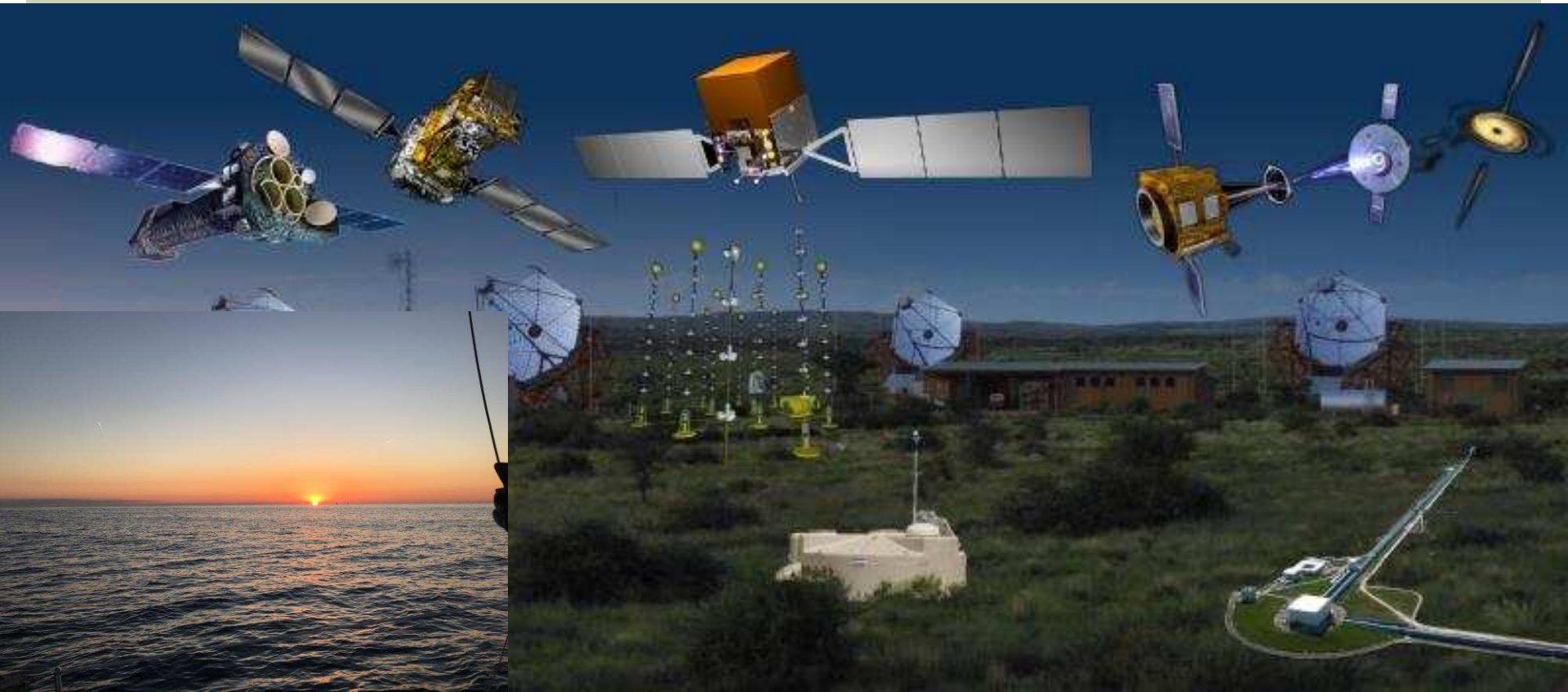
M. Boër, Vulcano workshop 2016

The Dawn of Multimessenger Astrophysics

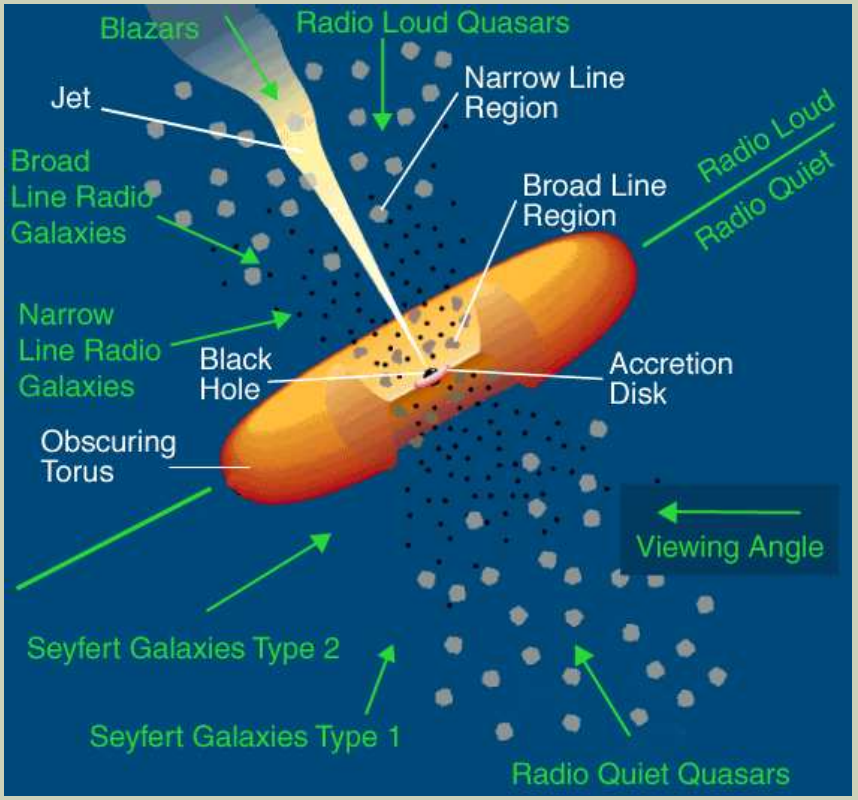


LIGHT, THE HISTORICAL MESSENGER

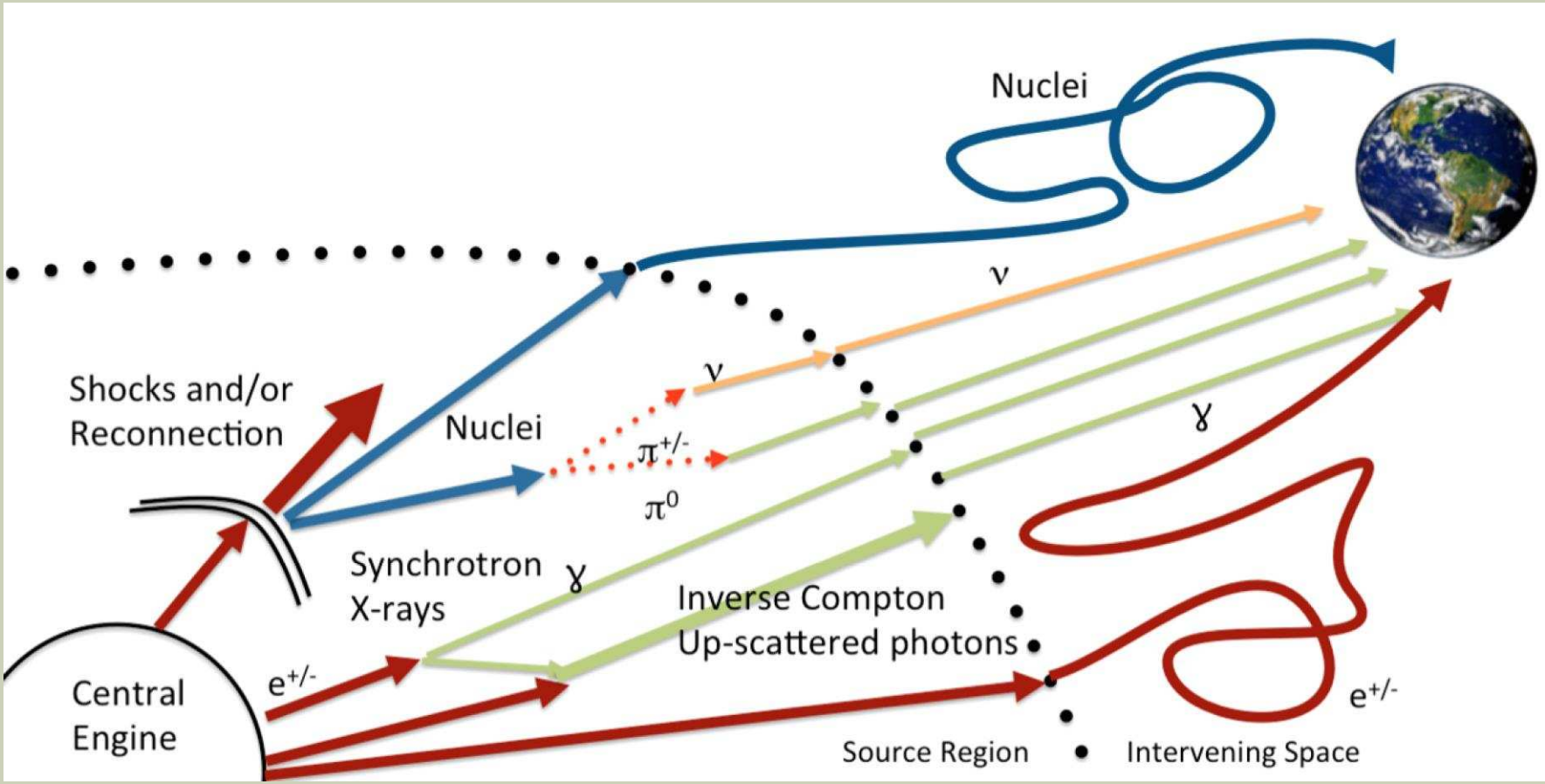
- Since *H. Neanderthalensis* and *H. Sapiens* the photon has been the main « messenger » for the observation and understanding of the sky
- Astronomy, as a science, started with physics, hence it evolves also with particle physics
- In the XXth century start of multi-wavelength astronomy

WHAT MEANS MULTIMESSENGER

- Information drawn from one messenger is partial
- Deriving a consistent picture of a phenomenon / source from a variety of information sources
- Exemple: multiwavelength astronomy
  - Galactic magnetism
  - AGN, and AGN in their galaxy
  - GRBs
- Multimessenger astronomy means the coordinated use of several particles/wavelengths as they provide complementary information about an astronomical source/phenomenon



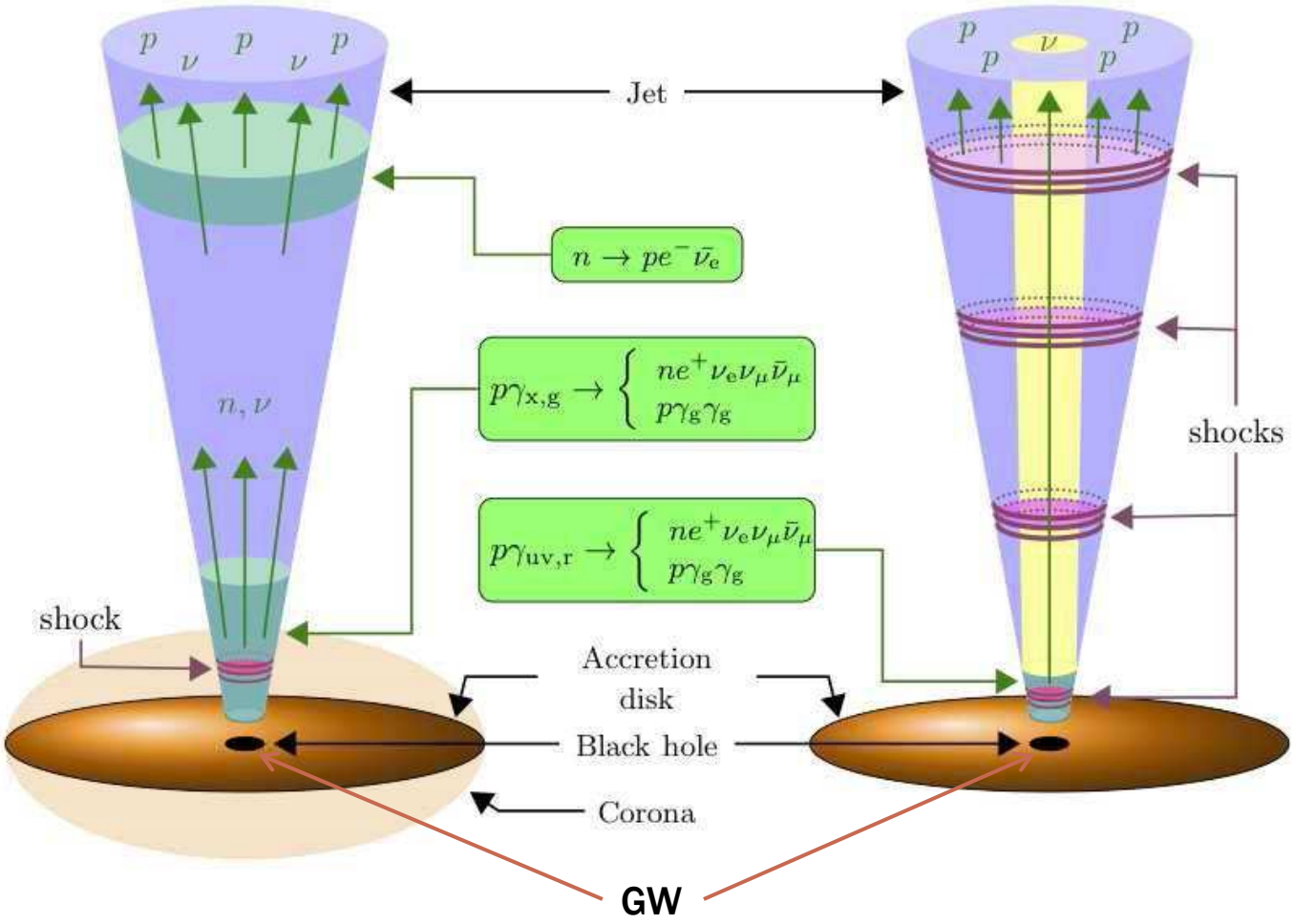
OVERVIEW OF A COSMIC ACCELERATOR

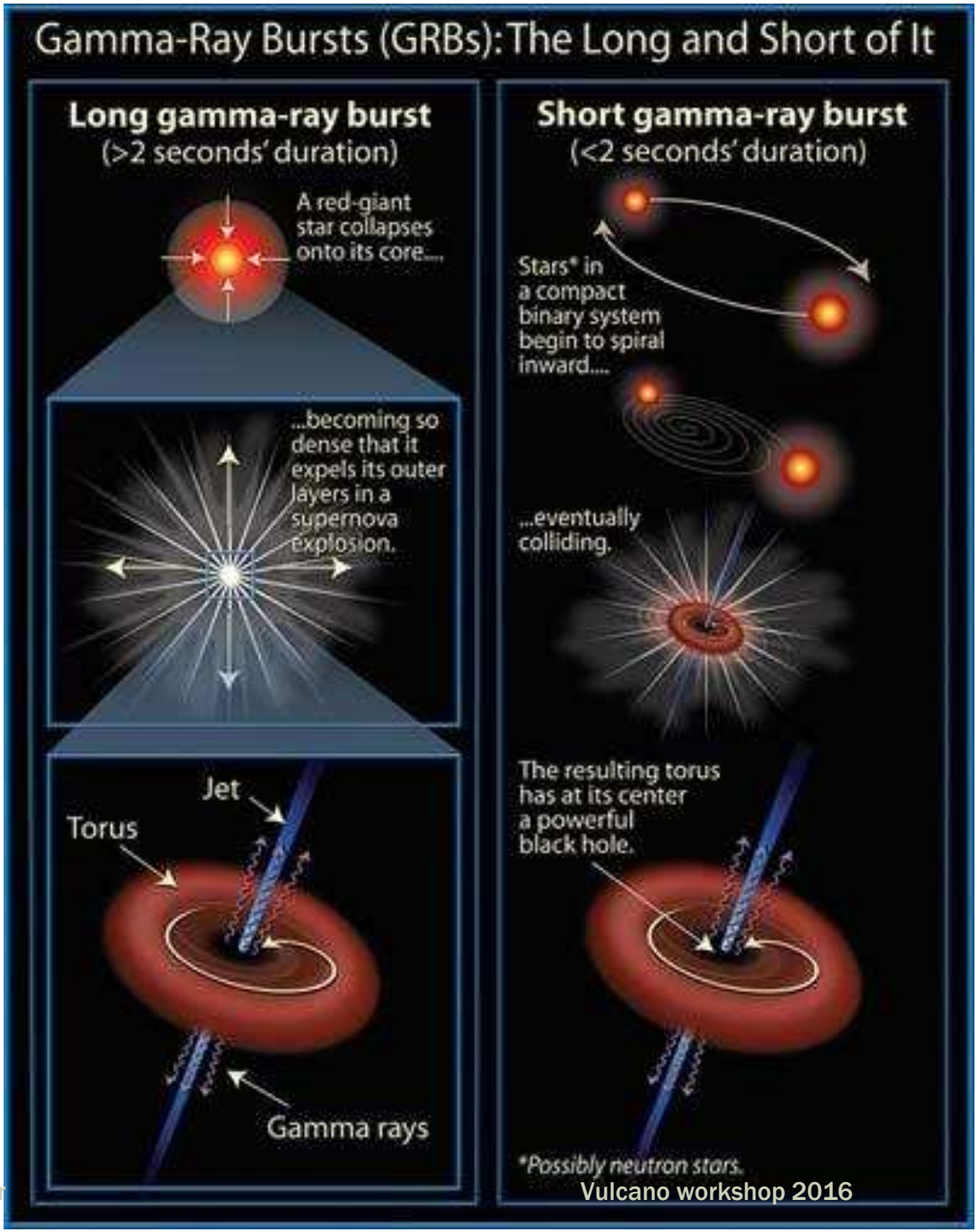


HAWK call, ICRC 2015

MULTI-MESSENGER EMISSION IN AGNS

Jacobsen et al., 2015

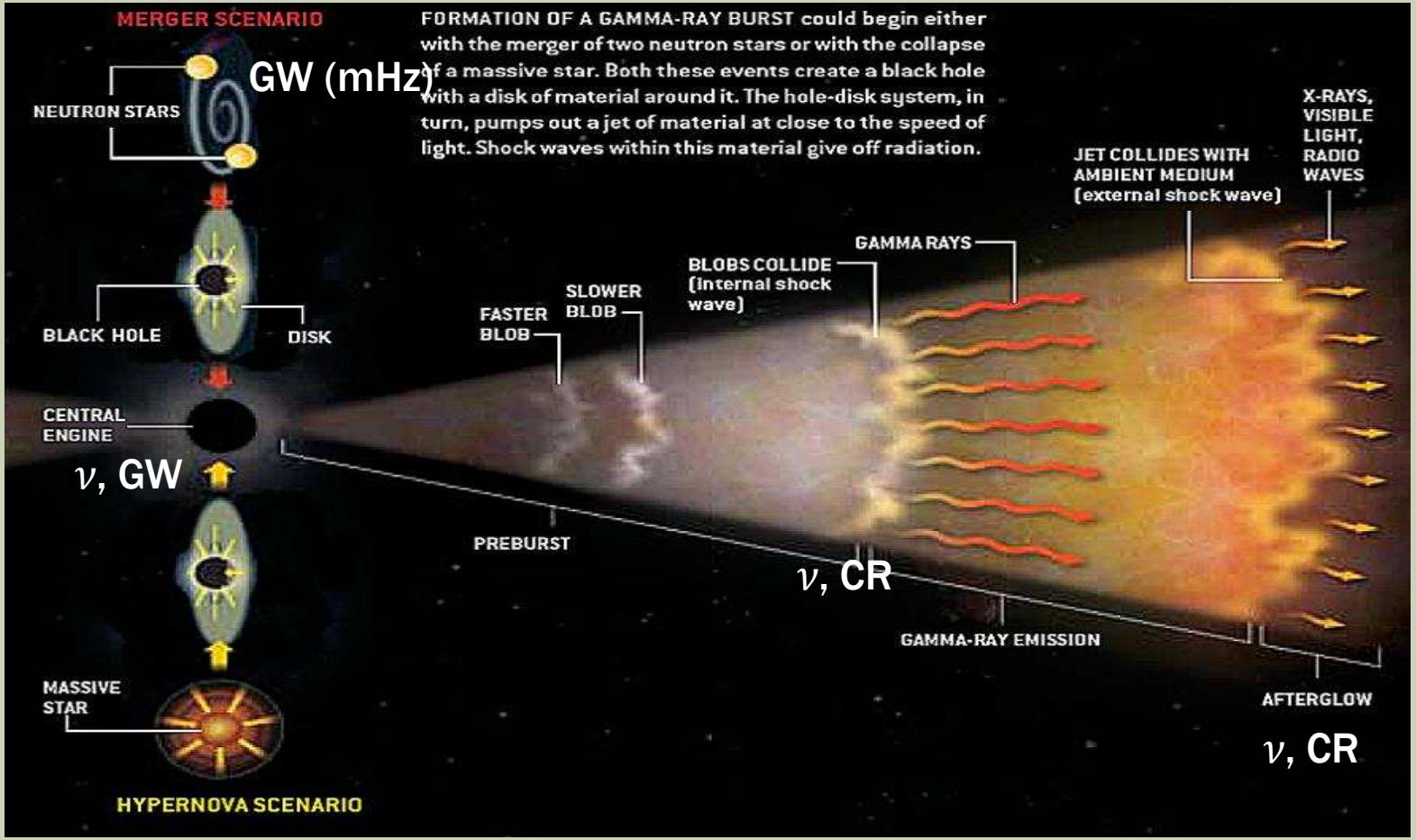




GAMMA-RAY BURSTS

Progenitor can be either a massive star collapsing in a black hole (long GRB) or the merger of a compact neutron star binary system (short GRB)

INTERNAL SHOCK SCENARIO

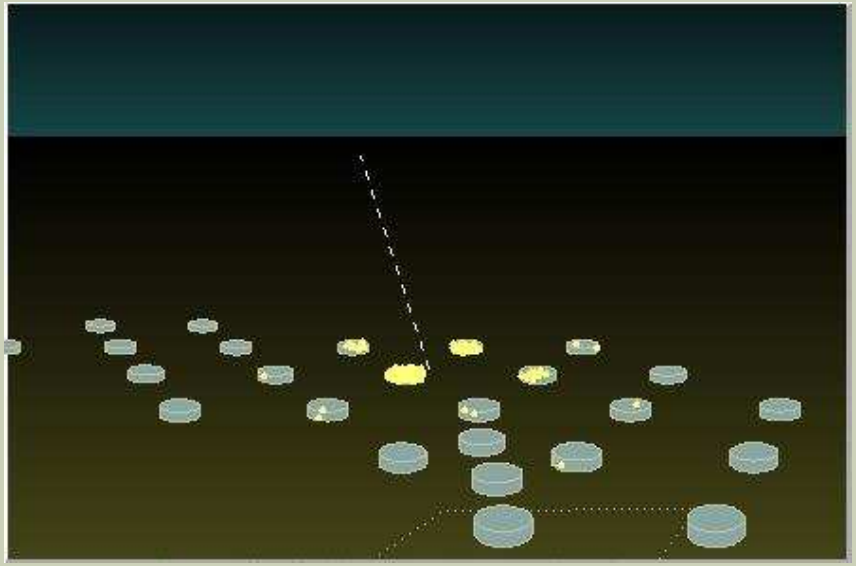


ASTROPHYSICAL OBJECTS SEND MORE THAN ONE MESSENGER

Object	EM Counterpart	VHE/UHE	Cosmic rays	Neutrinos	Gravitational waves
The Sun	Observed (since long)	HE gamma-rays	Observed	Observed	N/A
Supernovae / SNR	Observed (since long)	Observed	SNR	Observed (SN)	If in Galaxy
Hypernovae, (IGRB)	Observed	Up to 20 GeV	Predicted, but no association	Predicted, but no association	too faint
BHBH Merger	Probably very faint	No association	No association	No association	GW 150914
NSBH merger	faint, observed?	No association	No association	No association	Expected (>= 02)
NSNS	Observed (sGRB)	Observed (LAT)	No association	No association	Expected ALV and LISA (before merger)
SMBH/AGNs	Observed	Observed	Expected but no association (CenA)	No association	LISA (SMBH)?
Stochastic (discrete)	N/A		Observed	?	Expected (>02)
Stochastic (cosmological)	CMB		N/A		Too faint probably, can be indirect
Dark matter	Indirect evidence		N/A	Too light	N/A

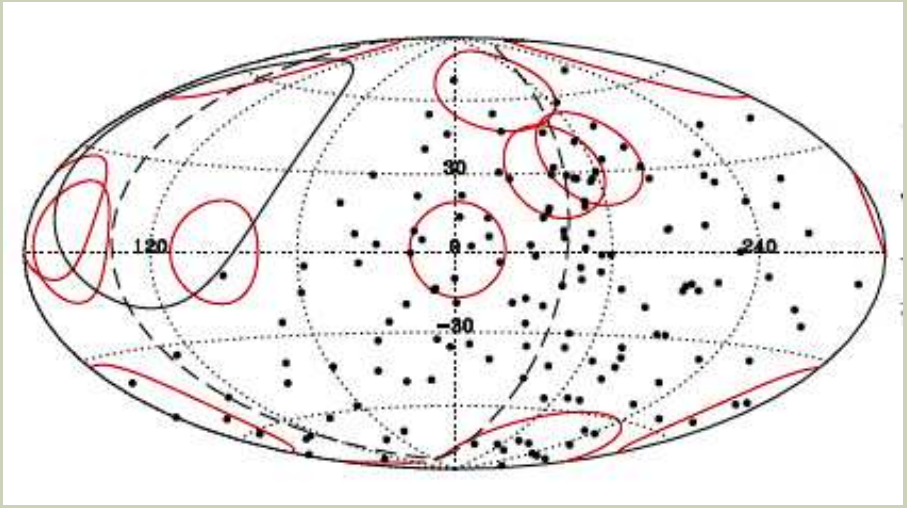
COSMIC RAYS

- Cosmic rays
  - Observed since beginning of XXth century
    - Several experiments, Auger, Tel. Array AMS, CREAM, PAMELA, ISS-CREAM…
    - Antimatter, CR composition, UHECR, missing baryons/dark matter.
  - Trace supernovae explosions and magnetic fields
    - SNRs Is knee connected to SNR turn off?
    - Origin of ankle?
    - In galaxy(ies)
  - HE/UHECR extragalactic?
    - Source?
      - AGNs (radiogalaxies)?
      - GRBs?
      - Why isotropy?
      - Other (topological defect, etc.)

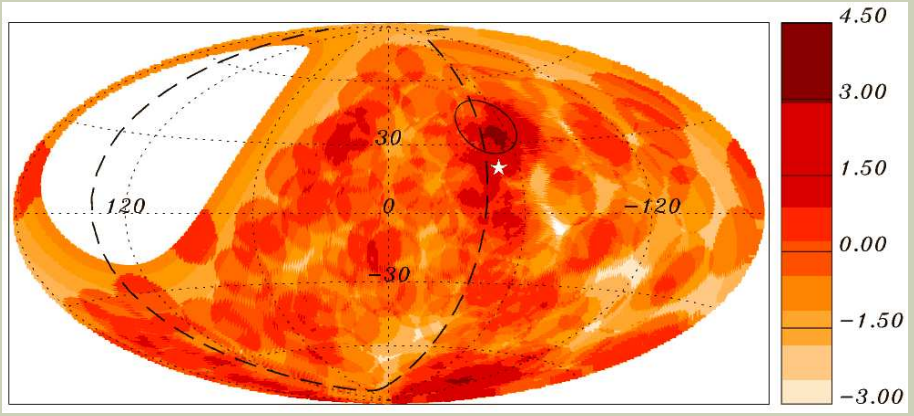


AUGER EVENTS

Swift sources (no correlation)



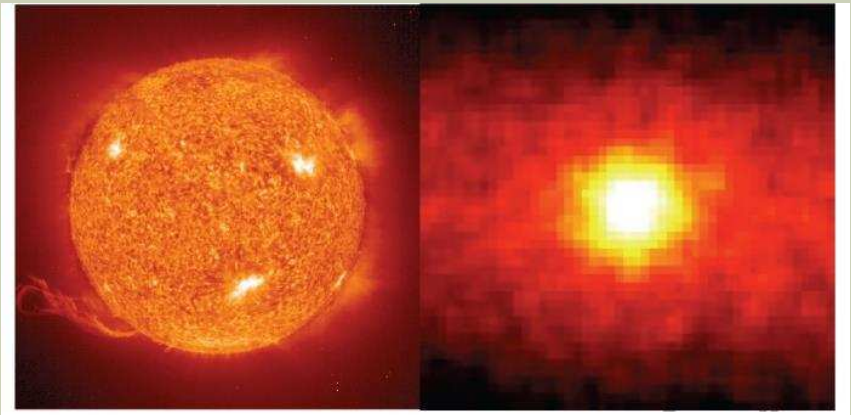
Cen. A hot spot (but needs more data)

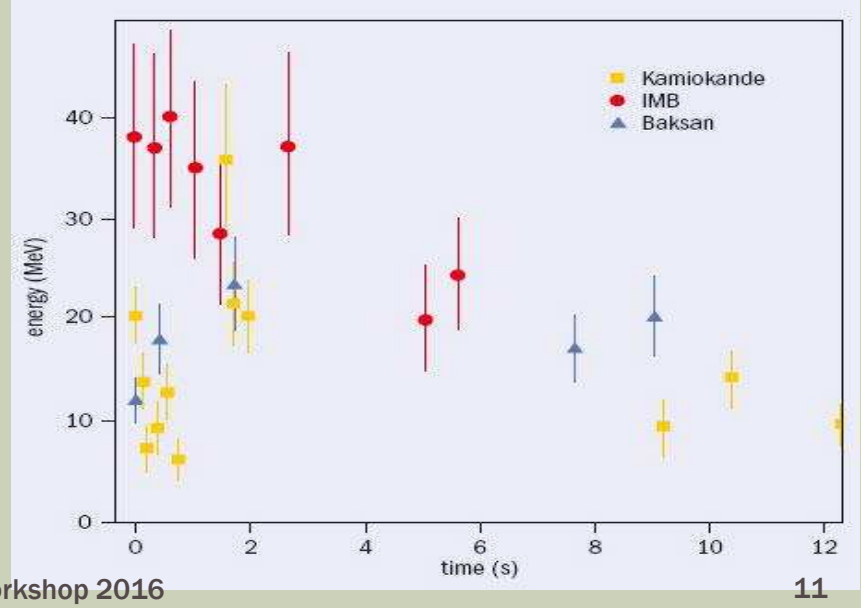


Auger coll., ICRC 2015

NEUTRINOS

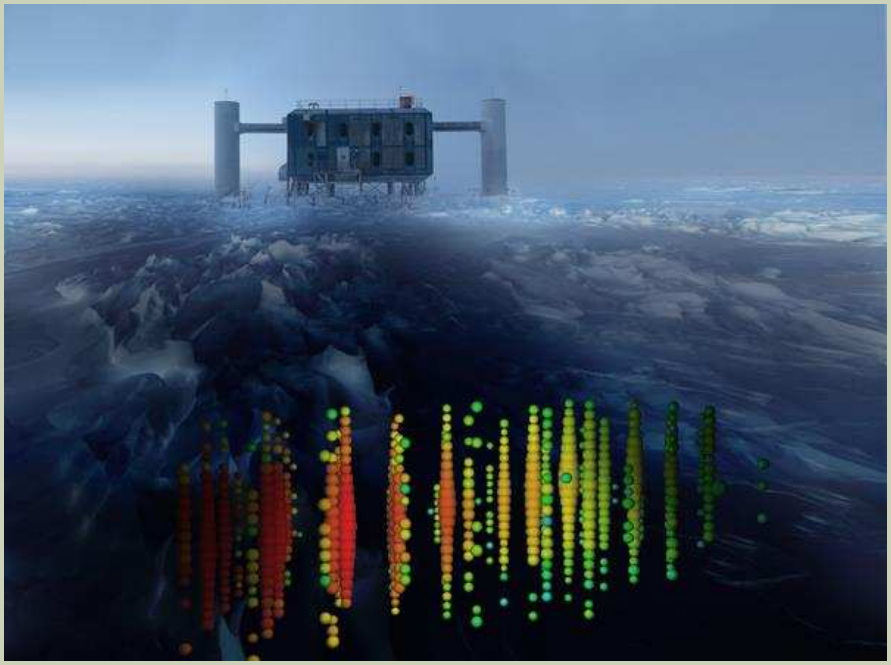
- Neutrino astrophysics has already started since the 80s
  - The Sun
  - SN 1987A
    - Probably the first « multimessenger » observation
  - Important results drawn
    - Neutrino oscillations
    - Supernovae models
    - Upper bonds on neutrino mass, charge, etc.
  - Wait for next galactic SN



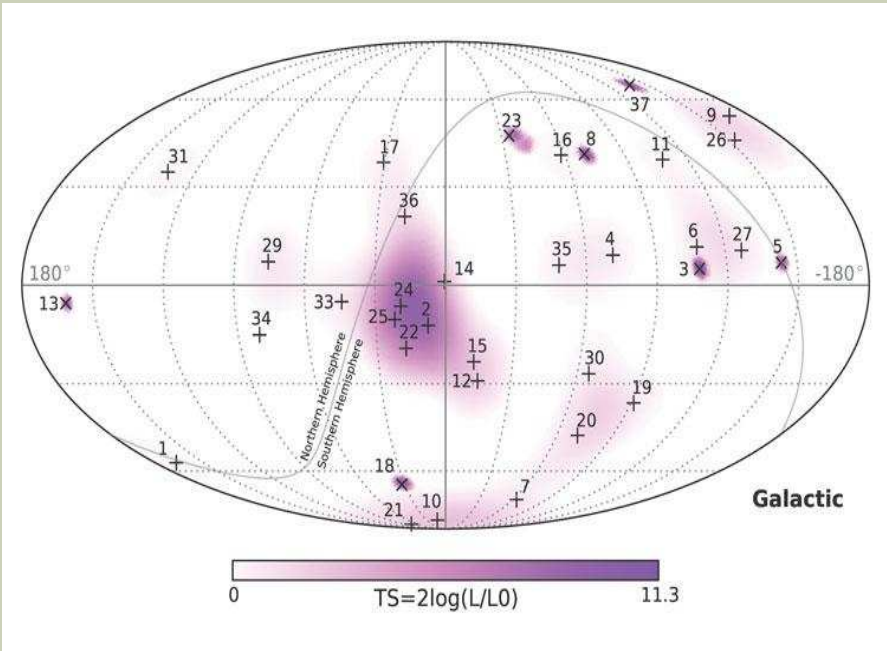


HIGH ENERGY NEUTRINOS

Icecube

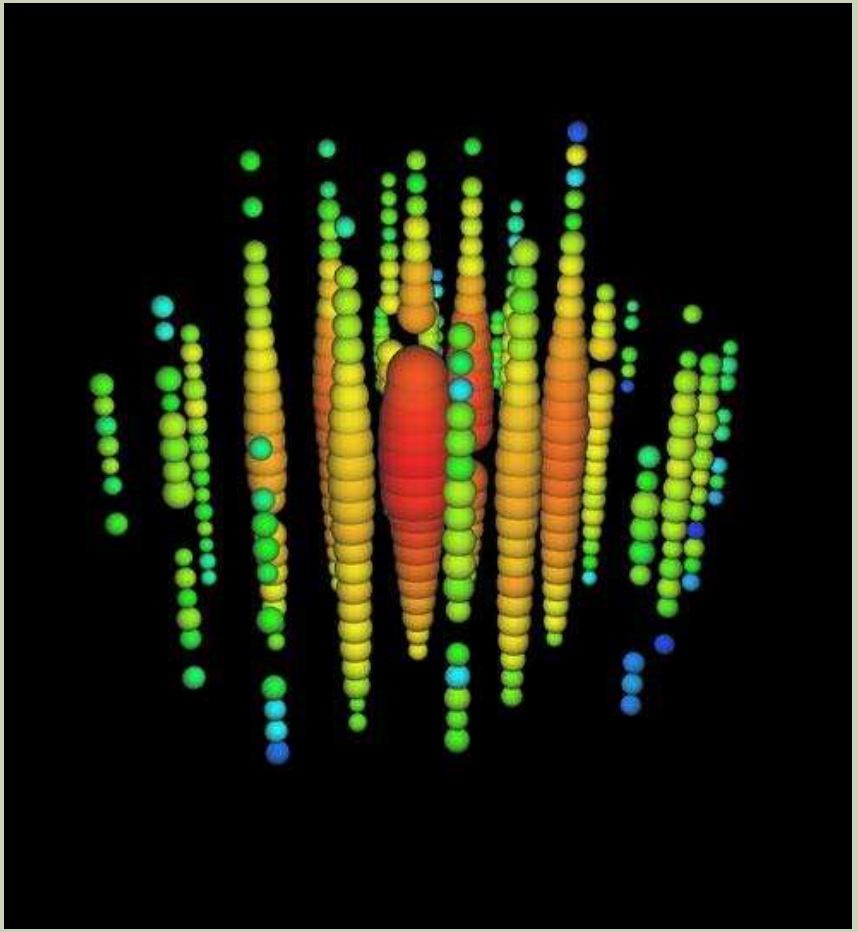


Map of 37 IceCube detections



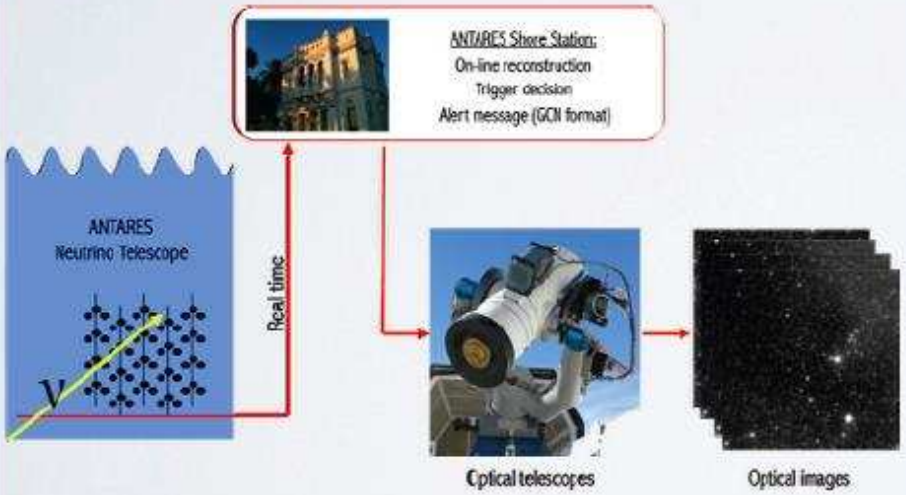
HIGH ENERGY NEUTRINOS

- Detected since 2012 by IceCube and now Antares
- 30 – 1200TeV
  - Photopion production from particle accelerated at UH energies (Fermi acceleration)
  - Origin: AGN?
  - GRB (no simultaneous detection)?
  - SN remnants?
  - Accumulation near Galactic Centre? Extended source?
- IceCube and ANTARES have been linked to automated telescope experiments (no positive results so far despite many observations with TAROT, Zadko and other telescopes)
  - TAToO program (TAROT/ROTSE/ANTARES)
- IceCube events now on GCN/TAN (Transient Astronomy Network) for prompt EM follow-up (http://gcn.gsfc.nasa.gov)
- Now correlated searches Neutrinos/UHECR/GW
- Perspectives:
  - IceCube-Grn2
  - Km3Net



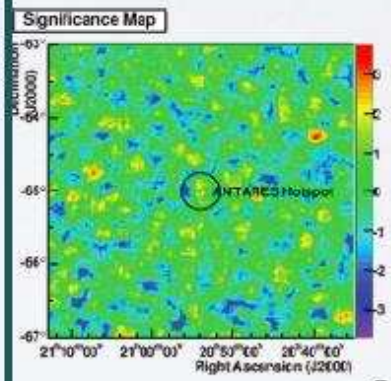
ANTARES FOLLOW-UP

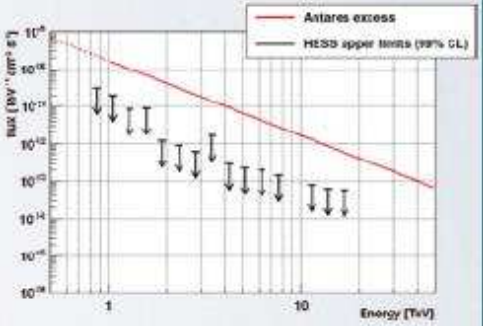
TAToO: optical follow-up



ANTARES collaboration
Astroparticle Physics 35 (2012)

HESS: gamma-ray follow-up





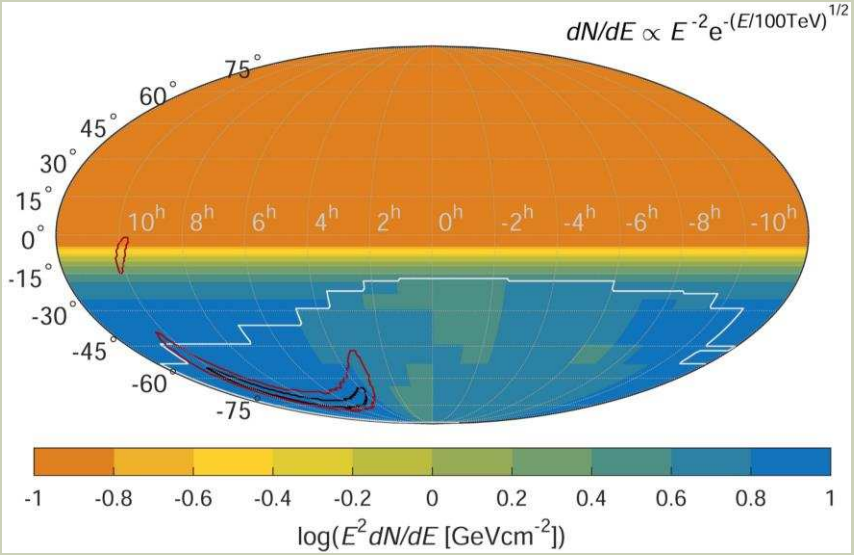
F. Schüssler et al.,
ICRC (2013)

+ IceCube and ANTARES alerts

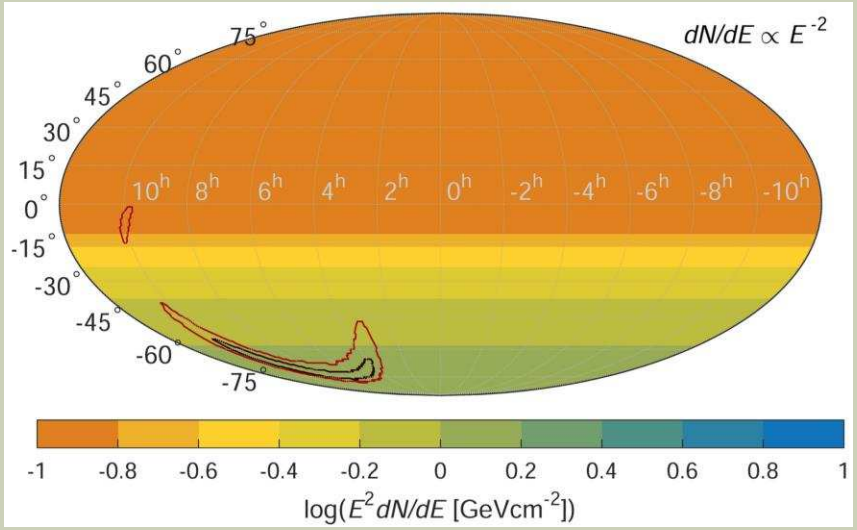
Slide fm A. Coleiro, ANTARES)

ANTARES/ICECUBE SEARCHES FOR NEUTRINOS FROM GW 150914

ANTARES
3 TeV – 1 PeV



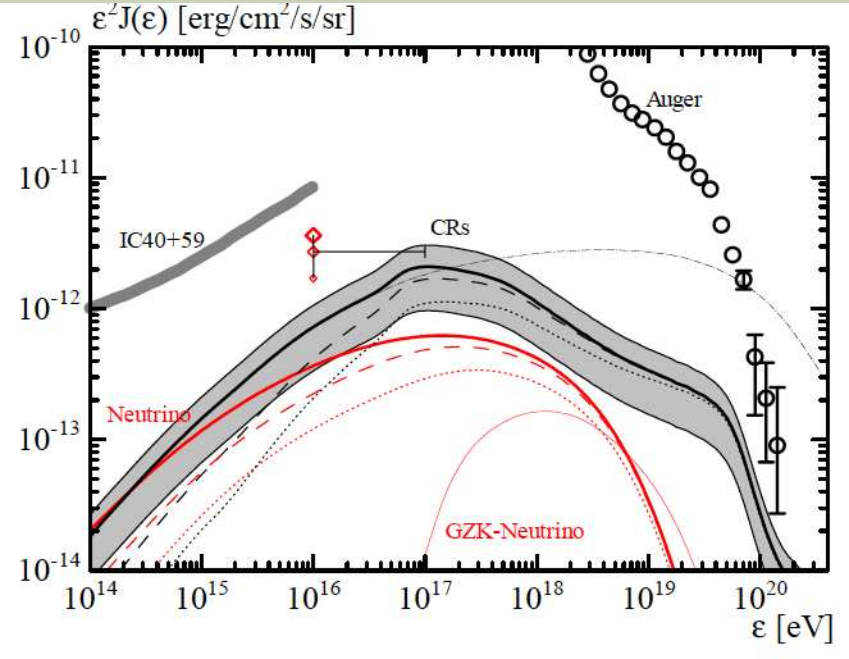
IceCube
200 TeV – 100 PeV



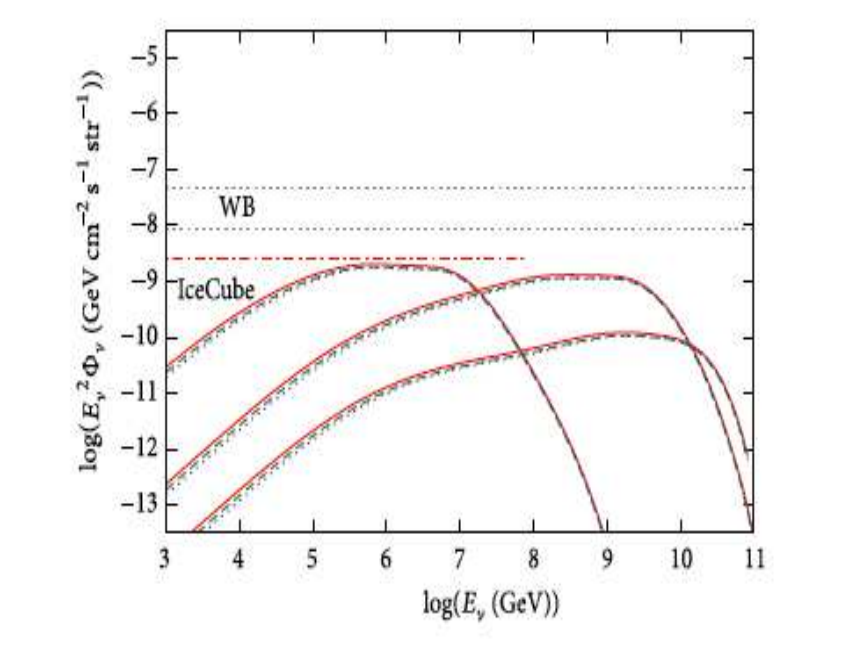
Adrian-Martinez et al., 2016

DIFFUSE COSMIC-RAY AND NEUTRINO FLUXES FROM GRBS

CR and ν spectra
(Asano & Mészaros, ApJ, 2014)

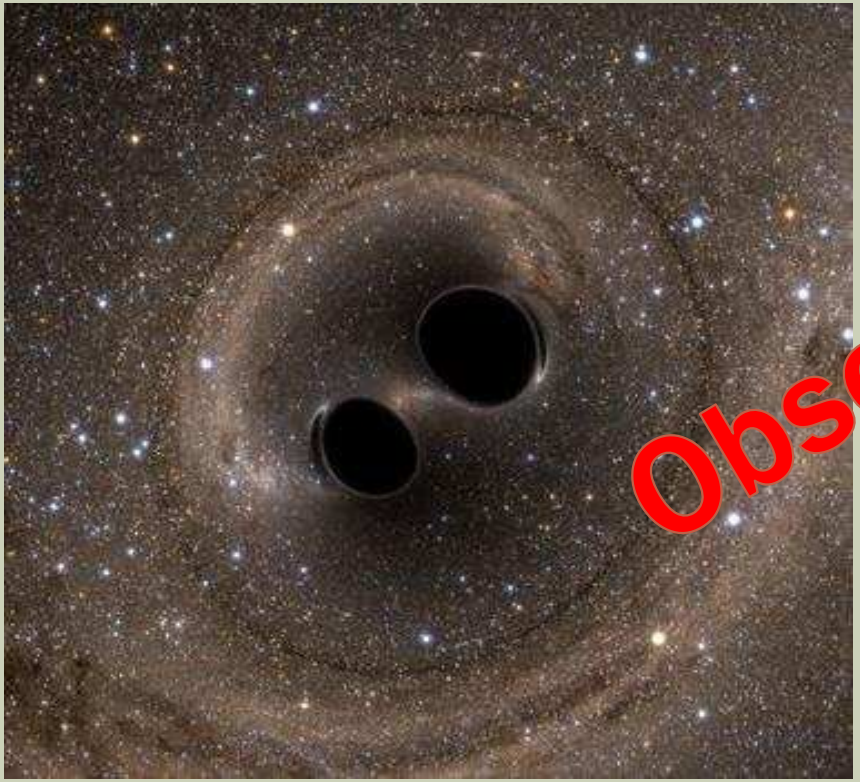


ν spectra
(Asano & Murase, Ad A, 2015)

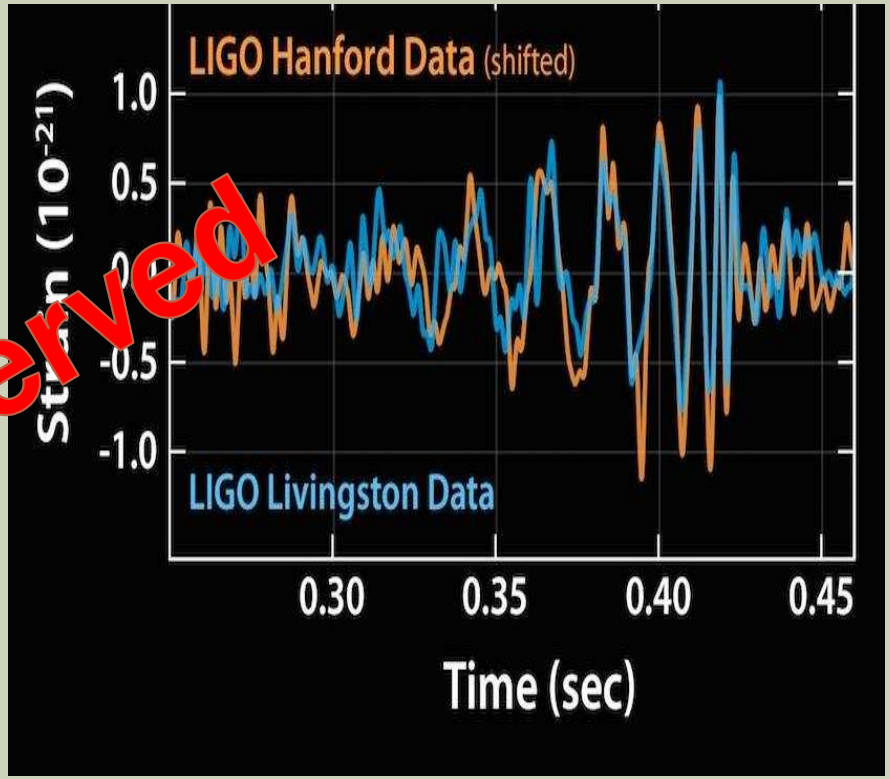


FIRST GW EVENT
MERGER OF BLACK HOLES

Merger of black holes
GW signal – EM???



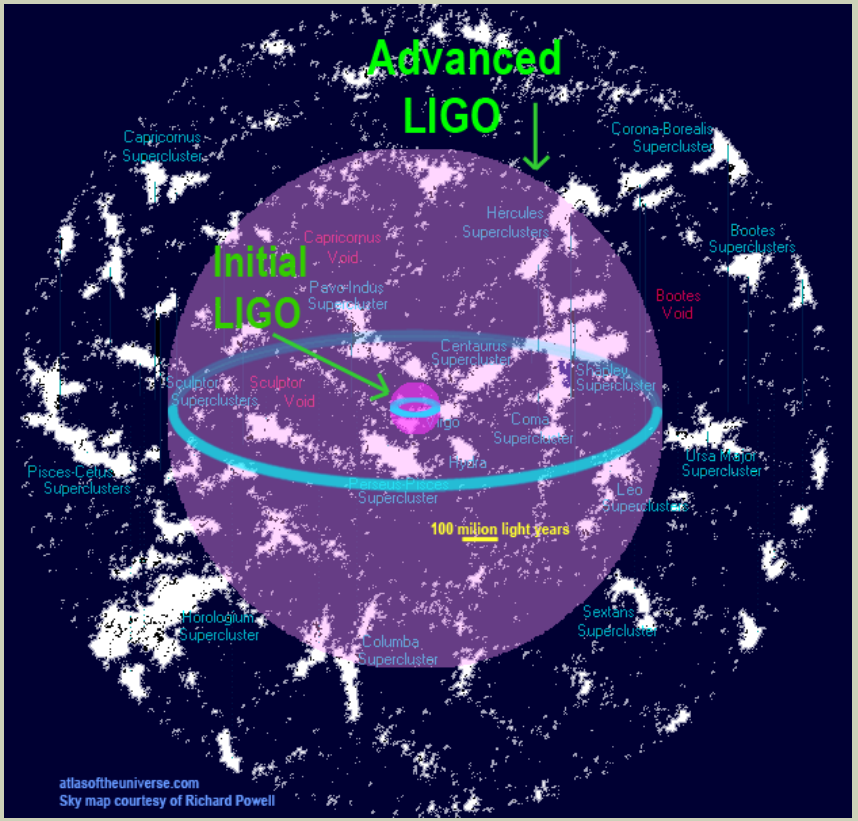
GW 150914



Observed

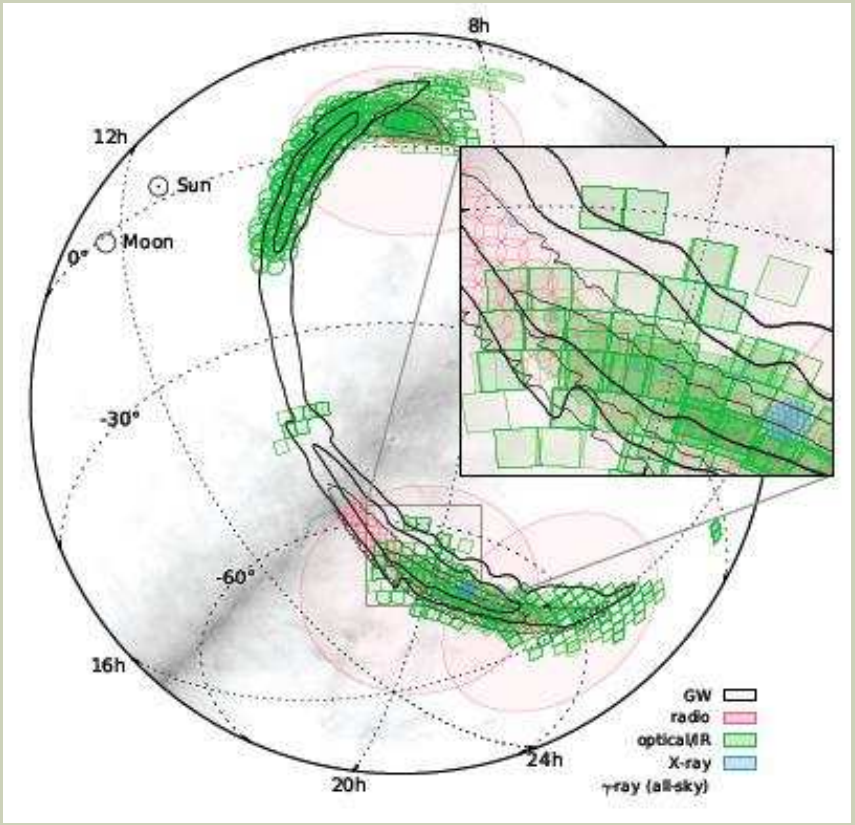
GRAVITATIONAL WAVES

- Last « new messenger »
  - Detection of GW 150914 while ALIGO was (almost) in its first run open expectations for a large number of sources
    - CBC (BHBH/NSBH/NSNS)
    - Impact on stellar evolution and SFR (we have the numbers)
    - Expect stochastic signal
    - See large number of papers by LIGO/Virgo collab.



EM FOLLOW-UP OF GW SOURCES

- 63 groups receive the GW alerts
  - 30 of them have actually followed-up the alerts
- Problem of error box size
  - 1000 sq. deg >> 100 sq deg
- Time to get the position
  - 2 days for GW 150914, expected several hours
  - Hope it will improve
- Is the source EM bright?
  - Few hopes for BHBH
  - Better for NSBH
  - sGRB for NSNS
- M. Branchesi talk Friday



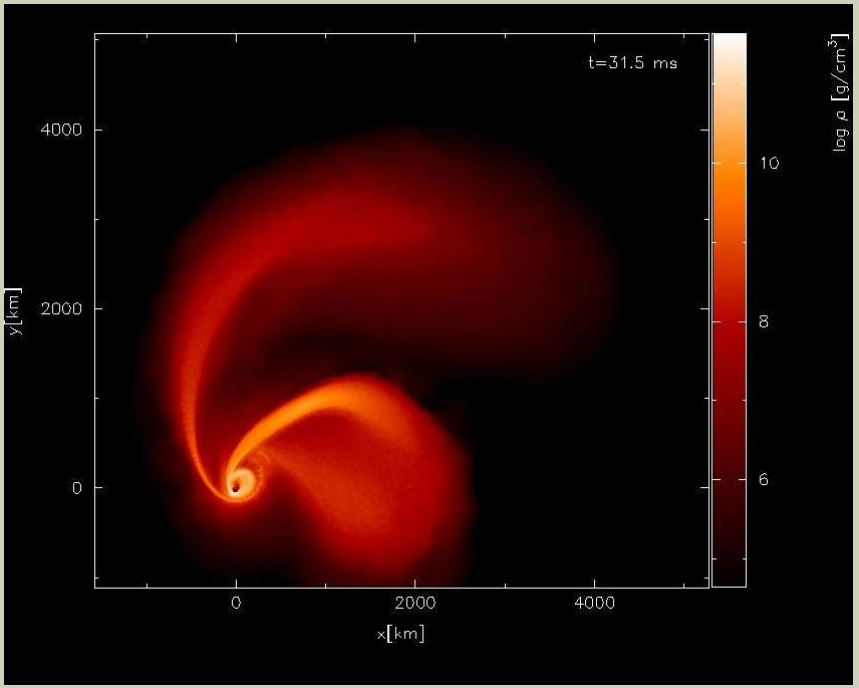
LIGO/Virgo Coll. et al. 2016, ApJL

NS – NS AND NS - BH

NS – NS Merger
GW + EM signal

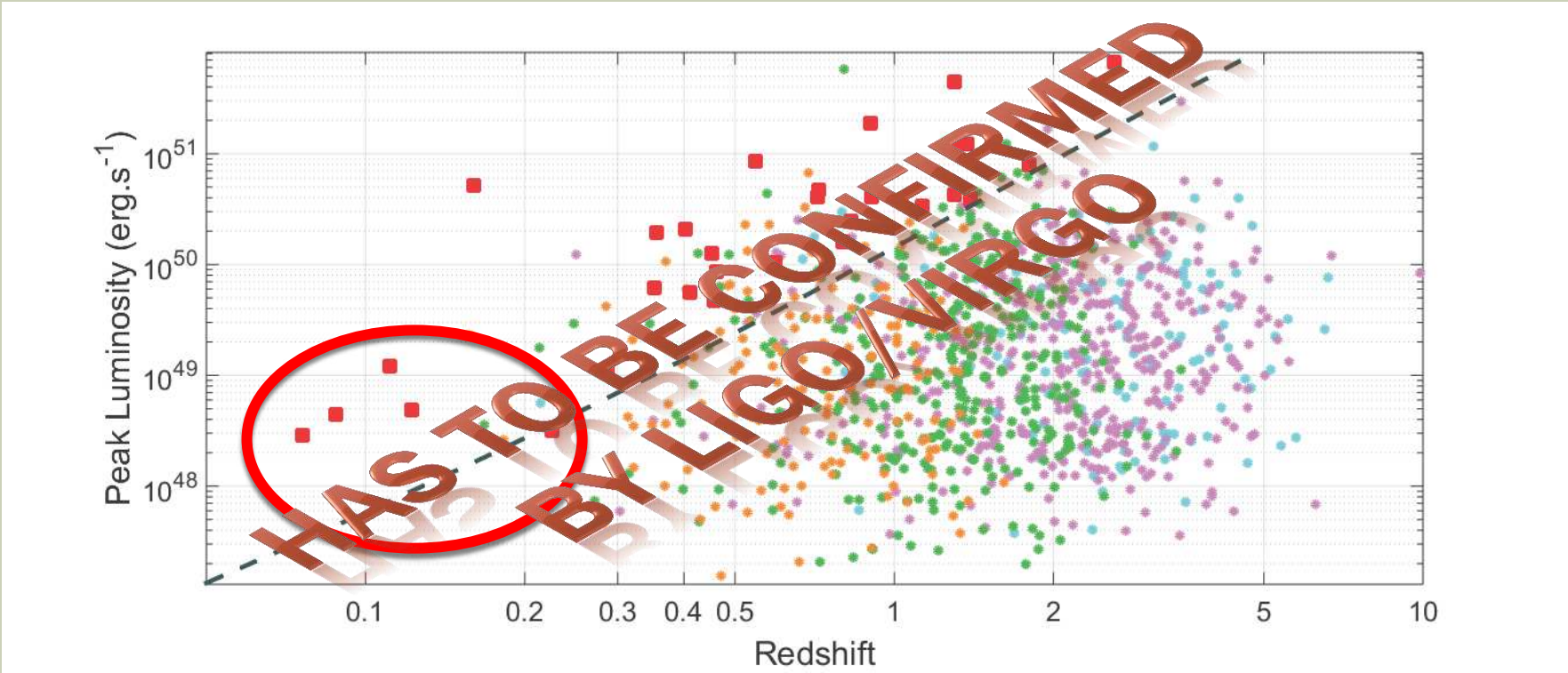
NASA GSFC

NS – BH Mergers
GW + EM? signal



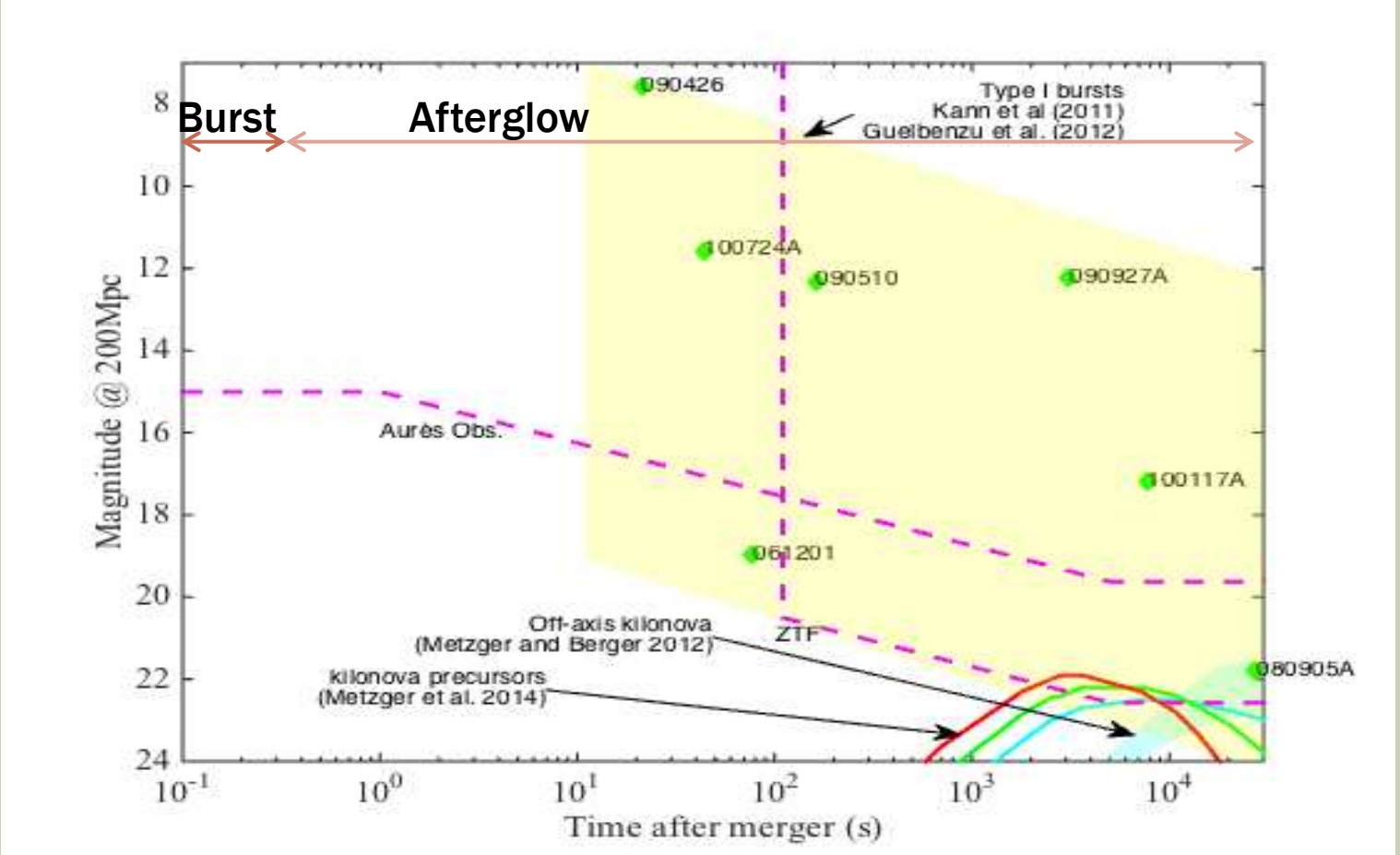
Piran, Nakar and Rosswog, 2013

DID SWIFT DETECT NSBH MERGERS?

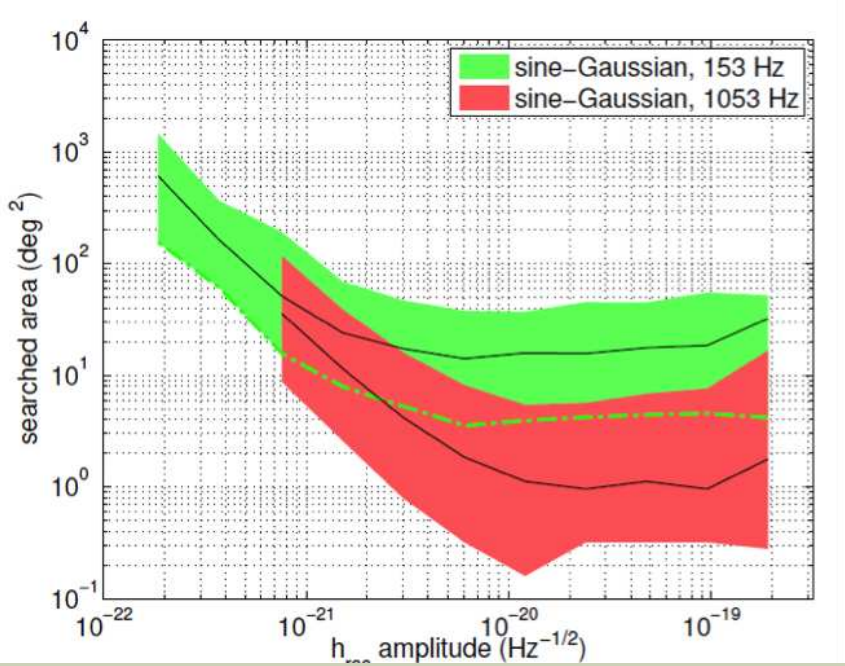


Siellez et al. 2016

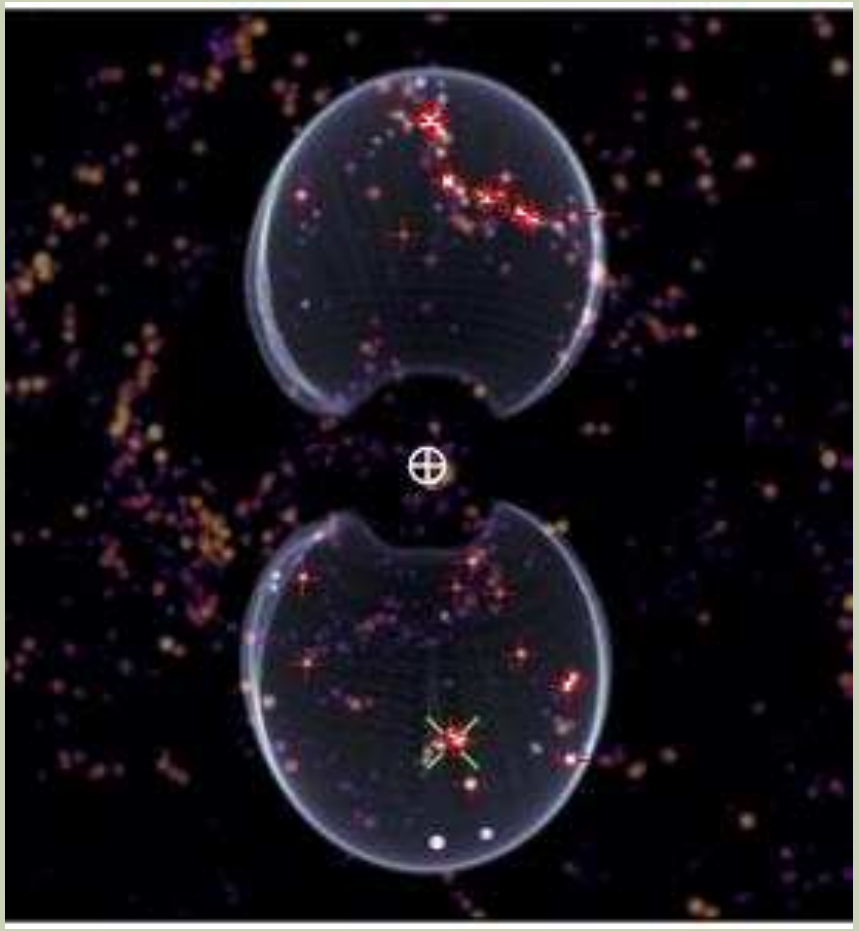
THE SEQUENCE OF EVENTS SNAPSHOT AND SENSITIVITY



THE ERROR BOX SIZE



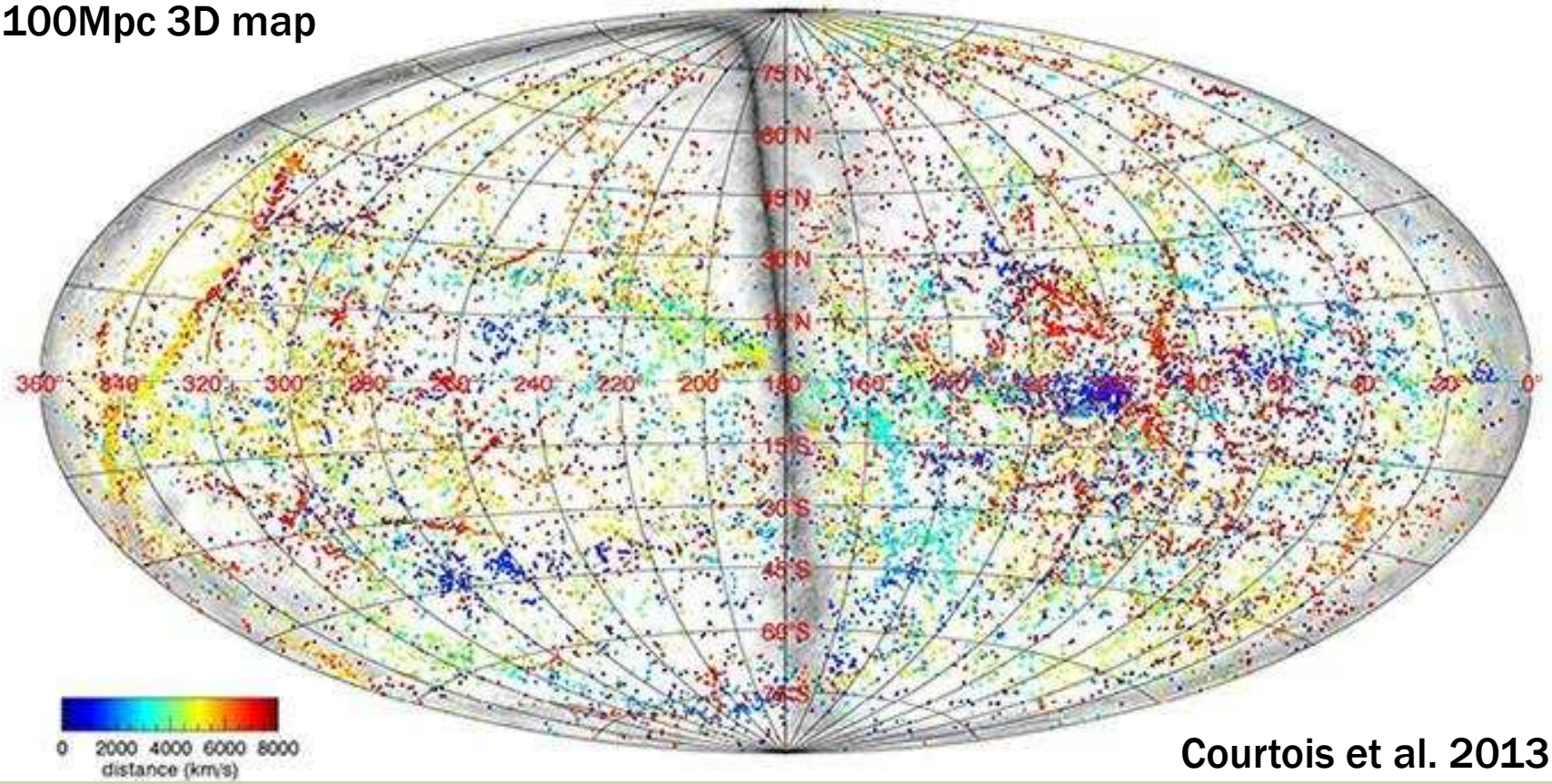
Abadi et al. 2012



Singer et al. 2016

CORRELATION WITH GALAXIES

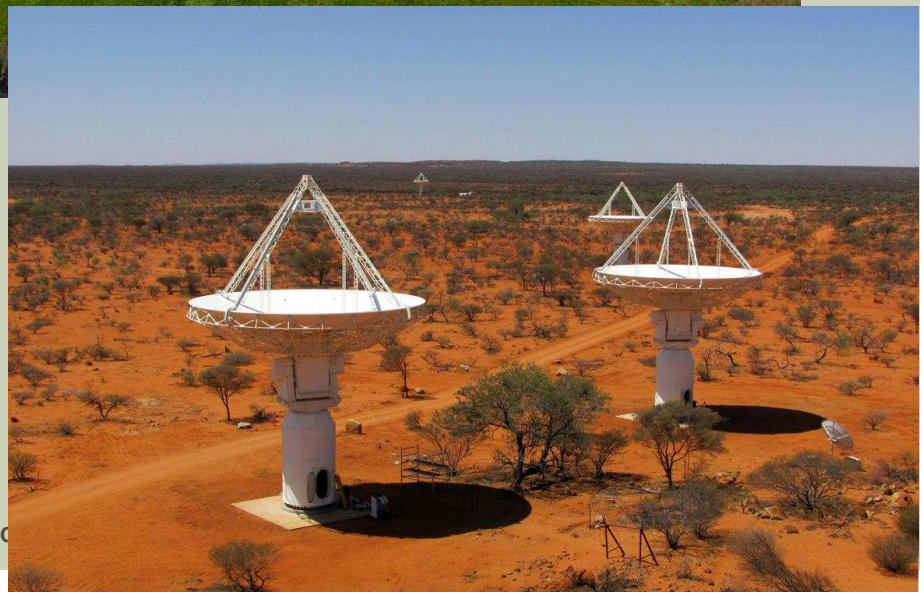
100Mpc 3D map



Courtois et al. 2013

FACILITIES FOR FOLLOW-UP

- In space, instruments with large fov
  - Swift, Fermi, SVOM
- Difficulty to use XMM-Newton
- On ground large facilities include SKA and LOFAR
  - But correlation in time not granted
- For optical/IR, large facilities
  - Needs galaxy catalog and information on distance (Singer et al. 2016)

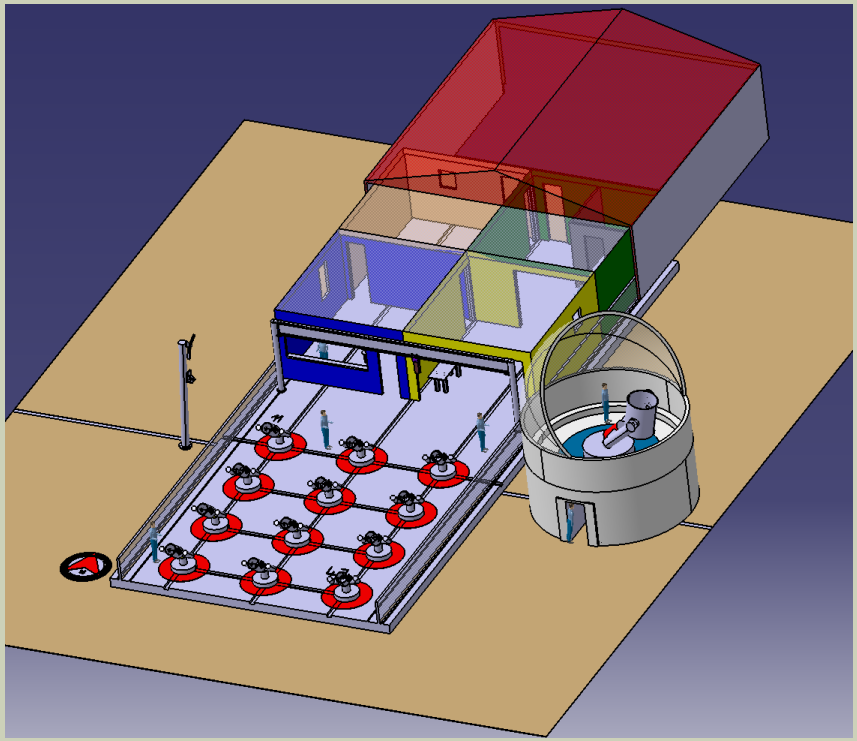


TAROT-ZADKO NETWORK
WIDE FIELD OF VIEW WORLDWIDE NETWORK

RAMSES PROJECT AT AURES OBS.

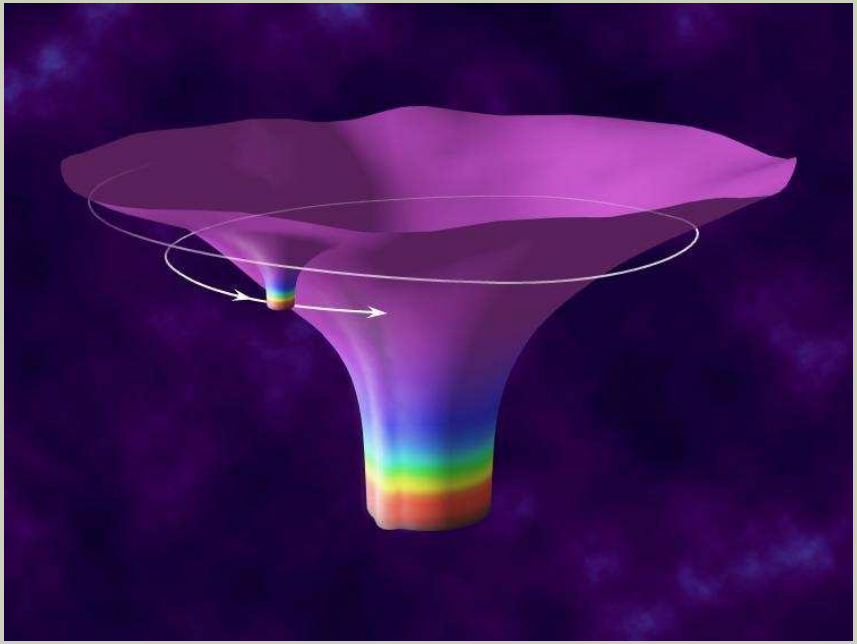
ROBOTIC ADVANCED MULTIMESSENGER AND SPACE ENVIRONMENT SURVEYOR

- Problem
  - Pave the field of 100 sq. deg.
  - With enough sensitivity
  - And reactivity:
    - Low latency trigger ~10s, i.e. 5s
  - And flexibility
    - Look at the whole field at the start, then concentrate on candidates
- The RAMSES project
  - “Métatélescope”, 16 x 45cm x 2.5° (Boër, 2015 + patent)
  - Generic instrument, chosen for the Aurès National Observatory (Algeria, Seghouani et al. 2015)
  - Reduced costs, modular maintenance

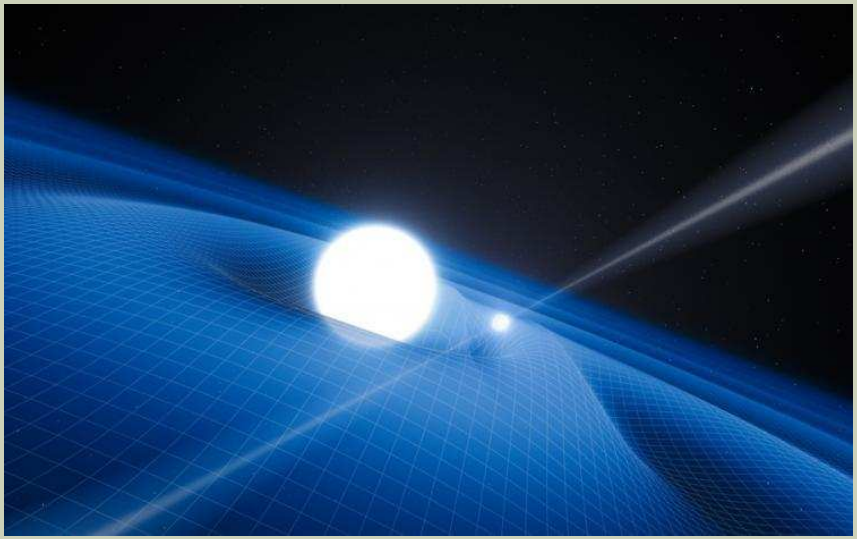


LISA (2034--)

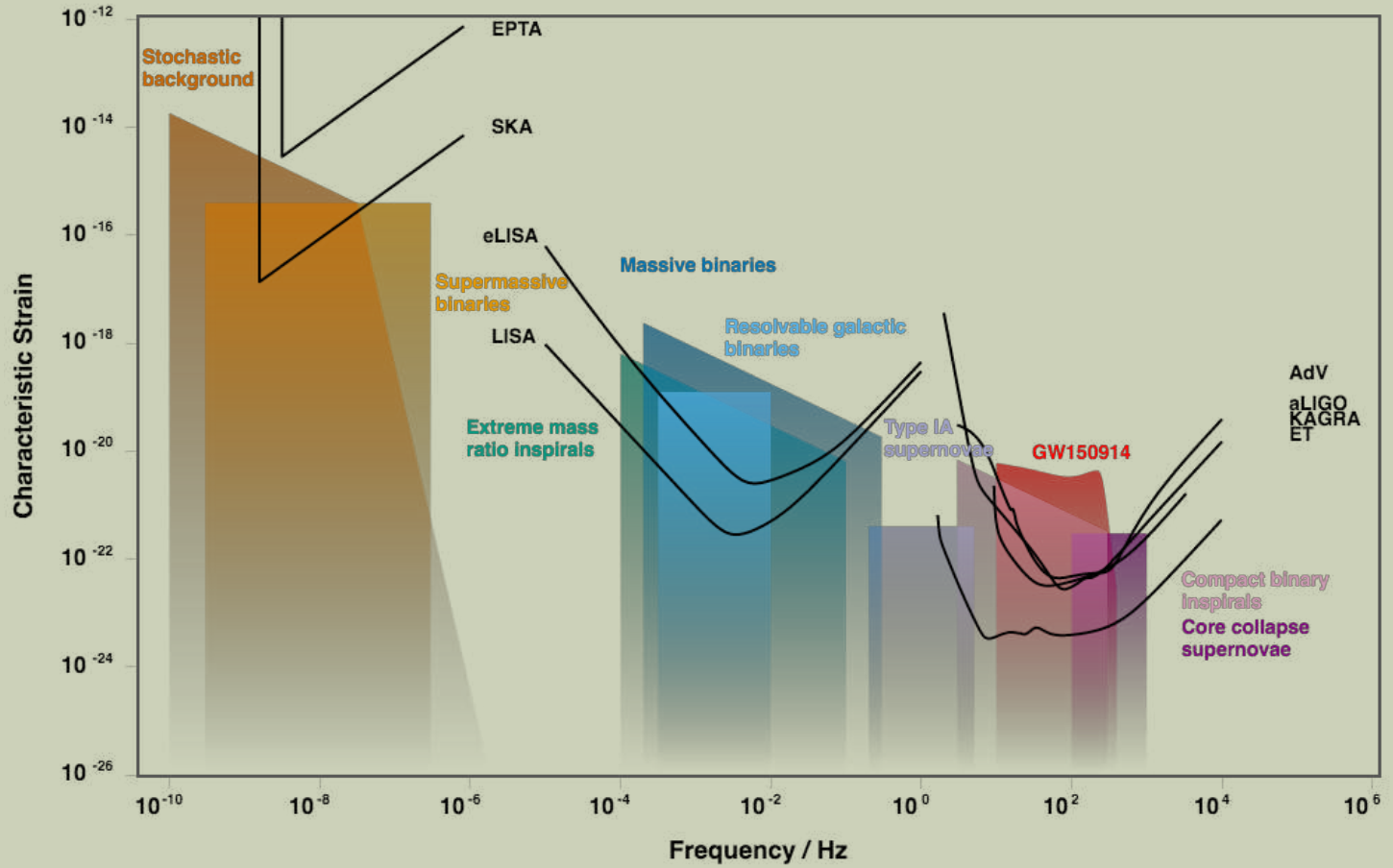
EMRIs
SMBH eating a smaller BH
(NASA)



Ultra-compact binary sytems
PSR J0348+0432 (ESO)



GRAVITATIONAL WAVE LANDSCAPE



http://rhcole.com/apps/GWplotter/

CONCLUSIONS

- XXth was the century of panchromatic and time domain astronomy
- The XXIst century sees the begining of multimessenger astronomy
  - UHECR: Auger, TA
  - ν: ANTARES/IceCube/KM3Net
  - GW: LIGO/Virgo/LISA/ET
  - VHE/UHE: Magic, HESS, CTA, Fermi
- In few years CR, neutrinos and gravitational waves have been observed
- But the EM follow-up needs dedicated strategies and facilities
  - Already existing or in construction
    - LOFAR/TAROT-Zadko, HESS, SKA, HAWK
    - Swift, Fermi, XMM
  - Or planned
    - RAMSES@ONA, BlackGem
    - SKA, CTA, JWST
    - SVOM, Athena, JEM EUSO
    - LSST
- Multimessenger is still in its infancy, but great results obtained (GW, CR, neutrinos)
- They open a window on many processes from fundamental physics to cosmology to stellar astrophysics
  - General relativity and beyond
  - Supermassive BH and galaxy core dynamics, jets…
  - Acceleration of CR and neutrino production
  - Compact binaries in a wide range of masses and type (BH/NS, and possibly WD with LISA)
  - Stochastic background from discrete sources
  - Cosmological stochastic background (may be)