Summary of the LRO Project Science Working Group Meeting Breakout Sessions

Gordon Chin

November 30, 2006

East-West Conference Center
University of hawaii – Manoa

LRO PSWG Meeting Objectives

- Broader familiarity with all lunar missions, including objectives and lunar measurements

- Breakouts will:
  - Identify current and future cooperative scientific opportunities
  - Review a proposed common coordinate system to facilitate LRO and inter-mission data comparison
  - Discuss international access to lunar data
  - Identify international EPO opportunities
  - Review proposed calibration sites

Summary and Synthesis of Breakout Reports

- Breakout reports are the collective thoughts of a large number participants to this PSWG meeting and also most importantly reflect inputs from the international lunar missions and the diverse range of meeting participants.

  - LRO PSWG attendees total 79
  - Sum of breakout participants 109

- Meeting outcomes will be briefed to the NASA Advisory Council via the Planetary Science Subcommittee (Sean Solomon, Chair)

- Rapidly review breakout sessions in entirety without repeating yesterday's in depth presentations
  - Highlighting key points in Red
  - Indicating my thoughts in Green

Common Coordinate System

Facilitator: Maria Zuber

Recorder: Brent Archinal & Lisa Gaddis

Common Coordinate System
ALL TEAM MEMBERS

- Maria Zuber (MIT)
- Brent Archinal (USGS/Astrogeology)
- Greg Neumann (GSFC)
- Kohji Matsumoto (Nat Astron Obs Japan or NAOJ)
- Lisa Gaddis (USGS/Astrogeology)
- Christian Veillet (CFH Telescope, HI)
- Randolph Kirk (USGS/Astrogeology)
- Frank Lemoine (GSFC)
- Ashwin Vasavada (JPL)
- Charles Acton (JPL)
- Ty Brady (Draper Lab)
- David Everett (GSFC)
- Anton Sanin (IKI)
- Roger Clark (USGS, Denver)
- Hiroshi Araki (NAOJ)
- Helene Winters (JHU/APL)
- Virender Kumar (ISRO)
- Bernard Foing (ESA)
- Joe Boardman (not present)

- Total 19

Common Coordinate System

BACKGROUND PRESENTATIONS PROVIDED

- **Brent Archinal:** Lunar Coordinate Systems
  - Two common systems:
    - Mean Earth (ME)
    - Principal Axis (PA)
  - Clementine
    - Mean Earth System
    - R = 1738 km
  - Recommended for LRO (see white paper)
    - ME system for products, e.g. for PDS archive
    - PA system can be used internally
    - Longitude 0 to 360 East
    - ME orientation (specific frame) defined by JPL LE 403 & Euler rotations (and improved LE if/when available)
    - Reference surface not yet adopted
    - Radius of 1737.4 km recommended by IAU; not yet adopted
  - LPRP and Constellation will likely adopt these conventions
  - International missions? Don’t know. Chandrayaan-1 may use r=1738? (unlike other missions)
  - Recommend immediate initiation of Lunar Geodesy and Cartography Working Group

Common Coordinate System
OPPORTUNITIES

- If we use a common coordinate system, it will be much more straightforward to use data from different missions to (e.g.) densify control and digital elevation models.

- Use of a common coordinate system and shape model will increase the value of all the data sets.

Common Coordinate System

OBSTACLES

- Some sort of local time system – for e.g. monitoring lunar illumination changes – needs to be set up.

- Noting/understanding the difference between the ME and PA systems.

- Not sure of which organization(s) to make recommendations to. Who at NASA should own this and champion it?
  - How should discussion be continued until this issue is resolved?
  - LRO Project can 'own' this for now, with Brent Archinal (USGS---barchinal@usgs.gov) and Gordon Chin as POC?
  - PLEASE add your name to email distribution list if you want to be involved in this discussion before, during, and after initiation of the WG

- Foing replayed experience with SMART-1 on how essential positional knowledge is…

Common Coordinate System
RECOMMENDATIONS/OPTIONS

Recommendations/Options: Lunar Coordinate System

- Unanimously recommend immediate initiation of Lunar Geodesy and Cartography Working Group
  - Use Mars Geodesy Working Group as model
    - Sponsored by NASA (Chair time, some small amt of travel paid by NASA)
    - Include international participation.
  - Make recommendations as need arises.
  - Create readily available web site as clearing house for participants and non-participants

- Recommended for LRO (see white paper)
  - ME system for products, due to historical use in most (all?) previous cartographic datasets
  - PA system can be used internally
  - Longitude 0 to 360 East
  - ME orientation (specific frame) defined by JPL LE 403 & Euler rotations (and improved LE if/when available)
  - Reference surface not yet adopted

- LPRP and Constellation will likely adopt these conventions

- International missions? Chandrayaan-1 may use r=1738 km (unlike other missions)

- Study the possibility of adding retroreflector(s) to LRO in order to use LLR observations to tie LLR and LRO reference frames. Future orbital and lander missions of extended length should have similar retroreflectors for the same reason.

- Another possibility is creation of local DEMs at LLR sites; less accurate than orbital retroreflector but still an important improvement.

- Products should be well documented as to the coordinate system, frame, constants, time system, etc. used.

Common Coordinate Systems

IDEAS FOR COMMUNICATING OUR FINDINGS

- Pass information on to NAC, Constellation Program, LPRP, LHAT, international missions
  - LPRP/Plescia has passed upward to Program Office, relationship with Constellation Program needs to be addressed.

- Collect reactions to this information and update with a similar meeting at the next LRO PSWG and as needed until a LGCWG is established.

- Start a web site that contains existing information (e.g. the LRO white paper, results from this meeting)

International Access to Lunar Data

Facilitator: Susan Slavney

Recorder: Edward Guinness

International Access to Lunar Data
TEAM MEMBERS

- Susan Slavney, PDS Geosciences Node, Washington University in St. Louis
- Edward Guinness, PDS Geosciences Node, Washington University in St. Louis
- Maxim Litvak, Space Research Institute, Russia
- Karl Harshman, University of Arizona
- Ernest Bowman-Cisneros, Arizona State University
- Hirokazu Hoshino, JAXA
- Yoshimitsu Tanaka, JAXA
- Stan Scott, NASA GSFC
- Tom Morgan, NASA HQ
- Jeff Plescia, APL
- David Paige, UCLA
- Ben Bussey, APL

- Total 12

International Access to Lunar Data

BACKGROUND PRESENTATIONS

- Susan Slavney provided one background presentation containing a list of suggested discussion topics, agreements for starting points, and information about the IPDA. The next two slides are from the background presentation.

International Access to Lunar Data
FROM BACKGROUND PRESENTATION

- Starting point: Where do we agree?
  - International access to lunar data is a good idea, because all scientists benefit when data is shared.
  - Interchange of data can improve mission success.
  - Working to make data access easier is worth the effort.

The IPDA

FROM BACKGROUND PRESENTATION

- IPDA = International Planetary Data Alliance
- The IPDA began as a group of data engineers from NASA/PDS and ESA/PSA worked on a **data access protocol** that allows a user to query both the PDS and PSA catalogs.
- The group recognized the need for both agencies to agree on a set of minimum standards for archiving, so that the protocol would work.
- The IPDA is evolving into a group with representation from many space agencies, whose goal is to enable global access to planetary data by defining standards for science data archives.
- First meeting was at ESTEC, Nov. 8-10, 2006, with participants from ESA, JAXA, CNSA, RKA/RAS, and NASA.
- More information is at http://www.planetarydata.org.

International Access to Lunar Data
OPPORTUNITIES

- Levels of data access:
  - Public
  - Agency to agency agreement for program/project planning, e.g., refined gravity field for future mission design
  - Informal investigative team to team exchanges

- Sharing data and information early (before submission to archive) helps:
  - Mission planning
  - Accelerate science

International Access to Lunar Data
OBSTACLES

- Obstacles to early release of data:
  - It is hard work for teams to quickly release quality data/results.
  - The PI may have rights for research and publication.
  - It is hard to make informal team-to-team agreements because of the need to get permission from administrators.
  - It is hard to make agency-to-agency agreements because of higher level restrictions on communications.
  - There is a steep learning curve for making an archive.
  - It may be necessary to incorporate new technology, e.g., JPEG-2000, to make use of advanced instrument data.
  - At least for U.S. PDS seems to be able to surmount obstacles
- Obstacles to using data from another agency:
  - Lack of common data archiving or formatting standards
  - Not knowing how to access data stored in multiple archives
  - Lack of raw data may limit how high-level data are used
    - The PI may be concerned that raw data may be used incorrectly.
    - On the other hand, a user may not be able to make full use of derived data without access to raw data.
    - Inadequate funding can limit archiving of raw data.

International Access to Lunar Data

OPTIONS for taking advantage of opportunities and overcoming obstacles

- Options for overcoming obstacles to early release of data:
  - Have a defined method for teams to make team-to-team agreements.
  - Incremental data releases are better than one release after end of mission.
  - Data exchange discussions between agencies should be done at the appropriate level. The appropriate level depends on the countries involved and the degree to which a relationship has already been established.
  - Face-to-face meetings, workshops and conferences, as well as exchange of personnel for longer periods, are important for establishing international relationships and ongoing process communications.
  - Streamline the archiving.

International Access to Lunar Data

OPTIONS for taking advantage of opportunities and overcoming obstacles

- Options for overcoming obstacles to using data from another agency:
  - Use web-based access tools with common features for searching and downloading data.
  - Provide some quality control or knowledge of data quality, e.g., peer review of data by the archiving agency or peer review of results by a science journal.
  - Use a minimum common set of meta-data to allow searching for data across missions, such as that in development by the IPDA. Look for examples of similar work done by other organizations, such as CEOS (Center for Earth Observing Satellites).
  - Encourage teams to publish papers about their instruments and data sets in the scientific literature.
  - Establish policy that science data and metadata should not be subject to government export controls such as ITAR. Recommend that the IPDA advocate this position.

International Access to Lunar Data
IDEAS FOR COMMUNICATING OUR FINDINGS

- The facilitator of this group will convey the findings to
  - The IPDA
  - PDS management
  - Other agencies or groups interested in access to lunar data, upon request

Hopeful IPDA can start to offer solutions that enable international access to lunar data

International EPO Opportunities

LRO PSWG Meeting
28-30 November 2006
Honolulu, Hawaii

Facilitator: Cherilynn Morrow

Recorder: Stephanie Stockman

International EPO Opportunities – PARTICIPANT INFO

NAME	AFFILIATION
Cherilynn Morrow (Facilitator)	SETI Institute, USA
Stephanie Stockman (Recorder)	Denver Museum of Nature & Science, USA
Polly Andrews	Denver Museum of Nature & Science, USA
Bruce Betts	Planetary Society, California, USA
Bernard Foing	European Space Agency (ESA)
Nicholas Gross	Boston University, USA
Hirokazu Hoshino	JAXA, JAPAN
Sheri Klug	Arizona State Univ. USA
Doug Roberts	Adler Planetarium, USA
Cass Runyon	Charleston University South Carolina, USA
Anton Sanin	IKA/RAS, RUSSIA
Maxim Litvak	IKA/RAS, RUSSIA
Mark Nall	Marshall Space Flight Center
David Everett	NASA GSFC
Wayne Hartford	JPL
Carmen Salas	Arizona State University
Ashwin Vasavada	JPL
Linda Martel	University of Hawaii
Nori Namiki	Kyshu University
TOTAL 19	

INTERNATIONAL EPO OPPORTUNITIES

BACKGROUND PRESENTATIONS PROVIDED

• Cherilynn Morrow	International Heliophysical Year	(3-5 min)
• Bruce Betts	International Lunar Decade Chang'E & SELENE Outreach Collaborations	(10 min)
• Bernard Foing	SMART-1 Multi-lingual EPO	(5 min)
• Stephanie Stockman	NASA LRO EPO	(10 min)
• Cass Runyon	Chandrayaan EPO	(5 min)

ACTIVE LISTENING:

As these presentations are being made, we will capture any obvious Opportunities, Obstacles, Options, and Ideas for Communicating our Outcomes on the wall charts. Also, please note any ideas that occur to you vis-à-vis connections to your own EPO efforts, and we'll brainstorm on this afterward.

INTERNATIONAL EPO OPPORTUNITIES
MANY OPPORTUNITIES

- AGU's Growing Interest in international community membership
- Cospar IHY volume – possibility to publish on lunar EPO projects
- **Lunar EPO Via International Heliophysical Year, International Year of Astronomy**
- **Connection with the International Lunar decade (Planetary Society) which is reaching out to China, Japan, India, and ILEWG.**
- Planetary Society Dissemination Opportunities
- GLOBE international network – linking Moon to Earth
- ESA Dissemination
- **Build on ESA EPO program Earth View and Adopt a Crater (Bernard Foing)**
- **Lunar Student Imaging (Sheri Klug) - enhance partnerships between schools in US and those in countries exploring the Moon**
- Cross Cultural Stories (Chandrayaan – Cass Runyon)
- **Chandrayaan EPO Via M3**
- International input on landing site map and distribution (Cass Runyon)
- Online courses- possibility of international access
- **International Planetarium Association - annual meeting in 2008 at Adler – with theme of lunar exploration Adler is LRO EPO partner**
- **Museum visualization alliance – invite international partners to contribute 2-D and 3-D data that can be distributed. Enhance alliances between museums & planetariums in US and those in countries exploring the Moon.**
- Extensive partnerships of the LRO EPO team in the US International sister organizations to Girl Scouts
- Special needs students
- LROC connection in Germany
- **LEND Russia Student Exchanges (AAAS money to fund students abroad?)**
- **SELENE's High Definition TV Camera showing Earth rise - can it be available?**

INTERNATIONAL EPO OPPORTUNITIES
OBSTACLES

- NASA constrained internationally
- Commercial camera on SELENE copyrighted material
- Funding for LRO E/PO
- Redundancy of effort internationally
- Mars has raised expectations
- Moon considered passe – “Been there, done that!”
- Translation and language barrier

International EPO Collaboration

OPTIONS for taking advantage of opportunities and overcoming obstacles

- **Engage NGOs (e.g., The Planetary Society, AGU, UN-IHY, AAS, Globe, IPS, HOU**
- Let people know why the Moon - "that we haven't been there done that"
  - Permanent settlement
  - Mars forward
  - Economic expansion
  - Science
  - International collaboration
  - Public inspiration / engagement

- Engage with organizations who have translation capabilities
- Identify what has been done and what is being done internationally
- Web-based international clearinghouse outside the NASA Portal
- **Pursue funding by completing LRO E/PO Plan**

INTERNATIONAL EPO OPPORTUNITIES
IDEAS FOR COMMUNICATING OUR FINDINGS

- We want to be represented strongly as a integral part of whatever is communicated as the results of this meeting

INTERNATIONAL EPO OPPORTUNITIES
COMMENTS FROM PLENARY

- LEND has already had two students from the US come to the U of Maryland. They want US students to come to Russia but want to review their research proposals.
- SELENE and Hi-DEF TV…will negotiate with NHK and let us know about public accessibility of Earth rise images
- Bernard re-iterated availability of SMART data….Host LRO expert or EPO person…TV production service…looking to film other missions.
- Moon SCi-TECH & ILWEG website..info about other lunar missions Suggestions about using digital cameras to photograph the moon…
- Sylvie – her group of scientists built a tool to trigger student interest in the Moon 3-D interactive model on a website…one idea
- Website comparison of any mission at any time…track their orbits and where they are…Lunar Prospector
- How do we fund?

- Lively interest and great deal of commentary in the plenary session

CALIBRATION SITES

Facilitator: Carle Pieters

Recorder: David Smith

CALIBRATION SITES
CORE TEAM MEMBERS

• Carle Pieters	Facilitator
• David Smith	Recorder
• Manabu Kato	
• Christian Veillet	
• Ed Guinness	
• David Paige	
• Bernard Foing	
• Harlan Spence	
• Igor Mitrofanov	

CALIBRATION SITES
PARTICIPANTS

- Carle Pieters Facilitator
- David Smith Recorder
- David Paige
- Bernard Foing
- Harlan Spence
- Igor Mitrofoanov
- Kurt Retherford
- Rick Saylor
- Justin Kasper
- Joe Mazur
- Frank Lemoine
- Jeffery Gillis-Davis
- Samuel Lawrence
- Josh Cahill

TOTAL 28

- Brett Wilcox Denevi
- Ernst Cisneros
- Randolph Kirk
- Maria Zuber
- Brent Archinal
- Lisa Gaddis
- Yoshimiten Tanaka
- Kasi Matsumoto
- Hiroshi Araki
- Marc Fotte
- David Blewett
- B. Ray Hawke
- Jerry Fishman
- Roger Clark
- Michael Wargo

CALIBRATION SITES

BACKGROUND PRESENTATIONS PROVIDED

- Carle Pieters
- Jack Trombka

COORDINATED CALIBRATION
Topics & Issues - 1

- Primary objective is select a small number of sites, especially on which data can be released early for use by other missions
  - What data sets will be inter-compared?
  - What sites and are they self-consistent enough to be used for spatial extrapolation
    - do optical instruments provide the same values?
    - do mineralogy values agree?
- It might be more useful to select 4 or 5 sites per type of instrument, rather or in addition to a general 4-5 sites?
- Calibration standards would be beneficial to many instruments, but
  - some instrument results are model dependent
  - some are based on the data provided by other sources
- Targets near the poles will present opportunities to observe changing light conditions and confront some of obstacles that are unique to the polar regions.
- Some targets are suitable for monitoring changes with season, illumination etc
- Calibration could help understand cross-talk between instruments, which is sometimes a potential problem

COORDINATED CALIBRATION
Topics & Issues - 2

- Secondary calibration targets should be defined
- Consider using the sun/earth/stars for calibration
- Must consider effect of the size of target and the instrument field of view in any comparison.
- Propose five or more calibration sites (~200 km^2+) proposed; specific well focused areas which everyone agrees to use
  - Sites selected to be representative of different terrains
  - Will allow cross-comparison between multiple instruments, missions and data sets, also offers opportunities for those new to lunar exploration to become more familiar with the overall lunar environment
  - Apollo 16, Lichtenberg, Hadley Rille (more challenging), South Pole Aitken Thorium “Anomaly”, Tycho Crater, and LCROSS impact site have been suggested
  - Large, homogeneous mare site is also recommended as a site selection
    - Suggested that we may like to select a region that has been characterized in the lab (such as one of the Apollo sites)
  - Recommend that at least one site selection resides at higher latitudes that are more accessible to missions

COORDINATED CALIBRATION
Topics & Issues - 3

- Sites that offer multiple science opportunities are generally highly complex, and not accessible or suitable to ALL instruments
- Data should be released early enough to be useful to all participants in a location and format that is functional for everyone
  - Many missions will take time to acquire high resolution data on these sites
- Scale of calibration sites are a factor for many instruments
  - Inter-comparisons should be on the same scale
- Not all sites will be relevant for all instruments
- Differences in sampling depths present challenges for comparison
- Observations on a single orbiter will be simultaneous between instruments so that boresight differences can be sorted out
- Timeframe of calibration site selection is important - first launch next summer
- Phase angle calibration possible and needed
- Calibration standards will enable interpretation of the space data
- Image convolution
  - Edge enhancement techniques can insert erroneous high frequency signals

CALIBRATION SITES
OPPORTUNITIES

- Five calibration sites (~200 km^2); specific well focused areas which everyone agrees to use
  - Sites selected to be representative of different terrains, science opportunities
  - Will allow cross-comparison between multiple instruments, missions and data sets, also offers opportunities for those new to lunar exploration to become more familiar with the overall lunar environment
  - Apollo 16, Lichtenberg, Hadley Rille (more challenging), South Pole Aichen Thorium “Anomaly”, Tycho Crater, and LCROSS impact site have been suggested
    - Large, homogeneous mare site is also recommended as a site selection
      - Suggested that we may like to select a region that has been characterized in the lab (such as one of the Apollo sites)
    - Recommend that at least one site selection resides at higher latitudes that are more accessible to missions

CALIBRATION SITES

Numerous Subtle OBSTACLES

- Sites that offer multiple science opportunities are generally highly complex, and not accessible to ALL instruments
- Data should be released early enough to be useful to all participants in a location and format that is functional for everyone
  - Many missions will take time to acquire high resolution data on these sites
- Scale of calibration sites are a factor for many instruments
  - Inter-comparisons should be on the same scale
- Not all sites will be relevant for all instruments
- Differences in sampling depths present challenges
- Some instruments require external data available for interpretation of their data sets; changes in the model of that external data will be reflected in the interpretation of the affected data sets
- Observations on a single orbiter should be simultaneous between instruments so that bore-sight differences be sorted out, and should be repeated observations
- Timeframe of selection is important
- Phase angle calibration
- Calibration standards that could be used to interpret the space data
- Image convolution
  - Edge enhancement techniques can loss of scale, insertion of high frequency components

COORDINATED CALIBRATION

Additional Comments in Plenary

- Sample return sites should be on an extended list of calibration sites
- Apollo 11 site is a good candidate for orbital radar and Aricebo radar
- Lamp will get an early global map and needs a high latitude “calibration” site
- A write-up on calibration could be very beneficial to EPO
- SELENE team will discuss suggestions internally and provide input separately
- Can we put together a “calibration cookbook”??
- General recommendation:

  To the suggested 5 sites
  - Add a high latitude calibration site
  - Add a polar calibration site
  - Add a homogeneous mare site.
- Carle plans to modify COSPAR white paper and to add Benard (and others?) as co-author to reflect feedback from this breakout session

Cooperative Scientific Opportunities

Facilitator: Alan Stern

Recorder: John Keller

Cooperative Scientific Opportunities

CORE TEAM MEMBERS

- Manabu Kato
- Keith Raney
- Carle Pieters
- Bernard Foing
- Sylvie Espinasse
- Igor Mitrofanov
- David Smith
- Martin Houghton
- Dave Everett
- Jerry Fishman
- Ben Bussey
- Stu Nozette

Cooperative Scientific Opportunities

PARTICIPANTS

- Cherilynn Morrow
- Kurt Retherford
- Keith Raney
- Mary Reden
- Joe Mazur
- Justin Kasper
- Harlan Spence
- David Blewett
- Ben Bussey
- Jeffrey Gillis-Davis
- Josh Cahill
- Mark Nall
- Jerry Fishman
- Igor Mitrofanov
- Jacob Trombka
- Stephen Ballard
- Marc Foote
- Wayne Hartford
- Bruce Betts

Total 31

Cooperative Scientific Opportunities

BACKGROUND PRESENTATIONS PROVIDED

- Selene ion mass analyzer observation of LCROSS impact, J. Keller
- Scientific operations and cooperation – Bernard Foing
- LRO orbit details – Martin Houghton

Many Cooperative Scientific Opportunities

- Coordinating for calibration AND for high coverage, need coordinated and large list of prime targets and potential landing sites
- Common language - terminology to describe landing sites
- Coordinate the mission terminations
- Understanding the lunar atmosphere – even orbiting instruments perturb the atmosphere. Common database for atmospheric measurements. Event Calendar
- Target of opportunity – Solar events. Planning for events to preserve data during safe mode, keep monitors on during events. High data rates for these instruments. Be ready for anything. Preserve engineering data during energetic particle events.
- Mechanical coordination of the spacecraft – each spacecraft orbit is fixed inertially
- RF coordination – interference from spacecraft and Arecibo active interactions may damage instruments any other active assets including lasers.

Cooperative Scientific Opportunities

- Coordination of measurements between spacecraft LRO and Chandrayaan radar, imagers (glints).
- Measurements by other assets – Swift, Sodium measurements, Impact events and coordination of other assets. Use data from upstream monitors and magnetospheric measurements
- Laser Ranging from Earth – Tying of lunar and orbital coordinate systems.
- Comm relay mode for some spacecraft.
- Prepare for coordination for lander missions – active experiments.
- Coordination of lander missions – maximize return.

13 Opportunities listed

Coordination of Target Sites

- What is the optimal strategy for coverage of the moon by high bandwidth instruments? Split strategy--
  - Cover much of the moon
    - Develop list of targeting instruments
  - Heavy overlap on potential landing sites and calibration targets
  - Develop common terminology for site selection

Impacts

- Coordinate measurements of LCROSS by all spacecraft.
  - Observe time variability of the debris field
  - Mass spectroscopic observations from SELENE
- “All missions are doomed to impact”
  - Learn from Smart 1 and then LCROSS
  - Take advantage of all impacts

Understanding Mission Impacts On the Lunar Atmosphere

- Even orbiting spacecraft engine maneuvers perturb the atmosphere. Common database to facilitate atmospheric measurements - event database.
- What is the status of the Moon before we start hitting it hard – surface as will as atmosphere
- Target Apollo impacts

Energetic Particle Events

- Planning for events to preserve data during safe mode, keep particle monitors on during events.
- Preserve engineering data during energetic particle events.
- Also aids some kinds of science observations, radiation hazard research

Mechanical coordination of the spacecraft radar measurements

- Each spacecraft orbit is fixed in inertial space.
- Some coordinated measurements require a degree of co-planarity
  - decisions are made before launch.
  - LRO aims for beta = 0 during lunar solstices
- In-plane phasing is possible

Safety and interference

- RF coordination – interference from spacecraft and Arecibo active interactions may damage instruments any other active assets including lasers.
- Glint from ground lasers may affect imaging instruments

Coordination with Other Assets

- Swift, other spacecraft observing solar and space backgrounds, possibly assets observing the moon from Earth or Earth orbit
- Laser ranging from Earth
  - Tying of lunar and orbital coordinate systems.
- Comm relay coordination after prime missions
  - Not a long term solution

Prepare for coordination for lander missions

- Active experiments – e.g., follow, from orbit, propagation of released gasses.
- Coordinate landing site selections to maximum benefit of lunar exploration

Cooperative Scientific Opportunities

OBSTACLES

- Schedule – many decisions must be made early based on events such as launch dates and LCROSS impact
- Conflicting science and exploration objectives
  - E.g., it may make sense on some level to coordinate orbital planes of the spacecraft but individual spacecraft may all go for the same perceived optimal lighting conditions
- Primary mission – spacecraft generally must fulfill full mission success before taking on supplemental science objectives
- Cost – Study, implementation and analysis of cooperative measurements may require additional funding.
- Management – decisions to go forward will require buy-in at multiple levels of each agency.
- Many good ideas. Can't do them all, need to prioritize and develop consensus
- Safety – **Must coordinate** mission or Earth observations to prevent damage to spacecraft and instruments or data corruption.

Cooperative Scientific Opportunities

FEW OPTIONS for taking advantage of opportunities and overcoming obstacles

- E-mail communication between project scientist or representatives (email list coordination J. Keller)
  - To inform within a few days of major changes to spacecraft operations.
  - Way to communicate white papers for high level descriptions of the instrument
  - Orbital information and *rationale* and general engineering data (ephemeris etc.)
  - Coordinate session at science meetings (COSPAR AGU etc.)
  - Sub-groups (measurement types, science objectives) will develop channels of communication amongst like-minded investigators.
- Form a core working group consisting of PI's, agency leadership, and lunar science community – white paper with specific recommendations
  - Recommend follow-on meeting devoted to this subject.
  - Solicit agencies funding to support study group
  - Effective steps can be low impact and implemented under the radar screen – **keep talking to each other!**
- Develop Event List from all relevant operations (volunteer???)
  - Earth observations e.g. radar, lasers
  - Inter-spacecraft interactions
  - Individual Instrument teams should assess risks.

Cooperative Scientific Opportunities

IDEAS FOR COMMUNICATING OUR FINDINGS

- Short note in COSPAR publication
- EOS communication describing this meeting.
- Linking web sites – each site could have a page devoted to cooperative measurements.

Meeting Format

- The format, especially the breakout sessions, of this meeting is designed to:
  - Formulate strategies for implementation
    - In a nutshell - Opportunities, Obstacles, and Options
  - Capture the collective wisdom from all participants
    - Greater emphasis on discussion rather than presentations
    - Facilitator solicits discussions from diverse points of view
    - Reporter captures discussion while enabling the facilitator
    - Presentations bring breakout results to plenary for consensus and further comments
- I want to acknowledge the contribution of Cherilynn Morrow who designed this meeting format.
- We want to solicit feedback from all the LRO PSWG participants for improvements and comments for the next time we meet.