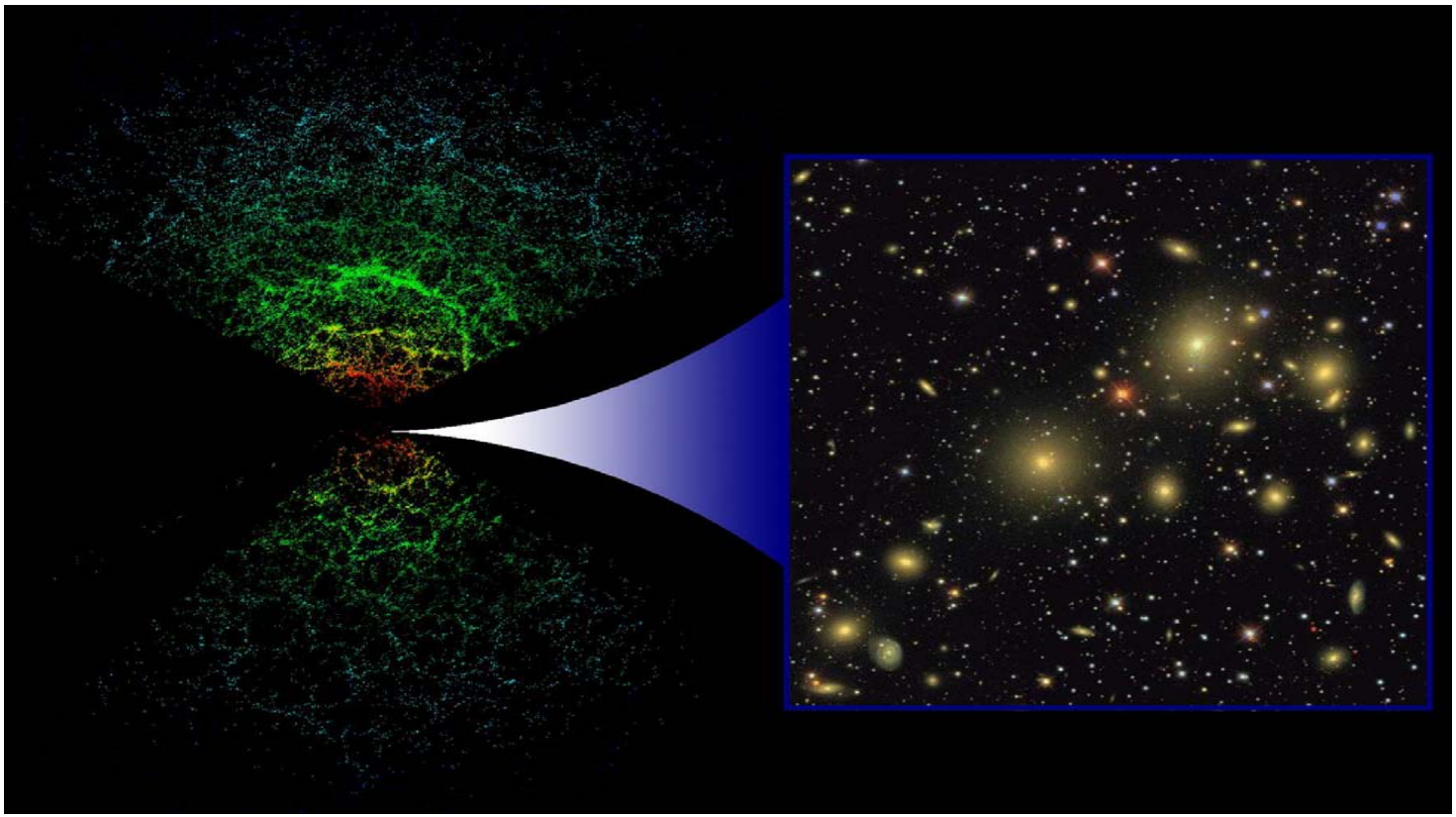
# A comparative study of void searching algorithms

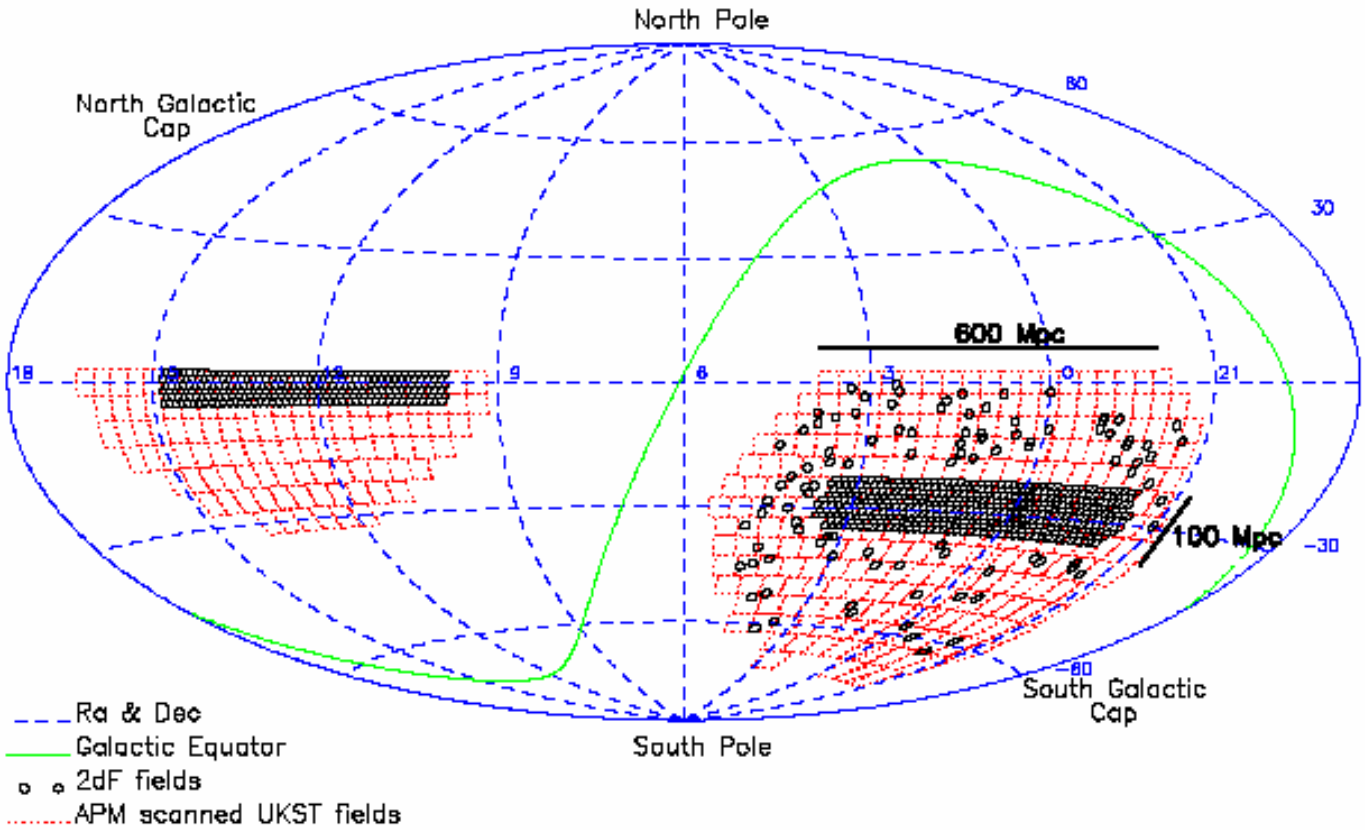
Sepehr Arbabi Bidgoli

# Large Scale Structure Surveys



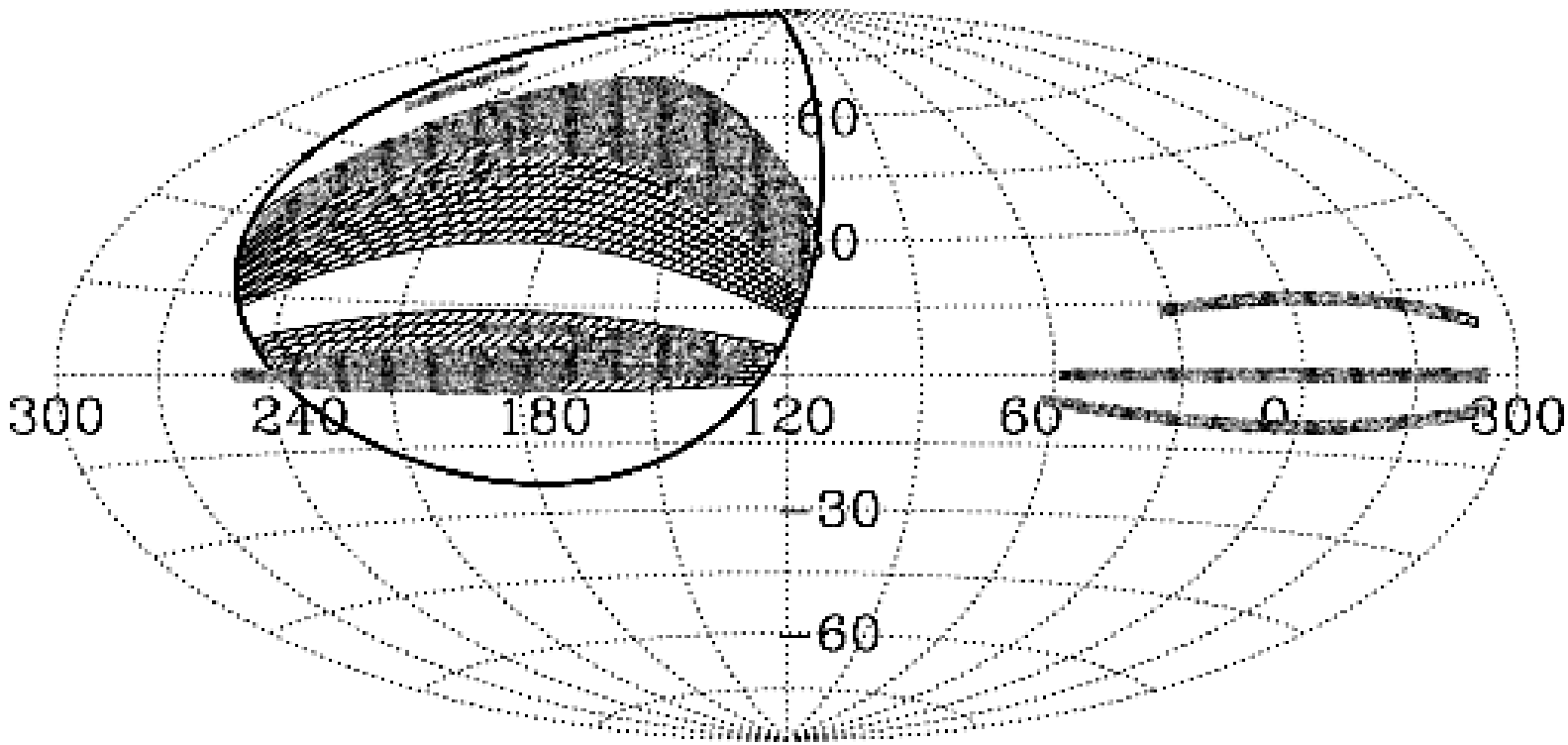
# The 2dF Galaxy Redshift Survey

220.000 redshifts based on APM

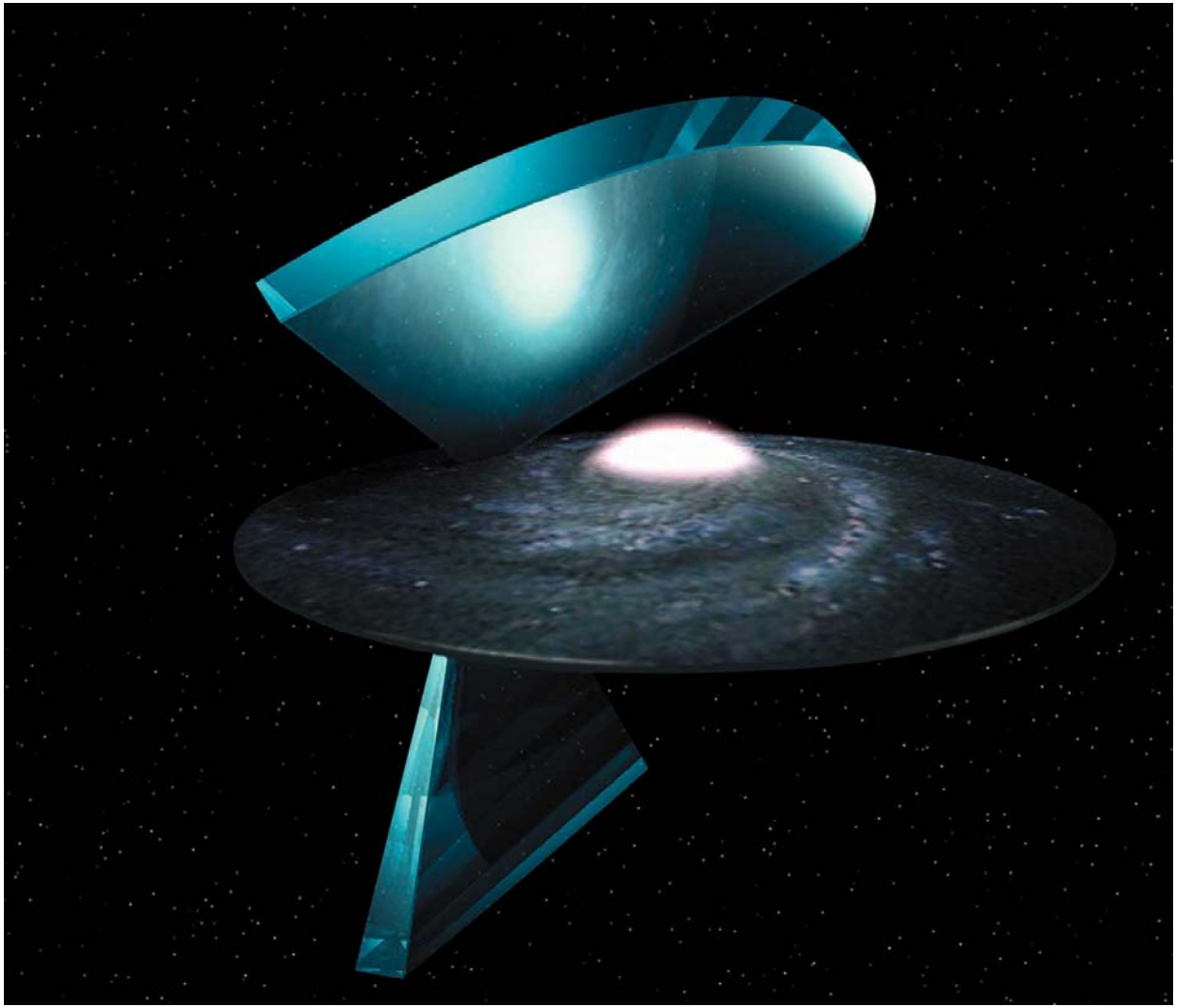


# The Sloan Digital Sky Survey

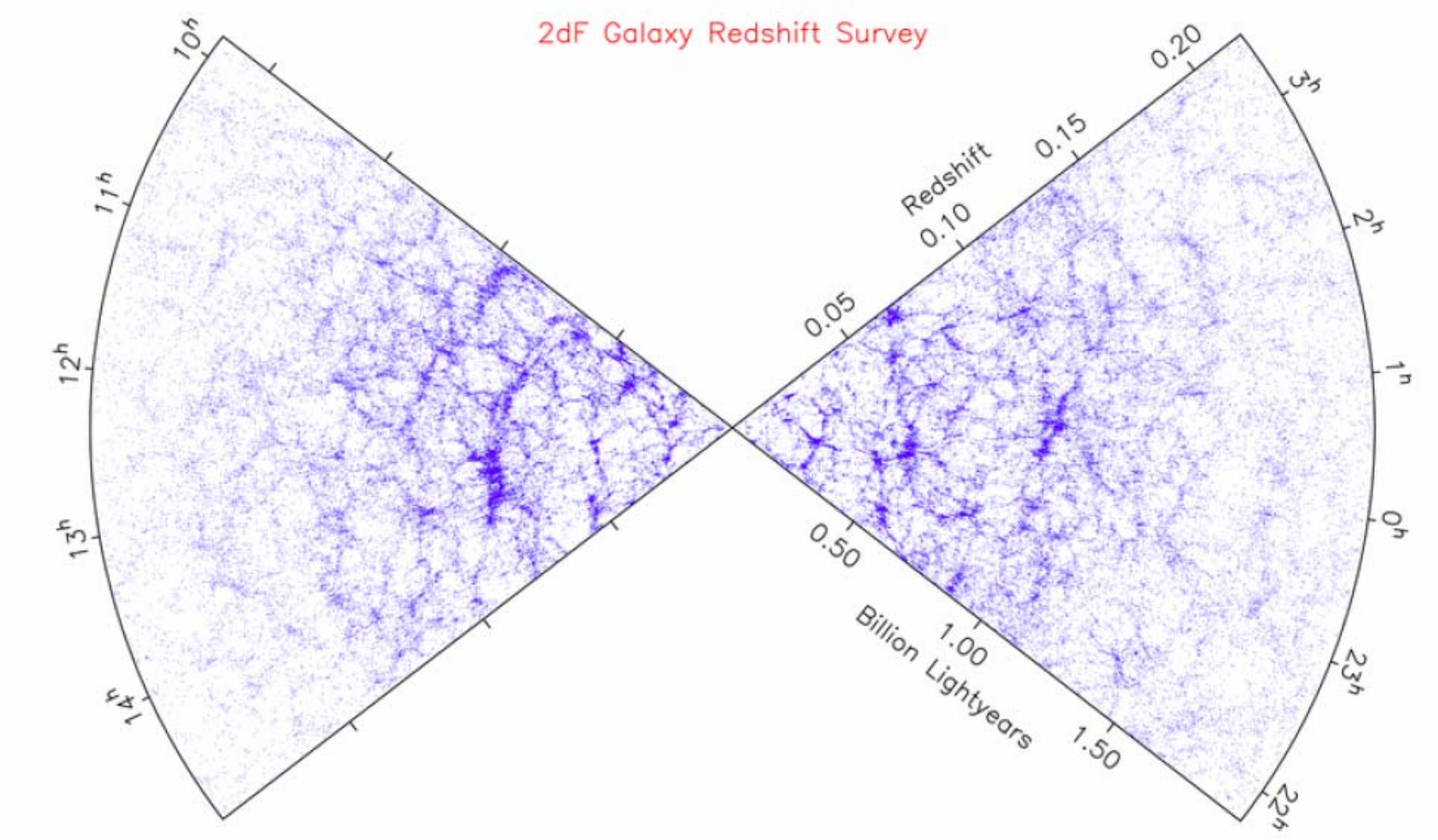
- SDSS, DR4 : ~ 850.000 spectra ➔ ~ 566.000 Galaxies



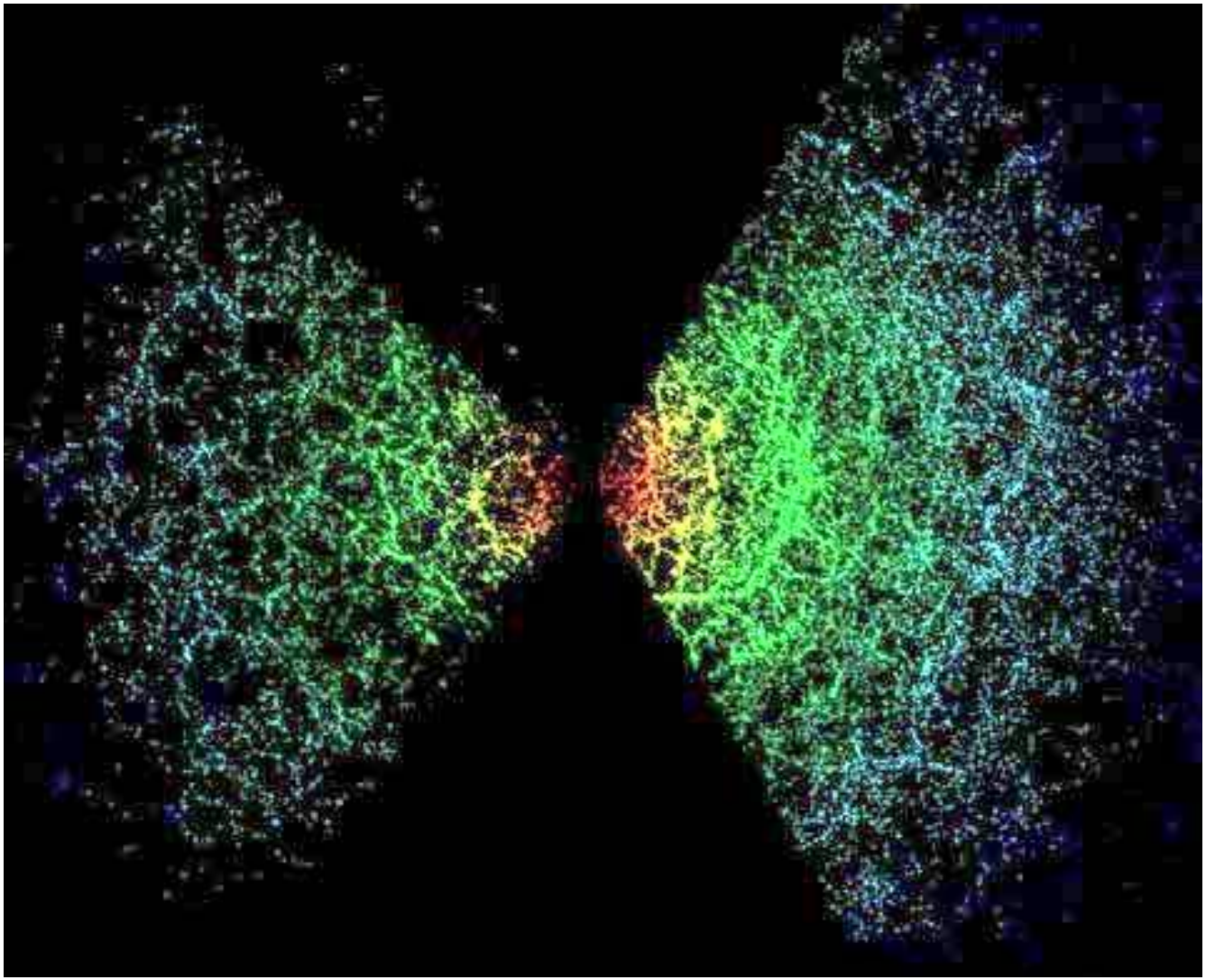
# Cosmic Voids



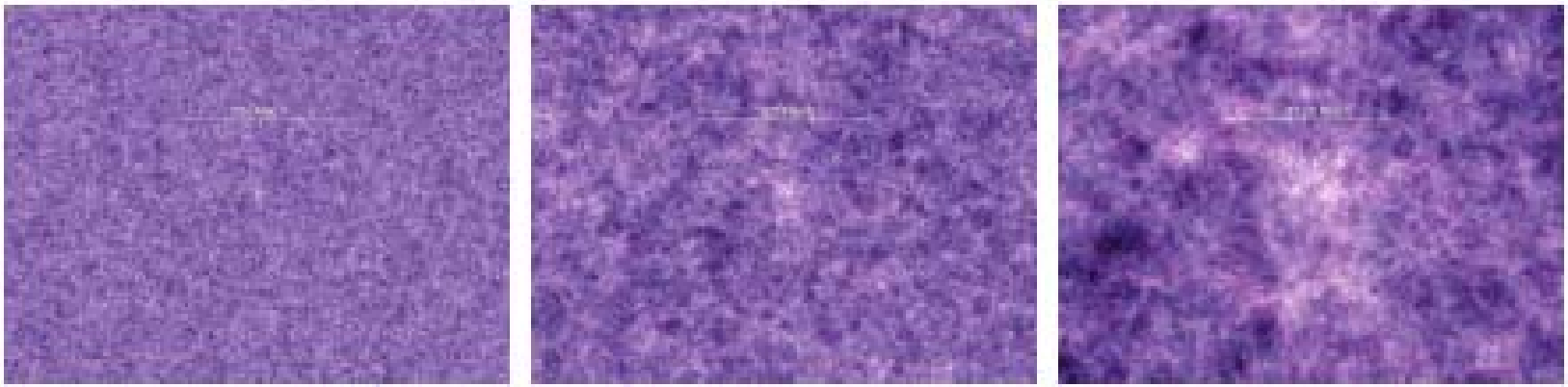
# The 2dF Galaxy Redshift Survey



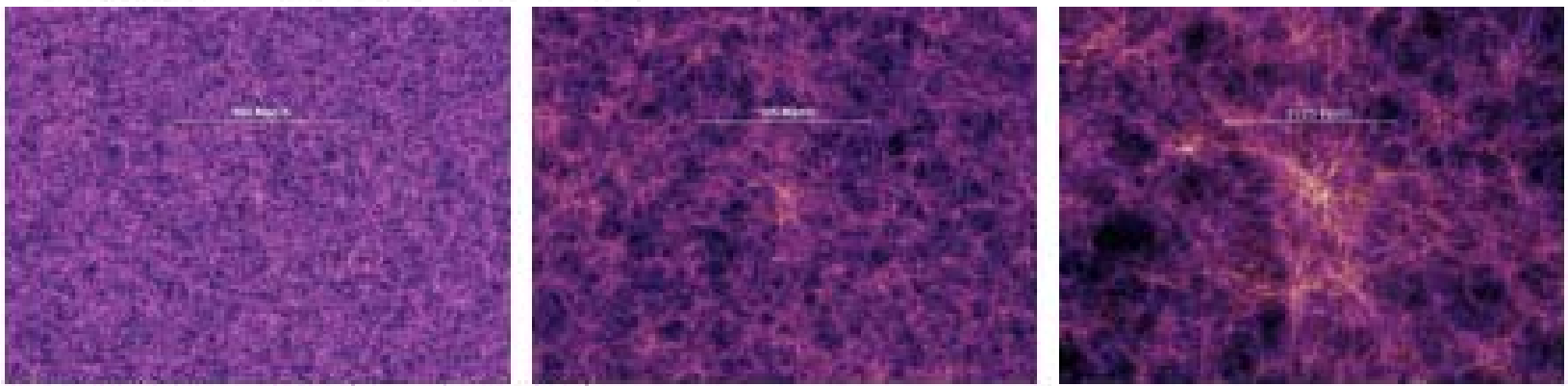
# The Sloan Digital Sky Survey



# The Millennium Simulation

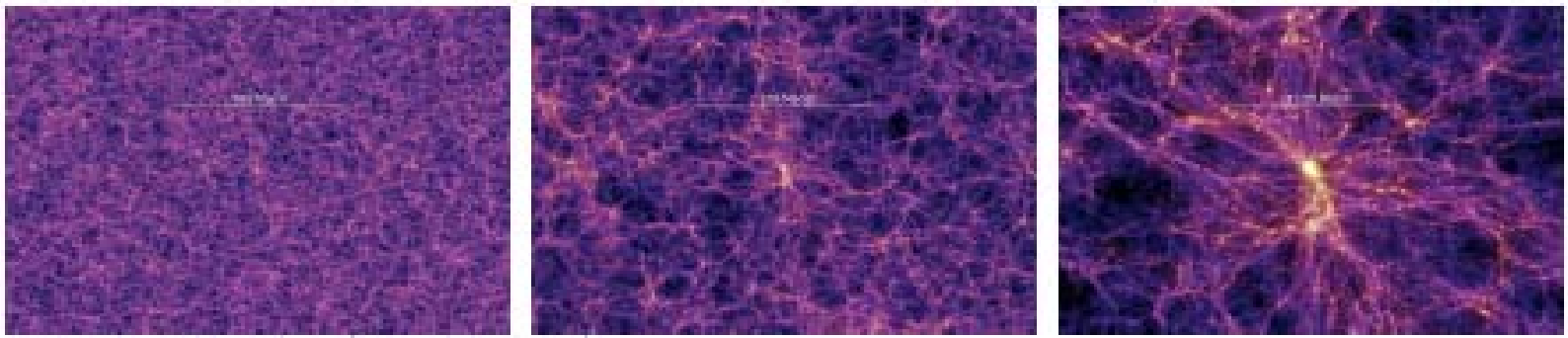


Redshift $z = 18.3$ ($t = 0.21$ Gyr)

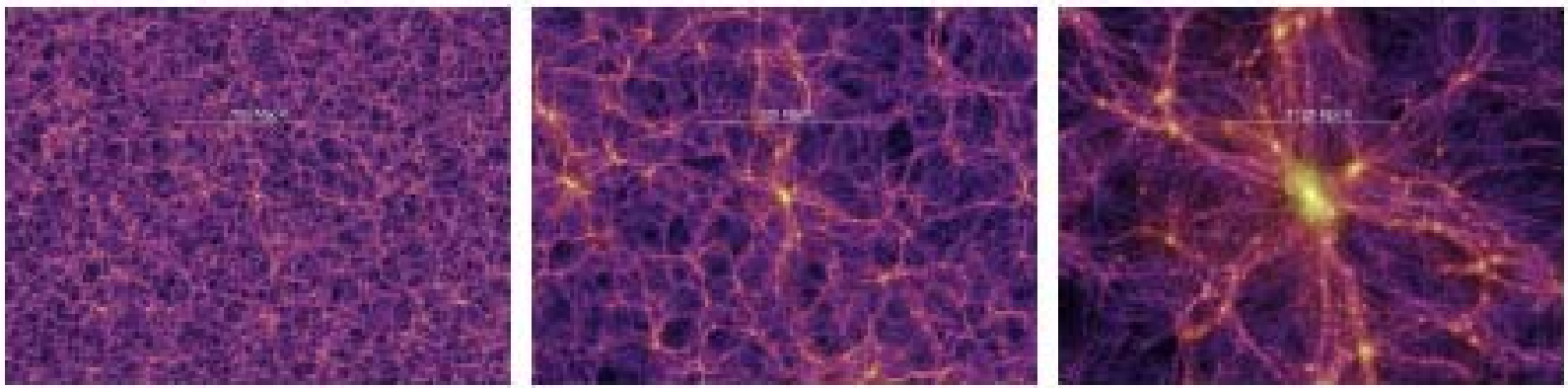


Redshift $z = 5.7$ ($t = 1.0$ Gyr)

# The Millennium Simulation

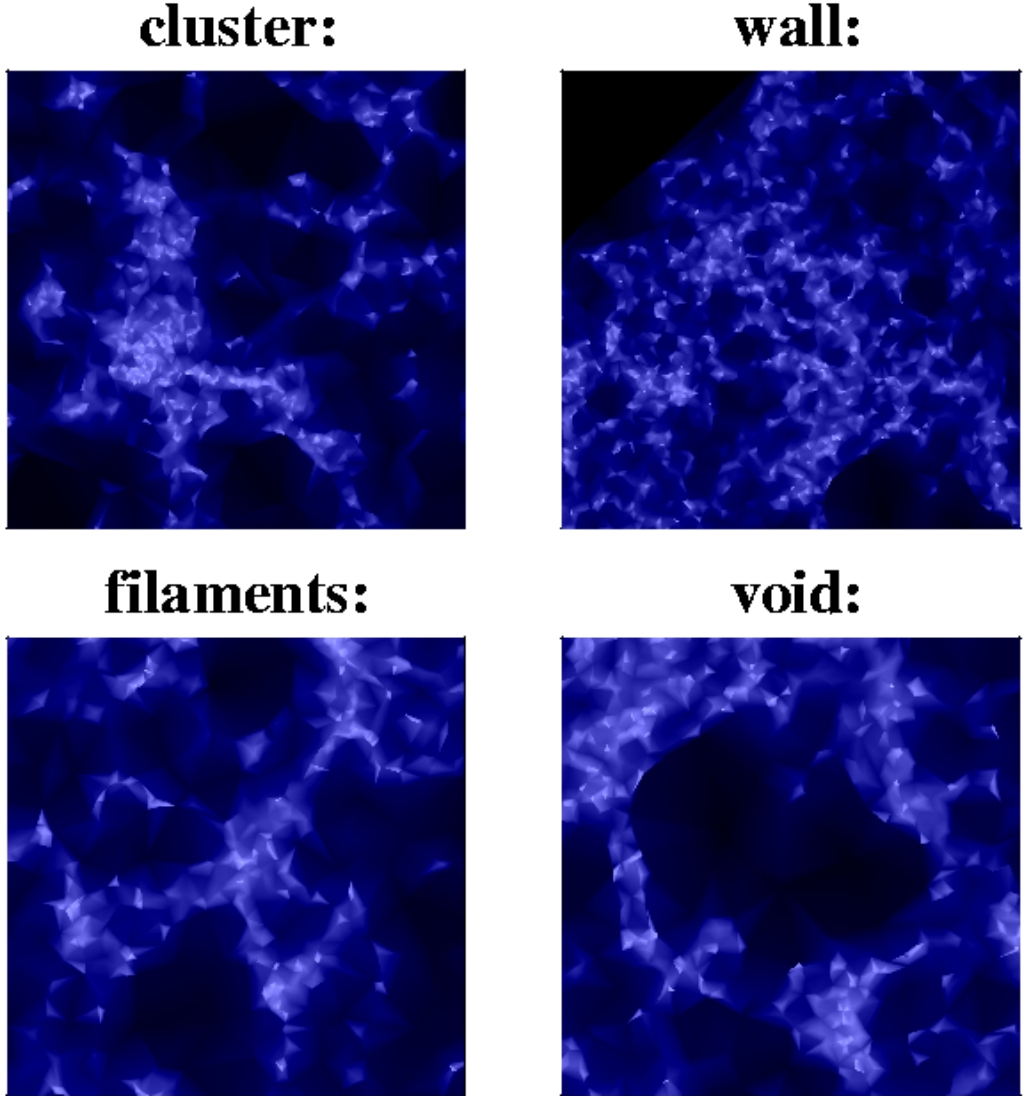


Redshift $z = 1.4$ ($t = 4.7$ Gyr)

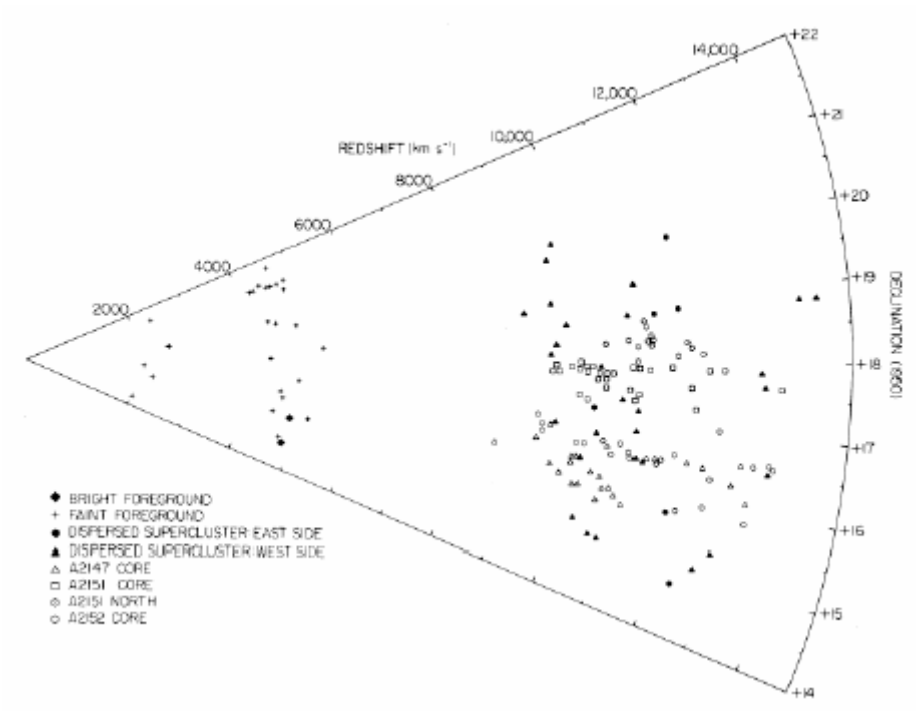


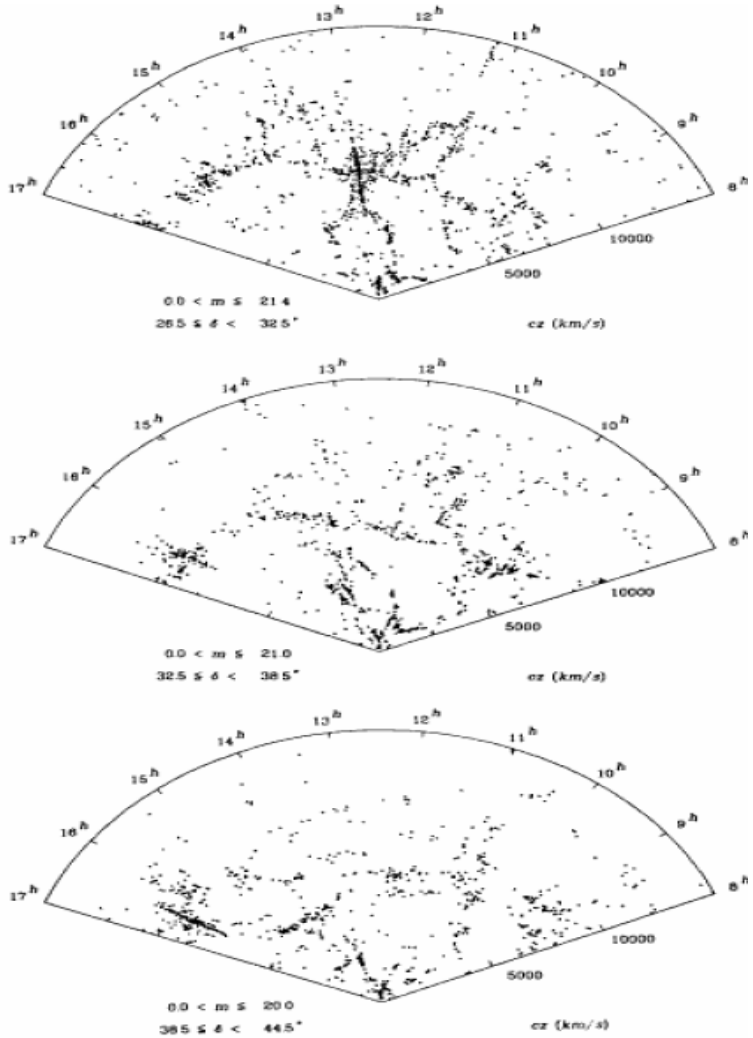
Redshift $z = 0$ ($t = 13.6$ Gyr)

# Large scale structure Surveys



# Cosmic Voids



# Cosmic Voids

**Observations:**

- Voids are the largest components of the large scale structure.
- Voids are hierarchical:
  - Voids of clusters are up to 100 Mpc/h
  - Voids of  galaxies with typical sizes between 10-50 Mpc/h
  - Smaller galaxies populate voids and subdivide them into smaller voids

# Cosmic Voids

**Applications:**

- Huge voids are a challenge to models of structure formation
- The formation of voids is connected to the formation of galaxies
- Probe of the large scale structure at large distances, where $\xi_2$ and VPF are uncertain

# A comparative study of void finding algorithms

## بررسی مقایسه‌ای آلگوریتم‌های یافتن تهی‌جاها در ساختار بزرگ‌مقیاس عالم


**اربابی بیدگلی، سپهر [۱] توسلی، سعید [۲] تولیت کاشانی، طهمورث [۲] رحمانی، هادی [۲] شفیعی، زینب [۲]**

**شقاقیان، محبوبه [۲] شیخ بهایی، زهرا [۲] عنبرانی، امیر [۲] واسعی زاده، کاوه [۲]** (اعضای تیم به ترتیب الفبا)

[۱] پژوهشکده فیزیک پژوهشگاه دانش‌های بنیادی

[۲] دانشکده علوم دانشگاه فردوسی مشهد



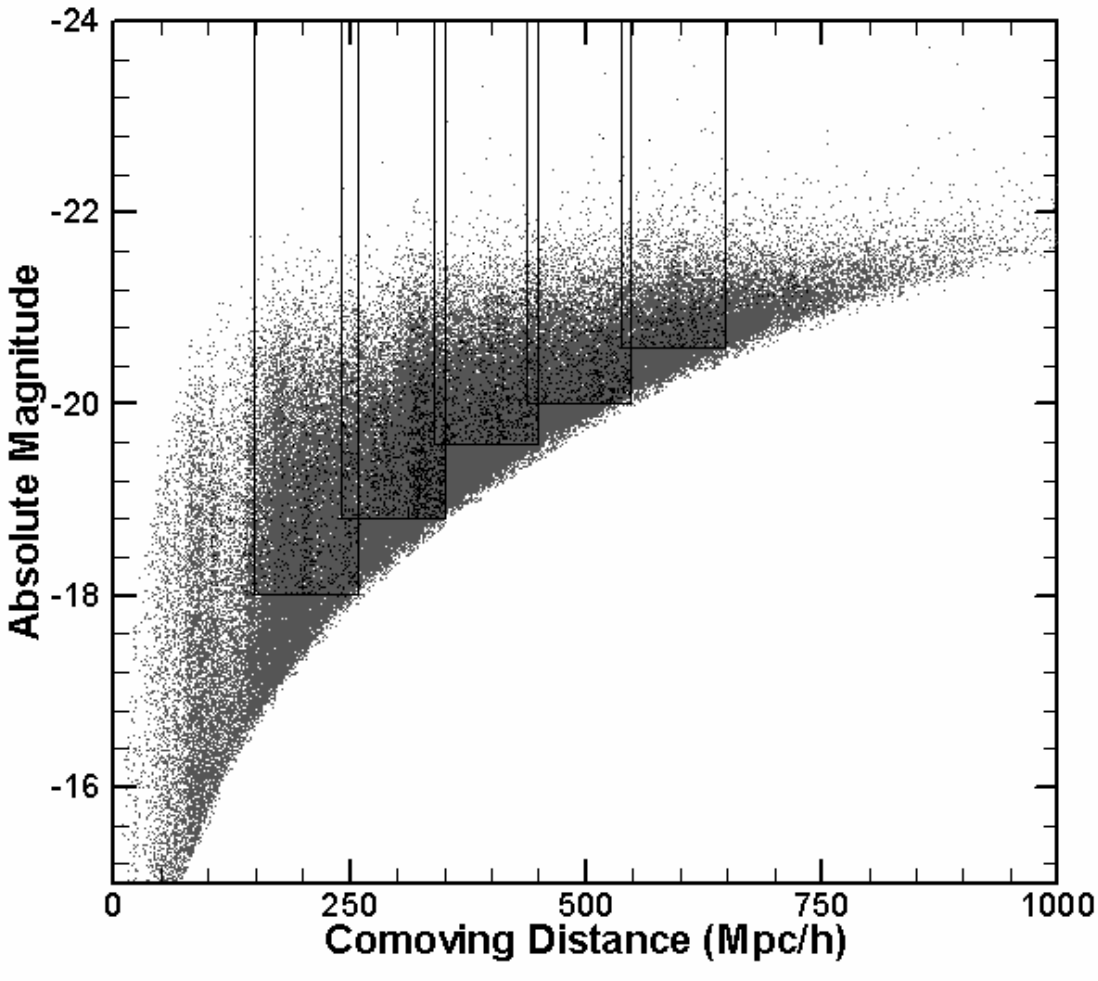
### چکیده

*علی رغم گذشت نزدیک به ۳۰ سال از نخستین کشف تهی جا ها، هنوز تعریفی از آنها که مورد توافق اکثریت کیهانشناسان باشد وجود ندارد. تهی جاها بزرگترین ساختارهایی هستند که در عالم یافت می شوند و بخش مهمی از ساختار بزرگ مقیاس عالم را تشکیل می دهند که سراسر کیهان را فراگرفته است و به مراتب کمتر از میانگین عالم حاوی ماده و کهکشان هستند. برای توصیف میزان تهی جا ها در عالم و بررسی آماری خواص آنها در نقشه های انتقال به سرخ مانند توزیع بزرگی، میانگین چگالی و شکل هندسی، تعریف مشخصی از تهی جا مورد نیاز است. تعریف تهی جا وابسته به روشی است که برای یافتن آنها در نقشه های رصدی یا شبیه سازی به کار می رود و تا کنون بیش از ۱۰ روش مختلف یافتن تهی جا مطرح شده و برای بررسی نقشه های متفاوت مورد استفاده قرار گرفته است. در این طرح پژوهشی در نظر داریم روشهای موجود را مورد مطالعه قرار دهیم، آنها را باسازی کرده و مقایسه آماری نتایج آنها را در یک نقشه واحد انجام دهیم و اولین گام را برای ارائه یک تعریف جامع برداریم.*

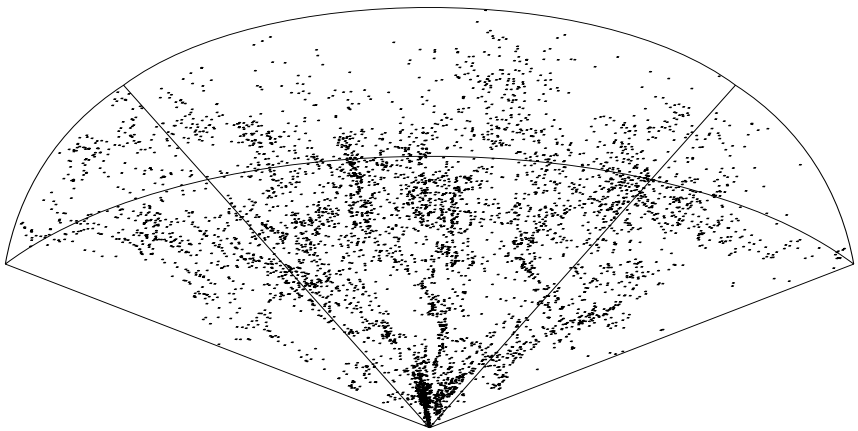
# Selection effects and Corrections

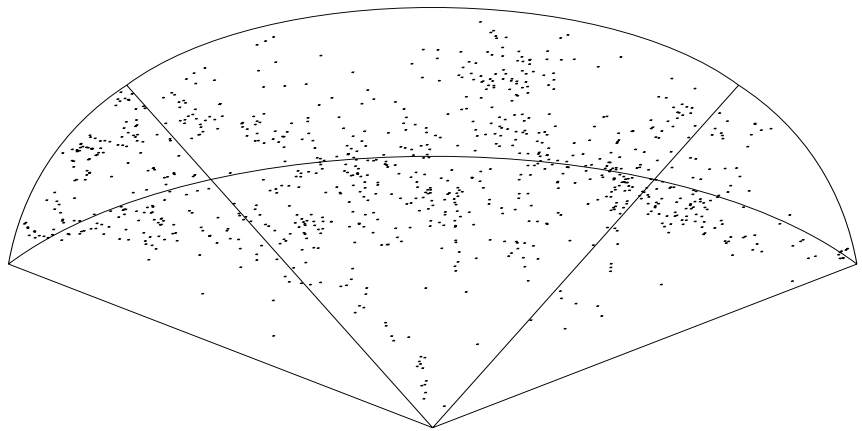
- Magnitude limited data
  - ➔ Volume limited subsamples
- Redshift and Evolution
  - ➔ k- and e-correction
- Moving observer, redshift artifact
  - ➔ Coordinate transformation
- Sampling incompleteness
  - ➔ Dilution of the samples

# Selection of the volume limited samples



# Selection of the volume limited samples





# Void finding algorithms

| Year | Author(s) | Title and source | Survey | Algorithm |
|---|---|---|---|---|
| 1989 | Geller & Huchra | Mapping the universe **Science, 246, 897** | CfA Some parts (8 slices) | Voids as regions with 20% of the mean density |
| 1989 | Einasto, Einasto & Gramann | Structure and formation of superclusters. IX - Self-similarity of voids **MNRAS (1991) 238, 155** | Galaxy and Cluster samples, Numerical Simulations | 2 complementary algorithms, empty sphere and pencil beam methods |
| 1991 | Kauffmann & Fairall | Voids in the distribution of galaxies: an assessment of their significance and derivation of a void spectrum **MNRAS (1991) 248, 313-324** | Two merged catalogues: (1) ZCAT with SRC and (2) CRVG with SRC | Void finder in 2D. Connected empty cells on a grid, where first square base voids are identified, and then boundary layers are added if they are empty and larger than 2/3 of the previous extension. |
| 1996 | El-Ad & Piran & da Costa | Automated Detection of Voids in Redshift Surveys **MNRAS (1997), 287, 790** | SSRS2 redshift survey | Similar to Hoyle & Vogeley |
| 1998 | Aikio & Maehoenen | A simple void-searching algorithm **ApJ, 497, 534** | Numerical Simulations | Voids as arbitrary shaped 3D objects, friends-of-friends percolation of subvoids |

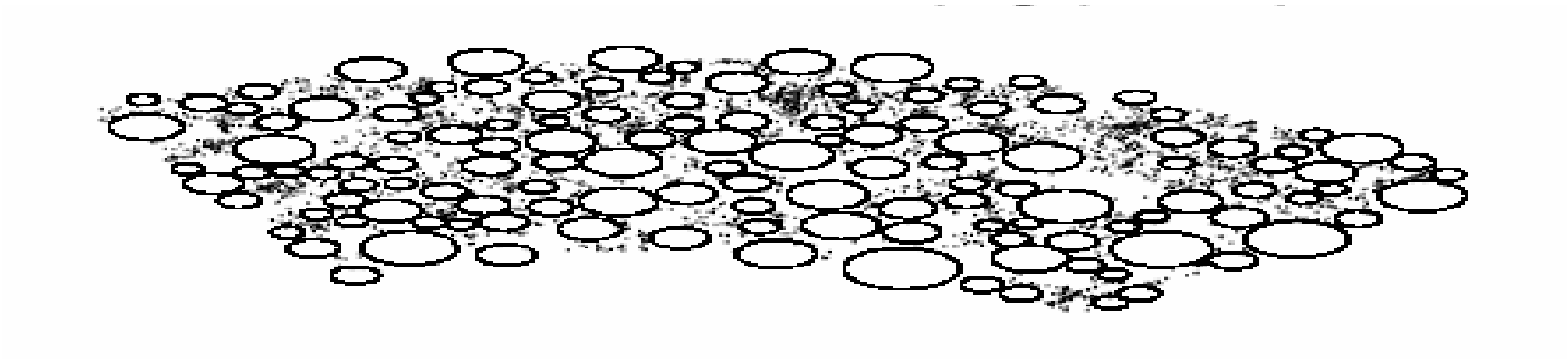
# Void finding algorithms

| Year | Author(s) | Title and source | Survey | Algorithm |
|---|---|---|---|---|
| 2000 | Mueller, Arbabi-Bidgoli, Einasto & Tucker | Voids in the Las Campanas Redschift Survey versus Cold Dark Matter Models **MNRAS (2000), 318, 280** | LCRS Las Campanas Redshift Survey and numerical Simulations | Kauffmann & Fairall in 2D |
| 2002 | Plionis & Basilakos | The size and shape of local voids **MNRAS, 330: 399-404** | PSCz | Smoothing at lengths of 5 and 10 Mpc/h , underdensity thresholds, at -68% and -39%, Arbitrary shape |
| 2002 | Hoyle & Vogeley | VOIDS IN THE POINT SOURCE CATALOGUE SURVEY AND THE UPDATED ZWICKY CATALOG **ApJ, 566:641- 651** | PSCz Point Source Catalog and UZC | 1. Classification of galaxies as wall or field galaxies. 2. Detection of empty cells in the distribution of wall galaxies. 3. Growth of the maximal empty spheres. 4. Classification of the unique voids. 5. Enhancement of the void volume. |
| 2002 | Brown & Bhavsar | The Void Distribution Function for the LCRS Data. **Bulletin of the American Astronomical Society, Vol. 34, p.1208** | LCRS Las Campanas Redshift Survey | polygonal voids from point data sets |

# Void finding algorithms

| Year | Author(s) | Title and source | Survey | Algorithm |
|---|---|---|---|---|
| 2002 | Arbabi Bidgoli & Mueller | Void Scaling and Void profiles **MNRAS (2002) 332, 205** | Las Campanas Redshift Survey and Numerical simulations | Kaufmann & Fairall algorithm, extended to 3D |
| 2003 | Hoyle & Vogeley | Voids in the 2dF Galaxy Redshift Survey **Astro-ph/0312533** | 2dF Galaxy Redshift Survey (2dFGRS) | Same as Hoyle & Vogeley 2002 |
| 2003 | Gottloeber, Lokas, Klypin & Hoffman | The Structure of Voids | Numerical Simulations | 3D spherical voids using the minimal spanning tree |
| 2004 | Vogeley, Hoyle, Rojas & Goldberg | The Void Spectrum and Properties of Void Galaxies in the SDSS**. American Astronomical Society Meeting 205, 94.04** | SDSS | Objective void finding algorithm |
| 2005 | Patiri, Betancort-Rijo, Prada, Klypin & Gottloeber | Statistics of Voids in the 2dF Galaxy Redshift Survey | 2dFGRS | Two complementary methods: Cell-Void finder, HB-Void finder, maximizing spheres of empty cells |
| 2005 | Padilla, Ceccarelli & Lambas | Spatial and dynamical properties of voids in a LambdaCDM universe | Numerical Simulations | Spheres with density contrast of <90% removing overlaps |

# Cell Algorithm (Patiri et al.2006)

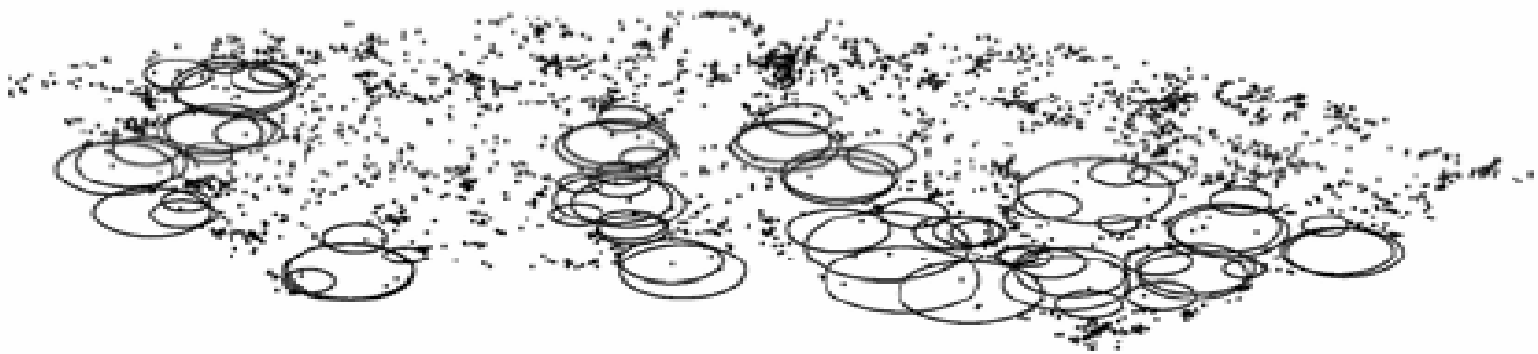


- Put Galaxies into a grid
- Calculate the Distance field
- Find Local Maxima
- Find Overlaps
- Remove smaller voids with overlaps

# Empty Sphere Method (Stavrev 2000)

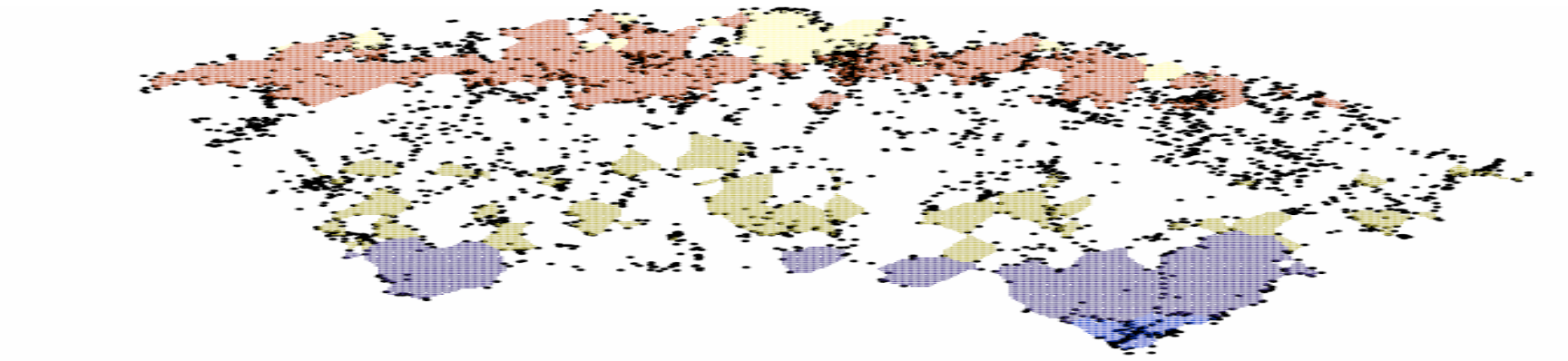
- Put a large number of random empty circles
- Expand them to the 3 nearest Galaxies
- Find Overlaps
- Remove smaller voids with overlaps

# Hoyle Vogeley Algorithm (HV 2002)



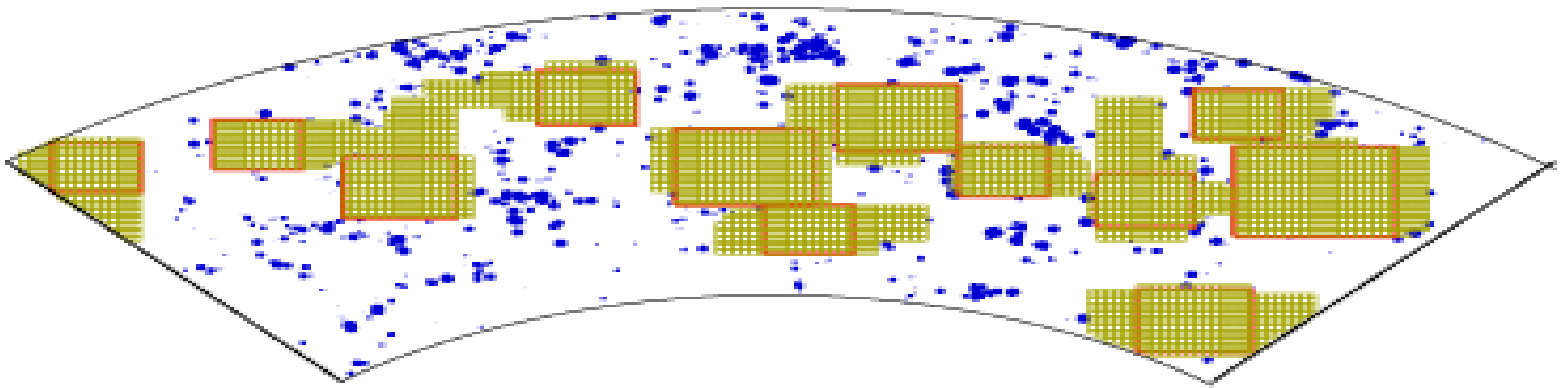
- Distinguish between Wall and Field Galaxies
- Put Galaxies into grid with size l3=d3+1.5*sigma
- Start from empty cells and grow spheres until 3 galaxie lie on them = holes
- Join holes to voids under the overlap condition

# Aikio Mähönen Algorithm (AM 1998)



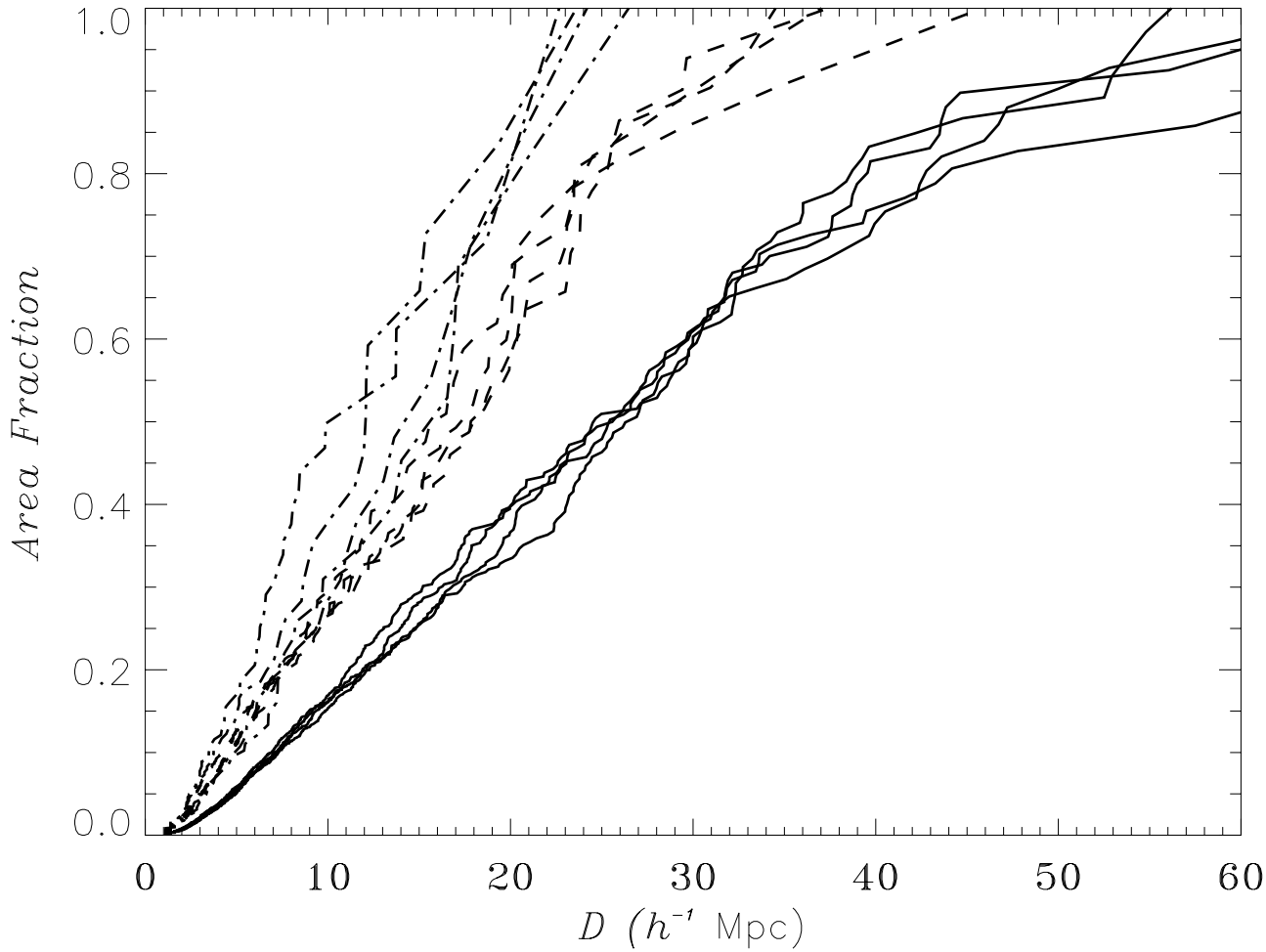
- Calculating the distance field
- Find Local Maxima
- Asigning empty cells to the Local maxima
- Joining these subvoids via FOF algorithm

# Kaufmann Fairall (KF1991)

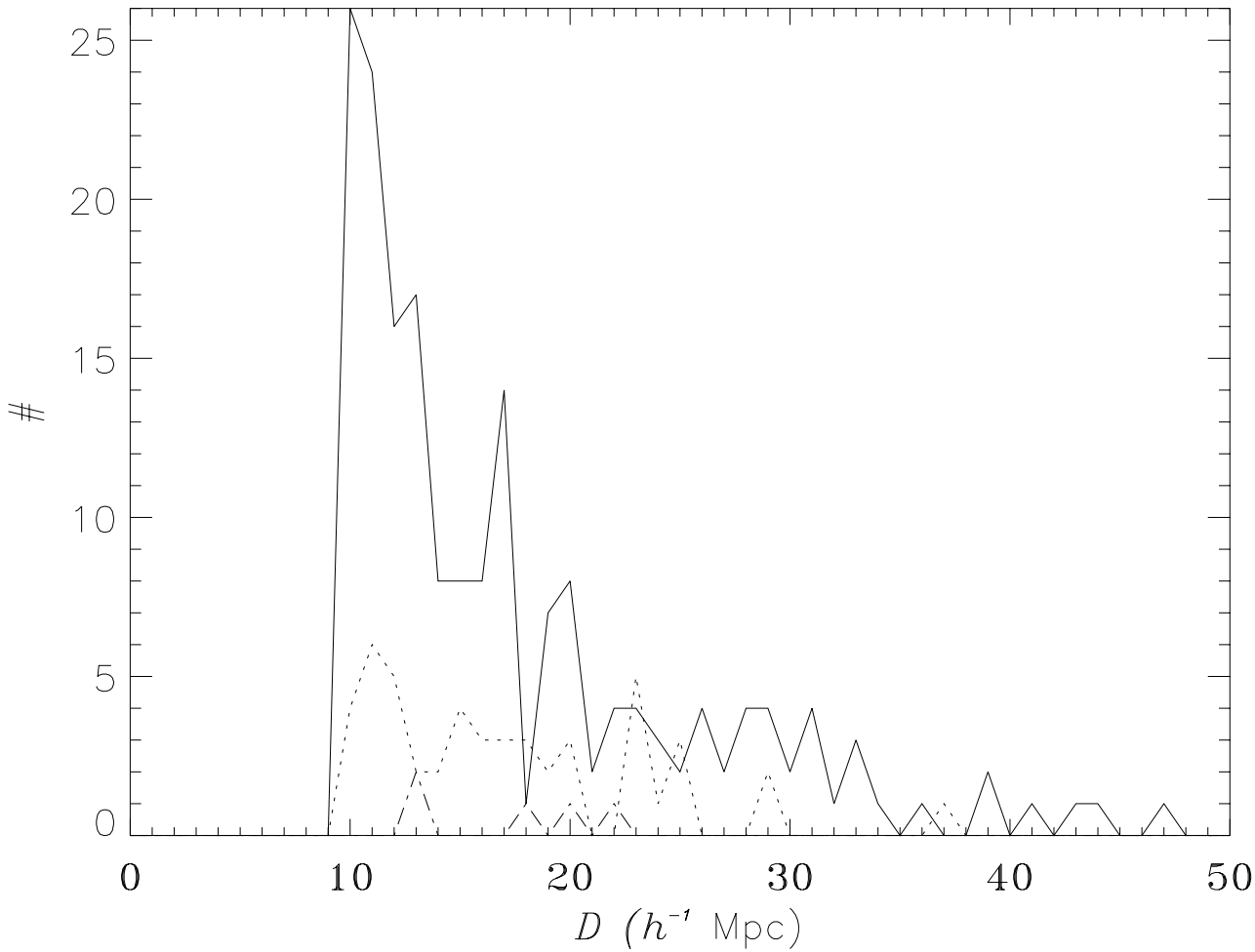


- Putting galaxies into a grid
- Finding maximal empty squares
- Asigning empty cells along the edges to the base voids

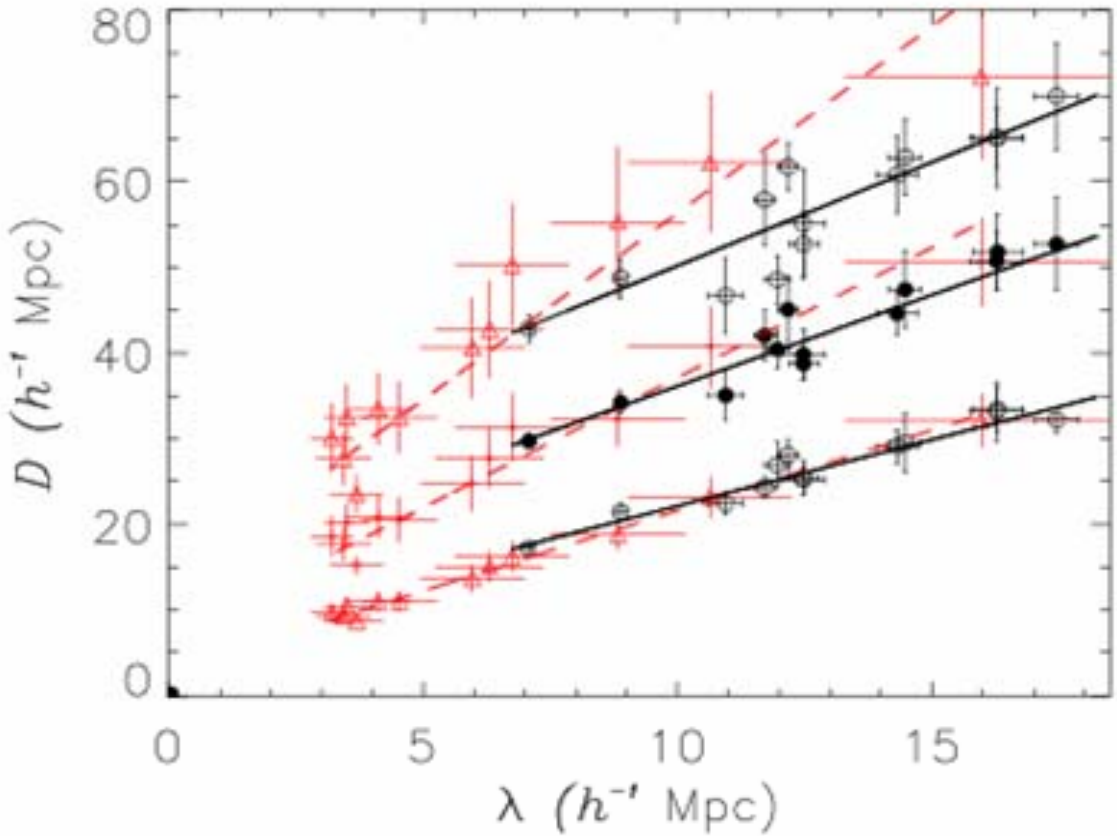
# Cumulative Void size Distribution



# Void spectrum (abundance vs size)



# Statistical measures of the Void Size Distribution



# Other work in progress

Voids are underdense regions in the LSS:

- Lensing effect (Weak lensing of Clusters)
- Density profiles (spherical approximation, NFW profiles of galaxies)
- Galaxy mass function (Press-Shechter formalism, excursion set theory)
- Galaxy evolution in and near voids (Void phenomenon)