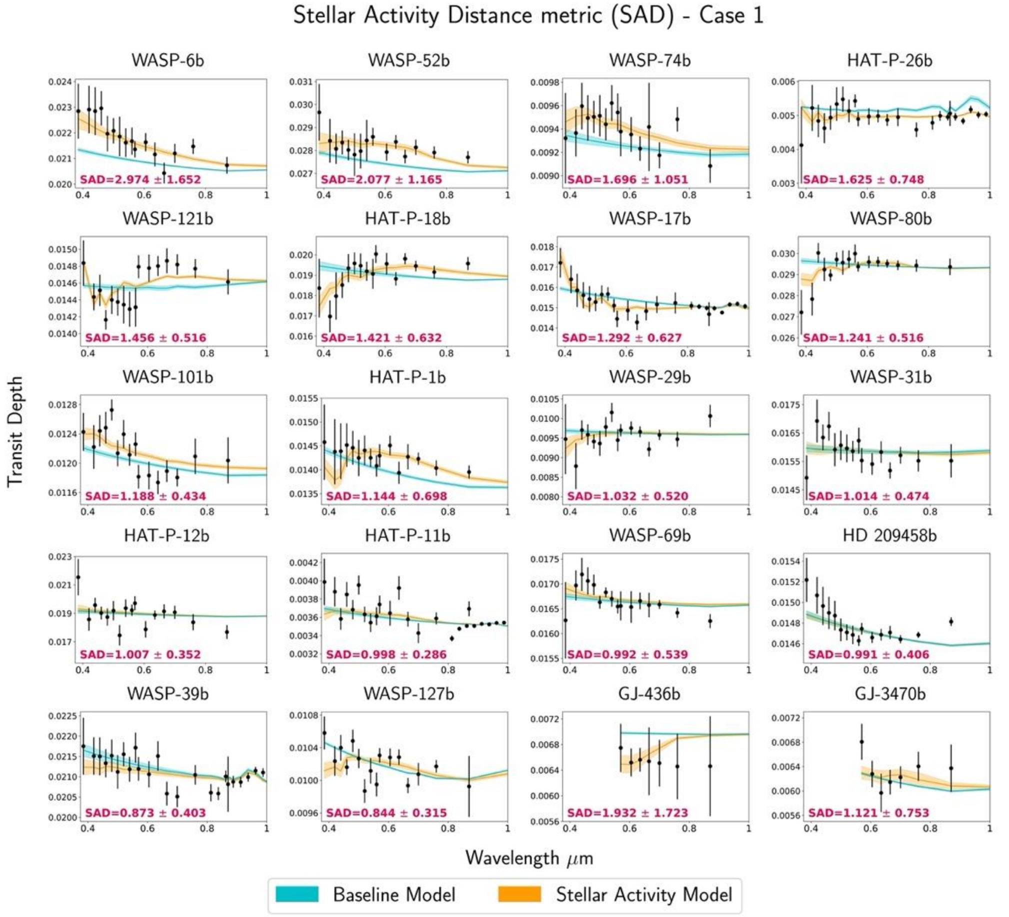
UCL

<u>New Metrics for Stellar Contamination:</u>

- Stellar Activity Distance metric (*SAD*) to quantify if an active star model fits observational data better than a quiet star model.

<u>*SAD* Results:</u>

- High SAD value indicates a stronger preference for the stellar activity model.
- SAD below 1: base model best describes the data.
- SAD equal to 1: either model explains the data adequately.



Stellar Activity Temporal metric (*SAT*)

<u>New Metrics for Stellar Contamination:</u>

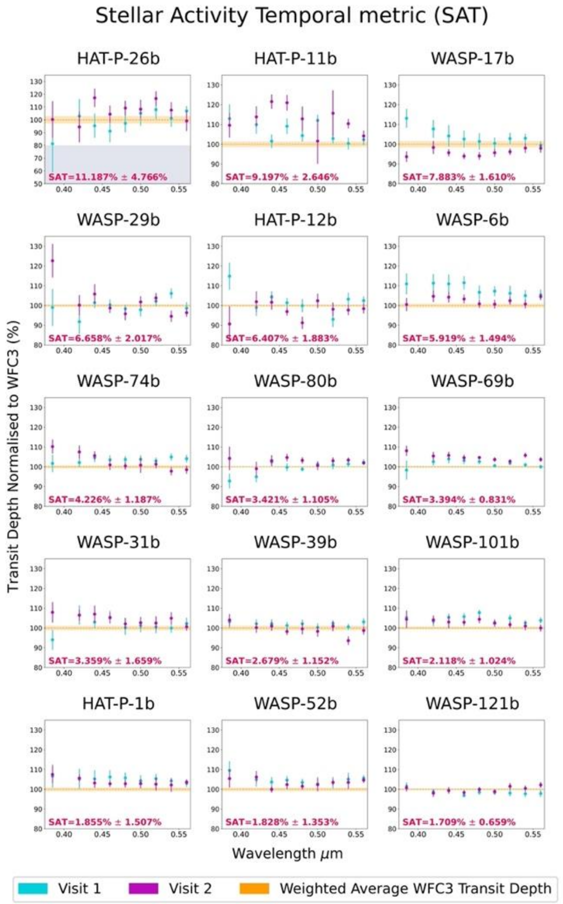
- Stellar Activity Temporal metric (*SAT*) assesses repeatability and consistency of observations.
- Compared data sets acquired with the same STIS grating for each individual planet.
- Stellar activity is likely responsible for spectra divergence at different epochs.

<u>Reversal in optical slope observed, among other planets, for:</u>

- WASP-6 b, WASP-17 b, WASP-80 b.
- ➢ Indicates that the host star is transitioning between spot-dominated and faculae-dominated regimes.

<u>*SAT* Results:</u>

- Revealed a bimodal distribution which indicates that spectral variations in the visible regime within this limited planet sample are either minimal or moderately significant.



Stellar activity has a predominant influence on exoplanet spectra at a population level

Consistency and Ranking:

- Standard competition-style ranking for 15 planets with consistent observations.

Colour Coding:

- Green: Unanimous or nearly unanimous indications of significant activity.
- Yellow: Uncertain outcomes; mixed indications of stellar activity.
- Red: Predominant preference for an inactive star.

Purpose:

- Not a definitive assessment of stellar contamination.
- Highlights systems for which activity-oriented photometric monitoring should be conducted.

Planet	Bayes Factor				*SAD*				*SAT*
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4	G430L or other data combinations
WASP-6 b	✓	✓			✓	✓			✓
WASP-52 b	✓	✓			✓	✓			×
WASP-17 b	✓	✓			✓	✓			✓
WASP-121 b	✓	✓			✓	✓			×
WASP-74 b	✓	×			✓	×			×
HAT-P-26 b	×	×			✓	×			✓
WASP-101 b	✓	✓			✓	✓			×
HAT-P-11 b	×	✓			×	✓			✓
HAT-P-1 b	✓	✓			✓	×			×
WASP-31 b	×	×			×	✓			×
WASP-69 b	×	✓			×	✓			×
WASP-80 b	×	×			✓	×			×
HAT-P-12 b	×	×			×	✓			✓
WASP-29 b	×	×			×	×			✓
WASP-39 b	×	×			×	×			×
HD 209458 b	×	×	×	×	×	×	×	×	× (G430L); × (G750L)
HAT-P-18 b	✓				✓				
WASP-127 b	×				×				
GJ 3470 b	✓	✓	✓		✓	✓	×		✓ (V1-V3); ✓ (V1-V2); × (V2-V3)
GJ 436 b	×	×			✓	✓			×

Summary & Conclusions

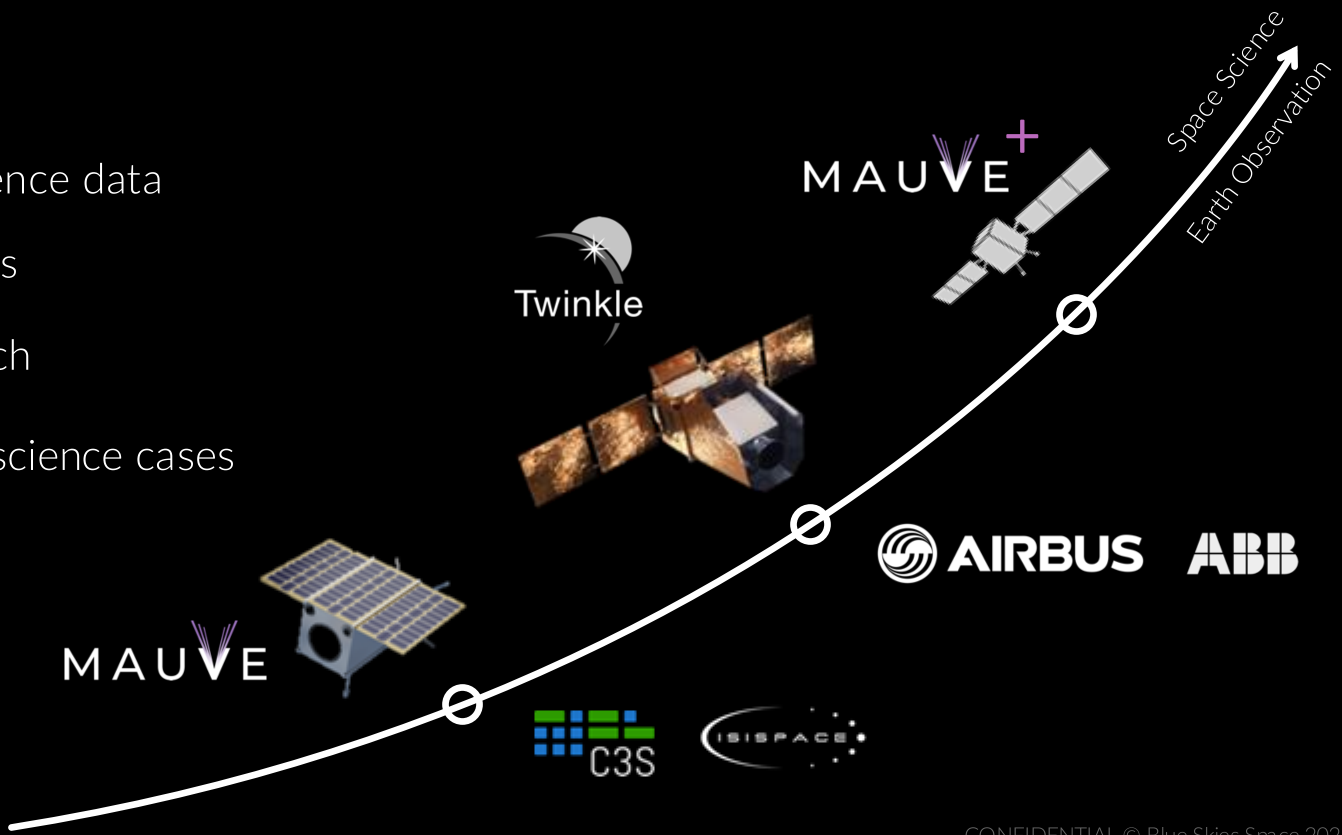
UCL

- The largest sample of hydrogen-rich exoplanets observed from near-UV to near-IR.
- A uniform analysis and interpretation across the whole population.
- Multiple observations allowed to study temporal variability in exoplanet atmospheres.
- Significant differences in the optical wavelengths suggest time-varying stellar surface heterogeneities imprinted in the exoplanetary spectra.
- Statistical metrics to assess the extent of stellar activity contamination:
  Bayes factor, *SAD, SAT*
- Stellar contamination plays a significant role in exoplanet spectra.
- We invite the community to consider stellar contamination in transit studies, perform long term stellar monitoring and to further investigate this catalogue of potentially active stars.

Link to the paper:

BLUE SKIES SPACE LTD.

- Provider of space science data
- Fleet of small satellites
- High heritage approach
- Focus on in-demand science cases



Mauve - a time domain opportunity

MAUVE

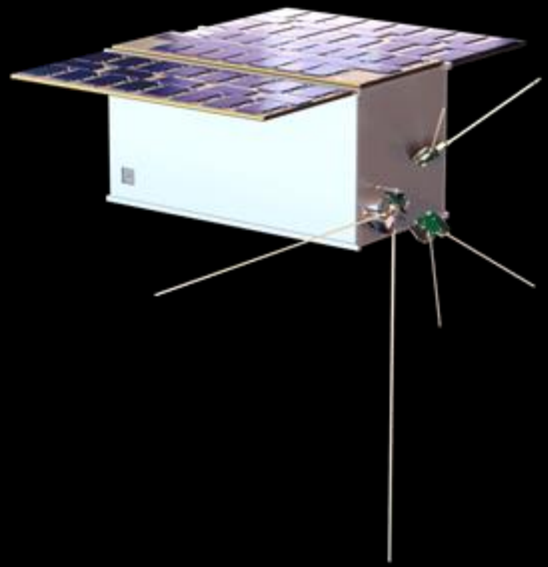
Small sat conceived for monitoring stars

UV – Visible spectrophotometry (200 – 700nm) at low spectral resolution R~20-65

3-year collaborative survey programme

1000's of yearly observation hours

Science team seats for early joiners



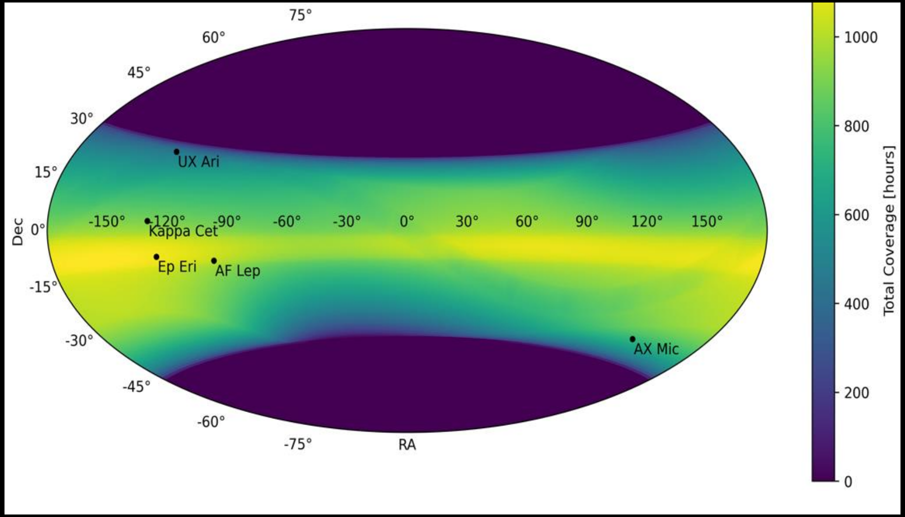
C3S

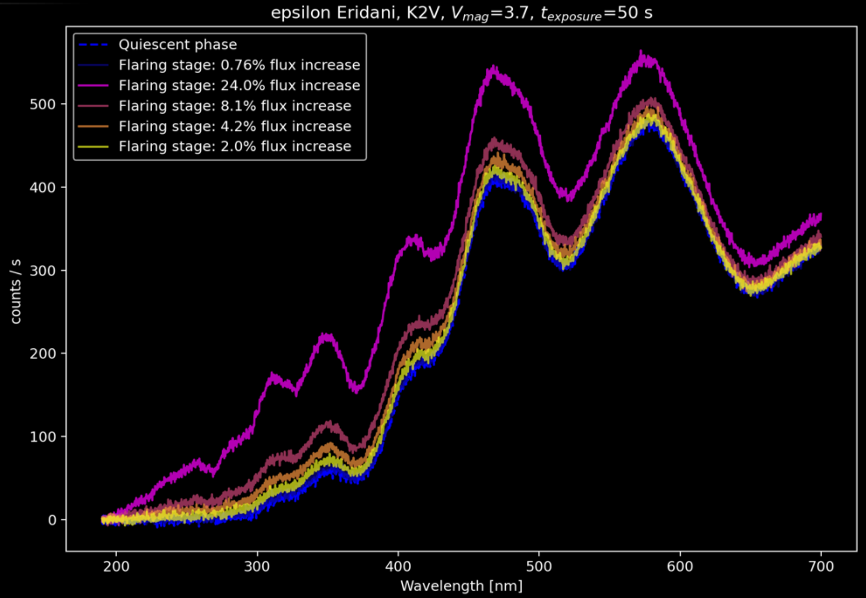
ISISPACE

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101082738.

Continuous monitoring of flaring stars





Target Name	Stellar Type	V (mag)	Spectral Type	Total available yearly coverage (hours)	Maximum continuous coverage (hours)
Kappa Cet	BY Dra Variable	4.8	G5V	852	1
UX Ari	RS CVn Variable	6.4	G5 V + K0 IV	443	1
AX Mic	Eruptive Variable	6.7	M1V	722	1
Epsilon Eridani	BY Dra Variable	3.7	K2V	1029	149
AF Lep	RS CVn Variable	6.3	F8V	918	1