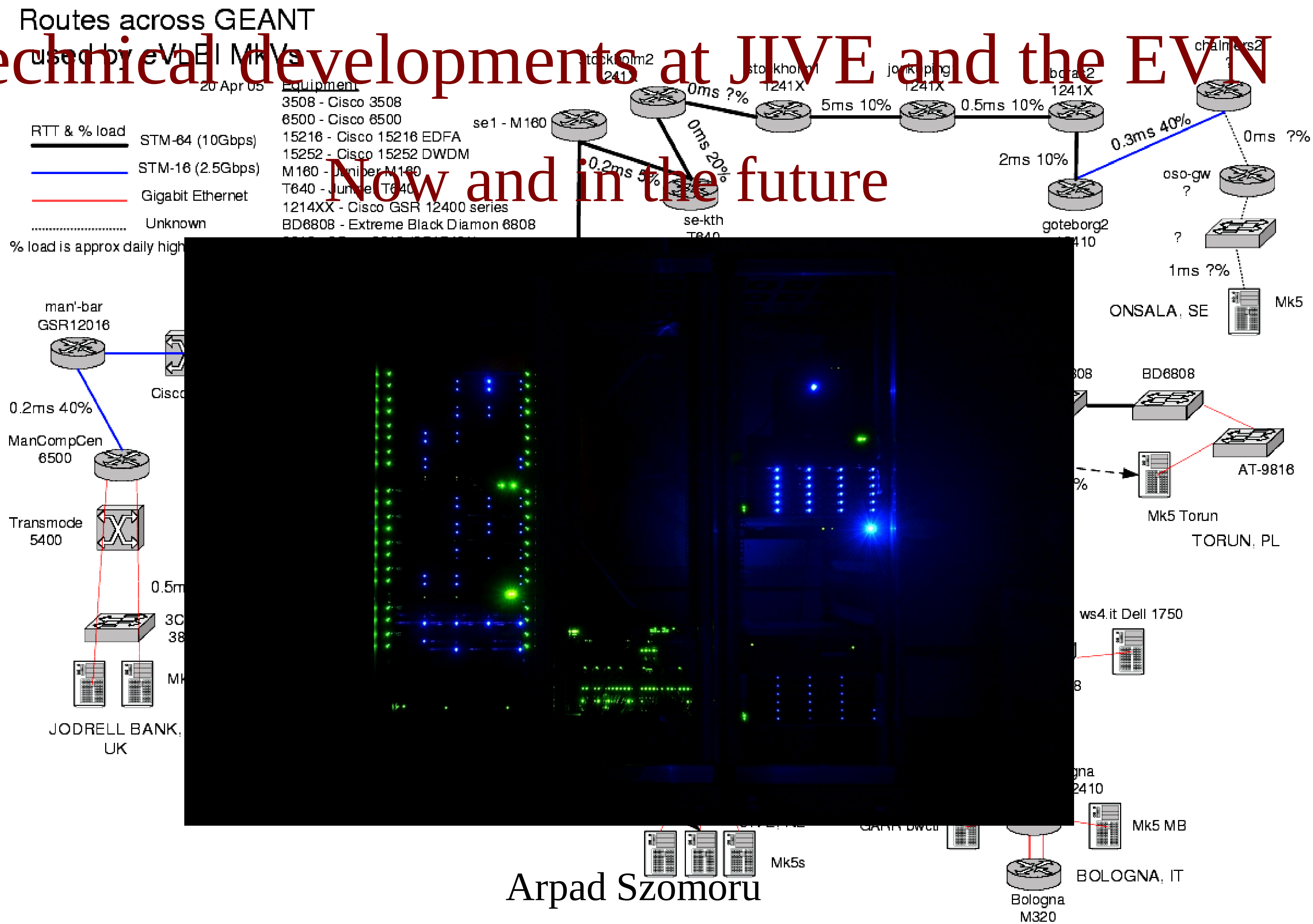
Technical developments at JIVE and the EVN

Now and in the future



Arpad Szomoru

JIVE - Joint Institute for VLBI ERIC -

- Promote and advance the use of VLBI for astronomy
  - Central correlation for European VLBI Network
  - Operational feedback to stations
  - User support
    - Preparation of observations
    - Data reduction
  - Improvement of VLBI technique in general
- Base budget from partners in 8 countries:
  - China, France, Germany, Italy, Spain, Sweden, United Kingdom, the Netherlands, South Africa
  - hosted by ASTRON
  - European Research Infrastructure Consortium (ERIC) since end 2014

Projects

No R&D budget

- R&D financed through EC and NWO projects

2006	**EXPReS**	**SA1**
		SA2
		JRA1
2008	**NWO-SCARIe**	
2009	**NWO-ExBox**	
	RadioNet FP7	**UniBoard**
		ALBiUS
2010	**NWO-ShAO collaboration**	
	NEXPReS	**SA1**
		SA2
		JRA1
		JRA2
2012	RadioNet3	**UniBoard^2**
		Hilado
2014	BlackHoleCam	WP1.1
		WP1.3
	NWO SKA-NL roadmap	SaDT: SAT architect
		SKA-VLBI
2015	H2020 ASTERICS	**Cleopatra**
		Obelix
	NWO KAT7-VLBI	

Not counting Space Science projects!

What do we do?

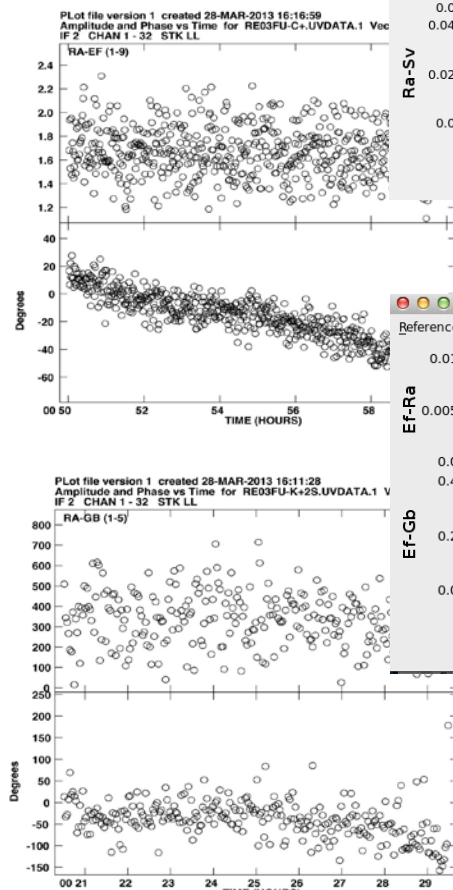
- Correlators
  - More capacity, new telescopes, development of AVN
  - New features, new science
- Data recording/playback/transport
  - Real time/near-real time
  - Higher bandwidths: 2 and 4 Gbps
- Automated operations
  - Get rid of disk shipping
  - Monitoring, automated fringe checking
  - Triggered observations
- SKA and mm VLBI
  - **User software**, VLBI with CASA
  - Simulations for BHC
  - Fringe checking
- Time and frequency transfer
  - For SKA
  - And on public networks

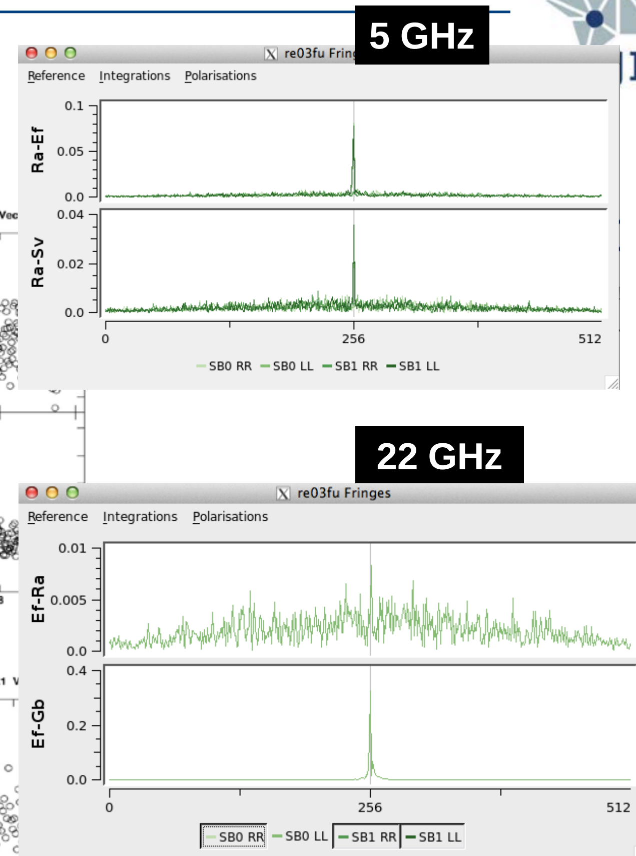
SFXC software correlator at JIVE

- 40 nodes; 384 cores
  (Intel Xeon 5500/5600/E5-2600)
- 13 stations @1Gbit/s real-time
  (with cross-polarisations)

- Multiple phase centers
- Combination of gating and binning
- Coherent de-dispersion
- Phasing up of the EVN
- Mixed Bandwidth Correlation
- Accepts Mark5B, VDIF
- And 4GHz bands

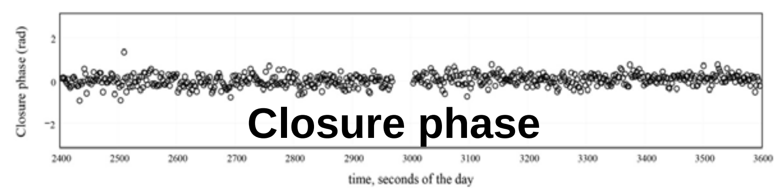
RadioAstron fringes on SFXC at JIVE



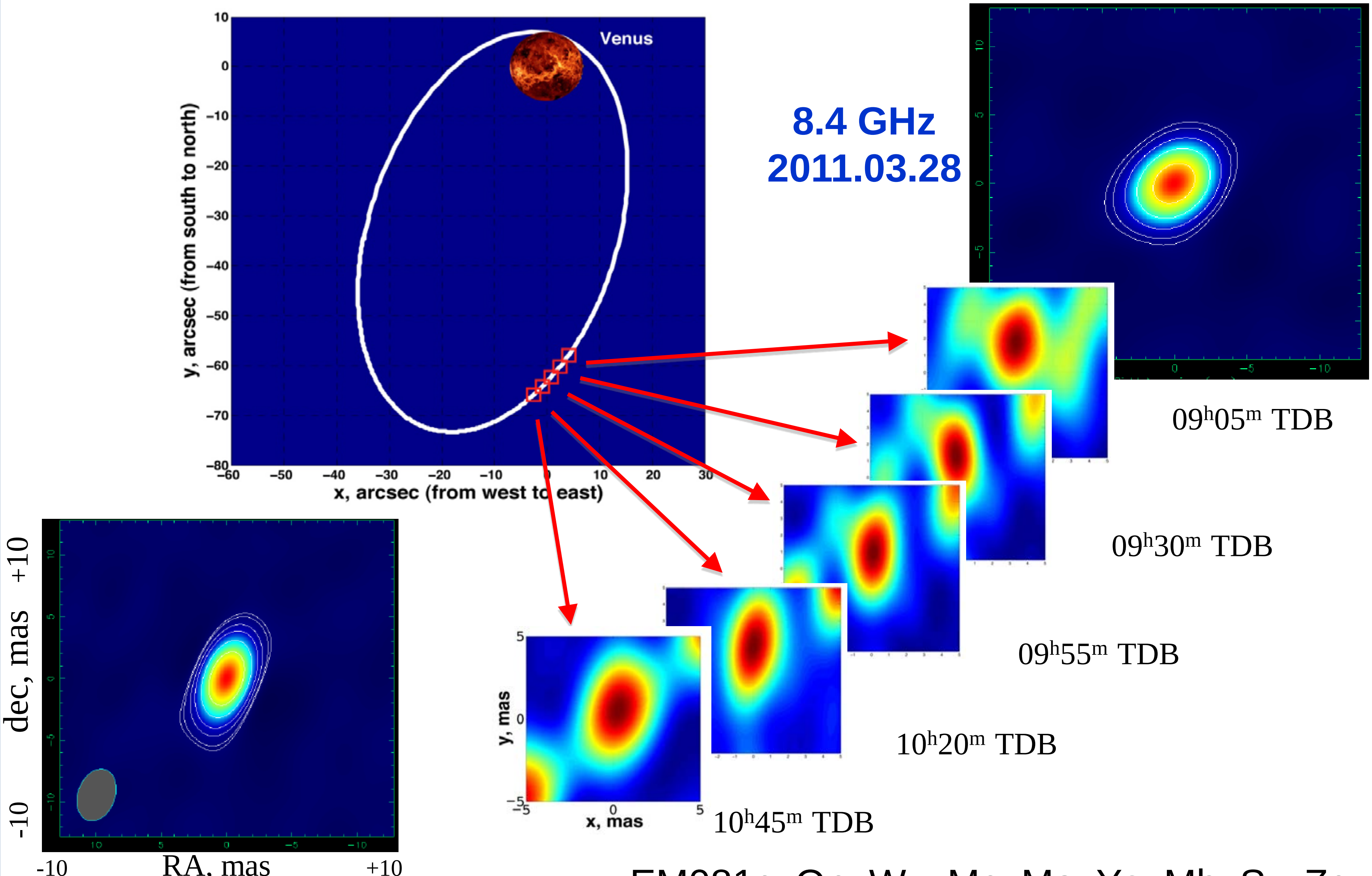


0716+714

B ≈ 2.5 D_{Earth}

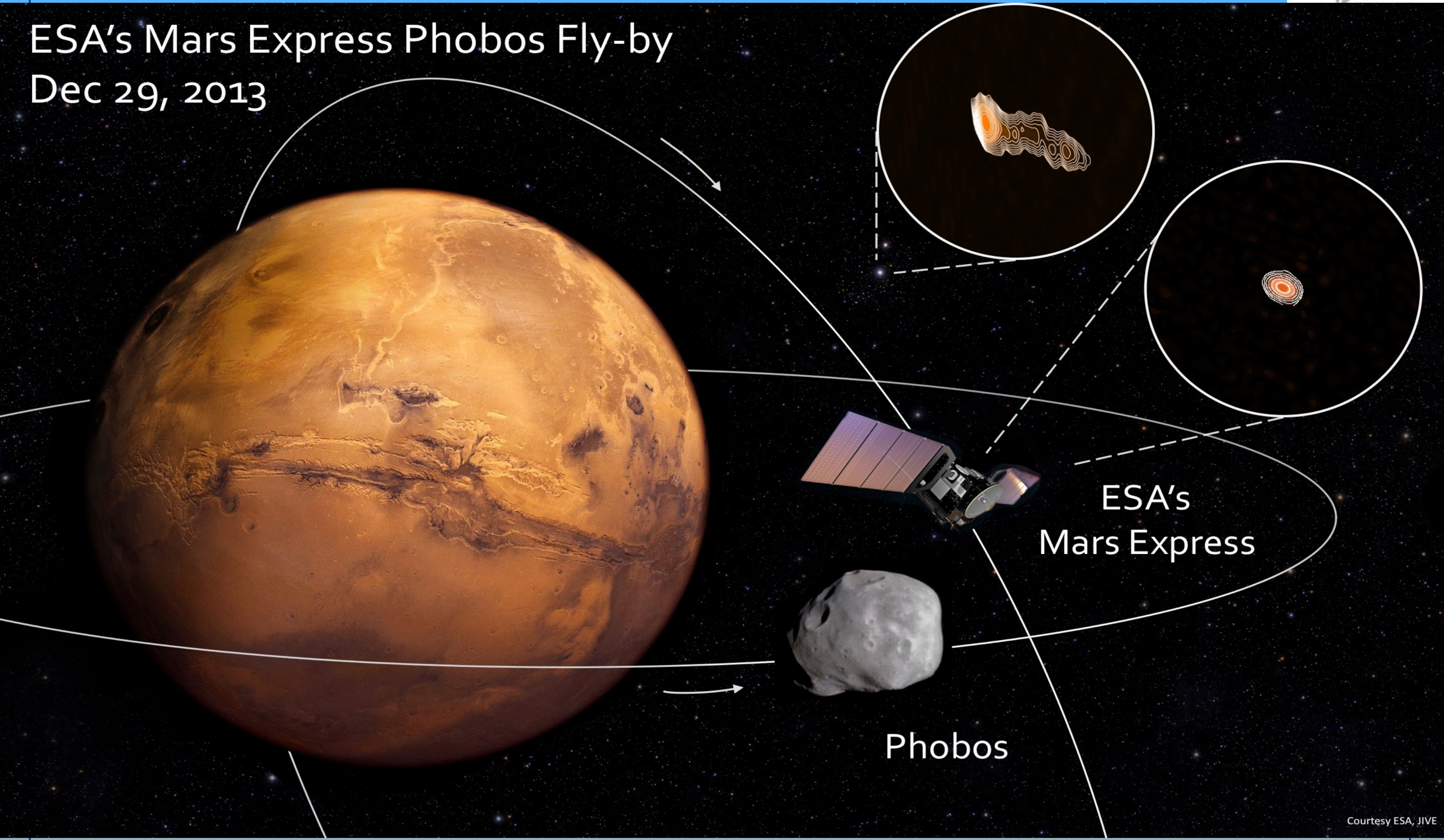


Space Science: tracking of VEX



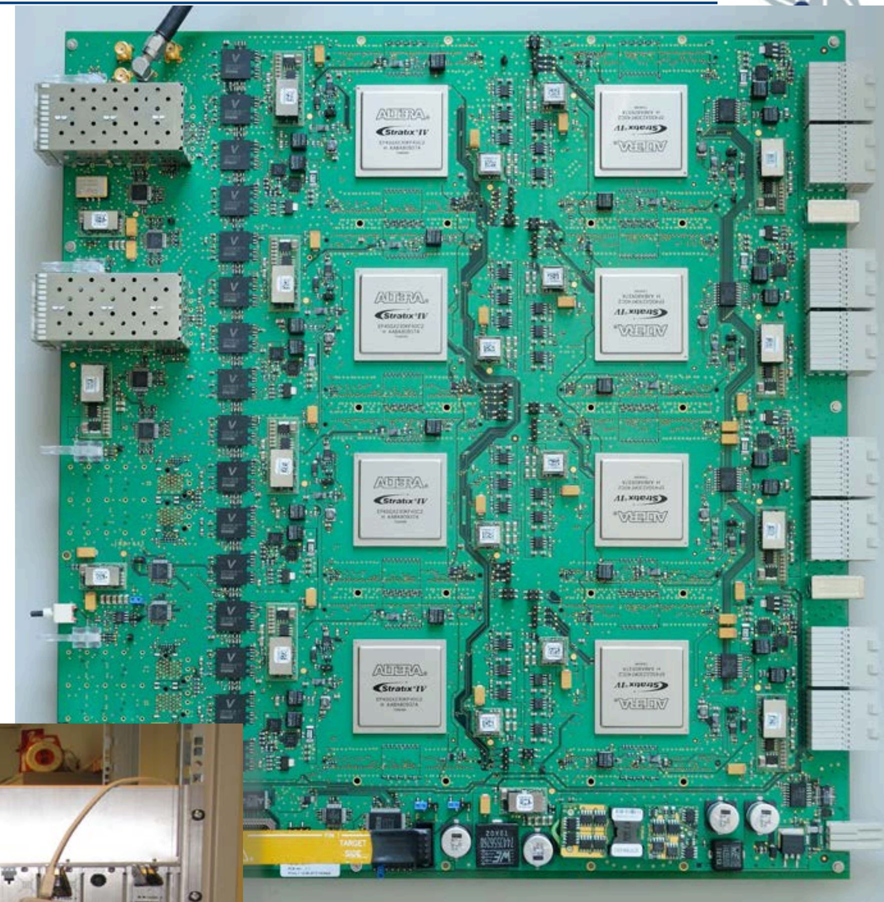
EM081c: On, Wz, Mc, Ma, Ys, Mh, Sv, Zc

ESA's Mars Express Phobos Fly-by
Dec 29, 2013



JUC (JIVE UniBoard Correlator)

- UniBoard: EC-funded, led by JIVE
  - JRA in RadioNet FP7 (also in RadioNet3)
  - Create generic, high performance computing platform for radio astronomy
  - ASTRON in charge of hardware development, various partners developing different personalities of board



Data recording/transport: Jive5AB

- Born out of despair of ever getting e-VLBI going with "standard" Mark5 control code
- Made e-VLBI possible at all
- Slowly has grown into "the Swiss knife of (e) VLBI"
- Now supports virtually any hardware
  - Mark5 in all its flavors, Mark6, FlexBuff, regular PCs
- Together with M5copy, very powerful and user-friendly tool
  - Transfer data from anything to anything
- Gaining traction in geo community as well

Jive5AB: too much to mention….

- Runs on Mark5A, Mark5B and Mark5C and auto-detects hardware
- Runs on non-Mark5 platforms and offers ethernet packet recording; the machine becomes a FlexBuff or Mark6 depending on how the software is configured
- Efficient synchronizing of a FlexBuff recording between two FlexBuff machines: only data for the recording not yet present on the destination FlexBuff is transferred
- Supports the following data formats: MarkIV/VLBA, Mark5B and VDIF
- Has a selection of data transport endpoints ("file", “disk pack", "formatter", "network", "generated fake data", "shared memory buffer") and implements almost a full matrix of "from" => "to" for all combinations
- Exploits the Mark5 StreamStor "forking" capability: a copy of the recorded data stream can be stored in a shared memory buffer
- Supports many protocols for network transfer: UDP/IPv4 for real-time transfers, TCP/IPv4 for local offline transfers and UDT/IPv4 for fast and reliable long-haul
- Can do real-time de-channelization/corner-turning of multi-channel VLBI data
- Is documented!
- Etc etc etc
- Talk by H. Verkouter

Data recording/transport: M5copy

- Made “disk-shipping-less operations” possible
- Complete EVN session recorded locally on FlexBuff at Onsala
    - Transferred fully automatically to FlexBuff at JIVE
    - Nearly real-time
    - Could even start correlation automatically
    - No more disk shipping!!

Automated triggering

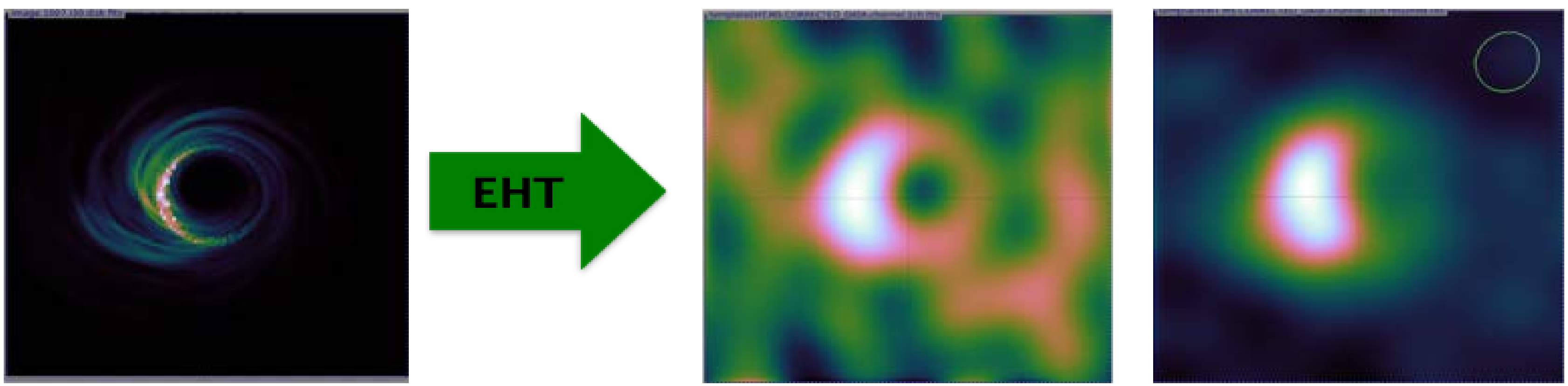
- Prototyped in NEXPReS
- And shown to work in several demos
- Now offered as observing mode
  - Albeit only during e-VLBI
- Pre-approved triggers can override lower-ranked observations

- Need mechanism, and software of course
  - VOevents
  - Working with PI on protocols, verification

- First step towards offering this as general EVN observing mode

JIVE involvement in BlackHoleCam

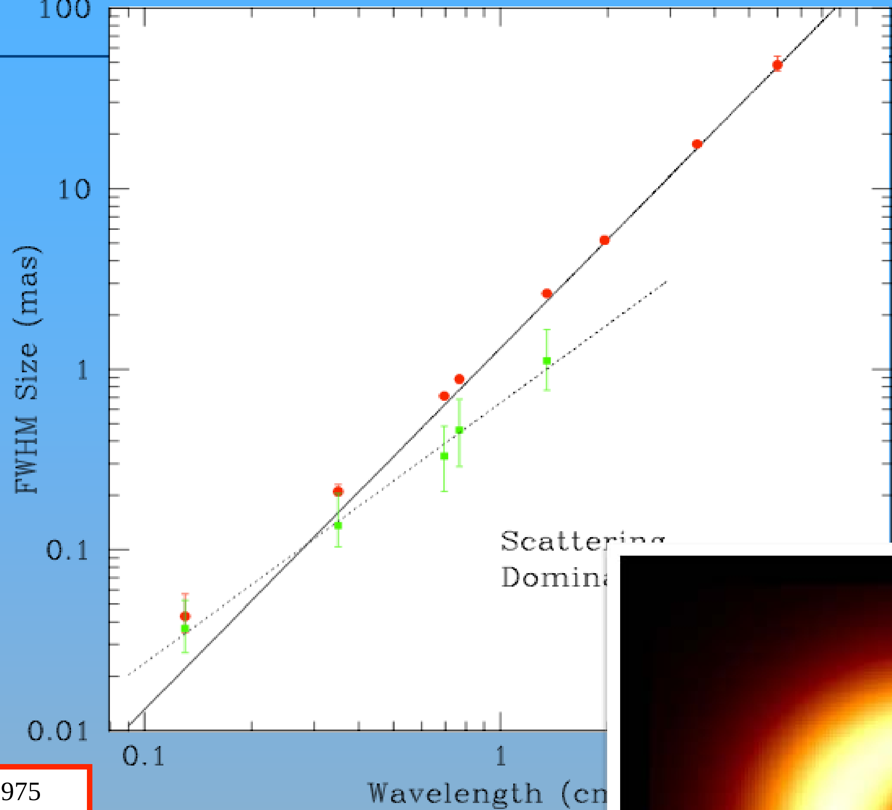
- Software pipeline [JIVE]
  - CASA-based fringe-fitter for VLBI
- Array simulation [JIVE, Radboud, Rhodes]
- Semi-automated fringe checks for mm-VLBI [JIVE, MPIfR]



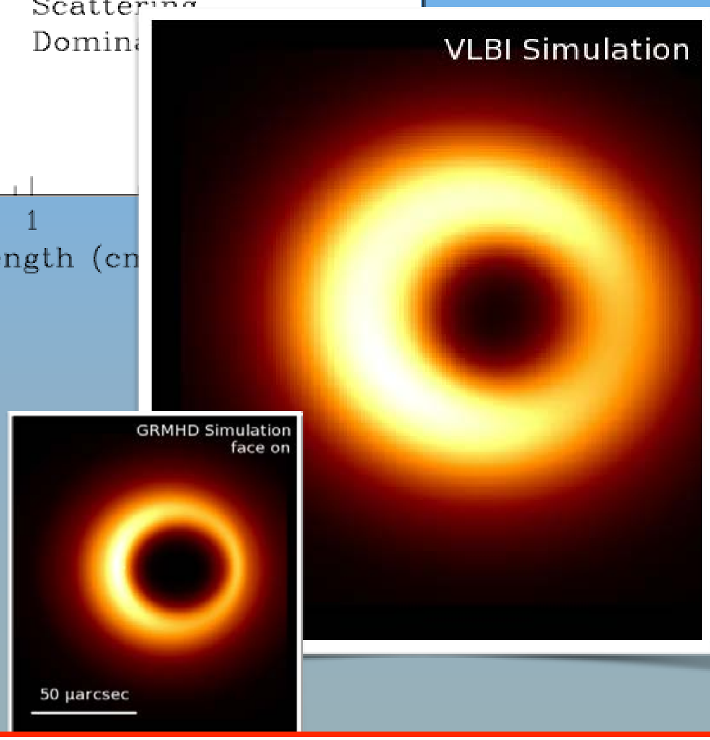
Courtesy: Monika Moscibrodzka, Roger Deane

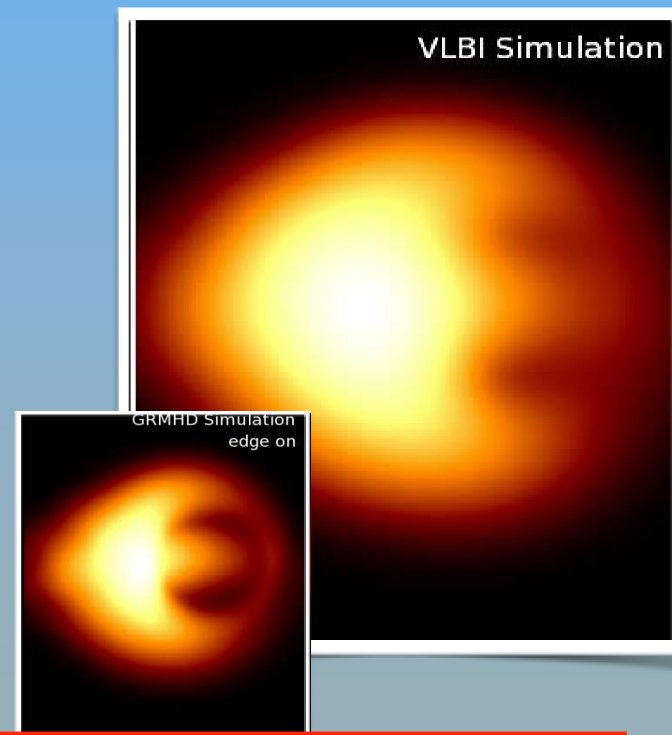
Measured size of SgrA*

- At Centre of Galaxy
- Best constrained SMBH
- Resolvable at mm wavelengths



Lo 1975
Jauncy 1989
Lo 1985
Marcaide 1999
Backer 1993
Krichbaum 1993
Bower 2004
Rogers 1994
Krichbaum 1998
Shen 2005
Doeleman 2008
Fish 2011





- **The event horizon shadow lensed to 50μas in diameter submm-wave VLBI resolution 12-20μas**

New (again): user software

- *Work on SKA-VLBI:*

- Modifications of the correlator code
  - Allow the use of separate calibrator beams.
  - Application of primary beam corrections

- CASA-specific, complementing work for BlackHoleCam
  - Fringe fitting (both Schwab-Cotton and HOPS methods)
  - Remove assumption that arrays consist of (nearly) identical elements.
  - Three more will be deployed to participate in in-beam calibration with the other elements of the VLBI array. Adaptations to the correlator code and additional bookkeeping in data processing will be needed.
  - Fix the assumption that system temperature measurements are provided on a uniform grid for all array elements
  - Support for user-provided gain curves
  - Tools for polarization basis conversion will be needed

Asterics

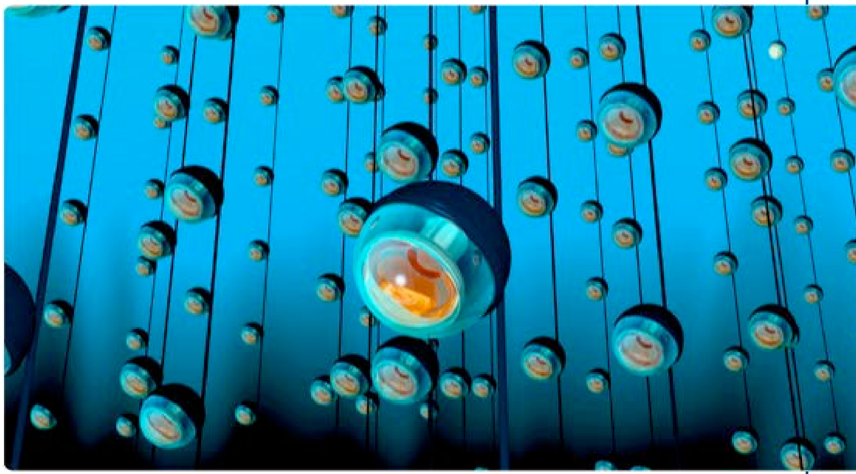
Astronomy ESFRI & Research Infrastructure Cluster

Addressing Cross-Cutting Synergies and Common Challenges for the Next Decade Astronomy Facilities

Background

- The European Strategy Forum on Research Infrastructures (ESFRI) is a strategic instrument to develop the scientific integration of Europe
- For the Astronomy and Astroparticles communities ESFRI has identified four facilities whose science cases are so out-standing that they can be considered as the main (ground-based) priorities in Europe:

  - the Square Kilometer Array (SKA)
  - the Cherenkov Telescope Array (CTA)
  - the km^3 Neutrino Telescope (KM3NeT)
  - the European Extremely Large Telescope (E-ELT)



What is ASTERICS ?

- Astronomy ESFRI Research Infrastructure CluSter (ASTERICS)
- Topic: Implementation of cross-cutting solutions for clusters of ESFRI research infrastructures and ERICs
- Focus of ASTERICS is on projects endorsed by ESFRI: SKA, CTA, KM3NeT, with close links to EELT and EGO, plus path-finders and world-class experiments (e.g. LOFAR, Euclid)
- ASTERICS represents the first major European collaboration Astronomy/Astrophysics/Astroparticle Physics
- 23 partners funded by EC Horizon2020 at 15 M€ for 4 years

ASTRON, CNRS, INAF, UCAM, JIVE, INTA, UEDIN, UHEI, OU, FAU, VU, CEA, EVA, UGR, FOR, IEEC, IFAE, UCM, INFN, STFC, DESY, SURFnet, Oxford (with external support of ESO)

ASTERICS Programme

ASTRONET is an initiative created by a group of European funding agencies in order to establish a strategic planning mechanism for all of European astronomy.

- ASTRONET has identified some key common challenges for Astronomy:
  - Public engagement
  - Big Astronomical Data (BAD?)
  - extended use of the Virtual Observatory (VO)

- ASTERICS has also identified some common R&D h/w (and s/w) technology challenges.

Basic Data

- Awarded ~ 14.991 M€ from EC.
- 22 partners from 7 different countries.

WP Number [9]	WP Title	Lead beneficiary [10]	Person-months [11]	Start month [12]	End month [13]
WP1	Management	1 - ASTRON	88.00	1	48
WP2	Dissemination, Engagement and Citizen Science (DECS)	9 - OU	53.00	1	48
WP3	OBELICS (OBservatory E-environments LInked by common ChallengeS)	2 - CNRS	752.00	1	48
WP4	DADI (Data Access, Discovery and Interoperability)	2 - CNRS	476.00	1	48
WP5	CLEOPATRA: Connecting Locations of ESFRI Observatories and Partners in Astronomy for Timing and Real-time Alerts	5 - JIVE	332.00	1	48
		Total	1,701.00		

ASTERICS Work Packages

JIVE

WP2 – DECS: Dissemination, **E**ngagement and **C**itizen **S**cience

WP3 - OBELICS: Observatory **E**-environments **Li**nked by **C**ommon challenge**S**

- Software interoperability
- Training in parallel programming and big data frameworks
- Adapt and optimise extremely large database systems for ESFRIs
- Data mining tools and statistical analysis techniques on petabyte data sets

WP4 - DADI: Data **A**ccess, **D**iscovery and **I**nteroperability

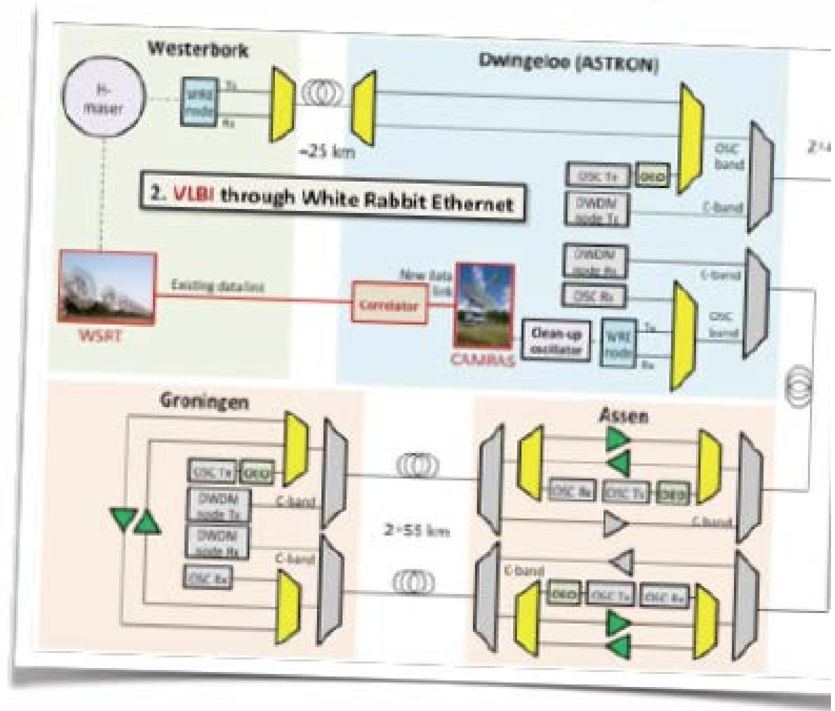
- Training and support for the scientific use of VO in general
- Train and support staff of ESFRI projects
- Adapt VO framework and tools to ESFRI projects needs

WP5 - CLEOPATRA: Connecting **L**ocations of **E**SFRI **O**bservatories and **P**artners in **A**stronomy for **T**iming and **R**eal-time **A**lerts

- Time and frequency transfer
- relaying alerts
- data streaming software
- advanced scheduling algorithms

5.1 Synchronisation

- White Rabbit Ethernet (WRE)
  - To be used in wide-spread, long-haul facilities
    - Like radio arrays
  - Or many detector arrays
    - CTA and neutrino telescopes



- Aims
  - Upgrade to long-haul
    - Do a Westerbork - Dwingeloo VLBI test
  - Improve phase stability
    - 10^{-13} needed for VLBI
  - New calibration tools
    - Automated for many detector arrays (CTA/KM3Net)
    - Working in harsh conditions

Talk by T. Pinkert

- VU, ASTRON, JIVE, UGR, FOM, DESY, SURFnet

5.2 Multi-messenger methods

- Exchange of events
  - Can be done through VOEvents
- But policies and handshakes need to be done
  - Between various facilities
  - Filter million alerts to the one that justifies override
- Standards
  - For generation, dissemination, distribution, reaction
- Delivers:
  - Prototyping: LOFAR & EGO
  - Policies
  - Workshop
- ASTRON, CNRS-APC, JIVE, UVA

5.3 User domain data streaming

- Small project
  - Build client based on NEXPReS experience

- Inventory
  - Intelligent data streaming decisions for user domain
  - Allow users and operators to make decisions about data volume to transport
  - Setting up the appropriate protocol

- Delivers a tool…

- JIVE

5.4 Scheduling

- To schedule complex, many-element arrays
  - Important for effective return
  - Planning and decision making

- AI software
  - Optimise science return
  - Initially aimed at CTA and SKA
  - Usable for multiple frequency, multiple messenger science

- IEEC, STFC, GTD

Time and frequency transport: White Rabbit

- SKA:
  - Measure timing performance with WR-ZEN board
  - Test with 10km fibre in climate chamber
  - Test on 24.4 km dark fibre Dwingeloo – WSRT
  - Test on e-Merlin fibre, eventually on Meerkat/ASKAP sites

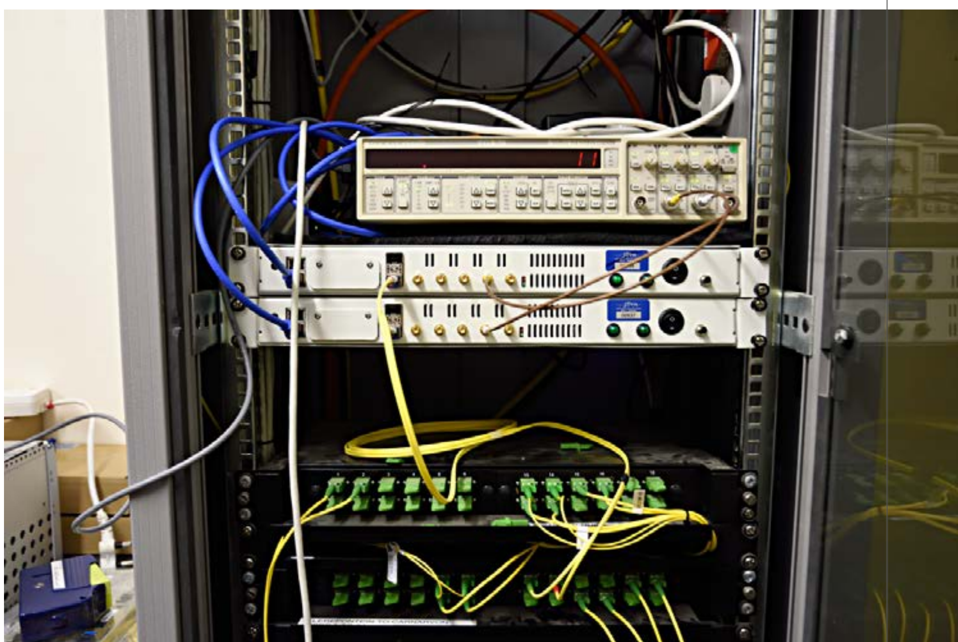
- CLEOPATRA:
  - Verify/demonstrate achieved 10^-13 stability (1s) and 1ns timing performance
    - by showing fringes between WSRT and Dwingeloo dish
  - Transfer of H-Maser signal from the WSRT to Dwingeloo

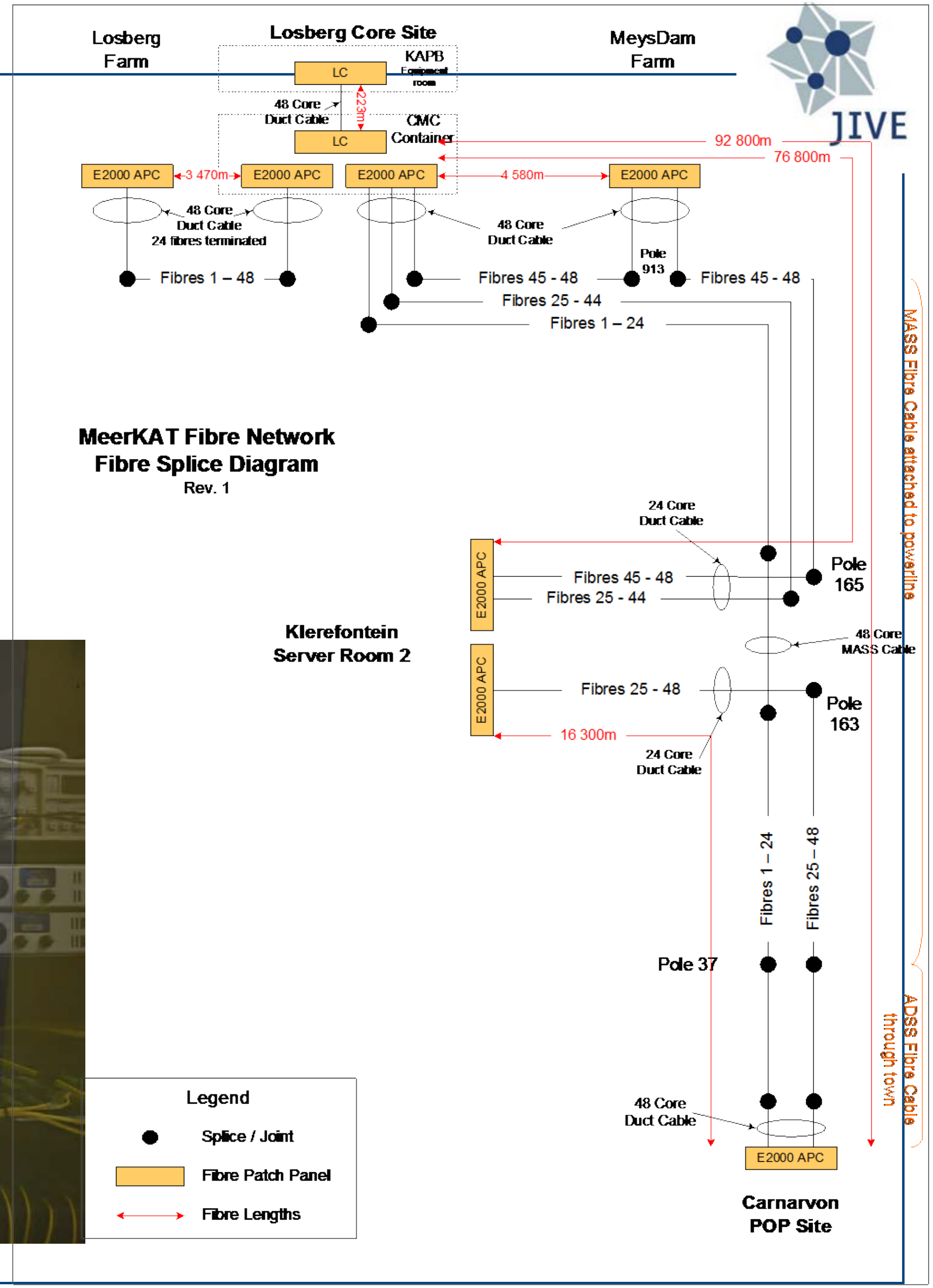
On the spot

SKA IN AFRICA
The Department of Science and Technology welcomes you to
CARNARVON, home of the Square Kilometre Array
www.dst.gov.za
www.nrf.ac.za
www.ska.ac.za
www.skatelescope.org
science
technology
NRF
National
Research
Foundation
SKA
SKA Africa
Kareeberg Municipality
SKA
www.skatelescope.org

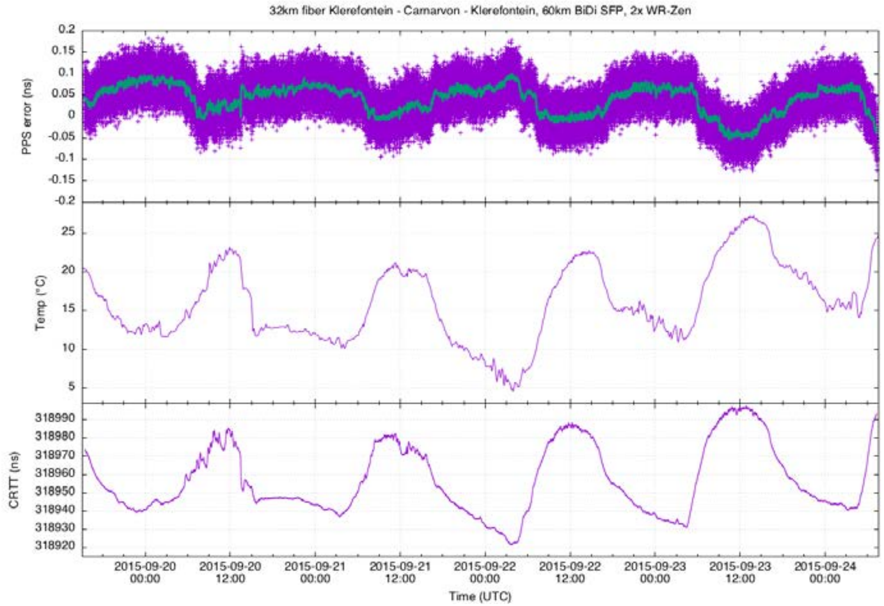
Desolation and overhead fibres

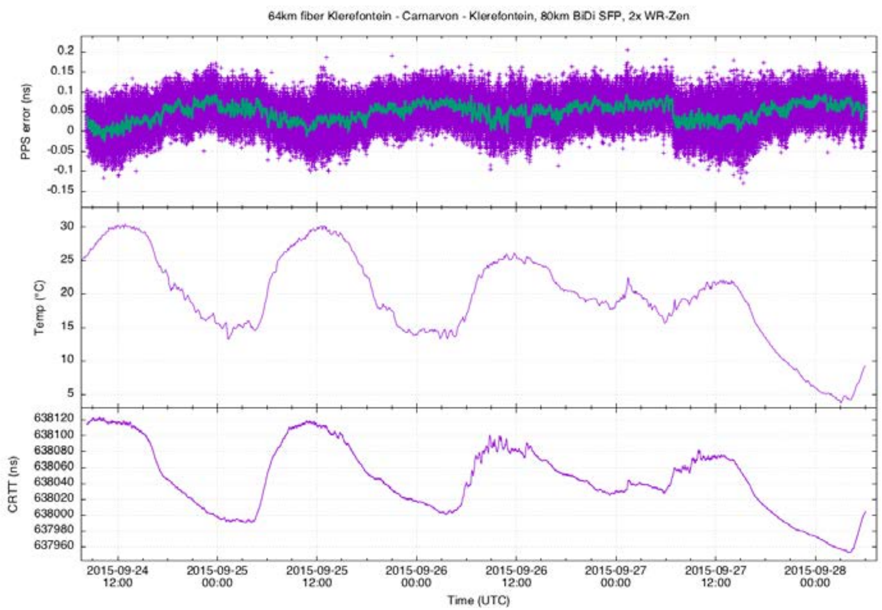
The setup




Losberg Farm
Losberg Core Site
MeysDam Farm
KAPB
LC
48 Core Duct Cable
223m
CMC Container
LC
92 800m
76 800m
E2000 APC
3 470m
E2000 APC
E2000 APC
4 580m
E2000 APC
48 Core Duct Cable 24 fibres terminated
48 Core Duct Cable
Pole 913
Fibres 1 – 48
Fibres 45 - 48
Fibres 45 - 48
Fibres 25 - 44
Fibres 1 – 24
MeerKAT Fibre Network
Fibre Splice Diagram
Rev. 1
24 Core Duct Cable
E2000 APC
Fibres 45 - 48
Fibres 25 - 44
Pole 165
Klerefontein Server Room 2
48 Core MASS Cable
E2000 APC
Fibres 25 - 48
Pole 163
16 300m
24 Core Duct Cable
Fibres 1 – 24
Fibres 25 – 48
Pole 37
MASS Fibre Cable attached to powerline
ADSS Fibre Cable through town
48 Core Duct Cable
E2000 APC
Carnarvon POP Site
Legend
Splice / Joint
Fibre Patch Panel
Fibre Lengths
JIVE

First results





- WR system measures the total round trip time
  - determines one way delay between master and slave (taking dispersion into account)
  - steers the PPS on the slave to be at the same time as the master.
- Top panel: PPS error between -0.1 to 0.2 ns
  - clearly exceeding the WR specifications.
  - PPS error: difference in arrival time between the pulse generated by the WR-master and WR-slave
- Second panel: temperature measured by the C-Bass telescope weather station at Klerefontein.
  - Interesting variation in weather, including thunderstorms with hailstones up to 2cm in size.
- Third panel: fibre round trip time in ns, as measured by WR.
  - The total link delay varies by more than 50ns in the measurement period. The correlation between outside temperature and link delay is obvious.


JIVE
VLBI-friend