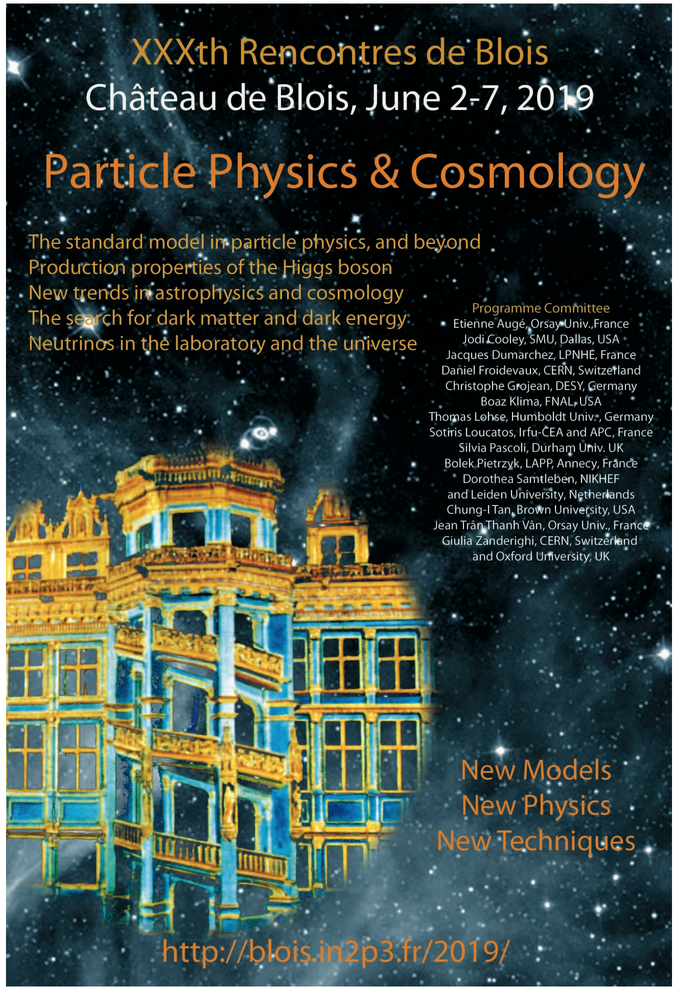
Blois 2019:
(Ideosyncratic) Highlights and Outlook

Graciela Gelmini - UCLA

U.S. DEPARTMENT OF ENERGY | Office of Science DE-SC0009937

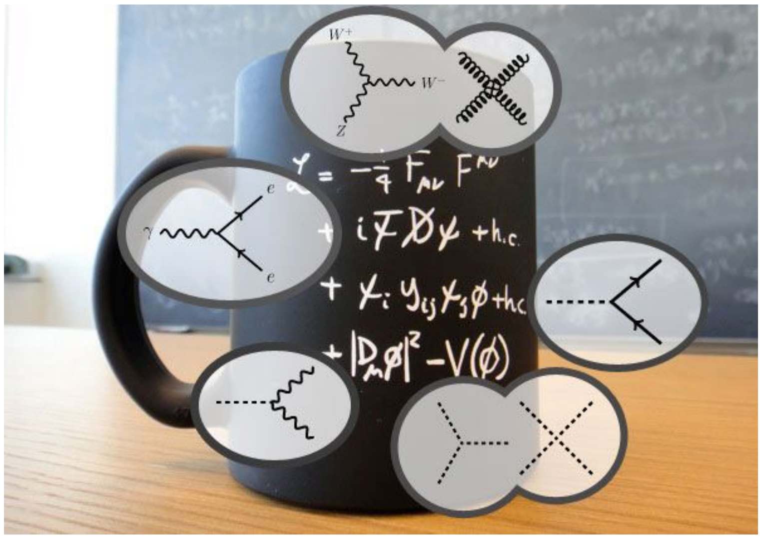
31st Rencontres de Blois, Blois, June 2-7, 2019

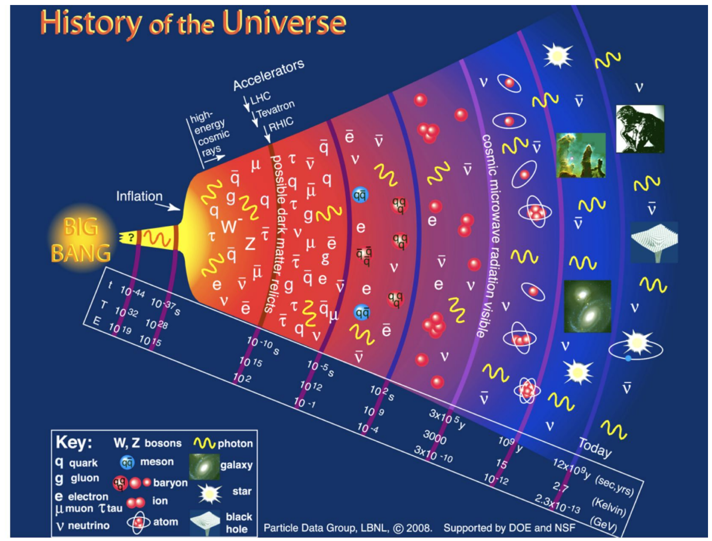


Particle Physics and Cosmology/Astrophysics are inextricably intertwined

Since the 1970s: **The two Standard Models**

SM of Elementary Particles and ideas about how to go beyond it, and
SM of Cosmology combined provide a common framework





Since the 1970s: **The two Standard Models**

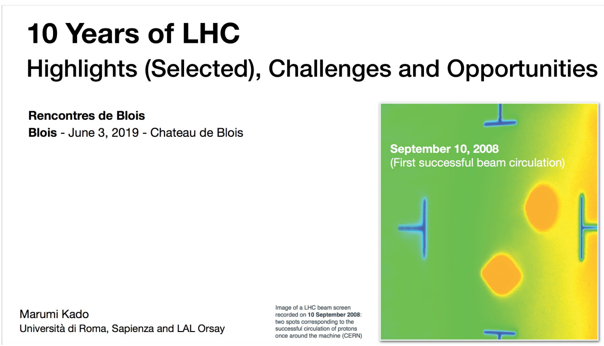
SM of Elementary Particles and ideas about how to go beyond it, and the **SM of Cosmology** **combined provide a common framework to try to explain:**

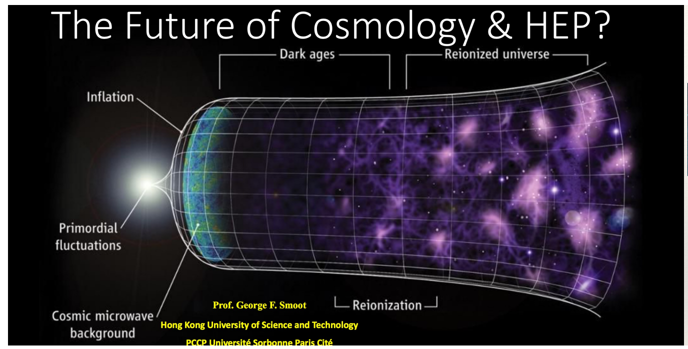
- the flatness and horizon problems of the Universe through inflation,
- structure formation in the Universe (primordial inhomogeneities generated as quantum fluctuations during inflation),
- the matter-antimatter asymmetry of the Universe,
- dark matter,
- dark energy...

We are in an era of major discoveries which confirm these two SM and we love anomalies, to challenge these SM's and make progress...

Major Discoveries in Recent years

Highlighted by the three inaugural talks of the conference (by George Smoot, Stanislav Babak and Marumi Kado)





2012: Higgs boson (LHC)- Completion of the EP SM
2013 (2015, 2018): Planck - unprecedented precision CMB data
2015: Gravitational waves (LIGO, VIRGO)- new eyes on the Universe

Each determined a before and an after in our field

(Could add others... e.g. 2014: Extragalactic PeV neutrinos in IceCube, 2017 1st multimessenger observation of NS-NS merger in GW and γ.)

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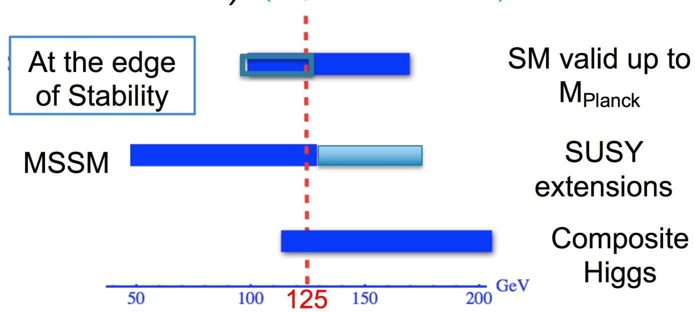
Before and after the Higgs boson

Before: "no lose theorem" for the LHC, guaranteed discoveries at the EW scale
After: just the Higgs and nothing else reachable at the LHC is possible, no guaranteed discovery. (Alain Blondel: "We have no scale")
But the EP SM has problems that should lead to new physics:
- EW hierarchy problem: Elementary scalars are quadratically sensitive to physics at higher scales (the Planck scale if there are not other lower scales of BSM)

Higgs mass value + all other data leaves open SUSY (but not "light-vanilla" SUSY) and composite models where the Higgs is a pseudo-GB or dilaton (but rejected many: "higgless" models, models with many new particles at the EW scale) (Fig. of M.Carena)



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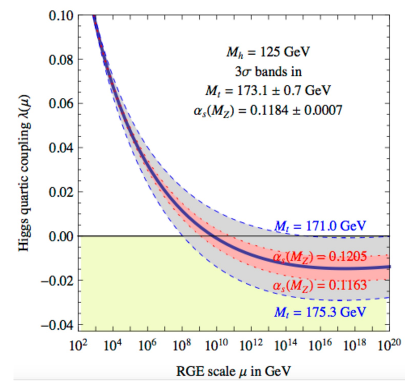
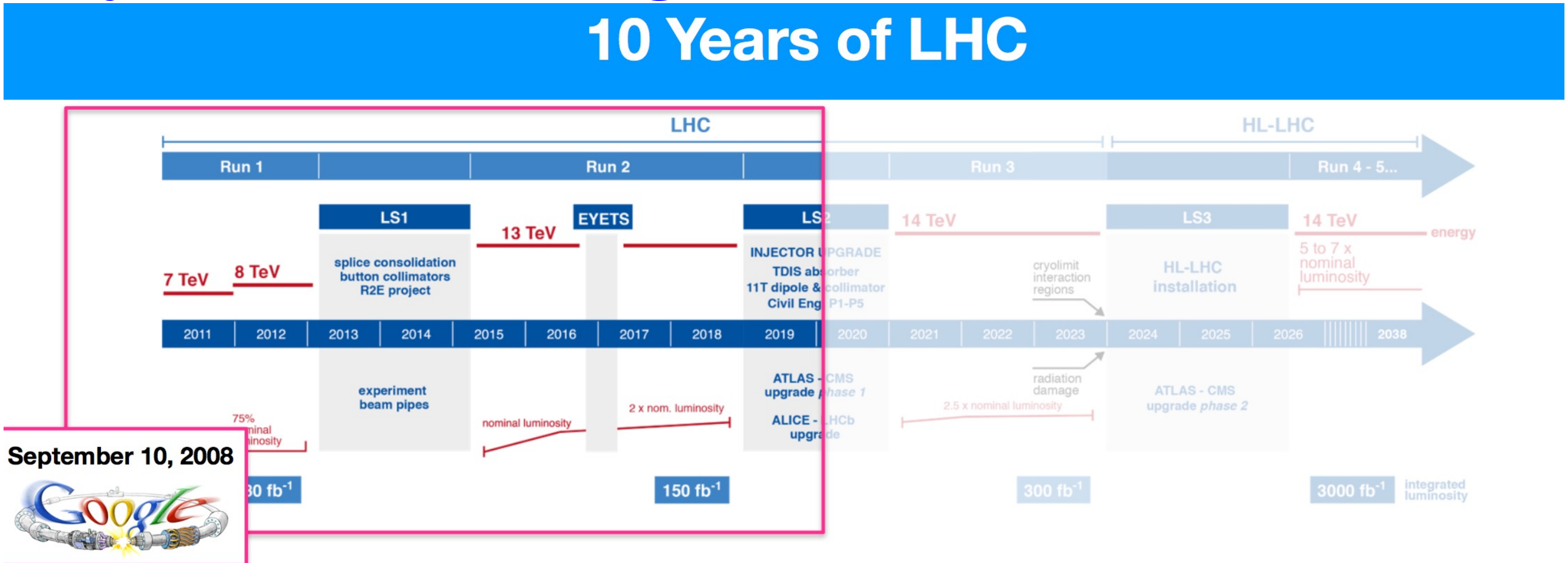
- Stability of the vacuum: the quartic coupling λ may go negative at a scale of 10^{11} GeV? (Oleg Levedev)



- Neutrino masses...(Mu-Chun Chen)

10 years of LHC running (Marumi Kado)



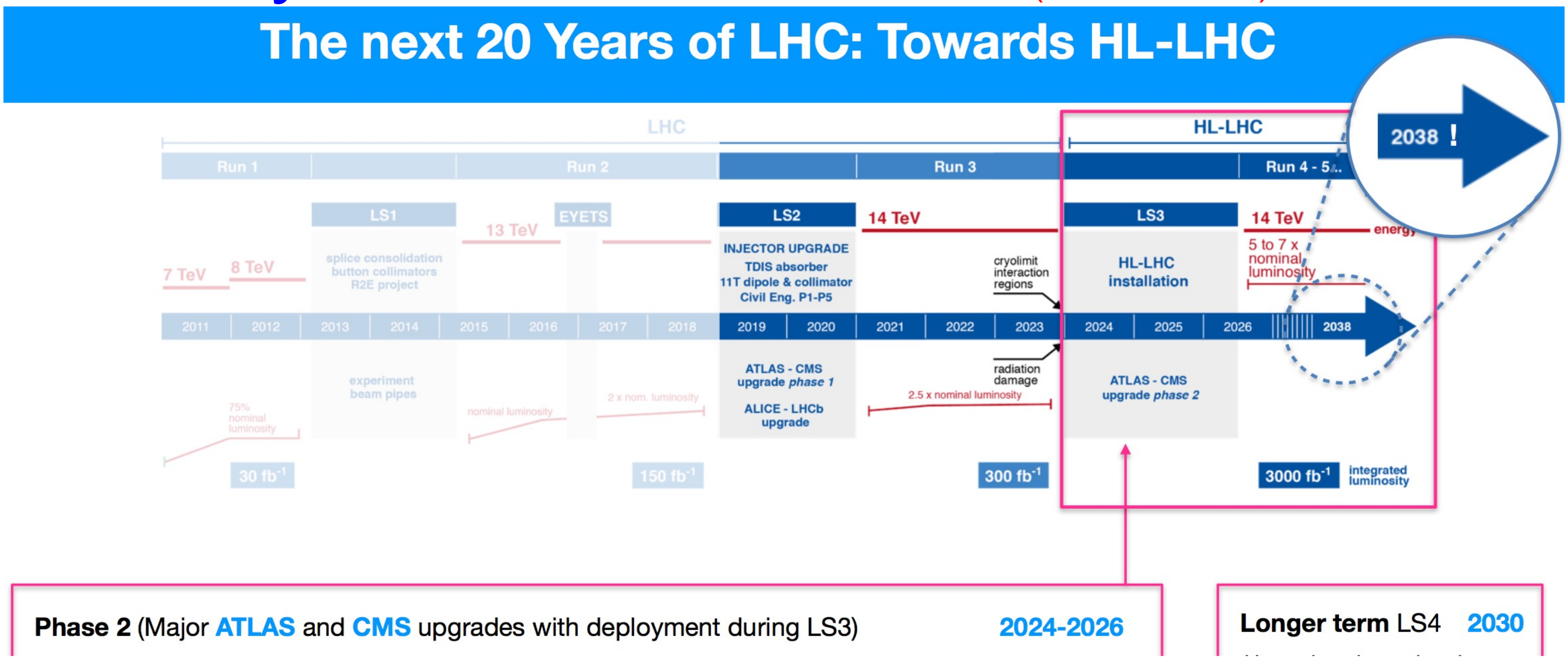
The day the world switched on to particle physics

- **Run 1 :** COM Energies of 7 and 8 TeV and luminosities of ~20 fb-1 for ATLAS and CMS and Pile-Up of ~30-40.

- **Run 2 :** COM Energy of 13 TeV and luminosities (for ATLAS and CMS) of ~140 fb-1 with Pile Up of ~30-40 (at 25ns - makes quite a difference out-of-time PU!)

Huge number of lessons learned on how to mitigate PU.

Next 20 years of LHC: Run 3 and HL (Marumi Kado)



So far the Higgs and nothing else!

Many plenary and parallel sessions talks on LHC BSM physics searches

LHC overview: Marumi Kado,

Higgs couplings: Marco Delmastro,

Rare Higgs decays/production: Lindsey Gray,

SUSY/exotics: Monica Weilers,

Dark matter: Alex Tapper,

Long Lived Part.: Juliette Alimena and Marco Drewes,

Multibosons: Tiesheng Dai,

Vector-boson scattering: Narei Lorenzo Martinez,

VBS and VBF: Meng Lu,

W/Z/top at LHCb: Oscar De Aguiar,

Precision EW: Elena Yatsenko and Carlos Erice Cid,

W-mass: Mauro Chiesa,

V jets: Ewelina Lobodzinska,

EW corrections to Higgs: Armin Schweitzer...

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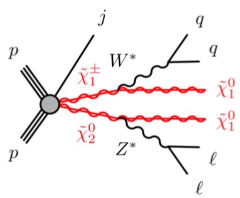
So far the Higgs and nothing else! (Marumi Kado)

Many plenary and parallel session talks devoted to BSM physics searches

Can we still find SUSY or other BSM? Yes.... emphasis on models which "hide" them.

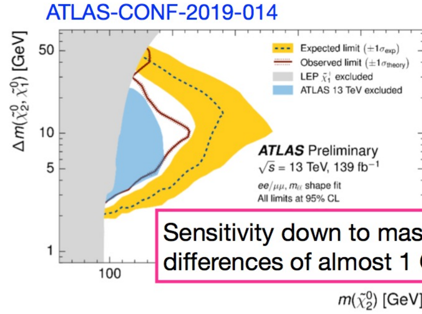
Electroweakinos or How can Natural SUSY have Escaped?

Weak production of chagrinos and neutralinos

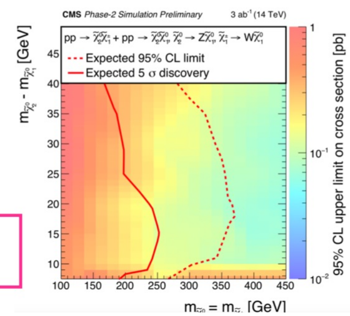


Example of boosting to find small mass differences.

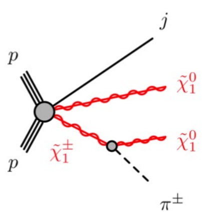
ATLAS-CONF-2019-014



Sensitivity down to mass differences of almost 1 GeV!



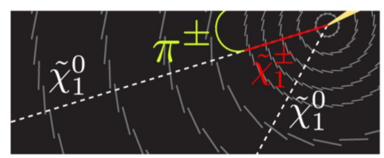
SUSY in highly compressed scenarios



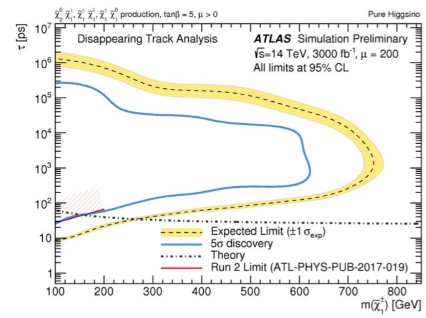
Disappearing tracks topologies

(Uses MET Trigger - requires ISR jet)

ATLAS-PHYS-PUB-2018-031



Scenario where the charginos and neutralinos are almost degenerate (chargino has significant lifetime and is seen in the first layers of the ID).



Notice excess at 1σ in dilepton searches...this is e.g. how a SUSY signal may appear

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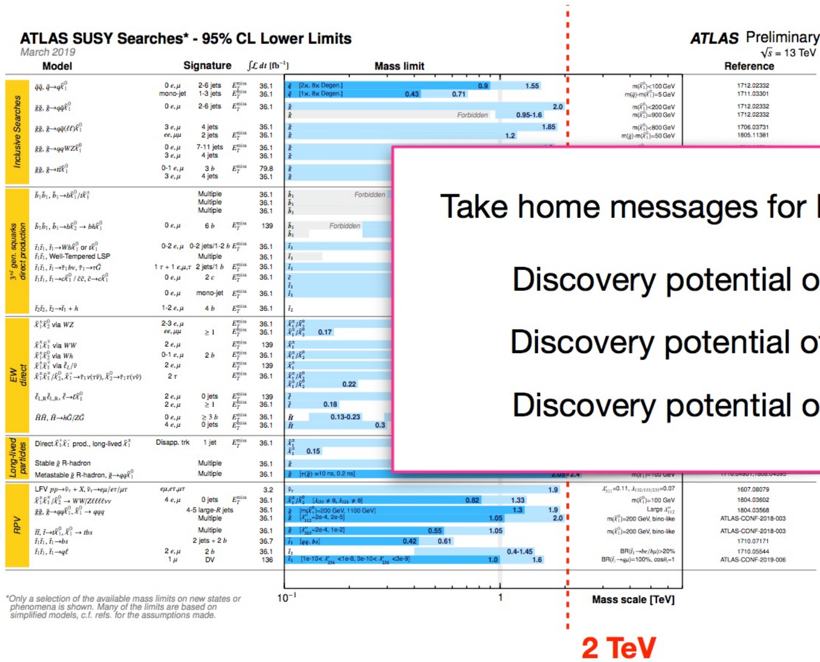
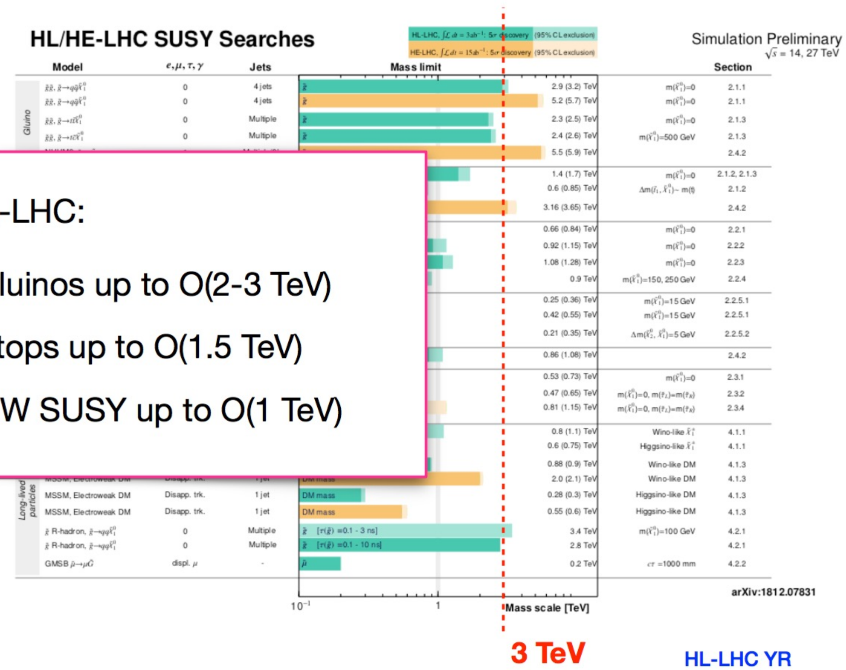
So far the Higgs and nothing else!

Very Large Number of SUSY Searches

(in large variety of topologies and models)



Example from ATLAS (same for CMS)



HL-LHC YR
1812.07831

Take home messages for HL-LHC:

Discovery potential of gluinos up to O(2-3 TeV)

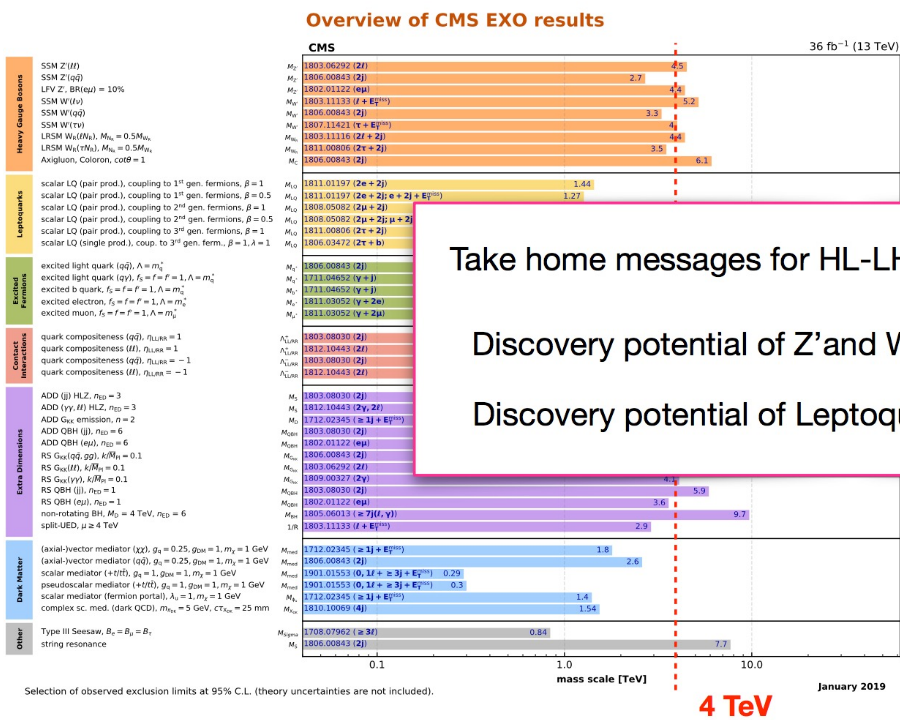
Discovery potential of stops up to O(1.5 TeV)

Discovery potential of EW SUSY up to O(1 TeV)

So far the Higgs and nothing else!

Very Large Number of Searches

(in large variety of topologies and models)

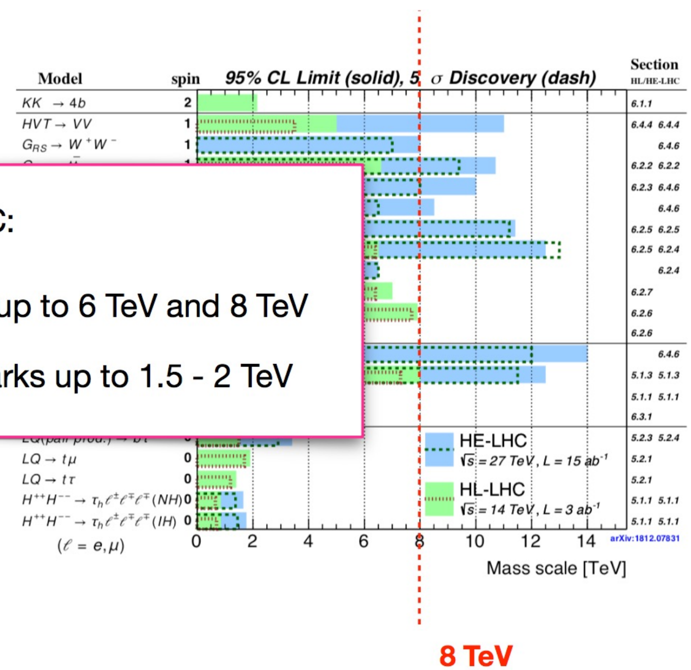


Example from CMS (similar for ATLAS)

Take home messages for HL-LHC:

Discovery potential of Z'and W'up to 6 TeV and 8 TeV

Discovery potential of Leptoquarks up to 1.5 - 2 TeV



HL-LHC YR
1812.07831

Higgs and nothing else in direct searches?
We still have precision measurements!

Decoupling regime: If the spectrum of the Higgs sector contains one Higgs boson of mass m_h and all other particles have a larger mass at least M, then their influence on the properties of the Higgs boson is proportional to m_h^2/M^2.
Thus, the effects of new physics at the TeV scale on the properties of the Higgs are at the % level, at 10 TeV are at the 10^{-4} level....

Thus, precision measurements of the Higgs properties at the HL-LHC and future colliders give a different path to BSM...

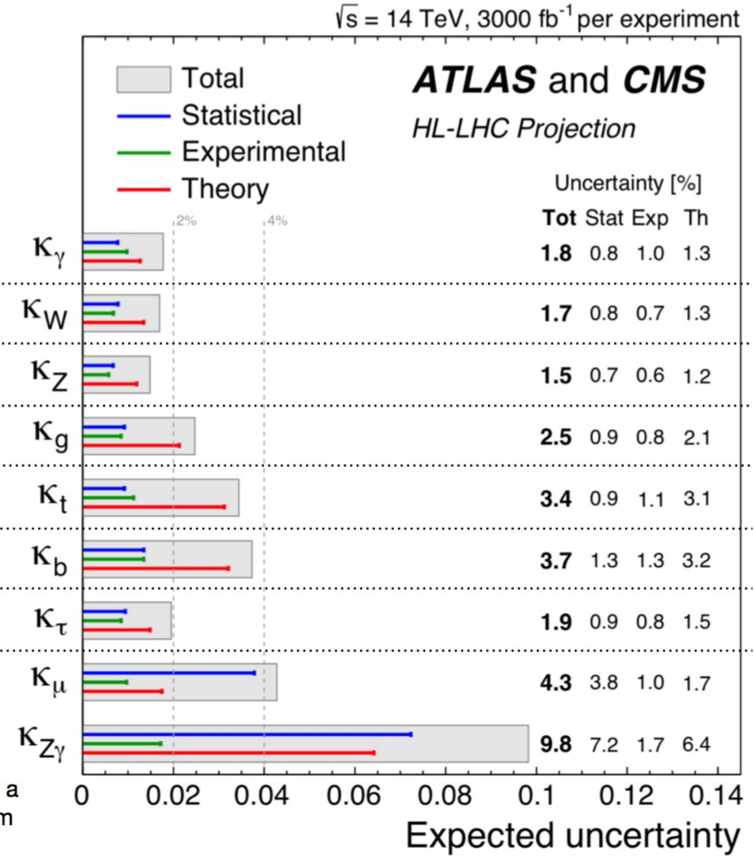
Precision measurements of Higgs decays (Marumi Kado)

Measurement of the couplings properties of the Higgs boson are key to further understand the nature of the Higgs boson (**is it composite?**)

	ATLAS - CMS Run 1 combination	ATLAS Run 2	HL-LHC
κ_γ	13%	9%	1.8%
κ_W	11%	8.6%	1.7%
κ_Z	11%	7.2%	1.5%
κ_g	14%	11%	2.5%
κ_t	30%	14%	3.4%
κ_b	26%	18%	3.7%
κ_τ	15%	14%	1.9%
	JHEP 08 (2016) 045	ATLAS-CONF-2019-04	HL-LHC YR 1902.00134

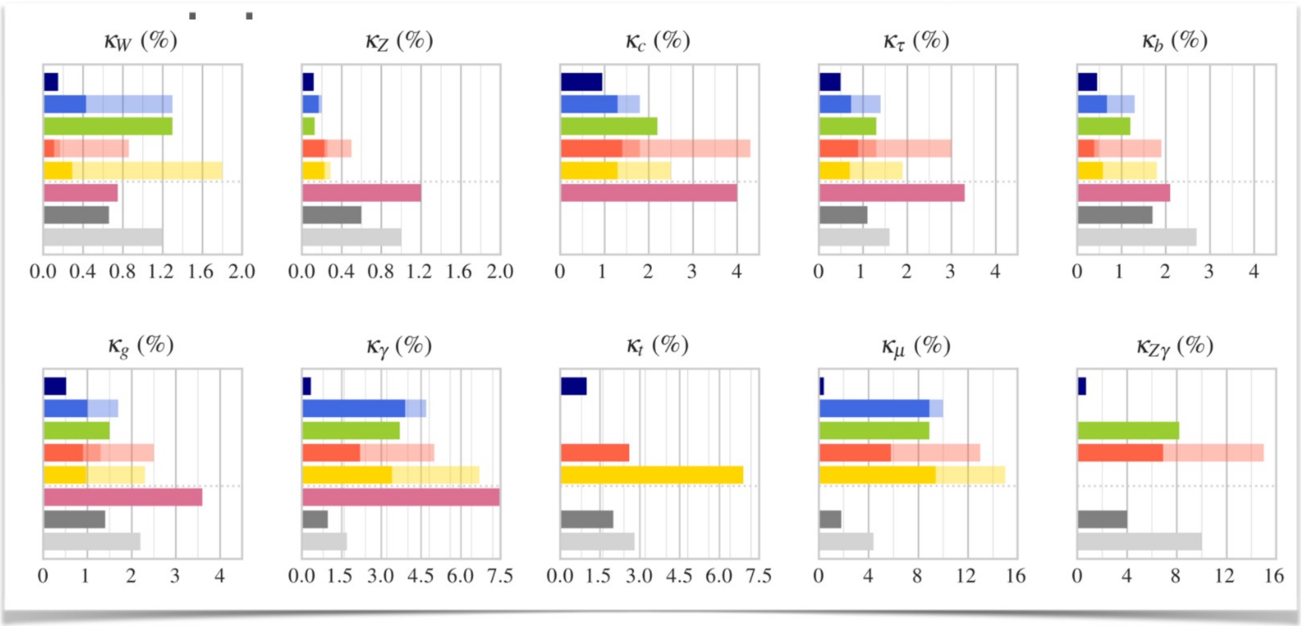
Measurements here assume no BSM in Higgs width

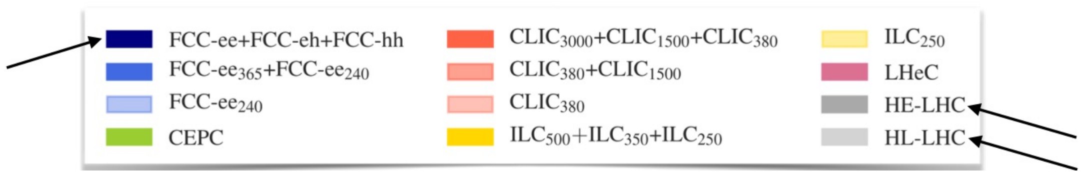
Improved TH and PDF uncertainties by a factor of 2 w.r.t. current (motivated from current PDF studies and current TH uncertainties assumptions)



Precision measurements of Higgs decays (Heather Gray)

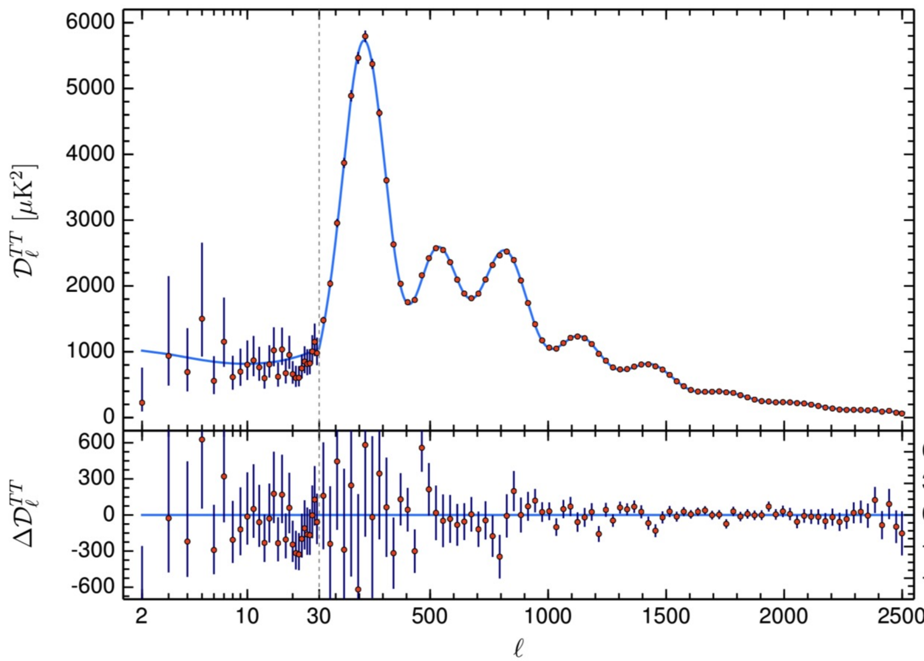
Higgs Precision at HE-LHC and FCC





Before and after the Planck CMB data

Before: Only 3 peaks of the CMB anisotropies angular power spectrum
After: 7 TT peaks observed, E modes, precision cosmological parameter determination.(see G. Smoot talk). No proposed "alternative to dark matter" allowed!



After the Planck CMB data

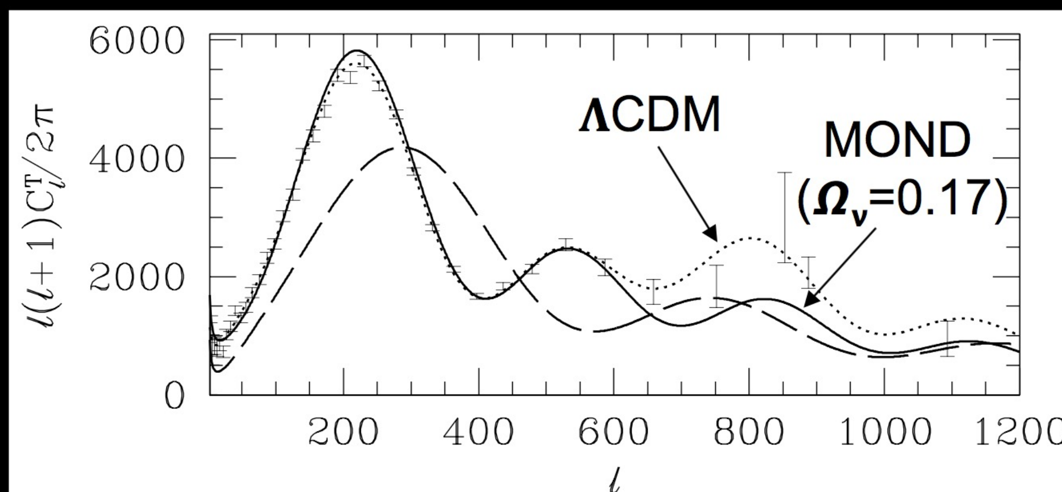
Dark Matter is defined by the role it has in astrophysics and cosmology, in the CMB anisotropy spectrum, BAO, formation of structure in the Universe... not only galaxy rotation curves or galaxy morphologies ...

No proposed "alternative to Dark Matter" explains the CMB anisotropy spectrum after 2013 and the BAO

Dan Hooper talk- KITP 4/30/2018 "In Defense of Dark Matter"-in debate with Eric Verlinde

What The CMB Really Tells Us About Dark Matter and Modified Gravity

- Here is an example, (as calculated within TeVeS), Skordis et al. (2005)
- At the time, this was marginally consistent with the data (if one allows for ~2 eV neutrinos), but cannot accommodate modern CMB measurements



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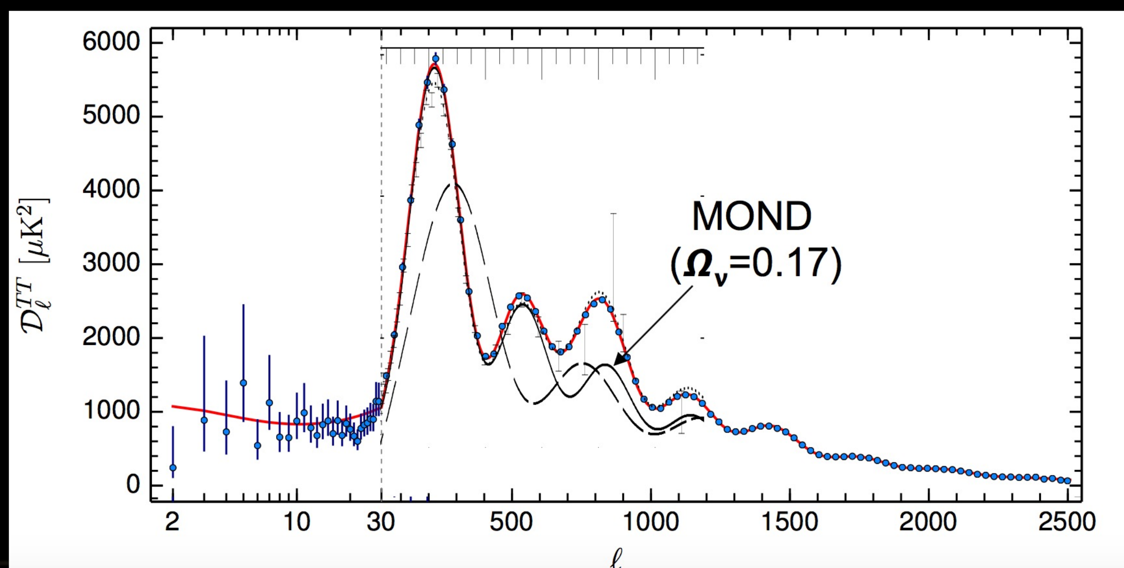

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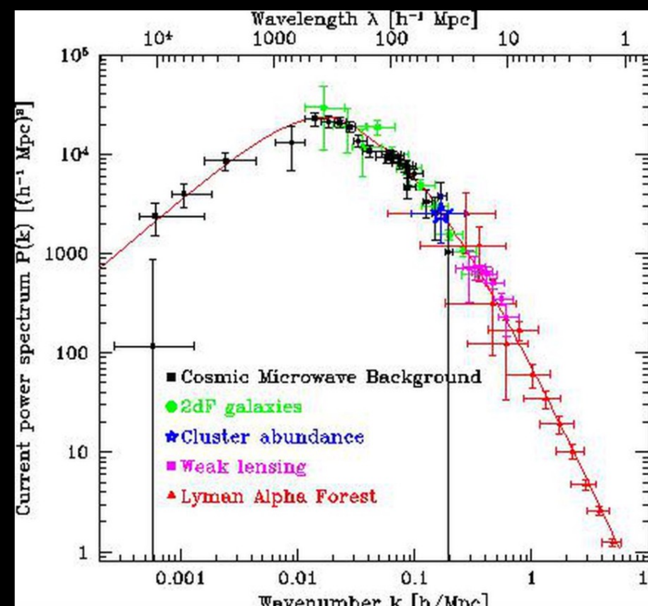
Matter Power Spectrum

- If you look closely, you can see small wiggles in the matter power spectrum, resulting from baryon acoustic oscillations (BAO)
- These BAO are small in standard ΛCDM cosmology, because they are suppressed as baryons fall into the potential wells formed by dark matter – only a few percent of the primordial oscillations survive



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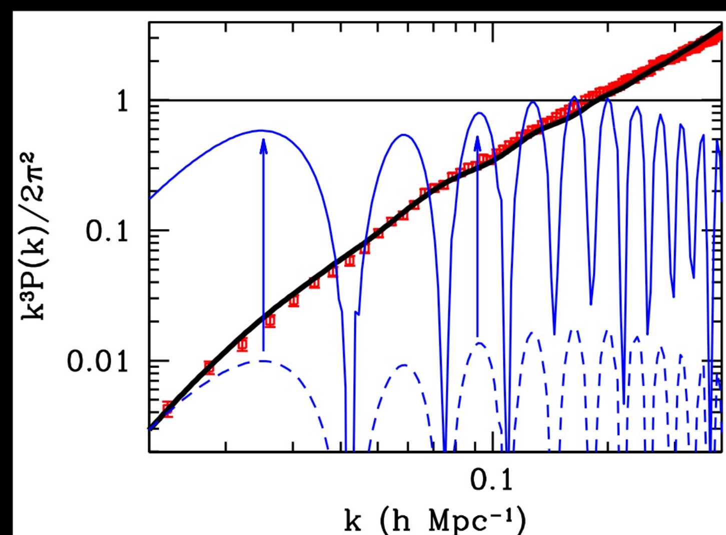
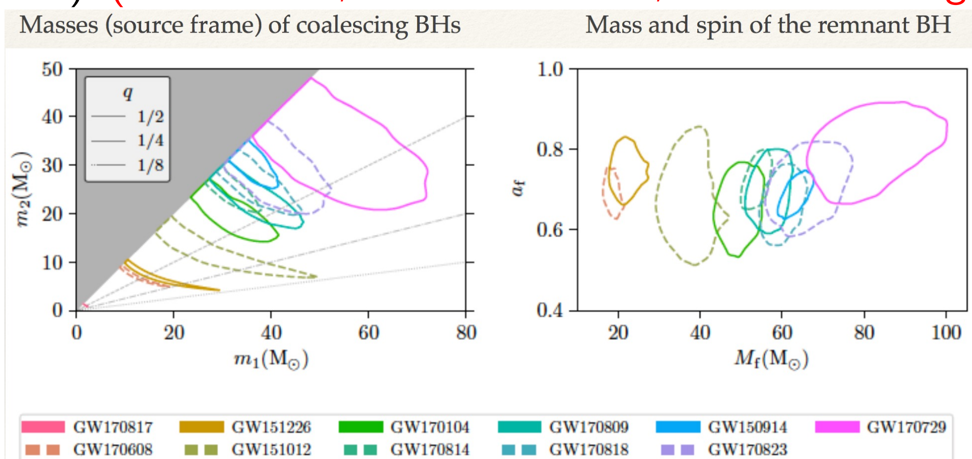
- In a universe without dark matter, however, these oscillations should be *much* larger
- Even if structure growth is somehow enhanced through modifications of gravity, without dark matter, BAO should be ~30 times larger than observed



Dodelson (2011)

Before and after the LIGO-VIRGO gravity waves

Before: Gravitational radiation detected indirectly (pulsars slowdown). No $\sim$10 $M_\odot$BH observed.
After: Entirely new eyes on the Universe! Many $\sim$10 $M_\odot$ BH-BH mergers. Multimessenger observation of a binary neutron-star merger, 70 observatories (GW17081) LIGO, Virgo, Fermi GBM, INTEGRAL, DES... searched and not found in neutrinos by ANTARES, IceCube, Pierre Auger ...) (Imre Bartos, A. Carnero-DES, D. Boncioli-Auger)

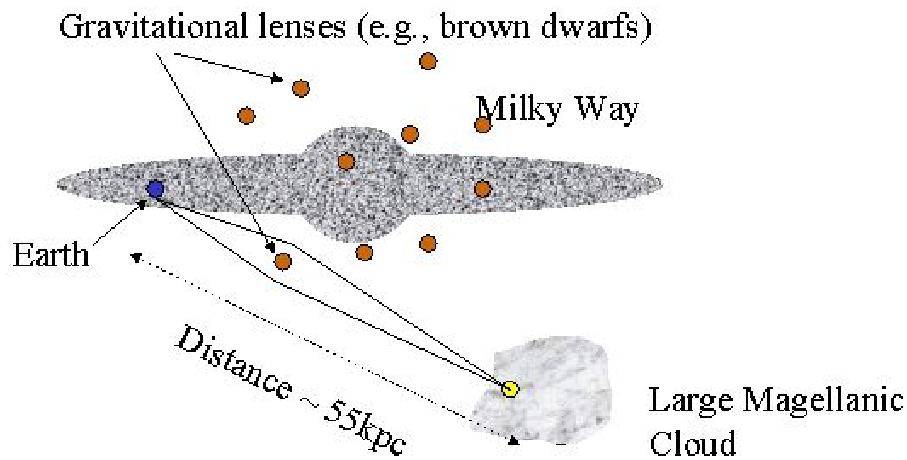


Can be stellar (formed with M<70 $M_\odot$, otherwise progenitor star is unstable + mergers) Can they be instead Dark Matter BH (i.e.Primordial Black Holes, PBH)?

Limits on MACHOS (Massive Astrophysical Compact Halo ObjectS):

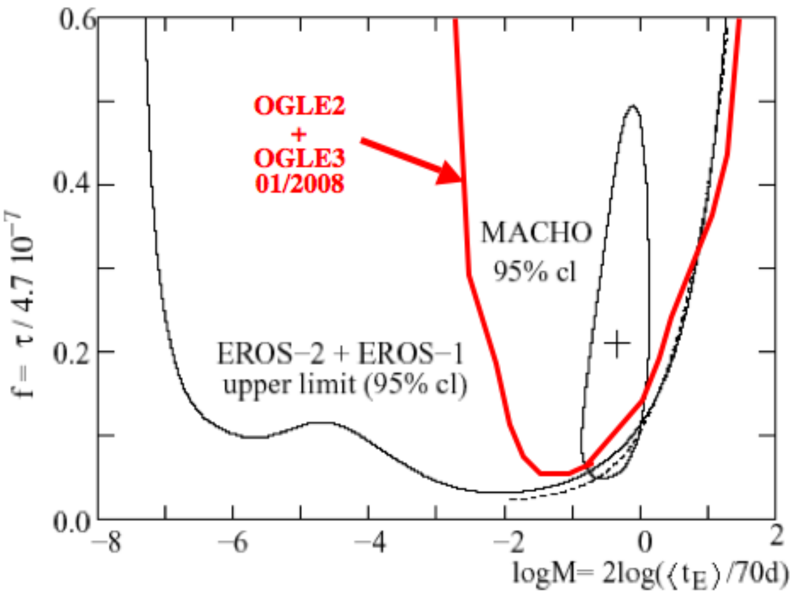
MACHO and EROS collaborations 2009 M. Moniez arXiv:0901.0985 [astro-ph.GA], Griest, Cieplak and Lehner 1307.5798

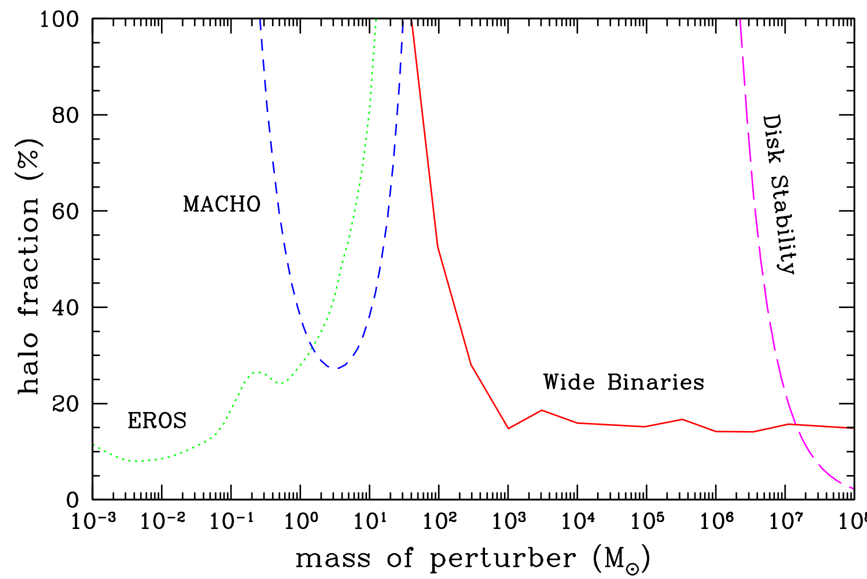
Searched for using gravitational "microlensing" of stars in satellite galaxies and the Galactic Center: multiple images are superposed producing an "anti-eclipse" (star becomes brighter for a while).



Dark Matter: not MACHOS

M. Moniez arXiv:0901.0985 [astro-ph.GA] Combined with older results for larger masses: Yoo, Chaname, Gould, ApJ**601**, 311, 2004 Griest, Cieplak and Lehner 1307.5798





2009 limit: $m > 10^{-7}$ $M_\odot$ cannot be the bulk of the DM ($M_\odot = 10^{57}$GeV)

2013 limit: (using Kepler satellite data) $m >$2 10^{-9} $M_\odot$ cannot either.

Notice, possible window 20 $M_\odot < m <$100 $M_\odot$? (LIGO $M_{BH} \simeq 30 M_\odot$)

Problem with MACHOS: how would they form? Only viable MACHOs are PBH

Dark Matter: could be Primordial Black Holes (PBH)?

PBH are a hypothetical type of black hole not formed by the gravitational collapse of a large star but in an early phase transition, before BBN (thus non-baryonic)

Zel'dovich and Novikov, 1966; Hawking, 1971; Carr and Hawking, 1974

Many limits exclusively applying to BH:

- $M > 10^{15}\text{g} = 6 \times 10^{38}$ GeV, lighter would have evaporated by now
- $M > 10^{17}$g or evaporating BH would have been observed (by EGRET and Fermi)
- 5 10^{17}g< $M < 10^{20}$g excluded by non-observation of "femtolensing" of GRB 1204.2056

Revised: wave effects (wavelength larger than Schwartzschild radius) and finite source size effects

- 10^{16}g< $M < 10^{22}$g excluded- its accretion in stars would destroy compact remanent 1209.6021
- 3 10^{18}g<M< 5 10^{24}g excluded- its accretion in n stars in GC would destroy them (NS limit)

1301.4984 Revised: required a too high density in GC1807.11495

- $M >$ 100 $M_\odot$= 2 10^{35}g excluded by absence of CMB spectral distortions 0709.0524

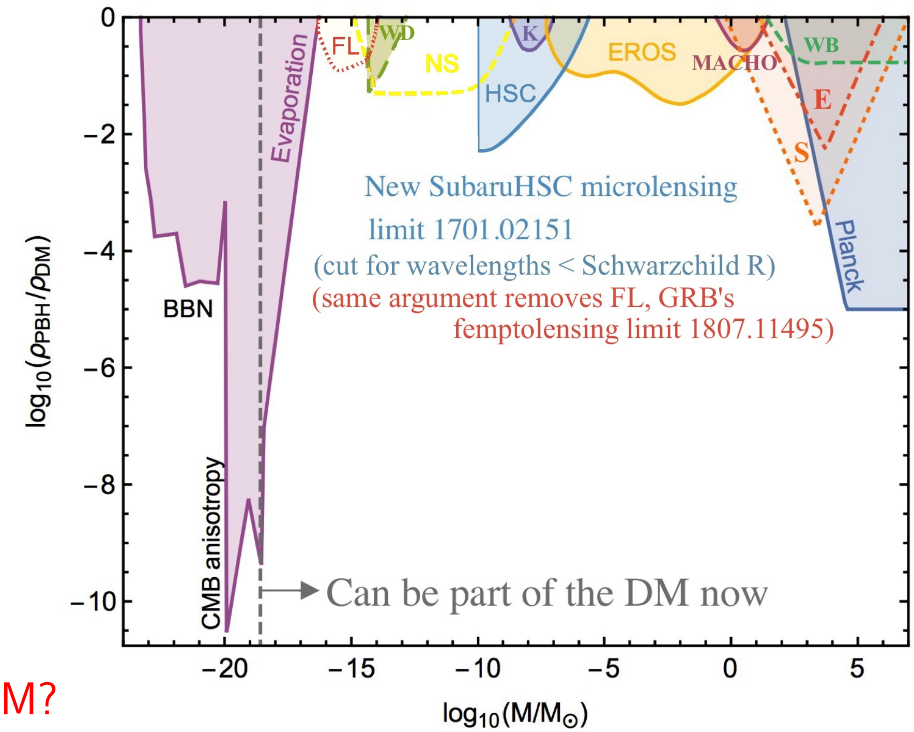
Many limits revised after LIGO's BH-BH mergers events!

Could Dark Matter be Primordial Black Holes (PBH)?

compilation of bounds on PBH DM density fraction f for single mass PHB (dashed limits can be avoided with special assumptions)

Carr, Tenkanen and Vaskonen 1706.03746 + modified

($M_\odot = 10^{57}$GeV)

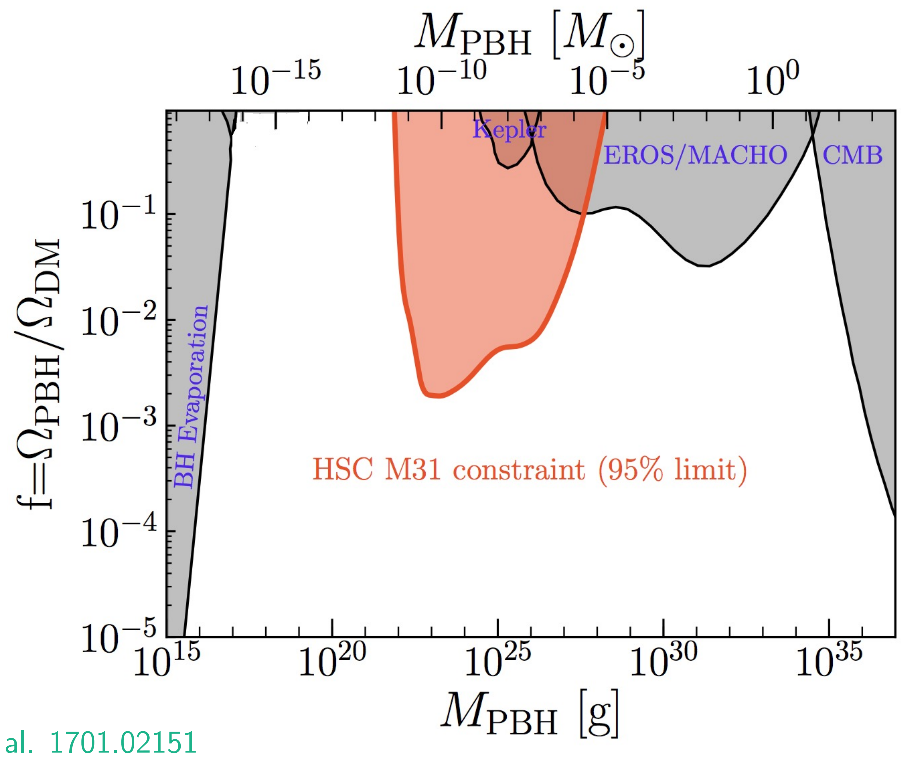


Could LIGO BH ∼10's $M_\odot$ be most of the DM?

Bird etal. 1603.00464, Clesse&Garcia-Bellido 1603.05234, 1501.07565; and before the LIGO events Frampton 0905.3632, Frampton, Kawasaki, Takahashi &Yanagida 1001.2308

Could Dark Matter be Primordial Black Holes (PBH)?

compilation of bounds on PBH DM density fraction f for single mass ($M_\odot = 10^{57}$GeV)



New Subaru/HSC camera limit Niikura et al. 1701.02151

They also have a candidate PBH event consistent of a PBH of mass 10^{-7} $M_\odot$.

(For a limit on <10^{-16} $M_\odot$ using Voyager-see Marco Cirelli at the conference)

Anomalies

Cambridge English Dictionary:

anomaly: a person or thing that is different from what is usual, or not in agreement with something else and therefore not satisfactory.

anomalous: deviating from what is standard, normal, or expected.

We have an anomalous appreciation for anomalies!
We love them, as a way to challenge our Standard Models and make progress...

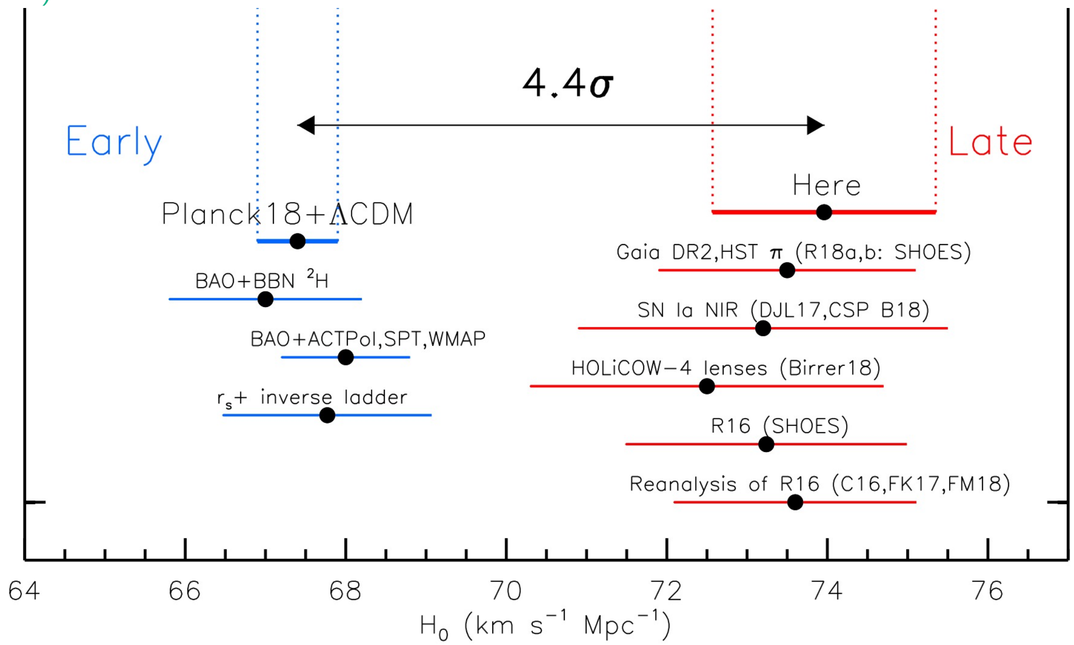
Anomalies

- in Cosmology: H_0
- in Particle Physics: b decays
- in Particle Physics: LSND/MiniBooNE
- in Astroparticles: 3.5 keV X-ray line
- in Astroparticles: PAMELA-AMS e^+ excess
- in Astroparticles: Galactic Center GeV excess
- in Cosmology: EDGES 21 cm signal
- in Astroparticles: the DAMA modulation signal

Anomaly in Cosmology: H_0

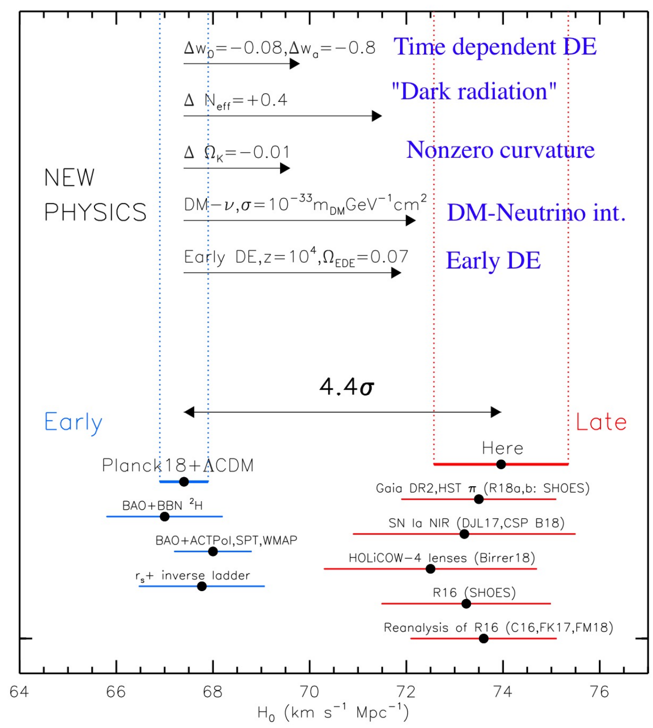
(discussed by Cristian Rusu-H0LiCOW, Aurelio Carnero-DES, Ed Copeland)

The Hubble constant, H_0 can be measured locally and can be derived from the angle subtended by the sound horizon as observed in CMB temperature fluctuations and BAO.There is a tension between measurements of H_0. (Riess et al. 1903.07603 and 1604.01424)



Anomaly in Cosmology: H_0 Many New Physics solutions proposed

either to modify cosmology at CMB emission so that the CMB/BAO inferred value increases, or at late-times, so that the expansion rate matches the CMB at decoupling and the local rate today. (Riess et al. 1903.07603 and 1604.01424, Vattis, Kuoshiappas and Loeb 1903.062220, Poulin et al. 1803.02474, Mortsell and Dhawan 1801.07260, Di Valentino et al 1710.02559 etc)

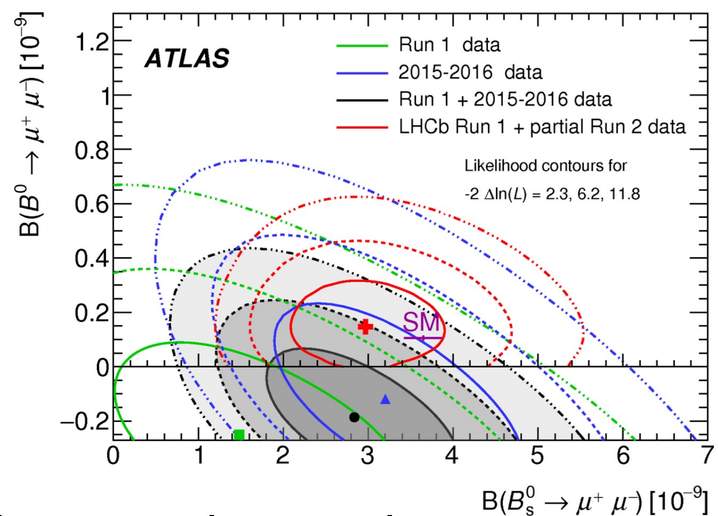


Anomaly in Particle Physics: b decays at LHCb, BaBar, Bell

(Discussed by Marumi Kado, Mitesh Patel, Tobias Hurth)

R(D(*))= $\frac{B(\bar{B}\to D(^*)\tau^-\bar{\nu}_\tau)}{B(\bar{B}\to D(^*)\ell^-\bar{\nu}_\ell)}$ and R(K(*))= $\frac{B(B\to K(^*)\mu^+\mu^-)}{B(B\to K(^*)e^+e^-)}$

- R(D(*)) ratios: were at 4.4σ level, reduced with 2019 Belle to 3.1σ
- R(K(*)) ratios: $=1$ in SM, LHCb run 1 were $\simeq 0.7$, for run 2 are $\simeq 0.9$ combined σ smaller so still at 2.5σ from SM
- and $B_{s,d}\to\mu^+\mu^-$



Models exist to solve these anomalies separately or simultaneously.

New data seems to move back towards SM. Need confirmation of anomalies

Rich B physics ahead with future new data from LHCb and Belle II.

Anomaly in Particle Physics: LSND/MiniBooNE

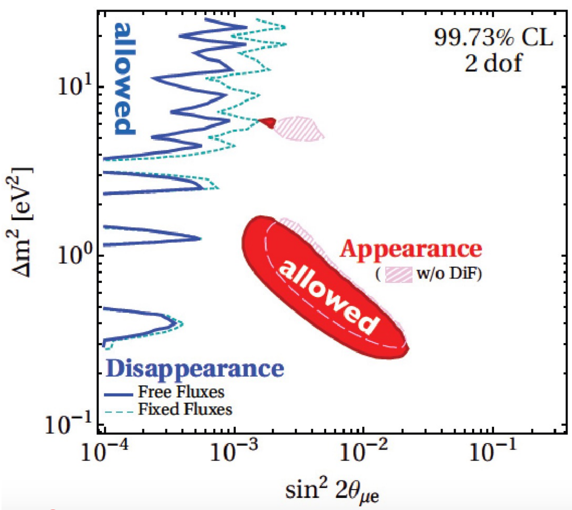
(Discussed in parallel session by Carlos Argüelles) Measured $\bar{\nu}_e$ appearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

Indication of a 4th, sterile, neutrino coupled to both $\nu_\mu \rightarrow \nu_s \rightarrow \nu_e$?

$\nu_\mu \to \nu_e : \sin^2 2\theta_{\mu e} \equiv 4|U_{\mu 4}|^2 |U_{e4}|^2$ → LSND, MiniBooNE, OPERA, ...

$\nu_e \to \nu_e : \sin^2 2\theta_{ee} \equiv 4|U_{e4}|^2 (1 - |U_{e4}|^2)$ → Reactors, solar, Gallium, ...

$\nu_\mu \to \nu_\mu : \sin^2 2\theta_{\mu\mu} \equiv 4|U_{\mu 4}|^2 (1 - |U_{\mu 4}|^2)$ → MiniBooNE, MINOS, IceCube, ...



ν_μ to ν_e appearance

$\sin^2 2\theta_{\mu e} = 4\, |U_{e4}|^2 |U_{\mu 4}|^2$

ν_e disappearance ν_μ disappearance

4.7 σ tension

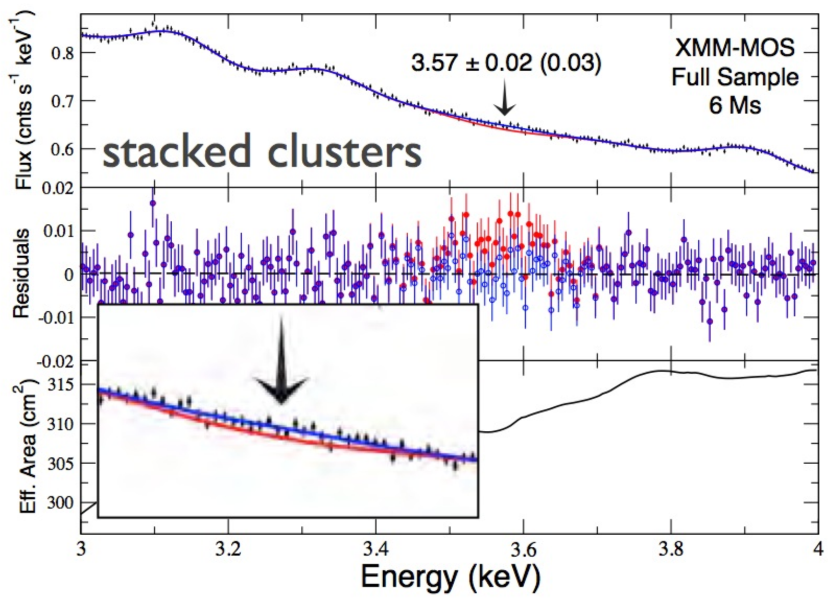
between APP and DISAPP data sets under eV sterile interpretation

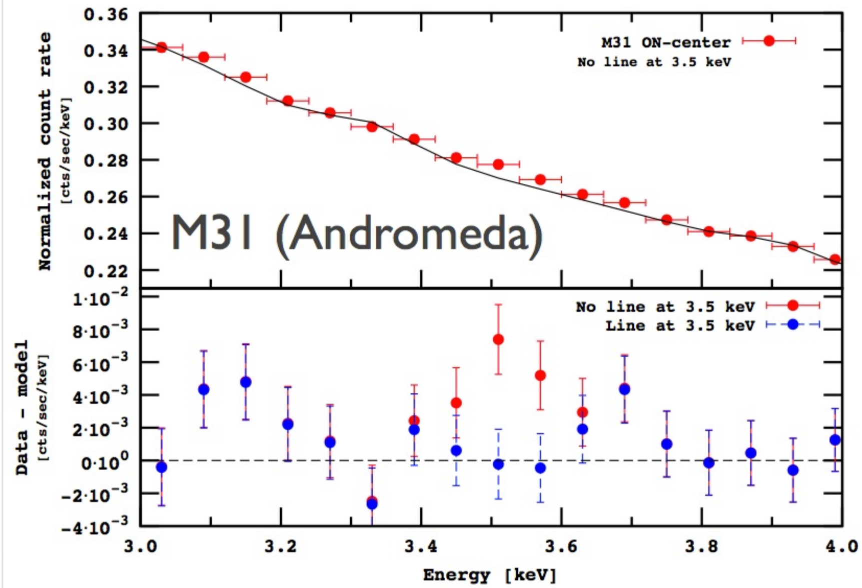
Figs: P. Machado SUSY 2019
Fits: Dentler et al 2018

Other explanations? MiniBooNE: no distinction between e and γ, so maybe γ or exotic Z' emission play a role? LSND: some nuclear physics? unexpected background??

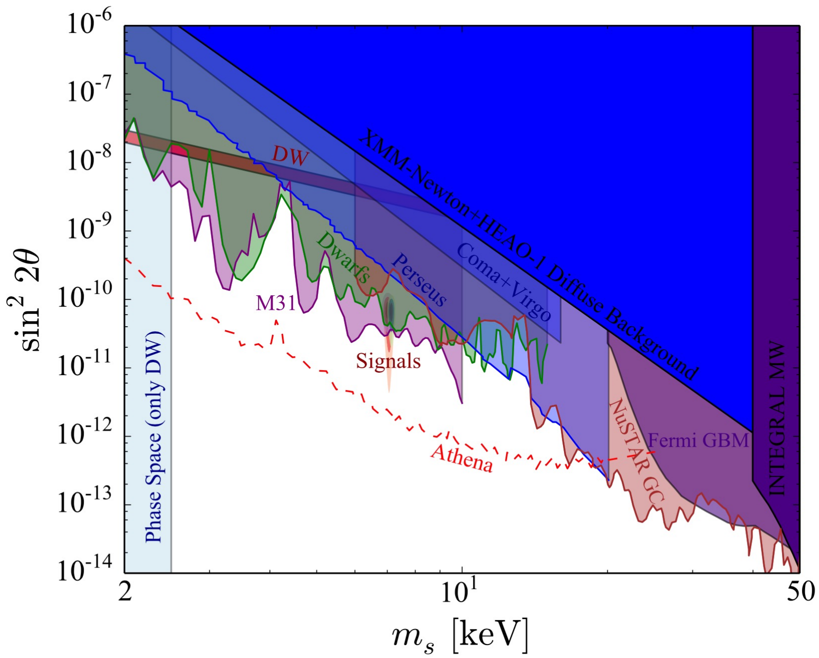
Anomaly in Astroparticles: 3.5 keV X-ray line- 7 keV sterile neutrino?

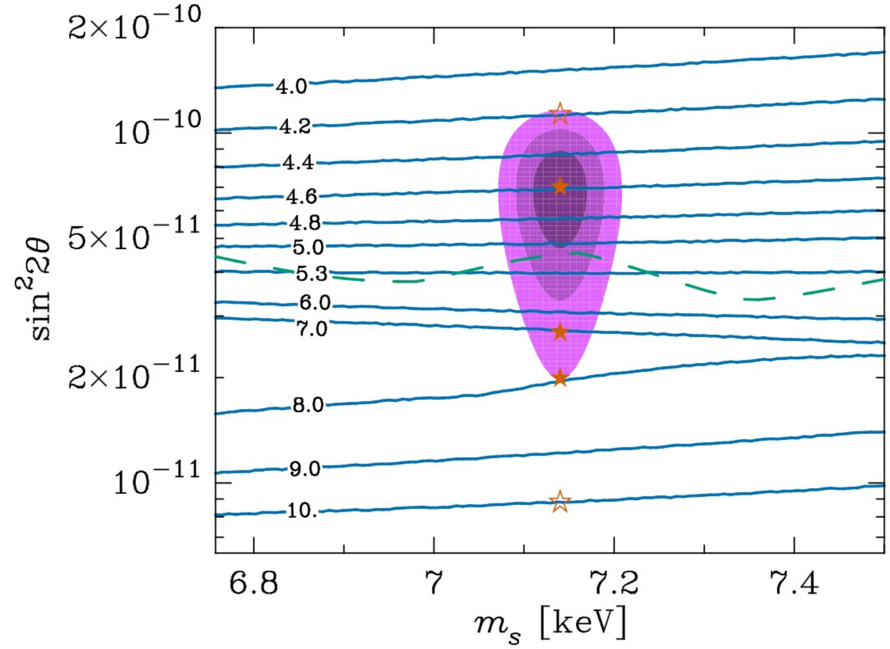
found in X-rays from 74 stacked Galaxy Clusters E. Bulbul et al. 1402.2301 and from the Andromeda galaxy and Perseus cluster A. Boyarsky et al 1402.4119. Could correspond to a 7 keV mass sterile neutrino $\nu_s \to \nu_a \gamma$ $(E_\gamma = m_s/2)$





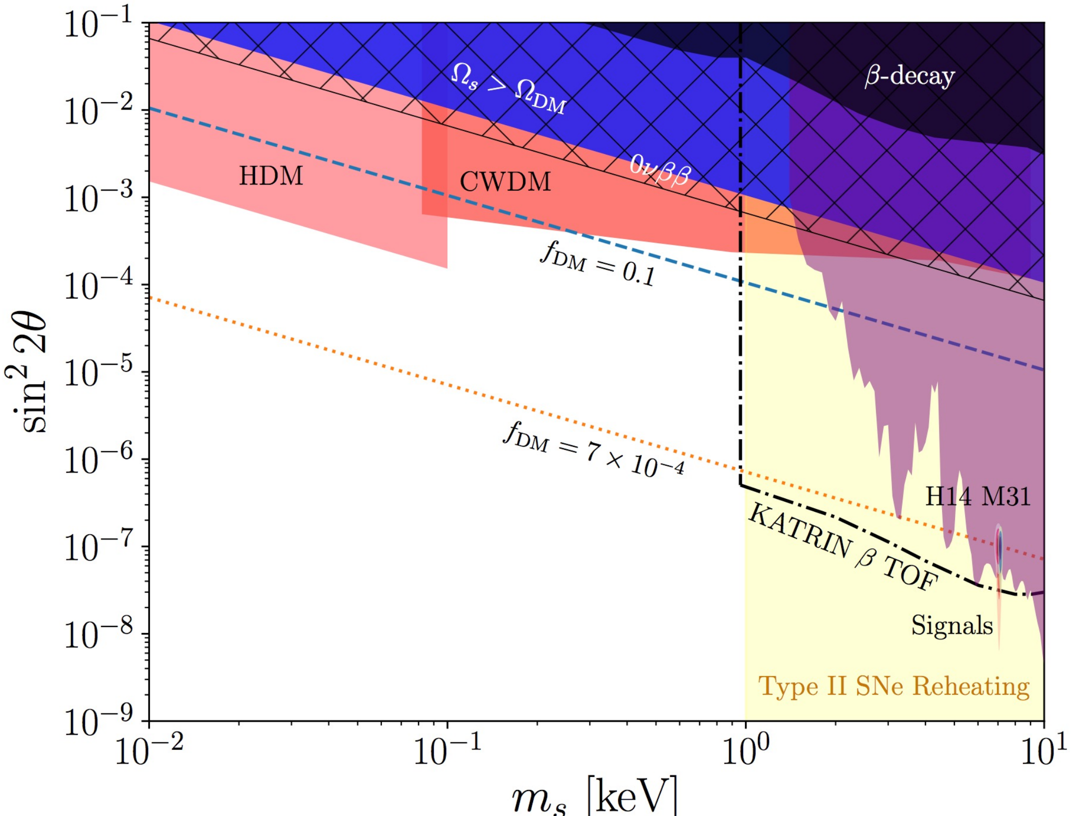
A 7 keV decaying sterile neutrino Abazajian 1705.01837, 2017





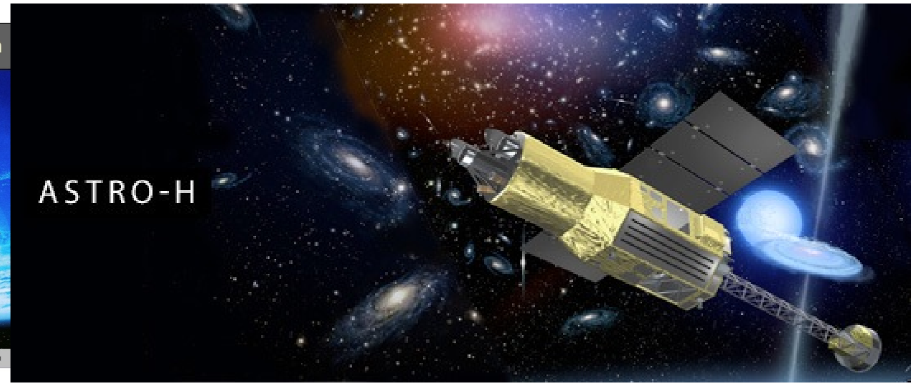
LEFT: assuming this neutrino accounts for all the DM, in the standard cosmology would require a large Lepton Asymmetry L $\simeq 5\times10^{-4}$ RIGHT: L in units of 10^{-4}

A 7 keV decaying sterile neutrino Abazajian 1705.01837, 2017



In the low reheating temperature model of GG, Palomarez and Pascoli, 2004, DW produced neutrinos constituting a fraction 0.7 10^{-3} of the DM and could be detected by KATRIN.

ESA's XMM-Newton & NASA's Chandra do not provide enough energy resolution of the line.



JAXA's ASTRO-H (Hitomi after "first light"), launched on Feb. 17 2016 expected to measure the profile of the line and prove/disprove that it is due to DM in 1 year!
But it was destroyed on March 26, 2016.

Prospect: Will be tested by JAXA-NASA by the X-Ray Astronomy Recovery Mission (XARM) in 2021 (next planned X-ray astronomy satellite is ESA's ATHENA, scheduled for 2028)

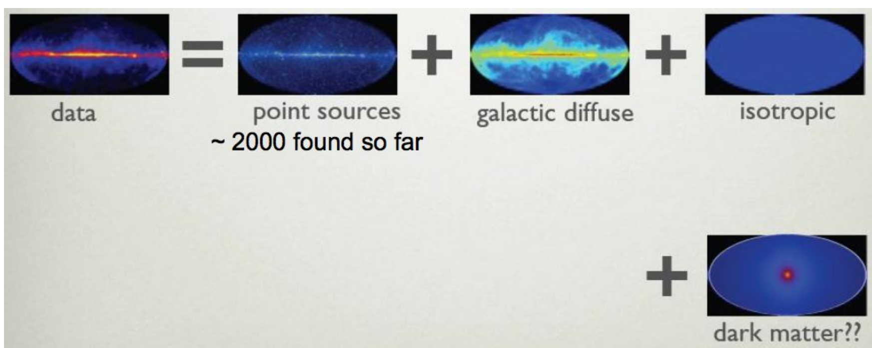
Anomaly in Astroparticles: PAMELA 10-100's GeV e$^+$ excess Confirmed by the Fermi Space Telescope-LAT and AMS (Alpha Magnetic Spectrometer) in 2013 and as of 2016
(Discussed by Marco Cirelli, Harm Schoorlemmer- HAWC)

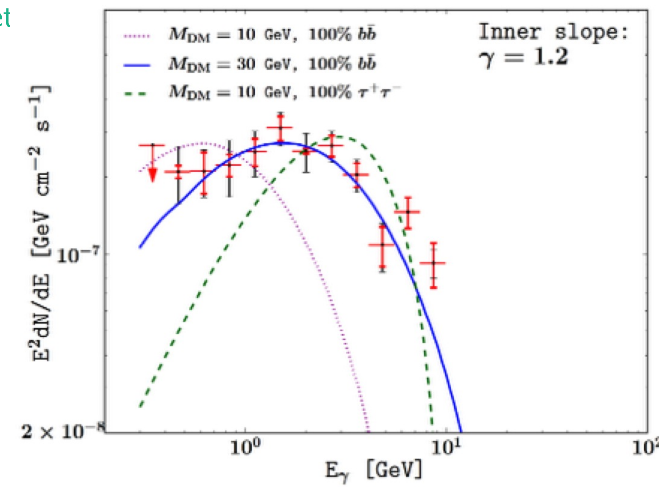
In 2017, HAWC first measurements 1702.02992 of the very high-energy (multi-TeV) γ-ray emission from the Geminga and Monogem pulsars- show they inject a flux of e^+ into the local interstellar medium as necessary to account for the observed e^+ excess.
This strongly favors nearby pulsars as the origin Hooper et al 1702.08436.

Anomaly in Astroparticles: Galactic Center GeV excess

(Discussed by Marco Cirelli in posted slides)

GeV γ's from extended region at the Galactic Center and Inner Galaxy. From annihilation of DM with m =7-10GeV into $\tau^+\tau^-$ or 30-45GeV into $q\bar{q}$? Goodenough& Hooper 0910.2998, Hooper& Goodenough 1010.2752, Hooper& Linden 1110.0006; Hooper 1201.1303; Abazajian& Kaplinghat 1207.6047, Hooper etal 1305.0830, Macias& Gordon, 1306.5725, Abazajian et al. 1402.4090, Dayland et al. 1402.6703, Cholis, Hooper& Linden 1407.5625, Calore, Cholis& Weniger 1409.0042, Bartels, Krishnamurthy& Weniger 1506.05104, Lee et Fermi-LAT 1511.02938 and 1704.03910, ...





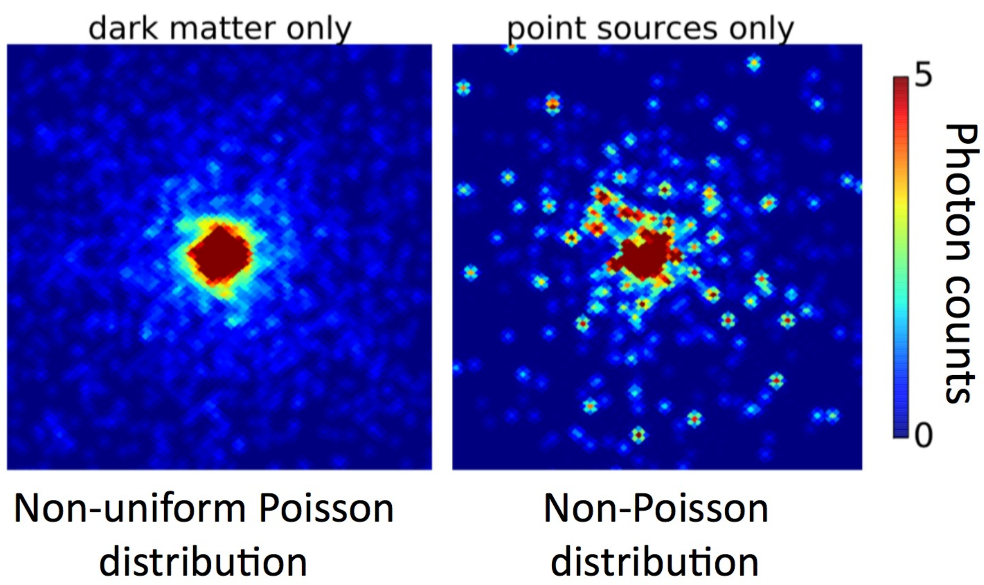
Extended spherically symmetric GC excess in GeV's gamma rays! Confirmed by many groups..

DM annihilation or astrophysical? Unresolved millisecond pulsars

Potential astrophysical sources of the GC excess:

- Unresolved millisecond pulsars Abazajian 1011.4275, Bartels, Krishnamurthy & Weniger 1506.05104

Differences in the statistics of the photon counts can be quantified - tentative evidence of an unresolved point source population found Lee et al 1506.05124, Bartels et al 1506.05104 or small scale structure of the diffuse background? Horiuchi, Kaplinghat & Kwa 1604.01402



Still jury is out on the origin of the GC excess:

"DM Strikes Back": Statistical evidence suggested that the GC excess originates from point sources. But, unmodeled sources in the Fermi Bubbles can lead to a DM signal being misattributed to point sources Leane and Slatyer 1904.08430

- GC excess traces the stellar over-density of the Galactic bulge ("Boxy Bulge" due to the bar in our galaxy), so no more room for DM Macias et al 1901.03822

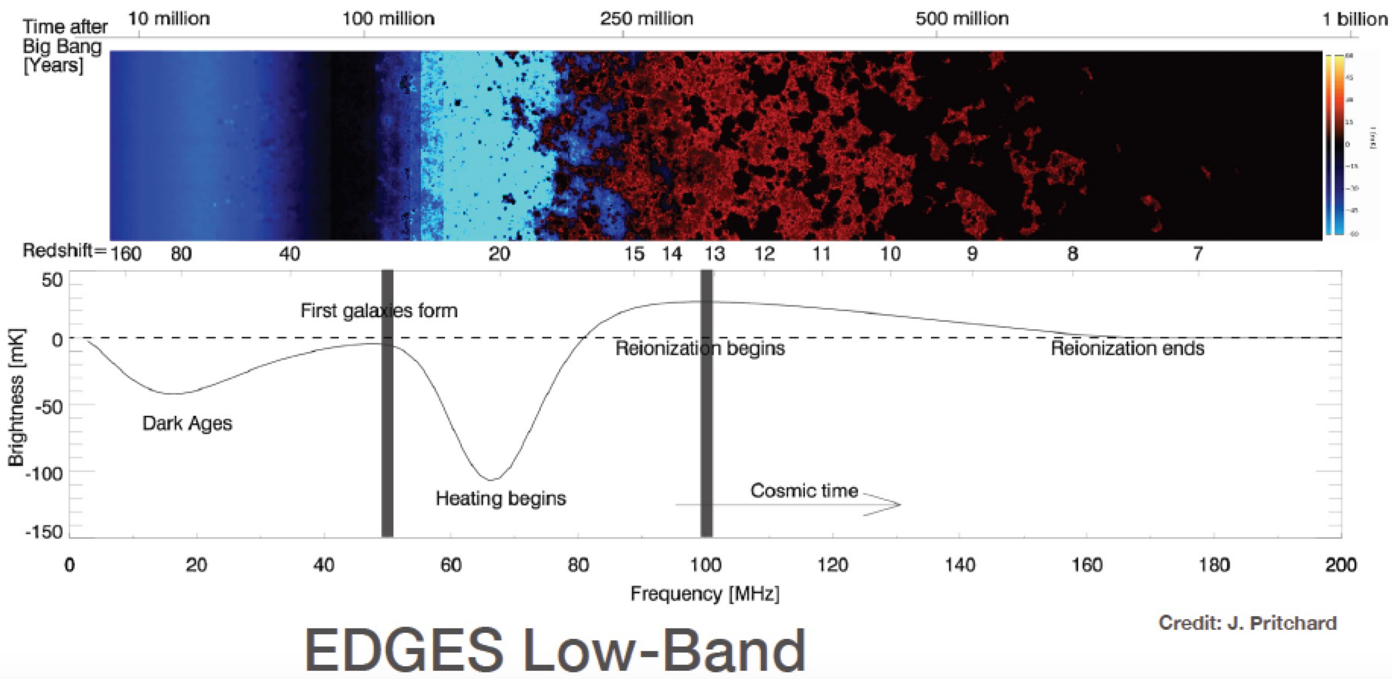
but given the large astrophysical uncertainties this could constitute at most a corroboration of a discover of DM somewhere else

Anomaly in Cosmology: EDGES 21 cm signal

(Discussed in parallel session by Ely Kovetz)

The observable:

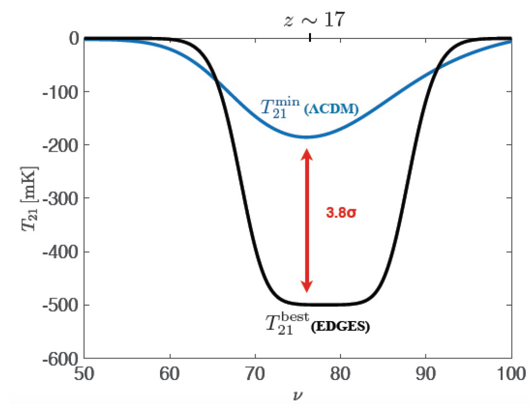
$$T_{21}(z) \approx \frac{T_{\rm Spin} - T_{\rm CMB}}{1+z}\tau \sim 23\,{\rm mK} \times x_{\rm HI}(z) \left[\left(\frac{0.15}{\Omega_m}\right)\left(\frac{1+z}{10}\right)\right]^{1/2} \left(\frac{\Omega_b h}{0.02}\right)\left(1 - \frac{T_{\rm CMB}(z)}{T_{\rm Spin}(z)}\right)$$

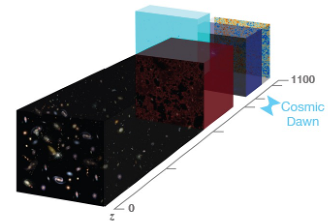


Anomaly in Cosmology: EDGES 21 cm signal

(Discussed in parallel session by Ely Kovetz)

EDGES (Experiment to Detect the Global Epoch of Reionization Signature) in 2018: 1st claim of detection of the cosmic dawn, an absorption feature much deeper than expected. Could be explained if the gas producing the absorption line is much colder than the CMB





Explanations: problem in background subtraction, DM (e.g. millicharged DM) interacts with gas and cools it, or decays heats up the radiation.... (Kovetz: millicharged DM does not work Kovetz, Poulin, Gluscevic, Boddy, Barkana and Kamionkowski, PRD 2018)

To be checked by 21cm observatories LEDA, PRIZM, SARAS2, HERA, SKA (Miguel Floranes)

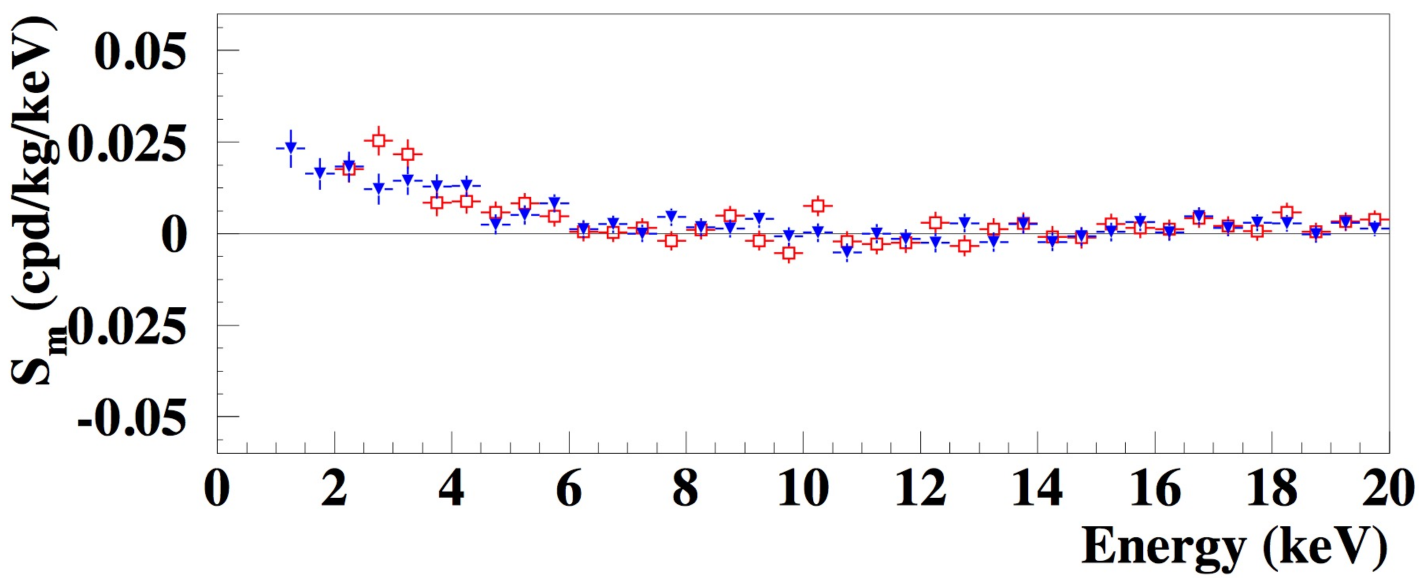
Anomaly in Astroparticles: the DAMA modulation signal

The DAMA/LIBRA modulation signal remains significant: 12.9σ C.L. in 2-6 keVee, 20y of data, 2.46 ton y (9.5σ in 1-6 keVee) NaI (5/2018)

DAMA/LIBRA phase 2- arXiv:1805.10486

Lower threshold (1keVee) after 6 years Older data

$$S_i(E) = S_0(E) + S_m(E) \cdot \cos\omega(t_i - t_0)$$



Anomaly in Astroparticles: the DAMA modulation signal

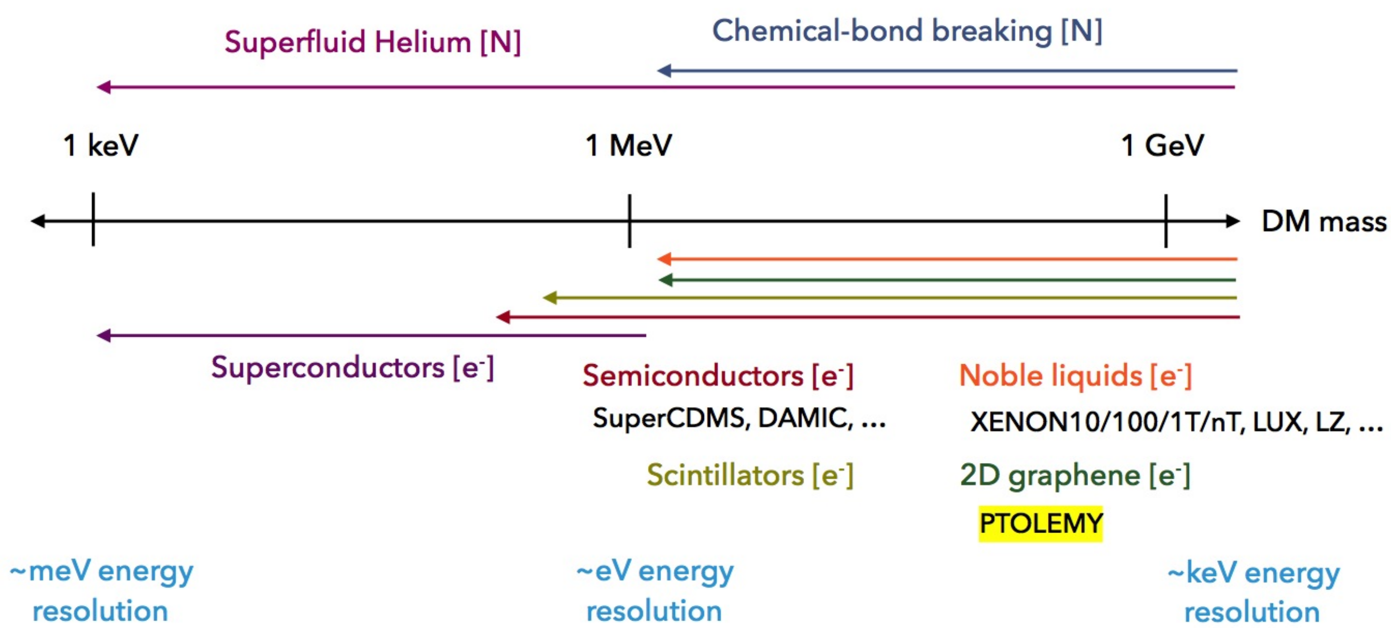
DAMA clearly sees an annual modulation at 12.9σ, DM or instrumental?
"Global NaI(TI) Collaborative Effort": COSINE:KIMS (52 kg) and DM-Ice (55 kg), in YangYang Lab. (S Korea), ANAIS (112 kg), in Canfranc Lab. (Spain) and SABRE (50 kg) in two sites, Gran Sasso Lab. (Italy) and Stawell Lab., Australia
Very important to check in the Southern Hemisphere!

First results presented at the conference by ANAIS (Maria Martinez) reject modulation at the $\simeq 1.8\sigma$ level- more statistics needed (3σ in 2.5 y) and COSINE-100 (Kyungwon Kim) no modulation but statistically limited still.

Many other direct detection experiments (overview of Priscilla Cushman and parallel session talks of J-P Zopounidis, Dimitri Missiac, Patricia Sancez-Lucas, Murat Ali Guler)
XENON1T, LZ, XENONnT, DarkSide20T, SuperCDMS, PICO, DARWIN...
Further future: Directional Direct DM detectors

Many ideas for sub-GeV "Light Dark Matter" (LDM) direct detection are being actively explored (overview by Rouven Essig)

"Dark Sector Workshop", 1608.08632, DOE workshop "U.S. Cosmic Visions: New Ideas in Dark Matter" in March of 2017



Materials that could be used to probe LDM, by scattering off electrons [e^-] or inelastic scattering nuclei [N] (photon emission in the nuclear recoil, breaking of chemical bonds in molecules or crystals, multi-phonon processes in superfluid helium or insulating crystals)

Many ideas for sub-GeV "Light Dark Matter" (LDM) direct detection are being actively explored We heard from two

SENSEI "Direct-Detection Constraints on sub-GeV Dark Matter from a Shallow Underground Run Using a Prototype Skipper-CCD" - SENSEI: 100 g at SNOLAB (funded, 2020), DAMIC-M: 1 kg gram at Modane (funded, 2023) a 10 kg Skipper-CCD (planned, longer term)
(Rouven Essig)

ABRACADABRA-10cm Prototype - "A Broadband/Resonant Approach to Cosmic Axion Detection with an Amplifying B-Field Ring Apparatus": new idea for axion dark matter via interaction with a toroidal magnetic field- in study a 1m scale ABRACADABRA-75 cm
(1st results presented by Jonathan Ouellet)

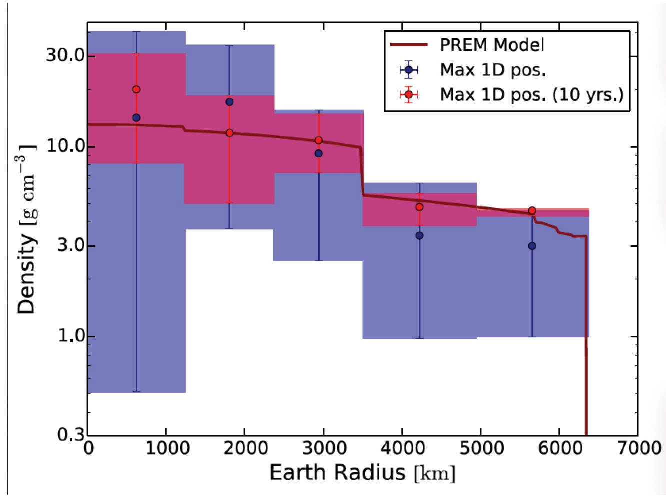
Neutrinos

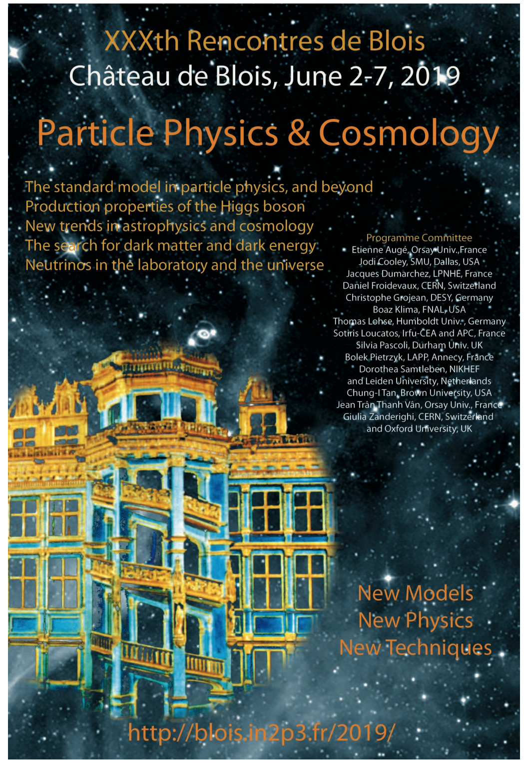
Very active field of research, from HE to sterile neutrino searches to $0\nu\beta\beta$ decay (we heard from Luigi Fusco-ORCA, Stefan Schoppmann-STEREO, Ann Schutz- GERDA, Guido Fantini-CUORE, Luca Gironi-CUPID-0, Claudia Nones- bolometer, Justo Martin-Albo NEXT
Would like to single out two:

- A proposal to detect GeV neutrinos produced in solar flares and other transients with IceCube and KM3NeT, optimizing the detection window using Fermi LAT γ-ray data (Gwenhaël de Wasseige)

-"Earth Tomography" with atmospheric neutrinos passing through Earth observed by IceCube Sergio Palomares-Ruiz

Donini, Palomares-Ruiz, Salvado, Nature 2019





Particle Physics and Cosmology/Astrophysics are inextricably intertwined. It is a tremendously vibrant, data driven field. I feel very lucky to be in it at this time. There are many anomalies to resolve and fundamental discoveries to make. There will be many more Rencontres at Blois...

THANKS TO THE ORGANIZERS

for such a wonderful workshop in such a wonderful place...