The eve of multimessenger astronomy

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Some historical note

- From the eve of humankind to the XIXth century, the photon (visible), i.e. the eye has been the messenger of choice
- Most of the time (‘til XVIIIth), photons were actually giving messages (but other existed, e.g. beef entrails, chicken, London tower ravens…)
- Discovery/use of telescope, then photograph gave better sensitivity, not a new messenger: visible radiation was still only astronomical information

Detail of the Tapestry of Bayeux (circa 1070

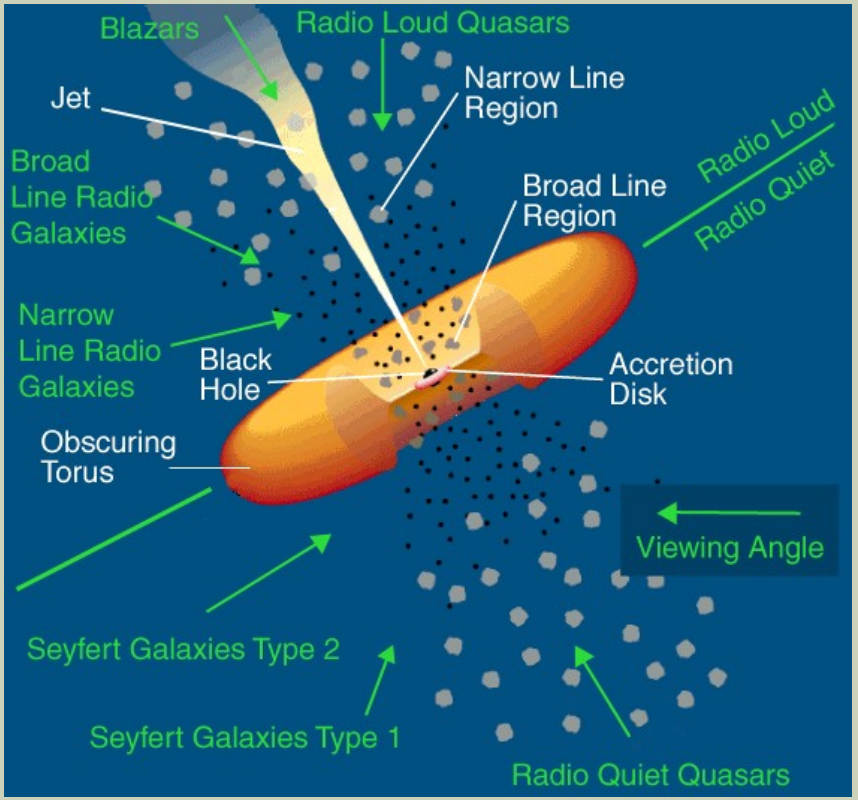
What is a « new messenger »

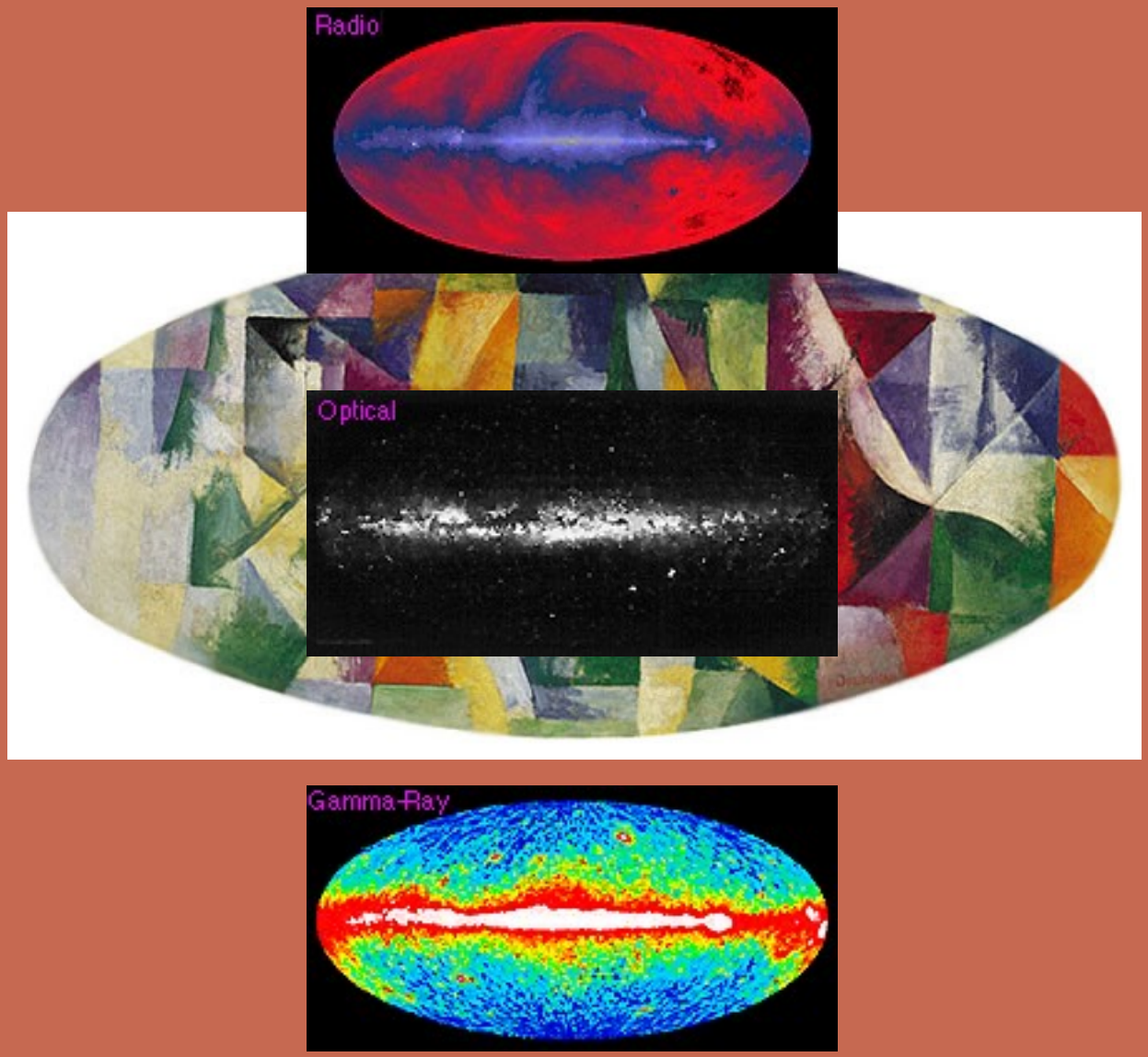
- New messenger means
  - Different processes
  - Thermal/non thermal
  - Magnetism, etc.
  - Masses
  - Accretion…
  - Different ways to get the information
  - Panchromatic spectrum
    - Aperture of the radio, then UV, IR, X-ray, ϒ-ray, sub-mm
    - Discoveries: CMB, pulsars, X-ray binaries, SNRs, 26Al, AGNs
  - Time domain astronomy
    - GRBs, AGNs, Pulsars,…
  - Different emission regions…
    - VLBI, Optical interferometry, …
    - Jets in AGNs, µquasars, proto-stars…
    - Planet around stars

Mercury delivering the message of the gods to Calypso to free Ulysses. He will become mortal again, but will be back in history (Gérard de Lairesse, 1670, RijkMuseum, Amsterdam)

What means multimessenger

- Information drawn from 1 messenger is partial
- Deriving a consistent picture of a phenomenon / source from a variety of information sources
  - 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
- On the contrary, GW evidence from binary pulsar and BICEP results are not multimessenger astronomy (indirect evidence using photons as messengers)





Art is precursor: our galaxy…

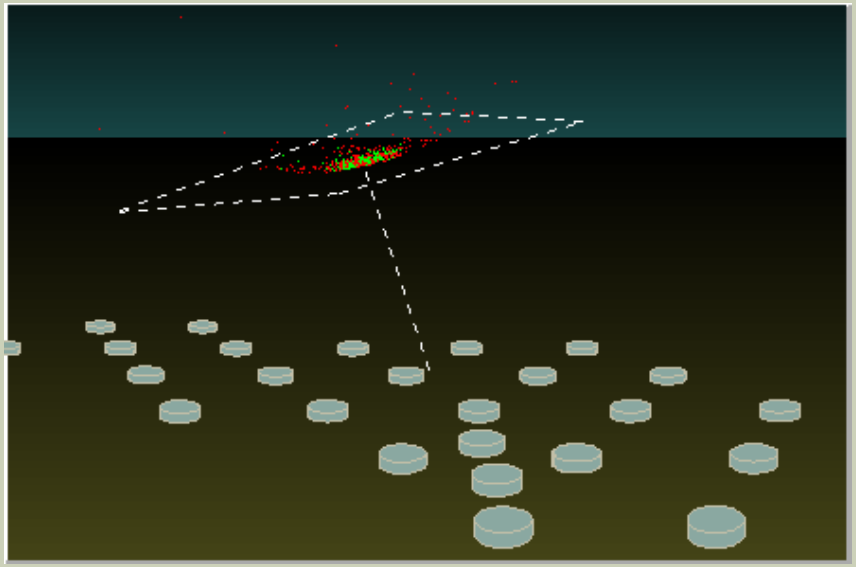
Robert Delaunay, « Fenêtres ouvertes simultanément, 1ère partie, 3ème motif », 1912

(*Simultaneously opened windows, part 1, frame 3*)

Our current understanding of the Milky Way has been revolutionarised with the opening of the « particle », high energy, IR and radio windows

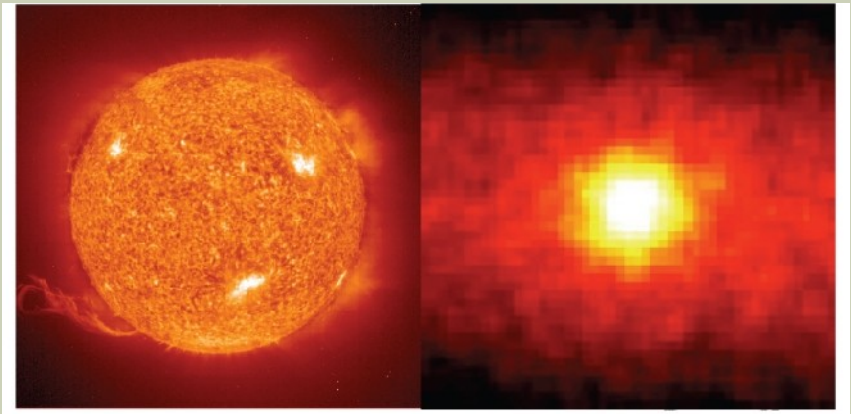
Multi particles

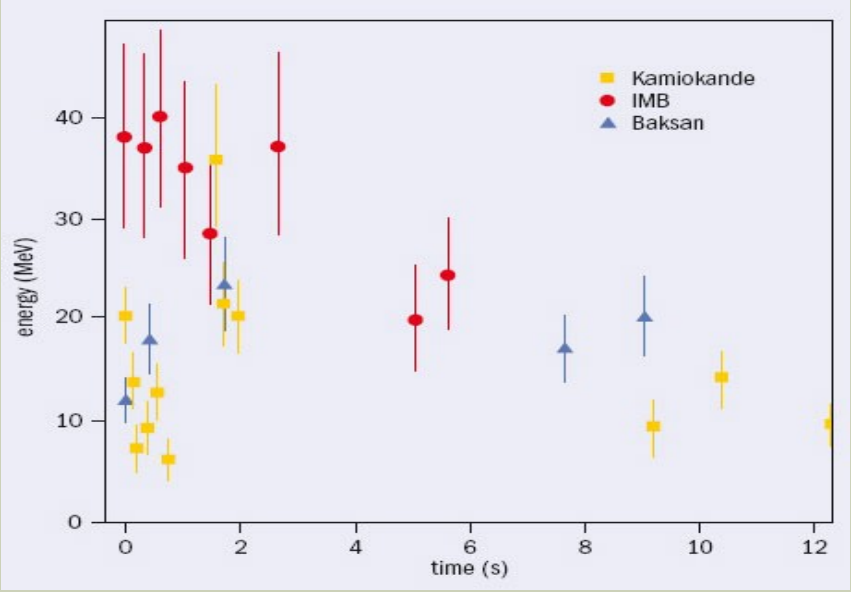
- Cosmic rays
  - Observed since begining of XXth century
  - Several experiments, Auger, AMS, etc.
  - Antimatter, CR composition, UHECR, missing baryons/dark matter.
  - Trace supernovae explosions and magnetic fields
  - At source
  - In galaxy(ies)
  - UHECR extragalactic
  - Source?
    - AGNs?
    - GRBs?
    - Why isotropy?
    - Other (topological defect, etc.)
  - Talks Friday



Neutrinos

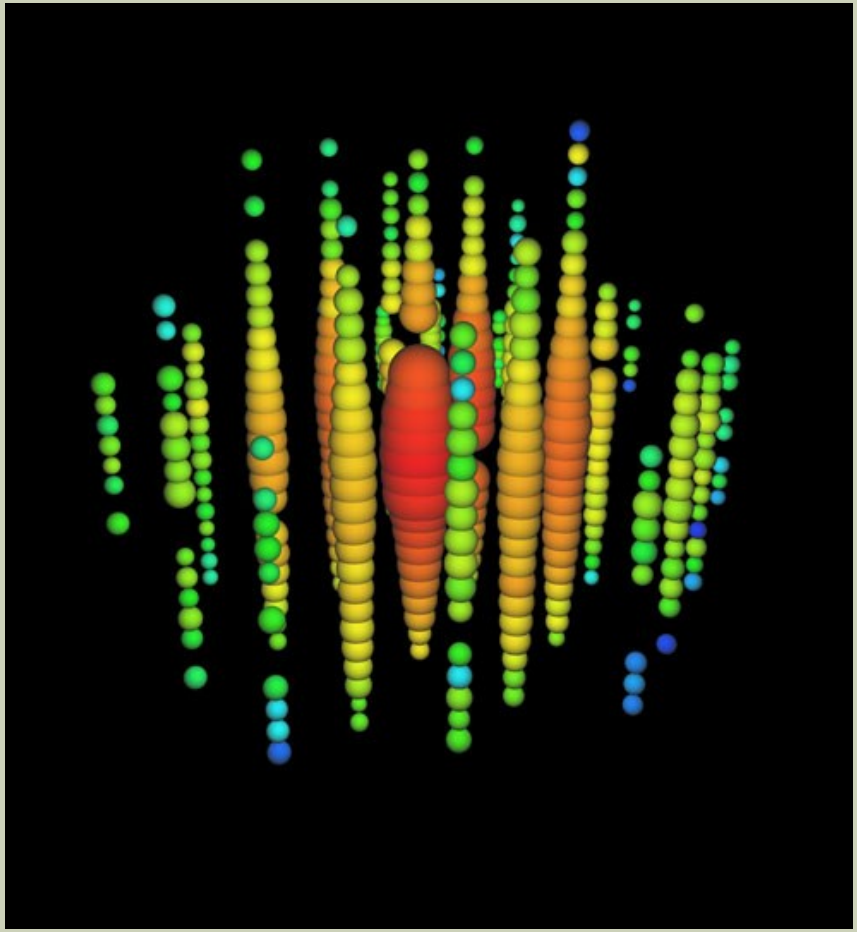
- Neutrino astrophysics has already started
  - The Sun
  - SN 1987A
  - Probably the first (and only) « multimessenger » observation
  - Important results drawn
  - Neutrino oscillations
  - Supernovae models
  - Upper bonds on neutrino mass, charge, etc.





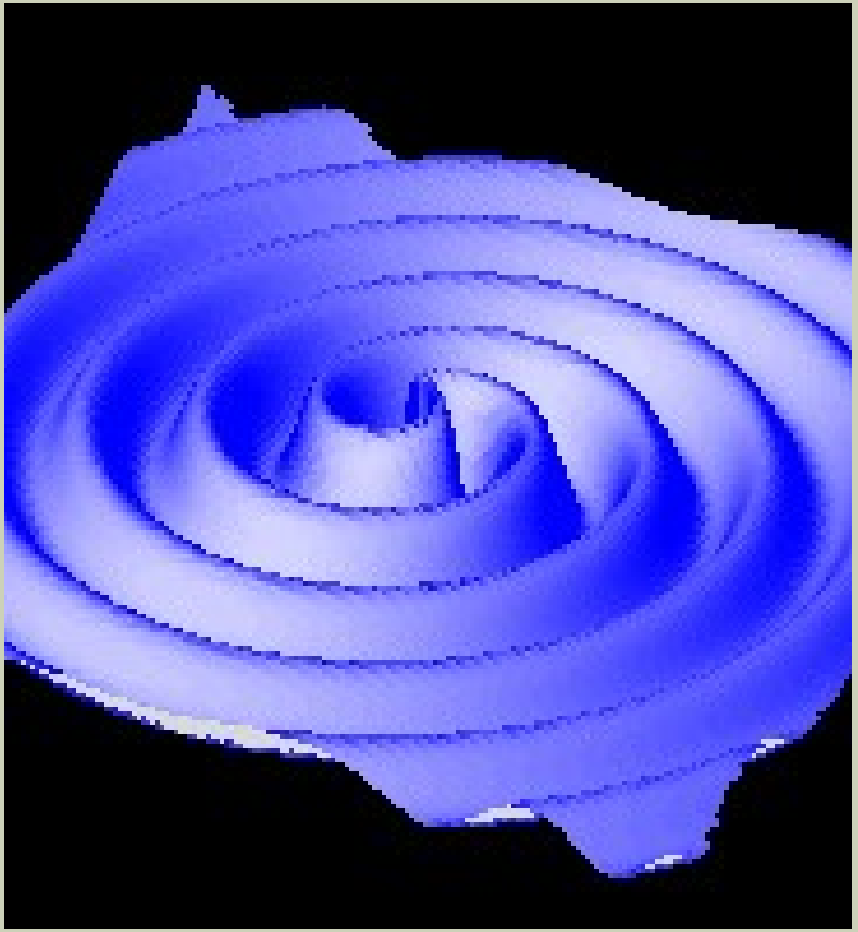
High energy neutrinos

- Detected! (The IceCube coll. 2012)
- 30 – 1200TeV
  - Photopion production from particle accelerated at UH energies (Fermi acceleration)
  - Origin: AGN?
  - GRB (no simultaneous detection)?
  - SN remnants?
  - Talks Thursday
- IceCube and ANTARES have been linked to automated telescope experiments (no positive results so far despite many observations with TAROT)
- Perspectives:
  - upgrade of IceCube
  - Km3NET



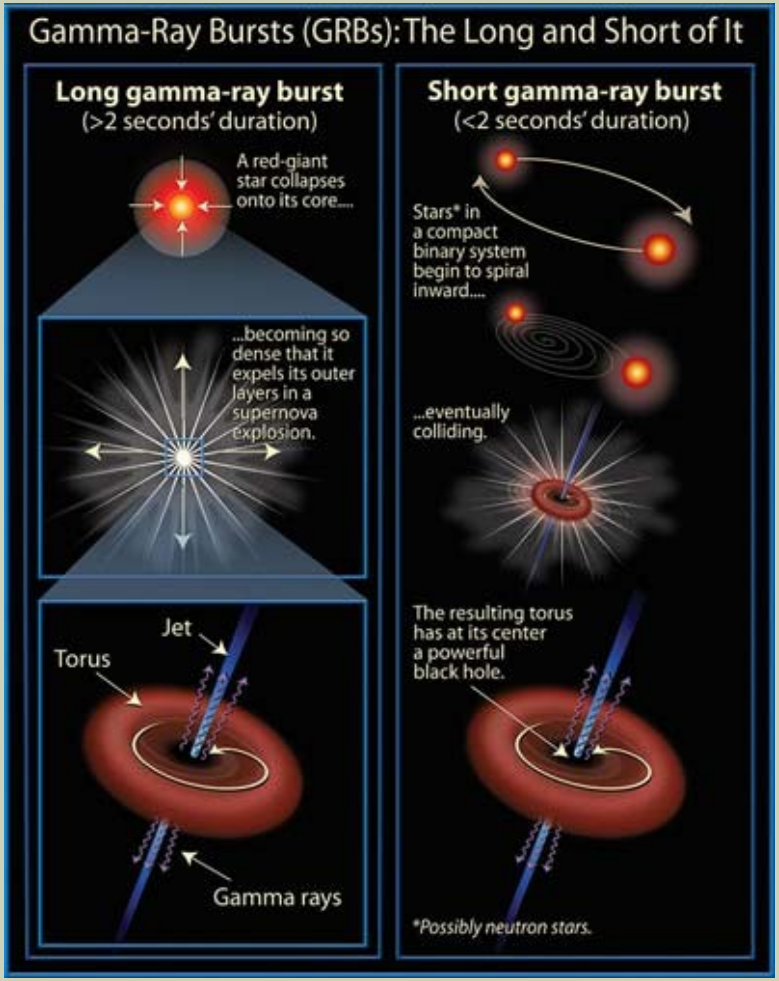
Gravitational waves

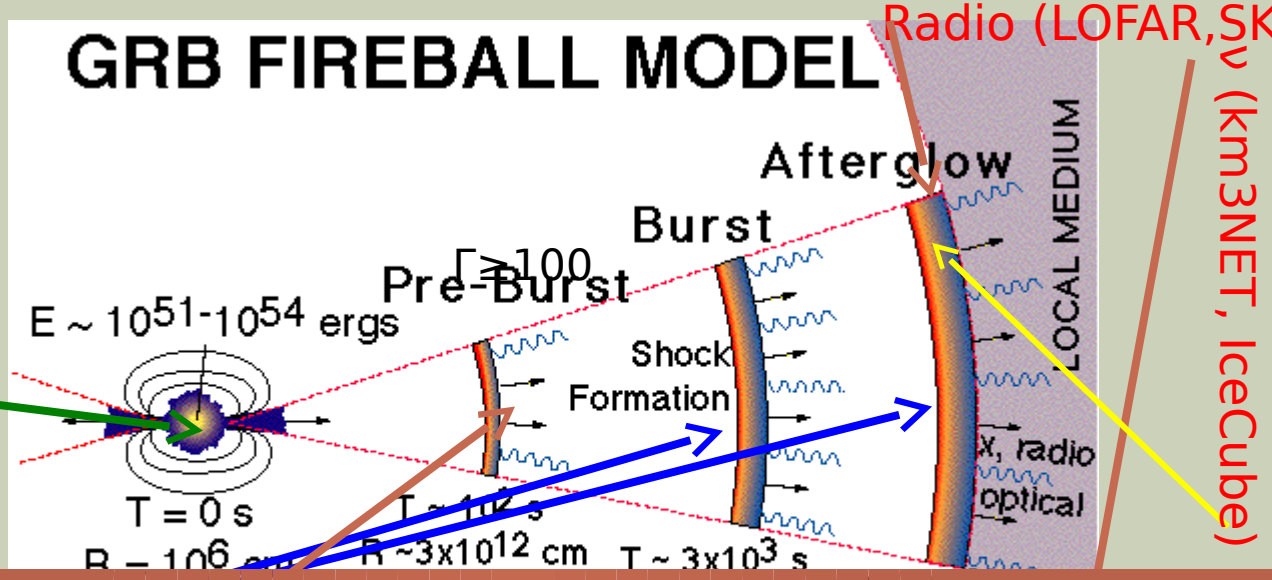
- Strong prediction of the General Relativity, and indirect evidence
- Best chance in the short term
  - Advanced LIGO
  - Advanced Virgo
  - Detection in 2016/17?
  - Then KAGRA and INDIGO
  - « Gravitational » mission selected by ESA as L3 in 2034! (eLISA)
  - Talks Monday



Multimessenger astronomy with GW

- NSNS/NSBH coalescence
- Produces strong GW emission (transient)
- "Standard" model for short GRBs
  - Association needs to be proven
  - Multimessenger campaign
  - Already done during S3 and S6 runs of LIGO/Virgo with no results (no GW detection)
  - However, even for AdV/ALIGO, expected common detection rate low (< 1 event/year)
- What can we learn from EM/GW
  - Evolution of massive stars
  - Cosmological parameters (future, from different dependence in distance)
  - Equation of state of matter
  - What is the residual of a NSNS coalescence BH or magnetar?
  - Etc.
- Other sources
  - BHBH
  - CC SN?





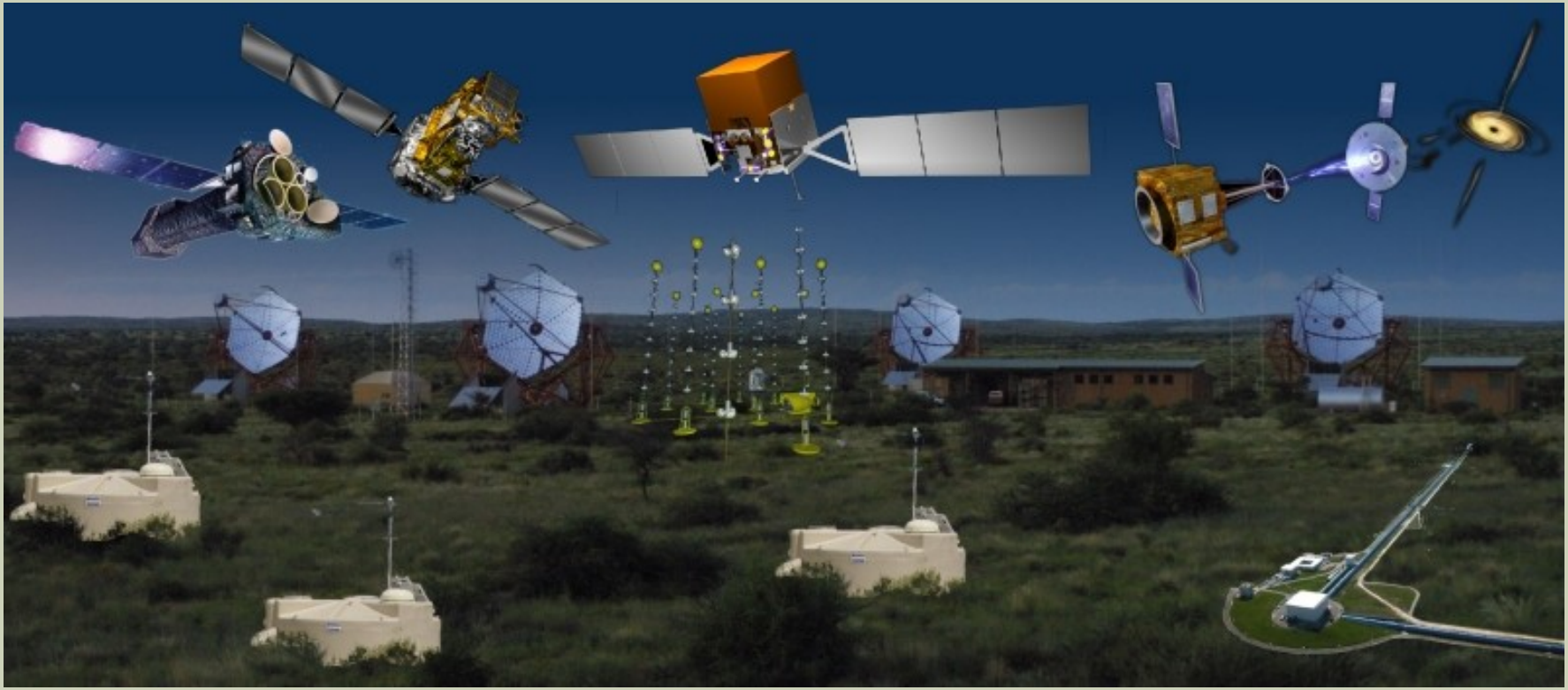
GW: AIGO, VIRGO, LIGO

Radio (LOFAR,SKA/ASKAP

ν (km3NET, IceCube)

GRB are interesting sources
cause both styles (short/lo
are thought to produce
oton, UHECR, neutrinos, G

Multimessenger astronomy: HOW?



The difficulty of multimessenger astronomy

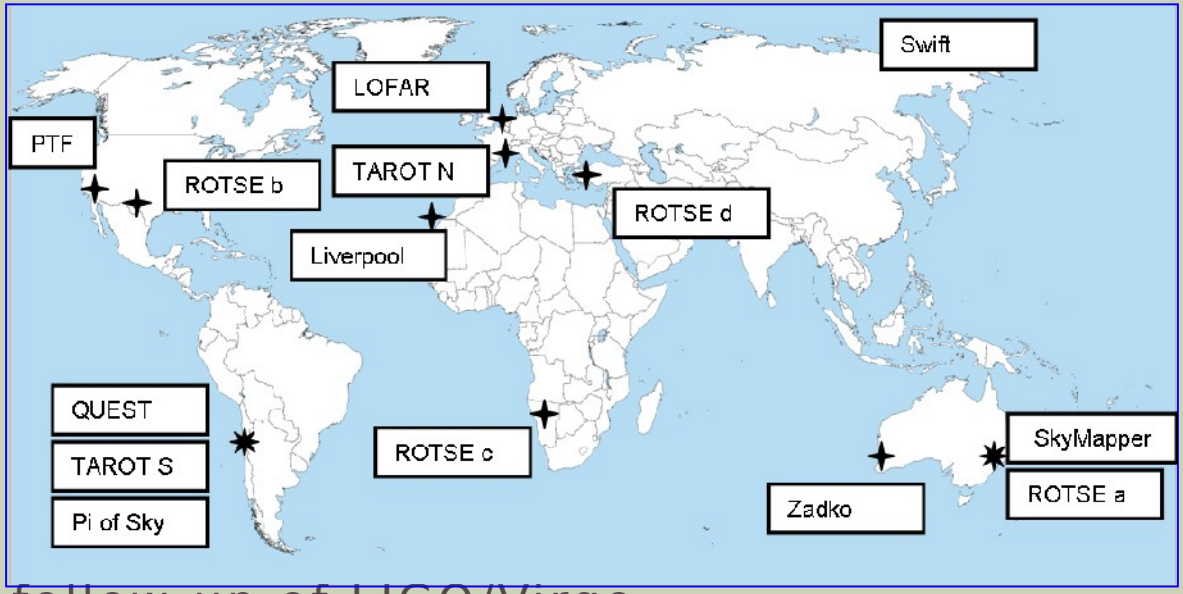
Electromagnetic

- Many detectors
- From radio to HE ϒ-rays
- Spectrum, polarimetry…
- Resolution: mas to >degree
- Field of view: arcsec to degrees (and more)
- Time to slew: s to h
- Time res.: ms to min
- Duty cycle: 10% visible, more for radio

Non electromagnetic

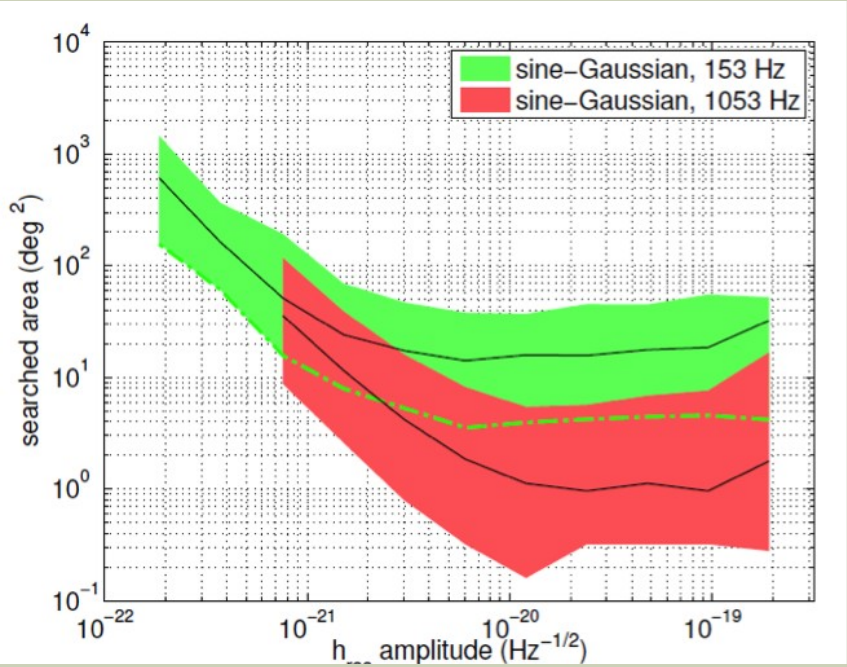
- Few instruments
- 3 particle types
- Alert time: > 10min to days
- Resolution: degrees to many degrees
- Respective temporal scale???
  - Long GRBs: neutrinos delayed? (like GeV emission)
  - Short GRBs: GW before EM

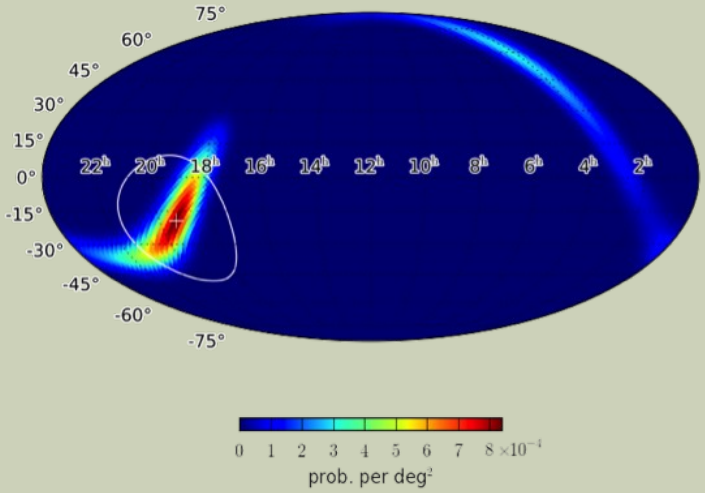
Some instruments



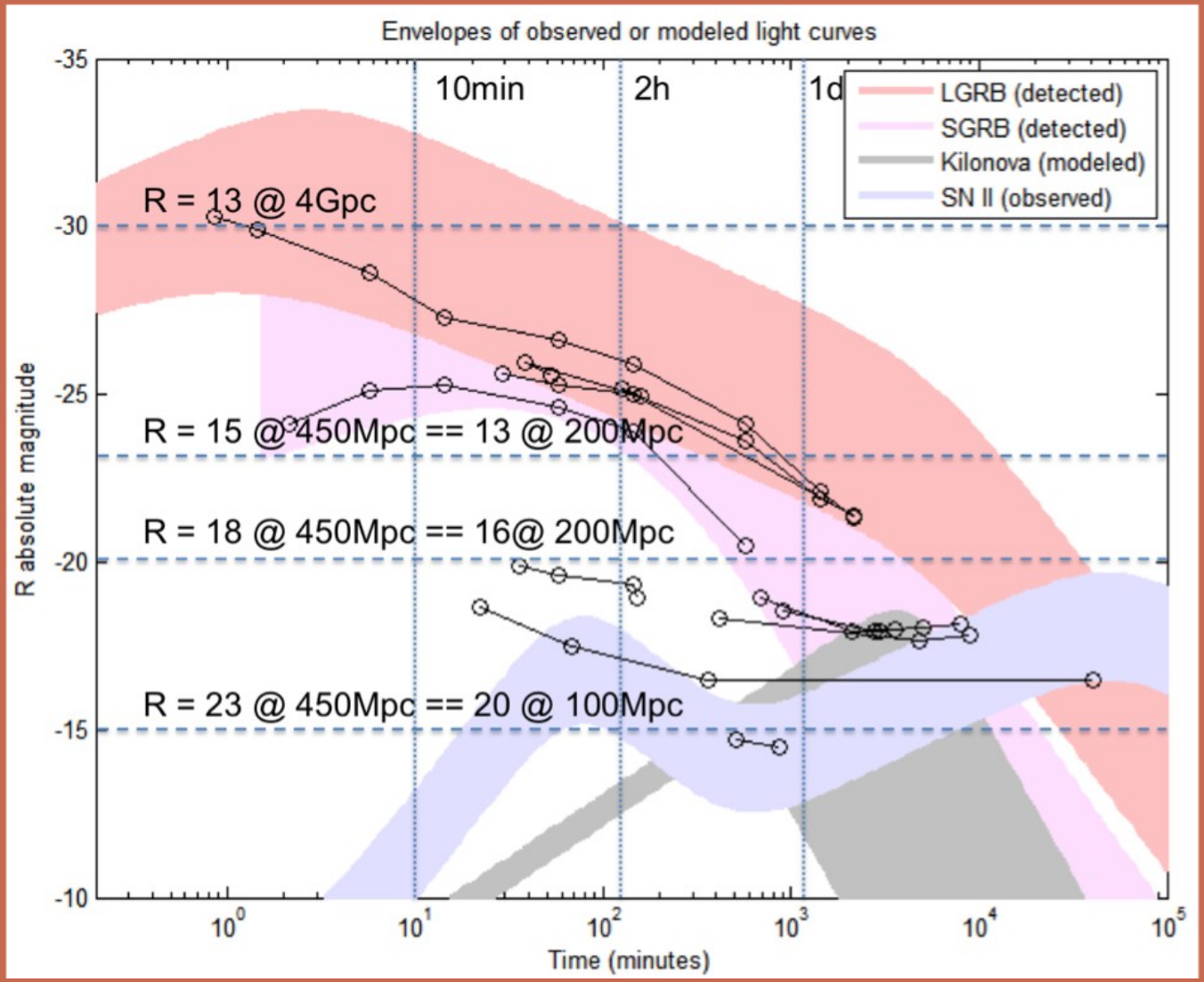
- Used for follow-up of LIGO/Virgo
- Robotic instruments are flexible and often large fov
- Some projects, like ORMES, BlackGEM designed for GW

The error box size problem





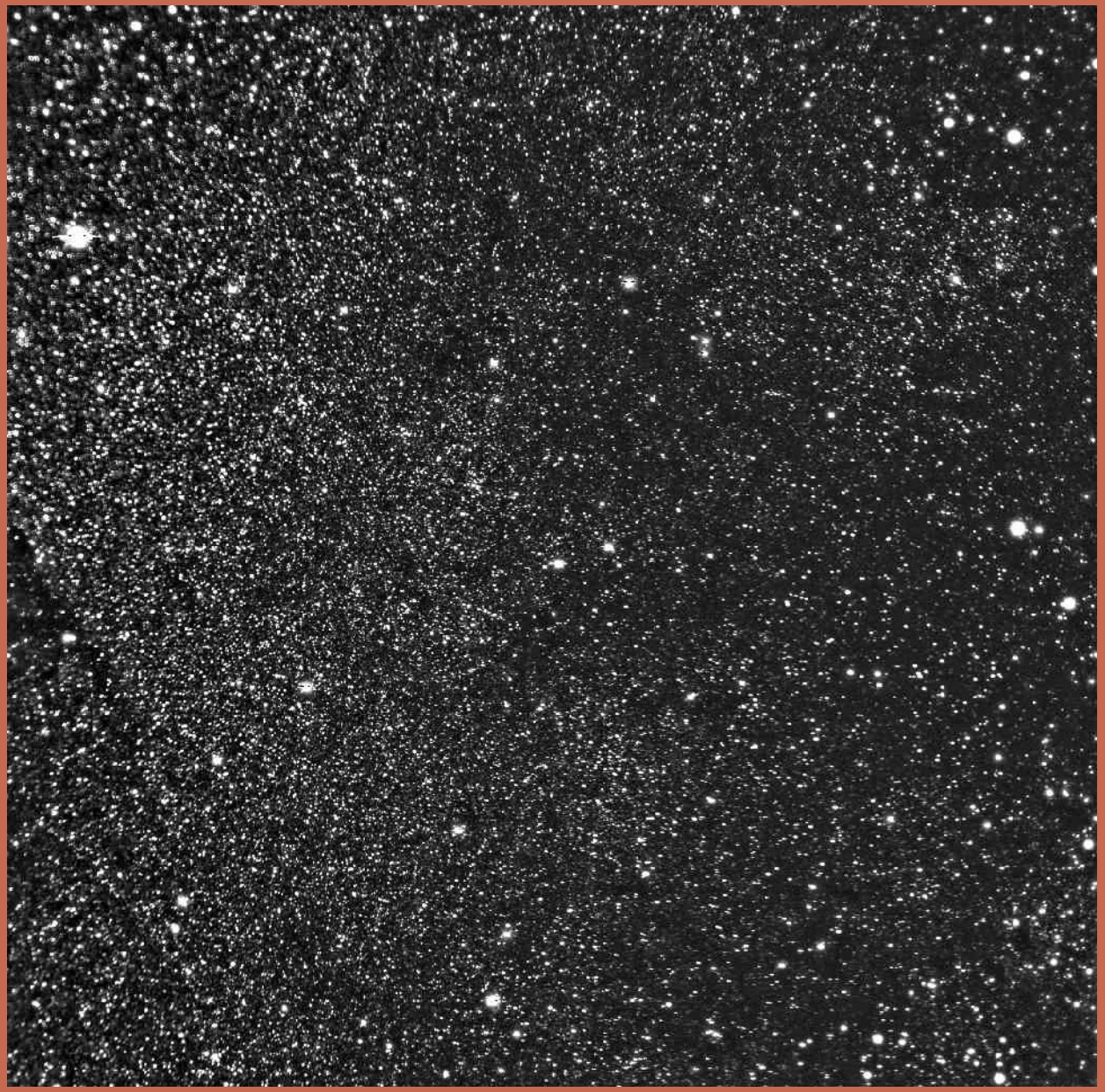
The sensitivity problem



Enveloppe of sGRB and lGRB, SNII light curves, kilonova model added

Data and models adapted from

Kann et al., 2010, Tanvir et al. 2013, Berger et al. 2013



The Where is my needle problem?

This TAROT image of GRB 050904A is only 5 x 5 arcmin (out of 2°x 2° for TAROT)

zPTF will be 47sq. Deg.

ORMES will be 100 sq. deg.

Also I see nothing, or nothing specific

Despite difficulties several trials

- Efforts started with small sized telescopes for GRBs
  - ROTSE, TAROT, RAPTOR, ISON, REM…
- Then medium large with adapted and/or designed instruments
  - Liverpool, GROND, VLT X-shooter, LOFAR, CTA, Zadko…
  - Use more TOO program with XMM, HST, and other large ground/space facilities
- New generation experiments
  - Larger
  - Faster
  - Wide fov
  - zPTF
  - ORMES, BlackGEM

- Rapid reaction is crucial
  - Transient phenomena
  - Luminous when caught early
  - Favours robotic telescopes
  - We are talking of seconds, not minutes
  - A 25cm telescope (TAROT) was able to catch a source at z = 6.25
- Building a permanent link between “alert” provider and its customer is crucial
  - GCN-BACODINE
  - VO-transient
  - Low latency for LVC
  - TAToO for ANTARES/TAROT
- Public (or semi-public) data is crucial
  - Get positions in time
  - Counter-example: FRB, no source follow-up, are they real?
  - Wide dissemination for LVC through MOU (60 signed)
  - Don’t sit on your fresh data, it will expire soon

Raoul Dufy: Interior with open windows

Artists precede scientists

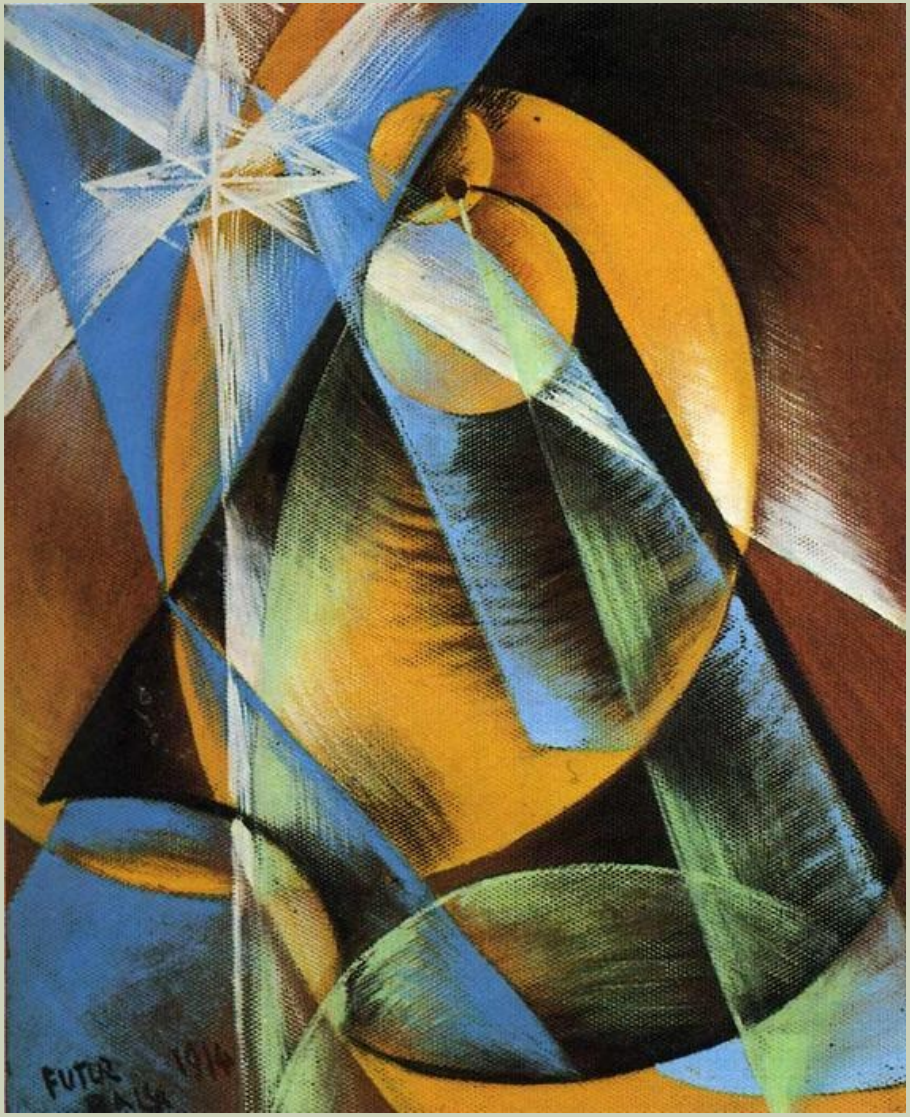
Each window gives a different aspect of the « baie des anges »; together, they give a full view of the Riviera, and of the context of the painting (observer)

Each « messenger » provides a different approach

Conclusions

- Multimessenger astronomy is an extension of panchromatic astronomy
  - Consistent observations of astrophysical phenomena and/or sources
  - Photons at all wavelengths and neutrinos/(UHE)CR/GW
  - Usually transient phenomena (can be of different scales)
- Sources
  - AGN: jets, dynamics of central black hole
  - SN: central source, neutrinos from CRs
  - sGRBs: swinging masses, jets
  - lGRBs: jets, acceleration of CR -> neutrinos
  - Stochastic background, Big Bang…
- Information
  - Direct information on masses at play (e.g. masses of NS)
  - Full dynamics of system
  - Quantum gravity (in the future)
- Difficulties
  - Avalanche of data
  - Fov, sensitivity, timing association of source in different “particle” observation
  - Need probably dedicated (or at least built from requirements) robotic observatories
- But success of joint observations with LIGO/Virgo and ANTARES give confidence
  - Lot of answers from call from LVC: LOFAR, ASKAP, CTA, optical (many), XMM…
- Multimessenger astronomy has already started with neutrinos, it will explode before the end of the decade

Salon de Mercure (Versailles ca 1682;
Jean-Baptiste de Champaigne)



Planet Mercure passing in front of the
Sun (Giacomo Balla, 1914)