# Correlators in radio-astronomy (DiFX)

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# Outline

- Radio-astronomical interferometers
  - History
  - Connected interferometry
  - Disconnected interferometry
- VLBI
  - Description, science and specificities
  - Difx software correlator

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  - Ryle and Vorberg observation with 2 dipoles (1946)
  - Ryle introduced phase switching and create interferometric correlation (1952)
  - 4 station interferometer in Cambridge (1955)
  - Many various telescopes
  - VLA (1980 for official opening)

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  - ALMA (2013 official opening)
  - SKA !

# Interferometers in Radio-astronomy

- Connected interferometer
  - Widely known examples: VLA, ALMA
  - All antennae are connected to each other (via analog cables, optical fibers or even radio signals)
  - Site's size is limited
  - Correlation is done on-site
  - Raw data is generally not recorded

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Why?!

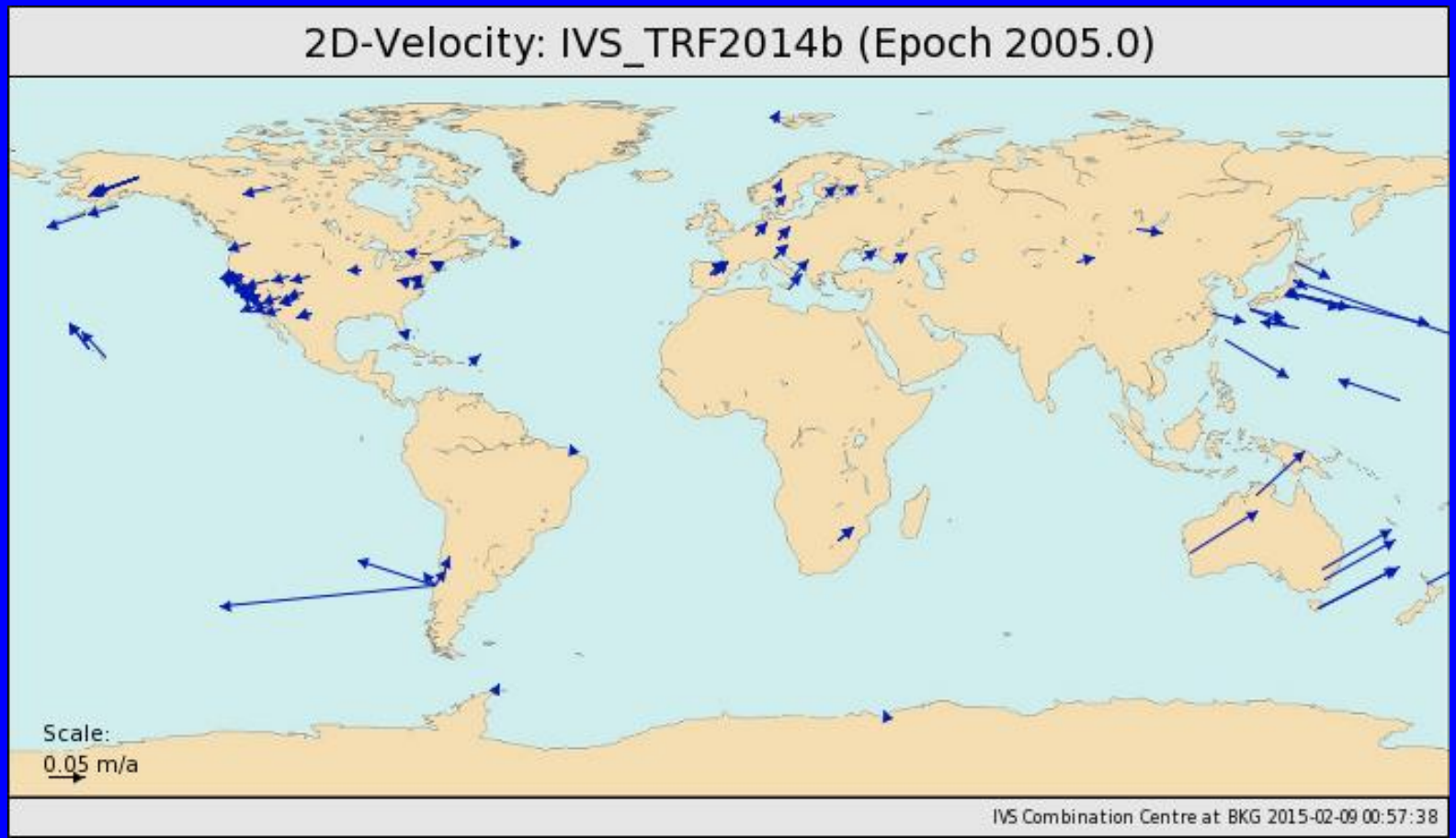
# Very Long Baseline Interferometry

# VLBI: description

- Stand for: Very Long Baseline Interferometry
- Disconnected interferometry
- Technique developed in the late 60’
- Built-in array in the 90’
- World-wide arrays, or even larger with satellites

# VLBI: science

- Highest possible angular resolution ($10^{-7}$º or less)
  - Use for celestial and partly terrestrial frame



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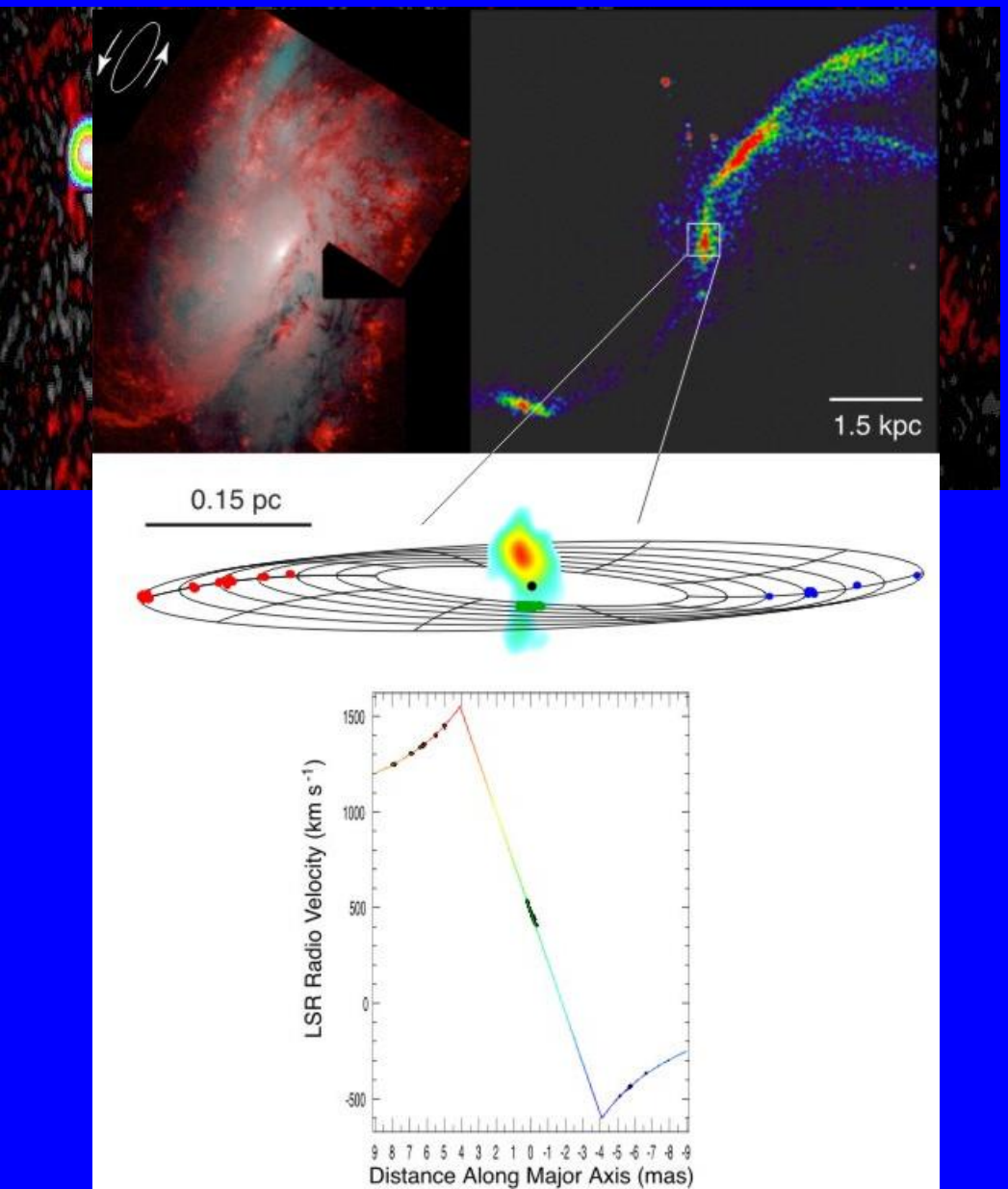


Major scientific results

- AGN image at parsec scale
- “Superluminal movement”
- Super massive black hole masses
- …

# VLBI: specificities

- Disconnected interferometry
  - Need to record the raw data
    - Media (magnetic tapes, hard disks)
  - Need to accurately time stamp the data
    - H-maser needed (or more accurate clocks)
  - Need to correlate the data after the observations
    - Correlator system (hardware, software, FX, XF…) and site
- In the last decade, “e-correlation” was developed and is used in many observations, but not possible all the time (remote stations, high data rate…)

# VLBI: correlation

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- VLBI correlation tried to follow data rate technologies
  - 720 kb/s for first observation in 1967
  - 4 Mb/s early 70s
  - 224 Mb/s per station in 1979
  - 256 Mb/s per station in the 90', 10 dedicated stations
  - 512 Mb/s in 2000 to 1 Gb/s per station in 2005, up to 20 stations
  - Disk-based recorded released in 2003
  - up to 8 Gb/s per station now and ongoing projects to go to 64 GB/s per station (ALMA)

# VLBI: correlation

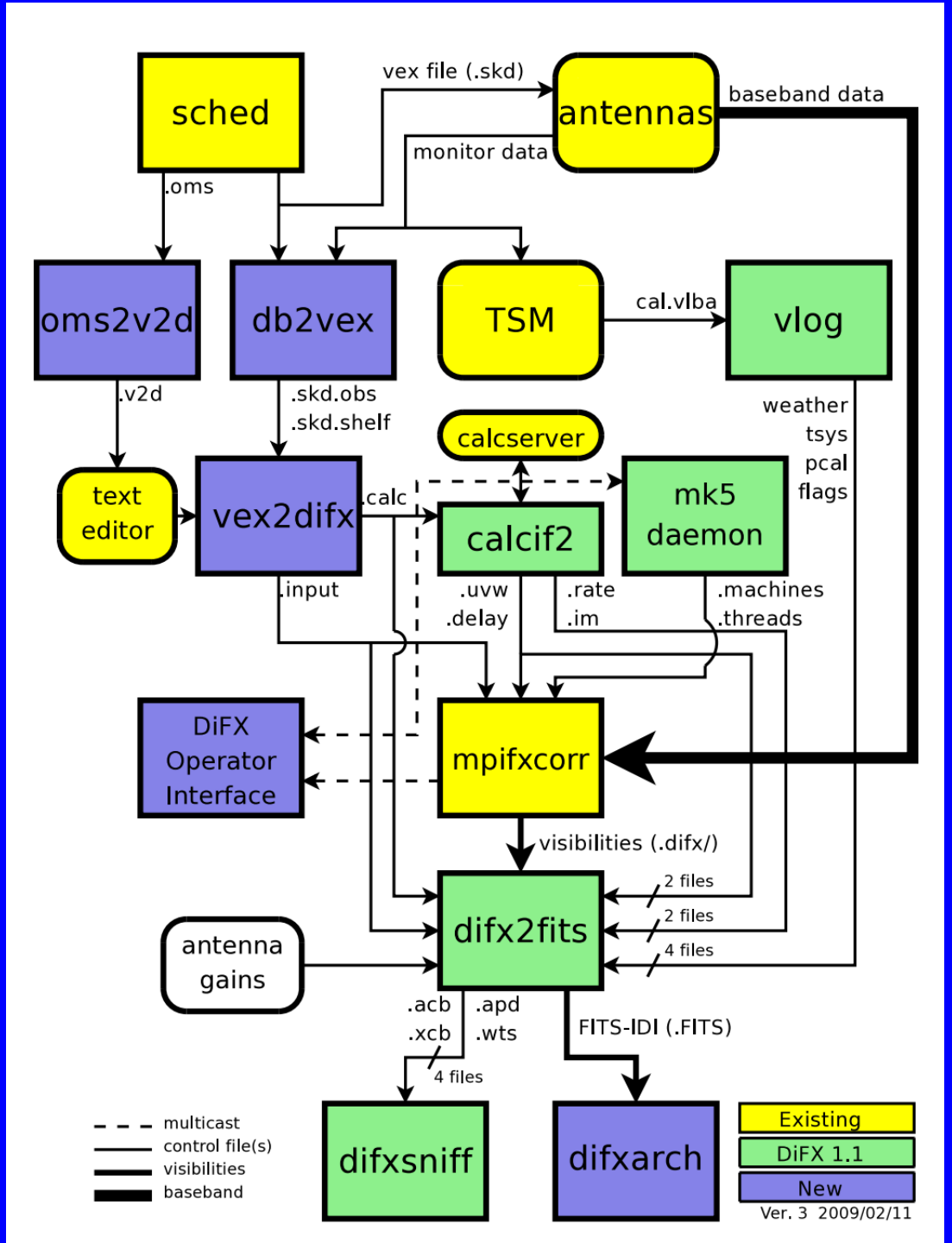
- Until ~2005, correlators were home-made and used various technologies
  - Mostly hardware
  - Mostly XF (“lag” correlators)
- With the great increase in (commercial) computing power, software solutions were created
  - SFXC (JIVE for European VLBI Network)
  - DiFX (almost everywhere else)

# DiFX correlator

- DiFX: Distributed FX software correlator
  - First created by Adam Deller in 2007 in Swinburne
  - FX correlator (FFT then cross-multiplication/accumulation) using CPU only
  - Uses Intel Integrated Performance Primitive libraries for FFT, and MPi to parallelize the computation
  - Gradually improved by DiFX developer community to fit various purposes and to add more capabilities and compatibilities
  - Gradually accepted as functional VLBI correlator and now used by nearly all the VLBI correlator sites

# DiFX correlator

- From observation metadata, operator
  - writes correlation description file (v2d)
  - calls for delay model application and cluster configuration files
  - creates correlation control file
  - runs the correlation
  - exports the data to various post-processing ready format



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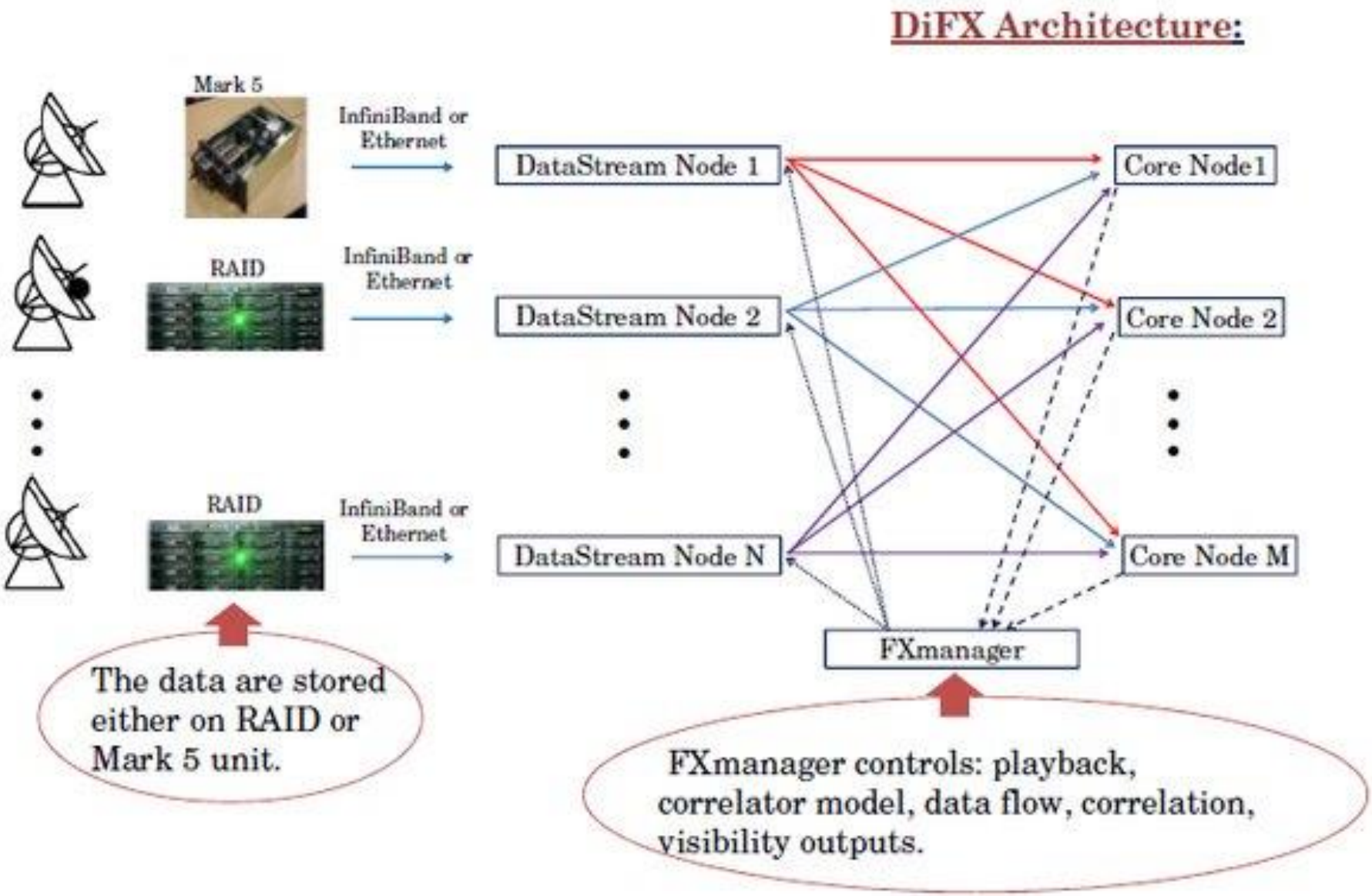

# DiFX and SKA

- Even if DiFX is not usable for SKA (CPU based, VLBI oriented)
- DiFX shares some performance issues with SKA
  - High input data rate
  - Cross-multiplication over various data streams implies large internal data transfer
  - FFT parameters tuning to optimize performance
- DiFX performances
  - scale linearly over bandwidth of the data
  - scale linearly over number of stations up to 20 stations (I/O network limitation) then linearly over number of baselines (interconnect limitation)
  - do not depend on CPU clock speed (saving money and power)

Thank you