Search for Habitable Stellar Environments in Kepler Objects of Interest Systems

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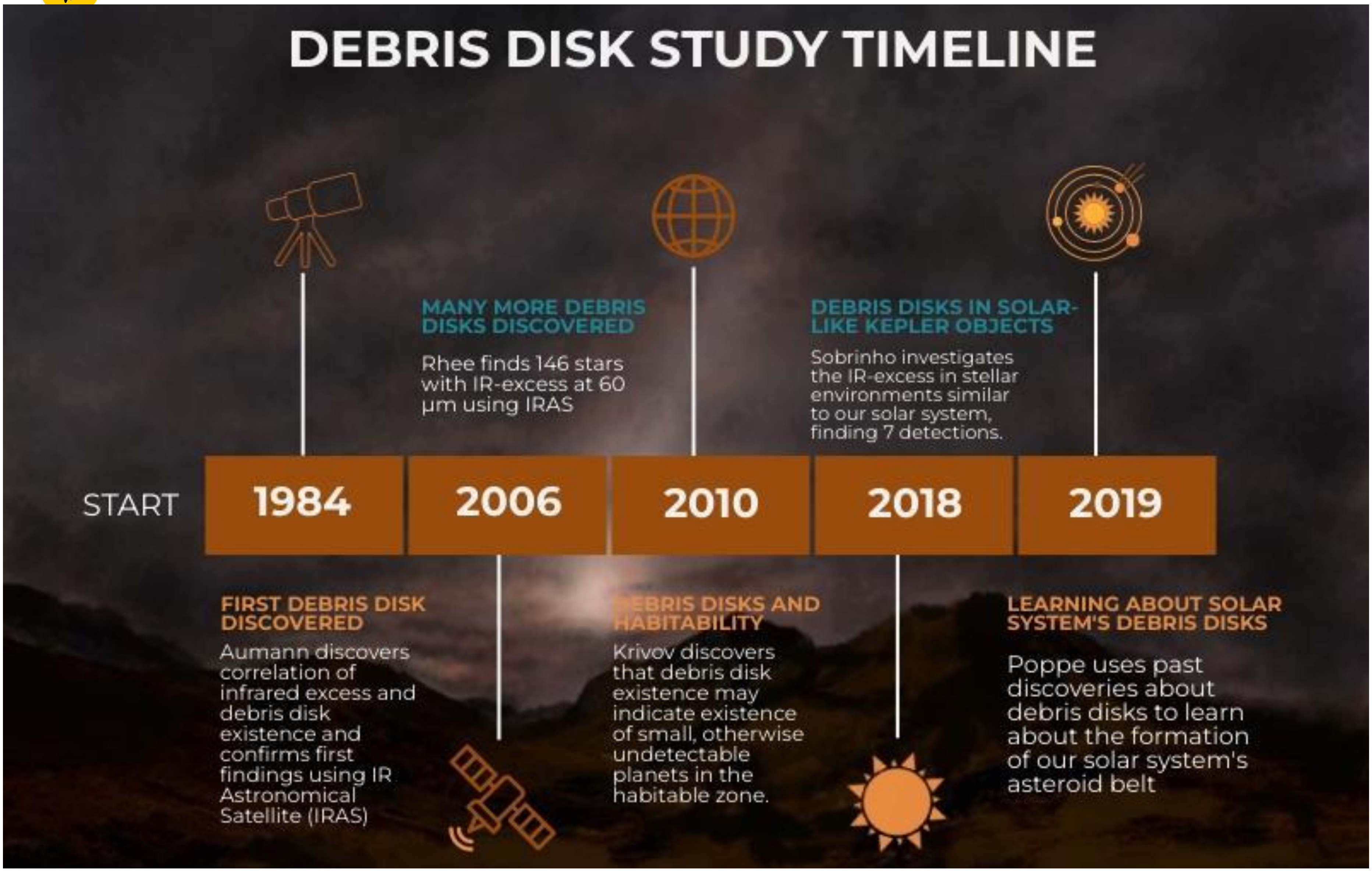
Introduction - Background Research



Introduction - Research Purpose and Question

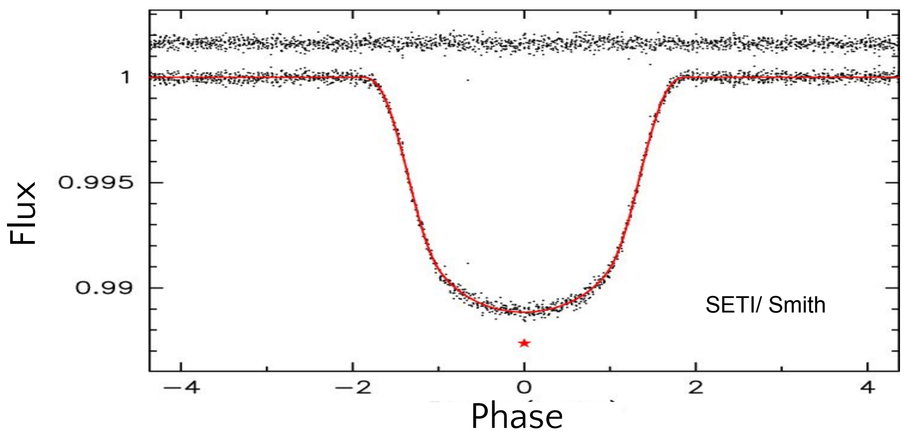
"How do Jupiter-containing systems ***affect frequency of significant IR-excess emission*** *and how do the results tell us more about the* ***formation of Earth's stellar environment?****"*

- Past Research Coverage
  - Debris disk discovery through IR emission
  - Debris disks in solar-like environments
  - Debris disk and habitability
- Discrepancy
  - Research on debris disks frequency in systems with confirmed Earth-like planet
  - Research on debris disks frequency in Jupiter-containing systems
  - Using PSF interpolation for accurate flux measurements
    - Prone to false-positive IR excess due to companion flux emission

Methods - Data Collection

Small Planet Sample:

- Used Thompson et al. 2018's 47 Kepler Object of Interest Sample
  - Perform transit fits on light curves from transit photometry analysis



- Roughly Earth-sized and likely with similar environment as Earth

Jupiter Control Sample:

- 53 Jupiter-containing Kepler systems found with following stellar parameters:
  - Effective Temperature (K)
  - Surface gravity (log g)
  - Metallicity (Fe/H)
  - Planet Radius [10 R⊕, 20 R⊕] (Earth Radii)
  - Orbital Period (days)

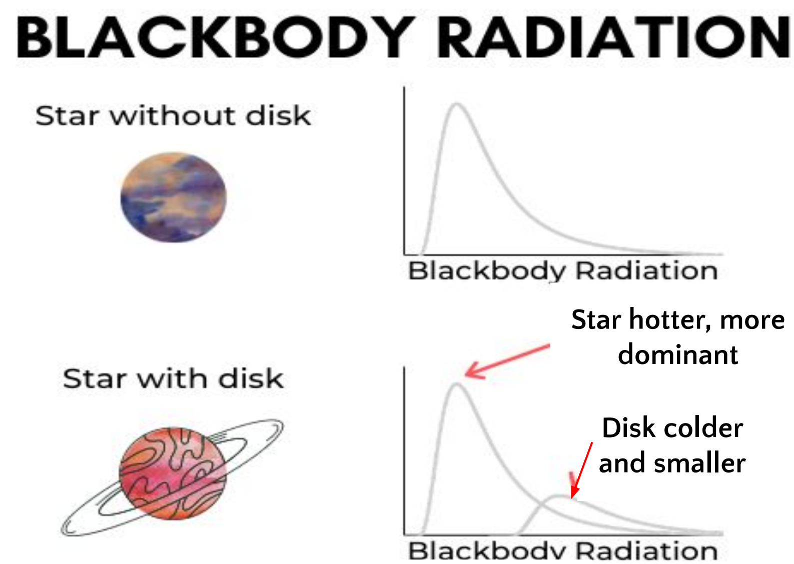
Methods - Photometry/SED Fitting

Purpose: use photometric measurements to identify accurate far-infrared flux for spectral energy distribution (SED) fits.

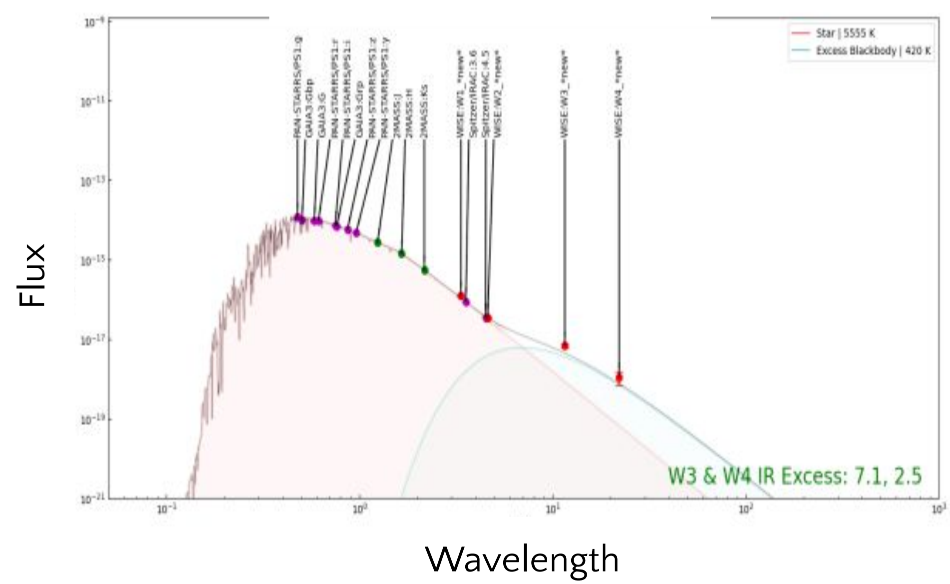
- Photometry:
  - Square Aperture (control), Moffat, PSF fitting
  - Moffat best for nominal flux, square aperture of WISE err map best for flux error
- SED fitting
  - Sobrinho value for statistical significance

$$X_\lambda = \frac{F_{\lambda, obs} - F_{\lambda, phot}}{\sqrt{\sigma^2_{\lambda, obs} + \sigma^2_{\lambda, cal}}}$$

  - Check if flux values fit blackbody excess curve



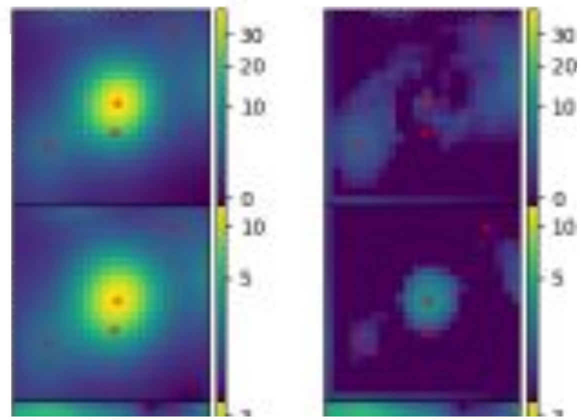
Initial SED Fit



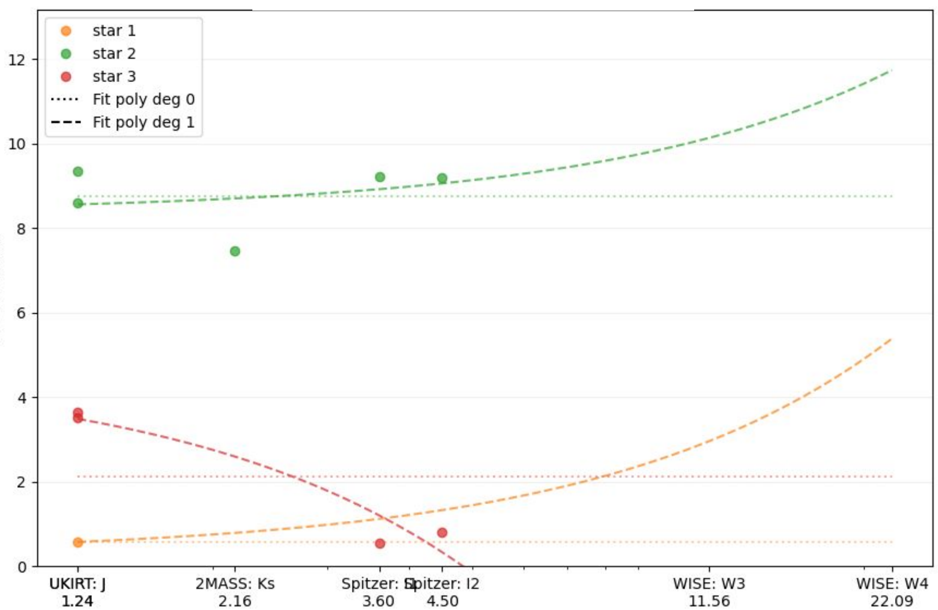
Methods - Checking Contamination and Refitting

- Interpolation
  - Use 25 nearby, similar stars to interpolate a solved point spread function (PSF)
- PSF subtraction
  - Subtract flux as seen on right to take flux of target and all nearby contaminants

PSFs Labeled | **Resid After Subtraction**



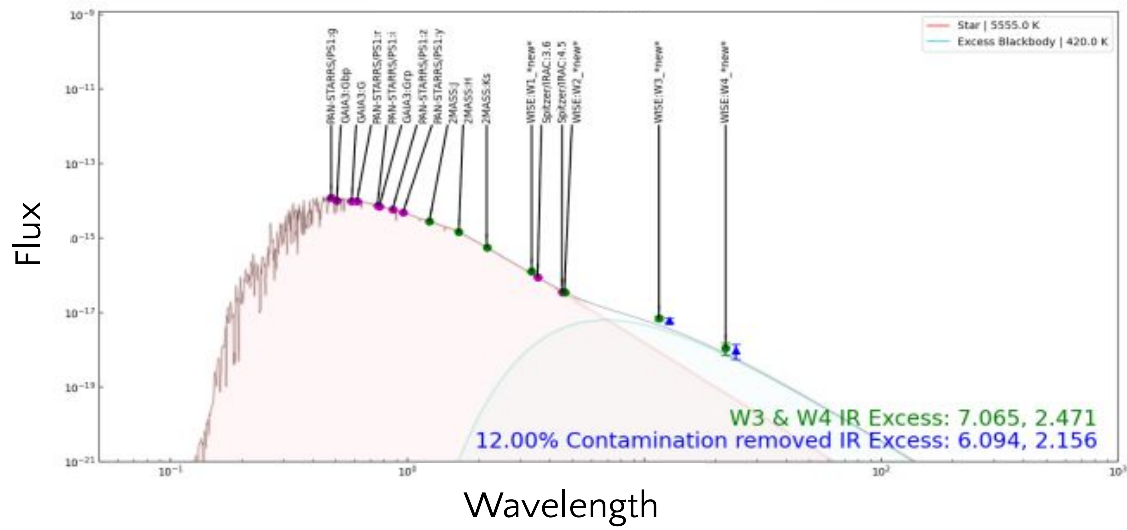
Flux Ratios (%)



Flux ratios of UKIRT, 2MASS, and Spitzer

- Take ratio of contaminant flux and target flux
- Use ratios to approximate W3 band contamination ratio

Calibrated SED Fit



- SED Refit
  - Recalibrate W3 and W4 flux based on contam, refit

Results - Final sample

Conditions

- IR-excess parameter > 2
- Target star looks round, not distorted
- Companion flux ratio < 20%
- Companions must not be too close to each other or target

Small-Planet Kepler Sample

- Of 47, 3 follow the conditions (~6%)

Jupiter-Planet Kepler Sample

- Of 53, 6 follow the conditions (~11%)

47 KOI Thompson Sample Infrared Excess Parameter Values

KOI	W3	W4	W3 Correction	W4 Correction	Contamination Estimate
172	3.2	1.5	2.5	1.2	0.82
2418	7.06	2.47	6.09	2.16	0.88
2650	2.8	1.4	2.6	1.3	0.95

53 KOI Jupiter Sample Infrared Excess Parameter Values

KOI	W3	W4	W3 Correction	W4 Correction	Contamination Estimate
191	2.969	1.431	2.833	1.369	0.96
254	3.23	1.59	3.21	1.58	1
421	5.55	2.13	4.59	1.75	0.87
908	4.04	3.77	3.71	3.47	0.92
1549	3.5	2.89	3.32	2.74	0.95
3013	2.94	1.09	2.94	1.09	1

Discussion - Interpreting the Results

<u>Statistical Analysis</u>

- Small Planet Sample
  - p̂ = 3/47 = 0.638
  - σ = $\sqrt{\frac{p(1-p)}{n}}$ = 0.0356
  - Proportion value is similar to that of Krivov et al. 2010

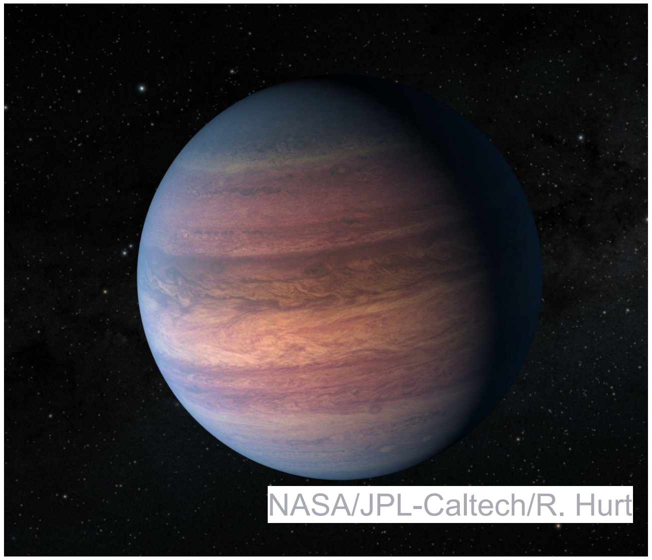
- Jupiter Planet KOI Sample
  - p̂ = 6/53 = 0.113
  - σ = $\sqrt{\frac{p(1-p)}{n}}$ = 0.0280
- Jupiter sample proportion 1.757 deviations from Small planet sample proportion
  - Relatively confident that Jupiter Sample has greater prop with IR-excess

Discussion - Potential Errors

- Quantify Roundness

$$Roundness \propto \frac{(\sigma_x - \sigma_y)}{\frac{(\sigma_x + \sigma_y)}{2}}$$

- Over-Elimination
  - Criteria may have caused false-negatives
- Use larger Jupiter sample
  - Reduces standard deviation
  - Less overlap of Gaussian curves, higher confidence of difference



Conclusions - Implications of Research

- Specific
  - First debris disk study about Jupiter and small planet-containing stellar systems
  - Interpolation method not used before
    - Takes true flux rather than contaminated flux with neighboring stars
    - Allows for false positive reduction, more realistic flux excess
  - Use newer infrared surveys: Spitzer, UKIRT, 2MASS

Jupiter-containing systems lead to a ***greater proportion of systems with IR-excess*** *indicative of significant amounts of zodiacal dust. This is likely because the large mass of Jupiters* ***instigate asteroid collisions*** *within the system. This teaches us about the role our Jupiter plays in the creation of our solar system's habitable environment*

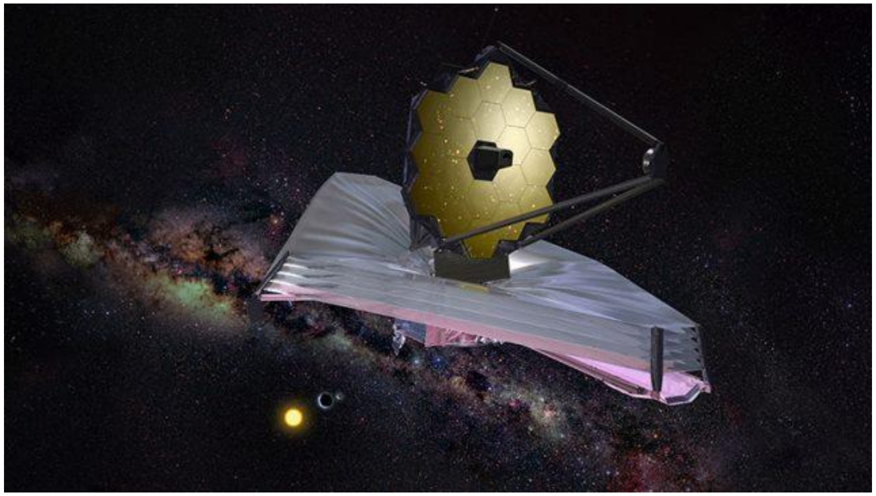
Conclusions - Applications & Next Steps

Applications

- My methodology for observing significant IR excess can be used in future studies
  - Faster, more accurate due to subtraction of other fluxes
  - Lower false-positive rate

Next Steps

- Continued study with James Webb Space Telescope (JWST)
  - Able to survey potentially habitable planets with precision
  - High res spectroscopy allows direct measurement of IR excess



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