WHAT IS DARK MATTER?

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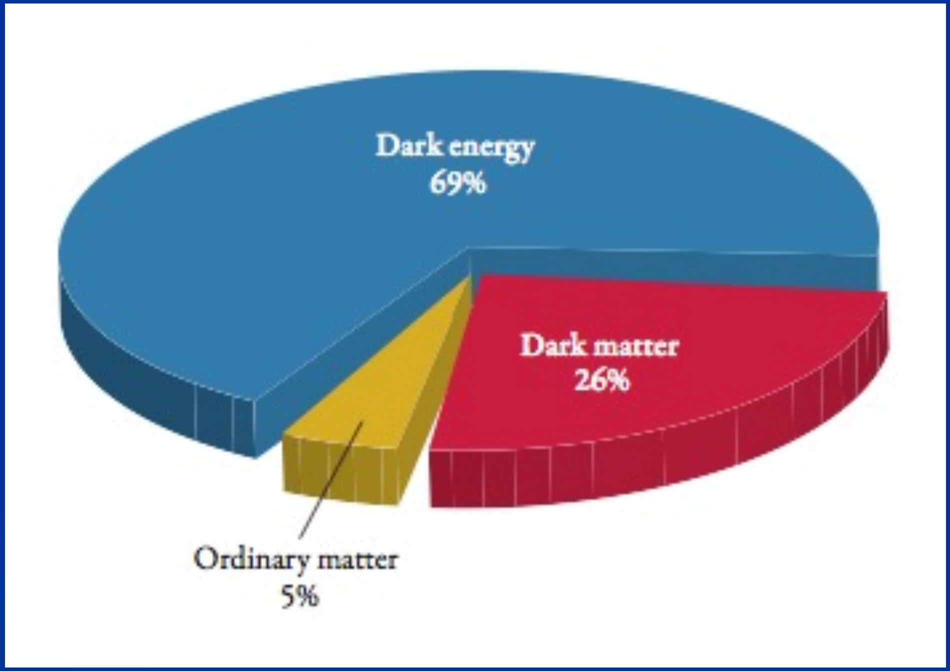
PIE CHART OF THE UNIVERSE



WHAT ARE THE PIECES OF THE PIE???

What is the Dark Matter? Candidates:

- 1980: Neutrinos? They exist. Too light, ½% of universe
- NEXT: Cold Dark Matter w/ strong theoretical motivation:
- WIMPs (SUSY or extra dimensions)
- Axions (exist automatically in solution to strong CP problem)
- --
- Now what? Sterile Neutrinos: no Standard Model interaction, 3.5 keV x-ray line?
- Primordial black holes (did LITO discover them?)
- Asymmetric Dark Matter
- Light Dark Matter, Fuzzy Dark Matter
- Self Interacting Dark Matter
- Q-balls, WIMPZillas (Rocky and Dan), Planck scale DM

Historically, in the 1980s: Neutrinos as Dark Matter? No

- Nearly relativistic, move large distances, destroy clumps of mass smaller than clusters
- Too light,

$$\Omega_\nu h^2 = \frac{\sum m_\nu}{93.5\text{eV}}$$

- 50 eV neutrinos would "close" the Universe.
- BUT
- The sum of the neutrino masses adds to roughly 0.1 eV
- Neutrinos contribute ½% of the mass of the Universe.

Neutrino Mass close to being measured (for the 3 active neutrinos)

- From oscillation experiments:
- $\sum m_\nu$ > 0.06 eV (Normal Hierarchy)
- > 0.1 eV (Inverted Hierarchy)
- Upper bounds from tritium beta-decay (KATRIN…), neutrinoless double beta decay
- From cosmology (CMB + Large Scale Structure +BAO)

$\sum m_\nu$ < 0.15 eV at 95% C.L.

Vagnozzi, Gerbino, KF etal
arXiv:1701.0872

Planck Satellite: < 0.12 eV

THEORY: WHAT IS THE ORIGIN OF NEUTRINO MASS?
ONLY KNOWN PHYSICS BEYOND THE STANDARD MODEL

Two well motivated DM candidates, solve problems in particle physics

Axions and the strong CP problem in QCD (Weinberg and Wilczek)

WHERE ARE THE DAMN WIMPS?

The "WIMP" miracle. Particles interacting via the Weak Interactions in the early universe lead to the correct abundance of WIMPs today as dark matter

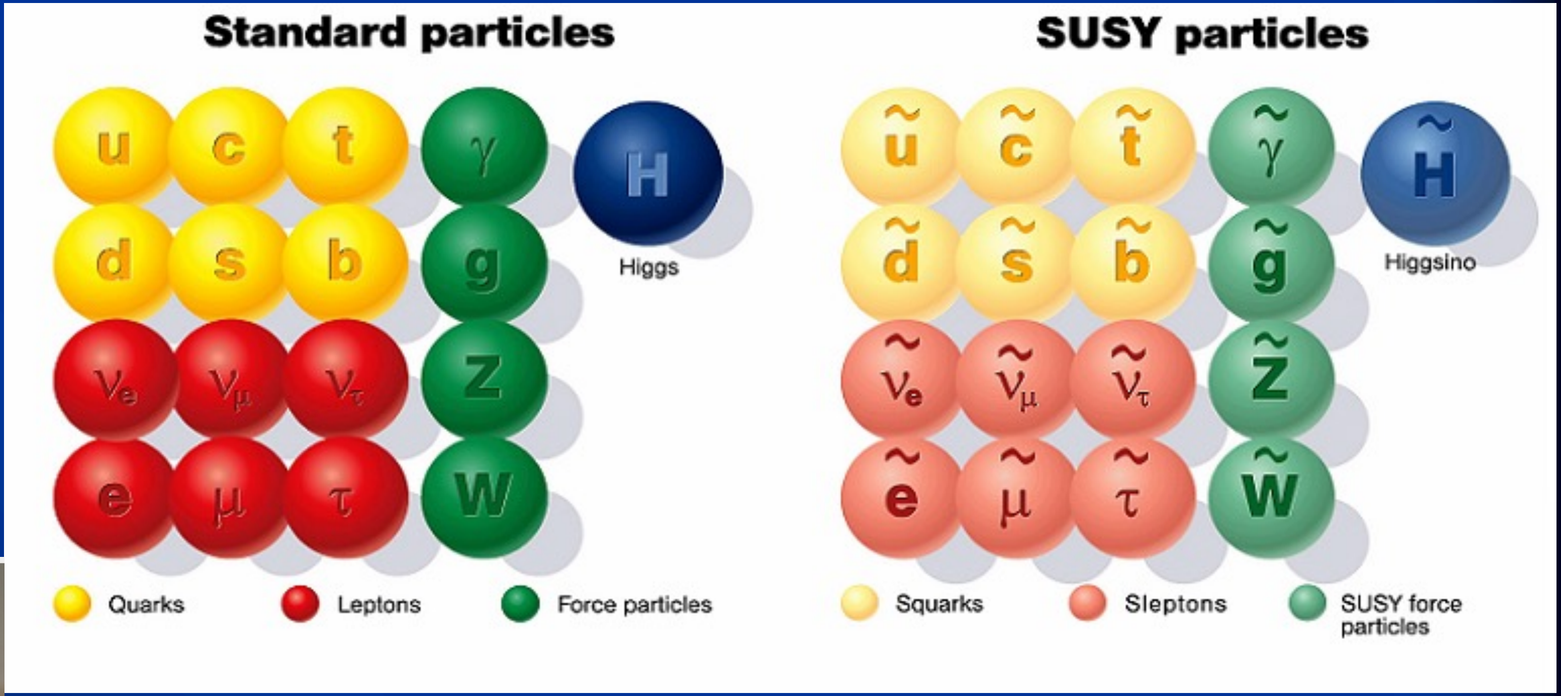
- SUSY SUSY SUSY

Second motivation for WIMPs: in particle theories, eg supersymmetry

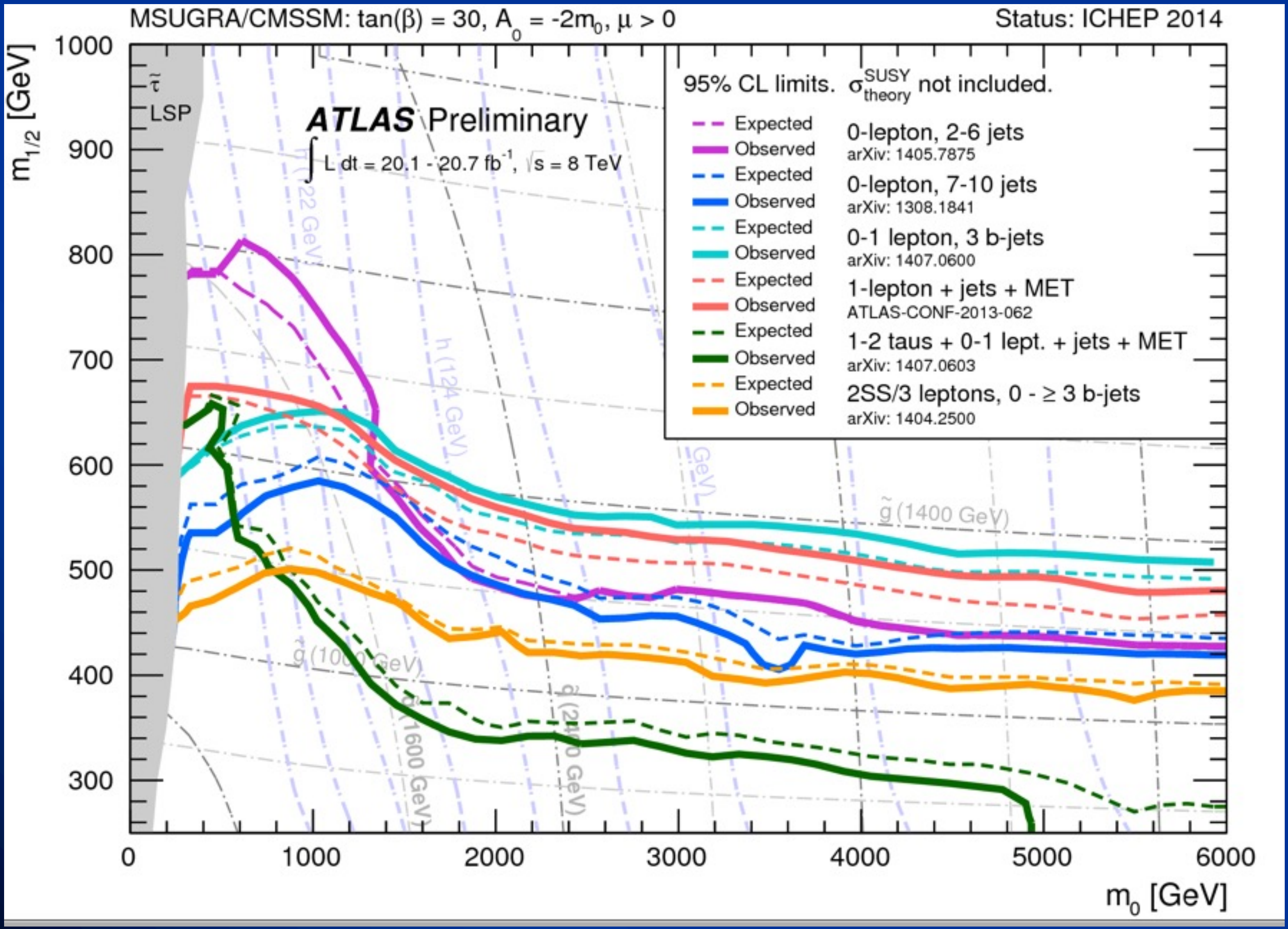
CARLOS AND MARCELA

Sebastian Baum

- Every particle we know has a partner

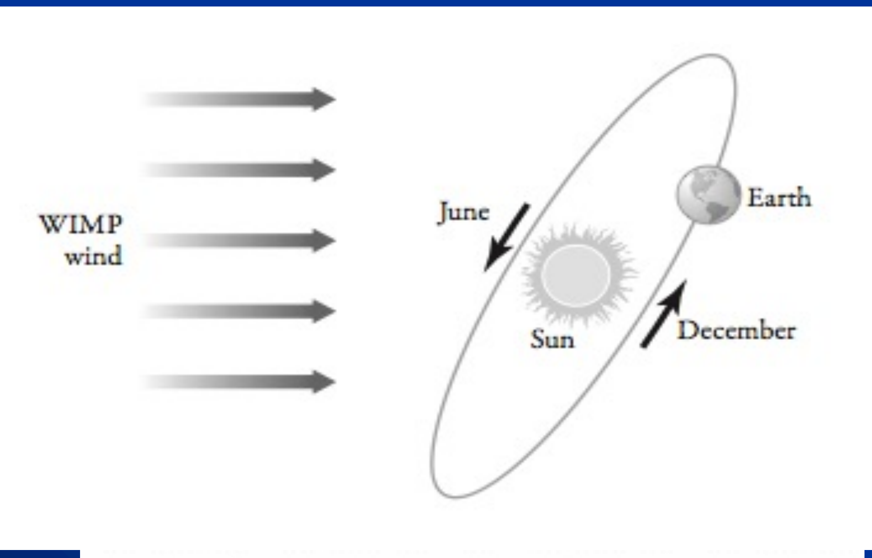


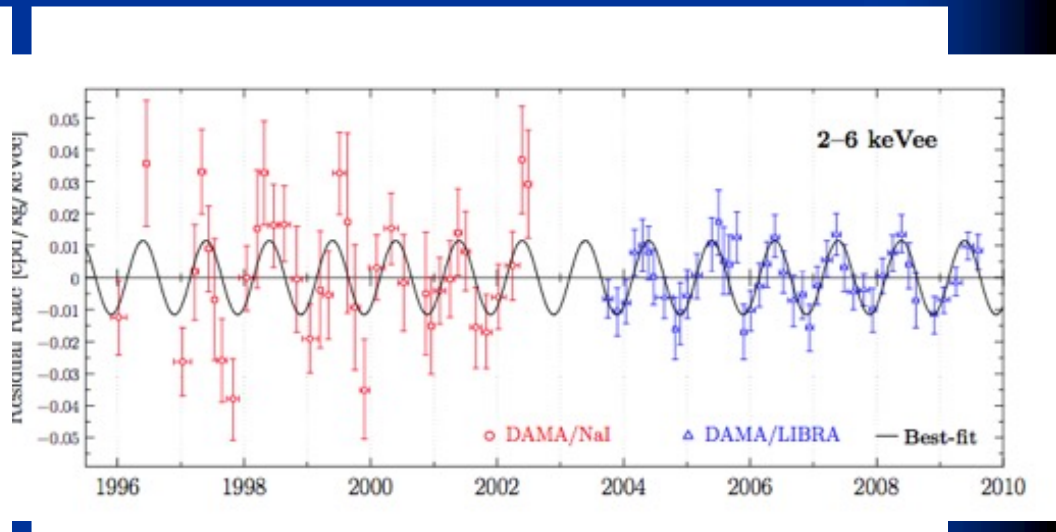
ATLAS bounds on CMSSM



DAMA annual modulation

Drukier, Freese, and Spergel (1986);
Freese, Frieman, and Gould (1988)

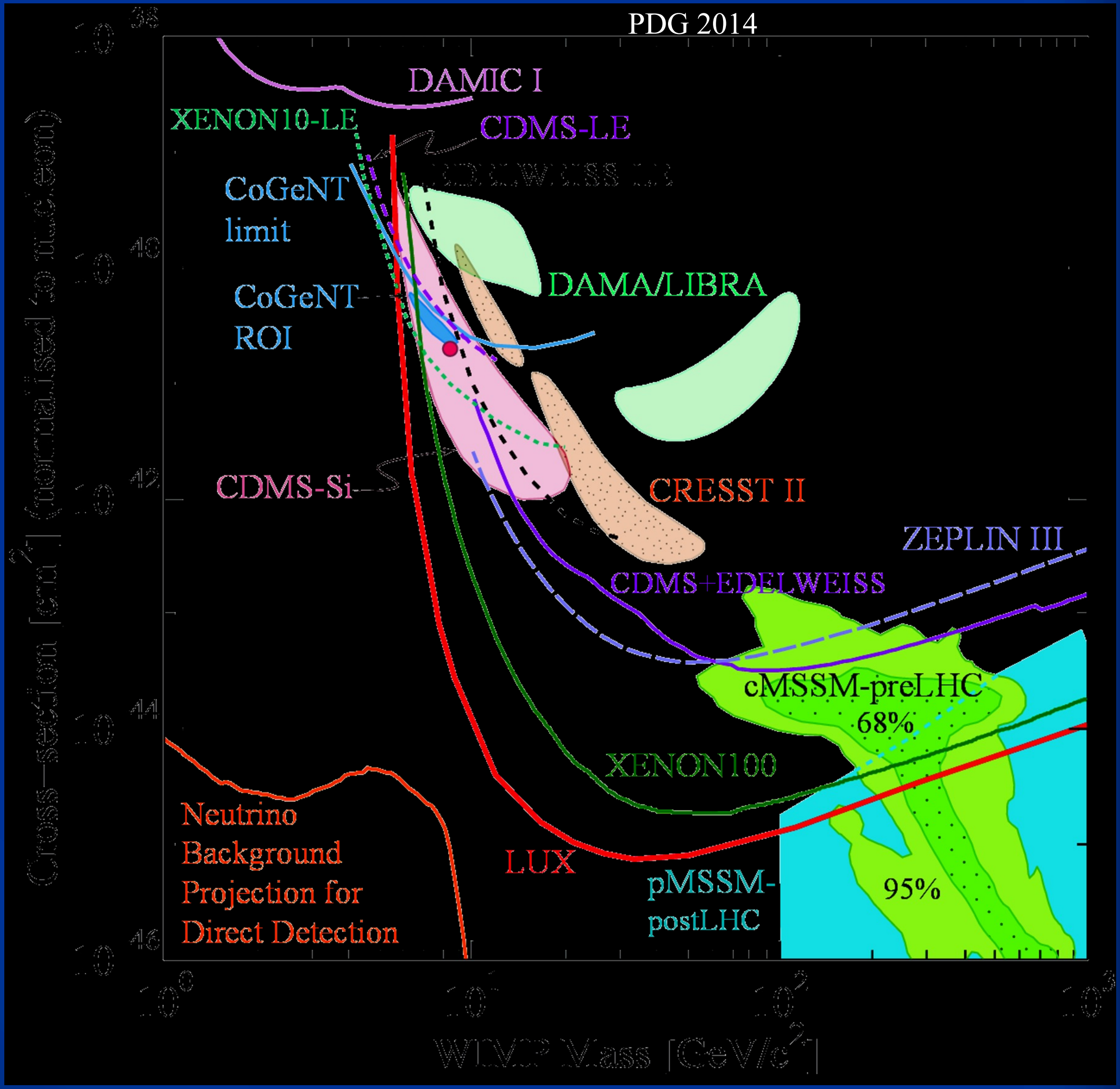




NaI crystals in Gran Sasso Tunnel under the Apennine Mountains near Rome.

Data do show modulation at 12 sigma! Peak in June, minimum in December (as predicted). Are these WIMPs??

Bounds on Spin Independent WIMPs



BUT:

--- it's hard to compare results from different detector materials

--- can we trust results near threshold?

To test DAMA within next 5 years

- The annual modulation in the data is still there after 13 years and still unexplained.
- New DAMA data down to keV still see modulation (DAMA all by itself is not compatible with SI scattering)

Baum, Freese,Kelso 2018

- Other groups are using NaI crystals:
- COSINE-100 has 1.7 years of data release, will have an answer within 3-5 years
- SABRE (Princeton) with Australia
- ANAIS
- COSINUS

Paleodetectors

WIMPs leave tracks in ancient minerals from 10km below the surface of the Earth.

Collecting tracks for 500 Myr.

Backgrounds: Ur-238 decay and fission

Take advantage of nanotools: can identify nanometer tracks in 3D

Baum, Drukier, Freese, Gorski, Stengel arXiv:1806.05991

Pat Stengel

Sebastian Baum

article in New Scientist

Digging for dark matter

Despite making up most of the universe, we still haven't detected dark matter. A clue could lie buried in ancient rocks, says physicist Sebastian Baum

MOST of our universe is missing. Observations of the smallest galaxies to structures spanning the entire universe show that ordinary matter – the stuff that makes up you, me and everything we see in the cosmos around us – accounts for only one-fifth of all matter. The remaining 80 per cent is a mystery.

After decades trying to hunt down this

Mineral Detection of Neutrinos and Dark Matter. A Whitepaper

Recoiling nuclei lead to defects:
Fission tracks, vacancies in crystal lattice, etc

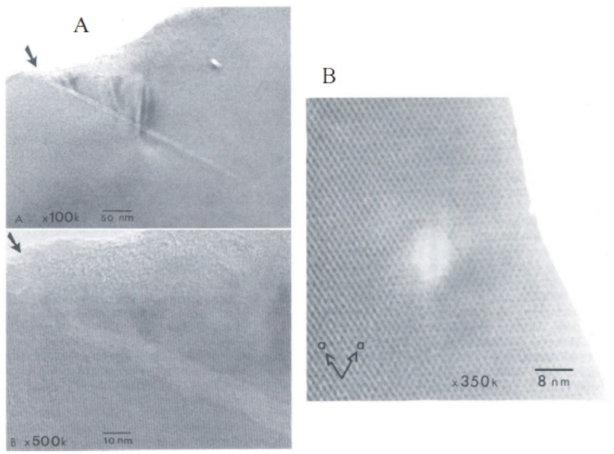


Figure 1: TEM-images of latent fission-tracks in apatite. *Left (A)*: Images taken parallel to the flight trajectory (light grey). *Right (B)*: Image taken perpendicular to the flight trajectory. Core of a fission-track is visible in the central part of the image. Figure taken from Ref. [90].

Color Centers:
Vacancies in crystal lattice,
e pairs fill in, get excited and fluoresce,
the crystal changes color

https://arxiv.org/pdf/2301.07118.pdf

Fourth Way: Find Dark Stars (hydrogen stars powered by dark matter) in James Webb Space Telescope, sequel to Hubble Space Telescope

W Doug Spolyar, P. Gondolo

Dark Stars

The first stars to form in the history of the universe may be powered by Dark Matter annihilation rather than by Fusion. Dark stars are made almost entirely of hydrogen and helium, with dark matter constituting 0.1% of the mass of the star).

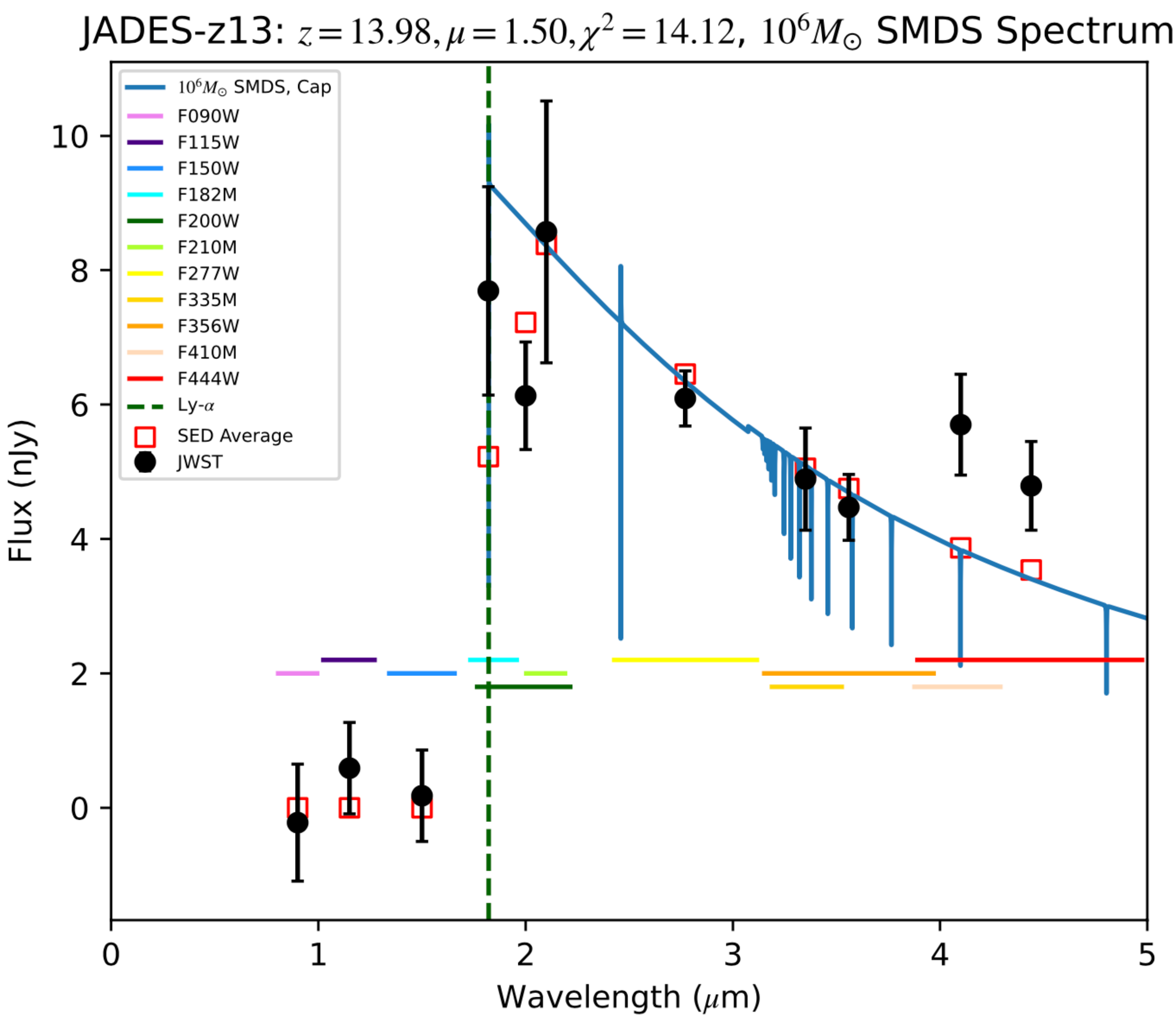
- This new phase of stellar evolution may last millions to billions of years
- Dark Stars can grow to be very large: up to ten million times the mass of the Sun. Supermassive DS are very bright, up to ten billion times as bright as the Sun. **We have found candidates in James Webb Space Telescope**
- Once the Dark Matter runs out, the DS has a fusion phase before collapsing to a big black hole: **IS THIS THE ORIGIN OF SUPERMASSIVE BLACK HOLES?**

Has JWST found Supermassive Dark Stars?

- JWST has found ~ 100 high redshift objects with z > 10. They assume these are “galaxy candidates”
- Too many galaxies for Lambda CDM
- Are some of them Dark Stars?
- NIRSPEC on JWST has spectra for 9 of these; so far 5 are on the arxiv or published. One is a galaxy.

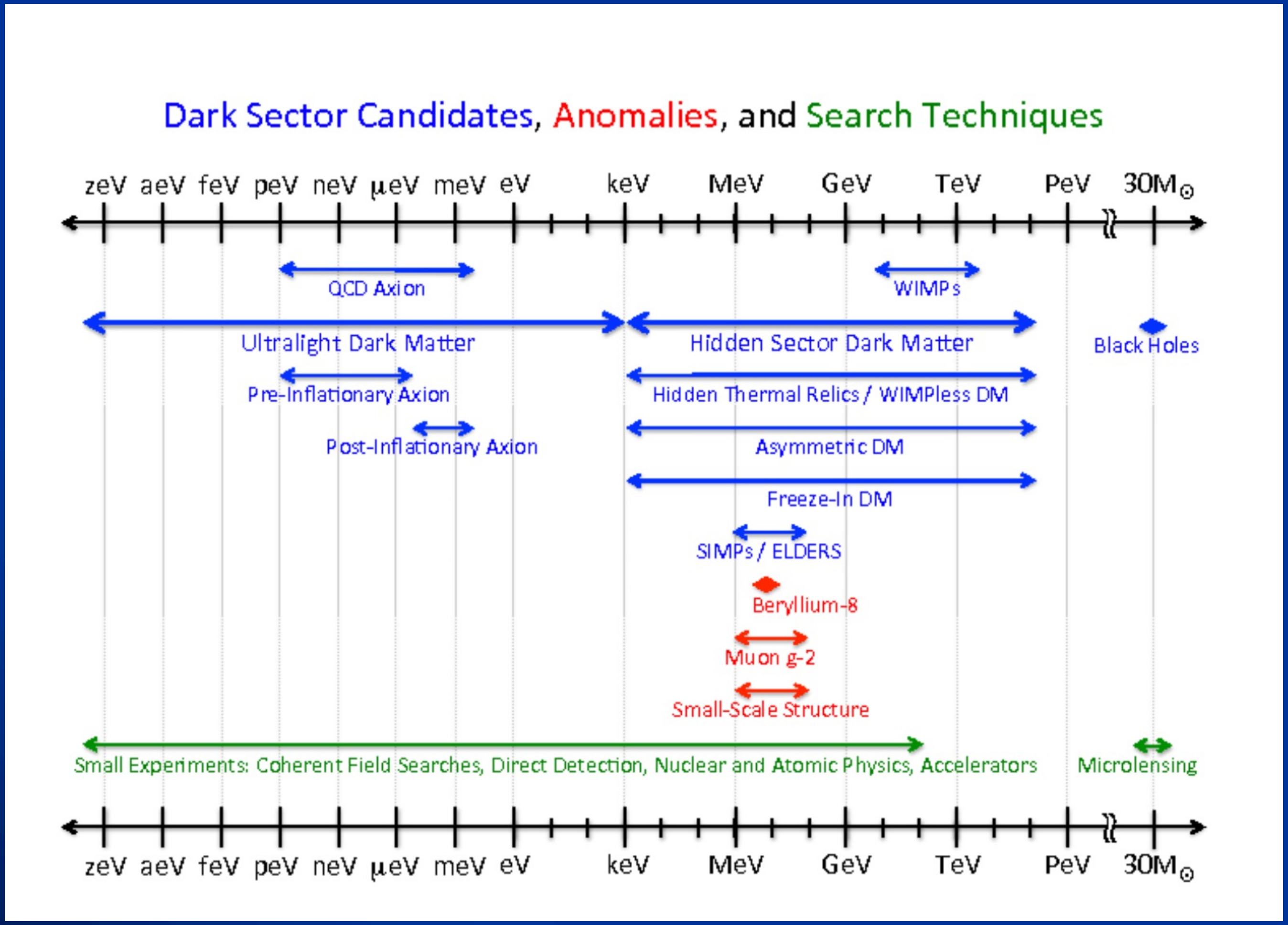
(W/out spectra, can’t be sure of redshift; some are low redshift)

- Specifically, JADES has four. So far, these are the ones we have studied. (JWST Advanced Extragalactic Survey)
- OUR RESULTS: Three of the five hi-z JWST objects w published spectra are consistent with Dark Stars.



JADES-z13: $z = 13.98, \mu = 1.50, \chi^2 = 14.12,\ 10^6 M_\odot$ SMDS Spectrum
$10^6 M_\odot$ SMDS, Cap
F090W
F115W
F150W
F182M
F200W
F210M
F277W
F335M
F356W
F410M
F444W
Ly-α
SED Average
JWST
Flux (nJy)
Wavelength (μm)
0
2
4
6
8
10
0
1
2
3
4
5

HELP! We don't know what all the possible candidates are, and we don't know how to look for them!



US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report -