Global Science Forum
Working Group on Astroparticle Physics

Report to HEPAP

C. Baltay with input from Kathy Turner

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OECD

Organization for Economic Co-operation and Development

- The OECD is an international forum to advise the governments of about 30 countries on economic, social, environmental and scientific challenges of globalization
- The Global Science Forum is a branch of OECD that advises governments on global science policy
- In the past, the Global Science Forum had working groups that wrote reports on international cooperation in Nuclear Physics, Elementary Particle Physics, Astrophysics, etc. etc….

Working Group on Astroparticle Physics

- In October of 2008 the Global Science Forum established the Working Group on Astroparticle Physics.
- The Working group held 5 meetings over the last two years
  - Paris, France
  - Krakow,Poland
  - Mumbai, India
  - Paris, France
  - Stanford, USA

Members of the Working Group

Chair	Michel Spiro (France)
Argentina	Alberto Echtegoyen
Australia	Bruce Dawson
Belgium	Daniel Bertrand
China	Hesheng Chen
France	Stavros Katsanevas
	Philippe Chomaz
Germany	Thomas Berghofer
	Guido Drexlin
	Karsten Danzman
India	Naba Mondal
Italy	Benedetto D'Ettore
Japan	Toshikazu Ebisuzaki
Korea	Doo Jong Song

Members of the Working Group

Netherlands	Anna Lipniacka
Norway	Michal Ostrovski
Russia	Victor Matveev
Spain	Manel Martinez
Switzerland	Maurice Bourquin
	Martin Steinacher
UK	Janet Seed
	Deborah Miller
United States	Kathy Turner
	Gene Henry
	Vernon Jones
	Stephen Murray
	Vernon Pankonin
	James Whitmore

Members of the Working Group

OECD Coordinator	Stefan Michalovski
PaNAGIC Observer	David Sinclair
CERN Observer	Felicitas Pauss

Invited Experts	Charles Baltay
	Christian Spiering
	Jay Marx
	Benoit Mours
	Yoichiro Suzuki
	Roger Blanford

Charge to the Astroparticle Physics Working Group

- Better define this emerging new field at the intersection of Particle Physics, Cosmology, Astrophysics and Nuclear Physics
- Asses the present level of activity world wide in this new field
- Develop a 20 year vision for the scientific opportunities in this new field

Comment on the “Vision”

- There was no intention of developing a prioritized plan or roadmap, although there was a lot of discussion about this point.
- The committee was not constituted to decide on priorities in the program.
- Different countries get their planning advice in different ways!

Astroparticle Physics

- Astroparticle physics is the study of particles and radiation from outer space, and of rare, cosmologically-significant elementary particle reactions.
- The scales of distance examined range from the realm of elementary particles to the outer reaches of the observable Universe.
- This places the field at the intersection of cosmology, astrophysics, particle physics and nuclear physics.

Astroparticle Physics

- What is the Universe made of
  - Dark Matter
  - Dark Energy
- What is the role of high-energy phenomena in the Universe
  - High energy messengers: charged particles, gamma rays, neutrinos from space
  - Gravitational waves
- What is the nature of matter and interactions at the highest energies
  - Nonaccelerator neutrino physics, mass and mixing
  - Proton decay

Comment on what is included in Astroparticle Physics

- There was a spread of opinion on what should be included in Astroparticle Physics. Different countries had different views.
- For example, from the point of view of the US program non-accelerator neutrino physics and proton decay are a part of HEP and/or Nuclear Physics and would not be included in Astroparticle Physics
- Some of the Europeans felt that non-accelerator physics is not currently globally coordinated and should be included here not to “fall in a crack”

The Importance of the Field has Increased Steadily in Recent Years

- Major fundamental challenges in the field are within the reach of experimental capabilities, notably, understanding the properties of dark matter, dark energy, gravitational radiation, and exploring the nature of high energy particles from space.
- Extreme astrophysical phenomena that produce high-energy particles and radiation are of intrinsic interest since they have had, and continue to have, a major influence on the structure and evolution of the Universe.

Dark Matter Search Experiments

	Scintillation or Ionisation	Bolometers	Liquid Xenon	Liquid Argon
Data Taking or G1	Scintillation DAMA/LIBRA Ionisation COUPP PICASSO PICASSO	SCDMS EDELWEISS-II CRESST ROSEBUD CoGENT DAMIC	XMASS ZEMPLIN XENON-100 ZEPLIN-III	DEAP/CLEAN CLEAN WARParp ArDM
Construction	ANAIS	EDELWEISS-III	LUX	darkSideDARKSIDE
DEAP Or G2	KIMS	SCDMS-II	Xenon-1t	Argon 1t
Planned Or G3	LIBRA 1t	EURECA GEODM	Darwin/Xenon MAX/Max LZS XMASS-10ton	LZSMAX(merge cells) Argon-10t Darwin/(merge cells) Argon

Dark Matter Searches

- It is highly probable that the complexity of future dark matter experiments, the potential worldwide scarcity of target materials (e.g., germanium or noble liquids) and the funding required (with budgets projected between 50 and 100 million dollars) will necessitate global collaborations.
- If, as is likely during the next few years, a dark matter discovery claim is made, independent confirmation will be needed using a wide variety of techniques, including different target nuclei.

Experiments on Dark Energy

	Supernova	Weaek lensing	Baryon Acoustic Oscillation	Galaxy clustering
Projects Completed or Underway	CofA SCP SNLS ESSENCE HST SDSS II CofA SP Snfactory CSP KAIT	CTIO COSMOS CFHLS DLS	SDSS/BOSS	PISCO SPT ACT XCS RCS2 KIDS DEEP2
Projects in Preparation	PanSTARRS1 LRSC Sky Mapper	DES KDS ALPACA ODI	HETDEX BOSS	CIX CCAT
Proposed Future Projects	WFIRST	PanSTARRS4 EUCLID LSST SKA	Big BOSS SuMIRe	10 XbRay NASA MEM Constellation X CCAT

Dark Energy

- Systematic international consultations among the relevant agencies could ensure that the future array of ground- and space-based telescopes exploits the full spectrum of desirable capabilities and experimental methodologies.
- In some cases, pooling of funds and merging of projects could be the optimal solution.

High Energy Cosmic Messengers

	Low and Medium energy CR	Ultra High Energy CR	Gamma Rays	High Energy Neutrino
Data Taking	**ATIC (balloon)** **CREAM (balloon)** **PAMELA (space)** **Tunka** **ARGO-YBJ(along columns)** Tibet AS γ	**Telescope Array** **Yakutsk** **Auger—South(along lines)**	**H.E.S.S** **MAGIC** **VERITAS** **CANGAROO** **ARGO-YBJ** **AGILE (space)** **Fermi (space)** Tibet AS γ	**Baikal NT200+** **ANTARES** **IceCube** **ANITA** **Auger**
Construction	**AMS (space)** **AMIGA/Auger** Tibet AS γ /YAC		**MACE** Tibet AS γ /MD	**NEMO** **NESTOR**
Prototypes or Planned	**CALET (space)** **LHAASO**	**Auger-North** **Auger upgrades** **JEM-EUSO (space)** **TUS (space)**	**CTA/AGIS** **HAWC** **LHAASO**	**KM3NeT** **ARA** **GVD**

High Energy Cosmic Messengers

- In this domain, coordination and coherence among scientists has been achieved.
- For the funding agencies, challenges for the future include configuring truly international institutional arrangements (when desired), managing international facilities (including issues of access, operating costs and data availability) and developing procedures for resolving site selection issues.

Gravitational Wave Detectors

	Ground Interferometric antennas	Space antennas and pulsar timing
Data taking or G1	VIRGO/LIGO/GEO/TAMA	IPTA
Constructon R&D or G2	advLIGO/advVIRGO:GEO-HF/ LCGT AIGO/INDIGO	LISA-PathFinder
Planned Or G3	ET Other 3rd generation Antennas	LISA DECIGO/BBO/ALIA

Gravitational Waves

- Overall, international coordination in gravitational wave astroparticle physics is advanced and healthy, both in the scientific and policy communities, but would benefit from strengthening and consolidation in view of the ambitious plans for the future.
- The projected size and billion-dollar cost of third-generation facilities makes them candidates for global-scale planning, funding, and implementation.
- This applies to the proposed constellation of laser interferometer satellites (dubbed LISA) that would, presumably, be jointly realized by ESA and NASA, and to an advanced large underground interferometer, such as the so-called Einstein Telescope (a current European conceptual design).

Neutrino Experiments
Double Beta Decay

	Calorimetric Bolometer	Calorimetric Semiconductor	Calorimetric Liquid/gas	Tracking Calorimetry
Data taking or G1	COUORICINO	Heidelberg-Moscow		NEMO3
Constructon R&D or G2	CUORE CANDLES LUCIFER	GERDA-I-II Majorana Demonstr COBRA	XMASS SNO+ KMAMLAND EXO @WIPP NEXT	SuperNEMO DCBA MOON
Planned or G3		GERDA-III Majorana	XMASS-10ton EXO	

Neutrino Properties

- Healthy competition among projects is the rule in the investigation of neutrinoless double beta decay.
- However, global-scale coordination and avoidance of duplication would be beneficial, especially for the procurement of crystals and scarce enriched isotopes.
- A future generation experiments, using target masses of approaching one ton, will certainly need international coordination.

Neutrino and Proton Decay Experiments

	Water Cherenkov	Liquid Scintillator	Argon	Tracking
Data taking or G1	SuperKamiokaSuperKamiokande	KAMLAND Borexino DCHOOZ /DAYA-BAY/RENO	Icarus ArgoNEUT	MINOS / T2K OPERA T2K
Constructon R&D or G2			ModularArgoNEUT T2K Argon Modular	NOVA
Planned or G3	HyperKamiokaHyperKamiokande LBNE @ DUSEL MEMPHYS	LENA	GLACIER LBNE@DUSEL	INO

Proton Decay and other Underground Experiments

- The coordination of underground laboratory operations, exchange of knowledge, and policy harmonisation are desirable at the world level.
- The goal should be to raise the level of international coordination for underground experiments to the same level that characterises other astroparticle physics activities, such as gravitational wave experiments.
- Megaton scale proton decay and neutrino detectors whose cost, complexity and multiple links to neighbouring scientific disciplines (astrophysics, cosmology, particle physics) present a strong case for worldwide convergence or, at a minimum, for avoidance of unnecessary duplication.

Policy Recommendation: Establish APIF

- To address the policy challenges enumerated above in each of the six scientific domains of astroparticle physics, the Working Group recommends the establishment of a venue for consultations among officials of funding agencies that make significant investments in the field.
- The overall goal should be to ensure that, during the next 10-15 years, progress in astroparticle physics will be a globally coherent response to the scientific challenges, using an optimal set of national, regional, and international projects.
- The new consultative group would be called the Astroparticle Physics International Forum (APIF), and would be a subsidiary body of the OECD Global Science Forum.
- The emphasis should be to provide a venue for the agencies to talk to each other about international coordination.

Personnel in Astroparticle Physics

FTE's	Permanent	Postdocs	Grad Stds	Other	Total
Europe	1021	269	439	197	1926
US	269	135	220	68	692
Canada	46	35	63	55	199
S America					
Russia	500	60	50	100	710
India	45	5	20	0	70
China	100	20	90	35	245
Japan	150	48	98	29	325
Australia	6	4	20	0	30
TOTAL	2131	576	1000	484	4197

Astroparticle Physics Budgets

Annual Funding	Lab Operations	Investment	Salaries	Other	Total
Europe	26.0	50.6	90.4	10.0	177.0
US	9.9	34.9	56.3	2.1	119.2
Canada	5.0	6.0	3.0	1.0	15.0
S America					
Russia	3.5	2.5	6.0	0.5	12.5
India	1.5	2.5	1.0	0.5	5.0
China	3.5	5.6	4.6	0.5	14.2
Japan	14.0	13.2	24.4	0.4	52.0
Australia	0.3	0.3	1.4	0.0	2.0
TOTAL	63.4	114.8	187.1	15.0	396.9