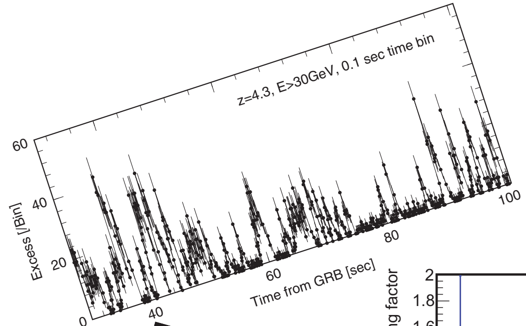
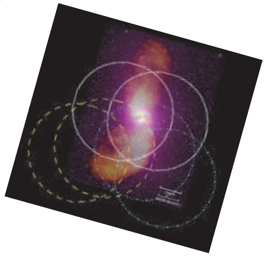
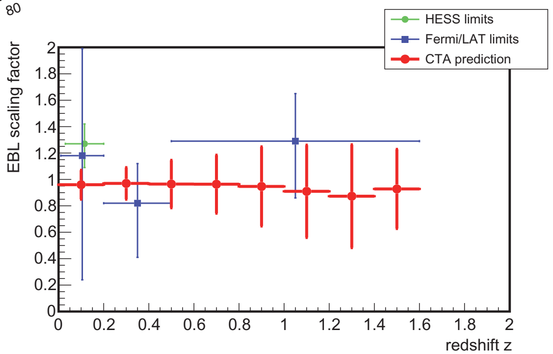
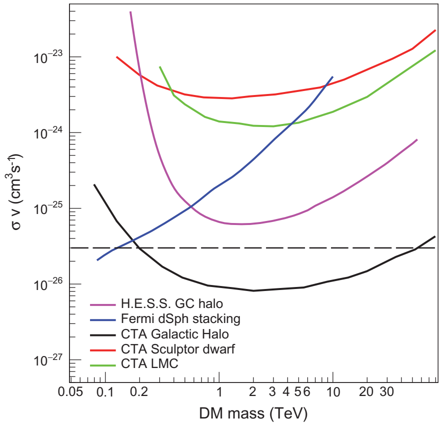
New physics in key science projects

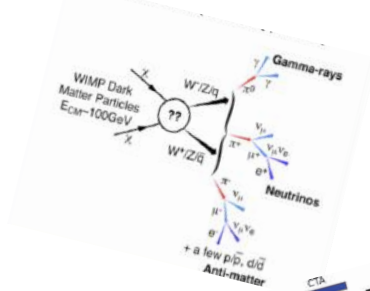
cherenkov telescope array

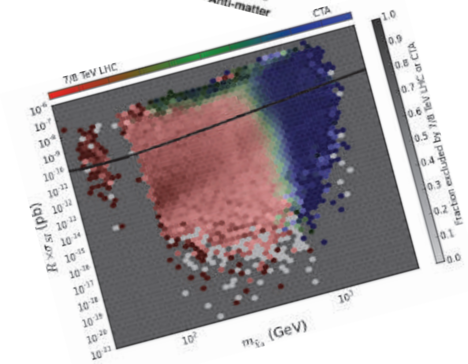












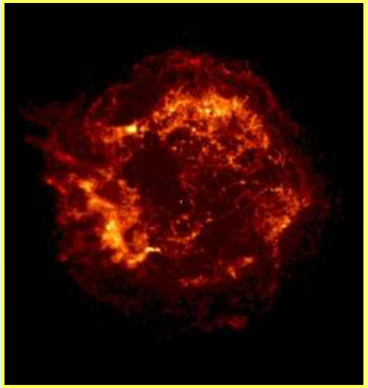
Subir Sarkar

UNIVERSITY OF OXFORD

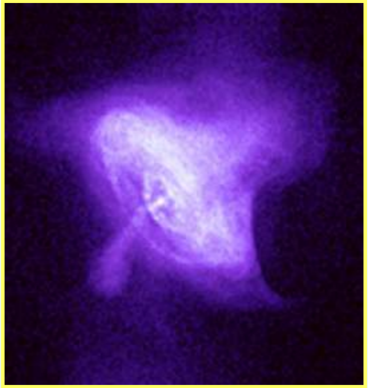
CTA 1st Science Symposium, Bologna, 6-9 May 2019

Astro/physics objectives

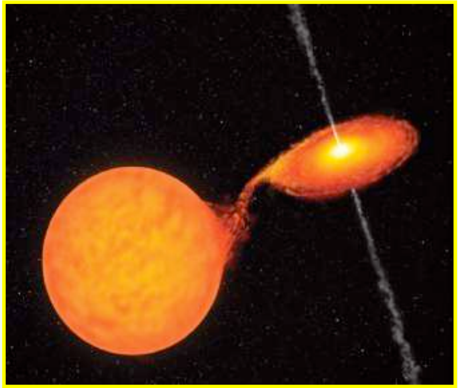
cherenkov telescope array



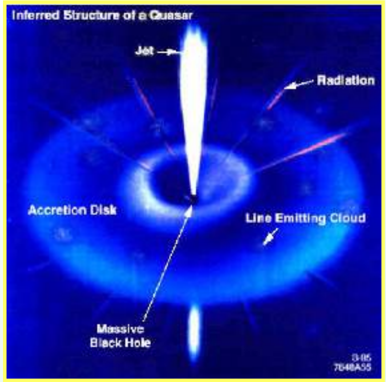
SNRs



Pulsars and PWNe



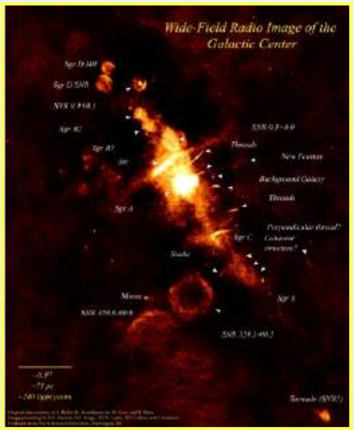
Micro quasars X-ray binaries



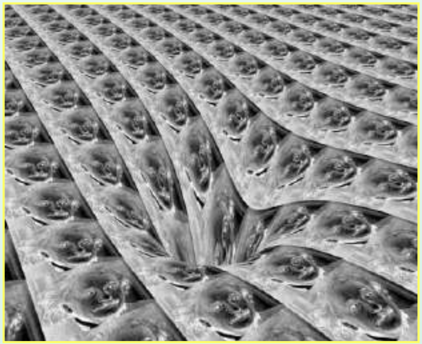
AGNs

GRBs

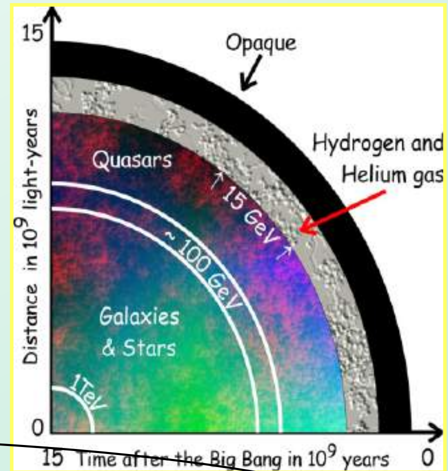
Origin of cosmic rays



Dark matter

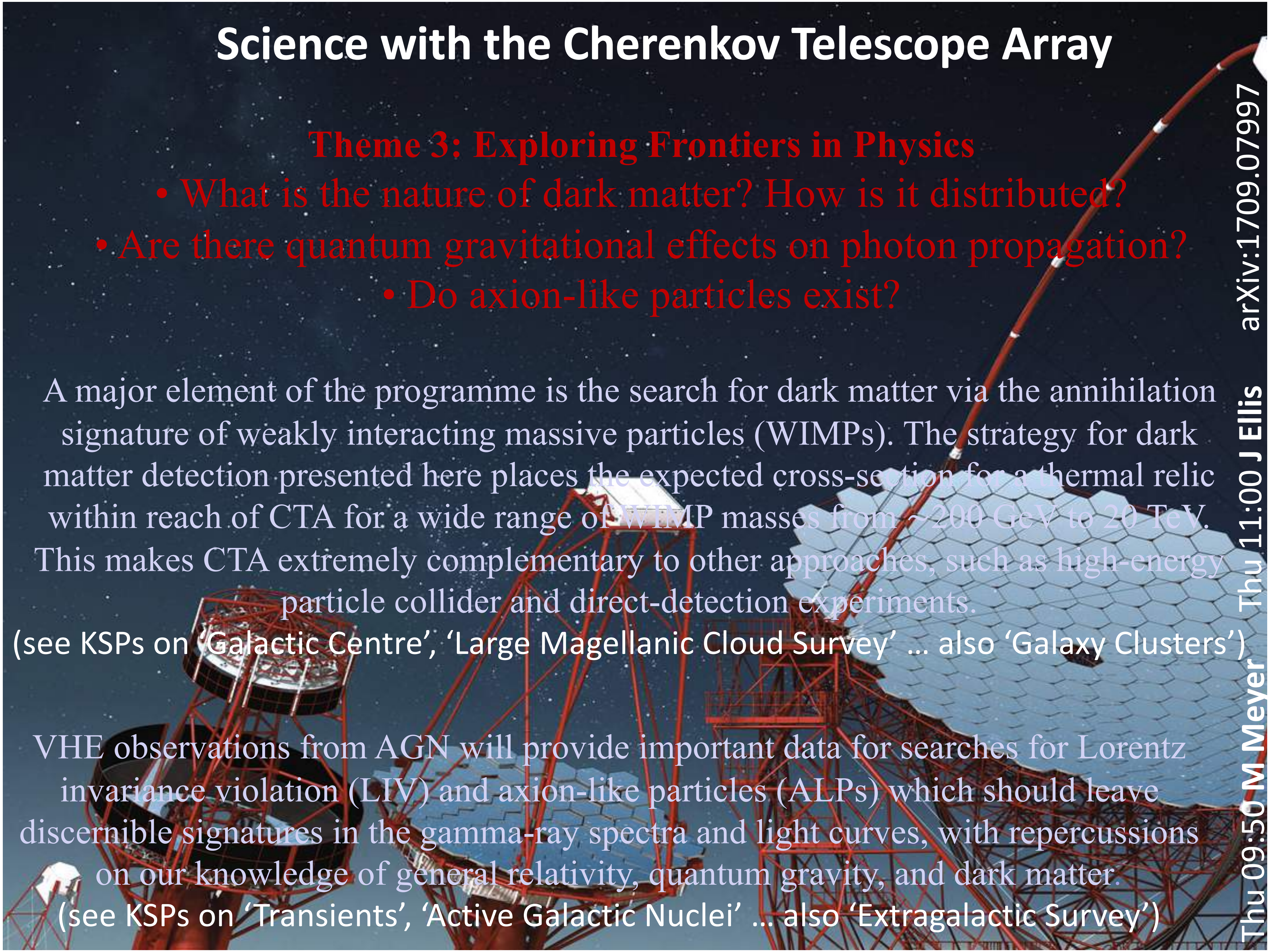


Space-time & relativity



Cosmology

Science with the Cherenkov Telescope Array



Theme 3: Exploring Frontiers in Physics

- What is the nature of dark matter? How is it distributed?
- Are there quantum gravitational effects on photon propagation?
- Do axion-like particles exist?

A major element of the programme is the search for dark matter via the annihilation signature of weakly interacting massive particles (WIMPs). The strategy for dark matter detection presented here places the expected cross-section for a thermal relic within reach of CTA for a wide range of WIMP masses from ~200 GeV to 20 TeV. This makes CTA extremely complementary to other approaches, such as high-energy particle collider and direct-detection experiments.

(see KSPs on 'Galactic Centre', 'Large Magellanic Cloud Survey' … also 'Galaxy Clusters')

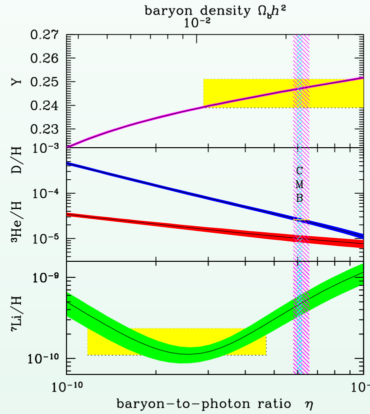
VHE observations from AGN will provide important data for searches for Lorentz invariance violation (LIV) and axion-like particles (ALPs) which should leave discernible signatures in the gamma-ray spectra and light curves, with repercussions on our knowledge of general relativity, quantum gravity, and dark matter.

(see KSPs on 'Transients', 'Active Galactic Nuclei' … also 'Extragalactic Survey')

Thu 09:50 M Meyer Thu 11:00 J Ellis arXiv:1709.07997

THE OTHERWISE HUGELY SUCCESSFUL STANDARD MODEL HAS LITTLE TO SAY CONCERNING THE CONTENT OF OUR UNIVERSE!

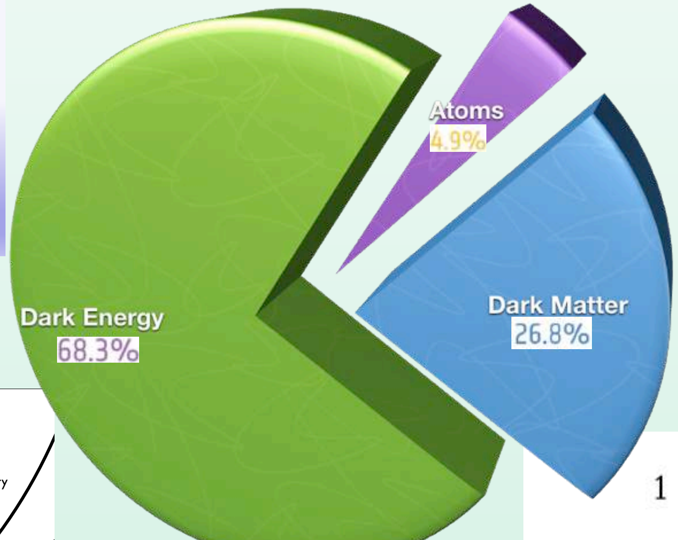
Strong evidence for dark matter (*assuming* Newtonian dynamics is valid) from galactic rotation curves, gravitational lensing, structure formation, cosmic microwave background …



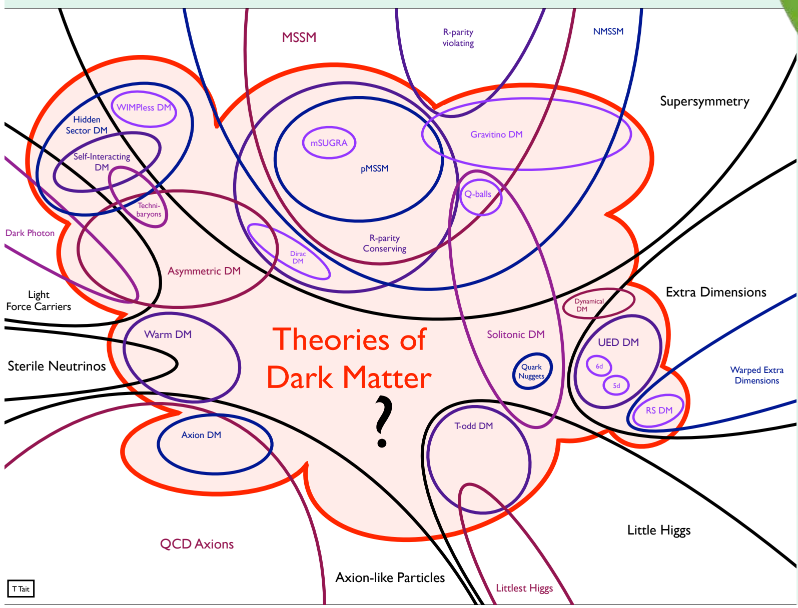
PDG, PR D**98**:030001,2018

Baryons
(*no* anti-baryons)

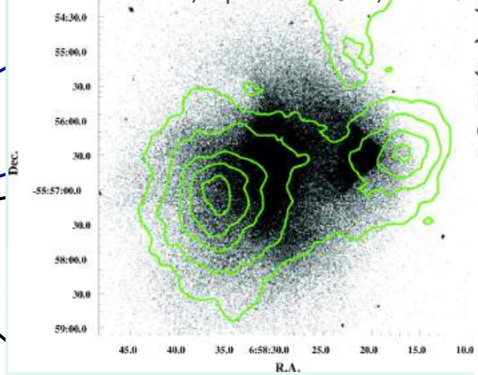
Dark matter did *not* participate in nucleosynthesis … so *must* be non-baryonic, i.e. Beyond-Standard-Model

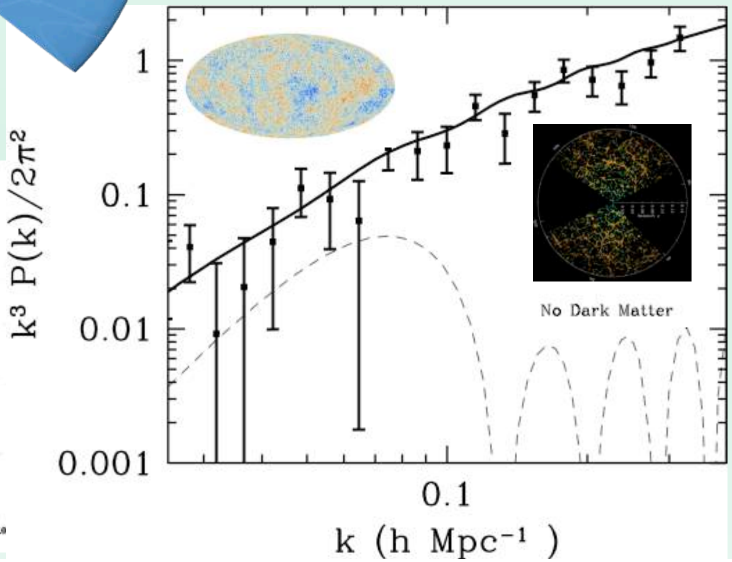


But there are *many* candidates



Randall *et al*, ApJ **679**:1173,2008

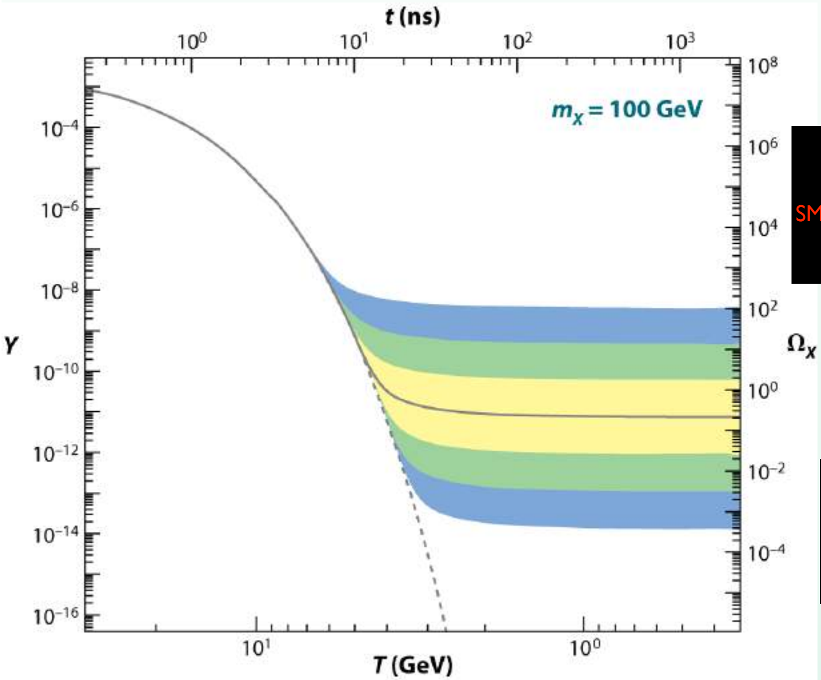


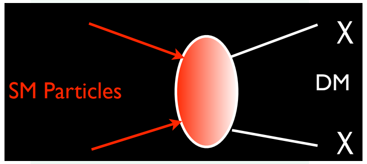


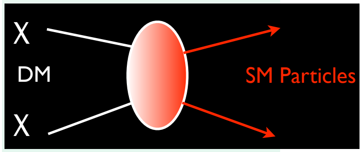
Dodelson & Liguori, PRL **97**:231301,2006

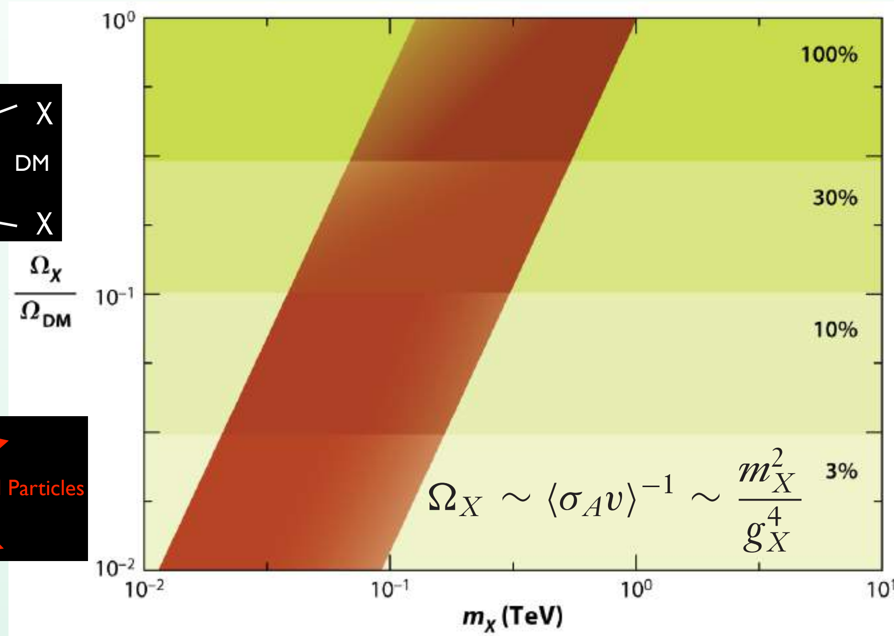
CTA is well-suited to look for TeV scale thermal relic dark matter

(which is independently motivated by BSM models addressing the 'hierarchy problem')





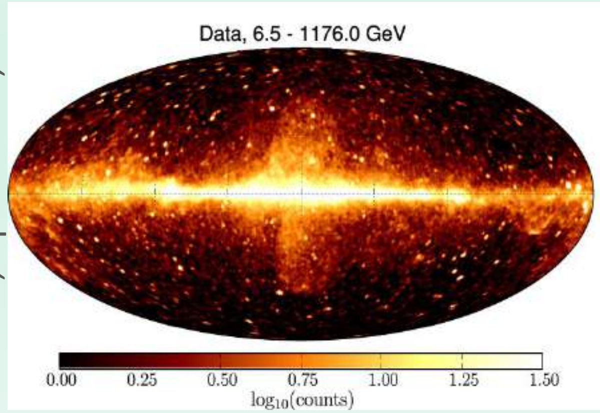


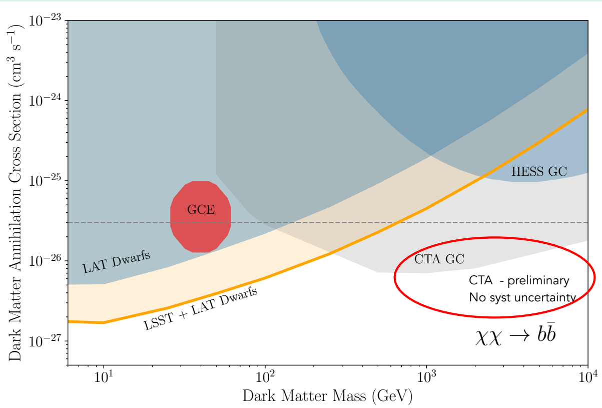


Feng, ARNPS **48**:495,2010

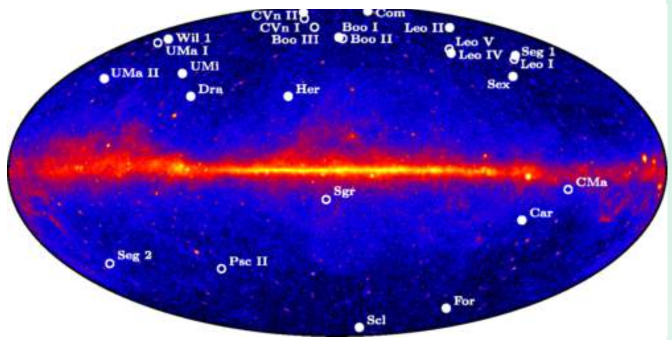
Good targets for the self-annihilation γ-rays are the **Galactic Centre** (highest DM column density but rather complicated region, Bergstrom *et al*, AP **9**:137,1998) and **dwarf spheroidal galaxies** (DM-dominated and *no* astrophysical background, Ferrer *et al*, PR D**69**:123501,2004)

Fermi-LAT, ApJ **840**:43,2017



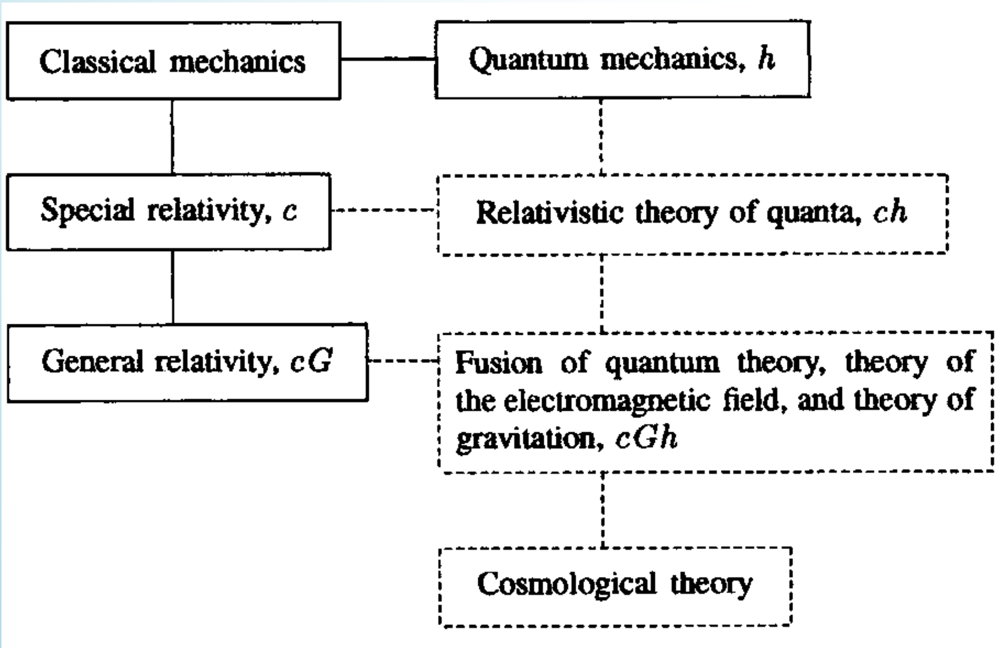


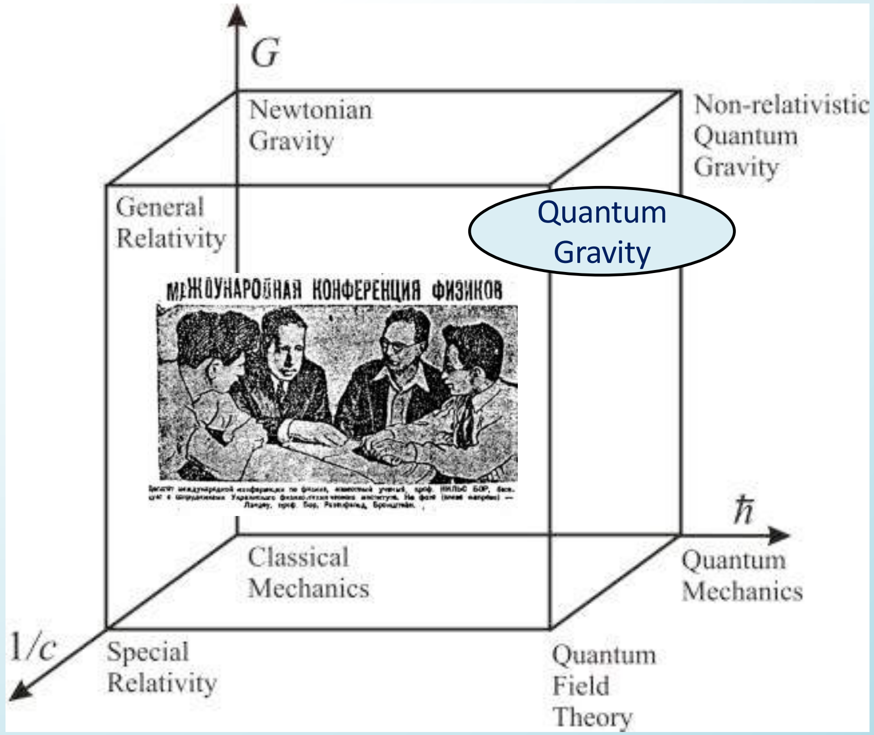
LSST, arXiv:1902.01055



Fermi-LAT, PR D**89**:042001,2014

Bronshtein's 'cube of theories'

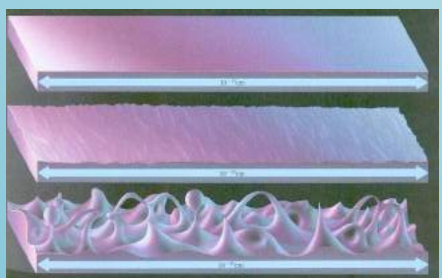




"After the relativistic quantum theory is created, the task will be to develop the next part of our scheme, that is to unify quantum theory (with its constant h), special relativity (with constant c), and the theory of gravitation (with its G) into a single theory" Matvei Petrovich Bronshtein (1935)

(see Gorelik, Uspekhi **48**:1039,2005; Duff, Okun & Veneziano, arXiv:physics/0110060; Oriti, arXIv:1803.02577)

May LEAD TO MODIFICATIONS OF SPACE-TIME STRUCTURE ON THE QUANTUM GRAVITY SCALE



$$\ell_{\rm P} \equiv \sqrt{\frac{\hbar G_{\rm N}}{c^3}} \simeq 1.6 \times 10^{-35}{\rm m} \Rightarrow 1.2 \times 10^{19}{\rm GeV}$$

… resulting in violation of Lorentz invariance

➞ **test using high energy cosmic γ-rays!**

Can lead to energy-*dependent* photon speed:

$$v = \frac{\partial E}{\partial p} \approx c\left(1 - \xi \frac{E}{E_{QG}}\right) \Rightarrow \Delta t \approx \xi \frac{E}{E_{QG}} \frac{L}{c}$$

(Amelino-Camelia *et al*, Nature **393**:763,1998)

… possibly also suppress $\gamma_{source}\ \gamma_{EBL} \rightarrow e^+e^-$ thus raising γ-ray 'horizon' above expected

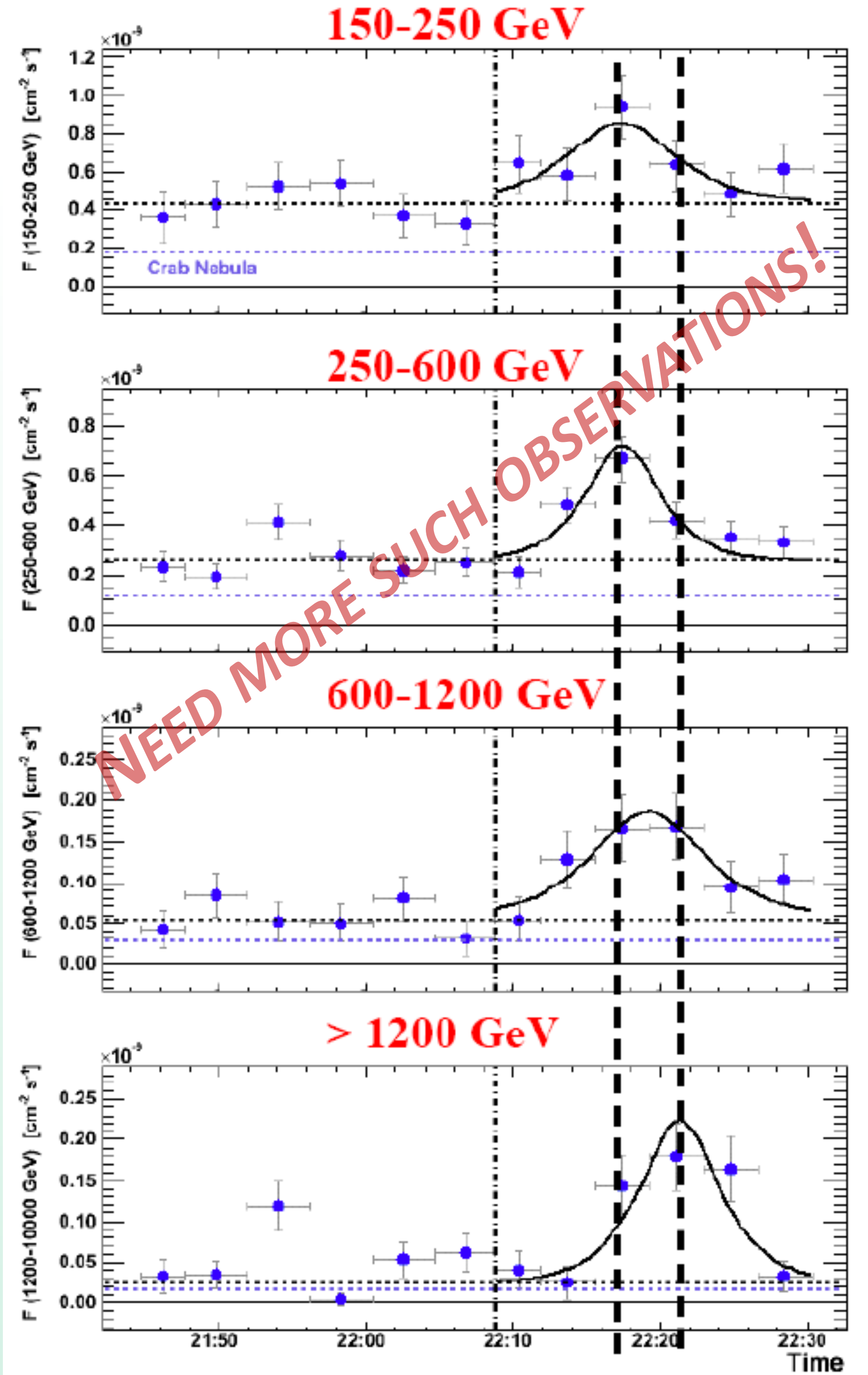
(Kifune, ApJ **518**:L21,1999)

> *Last month, the MAGIC gamma-ray telescope collaboration based on La Palma in the Canary islands announced that they had measured a 4-minute time difference between the arrival time of high and low-energy gamma rays released at the same time in a flare from the Markarian 501 galaxy, some half a billion light years away. According to Einstein's theory of special relativity, both sets of photons should have arrived simultaneously, and the team is controversially …* New Scientist, 29 April 2007

Time delay of 0.03 s/GeV from dispersion of photons from Mrk 501 at $L \sim 150$ Mpc

$\Rightarrow E_{QG} = 0.47^{+0.31}_{-0.13} \times 10^{18}$ GeV

… *if* no conspiring intrinsic source dispersion



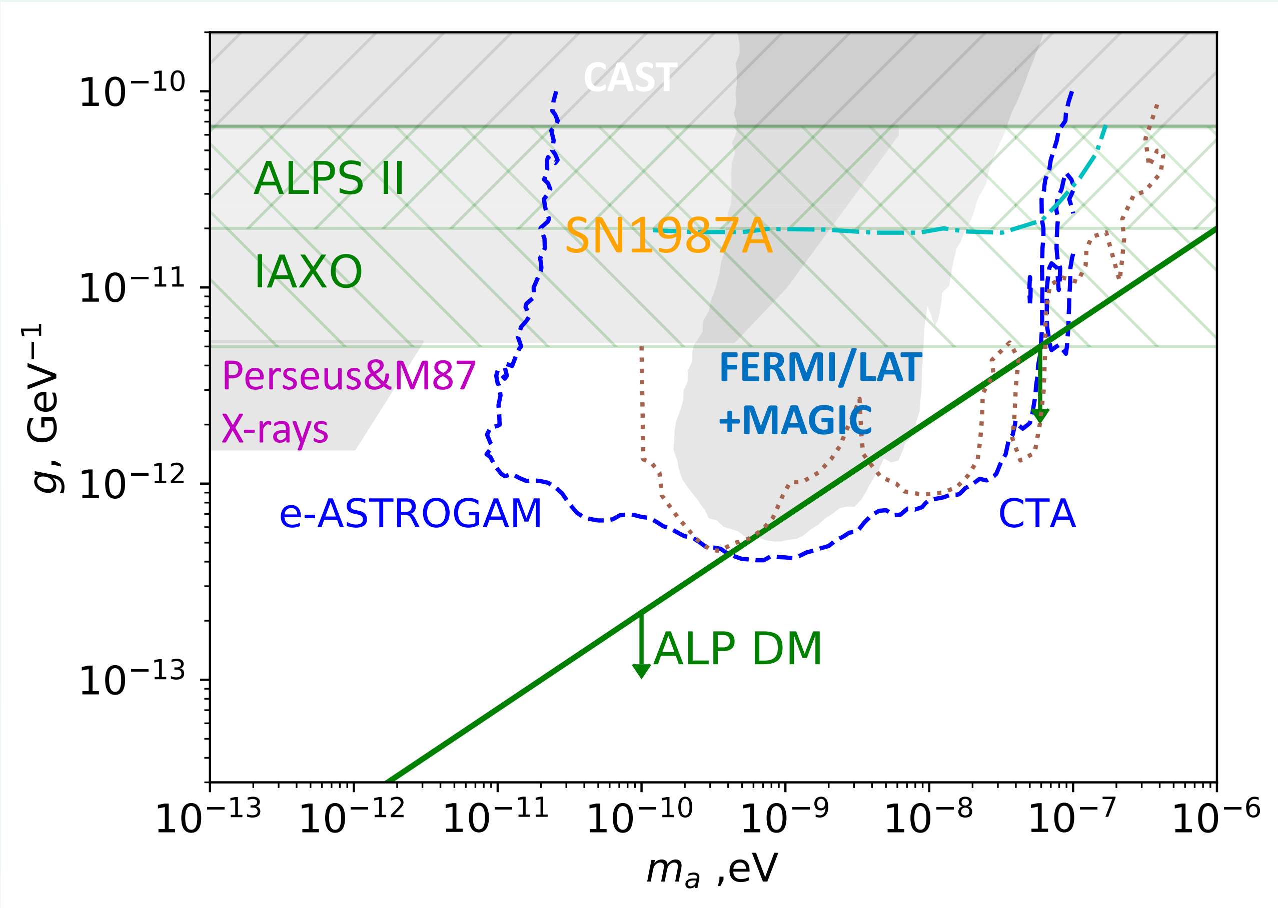
(Albert *et al*, Phys.Lett.B**668**:253,2008)

CTA can also probe axion-like particles which couple to photons

$$\mathcal{L}_{a\gamma} = -\tfrac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a = g_{a\gamma} \mathbf{E} \cdot \mathbf{B} a$$

… so can alter their propagation through intervening/source magnetic fields

Photon-ALP oscillations may make universe more *transparent* to high energy γ-rays (e.g. De Angelis *et al*, PR D**76**:207,2007; Sánchez-Conde *et al*, PR D**79**:123501,2009) and imprint characteristic features in blazar spectra (e.g. Hooper & Serpico, PRL **99**:231102,2007, Meyer *et al*, PR D**87**:035027,2013) … so CTA provides sensitive probe of ~10^{-9} eV ALPs



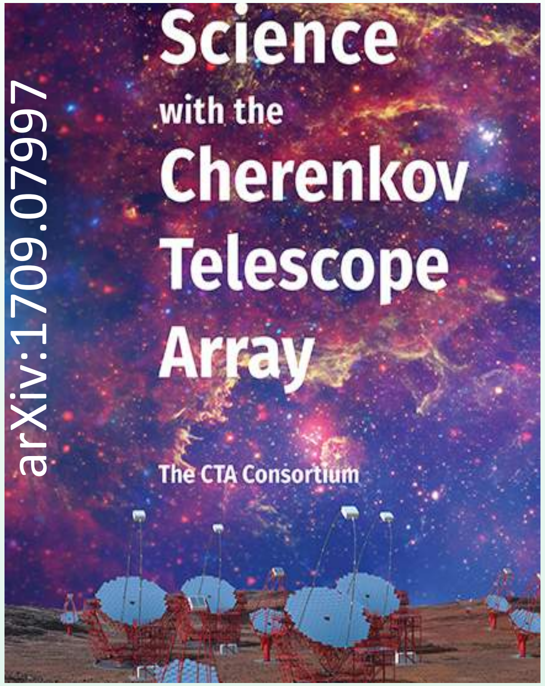
Malyshev *et al*, arXiv:1805.04388

First LINK Workshop: Probing Physics Beyond the Standard Model with CTA
12 Nov 2010, Cosener's House, Abingdon, GB

Gianfranco Bertone (IAP Paris), Jan Conrad (Stockholm University), Manel Martinez (IFAE Barcelona), Subir Sarkar (University of Oxford)

cherenkov telescope array

SUMMARY



"The reach of CTA encompasses considerable discovery space in the area of fundamental physics. CTA will reach the expected thermal relic cross-section for self-annihilating dark matter for a wide range of dark matter masses, including those inaccessible to the Large Hadron Collider (LHC). The long travel times of gamma rays from extragalactic sources combined with their short wavelength make them a sensitive probe for energy-dependent variation of the speed of light due to quantum-gravity induced fluctuations of the metric. CTA will be sensitive to such effects on their expected characteristic scale: the Planck scale. On their long journey, gamma rays may couple to other light particles such as axion-like particles (ALPs), under the influence of intergalactic magnetic fields. Such photon-ALP oscillations effectively make the universe more transparent to gamma rays and, akin to neutrino oscillations, introduce a spectral modulation. Each of these effects would represent a very major discovery, alone worth the effort of constructing and operating CTA. The major step in sensitivity and energy coverage that CTA represents brings such effects within reach and could well allow further issues in fundamental physics to be addressed."

"In the fields of observation chance favors only the prepared mind"

Louis Pasteur

THANKS TO ALL CTA COLLEAGUES FOR A VERY ENJOYABLE COLLABORATION!