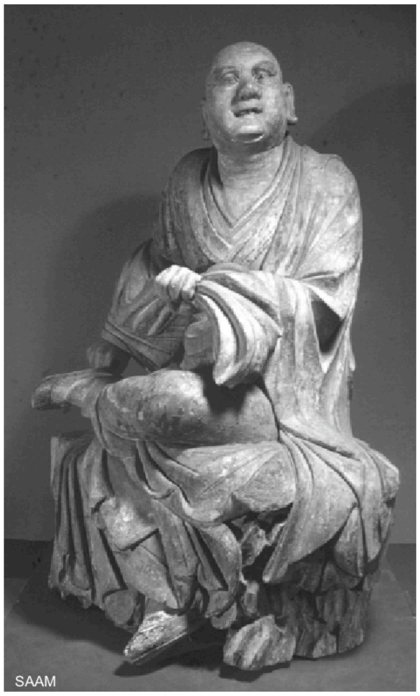

Moving from 2-D to 3-D EEG-based brain imaging

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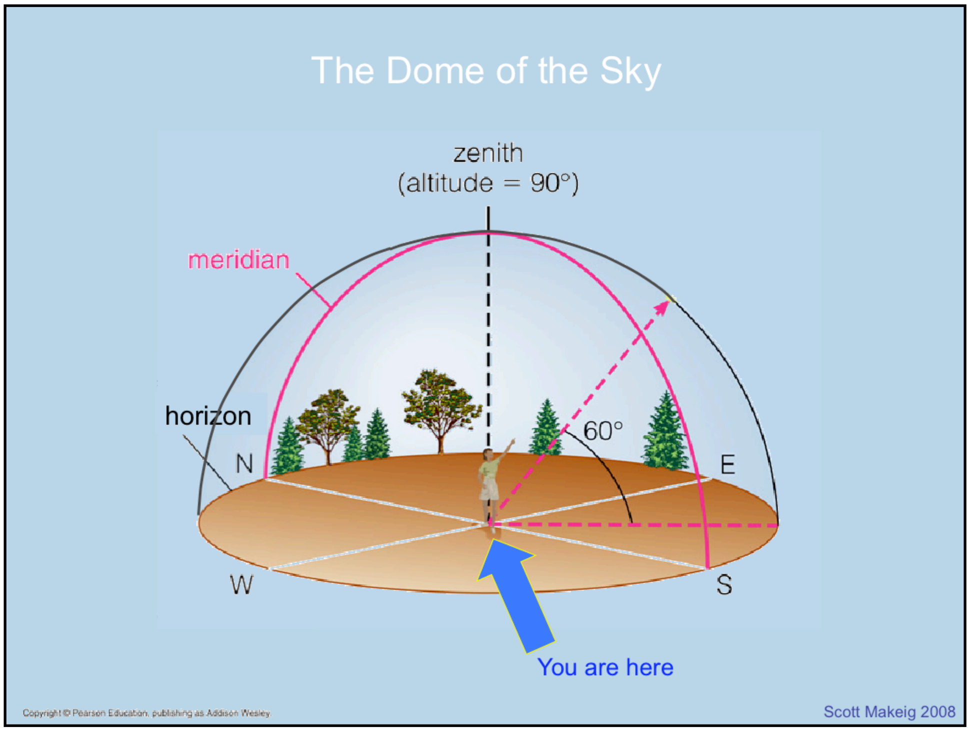
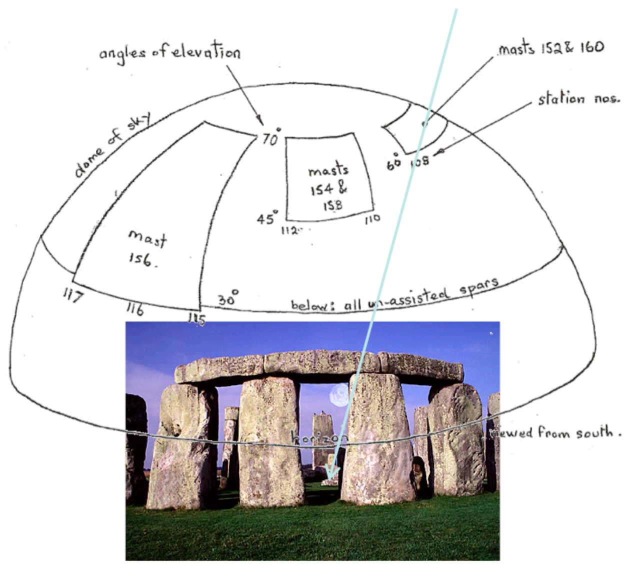
Portion of a Powerpoint presentation by Scott Makeig to the workshop, "Insights on Insight" at the Rancho Santa Fe Inn, San Diego CA, September 2008.



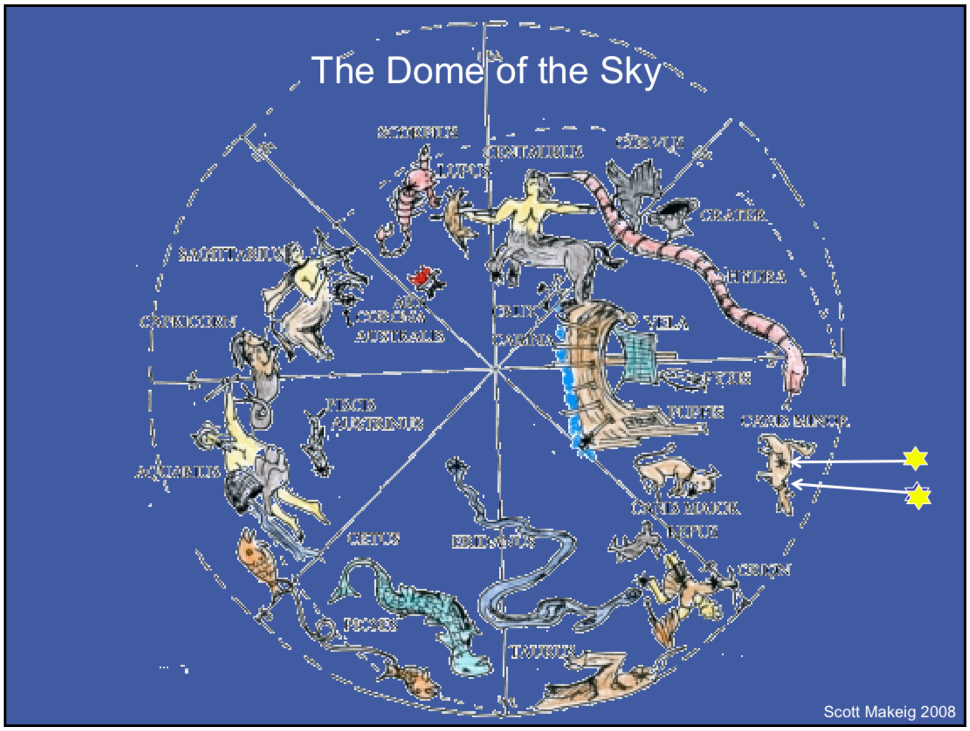
Our naïve perceptual view of the sky above us is of a dome on which, at night, the stars are hung – with us in the center of the dome.

The Dome of the Sky

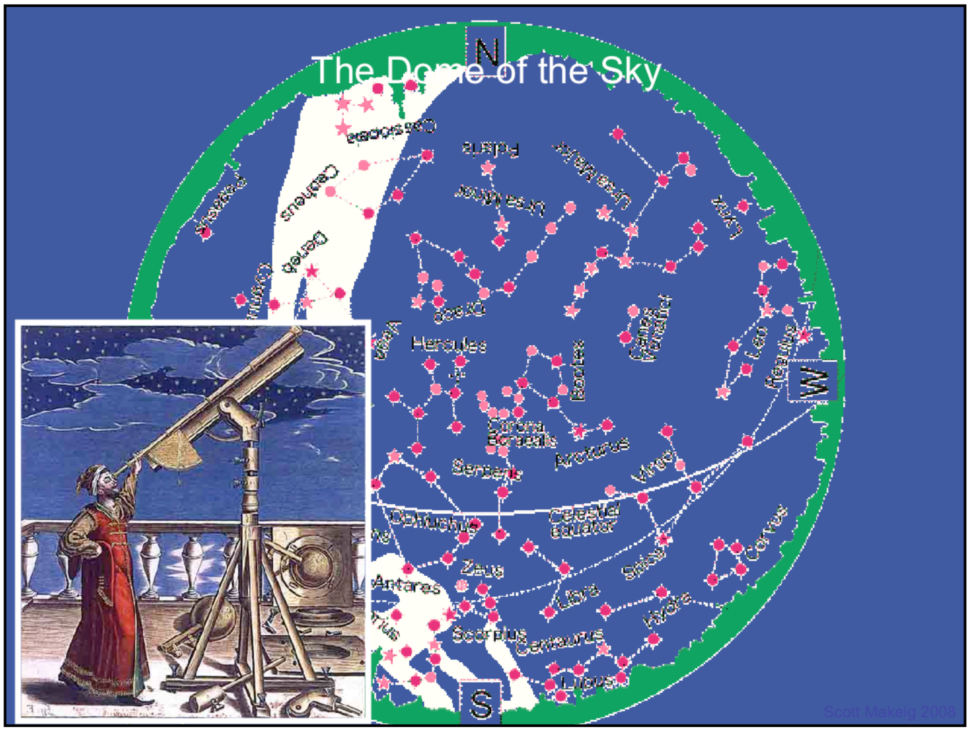


Scott Makeig 2008

Ancient cultures attributed power to the light of the stars, sun, and planets, constructing monuments (as here, Stonehenge) to focus their light at key moments in the yearly astronomical cycle.

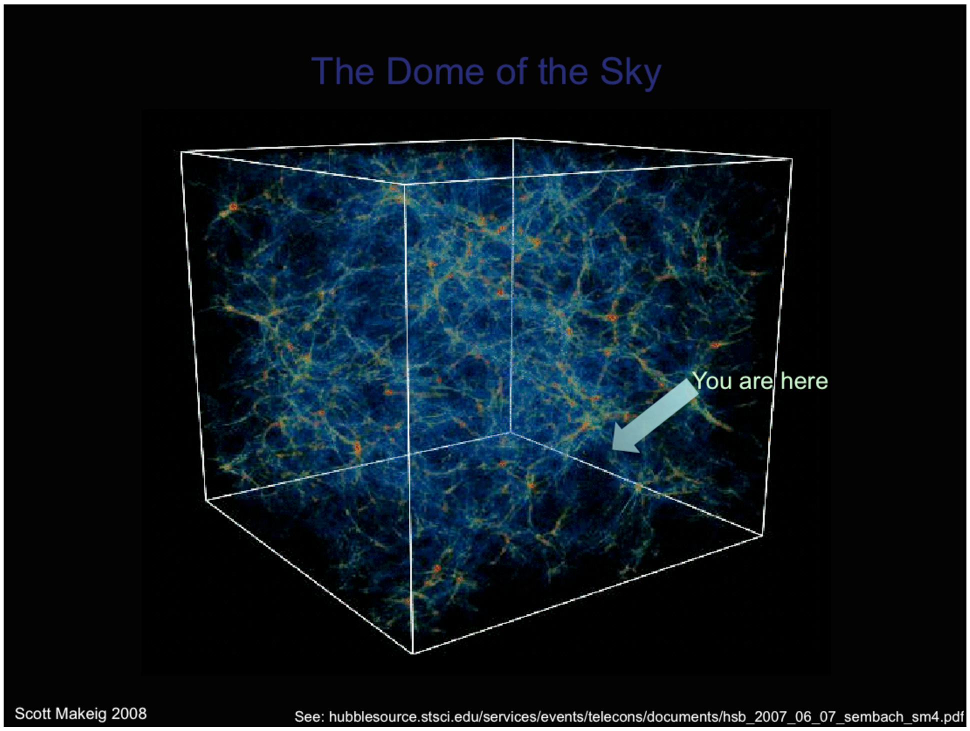


In ancient cultures, distances between stars were measured in two dimensions (by the angle between them on ‘the dome of the sky’).

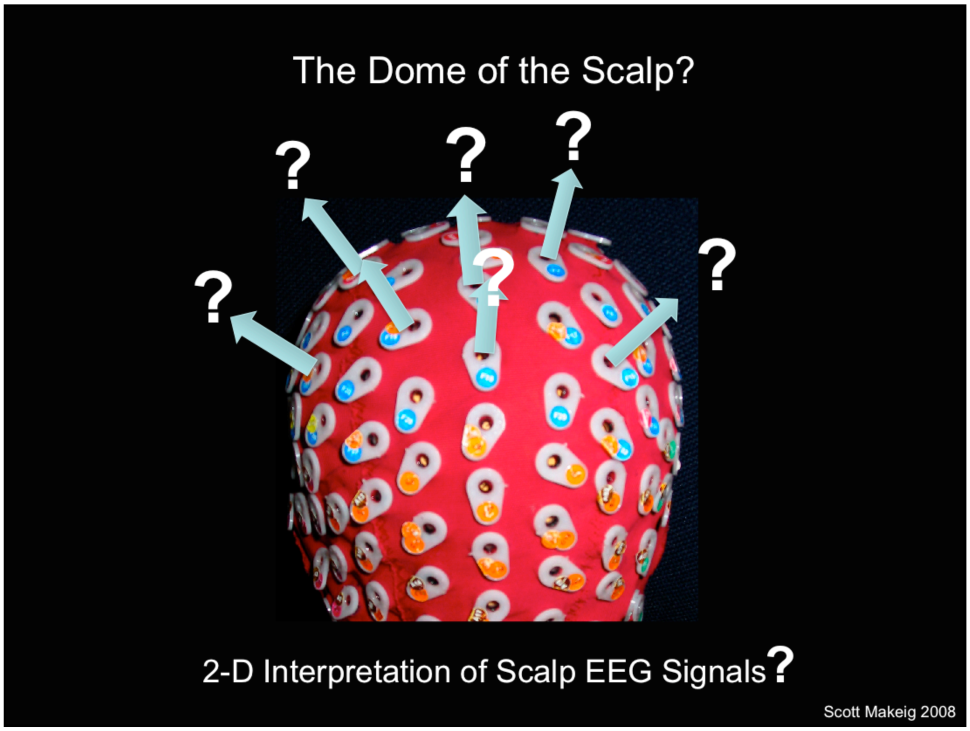


Millenia of advances in astronomical observations gave rise to increasingly more detailed knowledge and more realistic viewpoints…

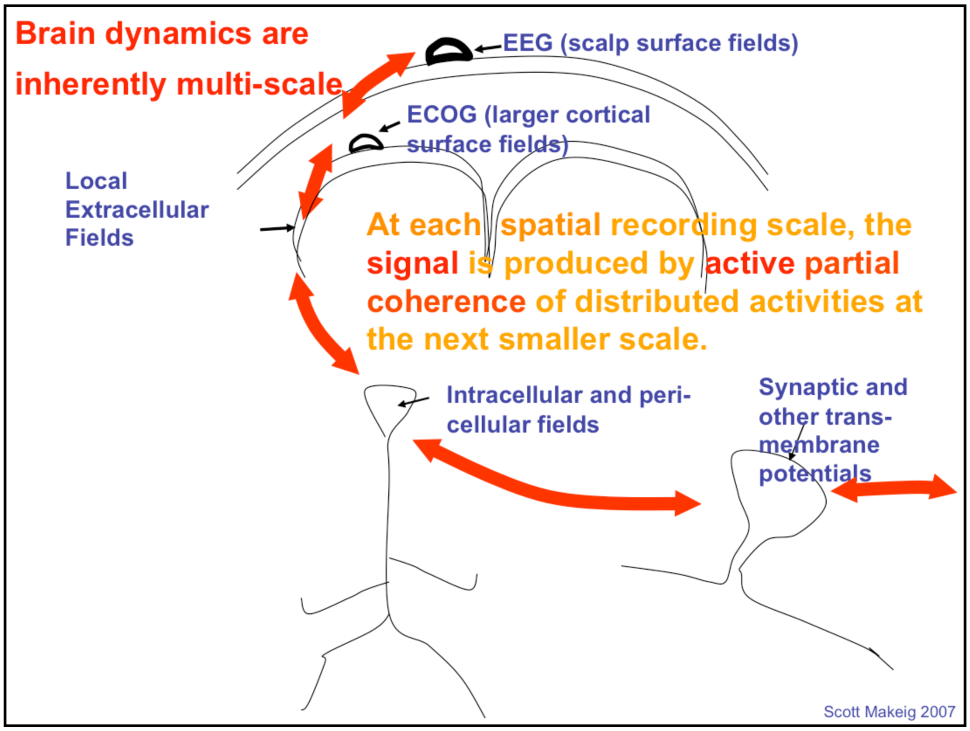
Modern astronomy delivers images that make clear that the stars are arrayed in a vast 3-D space (which Einstein and later physicists have expanded into 4-D or even 8-D universe models).



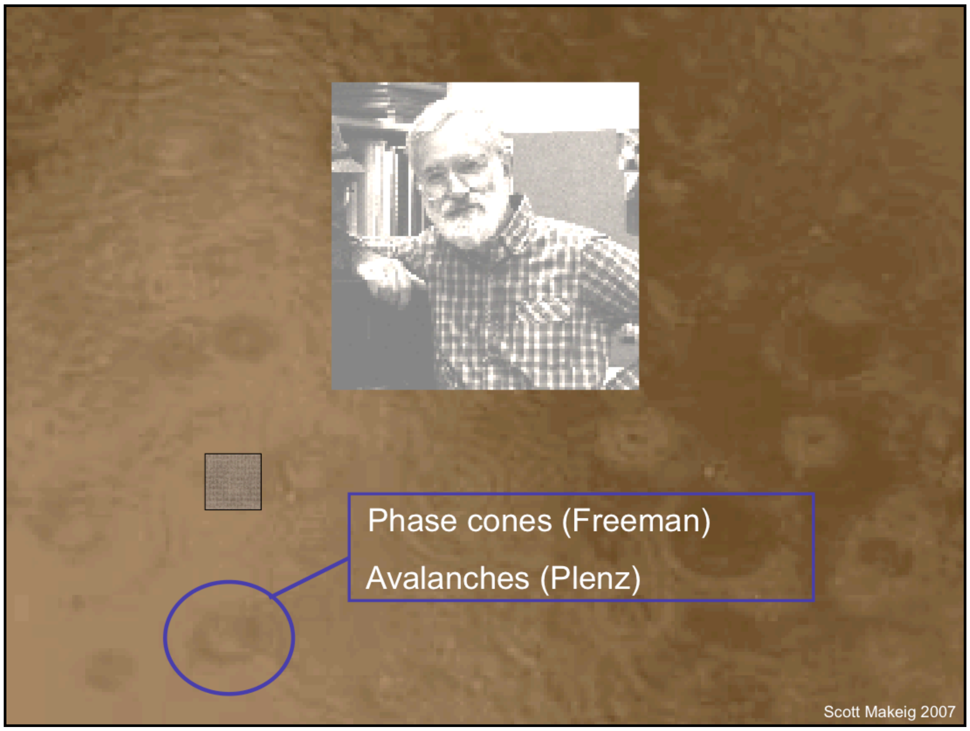
A 2008 tour-de-force computation based on Hubble satellite imaging shows the macro 3-D structure of the universe, with puzzling filaments of galazies and deep voids. The stars (in their galaxies) no longer are viewed as existing in a 2-D ‘dome of the sky’



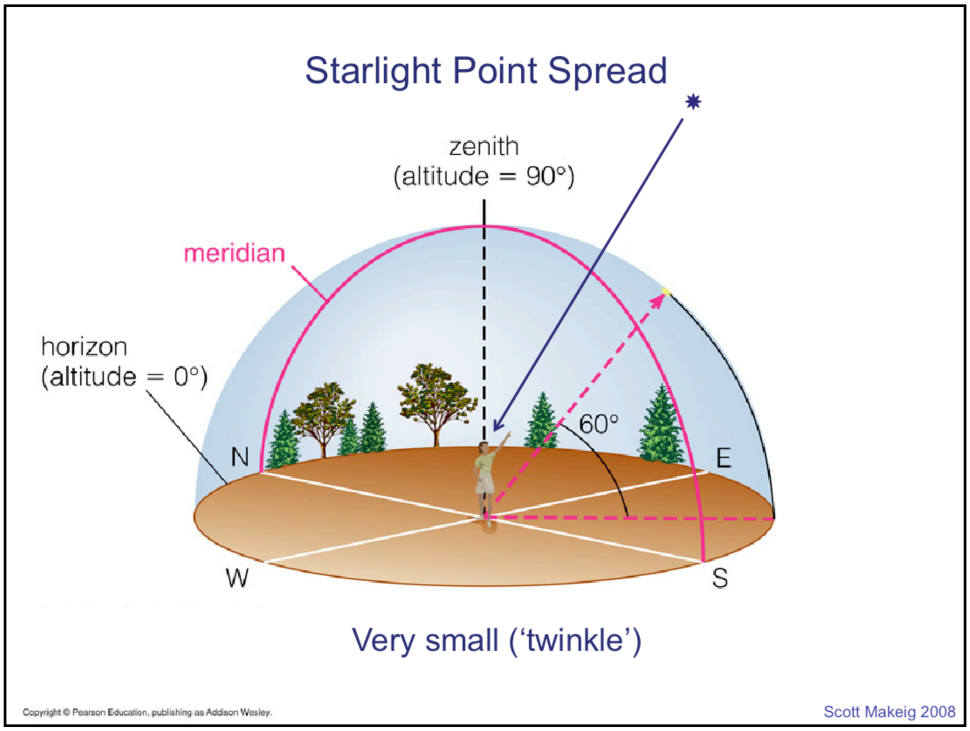
Since its modern beginnings in the late 1920s, however, EEG has been interpreted by most investigators as if it were a 2-D brain imaging modality…



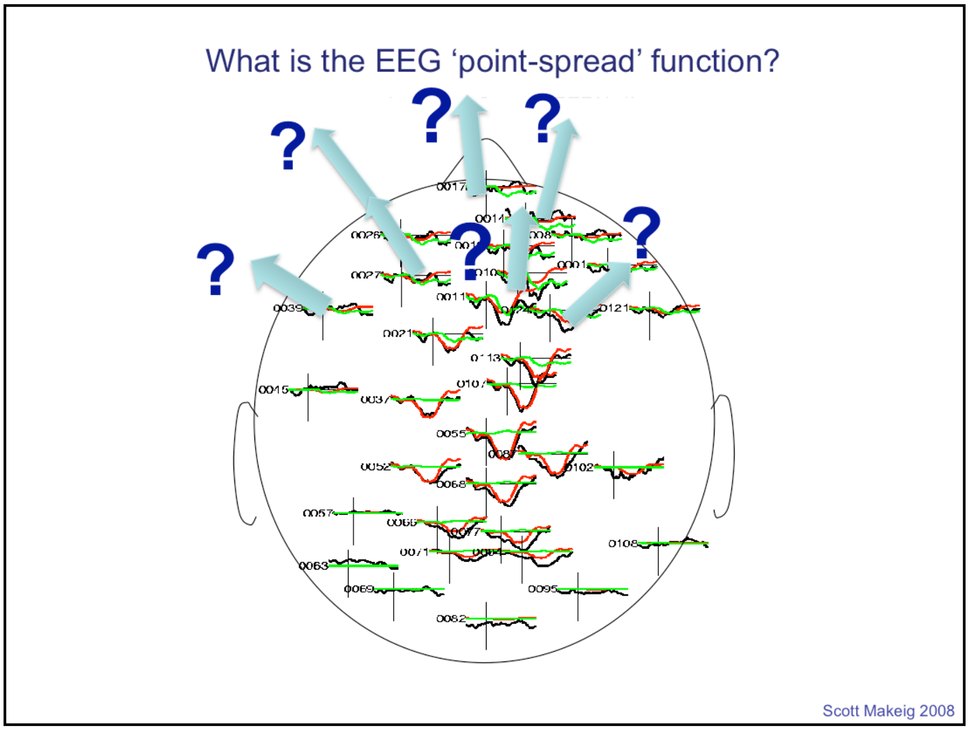
However, brain dynamics are inherently multiscale, to an extent matched by no manmade system….



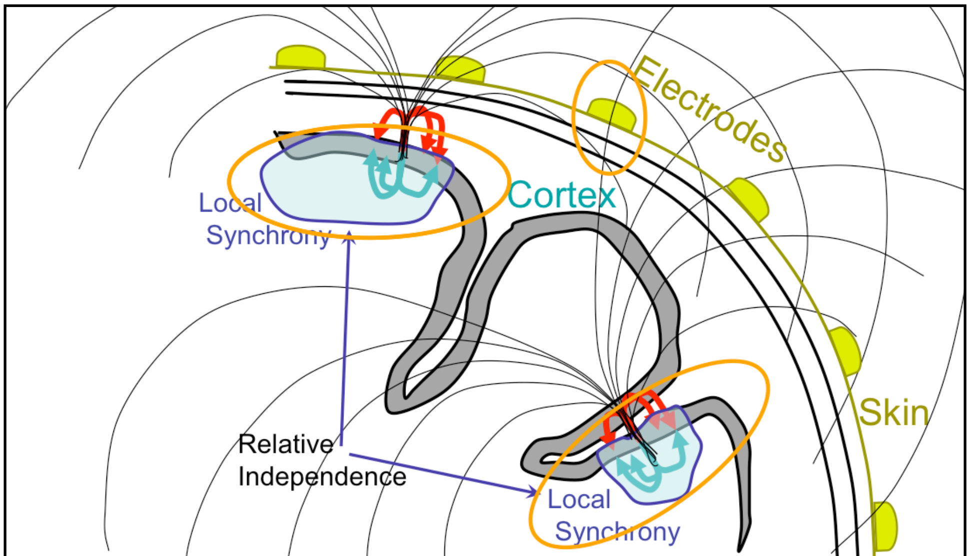
Pond ripples is the EEG model or metaphor offered by Walter Freeman from his long observation of field patterns in small (3 mm x 3 mm) arrays on the cortex of animals.



Now, the 'point-spread' function for starlight is rather small (stars seem only to 'twinkle')…

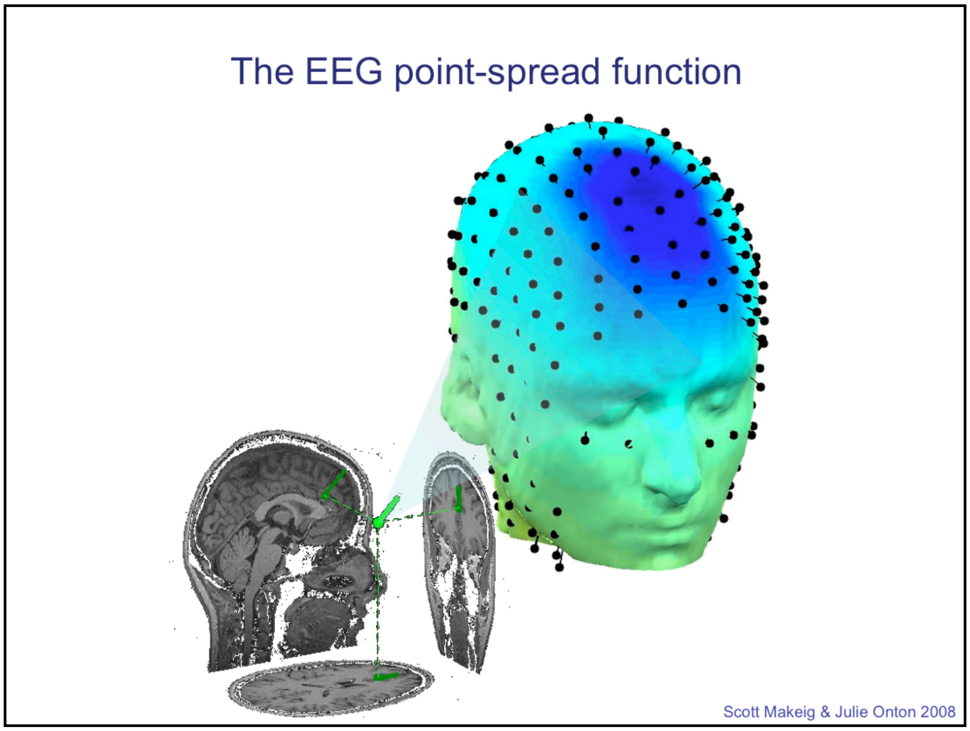


But what about the point-spread function for EEG signals? Measures at scalp channels (here, event-related potential or ERP waveforms) appear as if they should eminate from different parts of the brain…

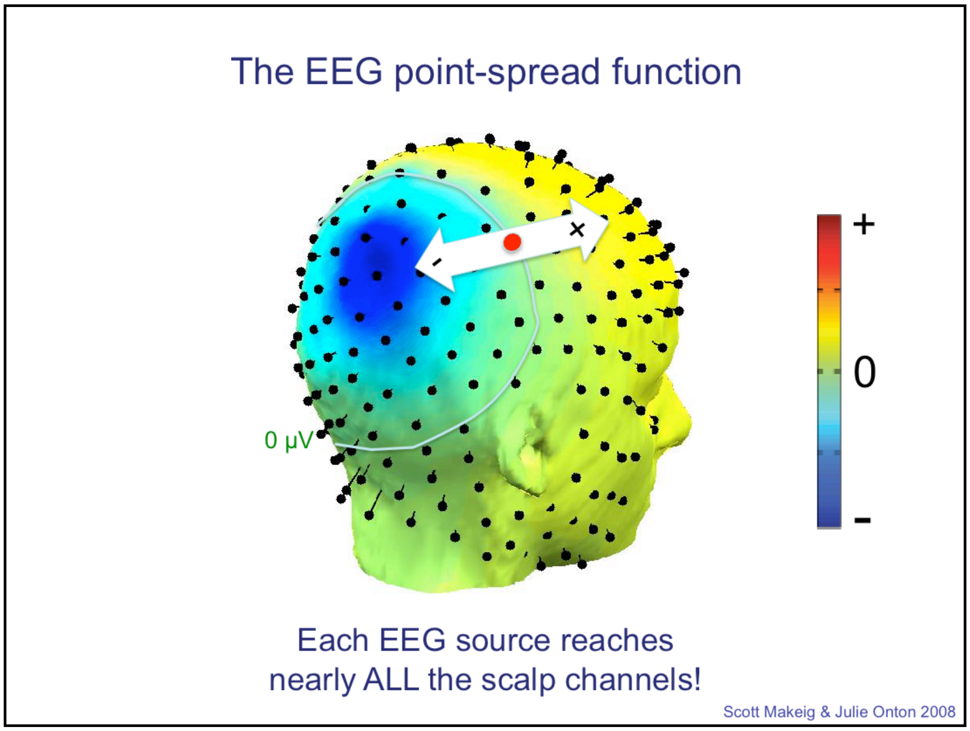


SPATIAL SOURCE FILTERING

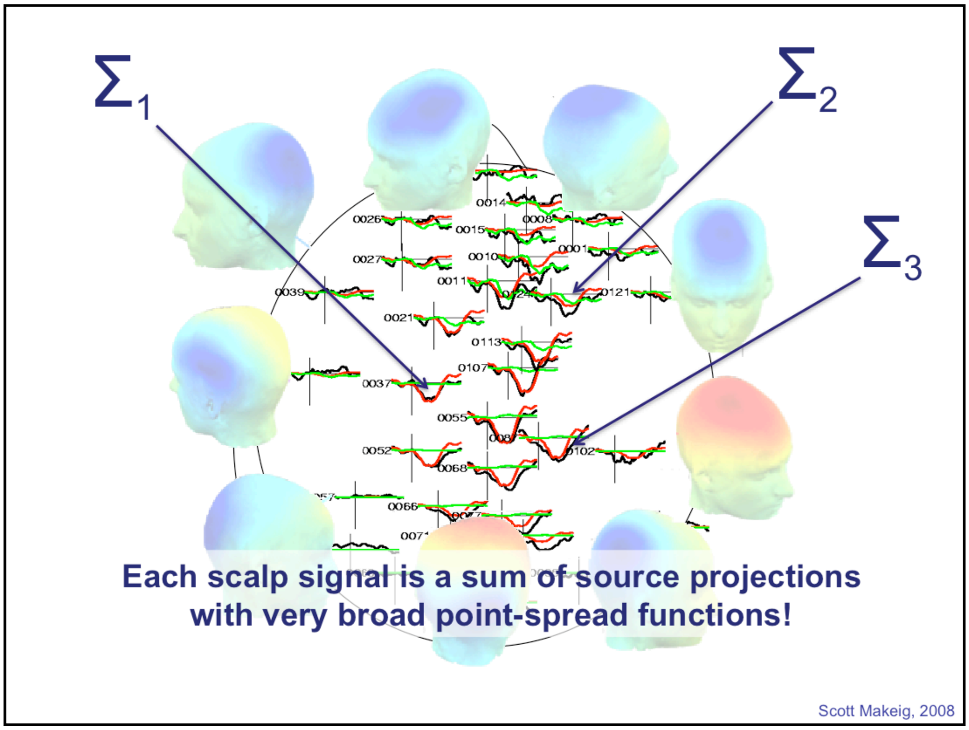
However, basic biophysics dictates that field activity originating in a cortical patch (here drawn in schematic cartoon view only) project very widely across the scalp --- meaning that the signals received by (and summed at) electrodes on the scalp surface are mixtures of acitvities originating in main places – mainly in the brain's cortex. For this reason, it makes little sense to consider the time courses of activity as they are received at scalp electrodes, but instead to concentrate on building spatial filters for activity generated in each source region… In the past, this was technically challenging…



Here, the scalp projection of spatially coherent activity in a small patch of cortex (e.g. in the cingulate cortex) projects to nearly all the scalp electrodes (only green here signifies no projection).

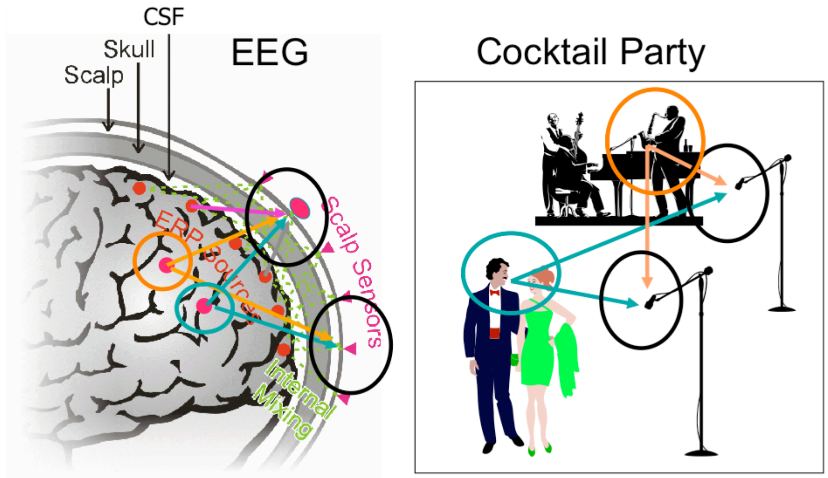


Actually, the projection from a cortical patch is bi-directional (matching that of an equivalent current dipole), so as here, only a thin ‘equator’ line of channels receive no contribution at all from each cortical EEG source area…



Thus, data recorded at each scalp channel actually represents a unqiue mixture (weighted sum) of very broad spatial projections, and is NOT dominated by activity originating just below the electrode!

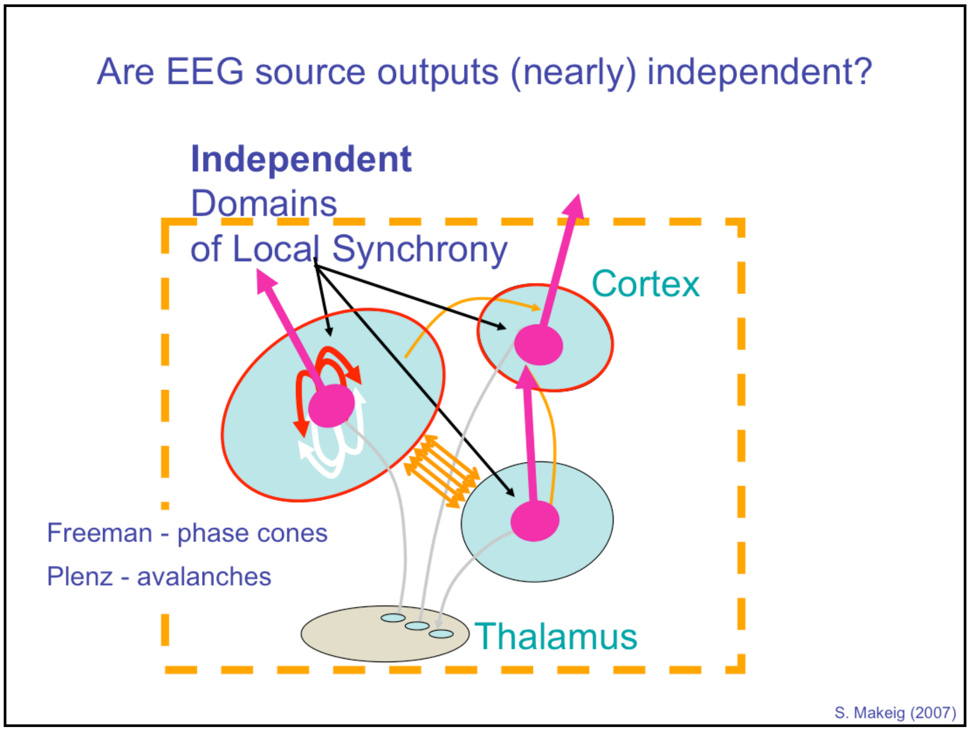
EEG Source Filtering
by Independent Component Analysis



S. Makeig (2000)

Independent Component Analysis (ICA) (right) can be used to separate N sound sources summed in recordings at N microphones, without relying on a detailed phonological model of the sounds characteristics of each source – this is so-called “blind separation.” ICA uses the presumption that the waveforms of the individual sound sources are independent over time.

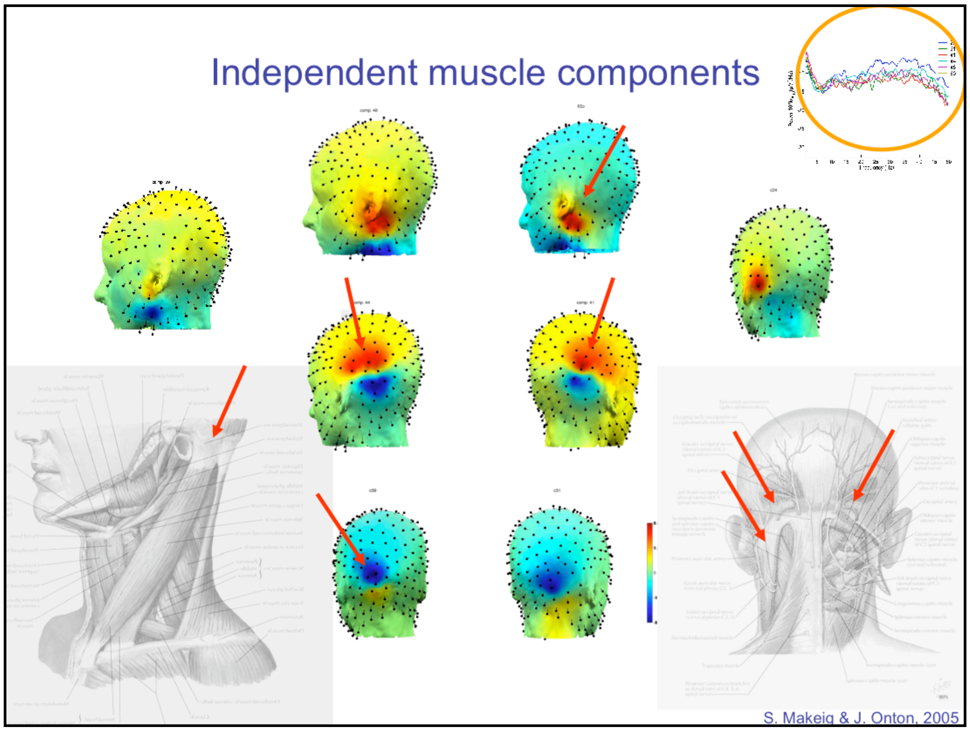
Applied to EEG data (left), ICA assumes that the EEG is predominantly composed of a number of domains of synchronous neural (or neuroglial) activity, each of which must, by simple biophysics, project to most of the recording scalp electrodes. If synchronous activity within these domains are predominantly independent of each other, ICA can separate the summed signals from these domains into records of their separation activities, given that the number of such domains making large contributions to the recorded signals are smaller than the number of recording sites.



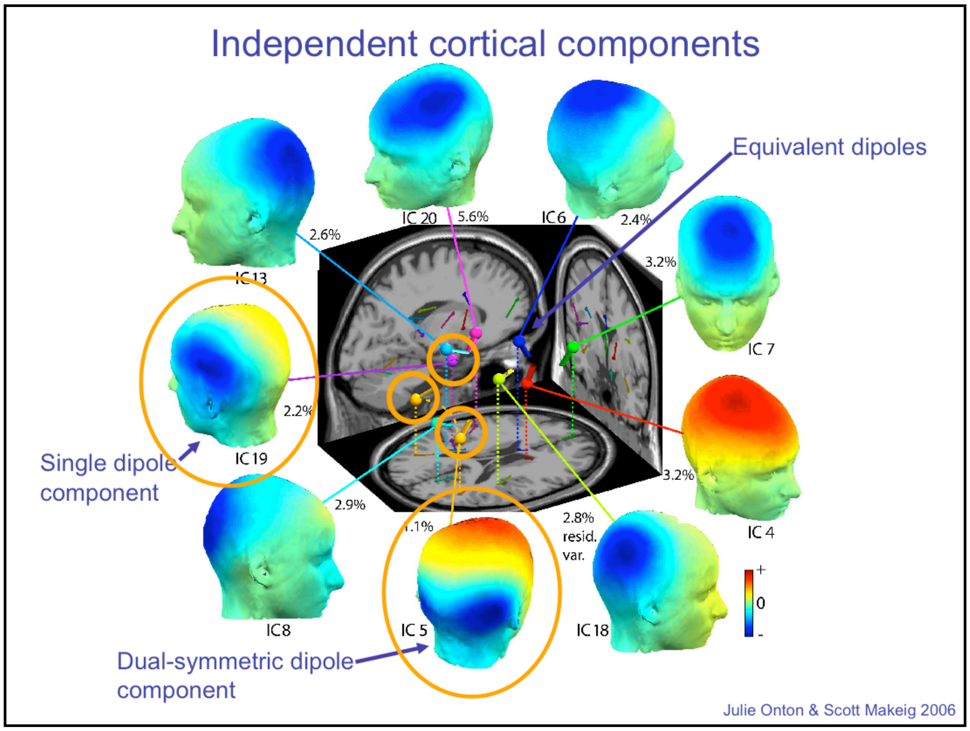
Basic biology of cortical connectivity (highly weighted toward short-range connections between neurons, particular among inhibitory neurons (here coded by white arrows) and in excitatory and inhibitory neural loops, make the concept of relative independence over time in the coherent local field activity time courses of different cortical patches physiologically natural – thus fulfilling a key assumption of ICA.

Mathematically, the scalp projection of a (near) synchronously active cortical patch must match that of an equivalent current dipole (infintesimal battery) typically located below the center of the patch). That is, the sign of an EEG source should be a scalp projection map that closely resembles a map produced by an equivalent current dipole.

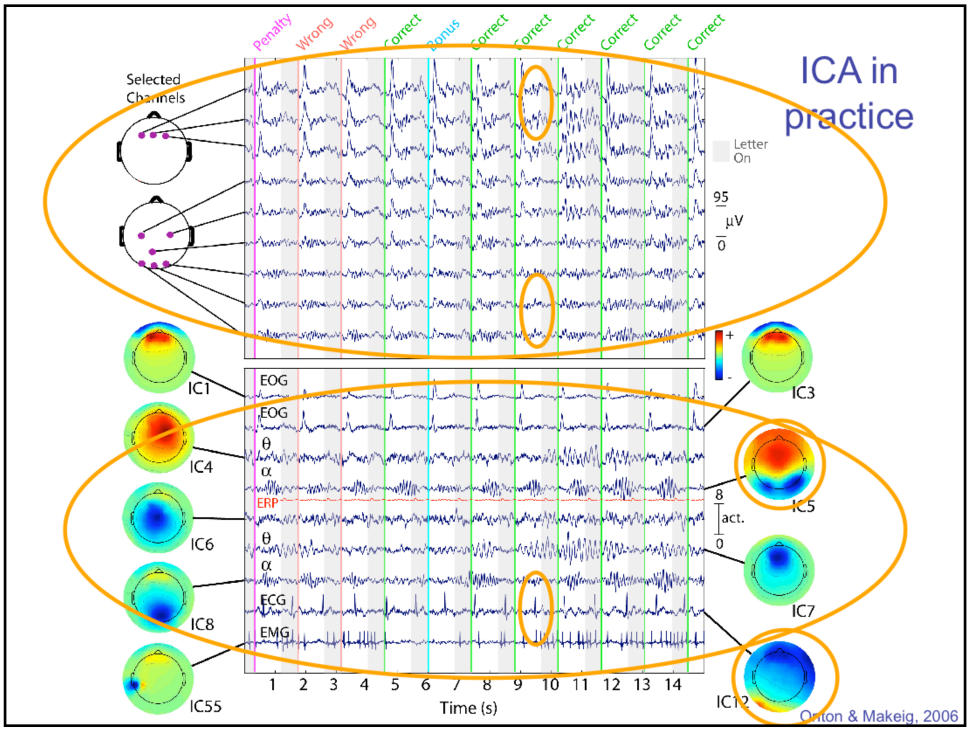
In some cases, resonant activity may arise in two highly coupled cortical areas. In this case, their summed scalp projection map can be modeled by two equivalent dipoles, in particular dipoles symmetrically located (though not necessarily similarly oriented) across the brain midline – a result expected when the two couple cortical domains are connected across the massive left -to-right coupling corpus callosum.



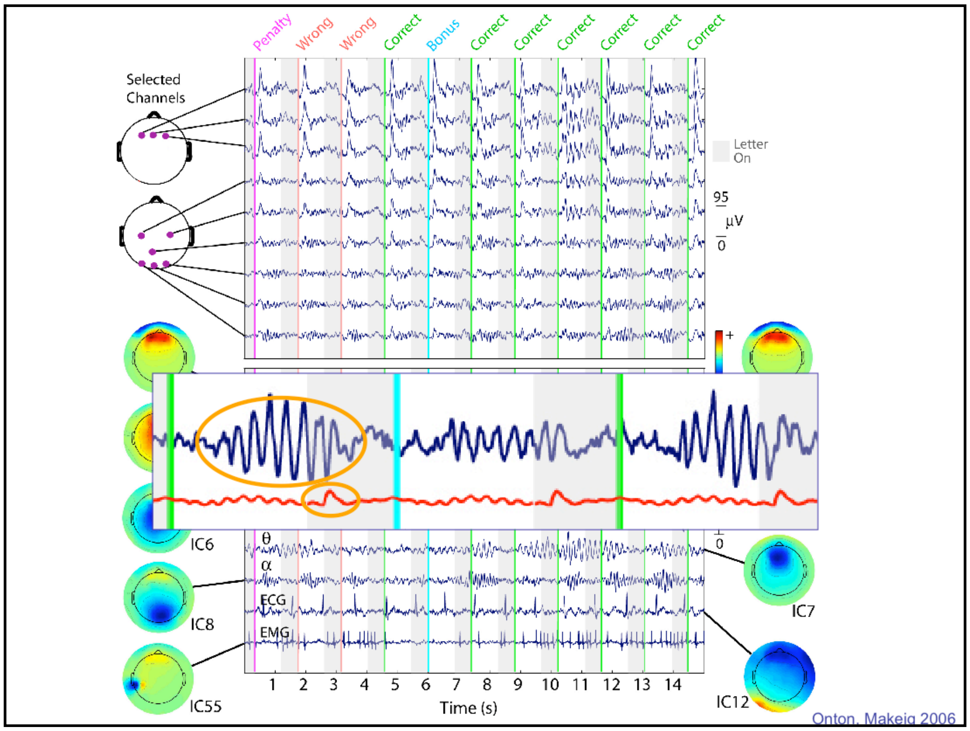
An immediate advantage of ICA dcomposition of EEG signals is its ability to separate out electromyographic (EMG) activity from individual scalp and neck muscles, as here from a single session. Other non-brai artifacts including eye blinks and eye movements, ECG, and line noise, may be separated by ICA into one or a small number of component processes, thereby separating them from the (brain-generated) EEG data.



In the same session, these independent component processes were also identified by ICA. Each of them can be extremely well accounted by a single equivalent dipole (or in the bottom center case, by two symmetrically placed equivalent dipoles). This supports the assumption that independent EEG components should arise in a compact cortical patch brought into (near field synchrony.



This shows 15 seconds from an hour-long session in which the subject performed a difficult working memory ('Twoback') task. The tope panel shows 9 of 100 scalp electrodes, and the bottom panel 9 of 100 derived maximally independent component signals that together sum to the recorded data (above). Note the 'distinctiveness' of the derived independent component waveforms, and their clear accounting of EMG (muscle), ECG (heart), EEG, and eye blink signals respectively. Note the highlighted spike in the ECG component process – and the difficulty of extracting this single signal from the scalp-recorded mixtures (above).



Here, we zoom in on one independent component waveform (in blue) – that of a bilateral posterior (occipital) component that emits a burst of alpha (circa 10 -Hz) activity following each task trial (and eye blink, see preceding slide). For comparison, we have copied (in red) the average ERP for this component time locked to the onsets of the visual stimulus (beginning of the grey background), here repeated for visual effect 3 times in succession. Note the extreme loss of data involved in response averaging, and the fidelity with with moment-to-moment changes in the output of these coupled visual brain areas can be monitored from scalp recordings… making possible a new 3-D brain imaging modality based on non-invasive scalp EEG recordings.

Scott Makeig

September, 2008