

Radio-wavelength Facilities

- Time-domain & Multi-messenger

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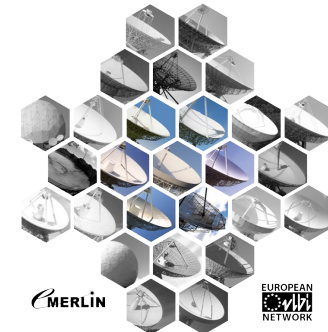
Zsolt Paragi (JIVE-ERIC)

Joint Institute for VLBI ERIC



JIVE

Joint Institute for VLBI
ERIC



...Overview* ...

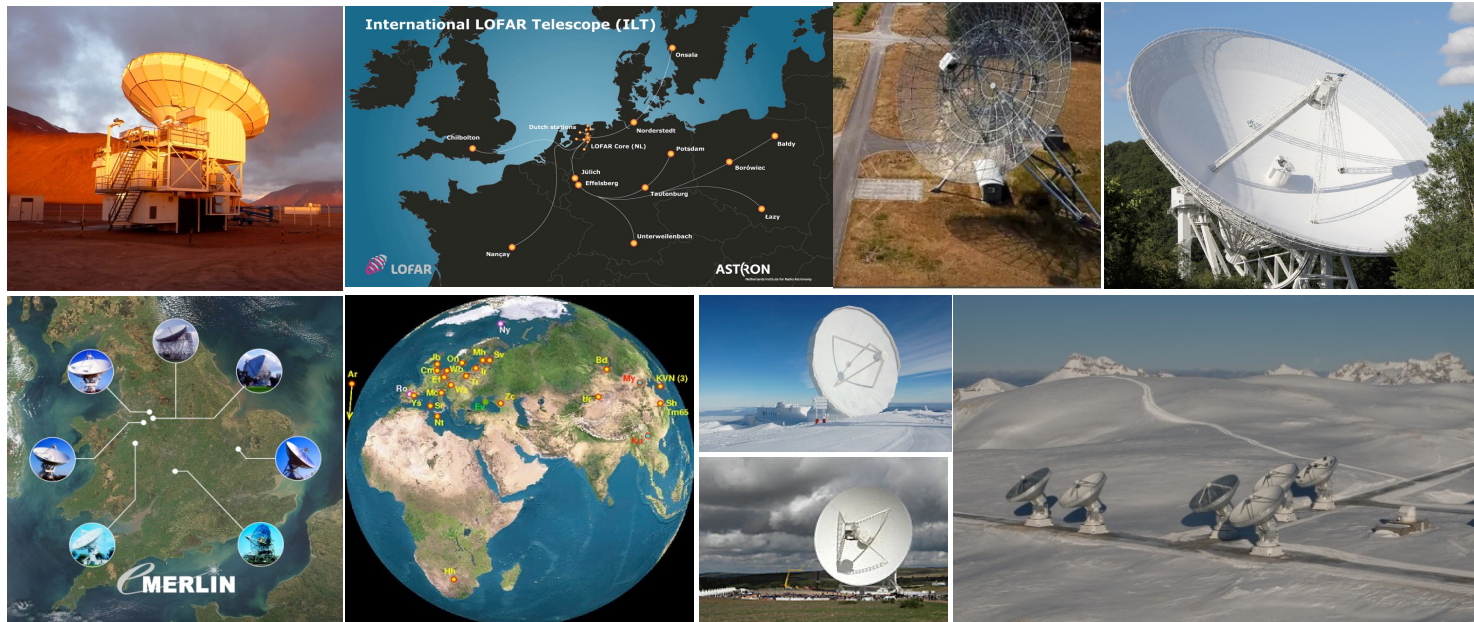
- Current and near future facilities
 - Capabilities, attributes & opportunities
- Recent science exemplars
 - Unique radio contributions
 - VLBI

Rob

Zsolt

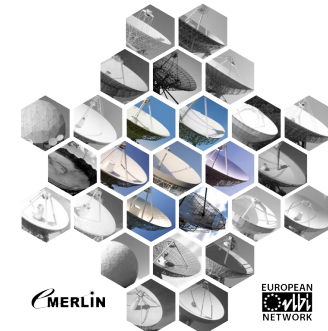
* caveats & acknowledgements: We will deliberately take a slightly European-centric view in places. It is not possible to cover everything. ALL of the work presented as examples is led by multiple teams/facilities/project. They deserve the ALL the credit.

Current ORP Radio TA/VA Telescopes & Facilities



World class facilities – with long track record of providing TA/VA provision through various EC programs from RadioNet to ORP

- Established processes, full support (e-2-e)



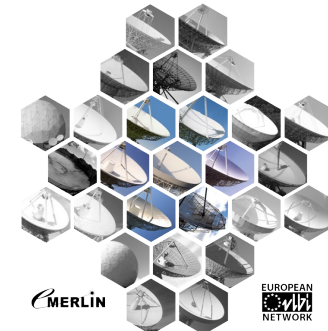
...arrays & telescopes...

Rapid transient follow-ups available on most arrays – e.g. via Target of Opportunity (ToO) or discretionary time requests (e.g. DDTs)

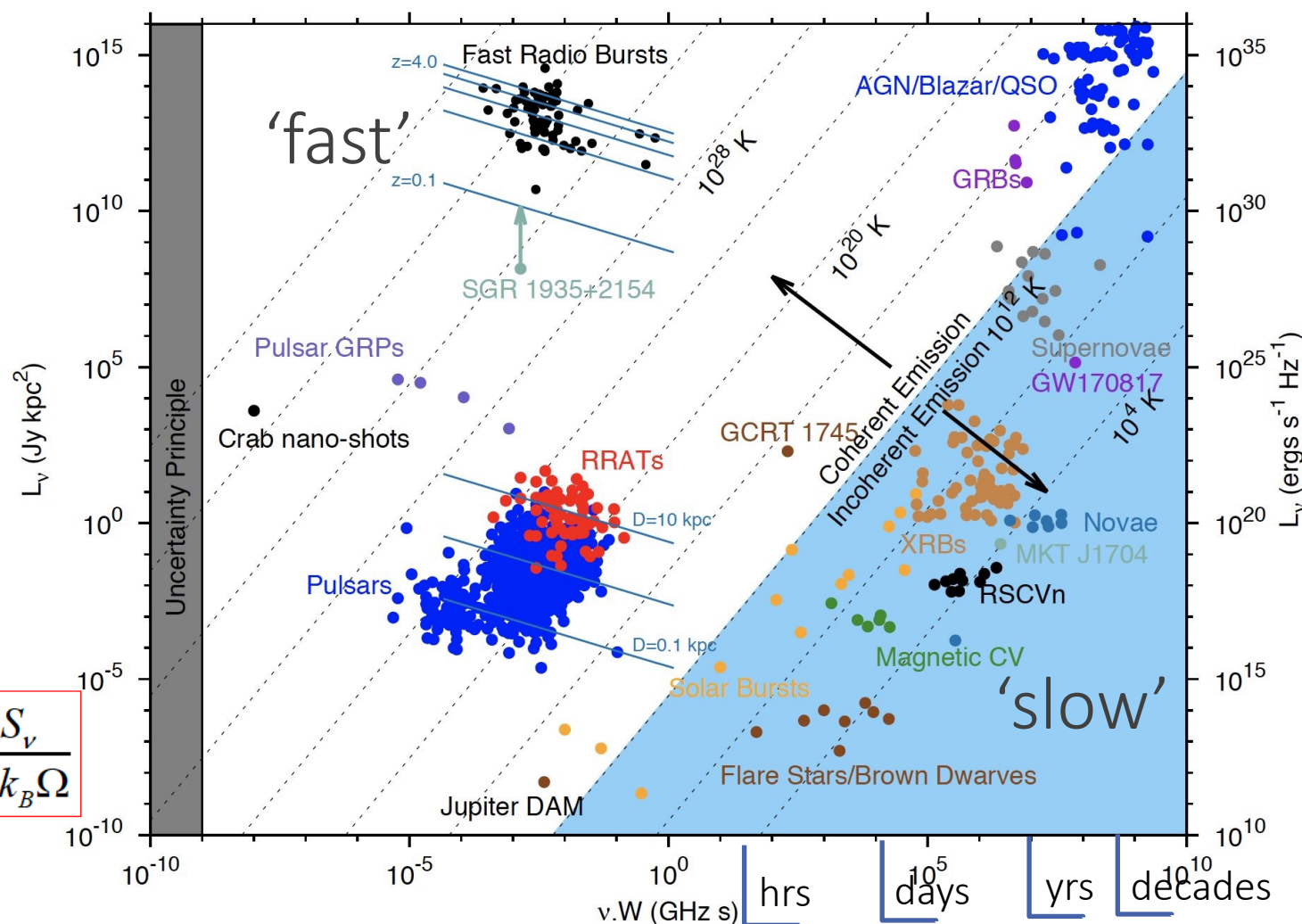
...Different facilities for different, complementary jobs & different goals...

- *e-MERLIN* – real-time, rapid response (hrs-days), high resolution (10-100s mas)
- *AMI* – low resolution, fixed frequency – very rapid follow-up(mins), high cadence (private*)
- *EVN/e-VLBI* – extreme resolution – (continental scale distributed array). e-VLBI offers quicker turn around via real-time observations.. (other VLBI arrays exists)
- *VLA* – great flexibility, sensitivity and rapid-response (less resolution - can suffer confusion)
- *LOFAR/ILT* – low frequency (150-240MHz), wide fov, rapid follow capabilities
- Large 100-m class Single dishes – e.g. Effelsberg, SRT etc
- Mm/sub-mm facilities – e.g. NOEMA, PV30m, ALMA

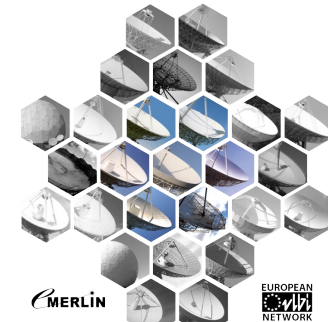
Ideally want – superb time, frequency & resolution coverage....



Radio time-domain - coherent & incoherent (fast & slow)



$$T_B = \frac{c^2 S_\nu}{2\nu^2 k_B \Omega}$$



Radio Time-domain astrophysics – ‘fast-transients’

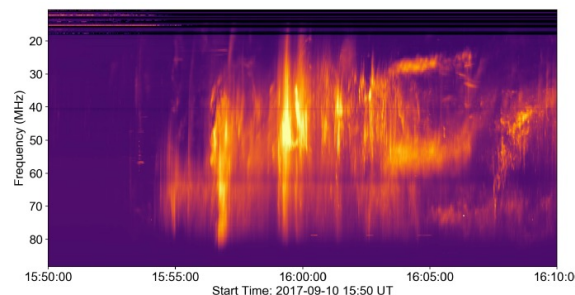
Fast-transients (ns to mins → Time-series analysis)

- Coherent emission
- Variable on timescales (ns to minutes)
- V. High brightness temp (up to at least 10^{30}k)

Examples:

- neutron stars, Pulsars
- FRBs
- ETI signals?
- Flare stars
- Solar burst (type II & III)
- Planets & exoplanets
- pulsing brown dwarfs
- CR air-showers
- Atmospheric physics –

Lightning propagation.... etc



Solar bursts – CME (Morosan+)

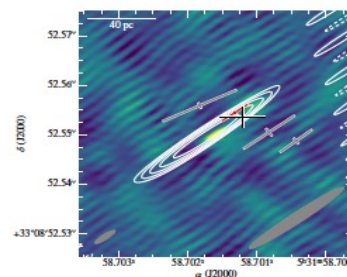
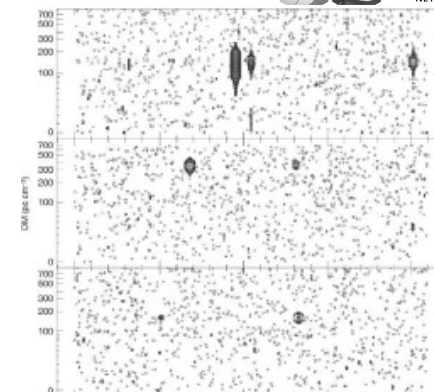
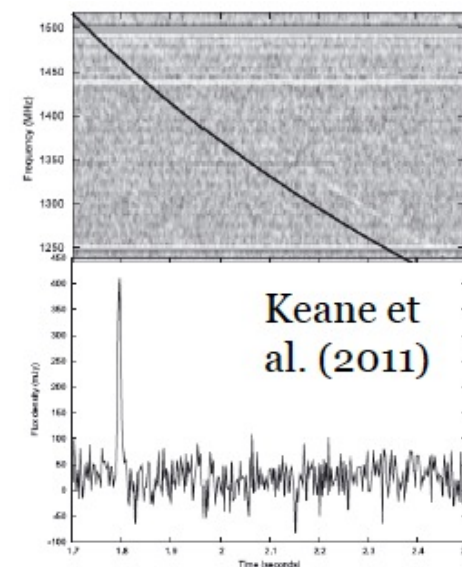


Figure 1. EVN image of the persistent source at 1.7 GHz (white contours) together with the localization of the strongest burst (red cross); the other three observed bursts (gray crosses), and the position obtained after averaging all four bursts detected on 2016 Sep 20 (black cross). Contours

[Marcote et al 2017]

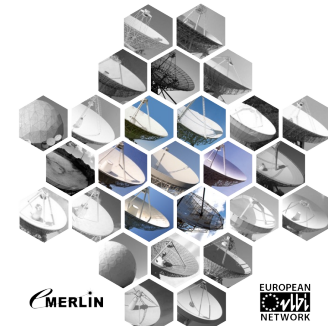


RRATS – McLaughlin + 2006



Keane et al. (2011)

Radio Time-domain astrophysics – ‘slow-transients’



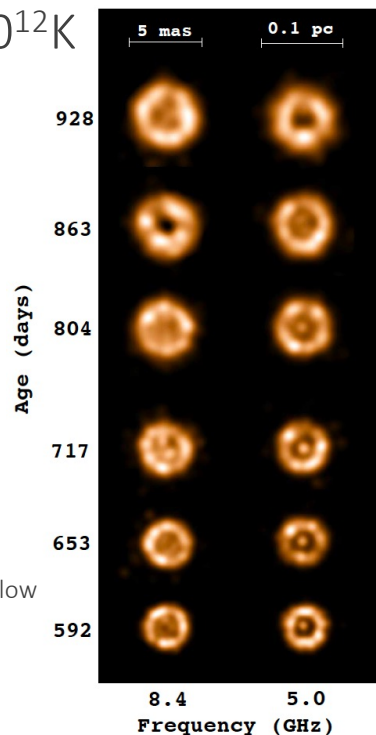
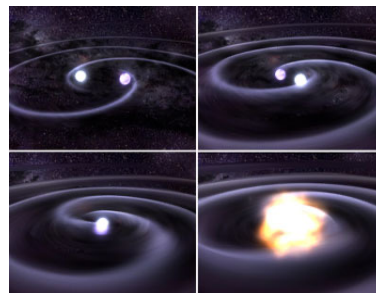
Slow-transients (.... >>1s)

- Incoherent emission
 - Typically Synchrotron (occasionally thermal)
- Longer timescales (Minutes to Years)
- Typically brightness temp $<10^{12}\text{K}$
- Explosive or outflow events...
- Dynamical imaging detection
- Examples:

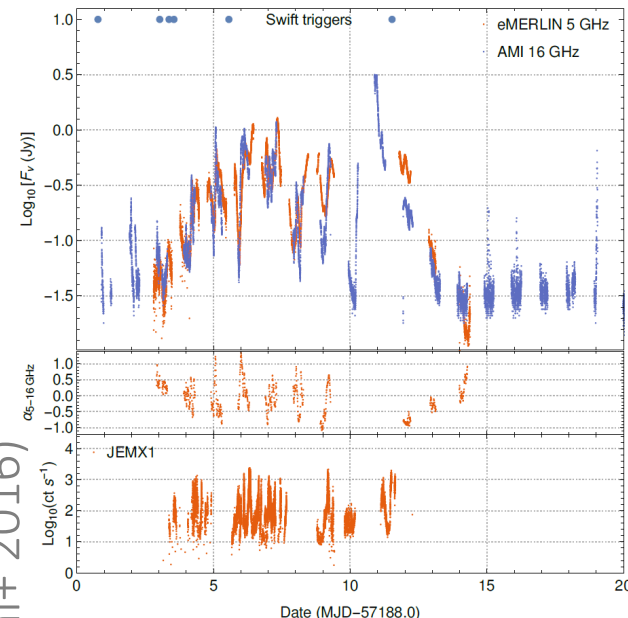
- AGN & microquasar/XRB jets
- Supernovae (core-collapse)
- GRB afterglows
- TDEs
- Giant flares from Magnetars
- Cataclysmic Variables
- Novae...
- M.Messenger EM counterpart: GW-EM afterglow

Also, scintillation (ie. non-intrinsic variability)

- probe the scattering medium (ISM/IGM)



Radio Sne (Kimani+ 2016)



V404cyg outburst from stellar mass Black-Hole binary

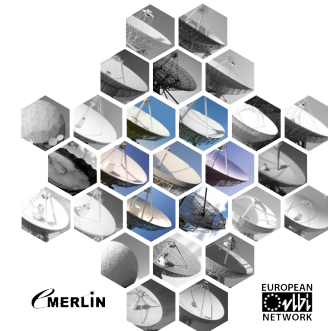
- Unprecedented coverage of particle acceleration (Fender et al., 2022)



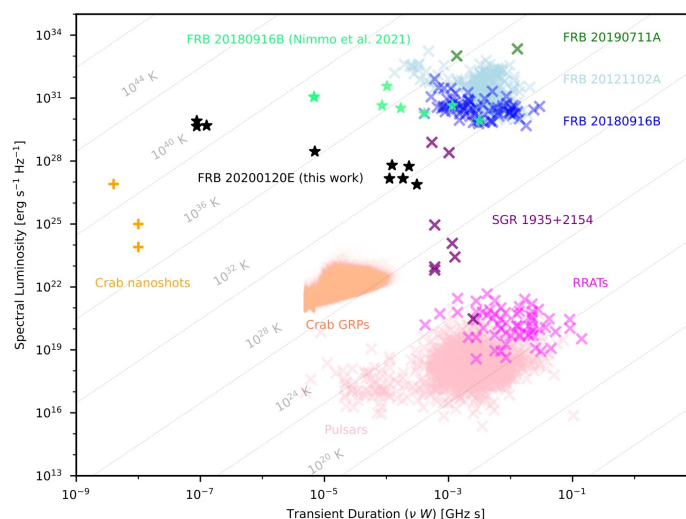
TDE - (Matilla+2018)

Single dish facilities – e.g. Effelsberg

- Large, versatile single dish facilities
- ToO/Override capabilities
- High time resolution capabilities
- ORP TA

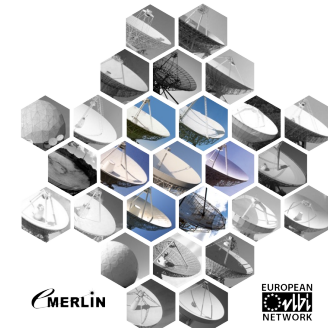


100m Effelsberg



SRT

Nimmo+ '21



High(er) frequencies – 30m, NOEMA...

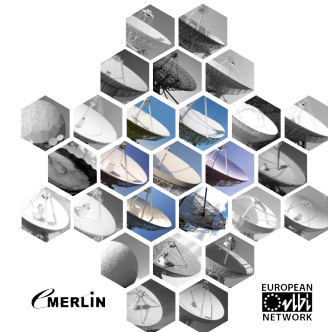
30m:

- 73-117 GHz (3mm band), 125-184 (2mm band), 202-274 (1mm band), 277-350 (0.8mm band).
- 34 arcsec @ 73 GHz to 7 arcsec @ 350 GHz

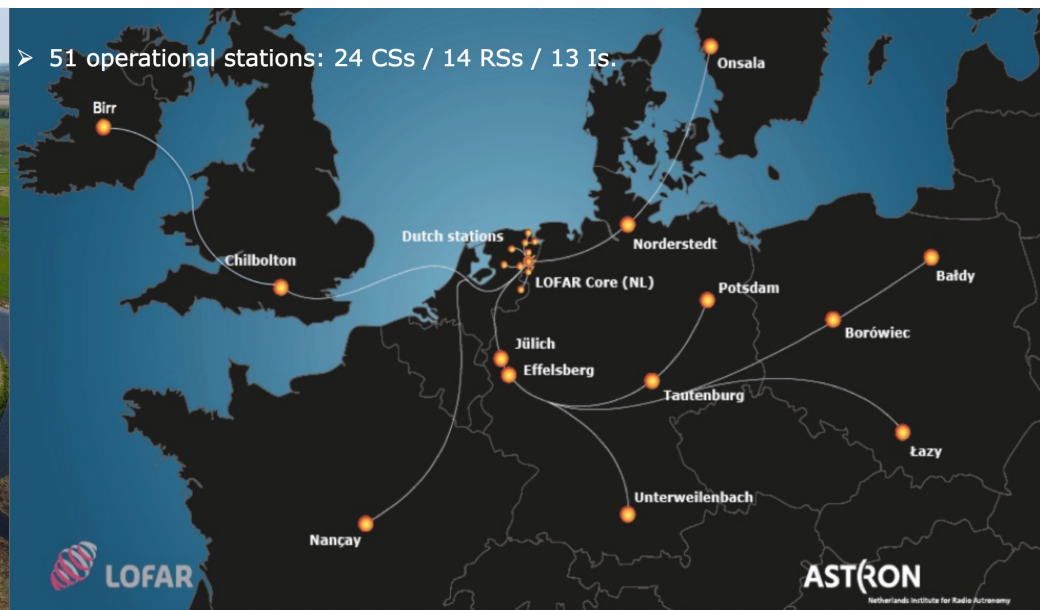
NOEMA:

- 70.4-119GHz (3mm band), 127-182GHz (2mm band) and 167-276GHz (1mm band)
- 0.5 arcsec @ 100GHz (0.2 arcsec @ 250GHz)
- IRAM - ToO proposals opportunities for both 30m and NOEMA array, & DDT)
 - Trigger reaction times can be as quick as ~few hours (30m & NOEMA)
- Wide range of science from GRB & SNe lightcurves, transient X-ray binaries, GW follow-ups, ...
- ORP TA





Low-frequency radio follow-up with the LOw Frequency ARray (LOFAR)



Targeted multiwavelength/messenger counterpart science

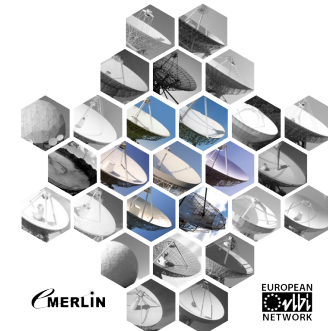
- Forced source extraction

- Blind searches in wide-fields – large instantaneous FoV

- Well established processing pipelines

- Extensive Archive capabilities and Virtual Access.

- Established TA facility



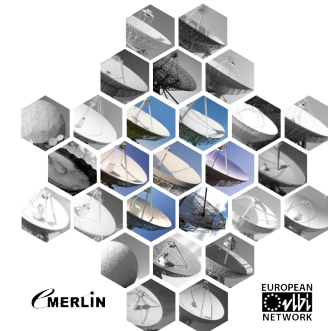
High angular resolution : e-MERLIN /VLBI - UK's National radio Astronomy Facility

e-MERLIN (SKA-pathfinder) operating
at cm- λ with μ Jy sensitivity and \sim 10-
220km baselines



Key/integral part of the e-MERLIN+EVN

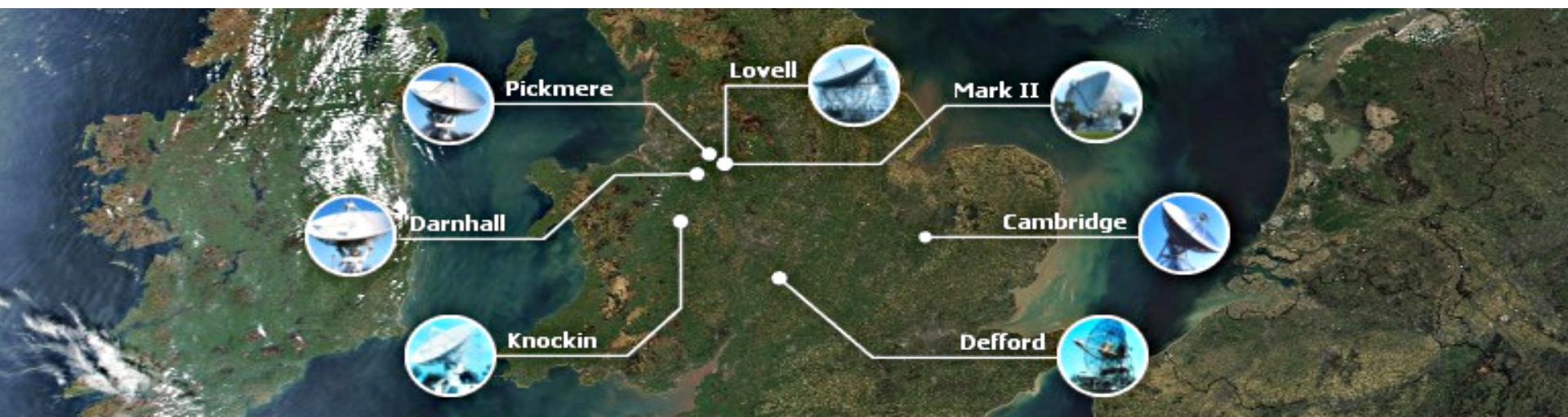
- providing 'short' spacing baselines
- fully integrated operations (baselines 10-10,000s-km)

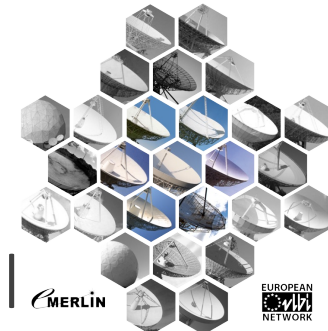


e-MERLIN - intermediate baseline (12-217km) between the VLA and VLBI



- New more sensitive receivers for all observing bands
- Wide-band deep high-resolution imaging, wide FoV
- Unique position → high-resolution imaging at 1 to 25GHz
- Links VLA and VLBI with combination imaging to both
- Rapid automated delivery of images from large datasets
- e-MERLIN data routinely available as short baselines for EVN
- LOFT-e development for v. high time resolution imaging (non-imaging)
- Rapid scheduling & data delivery for time-critical experiments
- Quick turn-around for time-critical actions – on-source in mins/hours/days depending on event type & request





Even higher resolution:
Continental scale arrays – e.g. EVN/e-VLBI

EVN – 20+ of largest
telescopes in the
world.

...most sensitive VLBI array...

- Wide frequency coverage
- mas imaging
- Extended baselines e-MERLIN+EVN
- Real-time eVLBI over fibre
- Increasing availability

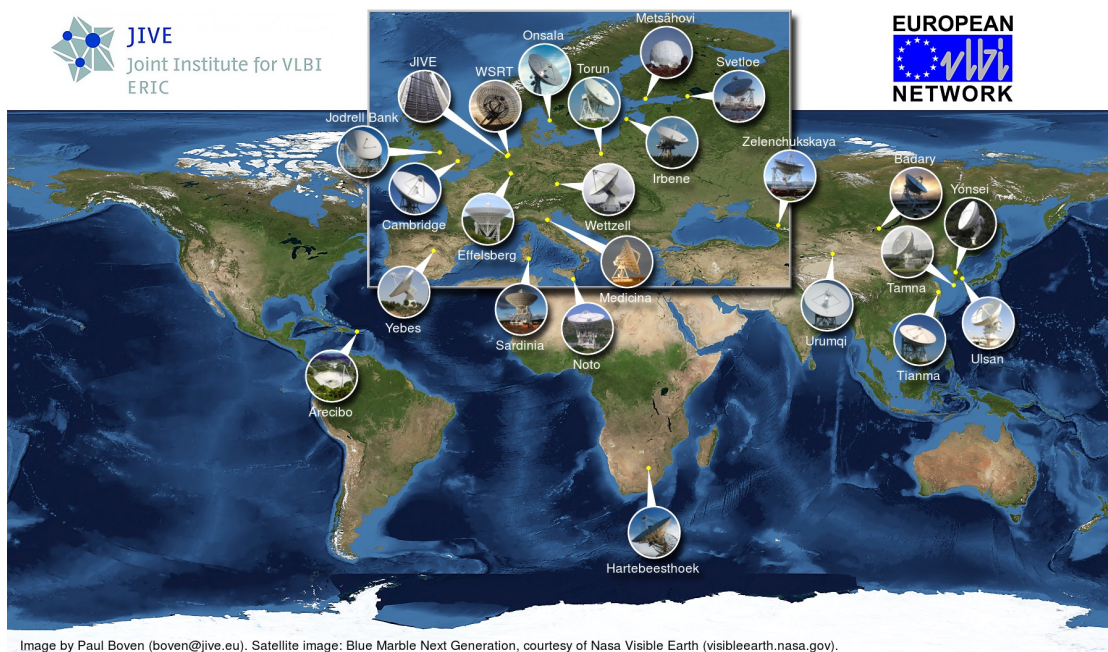


Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Very high resolution allows sources and events to be resolved and tracked

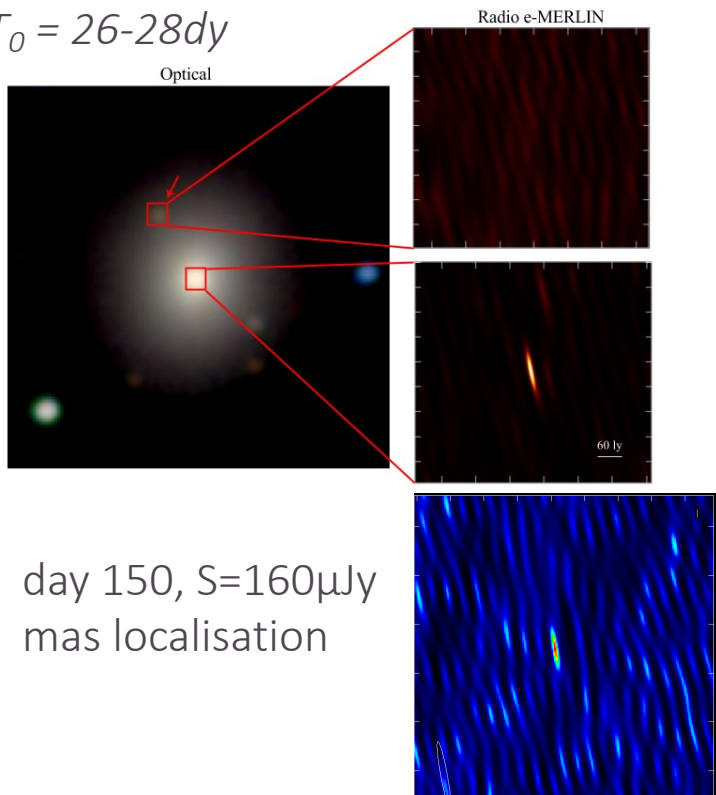
- Unique capability of VLBI arrays

The role of radio (& e-MERLIN/VLBI)

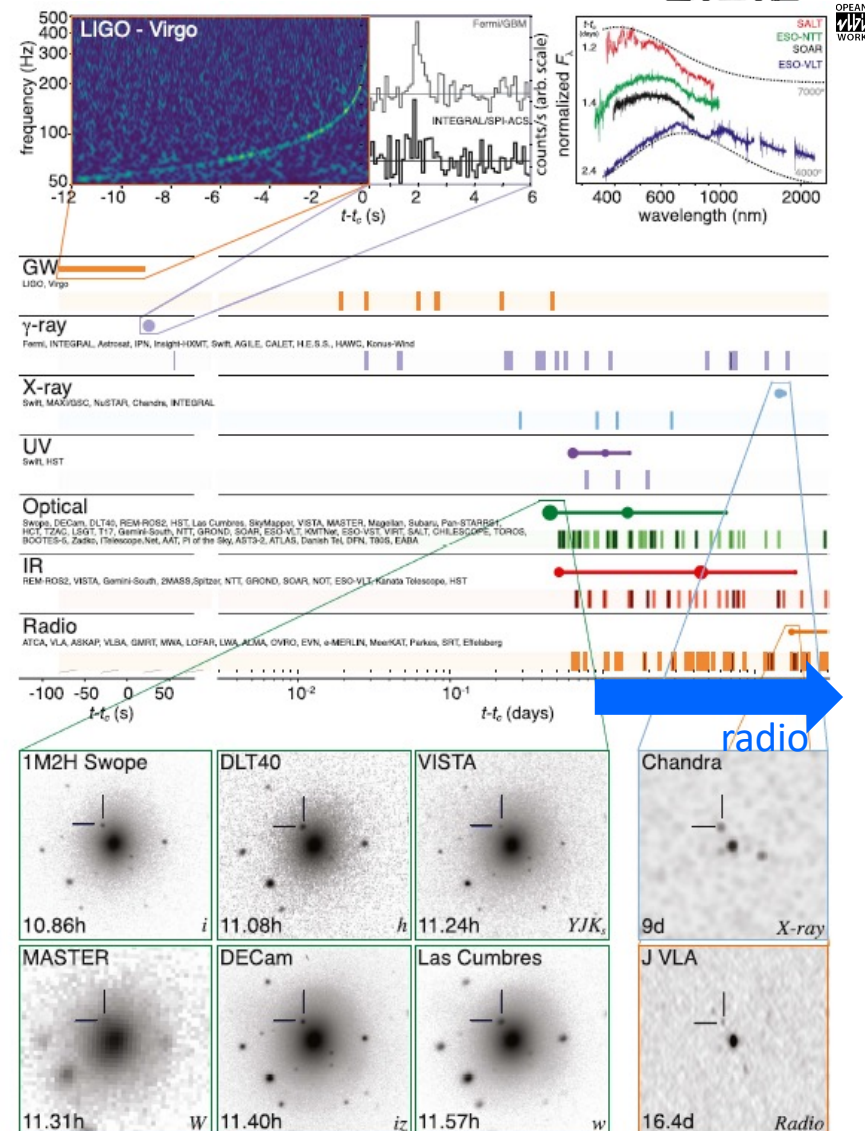
eMERLIN/EVN EM-GW follow-ups

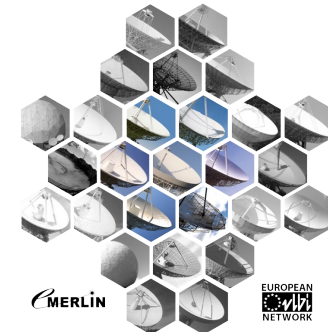
e-MERLIN follow-up extremely challenging due to sky position (Dec = -23.4deg → very short duration observations, <15deg max elevation)

$T_0 = 26-28\text{dy}$



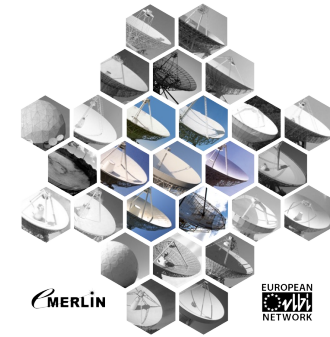
day 150, $S=160\mu\text{Jy}$
mas localisation





Future facilities (radio)

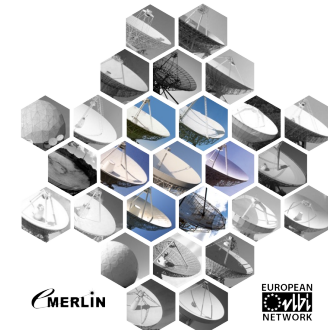
- SKA pathfinder/precursors ...now...
 - MeerKAT, ASKAP, MWA, etc
 - LOFAR, e-MERLIN, Effelsberg, uGMRT
- SKA - mid- (SA), low (Aus) ...from 2029+...
- ngVLA ...from 2030s+...
- Expanding VLBI arrays and capabilities (see Zsolt)
- Continuing capability upgrades maintaining world-class facilities (e.g Noema, LOFAR2.0, etc)



Virtual access & expertise centres (facility – user interface & services)

- ALMA Reg centres – ESO + National nodes
 - Long track record of world-leading support
- Existing – user support centres of excellence and virtual access archives –
 - e.g. ASTRON (LOFAR, APERITIF), JIV-ERIC (VLBI), UNMAN (e-MER/VLBI, SKA pathfinders, ALMA)
- SKA Regional Centres –
 - Part of Global SRCNetwork. National funded centres in partner countries – under-development

Facilities in their own right: combining expertise & support, archive access, and e-infrastructure to support user analysis.



SKA Reg Centres – global project

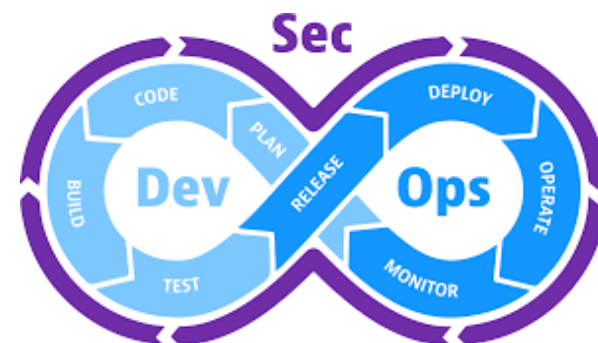
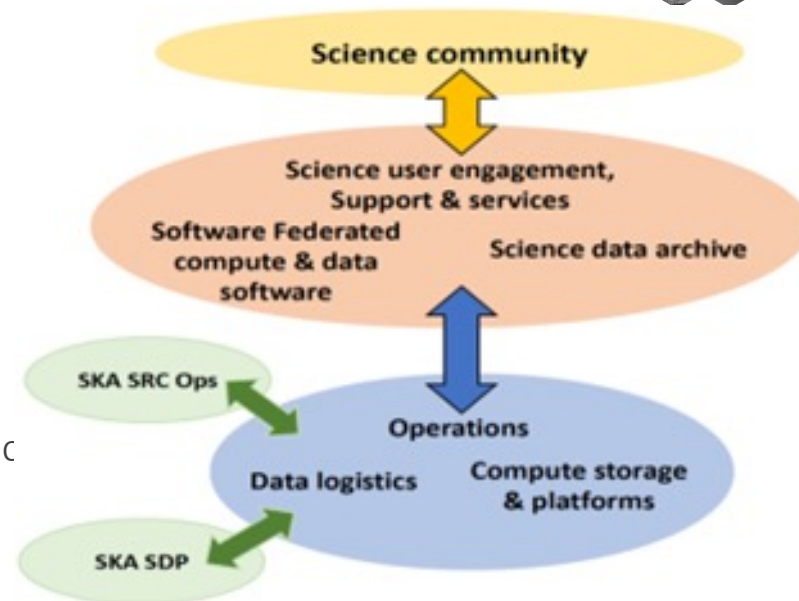
- SRCs will be sole-access point between users and SKAO data
- Support to create, archive Advanced data products
- Supply necessary compute & data storage
 - Huge Data logistics and big data challenge

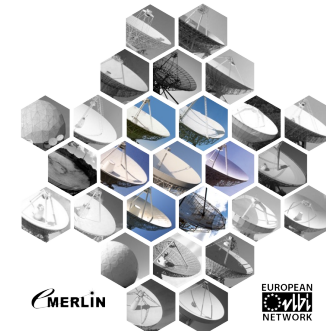
e-infrastructure to deliver and maximize SKA science

Distributed network in SKAO partner countries

Partnership between SKAO-SRCSC (country partners)

Major global development in preparation for SKA (full obs c. 2028/29). Will support pathfinder facilities as well – virtuous circle of development and support.



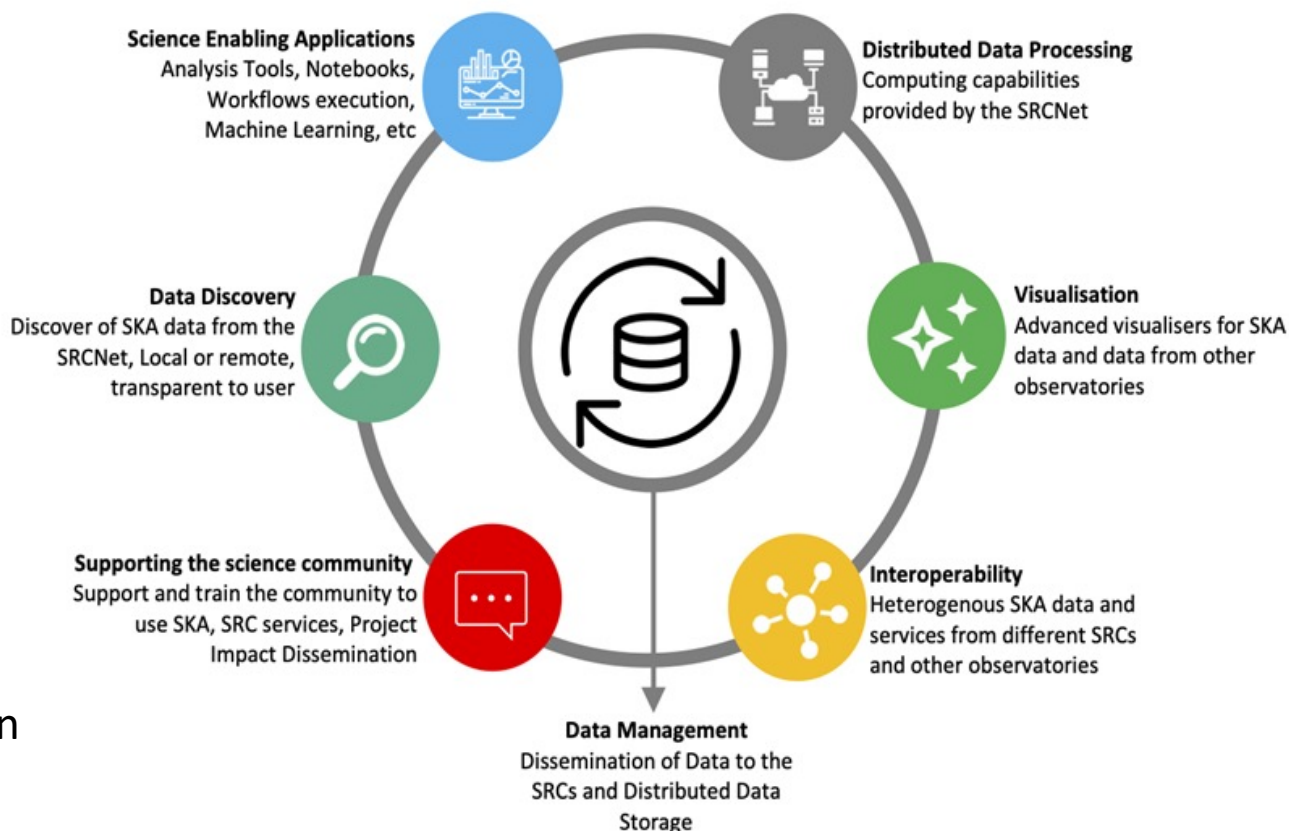


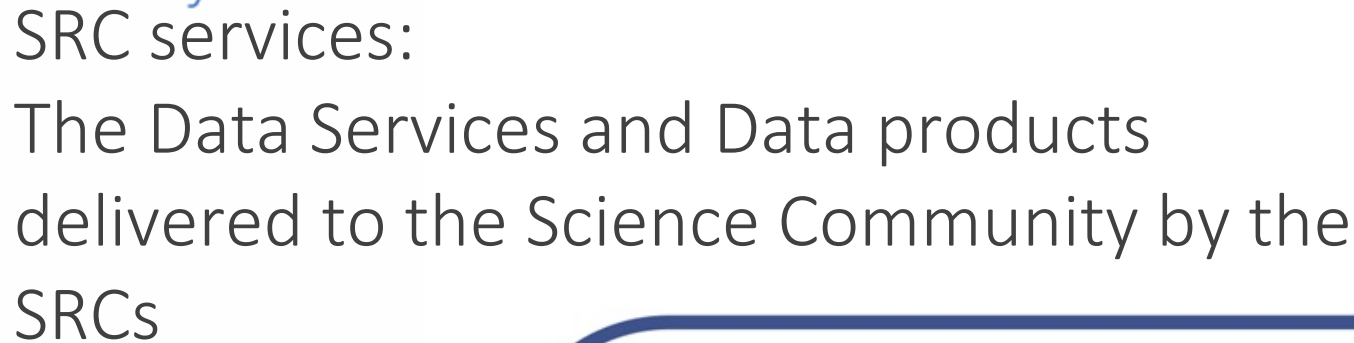
Essential Services to be delivered by the SRCs

These services sit on 3 major technologies

- Cloud technology – Openstack
- Performant hardware Platforms for Computing and Storage
- Performant Networks

Courtesy of Rosie Bolton





- Workflows & analysis tools**

Advanced Data Products & Science

Power spectra

Image cutouts

Publication plots

Beginning to End Science Support

Advanced analysis resources

Domain Expertise

Training and engagement

Catalogues & source lists

SKA Regional Centres: maximising science returns from the SKA

Iterative co-development of UKSRC functionality... deploying a powerful proto-SRC

WP3 – community engagement & support, demonstrator cases, champion scheme

User support

Demonstrator
& Champion
Schemes

UK
Astronomy
community

Better support for
researcher-users

Researchers'
experience &
feedback from
using proto-UKSRC

New research
ideas & community

Better researcher-
user understanding
of the technology
& their ability
articulate technical
needs

Agile framework & shared WP2.3 /WP3 posts enable
rapid feedback between work packages

Iterative development
of UKSRC's capabilities

Aligning technical and research activities enable us to
meet both the SRCNet technical and UK research
community requirements.

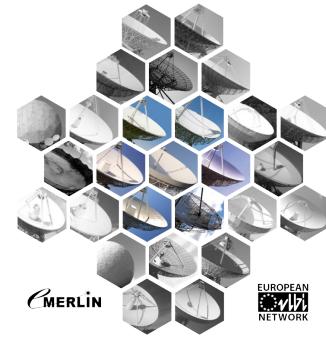
WP2 – technical development

New UKSRC
technical
capabilities to
available to
researchers via
'Science
Platform'

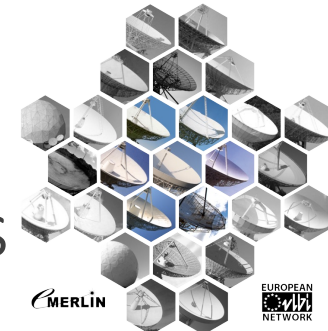
New bleeding-
edge hardware
and software
available from
vendors

UKSRC and SRCNet
engineering teams

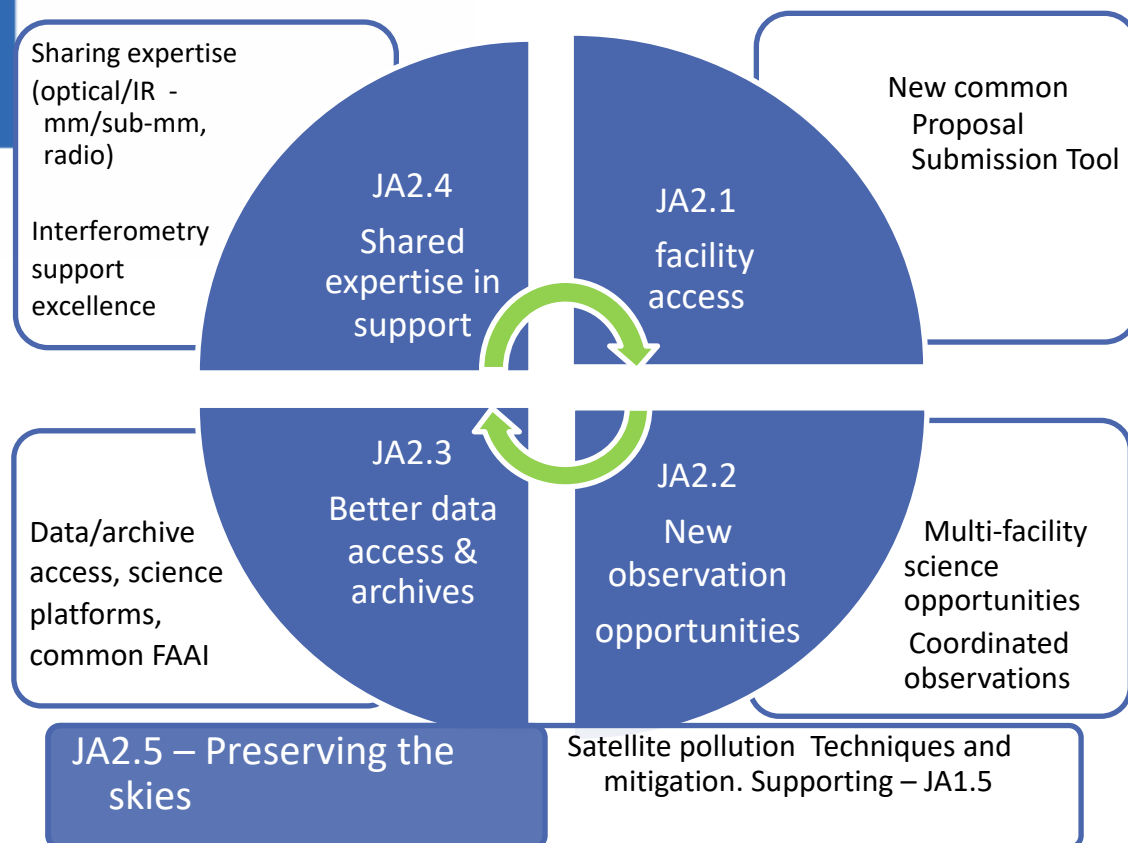
Capital
Development
Programme



... coordinated facility developments ...



H2020 ORP: JA2: Harmonization Activities



Action: tailored to target key parts of the project lifecycle:

- common points of user-facility interfaces (e.g. proposals, support, data access).

5 sub-WP:

JA2.1 – multi-facility, Common proposal standards and tools

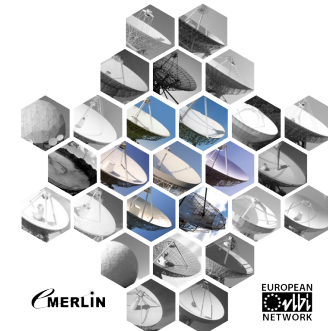
JA2.2 – Multi-facility observations and supporting tools

JA2.3 – Archival data access and tools

JA2.4 – User-support excellence

JA2.5 – Common threats and challenges (mega-constellations)

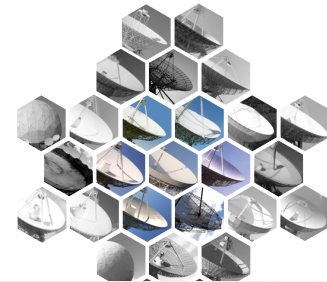
Challenges and opportunities: Decades of experience across multiple facility communities, but remain mindful of differences and operational needs of facilities (well-established and well-founded practices)



Summary pt1 -

- Wide range of radio facilities
- Full-services, and experience in e-2-e user support
- Long-track record of TA/VA involvement
- Unique set of complementary science capabilities – high relevance to MM & Transient science - see next
- Extensive and growing suite of VA & excellence centres
- Radio & mm-wavelength coverage is vital to transient & multi-messenger science

ACEME: Opportunities across all parts of the programme, from traditional TA to VA and virtual expertise centres, and technical enhancements/standards to increase coordinated approaches. (c.f. LOFAR & e-MERLIN document inputs for more details)



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