Jessie Christensen

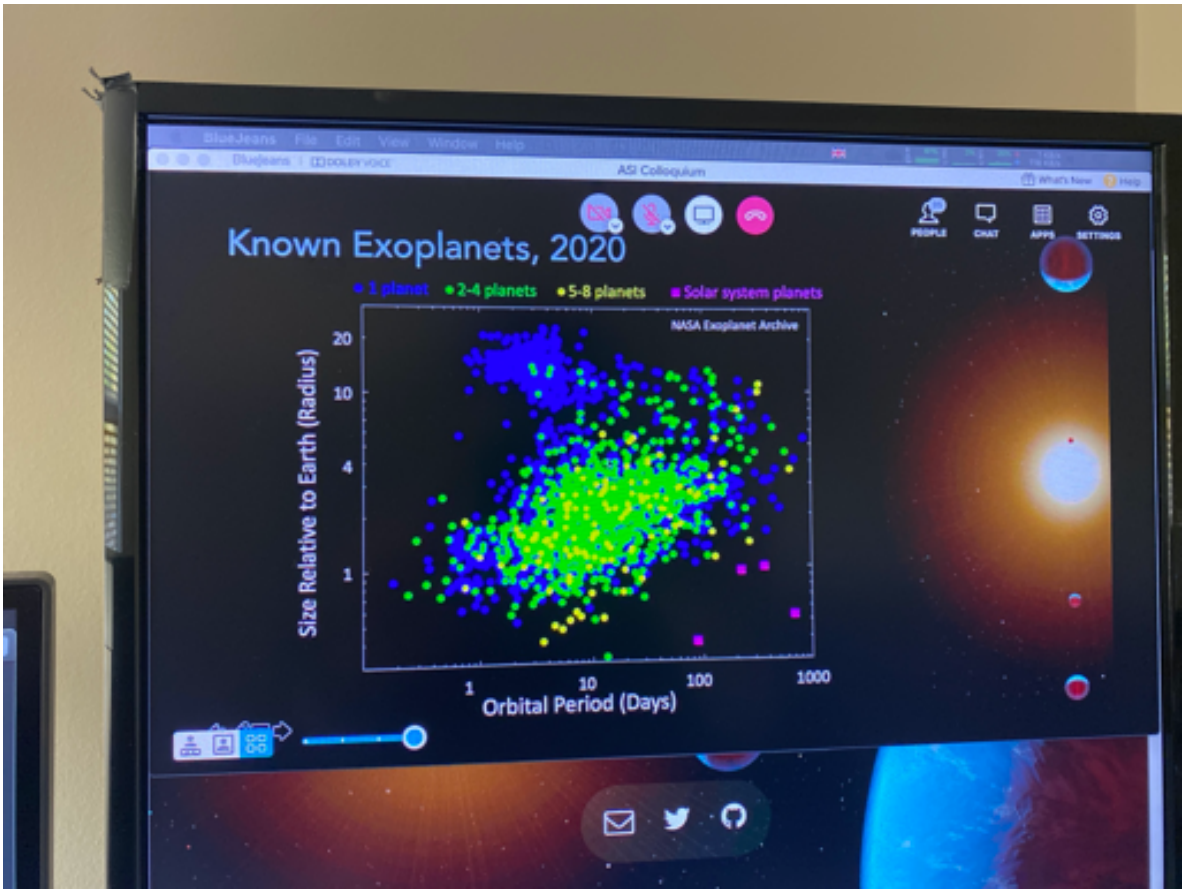
Exoplanet Demographics
Towards an Exoplanet Demographics Ladder

IPAC at Caltech - advances exploration of universe through science ops, data archiving and community support - focus on cosmology and galaxy evolution, exoplanets, asteroid, solar system and infrared sub mm astrophysics. Data processing and archiving for major projects ands all sky surveys, and smaller nasa NSF and privately funded projects

Known exoplanets pre 2010

Pre 2010, exoplanets looked very different to the solar system- all hot

Jupiters, short periods and large



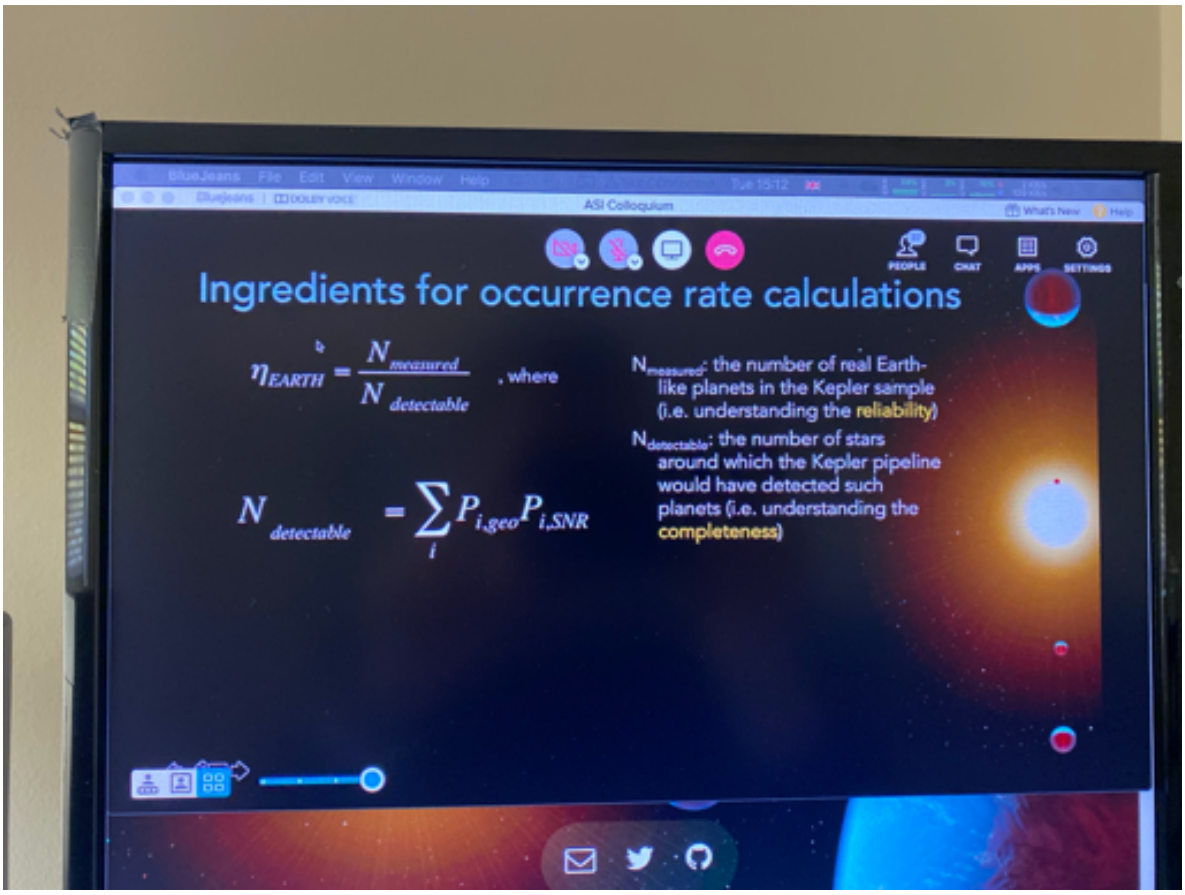
Post 2020 - most of these found in Kepler
Moving away from stamp collecting of 'coldest, hottest etc' into proper population statistics

How do we correct our observations (due to their bias,) to account for true population
What are formation and migration mechanism, how do planet occurrence rates change with stellar properties?

Overview - 4 topics
Kepler (Statistics of occurrence rate calc)
K2 - occurrence rates along new axes
Tess - Occurrence rates of planets
Extending too new orbits -i.e., the future discoveries

Kepler Mission (2009-2013) 1m Opt telescope in space

Uses transit methods of planet discovery
e..g Trappist 1
Science goal --- Number of Earth like planets in habitable zones, with a sun like star
Monitored 200 K stars for 4 years.



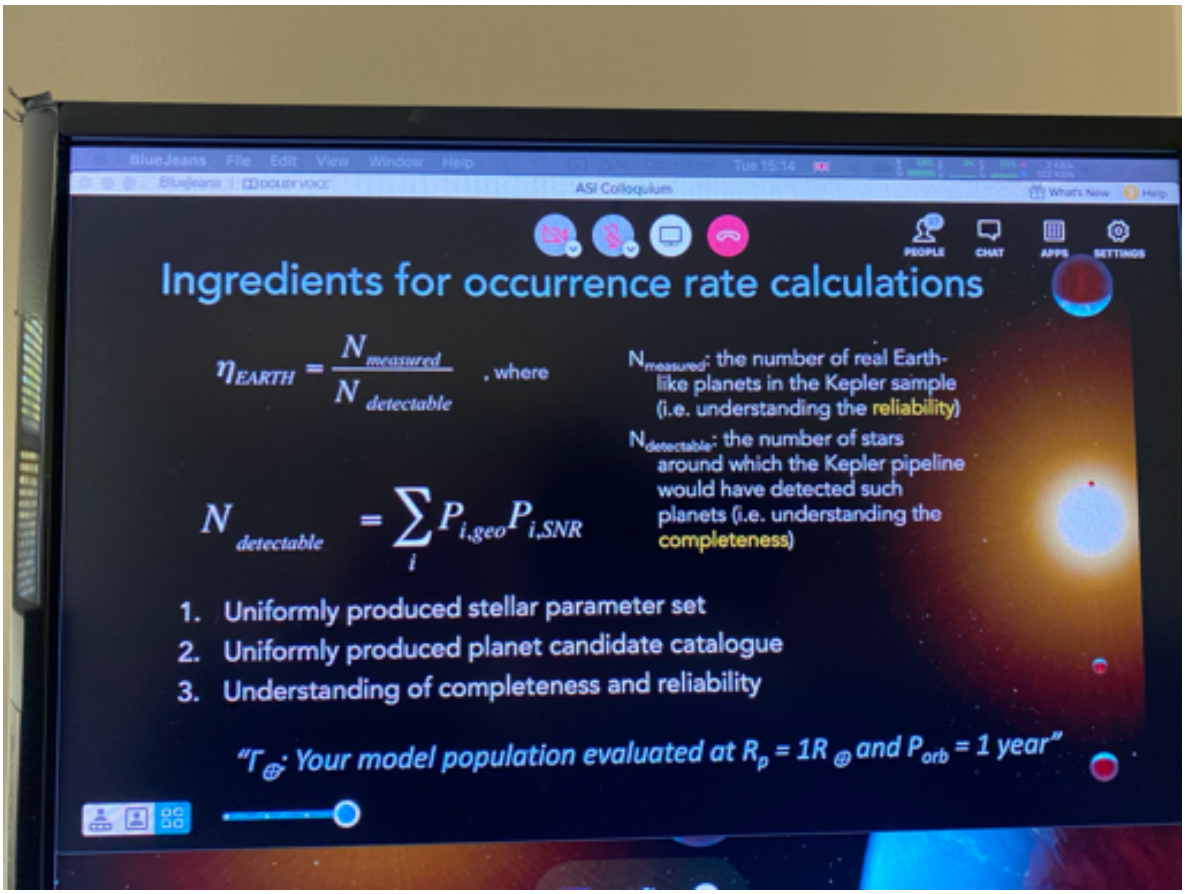
Reliability is effectively rate of false positives

The completeness is due to geometric probalitty (i.e. how probable is a transit due to geometry), and also the SNR of the pipeline, i.e., if its there can we see it

The requirements for calculating gamma Earth (the probability of earth like planets) are

Uniformly Produced stellar parameter set
Uniformly produced planet candidate catalogue (no humans involved)

Understanding of completeness and reliability -i.e., How many planets could there be, and what is false positive rate



New parameter is r_earth - Gamma Earth. Evaluate your model at earth conditions, so can compare apples to apples, I.e. these parameters are always set to their own model params, so need a uniform comparison

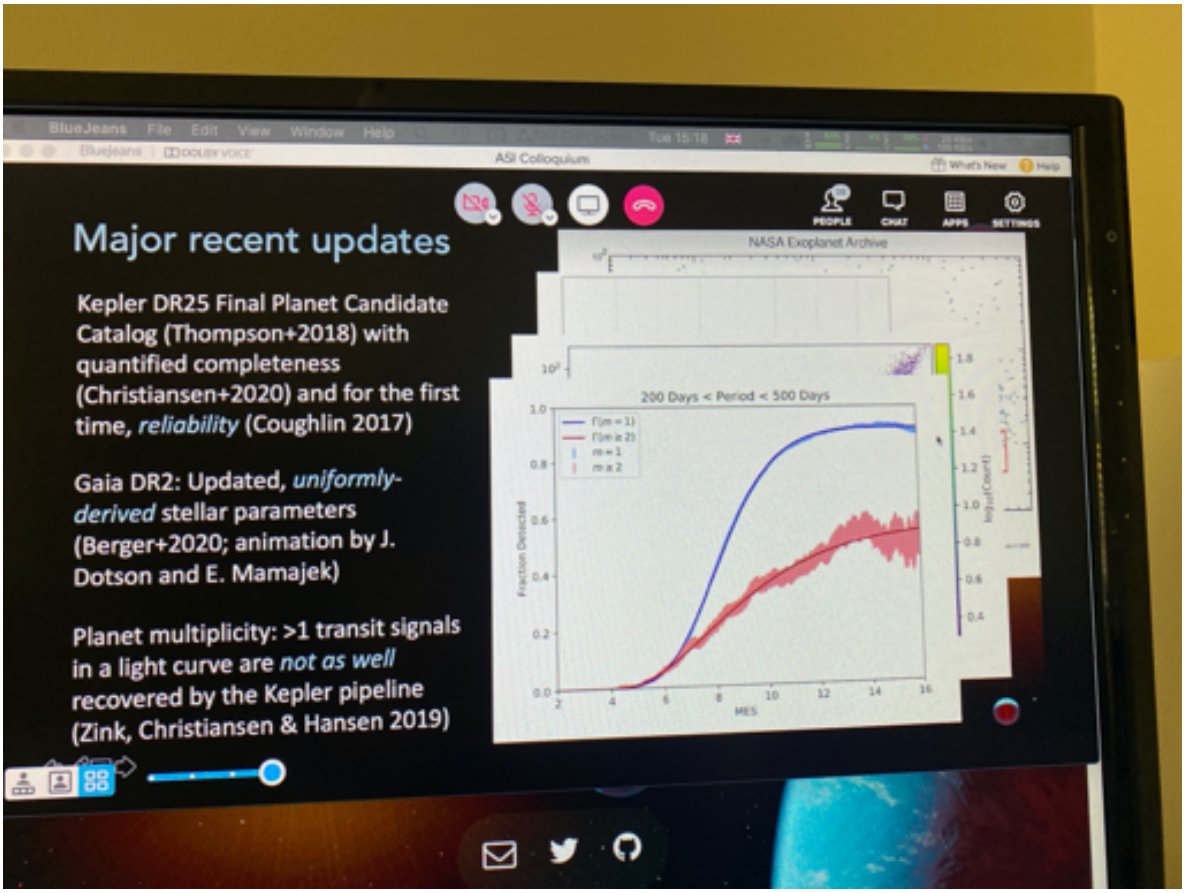
Major Kepler Updates
Final; Planet candidate catalogue came out with quantified complement and reliability (Thompson 2018) (Christiansen 2020), (Couhglin 2017)

Not many Earth like candidates - only a handful

Gaia DR2 came out, which has uniformly derived stellar parameters (Berger et al 2020, animation by J Dotson and E Mamajek) -this revealed a bias in stellar parameter in Kepler - the stars were larger

and hotter than expected, so the planets became larger and hotter, therefor habitable planets candidates went down

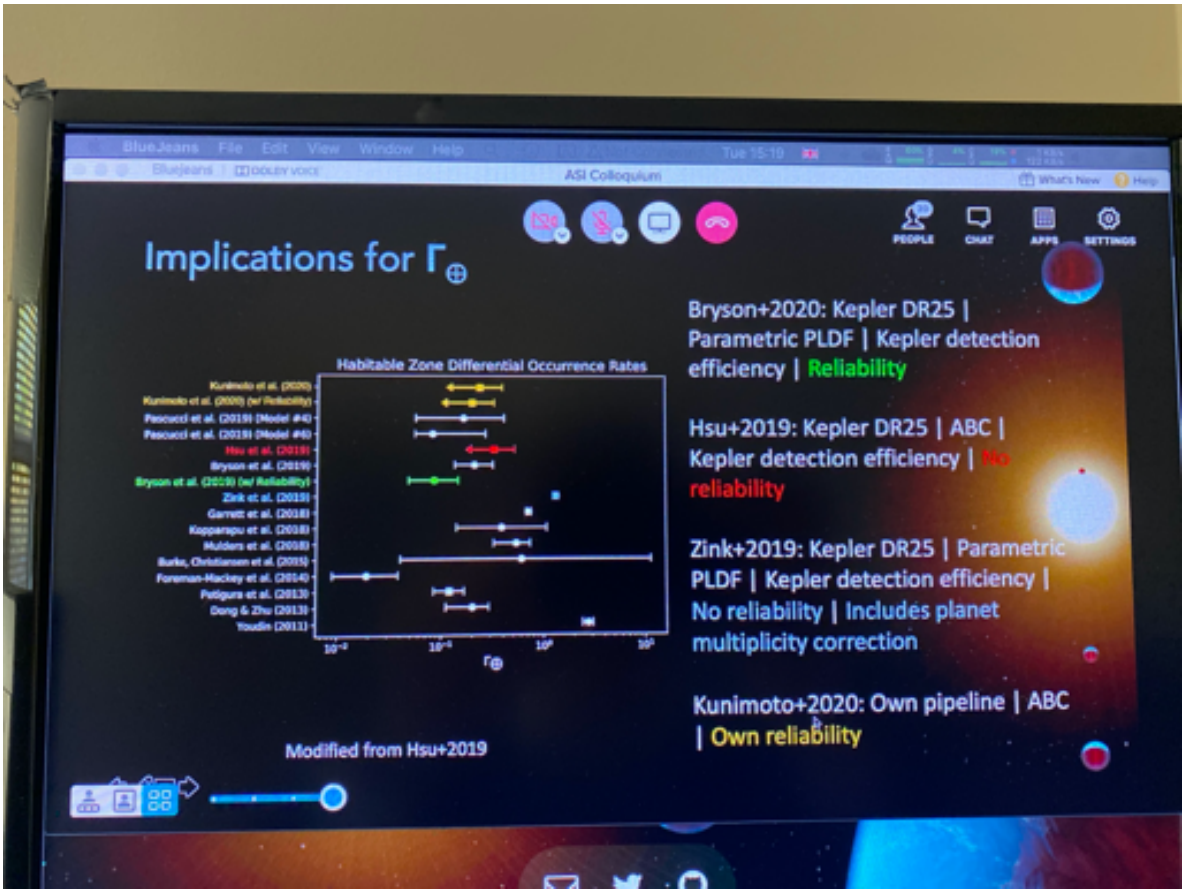
Planet multiplicity > 1 - can't treat recoverability of planets independently - (Zink, Christiansen and Hansen 2019)



First planet has 90 % change of recoverability, but this drops to approx 50% as the num of planets go on. This may serve to change final Gamma Earth Level.

Implications for Gamma Earth

Up until 2015, Gamma Earth had a 3 order of mag spread from 1-1000 %.
In last 5 years, lit has converged

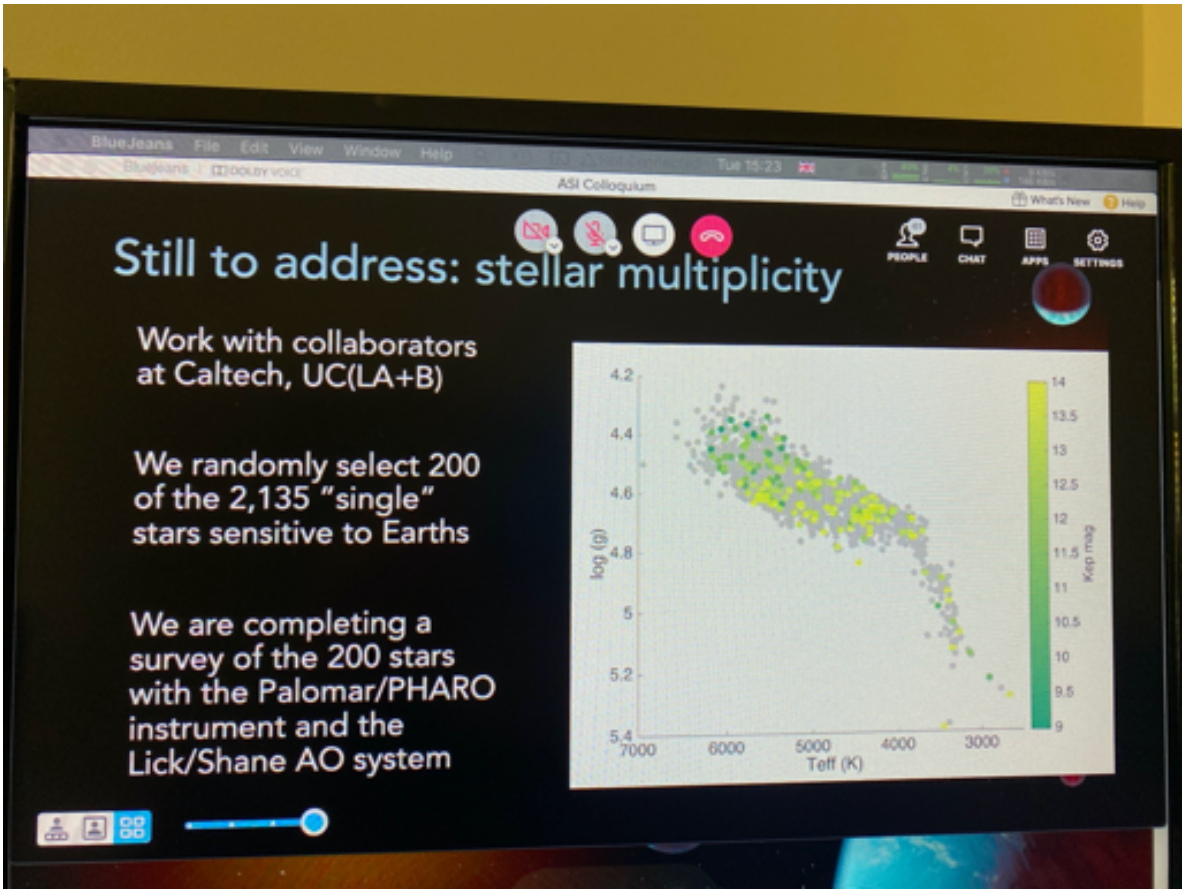


But, still have not had multiple studies with same analysis exactly.

10 % is limit we are converging to - ***10-50 % of stars like sun have a planet in the habitable zone***
10 billion G stars in the galaxy, so approx 5 billion rocky habitable planets
(This is correcting for detectability, these aren't maybes they should be there)

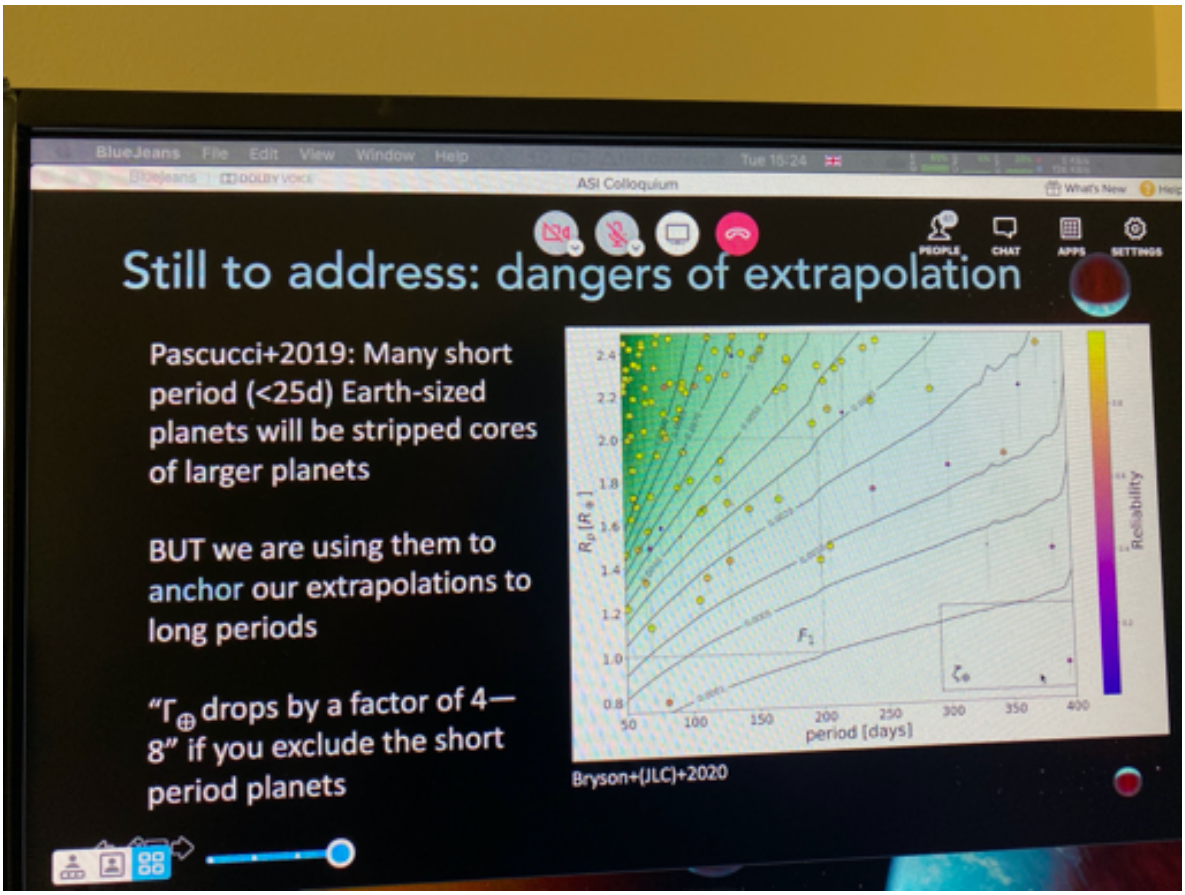
Still need to address Stellar Multiplicity (2 out of 3 stars are binary)

Kepler input catalogues assumed 1-2 arc sec unresolved sources were single stars. This will be improved by GAIA, but still not there
If we assume kepler stars are singles, we derive incorrect planet parameters for host stars. A second more subtle effect, for the non-host stars we infer the incorrect detectability. i.e., could be off by a factor 0f 2

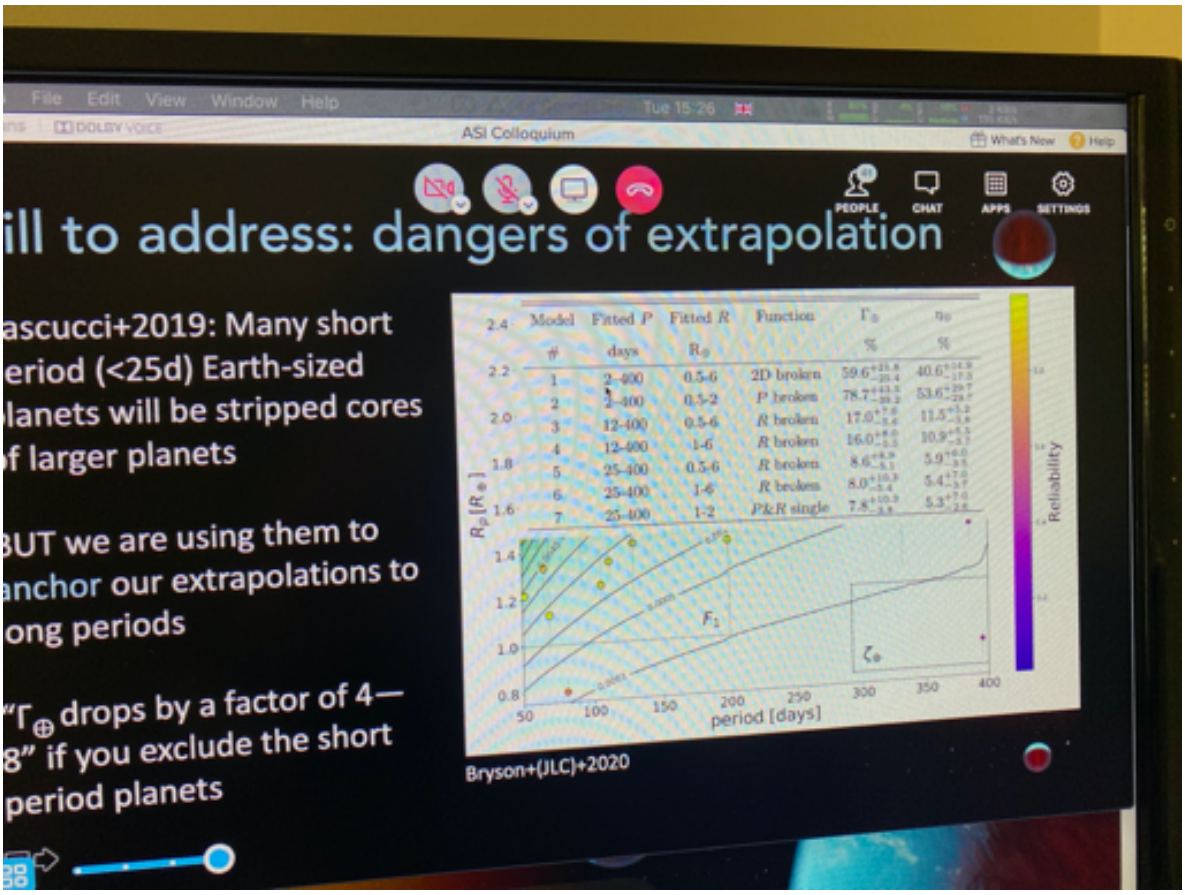


First one they looked at turned out to be a triple. Prelim results - multiplicity rates is higher (40 %) for non hosts then non-hosts (30 % for hosts)

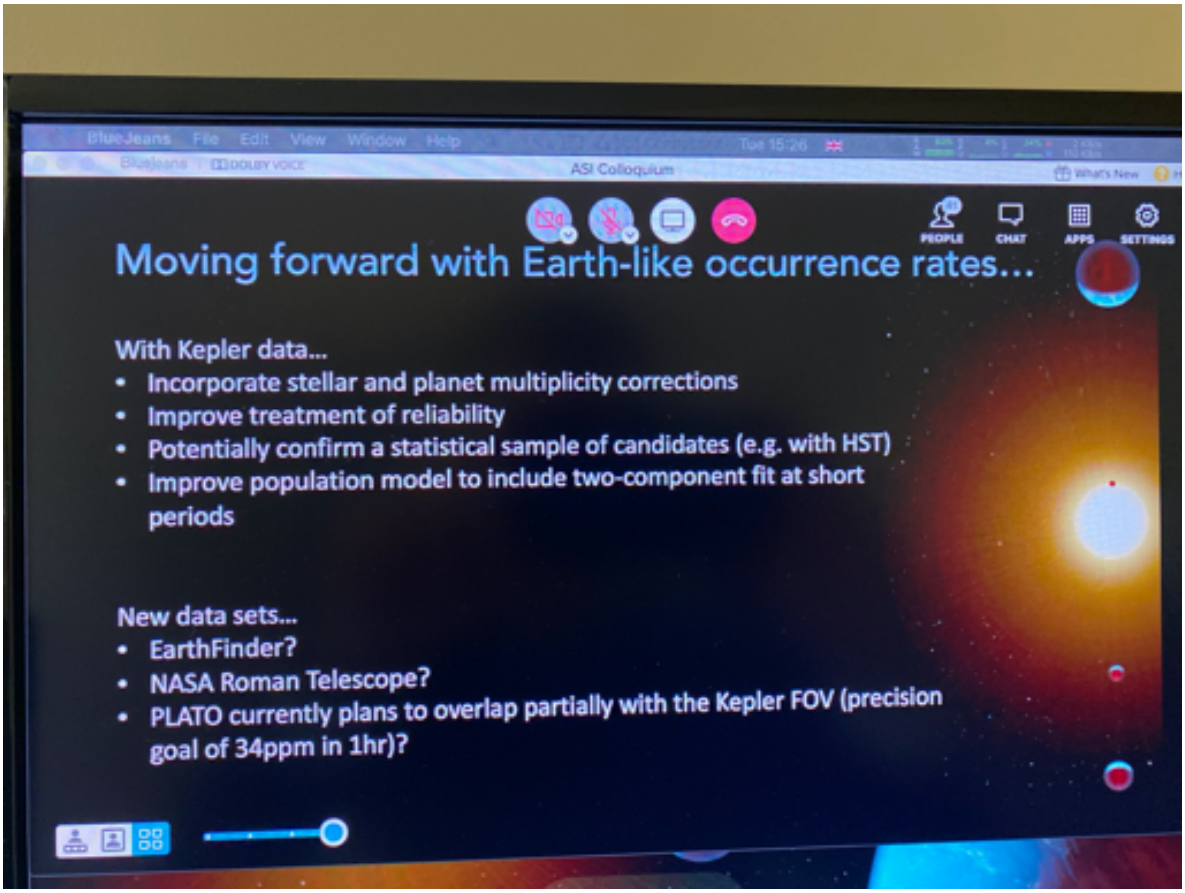
Also need to address dangers of extrapolation



- There are physical reasons to believe we can fit a power law --- however, this can be misleading, as short period planets might not originally have been short period small planets - could have been larger and had their atmospheres and cores stripped.

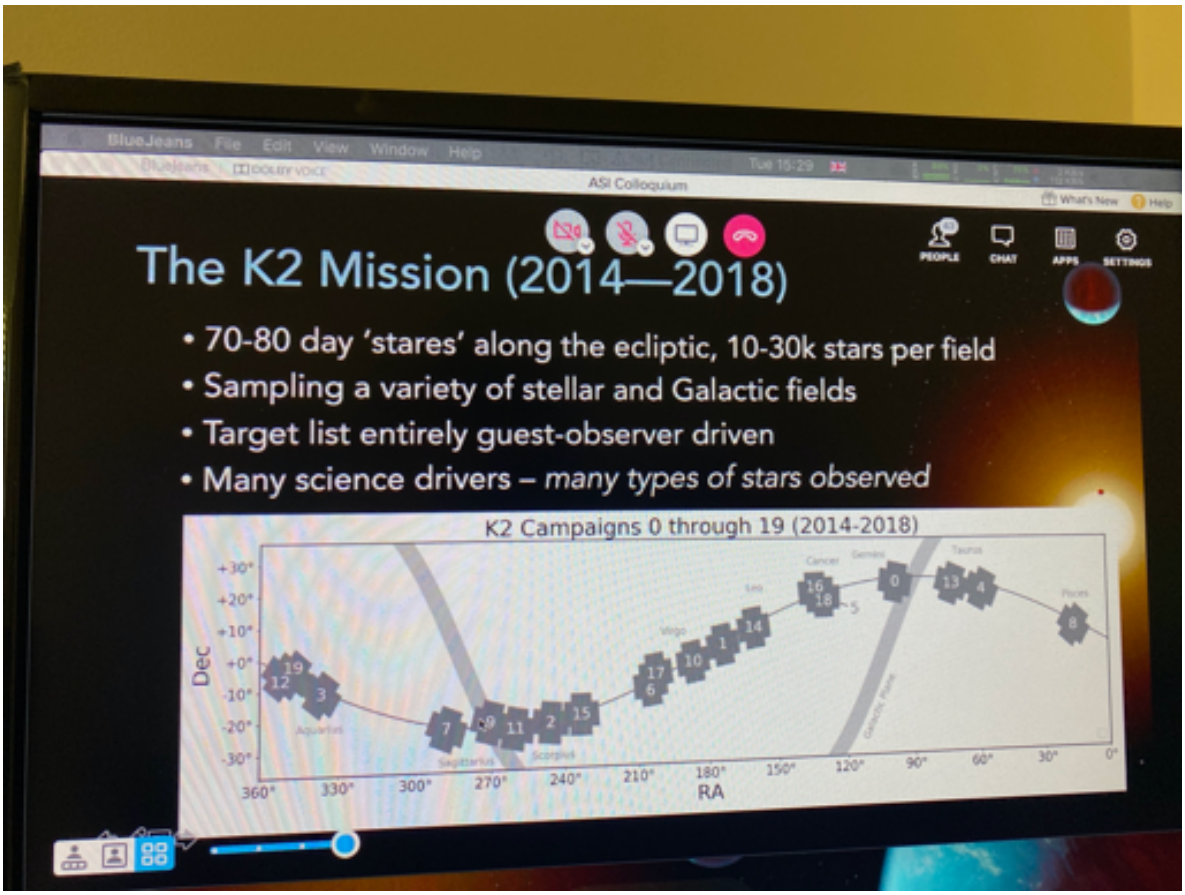


Moving forward



New data sets are key - Earth finder still a concept. Roman telescope is microslensing - just marginally sensitive to Earth like planets. Plato plans to go back to kepler FOV - with more robust tools

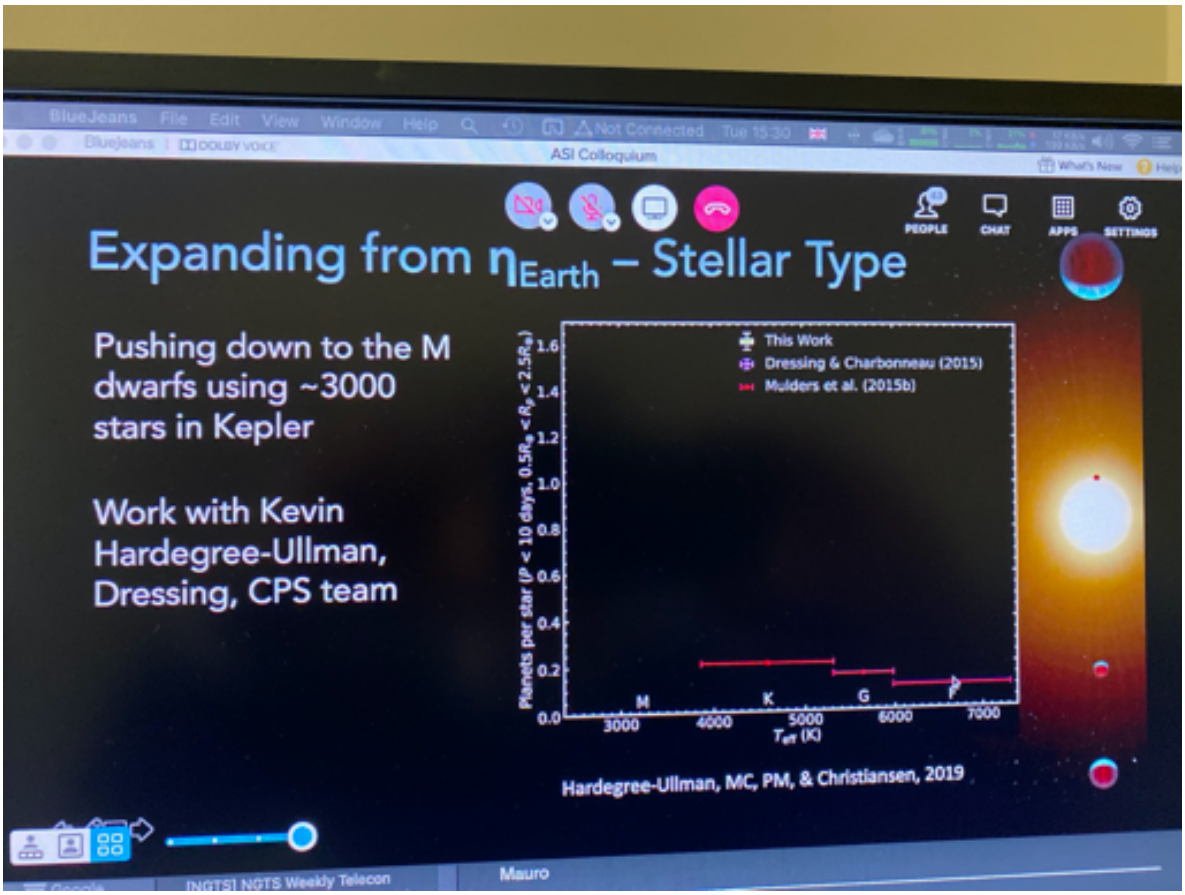
K2 Mission (2014 to 2018)
Ecliptic plane survey



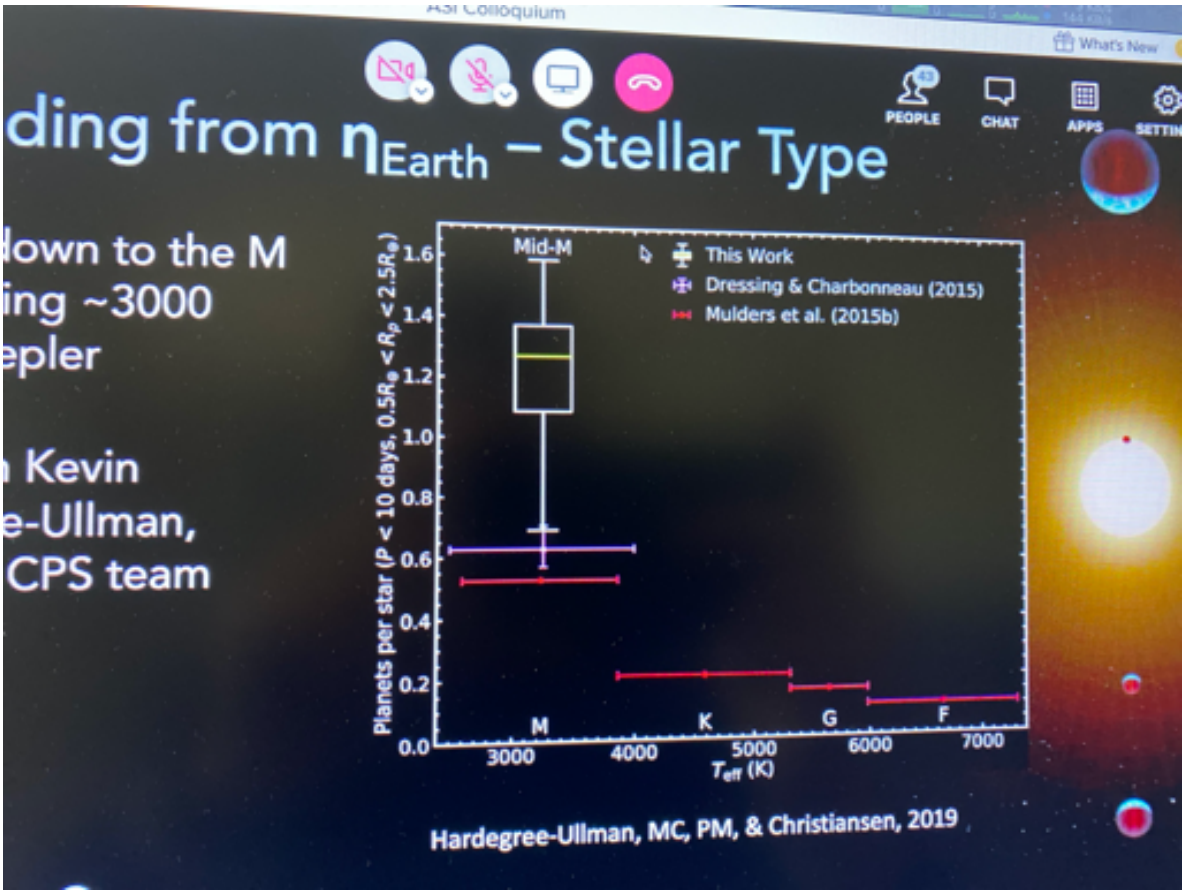
K2 looked at a range of stars - a range of age, metallicity, stellar types

Expanding from Gamma Earth -how does stellar type affect this

Only 3000 M dwarfs observed with Kepler



Increase of occurrence rates at cooler stars. Why were smaller stars better at making super earths at low periods

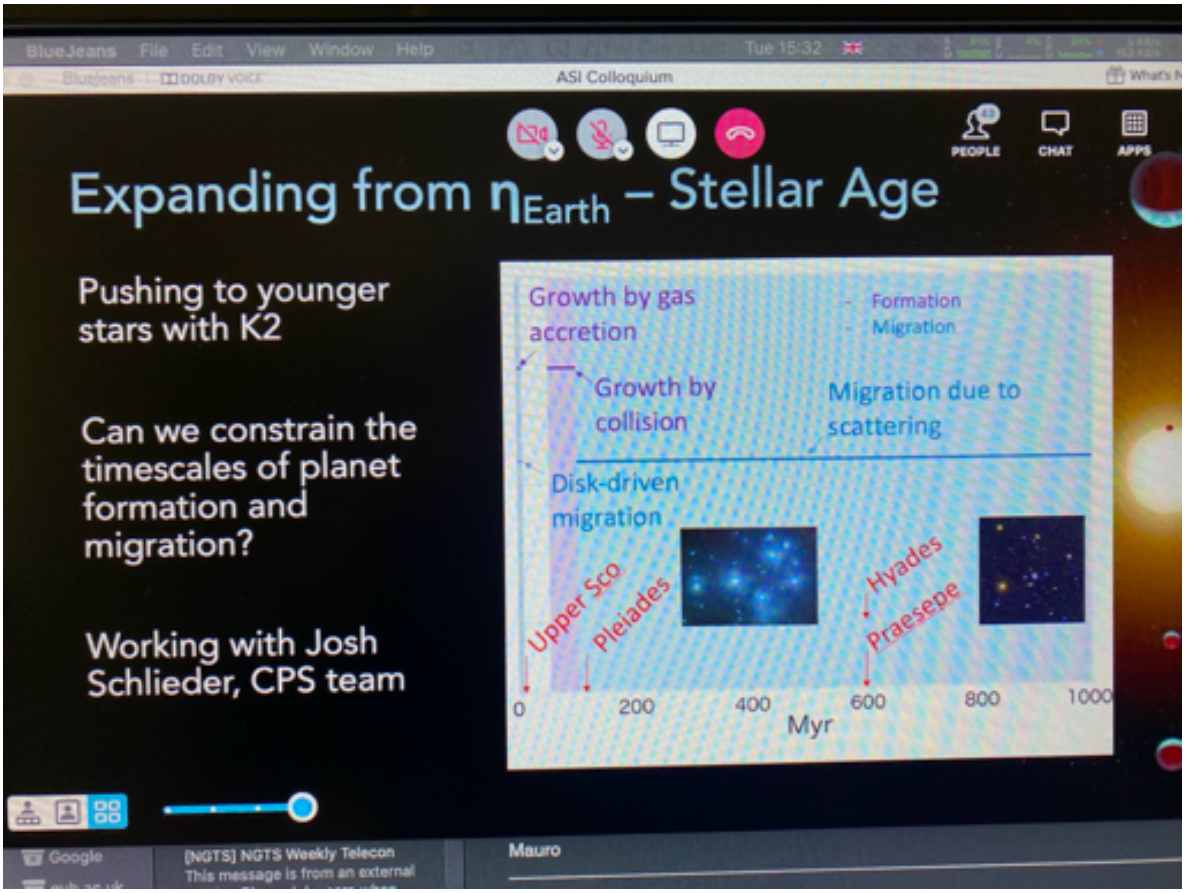


This trend is increasing

Plan to use the 30,000 cool stars from K2 to better investigate this

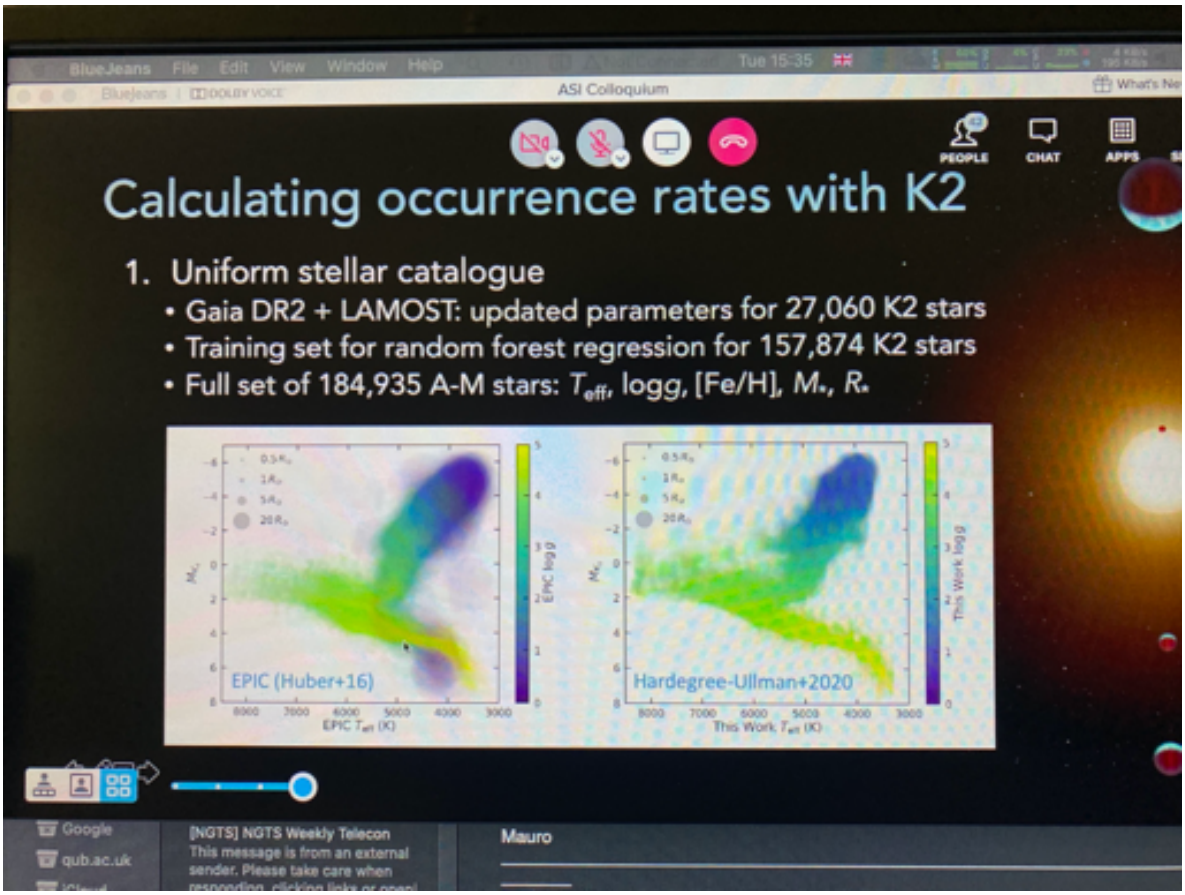
Kevin Hardegree Ulman working oil this

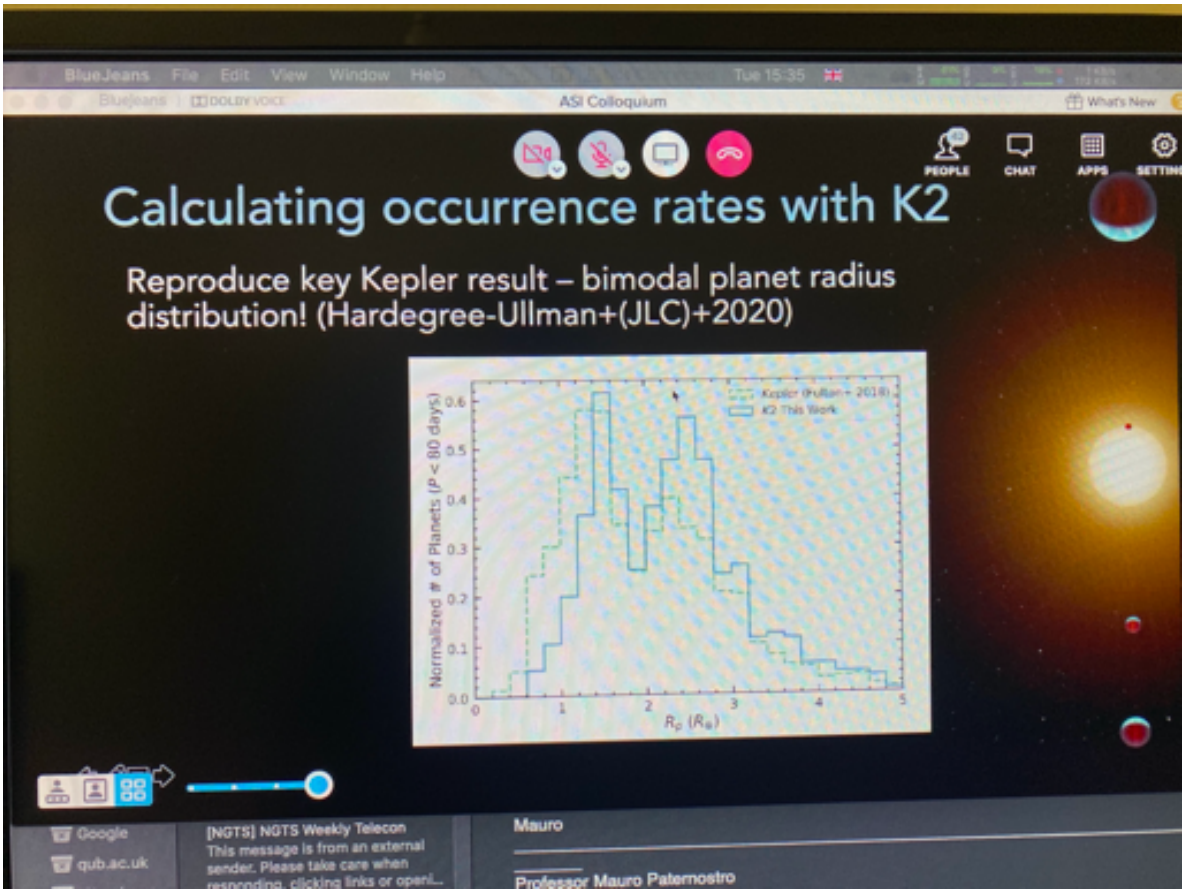
Expanding from gamma Earth - Effect of Stellar Age



Each of these competing theories makes different predictions for the timescales - can we constrain this with observations?
K2 observed 4 clusters, seen on diagram. Look at planet occurrence rate in these 4 clusters, and compare to the Kepler field occurrence rates
This is being done with CPS team

How do we calc. Occ. rates with K2? (Same requirements as Kepler had)
Need a Uniform stellar catalogue





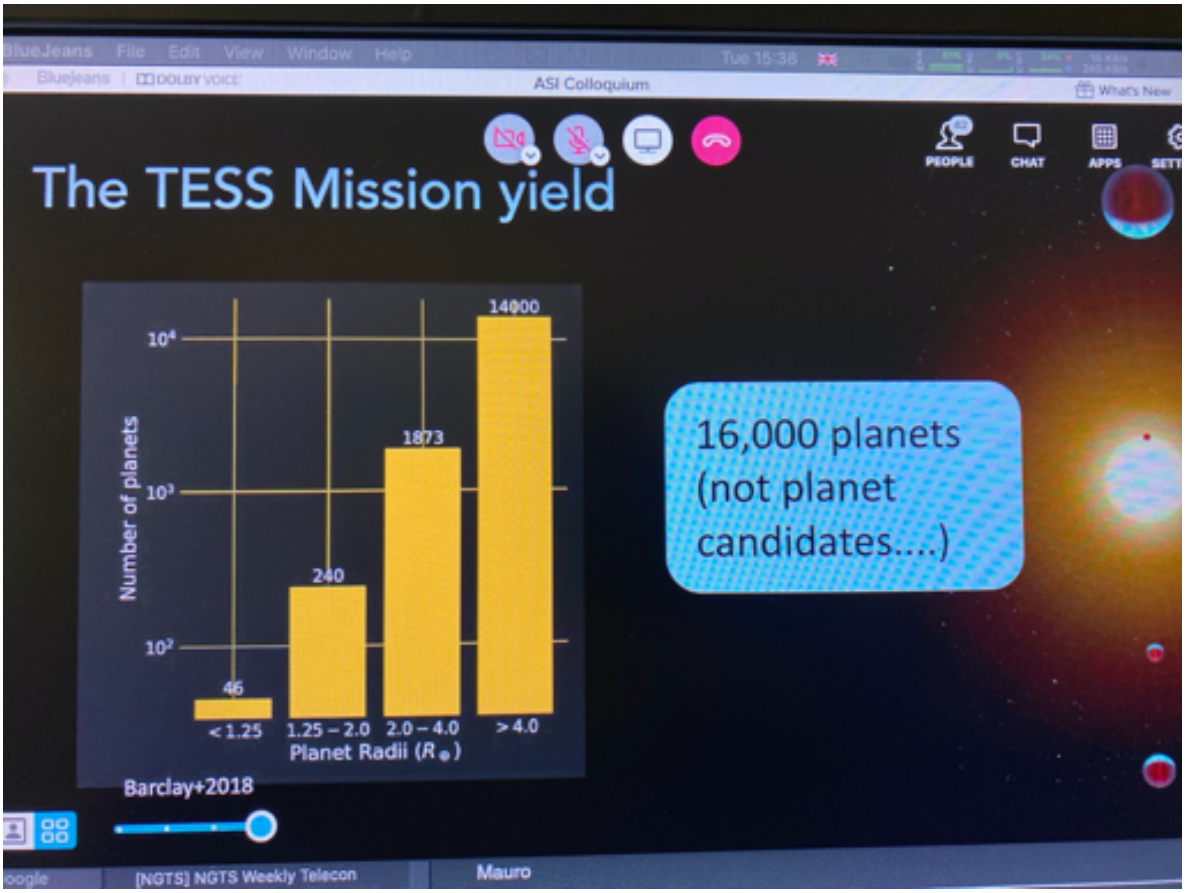
Bimodal distribution for short period planets - sub Neptune and super earths, valley in between

Explanations are about atmosphere loss, or core powered mass loss
The K2 data reproduced the bimodal dist seen in the Kepler data - first independent check of this result from Kepler

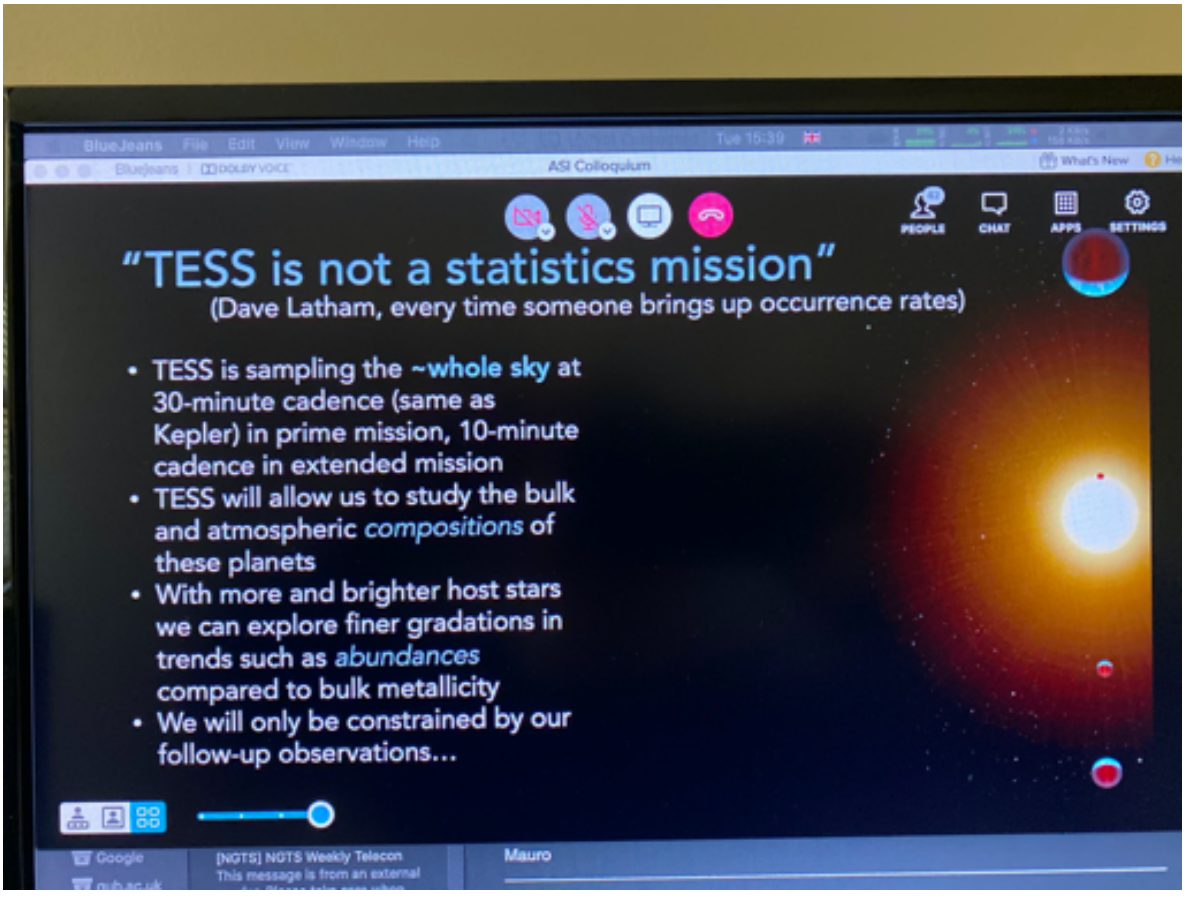
Uniform planet candidate catalogue. Down to earth sized planets at short period (40 days)

They are currently working on completeness and reliability of the K2 survey now

Tess Mission (2018)
Kepler was a narrow deep survey,. Tess is a wide shallow survey
Goal is to cover all bright stars in sky down to 12 mag (maybe 14 for giant planets)
Can do more interesting followup on bright stars



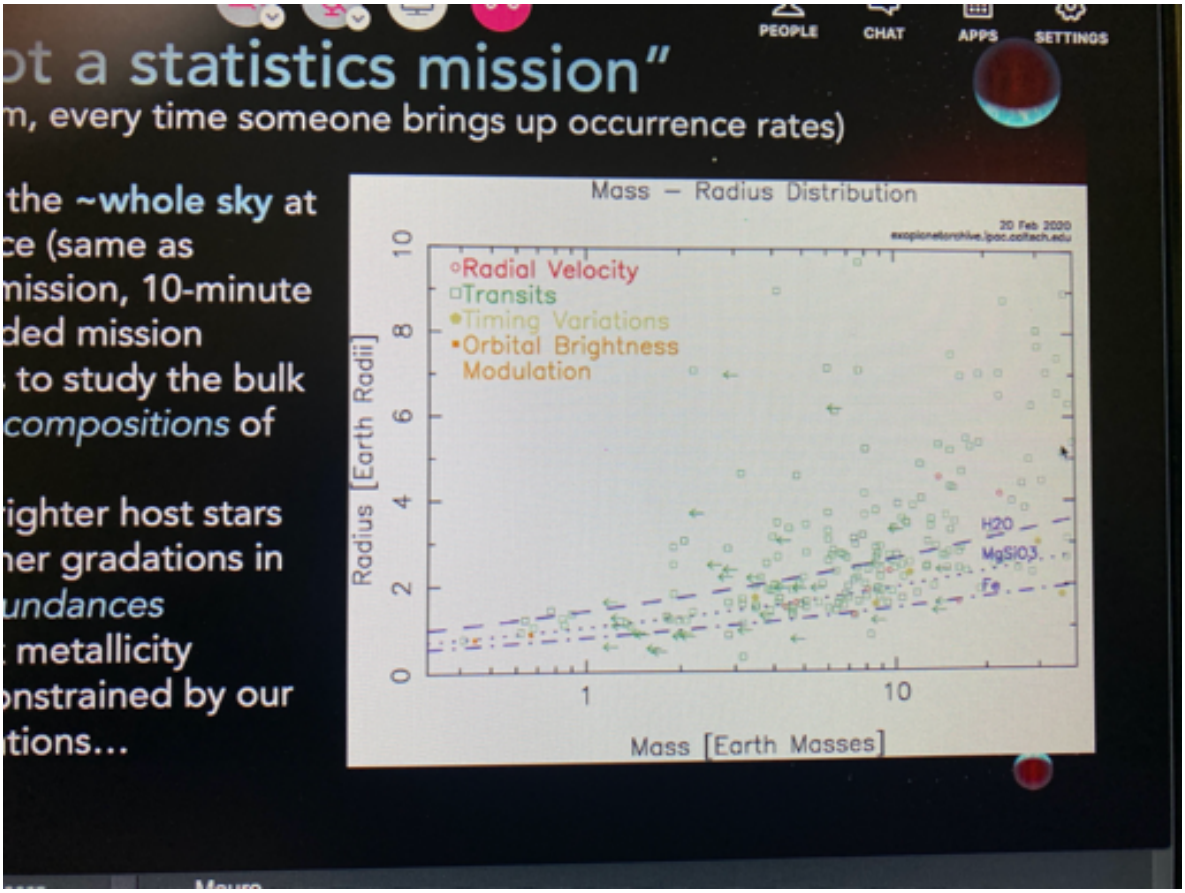
Could quadruple the number of known planets

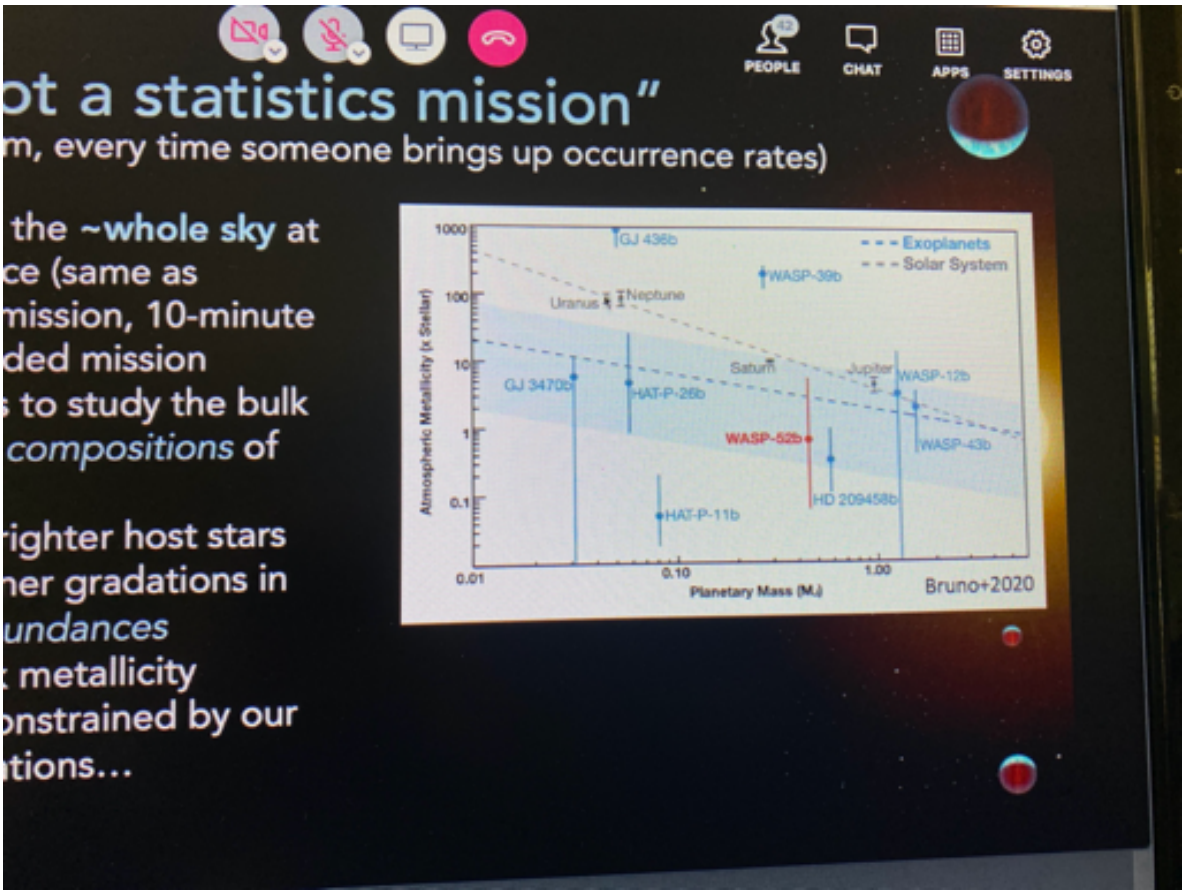


Can look at different atmospheres

Bulk metal rich stars make more planets. Do carbon rich stars make more rocky planets, more wet planets, more wet etc. Where do planets form, using these abundance measurements

We will be constrained by follow up, due too how many candidates we have

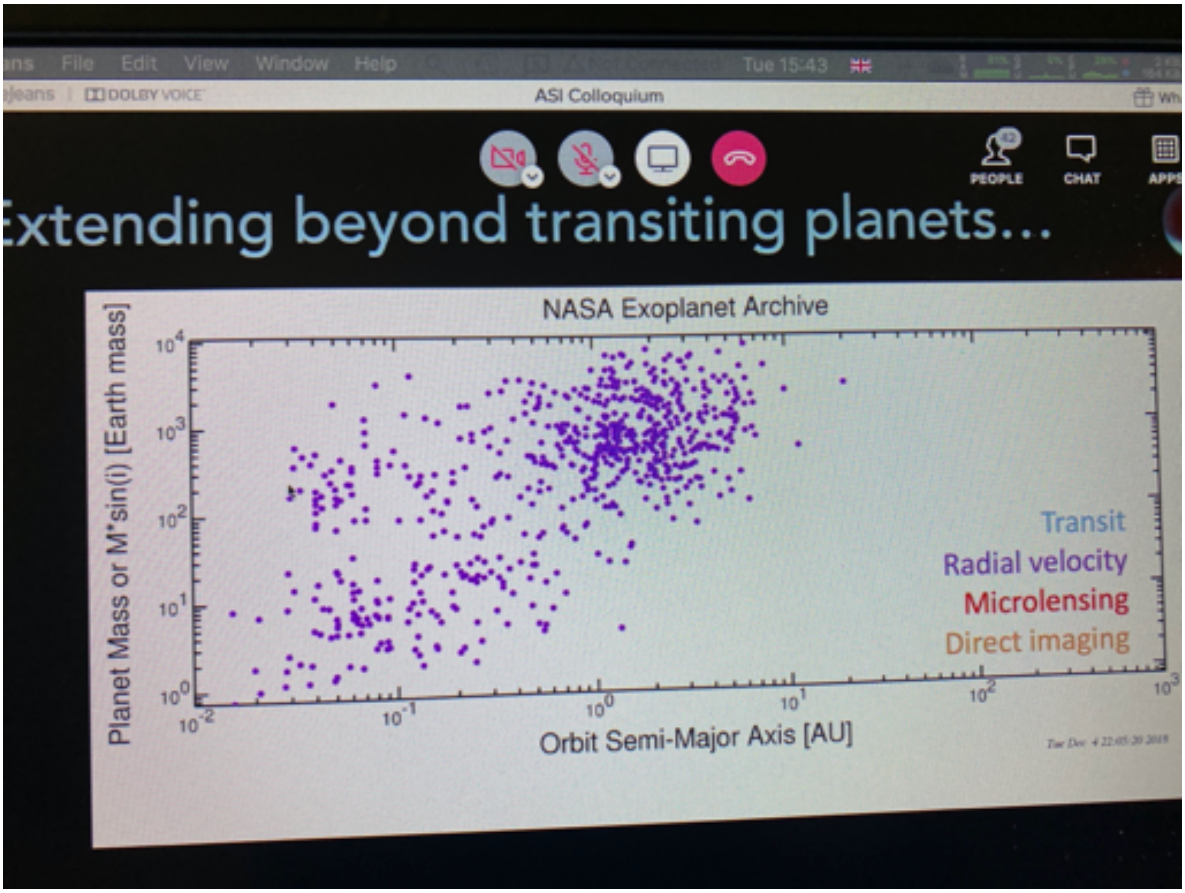




Our solar system has a nice neat trend of metallicity, but do exoplanets have the same trend?? TESS can help us with this, as it will look at atmospheres

Extending beyond Transiting Planets

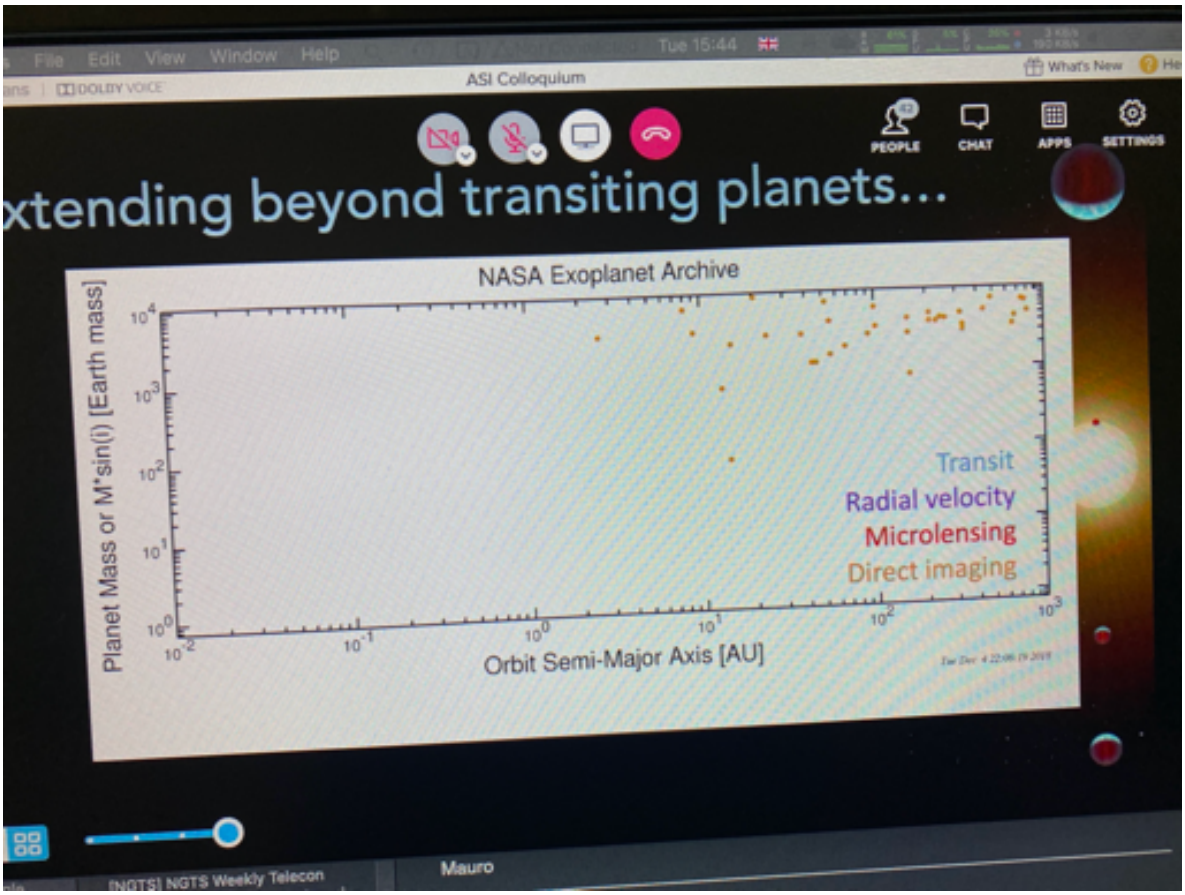
They are biased by detection technique to short periods
Excess of Super earths etc is real, compared to Neptune desert which might not be (I don't know If I heard this correctly not gonna lie)



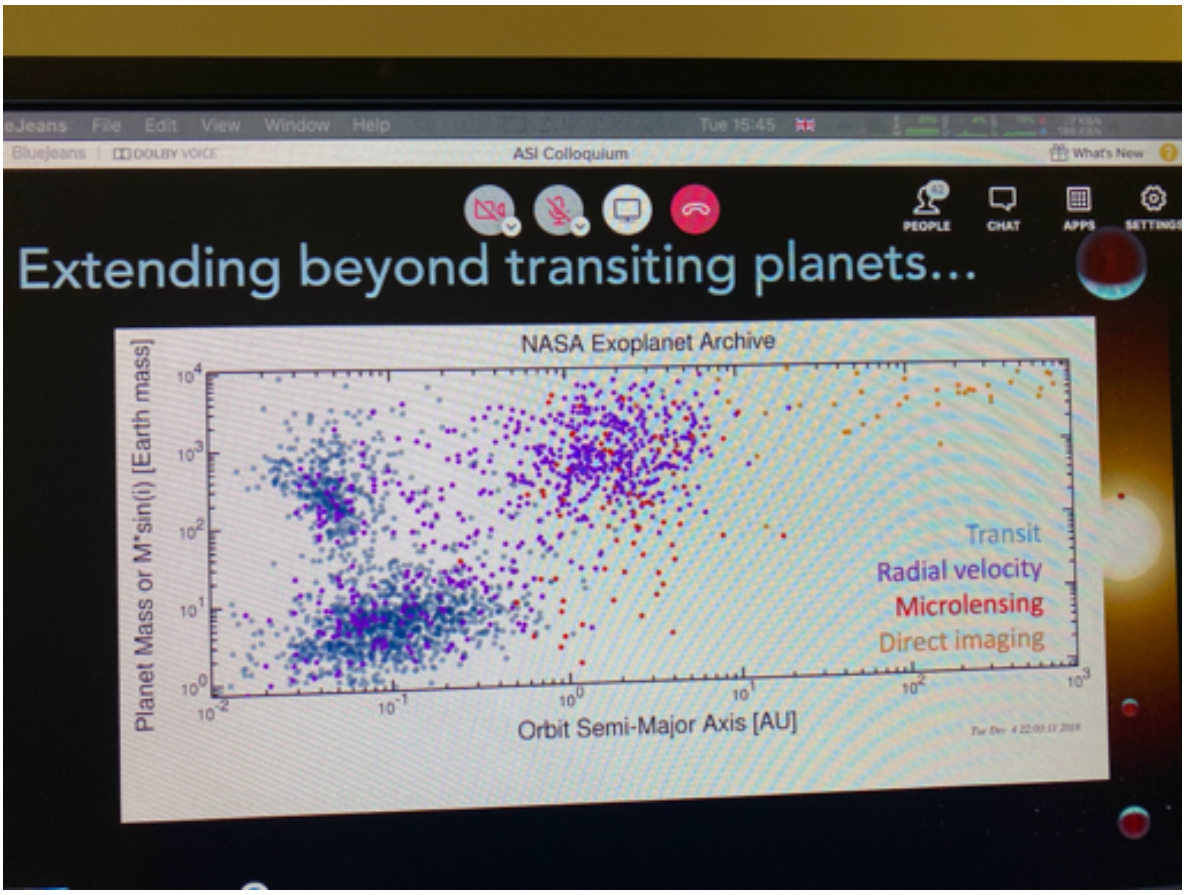
RV method Biased to heavier planets

Microlensing planets

Don't see the same trend of mass drop-off. Only sensitive to mass ratio, not to mass itself. Can remove some of mass dependence. Most sensitive to planets around the snow line

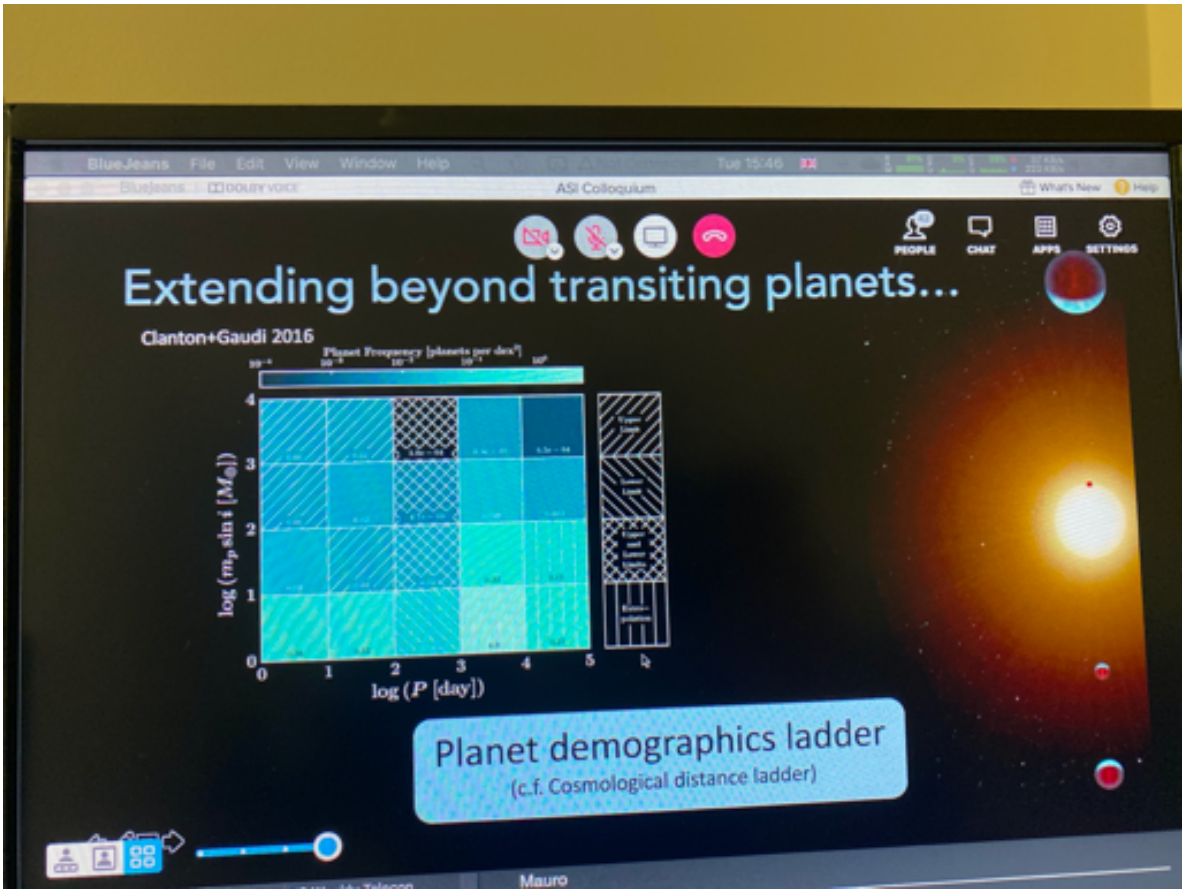


Only works for big planets far away from the star. Don't measure mass directly, have to use their lumunmoity, and modelling to determine th9is

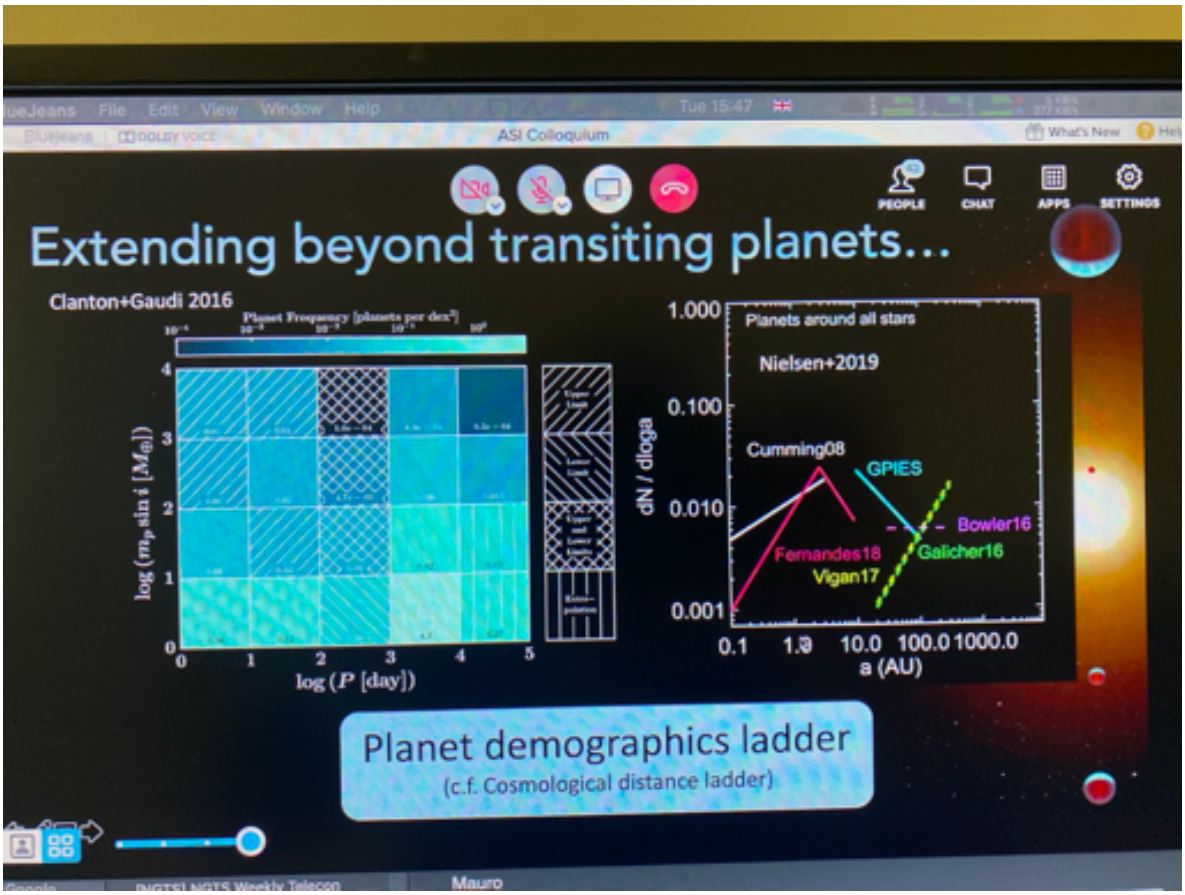


On the same plot -not trivial to get them all on same plot. Each technique overlaps. The means there is possibility for a planet demographics ladder (analogous to cosmological distance ladder) allowing for a diagnostic / calibration between these distinct techniques.

Has been tried before

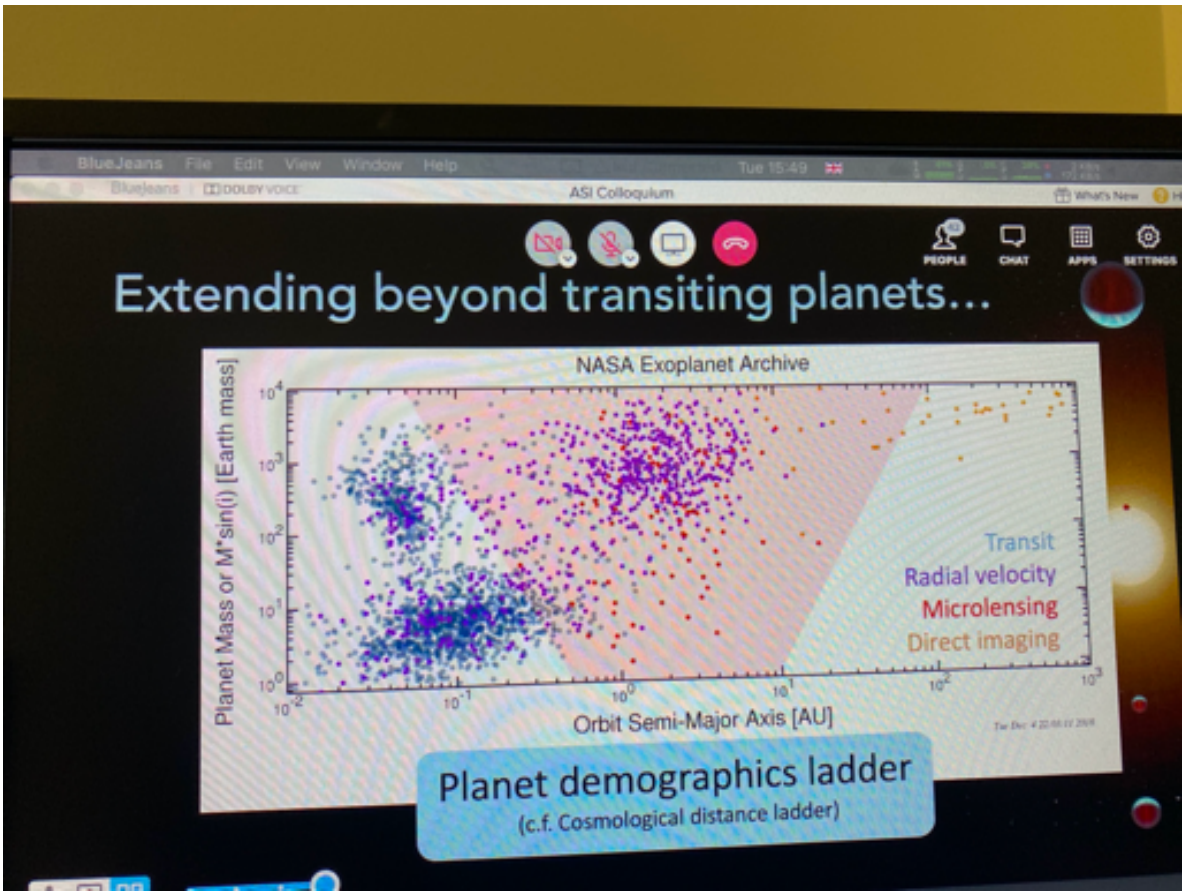


If you squint, the peak is between 1000 and 10000 days

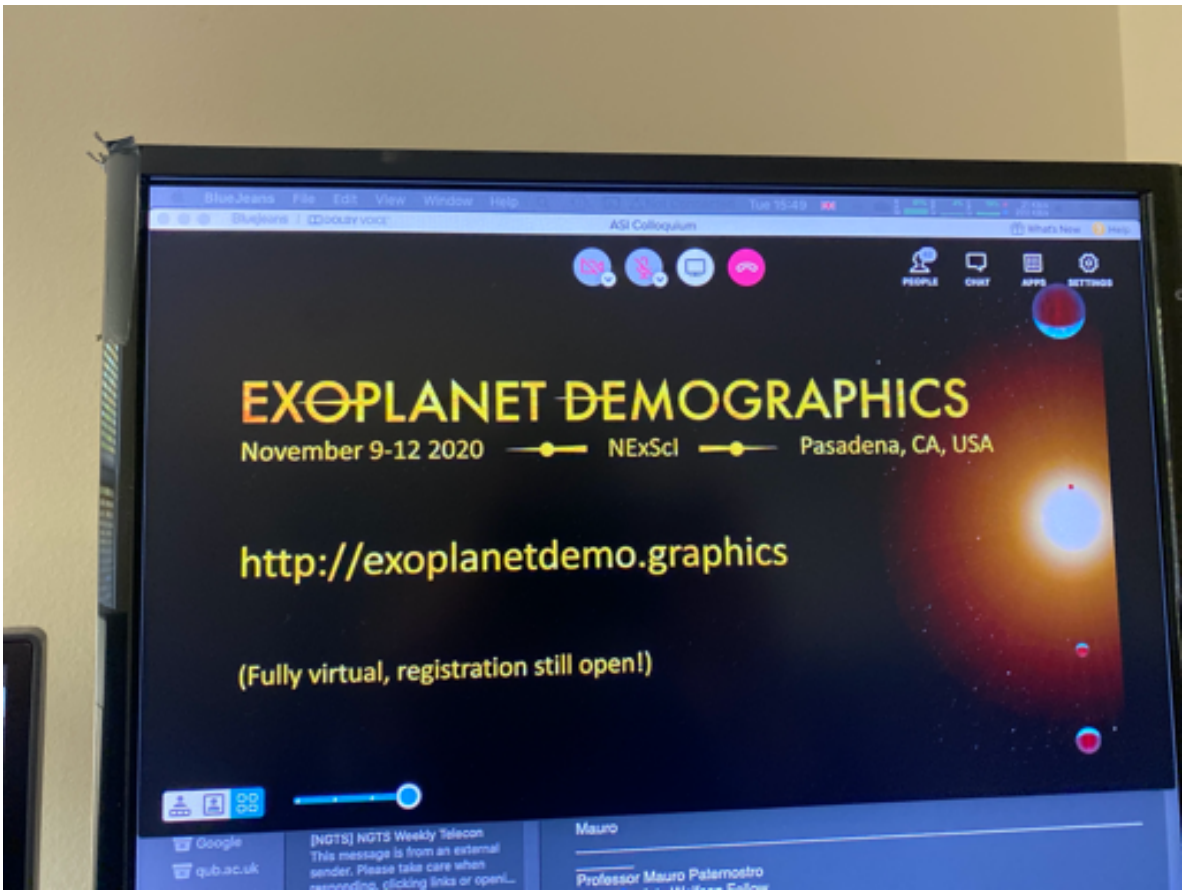


These 2 results agree - by 10 Au there is a 'turnover' in planet rates
Need to make self consistent planet population we can looko at different catalogues, and see if they agree

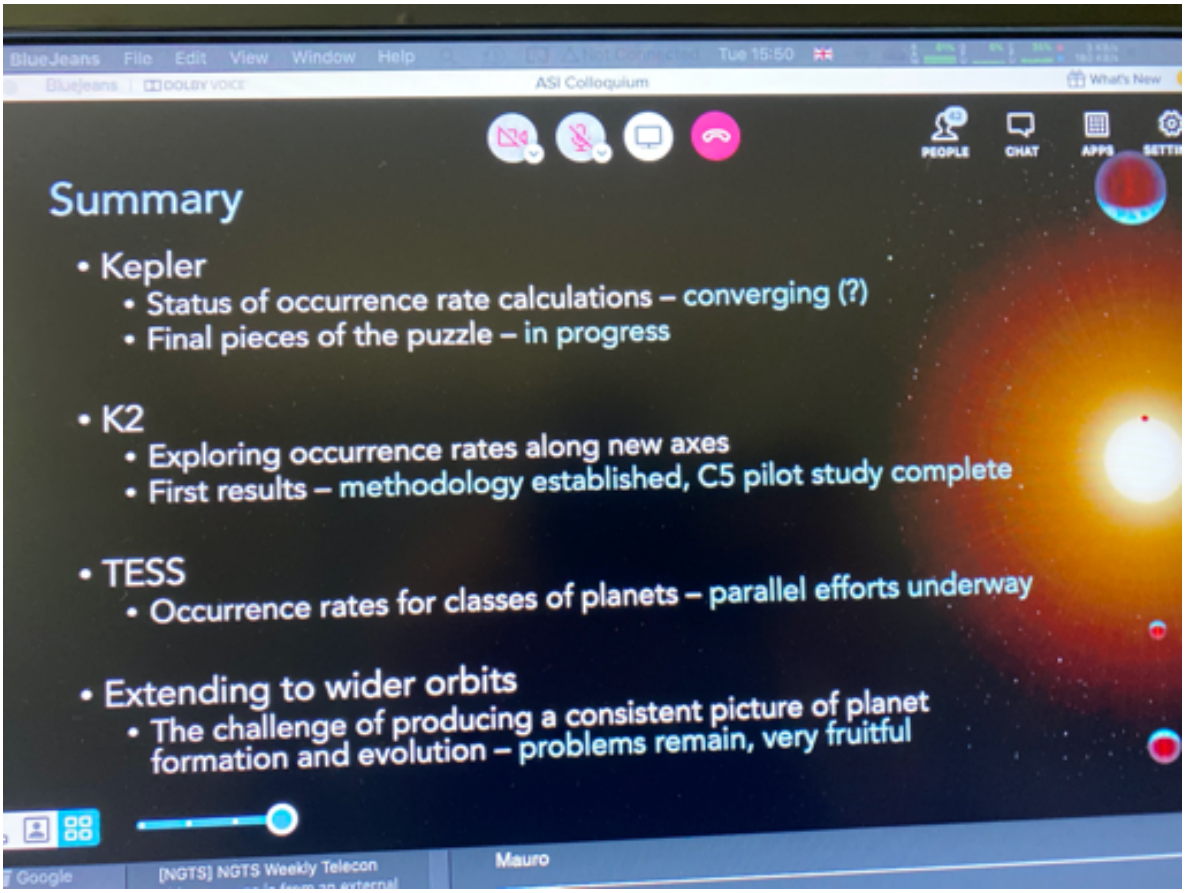
With all the overlaps in these types of detection, we can look at so many things



Pink cone is the detection range of ROMAN telescope (if it gets made) which looks at a range of these, so could be a great calibration tool



Virtual conference in 2 weeks - Free as its a NASA conference, please apply! :)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Tue 15:50
ASI Colloquium
What's New
PEOPLE
CHAT
APPS
Summary
• Kepler
• Status of occurrence rate calculations – converging (?)
• Final pieces of the puzzle – in progress
• K2
• Exploring occurrence rates along new axes
• First results – methodology established, C5 pilot study complete
• TESS
• Occurrence rates for classes of planets – parallel efforts underway
• Extending to wider orbits
• The challenge of producing a consistent picture of planet formation and evolution – problems remain, very fruitful
Google
[NGTS] NGTS Weekly Telecon
Mauro