A novel imaging algorithm for broadband aperture synthesis data

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Michelson Summer School 2001

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Overview

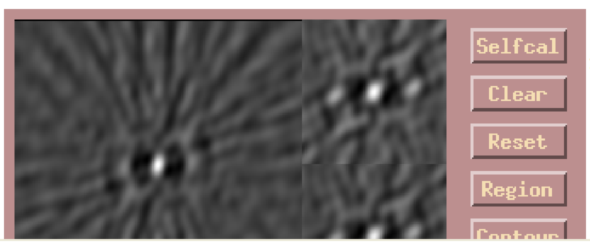
PEARL is a recent addition to OYSTER and therefore not very sophisticated. However, it implements a new algorithm capable of dealing with broad-band data of composite spectrum binaries. In this example, with Mizar consisting of two identical components, we can just apply the classic CLEAN deconvolution algorithm in conjunction with a phase self-calibration step ("hybrid mapping") to the combined data of all NPOI channels.

PEARL

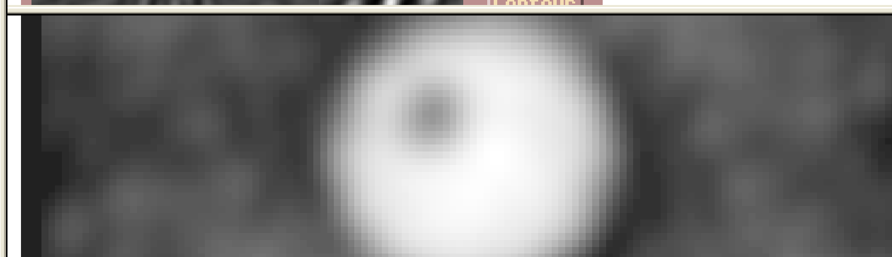
Startup PEARL by typing

```
set_complexvis
pearl,'FKV0497'
```

The first command creates complex visibilities from the observed squared visibility amplitudes and closure phases.



This is the PEARL widget. It is a clickable map for explanations of the maps and buttons.



Interferometry in the radio: VLBI

- 1967: first VLBI observations in US and Canada
- 1974: first use of closure phases
- 1977: first maps
- 1981: phase self-calibration and CLEAN
- 1981: 5-9 telescope arrays (15 years later)
- 1988: 16+ telescopes

Optical LBI in the footsteps of VLBI

- 1974: technique invented by A. Labeyrie
- Single baselines: I2T, GI2T, Mark III, SUSI
- 1996: 3-telescope arrays COAST, NPOI, IOTA
- 2003: NPOI (6T), NPOI (4T)
- 2004: VLTI/MIDI (2T), ISI (3T) 10μ operations
- 2006: VLTI/AMBER (3T), CHARA/MIRC (4T)

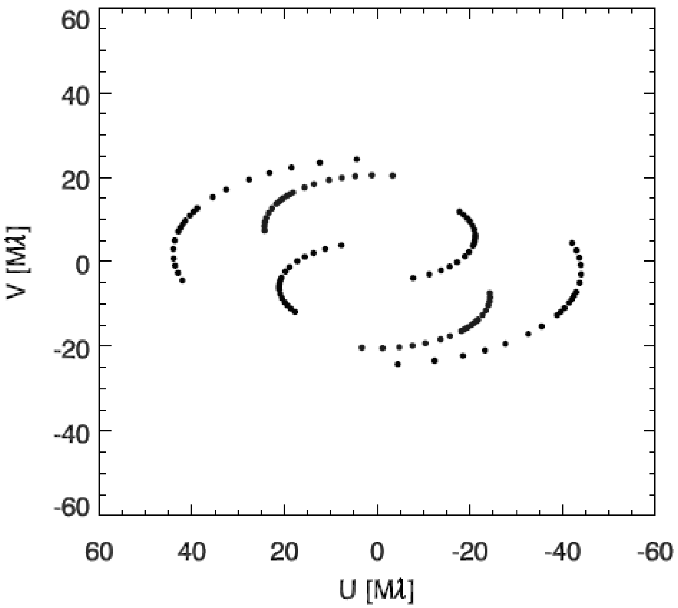
OLBI at the crossroads

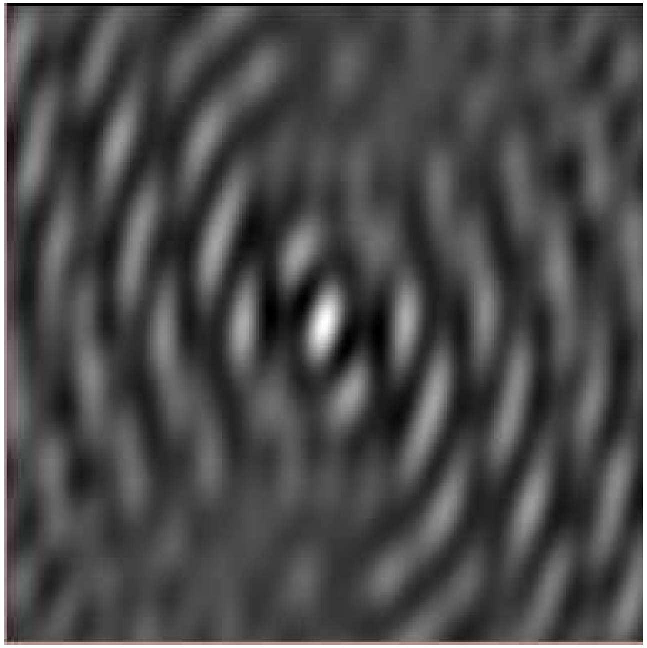
- 30 years after invention, still no more than 4 telescopes combined simultaneously
- Outlook: MRO designed to combine 10, but still only 1/3 of the baselines VLBI can deliver
- Conclusion: we have hit a “wall” and need to re-invent OLBI for imaging

Broadband aperture synthesis

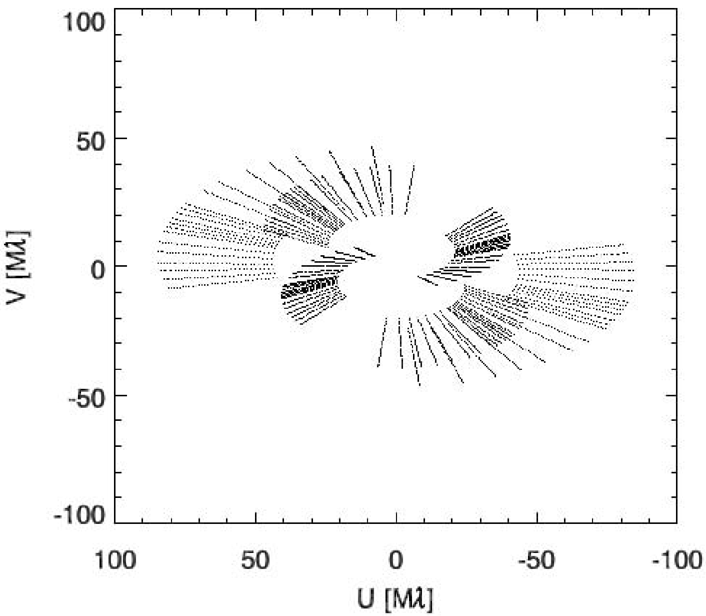
- Modern interferometers provide fractional bandwidths between 20% and 30% (or more)
- Provides better (u,v)-coverage
- So far, only grey images reconstructed
- Need to develop algorithms to constrain image cubes, i.e. the dependence of source structure on wavelength

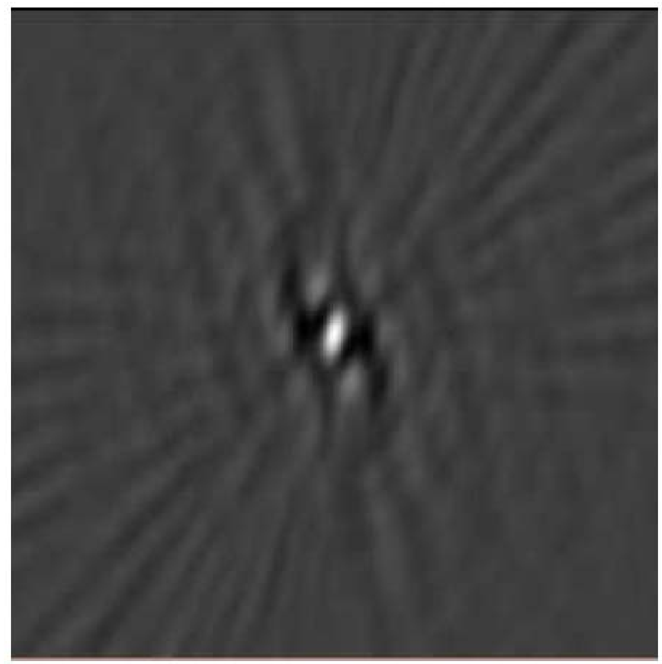
Single channel observation





16-channel observation





CLEAN, by Högbom

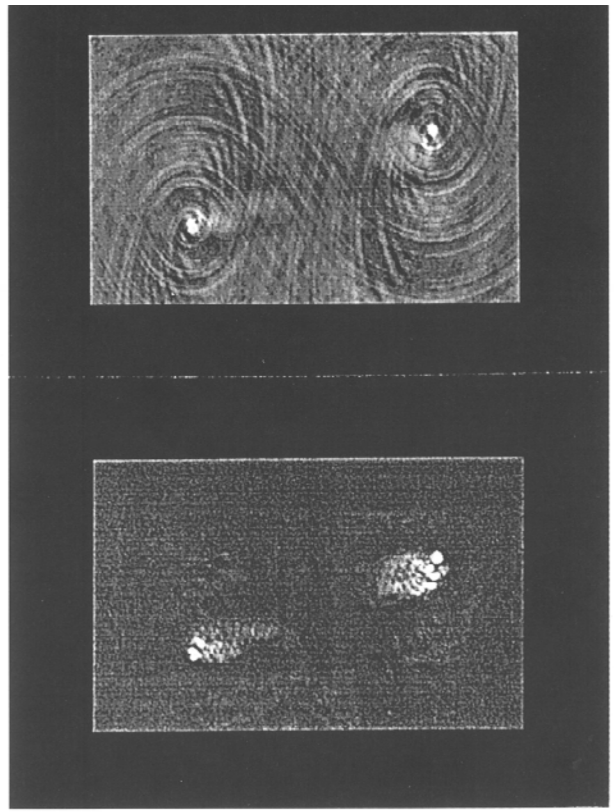


Fig. 6.8. The CLEAN process: maps of Cyg A made by MERLIN at 408 MHz (resol
arcsec), before (a) and after (b) the process (courtesy T. B. Muxlow).

Broadband CLEAN

CLEAN iteratively deconvolves a "dirty" map (DM), i.e. the direct Fourier transform of the complex visibility data, from the synthesized beam (DB) by subtracting (a fraction of) the latter centered on the location of the brightest pixel. The subtracted flux is entered as a Dirac function in the clean map (CM). I now assign each CLEAN component an effective (blackbody) temperature based on the location in the map, allowing us to combine all data by being able to compute the entire image cube. Thus I write DM as a sum over all spectral channels j,

$$DM = \sum_j DM_j.$$

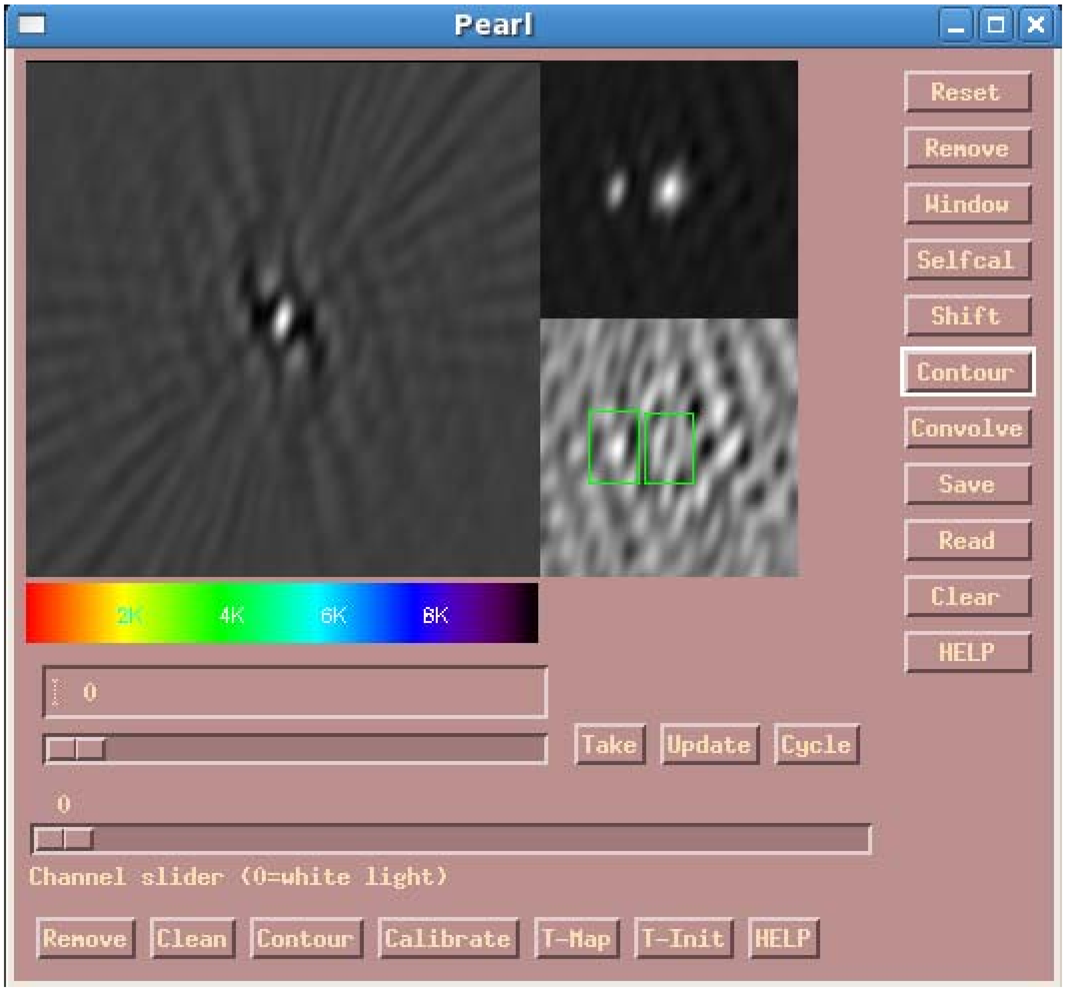
Given a (white light) flux f^i of a CLEAN component at iteration i, and its effective temperature T^i, the flux for channel j, f^i_j, is computed using the blackbody radiation law and normalized by the total observed flux in that channel, F_j. The reason for the normalization is the fact that maps are computed from normalized visibilities, not correlated fluxes. The dirty beam of channel j, DB_j, is then multiplied by f^i_j/F_j and subtracted from RM_j. RM is the residual map, which is initially identical to DM. This procedure ensures that the correct fraction of flux is subtracted as a function of wavelength. Thus I compute the residual map at iteration $i+1$ as follows:

$$RM^{i+1} = RM^i - \sum_j \frac{f^i_j}{F_j} DB_j.$$

Composite spectrum binary

- Components of 10000 K and 5000 K
- 3-telescope simulation
- 550 nm to 800 nm wavelength coverage
- Noiseless data, with phase self-calibration
- Algorithm needs SED

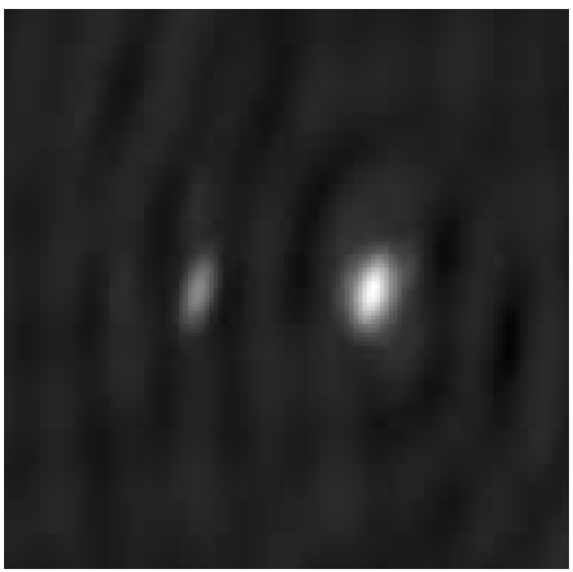
White light combined image



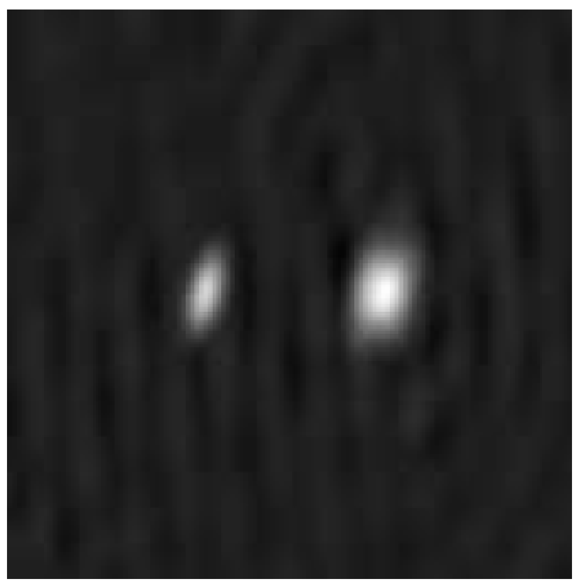
Constrained channel CLEAN

- Use phase solution from combined map
- Clean flux only where combined map has flux

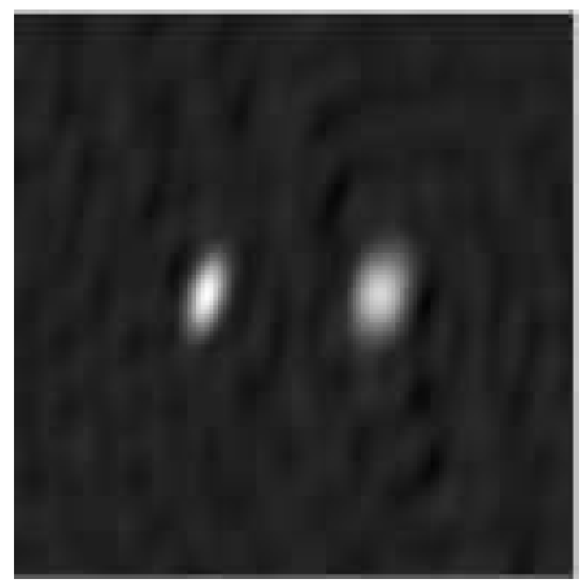
800 nm



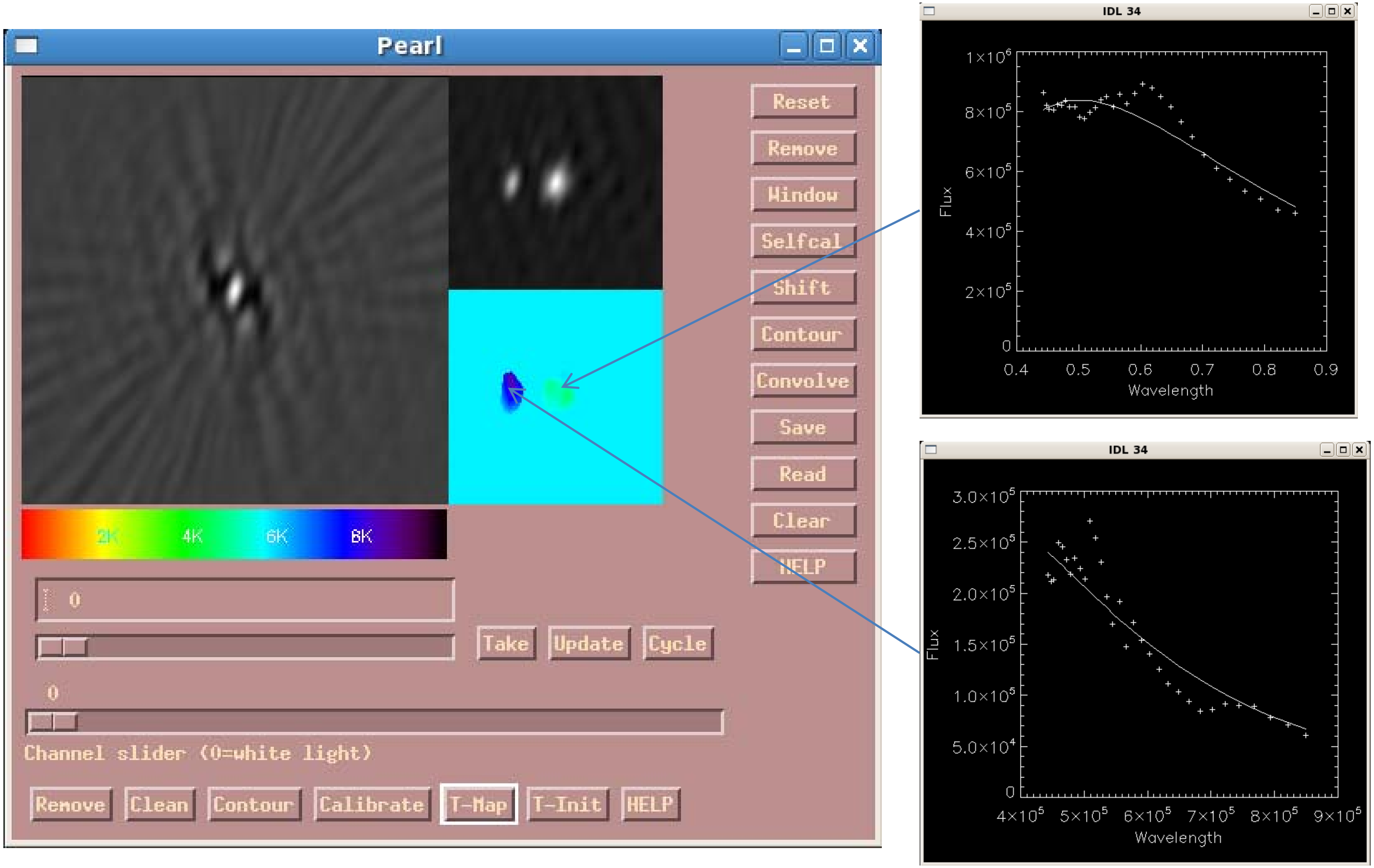
700 nm



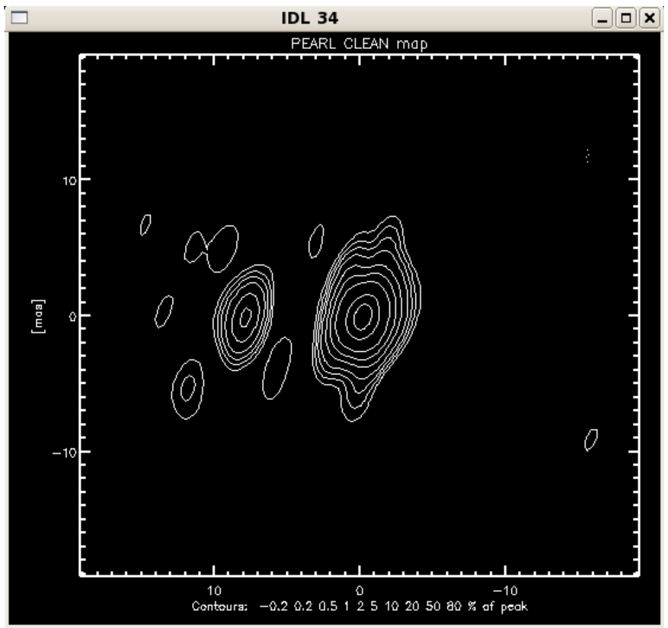
550 nm



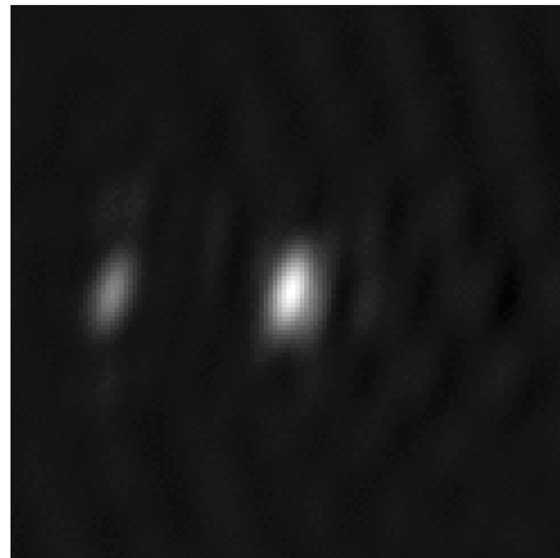
Temperature calibration



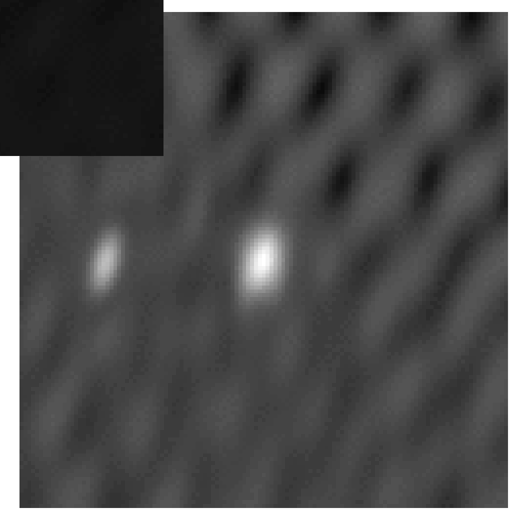
Results for the binary



Combined CLEAN map



Single channel
from data cube

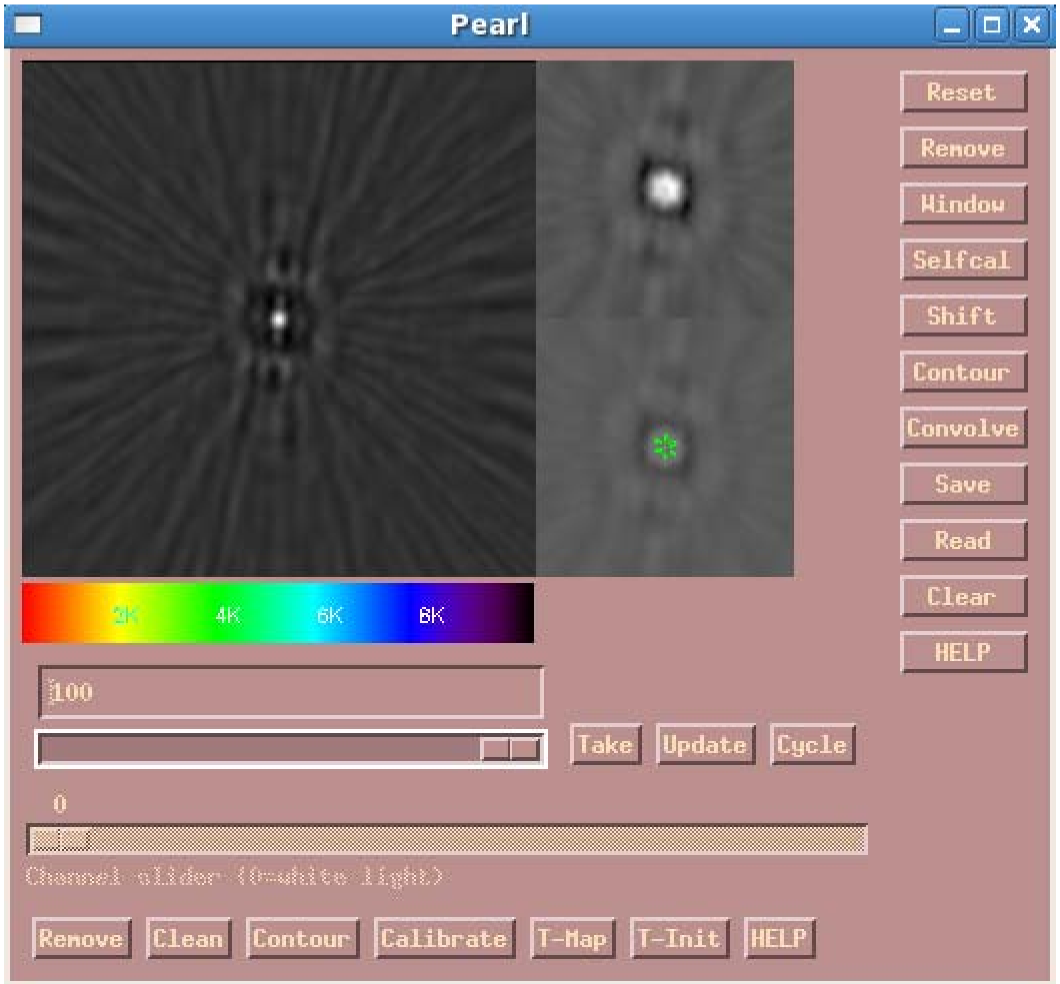


Single-channel CLEAN

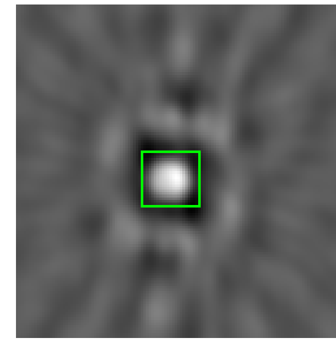
Application to stellar surface

- Simulated data of Altair
- Very good (*u,v*)-coverage
- Model of Peterson et al. 2006
- 6-station NPOI configuration
- 550 nm to 800 nm wavelength coverage

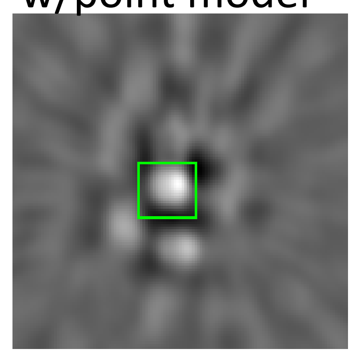
Phase self-calibration



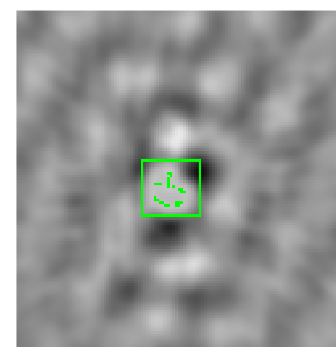
Perfect phases



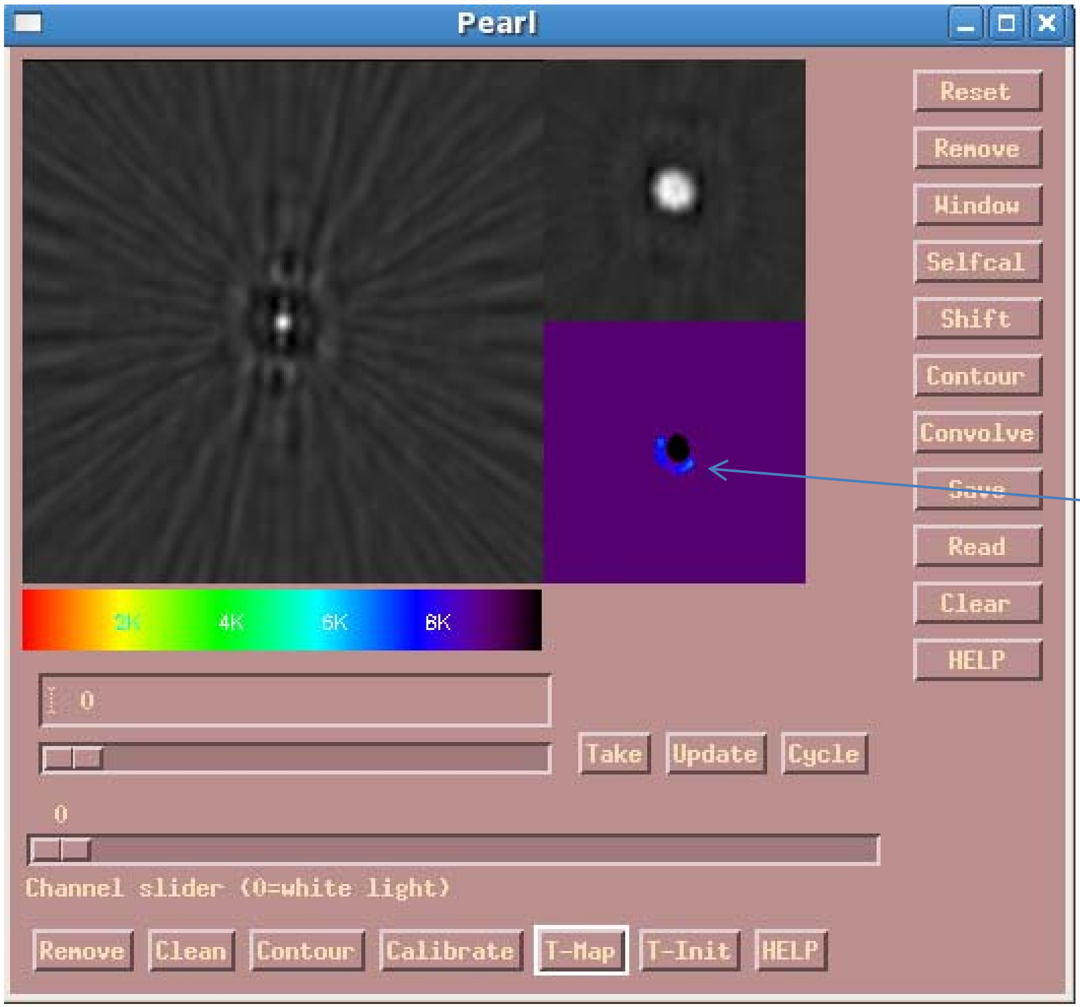
Phase self-calibration w/point model



Need to use windows



Effective temperature map



Hot pole to the upper right, cool equator towards lower left.

Combined and channel maps