Exoplanet Probe to Medium Scale Direct Imaging Mission Requirements and Characteristics - (SAG9)

Rémi Soummer (STScI)
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SAG9 group (~40 members, open membership to the community)
Apai, Belikov, Breckinridge, Brown, Cahoy, Cash, Choquet, Cowan, Danchi, Fortney, Gaudi Goldman, Greene, Kasting, Lawson, Levine, Lillie, Lo, Lyon, Lipscy, McElwain, N'Diaye, Mennesson, Noecker, Plavchan, Roberge, Savransky, Serabyn, Shaklan, Solmaz, Unwin, Stapelfeldt, Thomson, Trauger, Turnbull, Vasicht,

soummer@stsci.edu

SAG-9 status report

- SAG9 has refocused its goals to avoid duplication with STDT-C, STDT-S, AFTA-SDT
  - Cross-Validation of Design Reference Missions (Bob Brown)
  - Synthesize / Compare output of STDT-S/C and AFTA-C
  - Radial Velocity Complementarity with imaging

- Actions completed by SAG9:
  - DRM studies (Brown): comparison probe/super-probe/medium
  - DRM studies (Brown): AFTA performance on *known* RV planets for various assumptions (IWA, Resolution, throughput, etc)
  - Cross-validate ETC calculations
  - Definition of science goals for precursor RV surveys

- Report by the end of the year

Future DI missions/ground instruments

		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
8m Class	VLT + SPHERE	Young jovian planets: detection + spectroscopy (1–1.6 μm)															
	Gemini + GPI	Young jovian planets: detection + spectroscopy (1–1.6 μm)															
	LBT/AO	Young + Older Super-jupiters: detection + photometry (1–5 μm)															
	Subaru/ScExAO	Super-jupiters: detection + photometry (1–2 μm)															
30m Class	GMT/ExAO?														No approved concept; Super-earths?		
	TMT/ExAO?														No approved concept; Super-earths?		
	EELT/EPIC												HZ low-mass planets, few Earth analogs, old GPs in reflected light (1–1.7 μm)				
	EELT/METIS												MIR imaging spectroscopy of disks and planets (3–10 μm)				
Space	HST	Photometry of exceptionally bright super-jupiters (1–1.7 μm)															
	JWST				Young GPs + Few Older Jovian planets (2 M_J at 4pc): detection + LR/MR spectroscopy. Disk Imaging + MR spectroscopy; IWA 0.5" 10^{-5} (1–5 μm)												
	WFIRST-2.4m Coron?									Jupiter analogs and disks, RV planets, Imaging+Spectra, 10^{-9} IWA 0.1" (0.3–1 μm);							
	Probe-class Off-Axis Mission?									Jupiter analogs; Disks and some RV planets, Imaging+LR Spectra, 10^{-9}–10^{-10} IWA 0.1"–0.3" (0.3–1 μm)							

(chart courtesy D. Apai)

Future DI missions/ground instruments

- Overlap between missions/interesting potentially interesting at two levels (followup same target if possible, complement a science program with different targets)

- Probe/medium mission and ELT potential target overlap
- Overlap/complementarity with JWST? e.g. for disks?
- Gap on ground post-GPI/SPHERE. Is there a role for 8-10 m class DI instruments in E-ELT/JWST/probe era?

Design reference missions (DRMs)

- Science Metric: number of RV planets characterized by the mission
- Merit function for the DRM: information rate, i.e. net completeness per unit time.
  - about 30 parameters included in the merit function
    - *IWA, Resolution, detector parameters, telescope diameter, sharpness, albedo, radius of planet, etc.*
  - At each step in the DRM the merit function is calculated with remaining planets in play
  - Next target scheduled has the highest merit function

- Several DRMs Developed for SAG-9
  - Comparison probe/large probe/AFTA
  - Specific case of AFTA, comparision 3 vs. 4 lambda/D at 800nm

Credit: Bob Brown

AFTA DRM summary (RV targets)

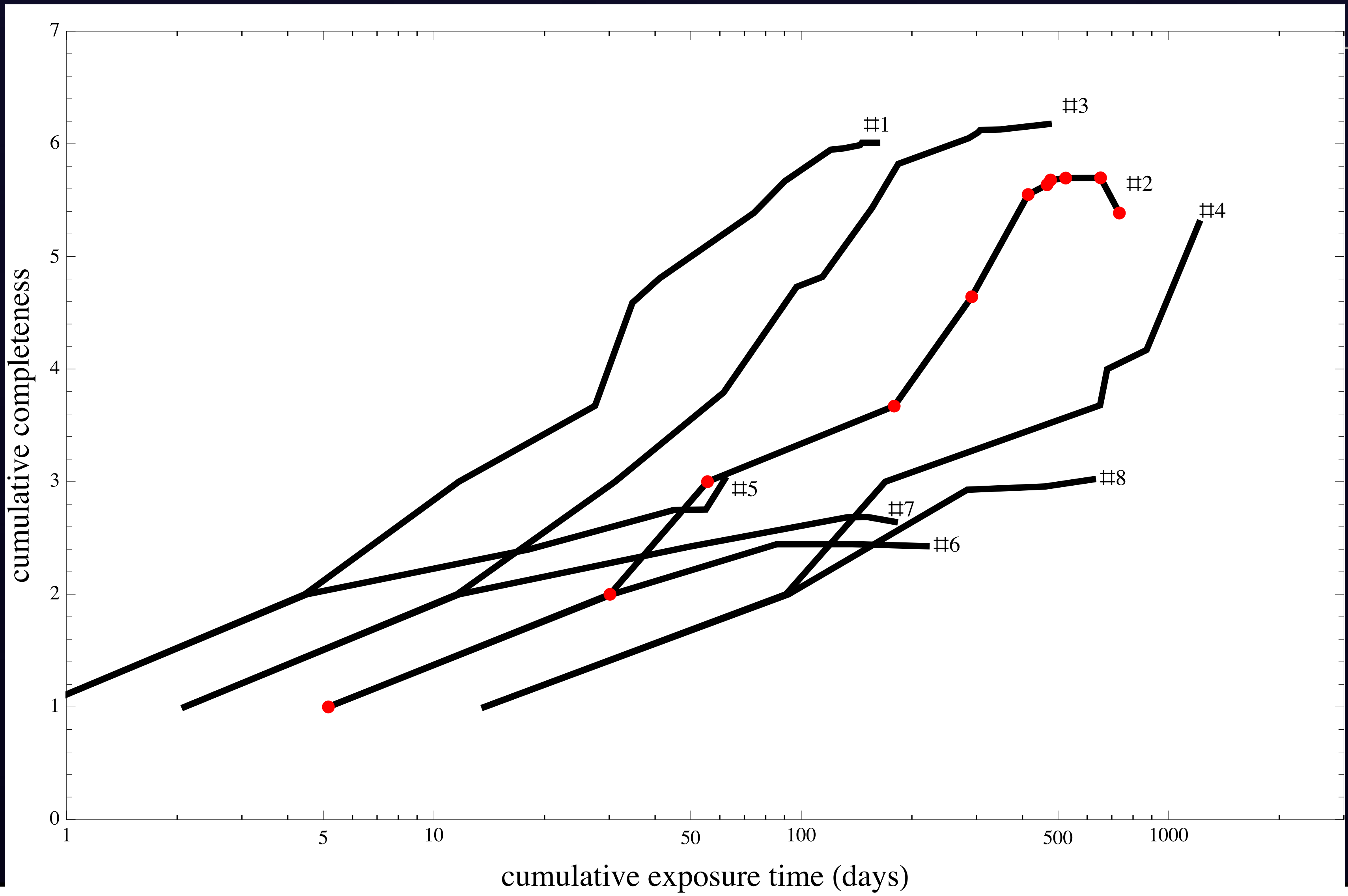
- Science metric (i.e. expected number of RV planets characterized) for different efficiency (h) and resolution (R) and IWA

- Result averaged from 100 DRMs computed for each combination of parameters (IWA, throughput, resolution)

IWA	0.200"				0.274"			
h	0.05		0.3		0.05		0.3	
R	20	50	20	50	20	50	20	50
50 d	2.50	1.00	4.78	3.64	2.00	1.00	2.74	2.42
100 d	3.63	2.00	6.00	4.84	2.45	2.00	2.74	2.71
200 d	4.75	3.00	6.04	5.73	2.45	2.49	2.74	2.71
400 d	5.48	3.76	6.04	6.18	2.62	2.49	2.74	2.71

Credit: Bob Brown

DRM results with cumulative exp time



- All these DRMs run out of RV planets, not time (except case #4: 3lambda/D IWA, R=50, 5% efficiency)
- main effect of "h" or "R" is to move the DRM to the right, i.e. increase all exposure times
- IWA here has a factor of two impact on DRM

case number	IWA (arcsec)	h (efficiency)	R (resolution)	Comment
1	0.200	0.3	20	original, 3λ/D
2	0.200	0.05	20	...low h
3	0.200	0.3	50	...high R
4	0.200	0.05	50	...low h, high R
5	0.274	0.3	20	new, 4λ/D
6	0.274	0.05	20	...low h
7	0.274	0.3	50	...high R
8	0.274	0.05	50	...low h, high R

Credit: Bob Brown

Target list for these DRMs comparions

- ~15 RV planets with a(1+e)/d<IWA
  - few more ~20 targets if a little less strict (0.19 arcsec)
  - results for AFTA:

	mag	d	a	T	ϵ	ω	T_0	$a(1+\epsilon)/d$
epsilon Eri b*	2.78	3.22	3.38	2500.	0.25	6.	1940.	1.312
47 UMa c*	4.34	14.06	3.57	2391.	0.10	295.	5441.	0.279
mu Ara c*	4.35	15.51	5.34	4206.	0.10	58.	5955.	0.378
55 Cnc d*	5.03	12.34	5.47	4909.	0.02	254.	6490.	0.452
upsilon And d	3.51	13.49	2.52	1278.	0.27	270.	6938.	0.237
14 Her b	5.68	17.57	2.93	1773.	0.37	23.	4373.	0.229
HD 154345 b	5.96	18.59	4.21	3342.	0.04	68.	5831.	0.237
HD 39091 b*	4.98	18.32	3.35	2151.	0.64	330.	820.	0.300
HD 190360 b*	4.91	15.86	3.97	2915.	0.31	13.	6542.	0.329
HD 87883 b*	6.57	18.21	3.58	2754.	0.53	291.	4139.	0.301
GJ 832 b*	6.43	4.95	3.40	3416.	0.12	304.	4211.	0.769
HD 217107 c*	5.35	19.86	5.33	4270.	0.52	199.	4106.	0.408
HD 134987 c	5.71	26.21	5.83	5000.	0.12	195.	4100.	0.249
GJ 849 b	8.19	9.10	2.35	1882.	0.04	355.	4488.	0.269
GJ 179 b	9.40	12.29	2.41	2288.	0.21	153.	8140.	0.238

Credit: Bob Brown

RV completeness for nearby stars

- RV census of nearby Sun-like stars is fairly complete for giant planets in <5.5 year orbit
- Out of the 54 stars within 5pc
  - 9/54 = 17% have at least one planet
  - 7/36 = 19% of F5-M5 stars have at least one planet
  - 6/36 = 17% of F5-M5 stars have at least one giant planet
  - 5/36 = 14% of F5-M5 stars have at least one giant planet in a <5.5 yr orbit
- Consistent with Cummings et al. (2008)
  - 10.5% of Sun-like stars (F5-M5, but mostly G and K) host a giant planet with <5.5 yr orbit
  - 17-20% have a giant planet within 20 AU

- RV surveys for nearby M stars is quite incomplete (however not typically good targets for direct imaging with small telescope (faint)

Credit: Nick Cowan

RV surveys needs for direct imaging

- Question: what can RV do now in preparation of future DI mission?
- New approach to this question started at ExoPAG9
  - Define the science goals for a RV survey in support of a future DI mission
  - Define a DI target list for RV surveys (starting point ExoCat, Turnbull/Traub/ExEP)
  - Coordinate with RV teams (D. Latham)
    - *Cadence, precision and time baseline*
    - *Existing overlap with existing RV surveys (bright/known stars)*
    - *Determine and scope resources (telescope time, work) needed to complete such RV surveys for future DI mission*
  - Determine if additional resources are needed for RV surveys and investigate path forward for funding.

- SAG9 identified 5 science cases for these surveys

Science cases for precursor RV survey

- Identify and get masses Giant Planets at >0.1-0.2 arcsec
- Identify and get masses for some sub-Neptunes (~10MEarth)
- Identify the mass upper limit of possibly existing planets
- Identify RV trends at and beyond HZ separation
- In-depth study of special-interest target stars
- Other?

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    - Most interesting targets are brightest stars brighter than mag ~7-8, since giant planet typically mag<30
    - Planets with separation <~5AU most interesting (i.e. <~1e9 contrast)
    - IWA in 0.1-0.2 depending on starshade or internal coronagraph type, stars within 50pm
    - Kepler: hot-jupiter tend to be lonely, then is it worth continuing to monitor them?
    - 4000 stars within 20pc, 85% M dwarfs, not good targets for probes (ELTs, ATLAST)
    - Role of Gaia, but bright limit (improved recently) and precision

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  - Kepler shown they are frequent in Kepler field, so assume here they are also frequent around nearby stars
  - Hard to do for probe/medium size - focus on sep<2-3AU, nearby (10-20pc) earlier types for more photons
  - Focus on a few, ~20 stars (preliminary short list from Exo-S)

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  - Identify possible giant planet interacting with HZ in order to rule-in or rule-out most of the targets for HZ searches (relevant for Flagship mostly
  - Simple criterion (e.g. 3-Hill sphere radius) can be sufficient for broad brush purposes to rule-in/rule-out target for observations (Turnbull)
  - Identify the upper-limit mass of possible existing planets from non-detections a a function of separation.

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  - RV trends useful beyond HZ at larger separation
  - Ruling out “Nemesis” companions to the star that will disturb HZ (Flagship), RV only part of the picture (imaging etc.)
  - Trends indicating sub-Neptunes? could be difficult if multiple planets, but to investigate for target selection purposes

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    - e.g. Alpha Cen: very high contrast, but large separation.
    - contrast from the other star 1e8 - possible post-processing/DM diversity being investigated (Belikov)
    - other particular stars of interest

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