Development of a subthreshold transient catalog with MAXI data

Naoaki Katsumata, Wataru Iwakiri, Nobuhiro Shimizu
Chiba University, International Center for Hadron Physics (ICEHAP)
contact: 25wm7101@student.gs.chiba-u.jp

Introduction

Cosmic neutrino background

- The TeV–PeV diffuse neutrino sources remain largely unidentified.
- X-ray–bright transients (e.g., LLGRBs) remain promising counterparts.
- MAXI's soft-X-ray sensitivity provides time- and direction-resolved coverage.

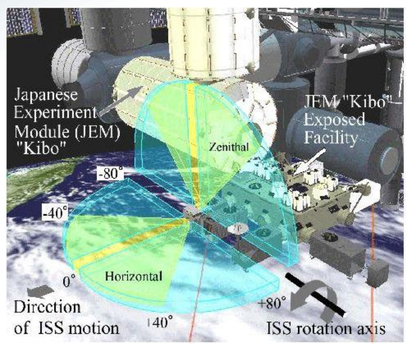
→ Updating the MAXI subthreshold catalog can sharpen counterpart searches and inform neutrino-origin studies!!

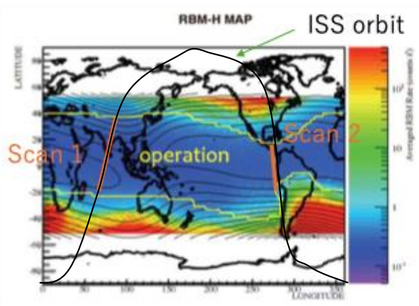
MAXI overview

Energy range: 2-20 keV
FOV: 1.5 (FWHM) x 160 degree^2
PSF: 1.5 degrees (FWHM)

Observation method

- Scans ~85% of the sky every 90 minutes along the ISS orbit.
- Field of view covers the zenith and forward directions.
- Average exposure per scan: ~40 s for a given sky direction.





MAXI operation

Current MAXI transient search vs This work

Nova Search system

- Evaluates simultaneous significance across using multiple time bins (1,3,5,30s/1 scan/ 4 orbits/ 1 day/ 4 days) × multiple energy bands.

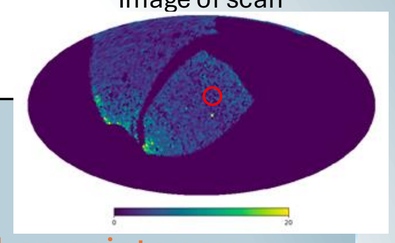
→ Calculate a p-value for the latest time-bin using past data. = Time-series consistency

"broad and reliable" analysis method is not optimized for detecting transients that appear only once per scan.

This work (new method)

- Capture transient events detectable only in a single scan using HEALPix. = Spatial consistency

Image of scan



Research goals

Optimize this method to search for undiscovered short transients (~40s) in addition to those currently known.

New method concept & procedure

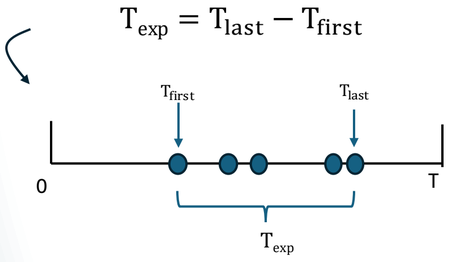
①Fill photons to HEALPix map

- Aggregate observation hits into HEALPix cells per scan

$$N_{count} = N_{hit}/N_{cam}$$

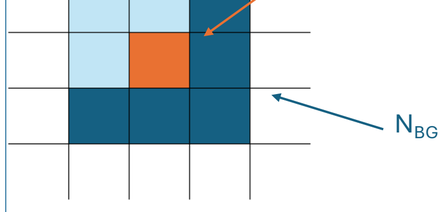
- Reject bad photons (out-of-view, out-of-band(2-10keV), out-of-time)

$$T_{exp} = T_{last} - T_{first}$$



②BG photon subtraction & p-value definition

Define N_{BG},N_{sig};
N_{BG} = mean of the **smallest 5 of the 8 neighbors**
$N_{sig} = N_{center} - N_{BG}$



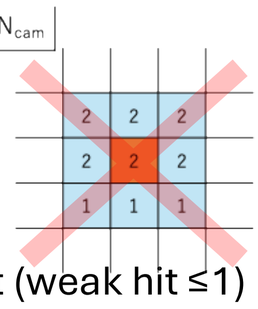
- Assign a p-value to each pixel

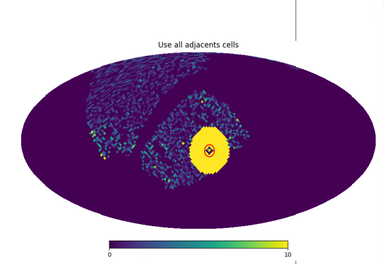
③Final quality cuts & candidate selection

Cut1, Quality selection for a scan N_{cam}

Cut2, Number of camera(Ncam) consistency

Cut3, Confirming nearby hits
→ If weak hits are frequent, reject (weak hit ≤1)





$3° < \psi < 20°$

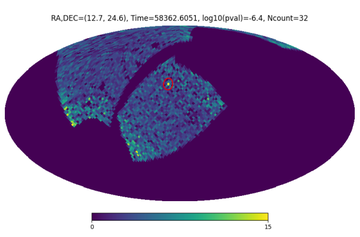
Cut4, Avoid known sources

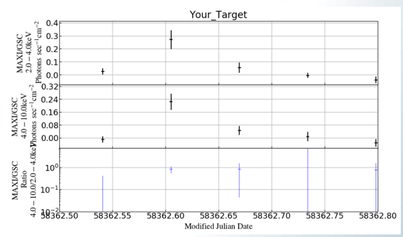
- remove pixel having sources and in opening angles of $r(2°, 3°, 5°)$

ex. If the signals are subthreshold…
$p_{sig} < 10^{-6}$ & $N_{sig} > 10$

Discover transient candidate & Map drawing !!

Unlisted candidate's map & lightcurve





Candidates: 18/4000days
→One of them is not listed in the MAXI GRB lists so far

Development

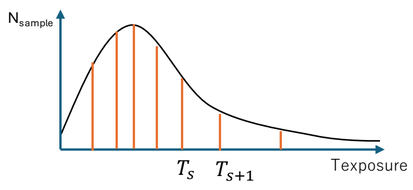
- Improved Method for Evaluating p-values
- Quantifies efficiency to enable evaluation of signal detection rates

p-value definition

According to the T_{exp} definition, T_{exp} distribution is Ncount-dependent.

$$f_{R,N}(t) = \frac{N(N-1)}{T^N} t^{N-2}(T-t)$$

$$E[R] = \frac{N-1}{N+1} T$$



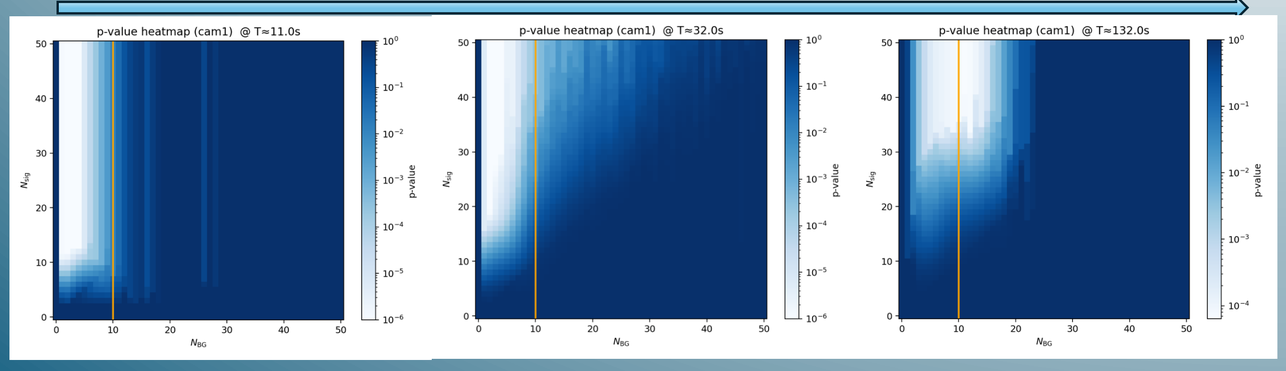
→Define pvalue as follows;
Refer to the distribution of the 2D histogram ($C(N_{sig}, N_{BG})$) in each Ncam & Texposure band.

$$cdf(n, N_{BG}, s) = \sum_{k \geq n} C(k, N_{BG}, s)$$

$$p(n \mid N_{BG}, T \in I_s) = cdf(n, N_{BG}, s) \Big/ \sum_{k} C(k, N_{BG}, s)$$

Evaluation of "rarity within the same exposure conditions" is possible.

short → Texposure → long



Efficiency evaluation

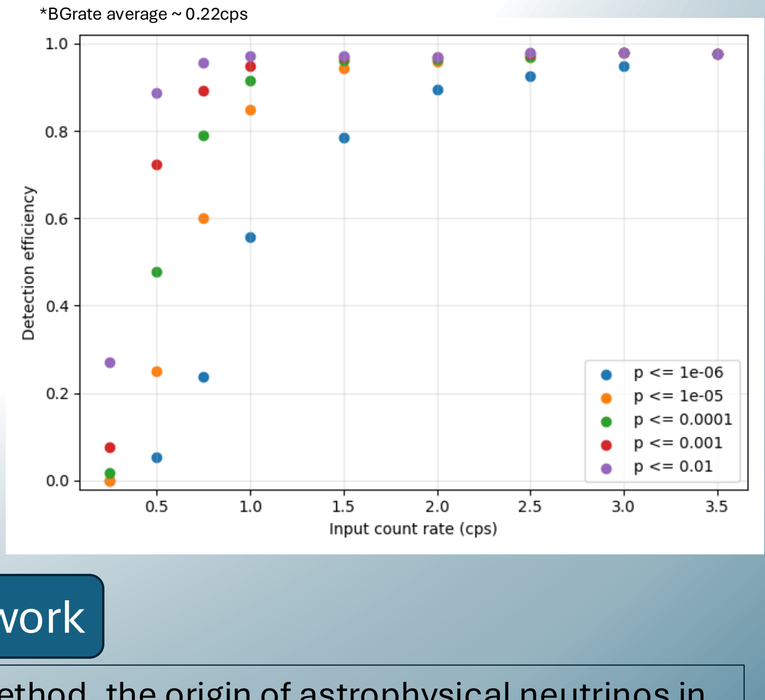
- Inject signals at various counts into the map to define detection efficiency

By evaluating the precision of this method based on efficiency,

we can discuss the subthreshold of flux objects detectable by MAXI

Ex. 1.0cps → ~2 × 10^{-9} erg/s/cm^2

*BGrate average ~ 0.22cps



Conclusion & Future work

By developing this analysis method, the origin of astrophysical neutrinos in the TeV-PeV range can be investigated using X-ray data. In my current work,

- Setting p-values for Ncam, Texposure, and N_{BG}
- Accuracy Assessment of Analysis Through Quantification of Efficiency

Next

- Discuss the threshold limit in actual Flux

References: [1]maxi.riken.jp Optimization of the auto-detection algorithm in the MAXI nova alert system and reanalysis of archival data