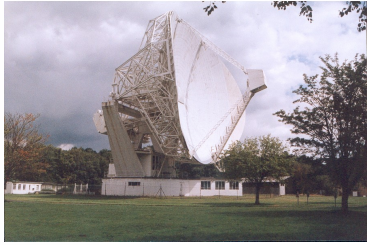
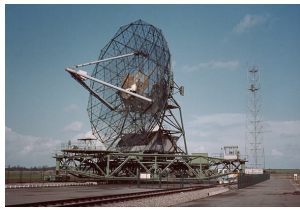
The University of Manchester
Jodrell Bank Observatory



EXPReS



# Progress and Status of e-MERLIN

Ralph Spencer
on behalf of the e-MERLIN team

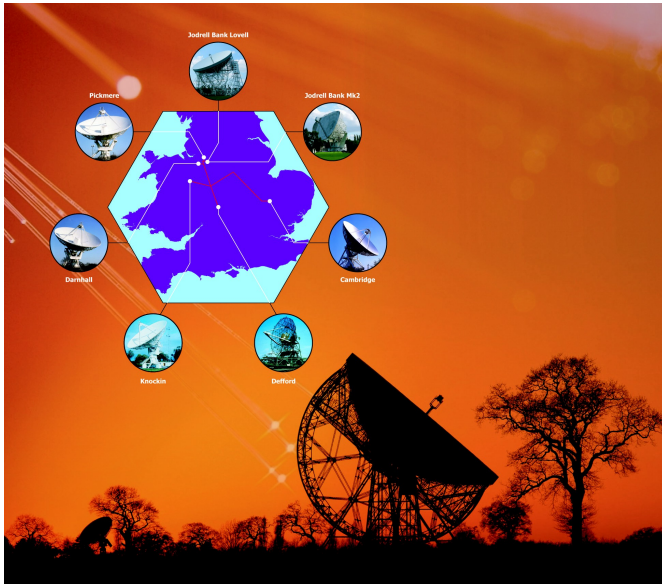
Madrid June 2009

The University of Manchester
Northwest Regional Development Agency
University of Cambridge
Science & Technology Facilities Council
liverpool JMU

The University of Manchester
Jodrell Bank Observatory

# e-MERLIN

- **Major upgrade to MERLIN array**
- **New optical fibre network connecting 7 telescopes to new correlator at Jodrell Bank Observatory**
- **Unique combination of 50-150 mas resolution and μJy sensitivity**
- **Crucial to resolve AU-scale star-formation processes in Galaxy and kpc-scale regions at z~1**

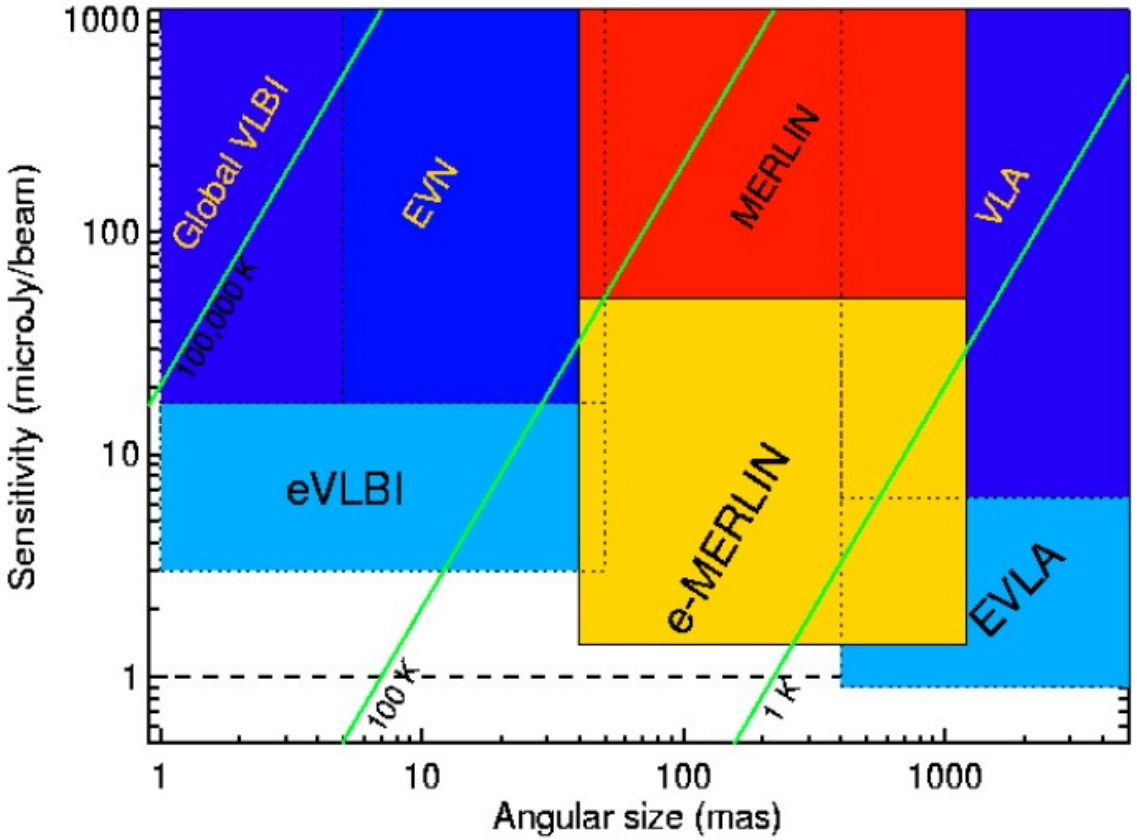



**New Receivers**
**New IF system**
**New Links**
**New Science!**

The University of Manchester

# Capabilities

- **150, 40, 10 mas re**
- **~2 μJy sensitivity i**
  - **<μJy in deep fie**
  - **~30 μJy in ~1 r**
- **Wide fields**
  - **Out to HPBW of**
- **Spectroscopy**
  - **16 placeable su recirculation**
  - **Can mix/trade polarisations**
  - **Correlator almo**
- **Much improved ape**
  - **Via frequency c**
  - **May help snaps**
- **Spectral mapping**
  - **1.3-1.7; 5-7/4-**
- **Polarization (L,R → IQUV)**
- **Astrometry**
  - **Goal is < 1 mas wrt ICRF: using GPS measurements of troposphere delay (5cm error -> 5mm); closer calibrators**

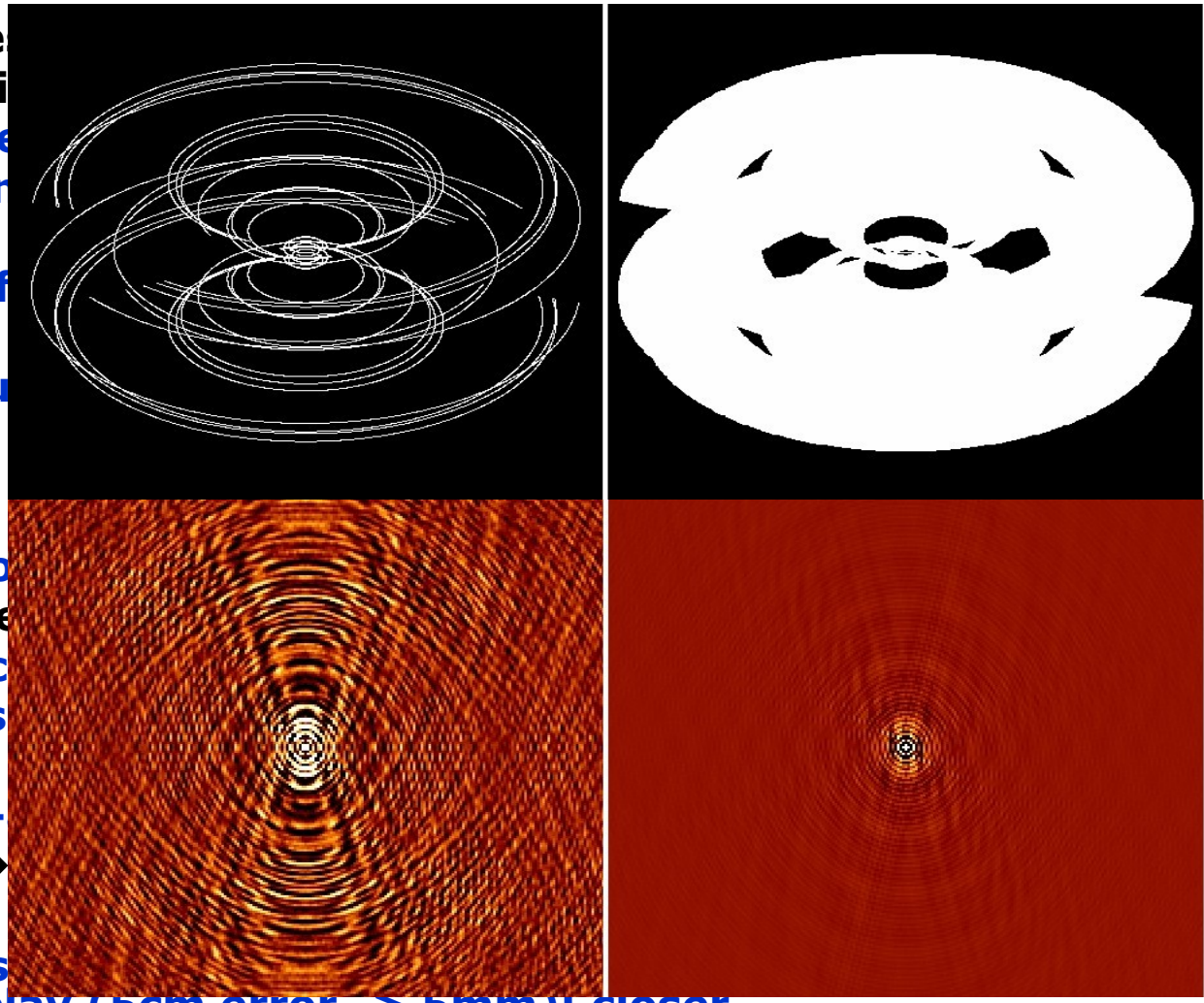


The University of Manchester
Jodrell Bank
Observatory

MANCHESTER 1824

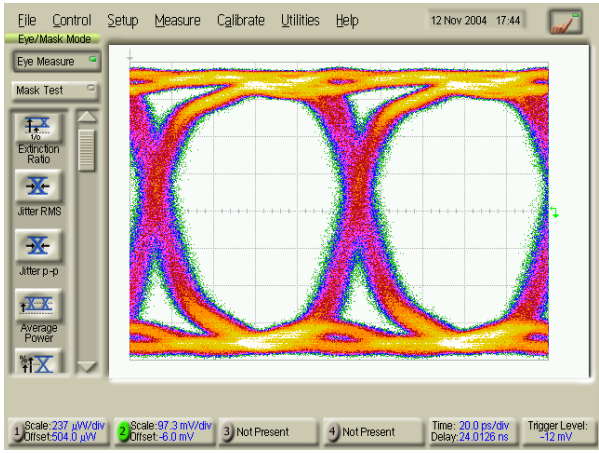
# Capabilities

- 150, 40, 10 mas re
- ~2 μJy sensitivity i
  - <μJy in deep fie
  - ~30 μJy in ~1 r
- Wide fields
  - Out to HPBW of
- Spectroscopy
  - 16 placeable su recirculation
  - Can mix/trade polarisations
  - Correlator almo
- Much improved ape
  - Via frequency c
  - May help snaps
- Spectral mapping
  - 1.3-1.7; 5-7/4-
- Polarization (L,R →
- Astrometry
  - Goal is < 1 mas troposphere delay (5cm error -> 5mm); closer calibrators



The University of Manchester
Jodrell Bank Observatory

# Schematic diagram of the e-MERLIN fibre network







**Global Crossing PoP**
**Interconnect to Global Crossing network**

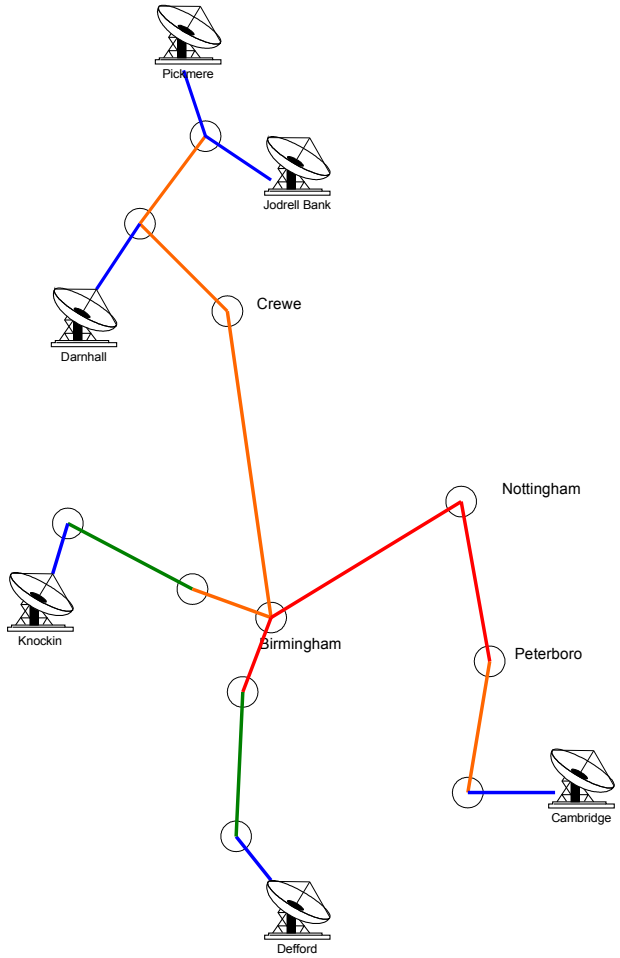
**Antenna**
**Dark fibre**

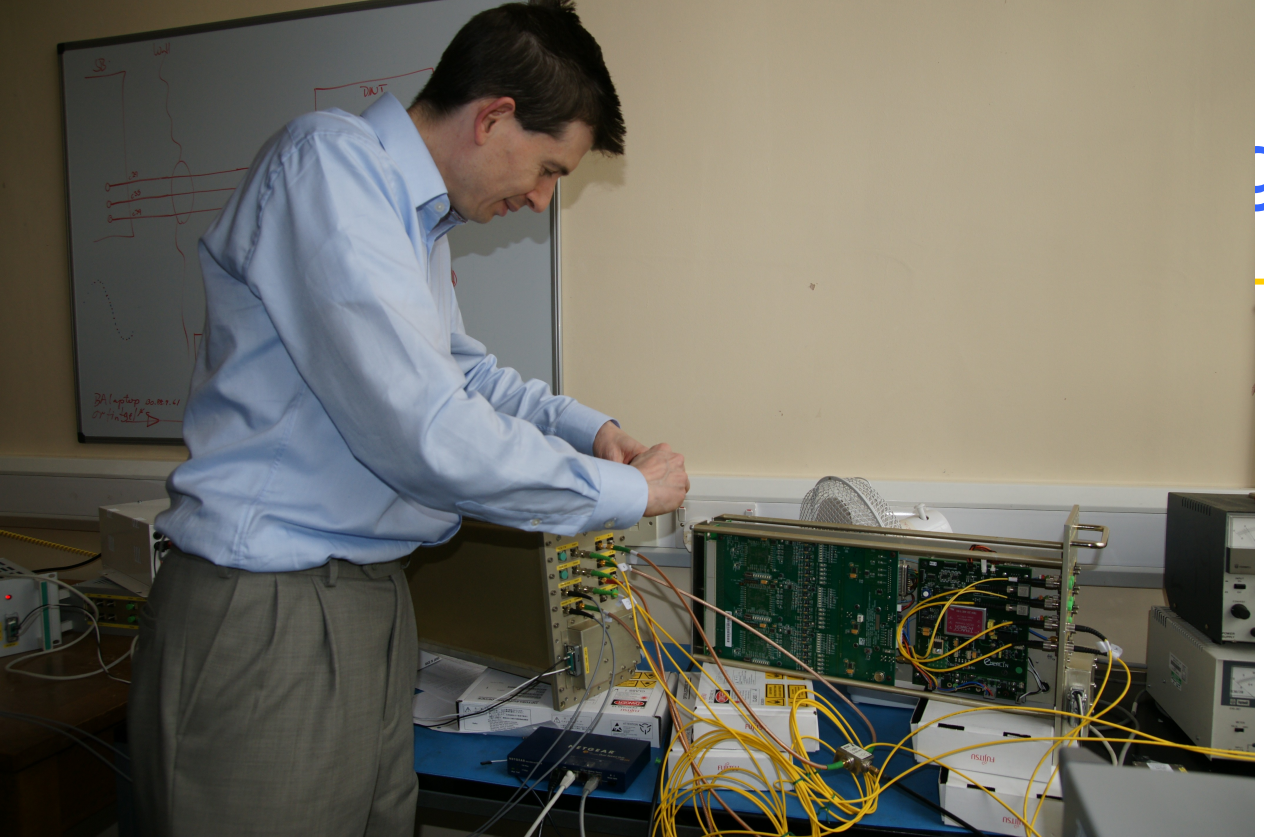
**New fibre build**

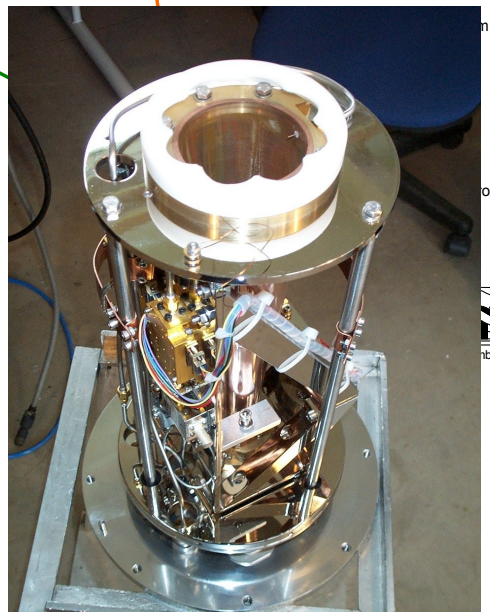
***570 km of dark fibre***
***100 km of new build tails.***

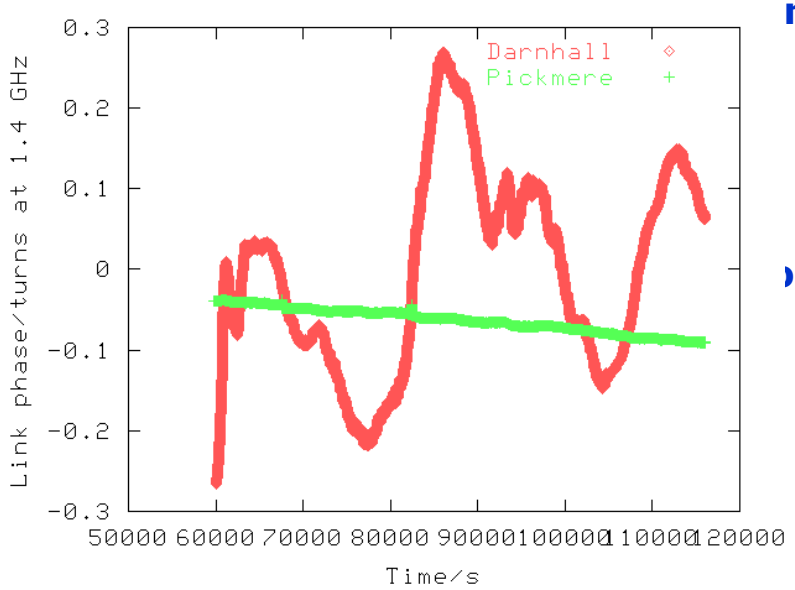
# Commissioning

- **New receivers/IF installed**
  - **wider bandwidth, improved Tsys, quick band-change**
- **Samplers & data transmission being installed (2 done)**
  - **0.5 GHz (covers L-band) done, 2 GHz (NRAO design) later this year**
- **Optical fibre network in place**
- **New timing system developed and being installed (2 done)**
  - **H-maser signal transferred on fibre + GPS at each telescope**
- **Prototype correlator (DRAO, Penticton) arrived over last few months**
  - **2 station boards + 1 correlator board + Xbar**
  - **up and running**
- **New array control software**
  - **up and running**





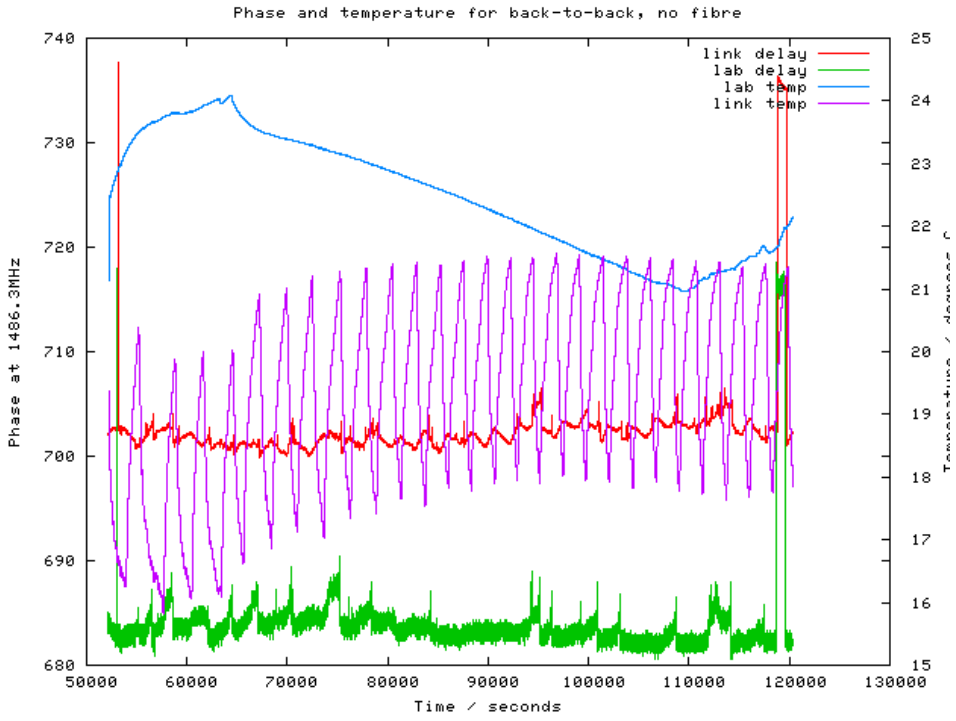


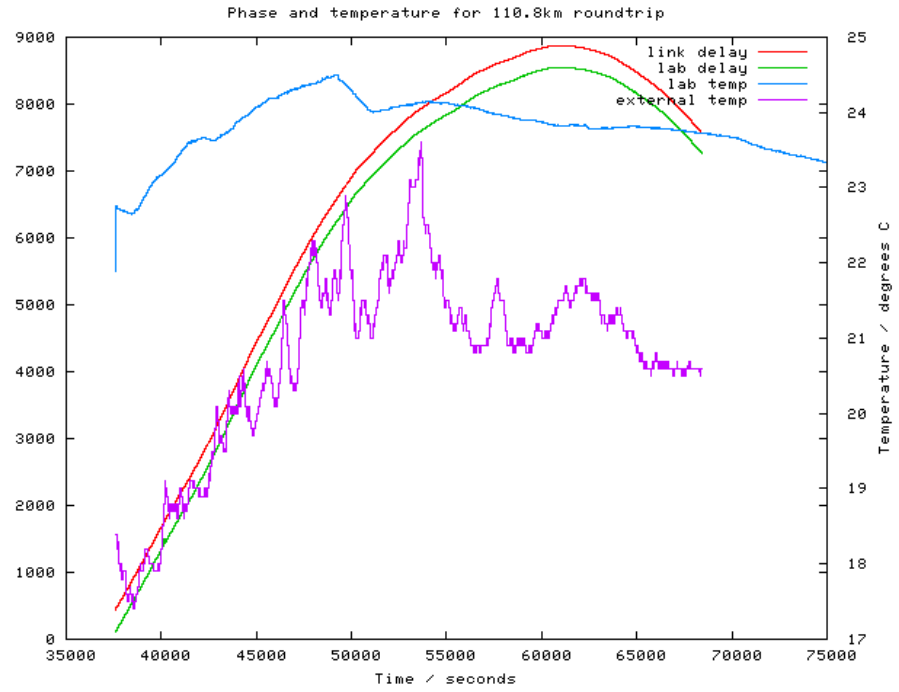

Darnhall
Pickmere
Link phase/turns at 1.4 GHz
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
50000 60000 70000 80000 90000 100000 110000 120000
Time/s

The University of Manchester
Jodrell Bank Observatory

# Results

## $\Phi_{\text{one way}}$ & $\Phi_{\text{round trip}}/2$




B2b

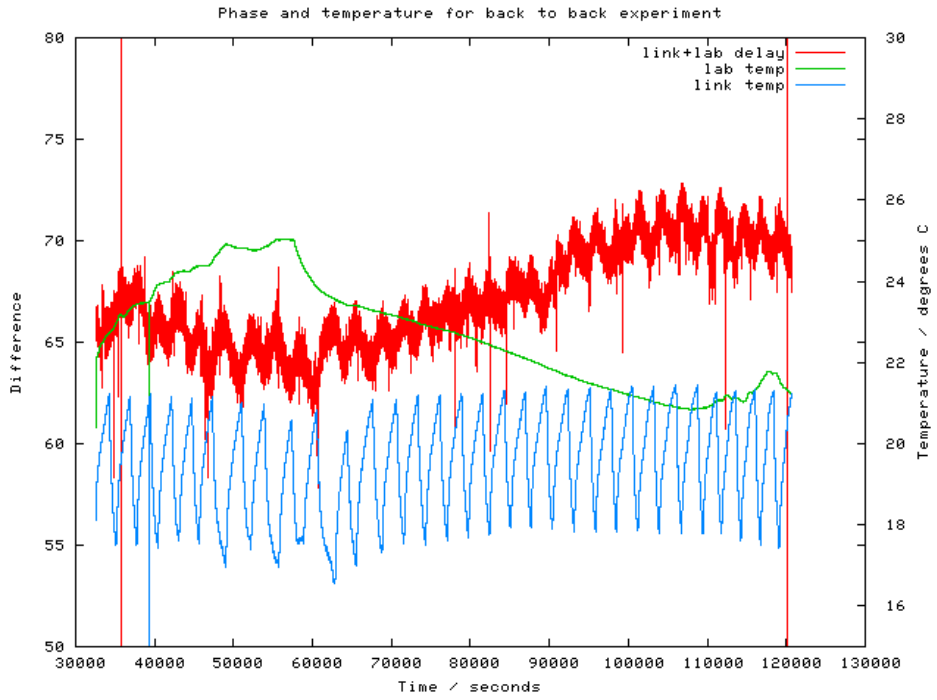
110 km

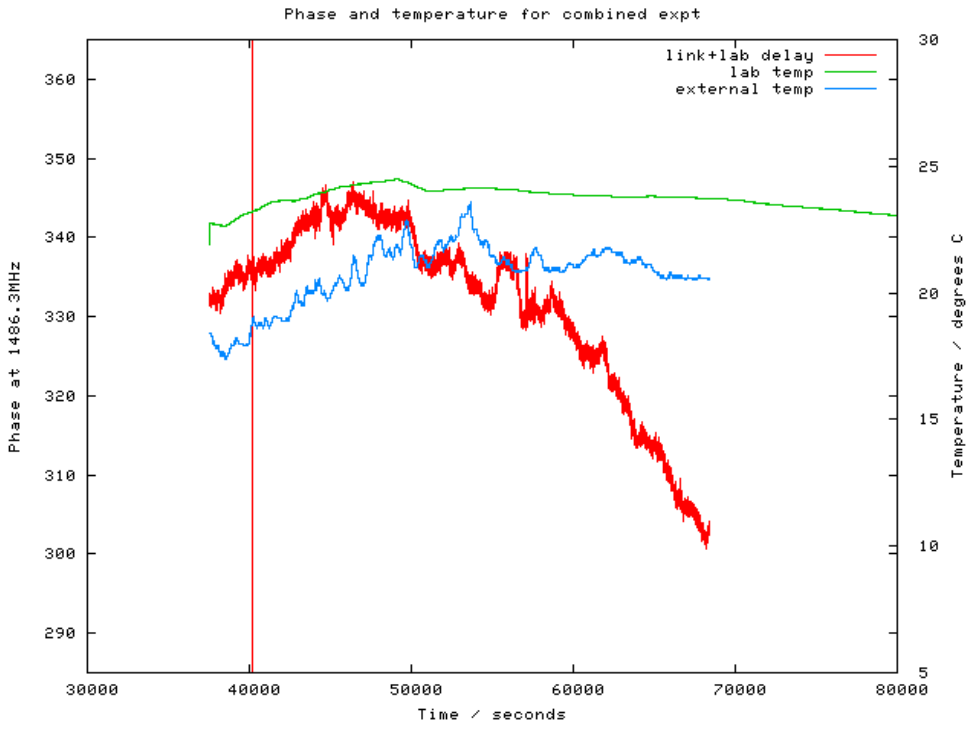
The University of Manchester
Jodrell Bank
Observatory

MANCHESTER 1824

# Difference plot

$(\Phi_{\text{one way}} - \Phi_{\text{round trip}}/2)$

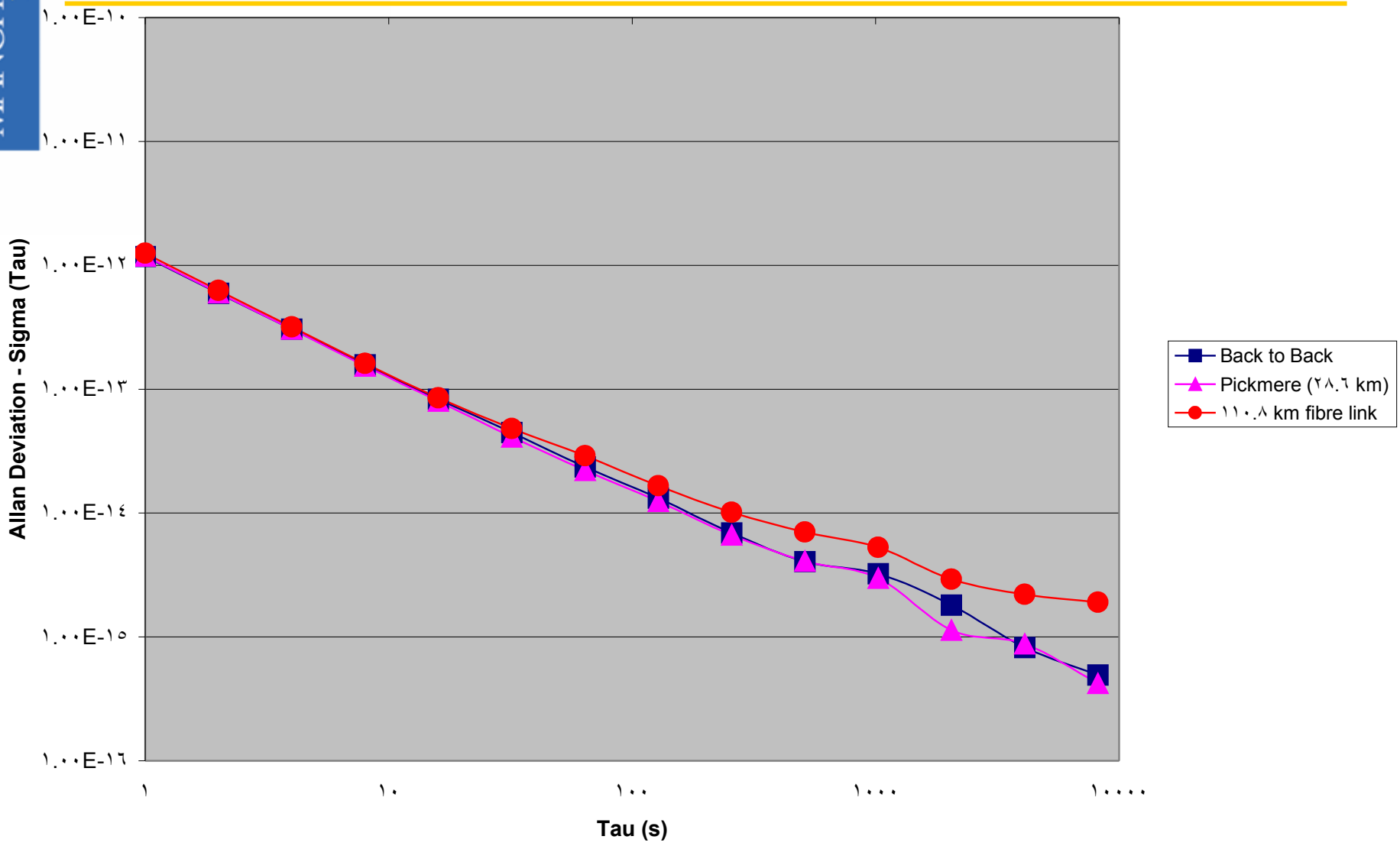


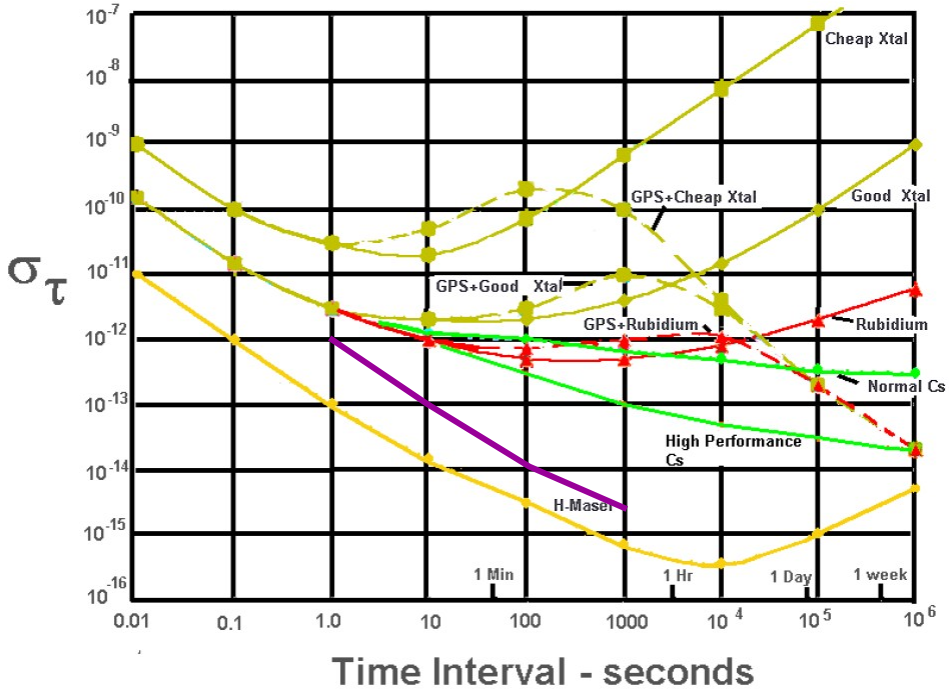



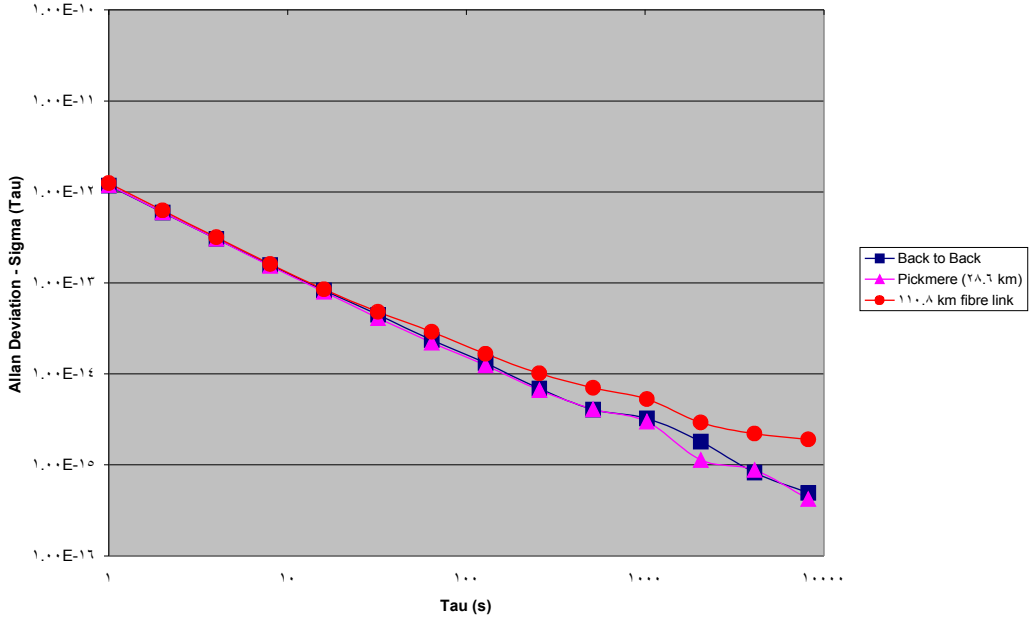
The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

# Allan deviation plot




$\sigma_\tau$
Cheap Xtal
GPS+Cheap Xtal
Good Xtal
GPS+Good Xtal
GPS+Rubidium
Rubidium
Normal Cs
High Performance Cs
H-Maser
1 Min
1 Hr
1 Day
1 week
Time Interval - seconds

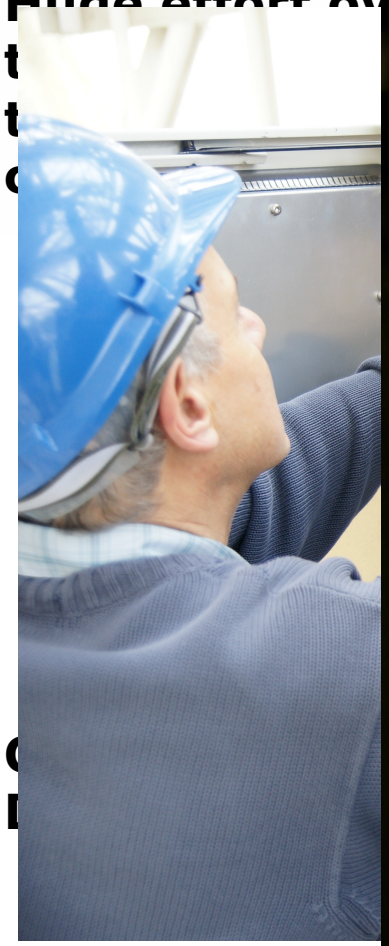

Allan Deviation - Sigma (Tau)
Tau (s)
Back to Back
Pickmere (٢٨.٦ km)
١١٠.٨ km fibre link

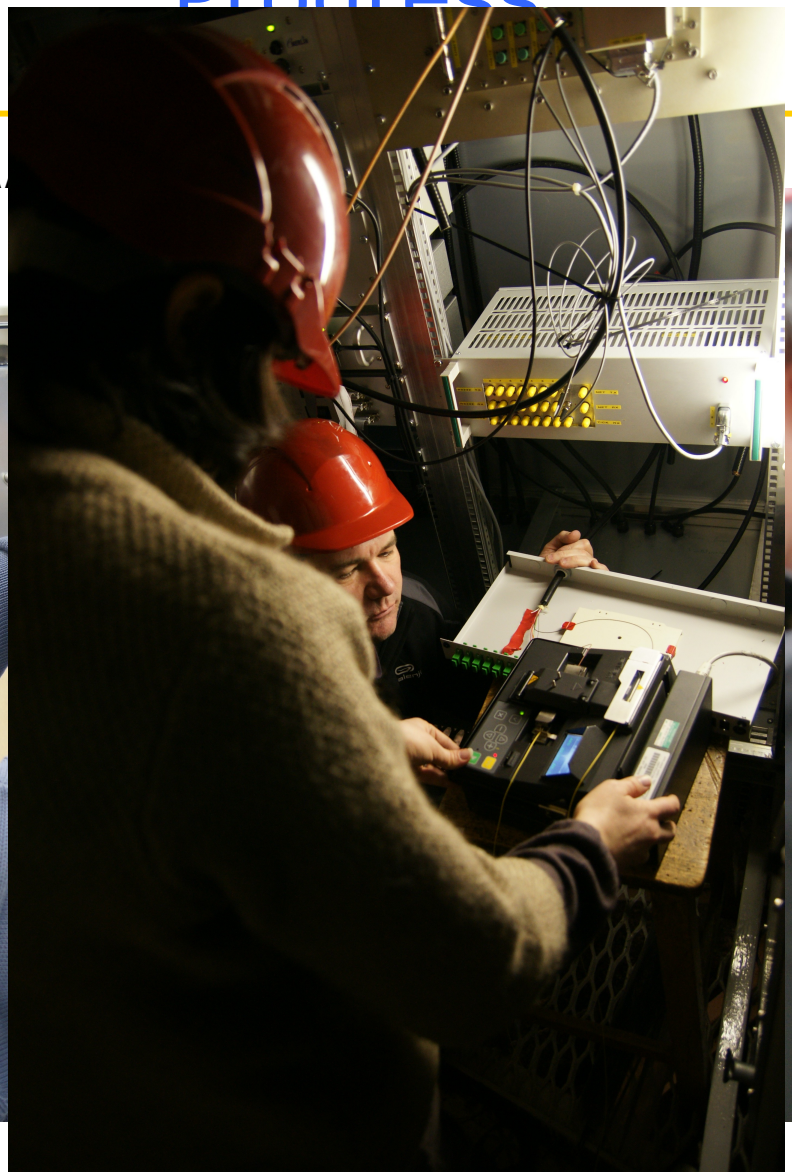
The University of Manchester
Jodrell Bank
Observatory

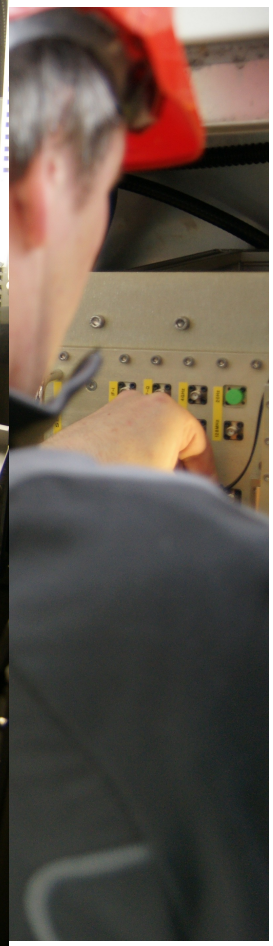
MANCHESTER 1824

# Progress

- **Huge effort ov**
  **t**
  **t**
  **c**







- **C**
  **D**

The University of Manchester
Jodrell Bank Observatory

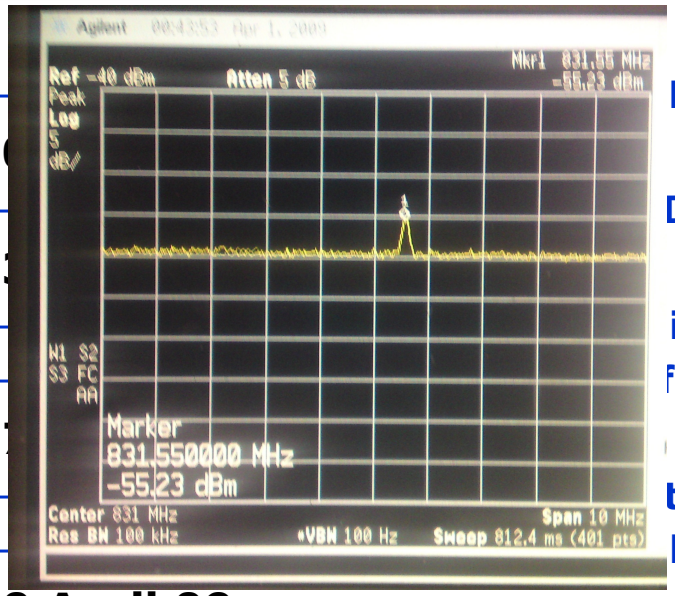
MANCHESTER 1824

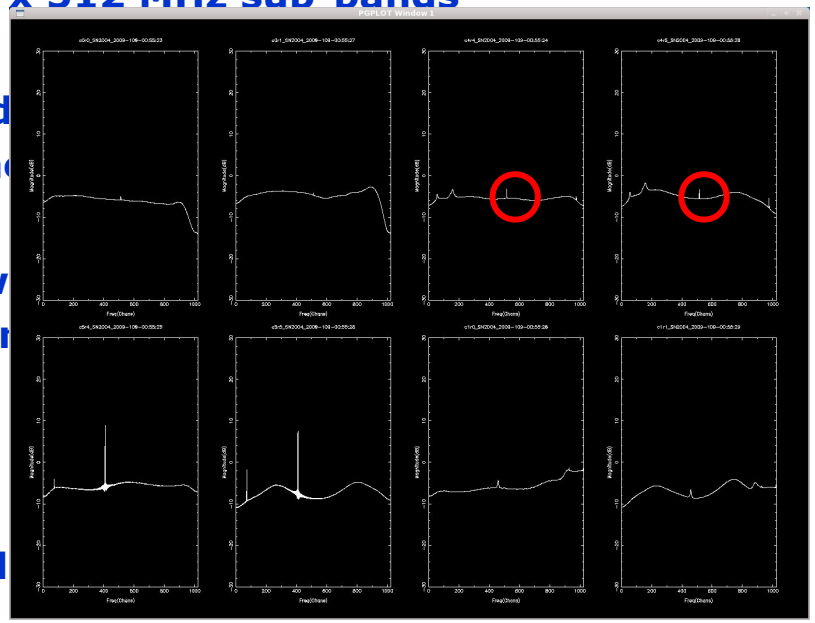
# Current Status

- **1 April 09**
  - **first 'analogue light' with 4 GHz IF - 6.8 GHz methanol line in IF**
- **10 April 09**
  - **first 'digital light' - 512 MHz IF through samplers into correlator**
- **13 April 09**
  - **autocorrelation of methanol line**
  - **1024 channels across each of 8 x 512 MHz sub-bands**
- **17 April 09**
  - **first remote telescope out-fitted and connected**
  - **auto correlation of methanol line**
- **20 April 09**
  - **correlator synchronised with two telescopes**
  - **delay models running; started fringe search...**
- **24 April 09**
  - **first fringes, 3C84: delay model OK**
- **May 09**
  - **checking fringe rotation, 0.5 GHz/1 GHz input, synchronisation...**
- **June 09**
  - **Expres 4 Gbps input from IBOBs**

# Current Status

- **1**
  - **Hz IF - 6.8 GHz methanol line in IF**
- **1(**
  - **IF through samplers into correlator**
- **1:**
  - **ine**
  - **f 8 x 512 MHz sub-bands**
- **1:**
  - **ted**
  - **lin**



- **20 April 09**
  - **correlator synchronised with tw**
  - **delay models running; started fr**
- **24 April 09**
  - **first fringes, 3C84: delay model**
- **May 09**
  - **checking fringe rotation, 0.5 GH**
- **June 09**
  - **Expres 4 Gbps input from IBOBs**

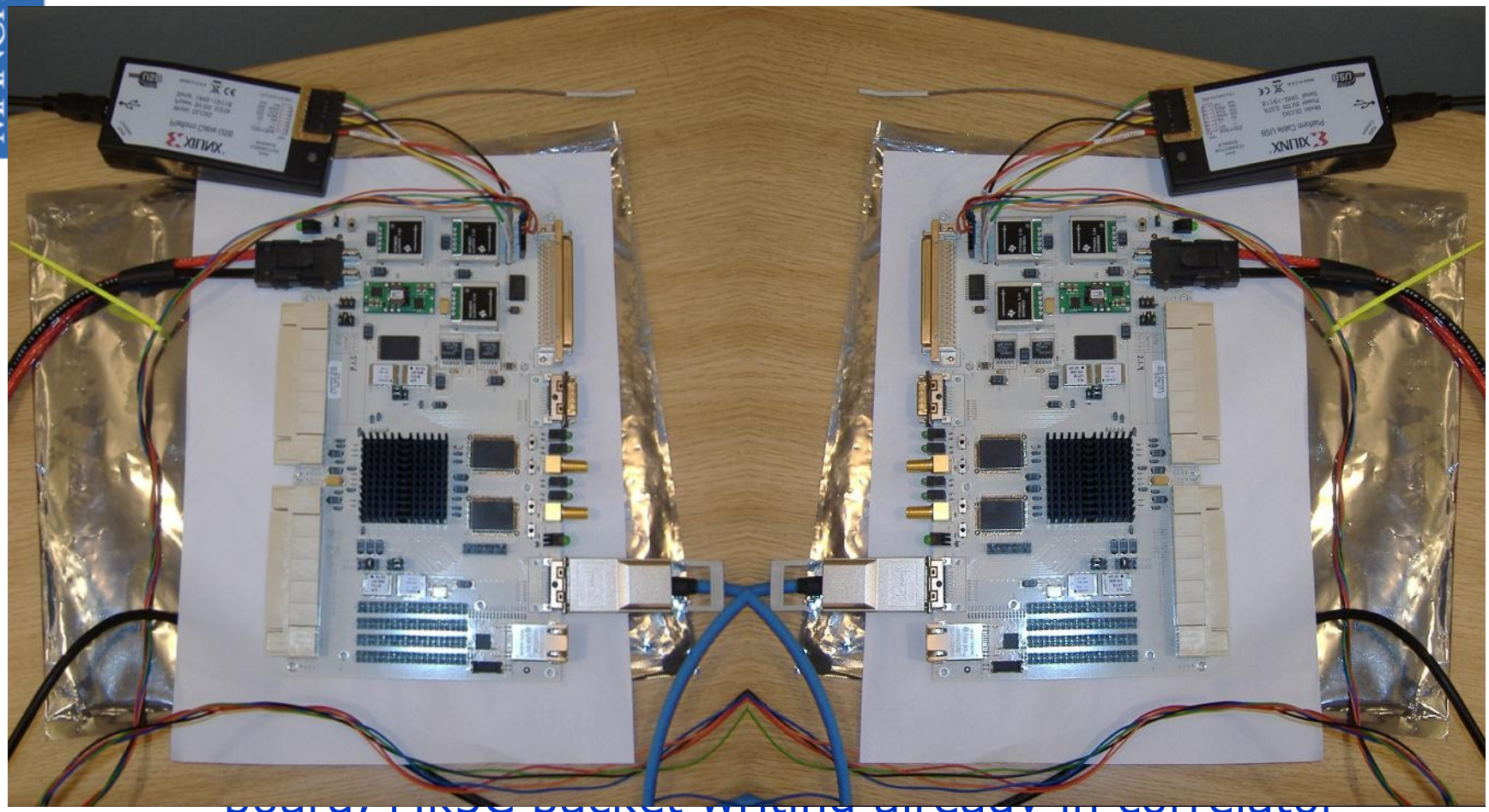
# Coming months

- **Continue single baseline tests**
- **4 station tests**
  - **next 2 station boards now installed**
  - **next production run of IF, digital boards: Summer 09**
- **Full array & full bandwidth**
  - **requires further SB, BB (Nov 09), 4 Gs/s samplers**
  - **regeneration electronic for last, most distant telescope at Cambridge (Dec 09)**
- **Engineering/commissioning obs 2009**
- **Limited, shared-risk observations in 2010A**
- **Standard operations 2010B**

The University of Manchester
Jodrell Bank
Observatory

MANCHESTER 1824

# e-MERLIN & VLBI




board, Mk5C packet writing already in correlator

# e-MERLIN Legacy Programme

- National and international consortia prepared proposals for large, high impact science projects
- 15 proposals submitted from 325 scientists from 119 institutes
  - already reaching a much wider community
- Reviewed by external referees and Legacy Steering Group chaired by Prof R Ivison; rigorous assessment following UK PATT procedure
- 5000 hours allocated to 11 projects, covering topics from the formation of planets to the formation of galaxies in the early universe.
  - important demonstration of community interest & potential science

The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

# Legacy programme as a whole: Proposed projects

- Breadth of legacy proposals demonstrate the versatility of e-MERLIN
- Programme covers ~50% of e-MERLIN time in first 5 semesters
- In total ~10,000hrs of e-MERLIN time were proposed for
  - **Well oversubscribed**

The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

# Allocated programme:

**GALACTIC PROJECTS:**

- e∏ - Pulsar interferometry – Vlemmings/Stappers et al. 160hrs **
- PEEBLES – Greaves et al. 72hrs **
- Feedback processes in Massive SF – Hoare/Vlemmings et al. 450hrs
- Thermal jets from low mass stars - Rodriguez et al 180hrs
- COBRaS – Prinja et al. 294hrs

**EXTRA-GALACTIC PROJECTS:**

- LEMMINGS – Beswick/McHardy et al. 810hrs
- LIRGI – Conway/Perez-Torres et al. 353hrs
- Extragalactic Jets – Laing/Hardcastle et al 375hrs
- AGATE – Simpson/Smail et al 330hrs
- e-MERGE – Muxlow/Smail/McHardy++ 918hrs
- Gravitational lenses – Jackson/Serjeant et al 228hrs **

**TOTAL : 4170hrs**

- ****Up to 5000hrs can be allocated. Remaining 830hrs to be allocated by LSG to pre-identified projects pending initial results**

- DETAILS OF ALL PROJECTS (inc Proposals allocations etc) ARE AVAILABLE AT

http://www.merlin.ac.uk/legacy/

The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

# Legacy projects (1)
## galaxy formation and evolution

**Galaxy formation (Grav lenses)**

- **Gravitational lenses - test CDM models (halo substructure) and probe central ~10pc**
  - **Requires e-MERLIN sensitivity & resolution/astrometry**
- **New survey (>1000 lenses)**

  **Herschel - SCUBA2 -e-MERLIN**
  - **e-MERLIN vital for confirmation (CLASS experience)**

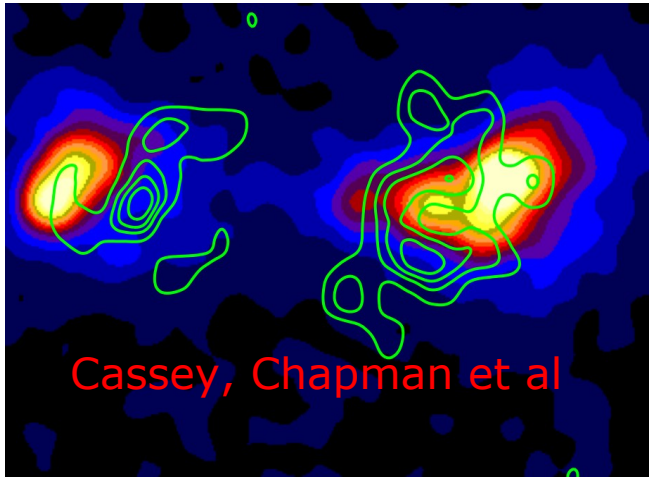
**Galaxy evolution (e-MERGE, AGATE)**

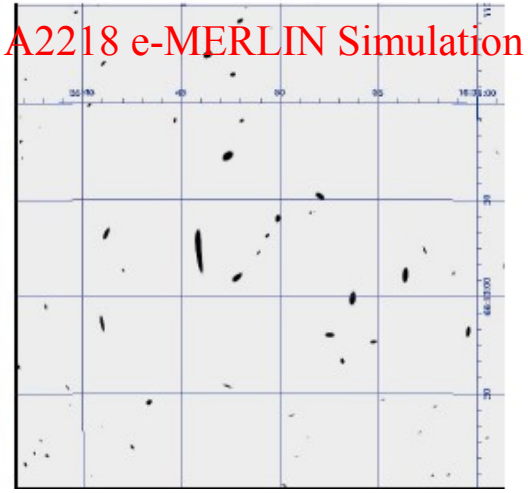
- **Ultra-deep (cluster lenses): star-formation in normal galaxies at z~5**
- **Deep (0.25 dg$^2$): star-formation history z~0.5-3 (extinction-free; AGN; sub-mm quiet SFG)**
- **Environmental impacts on galaxy evolution: clusters;**
  - **e-MERLIN required to resolve typical few-kpc star-forming regions at z~1 and identify/separate AGN (HDF experience)**

The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

# Legacy projects (1)
## galaxy formation and evolution

The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

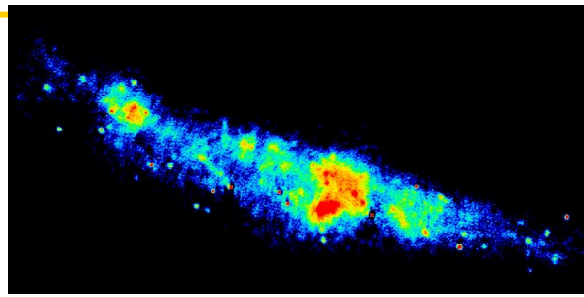
# Legacy projects (2)

## From galaxies to Star and planet formation

**Birth & death of stars in the Local Universe**

**(LeMMINGS, LIRGI)**

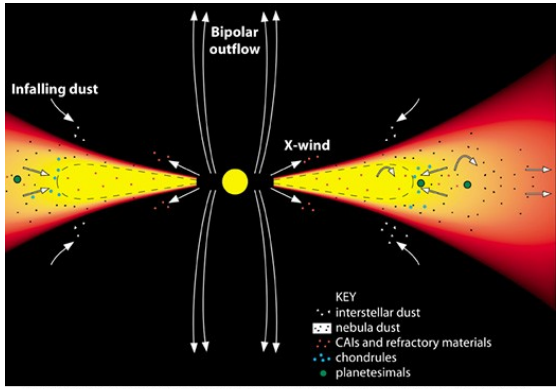
- **Add to multi-λ Nearby galaxy samples (SINGS,KINGFISH, GOALS…)**
- **Super star clusters; determination of IMF via SN rates**
- **Census of AGN; identify intermediate-mass black holes; ULX**
- **Magnetic field in LIRGS**
- **RSNe detection & AGN separation in LIRGS**
  - **e-MERLIN resolution essential to resolve SSC,SNR,AGN (M82 experience)**



**Physical processes of star-formation**

**(Massive star-formation, stellar jets, CoBRAS)**

- **Trace onset of feedback processes by jets/winds during early stages of massive star formation.**
- **First direct test of the X-wind model for protostellar jets**
  - **e-MERLIN can resolve key physical processes**

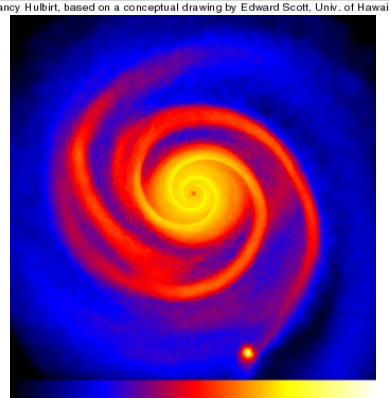


(PSRD graphic by Nancy Hulbirt, based on a conceptual drawing by Edward Scott, Univ. of Hawaii.)

**Formation of planetary systems**

**(PEEBLES)**

- **Detect cm-sized particles in planet-forming disks ~1 AU, ~1$M_E$**
- **Astrometric detection of Jupiter-mass planets around low-mass stars**
  - **e-MERLIN required for spatial and spectral separation of emission components**



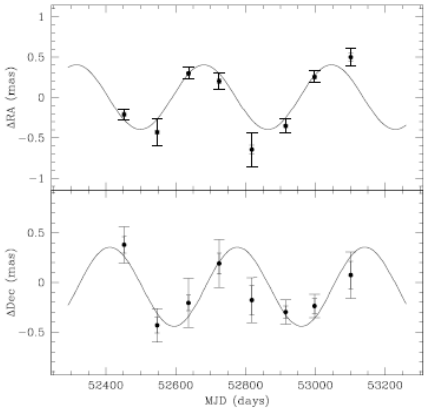
The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

# Legacy projects (3)
## Extreme environments

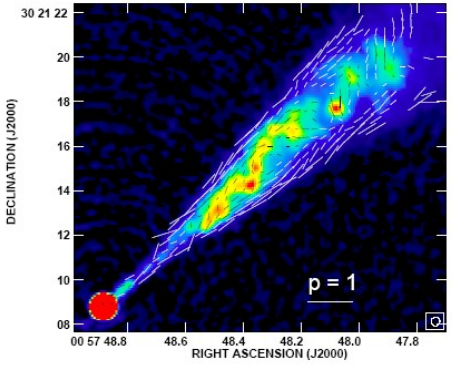
**Pulsar proper motions (eΠ )**

- **Proper motions of many pulsars**
- **Physics of neutron star formation during SNe**
- **Double the number of pulsars with accurate distances & velocities**
  - **e-MERLIN resolution essential, multi-epoch proper motions**




**Extragalactic Jets**

- **Dynamics of jets, low luminosity radio jet deceleration on sub-kpc scales**
- **Magnetic field configuration surrounding jets**
- **Particle acceleration in hotspots**
- **Polarisation and faraday rotation across e-MERLIN bands**
  - **e-MERLIN can resolve the key physical processes'**



# Conclusion

- E-Merlin will have a major impact on high resolution astronomy
- Huge progress in past few months but much to do

- E-Merlin igh resolutic
- Huge pr much to do