Project Update

PACE Science Team meeting

20-22 Jan 2016

presentation outline

- Welcome & introductions
- Project management update
- Review of science requirements
- Timing of studies & mission flow
- Pre-phase A OCI science
- Phase A OCI science
- Polarimeter update
- Coastal instrument update
- Direct broadcast
- Science data segment update
- Web site
- Topics for science team input
- Open discussion

jeremy.werdell@nasa.gov

introductions: PACE Project organization

Support Staff
Administration - Vacant
Plan/Sch – Bill Paradis
Config. Mgmt.– Lynette Sullivan

Financial Manager
Marsha Gosselin

Contract Officers
Vacant

Project Manager
Andre Dress
Deputy Project Manager
Kathy McIntyre
Deputy Project Manager Resources
Bill Sluder

Project Scientist
Jeremy Werdell
Deputy Project Scientist (Ocean)
Antonio Mannino
Deputy Project Scientist (Atmosphere)
Brian Cairns

Observatory Manager
Beth Weinstein

Ocean Color Instrument (OCI) Project Manager
Robby Estep
OCI Deputy Project Manager
Mike Hill & Phuc Nguyen

Polarimeter Instrument Manager
Tom Dixon

Mission CSO
John Rauscher

Technical Authority Reporting

Mission System Engineer
Ken Yienger
Deputy MSE
Jessica McCarthy

Mission Operations & Ground Operations Manager
Robert Schweiss

Science Data Segment
(alphabetical)
Sean Bailey
Gene Feldman
Bryan Franz

GSFC communications
(alphabetical)
Ivona Cetinic
Annette deCharon
Rani Gran
Norman Kuring
Stephanie Schollaert-Uz
Michael Starobin

Concept Studies

OCI Studies
Robby Estep

Polarimeter Studies Lead
Tom Dixon

Spacecraft Studies in House Lead
Beth Weinstein

Spacecraft Studies out of House Lead
Beth Weinstein

Launch Vehicle Studies Lead
Kathy McIntyre

OPS & Ground Studies Lead
Robert Schweiss

Architecture & Requirements Studies Lead
Ken Yienger

introductions: PACE Project organization

Support Staff
Administration - Vacant
Plan/Sch – Bill Paradis
Config. Mgmt.– Lynette Sullivan

Financial Manager
Marsha Gosselin

Contract Officers
Vacant

Project Manager
Andre Dress
Deputy Project Manager
Kathy McIntyre
Deputy Project Manager Resources
Bill Sluder

Project Scientist
Jeremy Werdell
Deputy Project Scientist (Ocean)
Antonio Mannino
Deputy Project Scientist (Atmosphere)
Brian Cairns

Observatory Manager
Beth Weinstein

Ocean Color Instrument (OCI) Project Manager
Robby Estep
OCI Deputy Project Manager
Mike Hill & Phuc Nguyen

Polarimeter Instrument Manager
Tom Dixon

Mission CSO
John Rauscher

Technical Authority Reporting

Mission System Engineer
Ken Yienger
Deputy MSE
Jessica McCarthy

Mission Operations & Ground Operations Manager
Robert Schweiss

Science Data Segment
(alphabetical)
Sean Bailey
Gene Feldman
Bryan Franz

GSFC communications
(alphabetical)
Ivona Cetinic
Annette deCharon
Rani Gran
Norman Kuring
Stephanie Schollaert-Uz
Michael Starobin

Concept Studies

OCI Studies
Robby Estep

Polarimeter Studies Lead
Tom Dixon

Spacecraft Studies in House Lead
Beth Weinstein

Spacecraft Studies out of House Lead
Beth Weinstein

Launch Vehicle Studies Lead
Kathy McIntyre

OPS & Ground Studies Lead
Robert Schweiss

Architecture & Requirements Studies Lead
Ken Yienger

jeremy.werdell@nasa.gov

introductions: PACE Project organization

Support Staff
Administration - Vacant
Plan/Sch – Bill Paradis
Config. Mgmt.– Lynette Sullivan

Financial Manager
Marsha Gosselin

Contract Officers
Vacant

Project Manager
Andre Dress
Deputy Project Manager
Kathy McIntyre
Deputy Project Manager Resources
Bill Sluder

Project Scientist
Jeremy Werdell
Deputy Project Scientist (Ocean)
Antonio Mannino
Deputy Project Scientist (Atmosphere)
Brian Cairns

Observatory Manager
Beth Weinstein

Ocean Color Instrument (OCI) Project Manager
Robby Estep
OCI Deputy Project Manager
Mike Hill & Phuc Nguyen

Polarimeter Instrument Manager
Tom Dixon

Mission CSO
John Rauscher

Technical Authority Reporting

Mission System Engineer
Ken Yienger
Deputy MSE
Jessica McCarthy

Mission Operations & Ground Operations Manager
Robert Schweiss

Science Data Segment
(alphabetical)
Sean Bailey
Gene Feldman
Bryan Franz

GSFC communications
(alphabetical)
Ivona Cetinic
Annette deCharon
Rani Gran
Norman Kuring
Stephanie Schollaert-Uz
Michael Starobin

Concept Studies

OCI Studies
Robby Estep

Polarimeter Studies Lead
Tom Dixon

Spacecraft Studies in House Lead
Beth Weinstein

Spacecraft Studies out of House Lead
Beth Weinstein

Launch Vehicle Studies Lead
Kathy McIntyre

OPS & Ground Studies Lead
Robert Schweiss

Architecture & Requirements Studies Lead
Ken Yienger

jeremy.werdell@nasa.gov

introductions: OCI Project organization

Current as of
02 Dec 2015

Instrument Project Manager (IPM)
Robby Estep (490)
Deputy Inst. Project Mgr (D-IPM)
Mike Hill / Phuc Nguyen (490)

Project Support
Gini Heilman (490)
Phill Blackwood (490)

Instrument Scientist (IS)
Gerhard Meister (616)

Business Support
Financial Manager *(Acting - Michelle Sohl/490)*
Resource Analyst *(Jonathan Carpenter/490)*
Configuration Manager *(Lynette Sullivan/490)*
Scheduler/Planner *(Bill Paradis/490)*

Instrument Science and Technology Manager
Ulrik Gliese (490)
Bryan Monosmith - Consultant (490)

Instrument Systems Engineer (ISE)
Wayne Roher (592) – Lead
Eric Gorman (596) – Deputy

Chief Safety & Mission Assurance Officer (CSO)
John Rauscher (383)
Oscar Cheatom (373)

Instrument I&T Manager
Dave Sohl (568)

Mechanical Lead
Claef Hakun (544)

Optics Lead
Mark Wilson (551)

Detector Lead
Peter Shu (553)

Front-End Electronics/DAU Lead
Max Pinchinat (564)

iMustang/ICDU Lead
Noosha Haghani (561)

Flight Software Lead
Mike Blau (582)

Contamination Lead
Therese Errigo (546)

Harness Lead
Gary Won (540)

EEE Parts
Antonio Reyes/562
Shavesha Rutledge/562

Thermal Lead
Edmonia Caldwell (545)

Materials Lead
Jill Mohammed (541)

introductions: OCI Project organization

Current as of
02 Dec 2015

Instrument Project Manager (IPM)
Robby Estep (490)
Deputy Inst. Project Mgr (D-IPM)
Mike Hill / Phuc Nguyen (490)

<u>Project Support</u>
Gini Heilman (490)
Phill Blackwood (490)

Instrument Scientist (IS)
Gerhard Meister (616)

<u>Business Support</u>
Financial Manager *(Acting - Michelle Sohl/490)*
Resource Analyst *(Jonathan Carpenter/490)*
Configuration Manager *(Lynette Sullivan/490)*
Scheduler/Planner *(Bill Paradis/490)*

Instrument Science and Technology Manager
Ulrik Gliese (490)
Bryan Monosmith - Consultant (490)

Instrument Systems Engineer (ISE)
Wayne Roher (592) – Lead
Eric Gorman (596) – Deputy

Chief Safety & Mission Assurance Officer (CSO)
John Rauscher (383)
Oscar Cheatom (373)

Instrument I&T Manager
Dave Sohl (568)

Mechanical Lead
Claef Hakun (544)

Optics Lead
Mark Wilson (551)

Detector Lead
Peter Shu (553)

Front-End Electronics/DAU Lead
Max Pinchinat (564)

iMustang/ICDU Lead
Noosha Haghani (561)

Flight Software Lead
Mike Blau (582)

Contamination Lead
Therese Errigo (546)

Harness Lead
Gary Won (540)

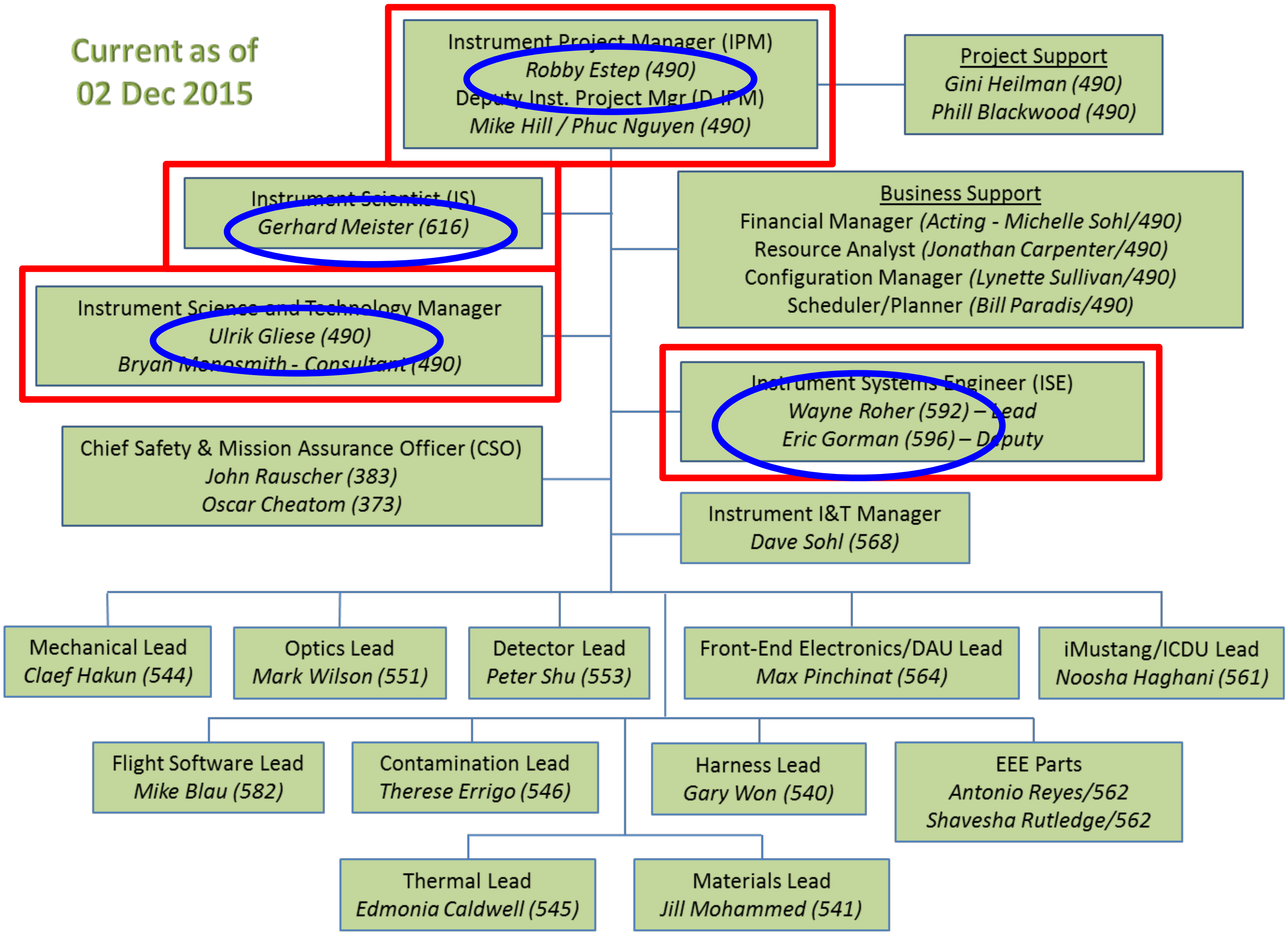
EEE Parts
Antonio Reyes/562
Shavesha Rutledge/562

Thermal Lead
Edmonia Caldwell (545)

Materials Lead
Jill Mohammed (541)

introductions: OCI Project organization

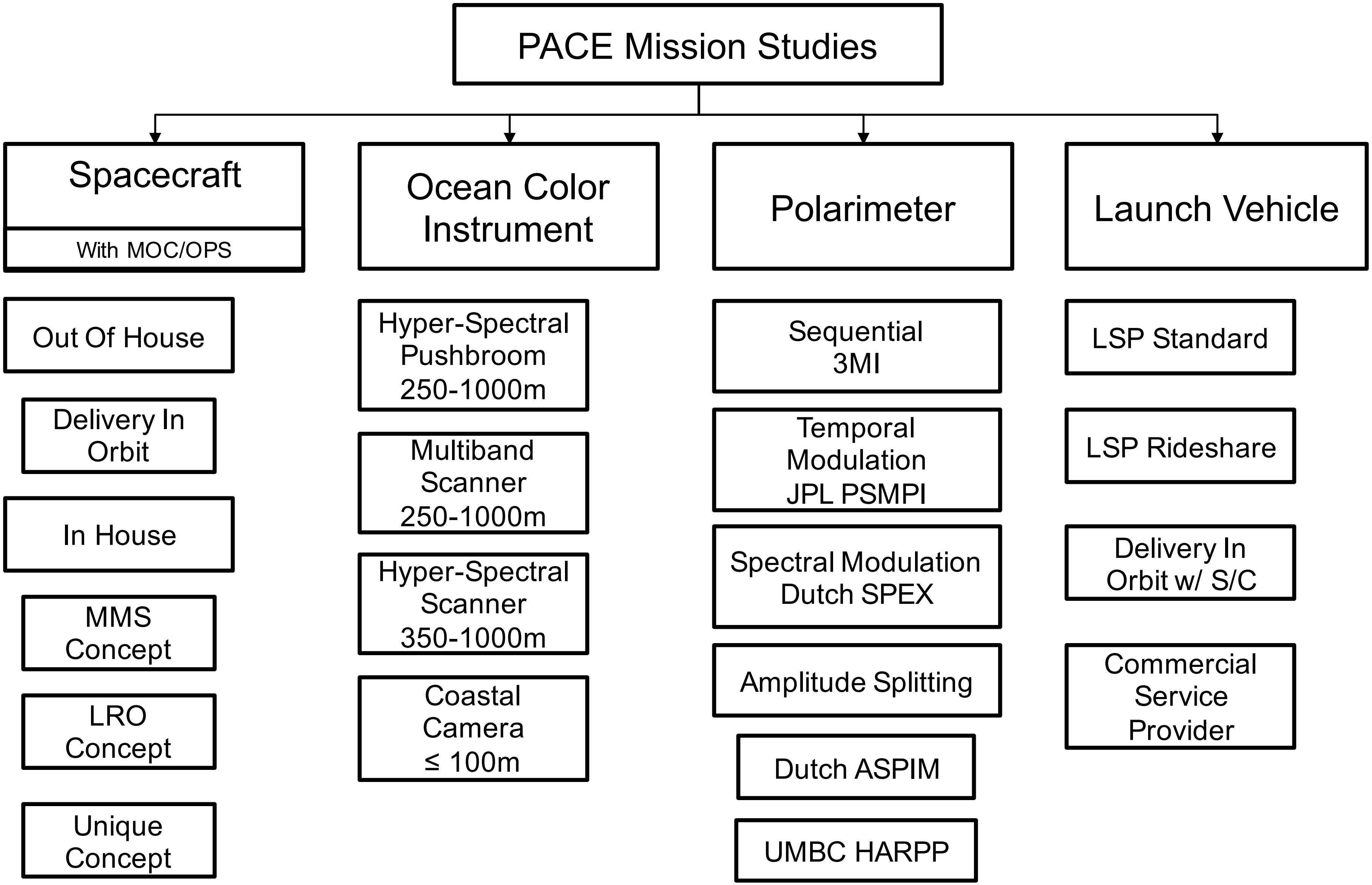
Current as of
02 Dec 2015



PACE mission direction & status

- PACE Mission was direct to GSFC via letter of direction from HQ on December 10, 2014
- PACE Kick off meeting held on January 13, 2015
- Mission defined as a Design to Cost development
- Project allocated $705M for management, instruments, spacecraft, launch vehicle, and operations
- HQ managed science allocated $100M for science, data processing and science systems
- Project is still in Pre-Phase A and performing trade studies across all the elements

mission trades performed across all elements



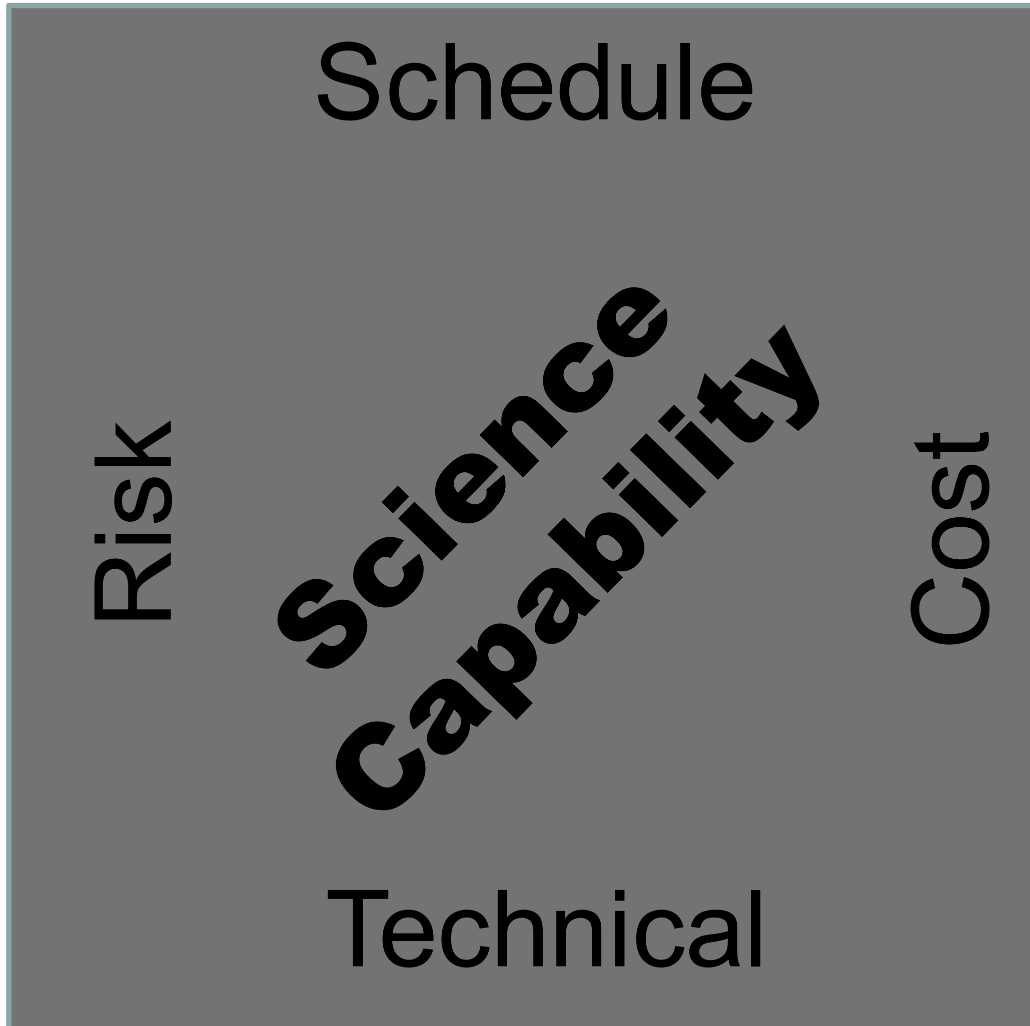
Design-To-Cost puts the requirements in the trade space

- Science (capability) and engineering requirements are part of the trade space
- System total cost is a requirement and cannot be traded
- Goal is to maximize the science capability at a high cost confidence (minimum of 65% is required)
- At the mission gates, a well formulated single mission concept is planned to be recommended

each capability & element has a trade to be evaluated

Mission Elements:

- Spacecraft
- Instruments
- Launch Vehicle
- MOC
- Operations
- Science
- Engineering
- Management
- Mission Assurance

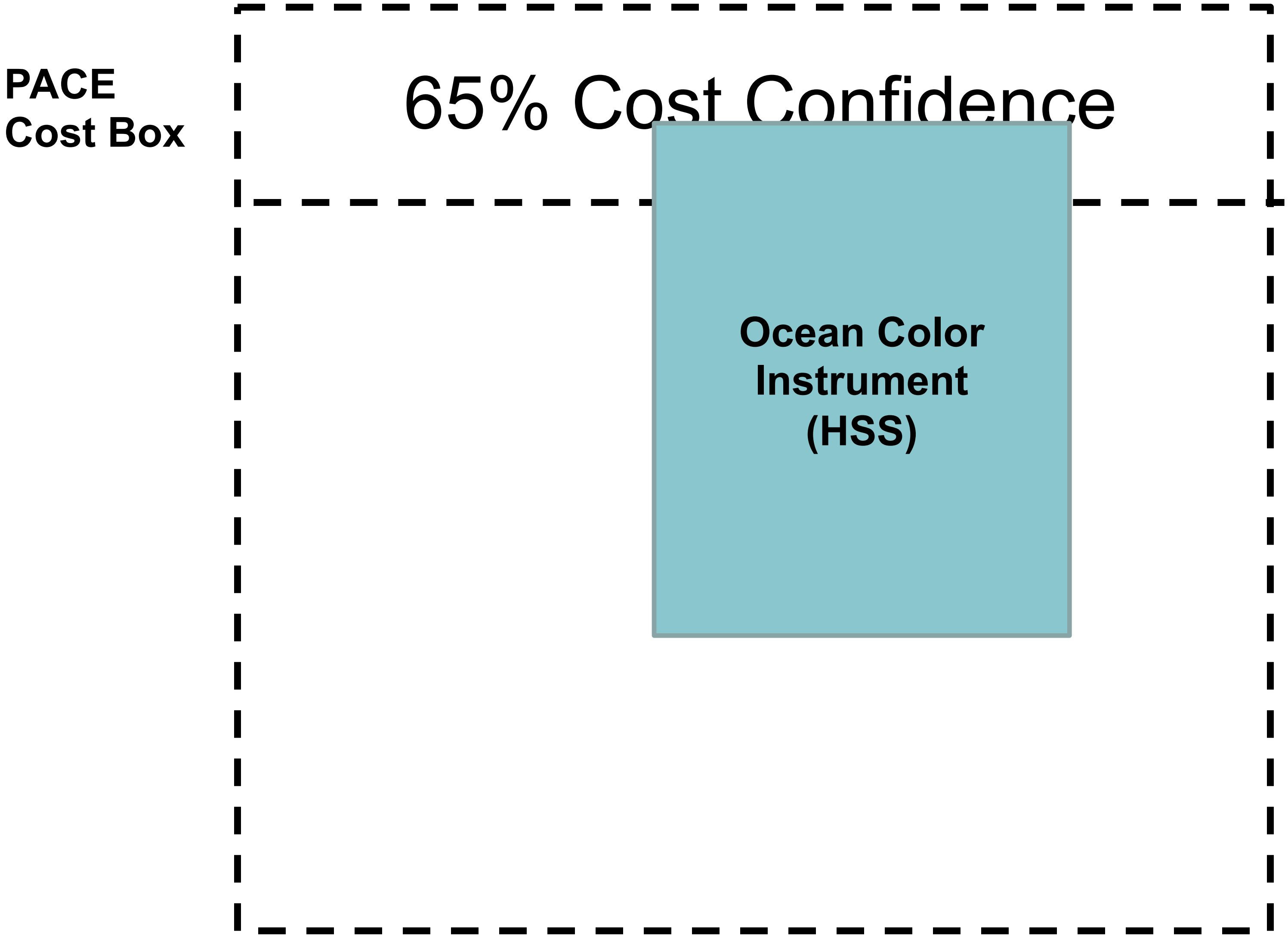


all elements evaluated to determine the best mission fit

PACE
Cost Box

65% Cost Confidence

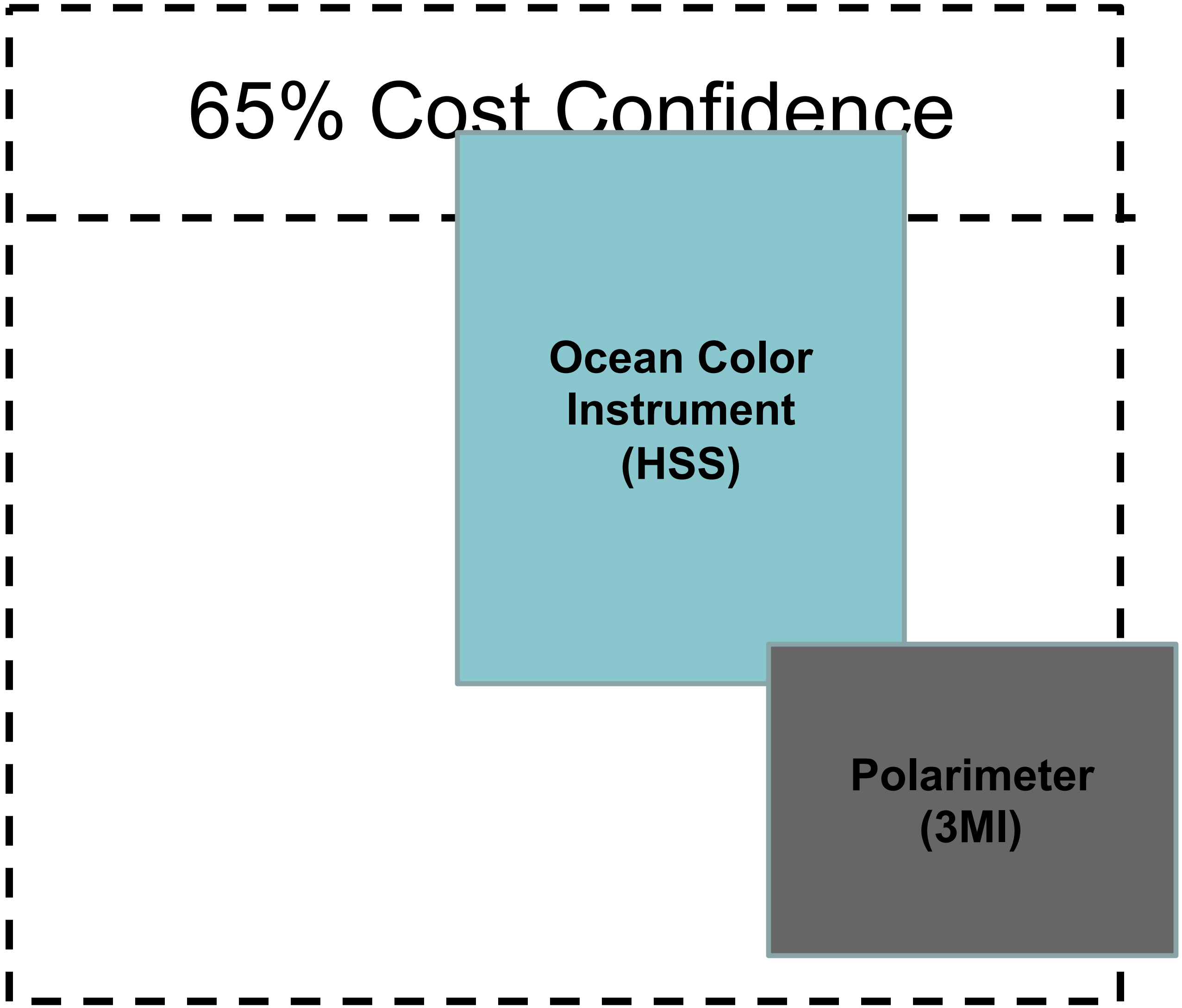
all elements evaluated to determine the best mission fit



jeremy.werdell@nasa.gov

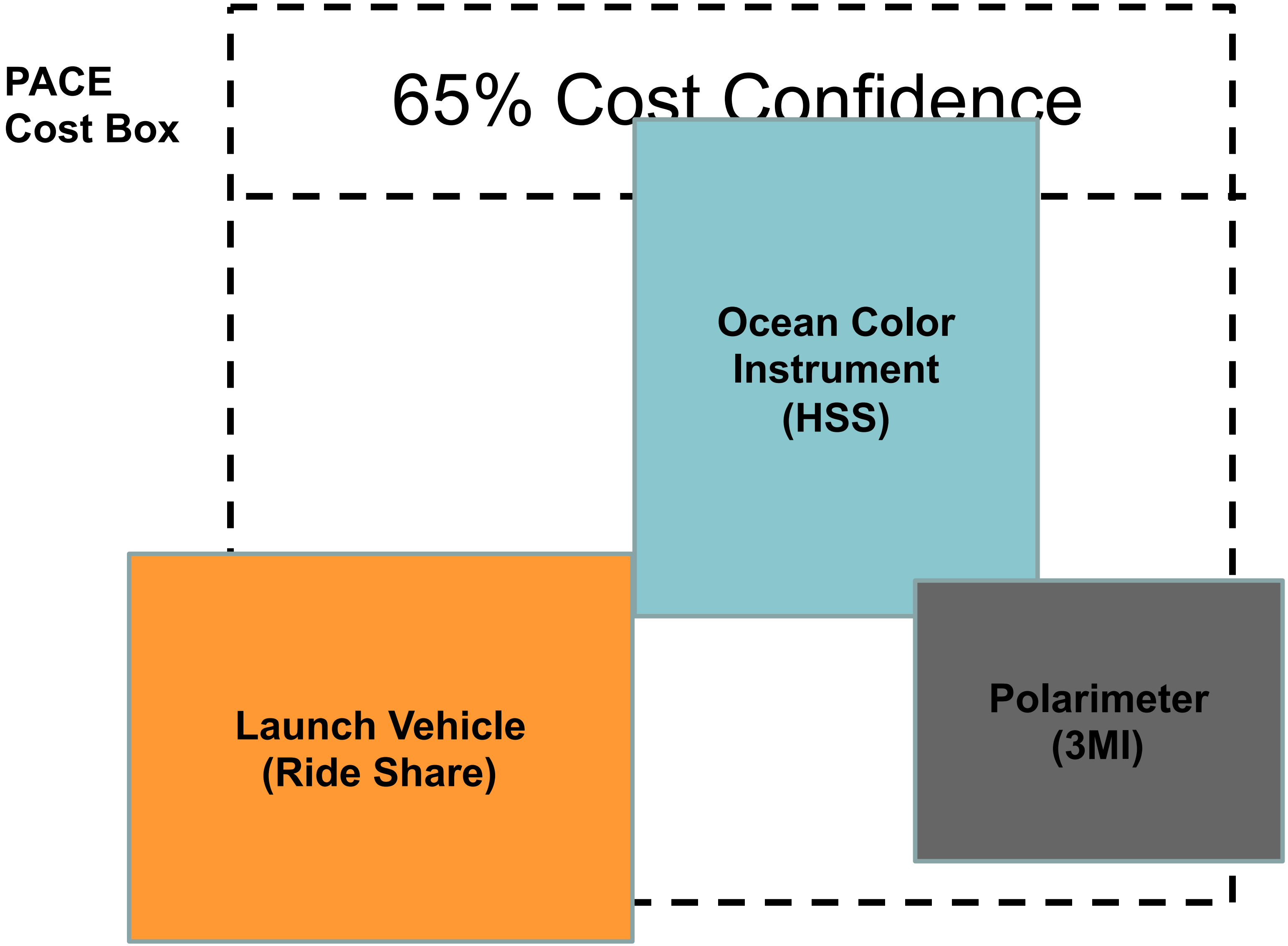
all elements evaluated to determine the best mission fit

PACE
Cost Box

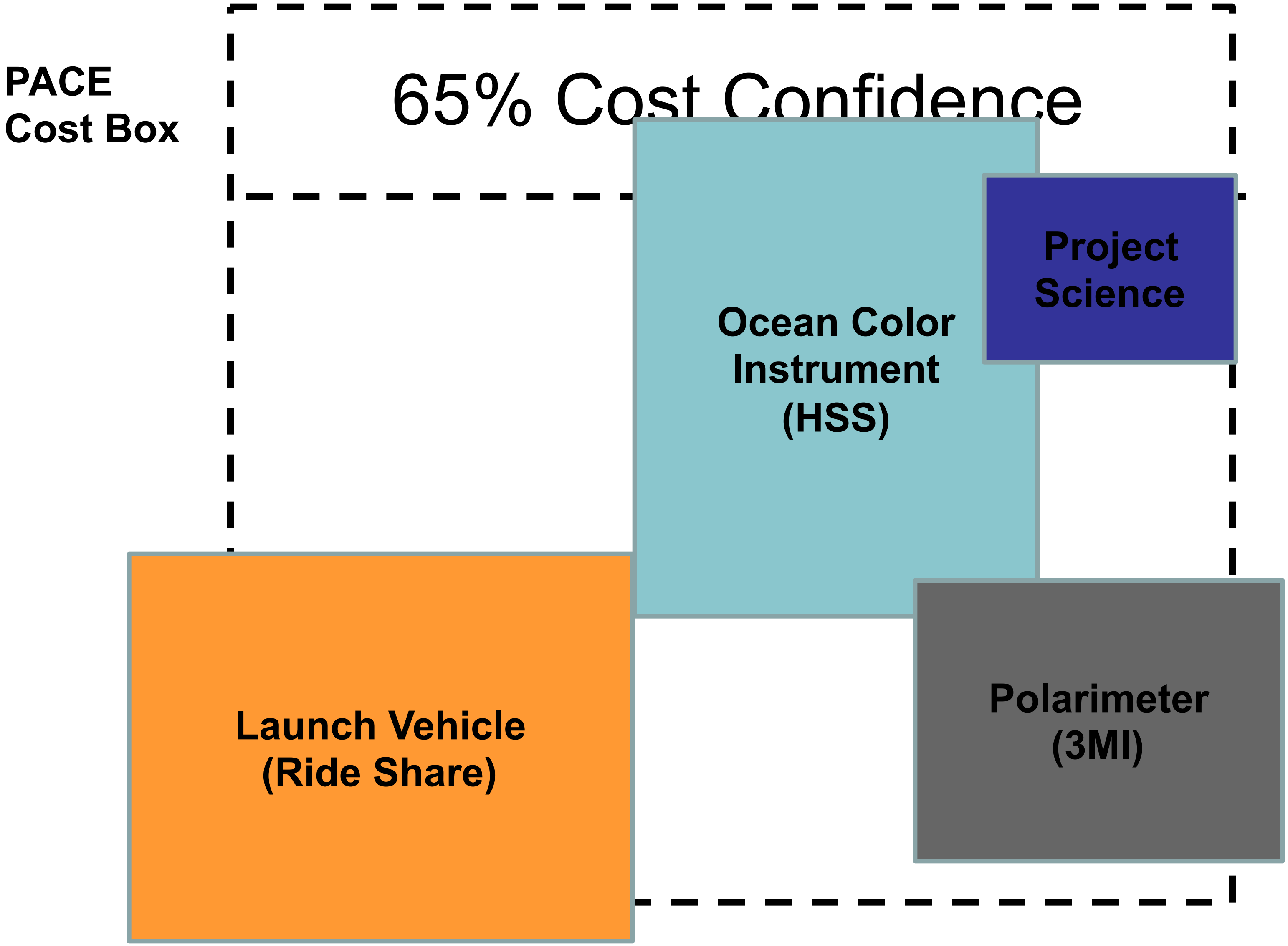


jeremy.werdell@nasa.gov

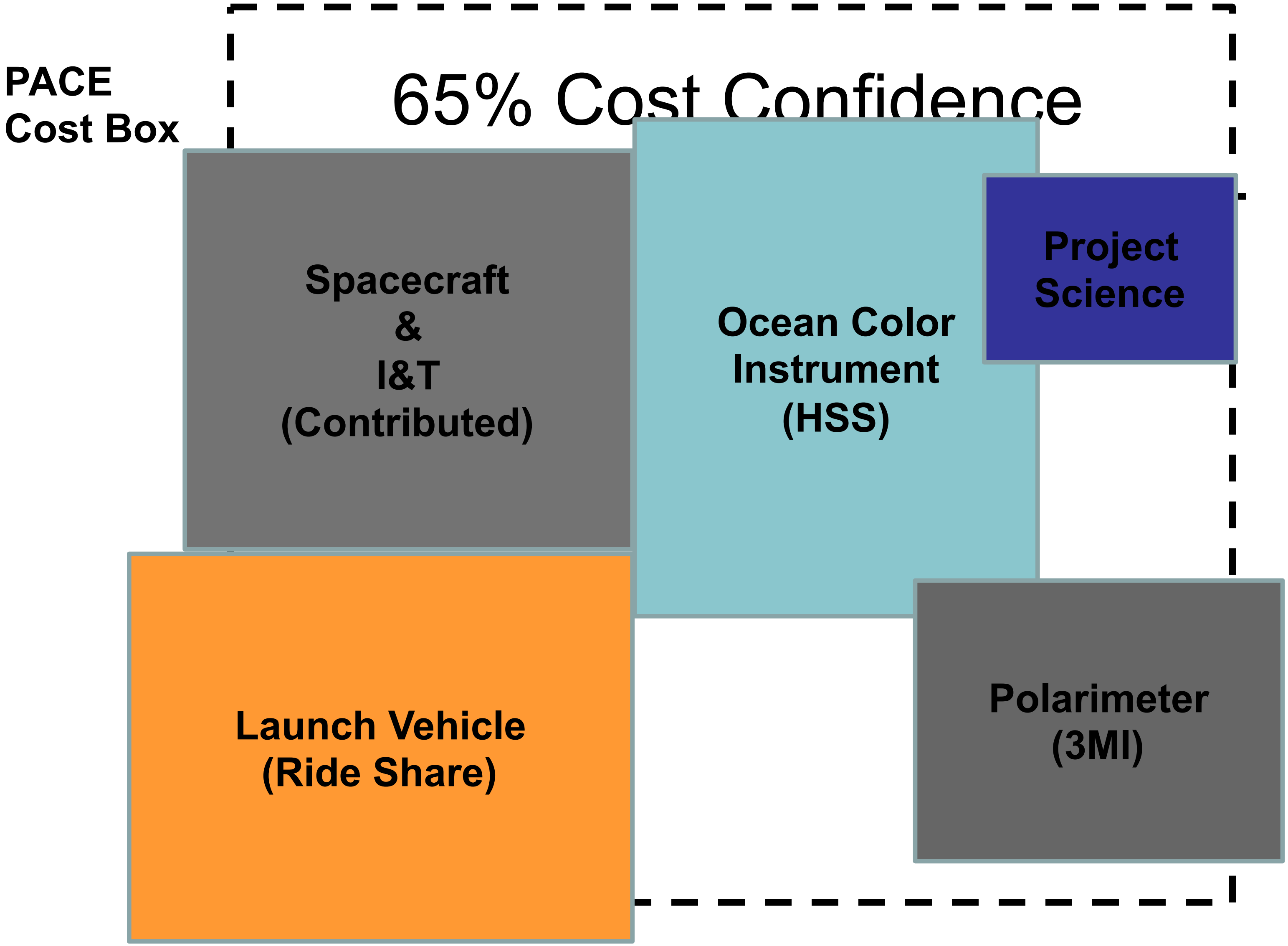
all elements evaluated to determine the best mission fit



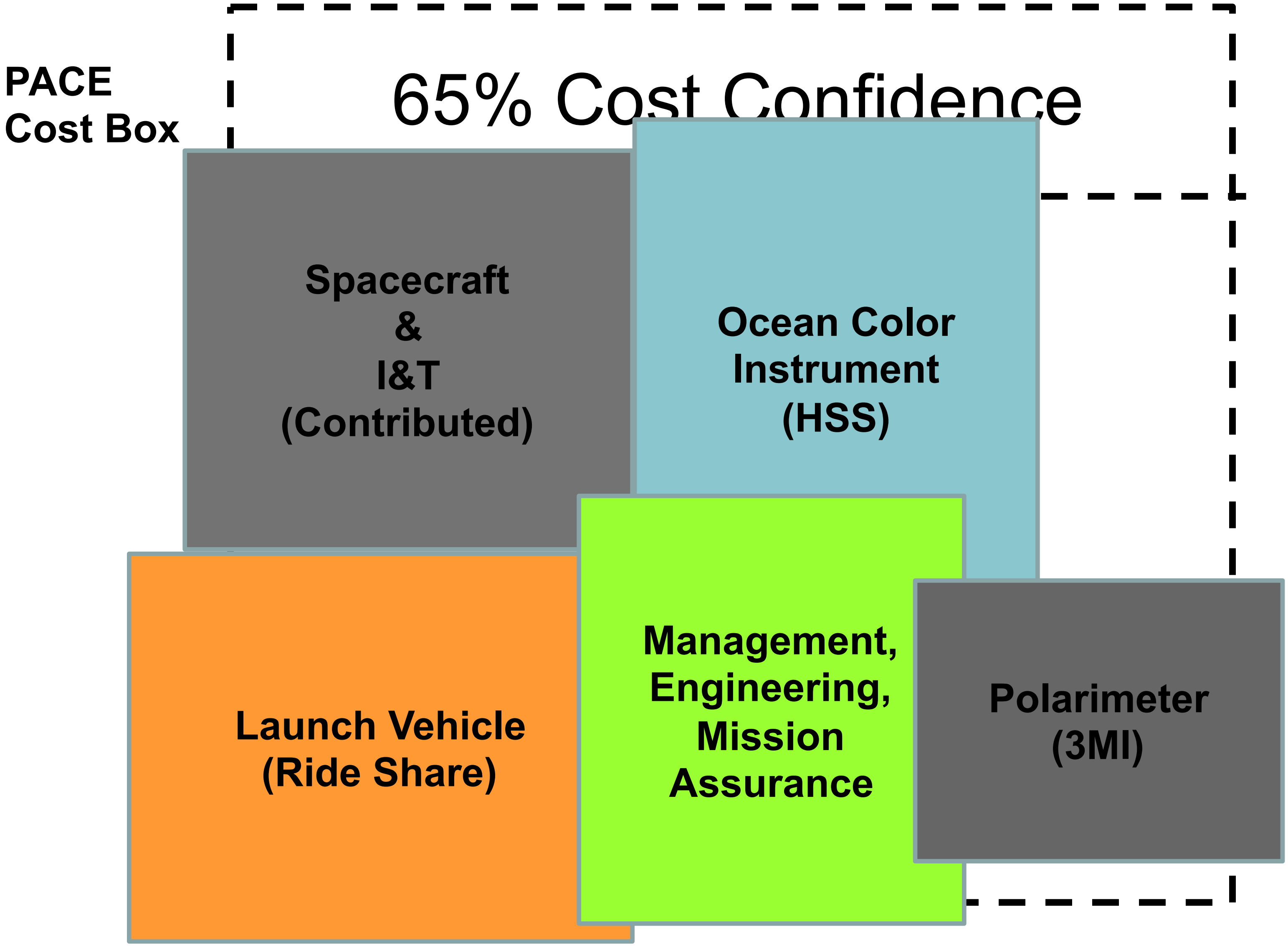
all elements evaluated to determine the best mission fit



all elements evaluated to determine the best mission fit

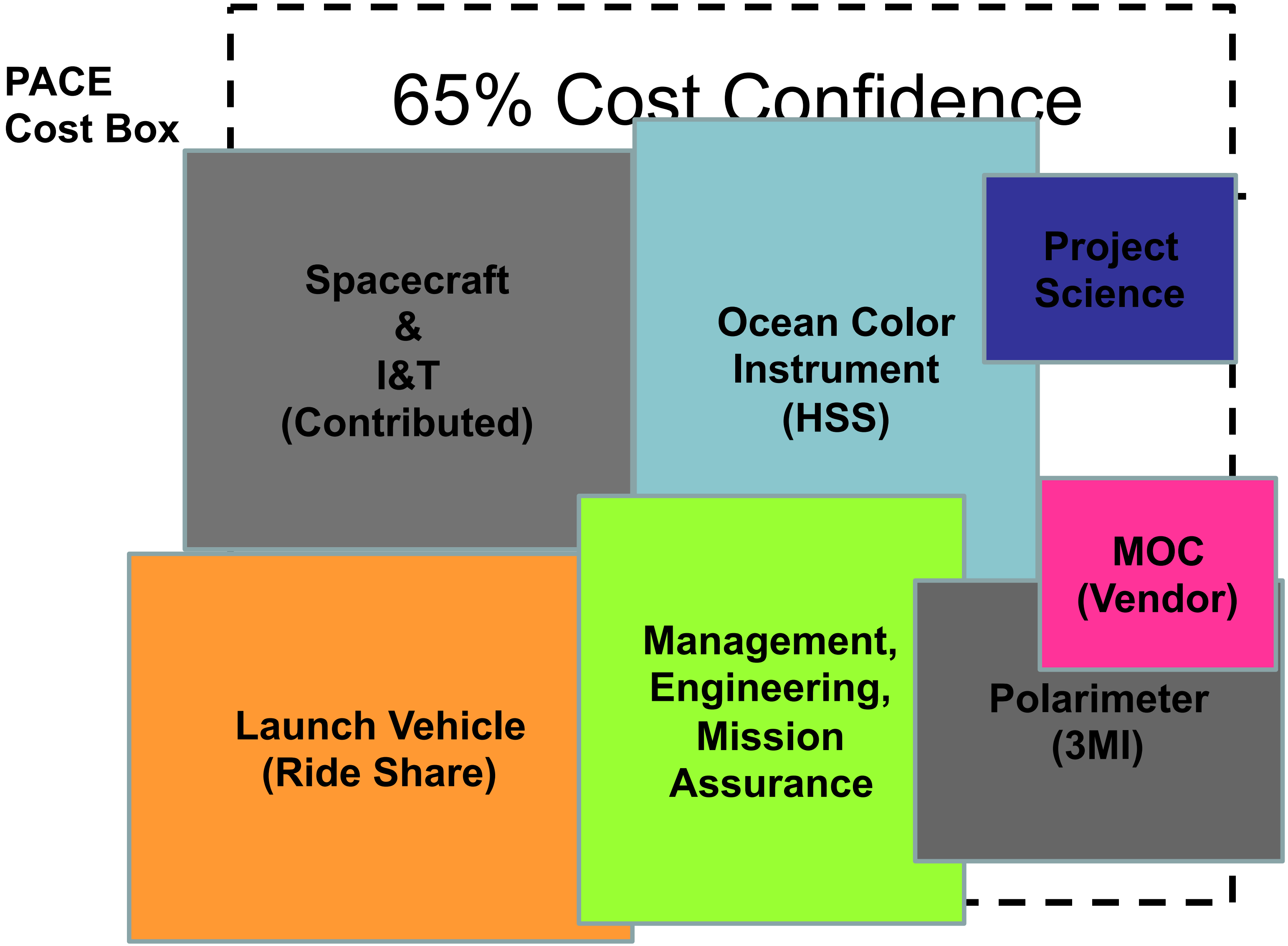


all elements evaluated to determine the best mission fit

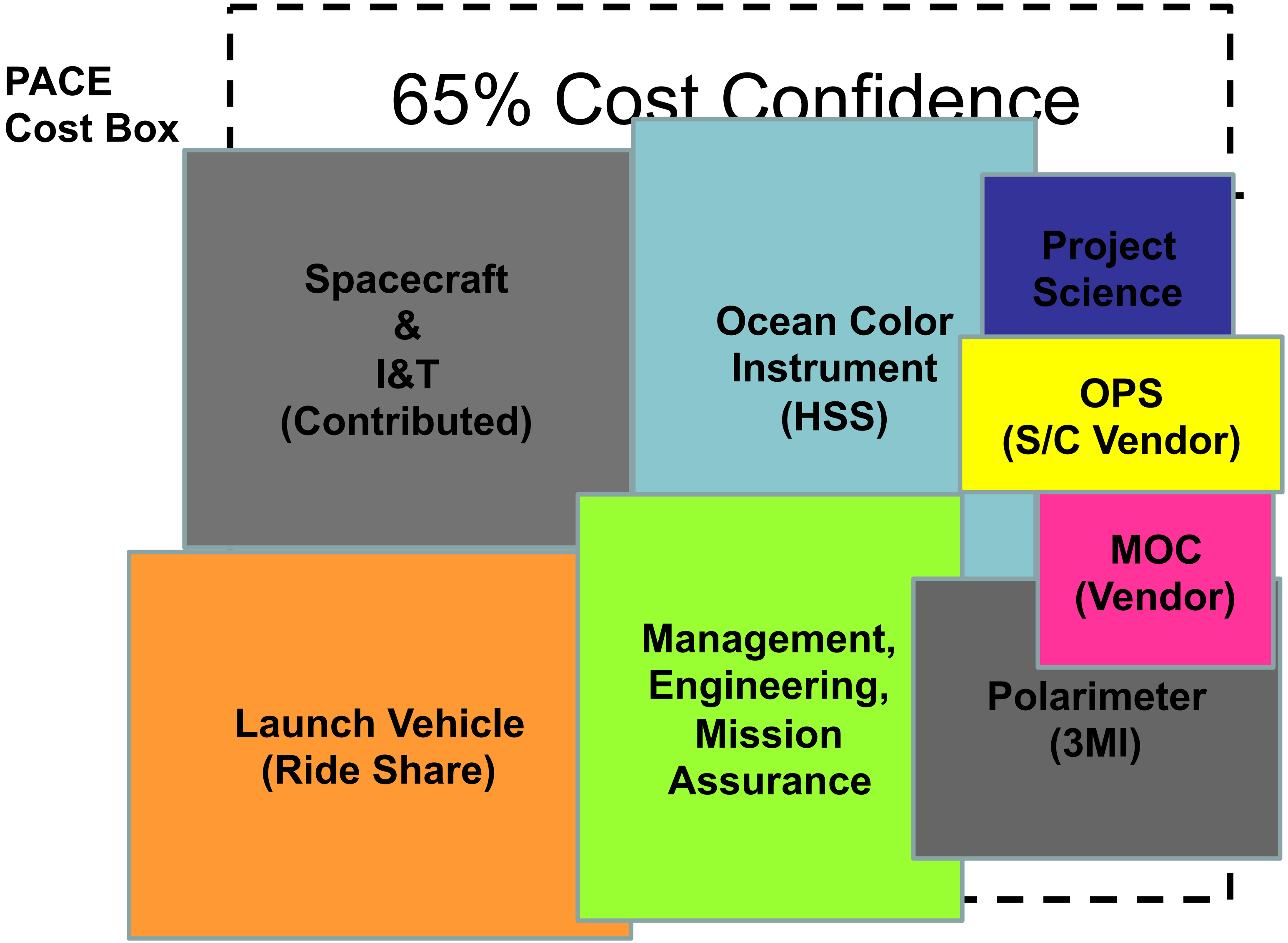


jeremy.werdell@nasa.gov

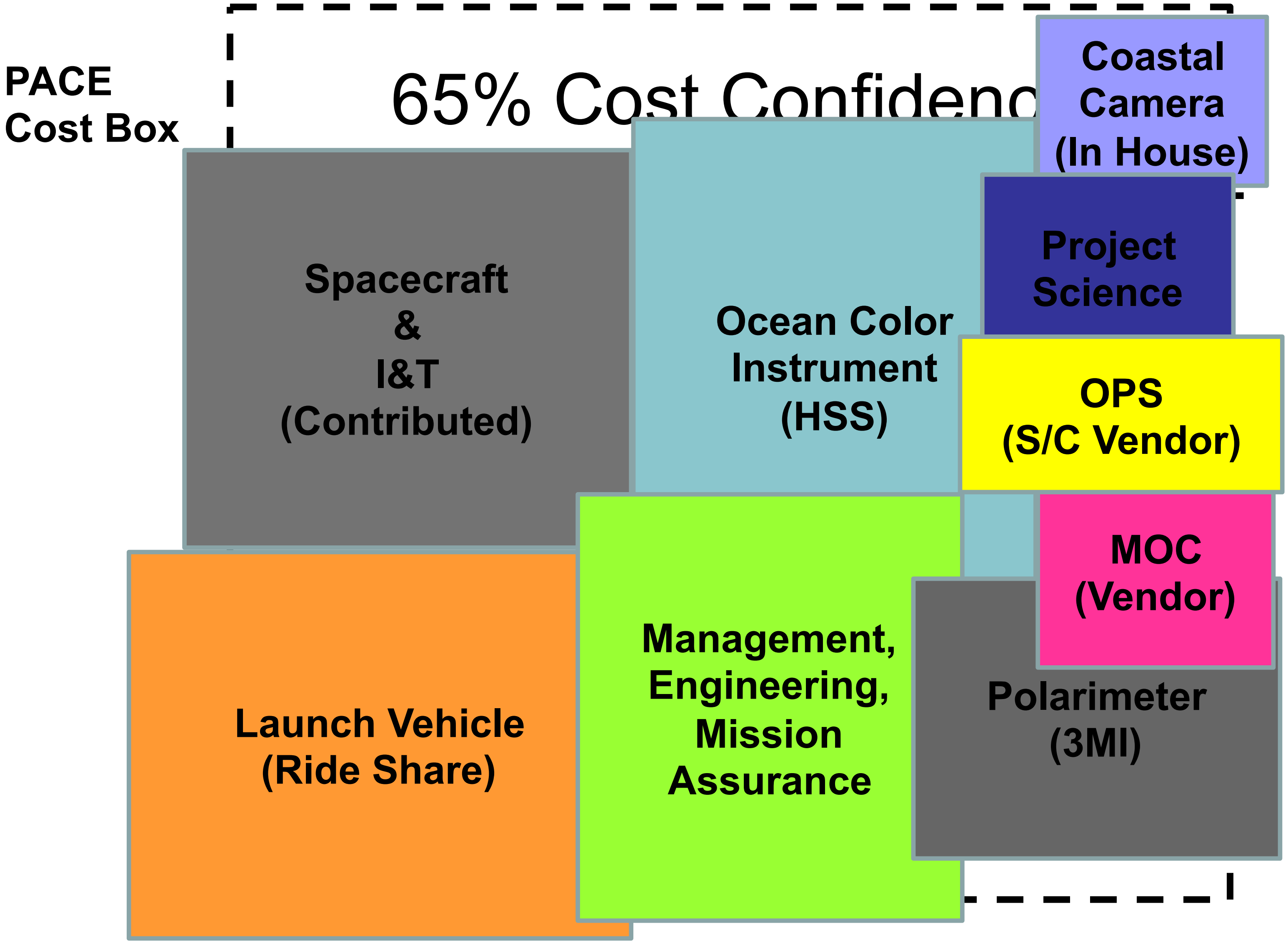
all elements evaluated to determine the best mission fit



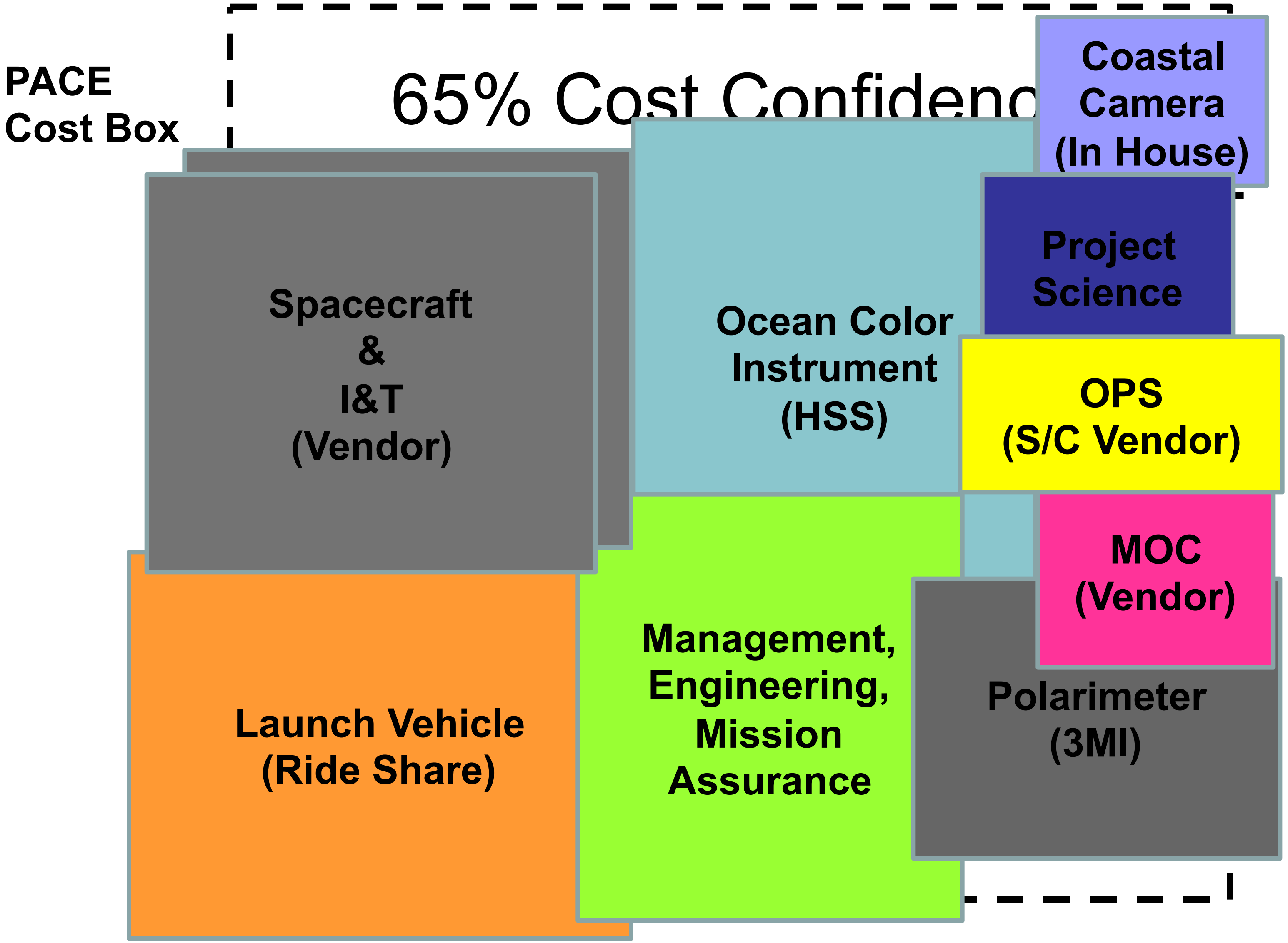
all elements evaluated to determine the best mission fit



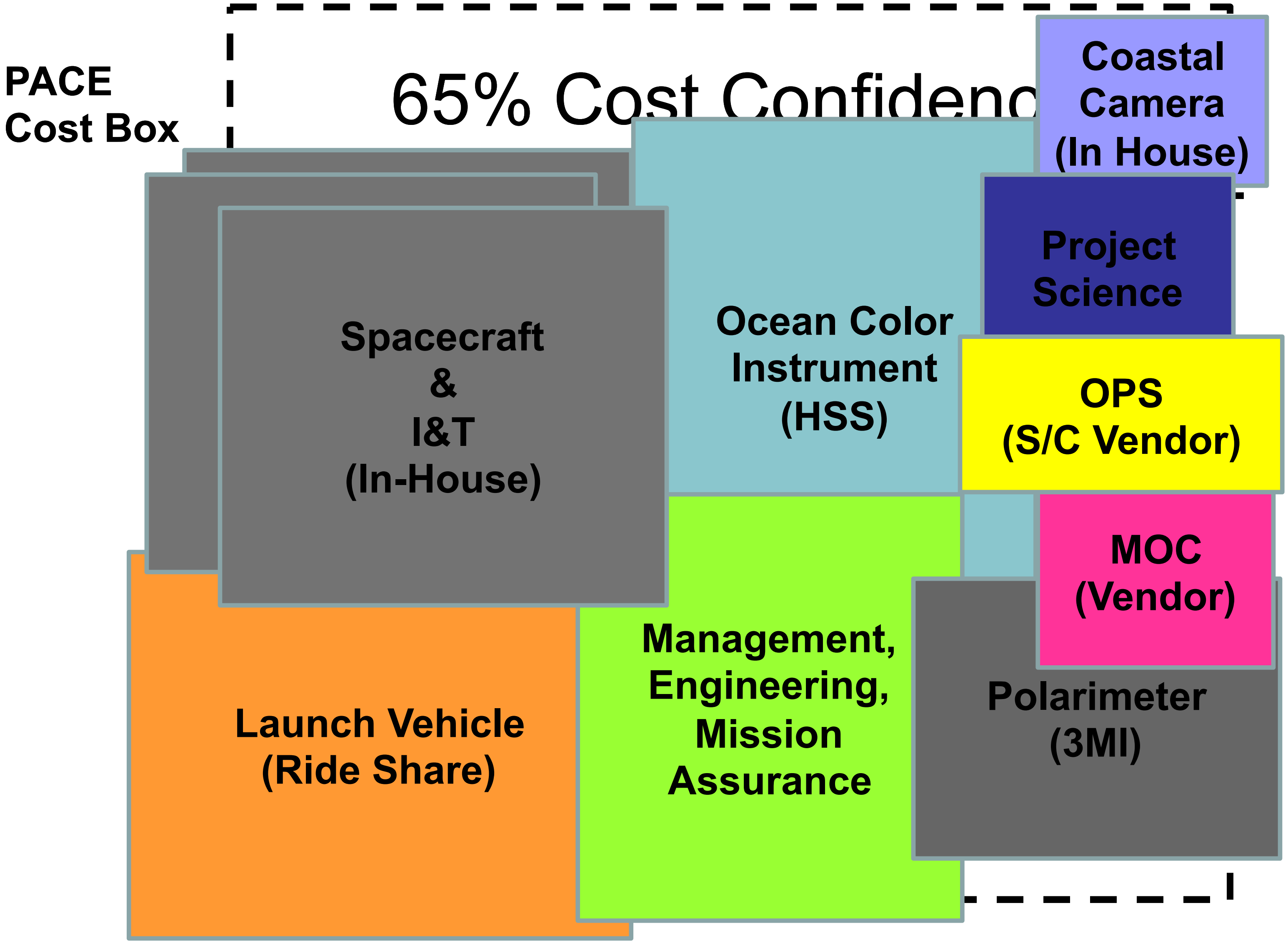
all elements evaluated to determine the best mission fit



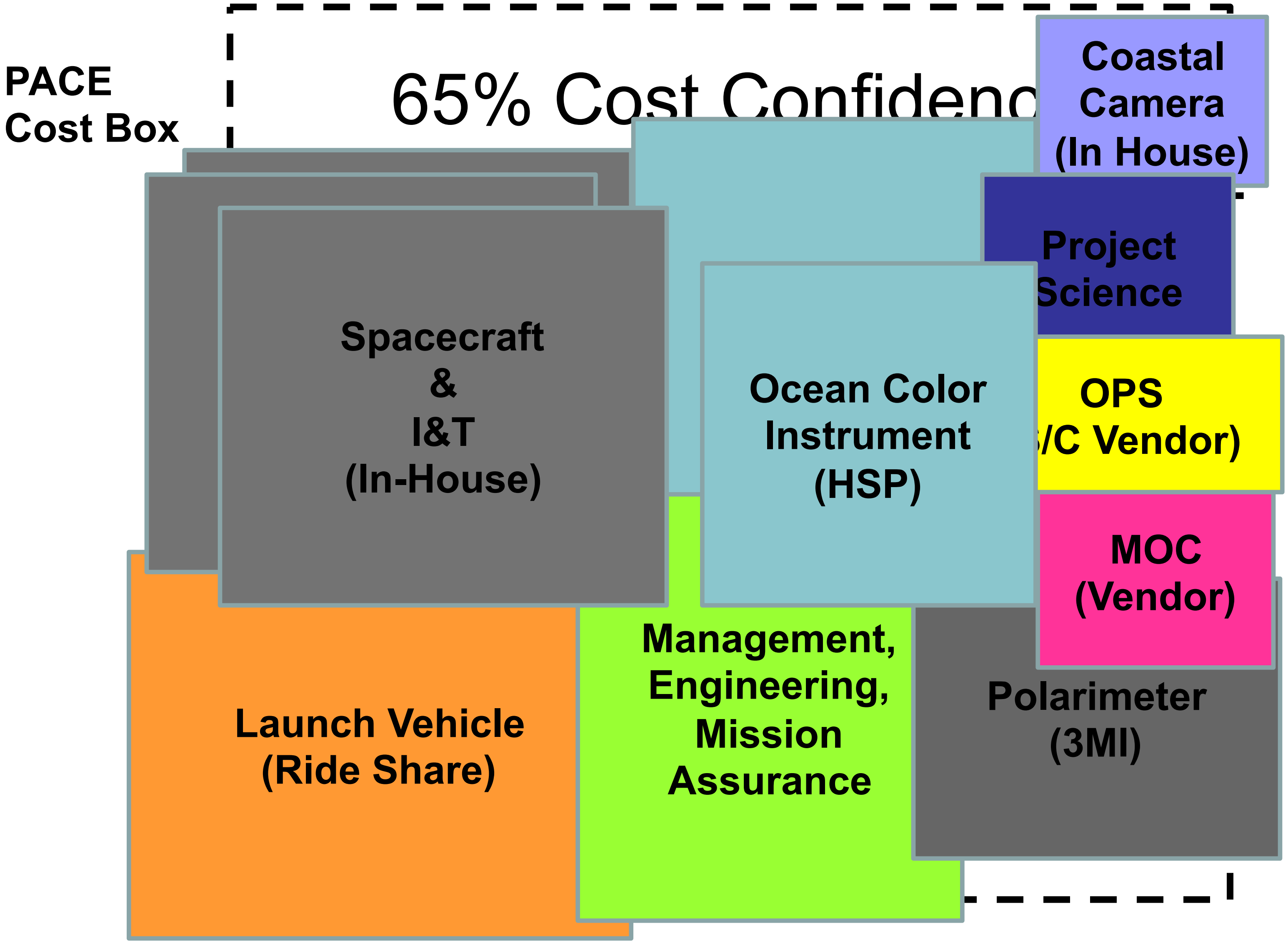
all elements evaluated to determine the best mission fit



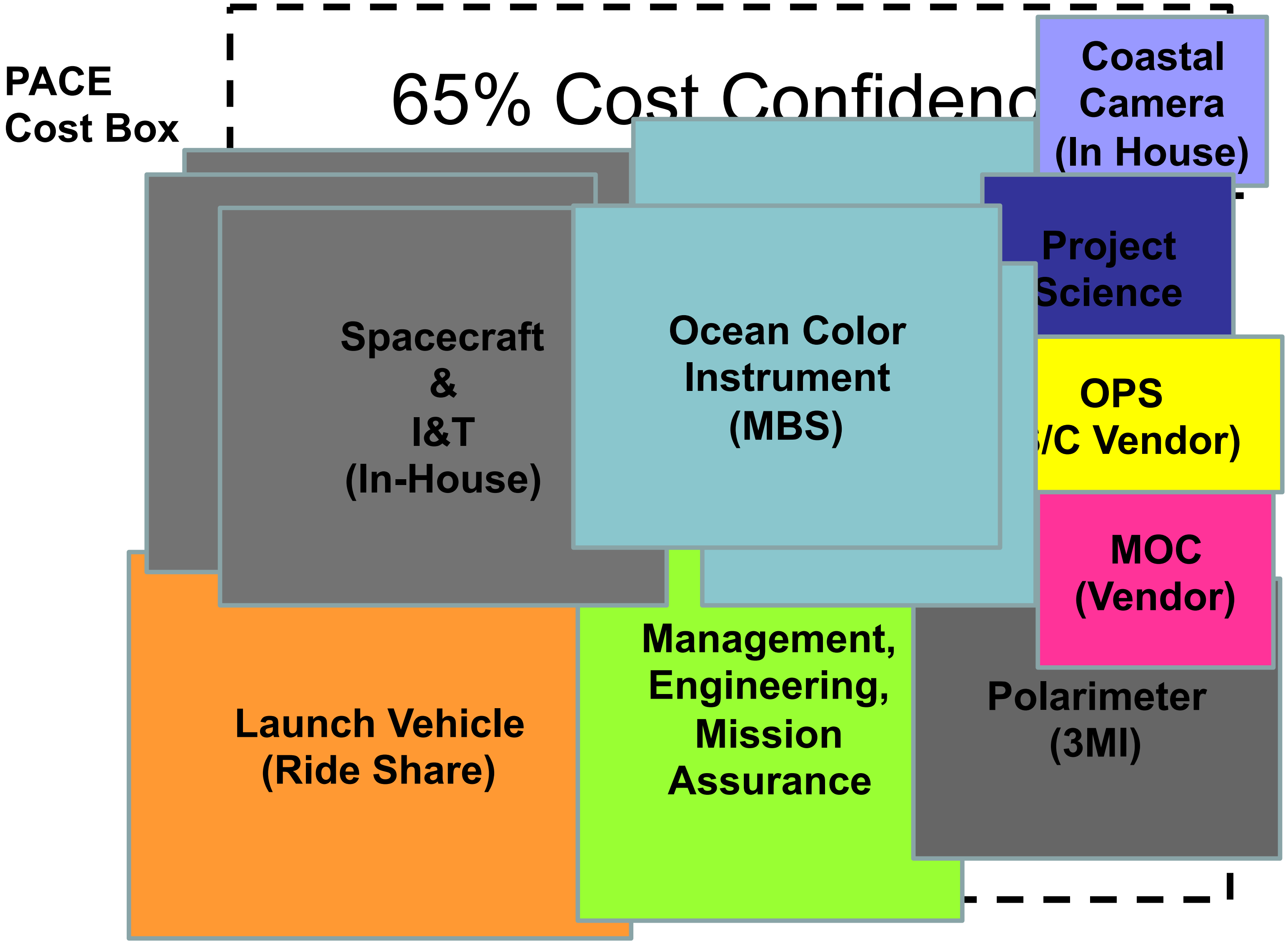
all elements evaluated to determine the best mission fit



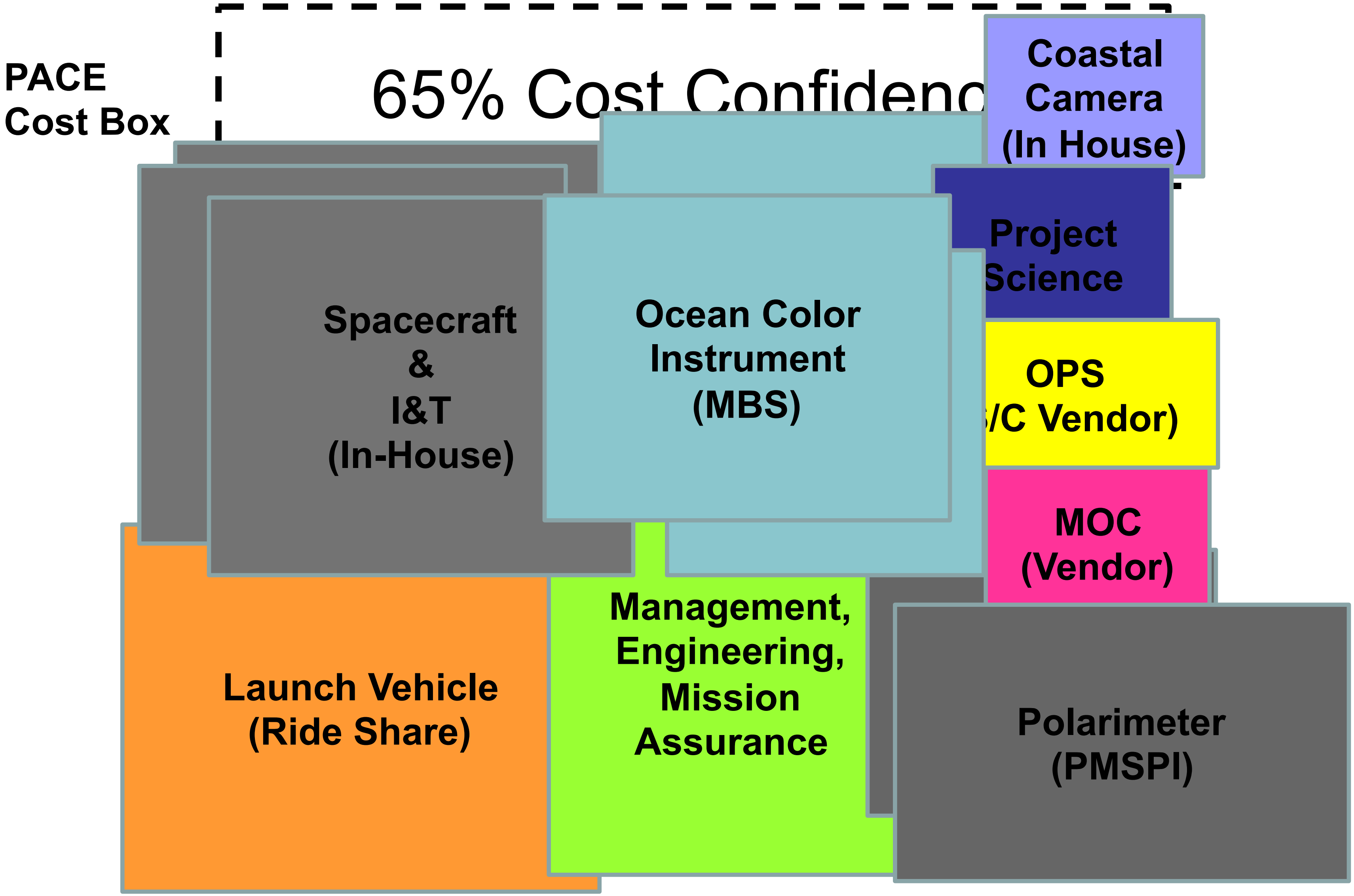
all elements evaluated to determine the best mission fit



all elements evaluated to determine the best mission fit

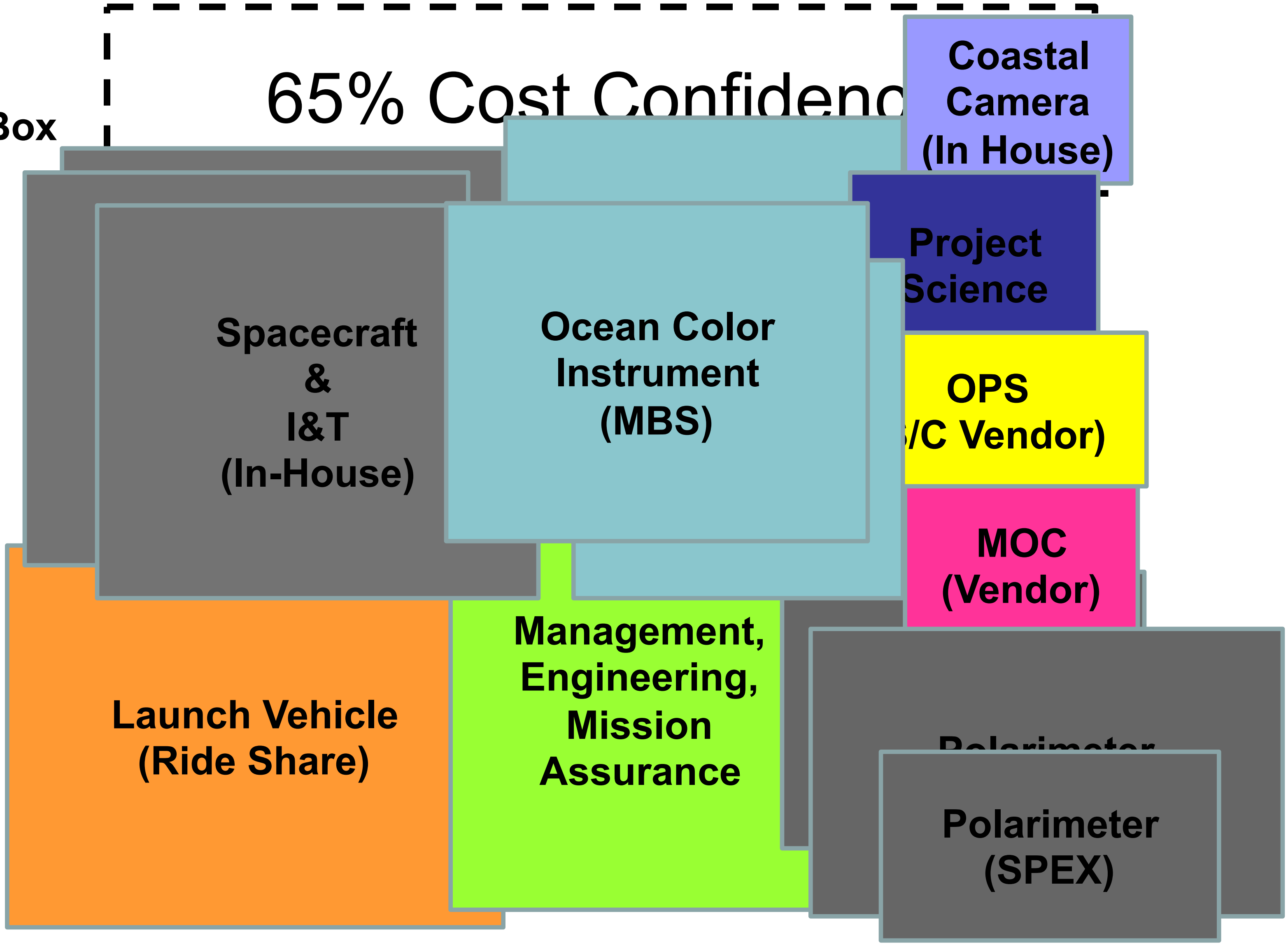


all elements evaluated to determine the best mission fit



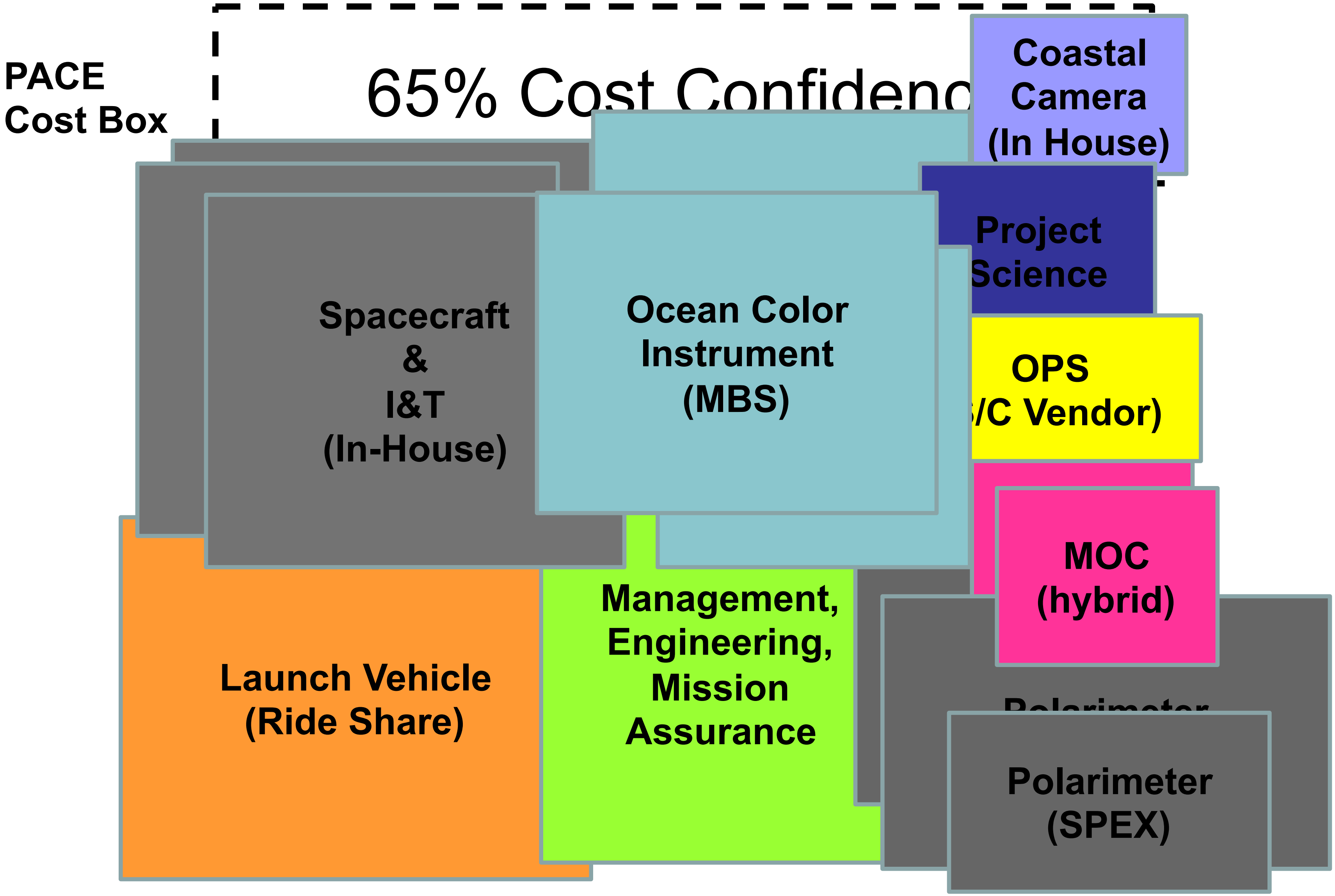
all elements evaluated to determine the best mission fit

PACE
Cost Box

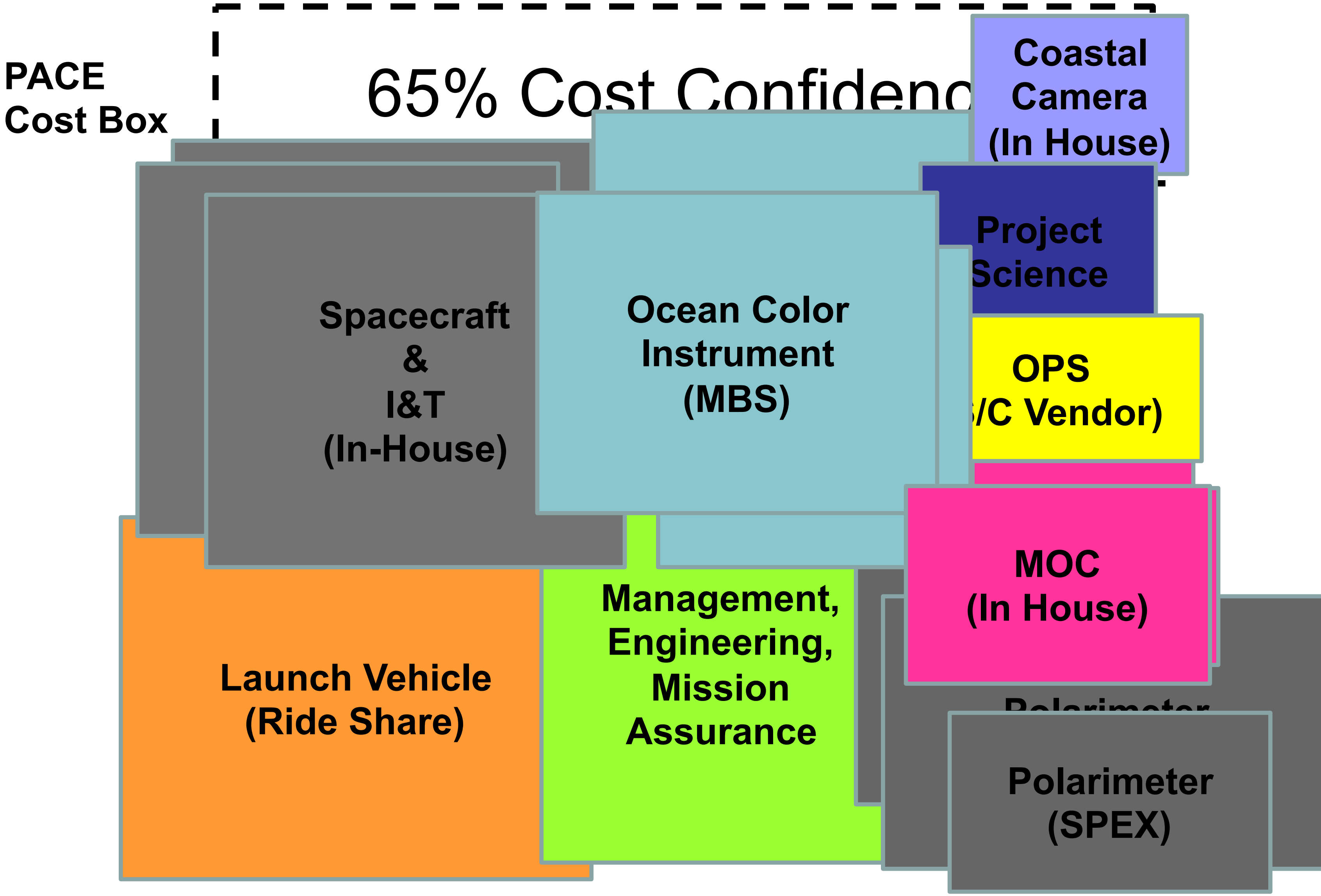


jeremy.werdell@nasa.gov

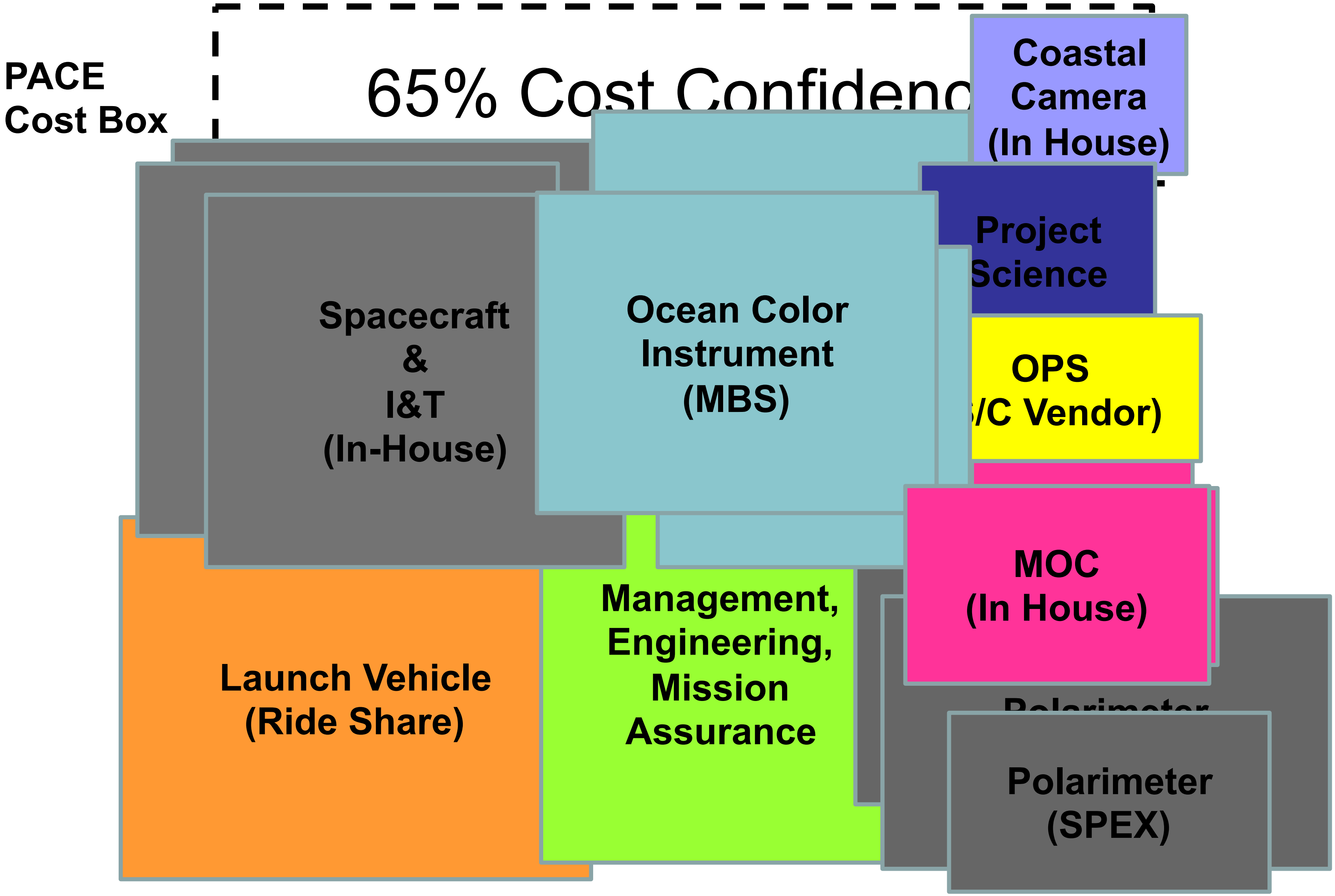
all elements evaluated to determine the best mission fit



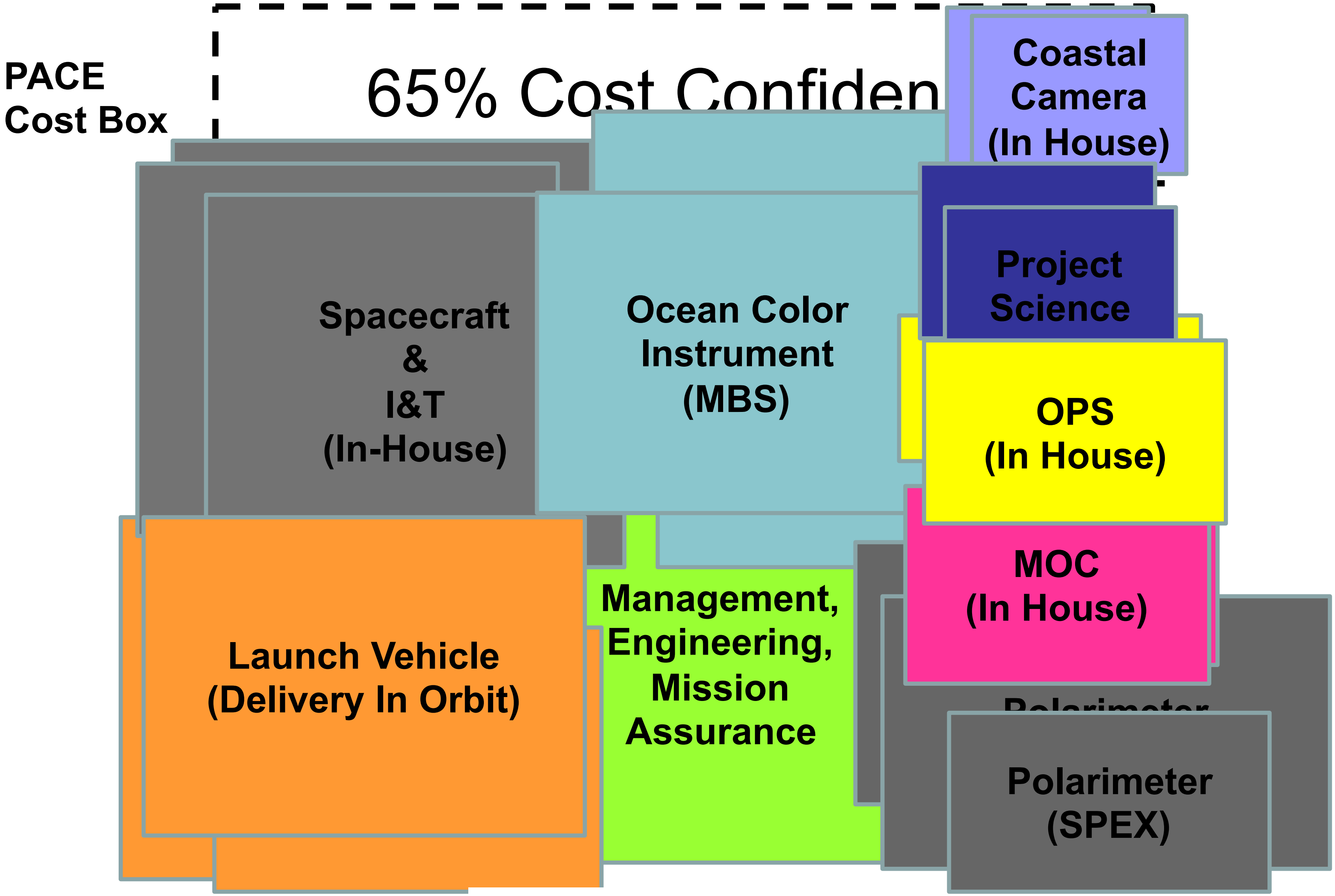
all elements evaluated to determine the best mission fit



all elements evaluated to determine the best mission fit



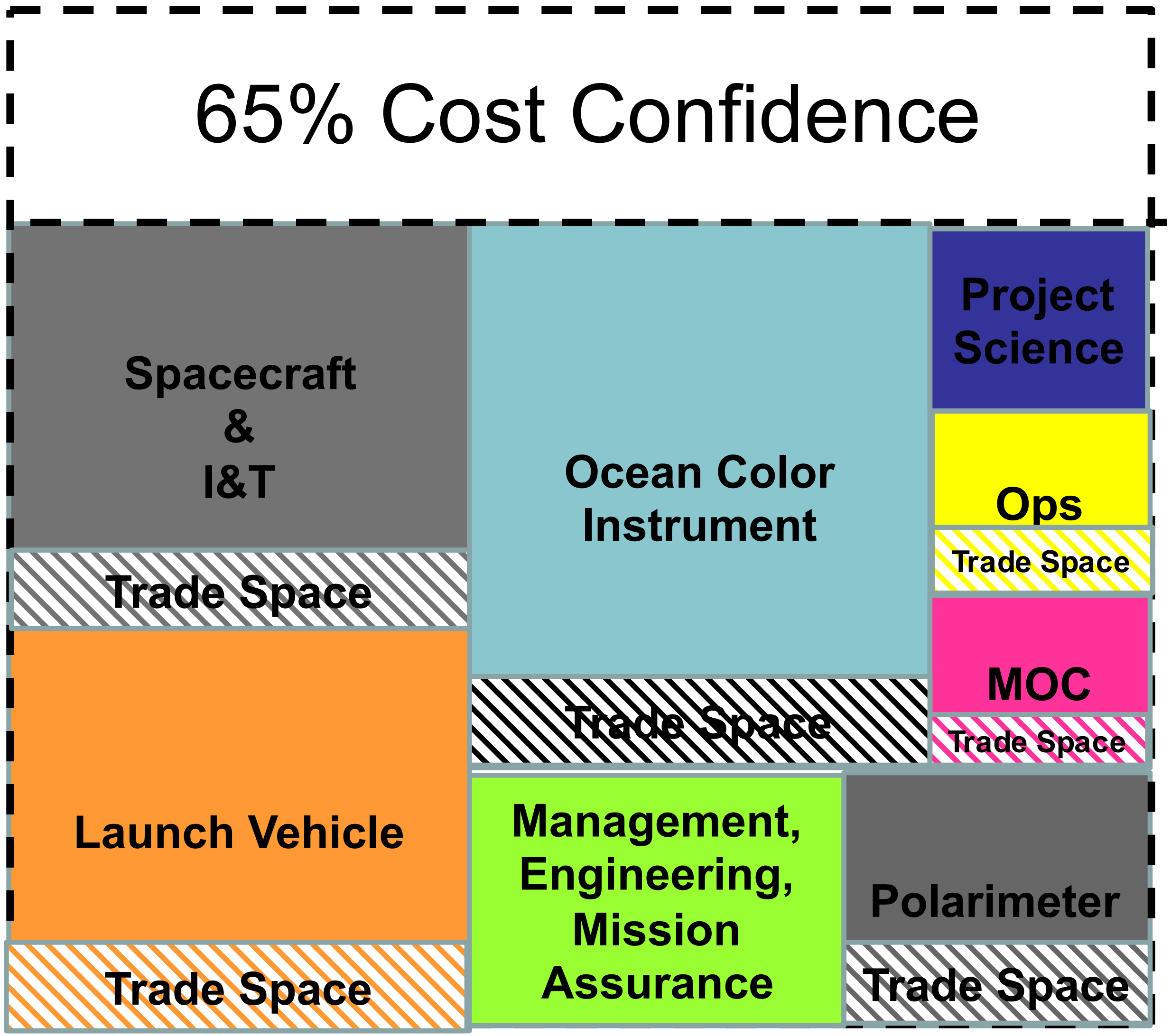
all elements evaluated to determine the best mission fit



at MCR a decision is made as to which single element(s) maximize science & fit in the cost box

PACE Cost Box

There is Still Trade Space Performed In Phase A/B



mission overview & top level schedule

Mission Overview

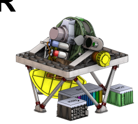
- 98° inclination; ~675 km altitude;
- Sun-Synchronous (1pm MLT AN); 2 day global coverage
- Design to Cost Mission – $805M with $100 Million for Science
- 65% JCL required at KDP-C
- Class C Mission
- Launch Readiness Date August 2022
- 3 years Phase E (after commissioning)
- 10 years fuel

Schedule

Phase A

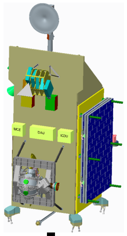
Spacecraft ATP

Instrument(s) CDR

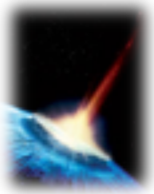


Spacecraft CDR

Observatory I&T



Launch



Decommission

CY16	CY17	CY18	CY19	CY20	CY21	CY22	CY22	CY23	CY24	CY25

review of mission requirements & trades

Official sources of requirements & trade studies:

Document	Date	Source
Mission Threshold Requirements	May 2015	HQ Earth Sciences Division
Polarimeter Desired Capabilities (no mission requirements)	June 2015	H. Maring (Dep. Program Scientist) B. Cairns (Dep. Project Scientist) S. Platnick (EOS Project Scientist)
Desired Trade Studies	May 2015	HQ Earth Sciences Division
PACE Science Definition Team Report	Oct 2012	PACE Science Definition Team

jeremy.werdell@nasa.gov

science implementation priorities

The priority of instrumentation to satisfy PACE science objectives is:

1) OCI with SWIR bands
2) Polarimeter
3) Coastal imager
4) Direct broadcast communications

These align with the documents provided by the Program @ HQ & the PACE SDT report

Cost & capability deltas for the coastal imager & direct broadcast are under evaluation

jeremy.werdell@nasa.gov

PACE in the context of other satellite missions

Present (circa 2022)

POLAR:
Landsat-8 (30 m)
ESA Sentinel 2a (30 m)
VIIRS (300 m)
OMPS

GEO:
ESA …

Planned

POLAR:
ESA OLCI (300 m)
AXA SGLI (250 m)
Landsat-9 (30 m)
Sentinel 2b (30 m)
SeaHawk Cubesat
HyspIRI (90 m)
GEO-CAPE (300 m)
Earthcare
3MI

GEO:
GOES-R
TEMPO
MTG
GOCI-II
GEMS

(spatial resolution not exact, just approximate)

HOW DOES PACE FIT IN?

- broad spectrum from UV to SWIR, at moderate resolution, on the same platform with the same geometry, & consistent calibration
- oxygen-A band techniques that substitute for the lack of thermal information for clouds.
- a global perspective, which is lost with a constellation of GEOs.
- multi-angle polarimetry

review of Level-1 mission requirements

	Mission Threshold Req.	SDT Threshold	SDT Goal
Earth surface spatial resolution	1 km^2 at nadir		
Orbit	Sun synchronous, polar orbit w/ equatorial crossing time near local noon		
Global coverage	2-day to solar zenith ≤ 75^o & sensor zenith ≤ 60^o		
Instrument tilt	Yes		
Lunar calibration	Through Earth view port w/illumination of all detectors		
Image artifacts	Striping artifacts ≤ 0.5% and correctable to noise levels		
Accuracy / precision	20% or 0.004 for 350-395 nm 5% or 0.001 for 400-600 nm 10% or 0.002 for 700-900 nm		
Mission duration	3 years w/ 10 years of fuel		
UV-VIS-NIR	350-800 nm @ 5 nm		
SWIR	940, 1380, 2130, 2250 nm		

colors show differences b/w SDT report & … eet or exceed; *unknown*; may/will not meet

jeremy.werdell@nasa.gov

review of Level-1 mission requirements

	Mission Threshold Req.	SDT Threshold	SDT Goal
Earth surface spatial resolution	1 km^2 at nadir	1 km^2 at nadir	
Orbit	Sun synchronous, polar orbit w/ equatorial crossing time near local noon	Sun synchronous, polar orbit w/ equatorial crossing b/w 11:00 & 13:00	
Global coverage	2-day to solar zenith ≤ 75° & sensor zenith ≤ 60°	2-day to solar zenith ≤ 75° & sensor zenith ≤ 60°	
Instrument tilt	Yes	Yes	
Lunar calibration	Through Earth view port w/illumination of all detectors	Through Earth view port w/ illumination of all detectors	
Image artifacts	Striping artifacts ≤ 0.5% and correctable to noise levels	Total artifact contribution to TOA < 0.5% & *striping ≤ 0.1%* of calibrated TOA	
Accuracy / precision	20% or 0.004 for 350-395 nm 5% or 0.001 for 400-600 nm 10% or 0.002 for 700-900 nm	5% or 0.001 for 400-*710* nm	
Mission duration	3 years w/ 10 years of fuel	5 years	
UV-VIS-NIR	350-800 nm @ 5 nm	350-800 nm @ 5 nm	
SWIR	940, 1380, 2130, 2250 nm	940, 1380, 2130, 2250 nm + 1240, 1640 nm	

colors show differences b/w SDT report & [obscured] eet or exceed; *unknown*; may/will not meet

jeremy.werdell@nasa.gov

review of Level-1 mission requirements

	Mission Threshold Req.	SDT Threshold	SDT Goal
Earth surface spatial resolution	1 km^2 at nadir	1 km^2 at nadir	*1 km^2 to edge of scan; 250 – 500 m^2 at nadir*
Orbit	Sun synchronous, polar orbit w/ equatorial crossing time near local noon	Sun synchronous, polar orbit w/ equatorial crossing b/w 11:00 & 13:00	Sun synchronous, polar orbit w/ equatorial crossing @ noon
Global coverage	2-day to solar zenith ≤ 75^o & sensor zenith ≤ 60^o	2-day to solar zenith ≤ 75^o & sensor zenith ≤ 60^o	1-day with solar zenith > 75^o
Instrument tilt	Yes	Yes	Same as threshold
Lunar calibration	Through Earth view port w/illumination of all detectors	Through Earth view port w/ illumination of all detectors	Same as threshold
Image artifacts	Striping artifacts ≤ 0.5% and correctable to noise levels	Total artifact contribution to TOA < 0.5% & *striping ≤ 0.1%* of calibrated TOA	Total artifact contribution to *TOA < 0.2%*
Accuracy / precision	20% or 0.004 for 350-395 nm 5% or 0.001 for 400-600 nm 10% or 0.002 for 700-900 nm	5% or 0.001 for 400-*710* nm	*10% or 0.002* for 350-395 nm
Mission duration	3 years w/ 10 years of fuel	5 years	10 years
UV-VIS-NIR	350-800 nm @ 5 nm	350-800 nm @ 5 nm	350-900 nm @ 5 nm
SWIR	940, 1380, 2130, 2250 nm	940, 1380, 2130, 2250 nm + 1240, 1640 nm	Same as threshold

colors show differences b/w SDT report & ... eet or exceed; *unknown*; may/will not meet

jeremy.werdell@nasa.gov

review of SDT SNR recommendations

PACE SDT Report Table 3-1

λ	Band Width (nm)	Spatial Resol. (km^2)	L_{typ}	L_{max}	SNR-Spec
350	15	1	7.46	35.6	300
360	15	1	7.22	37.6	1000
385	15	1	6.11	38.1	1000
412	15	1	7.86	60.2	1000
425	15	1	6.95	58.5	1000
443	15	1	7.02	66.4	1000
460	15	1	6.83	72.4	1000
475	15	1	6.19	72.2	1000
490	15	1	5.31	68.6	1000
510	15	1	4.58	66.3	1000
532	15	1	3.92	65.1	1000
555	15	1	3.39	64.3	1000
583	15	1	2.81	62.4	1000
617	15	1	2.19	58.2	1000
640	10	1	1.90	56.4	1000
655	15	1	1.67	53.5	1000
665	10	1	1.60	53.6	1000
678	10	4	1.45	51.9	2000
710	15	1	1.19	48.9	1000
748	10	1	0.93	44.7	600
820	15	1	0.59	39.3	600
865	40	1	0.45	33.3	600
1240	20	1	0.088	15.8	250
1640	40	1	0.029	8.2	180
2130	50	1	0.008	2.2	15

← SDT goal of 100

PACE SDT Report Table 3-4

Augmentation to baseline OCI (i.e., Threshold ocean requirements from section 3.2)								
Central Wave-length (µm)	Band-width (FWHM, nm)	Rmax [a] (μ_0=1)	Lmax [a] (W/m^2-sr-µm)	Rtyp [a,b] (μ_0=1)	Ltyp [b] (W/m^2-sr-µm)	NEdR@ Rtyp	SNR@ Ltyp [a]	Spatial Resolution (m) [Threshold, Goal [c]]
0.940	25	0.80	210	0.03	7.8	0.0002	150	1000
1.378	10 [d]	0.80	95	0.03	3.5	0.0003	100	1000
2.250 [e]	50	0.90	21	0.03	0.7	0.0002	150	1000 250

Mission Systems Engineering generates Level-2 & -3 req's – those more specific, technical req's needed to achieve the Level-1 req's

SNRs will appear as Level-2 req; they were not prescribed by HQ

review of Level-1 cloud & aerosol requirements

Atmospheric Aerosol Measurements

a) Aerosol Optical Depth
   a. UV at 0.05 or 30% (total)
   b. VIS at 0.05 or 15% (total) over land
   c. VIS at 0.03 or 10% (total) over ocean
b) Fraction of Total Visible Optical Depth contributed by the fine mode aerosol over dark water to ±0.25.

Cloud Measurements

Cloud Layer Detection of 5-10% at a cloud optical depth of ~0.3 with dependence on surface type as a partial continuation of MODIS and VIIRS

a) Cloud Top Pressure
   a. Low cloud when optically thick and/or over dark surface at ≤50 hPa
   b. High cloud at >50 hPa.
b) Cloud Water Path as a function of optical depth, effective radius and surface
   a. ~30% for liquid clouds
      ~50% for ice clouds
c) Optical Thickness as a function of optical depth, effective radius, wavelength and surface
   a. ~20% for liquid clouds with small sub-pixel heterogeneity
      ~30% for ice clouds
d) Effective Radius with upper layer weighting
   a. ~20% for liquid clouds with small sub-pixel heterogeneity
      ~30% for ice clouds

Shortwave Radiative Effect at ~10 Wm^{-2} TOA

cloud & aerosol threshold requirements from HQ:

- data products can be generated with the prescribed band set
- precisions can be achieved with SDT recommended OCI SNRs & calibrations (PACE SDT Tables 3-1,3-4)

jeremy.werdell@nasa.gov

review of polarimeter minimum capabilities

	Minimum capability	Enhanced capability
Spectral channels	4 polarized bands in 400-1600 nm range; 2200 nm band if only sparse angular sampling	940 nm or O2 A-band 1378 or 1880 nm (cirrus)
Swath width	±15º aerosol/cloud science ±25º atmospheric correction	±30º
Number of angles	4 for aerosols and atmospheric correction; 5-6 for clouds	10 for aerosols ~50 for cloud bows
Angular range	±50º at satellite in VNIR (400-1000 nm)	±55º at satellite in all bands
Pixel size	5 km	1 km
DOLP uncertainty	<0.01	<0.005
Radiometric uncertainty	5%	3%
SNR	Not specified	Not specified
UV/NIR Spatial Coverage	Not specified	Not specified
SWIR Spatial Coverage	Not specified	Not specified
% ground coverage of OCI Swath	Not specified	Not specified

hyper-spectral & number of polarized bands

capability to assist with O/C atm corr

Cairns, Maring, & Platnick identified these desired capabilities for a PACE polarimeter. The minimum capability follows those for 3MI, which was featured in the PACE SDT.

timing of science analyses & mission flow

GSFC review

today

MCR (Mar 8-9)

KDP-A (Apr/May)

ASM (May)

HQ reviews

Pre-Phase A

- evaluate all possibilities for all mission elements
- recommend a full mission concept that maximizes science under cost cap

OCI example:

evaluate multiple instrument concepts (e.g., scanning instrument vs. pushbroom)

[mission concept evaluated by HQ]

Phase A

- review and refine capabilities of each element
- trade capabilities w/i each element to ensure maximizing science under cost cap

iterate on capabilities of a single concept (e.g., ground sample distance vs. SNR)

MCR:	Mission Confirmation Review
KDP-A:	Key Decision Point A (gateway to Phase A)
ASM:	Acquisition Strategy Meeting

pre-Phase A science analyses

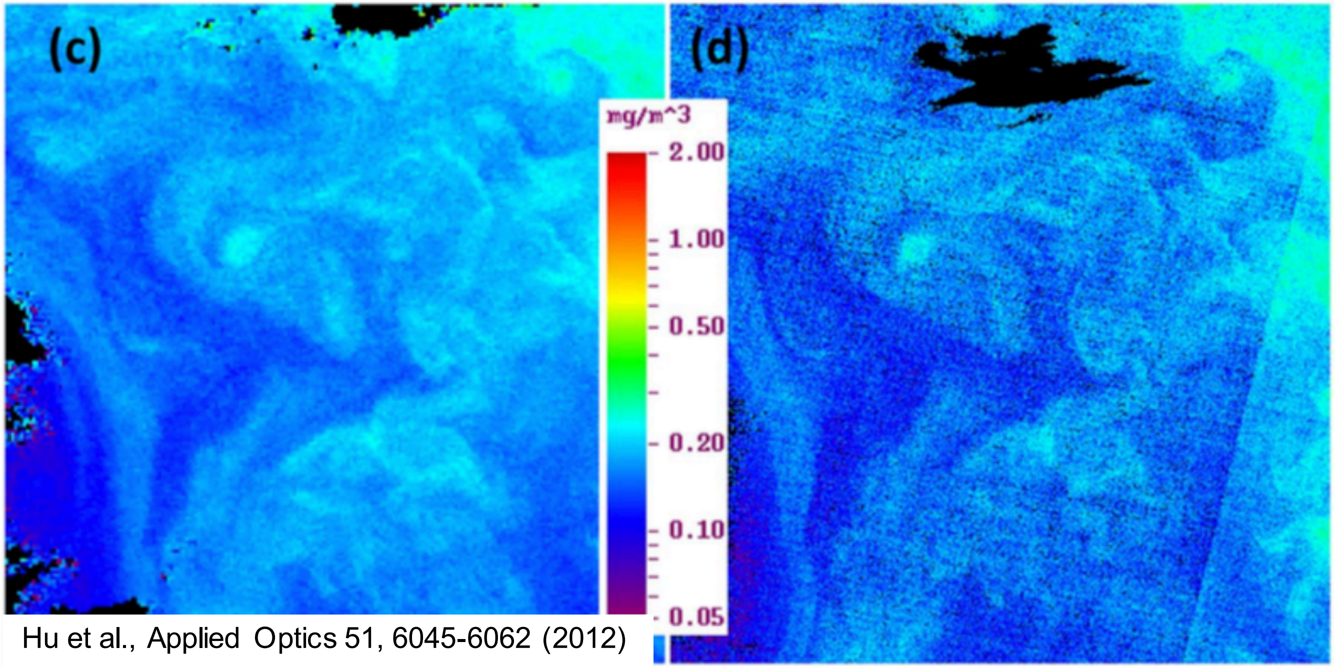
narrowing the OCI instrument concept

- impacts of image striping on science data products
- lunar calibration capabilities
- tilt requirements for Sun glint mitigation
  - OCI will tilt $\pm 20^o$ as did SeaWiFS & CZCS
- orbit altitude vs. global coverage
  - 675 km altitude
- polarimeter capabilities
  - 3 instrument concepts put forward; no RFI
- coastal instrument capabilities
  - RFI released; 13 responses received

jeremy.werdell@nasa.gov

narrowing the OCI concept: image artifacts

SeaWIFS scanner



Hu et al., Applied Optics 51, 6045-6062 (2012)

MERIS pushbroom

- Stripes appear in MERIS (pushbroom) imagery b/c it has multiple detectors & multiple cameras, all of which need to be calibrated independently. Plus, cannot track dark current/count drift over the course of an orbit.

- Stripes do not appear in SeaWiFS imagery b/c a single detector was used to image the entire Earth. Plus, scanners can collect a dark reference every frame.

narrowing the OCI concept: image artifacts

	Mission Threshold Req.	SDT Threshold	SDT Goal
Image artifacts	Striping artifacts ≤ 0.5% and correctable to noise levels	Total artifact contribution to TOA < 0.5% & *striping ≤ 0.1%* of calibrated TOA	Total artifact contribution to *TOA < 0.2%*

10:1 rule of thumb for error propagation from TOA to the sea-surface

– 0.5% mis-calibration at TOA leads to 5% uncertainty at sea surface

vicarious calibration is an essential part of achieving high quality data

– process is well demonstrated with heritage missions (SeaWiFS) & is straightforward with O(1) detectors

– a multi-camera system (MERIS) cannot routinely view MOBY w/ all detectors on all cameras; otherwise requires very good relative detector-to-detector calibration of the O(1000) detectors

– image stripes add uncertainty to the satellite pixel box (e.g., 3x3) averages used in the MERIS-to-MOBY calibration match-ups

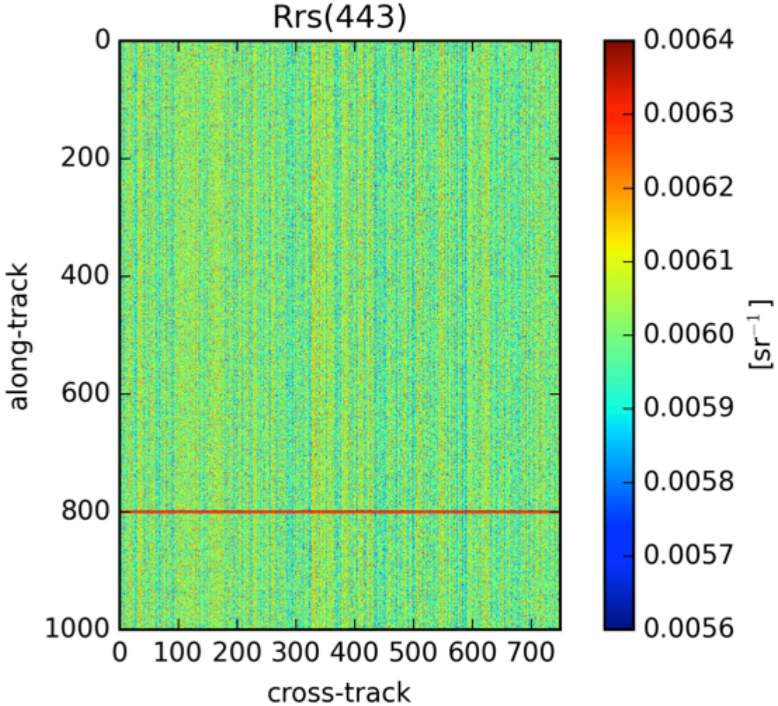
science data products can be intolerant of image artifacts

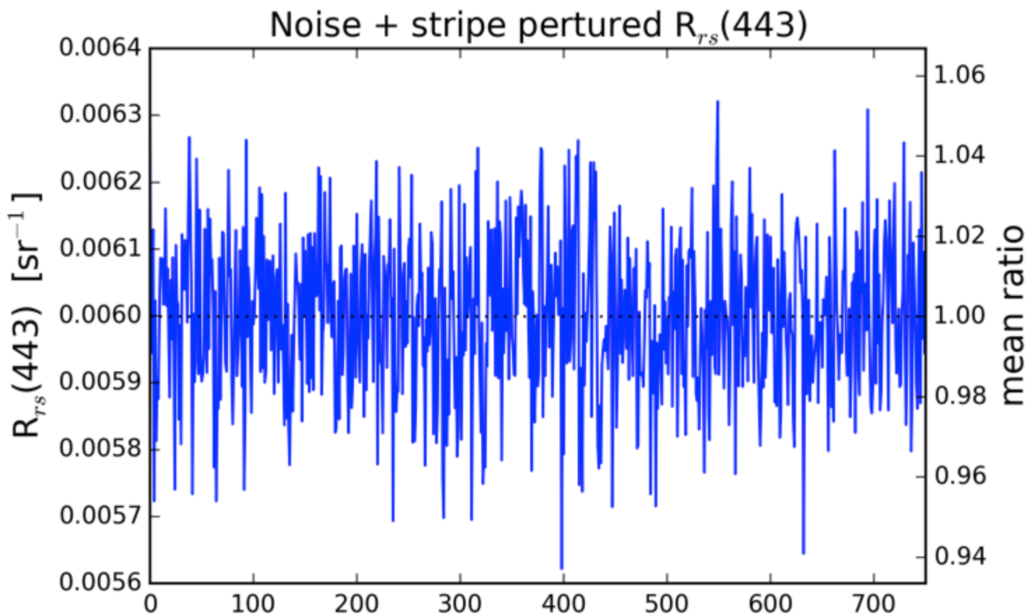
– image striping, e.g., imposes 10-50% uncertainty on O/C products

jeremy.werdell@nasa.gov

modeled CCD noise to evaluate the impact of image artifacts on data products

(1) model TOA radiances over an average ocean (~0.13 mg Chl mg m^{-3})
(2) add Gaussian noise based on PACE SDT SNRs
(3) add image striping from random 0.1% miscalibration error
(4) (re)calculate water-leaving radiances



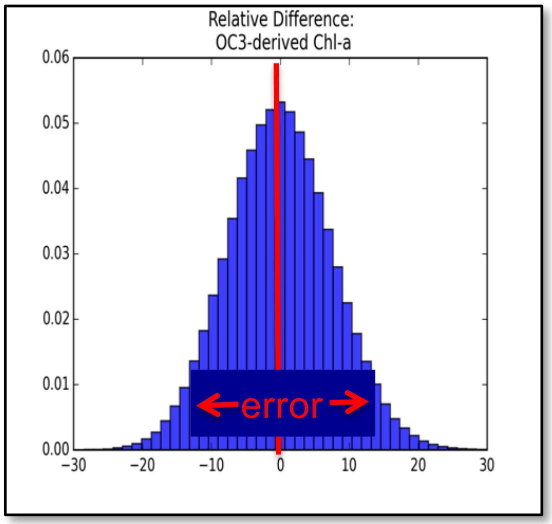


Ex. result: artifacts add 1-4% uncertainty in water-leaving reflectance at 443 nm, which cuts deeply into the 5% accuracy requirement

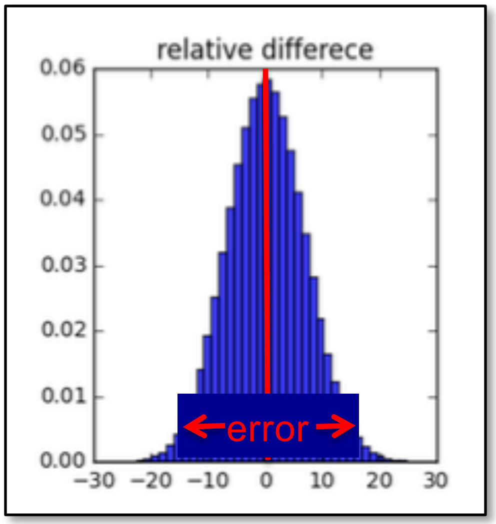
jeremy.werdell@nasa.gov

image artifacts degrade science products

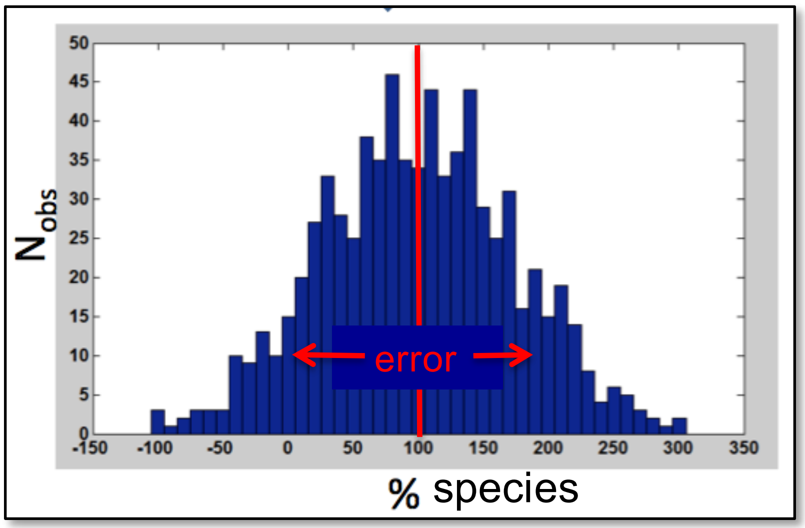
errors in science data products increase substantially when noise (per PACE SDT SNRs) & miscalibration errors (0.1% at TOA) are imposed



heritage band-ratio chlorophyll concentration



heritage spectral matching phytoplankton absorption



advanced PACE derivative analyses of phytoplankton species identification

increasing model complexity

increasing error

relative percent differences for open ocean image with noise added compared to the original clean image (chlorophyll ~ 0.13 mg m^{-3})

science analyses to assess image striping

Analysis	Approach	Results
Model image striping in a CCD camera	Model TOA radiances, add noise (per PACE SDT SNRs) & miscalibration error (0.1%), recalculate water-leaving values	Added 1-4% uncertainty in water-leaving reflectance at 443 nm, which cuts deeply into the 5% accuracy requirement
Review of destriping algorithms	Literature review – Table in backup slides. Many approaches exist w/o consensus. Most solve targeted problems, all have residual artifacts, none address both along- & cross-track stripes, none have been applied to operational O/C data processing.	Camera seams difficult to remove; over-smooths & modifies surrounding data points; no information loss metrics applied. Post-launch science & calibration teams will need to invest substantial effort into evaluating, validating, & implementing image stripe suppression algorithms
Destriping in operational environments	Create 3 images with random stripes from common truth image; apply destriping algorithm; quantify & compare residual differences in 3 destriped images	The unperturbed image was neither recovered by the destriping algorithm, nor were multiple applications of the destriping algorithm able to produce consistent versions of the destriped imagery when the noise patterns were spatially varied.
Uncertainties in derived geophysical products	Generate imagery with artifacts (noise & 0.1% TOA miscalibration error), generate derived geophysical products, compare results with unperturbed imagery.	Stripes added (1 s) deviations of: (1) 10% for heritage band-ratio algorithms; (2) 15% for heritage spectral matching algorithms; & (3) 50% for derivative algorithms.

jeremy.werdell@nasa.gov

impacts of image striping on science data

Science Benefits	• None
Science Impacts	• Image striping at TOA of O(0.1%) leads to variability in water-leaving radiances of O(1%) & derived geophysical products of O(10-100%) • Core science questions cannot be addressed with temporal & spatial product variability of 10-100%; many oceanographic trends are O(1-5%)
Technical Impacts	• Requires development & application of destriping algorithms that can resolve both along- & cross-track artifacts in an operational processing environment • These algorithms do not currently exist & their development will required substantial effort by both the pre- & post-launch calibration & science teams
Cost/Schedule Impacts	• Development, verification, & implementation of adequate destriping algorithms will require substantial effort by both the calibration & science teams • Destriping algorithm verification will delay delivery of post-launch geophysical data on O(years)
Risks	• Substantially degraded quality of PACE science data products • All destriping algorithms leave residual image artifacts • Fewer peer-reviewed publications • Delays in delivery of PACE science data products • Degraded adoption by Applied Science stakeholders (early adopters)

narrowing the OCI concept: lunar cal

high mission-long radiometric stability (0.1%) is required to detect trends in geophysical variables that vary on O(1-5%) per decade

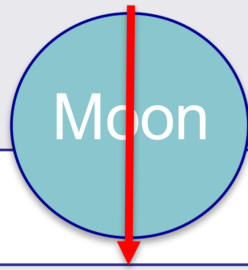
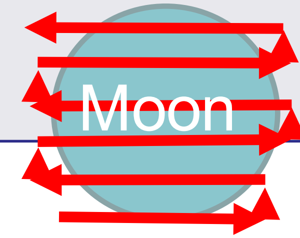
HQ threshold req: Perform lunar calibration through Earth view port w/ illumination of all detectors

all NASA Ocean Color missions (minus CZCS) have relied upon monthly lunar calibrations to achieve mission-long radiometric stability

- MODIS & VIIRS both have solar diffusers with stability monitors, but still require lunar calibration to achieve the radiometric stability required for O/C
- at best, a stability monitor on PACE would be able to track the diffuser change at a single angle, not the full angular dependence (BRDF)
- ocean, cloud top, & desert targets too variable (scale or characterization)

narrowing the OCI concept: lunar cal

each detector needs a full disk view of the Moon for comparison with ROLO model

Scanner	Pushbroom
O(1) detector 	O(1000) detectors O(5) cameras 
1 orbit	6 orbits
single monthly pitch / roll maneuver w/ single sweep of the entire lunar disk	complicated raster sequence requirement for 0.1% consistency across all detectors imparts pitch/yaw control accuracy requirement of 0.2 arcmin, which is beyond the current capabilities of the S/C
homogeneous sampling of the full surface of the lunar disk in the single sweep	geometric viewing conditions will change during each orbit & for each calibration event (due to S/C & Moon motion) requires extensive planning of maneuvers for each calibration event

narrowing the OCI concept: lunar cal

Impacts defined as relative to a scanning instrument

Science Benefits	• None
Science Impacts	• Uncertainties increase b/c of changing geometries & pointing req's • Increased burden on calibration team and science data processing • Additional uncertainties will degrade science data products
Technical Impacts	• Pointing control that otherwise exceeds the S/C capabilities • Complicated sequence of pitch and raster maneuvers • 6 orbits per monthly calibration event • Significant planning and operations effort each month to plan maneuvers
Cost/Schedule Impacts	• Pointing accuracy may require a 2-axis gimbaled system & star tracker • Real-time feedback from the S/C ACS to the gimbal will be required • Pointing accuracy may require significant augmentation of the S/C ACS • O(1) add'l FTEs/yr required to plan/execute maneuvers • O(2) add'l FTEs/yr will be required to conduct additional data analyses
Risks	• Additional H/W requires additional testing & adds new mechanisms • Complicated maneuvers need exacting precision to execute • Uncertainties will impact the quality of the science data products

narrowing the OCI concept: recommendation

the PACE Project will recommend pursing a hyperspectral scanning instrument concept for OCI (e.g., a hyperspectral SeaWiFS)

advantages:

- can satisfy all HQ & SDT threshold requirements
- no inherent image striping
- straightforward lunar calibration
- few detectors to calibrate

disadvantages:

- ground sample distance (GSD) cannot be <500 m given technological (e.g., rotation rate) & SNR limitations
  - while 500 m GSD will meet many SDT goals for coastal studies, a different instrument will be necessary to study finer scale processes
  - idea of a dedicated coastal camera put forth in HQ Desired Trade Studies document (May 2015)

Phase A science analyses

Quantify ground sample distance (GSD) vs. information content

- 50-150 m for coastal research and applications (coastal instrument)
- 500-1000 m for open ocean research and applications (OCI)

underway; priority

Explore utility of UV spectral range extended below 350 nm

- assess methods for quantifying ozone, CDOM, mycosporine-like amino acids

Explore utility of spectral subsampling

- e.g., what can be done if we sample @ 1-2 nm over the chlorophyll fluorescence peak
- assess spectral subsampling requirements & methods for quantifying NO_2 in the blue

Quantify improvement in algorithms with spectral resolution < 5 nm

(Re)define values for UV-visible-NIR-SWIR SNRs (verify SDT values)

Assess data collection, volumes, & distribution

- acceptable data latency (3 hrs, 6 hrs, 12 hrs) to support rapid use & direct broadcast
- CCD detector aggregation at the edge of scan to maintain GSD vs. loss in SNR
- can accurate retrievals be made at higher sensor & Solar geometries?

jeremy.werdell@nasa.gov

polarimeter update

per the HQ Letter of Direction, 4 options:

(1) no polarimeter
(2) JPL
(3) procured (no GSFC)
(4) contributed

all options are still under consideration; the Project does not yet have a polarimeter recommendation

polarimeter options put forward to the Project

Type/Provider	Description
Sequential - ESA/SELEX 3MI	• Rotating filter wheel
Temporal Modulation - JPL PSMPI	• Rapid modulation over short spatial scales • Single pixel/detector for total & polarized contributions
Spectral Modulation - SRON SPEX	• Polarization encoded into the spectrum
Amplitude Splitting - JPL/UMBC HARPP - SRON ASPIM	• Use 3/4 images to create Stokes vector image

jeremy.werdell@nasa.gov

why a dedicated coastal imager?

All global ocean science objectives can be achieved with a scanning UV-to-SWIR ocean color instrument (OCI) **with 500-1000 m GSD** & multi-angle polarimeter

A different instrument is necessary to address many of the **goal** coastal ocean & Applied Sciences objectives listed in the SDT (which focuses on 250-500 m)

- no prescribed requirements; science benefits can be realized with a less capable instrument than OCI
- existing satellite assets include:
  - Past: MERIS (300 m), HICO (90 m)
  - Present: Landsat-8 (30 m), ESA Sentinel 2a (30 m), VIIRS (300 m)
  - Planned: ESA OLCI (300 m), JAXA SGLI (250 m), Landsat-9, Sentinel 2b
  - Possible: SeaHawk Cubesat (150 m), HysPIRI (90 m), GEO-CAPE (300 m)
- co-location with PACE OCI is beneficial
- minimum desired capabilities identified

jeremy.werdell@nasa.gov

justification for coastal O/C sensor on PACE

- Processes in coastal zone occur on spatial scales that cannot be fully captured by sensors operating at coarser than ~200 m GSD.
- Many estuaries, rivers, & lakes are too small to be studied with sensors possessing GSD >300 m
- Offshore ocean features cannot be fully resolved with GSD >300 m
- Fine GSD is critical for management applications
- PACE SDT report identified a scientific need for multi- to hyperspectral ocean color observations at GSD finer than 500 m (to ~250 m).
- Global OCI sensor type recommended by the Project is limited to GSD of 500 m or coarser.
  - Project concluded that a dedicated sensor would be required to address the coastal and inland waters science and applications objectives discussed in the SDT Report that a global OCI cannot*
    - Cost cap & science priorities dictate that a coastal sensor must be inexpensive

**** Global OCI sensor can meet some critical coastal science objectives***

coastal sensor trade feasibility study

- Coastal sensor is not part of PACE threshold requirements
- Program scientists requested a coastal ocean color sensor trade feasibility study
- Project conducted a trade study on a coastal ocean color sensor
  - RFI released July 2015 for minimum science capability
  - Performed IDL study for low-cost coastal camera in Oct. 2015
  - Project Science refined sensor capabilities (minimum to desired)
- Assessed 13 candidates for technical, cost and science capability
  - Industry (9 RFI responses)
  - Federal/Academic Institutions (JPL, APL, NRL)
  - Instrument Design Lab (GSFC)
- Primary trade criteria were cost, minimum science capability, heritage & OCI independence
- Mission cost for implementation of coastal sensor are ~$27M-$70M
- Under the current cost cap and confidence limit requirements, **coastal sensor is not part of the current PACE mission concept**

jeremy.werdell@nasa.gov

desired science capabilities from a coastal O/C sensor

Priority	Capability	Minimum Acceptable*	Preferred
1	Ground Sample Distance	≤150 m	≤100 m
2	# spectral bands[1]	8	12 or more
3	SNR[2]	600 Vis; 300 NIR[3]	>1000 Vis; >600 NIR
4	UV bands	none	1 or more
5	Glint avoidance	N/A	±20°
6	Gimbal to track coast	N/A	±15° or greater
7	Bandwidth	20 nm	10 nm
8	Swath	150 km	>300 km

[1] UV-Vis bands plus two NIR bands (748 and 865 nm)
[2] SNR capability should scale with GSD (lower SNR at finer GSD)
[3] SeaWiFS on-orbit SNR ranged from 183 in NIR to 790 in Vis (Hu et al. 2012)

Are these desired capabilities and prioritization on-target for coastal and inland waters science and application objectives? If not, what is desired?

Date rate limited to 10 Mbps orbital average
IDL: 9 Mbps for 12 bands at 100 m GSD and 160 km swath (within 75-deg SZA; only coastal)

desired bands from a coastal O/C sensor

Band Center[1]	Maximum Bandwidth	Preferred Bandwidth
350	20	15
360	20	15
385	20	15
412	20	10
425	20	10
443	20	10
460	20	10
475	20	10
490	20	10
510	20	10
532	20	10
555	20	10
583	20	10
617	20	10
640	20	10
655	20	10
665	10	10
678	10	10
710	15	10
748	10	10
765	40	40
820	15	15
865	40	40
940	30	30
1020	40	40
1240	20	20
1640	40	40
2140	50	50

Required Bands

360, 412, 443, 490, 510, 555, 617, 665, 678, 710, 748, and 865 nm

Are the required band set & bandwidths ideal?

Prioritization of additional bands?

If not, what is desired?

jeremy.werdell@nasa.gov

science-relevant facts about direct broadcast

PACE could support a limited, but significant, community through direct broadcast, but will not be the perfect tool to do so.

Climate science & the PACE science data processing segment (OBPG) do not use direct broadcast (Expected average latency for OCI is **6 hours**)

11 U.S. & 16 int'l organizations make use of MODIS & VIIRS direct broadcast products (from directreadout.sci.gsfc.nasa.gov):

- 7 U.S. academic institutions (few with evidence of near real time requirements)
- 4 U.S. federal & military institutions

Most relevant near-real-time requirements rely on imagery of:

- Clouds & aerosols (e.g., true color imagery & smoke detection)
- Fires (**PACE will not have thermal bands**)
- Military applications (e.g., diver visibility)

A primary future focus on use of direct broadcast will be supporting responses to hazards & disasters (e.g., oil spill monitoring)

The U.S. EPA & NOAA do not currently use direct broadcast for monitoring harmful algal blooms or for fisheries / resource management

Direct broadcast has historically impacted the science data segment (OBPG) through software development (to handle additional file formats & different band aggregations/algorithms) & user support

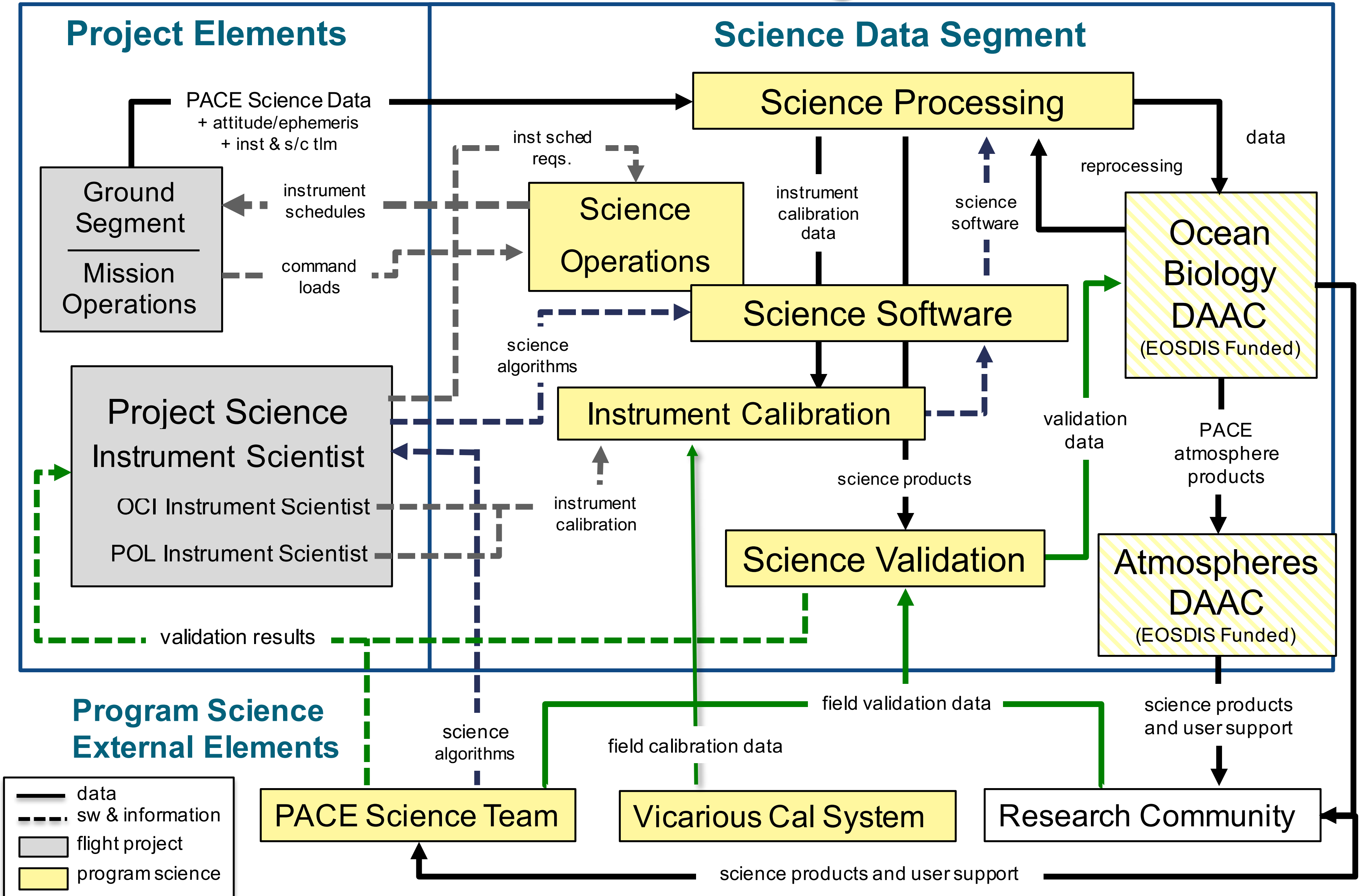
jeremy.werdell@nasa.gov

science data segment update

- Assuming PACE science payload consists of one ocean color imager, OCI, and one multi-angle polarimeter, POL.
- PACE Science Data Segment (SDS) will ingest all science data (Level-0) and produce ocean color and atmospheric (cloud & aerosol) science products from OCI and POL.
- PACE SDS will also provide support for instrument scheduling, on-orbit calibration analyses, software development, algorithm integration and testing, and product validation.
- Responsibility for PACE SDS was directed to the Ocean Biology Processing Group (OBPG) at GSFC.
- OBPG operates a multi-mission distributed processing system and range of supporting facilities that will be augmented for PACE.

jeremy.werdell@nasa.gov

science data segment



jeremy.werdell@nasa.gov

Website – capabilities

Modeled after NASA Aquarius (e.g., database)

- *Data Gallery* (>1170 maps)
- *Publications* (~200)
- *Science Meetings* (artifacts from 15 events)
- *Multimedia Gallery* (>120 image, videos, etc.)
- *FAQs*, *Mission Status & Events*, *News* (> 240 items)

Continues successful collaboration with GSFC

- PACE public website will use Drupal
  - Open source content management system

Website – development

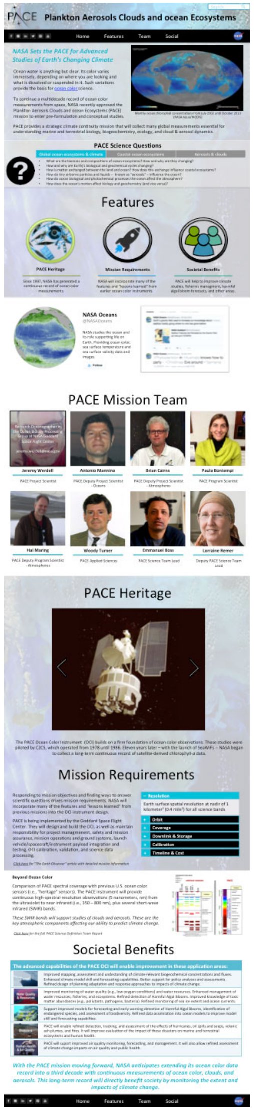
"One-stop shopping" approach

- Resources for scientists *and* non-scientists

PACE website will have responsive design

- Layout will evolve with mission
- Will add breadth and depth over time
- Interactivity through innovative modules

Initial design is shown at right and in following slides...



Website – development

PACE **Plankton Aerosols Clouds and ocean Ecosystems**

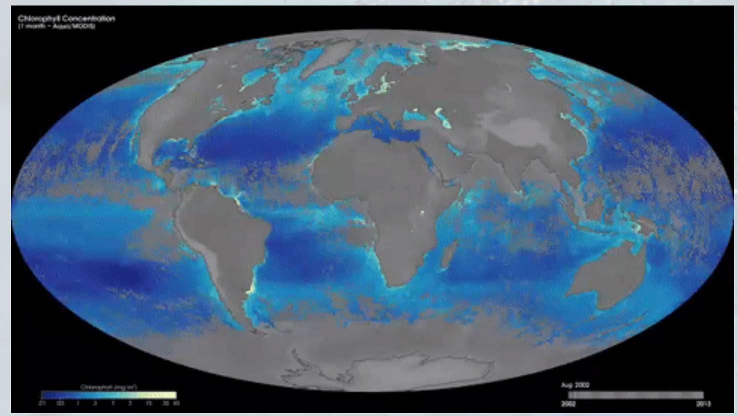
Search

Home Features Team Social

NASA Sets the PACE for Advanced Studies of Earth's Changing Climate

Ocean water is anything but clear. Its color varies immensely, depending on where you are looking and what is dissolved or suspended in it. Such variations provide the basis for ocean color science.

To continue a multidecade record of ocean color measurements from space, NASA recently approved the Plankton Aerosols Clouds and ocean Ecosystems (PACE) mission to enter pre-formulation and conceptual studies.



Monthy ocean chlorophyll concentrations from July 2002 until October 2013 (NASA Aqua/MODIS)

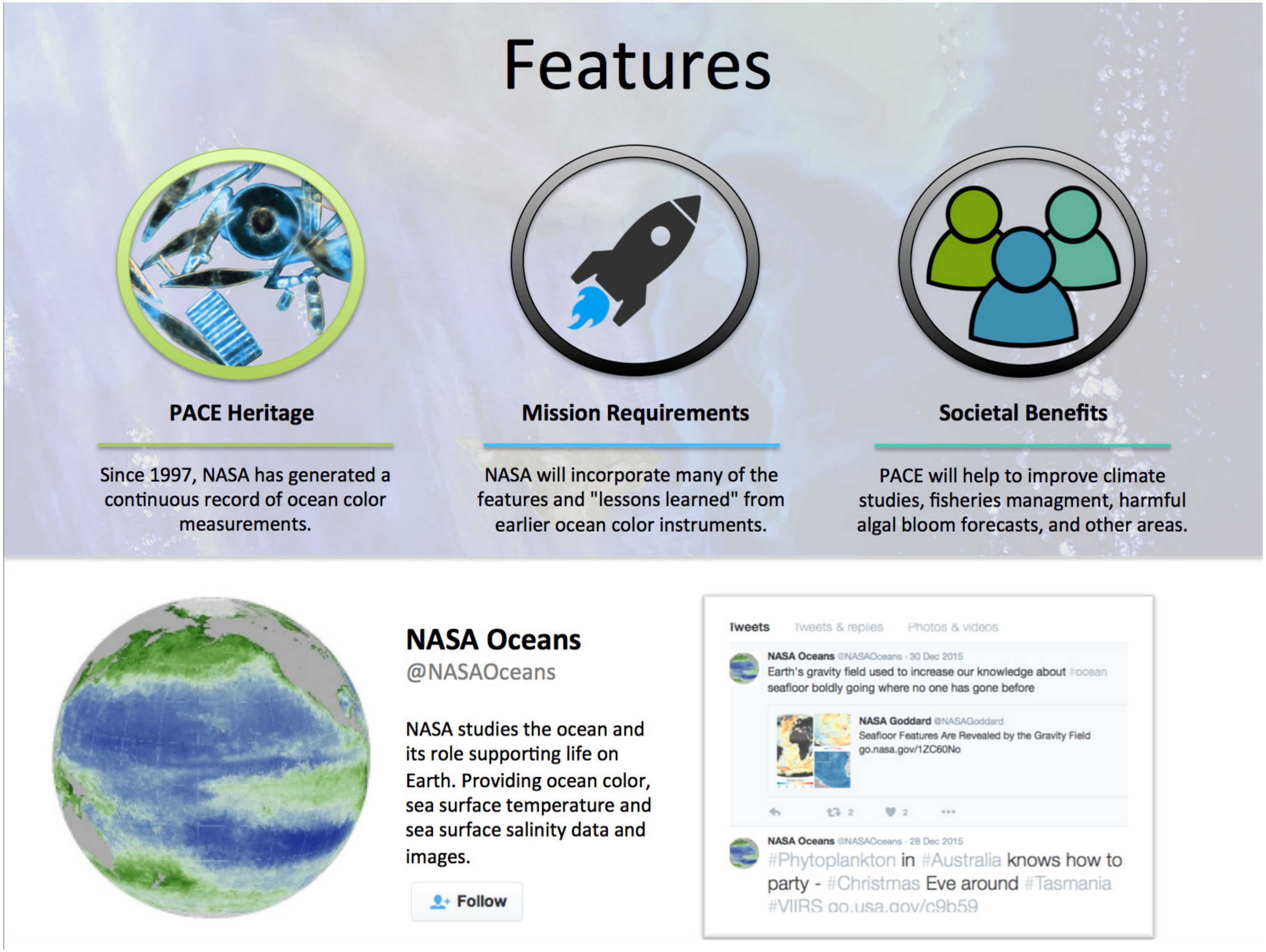
PACE provides a strategic climate continuity mission that will collect many global measurements essential for understanding marine and terrestrial biology, biogeochemistry, ecology, and cloud & aerosol dynamics.

PACE Science Questions

Global ocean ecosystems & climate	Coastal ocean ecosystems	Aerosols & clouds

- What are the biomass and compositions of ocean ecosystems? How and why are they changing?
- How and why are Earthj's biological and geochemical cycles changing?
- How is matter exchanged between the land and ocean? How does this exchange influence coastal ecosystems?
- How do tiny airborne particles and liquids -- known as "aerosols" – influence the ocean?
- How do ocean biological and photochemical processes the ocean affect the atmosphere?
- How does the ocean's motion affect biology and geochemistry (and vice versa)?

Website – development



jeremy.werdell@nasa.gov

Website – development

PACE Mission Science Team

Jeremy Werdell

PACE Project Scientist

Antonio Mannino

PACE Deputy Project Scientist - Oceans

Brian Cairns

PACE Deputy Project Scientist - Atmospheres

Paula Bontempi

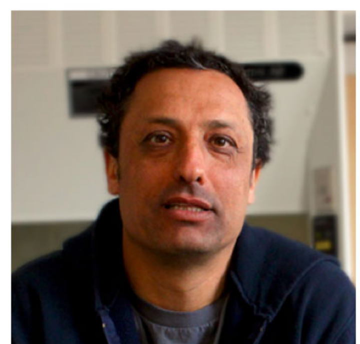
PACE Program Scientist

Hal Maring

PACE Deputy Program Scientist - Atmospheres

Woody Turner

PACE Applied Sciences



Emmanuel Boss

PACE Science Team Lead

Lorraine Remer

Deputy PACE Science Team Lead

Website – development

PACE Heritage

Coastal Zone Color Scanner (CZCS), NASA's proof-of-concept mission measured ocean color from space from 1978 until 1986.

The PACE Ocean Color Instrument (OCI) builds on a firm foundation of ocean color observations. These studies were piloted by CZCS, which operated from 1978 until 1986. Eleven years later – with the launch of SeaWiFs -- NASA began to collect a long-term continuous record of satellite-derived chlorophyll-*a* data.

Website – development

Mission Requirements

Responding to mission objectives and finding ways to answer scientific questions drives mission requirements. NASA will incorporate many of the features and "lessons learned" from previous missions into the OCI instrument design.

PACE is being implemented by the Goddard Space Flight Center. They will design and build the OCI, as well as maintain responsibility for project managmenent, safety and mission assurance, mission operations and ground systems, launch vehicle/spacecraft/instrument payload integration and testing, OCI calibration, validation, and science data processing.

Click here for "The Earth Observer" article with detailed mission information

– Resolution

Earth surface spatial resolution at nadir of 1 kilometer^2 (0.4 mile^2) for all science bands

+ Orbit

+ Coverage

+ Downlink & Storage

+ Calibration

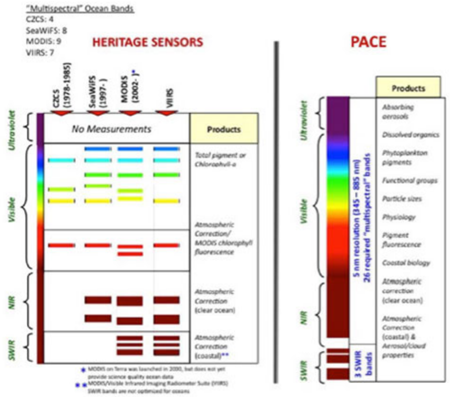
+ Timeline & Cost

Beyond Ocean Color

Comparison of PACE spectral coverage with previous U.S. ocean color sensors (i.e., "heritage" sensors). The PACE instrument will provide continuous high-spectral-resolution observations (5 nanometers, nm) from the ultraviolet to near infrared (i.e., 350 – 800 nm), plus several short-wave infrared (SWIR) bands.

These SWIR bands will support studies of clouds and aerosols. These are the key atmospheric components affecting our ability to predict climate change.

Click here for the full PACE Science Definition Team Report



Website – development

Societal Benefits

The advanced capabilities of the PACE OCI will enable improvement in these application areas:	
	Improved mapping, assessment and undestanding of climate-relevant biogeochemical concentrations and fluxes. Enhanced climate model skill and forecasting capabilities. Better support for policy analyses and assessments. Refined design of planning adaptation and response approaches to impacts of climate change.
	Improved monitoring of water quality (e.g., low oxygen conditions) and water resources. Enhanced management of water resources, fisheries, and ecosystems. Refined detection of Harmful Algal Blooms. Improved knowledge of toxic matter abundances (e.g., pollutants, pathogens, bacteria). Refined monitoring of sea ice extent and ocean currents.
	Support improved models for forecasting and early warning detection of Harmful Algal Blooms, identification of endangered species, and assessment of biodiversity. Refined data assimilation into coean models to improve model skill and forecasting capabilties.
	PACE will enable refined detection, tracking, and assessment of the effects of hurricanes, oil spills and seeps, volanic ash plumes, and fires. It will improve evaluation of the impact of these disasters on marine and terrestrial ecosystems and human health.
	PACE will suport improved air quality monitoring, forecasting, and management. It will also allow refined assessment of climate change impacts on air quality and public health.

With the PACE mission moving forward, NASA anticipates extending its ocean color data record into a third decade with continuous measurements of ocean color, clouds, and aerosols. This long-term record will directly benefit society by monitoring the extent and impacts of climate change.

Home Features Team Social

Website – Science Team

Science team members' products can be disseminated through the PACE *Data Gallery*

Science Meeting artifacts and *Publications* can be linked to *People* pages

Online events will allow the public to receive timely information about PACE science

- Website archives will ensure long-term access

Any additional suggestions?

jeremy.werdell@nasa.gov

PACE Town Hall

PACE Town Hall @ AGU Ocean Sciences Meeting

Monday evening, 22 Feb 2016

questions the Science Team can help address

What is gained (& lost) for research & applications by having:

1) 500 m at nadir with pixel growth (> 2-3 km) towards edges of scan vs. 1000 m from nadir all the way to the edge of scan?

1) an OCI with 500 or 750m resolution rather than 1000m?

2) an OCI with a UV range extended below 350nm?

1) an OCI w/ the ability to subsample (say 1-2 nm) in targeted spectral ranges?

2) an OCI with a native resolution smaller than 5 nm?

3) an OCI with different UV/VIS/NIR/SWIR SNRs that are different than the threshold values defined by the PACE SDT?

4) data latency of 3, 6 or 12 hrs?

5) retrievals at higher sensor & Solar geometries?

jeremy.werdell@nasa.gov

Backup Slides

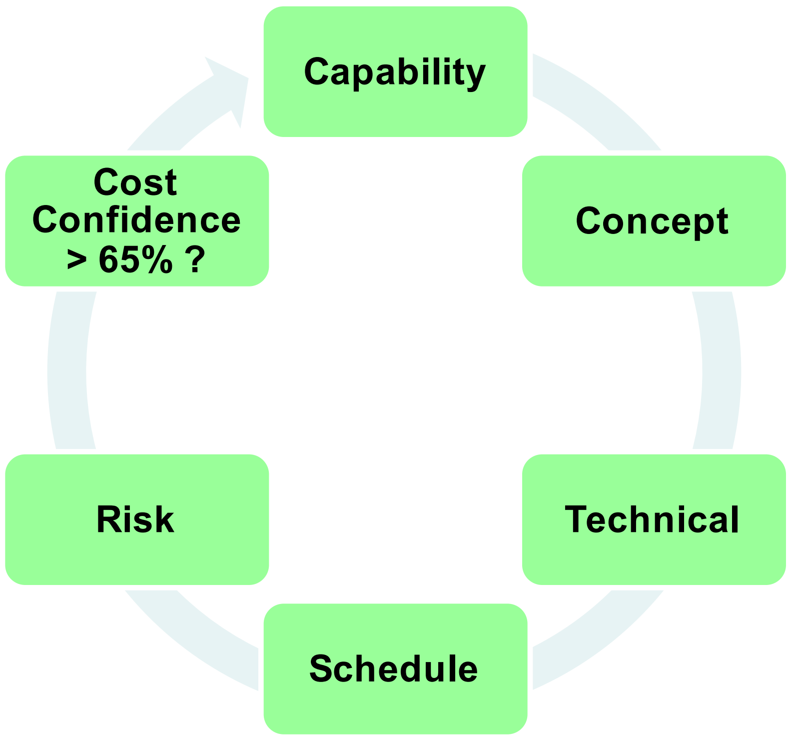
ESD Program Science priorities defined

1. Global Ocean Color, Clouds and Aerosols Science
   – Needs to be fully compliant with threshold requirements
2. Enhanced Clouds and Aerosols Science
   – Maximized capability at lowest cost
3. Coastal Ocean Science
   – Approximately 100 meter spatial resolution
4. Direct Broadcast of Science Data
   – Requires an additional COMM (X-Band) service

jeremy.werdell@nasa.gov

Design To Cost in a nutshell

Mission Baseline Requirements (Not Established)



Pre-Phase A iterated on concepts until the capability/ science and cost confidence was maximized

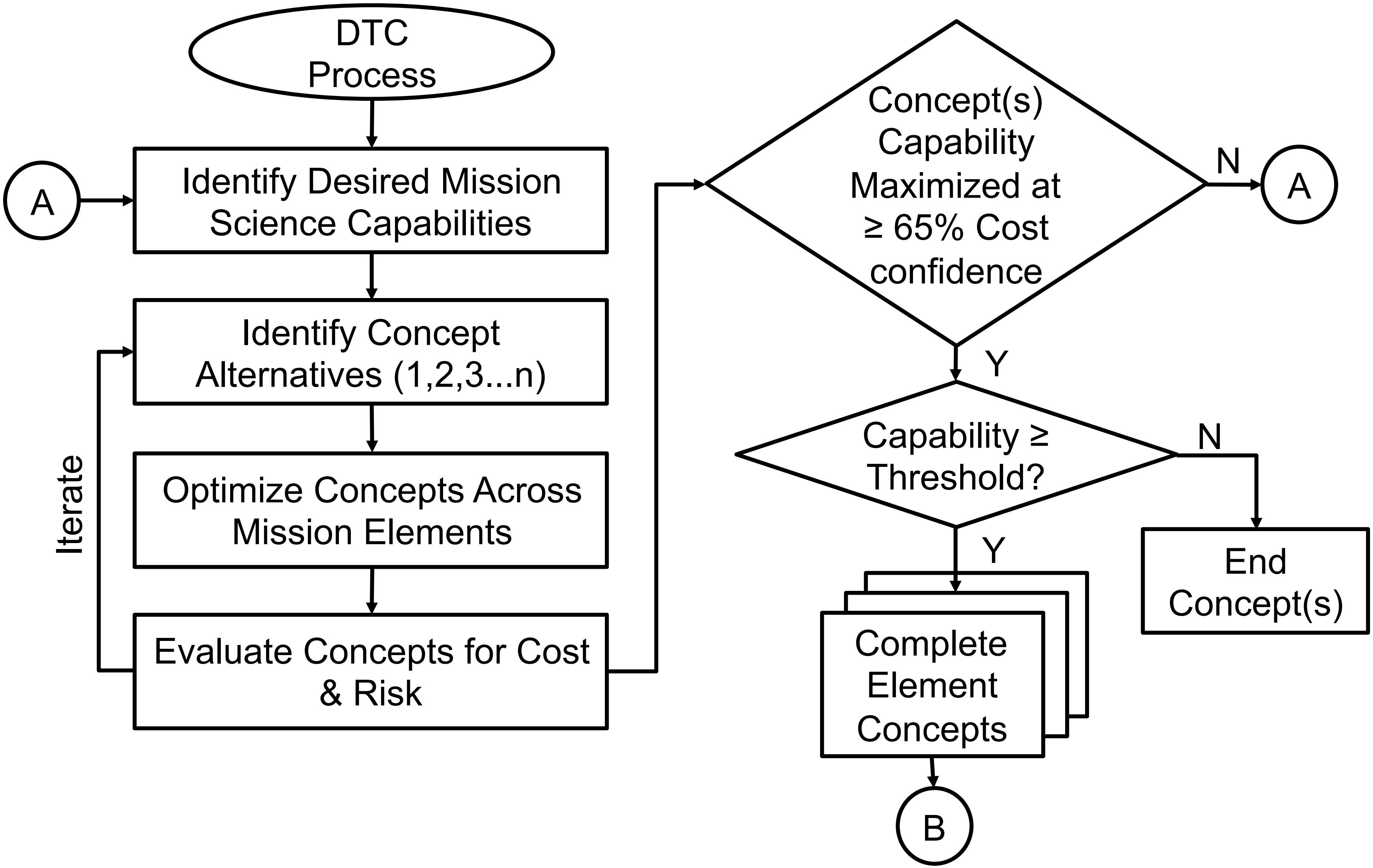
Phase A/B will continue to iterate within an element single concept

Mission Threshold Requirements (Established)

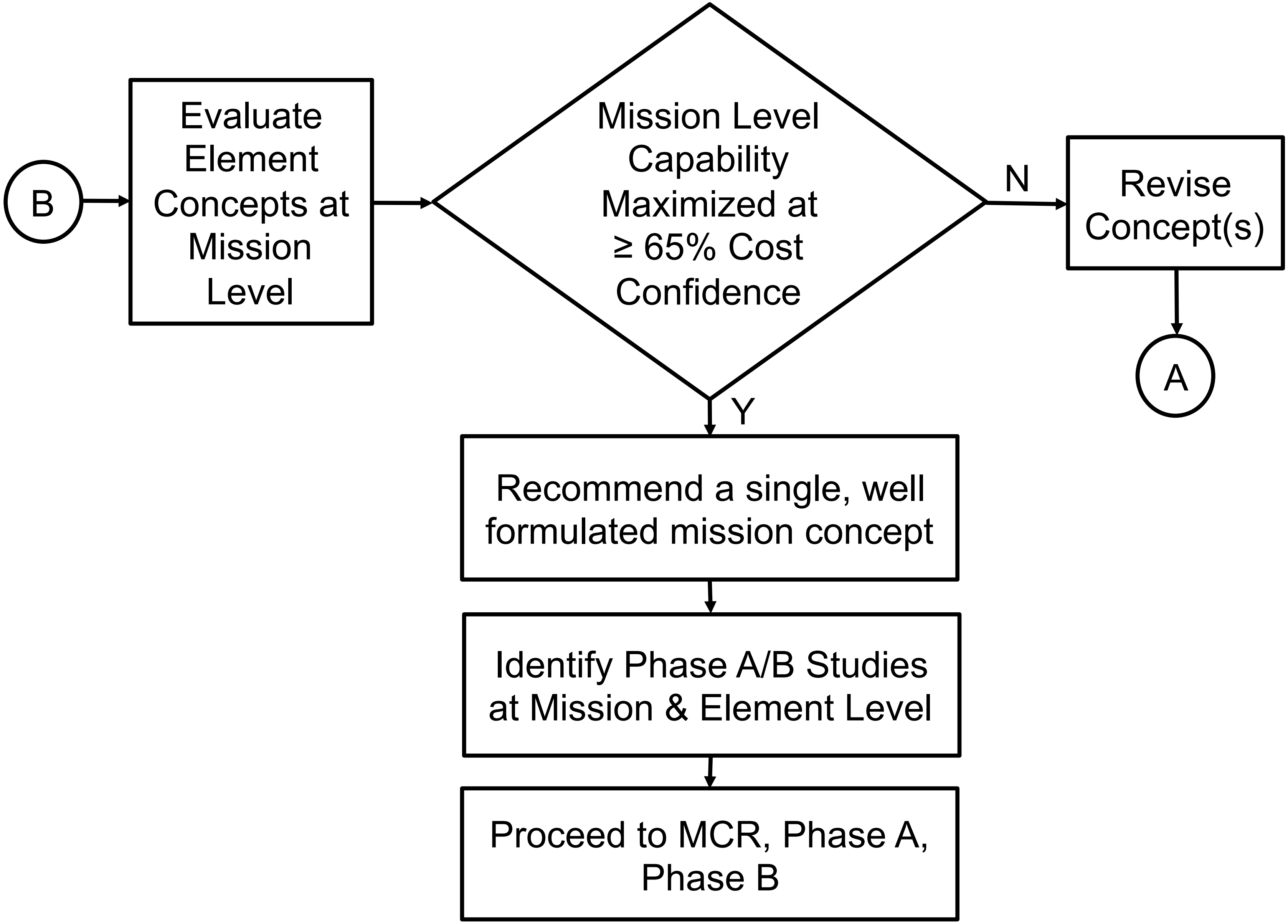
Capability below the Threshold and/or below 65% cost confidence is a non-starter

jeremy.werdell@nasa.gov

PACE Design to Cost process



PACE Design to Cost process



jeremy.werdell@nasa.gov

PACE acquisition options

Item	Description	Acquisition Approach
Spacecraft	BUS	- Independent procurement - RSDO Rapid III - In-House Build - Contributed
Aerosol Instrument	Polarimeter	- Competitive - JPL Provided - Contributed - None
Launch Vehicle	Falcon 9, Atlas	- KSC/ULA - Provided by Spacecraft Vendor (Delivery in Orbit) - Contributed
Ocean Color Instrument	Scanner or Pushbroom Coastal Camera	- Build in house at GSFC - Coastal Camera procured or Built In House

jeremy.werdell@nasa.gov

stripe suppression literature review

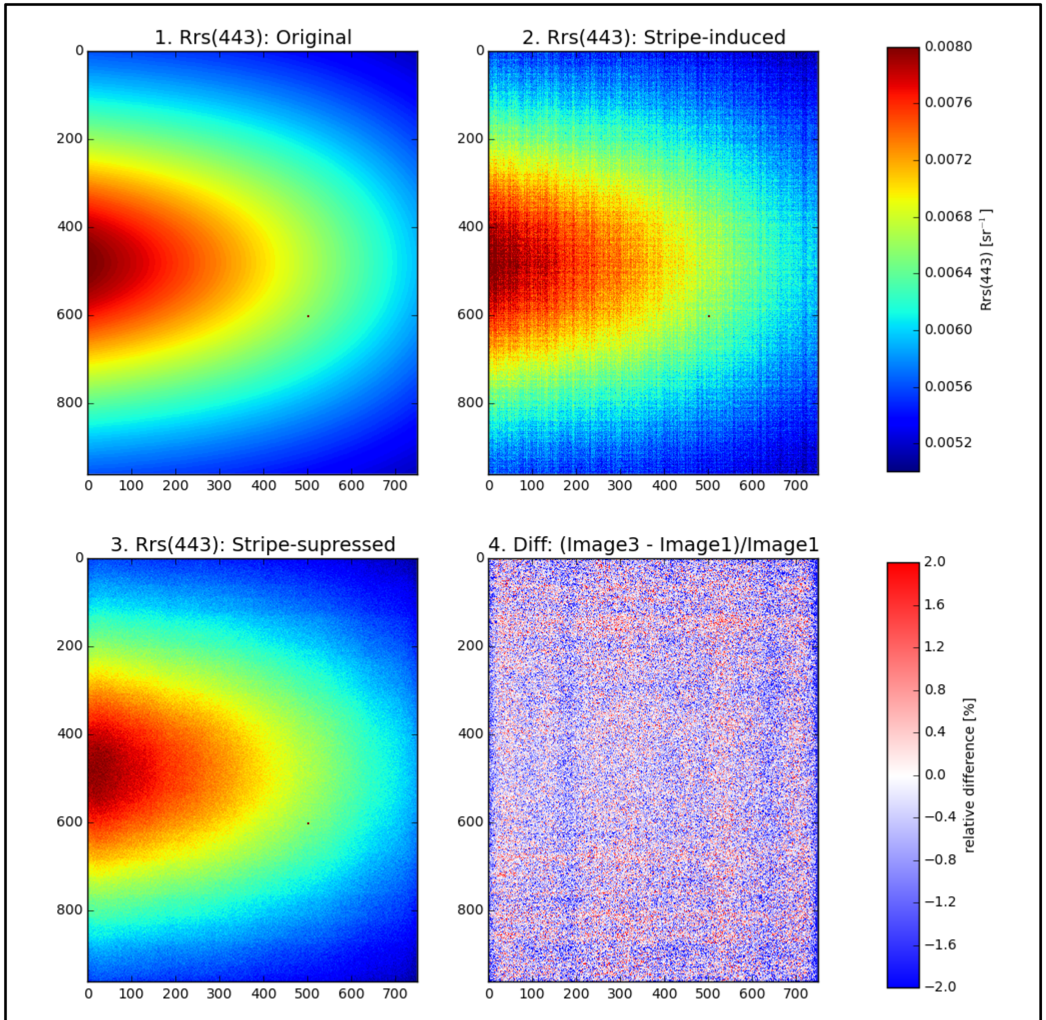
	TECHNIQUE	STRIPING TYPE	USED IN AUTOMATED OC PROCESSING	RESIDUAL STRIPING ARTIFACTS	LEVEL OF EFFORT	TEST SENSOR	REFERENCE
Pushbroom	Polynomial fitting	Along-track	✖	✔	Low	MOS	Franz (1998)
Pushbroom	Heterogeneous single image-based band equalization	Along-track	✖	✔	Low	OCM	Lyon (2009)
Pushbroom	2D Wavelet Fourier-adaptive filtering	Along-track	✖	✔	Moderate	Hyperion	Pande-Chhetri and Elrahman (2011)
Pushbroom	Homogenous multiple image-based band equalization	Along-track	✖	✔	Moderate-to-high	MOS MERIS	Corsini and Diani (2000) Bouvet and Romoino (2009)
Scanner	Frequency/impulse filtering	Cross-track	✖	✔	Low	CMODIS GOES	Chen et al (2003) Simpson et al (1995)
Scanner	Moment matching	Cross-track	✖	✔	Low	Landsat TM	Gadallah et al. (2000)
Scanner	Histogram matching	Cross-track	✖	✔	Low	Landsat GOES	Wegner (1990) Wienreb et al (1989)
Scanner	Non-linear variational model	Cross-track	✖	✔	Moderate	VIIRS	Bouali and Ignatov (2014) Mikelsons et al. (2014)
Scanner	Mirror-side effect corrections	Cross-track	✔	✔	High	MODIS	Meister et al. (2009)

Many stripe suppression algorithms exist

- Most solve targeted problems & are applied image-by-image
- Few address along- & cross-track striping
- Few (any?) applied operationally for OC processing

destriping in operational environments

image 1



Create 3 randomly striped images. De-stripe them using a common method. Identify residual stripes in the 3 images. Quantify between-image differences in residual striping.

Result: the destriped images for all 3 runs vary in their relative difference to the original (unperturbed) image

image 2

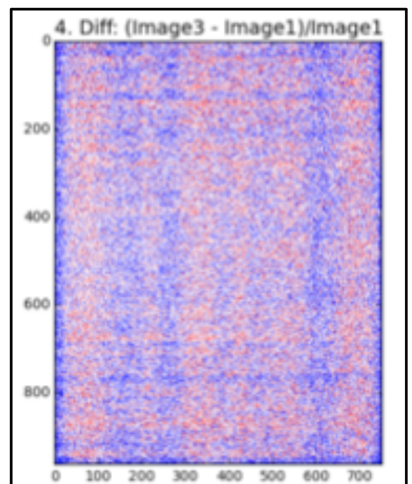
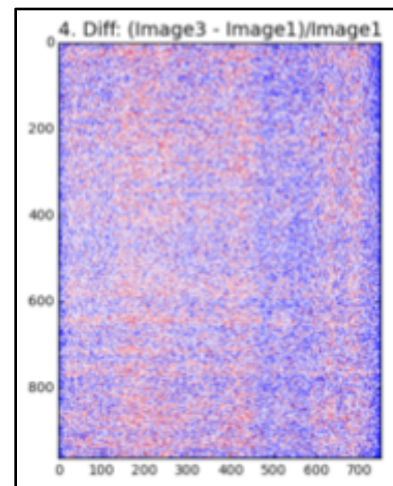


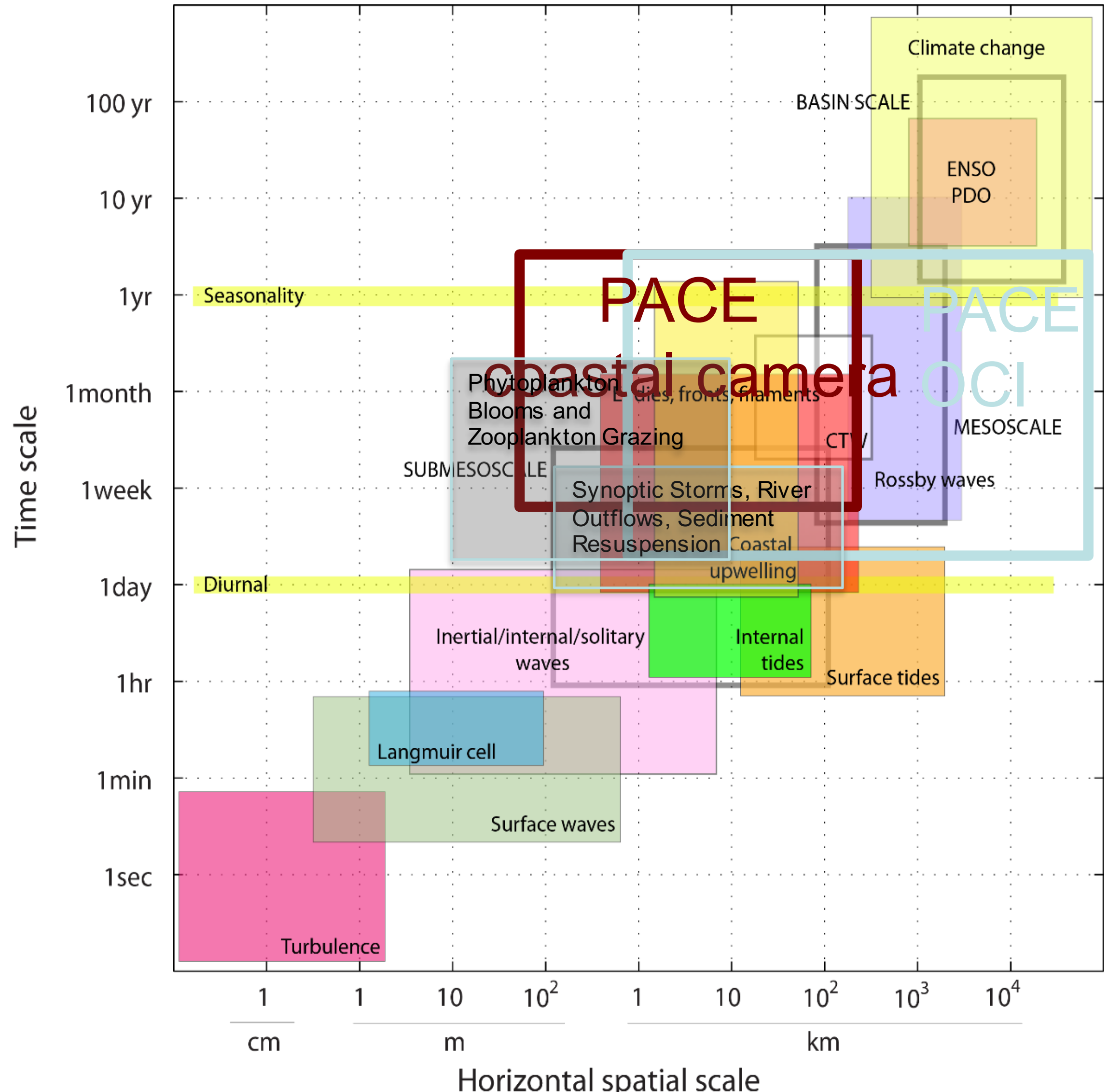
image 3



background - spatial & temporal scales of physical oceanographic processes

Physical processes regulate the spatial-temporal dynamics of biological and biogeochemical processes and constituent distributions.

High spatial resolution capability is necessary to resolve the spatial variability of these processes and constituents within estuaries, nearshore ocean, and inland waters and sub-mesoscale features in continental shelf and open ocean waters.



(Chelton 2001, Dickey *et al.* 2006; Kim 2015)

science background for fine GSD sensor

- **Coarser spatial resolution can lead to underestimation in satellite retrievals of biogeochemical properties** (Kutser 2004; Lee et al. 2013).
- Moline et al. (2005) reported minimum length scales of 50-300 m based on spatial scales of optical properties from an autonomous underwater vehicle.
- Bissett e al. (2004) also reported optimal ground sampling scales for inner shelf waters of 50-200 m for locations 1-10 km from shore.
- Davis et al. (2007) concluded that <100 m GSD is required to resolve the spatial variances of optical properties within turbid near-shore waters.
- Based on 250 m MODIS, a GSD of <520 m is required to resolved gradients in suspended particulate matter in river plumes with required GSD increasing to ~750 m on the shelf and ~1350 m in the open ocean (Aurin el al. 2013)
- Lohrenz documented variance in chlorophyll residuals for features having spatial scales on the order of 500 m or less.
- Moses and Ackleson observed a significant increase in spatial information for ocean constituents/optical properties occurs at GSD of <200 m in near-shore waters and GSD of <500 m in offshore waters.
- Tzortziou et al. found that a GSD of ≤100 m is needed to resolve the spatial gradients in CDOM, DOC and chlorophyll within 1 km of tidal marshes.
- GSD analysis using OLI and in situ observations show results consistent with these prior analyses (Signorini, Cetinic, Pahlevan).

industry survey

What we <u>provided</u> in the RFI:

Element	Requirement
Orbit	• 650 km, ~98 degree inclination polar • Sun synchronous orbit with a local equator crossing time close to Noon
Mission Life	• 3 years
Spatial resolution	• 50 to 150 m
Spectral Range	• VIS-NIR range and include two NIR bands for atmospheric correction • Coverage of the VIS-NIR range can be accomplished with either a spectrograph design or with the selection of 8 to 12 spectral bands • Coverage in the UV range is desirable, but optional to help keep cost down

industry survey

What we provided in the RFI:

	Band Width (nm)	L_{typ} * mW/(cm² μm sr)	L_{max} ** mW/(cm² μm sr)	Purpose
350 (optional)	15	7.46	35.6	Atmospheric Correction, Ocean color science
360 (optional)	15	7.22	37.6	Ocean color science
385 (optional)	15	6.11	38.1	Ocean color science
412	15	7.86	60.2	Ocean color science
425	15	6.95	58.2	Ocean color science
443	15	7.02	66.4	Ocean color science
460	15	6.83	72.4	Ocean color science
475	15	6.19	72.2	Ocean color science
490	15	5.31	68.6	Ocean color science
510	15	4.58	66.3	Ocean color science
532	15	3.92	65.1	Ocean color science
555	15	3.39	64.3	Ocean color science
583	15	2.81	62.4	Ocean color science
617	15	2.19	58.2	Ocean color science
640	10	1.90	56.4	Ocean color science
655	15	1.67	53.5	Ocean color science
665	10	1.60	53.6	Ocean color science
678	10	1.45	51.9	Ocean color science
710	15	1.19	48.9	Ocean color science
748	10	0.93	44.7	Ocean color science
820	15	0.59	39.3	Ocan color science
865	40	0.45	33.3	Ocean color atmosheric correction
940	30	0.78	21	Cloud and aerosol science

- Ltyp, the expected open ocean cloud free radiance per spectral band
- Ltyp used to compute SNR
- Lmax, the maximum expected radiance – typically for cloud cover. Note, the camera should not saturate at Lmax
- The swath width should be on the order of 400 to 600 km.

industry survey

What we <u>requested</u> in the RFI:

- Camera technical capabilities, key interfaces, and heritage
- Expected Signal to Noise Ratios with the camera
- Mass, power and volume for a single; second; third camera
- Company capabilities, applicable facilities, experience base
- Notional schedule; assume authority to proceed April 2017
- ROM cost of a single camera design and the cost of adding a second and/or possibly a third camera in real year dollars
- Key technical, schedule, and price drivers and options to mitigate risks and/or reduce schedule

jeremy.werdell@nasa.gov

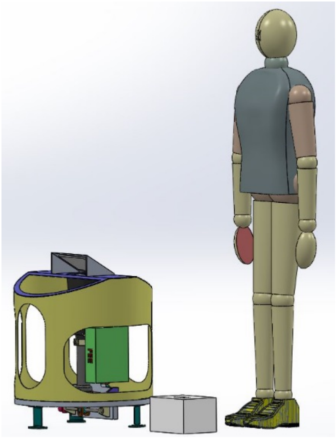
coastal camera IDL study input

- Cost is most critical ($3M to $10M)
  - The performance of this instrument is in the trade space to optimize the lowest cost
  - Maximum science for lowest cost
- Coastal Camera will be a single pushbroom camera Class D
- Do no harm to primary Science
- Mission Requirements
  - 675km Sun-Synchronous Orbit (i~98deg); Equator crossing between 11:00 and 13:00
  - 3 year mission
  - Monthly Calibration
  - No saturation at L max
  - Investigate mechanism for glint avoidance
- High fidelity optical model requested

IDL coastal camera specifications

Capability	Minimum	Preferred	IDL Concept
GSD (m)	≤150 m	≤100 m	100
# Spectral Bands	8	≥12	12 to 14
SNR	300 NIR; 600 Vis	>600 NIR; >1000 Vis	~533 to 1725
UV bands	none	1 or more	1 to 2
Avoid Glint	N/A	±20°	±20°
Gimbal to Track Coast	N/A	±15° or greater	±15°
Bandwidth	20 nm	10 nm	10
Swath (km)	150 km	>300 km	160

- IDL coastal camera is a simple refractive optical design with a butcher block filter assembly to image 12 bands onto a single off the shelf detector
  - band set is easily expandable to 14 bands
- Classified and grass roots costed as a do no harm instrument
- Simple 2-axis gimbal for along track glint avoidance (+/- 20^o) and cross track coast line tracking (+/- 15^o)
- Integrated fixed solar diffuser enables daily solar calibration without an additional mechanism

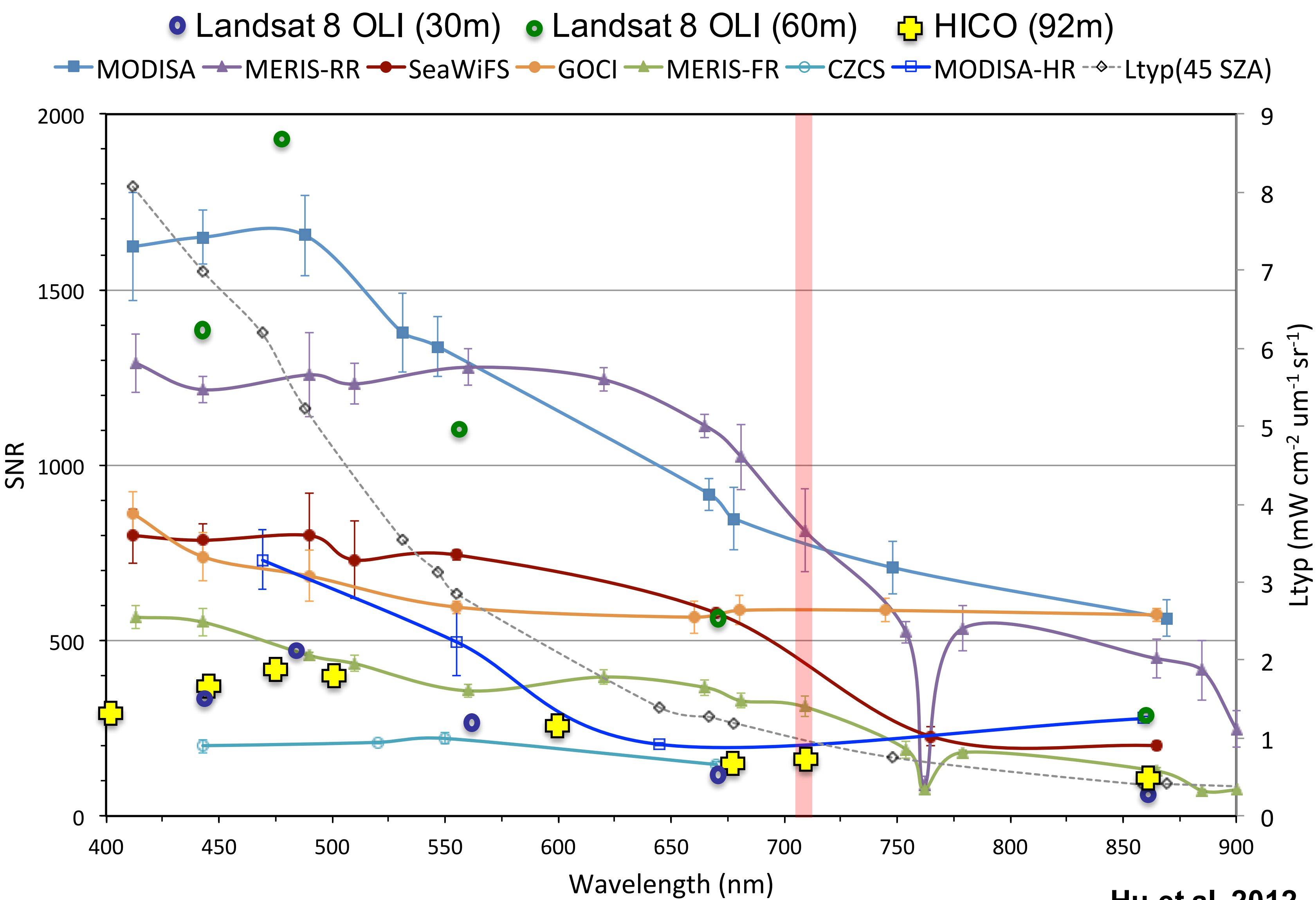


ground sample distance analyses

Analysis	Approach	Results
Method 1 Aurin et al. (2013) Rem. Sens. Environ. Uses OLI imagery	Variance of ocean color products (σ_i) & total uncertainties associated w/instrument noise (σ_t) are calculated stations as pixel box sizes are increased until $\sigma_i > \sigma_t$. Define optimal GSD as the average b/w the size of the inconclusive array ($\sigma_i \leq \sigma_t$) & the size of the array which marked the upper limit of a GSD that could resolve significant differences in ocean constituents ($\sigma_i > \sigma_t$).	Median optimal GSD: • O(50 m) for highly complex water (Chesapeake Bay) • O(250 m) for continental shelf water (Exmouth Gulf, Australia) • O(500-1000+ m) for open ocean waters (Sargasso Sea)
Method 2 Moses & Ackleson (2015) IOCS poster Uses high resolution field measurements	Use high spatial resolution in situ measurements to estimate spatial variability (SVI) relative to GSD. SVI = average coefficient of variation of pixels in box / average coefficient of variation of all pixels in image/transect	In coastal waters, relative to 50 m: 11% less variance explained @ 100 m 33% less variance explained @ 250 m 36% less variance explained @ 500 m If a coastal oceanographic process occurs on a scale of O(50 m), a 250 m pixel will only contain O(67%) information about that process

jeremy.werdell@nasa.gov

SNR of heritage sensors scaled Ltyp values



Hu et al. 2012