Multi-messenger Science in Astronet

Nanda Rea and Andrew Levan

AstroNet

(see also for Colin Vincent's talk yesterday!)

AstroNet is a consortium of European funding agencies which makes roadmaps and recommendations for future priorities and major infrastructures.

Organizations

Team members

NWO
Netherlands Organisation for Scientific Research

CNRS-INSU
Institut national des sciences de l'Univers - CNRS

Science and Technology Facilities Council
STFC
Science and Technology Research Council

ESO
European Southern Observatory

FWO
Fonds Wetenschappelijk Onderzoek Vlaanderen (Research Foudation Flanders)

INAF
Istituto Nazionale di Astrofisica

MCIN
Ministerio de Ciencia e Innovación-Gobierno de España

Astronomische Gesellschaft
German Astronomical Society
RDS
Rat-Deutscher-Sternwarten (Council of German Observatories)

Vetenskapsrådet
Swedish Research Council
Swedish Research Council

Observers

Astronomical Society of Ireland
ASI
Astronomical Society of Ireland

ESA
European Space Agency

Portugal Space
Portugal Space
Portugal Space Agency

SKA
Square Kilometer Array

Invitees

APPEC
Astroparticle Physics European Consortium

EAS
European Astronomical Society

AstroNet

Currently the "Science Vision and Infrastructure Roadmap 2020-2030", contains 7 independent chapters:

- Origin and Evolution of the Universe
- Formation and Evolution of Galaxies
- Formation and Evolution of Stars
- Formation and Evolution of Planetary Systems
- Understanding the solar system and conditions for life
- Extreme Astrophysics
- Societal Aspects: education, public engagement, equality, diversity and inclusion
- Computing: big data, high performance computing, data infrastructure

https://www.astronet-eu.org/science-vision-infrastructure-roadmap-2020-2030

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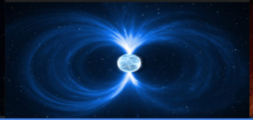
- Origin and Evolution of the Universe
- Formation and Evolution of Galaxies
- ***Formation and Evolution of Stars***


- Formation and Evolution of Planetary Systems
- Understanding the solar system and conditions for life
- ***Extreme Astrophysics***



- Societal Aspects: : education, public engagement, equality, diversity and inclusion
- *Computing: big data, high performance computing, data infrastructure*

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Formation and Evolution of Stars

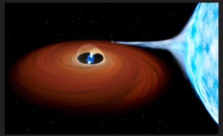
Chris Evans *(Chair)*	UKATC
Jason Hessels	Universiteit van Amsterdam
Alfio Maurizio Bonanno	INAF
Anaelle Maury	Université Paris-Saclay
Sylvia Ekstrom	Sauverny Observatory
Patrick Roche	University of Oxford
Sana Hugues	Leuven University
Antoine Mérand	ESO Garching
Victor Silva Aguirre	Aarhus University
Nanda Rea	Instituto de Ciencias del Espacio
Alberto Sesana	University of Milano-Bicocca
Estelle Moraux	Université Grenoble Alpes

Extreme astrophysics

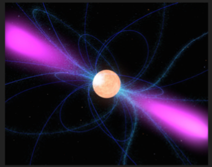
Andrew Levan *(Chair)*	Radboud University
Nanda Rea *(co-Chair)*	Instituto de Ciencias del Espacio
Jason Hessels *(co-Chair)*	Universiteit van Amsterdam
Chris Evans	UKATC
Paula Chadwick	Durham University
Elena Amato	INAF
Matteo Guainazzi	ESA
Chris Reynolds	Cambridge University
Giovanni Miniutti	Centro de Astrobiología (CSIC-INTA)
Antoine Kouchner	Université de Paris
Andreja Gomboc	University of Nova Gorica
Gergely Barnaföldi	Research Institute for Particle and Nuclear Physics in Budapest
Agnieszka Słowikowska	Nicolaus Copernicus University
Andrey Timokhin	NASA
Sara Motta	Oxford University
Dorothea Samtleben	Leiden University

Formation and evolution of stars: WDs and NSs

White dwarfs (isolated and binaries): 1. Understand the population as Type Ia SN progenitors. 2. Model thermonuclear reaction during novae

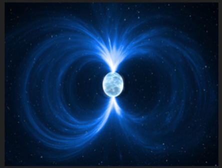


Accretion onto NS and WDs: 1. Magnetic fields and plasma interaction. 2. Binary population models. 3. Use them to constrain NS EoS. 4. How they launched jets and the role of the B-field.



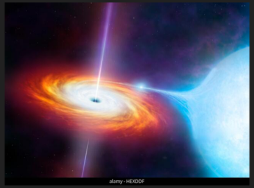
Pulsars: 1. How do they accelerate cosmic-rays. 2. Which is their relation to Pevatrons. 3. Physics of their radio emission. 4. Spin and B-field at birth of the population.

Binary pulsars in the Galaxy: 1. Model evolutionary the NS-NS population. 2. Test GR at several orders. 3. Short-GRB and GW connection.



Magnetars: 1. How many are they. 2. How strong B-fields are formed. 3. Consequences for neutron stars population studies. 4. Relation with Fast Radio Bursts. 5. Crucial for SN simulations, and for GW/neutrinos (axions?) emission at different stages…

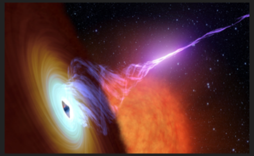
Formation and evolution of stars: BHs



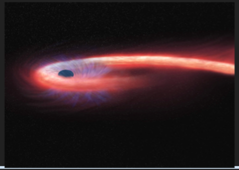
Accreting BH binaries: 1. Population studies of solar mass BH and connection with larger scales. 3. Test plasma physics under extreme conditions. 4. GR tests. 5. Measure Spins.

Isolated BHs: 1. How many are they wandering around the Galaxy. 2. How to detect them. 3. Possible dark matter relation (?).

Intermediate-mass BHs: 1. Where are them in the Galaxy: ULXs?. 2. Formation and evolutionary models. 3. Strong connection with GW detections.



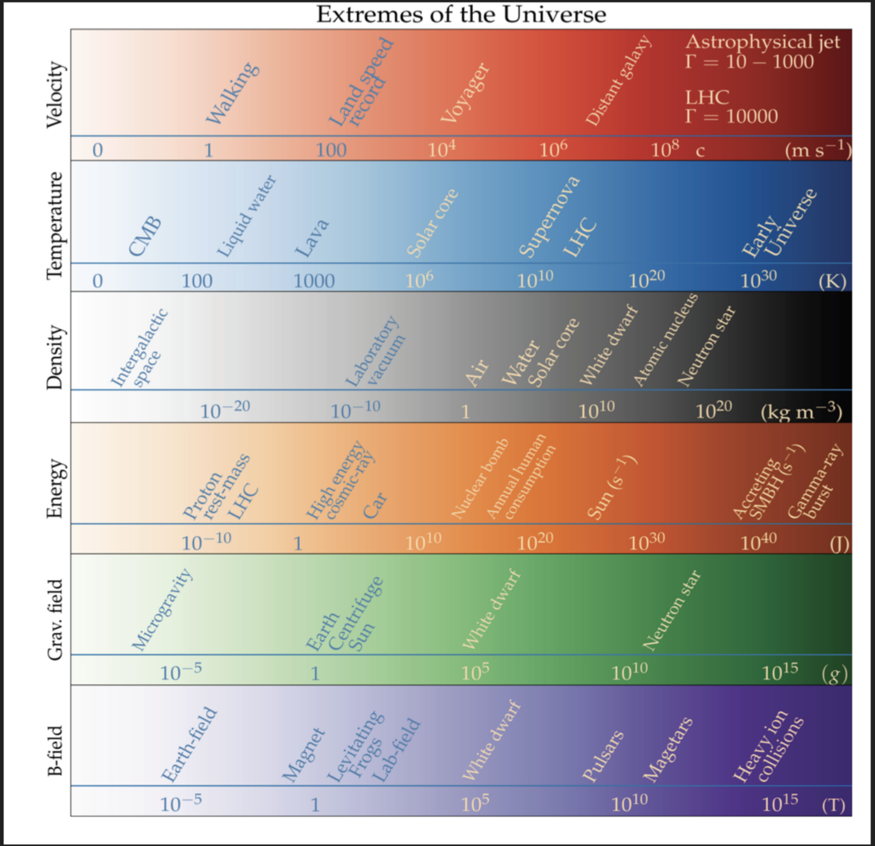
BH jets: 1. How jets are launched at all scales. 2. Relation with the parameters of the stellar mass BH system (mass, spin, companion star).



Tidal disruption events: 1. Rates in the Galaxy. 2. Important proxy with larger scales ones.

Prof. Nanda Rea - Institute of Space Sciences (ICE-CSIC, IEEC), Barcelona, Spain

Extreme Astrophysics chapter



The most exotic conditions commonly exist within and around compact objects – white dwarfs, neutron stars, and black holes. These systems provide a route to probing extremes of gravity, density, energy, temperature, velocity and magnetic field.

In this chapter we focus on multi-messenger astronomy.

Extreme Astrophysics: main topics

What is the nature of matter at nuclear densities?

How do compact objects form and evolve?

How do compact objects produce energy and accelerate particles at all scales?

Where are the heavy elements made?

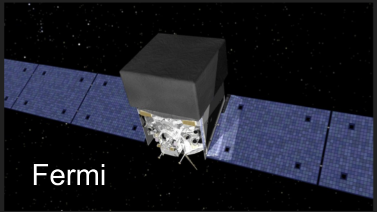
What is the origin of cosmic rays of all energies?

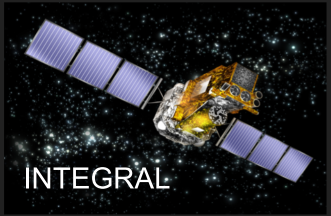
To what precision can general relativity describe gravity?

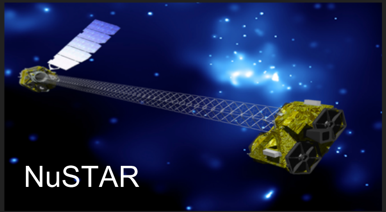
What new fundamental physics can be probed with extreme astrophysical objects?

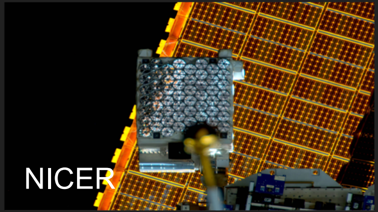
Extreme Astrophysics: current large instrumentation

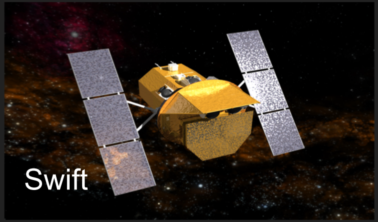
SPAC
E

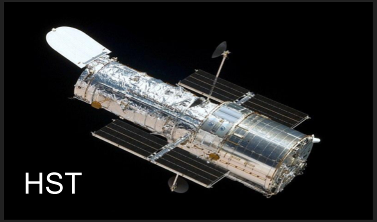


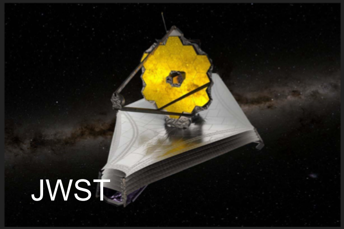






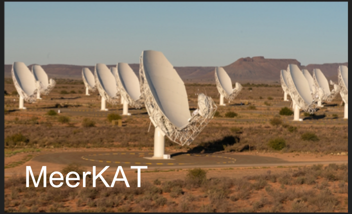






Extreme Astrophysics: current large instrumentation

GROUND



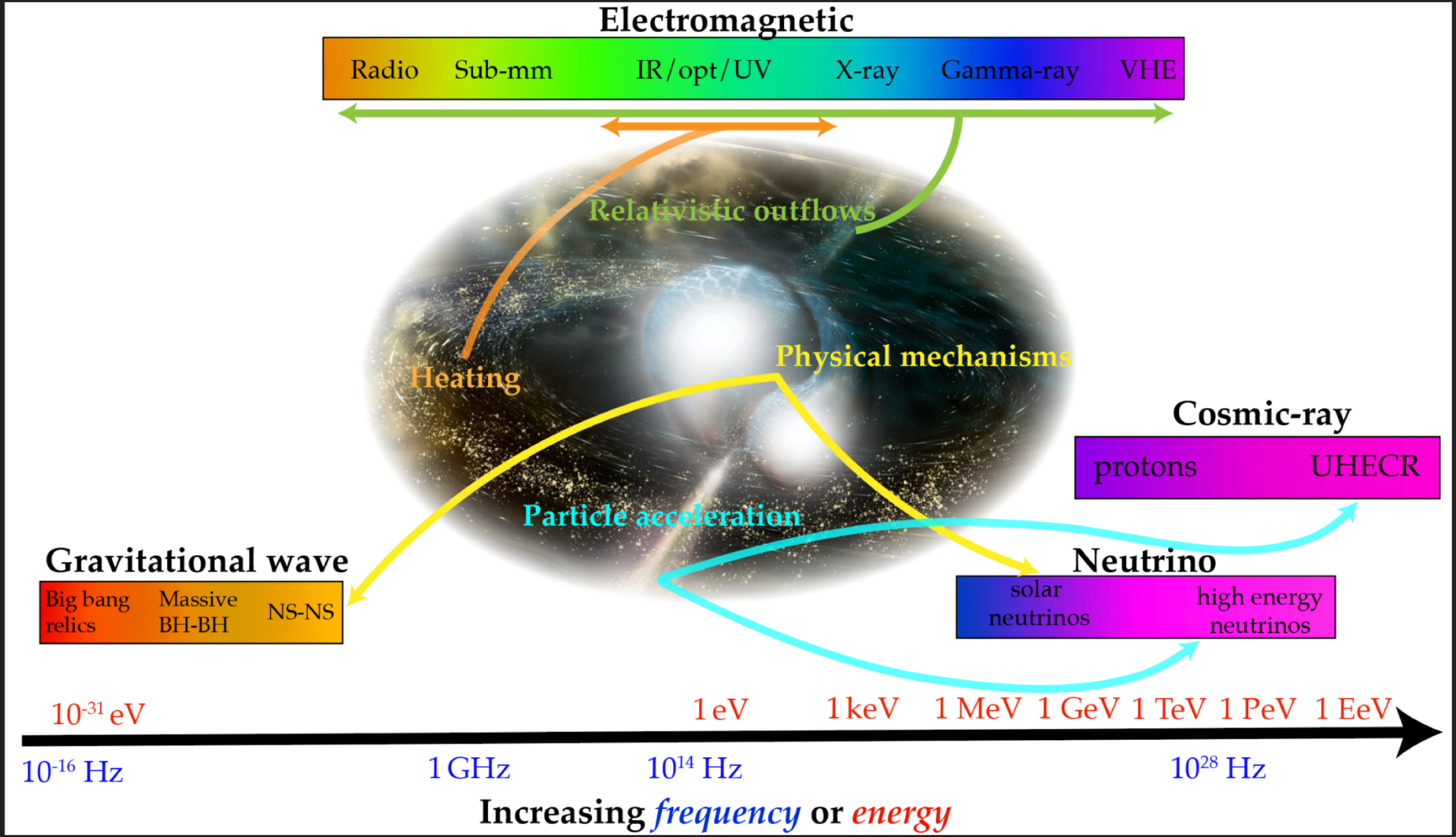
AstroNet: general summary

- AstroNet is a consortium of European agencies and it is now defining its Roadmaps for 2030. It has important synergies with APPEC and other similar initiatives.
- Science topics related to MM physics and instrumentations are now prominently present in the current draft (after the first community feedback).
- Current large arsenal of facilities (large and small) are key to MM science: i.e. GW170817 or any of the recent multi-band or multi-messenger campaigns.
- Big breakthroughs in the future will need investments in both large AND smaller facilities.
- Big breakthroughs in Extreme Astrophysics need multi-disciplinary, multi-visionary, multi-colored, multi-field, multi-multi efforts. A single restricted community will hardly succeed.

Where a MM approach is/will be key?

Multi-messenger science

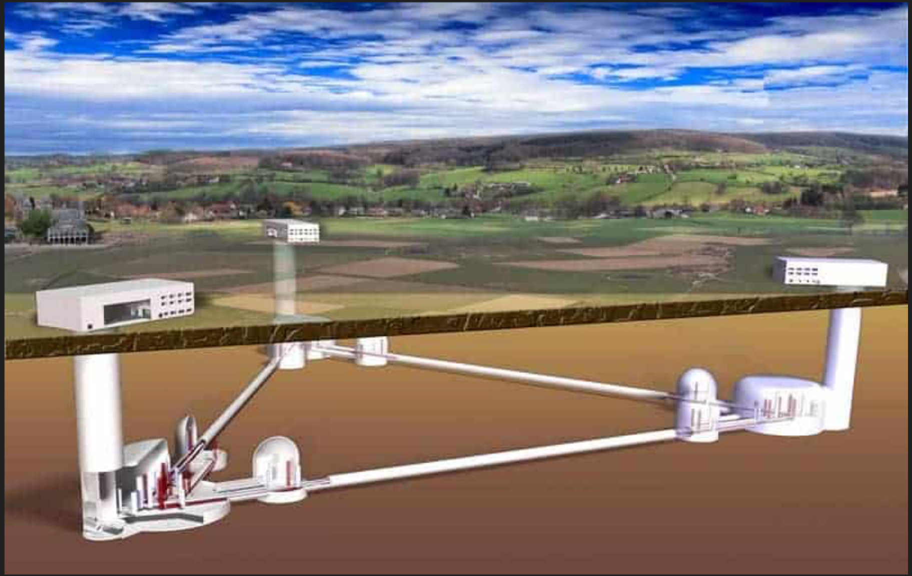
Relevant to many areas (Cosmology, Galaxies, Stars), but primarily covered in "Extreme Astrophysics"



General plea

Multi-messenger opportunities rely on headline large infrastructure to the non-EM signals, but often on modest facilities for follow-up. Bear in mind the extra-"bang" for small extra outlay.

e.g. the GW170817 optical light was identified first by a 1m telescope.



€1 billion - ET

€1.01 billion - ET + optical telescopes

€1.2 billion - ET + opt + radio + keep satellites operational + LVK?

Core science goals for MM-science

Fundamental physics:

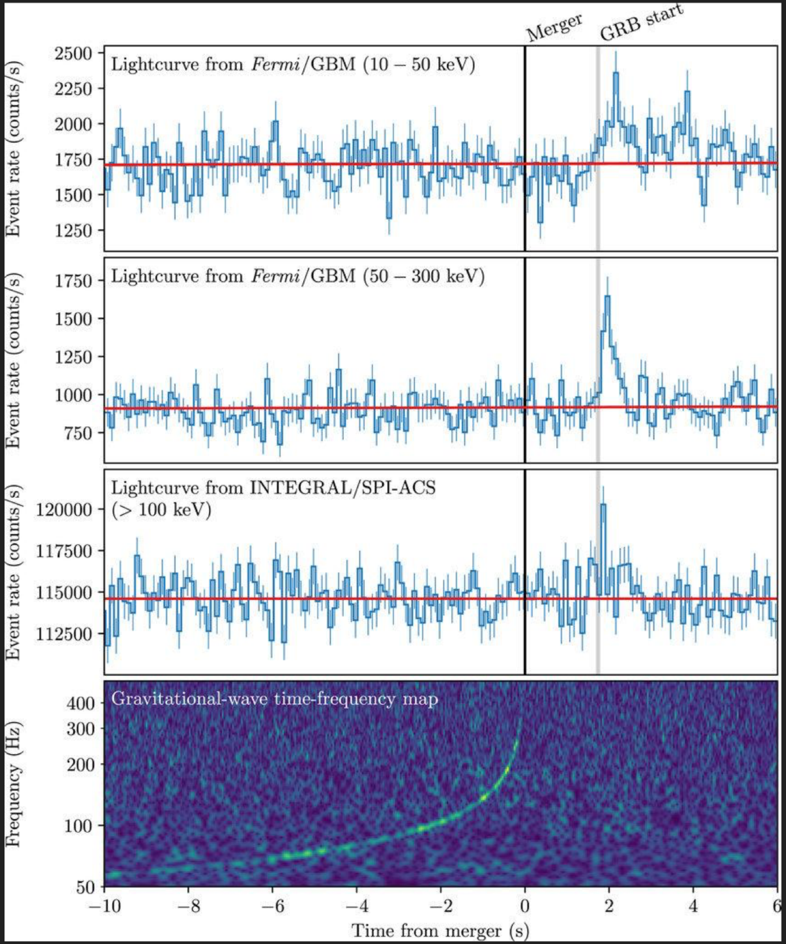
e.g. speed of light = speed of gravity ~ speed of neutrinos

Requirements:

GW detector network

Neutrino detectors (ideally sensitive enough to detect same objects as GW)

EM (gamma-ray best) detectors



Core science goals for MM-science

Heavy element enrichment:

BNS, BH-NS mergers with EM counterparts

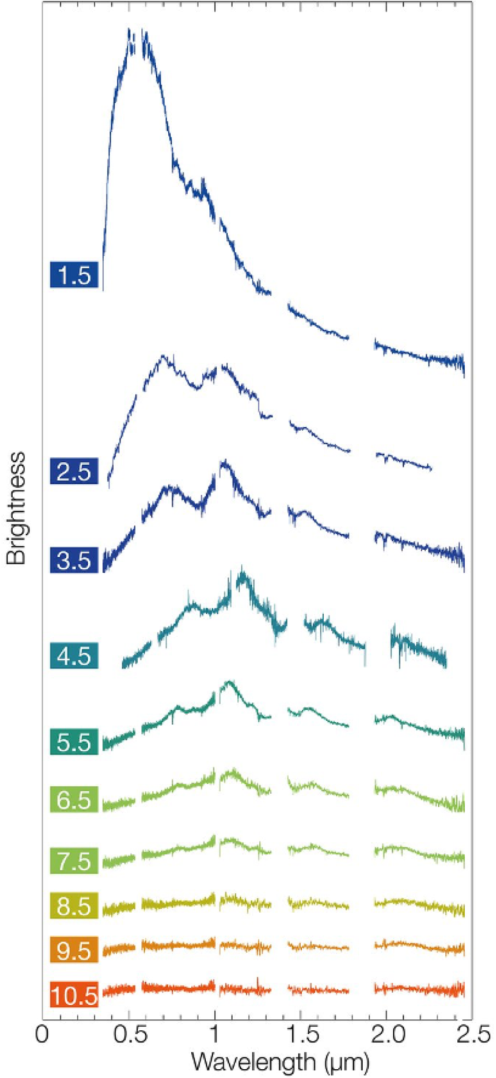
Characterise the kilonovae to get yields

Requirements:

GW detector network (localisation becomes more important than range)

EM Search machines

Follow-up capability



Core science goals for MM-science

Dense matter equation of state:

Combination of deformability measurements (GW),

EM follow-up (kilonova properties)

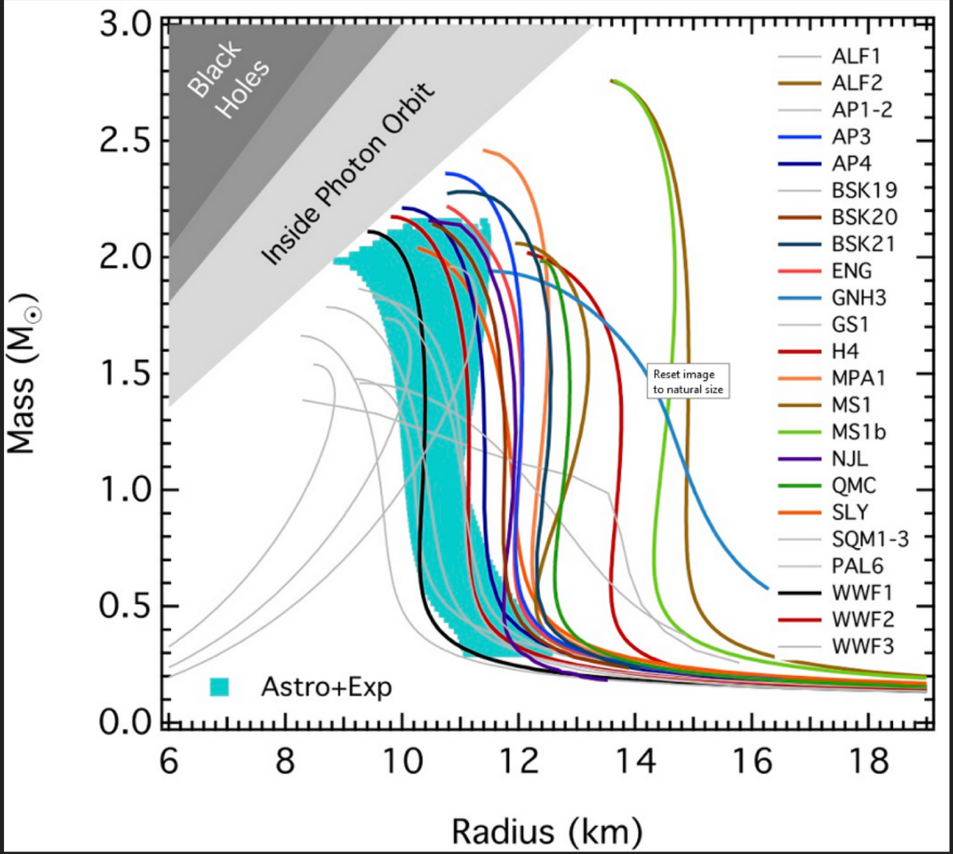
X-ray/radio timing

Requirements:

GW detector network (sensitivity key, freq. sensitivity TBD)

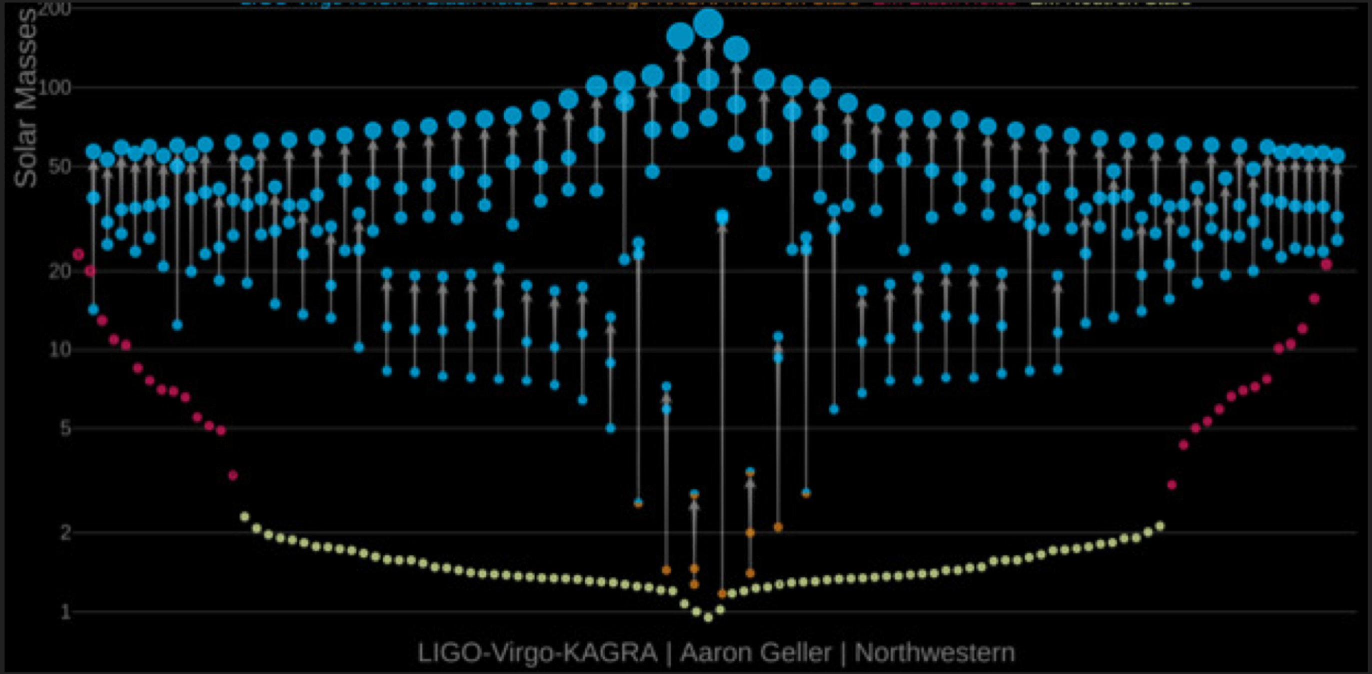
Follow-up machines

Complementary probes (e.g. radio and X-ray timing)



Core science goals for MM-science

Evolution of source populations:



Requirements:

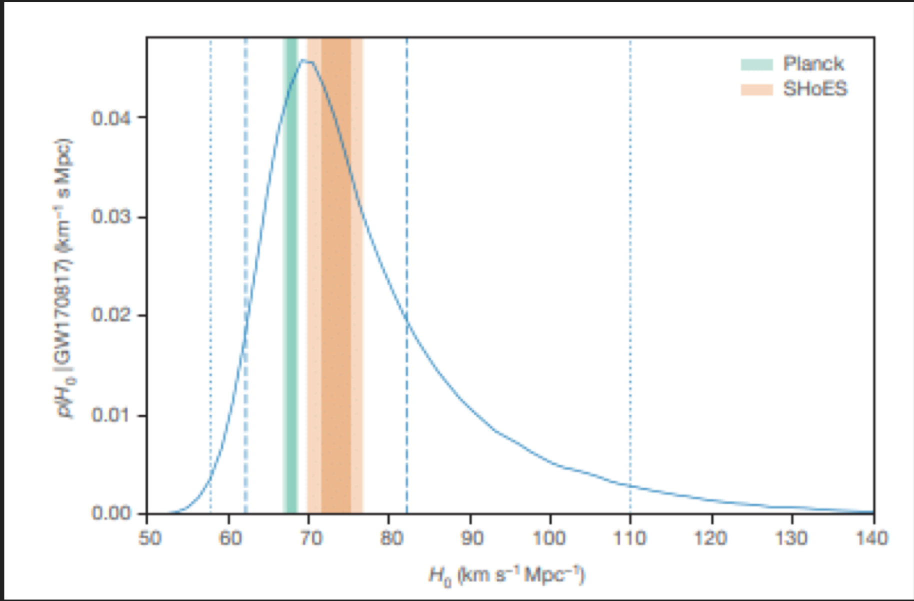
GW detector networks (sensitivity key)

Counterpart finders (redshift machines)

Longer term: SMBH mergers as well

Core science goals for MM-science

Measurements of cosmological parameters



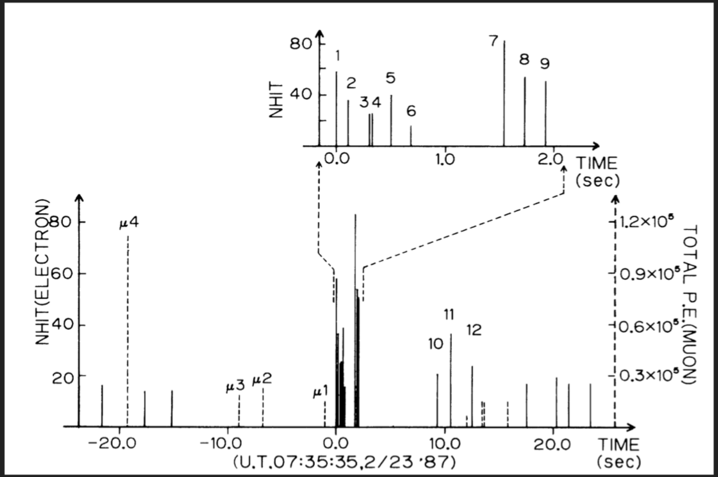
Requirements:

GW detectors (balance range / sensitivity)

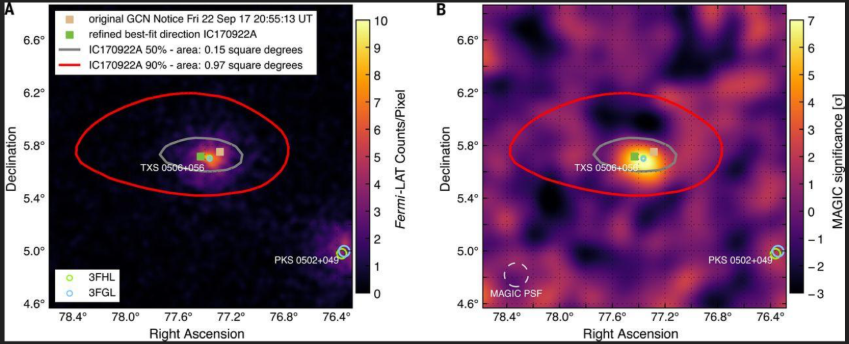
EM follow-up for redshifts

Core science goals for MM-science

Identification of supernova neutrinos



The origin of high energy neutrinos



Requirements:

Neutrino detectors

Wide-field optical/IR searches (find SNe, unusual transients)

Core science goals for MM-science

Sites of extreme particle acceleration:

Details of cosmic-ray energy spectrum and composition

Neutrino acceleration sites

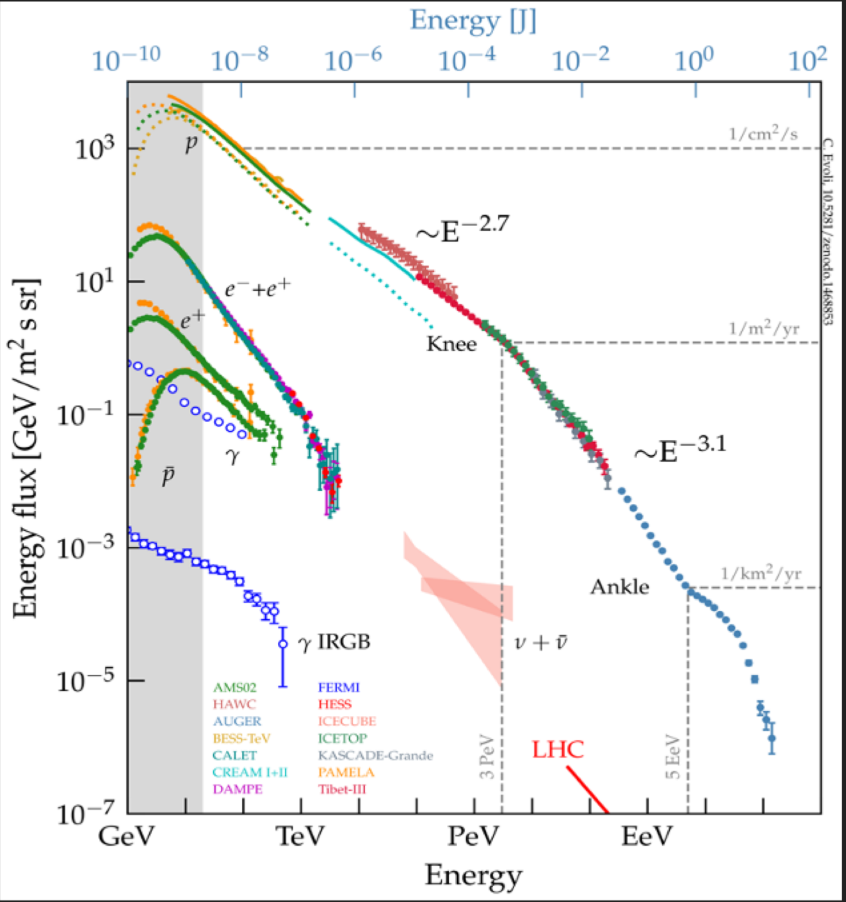
Required facilities:

Next generation cosmic-ray detectors

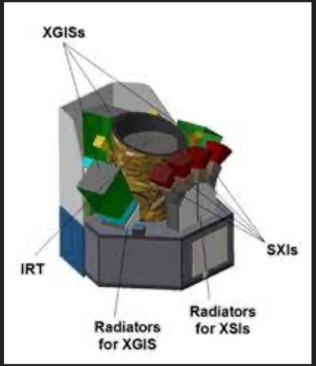
VHE gamma-ray (e.g. CTA)

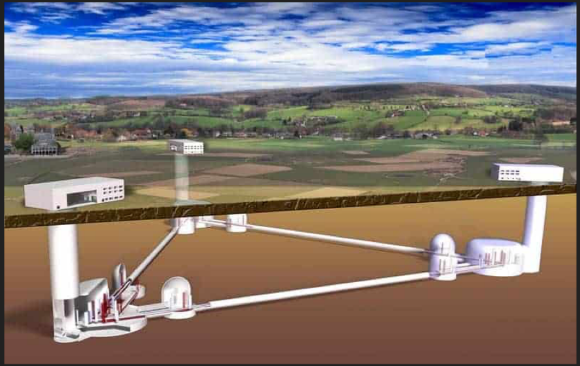
Neutrino detectors

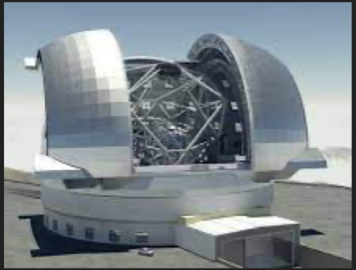
Better models (e.g. cosmic-ray propagation)



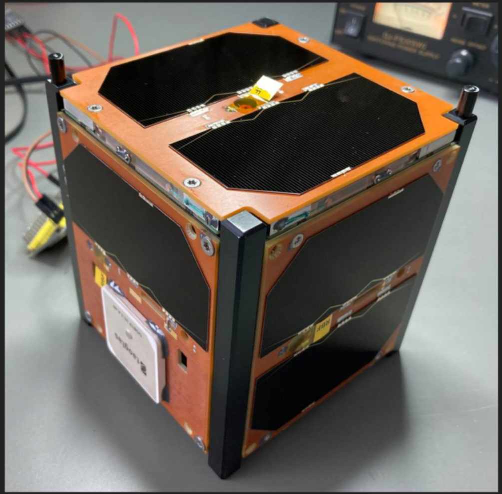
Sample future facilities (larger)







Sample facilities (smaller)



These smaller facilities may be operational on smaller scales that government funding agencies. Still, significant advantages in collaboration and co-ordination across many people (e.g. not all at the same wavelength on the same mountain).

Because the lead times for smaller projects are shorter, we might not even know about some great ideas yet. We need to keep the flexibility to do them.

Summary

Multi-messenger astronomy offers novel and often unique routes to answering a wealth of astrophysical questions. **We should be driven by these questions.**

But it is not just challenging scientifically, but all technologically and budgetarily – many results need multiple ~€1 billion investments.

Despite this, its realisation requires combining these headline detectors with much more modest resources, and we should not forget about these (ideally we should budget them with the headlines when they are needed).

Coordination across groups and facilities is also likely to be key in realising scientific output.