Cosmic Origins Program Analysis Group (COPAG)

Astrophysics Subcommittee Meeting

July 21-22, 2015

Kenneth Sembach

Current COPAG Executive Committee Membership

Name	Institution	Term Expiration
Daniela Calzetti	U. Mass. Amherst	Jan 2017
Dennis Ebbets	Ball Aerospace (retired)	Jan 2017
James Green	U. Colorado	Jan 2017
Matthew Greenhouse	NASA GSFC	Jan 2018
James Lowenthal	Smith College	Rotated off Mar 2015
Sally Heap	NASA GSFC	Jan 2017
Lynne Hillenbrand	Caltech	Rotating off Oct 2015
Mary Beth Kaiser	Johns Hopkins U.	Oct 2017
Joseph Lazio	NASA JPL	Oct 2017
Pamela Marcum	NASA ARC	Oct 2017
Ken Sembach - Chair	STScI	Mar 2016

10 members + ex-officio (S. Neff & D. Padgett in COR office, M. Perez & K. Sheth at HQ)

COPAG Executive Committee Member Needed

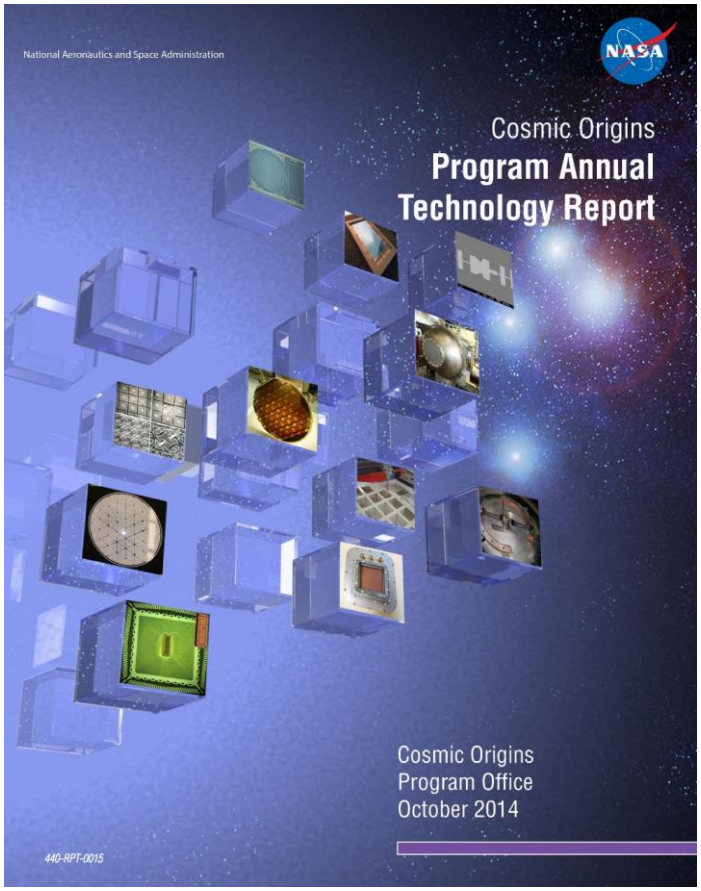
- “Dear Colleague” letter will be sent to the community in the near future
- Member for this particular slot must be selected from an academic institution, as per guidelines from NASA HQ
  - Institutional balance of committee
- Deadline for nominations in late August
- Selection in late September
- Self-nominations welcome

Yearly Technology Gap Inputs

- COPAG provides input each year into Cosmic Origins Program Office assessment of technology gaps
  - Solicited community input for 2015
  - Reviewed 33 gaps (17 carryover, 16 new)

Table 3-1. Technology Gaps Evaluated by TMB in 2014 (continued)

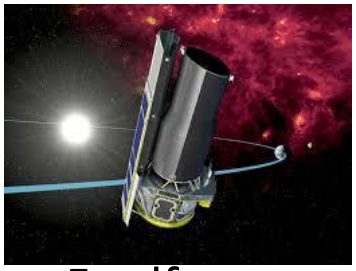
Name of Technology	Photon-counting large-format UV detectors
Description	Future NASA UV missions, particularly those devoted to spectroscopy, require high-QE, low-noise, large-format, photon-counting detectors for operation at 90-350nm or broader. Red-leak (longer wavelength) suppression is highly desirable for some applications.
Current State of the Art	Previously-flown UV detectors obtain ~5-20% QE (wavelength dependent), require high voltage, and can be difficult to fabricate. Silicon-CCD detectors are TRL 4-5. Other technologies (MCP; avalanche photo-diode, APD; Electron-Bombarded CCD, EBCCD; with GaN Photocathodes) are TRL 2[§§]-4.
Current TRL	2 – 5
Performance Goals and Objectives	The goal is to produce large-format (>2k×2k pixels), high-QE (> 50%), low-noise (<10^{-7} ct/pixel/s) UV-sensitive detectors routinely that can be used in a variety of Explorer, medium, and strategic missions for imaging and spectroscopy of the UV sky. Further enhancement would be to achieve energy-resolving capability.
Scientific, Engineering, and/or Programmatic Benefits	High-performance detectors can increase the science impact of missions by ×10-1000, depending on areal coverage and QE.
COR Applications and Potential Relevant Missions	The science impact of cost-constrained, aperture-constrained future missions is dramatically improved by reaching near-perfect detector performance. The 2010 Decadal Survey noted the importance of technology development for a future 4m-class UV/visible mission for spectroscopy and imaging. Benefits will also accrue to planetary, heliospheric, and Earth missions in the UV band.
Time to Anticipated Need	As early as possible since mission definition and capabilities are built around detector performance. There is a clear plan to achieve this technology. Users identified. To support Explorer AOs in the second half of this decade, a focal-plane technology development + flight testing project should be started in 2014 – 2015 (*i.e.*, immediately). This would allow time for a suborbital mission to fly in 2017 – 2020.



Active Science Analysis Groups

- SAG #8: Cosmic Origins Science Enabled by the WFIRST-AFTA Data Archive
  - COPAG Lead: Sally Heap
  - Overview at March 2015 ApS meeting (see backup slides)
  - In progress, final draft nearly ready for review by ApS
  - Report is timely given the upcoming selection of WFIRST Science Investigation Teams

- SAG #9: Science Enabled by Spitzer Observations Prior to JWST
  - COPAG Lead: Daniela Calzetti
  - Overview at March 2015 ApS meeting (see backup slides)
  - Report emailed to ApS on 15 June 15, 2015
  - Available here: http://cor.gsfc.nasa.gov/sags/SAG9_Report_v5.pdf
  - Seeking ApS approval to accept the report and formally close this SAG



Inactive Science Analysis Groups

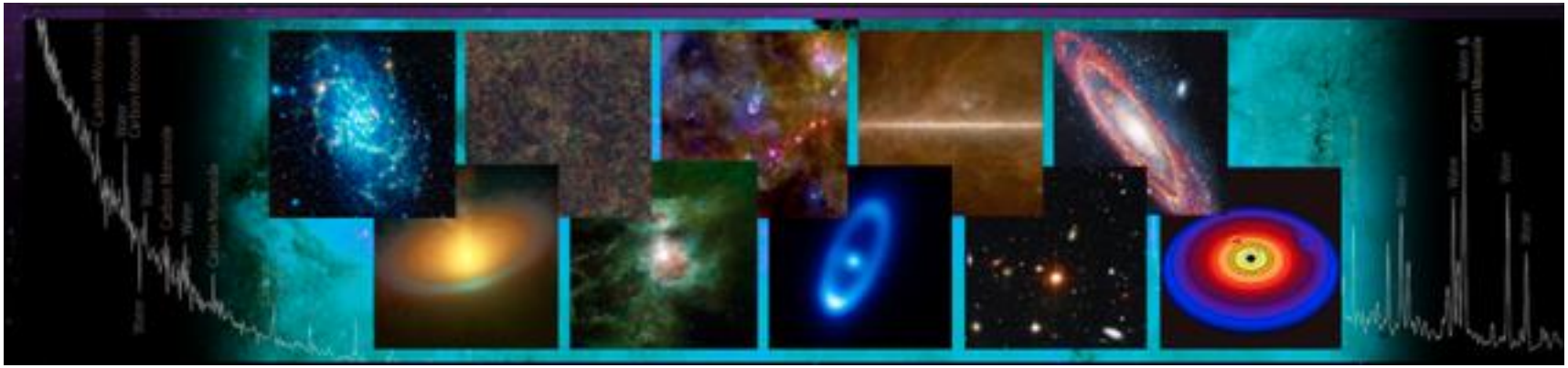
- SAG #5: Science Objectives and Technology Requirements for a Series of Cosmic Origins Probes
  - SAG #5 has been inactive for several years
  - Discussions with the community at the NASA RFI workshop at STScI in September 2012 and at the January 2013 AAS meeting
    - No substantive work since this time
  - Seeking ApS concurrence to formally terminate this SAG
    - Topic/discussion now falls under the umbrella of COPAG SIG#2 (UV/Vis)
    - May be proposed/recast later as component of a cross-PAG SAG dealing with Probe-class missions (still under discussion with the other PAGs)

SIG #1: Far-Infrared Cosmic Origins Science and Technology Development

- COPAG Lead: Pamela Marcum (EC member)
- External Leads: David Leisawitz / Paul Goldsmith

<u>Primary activity since last ApS meeting</u>

- Far-IR Surveyor Workshop held June 3-5, 2015 at Caltech
  - Purpose was to seek community input on the Far-IR Surveyor flagship concept
  - Broad representation, with >100 people in attendance and 30+ on webex
  - Excellent discussions about key science drivers and technology needs
  - Workshop report (Armus et al.), agenda, and talks can be found at:http://conference.ipac.caltech.edu/firsurveyor/



SIG #2: Ultraviolet/Visible Cosmic Origins Science and Technology Development

- COPAG Lead: Mary Beth Kaiser
- External Lead: Paul Scowen

<u>Primary activity since last meeting</u>

- SIG workshop held at GSFC on June 25-26, 2015
  - Purpose was to discuss future mission science drivers and to allow subcommittees to work together
  - Broad representation, with 80-100 participants in person and on webex
  - Excellent discussions about key science drivers and technology needs, focusing mainly (but not exclusively) on UVOIR flagships

- Workshop participants, agenda and talks can be found at: http://asd.gsfc.nasa.gov/conferences/uvvis/

SIG #3: Cosmic Dawn Science

- COPAG Lead: Joe Lazio

Primary activity since last meeting

- SIG #3 has been formed and is in the process of organizing activities, mailing lists, etc.
- Initial discussions with high energy community (HEAD meeting), but no formal coordination yet
- Expect to have splinter session at January 2016 AAS

Responding to the Charge: Preparing for the 2020 Decadal Survey

- Bi-weekly COPAG telecons
- Joint activities covered by Scott's talk
  - COPAG supported the ExoPAG12 meeting in Chicago (June 13-14)
  - COPAG representation at the HEAD meeting in Chicago (July 1)
  - COPAG SIG#1 (Far-IR) SIG#2 (UV/Vis) workshops
  - COPAG will participate in joint PAG meeting at AAS
  - COPAG virtual town hall planned for August 20
  - Future flagship session at AIAA Space 2105 Conference in Pasadena (August 31)

Responding to the Charge: Preparing for the 2020 Decadal Survey

- COPAG community white paper solicitation
  - Wide range of inputs on science needs, technology, mission drivers
  - All responses posted on COPAG website: http://cor.gsfc.nasa.gov/copag/
  - See backup slides for list of papers
  - All responses made available to ExoPAG and PhysPAG
  - Many white papers have common science themes or mission considerations applicable to multiple flagships (e.g., UVOIR and X-ray Surveyors, UVOIR Surveyor & HabEX mission, UVOIR and Far-IR Surveyors)

- COPAG also received the AURA report "Cosmic Births to Living Earths", which is a community-based two year study on future space-based options for UV and optical astronomy to advance understanding of the origin and evolution of the cosmos and the life within it
  - Study chaired by Julianne Dalcanton (U. Washington) and Sara Seager (MIT)
  - See http://www.hdstvision.org

Backup Slides
Flagship Mission Call for White Papers
(see http://cor.gsfc.nasa.gov/copag/)

Flagship Mission RFI: White Papers (1/3)

- Science Cases for Ultraviolet Polarimetry in the 21st Century
- Mapping Turbulent Energy Dissipation Through Shocked Molecular Hydrogen in the Universe
- Are Flagships the Best Way to Advance Astrophysics?
- The Dusty Co-evolution of Black Holes and Galaxies: A Science Case for a Large FIR Space Telescope
- Actuated Carbon Fiber Reinforced Polymer Mirror Development
- Astrophysics Enabled by Extreme Contrast Ratio Technologies
- A FIR-Survey of TNOs and Related Bodies
- Unlocking the Secrets of Planet Formation with Hydrogen Deuteride
- Cryogenic Telescope for Far-Infrared Astrophysics: A Vision for NASA in the 2020 Decade
- Imaging Polarimetry for ExoPlanet Science & Astrophysics
- Dust in Distant Galaxies - Overcoming Confusion Noise with a 5m FIR Facility
- Far-Infrared Spectral Line Studies of the Epoch of Reionization
- A Joint Exoplanet & UVOIR Surveyor
- The Earliest Epoch of Star-formation in the Very Young Universe
- Characterizing the Habitable Zones of Exoplanetary Systems with a Large UV/Visible/NIR Space Observatory
- The Bulk Composition of Exo-Planets
- Flagship Missions for the Decadal Review

Flagship Mission RFI: White Papers (2/3)

- Life Finder Telescope
- Galaxy Evolution Spectroscopic Surveyor (GESS)
- Precision Ages for Milky Way Star Clusters
- Importance of Design Reference Missions for Developing the Next Large Mission Concepts
- An Evolvable Space Telescope for the Far Infrared Surveyor Mission
- Exoplanet Environment Monitor
- Definitive Determination of Galaxy Luminosity Functions at Energies Above the Hydrogen Ionization Edge, Covering 11 Billion Years of Evolution
- Probing Transient Structures in the Universe
- An Evolvable Space Telescope for Future UV/Opt/IR Astronomical Missions
- A Rotating Synthetic Aperture Space Telescope for Future UV/Opt/IR Astronomical Missions
- UVOIR Surveyor: The need for high resolution, wide field, deep multi-wavelength imaging and IFU spectroscopy
- The First Stars and the First Metals
- The Origin of the Elements Heavier than Iron
- HabX2: a 2020 mission concept for flagship science at modest cost
- Listening to the Cosmic Dawn
- A Large-Aperture UVOIR Space Telescope

Flagship Mission RFI: White Papers (3/3)

- A Large-Aperture UVOIR Space Telescope
- Galaxy Fueling and Quenching: A Science Case for Future UV MOS Capability
- UV/Optical/IR Surveyor: The Crucial Role of High Spatial Resolution, High Sensitivity UV Observations to Galaxy Evolution Studies

Backup Slides
SAG #8 Report
(Slide set from January 2015 AAS)

SAG#8: Cosmic Origins Science Enabled by the WFIRST-AFTA Data Archive

Sally Heap & the SAG#8 Team

SAG#8 Charter

How will the WFIRST-AFTA data archive be used for Cosmic Origins science?

- Cross-section of COR science investigations
- High-level science data products
- Catalogs
- Archive interface design
- Calibration requirements
- Data accessibility & distribution
- Computing resources
- Archive operations

What are the data requirements needed to conduct COR science?

How to maximize the return via coordination with other astronomical archives?

Partial Inventory of Objects to be Observed by WFIRST

High Latitude Surveys

- 400M galaxies with measured shapes
- 30M galaxies in redshift survey
- 20M Hα galaxies at z=1-2
- 2M [O III] galaxies at z=2-3
- 10^5 galaxies at z≥7.5 brighter than 26 mag
- 40K massive galaxy clusters
- 2700 SN Ia at z=0.1-1.7

Microlensing Survey

- $2x10^8$ stars in galactic bulge (~40,000 obs. per star)
- 3000 planets; 300 with $M \leq M_{\oplus}$
- 10^5 transiting planets
- 5000 KBO's down to 10 km with orbits

The answer is here …somewhere

WFIRST-AFTA SDT Interim Report, p. 16

WFIRST-AFTA Deep Field reaches >1,000,000 galaxies in each image

How to find what *you* want?

Developing Query System to the WFIRST Archives

WFIRST SDT Reports + 1-Page Science Ideas

WFIRST-AFTA SDT Final Report, May 24, 2013 including Appendix A: 1-page science ideas

WFIRST-AFTA SDT Interim Report, Apr 30, 2014

\+ Typical Queries of the SDSS Archive

Designing & Mining Multi-TB Ast. Archives: SDSS Szalay et al. (2000) Proc. ACM SIGMOD 2000, p. 451

= Typical Queries of the WFIRST Archive

Cosmic Origins scientists have told us how they want to use the WFIRST archives

WFIRST Sample Queries*

- Microlensing Field (Z087, W149) – COPAG queries

- *ML1: Find all microlensing events of stars in the galactic bulge in which the apparent position of the lens shifted by a measurable amount during the microlensing event. (Sahu, A-18).* This is a search for neutron stars and stellar-mass black holes in the Galaxy.
- *ML2: Provide a complete database of the fluxes, positions, proper motions and parallaxes of all bulge and disk stars (~10^8 stars) in microlensing survey of the galactic bulge. (Gaudi, A-19)*
- *ML3: Provide a list of all bulge stars showing evidence of having a transiting planet(s). (IR-53,57)*
- *ML4: Find all KBO's (Gould 2014, IR-57)*
- *ML5: Find all objects whose absolute magnitudes and colors are consistent with blue stragglers /red giants / white dwarfs / <keyword>. (31Oct14 WFIRST SDT telecon)*

- All queries inspired by references; not direct quotes
- References: author of 1-page science idea; Appendix A, page #

WFIRST Sample Queries*

- High latitude imaging (~R, Y, J, H, F184)

Find all stars brighter than J~25 whose WFIRST+WISE colors are consistent with an L or T brown dwarf (Tanner, A-12)

Find all galaxies showing double nuclei (Conselice, A-32)

Find all galaxies whose LSST + WFIRST SED's indicate a $z_{phot}>7$

WFIRST Sample Queries

- High-latitude spectra (1.35-1.95 μm)

Find all elliptical z>1 galaxies whose spectra show an anomalous emission line (Szalay, Q11)

Find all z>1 galaxies observed by both WFIRST and Euclid (0.9-2.0 μm) having Hα and [O III] emission lines (Scarlata, A-47).

- Supernovae

Find all galaxies in clusters at z~0.5-1.5 in which >0.5-mag flux variations were detected

The 20 Queries around which the SDSS SkyServer was built

Q1: Find all galaxies without unsaturated pixels within 1' of a given point of ra=75.327, dec=21.023

Q2: Find all galaxies with blue surface brightness between and 23 and 25 mag per square arcseconds, and -10<super galactic latitude (sgb) <10, and declination less than zero.

Q3: Find all galaxies brighter than magnitude 22, where the local extinction is >0.75.

Q4: Find galaxies with an isophotal surface brightness (SB) larger than 24 in the red band, with an ellipticity>0.5, and with the major axis of the ellipse having a declination of between 30" and 60"arc seconds.

Q5: Find all galaxies with a deVaucouleours profile ($r^{1/4}$ falloff of intensity on disk) and the photometric colors consistent with an elliptical galaxy. The deVaucouleours profile

Q6: Find galaxies that are blended with a star, output the deblended galaxy magnitudes.

Q7: Provide a list of star-like objects that are 1% rare.

Q8: Find all objects with unclassified spectra.

Q9: Find quasars with a line width >2000 km/s and 2.5<redshift<2.7.

Q10: Find galaxies with spectra that have an equivalent width in Ha >40Å (Ha is the main hydrogen spectral line.)

Q11: Find all elliptical galaxies with spectra that have an anomalous emission line.

Q12: Create a grided count of galaxies with u-g>1 and r<21.5 over 60<declination<70, and 200<right ascension<210, on a grid of 2', and create a map of masks over the same grid.

Q13: Create a count of galaxies for each of the HTM triangles which satisfy a certain color cut, like 0.7u-0.5g-0.2i<1.25 && r<21.75, output it in a form adequate for visualization.

Q14: Find stars with multiple measurements and have magnitude variations >0.1. Scan for stars that have a secondary object (observed at a different time) and compare their magnitudes.

Q15: Provide a list of moving objects consistent with an asteroid.

Q16: Find all objects similar to the colors of a quasar at 5.5<redshift<6.5.

Q17: Find binary stars where at least one of them has the colors of a white dwarf.

Q18: Find all objects within 30 arcseconds of one another that have very similar colors: that is where the color ratios u-g, g-r, r-I are less than 0.05m.

Q19: Find quasars with a broad absorption line in their spectra and at least one galaxy within 10 arcseconds. Return both the quasars and the galaxies.

Q20: For each galaxy in the BCG data set (brightest color galaxy), in 160<right ascension<170, -25<declination<35 count of galaxies within 30"of it that have a photoz within 0.05 of that galaxy.

Szalay's 20 questions were implemented as SQL queries of the SDSS archive

http://cas.sdss.org/dr4/en/help/docs/realquery.asp

"Click on the name of the query from the list below to go directly to that sample query. The queries are roughly in order of increasing complexity. You can cut and paste queries from here into your favorite search tool".

Basic SQL:
Basic SELECT-FROM-WHERE
Basic position search
Using PhotoTag
Search for a Range of Values
Rectangular position search
More than one table: JOIN...ON
Photometry & spectroscopy
Counting by type or category
Using flags

SQL Jujitsu:
Data subsample
Objects in close pairs
Selected neighbors in run
Object counts and logic
Repeated high-*z* objects
Splitting 64-bit values
Using LEFT OUTER JOIN
Using Nested Queries

Quasars:
QSOs by spectroscopy
QSOs by colors
FIRST matches for quasars

General Astronomy:
Only stars or galaxies
Clean photometry
Using Field MJD
Objects by spectral lines
Spectra by classification
Moving asteroids
Plates with repeat spectra
Galaxies blended with stars
Counts by type and program
Checking SDSS footprint

Stars:
Clean photometry - Stars
CVs using colors
Binary stars colors
Using sppLines table
Using sppParams table
Proper motions

Miscellaneous:
Photometric Redshifts
Spectra in Other Programs - I
Spectra in Other Programs - II
Using WISE Cross-Match

Galaxies:
Clean photometry - Galaxies
Galaxies with blue centers
Diameter limited sample
LRG sample selection
Galaxy counts on HTM grid
Classifications from Galaxy Zoo
BOSS target selection
BOSS Stellar Masses
BOSS Stellar Vel. Disps.

Varaibility Queries:
Stars multiply measured
Multiple Detections and Time Series

APOGEE:
All APOGEE Plate Visits
ASPCAP Parameters and Errors
APOGEE Stars No BAD Flags
ASPCAP Params for Cluster Mbrs
APOGEE Proper Motions
APOGEE Stars Near Cluster Ctr
RVs for Individual APOGEE Visits
APOGEE and SEGUE Spectra
SDSS photometry for APOGEE Stars

Sample Query

Query written
In SQL

Query contributed
by user

Galaxies with blue centers Top

```
-- Galaxies with bluer centers, by Michael Strauss. For all galaxies with r_Petro < 18,
-- not saturated, not bright, and not edge, give me those with centers appreciably bluer
-- than their outer parts, i.e., define the center color as: u_psf - g_psf and define
-- the outer color as: u_model - g_model; give me all objs which have
--     (u_model - g_model) - (u_psf - g_psf) < -0.4
--
-- Another flags-based query.
-- NOTE: This query takes a long time to run without the "TOP 1000".

SELECT
colc_u, colc_g, objID
FROM Galaxy
WHERE
( Flags & (dbo.fPhotoFlags('SATURATED') +
dbo.fPhotoFlags('BRIGHT') +
dbo.fPhotoFlags('EDGE')) ) = 0
and petroRad_r < 18
and ((colc_u - colc_g) - (psfMag_u - psfMag_g)) < -0.4
```

Q19: Find quasars with a broad absorption line in their spectra and at least one galaxy within 10 arcseconds. Return both the quasars and the galaxies.

QSO broadlines near galaxy


```
-- Find quasars with a broad absorption line and a nearby galaxy within 10arcsec.
-- Return both the quasars and the galaxies.

SELECT Q.BestObjID as Quasar_candidate_ID , G.ObjID as Galaxy_ID, N.distance
FROM SpecObj as Q, -- Q is the specObj of the quasar candidate
     Neighbors as N, -- N is the Neighbors list of Q
     Galaxy as G, -- G is the nearby galaxy
     SpecClass as SC, -- Spec Class
     SpecLine as L, -- L is the broad line we are looking for
     SpecLineNames as LN -- Line Name
WHERE Q.SpecClass =SC.value -- Q is a QSO
     and SC.name in ('QSO', 'HIZ_QSO') -- Spectrum says "QSO"
     and Q.SpecObjID = L.SpecObjID -- L is a spectral line of Q.
     and L.LineID = LN.value -- line found and
     and LN.Name != 'UNKNOWN' -- not not identified
     and L.ew < -10 -- but its a prominent absorption line
     and Q.BestObjID = N.ObjID -- N is a neighbor record
     and G.ObjID = N.NeighborObjID -- G is a neighbor of Q
     and N.distance < 10.0/60 -- and it is within 10 arcseconds of the Q.
```

Conclusions & Recommendations

To accommodate Cosmic Origins users, the WFIRST data processing system must include Levels 1, 2, *and* 3

- Level 1 ~ data capture, error checking, formatting, etc.
- Level 2 ~ data reduction and flux & wavelength calibration, etc.
- Level 3 ~ object classification (Gal, Star, QSO, KBO, variables, etc), & measurements (mag, colors, morphology, redshifts, sizes, shapes, morphological parameters, environmental parameters, etc.)

NASA Astrophysics Division has traditionally supported Level 1 and 2 data processing, but not level 3

The usefulness of the WFIRST Archives to Cosmic Origins scientists depends on having access to Level-3 data

Make it better

Get the full list of 40+ queries for WFIRST archives

Send suggestions and criticisms to:

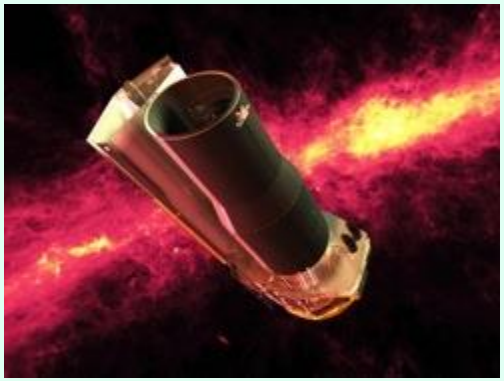
Sally.Heap@NASA.gov

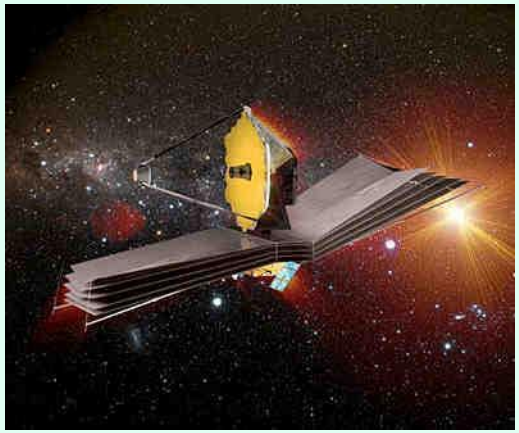
Better yet, join the COPAG and participate in the Science Analysis Group #8

We need your help

Backup Slides
SAG #9 Report
(Prepared for the ApS)

COPAG/SAG 9:
Science Enabled by Spitzer Observations Prior to JWST Launch
- Progress Report -





Presentation to the Astrophysics Subcommittee, March 2015

Picture credits (for entire presentation): ESA and NASA

Charter of SAG 9

- Much of the science conducted with JWST will build off of existing Spitzer data and science results.
- Spitzer has now entered the 6th year of its Warm Mission, and its capabilities still offer unique science opportunities for JWST precursor observations and science.
- Identify compelling science to be done with JWST, that is enabled by or that benefits from large blocks of Spitzer observing time prior to JWST launch.
- Document its findings in a report to the Astrophysics Subcommittee (currently in draft form).

SAG 9 Membership

Daniela Calzetti (co-Chair)		- calzetti@astro.umass.edu
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Ned Wright	- UCLA	- wright@astro.ucla.edu

Observers:

Pierre Ferruit	- ESA	- Pierre.Ferruit@cosmos.esa.int

Community Involvement

- Community inputs solicited through a number of channels:
  - Mail exploders (COPAG, Spitzer Users, DPS members, and the Planetary Exploration Newsletter)
  - Presentations at science meetings (Winter 2015 AAS Meeting, January 4th, 2015; SBAG winter meeting, January 6th, 2015)
  - Advertisement via the above channels of a general email address (copag.sag9@gmail.com), set-up to facilitate inputs from the community
  - Community members also encouraged to contact individual SAG9 members.
  - In response to solicitations, several members of the community have provided inputs.

Current (Warm) Spitzer Capabilities

[courtesy of Sean Carey (SSC-IPAC)]

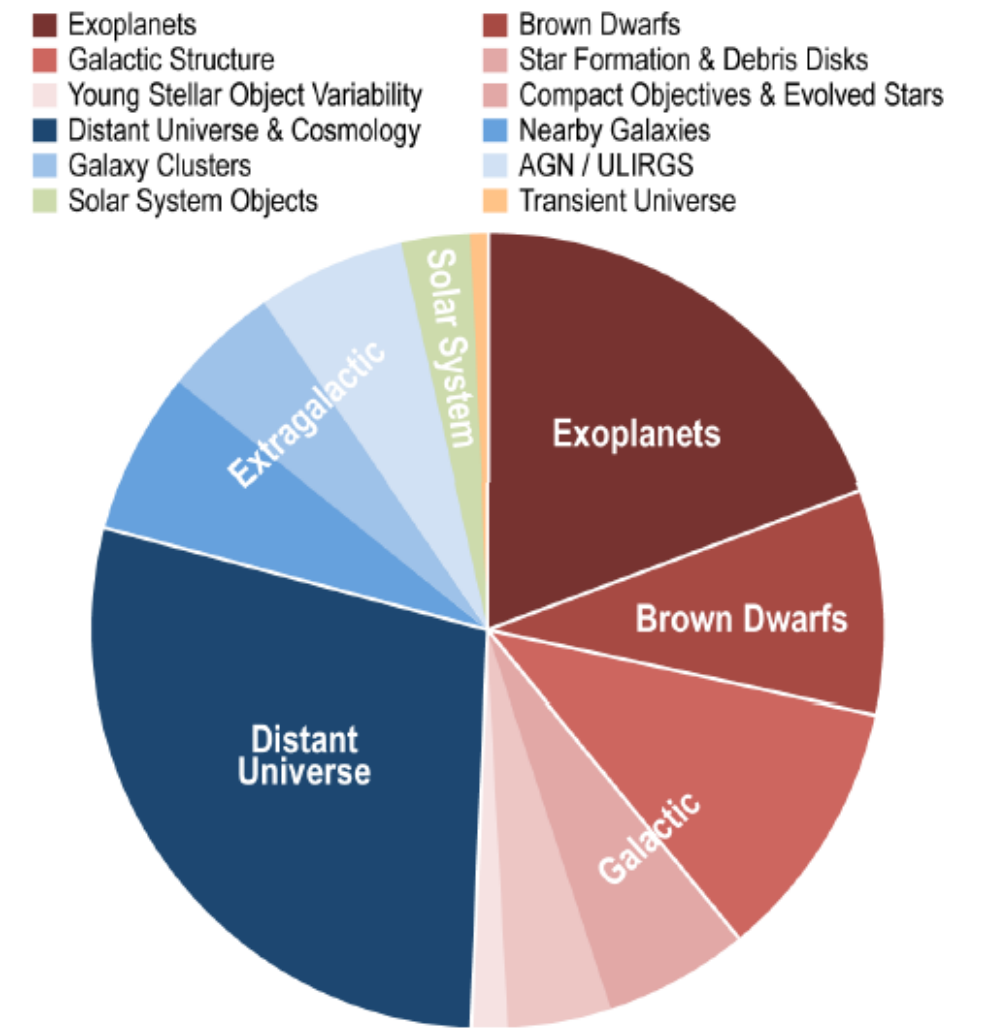
- Two IRAC Cameras at 3.6 and 4.5 μm, with ~1.7" resolution; 2% absolute calibration accuracy.

Channel	λ_0	$\lambda/\Delta\lambda$	FOV	1σ in 1hr integration	Mapping speed[A]
	μm		arcminutes	μJy	hours
3.6	3.550	4.7	5.2 x 5.2	0.14	3.3
4.5	4.493	4.4	5.2 x 5.2	0.21	3.3

[A]To confusion limit ([3.6], [4.5]~17 Vega magnitudes, 49 & 28 uJy, respectively) in Galactic plane at $l = 60°$, $b = 0°$ for 1 square degree in hours.

- Deep Imaging: Demonstrated depth of 81 nJy (3 σ) in 34 hours for unconfused sources. SB limit ~0.5 kJy/sr. SNR increases as $t^{0.4}$ for total integration times above 10 hours.
- Exoplanets: near Poisson limited precisions for relative photometry at both 3.6 and 4.5 μm. The best precision obtained with IRAC for an eclipse is 28 ppm from four epochs of observations of 55 Cnc e.
- Solar System: Track moving targets at 0.1 milliarcsec/sec to 1 arcsec/sec rates. Demanding result: detection of 2011 MD with a flux density of 0.6 μJy and rate of 0.14 arcsec/sec detected in a 19.3 hour observation with IRAC.
- Zodi Light: absolute measurements possible for a range of solar elongations 82.5° to 120° with an accuracy of <2% if the IRAC shutter is used to remove the instrumental bias pattern.
- Orbital Stability+Uninterrupted Viewing: Monitoring 20+ days of M dwarfs for Earth-size companions; monitoring 20+ hrs of Sgr A for variability (in sync with Chandra)

Warm Spitzer Observing Time Distribution



Excerpted from Senior Review Report 2014

Science Areas of SAG 9

- Galaxy Evolution and Cosmology
  - Ranga-Ram Chary (Lead), Lee Armus, Pierre Ferruit, Adam Stanford, Massimo Stiavelli, Rogier Windhorst
- Nearby Galaxies
  - Daniel Dale (Lead), Kathleen Kraemer, Massimo Stiavelli, Mike Werner
- Milky Way (incl. Evolved Stars, etc.)
  - Kathleen Kraemer (Lead), Rachel Osten, John Stauffer, Mike Werner
- Extra-solar Planets
  - Avi Mandell (Lead), Sean Carey, Drake Deming, Pierre Ferruit, Rachel Osten, John Stauffer
- Solar System
  - Stefanie Milam (Lead), Sean Carey, Josh Emery

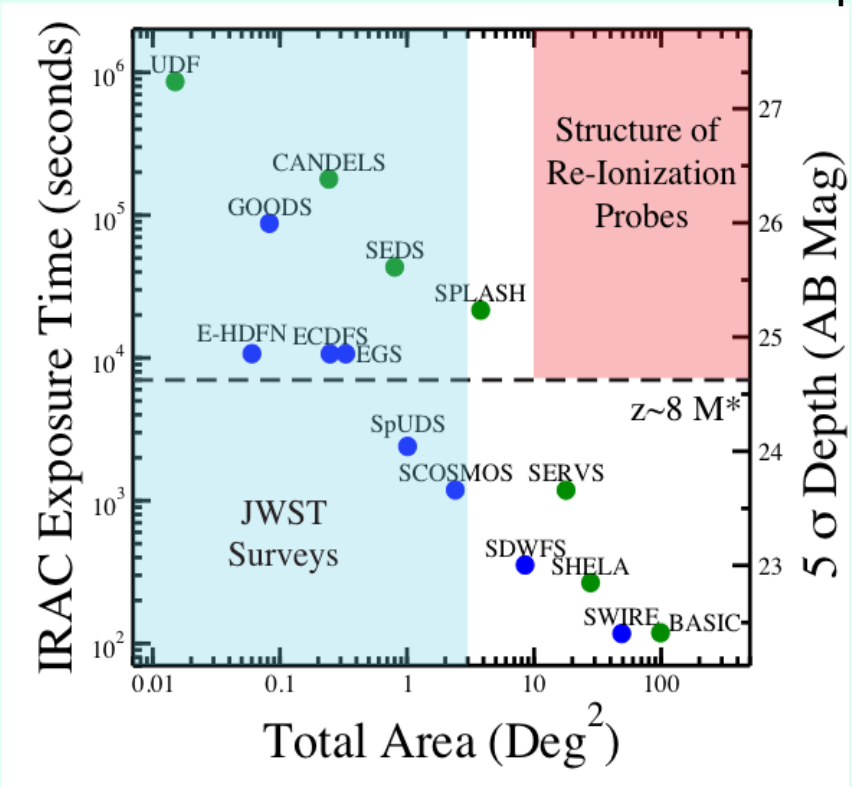
Galaxy Evolution and Cosmology

From P. Capak

A number of surveys already in existence. See Figure: blue points for cryogenic and green points for warm Spitzer. 1σ depth of 26.2 – 27.4 AB in 50 hours. Light-blue area is practical region for JWST.

Recently approved observations push into confusion noise (~200 hrs per pixel), and require use of priors, e.g., from HST.

Pink area accessible with Spitzer with >1 year observing time.



- Key questions/observations:
  - Characterize Zodiacal Light, for stray-light model of JWST and for accuracy improvement of cosmic infrared background (integrated galaxy starlight, reionization sources, …)
  - Wide fields for rare and/or lensed sources (z<2 clusters, galaxy-galaxy lenses, z>7 QSO candidates)
  - Deep Fields: surveys of 0.5<z<1 clusters for lensed, first-light galaxy candidates

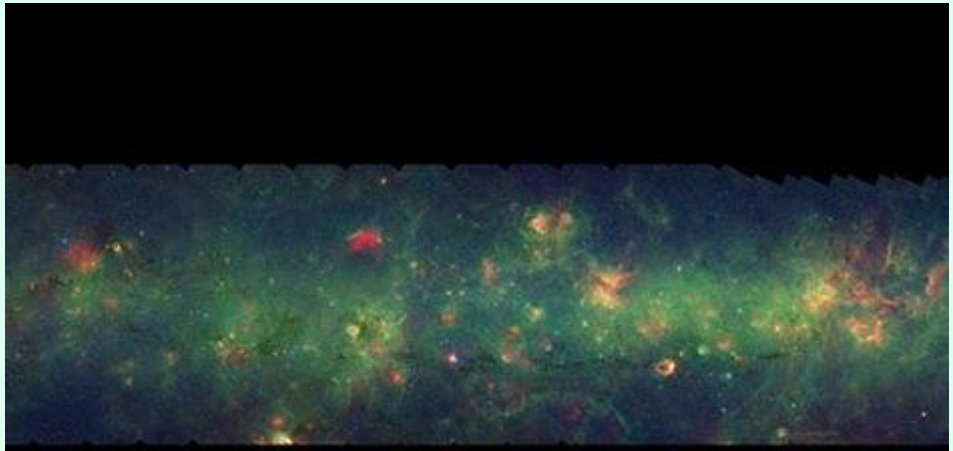
Nearby Galaxies

Many surveys of the local Universe in the archive, both with cryogenic (e.g., SINGS, LVL, SAGE, …, see Figure) and warm Spitzer (e.g., S4G, EDGES, etc.)
Programs have focused on both inner and outer disk regions, including subregions (e.g., HII regions, nuclear and circumnuclear regions, etc.).

- Key questions/observations:
  - IRAC characterization of ultrafaint dwarf galaxies around the Milky Way (the missing dwarf galaxy companions problem), for JWST follow-up
  - Extended stellar emission in galaxies outskirts, to test models of galaxy assembly, as precursor science
  - Time-domain science (e.g., IR transients) may benefit if Spitzer and JWST can operate simultaneously (unclear whether possible)

The Milky Way

The Milky Way has been extensively mapped with both the cryogenic and the warm Spitzer missions. Extended areas as well as regions of interest have been targeted (GLIMPSE+extensions, MIPSGAL, c2d, SMOG, …).
Both the plane and the outer regions, as well as the far side of the Galaxy have been imaged.



Milky Way: 3.6, 8, 24 μm (GLIMPSE-MIPSGAL; detail)

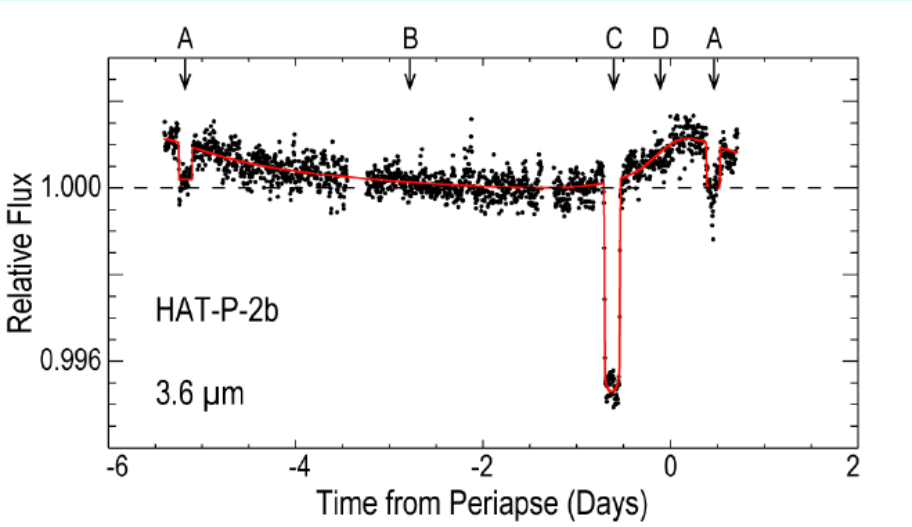
- Key questions/observations:
  - Expand samples of externally-polluted White Dwarfs for bulk composition comparison of extra-solar minor planets observed with JWST
  - IRAC Photometry for GAIA RR Lyr & Cepheid Variables for new cosmic distance ladder, to be extended with JWST
  - Galaxy structure via IRAC Photometry of Bulge Microlensing Fields
  - Outer Galaxy star forming regions and Disk Warp characterization

Exoplanets

Key capability: photometric precision to better than 30 ppm over several hours.

Existing and on-going work:

- Secondary eclipse measurements of newly discovered hot Jupiters
- Thermal phase curves for new and remaining key targets
- Microlensing parallax measurements
- Transits for Neptunes/Super-Earths to lock down presence of clouds
- Imaging outer planets with precise PSF subtraction – long time baseline for JWST
- Repeating eclipse and transit measurements to search for variability

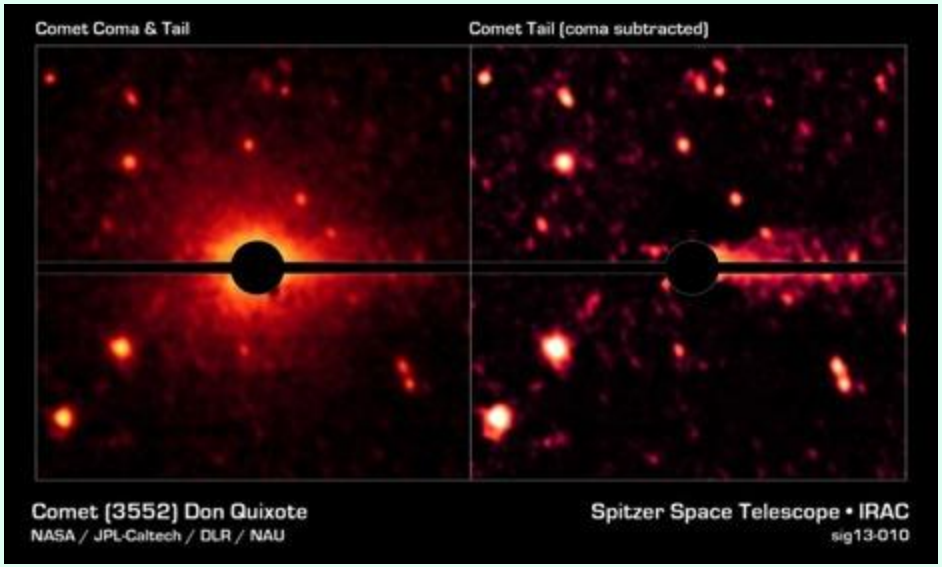


Spitzer's measurement of the phase curve of the transiting planet HAT-P-2b. A: Eclipse— the planet moves behind the star; B: Apoapse; C: Transit—the planet moves in front of the star; D: Periapse. Data from Lewis et al. (2013).

- Key questions/observations (prioritize/optimize targets for JWST):
  - Constraints on thermal profiles of new exotic hot extra-solar planets
  - Characterization of known super-Earths
  - Prioritization of super-Earths and Earth size planets for biological activity tracers with JWST
  - Continue characterization of newly discovered (K2, TESS, etc.) exoplanets

Solar System

The archive contains a robust inventory of observations of solar system objects, including satellites, comets, asteroids, NEOs, etc., in some cases including monitoring (e.g., weather).
Spitzer has the mid-infrared sensitivity and required orbital geometry for many observations.



- Key questions/observations:
  - Secure statistically-significant samples of icy bodies to be followed up with JWST for physical and chemical characterization
  - Prioritization of small bodies (e.g., Near Earth Objects) lists for JWST thermal spectroscopy (size and albedo)

End Backup Slides