Cleopatra

Connecting Locations of ESFRI Observatories and Partners in Astronomy for Timing and Real-time Alerts

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Joint Institute for VLBI ERIC (JIVE)

On behalf of the Cleopatra collaboration

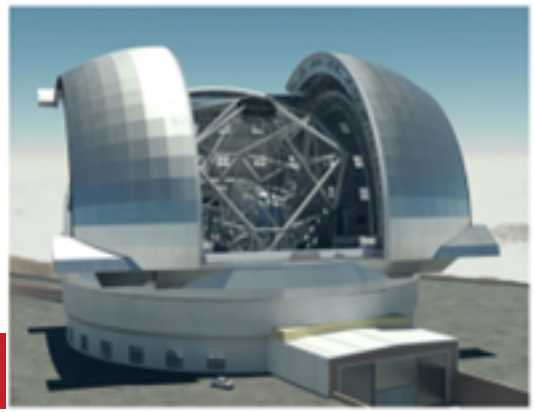
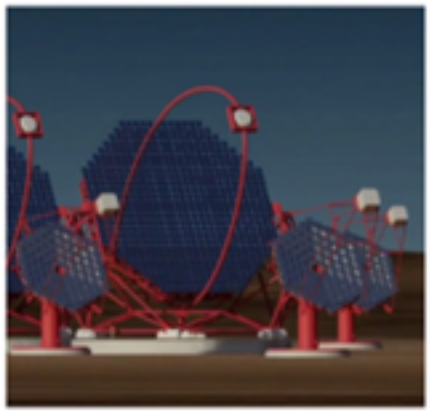
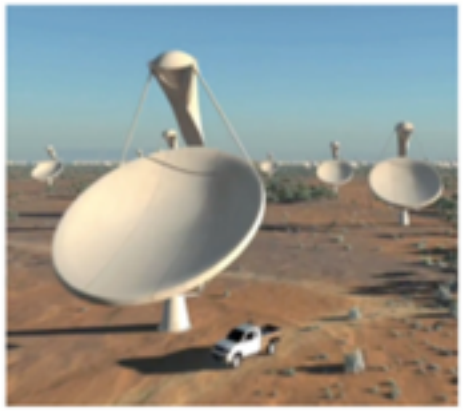
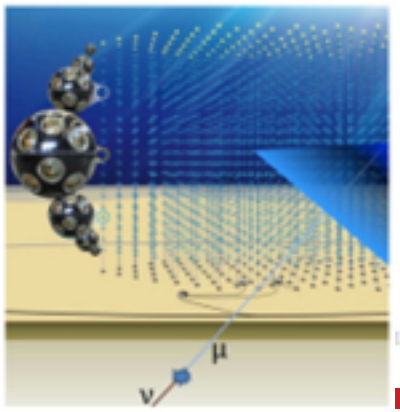
Astronomy ESFRI & Research Infrastructure Cluster

What is ASTERICS?

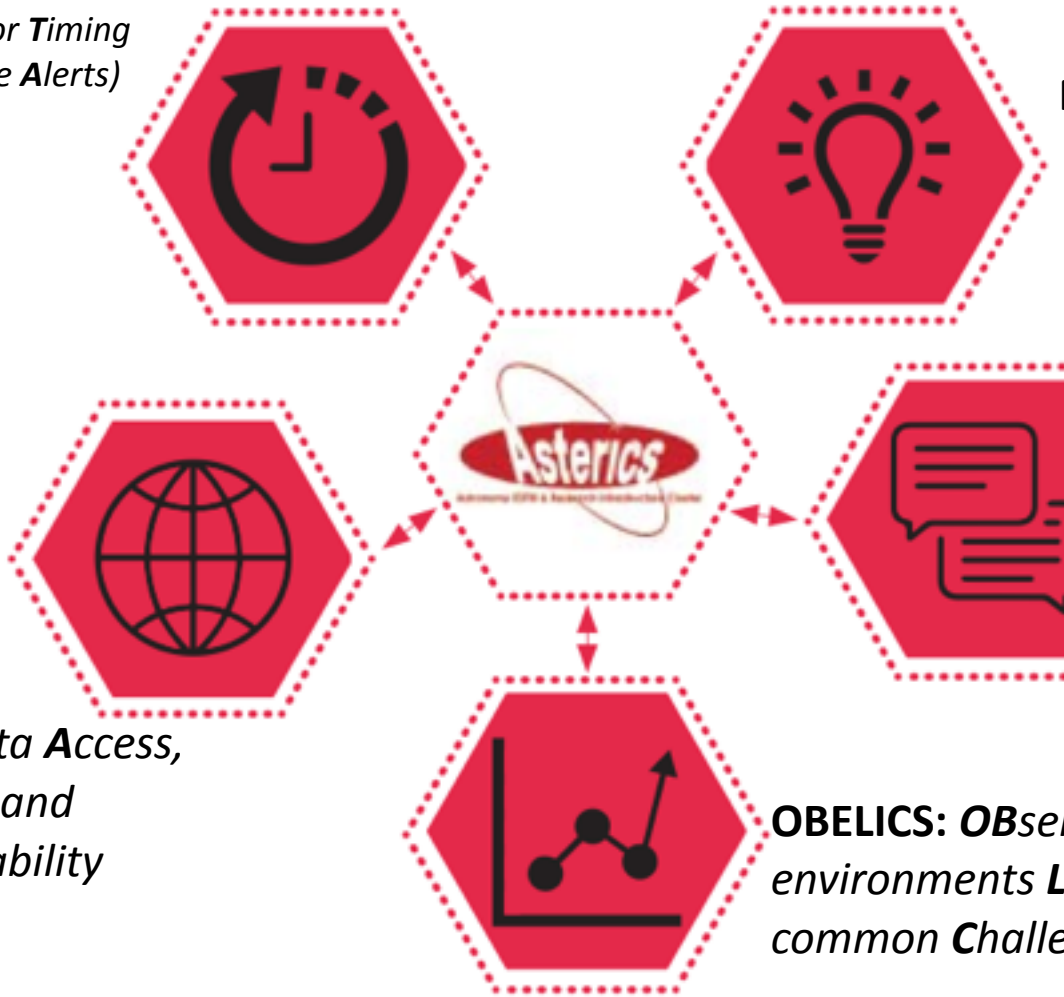
- A €15 million Research Infrastructure funded by EC Horizon 2020 framework *(2015-2019)*
  - To help solve the **Big Data** challenges of European astronomy
  - To provide **direct interactive access** to the best European astronomy data in an international framework
  - Address **common challenges** in astronomy and astroparticle physics
  - *Cross-cutting synergies and common challenges*

Partners

- Supporting the European Strategy Forum on Research Infrastructures (ESFRI)
- Aspiring ESFRI projects + pathfinders
- Other world-class research infrastructures
  - e.g. LOFAR, Euclid, LSST, Virgo, EVN

CLEOPATRA: ***C****onnecting* ***L****ocations of* ***E****SFRI* ***O****bservatories and* ***P****artners in* ***A****stronomy for* ***T****iming and* ***R****eal time* ***A****lerts)*



Management

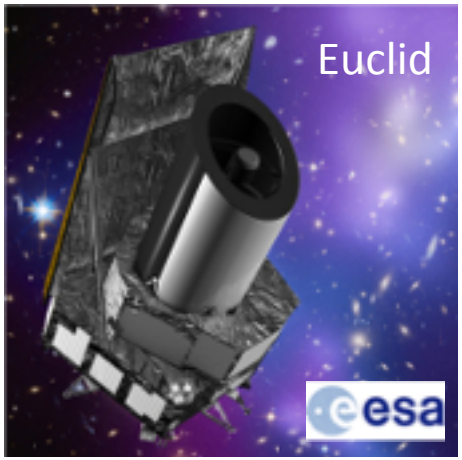
DECS: ***D****isseminaton,* ***E****ngagement and* ***C****itizen* ***S****cience*

DADI : ***D****ata* ***A****ccess,* ***D****iscovery and* ***I****nteroperability*

OBELICS: ***OB****servatory* ***E****-environments* ***LI****nked by common* ***C****hallenge****S***

WP5: Cleopatra

- Connecting real facilities now as path to connected future facilities



- ~2.5 M€, 4 tasks

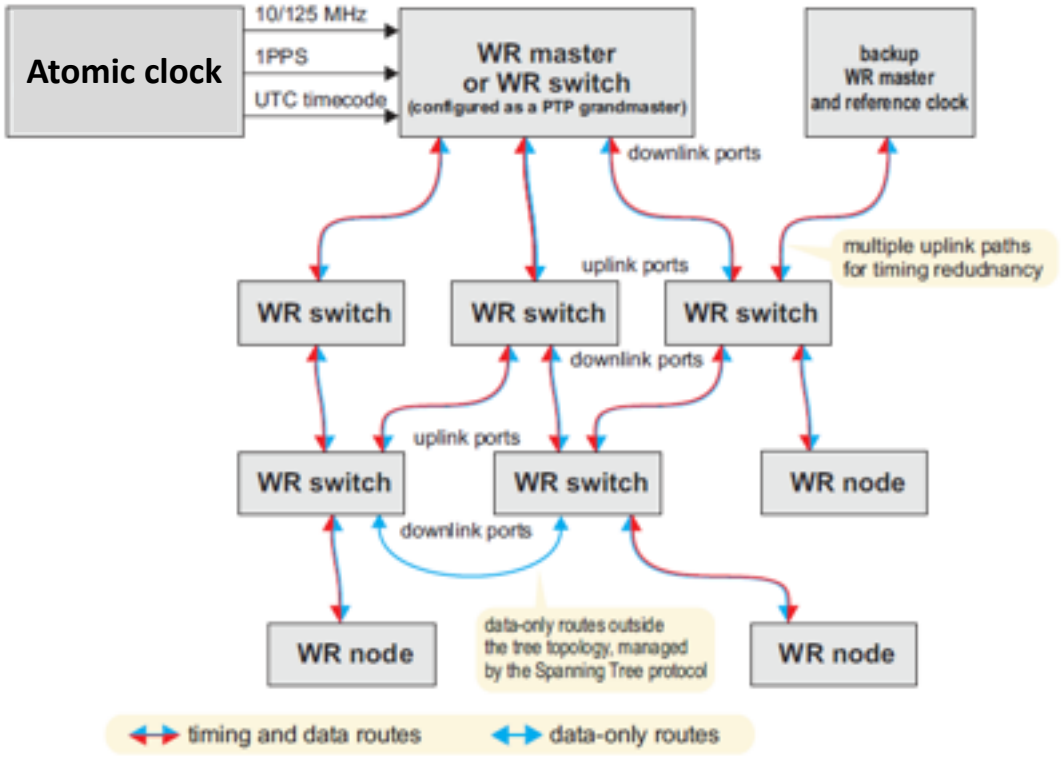
Task 1: Synchronization

VU, ASTRON, JIVE, UGR, FOM, DESY, SURFnet (Koelemeij, Berge)

- **Time and frequency transfer on optical fiber networks** through White Rabbit Ethernet (WRE)

What is White Rabbit?

- *White Rabbit* Ethernet (CERN, based on IEEE Precision Time Protocol)



- Time, frequency, and 1 Gb/s data in one
- 1 PPS, 10 – 125 MHz
- Designed for 1 ns timing over distances <10 km (LHC, CERN)
- Commercially available

Task 1: Synchronization

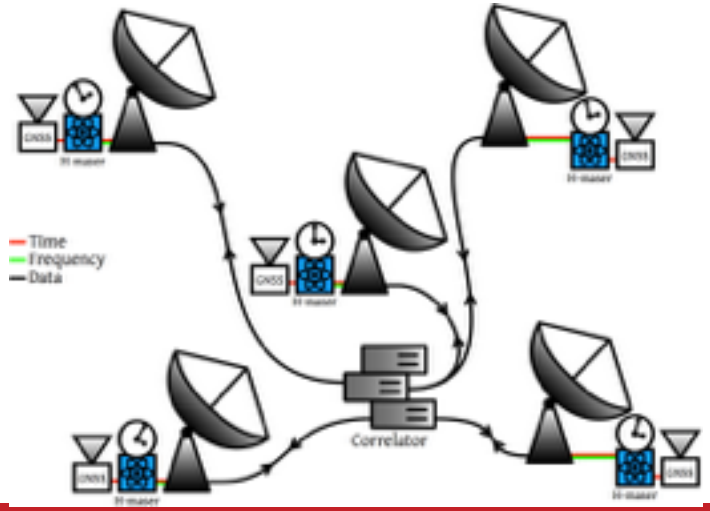
VU, ASTRON, JIVE, UGR, FOM, DESY, SURFnet (Koelemeij, Berge)

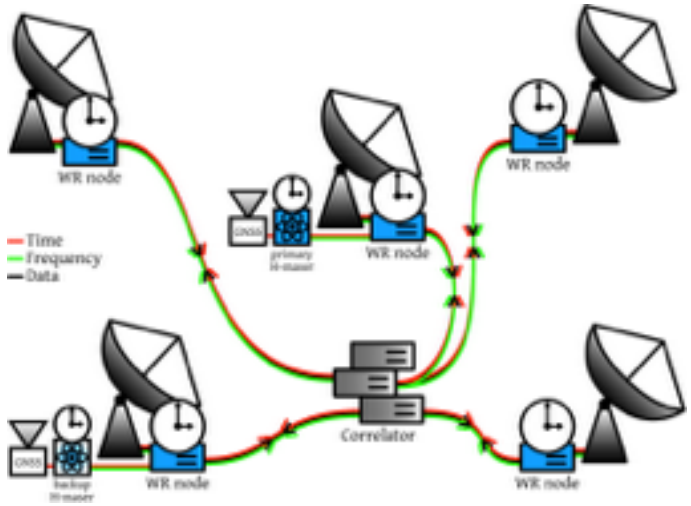
- **Time and frequency transfer on optical fiber networks** through White Rabbit Ethernet (WRE)

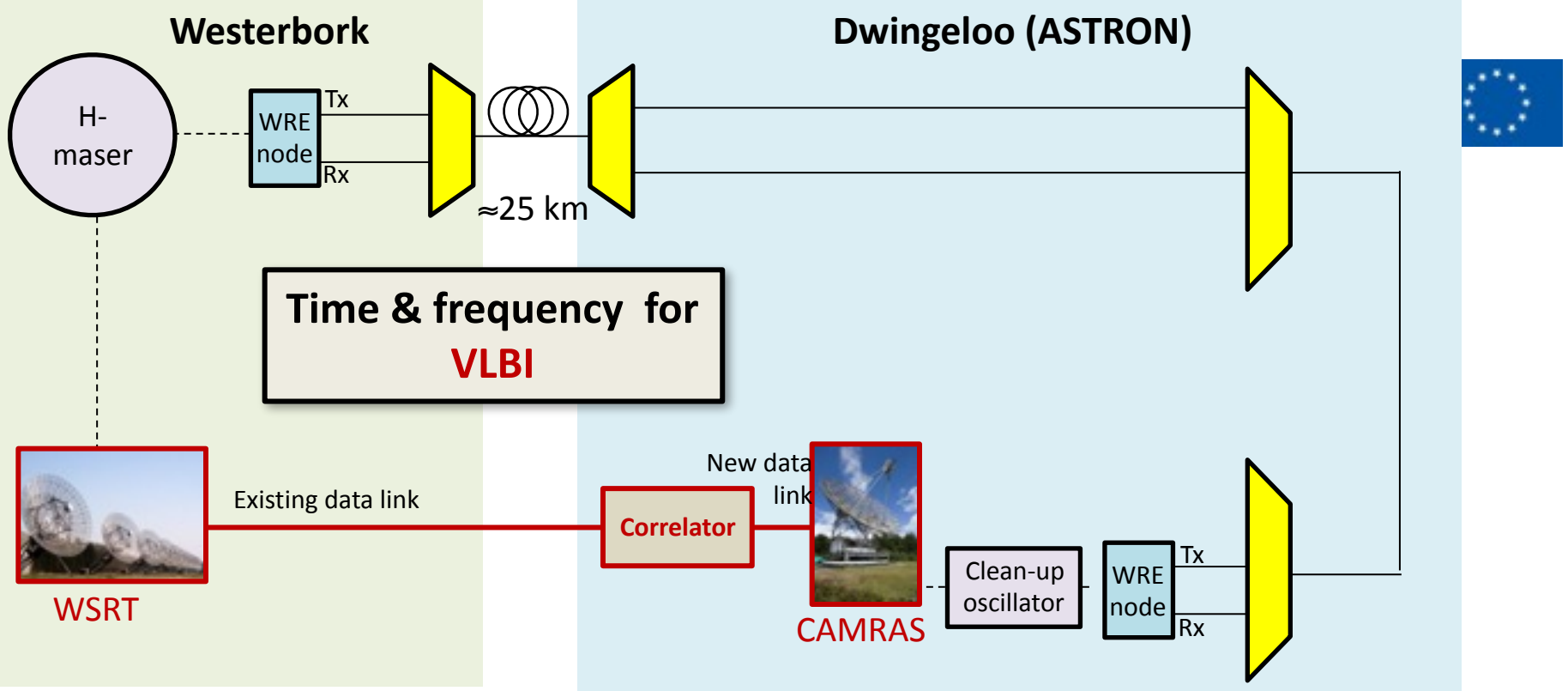
- **Alternative** to the intricate and custom-built timing solutions used in previous neutrino telescopes and radio telescope arrays
- Enable **highly synchronized real-time observations** by widely separated instruments, providing a unique "multi-messenger" view of astrophysical phenomena
- **Back-up or augment timing and navigation** through the Global Navigation Satellite Systems
  - Centimeter-level positioning for indoor navigation
  - Autonomous vehicles using hybrid optical/wireless networks

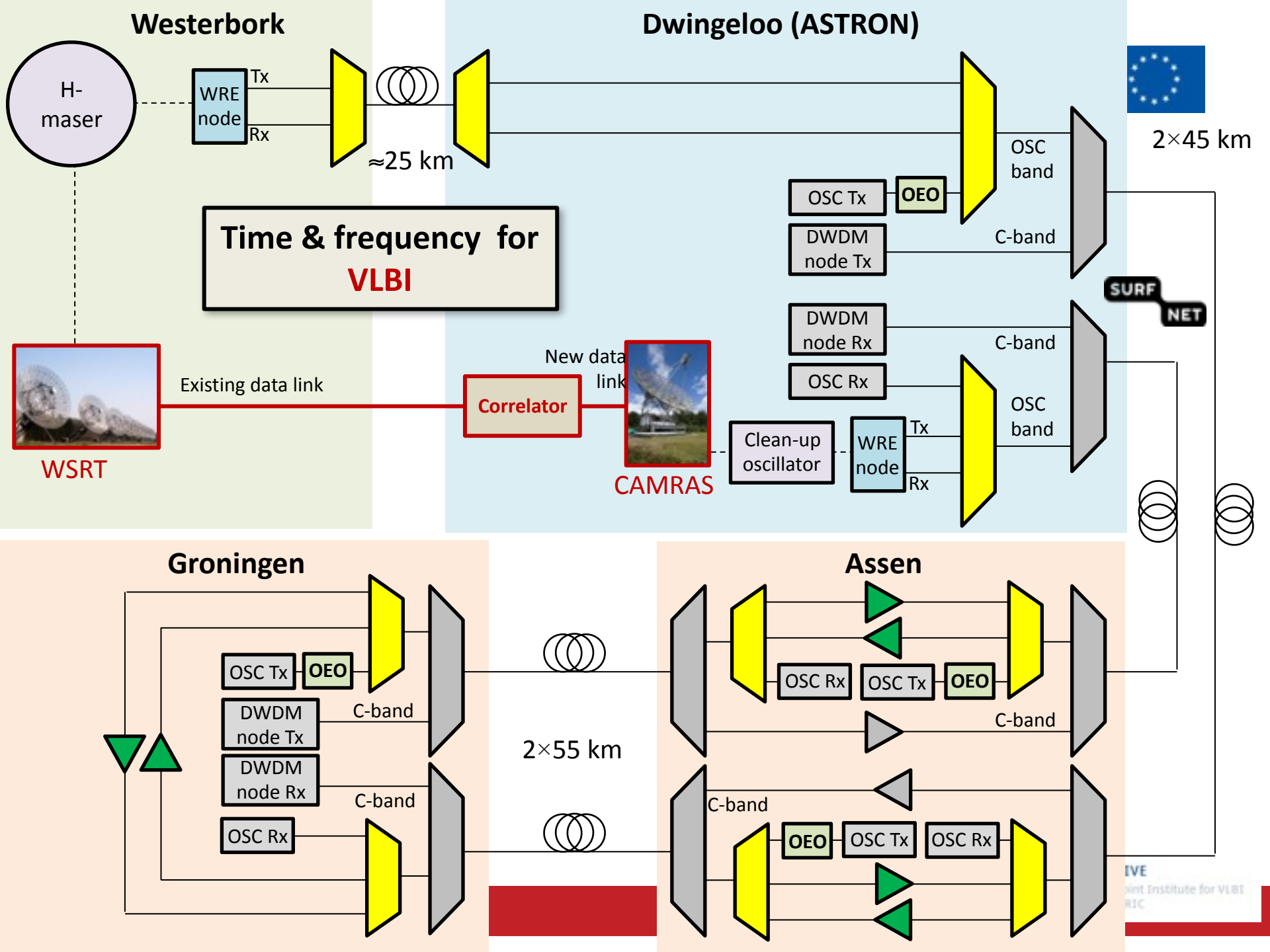
WRE and VLBI: a demo

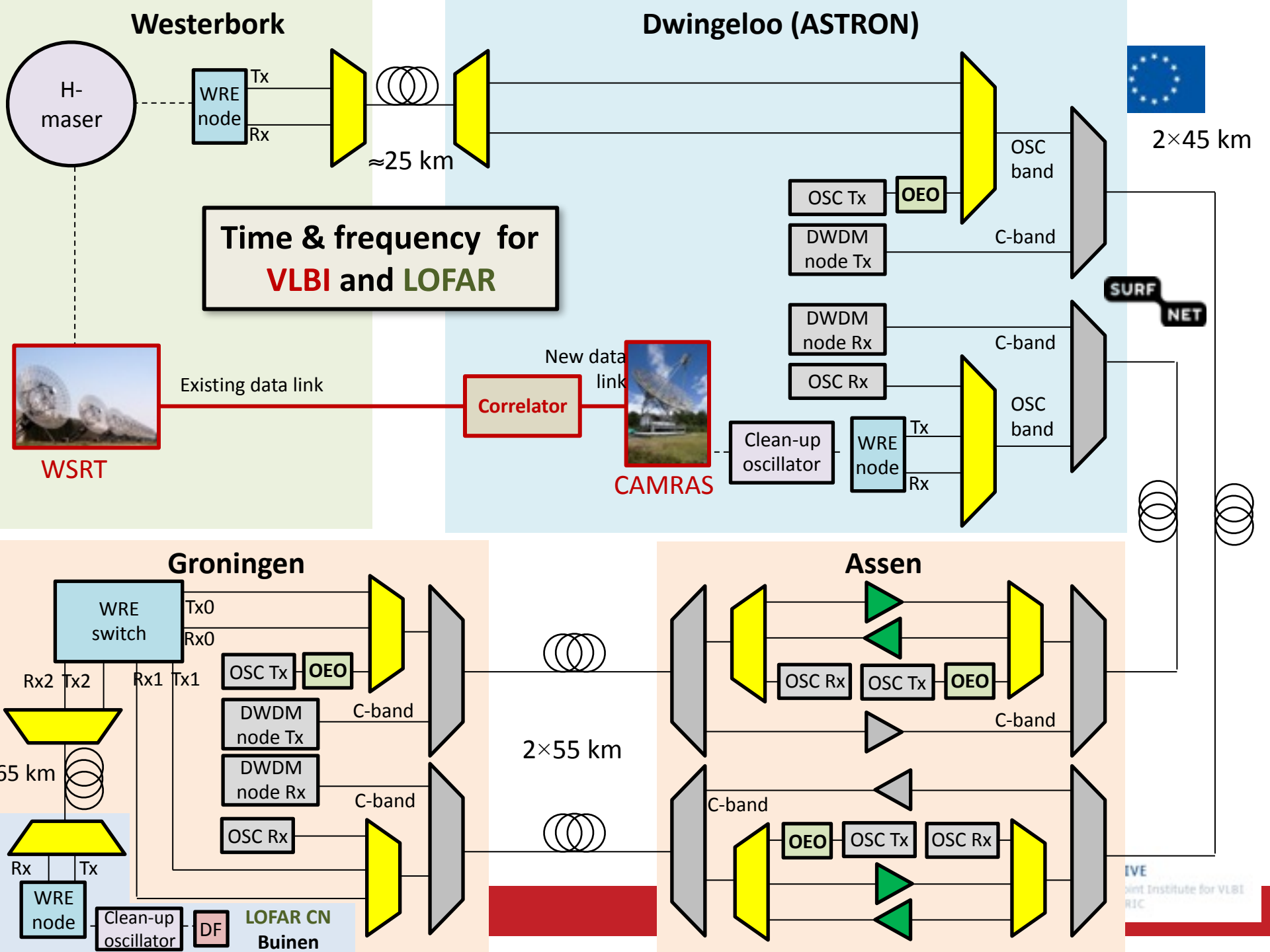
- Need **three orders** of magnitude improvement in frequency stability
- New calibration and characterization tools
- Bi-directional light paths on operational fiber-optic telecommunication networks






Westerbork
Dwingeloo (ASTRON)
H-
maser
WRE
node
Tx
Rx
≈25 km
Time & frequency for
VLBI
WSRT
Existing data link
Correlator
New data
link
CAMRAS
Clean-up
oscillator
WRE
node
Tx
Rx


Westerbork
Dwingeloo (ASTRON)
H-maser
WRE node
Tx
Rx
≈25 km
2×45 km
OSC band
OSC Tx
OEO
DWDM node Tx
C-band
Time & frequency for VLBI
SURF NET
DWDM node Rx
C-band
OSC Rx
OSC band
New data link
Existing data link
Correlator
Clean-up oscillator
WRE node
Tx
Rx
WSRT
CAMRAS
Groningen
Assen
OSC Tx
OEO
DWDM node Tx
C-band
DWDM node Rx
C-band
OSC Rx
2×55 km
OSC Rx
OSC Tx
OEO
C-band
C-band
OEO
OSC Tx
OSC Rx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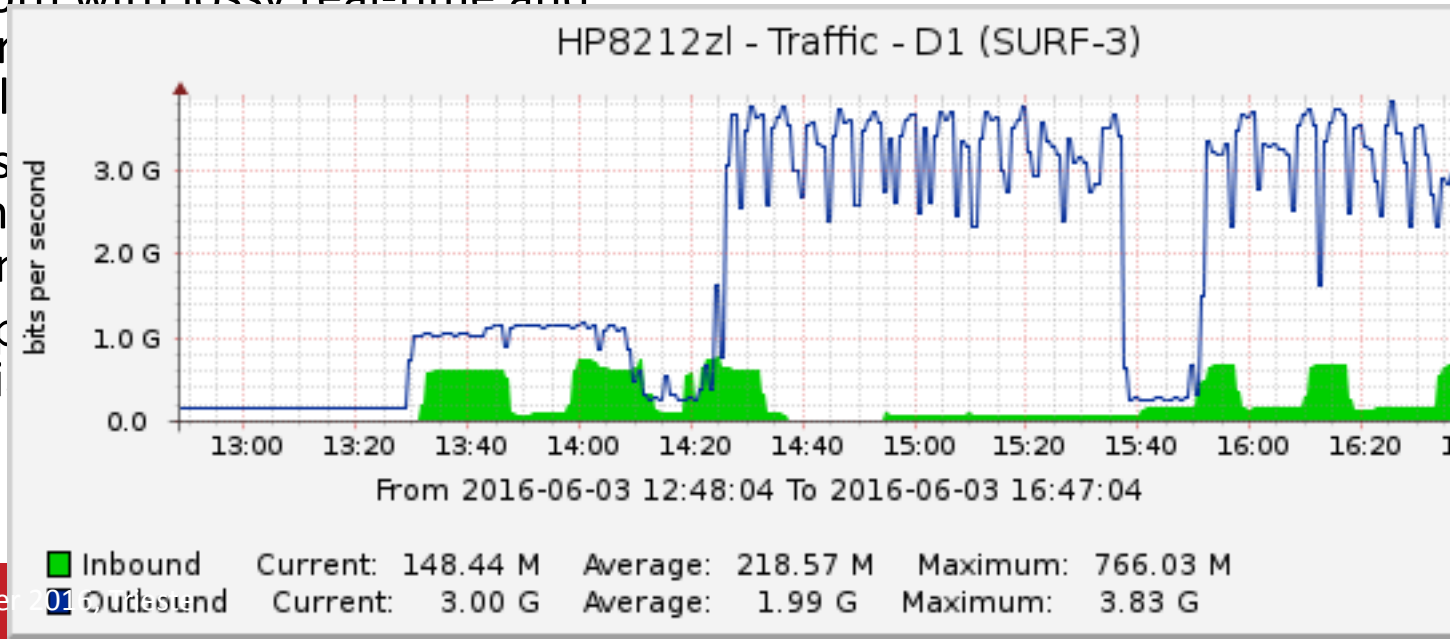
SURF NET
Time & frequency for
VLBI and LOFAR
DWDM node Rx
C-band
OSC Rx
OSC band
New data link
Existing data link
Correlator
WSRT
CAMRAS
Clean-up oscillator
WRE node
Tx
Rx
Groningen
Assen
WRE switch
Tx0
Rx0
Rx2 Tx2
Rx1 Tx1
OSC Tx
OEO
DWDM node Tx
C-band
DWDM node Rx
C-band
OSC Rx
65 km
2×55 km
OSC Rx
OSC Tx
OEO
C-band
C-band
OEO
OSC Tx
OSC Rx
Rx
Tx
WRE node
Clean-up oscillator
DF
LOFAR CN
Buinen

Task 2: User-domain data streaming

JIVE (Verkouter)

- Almost all high-throughput data transfer utilities use TCP
  - Abysmal performance on long-haul links
  - multiple streams for better throughput
  - some commercial tools use UDP but these are expensive
- Experience both with lossy real-time and reliable near-r through devel
- But, (e-)VLBI s specialized an file-to-file trar
- Developing op using the (reli



Task 3: Scheduling of large astronomical infrastructures

IEEC, STFC, GTD (Colome)

- Complex, many-element detector arrays

CTA observation modes

Monitoring
4 telescopes

Monitoring
4 telescope

Deep field
~1/2 of telescopes

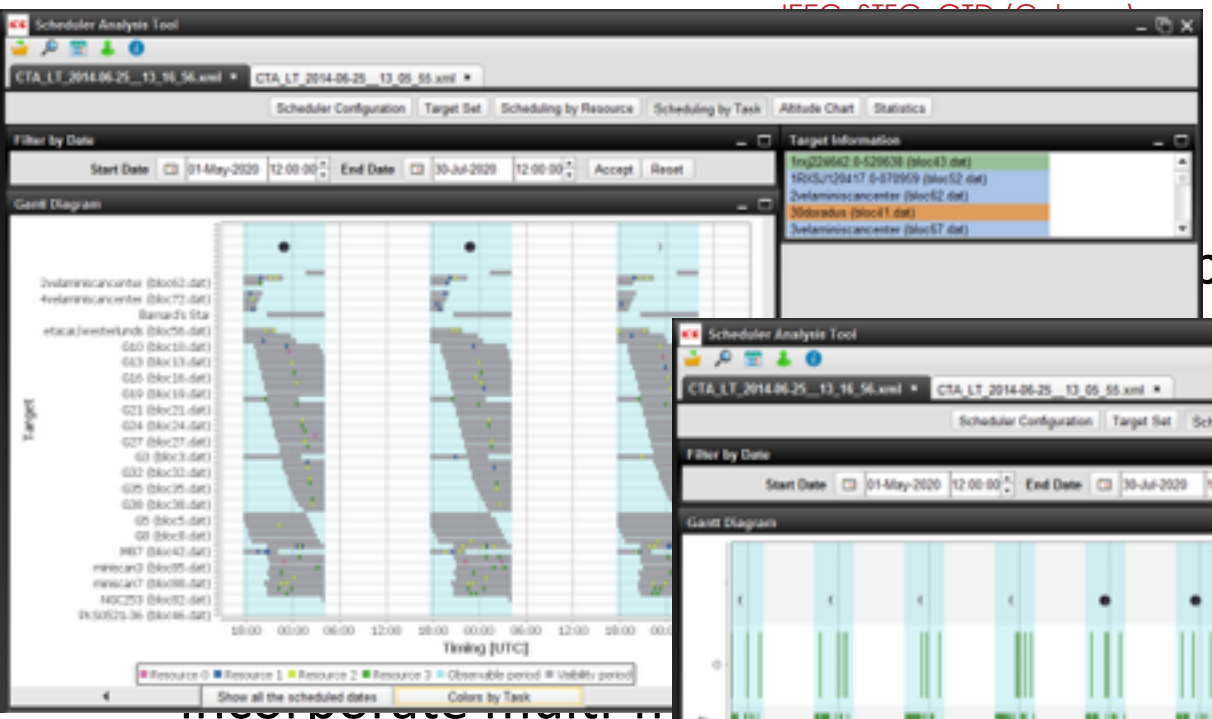
Monitoring
4 Telescopes

Deep field
~1/3 of telescopes

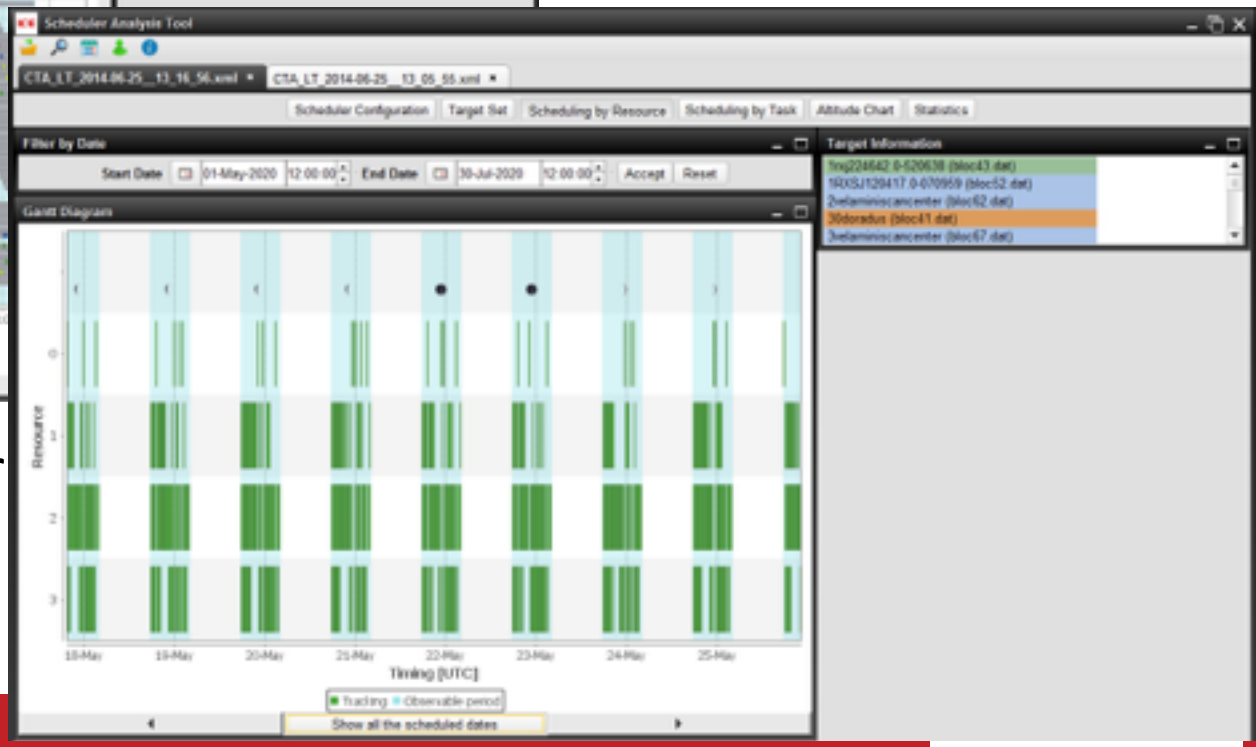
Monitoring
1 telescope

Divergent & convergent mode in
SUB-ARRAY configuration

Task 3: Scheduling of large astronomical infrastructures



ptimize procedures



- Provide a framewor
  facilities.

Task 4: Multi-messenger methods

JIVE, ASTRON, CNRS-APC, UVA (Kettenis)

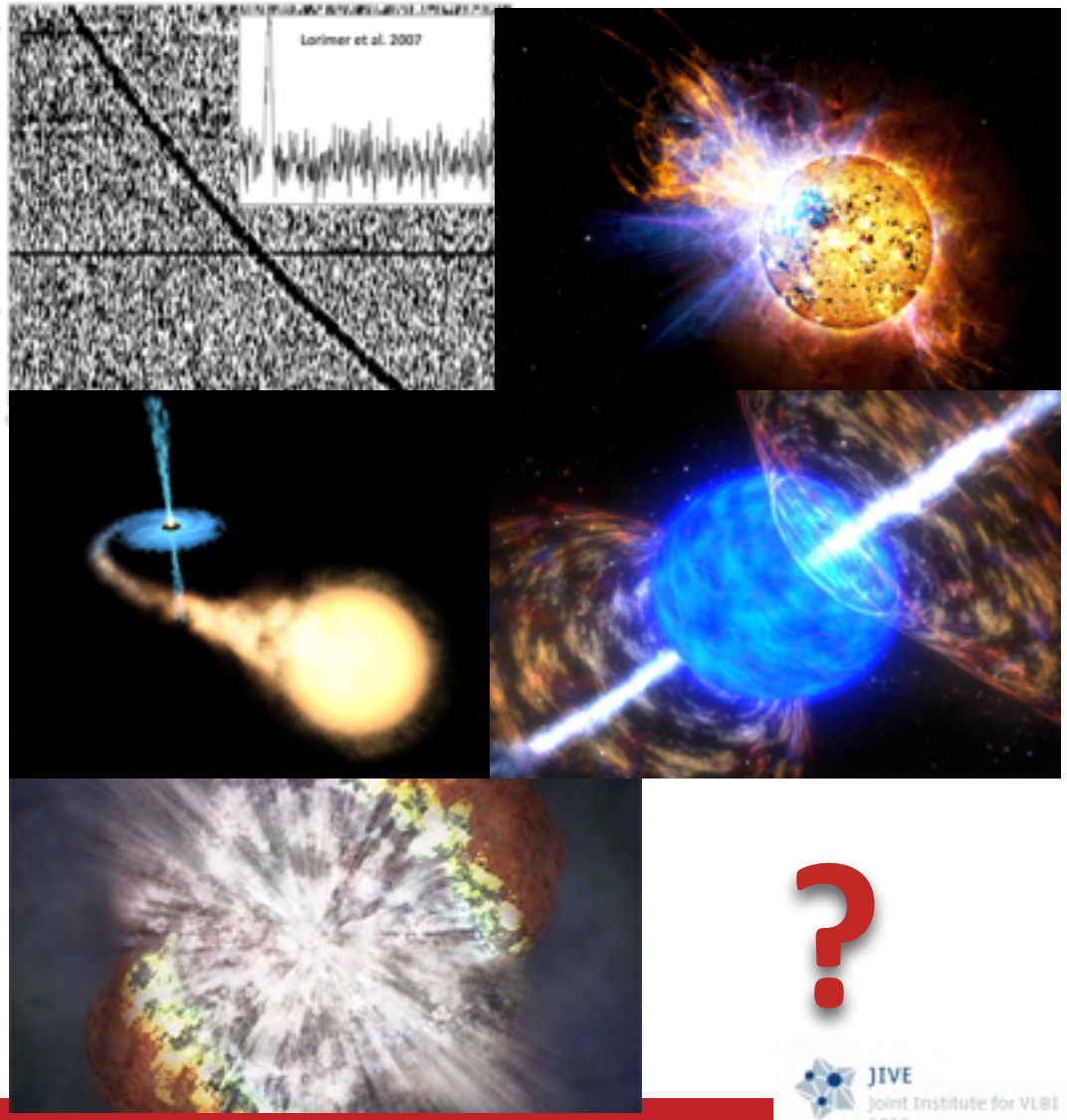
- Develop standards for generation, dissemination, distribution and reaction to transient events (based on **VOEvents**)
- Demonstration during which e.g. radio facilities like LOFAR, EVN, follow up a GW event
- Investigate scientific synergies for automated follow-up observations

Transients: what are we looking for?

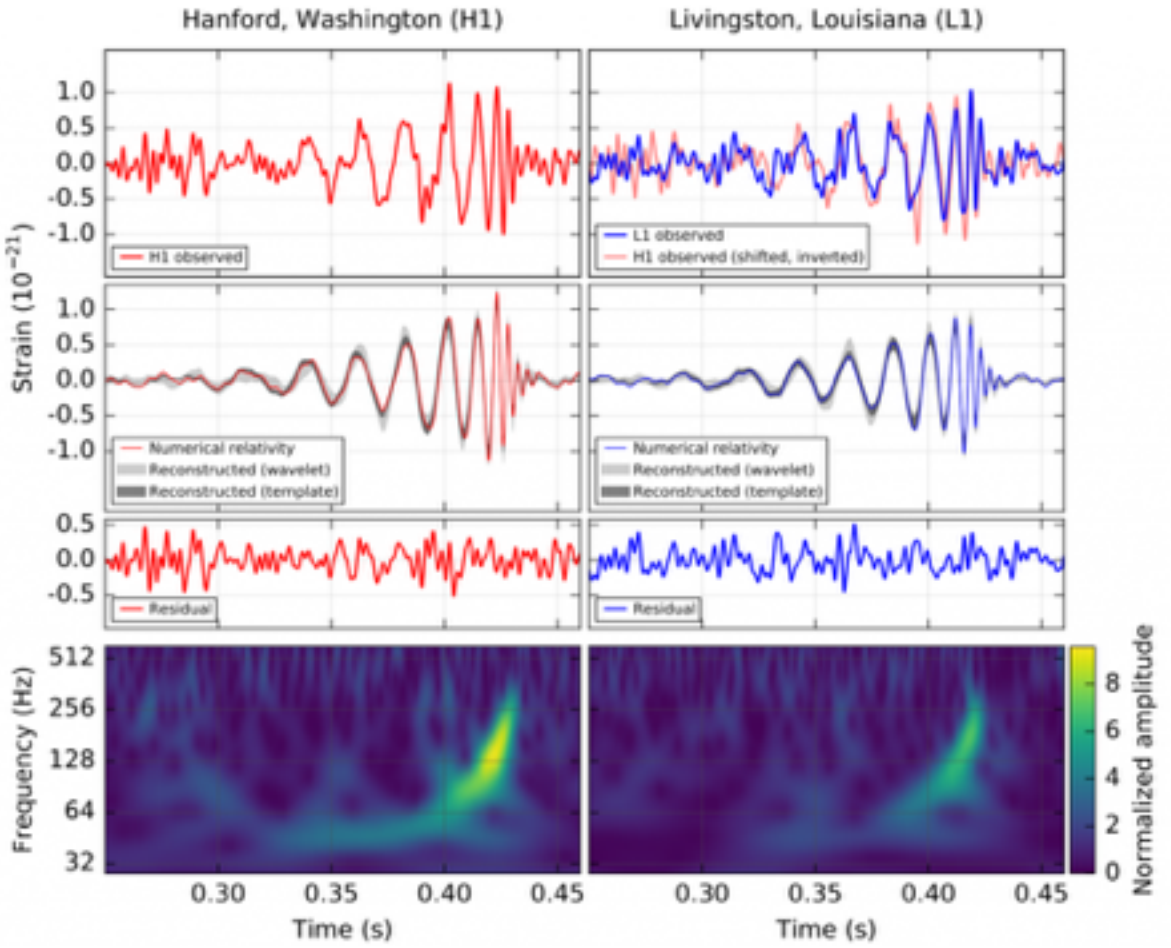
(with many thanks to Antonia Rowlinson, Sander ter Veen)

Possible targets

- Fast Radio Bursts
- Flare stars
- X-Ray Binary outbursts
- Gamma-ray bursts
- Supernovae
- Neutrino triggers
- Unknown
- …



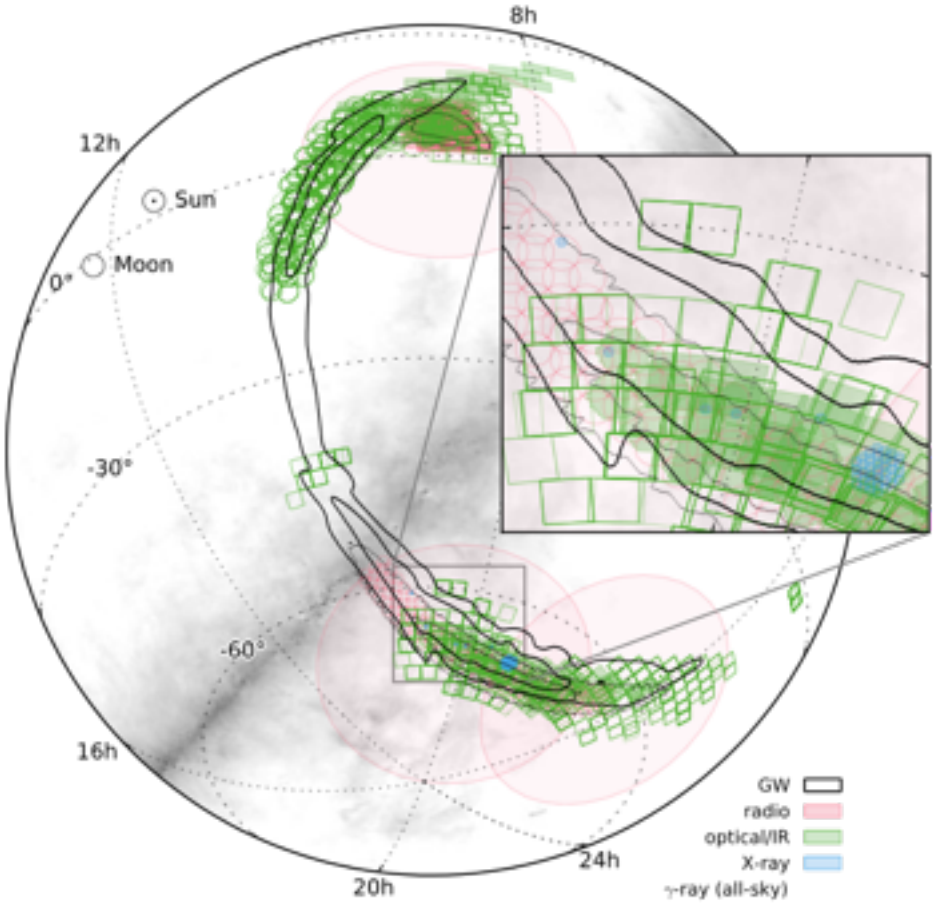
Gravitational waves: GW 150914



- Two black holes
- Distance of ~400 Mpc
- Masses of 36 and 29 $M_\odot$
- 3 $M_\odot$ of energy released

Abbott et al. (2016a)

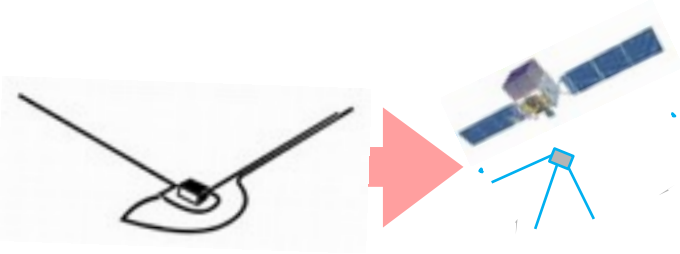
Multi-wavelength follow-up

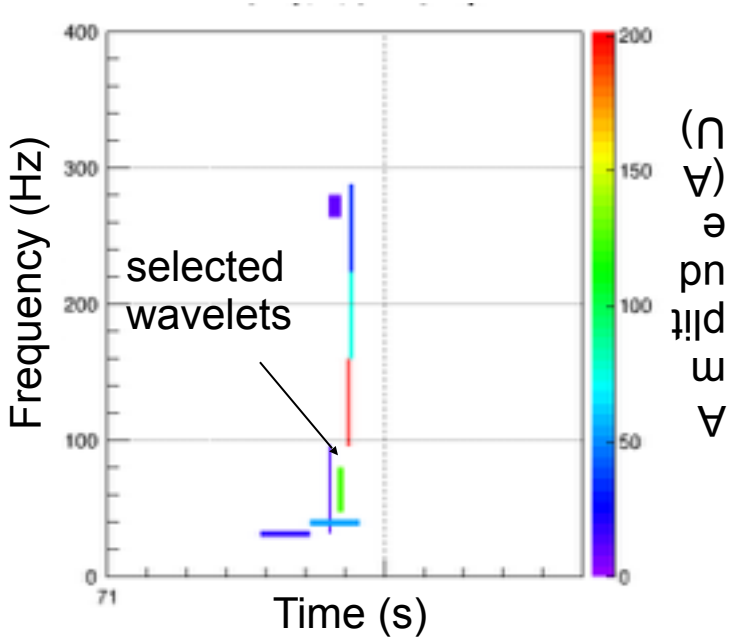


- Majority of localisation region covered at each wavelength
- Follow-up teams used a range of strategies

Abbott et al. (2016b)

Low-latency gravitational-wave alerts

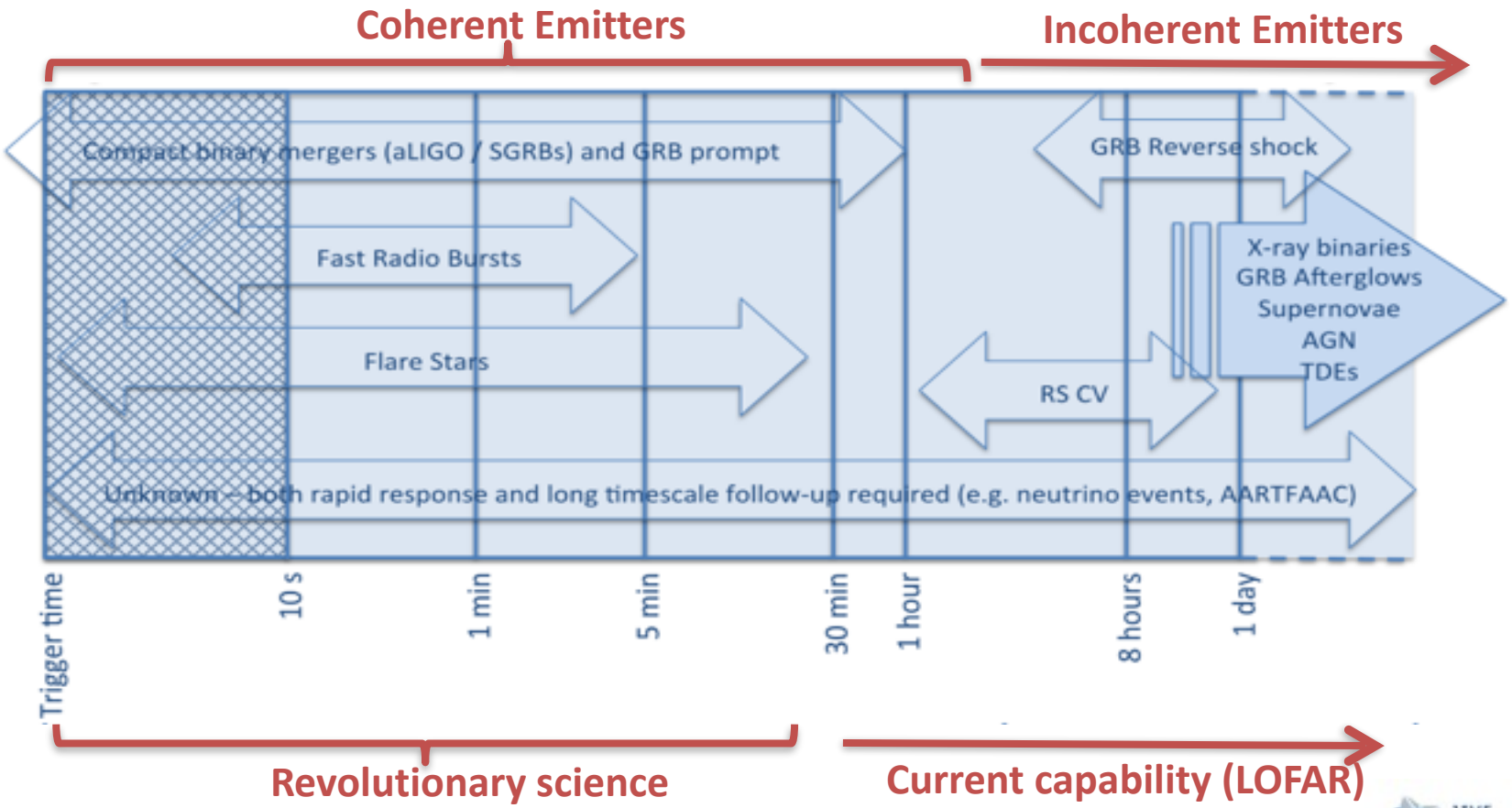




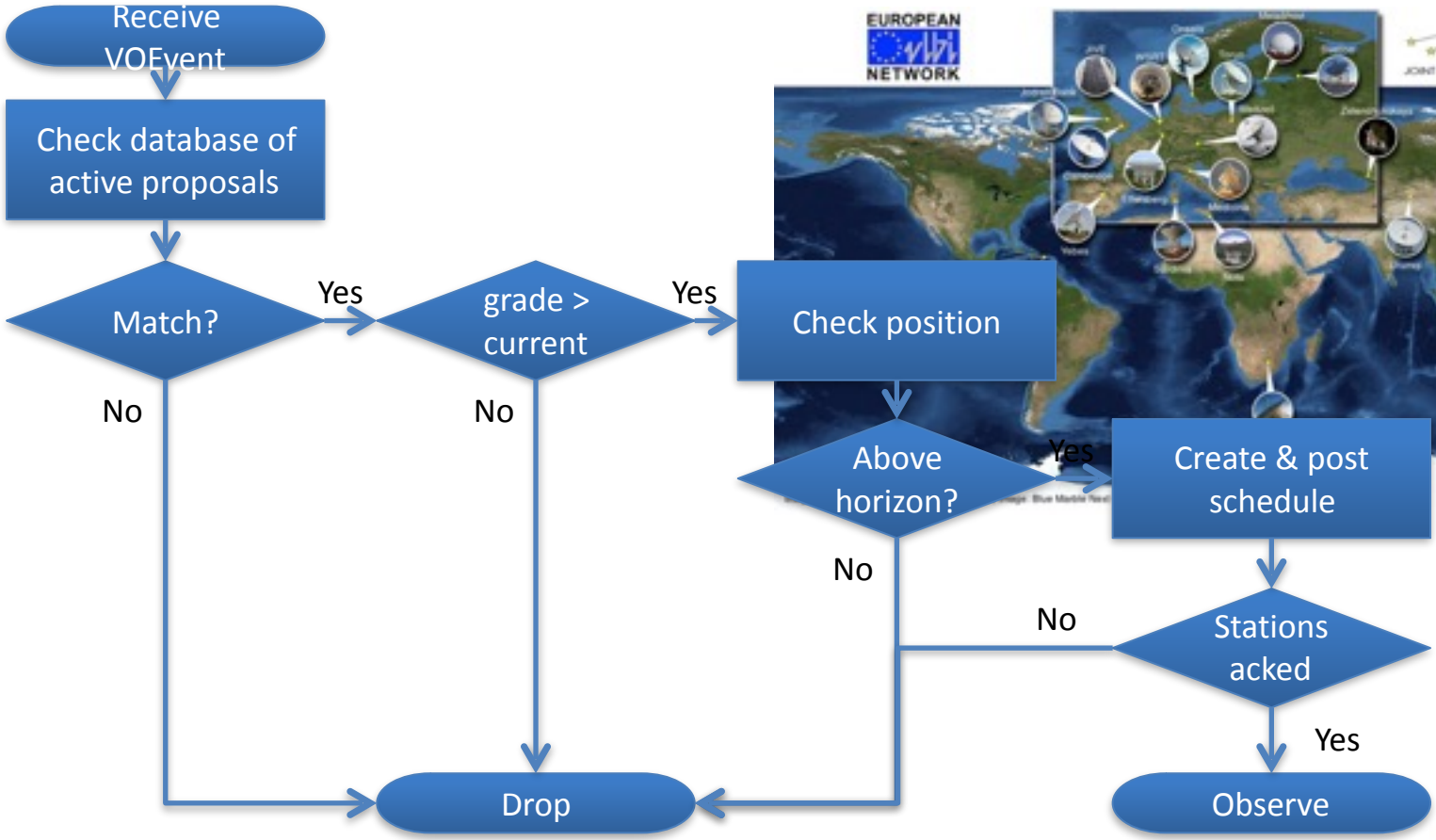
- Generation of GW triggers with low-latency allows to seek electromagnetic counterparts
  - A panel of low-latency pipelines **generates GW triggers** (+skymaps) **within minutes**
- Generic transient searches (Coherent Waveburst) have found GW150914 after 3 mins [1,2]
  - Principle: search for **time-frequency patterns that are coherent across detectors**

[1] Abbott et al, Phys. Rev. D 93, 122004 (2016)
[2] Klimenko et al, Phys. Rev. D 93, 122004 (2016)

Need for speed



e-EVN rapid response (~15 min)

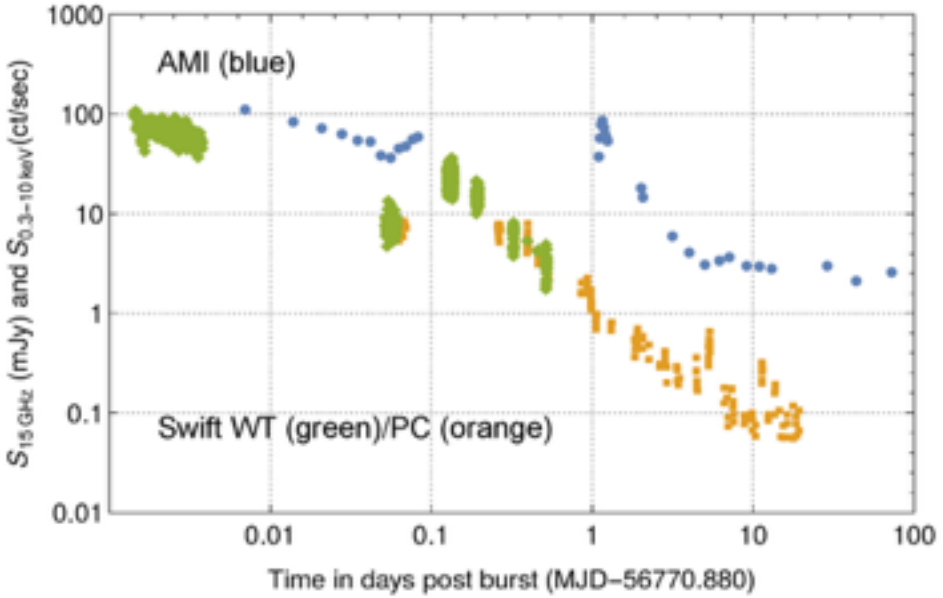


Arcminute Micro Kelvin Imager (AMI)

- Limiting factor on speed is the **slew time**

- Young M dwarf binary DG CVn - Gamma-ray superflare
- Observations started at **6 minutes** post flare

Staley et al. (2013), Fender et al. (2015)



Current rapid response capabilities at low frequencies

LOFAR

- ~30 minutes
- High spatial resolution
- Capability:
  - Imaging and/or beam forming

MWA

- ~10 seconds
- Low spatial resolution
- Capability:
  - Imaging

Current rapid response capabilities at low frequencies

LOFAR

- ~5 seconds
- High spatial resolution
- Capability:
  - Imaging and/or beam formed
  - **Transient Buffer Boards**

MWA

- ~10 seconds
- Low spatial resolution
- Capability:
  - Imaging

First commissioning test:
Transient Buffer Boards triggered from Effelsberg detection

Effelsberg 100m telescope
High frequency detection

LOFAR
Low frequency observation
Localization

Challenges

- Many different instruments are needed, and available, for follow-up of transient events
  - With completely different methods of scheduling, configuration, response time
- Filtering: number of transient detections will only increase (explode?)
- Ensure all necessary information is contained in message
- Define standards for the generation of triggers from triggered observations
- Involve outside parties (from small optical telescopes to space programmes) in these developments

Conclusions

- Cleopatra is well on its way
  - Already has made a real impact on WR development
    - Generated outside interest: JVLA
  - May produce a simple file-transfer tool that actually simply works
  - Is making excellent progress in dynamic scheduling of large arrays/global arrays
  - Will implement and demonstrate streamlined methods of filtering of and responding to triggering events

Participating institutions

Cluster 53477

JIVE
Joint Institute for VLBI ERIC

Supporting organisations and networks