Radio Interferometry packages and formats

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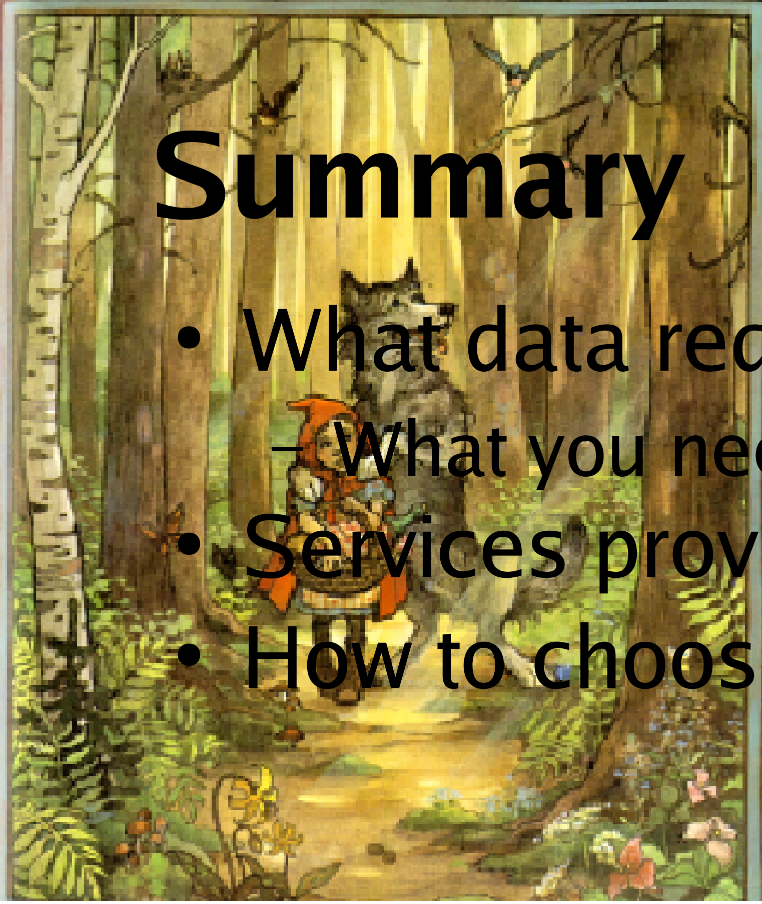


Summary

- What data red... packages ho...
  - What you nee...
- Services provi... ...uct...
- How to choos...

MIRIAD

AIPS

NEWSTAR

GILDAS SOFTWARE

GIPSY

DIFMAP

AIPS++

Astronomical Information Processing System

CASA

Summary

- Capabilities of C21 radio arrays
  - EVLA, e-MERLIN, ALMA, eVLBI, LOFAR
  - plus ATCA, VERA, IRAM, VLBA ...
- What to expect from data reduction packages
  - Services provided
- How to choose a package
- Data formats
  - Measurement Sets and FITS
- Radio Tutorials

International radio arrays

Omitting specialised e.g. CMB, solar arrays

WSRT (NL)

e-MERLIN (UK) LOFAR (NL/W.Europe)

IRAM (F)

VERA (Jap)

VLBA (USA)

Space VLBI (Jap/Global)

SMA, CARMA (USA)

EVLA(USA/Mexico)

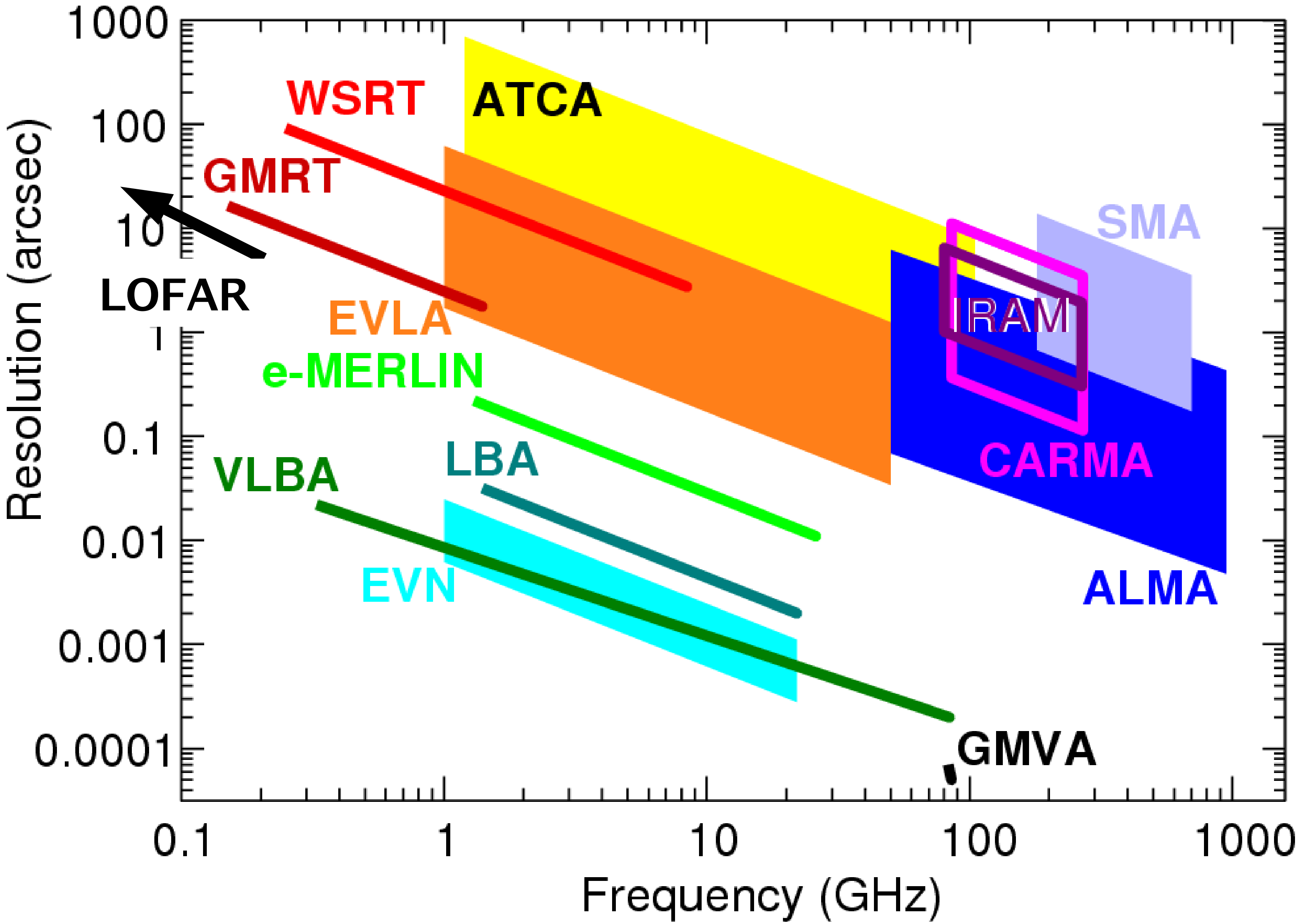
GMRT (India)

ALMA (ESO/N.America /E.Asia/Chile)

ATCA, LBA (Aus)

SKA and pathfinders (S.Africa/Aus/Global; project office UK)

Radio array imaging capabilities



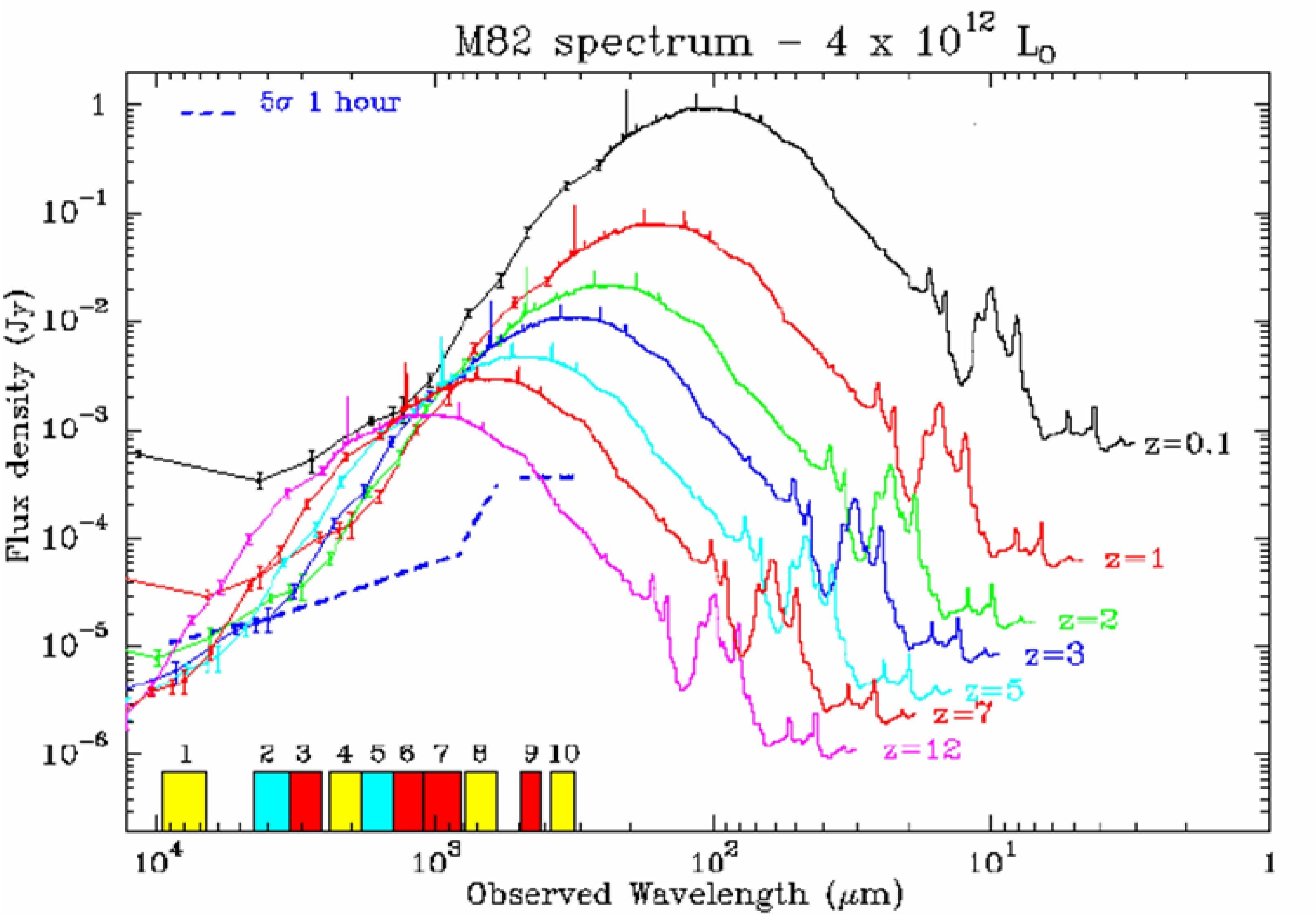
ALMA

- Atacama Large Millimetre Array
  - Europe (ESO), North America, East Asia, Chile
    - Built on Chajnantur Plateau at 5000 metres
  - 54x12-m, 12x7-m antennas
  - 30–950 GHz (10–0.3 mm) in 11 atmospheric windows
  - Full continuum sensitivity ~1 mJy per second
- Baselines 15 m to 14 km
  - 0.005 - few arcsec resolution
- From the Sun to the CMB
  - CO or C+ from the Milky Way at $z = 3$, in <24 hours
  - Kinematics of a $M_\odot$ protoplanetary disk at 150 pc.


Flexible reconfiguration

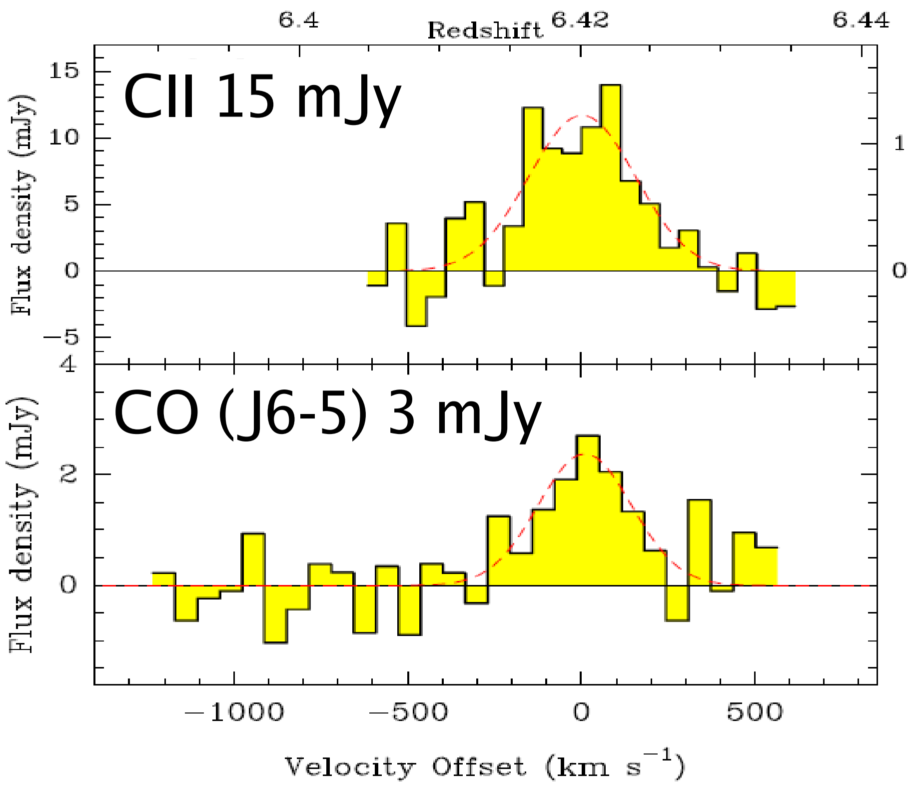

June 2010: five *real* antennas
at the high site
Nick Whyborn 2010

The sub-mm conspiracy

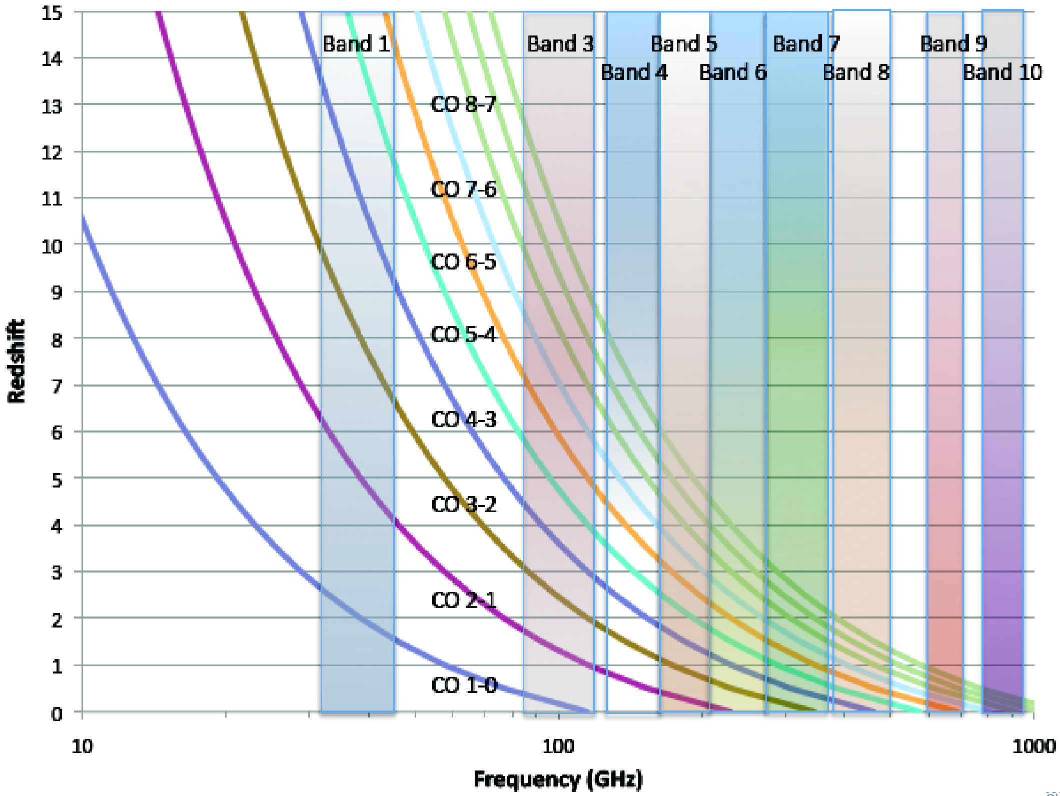


- Dust emission from starburst galaxies at any redshift is in ALMA bands (*Tarenghi*)

The first galaxies

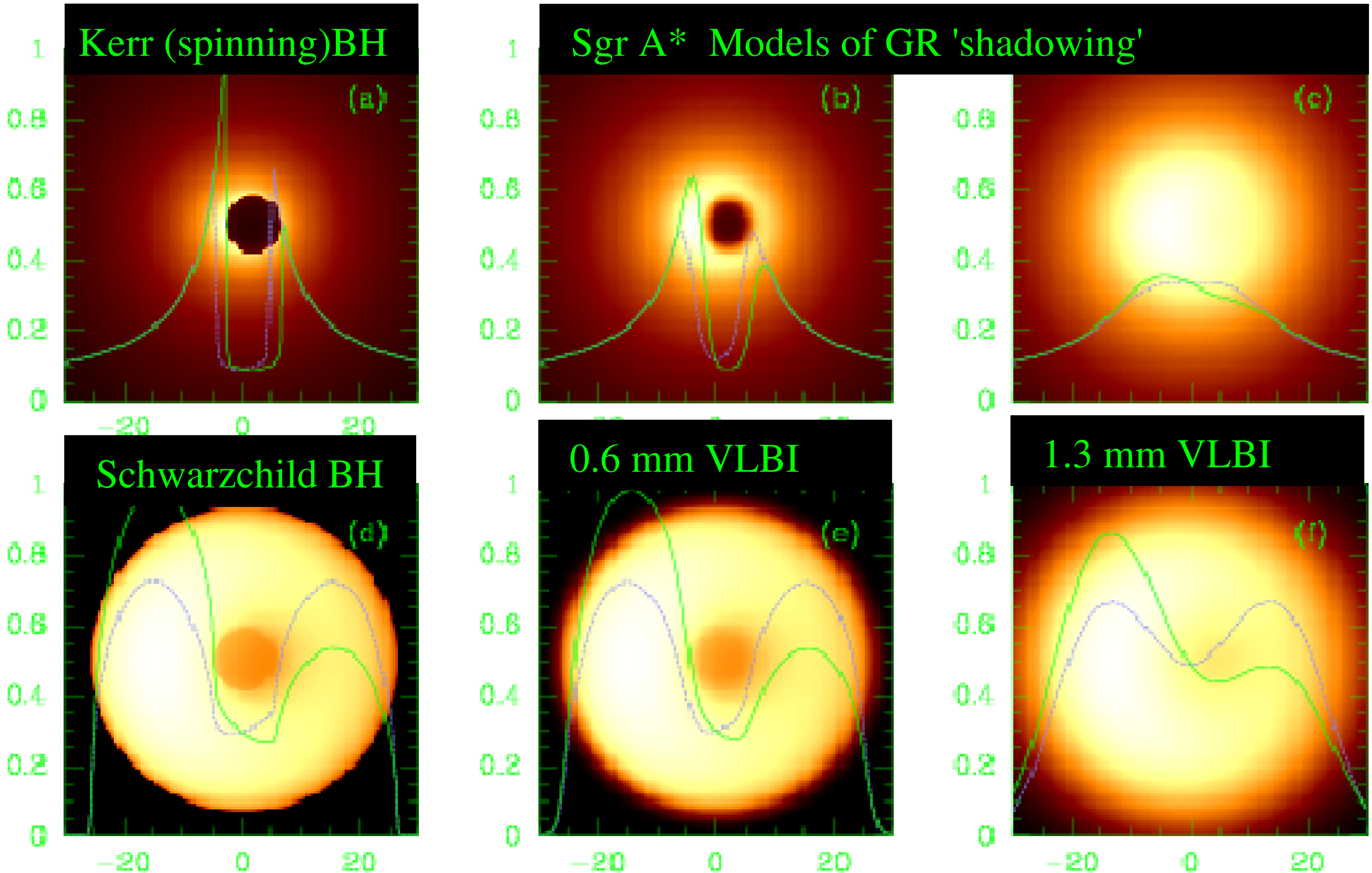


- CII
  - Main Milky Way coolant
  - Best tracer for EoR studies
  - Complement SKA HI



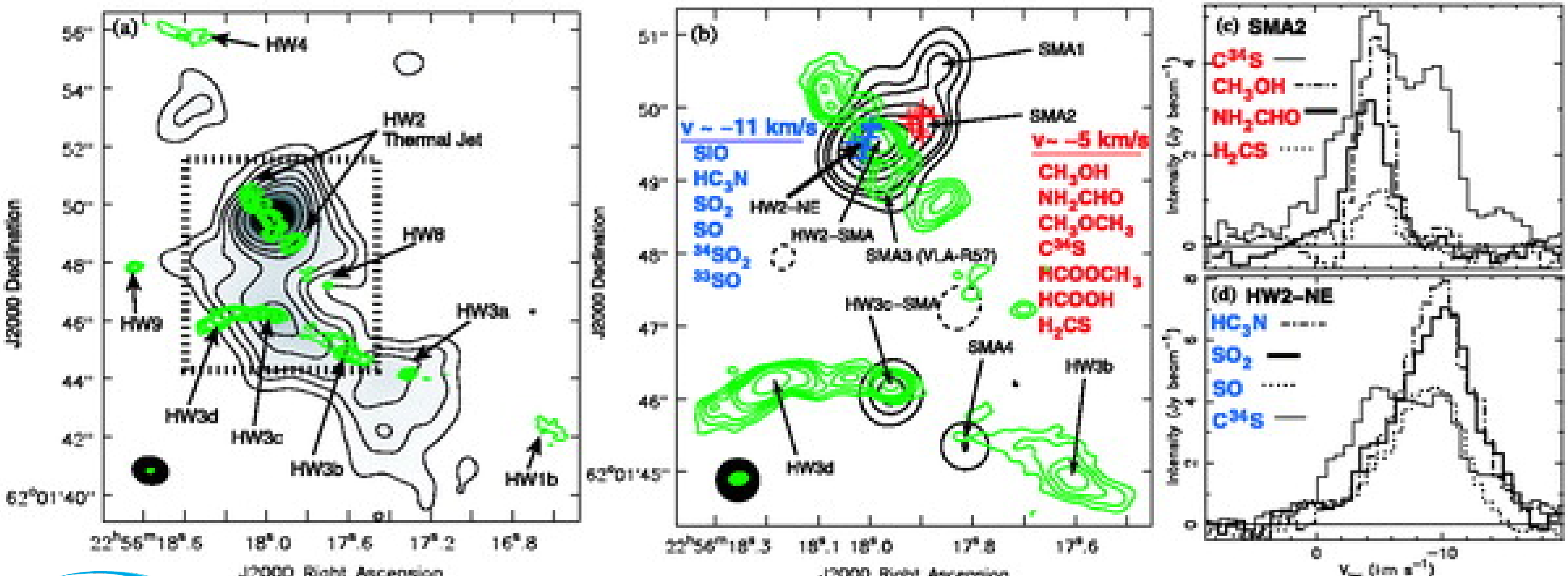
- CO
  - Multiple transitions at most redshifts
  - Complement EVLA

VLBI test GR in Galactic Centre



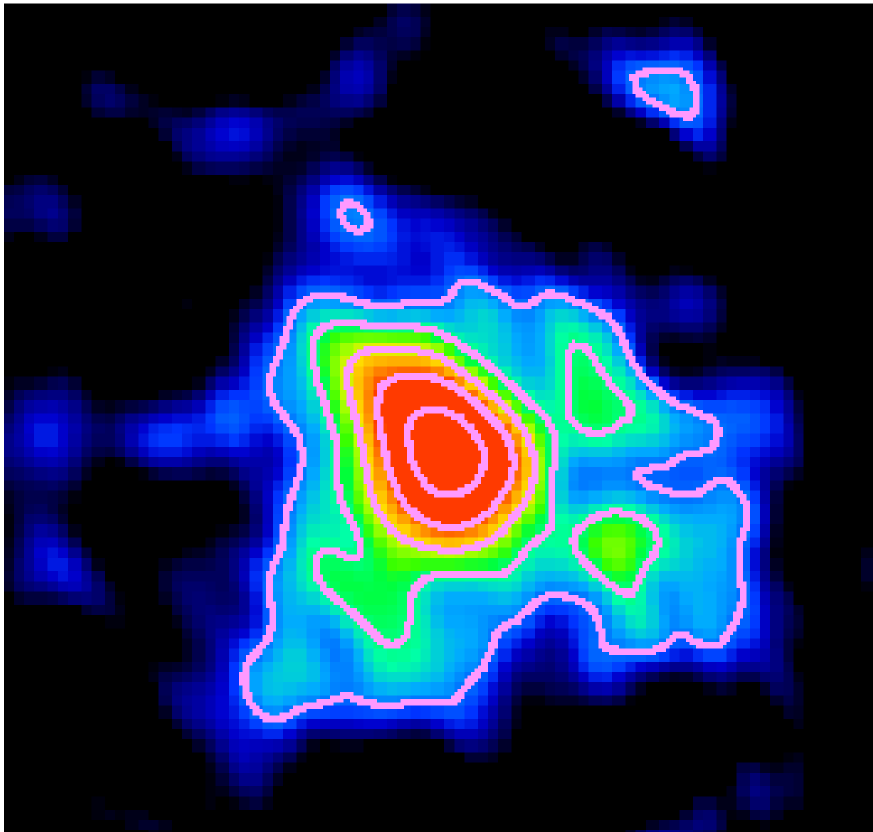
Chemical complexity in SFR

- Ceph A East - YSO with wind and disc?
  - Continuum contours SMA 875 µm; VLA 10 GHz
    - Spatial resolution <1"~750 AU
  - 2 groups of different lines implies different sources
    - Multiple protostars at different evolutionary stages?

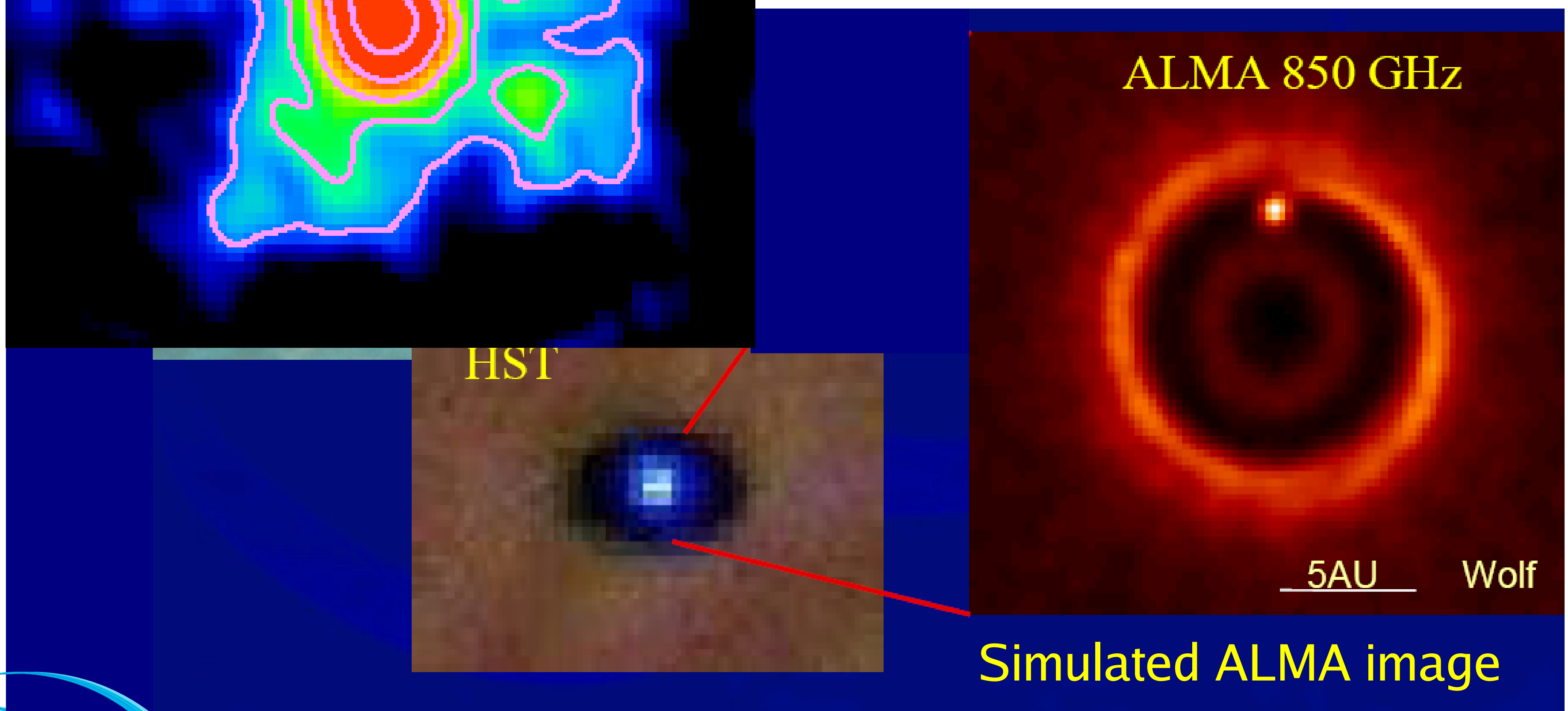


Brogan et al. (2007)

Direct imaging of planet birth

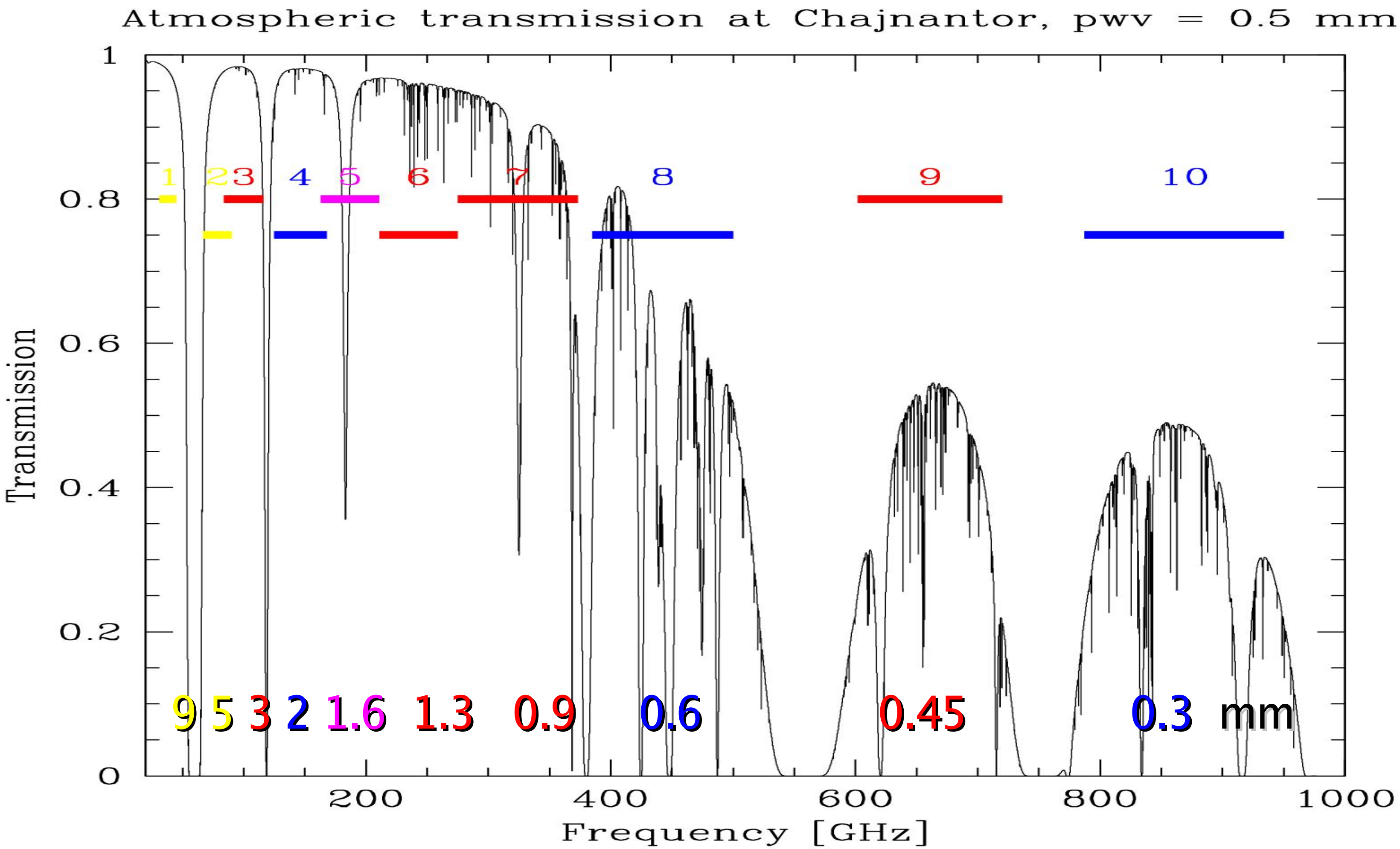


- Pebble growth from micron to cm
  - ALMA, EVLA, e-MERLIN
  - *Greaves et al.*



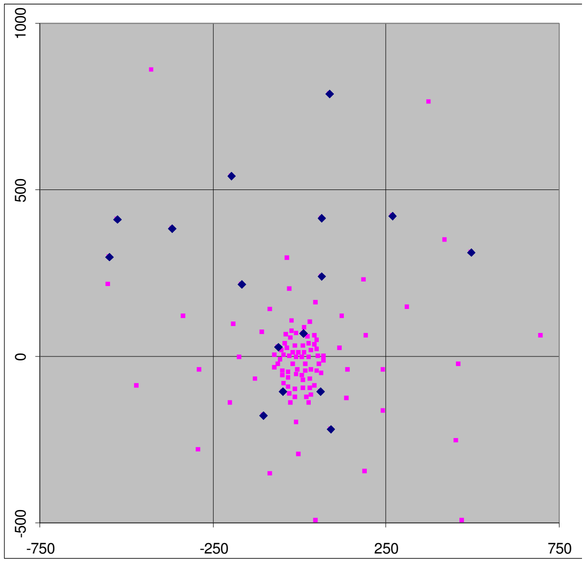
Early Science

- Band 3 on all; 6, 7 and 9 on most or all
  - Bands 4 and 8 on as many as possible

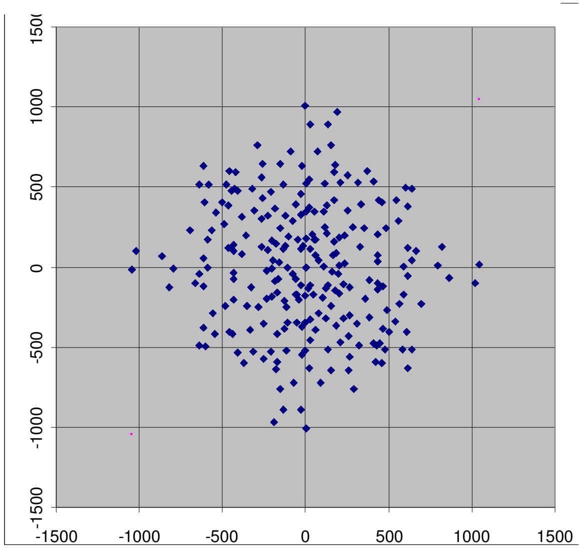


Early Science

- Observations in 2011 (1/3 time)
  - First call end 2010
- 250m baselines, 1 km if pos.
  - (few) 100 mas resolution
- About 16 antennas
  - Single fields, pointed mosaicing
  - Few mJy typical sensitivity
- User software
  - OT (proposing and scheduling)
  - CASA data reduction
- Calibration to state of the art
  - Pipeline-equivalent data products



1 km baselines



1.5 Mλ -1.5

EUROPEAN ARC
ALMA Regional Centre || UK

The University of Manchester
Jodrell Bank Observatory

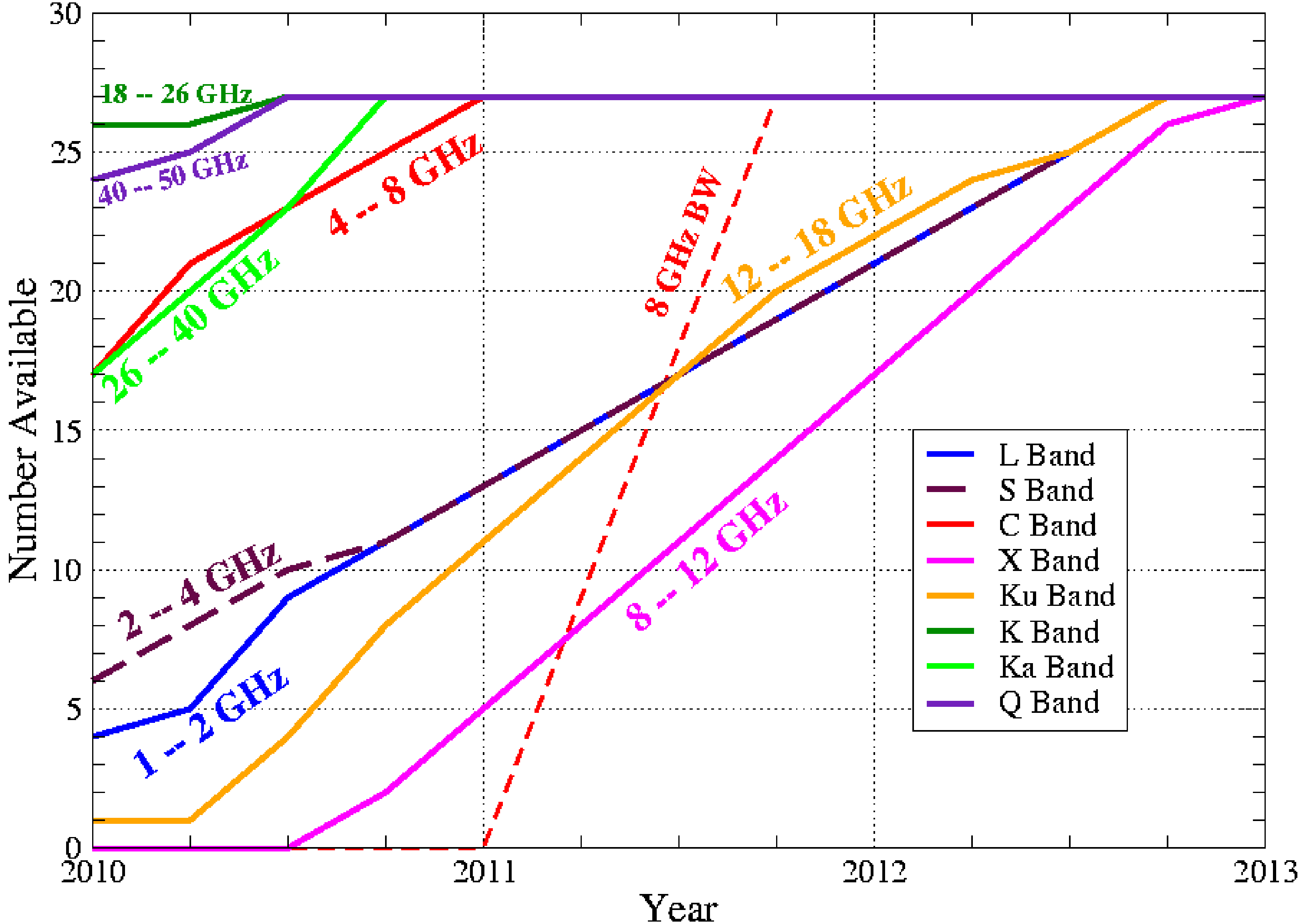
ALMA Regional Centres

- European support via ALMA Regional Centres
  - Bologna, Bonn, Grenoble, Leiden, Manchester, Onsala, Prague
  - coordinated by ESO www.eso.org/sci/facilities/arc
  - 2 Manchester Reseach Associate jobs! www.alma.ac.uk
- North American and East Asian ARCs
- Development: Advanced pipelines/archives; Band 2..?
- Forthcoming events in Europe
  - Oxford CASA & Molecules in Galaxies 19-20 & 26-9 July
  - Herschel-ALMA Garching Nov 17-19
  - IRAM school Oct 4-8; ALMA Nov-1 Dec
  - Early Science preparation Manchester December 2010

Extended Very Large Array

- Upgrade of USA VLA
  - Optical fibre links, new receivers & correlator etc.
  - 28 antennas, <1 to 36-km baselines
    - 0.05 - 45 arcsec resolution
  - 1 to 50 GHz continuous frequency coverage
  - Up to 8 GHz simultaneous bandwith
    - Continuum sensitivity <1 μJy/hr in central ν range
  - Full polarization
  - Up to ~4 million spectral channels
    - <1 mJy/hr/km s^{-1} in central ν range
- Radar, pulsar, solar modes
- Completion 2012
  - On time, on spec, on budget!

EVLA frequency roll-out



EVLA progress

- 18-50 GHz wideband receivers now available
  - 4-8 GHz end 2010; remaining bands 2012
    - Some old VLA receivers still available until then
- Ultra-flexible WIDAR correlator
  - 8-GHz b/w expected by end 2010
- Comissioning observations:
  - Basic modes, 256 MHz: OSRO program
  - Advanced modes, full b/w: RSRO (Socorro-based)
    - http://science.nrao.edu/evla/earlyscience/

Array	**B**	**A**	**D**	**C**
max (km)	11.1	36.4	1.03	3.4
2010-12	Dec-Feb	Mar-Jul	Aug-Nov	Dec-Feb

e-MERLIN

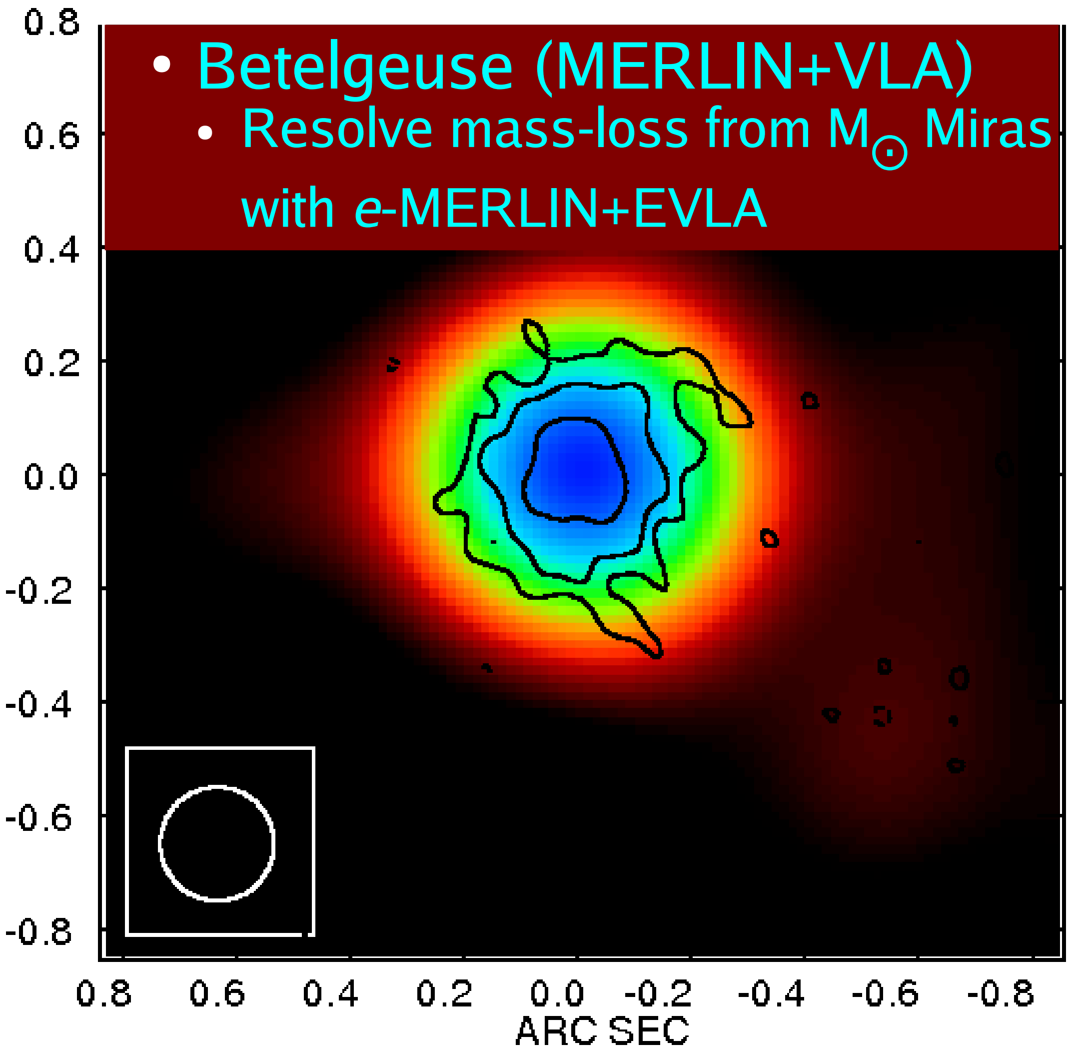
- '*electronic*'-MERLIN (UK)
  - Linking MERLIN telescopes with optical fibres
    - Up to 2 GHz bandwidth
    - Similar correlator as EVLA - up to ~10^5 channels
  - 5x25-m antennas, 1x32-m, 1x75-m Lovell
  - 1.3-1.7, 4-8, 21-26 GHz bands
  - Baselines up to 217 km
    - 0.01 - 0.2 arcsec resolution
  - Continuum sensitivity few μJy per 12 hr
- 5 GHz: 8-arcmin FoV = >10^8 pixels
- High frequency resolution
  - Multi-channel continuum wide-field observing
  - Integration times 1 sec or less

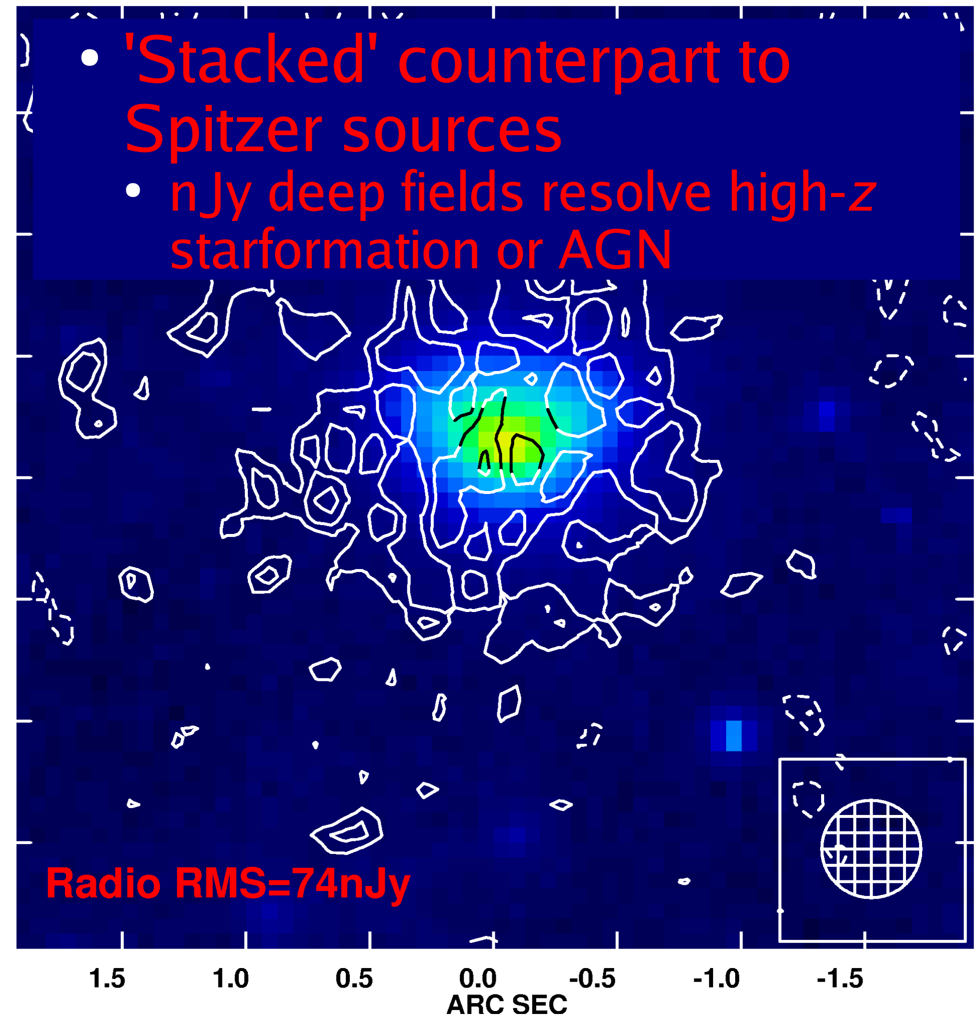
e -MERLIN capabilities

- Resolution matches HST/JWST/ALMA
  - Sub-mas ICRF astrometry, in-beam calibration
  - Full polarization
- 6 μJy 3-σ sensitivity in 12 hr at 4-8 GHz (2-GHz bw)
  - 40-mas resolution, up to 8-arcmin field of view
- ~15 μJy continuum sensitivity at other frequencies
- Spectral line sensitivity 7-20 mJy in 0.1 km/s
- Early science later this year, full operations 2010
  - Open access via UK PATT peer review
  - Joint observations with EVN/ Global VLBI
- http://www.merlin.ac.uk

e-MERLIN science

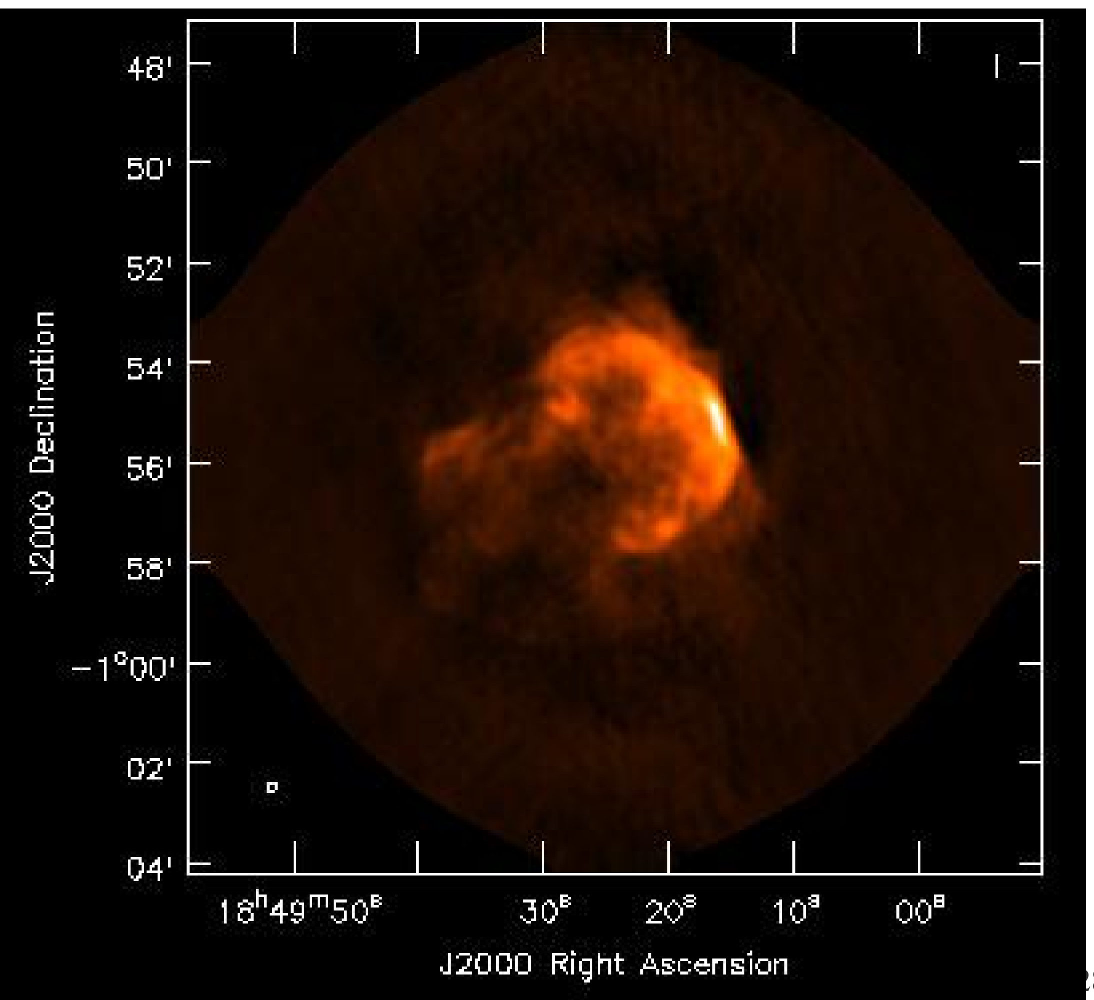
- High resolution and sensitivity

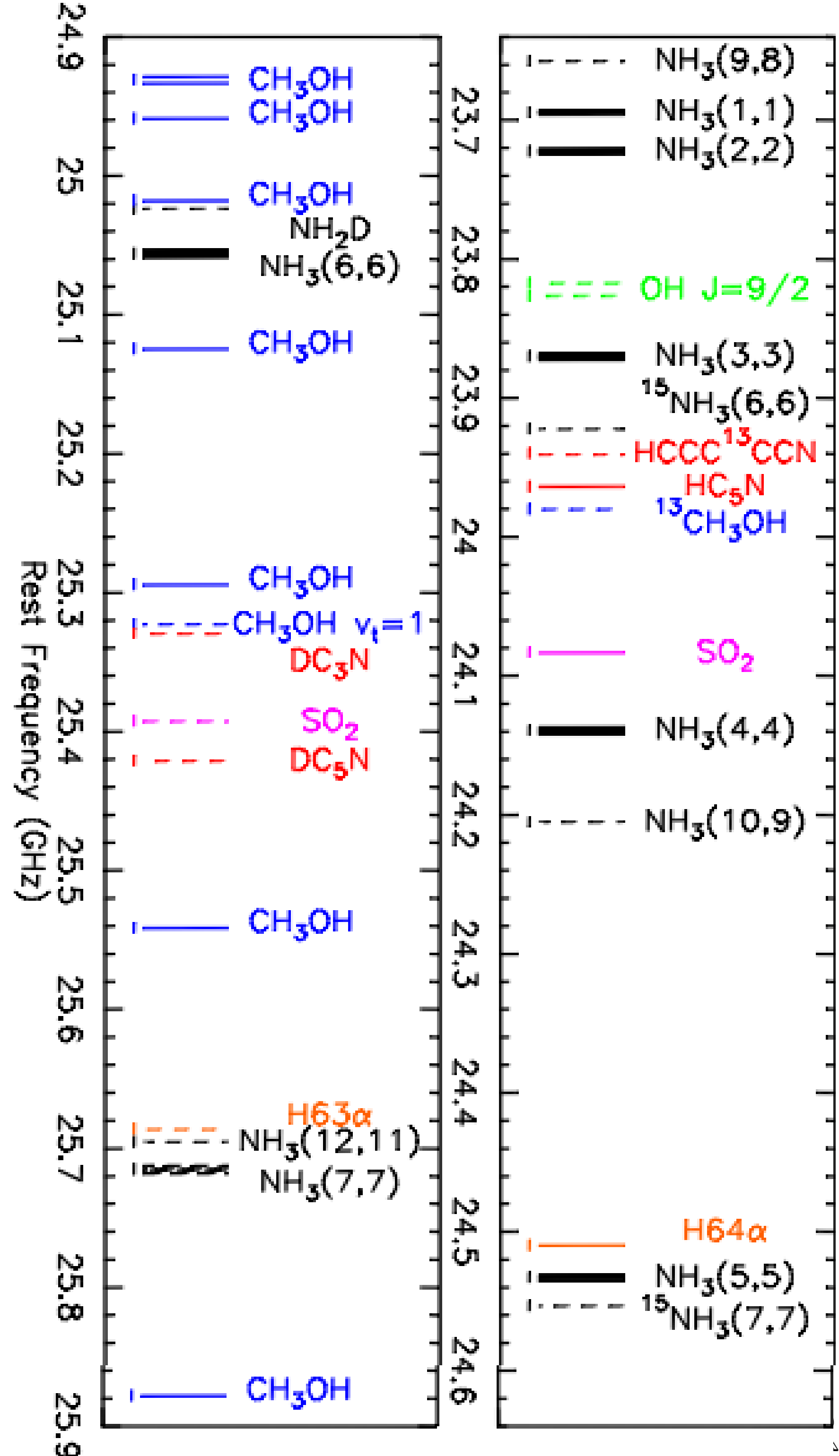




Early science

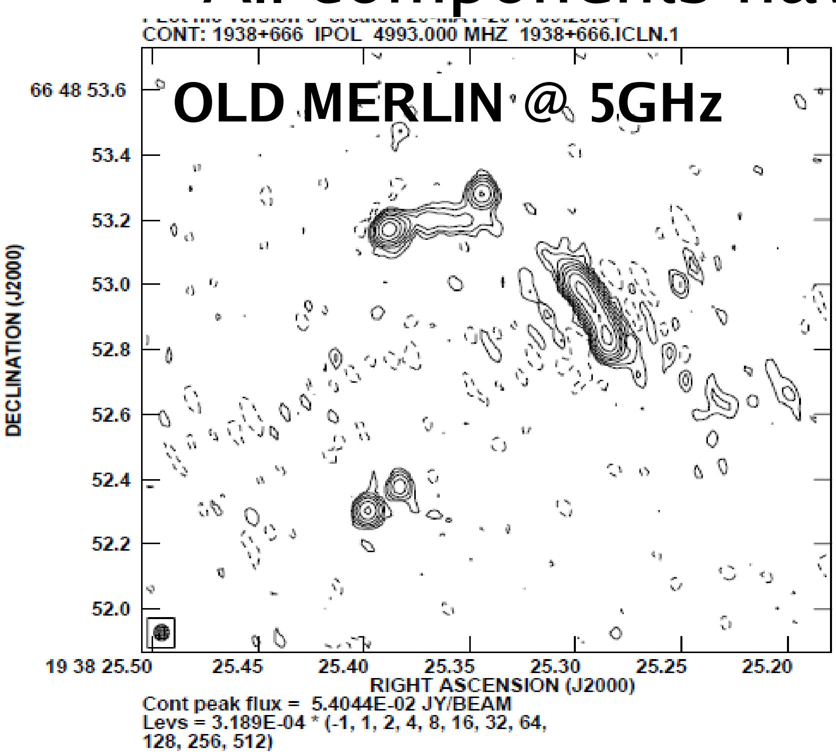
- SNR 3C391 - tutorial
- To come: 100's lines in SFR



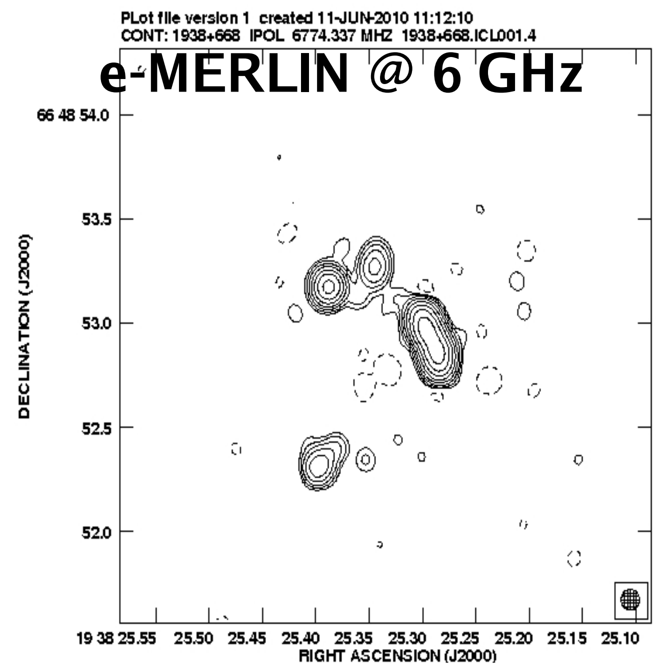


e-MERLIN progress

- Gravitational lens 1938+666
  - All components have the same spectrum



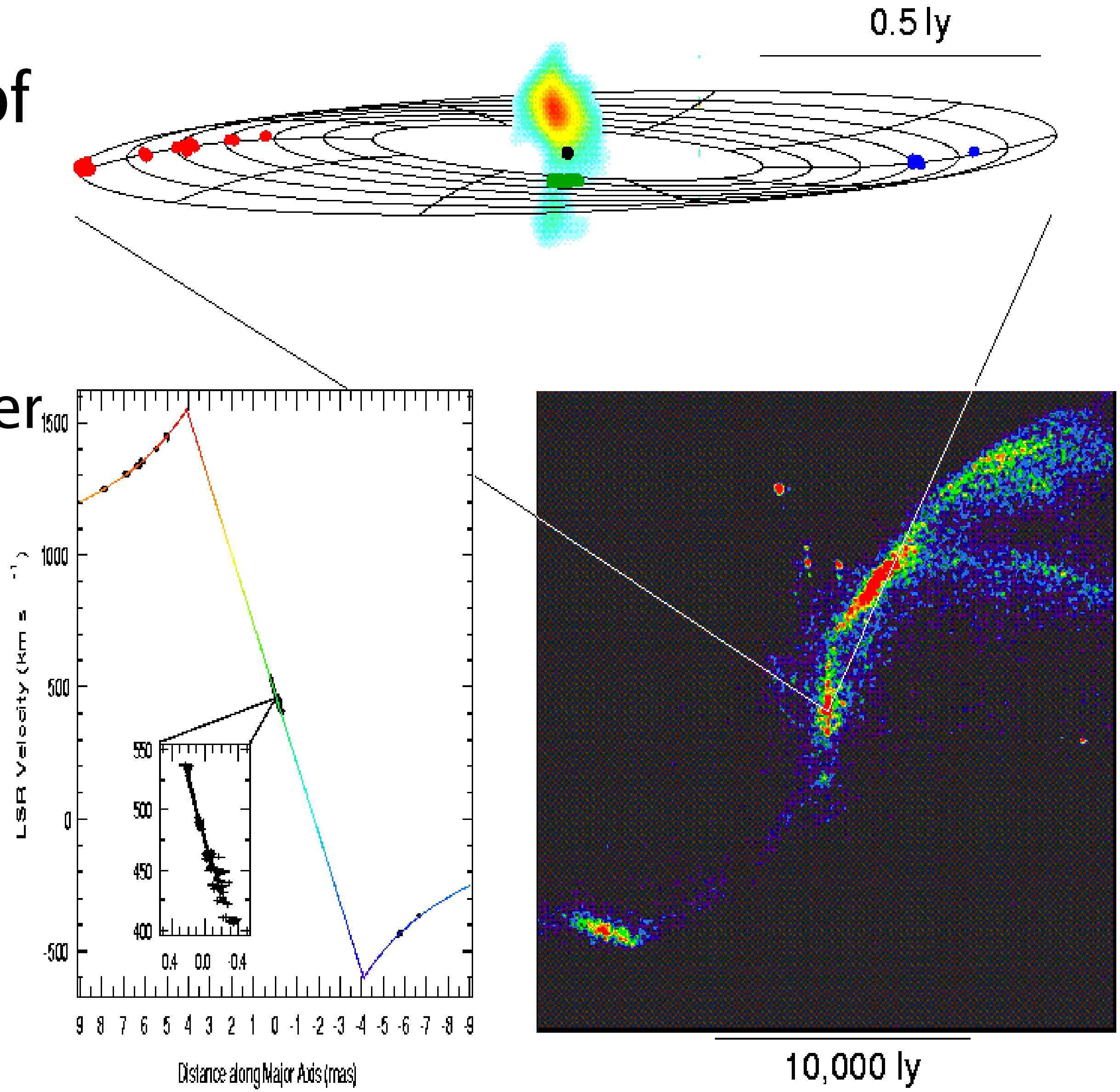
  - 6 antennas, LL+RR
  - 12 hr, 15 MHz



  - 4 antennas, LL only
  - 4 hr, 500 MHz
    - Increased fidelity as well as sensitivity

Best evidence for a massive black hole

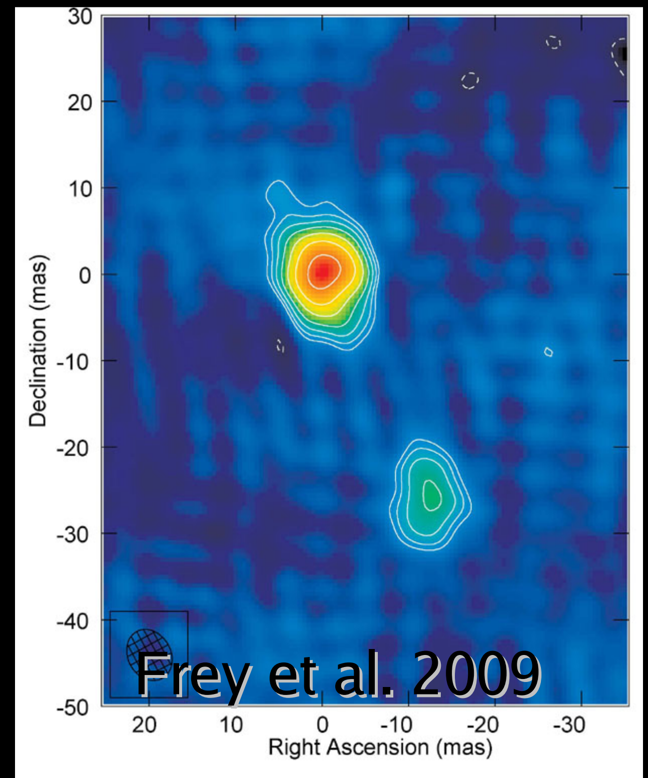
- VLBI and monitoring of NGC 4258
  - –Radio continuum jet
  - –22 GHz H_2O maser proper motions *&* Doppler velocities: 3D model
    - Warped Keplerian disk
    - 3.8 10^7 $M_\odot$ enclosed
    - Distance 7.2 Mpc
- New candidates identified by GBT
- e-MERLIN+VLBI: sensitivity+resolution
  - –New correlators
    - 1000s km s^{-1} ΔV



(*Miyoshi, Diamond, Herrnstein ...*)

Very Long Baseline Interferometry

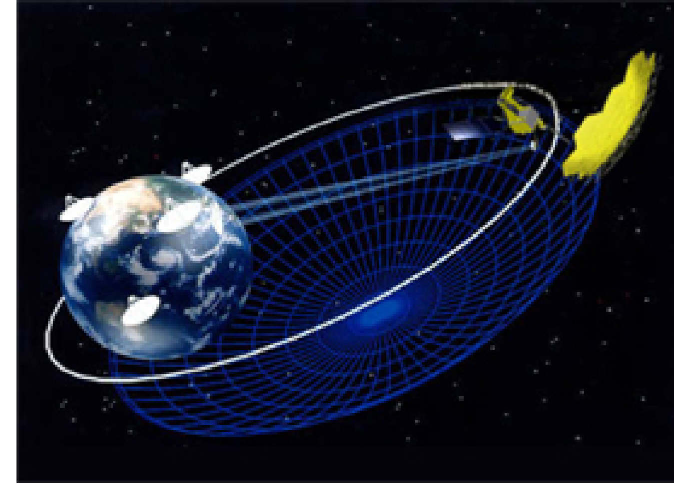
- Most distant radio QSO
  - J147+3312 *z*=6.12
    - 5000 km/s EVN baselines
    - 7 mas = tens pc resolution
  - Both lobes detected
    - Relativistic proper motions detectable in a decade



Very Long Baseline Interferometry

- VLBA spans USA from Hawaii to Virgin Islands
- VERA: 43+22 GHz astrometry (Japan)
- EVN links 5->20 telescopes
  - 3-5 sessions per year
  - Can integrate MERLIN and global telescopes
  - Data recorded on disk, correlated at JIVE
    - 1/64-sec integrations for wide-field VLBI
    - Rapid response e.g. to GRB real-time over public internet
- Other arrays incl. once and future space VLBI
  - Current sub-mm tests between APEX, JCMT
- Delay and rate calibration vital
  - Nano-sec accuracy needed to align signals
  - Significant atmospheric differences between stations

Resolution: Space VLBI

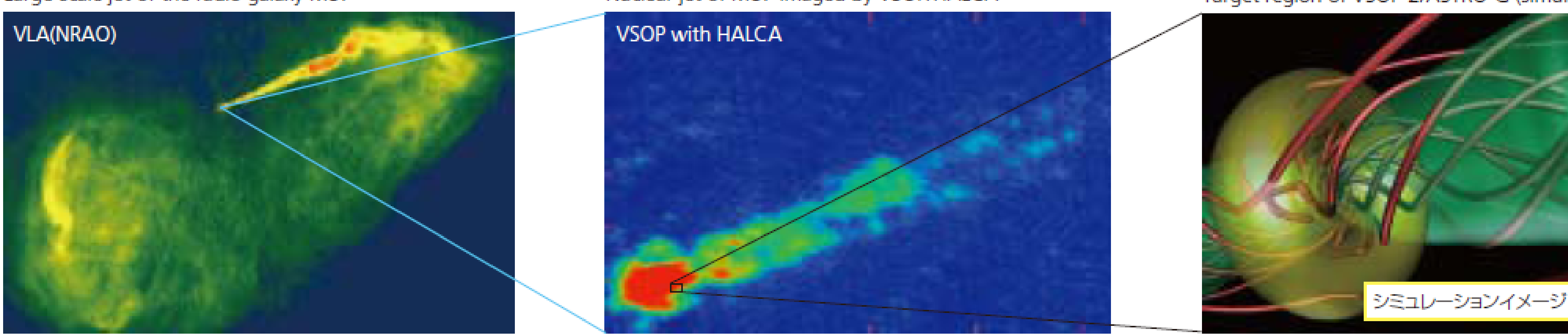


- HALCA flew in 1990's (cm-wave)
- ASTRO-G in preparation, led from Japan
  - 9-m antenna, cooled mm receivers, full polarization
  - Baselines up to 6xR⊕ (with full global VLBI)
  - Resolution <50 μas, 0.1 pc at highest possible *z*

電波銀河 M87 のジェットの広範囲なイメージ
Large-scale jet of the radio galaxy M87

VSOP/HALCAで撮影されたM87のジェットの拡大イメージ
Nuclear jet of M87 imaged by VSOP/HALCA

VSOP-2/ASTRO-Gが狙う領域(シミュレーション)
Target region of VSOP-2/ASTRO-G (simulation)



credit: Reid et al.

credit: Nakamura et al.

Sensitivity: Square Km Array

- Origins
  - Cosmology and Galaxy Evolution
  - Probing the Dark Ages - the first stars
  - Cradle of life
- Fundamental Forces
  - Strong-field tests of GR
  - Origin and evolution of Cosmic Magnetism
- The Unknown!
- Large collecting area
  - Spectral sensitivity: HI in the early universe
  - Rapidly varying sources: PSR and transients
  - Survey speed
  - 0.07 - 25 GHz
  - Baselines from filled aperture to VLBI

Sparse aperture arrays for the lowest frequencies

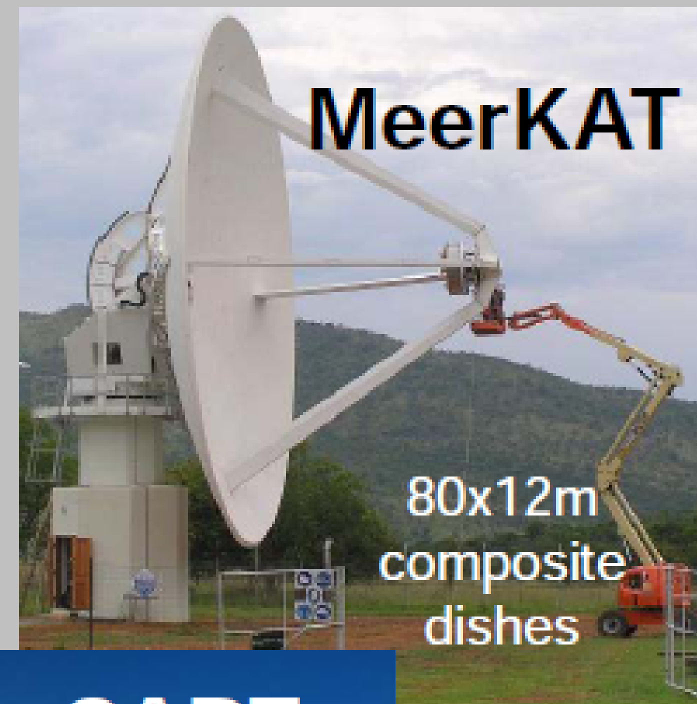
LOFAR (Netherlands et al)

LWA (USA)

MWA (USA, Australia)

Dishes


ATA
42x6m
hydroformed
dishes

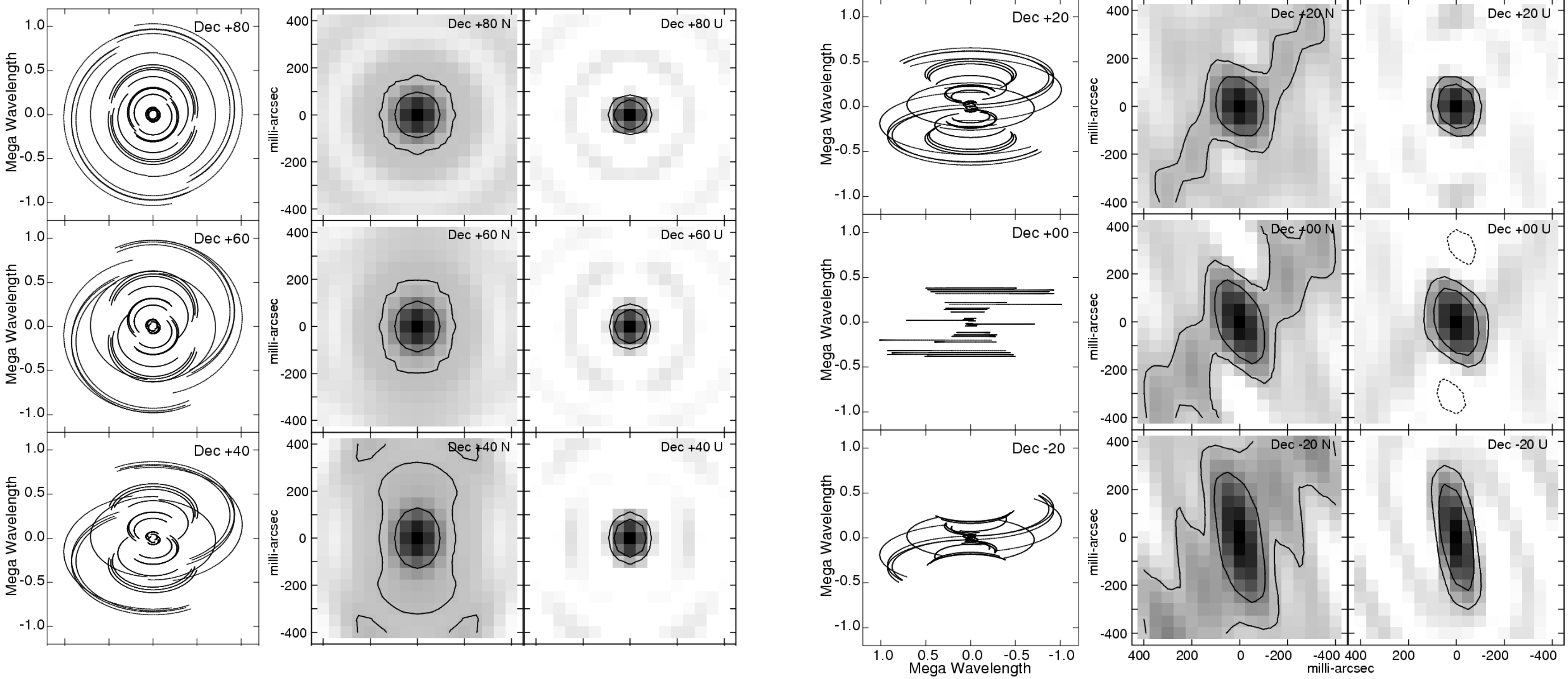

MeerKAT
80x12m
composite
dishes


ASKAP
36x12m
panel
dishes


CART
10 m composite prototype

Effects of sparse *uv* coverage

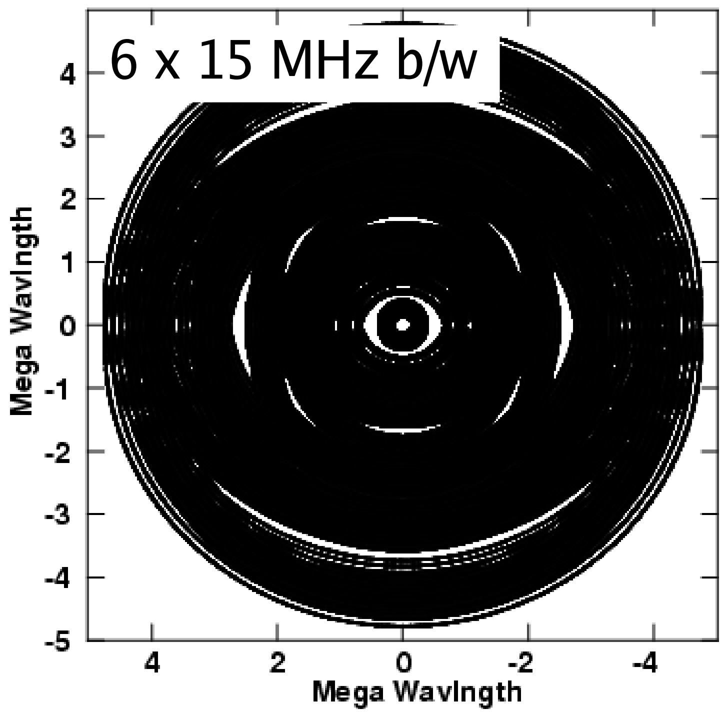
uv tracks Natural beam Uniform *uv* tracks Natural beam Uniform

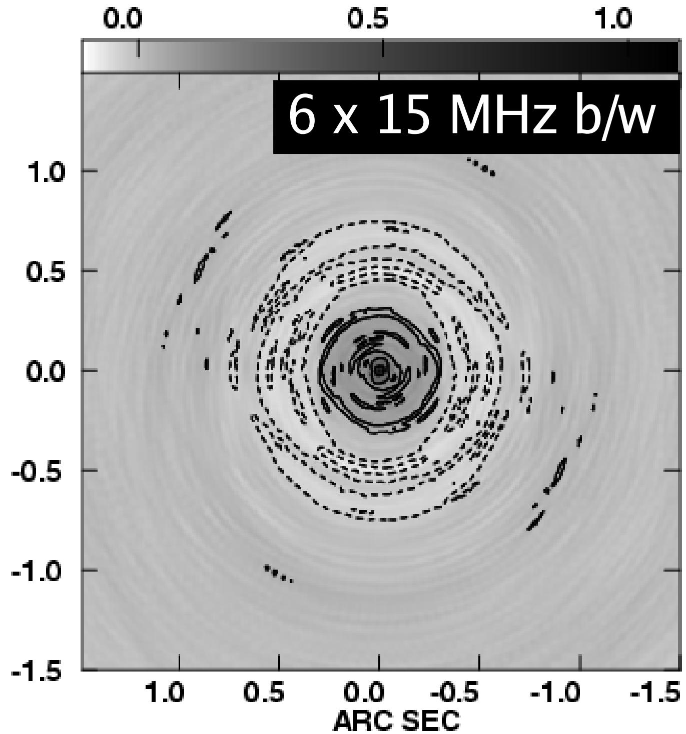


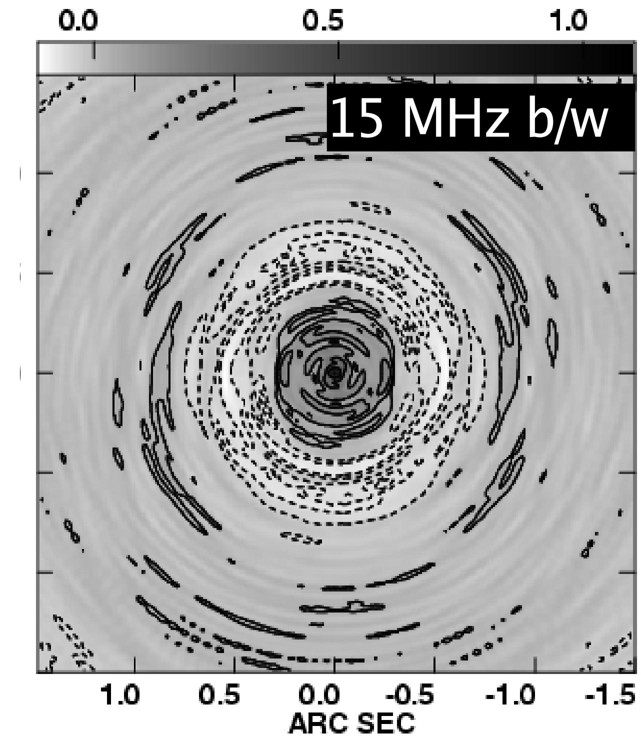
- Imaging issues for large gaps between uv tracks
  - Affects snapshots, narrow spectral channels, VLBI
  - Worse artefacts/resolution/missing spacings at low elevation
  - Uniform weighting = interpolation into empty parts of *uv* plane (can supress sidelobes *but* lose sensitivity)

Multi-frequency synthesis

- Poor visibility plane coverage affects image quality and dynamic range ("missing spacings")
  - as well as lower sensitivity and missing large-scales

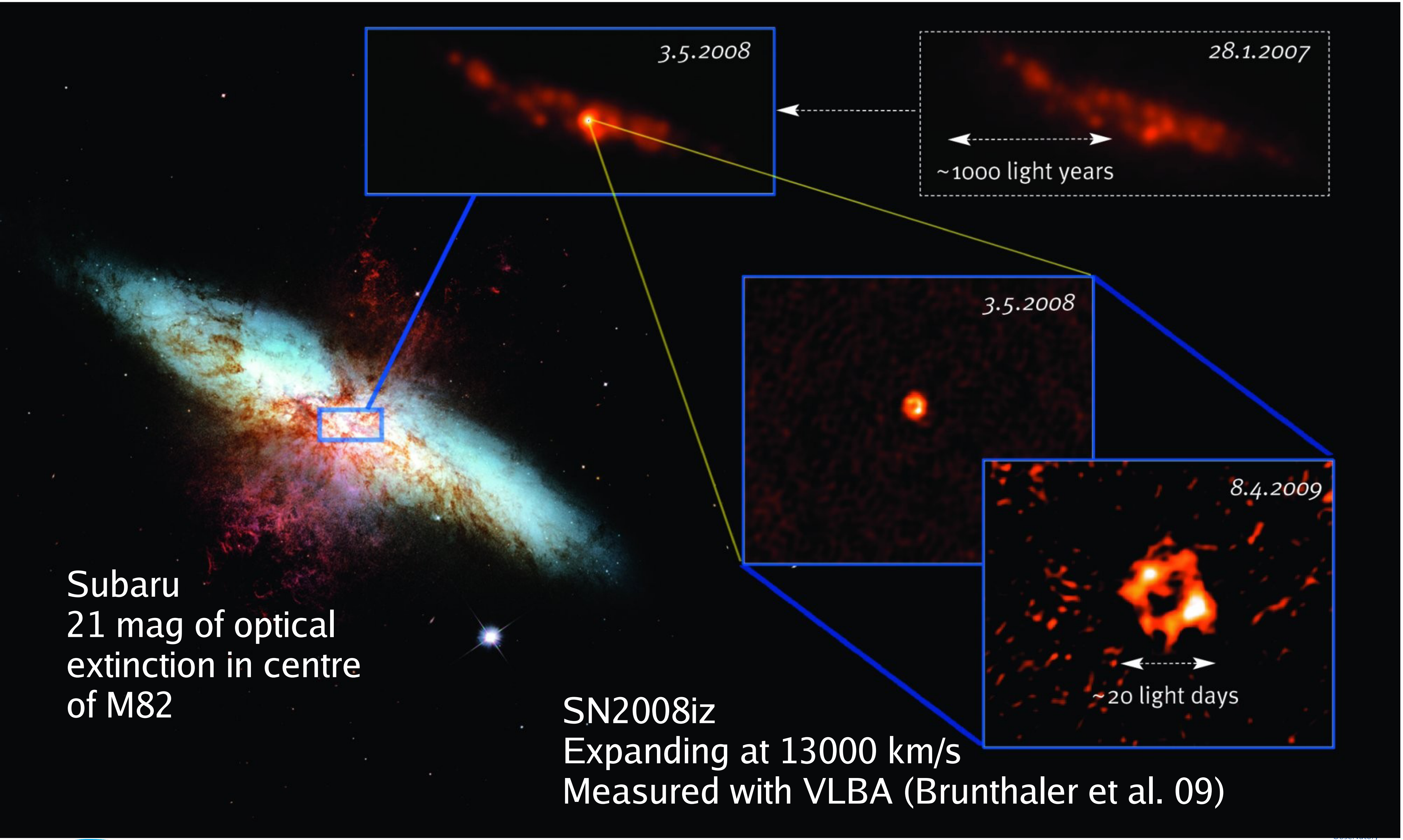




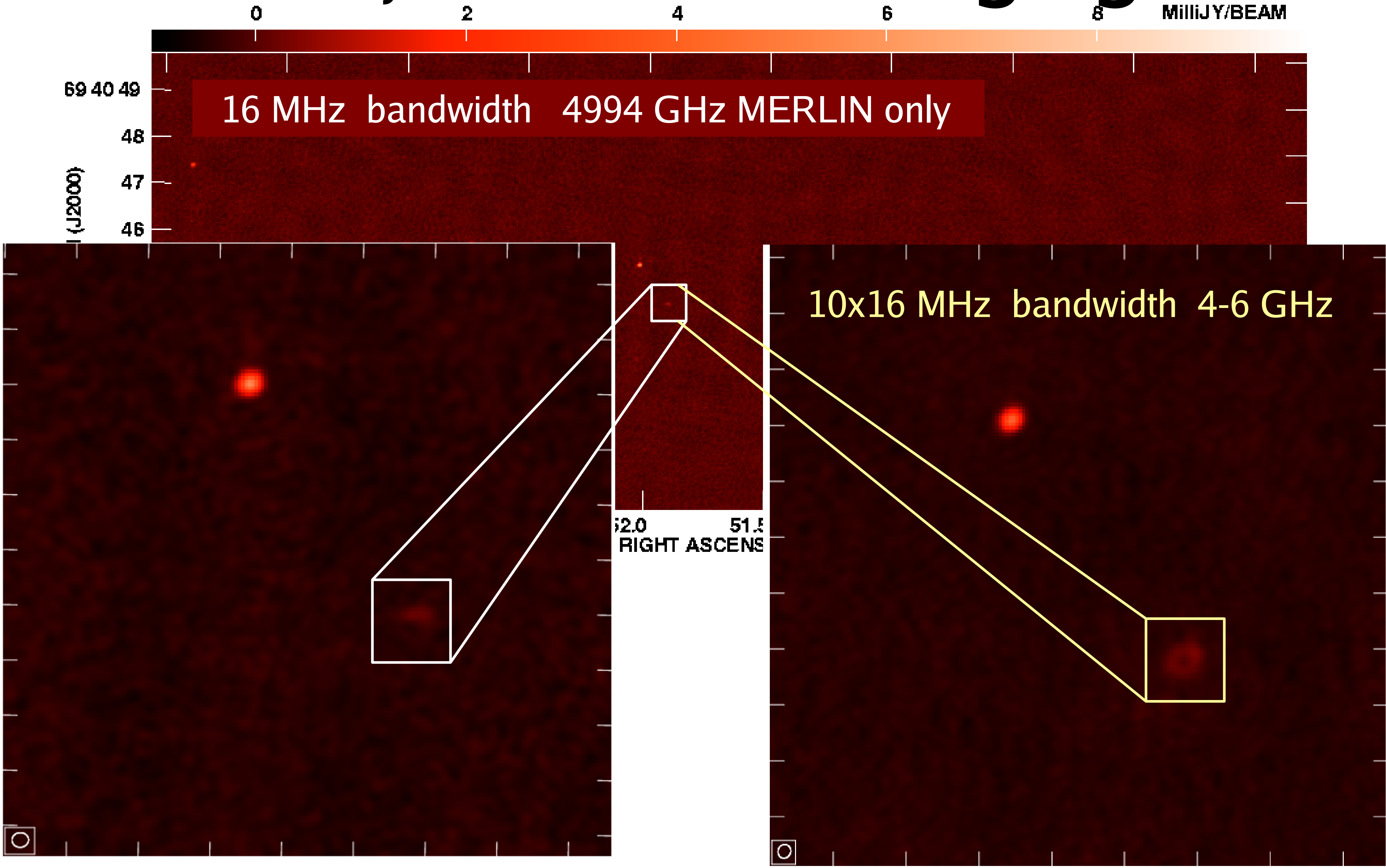


  - Filling in the *uv* plane (left) reduces beam sidelobes

M82: from arcmin to mas

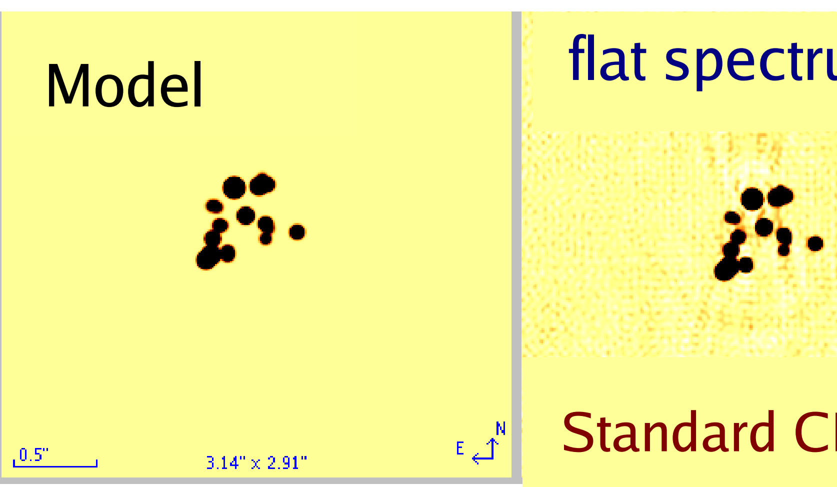


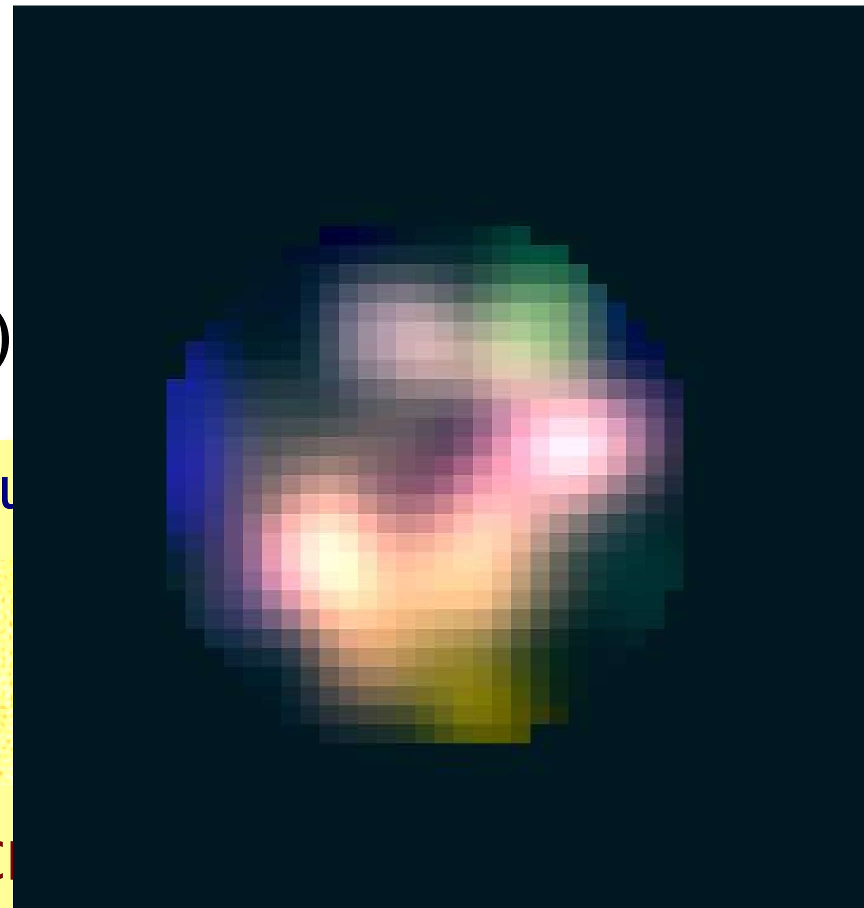
Wide field, wide band imaging



Wide-band imaging

- B/W spans 2 GHz at observing freq. 5 GHz
  - Source flux densities change with frequency
    - Different parts of source ⇒ different spectral slopes
- Solve for spectral index/curvature
  - Developing in CASA clean (Rau)





Three-frequency false colour supernova remnant

4546,6183, 6670 GHz

Fenech & Stewart Parseltongue prototype

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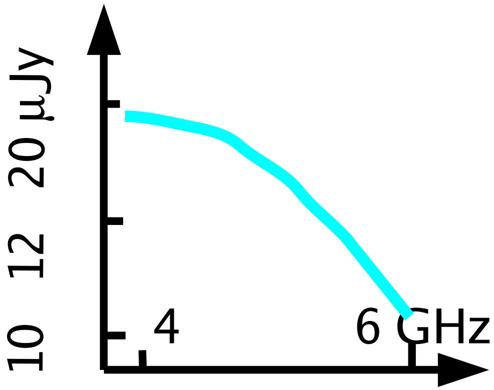
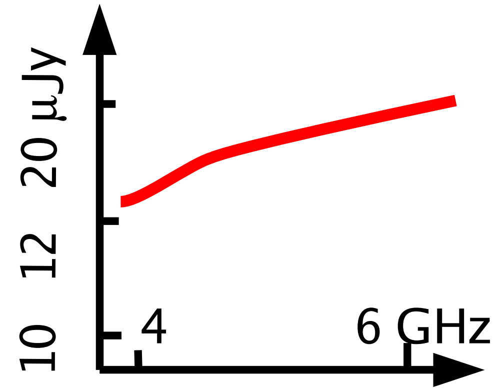
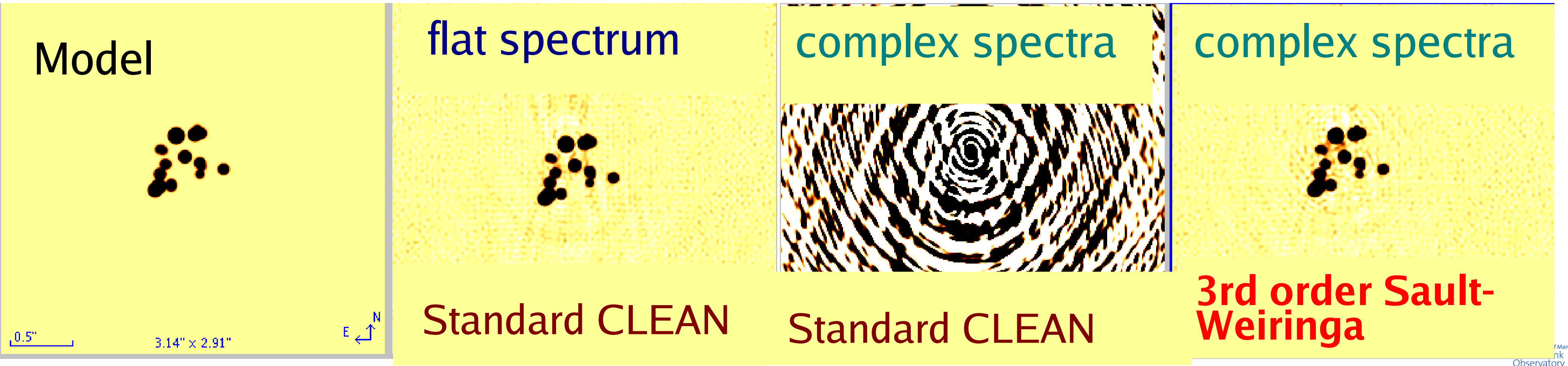
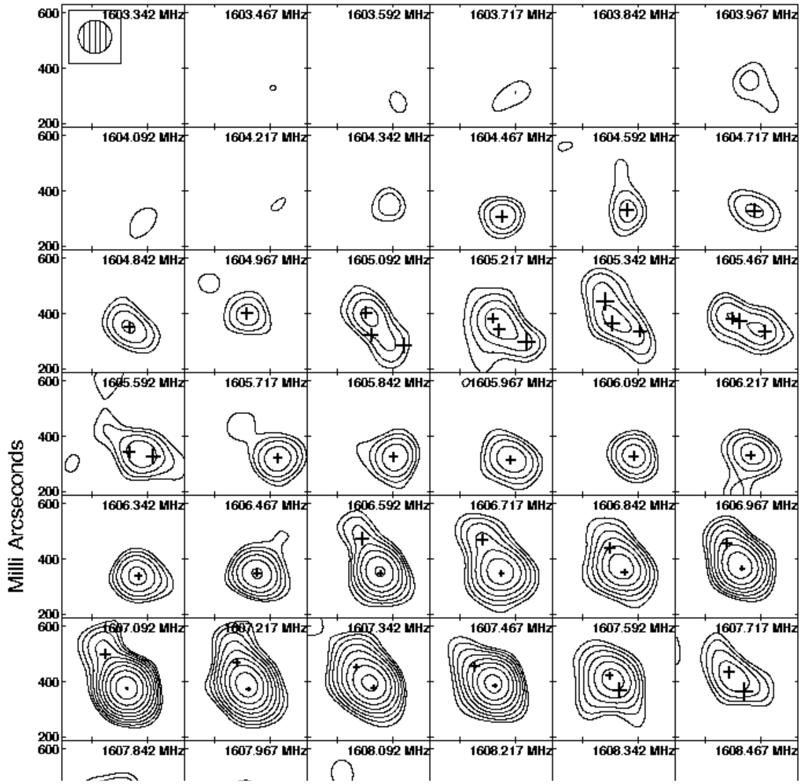


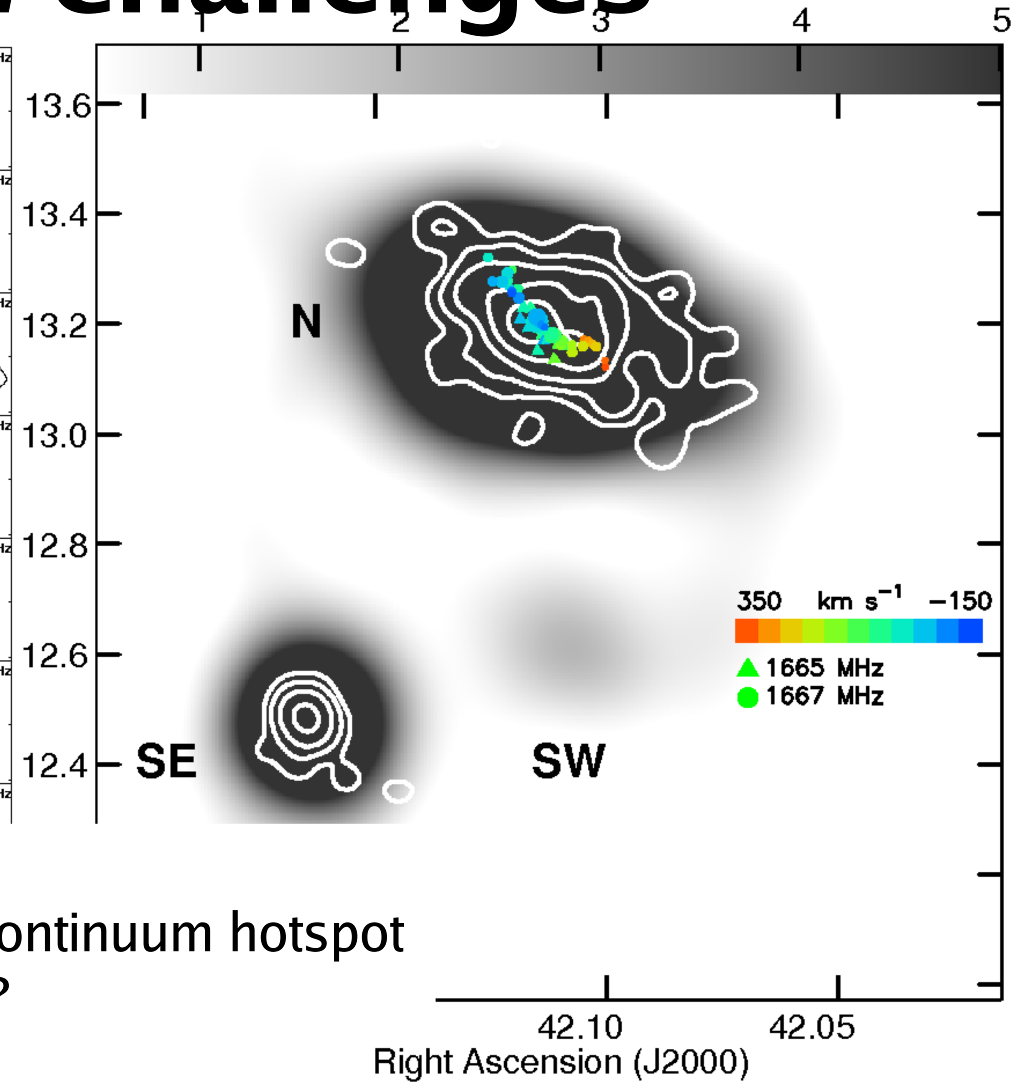




Fenech & Stewart Parseltongue prototype

Data *reduction* challenges

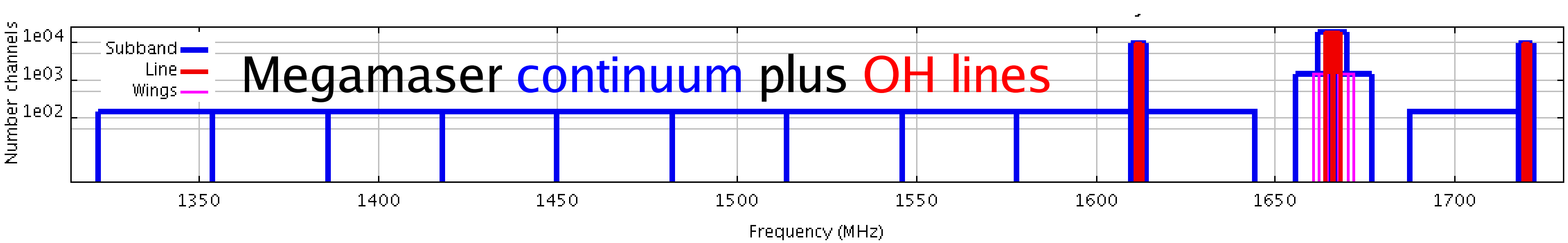




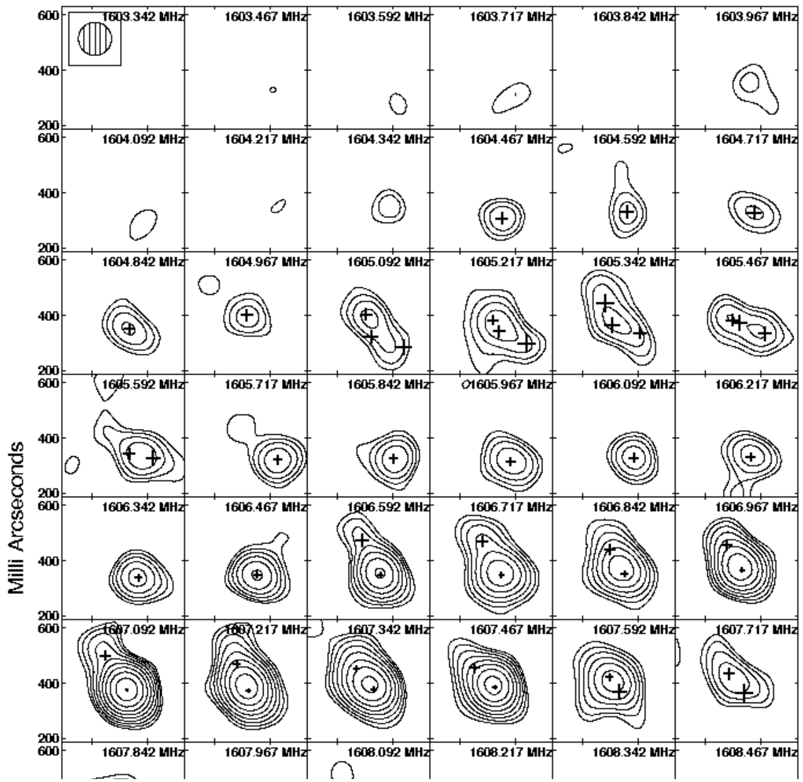
MERLIN

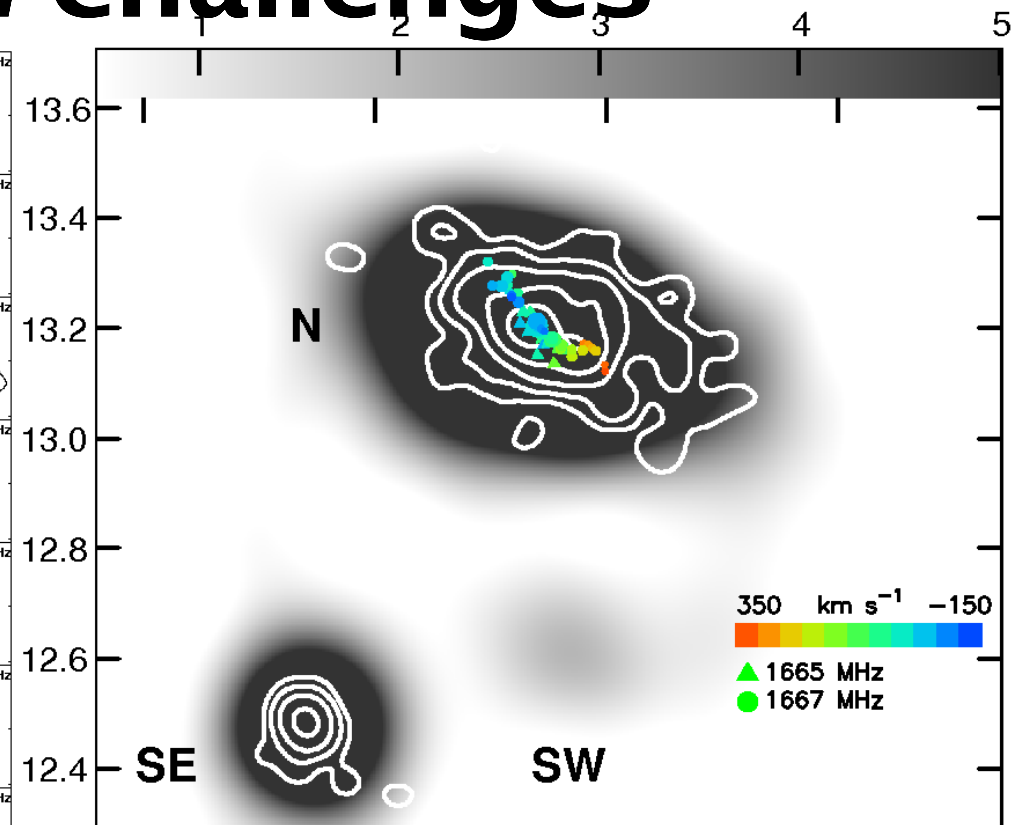
MKN 273 OH masers orbiting continuum hotspot

Black hole? Compact starburst?

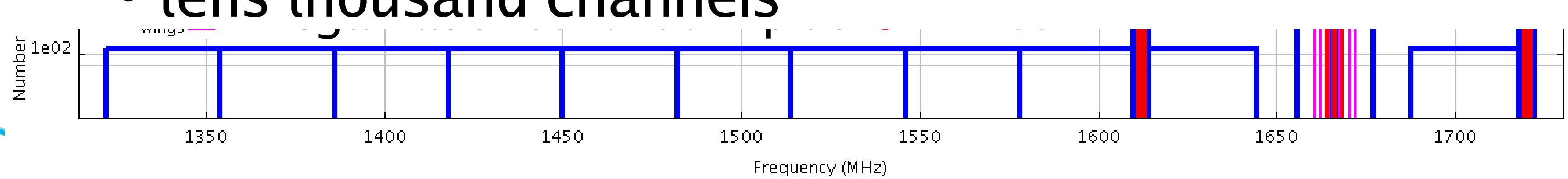


Data *reduction* challenges



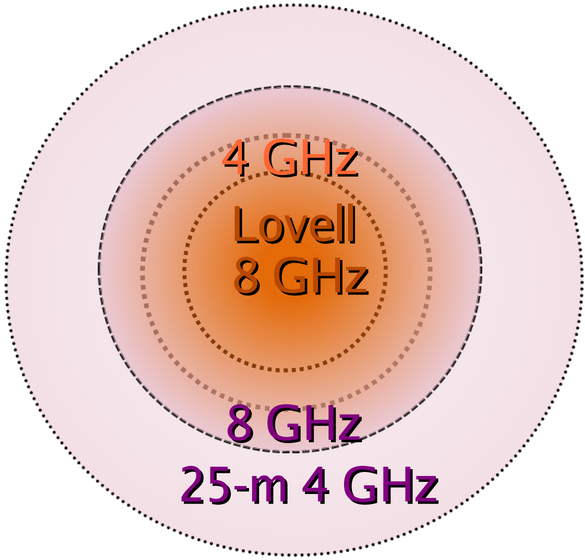


- TeraByte data sets
  - up to 8 GHz bandwidths, 16 sub-bands
    - can be all in different configurations
    - tens thousand channels



Next-generation array demands

- Wide-field imaging
  - Narrow channels, short integrations
    - GB - TB data sets
  - Subtract confusing sources
  - Allow for sky curvature



    - Faceting and *w*-projection
  - Array primary beam from a mixture of antennas
  - Non-isoplanatic fields –see LOFAR talk
- Wide-Band imaging
  - Spectral curvature
  - Mixed spectral and continuum configurations
- Huge raw data volumes
  - Pipelines and parallelisation
  - Automate flagging where possible

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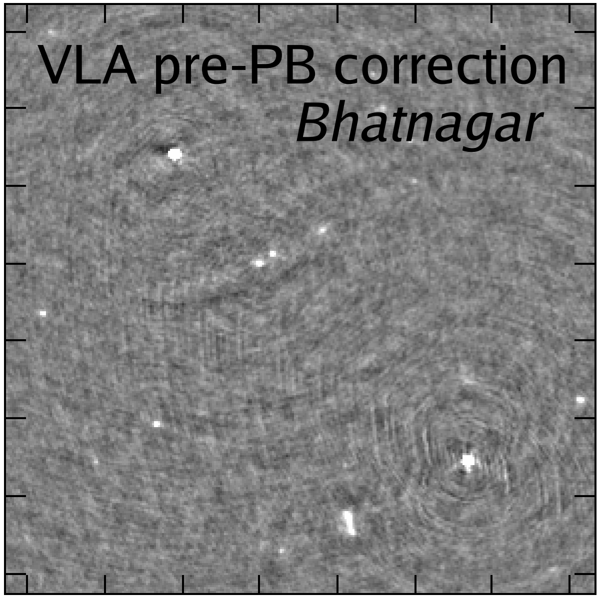
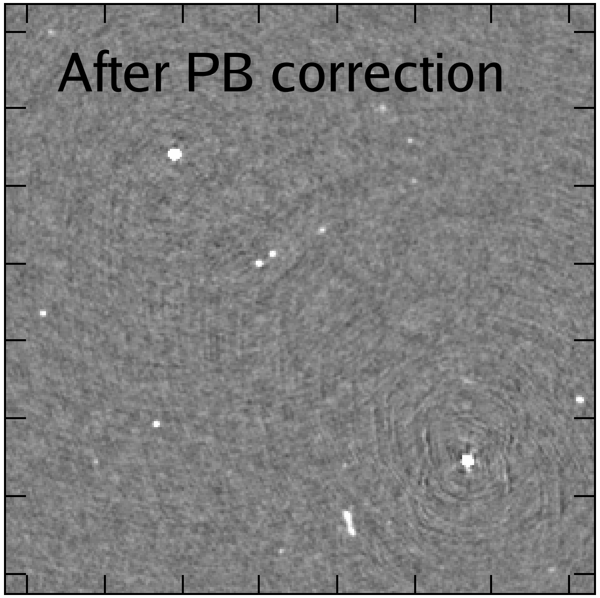
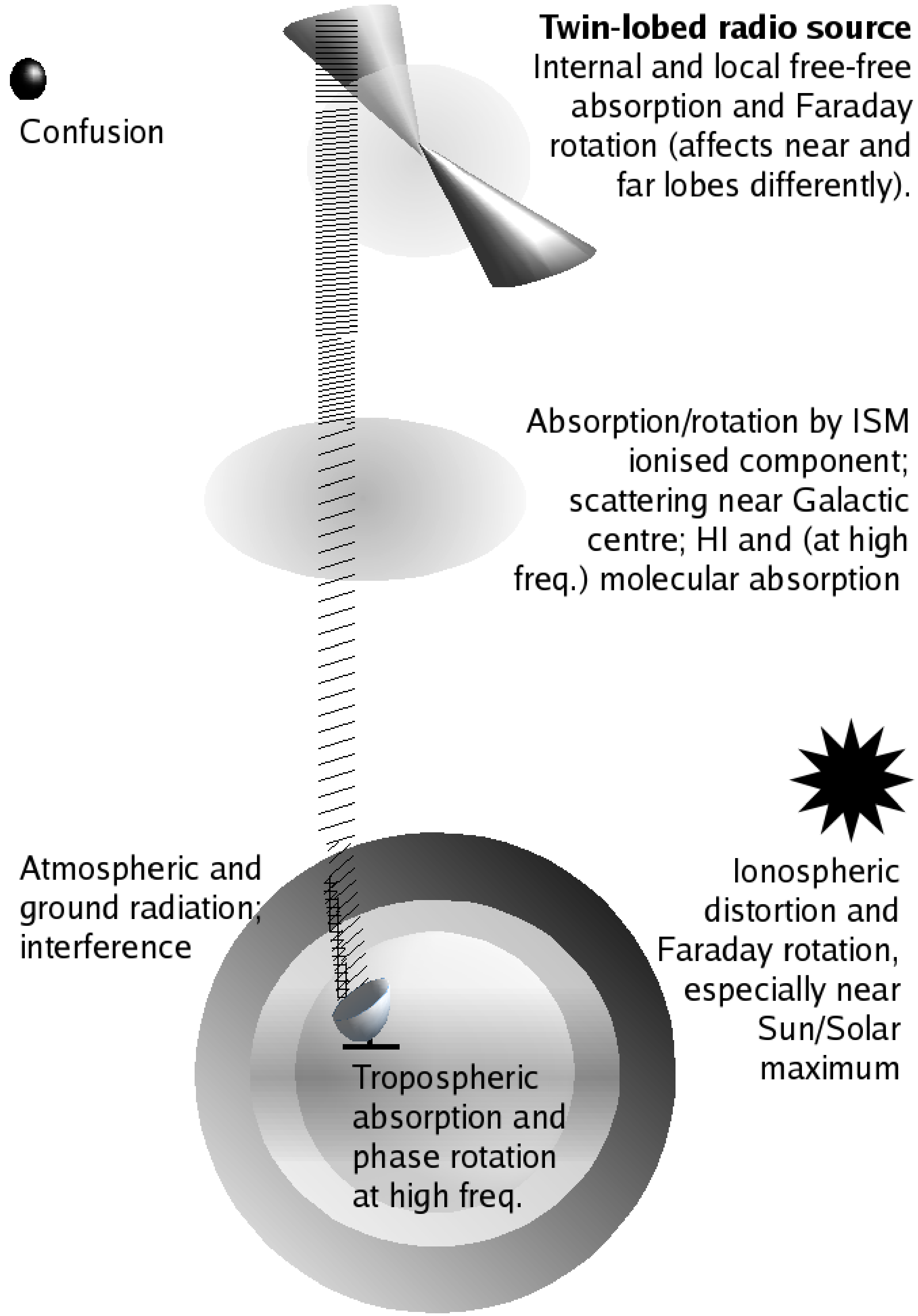
  - Automate flagging where possible





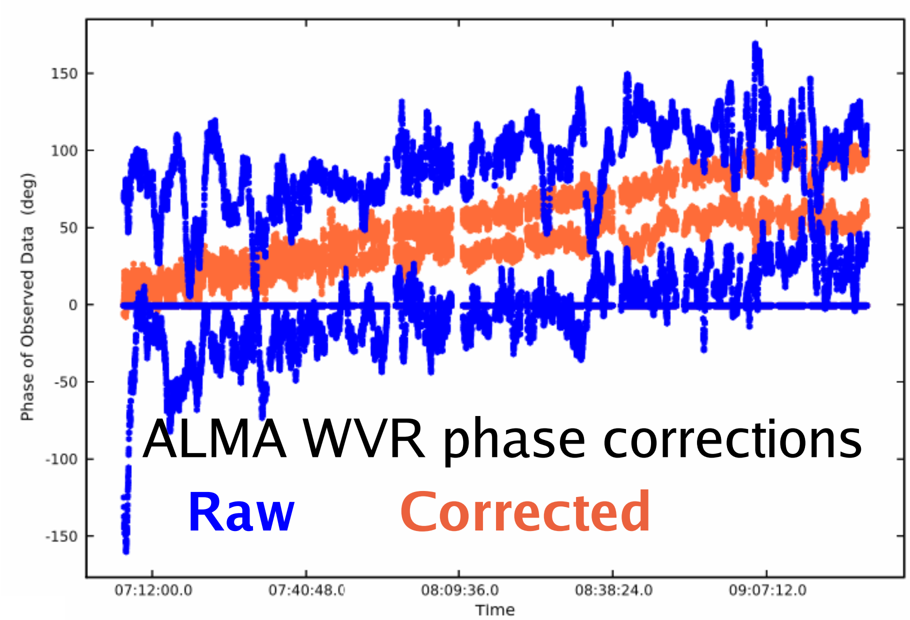
The demands of calibration

- Interstellar and atmospheric absorption and phase corruption
- Instrumental noise and delay errors
- Establishing astrometric and photometric scales



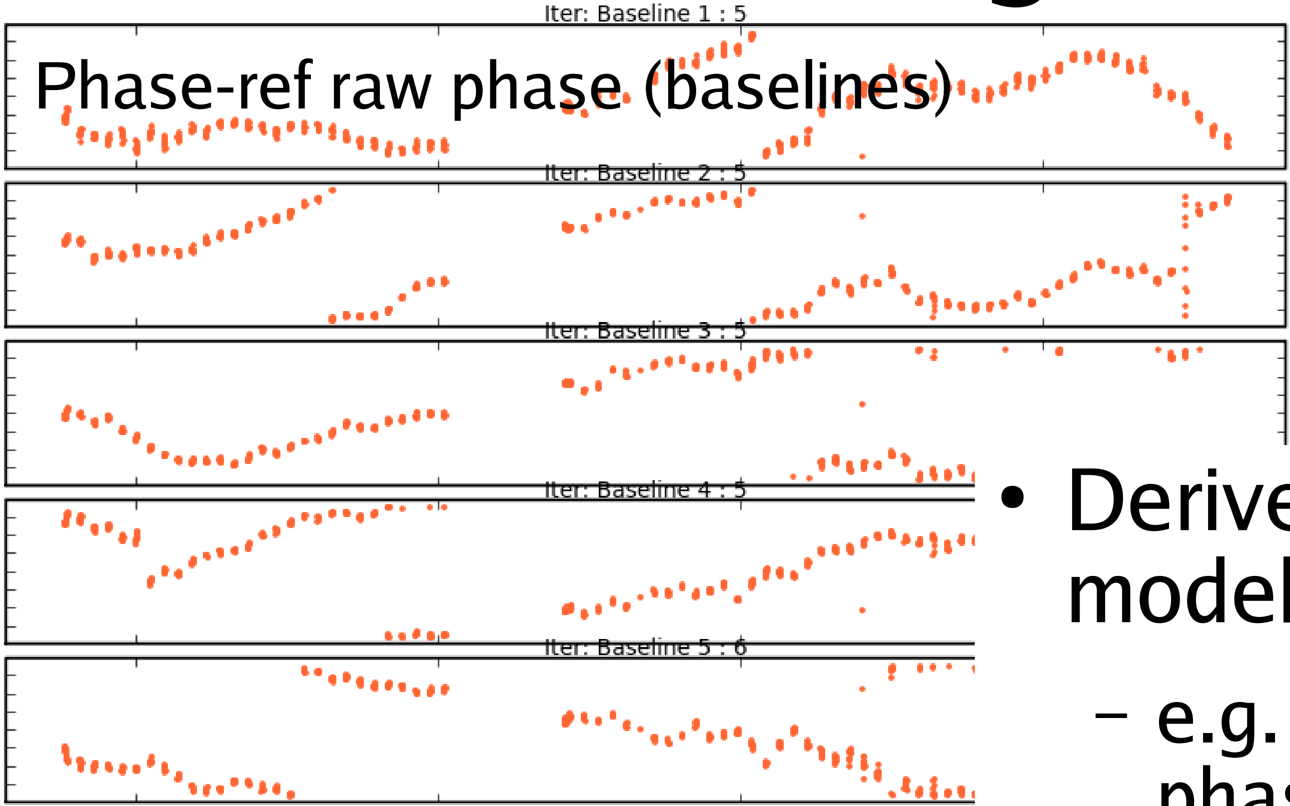
Unstable atmosphere

- Low frequencies - ionosphere
  - Polarization also affected
- High frequencies –water in troposphere
  - Phase rotated rapidly
  - Absorption affects amp's



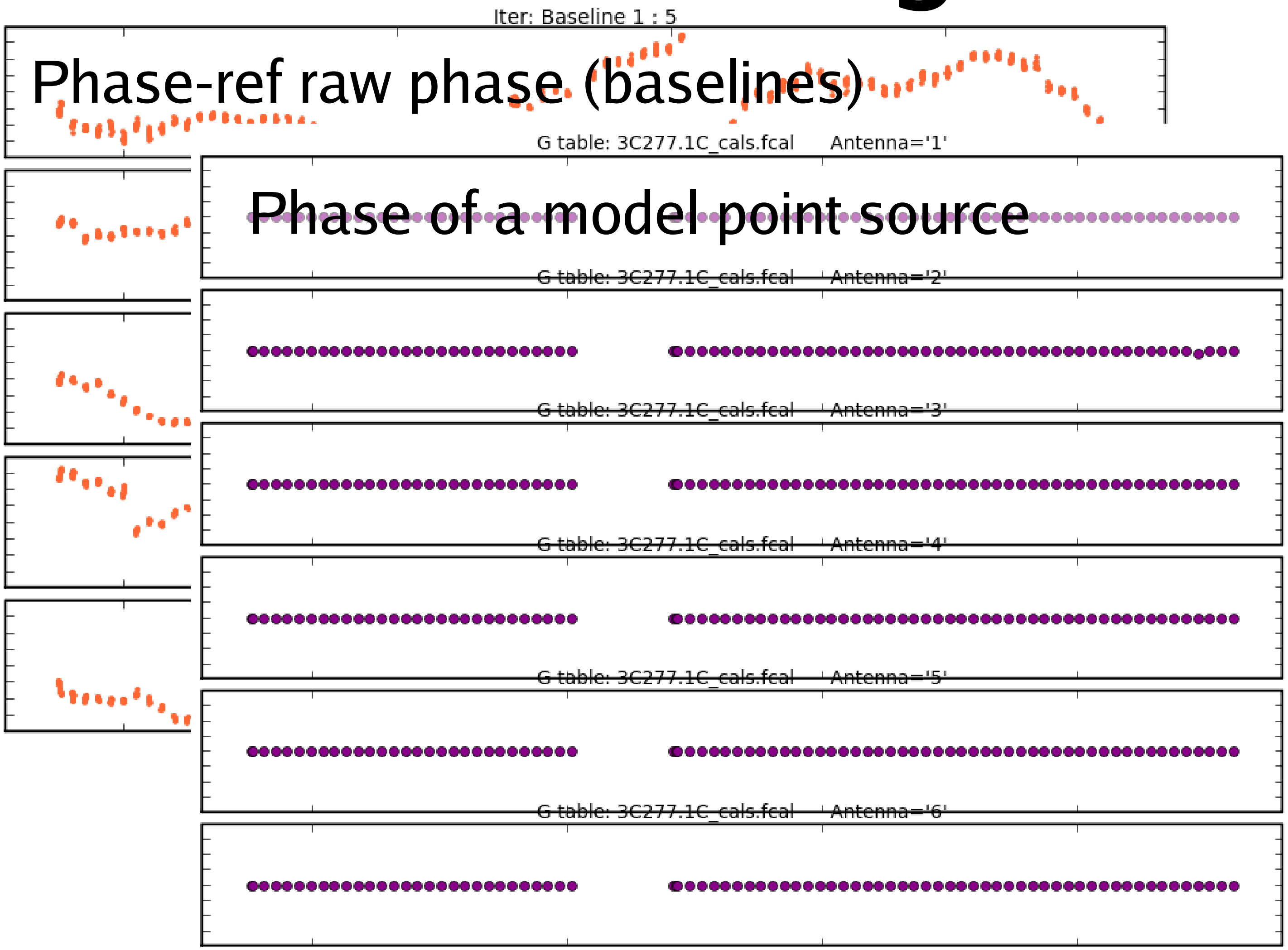
  - Rapid switching between phase-ref/target
    - Solve for rate or fit polynomials to phases
  - Measure atmospheric water vapour (WVR)
    - Apply corrections derived from model
  - Refractive phase effects ∝ ν - "delay"
    - Need to correct slopes within a band
    - Rescale corrections to apply across bands

Calibration using model of sky



- Derive calibration using models
  - e.g. point-like astrophysical phase-ref source
    - Solve for the differences between model and data
    - Find corrections needed to make data look like model

Calibration using model of sky



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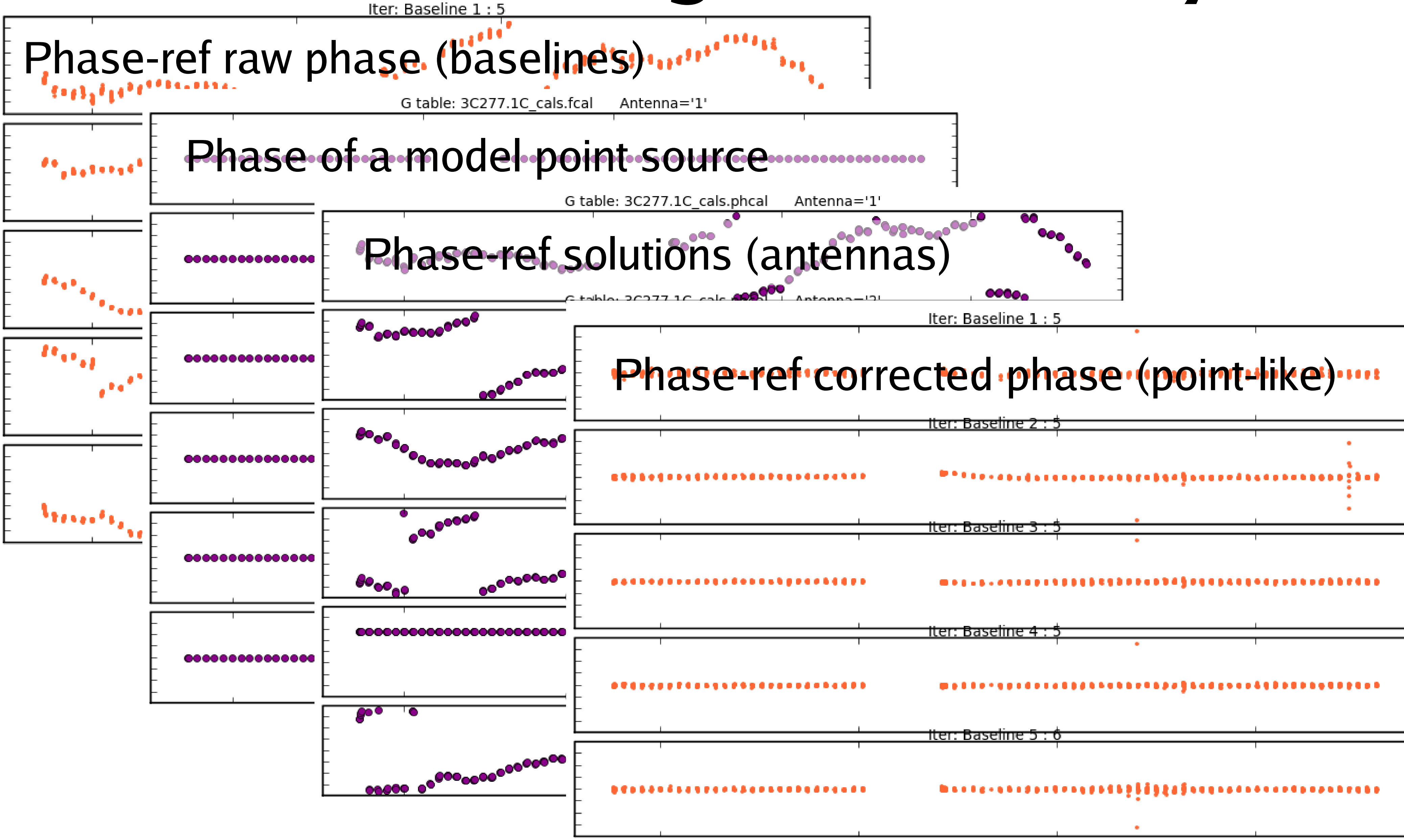
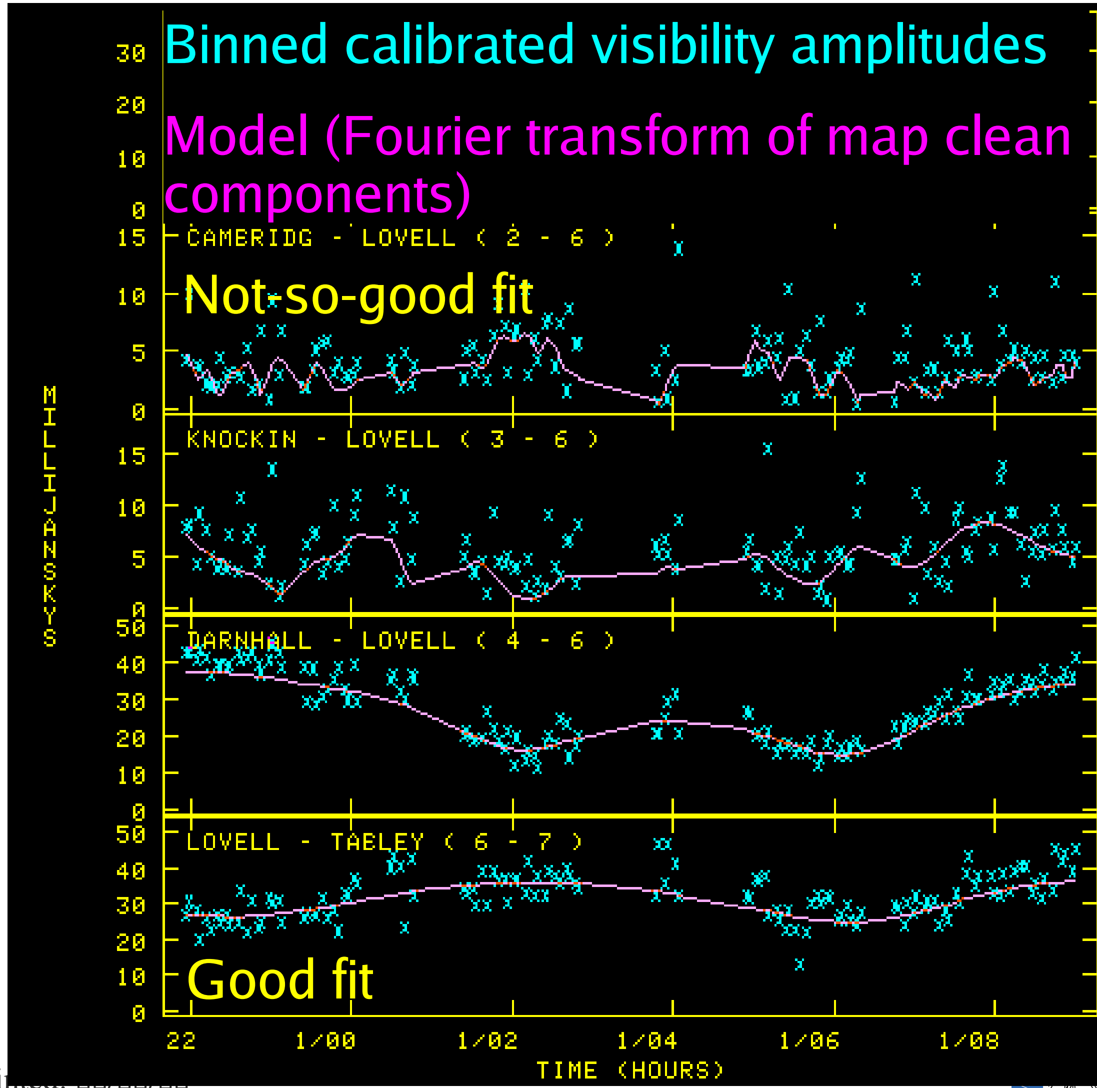
Calibration using model of sky



Inspect and correct data

- Tools to inspect the data, solutions, accuracy
  - e.g. compare model with data
- Model subtraction
  - Rescale data
- Correct astrometry
  - Combine datasets
- Apply calibration and flagging
  - Selectively
  - Reversibly
  - Transfer between targets/datasets
- *Keep history/logs*

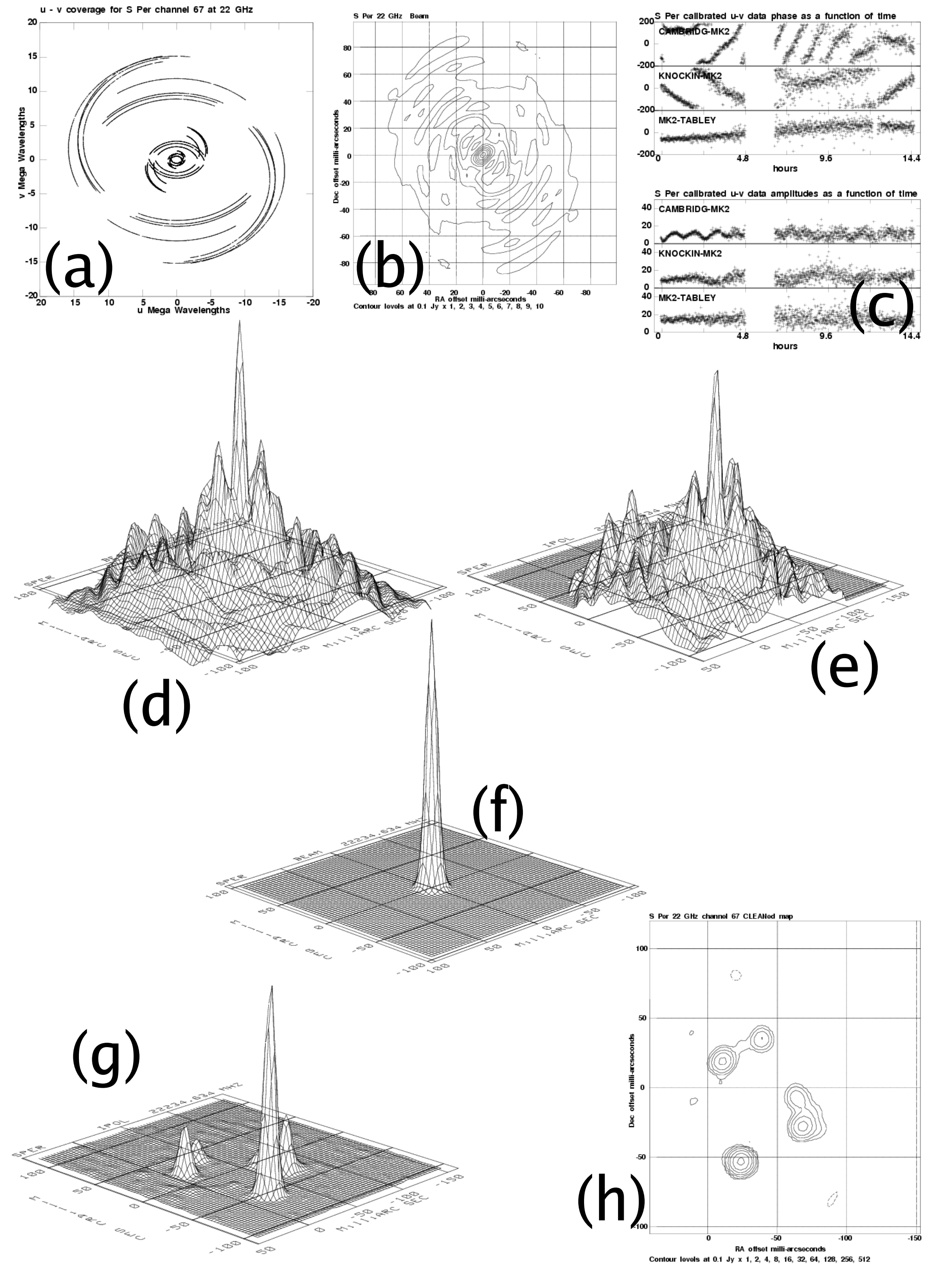


Continuum and line imaging

- Produce images and deconvolve the beam
  - Control of data weighting
    - by inverse of variance in averaging interval
    - by antenna sensitivity
    - for interpolating into missing *uv* spacings
  - Choice of methods
    - CLEAN - selected regions, multi-scale, etc.
    - Wide field and/or multiple facets, mosaicing
    - Wide band continuum and/or spectral line
    - Other methods –Maximum Entropy
  - Subtract continuum from line data (*uv* or image)
- Additional data products
  - Spectral index, polarization, spectral moments etc.
- Measurements
  - Noise, component fitting, sophisticated models...

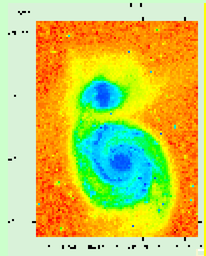
Cleaning

(a) *uv* coverage
(b) Dirty beam
(c) Calibrated visibilities
as a function of time
(d) Dirty beam:
deconvolve from
(e) Dirty map
to make a set of delta functions which are convolved with a
(f) Clean beam
to give a
(g) Clean map
(h) Clean map contours



Astronomical Image Processing System

- Originated by NRAO for VLA in 1978
  - Fortran, C
  - Limited built-in scripting/math operations
  - Currently most widely used package for cm-wave
    - VLA, MERLIN, most VLBI ... many more interferometers
    - Some support for single dish and any FITS images
  - Very wide functionality from calibration to analysis
- Needed for VLBI/manipulation of visibilities
  - RadioNet ALBiUS CASA-AIPS interoperability
  - Python wrapper (Parseltongue)
  - Wednesday tutorials and optional exercises



FITS The Astronomical Image and Table Format

Flex

- Sta
  - U
  - I
  - A
  - C
- Str
  - H
  - (
  - E

FITS Header

xterm

```
SIMPLE  =                    T /
BITPIX  =                  -32 /
NAXIS   =                    4 /
NAXIS1  =                   66 /
NAXIS2  =                   66 /
NAXIS3  =                  280 /
NAXIS4  =                    1 /
EXTEND  =                    T /Tables following main image
BLOCKED =                    T /Tape may be blocked
OBJECT  = 'SPER    '           /Source name
TELESCOP= 'MERLIN2 '           /
INSTRUME= '        '           /
OBSERVER= '        '           /
DATE-OBS= '1999-05-25'         /Obs start date YYYY-MM-DD
DATE-MAP= '2000-01-11'         /Last processing date YYYY-MM-D
BSCALE  =   1.00000000000E+00 /REAL = TAPE * BSCALE + BZERO
BZERO   =   0.00000000000E+00 /
BUNIT   = 'JY/BEAM '           /Units of flux
EPOCH   =     1.950000000E+03 /Epoch of RA DEC
VELREF  =                  257 />256 RADIO, 1 LSR 2 HEL 3 OBS
ALTRVAL =   1.66710997656E+09 /Altenate FREQ/VEL ref value
ALTRPIX =    -1.390000000E+02 /Altenate FREQ/VEL ref pixel
OBSRA   =   3.48128515485E+01 /Antenna pointing RA
OBSDEC  =   5.83592651738E+01 /Antenna pointing DEC
RESTFREQ=   1.66735906400E+09 /Rest frequency
DATAMAX =     5.355936050E+00 /Maximum pixel value
DATAMIN =    -5.429587513E-02 /Minimum pixel value
```

```
CTYPE1  = 'RA---SIN'           /
CRVAL1  =   3.48128515485E+01 /
CDELT1  =    -1.111111123E-05 /
CRPIX1  =     3.300000000E+01 /
CROTA1  =     0.000000000E+00 /
CTYPE2  = 'DEC--SIN'           /
CRVAL2  =   5.83592651738E+01 /
CDELT2  =     1.111111123E-05 /
CRPIX2  =     3.400000000E+01 /
CROTA2  =     0.000000000E+00 /
CTYPE3  = 'VELO-LSR'           /
CRVAL3  =   6.28035946778E+03 /
CDELT3  =    -1.756092529E+02 /
CRPIX3  =    -1.390000000E+02 /
CROTA3  =     0.000000000E+00 /
CTYPE4  = 'STOKES  '           /
CRVAL4  =   1.00000000000E+00 /
CDELT4  =     1.000000000E+00 /
CRPIX4  =     1.000000000E+00 /
CROTA4  =     0.000000000E+00 /
HISTORY AIPS HEADER2  WTNOISE  =  1.035
--More--(0%)
```

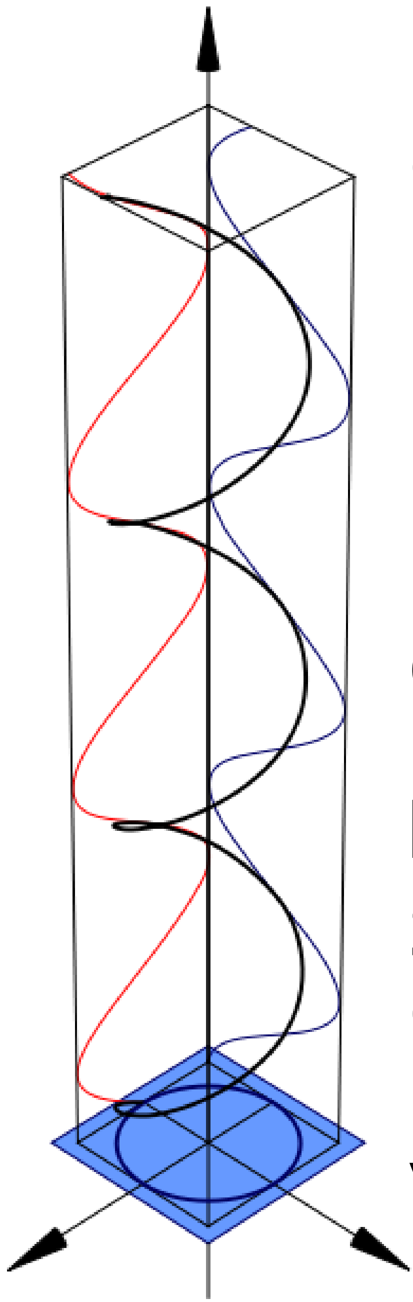
  - Fortunately there are tools
    - `IMHEAD` in AIPS or CASA

xterm

```
>getn 20;imh
AIPS 1: Got(1)   disk= 1  user=  89   type=MA   MKN273_MER.ICL001.1
AIPS 1: Image=MKN273A    (MA)          Filename=MKN273_MER  .ICL001.   1
AIPS 1: Telescope=MERLIN2              Receiver=
AIPS 1: Observer=                      User #=   89
AIPS 1: Observ. date=14-FEB-2004       Map date=19-AUG-2009
AIPS 1: Minimum=-4.29469685E-04        Maximum= 7.45257037E-03 JY/BEAM
      : ----------------------------------------------------------------
      :
      : Type      Pixels    Coord value      at Pixel     Coord incr   Rotat
      : RA---SIN    512    13 44 42.142      256.00       -0.015000    0.00
      : DEC--SIN    512    55 53 13.150      257.00        0.015000    0.00
      : FREQ          1    4.9929902E+09       1.00   1.2000000E+07    0.00
      : STOKES        1    1.0000000E+00       1.00   1.0000000E+00    0.00
      : ----------------------------------------------------------------
      : Coordinate equinox 2000.00
AIPS 1: Map type=NORMAL                Number of iterations=    1000
AIPS 1: Conv size= 0.13732 X 0.06835    Position angle= -22.69
AIPS 1: Rest freq       0.000          Vel type: OPTICAL wrt LSR
AIPS 1: Alt ref. value -4.20762E+05  wrt pixel     8.00
AIPS 1: Maximum version number of extension files of type CC is   1
AIPS 1: Maximum version number of extension files of type HI is   1
AIPS 1: Keyword = 'CCFLUX  '  value =  4.341595E-02
AIPS 1: Keyword = 'CCTOTAL '  value =  4.341595E-02
AIPS 1: Keyword = 'PARANGLE'  value = -1.239448E+02
AIPS 1: Keyword = 'ZENANGLE'  value =  6.472005E+00
>tvlo;tvzoom;tvps
```

Axes
Pos
Pos
Hz
1 = I = total intensity

Polarization jargon



CIRCULAR

Left-hand
LHC, L, LL

Right-hand
RHC, R, RR

Cross hands
LR RL make
linear

Stokes V =
(RR-LL)/2

Fractional
V/I, |V|/I, %

LINEAR

Stokes Q =
(RL + LR)/2

Stokes U =
(RL - LR)/2i

Polarized intensity
$P = \sqrt{(Q^2+U^2+V^2)}$

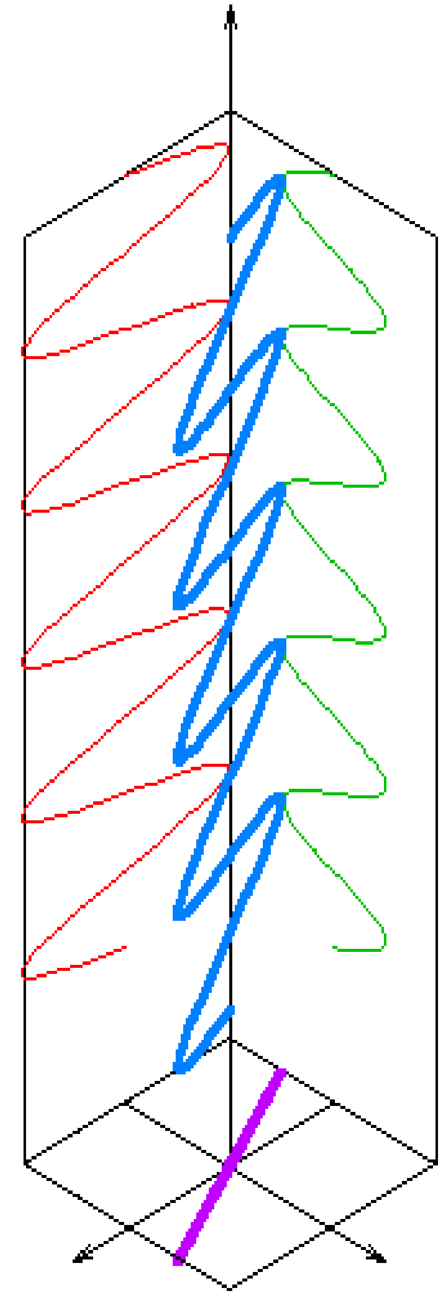
Polarization angle
χ = ½ atan2(U/Q)

Linear feeds

X, XX, Y, YY

Cross hands

XY YX



Diagrams thanks to Wikipaedia

FITS axes labels

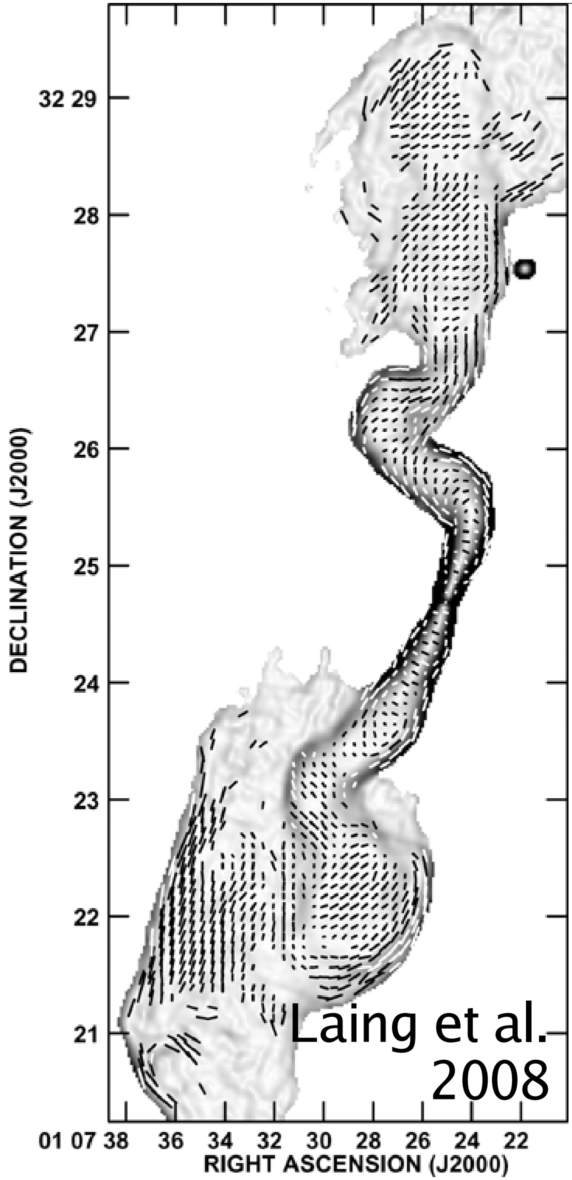
- Axes contain one+ pixels
- Quantization of physical variable e.g.
  - Position in RA
  - Frequency
  - Label
    - Types of polarization ⇒
      - I (one 'pixel')
      - IQUV (four 'pixels')

CASA

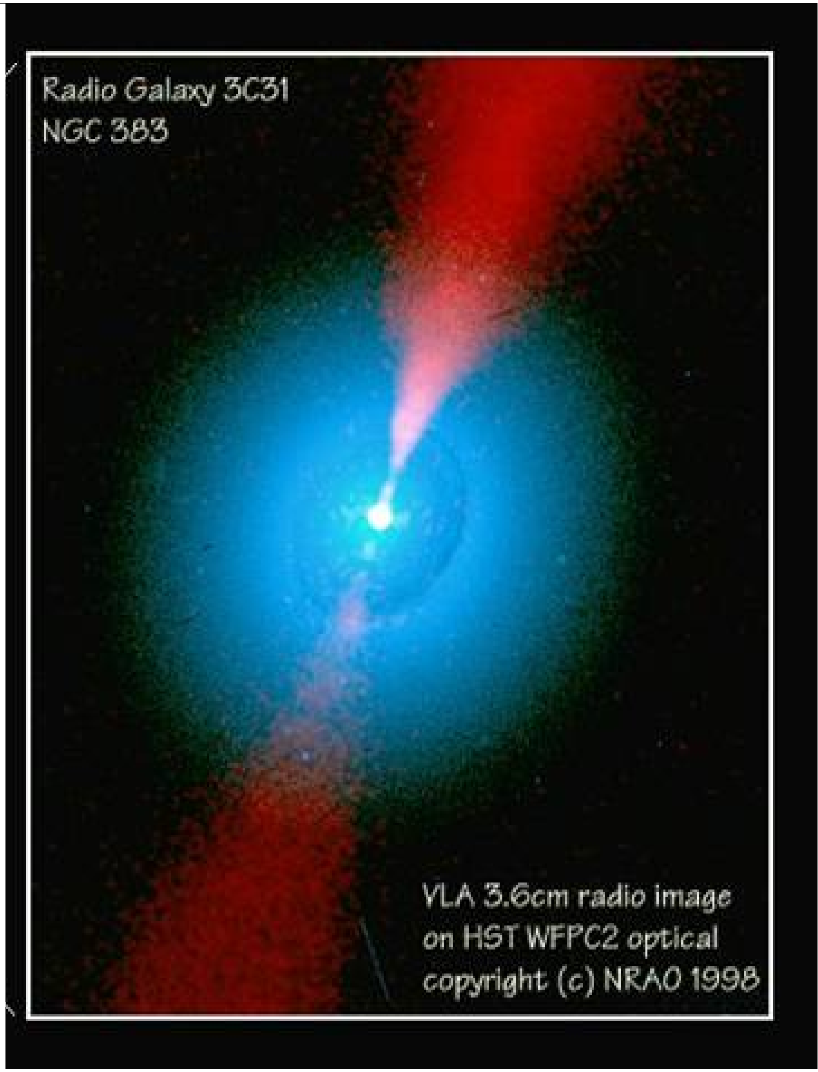
- Polarizations also termed correlations

Polarization type	Label	FITS code
Total	I	1
Linear	Q	2
Linear	U	3
Circular	V	4
Circular	RR	-1
Circular	LL	-2
Linear	RL	-3
Linear	LR	-4
Linear	XX	-5
Linear	YY	-6
Circular	XY	-7
Circular	YX	-8
Undef	UNDEF	---
Linear	POLI	5

Radio Galaxy 3C31



- Magnetic field vectors
  - Role in collimating jet
    - Compare magnetic and kinetic energies
  - Low-power jet confined by IGM
    - Polarization affected by host
    - 0.8c - 0.2c deceleration by mass entrainment



CASA developed to meet NG needs

- `aips++` development in c++ started in ~1994
  - Easier to maintain/develop/parallelise
- User-friendly python wrapper since 2007
  - Common Astronomy Software Application
  - 'Task' interface or scripting
  - Underlying `aips++` toolkit available
- Measurement Set data format
  - *uv* data and images in subdirectories anywhere
  - ALBiUS (RadioNet) developing interoperability with AIPS
- ***Still under development - check for updates***

AIPS or CASA? (or either or both)

- Either package for straightforward data
- Raw data format:
  - CASA for SDM, MS, UVFITS, soon IDE FITS
    - Might have to pass through array-native package first to apply instrumental calibration (for any other package)
  - AIPS for FITS (but harder for linear feeds)
    - Currently, easier to correct astometry, global flux scale, per-antenna weights etc.
- Calibration
  - CASA especially for EVLA and ALMA
    - Apply Water Vapour Radiometry corrections
    - Fit polynomials to phase
    - Flexible bandpass and polarization calibration
  - AIPS for easy delay and rate calibration
    - ALMA will also need this

AIPS or CASA? (or either or both)

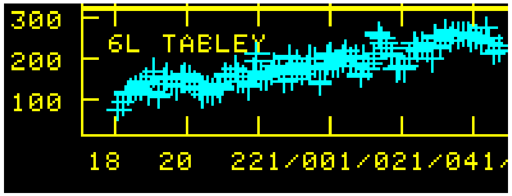
- Imaging
  - CASA slower but easier to parallelise
    - Wide-band MFS with spectral index/curvature
    - *w*-projection (3-D sky)
    - Heterogenous primary beams
  - AIPS
    - Faster for multi-facet wide-field images
    - Maximum entropy methods
    - At present, more measurement tools
- Interoperability
  - Script both in Python
  - Easy to swap data but apply calibration/flags first
    - Most extension tables lost
    - Cookbooks recipes a bit too VLA-specific

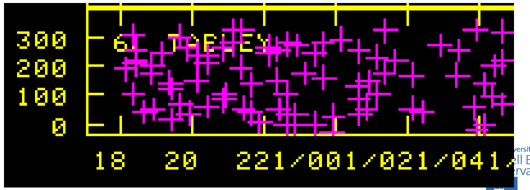
Choosing a data package

- What packages can handle your data?
  - Specialised requirements e.g.
    - cm-wave data *observed* in linear polarisation
    - VLBI-like phase-rate solutions needed
- Which of the possible packages does most?
  - Specialised packages may limit you in future
  - How easy is it to script/make pipelines?
- Is expert help available? How is it maintained?
  - Local; help desks; summer schools...
  - What do your collaborators use?
- Are you going to be an expert/developer?
  - Is there a framework for contributing algorithms?

Keep sight of the physics

- Brain gets filled with package jargon
  - `task 'CALIB'; calsour 'phaseref'; solint 0.5; docal 100; aparm(7) 3; gainuse 5; solmo 'p'`
- Rember this means
  - Take the visibility data for the phase ref and apply existing calibration table 5; minimum snr 3
  - If no other model is given, a point source at the field centre will be used
  - Compare the data with the model phase and calculate the corrections needed
- That way you will know to expect
  - and what to check if you get





Choose the right tool for the job

- Innovative projects or observatory staff developer
  - Use toolkit or write your own software
  - Construct pipelines
    - Document for future use

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artefacts

Choose the right tool for the job

- Innovative projects or observatory staff developer
  - Use toolkit or write your own software
  - Construct pipelines
    - Document for future use
- Experienced radio interferometer user
  - Use pipelined *uv* cal, guided by proposal metadata
  - Refinine self-calibration/editing
    - Adapt recipe parameters for array, custom products
  - Prefer to use a familiar package
    - Interoperability essential
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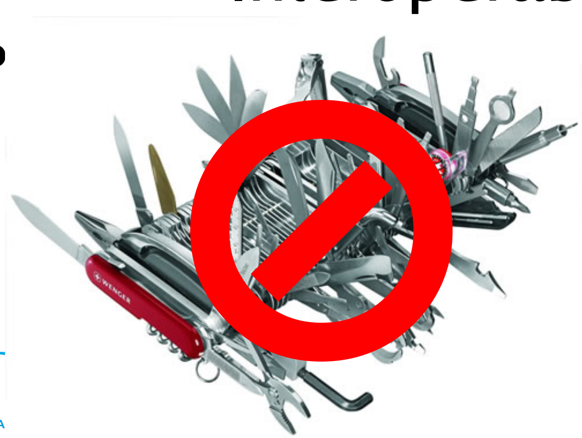
constraints

s/artefacts



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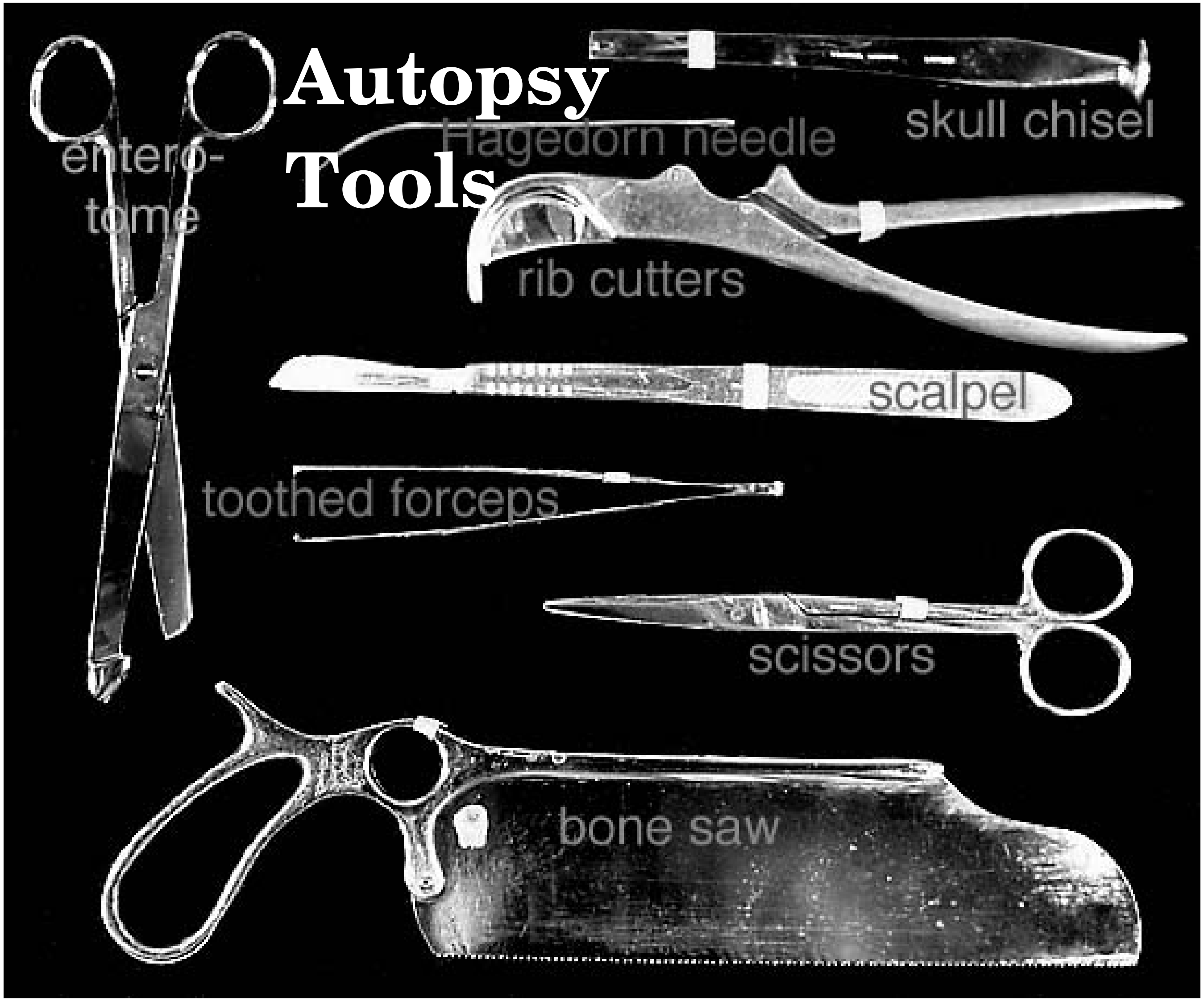
  - Use pipelined *uv* cal, guided by proposal metadata
  - Refinine self-calibration/editing
    - Adapt recipe parameters for array, custom products
  - Prefer to use a familiar package
    - Interoperability essential
- Beginner - or just in a hurry
  - Jargon-free pipeline interface
    - Steer within instrumental constraints
  - Clear explanation of pitfalls/artefacts

Keep a full processing history

- Use scripts, or
- Note parameter values
  - Examples for further processing
  - Troubleshooting postmortem



You know you're a geek when...

Which pipeline/package?

- Parseltongue
  - AIPS functionality
    - Plus extensions using Python maths, your programs etc.
  - Parellelisable
  - Uses OBIT which may need extra libraries
- CASA scripting
  - Integral part of package design
  - Include any Python or your programs
  - Includes (sub-)mm and other NG capabilities
  - Some tasks e.g. for VLBI not yet available
- MEQTrees
  - Powerful for LOFAR and other very wide-field data
  - Complex to install and steer
- ALBiUS interoperability should help in future!