



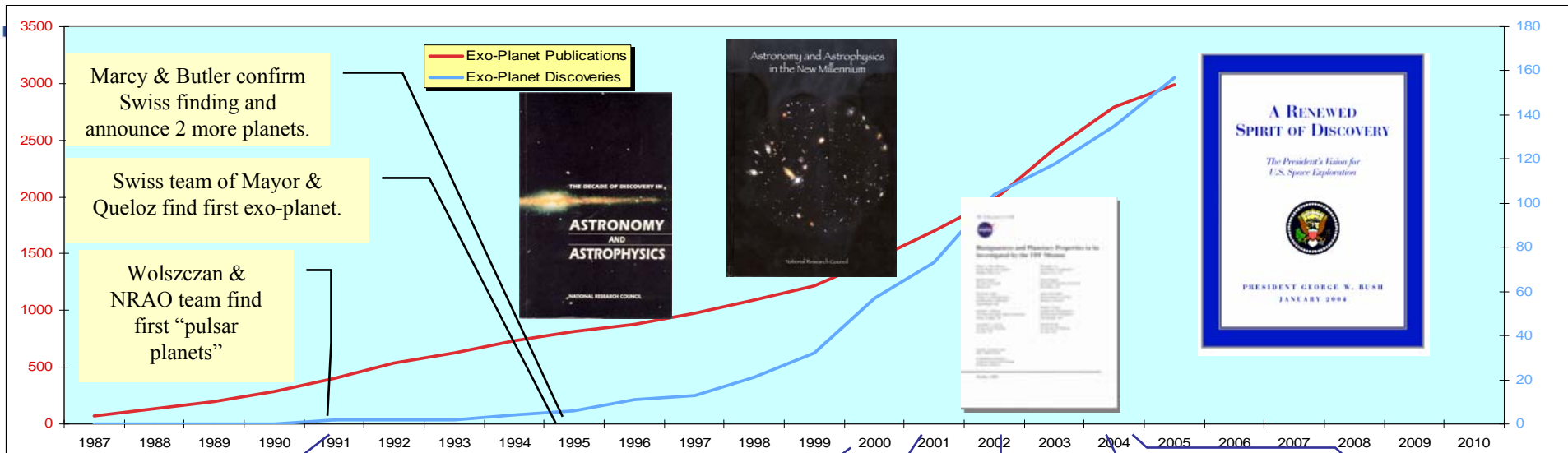
Navigator Program: *Exploring New Worlds*

Exploring Exoplanets – a new course

If one does not know to which port one is sailing, no wind is favorable.
Seneca (5 BC - 65 AD)

Michael Devirian
17 May 2007

A Rising Tide...

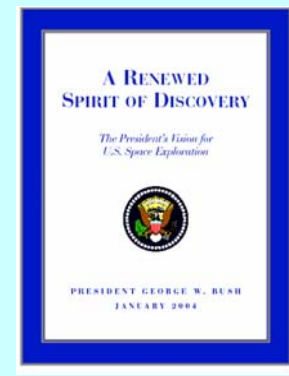
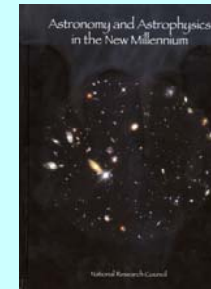
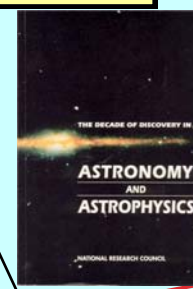


Marcy & Butler confirm Swiss finding and announce 2 more planets.

Swiss team of Mayor & Queloz find first exo-planet.

Wolszczan & NRAO team find first "pulsar planets"

Exo-Planet Publications
Exo-Planet Discoveries



Bahcall report (NRC 1991) endorses SIM:
 "... would permit definitive searches for planets around nearby stars"
 "... trigonometric distances throughout the galaxy"
 "... would demonstrate the technology required for future missions"

McKee/Taylor report (NRC 2000) sets 4 strategic goals including:
 "Search for life beyond Earth,... This goal is so challenging and of such importance that it could occupy astronomers for the foreseeable future."
 "The committee reaffirms the recommendations of the 1991 Astronomy and Astrophysics Survey Committee (NRC, 1991) by endorsing the completion of ... the Astrometric Interferometry Mission (now called Space Interferometry Mission, or SIM)."
 – endorses TPF for next decade.

Des Marais report advocates both optical and IR spectroscopy:
 "Both Mid-infrared and visible to near-infrared ranges offer valuable information regarding biomarkers and planetary properties; therefore both merit serious scientific consideration for TPF."
 – Leads to plan to eventually fly both IR and Vis TPF's.

CAA reaffirms scientific importance of SIM (2002):
 "The CAA reaffirms the scientific excitement of the 2001 AASC for the important new planet-finding narrow-angle science capability of SIM."

President's National Security Directive calls for:
 "Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars"

CAA endorses TPF's multi-wavelength approach (2004):
 "the identification of biomarkers ... requires observations in spectra that span not only the optical but also the mid-infrared (IR) bands"
 "What can be learned from the combination of TPF-C and TPF-I data is therefore far greater than what either mission alone would yield".

The Navigator Program

Exploring New Worlds



Exploring New Worlds

Navigator Program

Navigator Program Prime Objective

“Advanced telescope searches for Exo-Solar Planets and habitable environments.” *Vision for Space Exploration, 2004*

Primary Goals

- Create a census of extrasolar planets and measure their properties
- Detect and characterize Earth-like exo-planets
- Understand the formation, history and distribution of planetary systems in our Galaxy.



KECK

- Characterize inner exo-zodiacal dust environments
- Identify long-period planets, “warm-Jupiters”



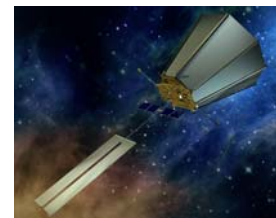
LBTI

- Characterize outer dust environments
- Observe giant planets



SIM PlanetQuest

- Search for terrestrial planets
- Characterize planetary systems
- Determine planet mass



TPF-C

- Detect Earth-like planets in visible light
- Characterize planet atmospheres
- Assess habitability



TPF-I

- Detect Earth-like planets in infrared
- Characterize planet atmospheres
- Search for indicators of life



Michelson Science Center

- Science community development
- Science operations for Navigation missions
- Multi-mission tools and science data archives to support Navigation Program projects and science community.

**SIM-specific
In Hiatus**

Where are we now?



Exploring New Worlds

Navigator Program

- The community is active and eager (10 years ago, the odd exoplanet paper at AAS; this summer, 10 sessions)
- NASA's Astrophysics budget is unable to fund major flagship exoplanet missions in next decade.
 - We (community, Navigator, NASA) must identify affordable scientifically significant exoplanet characterization missions.
 - We must steer for results that, while head-turning, are less than an exhaustive search for nearby exoplanets.
- Fast pace of discovery of lower mass planets point to significant science with smaller missions.
- Growing the field, producing scientific results, is fundamental to success of the "Vision".
- Technological and scientific foundations for planet characterization missions well laid with ~45% of TPF funding over past 10 years spent at Universities, observatories and industry.

What marks our course?



Exploring New Worlds

Navigator Program

Scientific

- More and more planets detected and the mass curve is pushing downward
- Corot on orbit and instrument is working well; Kepler is coming soon
- First crude spectral (color) data collected from large exoplanets; “maps” have been produced
- The field is rapidly moving from an emphasis on “finding” to “characterizing”

Programmatic

- SIM remains poised to proceed, probing 10’s to 100’s of Earth-mass planets, 1000’s of systems (as a large mission)
- TPF “Classic” not in the cards in the next decade, but affordable versions are coming
- ESA Cosmic Visions proposals will include interferometers, coronagraphs and external occulter; collaborative opportunities are likely
- NASA budget appears capable of supporting more than one medium mission (<\$1B) plus multiple small investigations (suborbital, balloons, etc.) between now and 2020.

Architecture

- Studies suggest that reduced scale characterization missions can address key science goals
- Recent Discovery proposals identified excellent planet characterization candidates for <\$1B (though not \$425M)

Technology

- State-of-the-Art testbed and facilities in place to serve community needs
- Starlight suppression & beam combination performance trending rapidly toward (or in some cases meeting) mission requirements
- Formation flying performance in laboratory and on ISS trending toward requirements for interferometers and meeting requirements for external occulter

Navigator Program is Recommending to NASA The Next Steps for TPF



Exploring New Worlds

Navigator Program

- Capitalize eight years of technology & mission analysis that demonstrated affordable exoplanet characterization mission concepts can be implemented in the next decade.
- Work with the community to prepare for such a mission by:
 - Continuing to engage the broad community through events like the Navigator Forum
 - Continuing to make existing testbeds available for community use and technology evaluation
 - Continuing modeling and analysis of a range of mission sizes and instrumental techniques to verify exoplanet science performance as a function of size/complexity/ technology readiness (aka cost)
 - Incorporating the AAAC Exoplanet Taskforce Report/Recommendations into NASA's plans
 - Incorporating the ESA Cosmic Visions results and potential for collaborations into NASA's plans
- Produce an balanced and executable plan for missions with accompanying suborbital and balloon investigations and foundation science
- In early FY08, solicit proposals for affordable exoplanet science instrument/mission concepts (e.g Lyot coronagraphs, PIAA coronagraphs, Occulters, Interferometers, Optical Vortex coronagraphs, Optical Nullers....) that can accomplish breakthrough results within available budget
 - Select several for funded \approx 6 month Step 2 studies in mid FY08
 - Downselect to a single instrument concept and instrument team for "TPF1" at the end of FY08
- Selected instrument team will be part of the TPF1 project team working to complete instrument technology, and perform science and implementation planning for "TPF1" as a function of telescope size/cost leading to a Mission Concept Review early next decade.
- Prepare for a start early in the next decade, with a telescope size and science performance consistent with NASA's available budget.

Summary



Exploring New Worlds

Navigator Program

- A decade ago exoplanet science was in its infancy
- A handful of giant, short period planets were known and a handful of astronomers were interested
- Today, through the support of NASA and NSF, there are lots of exciting data making exoplanet science a vibrant field with many active ground and space-astronomers and strong public interest
- Planets are abundant with 235 objects known including some as small as $<10M_{\text{Earth}}$
- The technology for exoplanet science missions has improved by many orders of magnitude in the laboratory

We are ready to move forward with affordable space missions to investigate nearby exoplanets and planetary systems and to begin the search for signs of habitability and of life itself.