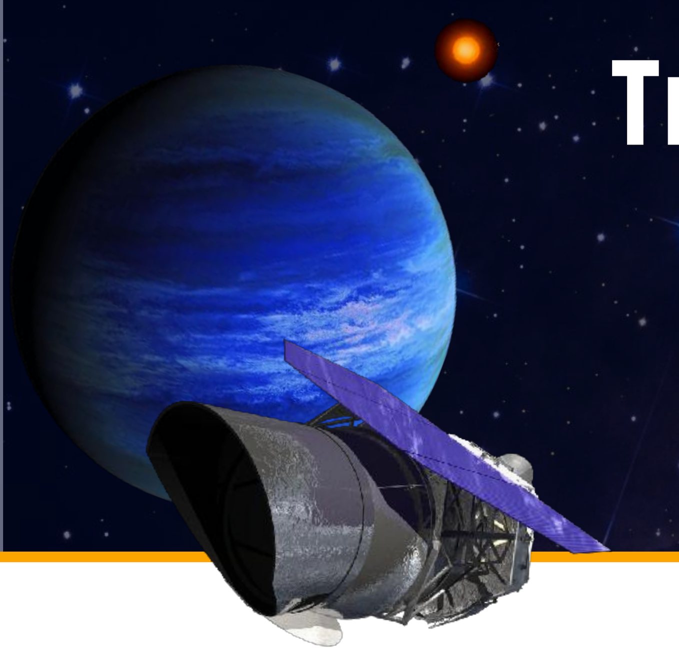
THE ROMAN EXOPLANET IMAGING DATA CHALLENGE

A MAJOR COMMUNITY ENGAGEMENT EFFORT



www.exoplanetdatachallenge.com

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SPIE.

ROMAN

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STScI NASA-GSFC JHU JPL UC Riverside IPAC SETI

A COMMUNITY ENGAGEMENT EFFORT

Organized by the Turnbull Science Investigation Team (SIT) the 2019-2020 Roman Exoplanet Imaging Data Challenge (DC) **launched in October 2019 and ran for 8 months**. It is **now closed**. This DC was a **unique opportunity for exoplanet scientists of all backgrounds and experience levels** to **get acquainted with realistic simulated data**. With a **new contrast regime**, Roman CGI enables to **unveil planets down to the Neptune-mass in reflected light!**

QUICK LINKS & DOWNLOADS

[Data Challenge Website]
[30-min Webcast for the Roman Lecture Series]
ROMAN @JPL @GSFC @IPAC @STScI @NASA
[The NASA Astrophysics Fleet]
[ROMAN CGI Simulations (OS6, OS9) @IPAC]

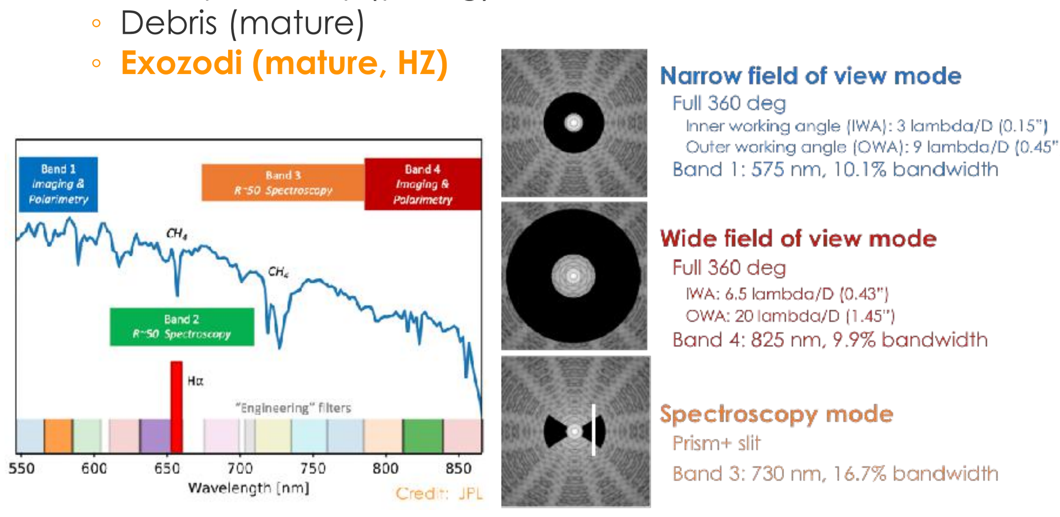
THE ROMAN MISSION

The Nancy Grace **Roman** Telescope (formerly WFIRST) is a NASA mission set to launch mid 2020s and will operate at the L2 Sun-Earth Lagrange point. Primarily a super wide field telescope, ROMAN also has a Coronagraph Instrument (CGI) onboard. CGI is a **Tech**nology **Demo**nstrator towards future flagship missions

CORONAGRAPH INSTRUMENT

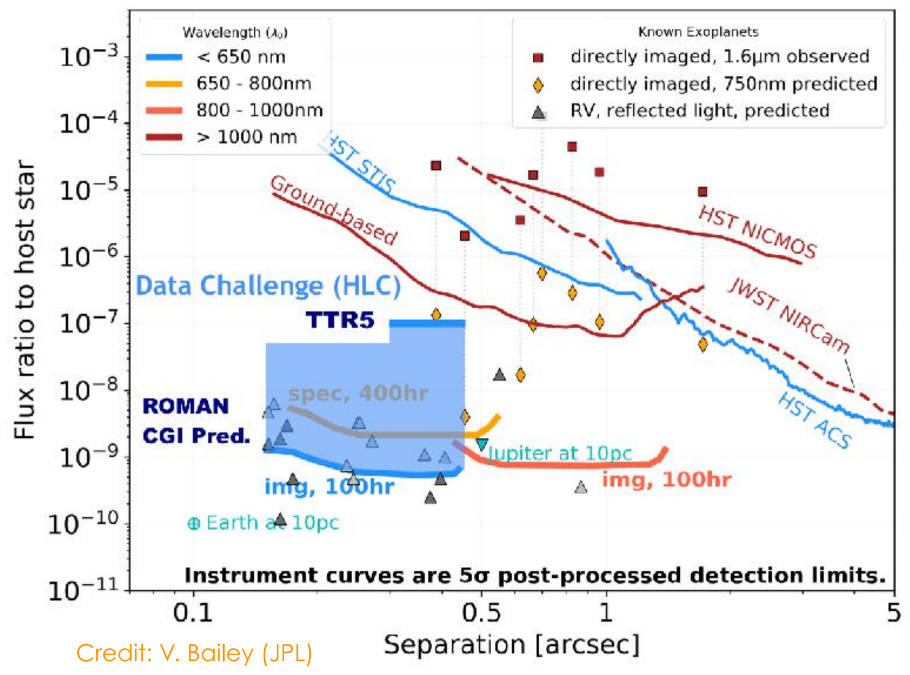
CGI's SCIENCE THEMES (TACKLED BY DC)

- **Mature Jupiter Analogues in reflected light**
  - **Blind search for exoplanets**
  - **Orbital solution, mass measurements**
  - Atmospheric properties
- Self-luminous, Young Super Jupiters
- **Circumstellar disks**
  - Protoplanetary (young)
  - Debris (mature)
  - **Exozodi (mature, HZ)**



CGI's MODES & CONTRAST REGIME

The DC makes use of of the narrow field mode of the HLC coronagraph at the shortest wavelength (575nm, band 1). The DC contrast regime rather optimistic, close to the CGI prediction line (bottom).



Credit: V. Bailey (JPL)

BLIND SEARCH & ASTROMETRY

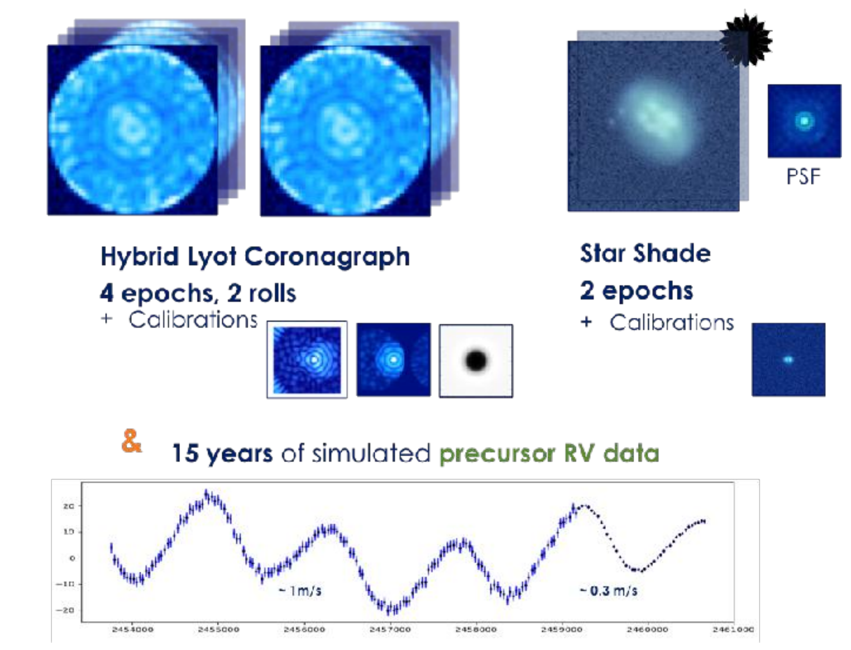
The **scope** of the challenge is **to unveil an exoplanetary system** of at least one planet **hidden** in **realistic CGI data** which includes wavefront control residuals, detector modeling & astrophysical contamination. Participating teams were given **6 imaging epochs** of the same target throughout mission, the nearby star 47 UMa as well as **calibration files** corresponding to the Observing Senario 6 (OS6) and ~15 years of simulated **precursor radial velocity data**.

> ***CGI is our best shot as a community to access these contrasts enabling direct imaging of exoplanets in reflected light in the 2020s***

INPUT DATA

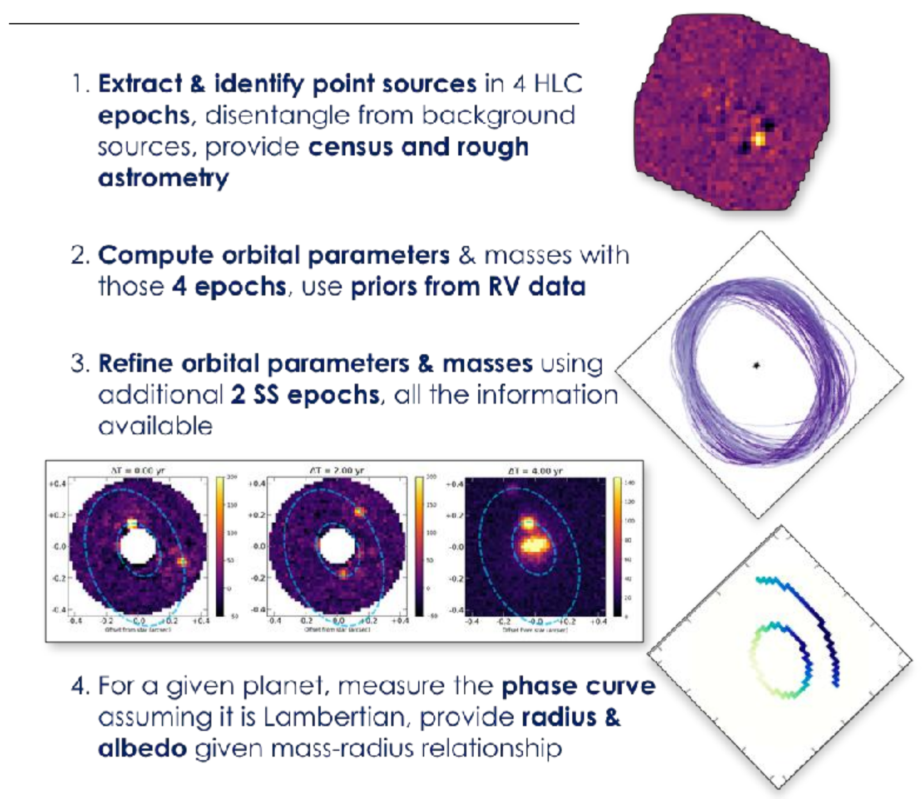
6 imaging epochs throughout the mission

Realistic simulations: OS6 Speckle field time series, detector model, background contamination sources, exozodiacal light



4 STEPS

1. **Extract & identify point sources** in 4 HLC **epochs**, disentangle from background sources, provide **census and rough astrometry**
2. **Compute orbital parameters** & masses with those **4 epochs**, use **priors from RV data**
3. **Refine orbital parameters & masses** using additional **2 SS epochs**, all the information available
4. For a given planet, measure the **phase curve** assuming it is Lambertian, provide **radius & albedo** given mass-radius relationship



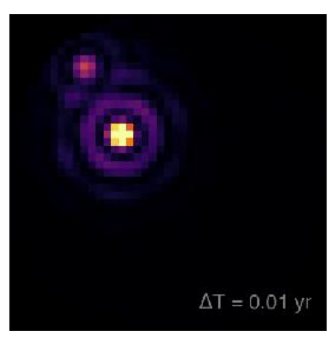
Note: Rehearsal data

DESIGN OF THE CHALLENGE

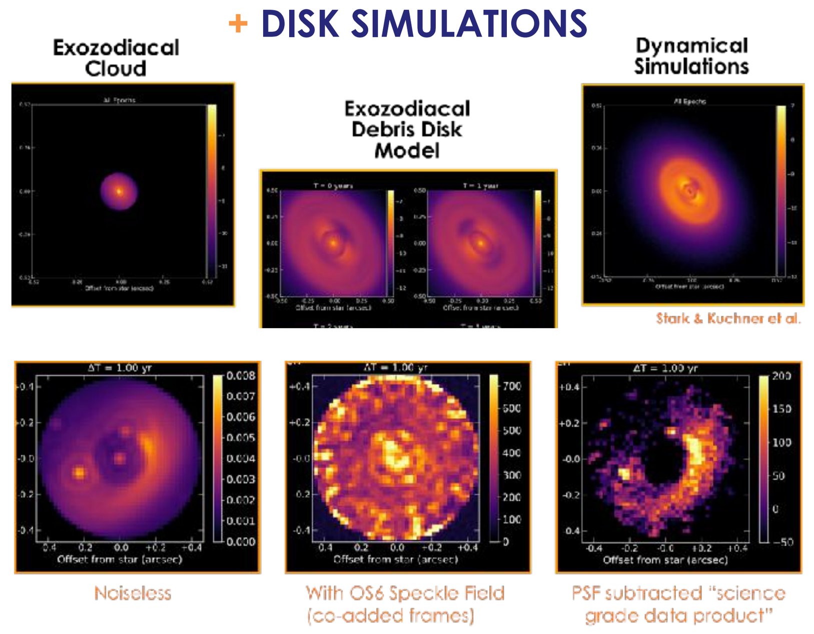
Our team designed the challenge to lear a maximum, to prepare as a community for when the CGI data will be available. Will we be able to discriminate planets from speckle or contaminants? How many epochs are needed to derive a meaningful mass? Can we **cope with the exozodiacal light?**

HLC POINT SOURCE SIMULATIONS

3 planets were inserted. Here's a 10-year movie of the system as seen by the HLC. One can see the flux of the planets greatly change with their position (phase in reflected light).



+ DISK SIMULATIONS

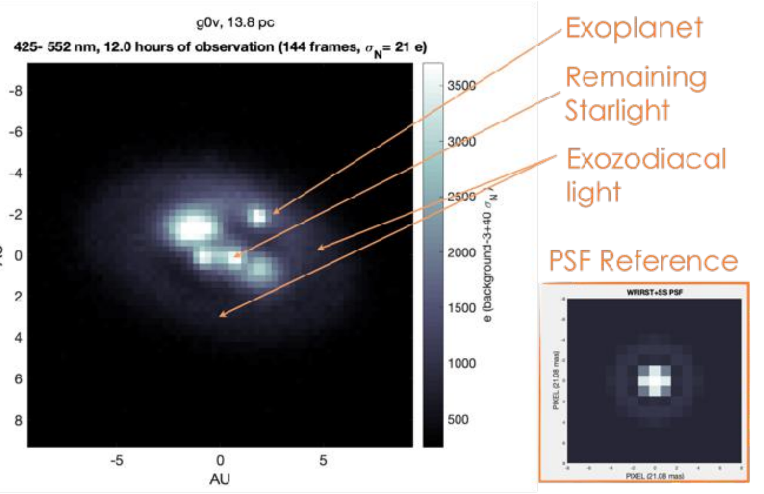


+ ASTROPHYSICAL CONTAMINANTS GALACTIC & EXTRAGALACTIC

= NOISELESS RAW PROCESSED DATA

STAR SHADE SIMULATIONS

In the event of a Rendez-vous towards the end of the mission, we included two epochs of Star Shade simulations (Sergi Hildebrandt, JPL).

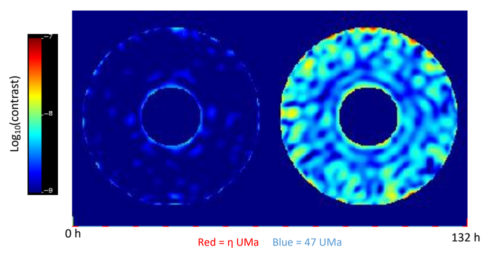


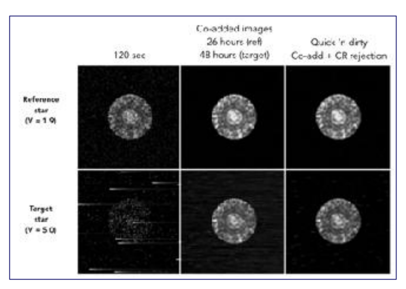
HLC OBSERVING SCENARIO 6

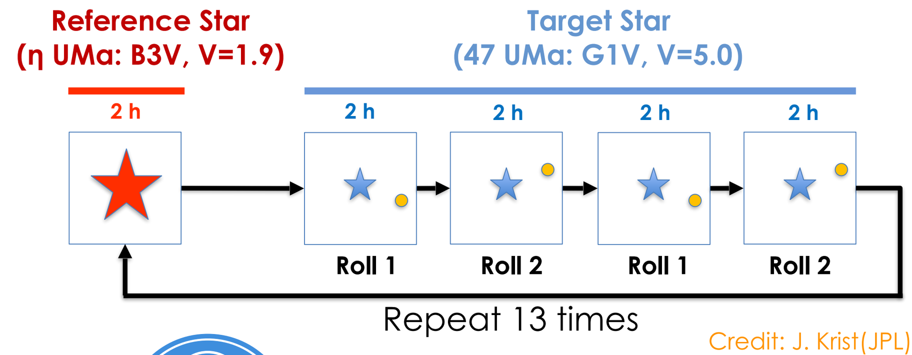
OS6 consist of digging a dark hole with a brighter reference star for 2h, then switching to the target star with four 2h sequences alternating roll positions (separated by 26°) and then repeating the whole sequence.

SPECKLE TIME SERIES SIMULATIONS

The realistic raw data simulations is performed at JPL (John Krist and others). They account for thermally-induced wavefront variations, pointing jitters, optical Model Uncertainty Factors (MUFs, right in the video bellow) and detector modeling (EMCCD detector in photon counting mode).







Credit: J. Krist(JPL)

MOTIVATIONS

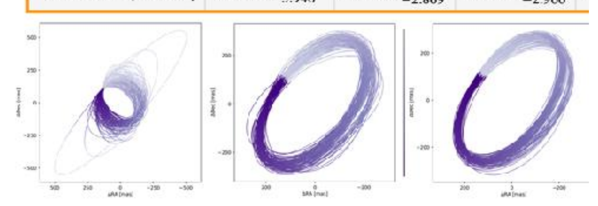
To **broaden and deepen our knowledge as exoplanet community**; To **get the community acquainted with the CGI data**: new contrast regime/astrophysics enabled: giant planets in reflected light; To **develop, use and improve data simulation and analysis tools**, cross-techniques (Direct Imaging, Radial Velocity); To **foster collaborations** and **train future exoplanet scientists!**

TRAINING

We organized 4 tutorial events in 2019 to get as many people on-board. This precious training material (mainly Jupyter notebooks written in Python) will remain online. A diverse crowd of ~70 persons participated to our events

IN HOUSE ANALYSIS

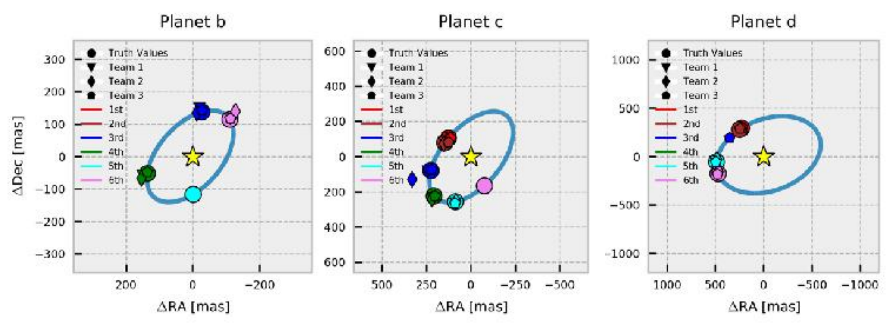
Orbital Parameters	2 epochs	3 epochs	4 epochs
str21	str29	str28	str28
semimajor axis (AU)	$4.236^{+0.217}_{-0.208}$	$4.202^{+0.147}_{-0.143}$	$4.234^{+0.119}_{-0.099}$
eccentricity	$0.073^{+0.032}_{-0.032}$	$0.066^{+0.019}_{-0.020}$	$0.067^{+0.017}_{-0.021}$
inclination (radians)	$64.978^{+11.730}_{-5.946}$	$58.765^{+2.151}_{-2.869}$	$58.591^{+1.794}_{-2.966}$



To have a baseline to compare the participants' results with. We used RadVel (Fulton) to get RV priors & Orbitize (Blunt+) to perform orbital fits. For planet c (the easiest), **3 epochs** is the "sweet spot"

PRELIMINARY RESULTS

3 teams were able to identify correctly the 3 planets and got impressively accurate astrometry.



FINAL RESULTS

Our analysis nearly complete We will organize a dedicated virtual event in early 2021 to announce the winner(s) and prizes.

LESSONS LEARNED

The DC proved to be an **excellent way to engage** with the intricacies of the first mission to perform wavefront control in space, as a pathfinder to future flagship missions with high contrast. It also generated a lot of positive interactions between open source package owners and a diverse crowd of young exoplanet scientists running them.

5 teams have produced astrometric solutions for at least one planet. **1 team has been able to recover a challenging planet** in some epochs for which we thought it was not possible! Post-processing and experience on precursor data helps! All struggled with calibrating photometry.

Some participants **developed their own tools** rather than use the publicly available packages (potential added value).

We have **papers in preparation**: 1: DC design/concept/in-house analysis of planet c; 2: DC organization and results with participants' contributions, discussions of lessons learned and future Data Challenges / Community Engagement.

ACKNOWLEDGMENTS

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