Imaging pulsar echoes at low frequencies

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Imaging pulsar echoes at low frequencies

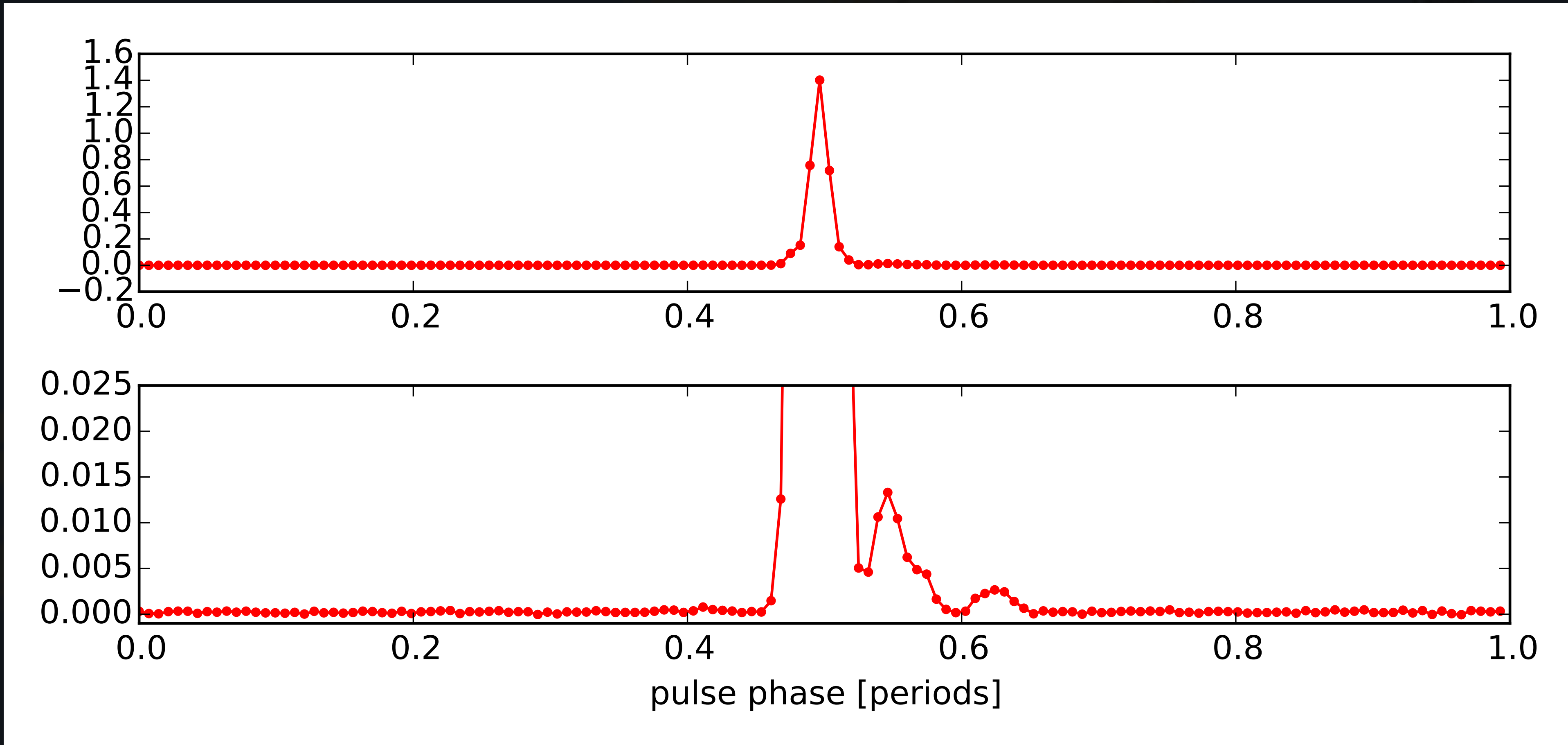
- LOFAR
- The ghost in B1508+55
- Offline VLBI with LOFAR
- First attempt 2016
- Relative motion 2016–2018
- New deconvolution method

LOFAR station (Tautenburg)

Low-band antennas (10-80 MHz, Ireland)

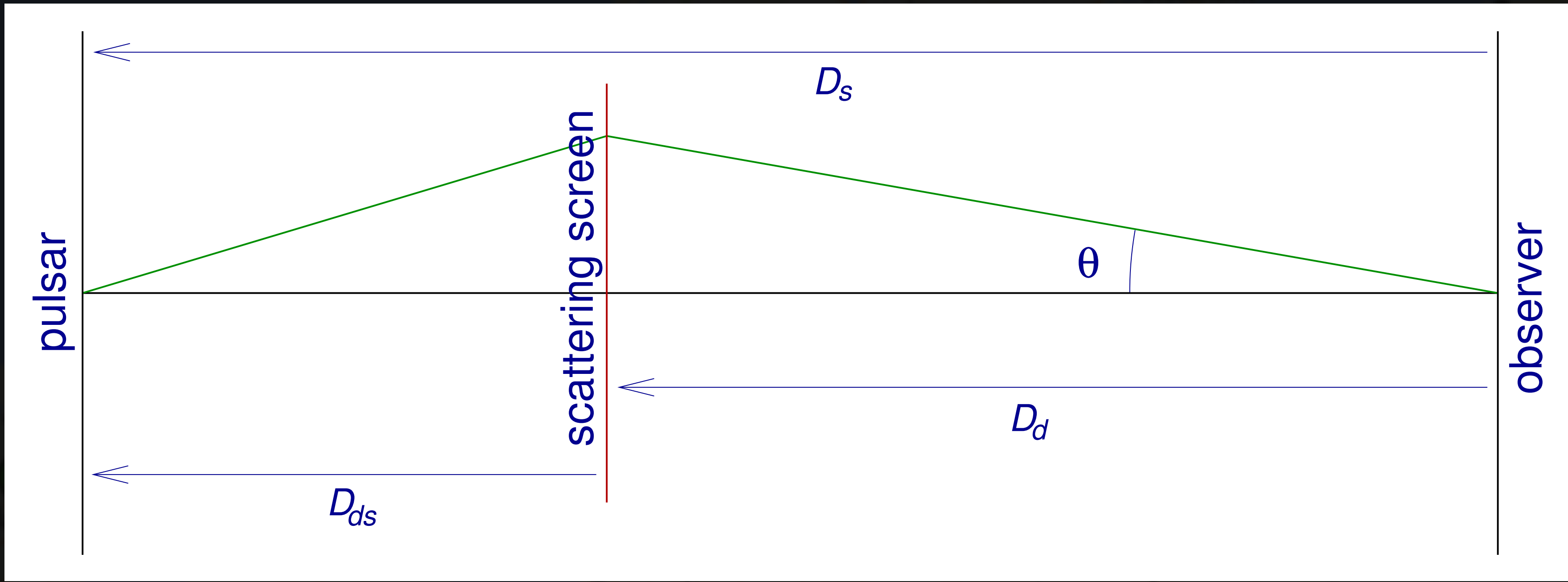
High-band antennas (110-250 MHz)

B1508+55: a pulsar and its ghost?



- 'ghost' component found by Stefan Osłowski with LOFAR
- moving relative to main component
- interpretation: scattering 'echo' *[Osłowski & Macquart in prep.]*

Interstellar scattering: geometric delay



$$c\tau = \frac{1}{2}\theta^2 D \qquad D = \frac{D_\mathrm{s}\, D_\mathrm{d}}{D_\mathrm{ds}}$$

Does the echo have a positional offset?

Can we localise the echo of B1508+55 ?

- $\tau \approx 50\,\mathrm{msec}$ (period $\approx 0.74\,\mathrm{sec}$)
- $D_\mathrm{s} = 2.13\,\mathrm{kpc} = 2.19 \cdot 10^{11}\,\mathrm{sec} \cdot c$
- assumption: $D_\mathrm{d} \approx D_\mathrm{ds} \rightsquigarrow D = D_\mathrm{s}$
- $\theta = \sqrt{\dfrac{2c\tau}{D}} = 0\overset{''}{.}14$ (more if closer to us)
- at high SNR this can be measured with LOFAR-VLBI !
- can test echo hypothesis and maybe determine D
- later: use two paths as interstellar interferometer

VLBI: German LOFAR (GLOW) baselines

length, fringe-spacing at 150 MHz

	[km]	[arcsec]
DE601–DE602	390	1.06
DE601–DE603	344	1.20
DE601–DE604	476	0.87
DE601–DE605	53	7.80
DE601–DE609	412	1.00
DE602–DE603	277	1.49
DE602–DE604	455	0.91
DE602–DE605	440	0.94
DE602–DE609	585	0.70
DE603–DE604	186	2.22
DE603–DE605	372	1.11
DE603–DE609	325	1.27
DE604–DE605	487	0.85
DE604–DE609	248	1.66
DE605–DE609	394	1.05

Offline VLBI with LOFAR

- LOFAR correlator limited (e.g. time resolution)

- need more flexibility
  - ⋆ arbitrary resolution
  - ⋆ pulsar gating
  - ⋆ re-correlations

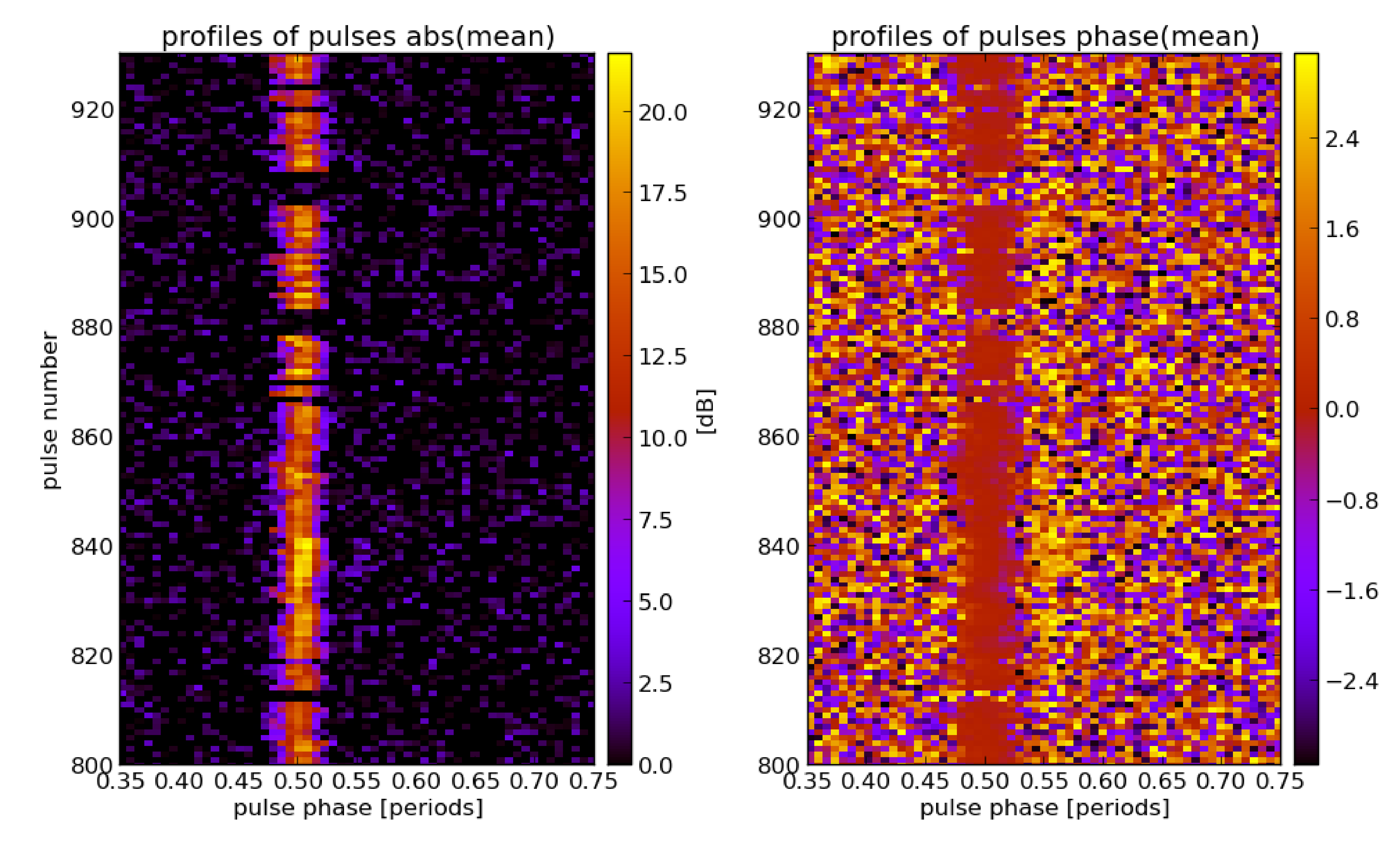
$\rightsquigarrow$ record locally, correlate centrally! (non-e VLBI)

- ⋆ GLOW recording in Bonn, Jülich
- ⋆ other stations recording locally (3 Gbps / station)
- ⋆ core centrally in Groningen
- ⋆ demanding logistics, huge effort

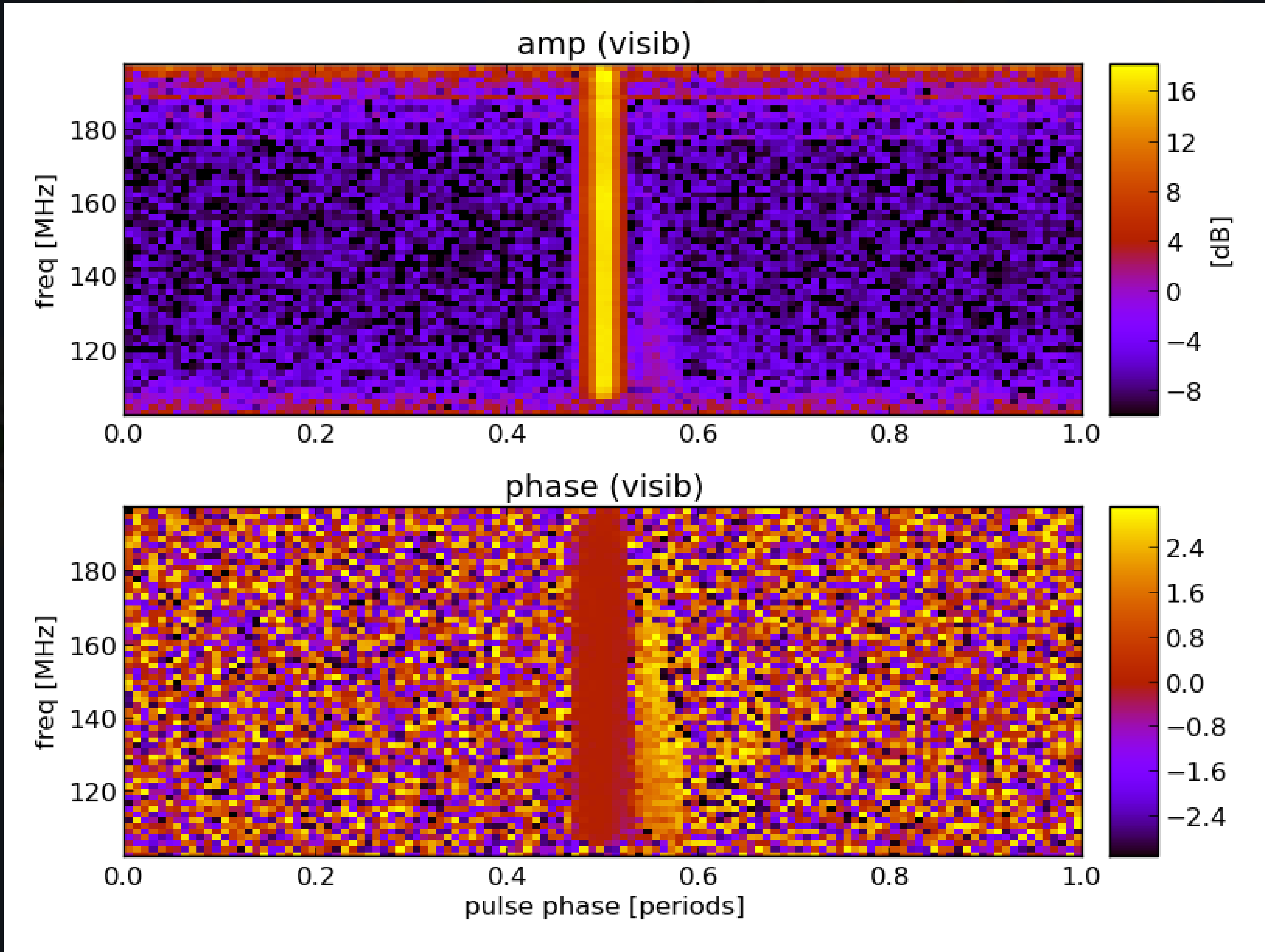
Correlation and calibration

- own software correlator
  - ⋆ standard FX architecture
  - ⋆ flexibility, not efficiency!
- calibration (own software)
  - ⋆ pulsar gating, main pulse as reference
  - ⋆ full station-based fringe-fitting for phases with dispersive/non-dispersive delays, rates, DFR
  - ⋆ bandpass calibration
- imaging and non-imaging analysis

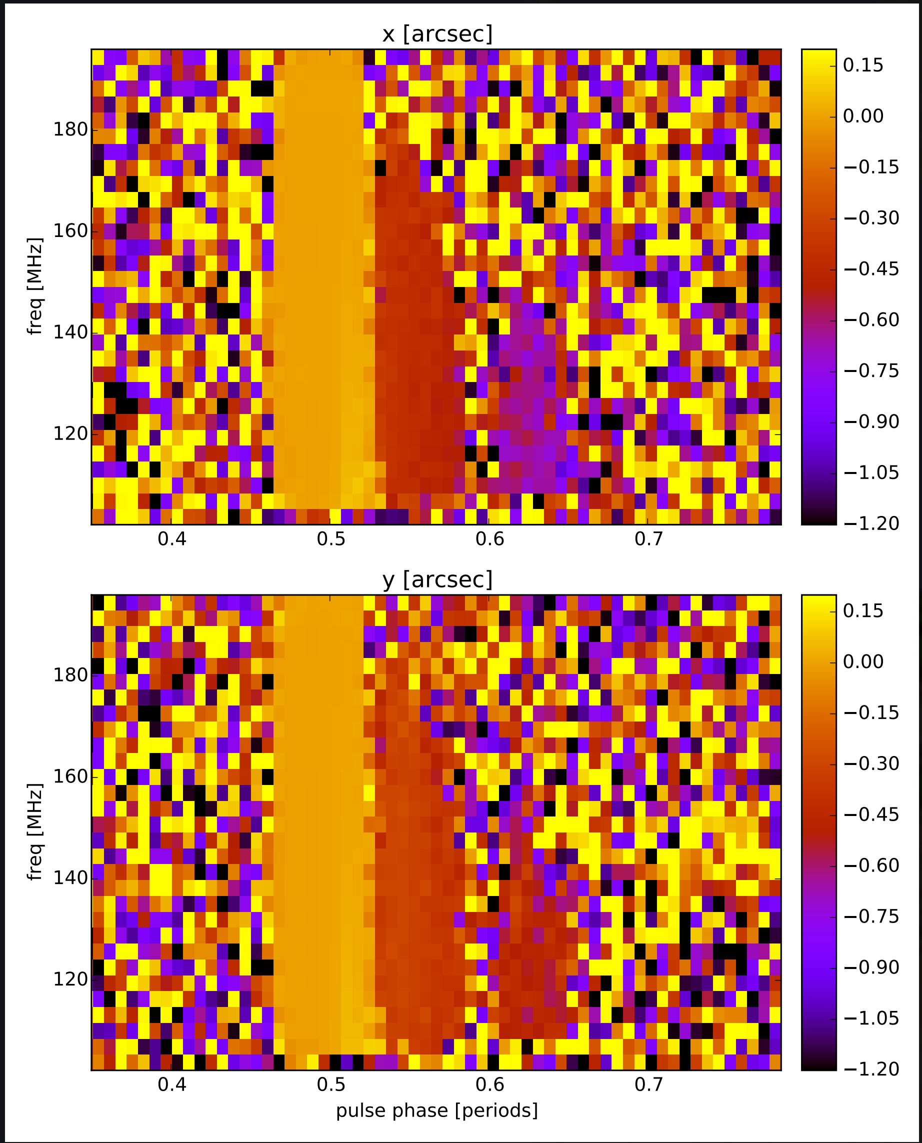
GLOW Oct 2016: Pulses (DE603–DE605)

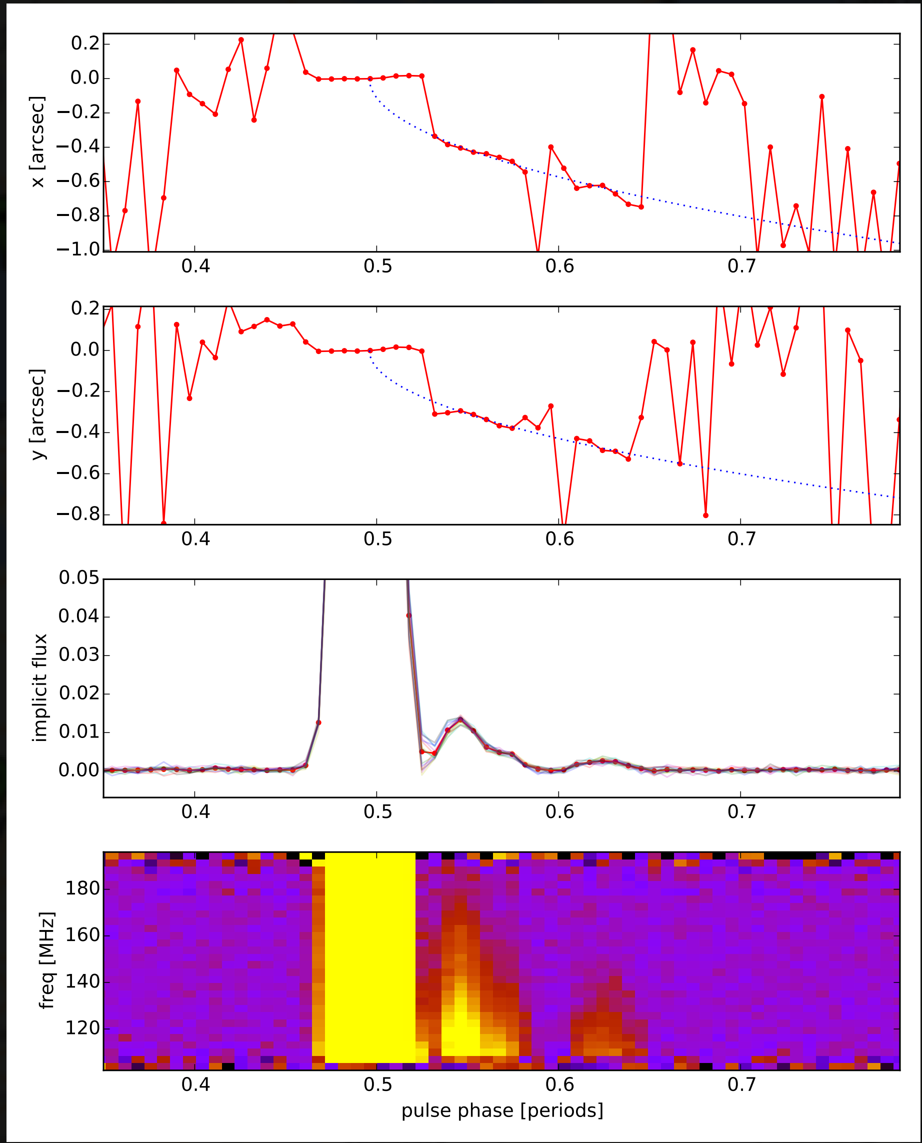


Folded amplitudes and phases (DE603–DE605)



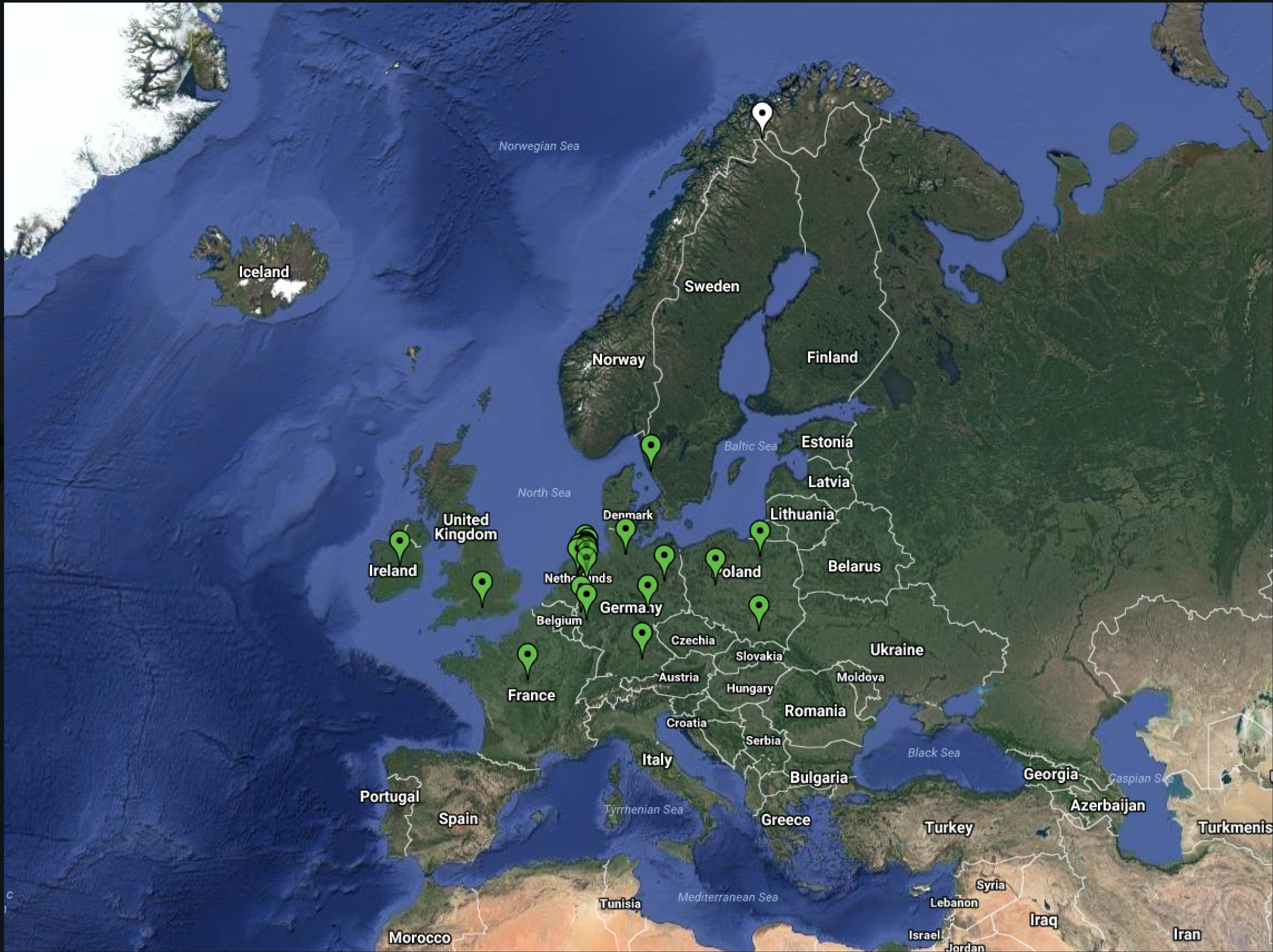
Echo position(s)





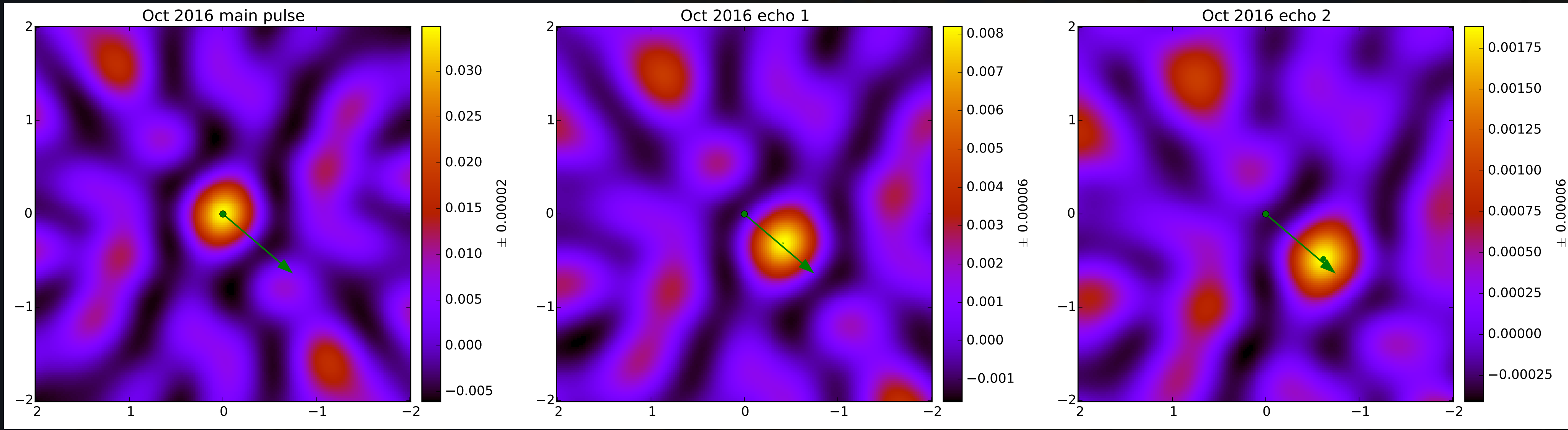
preliminary distance: 124 pc, very close to us!

The full array: LOFAR + KAIRA

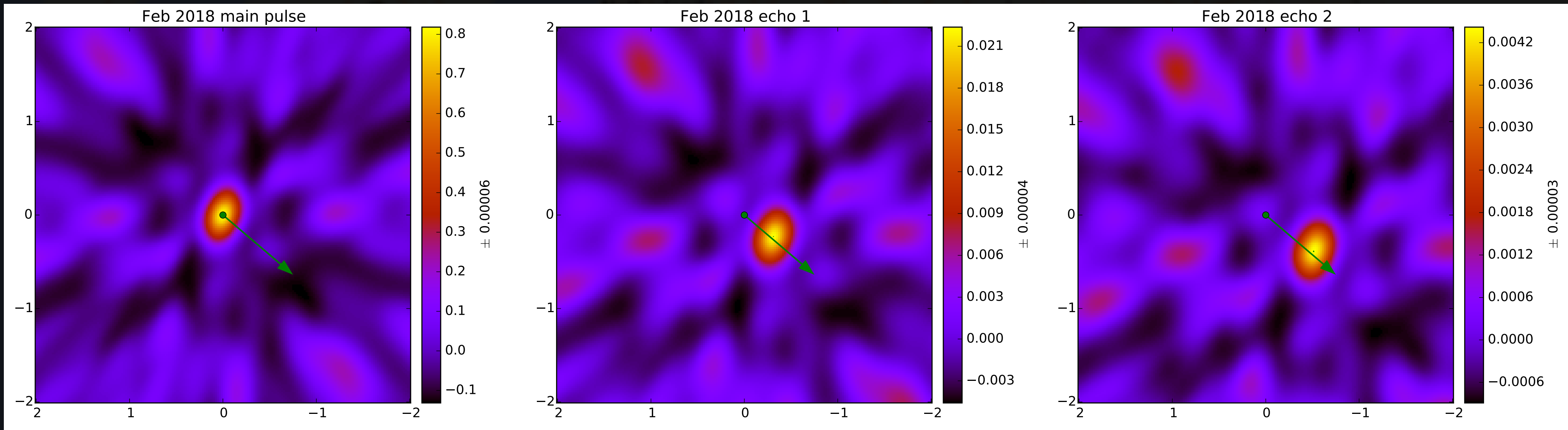


Main pulse and echoes (dirty maps)

October 2016 GLOW



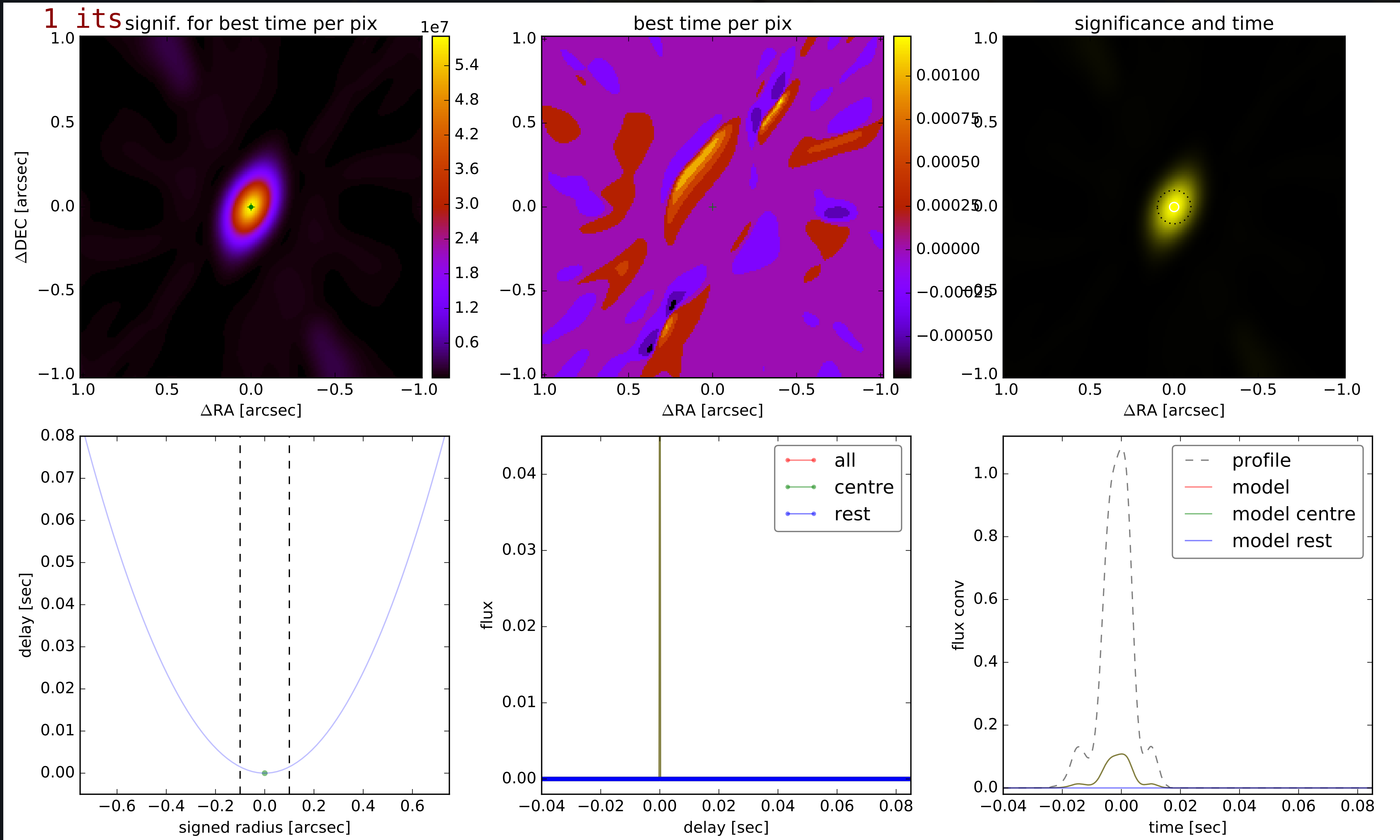
February 2018 international



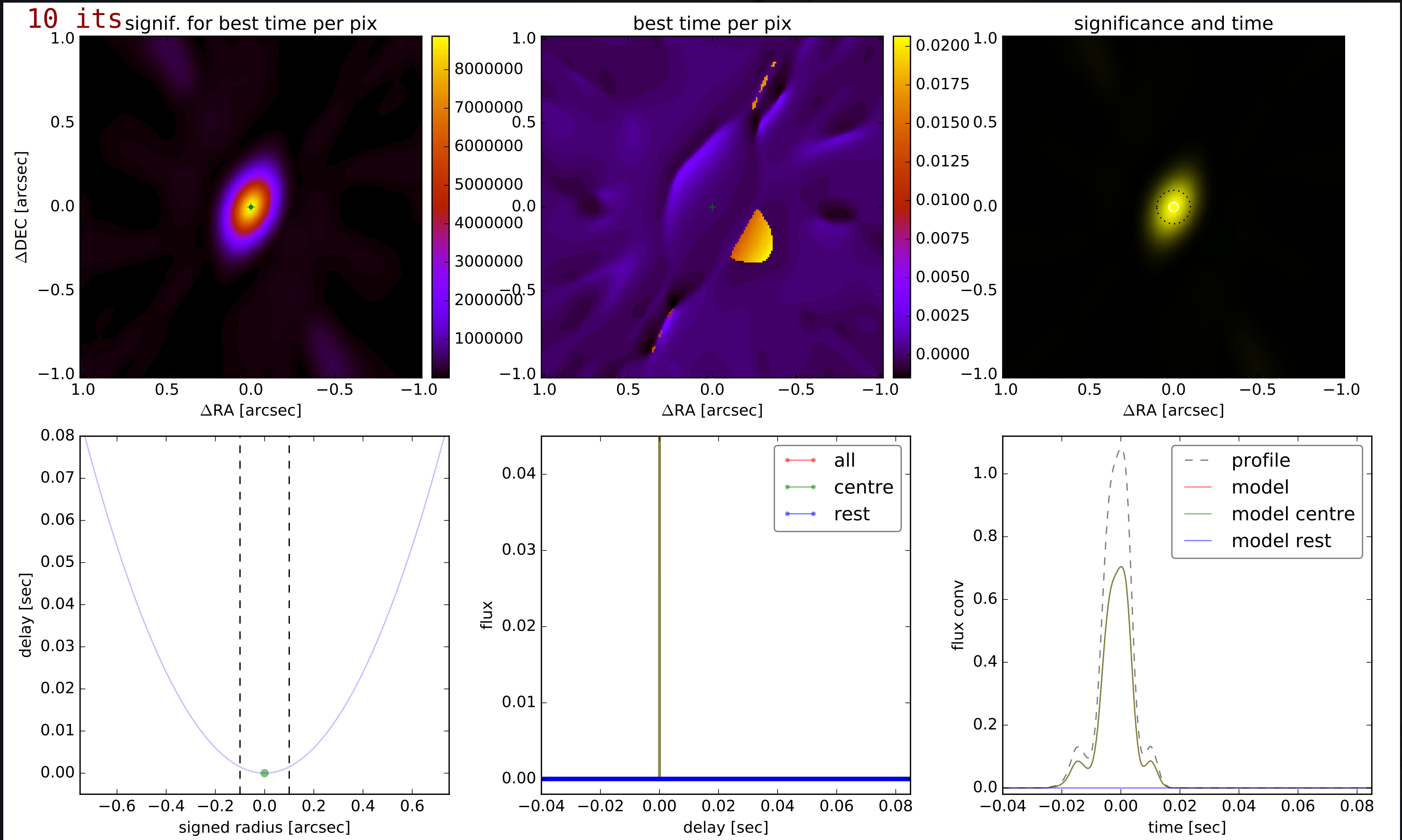
Delayed-profile-aware CLEAN

- gating mixes intrinsic tail and echo
- deconvolve dirty beam *and* intrinsic profile
- standard CLEAN components
  - ⋆ explicit: position
  - ⋆ implicit: flux
- generalised CLEAN components
  - ⋆ explicit: position (offset), delay
  - ⋆ implicit: flux, spectrum

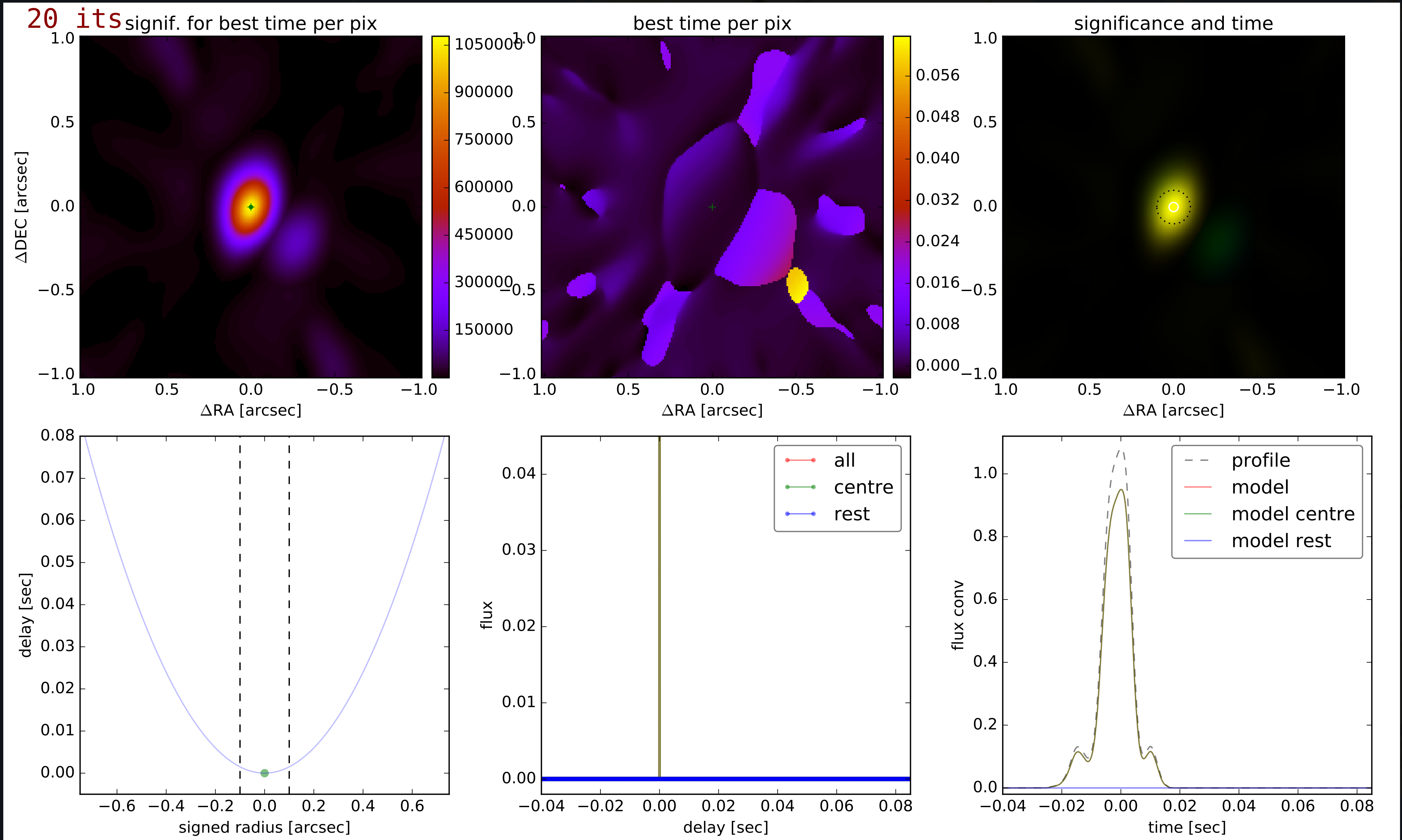
Delayed-profile-aware CLEAN (1 iteration)



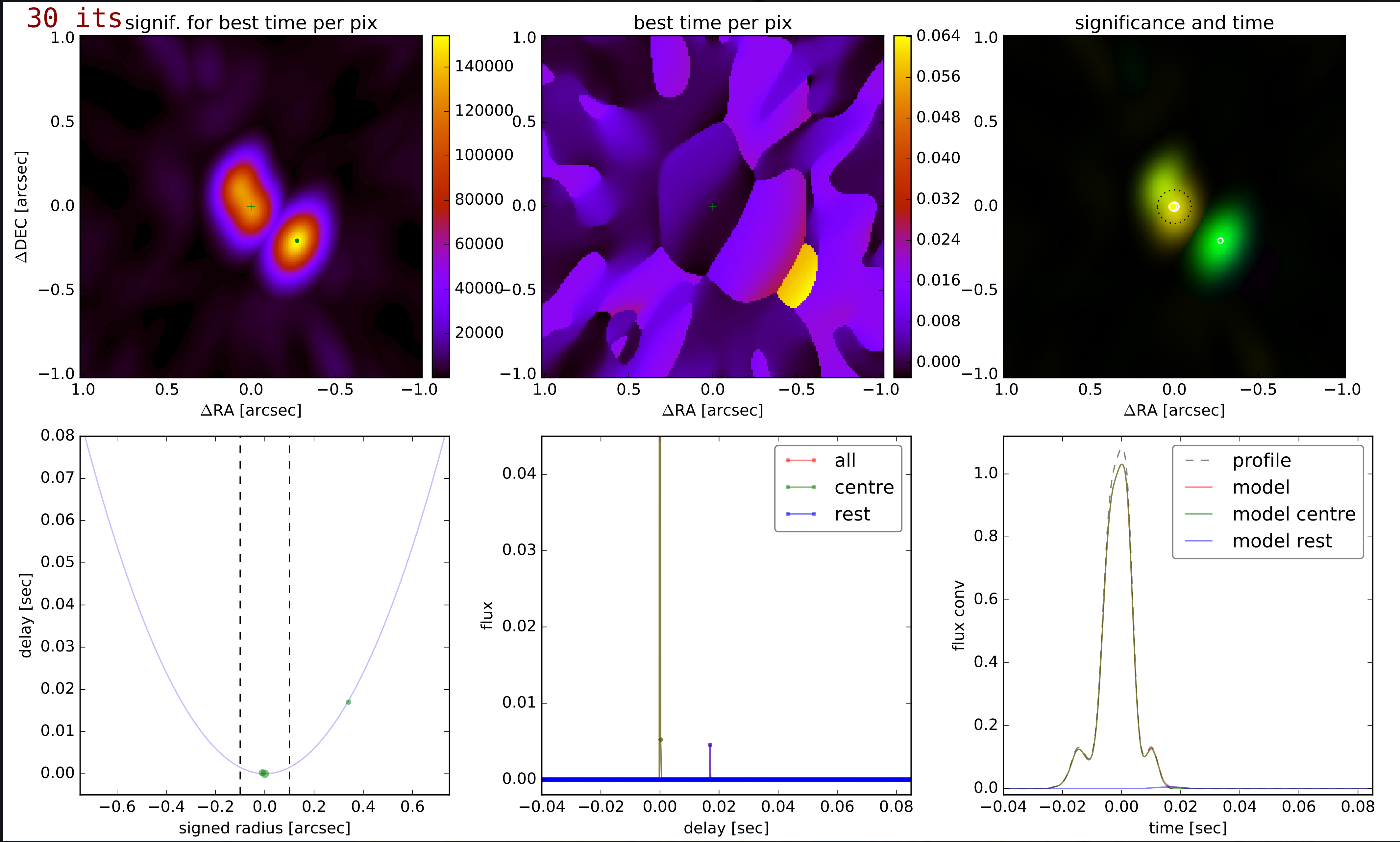
Delayed-profile-aware CLEAN (10 iterations)



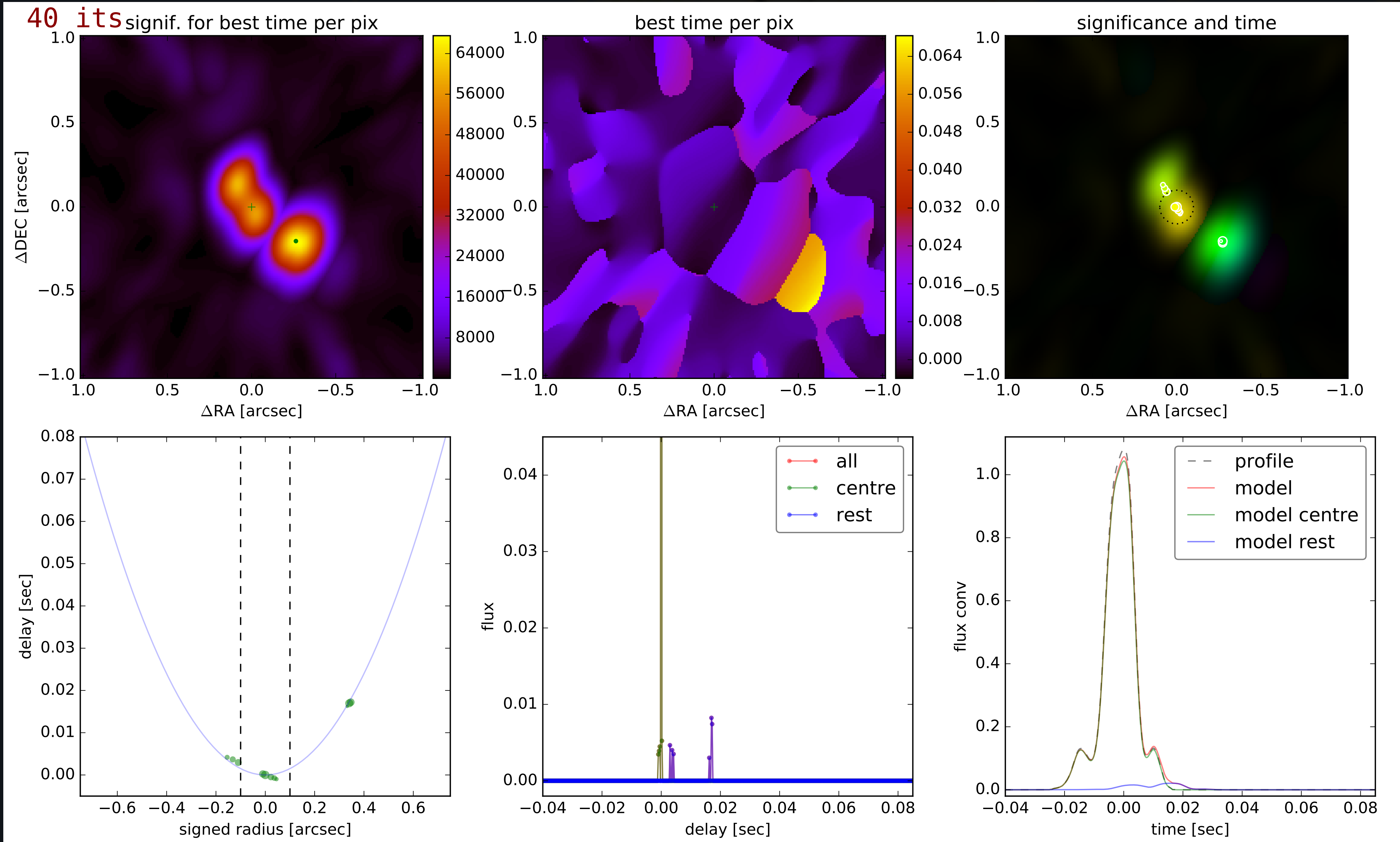
Delayed-profile-aware CLEAN (20 iterations)



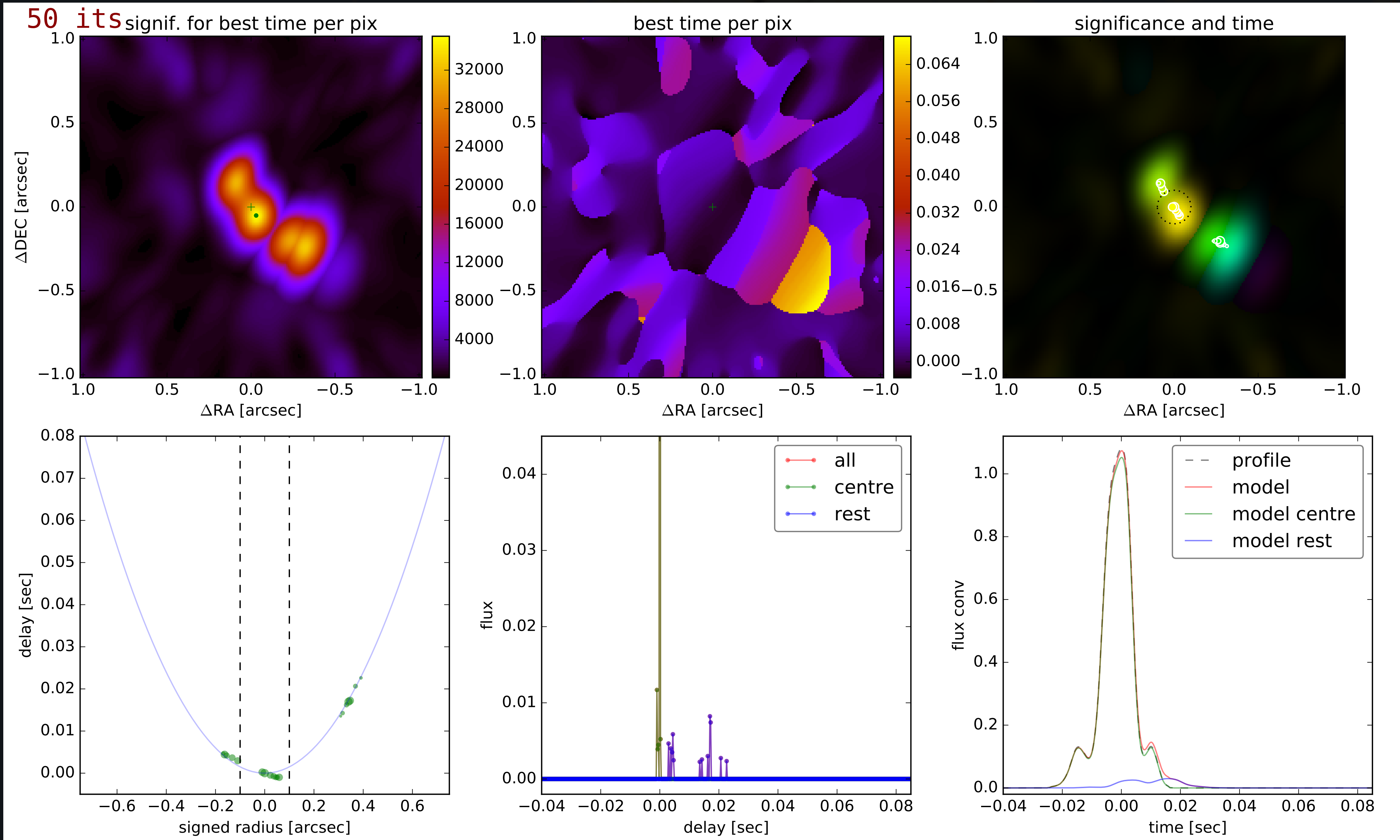
Delayed-profile-aware CLEAN (30 iterations)



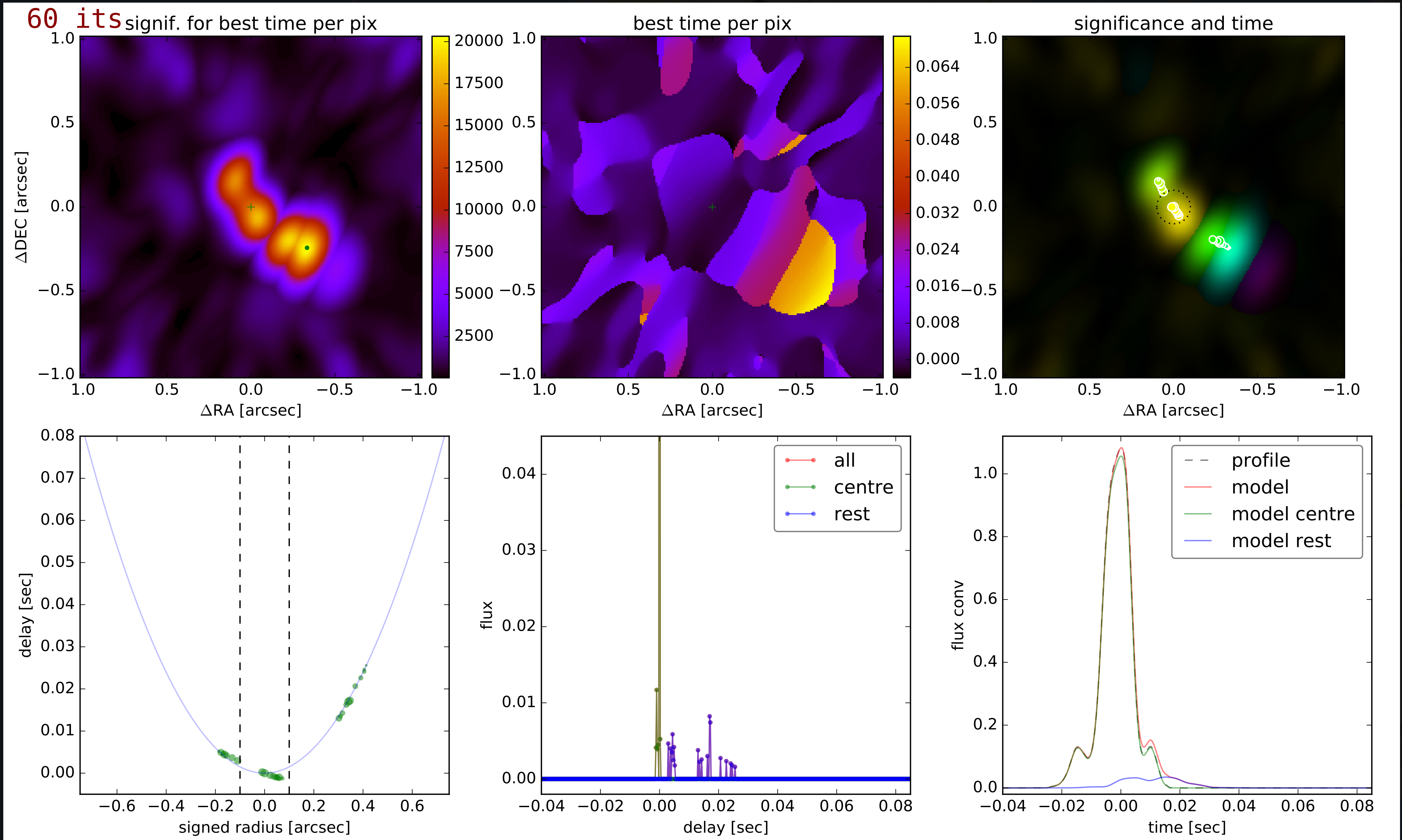
Delayed-profile-aware CLEAN (40 iterations)



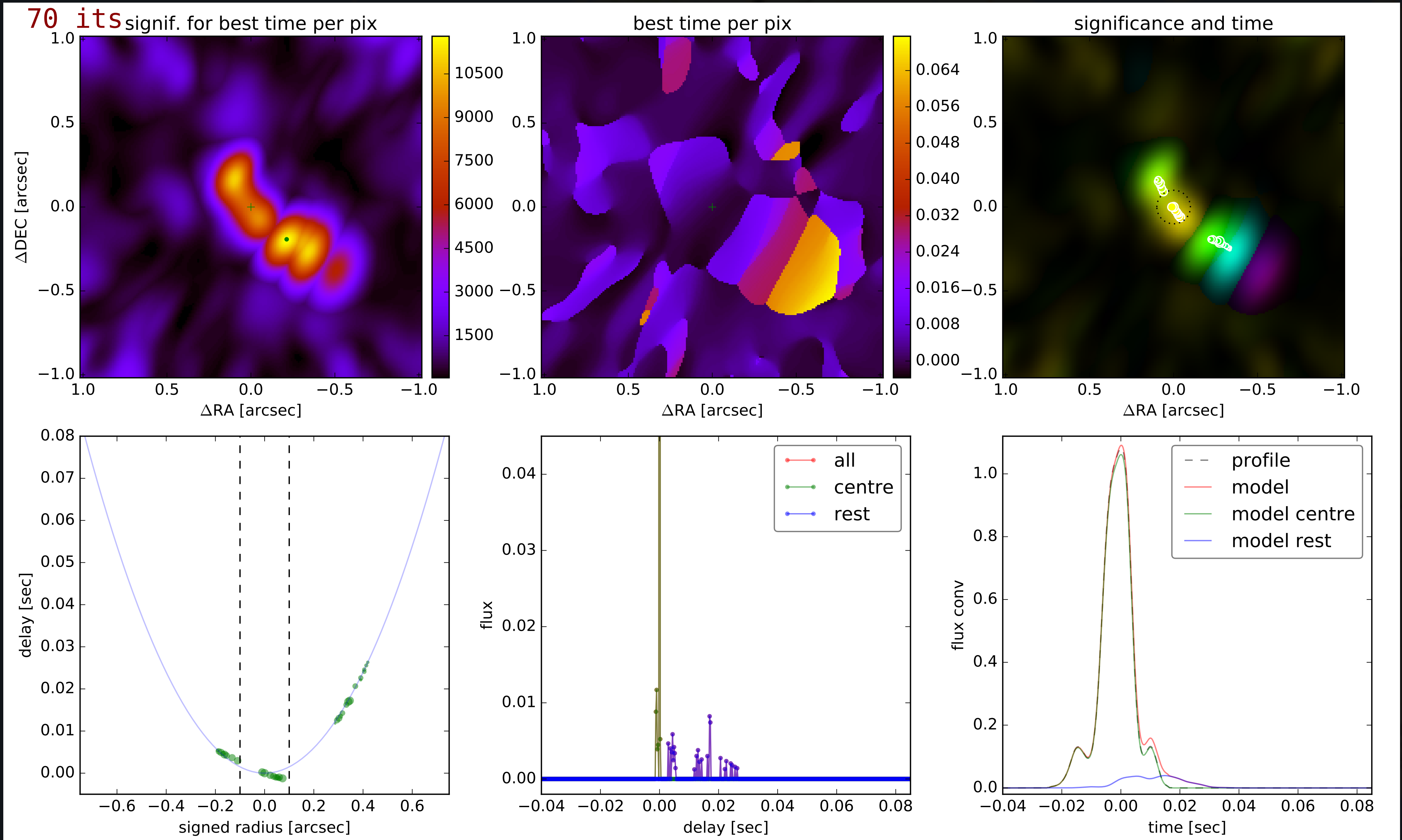
Delayed-profile-aware CLEAN (50 iterations)



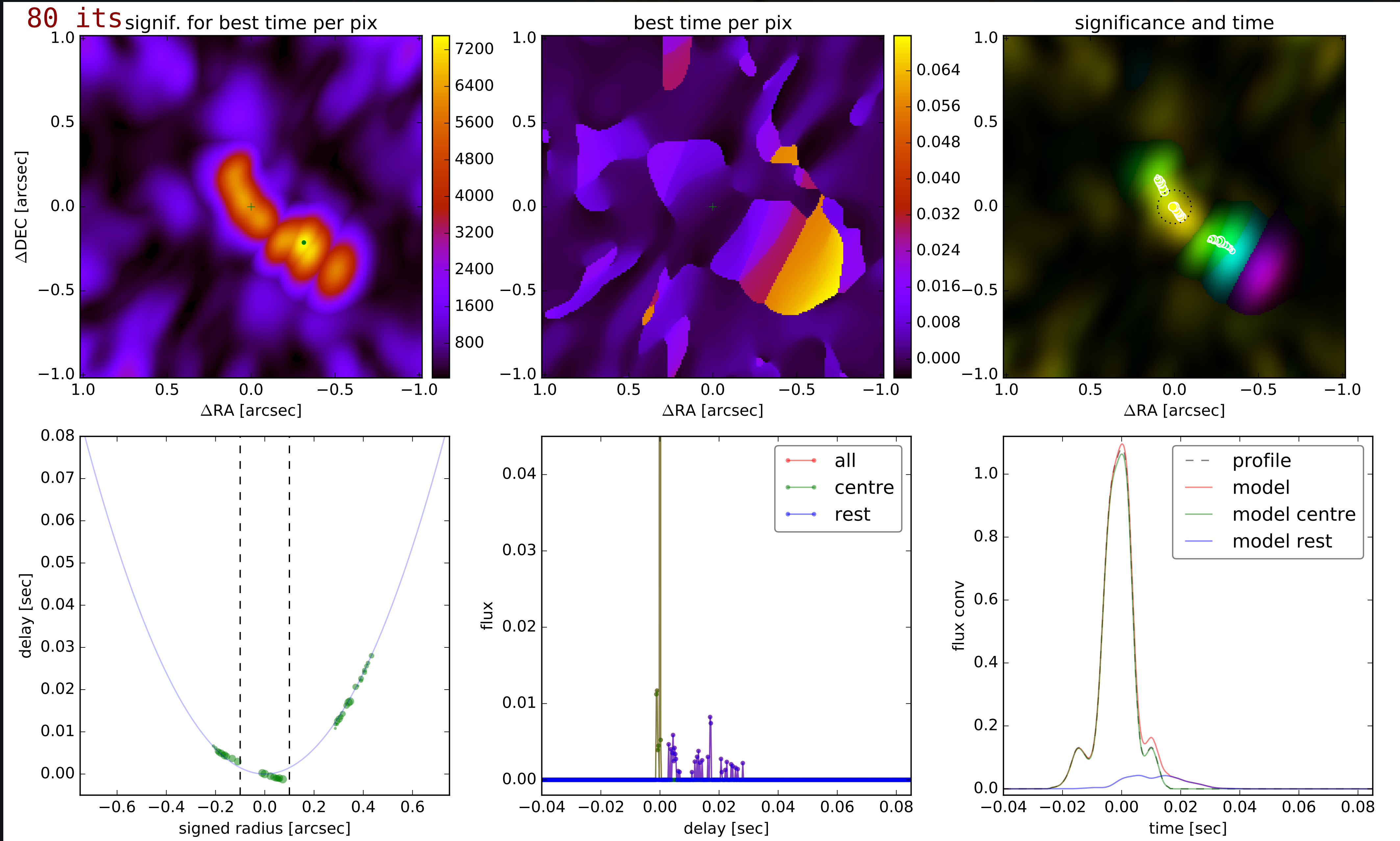
Delayed-profile-aware CLEAN (60 iterations)



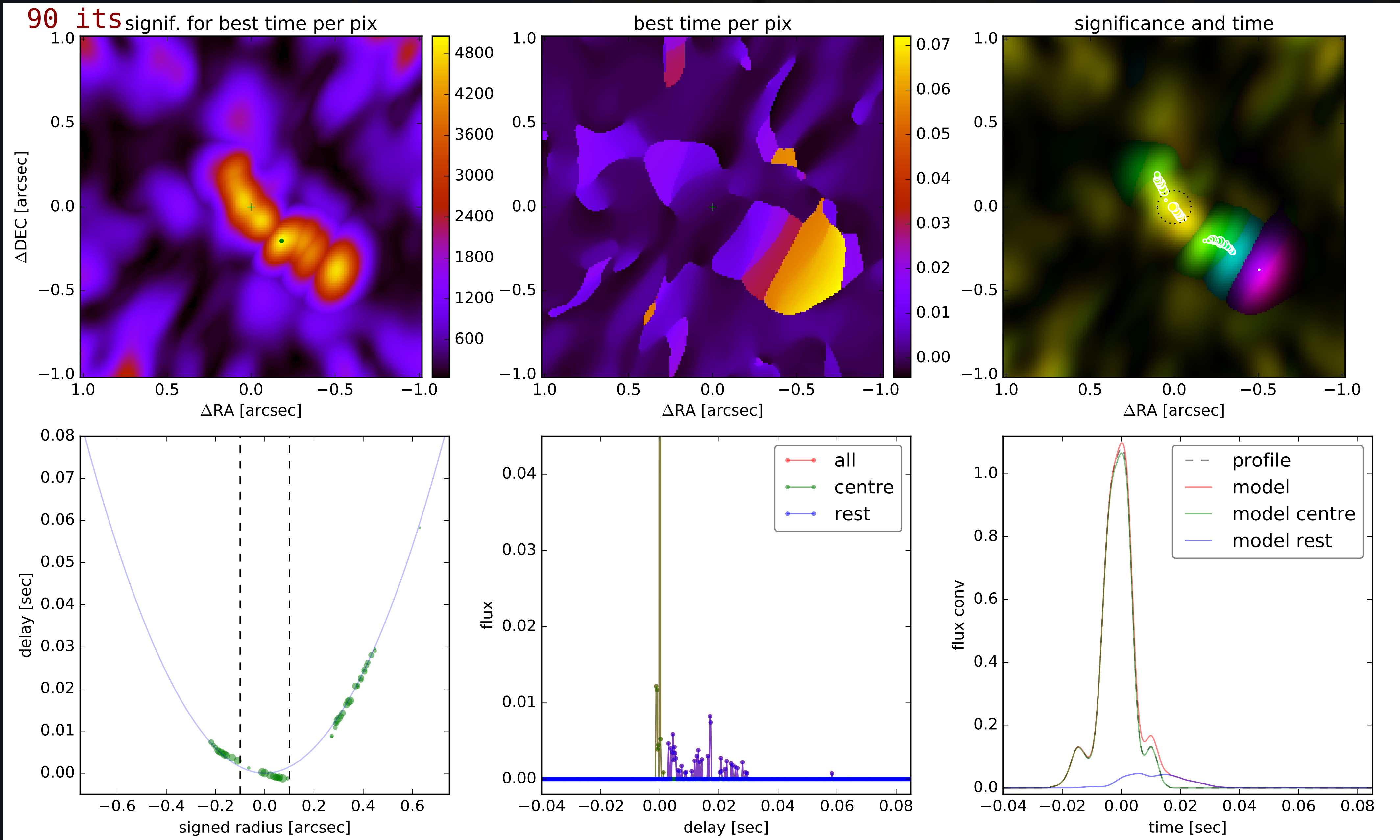
Delayed-profile-aware CLEAN (70 iterations)



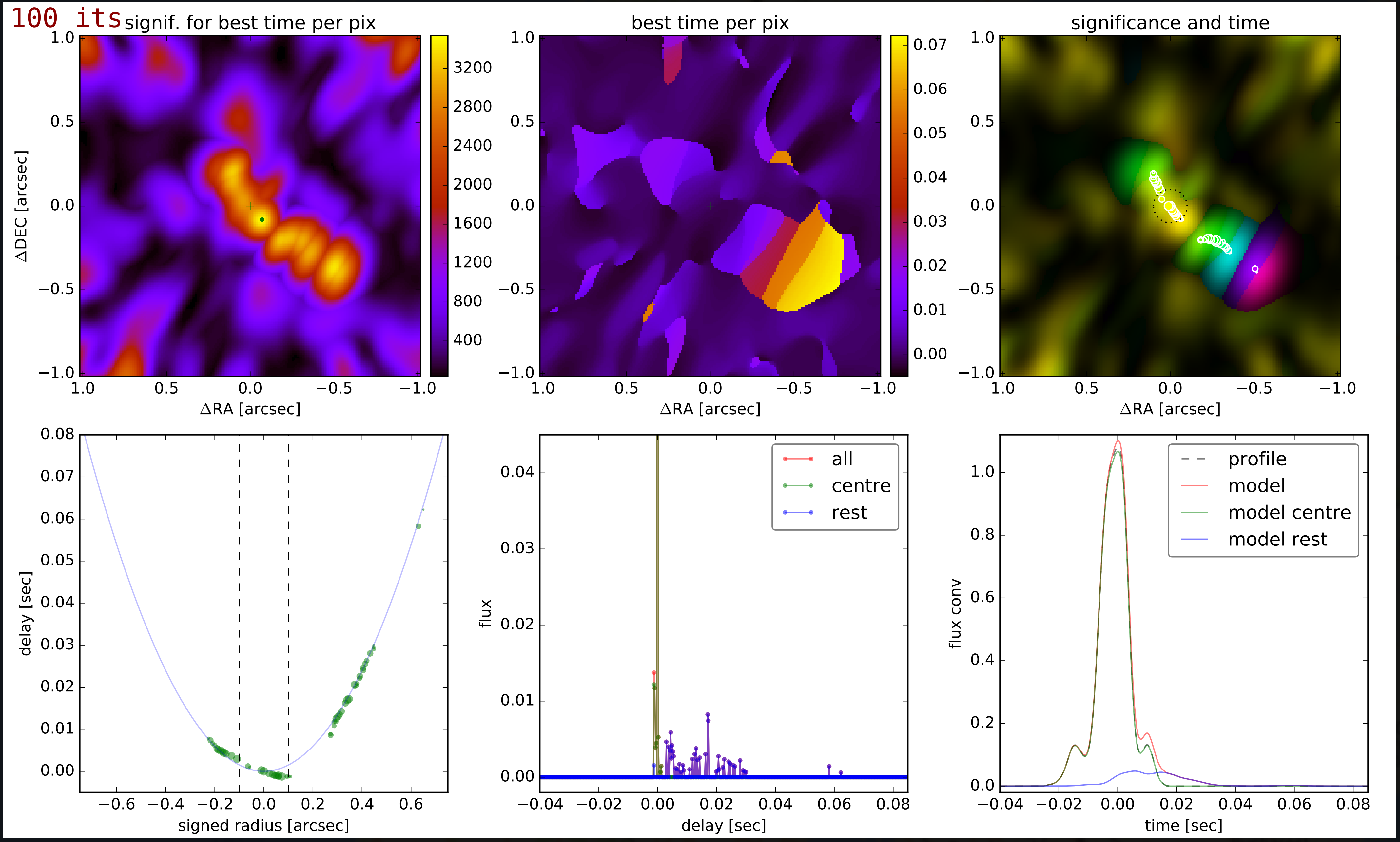
Delayed-profile-aware CLEAN (80 iterations)



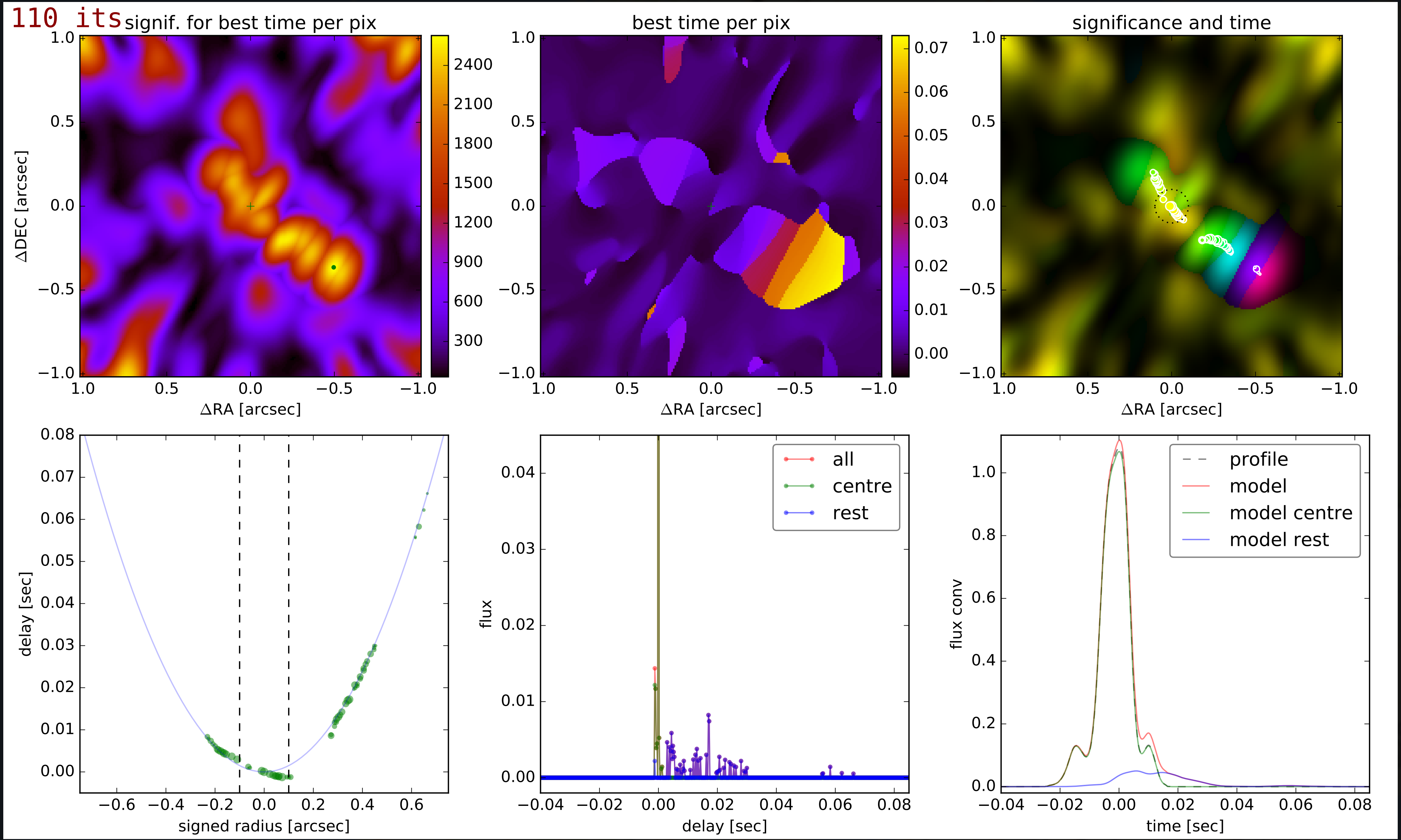
Delayed-profile-aware CLEAN (90 iterations)



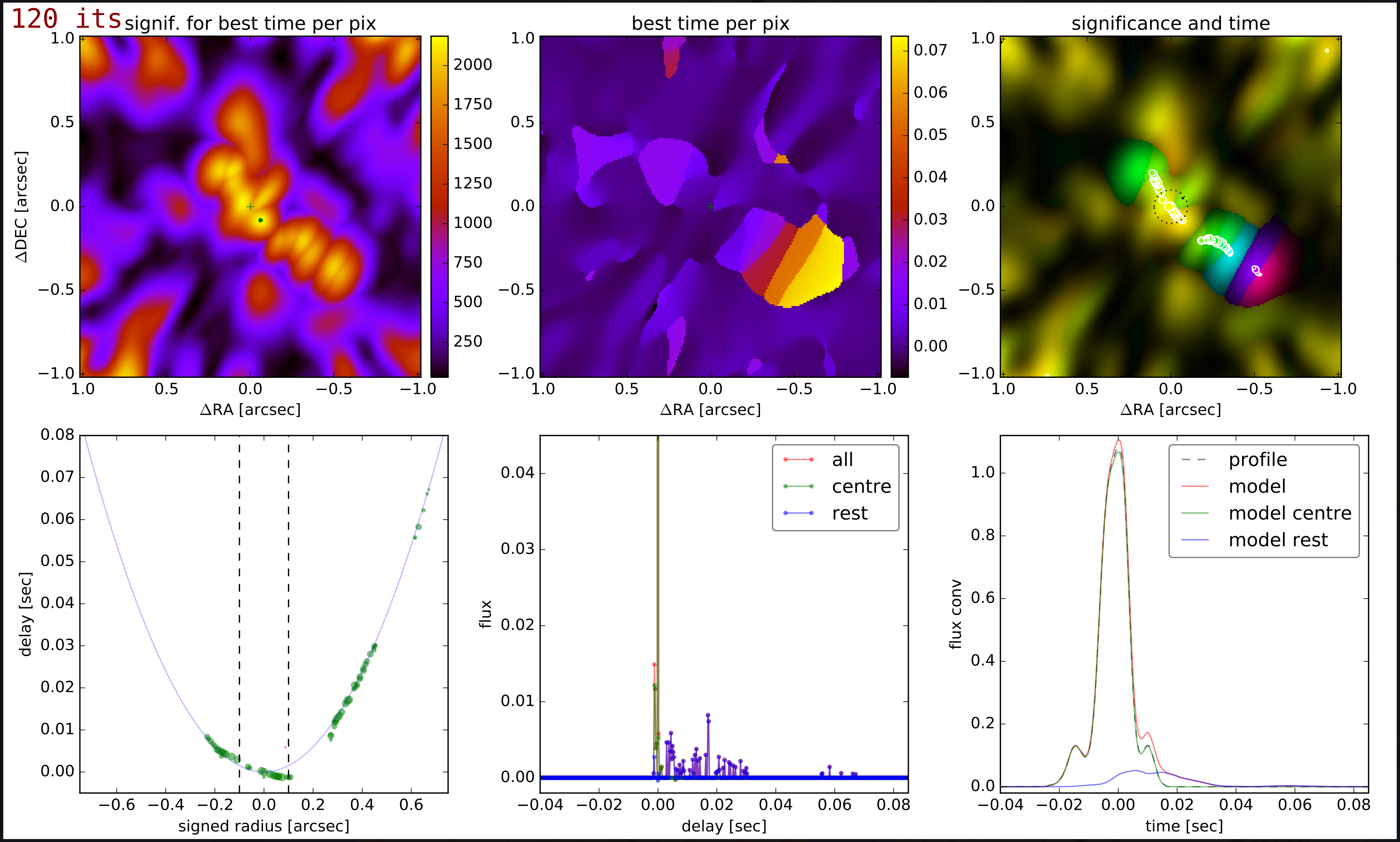
Delayed-profile-aware CLEAN (100 iterations)



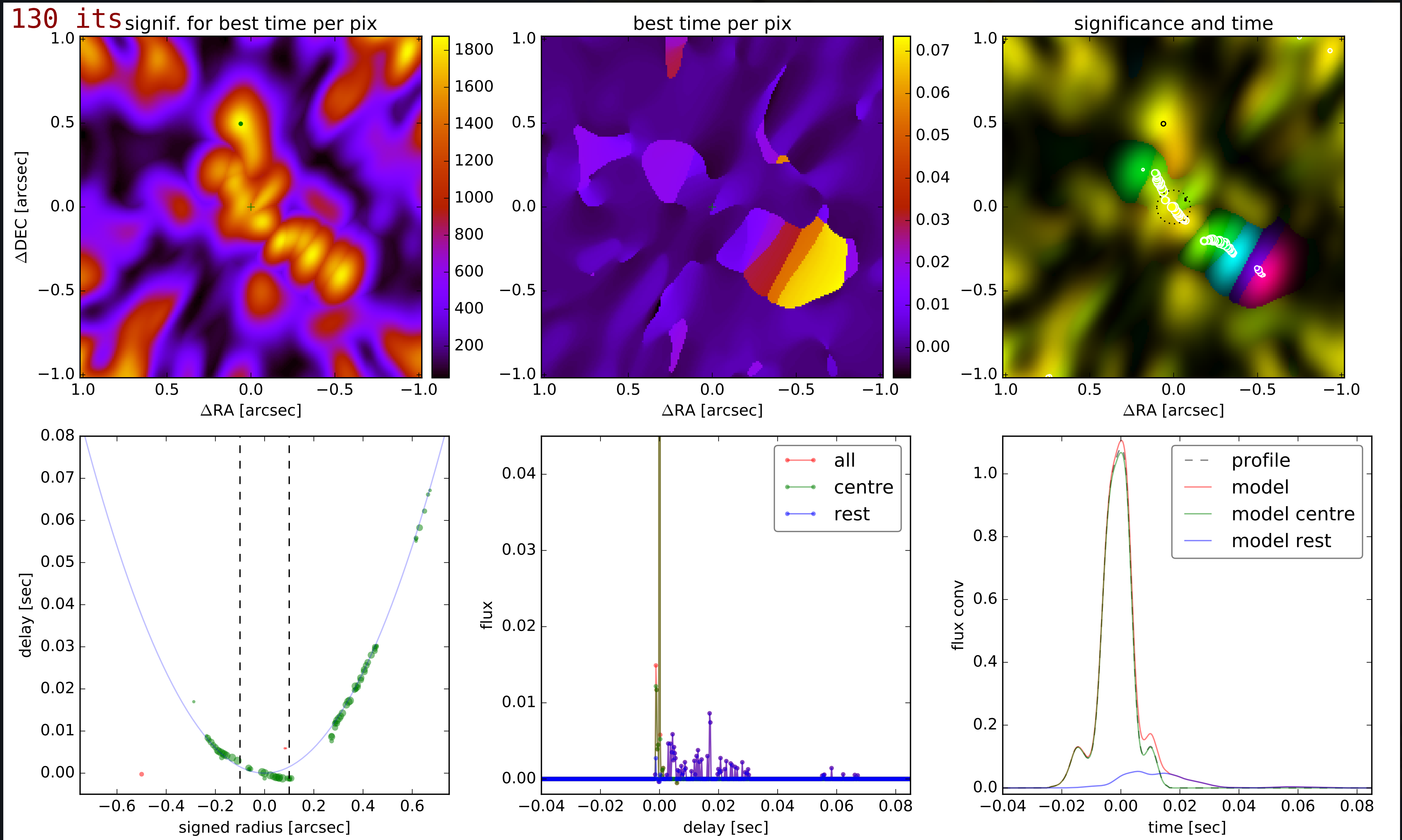
Delayed-profile-aware CLEAN (110 iterations)



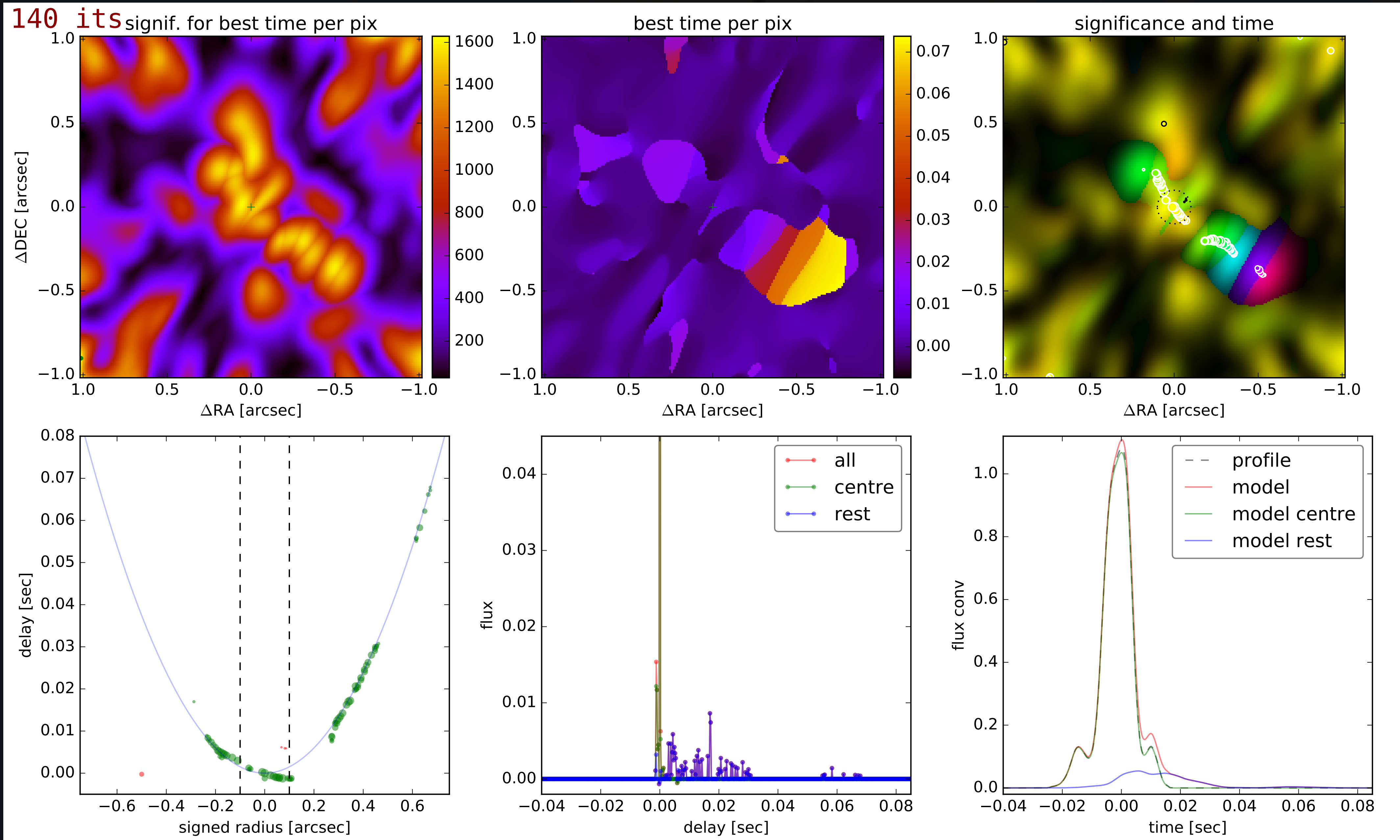
Delayed-profile-aware CLEAN (120 iterations)



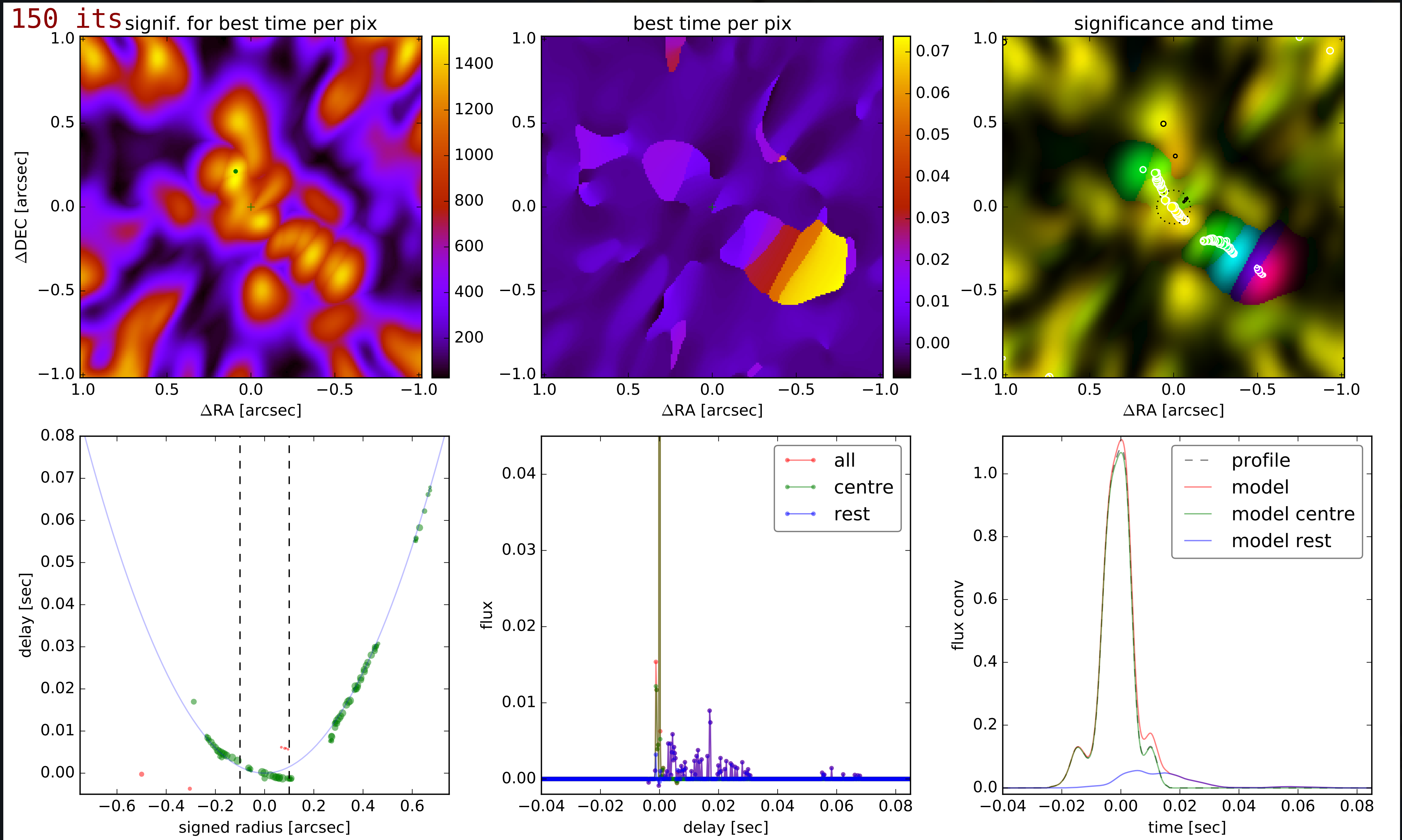
Delayed-profile-aware CLEAN (130 iterations)



Delayed-profile-aware CLEAN (140 iterations)



Delayed-profile-aware CLEAN (150 iterations)



Ionised matter around hot stars?

- *Walker et al. (2017): Extreme Radio-wave Scattering Associated with Hot Stars*

- IDV sources with (hot) stars near l.o.s.
  - ⋆ J1819+3845 with Vega
  - ⋆ PKS 1322–110 with Spica ($8'.5$)
  - ⋆ PKS 1257–326 with Alhakim

- ‘dense’ neutral matter around star, ionised by UV

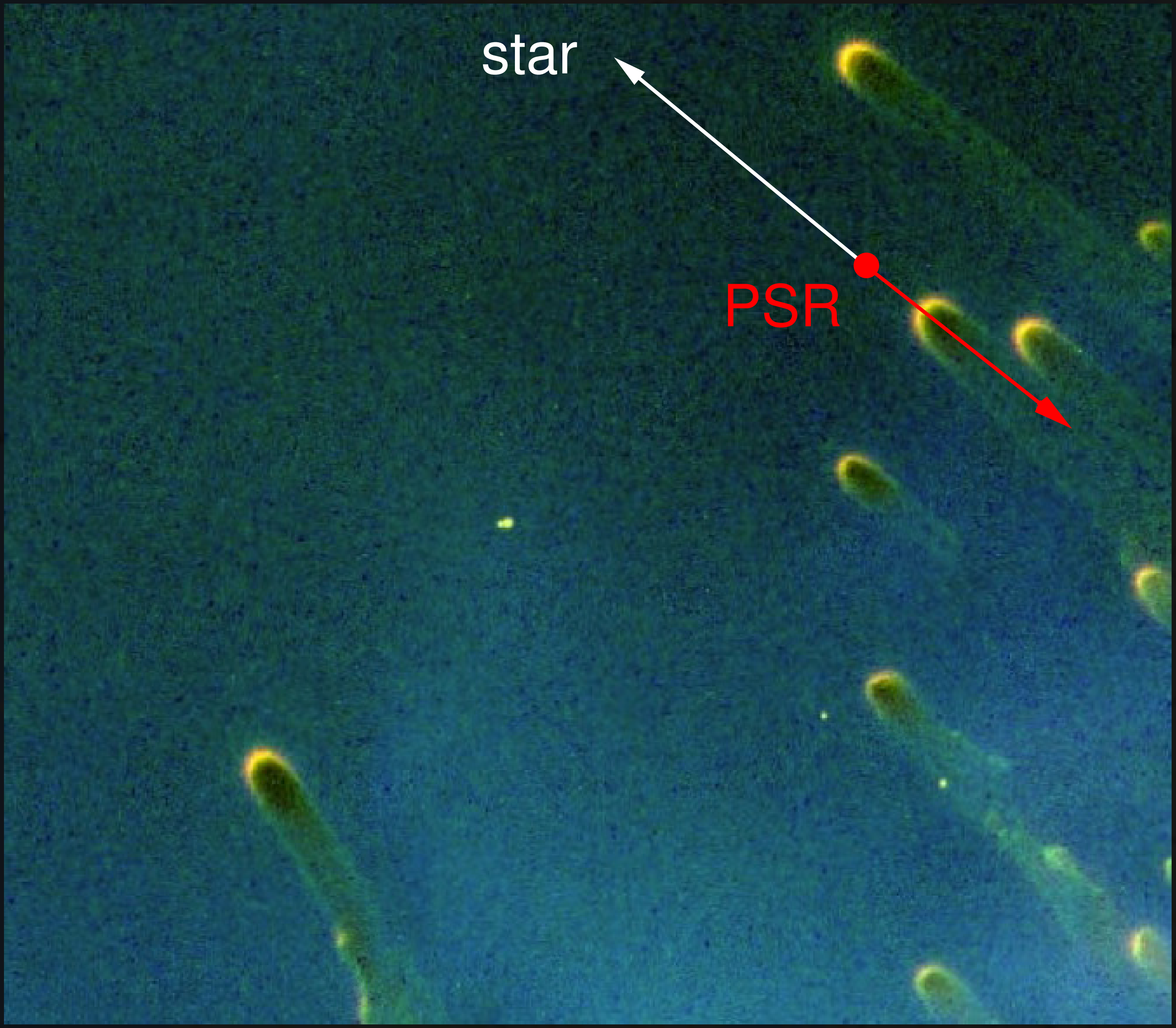
- elongated ‘elephant’s trunks’ may cause transverse lensing

- distances and orientation fit

Stars around B1508+55 ?

- A0 star Hip 74377 at 2.73 pc from l.o.s.
  - ⋆ distance from us ca. 260 pc
- A2 star Hip 74458 at 1.37 pc from l.o.s.
  - ⋆ $\pi = (8.36 \pm 0.57)$ mas
  - ⋆ distance (120 ± 8.2) pc
- compare with $D_\mathrm{d} = 124$ pc
- thanks to Mark Walker and Artem Tuntsov

Elephant's trunk lensing ?



Thanks to all people involved!

Mostly informal collaboration, great VLBI spirit!

GLOW: Andreas Horneffer, Caterina Tiburzi, Jörn Künsemöller, Julian Donner, Natasha Porayko

FR606: Jean-Mathias Grießmeier

SE607: Tobia Carozzi

UK608: Aris Karastergiou

PL610: Mariusz Pozoga, Barbara Matyjasiak, Hanna Rotkaehl

PL611: Marian Soida, Wojciech Lewandowski, Bartosz Smierciak

PL612: Tomasz Sidorowicz, Leszek Blaszkiewicz, Andrzej Krankowski

KAIRA: Derek McKay

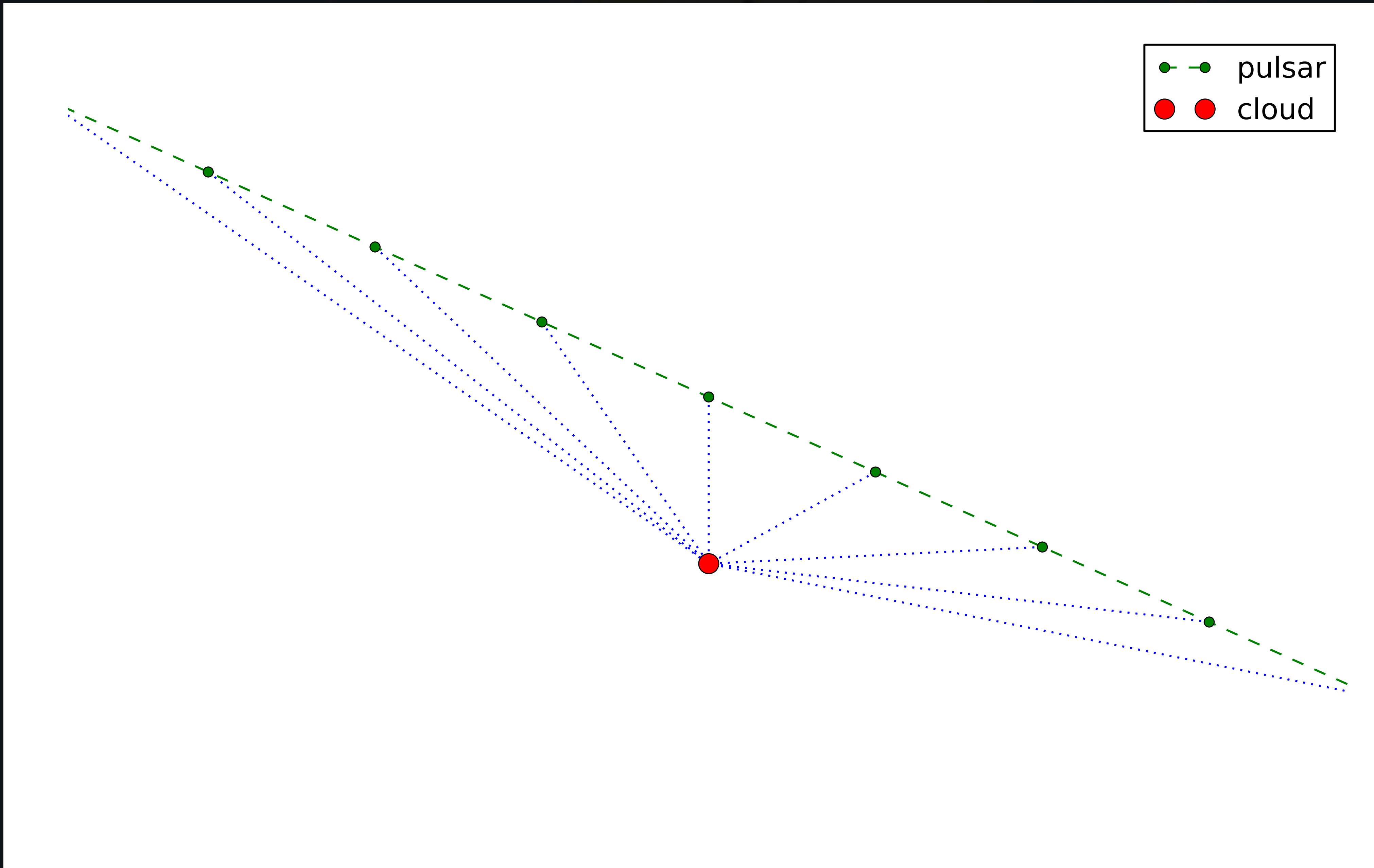
Summary

- offline-VLBI with LOFAR works!
- data can be calibrated
- ghost of B1508+55 really is echo
- distance of screen determined
- alignment with proper motion
- ongoing monitoring (data approaching 300 TB)
- will include GMRT, maybe others

$\rightsquigarrow$ other objects and projects

Bonus: Relative alignment in nature

Bonus: Cloud: no alignment



Bonus: Filament: relative alignment