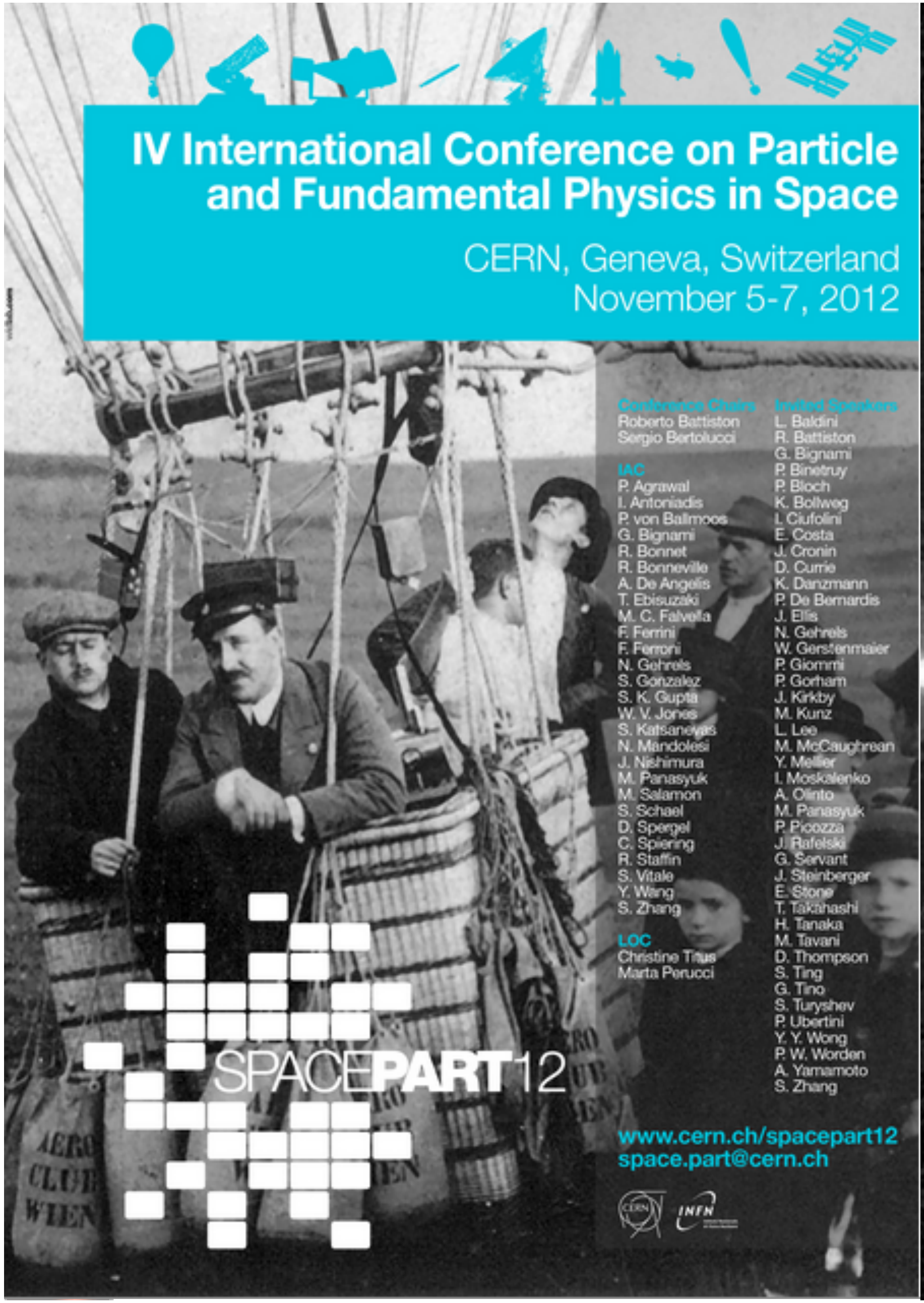


IV International Conference on Particle and Fundamental Physics in Space

CERN, Geneva, Switzerland
November 5-7, 2012

Conference Chairs
Roberto Battiston
Sergio Bertolucci

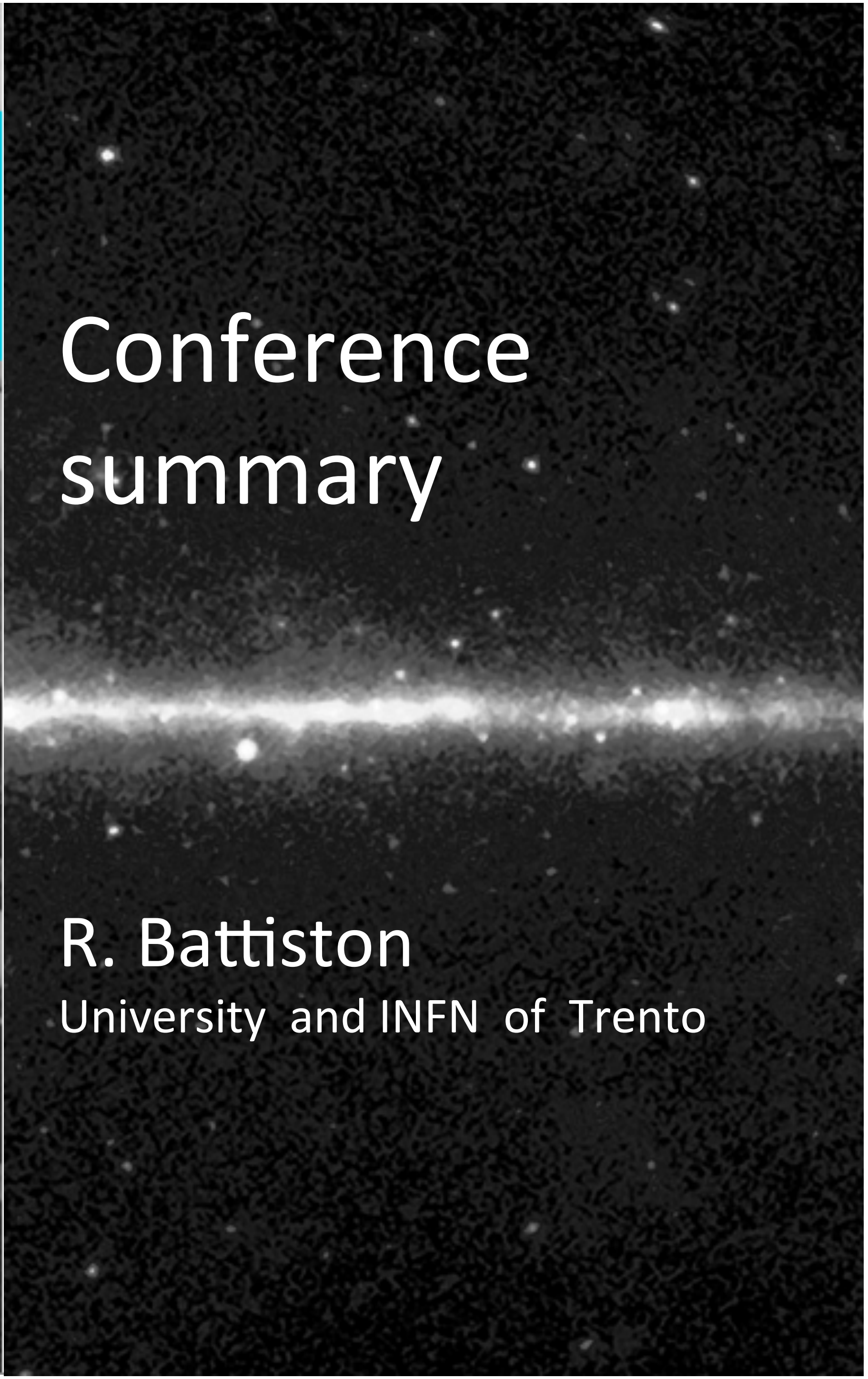
IAC
P. Agrawal
I. Antoniadis
P. von Ballmoos
G. Bignami
R. Bonnet
R. Bonneville
A. De Angelis
T. Ebisuzaki
M. C. Falvella
F. Ferrini
F. Ferroni
N. Gehrels
S. Gonzalez
S. K. Gupta
W. V. Jones
S. Katsanevas
N. Mandolesi
J. Nishimura
M. Panasyuk
M. Salamon
S. Schael
D. Spergel
C. Spiering
R. Staffin
S. Vitale
Y. Wang
S. Zhang

LOC
Christine Titus
Marta Perucci

Invited Speakers
L. Baldini
R. Battiston
G. Bignami
P. Binetruy
P. Bloch
K. Bollweg
I. Ciufolini
E. Costa
J. Cronin
D. Currie
K. Danzmann
P. De Bernardis
J. Ellis
N. Gehrels
W. Gerstenmaier
P. Giommi
P. Gorham
J. Kirkby
M. Kunz
L. Lee
M. McCaughrean
Y. Mellier
I. Moskalenko
A. Olinto
M. Panasyuk
P. Picozza
J. Rafelski
G. Servant
J. Steinberger
E. Stone
T. Takahashi
H. Tanaka
M. Tavani
D. Thompson
S. Ting
G. Tino
S. Turyshev
P. Ubertini
Y. Y. Wong
P. W. Worden
A. Yamamoto
S. Zhang

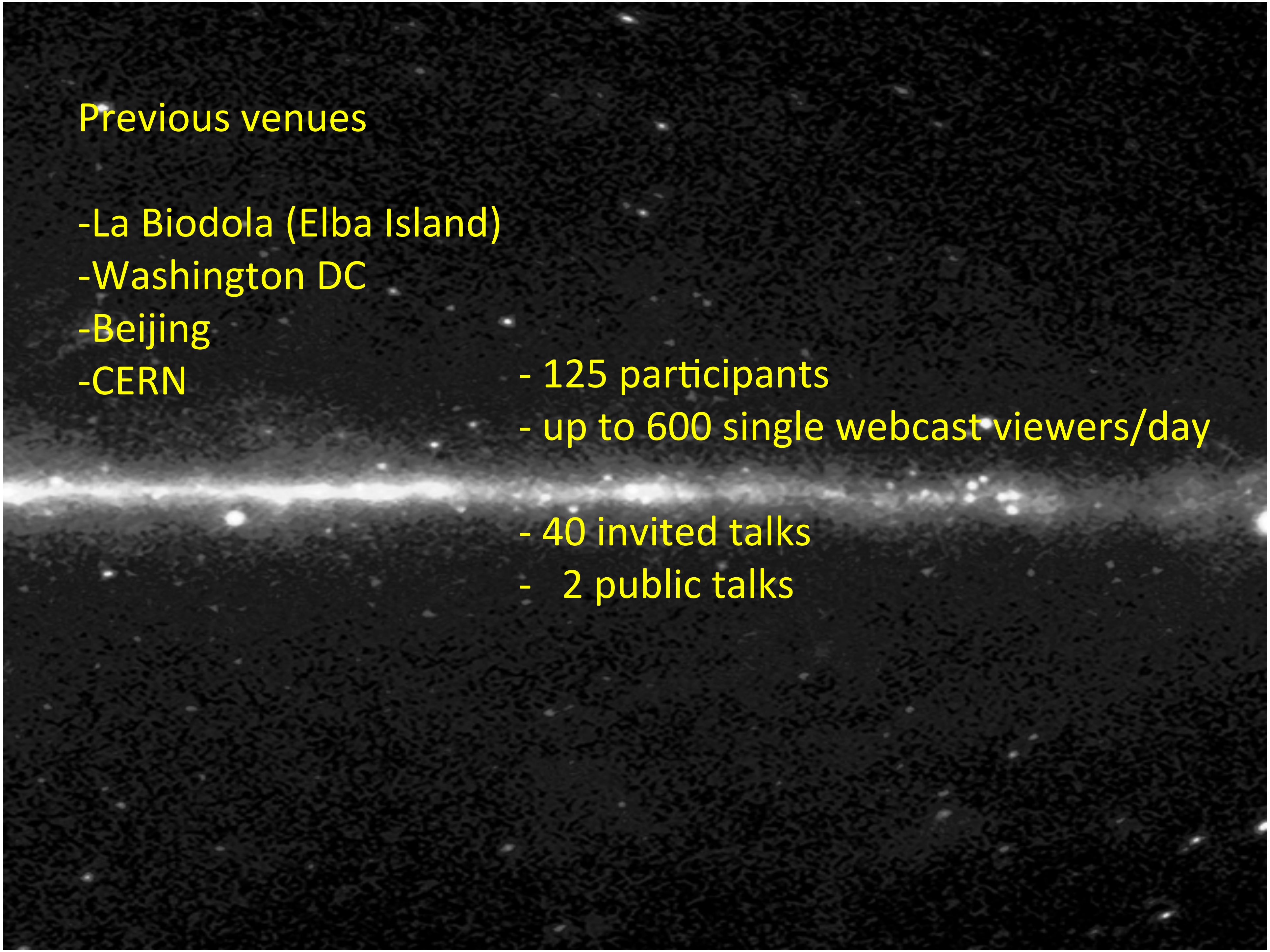
SPACEPART12

www.cern.ch/spacepart12
space.part@cern.ch



Conference summary

R. Battiston
University and INFN of Trento

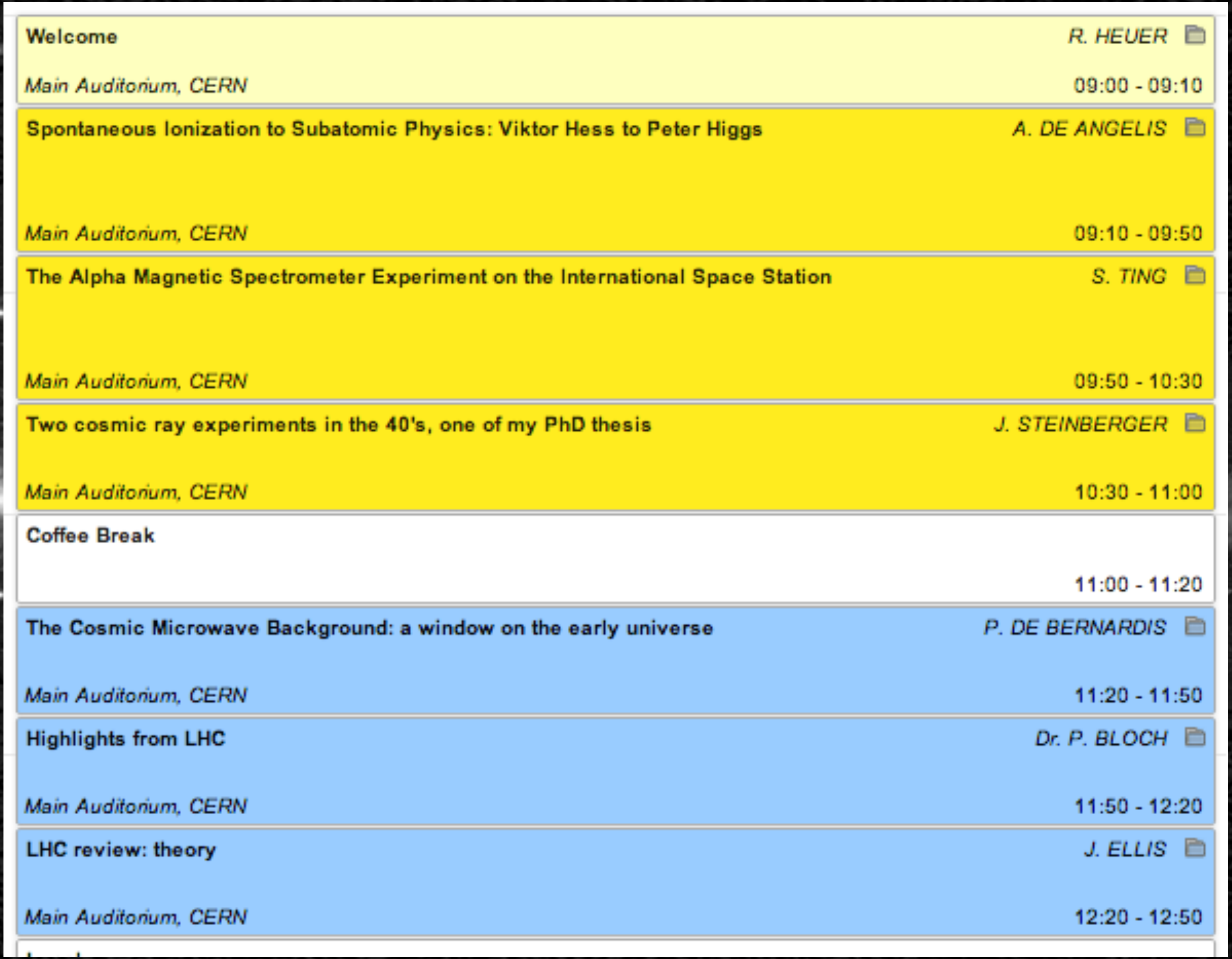


Previous venues

-La Biodola (Elba Island)
-Washington DC
-Beijing
-CERN

- 125 participants
- up to 600 single webcast viewers/day

- 40 invited talks
- 2 public talks



Welcome	*R. HEUER*	*Main Auditorium, CERN*	09:00 - 09:10
Spontaneous Ionization to Subatomic Physics: Viktor Hess to Peter Higgs	*A. DE ANGELIS*	*Main Auditorium, CERN*	09:10 - 09:50
The Alpha Magnetic Spectrometer Experiment on the International Space Station	*S. TING*	*Main Auditorium, CERN*	09:50 - 10:30
Two cosmic ray experiments in the 40's, one of my PhD thesis	*J. STEINBERGER*	*Main Auditorium, CERN*	10:30 - 11:00
Coffee Break			11:00 - 11:20
The Cosmic Microwave Background: a window on the early universe	*P. DE BERNARDIS*	*Main Auditorium, CERN*	11:20 - 11:50
Highlights from LHC	*Dr. P. BLOCH*	*Main Auditorium, CERN*	11:50 - 12:20
LHC review: theory	*J. ELLIS*	*Main Auditorium, CERN*	12:20 - 12:50

INTEGRAL highlights in the high energy astrophysics panorama *P. UBERTINI*
Main Auditorium, CERN 14:10 - 14:40

The Gamma-ray Sky with Fermi *D. THOMPSON*
Main Auditorium, CERN 14:40 - 15:10

NASA's Dark Matter and Dark Energy Program *N. GEHRELS*
Main Auditorium, CERN 15:10 - 15:40

Coffee Break
15:40 - 16:00

Cosmology, high-energy astrophysics, and fundamental physics in the ESA space *M. MC CAUGHREAN*
Main Auditorium, CERN 16:00 - 16:30

Russian Federal Space Program in a part of astrophysics: status 2012 *M. PANASYUK*
Main Auditorium, CERN 16:30 - 16:55

The High Energy cosmic-Radiation Detection (HERD) facility onboard China's *S. ZHANG*
Main Auditorium, CERN 16:55 - 17:20

High Energy Astrophysics and Fundamental Physics Missions in Japan *T. TAKAHASHI*
Main Auditorium, CERN 17:20 - 17:45

Space Programs in Taiwan: FORMOSAT 5 and FORMOSAT 7 *Lee LOU-CHUANG*
Main Auditorium, CERN 17:45 - 18:10

The Cosmic Ray Sky

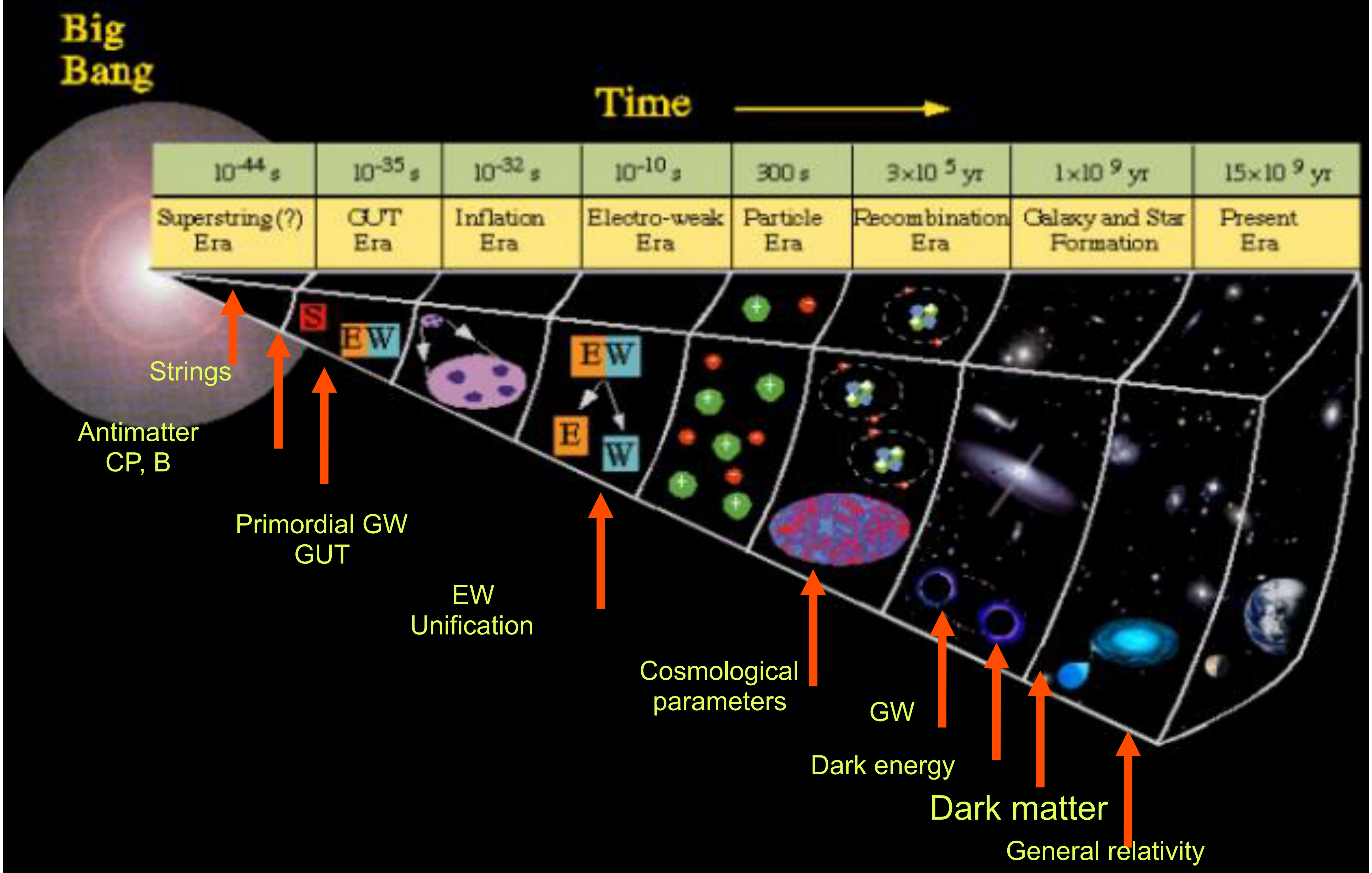
The Gamma and X Ray Sky

Cosmology and Particle Physics

Gravitation and Fundamental Physics

Applications and technologies

The Universe is the ultimate laboratory to test fundamental physics.....



Strings

Antimatter
CP, B

Primordial GW
GUT

EW
Unification

Cosmological
parameters

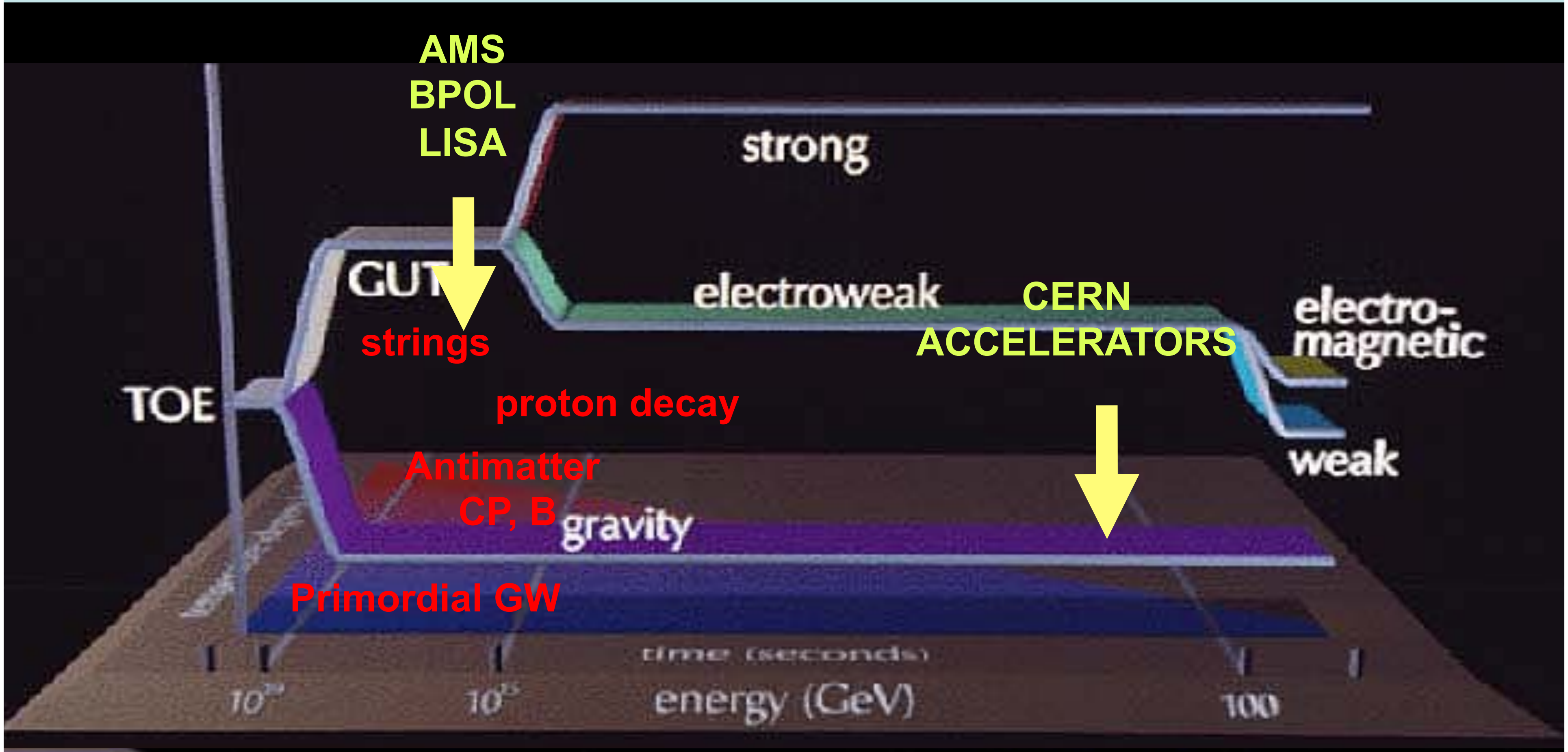
GW

Dark energy

Dark matter

General relativity

.......to scales which cannot be reached by the most powerful accelerators....



AMS
BPOL
LISA

strings

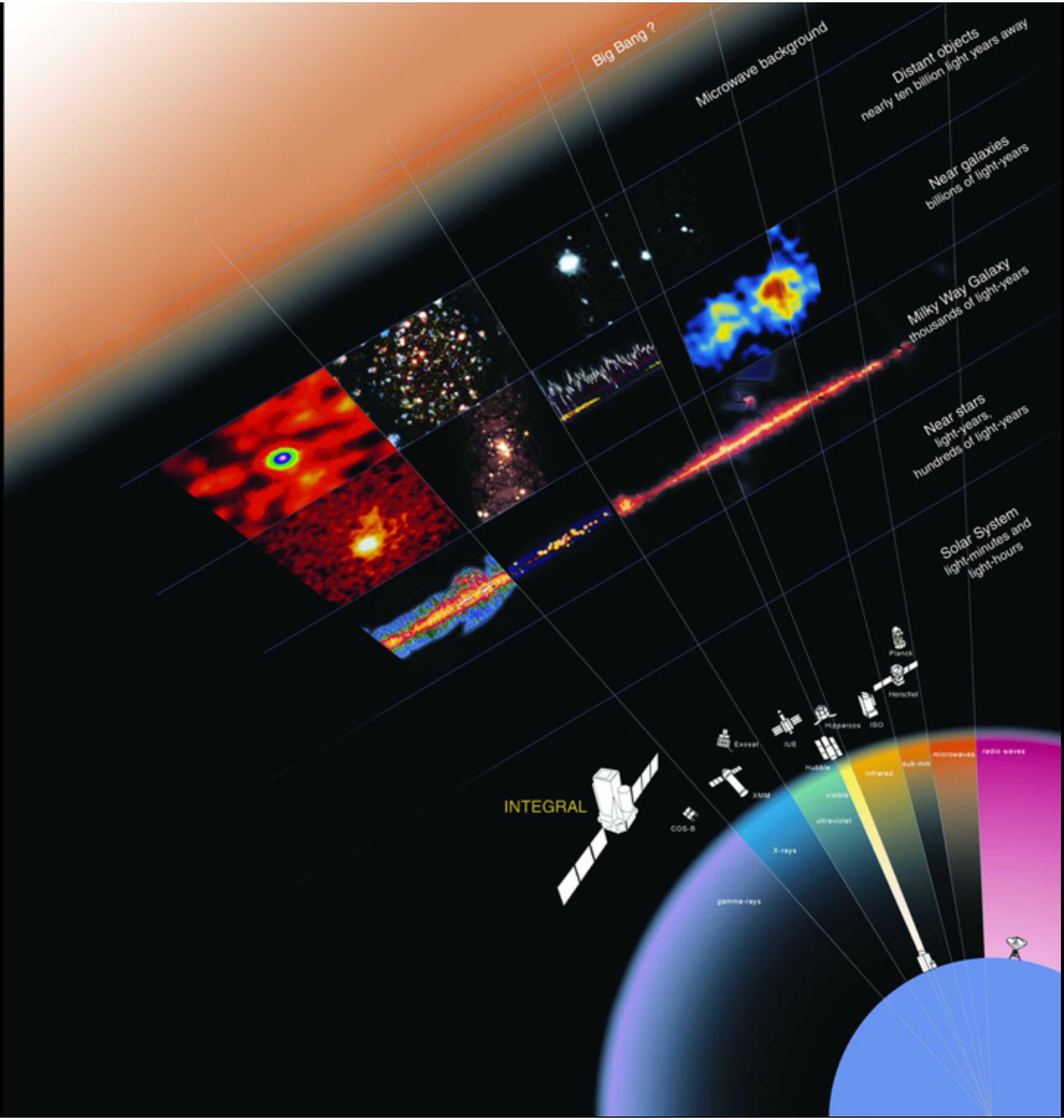
proton decay

Antimatter
CP, B

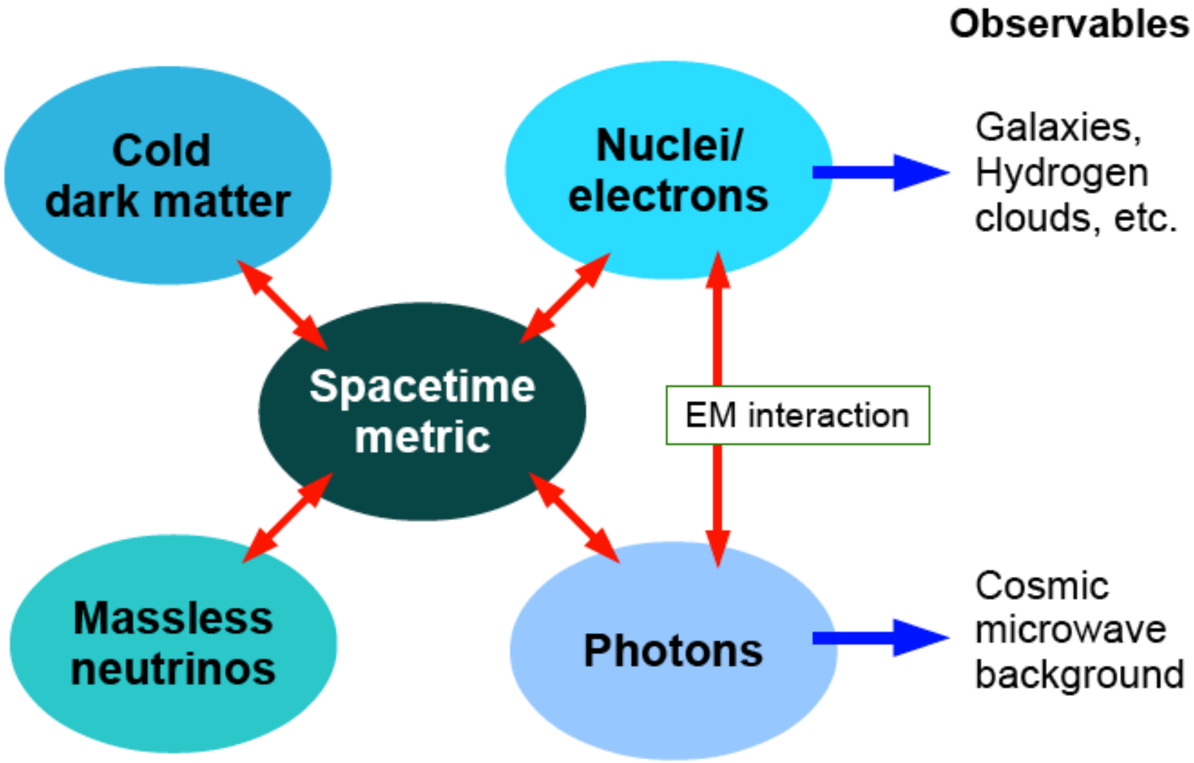
Primordial GW

CERN
ACCELERATORS

10^{-44} s	10^{-35} s	10^{-32} s	10^{-10} s	300 s	
rstring(?) ra	GUT Era	Inflation Era	Electro-weak Era	Particle Era	F


Big Bang ?
Microwave background
Distant objects
nearly ten billion light years away
Near galaxies
billions of light-years
Milky Way Galaxy
thousands of light-years
Near stars
light-years,
hundreds of light-years
Solar System
light-minutes and
light-hours
Planck
Herschel
Hipparcos
ISO
Exosat
IUE
Hubble
INTEGRAL
XMM
COS-B
radio waves
microwaves
sub-mm
infrared
visible
ultraviolet
X-rays
gamma-rays

Particle content of the concordance ΛCDM model...



Observables

Cold dark matter

Nuclei/ electrons

Spacetime metric

EM interaction

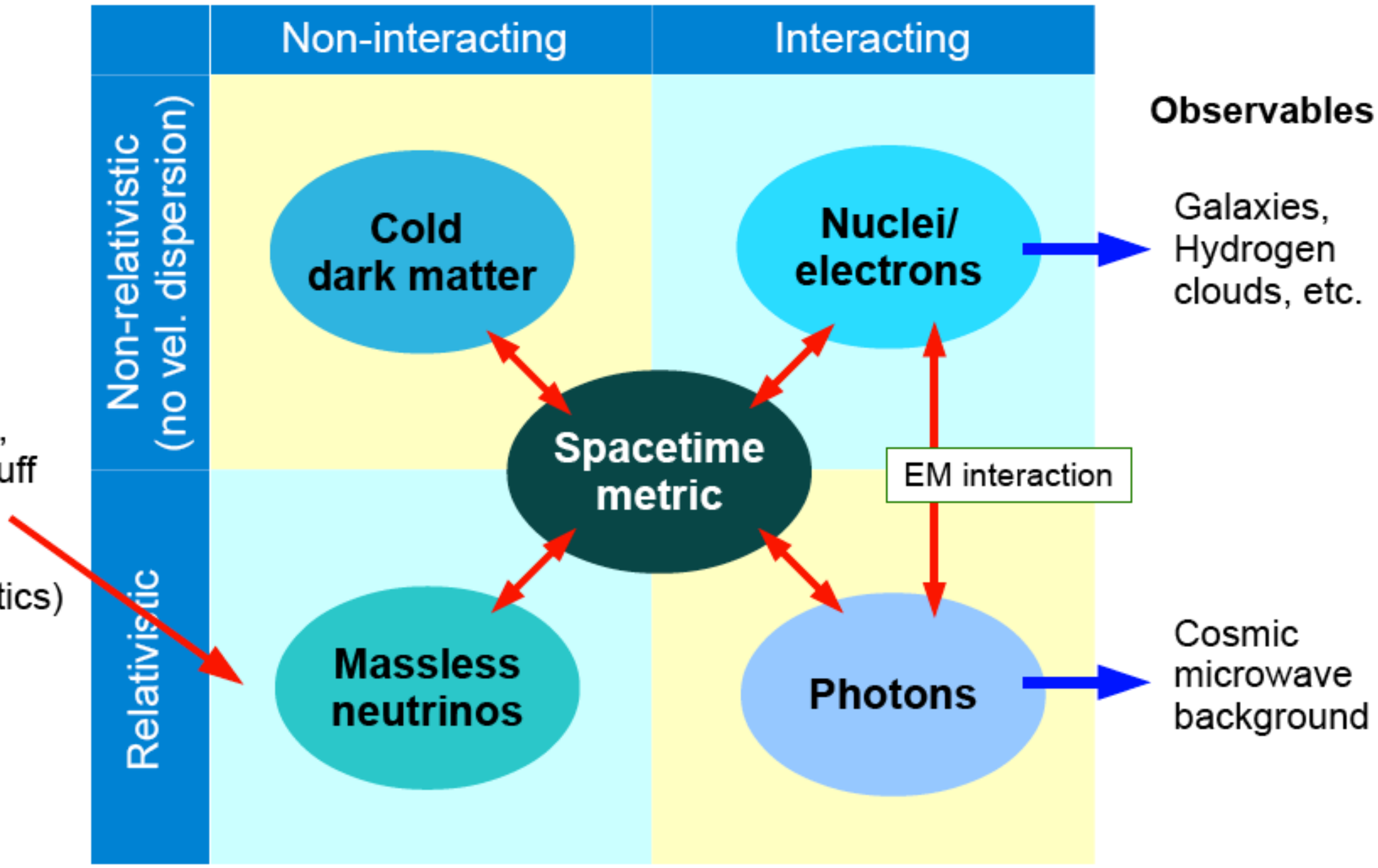
Massless neutrinos

Photons

Galaxies,
Hydrogen
clouds, etc.

Cosmic
microwave
background

Particle content of the concordance ΛCDM model...



Non-interacting

Interacting

Non-relativistic (no vel. dispersion)

Relativistic

Cold dark matter

Nuclei/ electrons

Spacetime metric

EM interaction

Massless neutrinos

Photons

Observables

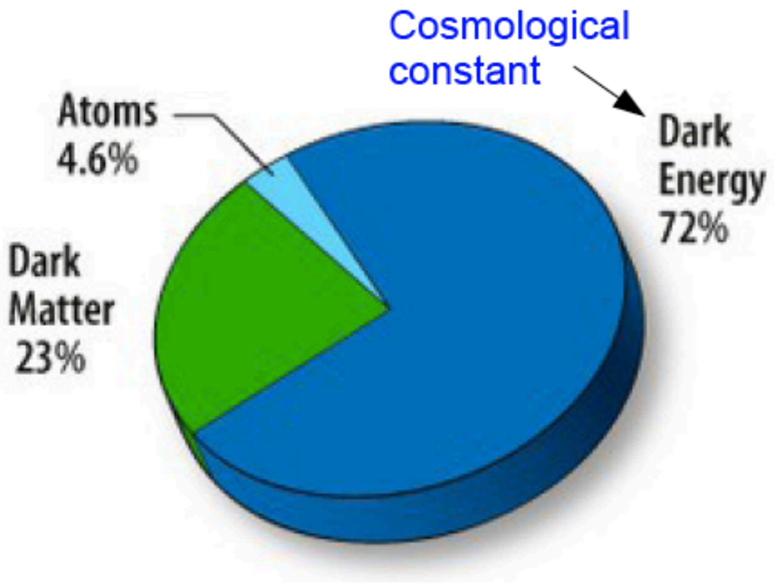
Galaxies, Hydrogen clouds, etc.

Cosmic microwave background

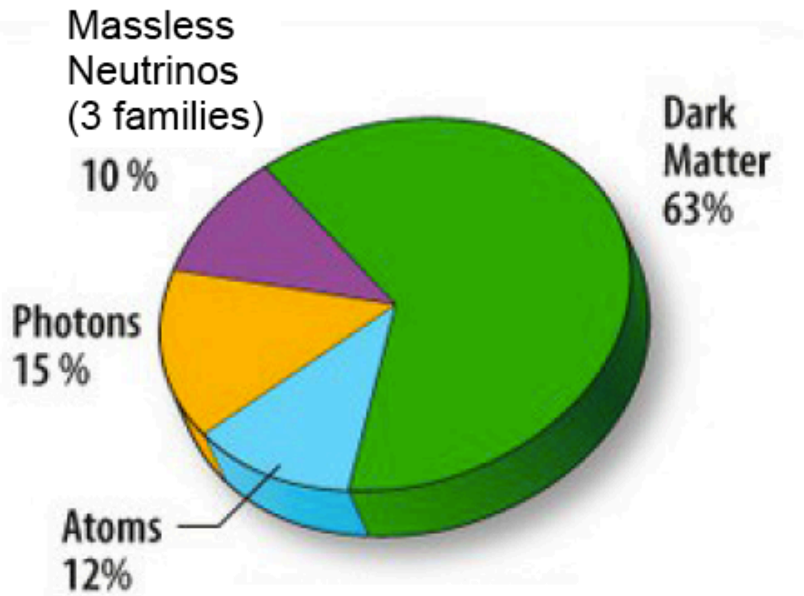
Extra neutrinos
= extra relativistic, non-interacting stuff (no requirement on the quantum numbers or statistics)

The concordance flat ΛCDM model...

- The simplest model consistent with **observations**.


Cosmological constant

Composition today



13.4 billion years ago
(at photon decoupling)

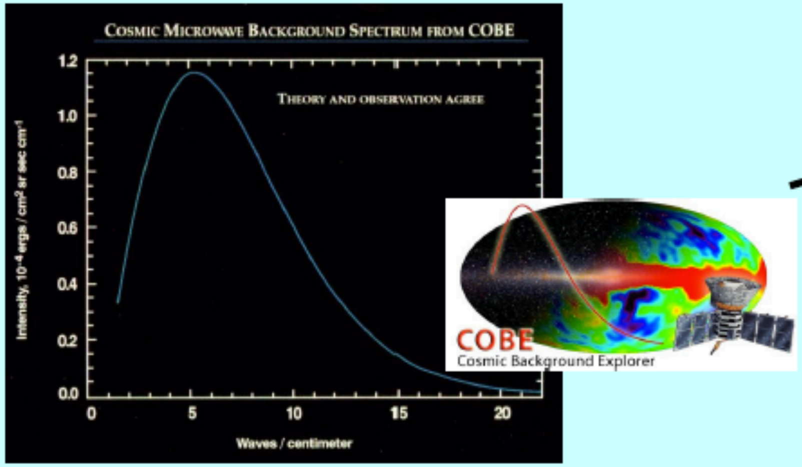
Plus flat spatial geometry+initial conditions
from single-field inflation

The concordance flat ΛCDM model...

- The simplest model consistent with **observations**.

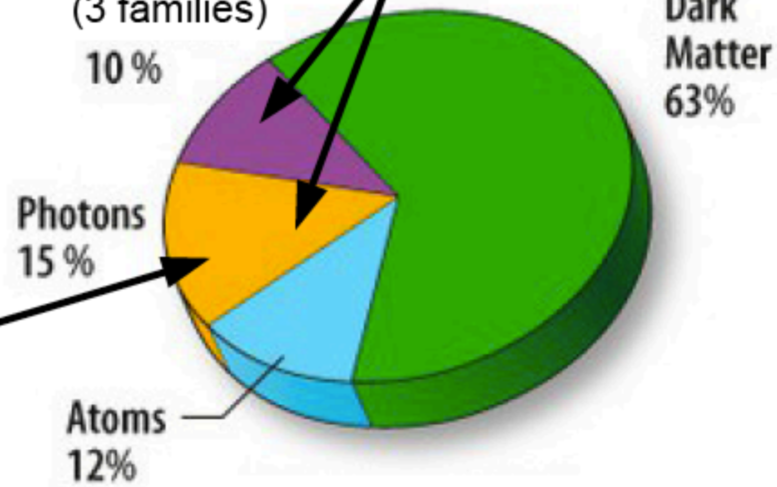
Photon energy density fixed by CMB temperature & spectrum measurements:

$$T_{\mathrm{CMB}} = 2.725 \pm 0.001\,\mathrm{K}$$



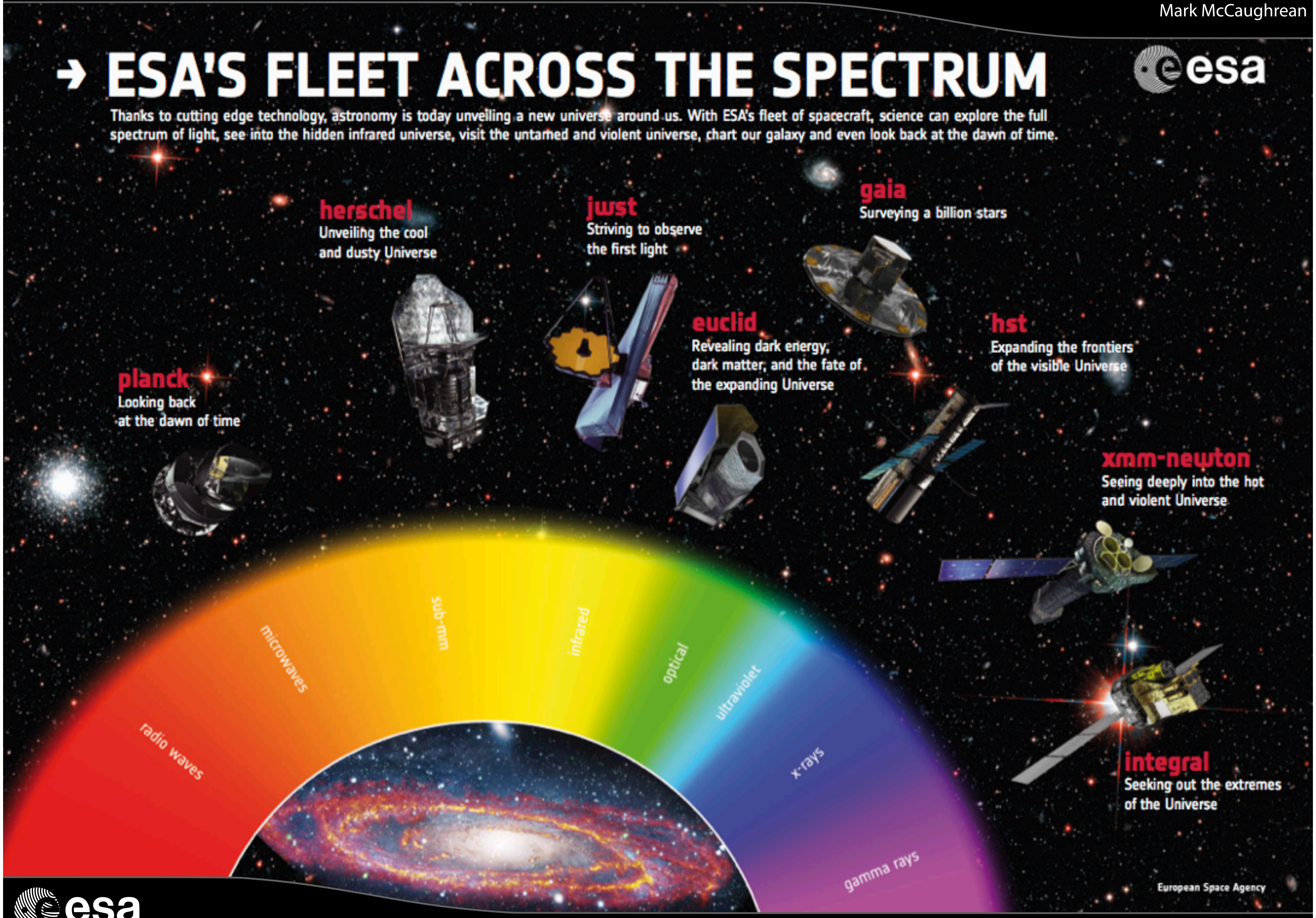
ν-to-γ energy density ratio fixed by **Standard Model** physics

Massless Neutrinos (3 families)



13.4 billion years ago
(at photon decoupling)

The colors of light



→ ESA'S FLEET ACROSS THE SPECTRUM

Thanks to cutting edge technology, astronomy is today unveiling a new universe around us. With ESA's fleet of spacecraft, science can explore the full spectrum of light, see into the hidden infrared universe, visit the untamed and violent universe, chart our galaxy and even look back at the dawn of time.

planck
Looking back
at the dawn of time

herschel
Unveiling the cool
and dusty Universe

jwst
Striving to observe
the first light

euclid
Revealing dark energy,
dark matter, and the fate of
the expanding Universe

gaia
Surveying a billion stars

hst
Expanding the frontiers
of the visible Universe

xmm-newton
Seeing deeply into the hot
and violent Universe

integral
Seeking out the extremes
of the Universe

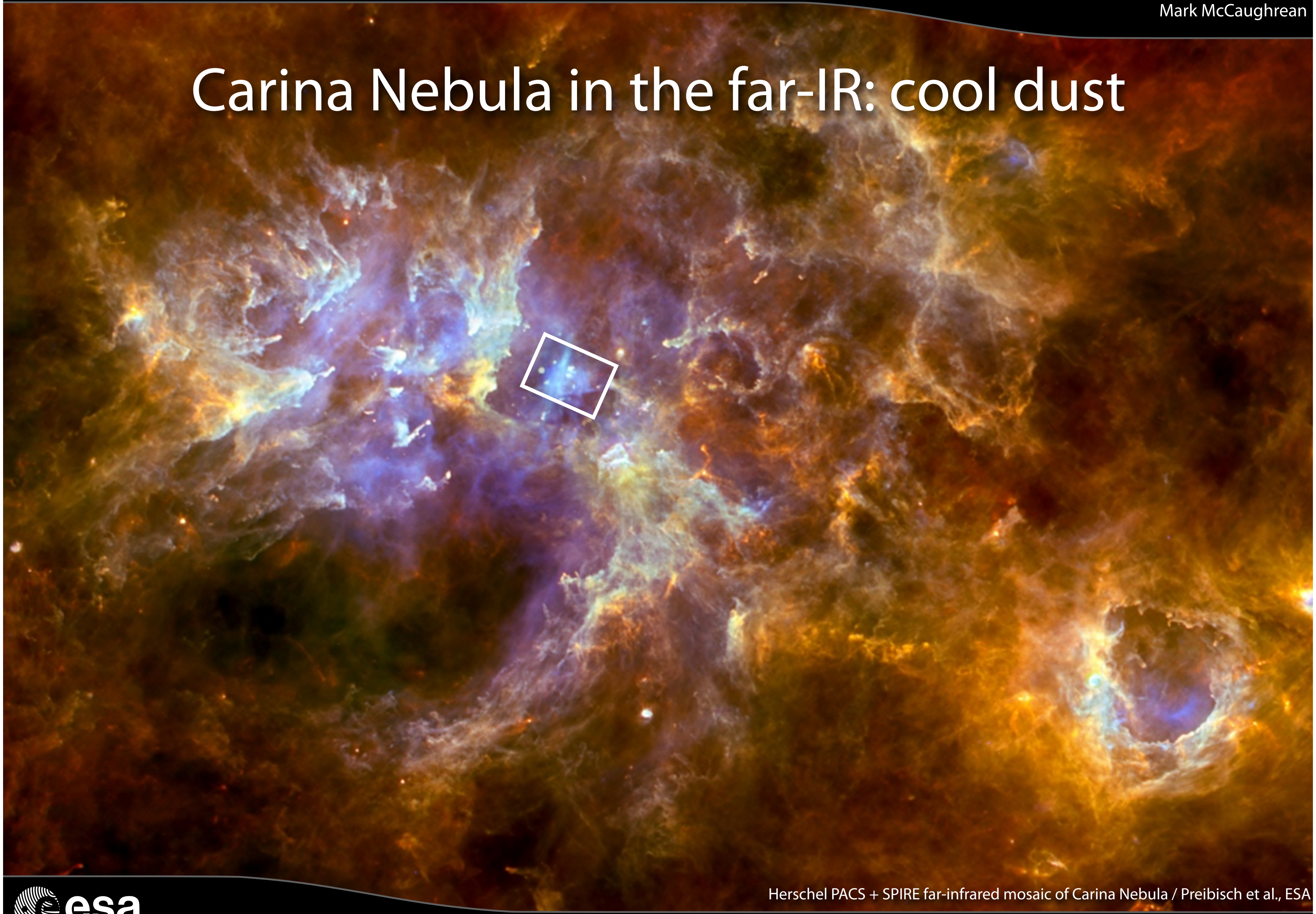
European Space Agency

esa
SCIENCE AND ROBOTIC EXPLORATION

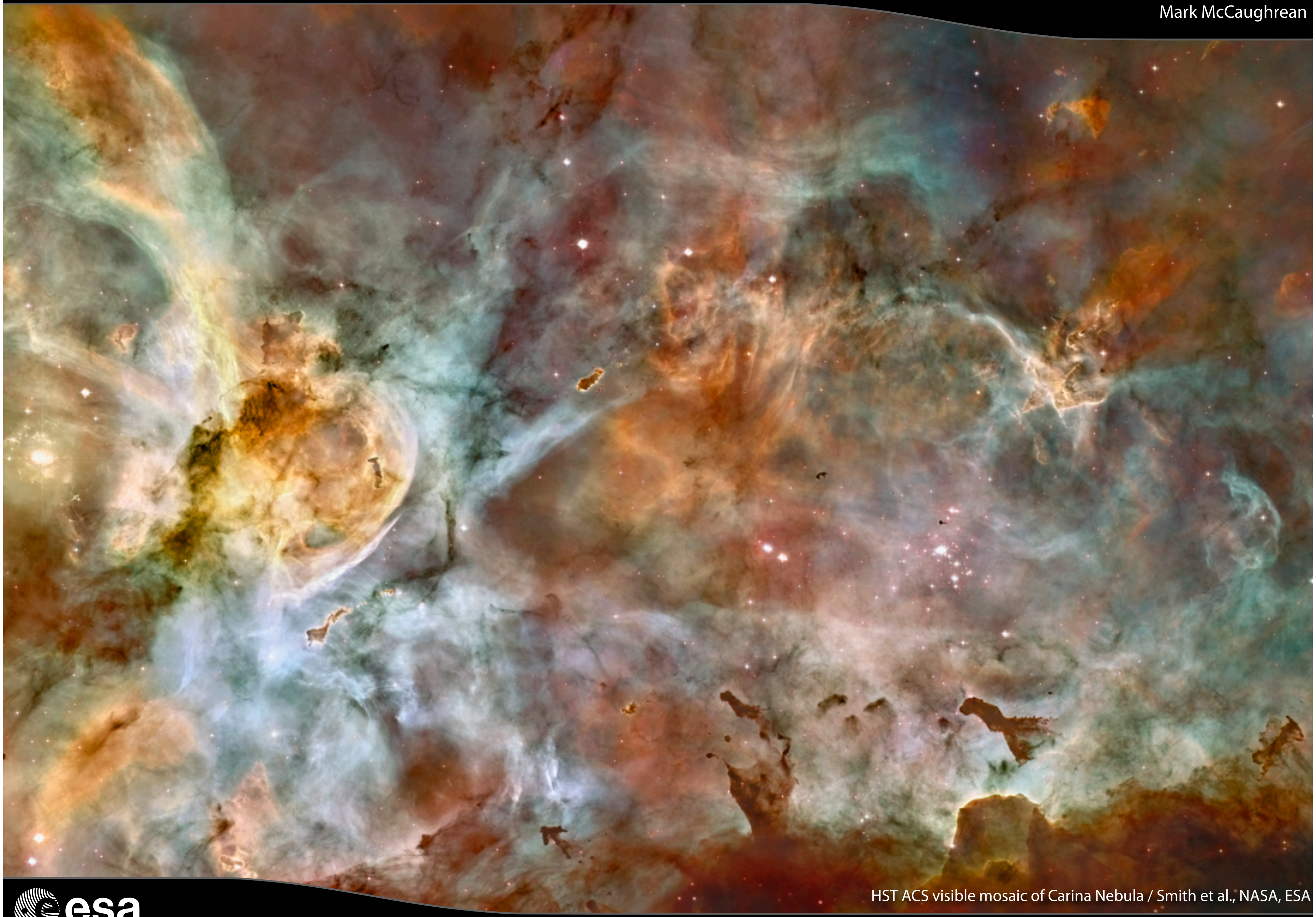
Herschel Space Observatory

ESA-NASA far-infrared astrophysics observatory, launched 2009

Carina Nebula in the far-IR: cool dust



Herschel PACS + SPIRE far-infrared mosaic of Carina Nebula / Preibisch et al., ESA

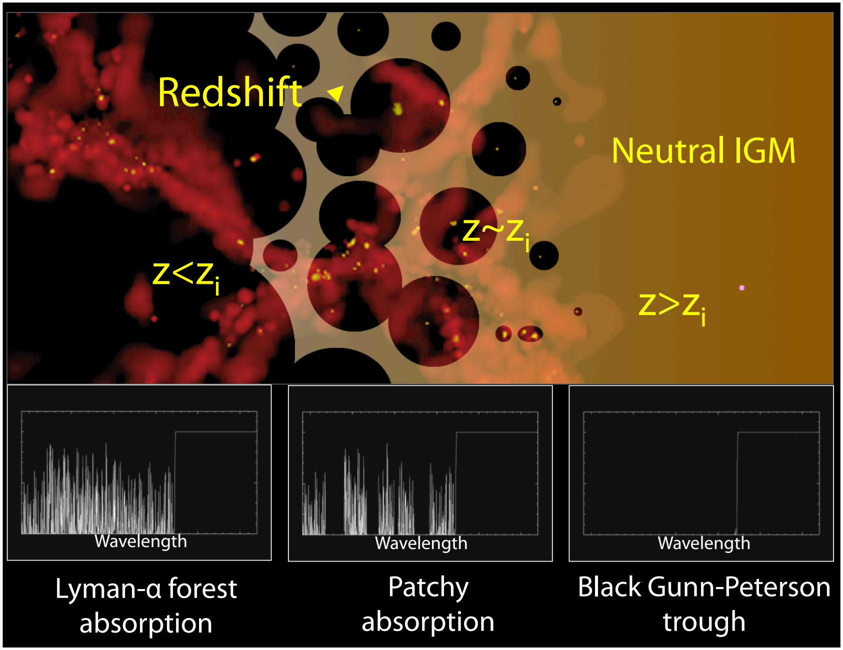


HST ACS visible mosaic of Carina Nebula / Smith et al., NASA, ESA

Hubble Space Telescope

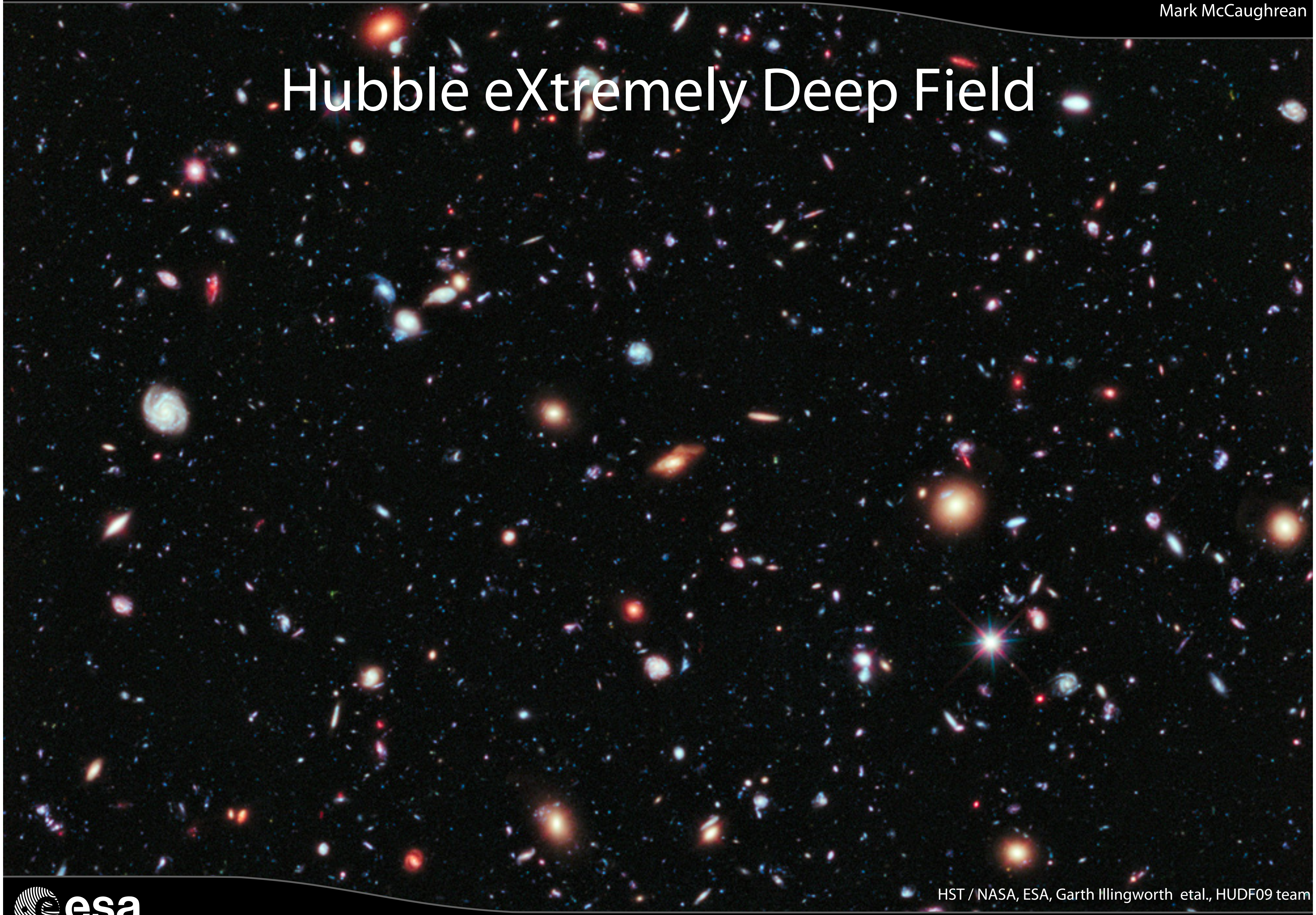
NASA-ESA UV-optical-near-IR astrophysical observatory, launched 1990, last servicing May 2009

Epoch of reionisation



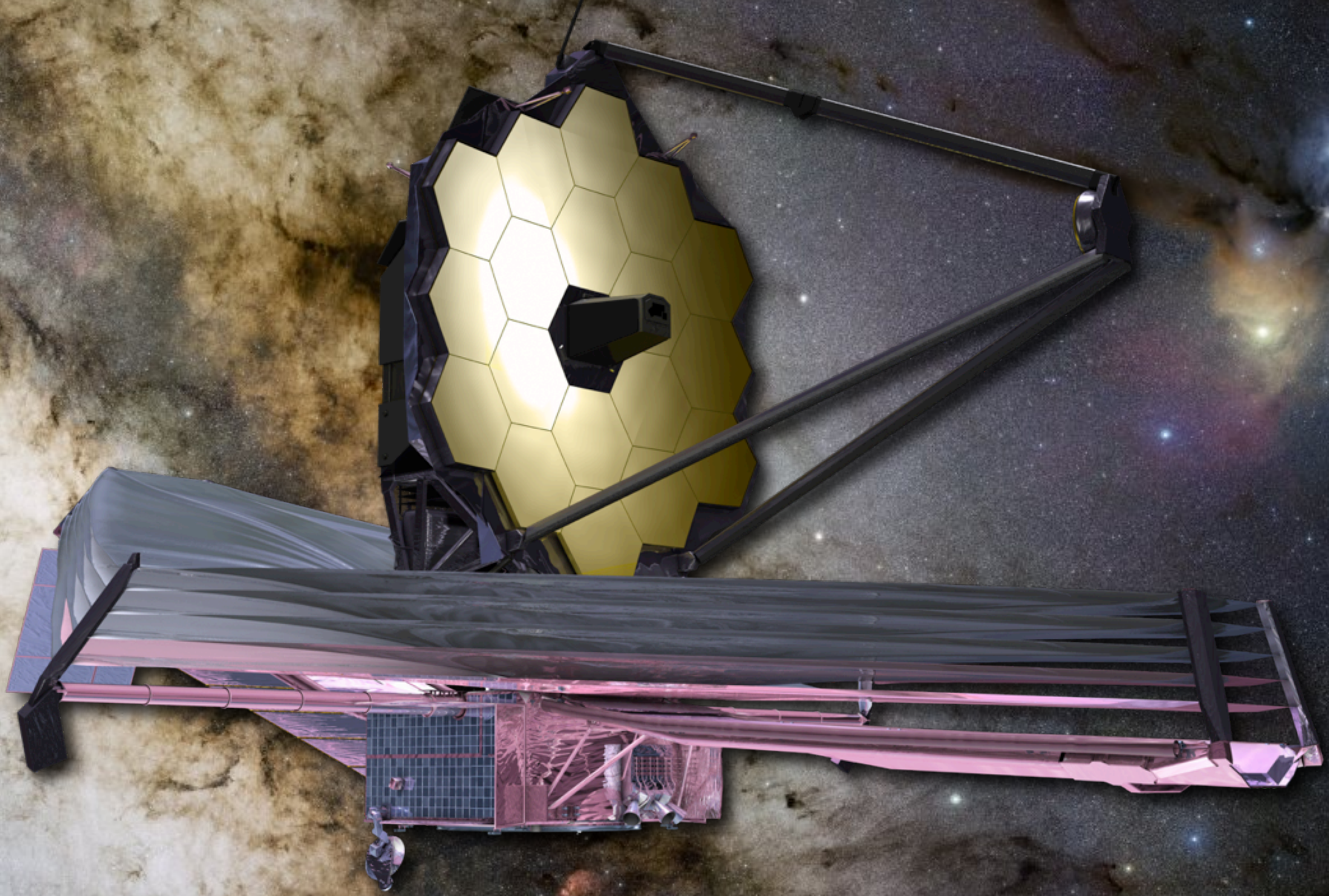
- Following the Big Bang, the Universe was fully ionised and opaque
- After cooling, recombination occurred, leading to CMB
  - Intergalactic medium became neutral and transparent: the “Dark Ages”
- Subsequently reionised to ~10%
  - When did it occur? Which sources caused it? What can we learn about “first light”?

Hubble eXtremely Deep Field



HST / NASA, ESA, Garth Illingworth etal., HUDF09 team

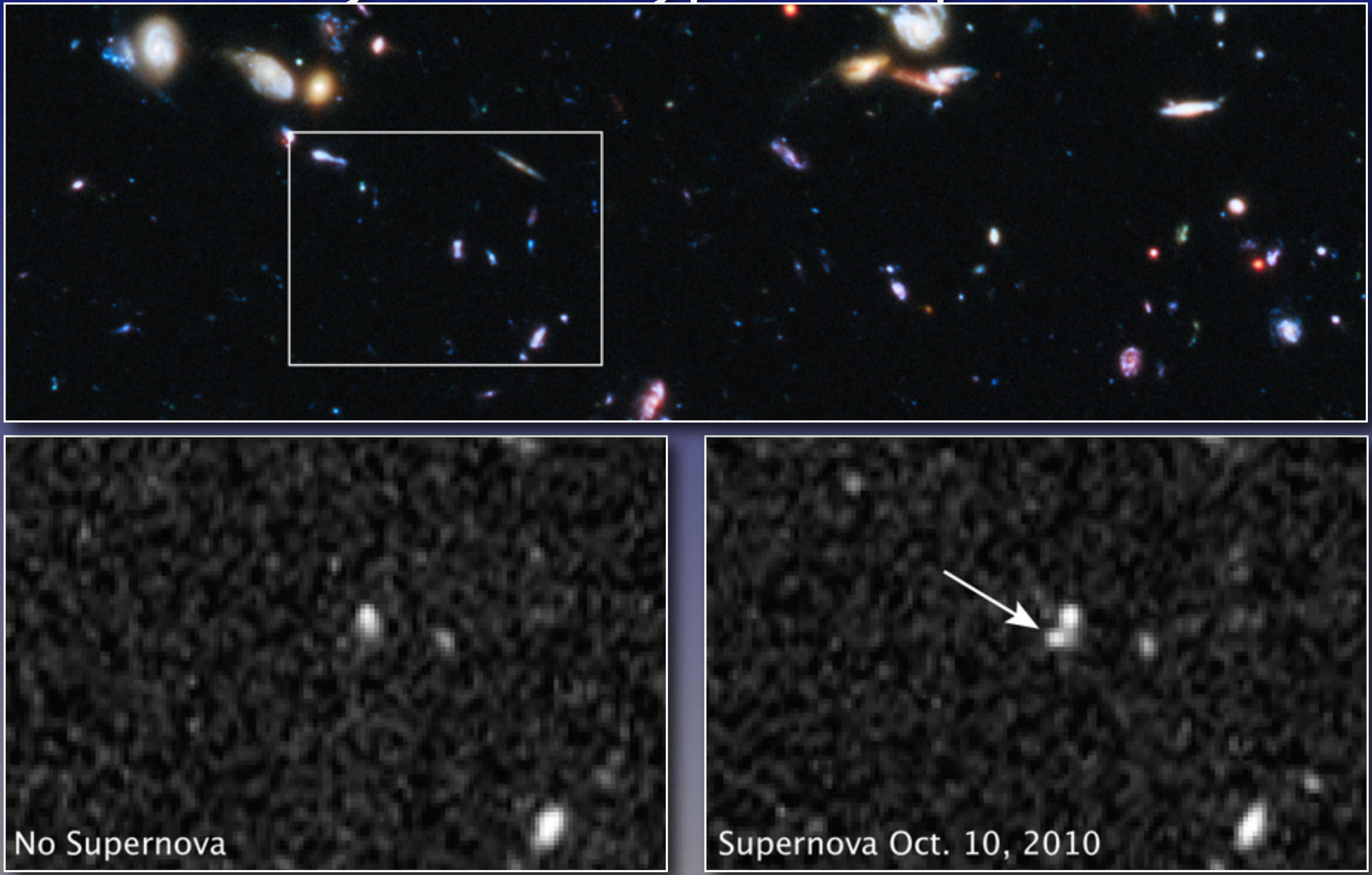
James Webb Space Telescope



Background: ESO/S. Guisard

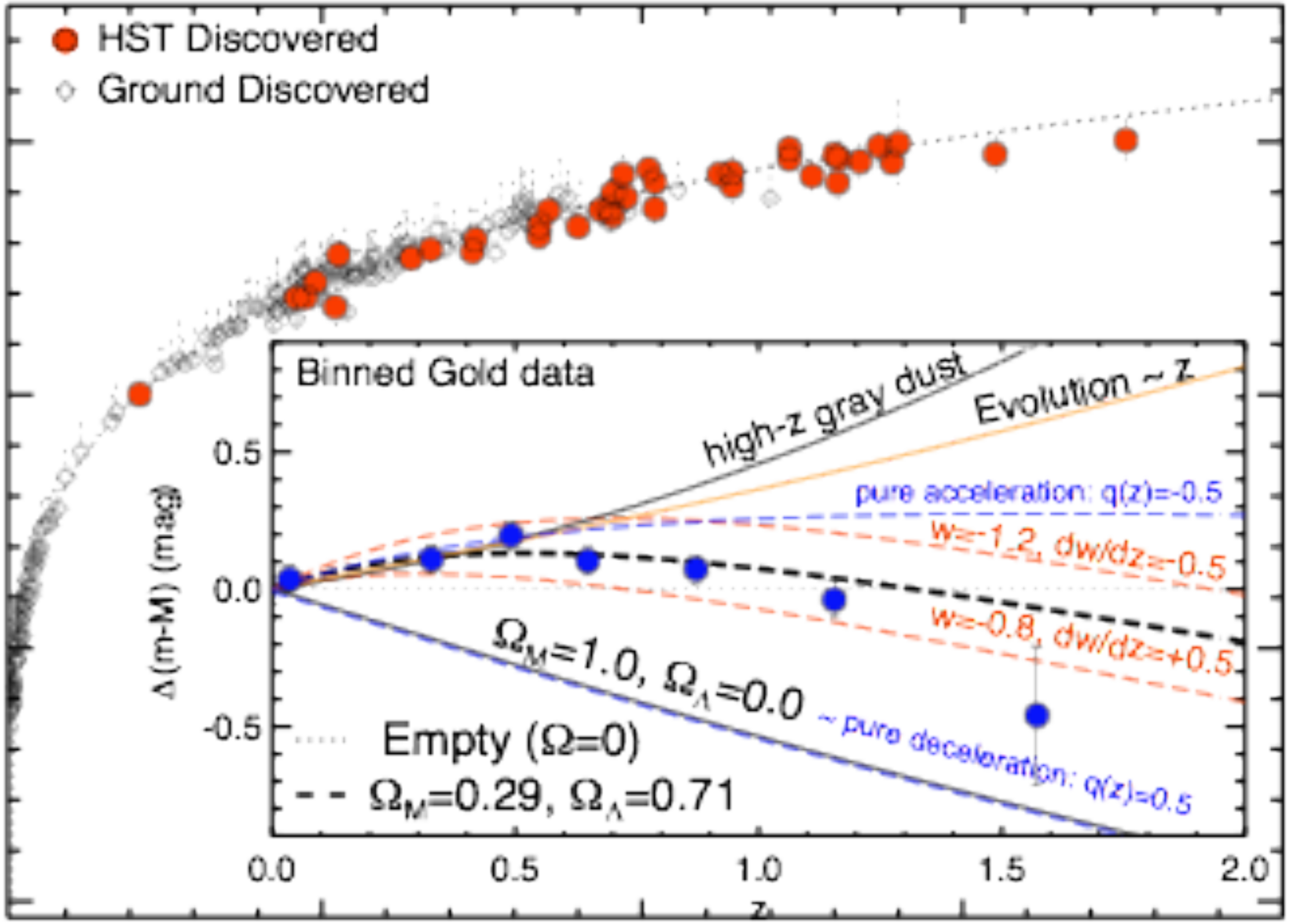
NASA-ESA-CSA optical-infrared astrophysics observatory, scheduled launch 2018

A very distant Type 1a supernova



HST WFC3 / Supernova in Hubble Ultradeep Field / ESA, NASA, Adam Riess, Steven Rodney

Evidence for an accelerated expansion

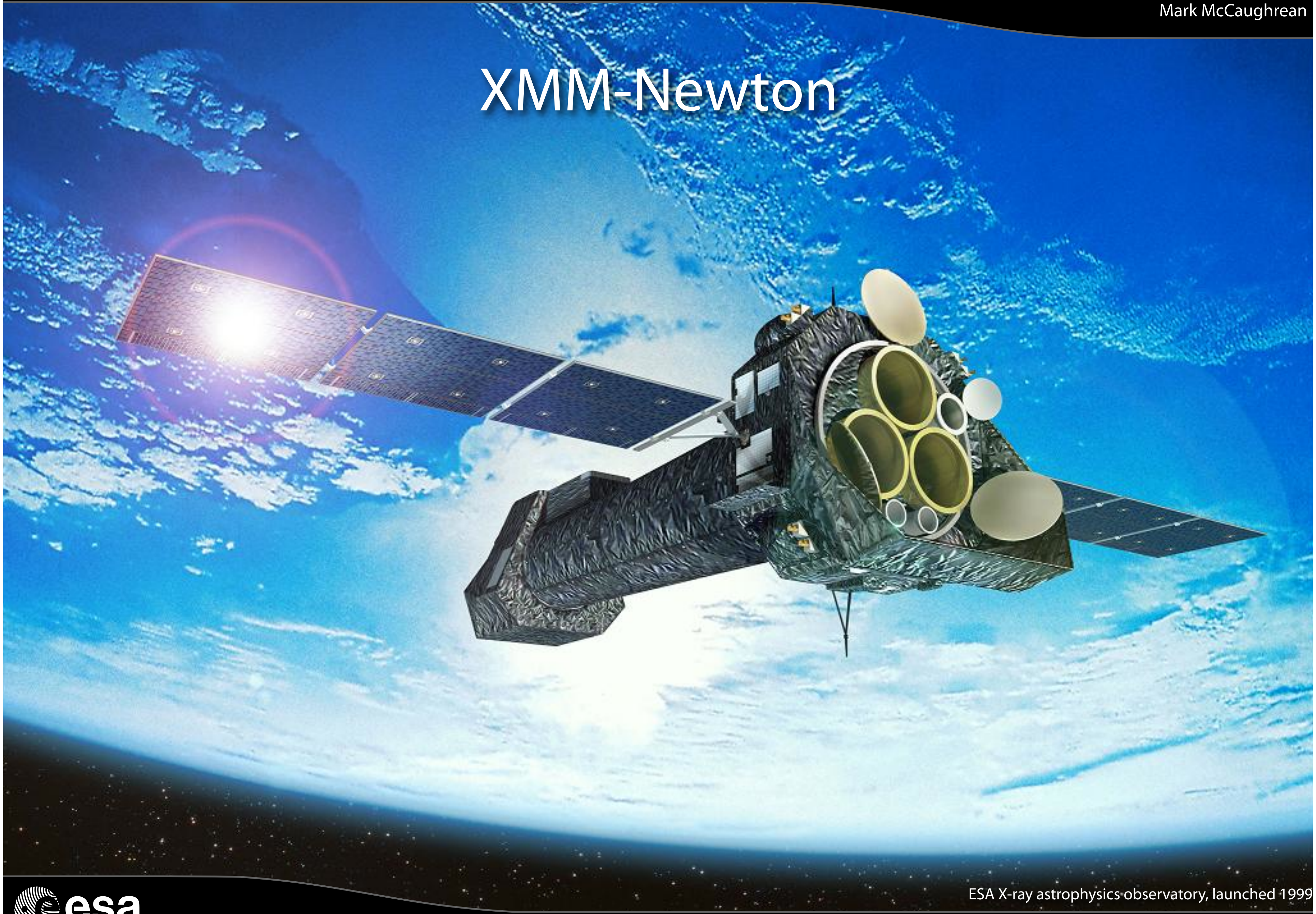


Accelerating Universe Discovery

- Ground and space observations of SN Ia showed accelerating universe, announced in 1998

- Nobel prize to Perlmutter, Schmitt and Riess
  - Supernova Cosmology Project (PI: Perlmutter)
  - High-z Supernova Search Team (PI: Brian Schmitt, Adam Riess)
  - HST observations, led by Riess, were key component

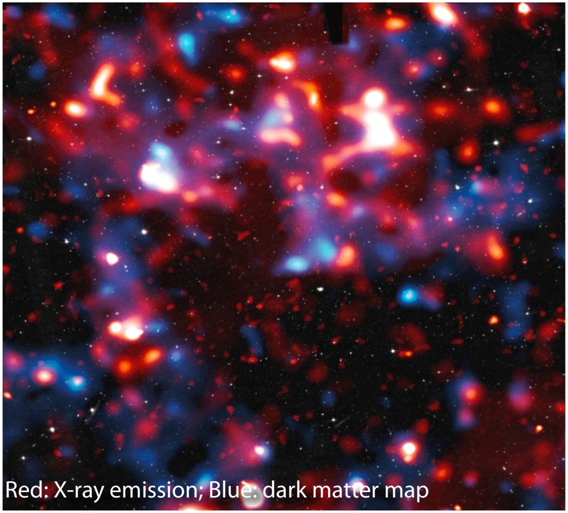
XMM-Newton



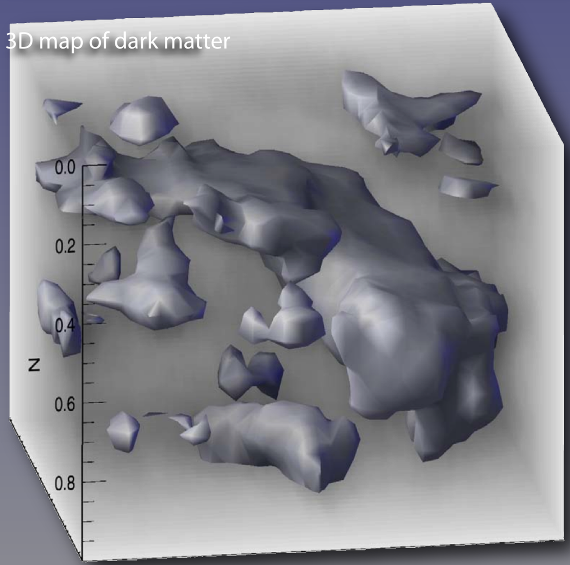
ESA X-ray astrophysics observatory, launched 1999

Dark matter maps reveal cosmic scaffolding

- Deep multi-λ survey of COSMOS field
  - 1.67 square degree field
  - 1000 hrs with HST
  - 400 hrs with XMM-Newton
- Sensitivity to different components
  - Optical-infrared: cold baryonic matter
  - X-ray: hot baryonic matter
  - Gravitational lensing: total matter (baryonic + dark)
- Tomographic reconstruction of dark matter
  - Large scale distribution resolved in 3D
  - Loose network of filaments, growing over time
  - Intersections coincident with massive galaxy clusters
  - Consistent with numerical simulations of gravitational structure formation



Red: X-ray emission; Blue: dark matter map

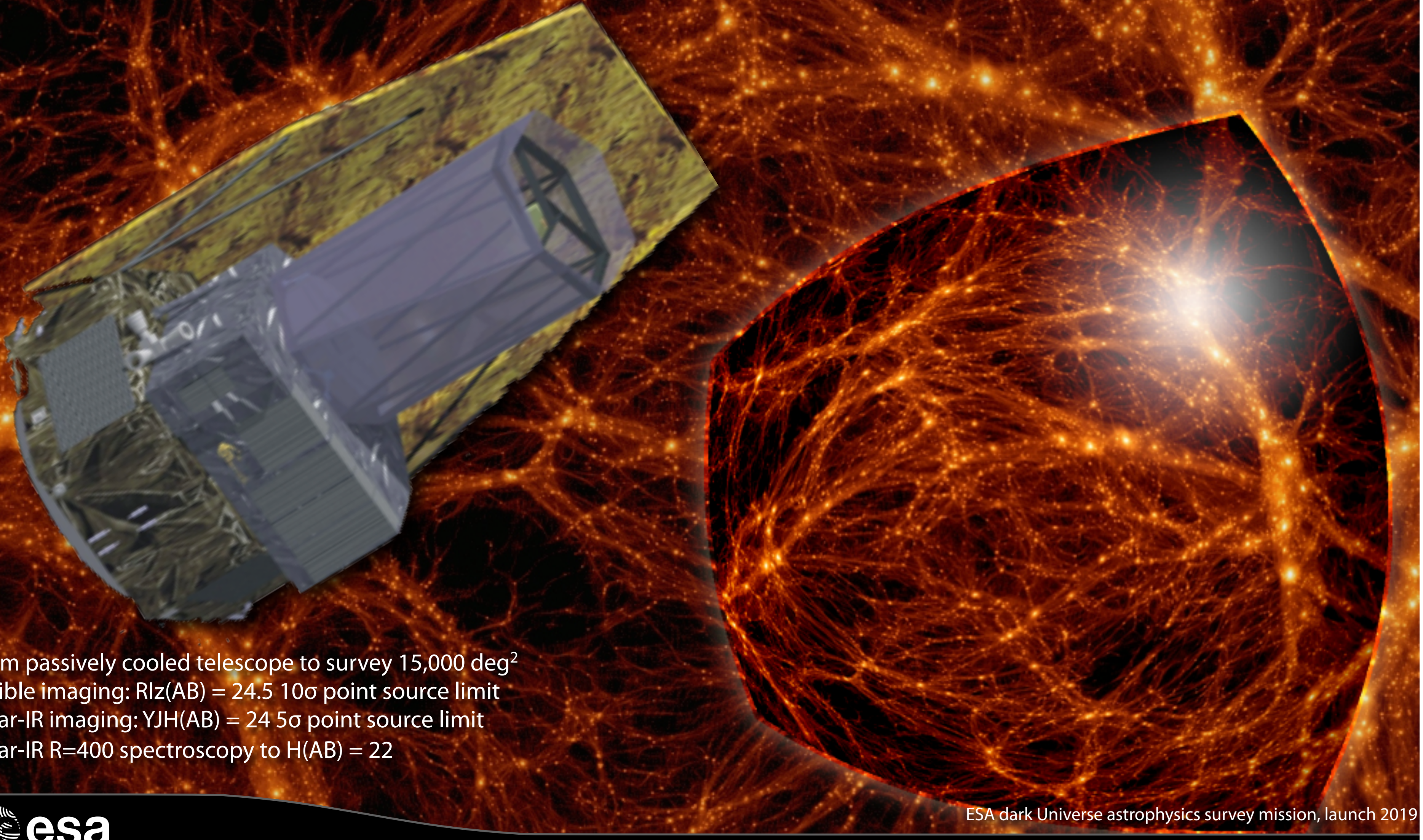


3D map of dark matter

Massey et al. (2007, Nature)

Euclid

Cosmic Vision M2 mission

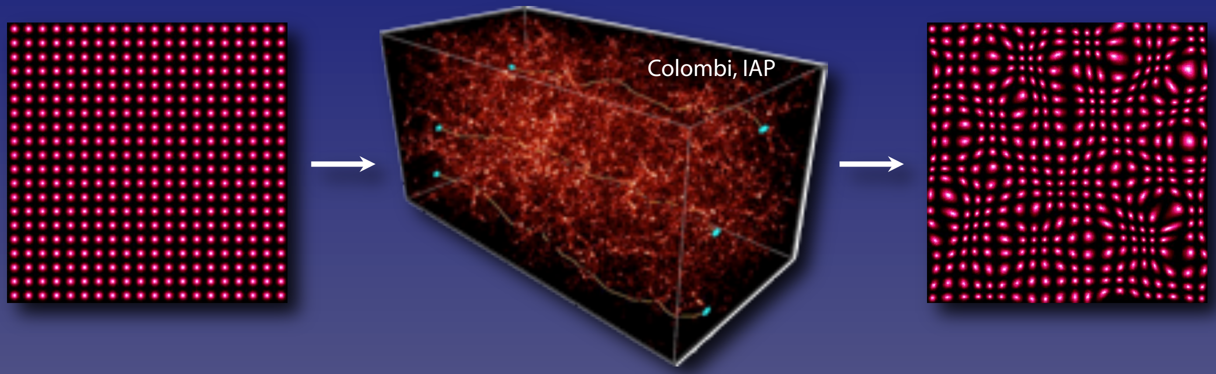


1.2m passively cooled telescope to survey 15,000 deg^2
Visible imaging: RIz(AB) = 24.5 10σ point source limit
Near-IR imaging: YJH(AB) = 24 5σ point source limit
Near-IR R=400 spectroscopy to H(AB) = 22

ESA dark Universe astrophysics survey mission, launch 2019

Multiple probes of evolving cosmic structure

Weak lensing

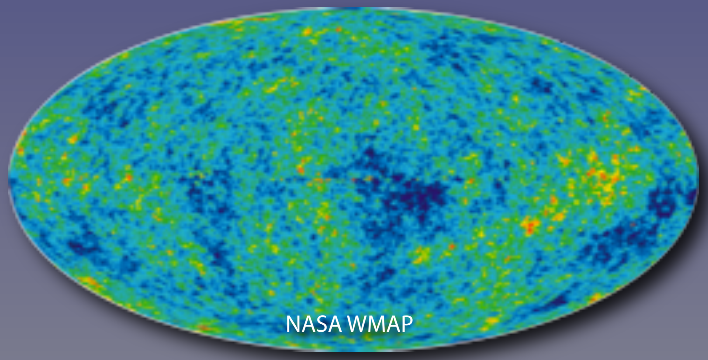


Colombi, IAP

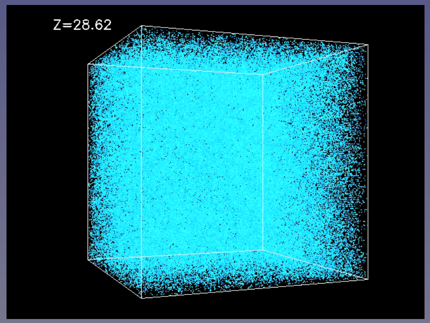
Galaxy shapes systematically distorted by intervening matter (baryonic and dark)

Wide-field, high-resolution visible imaging measures shear; near-IR imaging photometry measures photo-z's for lensed galaxies

Baryon acoustic oscillations



NASA WMAP



Center for Cosmological Physics, Chicago

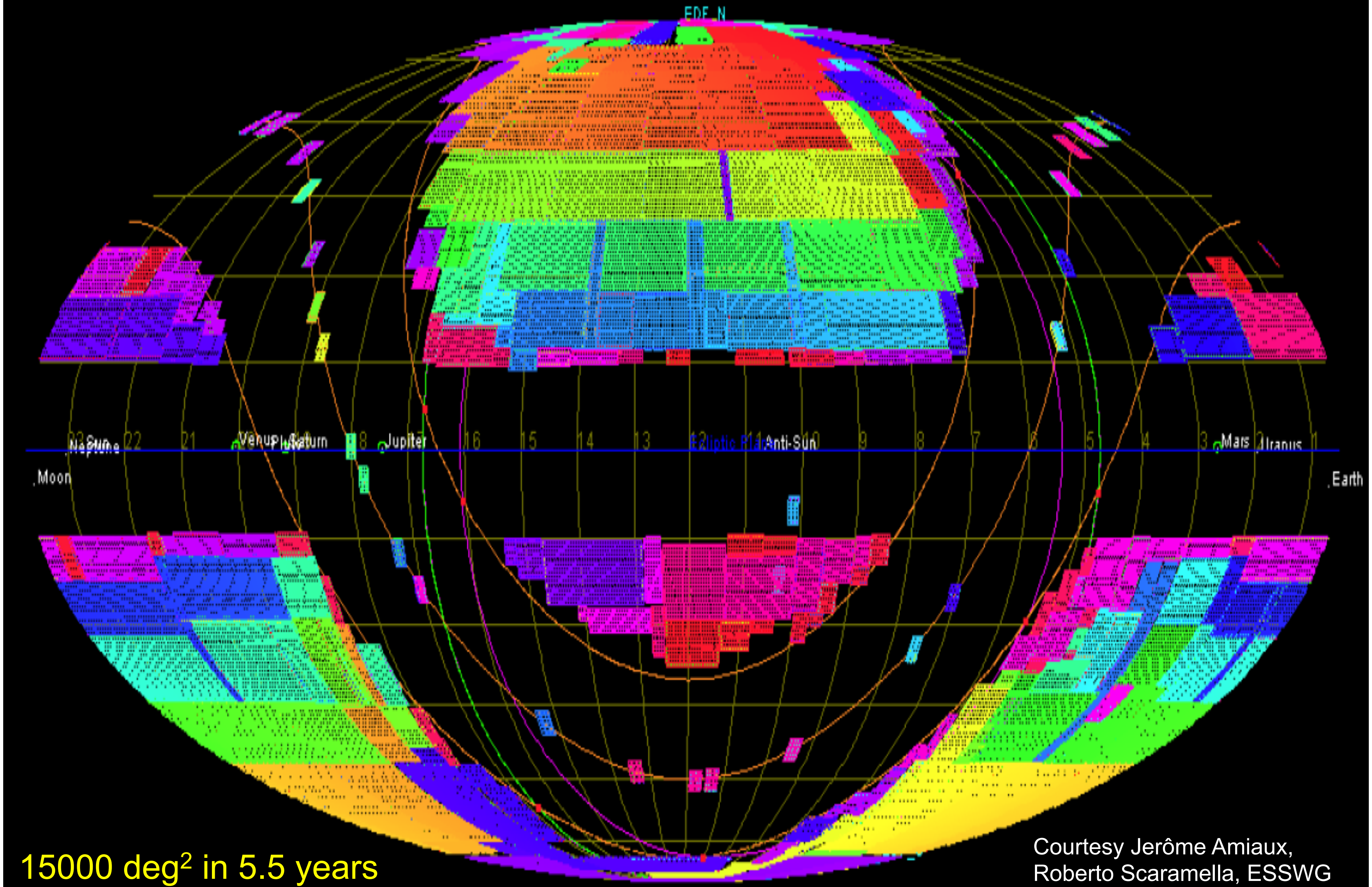
Initial structure imprinted on Universe at recombination has characteristic scale; follow its evolution as standard ruler to present epoch (now ~ 150 Mpc)

Near-IR spectroscopy provides accurate redshifts and 3D maps

Combined with Planck data, Euclid will yield DE parameters w to <1% and w_a to < 5%
Very large legacy survey data set for many other kinds of science

ESA

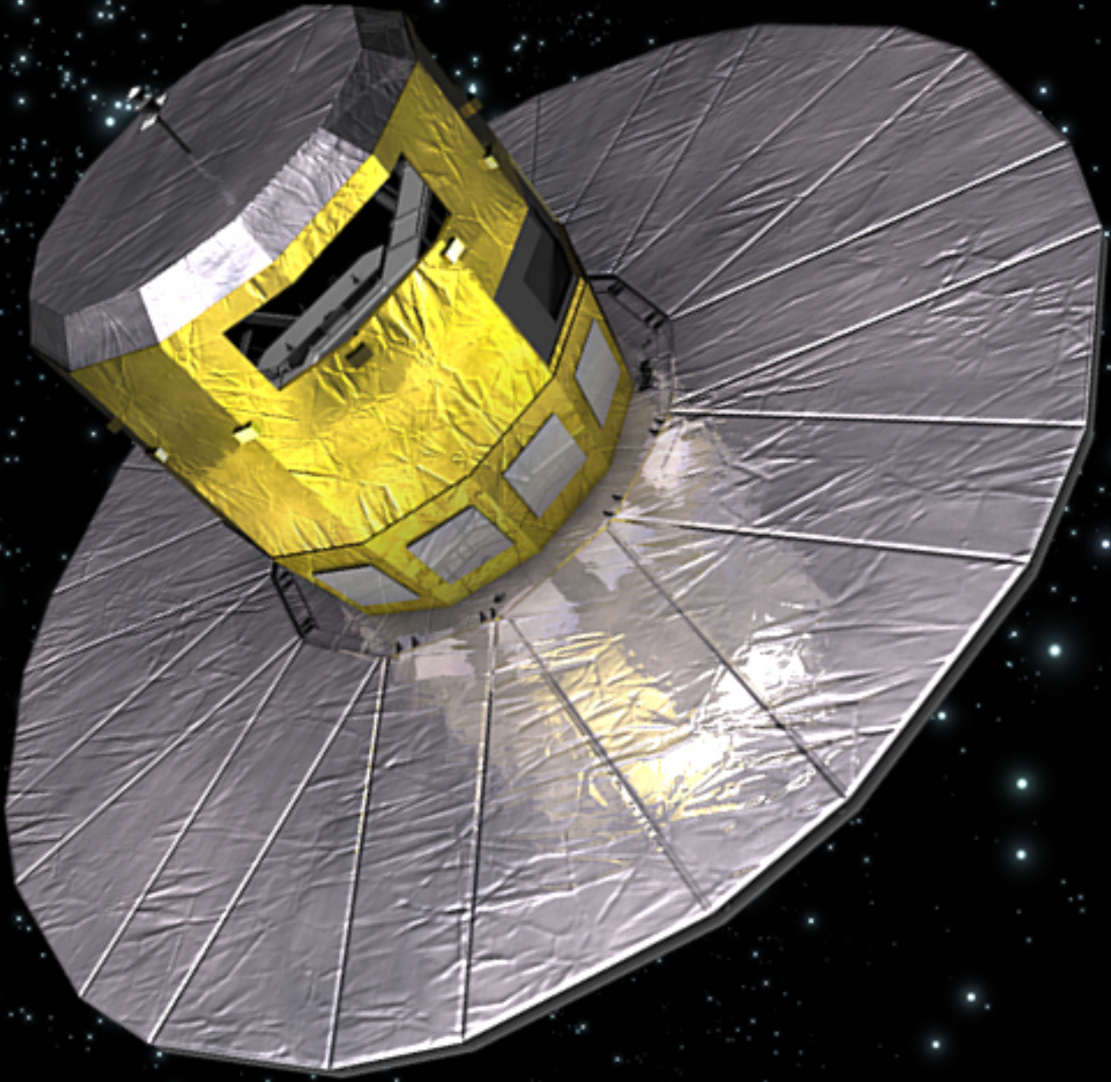
Euclid Deep+Wide survey model



15000 deg^2 in 5.5 years

Courtesy Jerôme Amiaux,
Roberto Scaramella, ESSWG

Gaia



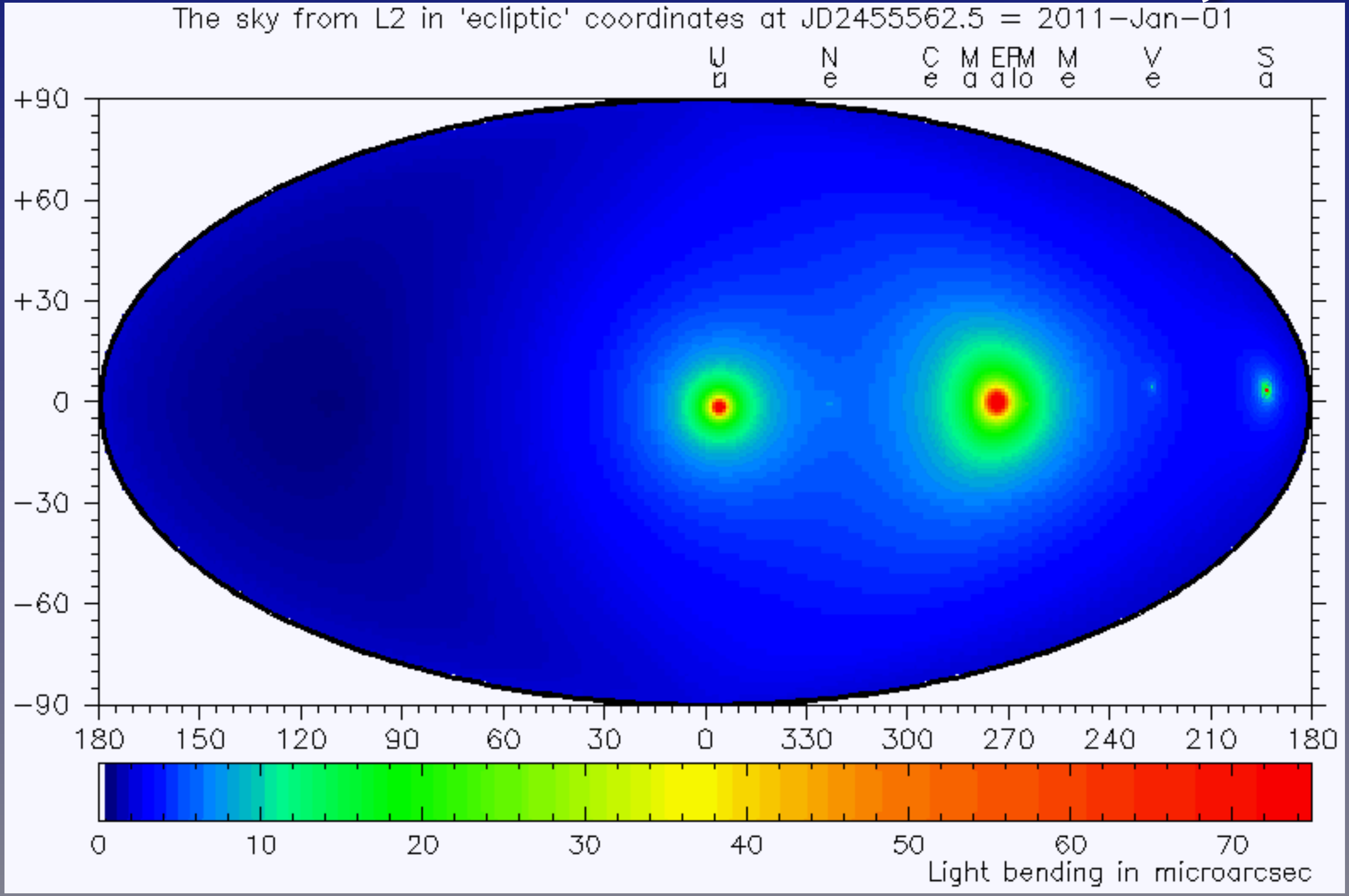
Scanning satellite measuring two fields simultaneously onto a gigapixel CCD array

Microarcsecond astrometry of a billion stars to V~20 to determine positions and velocities on plane-of-sky

Radial velocity spectroscopy to measure line-of-sight velocities

ESA precision astrometry mission, scheduled launch 2013

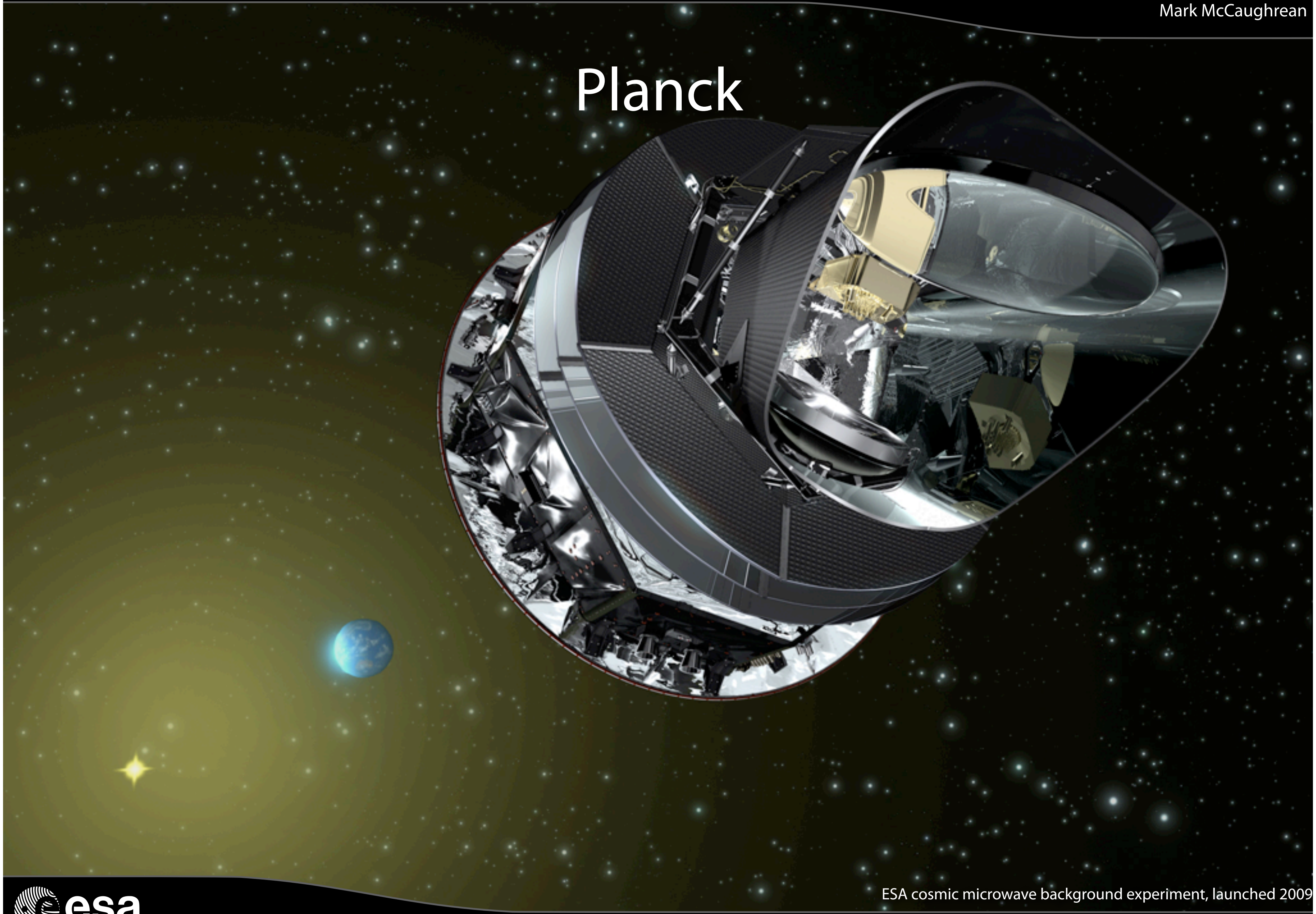
Gravitational deflection in the Solar System



Light bending after subtraction of much larger deflection due to the Sun

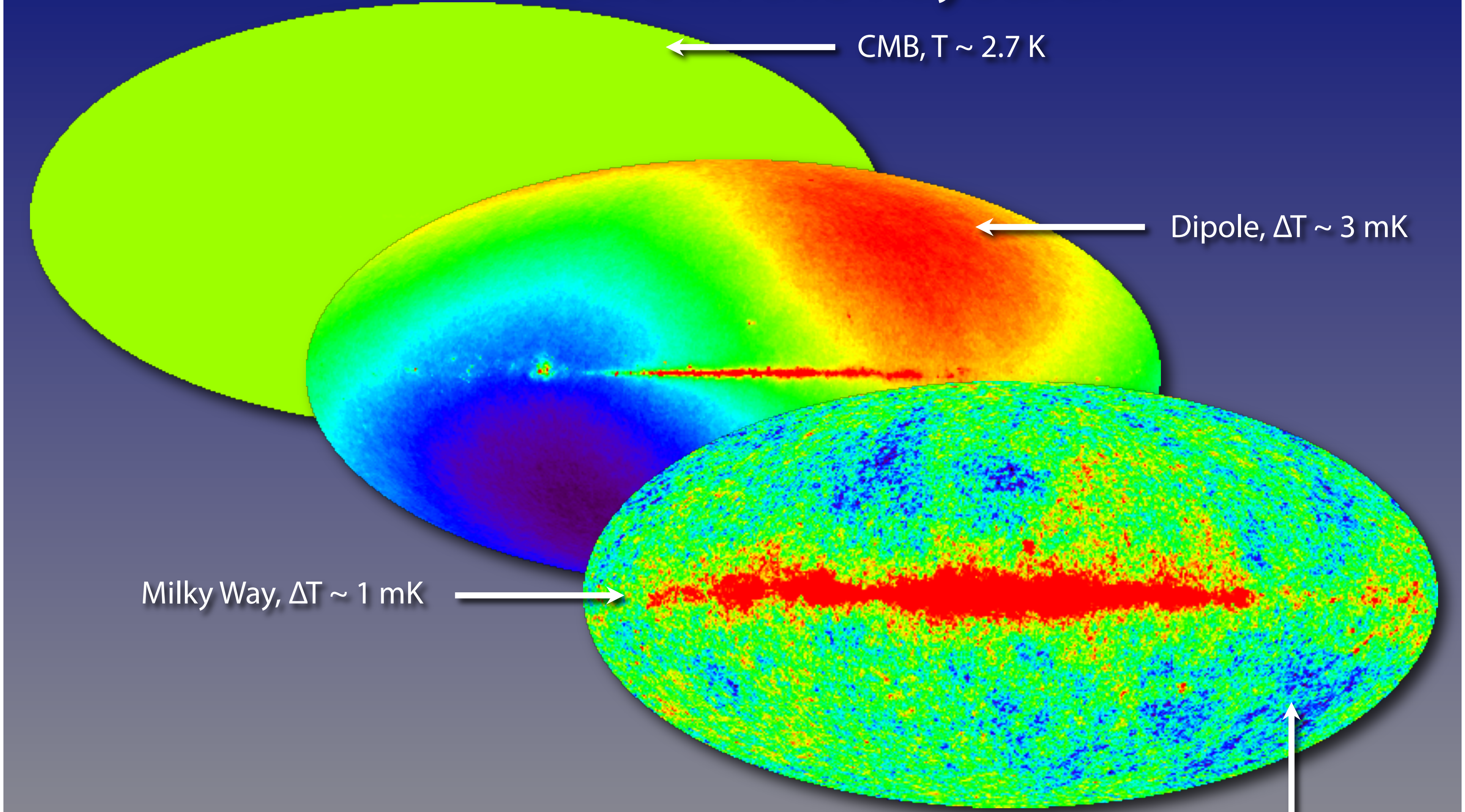
Jos de Bruijne / ESA

Planck



ESA cosmic microwave background experiment, launched 2009

The needle in the haystack



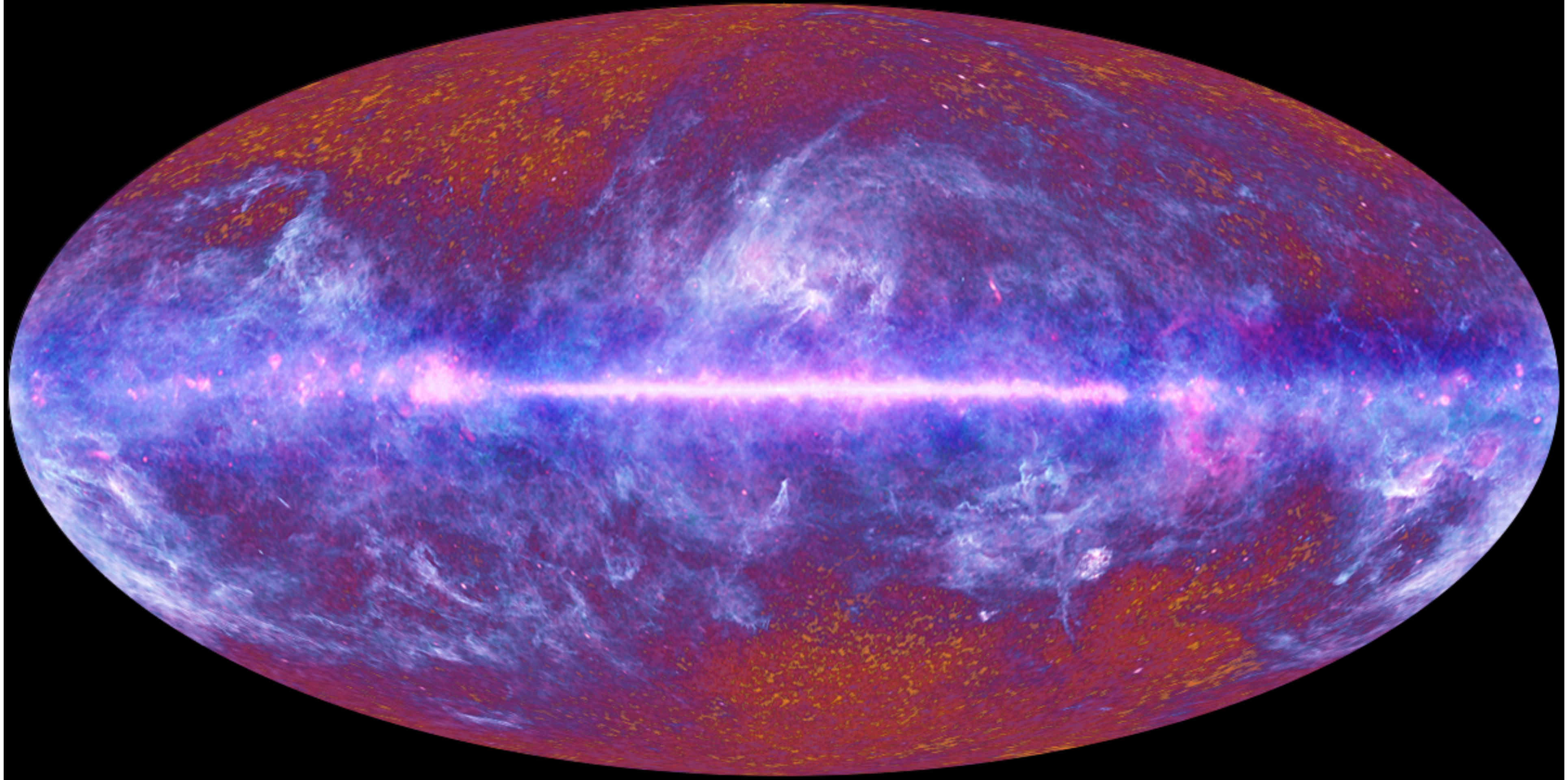
CMB, T ~ 2.7 K

Dipole, ΔT ~ 3 mK

Milky Way, ΔT ~ 1 mK

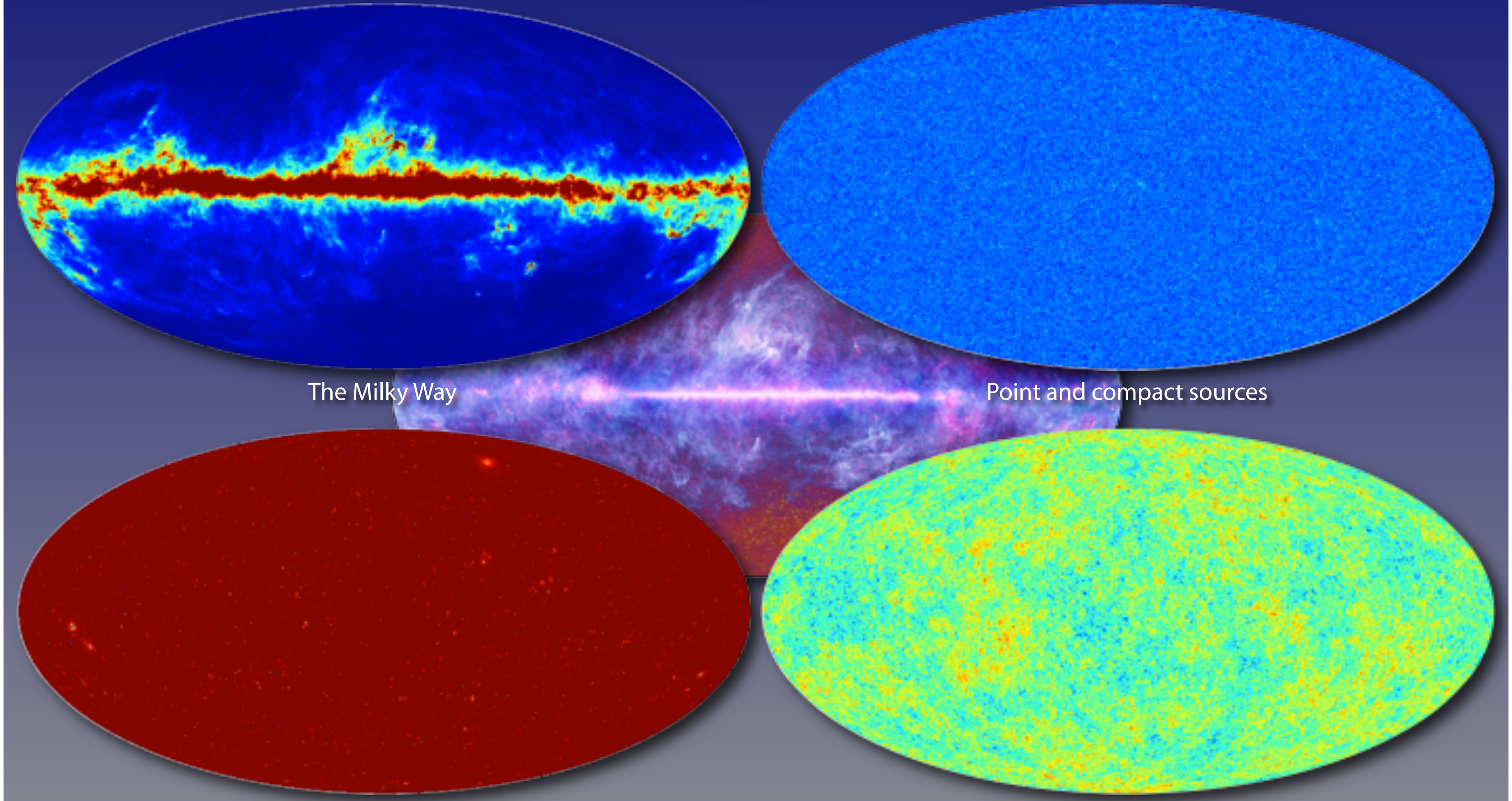
CMB anisotropies, ΔT ~ 50 μK

Planck all-sky image



ESA, HFI & LFI consortia; released July 2010

Decomposition



The Milky Way

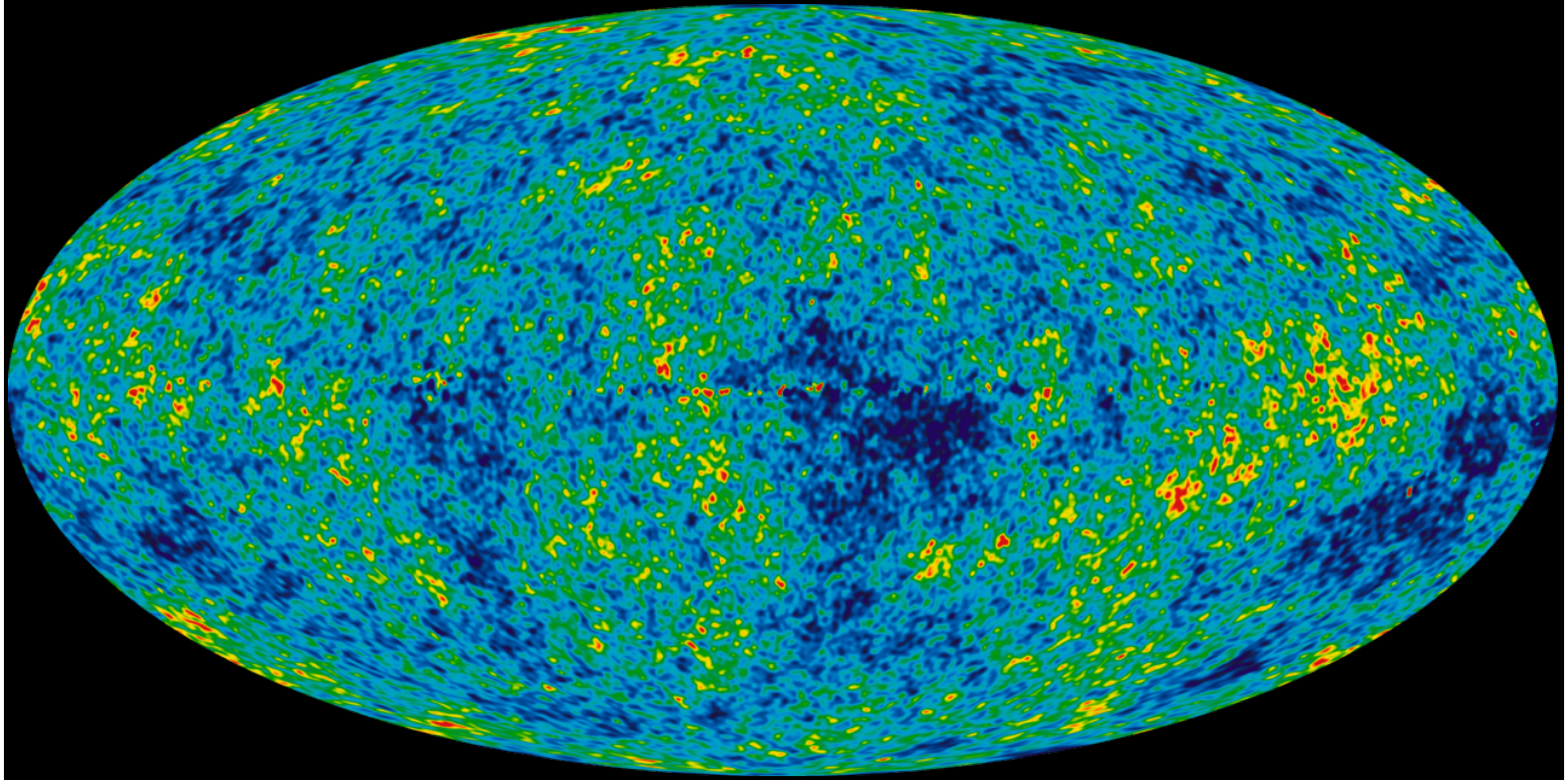
Point and compact sources

Sunyaev-Zel’dovich effect

Cosmic Microwave Background

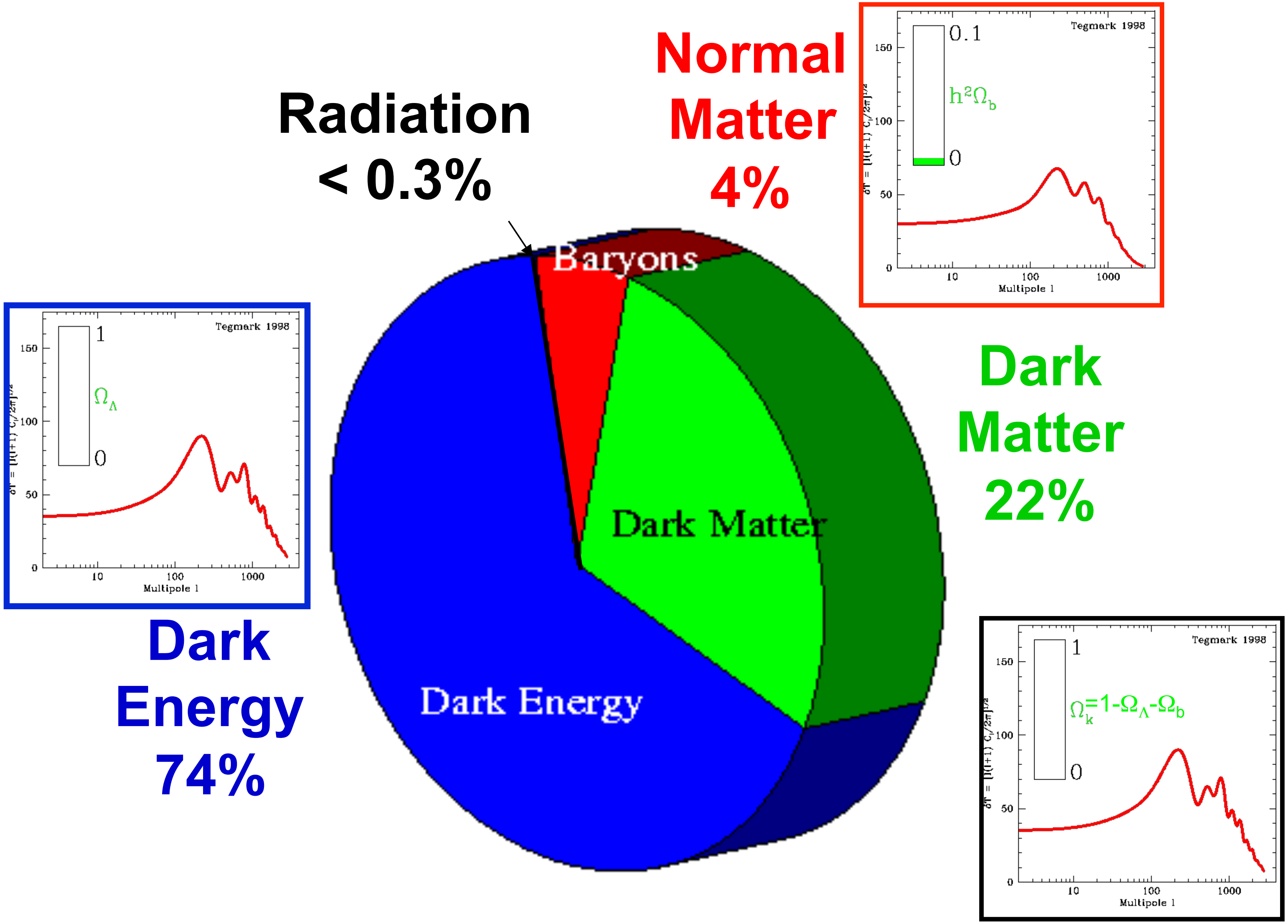
ESA, HFI & LFI consortia, Planck Collaboration

WMAP 7-yr CMB map



WMAP, Jarosik et al. (2010) / NASA

The power spectrum depends on the composition of the universe through the physics of the oscillations and the evolution of the bkg.



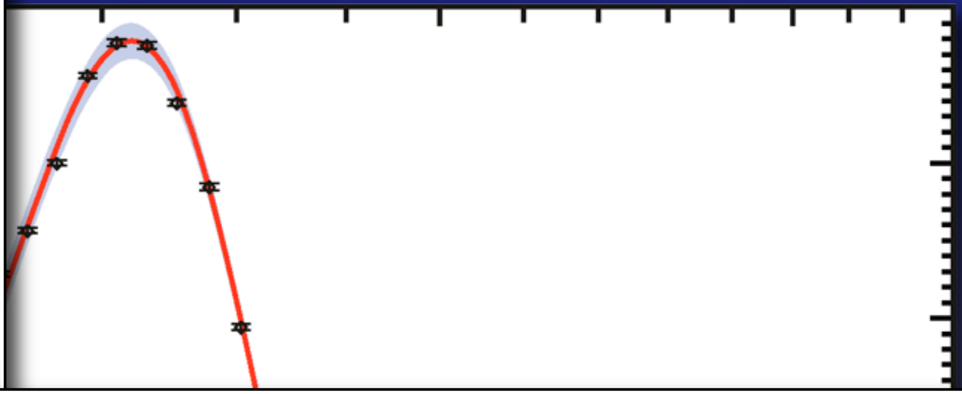
Radiation < 0.3%

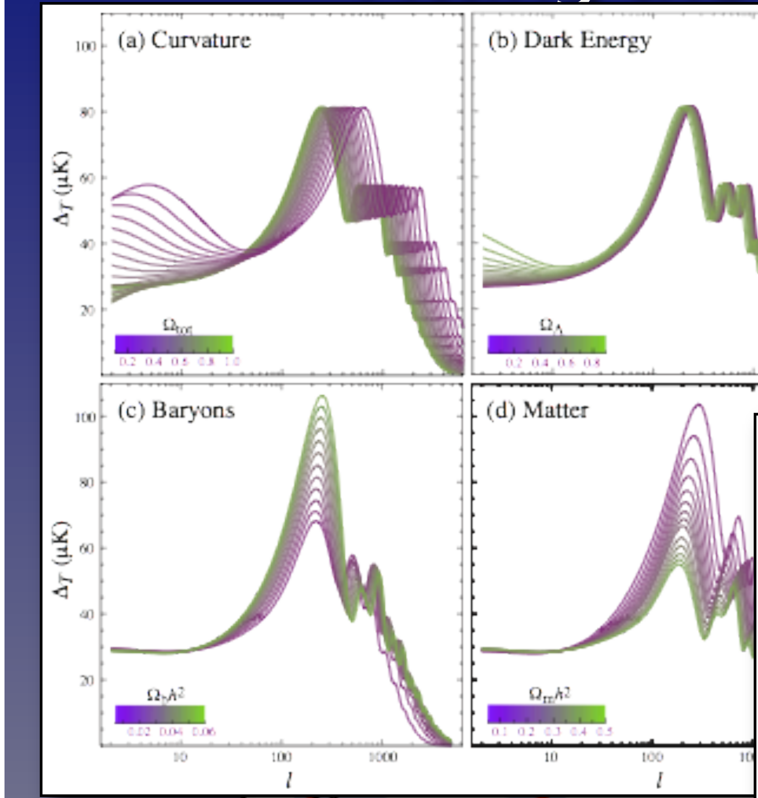
Normal Matter 4%

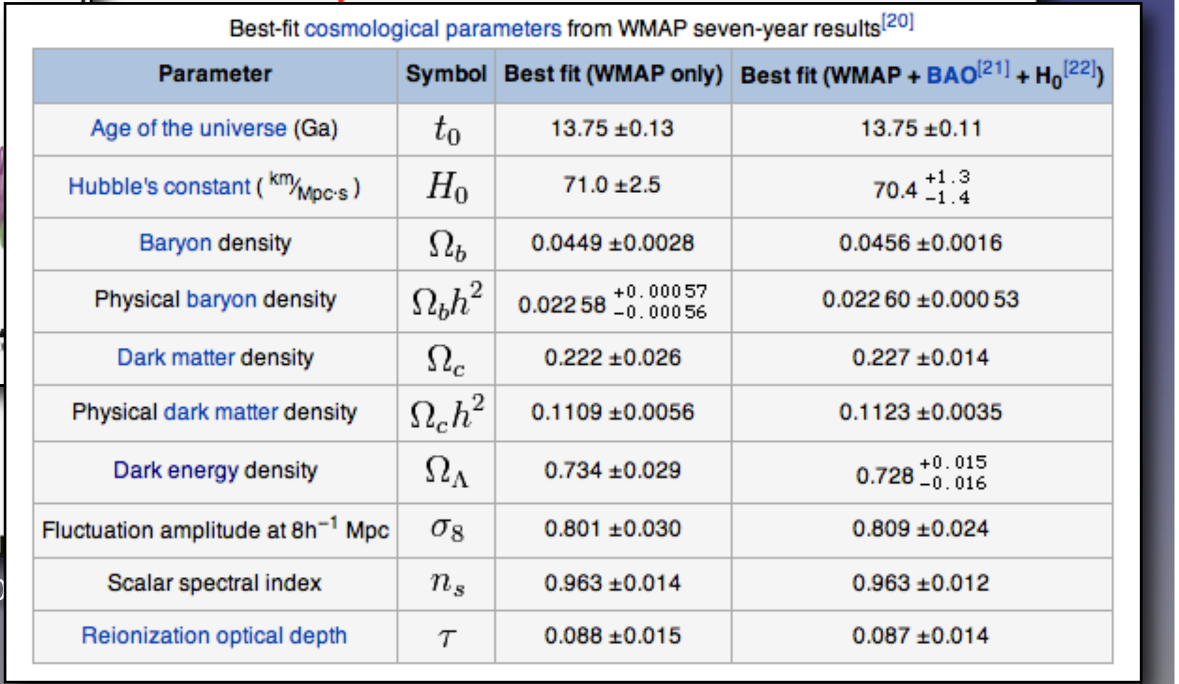
Dark Matter 22%

Dark Energy 74%

Fitting the CMB power spectrum







Best-fit cosmological parameters from WMAP seven-year results[20]

Parameter	Symbol	Best fit (WMAP only)	Best fit (WMAP + BAO[21] + H_0[22])
Age of the universe (Ga)	t_0	13.75 ±0.13	13.75 ±0.11
Hubble's constant (km/Mpc·s)	H_0	71.0 ±2.5	$70.4^{+1.3}_{-1.4}$
Baryon density	Ω_b	0.0449 ±0.0028	0.0456 ±0.0016
Physical baryon density	$\Omega_b h^2$	$0.022\,58^{+0.000\,57}_{-0.000\,56}$	0.022 60 ±0.000 53
Dark matter density	Ω_c	0.222 ±0.026	0.227 ±0.014
Physical dark matter density	$\Omega_c h^2$	0.1109 ±0.0056	0.1123 ±0.0035
Dark energy density	Ω_Λ	0.734 ±0.029	$0.728^{+0.015}_{-0.016}$
Fluctuation amplitude at $8h^{-1}$ Mpc	σ_8	0.801 ±0.030	0.809 ±0.024
Scalar spectral index	n_s	0.963 ±0.014	0.963 ±0.012
Reionization optical depth	τ	0.088 ±0.015	0.087 ±0.014

0

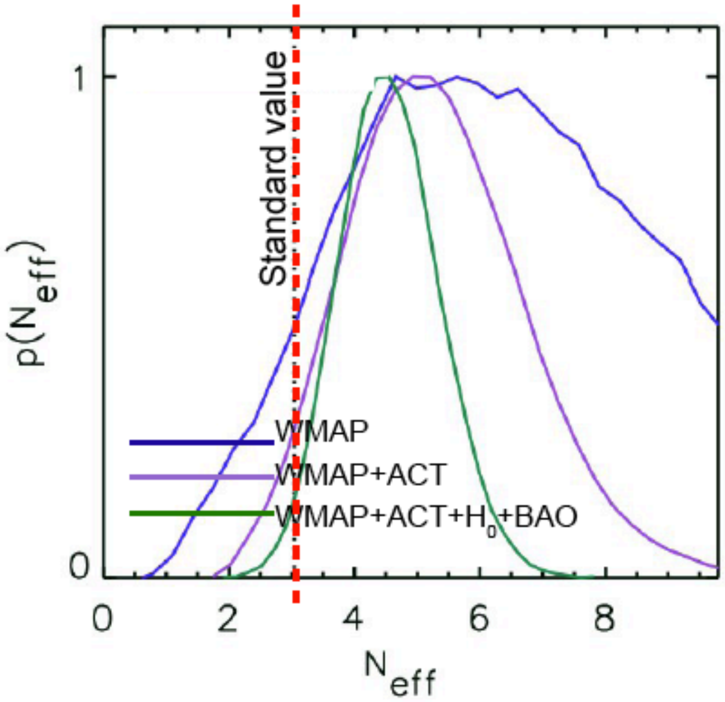
10

10

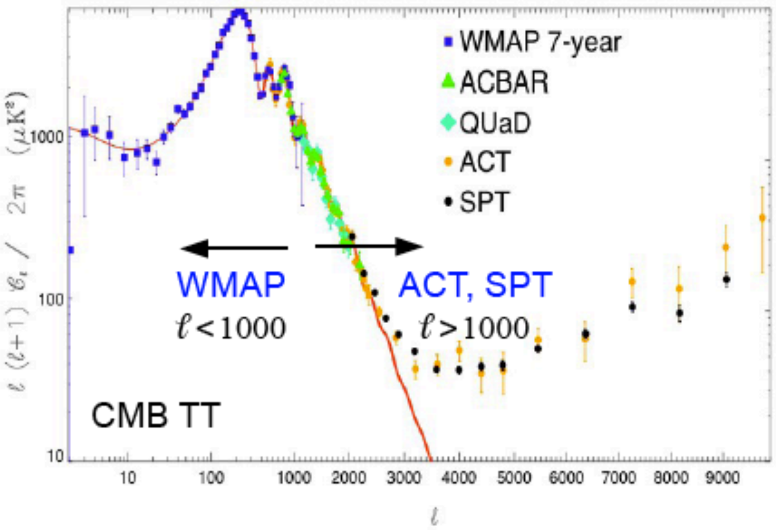
WMAP 7-yr CMB temperature power spectrum, Jarosik et al. (2010); parameter variations, Hu & Dodelson (2002)

Evidence for extra neutrinos...

- Treating the neutrino energy density as a free parameter, recent observations prefer $N_{eff} > 3$ at 2σ+.

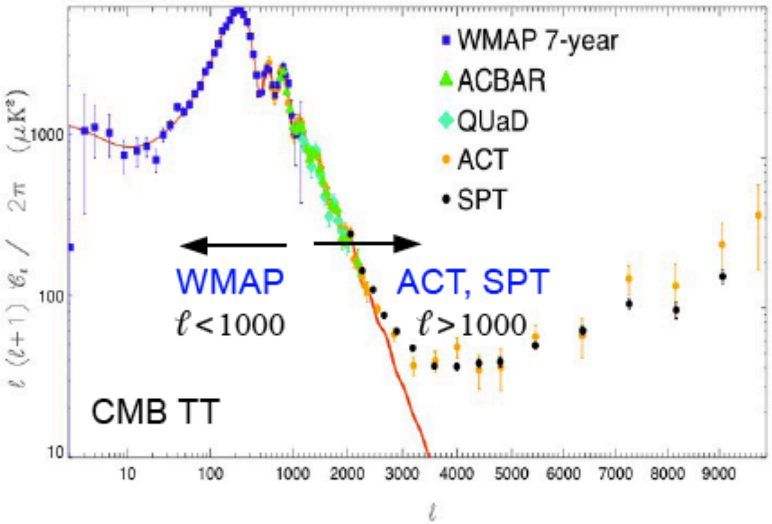


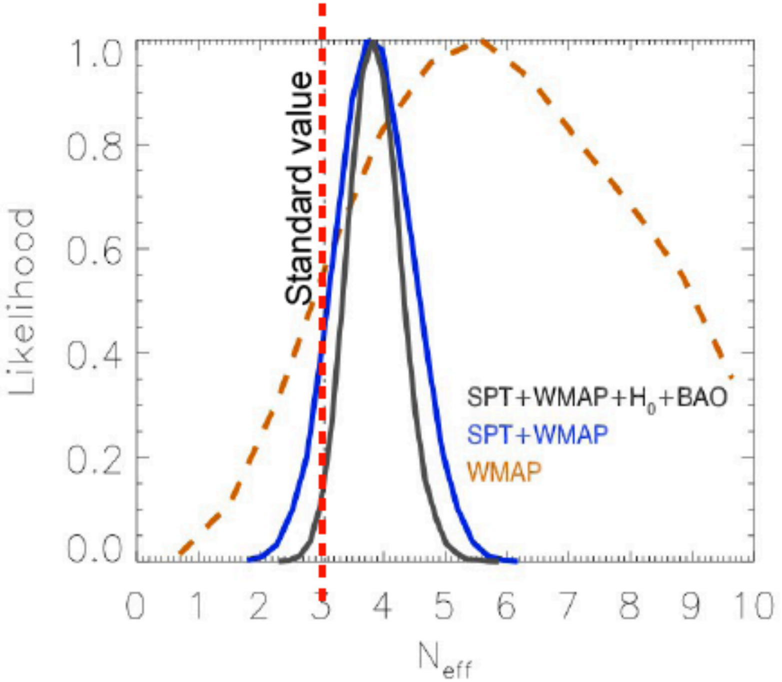
Dunkley et al. [Atacama Cosmology Telescope] 2010



Evidence for extra neutrinos...

- Allowing the neutrino energy density to be a free parameter, recent observations prefer $N_{eff} > 3$ at 2σ+.





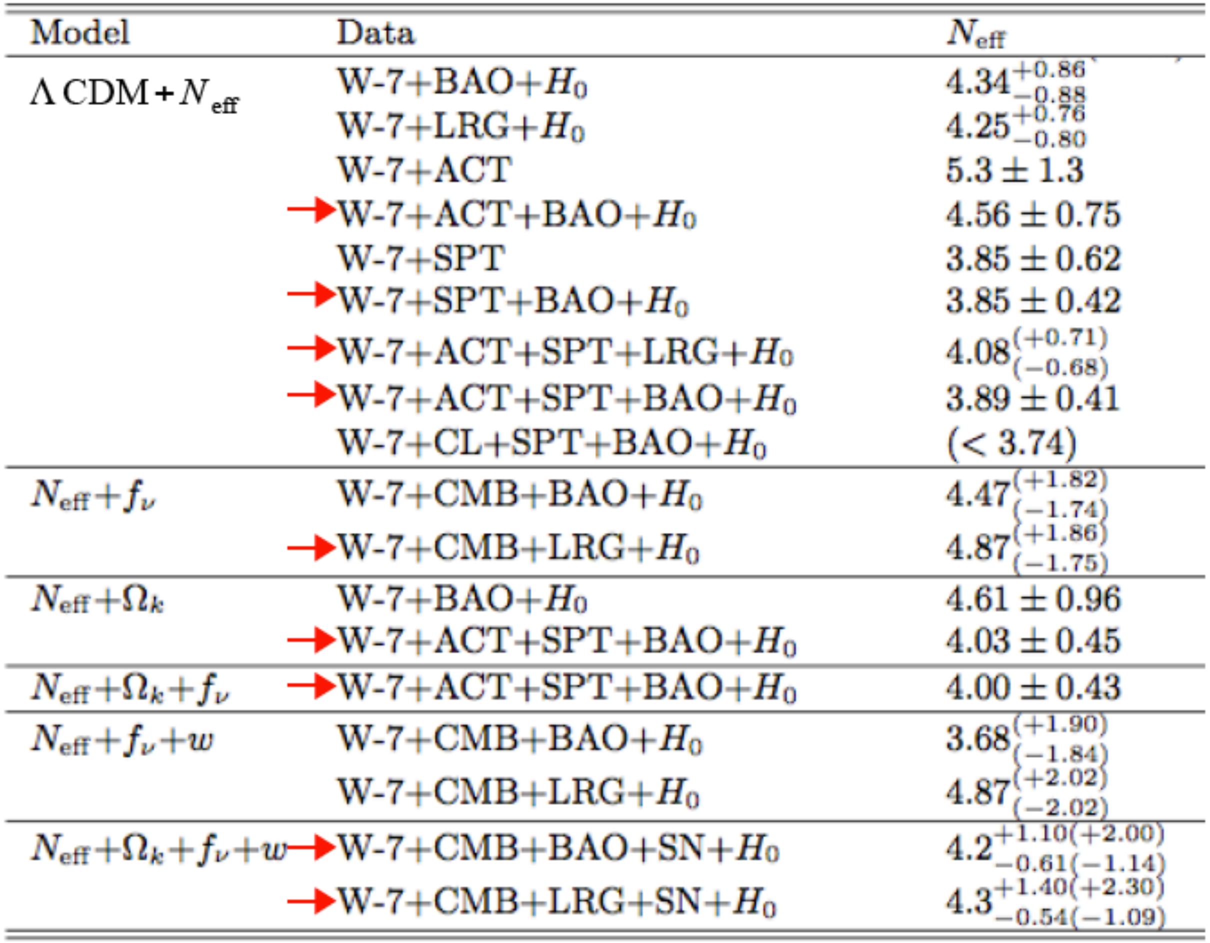
Keisler et al. [South Pole Telescope] 2011

W-7=WMAP-7

Simplest cosmological model

→ = 2-2.5σ evidence

More complex cosmological models



Model	Data	$N_{\rm eff}$
Λ CDM + $N_{\rm eff}$	W-7+BAO+H_0	$4.34^{+0.86}_{-0.88}$
	W-7+LRG+H_0	$4.25^{+0.76}_{-0.80}$
	W-7+ACT	5.3 ± 1.3
	→ W-7+ACT+BAO+H_0	4.56 ± 0.75
	W-7+SPT	3.85 ± 0.62
	→ W-7+SPT+BAO+H_0	3.85 ± 0.42
	→ W-7+ACT+SPT+LRG+H_0	$4.08^{(+0.71)}_{(-0.68)}$
	→ W-7+ACT+SPT+BAO+H_0	3.89 ± 0.41
	W-7+CL+SPT+BAO+H_0	(< 3.74)
$N_{\rm eff}+f_\nu$	W-7+CMB+BAO+H_0	$4.47^{(+1.82)}_{(-1.74)}$
	→ W-7+CMB+LRG+H_0	$4.87^{(+1.86)}_{(-1.75)}$
$N_{\rm eff}+\Omega_k$	W-7+BAO+H_0	4.61 ± 0.96
	→ W-7+ACT+SPT+BAO+H_0	4.03 ± 0.45
$N_{\rm eff}+\Omega_k+f_\nu$	→ W-7+ACT+SPT+BAO+H_0	4.00 ± 0.43
$N_{\rm eff}+f_\nu+w$	W-7+CMB+BAO+H_0	$3.68^{(+1.90)}_{(-1.84)}$
	W-7+CMB+LRG+H_0	$4.87^{(+2.02)}_{(-2.02)}$
$N_{\rm eff}+\Omega_k+f_\nu+w$	→ W-7+CMB+BAO+SN+H_0	$4.2^{+1.10(+2.00)}_{-0.61(-1.14)}$
	→ W-7+CMB+LRG+SN+H_0	$4.3^{+1.40(+2.30)}_{-0.54(-1.09)}$

Abazajian et al., “Light sterile neutrinos: a white paper”, 2012

What the CMB really probes: anisotropic stress...

- Apparent (i.e., not physical) partial degeneracies with primordial fluctuation amplitude A_s and spectral index n_s.

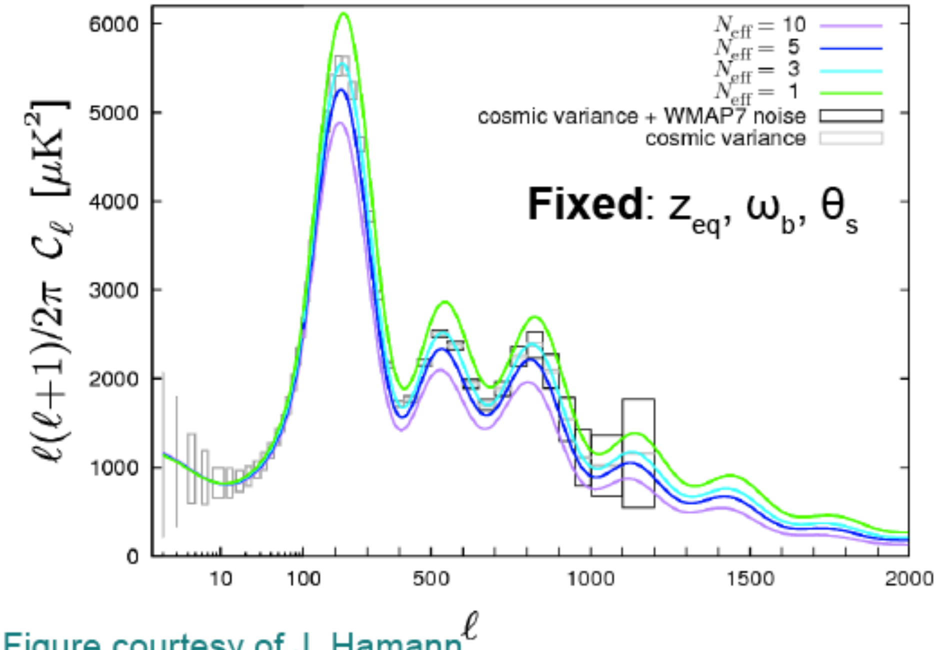
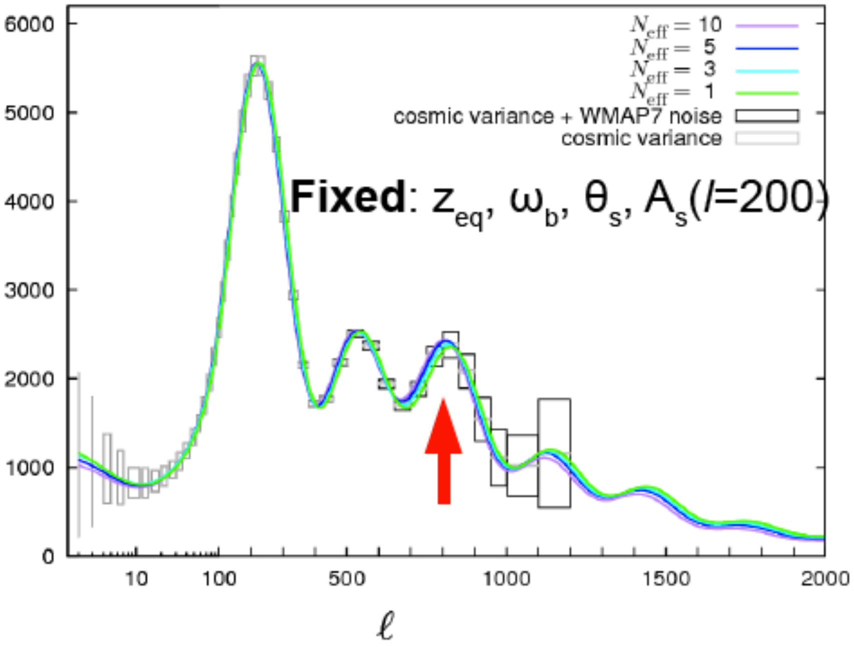


Figure courtesy of J. Hamann

- However, free-streaming particles generate **anisotropic stress**.
- First real signature of N_{eff} is in the 3rd acoustic peak!



Example 1: Hot QCD axions...

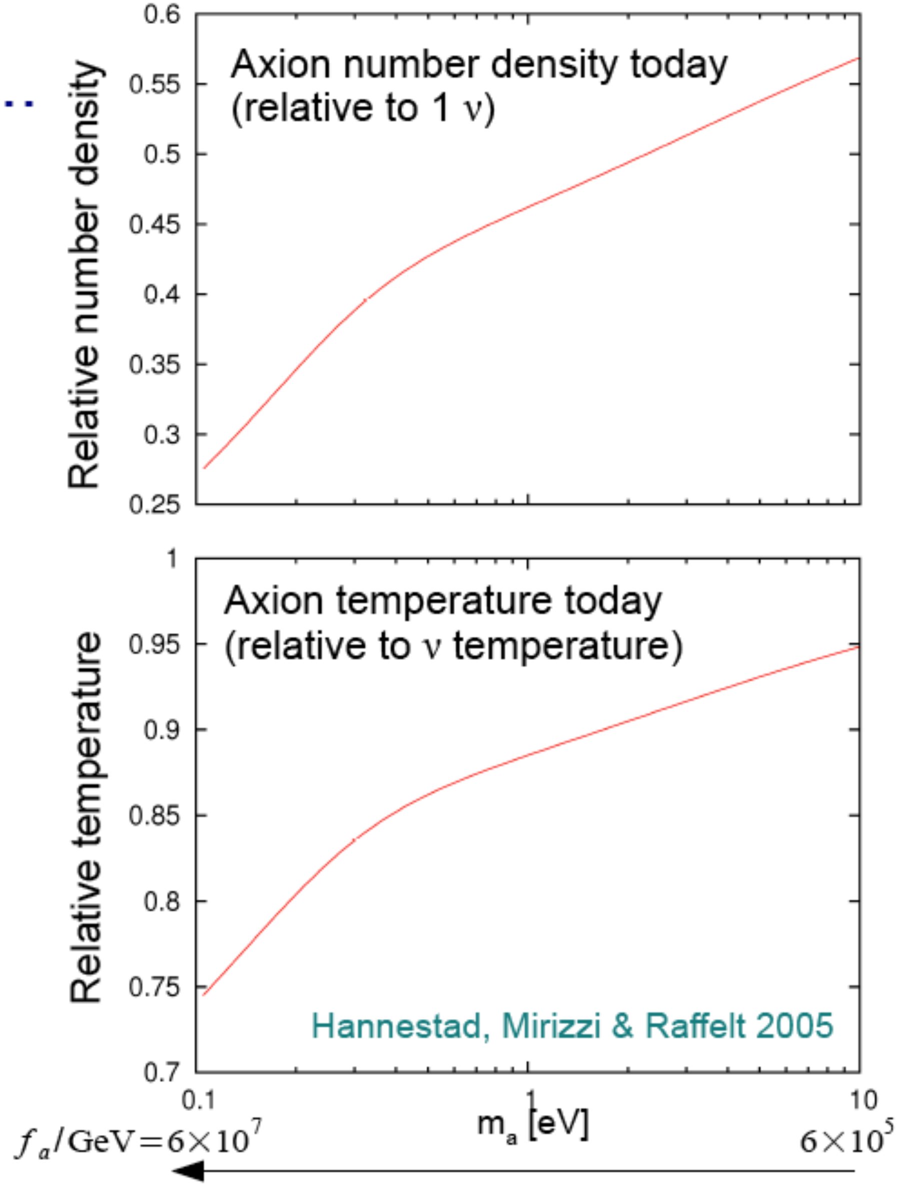
- **Peccei-Quinn scale** $f_a < 10^8$ GeV.
- Axion decoupling occurs **after** QCD phase transition (T < 150 MeV).
  - Dominant processes:

$$\pi + \pi \leftrightarrow \pi + a \qquad a + N \leftrightarrow N + \pi$$

- Can contribute up to

$$\Delta N_{\mathrm{eff}} < 0.57$$

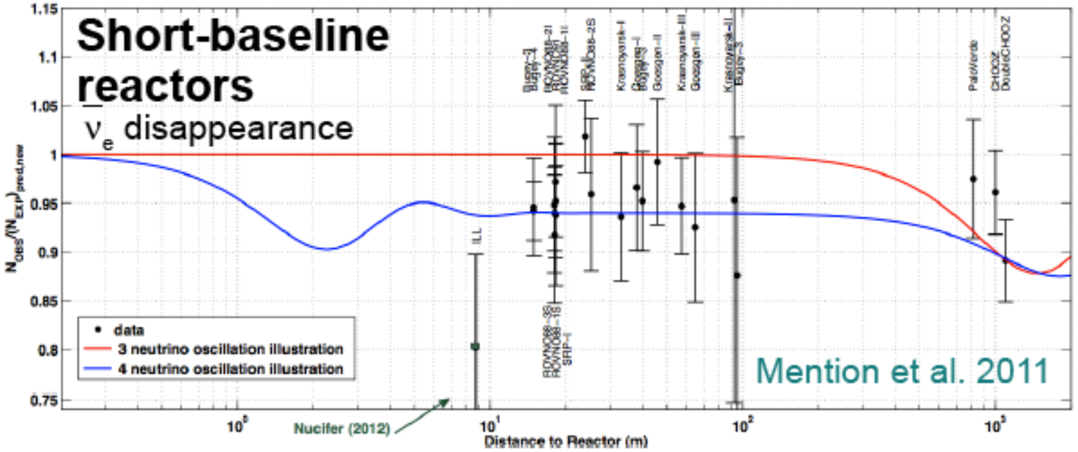
Pseudoscalar = 1 dof, Bose-Einstein statistics;
Axions are a little colder than neutrinos



Hannestad, Mirizzi & Raffelt 2005

Example 2: light sterile neutrinos...

Not coupled to the Z



Two-flavour oscillations:

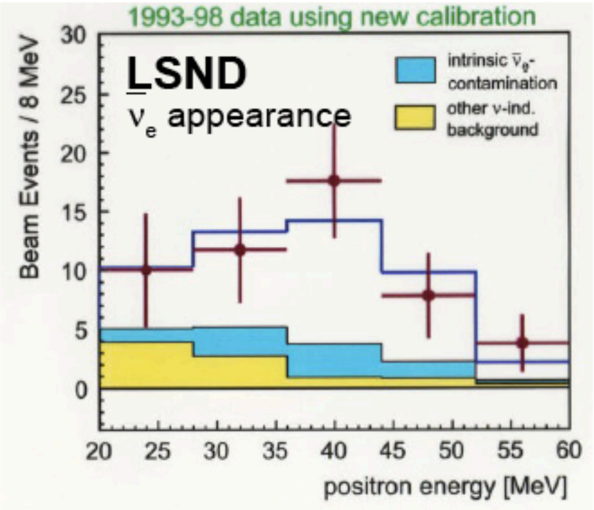
Mass splitting

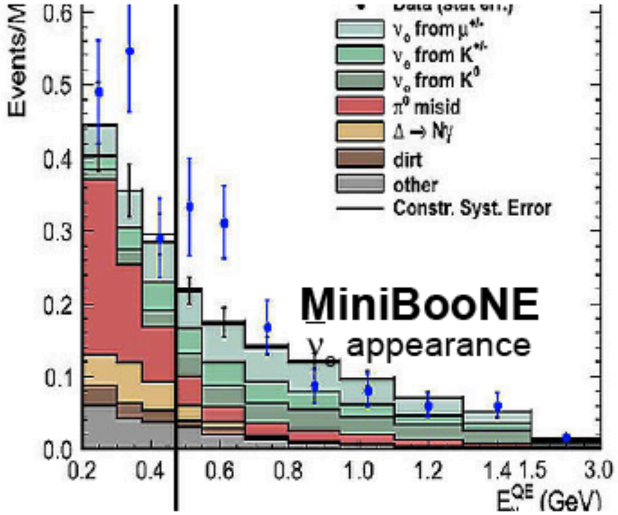
Baseline

$$\mathrm{Prob}_{\alpha\to\beta} = \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

$$\mathrm{Prob}_{\alpha\to\alpha} = 1 - \mathrm{Prob}_{\alpha\to\beta}$$

Energy





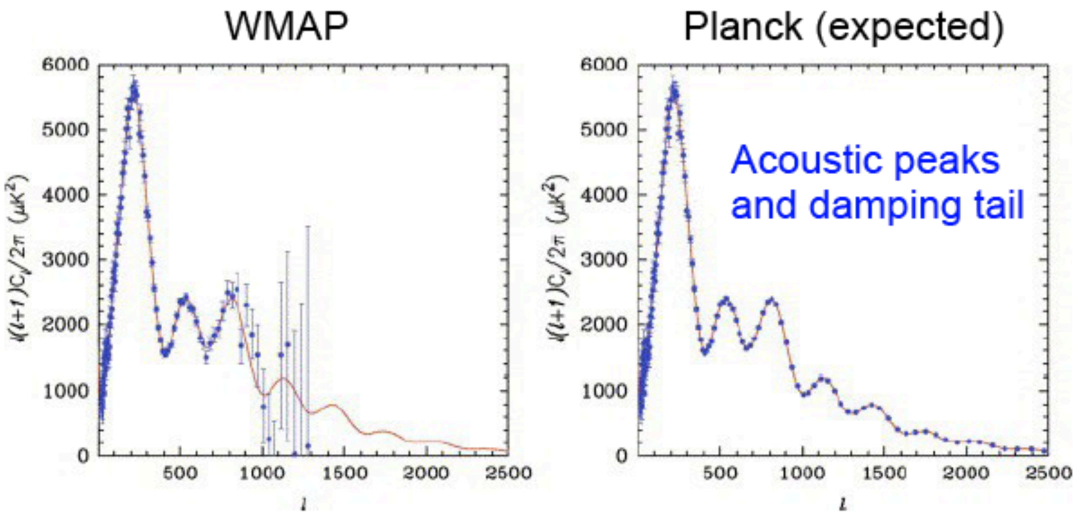
Each anomaly can be individually explained in terms of **active-sterile oscillations** with:

$$\Delta m^2_{\mathrm{SBL}} \sim 1 \to 10\,\mathrm{eV}^2$$

$$\sin^2 2\theta_{\mathrm{SBL}} \sim 10^{-3}$$

Planck and N_{eff}…

- If N_{eff} is as large as 4, it will be settled almost immediately by Planck (launched May 14, 2009; public data release early 2013).



WMAP

Planck (expected)

Acoustic peaks and damping tail

1σ sensitivities

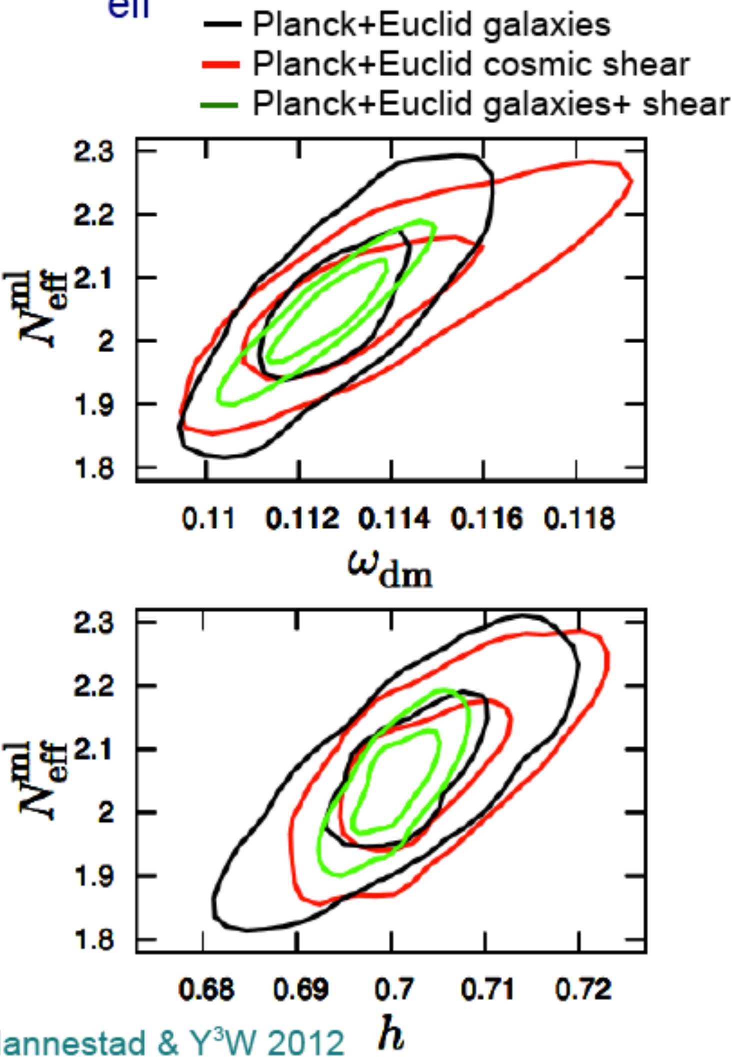
	Planck	P+BAO	P+HPS	P+HST	P+HST+BAO	P+HST+HPS
$\omega_{\rm dm}$	0.22	0.24	0.20	0.21	0.21	0.19
$N_{\rm eff}$	0.21	0.21	0.22	0.21	0.21	0.22
$\sum m_\nu$	0.68	0.81	0.44	0.67	0.73	0.44
w	2.14	1.16	0.72	0.74	0.76	0.55
$n_{\rm S}$	0.46	0.48	0.49	0.46	0.48	0.48

Hamann, Hannestad, Lesgourgues, Rampf & Y^3W 2010

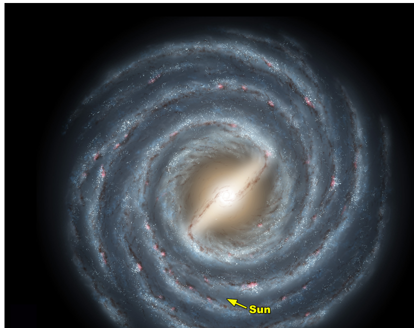
Further down the road: Euclid and N_{eff}...

- **Euclid** will improve Planck's sensitivity to N_{eff} by a factor of ~4 [$\sigma(N_{\mathrm{eff}})$ ~ 0.055].

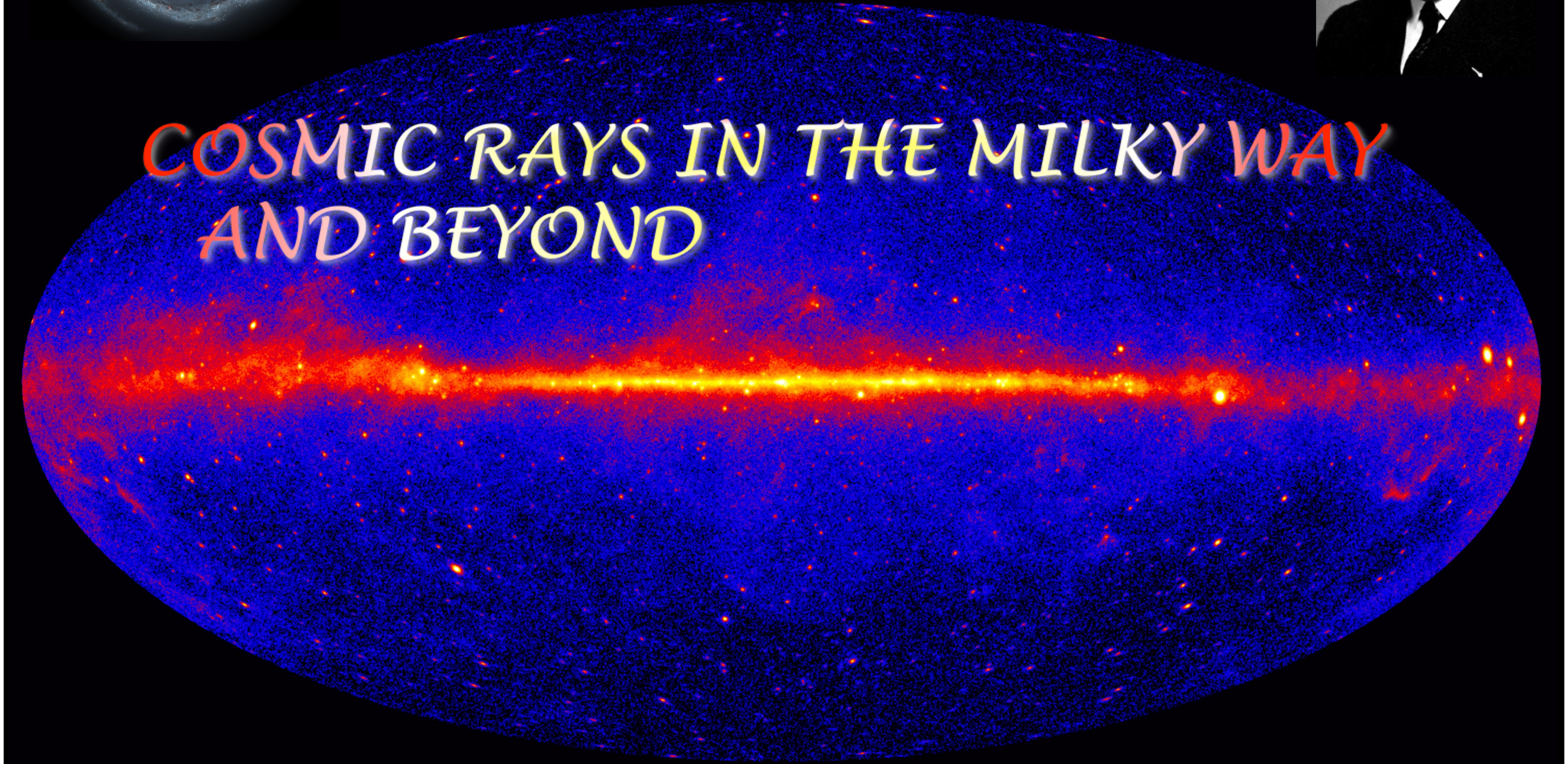
2 Euclid spacecraft concepts



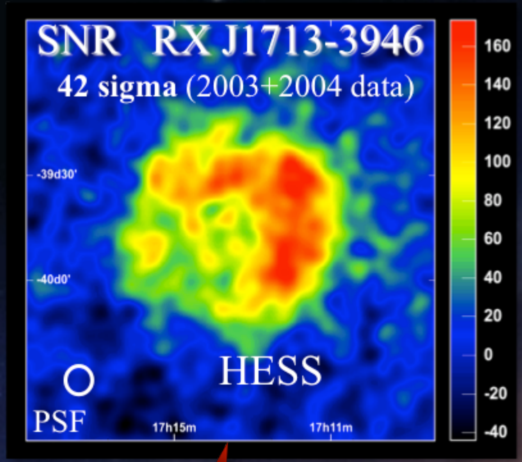
Hamann, Hannestad & Y^3W 2012

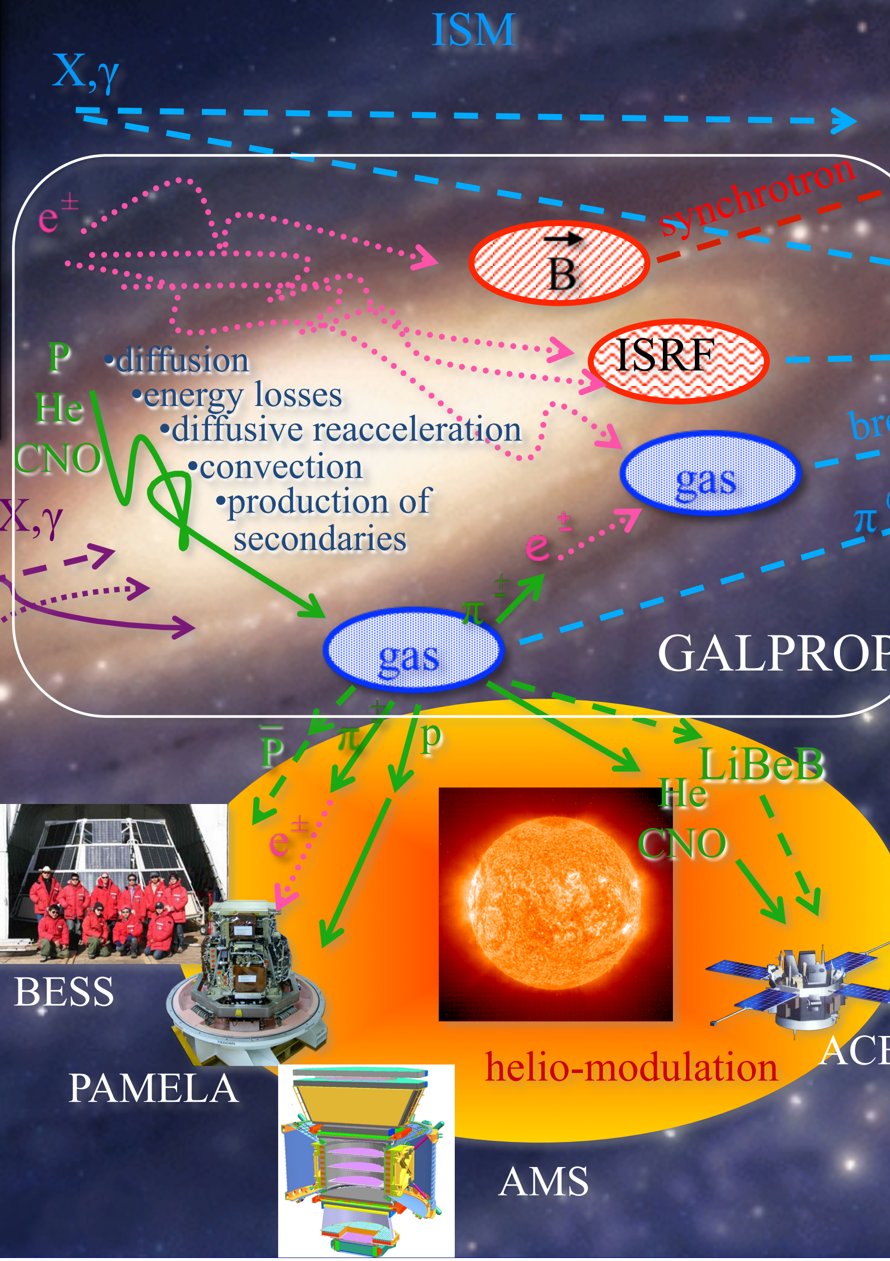


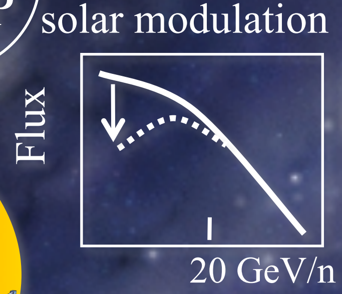
COSMIC RAYS IN THE MILKY WAY AND BEYOND

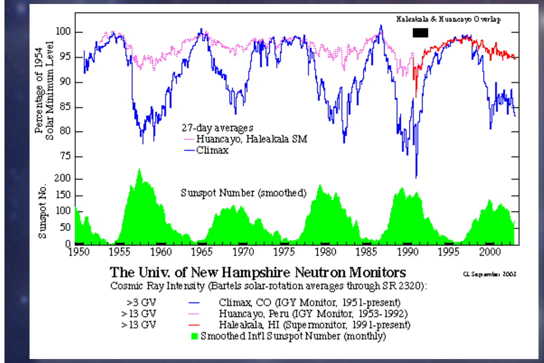


CRs in the interstellar medium







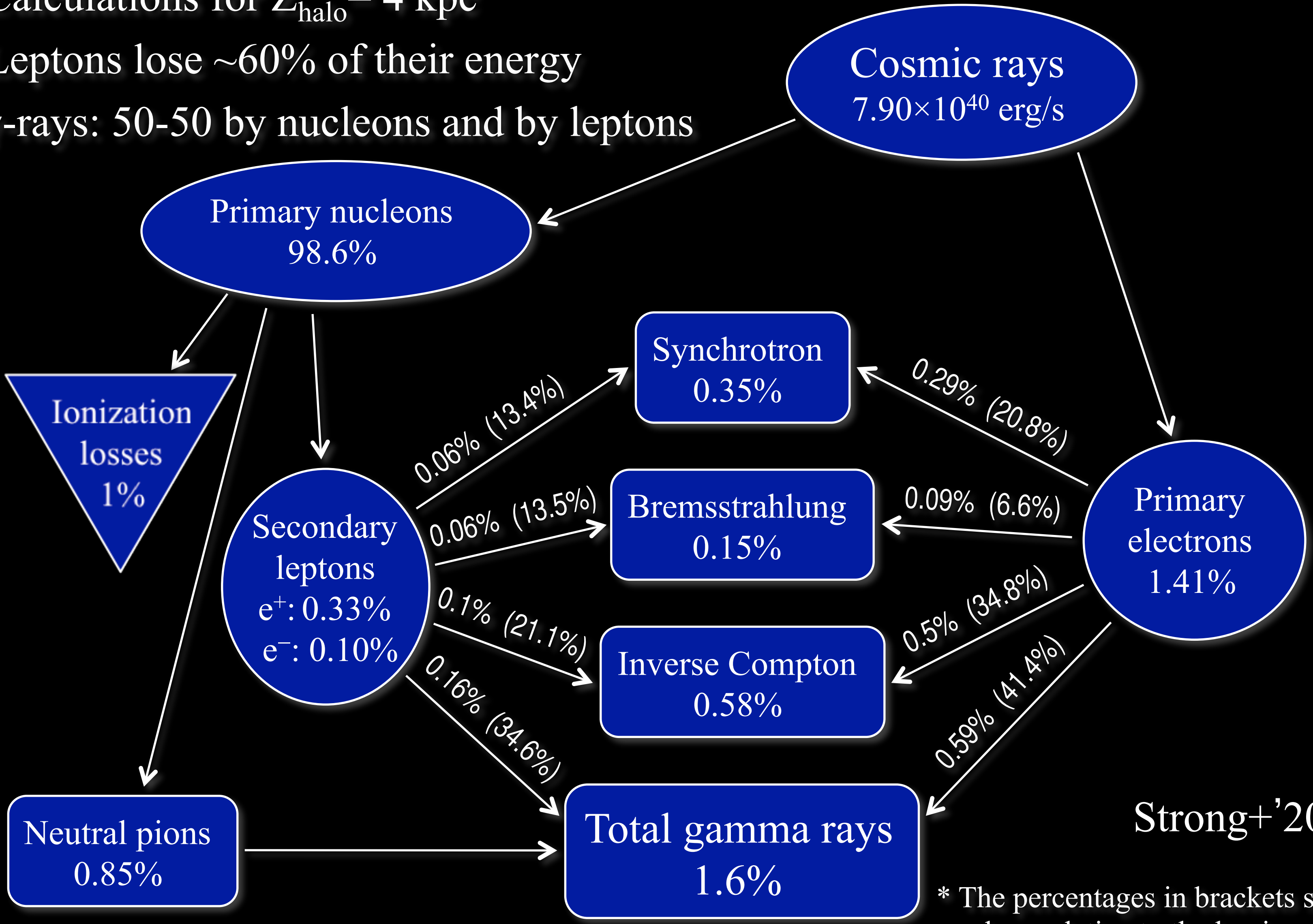


The Univ. of New Hampshire Neutron Monitors
Cosmic Ray Intensity (Bartels solar-rotation averages through SR 2320):
>3 GV Climax, CO (IGY Monitor, 1951-present)
>13 GV Huancayo, Peru (IGY Monitor, 1953-1992)
>13 GV Haleakala, HI (Supermonitor, 1991-present)
Smoothed Int'l Sunspot Number (monthly)

CR species:
- Only 1 location
- modulation

Milky Way as an electron calorimeter

- ✧ Calculations for Z_{halo}= 4 kpc
- ✧ Leptons lose ~60% of their energy
- ✧ γ-rays: 50-50 by nucleons and by leptons



Cosmic rays
7.90×10^{40} erg/s

Primary nucleons
98.6%

Ionization
losses
1%

Secondary
leptons
e^+: 0.33%
e^-: 0.10%

Primary
electrons
1.41%

Synchrotron
0.35%

Bremsstrahlung
0.15%

Inverse Compton
0.58%

Neutral pions
0.85%

Total gamma rays
1.6%

0.06% (13.4%)

0.06% (13.5%)

0.1% (21.1%)

0.16% (34.6%)

0.29% (20.8%)

0.09% (6.6%)

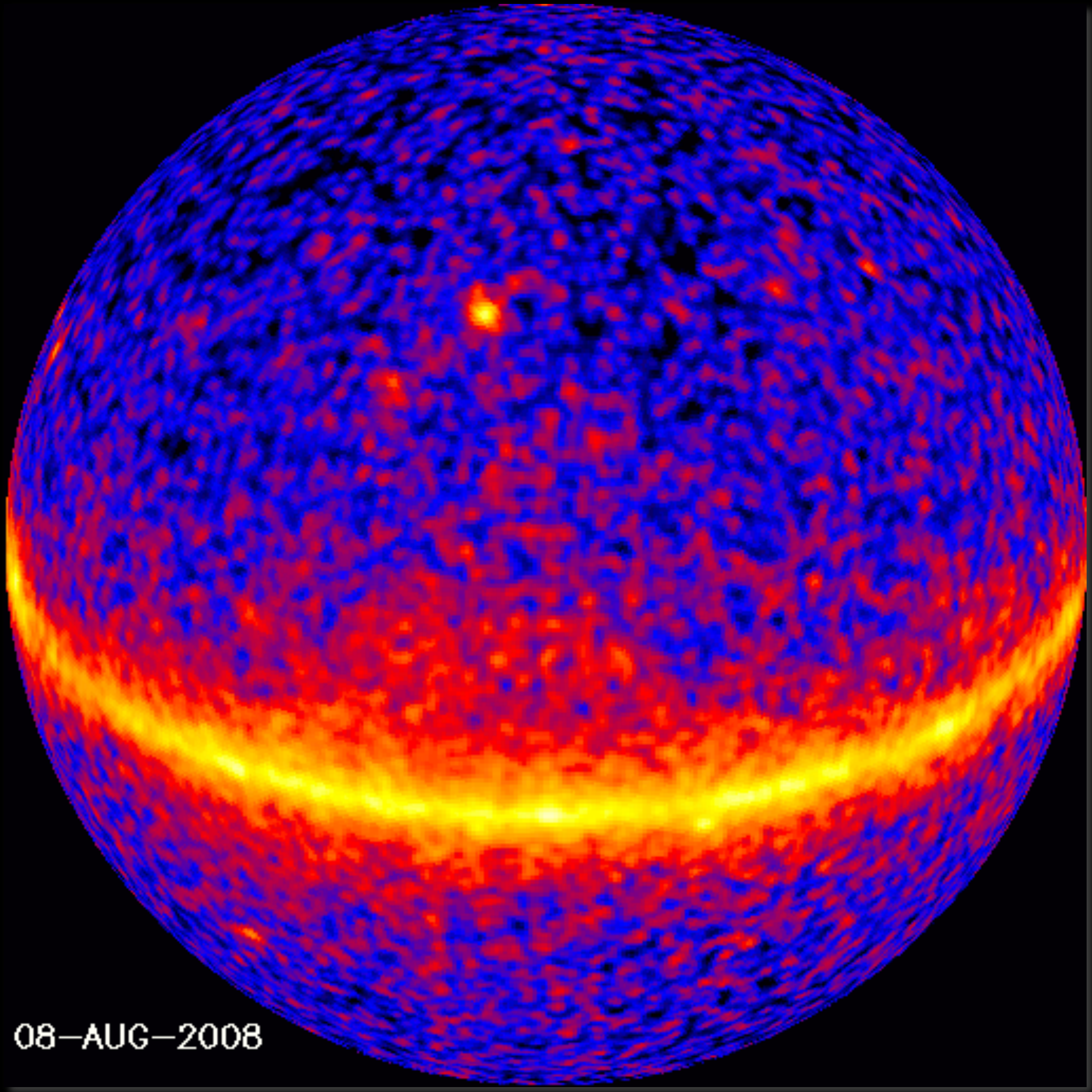
0.5% (34.8%)

0.59% (41.4%)

Strong+'2011

* The percentages in brackets show the values relative to the luminosity of their respective lepton populations

Fermi's skymap of particle interactions

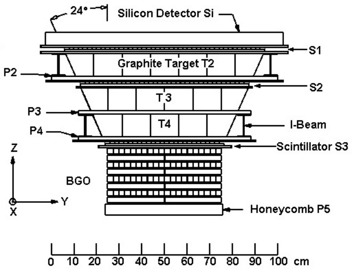


- ✧ >100 MeV, 36 months
- ✧ shows where accelerated particles meet target (gas, photons)
- ✧ ~80% of the emission is diffuse
- ✧ many transients in the γ-ray sky

Space Missions and LDF

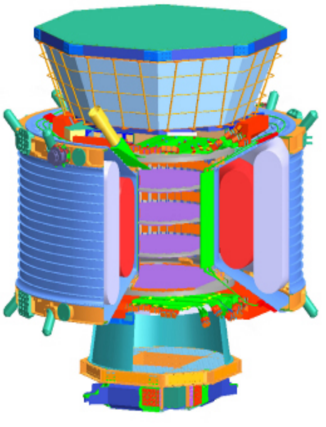
PAMELA
15-06-2006

ATIC
2002 - 2007



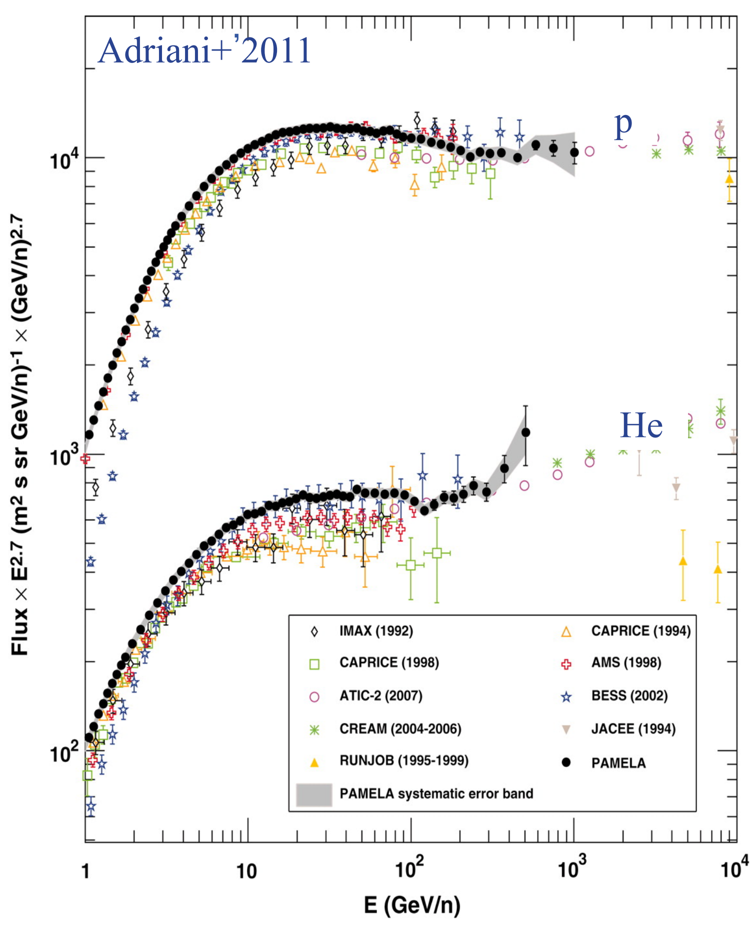
BESS
13-12-2004
23-12-2007

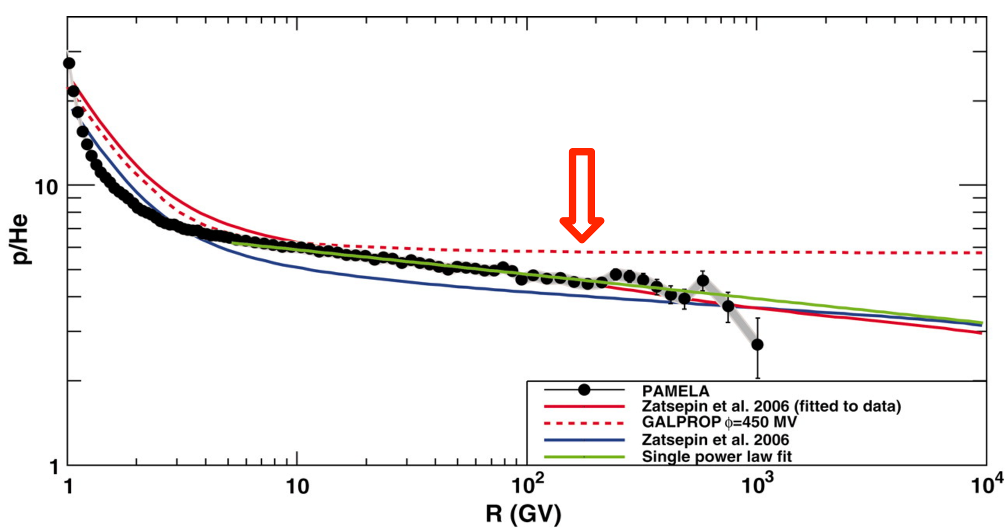
AMS-02
16 -5-2011



Fermi/GLAST
11-6-2008

Break in the CR p and He absolute fluxes



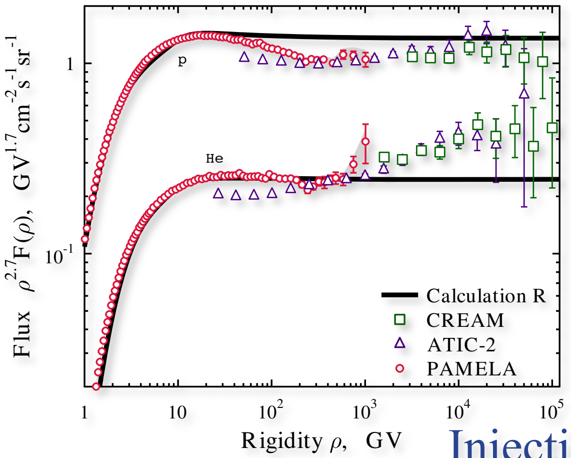


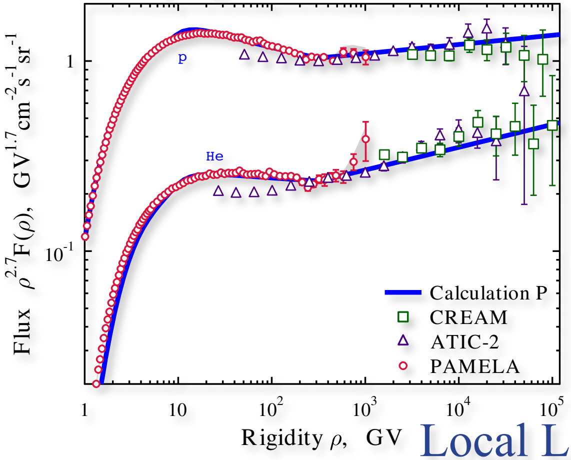
- ✧ Data from several experiments (BESS, AMS-01, ATIC'2009, CREAM'2010, PAMELA'2011) are all consistent and indicate spectral hardening above ~100 GeV/nucleon
- ✧ p/He ratio vs. rigidity R is smooth
- ✧ He spectrum is flatter than proton spectrum
- ✧ Heavier nuclei seem to share the same trend
- ✧ New data may provide us with a hint to the

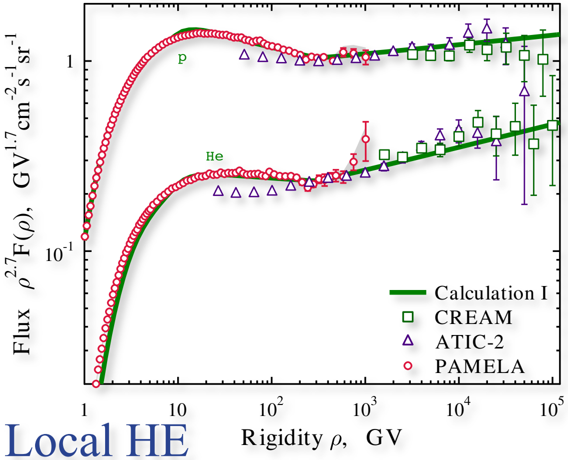
P and He spectra

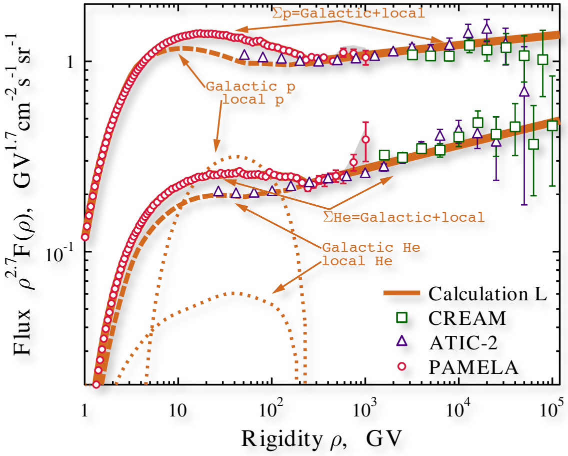
- ✧ All scenarios are tuned to the data, except the Reference scenario
- ✧ Scenarios L and H: the local source component is calculated by the subtraction of the propagated Galactic spectrum from the data
- ✧ The local source is assumed to be close to us, so no propagation; only primary CR species

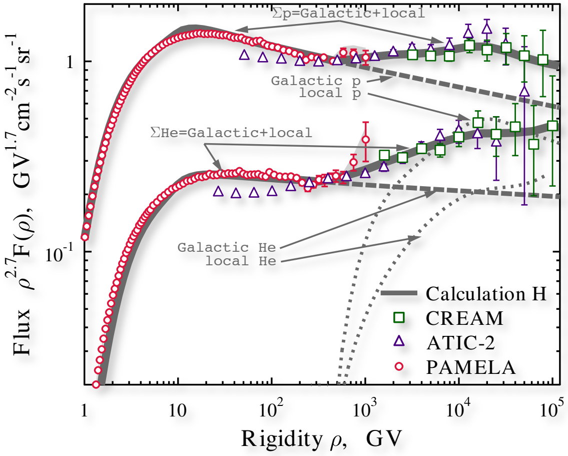
Vladimirov+’2012, ApJ 752, 68



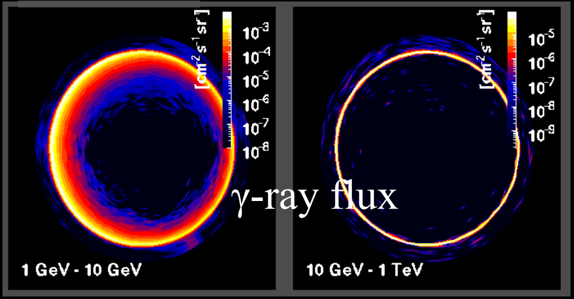


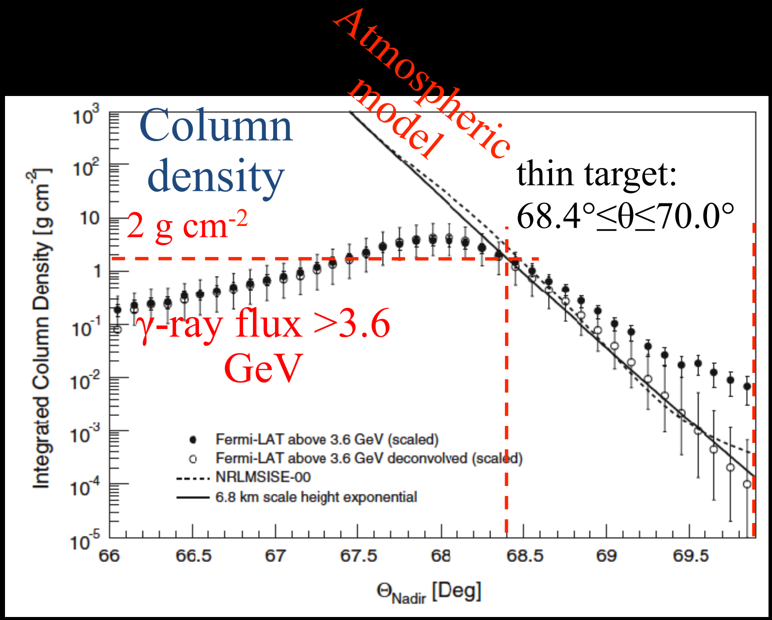


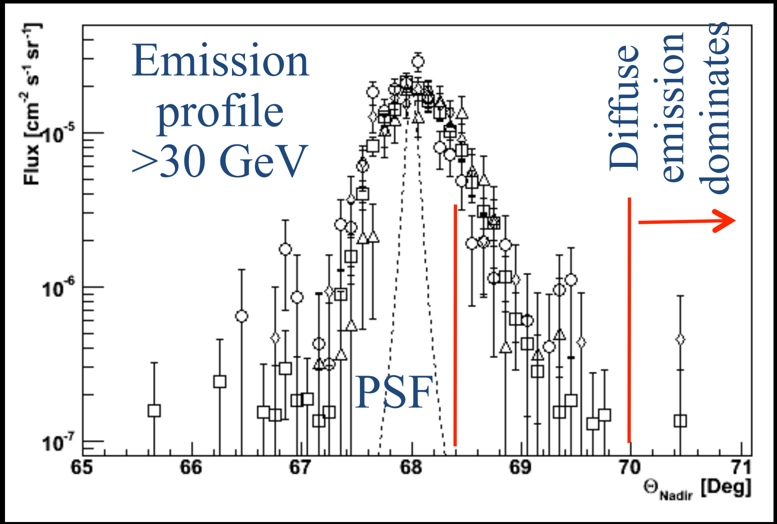


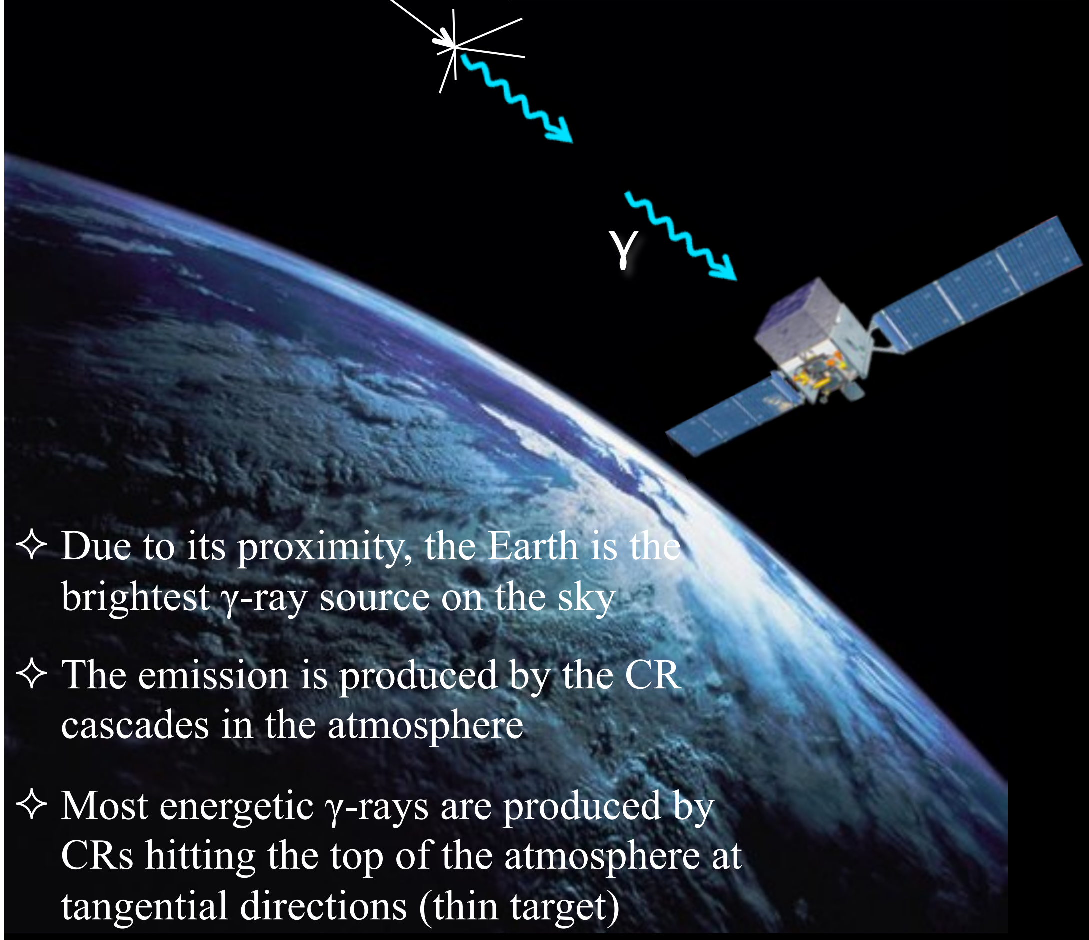


Fermi-LAT observations of the Earth’s limb



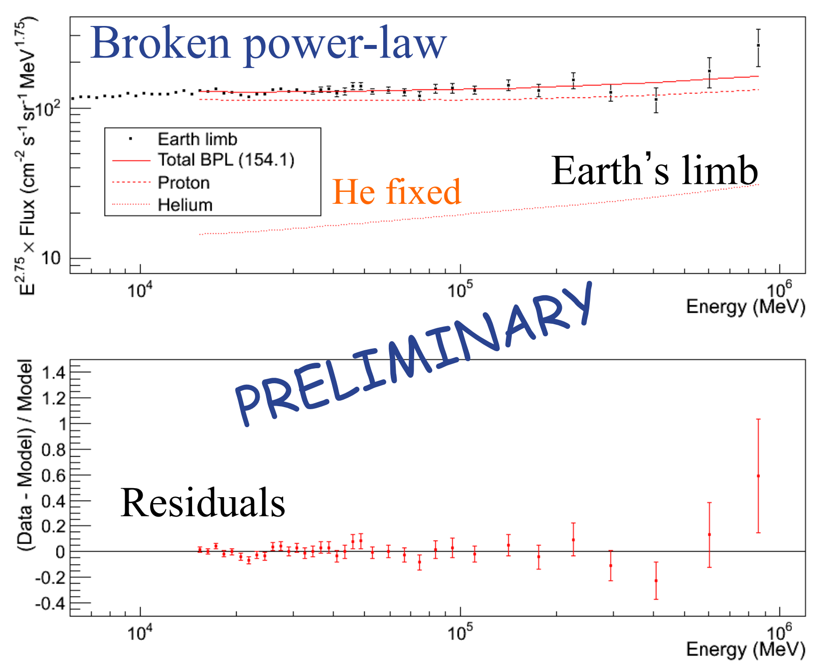


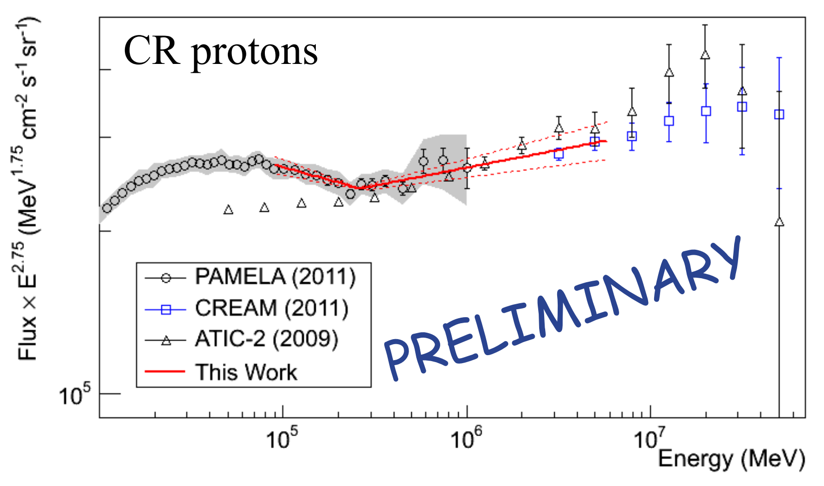




- ✧ Due to its proximity, the Earth is the brightest γ-ray source on the sky
- ✧ The emission is produced by the CR cascades in the atmosphere
- ✧ Most energetic γ-rays are produced by CRs hitting the top of the atmosphere at tangential directions (thin target)

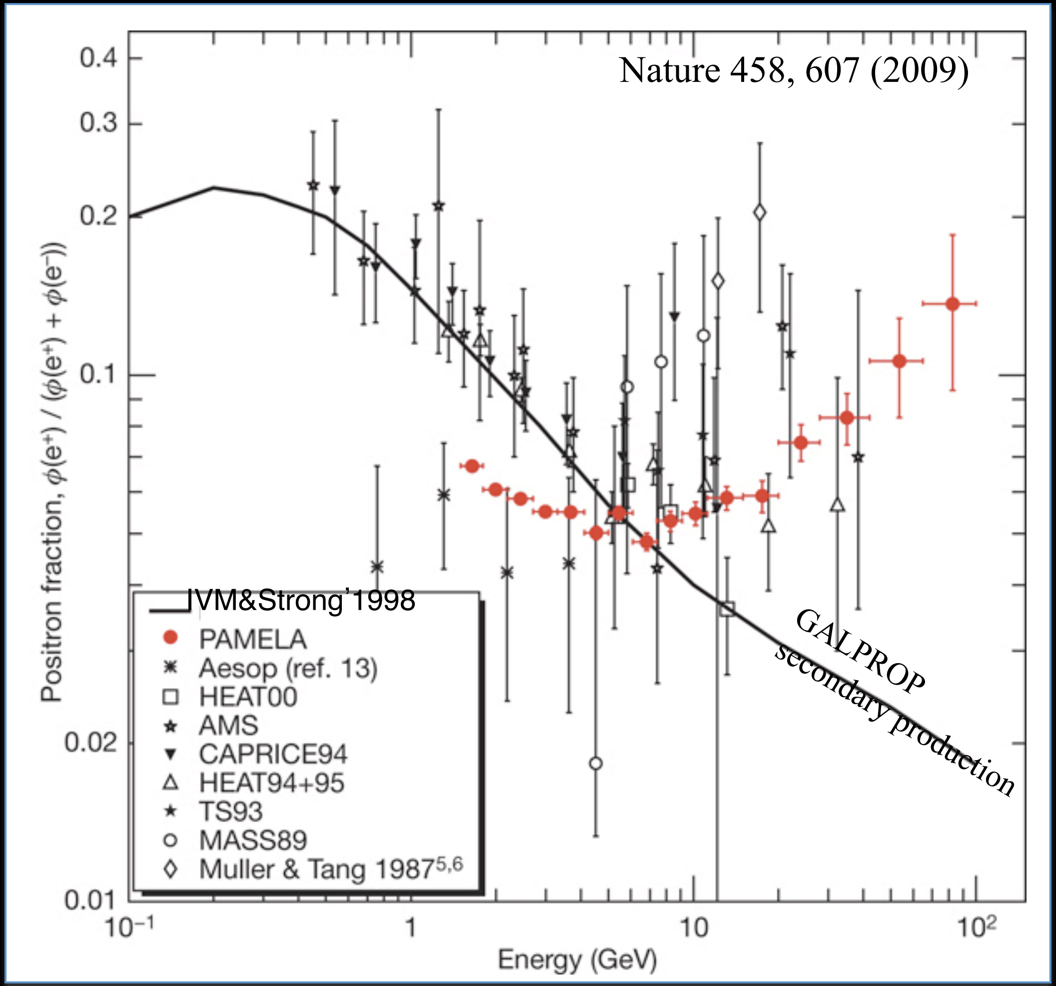
Inferring the CR spectrum - II





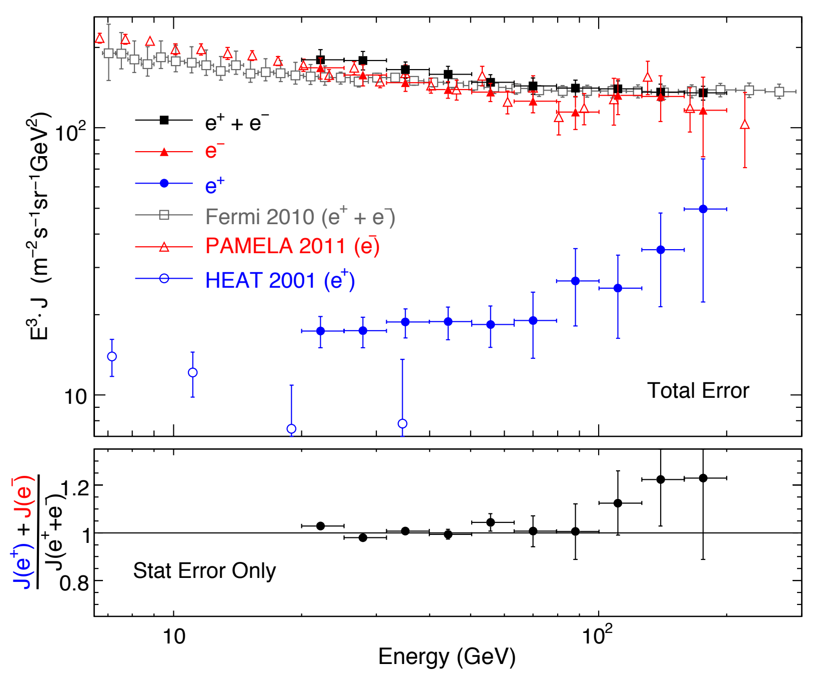
- ✧ Broken power-law provides the best fit with indices 2.84±0.03 / 2.68±0.02 below/above the break at 264±19 GeV
- ✧ In perfect agreement with direct CR measurements! cf. PAMELA: 2.85±0.015±0.004 / 2.67±0.03±0.05, break at 232+35-30 GV
- ✧ A single power-law with index 2.74±0.01 can't be ruled out yet
- ✧ Fermi-LAT continues to collect data: more statistics, and extension to higher energies
- ✧ Can be used for instrument

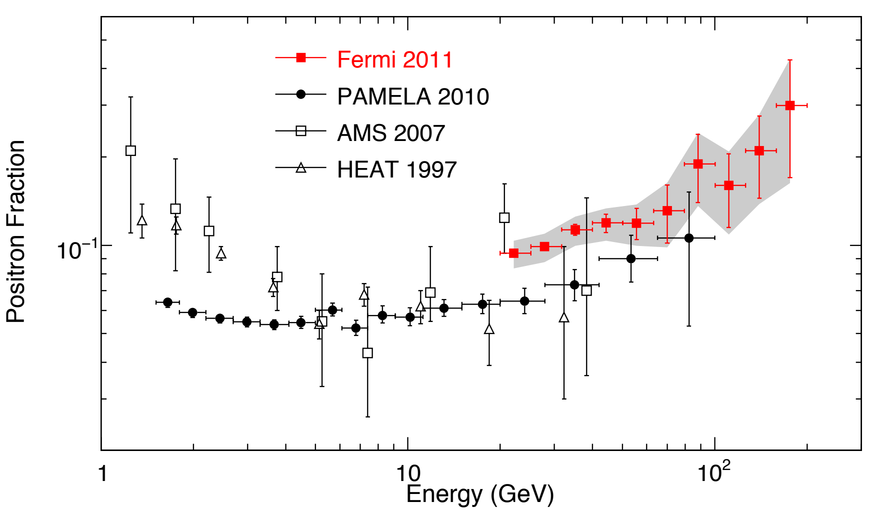
PAMELA data show rise in the positron fraction

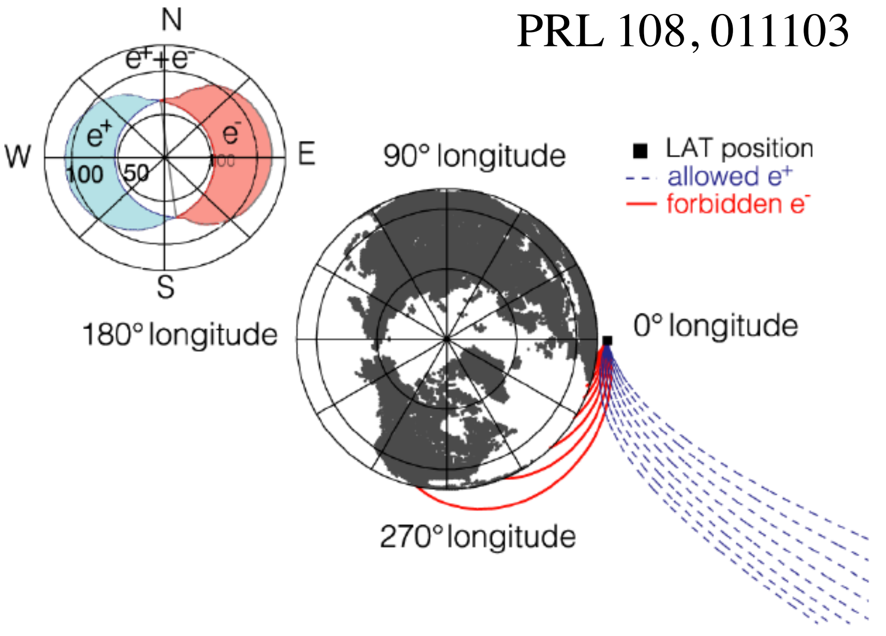


- ✧ PAMELA team reported a rise in the positron fraction perhaps due to “primary” positrons
- ✧ So unexpected, it can’t be true!
- ✧ Possible explanations:
  - ✦ primary astrophysical sources (e.g., pulsars)
  - ✦ dark matter
  - ✦ nonstandard secondary production (e.g., in the SNR shock)

Fermi-LAT: e^+ & e^- fluxes and positron fraction

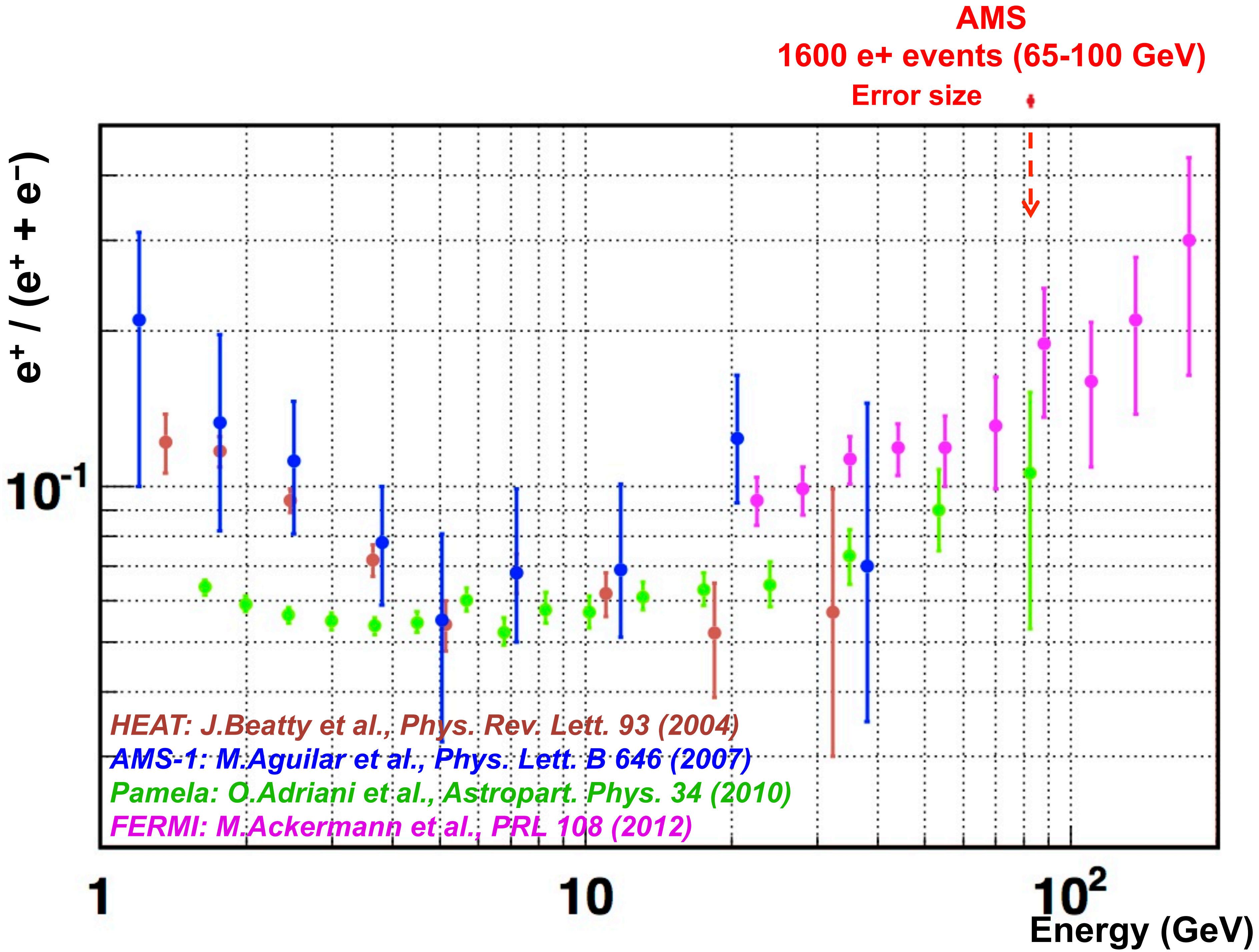





PRL 108, 011103

- State-of-the-art: Fermi-LAT does not have a magnet, but used geomagnetic field
- Measured absolute fluxes of e^+ & e^-
- Fraction = $\phi(e^+) / [\phi(e^+) + \phi(e^-)]$
- Confirmed rise in the positron fraction
- Extended measurements up to 200 GeV

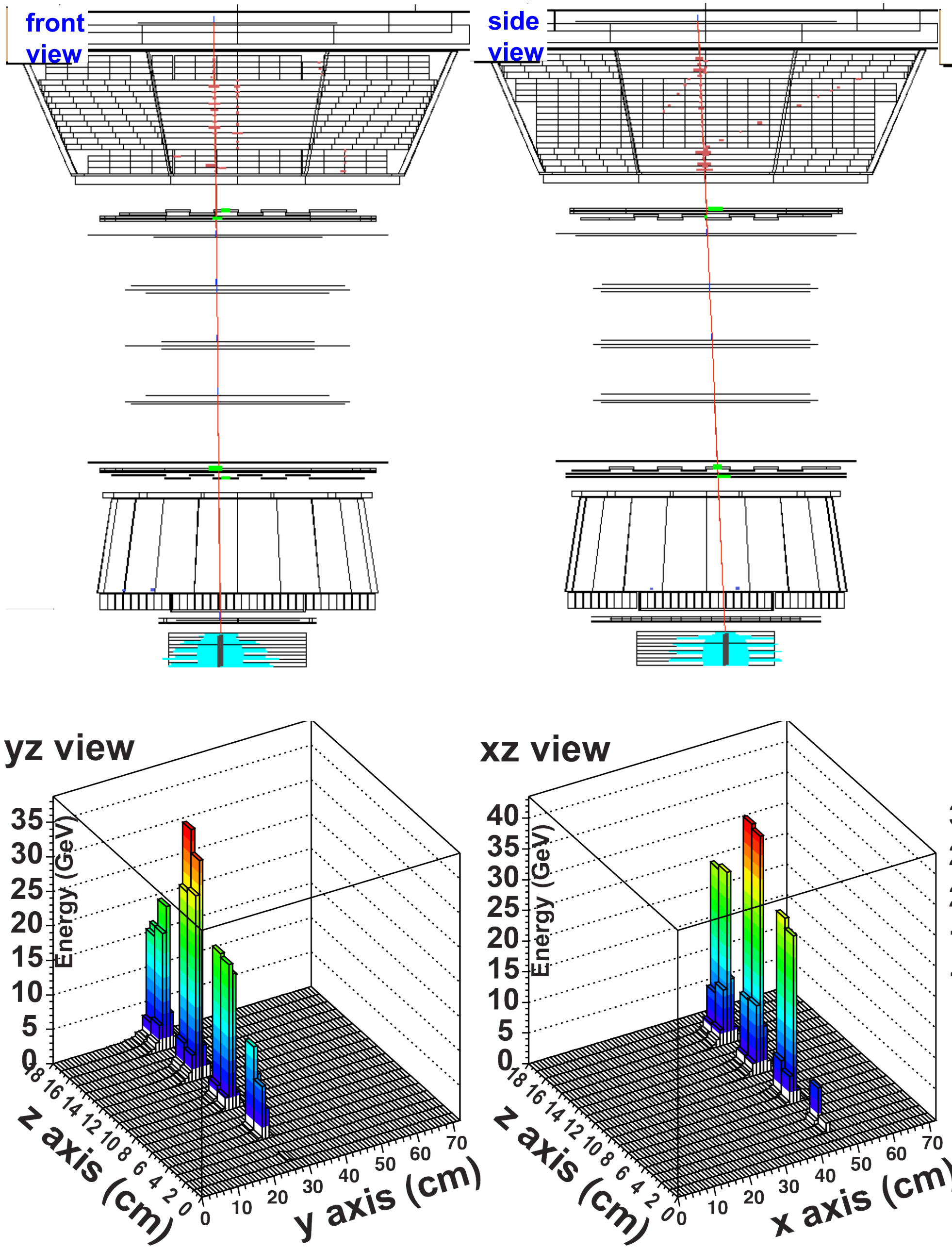
TRD Pump temperature



AMS
1600 e+ events (65-100 GeV)
Error size

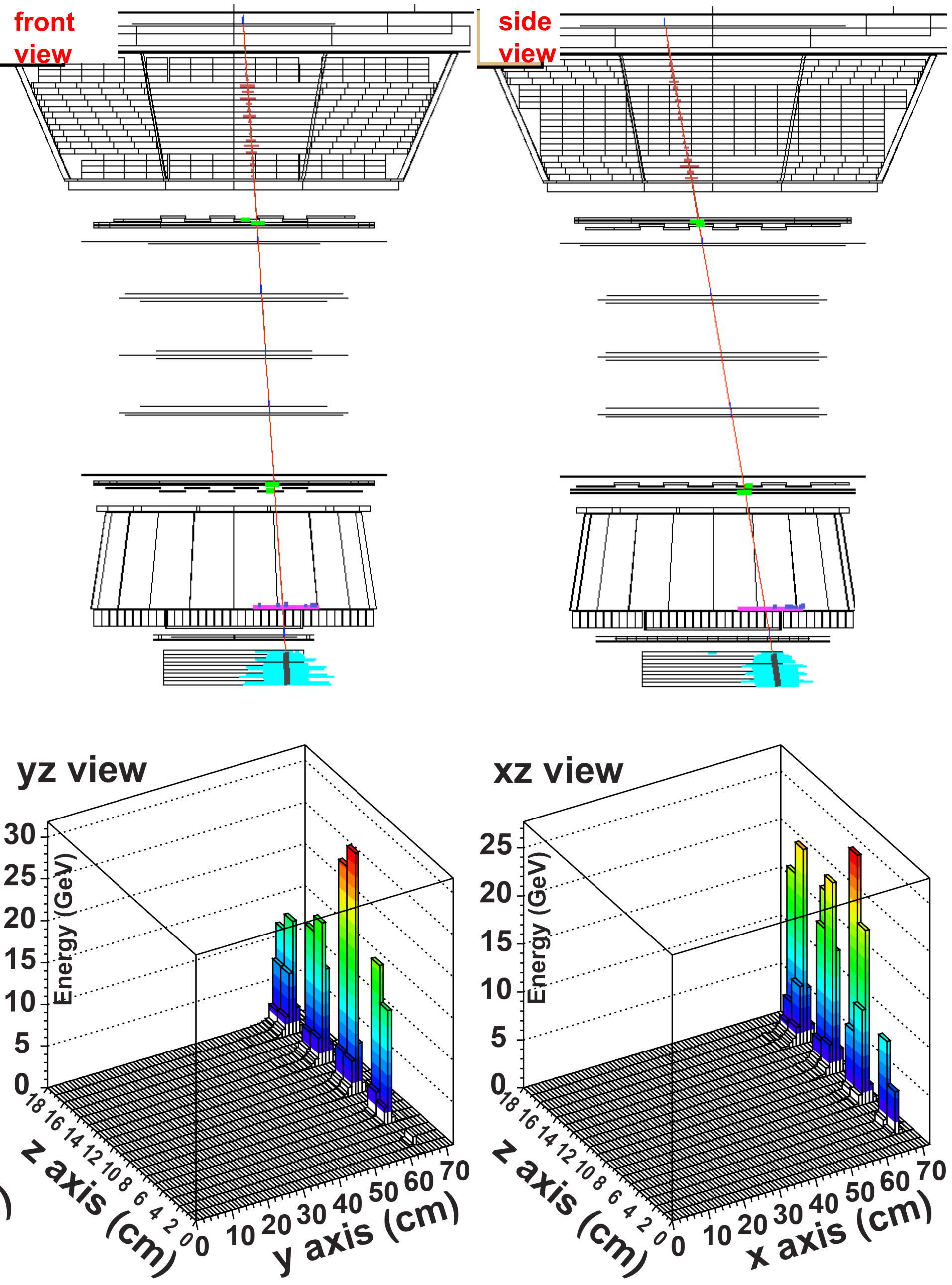
Electron E=982 GeV

Run/Event 1329775818/ 60709



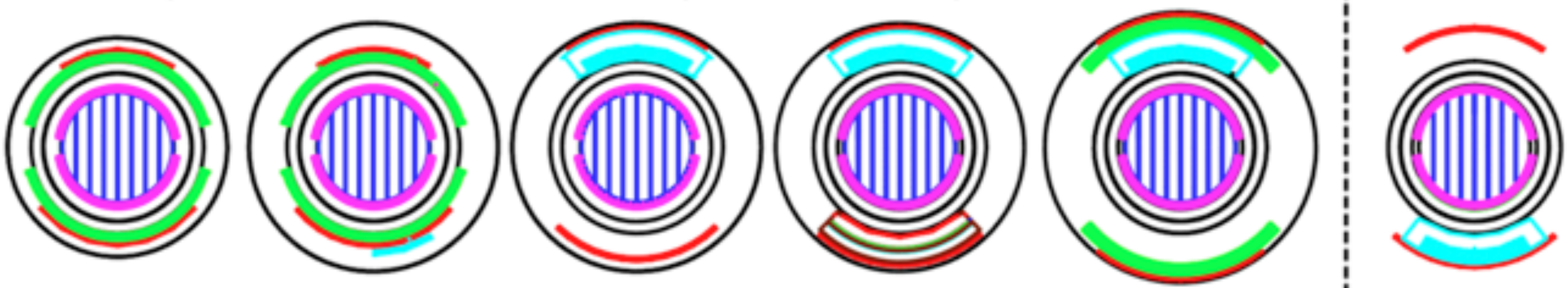
Positron E=636 GeV

Run/Event 133119-743/ 56950



Evolution of BESS

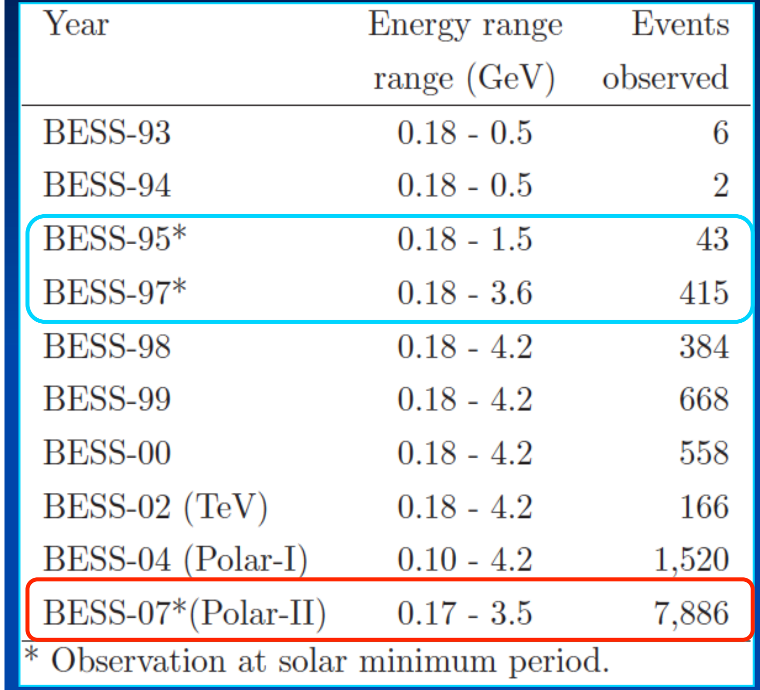
- Nine northern latitude flights (1+ days) 1993-2002 and two Antarctic flights in 2004 (8.5 days) and 2007 (24.5 days)
- Including BESS-Polar I and II: **11,643 antiprotons** reported 0.2 - 4.2 GeV



				2001, 2002	2004, 2007
BESS-93,94	BESS-95	BESS-97,98	BESS-99,00	BESS-TeV	BESS-Polar
	Larger Vessel			Larger Vessel	No Vessel
σ_{TOF} =300 ps	σ_{TOF} =110 ps	σ_{TOF} =70 ps Aerogel C 97 n=1.03 $\bar{p}$ 0.2-3.5 GeV 98 n=1.02	Shower Counter $2X_0$ Lead e/μ sep.	New ODC's New JET/IDC's p/He up to 1 TeV	New Mag (ultra thin)
$\bar{p}$ 0.2-0.6 GeV	$\bar{p}$ 0.2-1.4 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.2-4.2 GeV	$\bar{p}$ 0.1-4.2 GeV
$\bar{p}$ 6, 2	43	415, 398	668, 558	147	1,512, 7,886

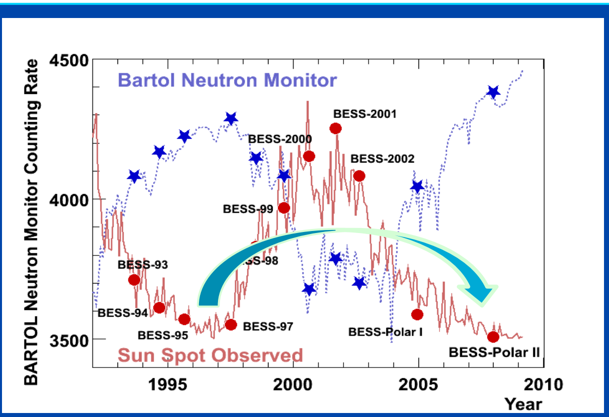
Maximizing advantages with balloon experiments

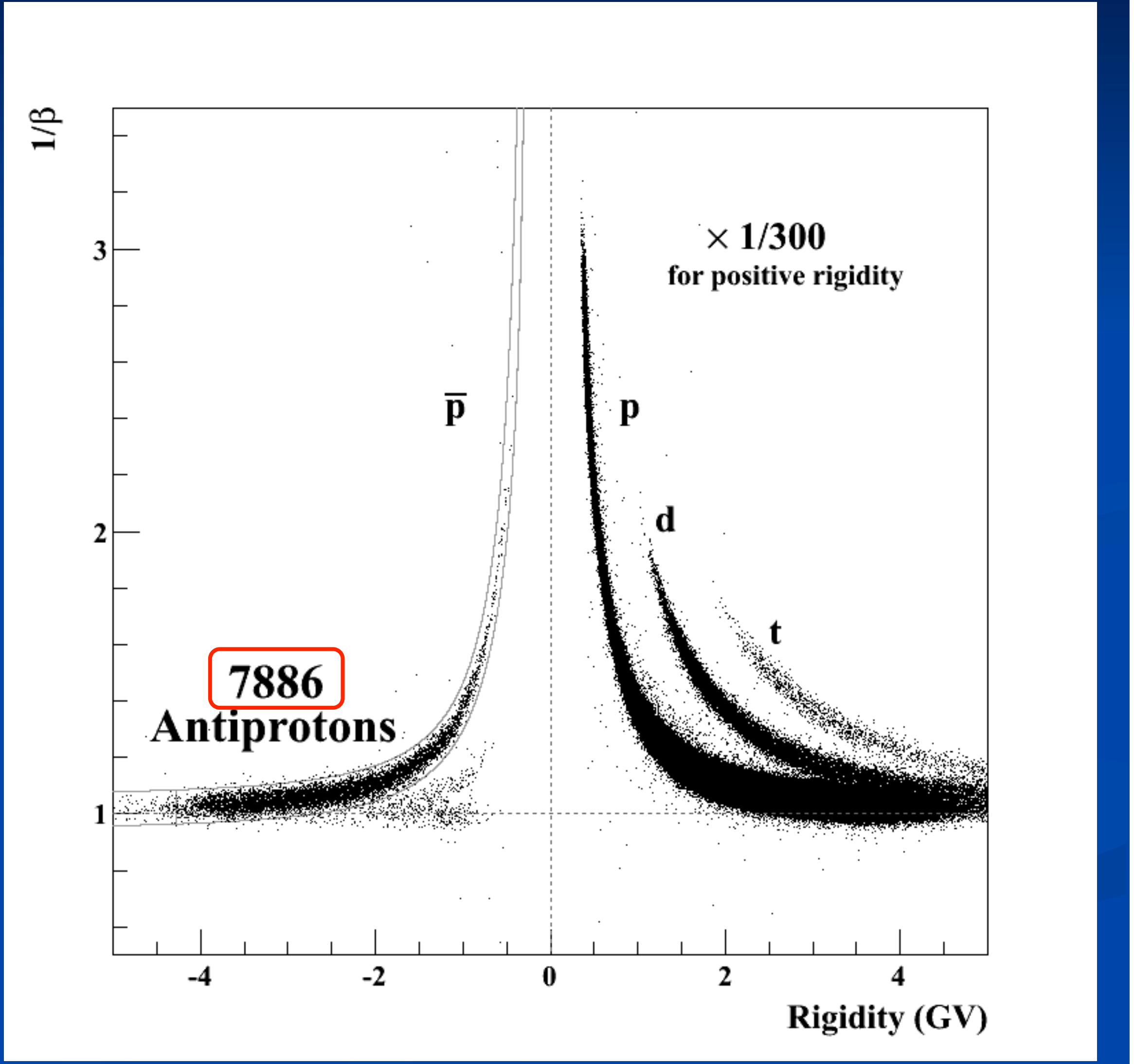
Particle Identification
in BESS-Polar II



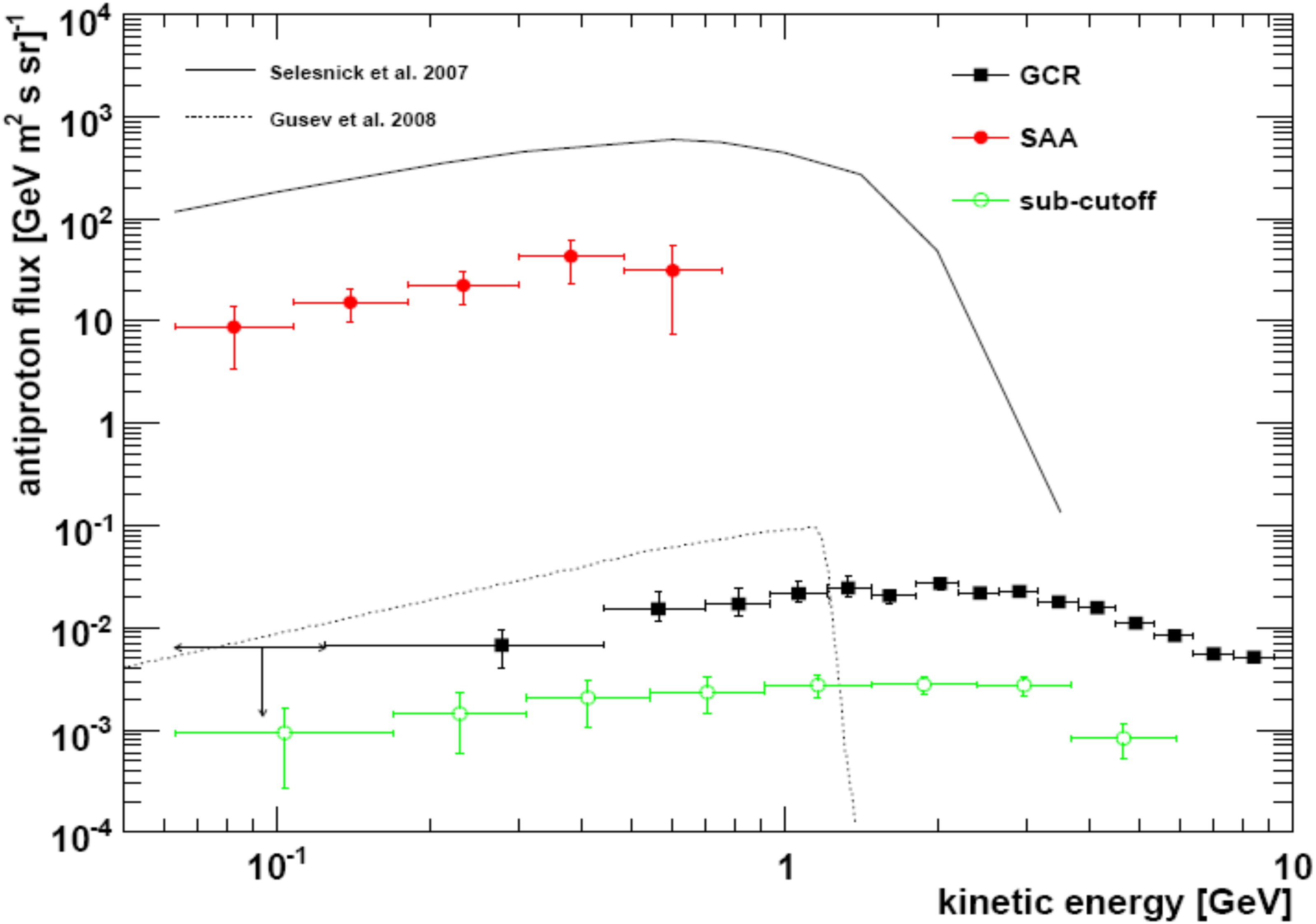
Year	Energy range range (GeV)	Events observed
BESS-93	0.18 - 0.5	6
BESS-94	0.18 - 0.5	2
BESS-95*	0.18 - 1.5	43
BESS-97*	0.18 - 3.6	415
BESS-98	0.18 - 4.2	384
BESS-99	0.18 - 4.2	668
BESS-00	0.18 - 4.2	558
BESS-02 (TeV)	0.18 - 4.2	166
BESS-04 (Polar-I)	0.10 - 4.2	1,520
BESS-07*(Polar-II)	0.17 - 3.5	7,886

* Observation at solar minimum period.





PAMELA trapped antiprotons

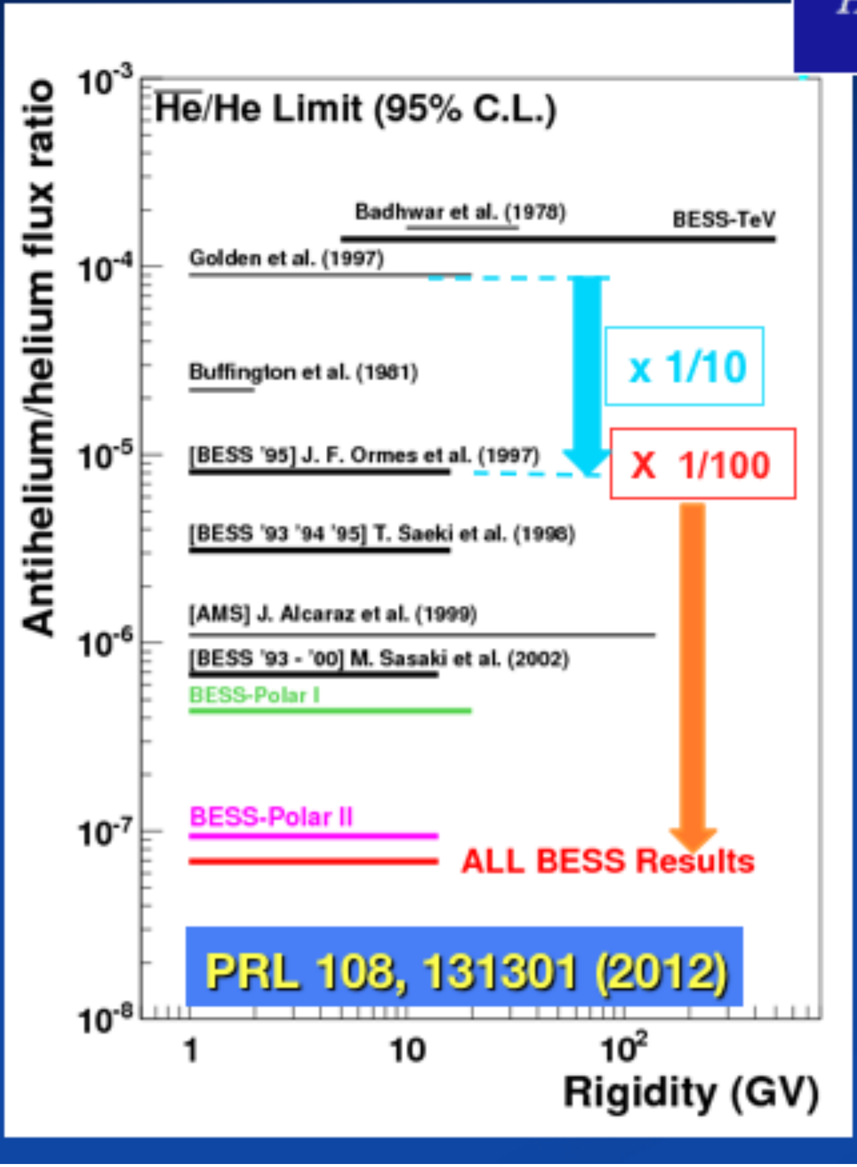


O. Adriani et al., APJL 737 L29 (2011); arXiv:1107.4882

ICRC##1029

Search for Anti-He: BESS & BESS-Polar

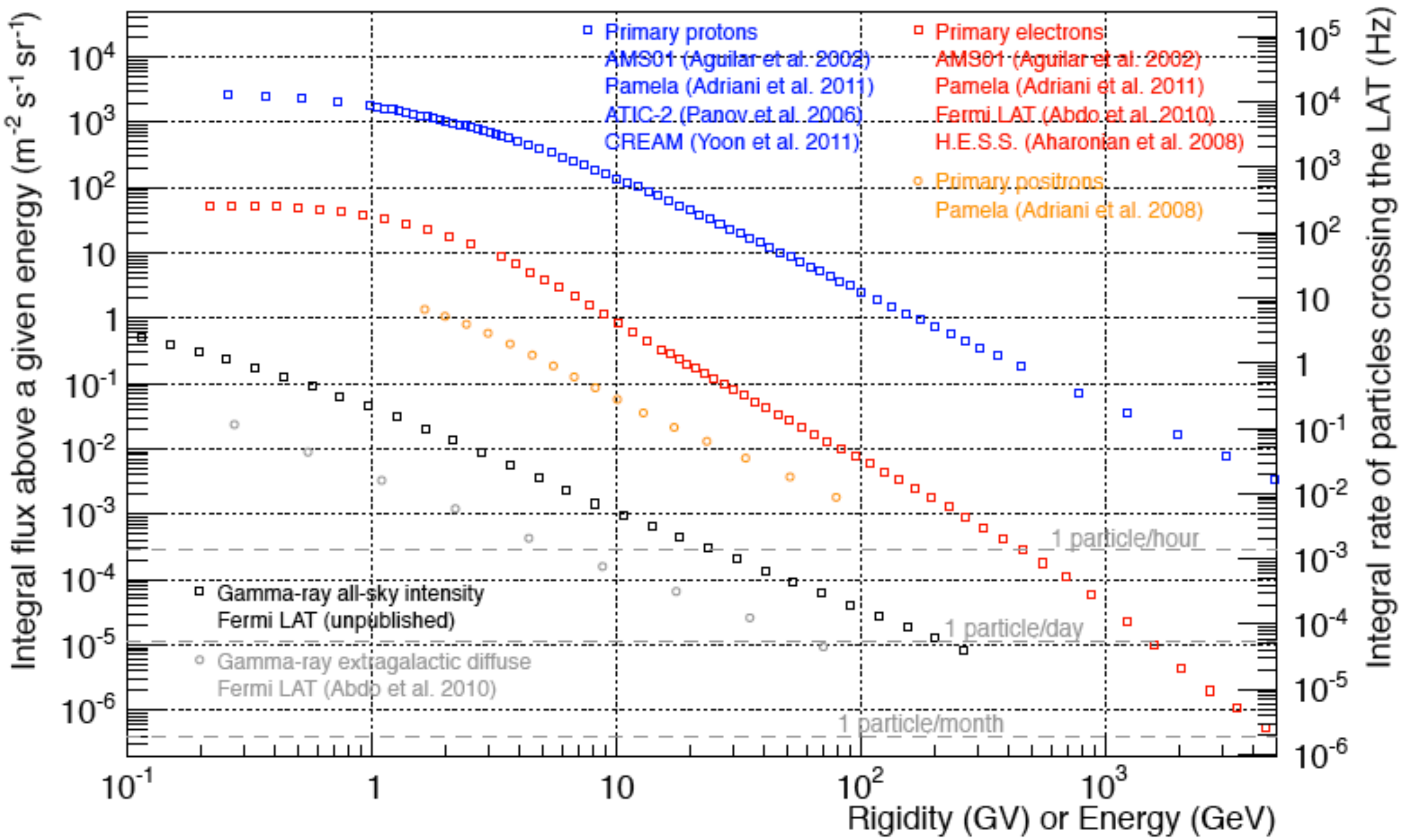
$$R_{\overline{He}/He} = \frac{3.1}{\int N_{obs} \cdot \frac{\bar{\eta}}{\eta} \cdot \frac{\bar{\varepsilon}_{single}}{\varepsilon_{single}} \cdot \frac{\bar{\varepsilon}_{Q-ID}}{\varepsilon_{Q-ID}} dE}$$



PRL 108, 131301 (2012)

- BESS-Polar I:
  Upper limit: 4.4 x 10^{-7}.
- BESS-Polar II
  Upper limit: 9.4 x 10^{-8}
- All-BESS results combined:
  Upper limit: 6.9x 10^{-8}
  (1x10^{-7} w/o spectrum assumption)
- This limit is improved by *three orders of magnitude* over first reported limits

STATISTICS MATTER AT HIGH ENERGY



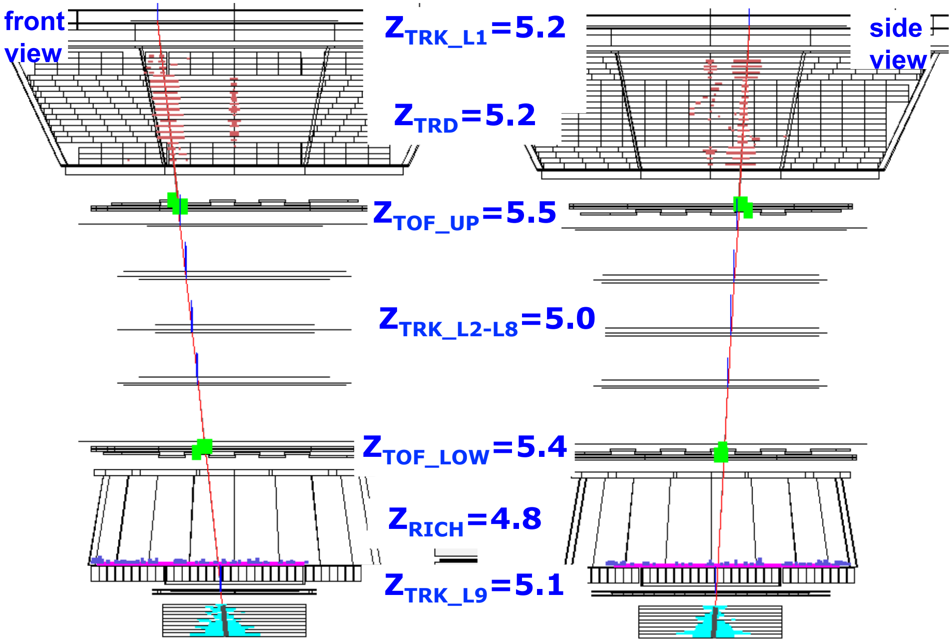
- Both for point source and diffuse studies
  - (e.g., $\sim$ 1 EGB γ-ray per week above 100 GeV)

Rigidity ~ 700 GV

Boron

Rigidity=680 GV

Run/Event 1319990213/ 235892



$Z_{TRK\_L1}=5.2$

$Z_{TRD}=5.2$

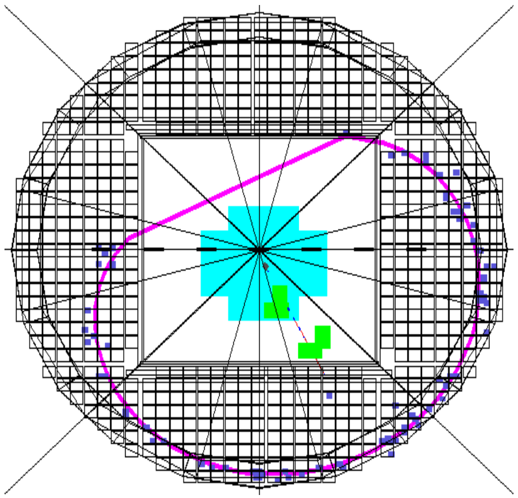
$Z_{TOF\_UP}=5.5$

$Z_{TRK\_L2-L8}=5.0$

$Z_{TOF\_LOW}=5.4$

$Z_{RICH}=4.8$

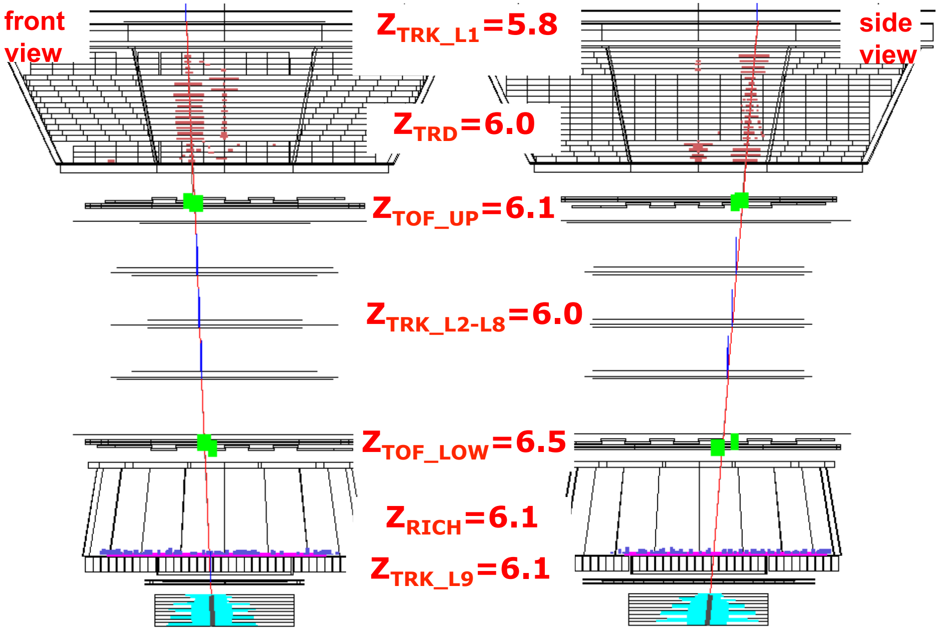
$Z_{TRK\_L9}=5.1$



Carbon

Rigidity=666 GV

Run/Event 1327184805/ 266043



$Z_{TRK\_L1}=5.8$

$Z_{TRD}=6.0$

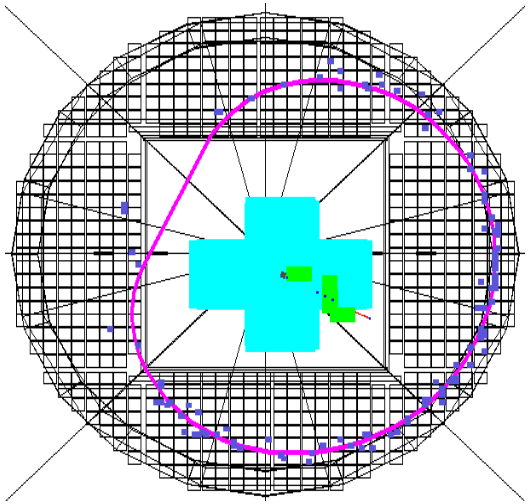
$Z_{TOF\_UP}=6.1$

$Z_{TRK\_L2-L8}=6.0$

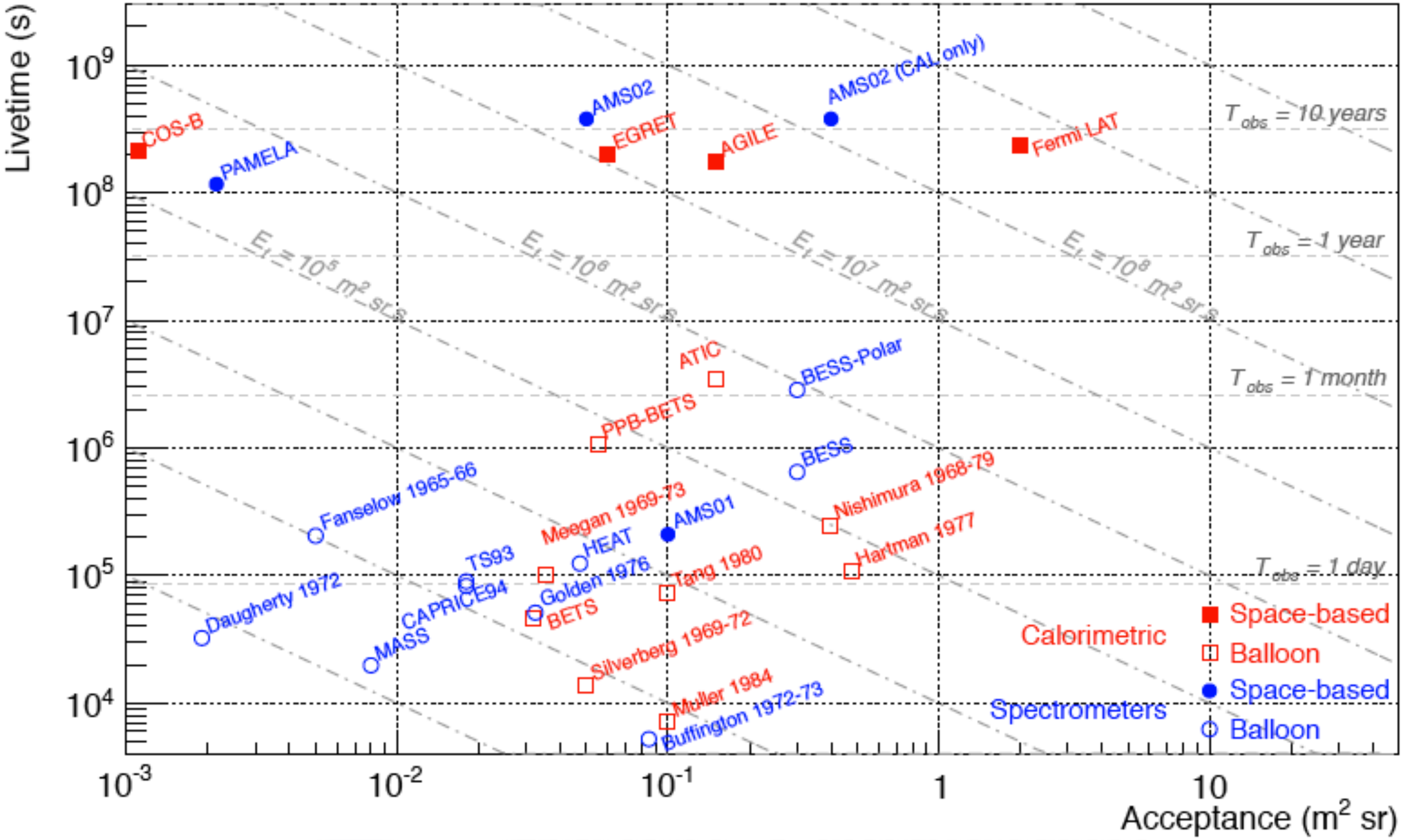
$Z_{TOF\_LOW}=6.5$

$Z_{RICH}=6.1$

$Z_{TRK\_L9}=6.1$

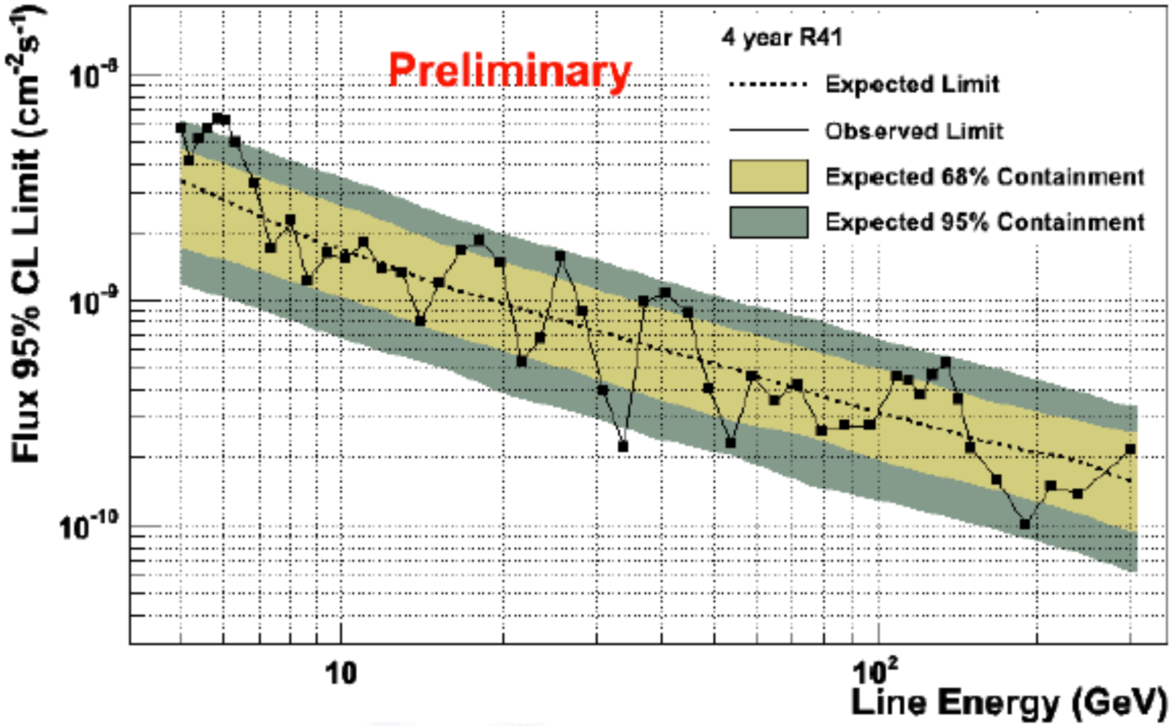


CR/γ-RAY MEASUREMENTS: THE LAT IN CONTEXT



- Fermi and AMS-02 are good examples of complementary design concepts:
    - i.e., acceptance vs. energy resolution and particle ID.

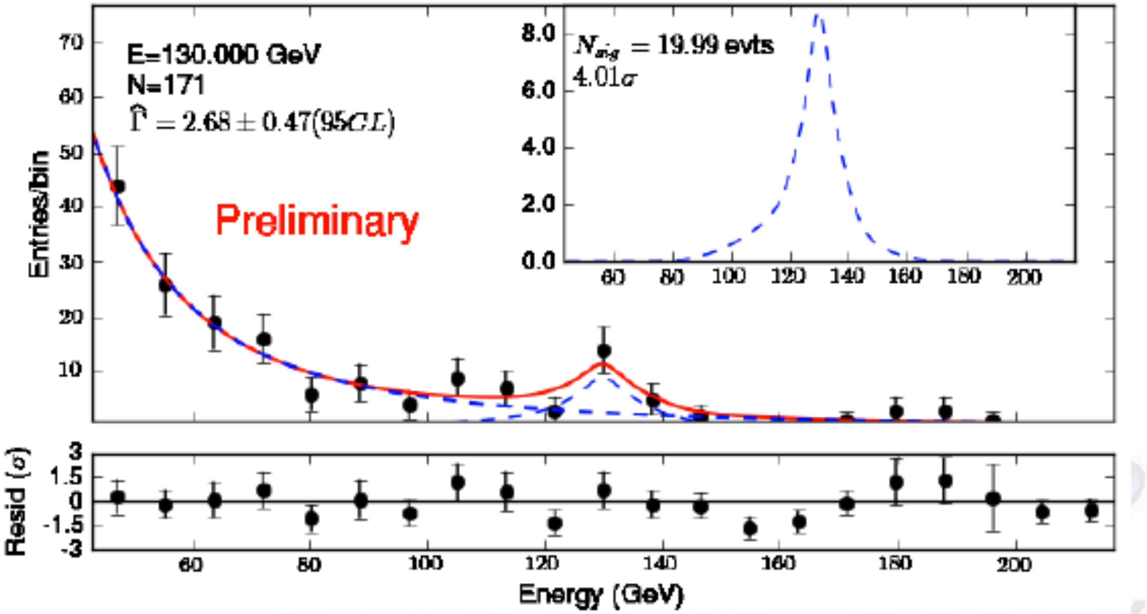
A Gamma-Ray Line at 130 GeV?



- NFW-optimized region of interest;
- Based on 4 years of reprocessed data.
- No globally significant lines found in our blind search:
  - Most significant fit at 5 GeV, $\sim 2+\sigma$ ($\sim 3.7\sigma$ local).
- Preliminary results presented at the Fermi Symposium, paper in preparation.

FITTING A 4° × 4° ROI AT THE GALACTIC CENTER

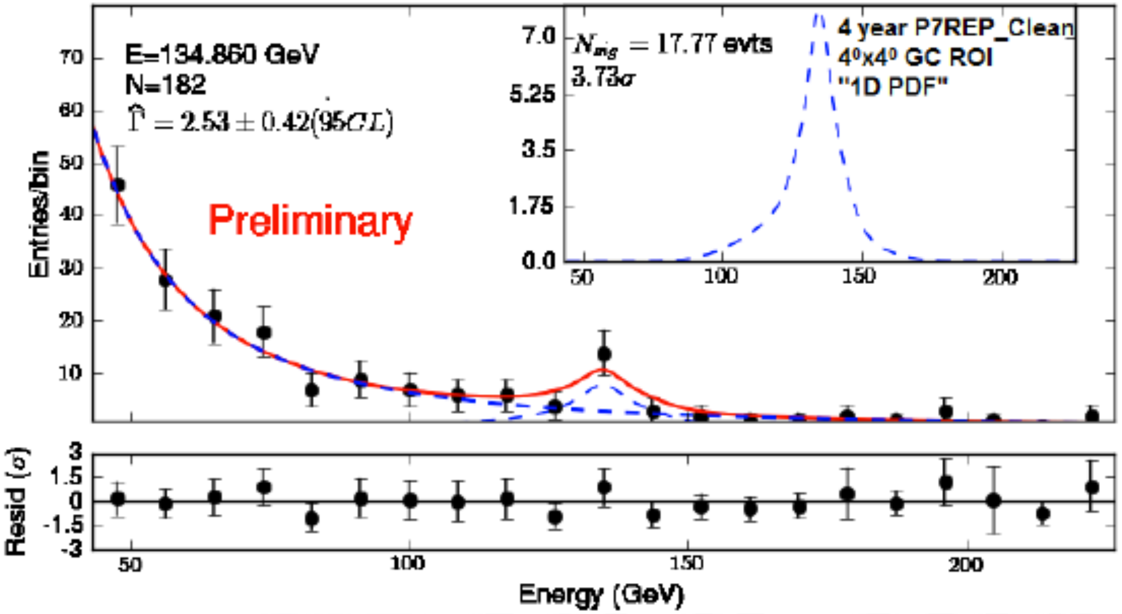
NOTE: NOT ONE OF OUR A PRIORI ROIS



- Fit at 130 GeV with 4 year publicly available data:
  - 4.0σ local.

FITTING A 4° × 4° ROI AT THE GALACTIC CENTER

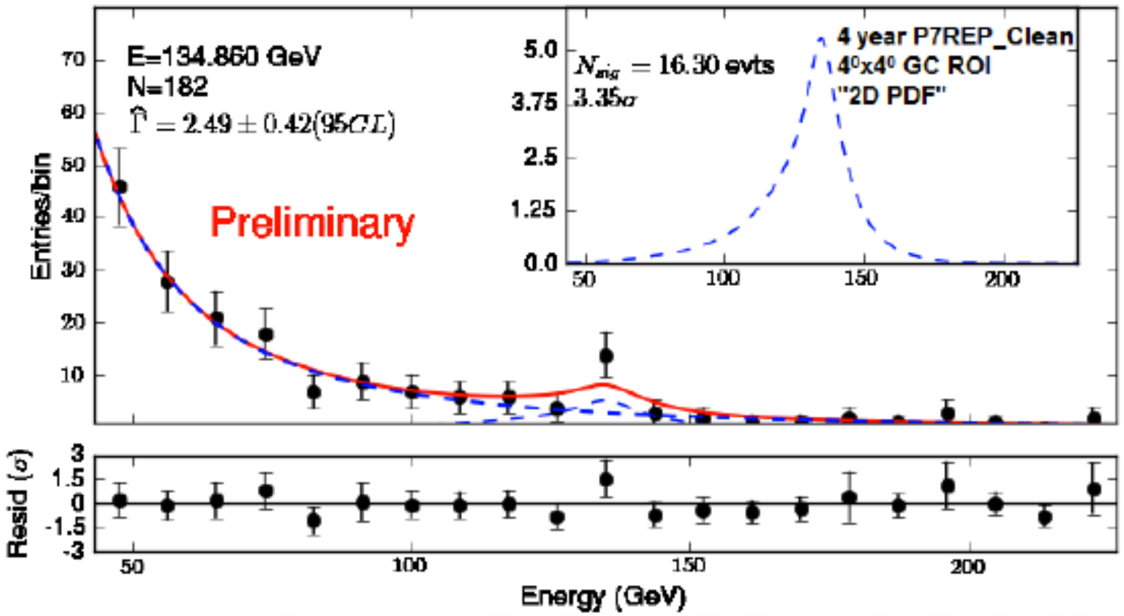
NOTE: NOT ONE OF OUR A PRIORI ROIS



- Fit at 130 GeV with 4 year publicly available data:
  - 4.0σ local.
- Fit at 135 GeV with 4 year *reprocessed* data:
  - 3.7σ local, features shifts to ∼ 135 GeV.

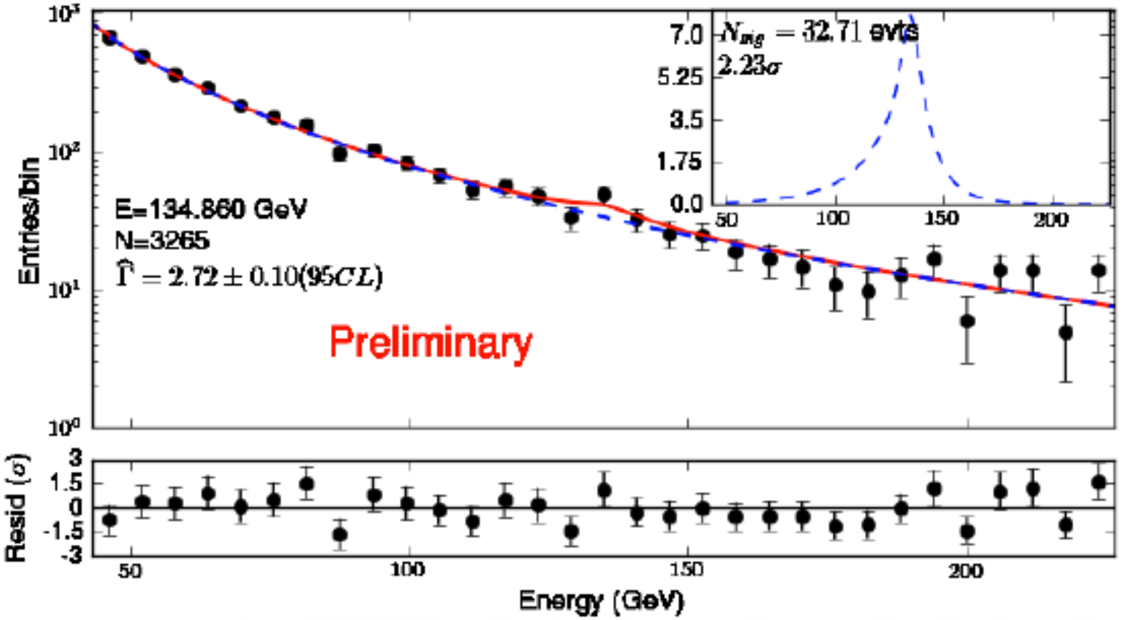
FITTING A 4° × 4° ROI AT THE GALACTIC CENTER

NOTE: NOT ONE OF OUR A PRIORI ROIS



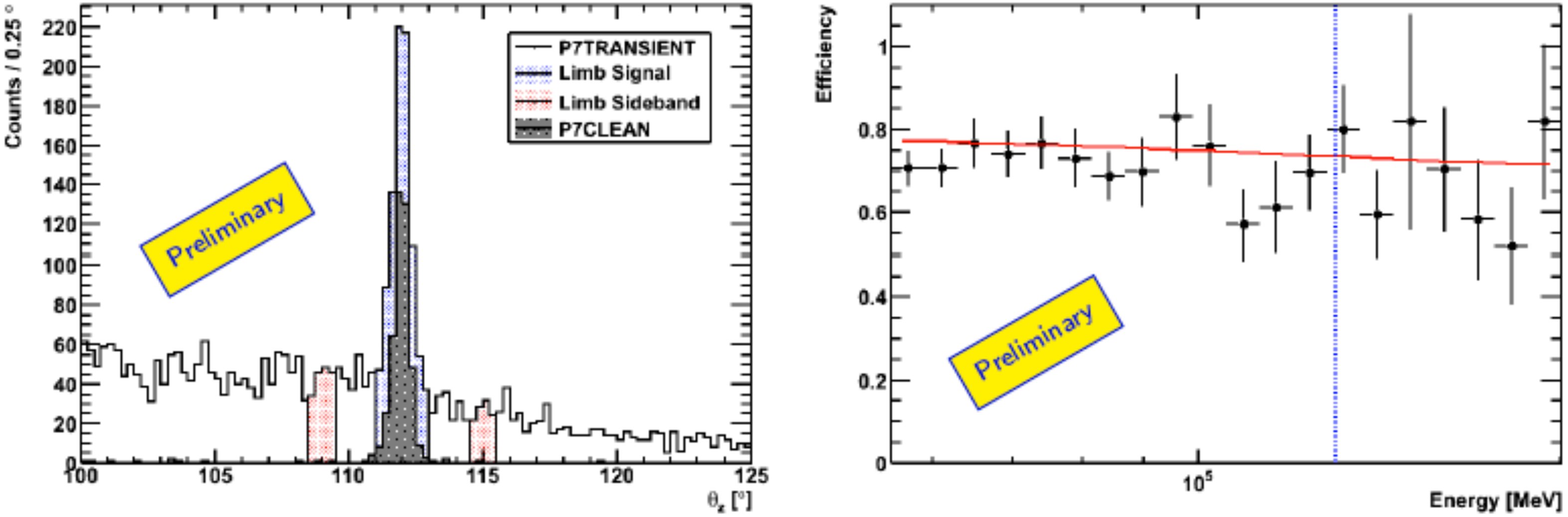
- Fit at 130 GeV with 4 year publicly available data:
  - 4.0σ local.
- Fit at 135 GeV with 4 year *reprocessed* data:
  - 3.7σ local, features shifts to $\sim$ 135 GeV.
- Fit at 135 GeV with 4 year *reprocessed* data and improved analysis (aka 2D pdf)—15% expected improvement in sensitivity:
  - 3.3σ local, feature slightly narrower than the energy resolution.
- And remember: we are talking about a handful of events.

FITTING THE EARTH LIMB

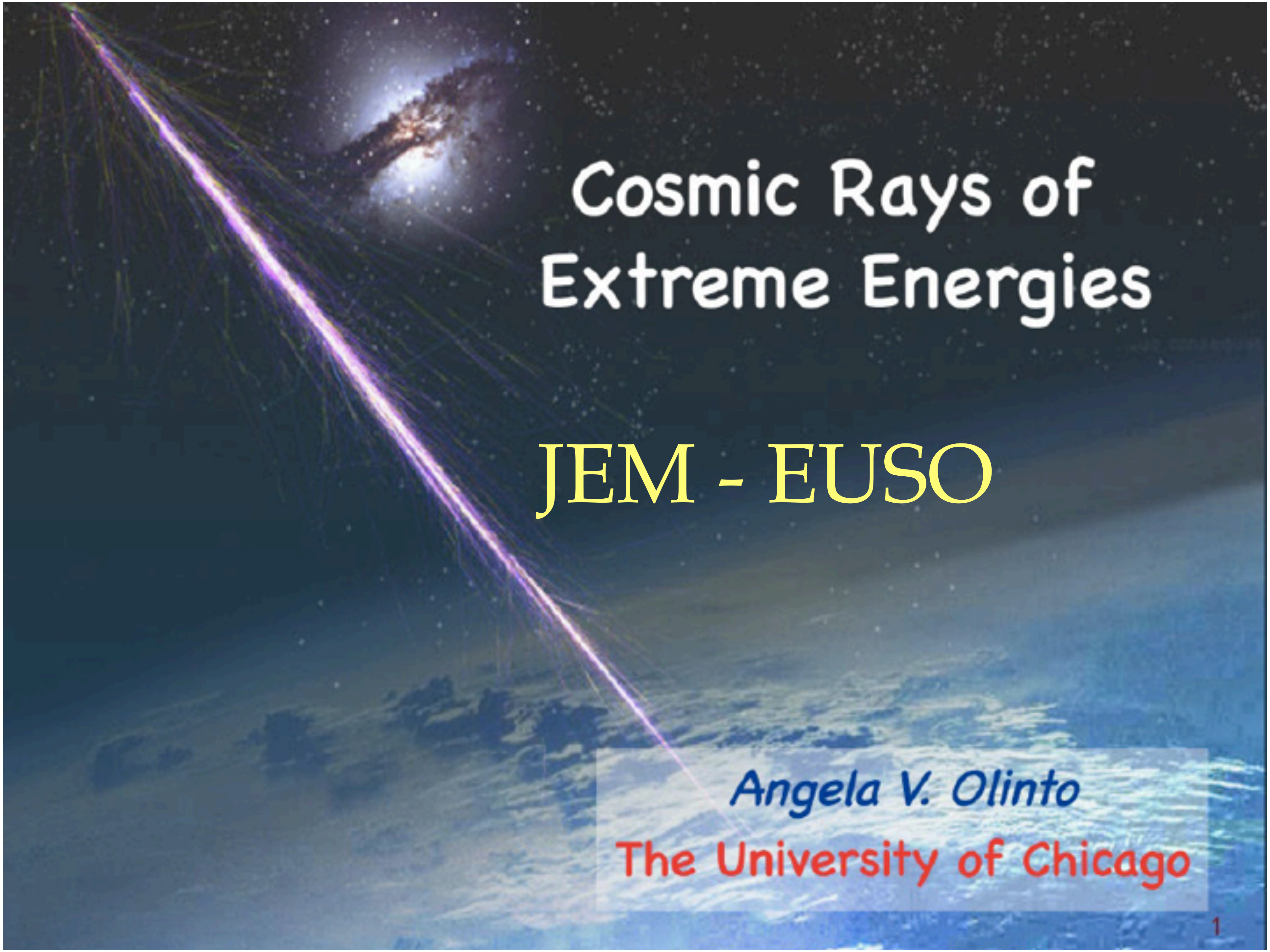


- Marginal line-like feature at 135 GeV (remember: these are reprocessed data):
  - $\sim 2.7\sigma$ with $\sim$ 16% fractional residuals.
- The fractional residual can account for only 30–50% of the excess at the Galactic center.
  - Not enough to explain the GC excess, but can increase the apparent significance.

MEASURING SIGNAL EFFICIENCY WITH THE LIMB



- The Limb is so bright that can be seen with loose event selections;
  - Can use it to measure the efficiency as you go to tighter selections.
- Decreased acceptance near the peak energy can boost the signal.
- All this not enough to come to a conclusive answer:
  - The *feature* in the Limb has a smaller S/N than that at the GC;
  - Why don't we see any excess in other control samples (e.g., integrating the Galactic plane outside ±10°)?
- Pass 8 will substantially improve our prospects for answering questions about the spectral feature at 130 GeV:
  - Larger acceptance, (slightly) better energy resolution, different (smaller) systematics, CAL-only events.

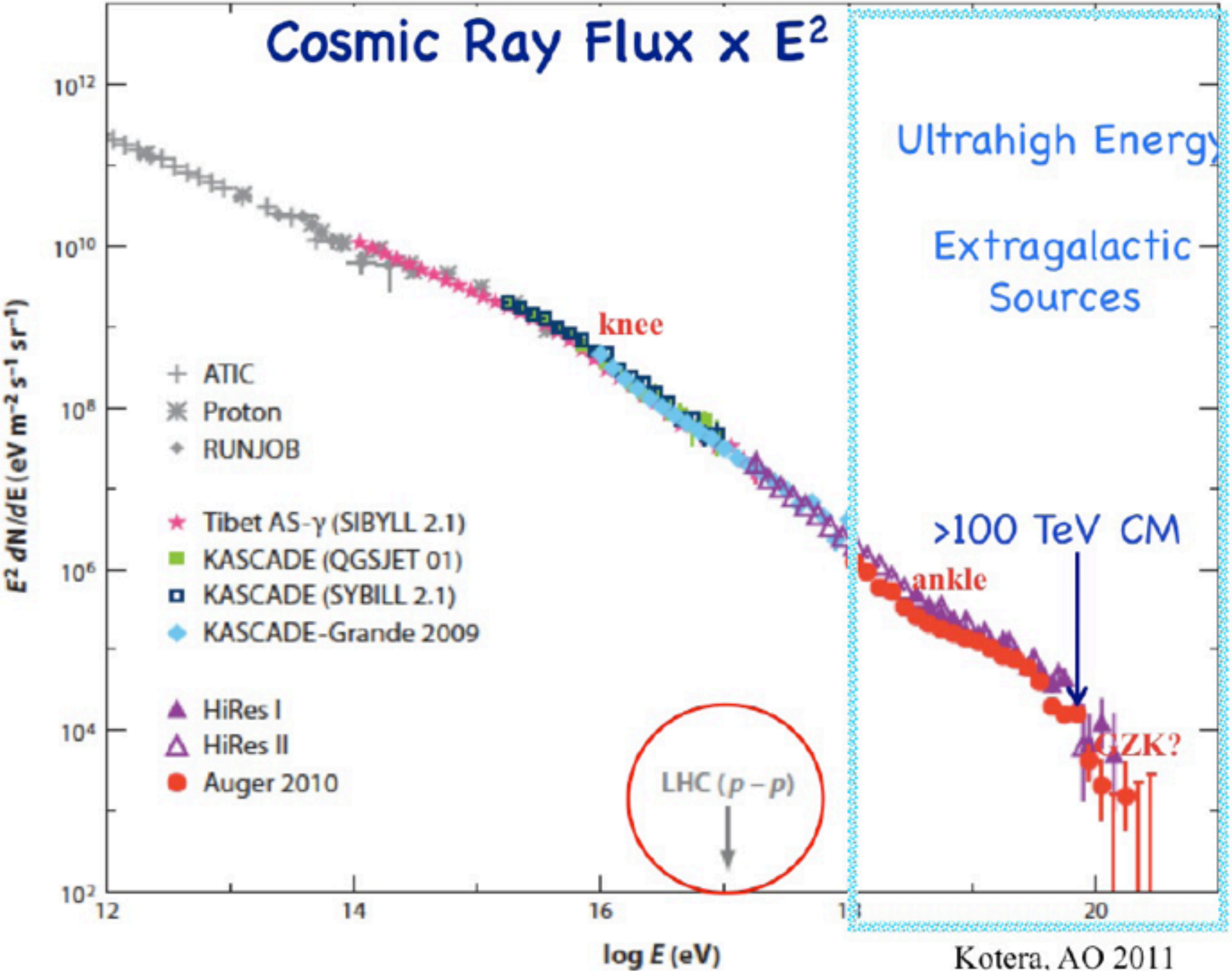


Cosmic Rays of Extreme Energies

JEM - EUSO

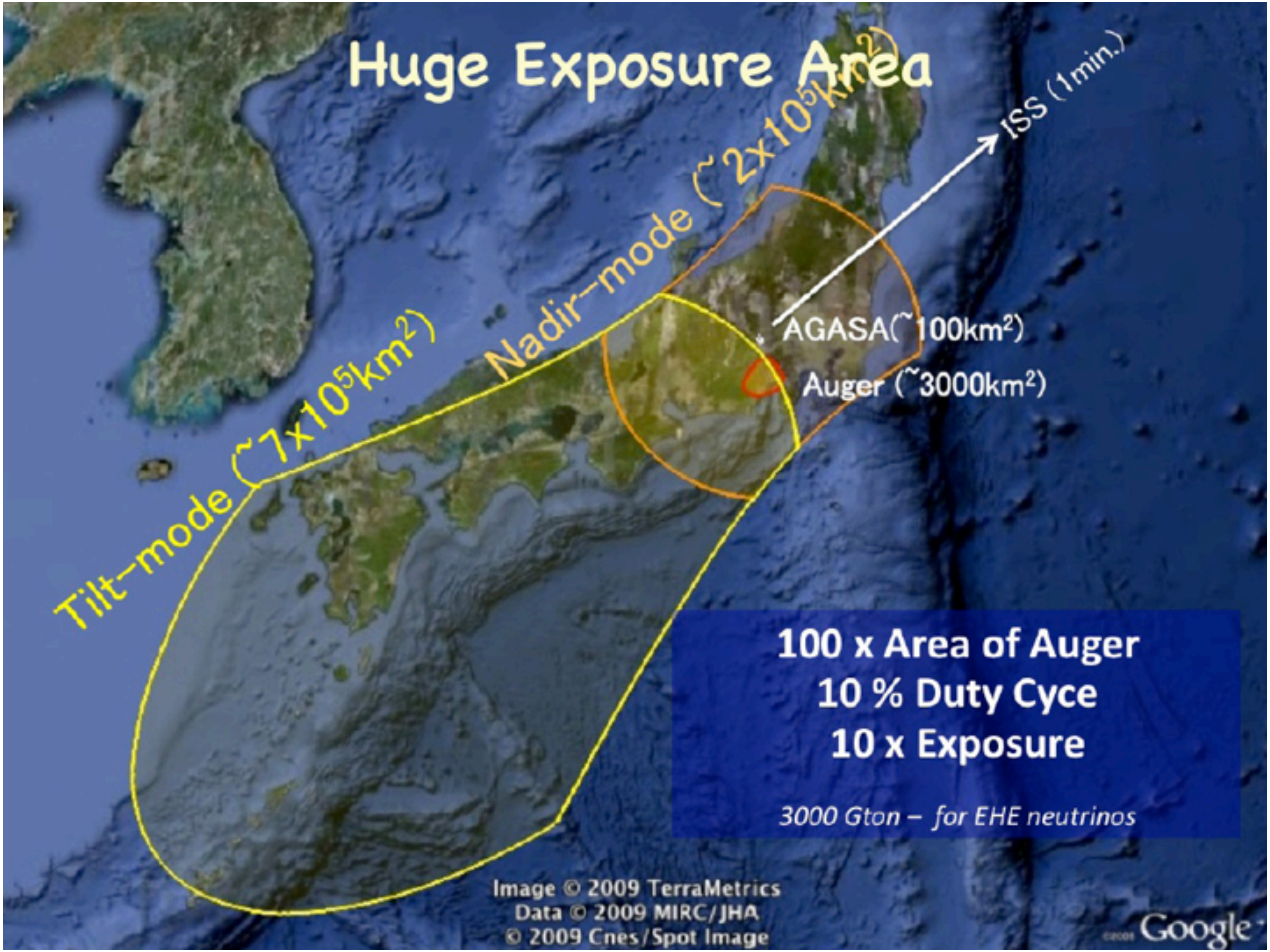
Angela V. Olinto
The University of Chicago

Cosmic Ray Flux x E^2



Kotera, AO 2011

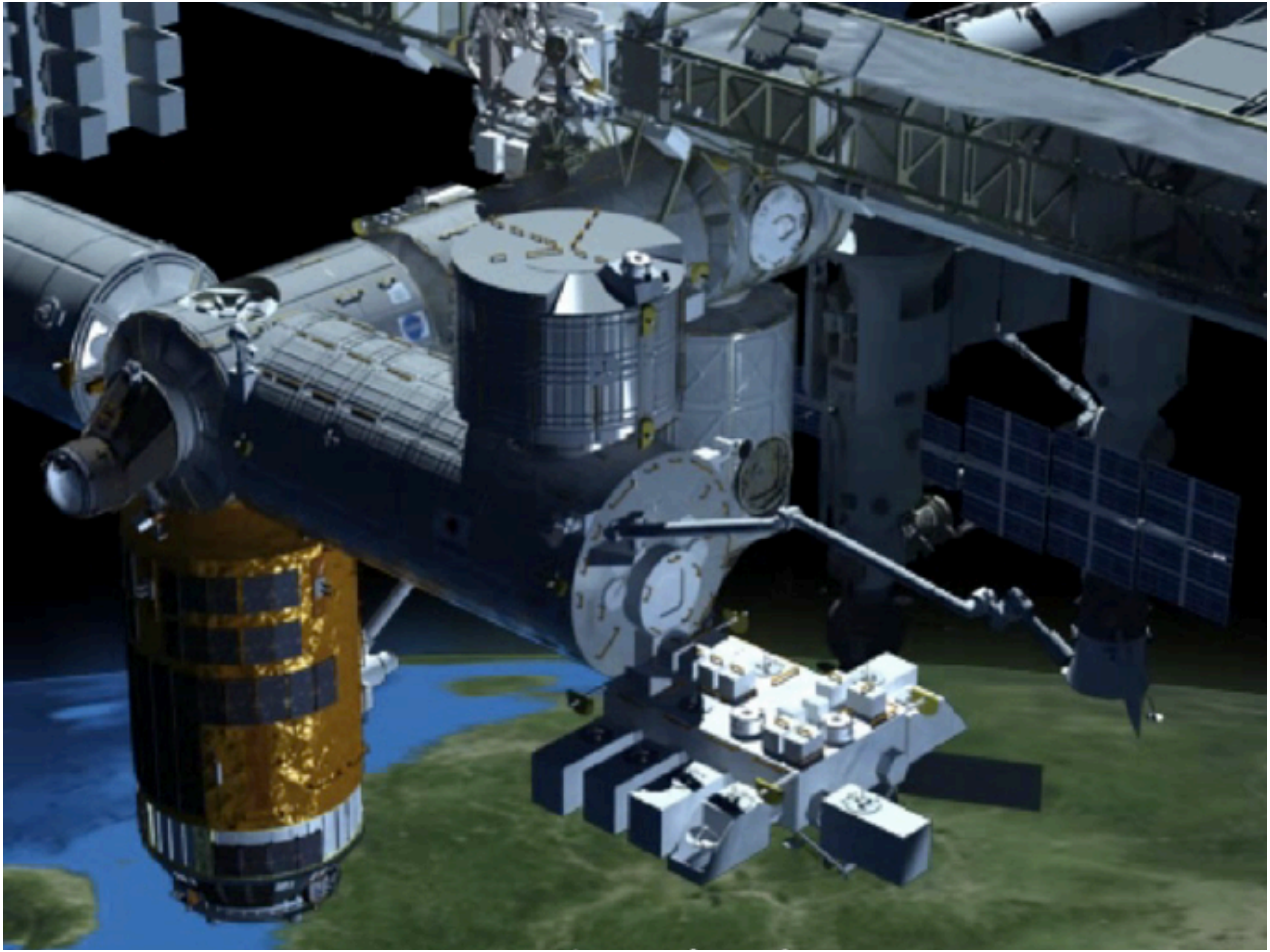
Huge Exposure Area



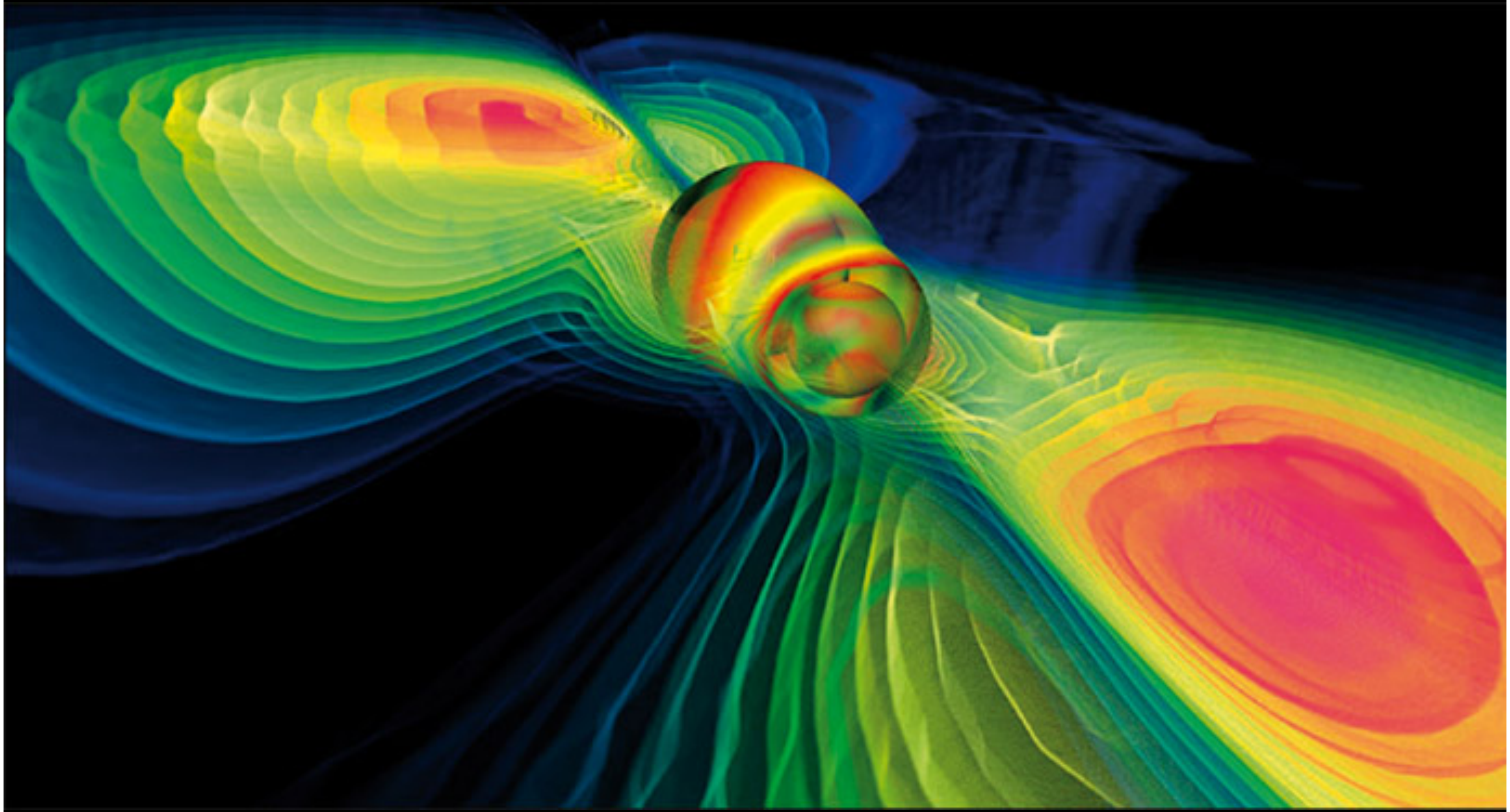
100 x Area of Auger
10 % Duty Cyce
10 x Exposure

3000 Gton – for EHE neutrinos

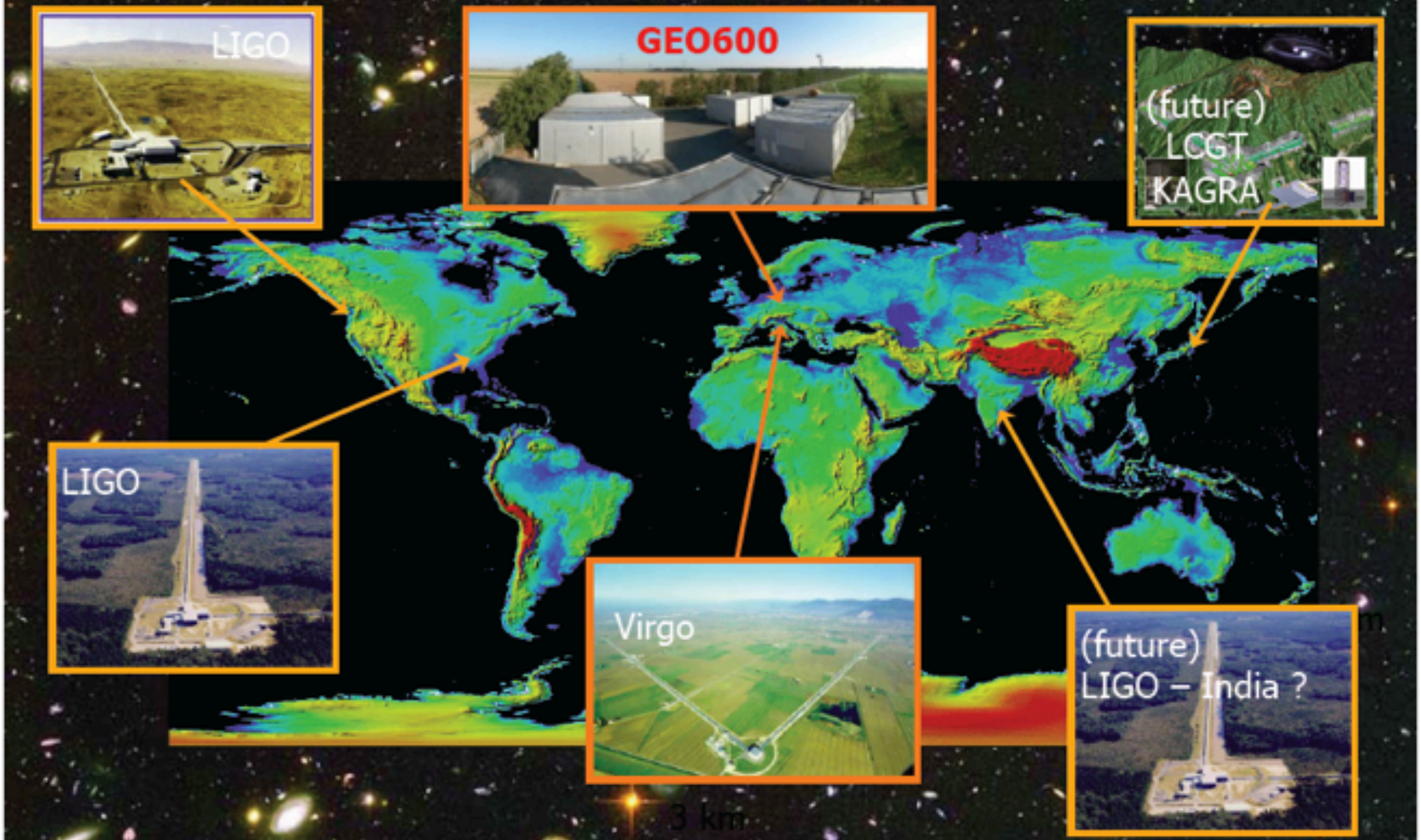
Image © 2009 TerraMetrics
Data © 2009 MIRC/JHA
© 2009 Cnes/Spot Image



Gravitational waves

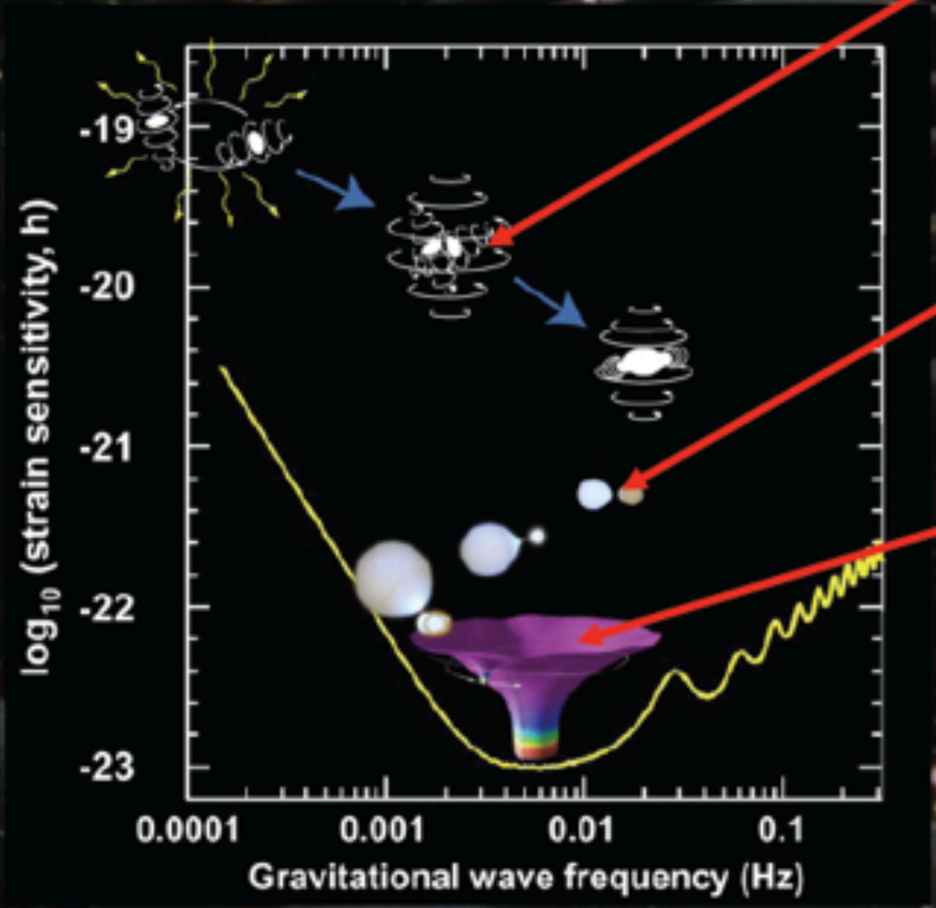


World-Wide Laser Interferometric Gravitational Wave Detector Network



Source: A. [illegible]

At Low Frequencies: A Universe full of Strong GW Sources



Massive Black Hole Binary (BHB) inspiral and merger

Ultra-compact binaries

Extreme Mass Ratio Inspiral (EMRI)

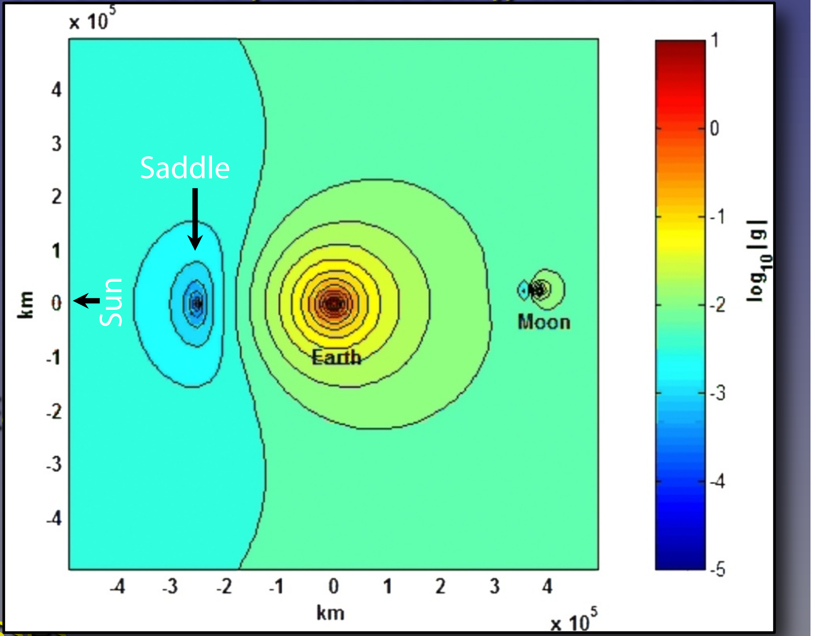
Cosmic backgrounds, superstring bursts?

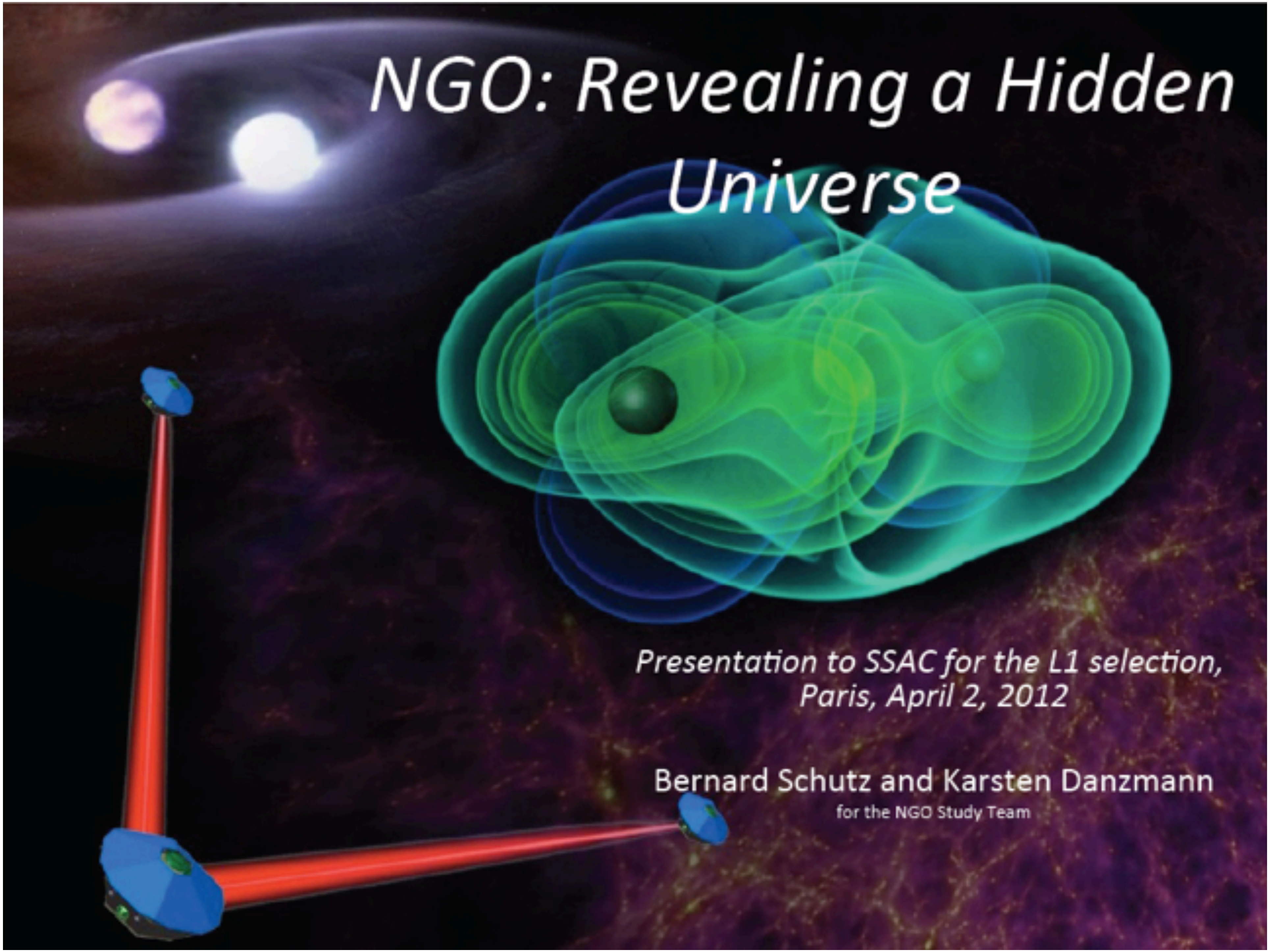
LISA Pathfinder

ESA gravitational wave detection technology testbed, scheduled launch 2014

Testing alternative theories of gravity

- Galaxies seen to have flat rotation curves
  - Standard solution is that they are embedded in massive dark matter haloes
- Alternative: breakdown in Newtonian dynamics when background gravitational field drops below threshold ~ 10^{-10} m s^{-2}
  - MOND (Millegrom), TeVeS (relativistic version of MOND, Bekenstein), and others
- Direct test of modified gravity difficult
  - e.g. at LISA Pathfinder station at L1, background acceleration ~ 6 x 10^{-3} m s^{-2}
- But there are saddle points (“bubbles”) where fields should cancel
  - e.g. Sun-Earth saddle, ~ 250,000 km from E
- After nominal mission, LISA Pathfinder could fly through “MOND bubble”
  - Monitor gravity gradient between test masses
  - Predicted MOND “signal”: ~10^{-13} m s^{-2} for ~300s
  - Only mission planned with required sensitivity





NGO: Revealing a Hidden Universe

Presentation to SSAC for the L1 selection,
Paris, April 2, 2012

Bernard Schutz and Karsten Danzmann
for the NGO Study Team

Theoretical Landscape of the 20th Century:

Competing Theories of Gravity

not a complete list…

Newton 1686
Poincaré 1890
Einstein 1912
Nordstrøm 1912
Nordstrøm 1913
Einstein & Fokker 1914
Einstein 1915
Whitehead 1922
Cartan 1923
Kaluza & Klein 1932
Fierz & Pauli 1939
Birkhoff 1943
Milne 1948
Thiry 1948
Papapetrou 1954
Jordan 1955
Littlewood & Bergmann 1956
Brans & Dicke 1961
Yilmaz 1962
Whitrow & Morduch 1965
Kustaanheimo & Nuotio 1967
Page & Tupper 1968
Bergmann 1968
Deser & Laurent 1968
Nordtvedt 1970
Wagoner 1970
Bollini et al. 1970
Rosen 1971
Will & Nordtvedt 1972
Ni 1972
Hellings & Nordtvedt 1972
Ni 1973
Yilmaz 1973
Lightman & Lee 1973
Lee, Lightman & Ni 1974
Rosen 1975
Belinfante & Swihart 1975
Lee et al. 1976
Bekenstein 1977
Barker 1978
Rastall 1979
Coleman 1983
Hehl 1997
Overlooked (20thcentury)

- Some authors proposed more than one theory, e.g. Einstein, Ni, Lee, Nordtvedt, Papapetrou, Yilmaz, etc.
- Some theories are just variations of others
- Some theories were proposed in the 1910s/20s; many theories in the 1960s/70s
- Overlooked: this is not a complete list!

Theory must be:

- **Complete**: not a law, but a theory. Derive experimental results from first principles
- **Self-consistent**: get same results no matter which mathematics or models are used
- **Relativistic**: Non-gravitational laws are those of Special Relativity
- **Newtonian**: Reduces to Newton's equation in the limit of low gravity and low velocities

Theoretical Landscape of the 20th Century:

Competing Theories of Gravity

"Aesthetics-Based" Conclusion for 20th Century

Newton 1686 Poincaré 1890
Einstein 1912 Nordstrøm 1912 Nordstrøm 1913 Einstein & Fokker 1914 **Einstein 1915**
Whitehead 1922 Cartan 1923 Kaluza & Klein 1932 Fierz & Pauli 1939 Birkhoff 1943
Milne 1948 Thiry 1948 Papapetrou 1954 Jordan 1955 Littlewood & Bergmann 1956
Brans & Dicke 1961 Yilmaz 1962 Whitrow & Morduch 1965 Kustaanheimo & Nuotio 1967
Page & Tupper 1968 Bergmann 1968 Deser & Laurent 1968 Nordtvedt 1970 Wagoner 1970
Bollini et al. 1970 Rosen 1971 Will & Nordtvedt 1972 Ni 1972 Hellings & Nordtvedt 1972
Ni 1973 Yilmaz 1973 Lightman & Lee 1973 Lee, Lightman & Ni 1974 Rosen 1975
Belinfante & Swihart 1975 Lee et al. 1976 Bekenstein 1977 Barker 1978 Rastall 1979
Coleman 1983 Hehl 1997 Overlooked (20th century)

- "Among all bodies of physical law none has ever been found that is simpler and more beautiful than Einstein's geometric theory of gravity"

  – Misner, Thorne and Wheeler, 1973

- "[...] Unfortunately, any finite number of effects can be fitted by a sufficiently complicated theory. [...] Aesthetic or philosophical motives will therefore continue to play a part in the widespread faith in Einstein's theory, even if all tests verify its predictions."

  – Malcolm MacCallum, 1976

Theoretical Landscape of the 21st Century:

Competing Theories of Gravity

First decade of 21'st century… they are back!

Newton 1686 Poincaré 1890

Einstein 1912 Nordstrøm 1912 Nordstrøm 1913 Einstein & Fokker 1914 **Einstein 1915**

Whitehead 1922 Cartan 1923 **Kaluza & Klein 1932** Fierz & Pauli 1939 Birkhoff 1943

Milne 1948 Thiry 1948 Papapetrou 1954 Jordan 1955 Littlewood & Bergmann 1956

Brans & Dicke 1961 Yilmaz 1962 Whitrow & Morduch 1965 Kustaanheimo & Nuotio 1967

Page & Tupper 1968 Bergmann 1968 Deser & Laurent 1968 Nordtvedt 1970 Wagoner 1970

Bollini et al. 1970 Rosen 1971 Will & Nordtvedt 1972 Ni 1972 Hellings & Nordtvedt 1972

Ni 1973 Yilmaz 1973 Lightman & Lee 1973 Lee, Lightman & Ni 1974 Rosen 1975

Belinfante & Swihart 1975 Lee et al. 1976 Bekenstein 1977 Barker 1978 Rastall 1979

Coleman 1983 Hehl 1997 Overlooked (20thcentury) **Scalar-Tensor Theories**

Arkani-Hamed, Dimopoulos & Dvali 2000 **Dvali, Gabadadze & Poratti 2003** **Strings theory?**

Bekenstein 2004 **Moffat 2005** **Multiple f(R) models 2003-10** **Bi-Metric Theories**

Need for new theory of gravity:

- Classical GR description breaks down in regimes with large curvature
- If gravity is to be quantized, GR will have to be modified or extended

Other challenges:

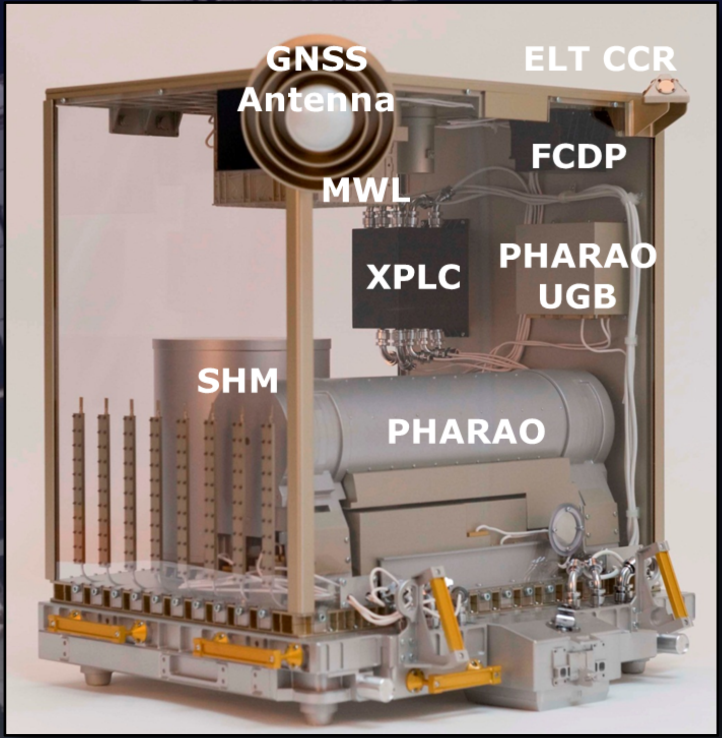
- Dark Matter
- Dark Energy

Motivations for new tests of GR:

- GR is a fundamental theory
- Alternative theories & models
- New ideas & techniques require comprehensive investigations

ACES

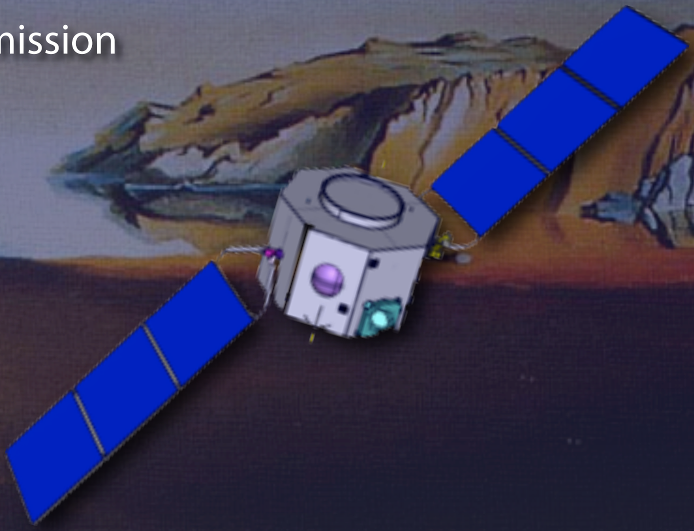
- Atomic Clock Ensemble in Space
  - PHARAO: Cs atomic clock (CNES)
  - SHM: Hydrogen maser (ESA)
  - Microwave link to ground terminals
- Science goals:
  - Measurement of gravitational redshift
    - Precision 50 x 10^{-6} in 300 s; 2 x 10^{-6} in 10 days
  - Time variations in fine structure constant
    - $\alpha^{-1} . d\alpha/dt < 10^{-17}\ yr^{-1}$
  - Search for anisotropies in speed of light
    - $\Delta c/c \sim 10^{-10}$
  - Relativistic geodesy at 10 cm level
- Low-Earth orbit
  - To be installed on ISS in 2015
  - Ground-terminals: Europe, US, Asia, Australia



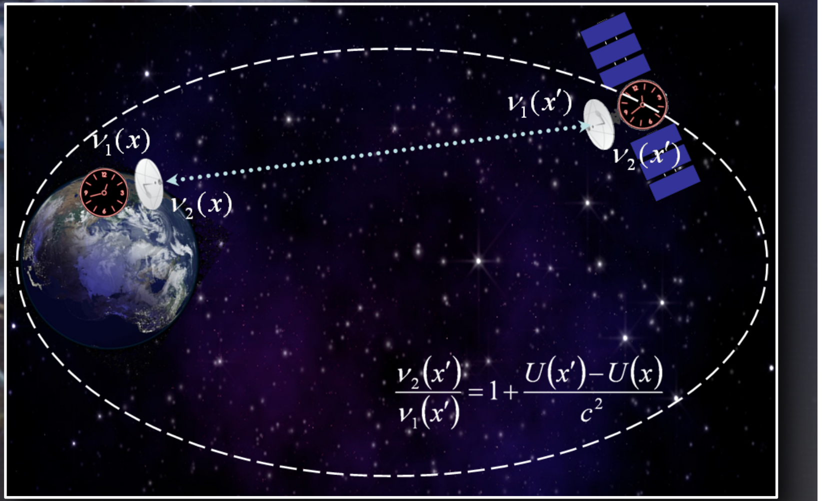
ESA (Human Spaceflight programme)-CNES

STE-QUEST

Cosmic Vision M3 candidate mission

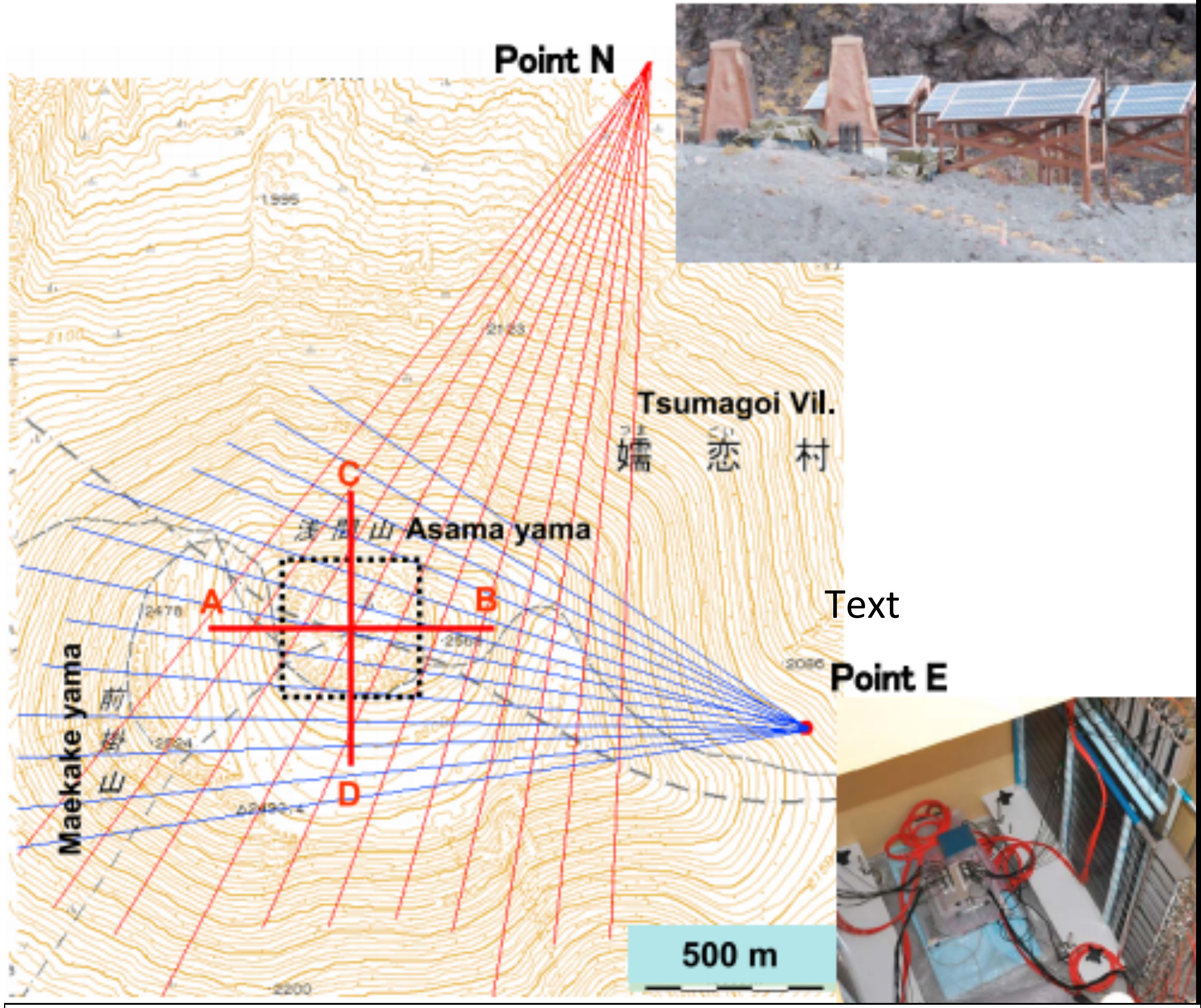


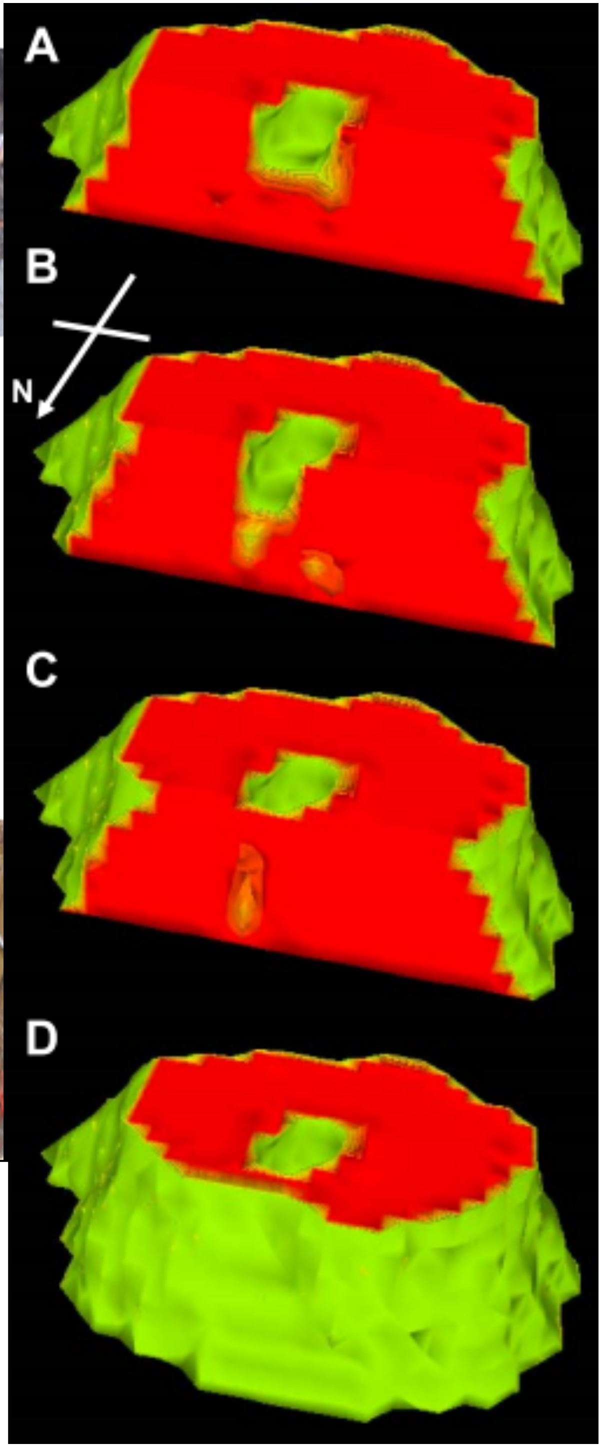
- Space Time Explorer and Quantum Equivalence Space Test
  - Laser-cooled Rb microwave atomic clock
  - ^{85}Rb/^{87}Rb differential matter interferometer
  - Microwave/optical links to ground terminals
- Science goals:
  - Earth gravitational redshift
    - Precision 2 x 10^{-7}; ultimate aim 4 x 10^{-8}
  - Sun gravitational redshift
    - Precision 2 x 10^{-6}; ultimate aim 6 x 10^{-7}
  - Universality of propagation of matter waves
    - Measurement of Eötvös parameter to < 10^{-15}
- Highly-elliptical Earth orbit



Mission to provide high precision test of Einstein Equivalence Principle, nominal launch in 2022–2024

Technologies and applications

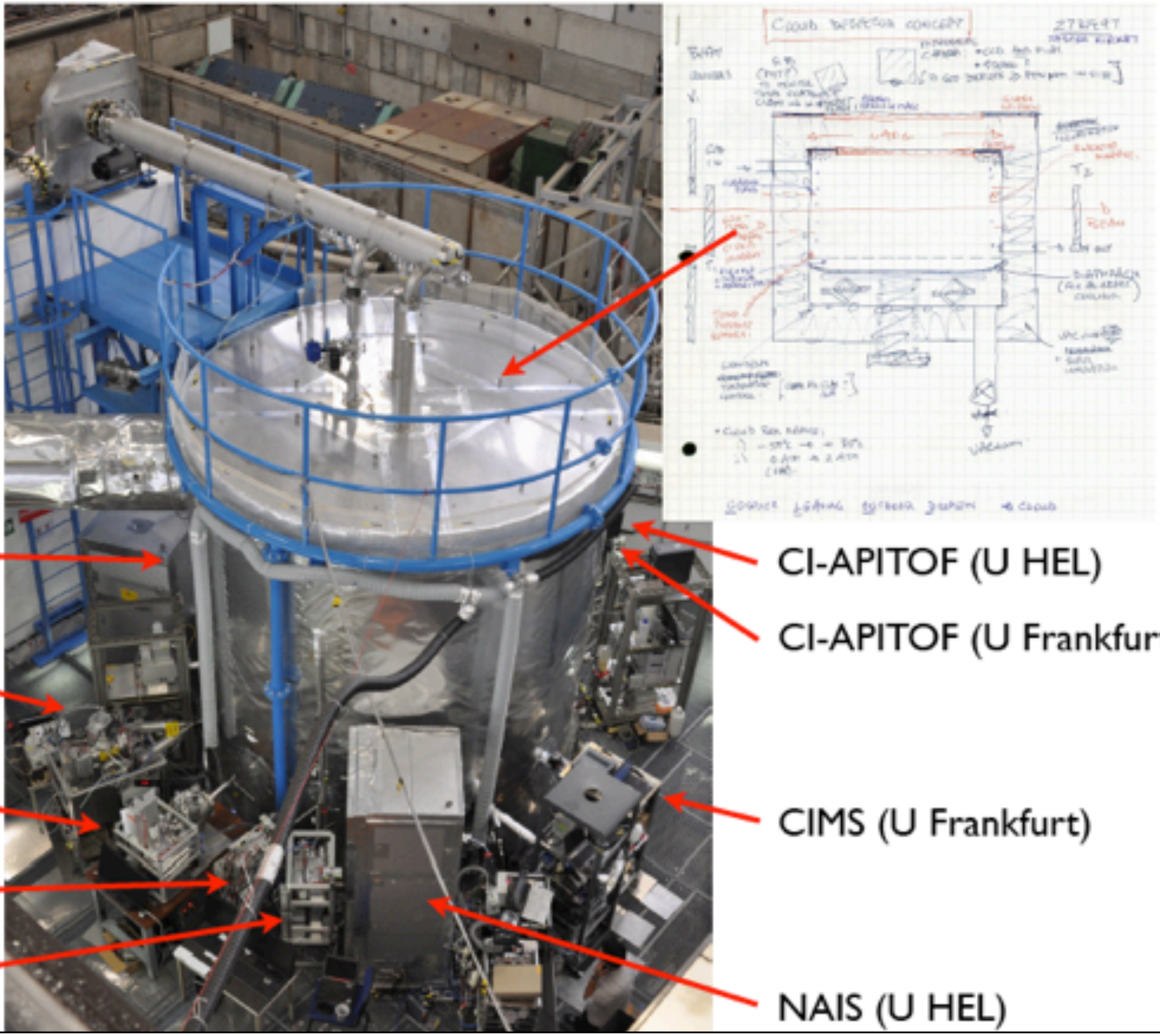




H. Tanaka
Volcanos muon radiography

The CERN CLOUD experiment

- 30 sampling instruments are currently attached to CLOUD, including 9 state-of-art mass spectrometers for unprecedented ion and molecular information on aerosol particle nucleation and growth:



PTR-TOF (U Innsbruck)

TD-CIMS (NCAR)

IMS-TOF (U HEL)

API-TOF- (U HEL)

API-TOF+ (PSI)

CI-APITOF (U HEL)

CI-APITOF (U Frankfurt)

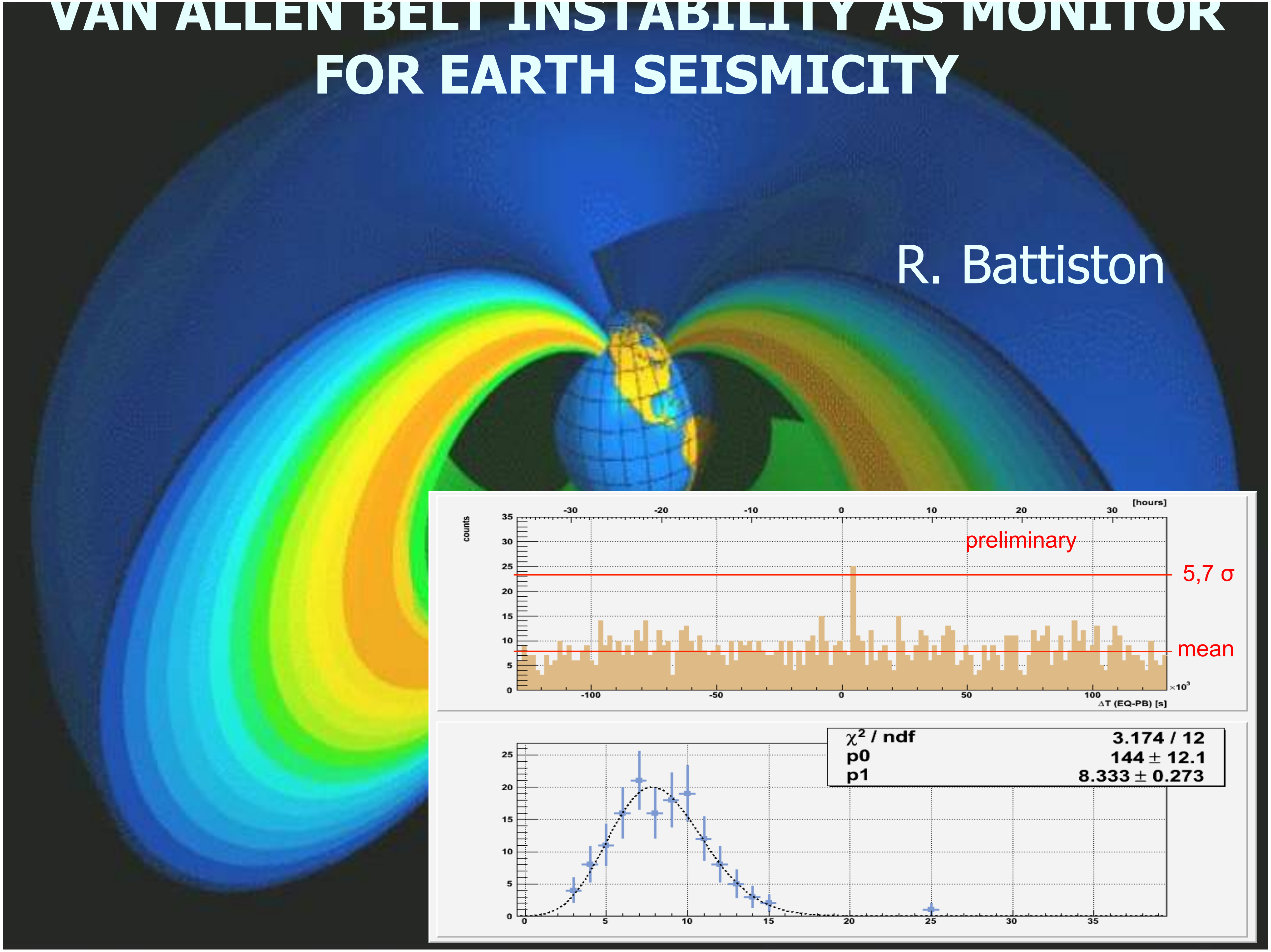
CIMS (U Frankfurt)

NAIS (U HEL)

J. Kirkby   Cosmic Ray influence on cloud formation

VAN ALLEN BELT INSTABILITY AS MONITOR FOR EARTH SEISMICITY

R. Battiston



Conclusions 1

One hundred years after the discovery of Cosmic Rays, in the era of the Higgs boson, multimessenger observation of the Universe continues to provide outstanding physics results

The Universe reveal itself through the interaction of mass and energy deforming the space-time texture

A modern class of space observatories is pushing the limits of sensitivities to the edge of space and time, using most sophisticated technologies and Europe is playng a key role in these global scientific enterprises

Current generation of space instruments compete in cost and complexity with the largest LHC experiments

Conclusions 2

The links between astrophysics, cosmology, astroparticle physics and the physics at the accelerators are stronger and deeper than ever

The detailed study of the CMB, light, gamma rays, cosmic rays and gravitational waves are providing extraordinary experimental insights in the early phases of the universe, testing fundamental concepts in particle physics like number of neutrino species, dark matter, symmetry breaking, inflation, phase transitions......

Still most of the Universe remain unexplained : dark matter, dark energy, absence of antimatter are striking examples of how long is our journey to understand the place we live

Thanks !