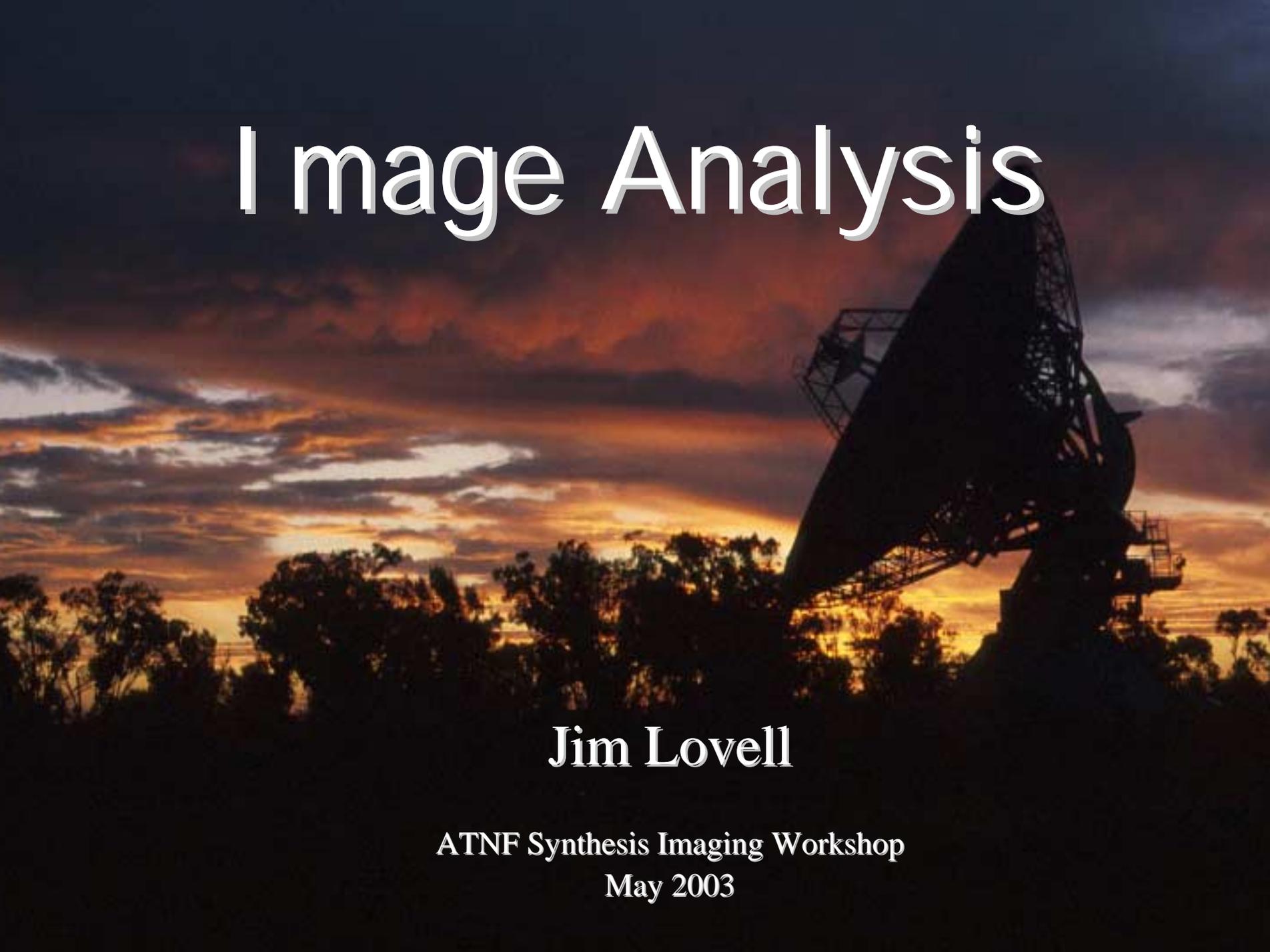


Image Analysis

A large radio telescope dish is silhouetted against a dramatic sunset sky. The sky is filled with orange and yellow clouds, and the sun is visible near the horizon. The telescope dish is on the right side of the frame, and its structure is clearly visible against the bright sky. The foreground shows the dark silhouettes of trees and the ground.

Jim Lovell

**ATNF Synthesis Imaging Workshop
May 2003**

What Do You Want to Measure?

(What you want to do and how to do it.)

- Flux density of components
- Absolute positions
- Relative positions and motions
- Flux density variability
- Spectral index, rotation measure etc (image combination).
- Overlay with other wavelength images
- Putting it all together

Image Analysis Software

- Miriad
- AIPS
- The package formerly known as Aips++
- Difmap:
 - Imaging (spectral line & continuum), model fitting, self-cal.
 - Very good user interface.
 - Not suitable for mosaicing or wide-field imaging.

Tasks, commands

	Miriad task	Difmap command	AIPS task	Aips ++ function
Visibility plane model fitting	Uvfit, uvmodel	Modelfit	Uvfit, (slime)	-
Image plane model fitting	Maxfit, imfit	-	Maxfit, jmfit, imfit, sad	(spatial), image.maxfit, image.fitprofile, image.profiler
Image plane integrated flux	Imstat	Imstat, "S" in mapplot	Mean, imstat, tvstat, blsum	image.statistics
Slices	Ellint	-	Sffit, xgaus	image.getchunk, image.getregion, image.putchunk, image.putregion
continuum subtraction	Uvsub, imlin, uvlin, uvmodel	Setcont	Uvmod, uvsub	image.modify
Forming polarisation images	Impol	multi_model true; polvec; maplpch	Comb	image.various
Rotation measure	Imrm	-	Comb	image.pol.rotationmeasure, image.fourierrotationmeasure
Spectral Index	Maths	-	Comb	image.calc
Other image combinations	Maths	-	Comb, sumim	image.calc

Resources

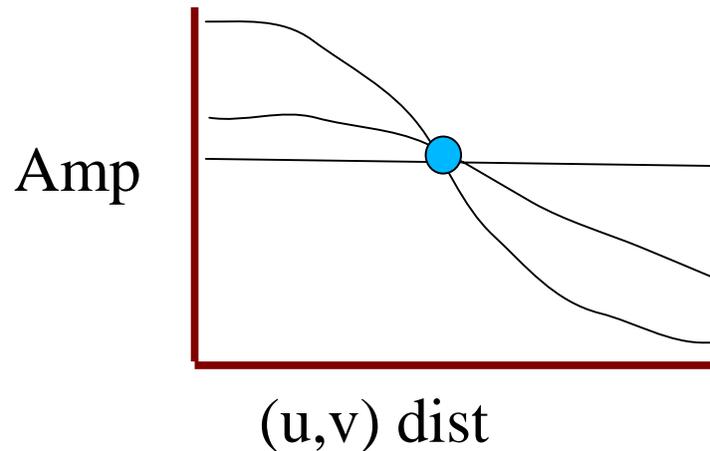
- Follow the links from the *ATNF Software And Tools* page:
www.atnf.csiro.au/computing/software
- TPFKA Aips++: see the *Getting Results* documentation for an overview of image analysis.
- Miriad: see Chapter 18 of the *Users Guide*
- Difmap: see the *Difmap Cookbook*
- AIPS: see chapter 7 of the *AIPS Cookbook*

Personal Bias/Ignorance

- TPFKA Aips++ has good image analysis capabilities. Can do almost everything that Miriad, AIPS and Difmap can plus more.
- Paths of least resistance (i.e hassle):
 - ATCA data:
 - Calibrate in Miriad
 - Imaging or model fitting in Difmap. If mosaicing or bandwidth smearing effects are important use Miriad.
 - VLBI /SVLBI data:
 - Calibration and fringe-fitting in AIPS
 - Imaging/model fitting in Difmap. Wide-field imaging with IMAGR in AIPS.
 - Detailed image analysis in Miriad or AIPS

Errors

- Errors given by fitting software should be treated with scepticism
 - Generally assumed errors are stochastic
 - No accounting for on-source errors etc
 - Components are not necessarily independent. e.g. Usually a strong correlation between intensity and diameter. Extreme example is one (u,v) point:

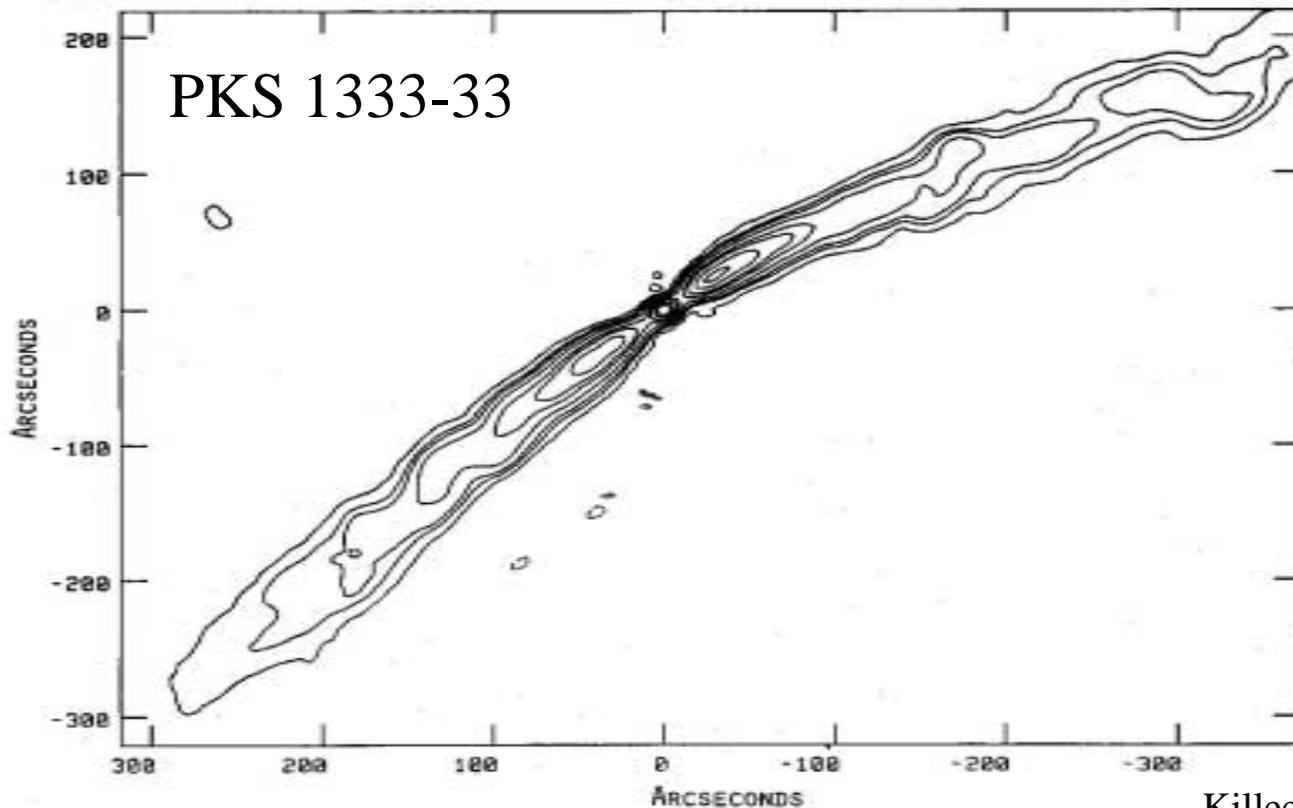


Component Fluxes

- 1 Discrete Components: Model Fitting
 - Model fitting is suitable for relatively discrete, isolated features.
 - Usually not a unique solution, so choose the simplest possible model (fewest components, simplest shapes)
 - Point source -> circular Gaussian -> elliptical Gaussian.
 - Model components tend to be too simple for more complex structures.

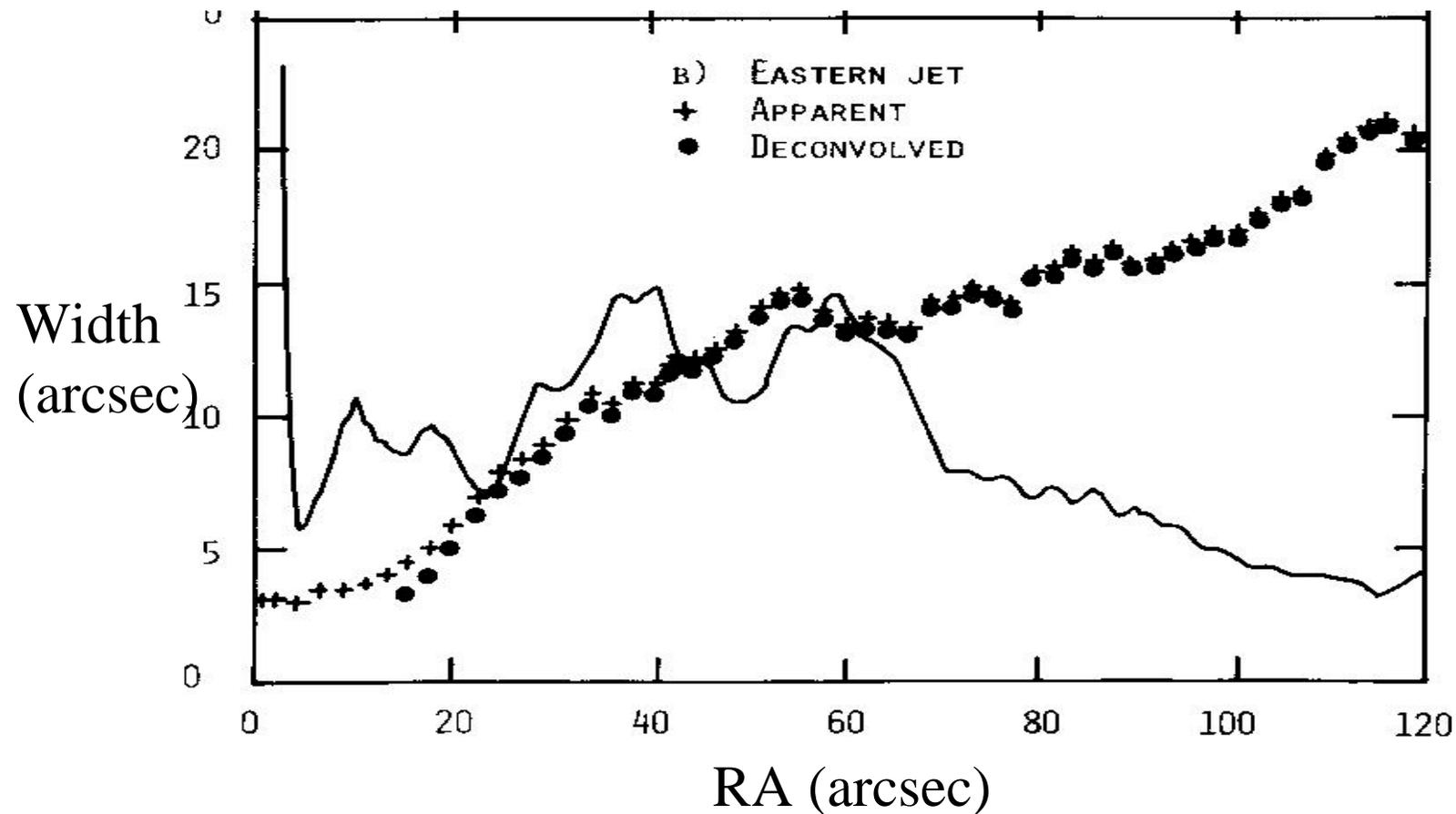
Component Fluxes cont.

- Extended Sources
 - Reducing the dimensionality can help.



Reducing the dimensionality

- Fit to jet width vs distance



Component Fluxes cont.

- Extended Sources
 - Reducing the dimensionality can help.
 - Integrated intensity.
 - Sum the intensity within a given region

Absolute Positions

- Depends on the quality of calibration:
 - Precision of the position of the phase-cal
 - Separation of source from phase-cal (closer the better)
 - Weather, phase stability
 - Signal to noise

Relative positions and motions

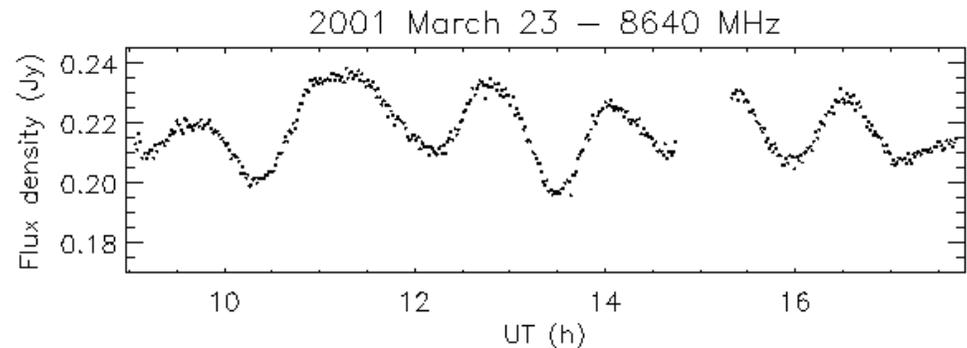
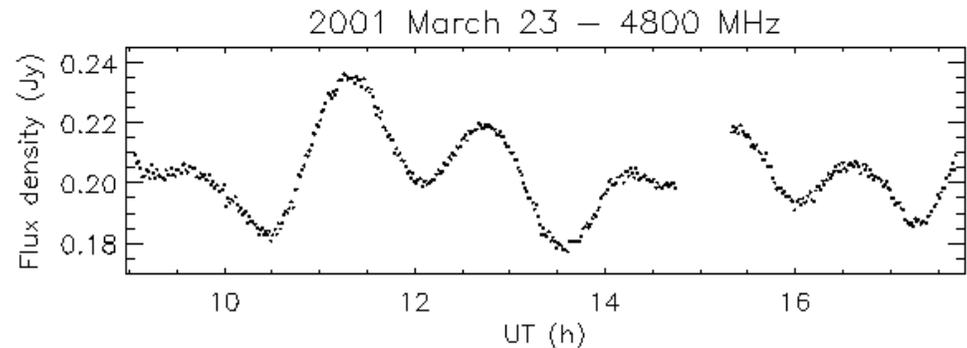
- Limited by signal-to-noise

Flux Density Variability

- Between epochs: easy.
- Within epochs: difficult.

NOTE: Check your secondary cal isn't an Intra-Day Variable!

- At any given time ~10% of flat spectrum sources show IDV of a few % or more at cm-wavelengths.
- Can seriously harm amplitude calibration.
- IDV can be episodic



Flux Density Variability

- Between epochs: easy.
- Within epochs: difficult.

NOTE: Check your secondary cal isn't an Intra-Day Variable!

- Imaging algorithms assume the source stays constant during the observation
 - 1 Split data into N segments and image each one separately
 - 2 Measure $S(t)$ of variable component(s)
 - 3 Subtract variable component from the visibility data.
 - 4 Image whole dataset
- A similar procedure may be required before combining data from different arrays or array configs.

Image Combination

- Often desirable to combine images to
 - Measure polarisation,
 - Measure spectral index,
 - Measure rotation measure,
 - Look for differences,
 - Compare with optical, X-ray etc.
- When combining radio images, restore all images with the same beam first.

Polarisation

- Alignment should not be a problem as any self-cal solutions from imaging I can be passed directly to Q and U.
- Polarised intensity:

$$I_P = \sqrt{I_Q^2 + I_U^2}$$

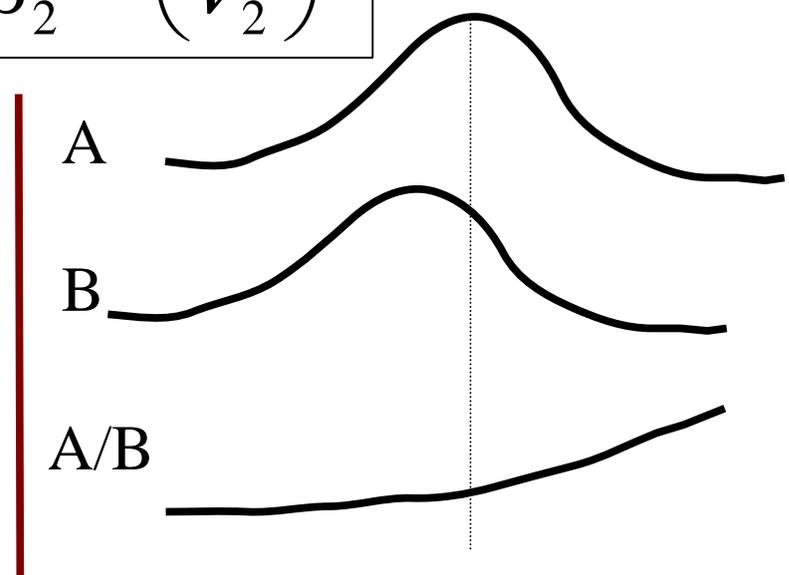
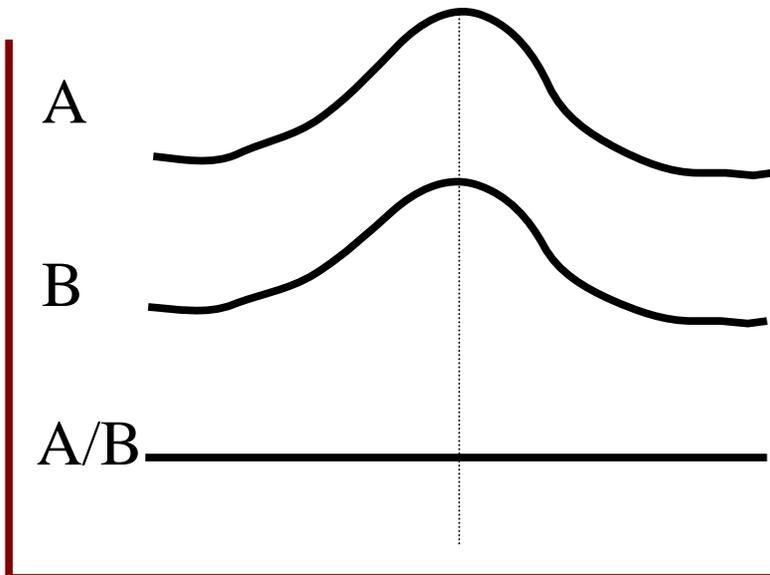
- Linear polarisation position angle:

$$\psi = 0.5 \arctan\left(\frac{I_U}{I_Q}\right)$$

Low S/N, Misalignment

- Beware of edge effects due to low S/N or image misalignment.
 - In spectral index measurements you can end up with a fake gradient.

$$\frac{S_1}{S_2} = \left(\frac{v_1}{v_2} \right)^\alpha$$



Low S/N, Misalignment

- Beware of edge effects due to low S/N or image misalignment.
 - Extreme rotation measures are possible

$$RM = \frac{\psi(v_1) - \psi(v_2)}{\lambda_1^2 - \lambda_2^2}$$

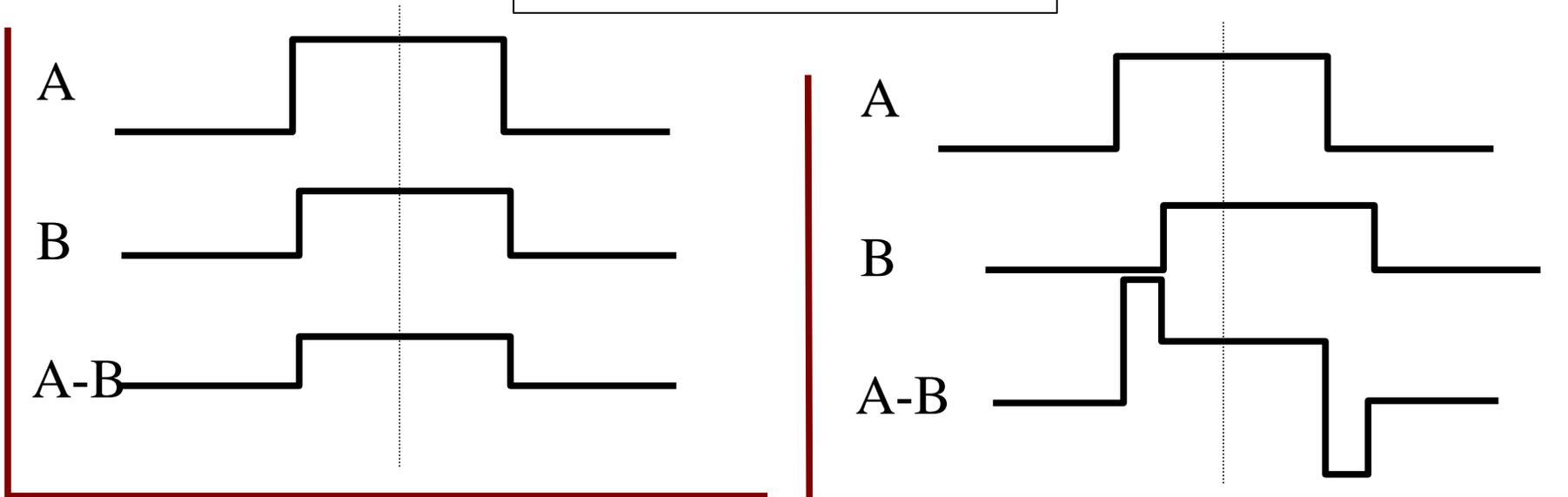


Image Overlays

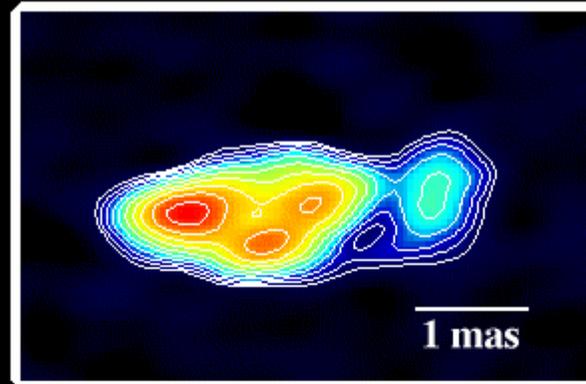
- Can be tricky if X-ray/optical/radio have different astrometric precision.
- Two approaches:
 - 1 Accept the uncertainties
 - 2 Make some assumptions. If there are multiple components in each image, look for an alignment with the best correlation.

Example: PKS 0637-752

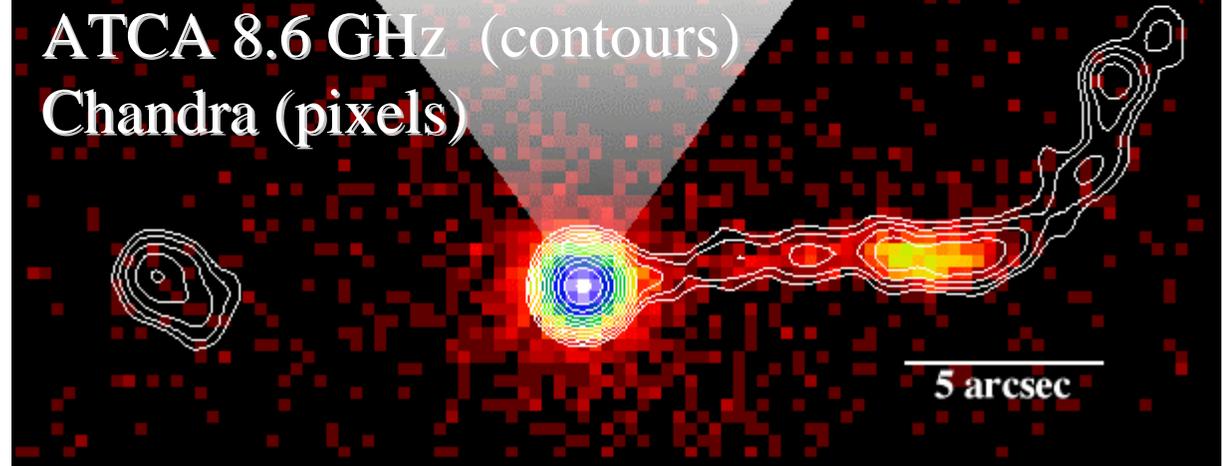
Quasar, $z=0.651$

(Montage from
Difmap image and
overlays in Miriad)

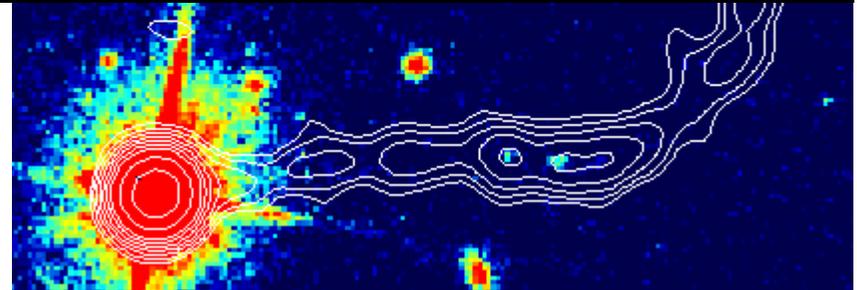
Space
VLBI
(VSOP)



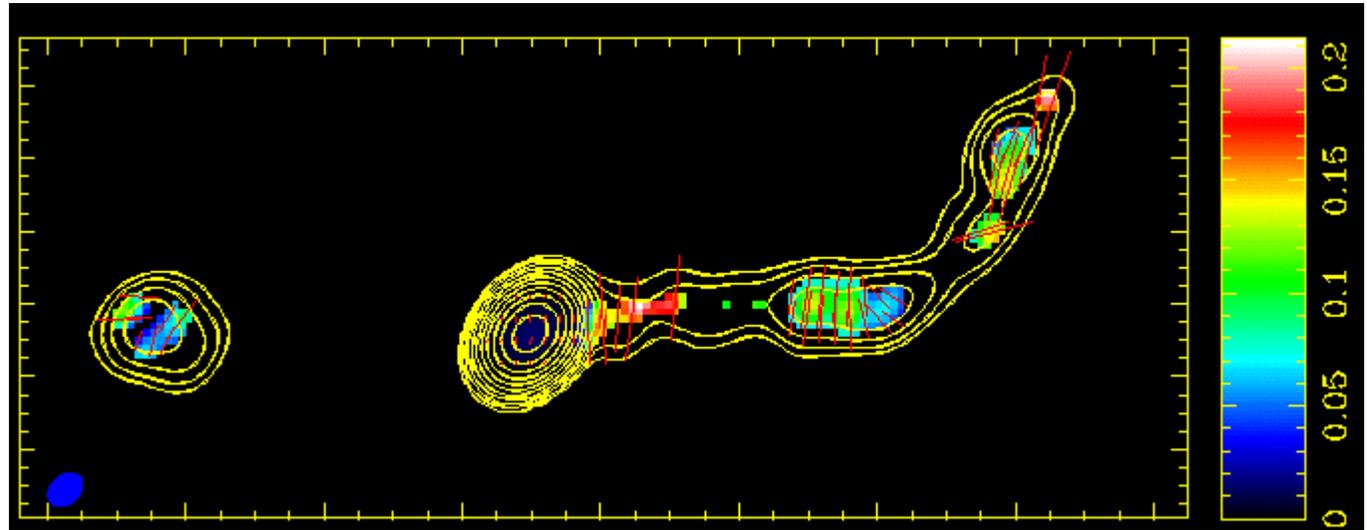
ATCA 8.6 GHz (contours)
Chandra (pixels)



ATCA/HST overlay



PKS 0637-752 cont.

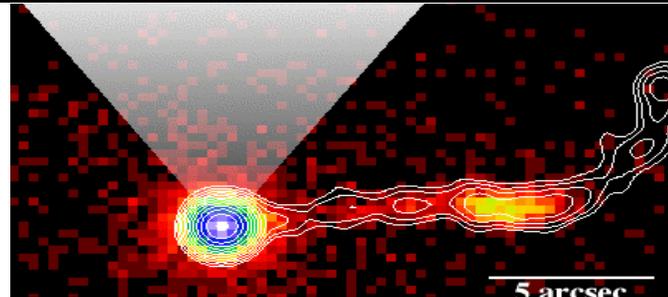


ATCA 8.6 GHz

Contours: total intensity

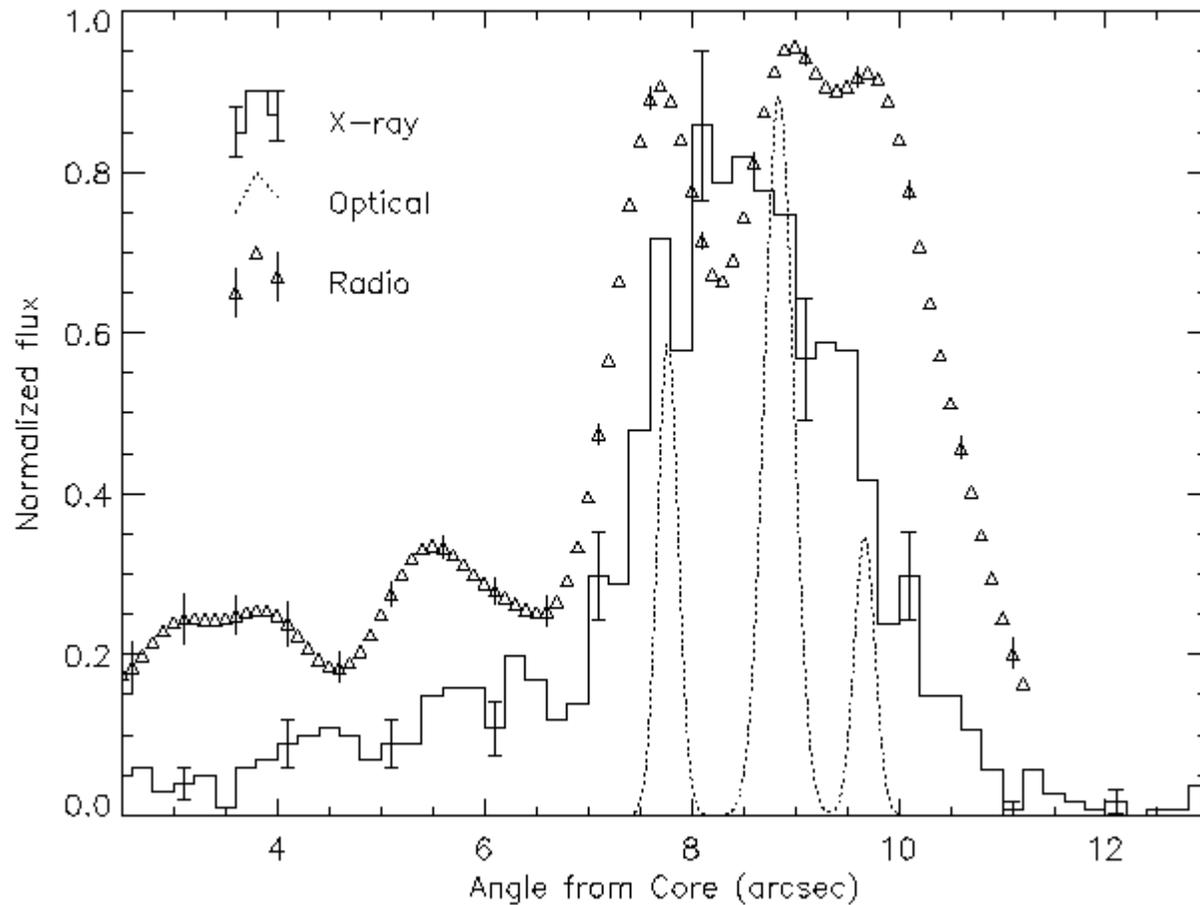
Pixels: fractional polarisation

Lines: polarisation E-vectors



(Imaged in Difmap, polarisation and overlays in Miriad)

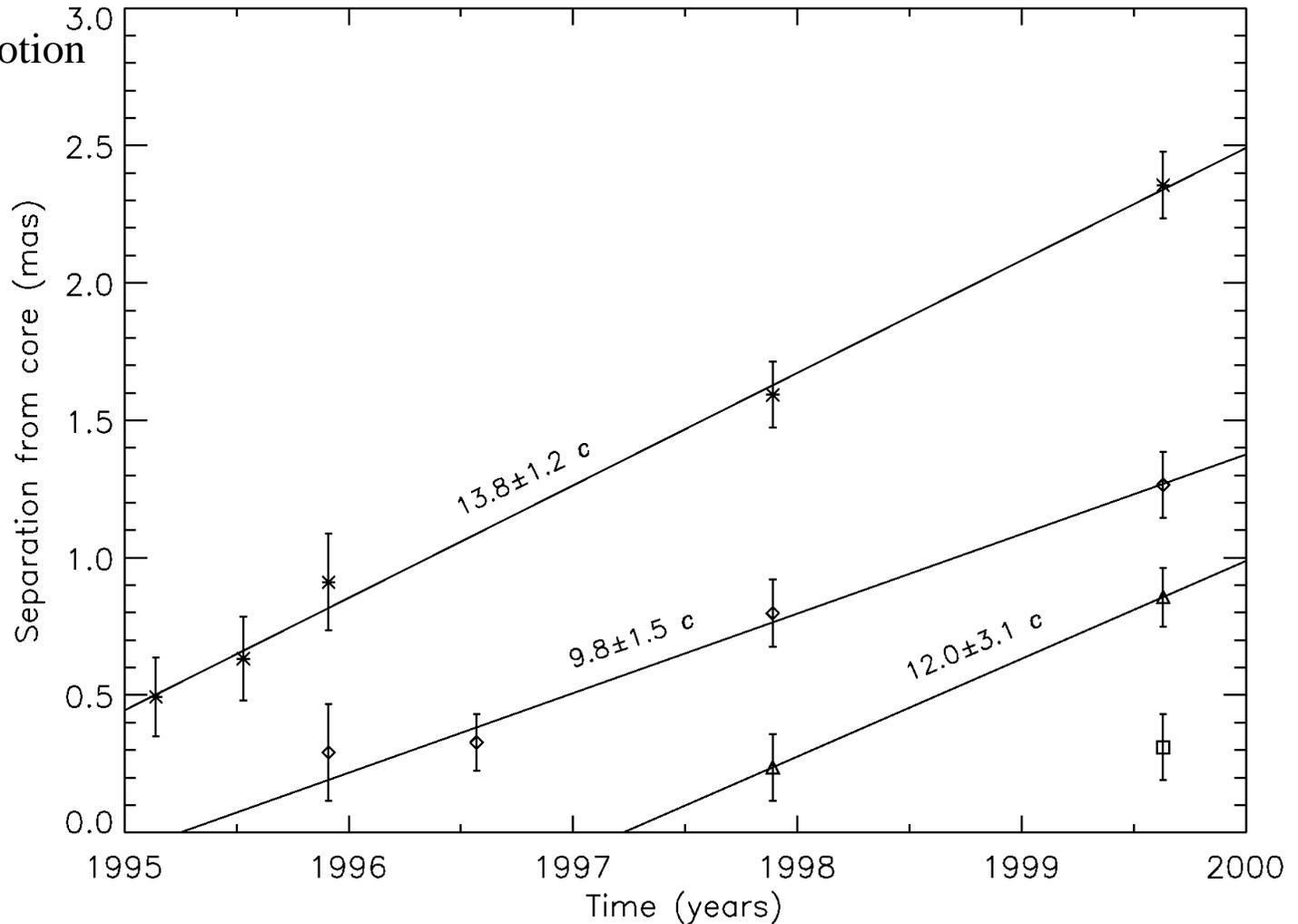
PKS 0637–752 cont.



(Slice along radio jet in AIPS)

PKS 0637-752 cont.

VLBI Component motion
(separation vs time).



(Model fit to VSOP and ground-only VLBI data in Difmap)