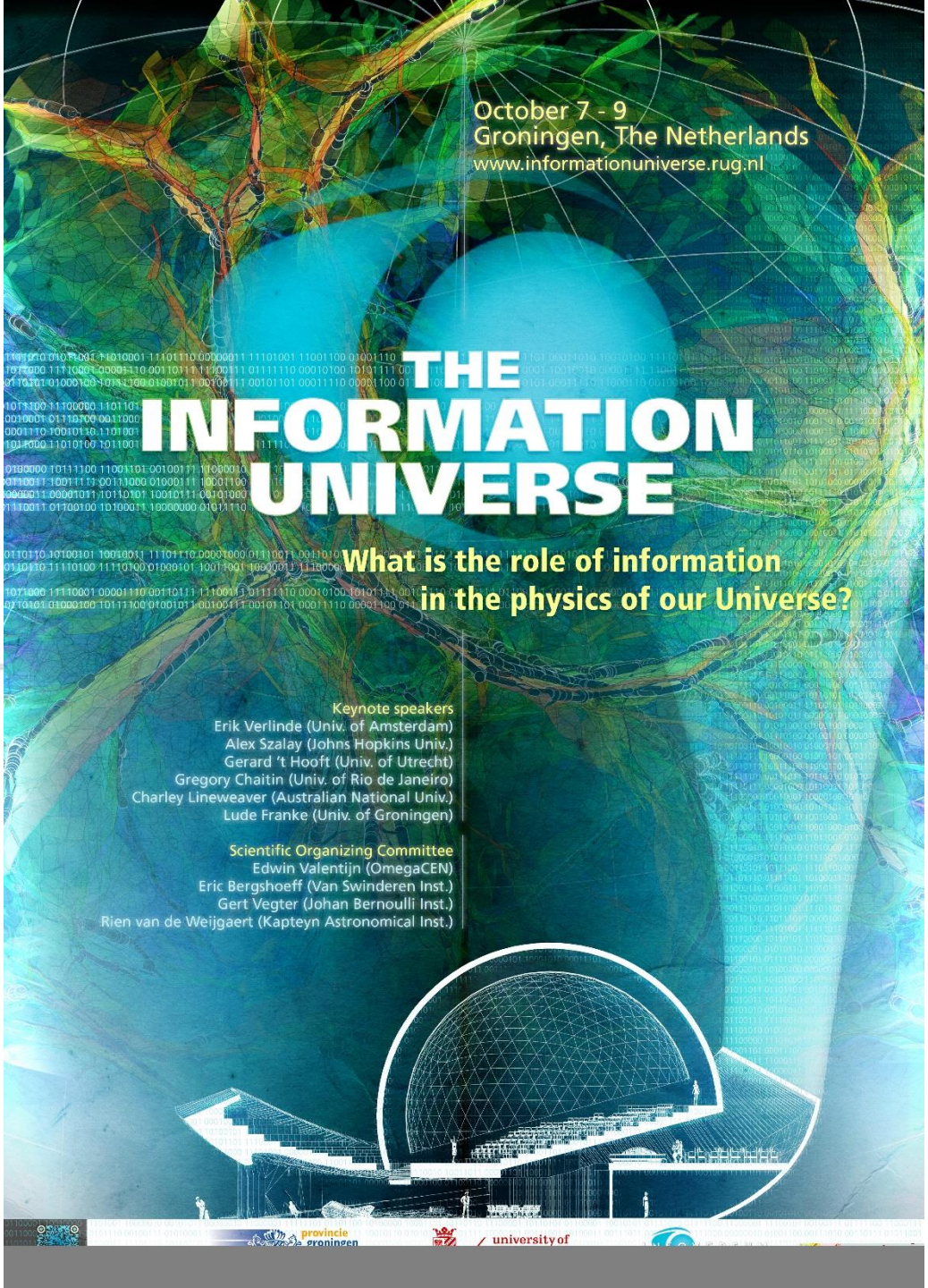
October 7 - 9
Groningen, The Netherlands
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THE
INFORMATION
UNIVERSE
What is the role of information
in the physics of our Universe?
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Erik Verlinde (Univ. of Amsterdam)
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Gerard 't Hooft (Univ. of Utrecht)
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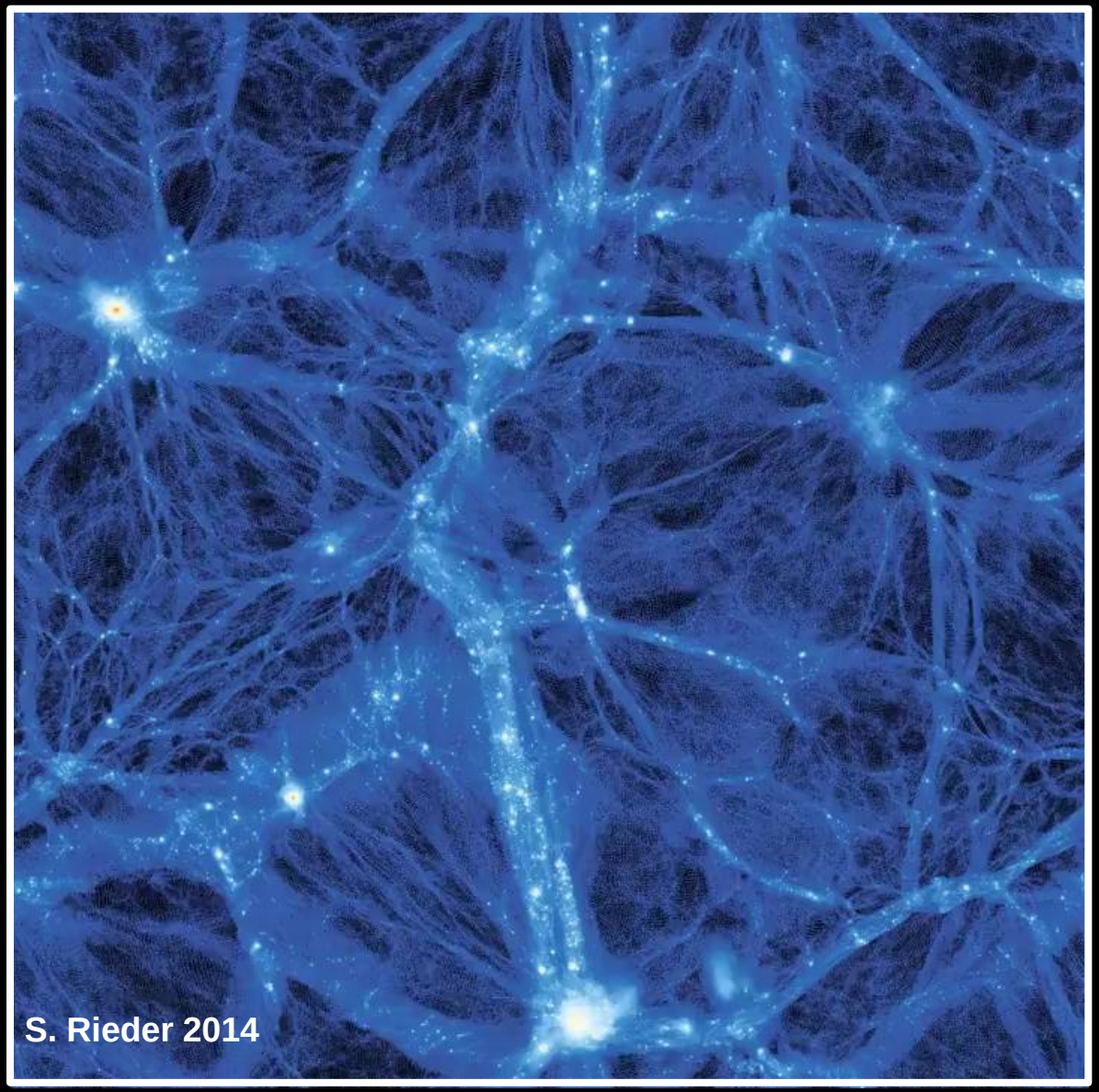
Charley Lineweaver (Australian National Univ.)
Lude Franke (Univ. of Groningen)
Scientific Organizing Committee
Edwin Valentijn (OmegaCEN)
Eric Bergshoeff (Van Swinderen Inst.)
Gert Vegter (Johan Bernoulli Inst.)
Rien van de Weijgaert (Kapteyn Astronomical Inst.)
provincie
groningen
university of

het Kosmische Web:

de Grootste Structuur in het Heelal

Rien van de Weijgaert, Inforversum, Groningen, 25 juni 2015



on scales of ~0.1-500
millions of lightyears

complex weblike pattern

in which
matter, gas & galaxies
are organized in

- compact clusters,
- elongated filaments
- flattened walss

around

- cosmic voids

Cosmic Web

Cosmic Fossil:

- our origin –

how did structure in the Universe emerge ?

Universe after 379000 years:

almost without any profile

$$\frac{\Delta T}{T} < 10^{-5}$$

$$\frac{\Delta r}{r} \leq 1.4 \times 10^{-3}$$

$$\frac{\Delta r}{r} = 10^{-5} : \; r = 60.4\,m$$

Cosmic Dilemma:

379000 jaar afterBig Bang:
uniform, nearly without any structure

How did the wealth of
objects and structure emerge?

Atlas of the Universe

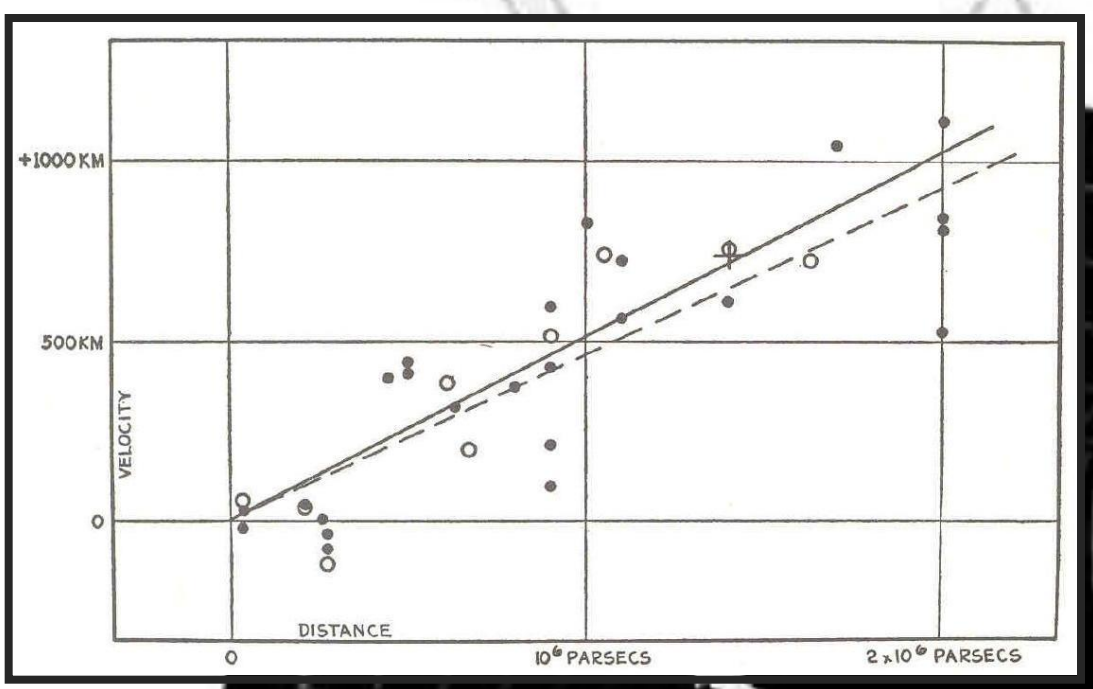
Map of the Universe

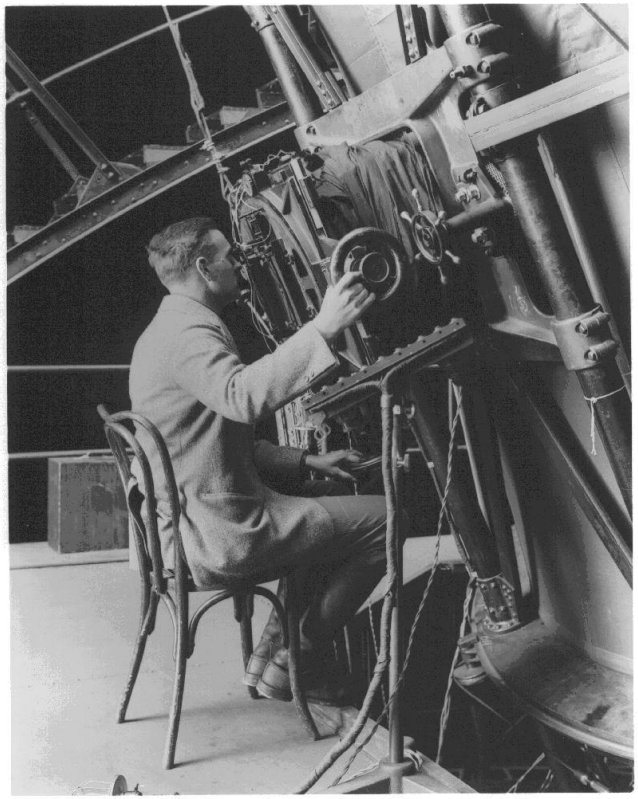
How to map structures
in the Universe ?

- Galaxies as light beacons
- Map of
  galaxy locations
- tracing of structures
  from distribution of galaxies

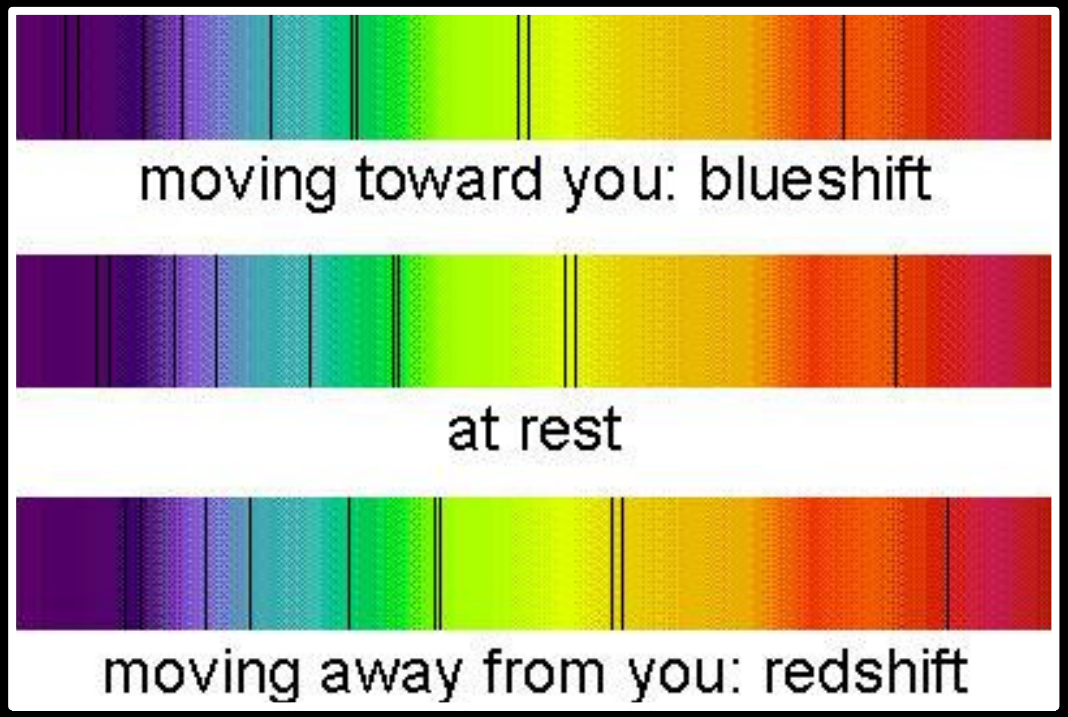
... Galaxies ...

Hubble Expansion



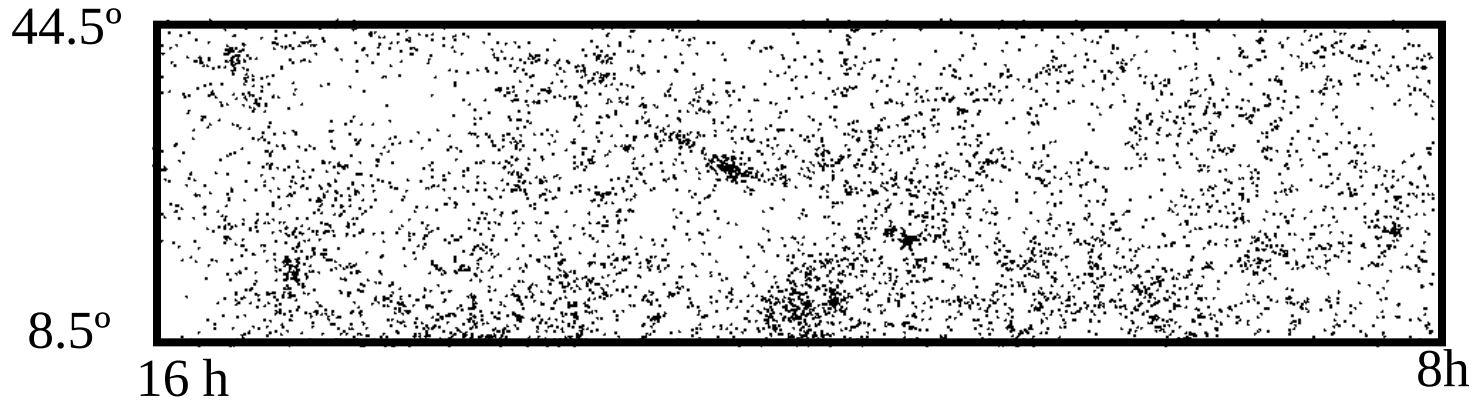


Distances in the Universe: redshift

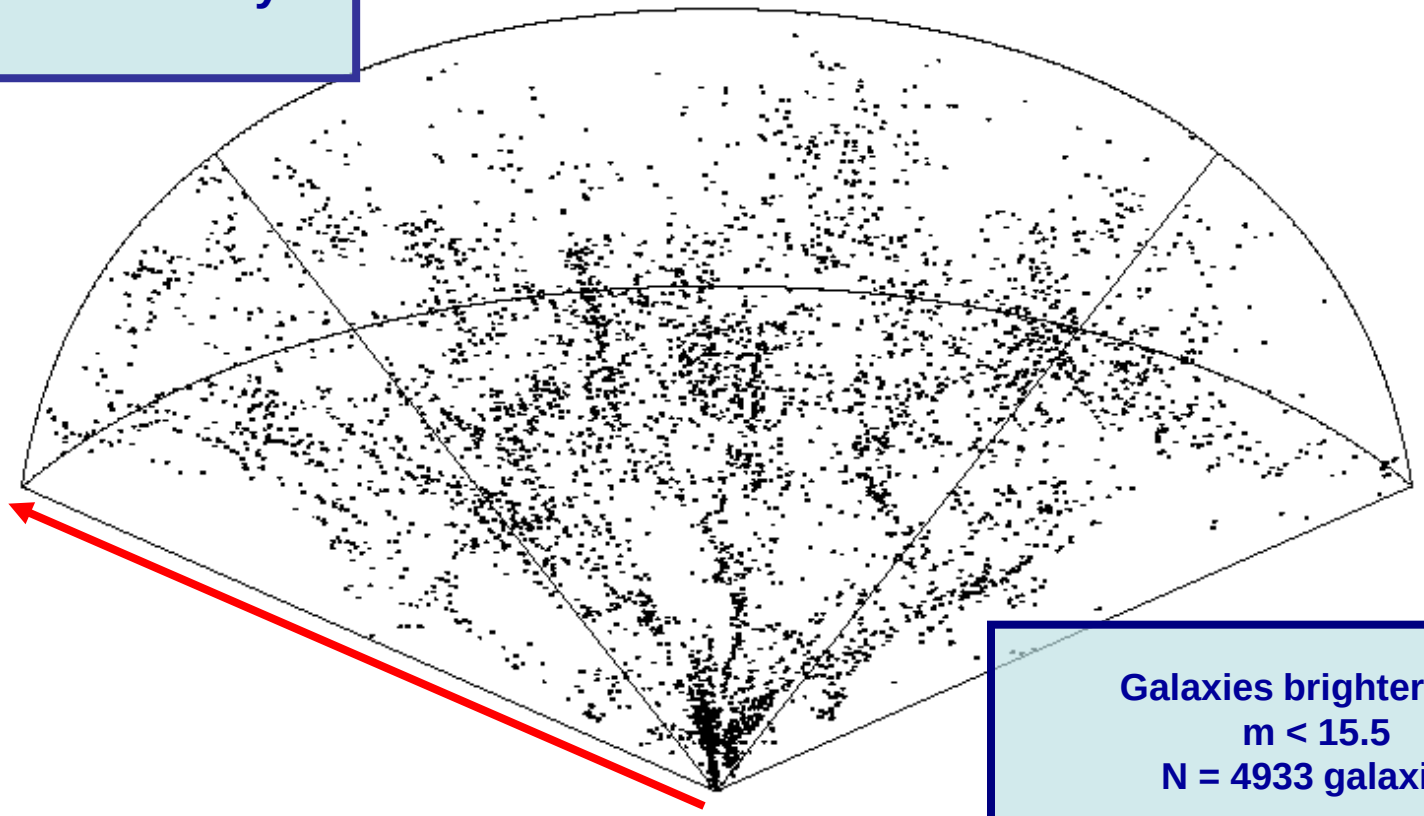


redshift ✪ expansion velocity ✪ Hubble: distance

$$c\,z = H\,r$$



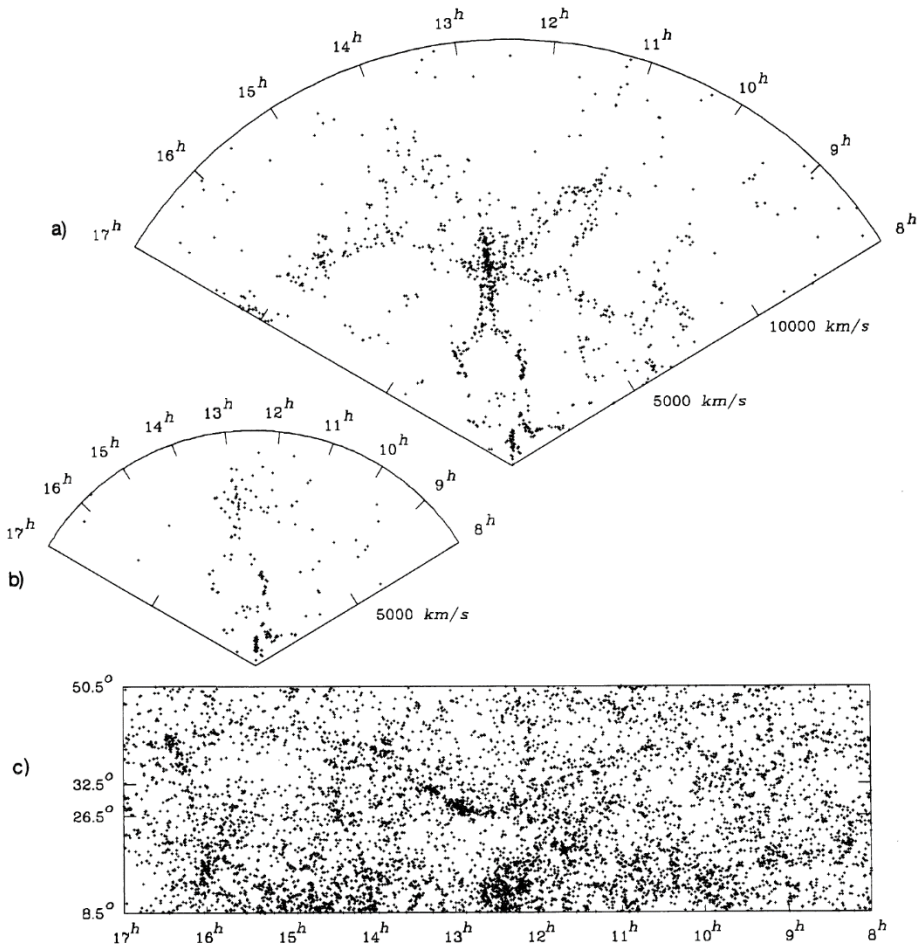
CfA2 survey



Galaxies brighter than
m < 15.5
N = 4933 galaxies

Figure courtesy: V. Martínez

“Stickman” & Soapsud

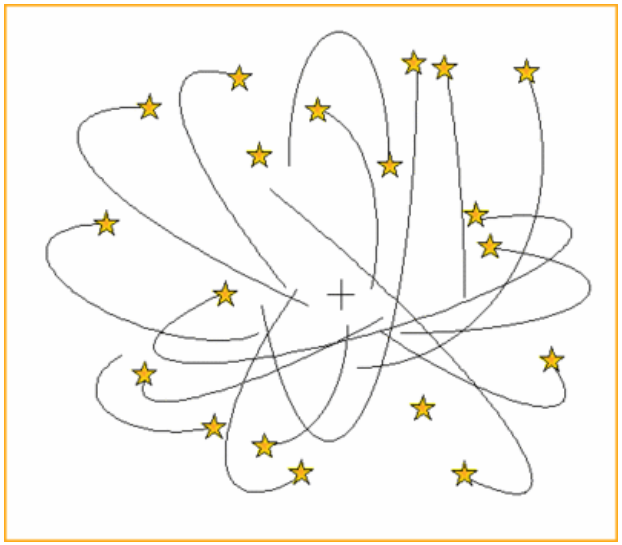


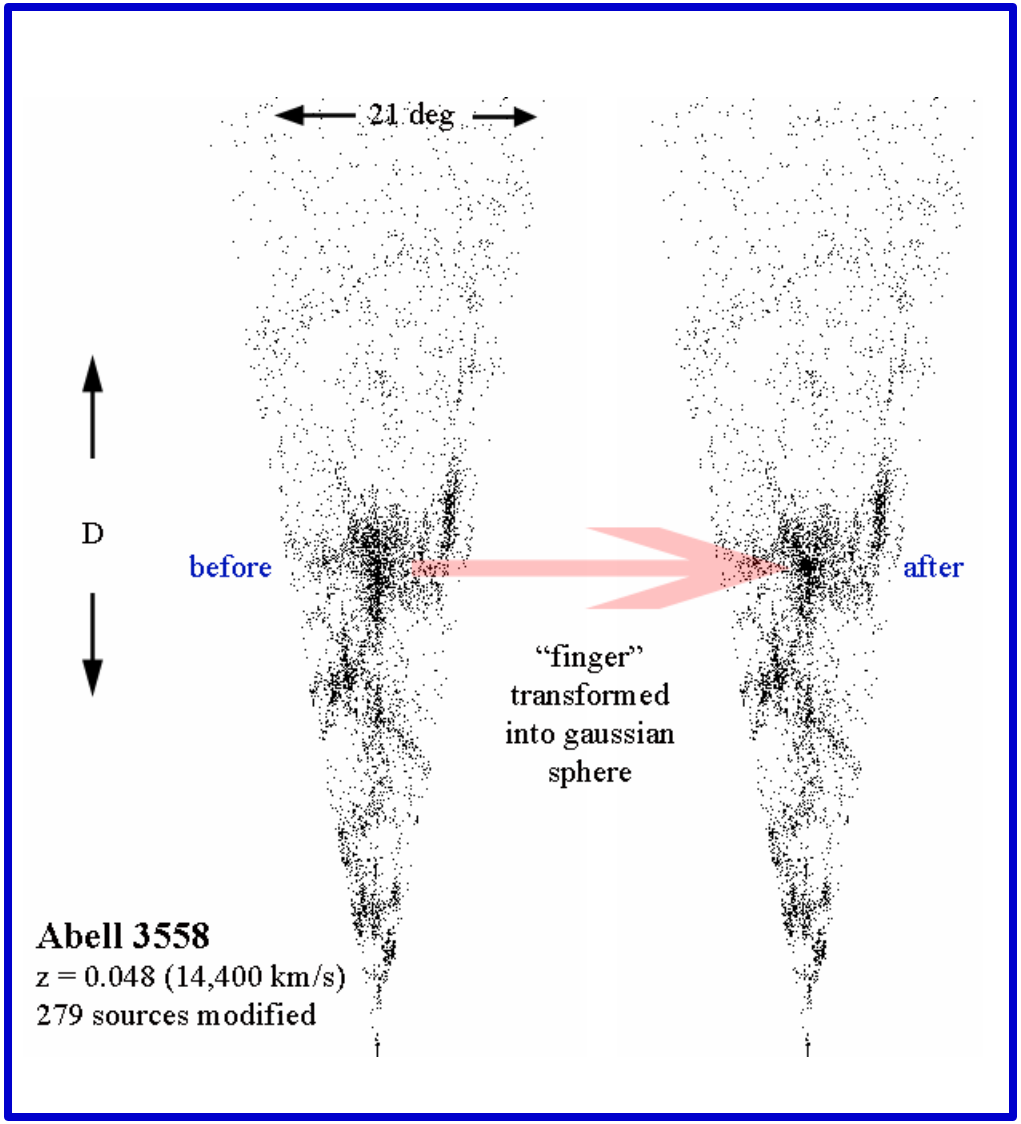
deLapparent, Geller & Huchra, 1986:

“a slice of the Universe”

Voids represent a key element of a galaxy distribution resembling a soapsud.

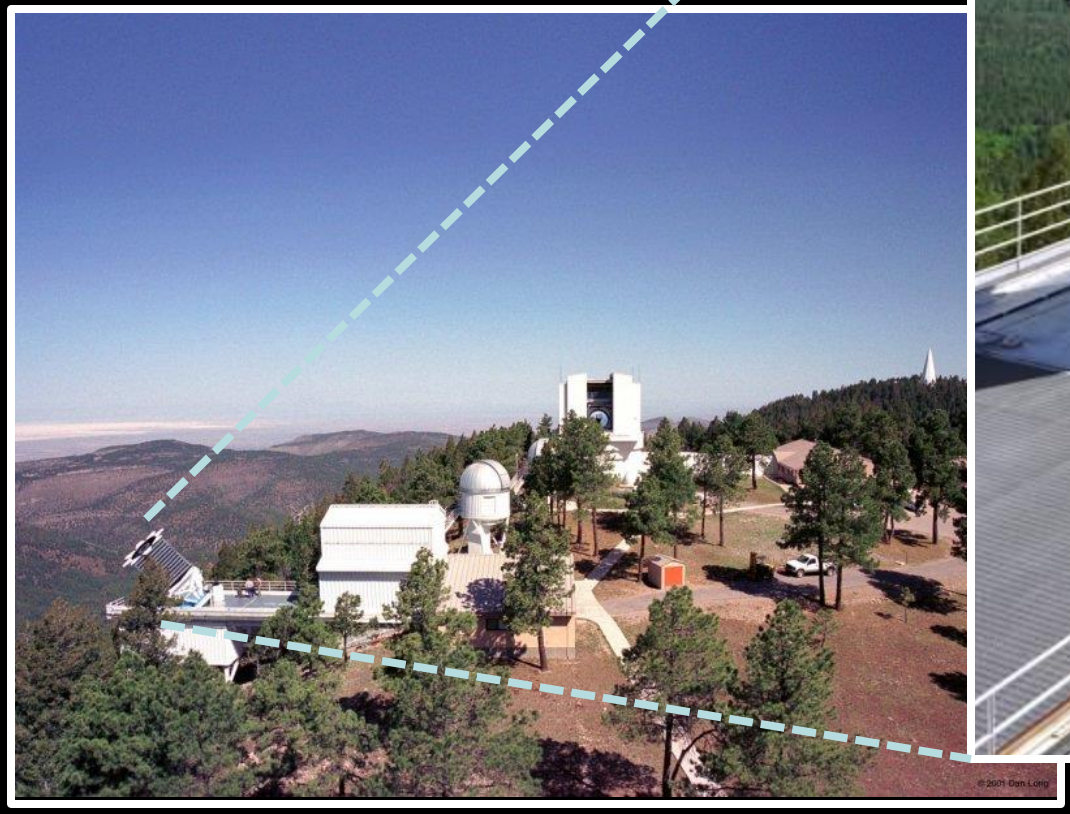
Fingers of God





Sloan Digital Sky Survey (SDSS)

special-purpose
2.5m wide-angle telescope
Apache Point Observatory (New Mexico)

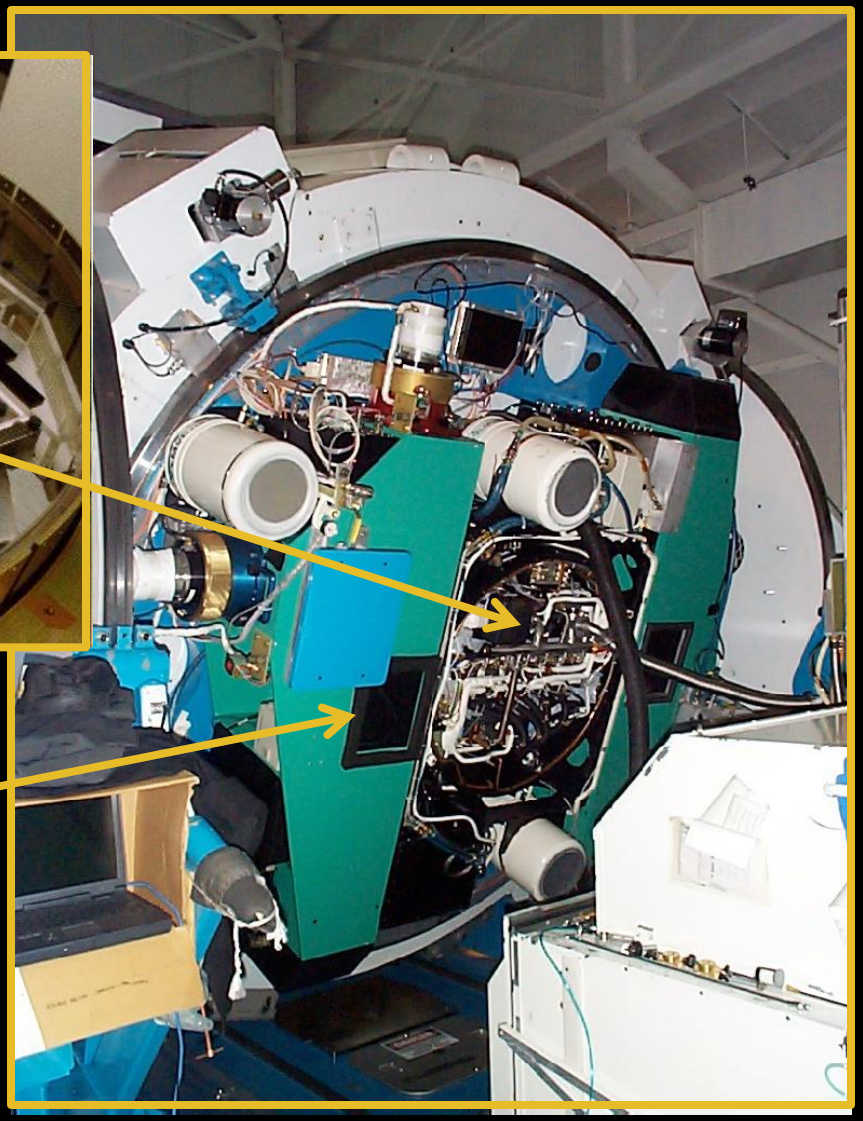


SDSS survey

5-color Camera

30 CCD chips

Fiber Spectrograph

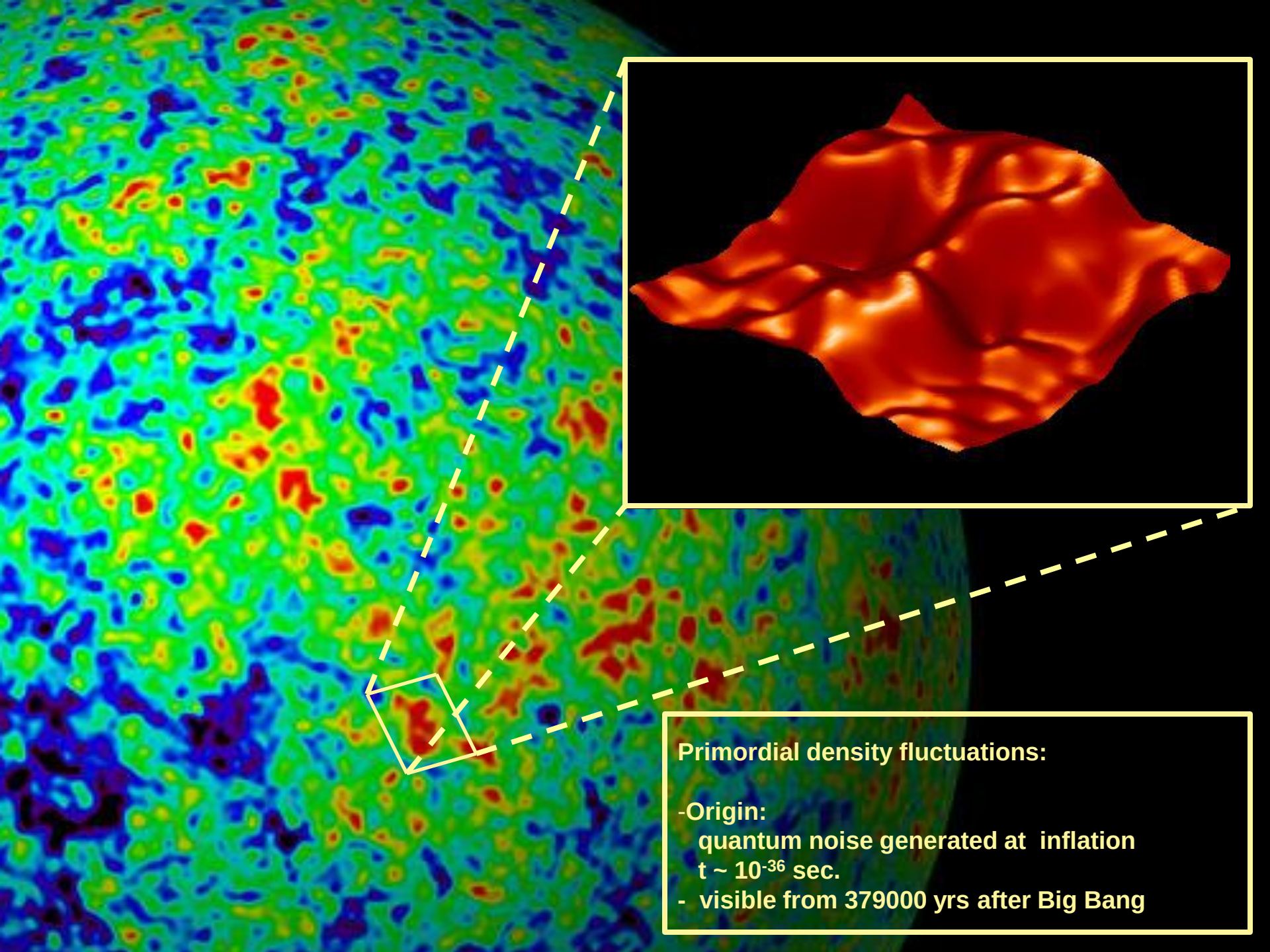


full-dome: SDSS-1

Structure Fomation:

gravitational origin

full-dome: WMAP-Planck

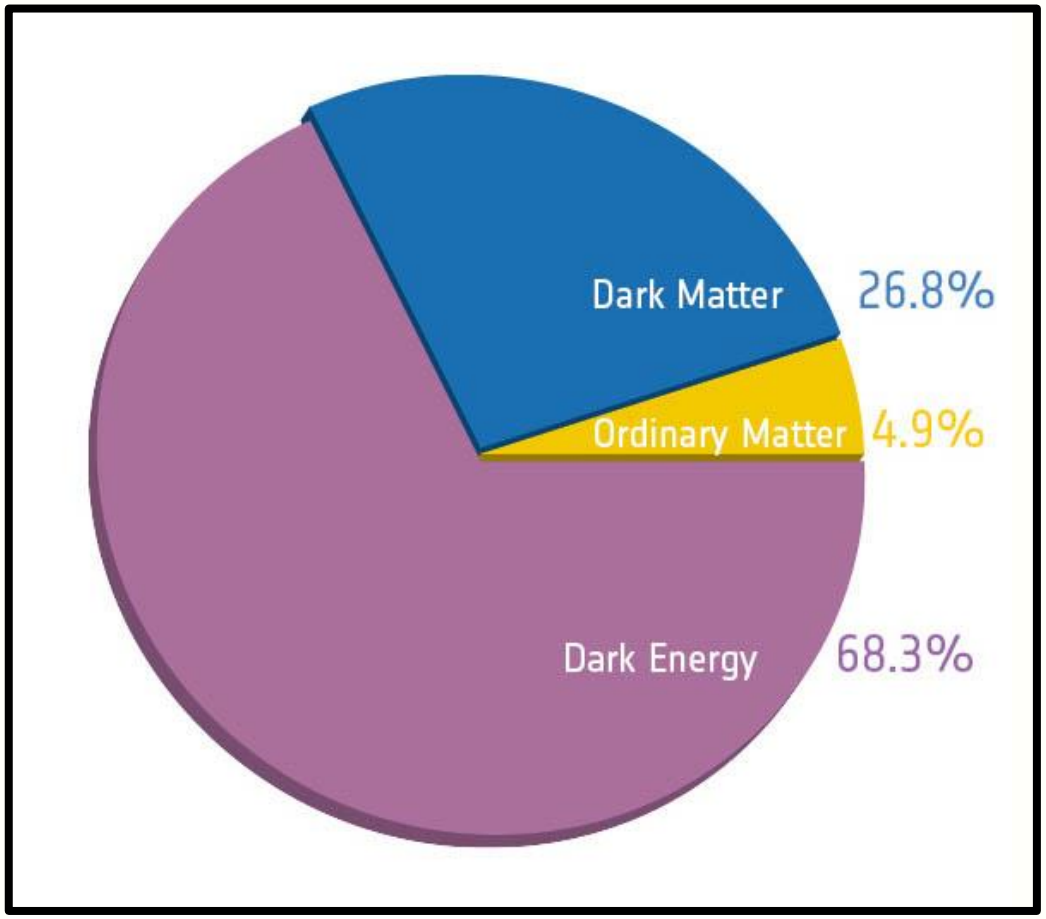


Primordial density fluctuations:

-**Origin:**
quantum noise generated at inflation
$t \sim 10^{-36}$ sec.
- visible from 379000 yrs after Big Bang

Gravity Perturbations

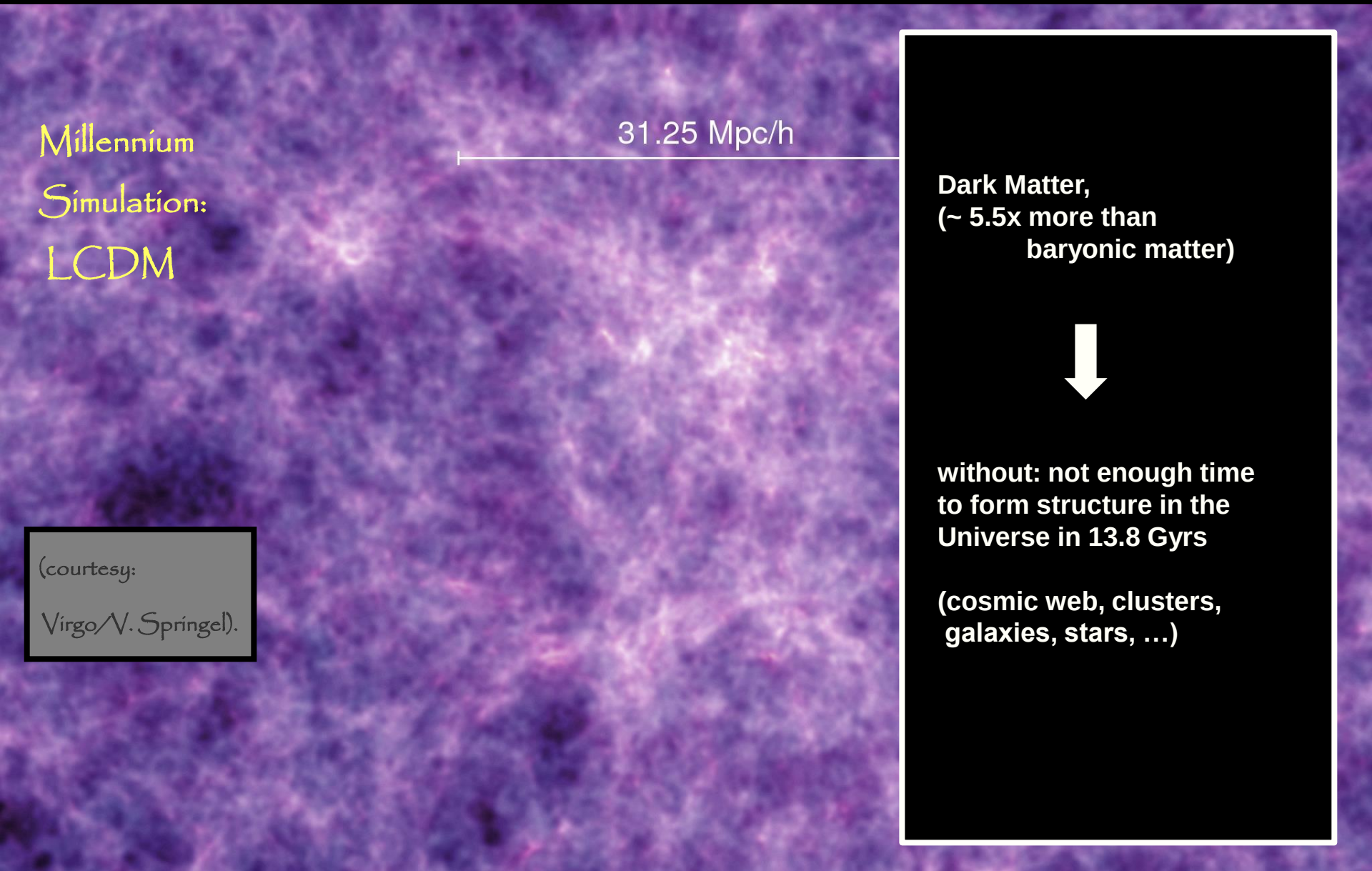
Cosmos: the Elements



Composition of the Universe

- **Baryonic (normal) matter ~ 4.9%**
  - atoms of which we ourselves consist
  - stars a mere ~0.20% !
- **Dark Matter ~ 26.8%**
  - gravitationally dominant
  - invisible
  - all structure in the Universe (galaxies, stars, planets, ...) only exist through role of dark matter
  - as yet unknown of which it consists
- **Dark Energy ~ 68.3%**
  - gravitational repulsion
  - dominates expansion (& fate) Universe
  - uniformly distributed over Universe,
  - does not/cannot clump: less decisive role in structure formation
  - only discovered in 1998 !
- **Straling ~ 0.001%**
  - because of cooling Universe no longer important
  - by far most abundant particle: 2 ⊛10^9 photons per atom

Cosmic Structure Formation

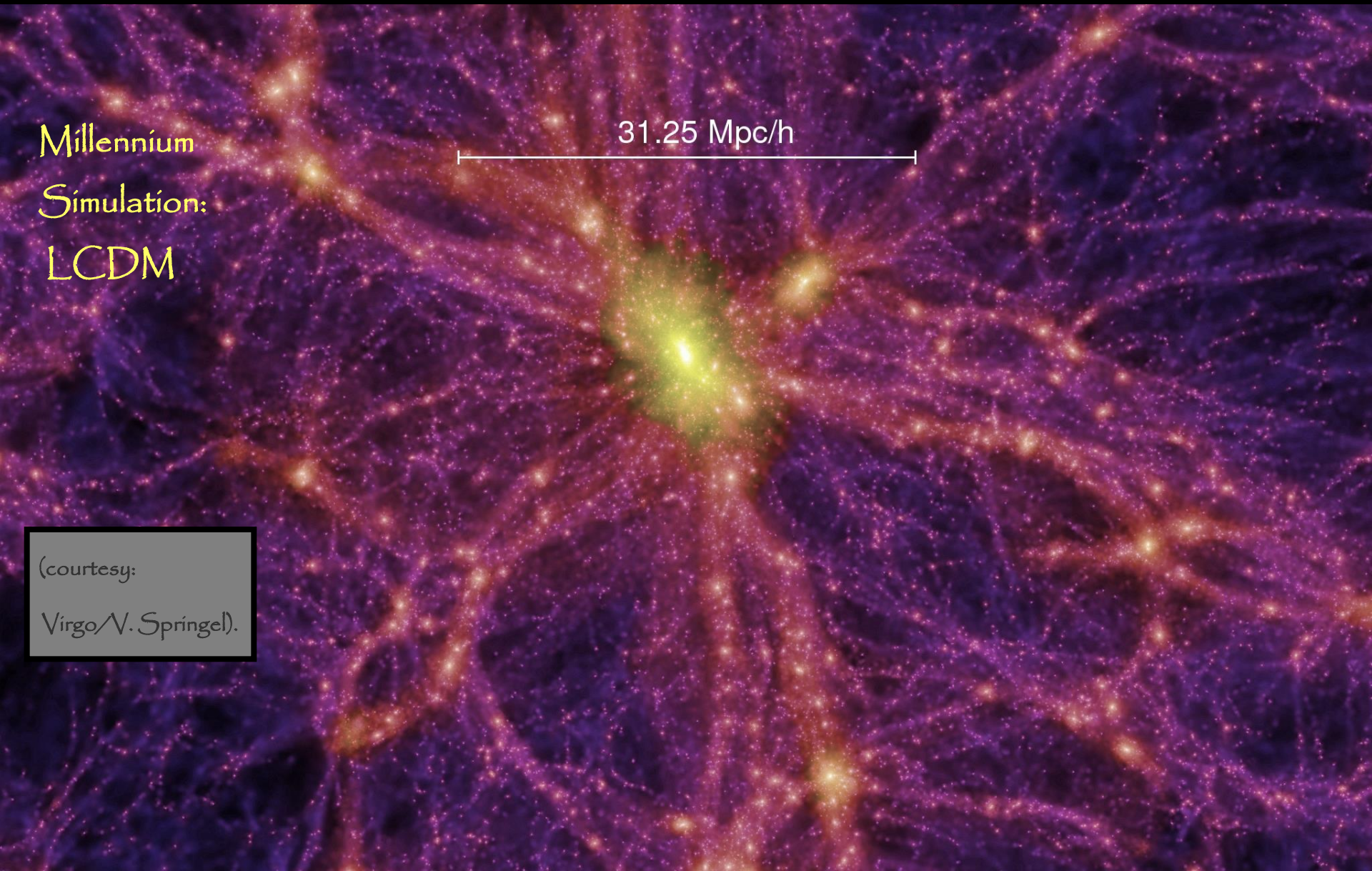


Dark Matter,
(~ 5.5x more than baryonic matter)

without: not enough time to form structure in the Universe in 13.8 Gyrs

(cosmic web, clusters, galaxies, stars, …)

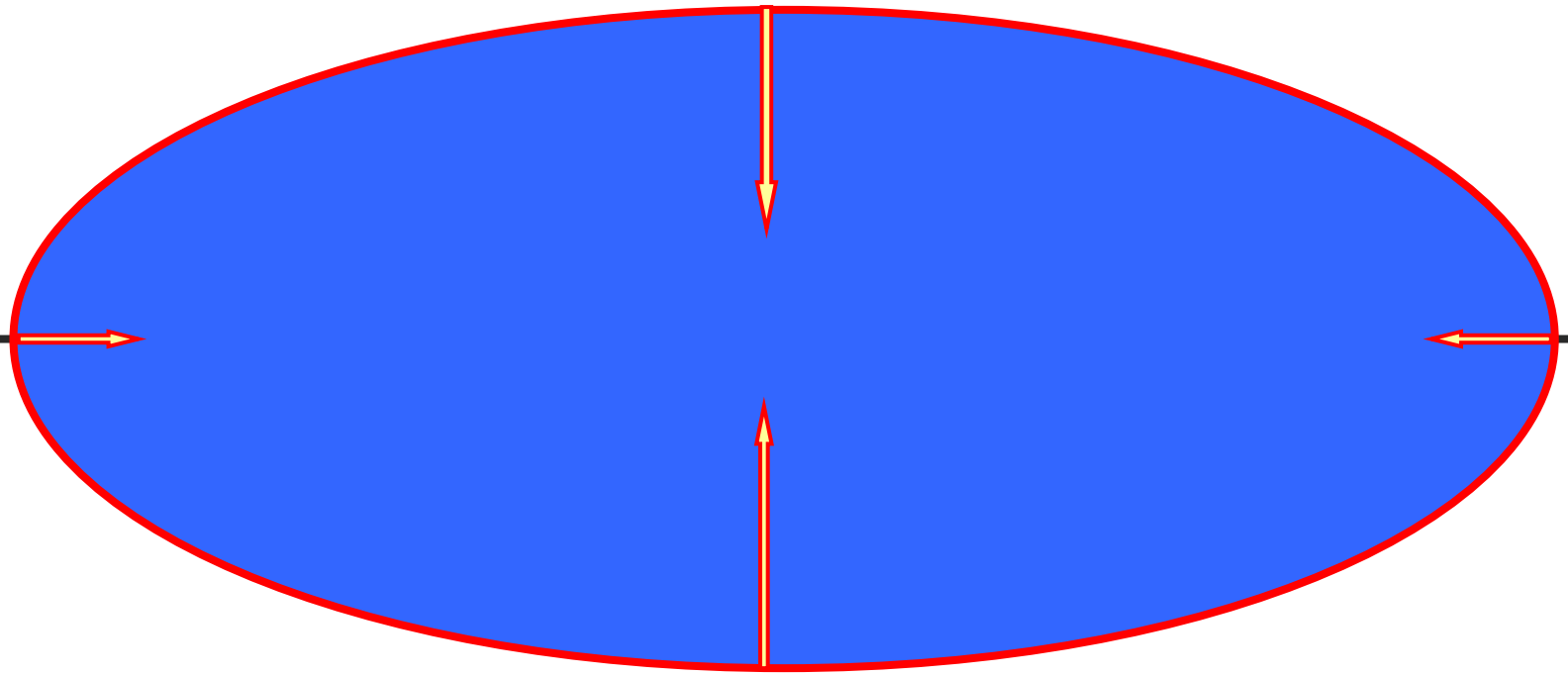
Cosmic Structure Formation



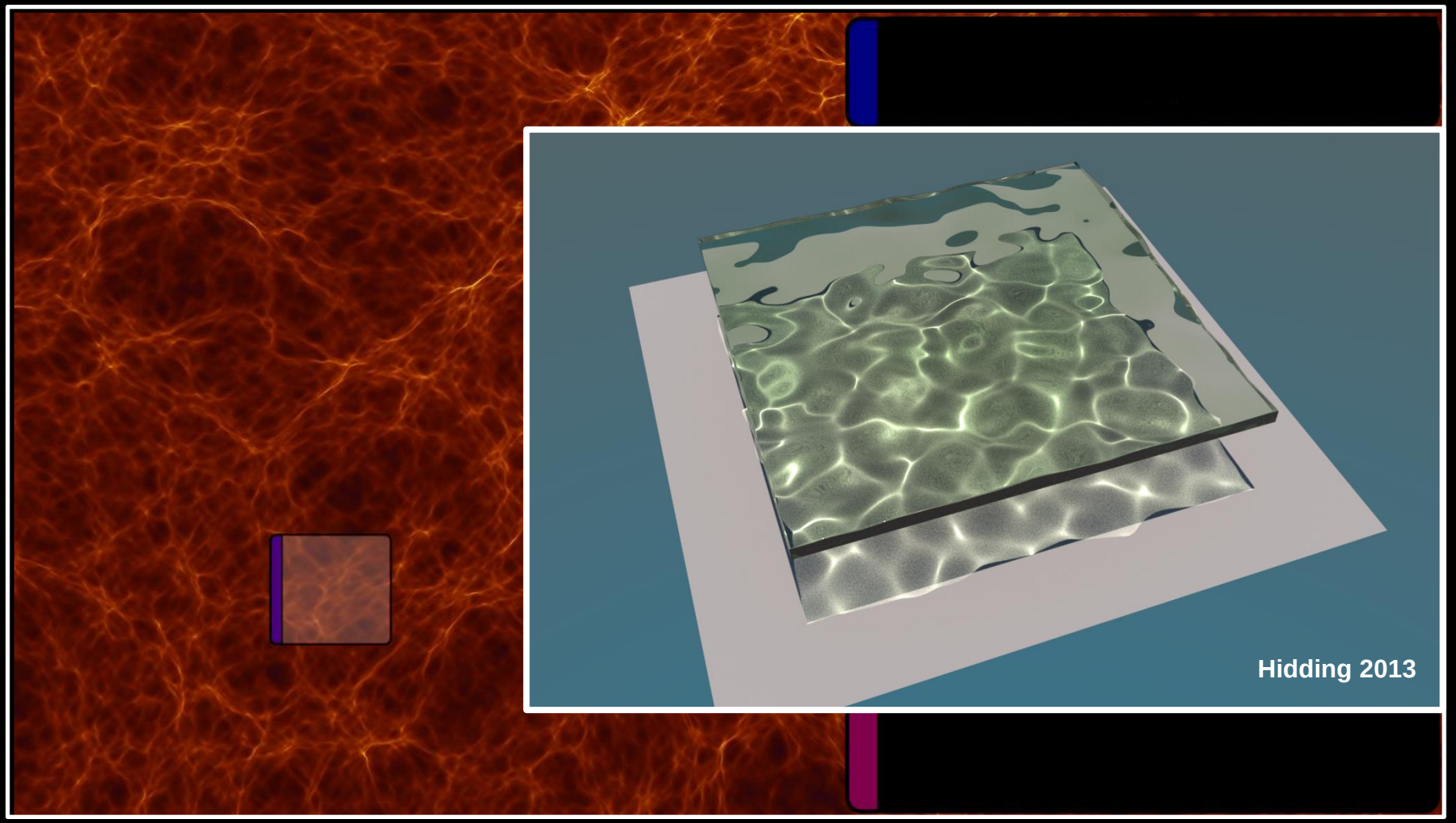
Anisotropic

Gravitational Collapse

Amplification
small perturbations in gravity along different directions (tidal forces)



Zel’dovich Approximation



full-dome: Zeldovich

Illustris

Donkere Materie

GAS

Kosmisch Web in Gas and Dark Matter :

- Dark Matter determines the gravitational structure of the Cosmic Web

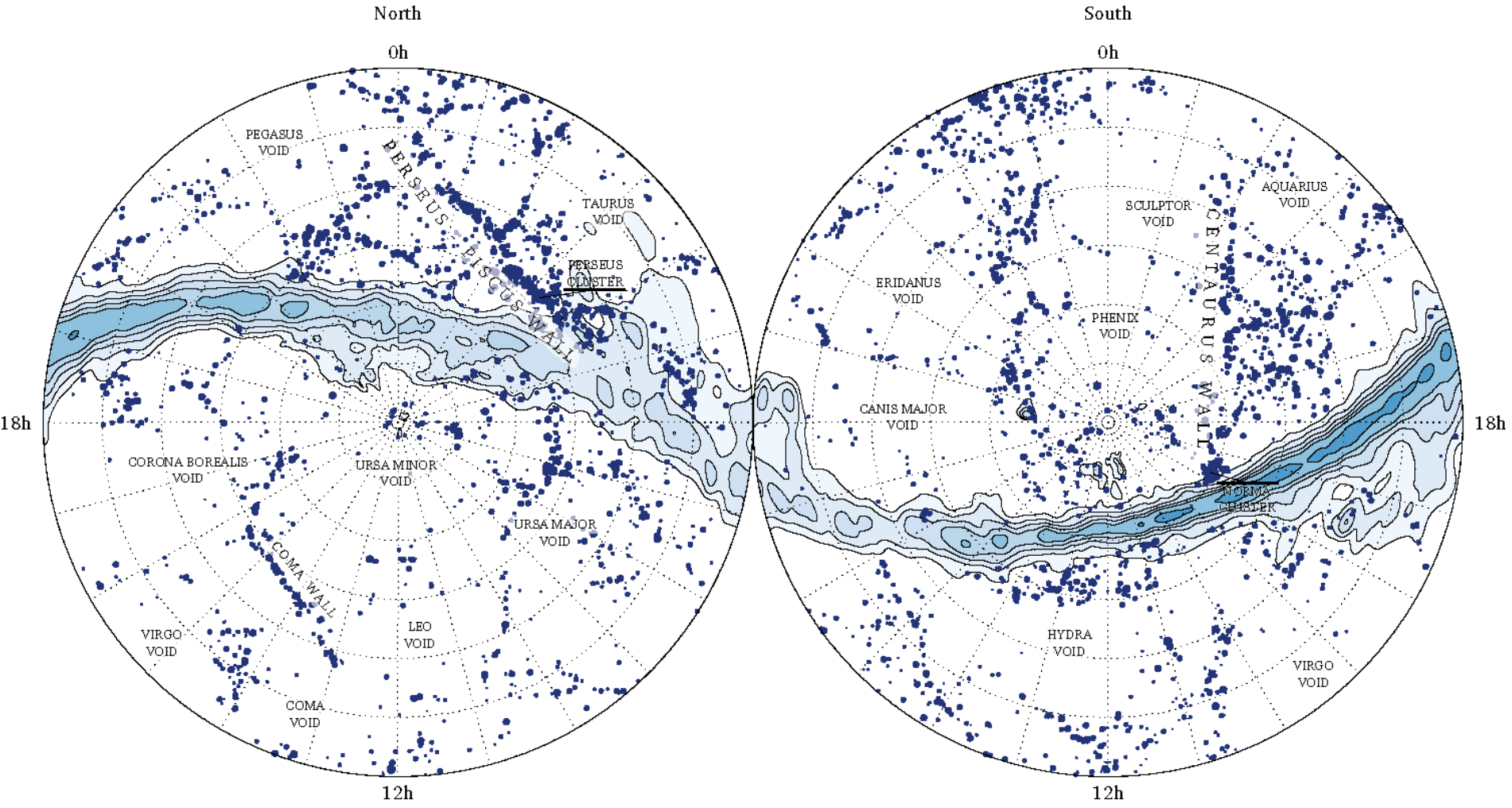
- Gas falls into the potential wells, heats up, following which they agglomerate in more diffuse and somewhat bloated filaments and walls.

full-dome: Illustris

Cosmic Web:

Local Universe

Galaxies up to 50 Mpc …

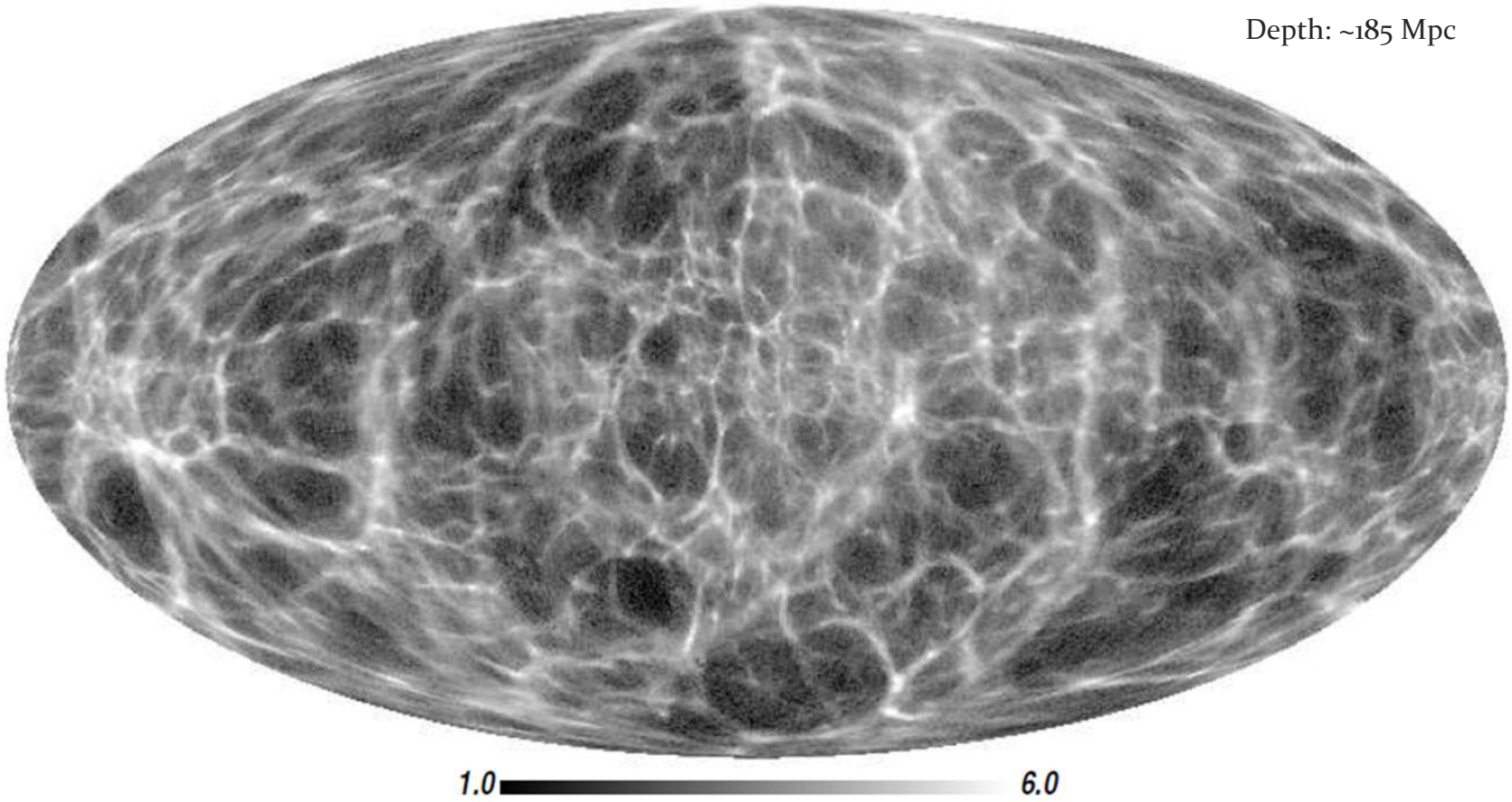


2MRS survey sky map: Hidding 2015

Caught wihin our Web ...

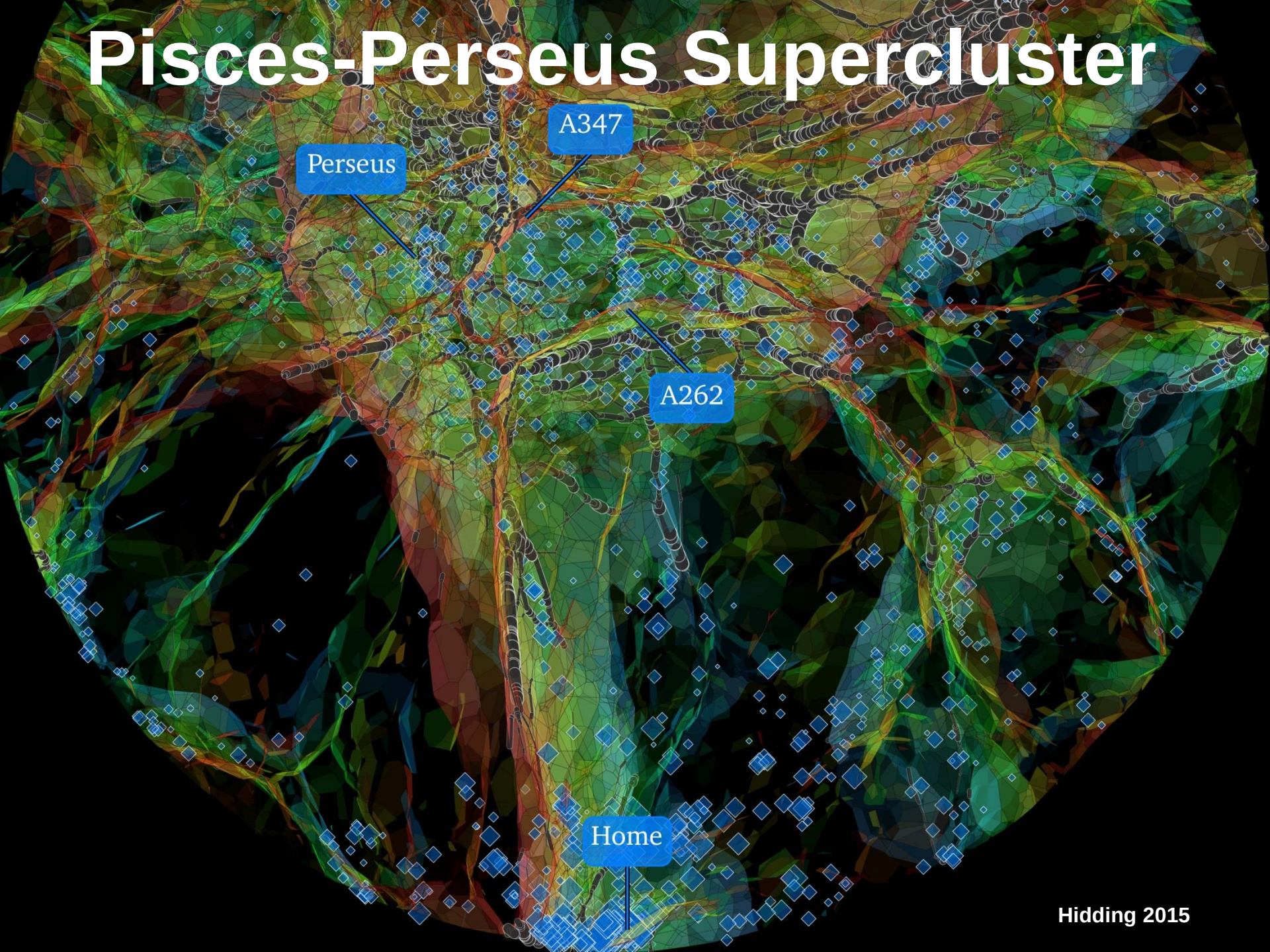
Most detailed
Reconstruction
Local Cosmic Web:

Depth: ~185 Mpc



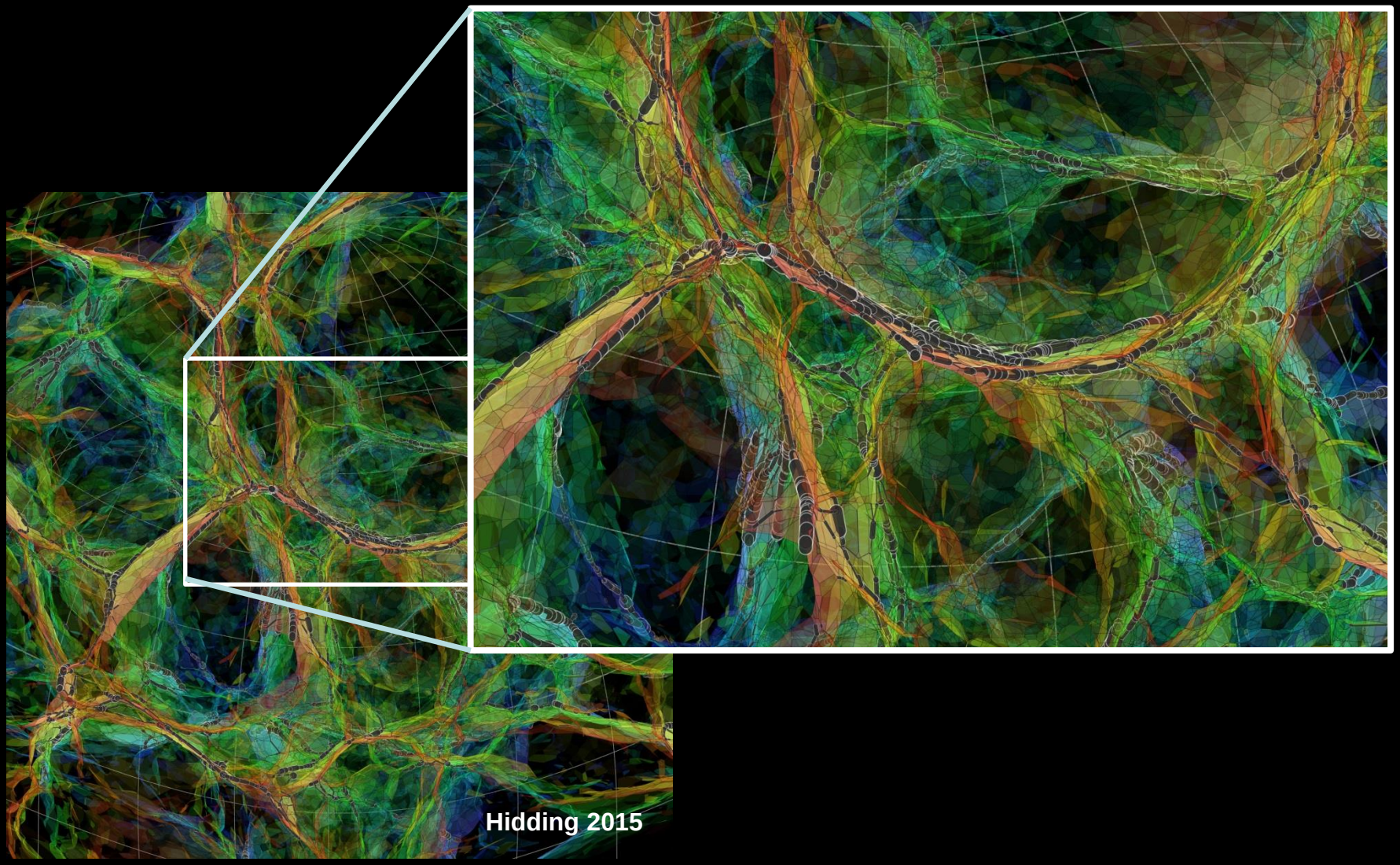
Courtesy: Francisco Kitaura

Pisces-Perseus Supercluster

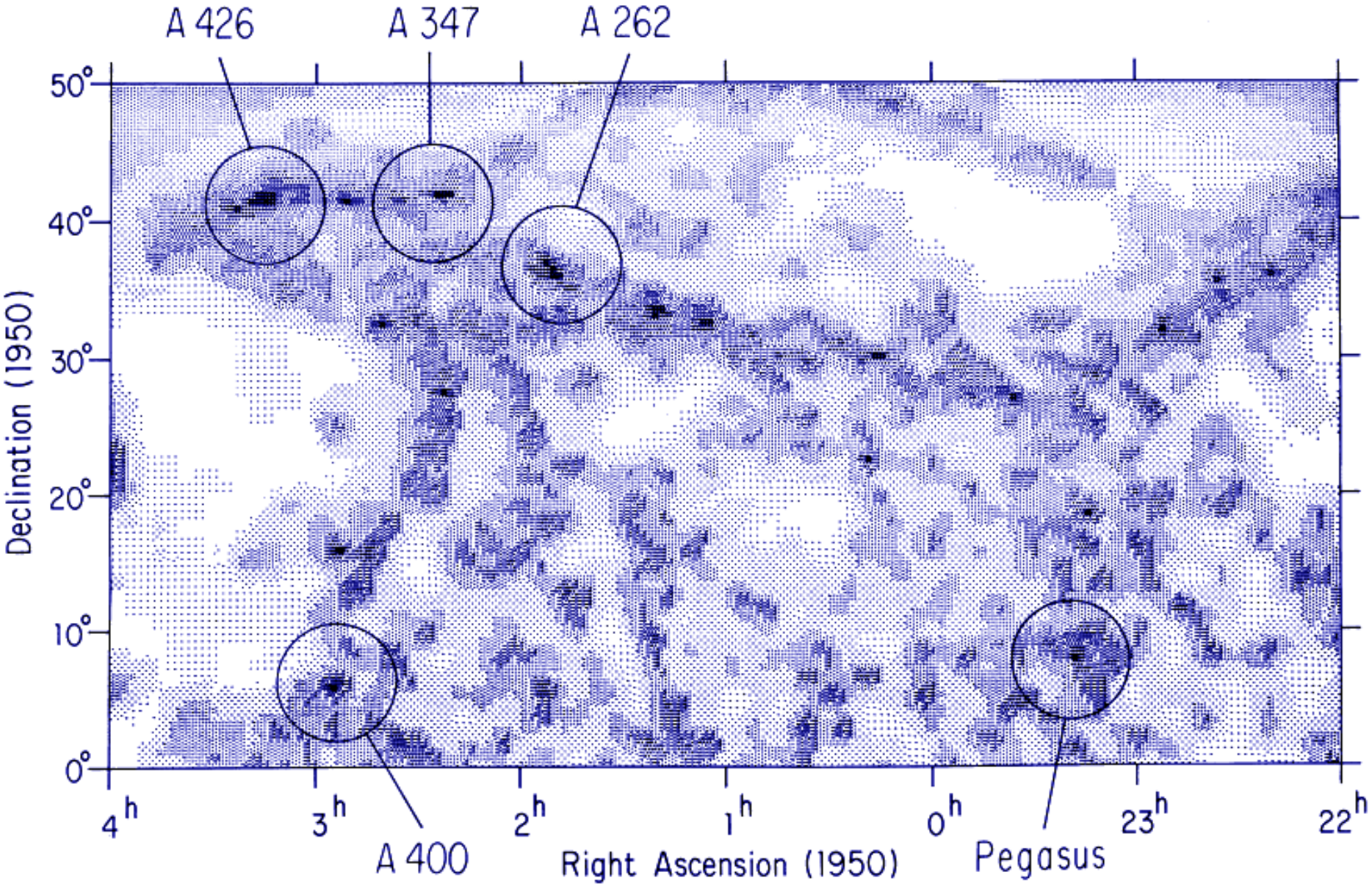


Hidding 2015

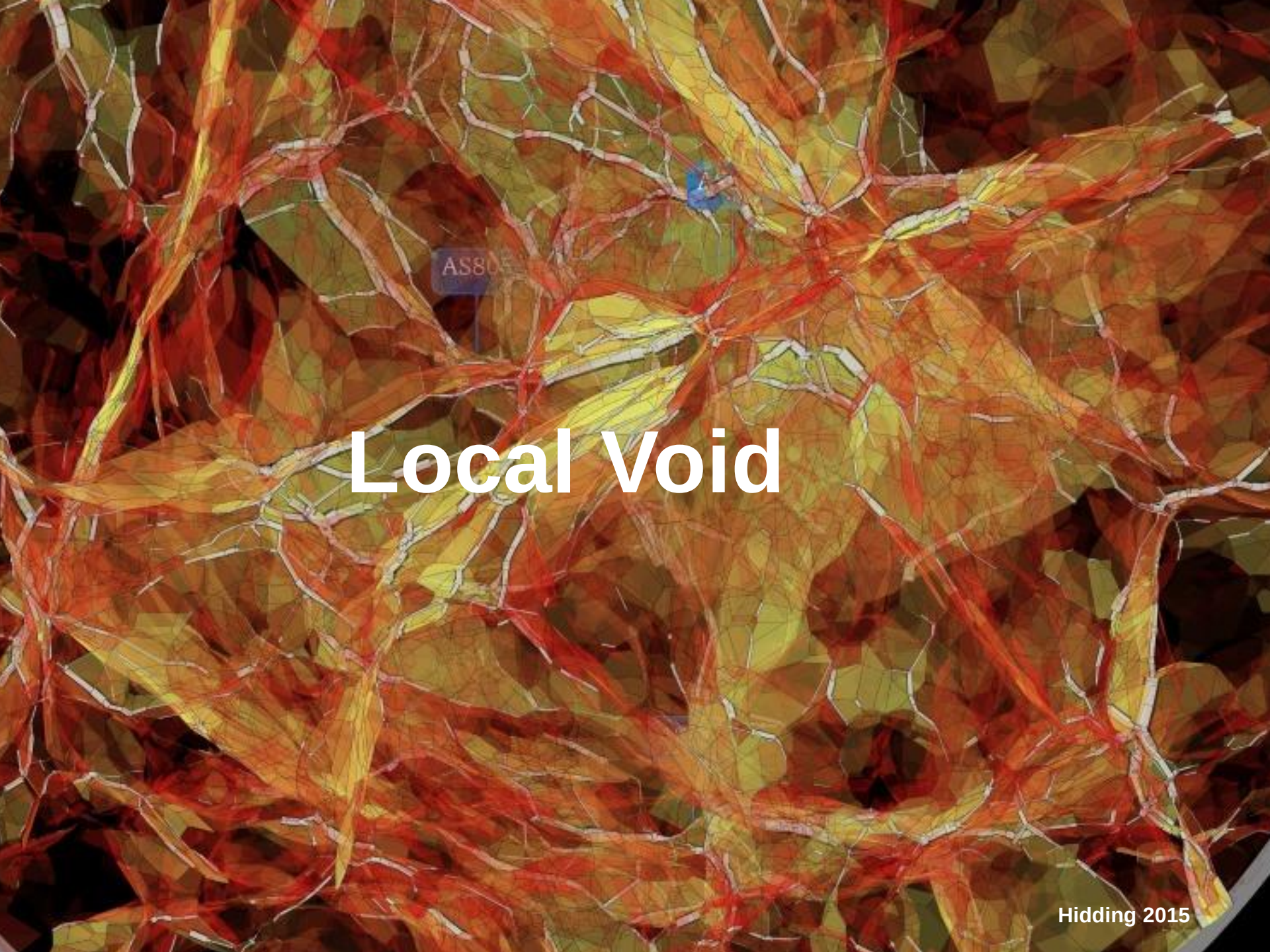
Pisces-Perseus Supercluster



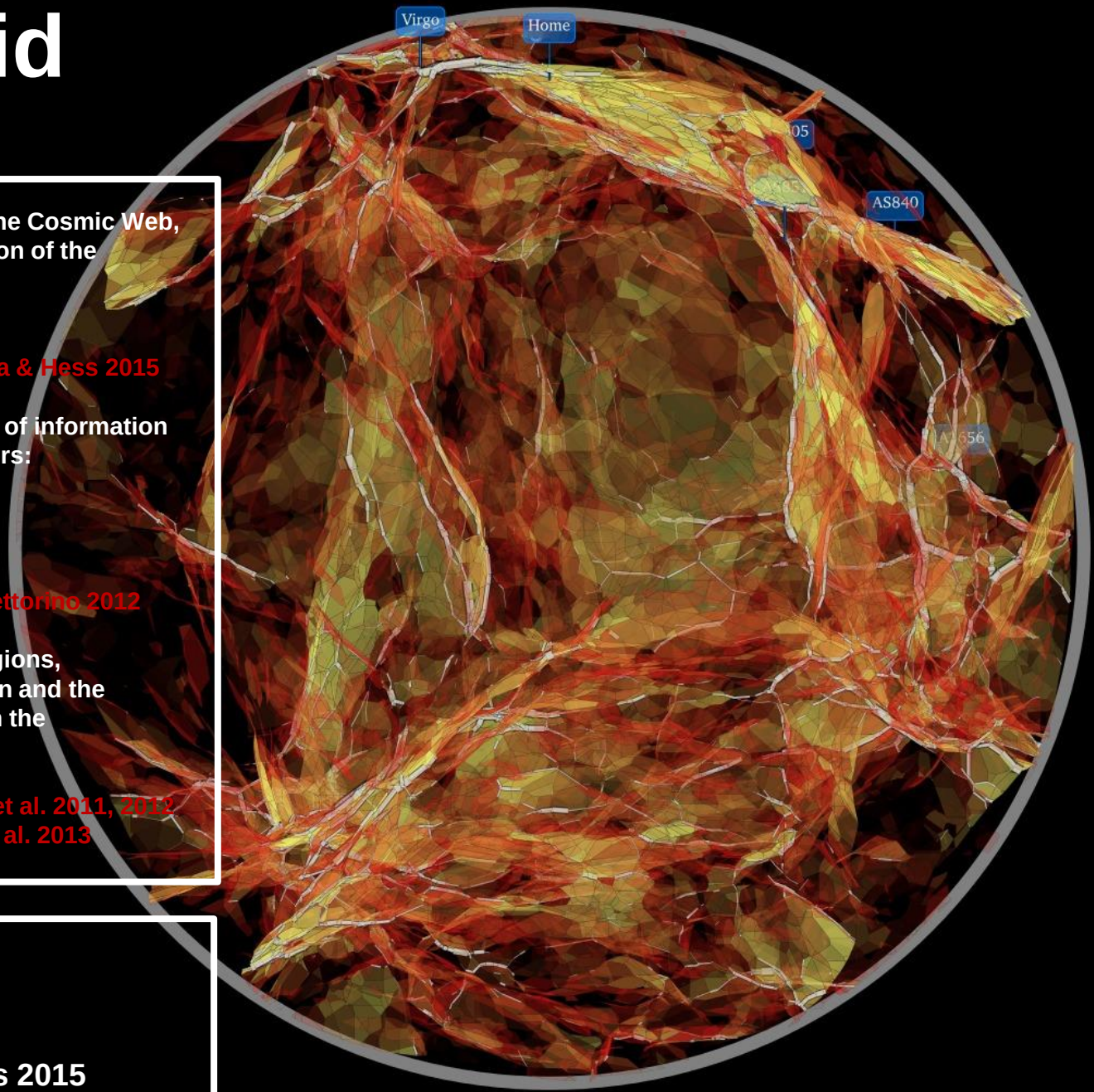
Pisces-Perseus Supercluster



full-dome: Johan-Pisces Perseus


Local Void
Hidding 2015

Local Void



- Voids are prominent aspects of the Cosmic Web, instrumental in spatial organization of the Megaparsec Universe.

  Sheth & van de Weygaert 2004
  Hidding, van de Weygaert, Kitaura & Hess 2015

- Voids contain significant amount of information on global cosmological parameters:
  - void outflow: dark matter
  - void shapes: dark energy
  - supervoids: existence

  Bos, van de Weygaert, Dolag & Pettorino 2012

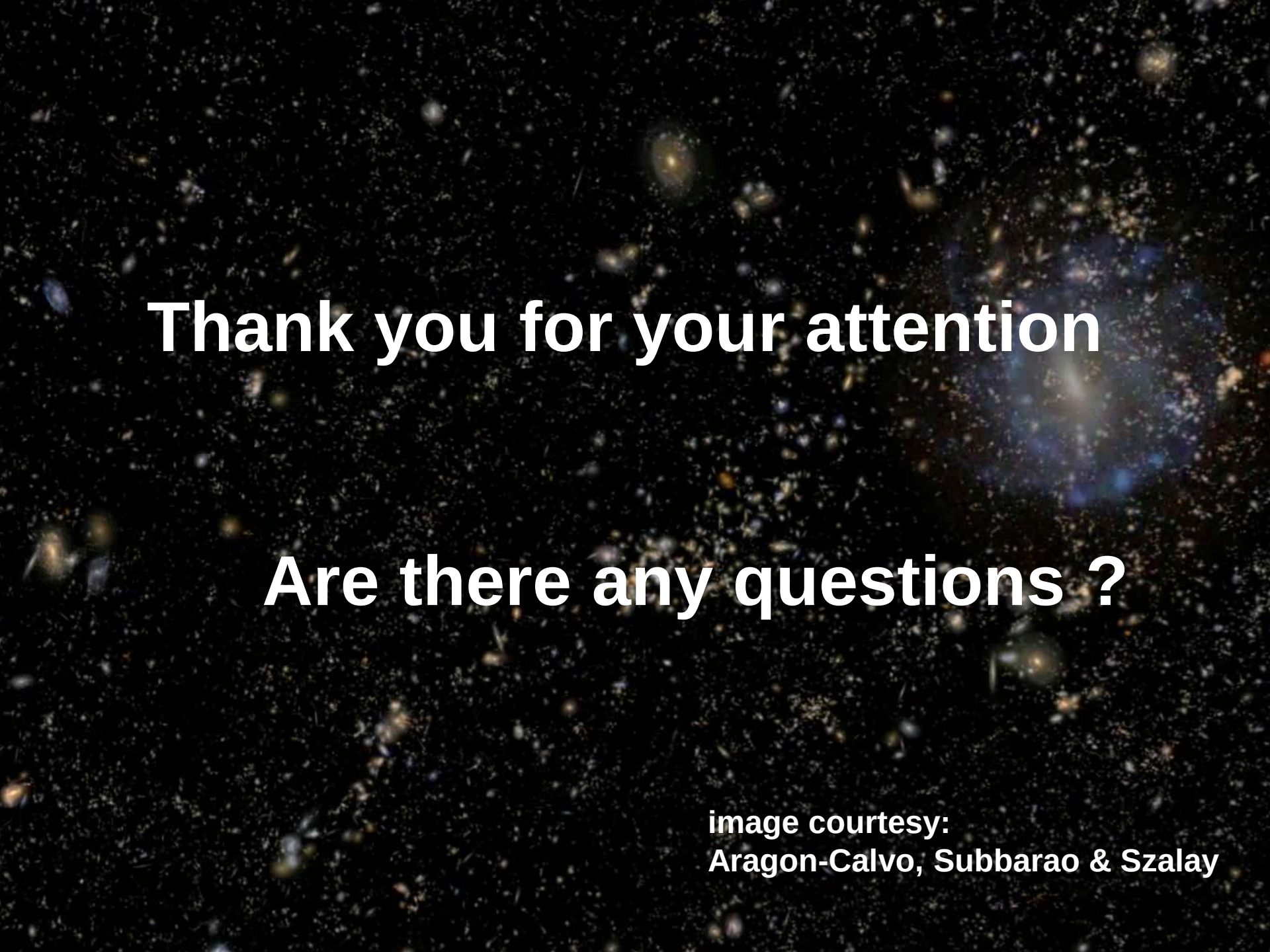
- Voids are pristine low-density regions, ideal for studying galaxy formation and the effects of cosmic environment on the formation of galaxies.

  Void Galaxy Survey: Kreckel et al. 2011, 2012
  Beygu et al. 2013

Lokale Void

Reconstructie:
Hidding, vdW, Kitaura & Hess 2015

full-dome: Johan-Local Void


Thank you for your attention
Are there any questions ?
image courtesy:
Aragon-Calvo, Subbarao & Szalay

full-dome: SDSS-2 (flythrough, music)