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 \( \gamma \)-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

- 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

see later discussion on the number
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
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

• 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 $r=2^\circ$ 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 $r=3^\circ$ 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

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

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Expectations from known source classes

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

1h exposure

South: 18 sources

North: 24 sources

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

- 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: $\sim 150$

- 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.
• 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 400deg² (8 times larger than pointed observation FoV) it would be 1-2 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?)
### 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]. $\Delta S$ 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.

<table>
<thead>
<tr>
<th>ARRAY / IRF</th>
<th>Spacing between the observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 degree</td>
</tr>
<tr>
<td></td>
<td>0.83h / obs.</td>
</tr>
<tr>
<td>South 2a-noLST</td>
<td>$S$</td>
</tr>
<tr>
<td>North 2NN</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>8.61</td>
</tr>
</tbody>
</table>

Northern array needs ~2-3 longer to reach the same sensitivity due to less MSTs and no SSTs.
build up excess / background maps as the survey goes and calculate sensitivities using 5sigma/10events/5%background
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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

![Image: Diagram showing serendipitous discoveries]

• 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 deg²

- 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

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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