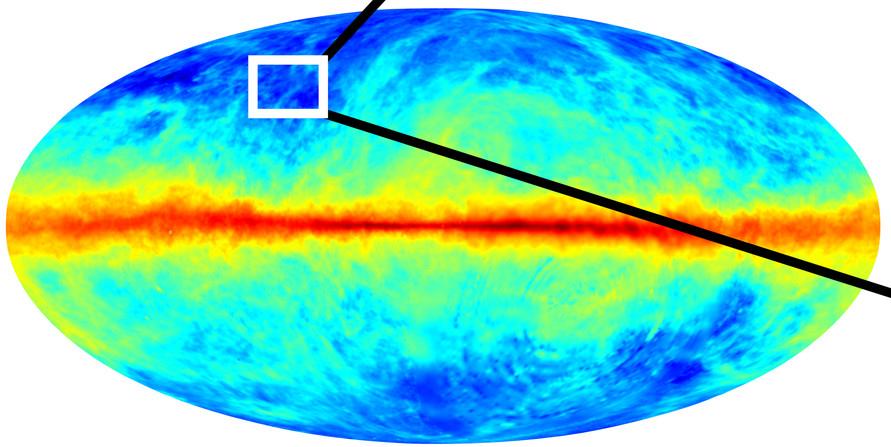
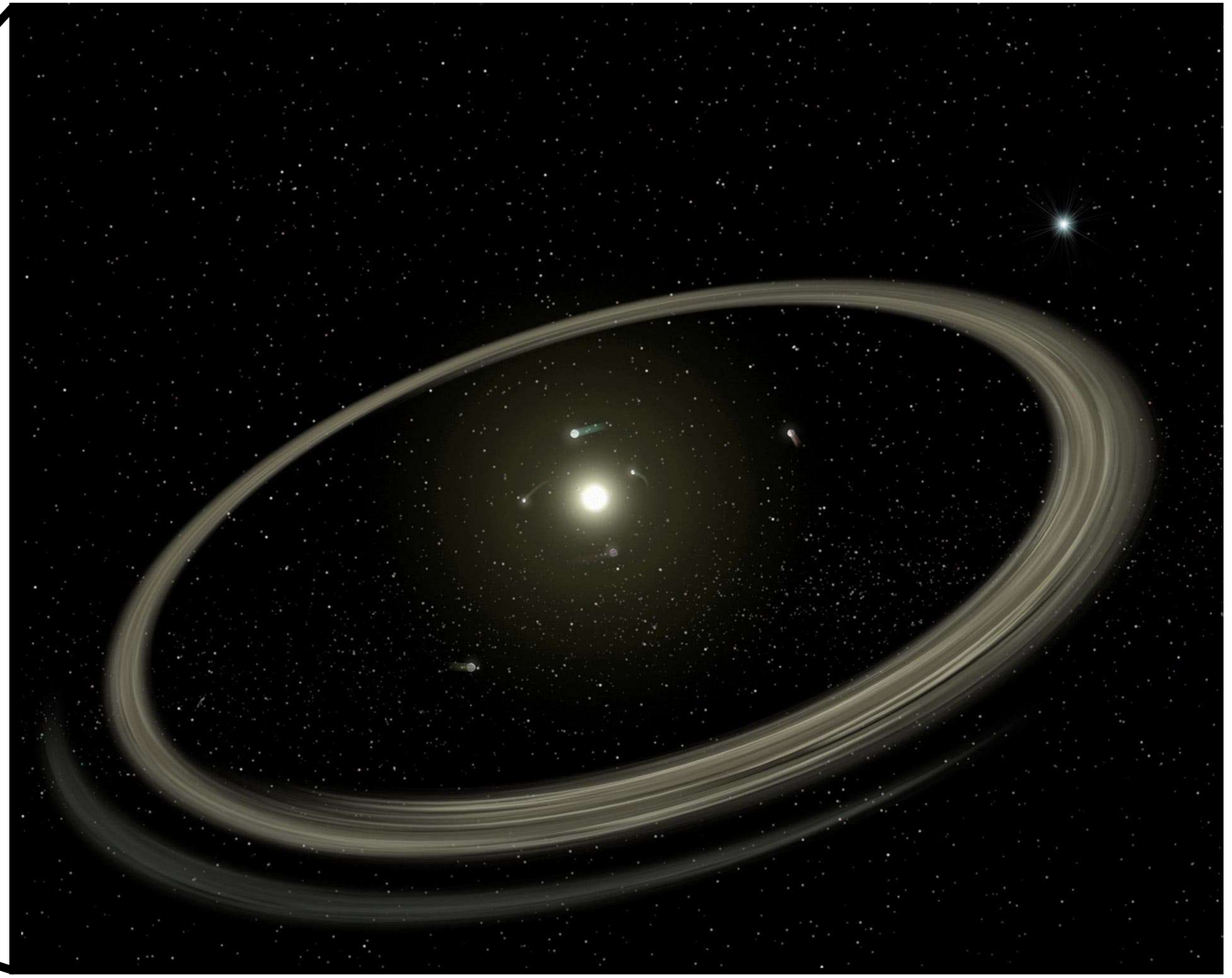
Constraining Exoplanetary Systems with high resolution CMB Surveys

Jacob Nibauer (Princeton University)



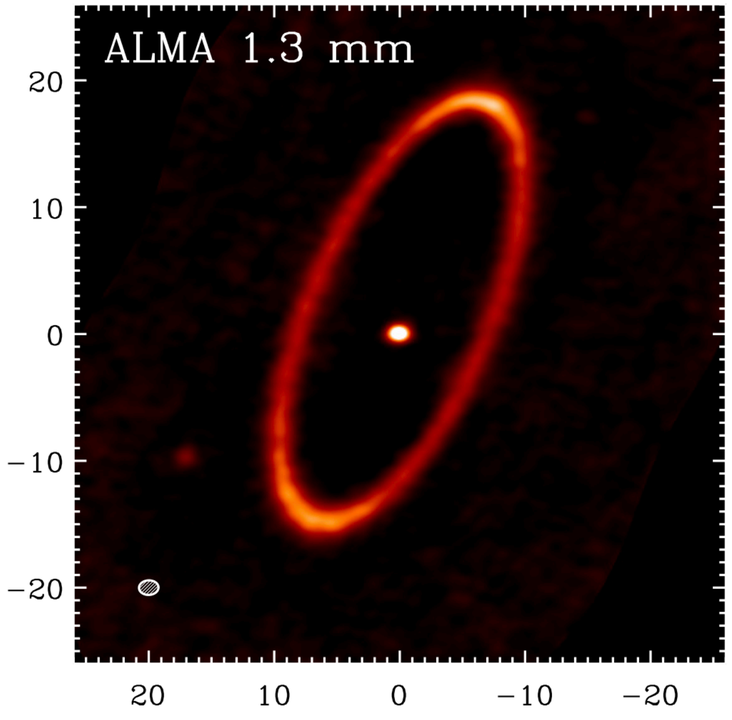


The Outer Edges of Planetary Systems

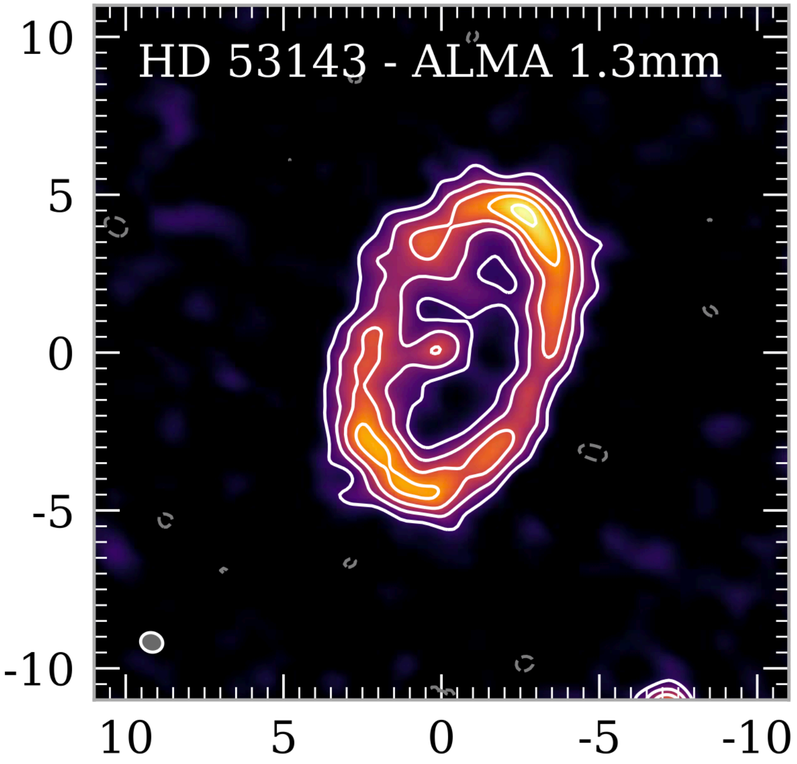
Debris Disks

- Similar to Kuiper belt
- Dusty remnants of planet formation, gas depleted
- $T \sim 10 - 100$ K | $R \sim 100$ AU
- Grains observed through reprocessed starlight at submm-cm wavelength

MacGregor+2017



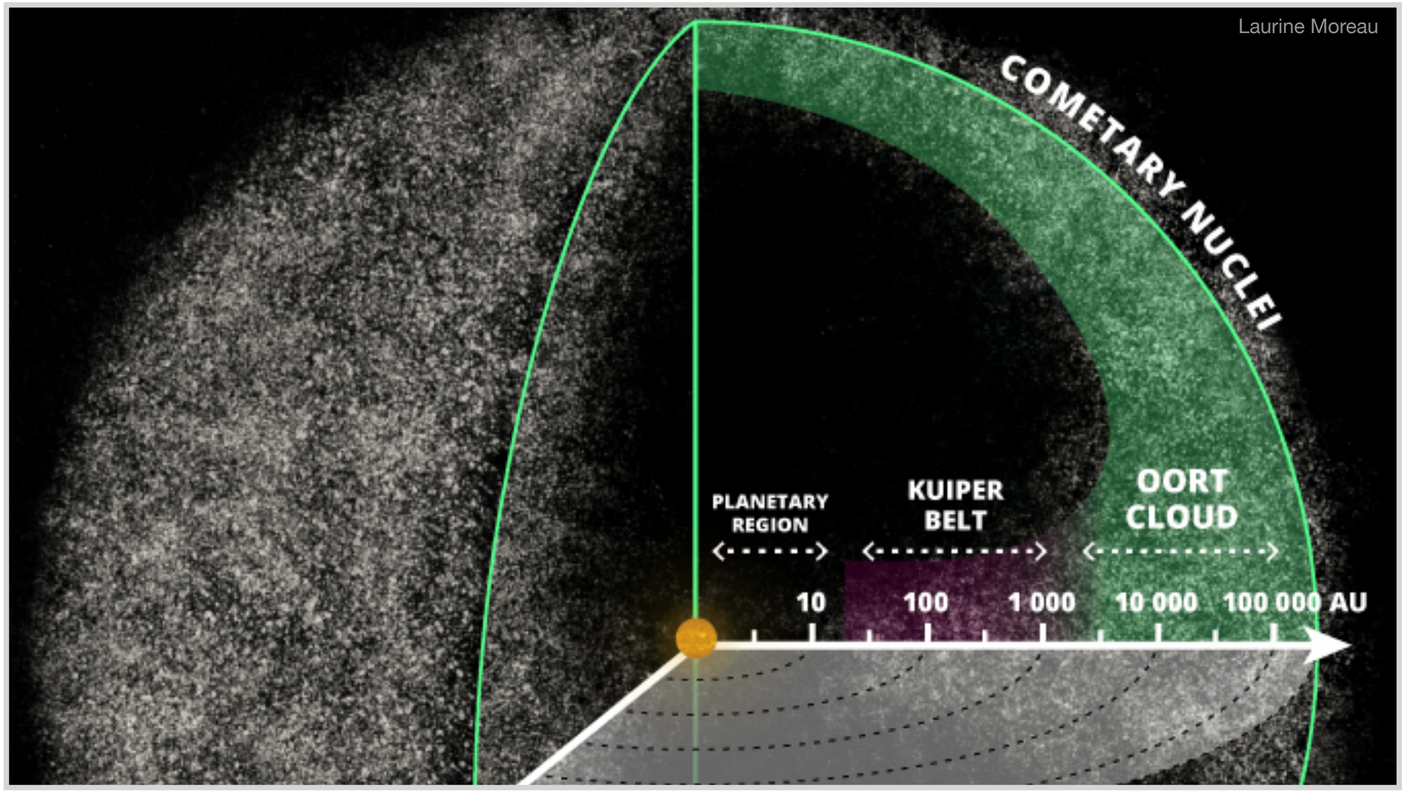
MacGregor+2022



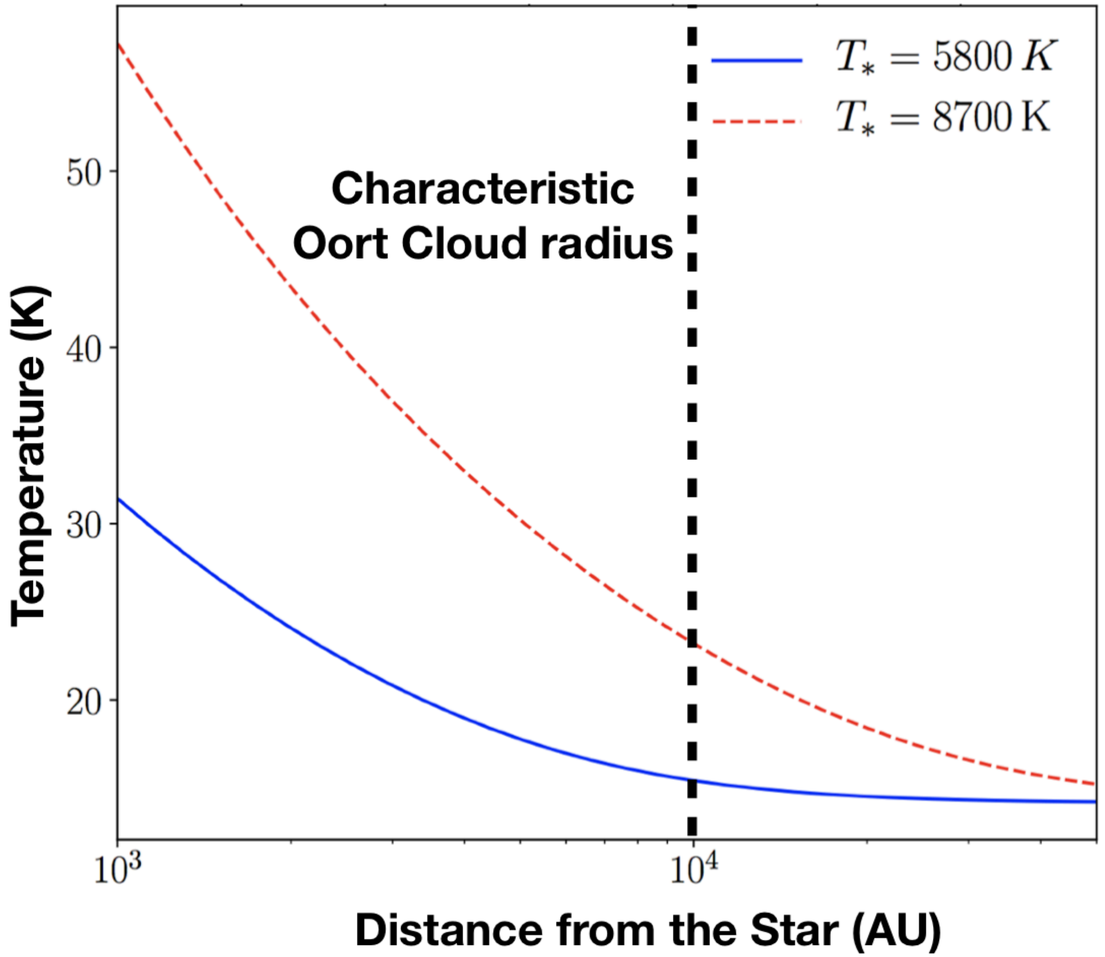
The Outer Edges of Planetary Systems

The Oort Cloud

- Roughly isotropic distribution of icy bodies
- Source of long period comets
- Origin: Orbital Perturbations from Giant Planets
- $R \sim 10^3 - 10^5$ AU | $T \sim 10$ K



Thermal Emission from the Oort Cloud



Wien Peak $\sim$ 1000 GHz

Emission Signal $\lesssim 10^{-2}$ MJy/sr

Baxter+2018
Baxter 2019

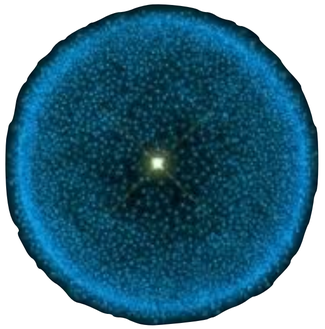
Exo-Oort Clouds

Oort Cloud around distant star — Exo-Oort Cloud

Potential Observable: Submillimeter emission signal tracing the optical depth profile of the cloud

---

$\sim 0.5^\circ$



$\sim 0.5^\circ$

$R = 5 \times 10^4$ au at 50 pc

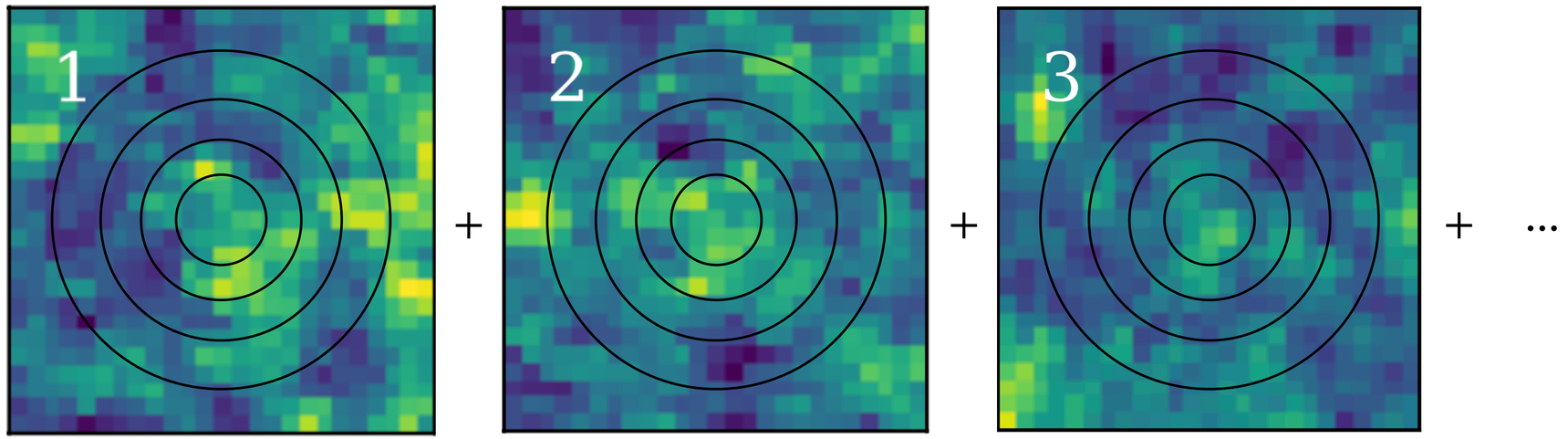
Exo-Oort Clouds in CMB Surveys

$\lambda_{\rm max} \sim 290\ \mu$m + Large angular scale —> CMB surveys provide a promising avenue!

Long wavelengths: stellar emission << Oort Cloud Emission (emitting areas)

Sensitivity: Require ~ 0.1 MJy/sr (stacking) or better

Gaia tells us where to look —> Stacked measurements with *Planck*, SO, CMB-S4, etc.



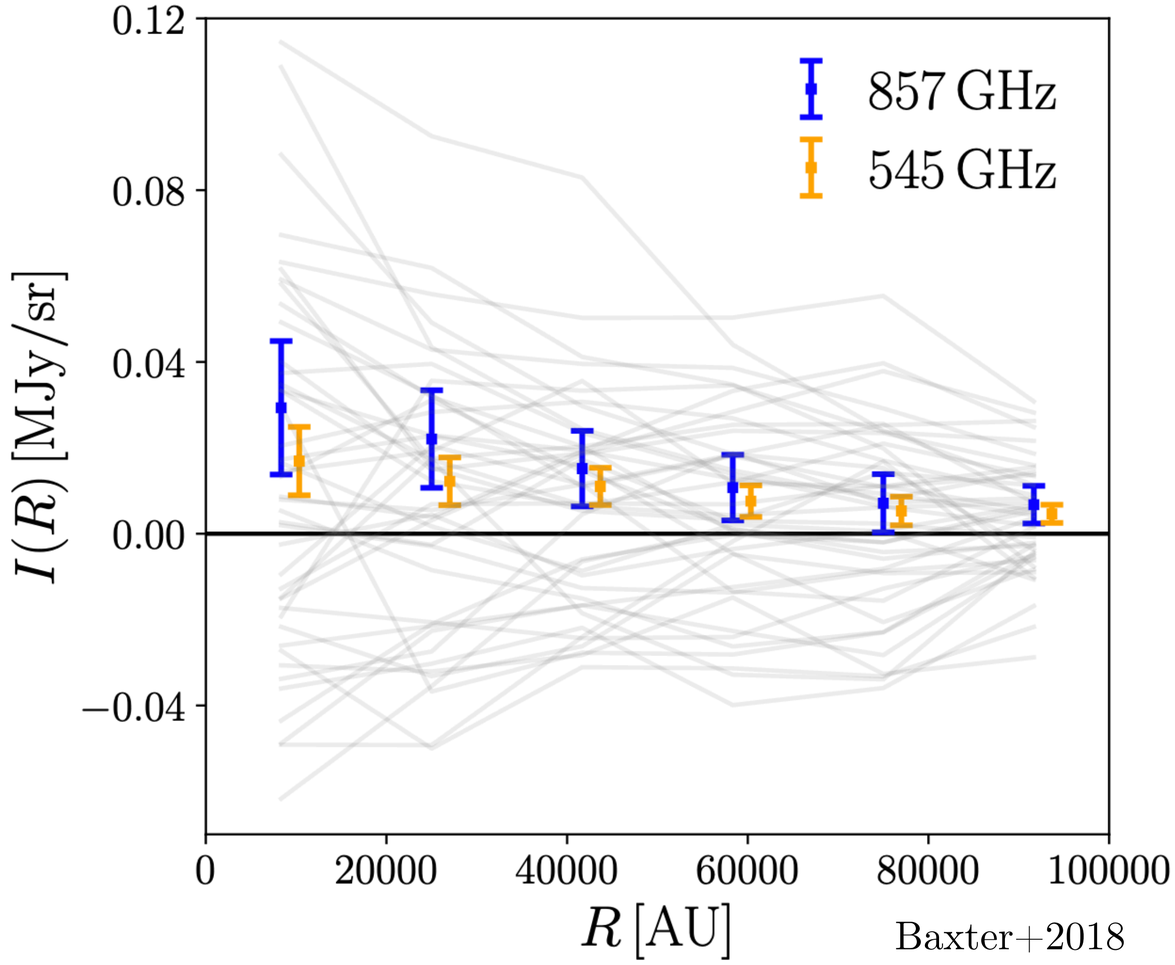
[*Planck* cutouts centered on *Gaia* stars]

Exo-Oort Clouds in CMB Surveys

Stacked *Planck* Measurements around *Gaia* Main Sequence Stars

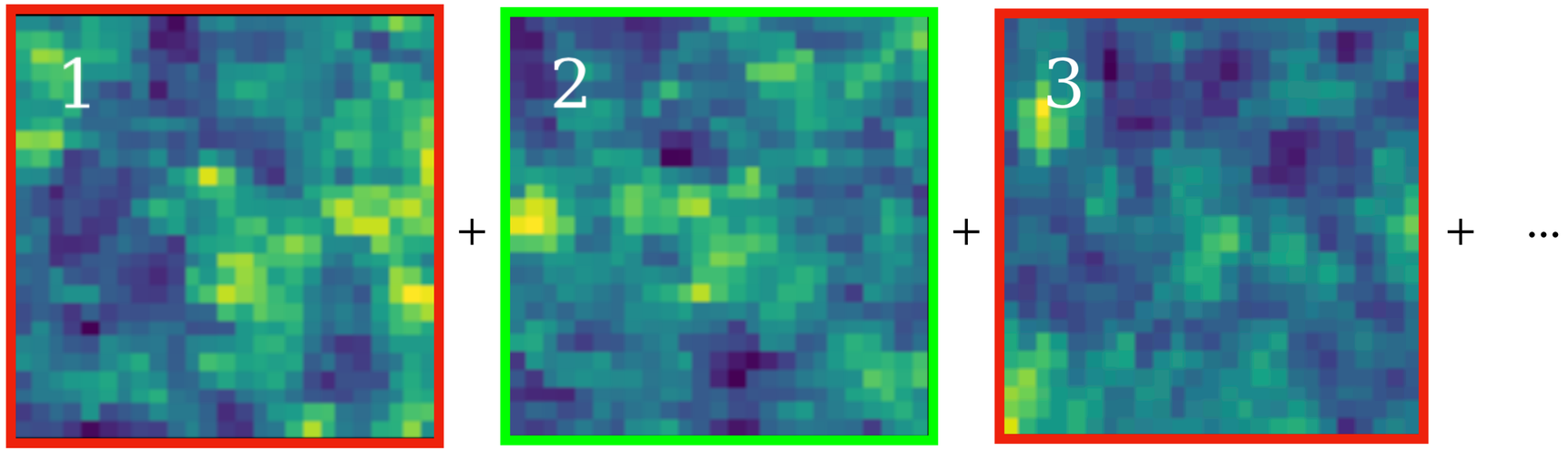
Stacking Assumption:

$$f_{\mathrm{Oort}} \sim 1$$



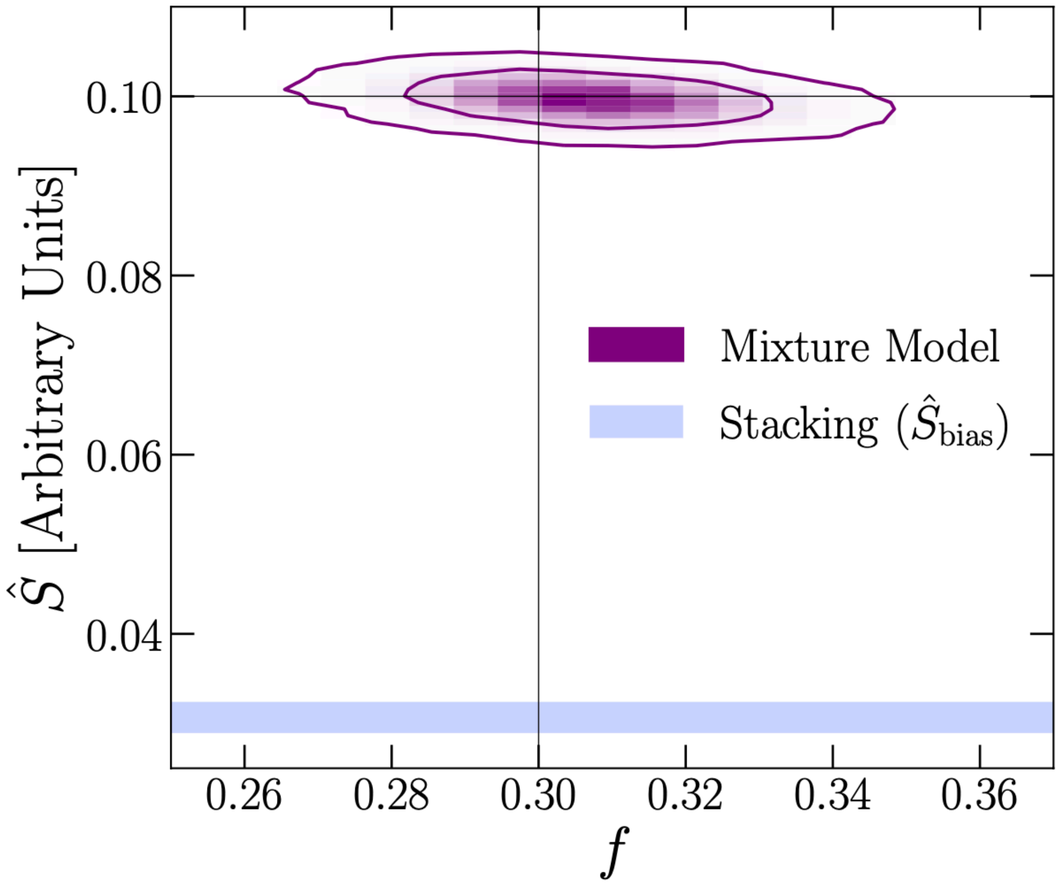
Data Challenge:

If Oort Clouds/Debris Disks are connected to the presence of Planets, f_{Oort} might be $\lesssim 0.5$



Measurements have low SNR in the first place... substantial dilution of signal for small f_{Oort}

One Approach: Mixture Models



Data generated from one of two populations:

(A) Oort Cloud Present w.p. $f_{\rm Oort}$

(B) Oort Cloud Absent w.p. $1 - f_{\rm Oort}$

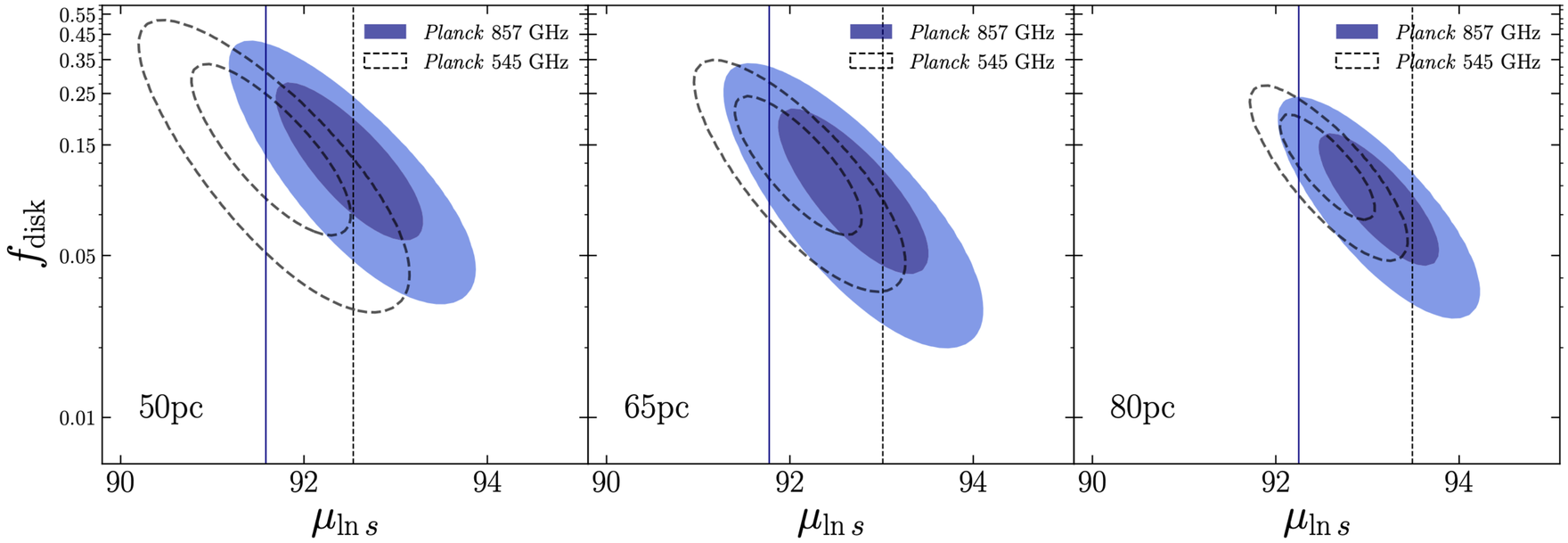
Make $f_{\rm Oort}$ a model parameter to be constrained

Assume some noise model (Gaussian)

Combine constraints at the likelihood level

See Nibauer+2020 for more details

Approach Applied to *Planck* Data: Thermal Emission from Debris Disks



High S/N constraint ($\sim 8\sigma$) from individually low S/N measurements

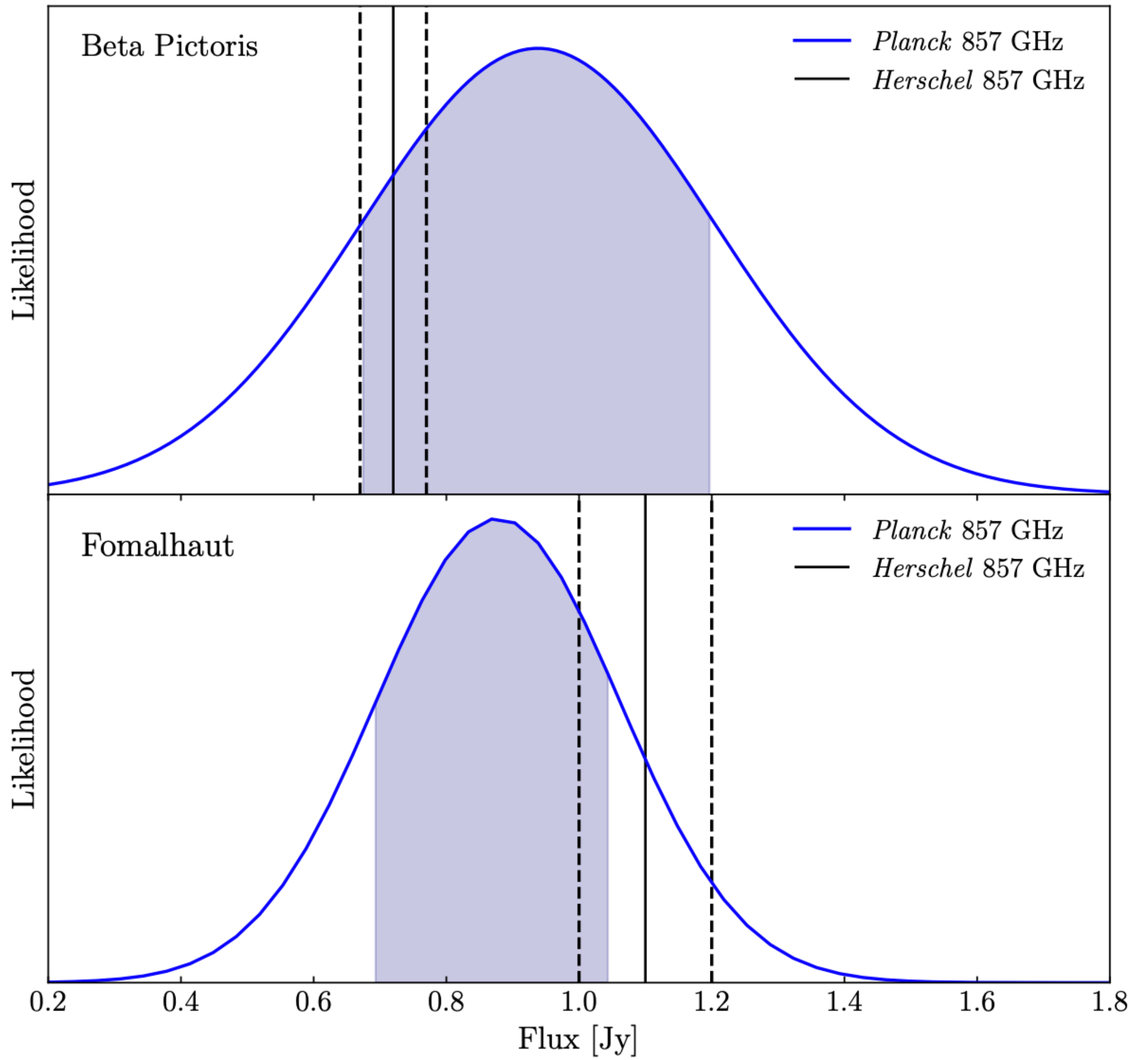
Nibauer+2020

Detection Probability obtained for each Star... useful for detailed follow up

Rank #	Name/ID	Type	Dist. [pc]	Visual	Prev. Candidate
0	36 UMa	F8V C	12.9	*	Y
1	CD-49 424	K5-V C	39.4	...	Y
2	LP 221-55	M0.5Ve	41.1	*	N
3	TYC 7501-1011-1	M1 D	33.6	...	N
4	CD-53 694	...	51.0	*	N
5	Ross 917	M0.5Ve C	35.7	...	N
6	L 177-19	...	35.9	...	N
7	BD+26 2415	K5 D	47.2	*	N
8	HD 87141	F5V D	51.9	...	Y
9	CD-28 1030 - Flare Star	M1Ve	19.6	*	N
10	HD 120004	F8 E	55.7	*	Y
11	phi Gru	F4V C	34.1	*	Y
12	G 267-3	...	32.4	*	N
13	CD-47 277	M0V(e) C	42.0	...	N
14	CD-27 470	...	76.0	*	N
15	G 56-19	...	40.7	*	N
16	BD+62 1259	G5 D	65.3	*	N

Nibauer+2020

Validation for known systems



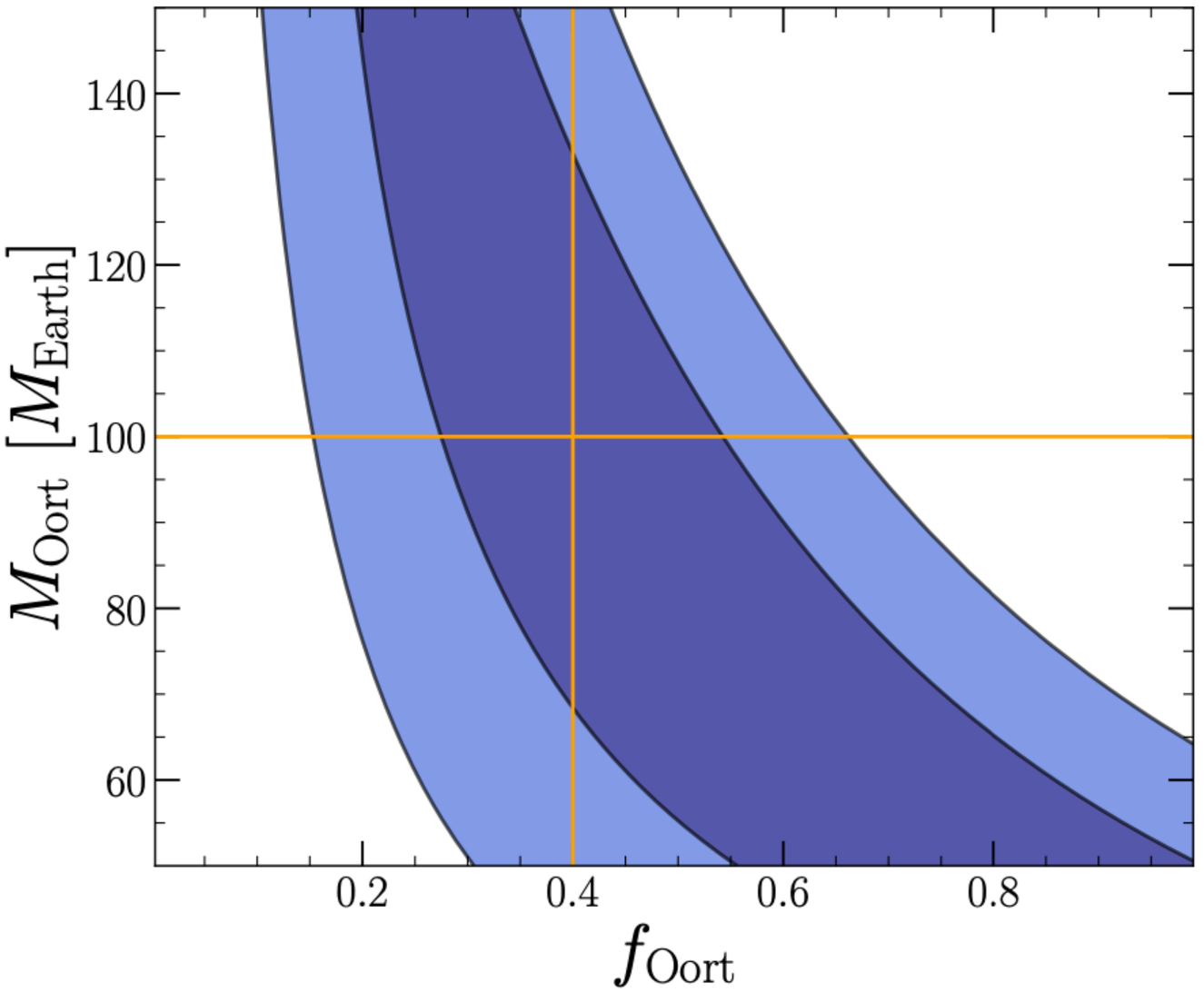
Nibauer+2020

Forecasting Thermal Emission from Exo-Oort Clouds with the Simons Observatory, future applications to CMB-S4

$$\text{Base Map} = \text{Galactic Dust Emission [PySm]} + \text{CIB [Websky]} + \text{Instrumental Noise [Internal]}$$

$$\text{Combined Map} = \text{Base Map}|_{280\ \text{GHz},\ \theta_{\text{FWHM}}} + \text{Oort Cloud Emission}|_{280\ \text{GHz},\ \theta_{\text{FWHM}}}\ \text{[Baxter+2018]}$$

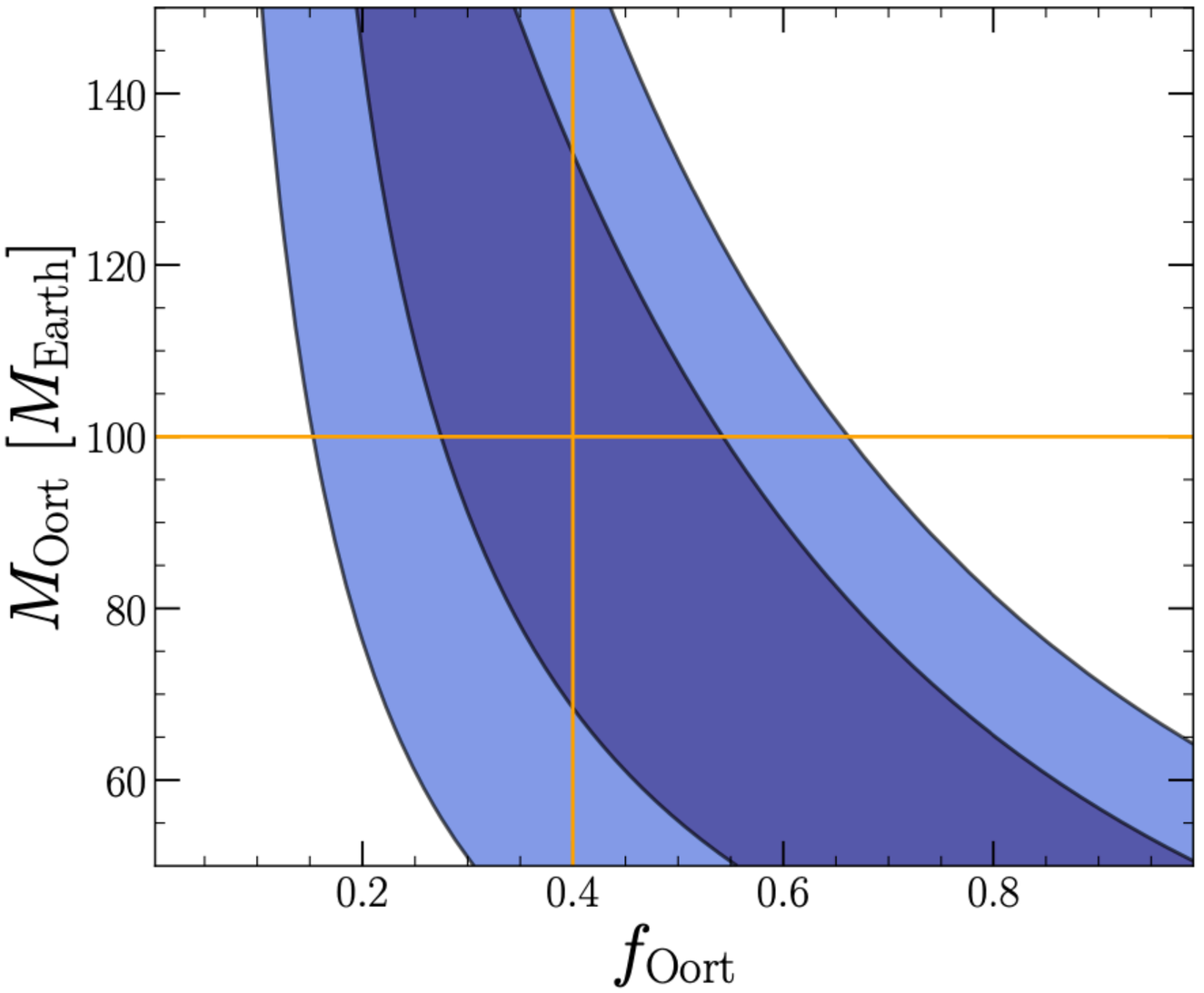
Application to Exo-Oort Clouds: Forecasts with the Simons Observatory



Hensley+2021

Application to Exo-Oort Clouds: Forecasts with the Simons Observatory

Likelihood Ratio Test, $\sim 2.9\sigma$ from $f_{\rm Oort} = 0$



Hensley+2021

Summary

- Next generation of high resolution CMB surveys will be sensitive to realistic Oort Cloud thermal emission profiles, debris disks

  - Potentially capable of detecting a population of Exo-Oort clouds for the first time

- Detection of this signal will provide a new window into the study of planetary systems

- Substantial sky coverage —> enhanced constraints on planetary population statistics

- Combined likelihood constraints: resolve the population, rather than individual systems

---

CMB Surveys can be useful for planetary science!

jnibauer@princeton.edu