

# SOLITONIC NATURE OF LIGHTNING

V. Skarka and N.B. Aleksić<sup>2</sup>

Laboratory POMA, University Angers, France

<sup>2</sup>Institutes of Physics, Belgrade, Serbia

PRIGOGINE'S SCHOOL: SELF-ORGANIZATION OF DISSIPATIVE STRUCTURES

nonthermodynamical branch

stable

unstable

thermodynamical branch

$m_c$



SPATIAL DISSIPATIVE STRUCTURE  
BÉNARD PROBLEM

DIFFERENT PHENOMENA MAY HAVE FUNDAMENTALLY THE  
SAME NATURE

# SELF-ORGANIZATION OF SPATIOTEMPORAL DISSIPATIVE STRUCTURES

TEMPORAL DISSIPATIVE STRUCTURES – BELOUSOV-ZABOTINSKI REACTION

SPATIOTEMPORAL DISSIPATIVE STRUCTURE: MASKARE - UPSTREAM PROPAGATION OF SALT WATER SOLITON IN RIVER DURING HIGH TIDE

LIGHTNING = ELECTROMAGNETIC BEAM PROPAGATING IN AIR

Bazelyan, Plasma Physics Reports, 21, 470 (1995)

MULTICOMPONENT LIGHTNING

Electromagnetic ionizing wave propagating from cloud to ground → Contact of highly conductive plasma channel with ground → Backward wave propagation

Fisher, Schnetzer, Thotappillil, et al., J. Geophys. Res. 98, 22887 (1993)

INHOMOGENEOUS ELECTRIC FIELD → NONUNIFORM CONDUCTIVITY

Fernsler, Phys. Fluids 27, 1005 (1984)

PLASMA CHANNEL  $\approx 2$  m

STRONG ELECTROMAGNETIC FIELD → NONLINEARITY

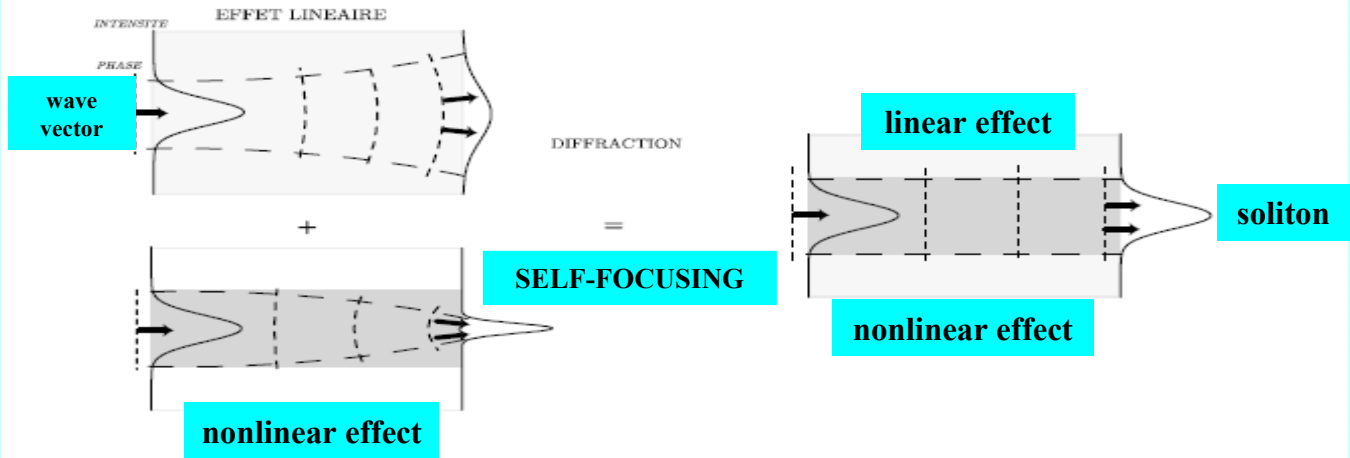
STRIKING VISUAL FEATURE OF LIGHTNING → WAVE NARROWS INTO LIGHT FILAMENT  $\approx 2$  cm WITHOUT COLLAPSING

→ LIGHTNING IS SELF-ORGANIZED DISSIPATIVE STRUCTURE LIKE SPATIOTEMPORAL DISSIPATIVE SOLITONS

# Lightning strikes



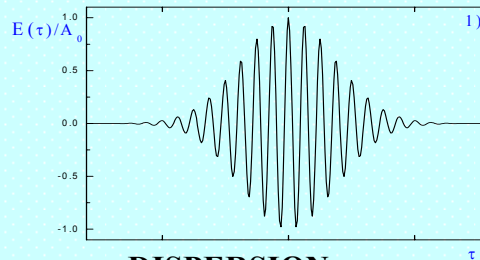
# CONSERVATIVE SPATIAL SOLITONS



$$i \frac{\partial E}{\partial z} + \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + |E|^2 E - \nu |E|^4 E = 0$$

DIFFRACTION
SATURATING NONLINEARITY

# CONSERVATIVE TEMPORAL SOLITONS



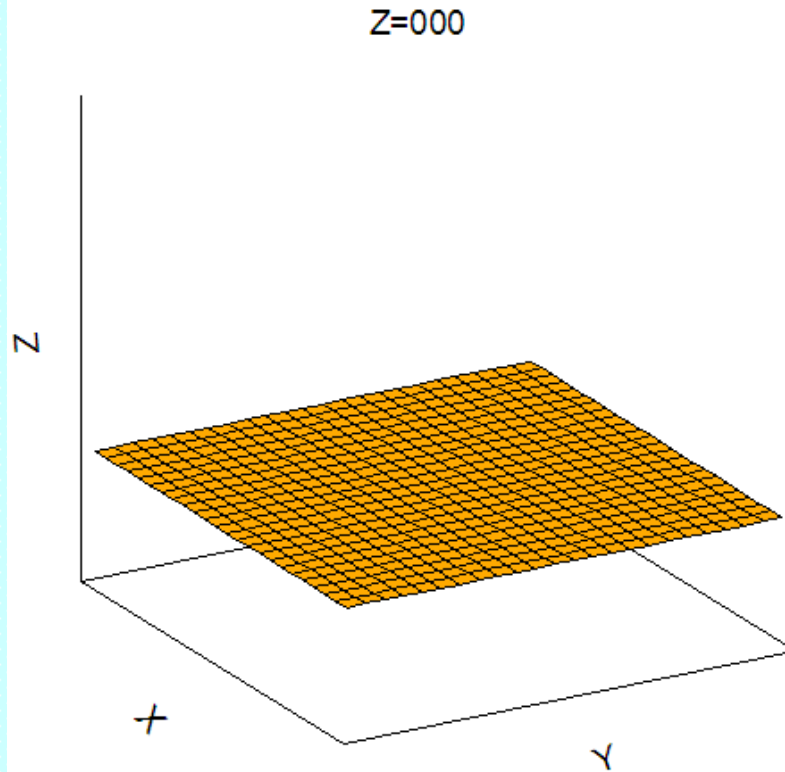
$$i \frac{\partial E}{\partial z} + \frac{\partial^2 E}{\partial t^2} + |E|^2 E = 0$$

DISPERSION

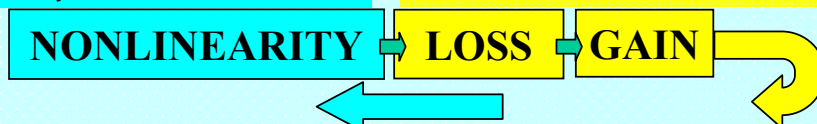
**SELF-ORGANIZED STABLE DISSIPATIVE STRUCTURE COMPLETELY LOCALIZED IN SPACE AND TIME → «DISSIPATIVE LIGHT BULLET»**

**NEGATIVE WAVE FRONT CURVATURE**  $C = 0.056\delta_o A^2 [1.125(\epsilon_o - \beta_o) + (\mu_o - \nu\beta_o)A^2]$

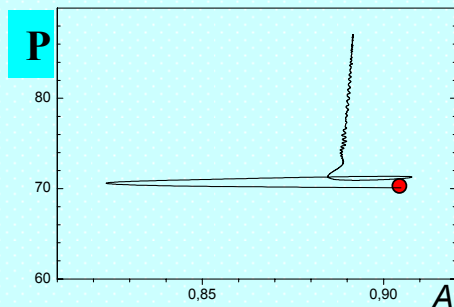
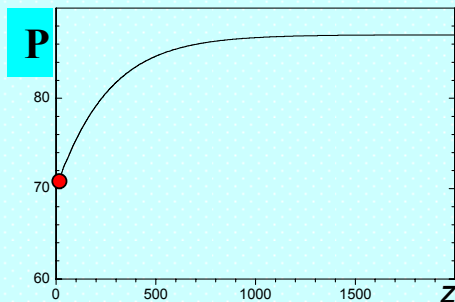
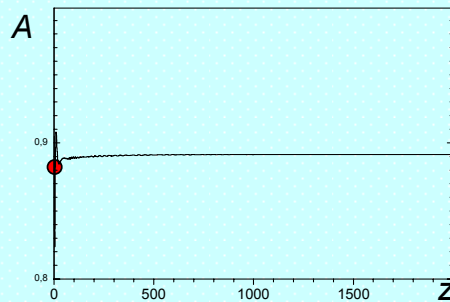
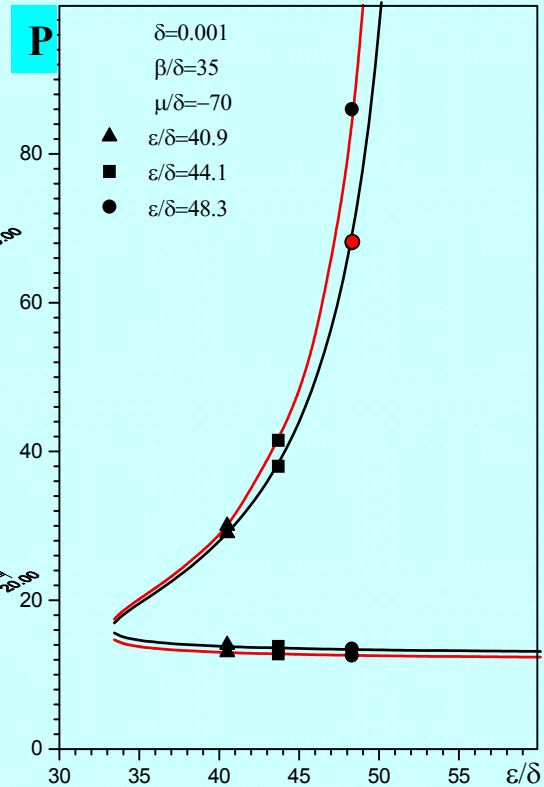
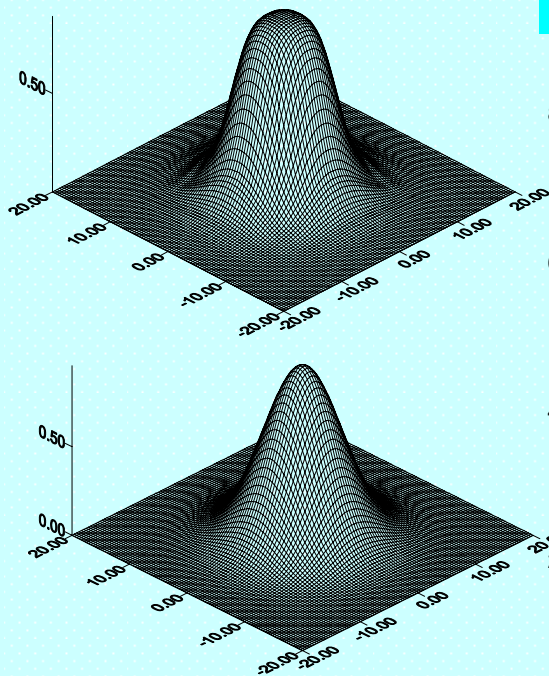
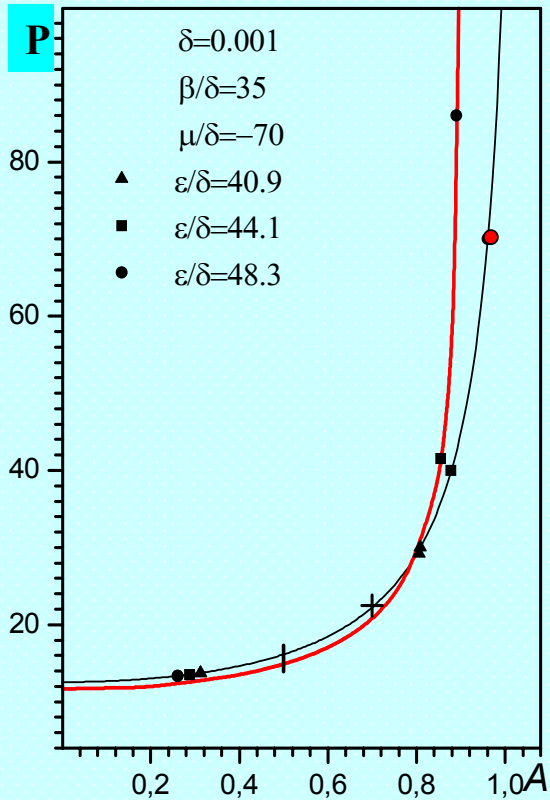
Skarka and Aleksić, Phys. Rev. Lett. 96 (2006) 0139031



$$i \frac{\partial E}{\partial z} + \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + |E|^2 E - \nu |E|^4 E = i \left\{ \delta E - \mu |E|^4 E + \varepsilon |E|^2 E + \beta \left( \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} \right) \right\}$$



# NUMERICAL SIMULATION OF DISSIPATIVE SOLITON EVOLUTION



# SPATIOTEMPORAL DISSIPATIVE SOLITONS IN ATMOSPHERE

## GINZBURG-LANDAU EQUATION IN AIR

DIFFRACTION-DISPERSION

SATURATING  
NONLINEARITY

$$i \frac{\partial E}{\partial z} + \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial t^2} + |E|^2 E - \nu |E|^{20} E =$$

KERR EFFECT      MULTIPHOTON IONIZATION

$$i \left\{ \delta E - \mu |E|^{20} E + \varepsilon |E|^2 E + \beta \left( \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial t^2} \right) \right\}$$

MULTIPHOTON ABSORPTIONS

LOSS

GAIN

SATURATING NONLINEARITY

DISSIPATIVE SYSTEMS

GAIN

BALA

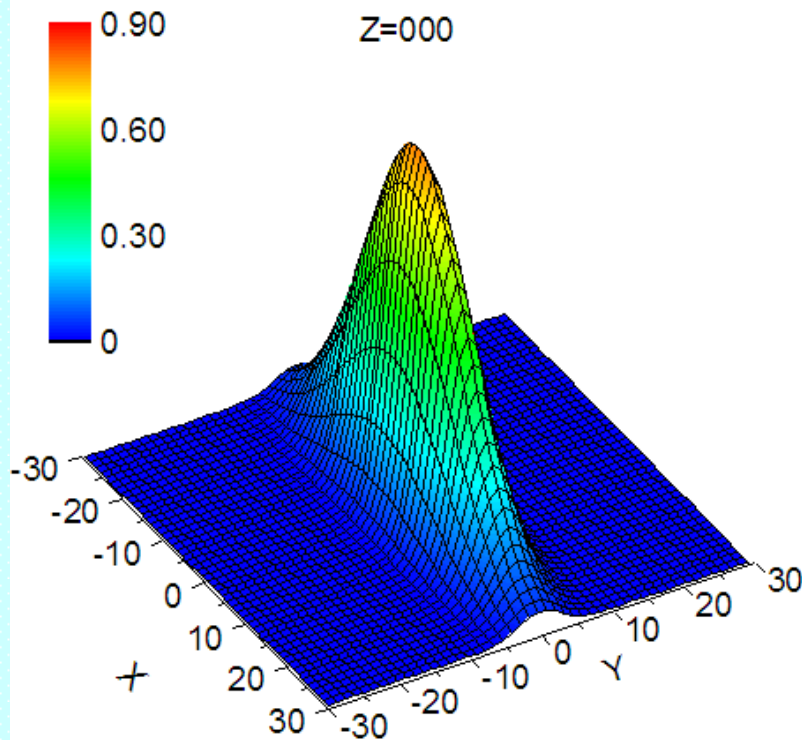
CING

LOSS

DIFFRACTION, DISPERSION

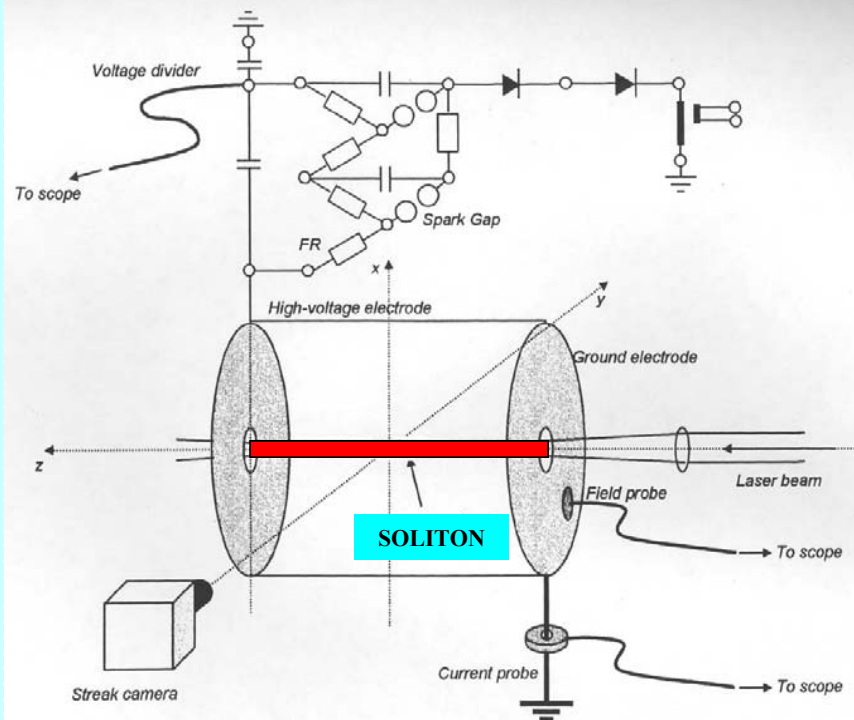
B  
A  
L  
A  
  
C  
I  
N  
G

# NUMERICAL SIMULATIONS OF ASYMMETRIC INPUT GENERATING A SPATIAL SOLITON



V. Skarka, D.V. Timotijevic, N.B. Aleksic,  
J. Opt. A: Pure Appl. Opt. 10 (2008) 075102

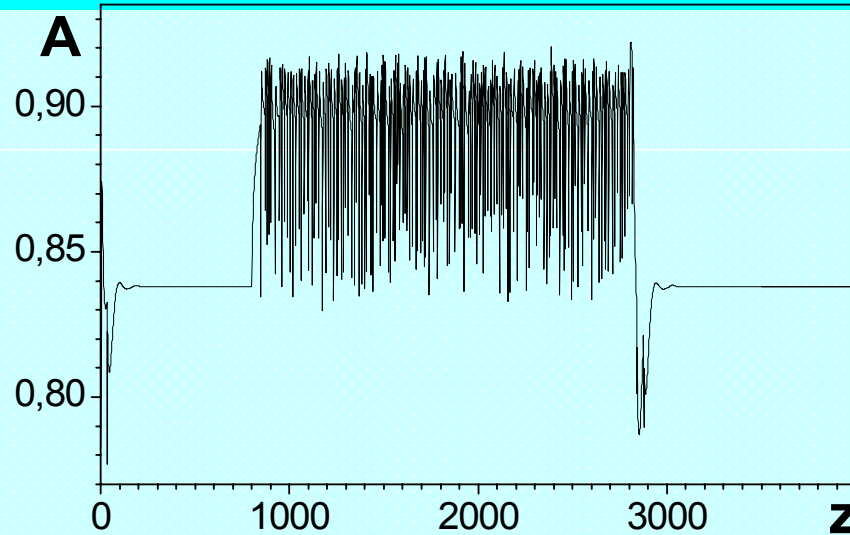
# PROPOSAL TO MAKE A MOVIE OF SOLITON TRIGGERED CONDENSER DISCHARGE USING ULTRAFAST CAMERA



Scheme based on experiment of  
La Fontaine, Quebec, Canada

# ROBUSTNESS

INCREASING OF AMPLITUDE BY 5% FOR EACH Z FROM Z=800 TILL Z=2800

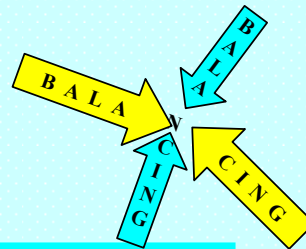


## CROSS COMPENSATION

$$i \frac{\partial E}{\partial z} + \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial t^2} + |E|^2 E - \nu |E|^{2n} E = i \left\{ \delta E + \varepsilon |E|^2 E + \mu |E|^m E + \beta \left( \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial t^2} \right) \right\}$$

## NONLINEARITY

GAIN

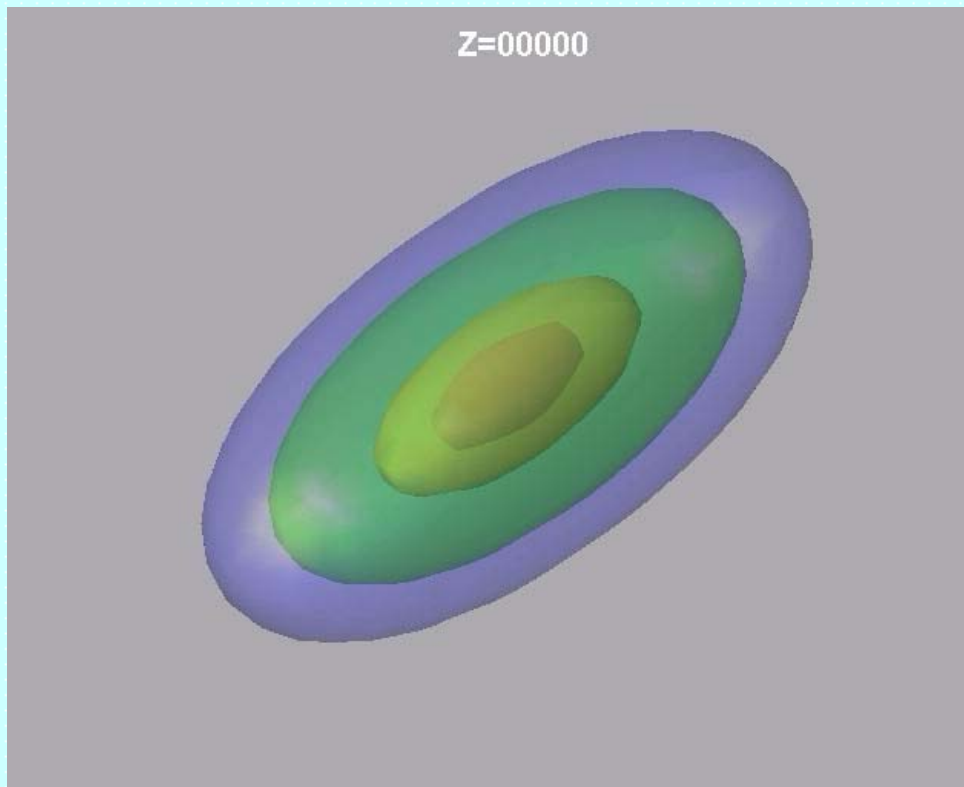


DISSIPATIVE SOLITON

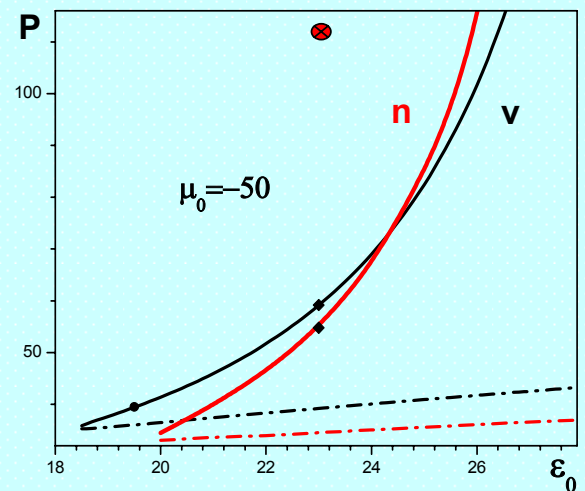
LOSS

## DIFFRACTION, DISPERSION

# ASYMMETRIC INPUT DURING EVOLUTION SELF-ORGANIZES INTO LIGHT BULLET



VARIATIONAL (v)  
BIFURCATION CURVE

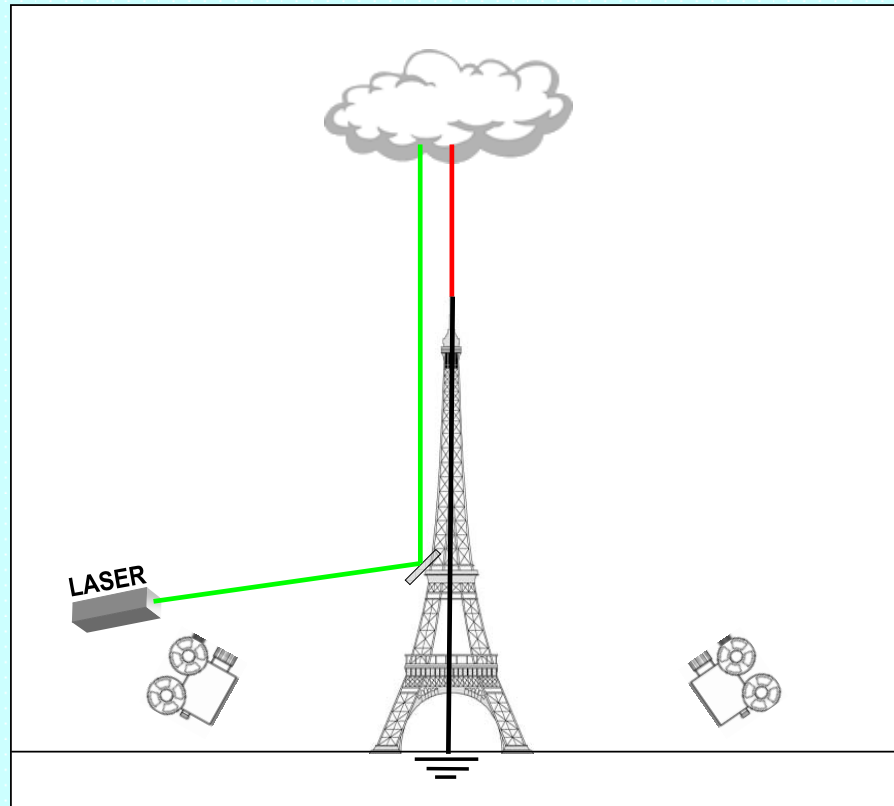


NUMERICAL (n)  
BIFURCATION CURVE

**M-component : Current pulses on background of  
quasi-stationary current  $\rightarrow$  LIGHT BULLETS**

# EXPERIMENT PROPOSAL

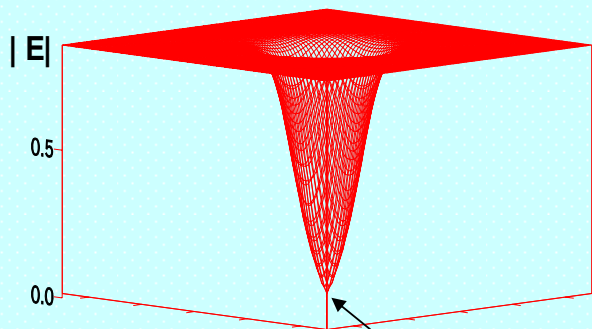
## LIGHTNING DISCHARGE MOVIE USING ULTRAFAST CAMERA



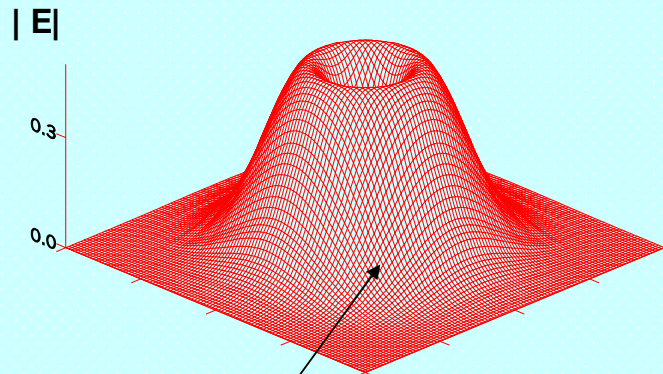
## SOLITON TRIGGERED LIGHTNING DISCHARGE MOVIE USING STREAK CAMERA

# VORTEX SOLITONS

Non - local

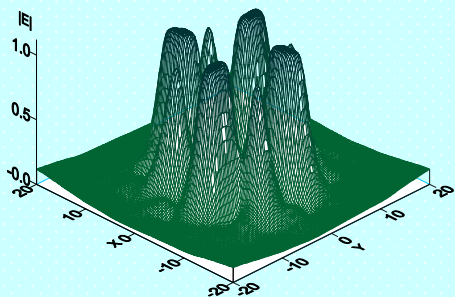


Local

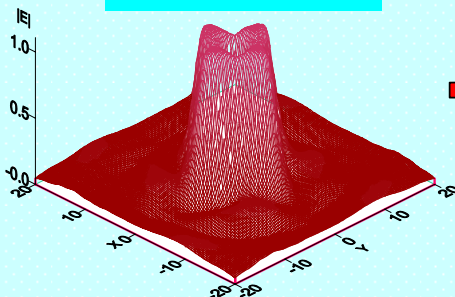


Topological singularity

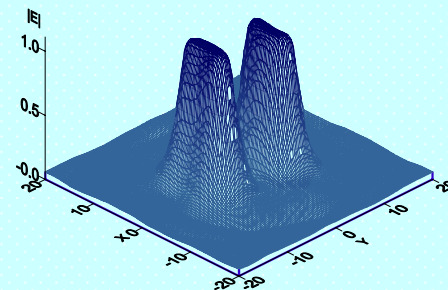
Filamentation



Coalescence



Splitting



Splitting instability induces lightning bifurcations ?

# VORTEX SOLITON STRUCTURES

Azimuthal modulation instability

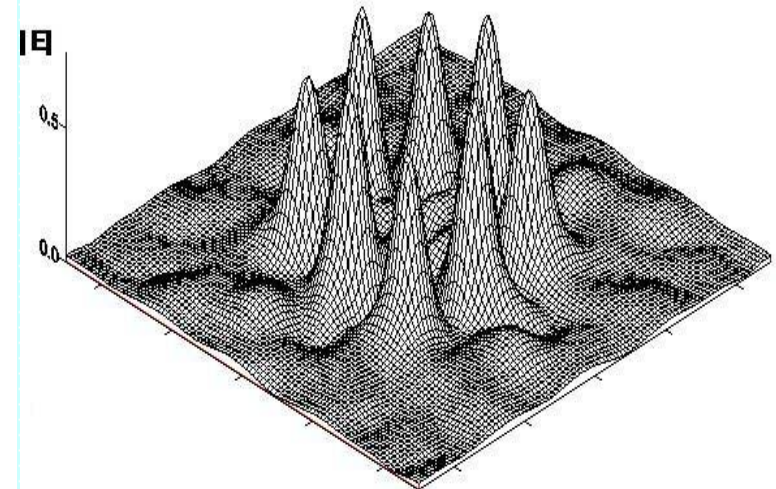
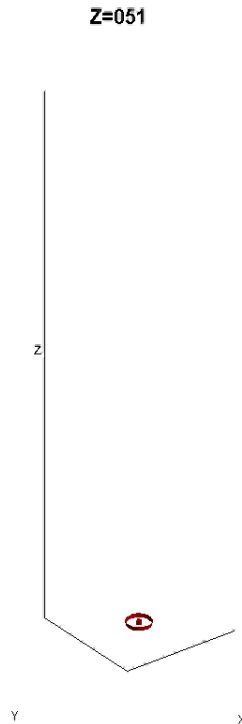


Filamentation

LIGHTNING BIFURCATION

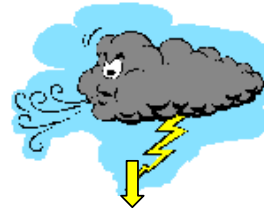
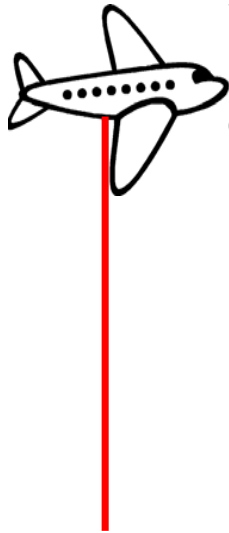


SPRITE



Berezhiani, Skarka, Aleksic, Phys. Rev. E 64, 057601 (2001)

**SPATIAL SOLITONS AND MACHINE GUN OF LIGHT BULLETS  
INDUCING STREAMER FROM AIRCRAFT OR SPACE SHUTTLE TO THE  
GROUND COULD BE GOOD PROTECTION FROM LIGHTNING**



**PROPOSED EXPERIMENTS IN SYNERGY WITH THEORY AND  
NUMERICAL SIMULATIONS MAY ELUCIDATE RELATION BETWEEN  
LIGHTNING AND SOLITONS AND CONTRIBUTE TO BETTER  
UNDERSTANDING OF LIGHTNING**