Dark Matter Science with LSST

LSST Community & Project Workshop
August 16 2017
I am looking for a scribe for the dark matter session next week. I am sure your effort will be rewarded with *fame and fortune*! Please let me know if you are available.

Thanks,
Will
Session Objectives

• Engage the LSST dark matter community beyond just the Dark Energy Science Collaboration
  • Provide the community with a summary of current DESC efforts
  • Provide some examples of current work ongoing in various LSST Science Collaborations
  • Have an open discussion

• Identify the next step
Agenda

• Introductory Remarks and Summary of DESC Effort; Will Dawson (10 min)
• Strong Lensing Constraints on Dark Matter; Nicola Napolitano (10 min)
• Milky and Local Volume Constraints on Dark Matter; Keith Bechtol (10 min)
• Transients/Variable Constraints on Dark Matter; Will Dawson (10 min)
• Discussion (50 minutes)
Probing the Nature of Dark Matter with LSST

Alex Drlica-Wagner
LSST DESC Meeting
July 12, 2017
The Dark Matter Problem

Plank Collaboration (2016)

How DESC usually thinks about dark matter

DARK MATTER
DARK ENERGY
ORDINARY MATTER

26%
5%
69%
The Dark Matter Problem

How particle physicists think about dark matter
The annihilating WIMPs) of have average cross sections (multiplied by the relative velocity of annihilate to the correct relic density to be dark matter typically on a number of model-dependent features, WIMP candidates that relics. Although the precise value of this cross section depends is the characteristic annihilation cross section of WIMP thermal neutrino telescopes [ray detectors, to large underground, under-ice, and underwater from space- and ground-based gamma-ray telescopes and cosmic-protection experiments include photons (gamma rays, X-rays, radio), produced in their annihilations or decays. Signals for indirect de-stead, they attempt to detect the standard model particles that be interpreted as very light (10 GeV) DM particles. Although this a number of experiments have reported potential signals that could improvement expected in the coming decade [for WIMP masses of }
The Dark Matter Search

Astrophysical Probes are the only approach that shows a high-confidence positive signal of dark matter.
Dark Matter: Micro to Macro

- Dark Matter Micro-Physics
  - Axions (BEC)
  - Evolutionary SIDM
  - Evolutionary FDM
  - Primordial FDM
  - Primordial SIDM

- Dark Matter Macro-Physics
  - Halo scale on which "weirdness" shows up

Matt Buckley & Annika Peter, in prep
OMEGA is a unique probe of multiple dark matter models. This means that when combined with other constraints (from direct detection and colliders) the "gravitational detection" of dark matter by OMEGA can provide orthogonal/complementary microphysical constraints to other detection platforms (indirect detection, direct detection, colliders).

OMEGA will probe density perturbations on scales about two orders of magnitude smaller than that currently possible [assuming subhalo mass function to 1000 Msun]. In doing so, it will either discover the cut-off in these perturbations due to dark matter particle properties predicted by many models, or allow the inflationary potential to be mapped out.

I. Imprint of particle properties of dark matter on the linear power spectrum of density perturbations. OMEGA will be sensitive to any particle physics property that leads to the fluctuations in density being erased on scales of order kpc or larger. In conjunction with direct and indirect detection experiments and the Large Hadron Collider, OMEGA will be able to inform the following fundamental questions in cosmology and particle physics:

How was dark matter produced in the early universe?

Standard CDM

-10^-3 -10^-2 -10^-1 10^0 10^1 10^2

10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 10^0 10^1 10^2

Dark matter transfer function

Wavenumber k (h/Mpc)

Collapse Mass (M_{sun})

-10^-3 -10^-2 -10^-1 10^0 10^1 10^2

10^18 10^16 10^14 10^12 10^10 10^8

Super WIMPS

Sterile Neutrinos

Warm Dark Matter

Self-Interacting Dark Matter

Deviations from Cold Dark Matter would be detected in the abundance of the smallest structures.

Image Credit: Massey & Moustakas
Small Scale Structure: Local Volume

Keith is going to talk about this much more…
Galaxy formation is expected to turn off for halo masses $<10^8 \, M_\odot$; gaps in stellar streams may allow us to probe lower masses.
Small Scale Structure: Strong Lensing

Vegetti et al. (2012) [1201.3643]

Nierenberg et al. (2017) [1701.05188]

Vegetti et al. (2012) [1201.3643]

Mass Modeling Anomalies

Flux Ratio Anomalies

200 Galaxy-Galaxy Lenses Identify with LSST — followup with other instruments

Galaxy Clusters

Non-Interacting Dark Matter

Self-Interacting Dark Matter
Galaxy Clusters


W. Dawson
Galaxy Clusters

- Many probes related to the galaxy cluster mass profile
- Wobbling BCGs
- Splash back radius
- Core/Cusp
- Follow up (spectroscopic, space-based, and multi-wavelength, etc.) will be important

Image Credit: Annika Peters
• Photon-axion conversion can happen in the vicinity of charged particles and magnetic fields.
• Axions offer an alternative (and faster) mechanism for cooling the interiors of stars.
Axions

Axion cooling increasing white dwarf cooling rate shifting the white dwarf luminosity function

\[ \log(L/L_\odot) \]

\[ \log N (\text{pc}^{-3} \ M_{\odot}^{-1}) \]

Isern et al. (2008) [0812.3043]

Ratio of Number of Stars in Red Giant Branch vs Horizontal Branch (Helium Burning)

M3 Globular Cluster

AGB

RGB

P-AGB

HB

SGB

BS

TO

MS

Raffelt 2006 [0611350]
• BBN and CMB set strict limits on the fraction of dark baryons

• Recent discoveries by LIGO have renewed interest in primordial black holes, which would not be counted in the baryon budget

• This has caused the community to resist previous constraints on primordial black holes (discarding some and adding others)

Will is going to talk about this much more…
To facilitate updates to the DM, the relative accessibility of the galaxies (e.g., the Large Synoptic Survey Telescope (LSST)) is crucial. J-factor determinations with deeper spectroscopy, and lack of any significant signal in the combined analysis, highlight uncertainties in the J-factors of these targets, and the frequent occurrence of excesses, the GCE, we refrain from a more extensive DM interpretation.

The limits derived from LAT data coincident with correlated emission from the U.S. Department of Energy, the U.S. National Science Foundation in China and the Collaboration for Astronomy and Astrophysics in Italy and the Centre National d'Études Spatiales in France. Acknowledged from the Istituto Nazionale di Astrofisica in Italy, the Ministry of Education, Culture, Sports, Science and Technology in Japan, and the K. A. Wallenberg Foundation. Support from a number of agencies and institutions that have supported both the development and the ongoing support from a number of agencies and institutions that have supported both the development and the operation of the LAT as well as scientific data analysis.

We would like to thank Tim Linden and Dan Hooper for helpful and engaging conversations. We also thank the anonymous referee for thoughtful and constructive feedback.

**Figure 9.** Upper limits (95% confidence level) on the DM annihilation cross section derived from a combined analysis of the nominal sample and a factor of 5 less constraining for lower DM masses (e.g., the nearby and recently discovered stellar systems). Relative to the combined analysis, the limits derived here are up to a factor of 2 more constraining at large DM masses.

The limits derived here are a factor of 5 less constraining for lower DM masses. Relative to the combined analysis, the limits derived here are up to a factor of 2 more constraining at large DM masses.

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Local Dark Matter Density

**Stars, MW, & Local Volume**

Read (2014) [1404.1938]

Mao et al. (2012) [1210.2721]

Understanding the dark matter distribution in our Galaxy is essential for interpreting results from direct detection experiments.
According to the SRM, the goal of DESC is to: “use of LSST to study observable signatures of ‘dark sector’ physics, including dark energy, dark matter, neutrinos, and signatures of inflation”

However, many of the topics discussed today have significant overlap with other LSST science collaborations.

Does dark matter science benefit from having a single home, and should DESC be that home?
How to Integrate with DESC?

• One example: Many dark matter studies will analyze point-like sources (local group, MACHOs etc.)
  • Model and examine stars in DC1/DC2
  • Star/Galaxy separation
  • Deblending in crowded fields
  • Photometric calibration (SLR, ubercal, etc.)

Will has a longer list in his to talk; topic for discussion…
How to Integrate with DESC?

A concrete example (and some dirty laundry from DES)...
Stars: a canary in a coal mine
Some Resources

Slack Channel:
#desc-dark-matter

Email List:
<lsst-desc-darkmatter@slac.stanford.edu>

Github Repo:
https://github.com/LSSTDESC/LSSTDarkMatter

Living Bibliography:
https://www.overleaf.com/10295894rskjrcqgwnzt
Research Scientist

Location: Livermore, CA
Category: Science & Engineering
Organization: Physical and Life Sciences
Posting Requirement: External w/ US Citizenship
Job ID: 102531
Job Code: Science & Engineering MTS 3 (SES.3)
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