Astroparticle Physics

The European Strategy

Christian Spiering, DESY

Brussels, Sept. 29, 2008

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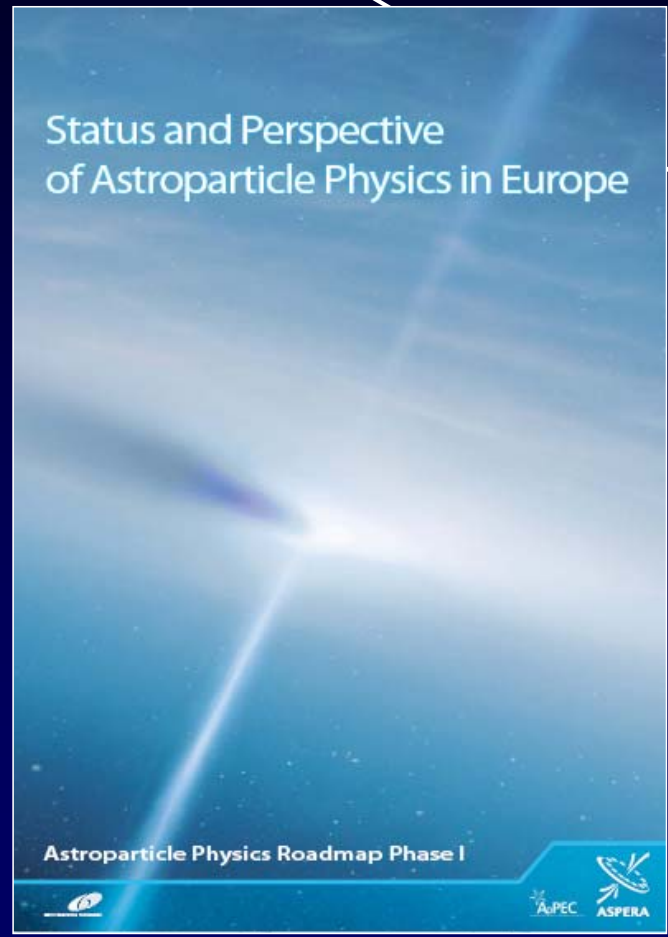
SIXTH FRAMEWORK PROGRAMME

http://www.aspera-eu.org

Phases of Roadmapping

- **Phase I:**
  - Roadmap Phase I: science case
  - Recommendations for convergence

- **Phase II:**
  - ASPERA Working Groups
  - Detailed questionnaires from subfields and agencies. Timelines and updated cost
  - **Amsterdam Meeting 20/21 Sept 2007**



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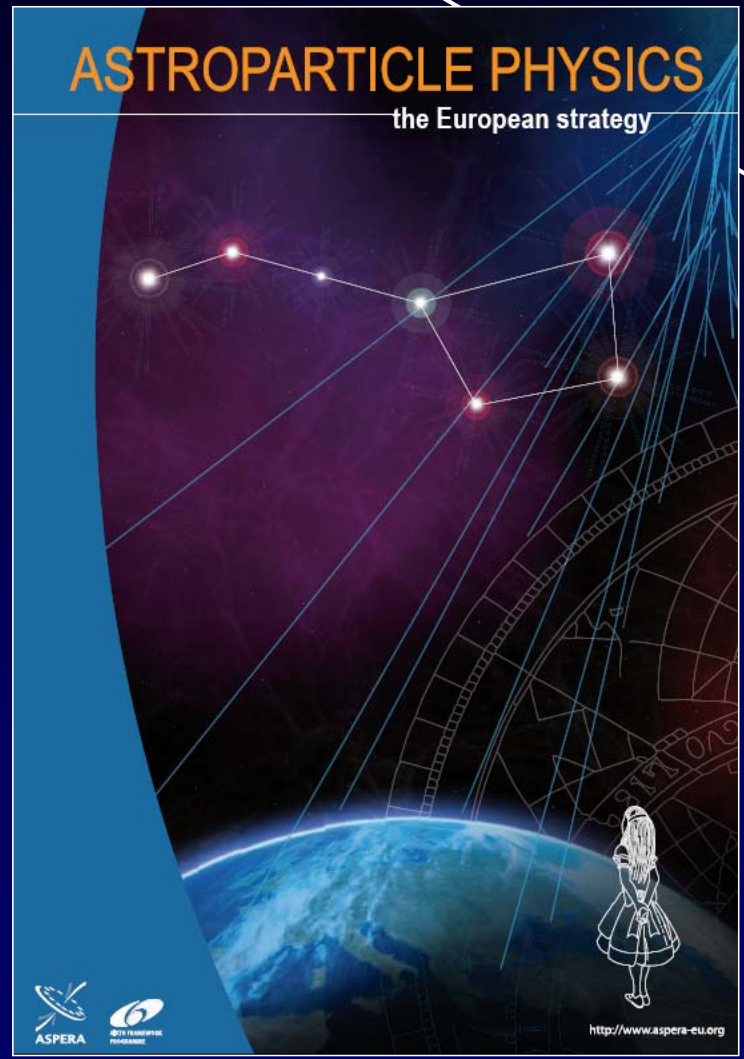
Phases of Roadmapping

- **Phase III:**
  - Critical assessment of plans
  - Calendar for milestones and decisions
  - Input for ESFRI Roadmap
  - Coordination with ASTRONET
  - Roadmap „Astroparticle Physics - The European Strategy“
  - Long write-up with detailed data and arguments (in work)



The long write-up

- **Executive Summary**
- **For each of the sub-fields**
  - **Goals**
  - **Overview**
  - **List of experiments**
  - **Assessment of priority experiments**
    - **Scientific impact**
    - **Uniqueness/complementarity**
    - **Timeliness, schedule, milestones**
    - **Strength of community**
    - **Project management**
    - **Technical challenges, readiness and risks**
    - **Industrial involvement**

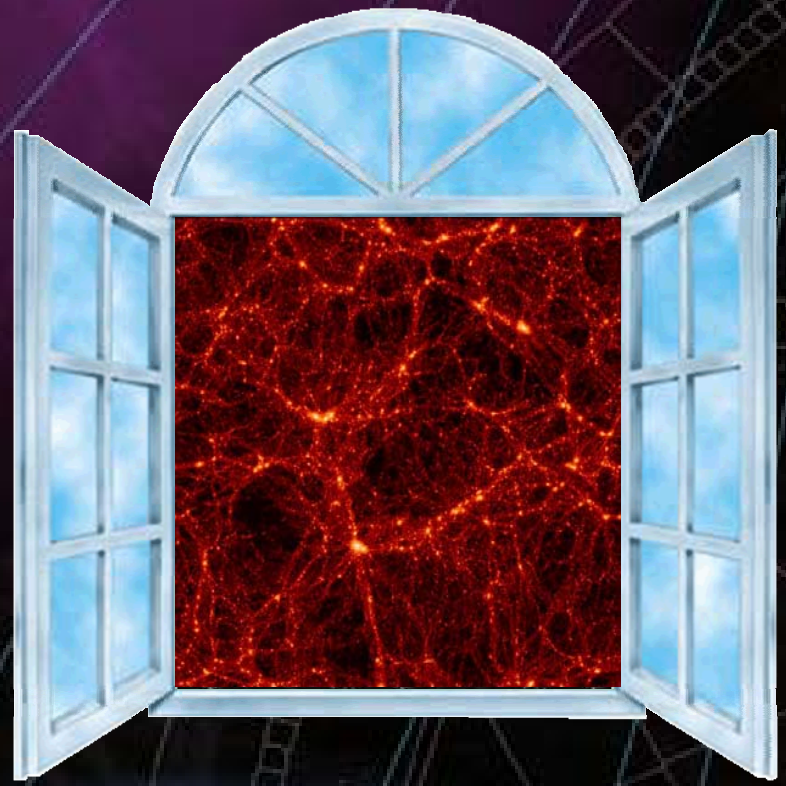
The long write-up

- Executive Summary
- For each of the sub-fields
  - Goals
  - Overview
  - List of experiments
  - Assessment of priority experiments
- **Infrastructures**
- **New Technologies**
- **Theory**
- **Computing**
- **Recommendations**
- **Costing details**

The Questions

- What is the Universe made of ?
  In particular: what is dark matter ?
- Do protons have a finite lifetime ?
- What are the properties of neutrinos ? What is their role in cosmic evolution ?
- What do neutrinos tell us about the interior of the Sun and the Earth, and about Supernova explosions ?
- What is the origin of cosmic rays ? What is the view of the sky at extreme energies ?
- What will gravitational waves tell us about violent cosmic processes and about the nature of gravity ?

Dark Matter and Dark Energy Searches



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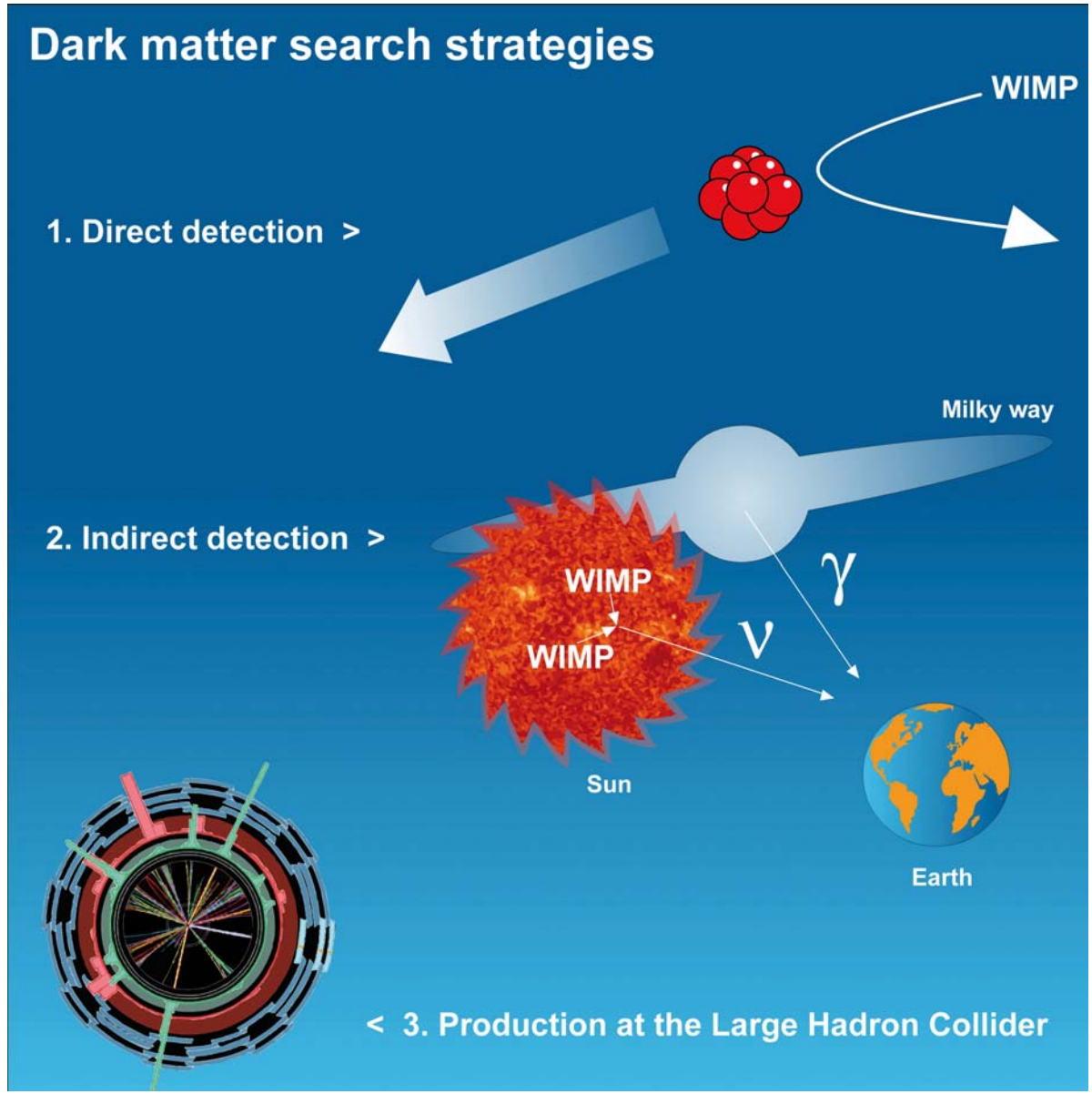
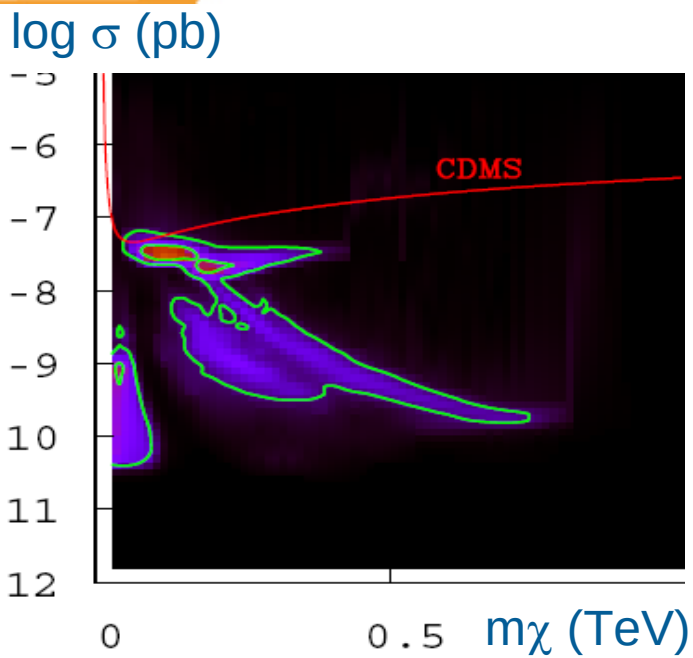
Dark Matter Searches

DM candidates:

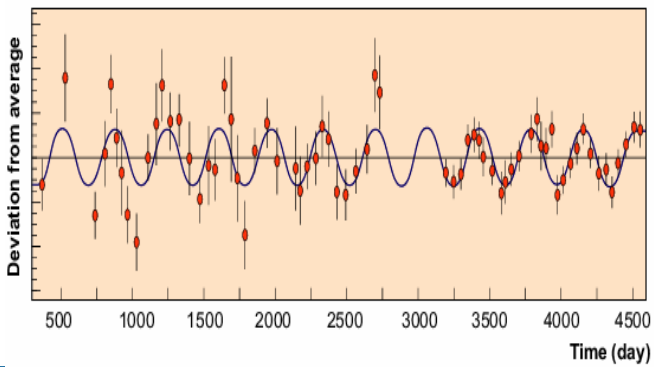
- **WIMPs**
- **Axions**
- **...**
- **something else**



Dark Matter Searches



DAMA annual modulation



COUPP, PICASSO, SIMPLE

DRIFT I, II

GENIUS, IGEX, NEWAGE

WIMP elastic nuclear recoils deposit < 50keV of energy at a rate 10^{-5} to 1 event/day/kg

ArDM, SIGN, WARP, XENON10, ZEPLIN III , LUX, XENON-100, WARP-140

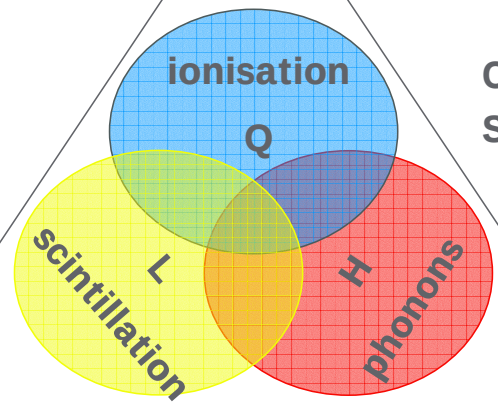
ANAIS, CLEAN, DEAP, KIMS, DAMA/LIBRA, NAIAD, XMASS, ZEPLIN I

High efficiency particle identification requires compound information and/or large self-shielding mass

CRESST II, ROSEBUD, EURECA

phonons, photons and charge whose relative proportions and /or characteristics depend on dE/dx ⇒ particle type

CDMS, EDELWEISS, SuperCDMS, EURECA



by T. Sumner
updated by
C.P.de los Heros
and C.Spiering

Astroparticle Physics for Europe

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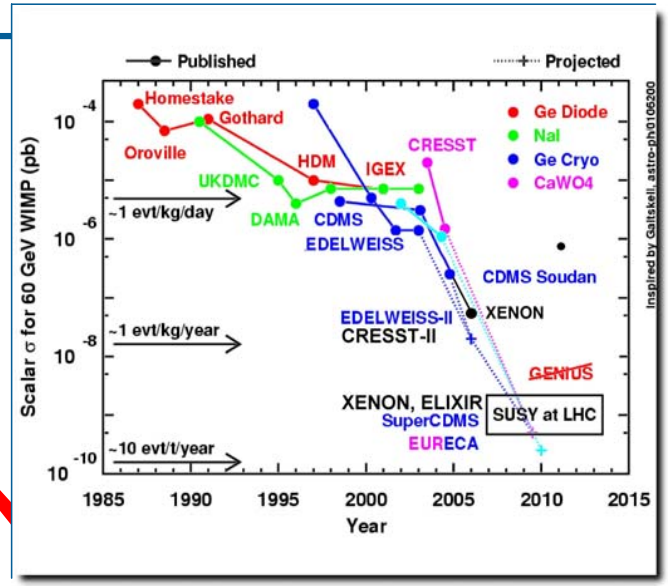
Dark Matter Searches



Cross section (pb)

10^{-4}

10^{-6}

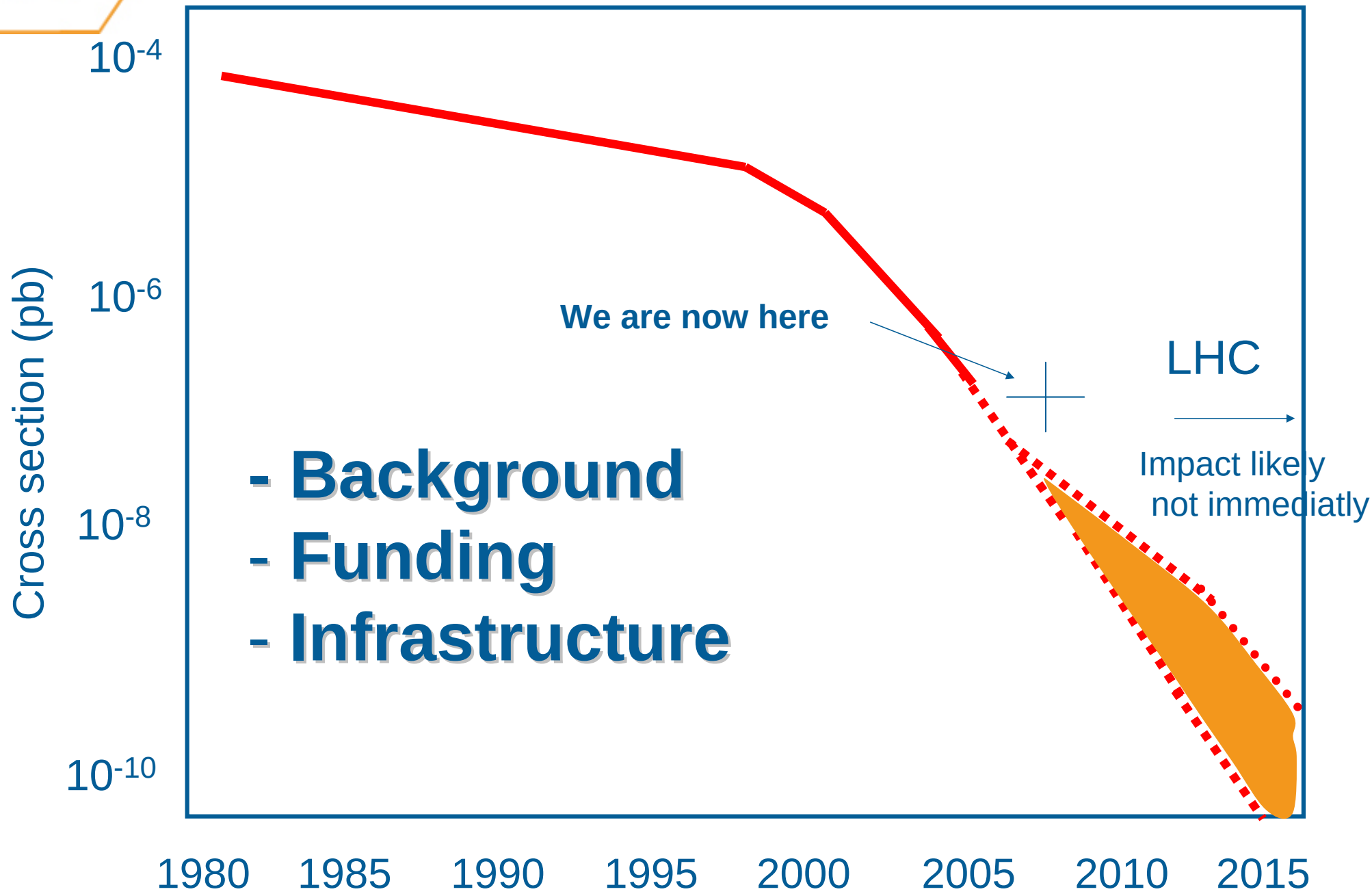
10^{-8}

10^{-10}

1985 1990 1995 2000 2005 2010 2015

- Background

- Funding / Infrastructure


Cross section (pb)
10-4
10-6
10-8
10-10
1980
1985
1990
1995
2000
2005
2010
2015
We are now here
LHC
Impact likely
not immediatly
- Background
- Funding
- Infrastructure

Towards 2 ton-scale zero-background detectors

Now: 10 kg scale | 2009/11: 100 kg scale | 2011-17: constr. ton scale

CRESST
Edelweiss
→ EURECA-100 → EURECA @ ton scale

modular expansion

LXe
LXe
LAr
LAr
...

XENON/LUX, WARP

Xe-100
Ar-100
→ Noble liquid @ ton scale

ELIXIR, ..

a possible convergence scenario, slide CS from one year ago.

Dark Matter Searches

Astroparticle Physics for Europe

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now

100 kg scale

ton scale

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017

operation ZEPLIN-II

construction operation ZEPLIN-III

construction operation LUX/ZEPLIN

liquid xenon

operation XENON

construction operation XENON-100

construction operation XENON-1Ton

operation WARP

construction operation WARP-140

Tests ArDM

liquid argon

Noble liquid detectors with European participation

Dark Matter Searches

- Support current round of experiments at high priority, also technology development towards their next-generation versions
- A recommendation on which of the technologies should first move to a next stage can only be made after first results from present experiments with 10-100 kg target mass become available and after noise rejection and sensitivity/cost ratio for ton-scale detectors can be judged on a more realistic basis.
- **This milestone can be reached by 2010 or 2011.**
- As soon as one of the technologies turns out to be clearly superior in sensitivity, cost, and timing → Promote it with priority!
  At the same time, a second technology must be systematically prepared since a possible positive observation by the first method would call for a prompt, independent confirmation.
- In an ideal scenario, LHC observations of new particles at the weak scale could place these observations in a well-confined particle physics context. Also, direct detection would be supported by indirect signatures. In case of a discovery, “smoking-gun signatures” of direct detection such as directionality and annual variations would be measured in detail.

Short version of recommendations:

We recommend the construction and operation of one – possibly two complementary – detectors on the ton scale or beyond with low background, capable of reaching a 10^{-10} pb sensitivity, with a European lead role or shared equally with non-European partners. We recommend a stepwise approach via 100 kg detectors, as present underway, and a prioritisation between different technologies around 2010. **We urge convergence of parallel worldwide efforts.**

Dark Energy

- Particle physicists engaged since the beginning: handling large data sets, cutting-edge technologies.
- Construction of future instruments – large telescopes and space missions – depends on choices beyond the single authority of the agencies charting this roadmap. We refer to the *ASTRONET Roadmap.*
- Next generation of cosmology missions, e.g.:
  - Planck (CMBR)
  - Dark Energy Survey, DES (from Europe Spain and UK)
  - After 2013 e.g. LSST, JDEM (DOE/NASA), EUCLID (ESA). Growing number of European institutions planning to participate in these projects.
  - Plus many other missions with a dominantly astrophysics motivation (see ASTRONET Roadmap).
- Implications for fundamental physics are profound. Therefore, DE missions find strongest support from the astroparticle physics community.

Properties of Neutrinos

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Properties of Neutrinos

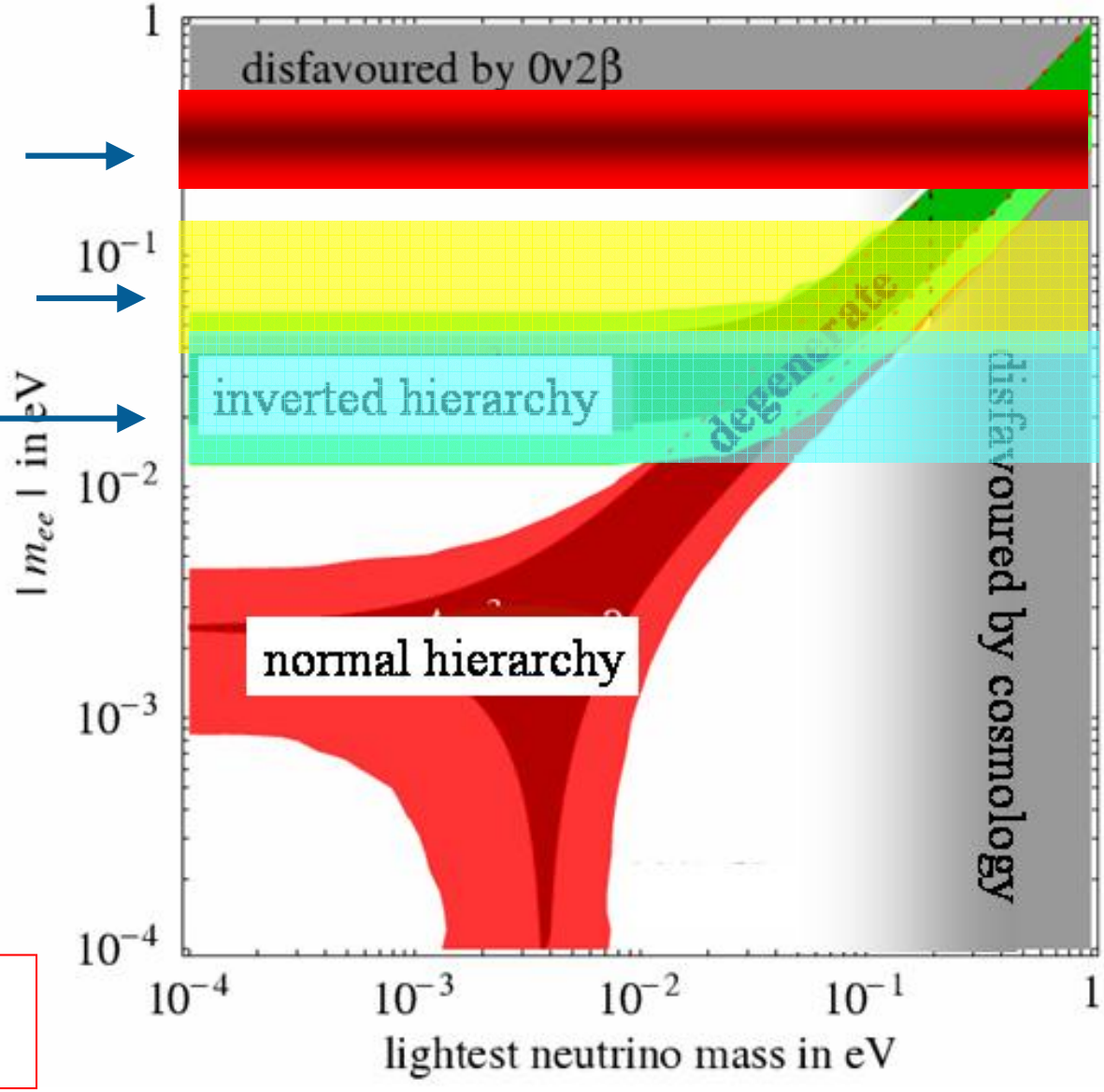
- **Direct Mass Measurements**
  - Present limit 2.3 eV
  - KATRIN, start 2011, down to 0.2 eV
  - Troitzk (Russia) start 2009, down to 0.8 eV
- **Double Beta Decay Experiments**
  - Cuoricino, Nemo-3
  - Gerda, Cuore, Super-Nemo
  - EXO
  - Cobra, NEXT, ….
- **Mixing Parameters**
  - Double CHOOZ
  - T2K
  - experiments with CERN beam (Opera, Modular, …)

Double Beta Decay

KKGH claim

GERDA, EXO200 CUORE, SuperNEMO

Ton-scale



Price tag for ton-scale 50-200 M€.

Double Beta Decay

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now

operation **CUORICINO** bolometric 41 kg ^{130}Te

construction operation **CUORE** bolometric 740 kg ^{130}Te

operation **NEMO-3** tracking 8 kg ^{130}Mo/^{82}Se

design study construction operation **Super-NEMO** tracking 100 kg ^{150}Nd/^{82}Se

construction operation **GERDA** 18 → 40 kg ^{76}Ge

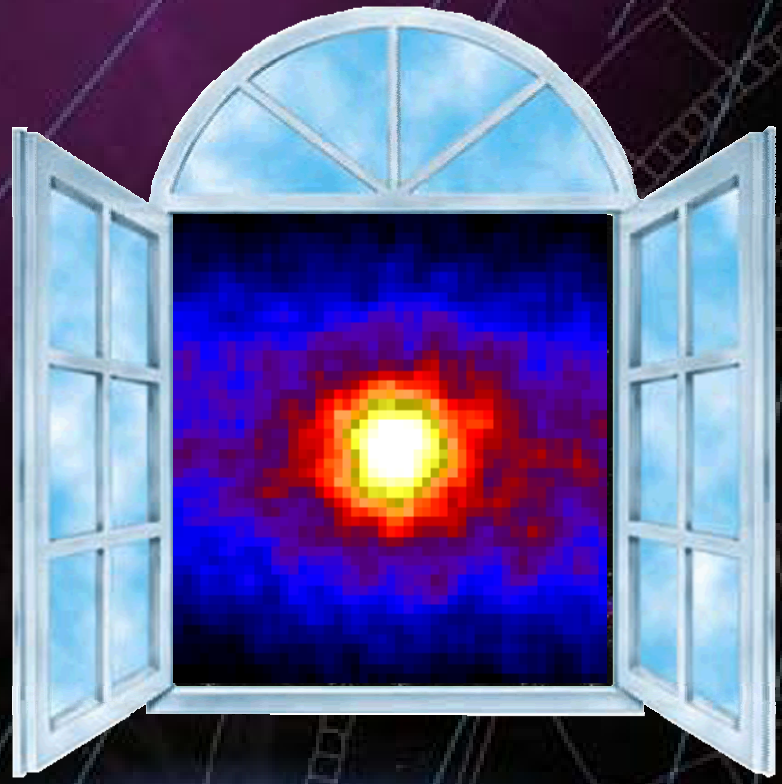
design study construction operation **EXO (USA)** 200 kg ^{130}Xe

(Projects running, under construction or with substantial R&D funding)

Double Beta Decay

- Priority to experiments starting operation within 5 years
  - **GERDA (phase I and II)**
  - **CUORE**
  - **Super-NEMO**
- Complementary nuclei/methods essential to judge any positive claim or upper limit.
- Will scrutinize the claimed evidence in ^{76}Ge, will touch the "inverted hierarchy" mass range and keep European leadership.
- Other methods may become competitive in the future.
- At the same time, envisage an experiment on the 1-ton-isotope scale, which will peer deep into the inverted hierarchy range. Two options discussed, both with worldwide cost sharing:
  - **GERDA III as merger of GERDA with Majorana (USA)**
  - **CUORE with enriched tellurium, USA participation.**
- Milestone: Decision on the isotopes/ techniques to be taken by 2012/13.

Low Energy Neutrino Astronomy and Proton Decay



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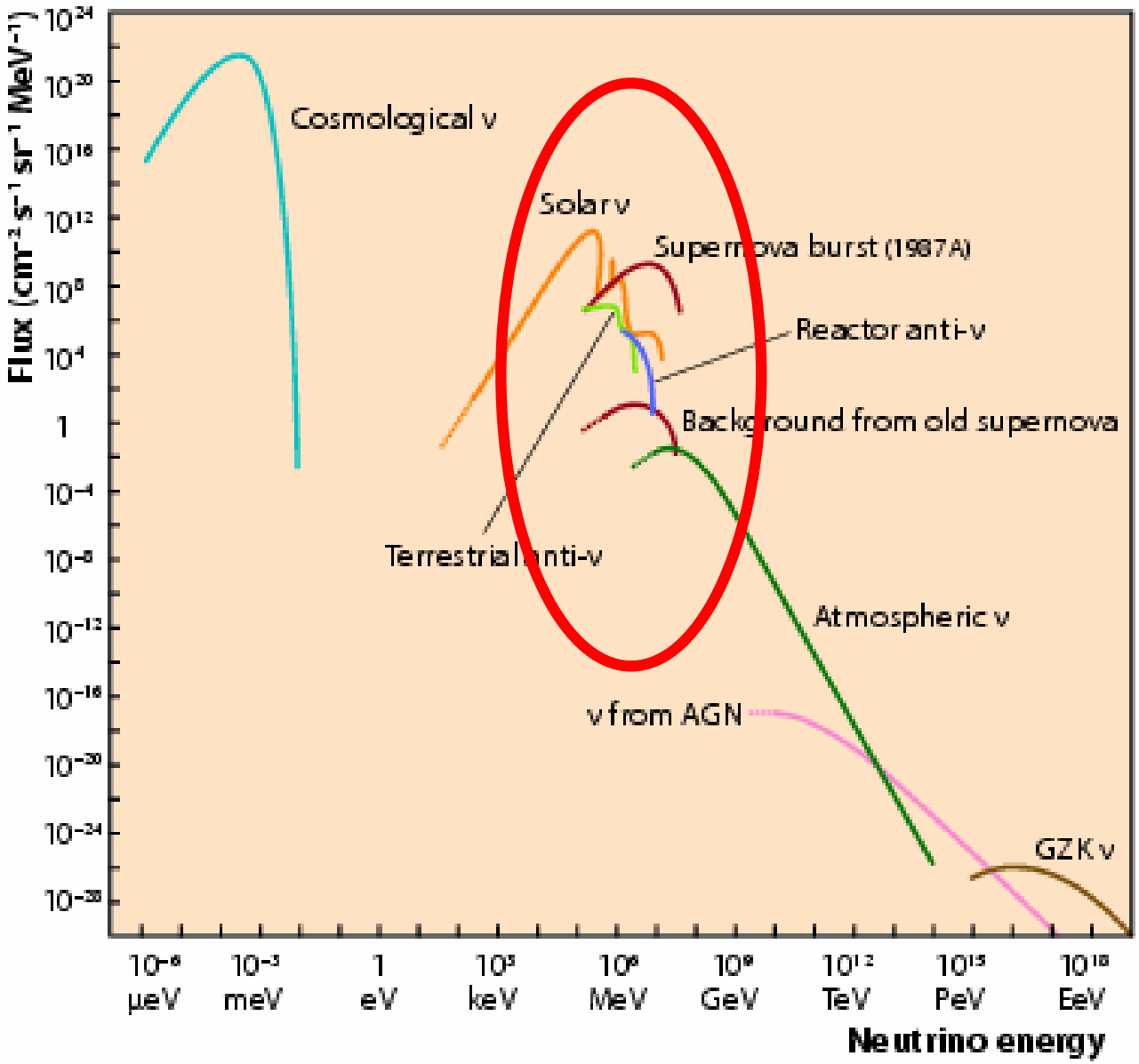
Neutrino Astrophysics & p-decay

- **Super-Kamiokande**
- **Europe, solar ν**
  - **GALLEX/GNO (closed)**
  - **BOREXINO**
- **Europe, SN ν**
  - **MACRO (closed)**
  - **LVD**
- **Europe, atm.ν**
  - **Frejus, MACRO (both closed)**
- **Europe p-decay**
  - **NUSEX, Frejus (both closed)**



LAGUNA

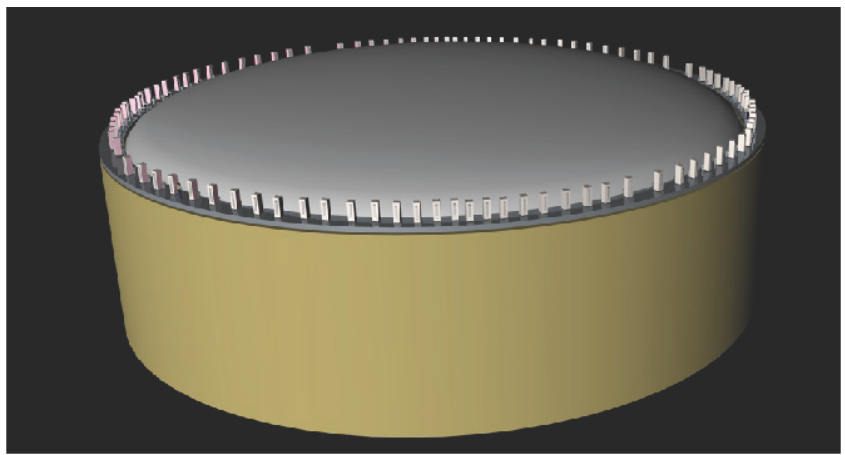
MEMPHYS

700 kton water

LENA

50 kt scintillator

50 m



GLACIER

100 kton liquid argon

Science at the Megaton scale

- **Proton decay:** improve sensitivity by > factor 10 and test a new class of Supersymmetry models
- **Galactic Supernova:** 10^4- 10^5 events
  Incredibly detailed information on the early SN phase
- **Diffuse flux from past SN:** probe cosmological star formation rate
- **Solar neutrinos:** details of the Standard Solar Model determined with percent accuracy
- **Atmospheric neutrinos:** high statistics would improve knowledge neutrino mixing and provide unique information on the neutrino mass hierarchy
- **Geo-neutrinos:** improve understanding of the Earth interior
- **Indirect WIMP search**
- **Neutrinos accelerators** over a long baseline (also with dedicated smaller detectors): neutrino properties

Neutrino Astrophysics & p-decay

- Continue rich legacy of underground detectors with worldwide 1 or 2 multi-purpose detectors of 100-1000 kilotons.
- Worldwide coordination and cost sharing (in total 250-800 M€)
- LAGUNA – FP7 design study evaluates 3 techniques and sites in Europe.
- ~ 2010: assess discovery potential of options and sites and then converge to a common proposal. Needs additional support to complete detector R&D programmes not fully covered by FP7 Design Study.
- **Necessity of a coherent approach with efforts in the USA and Japan is obvious**.

- Input from BOREXINO (liquid scintillator) and ICARUS-T600 (liquid argon), DoubleChooz and T2K. Proposals for dedicated liquid argon detectors, e.g. MODULAR at Gran Sasso.

- **<u>Recommendation:</u> We recommend supporting the work towards a large infrastructure for proton decay and low energy neutrino astronomy, possibly also accelerator neutrinos in long baseline experiments, in a worldwide context. Results of the LAGUNA FP7 design study are expected around 2010 and should be followed by work towards a technical design report. Depending on technology, site and worldwide cost sharing, construction could start between 2012 and 2015.**

The High Energy Universe

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- Gamma Rays

  CTA

- Neutrinos

  KM3NeT

- Charged Cosmic Rays

  Auger North

European Priorities

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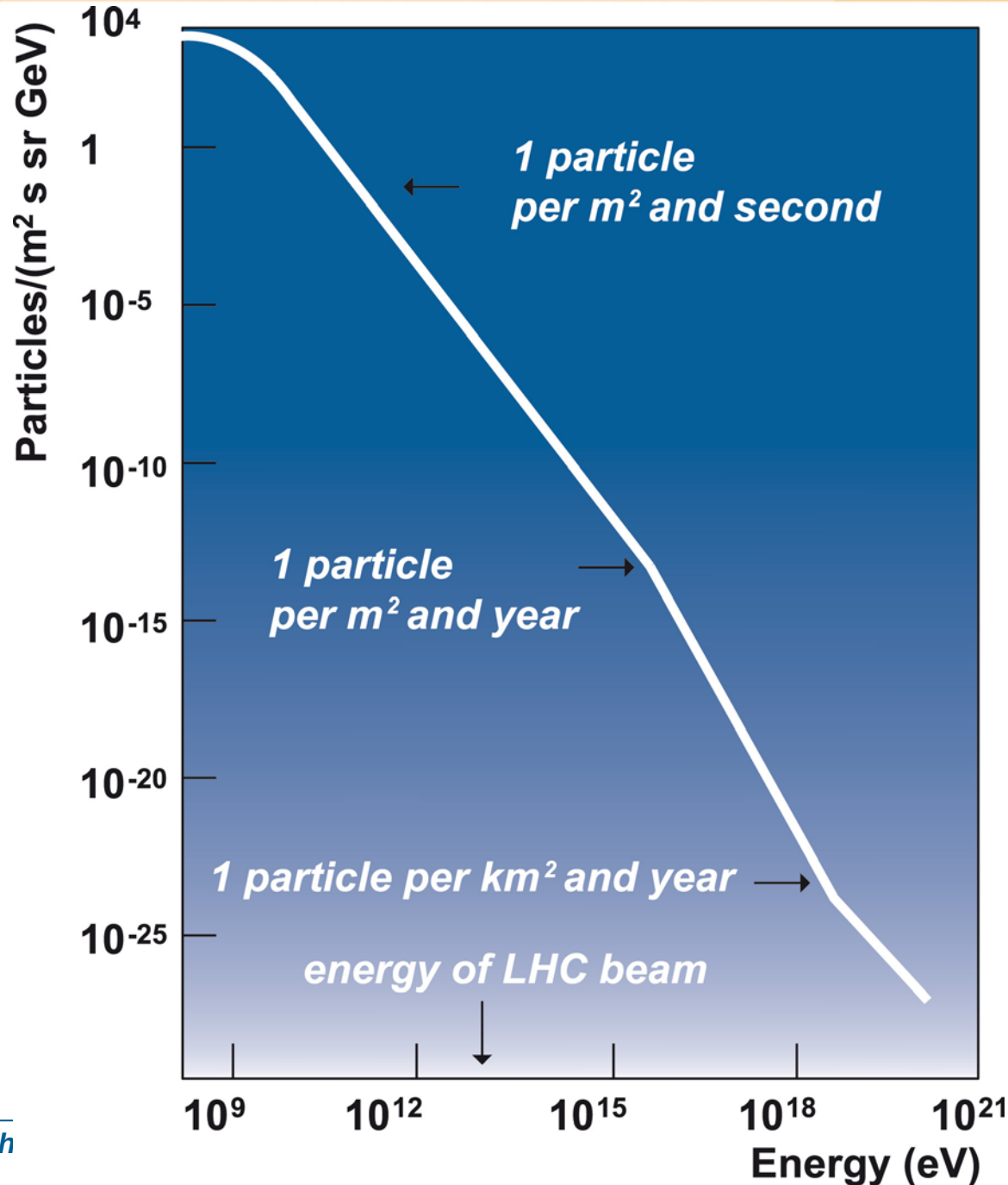
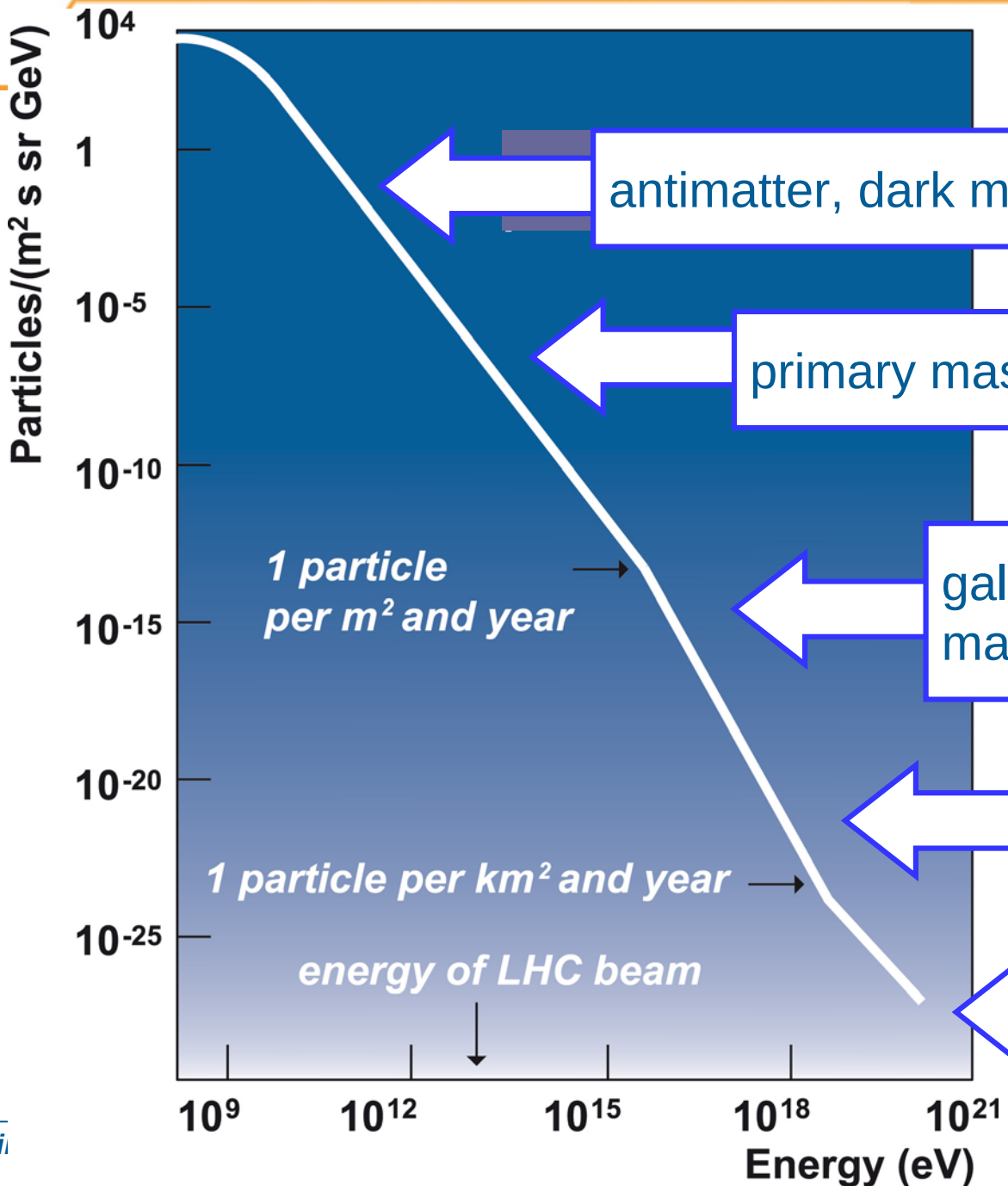
Charged Cosmic Rays



Charged Cosmic Rays



antimatter, dark matter, mass composition

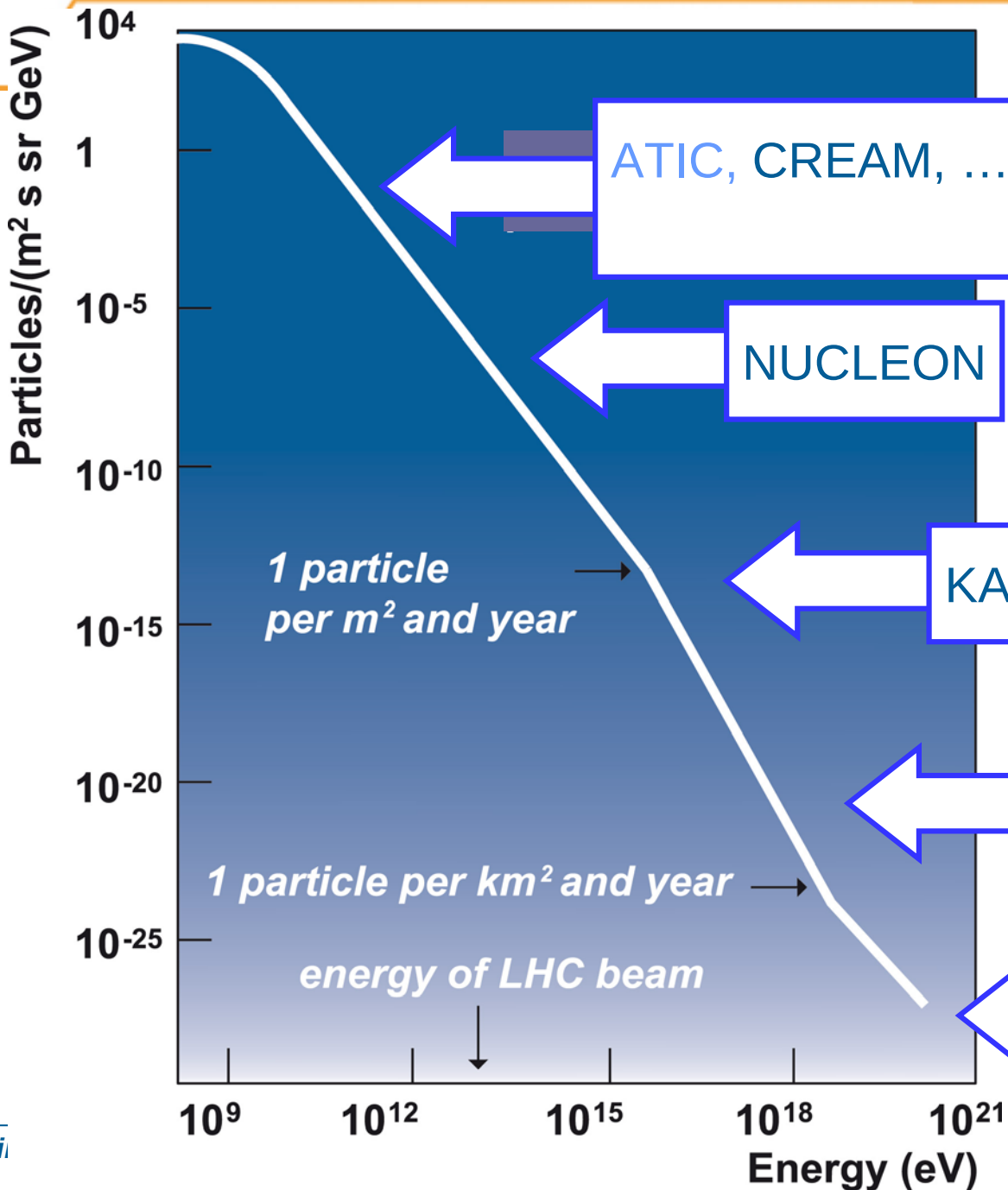
primary mass composition

galactic sources
mass composition

galactic → extragalactic

CR astronomy,
GZK physics,
HE neutrinos, …

Charged Cosmic Rays



ATIC, CREAM, …
Pamela, AMS

balloon

space

NUCLEON

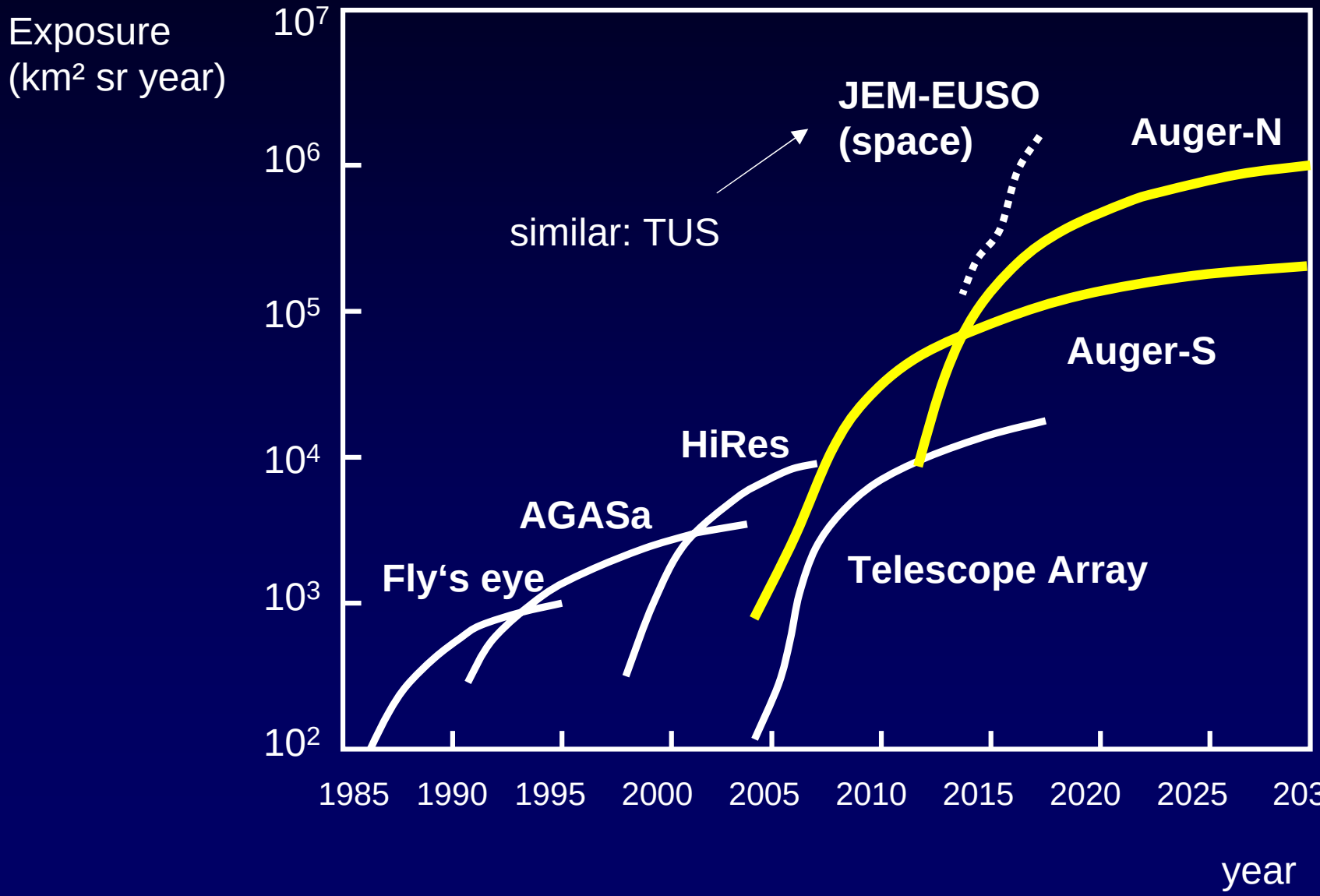
KASCADE + many others

KASCADE-Grande
IceTop/IceCube
Tunka-133

TA, Auger
TUS
JEM-EUSO

space

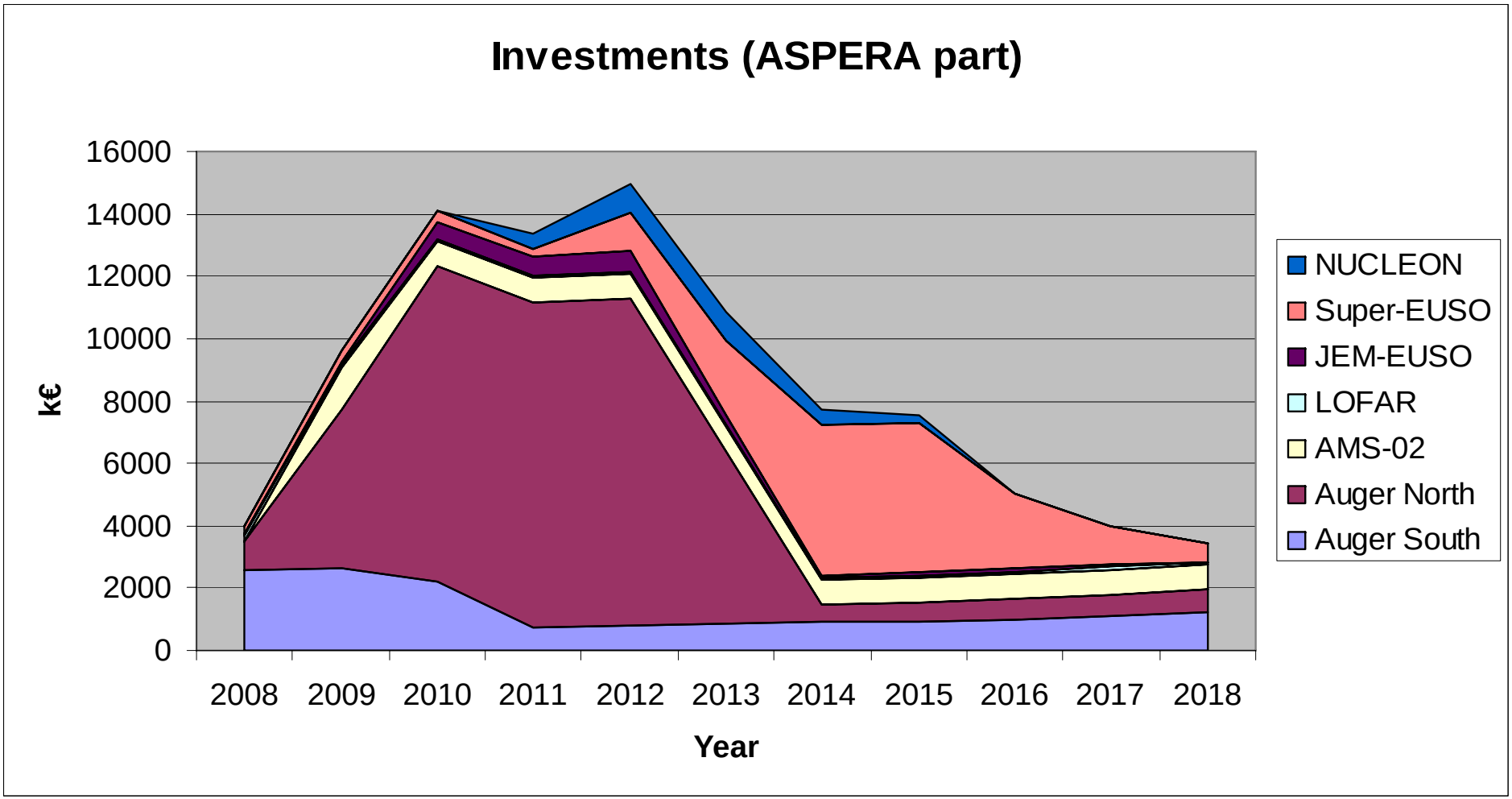
Charged Cosmic Rays



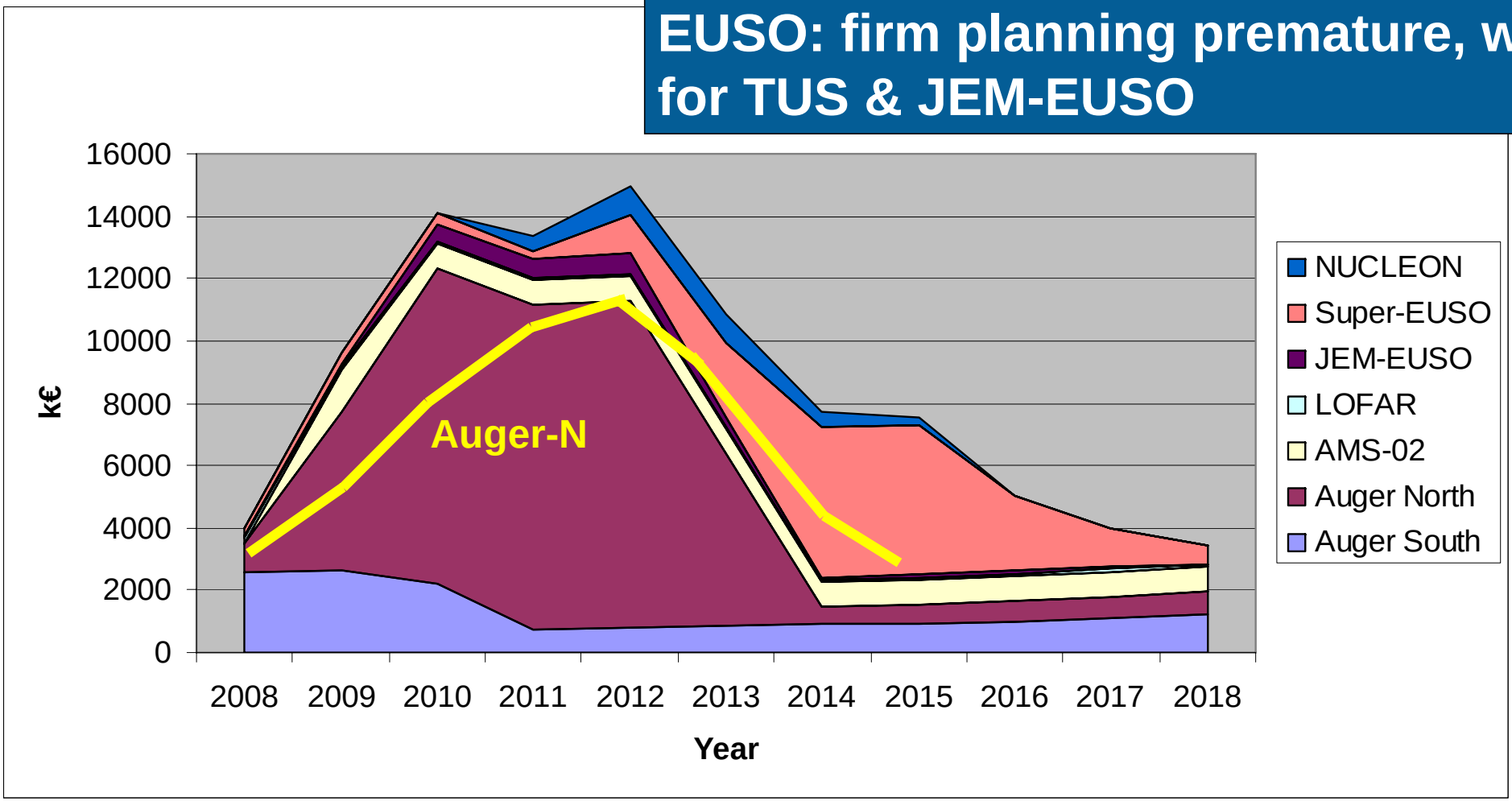
Charged Cosmic Rays

- The case for “Auger-North” is strong: high statistics astronomy with reasonably fast data collection calls for a substantially larger array than Auger South, full sky coverage calls for a Northern site. A larger array would also allow a more detailed inspection of the high energy cut-off of the particle spectrum, which recently has been firmly established by Auger-South.
- Recommendation: The priority project for high energy cosmic ray physics is Auger. We encourage the agencies in different continents to work towards a common path for Auger-North. We recommend the construction of such a large array as soon as worldwide agreements allow.

Result Working Group 2007

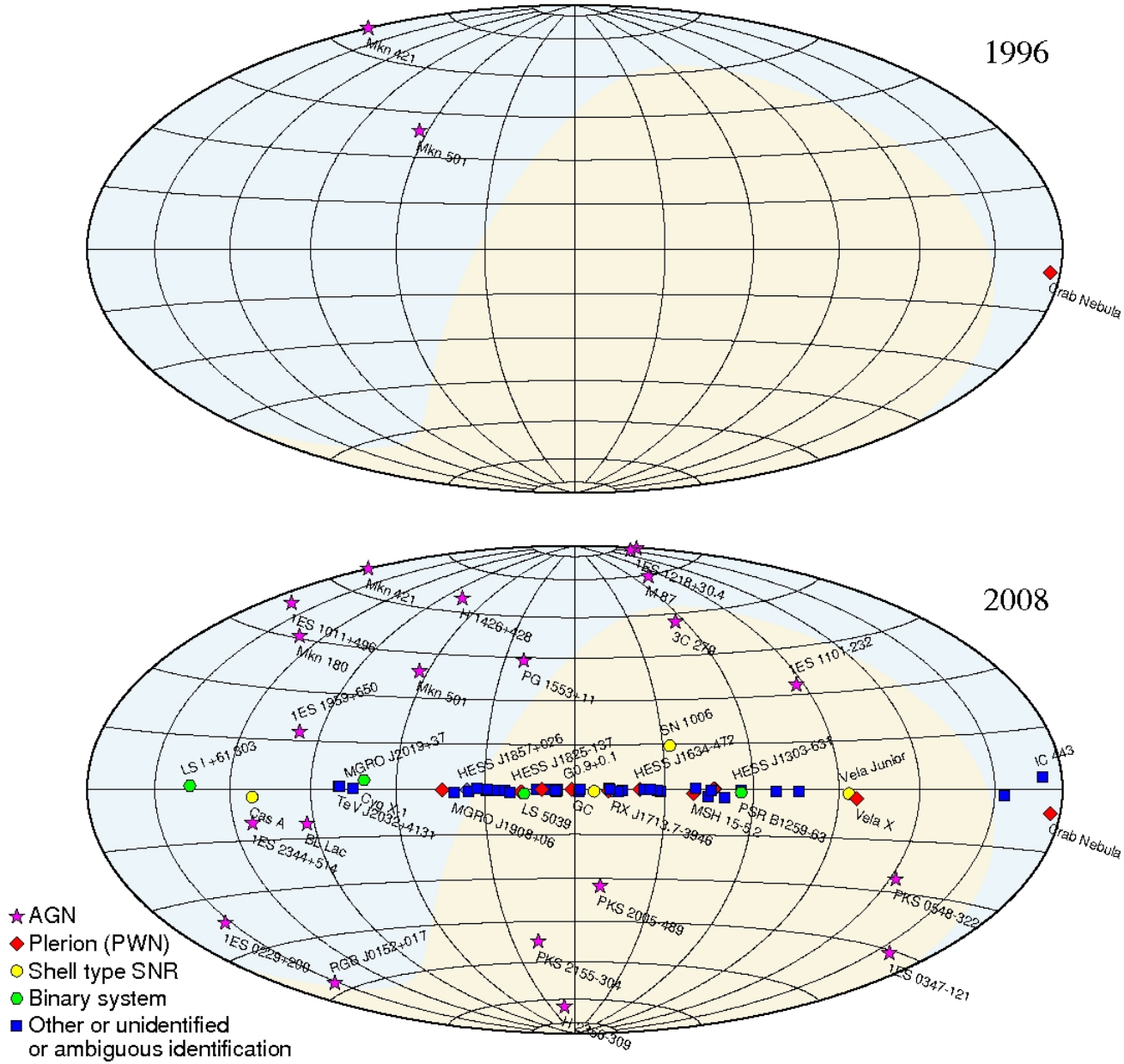


Roadmap:
Shift Auger-North, no cost reduction
EUSO: firm planning premature, wait for TUS & JEM-EUSO



High Energy Gamma Rays

- Enormous progress over last 15 years
- Mostly by Imaging Atmospheric Cherenkov Telescopes (IACT)
  - **Whipple**
  - **HEGRA, CAT, Cangaroo**
  - **HESS, MAGIC, VERITAS**
- Wide Angle Devices
  - **MILAGRO → HAWC**
  - **Argo/YBJ**
  - **GAW (R&D)**
- Future
  - **GLAST + IACTs + WADs**



Background colours indicating northern / southern sky

Graphics by Konrad Bernlöhr 2008

High Energy Gamma Rays

now

IACTs, Europe

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017

operation — **H.E.S.S.** — four 11-m telescopes

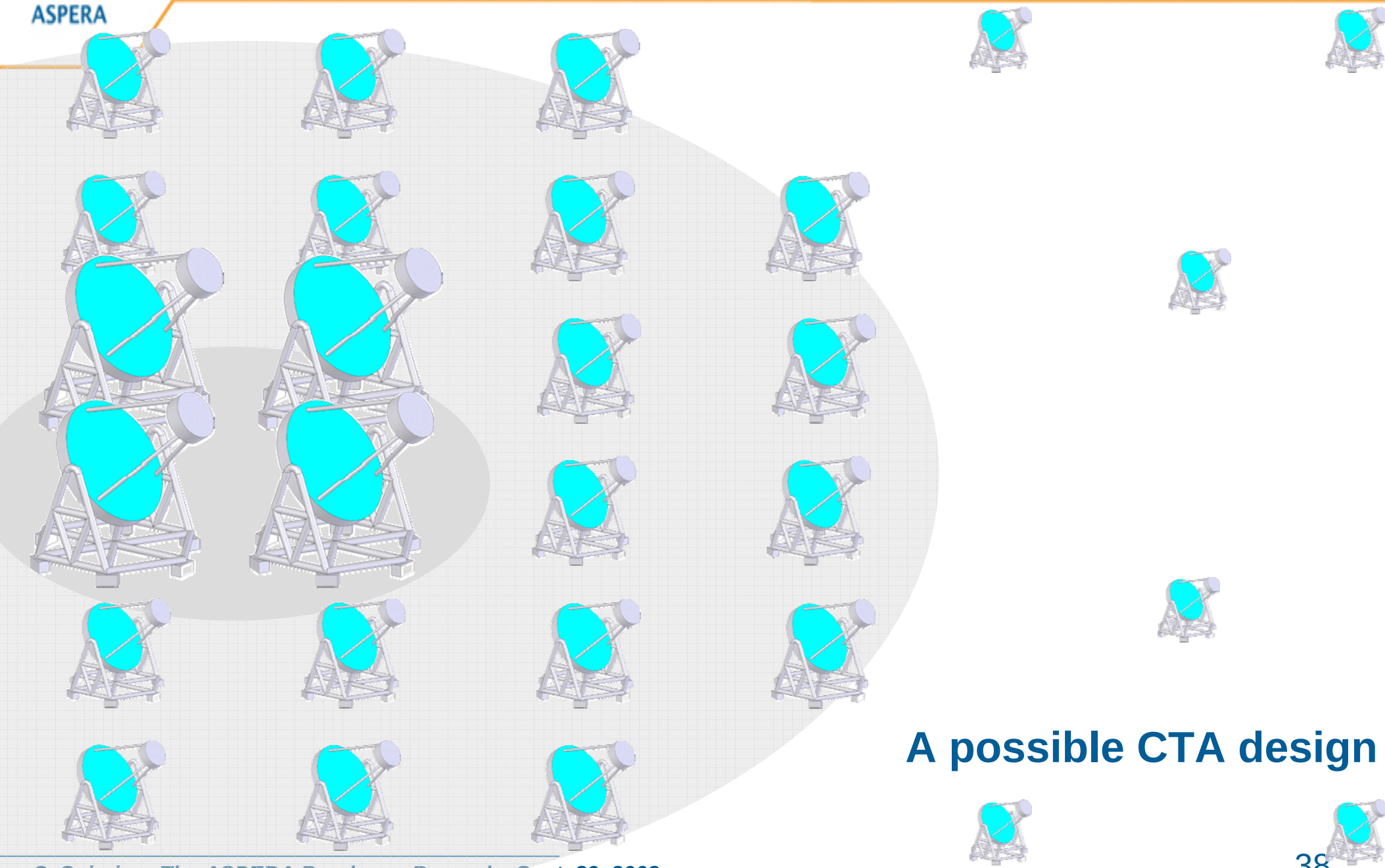
construction — operation — **H.E.S.S.- II** — + one 25-m telescope

operation — **MAGIC-I** — one 17-m telescope

construction — operation — **MAGIC- II** — 2nd 17-m telescope

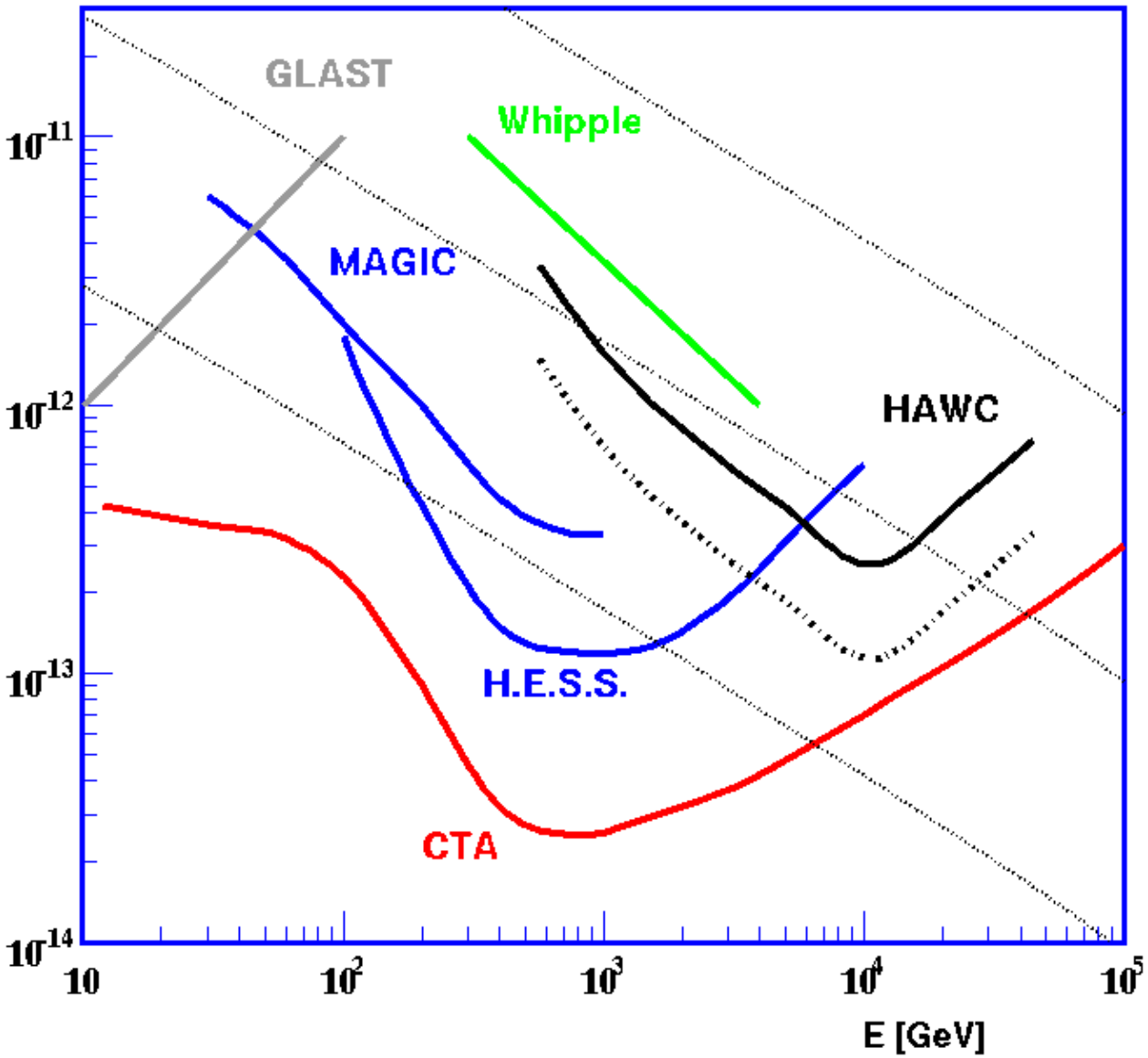
CTA — des… — …truction + operation — Oper.

Coordination with USA, Japan, Australia



A possible CTA design

High Energy Gamma Rays



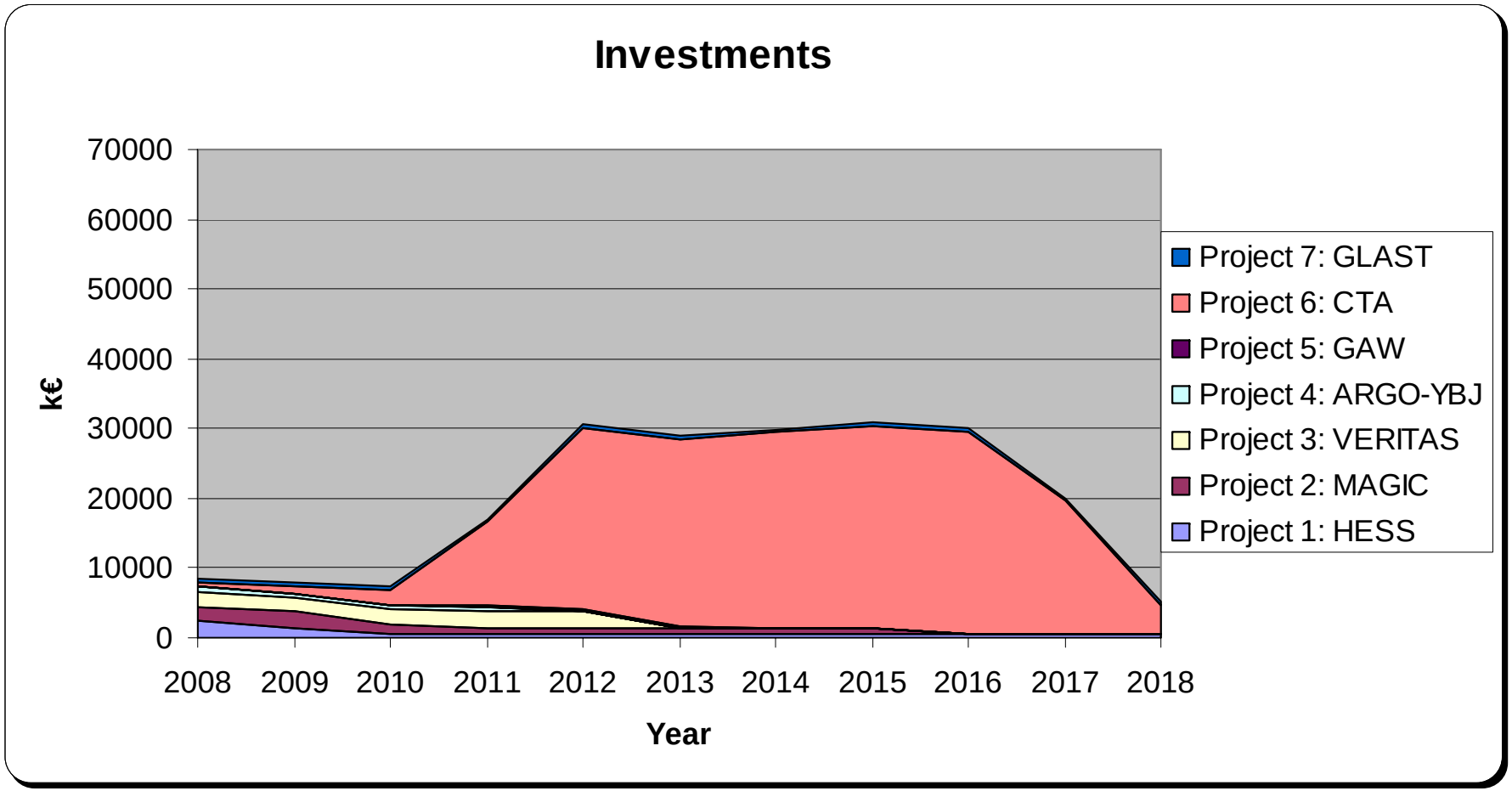
- **HESS/VERITAS, MAGIC, Whipple, CTA** sensitivity in 50 hours, (~0.2 sr/year)
- **GLAST** sensitivity in 1 year (4π sr)
- **HAWC** sensitivity in 1(5) years shown as solid (dashed) line (2π sr)

High Energy Gamma Rays

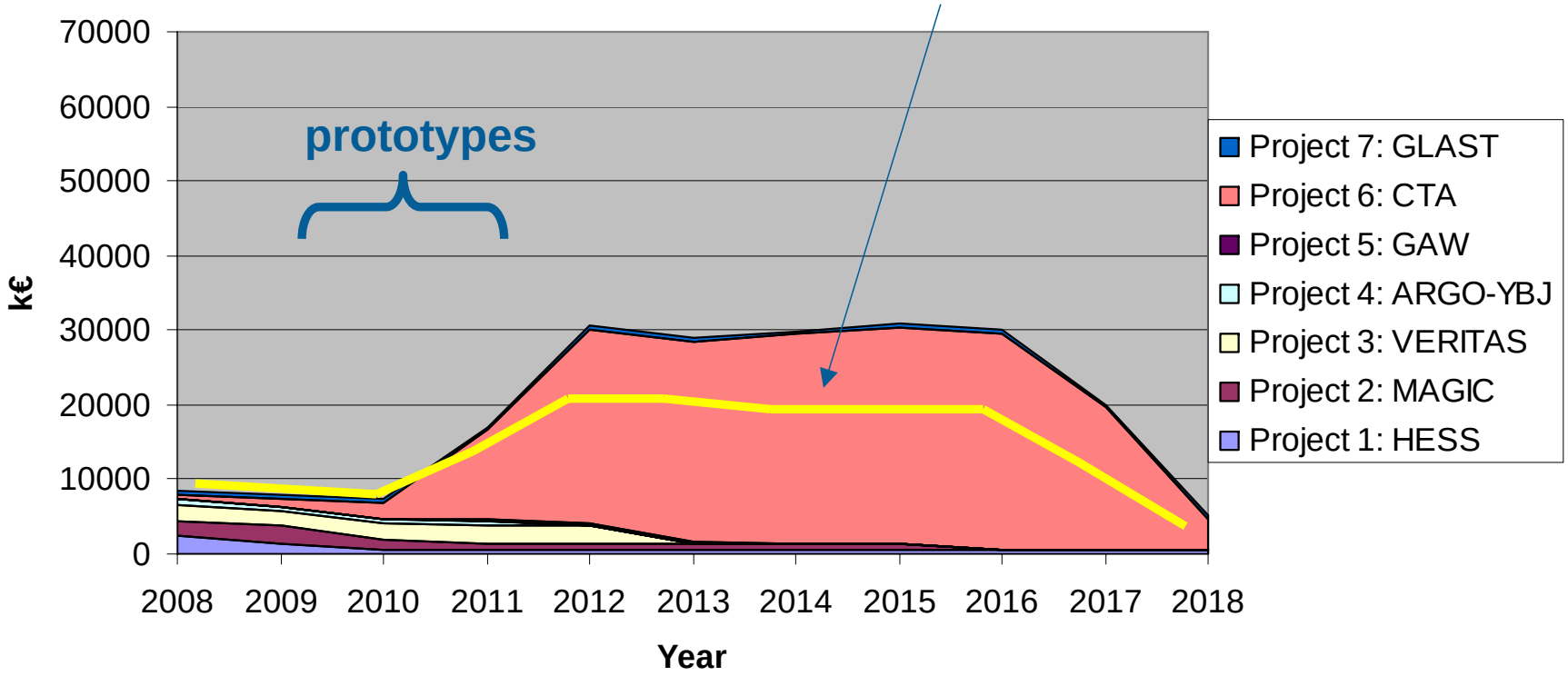
- From “experiment” to “observatory”
- 10-fold improvement of sensitivity, extension of energy range, significant improvement in resolution
- Expect ~ 1000 sources, explore spatial structure and energy spectra.
- Ultimately, a Northern and a Southern CTA instrument, operated under a common framework, should provide full-sky coverage.
- Operational overlap with GLAST provides seamless coverage of 20 octaves
- Priority project of European gamma-ray astronomy. Coordination with AGIS (USA) is underway. CTA on the ESFRI list of emerging projects, proposed as full ESFRI entry. Also listed as a priority entry in the ASTRONET infrastructure roadmap.

- **<u>Recommendation:</u> The priority project of VHE gamma astrophysics is CTA. We recommend design and prototyping of CTA and selection of site(s), and proceeding decidedly towards start of deployment in 2012.**

Result Working Group 2007

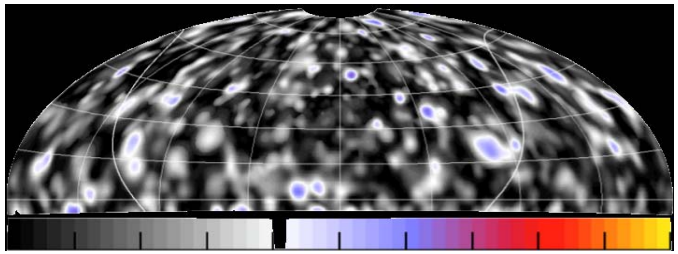


Roadmap:
Cost reduction from 170 to 120 M€
- technology
- trans- continental cooperation

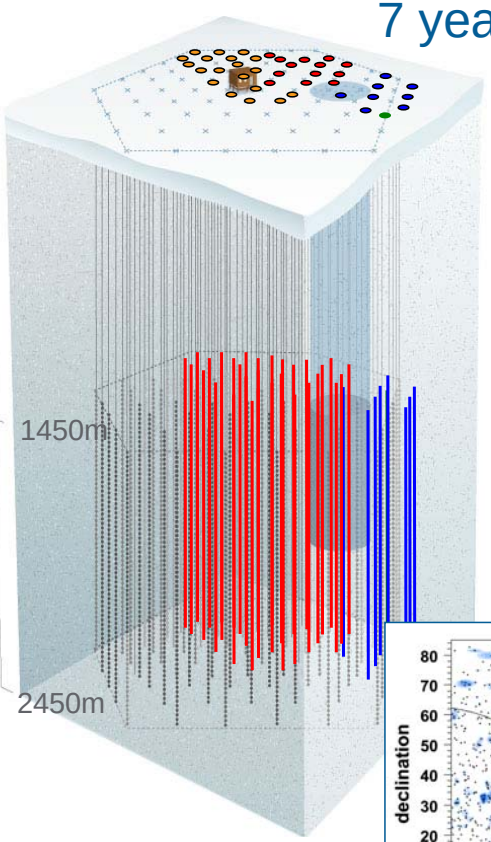


High Energy Neutrinos

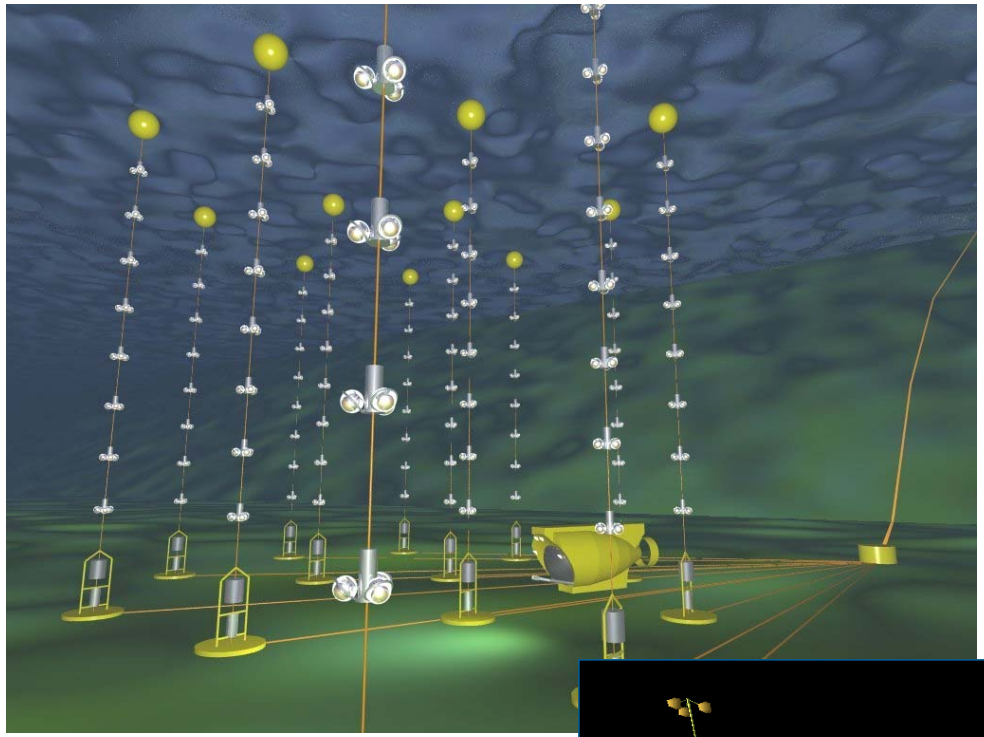
A fantastic year 2008



7 year skymap AMANDA

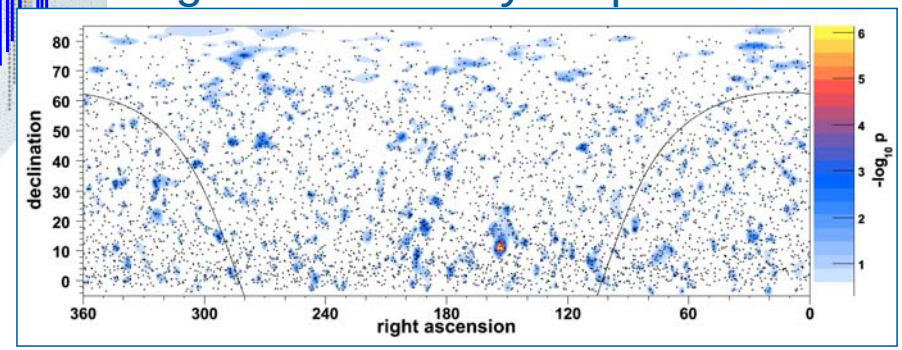


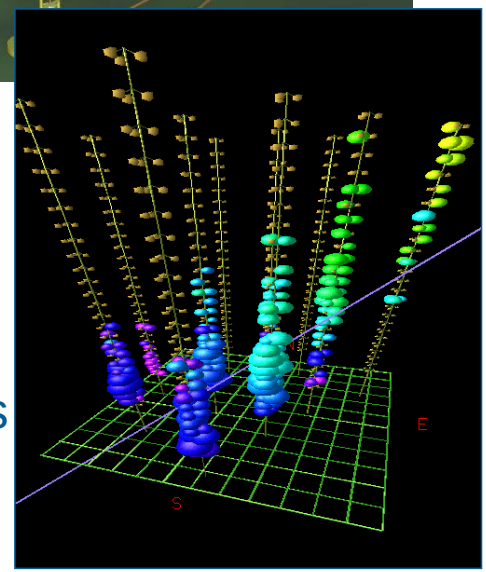
IceCube
50% complete



ANTARES fully
operational

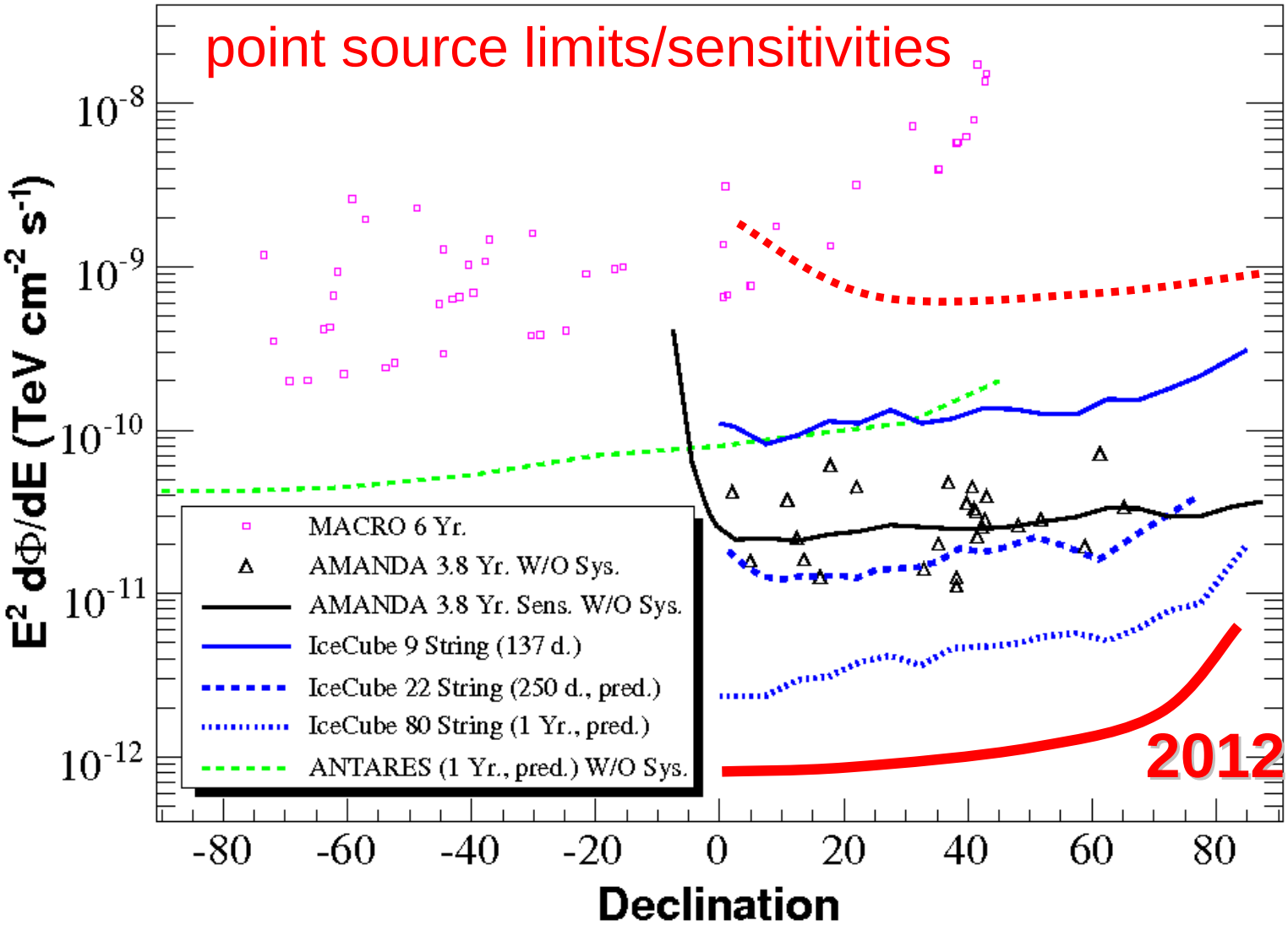
High-statistics sky-map IceCube





High statistics
of neutrinos
in ANTARES

Tremendous progress in sensitivity over last decade



High Energy Neutrinos

now

2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

operation — AMANDA

oonstruction + operation → operation — IceCube

operation — NT200, NT200+

GVD

design study → construction + operation → operat

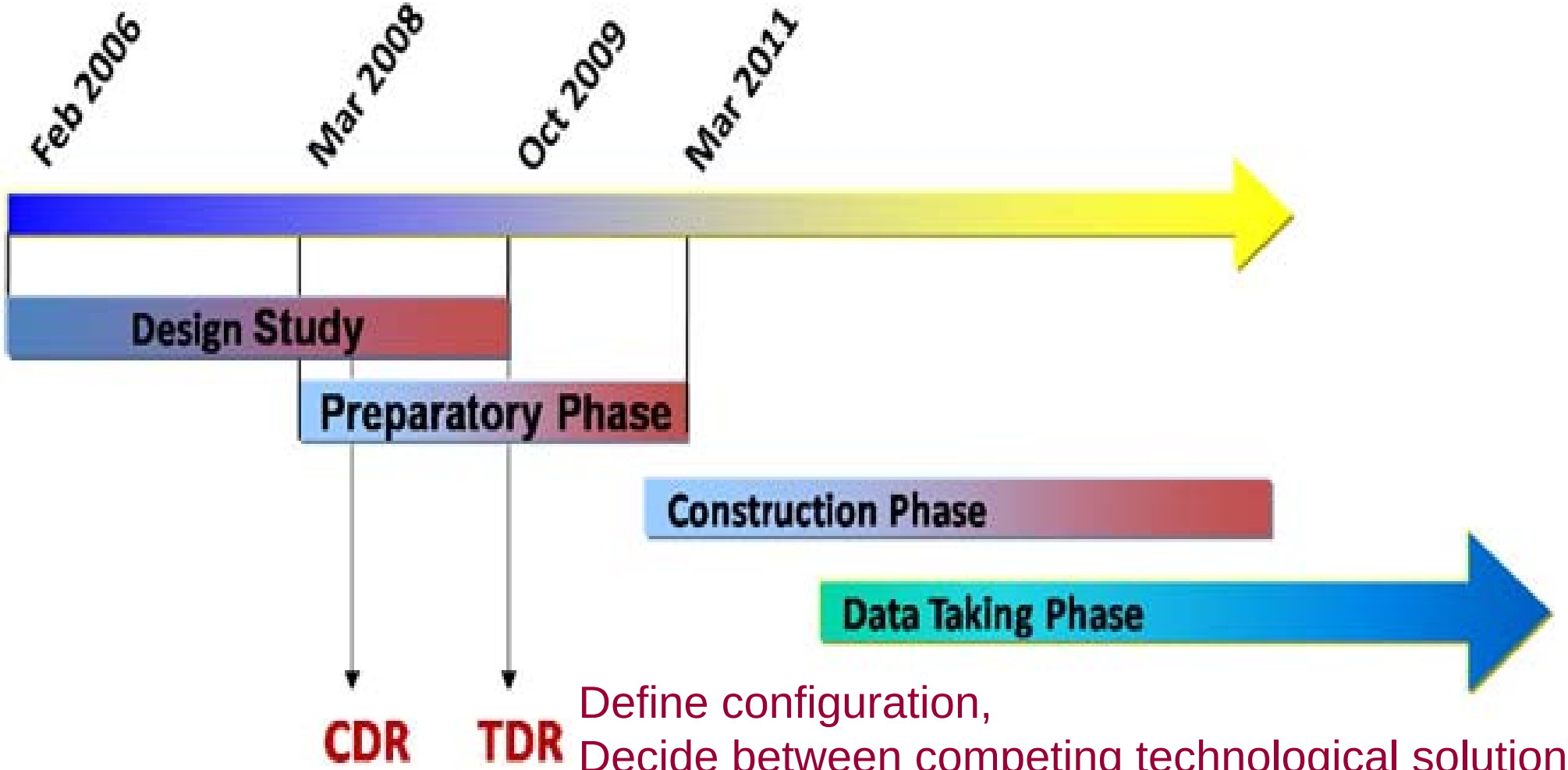
constrn. → c + o → operation — ANTARES

R&D KM3 — NESTOR, NEMO

KM3NeT

FP6 Design Study/Fp7 Prep. Phase → construction + operation → operat

KM3NeT marching line



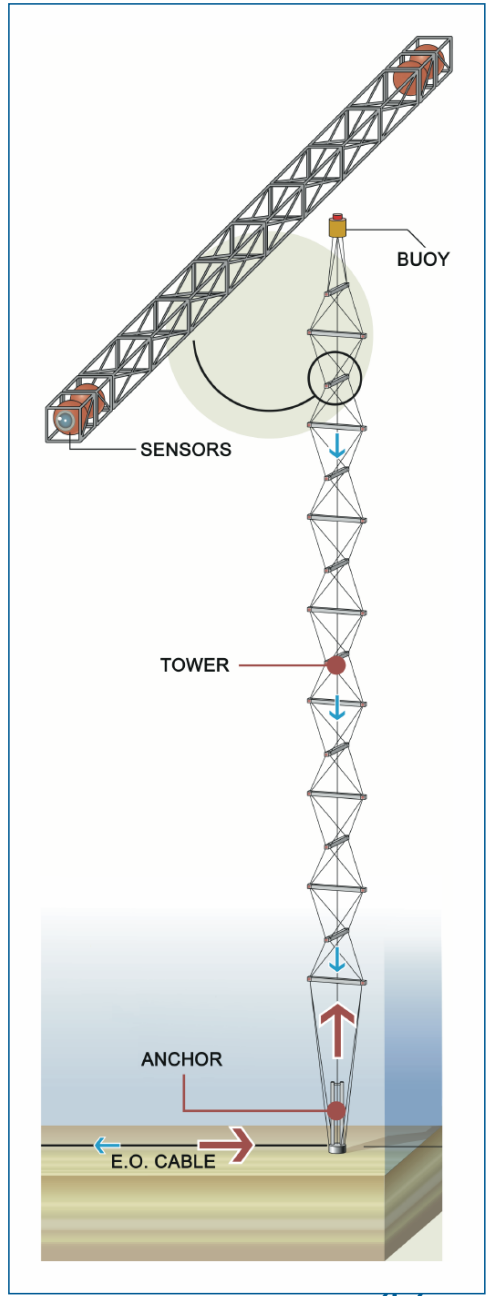
Define configuration,
Decide between competing technological solutions
Provide site arguments

Innovative Solutions

NESTOR: deployment platform

ANTARES: multi-PM module

NEMO:
tower structure



High Energy Neutrinos

- Europeans play strong role in IceCube. Support for analysis.
- Broad European community works towards KM3NeT.
- Commissioning of ANTARES defines a milestone towards KM3NeT.
- Prototype devices within NESTOR and NEMO.
- **KM3NeT:**
  - ESFRI list
  - FP6 design study: TDR expected in late 2009.
  - started FP7 Preparatory Phase.
  - one of priority entries in ASTRONET infrastructure roadmap.
- **<u>Recommendation:</u> The priority project for high energy neutrino astronomy is KM3NeT. Encouraged by the significant technical progress of recent years, the support for working towards KM3NeT is confirmed. Resources for a Mediterranean detector should be pooled into a single optimised design for a large research infrastructure, with installation starting in 2012. The sensitivity of KM3NeT must substantially exceed that of all existing neutrino detectors including IceCube.**

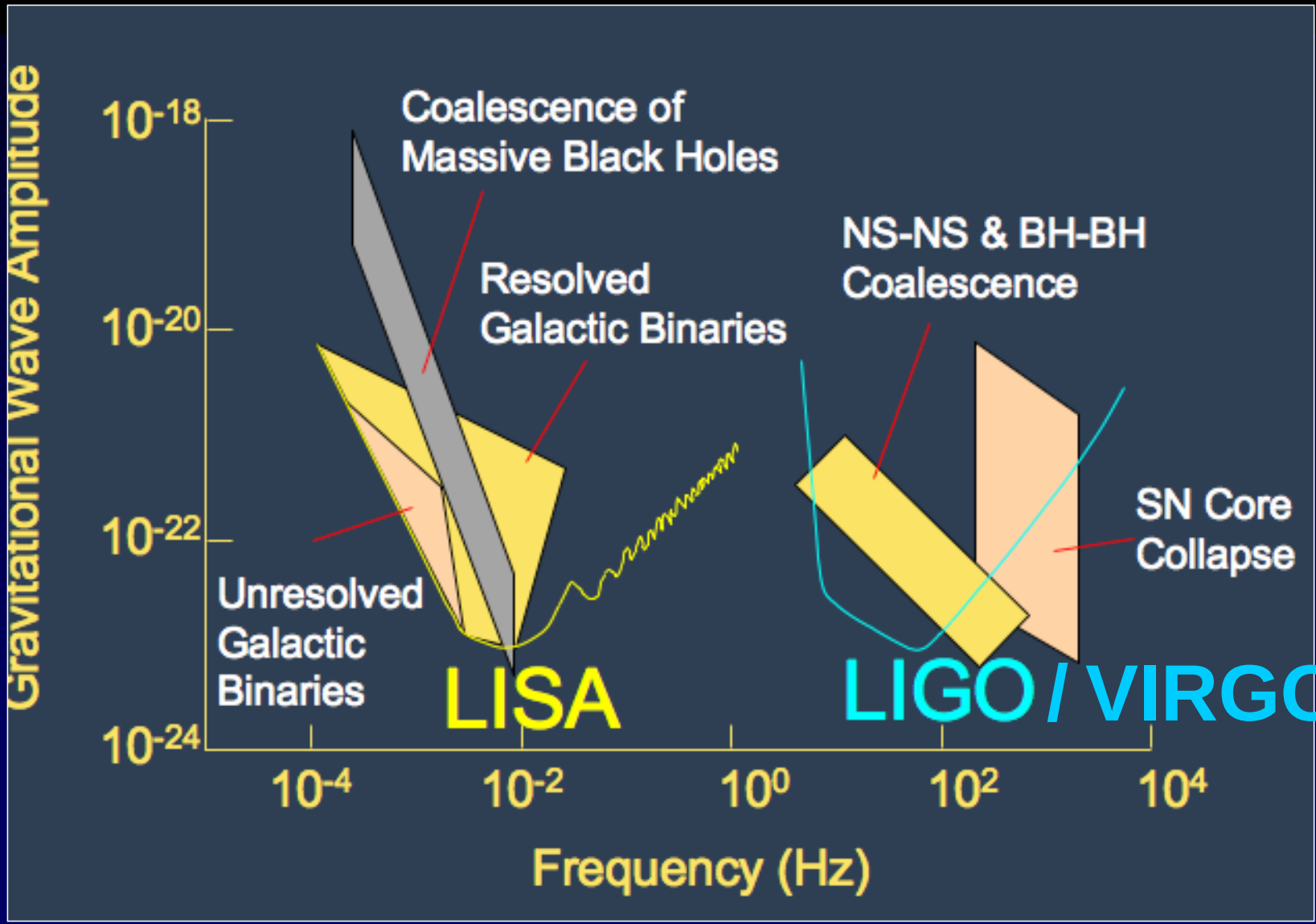
Gravitational Waves

ASPERA

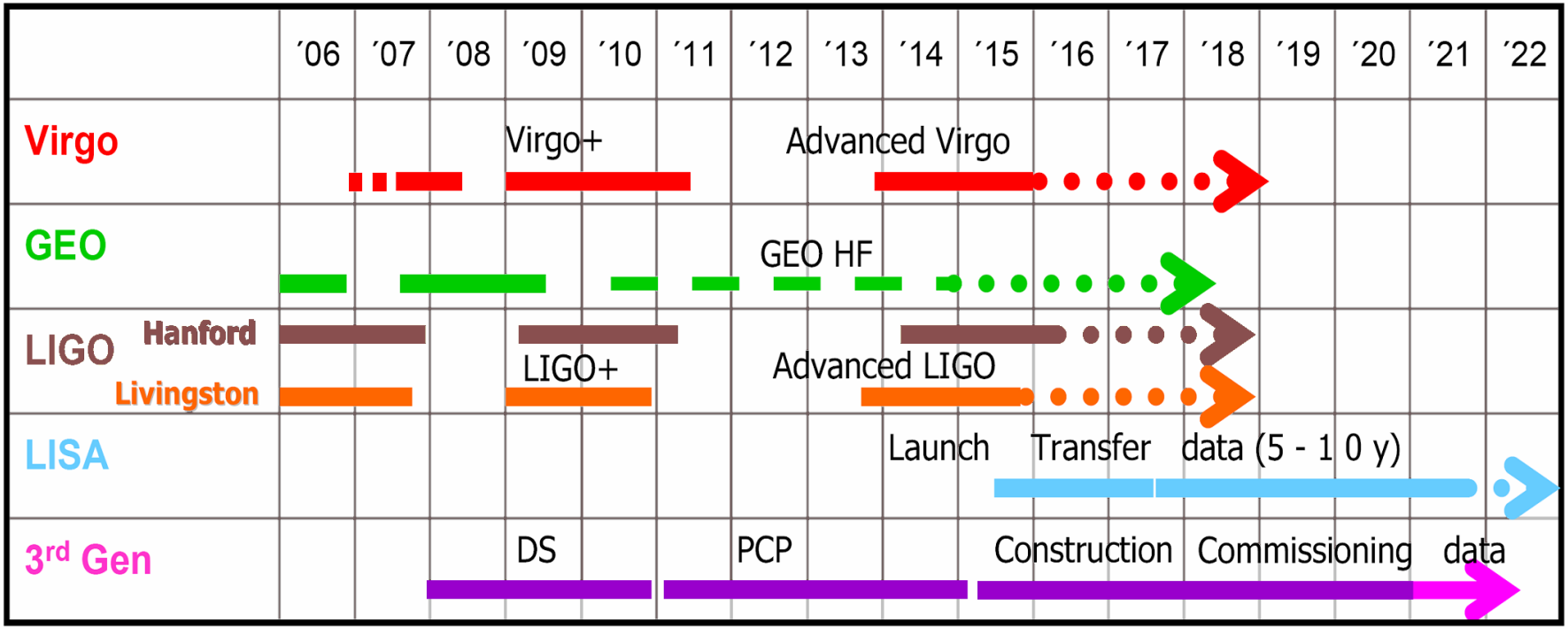
SIXTH FRAMEWORK PROGRAMME

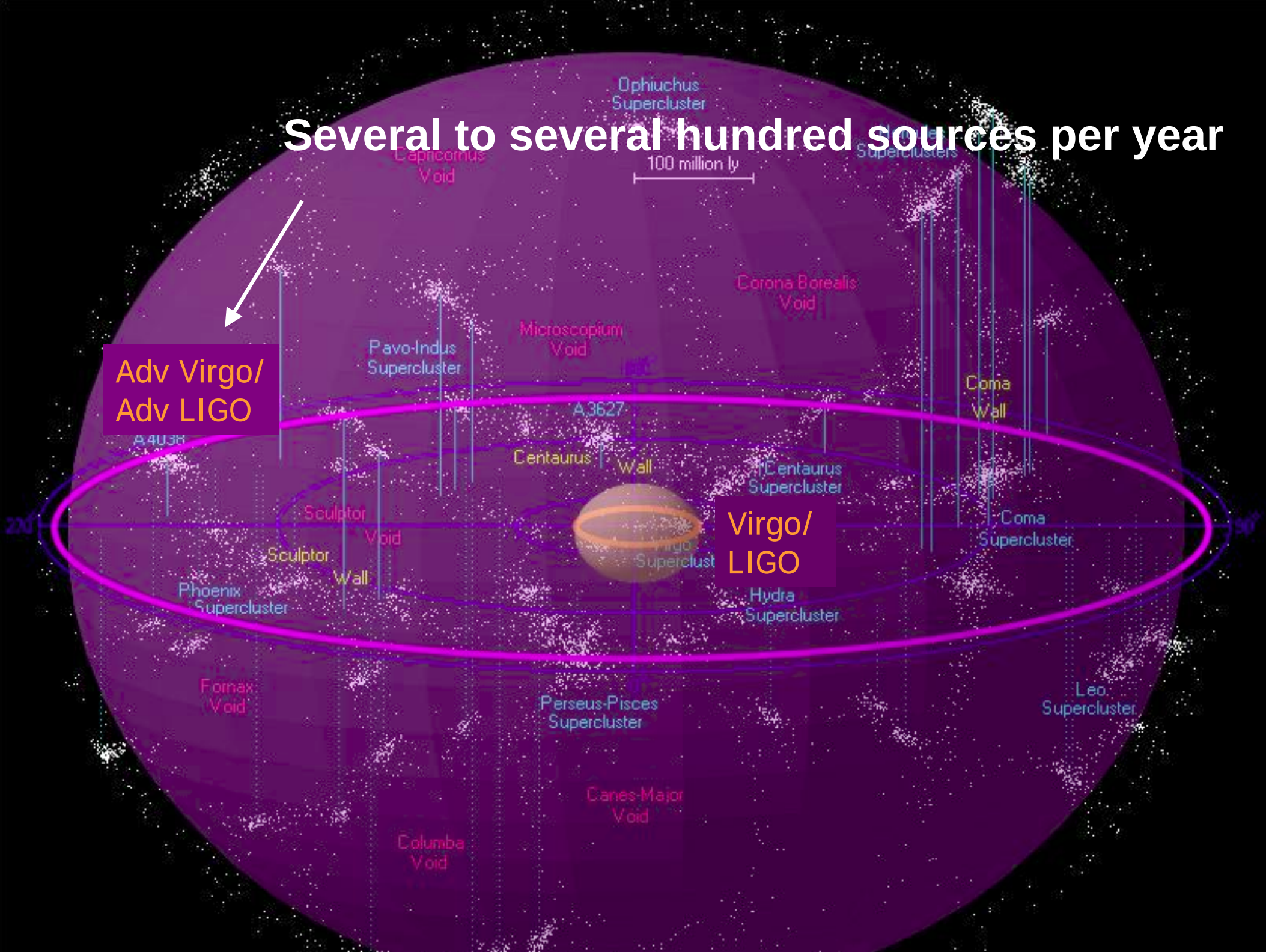
http://www.aspera-eu.org

Gravitational Waves

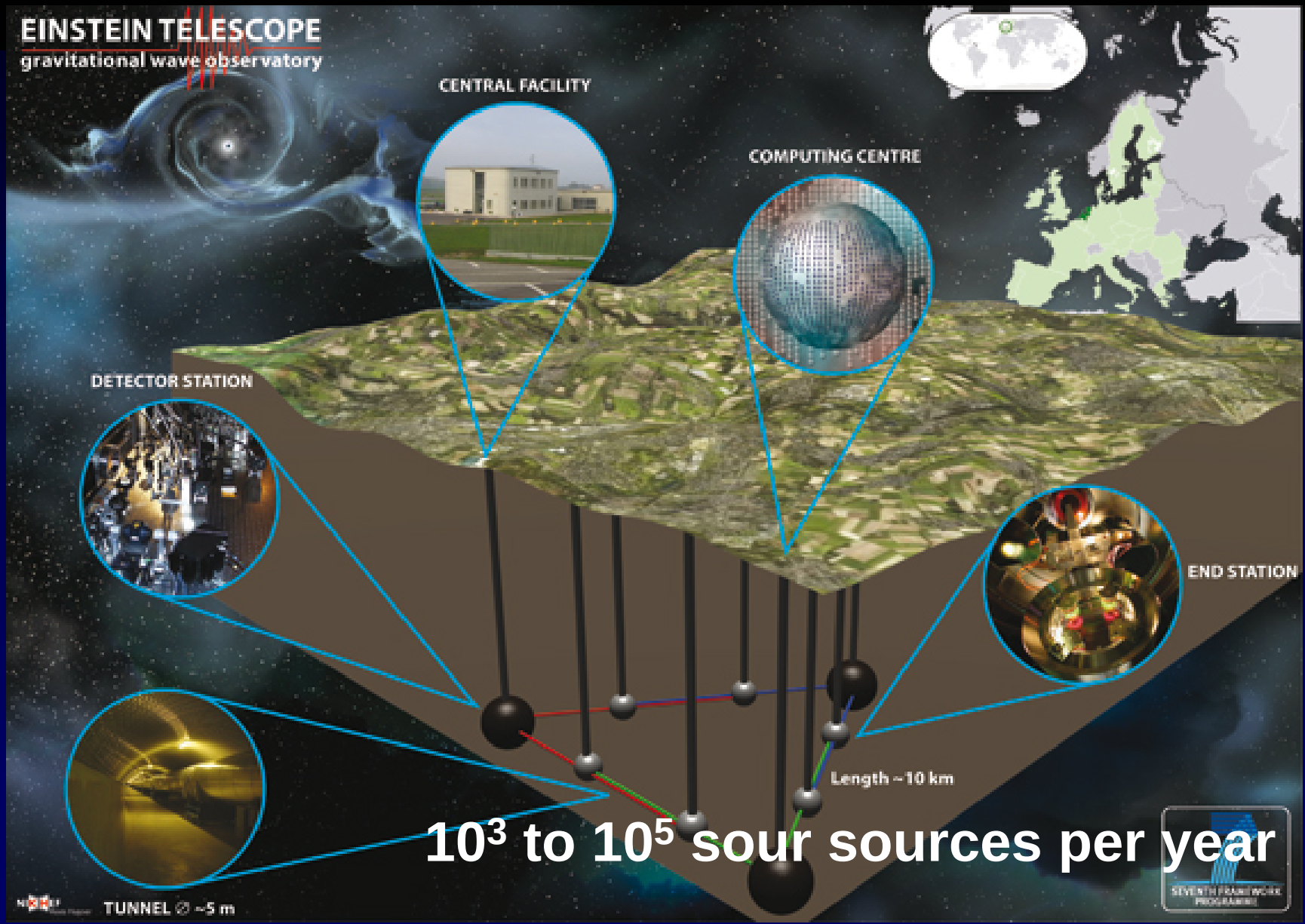


Time Chart


´06 ´07 ´08 ´09 ´10 ´11 ´12 ´13 ´14 ´15 ´16 ´17 ´18 ´19 ´20 ´21 ´22
Virgo
Virgo+
Advanced Virgo
GEO
GEO HF
LIGO
Hanford
Livingston
LIGO+
Advanced LIGO
LISA
Launch
Transfer
data (5 - 1 0 y)
3rd Gen
DS
PCP
Construction
Commissioning
data


Several to several hundred sources per year
Adv Virgo/
Adv LIGO
Virgo/
LIGO
Ophiuchus
Supercluster
Capricornus
Void
100 million ly
Corona Borealis
Void
Microscopium
Void
Pavo-Indus
Supercluster
A3627
Centaurus
Wall
Centaurus
Supercluster
Coma
Wall
Coma
Supercluster
Sculptor
Void
Sculptor
Wall
Phoenix
Supercluster
Hydra
Supercluster
Fornax
Void
Perseus-Pisces
Supercluster
Leo
Supercluster
Canes Major
Void
Columba
Void

Gravitational Waves



10^3 to 10^5 sour sources per year

Gravitational Waves

- **E.T. is the long-term future project of ground-based gravitational wave astronomy.**
- **Observed volume ~1000 times that of the 2nd-generation detectors**
- **Many thousands of events per year.**
- **European GW community has world-leading role in planning.**
- **FP7 Design Study, first technical design and associated costing expected in 2011, followed by a 'Preparatory Phase'.**
- **A decision on funding for the construction of E.T. will earliest after first detections with enhanced LIGO/Virgo but is most likely after collecting about a year of data with advanced LIGO/Virgo in approximately 2014/15. Targeted start of E.T. construction 2016 or 2017.**
- With European participation in upgraded versions of LIGO and GEO confirmed, full support for the VIRGO upgrade towards "Advanced VIRGO" still has to be secured. This would ensure the critical infrastructure for a coherent gravitational wave programme in Europe and lay the ground for E.T.
- At low frequencies: LISA (LISA-Pathfinder 2010)

- Infrastructures
- R&D
- Theory

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Infrastructure

- Underground Laboratories
  (see talk of R. Petronzio)
- Observatories
- Satellites

- Underground Laboratories:

  Which of the large experiments will be done at which site has to be decided over the next years. Significant activities are under way within the FP6 programme ILIAS, within the LAGUNA FP7 design study for a Megaton-scale detector, in the labs and within the individual experiments. There are clear advantages to have several deep underground laboratories in Europe and also to exploit both types of access – with road tunnels and mines. ILIAS and ASPERA promote this concept through formation and operation of a cooperative network of Deep Underground Laboratories with each partner contributing low-background facilities and specific infrastructures depending on user demands, techniques available and the specific features of each site.

Innovation

- Prerequisite for the enormous progress made over the last two decades and has enabled maturity in most fields of astroparticle physics.
- Cutting-edge of the existing (better, cheaper):
  - photo detectors,
  - cryogenic detectors,
  - high-purity crystals and noble liquids, isotope purification
  - optical elements for gravitational antennas
  - ….
- Principally novel methods, e.g.
  - radio and acoustic detection of cosmic rays and neutrinos
- Synergy with environmental sciences!
- ASPERA envisages common calls for joint funding of R&D. Calls will also stimulate cooperation with industry..

Theory

- Theoretical research is an invaluable source of inspiration for experimenters and a necessary tool to interpret experimental results, and must be supported with the same recognition like experiments.
- Discussed proposals for improved support and coordination of astroparticle theory include
  - a Europe-wide common call for theoretical proposals
  - a future European Centre for Astroparticle Theory, with the involvement of an international panel of expert referees.
- A **European Centre for Astroparticle Theory** could be established either in one of the European countries or at CERN. Given the synergy between LHC physics and astroparticle physics, CERN would be a natural host, particularly in view of several astroparticle experiments being CERN recognized experiments.

Cost

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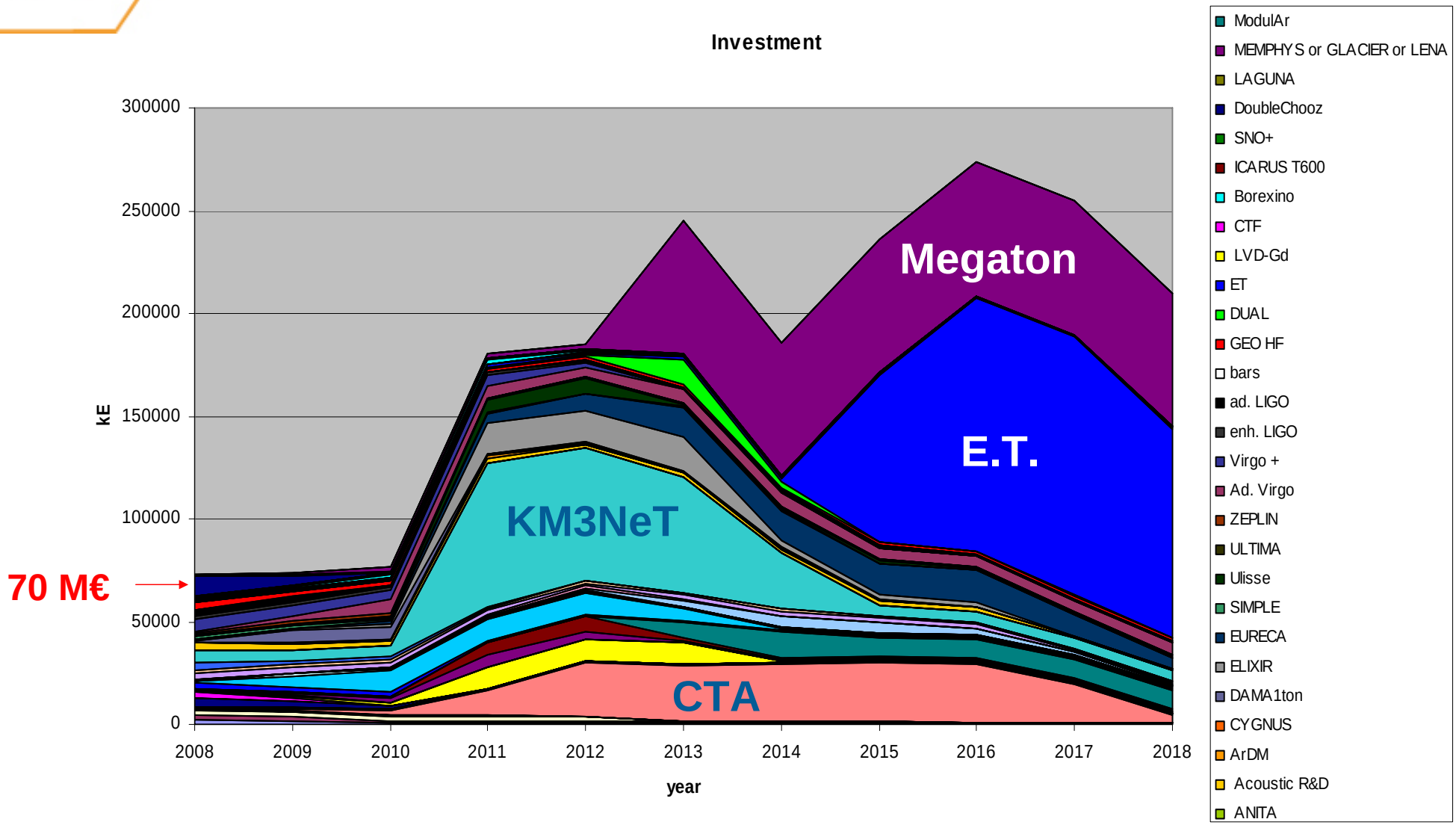
2007: Input from Aspera Working Groups

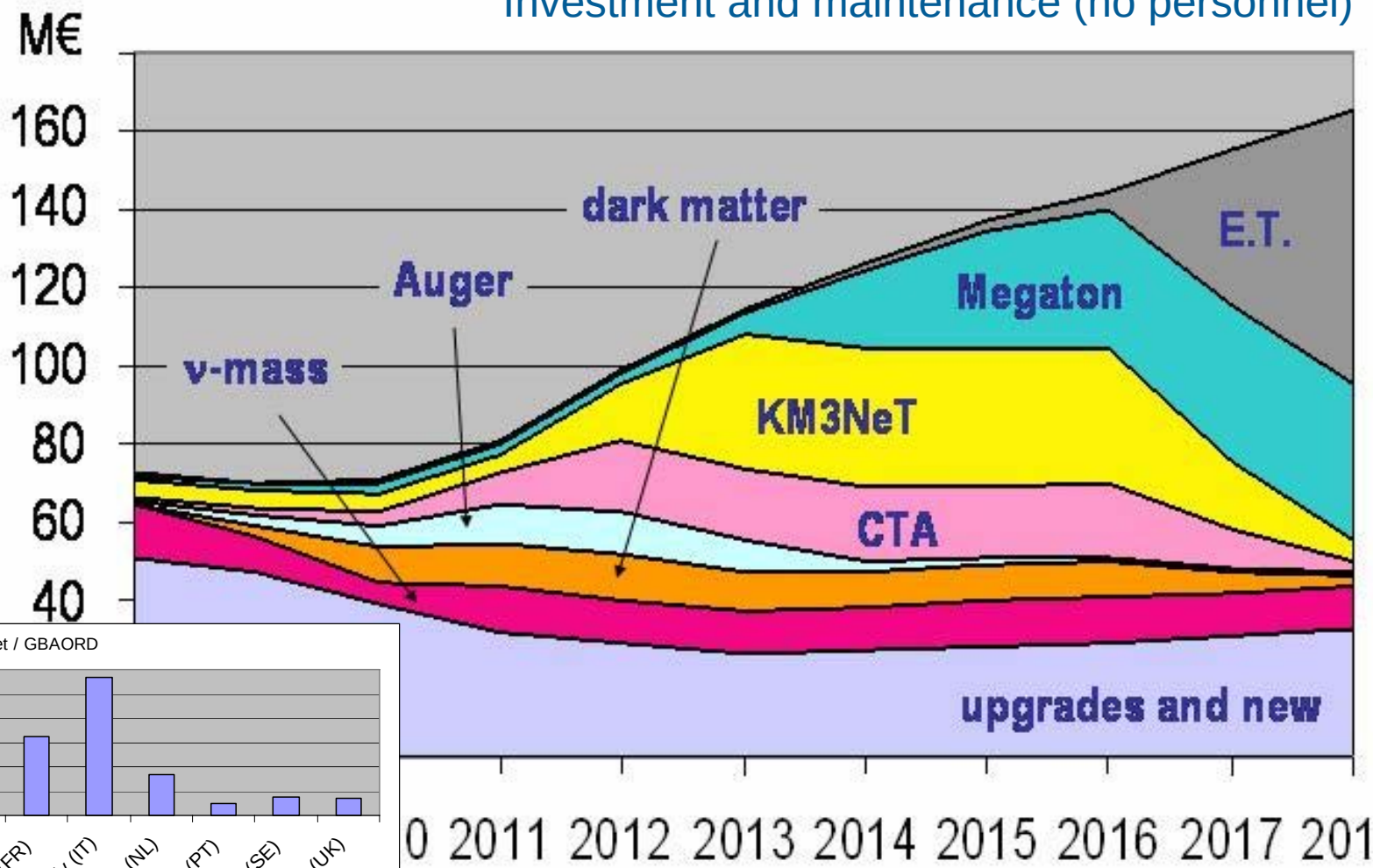


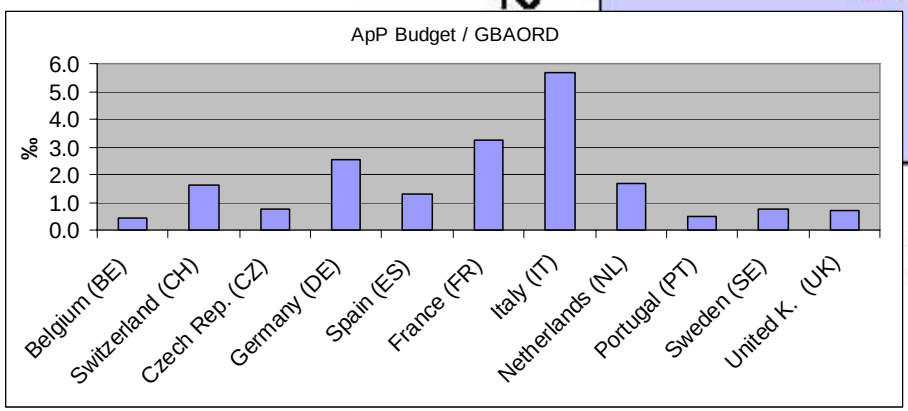
2011-2015: ~1000-1200 M€

The factor-2 scenario

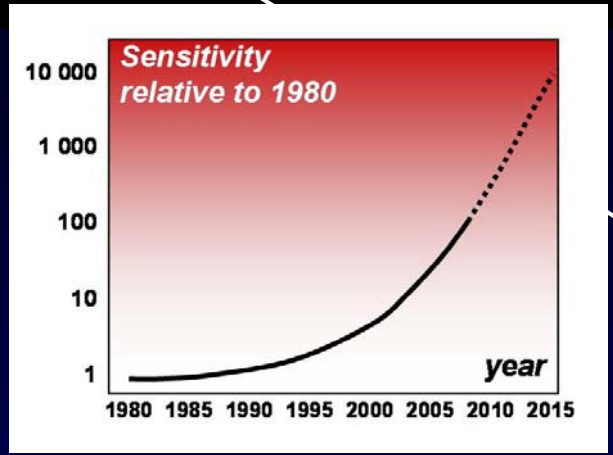
Increase in personnel cost will be smaller !

Investment and maintenance (no personnel)





Summary

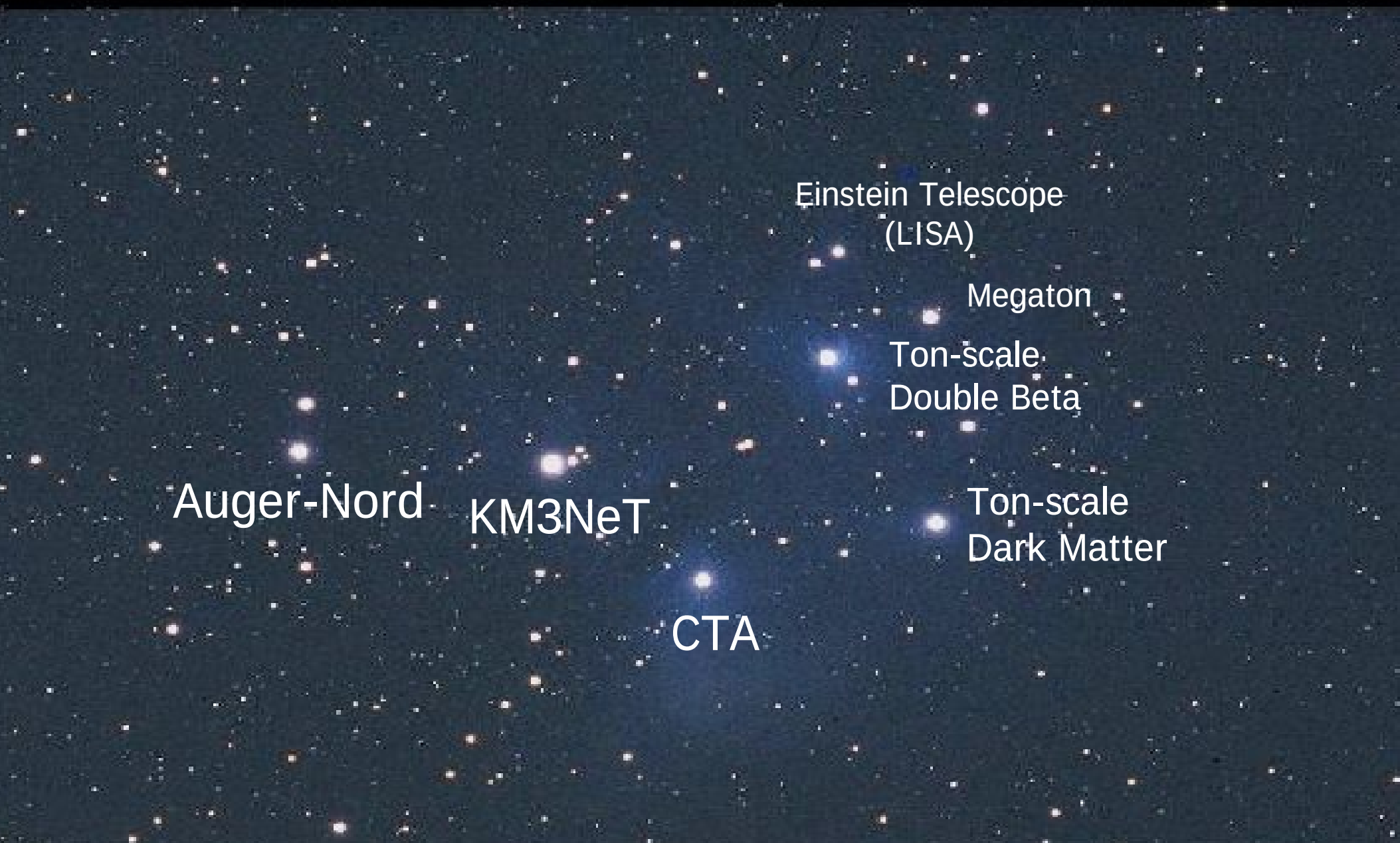


- From infancy to maturity: the past 1-2 decades have born instruments methods for doing **science with high discovery potential.**
- **Accelerated increase in sensitivity** in nearly all fields.
- A lot of advanced, interesting world-class projects **Europeans lead in many fields**.
- **Physics harvest has started** (TeV gamma) or is in reach.
- Need a **factor-2 funding increase** over next decade.
- **Initiated radical process of convergence.**

Astroparticle Physics for Europe

ASPERA

The Magnificient Seven



Backups

Visions

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- Dark Matter:
  - LHC has discovered SUSY.
  - First direct searches with sensitivity <10^{-9} pb discover DM.
    → dramatically accelerated speed with other nuclei and methods for confirmation. Push directional methods.
  - *If DM not yet discovered:*
    → move on with 2 experiments to 10^{-10} pb or below

- Neutrino Properties
  - Double-CHOOZ, T2K and others have measured finite Θ_{13}
  - KATRIN measures neutrino mass > 0.2 eV
  - and/or: Gerda/Cuore measure mass > 0.1 eV
  - *If no sign for mass:*
    → move further on towards 1-2 DBD experiments with sensitivity 0.03 eV , see what MARE could do

Sensational: cosmology !

- Megaton-Detector
  - Technology ready, worldwide consensus, construction going to start
- High Energy Universe
  - >200 gamma sources from HESS-II and MAGIC-II
  - CTA under construction, first results from prototypes
  - Sky-map with clear sources from Auger-South, also chemical composition
  - Auger-North under construction
  - IceCube has discovered neutrino sources
  - KM3NeT under construction
    - *If no neutrino sources in IceCube until 2011:*

      → consequent re-design towards > 5 cubic kilometers for affordable price
  - Exciting multimessenger astronomy, including satellites (GLAST)

- Gravitational Waves
  - LIGO+, VIRGO+ and GEO have seen their very first event
  - Adv LIGO, adv VIRGO, GEO-HF have started operation
  - E.T. in preparatory phase
  - Lisa-Pathfinder successful, clear way towards LISA

- New Methods
  - Variety of methods called „new m… acoustics, COUPP-lik… are being i…
  - Still, we hav… …erves for new „new methods“.

We have to keep reserves for new methods and approaches!

Visions

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SIXTH FRAMEWORK PROGRAMME

- Dark Matter:
  - Several experiments are below 10^{-10} pb and have detected WIMP DM
  - Move from DM searches to DM studies
- Neutrino mass:
  - DBD measures neutrino mass 20-70 meV and proves inverted hierarchy
  - *If not: hm …. There is no idea how to reach < 20 meV*
- Megaton detectors:
  - First subdetector operates
  - **>10000 neutrinos from SN2018A** (Feb 22, 2018) (IceCube measure precise early time profile)
  - New precision results on solar physics

something totally different