Notes on Presentations and Discussions at the Workshop on Innovative Approaches to Exoplanet Spectra

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Foreword

This volume contains notes on the presentations and discussions at the workshop "Innovative Approaches to Exoplanet Spectra." The workshop was sponsored by the Keck Institute for Space Studies, at Caltech, and by the Jet Propulsion Laboratory. The workshop was held on 10-13 November 2009, on the Caltech campus.

These notes were recorded in real-time by Roger Carlson, and transcribed here by him. The notes include additional comments and questions after the presentations, as well as some repetition of the presentation materials. The full set of presentation materials is at "talks" at http://www.kiss.caltech.edu/workshops/exoplanet2009/schedule.html

Workshop Participants

First	Last	Institution	Interest area
Konstantine	Batygin	Caltech	Atmospheres
Chas	Beichman	Caltech/NExScI	Proto-planet disks
Dan	Belden	USAF	DoD rockets
Rus	Belikov	Ames	Coronagraphs
Beth	Biller	U. Hawaii	observations
Jeff	Booth	JPL	balloons
Eric	Cady	Princeton	imaging exoplanets
Kerri	Cahoy	Ames	direct imaging & characterization
Roger	Carlson	JPL	technical writer
Joe	Carroll	Tether Appl.	Small spacecraft
Supriya	Chakrabarti	BU	Rockets
Pin	Chen	JPL	Atmospheric chemistry
Arvid	Croonquist	JPL	ISS
Carl	Grillmair	Caltech	Transits
Joe	Harrington	UCF	Exoplanet observations
Brian	Hicks	BU	imaging exoplanets
John	Johnson	Caltech, IFA	Exoplanet observations
Jeremy	Kasdin	Princeton	Coronagraphs, engineering
Nancy	Kiang	GISS/JPL	Photosynthesis
John	Krist	JPL	Coronagraphs, optics
Shri	Kulkarni	Caltech	Astrophysics
Mike	Line	Caltech	atmospheres
Tom	Mace	Dryden	Aircraft platforms
Bruce	Macintosh	LLNL	Exoplanet coronagraphy
Mark	Marley	Ames	Giant planet theory
Taro	Matsuo	JPL/NAOJ	coronagraphs
Beverley	McKeon	Caltech	Turbulence
Bertrand	Mennesson	JPL	Interferometry
David	Miller	MIT	Cubesats
Barth	Netterfield	U. Toronto	Balloon pointing, astrophys.
Lewis	Roberts	JPL	Atmospheric seeing
Rocco	Samuele	NGAS/JPL	Laboratory instrumentation
Dmitry	Savransky	Princeton	direct detection of exoplanets
Gene	Serabyn	JPL	Coronagraphs, interferometers
Michael	Shao	JPL	Interferometers, coronagraphs
Steven	Smith	SWRI	Stationary airships
Remi	Soummer	STScI	Coronagraphs
Karl	Stapelfeldt	JPL	Proto-planet disks
Mark	Swain	JPL	Exoplanet spectroscopy
Motohide	Tamura	NAOJ	Space telescopes
Wes	Traub	JPL	Exoplanet science, instruments
John	Trauger	JPL	Coronagraphs
Mitch	Troy	JPL	Coronagraphs, ground
Stephen	Unwin	JPL	Interferometers
Gautam	Vasisht	JPL	Observation, instrumentation
Erick	Young	SOFIA	SOFIA
Eliot	Young	SWRI	small payloads
Yuk	Yung	Caltech	Planetary atmospheres

Contents

1 DAY 1 (NOV. 10, 2009)

1.1 KISS Overview, Tom Prince, http:/kiss.caltech.edu

- The Keck Institute for Space Studies is a "think and do tank" whose primary purpose is to bring together a broad spectrum of scientists and engineers for sustained technical interaction aimed at developing new space mission concepts and technology.
- Formed around the Caltech campus, JPL, & the wider community.
- Besides Keck Institute funding, there is JPL R&TD funding.
- Keck supports science and engineering, research, and even public television.
- Five large programs: Coherent instrumentation for cosmic microwave background; large space structures, new directions in Mars exploration; single-photon counting detectors; and monitoring Earth surface changes from Space.
- Several mini programs, including this one: Climate feedbacks & future remote sensing observations Yuk Yung; Innovative Approaches to Exoplanet Spectra (Wes Traub & Yuk Yung).
- KISS is not interested in convening "yet another" workshop or symposium.
- Want to create an environment that will foster revolutionary science changes.

1.2 Workshop Purpose—Wes Traub

- Want to generate **new** ideas for exoplanet science observations.
- People should brainstorm. Don't think of costs … yet.
- Note to session chairs: Guide the discussions, keep them going.
- There are many related events.
- Q: We haven't heard about instruments; there needs to be more emphasis on the instruments instead of just the platforms. For instance, there is a new spectrograph.
- Comment: We don't want to do, "My coronagraph is better than your coronagraph!"
- There should be a matrix for what is good for a satellite, bad for a balloon, good for a balloon, bad for a satellite, etc.
- Jeff Booth at JPL has done some balloon proposals; Tom Mace, aircraft in Palmdale; Univ. Toronto, does balloon astrophysics; Joe Carroll, Tether Applications in San Diego
- Observation: There are a few people who are focused almost exclusively on exoplanets and related phenomena themselves (modeling of atmospheres, Yuk Yung; biosignatures, Nancy Kiang; exo-zodiacal disks, Lynn Hillenbrand). The major dichotomy is between instrument people (coronagraphs, spectroscopes) and the platforms people (who will help fund a ride on or help build or maintain my airplane, balloon, etc. The workshop demonstrated how difficult it was to straddle all three of these focus areas. In particular, it showed that none of the participants had a detailed and comprehensive knowledge of the entire gamut of science issues, instruments, and available platforms
- Post-Meeting Summary:
  The workshop was a valuable way to get those focused on the science up to speed on the technical capabilities of the different instruments and platforms. The bulk of the workshop discussion tended toward identifying technical capabilities/limitations and costs and then seeing what science would be possible. If there had been more time, once the instrument and platform capabilities had been summarized, it could have been valuable to have deeper discussion to develop more the scientific questions suited for each technical setup.

1.3 Exoplanet Properties, System Architectures, & Host Stars John Asher Johnson, Caltech

- In 1994, the first exoplanet found, only 15 years ago.
- Doppler measurements have found 95% of exoplanets.
- Massive planets (Jupiters) were expected beyond the "ice line" and circular orbits; however one of the first planets found had a 4.2 day revolution period and tremendous heat.
- Some orbits very eccentric; wide variations in structure/density.
- Better observations will allow finding "super Earths" with nine earth masses and less.
- Astronomy question of how hot Jupiters form; could they form elsewhere and migrate?
- 10 to 15 cm telescopes could find exoplanets, and then bigger scopes would get precise data.
- Spin of stars and planets cause a slight reddening or bluing; planets affect that spectrum.

Questions:

- These [10- to 15-cm telescopes] would be great balloon-borne projects
  J. Johnson: It takes very little capital to get them going—something the size of your hands in an arc.
- I. (Steve) Smith, SWRI: You could put up about ten of these up in balloons—or high altitude aircraft
- Some exoplanets have been found with ground-based coronagraphs
- Q: What are constraints of frequency in finding?
  A: Just found Jupiter analog recently—don't know. Eric Nielson study had a few numbers—super Jupiters seem to be rare beyond 20 AU
- There are several studies on numbers of planets around sol-type stars; A-stars not as well studied.
- B. Biller, UHI: The models may be optimistic about how bright planets are.
- Q: J. Asher: The instrument is like a Ferrari, great when it is running well. Submillimeter observations may be done routinely when developed.
- Comparisons of A type or solar stars with planets with other star-and-planet systems are difficult because fewer studies of A-type stars.
  W. Traub: Also, this is mostly true for giant planets because we can't detect smaller planets yet. Earth-like planets may have a different set of numbers.
  J. Asher: Kepler results will allow making that distinction.

1.4 “Zody” (Zodiacal Dust—from Primordial Disks to Planets), Lynne A. Hillenbrand, Caltech

- Disks are observed in thermal emission from infrared through submillimeter & millimeter and in scattered light from optical through ultraviolet.
-
- Disks are around all young stars (less than a few hundred million years), but then they disappear because of accretion onto the star, outflow, evaporation, and accretion into planets.
- Disks around older stars (more than a few tens of millions of years) are debris disks, second-generation dust produced by collisions of leftover planetesimals that are stirred by the giant planets
- Our debris disk consists of Kuiper Belt objects in the Outer Solar System (haven’t seen dust out there yet) and the Asteroid Belt, where dust has been observed.
- IRAS and Spitzer observations show that debris around G stars is common; they have about 50 K dust typically (like the KB), but a few stars have dust temperatures up to a couple hundred K (like the AB).
- The debris disks are the signposts to as-yet undetected planets

Questions/Comments

- How much of a dependency is there between spectra & distance from the star?
  A: The data are still mostly integrated spectra.
- W. Traub: Why study disks? They are interesting by themselves, and they are in the way while looking for Earths. If you can characterize the obstruction, you have a better chance of observing your target object.

1.5 Atmospheres of Exoplanets—Yuk Yung, Caltech

- Our Solar System has a set of atmospheres; Earth has major fraction with oxygen; others have CO_2, H_2, N_2
- Detection of methane on Mars exciting because it is destroyed the image of a totally nonfunctioning planet; so something must be generating the methane.
- Just starting examination of the atmospheres of hot Jupiters; there may be diurnal variations already in data.
- Data from two /super Earths; issue of runaway greenhouse (Venus) or snowball (Mars, almost Earth)

Questions/Comments

- Convergence of research from two communities. Would like to see NASA develop models for how planets would evolve.
  A: JPL has done some funding. These studies will take time.
- Atmosphere of Pluto doesn't have certain chemical species, why?
  Y. Yung: They freezes out & gets sequestered.

Debris Disks: Challenges & Opportunities, Chas Beichman, NExSci, Pasadena, CA

- Massive disks around young A stars may herald planets at large radii.
- Disks around mature may not correlate.
- Disks in habitable zone (HZ) may mask planets
- Fomalhaut-b had planet at 115 AU, shown in perturbing of the debris disk.
- Planets as small as Earth can cause visible wakes (brighter in front & behind planet).
- The issue is not just the metaphor of a firefly beside lighthouse in Hawaii as seen in CA; those two light sources are behind a fogbank of the ExoZodi (EZ) disk.
- ExoZodis are measured as Solar System being 1; 3 or 4 can be handled; 10 or more would make observations difficult.
- The Bryden paper [_______________?] found no statistical difference for with/without planets of debris disks; however, brighter disks may correlate with planets.
- The Keck interferometer has been able to push 3 to 5 times deeper than the Hubble Space Telescope (HST)—still not enough; want to get to 10 zodis using large binocular telescopes and then advanced space-based systems.

Questions/Comments

- What about polarization?
  A: Yes, but you need very good signal-to-noise ratio (SNR). It may be more useful for avoiding speckles. The photon noise is the one thing you must eliminate.
- J. Booth, JPL (Jeff): In the small space missions, are there any useful ________. Sub-orbital coronagraph has possibilities. A balloon mission has to be a very good instrument. Also balloons can't get the cold needed. Studying our Solar System Zodiacal Cloud would help develop models for use in studying exozodis.

1.6 Planetary System Stability and Evolution
N. Jeremy Kasdin, Princeton

- Roughly 400 planets detected; some are multi-planet systems.
- Three major theories: all planets started as brown dwarfs, nebular hypothesis, & core accretion.
- Stability? Some planets get thrown out. Even Solar System might have some major instability of inner planets—chaotic, quasi periodic; planets may drift in, be trapped for millions of years, and then fly out again.
- There was not enough disk material to form Uranus and Neptune. There needs to be a mechanism for them to form further in and move out to their present locations.

Questions/Comments

- What is the connection between these models and help with observations? For instance, Doppler observations get false positives so it would be good to know.
  A: Yes, we need more data.
- Any areas need support?
  A: Because it is a chaotic situation, there is great variation. Much is covered by standard corrections for general relativity, kinetic, ____

1.7 Photosynthetic Biosignatures, Nancy Kiang, Goddard

- Biogenic gases and chemical disequilibrium: oxygen, ozone, methane CH_3Cl, N_2O
- Need 20% cloud free to detect red edge of life signs

Questions/Comments

- Can energy harvesting be used for detecting plants under an exoplanet ocean?
  A: Chemosynthetic life exists on Earth. However, it would be hard to detect astronomically.
- What spectral resolution is needed to detect life?
  A: It can be as low as 5, but other static signals increase the requirements.
- B. Biller: How much might the red algae band change?
- It was not determined what would be an acceptable signal-to-noise ratio to identify a signature like the vegetation red edge. Earthshine studies indicate a red edge signal in the range of 0-11% in observations at different phases.
- Alternative photosynthetic pigment spectra may occur in 400–1100 nm range on extrasolar planets.
- If broad-band observations are to be done of extrasolar planets, band selection perhaps could take some cues from Earth remote sensing.

1.8 Combined Light Transits, Photometry, and Spectroscopy, Carl Grillmair, Caltech

- 85-cm observation
- Orders more magnitude more time or instrument capacity to observe photons from planet except several very close star systems.
- Problem with Spitzer was that observation time was heavily subscribed, so getting full transit time was difficult.
- Strong water showing in planet's spectrum.
- Two different observations were similar but significantly different. Could be drift in one of instruments or weather on the planet (which has been predicted).

Question

- Need to find more bright-star planetary systems
  J. Harrington, UCF: There is a gap between what the IR people do and what the transiting people do. A peep hole with a detector could work with a balloon payload.
  A: We can get spectrometers that are less sensitive to vibration.

1.9 Direct Detection: Colors and Spectroscopy, John Trauger, JPL

- There will be fabulous varied images.
- Spectropolarization is attractive to tell a planet from star and to tell about cloud structure.
- A 1.5-m aperture telescope (assumed to be orbital to avoid all atmospheric interference) still can’t find Earth-like planets.
- A coronagraph that was corrected and deconvolved could reach Earthlike detection.
- Coronagraphs separate the planet photons from starlight.

Questions/Comments

- Aren’t suborbital platforms limited?
  A: You can get 10 nm from a balloon. [More data coming tomorrow.]
- Can a balloon (for less than $5 million) look at the five closest HR stars?
  A: Similar things were done years ago so it should be possible.
  W. Traub: From 120,000 feet, the atmosphere is not the problem. The issues are correcting for temperature [actuators for adaptive optics and sensors to run them].

1.10 Astrometry, Michael Shao, JPL

- Looking from above, the Sun's orbit spirals because of planets. The stars of exoplanets should do the same.
- The Space Interferometry Mission (SIM) should be able to do use such observation to find Earths; Venus-like is questionable.
- We want Earth-sized planets in the habitable zone (HZ).
- Imaging can find different planets in the same viewing place. Astrometry and brightness help sort things out.
- Q on rationale for making 12 visits per visited star.
  A: That's assuming three planets, but there might be even more than three objects.
- For Einstein lensing (starting about 4 kpc out), you need to view 10^6 stars to see another star and 10^8 to see a planet.
- Angular resolution from the ground is not as good as space
- Ground observations can only get down to about 5 Earth masses.

Questions/Comments

- Bruce [Macintosh?]: Observations from Kepler and from microlensing are complementary. They serve different regimes.
- Is there any benefit of smaller apertures above the atmosphere for secondary transits?
- B. Netterfield, U. Toronto: In CNV, the telescopes are going to lower temperatures, which matters a lot. You can enclose the mirror in a helium bath to protect the mirror against water in the stratosphere.
- W. Traub: But, the thin plastic to keep the helium bath in has poor optical qualities.
- Transits using Spitzer and shorter wavelengths would be less sensitive to temperatures.
- It isn't a resolution problem, it's a _________.
- Spitzer is not sensitive at the __________ level
- We will start discovering longer-transit planets.
- Whatever we come up with must be complementary.
- One advantage of the Stratospheric Observatory for Infrared Astronomy (SOFIA) is large bucket size. The weakness is temporal coverage. We want an observing time of 4 or 5 hours; you end up flying west looking south. There are a few transatlantic legs coming back from spending time with the German co-sponsors. These legs would get several more hours of darkness moving west with the Sun.
- Another issue with SOFIA [and all other nonspace instruments] is that there is a several-hour period of cooling for instrument to adjust to ambient temperature.
- General instruments (such as Spitzer) do not have needed sensitivity.

- W. Traub: The *Nature* article [________________________] referred to Kepler problems. The actual fact is that of the 84 detectors, only three detectors had a factor of 2 more noise. The three bad channels are a factor because the instrument is rolling to different stars. The errors can be mostly removed by software (probably). The **Co**nvection, **Ro**tation & planetary **T**ransits (COROT) [astronomy satellite] had visible instrument drifting after a certain point in time.
- M. Shao: The degradations are similar, but Kepler has two orders of magnitude less of a problem, just as Spitzer had fewer problems than IRAS. There has been a learning curve on the instruments.

1.11 Planetary System Architectures: Filling Out Our Incomplete Picture, Karl Stapelfeldt, JPL

- There are many stars with Kuiper Belt type rings.
- Radial velocity (RV) planet studies are incomplete at large separations—but new brown dwarf or giant planet has been discovered.
- Fomalhaut's Eccentric Ring: Modelers guessed that a gap in ring was because of a planet—the last previous perturbed orbit leading to a planet discovery was the Uranus orbit perturbation that led to discovery of Neptune.
- HR8799 has three objects rotating around a star.
- Conclusion of above: shape of dust rings can be used to detect planets.
- There are 21 known disks so far (14 at Spitzer resolution).
- A 10X improvement in instrument resolution should cause a major increase in the visible belt systems. He wants a small coronagraph.

Questions/Comments

- Q: What is your opinion of the object found around Fomalhaut?
  A: We probably aren't seeing thermal emission from a planet. It could be a bright ring, but our expertise is in the atmospheres, not the rings.
- It's not just contrast; it's resolution.
  A: Just looking at the outer Kuiper Belt could be done with 1 meter scope.
- What might Herschel reveal?
  A: By having smaller ________, maybe could get down to the size of our Kuiper Belt.
- Would QAE [____________________?] be better?
  A: No, it won't do any better than a 10-m scope.

1.12 Multichannel Spitzer Observations, Joseph Harrington, UCF (filling in)

- Spitzer provides an example of instrument limitations in secondary eclipse.
- HD 149026b is Saturn sized.
- Raw binned data showed problems with some of flux observations: scintillation in one sensor from the spacecraft vibration, a wiring problem, and a flux trap in another. However, improvements from the corrections did show eclipses.
- However, the corrections can be … questionable. Models are guessing what the problems are to compensate _________
- Modestly larger apertures, including on balloons, could make major improvements.
- If you have two minima that are close & a broader sample that is further apart, still take the broader sample.

1.13 Gas Giants, Mark Marley, Ames Research Center, Moffett Field, CA

- Gas giants have fingerprints of formation (e.g., Jupiters enhanced in heavier elements compared to the Sun).
- More sunlight would evaporate ammonia & other compounds revealing bright white water clouds. Even more heat might evaporate water and make a blue planet.
- Color is sensitive to metallicity … and phase.

Questions/Comments

- E-mail us [Mark Marley,mark.s.marley@nasa.gov?] to get the models.
- What was the object that Karl talking about?
  We don't do rings?
- L. Hillenbrand, Caltech: When do we need spectra, and when are colors good enough? What problems go with each?
  A: Colors can give you a first step in characterization.

1.14 Super Earths: Reflection & Emission Spectra, Wes Traub, JPL

- Theory is that we shall eventually find vast number of Earths; however, not with technologies available for some time.
- Neptune & Uranus have low reflectivity because of deep clear atmospheres; terrestrial planets have high albedo.
- Earth viewed from 10 pc is ~1 photon/m^2—pretty dim.
- Super 10X Earth would have 2X diameter and 4X area.
- Things an 8-m telescope can see: Cloud surface, O_2, O_3, and CH_4.

Questions/Comments

- Secondary transmission?
  It is just a geometric calculation. There is a trade-off
- Super Earths are identical. Would water Earths be different?
  A: It might be 2X more for cross section because of less density. However, Earth is already 70 percent water covered.
  Q: A 10X Earth mass would hold water longer. What is definition?
  A: The same column abundance in the atmosphere
  Q: But a water planet having less gravity might have a larger water annulus. There might be more hydrogen in the atmosphere.

1.15 SOFIA Capabilities, Erick Young, Ames Research Center, Moffett Field, CA

- Sofia flies above 90% of atmosphere. It has a 2-m telescope operating in optical and IR; it has a sweet spot in 30–300 sub arcsecond pointing accuracy.
- SOFIA should have a long lifetime so it has years for instrument evolution.
- SOFIA will be looking especially at zodiacal disks.
- Will start flying as early as December; research calls will start in 2010.

Questions/Comments

- Q J. Harrington: How stable are the observations? Are there cloud problems for instance?
  A: SOFIA will fly over most clouds of water vapor and particulates. However, some frequencies dirtier than others.
  Q: Can SOFIA stare at one star and look for variation?
  A: The Kuiper Observatory already demonstrated stability, but exoplanet observations require more.
- _____________
  A: We expect it to be limited to around 10 microns. Ultimately we will get down to the 5 micron range
- Q: Is there a group working at mid-IR at 5 micron
  A: No, SOFIA is still a hot telescope. Very unlikely to get to cold because of thermal background
  Q: W. Traub: When does SOFIA get into upper atmosphere, and would water vapor contamination on way up from take-off until reaching cruising altitude cause an y problems.
  A: It is one hour to cruise altitude to start stabilizing
- The optimum operations would be flying west to increase night time available for operations. Are there any plans for extended flights?
  A: Mostly just around Palmdale. There would be a few flights coming back from Germany, and there would be some S. American longer flights.
- Q: Stratospheric weather reports (e.g., higher or lower water vapor)?
  A: Erick Young will check back. Some instruments require higher altitude.
- Q: Are there any means to compensate for turbulence issues?
  A: There are some, but too much turbulence would damage the instruments
- Q: What is the subarc pointing stability?
  Likely about 5 _______.

1.16 NASA Dryden Aircraft Capabilities, Tom Mace, Dryden Flight Research Center, Edwards, CA

High Altitude breakdown:

- WB57, __________ altitude, carries 2X as much weight as ER2
- ER2 , follow on from U2 spy plane 70kfeet, 7 (or was it 10) hours of flight, ______________ payload.
- Global Hawk, 30 hours, can cruise at 65,000 ft, 680 kg payload, can move K-band antenna from top of nose; has supported forest fire monitoring
  Q: Any instrument to fit Predator?
  A: You would have to build them.
- Rutan's White Knight and Space Ship 1 are neighbors of the DFRC. Rutan is developing a bigger carrier plane, called Eve, to supersede the White Knight. The plane could conceivably carry a bigger Pegasus or sounding rocket. However, it has not been marketed for anything but the Branson tourist flights so far. [Rutan's company subsequently offered an increased launch capability based on the Eve carrier plane--
  http://spaceflightnow.com/news/n0912/07launcherone/ ;

  http://www.atlasaerospace.net/eng/newsi-r.htm?id=4714].

Questions/Comments

- Q: Why are you using Iridium communications?
  A: For polar support. Most of the commercial comsats do not operate past latitudes in the seventies.
- Q: Would a payload need its own pointing?
  A: Mostly yes.
- Q: Do SOFIA instruments need FAA instrument certification?
  A: No, they are NASA certified.
- Q: Could the ______ bay be opened up?
  A: Probably yes.
- Q: Would unmanned Global Hawk be easier to modify?
  A: All the aircraft can be modified. Global Hawk has a forward upper radome that could be swapped out because Global Hawk is redundant with other radars.
- Q: By flying away from the Sun and/or flying at polar latitudes in the winter, you could keep in night for the full 30 hours of flight time?
  Yes.
- Q: Would there be turbulence problems from putting holes in fuselage for instruments problems?
  A: Yes, but difficulty increases geometrically with size. A small slit for a telescope would cause much less turbulence.

- Q: Would there be turbulence eddies?
  A: Yes, but you can add a "fence" that deflects the air flow around the hole for the instrument.
  Erick Young: wind tunnel checks are used to design things.
  T. Mace: There are a lot of instruments that need open spaces.
- Q: Is there any pre cooling?
  A: Pre-cooling is done for about 1 hour. The corollary is that very dry air must be pumped in.

1.17 Discussion: Exoplanet Observations Enabled by Aircraft

- 2.5 milliradians is common for scanners, some are finer
- On the science side, we need to decide what are the most important exo-planet questions. What will be the most important questions in 5 years?
- W. Traub: The whole exoplanet field is fixated on hot Jupiters because we can see them. That is good because it is something to do. On the other hand, there are many other things that we will eventually observe.
- Back up to the session on goals, why is it important to know certain things?
- W. Traub: Seeing colors is feasible and it would be wonderful.
- T. Mace: Just to be sure, aircraft people doing earth and climate observations talk about SNRs of 800 to one for practical data acquisition. The exoplanet numbers seem to be much less.
  A: YES! Exoplanet observations are chronically operating in regimes of very faint signals from distant objects and various static and signals from other sources around those signal sources.
- Is there a sweet spot !(say 10 to 40 ___________) where we might find a lot
- Q: 5 AU
- Young stars are typically far away, 3 to 10 pc.
- IR would be good.
- We want something easy.
- We need the near stars 5 to 10 AU. That’s not going to be done by JW.
- We want to reduce the _____ of extrazodis.
- Low zodis might be easy to do observations on,

2 DAY 2 (NOV. 11, 2009)

2.1 Stratospheric Balloons, Barth Netterfield, U. Toronto

- 35-km altitude, 3.5 mbar, $5M, 2 tons of payload
- World circumlocution from Canada across Russia was done in late 90s, but relations are not as good now.
- International collaboration
- Typical collaboration: Balloon-borne Large-Aperture Sub-millimeter Telescope (BLAST) went from proposal to publication in about 10 years (1999—2009).
- Polar at night?
  A: Talked to ______, but that agency didn't like that because of recovery issues
  W. Traub: The Antarctic vortex is more regular than Arctic. Also, the Arctic has more political issues of possibly unfriendly countries
- The primary mirror does not drop down to equilibrium before sunrise. Secondary almost made it. On BLAST, they used an actuator on the secondary to compensate for temperature.
  W. Traub: Mirror temperatures are the biggest weakness of all telescopes that are not space borne.
- The transmission rate during most of the flight (except over the launch point and a few other places) is100kbits/second. Researchers definitively want to recover the recorder!
  ______________: Some instruments have liquid nitrogen for cooling near the mirrors. However, researchers must be careful that vulnerable components are not the coldest areas because such a condition would cause them to accumulate ice, even in the relatively dry stratosphere.
  E. Young: On SOFIA, there is a pre-cooling system.
- After the payload has been designed and fabricated, flights are about $100K.
- Once a system is flying, it is easy to get permission for adding flights; the first one might be about 5 years to flight time (3 years for a test).
- Funding from multiple sources?
  A: There has been some talk about balloons under the Small Explorer (SMEX) program.
- There is a 2,000 kg payload for ultralong duration balloons (ULDB). Why is there this limit?
  A: It's difficult to get to 100,000 feet. They're talking about bigger balloons.
- Terms: A superpressure balloon is used as an ultra long duration balloon (ULDB).

2.2 Balloon Environment, Pin Chen, JPL

- Inhomogeneities (speckles): Turbulence bubbles in atmosphere can make speckles. This can cause problems for aircraft flights and even for high-altitude balloons.
- The performances shown were without adaptive optics.
- Q: What is the wind shear?
  A: 20 to 30 knots and changes within minutes of tens of knots. It would be 4 to 5 knots on good times. Of course, this is much less than for an airplane.
- Local seeing: For the most part, there are no atmospheric sources of heating (in the SPIE paper, ____________________________)
- There is an OH airglow emission at 80–100 km. There are no platforms short of satellites than get beyond that interference source.
- Stratoscope was a 0.9-m telescope (Danielson et al. 1964, *Ap.J.*). It was a 2300-kg payload that flew twice.
- Stratoscope had precooling of the primary cell and lower main tube; heaters to counter radiation loss.

Questions/Comments

- How heavy would a 2.5-m scope be today?
  W. Traub: It would be about a thousand pounds for a similar scope today using commercial off-the-shelf (COTS) equipment. [That is about one fifth of the 2500 kg (5500 lb) Stratoscope.]
- The Stratoscope had mercury bearings. Would that present any regulatory problems?
  A: The Occupational Safety and Health Administration (OSHA) probably would not allow it. However, there are alternatives. Active controls are available that would be better. Magnetic bearings might also be better.
- Would a stratoscope redo be practical?
  A: Yes.
  B. Netterfield: I would still like to close the tube, however.
- If a Stratoscope redo were to be funded, what would it be done that would be an improvement over Stratoscope?
  B. Netterfield: Maybe better pointing.

2.3 Report on Boulder Workshop on Balloon Low Cost Access to Near Space (LCANS09), Eliot Young, SWRI, Boulder, CO

- From top of Mauna Loa to space
- Several goals can be summarized as what to do when HST runs down.
- Talk Overviews from conference—excellent chart
- Q: 6,000 lb for ULDB??
  A: B. Netterfield: There is a footnote in the chart that the 6,000 lb is a development objective. The present deliverable payload is about 2,000 lb.
- ULDB scheduled to have first test flight of a 14-Mcf test flight in 2009 and a 25-Mcf test flight in 2011.
- B. Netterfield: There is a strong trade-off between payload and altitude. If you are willing to drop to 90,000 ft [27 km, 17 mi] altitude, you might double the payload.
- Funding?
  A: There is some NASA involvement.
- Torqueless telescope is an issue. Sunrise had flywheel and motor for more advanced compensation for azimuth.
- Fine pointing used for correction of slow flopping of balloon platforms. Fine steering mirrors are low cost.
- Exoplanet observations may be the driver that leads to an HST in the stratosphere. He suggests small easily demonstrated steps.

Questions/Comments

- RE small steps, has NASA shown any interest in technology development?
  A: You need a science driver, and I think there are a number of them. I don't think it would be technology for the sake of technology.
- _____________
  T. Mace: Earth science hand an earth science technology office.
  W. Traub: We don't have an exo office yet
- What is the time scale of the stepwise system?
  A: December 18 is next _______ proposal. You could propose a measurement and probably get a launch from Ft. Sumter within a year. That is much faster than a spacecraft instrument.
  B. Netterfield: Yes, bolting on to somebody else's gondola is much easier. Sometimes balloons have steel shot because their instruments have not taken all the capacity

- *****Elliot Young will collect names of anybody interested. efy@boulder.swri.edu**

2.4 Balloon Experiments, Rémi Soummer, Space Telescope Science Inst., Baltimore, MD

- 2-m scope should get down to 1 zodi
- Best performance of 1 nm rms between 4 and 5 a.m.

Questions/Comments

- B. Netterfield: Real Jupiters are at ~5 AU, could you find them?
  W. Traub: We could find brown dwarfs.
  B. Netterfield: Why not go for real Jupiters?
  ________: The number is not constrained.
  ____: We could look at the two closest stars; a one or two-shot deal. It might be a high pay off.

- B. Biller: There are a lot more M stars nearby. Maybe you should look for Neptunes around M stars
  _______: You can't do a 100-star survey.
- Q: What is the integration time?
  W. Traub: One night.
- Q: A super pressure balloon might give you 15 nights.

2.5 Combined Light from Balloons, Gautam Vasisht, JPL, for Mark Swain

- Roughly 1-m scope proposed, 1.55 microns spectrometer, scope all Aluminum and athermal.
- Q: Have you considered a _______
  A: You would consider it. Under sensors like Spitzer ___.
- Every 10 K of cooling helps a lot. Using LN_2, the telescope is at ambient of 240 K.
  A: Background temperature is variable and could cause problems.
  B. Netterfield: There is a 3 to 5 minute bobbing.
  A: When you are working at 10 to the minus four, there would be worries about sensitivity and fidelity.
  Eliot Young: Thermal control of sensors is also an issue.
  These are very bright objects. That helps a lot.
- Weight?
  A: 780 kg of cryogen, but that only gives 3 days.
- M. Swain: Balloons are improving, but caution that exoplanets is a fast-moving area. Five years of community building and engineering might be a problem. It might produce something that was no longer relevant.

2.6 Ultra-Long Duration Balloon Flight Logistics, I. (Steve) Smith, SWRI, San Antonio, TX

- Payload mass will be roughly same as supporting hardware (e.g., parachutes, batteries).
- Cannot do station keeping or 700-days operation.
- Float duration varies from minutes to months; define the requirements
  Conventional – only about 2 days because of dropping ballast at nights
  Long Duration Balloons -- zero pressure, but flying in Antarctica so ballast dropping not required, **get research requests 2 years in advance**
  Ultra-Long Duration Super-Pressure Ballooning (ULDB) – Super-pressure, 30–100 days, test flight in Australia just has test engineering payload so far.
- Other lighter than air craft (LTAs) being developed: HiSentinel being developed for US Army, conventional balloon launch with conversion to dirigible at 66 kft. Equipment pod forward near front, payload about 80 lb now. Aerial deployment from F111 fuel tank coming out of C130.

Questions/Comments

- Where do you lose geostationary communications? Aircraft lose at about 70 degrees.
  A: Maybe about 75 deg.
  B. Netterfield: We were able to keep contact with TDRSS about 85 percent of time.
- Iridium use?
  A: Yes, we use it for polar operations. [However, the data rate via Iridium is insufficient for major data downloads.]
- W. Traub: There was a Christ Church launch site.
  A: Many launches have come from there, and it avoids going over South Africa (which has complained of oversights).
- Alice Springs seems to be a preferred launch site?
  A: Yes, there you have a lot of continent for payload recovery.

2.7 Precision Pointing for Balloon Payloads, Jeff Booth, JPL

- Sunrise (joint mission with Germans) had a 50 mas angular resolution requirement, which is comparable to exoplanet studies
- Q: Rumor was that Germans spent $100M on Sunrise, and that was a reason for ESA rejecting another balloon project.
  A: Sw_____ heard $0.3 M for ________ and comparable for ________.
- What are the requirements for pointing? Is 50 mas good?
- Might we need to get to the 1 or 2 mas level?
  M. Shao: 1 or 2 mas is needed for the minus 9 level.
- High frequency noise is still not well known. Sunrise may have had a vibration because of a flywheel problem.
- The Wallops Gondola Pointing System tried damping swinging to 1 mas.
- He would like to add BLAST actual data to the Wallops hangar simulator.
- M. Shao: If there is 100-Hz noise, __________ .
- Without much work, we can probably match Sunrise and maybe do better.
- Sub-arcsecond pointing has been done. Still there would be work to be done.
- W. Traub: What was the feedback?
  A: We had an ideal sensor, then we put in white noise.
- B. Netterfield: People have used two strategies on pivoting. Torquing in between or continuous correcting motion. The first has jerks, and second has a continuous interference.
  A: I think sunrise was on/off.
  B. Netterfield: There are things like magnetic bearings to lessen the vibration.
- _________: Some coronagraphs can work with tens of milliarcseconds, but the beam can't be wondering. The telescope must be pointed to tenths of an arc second.
  __________: You can trade that off against the secondary mirror.
- W. Traub: We've been talking about the gondola and the telescope.
  A: The gondola frame is one axis; there are two other axes
  B. Netterfield: WASP also pointed
  __________ WASP had a long _______ because longer angular momentum helped.
- B. Netterfield: The balloon technology to do a coronagraph has not yet been demonstrated.
- M. Shao: A conventional space design has 0 _____ at room temperature so you just insulate very well. Works in space, but even a little atmosphere ________.
  ______________: Copper compounds exist with low CTE. I've been told that 0 CTE compounds are being developed. Also, I believe SiC has low CTE at low temp (about 100K)
  M. Swain: On the _____ side requirements are not so severe. You need an experiment

going in that has about _____ time spread _______ You need either long duration flights or many one-day flights. That pushes to at least a few days duration.
P. Chen: We are saying 5 years development duration is too long, but space missions sometimes go 20 years. Also, the updates are quick.

- But, I saw a lot of crashed payloads. You may not be able to reuse a payload.
- S. Chakrabarti: Barth gave 10 years for proposal to paper, so it's still fairly close to space.
- Transit discoveries on a balloon have not been discussed.
  M. Swain: It has to be on ULDB.
- ___: Night-time polar could also do it.
  M. Shao: What are night problems?
- A: Batteries, launch ops temps, political of flying over Russia
- It is doable, and you can do it on a ULDB budget
- M. Swain: The ideal flight would be Antarctic winter.
  Launching in the Antarctic winter would be very difficult.
- Someone said you cannot have two balloons operating at once.
  S. Smith: Depending on how data is brought back, the control operations can be a limit.
- S. Chakrabarti: Can you do transiting in day time?
  _________: You want 1.6 and you want sky background to be very low so probably not. OH background might be a background.
  ______: Surveys from ground might be better for IR and visible all-sky surveys.
- ______: As a science goal, take a note system & get visible light photometry and do that for two or three, would that be scientifically interesting. Three colors, if it's just a fishing expedition, wouldn't work. The case to make is get $30 M from SMEX that wouldn't take money from balloon funding. If we can get Jupiters
  B. Netterfield: You have to get the ________ frame
- J. Booth: In EPS, they did venture, and they will select four to six of them.
- We won't do anything for $3 million; $30 million would.
- W. Traub: Yes, also transiting and zodi. Going out and getting three bands would be interesting. Nobody has done it.
- Ten planets in three flights would be good.
- We don't have any solutions yet to get down to 1 zodi.
- P. Chen: What would it take to get NASA to fund these types of missions? In SMEX, they specifically forbid suborbital missions.
- One argument is with NASA & Decadal to try to get balloon missions.
- Eliot Young: Maybe argue for an element in SALMON.

- Fewer ITAR (International Traffic in Arms Regulations) issues with balloons helps in getting joint missions.
- B. Netterfield: Platform has 20% failure rate, so do we want to put a $30 million dollar instrument on it?
  A: You can amortize over ___ flights

Questions and Comments

M. Swain: The European trip to promote a joint exo mission went well, but the comments today about 5-year timelines scares him.

2.8 Exoplanet Observations Using Sounding Rockets, Supriya Chakrabarti, Boston U.

- Reference talked about a 1.5-m telescope.
- With [more ___________ observations?] a smaller scope would work.
- Sounding rocket gives 7 minutes of observation above 100 km
- Proposed to Mike [_____Swain? Shao?] to test a TPF-type nuller instrument in space.
- Brant sounding rocket flares out to
- The instrument launches in vacuum, very complex for sounding rocket; also thermal inertia is an issue
- They were given a 5-kg light primary mirror developed by Goddard (Kodak demo for TPF)
- They are system integrator, Goddard was to build the telescope (but they ran out of money), then it was procurement from the Edmunds Scientific catalog & a kind gift from Northrop.
- Cracks showed after shake test; they rebuilt more monolithically.
- Pointing requirement was relaxed from 0.2 to 2 mas.
- Brian Hicks is working on a monolithic (small) nuller.
- An Extended Duration Sounding Rocket launcher would extend mission duration to as long as several months. This is a sounding rocket with enough thrust to put an object in very low orbit. However, this longer mission duration would have greater costs for batteries, power conditioning, and in general components capable of working for weeks in space.
- What would right number have been?
  M. Shao: About $5 million
- I think for any launch, it has to be about $2 million. NASA does provide pointing, commo, etc., so that is an advantage.
- Is the sweet spot for sounding rockets at 7 minutes?
  A: No, another rocket gives 20 minutes. However, slightly above 400 km the danger becomes increasingly great that the returning objects may not stay within the White Sands Range. Also, the needed parachute mass increases at that point.
- Challenges?
  A: Never had reviewers say that technology advance was enough. They say pointing at a star will be a minimum success.
- W. Traub: The expected diagram from 2 years ago didn't have a zodi.
- What do the temporal pointing residuals in the milliarcsecond pointing?
  M. Shao and GS [G. Serabyn]: We don't have data. Yes, there is some drafting back and forth. Previously asked for vibration isolated valves.

A: And you do have an advantage that operating in milliseconds would have less variation.

- While it's coasting, what is the environment, good?
  A: There are some stage separations & other issues

Technical Issues for Sounding Rockets, M. Shao

- Sounding rockets are rougher than conventional launch & much rougher than balloons.
- Heat: The optics are at 25ºC looking to 3 K space. It's better to cool the lens cap with LN_2. That decreases thermal shock
- The payload needs greater stiffness than on a balloon.
- Q: Your calculation may be too conservative.
- ______: You never leave the outgassing regime?
- Q: Drying of air inside?
  A: It's under vacuum, so not applicable.
- The first two nulling interferometers broke in shake test. They had a high Q of about 100—had to be layered to reduce Q to 20. Also, always have glue between any glass–metal contacts (slamming together at 30 g.

Questions/Comments

- Lesson learned was that it should have been budgeted 2X larger?
  M. Shao: We learned to build instrument stronger.
  _: Would a big project have found that in analysis?
  __: It was still cheaper doing it this way.
- For scaling up?
  M. Shao: We would use a stiffer scope.
  S. Chakrabarti: There were a number of other technical issues. For instance, there was a scalloping problem with the mirror that required several trips to the foundry.
- W. Traub: How do you know that it is optically aligned after shake & cool?
  M. Shao: There is an alignment sequence in flight.
- Q: How confident are you in the 20-s adaptive optics (AO) sequence? My AO tech says give me 10 minutes.
  S. Chakrabarti: There are two experiments: (1) Doing the alignment, (2) 5 minutes is for a science star, but this is at a reference target.
- Q: What if you don't see a planet? Conversely, what would your confidence be on an observed planet?
- L. Hillenbrand: What is the next most favorable star?
- R. Soummer: What about the exozodiacal dust?
  Backman et al. has a study prediction of what radii the dust belt would have, hundreds of zodis.

- Would you cool the detectors?
  B. Hicks: The detectors are already cooled.
- Paper work?
  S. Chakrabarti: Important items must be documented. The balance can be discussed within a small team. That makes a major cost difference.
- S. Chakrabarti: The 90-day sounding rocket is a low orbit that lasts for weeks to even a few months. Space-X offered a $10M launch, possibly 200 to 300 lb of science payload. Falcon successfully launched the last two attempts.
  _______: the payload would have to do more of its activities for control, continued power, re-acquiring targets multiple times [data reception from orbit—data recorder and burst?]
- If you are doing low-Earth orbiting, how much can you leverage magnetic torquing, maybe as part of the control (couldn't do all pointing). It is smooth.
- C. Beichman: There is a host of things that could be done with small "microsatellites." Maybe, we could paper the sky with them.
  W. Traub: The cubesats will be described tomorrow.
  C. Beichman: Jamie succeeded with a small satellite.
  K. Cahoy: Iridium Next has offered positions.
  ____________; But they may never launch [because it isn't assured that they can get funding or even stay in business].
- C. Beichman: A useful thing would be doing a number of studies on the one hundred closest stars. It would like TES only with 24 little satellites with just one camera.
- What about being a secondary payload on a comsat?
  If you are willing to pay the $10–12M upfront, you can be a barnacle on the side, but ___
  S. Chakrabarti: The GOLD proposal to SMEX proposed exactly that.
- T. Mace: Can aircraft do things of use for exoplanet?
  ________: Maybe transits are the best opportunities.
  W. Traub: Yes, precursors may be one of the biggest uses of atmospheric instruments.
- T. Mace: The advantage of the aircraft program is that you can return the payload and modify the payload multiple times.
  K. Cahoy: The RB57 has a 41-cm scope that might do exoplanet research.
- Q: Do any gossamer aircraft exist?

  Global Hawk could fly 30 hours in Arctic or Antarctic staying in darkness. A Global Hawk can carry a 1500-lb payload.

  - The Earth Sciences Technology Office has a funding source; astronomy doesn't have a comparable office.
  - S. Unwin: An aircraft would need a fairing?
    M. Shao: Yes, because it would be flying quite fast.
    W. Traub: The window is a light barrier that is what we are going to high altitude to avoid. That was why the open area of SOFIA is so important.

Studies for the airborne laser may apply to instruments on Global Hawk. Likewise, SOFIA should provide examples of how to make things work.
K. Cahoy: Getting more information on the RB57 and other platforms (and their existing instruments) would likely be very useful.

- T. Mace after session: Global Hawk flying at 0.5 mach might be about 325 mph; however, that has much less effective air-flow force at higher altitude [say 1/10th bar = 1/100th of force (density squared) of that speed]. Also, looking to side and with a fence to deflect air flow would also allow a window that could be opened for operations.

_________________: Transit observations with sounding rockets not a good idea.

2.9 Commercial Spaceflight for Science and R&D, Mathew Isakowitz via telecon

- W. Traub: Any real numbers?
  Falcon has Dragon, 6,000 lb up & 3000 lb back down days to a month
  Sierra has an Atlas 5 follow on. They don't have much on vibration.
- Costs?
  Talk to individual companies. Falcon has offered the equivalent of Taurus for $7 million. There may be some cheap or even free flights on launchers under development.
- Sub orbital flight tickets only Virgin?
  A: There are five companies taking orders.
- Prices for a suborbital trip on Virgin are dropping from $200K to $20K in ten years.
  A: The model is the same as the Tesla electric car. First there is a sports car at high price. Then development proceeds and prices drop.
- S. Chakrabarti: $Space-X website has 1000 prices.
  S. Unwin: The Dragon 9 is the only system expected to reach the International Space Station (ISS) in near term. We would like to get a small payload to the International Space Station.
  A: According to the Augustine Report, eventually all supplies to the ISS will be commercial. It is great to test in suborbital, blah, blah, blah.
- S. Chakrabarti: Orbital Sciences does not seem to be in your consortium yet?
- S. Unwin: What is your relationship between your organization and the companies? Do you talk to NASA about how researchers might put their payloads on these nontraditional vehicles?
  A: NASA is developing a procurement strategy and maybe some set amount of seats. Payloads that could accept more risk would be preferred [that phrase "more risk seats" might be interpreted to mean instrument payloads].
- T. Mace: We've been tracking potential vendors, and it's been very volatile as they have been developing. The safety analyses won't be as rigorous as Shuttles; however, there

must be analyses. Some things, like accelerometers, are more expendable so they could go up on test flights.

- S. Unwin: Carrying vehicles are often the main cost drivers for our research.
  A: They call it the ignorasphere because it is between regimes.
- S. Unwin: The ideal would be orbital for $10 million or less so they would not need to be NASA Class A. Class C would be preferred so they could be much less than SMEX.
- $10 million per flight is much cheaper than we have seen before.
- To what degree does your industry talk to the insurance industry about amortizing costs over multiple flights? It might be cheaper to accept a larger amount of risk and spread that risk among a number of flights.
  A: Insurance would be good.
- T. Mace: You have to consider two kinds of risks. First, a vehicle malfunction might lose the payload. Second, a payload might damage a vehicle.
- K. Cahoy: How to get info on vehicles?
  A: Researchers can contact the companies now. The NASA organization will gather much of this information when the organization is set up.
- T. Mace: This type of info on aircraft has been done for thirty years. If these companies do rigorous tests, that will make the process easier. These things happen; Landsat 6 was lost.
- W. Traub: Your comments implied that NASA will develop a list of maybe approved vendors?
  T. Mace: That is just one possibility, but it has not been decided. In the past, there are bids for capacity, and researchers might pluck into that.
  C. Beichman: Just having an approved list (with its limitations) is still better. Delta 2 is sorely missed.
- Also, what about the Minotaur.
  D. Belden: Minotaur is owned by the Air Force. There are limited quantities, so it will probably not be turned over to commercial.
- What are the major drivers for the commercial market?
  A: Tourism is the prime driver. However, the science becomes important to say that the industry is also serving an important social role.
- K. Cahoy: Are there any venues for getting access before they are on an approved list, who would you go to?
  T. Mace: If it is a NASA-funded activity, it is NASA. If there is other funding available you can go elsewhere.
  C. Beichman: With a European co-PI, you can launch on a Russian rocket.
  D. Belden: DoD has launchers. We have talked to Space-X, Orbital, and Loral; but DoD still has not done the commercial.
- If you are just launching equipment, it has been going on commercial flights since Reagan. What is different?

A: The companies would say more electronics and younger workforce, but they all seem to be hoping to have a bigger flight rate to amortize costs.
J. Carroll: The manufacturing plant for Deltas could make 90 units; the production is more like ten. It is a recurring aerospace theme that small production runs keeps the prices high.

- Erick Young: What about hitchhiking secondary payloads on Indian and Chinese rockets?
  A:
- Is there any commercial entity looking at escape velocity?
  Isakowitz: We don't want to send people elsewhere in near term. [That apparently means instruments won't go either.]
- Has anyone told the companies about other markets besides passengers?
  A: They know about instrument launches for suborbital such as Black Brand.
- T. Mace: Part of this will be education of the scientists. When we did the first request for information (RFI), the vendors did well, but the scientists were a bit thin. Then we did $50 K studies, and they eventually came around.
  D. Belden: DoD has talked to Space-X and Sierra about science payloads.
- Does anybody have any comments on using these rockets?
- Falcon 1 might be able to provide1 year (maybe for a combined light spectroscope). The concern is the stability of orbit.
- That's why escape was the question.
- Falcon 1 does not have that capability.
- T. Mace: One issue seems to be coming up is finding good windows [and what would be the specs on such windows].
- J. Carroll: The high altitude wind generator (HAWG?) that can hover at 40–50 kft. It could carry 10-ton payloads every night. It would have prop wash and vibration. However, it would be in clean air, and the prop wash could be washed away. It would be about $5K per day—cheaper than SOFIA and more operating time. About an hour going up to station and the same going down. Tether and vehicle each about 40,000 lb, 4 MW, 70% capacity. If it is funded, it would be in about 4 years. The initial tests would be in restricted aerospace.

2.10 Unfettered Discussion of New Concepts —Ruslan Belikov, Ames Research Center, Moffett Field, CA

- M. Shao: What is a Fresnel telescope
  A: A Fresnel ring could be very large, and it could probably unfold from a small box.
  C. Beichman: It was considered for TPF and someone from Livermore, an origami specialist, was called in. It was fun, but there was a very unusual wave front.
- Use dark side of Moon as natural coronagraph. Maybe it's too fast, but are there any other objects that could be used?
  --Optical issue with that is that it is hard to ver____ the star without covering the planet,
  --The dark area of the Moon has been dark for several days, so it might have some merit.
- Earth's atmosphere can function as a lens, but it has many deformities.
  --Also, light bends the wrong way.
  --Earth isn't perfectly circular.
  --Part of the obstruction is luminous.
- Could there be radio occultations from pulsars?
- Telescopes are usually designed to get images. Planet finding just wants images of point sources. That would be telescopes with narrow field of view.
  -- That sounds like an interferometer
  -- Yes, almost a 3-D mirror.
  -- Then you rotate it.
  The phased-array coronagraph
- Explode something that makes a huge sphere of water that would act as a lens. However, that would saturate the water bands that would be used in searching for water on exo-Earths.
- Magnetic field for a plasma lens: Released gas would be ionized by sunlight and be held in by a strong magnetic field. The question is what spectral signature would the plasma have and thus what colors would be blocked.
- Amateur telescopes that could be ganged a la SETI; Transitsearch.com is already going on. The difference is that this would be automated so that the amateurs would not get bored.

3 DAY 3 (NOV. 12, 2009)

3.1 Missions, Rides, and Payload Classes—Joe Carroll, Tether Applications, Inc., Chula Vista, CA, tether@cox.net

- For Cubesats, paperwork is not your friend.
- Heliocentric orbits are the best, but the most expensive.
  They are best because the thermal environment is consistent, the pointing angles change very slowly, and you don't have to do safing of the design so that astronauts could come fix it (nice but very expensive).
- L2 is similar to heliocentric. It is slightly better because is stays closer to Earth for easier data linking. (In contrast, Spitzer may only do a limited number of follow-on missions, even if fully functional, because it is slowly drifting farther away.)
- NASA & DoD signed up on the first Falcon 1e is $10M for 800 kg to $100M for 10 tons.
- A Taurus launch is now about $20 M.
- Dollars per pound is not correct; price per unit mass decreases roughly geometrically as payload mass increases. A very tiny payload would not be proportionately cheaper.

Questions/Comments

- W. Traub: Are the rides the same with different rockets?
  A: No, solid rockets generally have more shake than liquid-fueled. Falcon has more low-frequency "stuff."
- How likely is it that Falcon prices will drop significantly (10X drop claimed)?
  A: We hope that it will be moderately cheaper. Rocket launches are inherently difficult. Also, once again, major price declines are based on a significant number of launches to amortize costs.
- L. Hillenbrand: Does this apply to all launches? What about orbital debris?
  A: Yes, there are about 2500 tons of material in-low Earth orbit. This year, a dead Russian satellite collided with an Iridium comsat. NASA now requires that vehicles have a 25-year de-orbit limit. If the orbit is low enough to come down in 25 years—and analysis shows that it will break into small enough pieces.
  [NASA Orbital Debris Program Office at http://orbitaldebris.jsc.nasa.gov/]

  Things falling from the sky are a liability issue.
- L. Hillenbrand: Who has been through the new approval process?
  A: Cubesats at Pomona have done it.
- As a secondary payload, you can save money, but they can change ____________.
- ITAR is a roomful of fly paper. All the people must be US citizens or resident aliens with green cards. That also includes US citizens working for a foreign company/agency. Also, riding on a foreign vehicle might not get NASA funding.
- Remember, orbital projects take 5 years and might get cancelled or fail.

- At some point, you have to step back and say what am I really trying to do?
- Secondary payload generally means that you will be mounted on the side and cantilevered out. This will cause increased shaking compared to the primary payload, and that might damage a telescope.
- Note: NiH and other metal batteries are magnetic. That could impact your payload.
- S. Unwin: Does a secondary payload stay attached?
  A: You may have the option to either stay attached or being released. Staying attached has a lot of advantages. One of the worst shocks a payload gets is the release of pressure when the clamp is released. Also, you have to do attitude control as a separate object. Of course, you may need to be changing your attitude.

  Utah State has smallsat conferences. The problem is that smallsats have had a high failure rate.
- Erick Young: A satellite has star trackers etc. [not in cubesats]. Is there any chance of getting a cheap small satellite that has those features?
  A: There is a price to be paid for microsats. They tend to have short lifetimes and lack features such as star trackers. Eventually, the needed additional features cause the price to creep back up to old space with old-space prices.
- W. Traub: What is one part per million thing?
  A: The U.S. government already has unlimited liability for anything done by a national. For instance, an Iridium satellite piece might have liability for Americans for the satellite and Ukrainians and Russians for different booster stages. Liability increases with 66 satellites.
- Insurance?
  A: Yes, but ITAR regulations forbid telling foreign insurance companies technical details. A government program already has liability. A private effort may pay $50K or $199K.
  S. Smith: Getting insurance can be an arduous process.

3.2 DoD Space Test Program (STP), Major Dan Belden, Space Development and Test Wing, Kirtland AFB, NM

- The DoD Space Test Program can provide or fund all services needed to access – space, except funding of the experiment itself. A DoD sponsor is required to access the DoD STP through the Space Experiments Review Board. DoD sponsors validate military relevance.
- What experiments fly?
  A: Space Experiments Review Board (SERB) select experiments based primarily on military relevance. Experiments do not have to be lasers or bombs, but can provide impact to DoD spacecraft or missions. For example Joint Milli-Arcsecond Pathfinder Survey (J-MAPS) will provide updates to the star catalog. About 20% of the experiments on the SERB list in 2008 were manifested for space flight last year. Though a relatively large list, many of the experiment PIs come to the SERB for DoD endorsement as a viable project. That makes their project more viable to the developers' home organizations.
- Integration, say drilling some holes & some rewiring?
  A: DoD STP is prohibited by regulation from funding work on the experiment itself.
- However, if you have funding and haven't gone through SERB process, you can get services from the Space Development and Test Wing and DoD STP on a reimbursable basis.
- STP has access to Space Shuttle, ISS, sounding rockets, and high-altitude balloons.
- STP has invested in standard hardware, e.g., ESPA (EELV secondary payload adapter) that a secondary payload might design to be in. Another would be FASTSAT.
- J. Carroll: Are any NASA payloads on ESPA at this time?
  A: NASA provided funds for ESPA Standard Service studies; in exchange, there are negotiations for NASA to get to ESPA flight slots.

Questions/Comments

- Any future opportunities for DoD telescope facilities?
  A: No experiments related to this at this time.
- What would happen with a high-altitude balloon?
  A: DoD STP has used high-altitude balloons in the past for experiments; however, there has not been any in recent history.
- Cubesats?
  A: Cal Poly San Luis Obispo leads development of the P-Pod. DoD STP has embraced the use of standardization demonstrated by the Cubesat and P-Pod. Cal Poly SLO has a conference every year in April. ESPA Standard Service has been funded by the Air Force to begin in FY 12. The experiment PI should build to the envelope of the ESPA standard, which allows "free" spaceflight under the Standard Service. The ESPA User's Guide documents are in development and will be available for all developers.
  J. Carroll: It is mostly there, although they still need to get the bolt patterns.

3.3 Japanese Platforms ISS/JEM, Taro Matsuo, JPL

- JEM would be a 2-m off axis visible and near infrared (VIS-NIR) balloon-borne instrument.
- It will use a Far-Infrared Telescope Experiment (FITE) balloon interferometer.
- IT will fly in Brazil.
- What does the ring gyro do?
  A: It does measuring.
- Erick Young: What does the Kalman filter do?
  A: It is used for the rotation rate.
- The JEM is also planning the Extreme Universe Space Observatory (EUSO) for attachment to the JEM area of the ISS.
- W. Traub: Is the JEM-EUSO just fixed and looking down.
  A: It could be moved.
  W. Traub: So this one could be removed and another one inserted.
- How far has the exoplanet telescope evolved?
  A: Still just a study.
- Have you seen the HESS telescope?
- JEM-based telescope will launch in 2020.

3.4 *Coronagraphy from Orbiting Platforms, Rémi Soummer, Space Telescope Inst., Baltimore, MD*

- Coronagraphs don't seem to scale down to useful things. It's big or nothing.
- The Space-X Dragon Lab is being offered at $90 million, but we might be able to attach some small experiments for a lesser amount.
- B. Netterfield: Could you have two interferometers?
  A: Yes.
- FK interferometer has a several-hundred-million-dollar two-telescope interferometer.
- J. Carroll: U. Michigan did no uplinking because every time they did choose, they chose wrong.
- B. Biller: This is flying a prototype, would there be any other applications of it?
  ______: Occulter allows you to get small. The problem is that you won't drive the costs down. The occulter is an independent spacecraft with all the attendant costs of deployment, station-keeping, etc.--$100M. It's the same as deployment of large antennas. Our 1.2-m telescope to see Earth will use a 30-m occulter.
  W. Traub: Deploying Mylar might be significantly different than deploying struts.
- Might there be solar sail pressure issues?
  J. Kasdin: Yes, there will be some, but it is not a major thing.

3.5 Combined-Light (Transits) Photometry on Orbiting Platforms, Joseph Harrington, U. Central Florida, Orlando

- There have been some finds in visible—Kepler and _______.
- Q: You don't need gigabytes of data to do this do you?
  J. Harrington: Yes, but you have to establish the background.
- You are competing with 8-m scopes on ground looking for tiny planets.
  ___: Unfortunately we there are not nearly as many Earth-instrument dollars as spacecraft dollars available.
- EpoXI & MOST have lower costs, but they haven't discovered anything.
  ___: The universe hasn't cooperated. The planets may be darker than they had in their models, but let's not dismiss them yet.
- Far out ideas: Join with other scientists to extend HST
- JW (Webb Telescope) is more exoplanet oriented, but doesn't do all.
  R. Soummer: Large-survey.
- Ground
  ___: What is the threshold for ground-based instruments?
  W. Traub: The University of New Mexico is going through a large effort to look through atmospheric issues (aerosols especially).
  _________: Turbulence is different across different lines of sight.

3.6 Transit Spectroscopy on Orbiting Platforms, Gautam Vasisht, JPL

- JW has a shared focal plane, but it isn't at same time. The two observations can be put together, but it increases required observation time, which causes a significant price increase.
- M. Shao: How about combined with ground-based observations?
  J. Harrington: It has been done, but it is difficult. You need an observatory dark at right time, with good weather, and willing to do the coordinated research.
- M. Shao: How long to stare at one star?
  G. Vasisht: No, it will be a survey.
  M. Shao: Can one mission observe the entire sky?
  G. Vasisht: No, you'll pick and choose [for certain regions?] just as Kepler is doing.

3.7 Planetary Science Experiments on Hosted, Eliot Young, SWRI, Boulder, CO

- Q: Why would the commercial comsat companies sell space to scientific payloads?
  A: The Comsats are giving mass and may be reducing satellite lifetime because it might give them a wider market.
- The STAR-2 bus will have extra power from the comsat during the first several years because they design extra power in the photovoltaic (PV) panels with the knowledge that the cells will degrade after several years. Also, if you want to send heavy data (e.g., pictures), you can buy a data channel to transmit to the ground.
- K. Cahoy can talk more on the SS/L1300.

3.8 Using ISS and Micro-Satellites in Support of Exoplanet Detection and Characterization, David Miller, MIT (via telecon)

- There are rumors of proposals to use ISS for research. The ISS may become more accessible with retirement of Shuttle.
- The ISS has power, data links, and a coarse attitude correction system (ACS).
- There are contamination problems, including vibration and glint.
- You could release and then retrieve micro-satellites (e.g., through the Japanese Kibo airlock). [However, comments elsewhere were that the ISS operations group is very cautious about independent craft flying about the ISS.]
- A number of experiments have run in the ISS, including formation flying little bowling balls that are helping develop formation flying software (Sphere, which is 22 cm in diameter).
- Things can come up in modules.
- An exoplanet cubesat employs a 3-unit stack staring at one star, 3 kg.

Q/C

- Cost of triple cube sat?
  A: Usually about $50K per cube. Don't know the exact price
- M. Shao: Is there sufficient PV power in that small cubesat area?
  A: The designers think so.
  J. Carroll: Pumpkin in San Francisco provides a great deal of the cubesat parts.
- Q: What kind of data rate is available?
  A: F-band 100 Kavli [sp?]
- Q: Has a cubesat flown with 3-axis control?
  A: I don't know if they have flown, but several are under development.
- S. Unwin: What about the lifetime?
  A: They are using PC104 architecture, and they are going with COTS to keep prices low.
- W. Traub: When will it launch?
  A: A high-fidelity prototype scheduled for June. The hope is that there will be a cluster of units, each looking to a particular star.
- W. Traub: Quick re-acquiring is needed in low-Earth orbit.
  A: Yes, re-acquiring is needed when it goes back to night side. It will only work on the night side.
- Are there any details on the vibration level of SS?
  A: An experiment called SAM had accelerometers measuring the various environments. [details coming from Arvid Croonquist] Instruments may have to have some damping.

3.9 Summary of ISS Specifications, Arvid Croonquist, JPL

- Dave [Miller] did his project for $2M and 2 years because he was practiced at it.
- Micro-gravity scientists were the happiest with the ISS.
- Only major acceleration is 15-min boost about every month and a half.
- Other g's and micro-accelerations come from bearings, air conditioning, etc. Analysis funding dried up about 4 years ago.
- Q: W. Traub: What is the rms?
  A: 10^{-6} g in the rms sense.
- W. Traub/M. Shao: Normally it's ten to the minus three (10^{-3}).
- L. Hillenbrand: How does this compare to ground scopes?
- ________: This seems to be equivalent to a good ground scope (better than Gemini. I would like detailed slices of the chart
  A: **A. Croonquist will get more data.**
  Q: J. Carroll: The ________________ (LBL) is more serious because you cannot point at one target for a long period of time. Also, when astronauts are up, vibrations increase.
  M. Shao: The ISS is slewing at a fast pace
  A. Croonquist: The fundamental frequency of the truss is below 1 Hz.
- Building something to JPL specs usually exceeds those required by ISS.
- W. Traub: 1.2 m tall is very short for a telescope.
  A: You would have to negotiate. The neighbors might be observing the sun, and equipment sticking up could be a problem for them. It's not a no, but negotiations would be required.
- G. Vasisht: Can payloads be launched or assembled at the ISS?
  A: They are launched in a carrier, such as the HTV, and the ISS arm picks them up.
- Code OZ coordinates between potential users and the ISS facility (e.g., the Japanese docks).
- There is 1-microgram contamination from outgassing, water mgmt, reboosts, etc.
  Q: Do reboosts, water mgmt, or other things cause any optical changes?
  [He didn't know.]
  J. Carroll: Early on, ISS wanted to be very clean, but it didn't happen. If you are the coldest spot around that area, material will accumulate.

Questions/Comments

- G. Vasisht: How bad is the free oxygen problem?
  A: There are materials experts who can deal with this issue.

3.10 Coronagraph on the ISS, John Krist, JPL

- Limited viewing window per target/orbit due to ISS structures (15 minutes)
- Vibration isolation/correction required
- Delivery choices more limited now that Shuttle is being retired.
- Jovian planet finder was proposed in a 2001 MIDEX proposal. It would have gone where the Alpha Magnetic Spectrometer going; 1.5-m telescope
- Q: Eliot Young: How good must the K-mirror be?
  A: Don't know.
- We couldn't afford a DM, so that's why we were doing the other observations and subtracting the smear. This wouldn't work for a face-on ____.
- A coronagraph on ISS; how small is useful or practical without the Shuttle?
  Maybe a free flyer would be better.

Questions/Comments

- G. Vasisht: Power requirements?
  A: it was well within power available, mostly for moving.
- The Japanese telescope was described as 2.5 m. Isn't that bigger than can be done?
  A: You can do folding and packing.

3.11 Transit Photometry, Gautam Vasisht, JPL (for R. Samuele)

- Like All-sky monitor, wants to find 100 planets transit nearby (<100 pc) stars; operates at L2 for 3 years; telescope baffles to shield from Sun (and Earth) may allow daytime operation.
- M. Shao: You may need three-axis stabilization.
  J. Harrington: The microsat this morning had ____________
  _: The orbit precesses in 5 hours.
  W. Traub It would be a hundred times better than if you had an az-el mount.
- _:How big are the pixels?
  A: The footprint of each star is about 5 arc seconds.
- A. Croonquist: Assembly in space is very involved with simulations in neutral buoyancy tanks.
- J. Carroll: Remember that the space plane wobbles over a 2-month period.
- A. Croonquist: Can you do processing onboard?
  A: Yes, that will decrease the required data rate.

3.12 Discussion: Exoplanet Observations from Orbiting Platforms and the ISS

J. Carroll: You want to be a modest multiple of the launch costs. That is a kind of equal partition law—a couple times launch cost.

There are missions out there. If we had money, we would fly Access or others. There are obviously some bounds that we haven't talked about. Maybe we could get into some boxes of NASA AOs.

Today, we started beating against those issues with costs of getting on ISS.

W. Traub: We didn't find out whether ISS missions need to be man rated.

A. Croonquist: They do, but it is not very difficult. The human factors cannot be ignored, but it is not as bad as you might fear if you have never done it before.

W. Traub: But it won't be by the astronauts.

A. Croonquist: But, they will, they will be installing, and they will be carrying things. You have simple issues such as sharpness and hot or cold.

__ & S. Unwin: We didn't start with cost.

SMEX is $105M and that is the smallest. For other than missions of opportunity, a hundred million dollars would be OK.

W. Traub: If we come up with some good ideas that are not tiny but less than a full mission, NASA might go with it, particularly in times of stringency. They might go for more small missions.

Eliot Young: A SMEX at $105M is very constrained now. By the time ACS and basic satellite things done, there is very little money for the actual payload.

W. Traub: By having a bunch of small payloads, that might make a new category; and it might encourage NASA to buy more small launchers, thus catalyzing a drop in cost.

S. Unwin: Must it stay as Class A, or could it slide to Class C?

J. Carroll: Some options can be sized to the different vehicles and their prices. We might be more particular about the orbit.

Eliot Young: As an alternative to price categories, how about different types of categories?

J. Carroll: Payload sizes might be a better category. The mass and fairing change significantly. You may want to stay below the Falcon to have a chance, and be no more than the EELV.

Eliot Young: Would it be possible to have two missions that would fit within (share) a Taurus or Falcon with a slightly different_____________.
S. Chakrabarti Regarding Taurus, The NASA cost is higher for Taurus, about $40M.

Eliot Young: Photometric projects looking for transits might be more cost effective. A coronagraph would be expensive.

Need 1.5 min. coronagraph for planets, but debris disks (further out) could work at a size of 0.5 m.

I think you might find some things larger than Jupiter, so you will probably find some other surprising things.

A mission with a cost of $15 million dollars would have friends in NASA; a $300-million mission would not.

R. Soummer: I see a whole spectrum of ideas. Is there a sweet spot of imaging and zodis to say 2-color imaging?

10 to minus nine on balloons. A thousand-zodi would be easy to do. A hundred-zodi would be harder.

J. Carroll: It would be a facility, not just an experiment.

B. Netterfield: Even if equipment is lost, you still have your design and software.

Crashing balloons makes me hesitate about a 1.5-m scope on a balloon. 0.5 m is more expendable.

How about a compromise of 0.7 m?

HST is doing an order of magnitude better. We hope that Bruce's [Macintosh's?] method will be as good as HST. An optical debris disk ____ at 10 to minus seven would do more than ground-based scopes can do for years. And you won't to be inside a dark hole … maybe further away. It would be at half micron.

Eliot Young: Balloons get a bad rap about destroying mirrors. Sunrise did not lose its mirror.

Q: Could this research be done on the HST?
Eliot Young: If it's on the order of ten targets, you could not get all the needed time on HST.

The Atacama Large Millimeter Array (ALMA) has 50 antennas at 12 m each; it will be good. However, Fomalhaut is fainter, so ALMA will not do better. HST is 600 for Fomalhaut; if it got a fifth of that, it would be good, 6 arc seconds. Once you start thinning the material in the disk, it fades out. It will give a good view of the massive debris disks, not the ones having planets.

B. Netterfield: Will you do emission?

ALMA won't do emission.

Need 1.5 m for colors of RV planets. Because they are point sources, you need a big telescope to see them.

R. Soummer: There are scopes in space near end of life that might be used: Spitzer, Dawn, and WISE (when out of cryogen)

Spitzer is out of the running because of communications. It's expected to run for 3 years after which the low-gain antenna (LGA) will no longer be enough. [Spitzer is in an Earth-trailing heliocentric orbit that is drifting away from Earth at 0.1 AU. That orbit reduces the amount of turning required and reduces the bright interfering objects by getting away from the Earth and Moon.]

J. Harrington: Spitzer is already doing 30% exoplanet observations.

W. Traub: We need a good science base first. Technology development should not be first or second. We need to get to the discussion leaders.

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Definitions note:

Class A is high redundancy space payloads

Class C (including SMEX) is low redundancy

4.1 B57 Nose Dome Telescope, Telecom from JSC, Facilitated by Kerri Cahoy, Ames Research Center, Moffett Field, CA

- 14” ? 41 cm
- Two systems and two planes
- There is nothing on the schedule for sensors; schedule for plane busy next 9 months.
- The earlier you get on the schedule, the better for the subsidized rate.
- The subsidized rates are $10K per hour plus a weekly fee.
- T. Mace: I suggest that if there is a chance of using this facility, put in a place holder request (that is allowed). He has the web address at Ames.
- The typical ground track of the B57 parallels the launch azimuth and is off about 10 miles.
- The telescope has automatic tracking.
- They use wave and ERRS [sp?] interchangeably because different instruments are swapped in.
- The big question from the exoplanet workshop is, what materials are in the dome window?
- They are doing the analysis for a gross weight increase. It can carry a 4500-lb payload, but decreasing weight would allow more fuel for longer flights—going from the 4 hours toward the 6-hour limit.
- T. Mace: There are additional pods that could be added to the wings of the WB57. They only look up now. There might be modification for different look angles.

4.2 *Aircraft Operations Report Breakout Group, Erick Young, Ames Research Center, Moffett Field, CA*

- What airplanes bring to table: More IR bands and less scintillation compared to ground. Much of the infrastructure in place.
- Limitations: limited time, vibration environment not well known, quality of seeing may be degraded because the instrument may have to look through a window.
- SOFIA: 2.5-m scope, 41-kft altitude ~2-3" images in near IR, 12-hr flight time
- Global Hawk, 60 kft
- Doing general surveys would not be good because time is limited.
- High resolution would not be good because of turbulence and vibration.
- **Good possibilities:**
- Global Hawk Photometer
    - Would require radome modification. Questions are how big a telescope is possible, and how good pointing would be?
- SOFIA Combined Light Spectrometer
    - Insensitive to pointing variations
    - Tip tilt
    - Very good sampling of PSF
    - Excellent stability
    - Dispersion must be ultrastable with n internal reflections
- Must calibrate to an exquisite level.
- Q: How does this compare with balloons & other platforms? That is the major question.
A: It is comparable to other instruments on SOFIA.
- There are funding mechanisms to get SOFIA instrument funding, possibly estimate $10 million.
- W. Traub: Systematics rather than sensitivity is the issue (e.g., stray light when trying to find star vs. planet).
- W. Traub: Someone interested would follow up in the lab regarding _______
Erick Young: Pixel sampling is probably not adequate for this use.
W. Traub: Unfortunately, Prof Beverly McKeon, the hydrodynamics expert, is not here to help us with the issues of hurtling through the air.
- W. Traub: You are above 99% of the H_2O bands.
Erick Young: There are still some water bands and other atmospheric variations that are minimized but still exist at these altitudes.
- Erick Young: The first instruments will be 5–30 ___, _______, and then Flightcam will start operating in a couple years.

- T. Mace: What is limiting Flightcam?
  E. Young: PI is very busy. Also, scheduling of flights and the flight development schedule is limiting things.
- T. Mace: It's not something that more personnel could fix. Also, the schedule could be hurt by problems with the open-door experiment.
- W. Traub: What if someone like Mark Swain wanted to do something early?
- Q: Are there any plans for ________________.
  Erick Young: Yes, Telescope Assembly Characterization flights will be doing that.
- Twenty percent of experiments go to European investigators because they provided a significant amount of the funding.
- J. Carroll: Are there any other aircraft available for research other than SOFIA, Global Hawk, RB57, [and ERS].
  Erick Young: No.
- J. Harrington: These flights could characterize turbulence in atmosphere. [They will add that to report.]

4.3 Balloon-Borne Missions Breakout Group, Barth Netterfield, U. Toronto

- W. Traub: 12-hour gaps
  B. Netterfield: Don't really know.
- Balloon-borne optical Debris Disk Imager (BODDI)
  Note: The Sanskrit Bodhi means enlightening or awakening
- BODDI is expensive to the point of maybe needing international collaboration and special dispensation from NASA.
- Q: J. Carroll: What about Antarctic winter launch for many nights continual observation with a zero-pressure balloon?
  B. Netterfield: Launch operations would be very difficult and power would be limited—but definitely keep thinking of it.
- _
  Tens of millimags would give us hot Earths.
- J. Harrington: You would need about a half dozen flights [for BODDI?]
  B. Netterfield: Yes.
- Australia new Zealand is about 40s in latitude—mid latitude
- BETS $3–5 million
  W. Traub: ___________ begins to give you sensitivity to N-stars and sort of straddles between the two.
- B. Netterfield: It's a subset of TES actually.
  Eliot Young: It may give you more resolution.
  W. Traub: Also, TES & ASTRO are doing only certain areas. This could be different areas.
  _____: If $3–5 million is credible, that would be great compared to a $100 million dollar mission.
- At 100,000 feet, this would have much less atmosphere than SOFIA.
- J. Carroll: What about data compression?
  B. Netterfield: Semi-processed data could be sent—just send what changes.
- J. Harrington: How often do you fly over land? For those times, you could get laser commo.
  K. Cahoy: There are commercial services for rates greater than TDRSS, or you could buy a million dollars of drives and drop them.
  Eliot Young: Near Space Corporation (http://www.nsc.aero/) has a PERV glider for dropping off disks.
- J. Carroll: How about use of Iridium?
  T. Mace: We've been using Iridium for instrument health & commanding. It's not good for much more.

4.4 Exoplanet Breakout for Suborbital Rockets, Supriya Chakrabarti, Boston U

- Recurring cost about a half million dollars.
- J. Harrington: What can you get at less than a micron? What can it do that Hubble can't?
  W. Traub: Close in view for a coronagraph
- Looking at two or more bands, which gives colors, but it will decrease the number of targets that can be imaged.
- $15.5M cost for short orbital is an estimate from Wallops.
  ____: Might be more. It's easy to try to extend mission from 3 months, and that starts raising costs.
- RS: Was the Falcon orbit 100 miles? Might there be any advantage for a very low orbit that would only last a few orbits.
  J. Carroll: It needs to be more like 300. 5 percent more cost gets you the three months.
  S. Chakrabarti: A short (several orbit) low orbital might save on a few things such as solar panels.
- Could a low orbital last longer than 90 days?
  S. Chakrabarti: In principle, yes.

4.5 Commercial/Air Force/Secondary Payload Breakout Group, Jeremy Kasdin, Princeton U.

- Air Force platforms are **FREE** … if the Air Force is interested in what you're doing. For instance, his work on DMs might interest Air Force and get the TRL to 5 or 6.
- ESPA free flyers are a 180 kg/ payload. Theoretically, you could use all three slots, but that is not likely.
- Secondary payloads are $6–10M.
- Nanosat/microsat (e.g., Sarah's experiment) must assume that someone will launch for you.
- $20–$60M might do a small coronagraph or occulter—maybe it might look at the brightest closest stars. However, otherwise, it's just technology development.
- ABBRA [?] supporting technology category is small but there are some.
- Second, teedum [sp?] can also fund.
- S. Unwin:
  J. Krist: There is always a draft phase where you are getting comments.
  S. Unwin: You can get two thirds of the science for half the cost.
- Eliot Young: Is there a list of projects that need to be done?
  D. Belden: The SERB vets proposals. The trick is finding a sponsor in the large DoD organization. Sponsorship can be as little as signing a form or as much as contributing funds for the mission.
  S. Chakrabarti: Might there be any New Millennium announcements of opportunity?
  J. Kasdin: They haven't had a call in a long time.
- D. Belden: NASA developed the ESPA ring. In return, NASA will get two units to disperse as they see fit.
- R. Soummer: Glen Snyder & ____ on 50-cm with coronagraph. That was the maximum that could fit in the SMEX envelope.
  M. Shao: Payload has to go with a nonSMEX.
  R. Samuele: SMEX is already Class D.
- The SIV bus is available commercially from Ball besides going through Air Force.

4.6 Exoplanet Science from the ISS Breakout Group, Gautam Vasisht, JPL

- J. Carroll: Kinetic isolation experiment did propose a tether from ISS.
- W. Traub: Number of cameras?
- G. Vasisht: TESS has six cameras.
- T. Mace: What would happen if the tether was a laser? They can transfer data, measure distances, and send power.
  J. Carroll: There is some paranoia about free-flying objects near the Space Station. If you are on station with parasitic power, that is a known technology. This is an interesting concept, but it would be hard to sell to the risk averse. Actually, the tether would be even harder to sell. It's not so much a measurement problem as the problem of the whole chain of things: Maneuvering of supply craft around the tether or laser, solar cells to receive laser power; on the ISS, you could have ordinary power.
- J. Carroll: Just moving an occulter on the ISS arm would only be a technology demonstration, but the only cost would be making the occulter (maybe about 10 m).

4.7 Final Discussion

- W. Traub:
    - We are asking the breakout group chairs to provide more details on what different bullets meant for more complete reports. Much of the report will be those breakout reports.
    - We are asking M. Judd to send out files to larger list of attendees plus larger list of interested parties.
    - Several people mentioned the $60-million category. If you have some comments, we could say more to NASA.
- J. Carroll: If you can make less cumbersome proposals for smaller ____________…
  S. Chakrabarti: The two types are very similar.
- Recommendations for a cover letter recommending more small research projects in the exoplanet area _____________
- J. Kasdin.: You can't submit something officially unless everybody gets access.
- W. Traub: Another point would be to encourage more smaller-sized experiments, especially if NASA cannot afford one large mission. This might be sent to some of the committees of after 2010,
- R. Soummer: Some of these issues are more general than just to us.
  W. Traub: They can generalize it. We should stick to our area.
- T. Mace: It will make things easier if this is NOT a consensus document. [FACA?]
  M. Judd: This workshop was not sponsored by the Federal government, so we are not a FACA.
- S. Unwin: ________[?] He would probably read it.
- W. Traub: It would be nice if all the people in this workshop were to generate proposals.
- _: Regarding the 2010 project, what?
  W. Traub: They have been asked to have dollars. They have been told that they do not have to have balance between different programs.
- W. Traub: If a letter was drafted, would people be comfortable endorsing it. A draft will be sent out. The two points would be the $60-million category and emphasis on several smaller missions if funds aren't available for any large projects.
  P. Chen: How about suggesting emphasis on pointing control.
  J. Harriman: We had a couple other items. First, it's harder to think of a balloon mission without a telescope.
  J. Carroll: There may be other communities who are interested but can't afford it by themselves.
- B. Netterfield: Talking about extremely expensive, if you start getting into $20 & $30 million dollar payloads, Falcon starts making more likely. I am worried about balloon payloads above $10 million.

W. Traub: You are saying that Falcon would be more reliable
B. Netterfield: No, but it would have a better environment for observing.

4.8 Keck Final Comments, Michele Judd

- Please keep in contact as collaborators
- You can sign up for ~1 email per month from KISS; you won't be automatically put on list.
- Please attribute to KISS if this workshop helped you generate a paper or other research documentation.
- Please fill out the survey.
- Presentations are posted except those needing permission, and those are coming. If you need to do any coordination with your home organization regarding the permission, please do so as soon as possible.

Attachment 1: Letter Sent to Dr. John Morse, Astrophysics Division Director, NASA Headquarters

The workshop co-chairs, Wes Traub and Yuk Yang, generated a letter to Dr. John Morse, NASA Headquarters Astrophysics Division Director, to summarize some of the most important ideas and suggestions from the workshop. This two-page letter is reproduced below.

Dr. Jon Morse, Director
Astrophysics Division, NASA HQ
<jon.morse@nasa.gov>

Dec 10, 2009

Dear Jon:

Last month we held an invitation-only workshop on the topic "Innovative Approaches to Exoplanet Spectra," sponsored by the Keck Institute for Space Studies (KISS). The workshop's conclusions are relevant to the Astrophysics Division; so we are keen to share them with you. At the workshop about 40 people met to discuss this question: **what kinds of missions could advance exoplanet science using innovative techniques and low-cost platforms?** In particular we looked for *moderate-cost missions*, with costs well below a SMEX.

We examined many platforms, including aircraft, ultra-long duration (ULD) balloons, secondary payloads, sounding rockets, and 'new space' vehicles – both orbital and suborbital. We developed a number of moderate-cost mission concepts using these platforms to do relevant and competitive exoplanet science. We do not enumerate those here, but rather we focus on our conclusions, since these extend into areas of astronomy well beyond the discipline of exoplanets.

Briefly, our general conclusions are:

1. A new generation of balloons will soon be available, allowing long-duration (several-week) mid-latitude flights for missions that require a near-space environment.
2. Secondary payloads, e.g., using the ESPA ring on an EELV vehicle, are very attractive, offering a low-cost ride to Earth orbit.
3. Commercial rockets are expected to provide both sub-orbital and orbital rides to space. Short-duration sub-orbital flights are suitable for technology maturation missions. Several-month (or longer) LEO flights are suitable for single-string, Class D science missions.

These conclusions have a common thread, which is the message of this letter:

To take full advantage of the opportunities listed above, there must be opportunities for investigators to propose to NASA for experiments or missions that are in a '*moderate*' category. This implies a total project cost roughly in the $10 – 40M range. We recognize that some experiments could be done in a mode that is much more experimental than is normally the case for NASA missions. This is already the case for balloon experiments, where the expectation of payload recovery and re-use is quite high.

Note that these moderate missions are substantially less expensive than the current opportunities for a nominally "small" mission, i.e., SMEX, at $105M plus launch vehicle.

Nevertheless these projects are also larger in scale than a typical present-day balloon or sounding rocket experiment.

Secondary payloads can be quite substantial experiments, if the launch is either free or reduced to the cost of integration. These could provide very cost-effective science for missions in the $10-40M range. This is especially true for missions that perform technology maturation as well as cutting-edge science.

To summarize, our workshop finds that there is a range of very interesting moderate-class missions that would be enabled by upcoming launch platforms. We believe that the astronomical community would welcome the opportunity to propose for these moderate-class missions.

Sincerely, and on behalf of the workshop participants,

Wes Traub (JPL/Caltech) <wesley.a.traub@jpl.nasa.gov>
Yuk Yung (Caltech) <yly@gps.caltech.edu>
KISS Workshop Co-chairs

Attachment: List of KISS Exoplanet Workshop Participants
Reference: http://www.kiss.caltech.edu/workshops/exoplanet2009/index.html

CC:

Dr. Edward Weiler, Associate Administrator, NASA Science Missions Directorate <edward.j.weiler@nasa.gov>

Prof. Roger Blandford, *Astro2010* Chair <astro2010@nas.edu>

First	Last	Institution	Interest area
Konstantine	Batygin	Caltech	Atmospheres
Chas	Beichman	Caltech/NExScI	Proto-planet disks
Dan	Belden	USAF	DoD rockets
Rus	Belikov	Ames	Coronagraphs
Beth	Biller	U. Hawaii	observations
Jeff	Booth	JPL	balloons
Eric	Cady	Princeton	imaging exoplanets
Kerri	Cahoy	Ames	direct imaging & characterization
Roger	Carlson	JPL	technical writer
Joe	Carroll	Tether Appl.	Small spacecraft
Supriya	Chakrabarti	BU	Rockets
Pin	Chen	JPL	Atmospheric chemistry
Arvid	Croonquist	JPL	ISS
Carl	Grillmair	Caltech	Transits
Joe	Harrington	UCF	Exoplanet observations
Brian	Hicks	BU	imaging exoplanets
John	Johnson	Caltech, IFA	Exoplanet observations
Jeremy	Kasdin	Princeton	Coronagraphs, engineering
Nancy	Kiang	GISS/JPL	Photosynthesis
John	Krist	JPL	Coronagraphs, optics
Shri	Kulkarni	Caltech	Astrophysics
Mike	Line	Caltech	atmospheres
Tom	Mace	Dryden	Aircraft platforms
Bruce	Macintosh	LLNL	Exoplanet coronagraphy
Mark	Marley	Ames	Giant planet theory
Taro	Matsuo	JPL/NAOJ	coronagraphs
Beverley	McKeon	Caltech	Turbulence
Bertrand	Mennesson	JPL	Interferometry
David	Miller	MIT	Cubesats
Barth	Netterfield	U. Toronto	Balloon pointing, astrophys.
Lewis	Roberts	JPL	Atmospheric seeing
Rocco	Samuele	NGAS/JPL	Laboratory instrumentation
Dmitry	Savransky	Princeton	direct detection of exoplanets
Gene	Serabyn	JPL	Coronagraphs, interferometers
Michael	Shao	JPL	Interferometers, coronagraphs
Steven	Smith	SWRI	Stationary airships
Remi	Soummer	STScI	Coronagraphs
Karl	Stapelfeldt	JPL	Proto-planet disks
Mark	Swain	JPL	Exoplanet spectroscopy
Motohide	Tamura	NAOJ	Space telescopes
Wes	Traub	JPL	Exoplanet science, instruments
John	Trauger	JPL	Coronagraphs
Mitch	Troy	JPL	Coronagraphs, ground
Stephen	Unwin	JPL	Interferometers
Gautam	Vasisht	JPL	Observation, instrumentation
Erick	Young	SOFIA	SOFIA
Eliot	Young	SWRI	small payloads
Yuk	Yung	Caltech	Planetary atmospheres