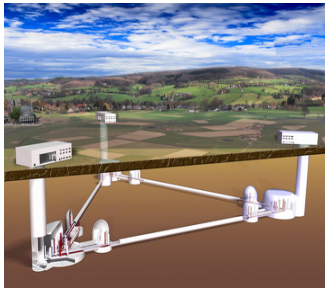
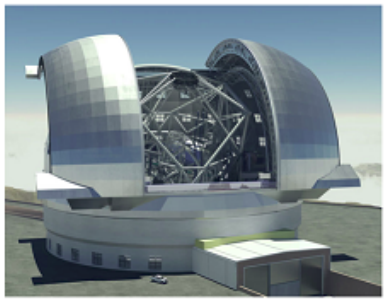
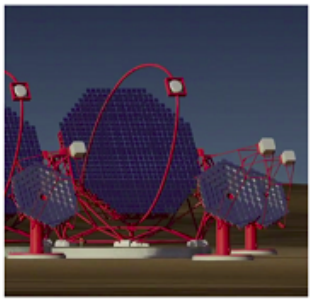
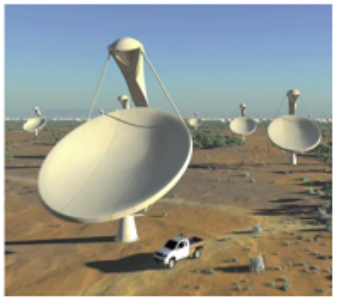
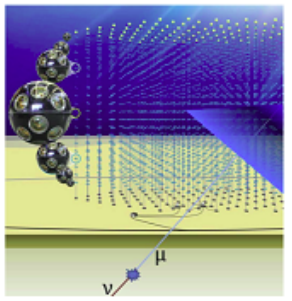
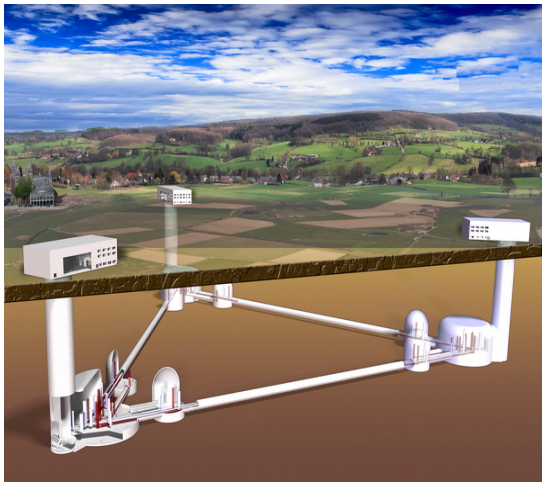







Statistical methods for multimessenger astrophysics with gravitational waves

Eric Chassande-Mottin

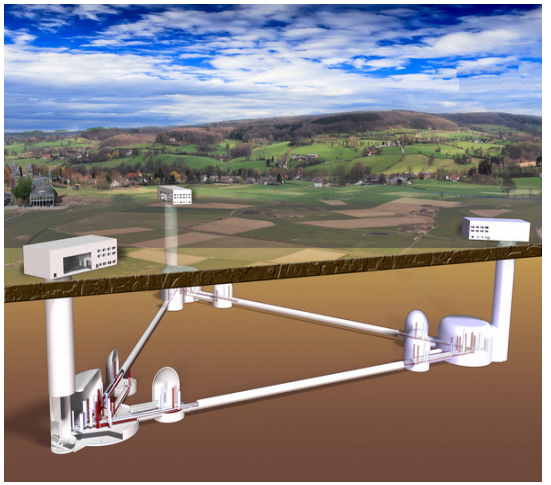
CNRS AstroParticule et Cosmologie
Université Paris Denis Diderot

Obelics face-to-face
Jan 26 2016, Rome, Italy


Context: detection of gravitational waves

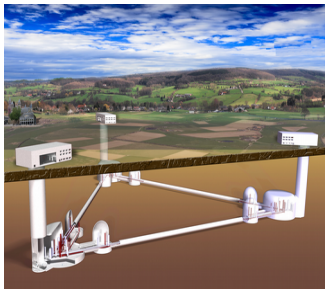
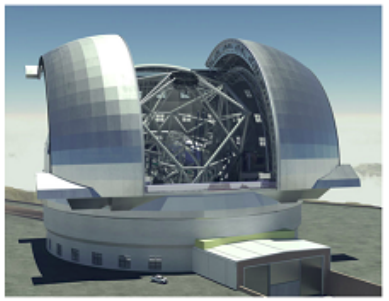
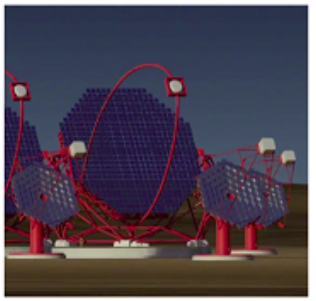
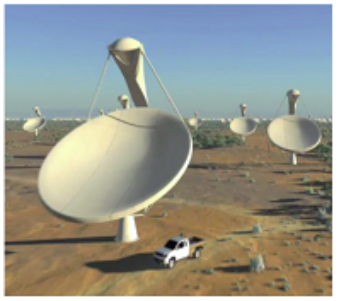
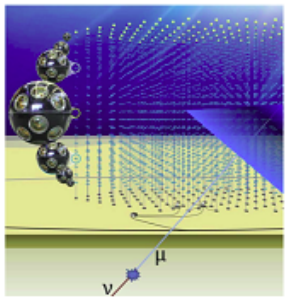
- **Gravitational waves**
  - Predicted by Einstein's General Relativity
  - Propagating distorsions of space-time
  - Generated by cataclysmic events involving massive, compact astrophysical objects (black hole, neutron star)
- **Develop a new astronomy based on GW**
  - Complementary to photons: “multi-messenger”


GW detectors and related institutions

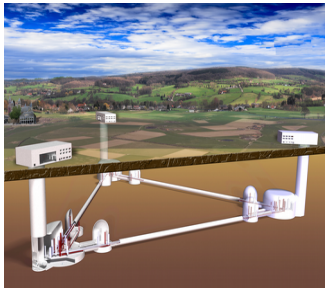
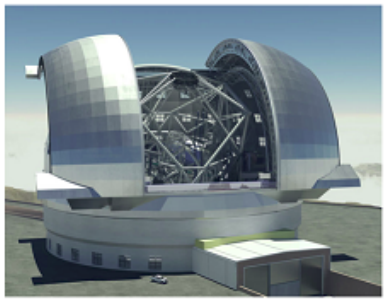
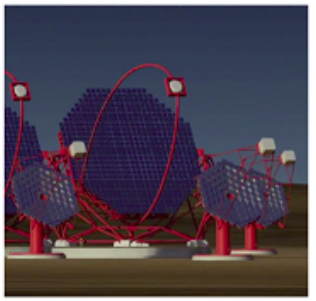
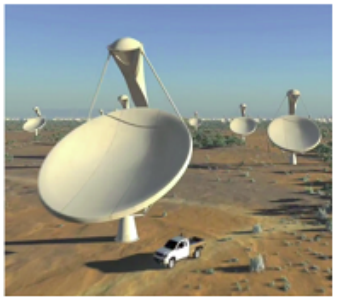
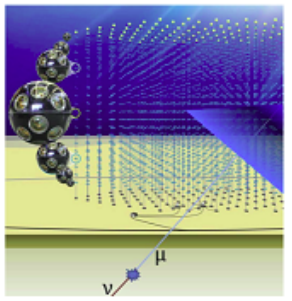
Km-scale Michelson type interferometers – high-precision metrology

- **Einstein Telescope** (3rd generation detector)
  - ✔ FP7 design study (2011).
    - ASPERA roadmap. **Candidate ESFRI**
- **Advanced Virgo "pathfinder"** (2nd generation)
- **European Gravitational Observatory, EGO**
  - CNRS-INFN consortium with other partners
  - Manages Virgo site (Italy) and hosts ET coordination

Advanced Virgo – status

- Initial Virgo (1st generation) operated between 2007-2012
  - Data sharing and joint analysis with US based LIGO
- Upgrading: **x 10 sensitivity** → x 1000 in the event rate
  - Observability horizon for binary neutron stars : 140 Mpc
  - Current BNS event rate estimates: few to tenth events/yr
- **First science data from advanced detectors**
  - Advanced LIGO 1st science run, sep 2015 – jan 2016
  - Advanced Virgo will take data jointly with aLIGO this year
- Opportunities for **multimessenger astrophysics**
  - Search for electromagnetic counterpart (i.e., GRB afterglow ...)
  - Extensive **electromagnetic follow-up program** inc. LOFAR, HESS, CTA, …

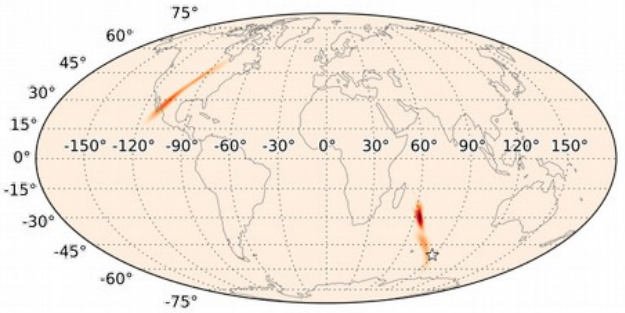







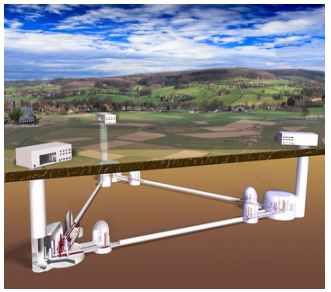
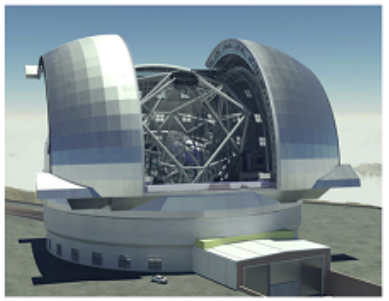
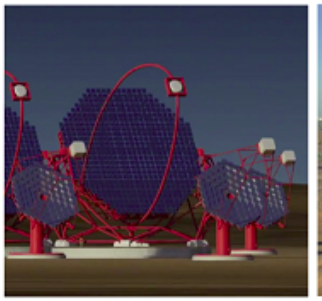
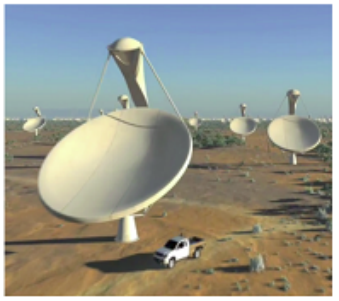
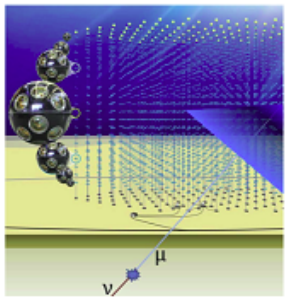
Significance of a GW-EM association

- An electromagnetic **counterpart** to a GW event can help to **increase our confidence** in the astrophysical nature of this event
- Sky location of GW source is **not well reconstructed**

  Typ. few 100 sq degrees observed with 2 detectors, or ~100 sq degrees with 3 detectors

  Larger for marginally significant events (μ $1/SNR^2$)
- Large sky area → Probability of a **false association is not negligeable**
- Requires a statistical procedure

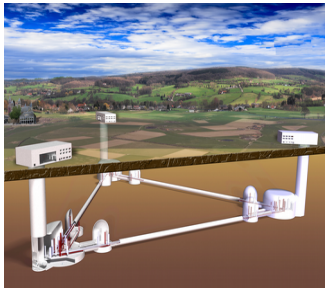
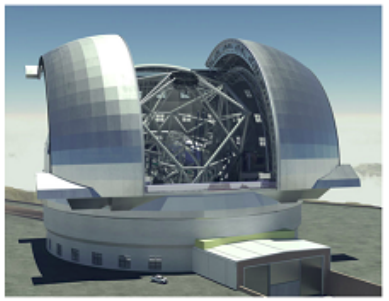
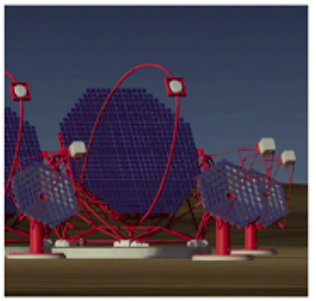
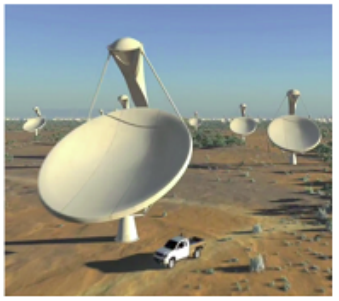
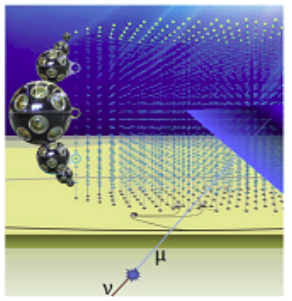


Ideas for GW-EM association statistical assessment

- Analyze data jointly – Define **joint GW-EM likelihood**
  - Different observables (cannot form images with GW)
  - Function of the characteristics of the GW and EM transients (luminosity, duration)
  - Measures the **overlap in direction** between GW and EM transients
- Estimate **joint background** from archival data
  - From random associations of simulated GW triggers and spurious EM transients (e.g., cosmic rays, ...)
- Deduce p-value for an observed association
  - How likely is this coincidence to be forfituous?

Bouhou et al, 2013. Evans et al. ApJS, 203, 28 (2012) and arXiv:1303.2174

Work plan – To be finalized

- Implementation of a joint GW-EM analysis scheme
  - ✔ Perform custom selection cuts to extract marginal sub 5-σ GW and EM events
- Test using real observations
  - ✔ Recent aLIGO data & INTEGRAL (ACS)

    Benchmark for GW/High-energy observation
- Questions to be answered
  - ✔ Provide quantitative assessment of a joint observation
  - ✔ Can two ~3-σ events be combined into one 5-σ ?