Space Opportunities: Hardware to Vaporware

- Characterization of Jupiters to Super Earths

- ***Spitzer (<2013)---senior review!***
- ***JWST (2018+)***
  - Planet imaging and transit follow-up
- SPICA (2018)
- Explorers (2017)
  - All sky transit surveys (vis & near-IR)
  - Transit follow-up
- PLATO (2018)
  - Transit over 50% sky, stellar ages
- ECHO (2022)
  - Transit follow-up

- Complete census over Mass-Period plane

- WFIRST/WIRES (2021++)
  - Maybe microlensing
- EUCLID (2018)
  - Maybe microlensing

- Characterization of Earths

- Optical/UV telescope with coronagraph (2025+)
- Astrometric mission (NEAT), 2030

EUCLID :

ESA mission with one Science goal that drives the requirements.

EUCLID is a Weak Lensing and BAO Machine.

The rest is legacy Science and has no right to fix requirements.

However :

- Cosmic Shear and Microlensing share the same needs!
- Due to EUCLID orbit strategy, 2+ month/year in galactic plane

Microlensing program :

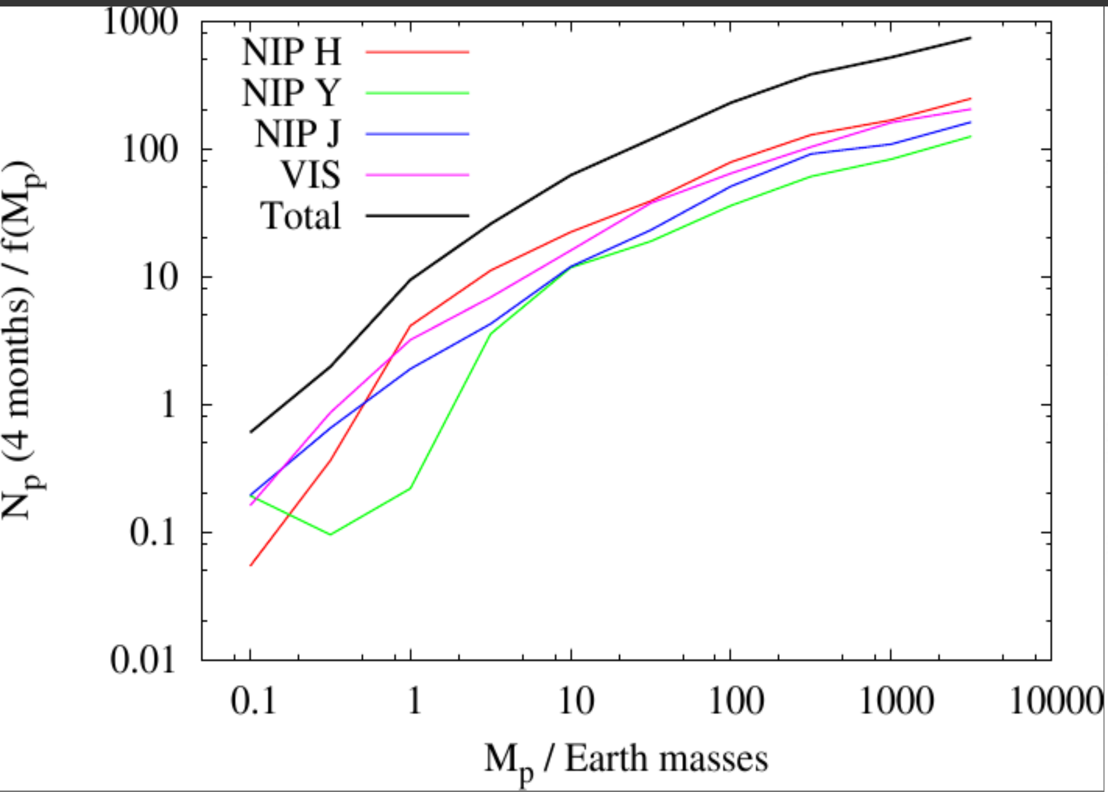
- 4 months -> census on cold planets
- 10 months -> towards habitable Earth

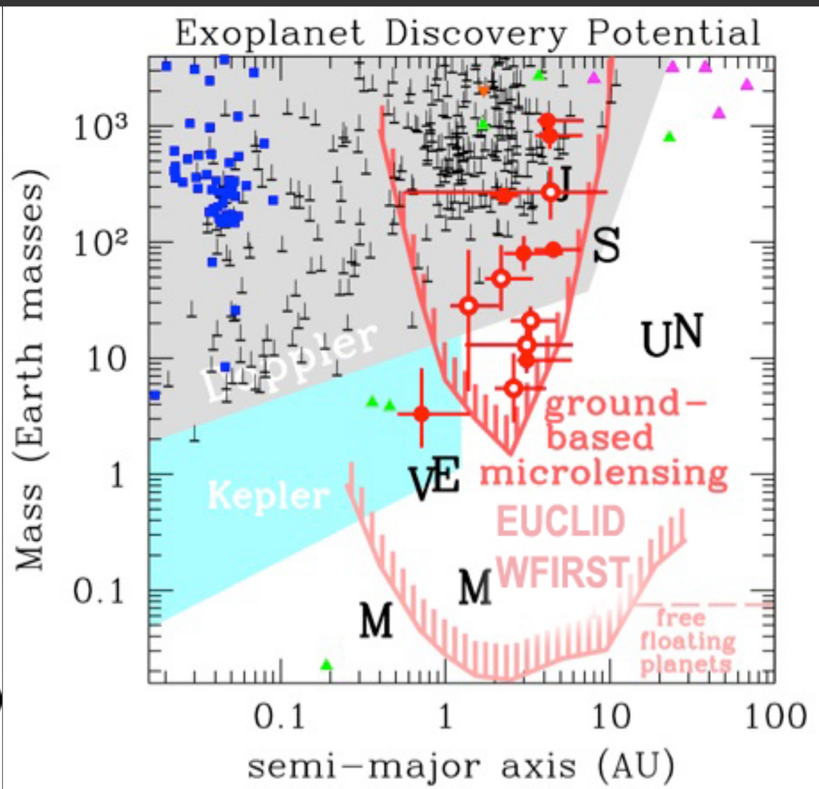
- 5 years mission
- L2 orbit
- Korsch telescope 1.2m
- Optical focal plane (0.55-0.92 μm) : 0.55 sq deg, 0.1 arcsec/pixel (36 CCDs)
- NIR focal plane (Y, J, H) : 0.58 sq deg, 0.31 arcsec/pixel (16 Hawaii RG II)
- NIR Spectroscopy channel : 0.5 sqdeg R=200-600, 0.9-1.7 mu, slitless redshifts

EUCLID

In competition with :
PLATO & Solar Orbiter
for ESA Cosmic Vision 2

Up to 2/3 will fly.
Selection in October 2011





Simulations by Penny et al.

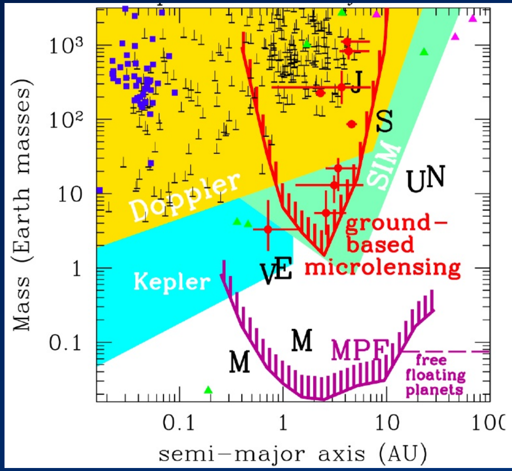
WFIRST

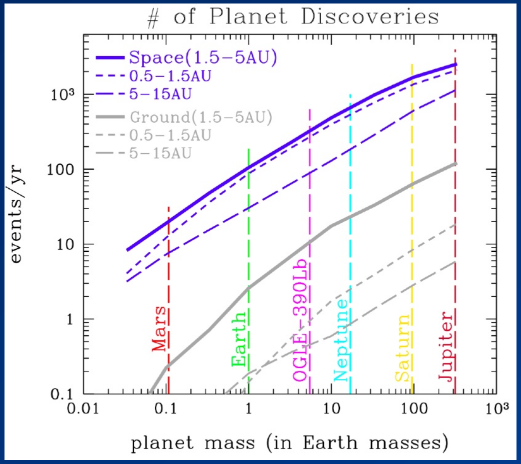
Science Goals:

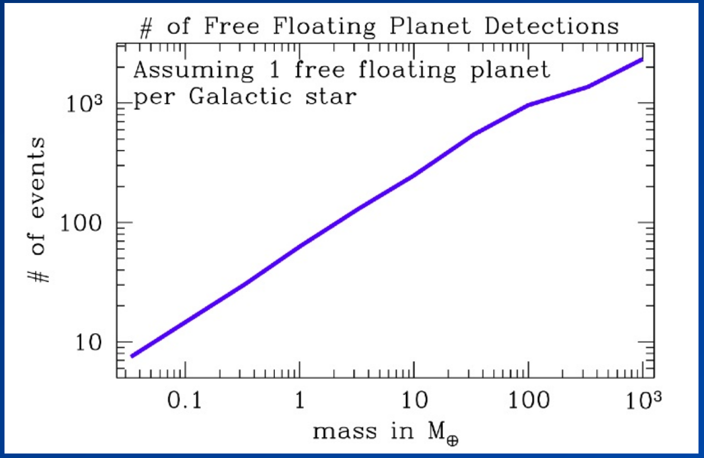
- Determine the mass ratio, and projected separation probability distribution (in units of the Einstein ring radius) for cold planets with $M>M_{Earth}$ and a>0.5 AU.
- Measure the frequency of potentially habitable planets.
- Measure the frequency of free-floating planets with $M> M_{earth}$.
- Measure the host star masses in order to determine the mass and projected separation distributions in physical units.
- WFIRST + Kepler = Complete demographics for $>M_{Earth}$ and 0-∞ (including habitable for FGK stars)

Current Status:

- Defining the science for a reference mission (=JDEM-Omega)
- Descopes and/or mergers with Euclid possible later.
- Microlensing is in a relatively good position: requirements are less stringent than other science.







Future Exoplanet Missions: The Case for Direct Imaging

Wesley Traub, JPL

Exploring Strange New Worlds, Flagstaff, 1-6 May 2011

Astro2010 View

- Complete JWST
- No SIM
- Advanced RV
- Exozodi from ground
- Eta-sub-Earth begun by Kepler
- Eta-sub-Earth completed by Microlensing on WFIRST
- Decide on direct imaging mission by 2015
- Tech development 2015-2020
- Propose direct imaging mission to Decadal in 2020

Zodiac II

Debris Disk Science from a Balloon

Principal Investigator: Dr. Wesley A. Traub

Science Investigation

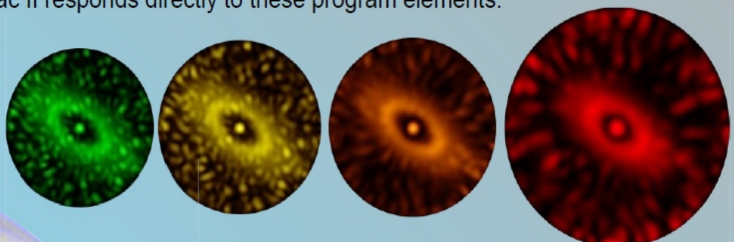
- Zodiac II is an investigation of debris disks around nearby stars, based on visible, four-color images, obtained with a telescope and coronagraph instrument, mounted on a balloon gondola, during four flights in the Earth's stratosphere.
- Debris disks around stars are the analogs of the Sun's Asteroid- and Kuiper-Belt rings.
- Zodiac II observations are crucial to theories of planet formation (e.g., the Nice model).

Science Questions

- Zodiac II images give us answers to these questions:
  - How are debris disks produced?
  - How are debris disks shaped by planets?
  - What materials are debris disks made of?
  - How much dust do debris disks make as they grind down?
  - How long do debris disks live?
- Target of Opportunity: What controls the visible brightness of hot, young exoplanets?

NASA Program Relevance

- NASA Science Mission Directorate plan for 2010:
  - *What are the characteristics of planetary systems orbiting other stars?*
  - *Can we understand planetary system formation and evolution?*
- Astro2010 (New Worlds, New Horizons) recommendation:
  - *A technology development program for a planet-imaging mission beyond 2020.*
- Zodiac II responds directly to these program elements.



Simulated 4-color image of a debris disk, after 1-hour integration.
Each image shows a highly suppressed central star, the surrounding debris disk, and realistically simulated noise ("speckles") from the instrument.

Instrument

- 1.1-m diameter telescope, for angular resolution and collecting power.
- Imaging coronagraph, to keep bright star from flooding disk image: final contrast 10^{-8}.
- Visible wavelength operation, to see reflected light from disk: 500-990 nm.
- Four spectral bands, to measure disk color.
- Stratospheric balloon platform, to get above Earth's turbulence: 35 km.
- Multi-hour integration times, to capture faint disk images: 4 flights, 25 targets.
- No current or planned facility can match Zodiac II on debris disks, by factor of 100.

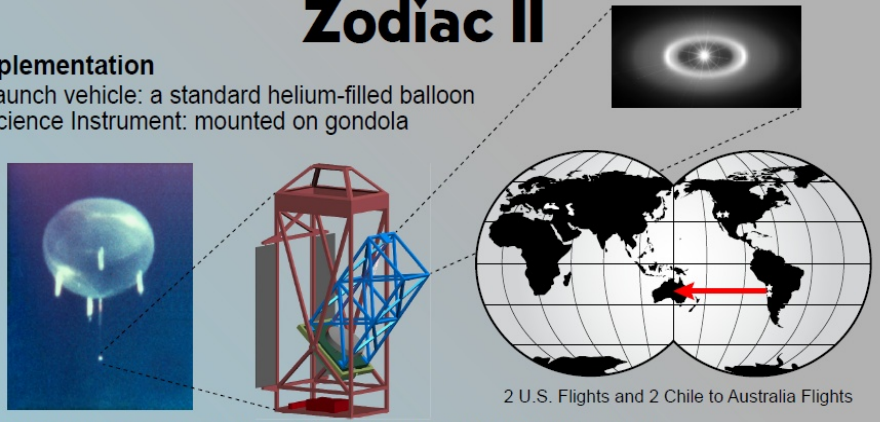
Technology Gains

Zodiac II flights will raise the technology readiness level of four technologies to TRL-7, directly relevant to a future strategic mission for imaging exoplanets.

Zodiac II

Implementation

- Launch vehicle: a standard helium-filled balloon
- Science Instrument: mounted on gondola



2 U.S. Flights and 2 Chile to Australia Flights

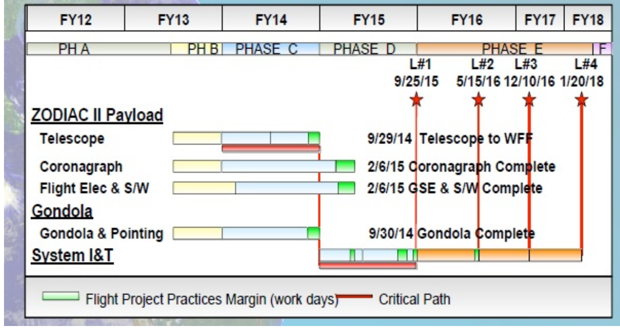
Zodiac II flies on a balloon like this (photo by the PI, of one of his 20 previous flights).
Insets show gondola, telescope, and a debris disk model.

Pointing & Wavefront Control

- Image positioning to 0.02 arcsec RMS (requirement is 0.04 arcsec)
  - German/U.S. Sunrise balloon focal plane achieved 0.04 arcsec in 2009
- Wavefront control is 0.3 nm RMS (require 1 nm)
  - JPL High Contrast Imaging Testbed demonstrated 0.05 nm in 2006

Team Expertise

Jet Propulsion Laboratory	
G. Bryden, K. Stapelfeldt, B. Mennesson	Debris disks and Zodiacal dust science
P. Chen, J. Krist	Wavefront sensing and control
D. Mawet, W. Traub, J. Trauger	Coronagraph theory and practice
S. Unwin, G. Vasisht	Interferometric instruments
R. Bruno, L. Roberts	Project manager and system engineer
Northrop Grumman & NG Xinetics	
C. Lillie	Large missions, SiC mirrors, deformable mirrors
NASA Wallops Flight Facility	
D. Stuchlik	Balloon flight systems, precision gondola pointing
Lawrence Livermore National Laboratory	
B. Macintosh	Coronagraphy, telescopes, adaptive optics
Boston University	
S. Chakrabarti	Coronagraphy on a sounding rocket



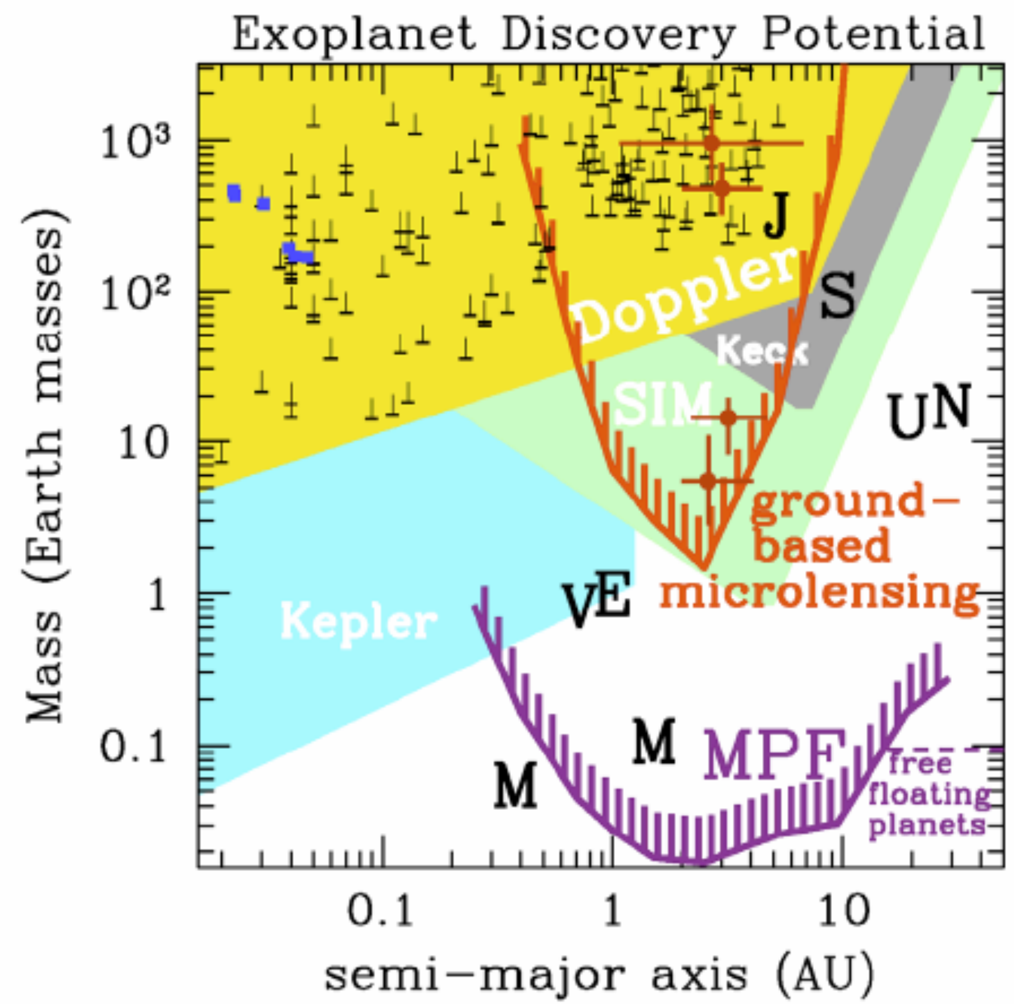
Cost Estimate

Total Cost: $54M (FY11)
$59M (RY)
Phase B/C/D: 30% reserve
Phase E/F: 20% reserve

Major Responsibilities

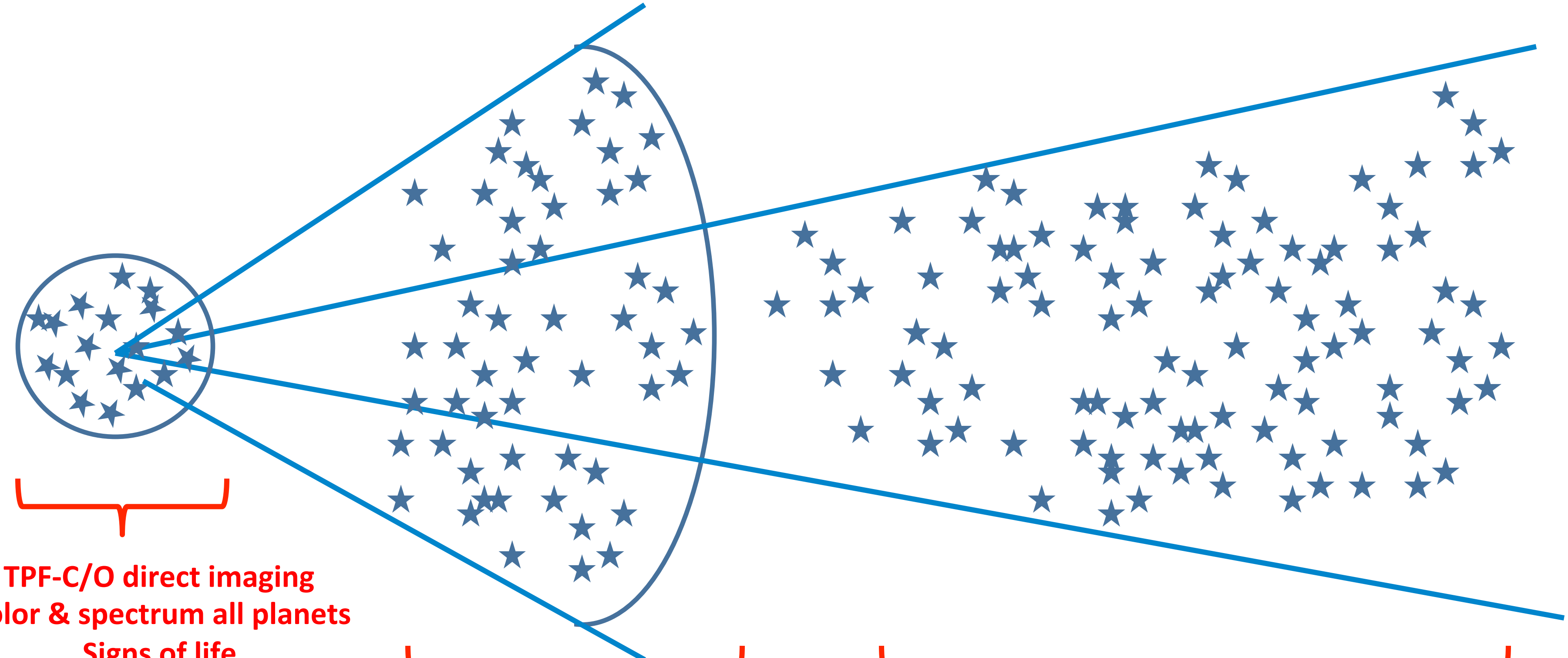
Telescope: NGAS-Xinetics
Gondola: NASA WFF
Coronagraph: JPL
Science & Mgmt: JPL

WFIRST mission



WFIRST mission, recommended by Astro2010, is 30% devoted to searching for exoplanets using the gravitational microlensing technique. This project will provide statistics of the numbers of planets in the 1-30 AU range, complementing Kepler's 0.1-1.0 AU range (both ranges approximate). Figure from the MPF proposal, 2006, Dave Bennett et al.

Exoplanet prospects, near and far



TPF-C/O direct imaging
Color & spectrum all planets
Signs of life

PLATO transits/seismology
100-400 pc distant
250,000 stars
10 to 13 mag
8% of sky
Expect 400 Earths (1/star)
Also related proposals

CoRoT transits/seismology
400 to 2000 pc distant
~40,000 stars
13 to 15 mag
0.01% of sky

Kepler transits/seismology
500 to 2000 pc distant
156,000 stars
14 to 16 mag
0.24% of sky
Expect 400 Earths (1/star)

ML on WFIRST,
TBD planets, kpc distances

Exoplanet Community Response to Astro2010

Jan. 2011: **ExoPAG* agrees on path to a single mission concept, by 2015, for an exoplanet direct-imaging mission in the 2020s,** as recommended by Astro2010:

- 2011: ExEP (Exoplanet Exploration Program) initiates Imaging Performance Study (IPS), a community-wide demonstration of simulated exoplanet detection and characterization using 3 direct-imaging architectures.

- 2012: IPS carried out, with 6 teams, competitively extracting planet signatures, from simulated imaging data, with realistic instrument and data sets.

- 2013: Interim Science Working Groups (ISWGs) produce Concept Study Reports on 3 direct-imaging architectures.

- 2014: Senior Review evaluates 3 ISWG reports, & recommends 1 architecture.

- 2015: NASA down-selects architecture, & informs CAA (not DSIAC).
- 2015-2020: Technology development of selected architecture.
- 2020: Exoplanet direct-imaging mission concept readied for Decadal Committee.

** ExoPAG: Exoplanet Program Analysis Group (chair Jim Kasting, Penn State), reports to Astrophysics Subcommittee (chair Alan Boss), of the NASA Advisory Council Science Committee (chair Wes Huntress).*

Task from Chas: Science Issues for direct imaging (IR) on Earth-like Planets : 1

Tamura's inputs

- Why IR? (compared with OPT)
  - Planets are cold, in particular habitable ones peak at MIR (~10 micron) in thermal flux.
  - Much better contrast to their host stars at MIR (10^7 vs 10^10).
  - Many MIR (& NIR) molecular features to characterize their atmosphere, especially biomarkers H2O and O3 (and CO2).
  - Less extinction for possible embedded planets (in the first core).
  - Recent great advances in IR (even MIR) detectors and their readout systems.
- Why not IR? (compared with OPT)
  - Poorer resolution; need larger telescope aperture or baseline.
  - High background and Earth atmosphere; need space mission.
  - Therefore, the only feasible mission is space IR interferometer; but still technically challenging; so after OPT mission?

Task from Chas: Science Issues for direct imaging (IR) on Earth-like Planets : 2

Tamura's inputs

- Goal
  - In spite of knowing diversity of exoplanets, we are (at least I am) "most" interested in the Sun-Earth analog (how frequent and life there or not).
  - HZ planets around M stars can be done w/ coming telescopes.
    - JWST's or SPICA's transit spectroscopy of Super-Earths around M stars.
    - TMT's (or E-ELT) direct imaging of habitable planets around M stars (SEIT; Matsuo, Tamura, Murakami, Kotani)
  - But direct imaging at OPT or IR is the only viable way for "characterizing" habitable planets around G stars.
  - Resolving planets need another technical leap; so our next goal should be the above.

Task from Chas: Science Issues for direct imaging (IR) on Earth-like Planets : 3

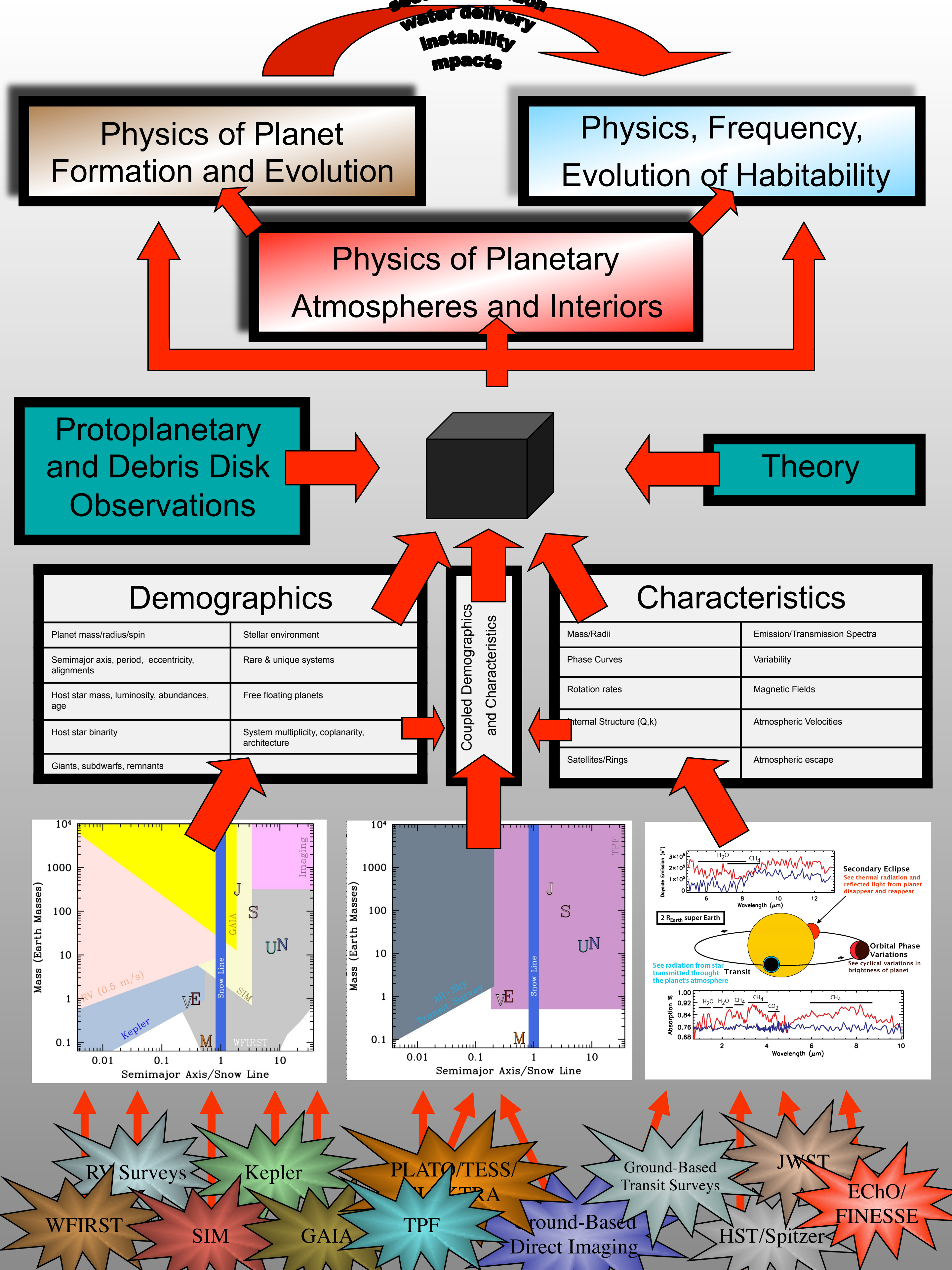
Tamura's inputs

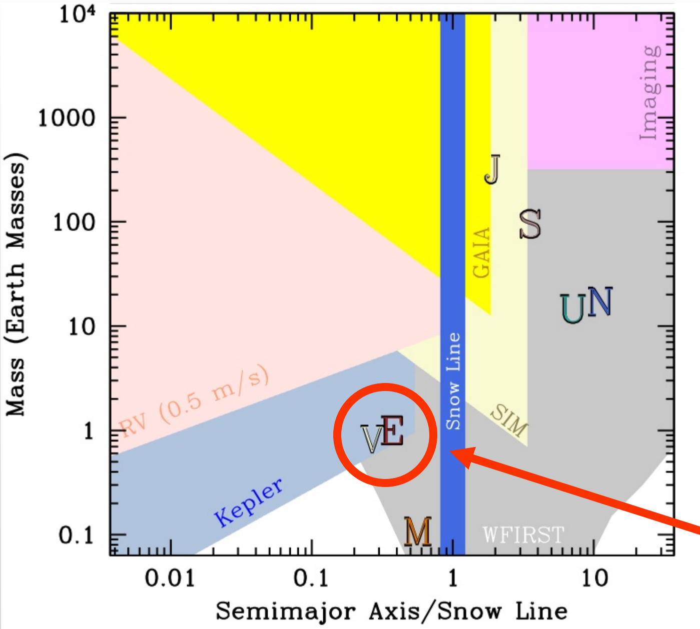
- More general interest
  - Comparative exoplanetology including both habitable and non-habitable (all rocky) planets, based on characterization, not simply on statistics.
  - Then, extension for various host stars (mass, age, metalicity)
  - Important questions
    - Origin and evolution of liquid water
    - Evolution of atmospheres
    - New types of planets

- Not conflict with general astrophysics

  ✓ high resolution IR astronomy merits to all fields.

  ✓ Not only astronomy but also planetary-science, physics, Astro-Bio

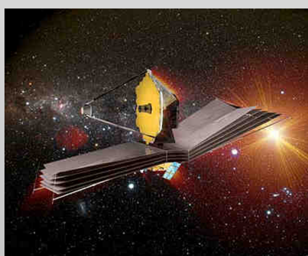

water delivery
instability
Physics of Planet Formation and Evolution
Physics, Frequency, Evolution of Habitability
Physics of Planetary Atmospheres and Interiors
Protoplanetary and Debris Disk Observations
Theory
Demographics
Planet mass/radius/spin
Stellar environment
Semimajor axis, period, eccentricity, alignments
Rare & unique systems
Host star mass, luminosity, abundances, age
Free floating planets
Host star binarity
System multiplicity, coplanarity, architecture
Giants, subdwarfs, remnants
Coupled Demographics and Characteristics
Characteristics
Mass/Radii
Emission/Transmission Spectra
Phase Curves
Variability
Rotation rates
Magnetic Fields
Internal Structure (Q,k)
Atmospheric Velocities
Satellites/Rings
Atmospheric escape
Mass (Earth Masses)
Semimajor Axis/Snow Line
RV (0.5 m/s)
Kepler
GAIA
SIM
WFIRST
Imaging
Snow Line
All-Sky Transit Survey
TPF
Secondary Eclipse
See thermal radiation and reflected light from planet disappear and reappear
Orbital Phase Variations
See cyclical variations in brightness of planet
Transit
See radiation from star transmitted throught the planet's atmosphere
Wavelength (μm)
RV Surveys
Kepler
PLATO/TESS/
Ground-Based Transit Surveys
JWST
WFIRST
SIM
GAIA
TPF
Ground-Based Direct Imaging
HST/Spitzer
EChO/ FINESSE

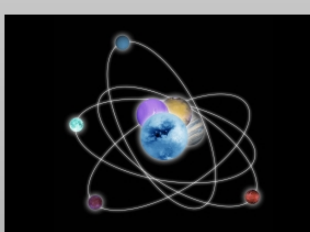


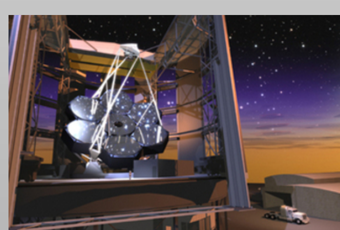
Demographics

Current	Future
RV Surveys	Ultra-Precise RV Surveys
Ground-based μlensing	GAIA
Kepler	SIM
…	WFIRST

Habitable Planets
nadir of detection sensitivity

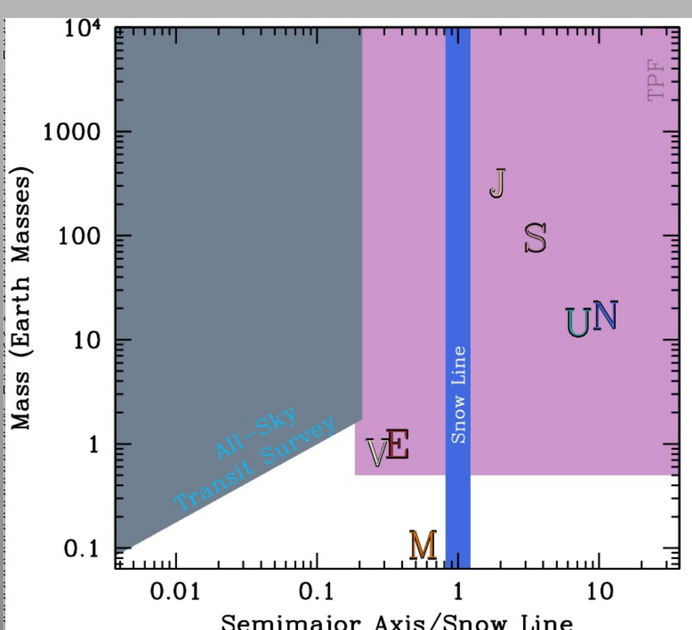






Characteristics

Current	Future
Ground-based Transit Surveys	VLTs
Ground-based Follow-Up	JWST
Spitzer	ECHO/FINESSE
HST	?



Demographics + Characteristics

Current	Future
Ground-Based Direct Imaging	PLATO/TESS/ ELEKTRA
…	TPF

Habitable Planets

	High Mass		Low Mass	
	Frequency	Habitability	Frequency	Habitability
Current	Kepler		RV	MEarth
Future	RV WFIRST	RV? SIM? ↓ TPF	MEarth TESS ASTRO PLATO	TESS ELEKTRA ↓ JWST VLT

“Pale Blue Dot”

“Small Black Shadow”

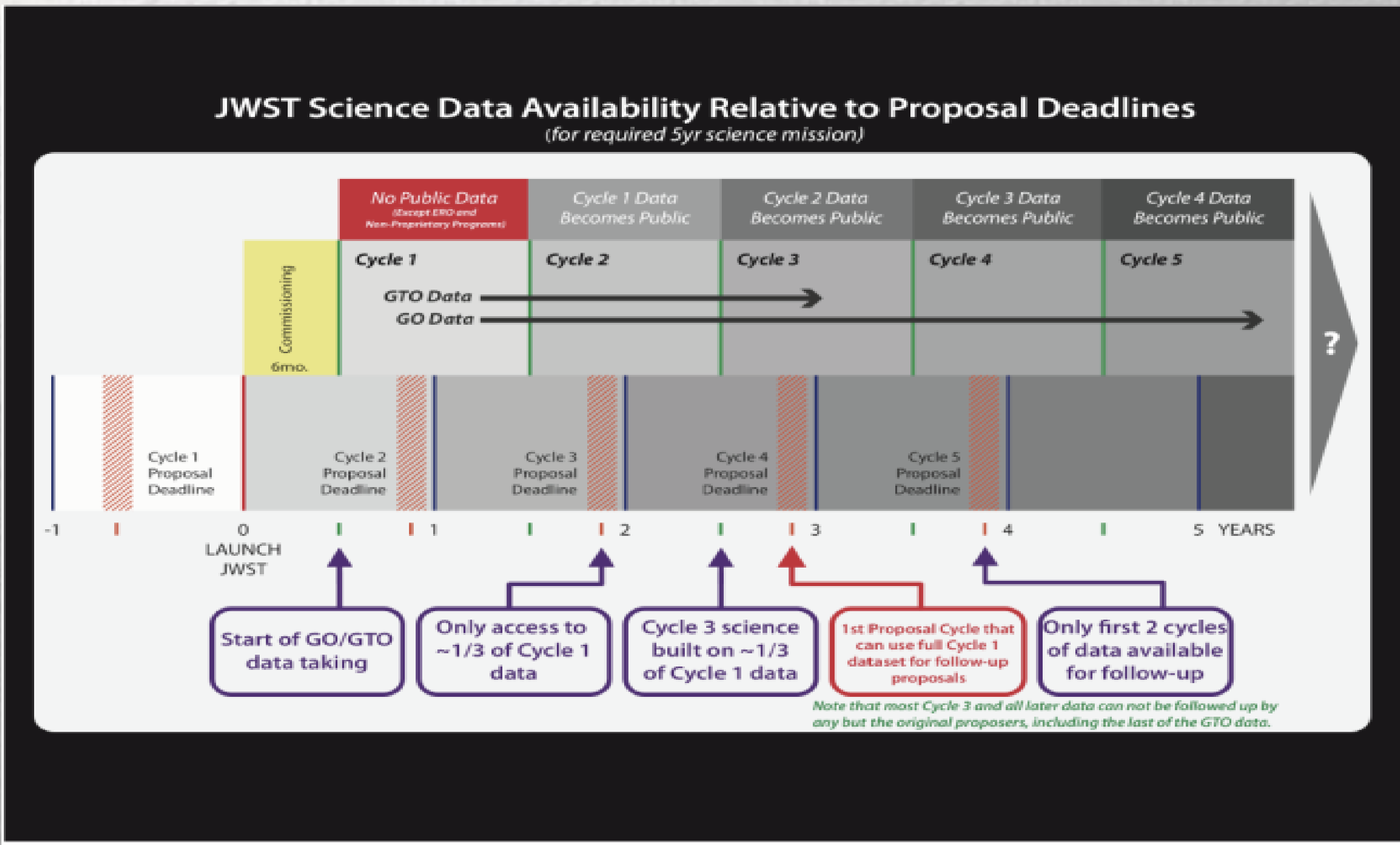
Exploiting JWST for the Exoplanet Community

Neill Reid, STScI

The JWST data release timeline

JWST will be an extremely complex telescope with complex instrumentation.

With a 12-month proprietary period, JWST Cycle 1 data is not fully available to the community until just before the Cycle 4 proposal deadline.



GDI – 11/04/09 JSTAC
(with 7-8 months between proposal deadline and start of science observations)

Getting ready for JWST

- JWST is a limited lifetime mission
  - 5-year requirement, 10-year goal
- ➔ Astronomical community needs to hit the ground running
- Accelerate Data Access
  - Early Release Observations will be non-proprietary – very limited
  - Early Release Science program – DD program on scale 200-800 hours
    - Provide observations in representative set of instrument modes
    - Targets chosen in consultation with community & publicised
  - STScI will encourage limited or null proprietary times for large programs
- Exoplanet community needs to organise itself
  - Take advantage of existing missions
    - HST - ~$25-28 million/year available in grant funding
      - If you want to increase your share, you need large programs
    - Chandra - ~$11 million/yr
    - Herschel, [Spitzer], Kepler - ~$6 million/yr total
    - SOFIA
  - Help identify potential targets
    - Simulations of JWST datasets
  - Develop coordinated programs

Status of our subject is good scientifically – 4-5 exomissions flying: MOST, SPITZER, CoRoT, Kepler, HST
Status of international collaboration is good

Status of new space missions

- JWST is delayed at least 4 – 5 years
- SPICA (?)
- EUCLID (?) and WFIRST are in the 2020:ties
- TESS & ELECTRA ?
- PLATO (?) 2018 — N.B. PLATO and EUCLID to be confirmed in October
- ECHO (in M3 study) 2020:ties

International collaboration is fine on JWST, SPICA and officially non-existent on the rest.
Contacts between PLATO Consortium and Brazil, US scientists ongoing
More need to be done!