Laboratório Interinstitucional de e-Astronomia

Observatório Nacional

Avanços e Perspectivas:
Participação Brasileira no Estudo da Energia Escura

L. Nicolaci da Costa

Observatório Nacional

LIneA

Achievements until the 80s

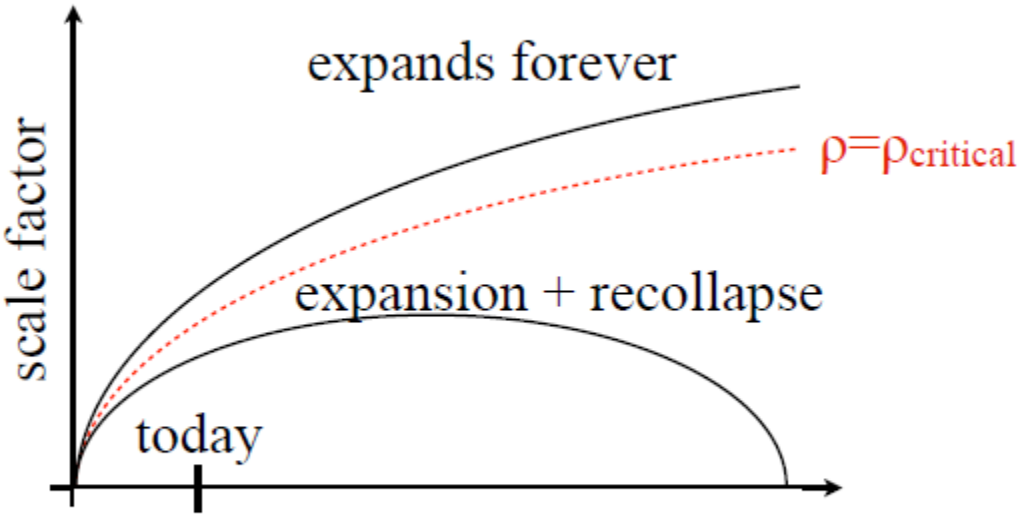
Theories

- GR
- Big-bang theory
- Inflation
- CDM paradigm
- Cosmological numerical simulations

Observations

- Hubble expansion
- Nucleosynthesis
- CMB temperature

Evolution of the Universe



$$\frac{\dot{a}}{a} \equiv H(z) = \sqrt{\Omega_M (1+z)^3} \qquad \Omega_M = \frac{\rho_M}{\rho_c}$$

Question: what is the value of Ω_M ?

How to measure Ω_m

- Growth of structures
  - Large-scale structures

$$\xi(r) = \frac{1}{2\pi^2} \int \mathrm{d}k\, k^2 P(k) \frac{\sin(kr)}{kr}.$$

  - Peculiar velocity of galaxies

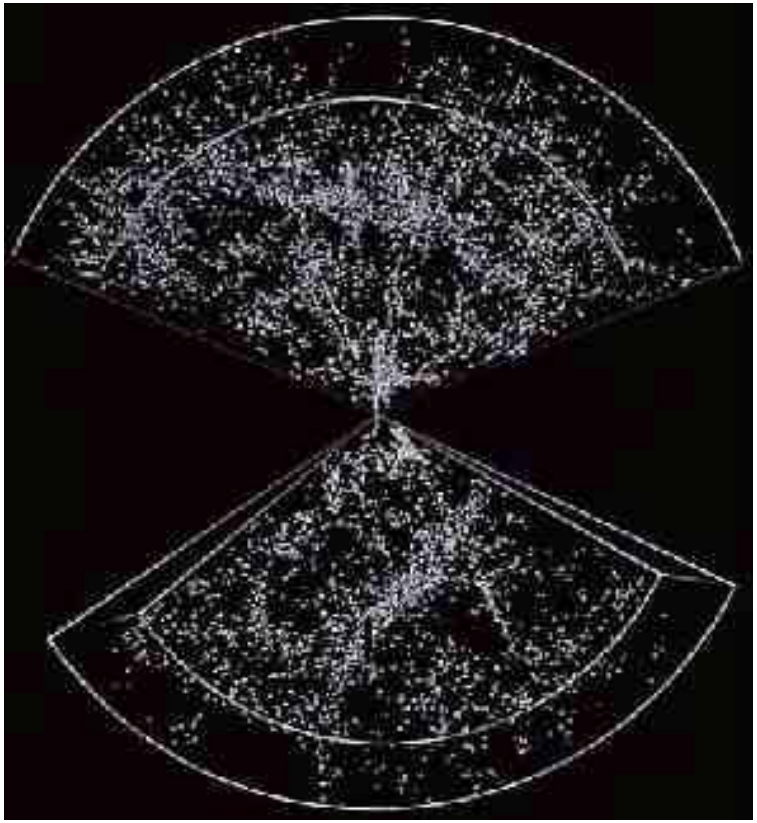
$$\boldsymbol{v}(\boldsymbol{r}) \approx \frac{\Omega^{0.6} H_0}{4\pi} \int \mathrm{d}^3 r' \delta_{\mathrm{m}} \frac{(\boldsymbol{r}' - \boldsymbol{r})}{|\boldsymbol{r}' - \boldsymbol{r}|^3},$$

- Geometry
  - Measuring distances to SN Ia (standard candle)

$$H^2(a) \equiv \left(\frac{\dot{a}}{a}\right)^2 = H_0^2 \left[\Omega_m a^{-3} + \Omega_r a^{-4} + \Omega_k a^{-2} + \Omega_X a^{-3(1+w)}\right].$$

Mapping the Galaxy Distribution

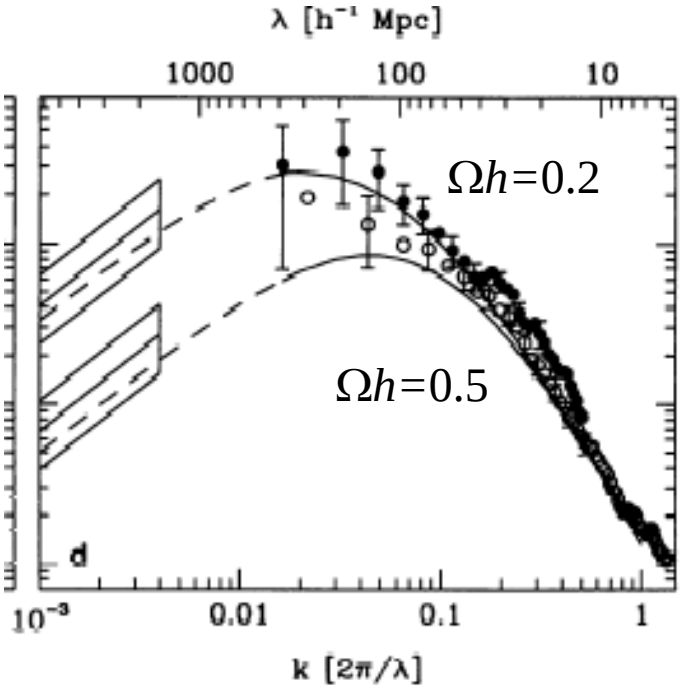
(1978-1994)



da Costa, Geller et al (1994)

CfA2

SSRS2



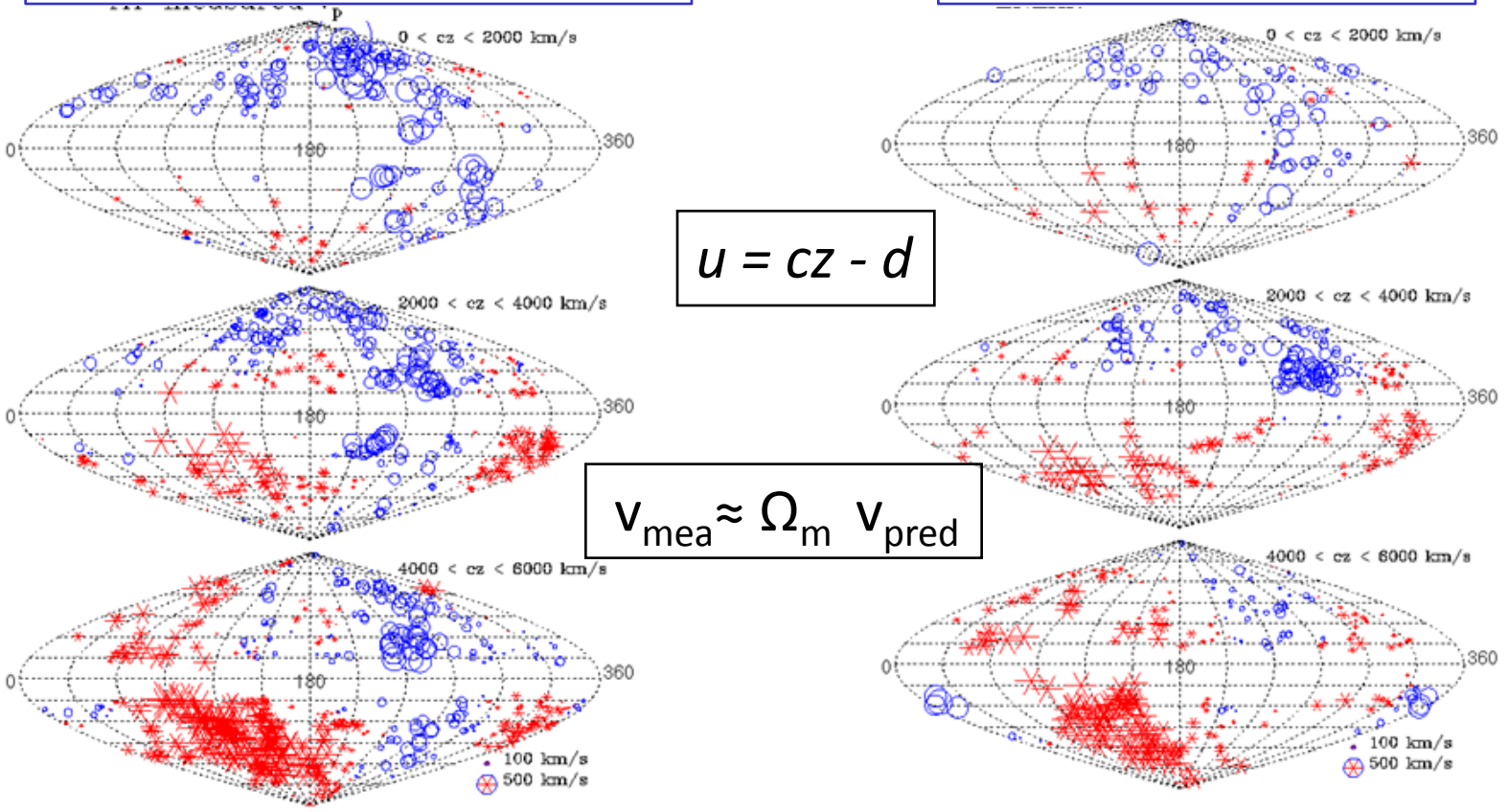
da Costa, Vogeley et al (1994)

Best-fit ΛCDM with $b \sim 1$; $\Omega_m = 0.3$

Mapping the Peculiar Velocity field
(1988-2001)

Spirals: Tully-Fisher relation

Early types: Dn-σ relation



$u = cz - d$

$v_{mea} \approx \Omega_m \; v_{pred}$

da Costa, Nusser et al (1998)

b ~ 1; Ω_m= 0.3

Nusser, da Costa et al (2001)

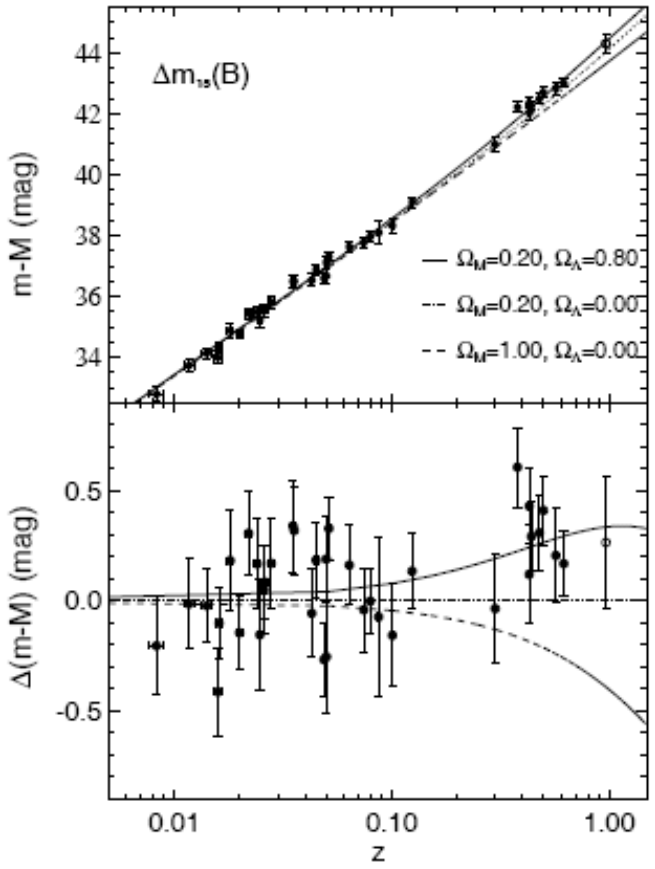
First Evidences ΛCDM/DE

After long debate concordance among:

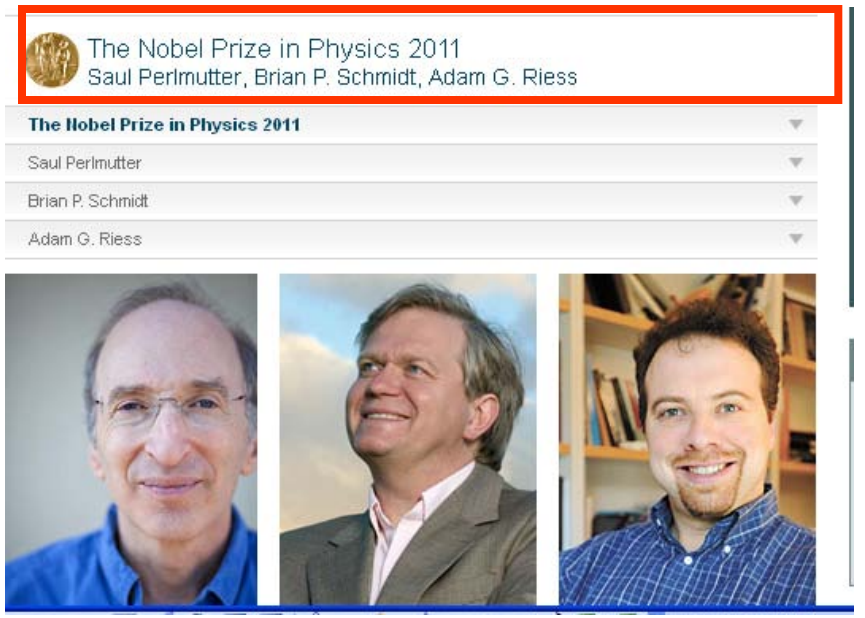
1) LSS
2) Peculiar motions on small and large scales
3) Other measurements (e.g. cluster abundances)

=> Flat Universe with low values of Ω_m

SN Ia



Riess et al (1998)

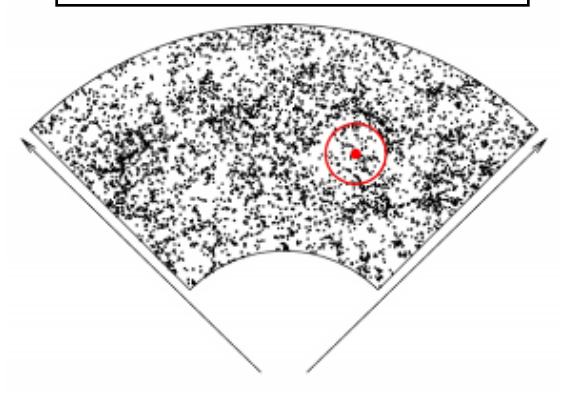


Best-fit: Ω_m=0.2 Ω_Λ=0.8

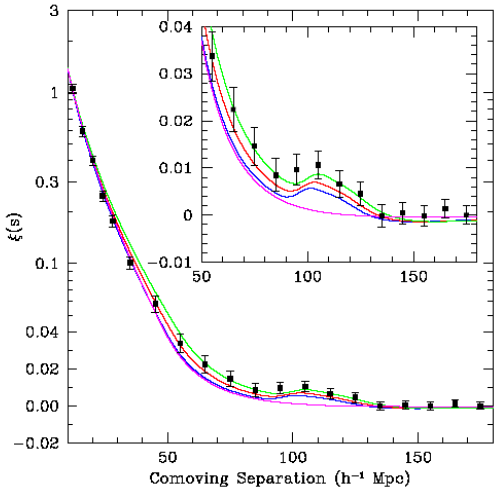
Direct evidence of accelerated expansion => Dark energy

Evidence for Dark Energy

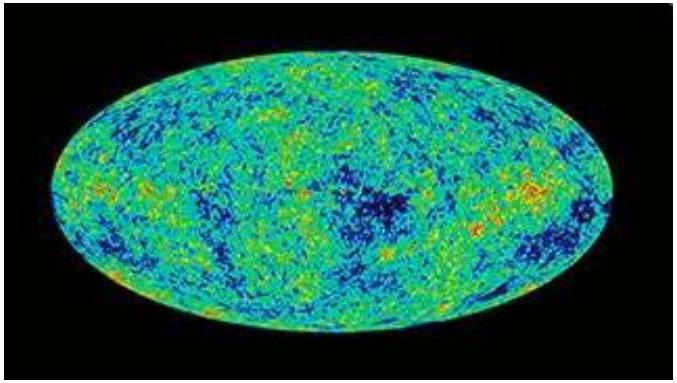
Eisenstein et al (2005)



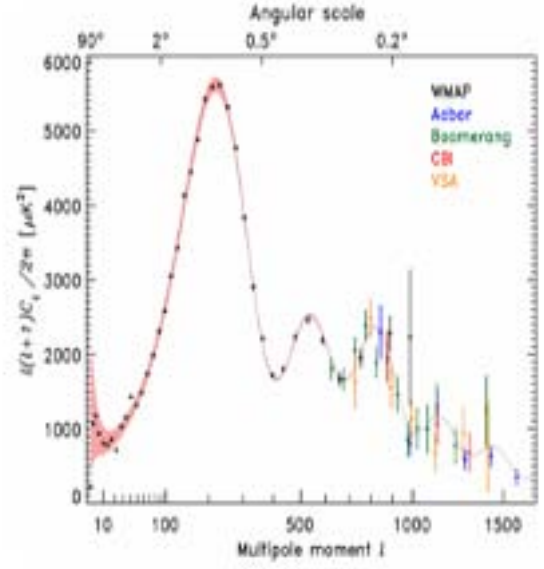
SDSS
BAO



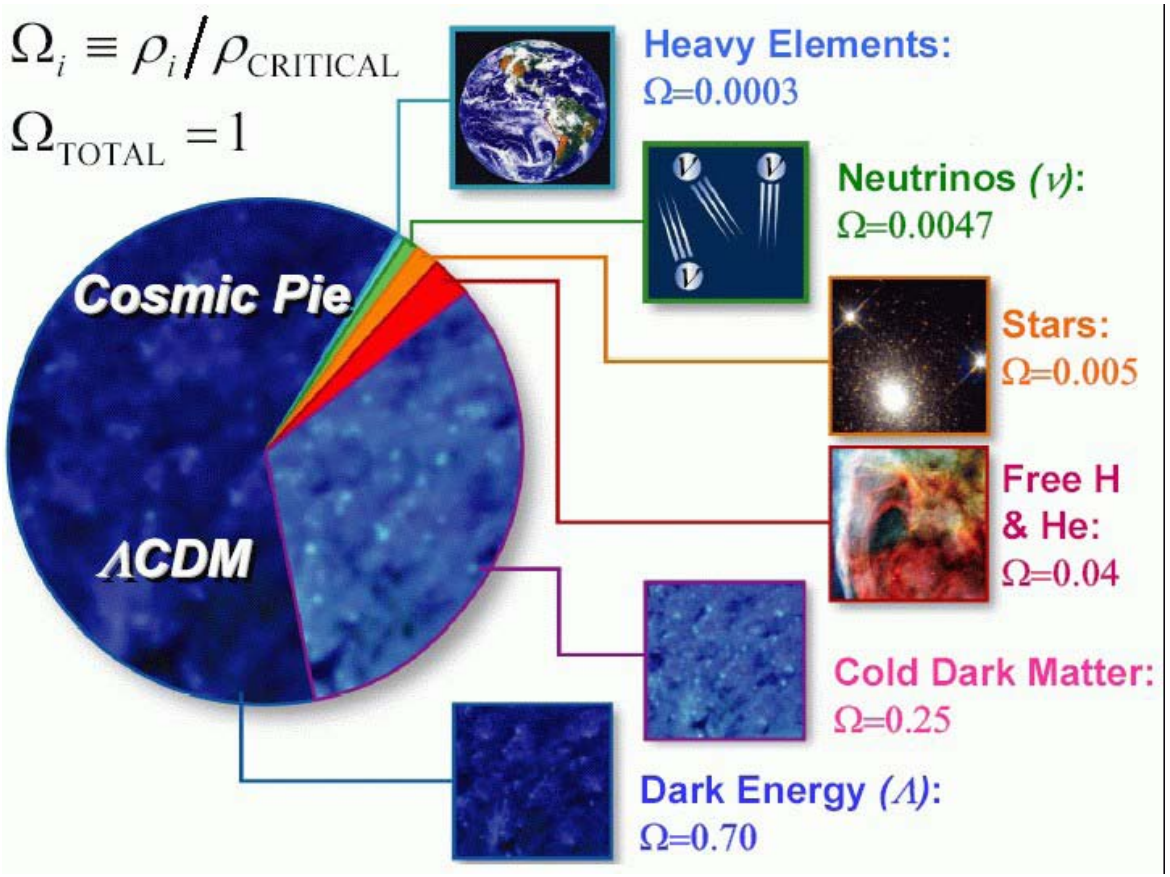
Hinshaw etal (2003)



WMAP
CMB



Components


$\Omega_i \equiv \rho_i / \rho_{\text{CRITICAL}}$
$\Omega_{\text{TOTAL}} = 1$
Cosmic Pie
ΛCDM
Heavy Elements:
Ω=0.0003
Neutrinos (ν):
Ω=0.0047
Stars:
Ω=0.005
Free H
& He:
Ω=0.04
Cold Dark Matter:
Ω=0.25
Dark Energy (Λ):
Ω=0.70

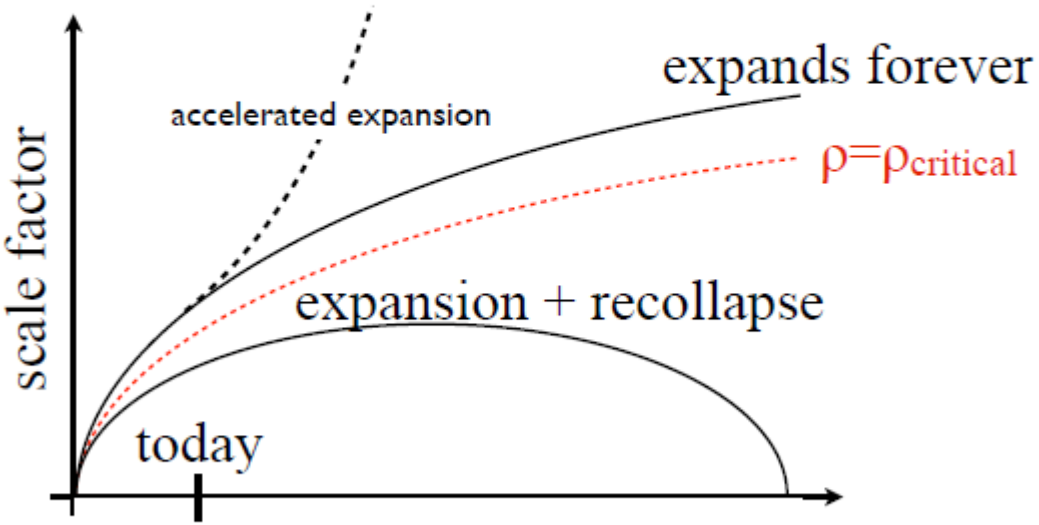
COSMOLOGY MARCHES ON



Implications

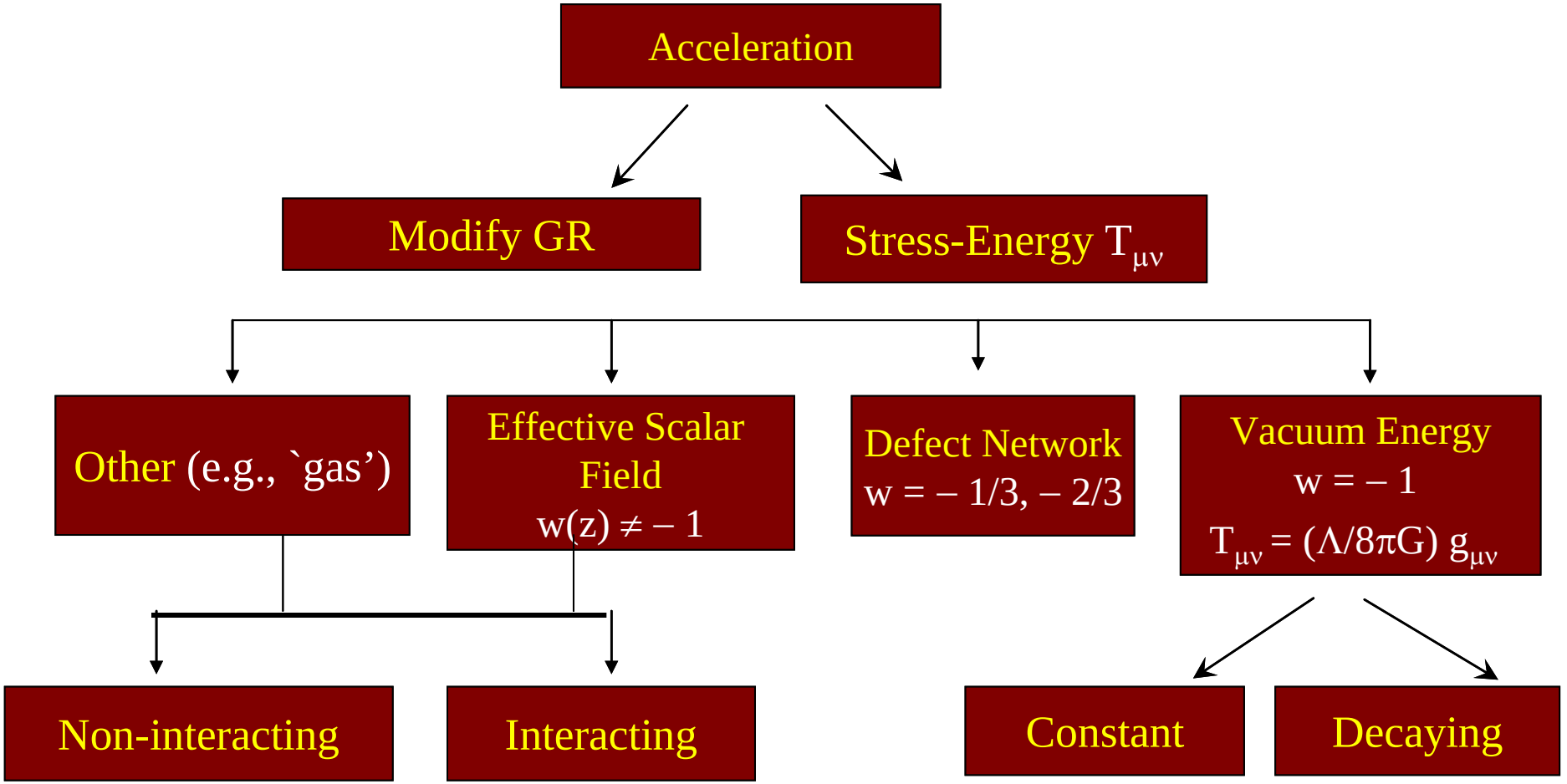
The future of the Universe?

Until ~ '98



$$H(z) = \sqrt{\Omega_M (1+z)^3 + \Omega_\Lambda}$$

What is the Nature of the Dark Energy ?



Dark Energy Task Force

Recommended techniques for probing dark energy

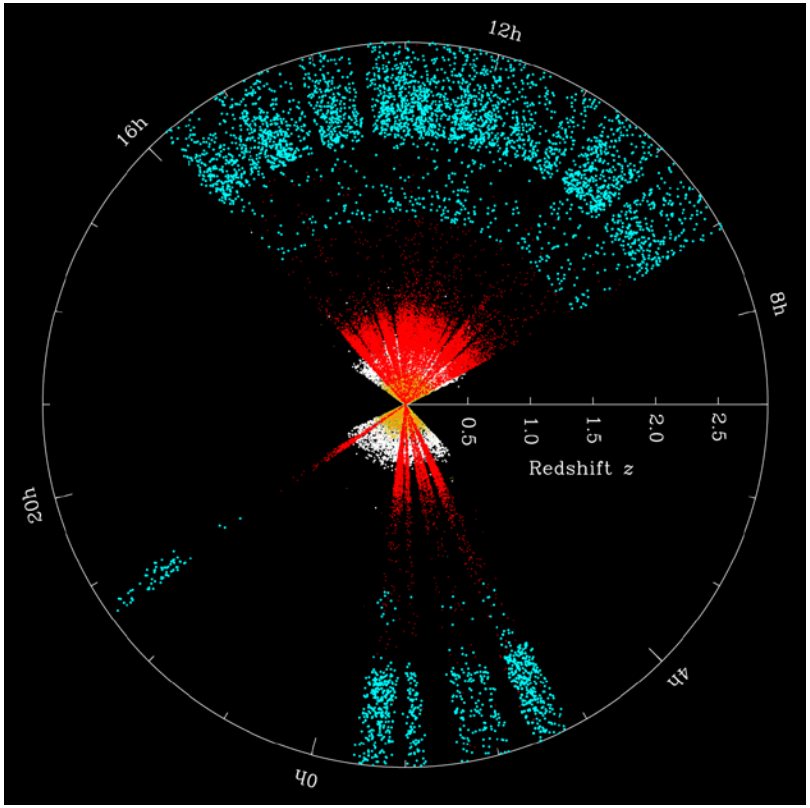
1. Supernovae
2. Baryon Acoustic Oscillations
3. Galaxy Cluster Counting
4. Weak Gravitational Lensing

geometry

growth of structures

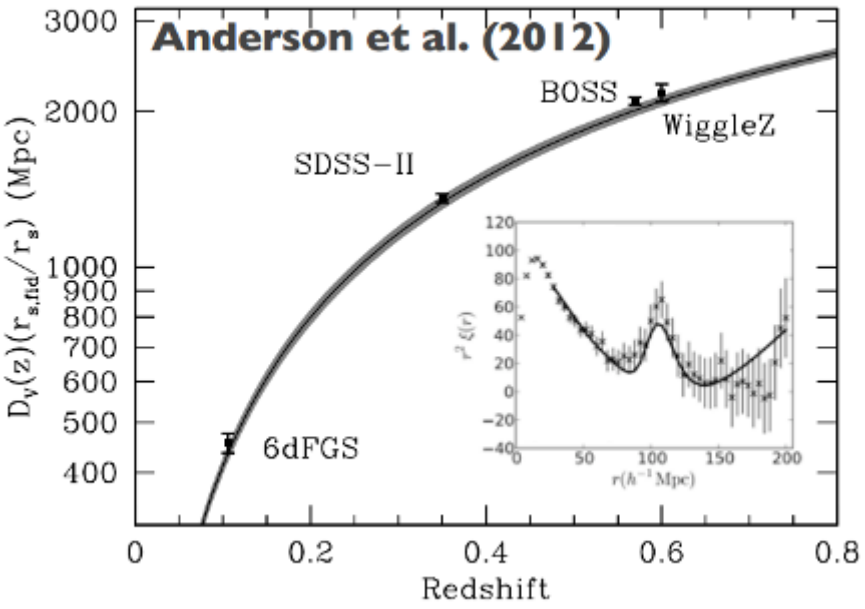
Ongoing Projects

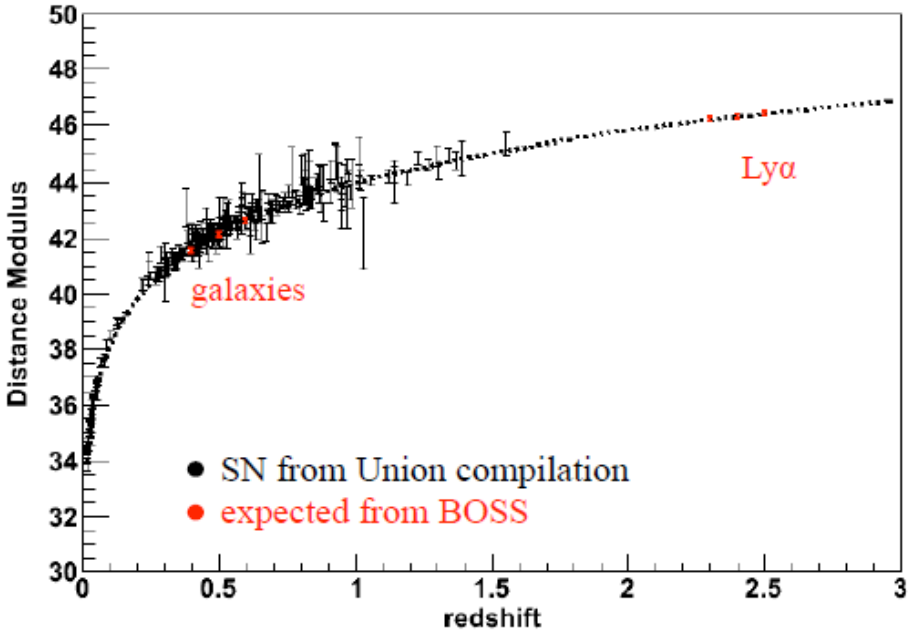
SDSS-III: BOSS





BAO





Galaxies

Lyα

SDSS-III Participating Institutes

1. University of Arizona,
2. **Brazilian Participation Group**
3. Brookhaven National Laboratory
4. University of Cambridge
5. University of Florida
6. French Participation Group
7. German Participation Group
8. Instituto de Astrofisica de Canarias
9. Michigan State/Notre Dame/JINA Participation Group
10. Johns Hopkins University
11. Lawrence Berkeley National Laboratory,
12. Max Planck Institute for Astrophysics,
13. New Mexico State University
14. New York University,
15. Ohio State University
16. University of Portsmouth
17. Princeton University
18. University of Tokyo
19. University of Utah
20. Vanderbilt University
21. University of Virginia
22. University of Washington
23. Yale University.

The Dark Energy Survey

- Stage III DE project using 4 complementary* techniques:
  - I. Cluster Counts
  - II. Weak Lensing
  - III. Large-scale Structure
  - IV. Supernovae

- Two multiband surveys:
  - 5000 deg2 *grizY* to 24th mag
  - 30 deg2 repeat (SNe)

- Build new 3 deg2 FOV camera and Data management system

Survey 2012-2017 (525 nights)

Blanco 4-meter at CTIO



DES Science Summary

DARK ENERGY SURVEY

Four Probes of Dark Energy

Galaxy Clusters

~100,000 clusters to z>1, overlap with SPT.
Sensitive to growth of structure and geometry

Weak Lensing

Shape measurements of 300 million galaxies
Sensitive to growth of structure and geometry

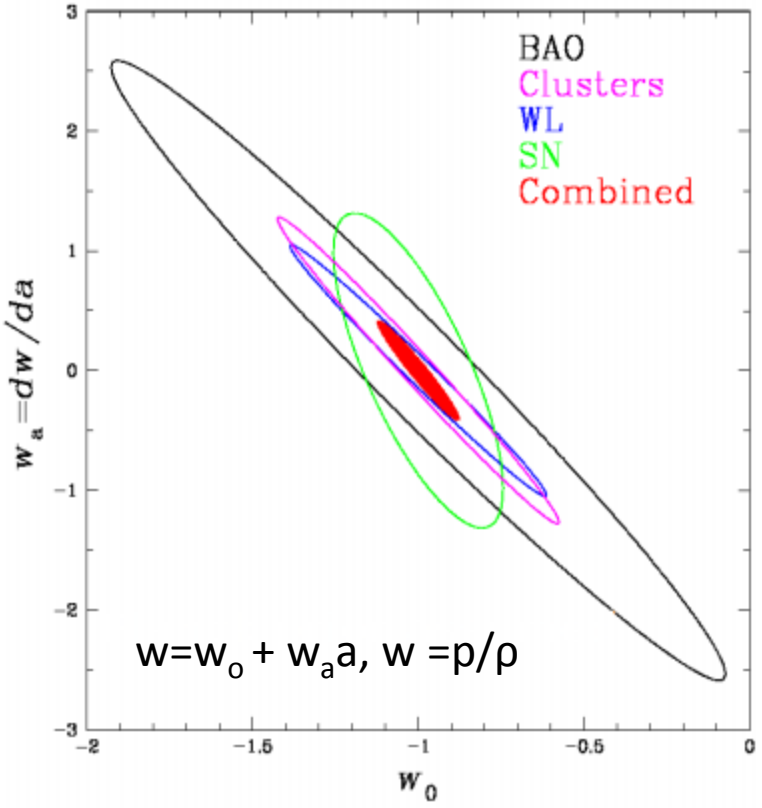
Baryon Acoustic Oscillations

Detection of ~40 million LRGs
Sensitive to geometry

Supernovae

30 sq deg time-domain survey
~4000 well-sampled SNe Ia to z ~1
Sensitive to geometry

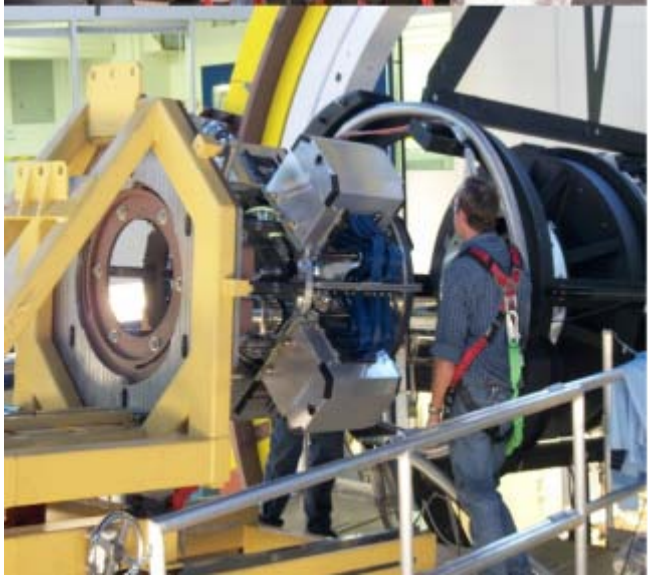
Forecast Constraints on DE Equation of State

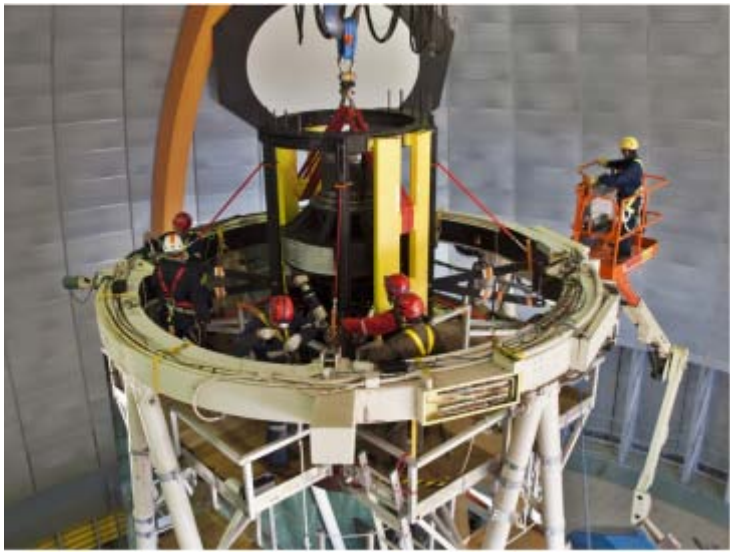


Factor 3-5 improvement over Stage II DETF Figure of Merit

DECam

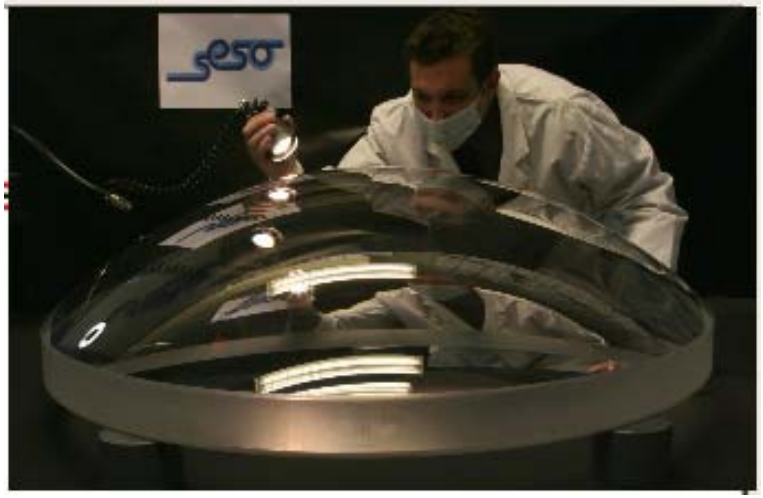


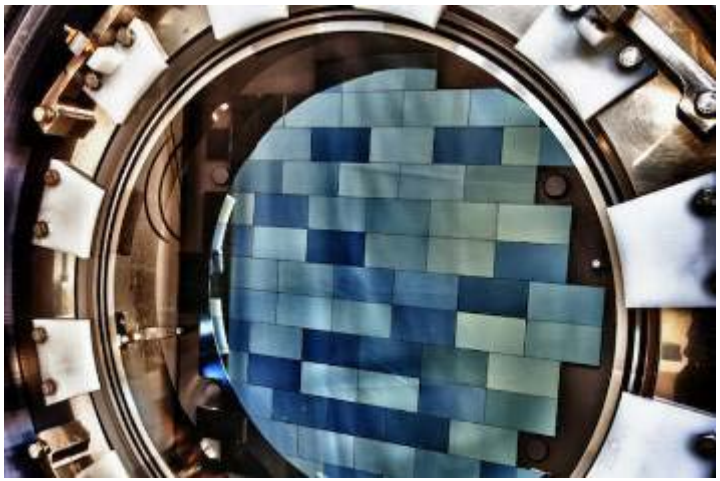




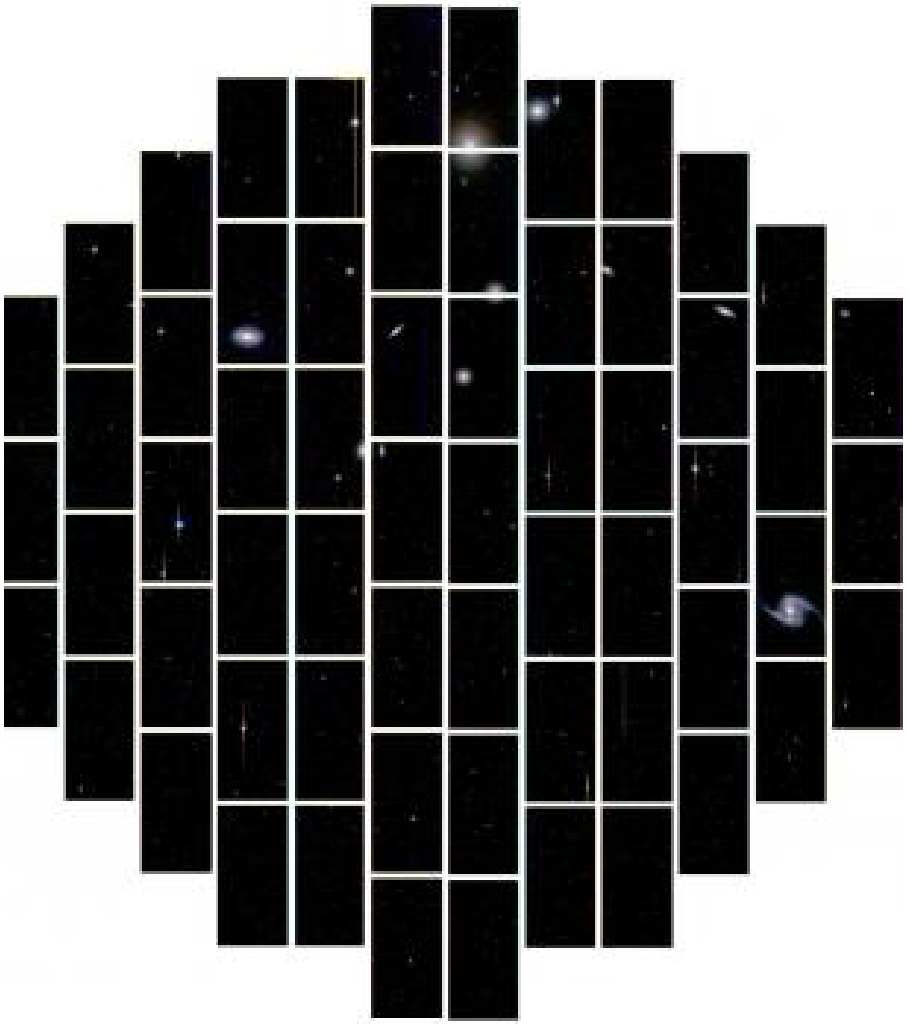


DECam First Light (9/12)





570 million pixels



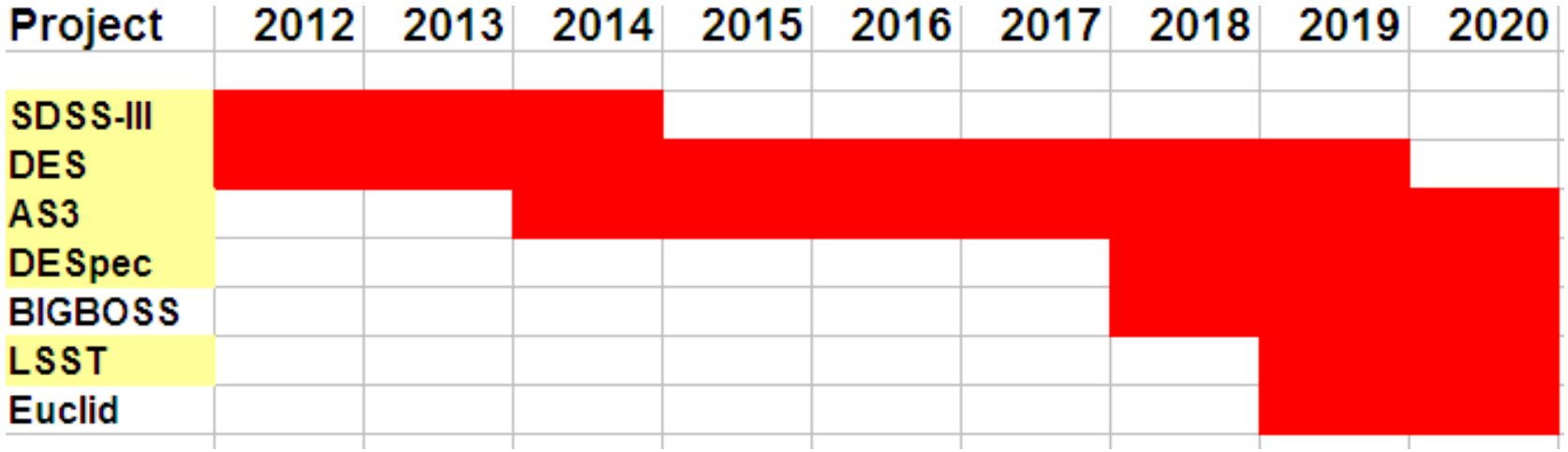
DES Participating Institutions

1. **Fermilab**
2. **University of Illinois at Urbana-Champaign**
3. **University of Chicago**
4. **Lawrence Berkeley National Laboratory**
5. **University of Michigan**
6. **NOAO/CTIO**
7. **Spain-DES Collaboration:** Institut d'Estudis Espacials de Catalunya (IEEC/ICE), Institut de Fisica d'Altes Energies (IFAE), CIEMAT-Madrid:
8. **United Kingdom-DES Collaboration:** University College London, University of Cambridge, University of Edinburgh, University of Portsmouth, University of Sussex
9. **The University of Pennsylvania**
10. **DES-Brazil (January 2007) ON, CBPF, LNCC, UFRGS, UNESP, USP, UFF + others**
11. **The Ohio State University**
12. **Argonne National Laboratory**
13. **Santa Cruz-SLAC-Stanford DES Consortium**
14. **LMU**
15. **Texas A&M**
16. **ETH-Zuerich**

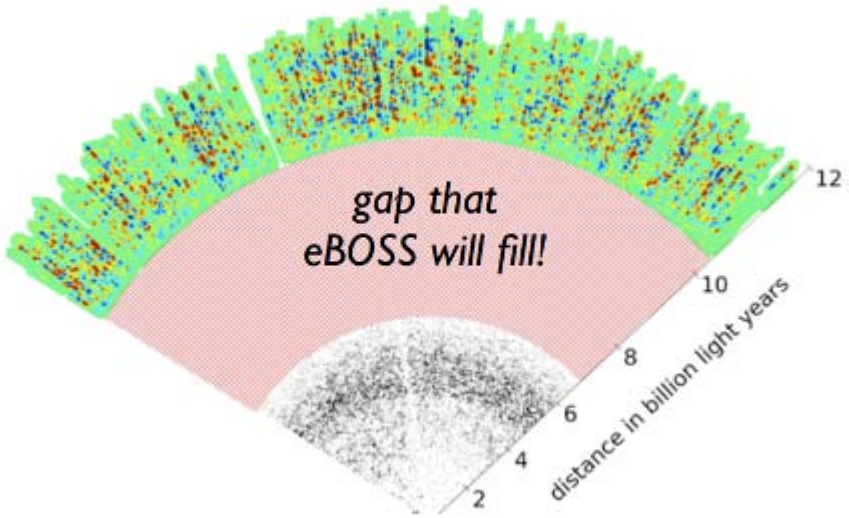
15 grupos, 25+ instituições e 150+

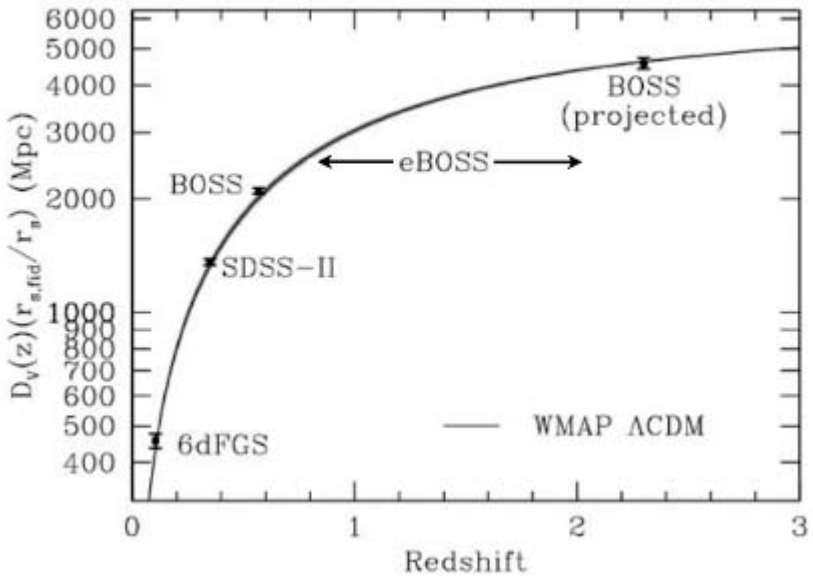
Future Projects

Timeline: Large Surveys



AS3/SDSS-IV (2014-2020)





Overlap with DES footprint => WL x RSD Test for DESpec

Large Synoptic Survey Telescope
(2020-2030)



LSST is designed to image the whole sky every few nights for 10 years



- **Cerro-Pachon**
- **8.4 meter**
- **3.2 Billion pixel camera (6 X DECam)**
- **Cadence 40 s**

LSST data products

- Image metadata consisting of 700 million rows
- A source catalog of with **3 trillion rows**
- An object catalog with **20 billion rows each with 200+ attributes**
- A moving object catalog with 10 million rows
- A variable object catalog with 100 million rows
- Ten years of operations of **60 PB for the raw data**, and **30 PB for the catalog database.**
- The total data volume after processing will be over one hundred PB, processed using **250 TFlops** of computing power.

http://www.linea.gov.br/

Nov 2010

MCTI Ministério da Ciência, Tecnologia e Inovação

Centro Brasileiro de Pesquisas Físicas

Laboratório Nacional de Computação Científica

Observatório Nacional

RNP Rede Nacional de Ensino e Pesquisa
Promovendo o uso inovador de redes avançadas no Brasil

LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA



- **12 Technical Staff**
- **30 scientists:**
  1. **AIP**
  2. **OAC**
  3. **Padova**
  4. **UFRJ**
  5. **UFRGS**
  6. **UNESP**
  7. **USP**
  8. **UFF**

FINEP

CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico

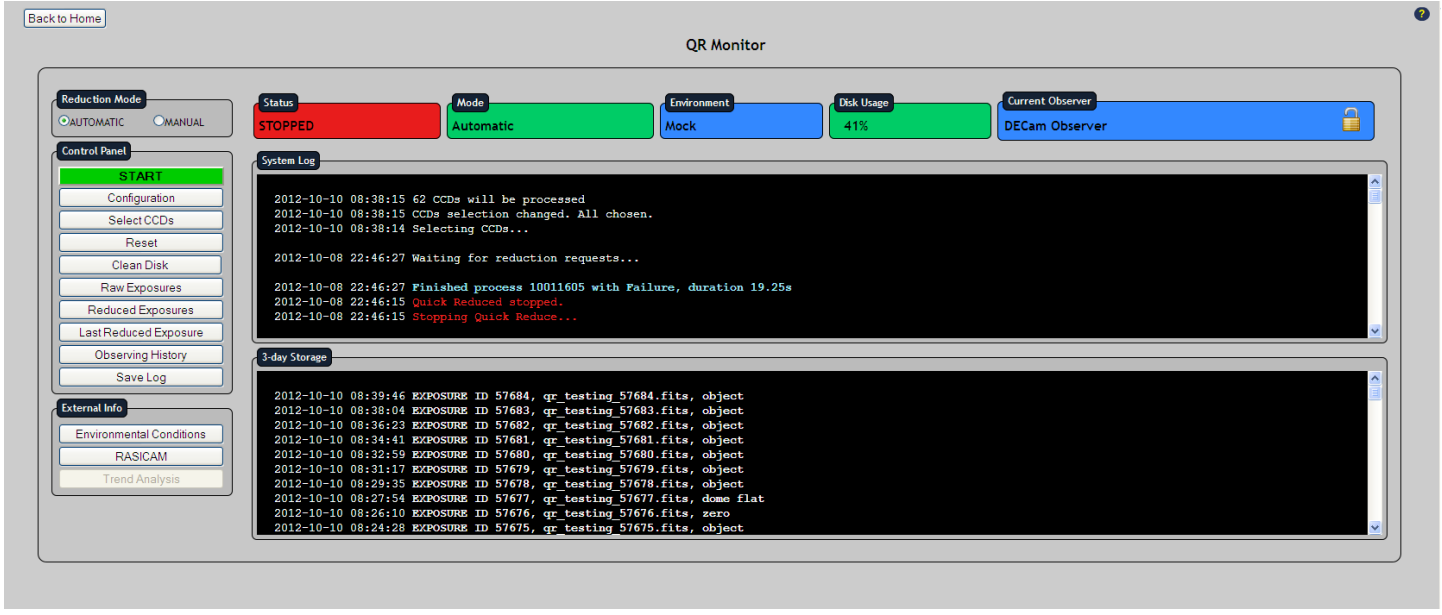
FAPERJ

Data Reduction

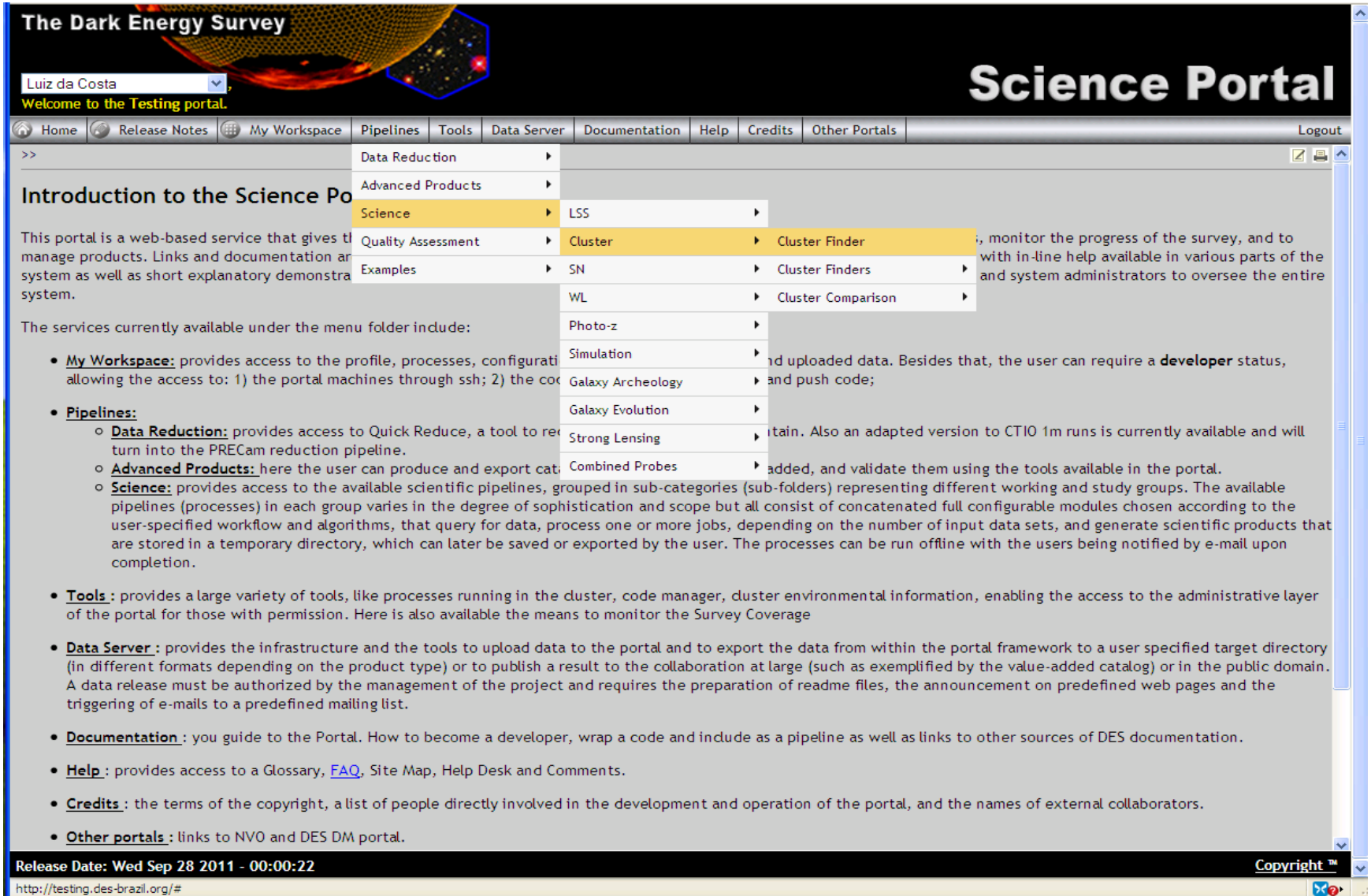


Observing room 4-m telescope CTIO

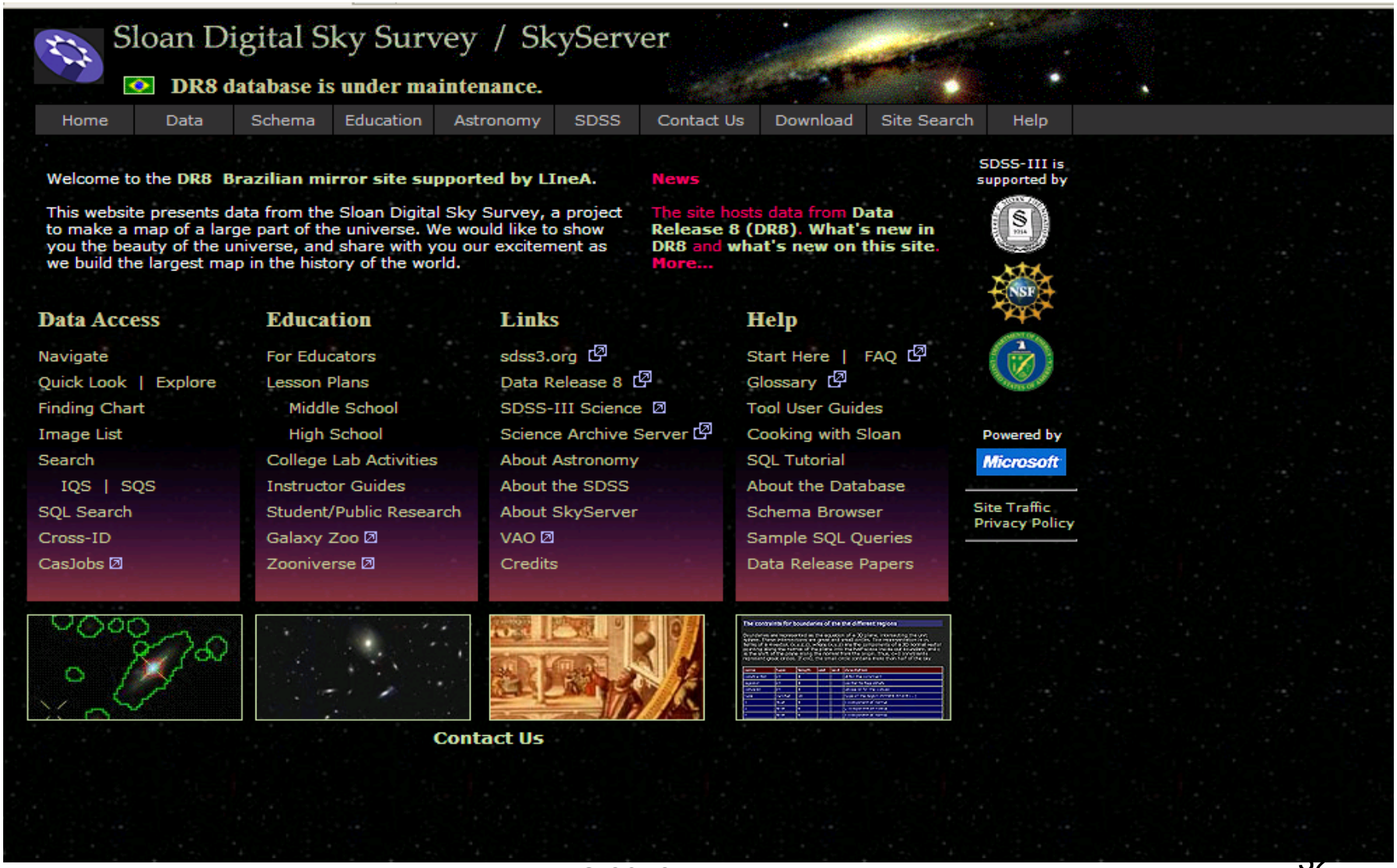
Quick Reduce pipeline



DES Analysis Portal



Data distribution



Conclusions

1. International collaboration with reliable partners key to remain competitive

2. Well-defined long-term strategy
   - LSST => DES extension - **improve FoM by factor of > 5**
   - DESpec => e-Boss extension
     - **WL X RSD test for DE x modified Gravity**
     - **DETF FoM DES + DESpec = 8 x DES**

3. LIneA: key for providing infrastructure for these projects