Cosmic Structures
Science Interest Group (CoSSIG) Update

Olivier Doré, Rachel Bean
JPL/Caltech, Cornell University

on behalf of the
PhysPAG/Cosmic Structure SIG (CoSSIG)

CoSSIG: A New Science Interest Group

- NASA developing robust large scale structure (LSS) and supernovae (SN) portfolio
  - ➡ Committed to play a key role in the ESA led mission Euclid.
  - ➡ Committed to the WFIRST mission.

- CoSSIG to serve a broad community of those interested in using LSS and SN surveys for cosmology

- Science applications include those of the NRC 2010 Decadal Cosmology and Fundamental Physics panel:
  - ➡ How did the universe begin?
  - ➡ Why is the universe accelerating (dark energy)?
  - ➡ What is dark matter?
  - ➡ What are the properties of neutrinos?

- As we move towards the 2020 Decadal, CoSSIG provides important way to give inputs to NASA on future missions including quantitative metrics and issues.

CoSSIG Near Term Goals

- Making the CoSSIG science case for relevant flagship studies to be performed before the decadal survey.

- Identifying areas where NASA missions such as Euclid or WFIRST could benefit from synergistic activities with other other on-going programs.

- Identifying other NASA programs that can support CoSSIG science, e.g., sub-orbital, or other mission class, such as probes, midex and smex, e.g., SPHEREx now undergoing phase A.

- Highlight developments in, and requirements on, potential foreground contaminants and systematics and their mitigation for upcoming missions.

- Identify areas in which increased technical development is a priority

- Building the communication within the CoSSIG community
  - ➡ Co-leads: Rachel Bean (Cornell) & Olivier Doré (JPL/Caltech)
  - ➡ Please sign up and join us: blank email to CoSSIG-subscribe@lists.nasa.gov.
  - ➡ More info @ webpage: http://pcos.gsfc.nasa.gov/sigs/cossig.php

Dark Energy Requires a Modification to Einstein's Equation

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

?

?

- A cosmological constant Λ?
- Deviation from general relativity on cosmological scales?

- New matter interaction?
- New matter component?
- Inhomogeneous Universe?

- Each of these modifications will lead to different observational signatures either in the expansion history of the Universe or in the growth of large scale structures:
  - ➡ To observationally and unambiguously solve this puzzle will require multiple probes (also critical for cross-checks)

Multi-Probe Survey Approach

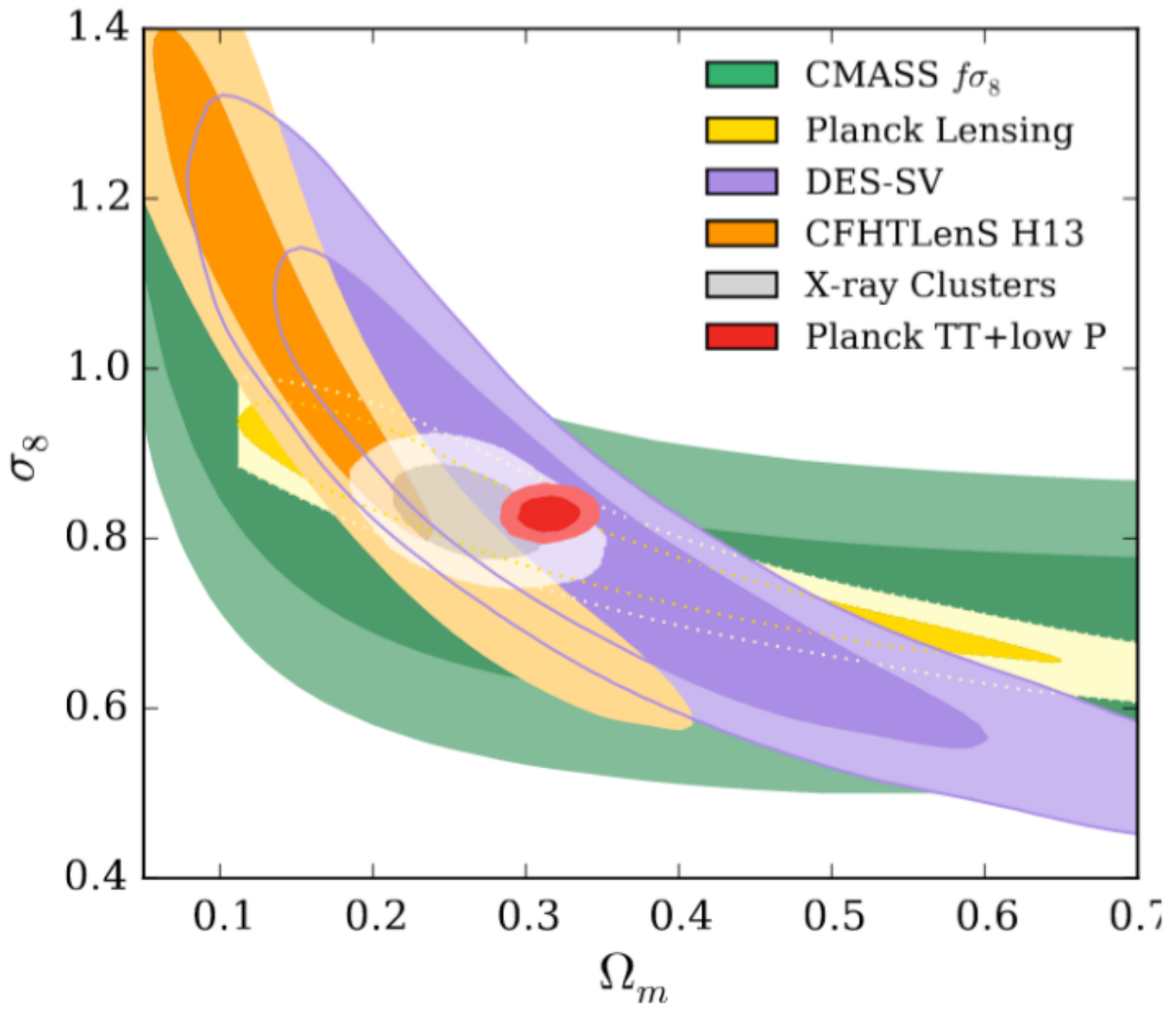
- NASA investment in upcoming “Stage IV” LSS and SN surveys, covers the full range of cosmological probes required to distinguish dark energy and modified gravity models
  - ➡ Type IA SN: standard candles to measure the expansion history (WFIRST)
  - ➡ Weak gravitational lensing: the apparent distortion of galaxy shapes by foreground dark matter measures the growth of structure (Euclid, WFIRST)
  - ➡ Galaxy clustering: Baryon acoustic oscillations (BAO) a standard ruler to measure the expansion history (Euclid, WFIRST)
  - ➡ Redshift space distortions (RSD): measure growth of structure (Euclid, WFIRST)

- WFIRST, Euclid along with ground-based Stage IV surveys, LSST and DESI, each provide valuable complementary datasets that comprise critical pieces needed to achieve percent level constraints on dark energy.
  - ➡ Key factors are systematic error mitigation in weak lensing measurements and complementarity of gravitational constraints from peculiar motions & lensing.

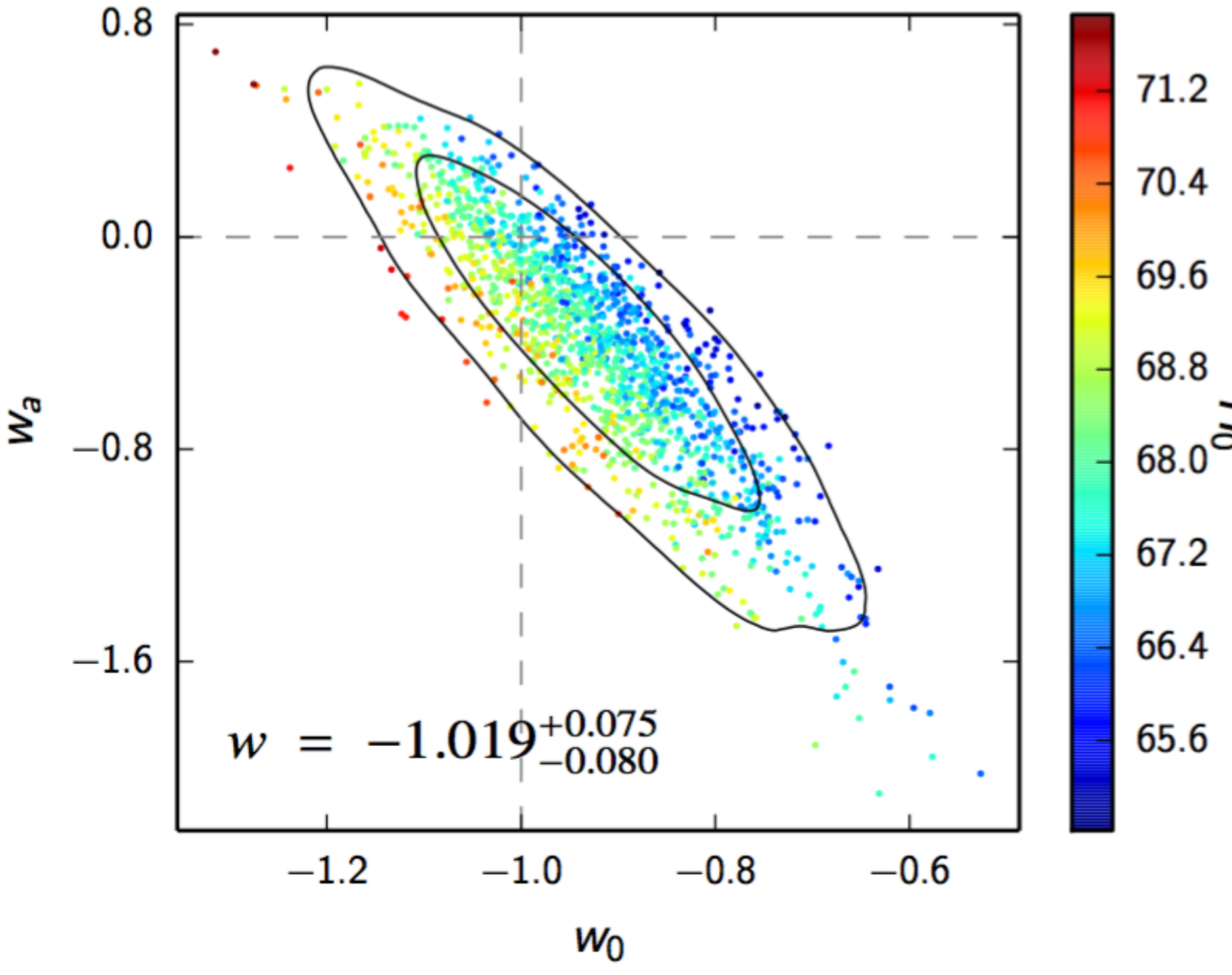
- Build on progress and lessons learned from a number of important current, near- term surveys (DES,HSC,Boss/e-BOSS, PFS)
  - ➡ White paper: “The Whole is Greater than the Sum of the Parts: Optimizing the Joint Science Return from LSST, Euclid and WFIRST” http://arxiv.org/abs/1501.07897

Multi-Probe Analysis State of the Art

- Combined Planck, BOSS BAO and SDSS/SNLS SN yield constraints on Dark Energy equation of state consistent with ΛCDM.
- Progress: DES and HSC taking data and early science verification results.



DES Collaboration 1507.05552



Ade et al (Planck 2015 XIII)

WFIRST-AFTA Dark Energy/Cosmology Roadmap

Supernova Survey

wide, medium, & deep imaging
+
IFU spectroscopy

2700 type Ia supernovae
z = 0.1–1.7

standard candle distances
z < 1 to 0.20% and z > 1 to 0.34%

High Latitude Survey

spectroscopic: galaxy redshifts

16 million Hα galaxies, z = 1–2
1.4 million [OIII] galaxies, z = 2–3

imaging: weak lensing shapes

380 million lensed galaxies
40,000 massive clusters

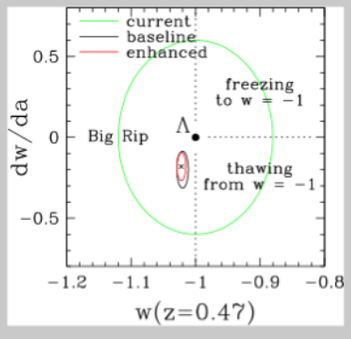
standard ruler

distances	expansion rate
z = 1–2 to 0.5%	z = 1–2 to 0.9%
z = 2–3 to 1.3%	z = 2–3 to 2.1%

dark matter clustering
z < 1 to 0.21% (WL); 0.24% (CL)
z > 1 to 0.78% (WL); 0.88% (CL)
1.1% (RSD)

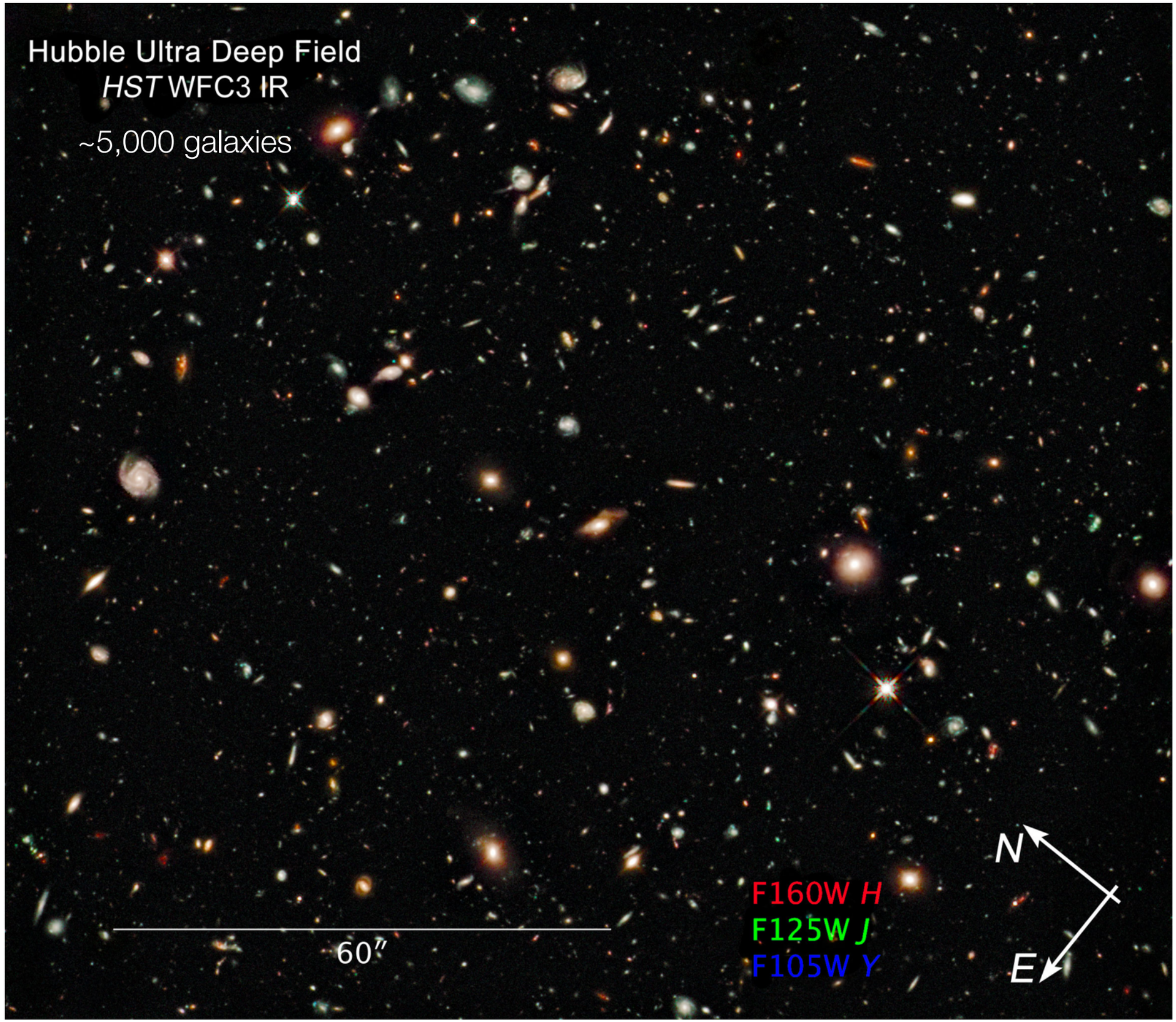
history of dark energy
+
deviations from GR

$w(z)$, $\Delta G(z)$, Φ_{REL}/Φ_{NREL}

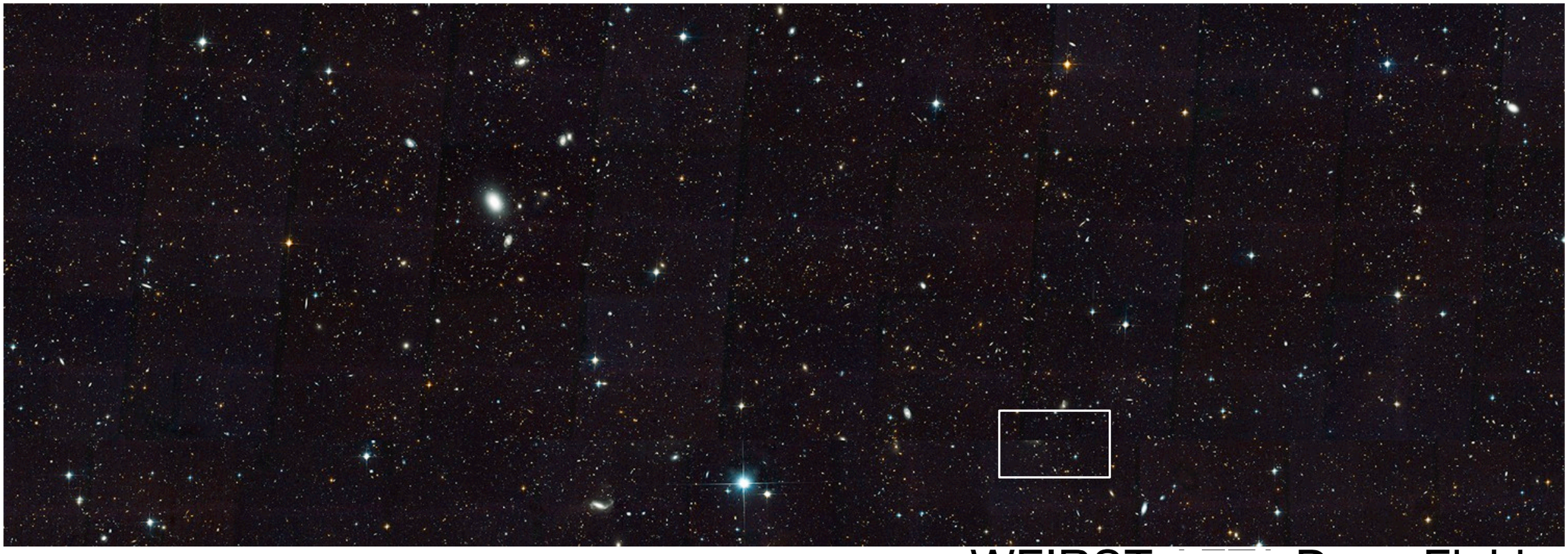


From WFIRST-AFTA SDT Final Report

WFIRST: Hubble over Thousands Square Degrees



WFIRST: Hubble over Thousand Square Degrees



WFIRST Deep Field
>1,000,000 galaxies in each image

http://wfirst.gsfc.nasa.gov/

WFIRST Updates

- Lots of progress on WFIRST in past 2 years:
  - ➡ $106M in FY14 & 15 has enabled major steps forward
    - Detector & coronagraph development
    - Design cycles, Project work
  - ➡ SDT 2014 & 2015 studies completed
  - ➡ ROSES community studies funded, $2M
  - ➡ Dec ‘15: Mission Concept Review successfully passed
  - ➡ Dec ’15: Formulation Science Working Group (FSWG) announced http://wfirst.gsfc.nasa.gov/
  - ➡ Jan ‘16: Formulation (KDP-A) passed (now Phase-A!)
  - ➡ Feb ‘16: First FSWG meeting
  - ➡ Feb ’16: Workshop on “Community Astrophysics with WFIRST: Guest Observer and Archival Science” in Pasadena
- Planned launch in ~2024

WFIRST Formulation Science Working Group

- Serves as WFIRST's science executive committee:
  - ➡ 24 members
  - ➡ Project Scientists and Instrument Scientists from GSFC and JPL
  - ➡ STSci and IPAC are preparing for a joint WFIRST Science Centers

- 2 Adjutant Scientists:
  - ➡ David Spergel — Wide Field Instrument, Adjutant Scientist
  - ➡ Jeremy Kasdin — Coronograph Instrument, Adjutant Scientist

- 10 Science Investigation Teams:
  - ➡ Olivier Doré — Weak lensing and galaxy redshift survey
  - ➡ Saul Perlmutter — Supernovae
  - ➡ Ryan Foley — Supernovae
  - ➡ Scott Gaudi — Microlensing
  - ➡ Bruce Macintosh — Coronagraphy
  - ➡ Margaret Turnbull — Coronagraphy
  - ➡ James Rhoads — GO science, cosmic dawn
  - ➡ Brant Robertson — GO science, galaxy formation & evolution
  - ➡ Benjamin Williams — GO science, nearby galaxies
  - ➡ Alexander Szalay — GI science, archival research

Euclid Update

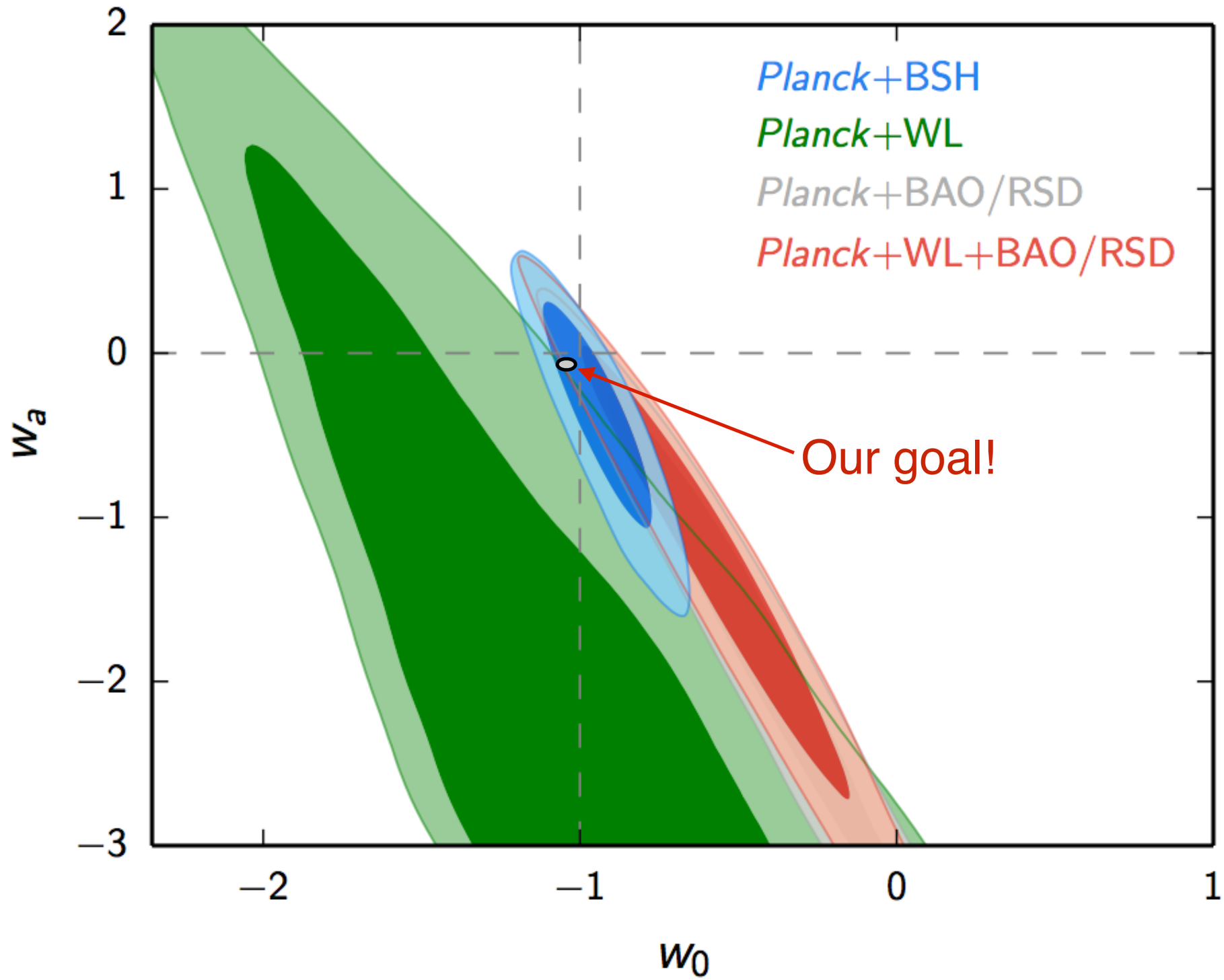
- Passed Preliminary Design Review (PDR) in Fall, 2015
- Editorial Board led by John Peacock and Peter Schneider has started work
- The Euclid NASA Science Center at IPAC (ENSCI):
  - ➡ integrated into the Euclid Science Ground Segment
  - ➡ planning to support the US community to use Euclid data
  - ➡ http://www.euclid.caltech.edu/
- Both visible (VIS) and near infrared (NISP) instruments have passed recent reviews
  - ➡ ~80 US scientist and engineers working on Euclid as part of the 1300 member Euclid Consortium
- Includes Working Group (e.g. Yun Wang, Galaxy Clustering) and Work Package Leads
  - ➡ Launch date set for December, 2020

Credit: ESA

http://euclid.jpl.nasa.gov/

Slide by Jason Rhodes

Dark Energy Equation of State Status and Prospects



Planck 2015 XIV

Summary

- New Science Interest Group formed: CoSSIG
  - ➡ Please join! http://pcos.gsfc.nasa.gov/sigs/cossig.php

- Mid-decadal current assessment of progress relative to NRC recommendations includes key CoSSIG-related science, including:
  - ➡ WFIRST: Astro2010 top ranked large-scale space-based mission and its coronograph satisfies the #1 medium-scale priority, i.e., to prepare for 2020s planet imaging mission.
  - ➡ Euclid: 2012 NRC endorsement of NASA participation in Euclid

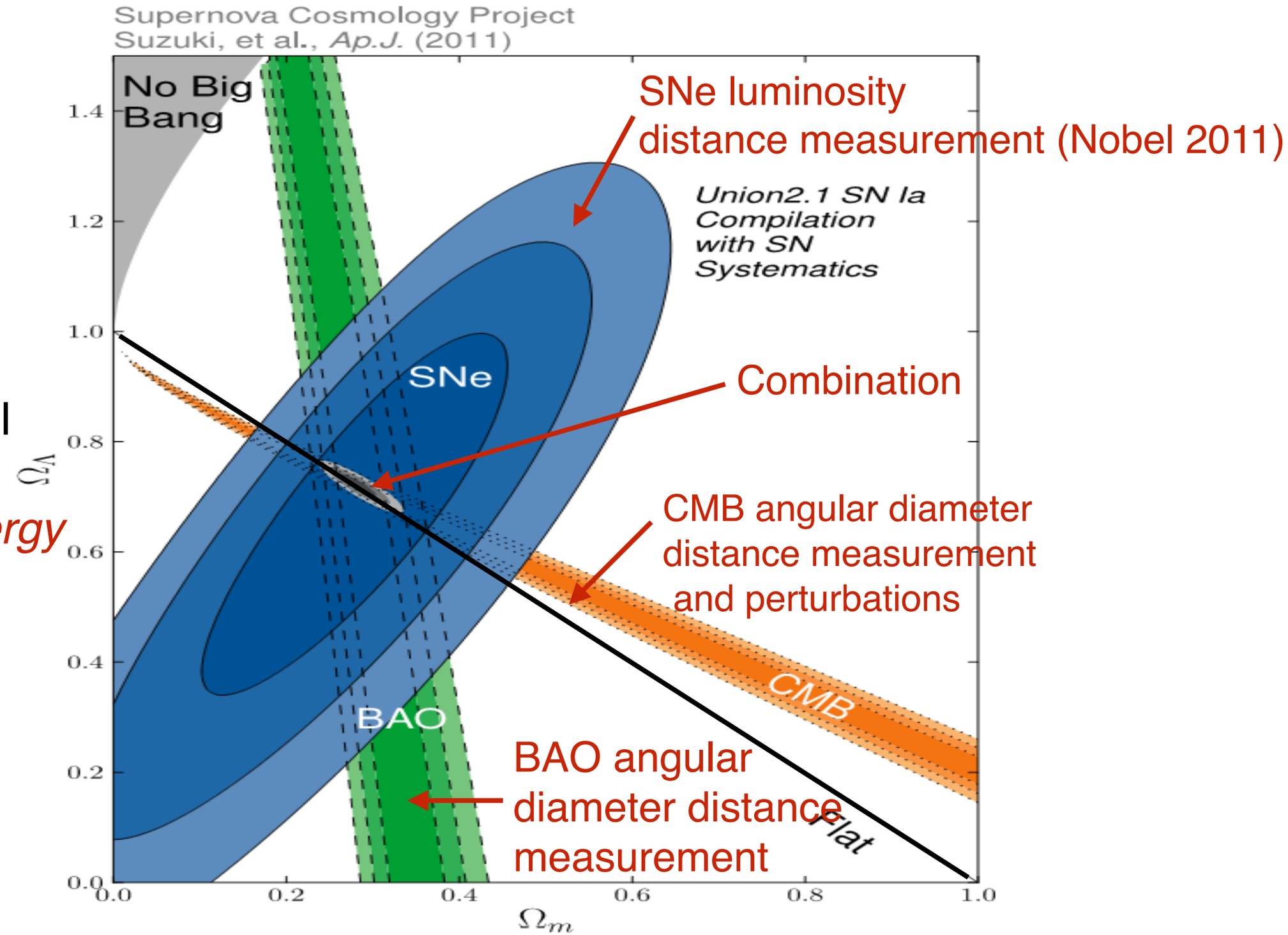
- NASA missions with CoSSIG science interests progressing well and have exciting year ahead:
  - ➡ Euclid – passed number of recent reviews, US team now well- established, NASA IPAC science center to support US community
  - ➡ WFIRST – healthy budget for formulation, Formulation Science Working Group announced in December, Phase A started.

- CoSSIG science with future flagship needs to be investigated.

- The answer to this puzzle will come from multiple observational signatures/probes and multiple missions.

FIN

The Observational Foundations of Dark Energy



Cosmological Constant, i.e. *Dark Energy*

Matter Density

- Weak-Lensing not presented is also complementary.

Multi-Probe and Survey Approach

Stage IV	DESI	LSST	Euclid	WFIRST-AFTA
Starts, duration	~2018, 5 yr	2020, 10 yr	2020 Q2, 7 yr	~2023, 5-6 yr
Area (deg^2)	14,000 (N)	20,000 (S)	15,000 (N + S)	2,400 (S)
FoV (deg^2)	7.9	10	0.54	0.281
Diameter (m)	4 (less 1.8+)	6.7	1.3	2.4
Spec. res. $\Delta\lambda/\lambda$	3-4000 (N_{fib}=5000)		250 (slitless)	550-800 (slitless)
Spec. range	360-980 nm		1.1-2 mm	1.35-1.95 mm
BAO/RSD	20-30m LRGs/[OII] ELGs 0.6 < z < 1.7, 1m QSOs/Lya 1.9<z<4		~20-50m Hα ELGs z~0.7-2.1	20m Hα ELGs z = 1–2, 2m [OIII] ELGS z = 2–3
pixel (arcsec)		0.7	0.13	0.12
Imaging/ weak lensing (0<z<2.)		~30 gal/$arcmin^2$ 6 bands 320-1080 nm	30-35 gal/$arcmin^2$ Broad visible band 550– 900 nm	68 gal/$arcmin^2$ 3 bands 927-2000nm
SN1a		10^4-10^5 SN1a/yr z = 0.–0.7 photometric		2700 SN1a z = 0.1–1.7 IFU spectroscopy

Compilation by Rachel Bean