

Source localization of seizure onset by phase maps

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This presentation was given during the Dianalund Summer School on EEG and Epilepsy, July 24, 2012.

The main purpose of this introductory talk is to show the possibilities of improved seizure onset analysis by using spectral tools, i.e. DSA, filtering, FFT and phase maps, as well as virtual and source montage to find the earliest rhythmic seizure onset activity and to localize a focal onset, if possible.

Disclosure:

Michael Scherg is a shareholder and employee of BESA GmbH.

He has been heading the development of the software packages BESA Research and BESA Epilepsy.

Easy analysis of seizure onset activity

1. Use **DSA** to navigate to seizure onset.
2. Select a **narrow filter band**, e.g. 3-20 Hz.
3. Select an **optimized montage** (source, AV33)
4. Mark periodic activity at apparent onset (< 1sec)
5. Perform **spectral analysis**
6. Select peak frequency and analyze **phase maps**
7. Adjust interval to confirm and redo **analysis**

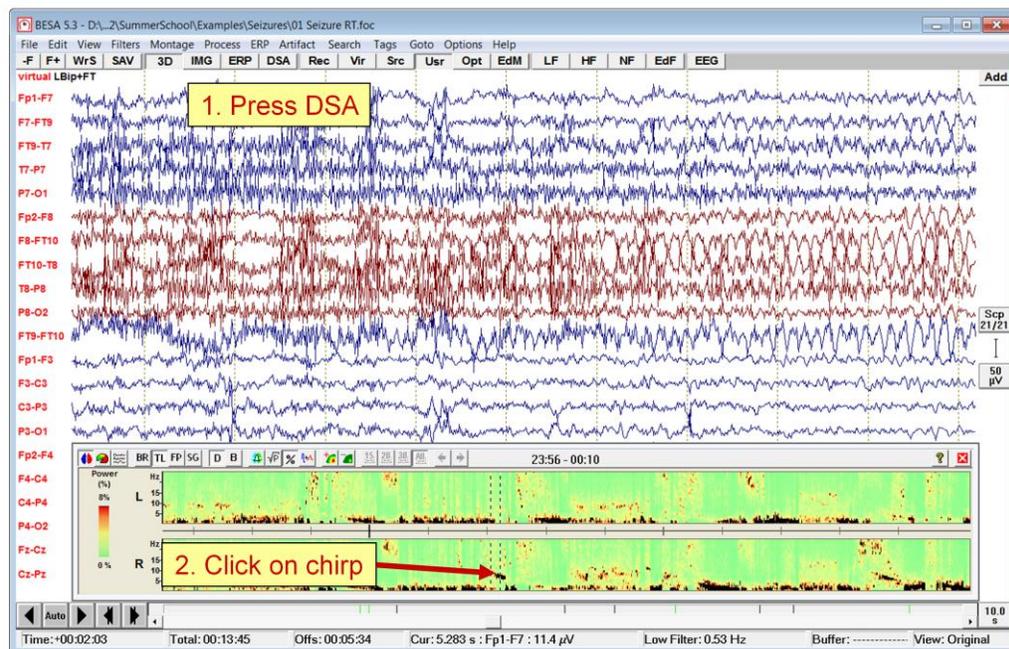


Seizure onset can be difficult to assess in scalp EEG. However, some tools can be used to increase the seizure onset activity over the EEG background:

Filtering (3-20 Hz) and regional source montages (e.g. Temporal Region, Frontal, Central and Parietal Regions) render seizure onset activity better visible. Also, the standard virtual average reference montage AV33 can be useful to observe the first periodic discharges more clearly.

If a rhythmic pattern is seen at or before EEG or clinical seizure onset, spectral analysis with 3D phase maps can help to identify the sublobar origin of this rhythmic activity.

Seizure review: navigation utilizes source DSA in 20 / 30 min epochs



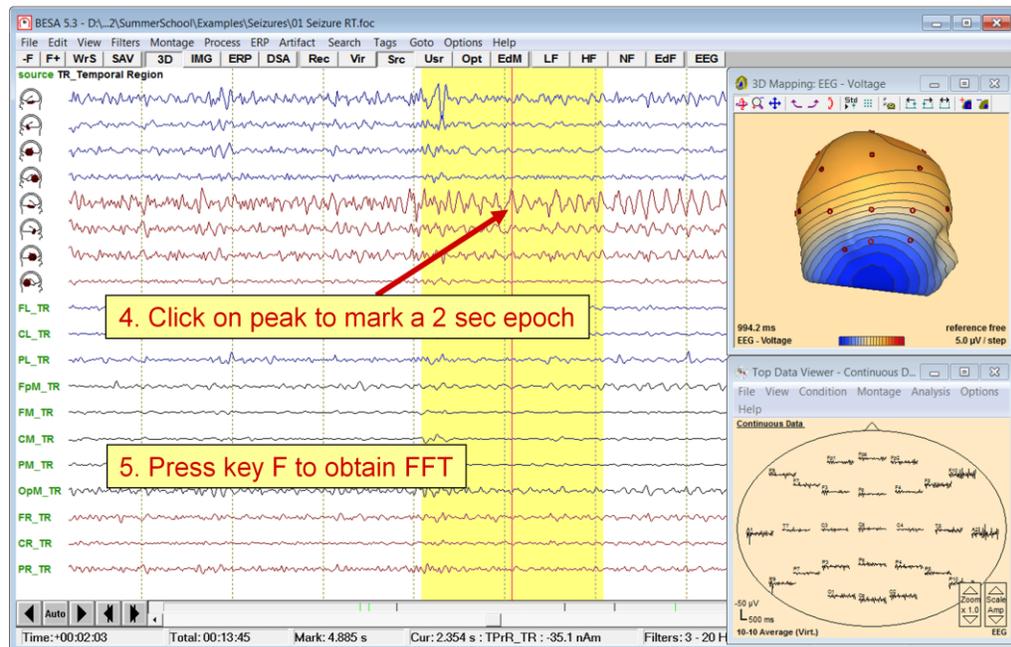
DSA (digital spectral arrays) can be used to identify periodic discharges with changing frequency that typically occur at seizure onset. These so-called spectral chirps can be well recognized using particular normalizations in the DSA time frequency diagrams depicting 15, 20, or 30 minutes of EEG.

In BESA, the activities of the right and left hemispheres are separated using regional sources. This helps to identify oscillatory activities occurring on one side only. The DSA display can be used to page through the EEG and jump to the onset of a seizure characterized by a spectral chirp (mostly an oscillatory burst with the base frequency going down).

The traditional EEG review settings with an extended longitudinal montage and widely open filters, as shown above, are not optimal to analyze seizure onset. Typically, the onset oscillation is buried in EMG activity as seen above and often obscured by slow EEG activities.



Seizure review: mark onset rhythm using source montage (or AV33)



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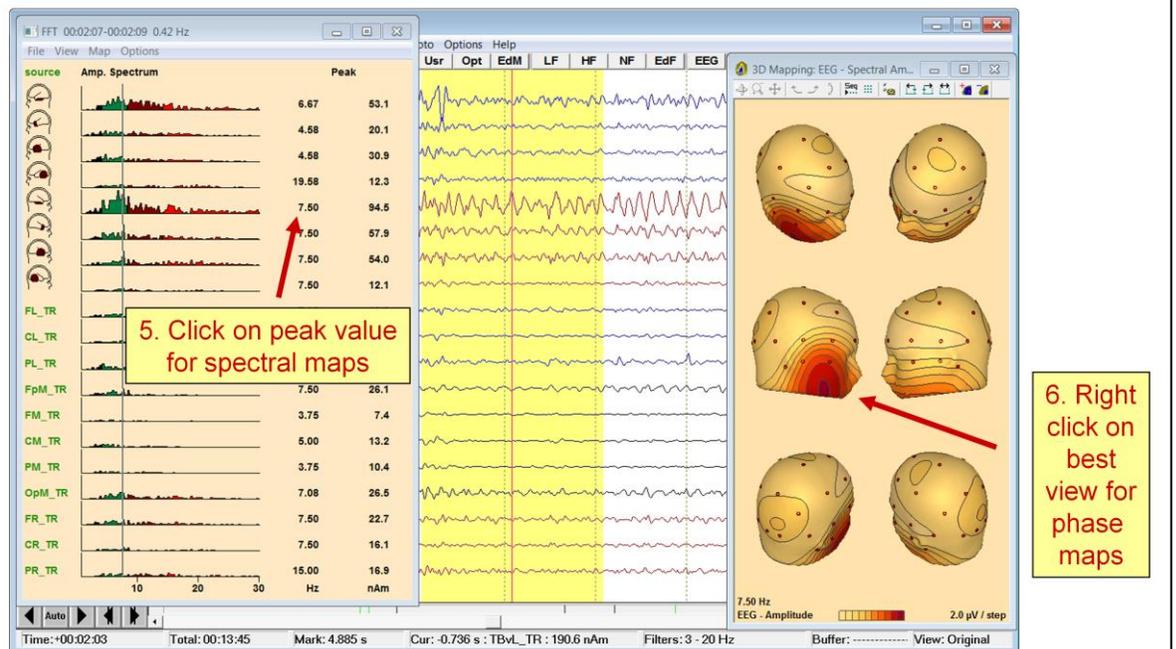
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Pressing F3, optimized seizure detection settings are provided: the temporal lobe source montage is set, a band filter is activated with relatively steep cutoffs at 3 and 20 Hz to remove both slow EEG as well as EMG artifacts, and the default block epoch is set to ± 1 sec.

Thus, after clicking on a periodic EEG activity at seizure onset, a 2 sec epoch is set around the cursor, and a spectral FFT analysis can be performed on the marked epoch by pressing key 'F'.

To change to a different montage quickly, you may use function keys **F12** (frontal region source montage), **F9** (AV33), **F10** (Lbip+Sp), or the montage buttons **Src** and **Usr**.

FFT at seizure onset: select spectral peak and view amplitude map



After pressing 'F', the amplitude spectrum over the marked block is calculated and displayed. The largest spectral peak is seen at the right temporal basal source channel (left).

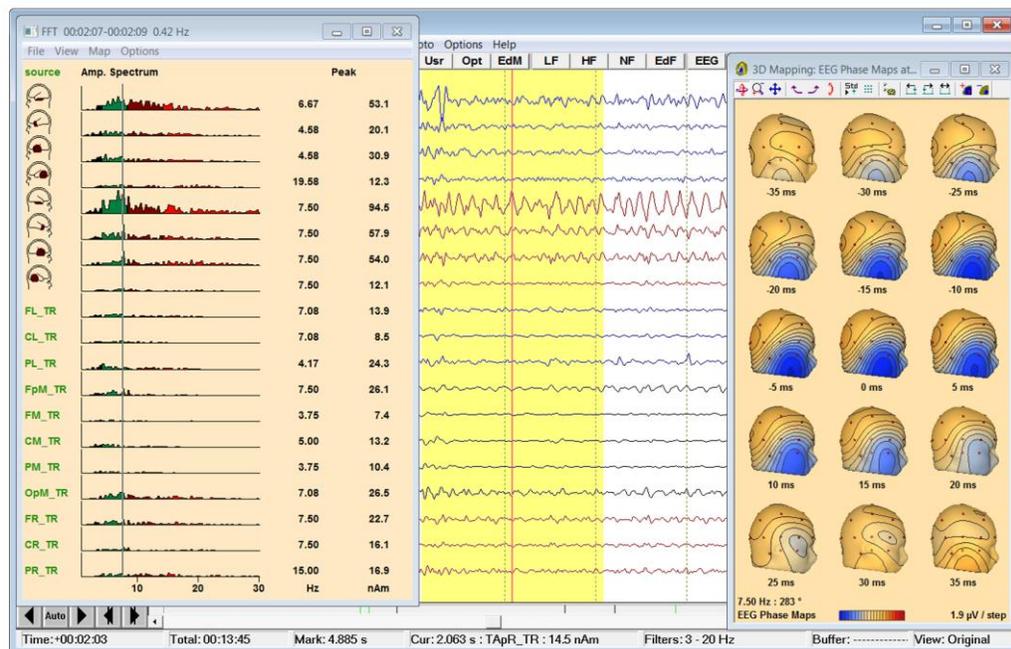
Click onto the peak frequency value next to the spectrum to obtain amplitude or power maps (right).

To obtain phase maps, right click onto the head view showing the largest activity.

Note: In the spectral display on the left, you can alter between amplitude and power spectra by clicking on the heading Amp.Spectrum. Power spectra show peaks more clearly.



Seizure onset: 3D phase-mapping of main frequency reveals generator



Inspect phase map

Phase mapping intrinsically uses an average over all seizure onset cycles that you have marked. They show the voltage topography at different phases throughout the averaged cycle. Considering the frequency, phase angles have been converted to relative latencies (in ms).

The displayed serial 3D maps in right lateral view show an initial basal pattern with a subsequent rotation to polar and lateral. Thus, the propagation from basal to polar-lateral appears to be preserved within the seizure onset cycles.

For a more convenient interpretation of the time lags between the source activities at the different aspects of the temporal lobe, the serial phase maps are plotted at subsequent phase angles that correspond to a time shift of 5 ms between maps. This interval between maps can be conveniently decreased for higher frequencies or increased for lower frequencies.

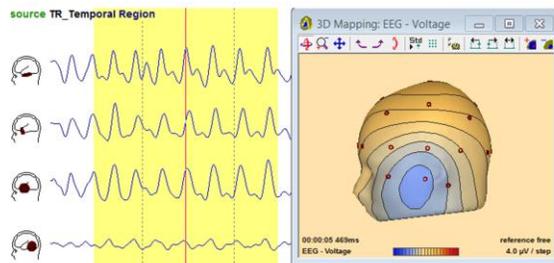
The interpretation of these phase maps is the same as for the voltage maps in the time domain, e.g. when clicking on spikes in an EEG. However, onset may be difficult to estimate from a cycling seizure pattern.



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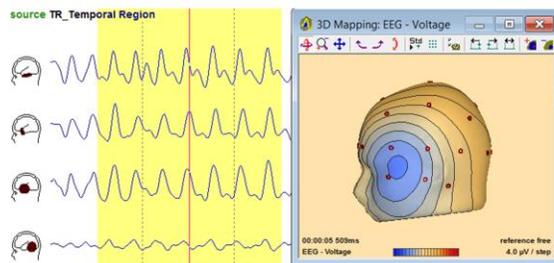
Why 3D phase-mapping and what is it?



Basal and lateral oscillations lead.

But, single cycle signal is poor and noisy.

We need to average!



Polar oscillation comes later.

-> phase lag



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If we try to map voltage at seizure onset to localize, we will mostly fail since the signal is not clear.

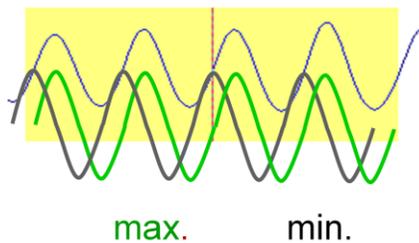
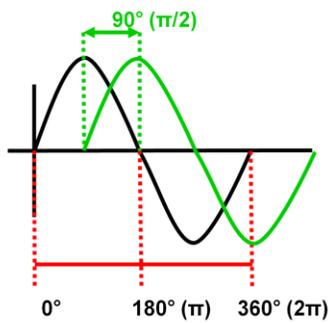
Sometimes, when looking over several cycles, we may observe systematic time lags between the (faster) upbeats in the different channels (corresponding to the spike orientations in the above example). This is best seen in source montages where the compound activities of the different cortical surfaces are largely separated, as shown above for the left temporal lobe.

When mapping at different phases of different cycles, there will be a large variability due to the EEG background, more so, if we have not used sufficient narrow-band filtering.

Therefore, we will need to average over the onset cycles. But, instead of doing this in a tedious way in the time domain, it is easier to use spectral analysis.

A clean EEG example can be seen above: the serial 3D maps displayed in left lateral view show an initial basal pattern with a subsequent rotation to polar and lateral.

Phase maps: FFT convolutes signals with a sine and a cosine function



For each marked channel and block, we know the magnitude and phases of the sine and cosine convoluted signals.

We can now shift the phase going 360° around the cycle and weigh the FFT output by the relative magnitudes of sine and cosine along the cycle. This is equivalent to shifting the sine function over the signal during one cycle.

For each channel, there will be a phase angles when the output is maximum or minimum.

The convolution provides an implicit average over the marked cycles.



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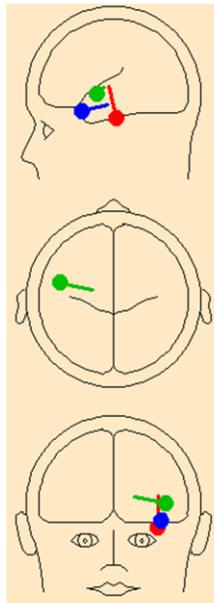
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Spectral analysis of a segment of EEG can be understood as taking a sinusoidal wave (over all cycles contained in the marked block) and shift the wave along the recorded (and filtered) signal. At every latency (or phase shift) we multiply both wave and signal and obtain an output signal of a certain magnitude. There will be maxima whenever the wave coincides best with the signal.

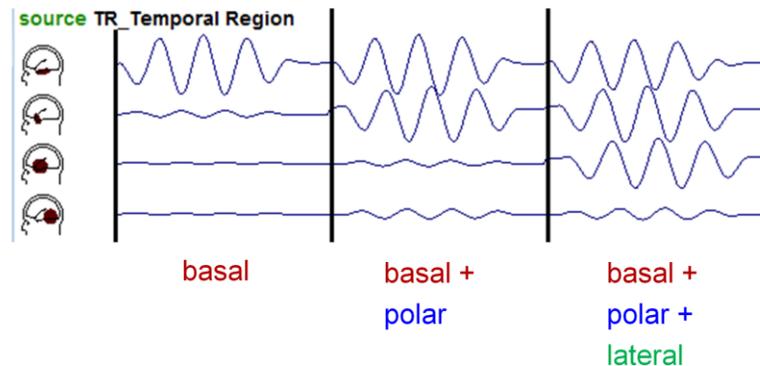
This procedure is called convolution. If we take the magnitudes and signs of the signal after convoluting with a cosine and sine wave (at 90 degrees), we obtain an overall magnitude for each phase and channel.

When plotting these magnitudes at a specific phase angle across all recorded channels, we obtain a phase map that is a true voltage map.

Phase maps: different aspects of left TL oscillate with time lags



Source montages recover the oscillatory signals and their delays in the 3 simulated regions:



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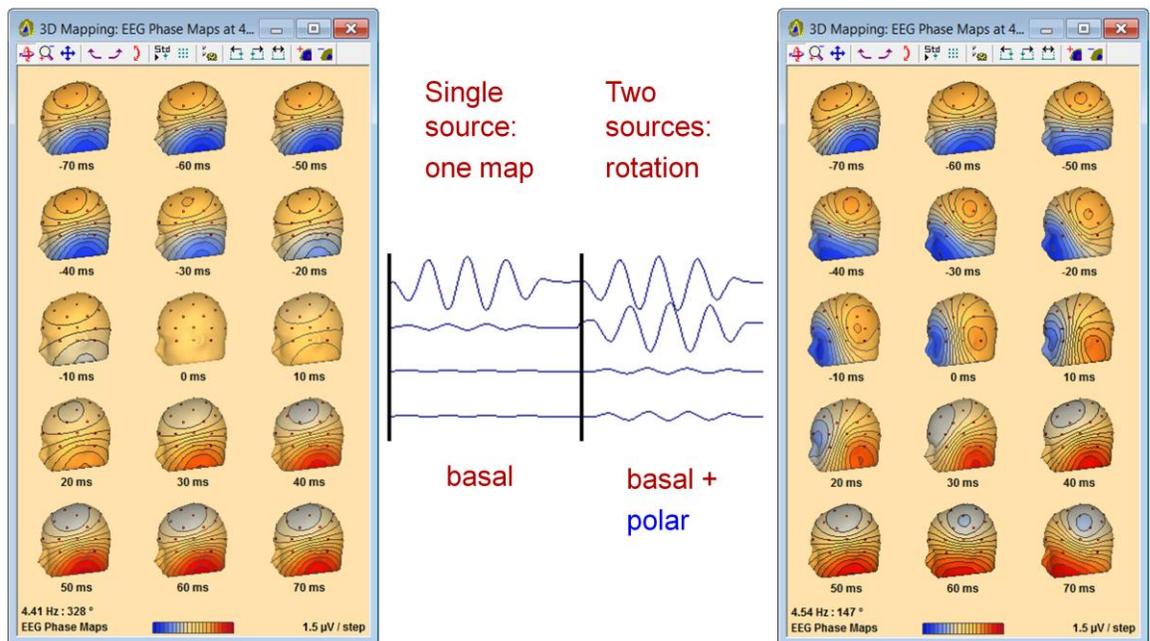
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The above signal have been created using the ‚DipoleSimulator‘ program to demonstrate phase maps resulting from oscillating activities at 1, 2 or 3 cortical surfaces having different orientations.

In the above example, we used the basal, polar and lateral surfaces of the left temporal lobe to understand what phase maps would result when the temporal base is oscillating alone (left), when the pole comes in with a time lag (middle) and, finally, when the lateral surface gets activated with a further time lag (right).

The simulation used equivalent dipoles for the 3 surfaces and a pattern of about 3 cycles. Frequency was the same but onset time delayed at the polar and lateral surfaces. The temporal lobe source montage shows a nice separation of these activities in time.

Phase maps: single versus two sources oscillating with time lags



Left: Phase map of a single oscillating generator. The map topography remains the same; only magnitude and polarity are alternating.

Right: If polar activity (at right angles to basal activity in the sagittal view) sets in with a delay, phase maps rotate from a basal to a polar pattern. Across the cycle there is a complete rotation, and it may be hard to tell the onset. However, the relative delay of polar versus basal is shorter than a half-cycle, indicating polar lag.

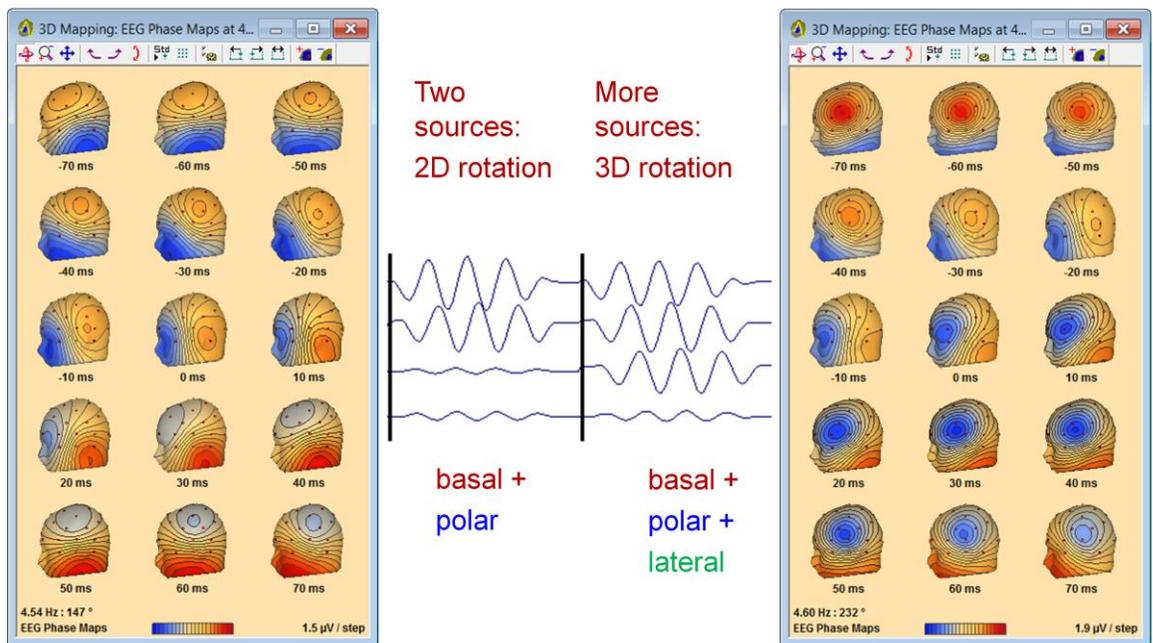
Note: If localizing from these voltage phase maps according to the rules laid out in the 'Quick guide on 3D maps', the left temporal center can be identified from all maps.



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Phase maps: two versus more sources oscillating with time lags



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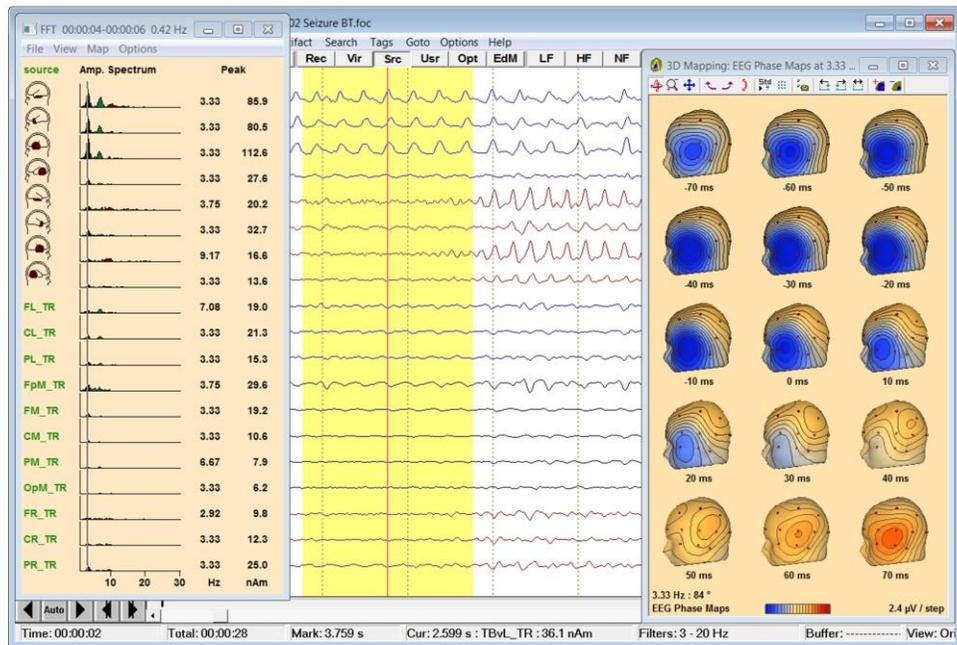
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Left: For comparison, the rotation of the basal-polar pattern is shown again.

Right: The delayed onset of the lateral activity leads to a more complex rotation in 3 dimensions. The basal pattern is partially blurred by the lateral positivity. However, the rotation towards polar and lateral can be seen well.

Note: If localizing from these voltage phase maps, the left temporal center can be identified from all maps. Orientation is more difficult to understand due to the complex overlap.

Bilateral seizure: left temporal onset, phase map of main rhythm



LT base frequency (3.33 Hz):

Lateral leads polar with small rotation of map



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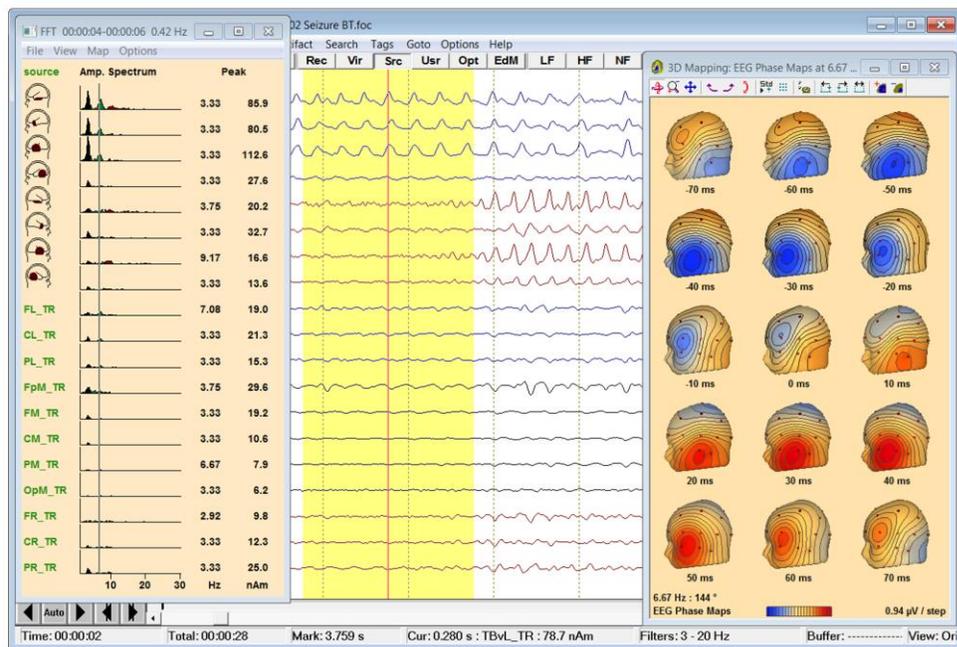
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In this seizure involving bilateral temporal cortex, we will analyze the different base rhythms near onset both in the left and right hemispheres as well as the first harmonic (at twice the base frequency).

The FFT of the left LT onset shows a clear bipeaked pattern in the spectrum of the left basal, polar and lateral channels (base: 3.33 Hz, 1st harmonic: 6.7 Hz).

The phase maps at the base frequency are dominated by the lateral pattern.

Bilateral seizure: left temporal onset, phase map of first harmonic



LT first harmonic (6.67 Hz):

Basal leads polar and lateral with strong map rotation.

Can be seen also in TL source montage in clean EEG.

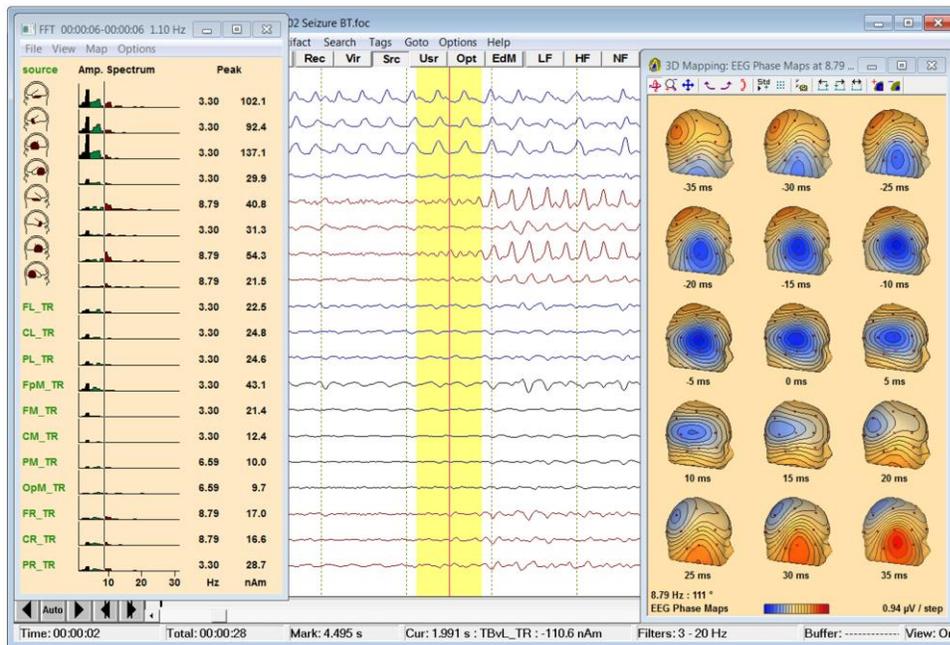
When analyzing the first harmonic (6.7 Hz), we observe the largest spectral peak at the base (this is in line with the sharper pattern in the basal source channel).

The phase maps now show a clear basal pattern with a propagation to polar and lateral.

This may be interpreted as showing a preservation of the delay pattern - typically also seen in the spikes of such cases - across the initial cycles of the seizure onset.



Bilateral seizure: right temporal onset, phase map of small high rhythm



RT first frequency (8.79 Hz):

Basal leads lateral.

Can be also be seen in TL source montage in clean EEG.



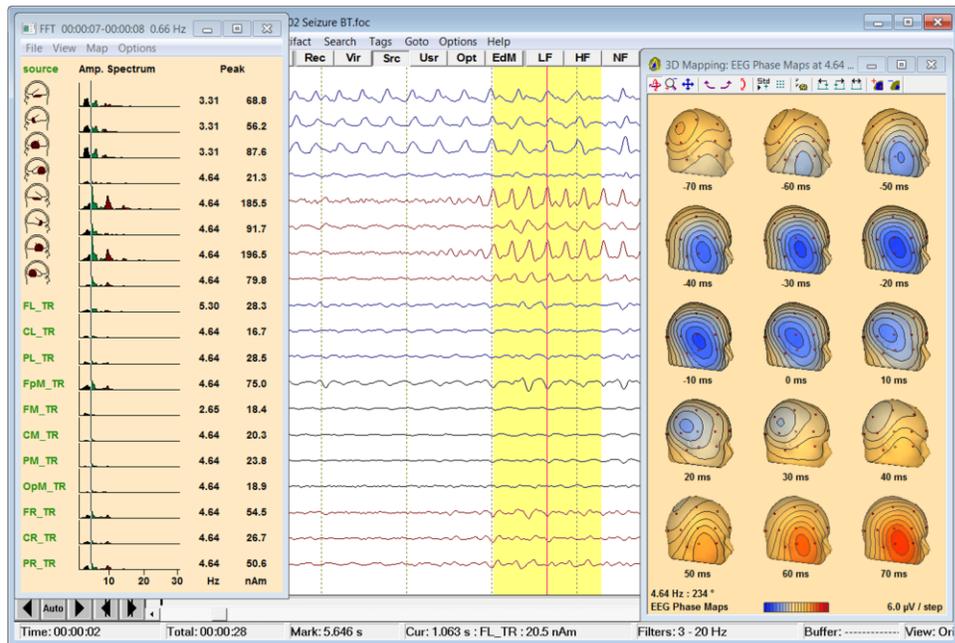
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The initial onset oscillation of 8.8. Hz in the right TL could easily go unobserved in view of the much clearer and larger oscillation of 4.5 Hz one second later.

The phase maps exhibit a basal to polar (weak) and lateral propagation.

Bilateral seizure: right temporal slowing, phase maps of main rhythm



RT second frequency (4.54 Hz):
Lateral pattern dominates. Basal lead is questionable.

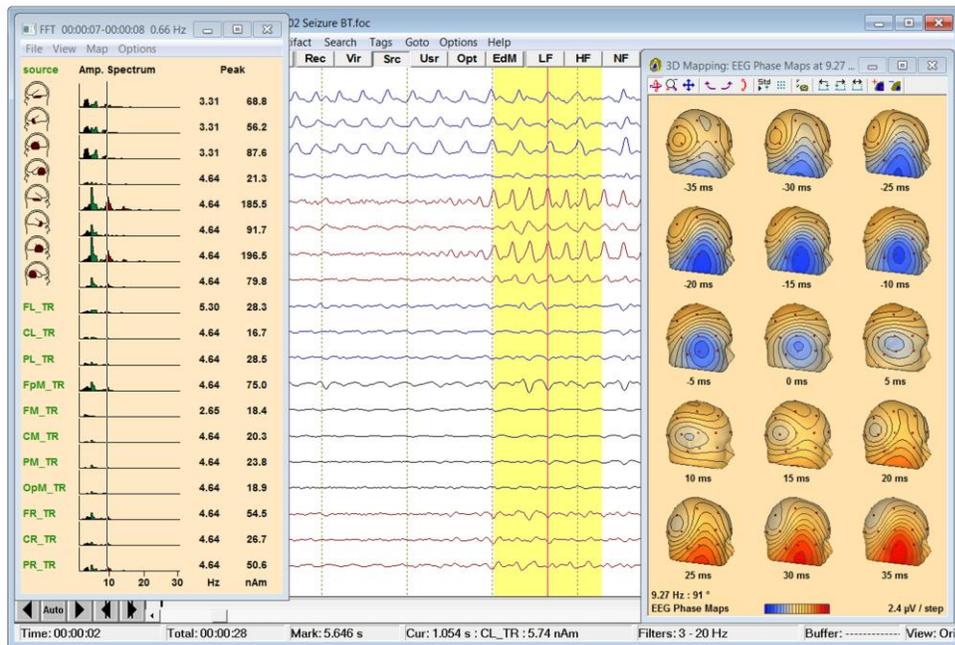


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The later and larger RT oscillation of 4.5 Hz shows a similar pattern that is more dominated by the lateral pattern.

Bilateral seizure: right temporal slowing, phase maps of first harmonic



RT second frequency, 1st harmonic (9.27 Hz):

Basal-polar lead is becoming clearer.



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The basal onset pattern can be seen better again when analyzing the first harmonic at 9.3 Hz.

Extratemporal seizure: transversal and longitudinal bipolar (virtual m.)



DSA

showing a clear chirp going down from 8 to 5 Hz.

DSA of an extra-temporal seizure:

A chirp can clearly be seen in the right hemisphere (R) going down from about 8 to 5 Hz. This chirp becomes most clear when selecting only the frontal and parietal source channels (FP) and not using all left versus right regional sources including those of the temporal lobe (BR).

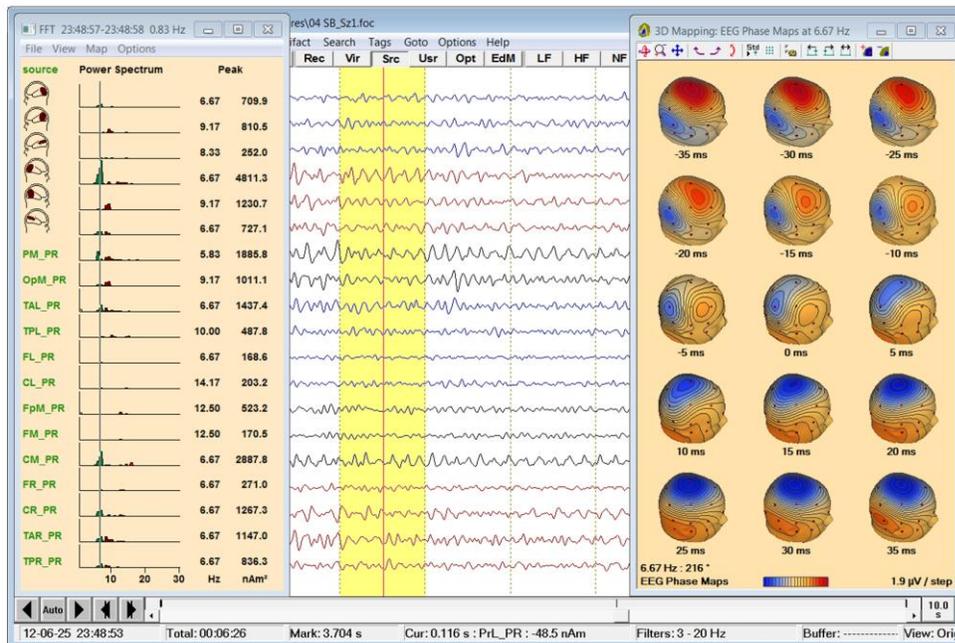
The traditional bipolar EEG channels show the seizure activity most clearly in the transversal channel C4-Cz and, more pronounced earlier, in PZ-OZ (the virtual montage BiHL combines horizontal and longitudinal bipolar channels).



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Extratemporal seizure: parietal source montage, phase maps



Phase maps

First clear rhythmic pattern is a 6.7 Hz.

FFT of the first relatively clear oscillatory pattern shows a spectral maximum in the radial right parietal source channel as well as in the regional source below Cz (CM).

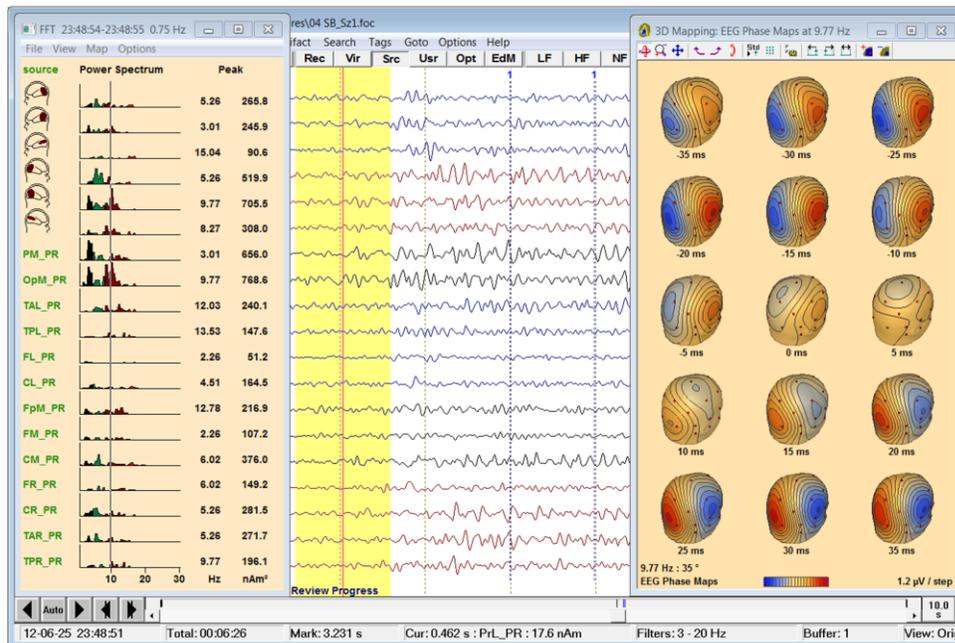
The phase map at 6.7 Hz shows a rotating center that is clearly over the right parietal region. There is no sufficiently large first harmonic to map.



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Extratemporal seizure: parietal source montage, phase maps at onset



Phase maps at earliest onset:

Clear dipolar pattern in phase maps.

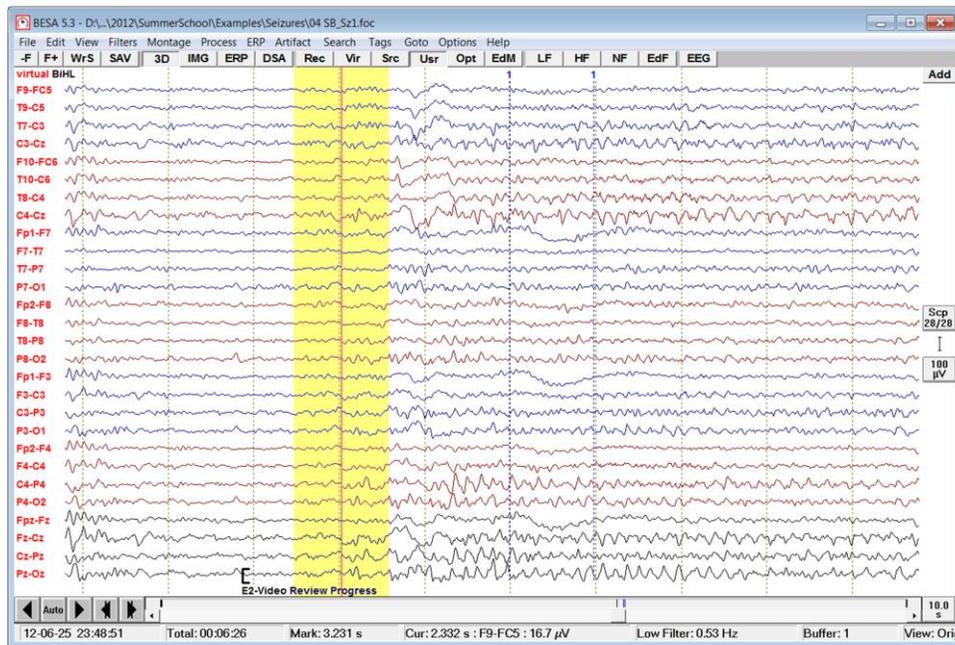
Barely visible onset rhythm of 9.8 Hz in right parietal tangential source trace.

Upon close inspection of the onset (out of a relatively calm EEG), we can observe an oscillation at a higher frequency (9.8 Hz) that occurs about 2.5 seconds earlier and shows up most prominently in the right parietal tangential source channel and on the regional source below Oz.

The phase maps at this higher frequency and earlier onset show a predominantly tangential pattern with a center slightly more posterior and towards Oz (mostly below P4).



Extratemporal seizure: transversal and longitudinal bipolar (virtual m.)



Onset rhythm of 9.8 Hz not clearly visible in P8-O2, P4-O2 and Pz-Oz without higher low cutoff filter.



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If we go back to the bipolar montages with the typical clinical filter settings (0.3 second time constant), it is unlikely that we would have detected the small initial oscillation observed by FFT, phase maps and the parietal source montage.

Conclusions

1. **DSA** is a useful tool to identify the frequency chirps associated with seizures.
2. Onset analysis using **FFT**, **phase maps** and **source montages** can help to identify the first oscillatory onset activity at an earlier latency as compared to using traditional EEG review.
3. Phase maps are voltage maps and can, thus, help to **localize** the onset zone.
4. Other EEG rhythms at onset can make the analysis difficult. Thus, tracing back to the onset is important.



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- Andrea Ostendorf, BESA GmbH, Gräfelfing / Munich
- Dieter Weckesser, BESA GmbH, Gräfelfing / Munich

More lectures and tutorials showing the analysis of epileptic spikes and seizures can be found along with recommended electrode settings on:

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