Revealing the Invisible
Strong Lensing Views and Clues of the Nature of Dark Matter Particle(s)

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Dark Matter in the universe

A quarter of the mass energy budget of the universe is in dark matter.

In the successful CDM “Weakly Interacting Massive Particle” (WIMP) scenario, the smallest self-gravitating structures are expected to be as small as 1E-6 Msun: merely the mass of the Earth!
DM Particle physics and “cutoff scales”

We see this from the scales to which the transfer function for (WIMP) matter extends to small scales – FAR to the right of this plot.

Vanilla WIMP CDM

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Dark matter particle candidates

While WIMP-type dark matter is successful from the horizon scale of 1E4 Mpc to ~1Mpc scales, there has been a lot of tension at smaller scales. Challenges include the “satellite problem” whereby the number of dwarf galaxies found around our Milky Way Galaxy is ...dwarfed by the orders of magnitude greater number of predicted WIMP-based subhalos.

This table shows many of the classes of candidates that satisfy all existing data!

<table>
<thead>
<tr>
<th>Dark Matter Candidate</th>
<th>Mass Range</th>
<th>Temperature</th>
<th>Complementary Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>I WIMP Neutralino</td>
<td>GeV–TeV</td>
<td>Cold</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>II SuperWIMP</td>
<td>GeV–TeV</td>
<td>Cold/Warm</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>III Light Gravitino</td>
<td>eV–keV</td>
<td>Cold/Warm</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>IV Hidden Sector</td>
<td>MeV–TeV</td>
<td>Cold/Warm</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>V Sterile Neutrino</td>
<td>keV</td>
<td>Warm</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>VI Axion</td>
<td>µeV–meV</td>
<td>Cold</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>VII Asymmetric</td>
<td>GeV</td>
<td>Cold</td>
<td>✓ ✓ ✓</td>
</tr>
</tbody>
</table>
A broad view of DM particle candidates
DM Particle physics and “cutoff scales”

[Graph showing the relationship between Wavenumber $k$ (h/Mpc) and Dark matter transfer function on a logarithmic scale. The graph includes a curve labeled 'Standard CDM' and a region marked 'Vanilla WIMP CDM'.]

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DM Particle physics and “cutoff scales”

[Diagram showing dark matter transfer function and decay lifetime, with decay lifetime curve and standard CDM region.]
Strong gravitational lensing probes DM!
Time delays and magnifications => DM

The apparent brightness of each lensed image at any one epoch of observation depends on the combination of several phenomena, which vary on different timescales. OMEGA will map the time domain data streams well enough to disentangle all of these, to measure the effects due to the dark matter substructure, which is the proxy for the fundamental dark matter constraints.

AGN: variability and amplitude is a function of wavelength.
Smooth potential delays and magnifications.
DM potential perturbations affect both delays & magnifications.
Stellar microlensing is stochastic by image & depends on parity & $f_{DM}/f_*$. 
The key: map delays to 2-hour precision!

Hour-cadence percent-level precision light curves over continuous observing campaigns of 6 weeks or longer allow us to map time delay and magnification ratio perturbations well enough to be sensitive to substructure to mass scales of $1E6$ solar masses.
The solution: OMEGA
The Observatory for Multi-epoch Gravitational Lens Astrophysics (OMEGA) Explorer:

An 89-cm optical multiwavelength imaging telescope, in Low Earth Orbit, dedicated to time domain observations of a set of 24 four-image strong gravitational lenses, with:

- High angular resolution
- ~1% stable photometric precision
- across the SDSS griz broad bands, with
- Hourly cadences, over
- Contiguous & continuous observing campaigns of more than six weeks for each target.

LOOK FOR THE OMEGA SCIENCE BOOK ON ASTROPH BEFORE SUMMER 2011!
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