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Netherlands Institute for Radio Astronomy

Edge of the Fringe - Deep, Wide-Field VLBI

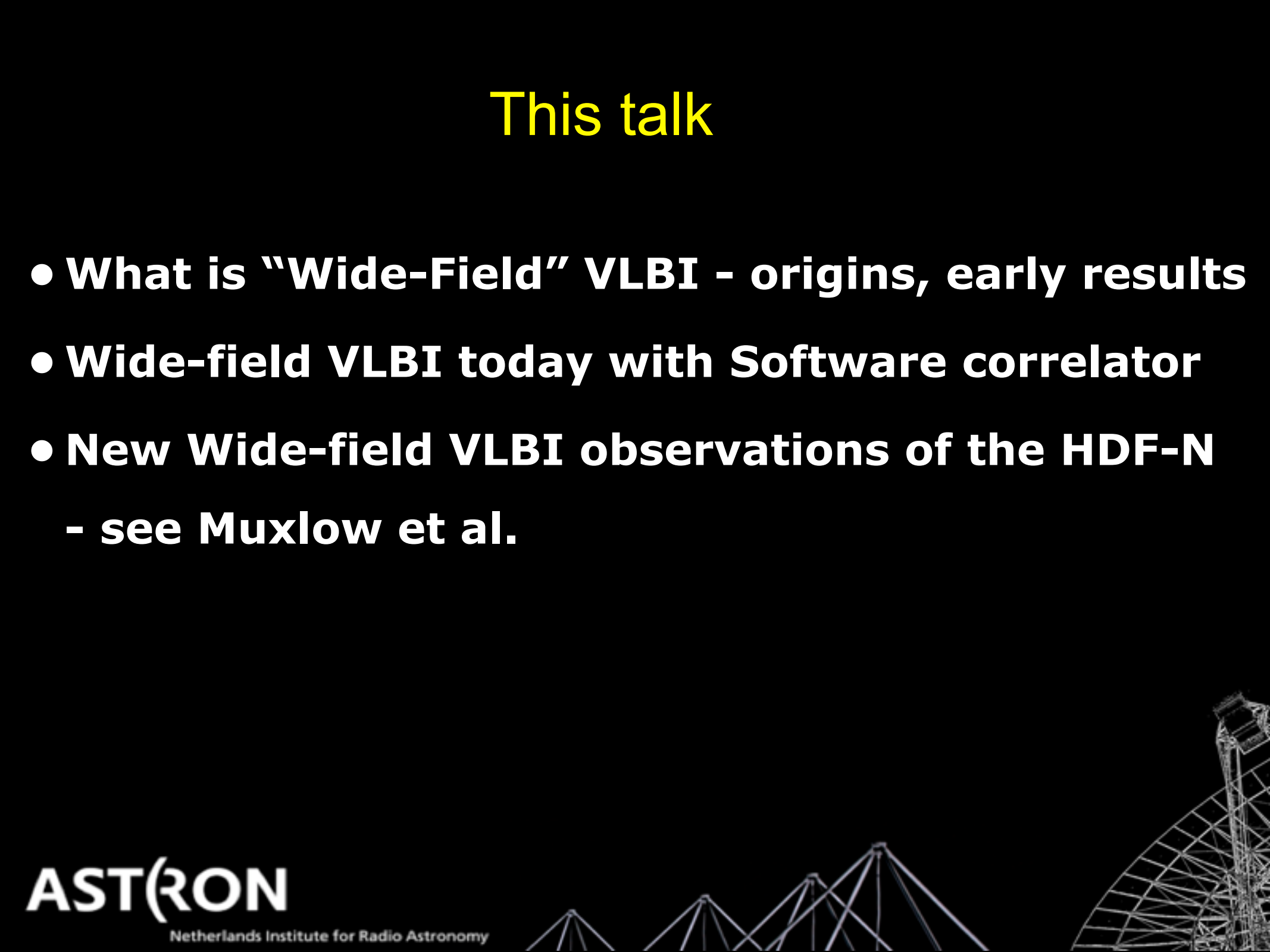
- Prof. Michael A. Garrett

General & Scientific Director, ASTRON

Also affiliated with Leiden Observatory.

This talk

- **What is "Wide-Field" VLBI - origins, early results**
- **Wide-field VLBI today with Software correlator**
- **New Wide-field VLBI observations of the HDF-N**
  - see Muxlow et al.



Origins: *VLBI observations of double (multiply imaged) QSOs*

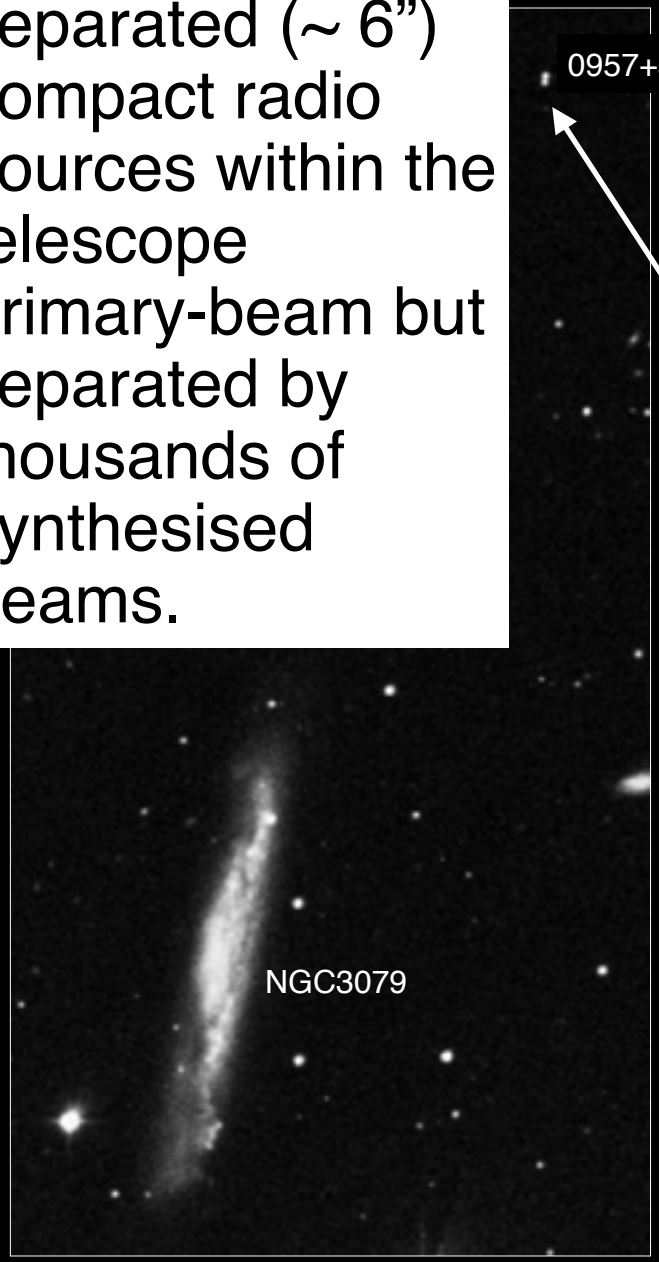
0957+561 A, B: twin quasistellar objects or gravitational lens?

D. Walsh
University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire, UK
R. F. Carswell
Institute of Astronomy, Cambridge, UK
R. J. Weymann
Steward Observatory, University of Arizona, Tucson, Arizona 85721

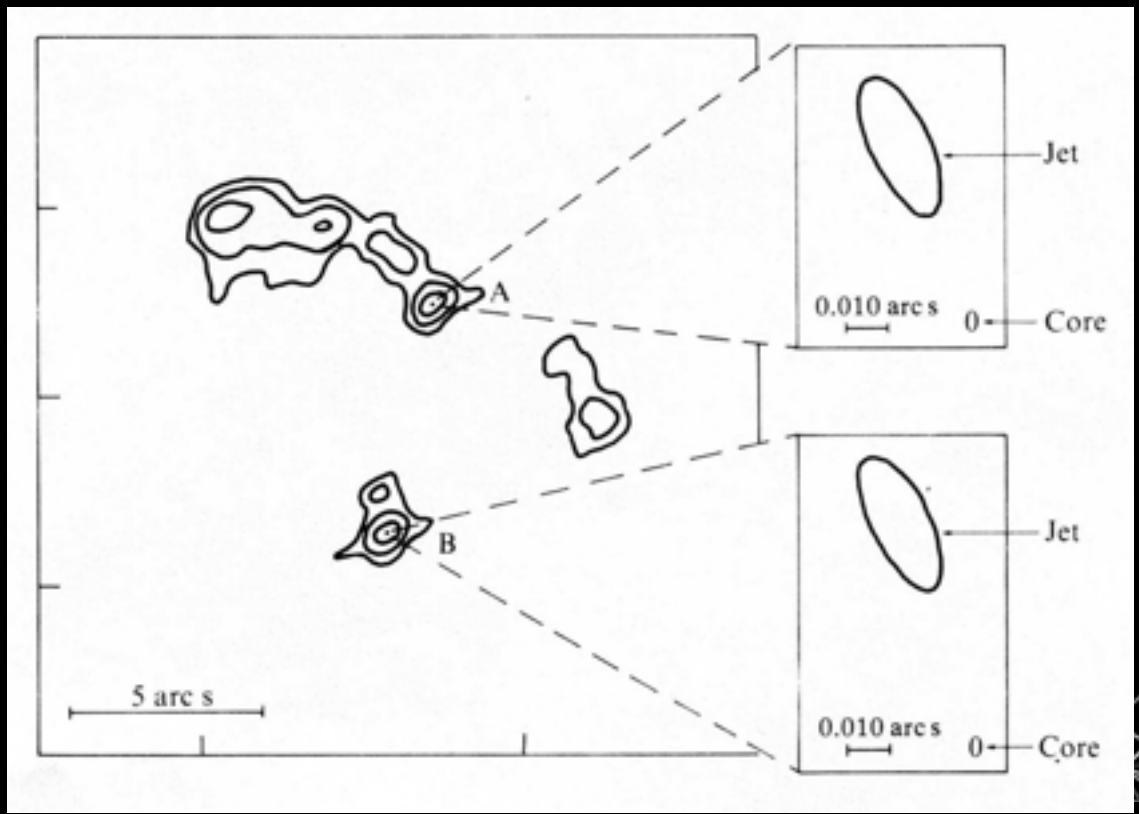
0957+561 A, B are two QSOs of mag 17 with 5.7 arc s separation at redshift 1.405. Their spectra leave little doubt that they are associated. Difficulties arise in describing them as two distinct objects and the possibility that they are two images of the same object formed by a gravitational lens is discussed.

Walsh, Carswell & Weymann 1979, Nature.

2 widely separated (~ 6”) compact radio sources within the telescope primary-beam but separated by thousands of synthesised beams.



Jodrell Bank students - 1986



Porcas et al. Nature 1980, 1981

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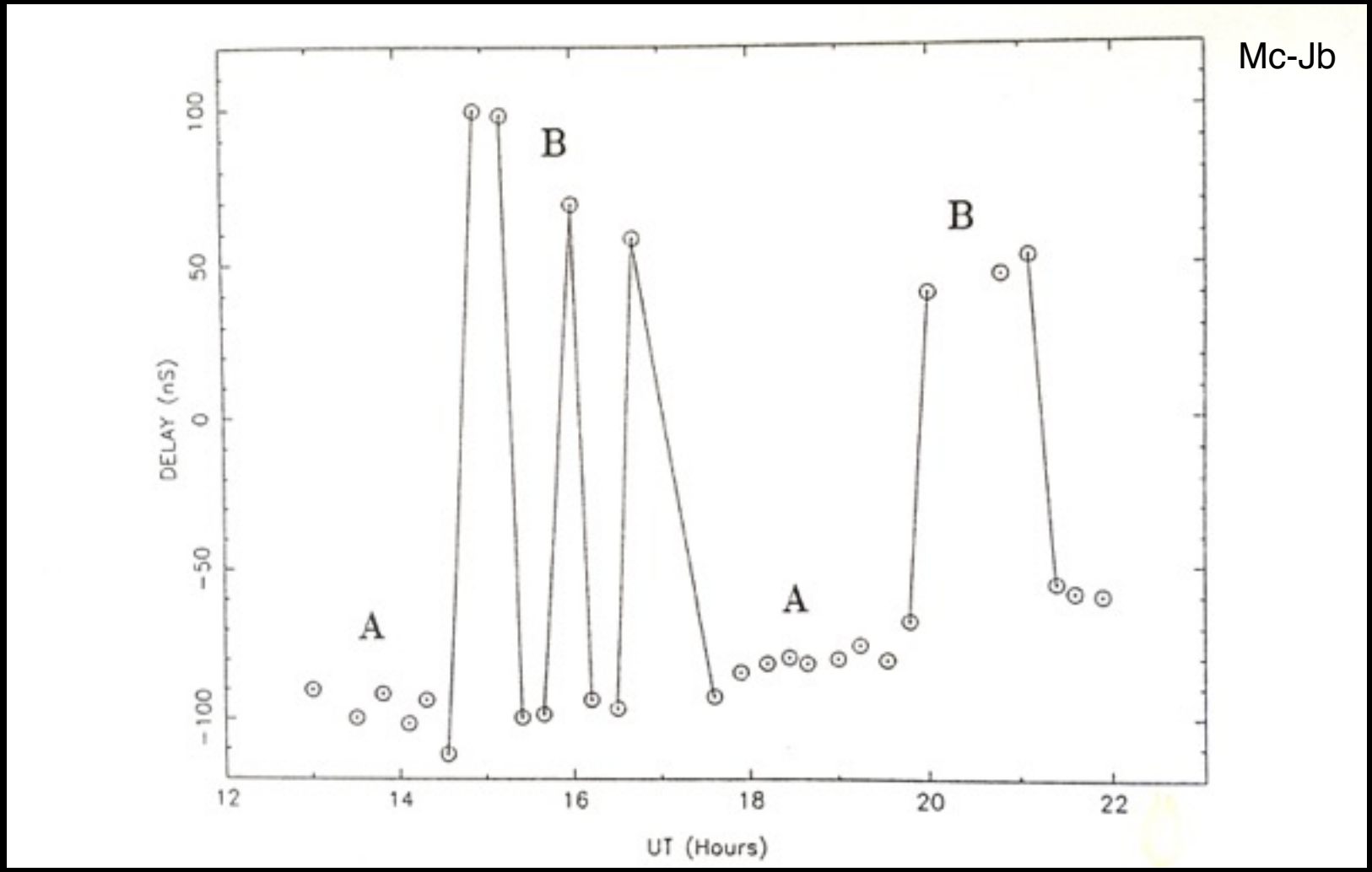
Fringe Benefits!

- Two sources for the price of one!
- Sounds like a good deal…
- Actually complicated things considerably…

RWP

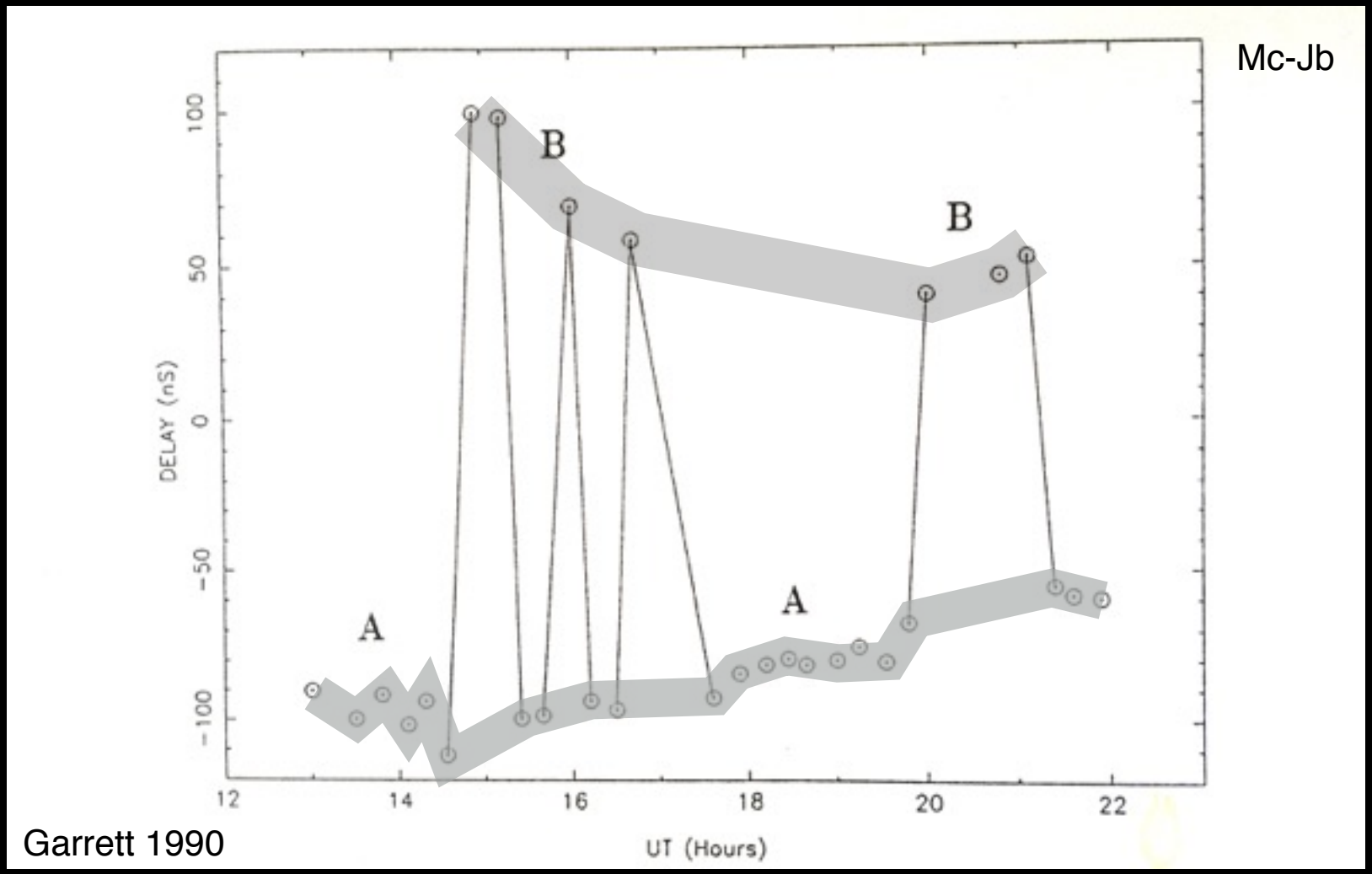
Two sources for the price of one!

- VLBI requires **Fringe-Fitting** - solves for residual errors - rapid phase excursions in frequency (and time).

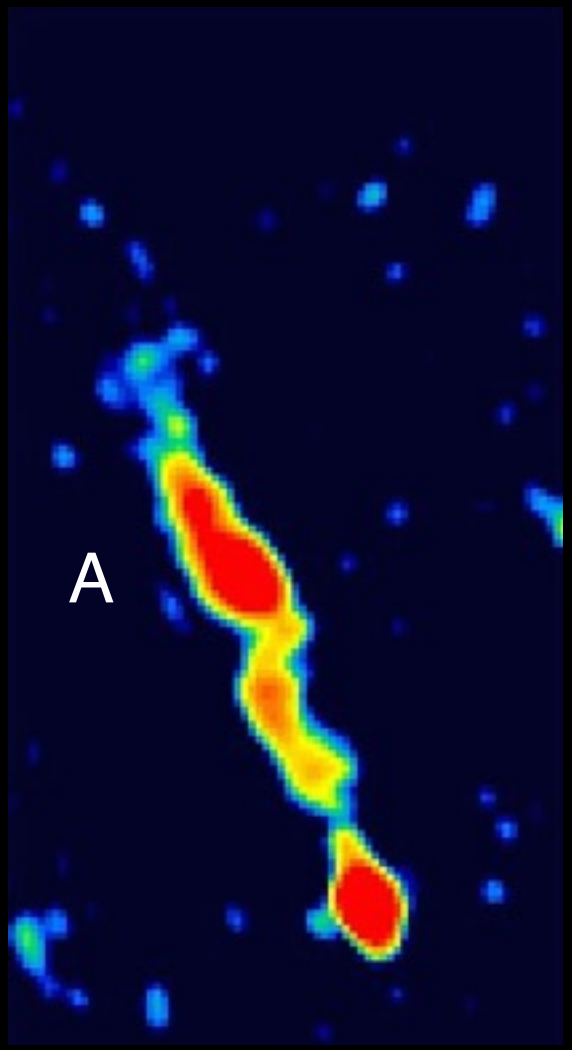


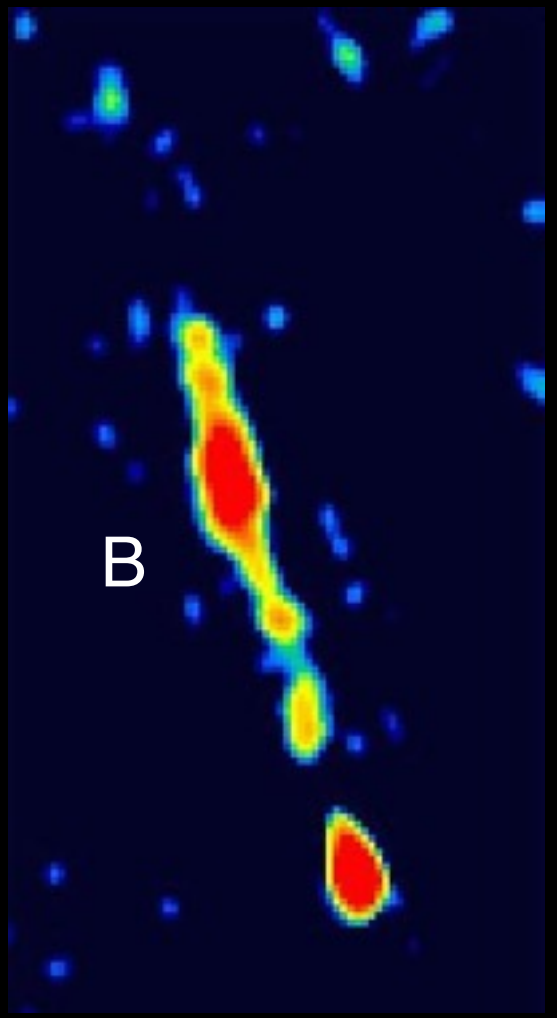
The solution ca. < 1990

- Generate 2 data sets for each component, refringe-fitting with narrow windows:



- Works mostly ok… (at least on the longest baselines).

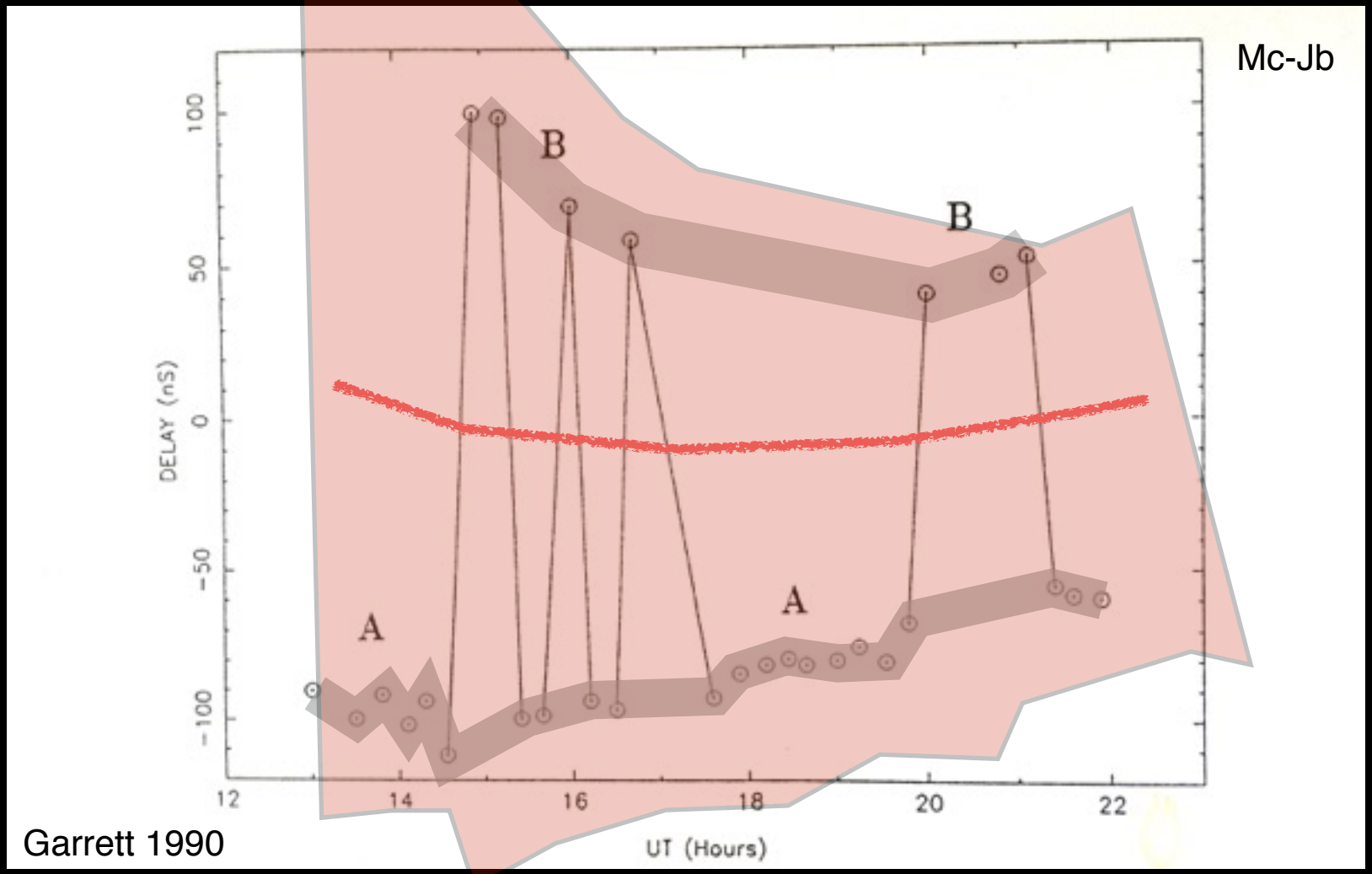




Garrett et al. 1994

The solution ca. > 1990

- Generate 2 data sets for each component, refringe-fitting central position with very high temporal and spectral resolution:

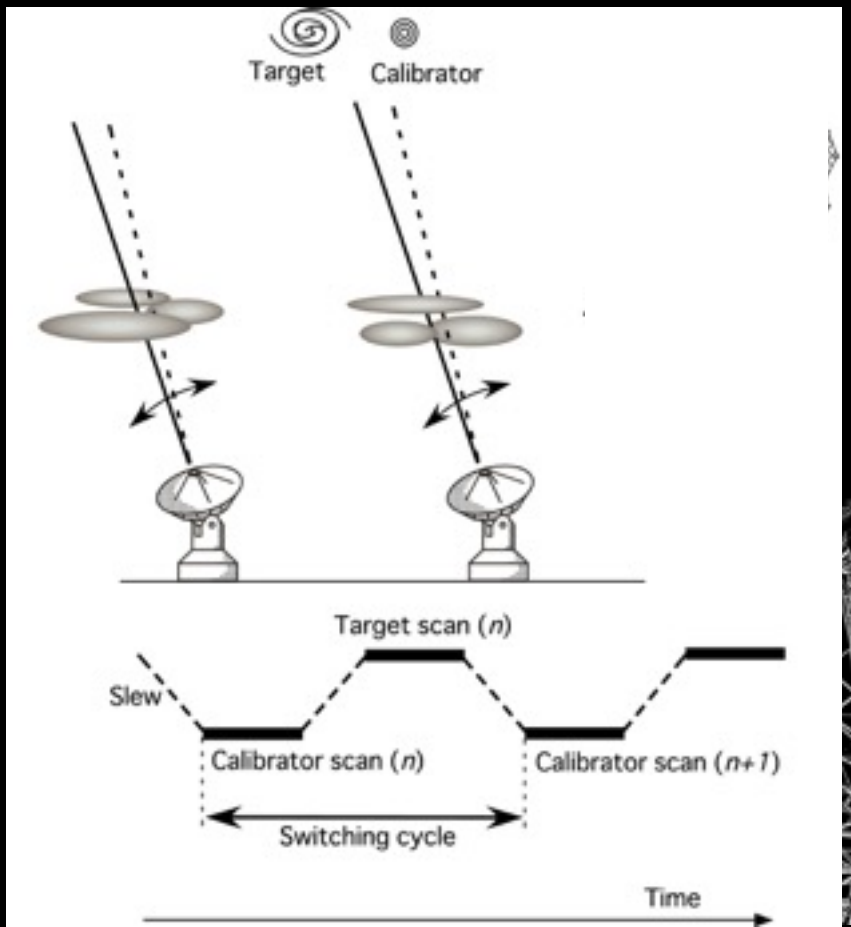


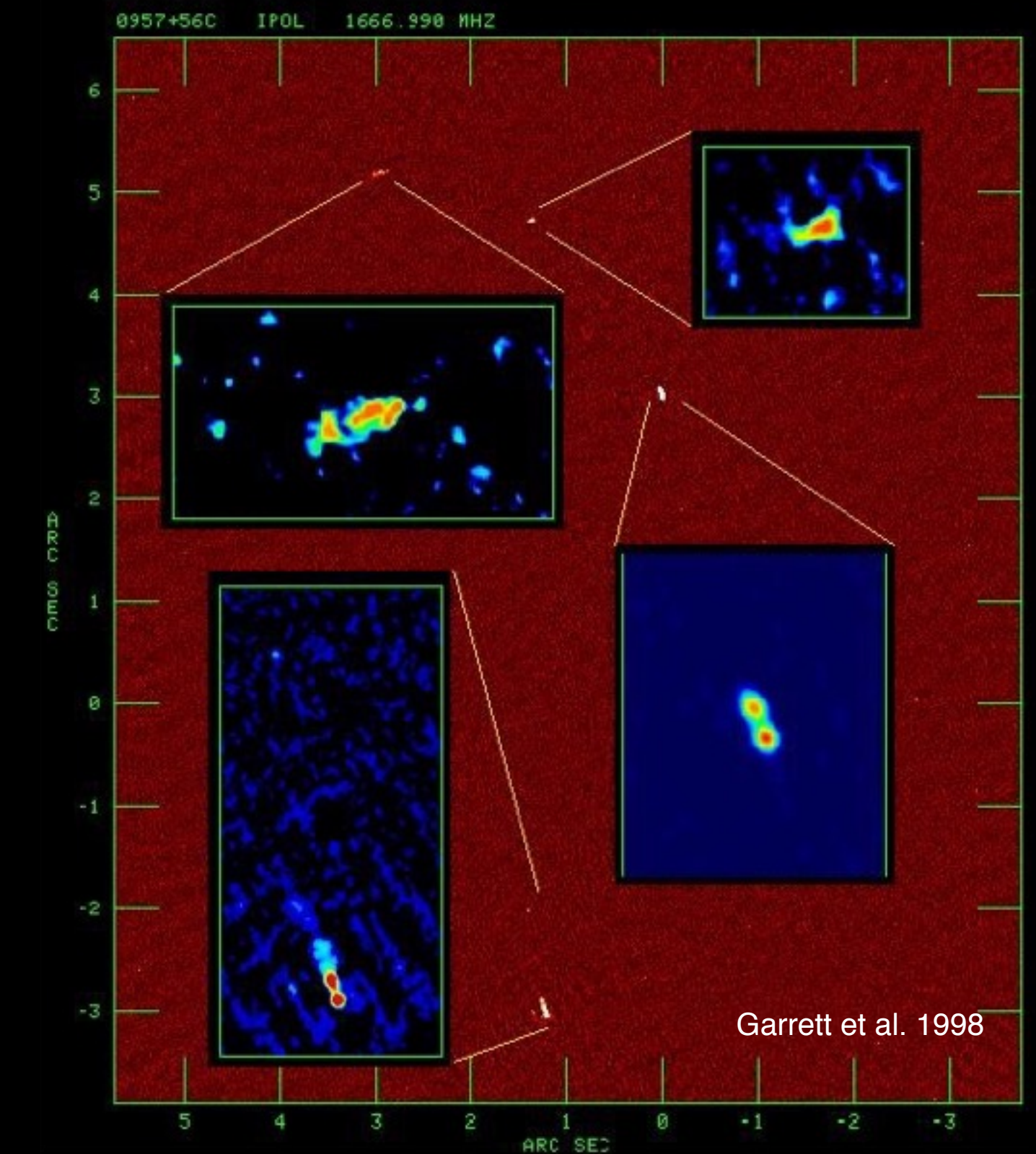
The solution ca. mid-1990s

- Generate a single data set encompassing response of both (all) sources.

  Maintain field of view (no time/frequency averaging)

- Simplify the Fringe-Fitting stage by employing phase (rate/delay) referencing.

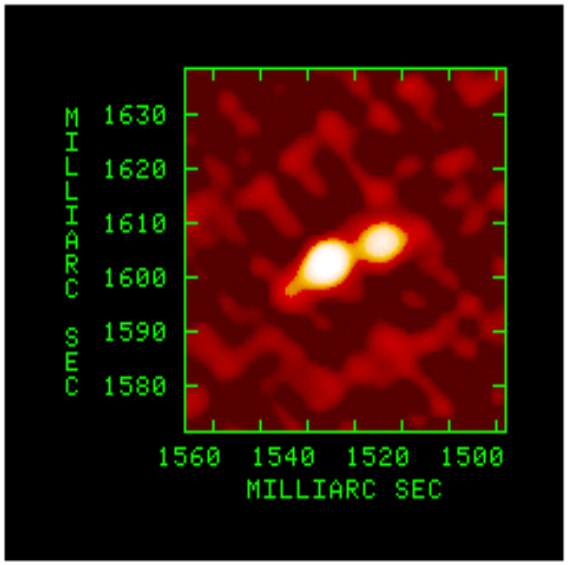


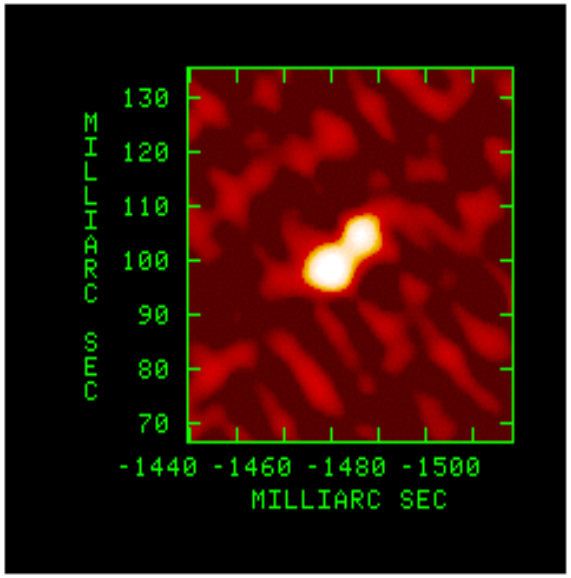


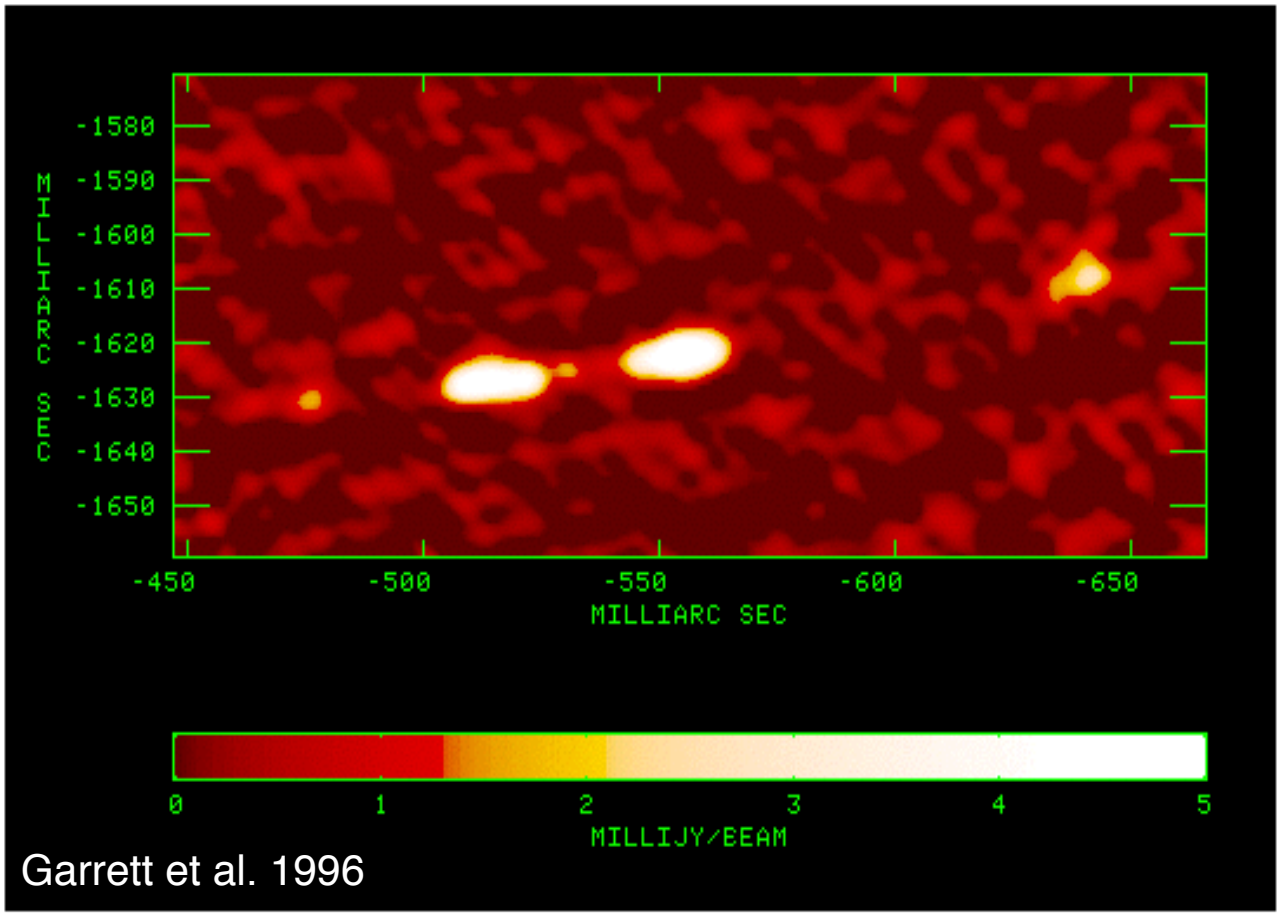
10”

Some early successes: EVN 18cm: B0957+561

Garrett et al. 1998





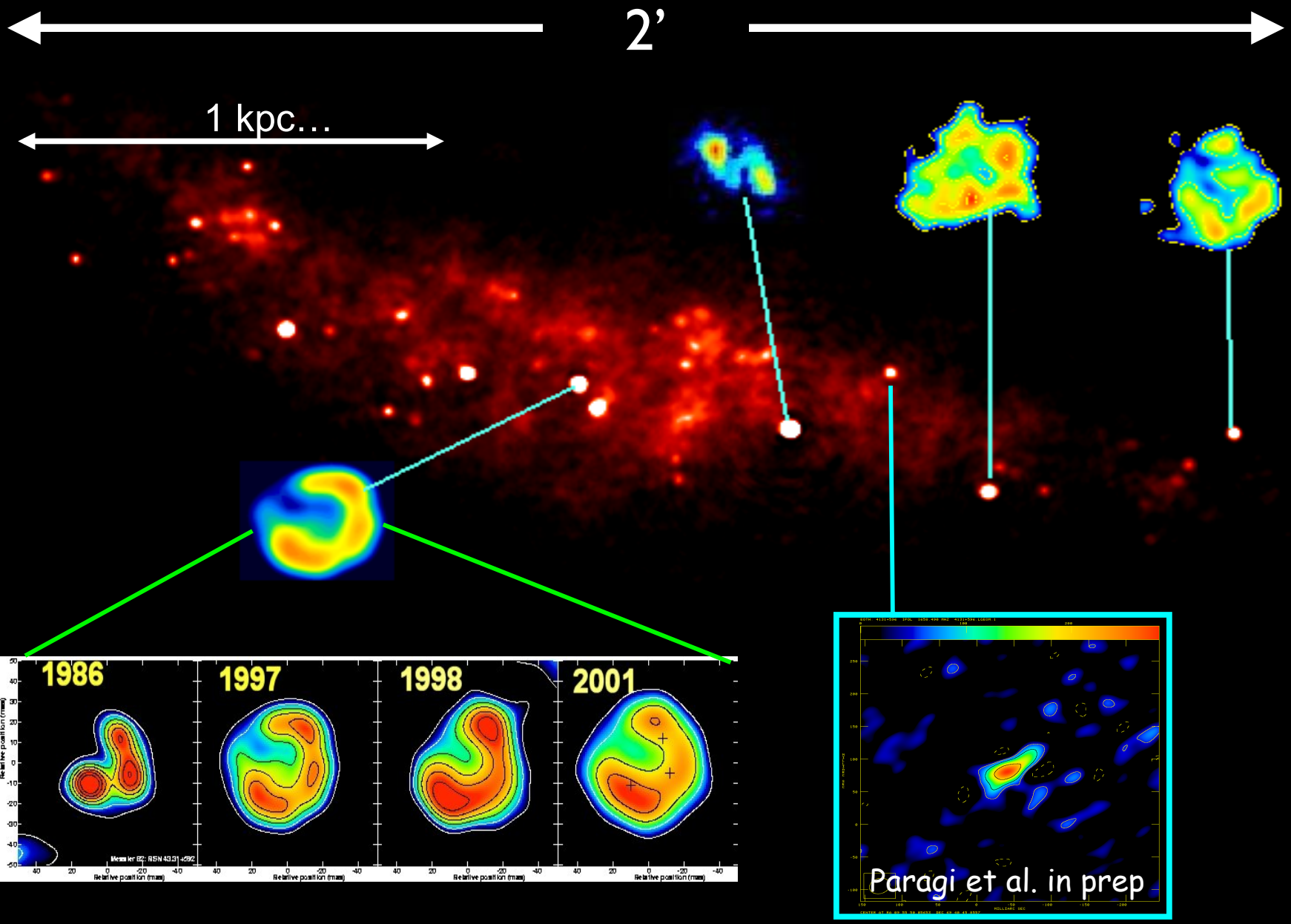


Garrett et al. 1996

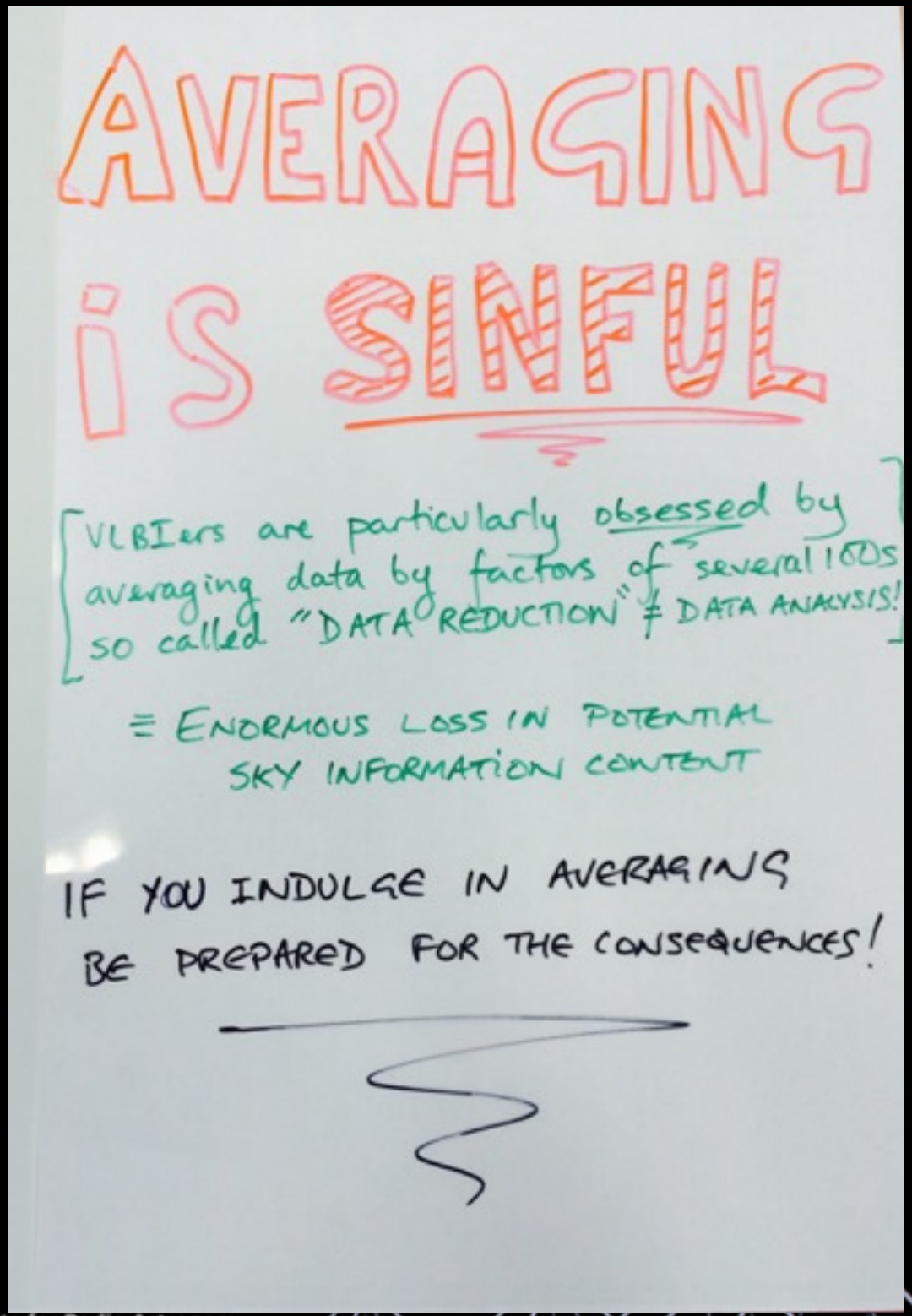
e.g. MG2016+112.

Some tricks of the trade: Simplify the calibration by *phase-rotating* raw data to the position of brightest/ simplest/… source, averaging data and using these as starting solutions for un-averaged full-field.

Wide-field imaging - beyond lensing…

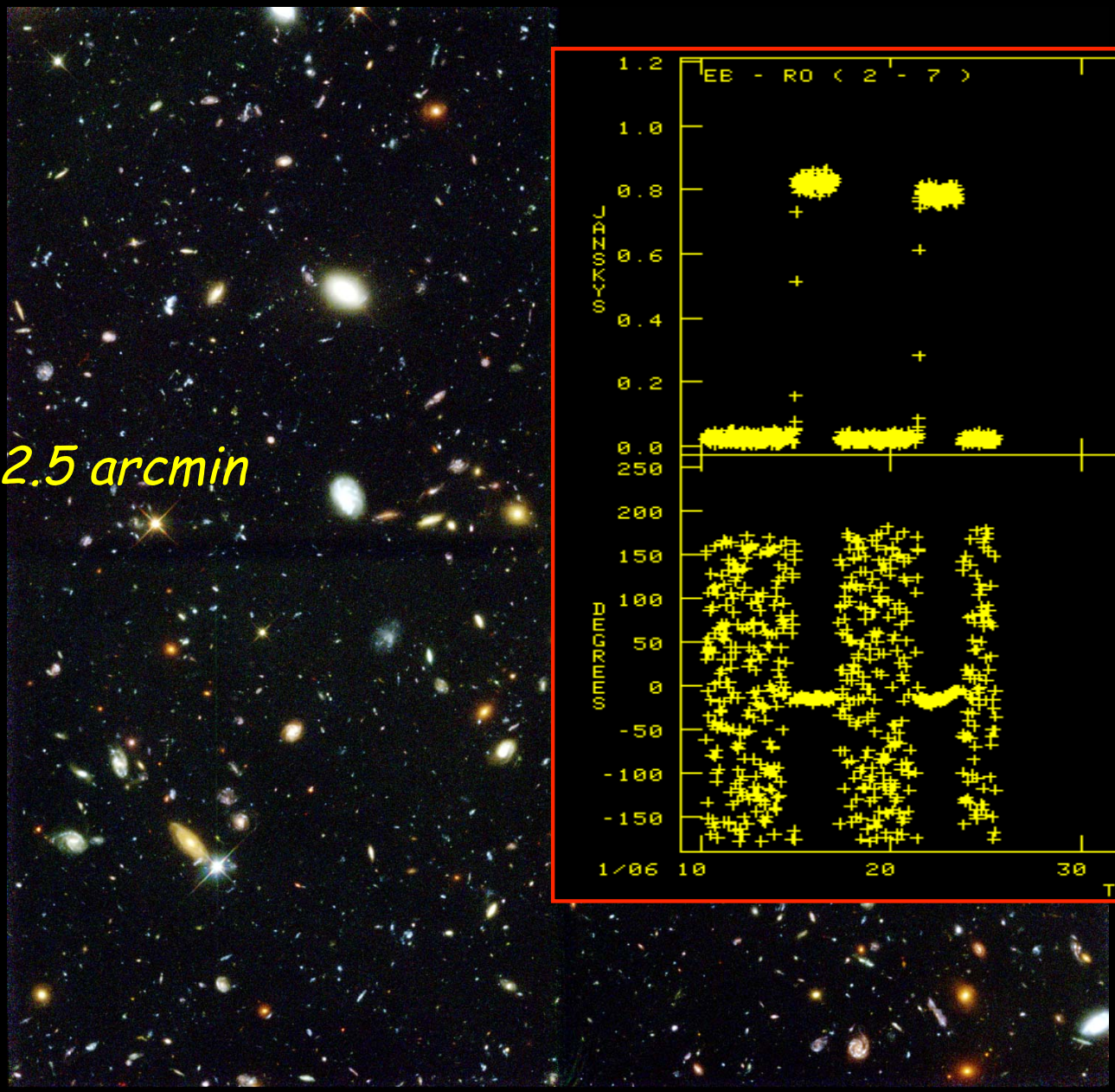


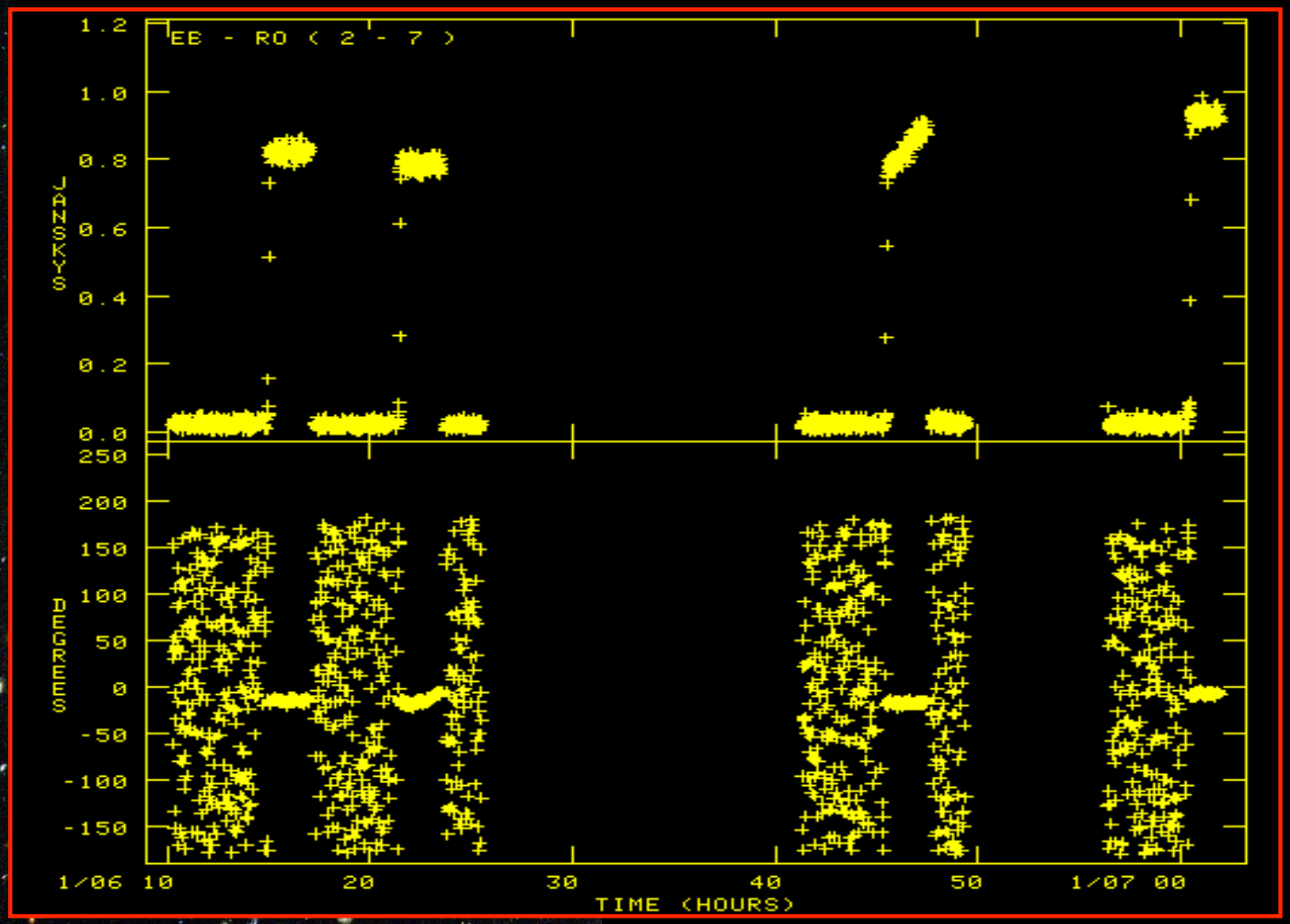
Muxlow et al. 1994, Pedlar et al. 1999, McDonald et al. 2001, Beswick et al. 2006



Garrett ca. 1997

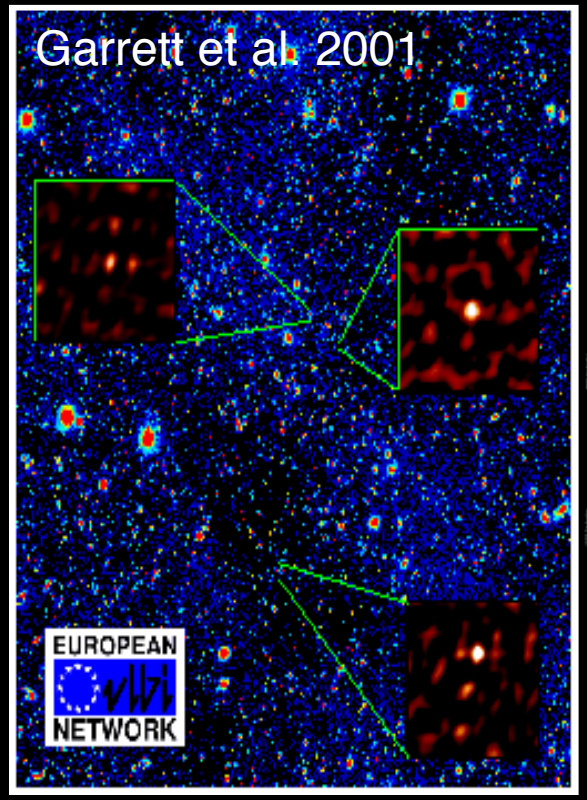
- Deep Fields (Blank fields) e.g. Hubble Deep Field - North:

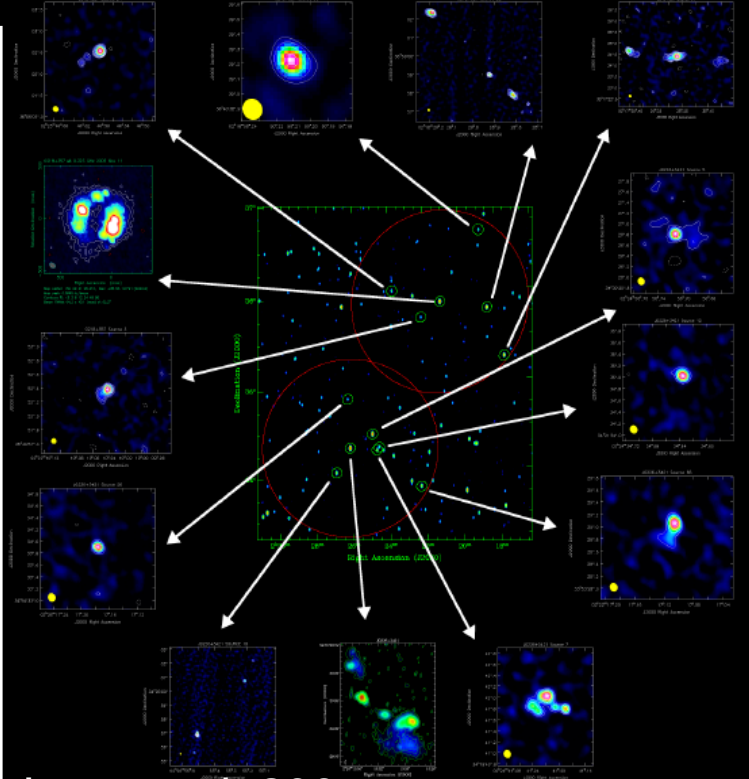


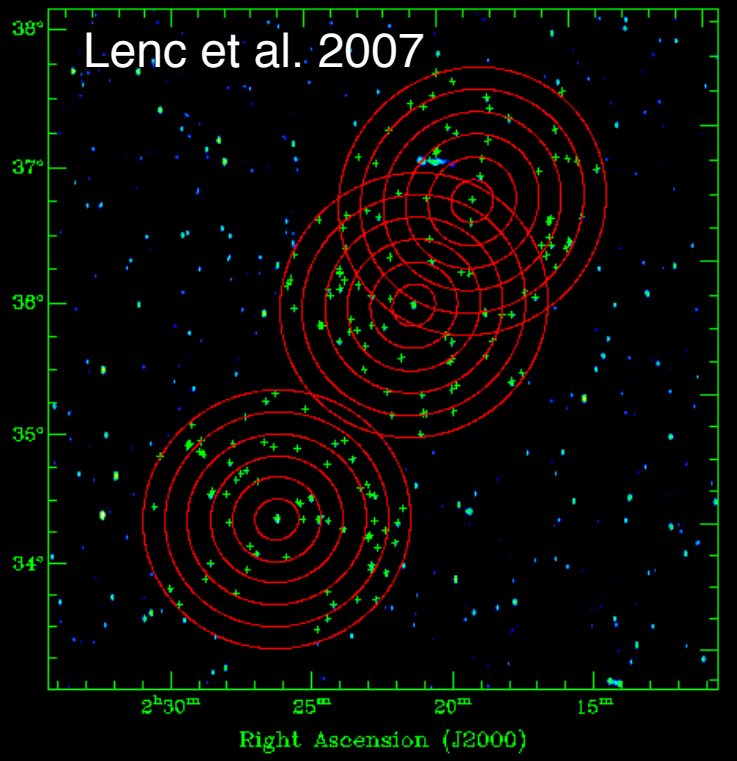


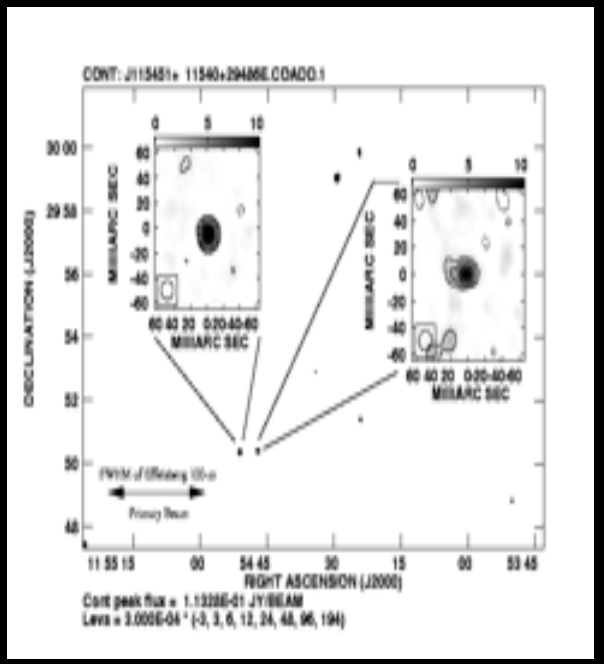
Hubble Deep Field **HST WFPC2**

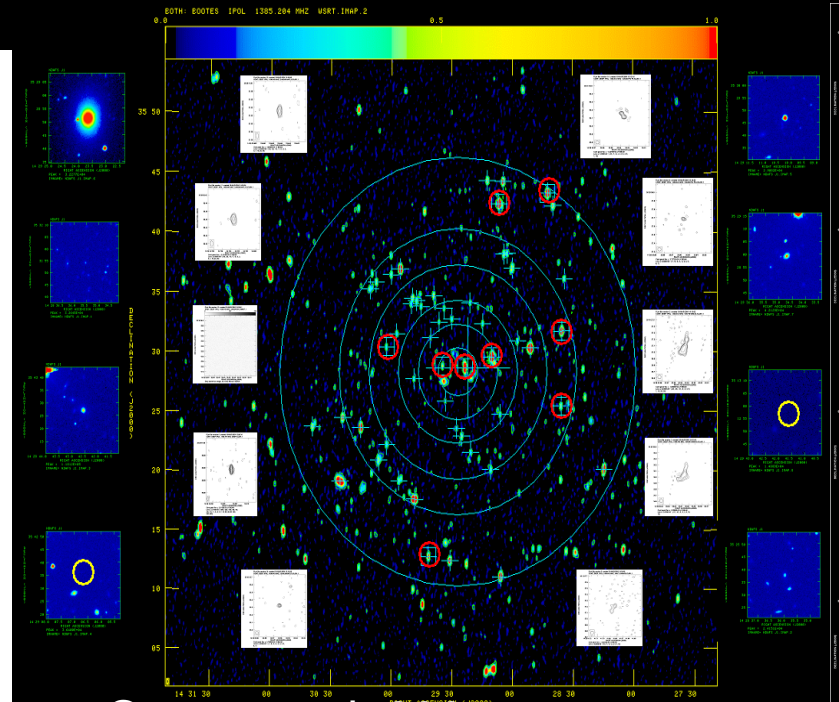
ST ScI OPO January 15, 1996 R. WIlliams and the HDF Team (ST ScI) and NASA

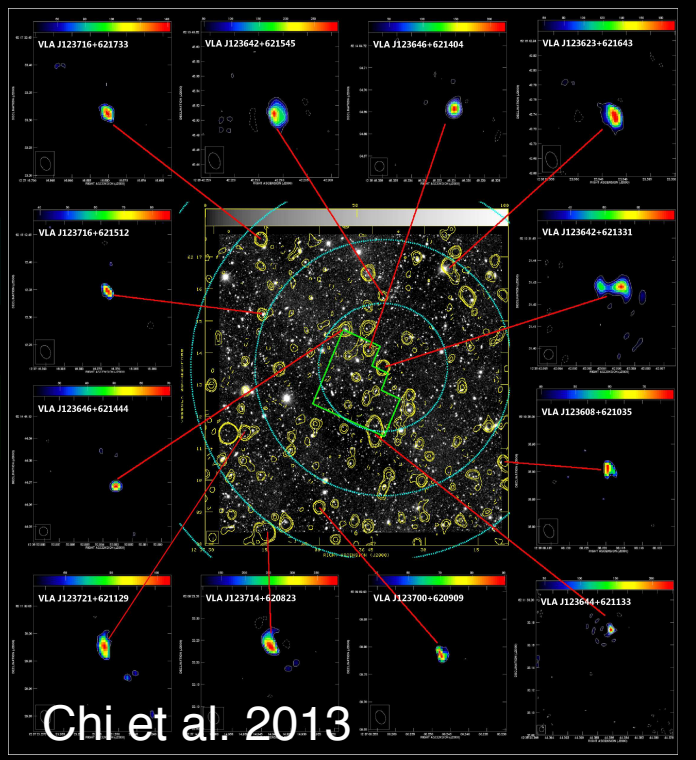

Garrett et al. 2001
EUROPEAN
NETWORK


Lenc et al. 2007

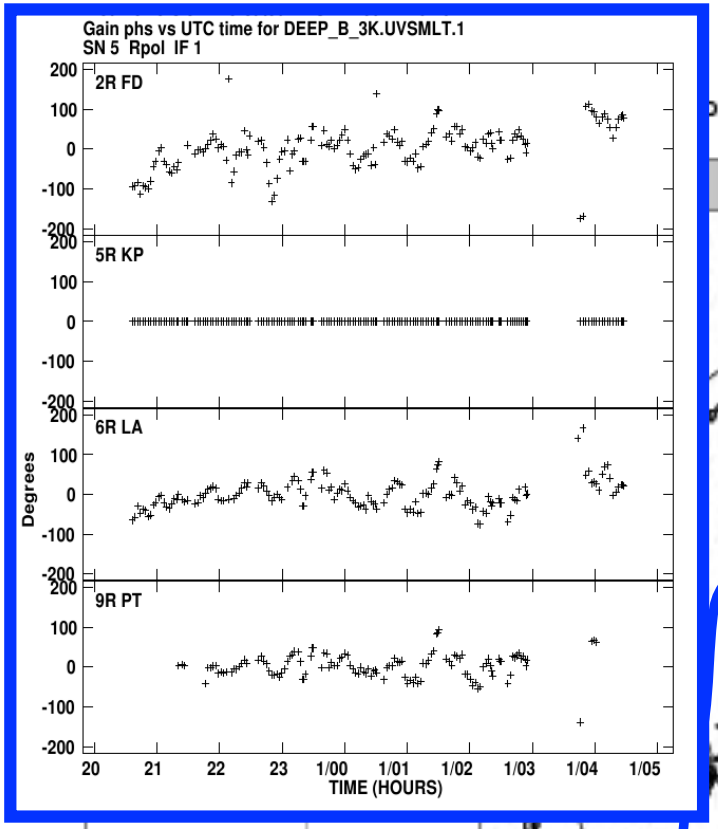

Lenc et al. 2007
38°
37°
36°
35°
34°
2h30m
25m
20m
15m
Right Ascension (J2000)


CONT: J115451+ 11540+294866.COADD.1
DECLINATION (J2000)
RIGHT ASCENSION (J2000)
MILLIARC SEC

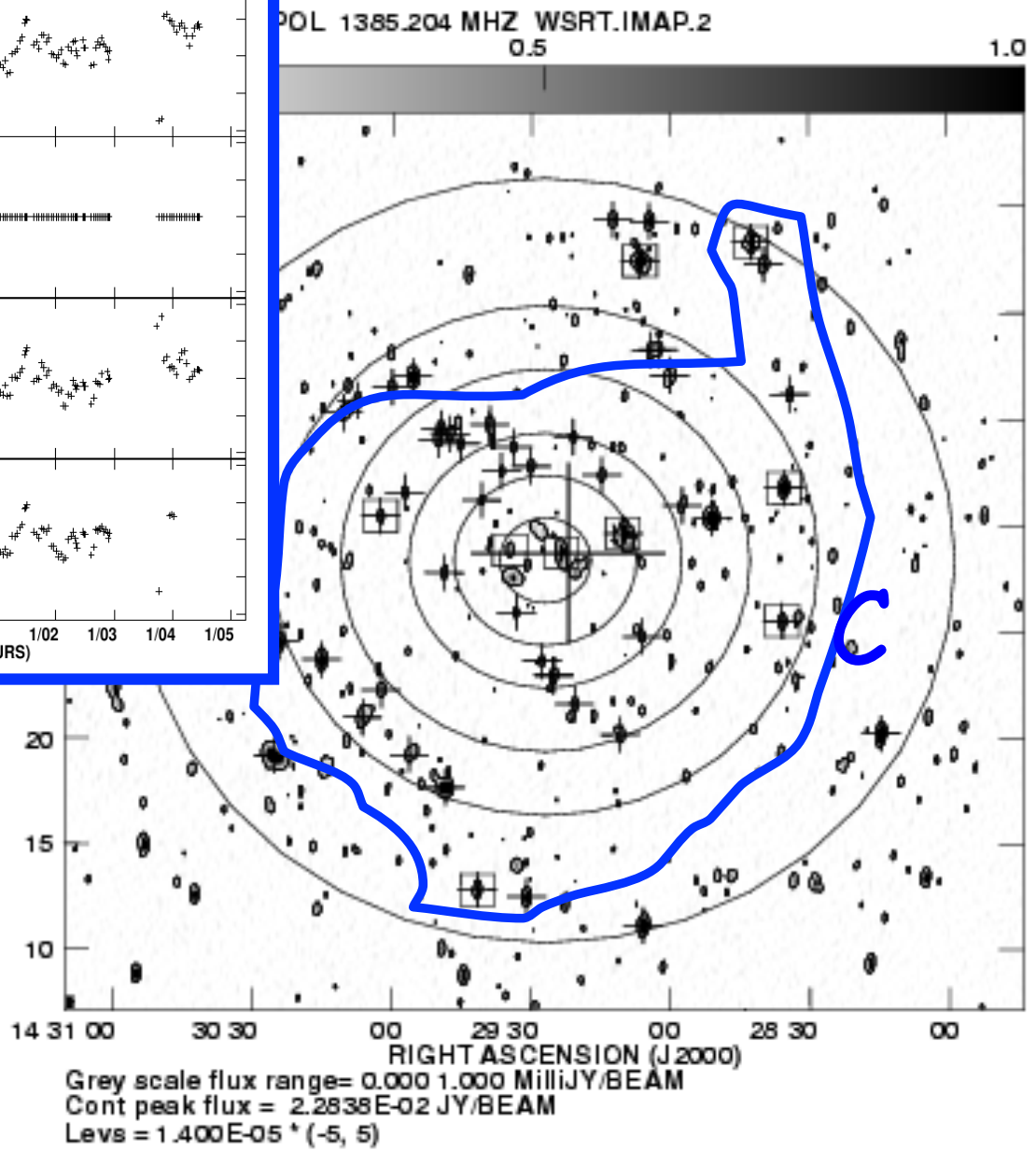

Garrett et al. 2005

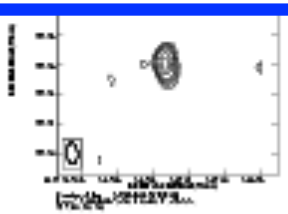

Chi et al. 2013
VLA J123716+621733
VLA J123642+621545
VLA J123646+621404
VLA J123623+621643
VLA J123716+621512
VLA J123642+621331
VLA J123646+621444
VLA J123608+621035
VLA J123721+621129
VLA J123714+620823
VLA J123700+620909
VLA J123644+621133

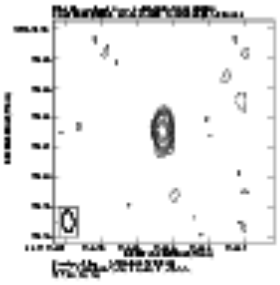
At L-band: even for VLBI, there are ***always*** enough sources within the unaveraged field-of-view to self-cal the data…

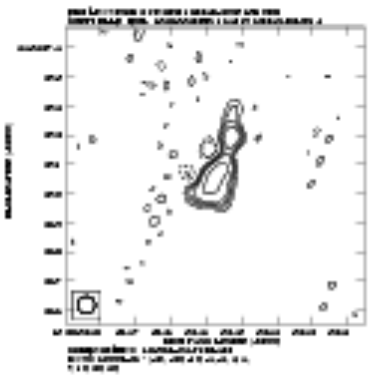


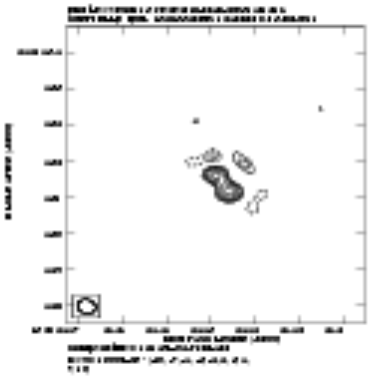
Garrett et al. 2005

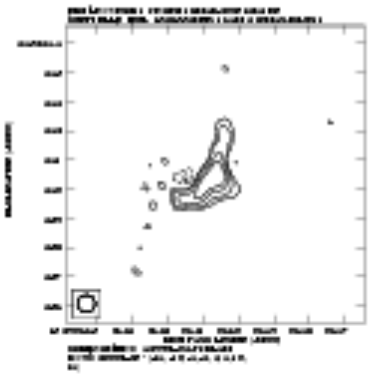






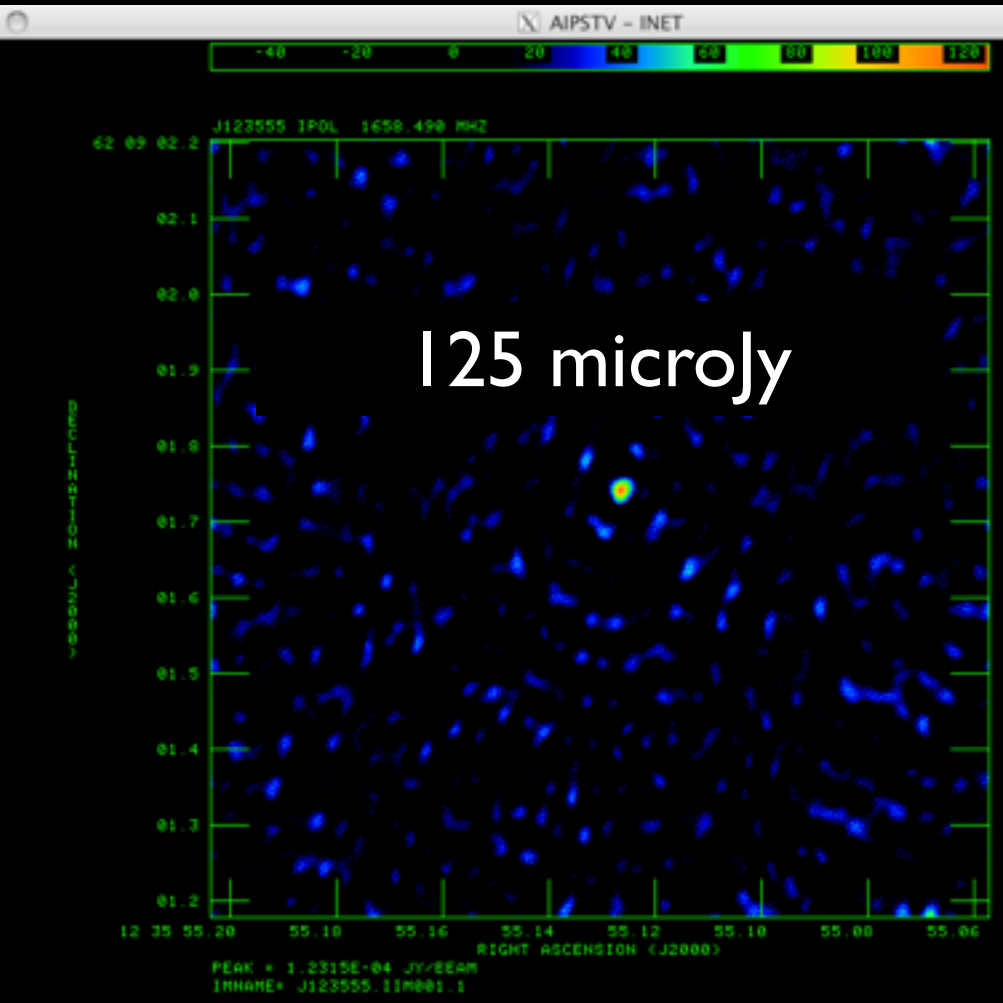


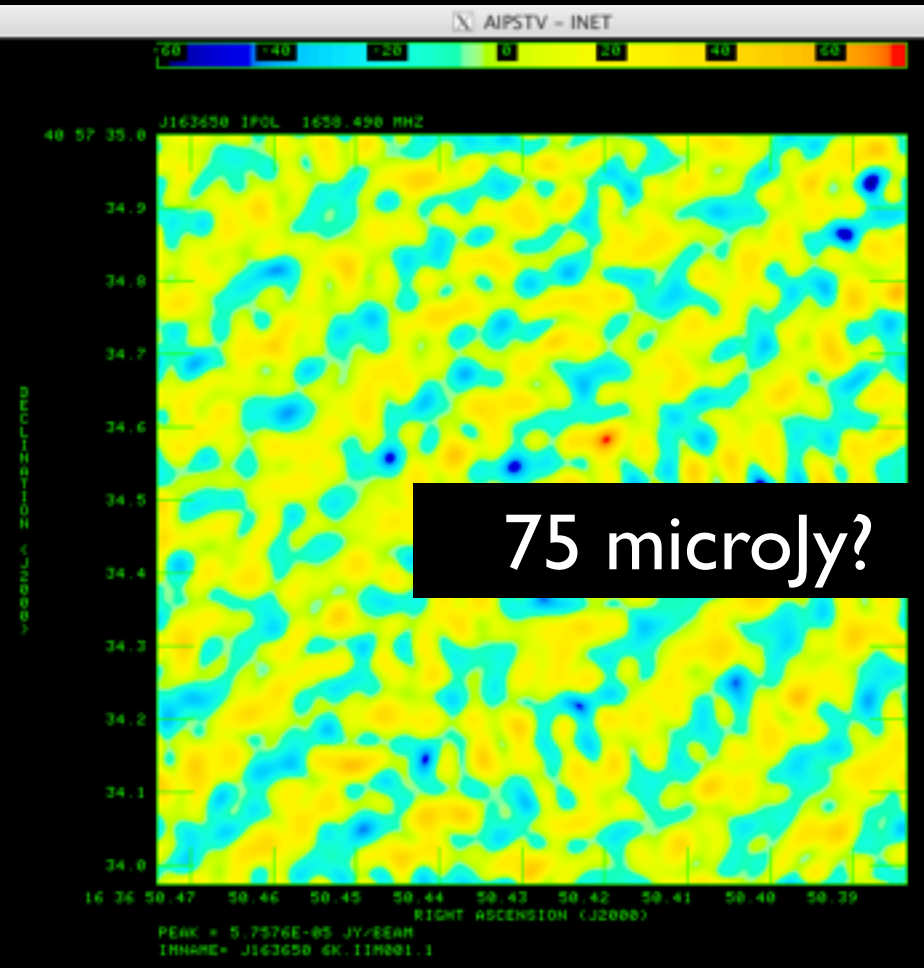




Wide-field imaging - very faint sources…

e.g. Sub-mm Galaxies - Biggs et al.





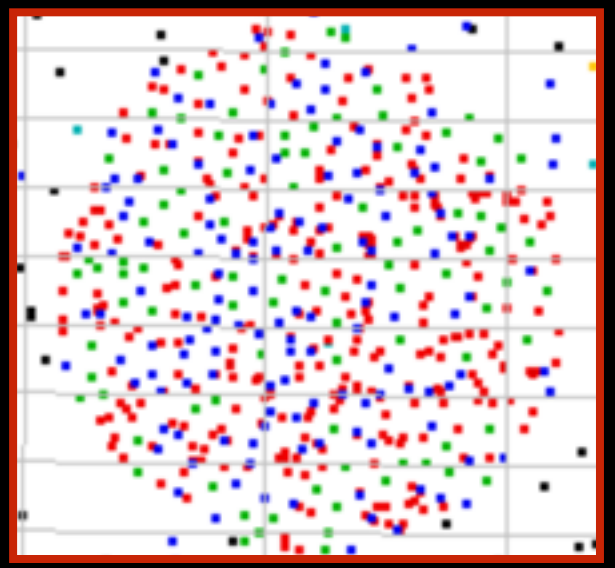
Garrett, Chi et al.

- **Brute-force wide-field VLBI method was very successful (1990-2013) but…**
  - produced a lot of monolithic data sets (Many TBs)
  - difficult to handle & manage
  - *very long* processing times
  - errors in shifting online algorithms [for vlbi]
  - nasty field-edge errors on VLBI scales

Wide-field VLBI 2015

- **Modern Software Correlators (e.g. DiFX - Deller et al. 2011, SFXC Keimpema et al, 2015) make things much easier:**

  - very high frequency and time resolution (kHz & msec) correlation possible
  - multiple-fields easily generated by shifting each visibility to many (100s) of different sub-fields
  - correlator corrections correct for each field individual centre.
  - data for each sub-field averaged-up to manageable data size (GB not TB!)



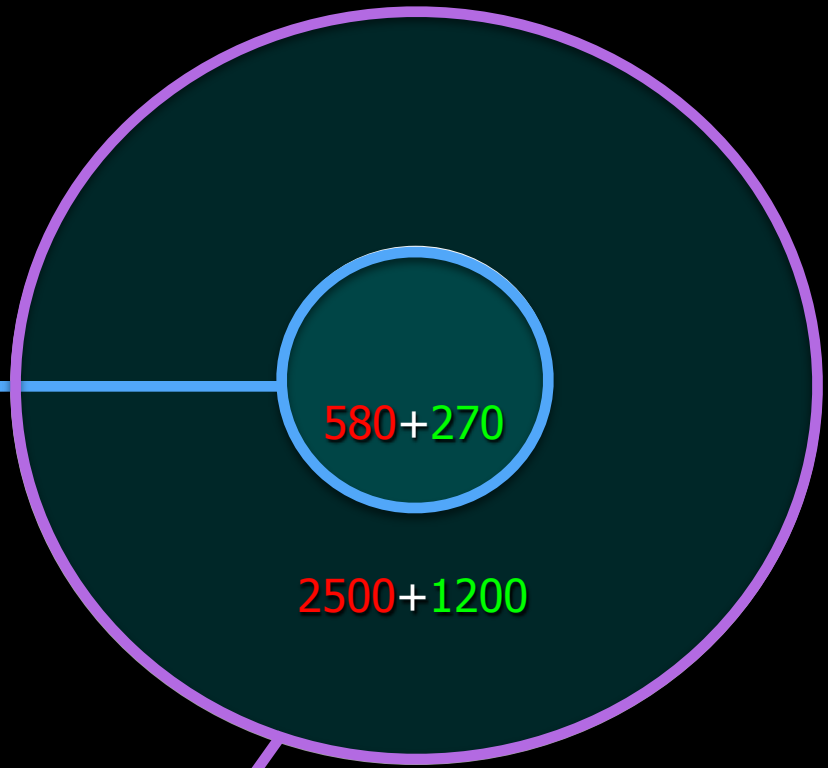
15’

New Ultra-deep e-MERLIN + JVLA observations of the HDF-N.

Inner 12 arcmin field, 1σ ~ 0.5uJy/bm.

Expectation: ~ 580 star formers
~ 270 AGN.

Hybrids: AGN + SF also likely to be present in same object.



Surrounding 800 arcmin^2, 1σ ~ 1 uJy/bm.

Expectation ~ 2500 star formers
~ 1200 AGN.

PI: Tom Muxlow

New Ultra-deep EVN observations

EVN: 3 days of observing time, 5 mas resolution; 1σ ~ 3uJy/bm, FoV ~ 15 arcmin (diameter).

Science goals:

- discriminate between AGN and star forming galaxies.
- Search for hybrids - AGN embedded in Star Formers.
- Conduct census of AGN unique to radio domain.
- Uncover Compton-thick AGN (AGN undetected in X-rays)
- Understand AGN fraction in SMGs and nature of the high-z tail of star forming galaxies.

PI: Mike Garrett

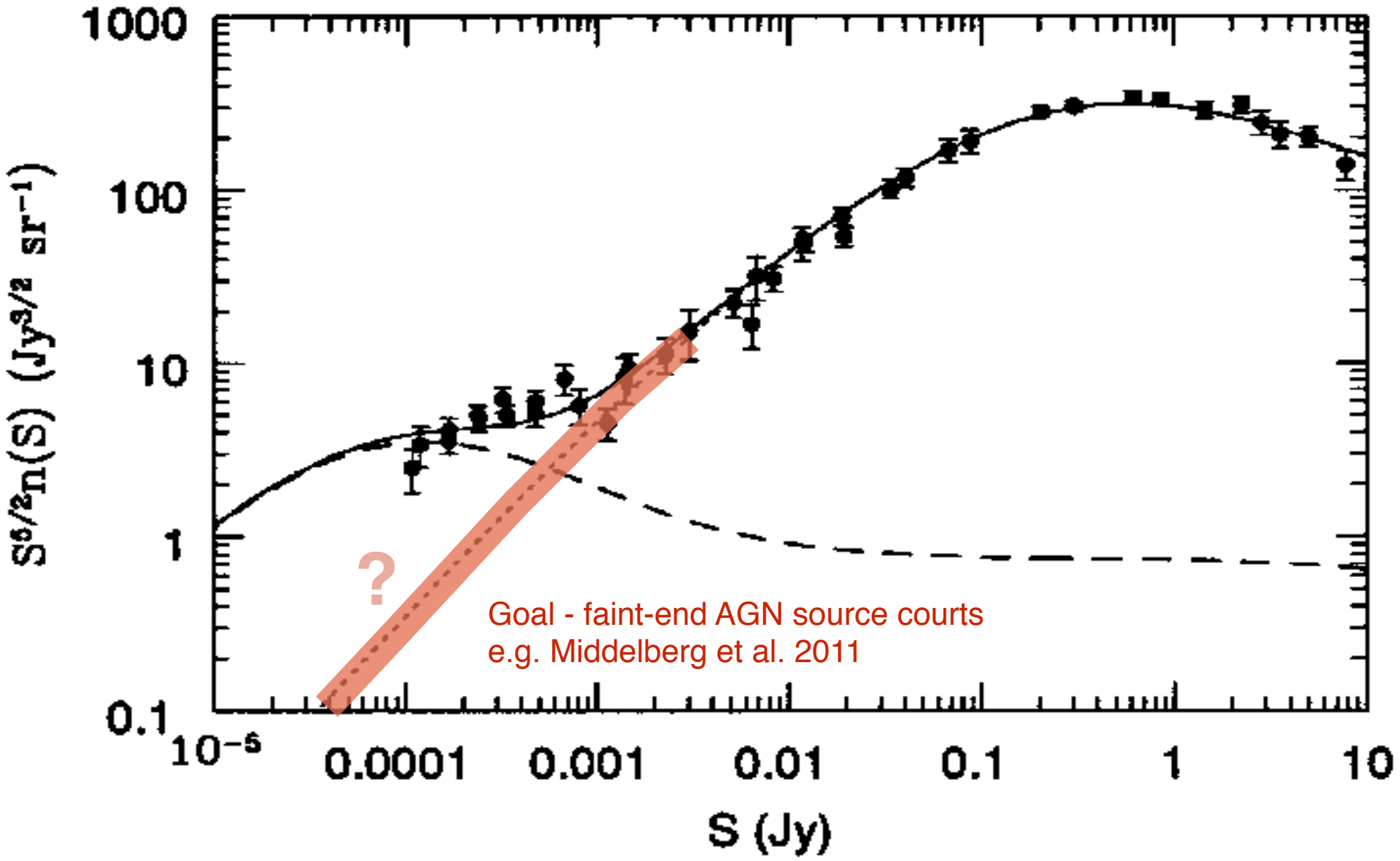


Figure 1. Weighted source count at 1.4 GHz (data points) and models indicating the contributions of evolving "monsters" in true AGN (dotted curve) and "starbursts" (dashed curve).

HDF-N Legacy Sky Coverage (3000 km baselines)

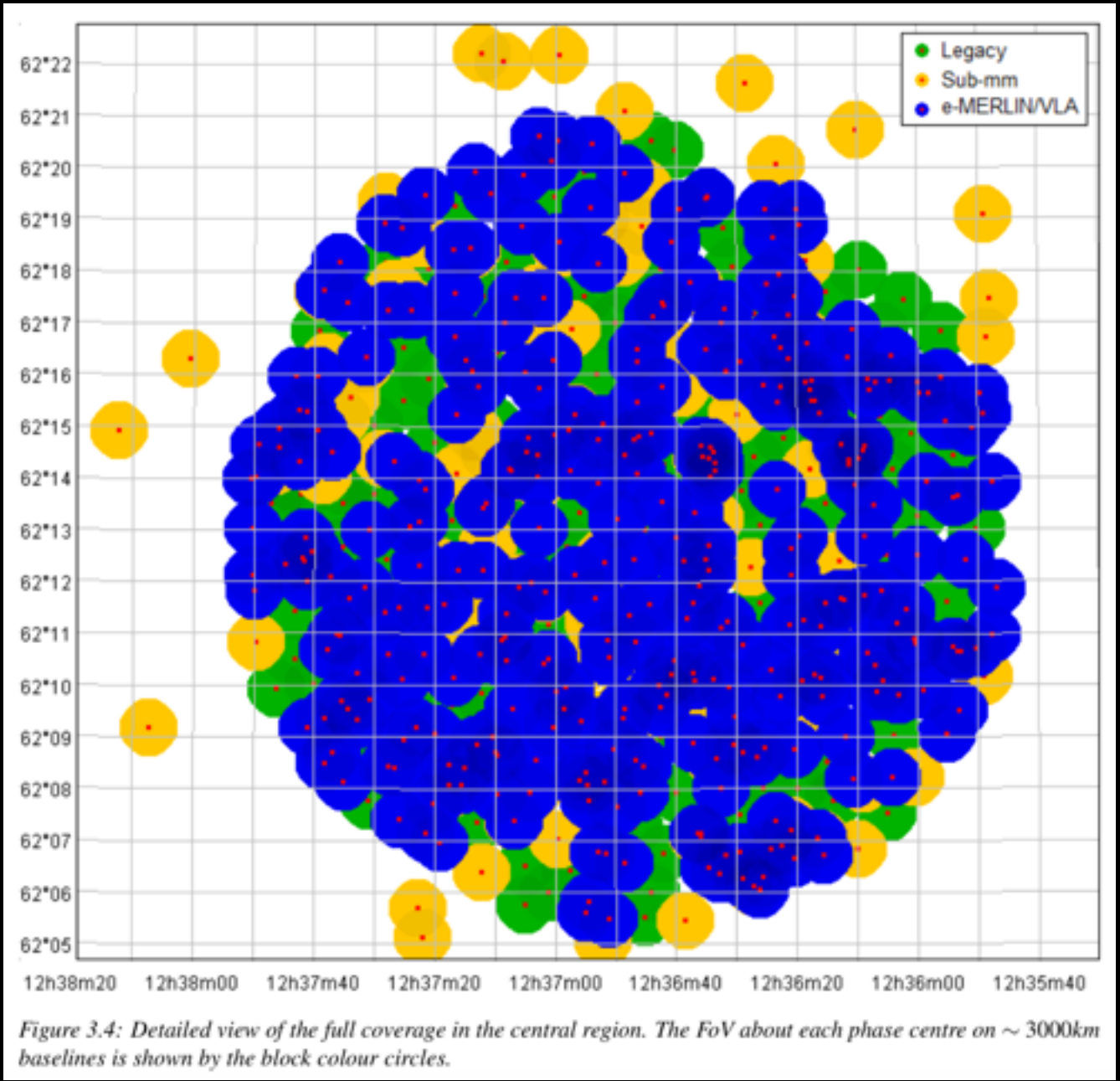
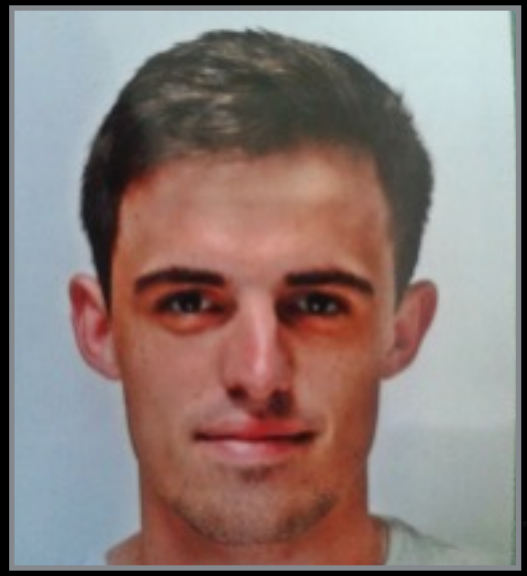


Figure 3.4: Detailed view of the full coverage in the central region. The FoV about each phase centre on ~ 3000km baselines is shown by the block colour circles.

100's of target sources!



Jack Radcliffe
(PhD student - Manchester, Groningen & ASTRON)

Thanks Dr. Bob!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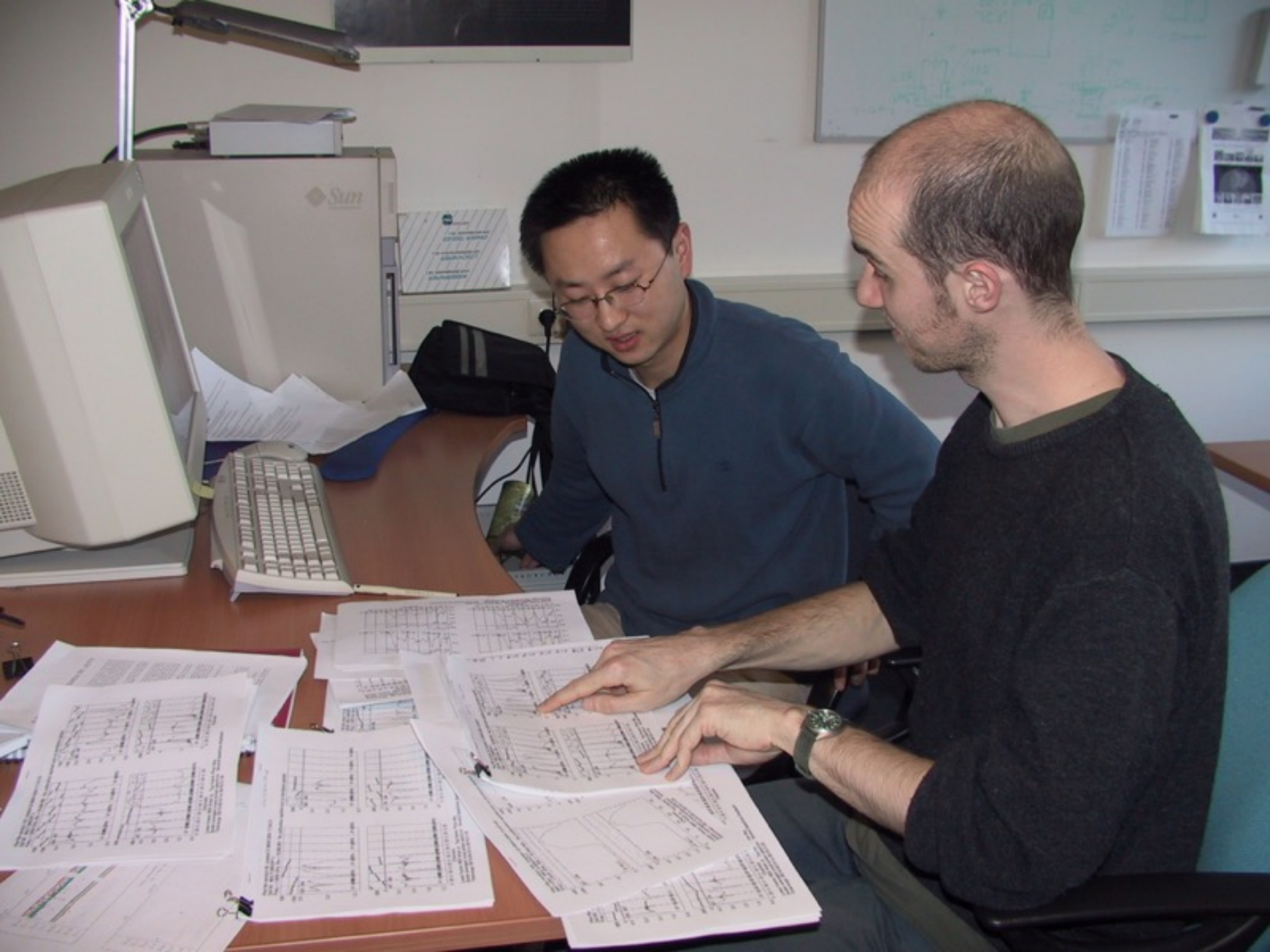
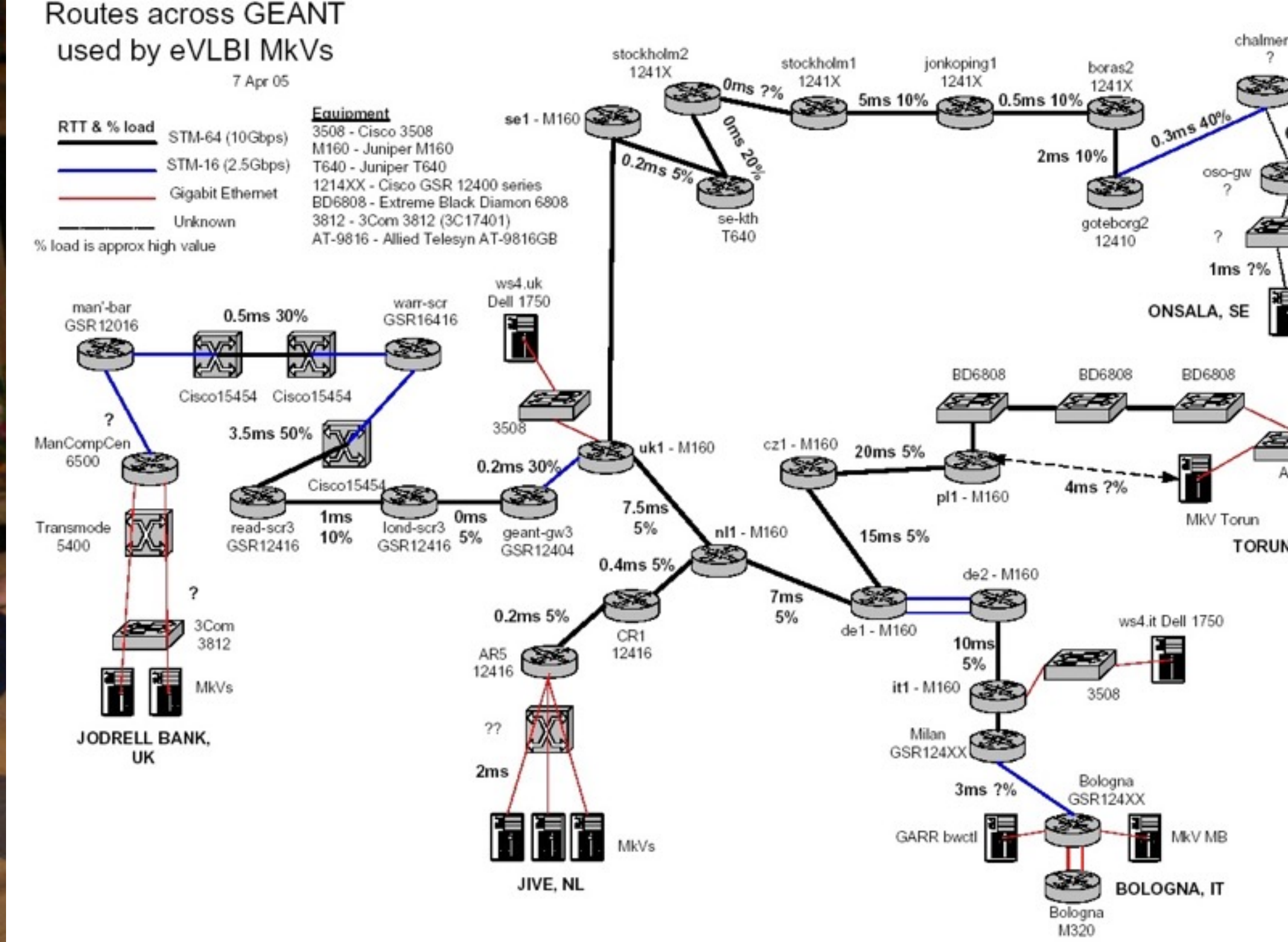
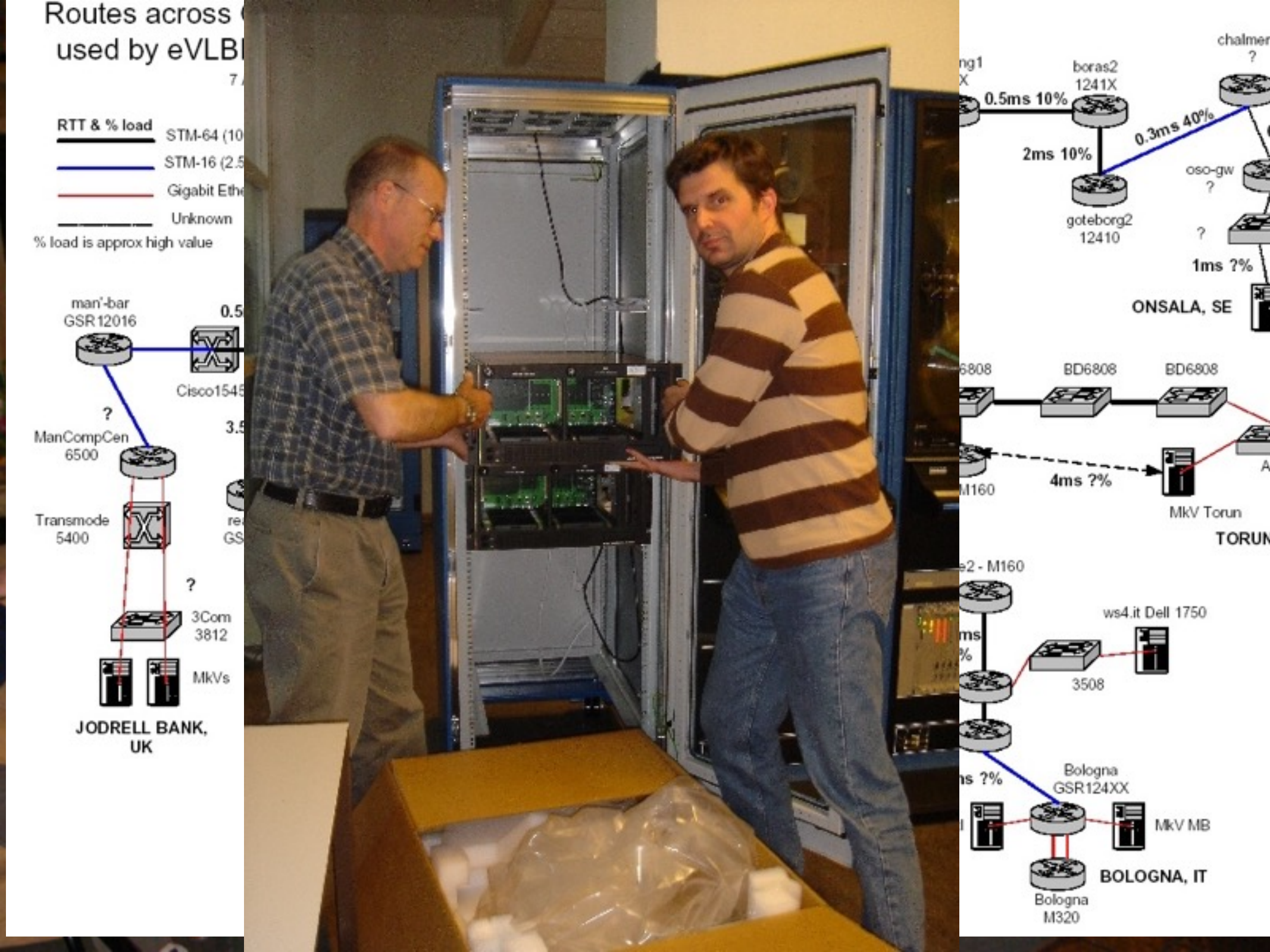
Netherlands Institute for Radio Astronomy
Some photos from yester-year


30 22:56


EUROPE

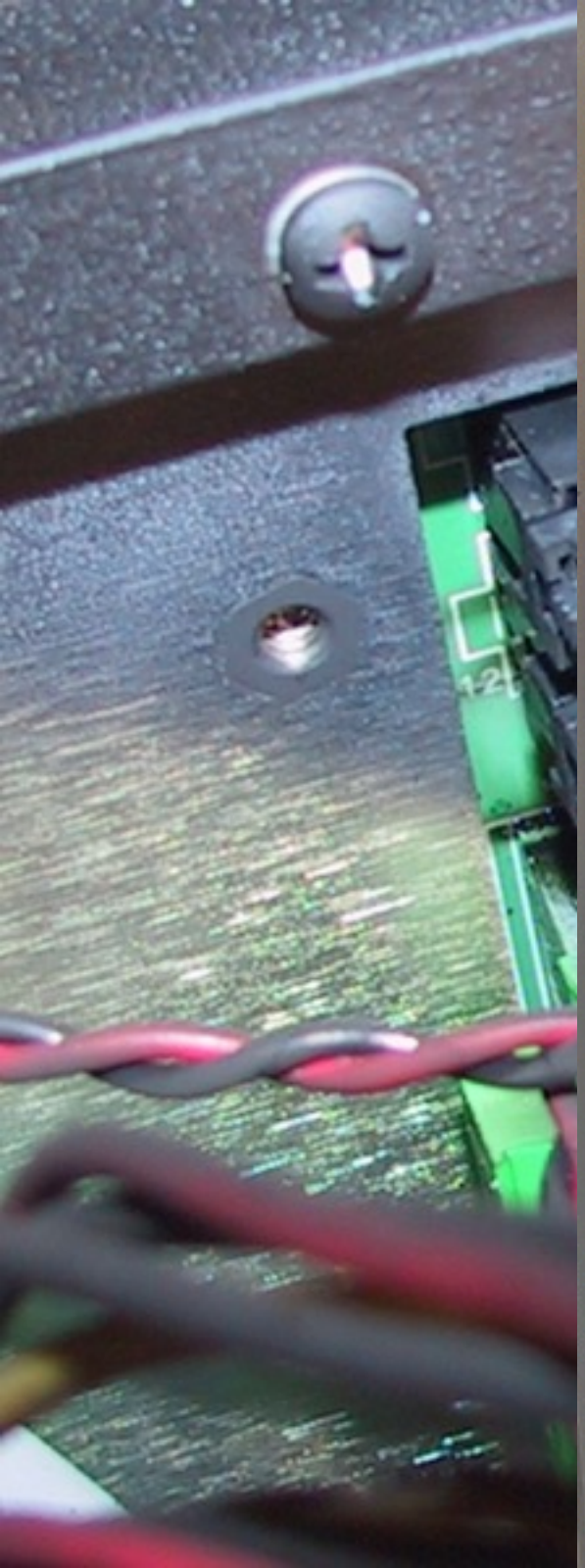



Routes across GEANT used by eVLBI MkVs
7 Apr 05
RTT & % load
STM-64 (10Gbps)
STM-16 (2.5Gbps)
Gigabit Ethernet
Unknown
% load is approx high value
Equipment
3508 - Cisco 3508
M160 - Juniper M160
T640 - Juniper T640
1214XX - Cisco GSR 12400 series
BD6808 - Extreme Black Diamon 6808
3812 - 3Com 3812 (3C17401)
AT-9816 - Allied Telesyn AT-9816GB
stockholm2 1241X
stockholm1 1241X
jonkoping1 1241X
boras2 1241X
chalmer ?
0ms ?%
5ms 10%
0.5ms 10%
0ms 20%
0.2ms 5%
2ms 10%
0.3ms 40%
se1 - M160
se-kth T640
goteborg2 12410
oso-gw ?
?
1ms ?%
ONSALA, SE
ws4.uk Dell 1750
man'-bar GSR12016
0.5ms 30%
warr-scr GSR16416
Cisco15454
Cisco15454
3508
3.5ms 50%
Cisco15454
0.2ms 30%
uk1 - M160
BD6808
BD6808
BD6808
cz1 - M160
20ms 5%
pl1 - M160
4ms ?%
MkV Torun
TORUN
ManCompCen 6500
Transmode 5400
read-scr3 GSR12416
1ms 10%
lond-scr3 GSR12416
0ms 5%
geant-gw3 GSR12404
7.5ms 5%
nl1 - M160
15ms 5%
0.4ms 5%
de2 - M160
7ms 5%
de1 - M160
0.2ms 5%
CR1 12416
AR5 12416
3Com 3812
MkVs
JODRELL BANK, UK
??
2ms
MkVs
JIVE, NL
10ms 5%
ws4.it Dell 1750
3508
it1 - M160
Milan GSR124XX
3ms ?%
Bologna GSR124XX
GARR bwctl
MkV MB
BOLOGNA, IT
Bologna M320


Routes across
used by eVLB
RTT & % load
STM-64 (10
STM-16 (2.5
Gigabit Ethe
Unknown
% load is approx high value
man'-bar
GSR12016
0.5
Cisco1545
?
ManCompCen
6500
3.5
Transmode
5400
?
3Com
3812
MkVs
JODRELL BANK,
UK
ng1
X
boras2
1241X
0.5ms 10%
2ms 10%
0.3ms 40%
chalmer
?
oso-gw
?
goteborg2
12410
?
1ms ?%
ONSALA, SE
6808
BD6808
BD6808
M160
4ms ?%
MkV Torun
TORUN
e2 - M160
ms
%
ws4.it Dell 1750
3508
ns ?%
Bologna
GSR124XX
MkV MB
BOLOGNA, IT
Bologna
M320


ive
OR VLBI IN EUROPE


+12V
LEFT




JIVE
JOINT INSTITUTE FOR VLBI IN EUROPE

ASTRON
Netherlands Institute for Radio Astronomy

Summary

Wide-Field VLBI has come a long way …

Wide-field VLBI surveys at uJy sensitivity on the horizon

HDF-N: will boldly go… deeper, wider, sharper…