DOING COSMOLOGY AND INVESTIGATING THE CMB COLD SPOT WITH EMU-ASKAP SURVEY

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Agenda:

- EMU-ASKAP
- Effect of survey depth, shot noise, sky coverage in cosmology analysis (ISW effect as example)
- EMU-Investigating the CMB Cold Spot
- EMU-Pilot

EMU-ASKAP

- Evolutionary Map of the Universe (EMU) will be the most sensitive large scale radio continuum survey of its time before Square Kilometer Array's first phase (SKA-1) is launched.
- It will cover around 75% or around (3π steradians) of the sky.
- It will include a full coverage of the southern hemisphere and the equatorial region, right to +30 degrees declination.
- The sensitivity of the survey is planned to be around 10 micro Jy rms with estimated 70 million plus sources (However now 20 micro Jy rms is the likely sensitivity and so numbers will be roughly 27 millions).
- EMU-ASKAP has a planned resolution of around 10 arcseconds

EFFECTS OF SURVEY DEPTH, SHOT NOISE, SKY COVERAGE IN COSMOLOGY ANALYSIS (ISW EFFECT AS EXAMPLE)

Theoretically, we can obtain integral source counts from differential count power law distributions as:

N(S>Smin)= $\int n(S)dS$

Here n(S) is the differential source count power law probability distribution in $Jy^{-1}\ Sr^{-1}$ as:

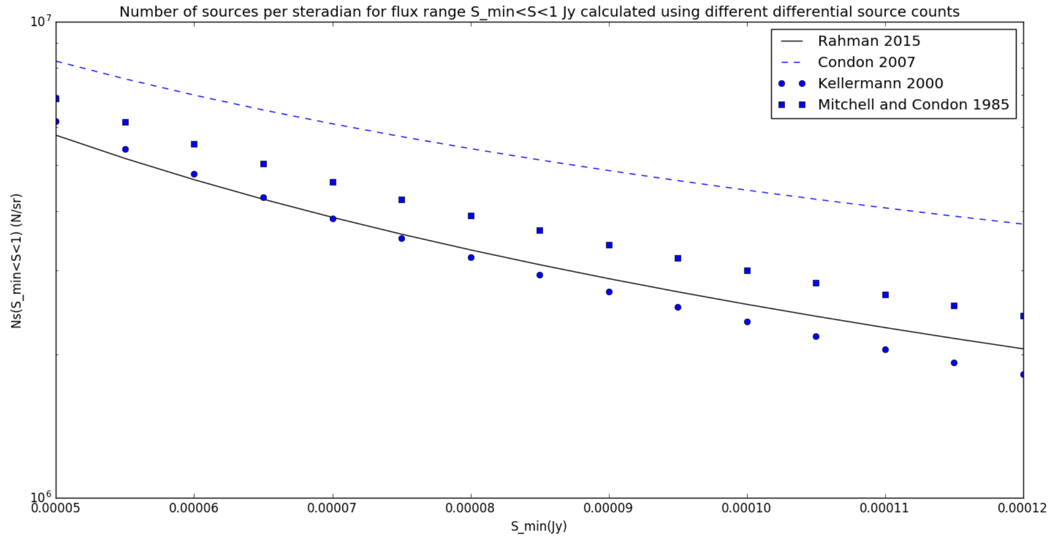
$$n(S) = \frac{dN}{dS} = kS^{-\gamma}$$

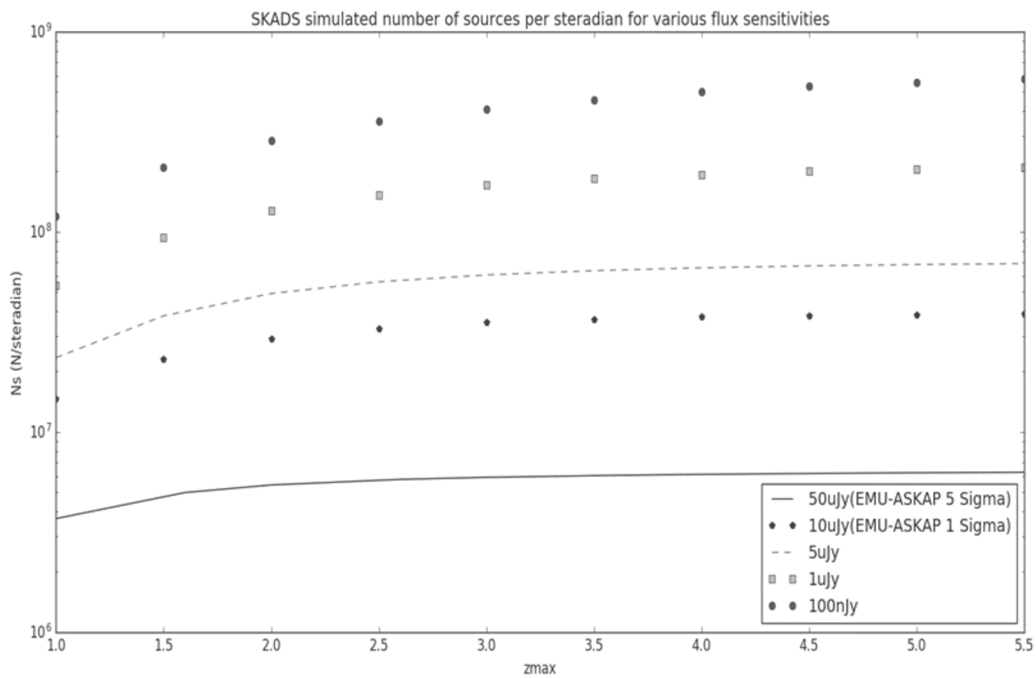
We can see the lower bound value for Smin>0 as it will be undefined for Smin=0Jy/beam which is also not a realistic value.

- We first use SKADS (S3- SEX) to get the differential source counts for 1.4 GHz sky with a flux density range of 50 micro Jy/beam < S<570 micro Jy/beam with a redshift range of 0<z<5.8, and obtain k=57.24 and γ=2.18 (Rahman 2015).
- Condon 2007, uses flux range of 1 micro Jy < S <100 micro Jy and estimated, k=1000 and γ =1.9. Kellermann 2000 measured k=8.23 and γ =2.4.
- Mitchell & Condon 1985 estimated k=57 and γ=2.2.

To obtain the estimated source counts N(S>Smin),we set the upper flux limit as 1 Jy.

(Rahman and Iqbal 2019)

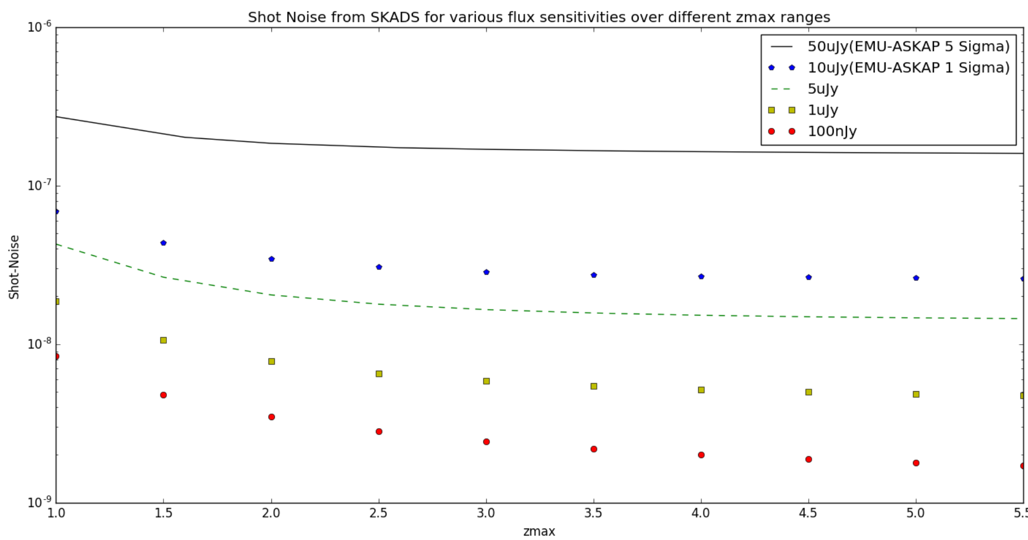


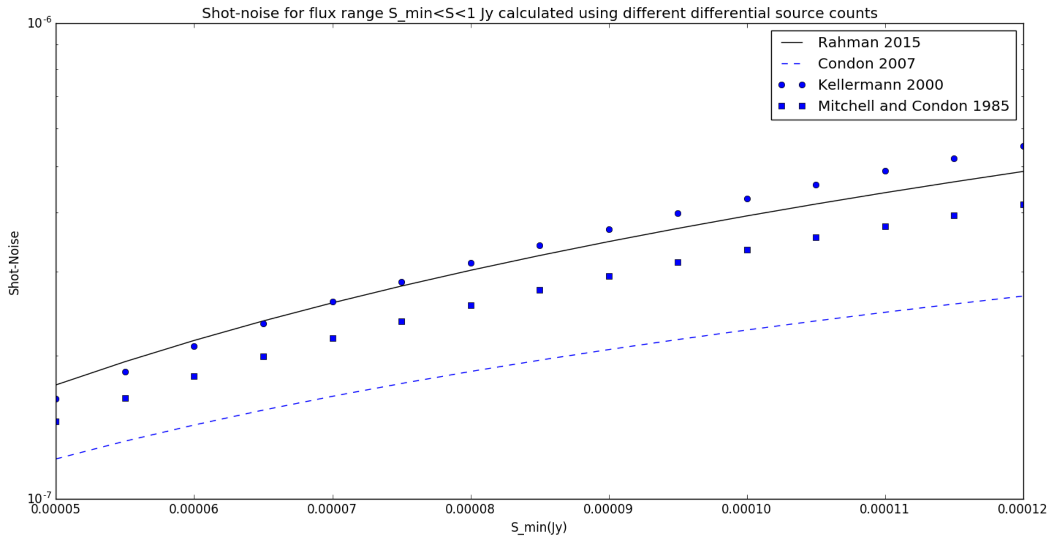


Shot noise consideration.

- In order to perform statistical error analysis for galaxy continuum surveys, the shot-noise measurements play an important part.
- Shot noise estimates or measurements are required to calculate the signal to noise ratios, measure error bars, and obtain correct covariance matrices, especially in relation to the theoretical or observed 'Cl' values obtained during cross or autocorrelation studies.
- We can define shot-noise as

$$Shot\ Noise = \frac{\Delta\Omega}{N}$$





Effect on science goals (ISW effect as an example).

A major scientific goal of modern radio continuum surveys and the cosmic microwave background surveys is the measurement of the late time integrated Sachs-Wolfe (ISW) effect.

The effect explains the blue-shifting of the photons from the cosmic microwave background rations once they pass through the large scale structures or the red-shifting of the photons once they pass through big voids.

The detection of ISW effect is used as a mean to constraint the dark energy which explains the accelerated expansion of our universe, the age of our universe and various other interesting phenomena.

The temperature fluctuations, due to the ISW effect, can be calculated using the gravitational potential as:

$$\frac{\Delta T}{T} = \int_{\eta r}^{\eta 0} (\Phi' - \Psi') d\eta$$

Where, $\Phi = -\Psi$, in the linear regime.

However, in fact, we measure a coefficient ‘Cl’ by cross-correlating the cosmic microwave background anisotropy maps with galaxy over/under density maps.

The cross-correlation angular power spectrum coefficient ‘Cl’ can be calculated as:

$$Cl^{gt} = 4\pi \int_{kmin}^{kmax} \frac{dk}{k} \Delta^2(k) Wl^g(k) Wl^t(k)$$

Here is $\Delta^2(k)$the logarithmic matter power spectrum, which can be calculated as:

$$\Delta^2(\mathrm{k}) = \frac{k^3}{2\pi^2} P(k)$$

Where P(k) is the power spectrum of the matter density fluctuations.

$Wl^g(k)$ and $Wl^t(k)$ represent the theoretical galaxy density fluctuations and the Integrated Sachs-Wolfe effect window functions respectively. $Wl^g(k)$ is dependent on galaxy survey details like bias, redshift distributions and magnification bias.

We ignored magnification bias in our signal to noise calculations here.

For our analysis, we will use limber approximations. We use CAMB to obtain the matter power spectrum values.

For our analysis, we adopt $\sigma_n = 50\mu Jy/\mathrm{beam}$ based on initially planned $10\mu Jy/\mathrm{beam}$ .sensitivity.

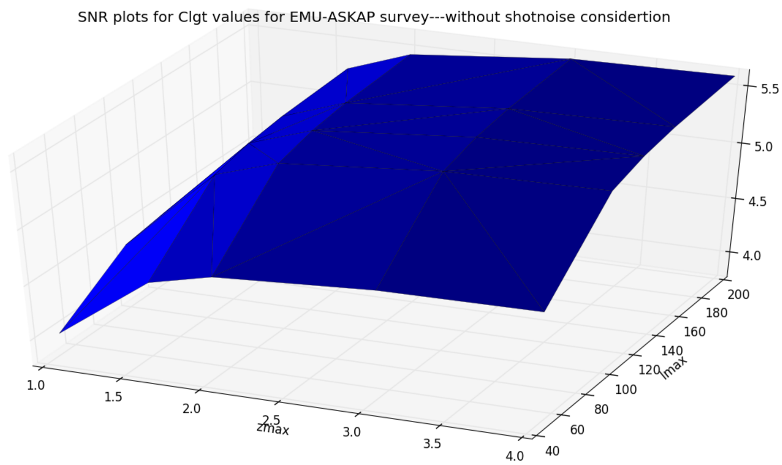
Error bars for the ‘Cl’ values can be calculated as:

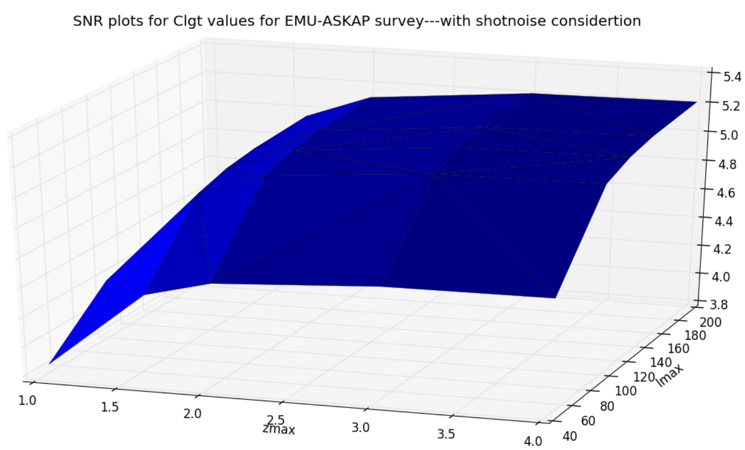
$$\Delta Cl^{gt} = \sqrt{\frac{((Cl^{gg} + Shot - Noise\ )Cl^{tt} + (Cl^{gt}\ )^2)}{(2l+1\ )fsky}}$$

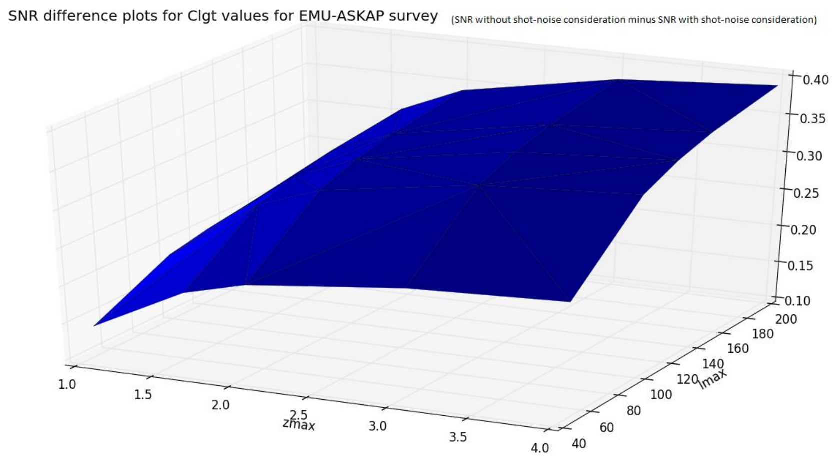
Here, Clgg is the galaxy-galaxy auto-correlation angular power spectrum, Cltt is the total CMB power spectrum, ‘l’ is the multipole value for the coefficient ‘Cl’ is being calculated and fsky is the ratio of the sky covered in the study.

The signal to noise ratio (SNR) can now finally be calculated as:

$$(SNR)^2 = \sum_l \left(\frac{Cl^{gt}}{\Delta Cl^{gt}}\right)^2$$



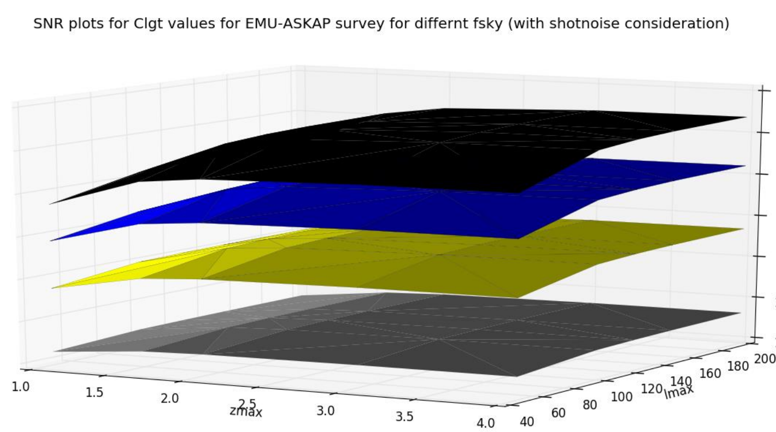




We now check effect of sky coverage using

fsky=0.05 (grey),fsky=0.25(yellow),fsky=0.5(blue),fsky=0.75(black)

Sky coverage is not only related to observed area but it is also affected by mapping issues, removing foreground contaminations, removing bad coverage areas etc.



EMU-INVESTIGATING THE CMB COLD SPOT

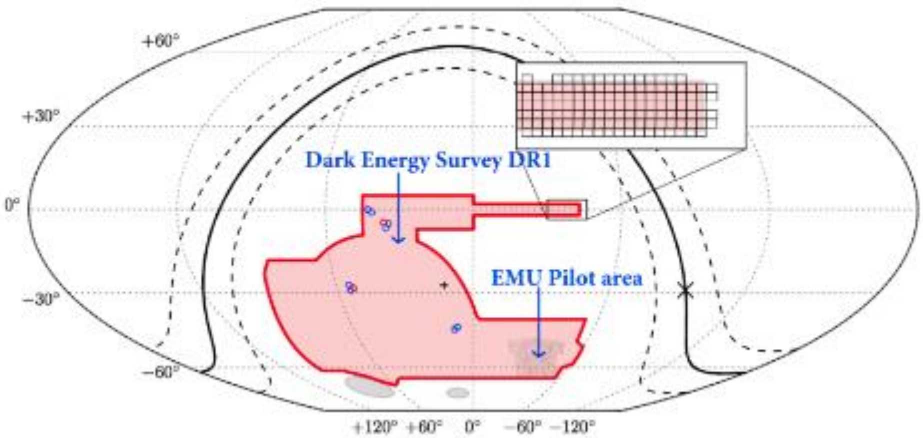
- Another interesting phenomenon related to the cosmic microwave background (CMB) is the presence of a cold spot.
- CMB Cold Spot is an unusually cold region on CMB maps observed by both WMAP and Planck. This area temperature deviates from average temp by >70 micro K.
- The area is located at RA 03h 15m 05s, DEC −19° 35′ 02″.
- With EMU-ASKAP's unprecedented depth and high resolution, we are planning to investigate this region.
- We will use EMU data to investigate if unusual source clustering, source properties or any other unusual phenomenon is causing this region to have an unusually low temperature.
- We will also use data from other surveys like NVSS, 2MASS, WISE,2CSz and other surveys to explore this region.
- We would also like to check its influence on cosmological parameter fitting particularly in relation with curvature and Hubble Constant problems.
- Getting redshift information and classification will be important (EMU has teams working on these. Their work will be helpful)
- We can test a lot of things using the cold spot area and compare results with other areas (ACF,CCF,redshift distributions,galaxy bias evolution,power laws for integral and differential counts etc.)

Some of the things we are planning to test are:

- Integrated Sachs Wolfe Effect : EMU Cosmology group is working for the whole survey area and we can use this to dig into the cold spot problem.
- Unusual clustering, masses, absence or lower than usual presence of dark matter and bias evolution in the CMB cold spot region galaxies (Related to both Auto and Cross correlations)
- Cosmological modeling: Flat-Lambda CDM, dynamic dark energy EoS, curvature issue and alternates to standard cosmological model etc.We can compare measurements from the CMB cold spot with other regions and see if there are deviations and then look for possible reasons.
- Unusual structures: Possible features similar to "Great Attractor" or “Dipole Repeller” or “South Pole Wall” or something else and how?
- Unusual power law fits (Integral and differential)
- Deviations from isotropy
- More exotic explanations

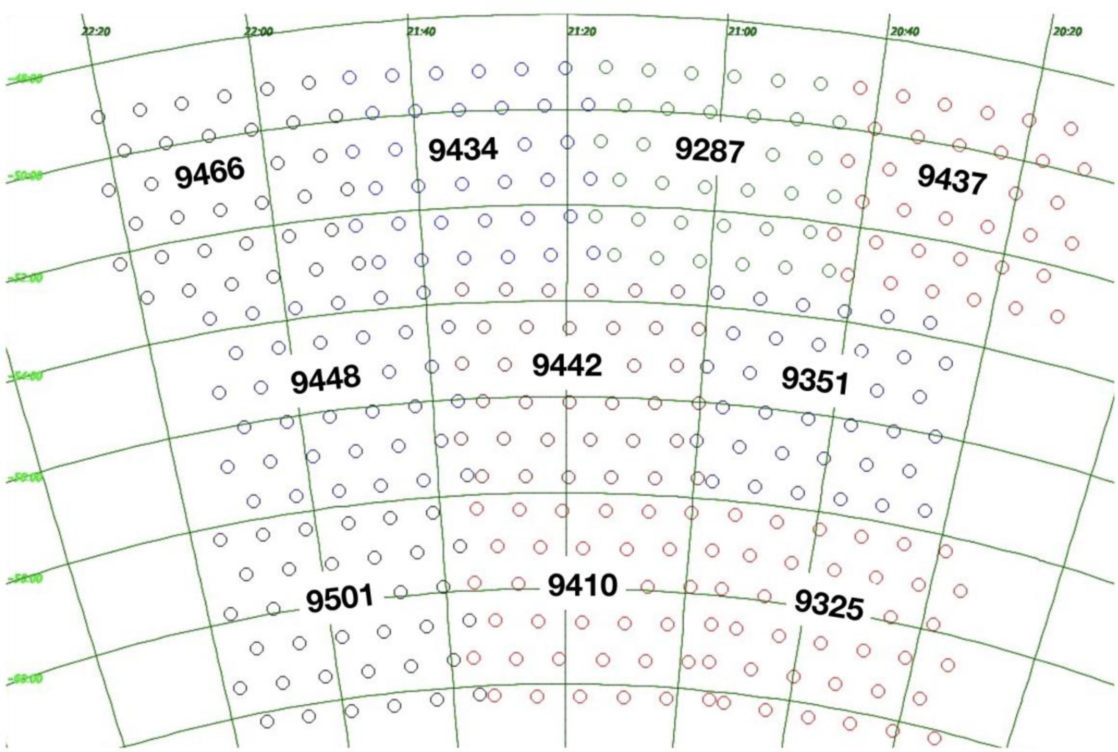
EMU PILOT

http://askap.pbworks.com/w/page/127907082/PilotSurvey



The EMU pilot survey covers about 270 square degrees down to an rms of about 25 uJy/beam.

The survey is divided into 10 fields.

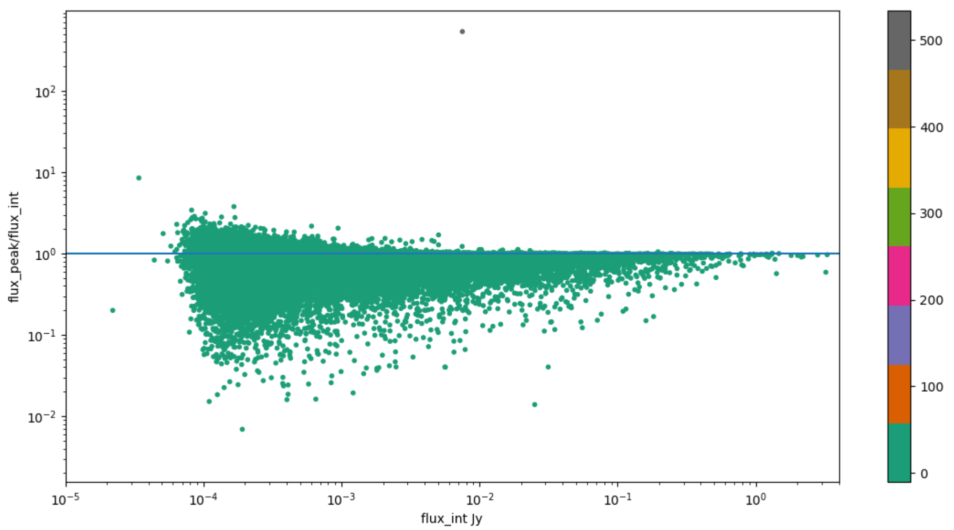


Total sources observed were around 200000. There were two catalogues generated.

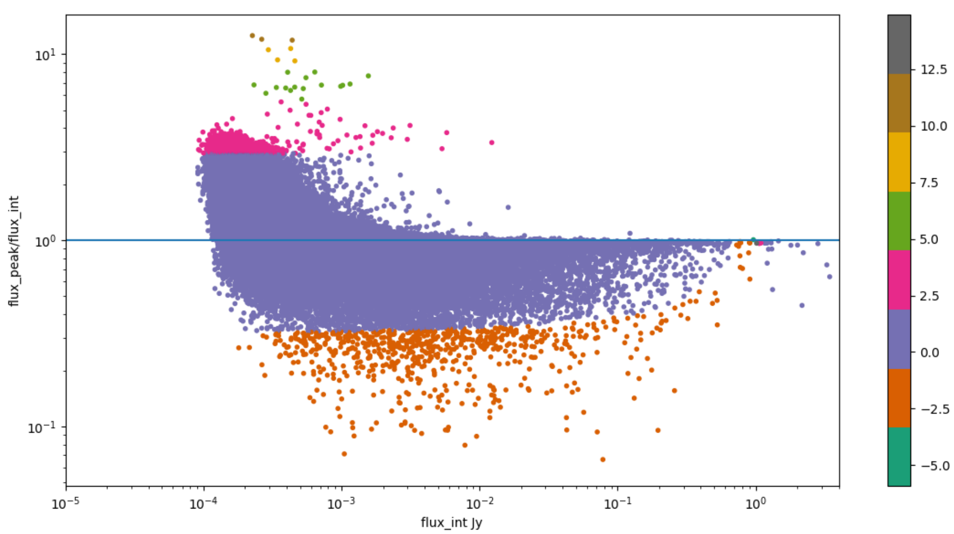
1) Components
2) Islands

To check if the catalogued fluxes make sense, we can apply different criteria.

he distribution of peak to integrated flux density ratio as a function of integrated flux density for pilot survey 10 fields using component catalog.
Color bar indicating (flux_peak/flux_int)-(1.0-(0.1/(np.log10(flux_peak))))



The distribution of peak to integrated flux density ratio as a function of integrated flux density for pilot survey 10 fields using island catalog.
Color bar indicating (flux_peak/flux_int)-(1.0-(0.1/(np.log10(flux_peak))))



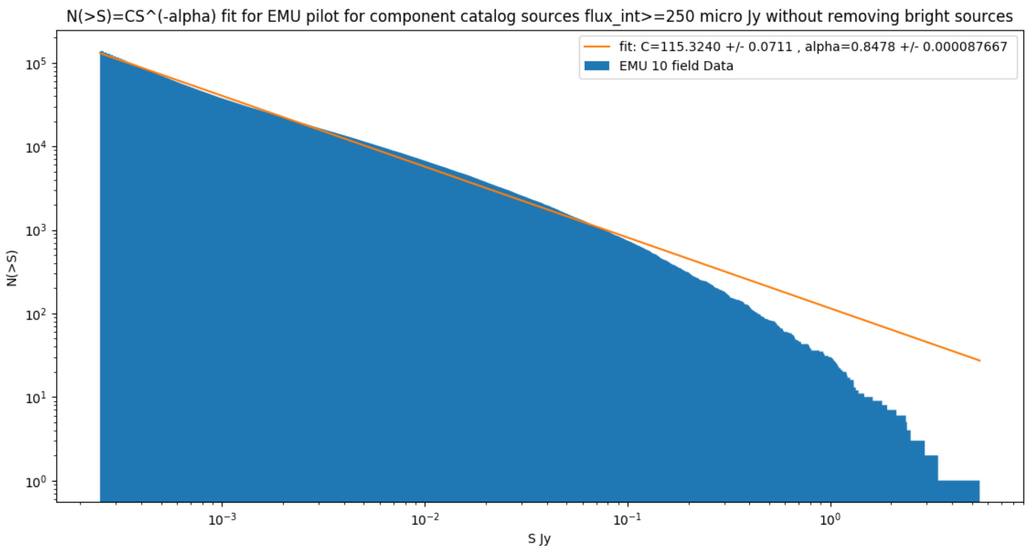
INTEGRAL SOURCE COUNTS RESULTS:

We can also observe a downward slope of the integral source counts with respect to the minimum flux. This can be quantified using the relation:

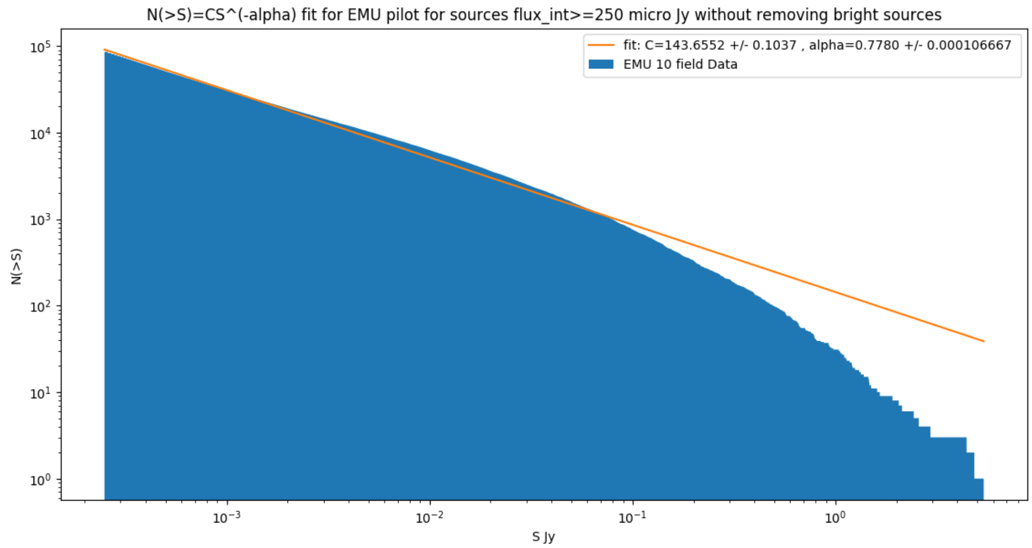
$N(S)=CS^{-\alpha}$

α plays an important part in accounting for the magnification bias in the galaxy window functions which affect both auto-correlations and cross-correlations (as in ISW).

Components catalog:



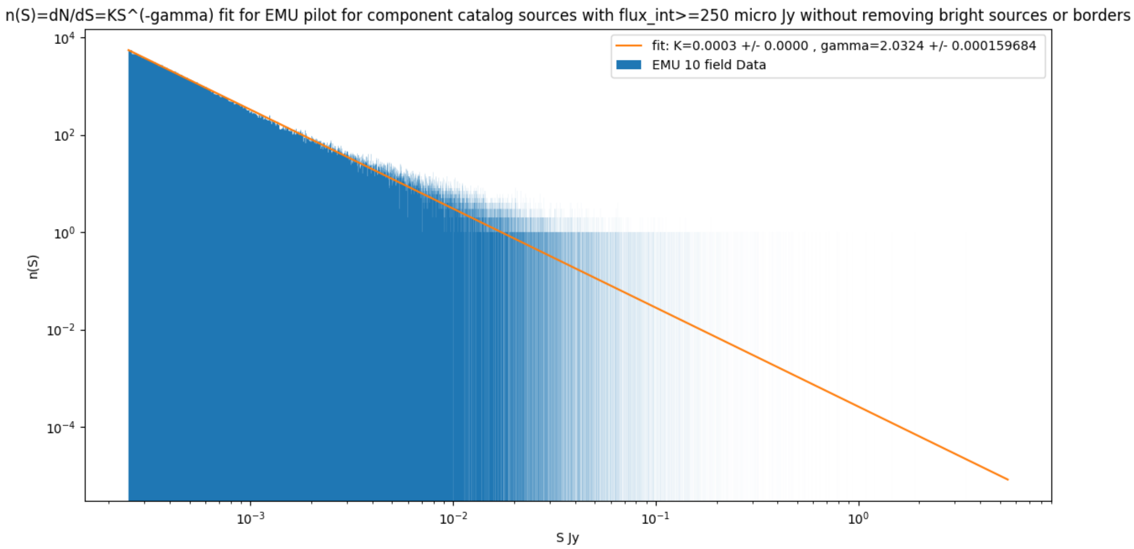
Islands catalog:

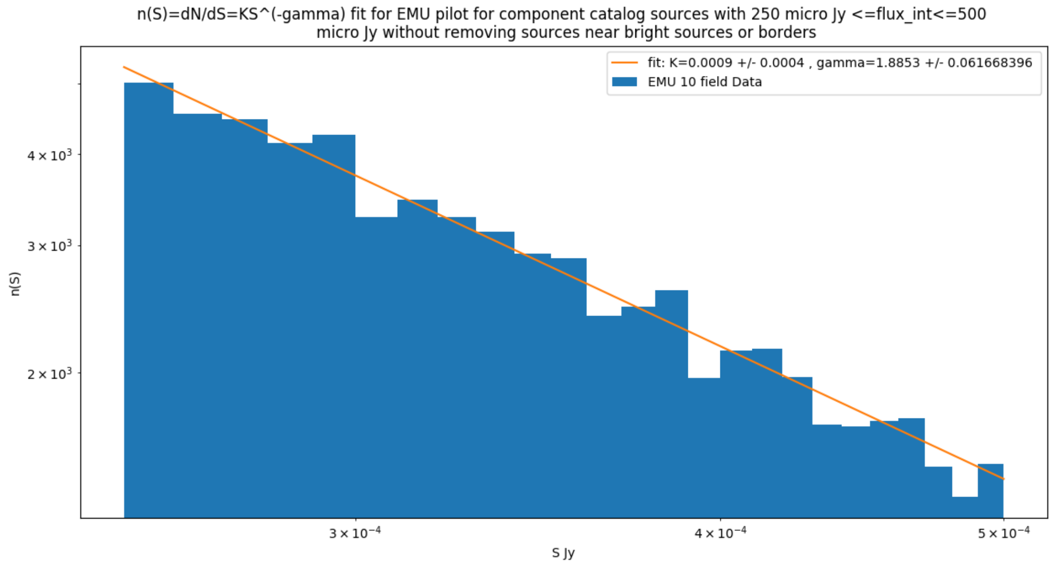


DIFFERENTIAL COUNTS RESULTS:

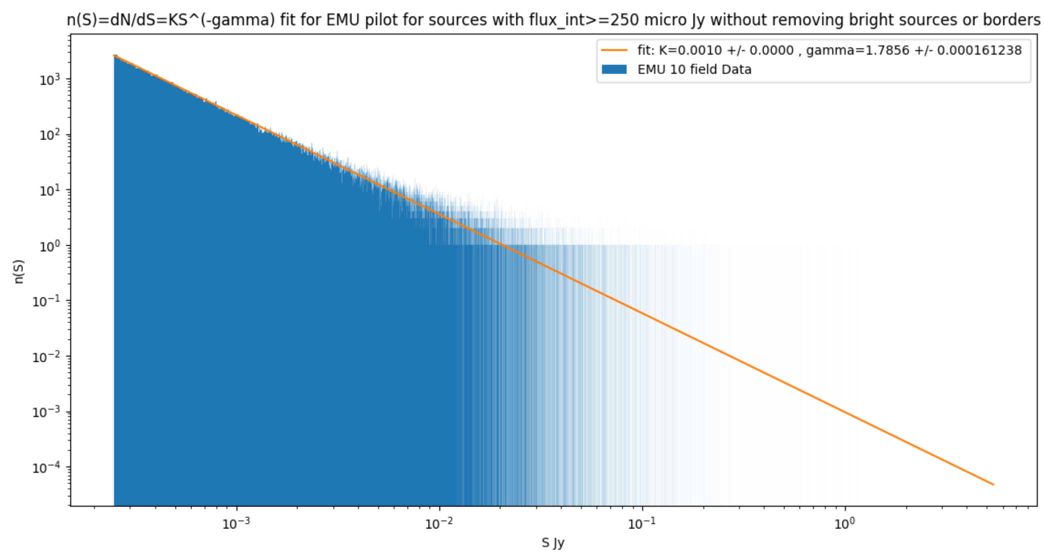
Differential counts help in estimating things like confusion and also help in understanding galaxy clustering.

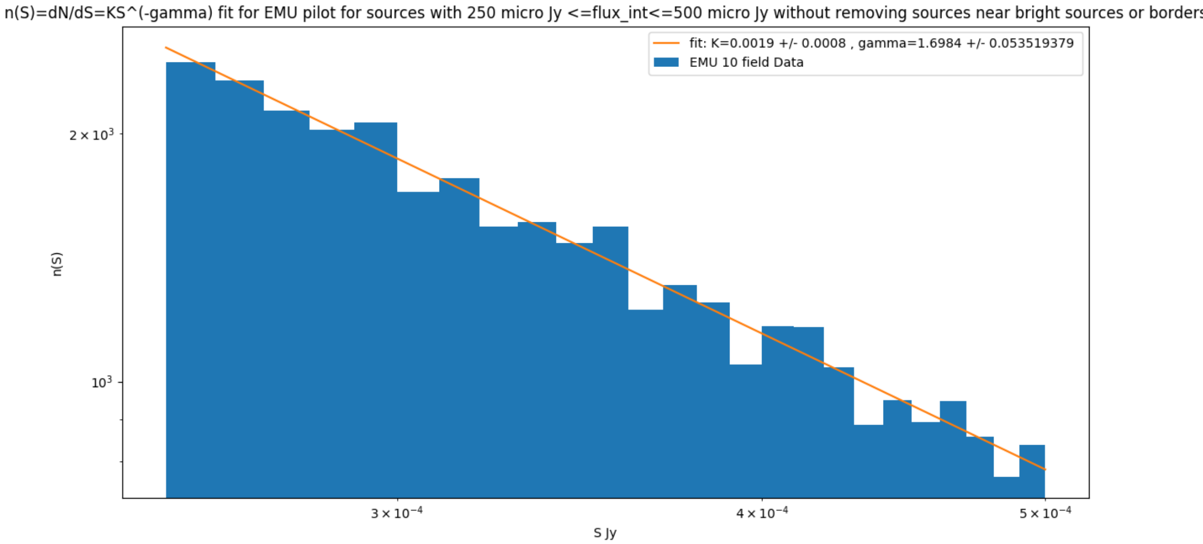
Components




n(S)=dN/dS=KS^(-gamma) fit for EMU pilot for component catalog sources with 250 micro Jy <=flux_int<=500 micro Jy without removing sources near bright sources or borders
fit: K=0.0009 +/- 0.0004 , gamma=1.8853 +/- 0.061668396
EMU 10 field Data
n(S)
S Jy
4 × 10^3
3 × 10^3
2 × 10^3
3 × 10^-4
4 × 10^-4
5 × 10^-4

Islands:

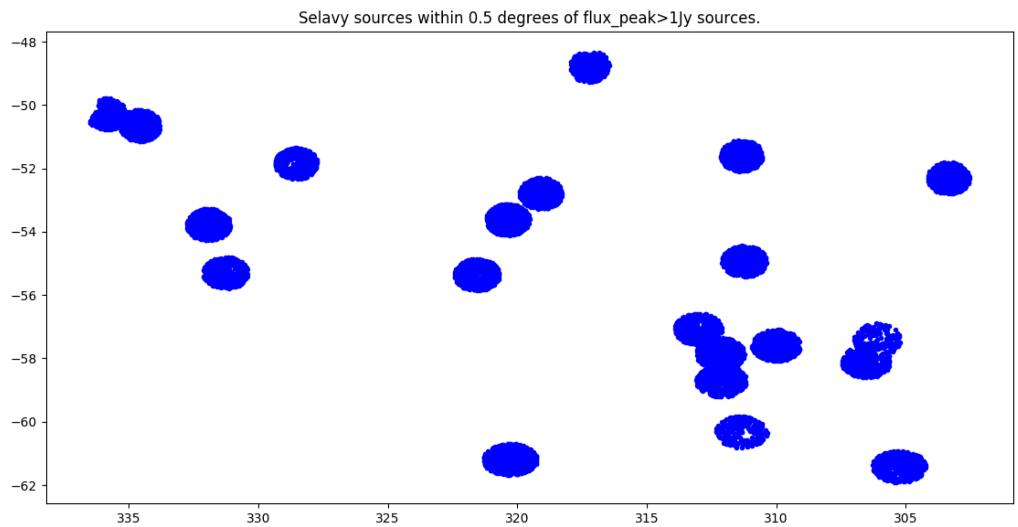

n(S)=dN/dS=KS^(-gamma) fit for EMU pilot for sources with flux_int>=250 micro Jy without removing bright sources or borders
fit: K=0.0010 +/- 0.0000 , gamma=1.7856 +/- 0.000161238
EMU 10 field Data
n(S)
S Jy
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-3
10^-2
10^-1
10^0



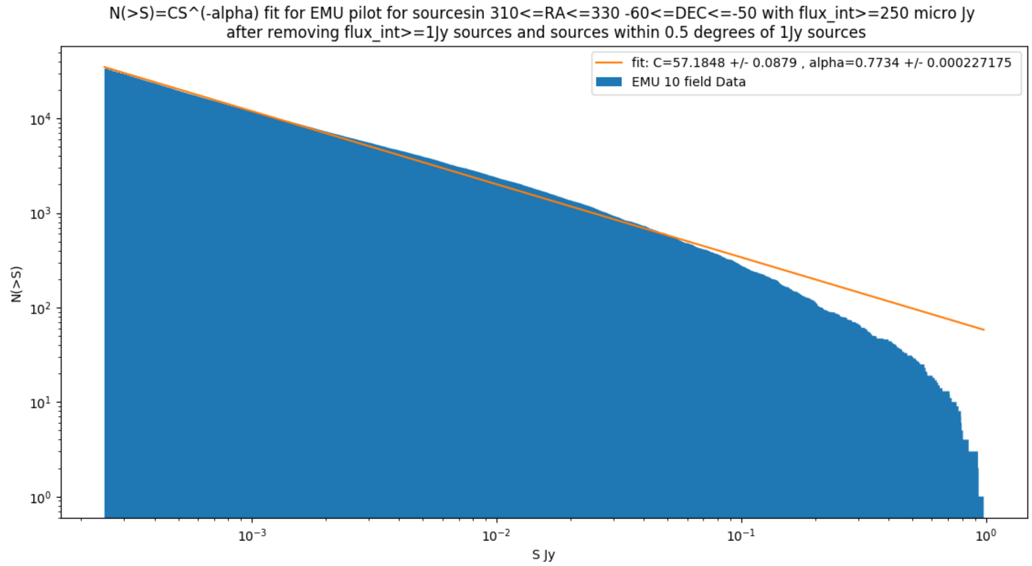
- There is a slight difference in slopes from components and island catalogues.
- Component catalogue has relatively steeper slopes which is likely due to the island absorbing one or more components and merging them into a single source.
- However this means it can not only merge a single source with multiple components but also multiple nearby sources as one island source.
- This is a big challenge of highly sensitive 2D surveys.
- EMU is developing another catalog EMUCAT which will provide more valuable details like redshift, cross-matching,

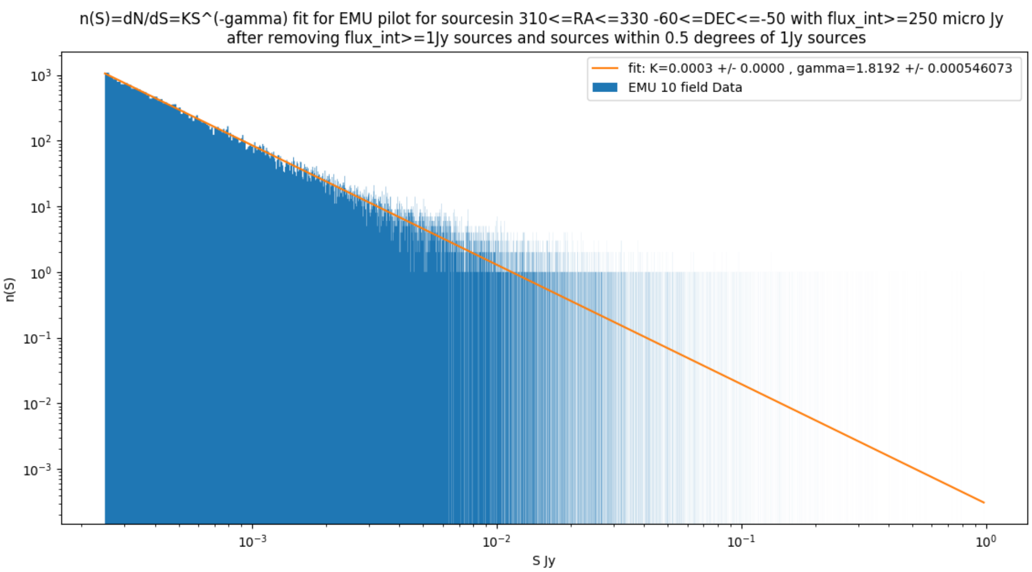
classifications etc by analyzing other catalogues and survey images. It will also benefit from new pattern recognition and machine learning algorithms. This will be really helpful in not only resolving issues between components and island catalogues but will also help in greatly understanding redshift distributions and galaxy bias.

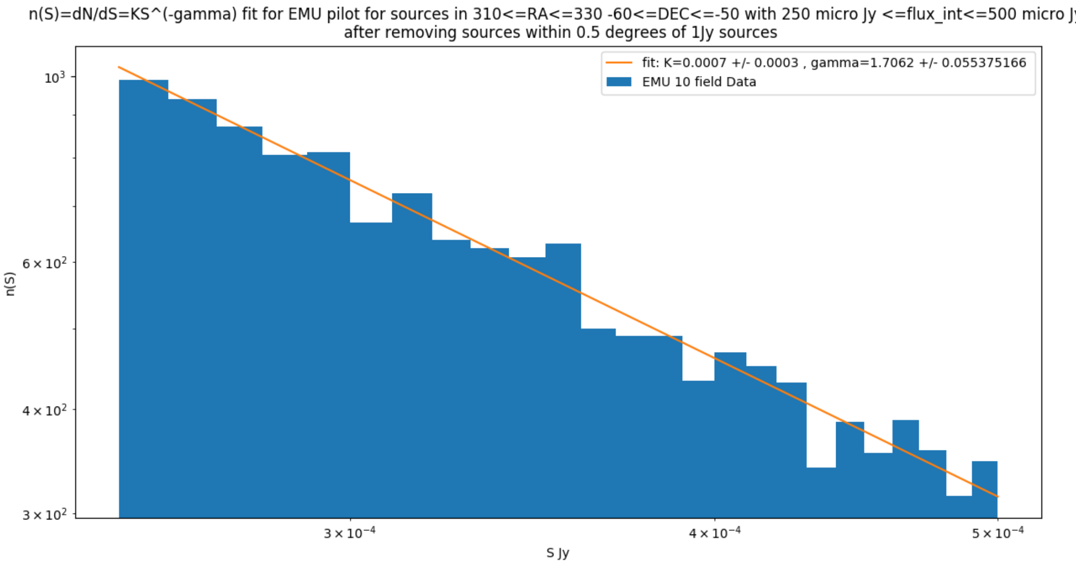
BRIGHT SOURCES EFFECT:



Not much effect of removing border areas with relatively higher rms and bright sources but more investigation may be needed.

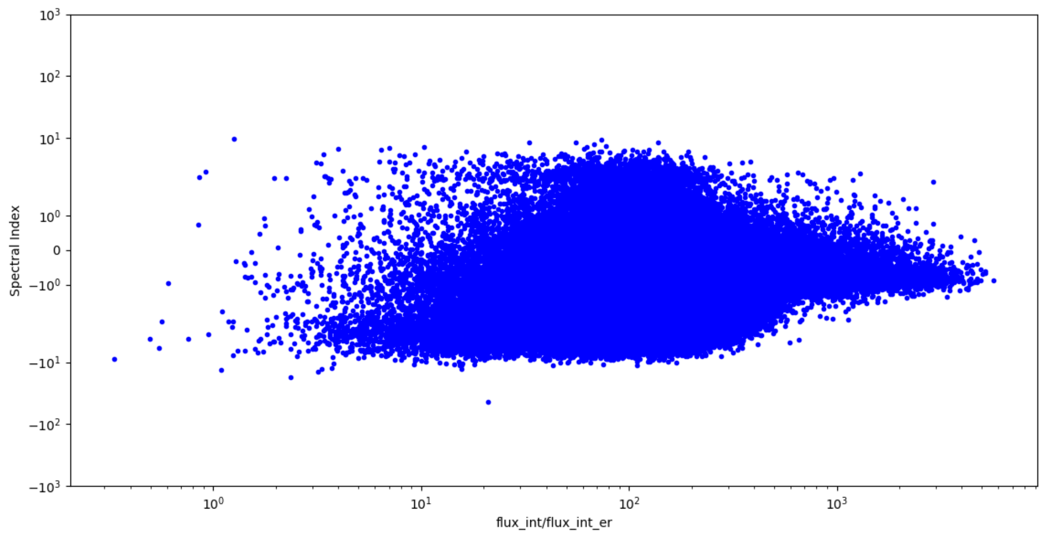

N(>S)=CS^(-alpha) fit for EMU pilot for sourcesin 310<=RA<=330 -60<=DEC<=-50 with flux_int>=250 micro Jy
after removing flux_int>=1Jy sources and sources within 0.5 degrees of 1Jy sources
fit: C=57.1848 +/- 0.0879 , alpha=0.7734 +/- 0.000227175
EMU 10 field Data
N(>S)
S Jy

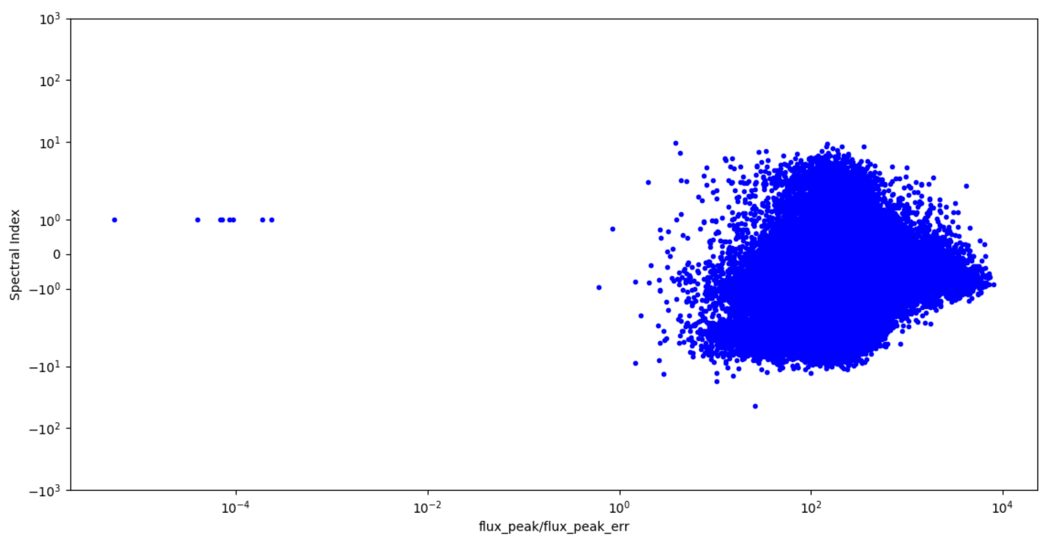

n(S)=dN/dS=KS^(-gamma) fit for EMU pilot for sourcesin 310<=RA<=330 -60<=DEC<=-50 with flux_int>=250 micro Jy
after removing flux_int>=1Jy sources and sources within 0.5 degrees of 1Jy sources
fit: K=0.0003 +/- 0.0000 , gamma=1.8192 +/- 0.000546073
EMU 10 field Data
n(S)
S Jy

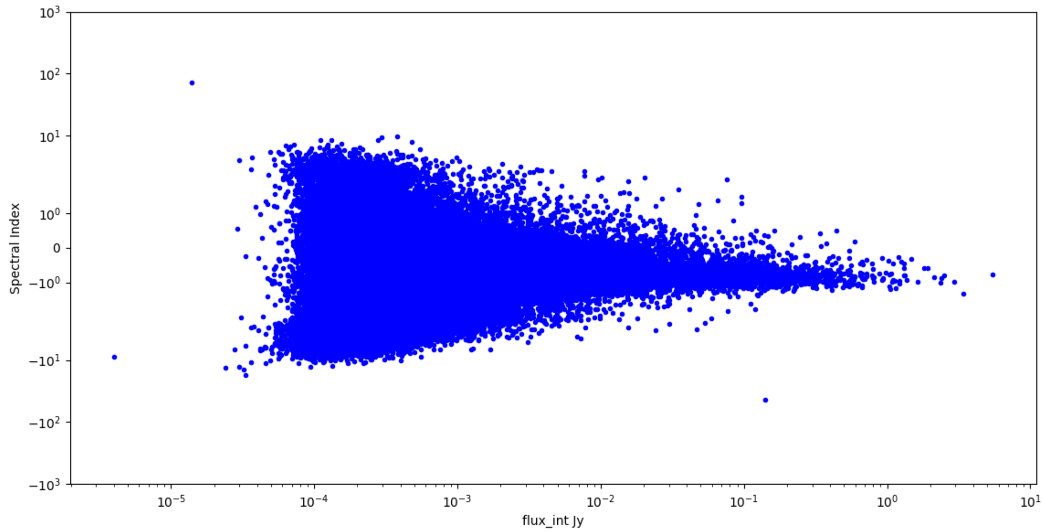

n(S)=dN/dS=KS^(-gamma) fit for EMU pilot for sources in 310<=RA<=330 -60<=DEC<=-50 with 250 micro Jy <=flux_int<=500 micro Jy
after removing sources within 0.5 degrees of 1Jy sources
fit: K=0.0007 +/- 0.0003 , gamma=1.7062 +/- 0.055375166
EMU 10 field Data
n(S)
S Jy
10^3
6×10^2
4×10^2
3×10^2
3×10^{-4}
4×10^{-4}
5×10^{-4}

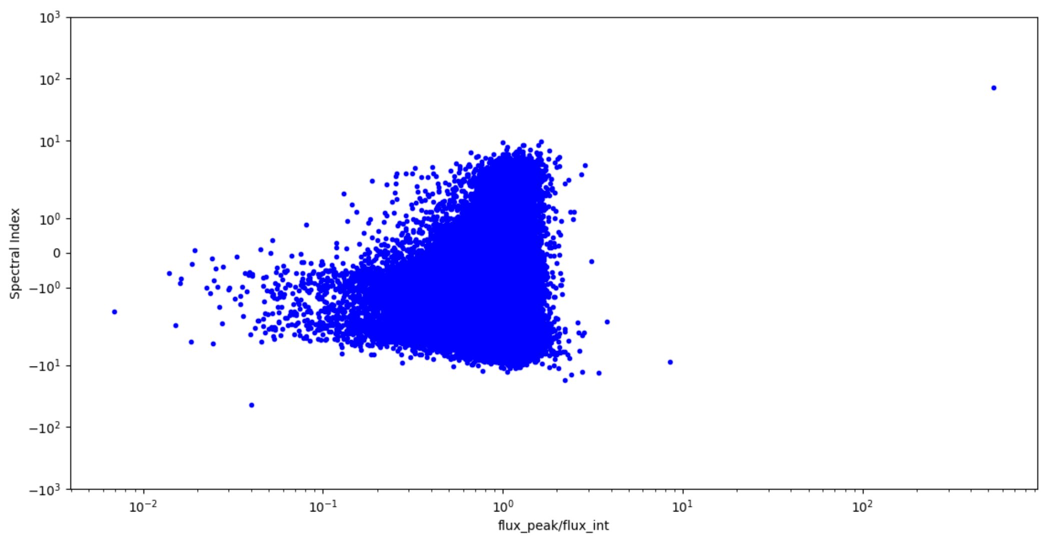
Spectral Indices

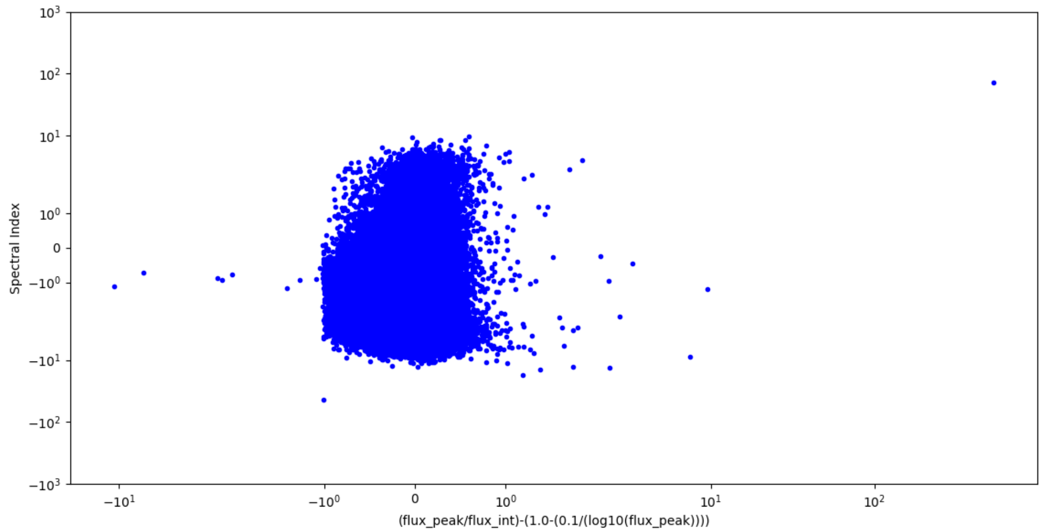
(May 2020 EMU-Pilot components catalog)






Spectral Index
flux_int Jy


Spectral Index
flux_peak/flux_int



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