Vera C. Rubin Observatory as a Dark Matter Experiment

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LSST DESC
Dark Energy Science Collaboration

100-Year History of Dark Matter

Trimble 2013;
Bertone & Hooper 2016

Cosmology/Astrophysics

Solar neighborhood mass budget
Kapteyn, Oort

Coma galaxies are booking it (dunkele Materie)
Zwicky

Rotation curves of spiral galaxies
*Van de Hulst, **Rubin**, Ford, Freeman, many others*

First galaxy surveys
(CfA)

CMB, galaxy surveys give cosmic abundance of CDM-like dark matter

Small-scale crises for CDM?

Cosmic simulations (& galaxies)
Davis, White, Frenk, MANY others

Rubin Observatory

1920 1930 1950 1970 1980 1990 2000 2010 2020 & beyond

←--WIMP searches---------->

←------Axion searches---------->

Is it neutrinos?
Zeldovich

No.

Supersymmetry?
Pagels, Primack

Axions?
Peccei, Quinn

Small-scale problems = interesting dark matter?

Experimental searches for interesting dark matter

Particle Physics/Laboratory

Primer to the Vera C. Rubin Observatory

- Originally called the “Dark Matter Telescope”
- 10-year **Legacy Survey of Space and Time** (LSST) from 2024 - 2034
  - **Wide:** 20,000 deg^2
  - **Fast:** >800 visits in each patch of sky over 10 years
  - **Deep:** ugrizy photometry to ~27th magnitude (100x deeper than SDSS)
- LSST will catalog more stars, galaxies, and Solar System objects in first year of operations than all previous telescopes combined
- Rubin Obs Community organized into Project + 8 Science Collaborations + LSSTC + broader community
  - The **Dark Energy Science Collaboration** (DESC) is focused on cosmology, including dark energy, neutrinos, dark matter, inflation, ...
    - No Dark Matter Science Collaboration; a **Dark Matter Working Group within DESC** formed in 2019.

*“The Large Synoptic Survey Telescope, funded jointly by the National Science Foundation and the Department of Energy, will honor the legacy of Dr. Rubin and her colleagues to **probe the nature of dark matter by mapping and cataloging billions of galaxies through space and time**.”* -- Vera C. Rubin Observatory Designation Act (link)

Rubin Observatory Dark Matter Community

2014 P5 Report (link)

Astrophysical probes

Although models of cold, collisionless dark matter agree well with cosmological observations, these models may break down at galactic or smaller scales. Simulations of dark matter structure formation suggest that the density in the inner cores of galaxies should be much higher than is currently observed. These simulations also predict the existence of many small subhalos, which could be identified with small galaxies orbiting the Milky Way; again the predictions for the number of satellites deviate from the observed number. It is possible that astrophysical effects explain these small-scale problems, but it is also possible that they are pointing to interesting properties of the dark matter particles. For example, dark matter with additional self-interactions (such as through heavy photon exchange) can give the same large-scale behavior as collisionless dark matter but different behavior at small scales. Warm dark matter, with mass ~1 keV, can suppress structure formation at small length scales compared to cold dark matter. Optical surveys (such as DES, LSST, and DESI) may be used to address these issues.

Table 1
Summary of Scenarios

	Scenarios			Science Drivers					
Project/Activity	Scenario A	Scenario B	Scenario C	Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	Technique (Frontier)
Large Projects									
Muon program: Mu2e, Muon g-2	Y, Mu2e small reprofile needed	Y	Y					✓	I
HL-LHC	Y	Y	Y	✓		✓		✓	E
LBNF + PIP-II	Y, LBNF components delayed relative to Scenario B.	Y	Y, enhanced		✓			✓	I,C
ILC	R&D only	R&D, possibly small hardware contributions. See text.	Y	✓		✓		✓	E
NuSTORM	N	N	N		✓				I
RADAR	N	N	N		✓				I
Medium Projects									
LSST	Y	Y	Y		✓		✓		C
DM G2	Y	Y	Y			✓			C

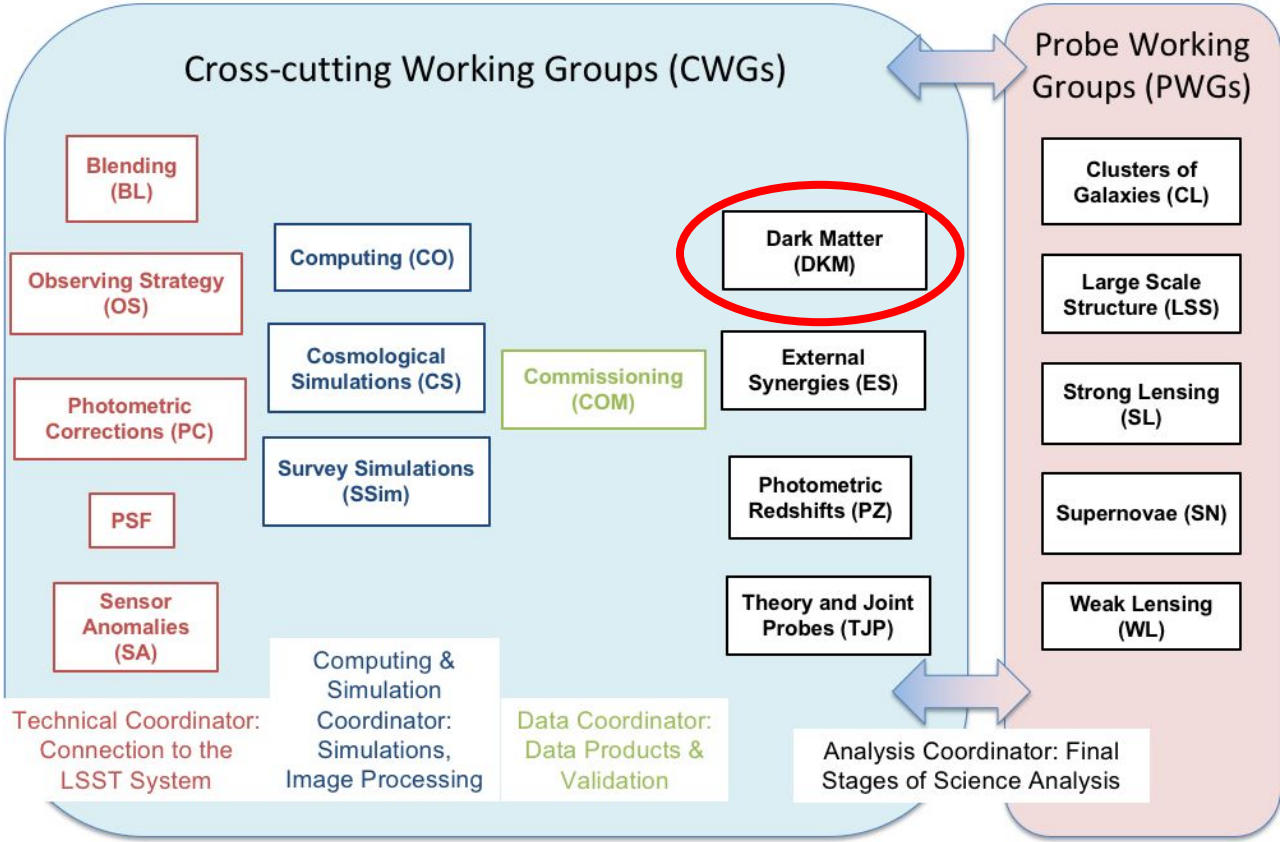
LSST not specifically identified as dark matter experiment in 2014 P5 report 😕

Rubin Observatory Dark Matter Community

- 2018-2019: series of workshops to build the science case for astrophysical probes of dark matter with Rubin Observatory
  - Formation of "LSST Dark Matter Study Group"
- early-2019: Main White Paper and Astro 2020 White Paper posted
- mid-2019: Dark Matter working group formally established within DESC
  - Established a formal "home" for observational, theoretical, and simulation/numerical efforts related to astrophysical probes of dark matter
  - Technical, scientific, and personnel overlap with other cosmology analyses

Rubin Observatory is noteworthy in the Snowmass process, in part it is a major near-future DOE Cosmic Frontier facility with an established dark matter community that is well integrated with other cosmology efforts via the DESC.

Dark Matter Working Group as part of the Dark Energy Science Collaboration (DESC)



By R. Mandelbaum 2019 Source

Rubin Observatory Dark Matter Community

Main White Paper
arXiv:1902.01055

Probing the Fundamental Nature of Dark Matter with the Large Synoptic Survey Telescope

LSST Dark Matter Group

April 25, 2019

The following people have contributed to or endorsed the LSST dark matter science case as presented here:

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Astro 2020 White Paper
arXiv:1903.04425

Astro2020 Science White Paper
Dark Matter Science in the Era of LSST

Thematic Areas:
☐ Planetary Systems ☐ Star and Planet Formation
■ Formation and Evolution of Compact Objects ■ Cosmology and Fundamental Physics
☐ Stars and Stellar Evolution ☐ Resolved Stellar Populations and their Environments
☐ Galaxy Evolution ☐ Multi-Messenger Astronomy and Astrophysics

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Rubin Observatory Science Portfolio

- **Minimum halo mass**
  - Ultra-faint galaxies (Milky Way satellites and beyond)
  - Strong lensing anomalies
  - Stellar stream perturbations
- **Halo mass profiles**
  - Dwarf galaxy halo density profiles from galaxy-galaxy weak-lensing
  - Galaxy clusters
- **Enhancing direct and indirect detection**
  - Dark matter distribution and velocity distribution within the Milky Way
  - Dark matter distribution on cosmological scales
- **Anomalous energy losses** in stars and supernovae
- **Compact objects**, e.g., microlensing searches for primordial black holes
- **Large-scale structure**
  - Light relics; coupling between dark matter and dark energy

Overlapping science and techniques with other LSST Science Collaborations (e.g., Stars, Milky Way, and Local Volume, Strong Lensing, Galaxies, Informatics and Statistics)

Plan for Snowmass Process

- The DESC Dark Matter Working Group intends to draft an LOI to specifically highlight Rubin Observatory as a powerful platform to explore a broad set of dark matter models (https://www.overleaf.com/read/qpmbpbndqfwx)
- We plan to update the “Main White Paper” for July 2021 submission to Snowmass process
- We encourage additional LOIs + white papers on specific observational techniques, dark matter models, follow-up observations and analysis, etc.

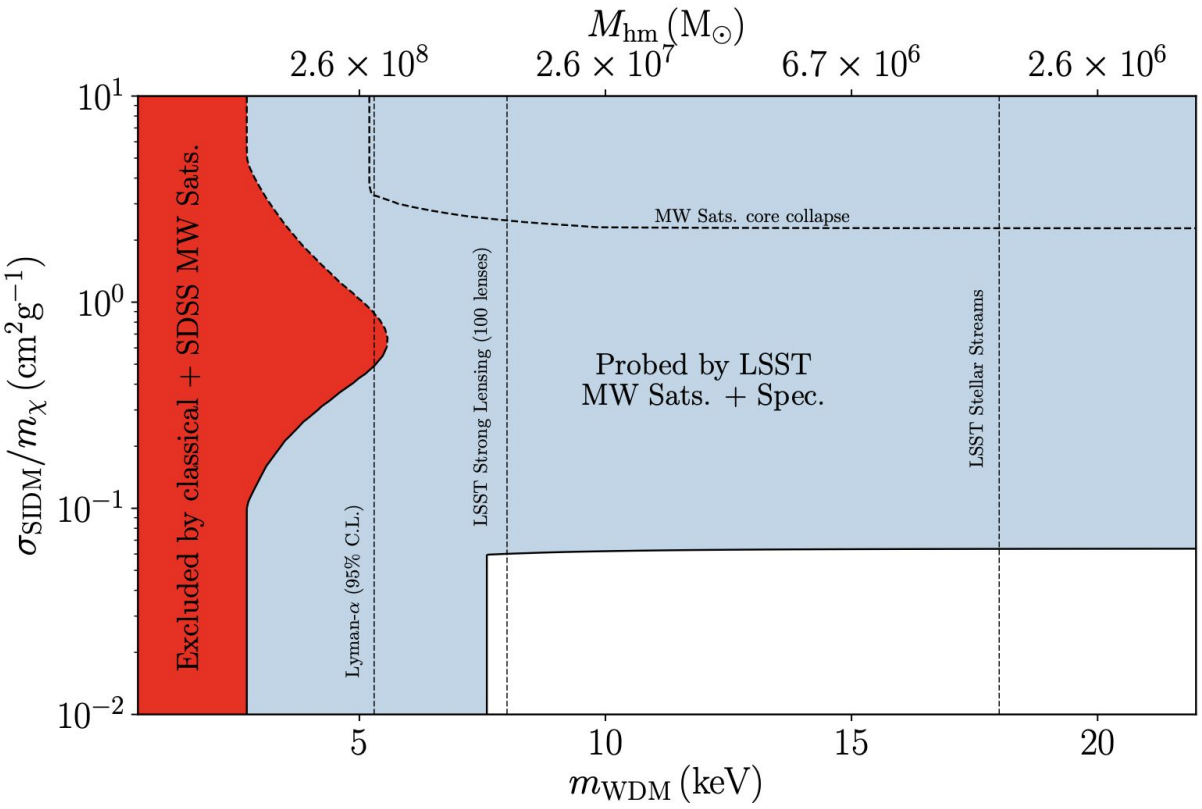
What should we advocating in Snowmass?

- Support for individual PI's and collaborative teams to analyze LSST data for dark matter science
- Support for DESC operations related to dark matter science
- Support for follow-up observations (e.g., spectroscopy, high-resolution imaging)
- Support for theoretical and numerical/simulations work
- Support for joint processing of Rubin Observatory data with space-based imaging surveys
- Support for cross-disciplinary, collaborative efforts to unite LSST dark matter analysis with particle theory and experiment
- Your suggestions here!

While Rubin Observatories' construction (and operation) is funded, the continued support for science activities is not guaranteed.

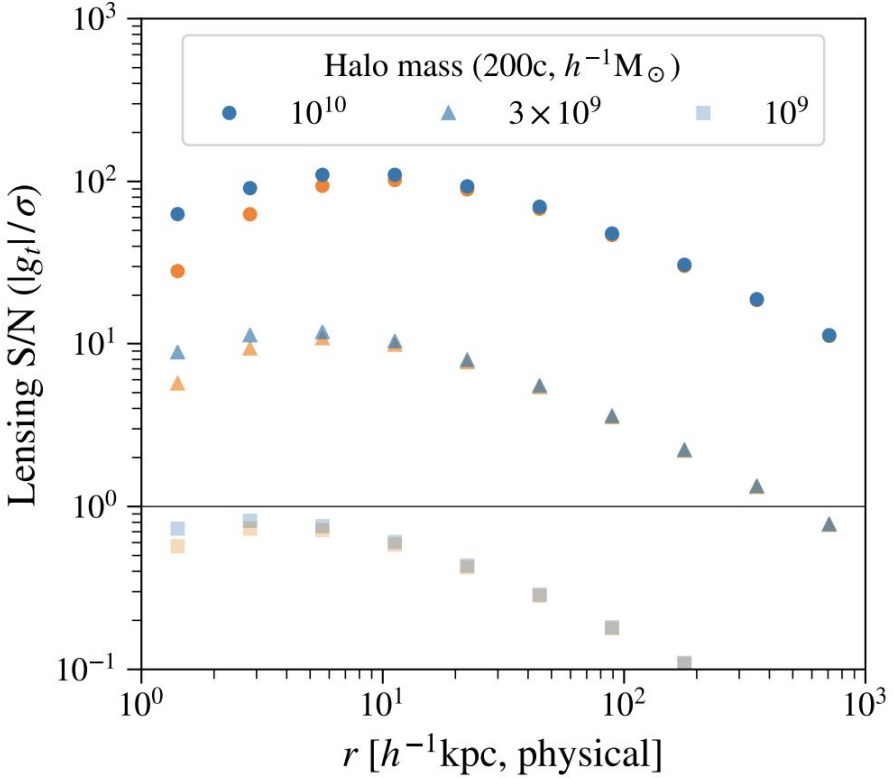
Extras

Minimum Halo Mass



Drlica-Wagner +
LSST DKM 2019

Halo density profiles



Drlica-Wagner +
LSST DKM 2019

Snowmass2021 LOI on Rubin + Dark Matter

Keith Bechtol, Alex Drlica-Wagner, Yao-Yuan Mao, Annika Peter

Snowmass2021 - Letter of Interest

The Vera C. Rubin Observatory as a Dark Matter Experiment

Thematic Areas: (check all that apply ☐/■)

■ (CF1) Dark Matter: Particle Like
■ (CF2) Dark Matter: Wavelike
■ (CF3) Dark Matter: Cosmic Probes
☐ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
☐ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
☐ (Other) *[Please specify frontier/topical group]*

Contact Information: (authors listed after the text)
Submitter Name/Institution:
Collaboration (optional):
Contact Email:

Abstract: (must fit on this page)

Astrophysical observations currently provide the only robust, empirical measurements of da

1. 1st paragraph good. Introduces DM as an astrophysics discovery, ar and the discovery potential for particle physics, cosmology, astroph ΛCDM. You can't understand "Λ", without understanding "CDM".
2. Astrophysical probes are unique. Sensitivity to broad range of model sector. Breaking model degeneracy. Sensitivity to free streaming lengt ter, self-interactions, baryon/photon/neutrino scattering, de Broglie w *surement* versus search.
3. Introduction of Rubin Observatory/LSST... directly into dark matter? M many different models because of richness of data.
4. Measurement facility rather than search facility. Discovery potential.
5. Small halos, density profiles, compact objects (inflationary physics), s

Habemus outline!