Microlensing 22

Update on WFIRST and the Microlensing Science Investigation Team Activities

Scott Gaudi (PI)
(on behalf of Matthew Penny)
OSU

Dave Bennett (Deputy PI)
GSFC

What is the Wide Field InfraRed Survey Telescope?

- #1 recommendation of the 2010 Decadal Survey for a large space mission.
- Notional mission, based on several different white paper inputs, including:
  - JDEM-Omega (Gehrels et al.)
  - MPF (Bennett et al.)
  - NISS (Stern et al.)
- Three equal science areas:
  - Dark energy (SNe, Weak Lensing, BAO).
  - Exoplanet microlensing survey.
  - GO program including a Galactic plane survey.

A Brief History of WFIRST.

- 2010: NASA put together two science definition teams to come up with “Design Reference Missions.”
- 2011-2012: Original Science Definition Team. (Green et al. arXiv: 1208.4012)
  - DRM1 (1.3m)
  - DRM2 (1.1m)
- 2012-2015: AFTA/WFIRST Science Definition Team. (Dressler et al. 2012, Spergel et al. 2013, 2015)
  - Studied the use of two telescopes donated to NASA.
    - Two 2.4m space-qualified telescopes.
    - Mirrors and spacecraft assemblies.
  - Also considered a coronagraph and serviceability.

A New Hope.

- 2015: WFIRST Science Investigation Teams announced on December 18, 2015.
  - Five year contract.
  - After which SITs are dissolved and re-competed.
- 2016: Key Decision Point A (February 18, 2016).
  - Essentially means WFIRST is ‘officially’ a mission.
  - At which point the ‘fun’ began:
    - Develop the Program-Level Requirements Appendix (PLRA) and Science Requirements Document (SRD).
    - Prepare for the Science Requirements Review (SRR) and Mission Design Review (MDR).
    - (and, assuming it passes, on to KDP-B).

A New Hope…?

- 2014: National Academy of Sciences Report.
  - *Evaluation of the Implementation of WFIRST/AFTA in the Context of New Worlds, New Horizons in Astronomy and Astrophysics.* (aka the Harrison report)
- 2016: National Academy of Sciences Report.
  - *Review of the Progress Toward the Decadal Survey Vision in New Worlds, New Horizons in Astronomy and Astrophysics*. (aka the Midterm Assessment, Hewitt report)
- To make a long story short: both reports thought the science was great and aligned with the NWNH priorities (including the coronagraph), but expressed concern about cost growth and maintaining a 'balanced' portfolio.
- Both reports recommended a independent review before Phase B.
- 2017: NASA's *WFIRST Independent External Technical/ Management/Cost Review (WIETR).*
  - Final report: October 19, 2017.

Meanwhile…

- Major redesign of the observatory.
  - Simplified design, allowed for more filters.
- Realistic estimates of slew and settle times.
  - Much longer slew and settle times wreaked havoc on the microlensing survey.
  - Project worked hard to decrease the slew and settle times.
  - Ultimately led to decreasing the number of fields from 10 to 6 or 7 (and decreases the yield).
- Project level "grassroots" cost assessment.
  - Came in at a much higher level than previous estimates.
  - Resulted in project-level descopes:
    - 6 -> 5 year mission
    - Eliminate IFS

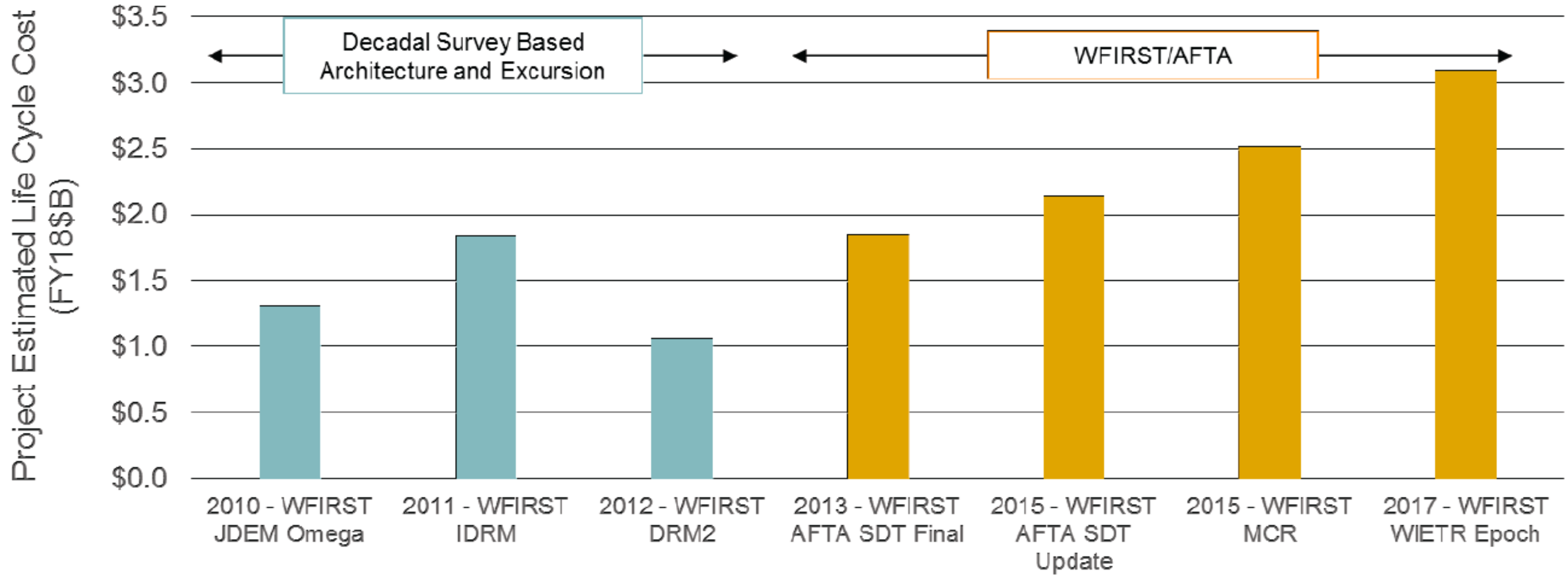
WIETR Findings – the good.

- The WFIRST planned science surveys program and system design offer groundbreaking and unprecedented survey capabilities to the Dark Energy, Exoplanets, and Astrophysics communities.
- The WFIRST team has done a considerable amount of work for a project that has yet to enter KDP-B, particularly in areas that minimize development and cost risk; key processes for execution and control are in place, and the science and mission system concepts are mature.
- The WFIRST Project and Subsystem Management, Science, Systems Engineering, and Business Management personnel are very experienced, including in the management of large/flagship missions, and have the necessary skills to lead a mission of the level of complexity of WFIRST.
- The WFIRST Project has been methodical, thorough, and inclusive in the analysis and derivation of the science and corresponding technical and data requirements, however, additional work is needed to: 1) negotiate and codify them clearly and unambiguously, 2) include Programmatic Direction that should be codified as Level 1 requirements; and 3) develop a plan to comprehensively validate them.
- The Wide-Field Instrument (WFI) is the primary instrument of WFIRST; a tremendous science capability that will be substantially more capable than Euclid, far better than HST or JWST, and well beyond what is possible from the ground in the science interest.

WIETR Findings – the bad.

- NASA has made a series of decisions (most notably: the 2.4m telescope, addition of a Coronagraph Instrument (CGI), Inhouse/ Out-of-house or hybrid acquisition strategy, Dual Science Centers, Robotic Servicing, Star Shade) that set boundary conditions and the stage for an approach and mission system design that is more complex than probably anticipated from the point of view of scope, complexity, and the concomitant risks of implementation.
- The CGI Team has made remarkable progress towards advancing technology. Accommodation of the CGI, however, has been one of the mission system design and programmatic drivers. Expectations regarding performance requirements, status as science versus technology secondary payload and concomitant risk classification, science community engagement, interfaces to the Exoplanet Program and its longer term plans, and risk classification, all paint an inconsistent story that is certain to present risks to the primary mission well into the verification and validation program.
- **The Class B risk classification for the WFIRST mission is not consistent with the uniform application of NASA policy for strategically important missions with comparable levels of investment and risks, most if not all of which are Class A missions.**
- **The management agreement signed at KDP-A for the WFIRST life-cycle cost and the budget profile provided as guidance to the Project are inconsistent with the scope, requirements, and the appropriate risk classification for the mission.**
- **There is an urgent need (before the SRR/MDR) for NASA to conduct a top-to-bottom cost-benefit assessment to balance scope, complexity, and the available resources.**
- The NASA HQ-to-Program governance structure is dysfunctional, and should be corrected for clarity in roles, accountability, and authority.

WFIRST Evolution and Corresponding Cost (FY18$)



Attribute	WFIRST Decadal	WFIRST IDRM	DRM2	AFTA SDT	SDT Update	@ MCR	2017 WFIRST WIETR Epoch
Concept Constraint	Decadal Survey Concept	Follows Decadal Survey	Minimize Cost	Incorporate AFTA Telescope	Add Coronagraph	Same Architecture	Same Architecture
Telescope dia	1.5 m	1.3 m	1.1 m	2.4 m	2.4 m	2.4 m	2.4 m
Payload Complement	NIR/Vis Imager, NIR Spec + FGS	NIR/Vis Imager, NIR Spec + FGS	NIR Imager/Spec + FGS	NIR Imager/Spec + IFC-Spec	NIR Imager/Spec, IFC-Spec, AGS + Coronagraph	NIR Imager/Spec, IFC-Spec, AGS + Coronagraph	NIR Imager/Spec, AGS + Coronagraph
Orbit	L2	L2	L2	Inclined GEO	Inclined GEO	L2	L2
Serviceable?	No	No	No	Yes	Yes	Yes	Yes
Dry Mass	2,424 kg	2,336 kg	1,868 kg	4,520 kg	4,861 kg	6,877 kg	7,324 kg
Launch Veh.	Atlas V 511	Atlas V 511	Falcon 9 v1.1	Atlas V 541	Delta IV-Heavy	Delta IV-Heavy	Falcon 9-Heavy
Lifetime	5 years	5 years	3 years	5 years	5 years	6 years	5 years

WIETR Findings – the ugly.

- The WIETR Independent Cost Estimate (ICE) for WFIRST is $3.9B in real year $.
  - Derived from the Project's Budget Option 1 scope and schedule.
  - This is 10% higher than Project Budget Option 1 of $3.6B.
- Given ICE uncertainty range, the present concept requires $3.9B to $4.2B (including Class A reclassification) or $350M to $600M more than the Project's estimate.

WIETR Recommendation.

The WIETR Panel recommends that NASA match funding and other resources to align with the accepted mission scope.

To better understand the options available, NASA should conduct a top-to-bottom cost-benefit assessment to determine whether to:

- 1A. Continue with the present mission requirements and scope with the proper resources (funding) and profile (schedule) required, or;
- 1B. Distribute the scope, and thus the risks over two missions (i.e. a Dark Energy/Microlensing- Exoplanets/Astrophysics mission, and a dedicated Exoplanet Imaging/Coronagraph mission), perhaps taking advantage of the system design that WFIRST has already invested in, or;
- 1C. If indeed the $3.2B “cap” is required, descoping the CGI from the WFIRST mission, together with some of the other smaller-value descopes, will approach that goal.

NASA's Response.

- On October 19, 2017, Thomas Zurbuchen (Head of the Science Mission Directorate of NASA) issued a memo with the following instructions:
- Descope and replan budget to meet $3.2B, including:
  – Keep the 2.4m.
  – Class B to Class A (A-? B+?).
  – Reductions in WFI.
  – Coronagraph shall be treated as a technology demonstration instrument and descoped.
  – Cost of SITs (second round) shall be reduced.
  – Use of commercial subsystems and components where possible.
- SRR/MDR in February 2018
- KDP-B in March/April 2018
- Another ICE before KDP-B to validate $3.2B.
- If ICE comes in at >$3.2B, another study.

Fallout.

- "Emergency" Formulation Science Working Group Meeting in November to discuss descopes.
- Descopes largely transparent to science for WFI.
  - e.g., improved budget profile (launch advanced 6 months)
- Coronagraph descoped, still part of GO but now 'shared risk'.
  - CGI related SOC funding large eliminated
  - IFS and starshade readiness retained
- WFI
  - Relax performance requirements to reduce number of detectors procured.
  - Reduce calibration capability.
- Others not directly or critically related to the microlensing survey (i.e., specifications on GO program)
- **Bottom line for μlensing: science largely unimpacted.**

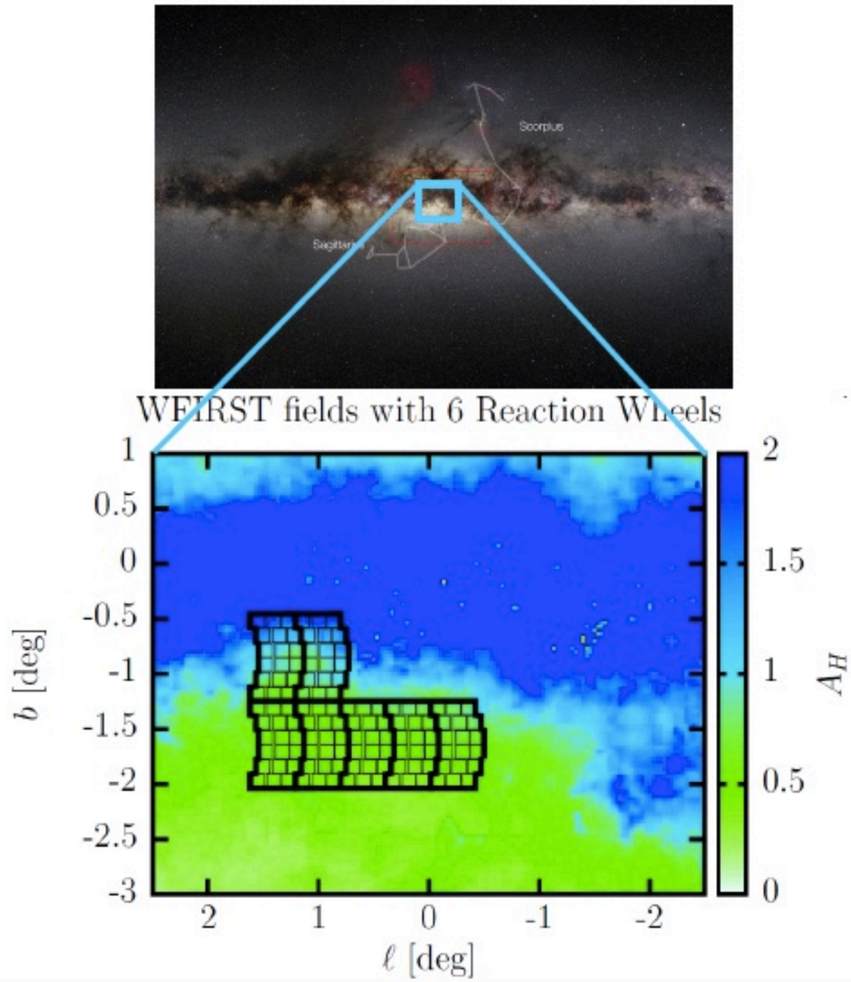
Bottom Line for Microlensing.

- Came out with science largely unimpacted (for now).
- Descopes largely transparent to science for WFI.
  - e.g., improved budget profile (launch advanced 6 months).
- Coronagraph descoped, still part of GO, but now ‘shared risk’.
  - CGI related SOC funding large eliminated.
  - IFS and starshade readiness retained.
- WFI
  - Relax performance requirements to reduce number of detectors procured.
  - Reduce calibration capability.
- Others not directly or critically related to the microlensing survey (i.e., specifications on GO program).

Current Status.

WFIRST Microlensing Survey

- 432 day survey
- 6x72 seasons over 5 years
- 2 deg^2
- 15 min cadence
- Wide 1-2um bandpass
- Discover ~1500 cold exoplanets, including ~200 Earth-mass planets and hundreds of free-floating planets



Current Estimate of Yields.

Bound Planets

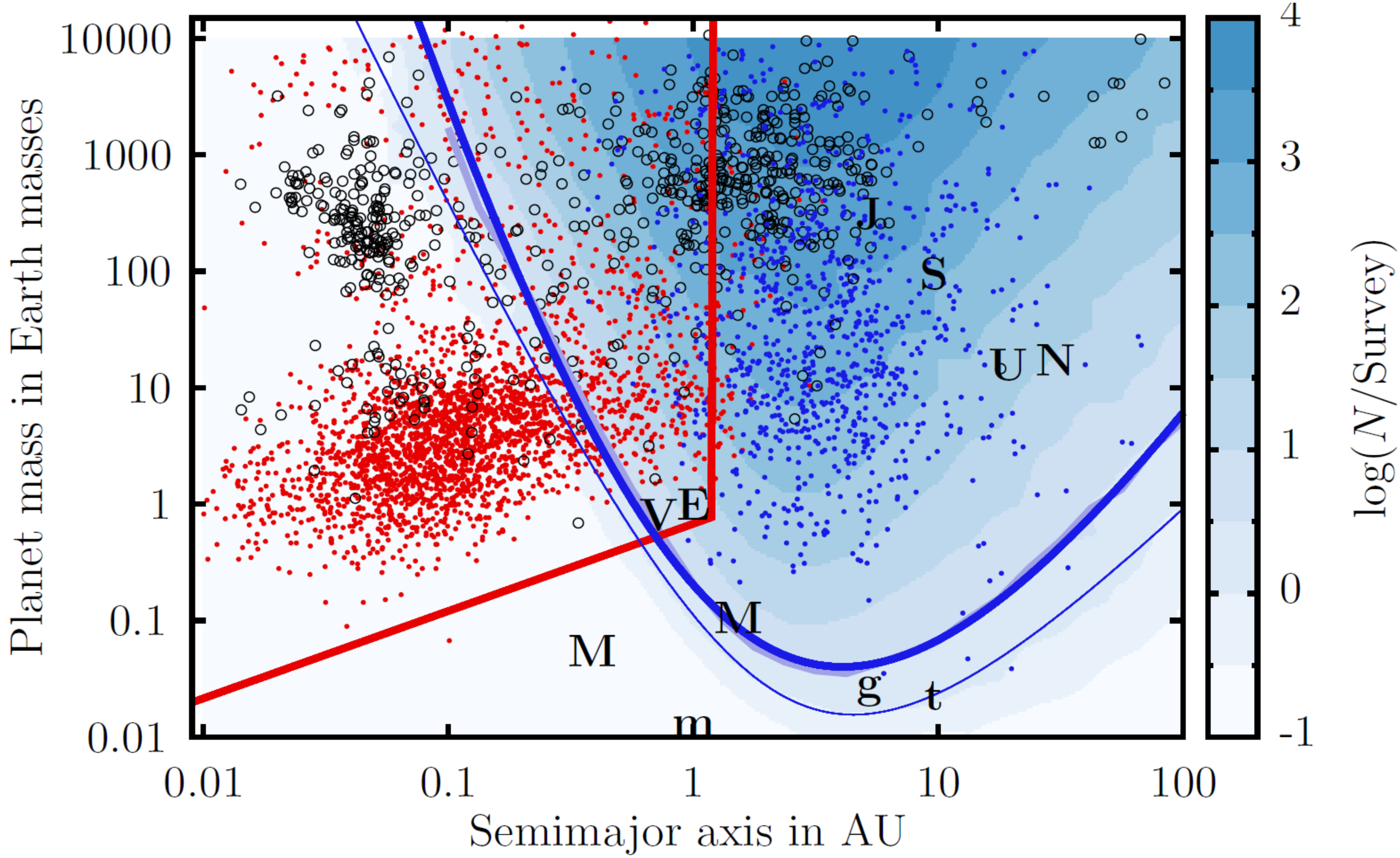
Mass (Mearth)	1/star	Cassan +2012	Suzuki +2016
0.1	10	20	<1
1	88	181	11
10	439	545	155
100	1784	412	399
1000	5208	224	140
10000	148	91	37
Total	7677	1473	742

Free-floating Planets

Mass (Mearth)	1/star	Cassan +2012	Suzuki +2016
0.1	5	9	<1
1	23	48	3
10	91	112	18
100	324	75	72
1000	1060	46	29
10000	3430	28	11
Total	4933	318	133

(Matthew Penny)

Revised Penny Plot.



Team Members.

MicroSIT Members

- Scott Gaudi (OSU, PI): gaudi.1@osu.edu
- Dave Bennett (GSFC, Deputy PI, Pipeline/Algorithm Lead): david.p.bennett@nasa.gov
- Jay Anderson (STScI, Co-I): jayander@stsci.edu
- Sebastiano Calchi Novati (IPAC, Co-I): novati@ipac.caltech.edu
- Sean Carey (IPAC, Co-I, Calibration Lead): carey@ipac.caltech.edu
- Dan Foreman-Mackey (UW, Co-I): foreman.mackey@gmail.com
- Andrew Gould (?, Co-I): gould.34@osu.edu
- Calen Henderson (JPL, Co-I, Precursor Data Lead): calen.b.henderson@gmail.com
- Davy Kirkpatrick (IPAC): davy@ipac.caltech.edu
- Matthew Penny (OSU, Co-I, Survey Optimization Lead): penny@astronomy.ohio-state.edu
- Radek Poleski (OSU, Co-I): radek.poleski@gmail.com
- Yossi Shvartzvald (JPL, Co-I): yossishv@gmail.com
- Rachel Street (LCOGT, Co-I): rstreet@lcogt.net
- Jennifer Yee (CfA, Co-I, Outreach Lead): jyee@cfa.harvard.edu
- Chas Beichman (JPL, Collaborator): chas@ipac.caltech.edu
- Geoffrey Bryden (JPL, Collaborator): geoffrey.bryden@jpl.nasa.gov
- Cheongho Han (Chungbuk National U., Collaborator): cheongho@astroph.chungbuk.ac.kr
- David Nataf (ANU, Collaborator): david.nataf@gmail.com
- Keivan Stassun (Vanderbilt, Collaborator): keivan.stassun@vanderbilt.edu

WPS Team Members

David Bennett (GSFC, PI, Advanced Modeling Lead): david.p.bennett@nasa.gov
Andrea Bellini (STScI): bellini@stsci.edu
Aparna Bhattacharya (Notre Dame, GSFC): Aparna.Bhattacharya.8@nd.edu
Valerio Bozza (Salerno): valboz@sa.infn.it
Takahiro Sumi (Osaka, WFIRST Japan PI): sumi@ess.sci.osaka-u.ac.jp
Daisuke Suzuki (GSFC): dsuzuki@nd.edu

Science Center Liaisons

Kailash Sahu (STScI): ksahu@stsci.edu
Sean Carey (IPAC): carey@ipac.caltech.edu

Microlensing Preparatory Working Group Co-Chairs

Rachel Akeson (IPAC): rla@ipac.caltech.edu
Davy Kirkpatrick (IPAC): davy@ipac.caltech.edu

Members from other SITs

Jessica Lu (Hawaii): jessica.lu@hawaii.edu

MicroSIT Organization.

WFIRST MicroSIT organized into subgroups: main immediate goal is to develop a list of deliverables and a timeline for each of these.

- Management Group. Develop a detailed investigation plan for the full five years, overall project management, define the science goals and requirements flowdown.
  - Leads: Gaudi, Bennett
- Group 1. Photometry/Astrometry Pipeline Algorithm Development
  - Lead: Bennett
- Group 2. Development of Lightcurve Analysis Tools and Community Engagement
  - Lead: Yee
- Group 3. Simulations: Improved Galactic Models, Trade Studies, Survey Yield and Optimization
  - Lead: Penny
- Group 4. Hardware, Software, Calibration, and Analysis Requirements
  - Lead: Carey
- Group 5. Required Precursor and Concurrent Data
  - Lead: Henderson and Shvartzvald
- Group 6. Advanced Microlensing Light Curve Modeling
  - Lead: Bennett

To Do.

WFIRST Mission:

- Make it through SRR/MDR and KDP-B.
- Make it through KPP-C before the next Decadal Survey.

MicroSIT:

- Improve our understanding of microlensing event rates:
  - Refine Galactic models.
  - Near-IR microlensing survey (UKIRT+PRIME).
  - Near-IR luminosity function.
  - Measure the Galactic distribution of planets (Spitzer, K2).
- Optimize strategy:
  - Field locations, number, and cadence.
  - Optimize number and choice of filters.
  - Contemporaneous ground and space-based observations.
- Determine the precision of the measured event parameters.
- Verify some hardware, software, and calibration requirements.
- Identify and carry out additional needed precursor observations.
- Develop data reduction and analysis tools.
- **Grow the microlensing community!**

Talks on MicroSIT-Related Activities. (likely incomplete; apologies)

- Spitzer – Sebastiano Calchi Novati
- VBBinary Lensing 2.0 – Valerio Bozza
- pyLIMA – Etienne Bachelet
- KSMS – David Bennett
- LSST – William Clarkson & Martin Donachie
- Data Challenge – Rachel Street
- K2 – Radek Poleski
- Characterization – Aparna Bhattacharya
- Astrometry using HST – Kailash Sahu
- Characterization – Calen Henderson
- K2 – Shude Mao
- Extinction – David Nataf
- High extinction fields – Geoff Bryden
- Community use of microlensing data – Rachel Akeson
- Galactic models – Supachai Awiphan