Hierarchy of Voids:

evolving substructure in voids

Rien van de Weygaert

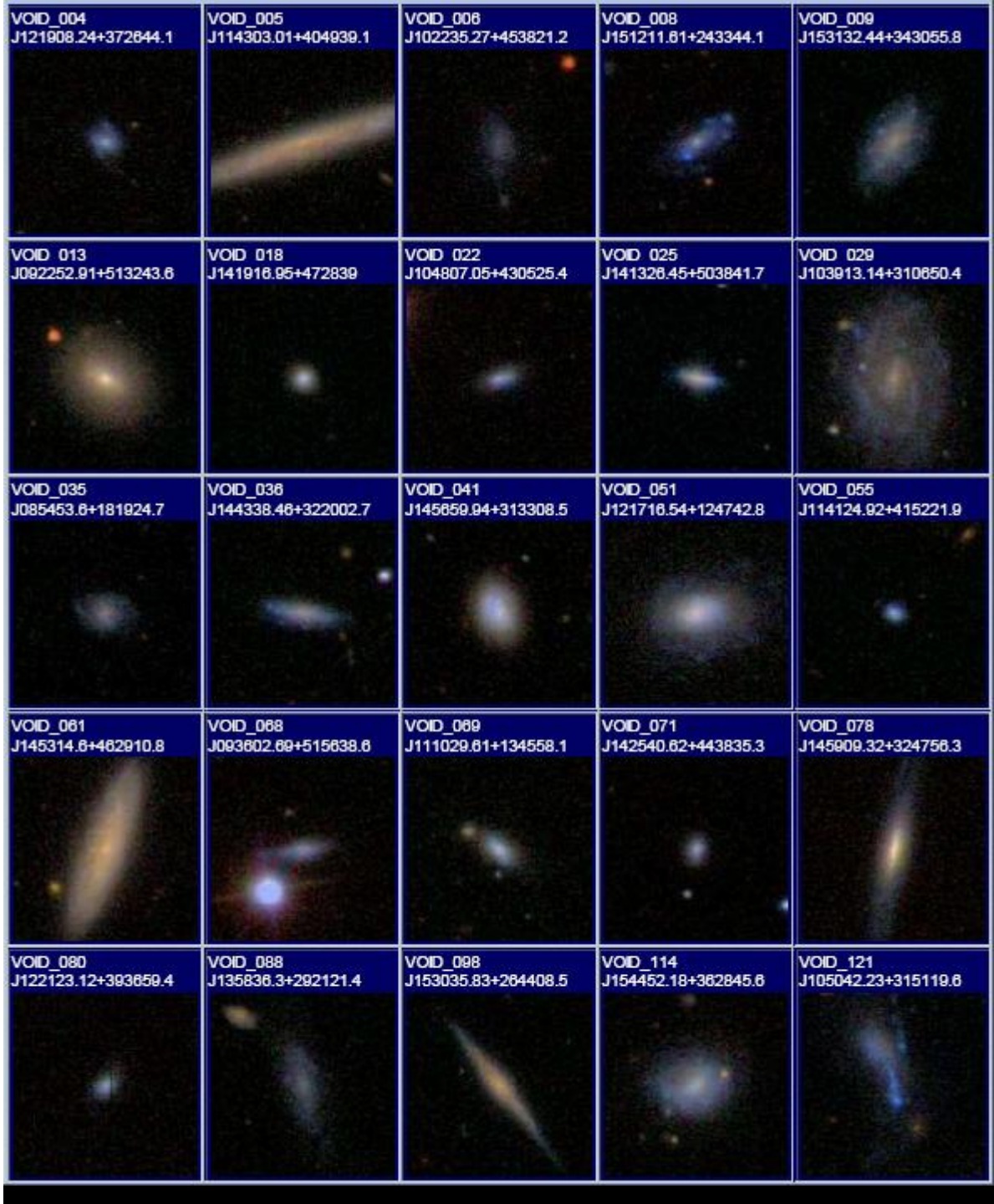
Galaxies in Isolation, May 13, Granada, Espana

Void Galaxies

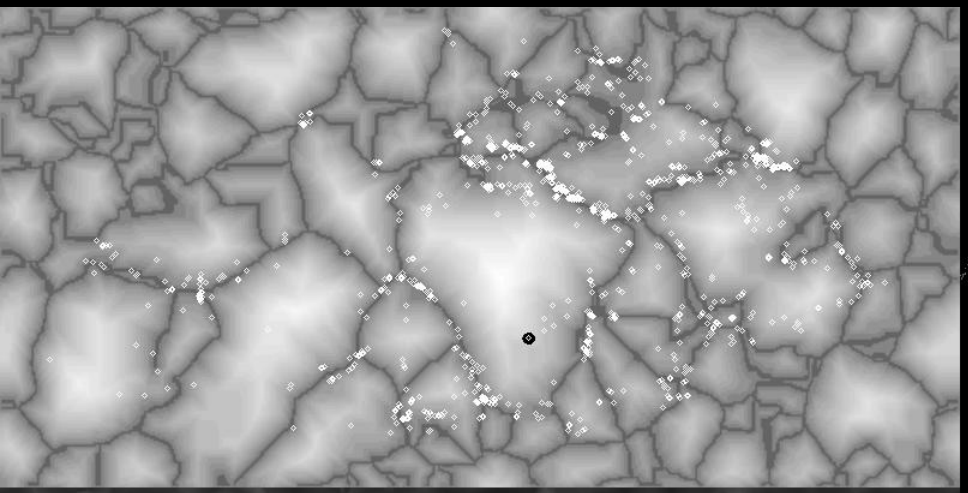
SDSS DR7

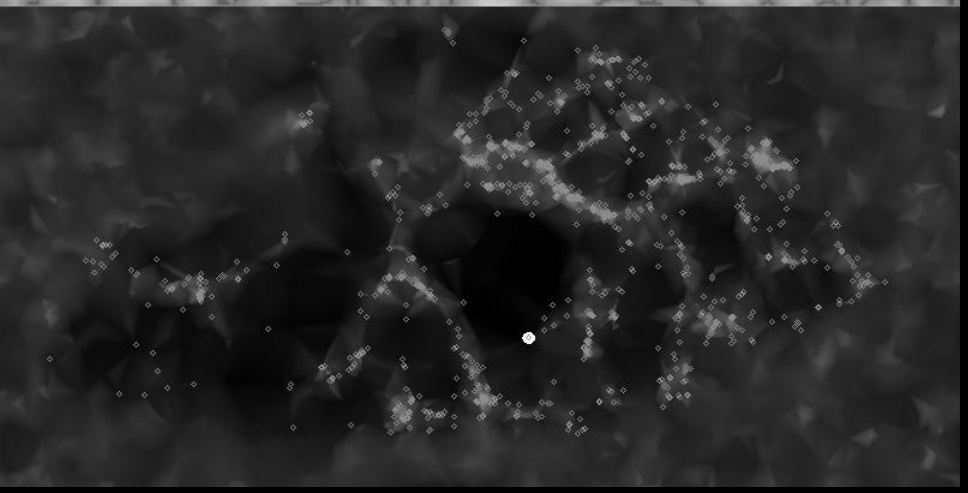
a selection

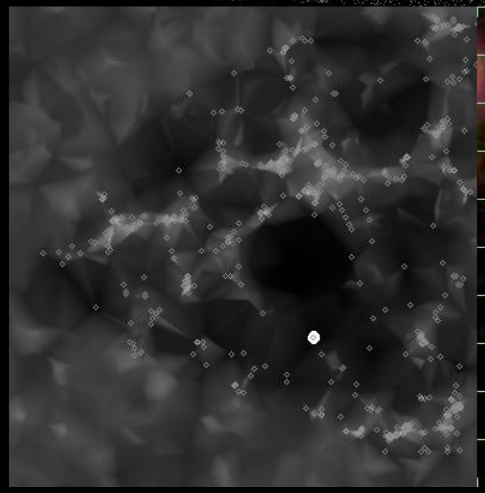
(see Platen presentation)

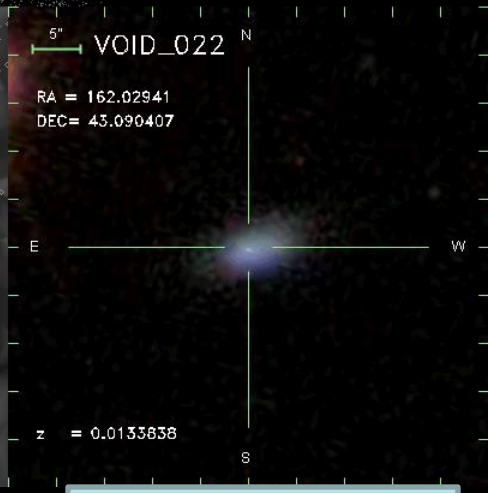


SDSS Voids & Voids Gal's









Void Finding (SDSS & 6dF): poster Danny Pan (nr. 65)
present. Erwin Platen

Image courtesy:
M. Aragon-Calvo

Void Environment of Galaxies

Subject of Interest:

- Does void environment leaves its mark on properties of galaxies ?

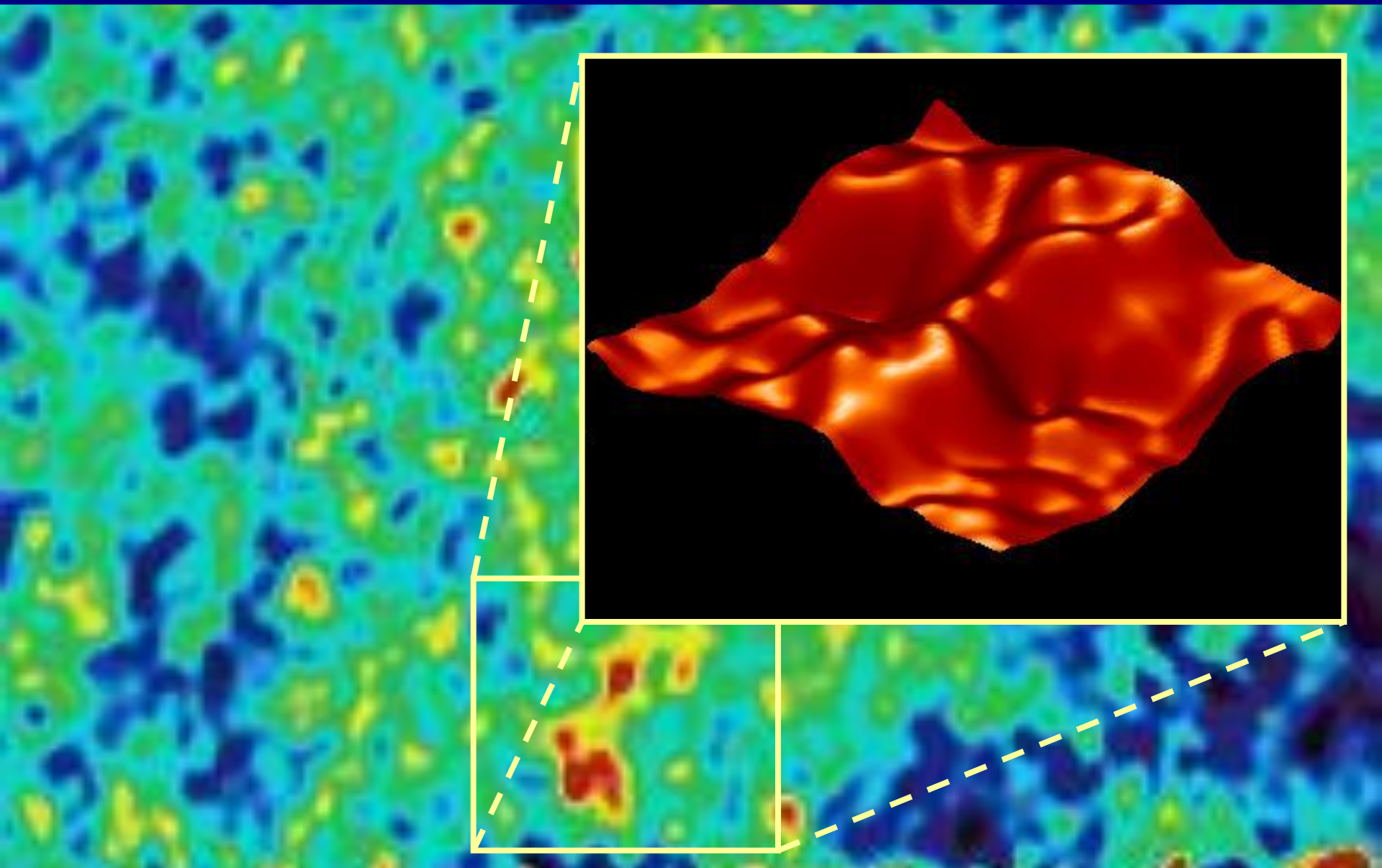
  (see contributions Platen, Stanonik, ...)

- How then about the environment itself ?
  What is the history/development of voids ?

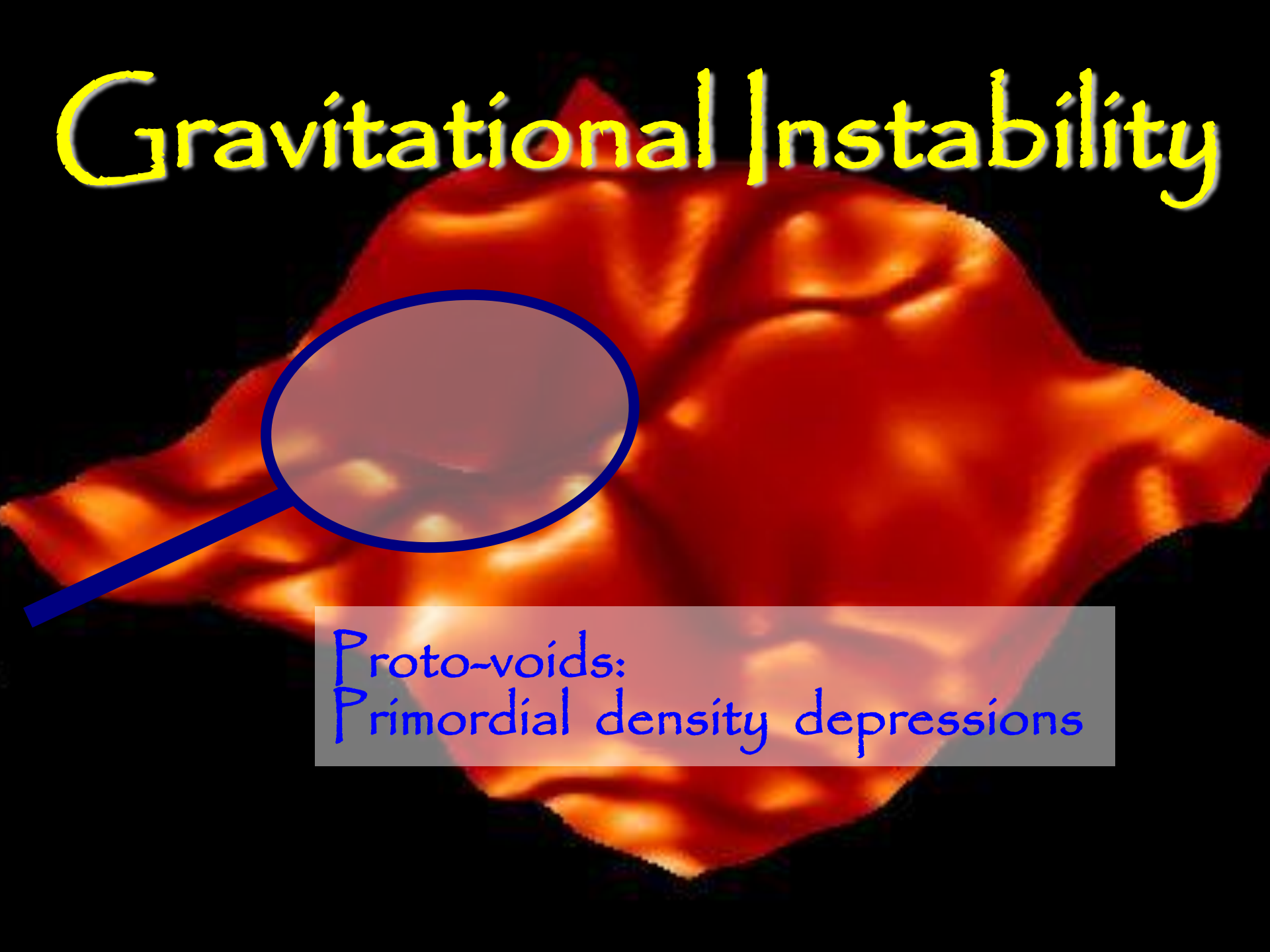
Emergence of Voids:

basic characteristics

Primordial Gaussian Perturbations



Gravitational Instability

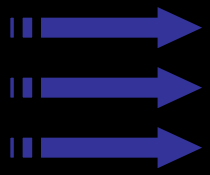


Proto-voids:
Primordial density depressions

Void Formation

Origin of Voids:

- Voids natural product gravitational instability
- Voids evolve out of primordial underdensities:
  - Underdensity
  - Gravity Deficit
  - Matter Emigration



- Primordial Density Troughs → Present-Day voids

Void Formation

Void Expansion

an illustration

cosmology:

$\Omega_m = 1.0$, $H_0 = 70$ km/s/Mpc

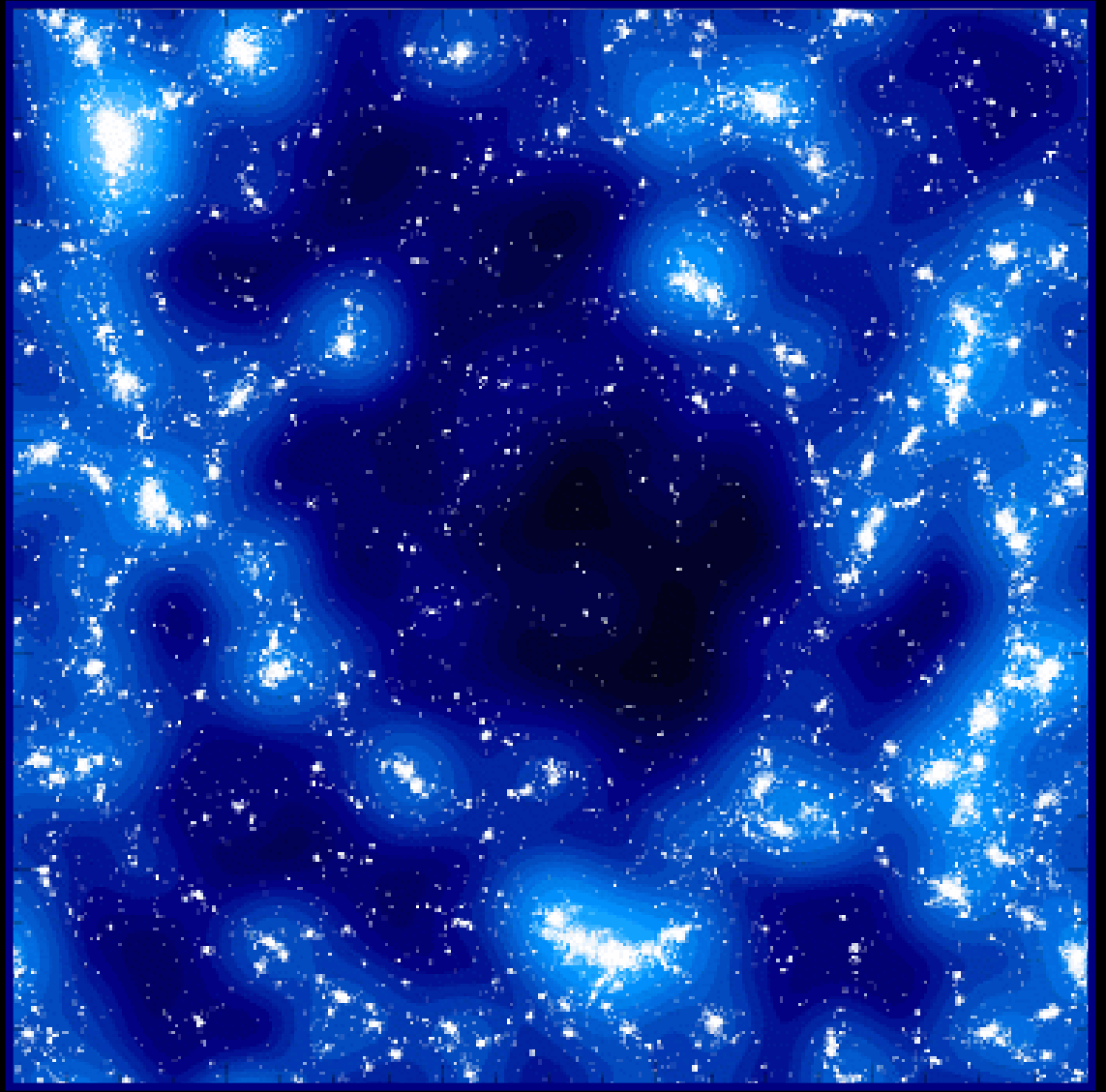
initial conditions:

underdensity,

$R_G \sim 4h^{-1}$ Mpc

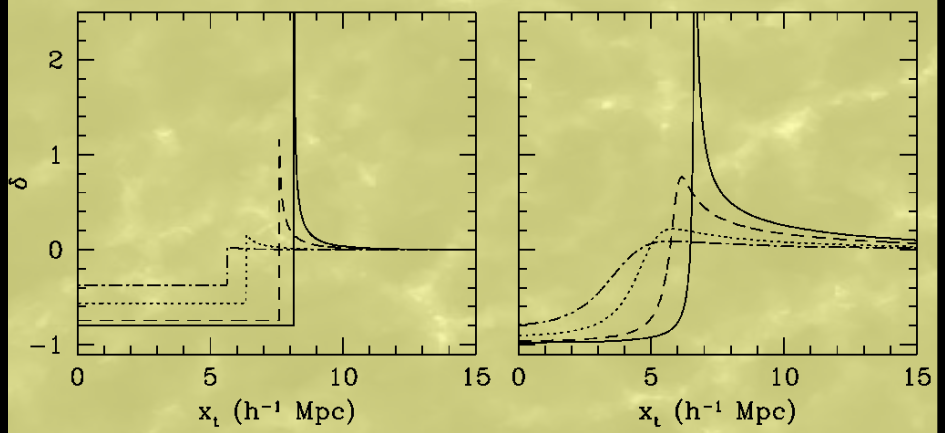
Gaussian field, $P(k) \sim k^{-0.5}$

courtesy:
Erwin Platen



Void Evolution: The Perfect Sphere, Tophat as well

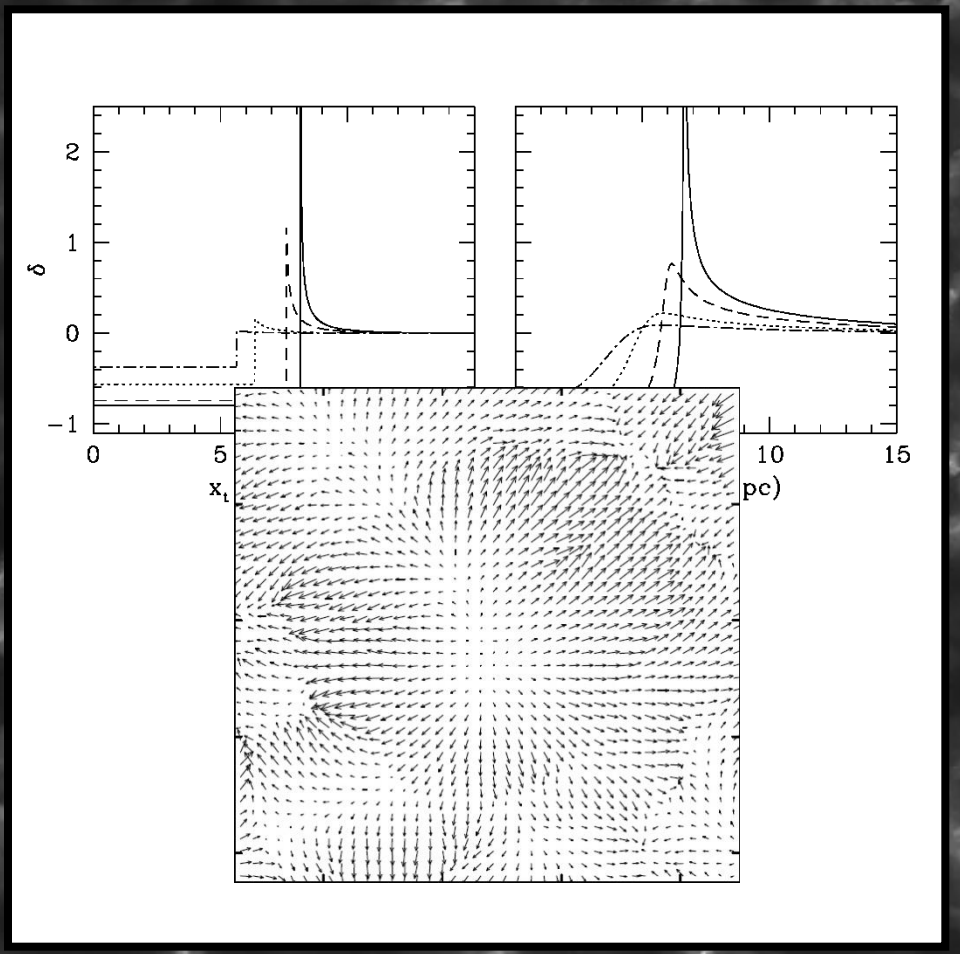
- ``Bubble Theorem"
  Voids become increasingly spherical, due to anisotropic outward directed force
- Tophat Configuration
  Any initial configuration tends towards tophat ("bucket") shape
- Density Ridge
  Except for gentlest initial density profiles, a ridge forms



Void Expansion

- Superhubble Expansion
  Tending towards "bucket" shape, the void outflow is one with uniform velocity divergence:

$$\theta \equiv \frac{1}{H}(\nabla \cdot \mathbf{v}) \longrightarrow \theta_{max} = 1.5\,\Omega^{0.6}$$



Void Sociology:

Interactions & Substructure

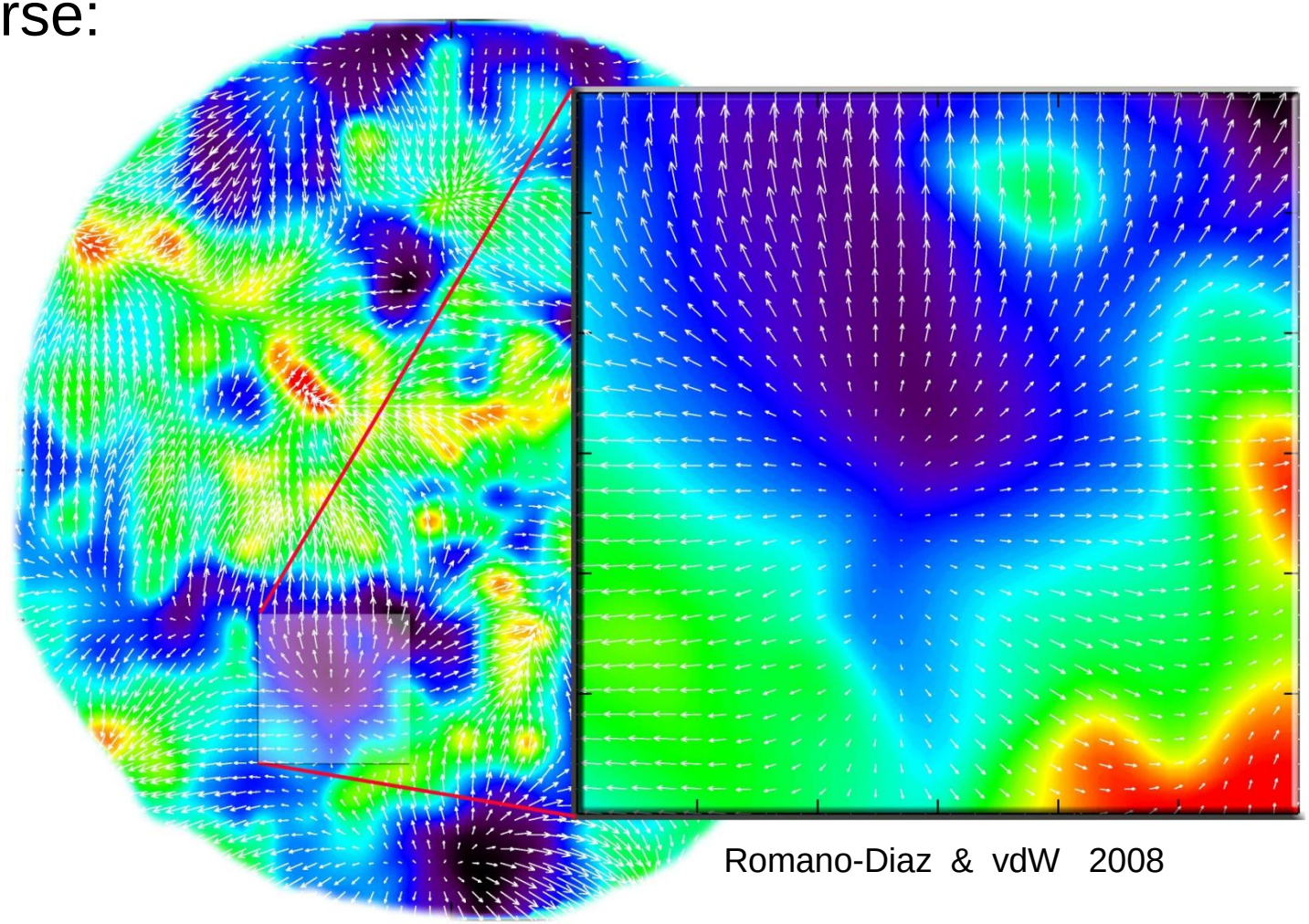
Void Sociology

Void Evolution:

- Heavily influenced by large scale environment:
  - as voids grow, they collide with surrounding structures
  - voids retain moderate density perturbations, by definition $|\delta| < 1$: tidal influence of environment remains relatively large throughout a void's life ...
- Voids also grow out of a hierarchical primordial density field:
  - complex hierarchical buildup ...

Void Environment

Local Universe:
PSCz map



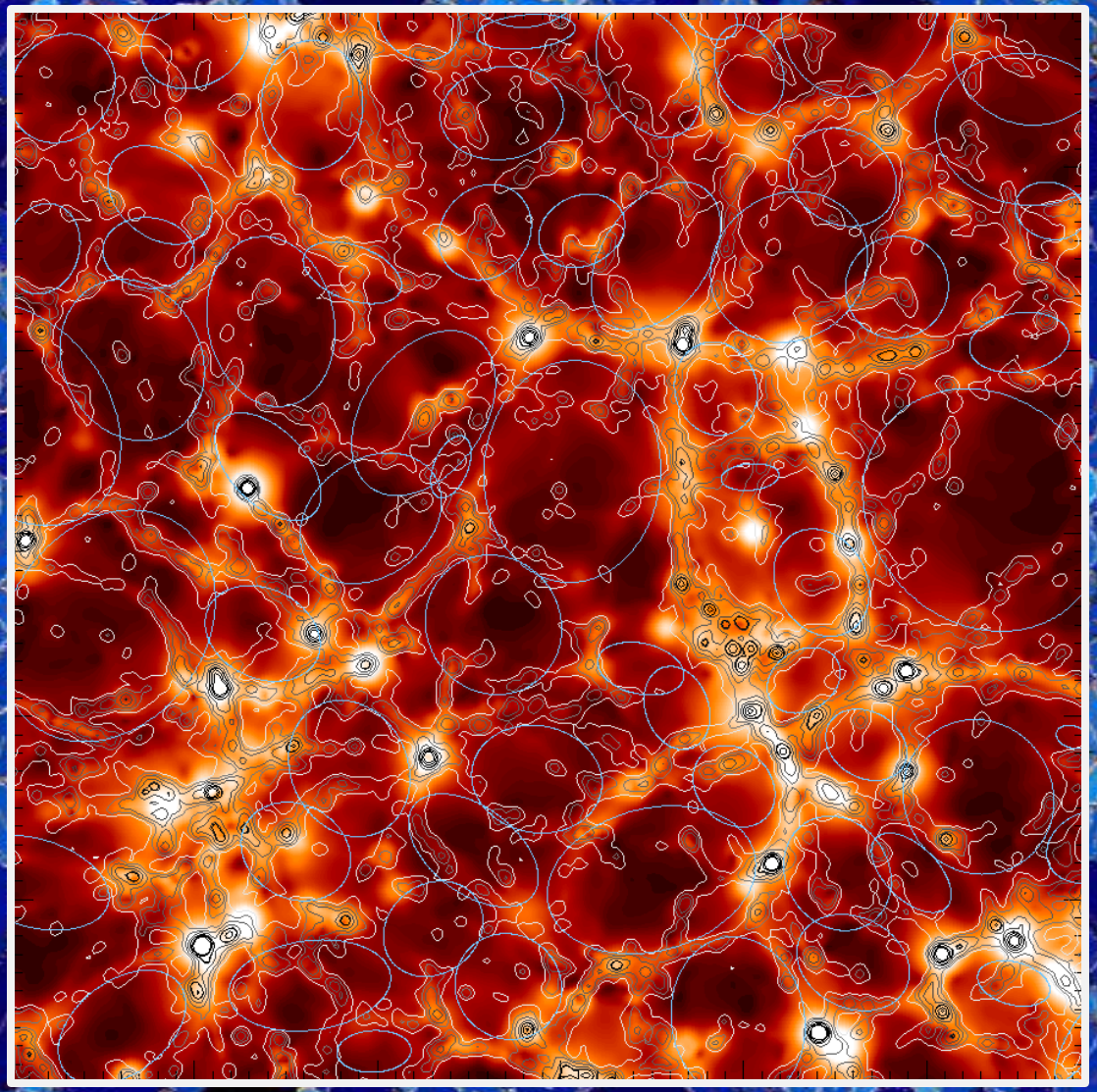
Romano-Diaz & vdW 2008

Tidal Influences: Aligning Voids

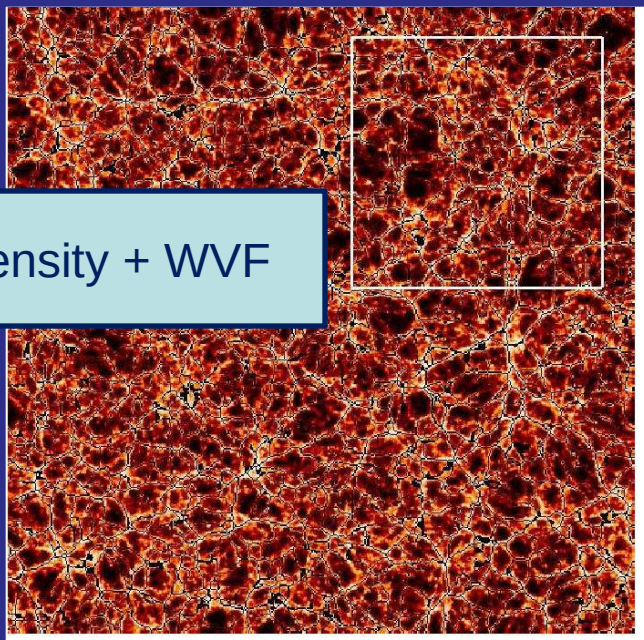
Large Scale External Tidal Influences:

Voids:
- **are not spherical**
- **have distinct elongated shapes**

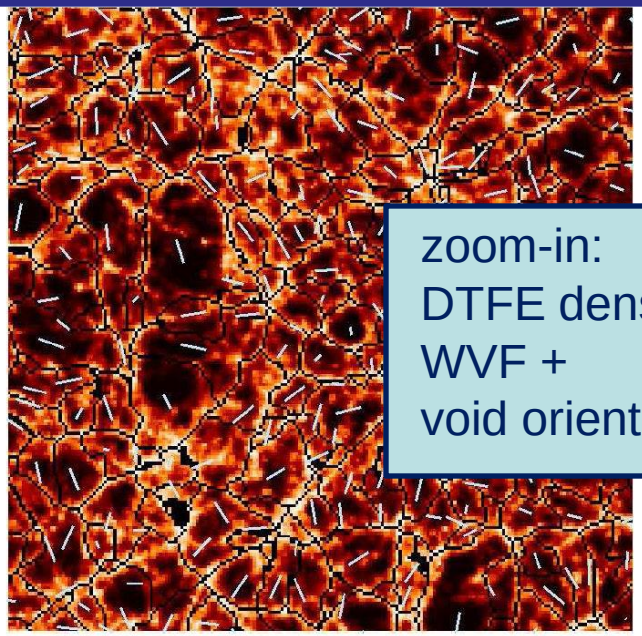
Voids:
- **aligned over d > 30 Mpc**



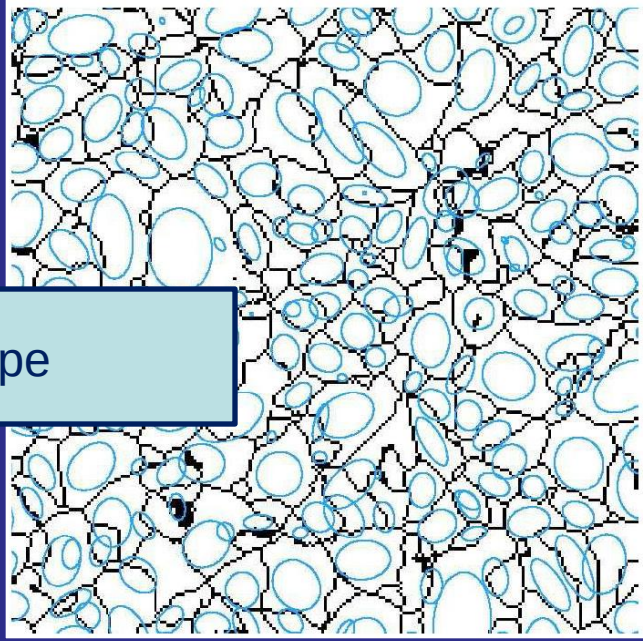
DTFE density + WVF



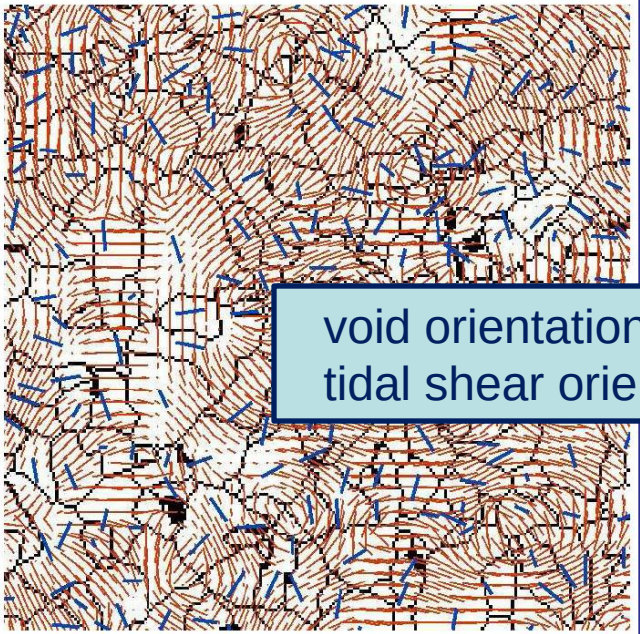
zoom-in:
DTFE density +
WVF +
void orientation

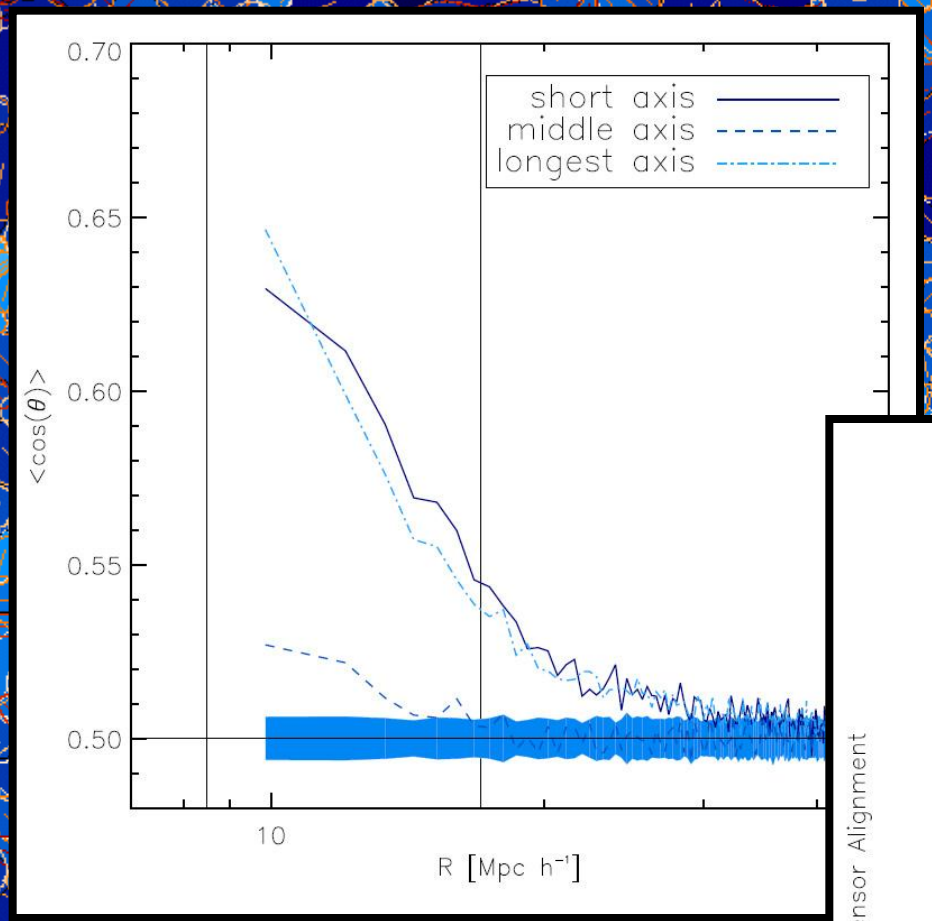


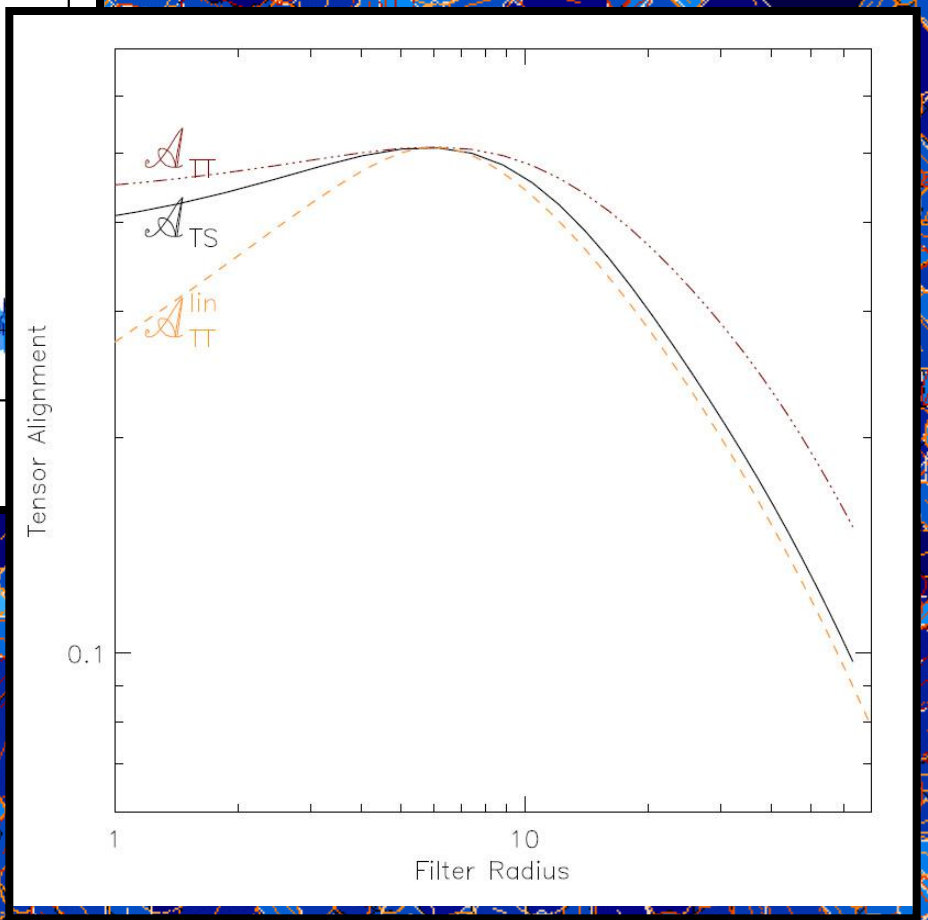
void shape



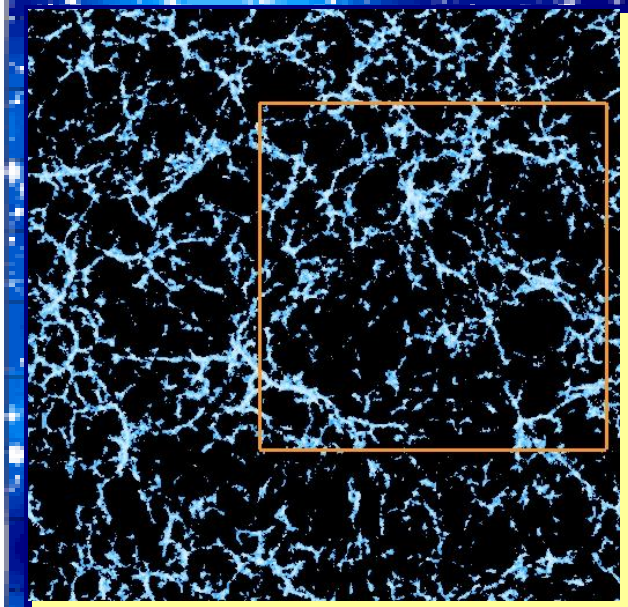
void orientation
tidal shear orientation

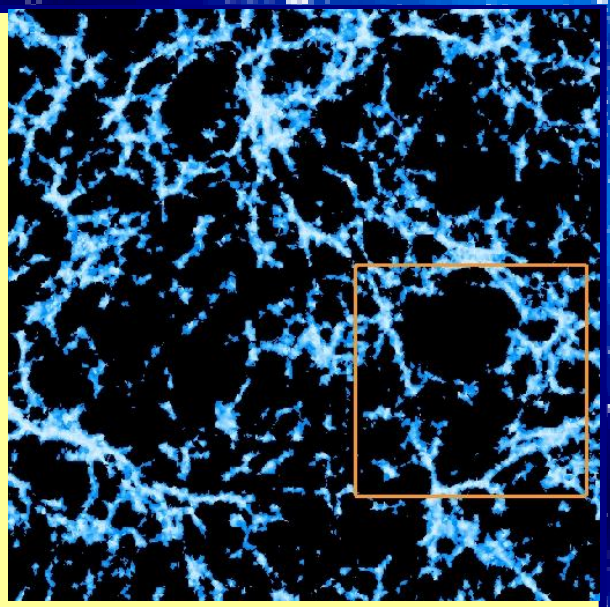


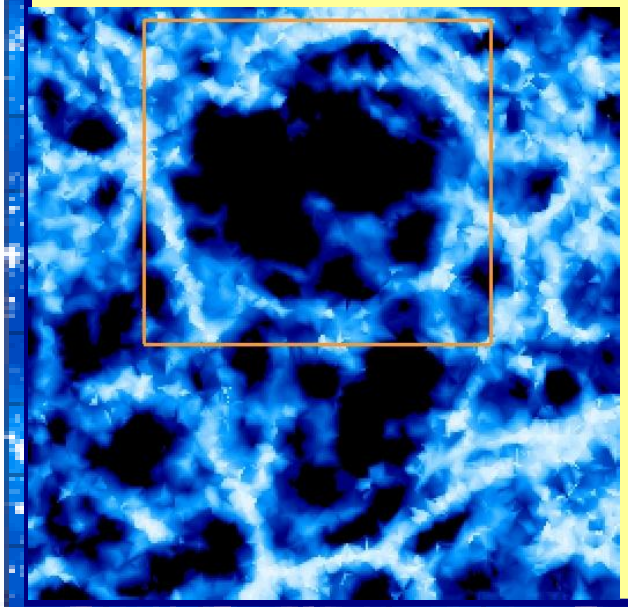

0.70
0.65
0.60
0.55
0.50
<cos(θ)>
short axis
middle axis
longest axis
10
R [Mpc h⁻¹]

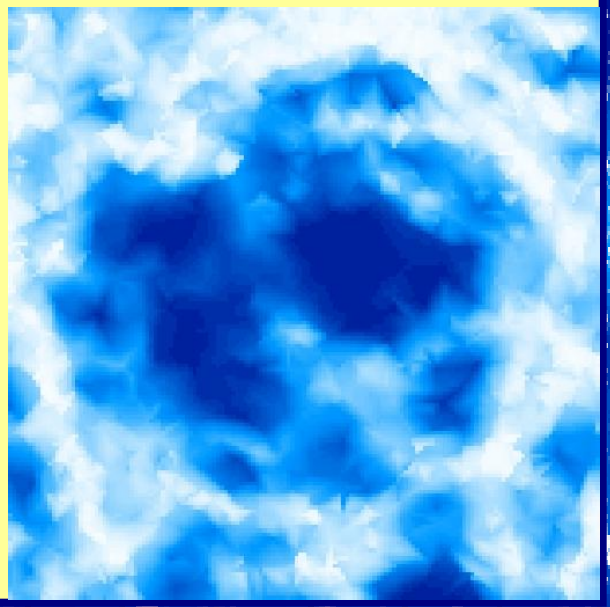

A_II
A_TS
A_lin TT
Tensor Alignment
0.1
1
10
Filter Radius

Void Substructure









Zooming in over 3 levels:

Substructure on every scale:

Amplitude diminishing at smaller scales

Hierarchical Evolution

(Sheth & vdW 2004;
Tigrak & vdW 2009, Platen et al. 2009)

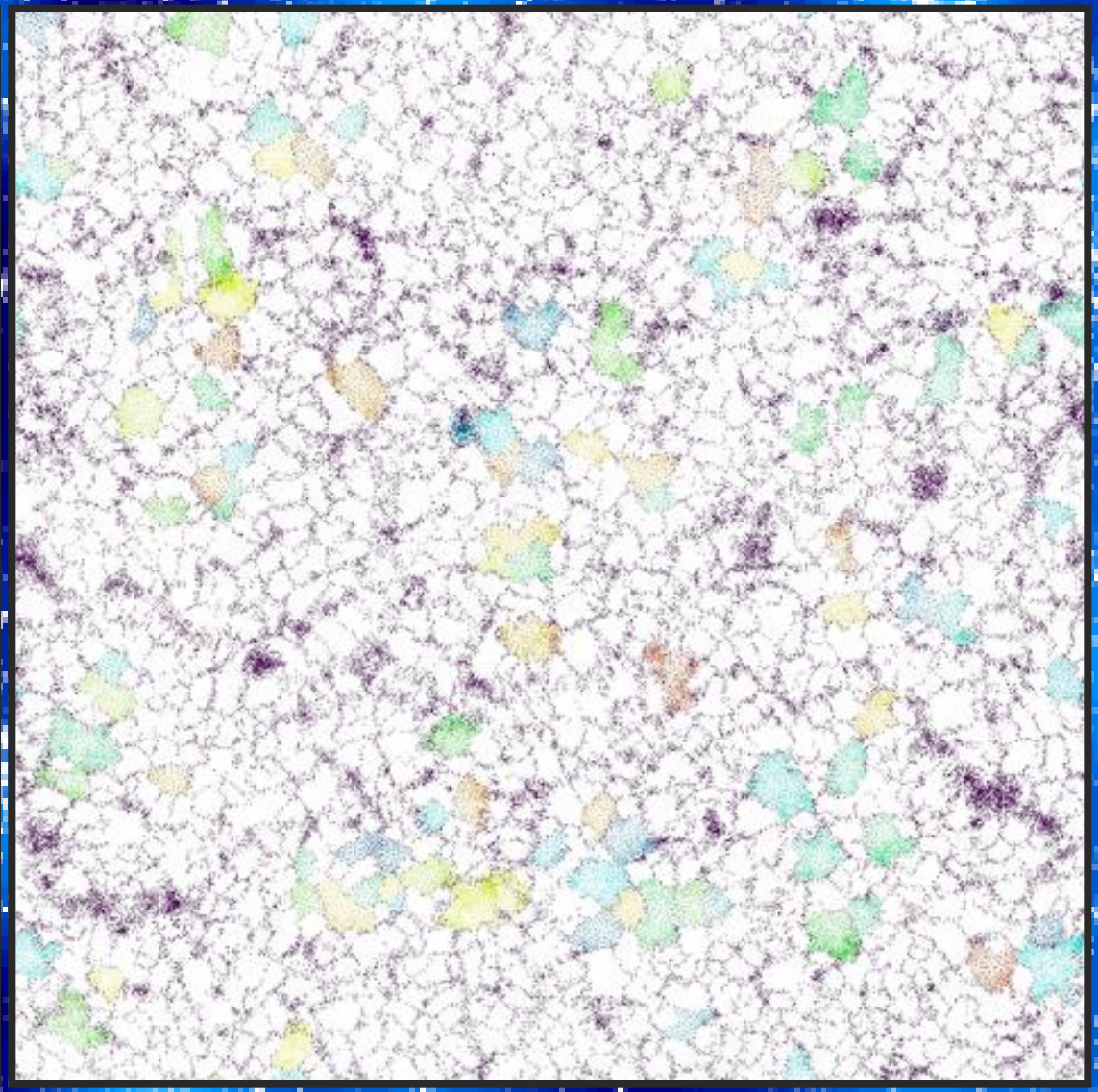
Hierarchical Void Evolution

Lagrangian Evolution Tracer

Identifying the merging and collapsing voids:

- Density field represented by particles
- Select at z=3 particles of segmentation (ie. in filaments and walls)

- Follow the particles along their paths



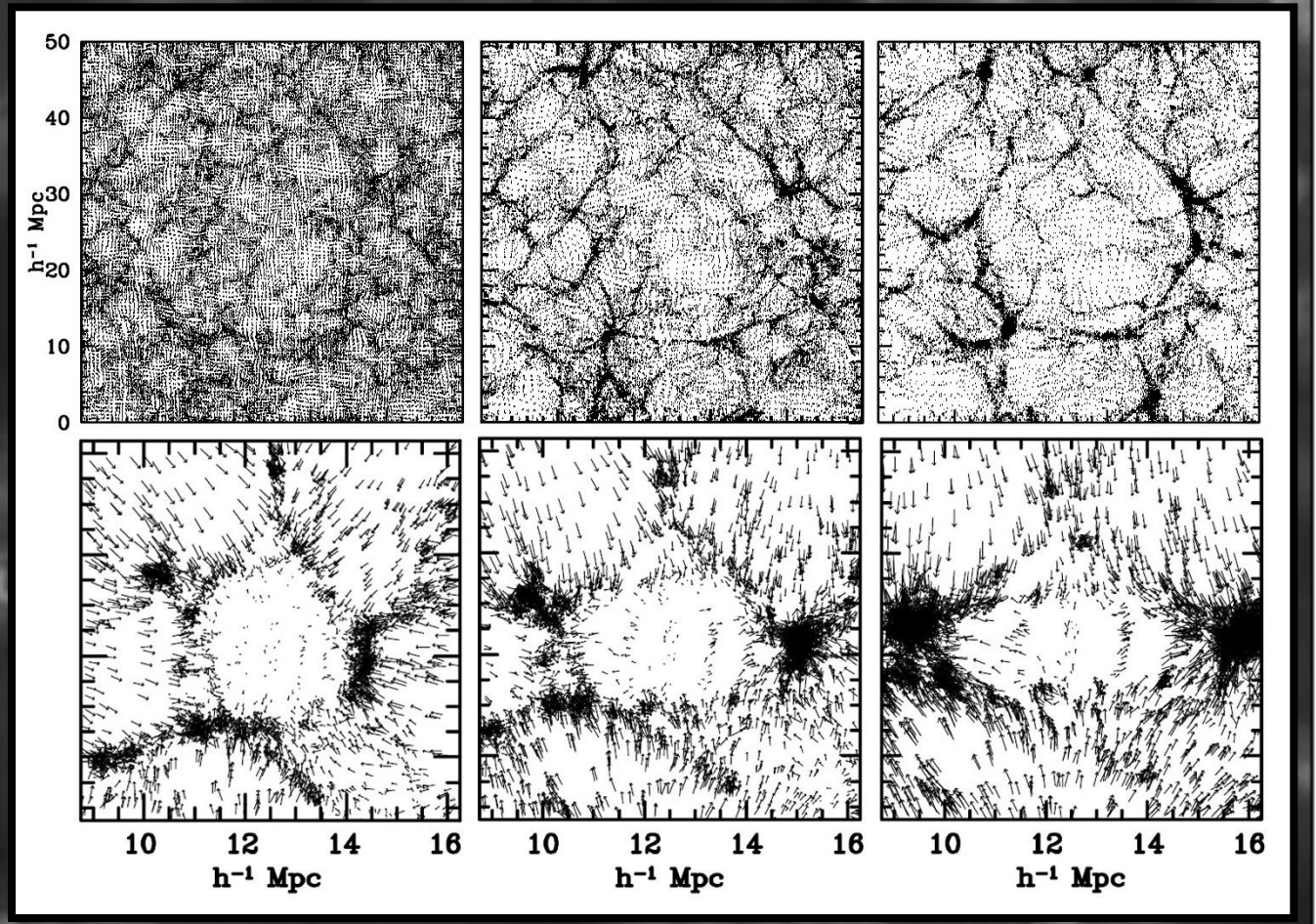
Void Merging & Void Collapse

- Merging Voids

  as voids expand and meet their peers, they merge into ever larger voids ...

- Collapsing Voids

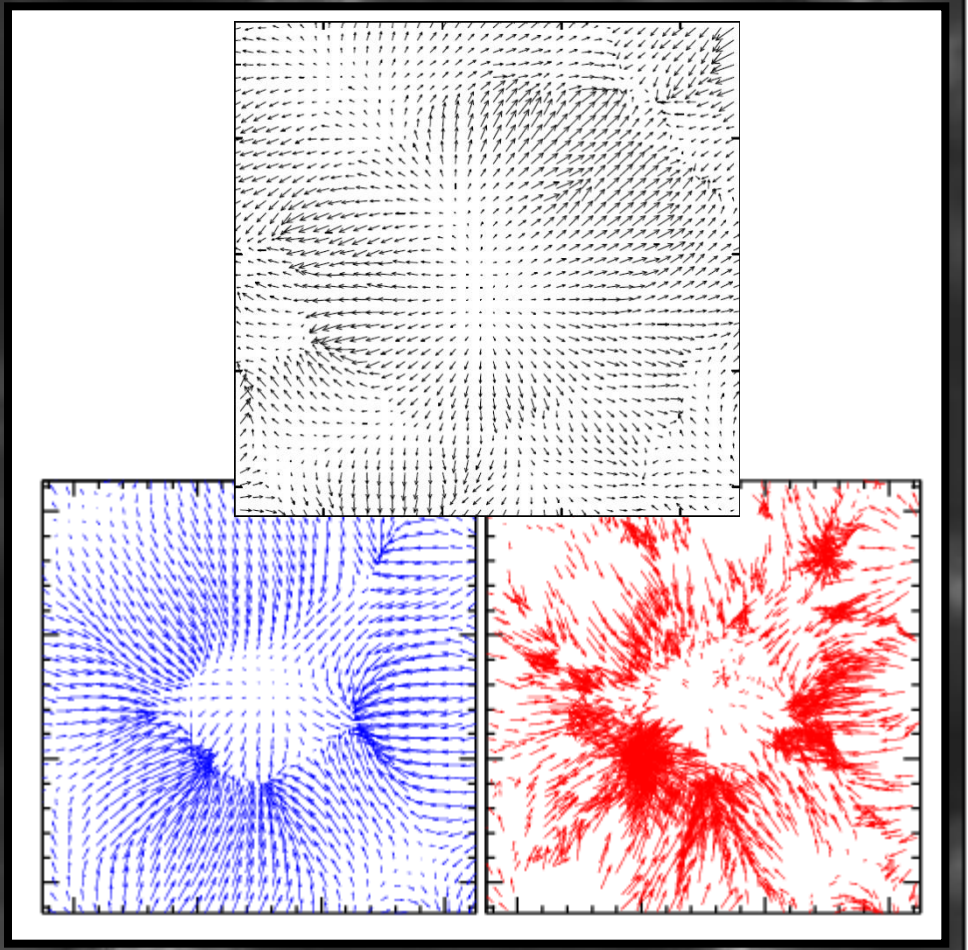
  when embedded in overdensity, small void collapses along ...



Void Flows: Expansion vs. Collapse

Two modes void flows:

- Void Expansion & Outflow
- Collapsing Voids



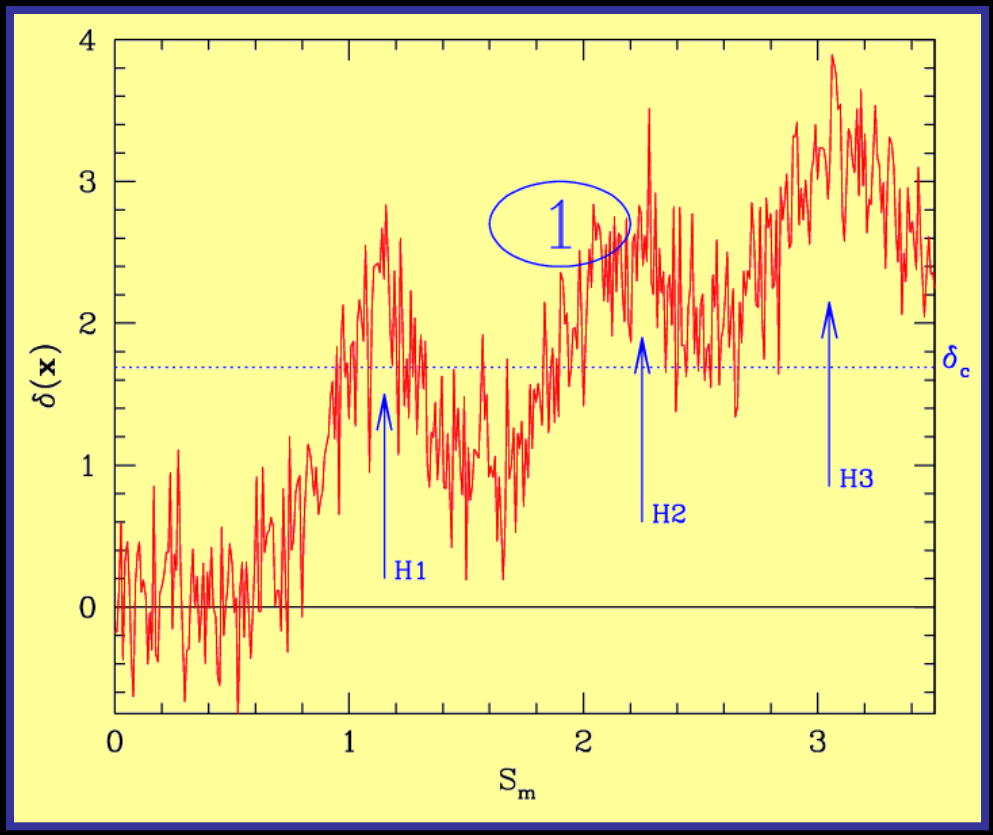
Extended Press-Schechter

Barrier Crossing

- Spherical
  linear collapse overdensity
  $\Delta_{lin}(r,S_m,t)$ > critical density δ_c
- Collapse time:
  $a_{coll}(r) = \delta_c / \Delta_{lin,0}(r,S_m)$
- Precise prediction
  object formation time
  from initial field $\Delta_{lin,0}(r,S_m)$

Collapse Barrier: δ_c

- Critical density value:
  EdS , Ω_0=1: $\delta_c \sim 1.69$



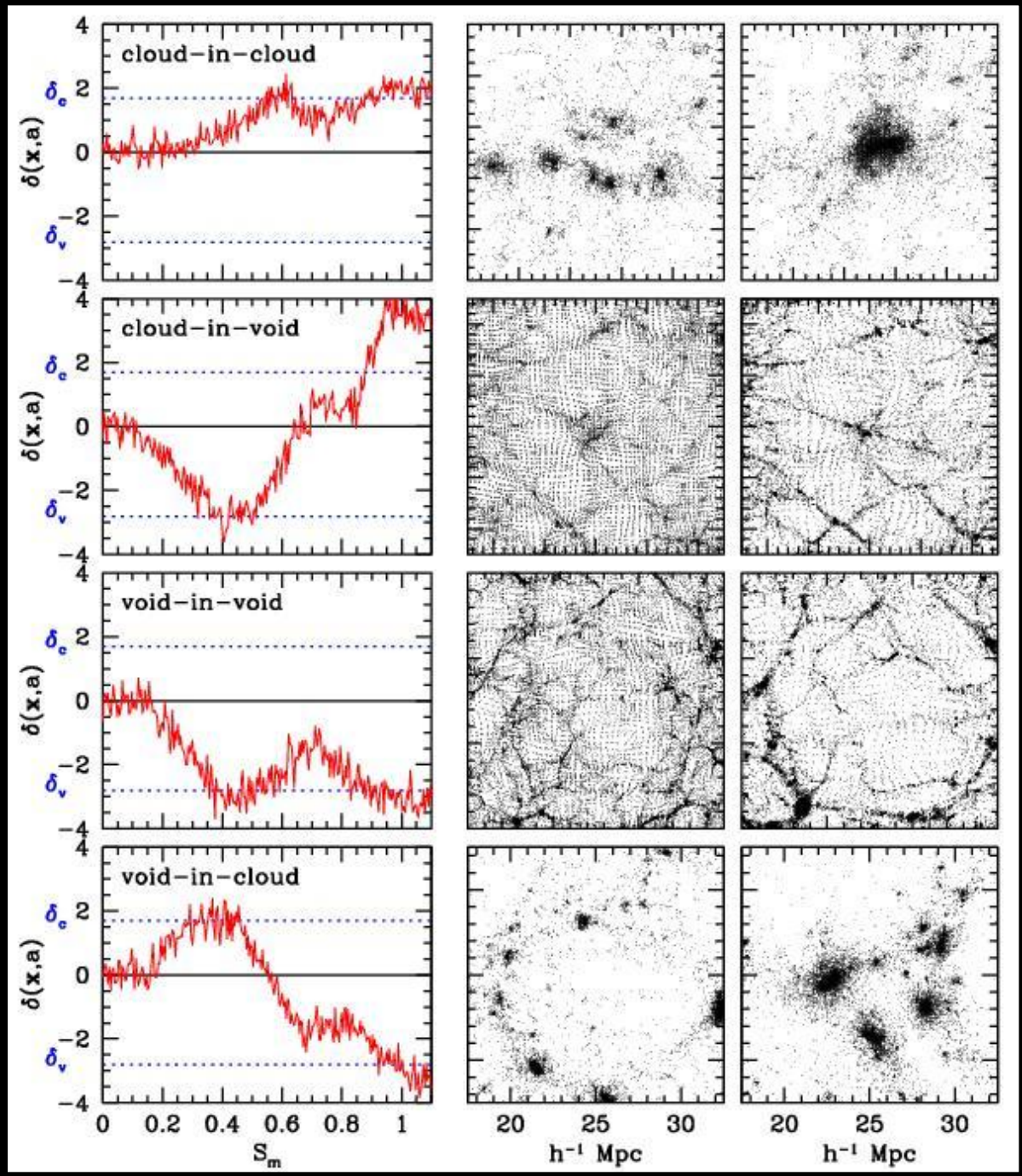
cumulative random walk:

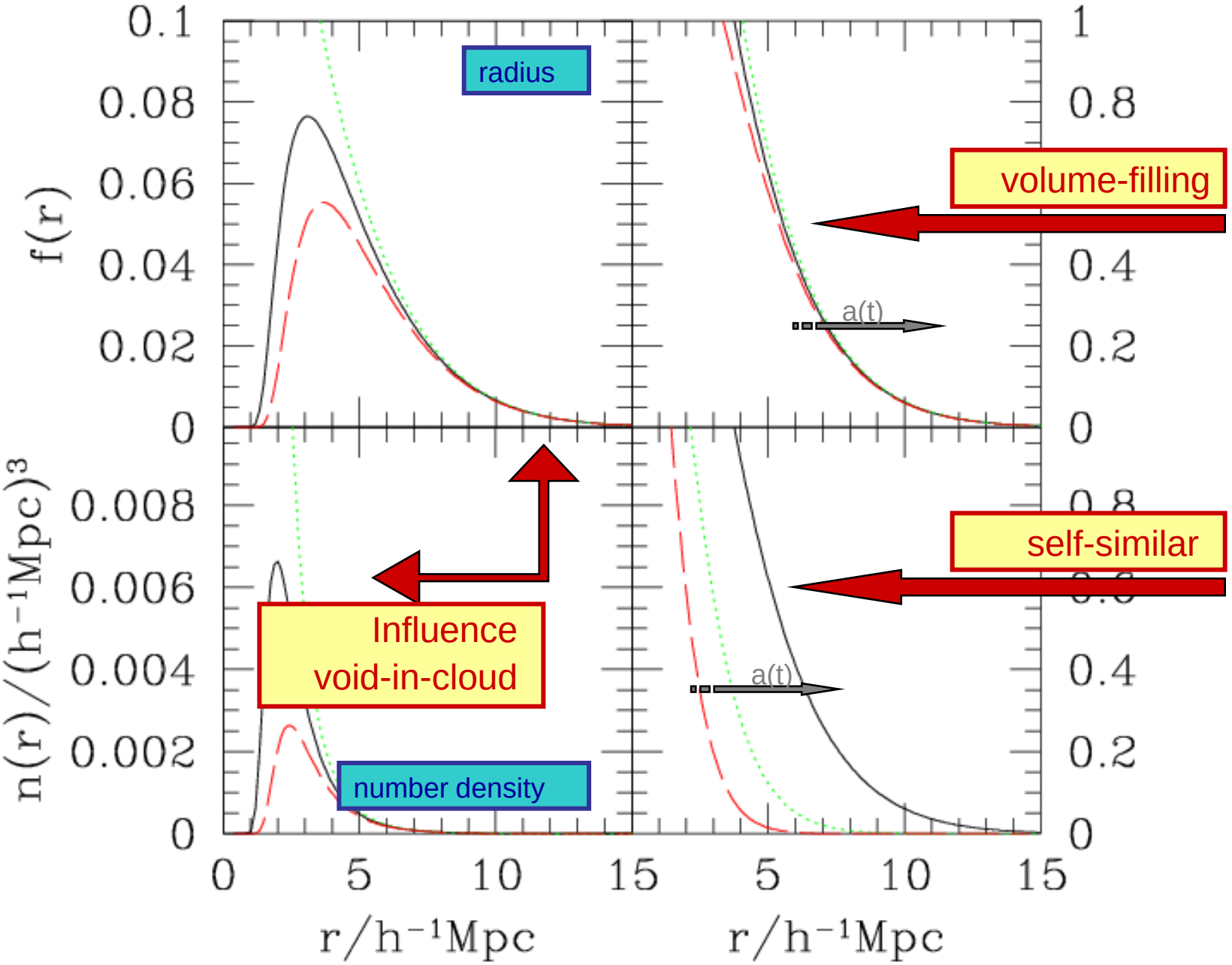
$$\delta_s(\mathbf{x};\lambda_m) = \int_{|\mathbf{k}|<k_m} \frac{\mathrm{d}\mathbf{k}}{(2\pi)^3}\,\hat{\delta}(\mathbf{k})\,\mathrm{e}^{-\mathrm{i}\mathbf{k}\cdot\mathbf{x}}$$

Proper Treatment
Full Hierarchy
Cosmic Structure

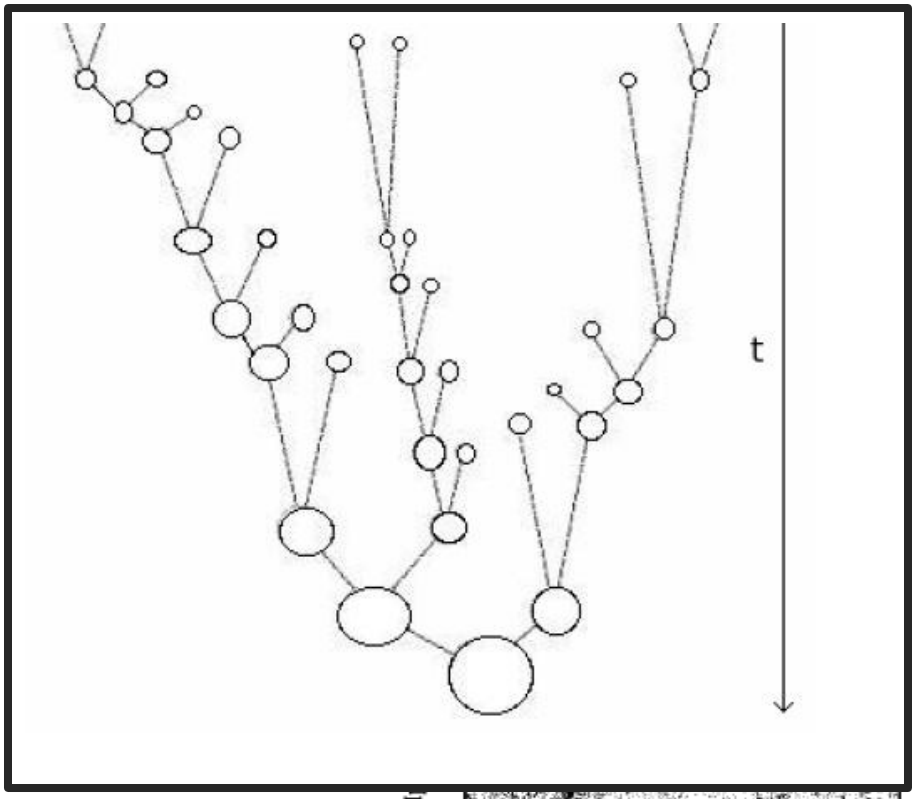
Excursion Modes:

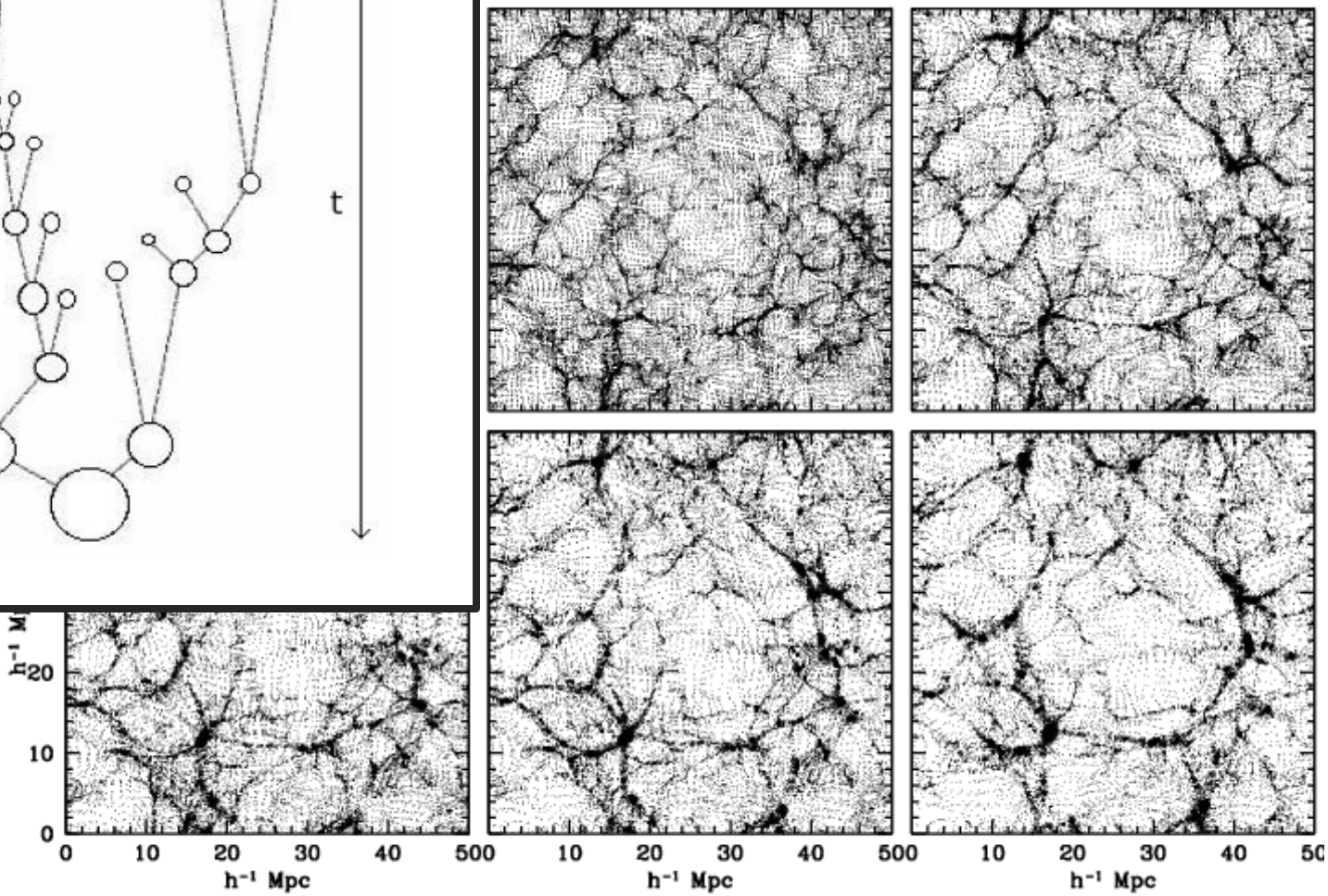
- Cloud-in-Void
- Void-in-Void
- Void-in-Void
- Void-in-Cloud




radius
volume-filling
a(t)
Influence
void-in-cloud
self-similar
a(t)
number density
f(r)
n(r)/(h⁻¹Mpc)³
r/h⁻¹Mpc
r/h⁻¹Mpc
0.1
0.08
0.06
0.04
0.02
0
1
0.8
0.4
0.2
0
0.008
0.006
0.004
0.002
0
0.8
0.4
0.2
0
0
5
10
15
5
10
15

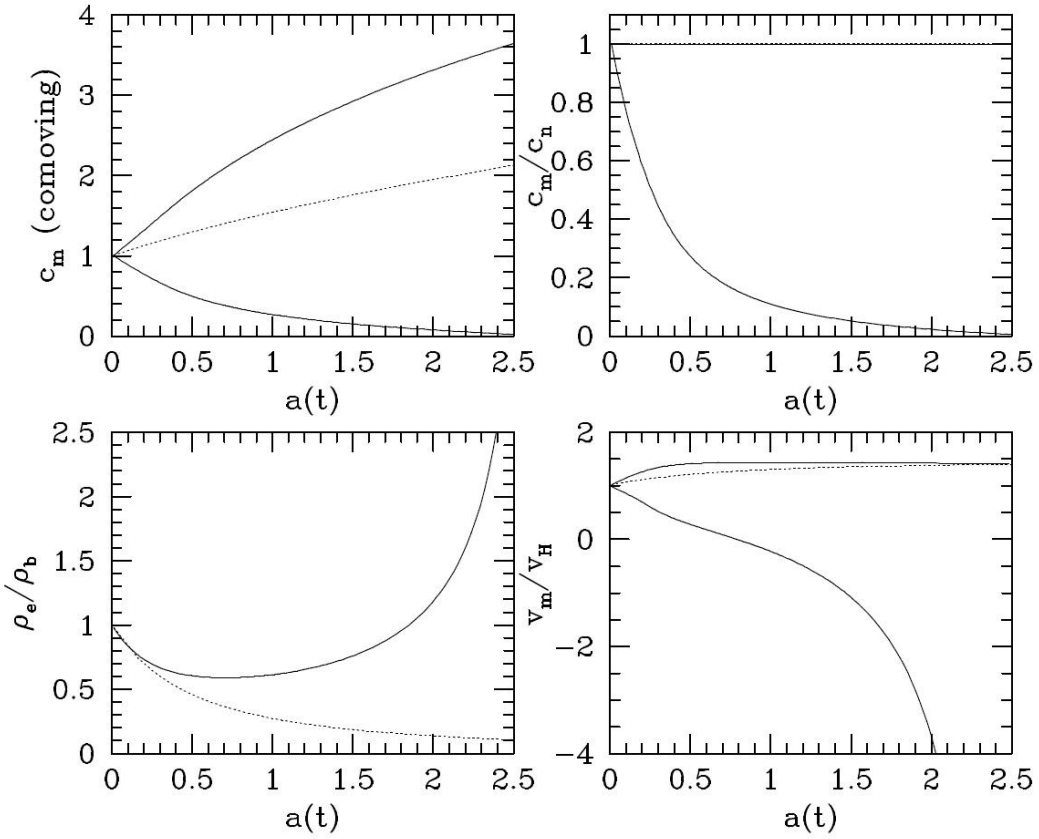
Void Merging Tree



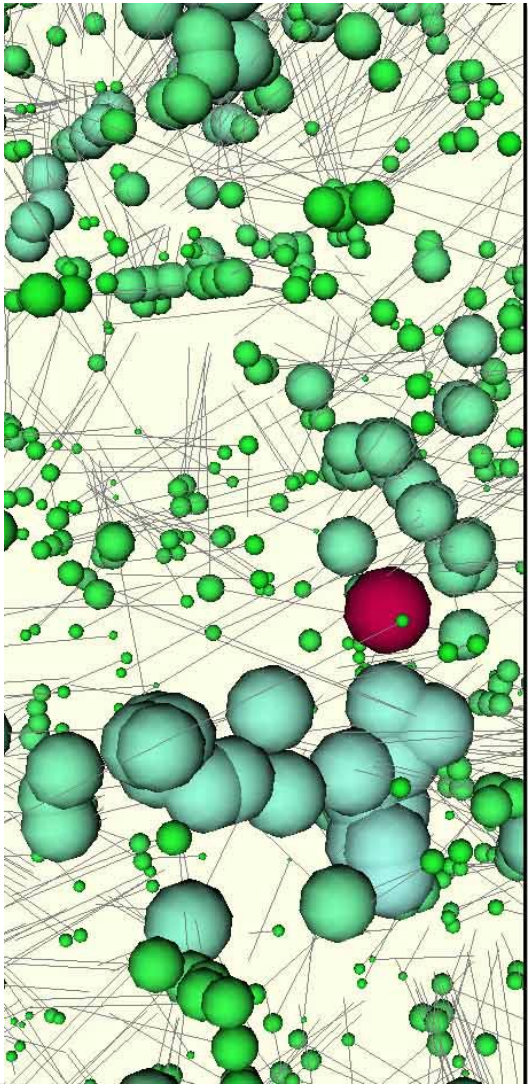


Tigrak & vdW 2009

Non-local: Voidpatch



Platen et al. 2009



Void-Cluster Dichotomy

- Voids emerge out of
  primordial density depressions
- Primordial Gaussian Density Field:
  symmetry overdense
  underdense

- Two-mode void evolution:
  Void population not dominated by small voids !

Void Galaxy Environment

search for loneliest galaxies

Voids: Dark Matter

GIF

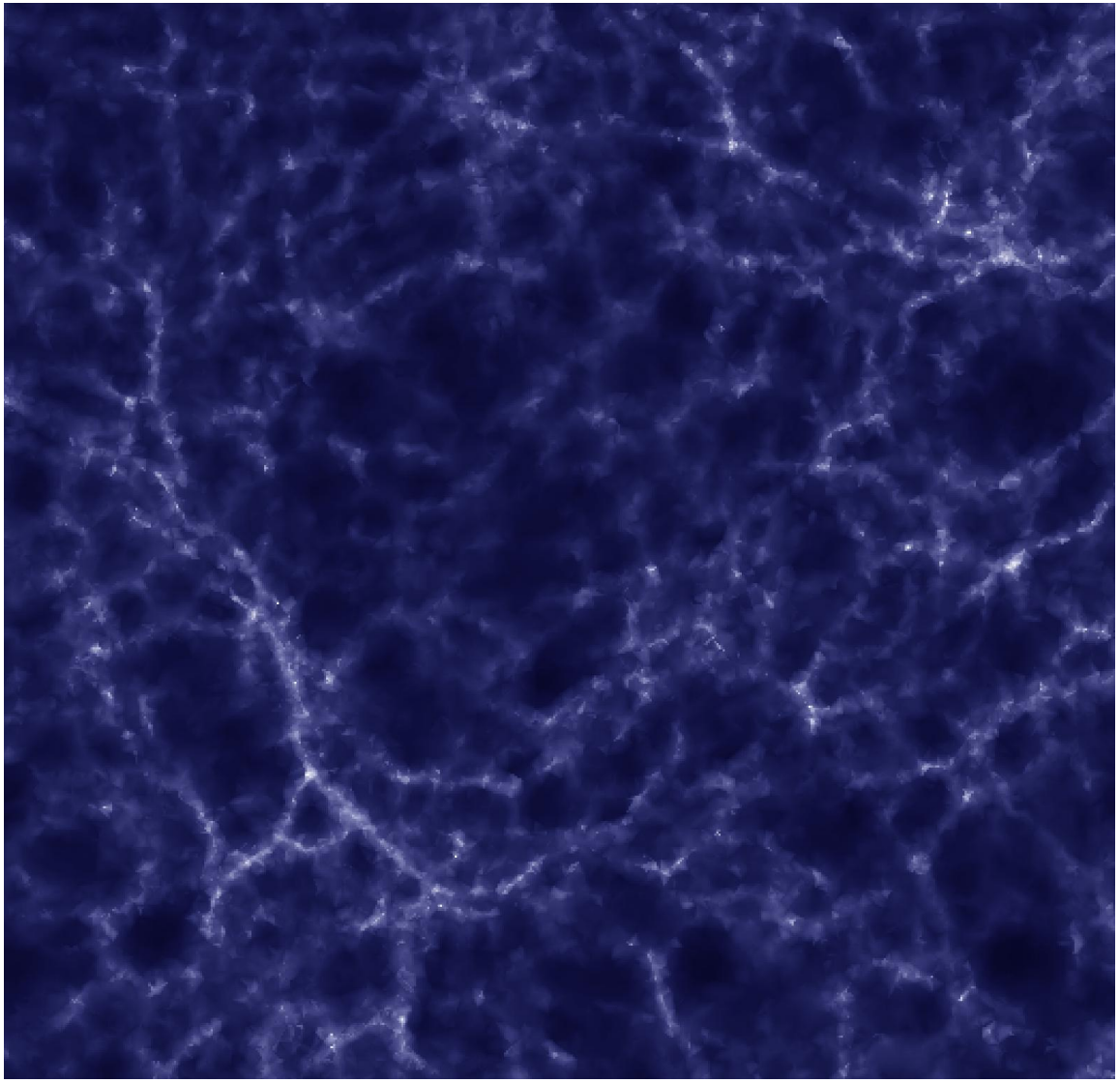
Simulation:

LCDM

DTFE density field

(courtesy:

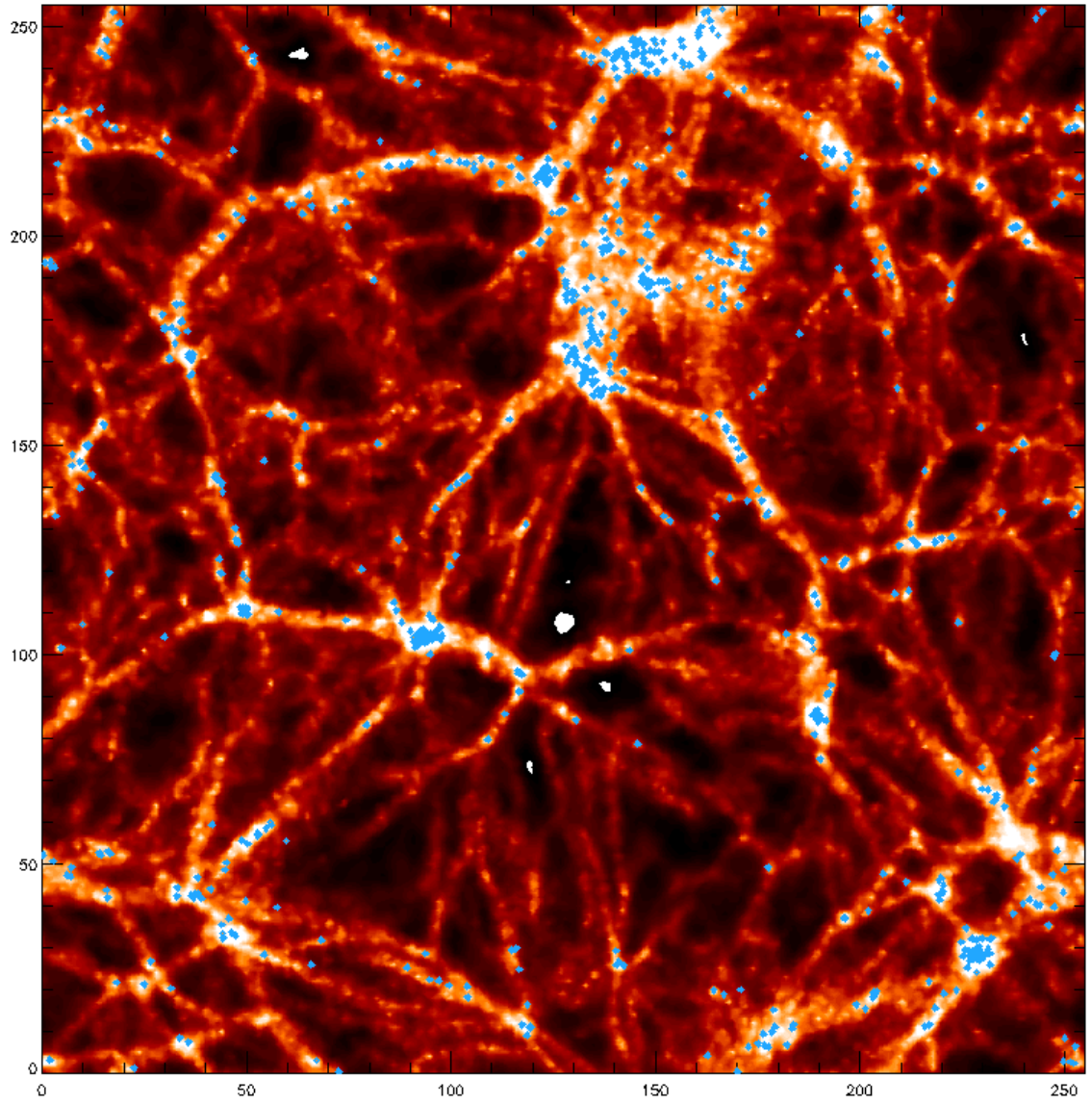
Virgo/J. Colberg).



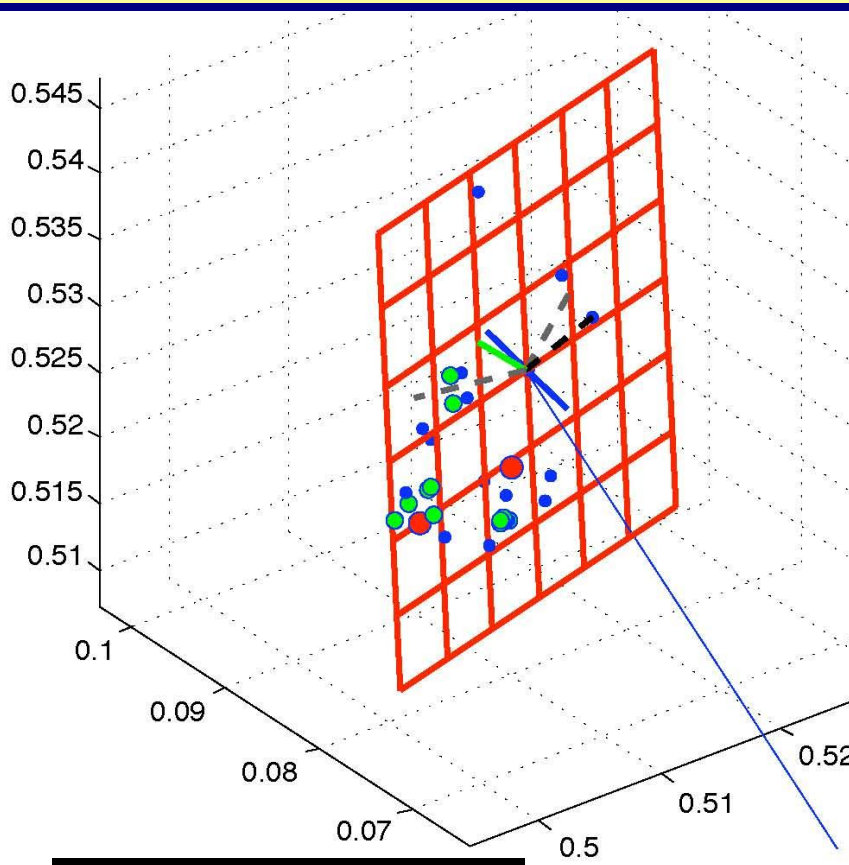
Voids: Dark Matter vs. Galaxies

Millennium Simulation: LCDM

(courtesy: E. Platen).



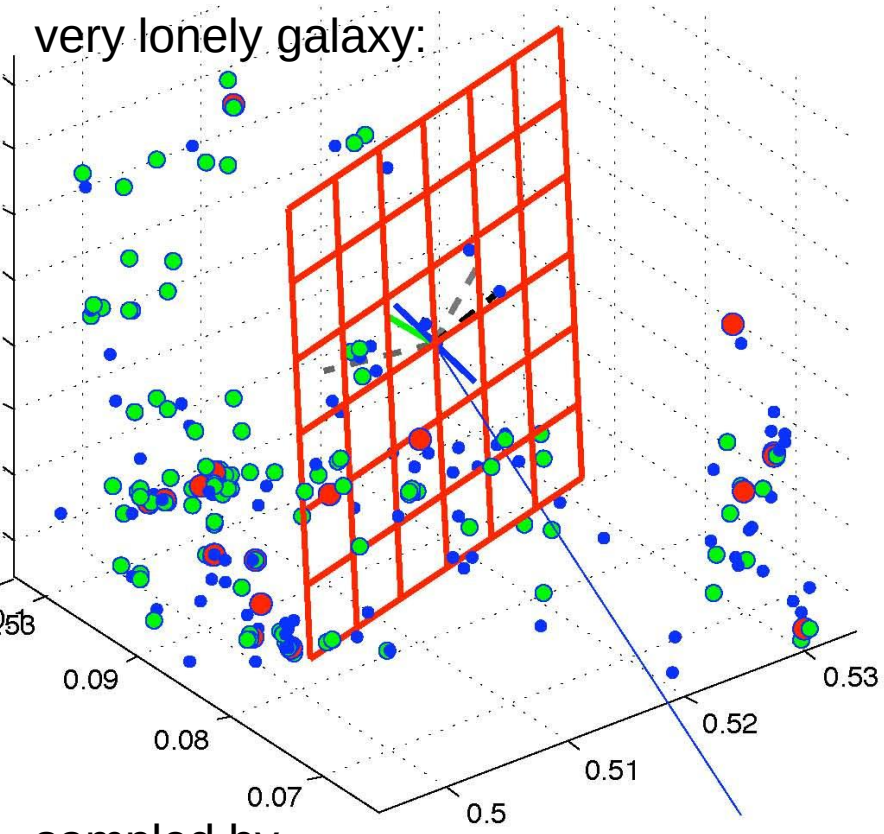
SDSS Voids & Galaxy Type



(courtesy:

P.J.E. Peebles & E. Platen)

SDSS void near
very lonely galaxy:

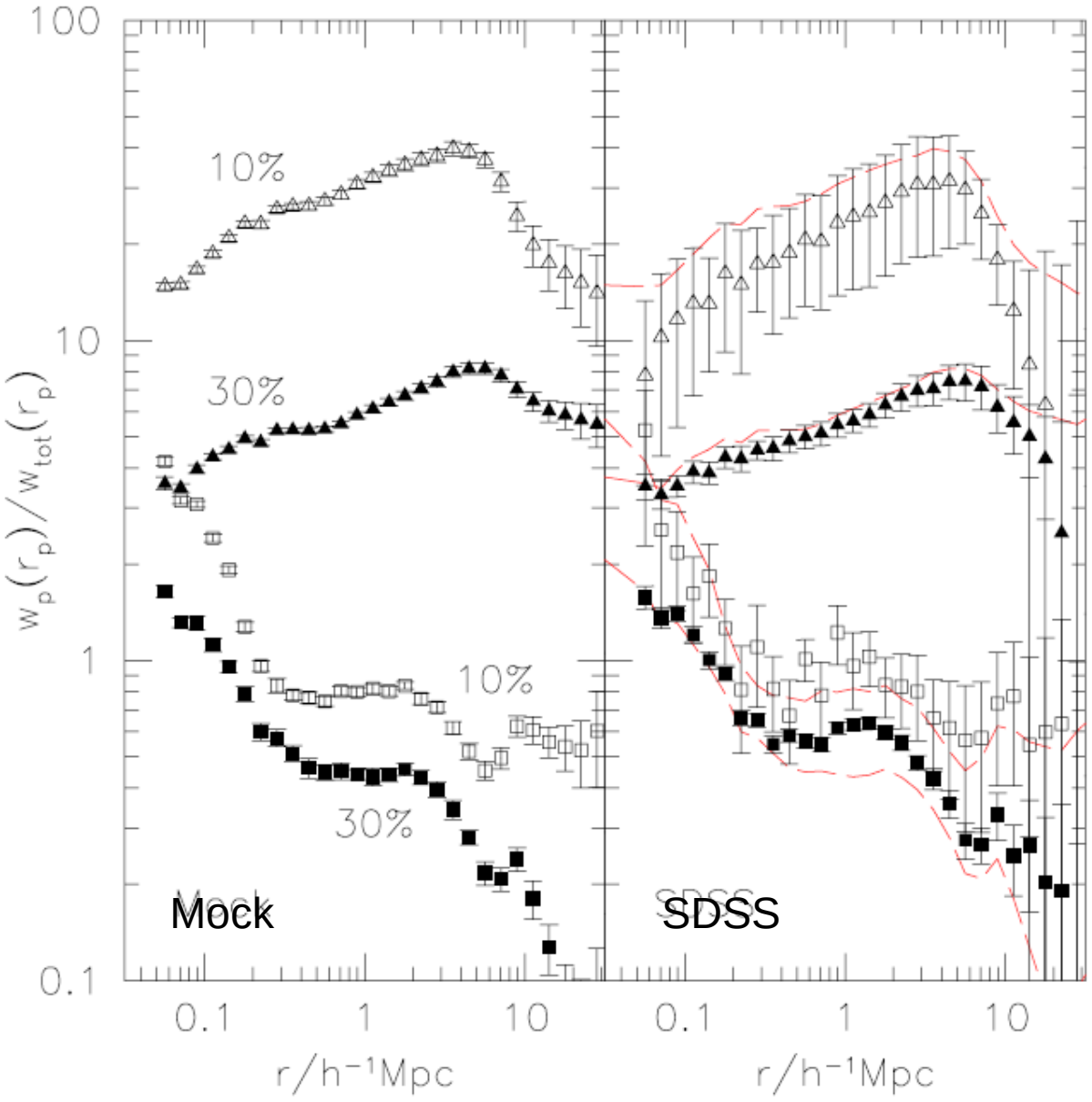


sampled by
galaxies different brightness:
no difference

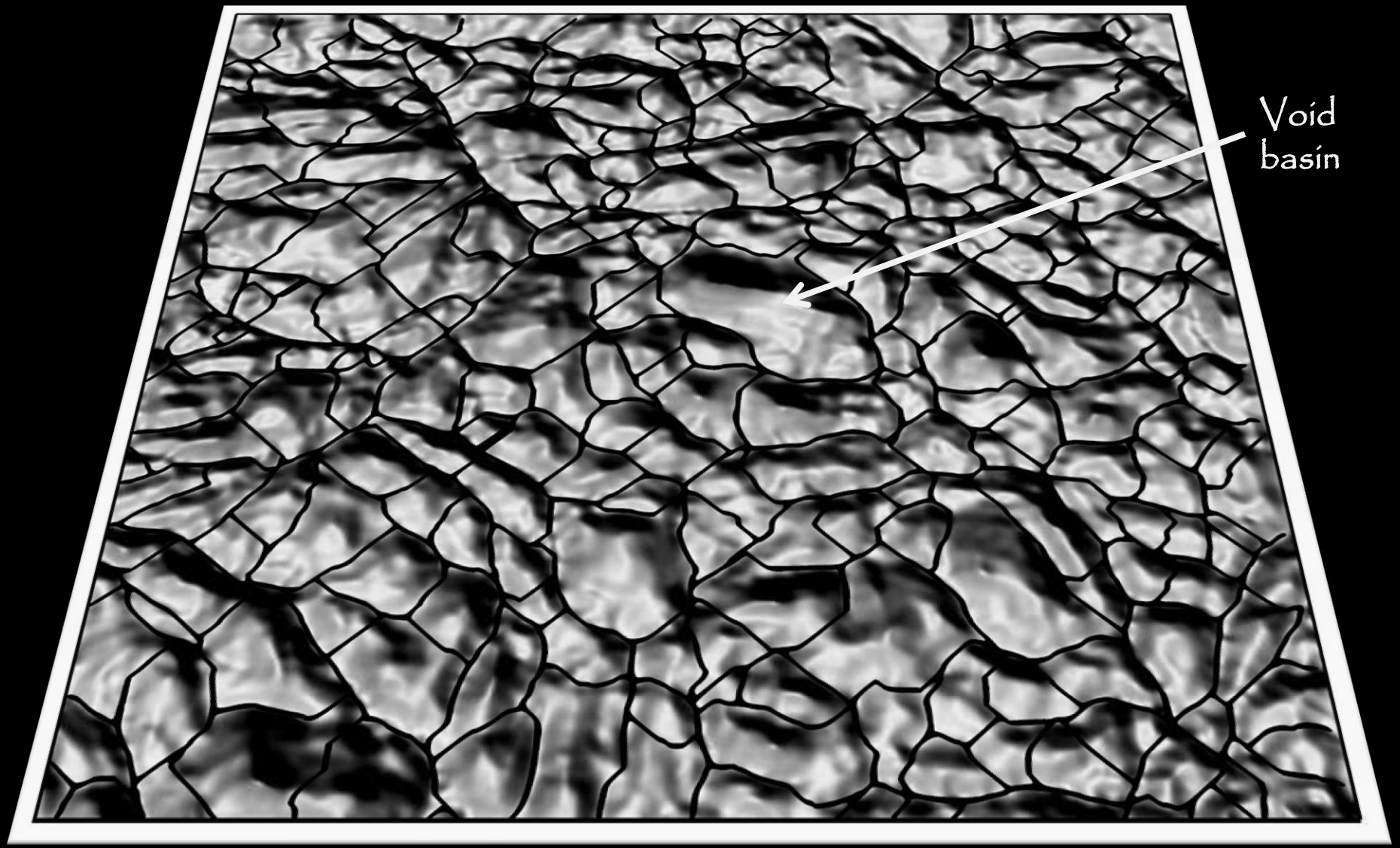
Abbas & Sheth 2007

Galaxies in void interior
more strongly clustered
than at periphery

Reflects
strong clustering
highest peaks
&
deepest troughs
in Gaussian random fields

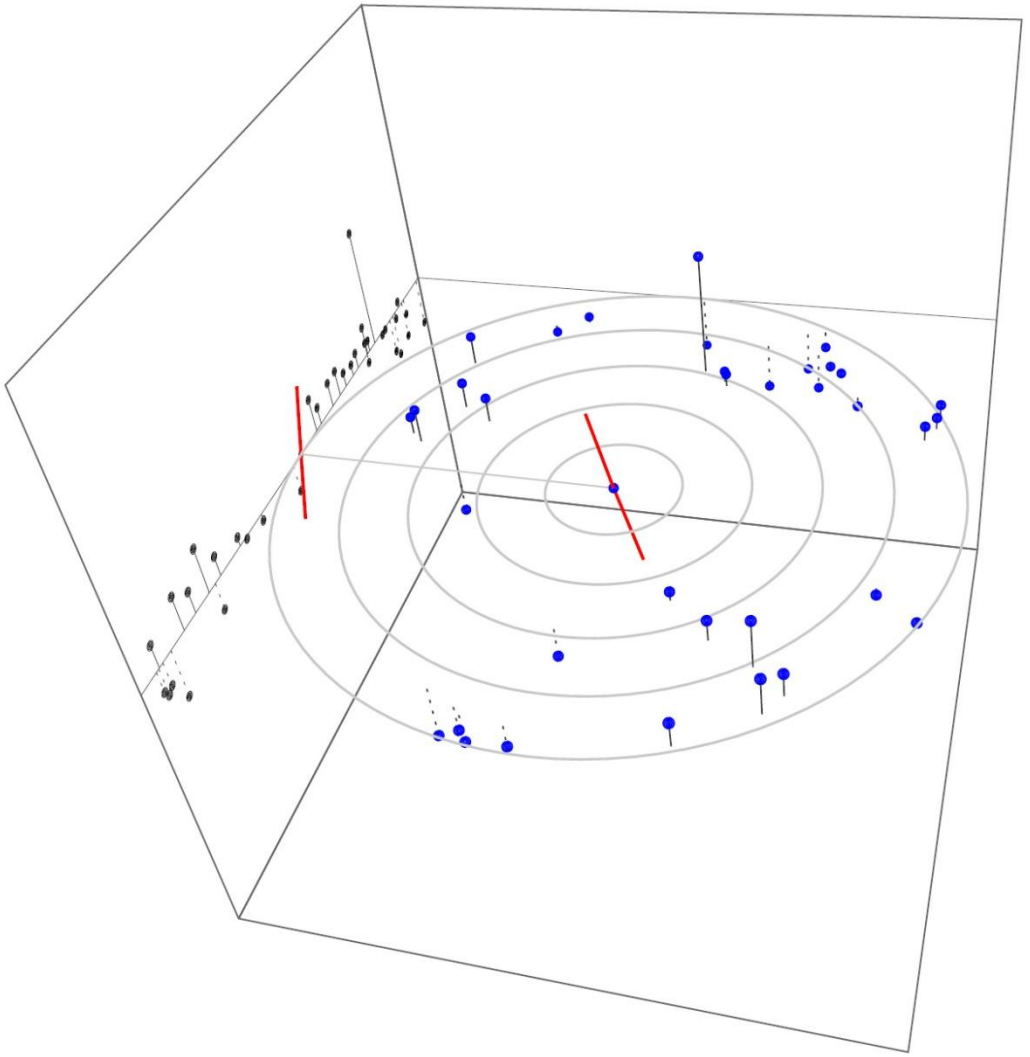


Watershed Transform: Morse Theory



"Colliding" SDSS Void ?

- SDSS void near very lonely galaxy
- "Void" galaxy in tenuous wall
- Boundary between two voids
- Amongst most lonely galaxies in our vicinity: $r_{ngh} > 4\ h^{-1}$ Mpc



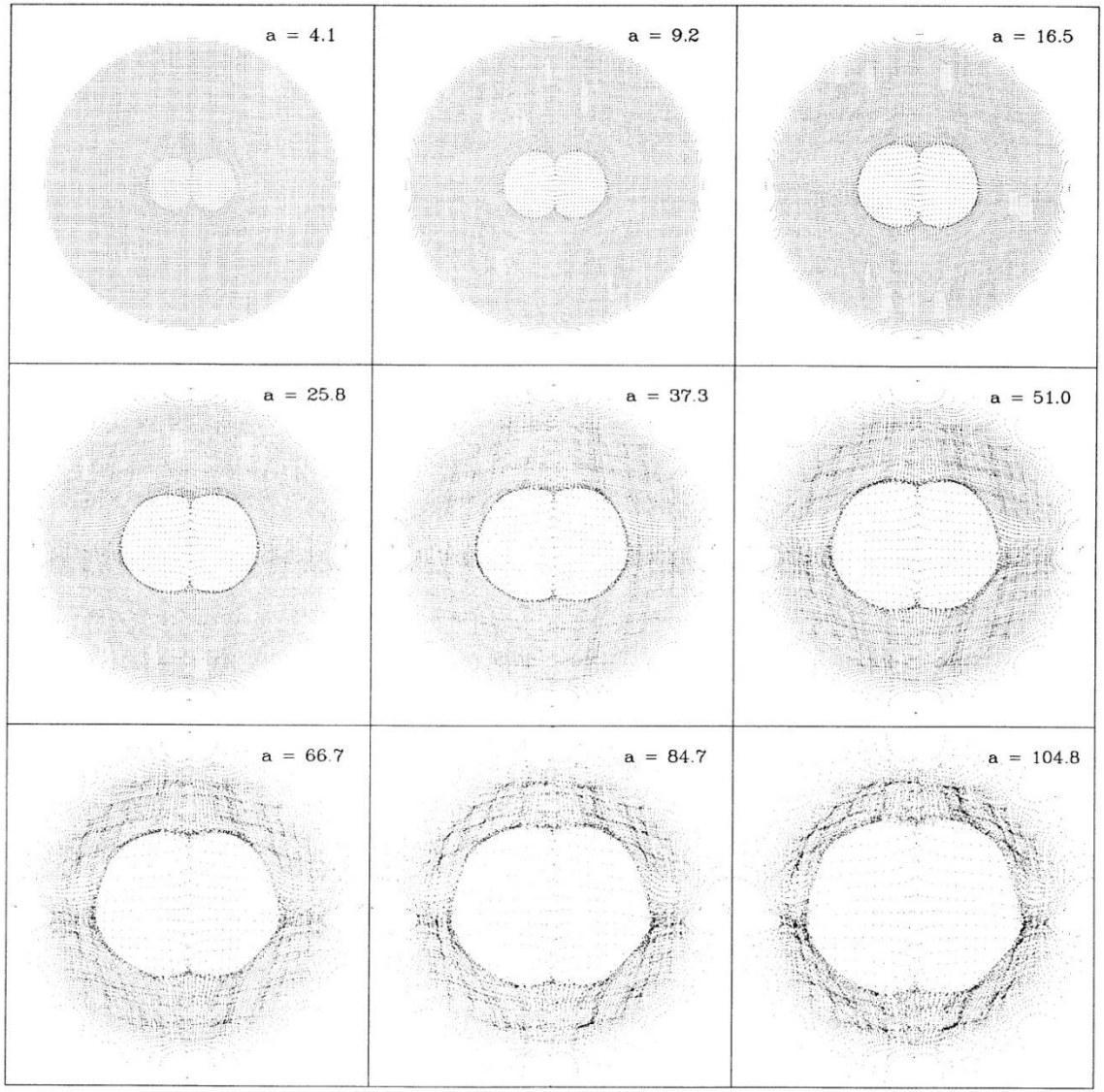
(map courtesy:

M. Aragon-Calvo)

"Colliding" SDSS Void ?

- Are we seeing a galaxy at the crosspoint of two

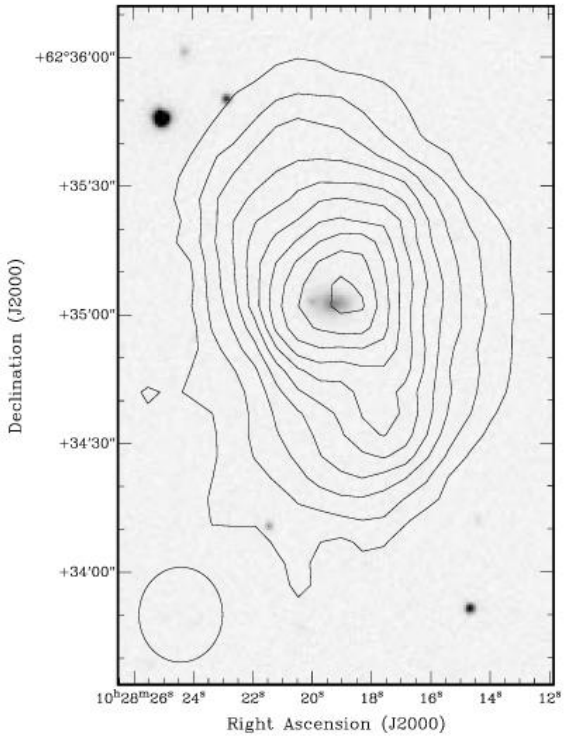
  merging voids … ?



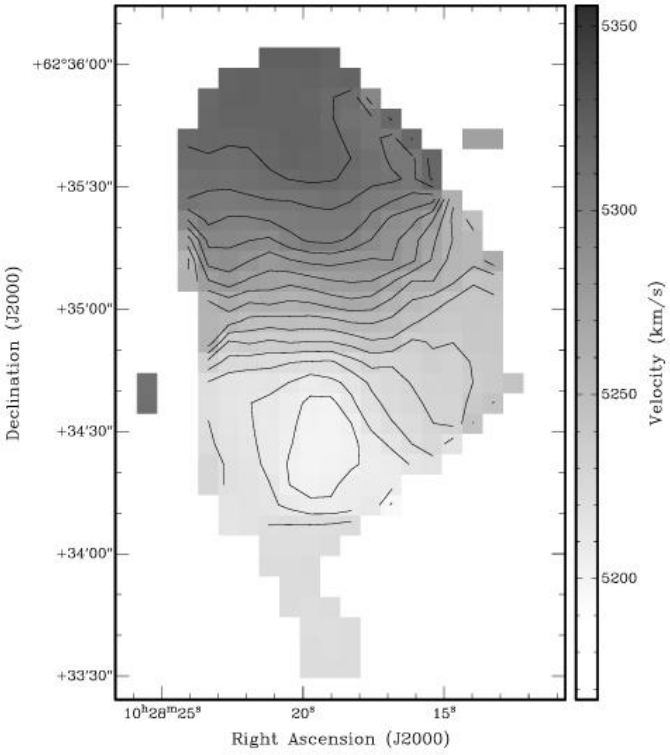
(map courtesy:

J. Dubinski)

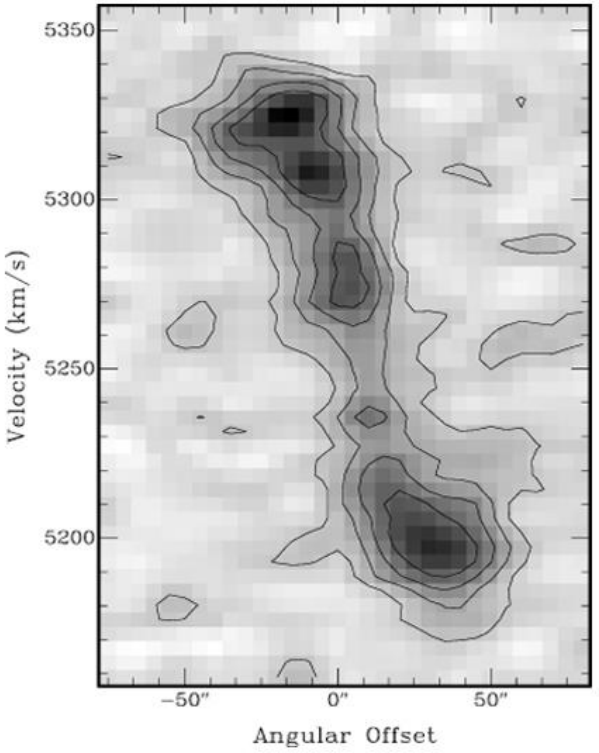
WSRT: void galaxy key program



HI surface density
Juxtaposition: optical



HI velocity map

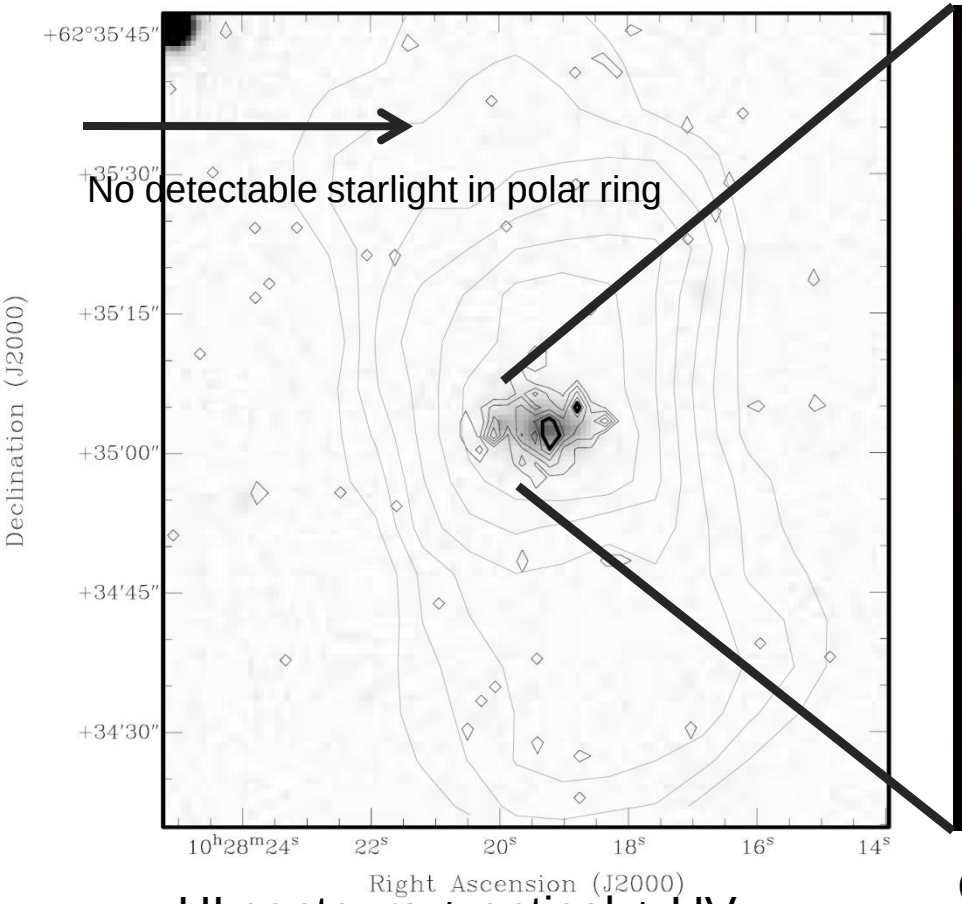


HI position-velocity:
rotating disk/ring

Lonely polar ring galaxy

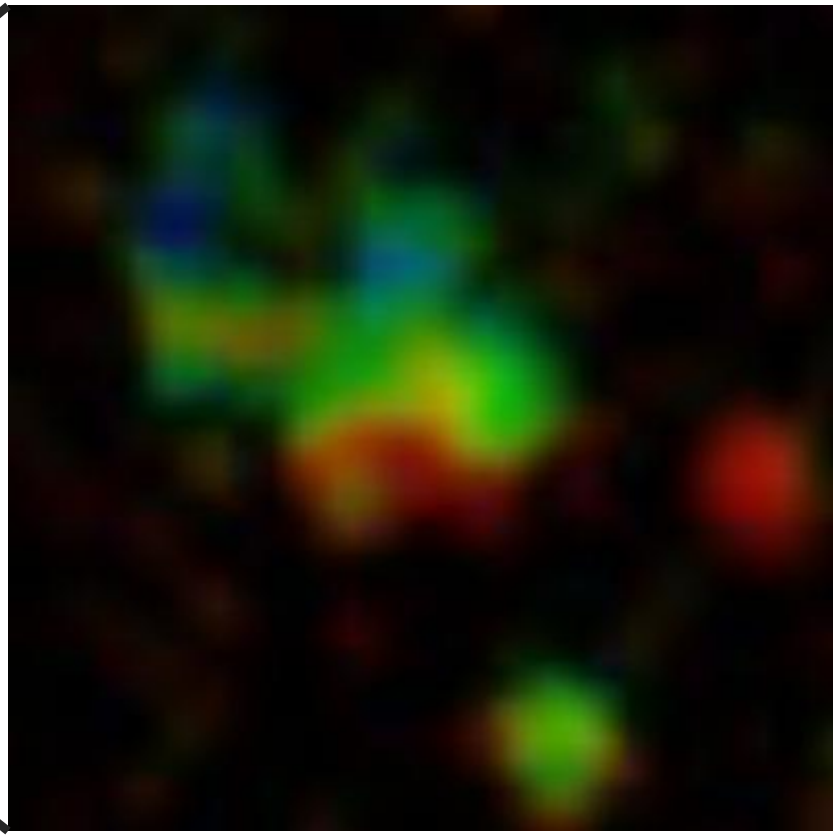
(Stanonik et al. 2009: see Stanonik poster)

WSRT: void galaxy key program



No detectable starlight in polar ring

HI contours + optical + UV



Galex UV map,
central “star cluster”: active star formation

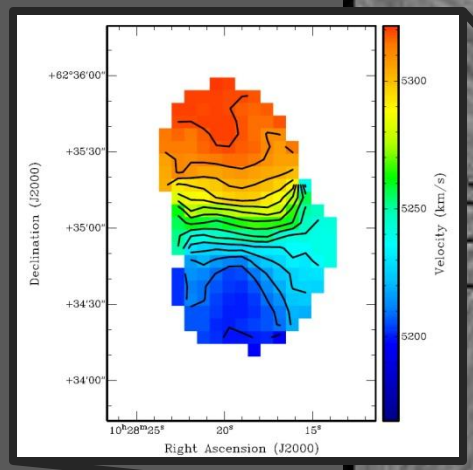
Lonely polar ring galaxy

(Stanonik et al. 2009: see Stanonik poster)

Cold Flow Accretion from Voids ?

Can cold flow accretion out of two voids explain the Polar Ring

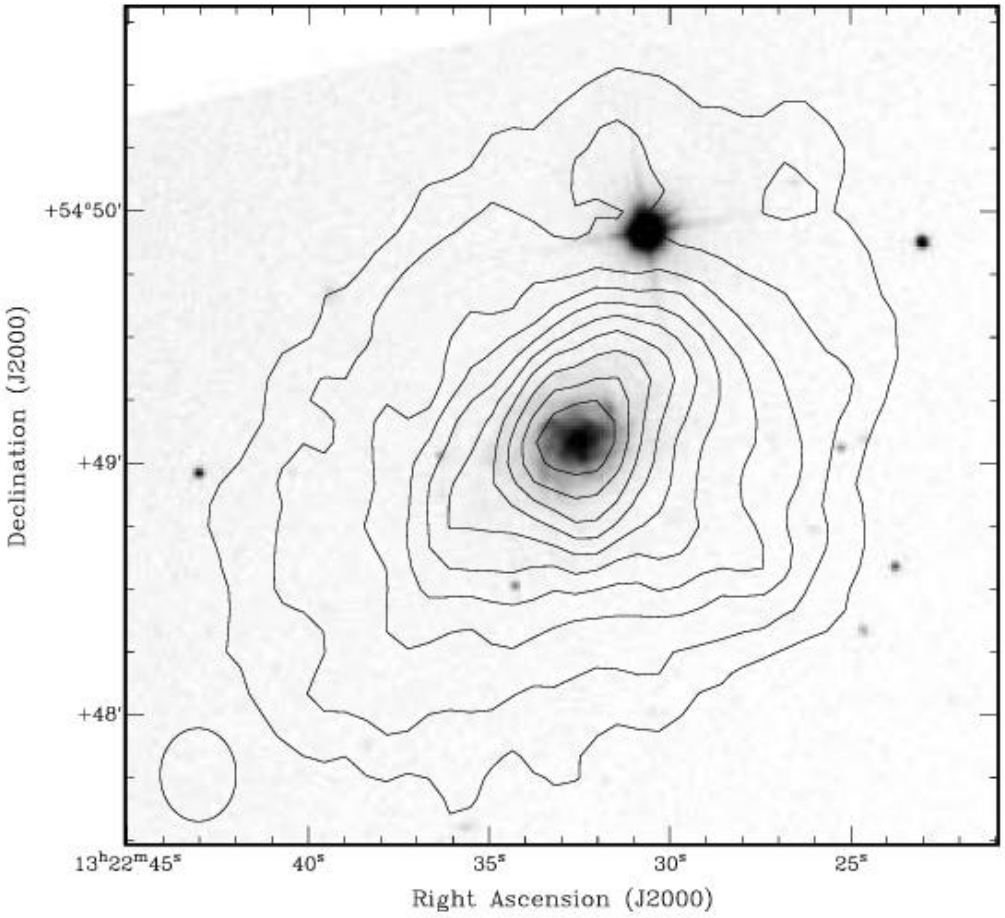
in this desolate Region ?

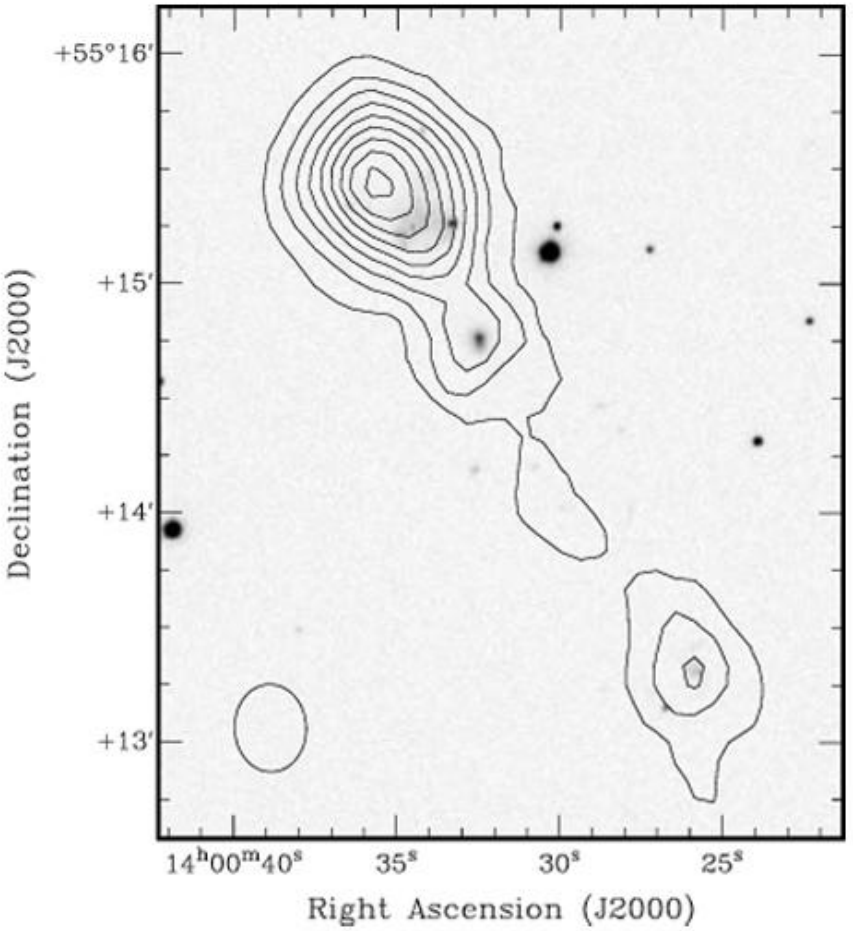


(courtesy:

M. Aragon-Calvo)

LEEG: Lonely & Empty Environment Galaxies





Void6 (flapping disk); Void10 (tidal tail ?)

see Stanonik nr. 20 poster !!!!

Summary:

- Void evolution marked by environment
- Voids evolve hierarchically:

  2 Void Processes: Merging & Collapse
- Void distribution peaked around characteristic scale
- Remnants of protovoid geometry: void substructure
- Void hierarchy manifest in void galaxy morphology ?