Pulsar scattering in space and time

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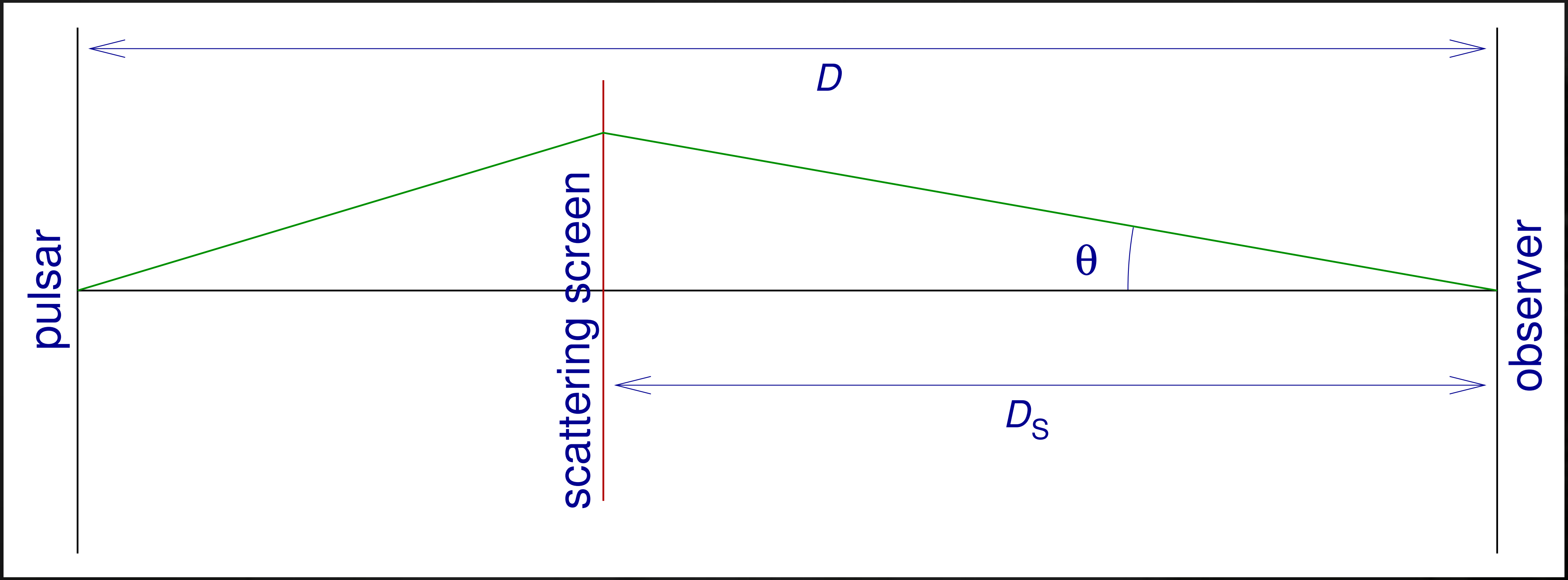
Pulsar scattering in space and time

- introduction
- temporal and angular broadening
- secondary spectrum
- direct 3-dim approach
- global VLBI project
- preliminary results
- outlook

Interstellar scattering: geometry



$$\tau = \frac{1}{2}\theta^2 D' \qquad D' = \frac{D\,D_s}{D - D_s} \qquad \sim D$$

Effects of scattering

- many 'speckles' with different θ

$\rightsquigarrow$ angular broadening (not always resolved)

- delays $\rightsquigarrow$ temporal broadening (not always resolved)
- scintillation, correlated over $\Delta\nu \approx 1/\tau$
- all smeared out for large sources

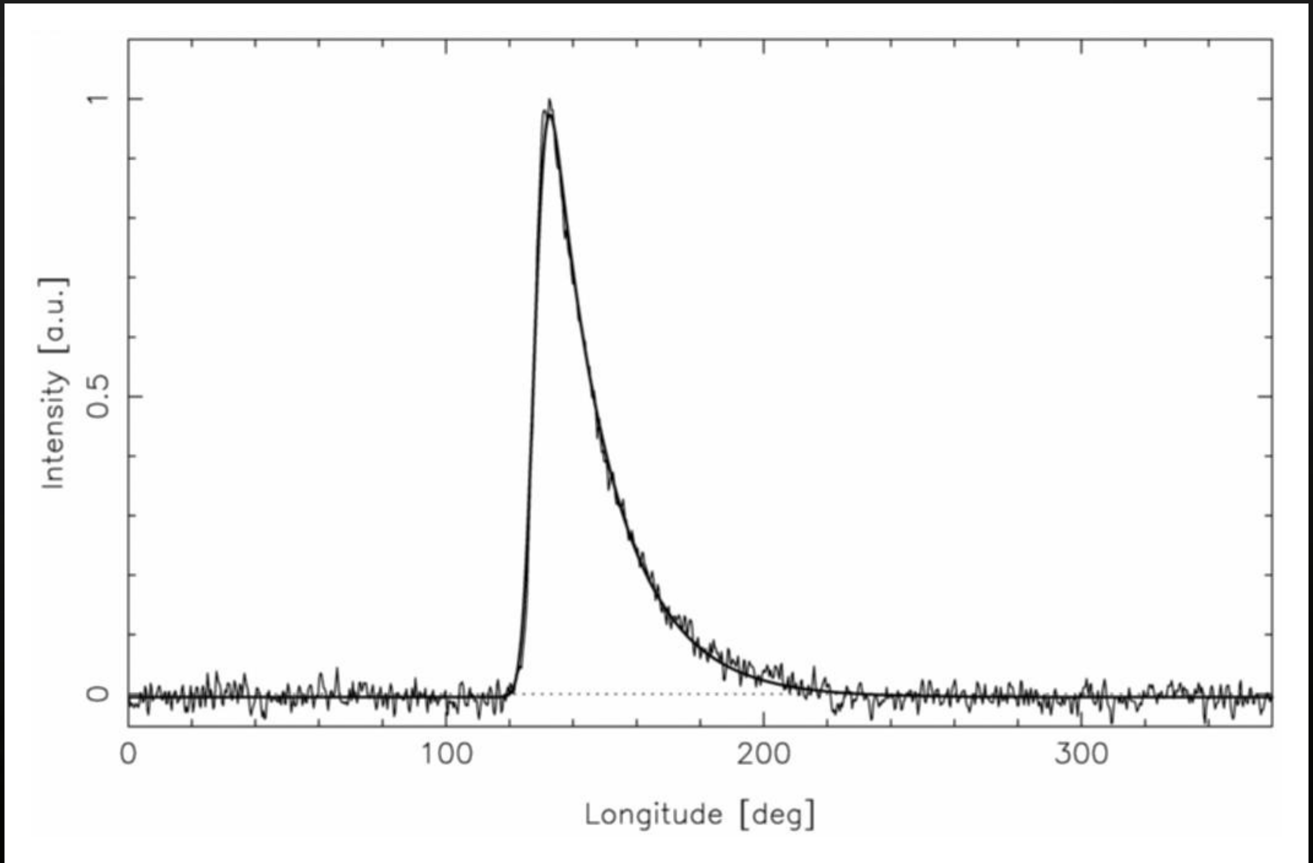
$\rightsquigarrow$ relevant for some AGN and for pulsars

- typical wavelength-dependence: $\theta \propto \lambda^{2.2}, \quad \tau \propto \lambda^{4.4}$
- What can we learn from $2\tau \sim \theta^2 D'$?

Pulsars

- . . . are sufficiently small
- . . . provide way to measure τ if $>$ intrinsic width

B1815–14 at 1.4 GHz



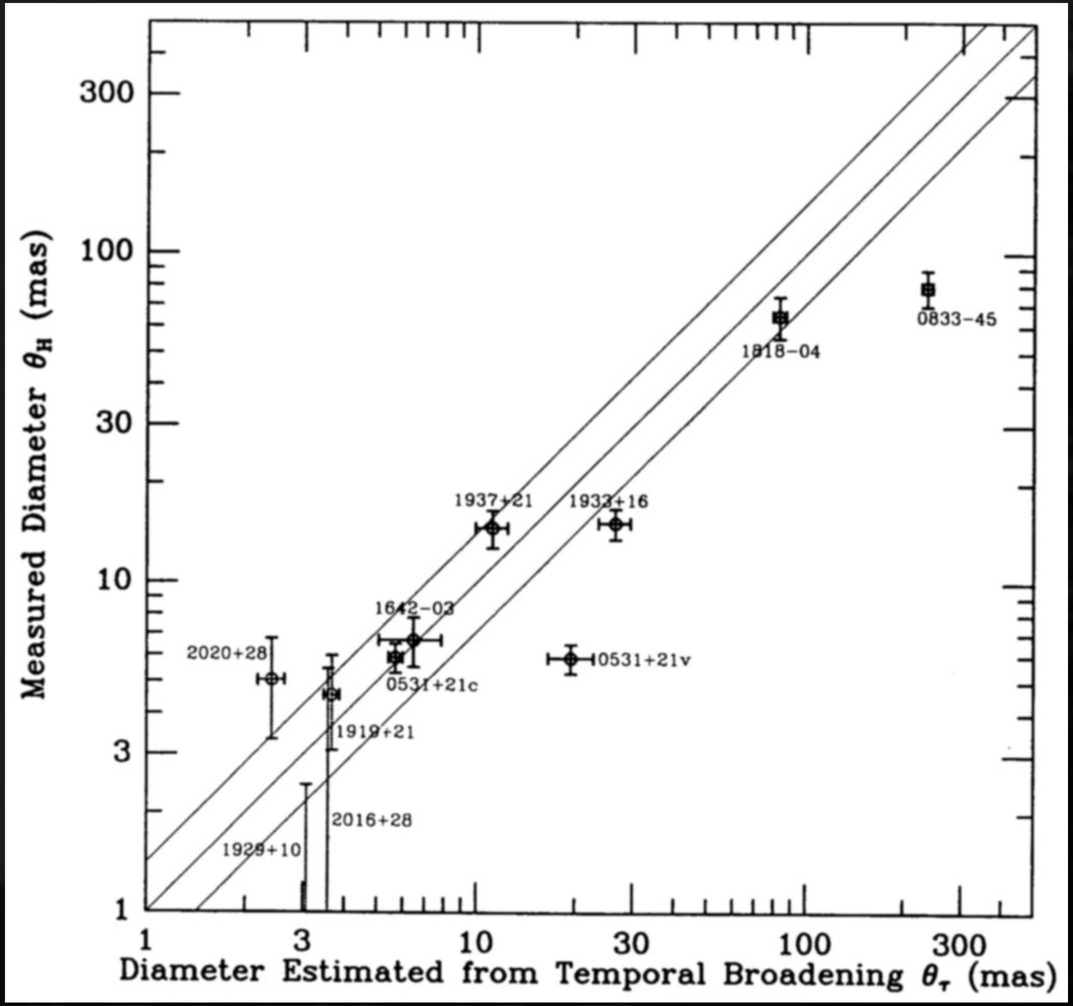
[Loehmer et al. (2001)]

- angular broadening can sometimes be measured with VLBI

Comparing angular and temporal broadening

for uniform distribution $0 \leq D_\mathrm{s} \leq D$

- $\tau = \frac{1}{2}\theta^2 \frac{D D_\mathrm{s}}{D - D_\mathrm{s}}$
- can determine 'effective' D_s
- but not the distribution!
- uniform (mostly) fits well

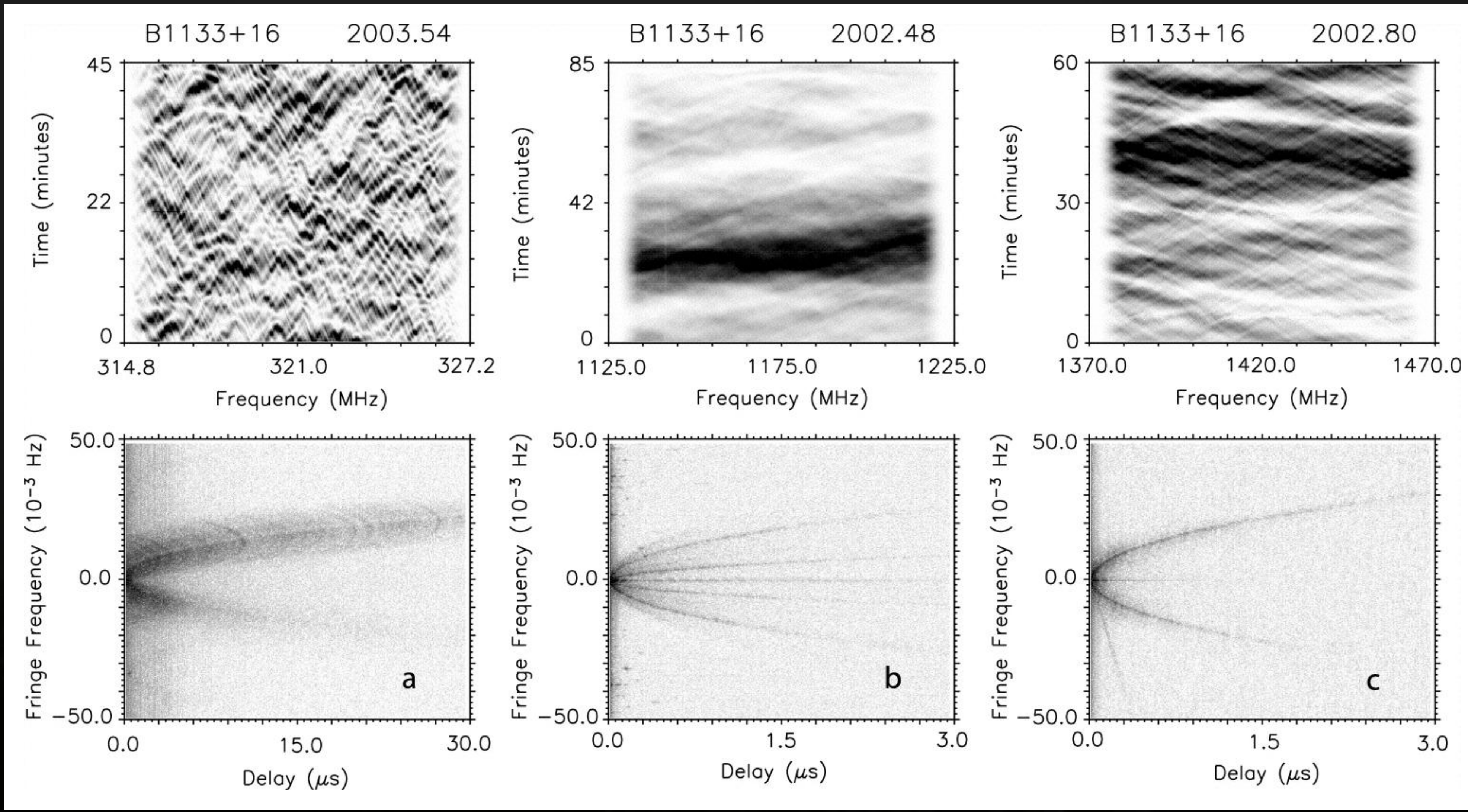


[Gwinn et al. (1993)]

at 326 MHz

Secondary spectrum

- 2-d Fourier transform of dynamic spectrum



[*Cordes et al. (2006)*]

Interpretation of secondary spectrum

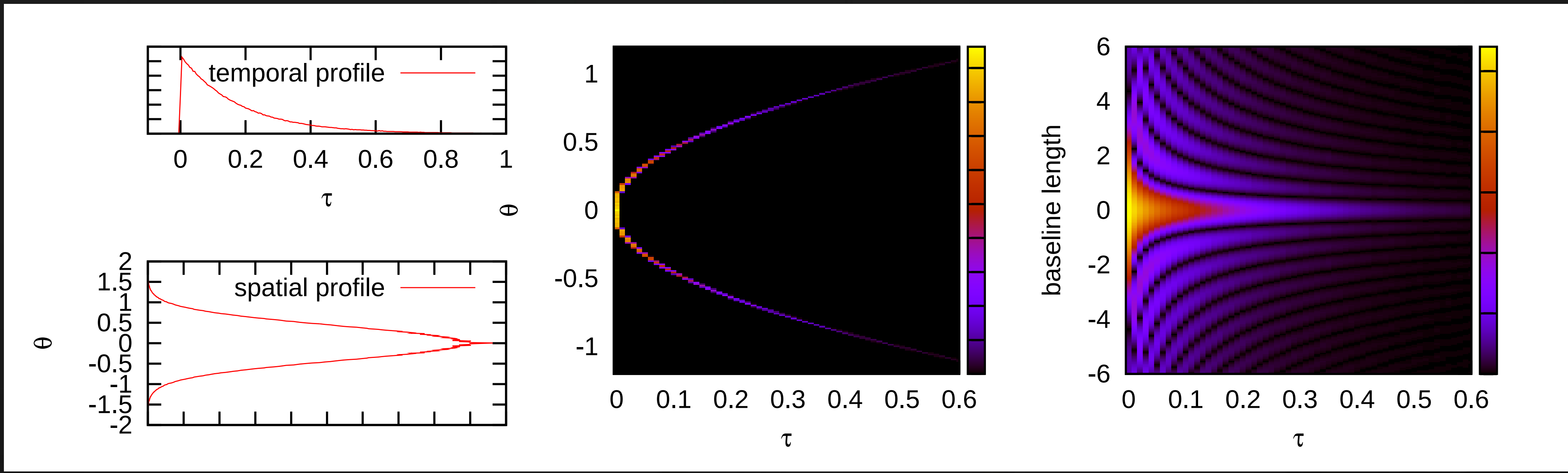
- τ from FT(freq)
- angle from FT(time) via Doppler effect: $\dot{\tau} \propto \theta \cdot \dot{\theta} \leq |\theta||\dot{\theta}|$
- $\tau \geq \text{const} \times \dot{\tau}^2$ relative to $\theta = 0$
- parabolic (inverted) arcs can be explained
- can be extended to interferometry *[Brisken et al. (2010)]*

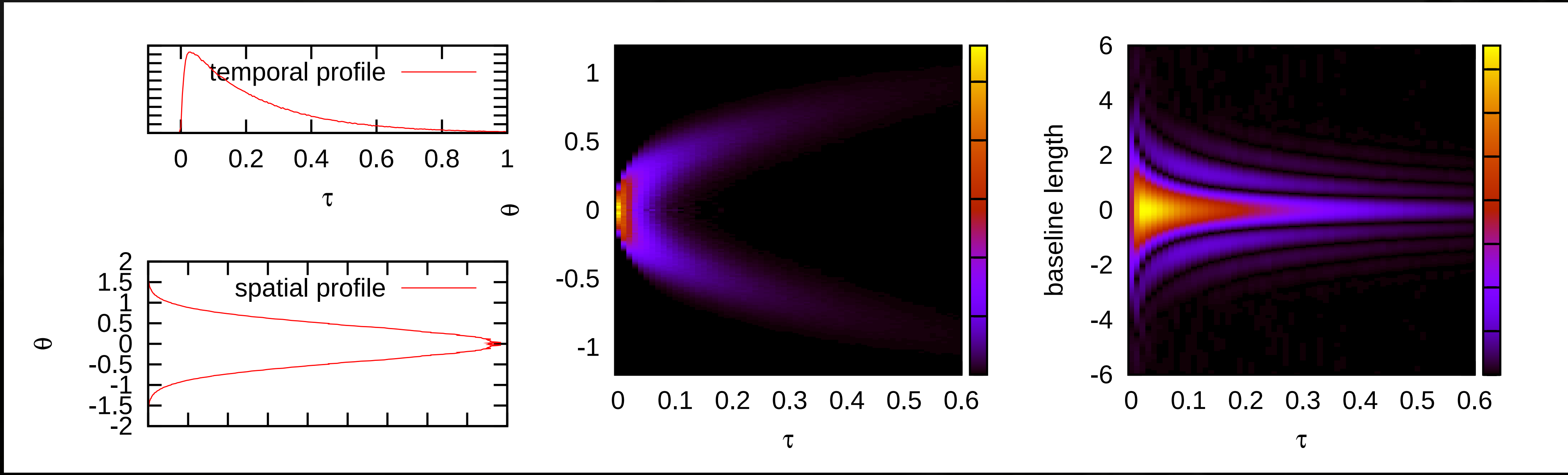
- needs Doppler as proxy for θ (model-dependent)
- does not utilise the pulses

- can we do it directly?

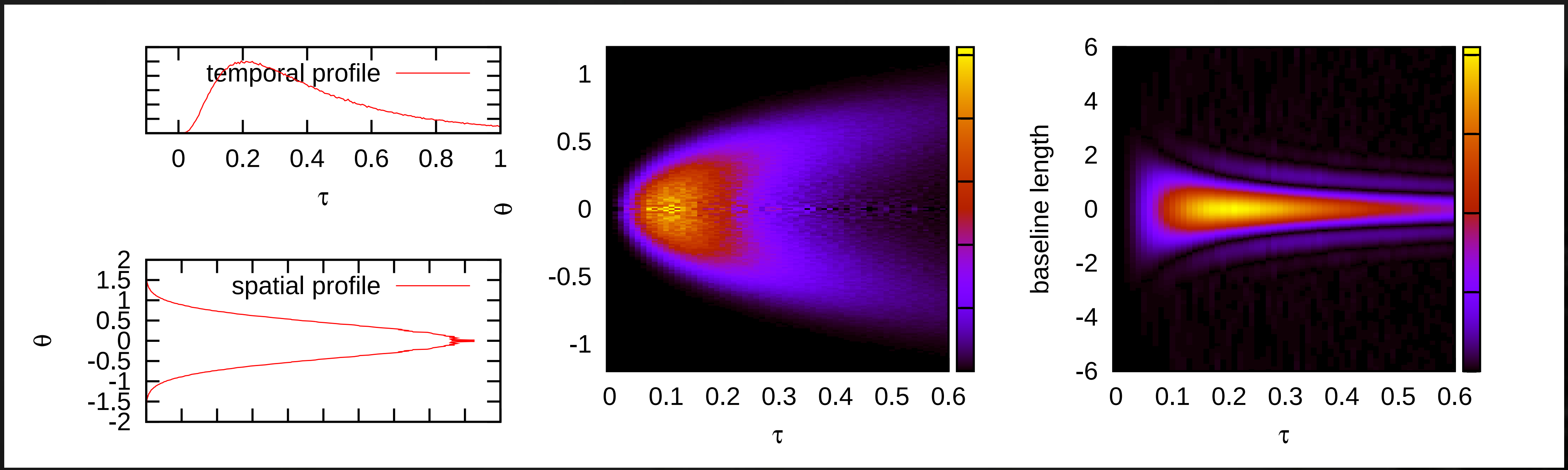
measure shape/size as function of τ or vice versa

Pulsar scattering: one/three screens





Pulsar scattering: continuous medium



- can not only determine distance
- but distribution
- detect anisotropies?
- less model-dependent

The project

- global VLBI experiment GW022A/B June 2011 with Michael Kramer, Joris Verbiest (ephemerides)

- 1.4 GHz
  - ⋆ 4 target pulsars, 3 control pulsars, fringe-finders
  - ⋆ VLBA, JB, WB, EF, ON, MC, TR, AR
  - ⋆ 8 h total (asked for more), 512 Mb/s

- 327/610 MHz
  - ⋆ 5 target pulsars, 3 control pulsars, fringe-finders
  - ⋆ VLBA, JB, WB, EF, AR
  - ⋆ 8 h total (asked for more), 256 Mb/s

The targets

names	D [kpc]	DM [pc cm^{-3}]	P [sec]	freq [GHz]	S [mJy]	τ [msec]	$\theta_{\rm FWHM}$ [mas]	λ/θ [km]
J1818–1422 B1815–14	8.1	622	0.2915	1.4	7.1	**15**	92	470
J1842–0359 B1839–04	4.2	196	1.8399	1.4	4.4	**4.6**	144	300
J1848–0123 B1845–01	3.8	159	0.6594	0.327 1.4	105 8.6	**142** **0.23**	410 17	460 2500
J1852+0031 B1849+00	10.0	787	2.1802	1.4	2.2	**34–280**	125–358	120–350
J1901+0331 B1859+03	8.0	402	0.6555	0.327	300	**200**	339	560
J1935+1616 B1933+16	4.6	157	0.3587	0.327	320	**0.9**	**15**–30	6300–13000
J1939+2134 B1937+21	8.3	71	0.0016	0.327	400	**0.13**	8.5–**15**	13000–22000
J1948+3540 B1946+35	7.9	129	0.7173	0.327	226	**32**	136	1400

Analysis

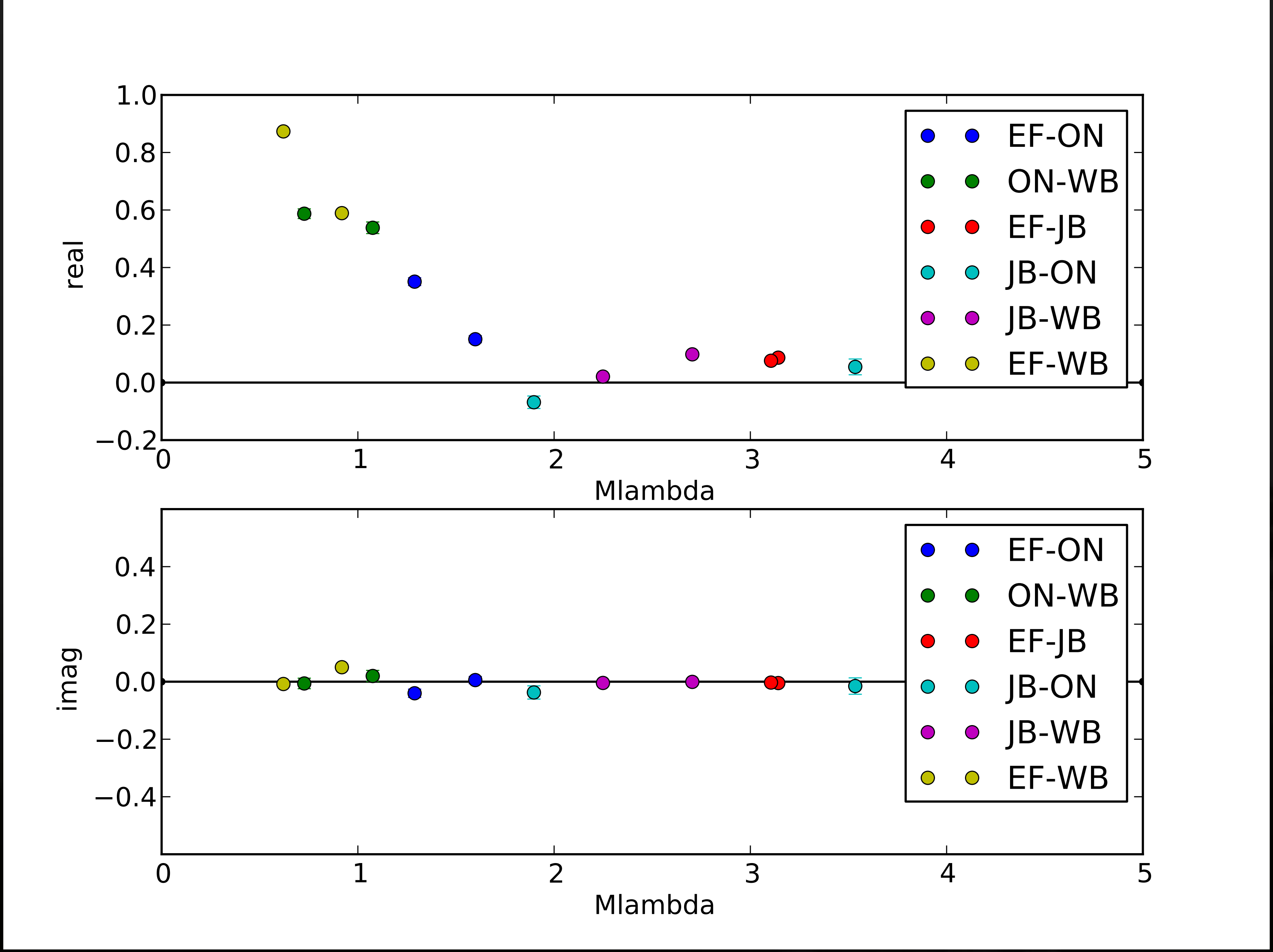
- *in progress. . .*

- correlation with DiFX in Bonn (MPIfR/AIfA)
  - ⋆ make profiles, create matched filter
  - ⋆ gated correlation (baselines and autos)
  - ⋆ calibration in AIPS (amplitudes from control pulsars)
  - ⋆ binned correlation (e.g. 400 bins)
  - ⋆ calibrate binned correlations with same CL

- produce
  - ⋆ images as function of pulse phase (τ)
  - ⋆ pulse profiles as function of baseline

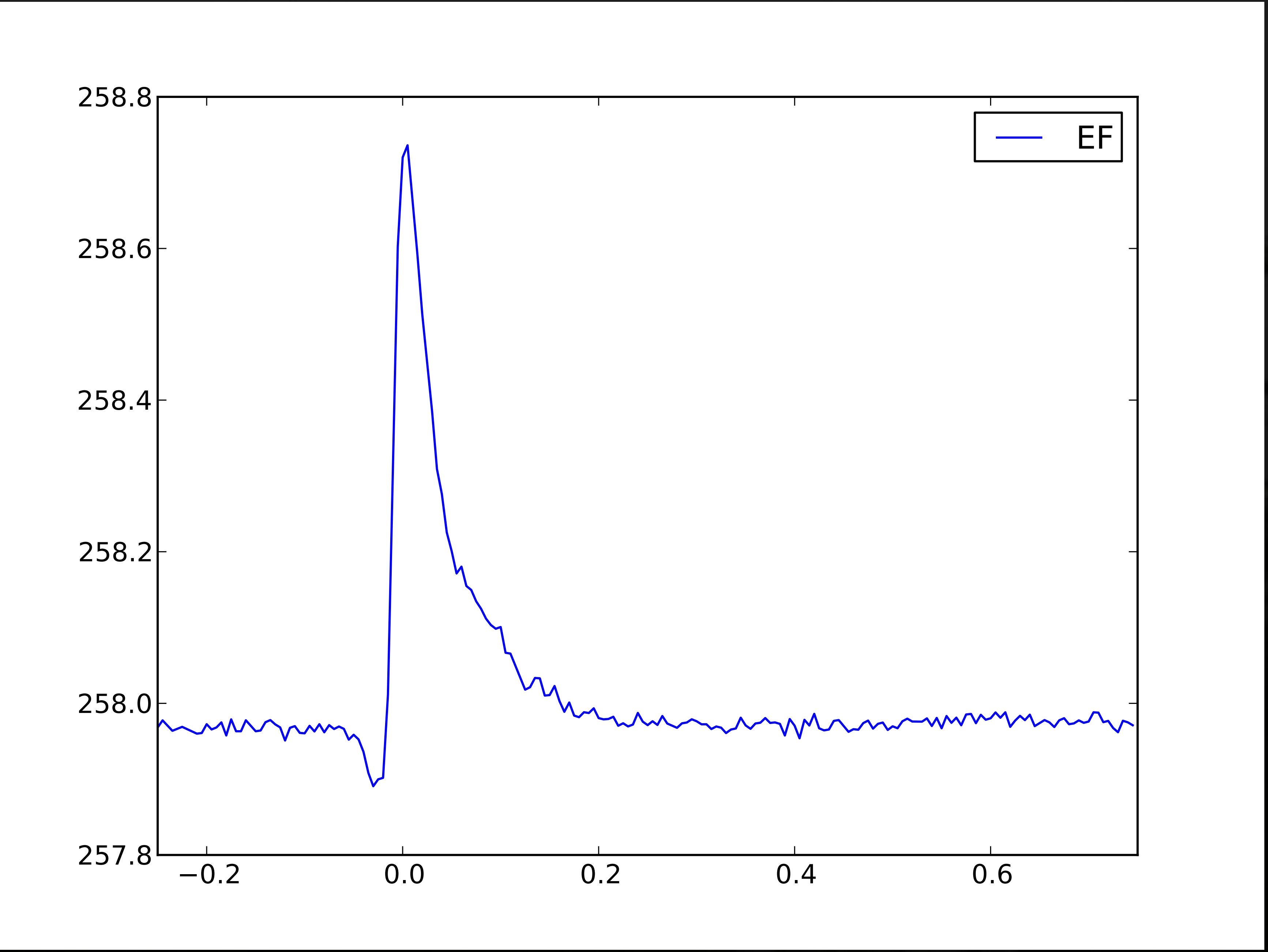
- show B1815–14 at 1.4 GHz, two scans: 15+21 min, EF,(JB),ON,WB

B1815–14 at 1.4 GHz: gated visibilities

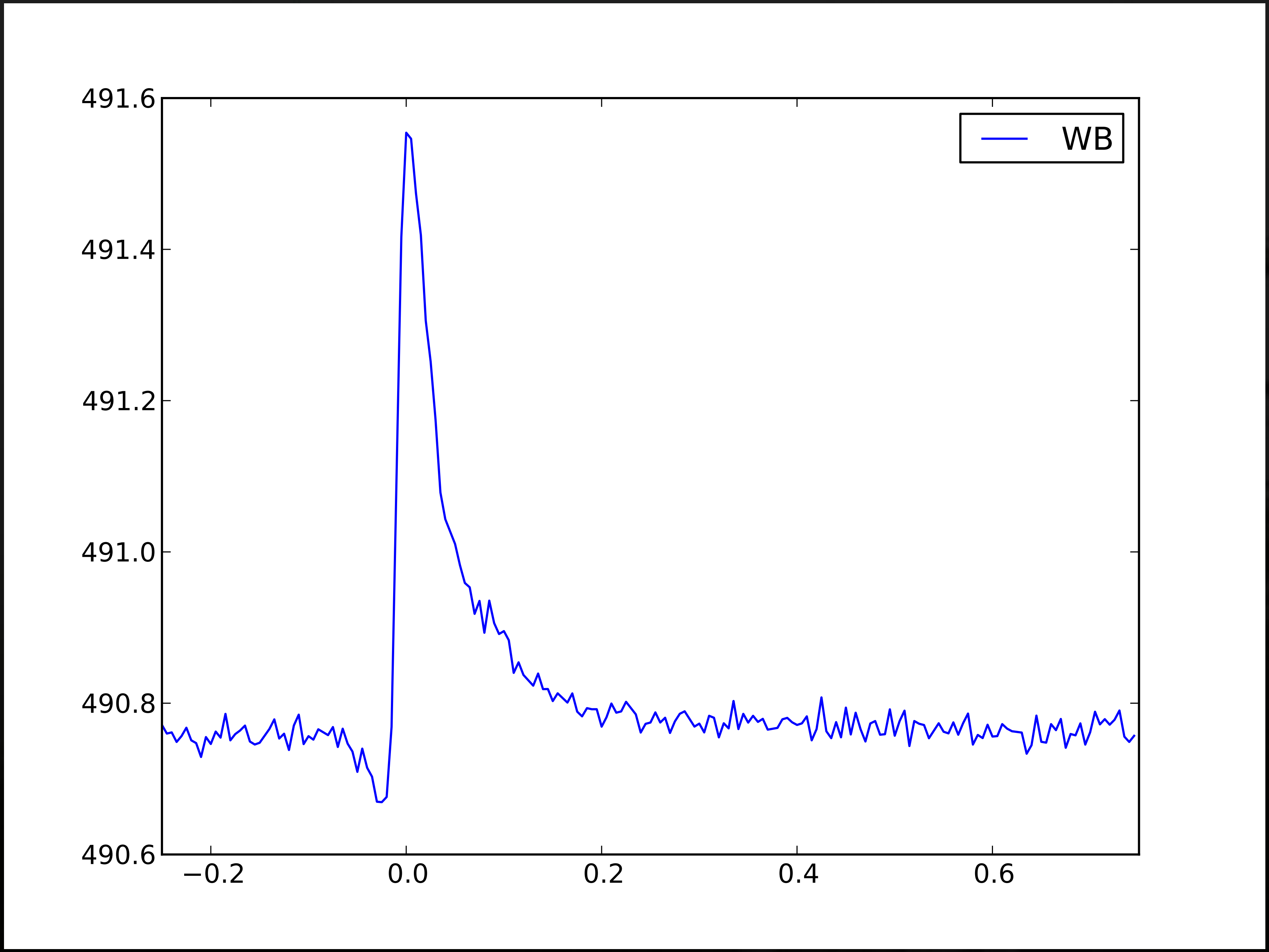


only short baselines, do not trust JB calibration

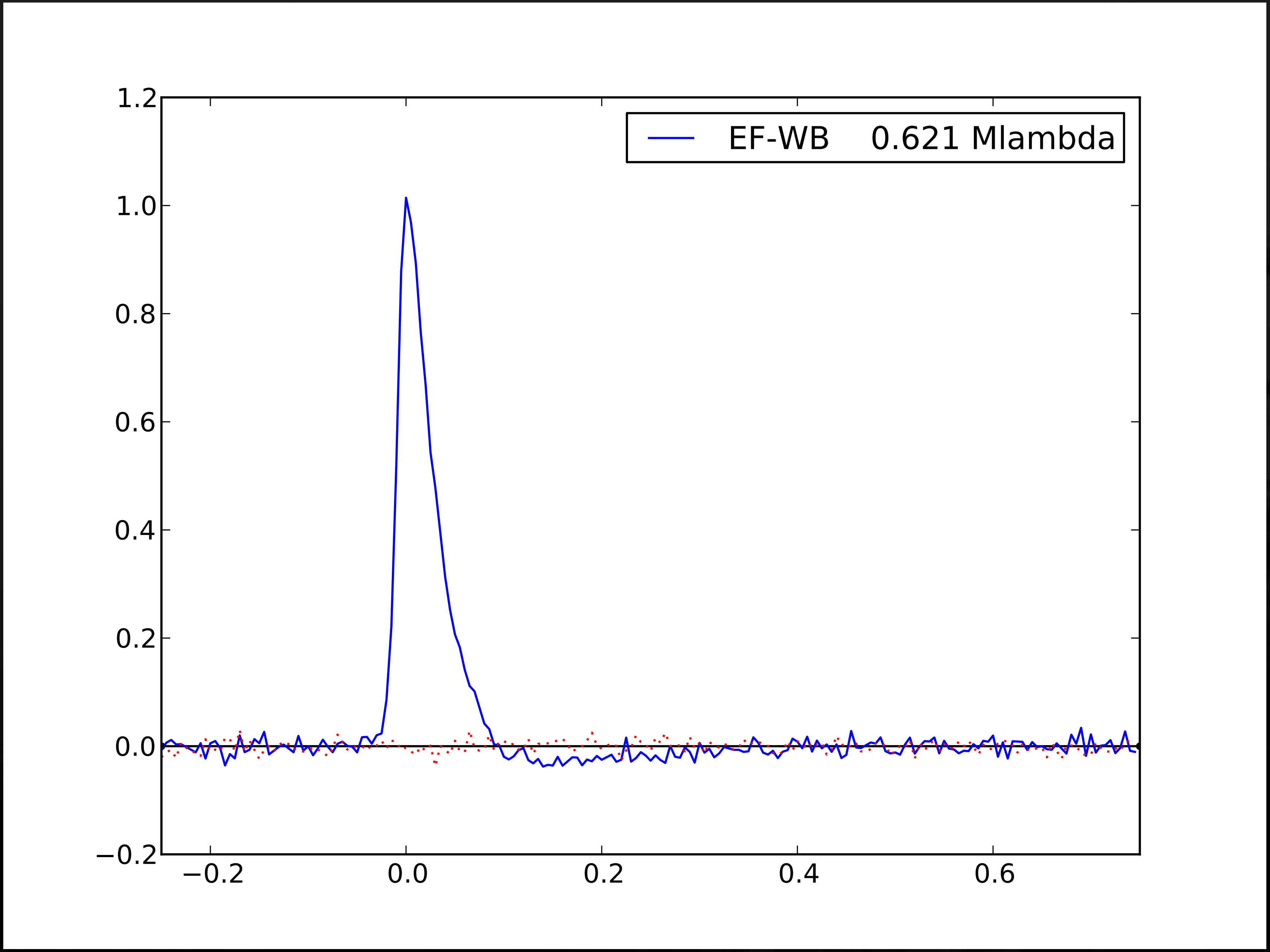
Pulse profiles: autocorrelations (1)



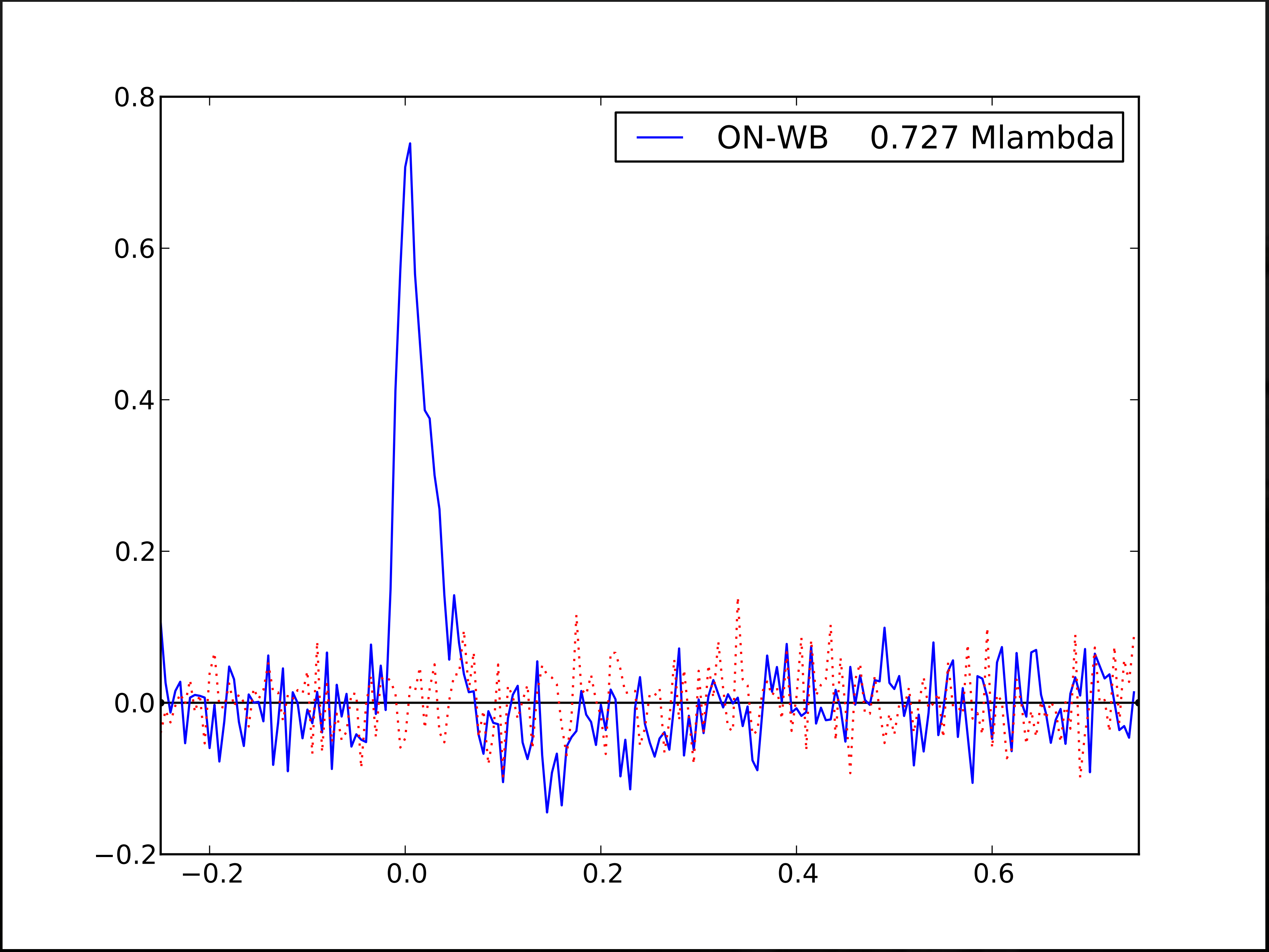
Pulse profiles: autocorrelations (2)



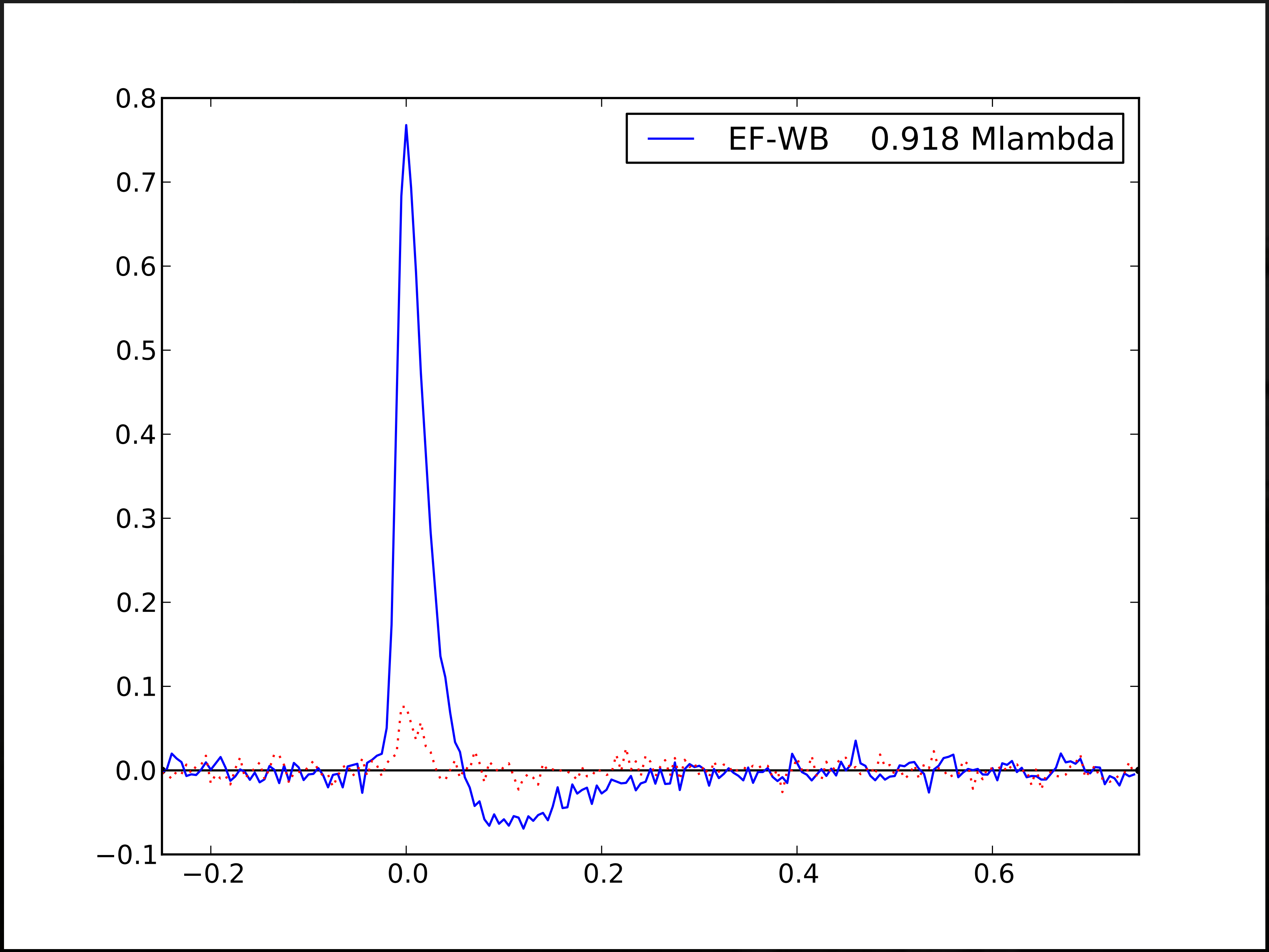
Pulse profiles: cross-correlations at 0.621 Mlambda



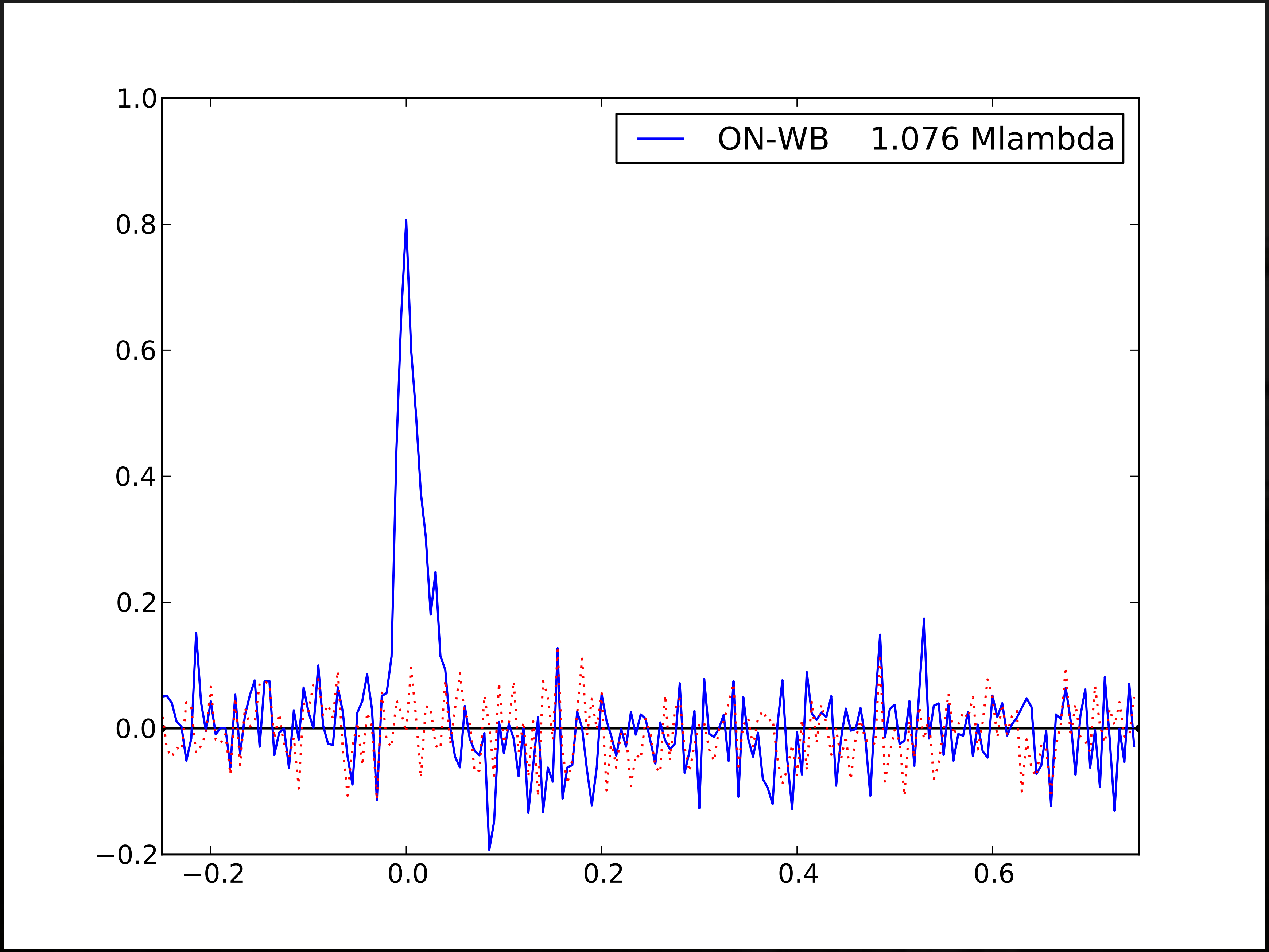
Pulse profiles: cross-correlations at 0.727 Mlambda



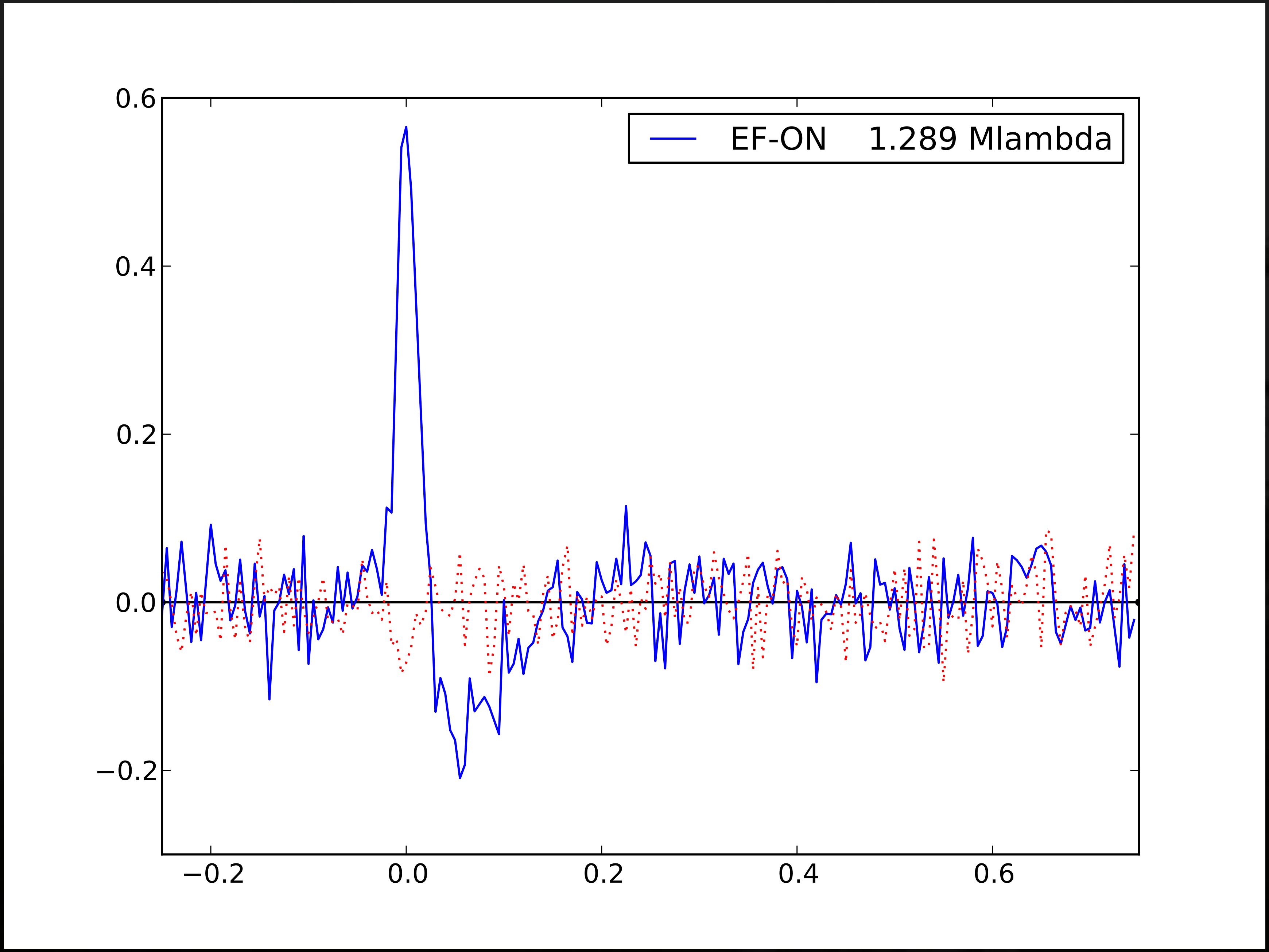
Pulse profiles: cross-correlations at 0.918 Mlambda



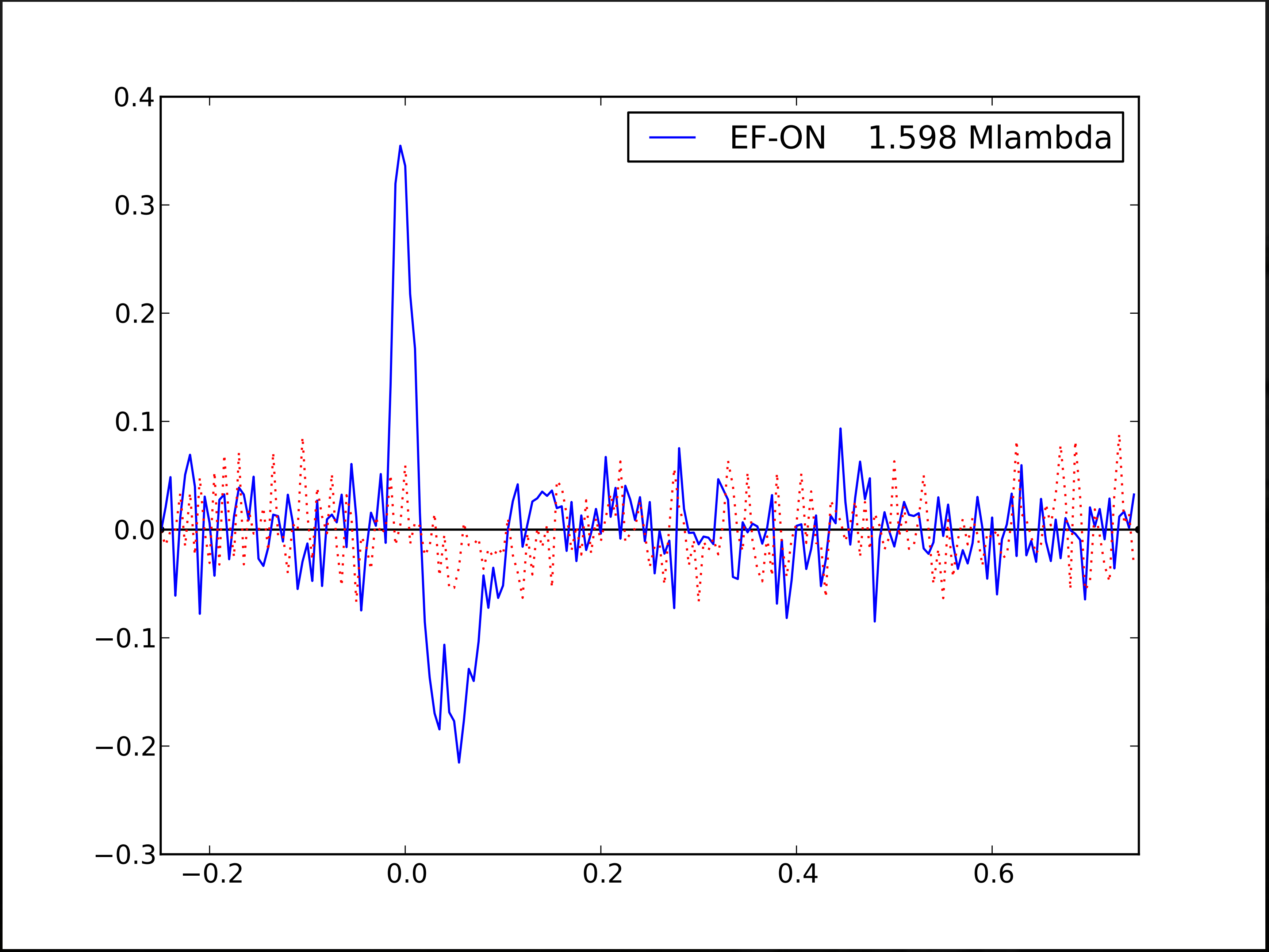
Pulse profiles: cross-correlations at 1.076 Mlambda



Pulse profiles: cross-correlations at 1.289 Mlambda



Pulse profiles: cross-correlations at 1.598 Mlambda



To come soon

- make images (show expanding rings?)

- amplitude calibration using autocorrelations
  - ⋆ baseline gains $g_{12} = g_1 \overline{g}_2$
  - ⋆ not possible in general (noise and RFI in autocorrelations)
  - ⋆ we have pulsars: can use folded profile
  - ⋆ 2-bit sampling: different scale for auto and cross
  - ⋆ for Gaussian signal: understand the maths, can correct
  - ⋆ pulse-cal, switched power: distort sampler statistics *(can introduce closure errors!)*
  - ⋆ can take that into account (extension of DiFX)
  - $\rightsquigarrow$ currently good to $\sim 10\,\%$

- quantitative analysis for ISM

Summary

- 3-dim scattering study
  - ⋆ temporal broadening (1 dim)
  - ⋆ angular broadening (2 dim)
- so far only radial, no full calibration
- will produce 2-dim images, expanding rings or blobs

⇝ distribution of scattering screen(s)

- 3 more targets at 1.4 GHz, 5 at 327/610 MHz
- future:
  - ⋆ use pulsar backends
  - ⋆ LOFAR (with LWA?), RadioAstron?