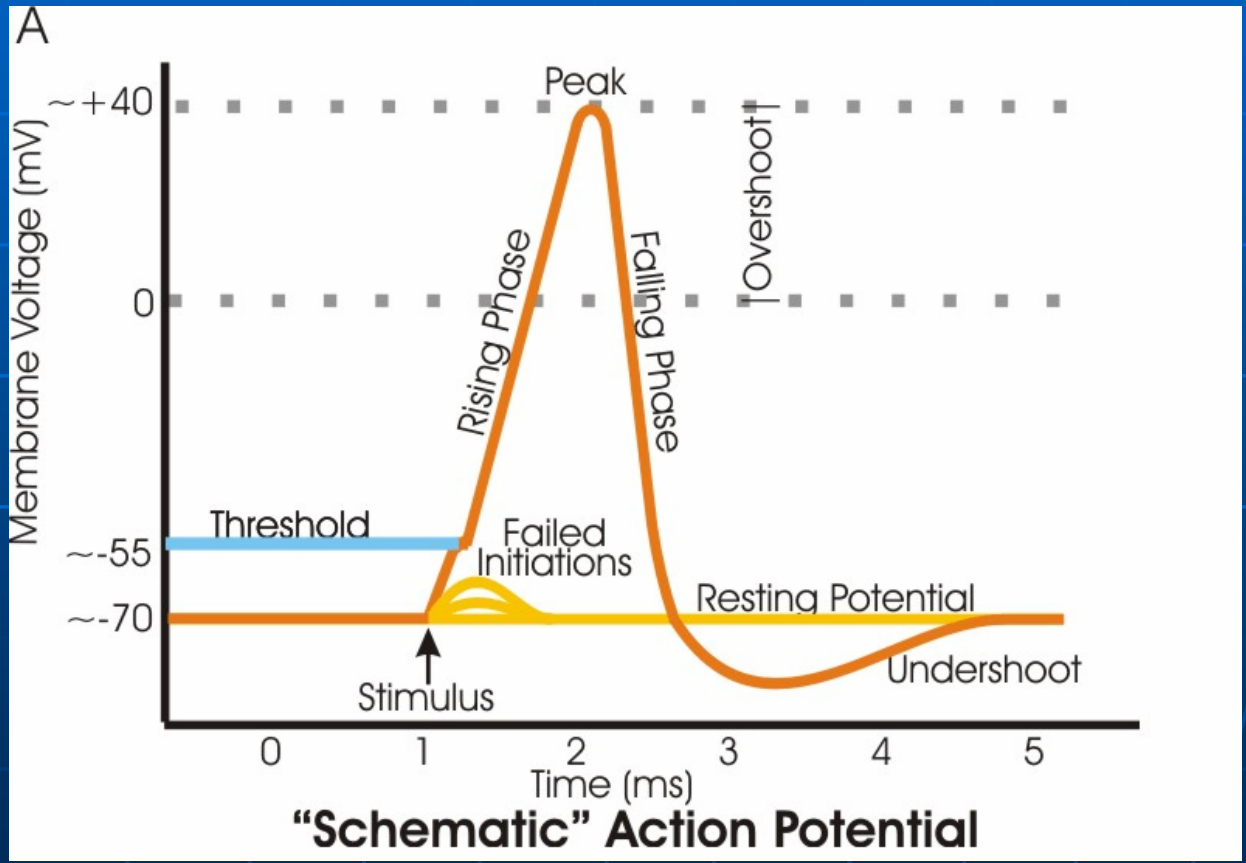
Spiral Waves in Disinhibited Mammalian Neocortex

Zofia Koscielniak

Based on a paper by Huang et al
Mentor: G. Bard Ermentrout
Group: Megan Jeans, Christopher Hackmeyer

Introduction: Action Potentials



Introduction: Spiral Waves

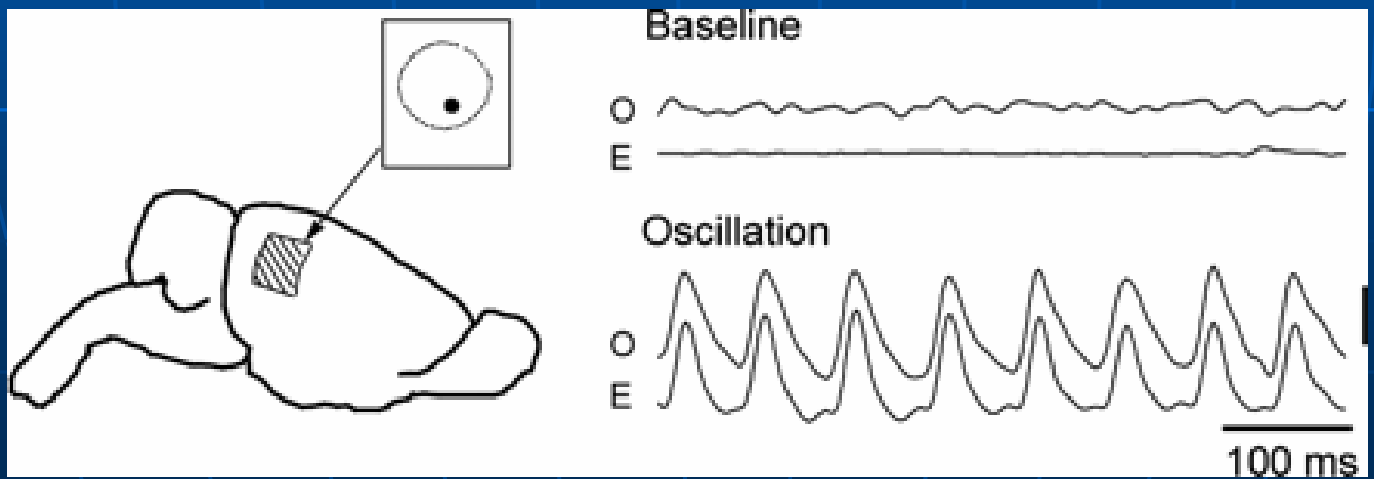
- Rotating wave traveling outward from a center
- Observed in
  - heart ventricular fibrillation
  - retinal spreading depression
  - fertilizing xenopus oocyte calcium waves
  - glial calcium waves in cortical tissue culture

Objectives

- Present evidence for stable spiral waves in rat neocortical slices with robust phase singularities
- Introduce a computational model of a cortical layer that predicts and replicates many features of the experimental findings

Experimental Methods

- Tangential slice of rat neocortex (occipital)
- Voltage-sensitive dye imaging



Computational Methods

- Each neuron is treated as a point
- Have excitation *u* and recovery *a*, no inhibition

$$\frac{\partial u(x,y,t)}{\partial t} = -u(x,y,t) + \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} w(x,y,p,q) f(u(p,q,t) - \theta) dpdq - a(x,y,t)$$

$$\tau \frac{\partial a(x,y,t)}{\partial t} = \beta u(x,y,t) - a(x,y,t),$$

$$w(x,y,p,q) = w_1 \left(\sqrt{(x-q)^2 + (y-p)^2} \right) g(q,p),$$

Results: Oscillation and Optical Signals

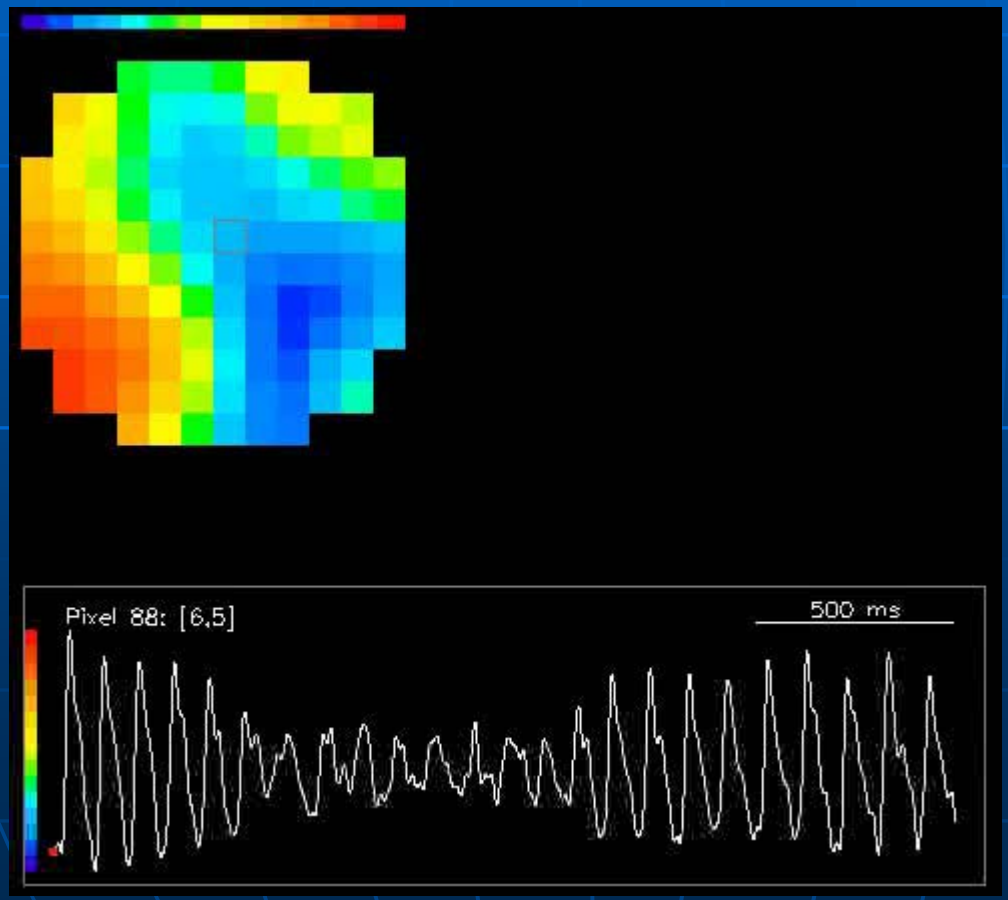
- 4-15 Hz
- Organized as epochs, each containing 10-50 cycles
- Occurred spontaneously
- Could be triggered by infrequent electrical stimulation

Results: Wave Patterns

- Oscillations developed into two-dimensional waves
- Four types of patterns
  - Spiral
  - Plane
  - Ring
  - Irregular
- Patterns occurred alternately within each oscillation epoch

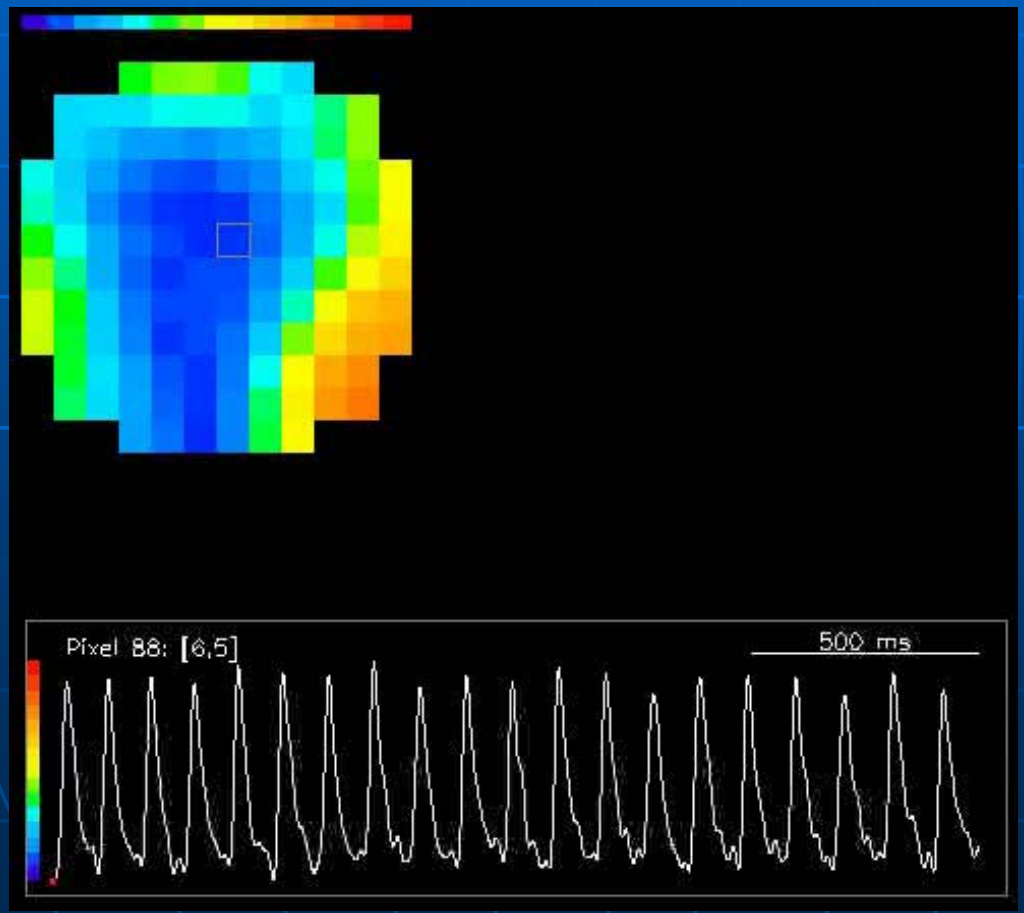
Results: Visualizing Waves

- Spiral Waves



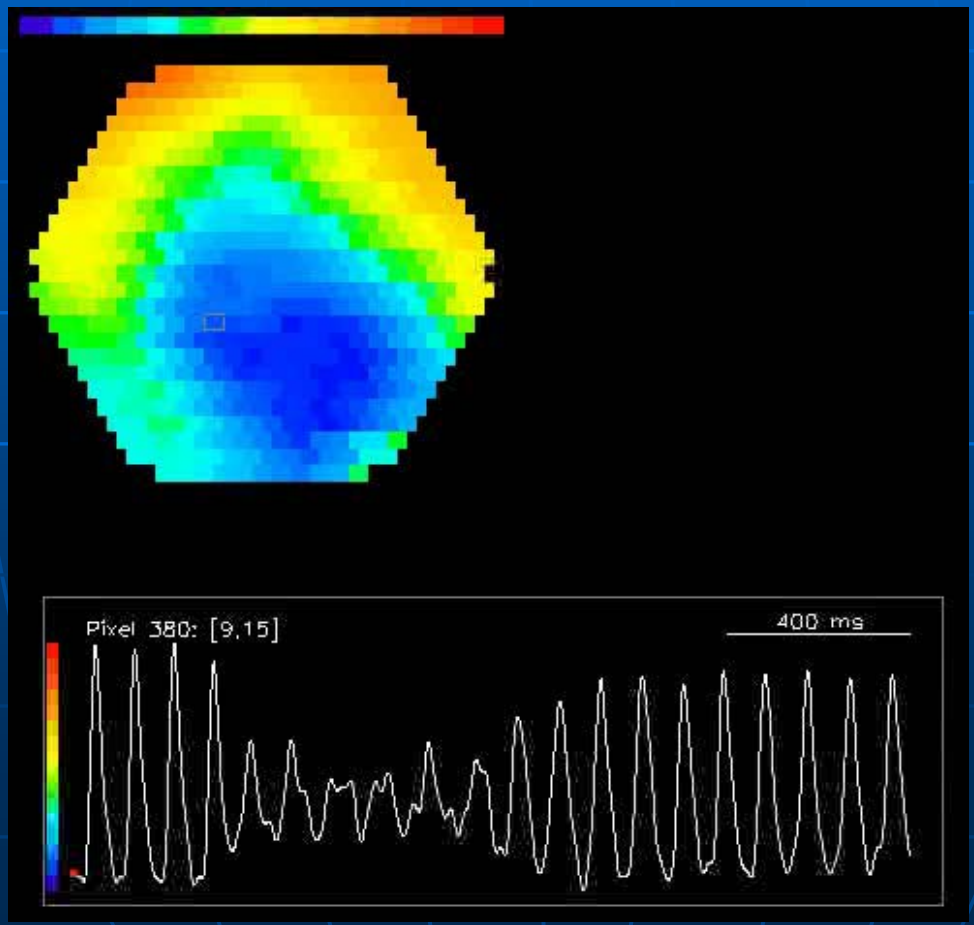
Results: Visualizing Waves

- Plane Waves



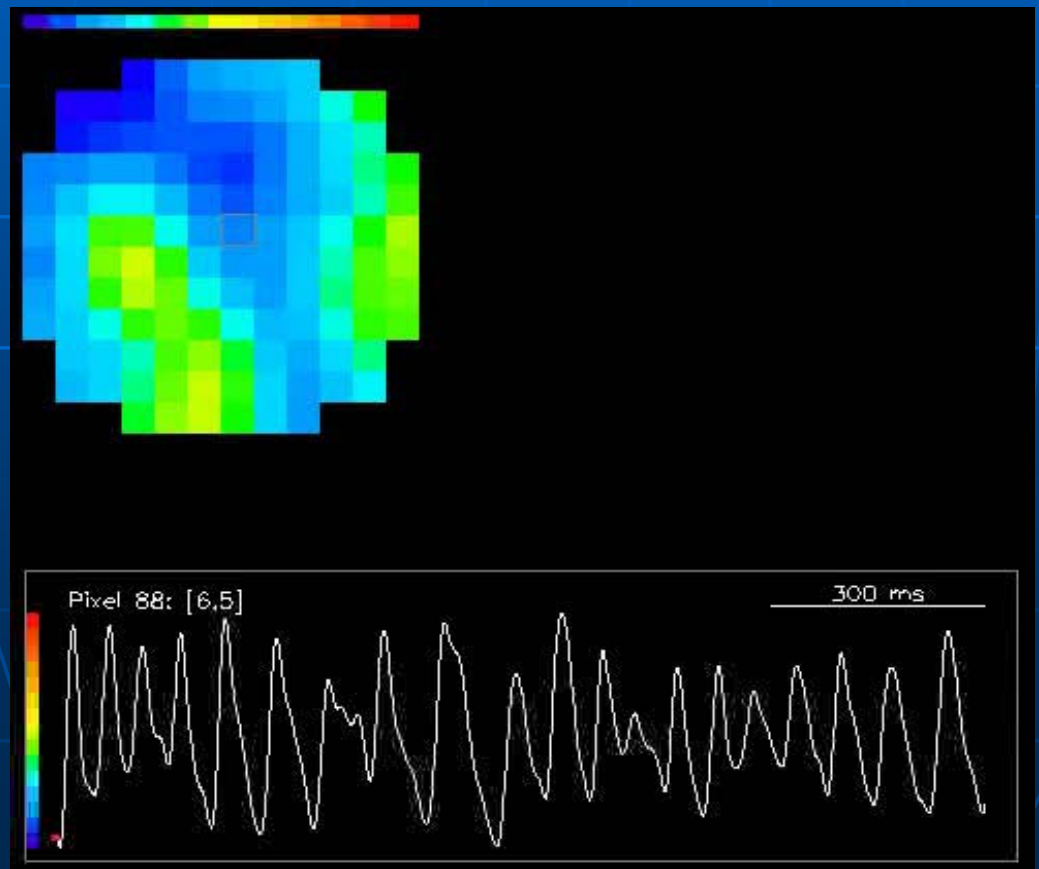
Results: Visualizing Waves

- Ring Waves (Movie: Ring to Spiral)



Results: Visualizing Waves

- Irregular Waves
- Multiple wavefronts with unstable directions and velocities



Results: Progression of One Epoch

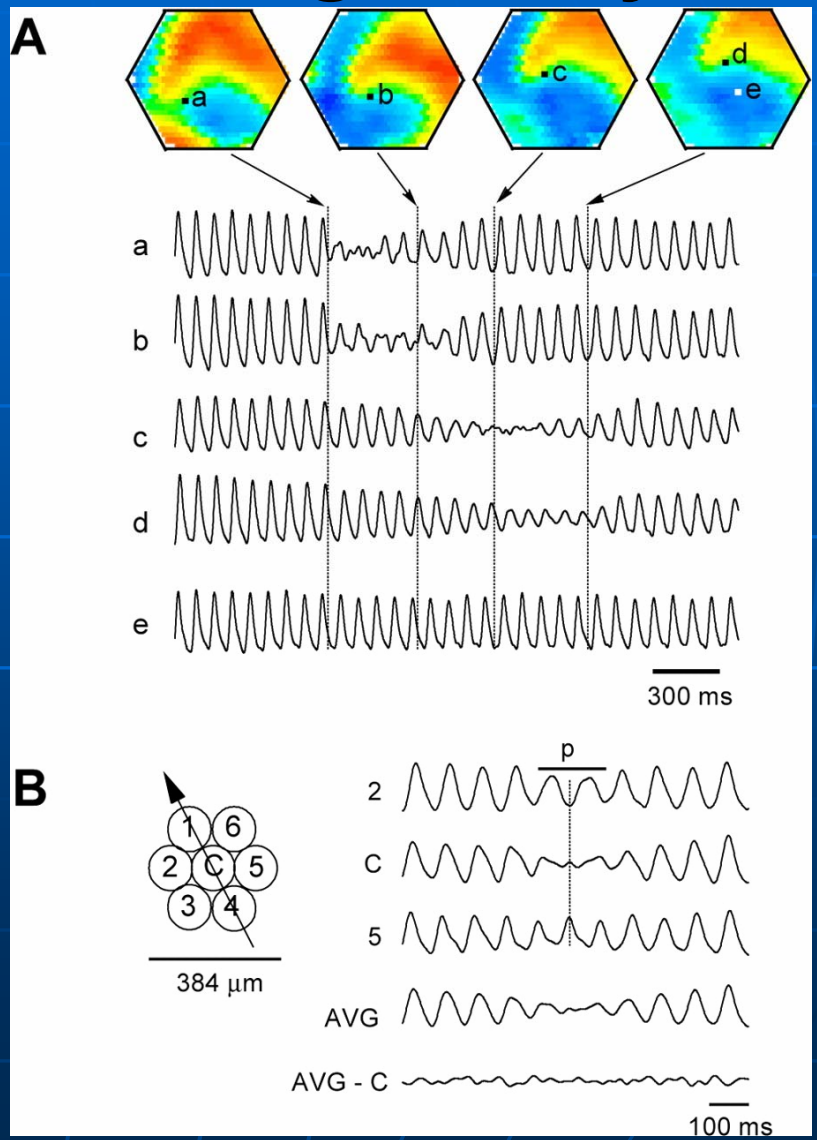
- Irregular waves occurred at the beginning and end of an epoch
- Plane, ring, and spiral occurred in the middle
- Relatively stable (similar patterns repeated with each cycle of oscillation)
- Spirals observed in 48% of trials
- 57% of those has at least 4 rotations
- Both clockwise and counterclockwise rotations were observed

Results: Phase Singularity

- Phase singularity: area of infinite phase gradient
- Hallmark of a true spiral wave
- Area of slice containing oscillating neurons with nearly all phases represented between $-\pi$ to π
- Used higher resolution to search for singularity

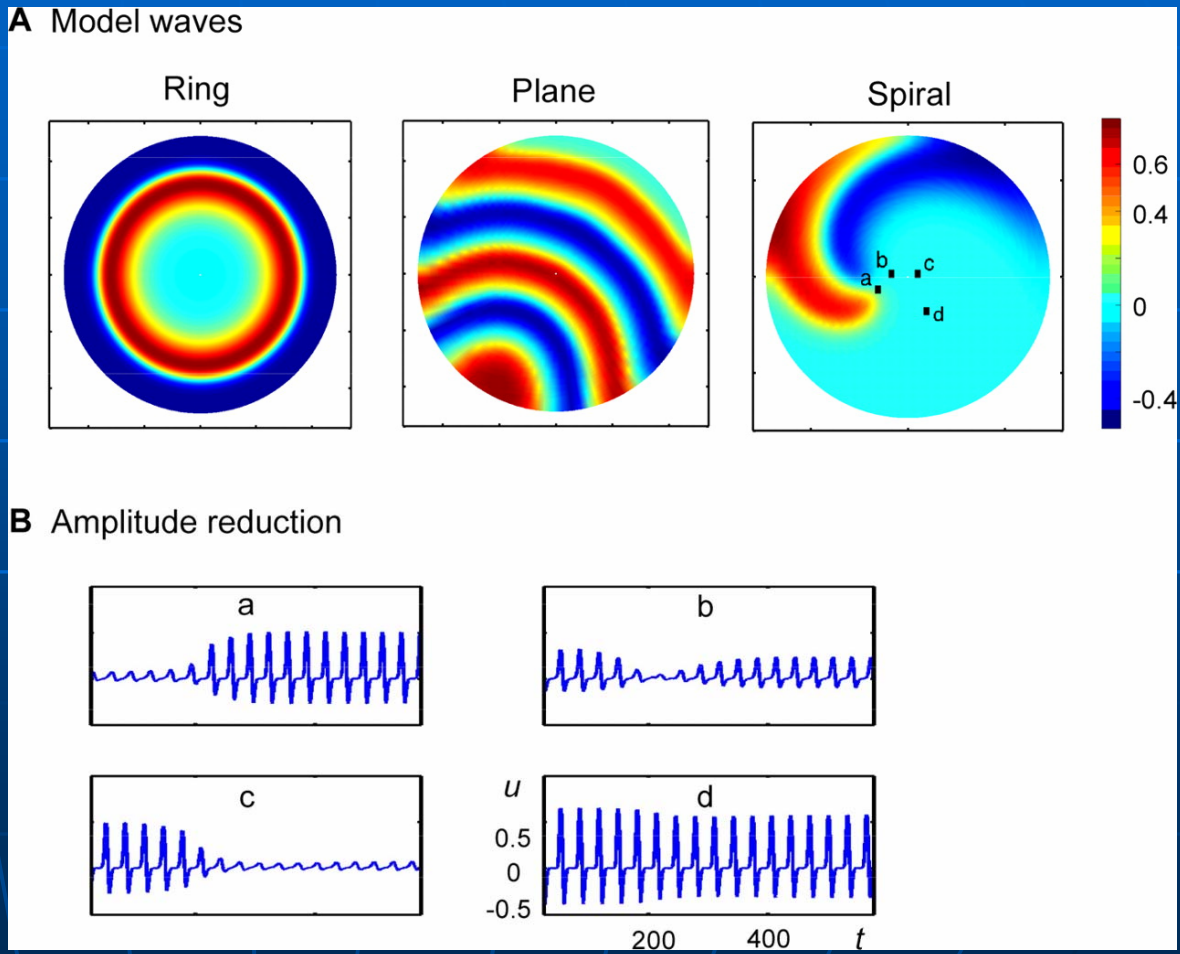
Results: Phase Singularity

- Detectors alternately recorded reduced amplitude
- Amplitude reduction localized as spiral center
- Phase singularity drifted (~1mm/10 turns)
- Reduced amplitude not caused by inactivity, but superimposition of multiple phases



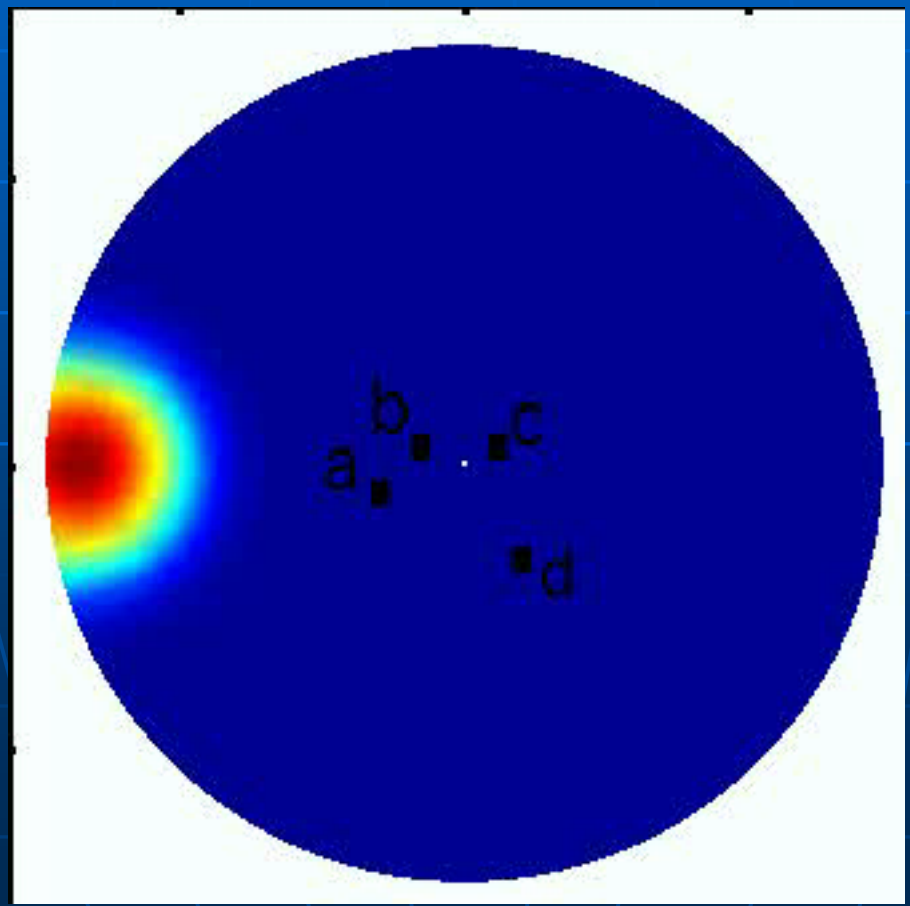
Results: Computational Model

- Point simulation successfully represented the qualities of the disinhibited network
- Amplitude reduction observed at center of spiral



Results: Computational Model

- Spiral wave from computational model



Conclusions

- Results support existence of true spiral waves in four respects
  - Phase singularities observed only in spirals
  - Oscillation amplitude reduced at center
  - The spiral center was smaller than any detector
  - Spirals not artifacts of boundary constraints because nonrotating waves alternate with spirals
- Cortical circuits are functionally two-dimensional

Future Developments

- Study the cellular organization at the phase singularity
- New technology needed to observe center (~100μm in diameter)

Questions?

References

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