Assembling a Map of the Universe with Blue Waters

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Mapping the Heavens

The Flammarion (1888)
Charles Messier (1730–1817)

• He observed Halley’s comet and decided to devote the rest of his life to finding comets
• From 1758–1782, using a 4” refracting telescope, he compiled a list of 110 diffuse (i.e. not stars) “objects to avoid” (i.e. not comets)
• Then the French Revolution happened and he lost his job
M42
Orion Nebula
M57
Ring Nebula
Planetary Nebula
How do we make color images?
Our current understanding

13.7 billion years ago

Today

Afterglow Light Pattern 400,000 yrs.

Dark Ages

Development of Galaxies, Planets, etc.

Dark Energy Accelerated Expansion

Inflation

Quantum Fluctuations

1st Stars about 400 million yrs.

Big Bang Expansion

13.7 billion years
Our Dark Universe

The Energy Budget

Please put on your dark matter goggles

Millennium Simulation
Like Galaxies, houses (and people) are not uniformly distributed.
But we can see Galaxies
The Project
The Dark Energy Survey (DES)

DECam 570 MegaPix

CTIO Blanco/4m
The Dark Energy Survey

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

Two multiband imaging surveys:
5000 deg$^2$ $grizY$ to 24th mag
30 deg$^2$ time-domain $griz$ (SNe)

DECam 3 deg$^2$ FOV, 570 Megapixel
Survey 2013-2018 (525 nights)

DECam on the Blanco 4m at CTIO
Night Sky at CTIO
The Problems
Problem 1:

Single and Multi-epoch Pipelines
Section of “raw” data from DECam
cross-talk correction
Bias and Flat corrected
Astrometric Alignment
Bleed Trails (saturated stars)
CR Masking and Satellite Trails
Co-added (stacked) image
Problem 2:

From catalogs to Dark Energy and Dark Matter

Galaxies randomly distributed

Slight alignment
Gravitational Lensing (real)
Gravitational Lensing
Problem 2:
From catalogs to Dark Energy and Dark Matter

\[ e = 0 \quad \gamma = 0.05 \quad e_{\text{int}} = 0.4 \quad e_{\text{obs}} = e_{\text{int}} + \gamma \]

- No ellipticity: \( e = 0 \)
- Cosmic shear: \( \gamma \sim 0.05 \)
- Galaxy ellipticity: \( e \sim 0.4 \)
- Observed ellipticity: \( e_{\text{obs}} = e_{\text{int}} + \gamma \)

Cosmic shear + Galaxy ellipticity = Observed ellipticity
Mass Distribution from Lensing
Mass Distribution from Lensing

- Science Verification Data
- Early results from 1/10th of the survey area.
DES Production Pipelines on Blue Waters

- Single-epoch (each exposure from telescope)
- Multi-epoch (coadd images from single-epoch)
- Weak-lensing (using coda data-products)
DESDM Summary

- DES produces 0.5 TB flow per night during observations
- Worked for 2 years with BW Team to enable DES framework + pipelines
  - Open ports of communication
  - Real time DB connections
  - All pipelines can run on Blue Waters
- We serve yearly data releases to the collaboration (~300 Scientists)
- Public releases to the world (DR1: Dec 2017, DR2: 2020)
- Extensive outreach effort (Latino Community Urbana, Amazon Prime Documentary)
- DES is pathfinder to other astronomy surveys (LIGO/LSST)

**Multi-epoch 30%**
**Single-epoch 15%**
**Weak Lensing 60%**
Thanks
Bonus Tracks
Galaxies from the Dark Energy Survey