c$^+$reative SIMULATIONS

Simulating the Structure of Our Universe

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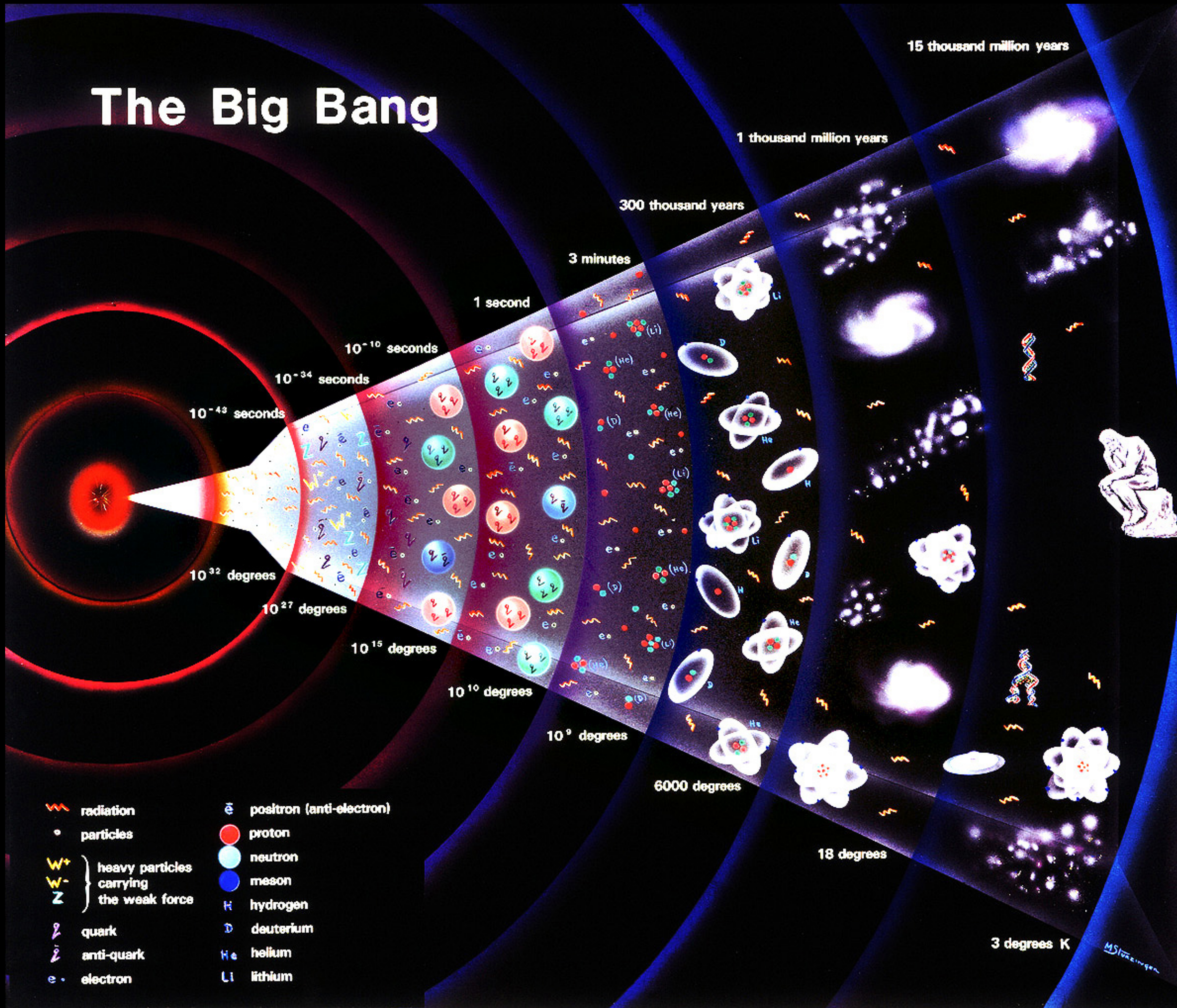
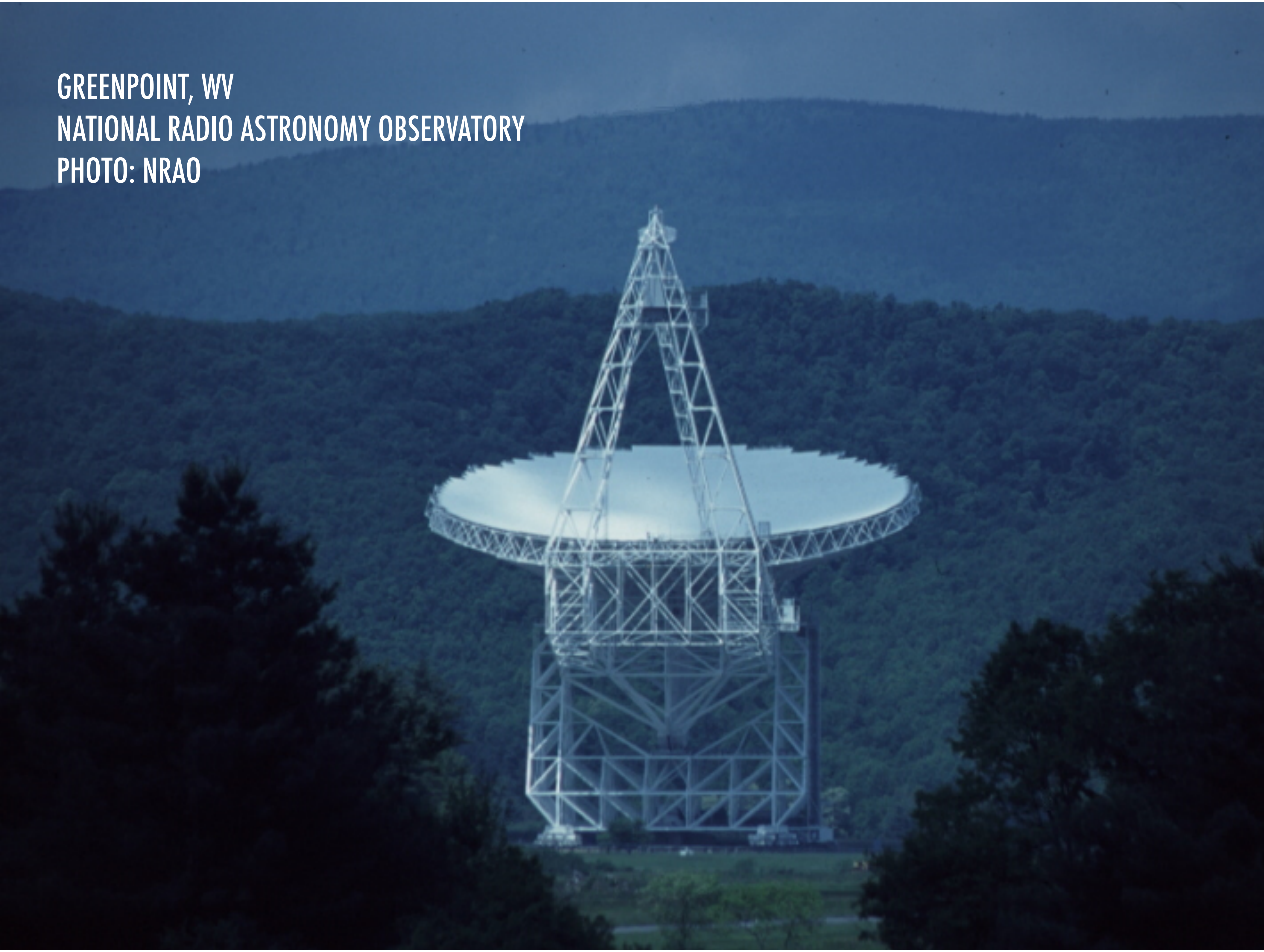
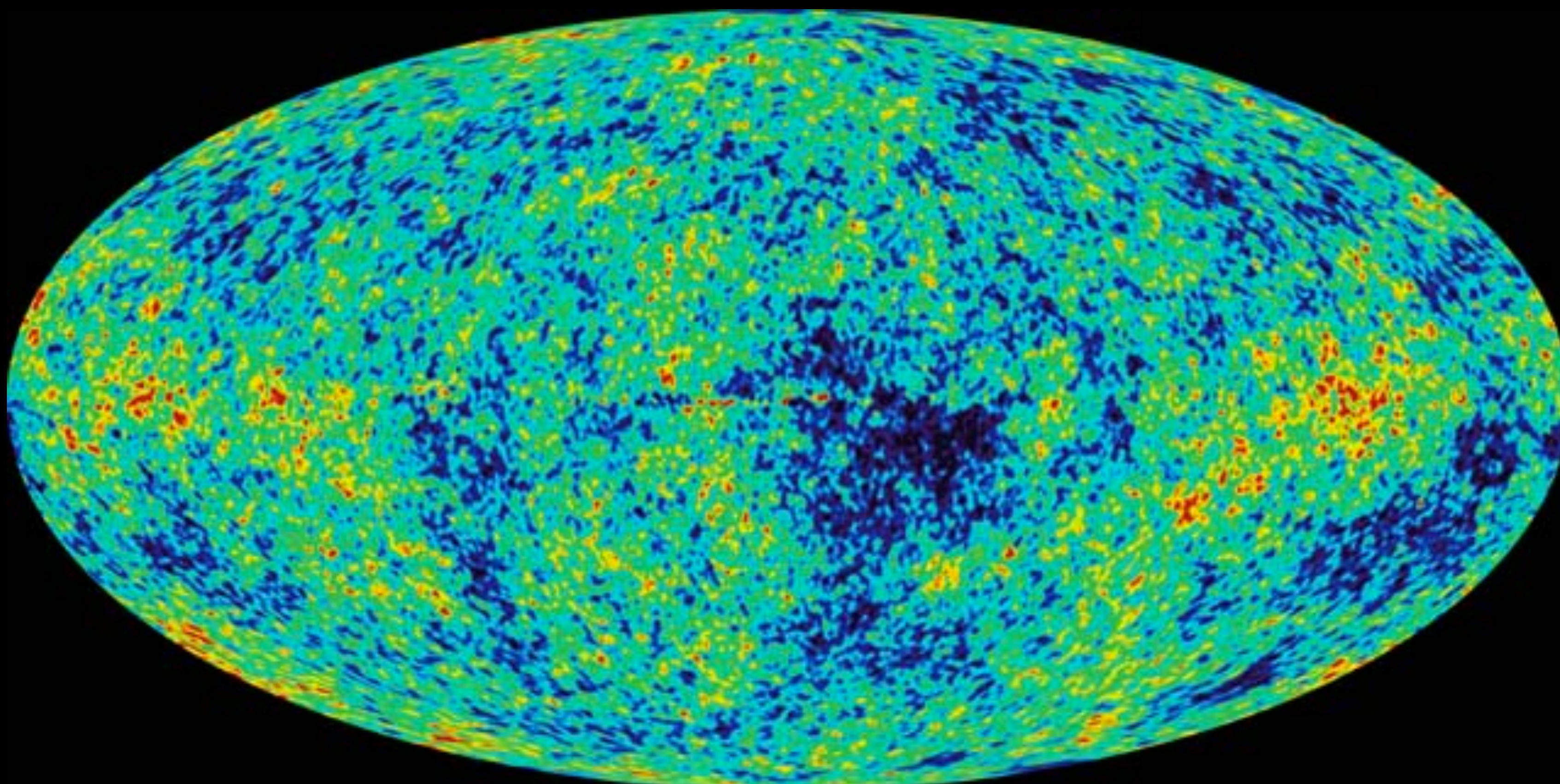
Background


The Big Bang
10^-43 seconds
10^-34 seconds
10^-10 seconds
1 second
3 minutes
300 thousand years
1 thousand million years
15 thousand million years
10^32 degrees
10^27 degrees
10^15 degrees
10^10 degrees
10^9 degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
W+ W- Z heavy particles carrying the weak force
quark
anti-quark
e electron
ē positron (anti-electron)
proton
neutron
meson
H hydrogen
D deuterium
He helium
Li lithium



GREENPOINT, WV
NATIONAL RADIO ASTRONOMY OBSERVATORY
PHOTO: NRAO

COSMIC MICROWAVE BACKGROUND



Radio Point Source Contamination of Low Redshift Galaxy Clusters

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Abstract

Observations of the Cosmic Microwave Background (CMB) with the Cosmic Background Imager (CBI) have revealed radio foreground signals that limit the accuracy of measurements of the anisotropic properties of the CMB such as the Sunyeav-Zeldovich Effect. By comparing CBI data to NVSS (and PMN) data, we made accurate counts of the number of radio sources in low redshift galaxy clusters. We determined that at 30 GHz there are 1.4 $\pm$0.3 sources per deg^2 brighter than 30 mJy in fields containing galaxy clusters. Comparing these results to the number of radio sources at random in the sky at 30 GHz (Mason et al.), a 1.38σ difference was found. We therefore do not detect a strong difference in the number of radio sources at 30 GHz in galaxy cluster fields. This work was done in collaboration with the Cosmic Background Imager project and with the support of the National Science Foundation and the California Institute of Technology.

Introduction

- The Cosmic Microwave Background (CMB), found in all directions in the sky, is the primordial radiation from the Big Bang and radiates at about 3K. Although it was once thought to be isotropic, it is known today that the CMB actually has anisotropic properties.
- An example of such anisotropies is the Sunyaev-Zeldovich Effect (SZE). When a photon attempts to pass through the hot gas in between clusters of galaxies, whose total masses are about 100 trillion solar masses, it is scattered by reverse Compton scattering thus boosting its energy and distorting its spectrum.
- In 1970 two scientists, Sunyaev and Zeldovich, first predicted this phenomenon and, in doing so, revolutionized the study of cosmology.
- Perhaps one of the most important results from the SZE is the possibility of a direct measurement of the Hubble Constant, H_0, and therefore the ability to determine with more accuracy the age and size of the universe.

The Cosmic Background Imager

- The Cosmic Background Imager is located in the Chilean Andes Mountains at 16,700 feet.
- This CMB specific instrument, meaning that it functions solely for performing CMB experiments, is a 13 element interferometer operating from 26 to 36 GHz. At such high altitudes the dry climate reduces atmospheric brightness fluctuations thus allowing for a very high sensitivity.
- The CBI is especially useful for observing SZE because it allows for relatively short baselines (about 1-2 meters). However, measuring the SZE does present certain challenges due to the limitations in the instrument. Such challenges are a result of contaminates like signals from the ground, atmospheric emission, and radio sources in the foreground.
- To address the latter challenge, radio source contamination, data can be taken at longer baselines, of 5-6 meters, and subtracted from the short baseline data.

The Experiment

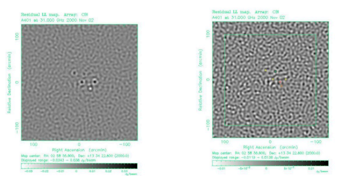
- We attempted to find the number of radio point sources in low red-shift galaxy cluster fields and then to compare this to the number of radio sources at random in the sky. The hope is that the results of this experiment will provide a statistical correction to the SZE CBI data taken at short baselines. The data was taken by the CBI collaboration over the period of December, 1999 to December, 2001.

DIFMAP and the CLEAN Process

- The data reduction was performed in DIFMAP which is a program that specializes in "difference mapping".
- The CLEAN process, a function within DIFMAP, allows the user to subtract a model of a given source from a "dirty map" thus creating what is known as a "residual map". By iteratively subtracting model sources, a "clean map" is eventually created. In each iteration a delta function is added to the model.
- For data reduction purposes the following selections were made: left circular polarization was used, griding weights were scaled by errors raised to the power -2, and the UV range was 0.3 to 1 Kλ. For the CLEAN routine 100 iterations were made at a gain of 0.1, and the cutoff was set to 5 times the noise.

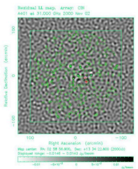
Locating Radio Point Sources

- There were a total of 19 fields of galaxy clusters used in this experiment. Each field was analyzed above a 5σ noise cut-off.



Dirty map of A401 on left. Large contaminants in the center of map show possible radio point sources. CLEAN map of A401 on right identifying the radio point sources above 5σ.

- It is possible to locate the radio source contamination by analyzing the values of each pixel in the map, where pixel values represent flux density, and checking if the value is 5 times greater than or equal to the noise. Cross marks are placed on those pixels which are above or equal to 5σ. Red and orange crosses represent negative flux densities, and green and yellow represent positive flux densities. This was first done manually using a command line routine in the DIFMAP environment and then using the CLEAN method. The manual method and the CLEAN method matched for all 19 galaxy clusters.
- Another check was made to verify the validity of our 5σ noise threshold. A comparison of our radio point sources to cataloged radio point sources was made with NRAO/VLA Sky Survey (NVSS) for sources north of a declination of $-40°$ and with Parkes-MIT-NRAO Survey (PMN) for all other sources.



- For a given field the database was searched for all radio sources within 100 arc minutes of the field center. The sources were then uploaded in DIFMAP onto the field map in order to visually match the "cleaned" sources to the "known" sources. A numerical check was also made by comparing the model file of a given field, containing right ascension (R.A) and declination (DEC) of the field center, with the R.A and DEC from the NVSS or PMN database.

Statistical Analysis

- A total of 38 sources were initially identified. However, since only positive sources are used in the NVSS and PMN databases, the negative sources in our data had to be eliminated. Therefore, the 27 sources counted in this analysis include only positive sources.
- To determine the number of sources greater than a given flux density in an area in the sky, the normalization, N_0, must be found.

$$N(>S) = N_0(\tfrac{S}{S_0})^{\lambda}$$

- The distribution of the area over which a source can be found in the sky was calculated using all 19 fields and all 27 sources. Area is given as the following where n denotes noise (subscript k) and S denotes flux density (subscript i):

$$A(S_i, n_k) = \pi * (-730.36) \ln \tfrac{5n_k}{S_i}$$

- A program was written in the IDL programming language to find the normalization N_0. The first task was to generate a routine to satisfy the equation and calculate the normalization. The following equation is an alternative way to write $N(>S)$:

$$N(>S_j) = \sum_{S_i>S_j} \tfrac{1}{A(S_i)} = \sum_{S_i>S_j} \tfrac{1}{\sum_k (-730.36)\pi \ln \frac{5n_k}{S_i}}$$

- Flux density S_j was randomly chosen to be between 15 and 300mJy. Note that i is for all the flux densities associated with each source, j is for all the randomly chosen flux densities, and k is for each field. Taking the log of both sides of $N(>S)$ gives

$$log(N(>S)) = \lambda log(S) + log(\tfrac{N_0}{S_0^{\lambda}})$$

- The value for λ was calculated as -1.4. Setting both S and S_0 to 30mJy and converting N(>30mJy) to deg^{-2}, we get a value of N_0 of 1.4 deg^{-2}.

Summary

- Identifying radio source contamination in the CBI SZE data not only provides a statistical correction to the data but, perhaps more importantly, helps in understanding the measurements of the Hubble constant, H_0, from the SZE data. Although it is possible to directly subtract those sources that are bright enough to be detected there are many sources that are found below the noise cut-off point and therefore bias a measurement of H_0. However, we can extrapolate just below our detection threshold and correct for those sources as well.
- Are there 4-7 times as many sources in galaxy clusters as in random fields in the sky as per the Cooray et al. result? Comparing our sample of radio sources in clusters to four times the CBI blank sky counts predicts 0.9 $\pm$ 0.2 sources per deg^2, whereas in our cluster sample we see 1.4 $\pm$ 0.3. Thus the cluster counts are 2.6σ *below* four times the blank field counts, and any difference, if present, is less dramatic than previously thought.
- Cooray et al. have also derived 30 GHz source counts in galaxy clusters. A direct comparison of the Cooray cluster counts to the CBI blank field counts shows only a 1.3σ difference. This is consistent although the sensitivity is poor due to small number statistics.

References

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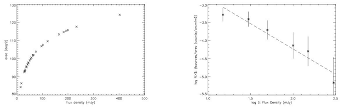


Area as a function of flux density on left. Extracting a slope to determine the value of λ on right.

Results

- From the statistical analysis it was determined that there are 1.4 $\pm$0.3 radio sources brighter than 30mJy in the sky per deg^2 as shown below.

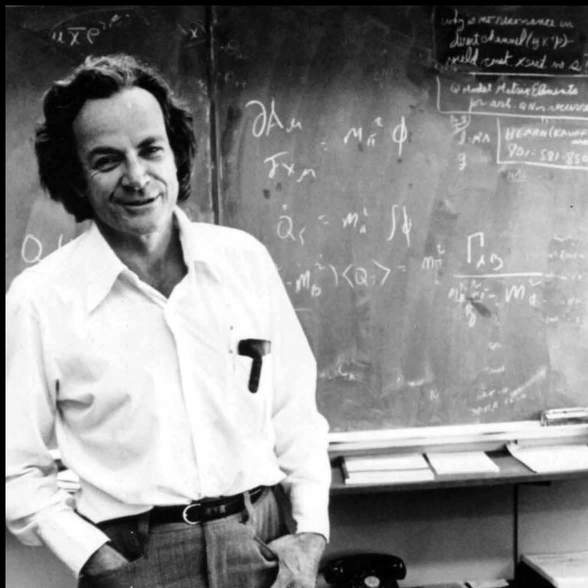
$$N(>S) = 1.4 \pm 0.3 deg^{-2}(\tfrac{S}{30mJy})^{-1.4\pm0.3}$$

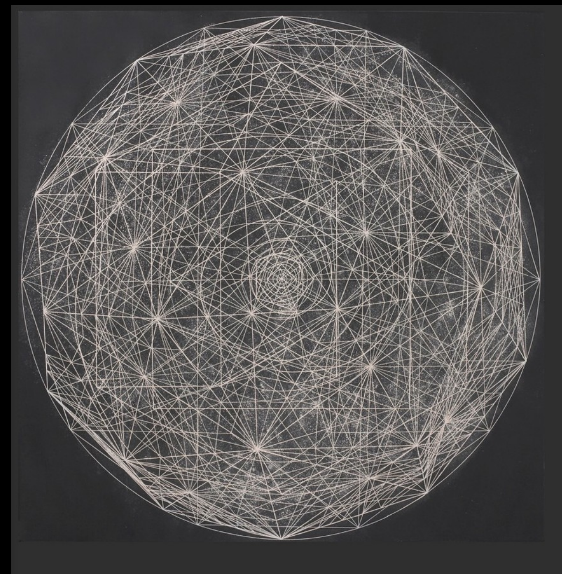
- This number includes the contribution both from the sources associated with the galaxy cluster as well as the sources that would be there if there were no cluster. Correcting the Mason et al. number for a 30mJy threshold flux density yields an N_0 of $0.9 \pm 0.2 deg^{-2}$.
- Comparing our result to the Mason et al. result a 1.38σ difference was found. Since this value is below 2σ, we can see that this value is not highly significant, and, therefore, there is inconclusive evidence as to whether or not this value is due to noise.
- In terms of this result, the number of radio sources in clusters per deg^2 is roughly the same as the number of radio sources per deg^2 at random in the sky.
- Cooray et al. find, in independent cluster observations, an N_0 of $2.25 \pm 0.7 deg^{-2}$ and a λ of -0.96 ± 0.14.
- Comparing this to our result, a 1.11σ difference was found. We see that this falls well below 2σ, and we can conclude that this value is not highly significant.
- The comparison of the result found in this paper to the Cooray result showed the uncertainty in the power law dominates.

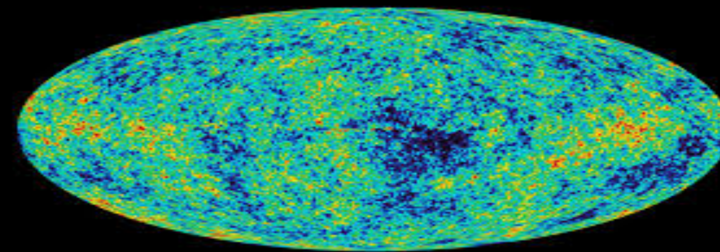
Table of subtracted sources.

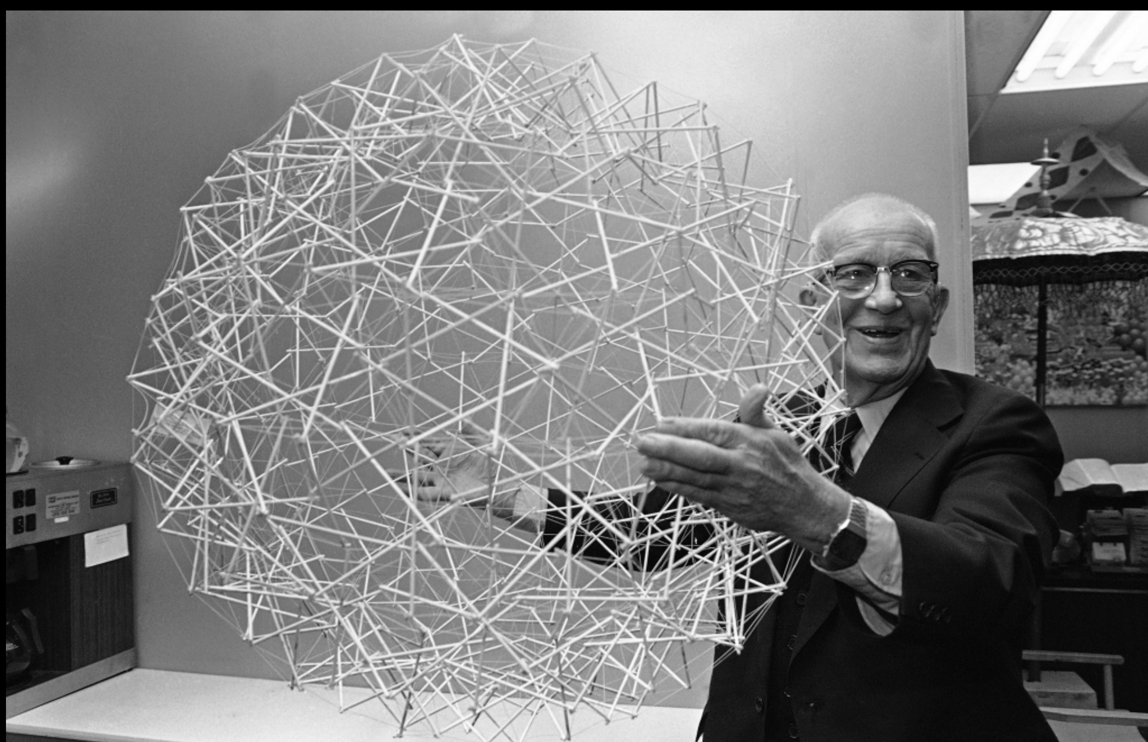
Field	$S_{observed}$ (Jy)	r (arcmin)	R.A	Dec	z
A1651.1	0.0418	17.82	12:59:48.54	-03:54:34.8	—
A2029.1	0.1425	27.54	15:11:41.19	+05:18:09.4	0.084
A2029.2	0.0654	16.86	15:09:47.46	+05:45:31.8	0.098
A2597.1	0.0417	1.00	23:25:19.82	-12:07:28.6	0.082
A3558.1	0.0627	30.97	13:30:19.07	-31:22:58.8	1.326
A3558.2	0.0134	8.84	13:28:31.49	-31:35:03.8	—
A3571.2	0.0136	33.70	13:46:28.76	-32:20:51.8	—
A3571.3	0.0154	21.88	02:58:10.39	+13:51:50.4	—
A401.4	0.0362	6.059	02:58:31.89	+13:34:17.4	0.064
A401.5	0.0219	23.21	02:59:37.57	+13:54:36.6	0.074
A401.6	0.0169	21.11	02:59:39.33	+13:55:24.3	0.074
A754.1	0.0440	10.10	09:08:27.44	-09:32:35.9	—
A754.2	0.0230	25.05	09:09:26.99	-09:22:49.4	0.059
A754.3	0.0284	17.93	09:09:30.98	-09:23:10.5	—
A754.4	0.0176	20.26	09:09:32.16	-09:22:18.7	—
A85.1	0.0154	10.25	00:42:30.38	-09:22:04.0	0.056
A1650.1	0.0573	8.32	12:59:06.60	-01:50:58.1	—
A1650.2	0.0173	21.61	12:57:14.68	-01:50:53.1	—
A2384.1	0.0997	11.80	21:51:51.00	-19:46:06.0	0.424
A3112.1	0.1834	0.52	03:17:58.60	-44:14:16.0	—
A3112.2	0.0387	26.62	03:16:38.30	-43:51:23.0	0.062
A3112.3	0.0167	29.97	03:20:24.50	-44:00:33.0	—
A3266.1	0.1702	10.86	—	—	—
A3667.1	0.0333	8.71	20:11:27.90	-56:44:01.0	0.053
A3667.2	0.0473	18.35	20:14:01.60	-57:01:10.0	0.057

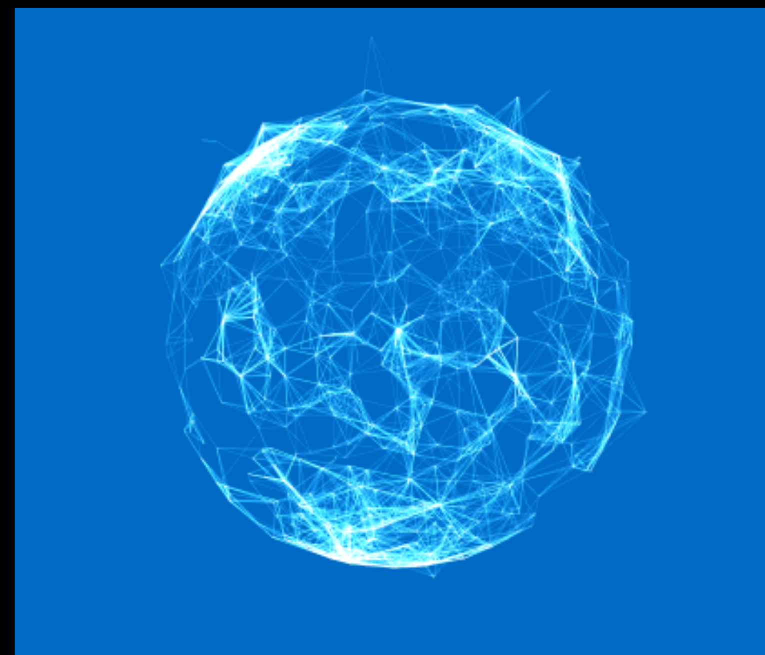
Code Project





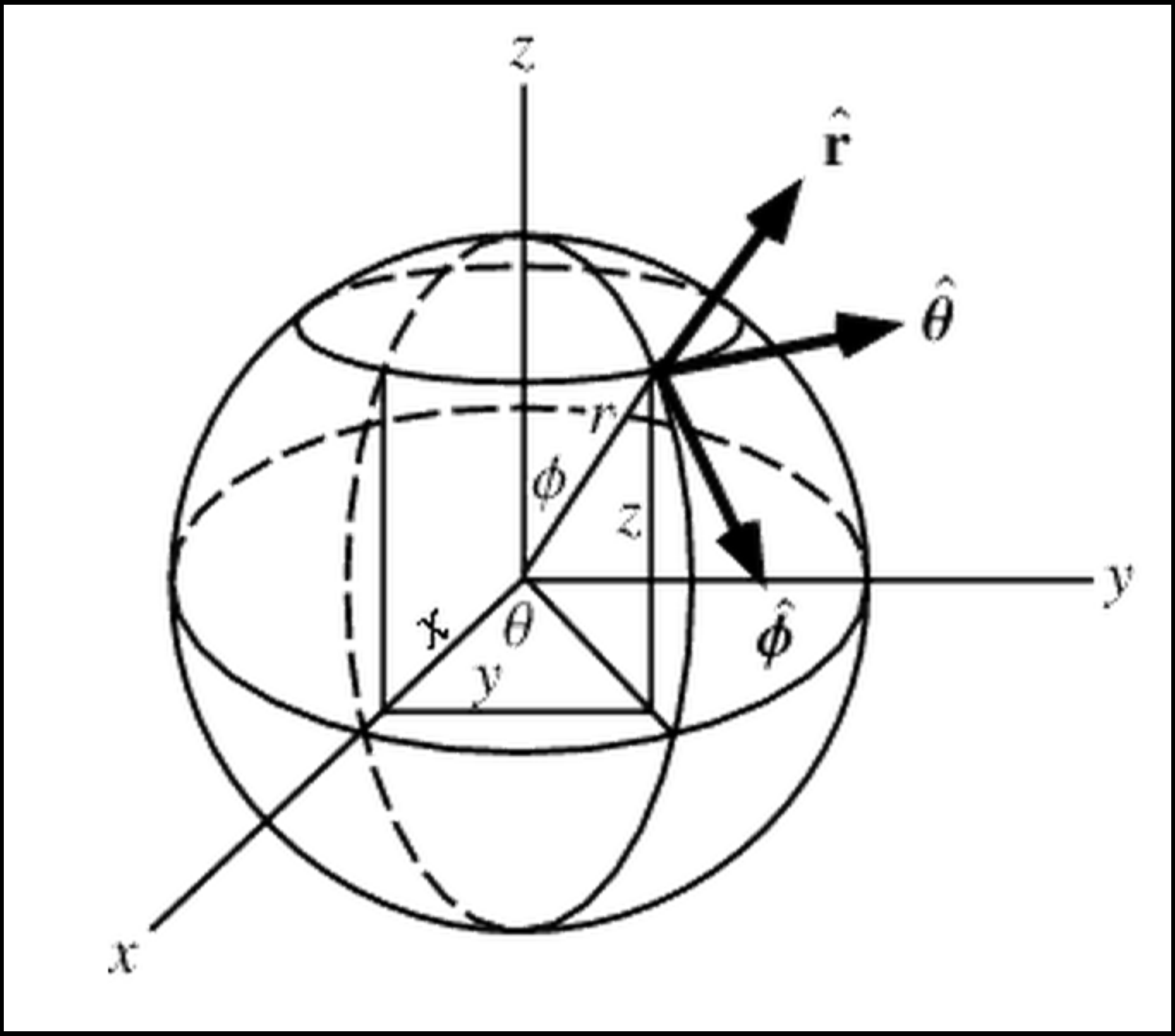







10^{+21}
10^{+14}
10^{+13}

Simple Math Can Create Immense Beaty



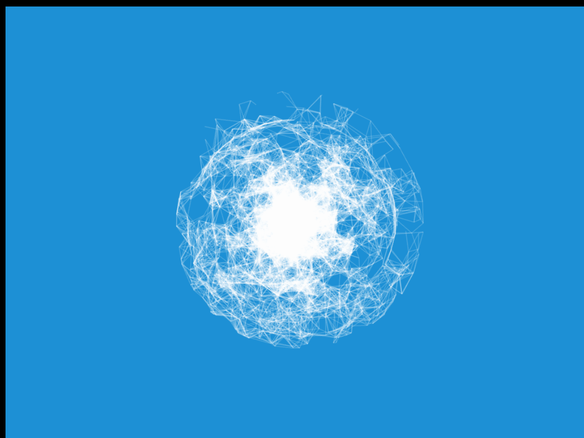
Spherical Coordinates:

$$x = r\cos\theta\sin\phi$$
$$y = r\sin\theta\sin\phi$$
$$z = r\cos\phi.$$

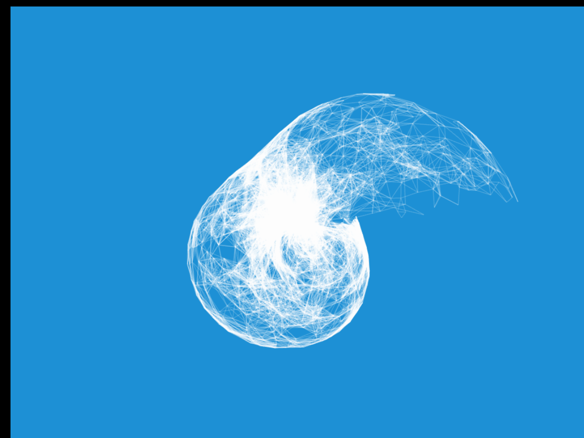
$0 \le \theta < 2\pi$ $0 \le \phi \le \pi$

```
//--------------------------------------------------------------
void ofApp::draw(){
    ofBackground(29,144,213);

    cam.begin();

    for(int i = 0; i < num; i++){

        points[i] = ofPoint(radius[i]*cos(theta[i])*sin(phi[i]), radius[i]*sin(theta[i])*sin(phi[i]), radius[i]*cos(phi[i]));


        if(radius[i] < 300){
            radius[i] ++;
        }

        theta[i] += changeTheta[i];
        phi[i] += changePhi[i];
    }

    for(int i = 0; i< num; i++){
        for(int j = i+1; j < num; j++){
            dist = pow(points[i].x - points[j].x, 2) + pow(points[i].y - points[j].y, 2) + pow(points[i].z - points[j].z, 2);
               // dist = sqrt(dist);

            if (dist < 2*mouseX) {
                ofSetColor(255, 50);
                ofSetLineWidth(1.5);
                ofLine(points[i].x, points[i].y, points[i].z, points[j].x, points[j].y, points[j].z);
            }

        }
    }
    cam.end();

   // cout<<ofToString("frame"+ofToString(ofGetFrameNum(), 1, 5, '0'))<<endl;
   //ofSaveScreen(ofToString("frame"+ofToString(ofGetFrameNum(), 1, 5, '0')+".png"));

}
```

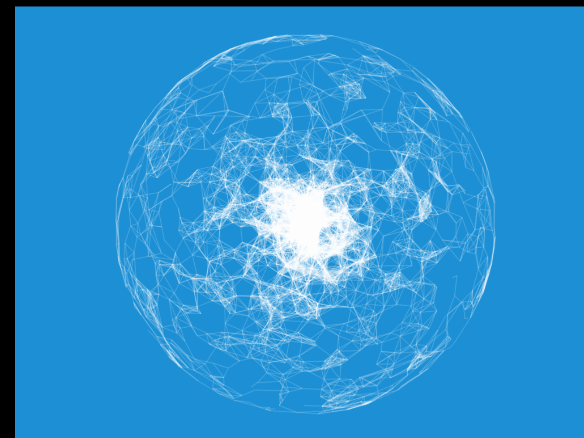
Basic geometries w mouse



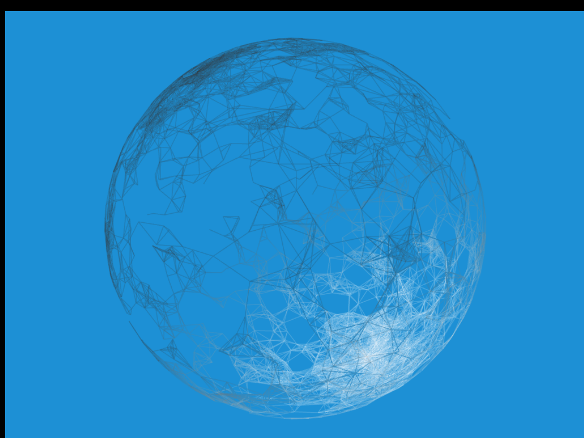
Adding Noise and Sin movements



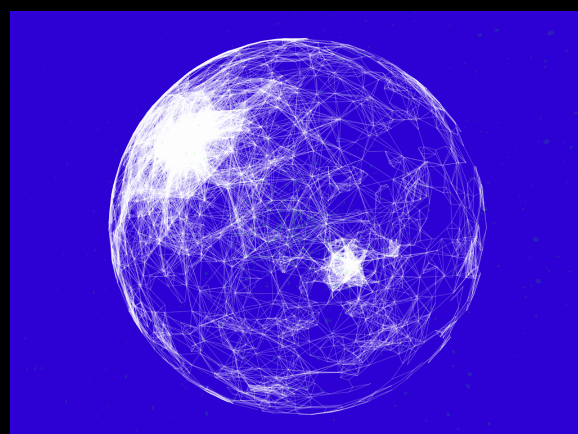
Experimenting w more Nodes



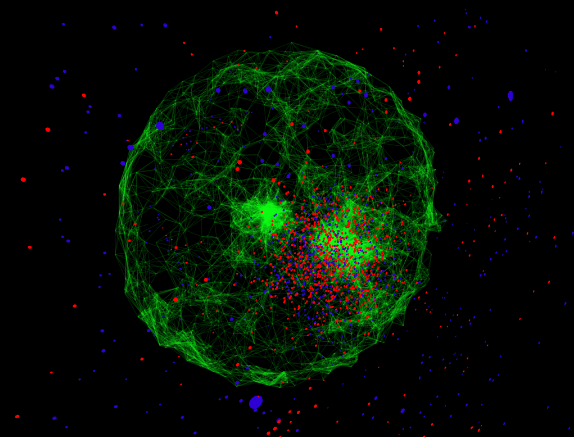
Experimenting w Light and Particles

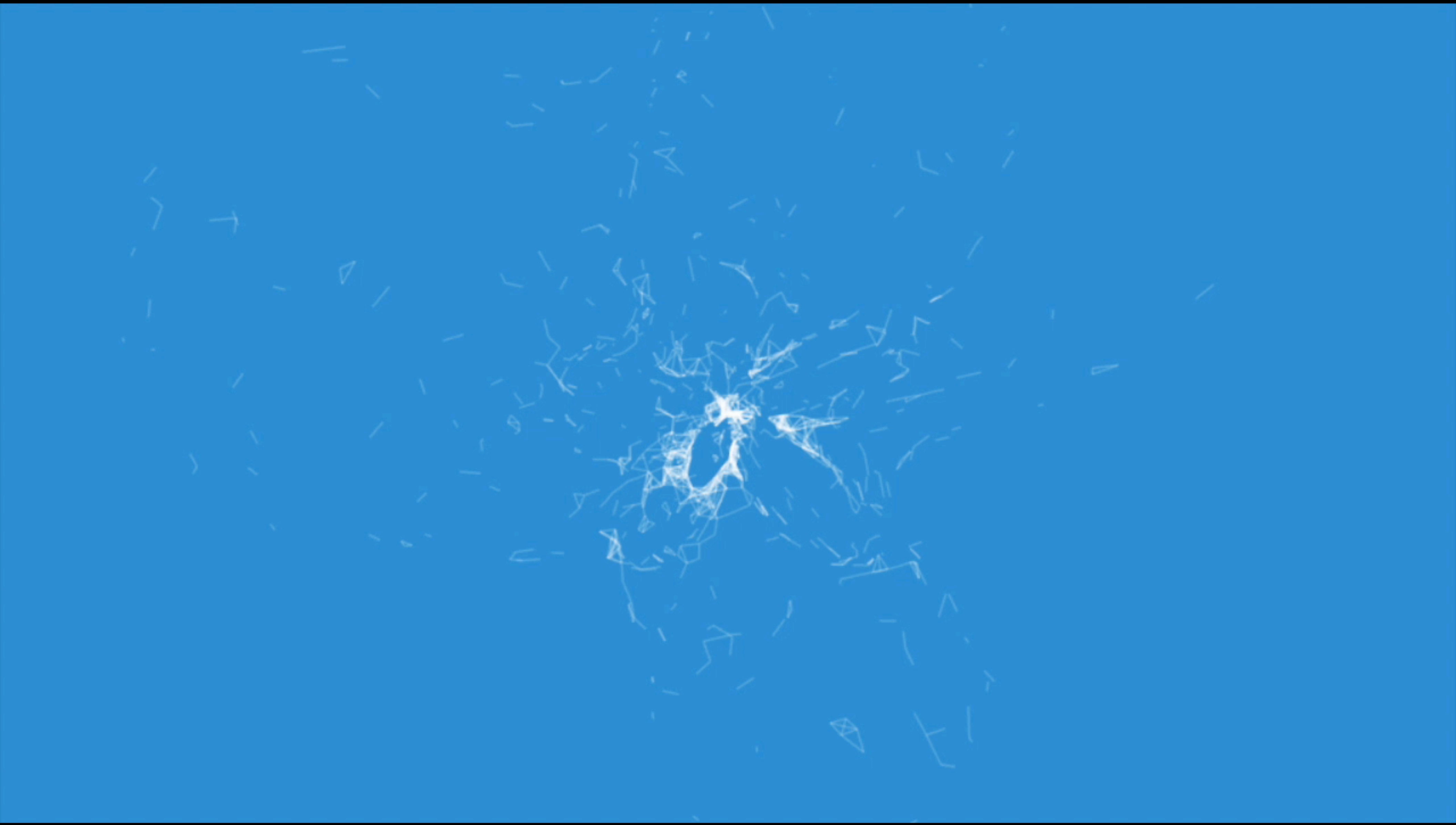


Experimenting w Light, Particles & color



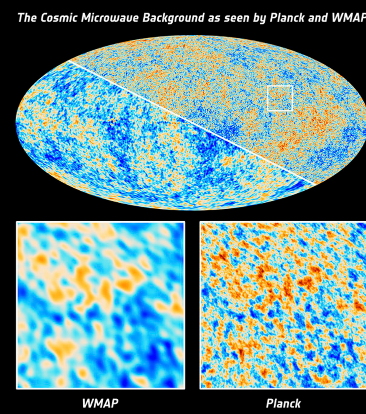
Elliptical geometries & playing w particles systems



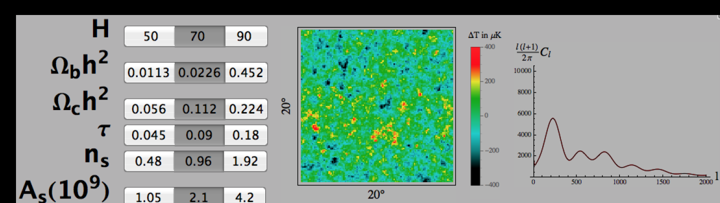


Next Steps

1. Further iterations need to be made on to more accurately model the CMB - specifically density fluctuations over surfaces



2. Work more with shaders to create different visual effects as various constants change



3. Research shadertoy.com and how they create their effects https://www.shadertoy.com/view/Xss3DS

Precedents

Reza Ali: A Drifting Up

http://www.syedrezaali.com/

Thank you

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