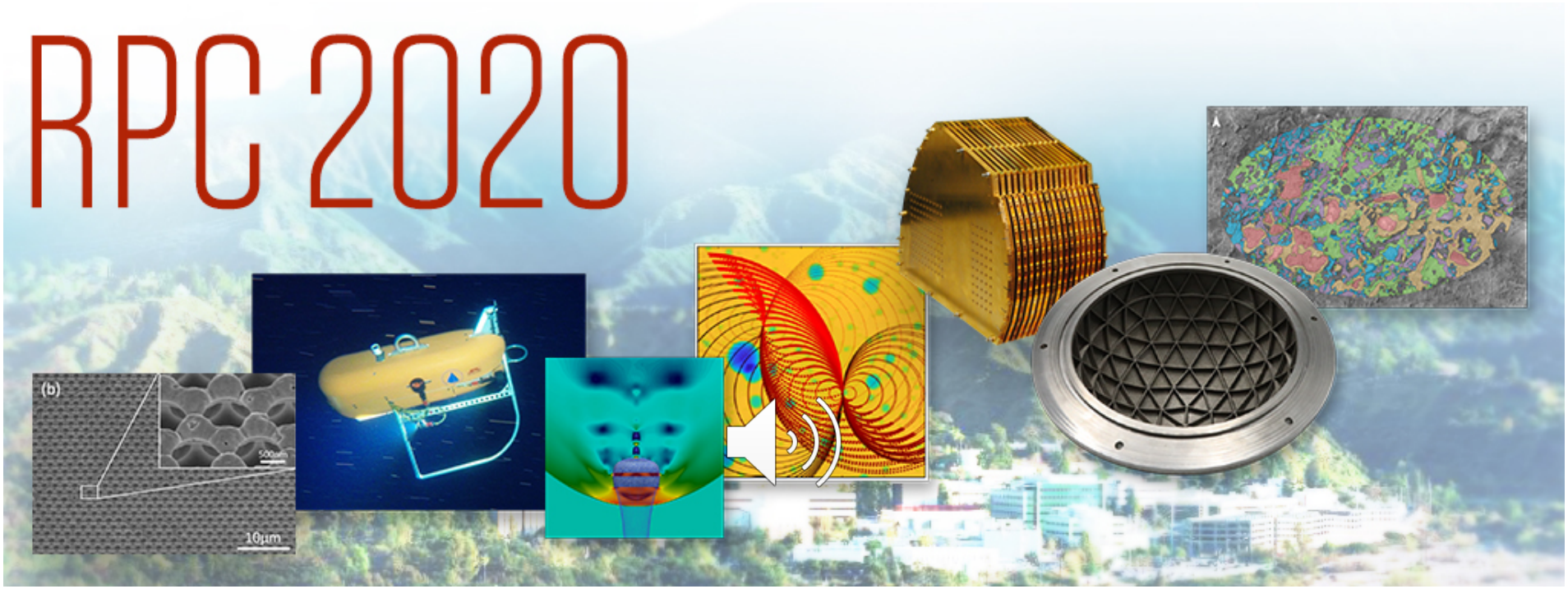

Virtual Research Presentation Conference

Multi-Mission, Multi-Instrument Data Analysis Software for Exoplanet Exploration

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Assigned Presentation RPC-123

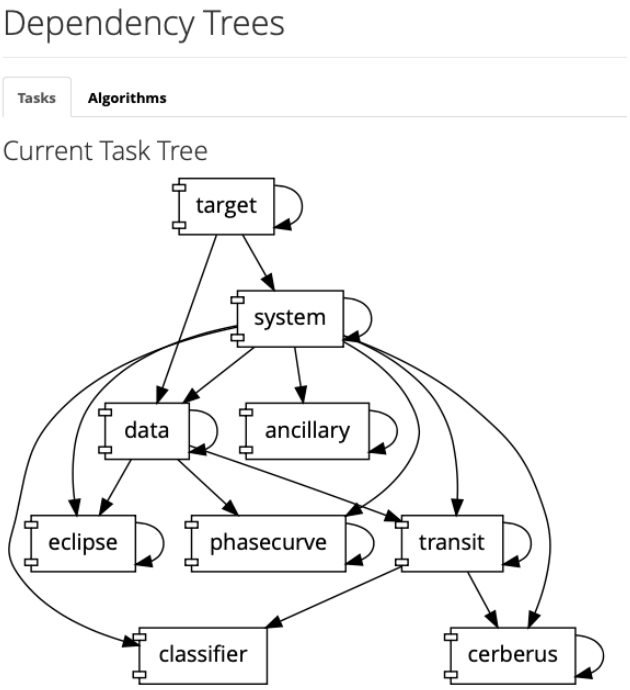
Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Abstract

Comparative planetology of exoplanets requires uniform processing and analysis methods to ensure that apparent differences between measurements are due to planet properties rather than differences in processing methods. To undertake such studies, EXCALIBUR (EXoplanet CALIbration and Bayesian Unified Retrieval), a novel, high-agility, automatous processing tool that maintains the chain of inference through persistent intermediate and final data products. Fresh science data products are maintained by an architecture were processing is triggered on change detection.

Multi-mission, multi-instrument data fusion and processing is monitored by integrated VVUQ (Verification, Validation, and Uncertainty Quantification) capability that includes quality metrics and time series evaluation using classifiers. EXCALIBUR currently processes selected JWST/HST/Spitzer instrument modes that are popular for observing transiting exoplanets and includes a modeling and retrieval capability based on the Cerberus code. A user interface and visualizer function allow users to interact with the data products.



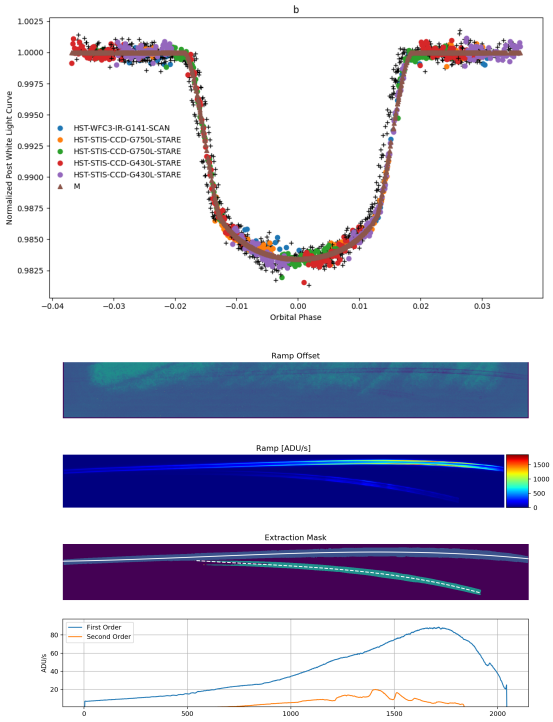
EXCALIBUR task tree.

Problem Description

a) Exoplanets is a rapidly evolving field with new observations constantly being made that add science value to both new and already known science targets. For comparative planetology, we needed a science data pipeline that could stay current with new results including those that characterize the parent star. Because of the large numbers of exoplanets and observations and the rapid pace of new measurement growth, we needed a highly automatous processing capability.

b) The concept of a uniform analysis for studying properties of a sample is well established and there are pipelines for transit spectroscopy that implement uniform processing for some instruments. But the high-agility process on change architecture, scale of processing, and breadth of data fusion appears unique, to our knowledge, in astrophysics. Outside of astrophysics, Google Earth has a conceptual similarities to EXCALIBUR.

c) EXCALIBUR will help maximize the exoplanet science impact of missions such as Hubble, Spitzer, and JWST. EXCALIBUR is also baselined as the science data system for the CASE Mission of Opportunity.

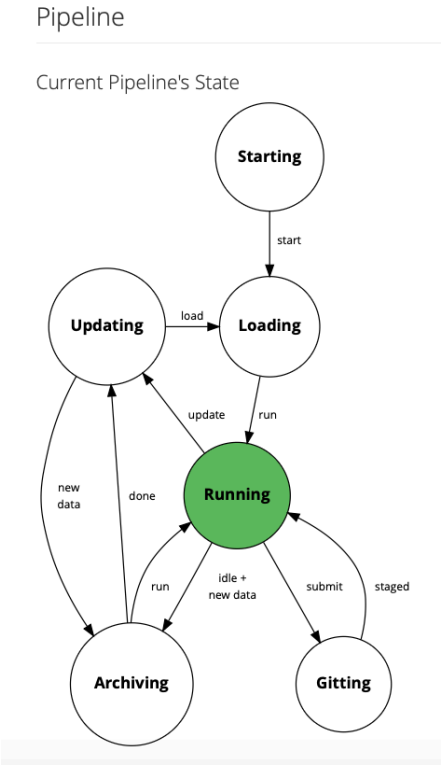


Top: EXCALIBUR Hubble multi-instrument transit light curve. **Bottom:** EXCALIBUR spectral extraction for JWST NIRISS simulated data.

Methodology

EXCALIBUR is a new type of science data pipeline. It is not something that a user "runs" when they want a result. EXCALIBUR is always "running," and it tells the user when a new result exists. This means that EXCALIBUR is always providing the current best estimate of the science data products. These data products depend on multiple inputs, including stellar parameters, planet ephemeris parameters, transit spectroscopy observations, and data reduction algorithms.

EXCALIBUR builds a directed graph from registered tasks and data objects identified with a unique hash. If any of the registered tasks/objects changes, EXCALIBUR rebuilds the directed graph and processes all dependencies from the change point(s). All intermediate and final data products are assigned a unique identifier so that the products can be assessed as a function of changes. EXCALIBUR has the capability to auto-scrape astronomical archives. All processing is automatic and algorithmic. EXCALIBUR is written in Python 3 and implements a fully scalable work-farm architecture to exploit cluster and cloud computing using docker container technology.



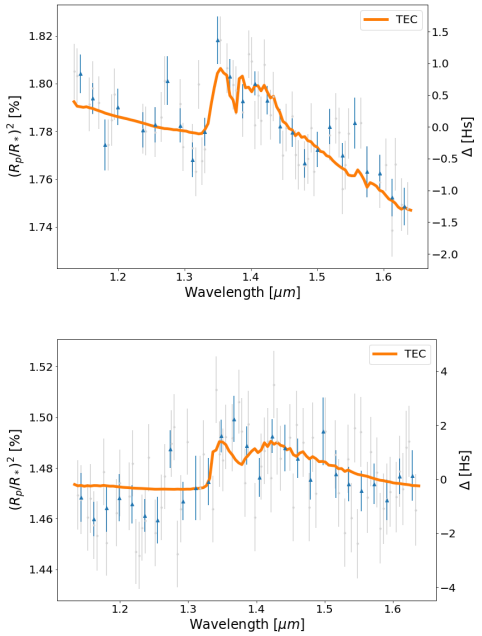
EXCALIBUR spends most of the time in the "running", either looking for changes or processing after a change detection.

Results

a) Accomplishments: The development of EXCALIBUR led to the development and demonstration of novel capability. This effort also resulted in three new NTRs and in EXCALIBUR winning an honorable mention in the 2018 JPL Software of the Year Award. With respect to the goals, we have accomplished implementation of the envisioned EXCALIBUR science data pipeline functions but publications have taken longer than originally planned.

b) Significance: EXCALIBUR establishes a new processing model for astrophysics data and adds new capability for comparative exoplanetology. Two peer reviewed science papers are submitted reporting significant findings that, in both cases, leveraged the unique capabilities of EXCALIBUR.

c) Next steps: Publish more EXCALIBUR enabled science results and work towards making the EXCALIBUR science data products a community resource.



Comparative planetology: these Hubble transit spectra show the presence of water but different amounts of atmospheric haze.

Publications

[1] Swain, M. R., Estrela, R, Christophe S., Roudier, G. M., Zellem, R. T. “Two Terrestrial Planet Families with Different Origins” 2019 Astrophysical Journal, 881, 117S

[2] Estrela, R., Swain, M. R., Gupta, A., Sotin, C. Valio, A. “The Evolutionary Track of H/He Envelopes of the Observed Population of Sub-Neptunes and Super-Earths” 2020 The Astrophysical Journal, Volume 898, Issue 2, id.104.

[3] Roudier, G. M., Swain, M. R., Gudipati, M. S., West, R. A., Estrela, R., Zellem, R. T. “Title Embargoed” The Astrophysical Journal - *submitted*

[4] Swain, M. R., Estrela, R., Roudier, G., Sotin, C., Rimmer, P., Valio, A., West, R., Pearson, K., Huber-Feely, N., Zellem, R. “Title Embargoed” Science - *submitted*