WP5: Cleopatra

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

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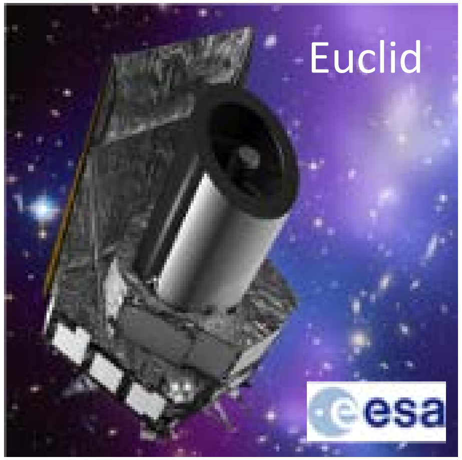
On behalf of the Cleopatra collaboration

WP5: Cleopatra

- ~2.5 M€, 4 tasks
- 12 partners: JIVE, VU, UGR, NIKHEF, SURFnet, ASTRON, UVA, DESY, CNRS-APC, IEEC, GTD, STFC



- Connecting real facilities now as path to connected future facilities

Objectives

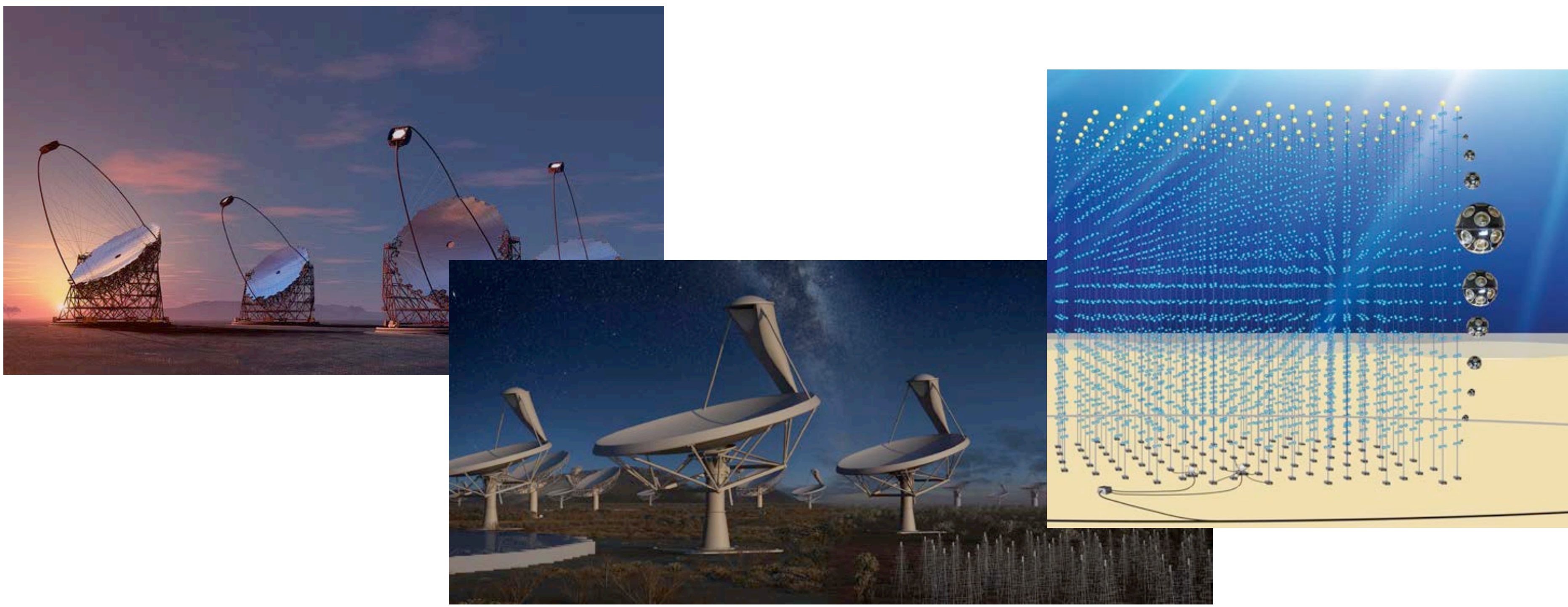
It's all about connectivity:

- Timing: enable and improve long-haul many-element **time and frequency transfer** over optical fiber networks
- Develop methods for **rapidly relaying alerts between facilities**, formulate scientific strategies, enabling joint observations of transient events
- Handling of **large data streams**: leverage the e-VLBI experience to develop user-friendly, transparent and robust data streaming software
- **Scheduling** of complex multi-element instruments, joint scheduling of multiple facilities around the globe, using advanced scheduling algorithms

Task 1: Synchronization

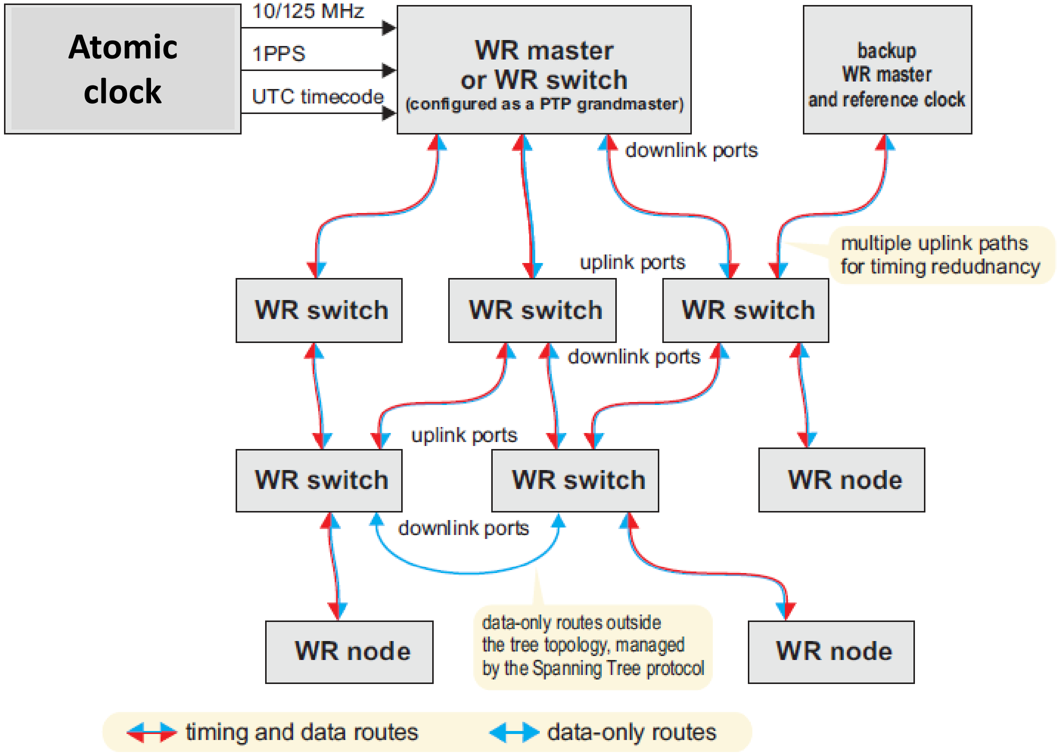
VU, ASTRON, JIVE, UGR, FOM, DESY, SURFnet (Koelemeij, Berge)

- 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

opnt. TIME PROVISIONING

Accurate Time Synchronization in live network Vodafone

Tallgrass

Press release

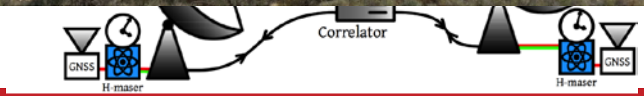
Amsterdam, The Netherlands; February 15, 2017

OPNT and Tallgrass are proud to announce that a Proof of Concept for distributing accurate timing through the live Vodafone network has been very successful, exceeding all customer expectations. Time was delivered with an astonishingly small error of less than 1 nanosecond over a cascade of four sites, spanning a total distance of 320 km.
This remarkable feat represents the world's first successful deployment of so-called White Rabbit timing in the production network of a commercial operator

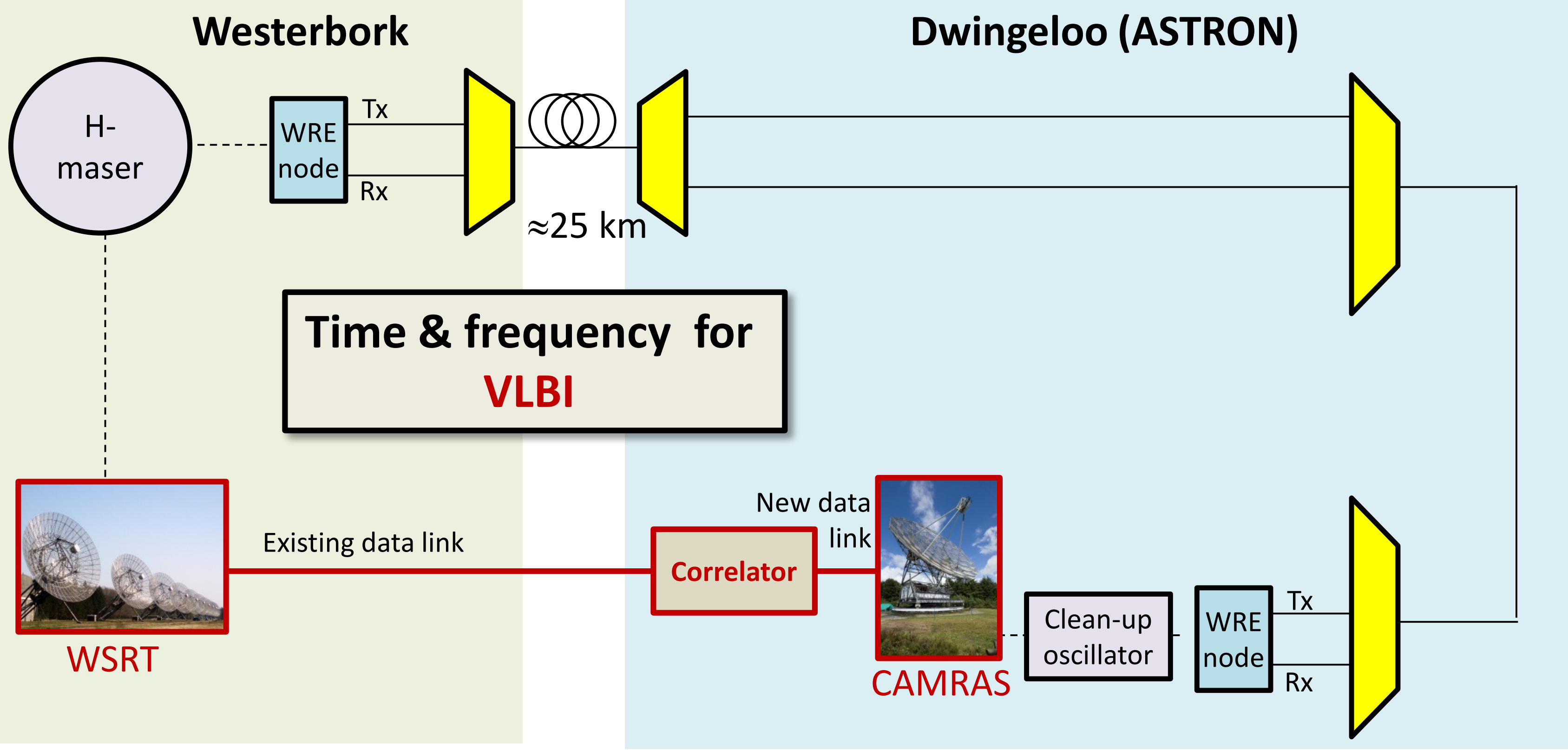
"The fantastic outcome of this Proof of Concept is the result of a close cooperation between Vodafone, Tallgrass and OPNT engineers. Achieving this accuracy in a live core-network while demonstrating the plug and play solution, the ease of implementation and calibration is noteworthy." said Marco Gorter, CEO of OPNT.

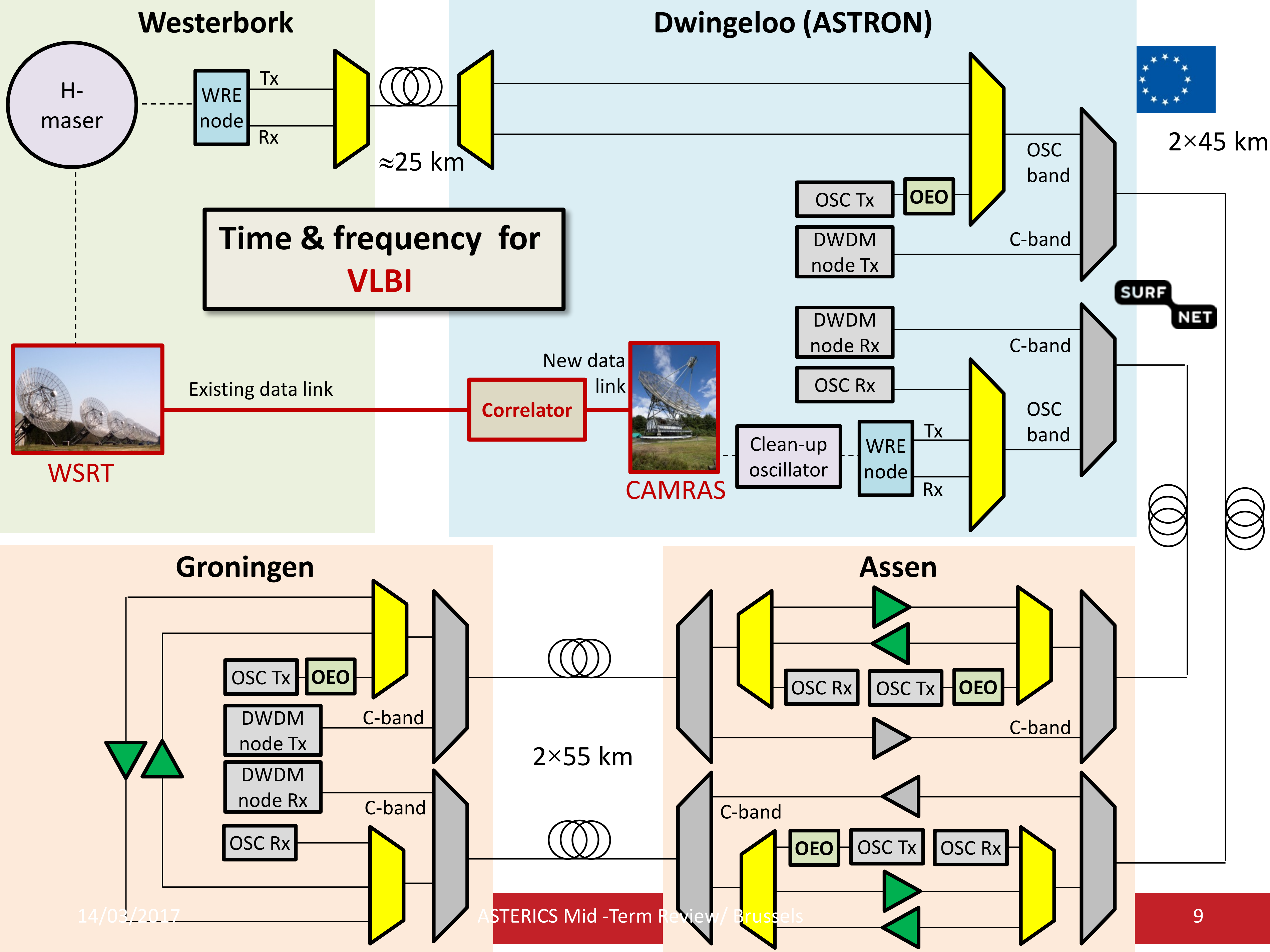
"One of the key factors in building next generation networks for mobile operators is accurate clock signals throughout the network. By combining the technology from OPNT and the field services experience from Tallgrass, we have provided a unique solution that could very well become the new industry standard." said Reindert Hommes, CEO of Tallgrass.

WRE and VLBI: a demo



Time & frequency for VLBI




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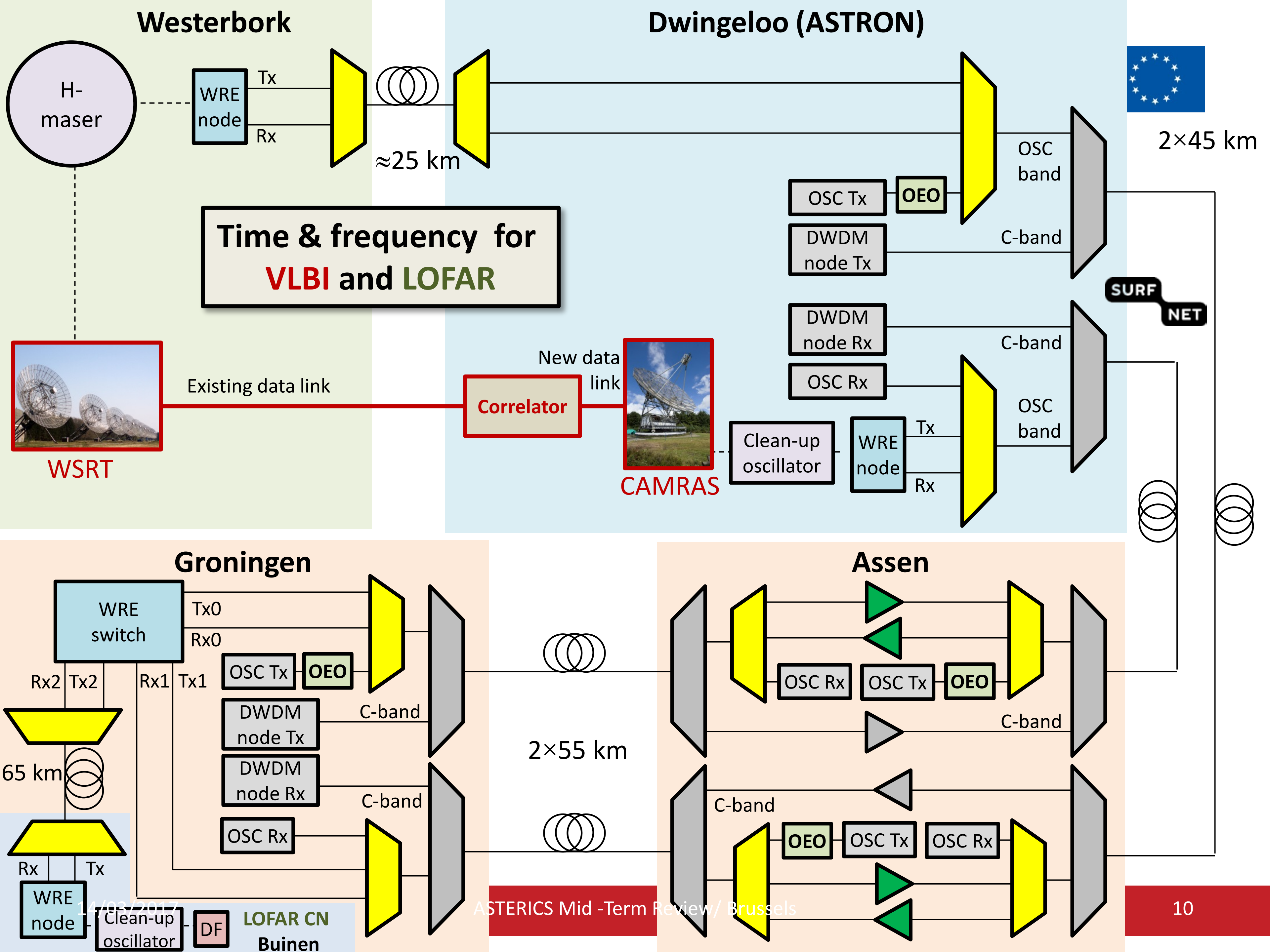
OEO
OSC Tx
OSC Rx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Tx
Rx
Groningen
Assen
WRE switch
Tx0
Rx0
OSC Tx
OEO
Rx2
Tx2
Rx1
Tx1
DWDM node Tx
C-band
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2×55 km
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OSC Tx
OEO
C-band
C-band
OEO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

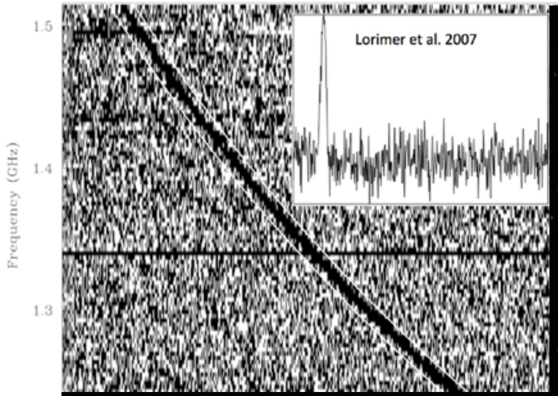
Task 2: Multi-messenger methods

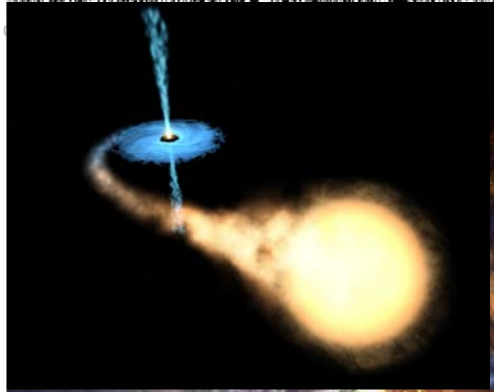
JIVE, ASTRON, CNRS-APC, UVA (Kettenis)

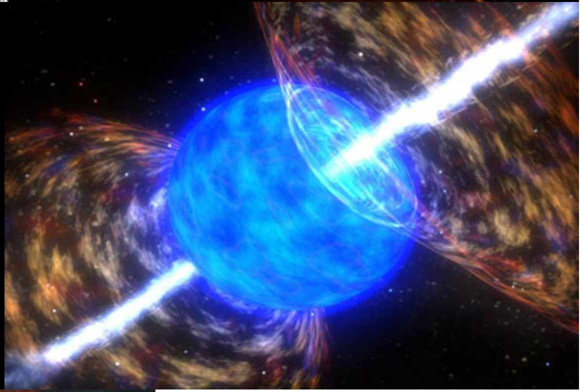
- Develop standards for generation, dissemination, distribution and response to transient events (based on **VOEvents**)
- Demonstration during which e.g. radio facilities like LOFAR, EVN, follow up a GW event
- Investigate scientific synergies for automated follow-up observations

Possible targets

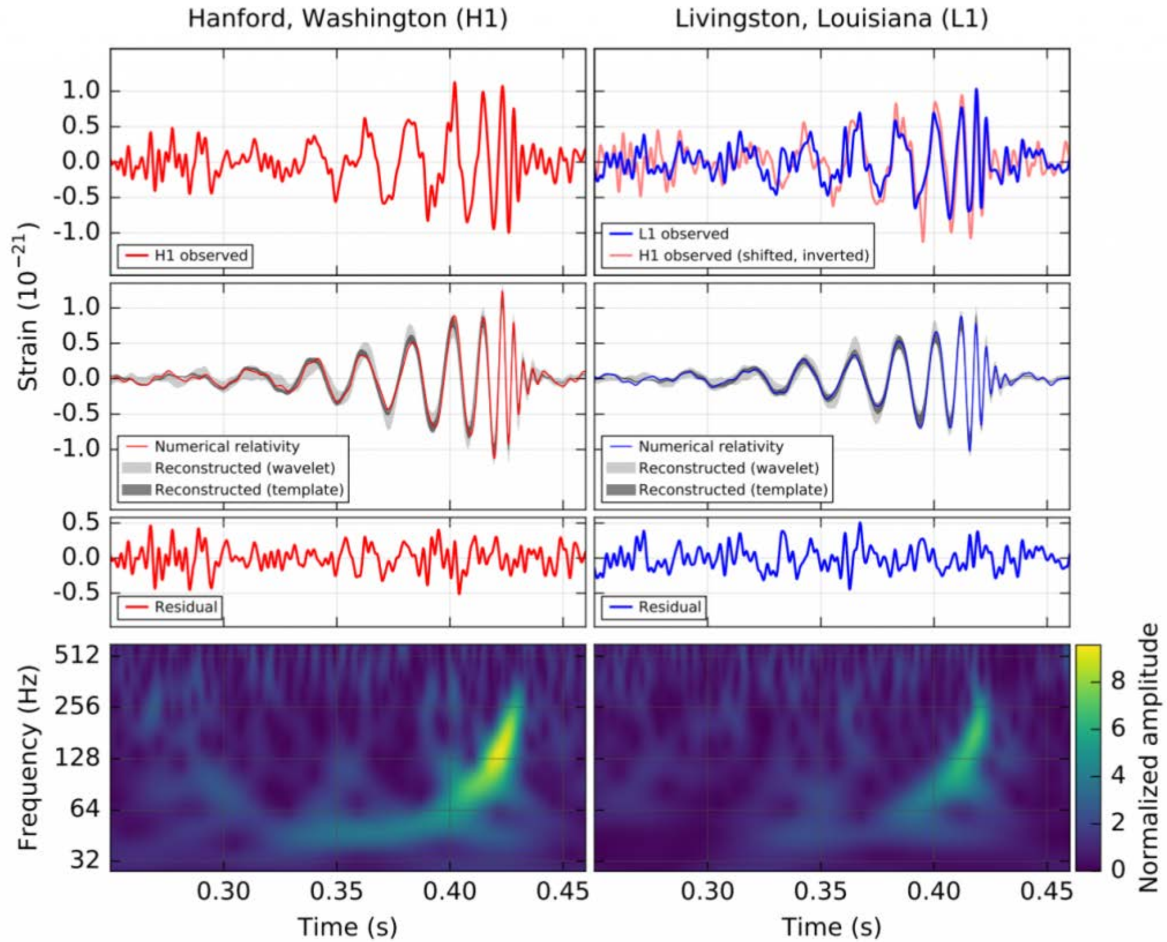
- Fast Radio Bursts
- Flare stars
- X-Ray Binary outbursts
- Gamma-ray bursts
- Supernovae
- Neutrino triggers
- Unknown
- …







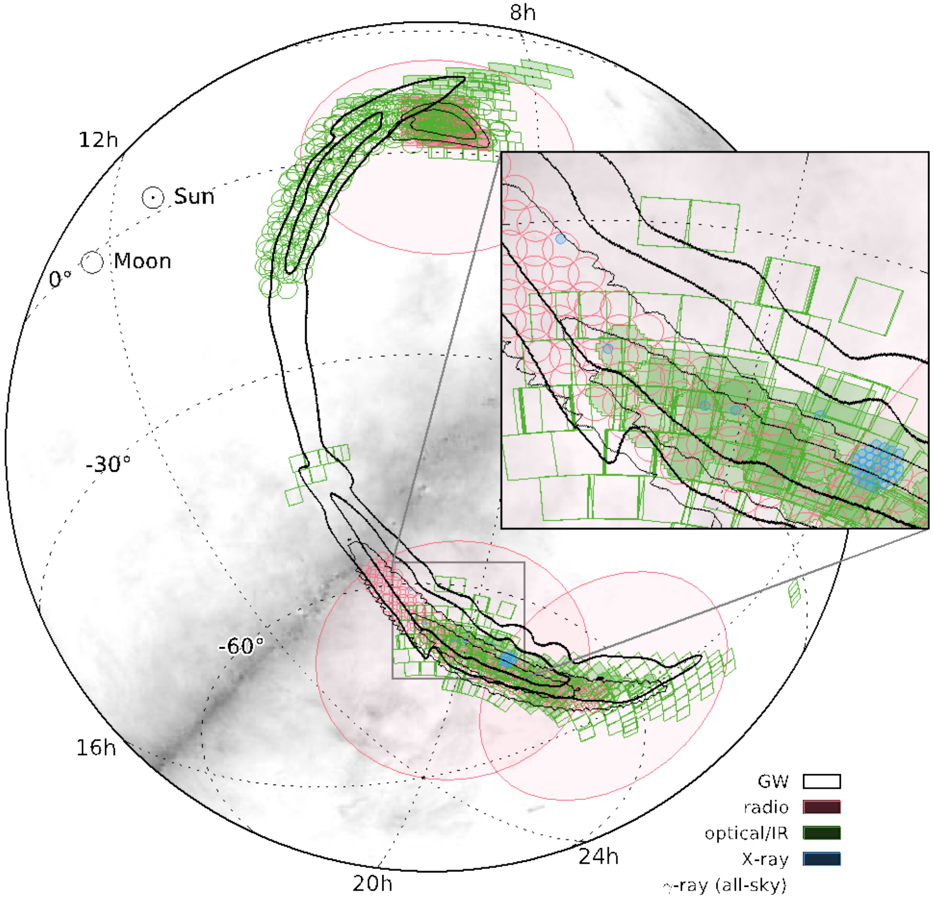
Gravitational waves: GW 150914



- 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)

Astronomy ESFRI & Research Infrastructure Cluster
ASTERICS - 653477

Task 3: User-domain data streaming

JIVE (Verkouter)

- High-throughput data transfer utilities mostly use TCP:
  - Abysmal performance on long-haul links
  - some commercial tools use UDP but these are very expensive
- Local experience both with lossy real-time and reliable near-real-time data
- But, (e-)VLBI software is way too specialized and non-standard for simple file-to-file transfers
- Developing open-source file transfer utility using the UDT protocol
  - Reliable, robust, user-friendly

Task 4: Scheduling of large astronomical infrastructures

IEEC, STFC, GTD (Colome)

- Complex, many-element detector arrays
  - SKA, CTA

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 4: Scheduling of large astronomical infrastructures (continued)

- Artificial Intelligence (AI) techniques to optimize procedures
  – Metaheuristic Optimization: Genetic Algorithms, Multi-objective Evolutionary Algorithms
  – Constraint-Based Reasoning: constraint propagation
- Maximize science return of SKA and CTA
  – But ensure solutions are applicable for other instruments
- Incorporate multi-frequency, multi-messenger astrophysics
- Provide a framework to coordinate and schedule multiple facilities.

Results: task 1

– Moving ahead at full speed, right from the start

- Has made real impact in WR community
  - Improvements are fed back: open source
- Generated serious outside interest: JVLA
- Some delay with one partner, but no risk to project
  - Has ramped up effort
- Fed into tender for new photonic equipment for SURFnet(8)
- WR timing in design of SKA-low
  - Frequency stability now good enough for frequency transfer
- Commercial applications under development

Results: task 2

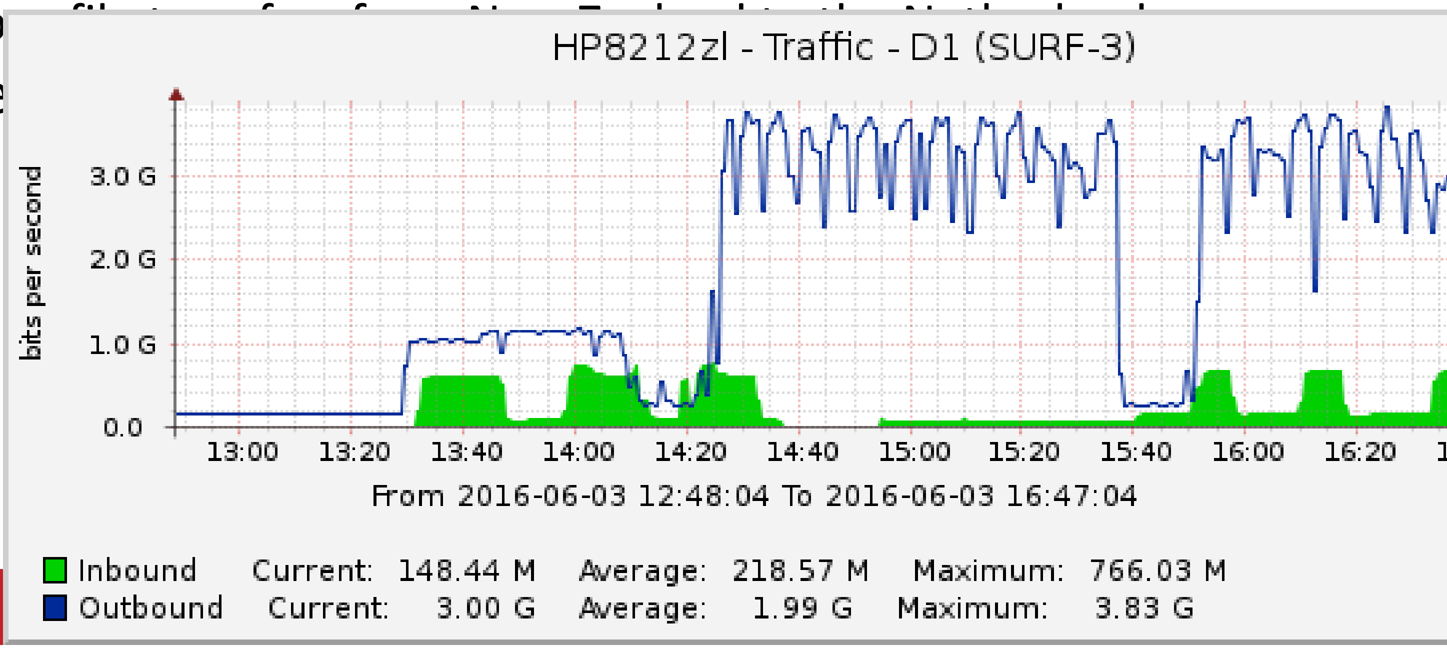
– Task 2: slow uptake

- Speed-up since last change of task lead
- Draft of first deliverable document
- Some delay, but no risk to project timeline
  - Will fit comfortably within the 4 years
- Active involvement of several astronomers interested in triggered observations
- Interactions with Work Package 4 and Cleopatra task 4
- MoU JIVE-EVN and LIGO regarding follow-up observations

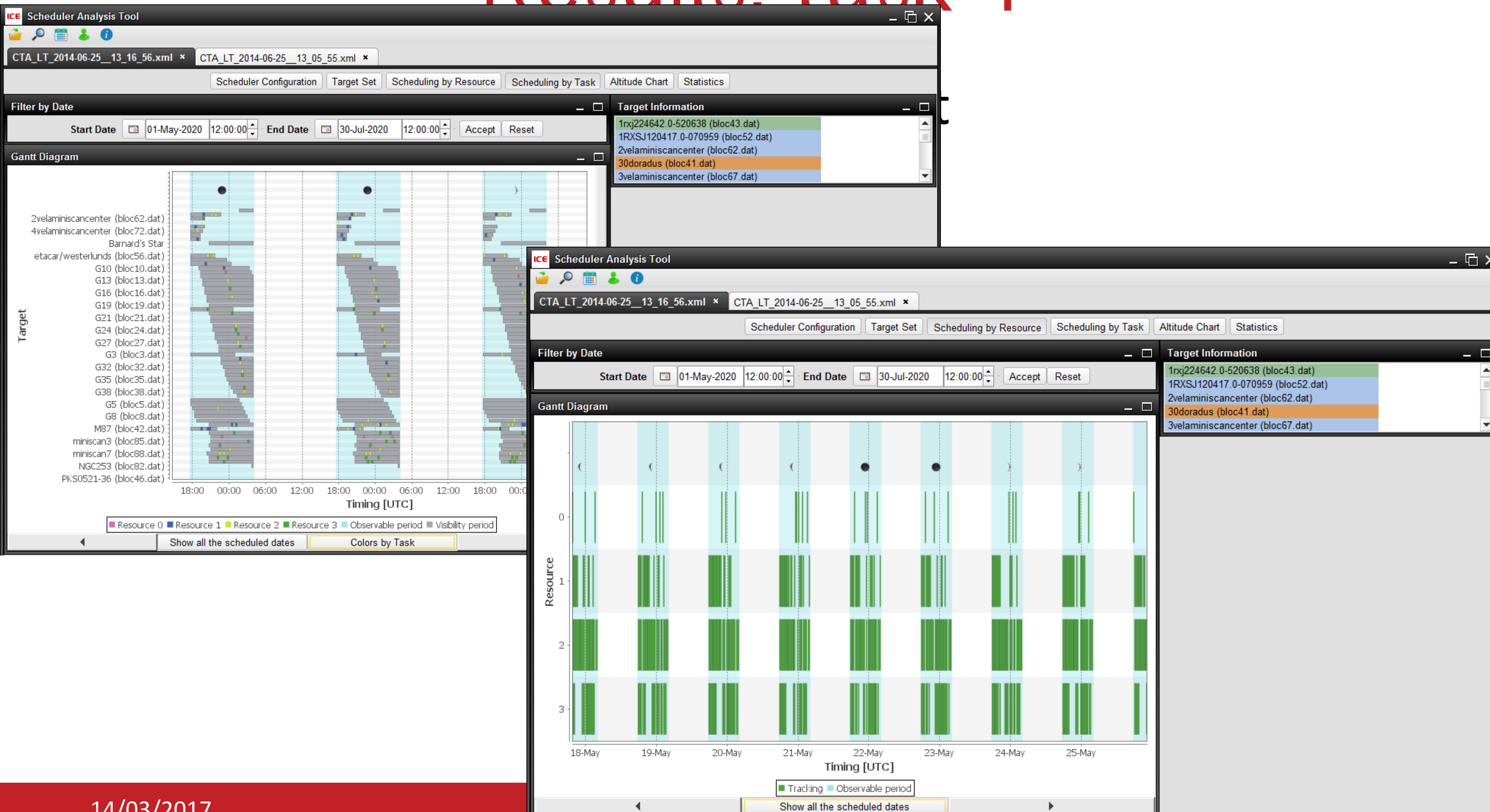
Results: task 3

– Fairly small task, one developer

- Prototype milestone reached well on time
- First tests very promising
  - 4Gb
- Now re



Results: task 4



Outlook

- No major obstacles or deviations: on track
- Task 2: most delayed, but high potential
  - Transient astronomy becoming more important (GW!)
  - Real need in community for standards, implementation of filters, protocols
- Task 3: small, but could deliver something very useful
- Tasks 1 and 4: clear use cases, big impact
- Several demos coming up, good PR
- Results feed back into commercial applications