Developing a NASA-NSF Initiative to Advance Radial Velocity Precision

Terms of Reference for an Extreme Precision Radial Velocity (EPRV) Working Group

July 18, 2019

A. Background

The National Academies recently published the Exoplanet Science Strategy[1] (ESS) report which documented findings and recommendations regarding the importance of exoplanet mass measurements. Knowledge of a planet's mass (along with a knowledge of its radius) is essential to understand its bulk composition and to interpret spectroscopic features in its atmosphere. The study of Earth-like planets orbiting Sun-like stars will require mass measurements to the sensitivity required for such worlds. Two report findings are:

1. The radial velocity method will continue to provide essential mass, orbit, and census information to support both transiting and directly imaged exoplanet science for the foreseeable future.
2. Radial velocity measurements are currently limited by variations in the stellar photosphere, instrumental stability and calibration, and spectral contamination from telluric lines. Progress will require new instruments installed on large telescopes, substantial allocations of observing time, advanced statistical methods for data analysis informed by theoretical modeling, and collaboration between observers, instrument builders, stellar astrophysicists, heliophysicists, and statisticians.

The ESS report recommends that "NASA and NSF should establish a strategic initiative in extremely precise radial velocities (EPRVs) to develop methods and facilities for measuring the masses of temperate terrestrial planets orbiting Sun-like stars". In response to this recommendation, NASA is commissioning the Extreme Precision Radial Velocity (EPRV) Working Group to recommend a ground-based program architecture and implementation plan to achieve the goal intended by the ESS report findings. This document establishes the plan for the EPRV Working Group deliverables, work flow and membership.

B. Deliverables

The EPRV Working Group is established to deliver to the NASA Astrophysics Division (APD) and the NSF Division of Astronomical Sciences (AST) a report, as a first step, that includes a recommendation for the best ground-based program architecture and implementation to achieve the goal of measuring the masses of temperate terrestrial planets orbiting Sun-like stars. In the Working Group deliverable recommendation and at decision points of the subsequent Initiative (if implemented) possible ground-based solutions will be identified. If ground-based solutions are not found then another study may be considered for a space-based solution. The recommendation will define a roadmap that NASA/APD and

[1] http://sites.nationalacademies.org/ssb/currentprojects/ssb_180659

NSF/AST can carry out jointly or separately to achieve the necessary breakthrough in extreme precision radial velocity measurement.

The report will be delivered by March 2020, after which the EPRV Working Group will be disbanded. The report will include scope, schedule, and planning-level funding requirements. The report may include both directed and competed scope. No selection criteria for specific competed scope will be developed, and all products and deliberations of the EPRV Working Group will be conducted and documented in an open forum.

NASA/APD and NSF/AST will discuss the report's findings within the context of the existing NASA-NSF Exoplanet Observational Research (NN-EXPLORE)[2] partnership agreement. NASA and NSF will consider the recommendations for implementation through their own processes.

C. Participation

NASA/APD and the NSF/AST are best served by a process that ensures transparency, inclusiveness, and consensus by the scientific and technical community. International participation is planned. The EPRV Working Group structure is illustrated in Figure 1.

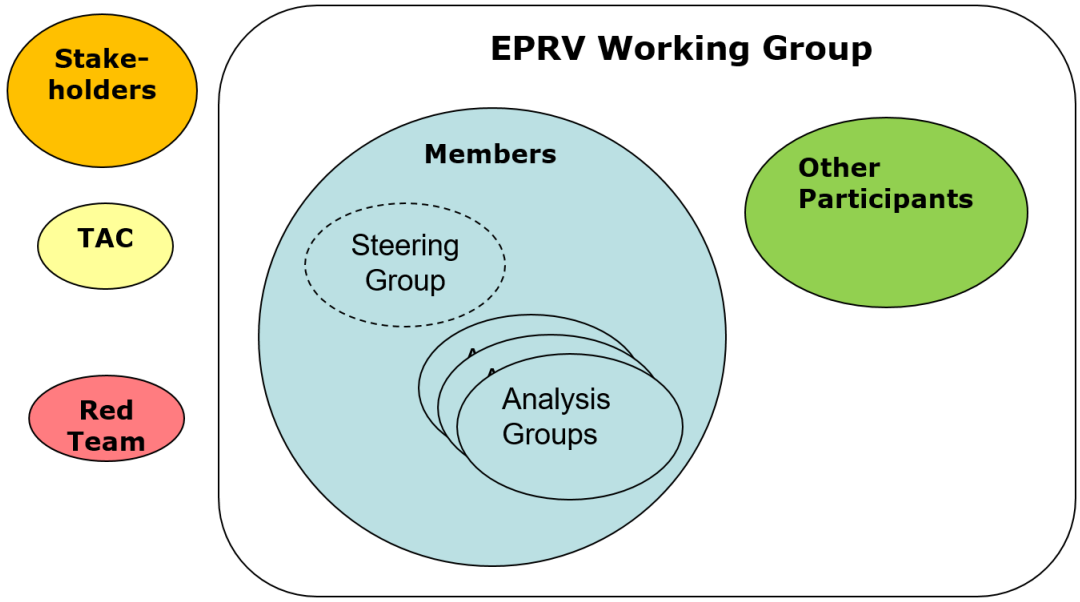


Figure 1. Context for Extreme Precision Radial Velocity Working Group.

The following groups will participate in the EPRV Working Group:

[2] https://exoplanets.nasa.gov/exep/NNExplore/

1. A **Steering Group** is a subset of the Members and is responsible for approving membership of subgroups termed Analysis Groups. Steering Group members may be part of, and participate in, the Analysis Groups. The Steering Group assists the Chairs in setting agendas. The Steering Group will provide periodic briefings to the NASA and NSF stakeholders. The Steering Group is formed by the Chairs with the concurrence of the stakeholders.

2. **Members** of the Working Group represent the breadth of science, technology, engineering, and programmatic (schedule, cost) expertise necessary to deliver the report recommendations. Members are identified with inputs from the Steering Group and invited by the Chairs with the concurrence of the stakeholders. Members are tasked to develop the EPRV Working Group report and support the formulation of recommendations. The Chairs intend for the recommendation to be reached by consensus of all Members. Members will provide analysis and recommendations through Analysis Group participation; individuals may serve on more than one group as expertise and time permits, including:
    a. Analysis Groups: as many as needed to define, analyze and develop options and program architectures. Teams are drawn from the Membership and Participants.
    b. Evaluation Team: one of the Analysis Groups will perform initial evaluations of the science, technical, and programmatic merit of architecture options and bring these to the full Working Group for consideration.
    c. At-Large Members

3. **Participants:** Other Participants consist of consultants, guests, and observers and are invited by the Steering Group to contribute as needed. Participants include subject-matter experts necessary to inform the recommendations. Expectations on the frequency and degree of participation are lower than for the Members. These Participants are welcome to participate in the full EPRV Working Group deliberations.

4. **Chairs** (of the collective Steering Group, Membership and Working Group) will facilitate the Working Group, are accountable to the Stakeholders, are responsible for bringing the Members and ideally the full Working Group to a consensus recommendation by the required date, and will support briefings of the final recommendation to stakeholders and the community.

The following groups are welcome to participate in the EPRV Working Group deliberations:

5. **Stakeholders** are representatives of NASA/APD and the NSF/AST. The stakeholders establish this Working Group through these Terms of Reference. The formal recommendation from the EPRV Working Group may be addressed solely to NASA/APD, solely to NSF/AST, or jointly to both Agencies at the discretion of the stakeholders.

6. The **ExoTAC**[3] (**Exoplanet Technical Assessment Committee**) members perform an independent assessment of the process and results of the Working Group and deliver that assessment to NASA/APD concurrently with the EPRV Working Group report. The ExoTAC are invited to observe all Working Group deliberations. The ExoTAC delivers its assessment directly to the Stakeholders.

7. A **Red Team** is accountable to the Steering Group will be convened to improve the quality of the final report.

8. Others may be added to the Working Group email list at the discretion of the Chairs.

C. Work Flow

The intended work flow is illustrated in Figure 2.

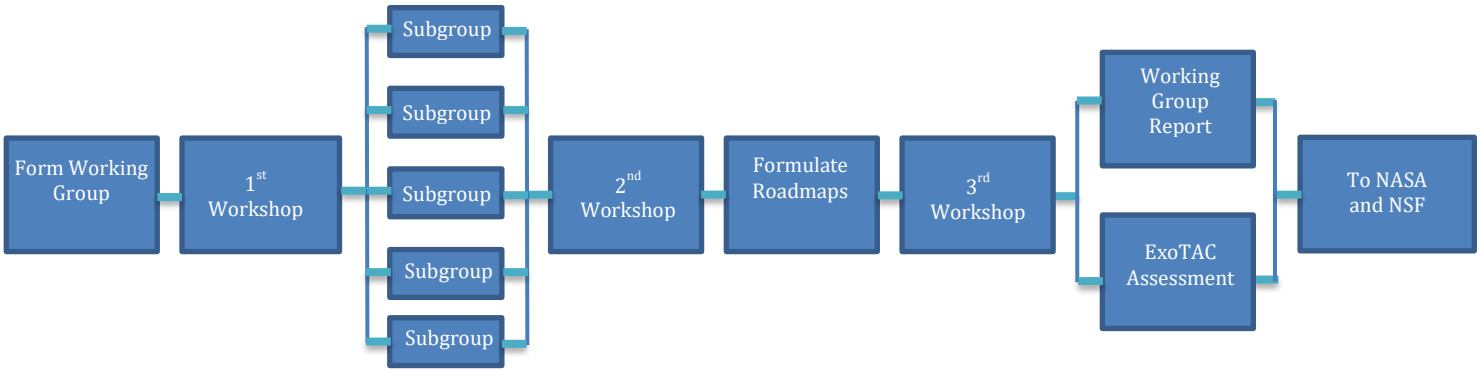


Figure 2. Work Flow of the EPRV Working Group

1. Coordination meetings/teleconferences with NASA and NSF.
2. Form a Steering Group and invite community experts to participate in the Working Group including an open call for nominations.
3. Kickoff telecon with Steering Group.
4. Kickoff telecon with EPRV Working Group.

<u>1st Workshop:</u>

5. Establish Success Criteria (requirements, figures of merit), confirm with stakeholders.
6. Review the current status and limitations of precision radial velocity measurements.
7. Define targets for near-term and long-term radial velocity precision.
8. Form Analysis Groups and appoint leads for specific areas of development.

<u>Multi-Month Activity:</u>

9. Formulation and analysis by the Analysis Groups.

[3] https://exoplanets.nasa.gov/exep/technology/technology-overview/

2nd Workshop:

10. Analyze and prioritize options within each Analysis Group, weighted in terms of benefit (impact), urgency, likelihood, feasibility.
11. Roadmaps: Define comprehensive multi-element roadmaps based on strongest options from each Analysis Group.

3rd Workshop (if necessary):

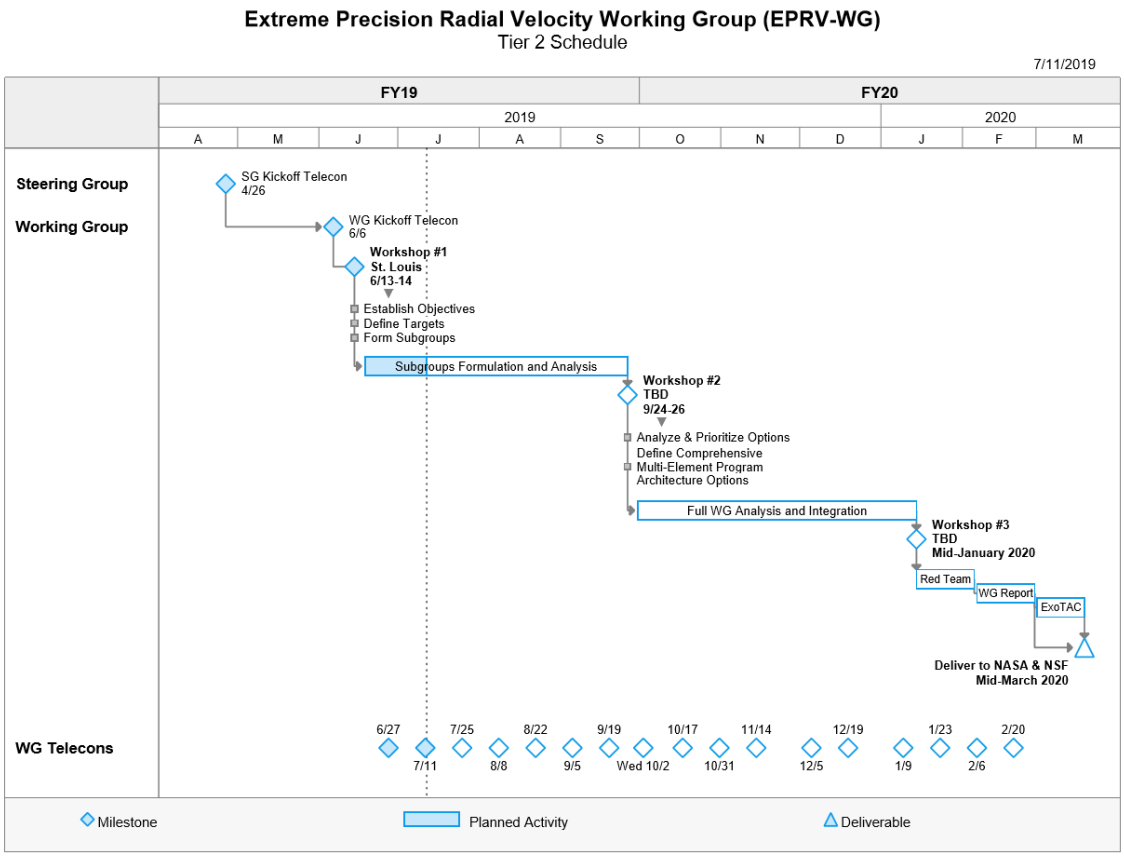
12. Evaluate these Roadmaps versus the Success Criteria for the recommendation. Balance these Roadmaps against existing programs and priorities at NASA and NSF.
13. Reach consensus on a recommendation.
14. Present recommendation jointly to NASA/APD and NSF/AST, along with a parallel independent assessment performed by the Exoplanet Technical Assessment Committee.

The EPRV Working Group is expected to hold approximately 2-3 in-person meetings of 1 to 3 days duration in addition to regular telecons. Periodic briefings are provided by the Steering Group to the NASA/APD and NSF/AST stakeholders.

- Workshop #1 (late Spring 2019) will identify subgroup focus, define objectives, establish membership and leadership for each Analysis Group.
- Workshop #2 (Autumn 2019) will review subgroup products, organize the top priorities, and begin formulation of Roadmaps.
- Workshop #3 (January 2020, if necessary) will confirm the evaluation of Roadmaps and reach consensus on recommendations, as needed.

Between workshops the Analysis Groups will formulate plans (via teleconferences) to make progress in each area.

D. Schedule


Extreme Precision Radial Velocity Working Group (EPRV-WG)
Tier 2 Schedule
7/11/2019
FY19
FY20
2019
2020
A
M
J
J
A
S
O
N
D
J
F
M
Steering Group
Working Group
WG Telecons
SG Kickoff Telecon
4/26
WG Kickoff Telecon
6/6
Workshop #1
St. Louis
6/13-14
Establish Objectives
Define Targets
Form Subgroups
Subgroups Formulation and Analysis
Workshop #2
TBD
9/24-26
Analyze & Prioritize Options
Define Comprehensive
Multi-Element Program
Architecture Options
Full WG Analysis and Integration
Workshop #3
TBD
Mid-January 2020
Red Team
WG Report
ExoTAC
Deliver to NASA & NSF
Mid-March 2020
6/27
7/11
7/25
8/8
8/22
9/5
9/19
Wed 10/2
10/17
10/31
11/14
12/5
12/19
1/9
1/23
2/6
2/20
Milestone
Planned Activity
Deliverable

E. Membership

Steering Group

Scott	Gaudi	Co-chair	The Ohio State University
Gary	Blackwood	Co-chair	NASA ExEP / Jet Propulsion Laboratory
Andrew	Howard		Caltech
David	Latham		Harvard-Smithsonian Center for Astrophysics
Debra	Fischer		Yale University
Eric	Ford		Pennsylvania State University
Heather	Cegla		University of Geneva
Peter	Plavchan		George Mason University
Andreas	Quirrenbach		Landessternwarte; University of Heidelberg
Jennifer	Burt		Massachusetts Institute of Technology
Eric	Mamajek	Ex officio	NASA ExEP / Jet Propulsion Laboratory
Chas	Beichman	Ex officio	NASA Exoplanet Science Institute / Caltech

Members

Chad	Bender	University of Arizona
Jonathan	Crass	Notre Dame University
Scott	Diddams	National Institute of Standards and Technology
Xavier	Dumusque	Université de Genève
Jason	Eastman	Harvard-Smithsonian Center for Astrophysics
Benjamin	Fulton	NASA Exoplanet Science Institute / Caltech
Sam	Halverson	Massachusetts Instititute of Technology
Raphaëlle	Haywood	Harvard-Smithsonian Center for Astrophysics
Fred	Hearty	Pennsylvania State University
Stephanie	Leifer	NASA / Jet Propulsion Laboratory
Johannes	Loehner-Boettcher	University Corp. for Atmospheric Research
Annelies	Mortier	Kavli Inst. for Cosmology, Univ. of Cambridge
Ansgar	Reiners	University of Göttingen
Paul	Robertson	University of California, Irvine
Arpita	Roy	Caltech
Christian	Schwab	Macquarie University
Andreas	Seifahrt	University of Chicago
Andrew	Szentgyorgyi	Harvard-Smithsonian Center for Astrophysics
Ryan	Terrien	Carleton University
Johanna	Teske	Carnegie Observatories/DTM
Samantha	Thompson	University of Cambridge
Gautam	Vasisht	NASA / Jet Propulsion Laboratory

Participants

Suzanne	Aigrain		Oxford University
Megan	Bedell		Flatiron Institute
Rebecca	Bernstein		Carnegie Observatories
Ryan	Blackman		Yale University
Cullen	Blake		University of Pennsylvania
Lars	Buchhave		Technical University of Denmark
John	Callas	Ex officio	NASA ExEP / Jet Propulsion Laboratory
David	Ciardi	Ex officio	NASA Exoplanet Science Institute / Caltech
William	Chaplain		University of Birmingham
Jessi	Cisewski-Kehe		Yale University
Andrew	Collier-Cameron		Saint Andrews University
Matthew	Cornachione		University of Utah
Nadege	Meunier		University of Grenoble
Joe	Ninan		Pennsylvania State University
John	O'Meara		W. M. Keck Observatory
Joel	Ong		Yale University
Sharon	Wang		Carnegie Institution for Science
Sven	Wedemeyer-Boehm		University of Oslo
Lily	Zhao		Yale University

ExoTAC (Exoplanet Technical Assessment Committee)

Alan	Boss	Chair	Carnegie Institution for Science
Rebecca	Oppenheimer		American Museum of Natural History
Joe	Pitman		Heliospace Corporation
Lisa	Poyneer		Lawrence Livermore Laboratory
Stephen	Ridgeway		National Optical Astronomy Observatory

F. Approvals and Concurrences

E-SIGNED by Douglas Hudgins on 2019-07-23 17:36:36 GMT 2019-07-23 17:36:36 UTC

Approve/_____/_____.

Dr. Douglas M. Hudgins Date

Exoplanet Exploration Program Scientist, NASA/APD

E-SIGNED by Jeff Neff on 2019-07-24 22:25:37 GMT 2019-07-24 22:25:37 UTC

Approve/_____/_____.

Dr. James E. Neff Date

NN-EXPLORE Program Director, NSF/AST