DiFX for LOFAR Data

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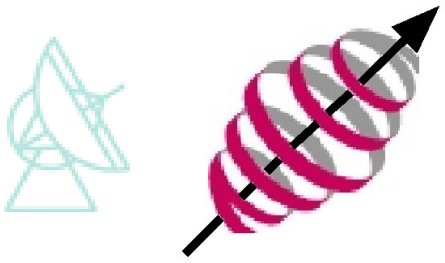

LOFAR

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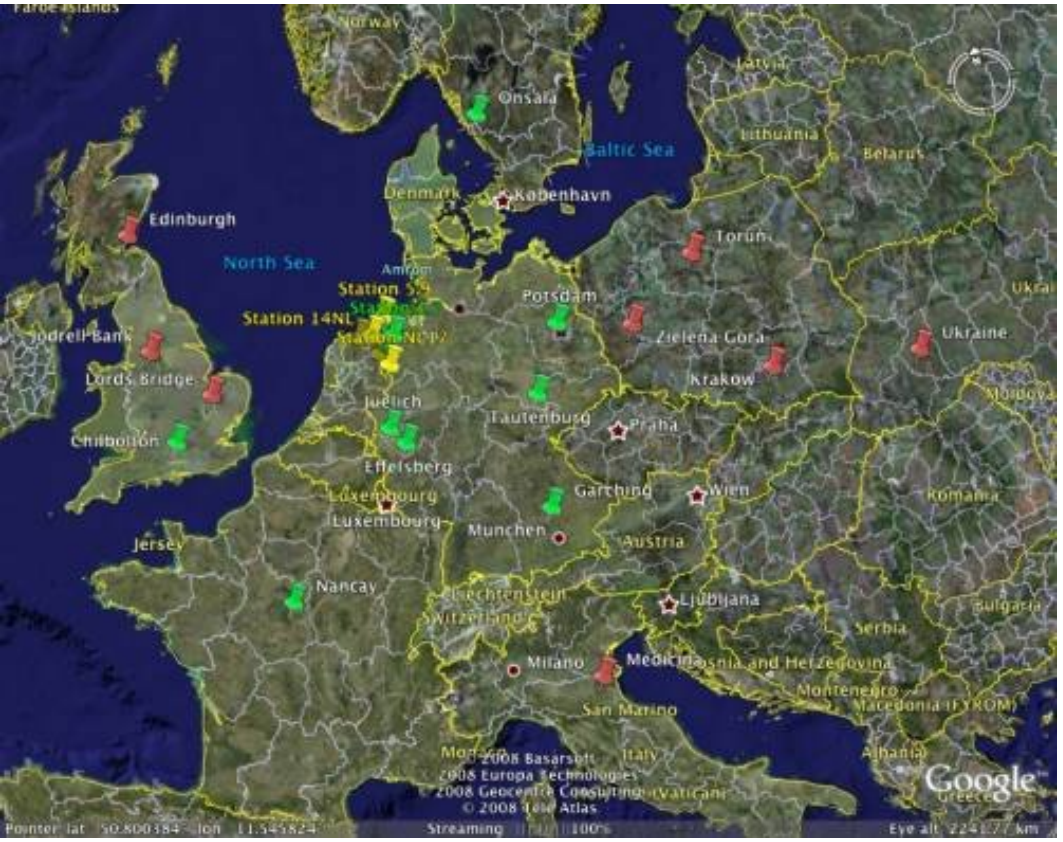
LOFAR:
The Low Frequency Array



- Aperture array technology
  - digital processing
- Low Band (LBA)
  - normally 30 to 80 MHz
  - can do 10 to 80 MHz
- High Band (HBA)
  - 120 to 240 MHz
- 3rd input unused

- Core (2 km diameter)
- Remote (inside NL)
- International (outside NL)

} Orginal LOFAR

} Current LOFAR

LOFAR Terms

- LBA --- Low Band Antennas (10—80 MHz)
- HBA --- High Band Antennas (120—240 MHz)
- Subband --- IF
- Dipole --- some bits of metal
- Antenna --- 2 dipoles, arranged to be at about the same location to measure different polarization senses
- Tile --- a square arrangement of 4x4 antennas, whose outputs are summed in an analog adder. Used for the HBA
- Station --- a collection of antennas (LBA) / tiles (HBA)
- Beam --- a pointing direction. Multiple beams can be formed simultaneously

Why am I (or LOFAR) Interested in DiFX?

(LOFAR already has a correlator running on an IBM Blue Gene in Groningen)

- No fringes detected with LOFAR Blue Gene correlator for baselines > 1 km
  - Ex—Ef, Ex—Dw, Dw—Ef baselines have no fringe detection yet
  - Probable cause: software bug in Blue Gene correlator (fringe rotation)
  - But, cannot rule out some problem with station hardware
    - This would be bad, as we are currently building stations with this hardware
    - So we need to figure this out quickly
  - Current signal to noise also low

- Blue Gene/L computer shut down in 2008 June
  - Only now coming back on-line
  - Software for new P system not quite worked out
- Idea: test long baseline correlation with a correlator which is known to work on long baselines

Other Reasons --- 1

- Want to operate long baseline telescopes independent of Dutch
  - German stations have plan for subarray operations, also Brits
- Single station correlator useful
  - Multiple beams can use different antenna subsets within station, to make short (intra-station) baselines when observing the same target
  - Short baselines critical for EoR and some Magnetism KSP observations
  - Pulsar gating in single station operation
- Hopefully easier to develop special correlation modes with non-Blue Gene software correlator
  - Blue Gene code being written in assembler
  - Very short integration times (ms) Solar, Transient KSPs
    - Realtime correlator cannot handle high output data rates
  - Pulsars (modes beyond standard pulsar mode)
  - Very many channels

Other Reasons --- 2

- Want to add in non-LOFAR stations
  - Nançay, Northern Cross, perhaps LWA
  - Not guaranteed to have same subband bandwidths for different telescopes
    - Hardware constraints of backends not likely to be changed
  - Nançay detects circular polarization, LOFAR detects linear polarization

Solution?

- DiFX being used in Bonn
- I was “asked” to get a fringe using a different correlator by LOFAR
- My postdoc position is supposed to involve software correlation anyway...
- So, this summer I began in earnest to hack DiFX to deal with LOFAR data

Changes Needed:1 --- Complex Data

- LOFAR data comes as a complex datastream out of the stations
- Many new instruments (aperture arrays, phased arrays) will produce complex datastreams
  - Might as well tackle this now, and have DiFX as capable as possible to deal with new instruments in the future
- Complex data: N samples
- Real-valued data: 2N samples

Changes Needed: 2 --- Timekeeping

- LOFAR datastreams do not fall on nanosecond timesteps
- LWA scans starting at ~ 10 ms boundaries
- Major pain in the rear given the current DiFX code
- Times currently defined as seconds, nanoseconds
- DiFX scans start at second boundaries
- Or as the number of samples since some time.
  - This becomes difficult with complex and real data
- I have implemented an FxTime class
  - Currently 2 doubles (seconds, fractional seconds)
  - Could be transparently changed to two 64-bit integers
    - Seconds and femtoseconds?

Changes Needed: 3 --- Multiple Beams

- Different station pointing directions
  - Antenna/tile datastreams combined to point station in different directions
  - LOFAR will have up to 32 pointing beams per station
  - Pointing beams can have different subsets of antennas/tiles
    - End up with different coordinates for (u,v,w) calculations, delay calculations
- Different correlation directions
  - 1 or more correlation directions per pointing beam
  - Correlation direction different from pointing direction
    - Need to keep track of pointing direction for later processing
- Subarrays
  - Stations/beams may go away and come back
- Different configurations
  - Different integration times, overlapping scans, different channels

Changes Needed: 4 --- Subbands

- LOFAR can have up to 864 subbands (or perhaps 832) per station
  - Minimum number of channels per subband is 256
  - Always correlate full cross-polarization
  - ~ 7 MB per baseline
  - 10 stations with autocorrelations ~ 400 MB
  - May have ~ 5 visibility buffers in array to fit in 2 GB
  - LOFAR will have ~ 62 stations by end 2009
- LOFAR post-correlator software expects each subband
  - Suggests breaking correlation down into manageable numbers of subbands
  - Write out each subband separately?
    - May be able to write to separate locations for each subband (write to the machine which will process the subband)
- Moved visibility writing to new FxWriter object/process

Changes Needed: 5 --- Other Things

- LWA plans to change sources on 10 ms timescales
- Station hardware creates delay breaks every 1 s as the pointing model updates
- Ionospheric corrections
  - Very large for low frequencies
  - May need to be fed into CALC/VTD
    - Also ionospheric effects on (u,v,w)s
  - Different delay for each subband
  - Different (u,v,w) for each subband
    - Up to 20% change at 20 MHz, 20 degrees elevation
  - Implement these later
- Scan/source information
  - Many places in code that need to access source ID and so on
  - Change to indicate when not on source, optimize time search

Changes Needed: 6 --- Other Things

- Multiple beams handled by separate FxManager processes
- New FxBoss process created
  - Relatively stupid --- only knows about start and stop time of experiment and a list of Cores
  - Assigns Cores to FxManagers in time order, keeping telescope access ordered in time
  - Each FxManager can have different integration times, number of channels, start/stop times, and so on
- Last integration of scan has modified integration time
- Beginning to allow T_{sys} to be different for each subband
- Visibility weights
- Large number of bits (up to 32 bits per sample for LOFAR)
- ...

Future Development

- Blue=directly LOFAR related, Green=peripherally LOFAR
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- Finish development to get LOFAR working
- Put the polyphase filter back in
- Write DiFX to MeasurementSet converter (?)
- Write DiFX to HDF5 converter
- Deal with multiple polarizations (Nançay)
- Deal with different bandwidths (perhaps Nançay, Northern Cross, Westerbork Mark5, LWA)
- Correlate different frequencies (A. Roy)
- Investigate DiFX operation at Jülich
- Realtime correlation from network stream (?)

Conclusion

- I have hacked DiFX a great deal
- I have made a lot of progress toward getting something useful for LOFAR
- The question is, have I made something reasonably valuable?

- Or is it garbage?