Extragalactic Survey Key Science Project

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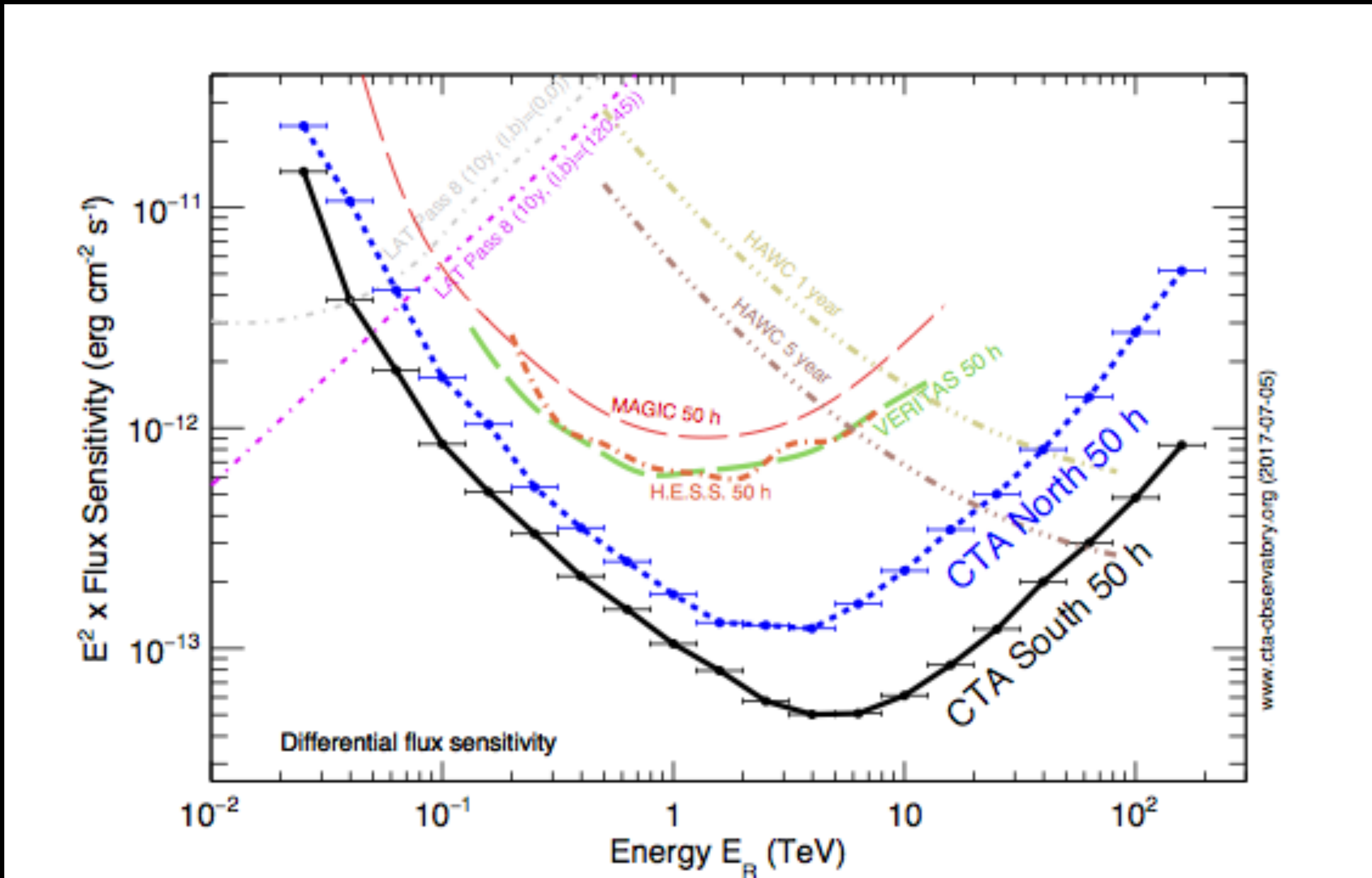
Sexten 2017 Gamma-ray Astrophysics with CTA

CTA has a survey capability



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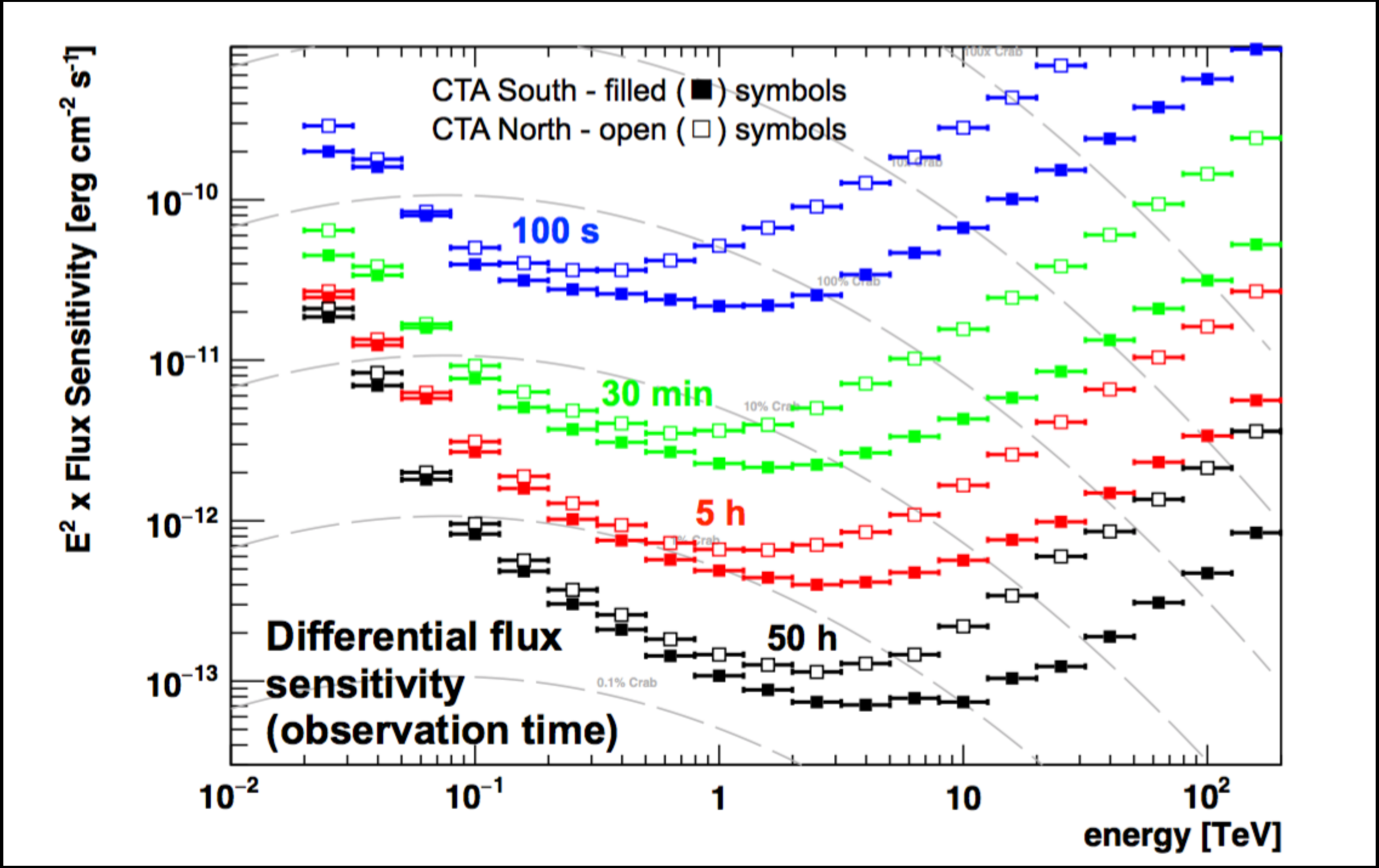


Key Science Questions

- What is the Gamma-Ray Luminosity Function?
- Does the blazar sequence (the synchrotron and inverse Compton (IC) peak photon energies decrease as the bolometric luminosity increases) hold?
- Is there a strong population of hard spectra extreme blazars?
- Are there VHE source classes other than blazars and radio galaxies?
- Are there dark accelerators?
- Is there a correlation with UHECR and HE neutrino events maps?
- What is the origin and strength of the diffuse γ-ray background?
- Large scale anisotropies (related to dark matter distribution?)

Why a KSP?

- Will answer some key questions (e.g. logN/logS)
- Legacy project for the community
- Needs long exposure (600h-1000h)
- Analysis will be more complicated than for the individual sources
- May profit from a special pointing mode: divergent mode

Extragalactic Survey Strategy

see later discussion on the number

- **1/4 of the sky: Quest for the unknown!**
- Unbiased and uniform survey of the extragalactic sky
- Serendipitous discovery of fast flaring sources
- + Added value. Preferred region should include e.g. Virgo cluster or/and Fermi Bubbles

Variability issue

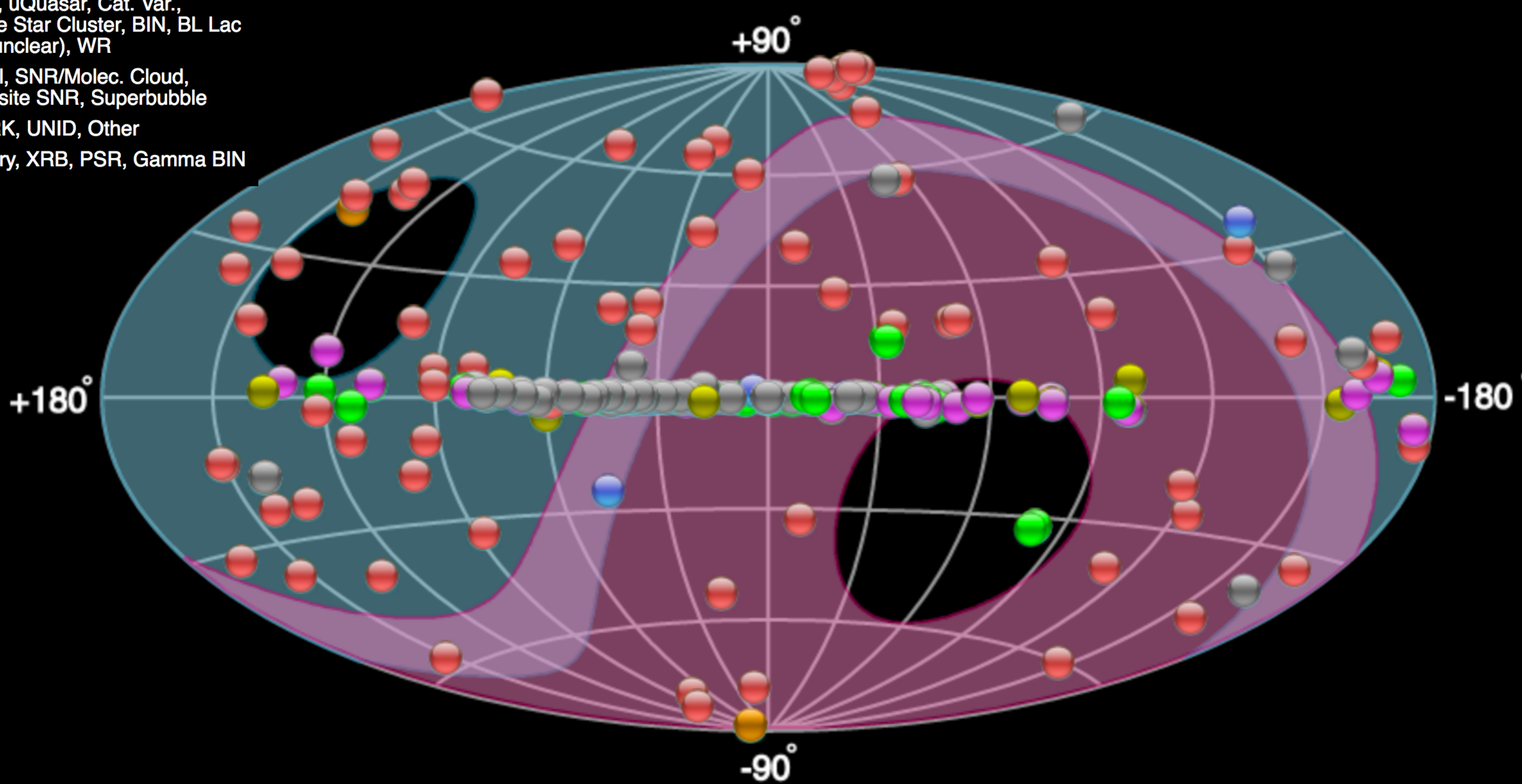
- Blazars are variable sources, especially at >100 GeV
  - flux increases by >1 order of magnitude
  - all time scales
- However, most of the time (90-95%?), blazars do not vary their VHE flux by more than a factor of 2
- <1% of the time blazars spend in flux states 5-10 times higher than the quiescent one
- Therefore, the survey will detect sources mostly (90-95%?) in quiescent or close to quiescent states

Preliminary numbers from Elina and Jonathan (Fermi/LAT data)

Current TeV catalog

- around 60 extragalactic sources
- most of them detected in flaring state

PWN
Starburst
HBL, IBL, FRI, Blazar, FSRQ, LBL, AGN (unknown type)
Globular Cluster, Star Forming Region, uQuasar, Cat. Var., Massive Star Cluster, BIN, BL Lac (class unclear), WR
Shell, SNR/Molec. Cloud, Composite SNR, Superbubble
DARK, UNID, Other
Binary, XRB, PSR, Gamma BIN

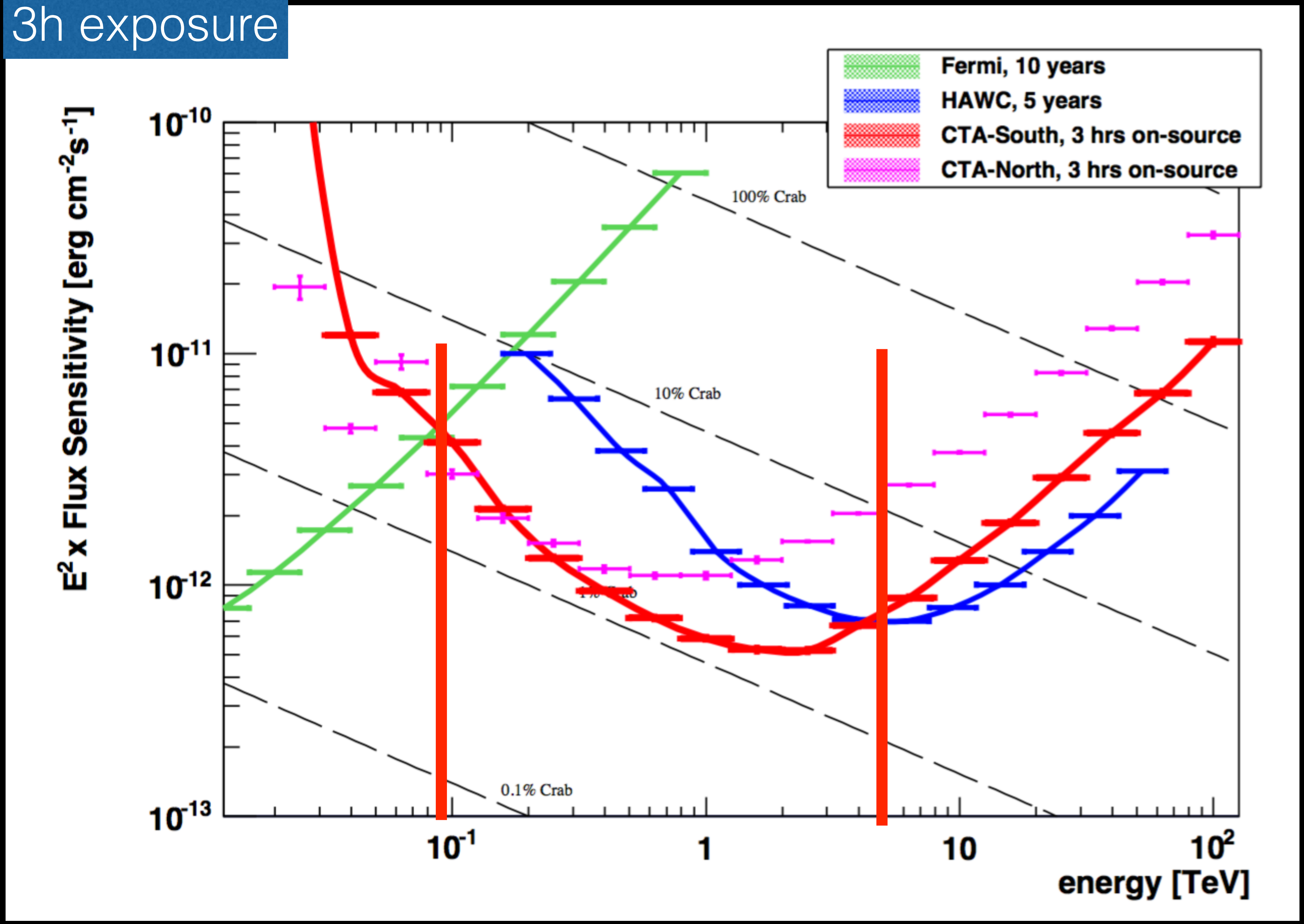


Survey Optimization

- Need to optimize between:
  - time spent
  - depth (in sensitivity) of the survey
  - area of the survey
  - divergent pointing? (is better for transients!)

Sensitivities

3h exposure



- If we aim for 1/4 sky, effective exposures of 2-3 hrs are feasible. On-source sensitivities for 3 h are shown above

Why 25%?

- We estimate that so far some 150 extragalactic FoV have been observed with HESS+MAGIC+VERITAS:
  - using radius of $r=2^{o}$ we obtain 5% of the sky (of course very non uniform)
- We estimate that with CTA we'll have some 70 extragalactic FoV in first few years
  - using radius of $r=3^{o}$ we obtain 5% of the sky (of course very non uniform)
- Seems that anything above 10% of the sky and above is a big step forward
- Obvious: Exposure vs Area: 2 times less area gives 1.4 better sensitivity for the same survey time

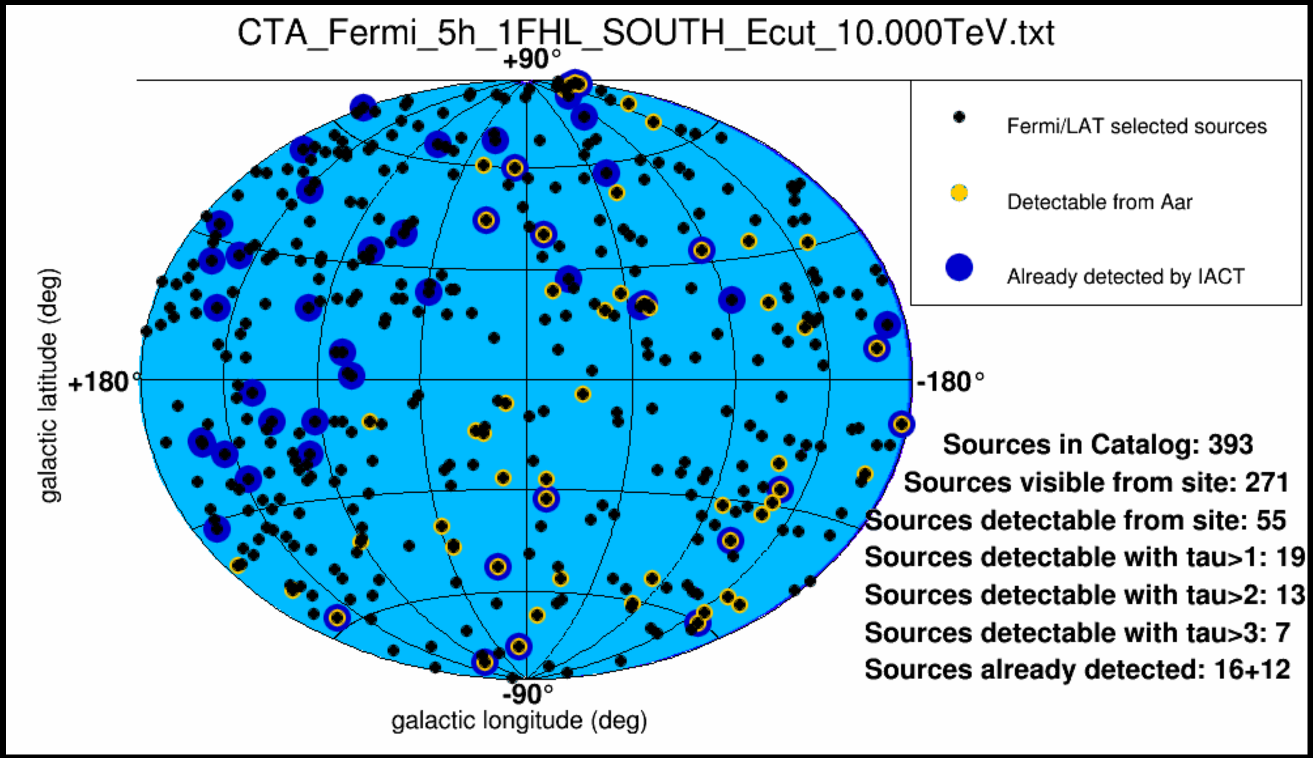
Expectations from known source classes

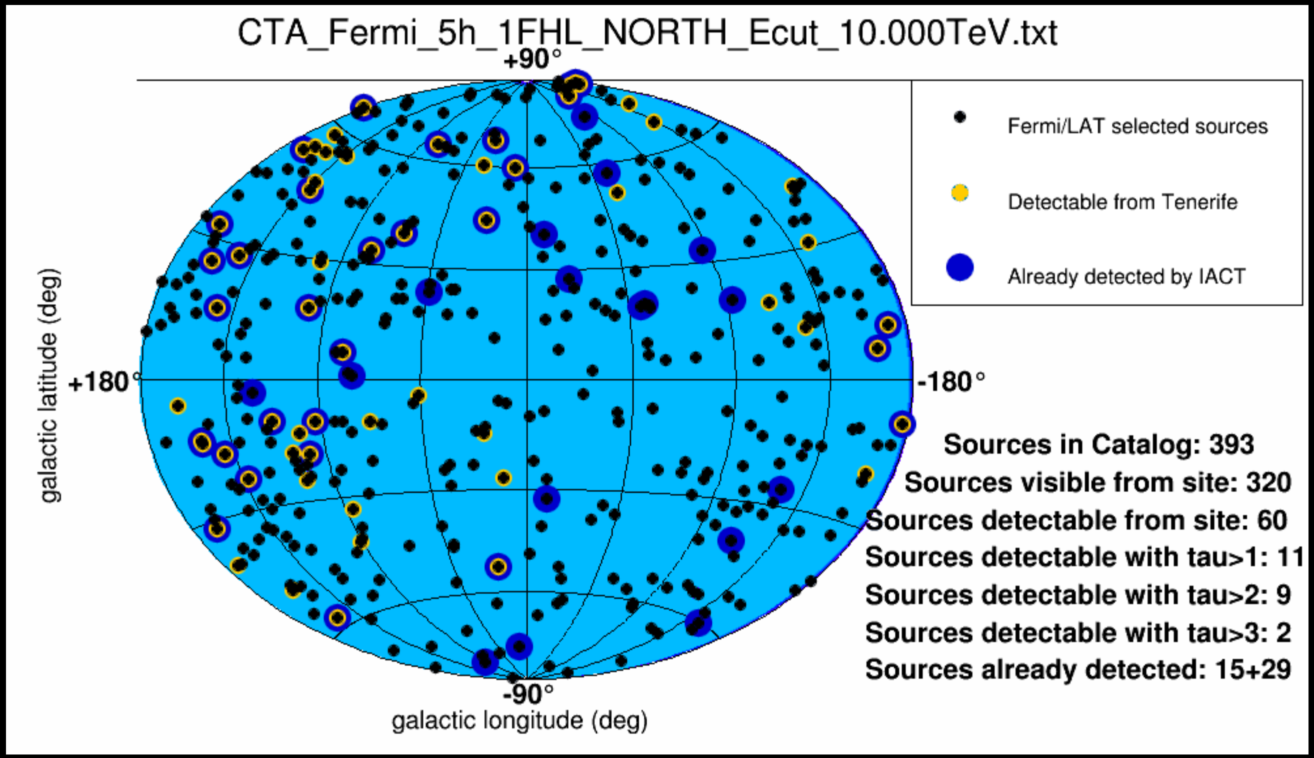
- Use Fermi/LAT (1FHL) to extrapolate into the CTA regime

5h exposure

South: 55 sources

North: 60 sources





using CTA macros

- differences in site configurations are taken into account
- For 1/4 of the sky this means around 25-35 sources

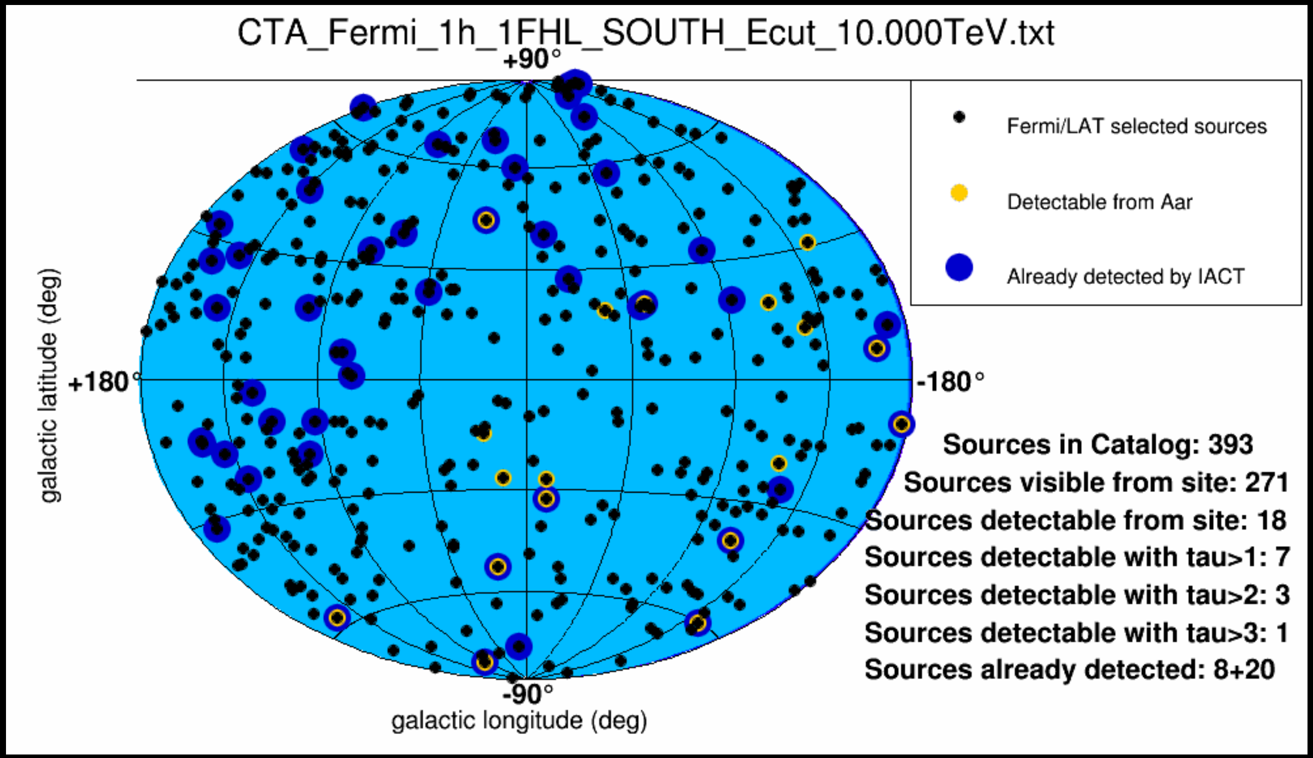
Expectations from known source classes

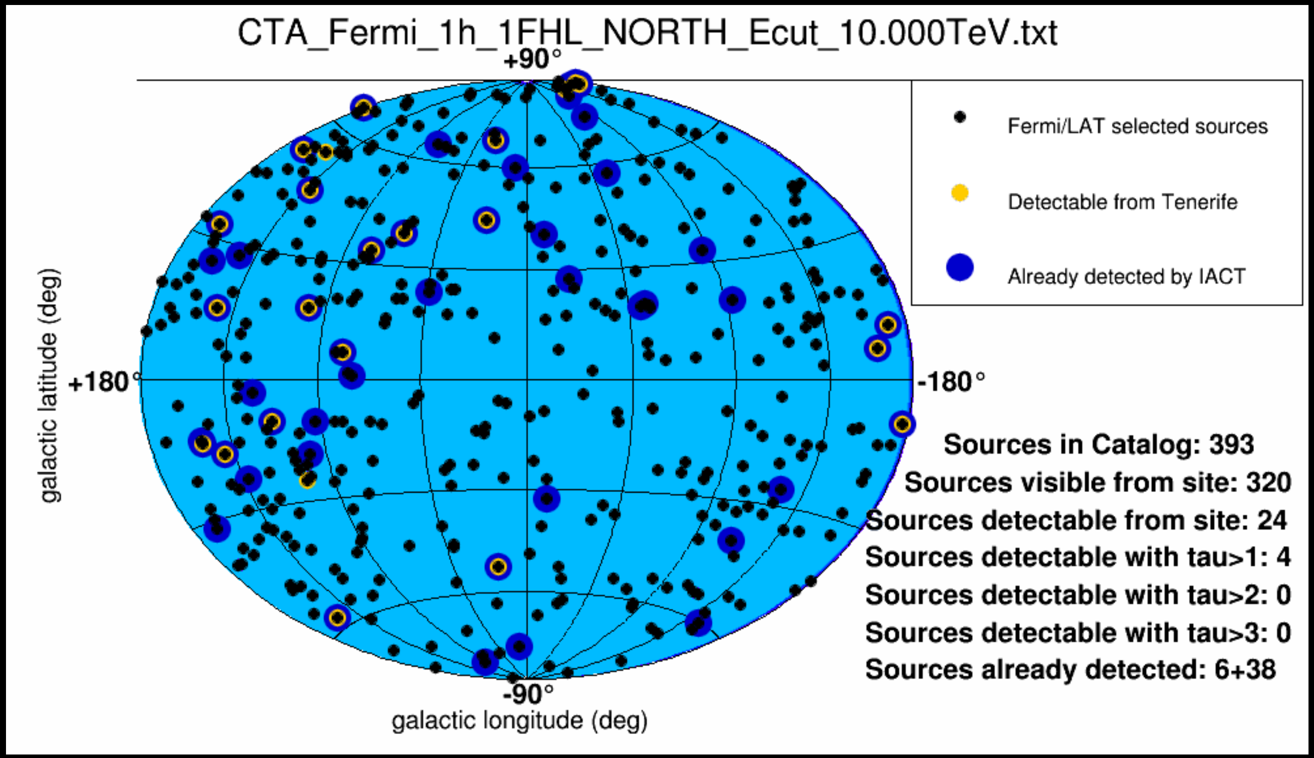
- Use Fermi/LAT (1FHL) to extrapolate into the CTA regime

1h exposure

South: 18 sources

North: 24 sources

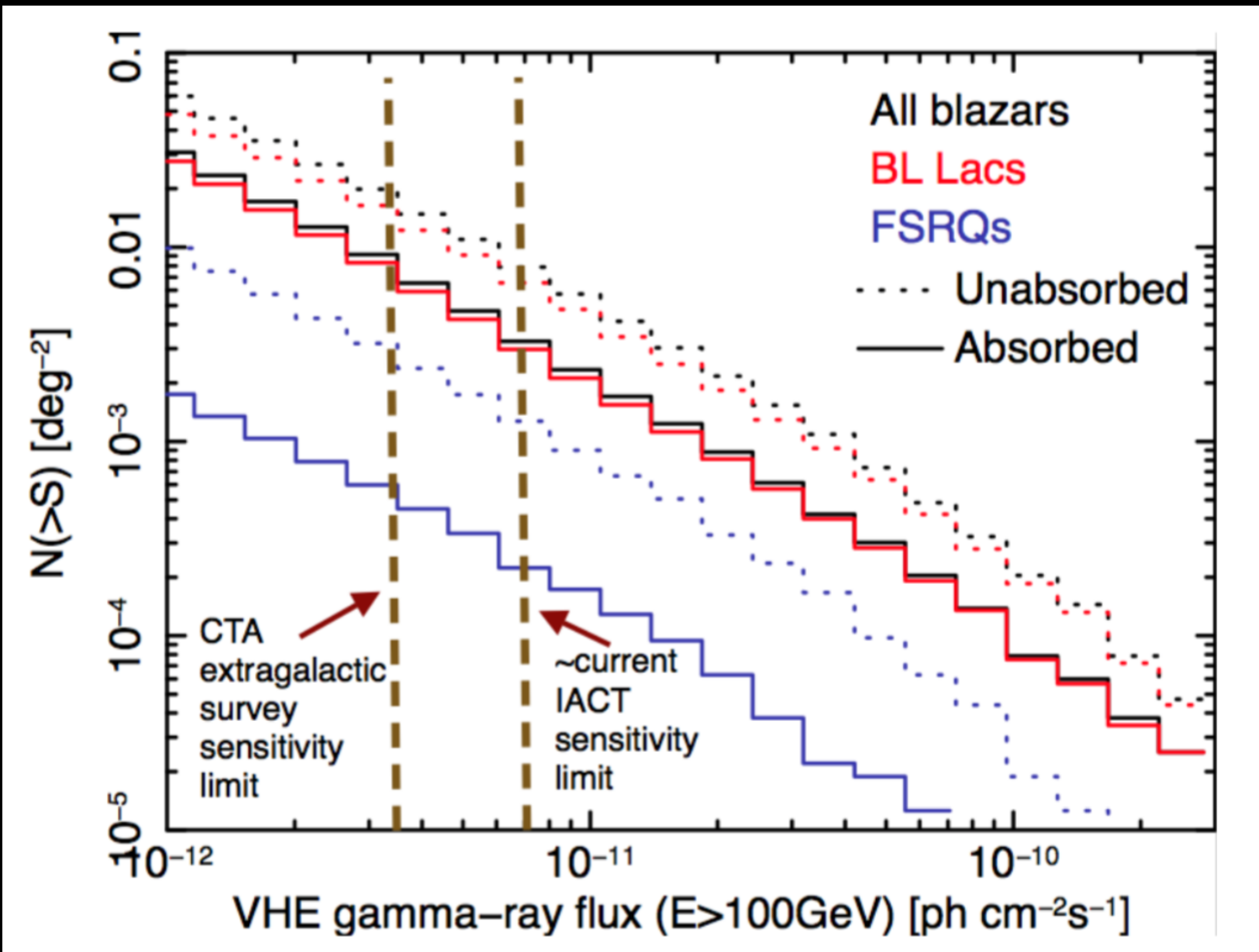


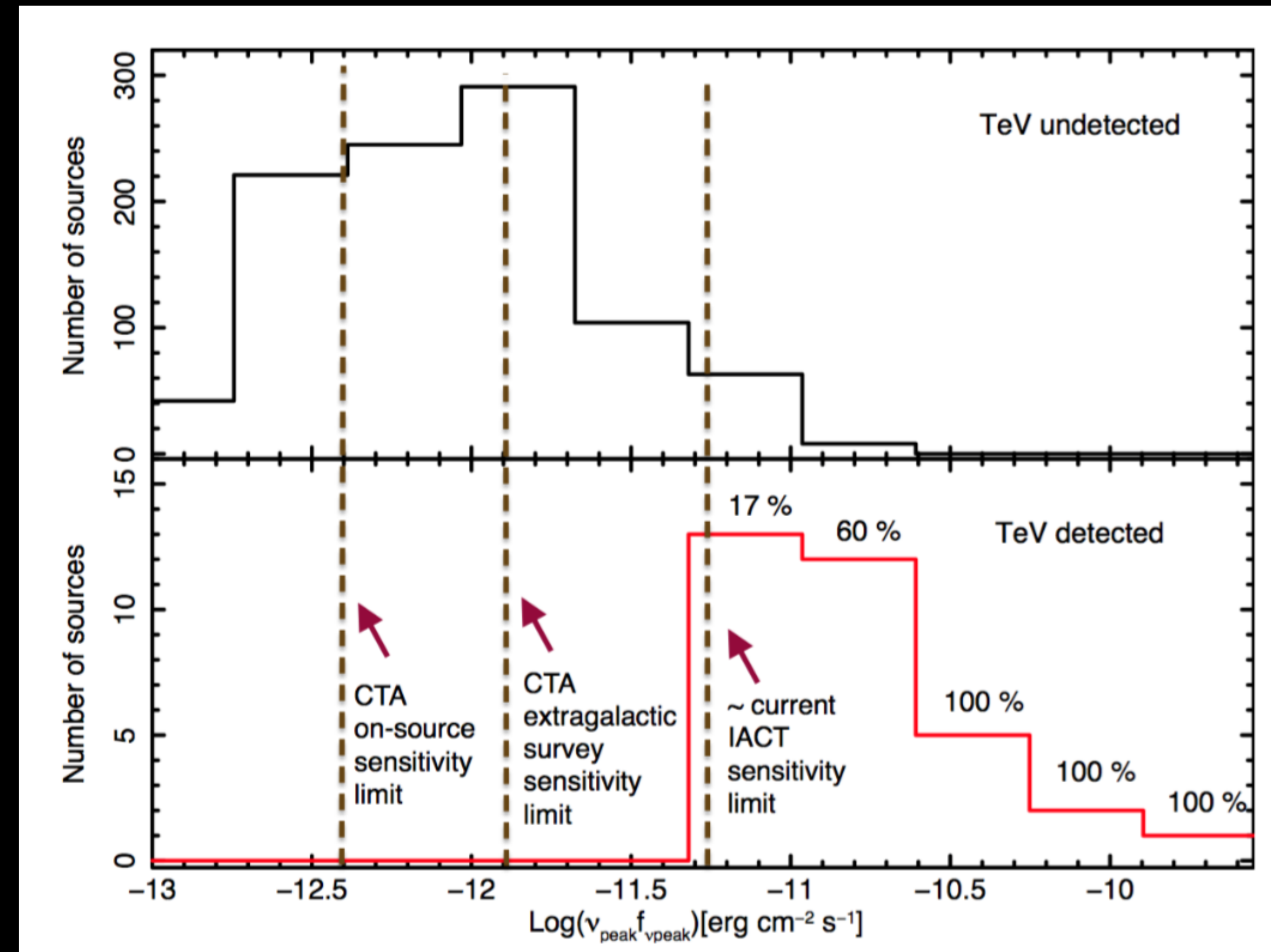


using CTA macros

- differences in site configurations are taken into account
- For 1/4 of the sky this means around 8-12 sources

Source number predictions



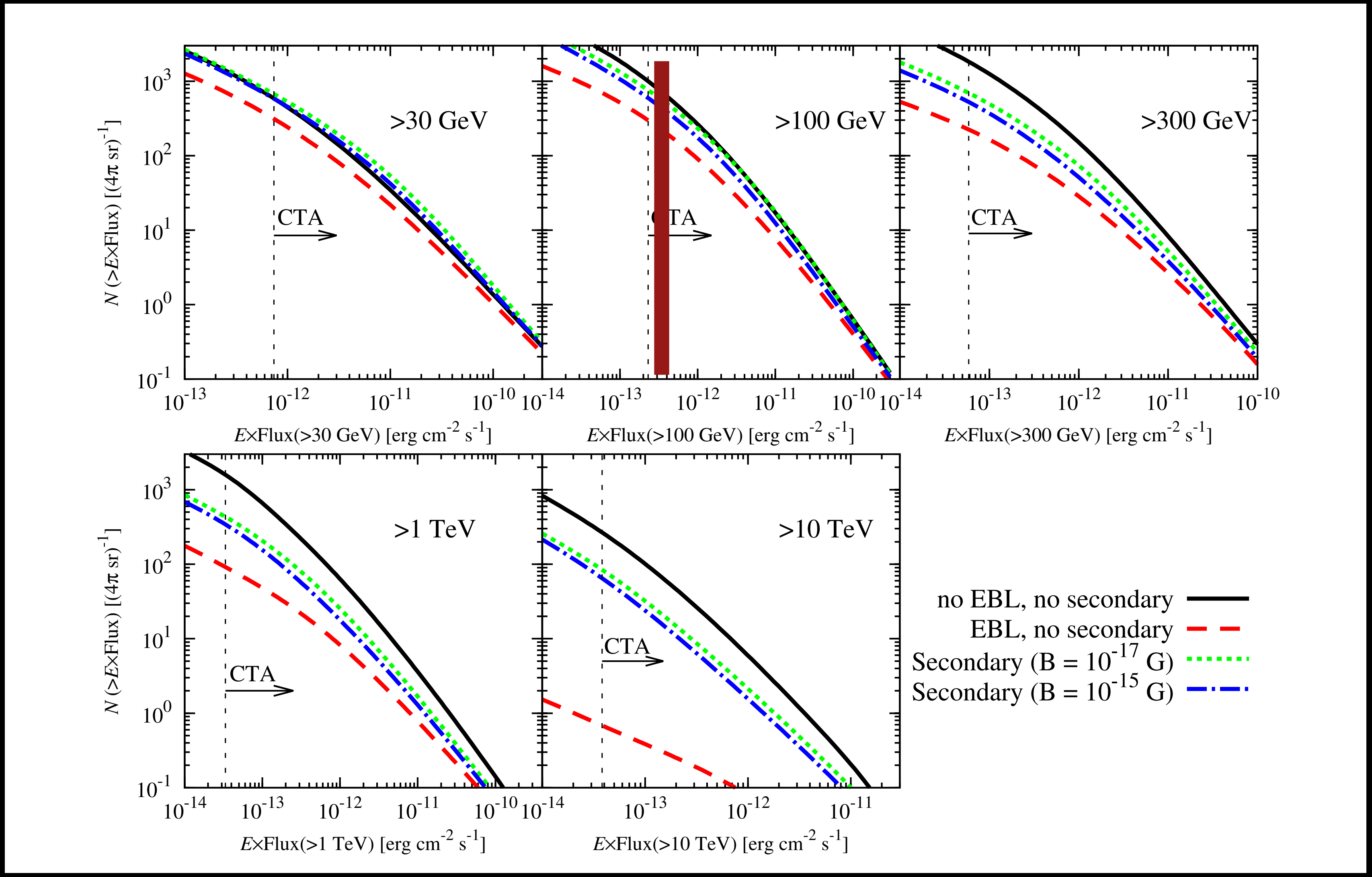


- Arsioli B., Fraga B., Giommi P. Padovani P., & Marrese, P.M., A&A 579 (2017) 34
- Expected source counts as a function of the integral gamma-ray flux above 100 GeV in 27,000 deg2
- scaled down to 1/4 of the sky: 77 source
- Incompleteness of the survey (conservative criteria), factor 2 larger: **~150**

- Padovani P. & Giommi P. (2015). A simplified view of blazars: the very high energy γ-ray vision. MNRAS, 446, L41
- Simulated log N - log S distribution. The dashed (solid) lines represent the expected distributions without (with) taking into account the absorption by the EBL. According to this study, with the 6 mCrab sensitivity during the proposed survey CTA should detect around 100 sources in 10,000 deg2.

Y. Inoue et al.

- EGRET + X-rays + UHECRs



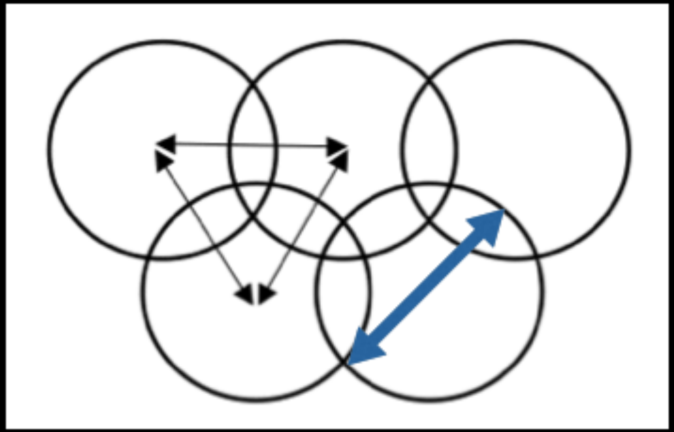
- May expect 200-300 sources in the full sky with 2h exposure per FoV: 50-75 sources in 1/4 of the sky

Survey strategy

- preliminary result of the optimization:
  - time spent: ~1000h
  - depth (in sensitivity) of the survey:
    ~6mCrab above 125 GeV = 3e-12 ph/cm2/s
  - area of the survey: 1/4 of the sky
  - no divergent pointing considered at this stage (no MC with divergent pointing in PROD2). However, with 400deg^2 (8 times larger than pointed observation FoV) it would be1-2 GRB in the FoV. And more transients of course

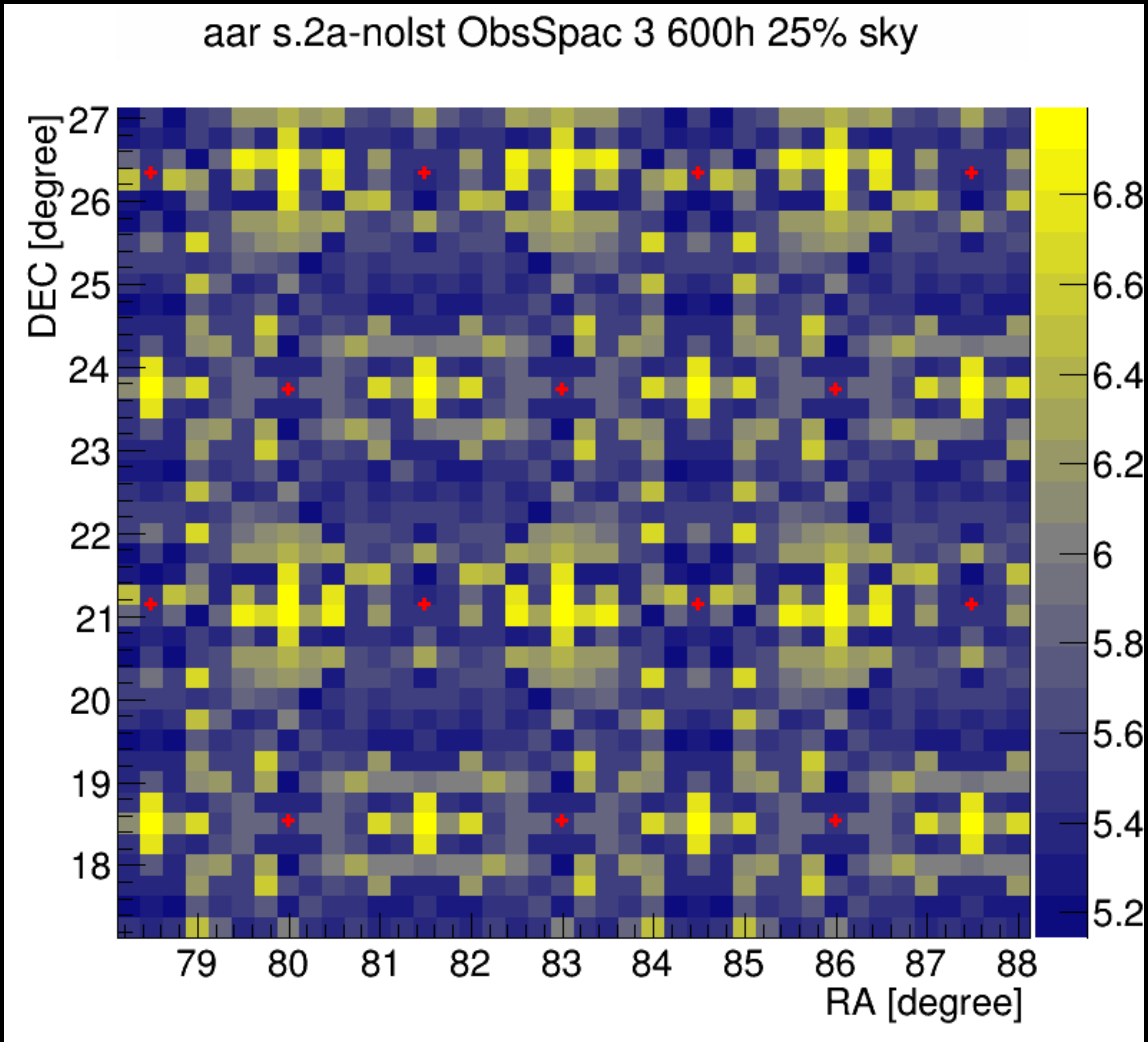
Feasibility

- Work by Lucie Gerard (DESY)
- Optimized spacing between 2, 3, and 4 deg
- Assumed 600h for 10.000 deg^2



- Used DESY performance files and software dubbed **CTOOLS**
- Simulated sources in 0.25deg grid
- No systematic limits but we checked that for integral results above 100 GeV there is no problem
- Cross-check by John E Ward (IFAE) using the same performance files and a simple macro (including systematic limits)

Scan sensitivities



- On the left: part of the scan and resulting sensitivities in mCrab
- This example is for 3 deg separations between pointings
- The pointing directions are indicated by red crosses
- Fluctuations are under investigation (intrinsic to the pointing separation or the binning in the off-axis performance files?)

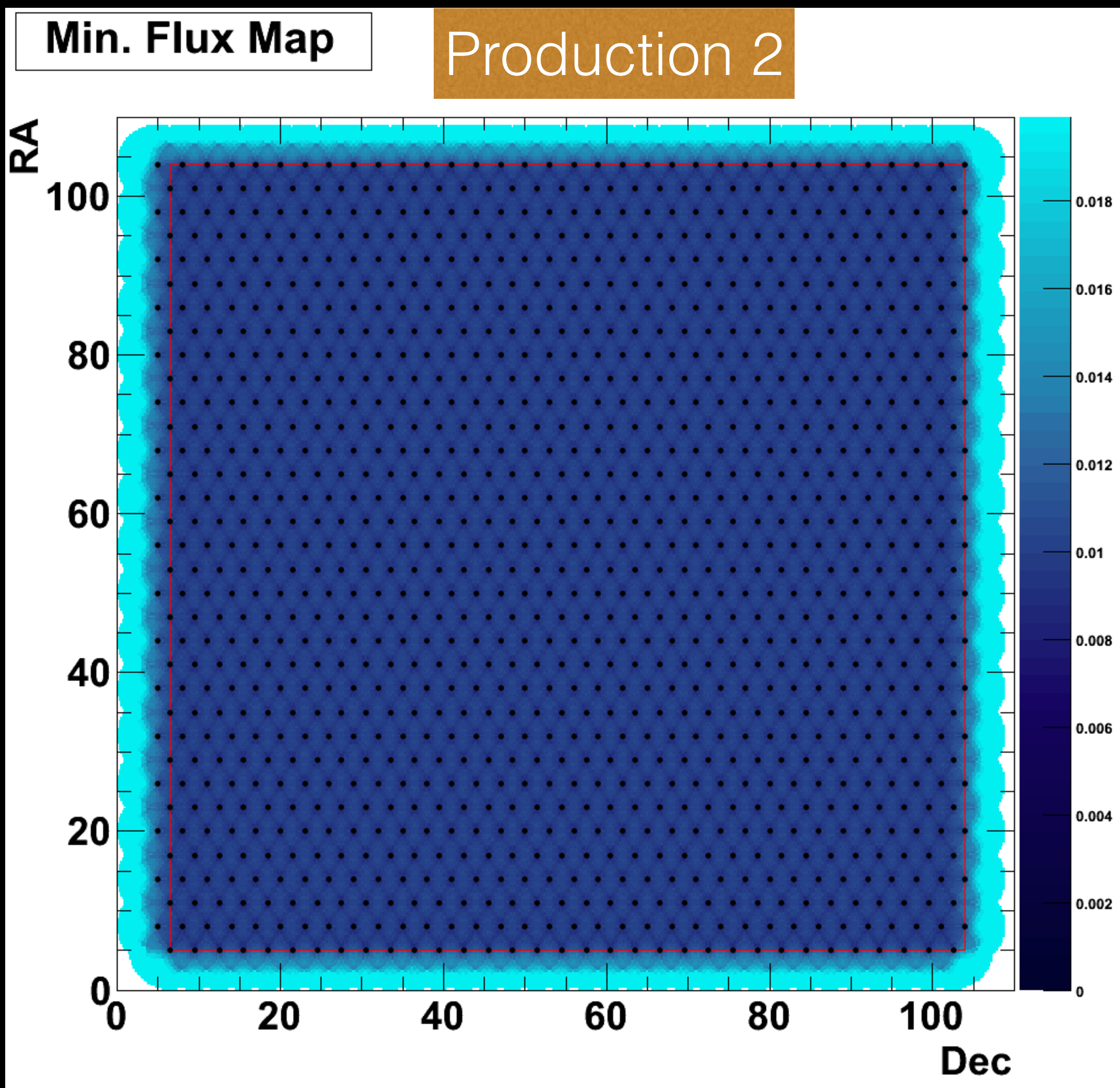
Sensitivities (Lucie Gerard)

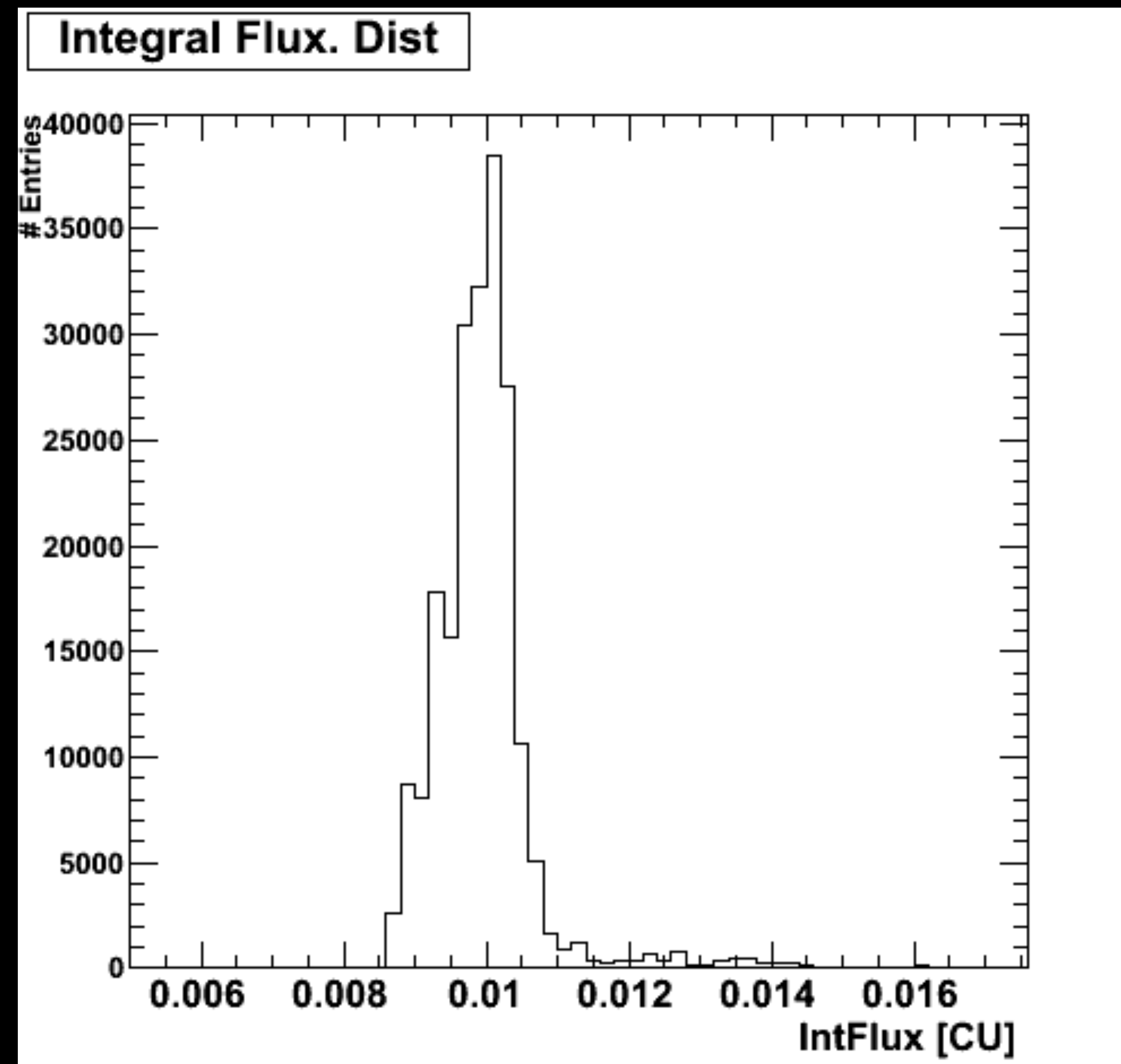
ARRAY / IRF		Spacing between the observations					
		4 degree 0.83h / obs.		3 degree 0.46h / obs.		2 degree 0.21h / obs.	
		S	ΔS	S	ΔS	S	ΔS
South	2a-noLST	5.4	0.9	4.8	0.4	5.0	0.5
North	2NN	8.61	1.2	8.0	0.8	8.1	0.8

Table 8.1 – Estimation of the survey sensitivity for a total of 600 h of observations and a coverage of 25% of the sky, for the south and north arrays and for various grid spacings (in degrees). The sensitivity, S, in milli-Crab units (mCU), is the average integrated sensitivity above 125 GeV assuming a Crab-like spectra [187]. ΔS represents the survey sensitivity fluctuation; this is the standard deviation of the sensitivity distribution over the sampled survey field-of-view. The instrument response function (IRF) refers to the particular array layout simulated; see text for details.

Northern array needs ~2-3 longer to reach the same sensitivity due to less MSTs and no SSTs

Sensitivities (JohnE Ward)

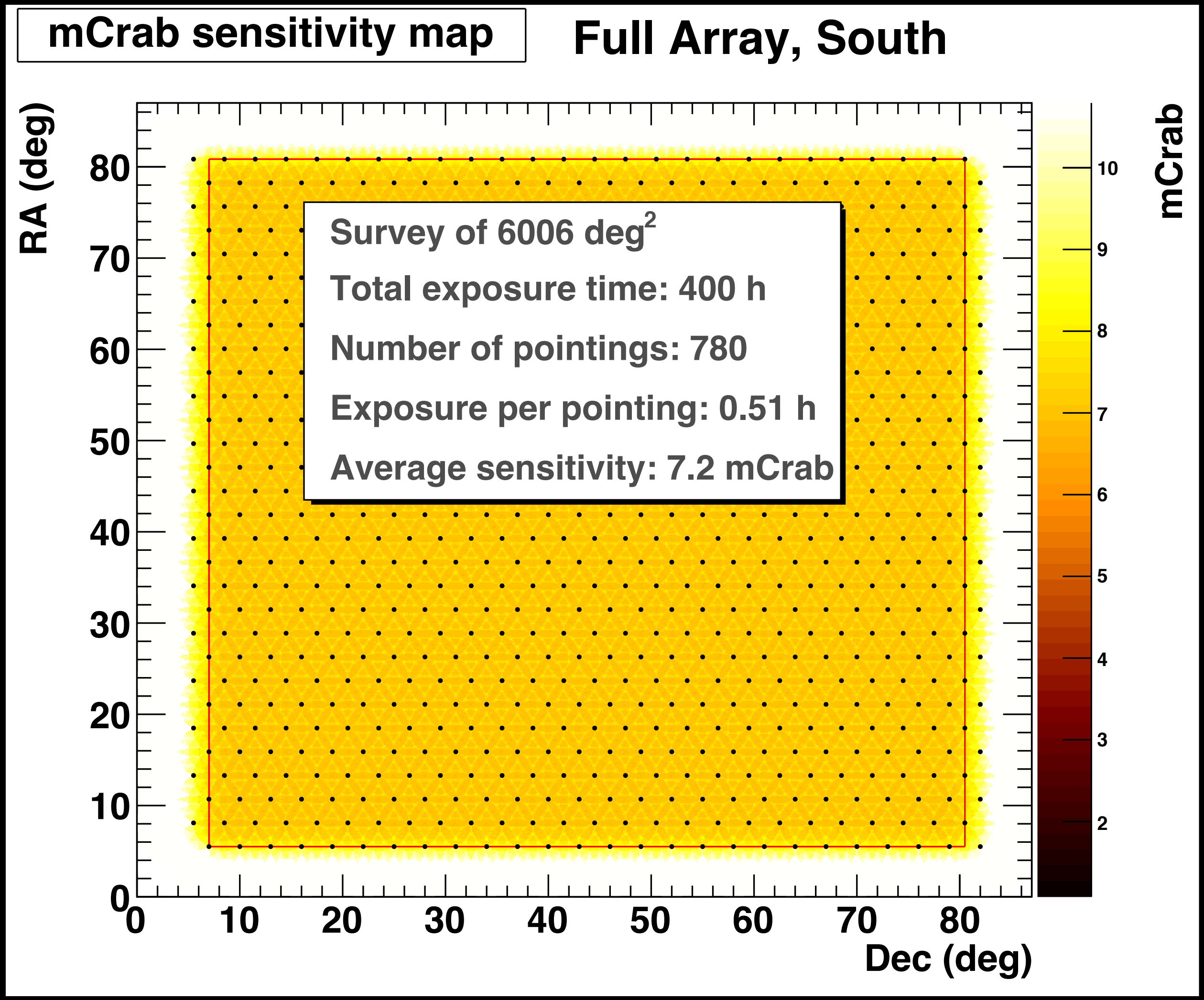


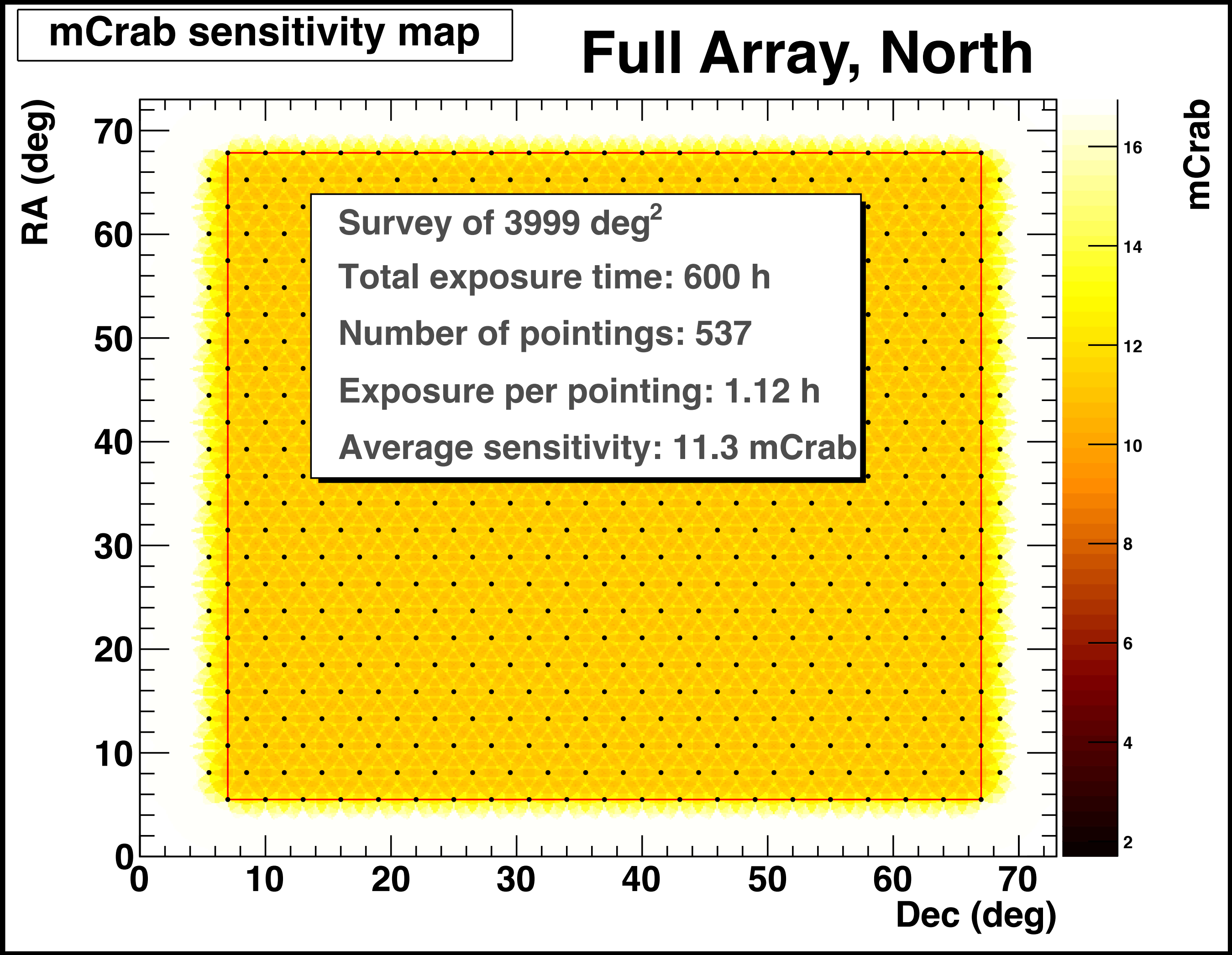


build up excess / background maps as the survey goes and calculate sensitivities using 5sigma/10events/5%background

Sensitivities (JohnE Ward)

Production 3



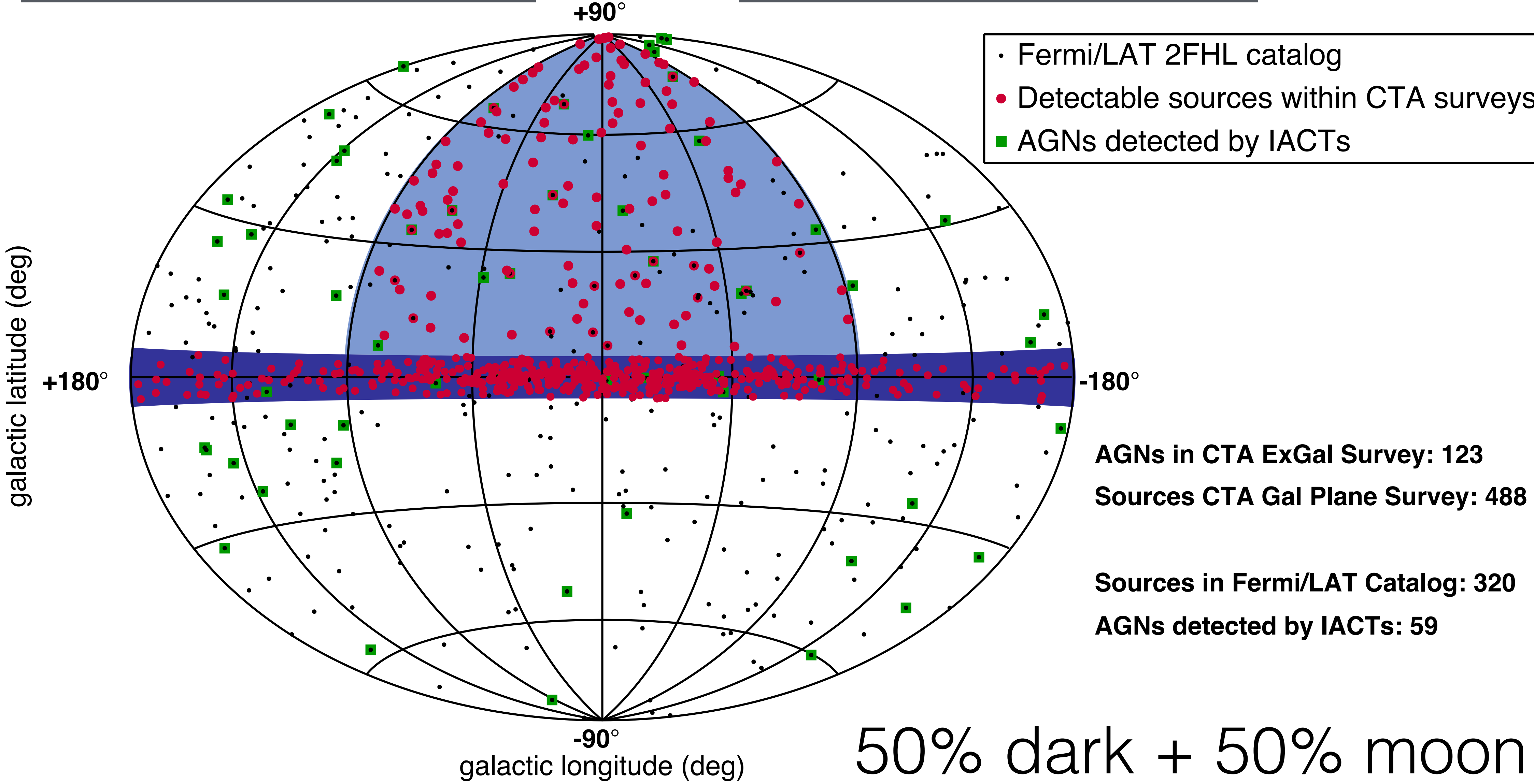


build up excess / background maps as the survey goes and calculate sensitivities using 5sigma/10events/5%background

Which region?

North: 60% of the time, 40% of the area

South: 40% of the time, 60% of the area



50% dark + 50% moon

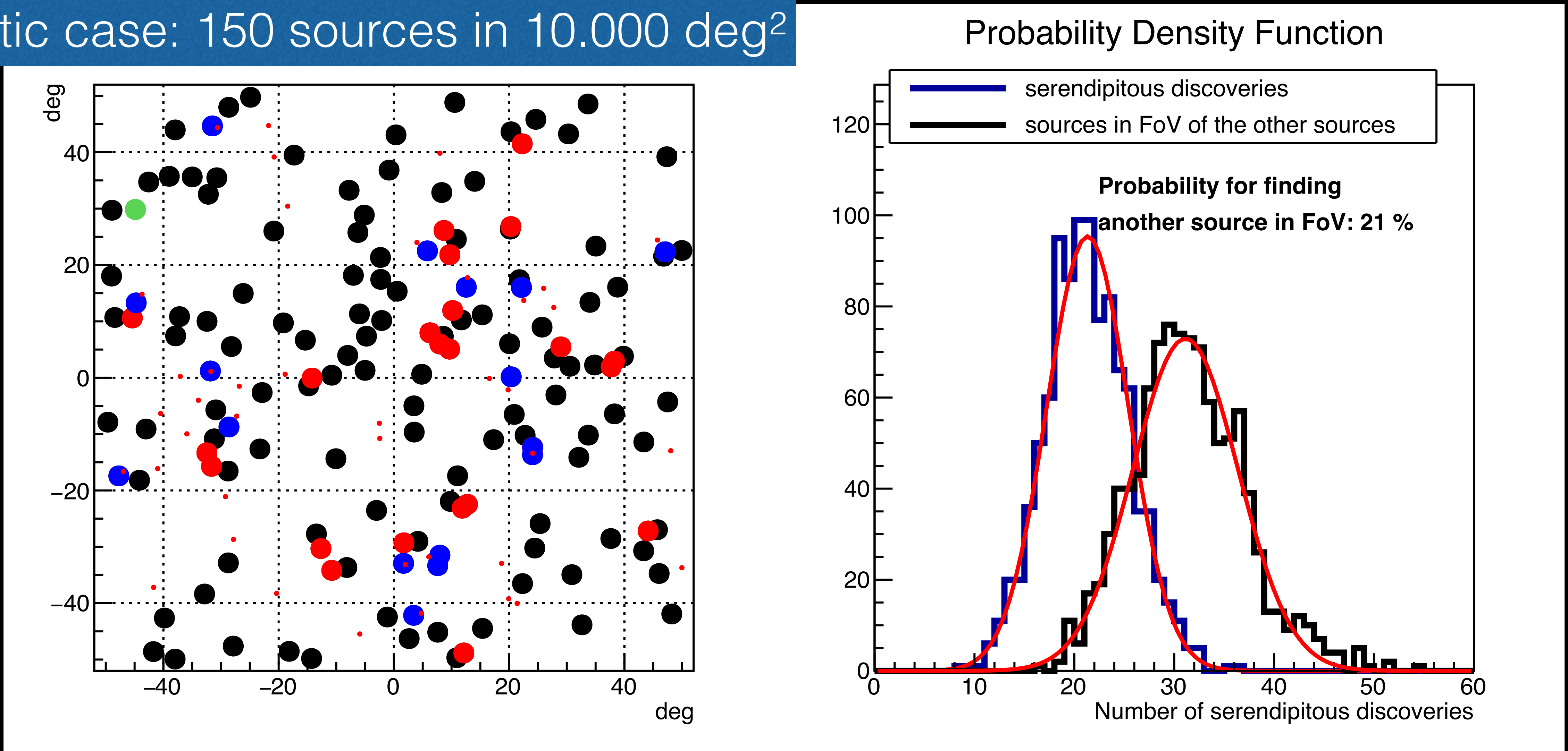
- Such scan would include Fermi Bubble (North), Virgo and Perseus clusters. It can be performed in part from the South and in part from the North

Serendipitous discoveries

- what is the probability to detect sources serendipitously?
  because we foresee some 50 observations of extragalactic objects for about 20h each before CTA is completed

Optimistic case: 150 sources in 10.000 deg²

Toy Monte Carlo



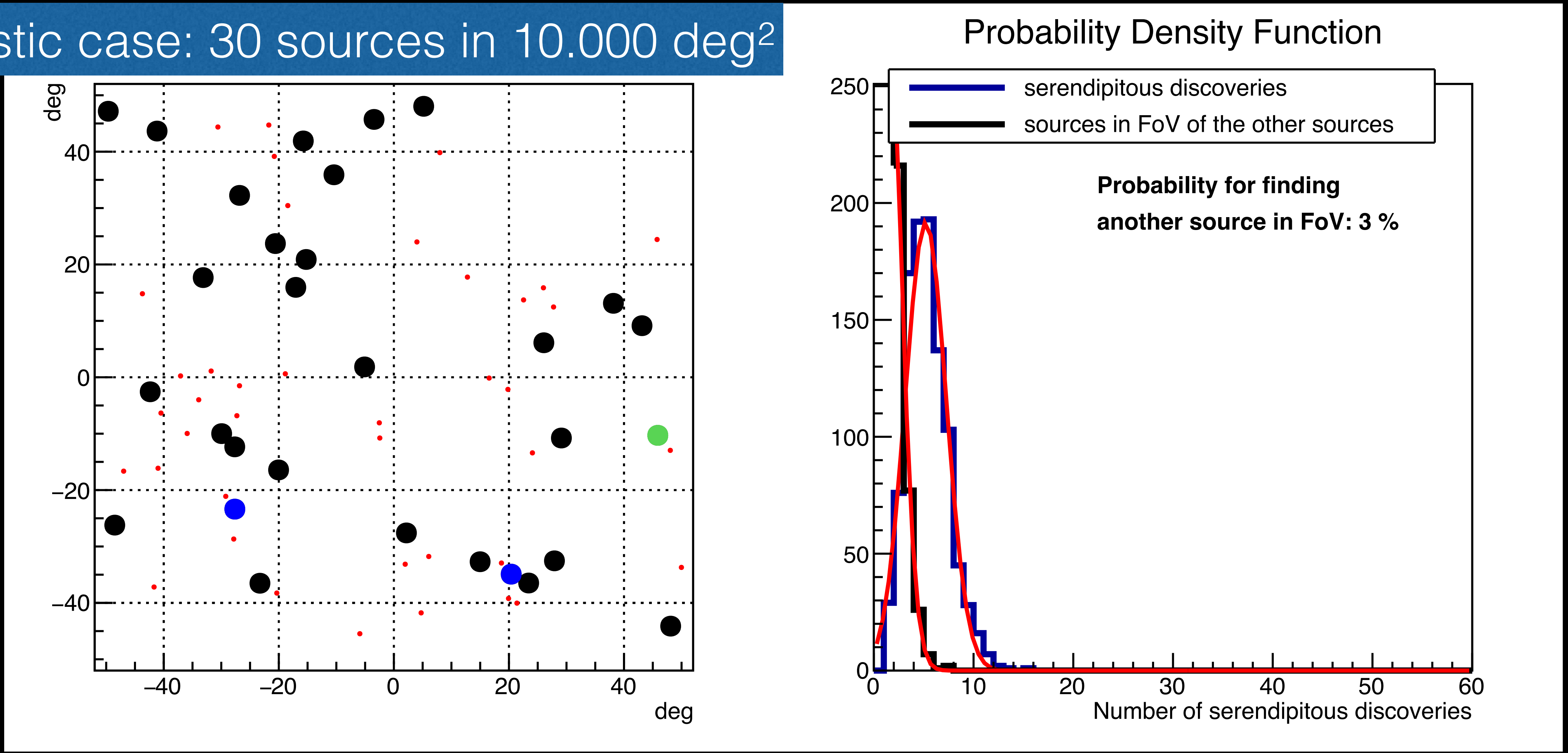
- black dots: sources; large **red** dots: sources in FoV of other sources; **green** dots: in FoV of known sources; **blue** dots: in FoV of random pointings
- Result: 20-30 serendipitous discoveries depending on the assumptions

Serendipitous discoveries

- what is the probability to detect sources serendipitously?
  because we foresee some 50 observations of extragalactic objects for about 20h each before CTA is completed

Pessimistic case: 30 sources in 10.000 deg^2

Toy Monte Carlo



- black dots: sources; large **red** dots: sources in FoV of other sources; **green** dots: in FoV of known sources; **blue** dots: in FoV of random pointings
- Result: 2-5 serendipitous discoveries depending on the assumptions

LSTs?

- Not increasing sensitivity at >100 GeV −
- Have smaller FoV −
- Provide low energy lever arm for most of the sources +
- + Detect factor 2 more Fermi/LAT known sources +
- Help in flare catching of soft source spectra +

Follow ups?

- The extragalactic survey may show many new interesting sources
- Some identifications will be difficult
- Energy spectra in ~2h exposure not well determined
- Suggest to allocate 20% extra time for follow up observations with full array

Conclusions

- A blind extragalactic survey for 1/4 of the sky is a strong KSP
- Feasible in 600-1000h with an integral sensitivity of 6mCrab above 125 GeV
- Perform the survey from both sites to cover regions like Fermi Bubble, Virgo and Perseus clusters
- Allocate for 200h more for follow up observations
- Use results on serendipitous discoveries of the years before the array is complete to adjust estimations and survey area
- Start survey when the array is 100% completed. Finish in first 2 years
- Recent results indicate we should focus the extragalactic survey on the Southern array