Behind the Scenes of the Universe

The Worldwide Race to Discover Dark Matter

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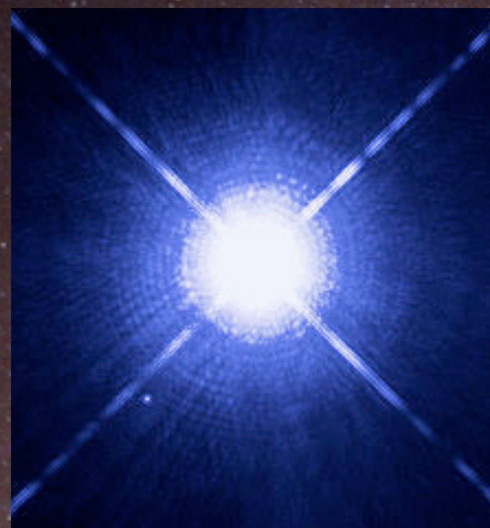
gianfrancobertone.net


Wally Pacholka / AstroPics.com


80
FRIEDRICH WILHELM BESSEL
1784 Astronom und Mathematiker 1846
DEUTSCHE BUNDESPOST
“If we were to regard Syrius and Procyon as double stars, the change of their motion would not surprise us.” F.W. Bessel (1844)
Wally Pacholka / AstroPics.com

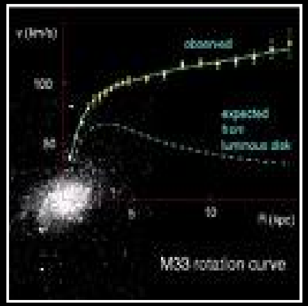


"The phenomena of varying motions of stars seem also to possess interest in relation to our knowledge of the physical constitution of the Universe." F.W. Bessel (1844)

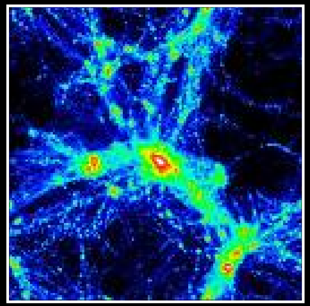
Evidence for Dark Matter

Evidence for the existence of an unseen, "*dark*", component in the energy density of the Universe comes from several independent observations at different length scales

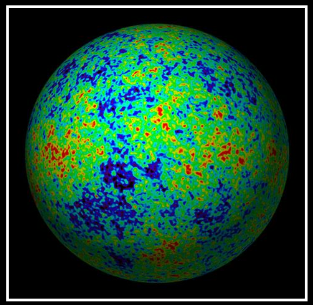
COSMOLOGICAL OBSERVATIONS



- Rotation Curves



- Clusters of galaxies



- CMB

- Type Ia Supernovae

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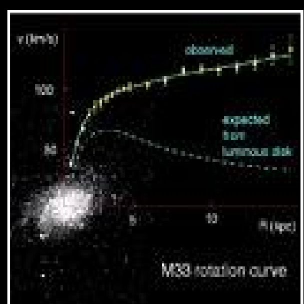

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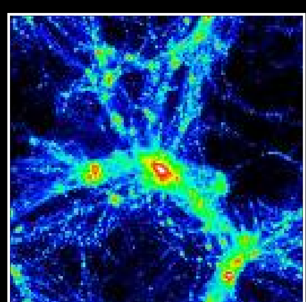

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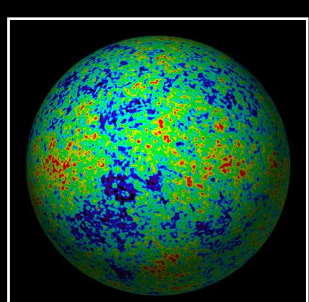

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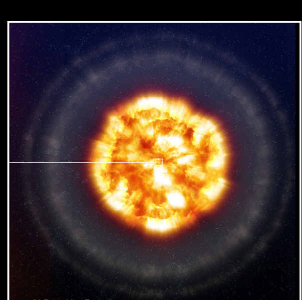

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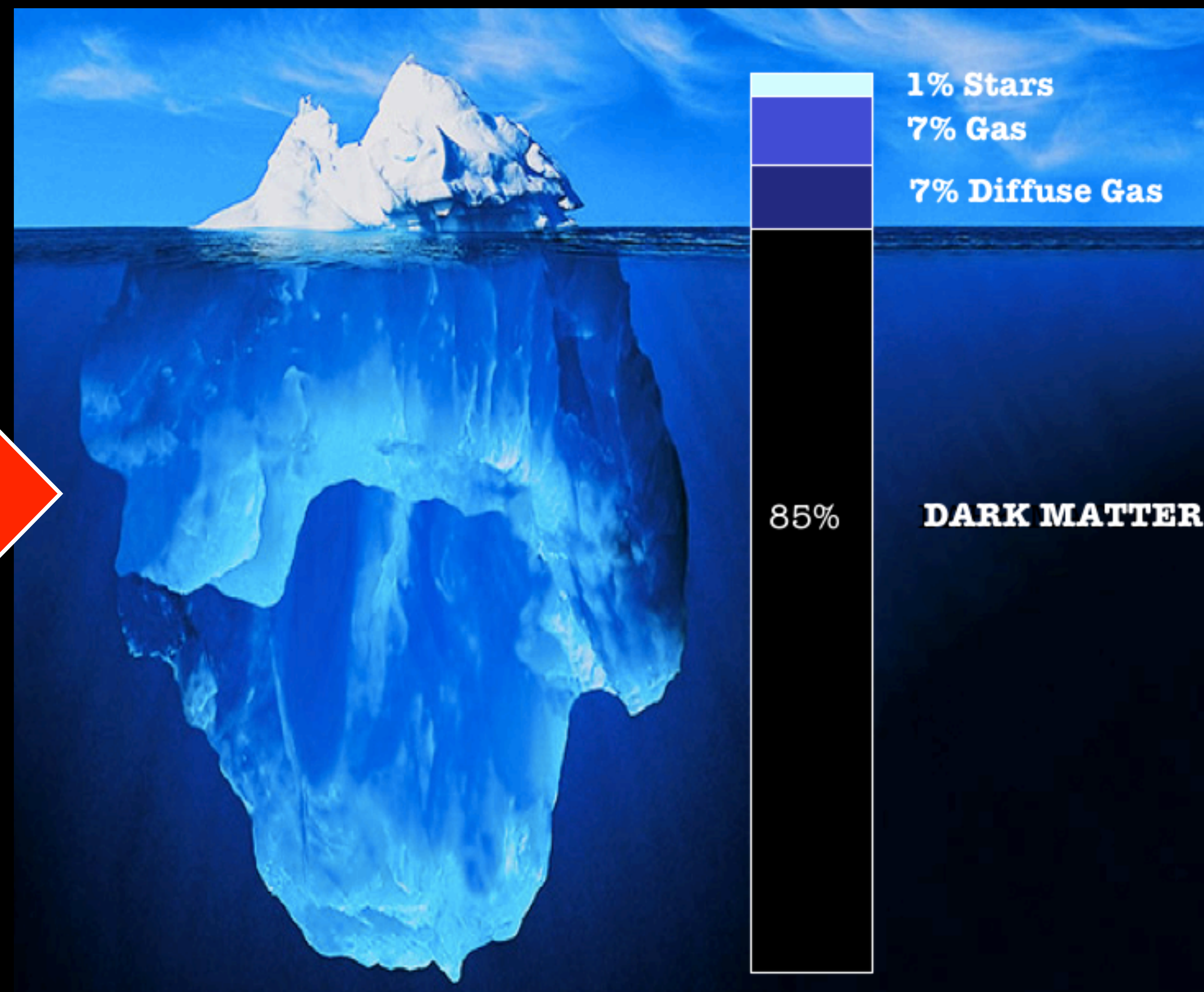
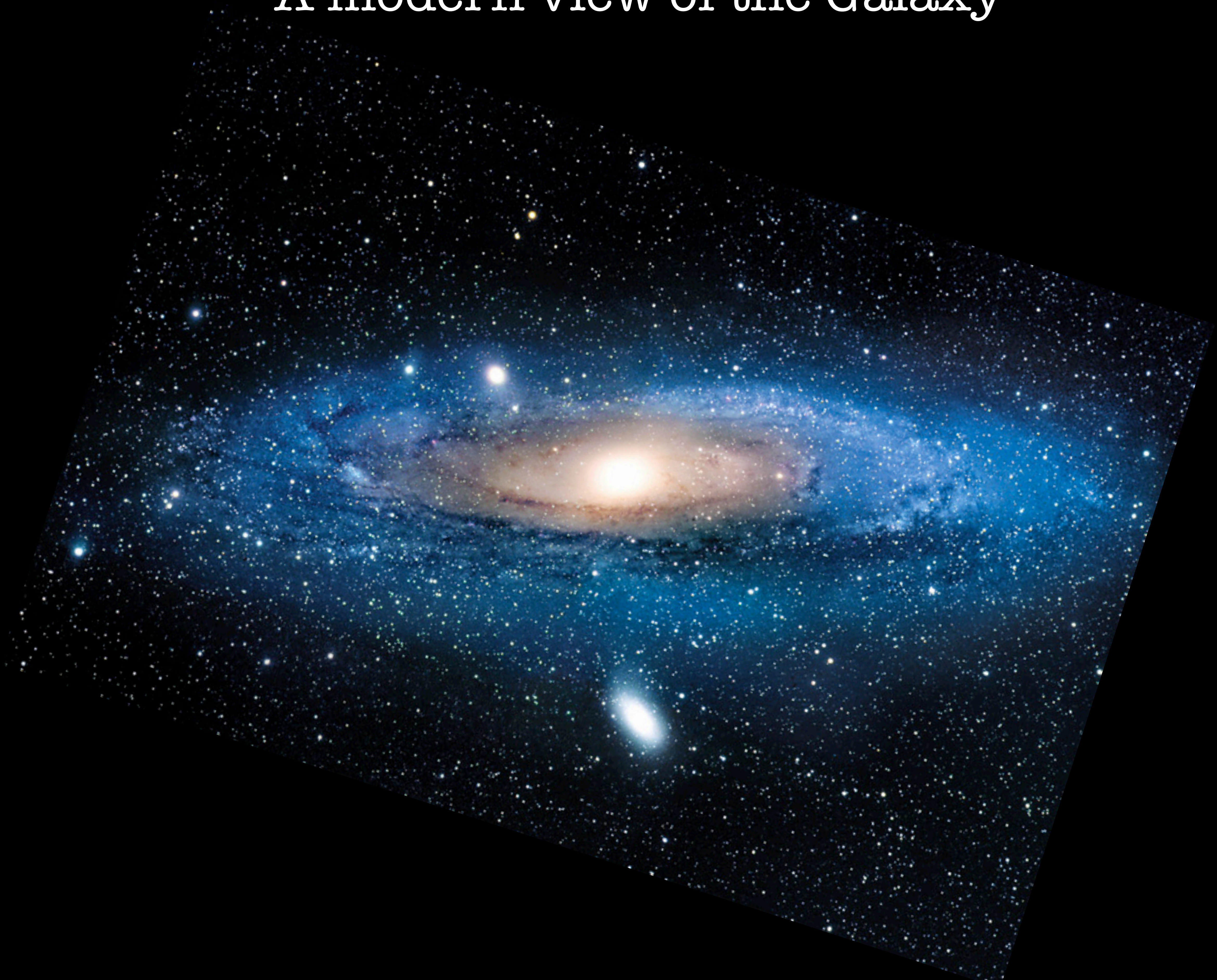


A modern view of the Galaxy



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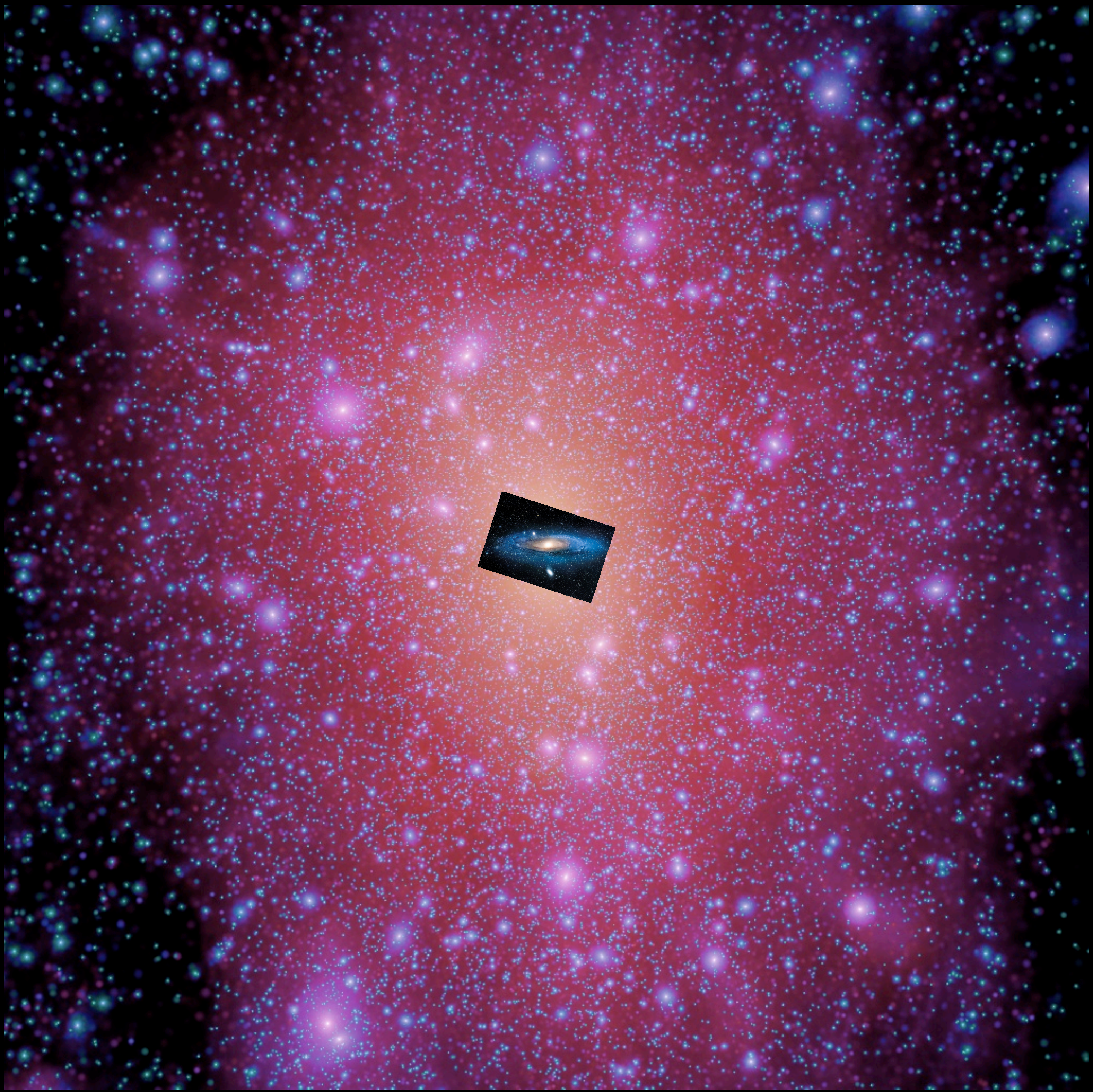
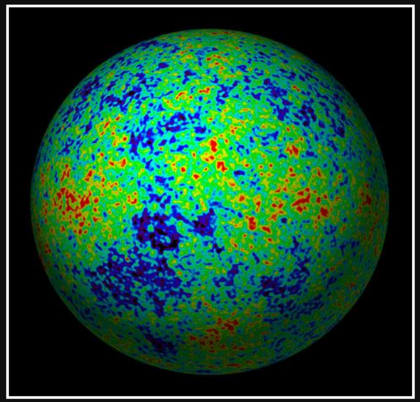


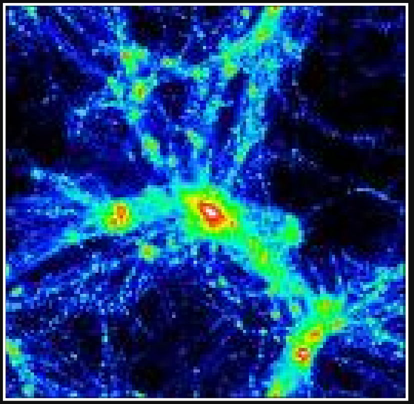
What do we know?

An extraordinarily rich zoo of non-baryonic Dark Matter candidates! In order to be considered a viable DM candidate, a new particle has to pass the following 10-point test

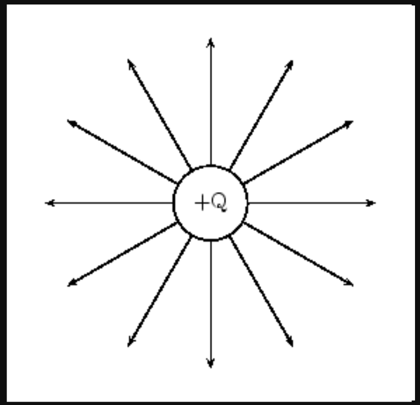
1) Abundance ok?



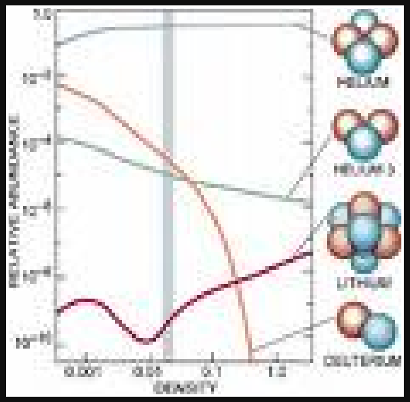
2) Cold?



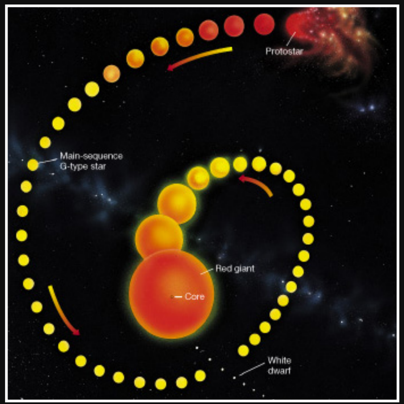
3) Neutral?



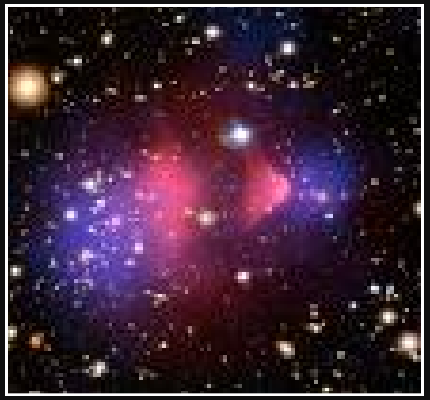
4) BBN ok?



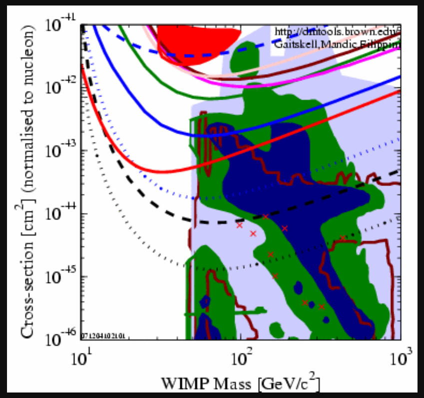
5) Stars OK?



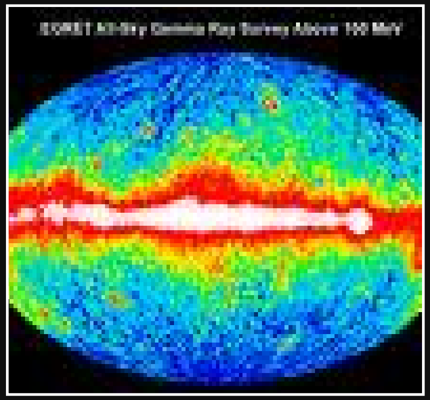
6) Collisionless?



7) Couplings OK?



8) γ-rays OK?



9) Astro bounds?

10) Can probe it?

Dark Matter candidates

Dark Matter candidates

- Neutralino?

Dark Matter candidates

Like ancient geographers..

Psalter map, drawn in 1260, conserved at the British Library in London.

So geographers, in Afric maps,
With savage pictures fill their gaps,
And o'er unhabitable downs
Place elephants for want of towns.

Jonathan Swift (1667 - 1745)

Dark Matter candidates

WIMPs

Weakly Interacting Massive Particles

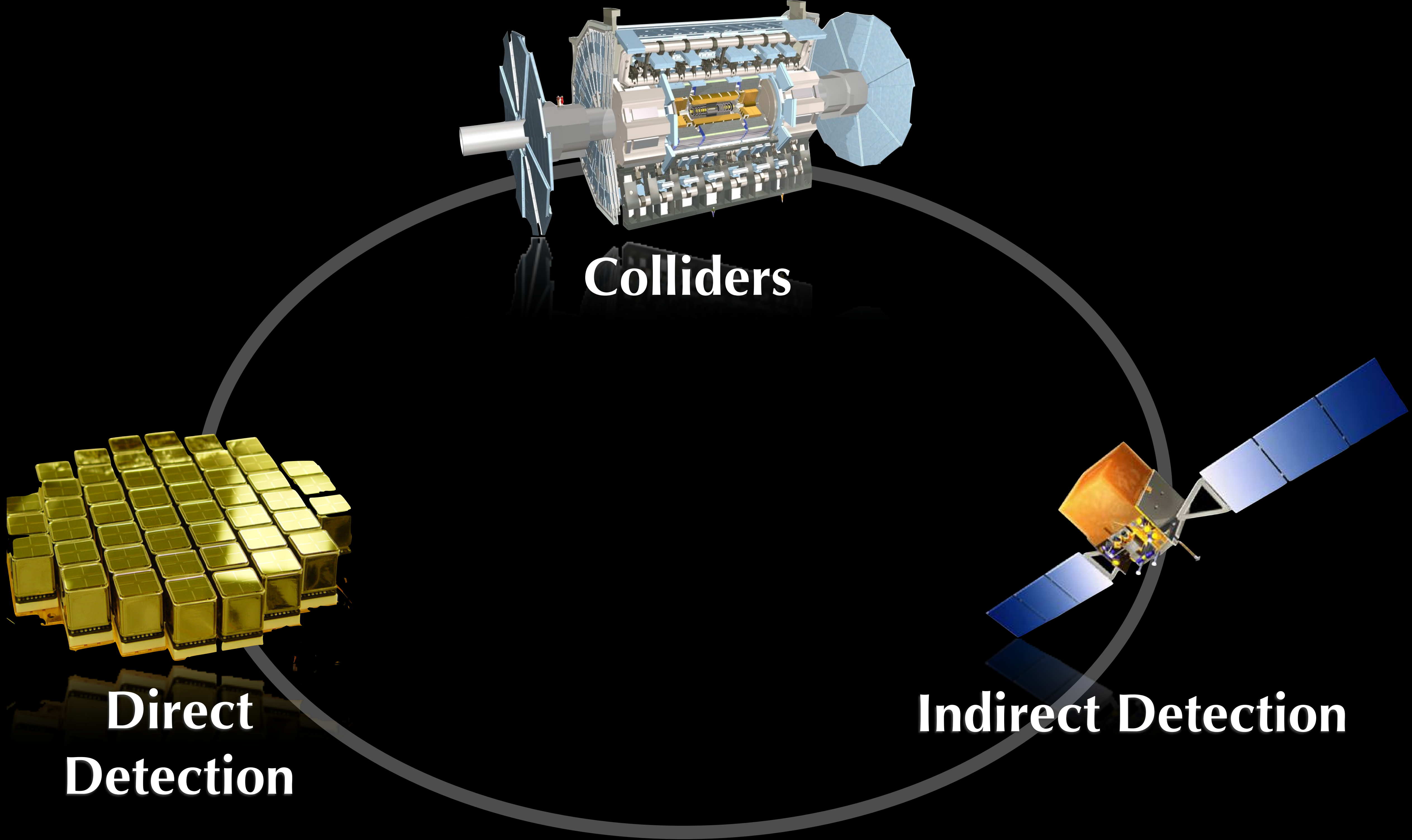
Natural Candidates: Arising 'as a bonus' from theories addressing the fundamental problems of particle physics

Ad-Hoc Candidates: Postulated to solve the DM Problem

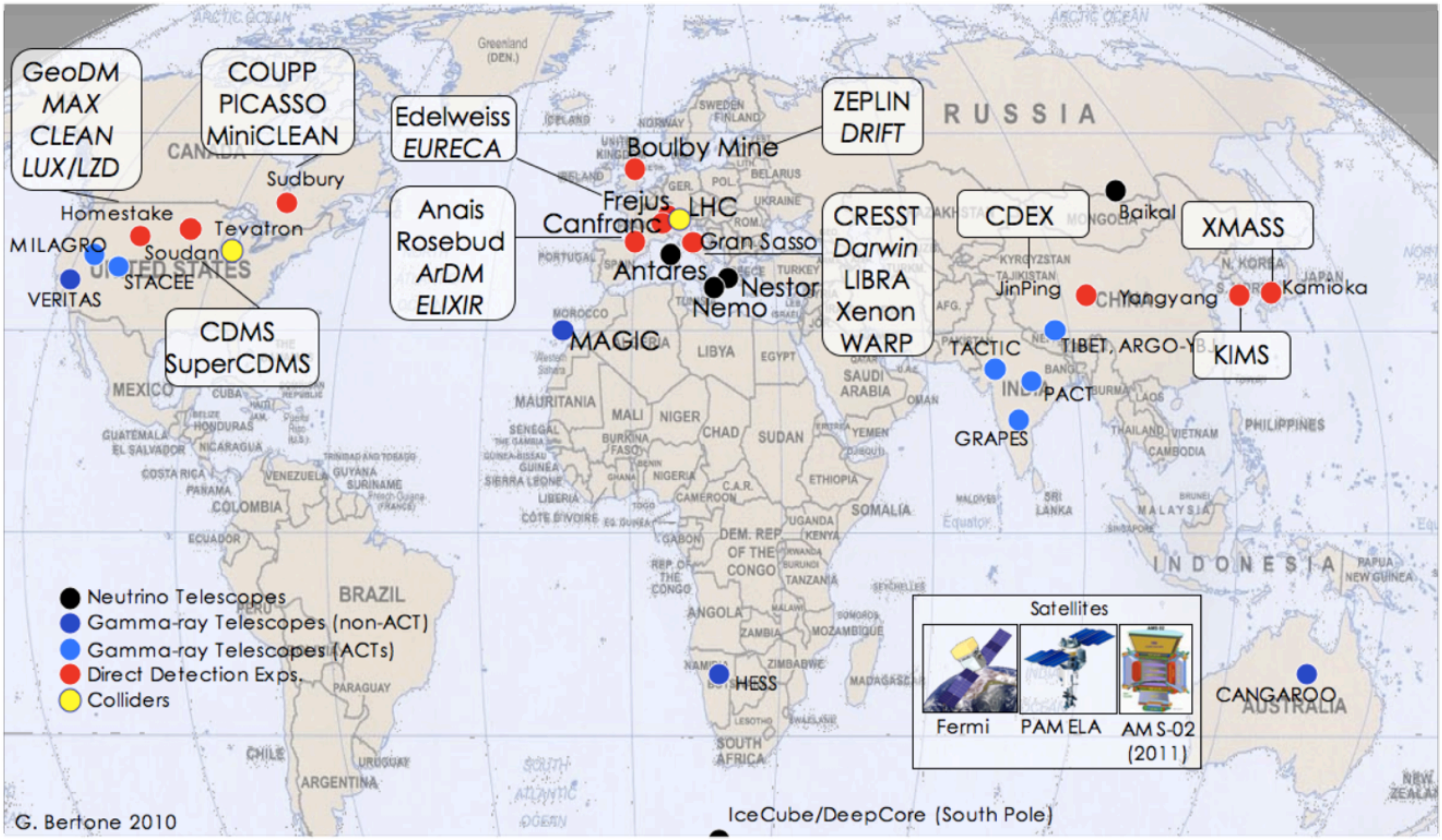
Others

- Axions, Sterile Neutrinos, SuperWIMPs, WIMPless, Axino, Q-balls, etc.

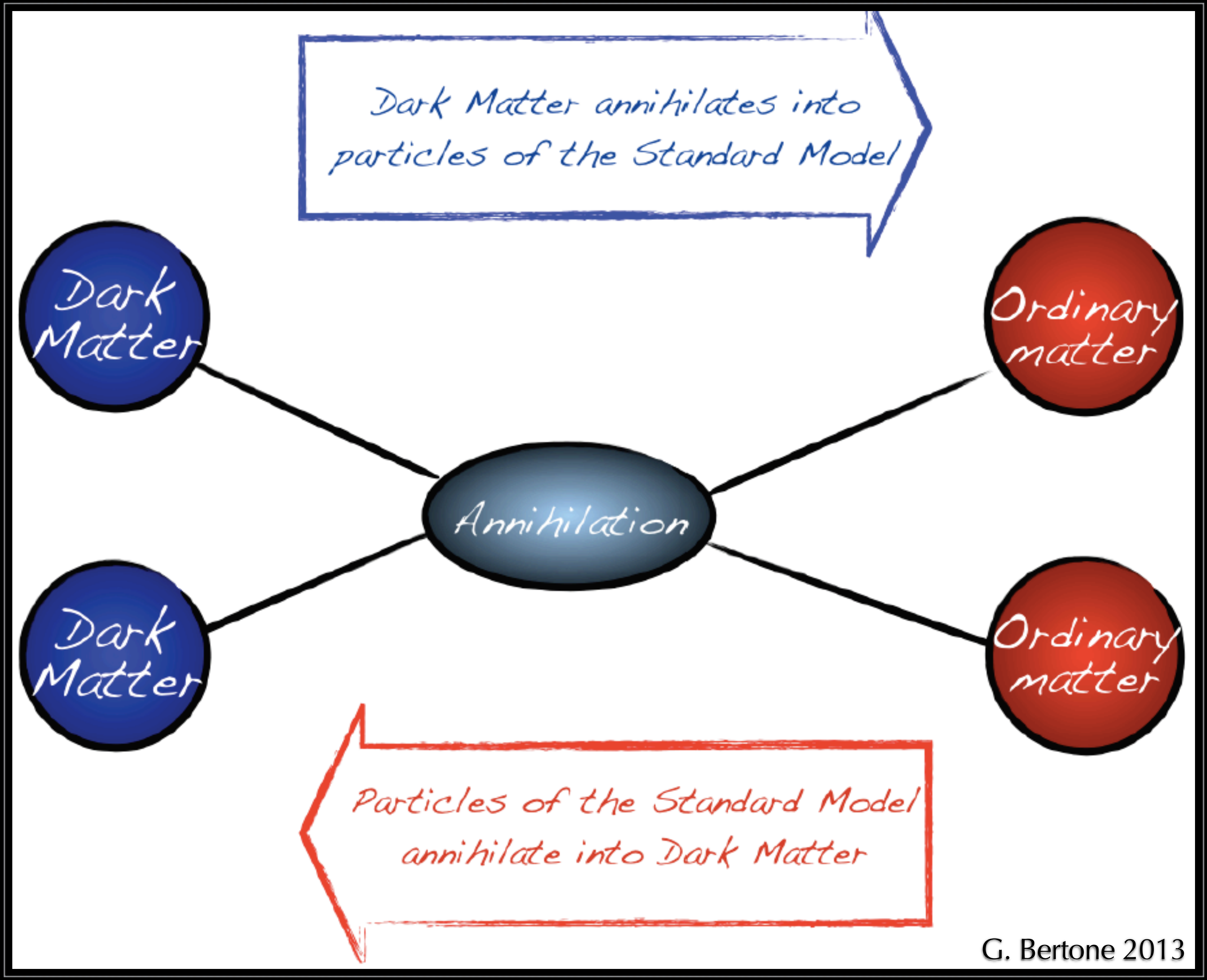
Dark Matter searches



The worldwide race



Indirect Detection



Simulating Galaxy Formation

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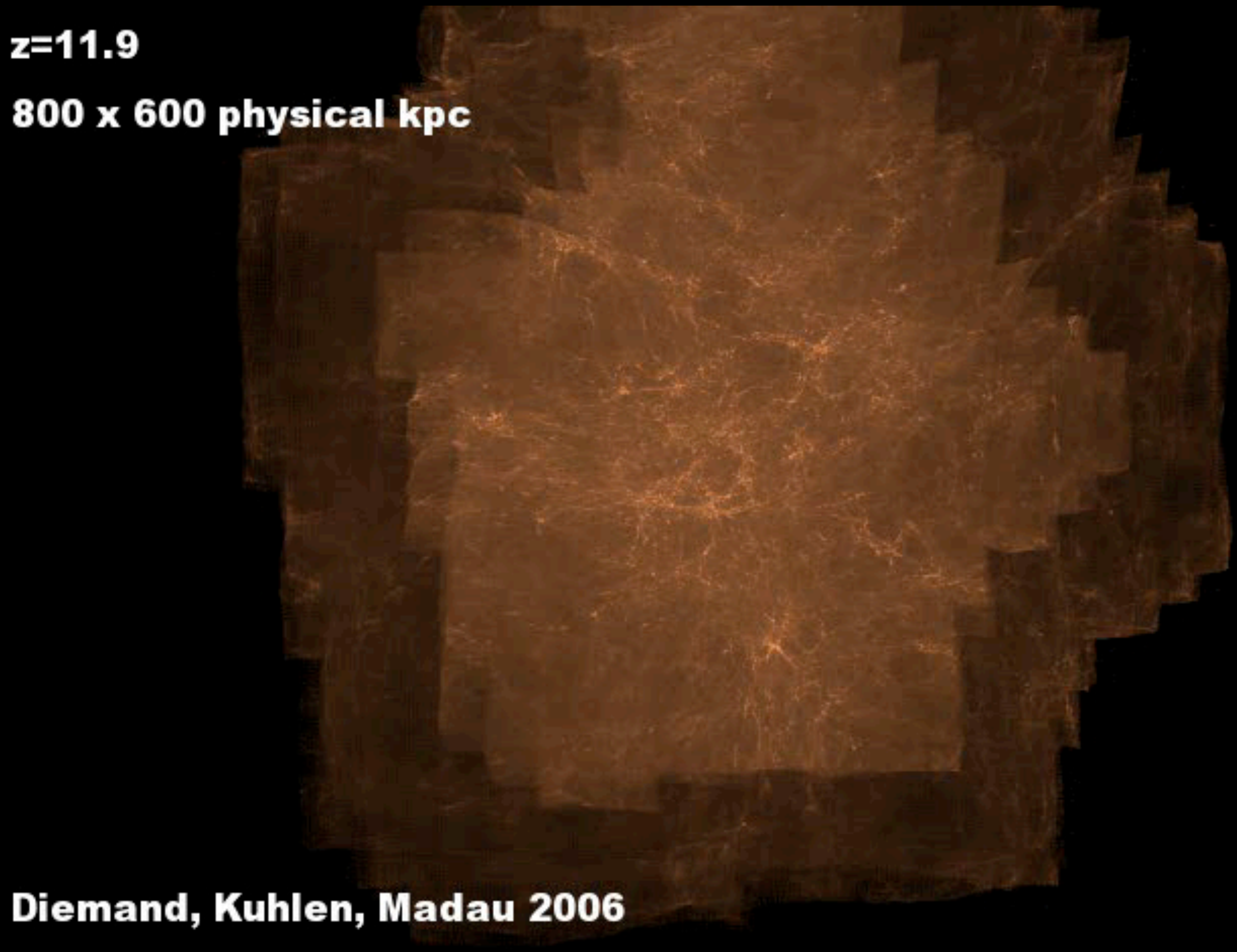


Including baryons (= gas and stars)

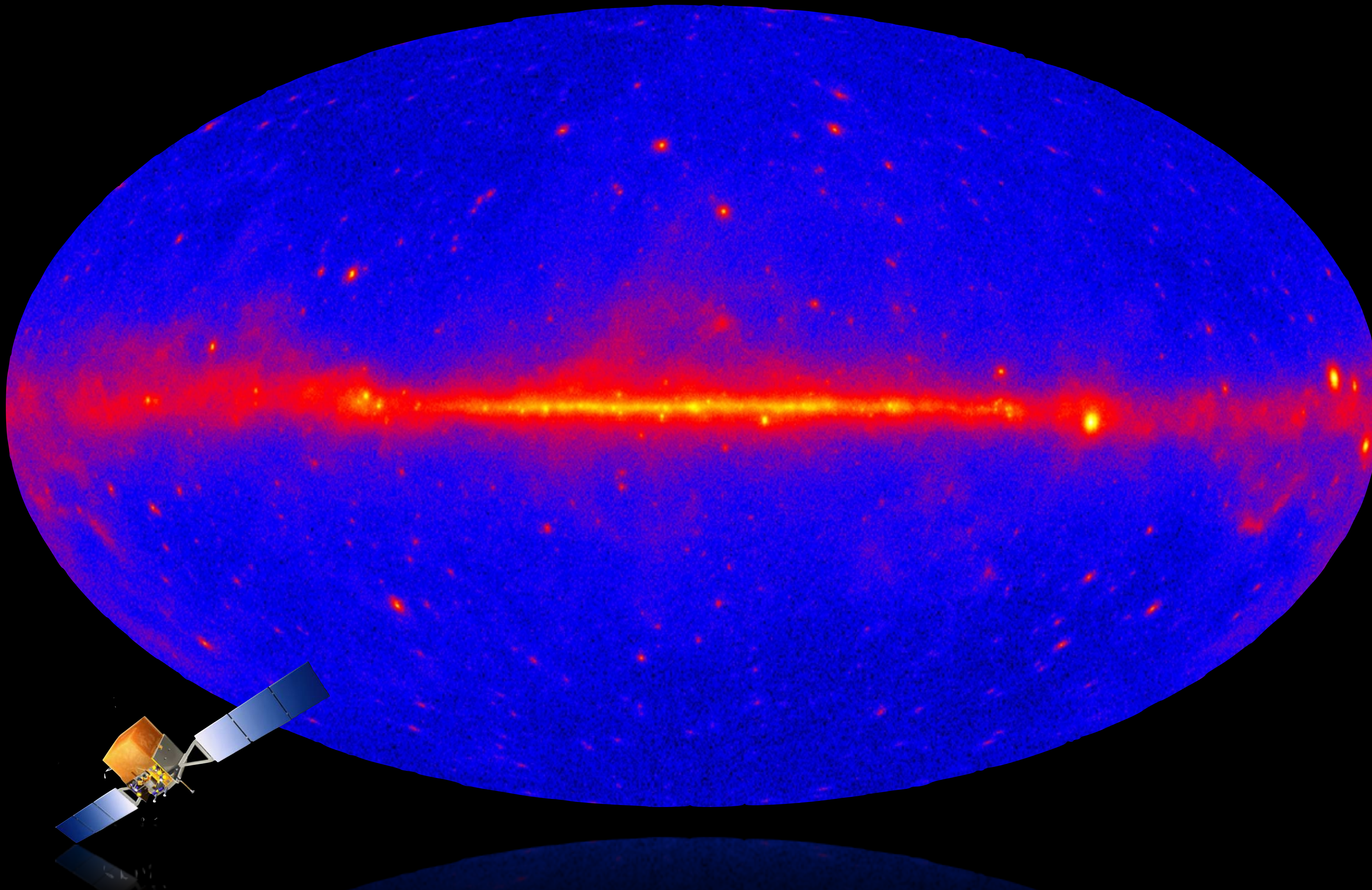
z=99.00

2 kpc

Agertz et al. (2009)

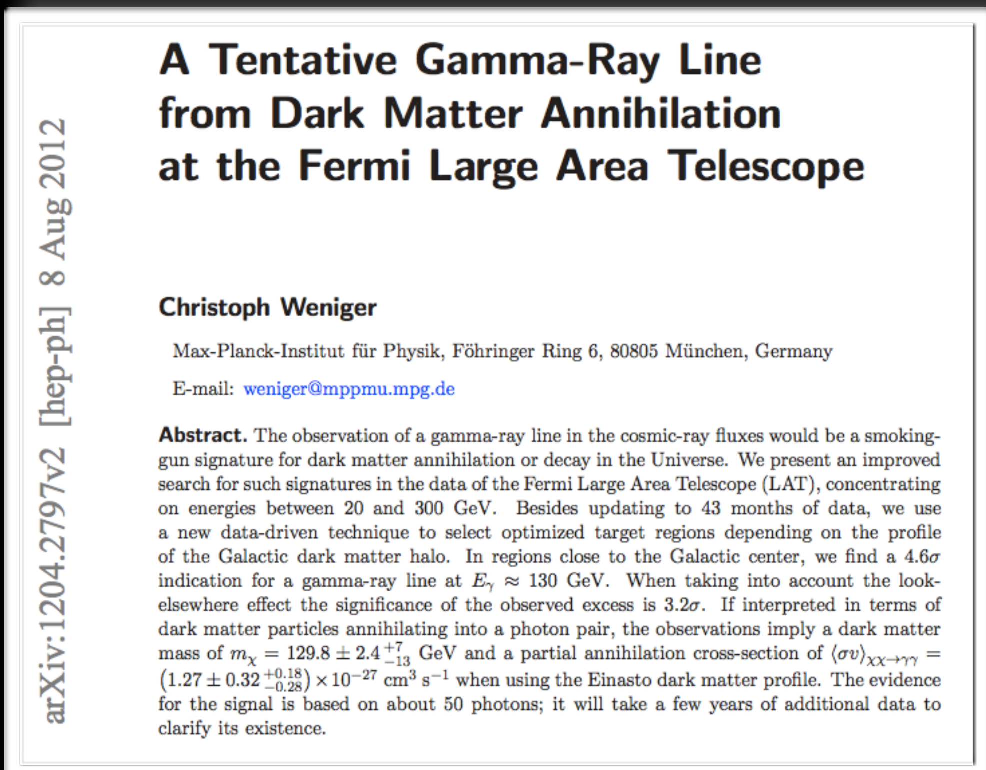
Evolution of the gas density (blue), temperature (red) and metallicity (green)

The gamma-ray Sky



1-year full-sky map. http://fermi.gsfc.nasa.gov

The 130 GeV Line



arXiv:1204.2797v2 [hep-ph] 8 Aug 2012

A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope

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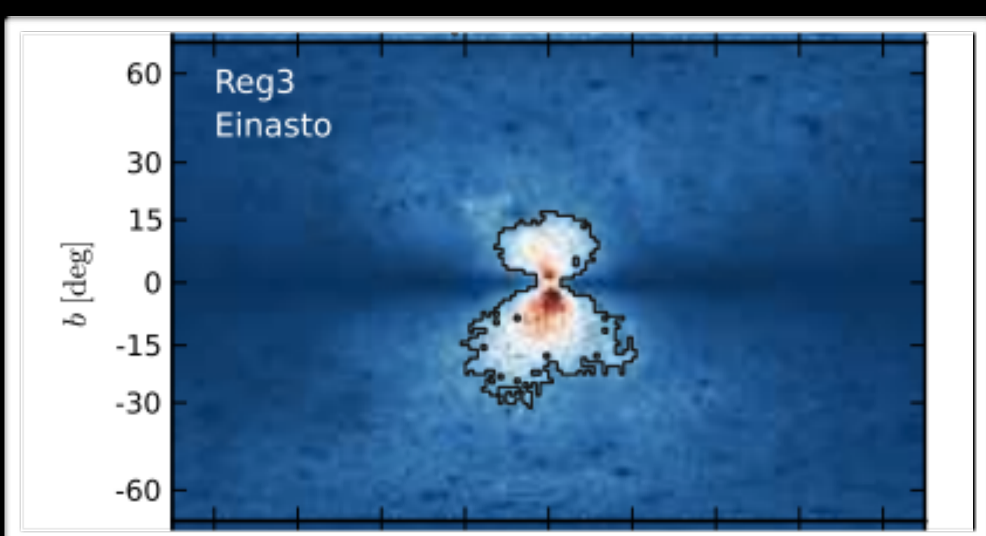
Abstract. The observation of a gamma-ray line in the cosmic-ray fluxes would be a smoking-gun signature for dark matter annihilation or decay in the Universe. We present an improved search for such signatures in the data of the Fermi Large Area Telescope (LAT), concentrating on energies between 20 and 300 GeV. Besides updating to 43 months of data, we use a new data-driven technique to select optimized target regions depending on the profile of the Galactic dark matter halo. In regions close to the Galactic center, we find a 4.6σ indication for a gamma-ray line at $E_\gamma \approx 130$ GeV. When taking into account the look-elsewhere effect the significance of the observed excess is 3.2σ. If interpreted in terms of dark matter particles annihilating into a photon pair, the observations imply a dark matter mass of $m_\chi = 129.8 \pm 2.4^{+7}_{-13}$ GeV and a partial annihilation cross-section of $\langle\sigma v\rangle_{\chi\chi\to\gamma\gamma} = (1.27 \pm 0.32^{+0.18}_{-0.28}) \times 10^{-27}\ \mathrm{cm^3\ s^{-1}}$ when using the Einasto dark matter profile. The evidence for the signal is based on about 50 photons; it will take a few years of additional data to clarify its existence.



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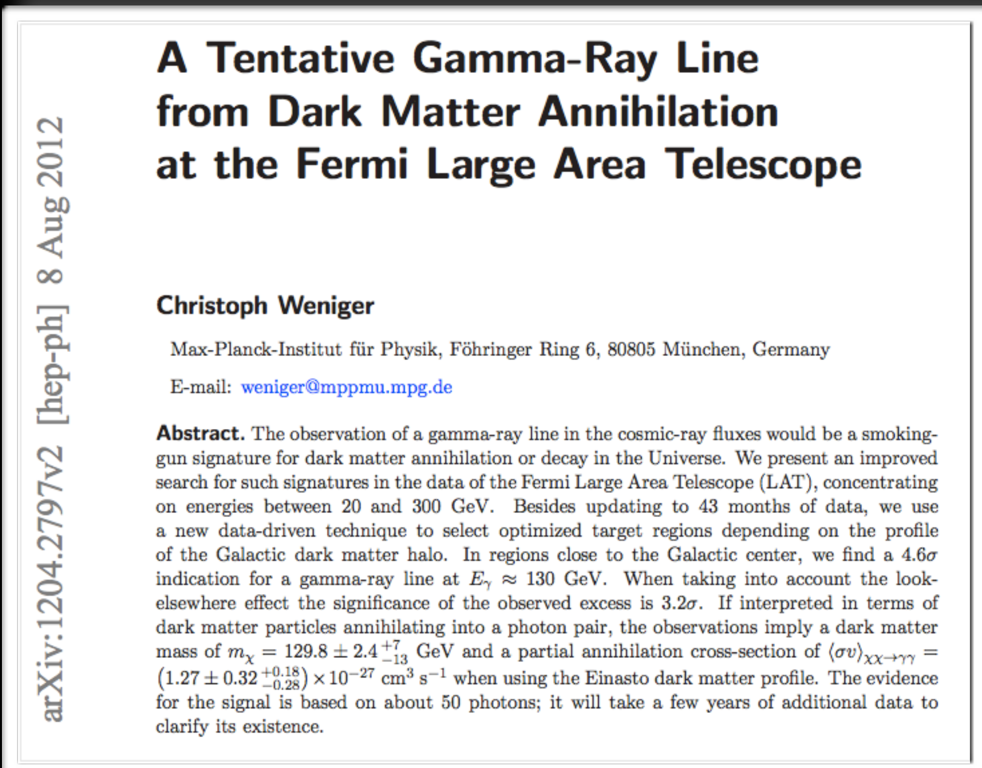

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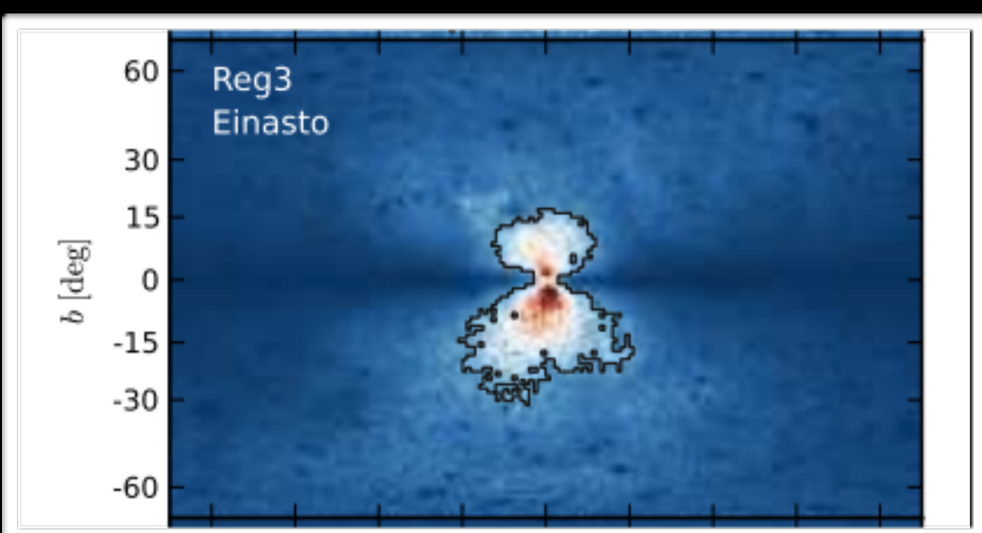
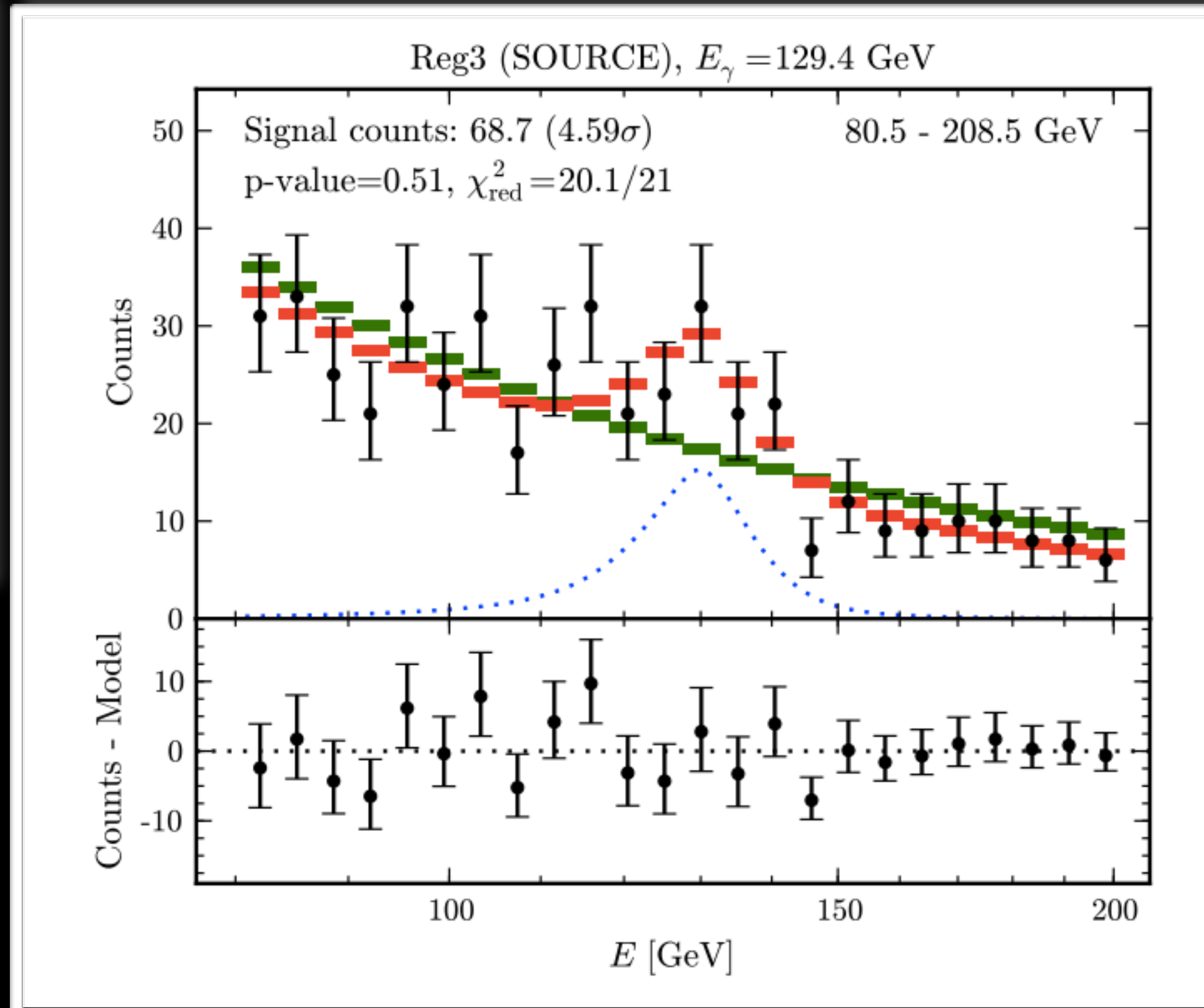


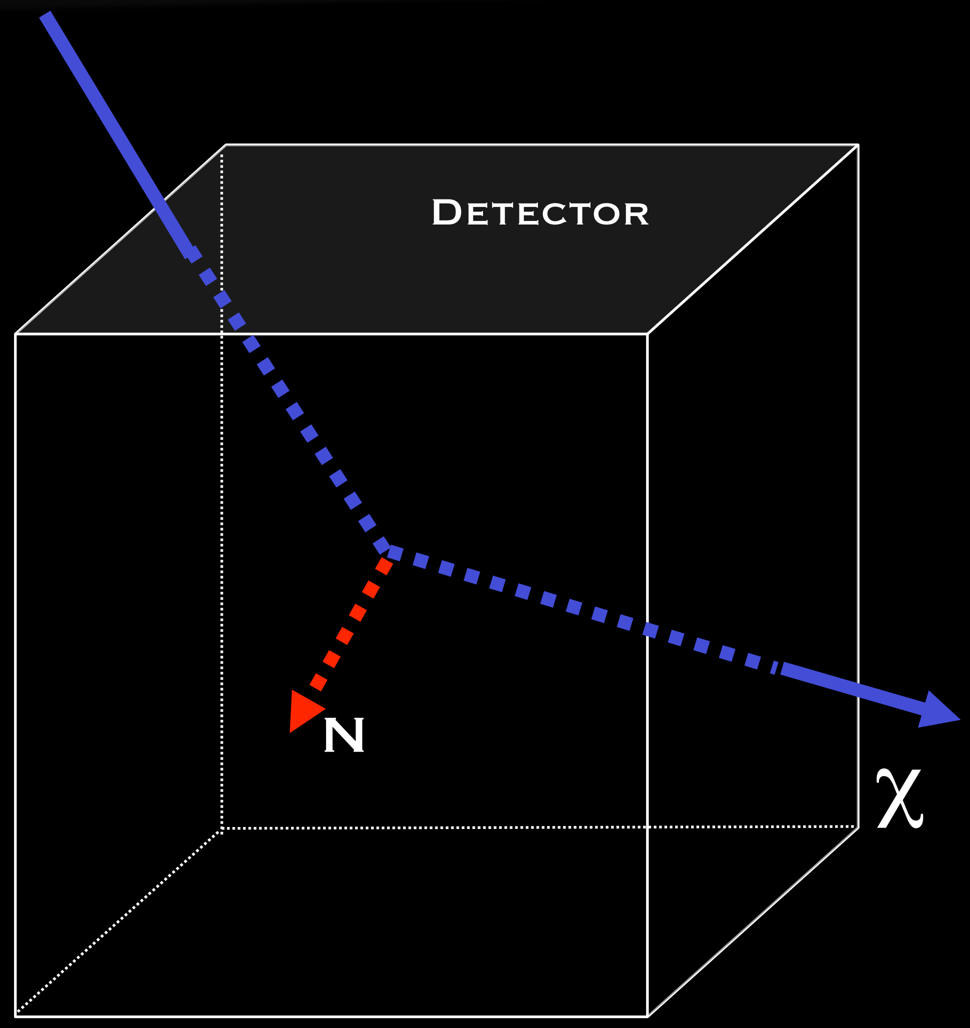


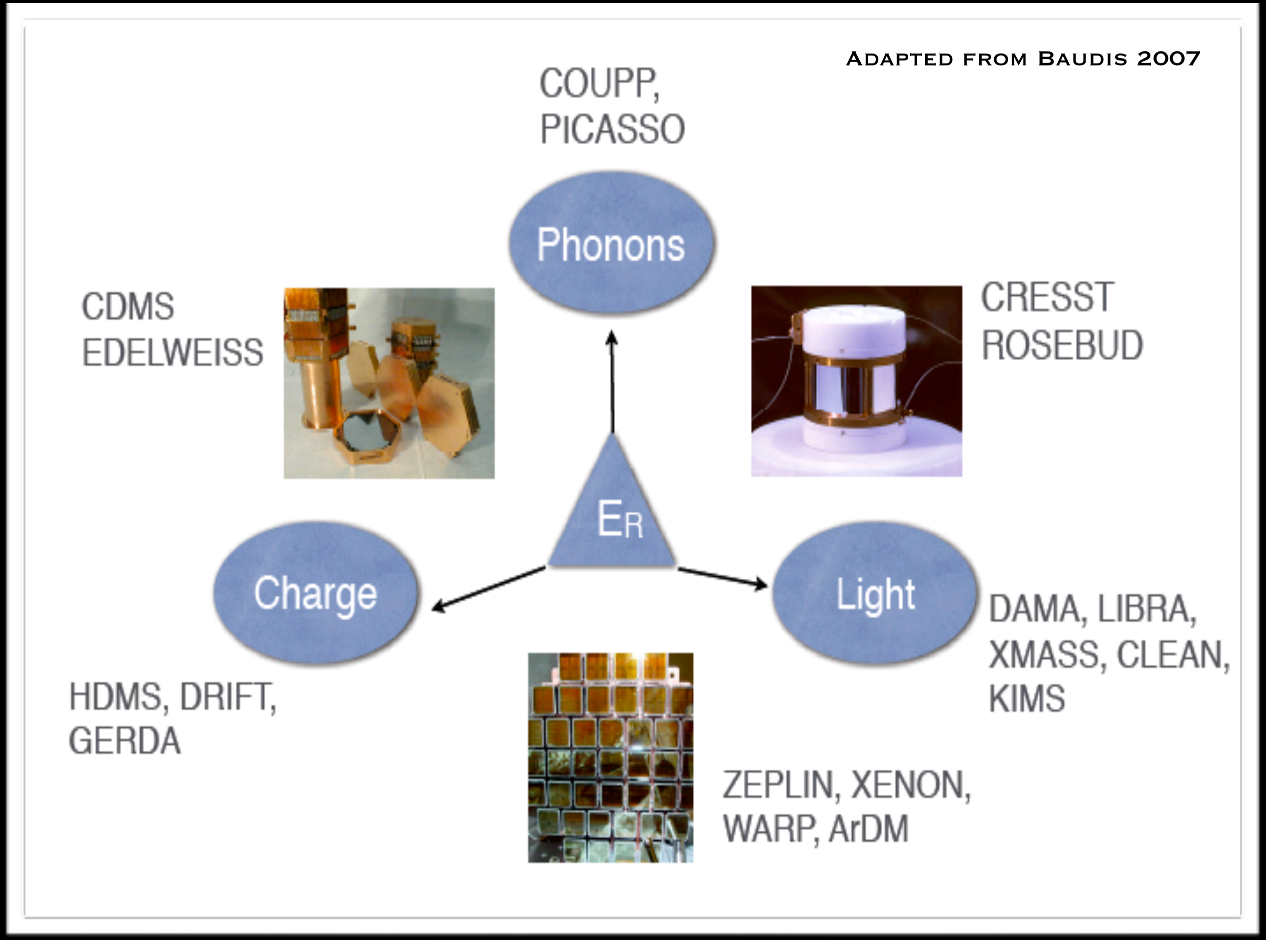
How to cross-check?

The HESS-II telescope in Namibia

Direct Detection

Principle and Detection Techniques

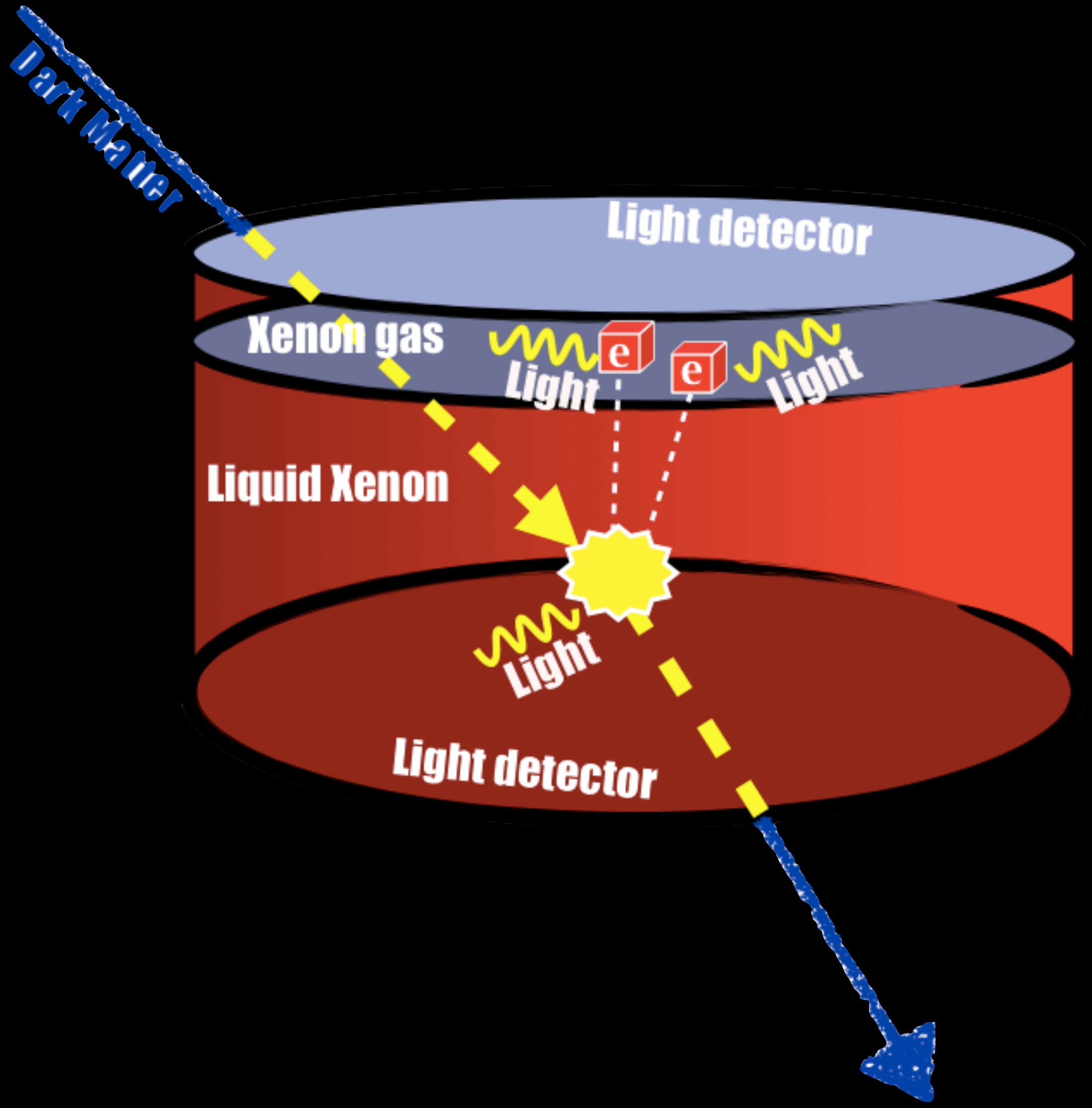




DM scatters off nuclei in the detector

Detection of recoil energy via ionization (charges), scintillation (light) and heat (phonons)

e.g. Xenon100...


Dark Matter
Light detector
Xenon gas
Light
e
e
Light
Liquid Xenon
Light
Light detector

Direct Detection

Differential Event Rate

$$\frac{dR}{dE_R}(E_R) = \frac{\rho_0}{m_\chi m_N} \int_{v>v_{min}} v f(\vec{v} + \vec{v_e}) \frac{d\sigma_{\chi N}}{dE_R}(v, E_R) d^3\vec{v}$$

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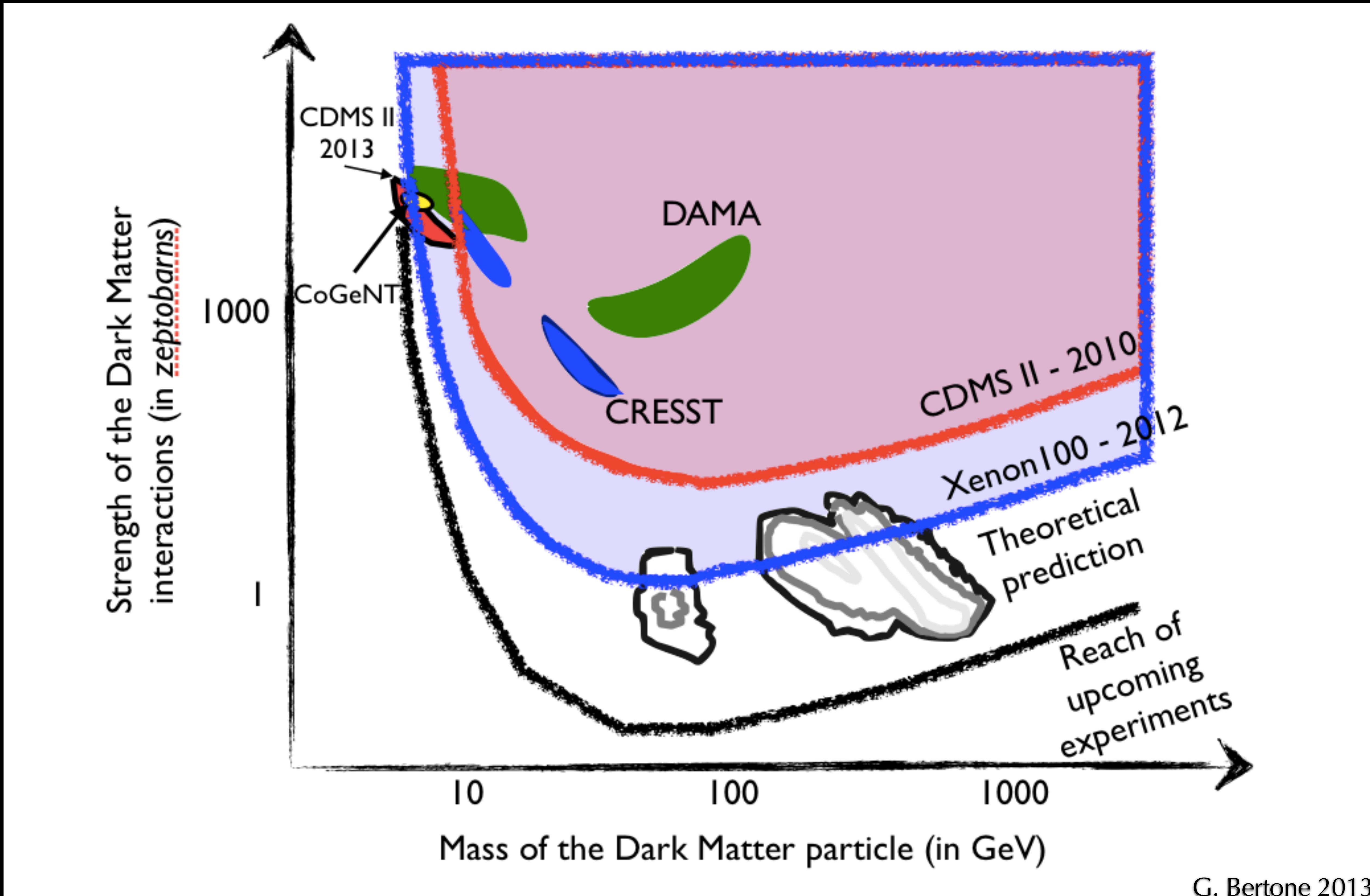
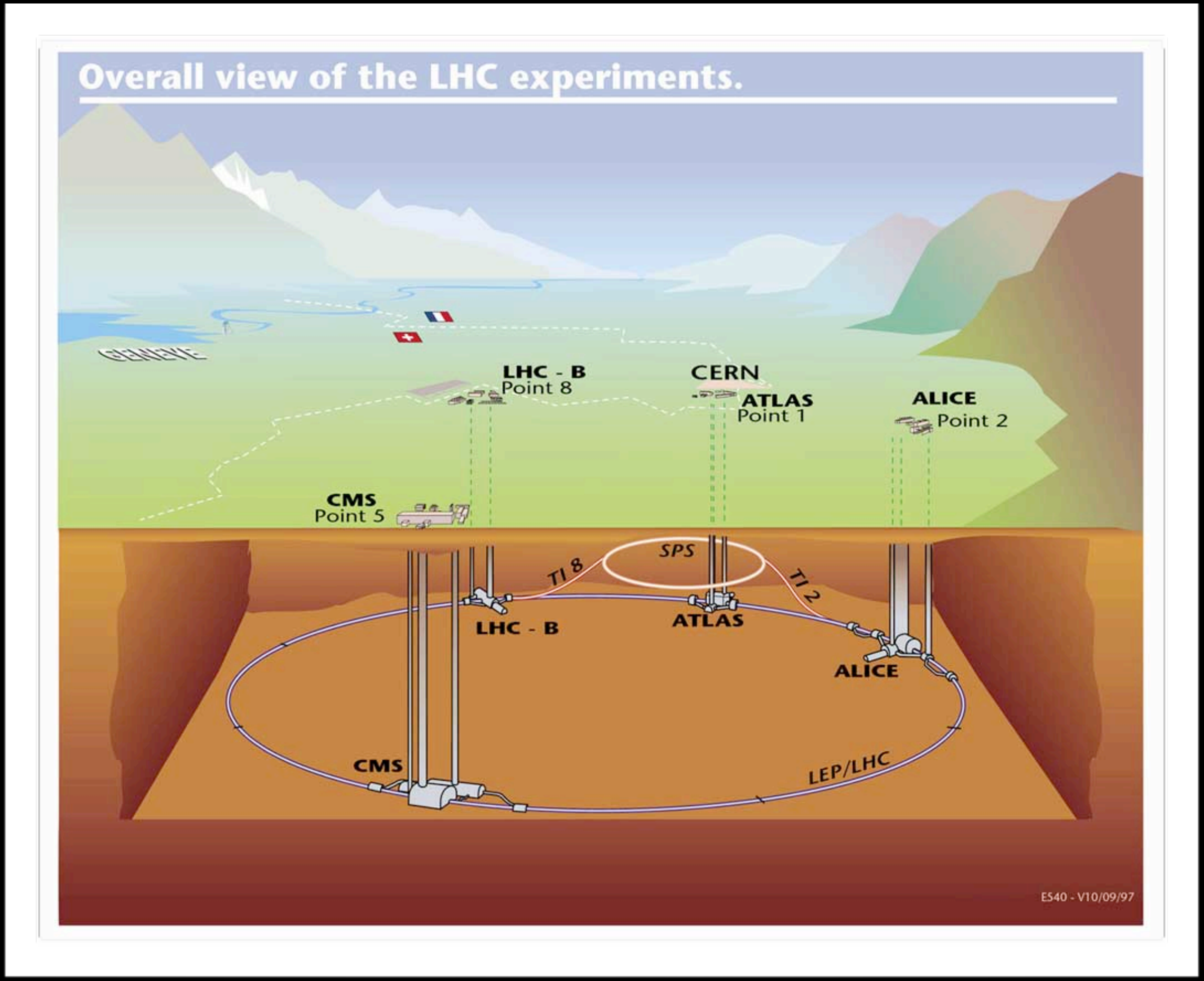
Particle Physics

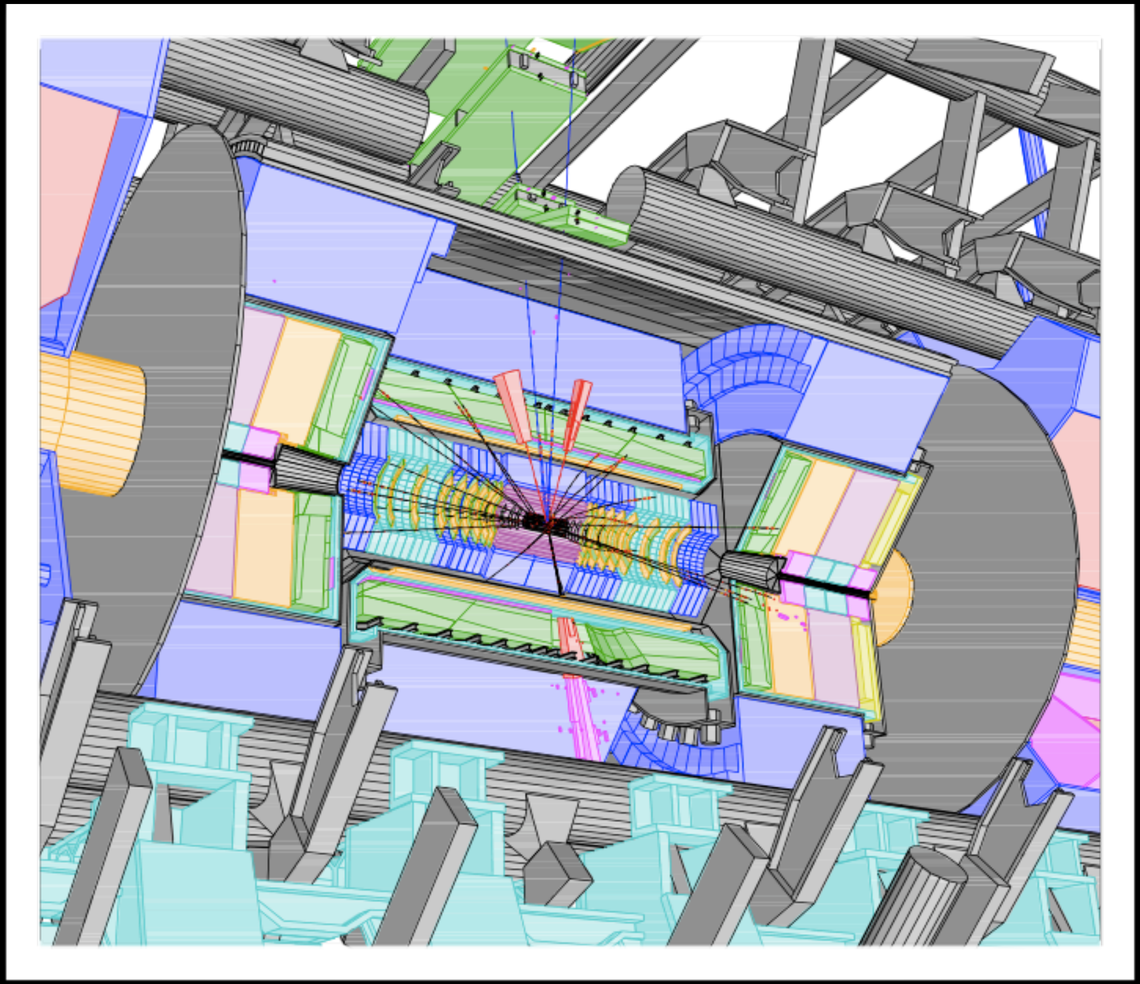
Astrophysics

Status of Direct Searches



Dark Matter Searches at the LHC





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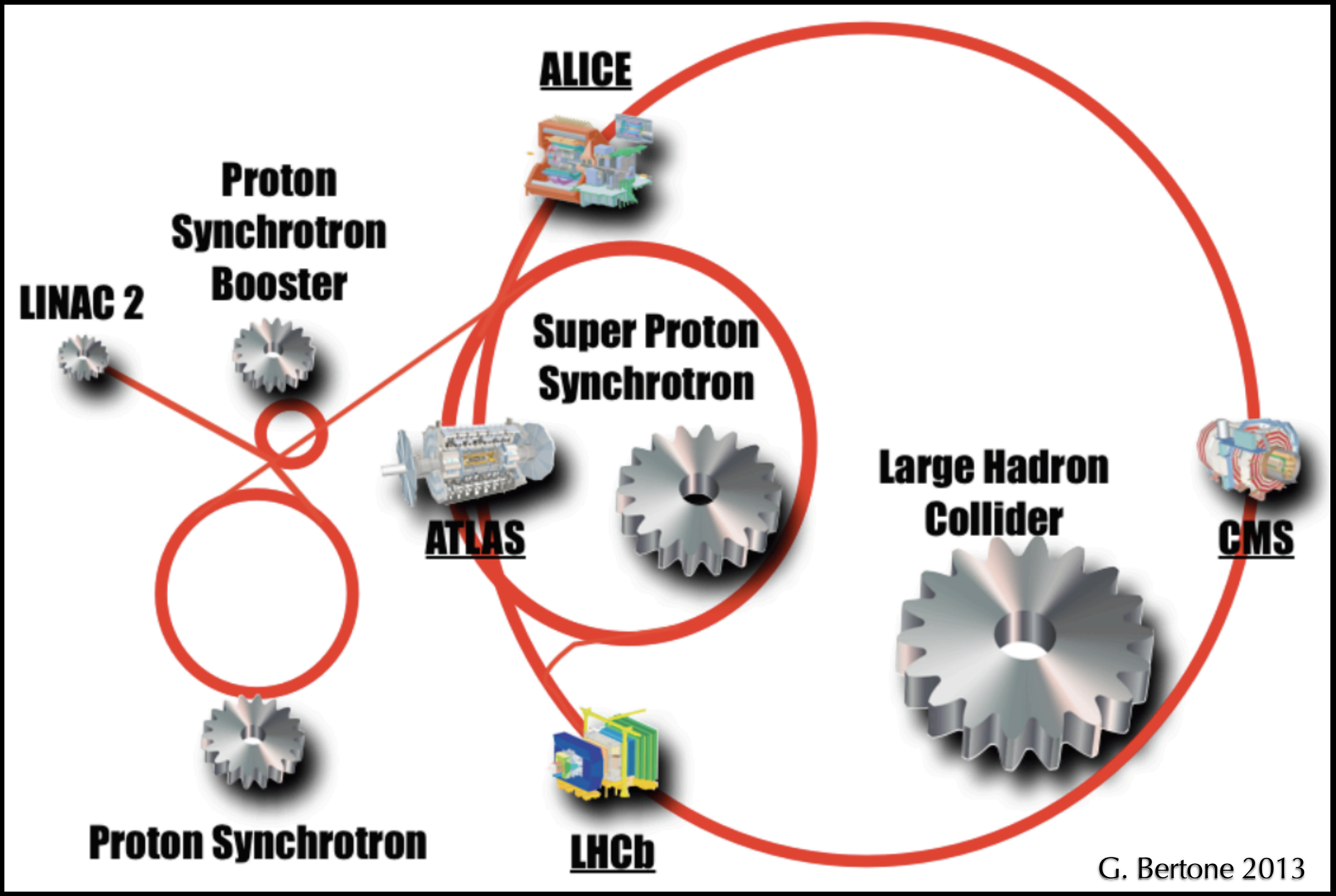
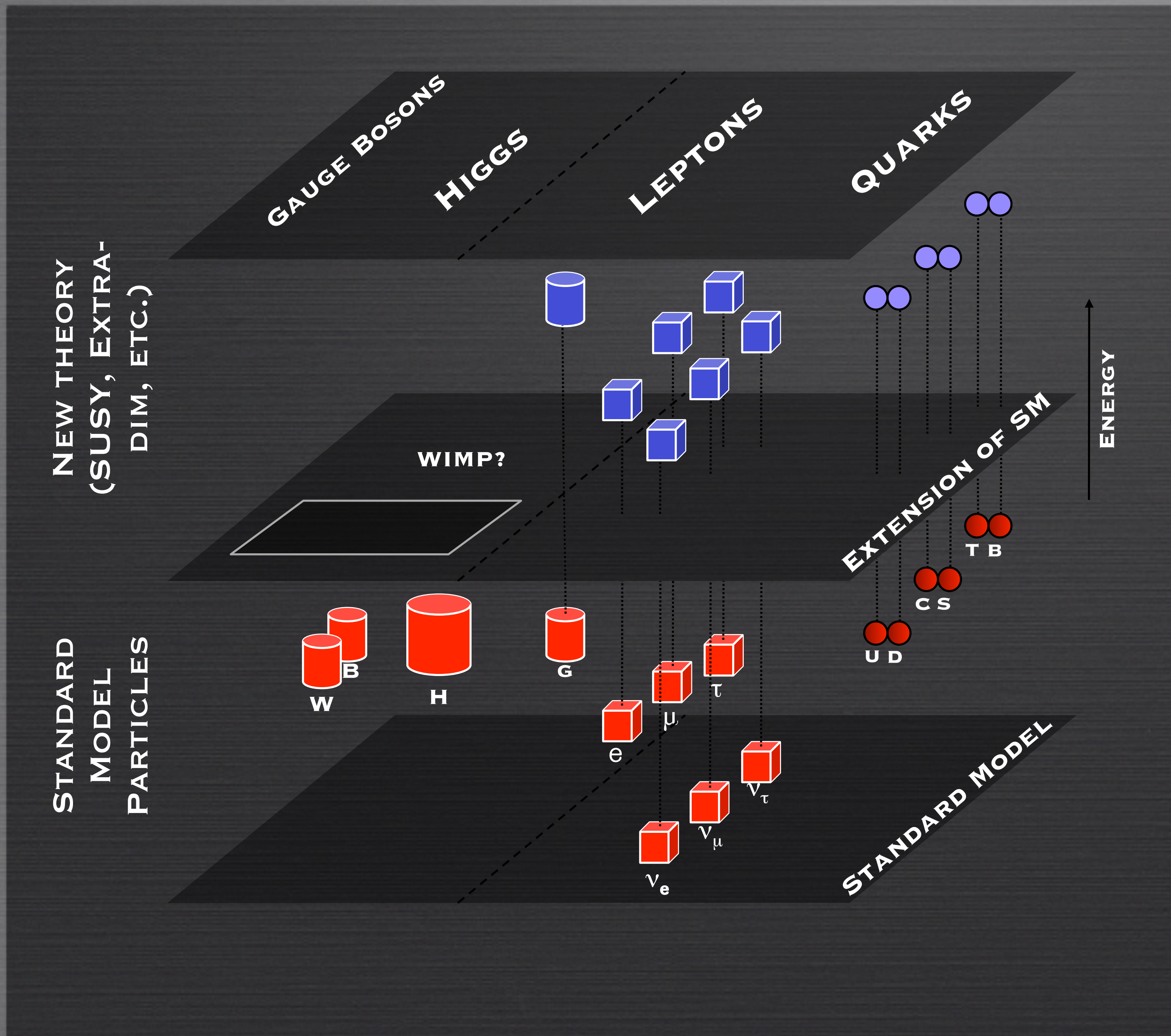


Beyond the Standard Model

The Standard Model provides an accurate description of all known particles and interactions, however there are good reasons to believe that the Standard model is a low-energy limit of a more fundamental theory



To explain the origin of the weak scale, extensions of the standard model often postulate the existence of new physics at ~100 GeV

On the left, schematic view of the structure of possible extensions of the standard model

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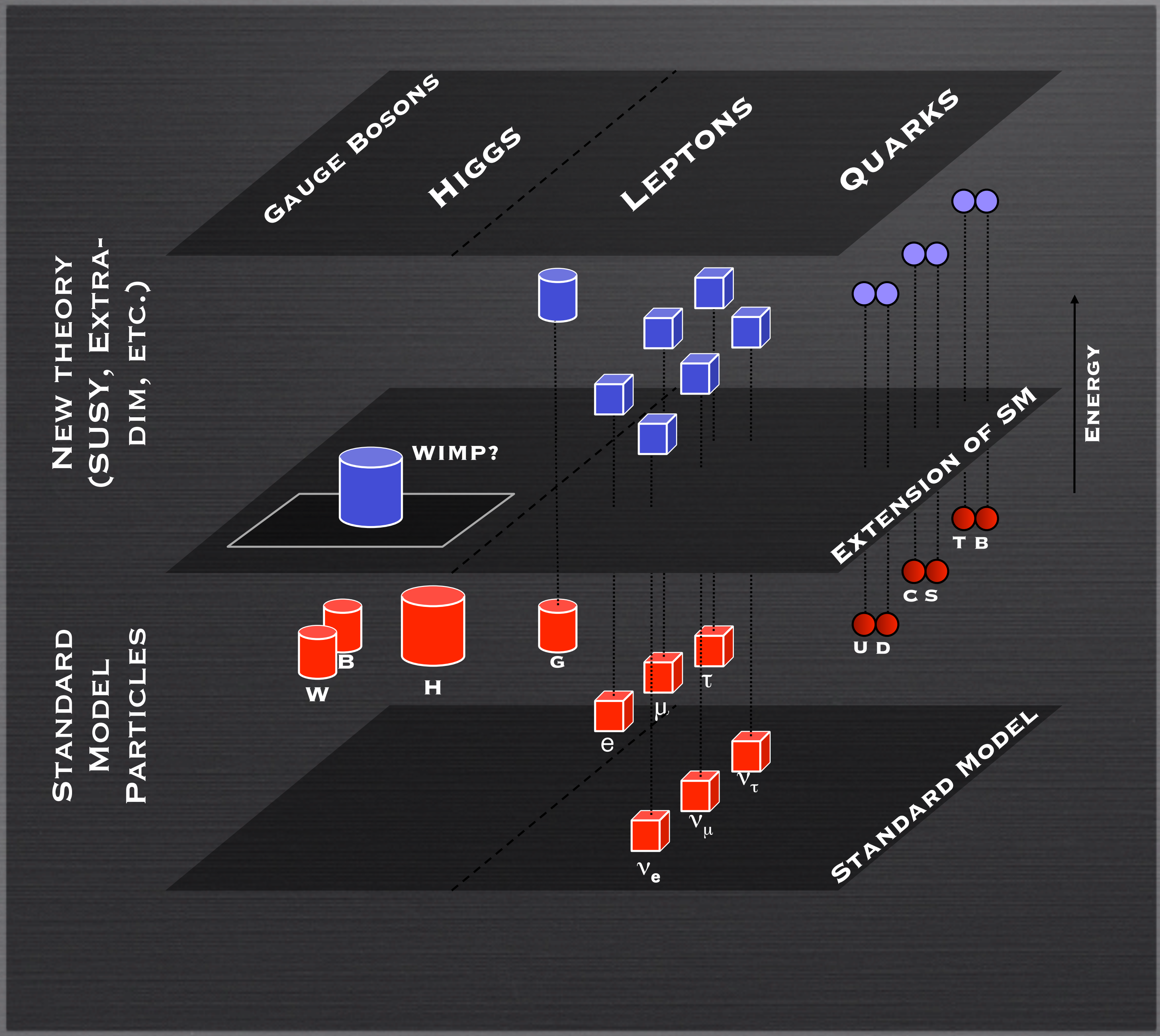

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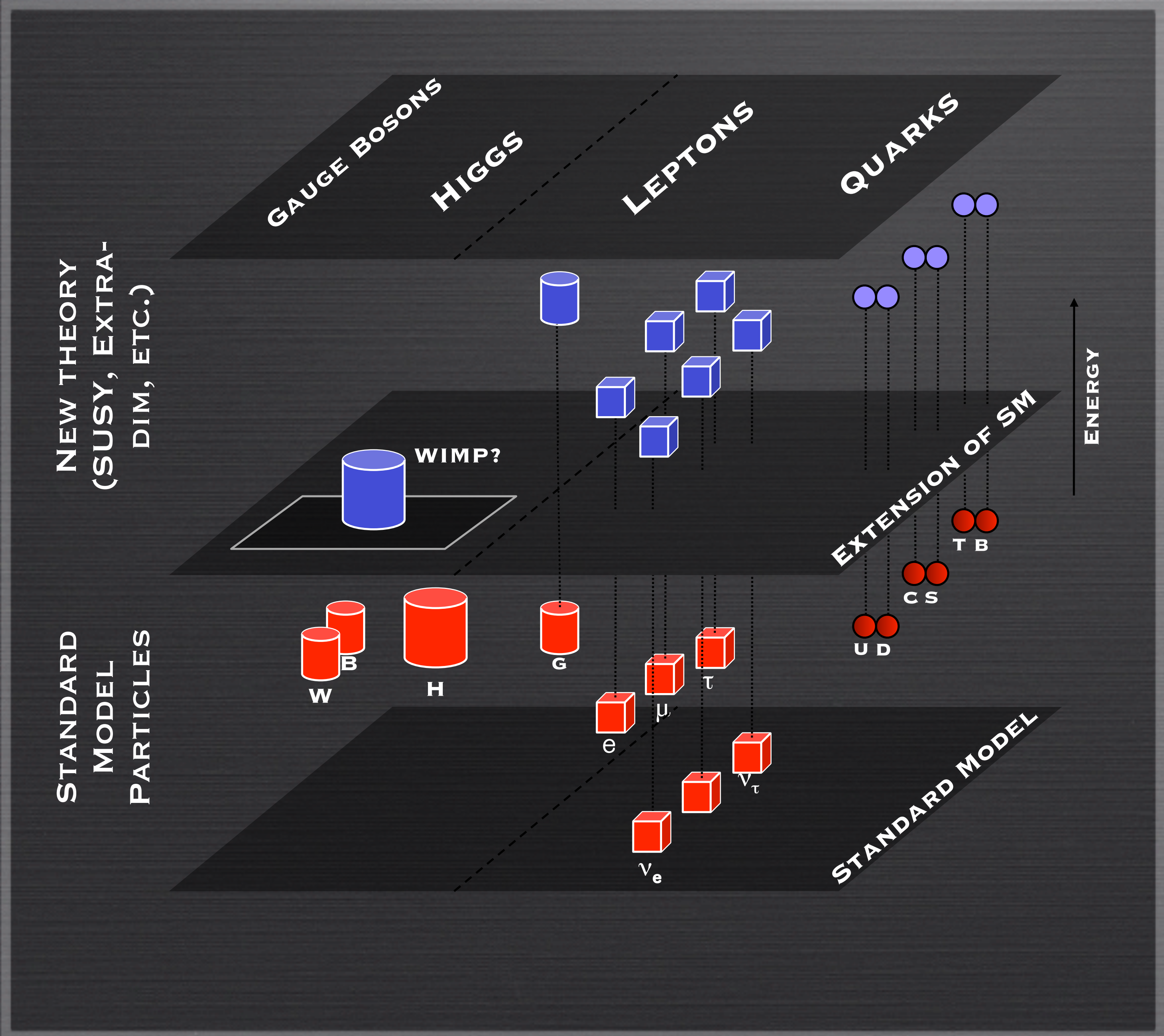
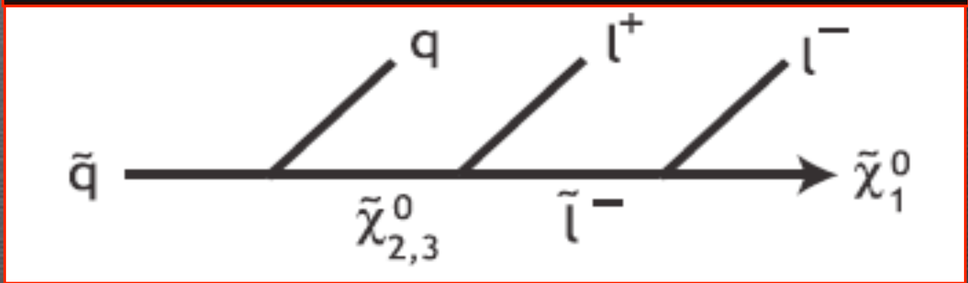
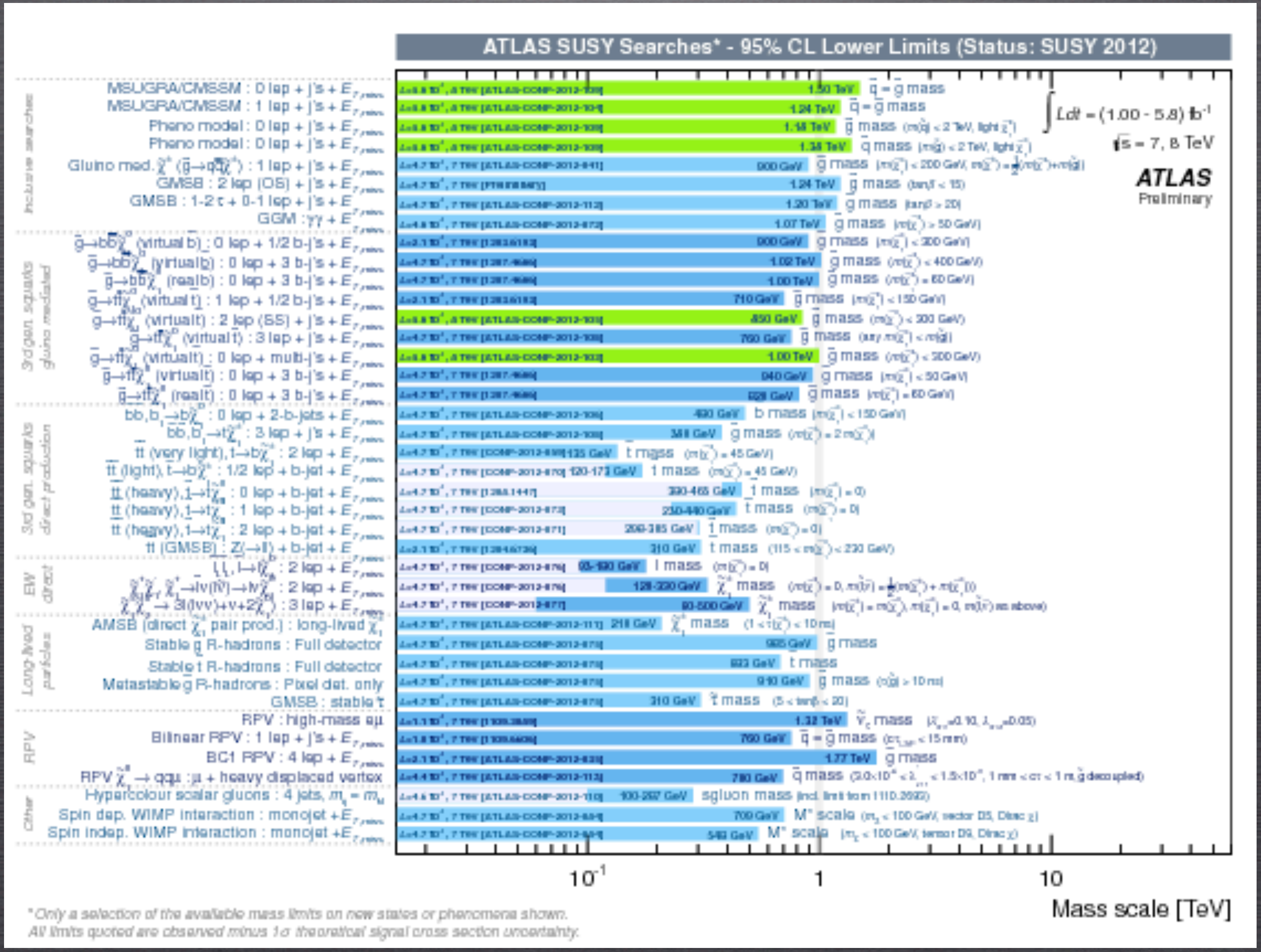


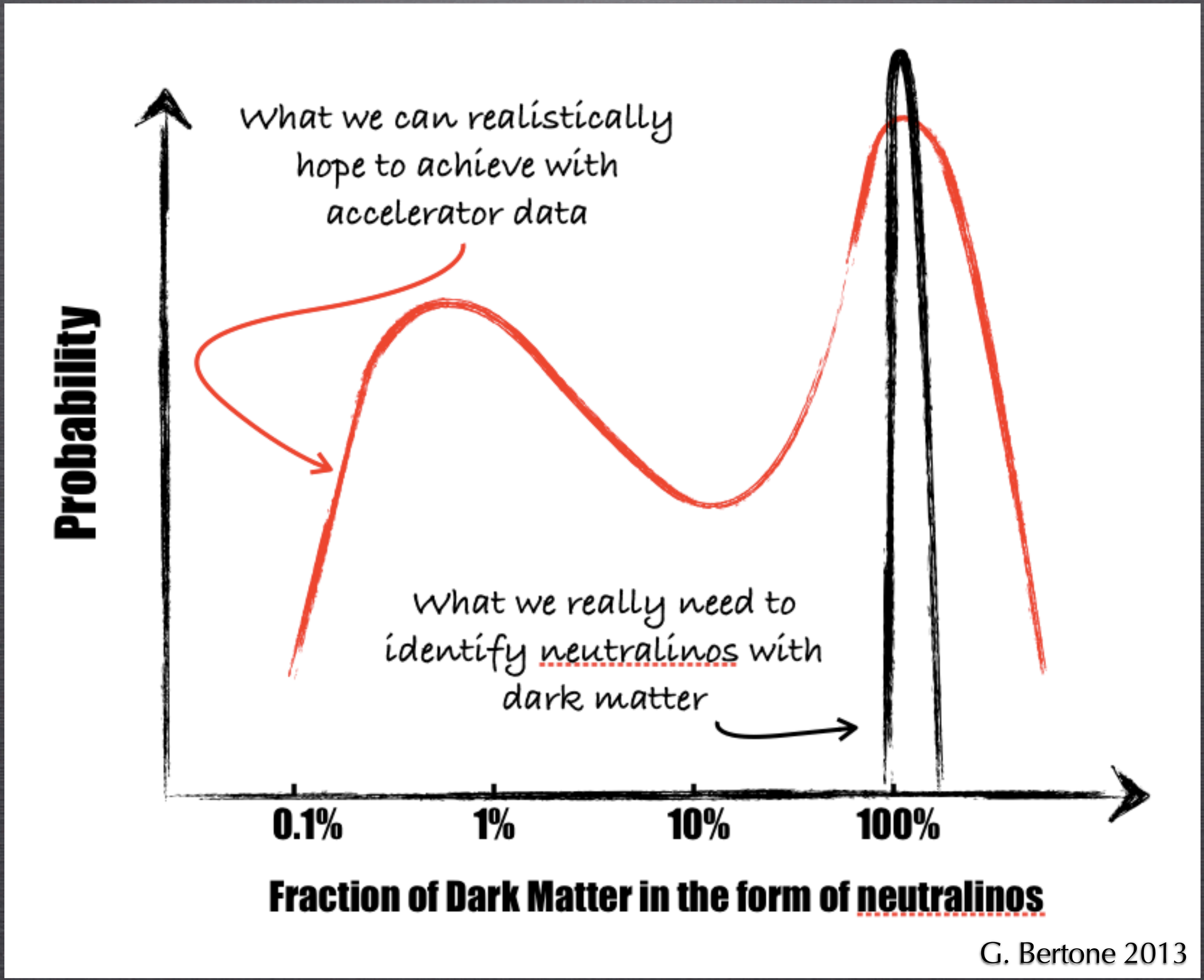
Search at LHC for processes like e.g.



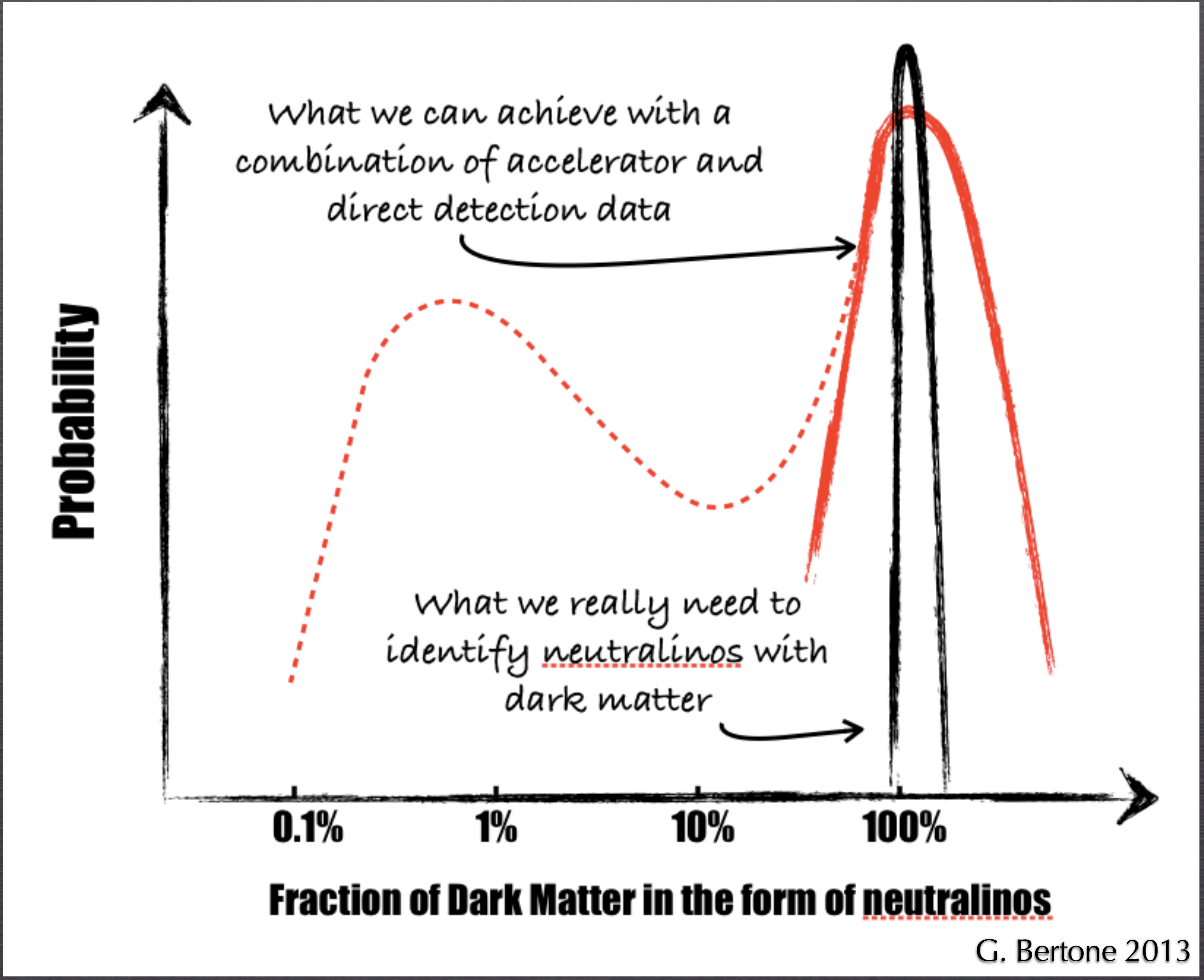
So far only constraints (no discovery)



What if we discover new particles?



Complementarity with Astroparticle experiments



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- Many new ideas and collaborations arose from the Dark Matter program that ends next week, thanks to the director and the KITP staff for hosting us!