Integration of Data Visualization and Citizen Science in the LSST-era

Or

New Vistas for Pro-Am Collaboration in Big Data-era

Padma A. Yanamandra-Fisher

Space Science Institute

and

The PACA Project
Summary

- Pro-Am collaborations ➔ “Big” Data Properties
- Science Drivers ➔ New Observing modes/tools
- Inclusion of Legacy Data ➔ Need for Visualization
- Inclusion of diversity of tools ➔ PCA/ICA, Time Series, ArcGIS
- Common repository for data/software/analysis for both Pros and Amateurs ➔ Jupyter? Hoping to learn at this workshop and provide help to pro-am collaborations
Outline of Talk

- Pro-Am collaborations through the ages
- UV/O/NIR Astronomers’ Tool Kit
- The PACA Project and its campaigns
- New Directions for Pro-Am Collaborations:
  - Polarization and Spectroscopy
- Solar System Polarimetry – Sun to Outer planets
- Need for Visualization: data and amat community
  - PCA/ICA
  - Time Series
  - ArcGIS
- Common repository for software =>Jupyter? Hoping to learn at this workshop
Pro-Am Data ➔ Big Data
Pro-Am Synergy: Historical

The “First” Pro - Amateur Observer Campaign
International Halley Watch (1985-86)

- IHW: ”Halley” Armada (ESA/Giotto, JAXA/Suisei, Sukigawa; Russia’s Vega 1,2) + global ground-based pro-am observing
- Observing modes: AstrometryPhotometry, polarimetry, Spectroscopy, Radio, Large scale phenomena, Infrared, meteors, and amateur observations (sketches, vis, CCD, spectra…)
- Dedicated network: comet was located at southern latitudes
- Other notables: 21P/Giaconi-Zinner; 26P/Grigg-Skjellerup; hibernation of s/c; discovery of heliocurrent sheath sector boundaries via disconnection events.

Planets

Disintegration of D/SL9; impact Jupiter

Monitoring of Jupiter; Saturn: record changes

Comets

The spectral energy distribution (SED): state of a comet
UV/O/NIR Astronomer’s Tool Kit

• Per ASTRO2010 Decadel report (Clemens et al). three independent tools for astronomers:

• Imaging – morphology and related changes -- commonly used

• Spectroscopy – composition (of surfaces or atmospheric scattering media) – in practice

• Polarization – optical properties of scattering media (surfical, aerosols, cometary dust, etc.) – not as advanced/in use due to lack of observations/lack of vector rt methods/lack of lab measurements/lack of s/c missions - starting to see rejuvenation of the field on all fronts

"Two tails look like beacons"

Sitko, Russell, Yanamandra-Fisher, NASA/IRTF/BASS

The Dust Environment of C/ISON: Pre- and Post-Perihelion
Fernando Moreno and The Granada Team
Cometas-Obs and Amateur Astronomers
Padma A. Yanamandra-Fisher, Space Science Institute, U.S.A.
Accepted for publication; Ap J, July 2014

Af proxy of dust (A'Hearn et al., 1984)

(L): Network of individuals, and robotic telescope networks; telescopes ranging from small to 0.5/1-m; filters R,G,B,NIR);
(R) Rob McNaught, at Uppsala Telescope, SSO,AU. The flyby was best observed from the southern hemisphere.
Different challenges: periodic comet, compare w/ previous apparitions
Current apparition not very bright
Characterized by s/c close to nucleus and professionals with big telescopes
Amateur data archived in ESA/PSA (almost complete)

Facebook group established: https://www.facebook.com/groups/paca.rosetta67p/
Flickr group started: http://www.flickr.com/groups/paca_67

Comparison of amateur and professional observations of comet on 19 December 2015.
Credit: Slooh CATS Team; A. Fitzsimmons, WHT
The PACA* Project
* Pro-Am Collaborative Astronomy

Science: identify gaps in scientific knowledge (SKG)

Community: scientists, amateurs; educators; students; citizen scientists

Media: bloggers, social media; astronomy groups, PR

Outreach: meetings/conferences; articles; internet radio; talks

Past Campaigns:

- Planets (JSUN);
- Comets (2017O1)
- Eclipses

Ongoing Campaigns:

- Specific Comets (46P)
- Polarization
- Spectroscopy

Upcoming Campaigns:

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PACA Project Observing Campaigns

PACA Groups
- Jupiter
- Saturn
- Icy Giants
- Mars
- Comets
- Polarization

Amateur/Pro Observations:
- Imaging (Vis/Nir)
- Spectra
- Polarization

Pros:
- + Thermal
- Retrievals
- Models

Pro-Am Integrated Research: support missions and temporal coverage in-between missions (evolution of planetary atmospheres).

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Polarization of Solar Eclipse

Why is the solar corona hotter than the solar “visible” surface or photosphere?

- Inner solar corona, 1.3 to 2.2 solar radii is not probed by spacecraft (as yet; NASA/Parker Solar Probe and ESA/Solar Orbiter may help)

- Inner corona is dominated by the K-corona (free electron) scattering, linearly polarized; accessible naturally during total solar eclipse (up to 7 minutes).

- Observations: distribution of polarization => polarization Brightness (pB) => local electron density; coronal structures/streamers correlated with solar activity - period of low solar activity, expect
Coronal Structure

Composite images of the corona during total solar eclipses of 2006 (left; credit SOHO/LASCO, Johnson, Brown) and 2016 (right; credit SOHO/LASCO, Vilinga, Wittich). The outer corona (red) is imaged from space by NASA/SOHO/LASCO instrument; the inner solar corona (white) is from ground-based observers and the image of the sun is shown on blue (left image) and is occulted (black in the right image).

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Variety of coronal streamers. Solar max (top) and solar min (bottom) (Credit: HAO Archives)
70 CATE Sites with identical equipment

27 UNIVERSITIES
1. Boise State University, ID
2. Montana State University, MT
3. BYU Idaho Falls, ID
4. University of Wyoming, WY
5. Chadron State College, NE
6. University of Nebraska Kearney, NE
7. Benedictine College, KS
8. University Central Missouri, MO
9. University of Missouri, MO
10. Drury University, MO
11. Jefferson College, MO
12. Southeast Missouri State University, MO
13. Southern Illinois Univ. Carbondale, IL
14. Western Kentucky University, KY
15. Morehead State University, KY
16. Tennessee Tech University, TN
17. Tri-County Community College, NC
18. Southwest Community College, NC
19. Austin Peay State University
20. Radford University
21. Clemson University, SC
22. Lander University, SC
23. Coker College, SC
24. South Carolina State University, SC
25. Orangeburg-Calhoun Tech. Univ., SC
26. Westminster College UT
27. Utah State University, UT

22 HIGH SCHOOLS
1. Mitchell High School
2. Dayville School
3. Grant City Schools, OR
4. Weiser High School ID
5. Bozeman High School
6. Teton High School, ID
7. Harlem High School MT
8. Teton School District, WY
9. Dubois High School, WY
10. Arapahoe School District
11. Lander High School, WY
12. Laramie High School, WY
13. Pathways Academy HS, WY
14. Goshen HS, WY
15. Beatrice High School NE
16. Cienega High School AZ
17. Hiawatha High School KS
18. Unity Point Schools
19. Gallatin County Schools, IL
20. Christian County Schools, KY
21. Spring City HS, TN

5 NATIONAL LABS
1. Space Telescope Science Institute
2. National Radio Astronomy Observatory
3. NASA/MSFC
4. LSST/NOAO
5. National Solar Observatory

8 INFORMAL SCI-ED
1. Boyce Research Foundation, CA
2. Nat. Space Sci & Tech Institute, CO
3. American Museum of Natural History, NY
4. The Exploratorium, CA
5. Pawnee City Public Library, NE
6. Astronomical Society of Kansas City, MO
7. Amateur Astronomy Assoc. of NY, NY
8. Amateur Telescope Makers of Boston
PACA_CATE_PolNet
PI: Padma Yanamandra Fisher
PACA_CATE Polarimeter

Characteristics
Industrial Partner: DayStar
Filters
“CATE” Camera:
80-mm f/5.5 doublet refractor
an equatorial mount, with a
battery–powered right
ascension drive, on a tripod;
4-megapixel rapid-readout
detector
Polarimeter
liquid crystal variable
retarder, white light linear
polarizer
## Total Solar Eclipse (TSE) 2017: Four Phases of Collaboration

<table>
<thead>
<tr>
<th>Science Knowledge Gap</th>
<th>Why is the corona hotter than the visible photosphere? What is the mechanism responsible for coronal heating?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td>NASA; AAS; Professional –amateur solar observers; professional community of modelers; umbraphiles; media; educators; students; solar viewer manufacturers, etc.</td>
</tr>
<tr>
<td>Outreach/Citizen Science</td>
<td>Social media; bloggers; star parties; 3D modeling; coordinated observations ; a new generation of observers, STEM-related influx of students; sketchers</td>
</tr>
<tr>
<td>Limelight</td>
<td>PRs, NASA , organized sessions at meetings (AGU, ASP, AAS), papers; other coordinated products; future eclipse campaigns</td>
</tr>
</tbody>
</table>

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Preliminary (qualitative) results: Intensity (Sobel filtered); polarization brightness (pB) X angle of linear polarization
New Modes for Pro-Am Data
Polarization: Is it unique?

**Rainbows** are caused by reflection of sunlight by water droplets in the atmosphere and are highly polarized.

**Haloes** are produced by reflections/refraction by hexagonal ice crystals, as opposed to water droplets, and are mostly formed in colder climes.

**Asteroidal Taxonomy**

**Comets**

**Planets and satellites**

Moon - minearlogy
Polarization of Jupiter/Outer Planets

Polarimetric observations allow direct characterization of planetary atmospheric aerosols and hazes

**Constraints:** Low phase angles for Earth bound observations; integrated polarization is essentially zero due to the symmetric backscattering.

Limb polarization, second order scattering effect, produces a measurable limb polarization for resolved planetary disks.

Measured changes in polarization can be related to changes in the atmosphere, and manifested as variability in the cloud and thermal fields.

Given Jupiter’s ever-changing atmosphere, polarimetric observations can provide real-time information re: the changes!
What is the polarization of Jupiter?  
(assuming a four-level Jovian model, with stratospheric aerosol layer)

**Linear**
- Polar asymmetry: increasing from equator to poles
- Seasonal asymmetry: possible several causes
- Caused by stratospheric haze/aerosols

**Circular**
- Two effects: polar: nearly equal magnitudes and opposite signs
  - \( q_N (\alpha) \sim - q_S (\alpha) \)
  - \( q_N (\alpha) = - q_N (-\alpha) \);
  - \( q_S (\alpha) = - q_S (-\alpha) \)
- Multiple scattering and/or (Rayleigh + secondary scattering)

Shalygina et al, 2008
New Generation of Polarimeters

- Large Facilities: (driven by exoplanet studies)
- Use 3D printing for parts;
- Amateur community starting to venture into polarimetric studies of SS
- 1-m telescope is sufficient (McLean 2016).
- Fearnside et al. (Icarus, 2015) – polarimetric behavior of lunar surface – expanding to include other amateur observers

Preliminary pol maps of Jupiter: Wesley (Aug 2016; Red; AU); Masding (May 2016; Blue; UK); pole-to-pole linear polarization in Blue

Pole-to-Pole graphs
Top: McLean
Bottom: Masding
Pro-Am Imager/Spectropolarimeter (Prototype)

Preliminary images of Jupiter (intensity – above); spectropolarimetry (below)

Credit: D. Elmore (AURA); Yanamandra-Fisher (SSI)

Potential “Big Data” from Pro-Am Collaborations now possible
Tools for Visualization
From 2.5 min to 83 min: 46 Site Quick-Look Animation

Co-adding/registering images; Sobel-filtering for fine structure (Credit: D. Elmore, AURA)
Static Tools

Principal Component Analysis (PCA): Interaction of Large Vortices on Jupiter

Next interaction coming up
Using Mission Support
Adapting ArcGIS to Dynamic Mapping

ArcGIS- geospatial mapping; reproject to sphere

Applied to terrestrial cases

Initiating application to planets (Jupiter, Mars, Saturn)

Pro 5.1 – micron data reprojected onto globe
Going Forward…

**Traditional**

- Traditional observations; models
- Increasing pro data sets
- Temporal/spatial/spectral coverage
- Mostly static of dynamic systems via s/c missions
- Data format, reduction pipeline consistent for immediate comparison and long-term modeling, but specific to obs facility/mission/research group

**New Modes**

- Imaging/polarimetric/spectroscopic observations => ”Big Data” via pro-am/citizen science
- Statistical methods – PCA/ICA
- Time Series
- Variety of Projections
- ArcGIS – cartographic mapping of pro-am data _rotate_ targets for evolution studies
- Major challenge of data fusion; visualization; archival;
- **Amat use social media, free software => potential users of Jupyter notebooks** (NASA requires GitHub repository)
A Common Approach for Pro-Am Campaigns

- From observing to analyses/publication
- Common procedures/tools for pro- and amat-data (current, legacy and mission)
- Inclusion of techniques common to each community
- Coding/annotation needed
- Crowdsourcing for scientific analyses

Potential Solution: Jupyter notebooks

Not tested yet – looking to learn at this workshop
Back-up Slides
Advantages of Multi-site Polarimeter Network

- The inner corona (between 1.3 – 2.2 solar radii) can be probed frequently synergy with the amateur community: value of citizen science in participation of such campaigns.

- Collection of large amounts of polarimetric data that be mapped and sample the solar cycle (this is a region of the corona that even the current spacecraft cannot sample, as yet).

- Our network: PACA_PolNet: Two teams:
  - Cate-Pol001 (David /Richard located in Tetonia, Idaho)
  - Cate-Pol002 (Padma/Adriana in Carbondale, Illinois)
Outer Planets (J, S, U, N)

- **Jupiter**
  Changes in atmosphere; polar aurorae; NASA/Juno mission has a Citizen Science component, JunoCAM; relies on the input/feedback from amateur observer network to target features

- **Saturn**
  End of Cassini mission – September 2017
  Pro- Amateur observations needed to continue coverage of planet+rings till next mission

- **Uranus/Neptune**
  Ground-based small apertures capable of resolving features in atmosphere and their satellites

Formation of Solar System; Analogs for exoplanetary systems
Science - Citizen Science At its Best

Comprehensive Study of the Sun
- Multiple wavelength study
- Multiple geometries
- Structures – sunspots, prominences
- Search for sungrazer comets
- Multiple modes of observation
- Comparative analysis of data with legacy/previous data
- The Solar Crown: the Corona: structures?

Response of the Earth system during a total solar eclipse
- Changes in environment (temperature, clouds, etc.)
- Response of flora/fauna (birds, plants, animals, etc.)
- Emotional feeling of people
- Auroare?

- Moon mapping
- “extending” the event: Citizen CATE – nearly 70 identical telescope setups along totality path to image the corona: increase the event from 2 min 40 sec to 90 min

TSE 2017 first major eclipse in digital era;
A new time domain astronomy window (TSE 2019, 2020,...2024 and beyond)
## Completed PACA Campaigns

<table>
<thead>
<tr>
<th>Campaign/ Yr</th>
<th>Science</th>
<th>Community</th>
<th>Technology</th>
<th>Outreach/ Citizen Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comet ISON (2013)</td>
<td>Oort cloud comet; potential to be a Great Comet</td>
<td>Pro-am amat observers global netwrok</td>
<td>Social media; synergy with pros</td>
<td>Flickr etc., paper; conferences</td>
</tr>
<tr>
<td>Comet Siding Spring (2014)</td>
<td>Oort-cloud comet, close approach to Mars</td>
<td>Pro-am comet and Mars communities</td>
<td>Imaging, spectra, social media</td>
<td>Interaction with JPL; international meetings; collaborations</td>
</tr>
<tr>
<td>Comet 67P/CG (2014-2016)</td>
<td>ESA/Rosetta target</td>
<td>Global ground-based obs support</td>
<td>Robotic netwroks, etc.</td>
<td>Fill-in data; visualization; 3d models; ebooks, etc.</td>
</tr>
</tbody>
</table>
Polarimetric Drivers: Characterization of Planetary Systems

Our solar system, with its unique linear polarimetric signatures of planets, satellites, comets, etc., provides a dynamic laboratory to directly detect and characterize exoplanetary systems discovered by the Kepler mission. Venus clouds probed by Pioneer Venus using polarimetry identified spherical droplets of sulphuric acid; lab measurements of many samples identified properties of regoliths and an empirical relation between polarization and albedo; methane spectrophotopolarimetry of Jovian planets probe deeper into the atmosphere, as methane is abundant.
Polarimetric Drivers:
Atmospheric Phenomena

**Rainbows** are caused by reflection of sunlight by water droplets in the atmosphere and are highly polarized.

**Glory** is produced by diffraction by spherical particles with a narrow size distribution. Although common on Earth, not observed on other planets until 2011 by Venus Express on Venus (Markiewicz et al., 2012), in the UV and attributed to nucleation of sulphuric acid droplets on iron chloride cores, size 1.2 microns.

**Haloes** are produced by reflections/refraction by hexagonal ice crystals, as opposed to water droplets, and are mostly formed in colder climes. Glory can be either white (due to internal reflections in the hexagonal crystal) and highly polarized, whereas colored glory is slightly polarized due to the birefringence of the ice crystal.

Credit: Bailey (2007). Effect of different liquids on rainbow scattering/polarization (left); effect of refractive index (right)

Credit: Wikipedia. A fogbow, sun glory and the Brocken Specter seen at the Golden Gate Bridge, San Francisco, USA.
Polarimetric Observations of Small Bodies: Moon, Ganymede, Asteroids, etc.

- Ganymede exhibits aurora (oxygen line) – anisotropies in local magnetic field?
- Fearnside et al. (2016) : polarimetric exploration of the moon: refractive indices of regolith
- Asteroid classification based on linear polarimetry (Belskaya, 2016).
- Cometary composition and origins – new results from Rosetta
- Amateur observing support for observations of polarimetric transits of exoplanets – synergy with pro-campaign (currently being organized)
PACA Pol_Net: Measure Inner Solar Coronal Polarization
PI: Padma A. Yanamandra-Fisher/SSI

- Qs: Why is the solar corona hotter than the solar “visible” surface or photosphere?
- Inner solar corona, 1.3 to 2.2 solar radii and polarized due to electron scattering, accessible during total solar eclipse.
- White-light polarimetric observations to map polarization brightness (pB) and degree of polarization (dolp) with Citizen CATE* telescope + white light polarimeter set-up (Daystar Filters)
- Two observation sites (shown in red on map) during the transcontinental US total solar eclipse 2017 (Tetonia, Idaho, and Carbondale, Illinois), consistent with Citizen CATE project.

* Citizen CATE (NASA CAN, PI: M. Penn, NSO)

Composite images of the corona during total solar eclipses of 2006 (left; credit SOHO/LASCO; Johnson & Brown) and 2016 (right; credit SOHO/LASCO, Vilinga, Wittich). The outer corona (red) is imaged from space by NASA/SOHO/LASCO instrument; the inner solar corona (white) is from ground-based observers and the image of the sun is shown on blue (left image) and is occulted (black in the right image).
Polarimetric Driver:
Habitability via Circular Polarization

Chirality or handedness is a property of molecules with non-superimposable mirror-image symmetry (right and left hands). Right- or left-chirality is characterized by right- and left-circularly polarized light. All biological activity and life forms on earth are chiral and pre-dominantly left-handed: chlorophyll exhibits a distinct “red edge” and is circularly polarized; earthshine (or light reflected of the moon); amino acids. Aurorae occur in response to changing local magnetic fields and exhibit circular polarization (Ganymede).
New Generation of Polarimeters/ New Results

- Large Facilities: (driven by exoplanet studies)
- 1-m telescope is sufficient (McLean 2016).
- 7 dates observing Jupiter pre-Juno arrival and various wavelengths
- See latitudinal structure
- At low phase angles (4 – 10.5), but need intermediate phase angles for other features like rainbows, etc.

Linear Polarization Results

2015 October V, B and R Latitudinal structure evident

LP increasing from equator to poles

S Pole > N Pole?
New Generation of Polarimeters/ New Results- Amateurs

- Amateur community starting to venture into polarimetric studies of SS

- Small apertures (8” -14”)

- We (including Fernside, Masding, Hooker, Rossi, McLean, Yanamandra-Fisher) started a pilot program to image Jupiter and other planets with pro and amateurs

Preliminary pol maps of Jupiter: Wesley (Aug 2016; Red; AU); Masding (May 2016; Blue; UK); pole-to-pole linear polarization in Blue
Total Solar Eclipse (TSE) 2017

Collaboration with Citizen CATE (PI:M. Penn)

Two-site identical telescope+camera+polarimeter set ups to increase the length of the total solar eclipse. White light linear polarization measured – arising from the scattering of sunlight by free electrons.

- Inner solar corona, 1.3 to 2.2 solar radii is not probed by spacecraft (as yet).
- Inner corona is dominated by the K-corona (free electron) scattering, linearly polarized; accessible naturally during total solar eclipse.

Observations: distribution of polarization => polarization Brightness (pB) => local electron density; coronal structures/streamers

Future TSE: Citizen Science and large volumes of data
How do we measure polarization?

CATE Equipment + Polarimeter = Our Setup!
Polarimetric Drivers: Composition via Dichroism and Birefringence

Many optically active materials are anisotropic and so their scattering properties differ with the objects principal axes (such as dichroic or birefringent materials) and are crystalline in structure instead of amorphous, e.g., the presence of olivines and silicates in cometary dust and circumstellar disks; Titan, etc. Ices (water and other species) are abundant in the system indicated in their near-infrared spectra. Gas giants form outside the frost line (where ices condense), and their satellites and ring systems exhibit signature of water ice; clathrates, non-ices (Si, C, Fe) in their NIR spectra and spectral dependence of linear polarization.
Jupiter’s Atmosphere: Intrinsic Changes (Seasonal/Temporal Changes; Oval Interactions)

Ref: Simon-Miller, Baines, Go, Trujillo, Orton, Wong
Why is this a unique citizen science project?

- First Total Solar Eclipse over the US in ~100 years

- One of the largest paths of totality – continental US

- Viewed by more people than any total solar eclipse in history

- Event was only 2.5 minutes in duration, but “stretched” to 93 minutes by utilizing identical set-ups at an optimum number of sites along totality, engaging astronomers, students, public

Continental American Total Eclipse (CATE)
Summary: Polarization of Jupiter/Poles/Aurorae

Probe aerosols/hazes – rejuvenation of a tested technique

Observe at multiple wavelengths – blue/red wavelengths

Synergy between optical, thermal, imagers and polarimetrists
modelers, amateurs

References for temporal studies of planetary atmospheres and
exoplanets characterization

Support JUNO mission in near-term and provide long-term
database for modelers, observers, future missions.

(Contact me for details: padmayf@gmail.com)
Saturn

Kumamori; Cassini/Imaging; Malakse (enhanced ISS image)

Near-simultaneous Visible (Amateur)/Thermal(VLT); IRTF-5micron

Saturn
2018-04-24 : 15:41.7 UT Alt: 68°
CMLL: 57.5° (RGB) 65.3° (IR) 0:11.3°

014 of 1/22, ASOS000
15min RGB, 5min IR, seeing 6.10
Andy Casely, Sydney

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The Solar Corona ("Crown")

Sun: interior, visible surface (photosphere) and atmosphere (lower region, chromosphere, transition range and corona), but the corona is much hotter than the photosphere.

The outer part of the corona becomes the solar wind that moves outward through the solar system and interstellar space, interacting with planetary atmospheres and other solar system objects, creating space weather.

Corona exhibits radial structure, correlated with solar activity thin and tenuous, visible during total solar eclipses and using coronographs

Three components:
(i)" K-corona or continuum scattering by free electrons;
(ii)" F-corona or Fraunhofer scattering by dust particles;
(iii)" E-corona or Emission spectra produced by ions present in the coronal plasma.
((iv) T-corona or Thermal…)

Qs: Why is the solar corona hotter than the solar “visible” surface or photosphere?
Pro-Am Data ➔ Big Data
Jupiter’s Atmosphere: Extrinsic Changes (Impacts, Aurorae, etc.)

Aurora in UV (HST; Clarke)

Aurora in Xray (Chandra; 2011)

Ref: Weaver et al., Orton et al., Hammel et al., Clarke et al., Wesley, McKeon
Using Mission Support