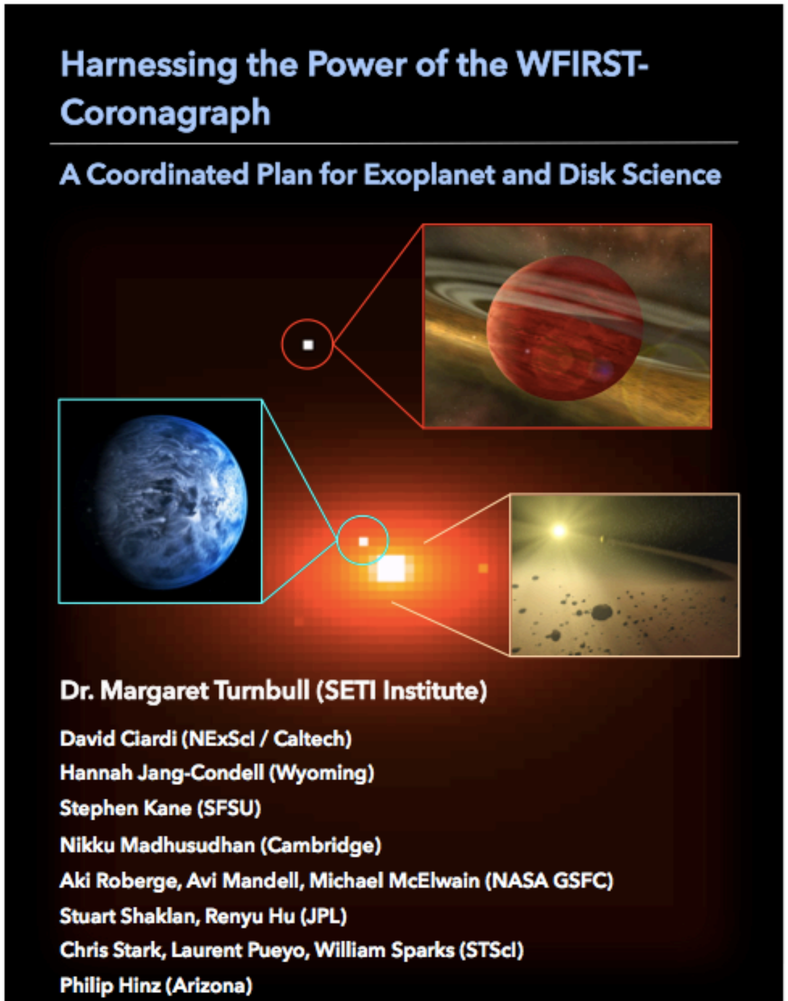
Harnessing the Power of the WFIRST-Coronagraph

A Coordinated Plan for Exoplanet and Disk Science

Dr. Margaret Turnbull (SETI Institute)

David Ciardi (NExScI / Caltech)
Hannah Jang-Condell (Wyoming)
Stephen Kane (SFSU)
Nikku Madhusudhan (Cambridge)
Aki Roberge, Avi Mandell, Michael McElwain (NASA GSFC)
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Chris Stark, Laurent Pueyo, William Sparks (STScI)
Philip Hinz (Arizona)

Exoplanet Data Challenge

Sergi Hildebrandt (srh.jpl.caltech@gmail.com)
Maggie Turnbull (turnbull.maggie@gmail.com)

Exoplanet Data Challenge*

Exoplanet Data Challenge #1: Test spectral retrieval using synthetic planet spectra with instrumental noise. This exercise will help reveal model-dependent interpretations of noisy data. It is led by Sergi Hildebrandt and Maggie Turnbull. Cycle 1: 2016-17. Cycle 2: 2017-18.

Exoplanet Data Challenge #2: Test post-processing and source extraction techniques with spectral image cubes containinng only a star and planets, processed with a simple instrument model. This exercise is intended as practice to begin developing the techniques.is led by Maxime Rizzo and Aki Roberge. Cycle 1: 2017-18

Exoplanet Data Challenge #3: Add astrophysical background sources to the data cubes, processed with the project's WFIRST instrument model.

Exoplanet Data Challenge #4: Add interplanetary dust for a complete exercise in harvesting scientific results from realistic simulated data

(*) In the proposal, the Exoplanet Data Challenge (EDC) was called Community Data Challenge (CDC)

Exoplanet Data Challenge

Exoplanet Data Challenge #1**:** Test spectral retrieval using synthetic planet spectra with instrumental noise. This exercise will help reveal model-dependent interpretations of noisy data. It is led by Sergi Hildebrandt and Maggie Turnbull.

Cycle 1: 2016-17. Simple planet atmospheres and simple WFIRST IFS instrumental models.

Cycle 2: 2017-18. More realistic atmospheres and latest available WFIRST IFS and CGI instrumental models.

The Exoplanet Data Challenge is possible thanks to a collaborative effort of many people across several institutions.

UNIVERSITY OF OXFORD

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Larry Sromovsky
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Mark Marley
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Mikey Nayak

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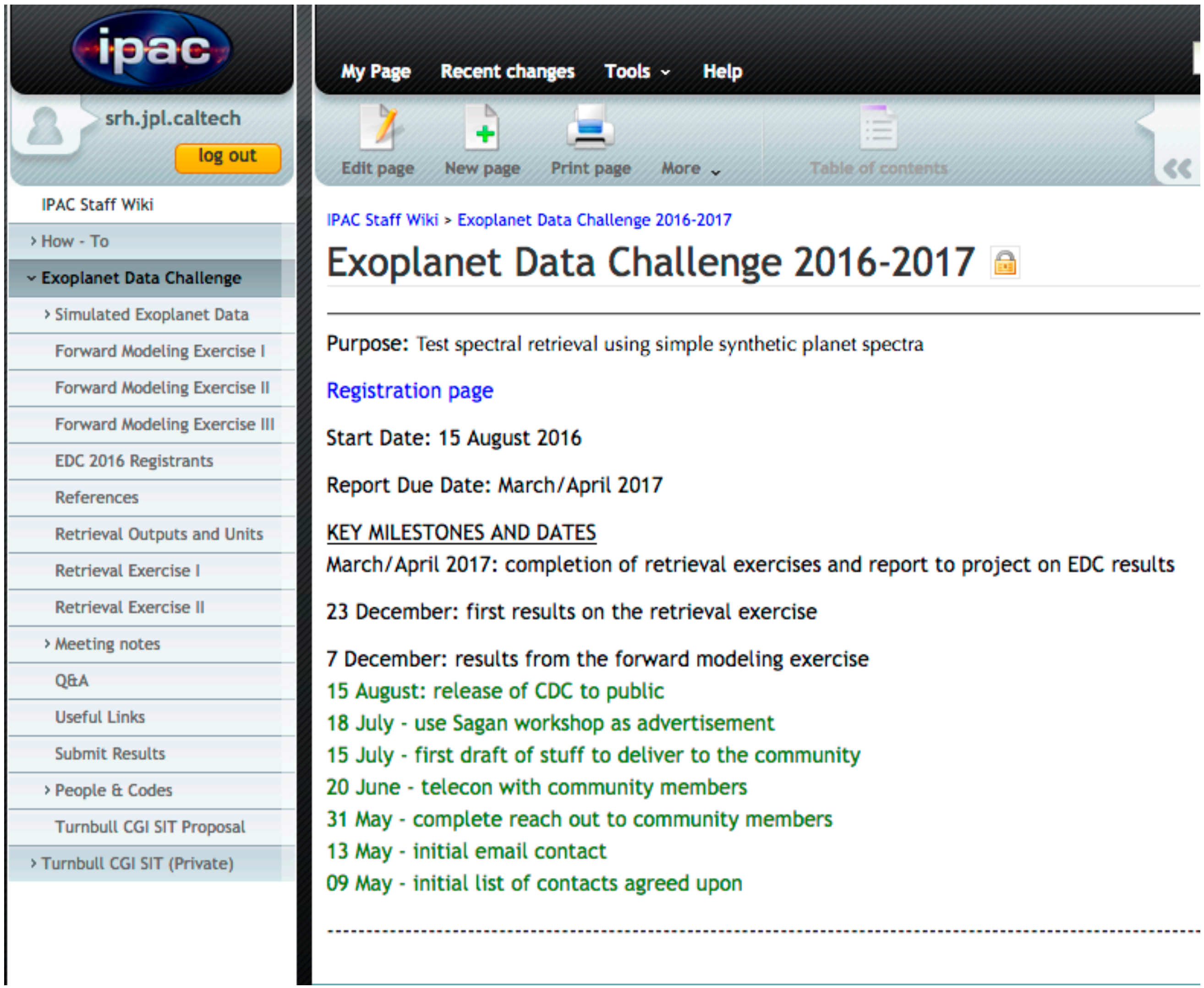
Maxime Rizzo
Aki Roberge

IoA UNIVERSITY OF CAMBRIDGE

Nikku Madhusudhan

Exoplanet Data Challenge

EDC Wiki space



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IPAC Staff Wiki

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⌄ Exoplanet Data Challenge

› Simulated Exoplanet Data

Forward Modeling Exercise I

Forward Modeling Exercise II

Forward Modeling Exercise III

EDC 2016 Registrants

References

Retrieval Outputs and Units

Retrieval Exercise I

Retrieval Exercise II

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Q&A

Useful Links

Submit Results

› People & Codes

Turnbull CGI SIT Proposal

› Turnbull CGI SIT (Private)

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IPAC Staff Wiki > Exoplanet Data Challenge 2016-2017

Exoplanet Data Challenge 2016-2017

Purpose: Test spectral retrieval using simple synthetic planet spectra

Registration page

Start Date: 15 August 2016

Report Due Date: March/April 2017

KEY MILESTONES AND DATES

March/April 2017: completion of retrieval exercises and report to project on EDC results

23 December: first results on the retrieval exercise

7 December: results from the forward modeling exercise

15 August: release of CDC to public

18 July - use Sagan workshop as advertisement

15 July - first draft of stuff to deliver to the community

20 June - telecon with community members

31 May - complete reach out to community members

13 May - initial email contact

09 May - initial list of contacts agreed upon

Exoplanet Data Challenge: Cycle 1

Methodology of the atmospheric retrieval data production and analysis:

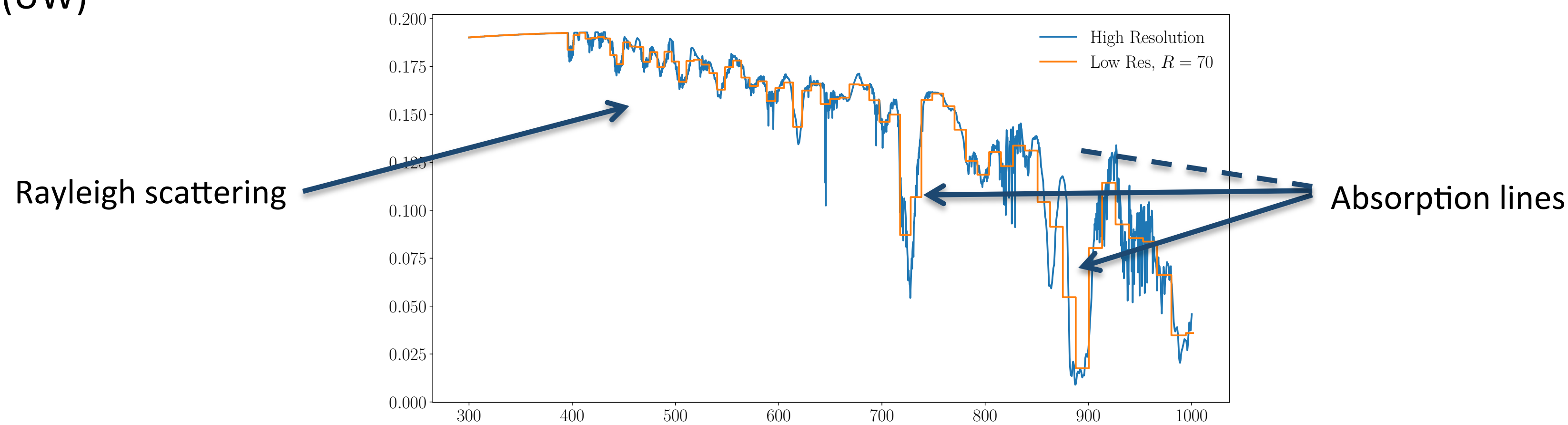
- Data created for different signal to noise ratios: SNR=5, 10 and 20
- For different spectral resolution: R=20, 50 and 70
- Blind analysis: only planet spectra, mass and orbital phase given.
- Results for two Jupiter-like planets (super-Neptune in cycle 2)
- Data analyzed with different atmospheric models (one cloud, two clouds, one cloud and haze, two clouds and haze)

PS: SNR=10 and R=50 may now be the maximum values for WFIRST. Still results from the cases with R70 and/or SNR20 remain highly informative.

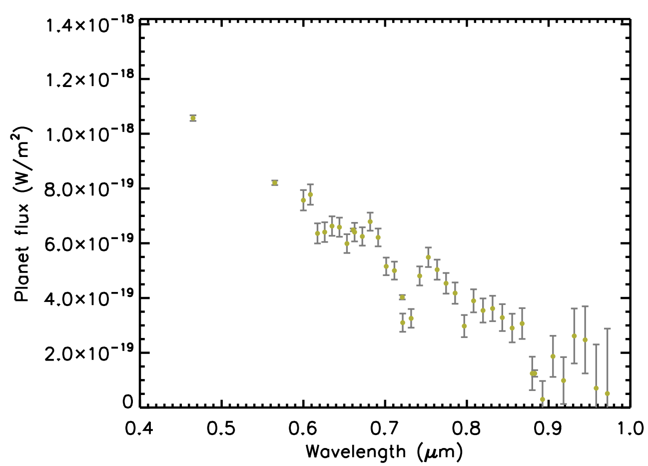
Exoplanet Data Challenge: Cycle 1

Sample of simulated data

- High Resolution spectra from Renyu Hu (JPL), resampled at lower resolution by Jake Lustig-Yaeger (UW)

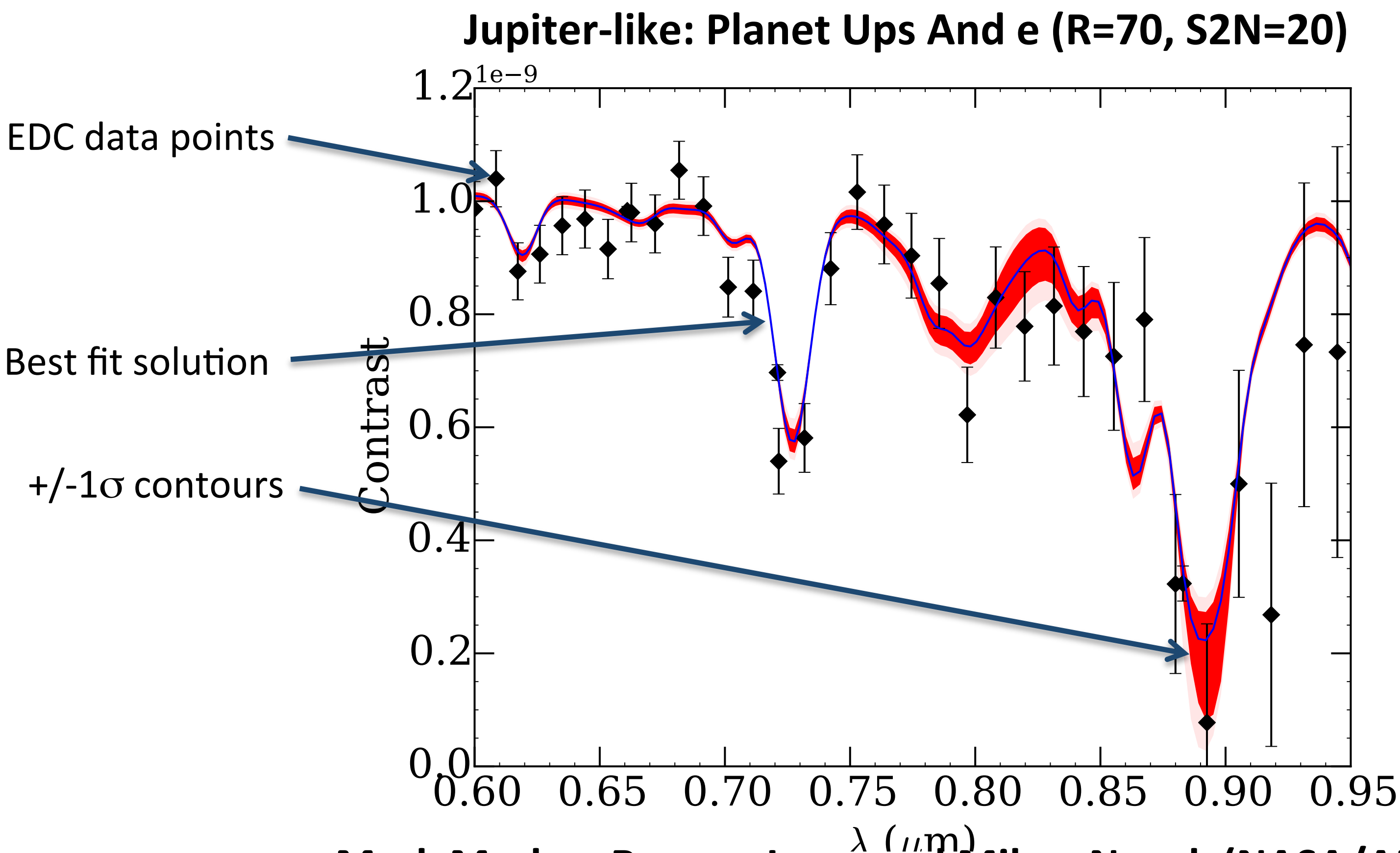


- Addition of instrumental noise and binned into WFIRST resolution by Tyler Robinson (USC)



This is the product given to the EDC participants

Exoplanet Data Challenge: Cycle 1 Results

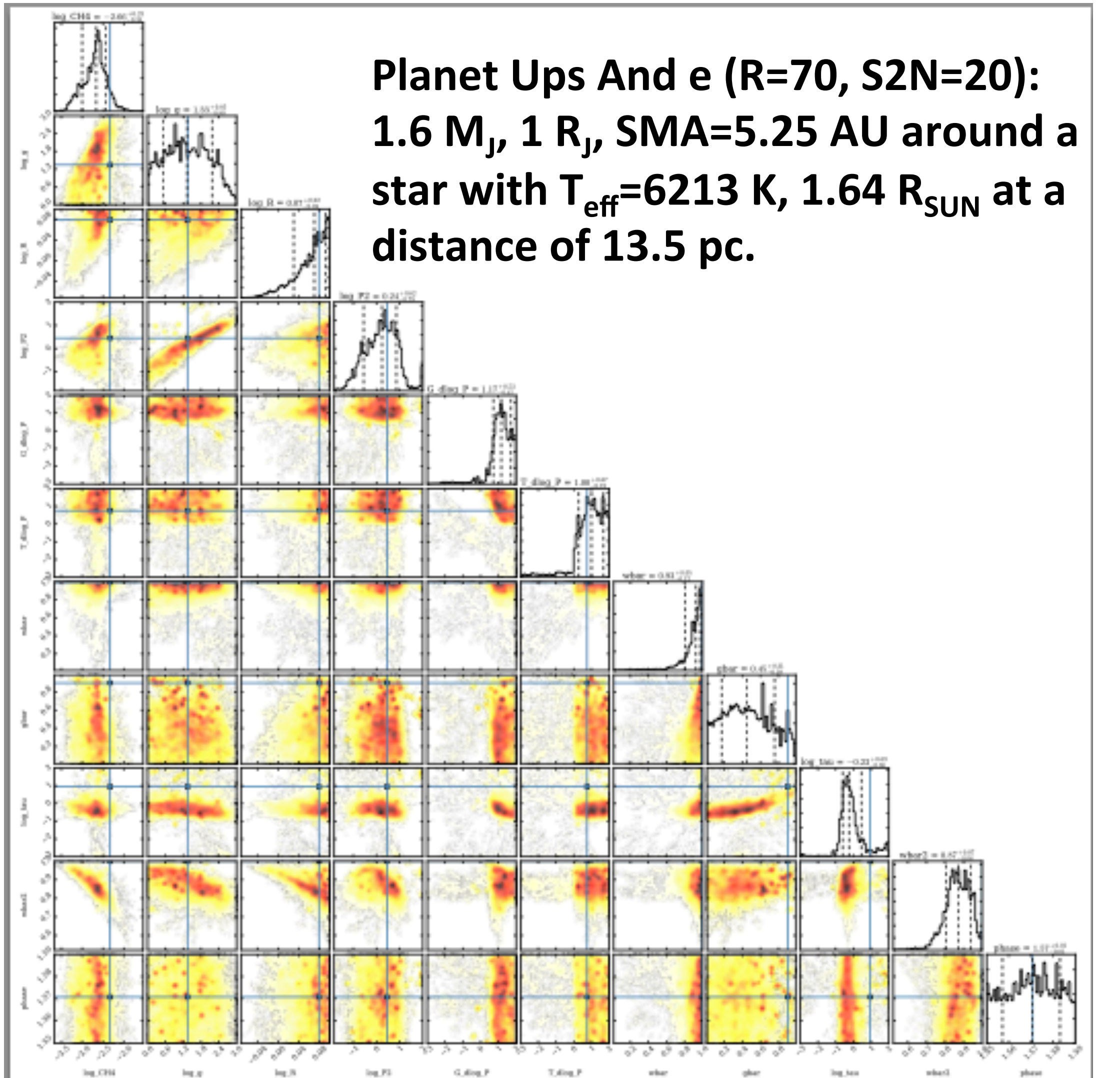


Mark Marley, Roxana Lupu and Mikey Nayak (NASA/AMES)

Obtaining results for one atmospheric model is computationally expensive (order of 1 week, 64 core machine). Some times bad fits happen, and the fit needs to be resubmitted.

Exoplanet Data Challenge: Cycle 1

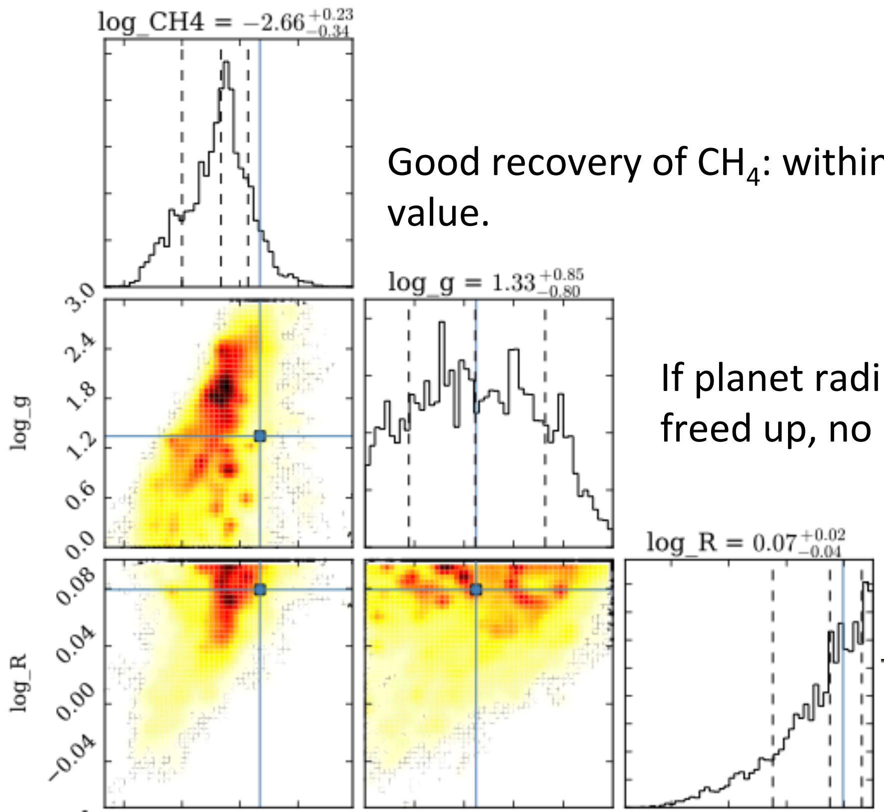
Results



Planet Ups And e (R=70, S2N=20): 1.6 M_J, 1 R_J, SMA=5.25 AU around a star with T_{eff}=6213 K, 1.64 R_{SUN} at a distance of 13.5 pc.

Mark Marley, Roxana Lupu and Mikey Nayak (NASA/AMES)

Exoplanet Data Challenge: Cycle 1
Results

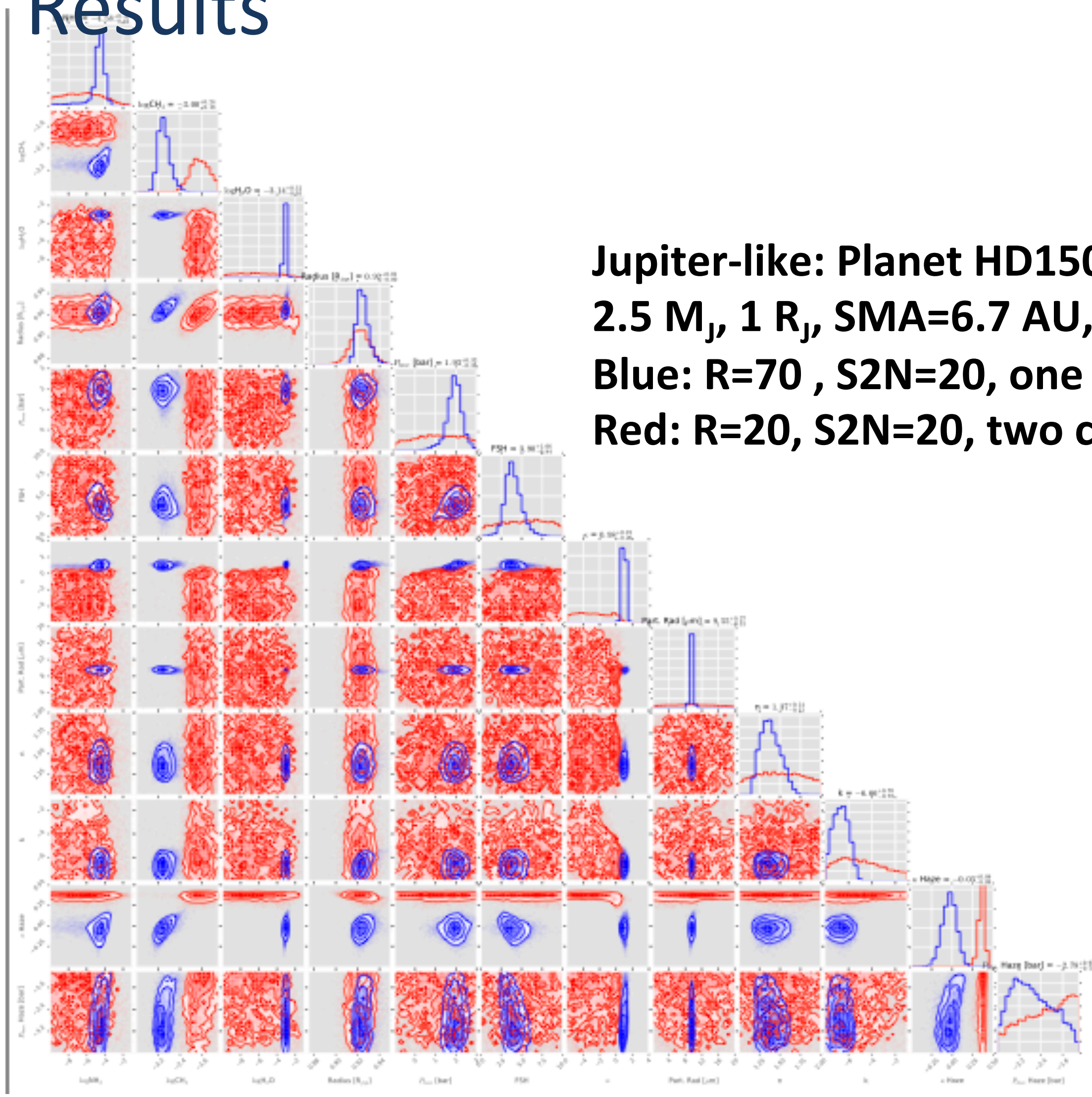


Good recovery of CH_4: within 1 sigma of the input value.

If planet radius and mass are freed up, no much constraint

Exoplanet Data Challenge: Cycle 1

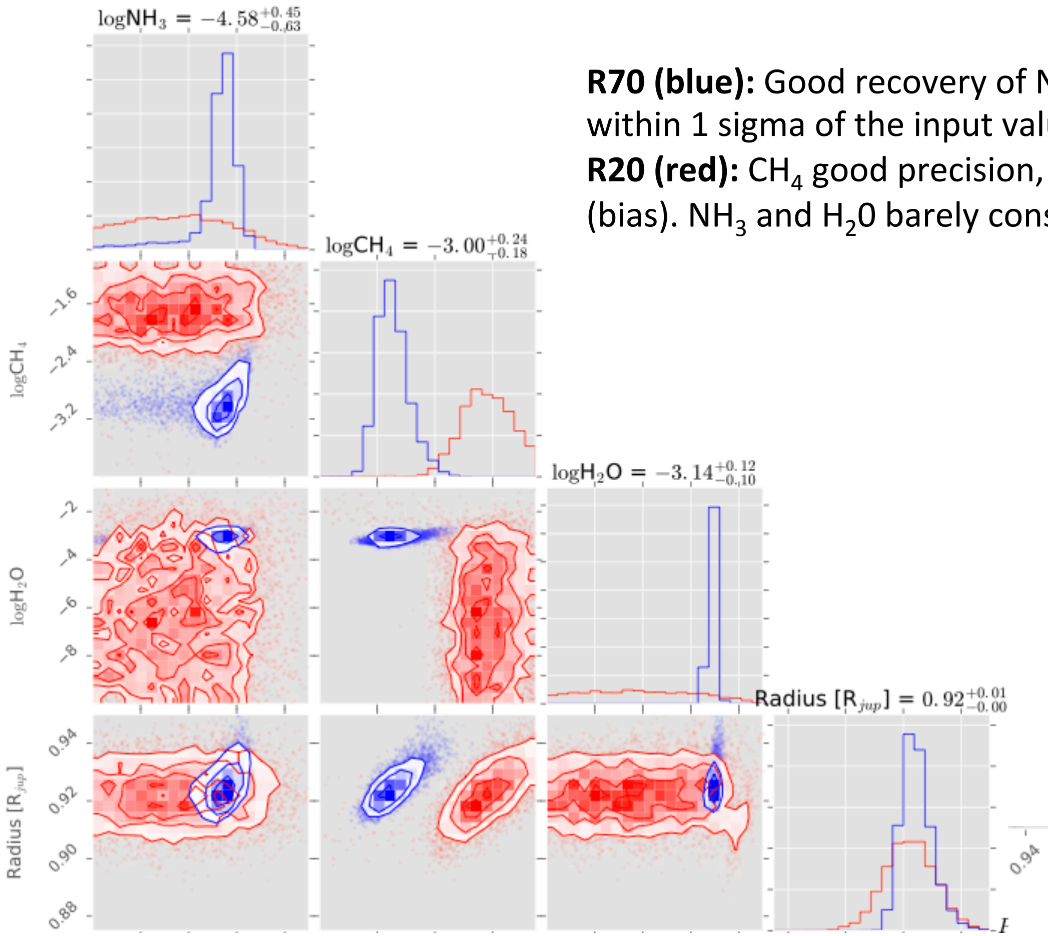
Results



Jupiter-like: Planet HD150706b:
2.5 M_J, 1 R_J, SMA=6.7 AU, Sun-like star at 28.2 pc
Blue: R=70 , S2N=20, one cloud
Red: R=20, S2N=20, two clouds and haze

Pat Irwin, Ryan Garland and Jo Eberhardt (NEMESIS team, OXFORD UNIVERSITY)

Exoplanet Data Challenge: Cycle 1
Results



R70 (blue): Good recovery of NH_3, H_20 and CH_4: within 1 sigma of the input value.
R20 (red): CH_4 good precision, but bad accuracy (bias). NH_3 and H_20 barely constrained

Radius (mass is given to the teams) good precision, but significantly biased (8σ)

Exoplanet Data Challenge: Cycle 1 Summary

- Very valuable information for **WFIRST.**

- Really helpful **comparison** among different retrieval teams: absorption line tables, numerical simplifications, integration methods, simplified retrieval model versus forward model.

- If the planet mass is known, **R70** has enough information for 2 clouds to be detected with reasonable results (Jupiter-like planet around a Sun-like star at 6.7 AU and 28.2 pc).

- Even if the planet mass is known, **R20** is complicated for more information than just a haze, but not a cloud and a haze. Enough information for 1 cloud with reasonable results on CH_4, H_2O, NH_3 and the radius. (Jupiter-like planet around a Sun-like star at 6.7 AU and 28.2 pc).

- Jupiter-like planet around slightly brighter star than the Sun at 13.5 pc can't determine radius and mass, though CH_4 is well determined.

Exoplanet Data Challenge: Cycle 2

- **Cycle 2**: 2017-18. More realistic atmospheres and latest available WFIRST IFS and CGI instrumental models

- **Planets** to be considered:

  - 1 JUPITER-LIKE PLANET
  - 1 SUPER-NEPTUNE

- No Super Earth until the results from these two planets are obtained

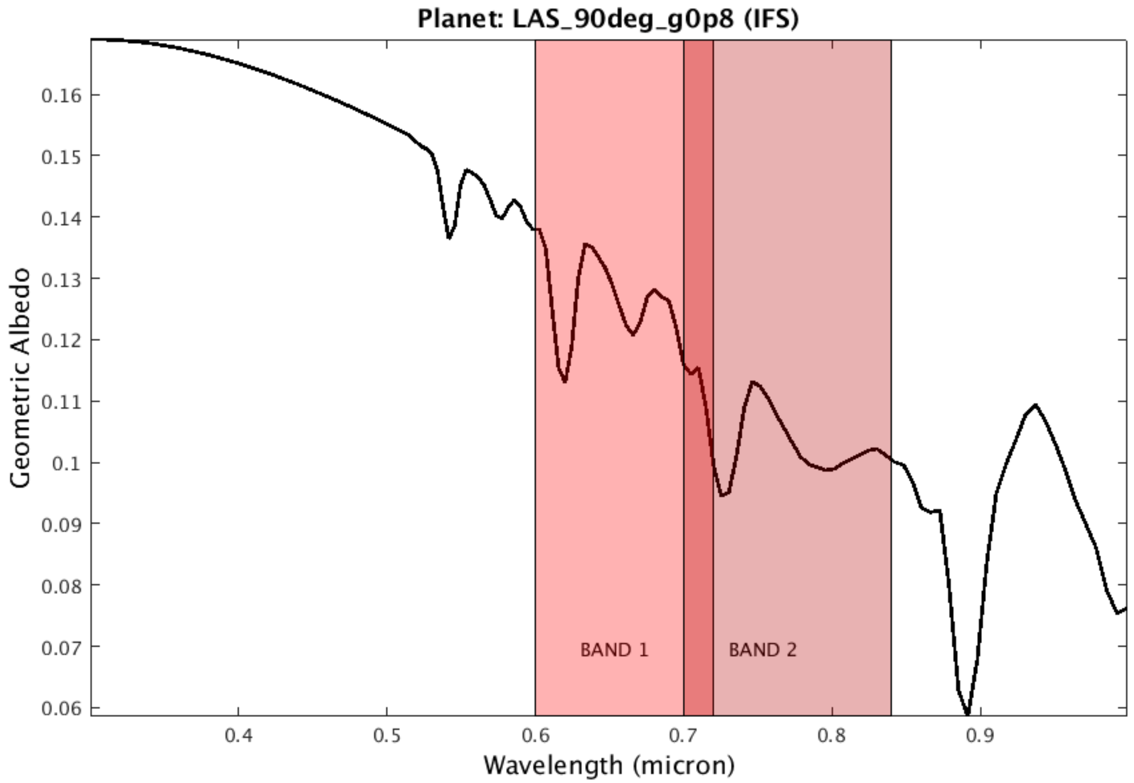
- Impose expected SNR and Resolution Power from Mission specs

Example: Jupiter-like planet, with 1 M_J and 1 R_J in quadrature at 3 AU from a G0V star. Data for the planet flux produced by Larry Sromovsky (SSEC). Other parameters:

Uniformly mixed cloud from 0.1 to 0.2 bars: single-scattering albedo = 0.99, optical depth = 5, Methane vmr = 1E-3 (nCH4/nH2=1.197E-3), nHe/nH2 = 0.19585, isothermal atmosphere at T=140K, NQUAD=16 hemisphere, NAZIMUTH=16 for radiation transfer, ngauss=ntcheb=18 for disk-average integration, RESOLVING POWER = 70, number of wavelengths=170, Collision-induced Absorption assumes Equilibrium H2, Atmosphere has 57 log-spaced layers from 5E-4 to 40 bars, Surface albedo=0.0, gravity = 20 m/s^2.

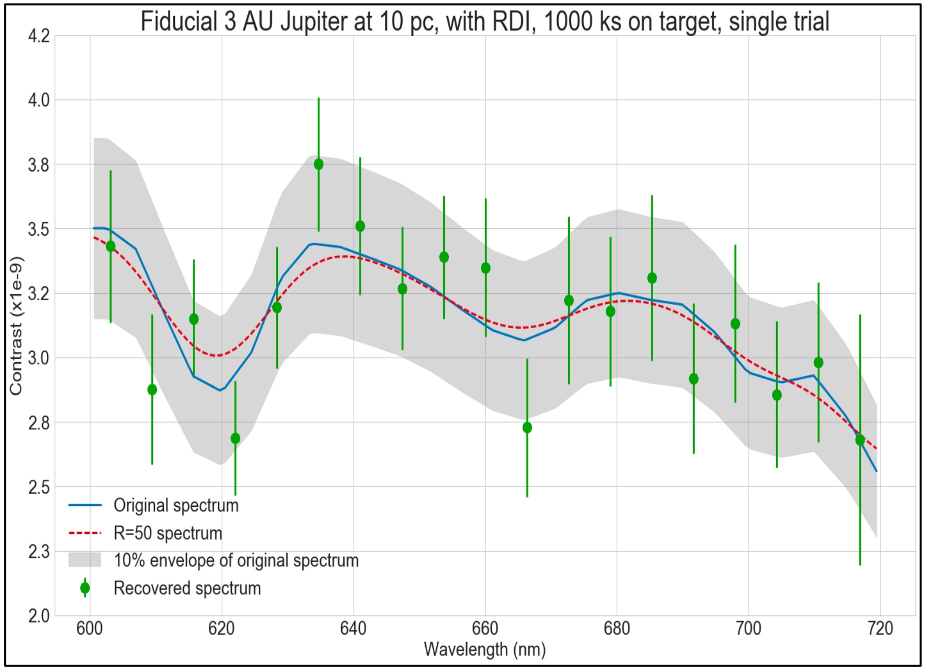
Exoplanet Data Challenge: Cycle 2

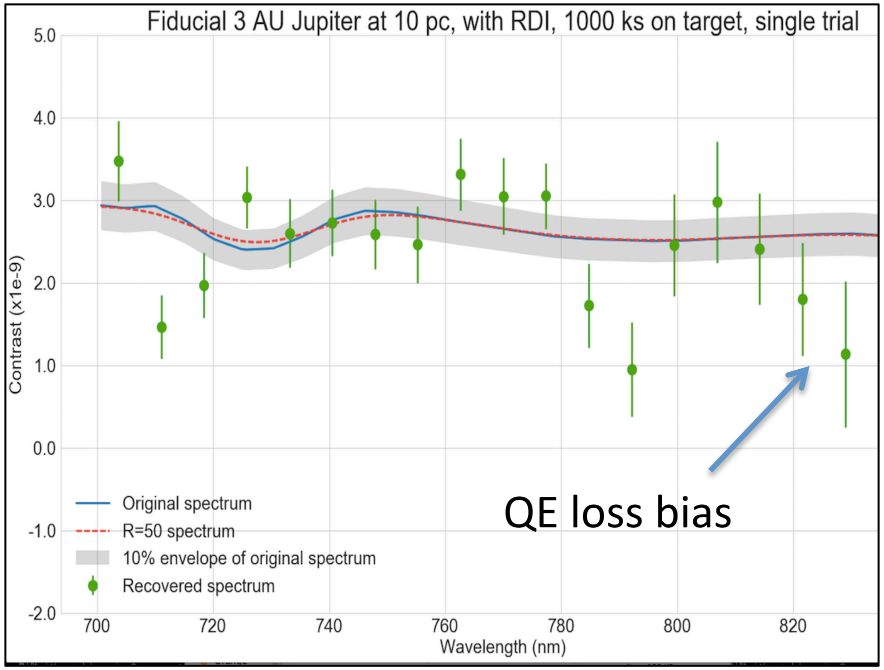
Simulated data



Exoplanet Data Challenge: Cycle 2
Simulated data

Planet flux data are then processed through the WFIRST IFS simulator





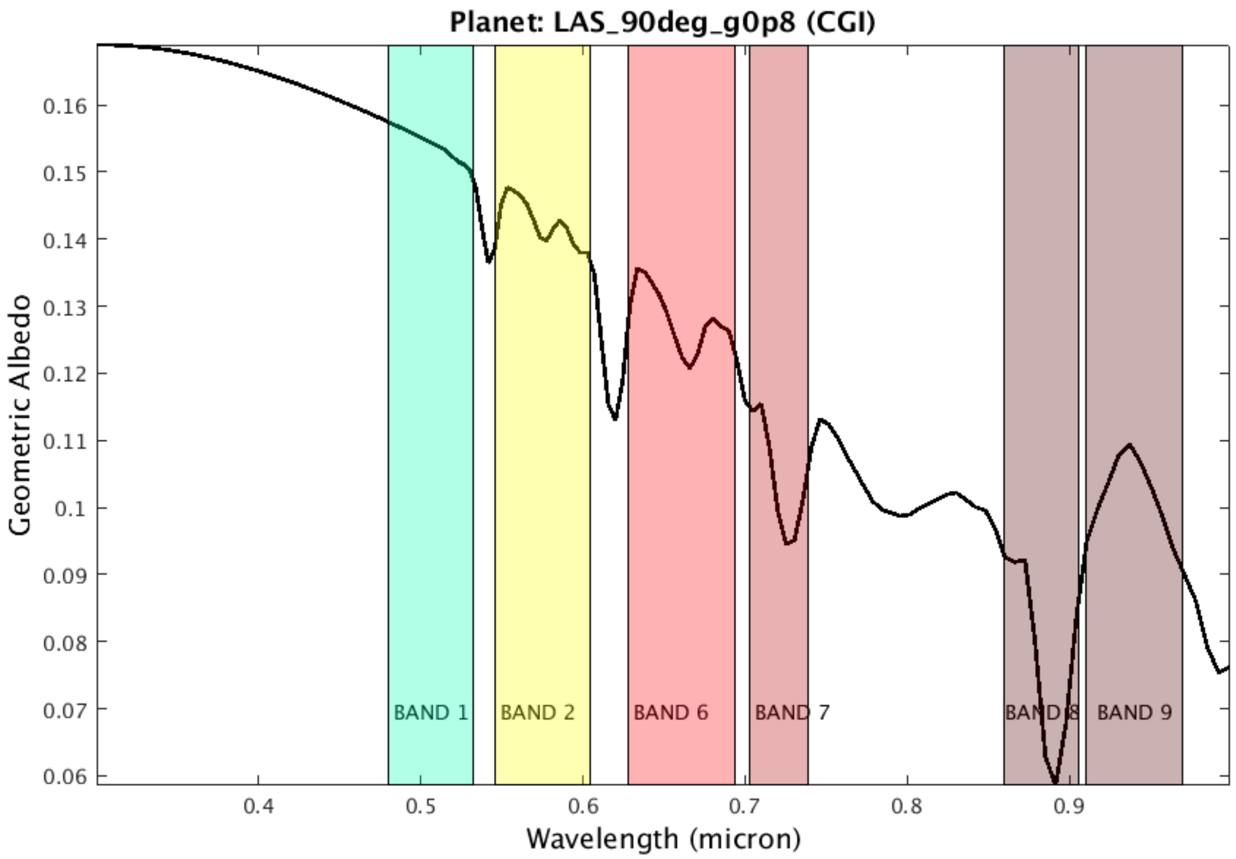
Credit: Maxime Rizzo (GFSC).

PS: RDI = Reference Differential Imaging (for PSF subtraction and flux estimation)

Exoplanet Data Challenge: Cycle 2

Simulated data

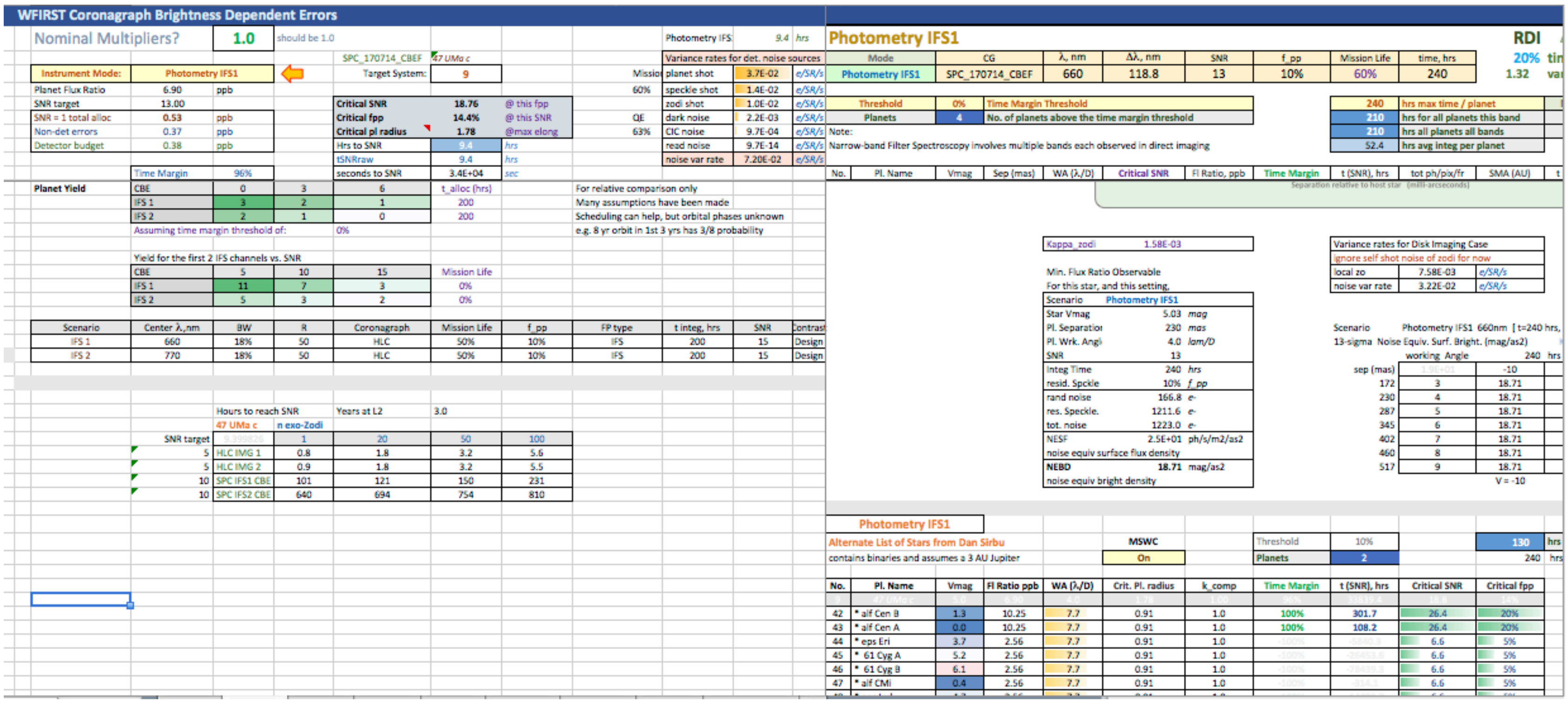
We may add photometric points from the CGI, in addition to the IFS, measurement using some relatively small portion of the IFS integration time.



Exoplanet Data Challenge: Cycle 2

Simulated data

Bijan Nemati (Univ. of Alabama in Huntsville) has written the very complete WFIRST Coronagraph Yield Calculator (Excel and Matlab versions are available).



Exoplanet Data Challenge: Cycle 2

Simulated data

- I have enhanced it by adding the possibility of considering planets with an Albedo that may depend on wavelength and/or orbital phase (until now, the albedo was a constant value across the spectrum).

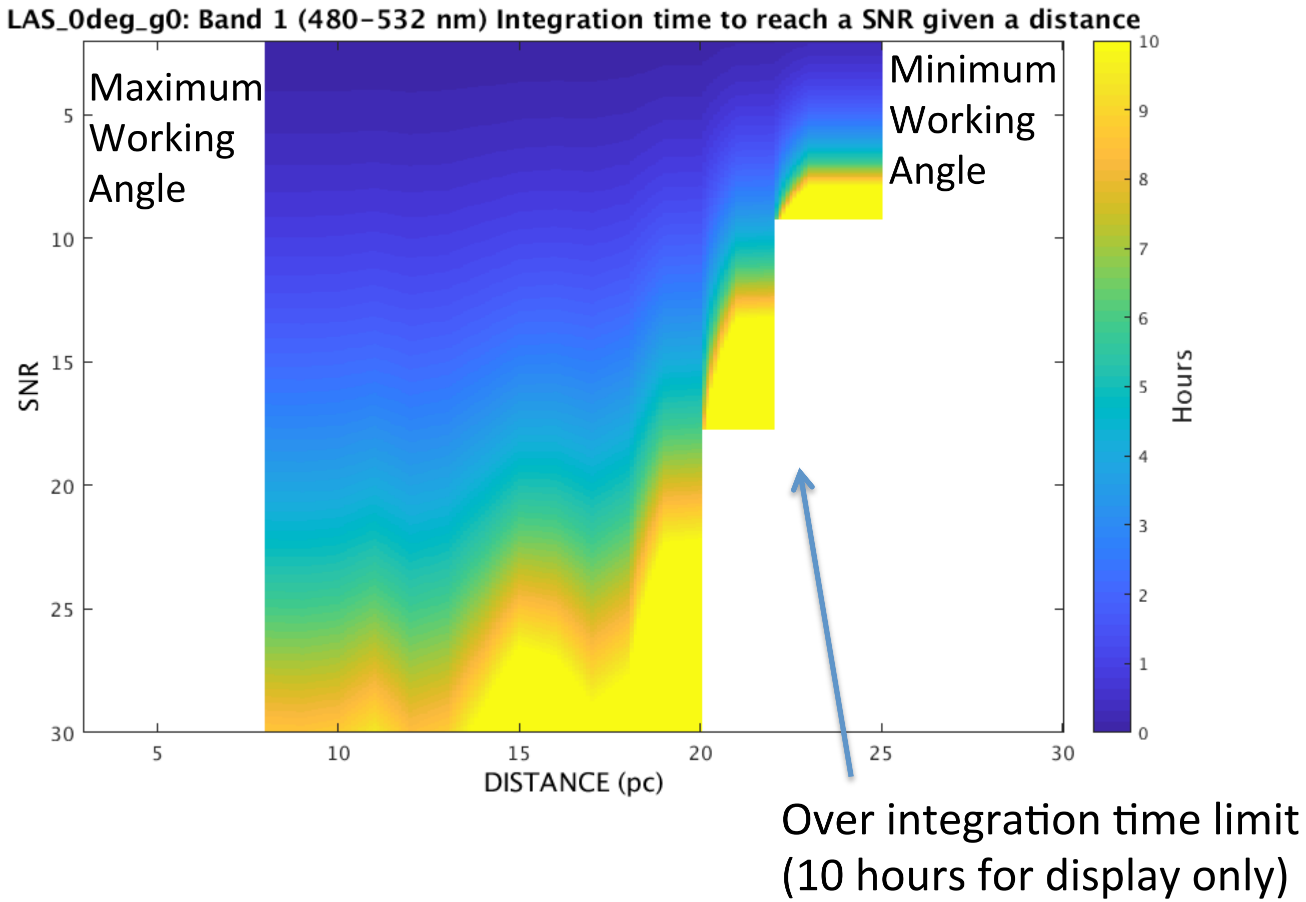
- The WFIRST Coronagraph Yield Calculator can handle any combination of cases for an arbitrary number of planets provided by the user and quickly return the results for the integration times, planet flux, contrast and geometric albedo.

- In the following, I will show the results for the planet considered in this presentation.

Exoplanet Data Challenge: Cycle 2

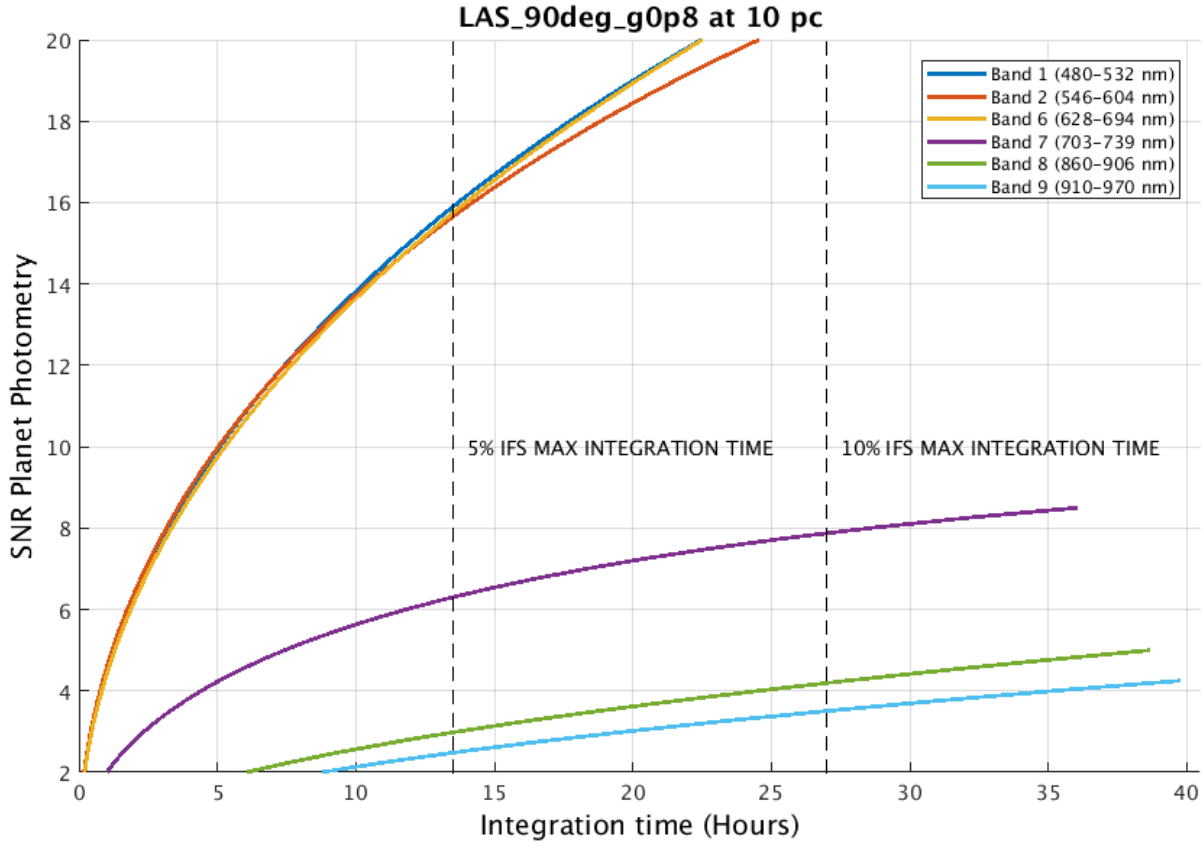
Simulated data

Results from the enhanced WFIRST Yield Calculator: Integration time as a function of the distance to the exoplanet and the SNR to be achieved.



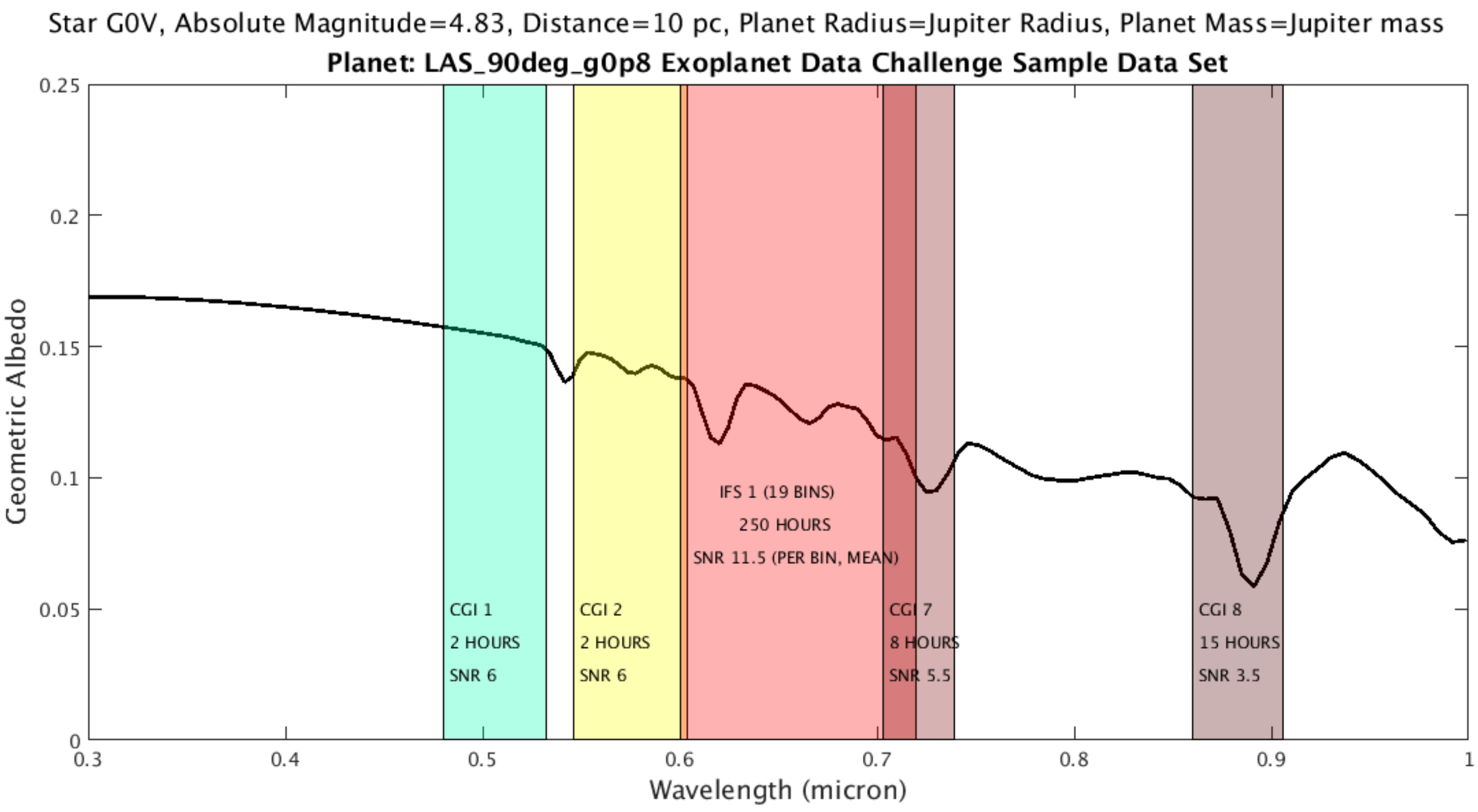
Exoplanet Data Challenge: Cycle 2
Simulated data

Focus on a system at 10 pc (same assumption as in the IFS simulation)



Exoplanet Data Challenge: Cycle 2

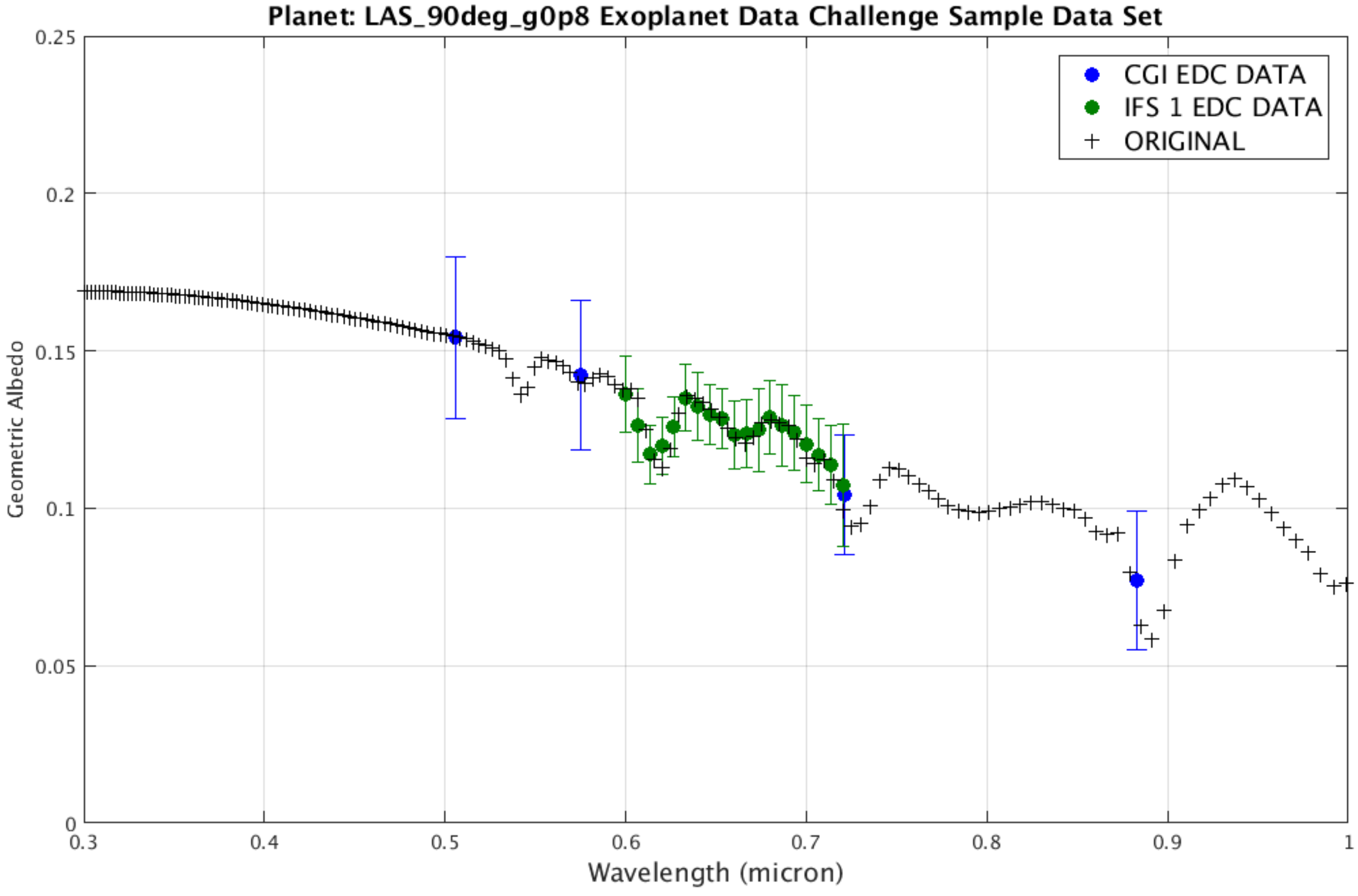
Simulated data



Exoplanet Data Challenge: Cycle 2

Sample of simulated data to be delivered for blind analysis of atmospheric retrieval

Star G0V, Absolute Magnitude=4.83, Distance=10 pc, Planet Radius=Jupiter Radius, Planet Mass=Jupiter mass



Thank you!

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Exoplanet Data Challenge

BACKUP SLIDES

Exoplanet Data Challenge

WFIRST-Coronagraph Exoplanets Data Challenge : Sheet1

	A	B	C	D	E	F	G	H	I	J	K	L
1	System Parameters Provided to Retrieval Teams											
2	Target	HIP#	Age (Gyr)	Distance (pc)	Planet Mass (Mj or Me)	Physical separation (AU) (=semi-major axis?)	Angular separation from star (")	Planet eccentricity	Planet Phase Angle	Stellar Radius (Rsun)	Teff (K)	Bolometric Stellar Luminosity (Lsun)
3	HD 150706 b	80902	3	28.22	2.5Mj	6.7	0.24	0.38	90	1.01	5903	1.11
4	Ups And e	7513	3.12	13.47	1.6Mj	5.25	0.39	0.005	90	1.64	6213	3.64
5	HD 192310 c	99825	9.3	8.91	0.08Mj	1.18	0.13	0.32	90	0.42	5080	0.42
6	tau Ceti - disco	8102	5.8	3.65	2Me	0.72	0.20	0	90	0.83	5283	0.52
7	tau Ceti - disco	8102	5.8	3.65	1.5Me	0.72	0.20	0	90	0.83	5283	0.52

Cycle 1 created simulated data for:

- 5 exoplanets: 2 hot giants, 1 super-Neptune and 2 Earth-like
- Different signal-to-noise ratios: SNR=5, 10 and 20
- Different resolving powers: R=20, 50 and 70

PS: SNR=10 and R=50 may now be the maximum values for WFIRST. Still results from the cases with R70 and/or SNR20 remain highly informative.

Exoplanet Data Challenge

From the proposal:

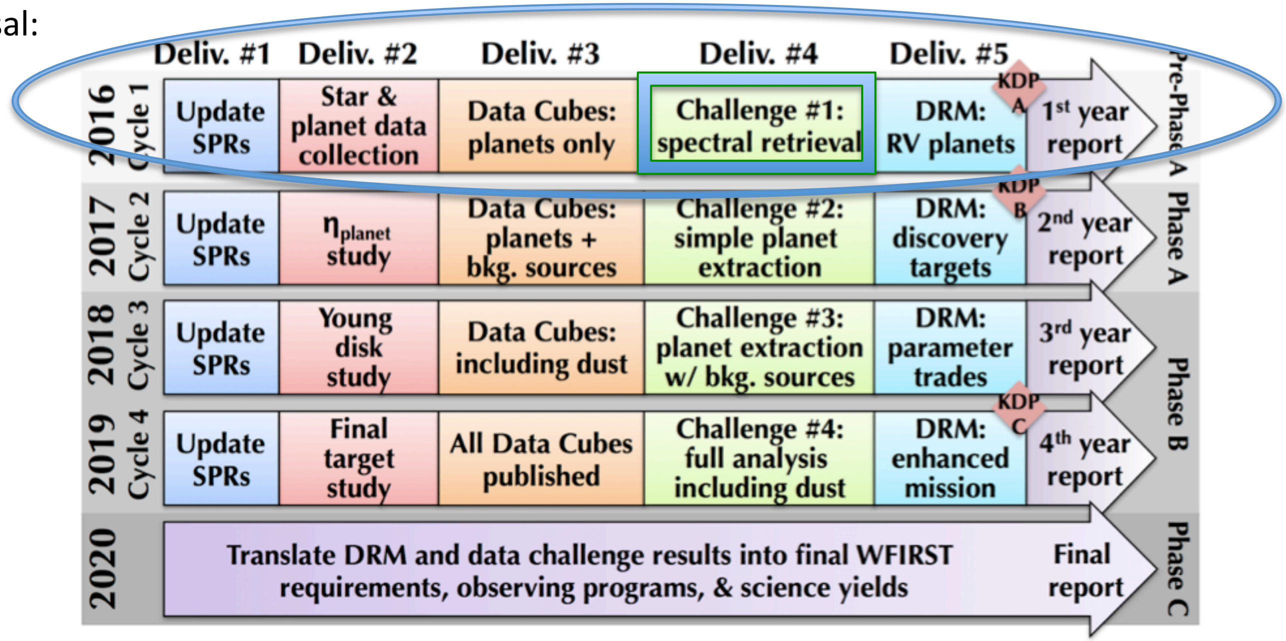

Figure 1.1: Plan for success of the WFIRST CGI. One full SIT Cycle occurs in each of Years 1–4. Scientific performance requirements (SPRs) tasks are shown in blue boxes (Deliverable #1; Section 2), target characterization in red (Deliverable #2; Section 3), data simulation in orange (Deliverable #3; Section 4), data analysis in green (Deliverable #4; Section 5), and design reference mission (DRM) tasks in aqua (Deliverable #5; Section 6).

Exoplanet Data Challenge Next Cycle 2

Targets Task List

Cycle 1

Collect orbital parameters and RV data for known giant planet targets. *[Kane]*

Use ExoCat to establish list of candidate stars for blind survey. *[Turnbull]*

Assemble list of interesting protoplanetary and debris disk targets. *[Jang-Condell]*

Cycle 2

Calculate occurrence rates for a range of planet types. *[Kane]*

Assess background contamination for all targets. *[Sparks]*

Coordinate blind survey and debris disk candidates with LBTI exozodi survey targets. *[Roberge / Hinz]*

Cycle 3

Construct models of protoplanetary disks including structures induced by forming planets. *[Jang-Condell]*

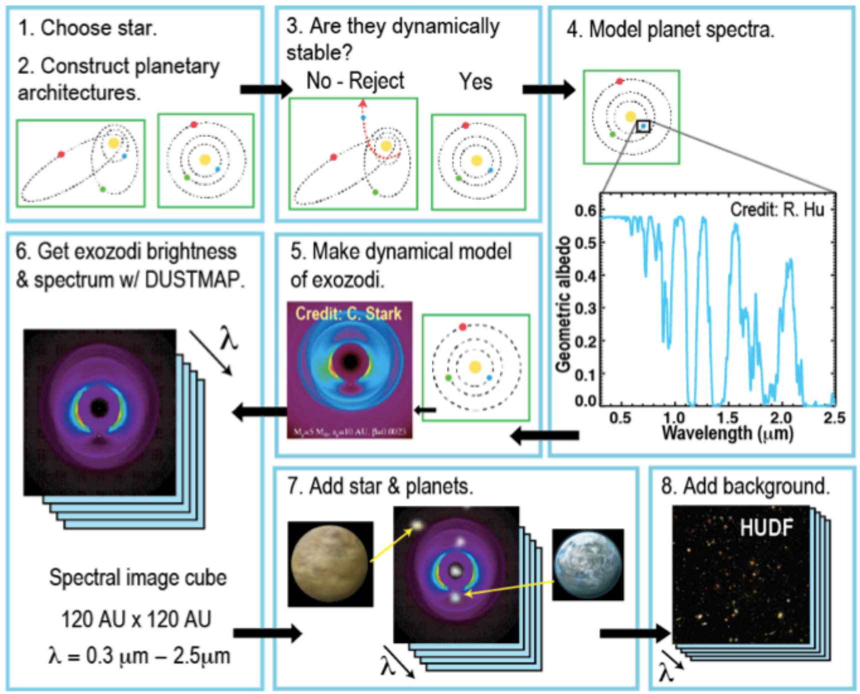

Figure 4.1: Creating a Haystacks spatial/spectral model of a whole planetary system. Each process step is described in the text. Credit: A. Roberge & the Haystacks team.

Data Simulation Task List

Cycle 1

Release Haystacks Solar System models. *[Roberge]*

Make simple 1-D synthetic spectra of warm giant planets for CDC #1. *[Hu]*

Construct dust-free Haystacks models of known RV systems w/out background sources. Process w/ simplified instrument model for CDC #2. *[Roberge / Pueyo]*

Cycle 2

Construct dust-free Haystacks models of known RV systems w/ background sources. Process w/ project instrument model for CDC #3. *[Roberge / Shaklan]*

Calculate possible dust structures for known RV systems. *[Stark]*

Construct complete Haystacks models for known RV systems. *[Roberge]*

Construct dust-free Haystacks models of imagined planetary systems. *[Roberge / Kane]*

Cycle 3

Calculate dust structures for imagined systems. *[Stark]*

Construct complete Haystacks models for imagined systems. *[Roberge]*

Use full Haystacks and instrument models to simulate realistic datasets for CDC #4. *[Shaklan / McElwain]*

Exoplanet Data Challenge

Community Data Challenge #2: Test post-processing and source extraction techniques with spectral image cubes containing only a star and planets, processed with a simple instrument model. This exercise is intended as practice to begin developing the techniques.

Targets Task List

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Coordinate blind survey and debris disk candidates with LBTI exozodi survey targets. *[Roberge / Hinz]*

Cycle 3

Construct models of protoplanetary disks including structures induced by forming planets. *[Jang-Condell]*

Sergi & Maggie have put together a list of questions, suggestions and ideas for the next cycle 2:

[SHARED GOOGLE DOC]

- Specific set of simulated data to be delivered to the EDC participants.
- List of specific challenges that need to be resolved.
- What can realistically be done this year for a community challenge?

Data Simulation Task List

Cycle 1

Release Haystacks Solar System models. *[Roberge]*

Make simple 1-D synthetic spectra of warm giant planets for CDC #1. *[Hu]*

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Use full Haystacks and instrument models to simulate realistic datasets for CDC #4. *[Shaklan / McElwain]*