

# Gaia Alerts in X-ray and Radio catalogues

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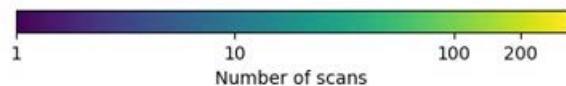
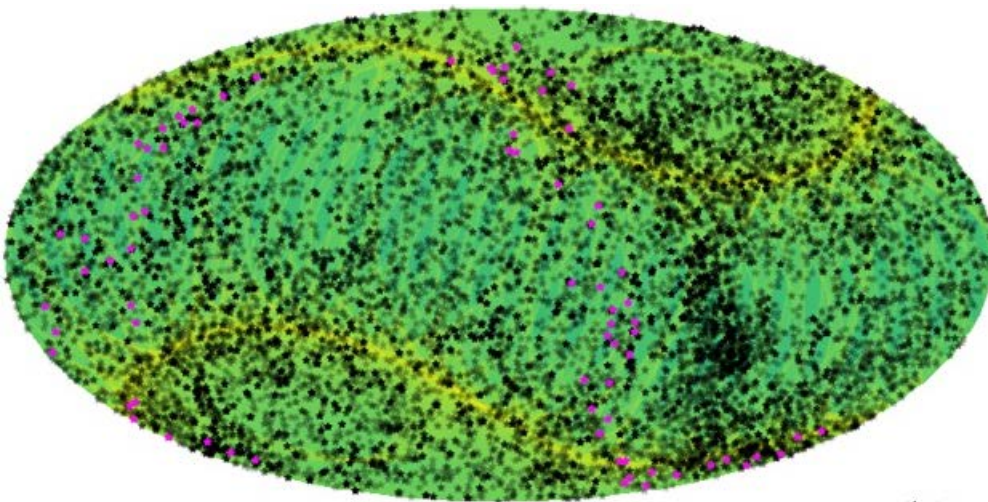
10th OPTICON Gaia Science Alerts Workshop

*Catania*

*18-20 December 2019*

# Gaia alerts

- > 10500 objects (December 2019)
- ~ 8000 objects have status “unknown”
- ~ 5.3 objects per day in average (it depends on year)



Alerts  
 \* last 7 days  
 older alerts  
 \* (fading with age)

|           |            | rved                   | RA<br>(deg.) | Dec.<br>(deg.) | Mag.  | Historic<br>mag. | Historic<br>scatter | Class   | Published              | Comment                                                                                             | RVs |
|-----------|------------|------------------------|--------------|----------------|-------|------------------|---------------------|---------|------------------------|-----------------------------------------------------------------------------------------------------|-----|
|           |            | 12-10<br>:11           | 277.10774    | -66.91449      | 18.55 |                  |                     | unknown | 2019-12-11<br>11:58:01 | candidate SN near galaxy LEDA 300882                                                                |     |
|           |            | 12-09<br>:45           | 317.80590    | -20.48910      | 17.42 |                  |                     | unknown | 2019-12-11<br>11:55:08 | candidate SN near galaxy NGC 7030, in footprint of GW event S191129u                                |     |
|           |            | 12-10<br>:50           | 165.04092    | -45.27869      | 16.25 |                  |                     | unknown | 2019-12-11<br>11:53:51 | apparently hostless blue transient                                                                  |     |
| Gaia19fmh | AT2019vyjq | 2019-12-10<br>00:52:03 | 323.01846    | -9.45530       | 18.61 | 19.06            | 0.11                | unknown | 2019-12-11<br>11:44:26 | slow rise of ~0.4 mags in Gaia source                                                               |     |
| Gaia19fmq | AT2019wvp  | 2019-12-09<br>12:31:33 | 315.15256    | -26.59592      | 18.79 | 19.57            | 0.24                | unknown | 2019-12-11<br>11:43:46 | long-term rise of ~0.7 mags in Gaia source                                                          |     |
| Gaia19fml | AT2019wvp  | 2019-12-08<br>13:58:05 | 339.26127    | 51.07896       | 18.69 | 19.10            | 0.11                | unknown | 2019-12-11<br>11:42:46 | blue source near the Galactic plane brightens by 0.3 mag                                            |     |
| Gaia19fme | AT2019wbc  | 2019-12-08<br>07:42:18 | 330.49291    | 38.41095       | 18.65 | 20.00            | 0.18                | unknown | 2019-12-10<br>12:24:04 | Gaia source coincident with galaxy brightens by ~1.5 mags, brighter transits are offset from centre |     |

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## Photometric Alerts

ed on these Gaia discoveries, we would appreciate an acknowledgement along the lines of: "We acknowledge ESA Gaia, DPAC and the Photometric Science Alerts .ac.uk/alerts)"

! to date. You might wish to view or download these as a table in CSV format or using any of the tools described in this page.

of the columns.

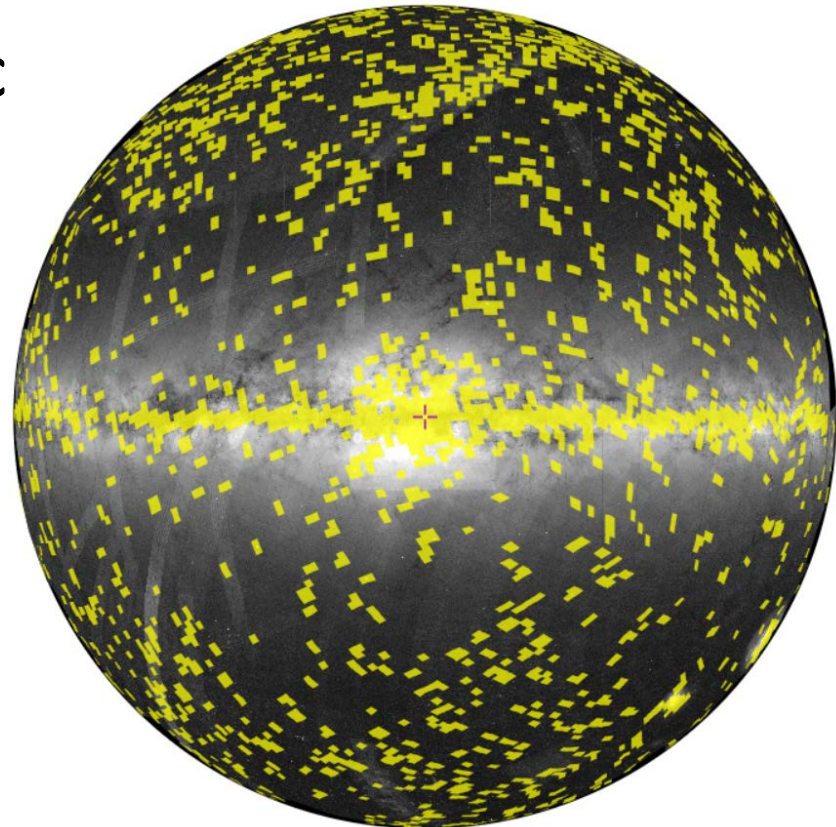
Search

# Main objective

- Compare all Gaia alerts with big surveys in X-ray and radio
- Catalogues:
  - The Chandra Source Catalog 2.0 (Ewans+, 2019)
  - The Faint Images of the Radio Sky at Twenty centimeters (Helfand+ 2015)
  - The GMRT 150MHz all-sky radio survey (Intema+, 2017)
  - The Westerbork in the Southern Hemisphere at 352 MHz (de Breuck+ 2002)
  - ...

# Chandra X-ray Catalogue

- 317167 objects in X-ray (0.08-10keV)
- Resolution  $< 0.5$  arcsec
- Coverage  $\sim 1\%$  of the sky (Milky Way more detail)
- Coordinates, sizes, fluxes etc



# FIRST – radio catalogue

- 946432 objects observed VLA (1.4GHz)
- Resolution  $\sim 5$  arcsec, sensitivity - 1mJy
- Coverage  $\sim 10,000$  deg<sup>2</sup> (25% of the sky)
- Coordinates, sizes, fluxes etc



# Data processing

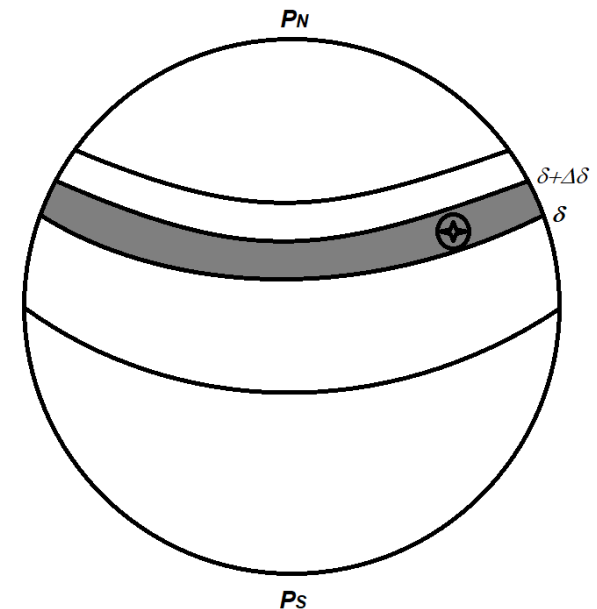
- Load target catalogue (X-ray, radio, etc)
- Re-sort catalogue objects
- Write inner catalogue (only ID, coordinates and sizes)
- Load Gaia alerts catalogue
- Compare alert objects with objects in the target catalogue
- Find close pairs (with some input criteria)

# Preprocessing

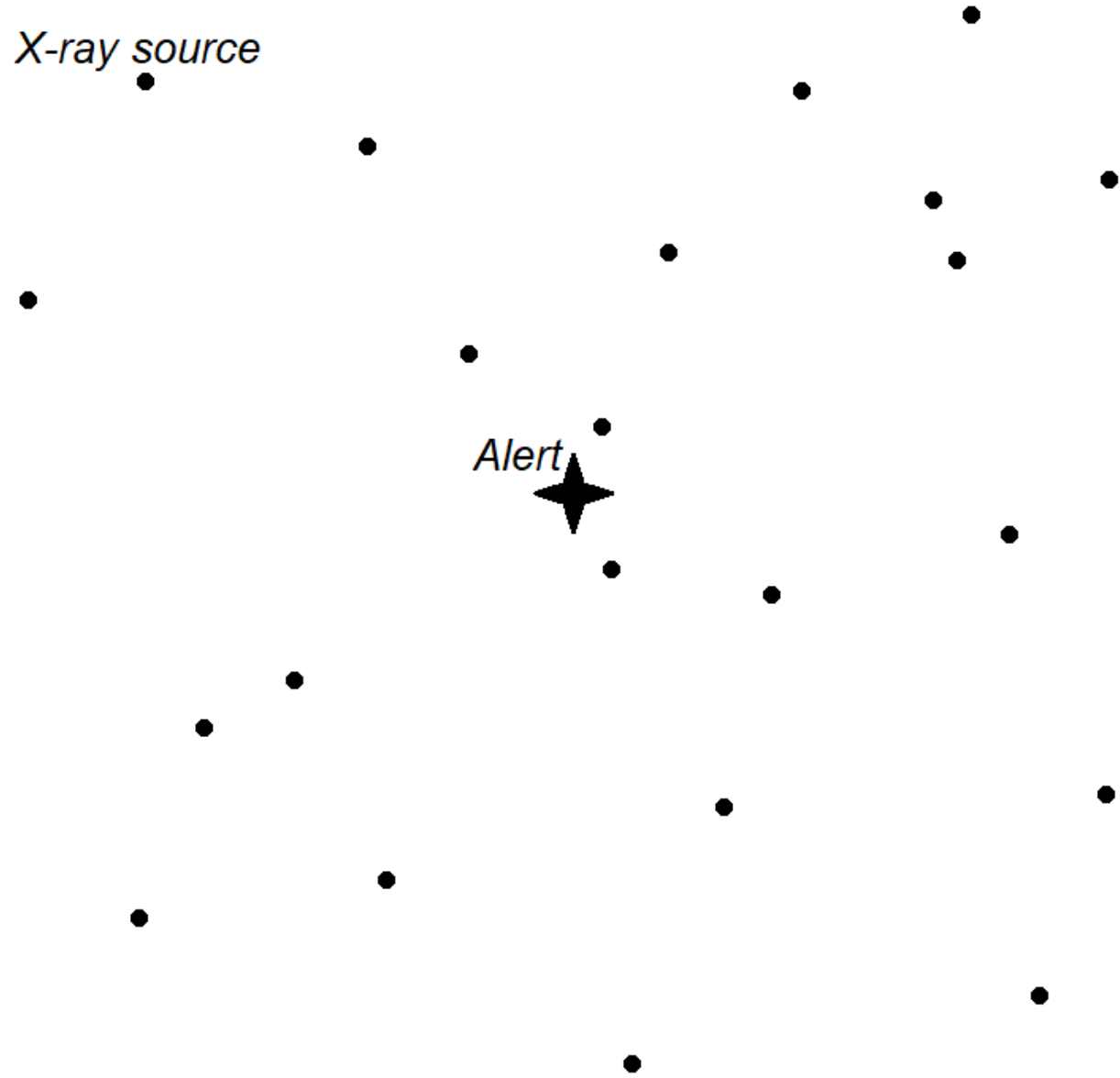
- Input catalogues have a huge size ( $\sim 100$  thousands)
- Rearrange objects in the catalogue to find only close to Gaia alert object

Solution:

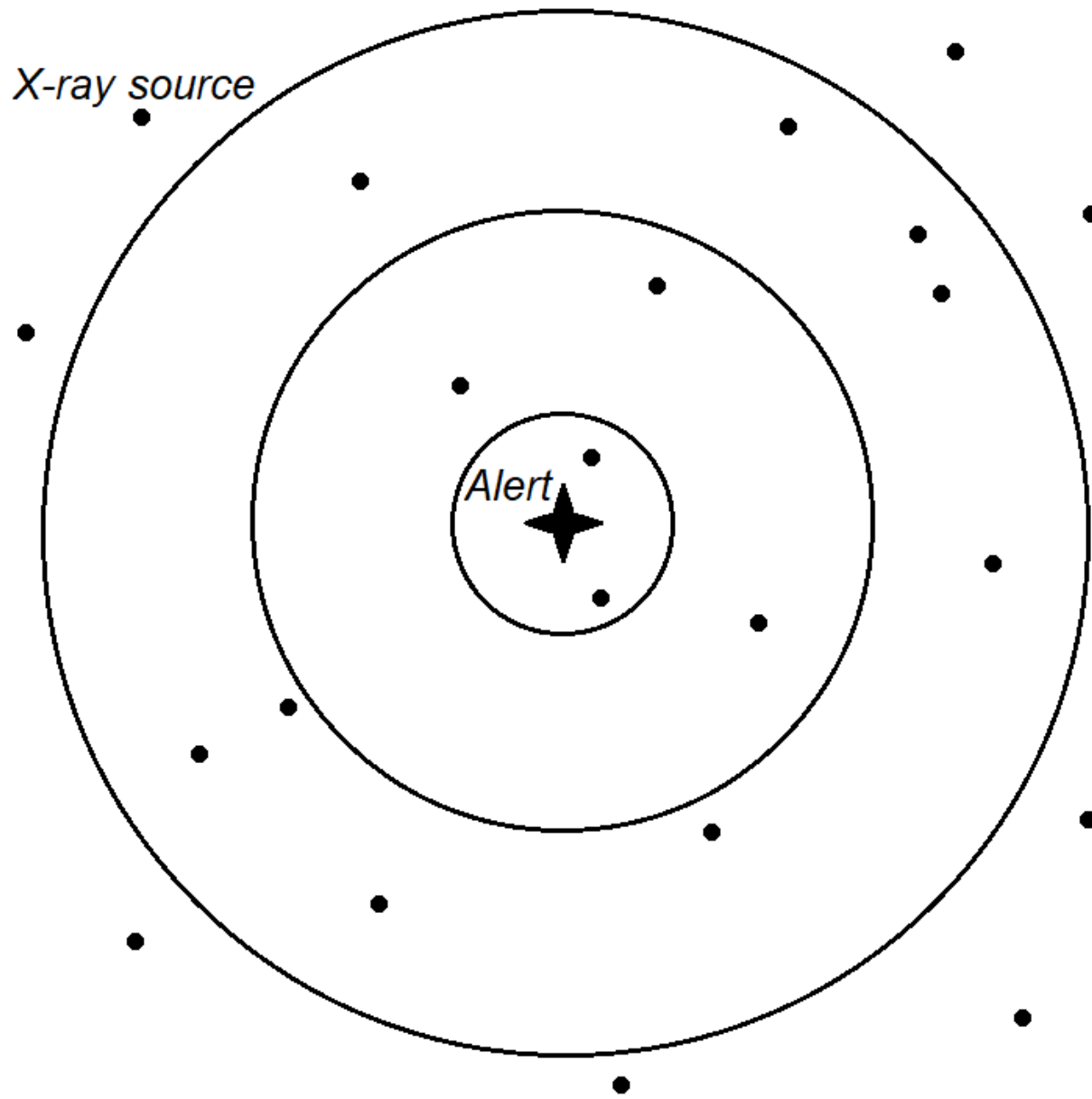
- Re-sort objects in the declination order
- Divide sphere on declination zones
- Try to find pair between objects in the alert zone only



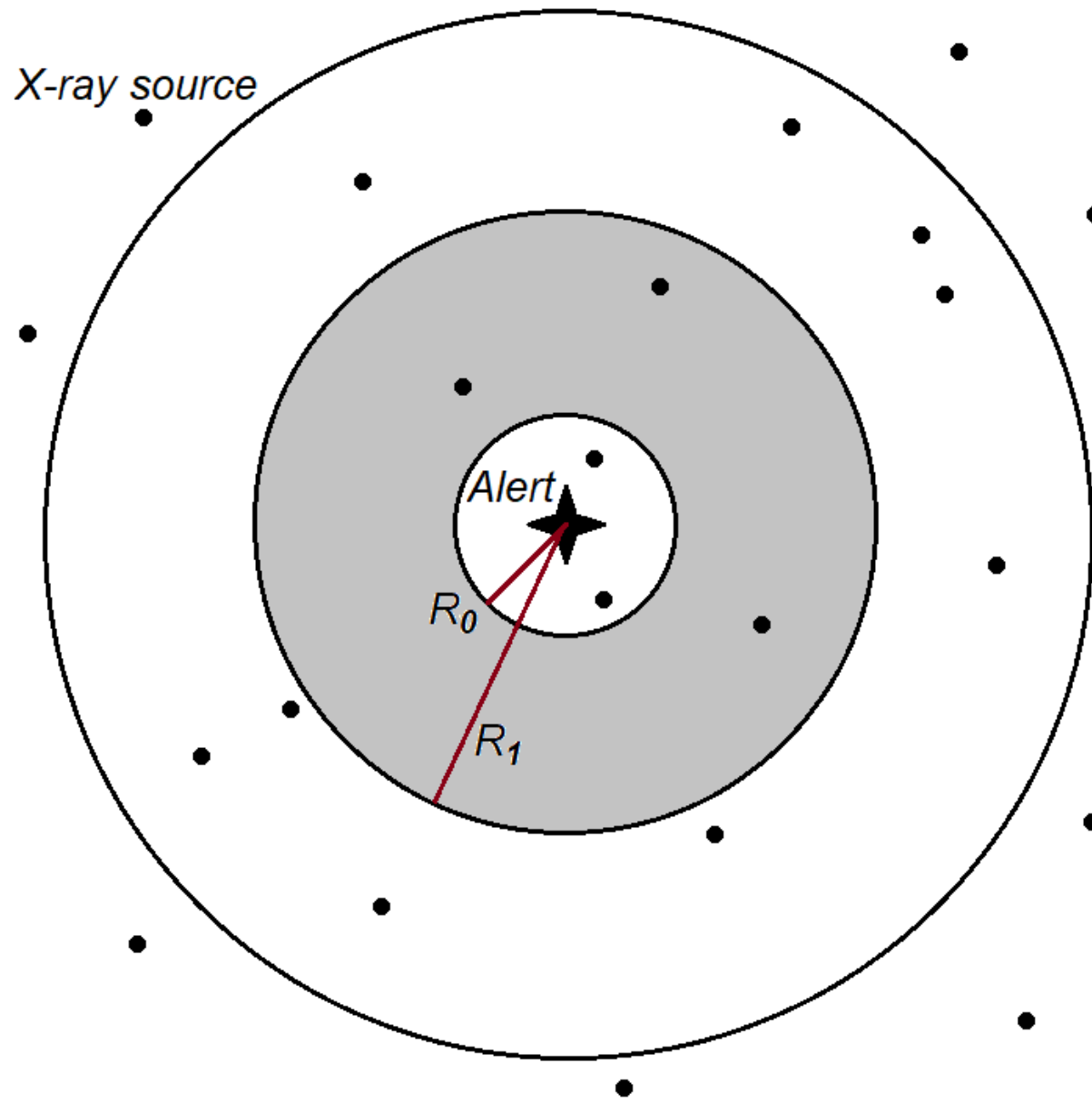
# Comparison



# Comparison



# Comparison



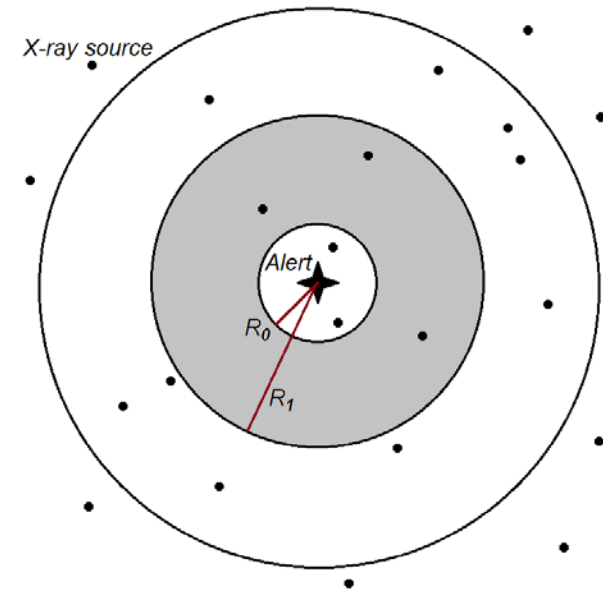
# Comparison

- Find angular distance from alert to objects in the zone  

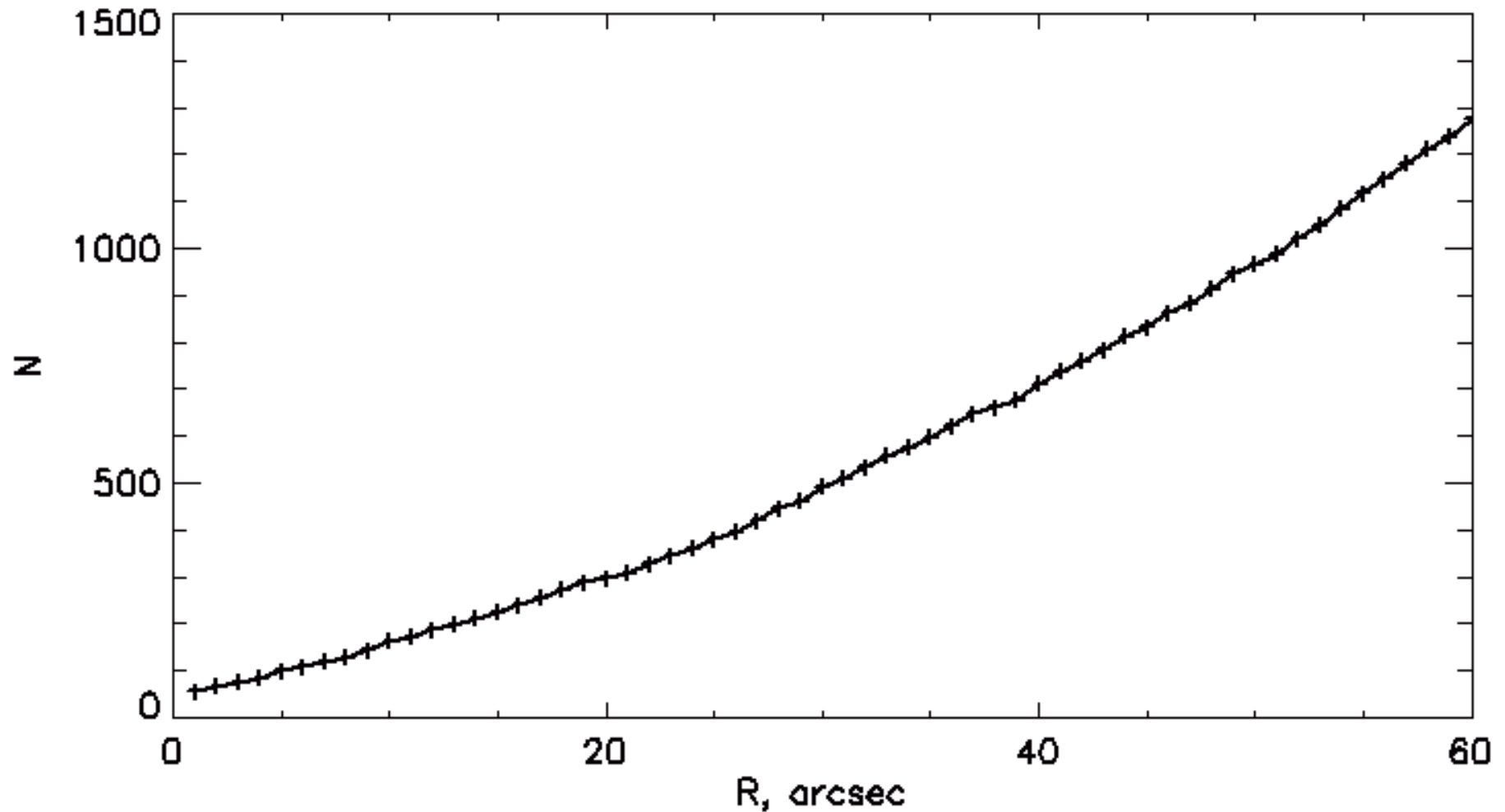
$$\varphi = \arccos (\sin \delta_{alert} \sin \delta_i + \cos \delta_{alert} \cos \delta_i \cos (\alpha_{alert} - \alpha_i))$$
- Find objects in the circle with radius  $R_i$  (input parameter) for some alert
- Calculate number of objects in the ring for some alert
- Calculate total amount of objects in the ring for all alerts
- Find density of the objects:

$$\rho_i = \frac{\text{Number of objects}}{\text{Square of the ring}}$$

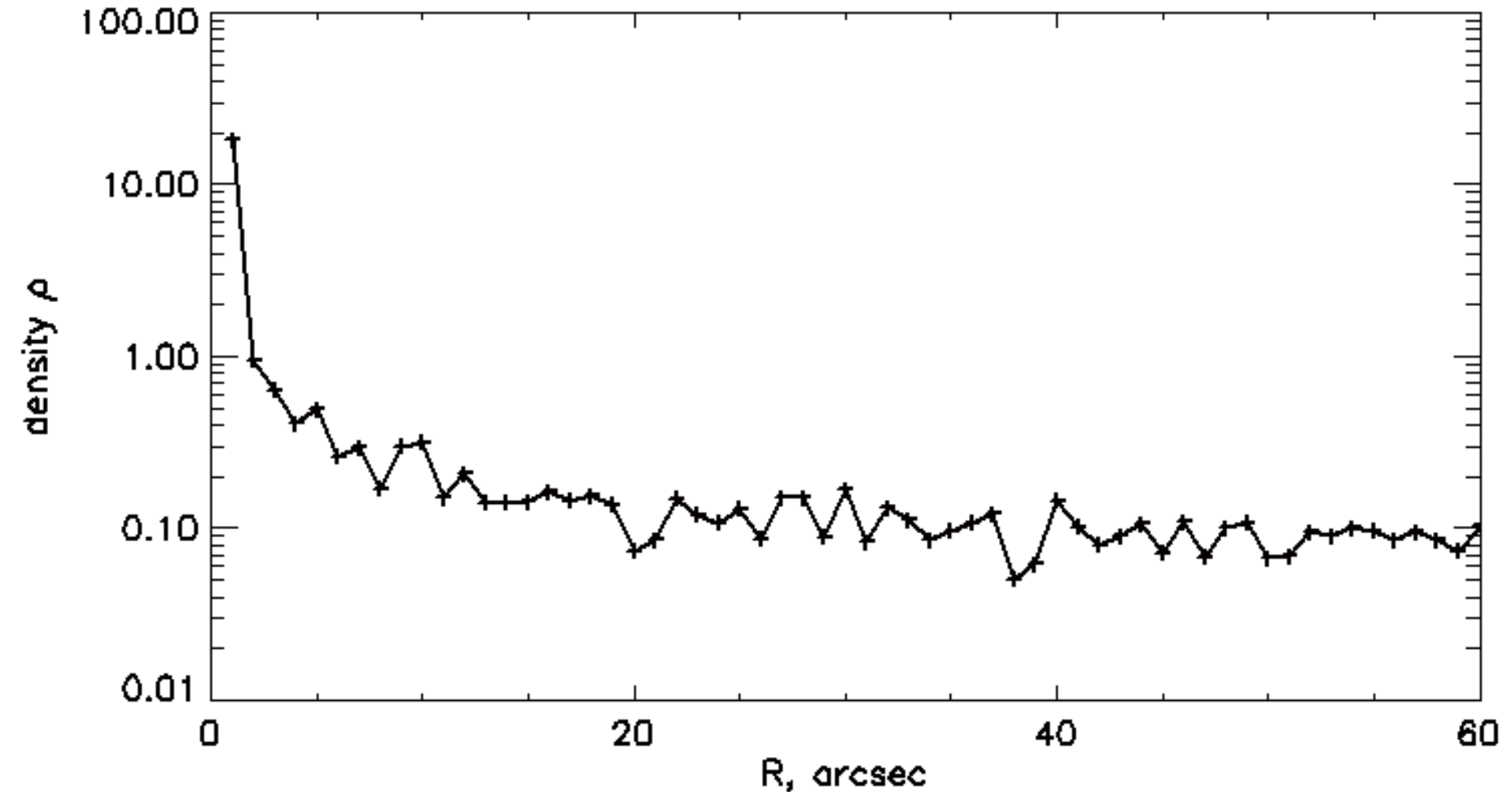
$$\rho_i = \frac{N_i - N_{i-1}}{S_i - S_{i-1}} \approx \frac{N_i - N_{i-1}}{\pi(R_i^2 - R_{i-1}^2)}$$



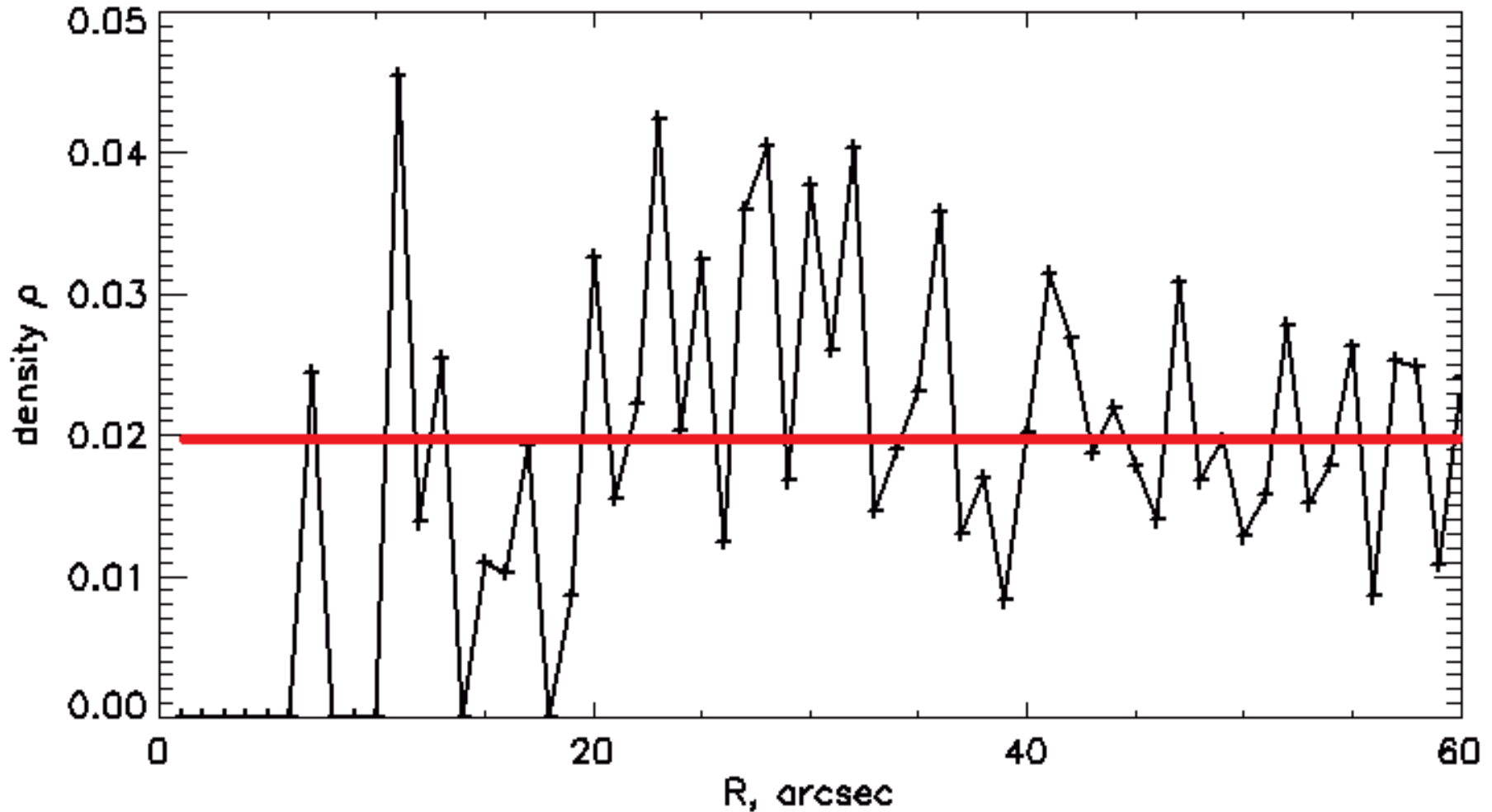
# Number of pairs (Chandra)



# Density of find pairs as a function of search radius R (Chandra)

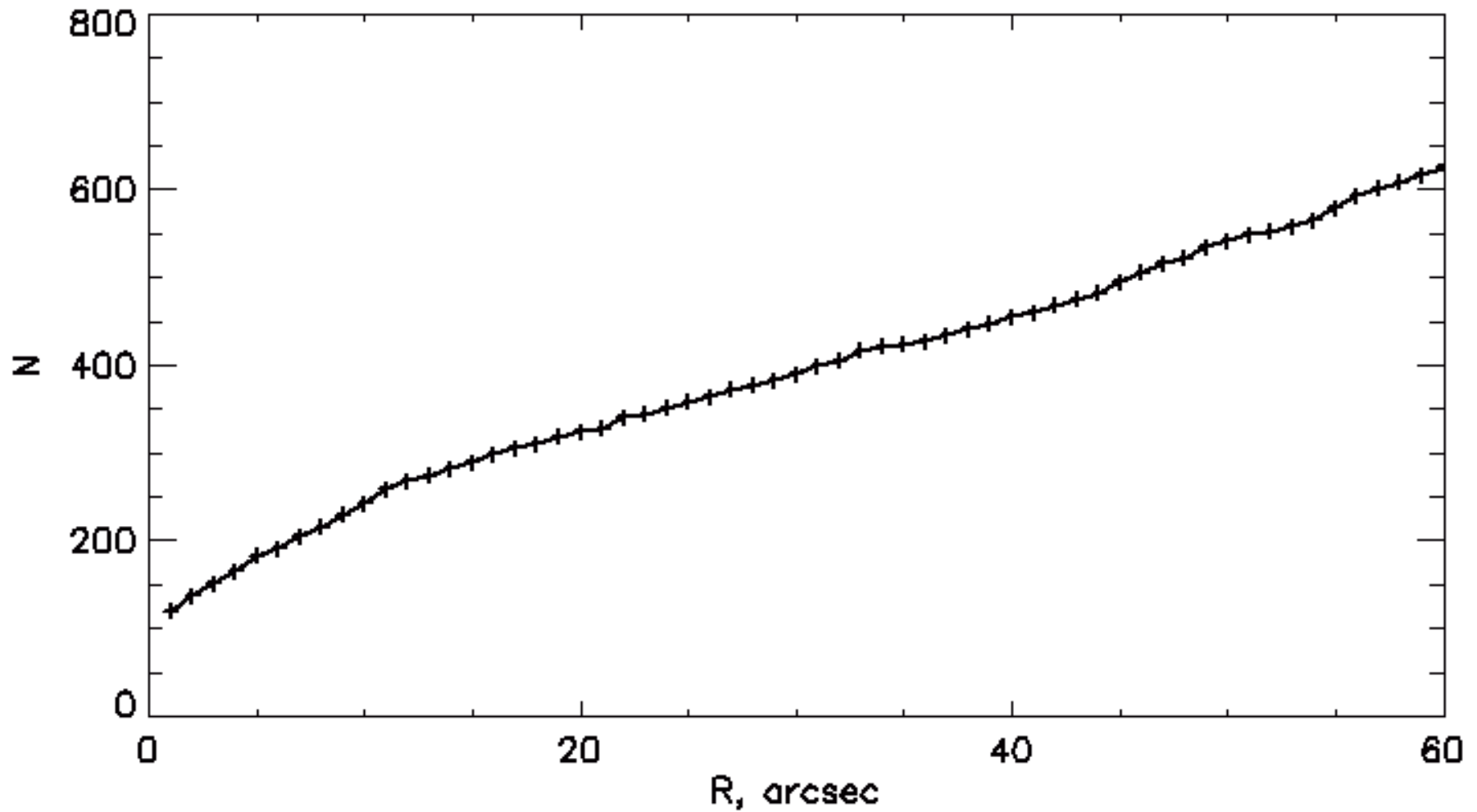


# Synthetic random data

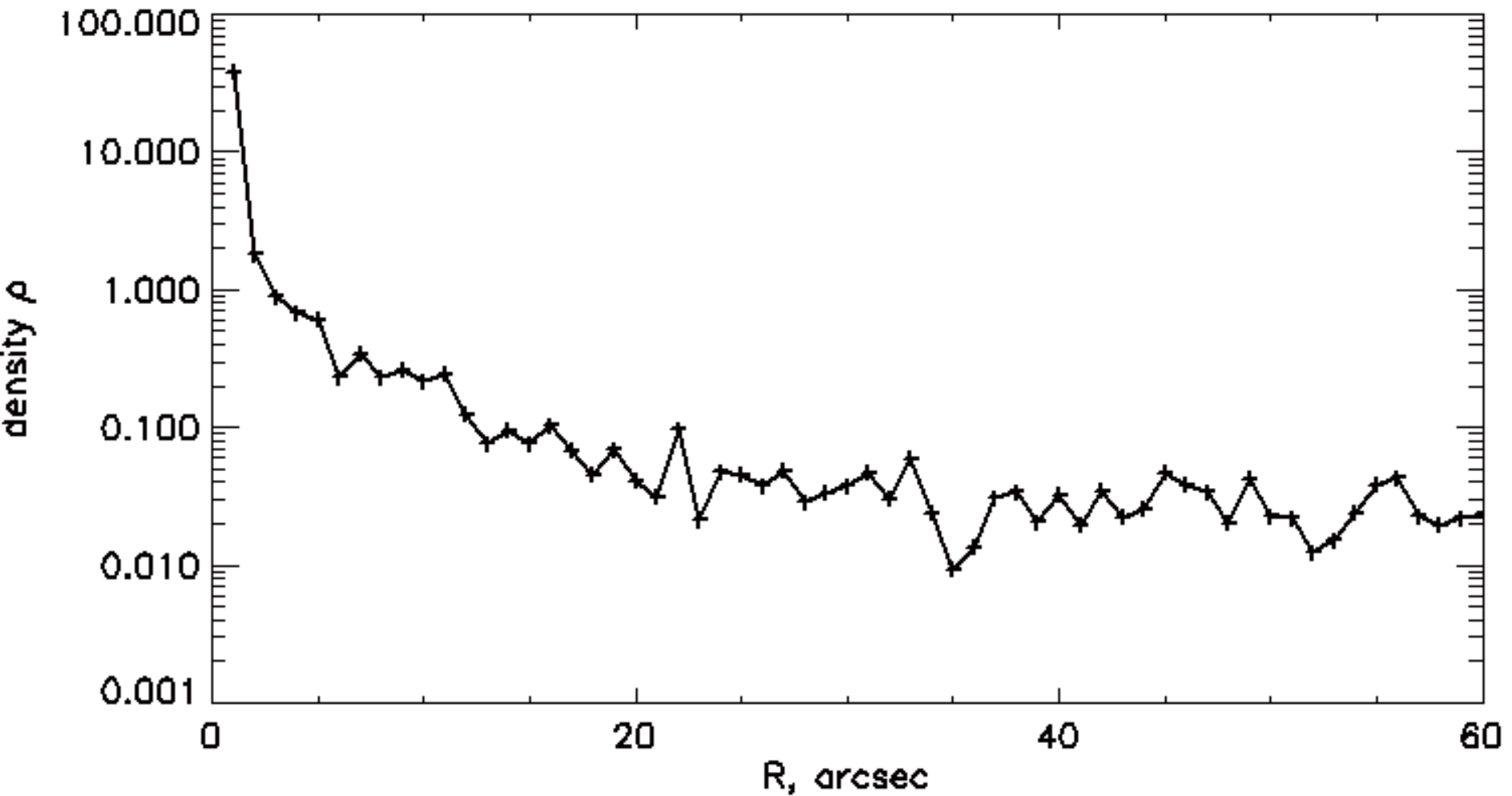


Quasi-uniform distribution for random objects

# Number of pairs (FIRST)



# Density of find pairs as a function of search radius R (FIRST)



# Some statistic

- Comparison of objects in X-ray and radio catalogues with Gaia alerts database ( $\approx 10500$  alerts)

|                         | Chandra    | FIRST |
|-------------------------|------------|-------|
| Coverage of the sky     | $\sim 1\%$ | 25%   |
| Number of pairs (8")    | 120        | 216   |
| Alerts inside of object | 65         | 177   |

# Interesting example

- Alert Gaia19aso (classified as QSO) has two objects in the Chandra catalogue:
  - 2CXO J071752.0+453801, RA=109.466897, dec=45.63387, rmax=3.43, rmin=1.55, position angle=142.18 (dist 3.43")
  - 2CXO J071751.8+453803, RA=109.466039, dec=45.63429, rmin=0.71, rmax=0.71, position angle=71.72 (dist 0.71")

*Possible we observe AGN and jet*

*Try to find jet-like structures  
in other alerts (?)*



# List of pairs

- It was created list of matches (Gaia alert and Chandra objects or FIRST objects)

| Alert     | RA        | dec       | class                                                                         | Comment                                                                           | ->               | Chandra_ID       | RA       | dec      | distance  | size     |
|-----------|-----------|-----------|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------|------------------|----------|----------|-----------|----------|
| Gaia19eug | 344.16320 | 26.31212  | "unknown"                                                                     | "0.9 mag rise in nucleus of galaxy, possible QSO"                                 |                  | J225639.1+261843 | 344.163  | 26.3121  | 0.152073  | 0.710498 |
| Gaia19etq | 145.85782 | 52.02464  | "CV"                                                                          | "Gaia source coincident with known CV brightens by ~3 mags"                       |                  | J094325.8+520126 | 145.858  | 52.0246  | 2.02100   | 2.36968  |
| Gaia19eln | 161.41020 | -60.21797 | "unknown"                                                                     | "erratic decline of ~2 mags in Gaia source, X-ray source, possible YSO"           |                  | J104538.4-601304 | 161.410  | -60.2180 | 0.295448  | 0.877756 |
| Gaia19edn | 264.63257 | -29.06309 | "unknown"                                                                     | "bright Galactic bulge transient"                                                 |                  | J173831.7-290346 | 264.633  | -29.0631 | 0.682883  | 1.81734  |
| Gaia19edg | 264.66127 | -28.59429 | "unknown"                                                                     | "new red Galactic bulge source, rising"                                           |                  | J173838.7-283539 | 264.661  | -28.5943 | 0.619623  | 2.24690  |
| Gaia19dse | 271.21823 | -24.42410 | "unknown"                                                                     | "yso candidate dims by 1.5 mag"                                                   |                  | J180452.3-242526 | 271.218  | -24.4241 | 0.300756  | 0.754139 |
| Gaia19dqi | 98.04993  | 5.00861   | "unknown"                                                                     | "candidate YSO brightens by 0.7 mag"                                              |                  | J063211.9+050031 | 98.0499  | 5.00861  | 0.256087  | 1.11049  |
| Gaia19dok | 86.60787  | 0.15886   | "YSO"                                                                         | "known YSO 2MASS J05462588+0009319 fades by 1 mag"                                |                  | J054625.8+000931 | 86.6079  | 0.158860 | 0.477594  | 1.12716  |
| Gaia19doi | 86.82992  | 0.32238   | "red Gaia source with associated X-ray source brightens by 0.3 mag. cand YSO" |                                                                                   | J054719.1+001920 | 86.8299          | 0.322380 | 0.105626 | 0.871480  |          |
| Gaia19dnu | 83.99881  | -5.49547  | "unknown"                                                                     | "irregular variable, candidate YSO, fades by ~0.8 mag"                            |                  | J053559.6-052943 | 83.9988  | -5.49547 | 1.53230   | 2.68083  |
| Gaia19dnm | 83.61638  | -5.44297  | "YSO"                                                                         | "YSO V397 Ori fades by ~1 mag"                                                    |                  | J053427.9-052635 | 83.6164  | -5.44297 | 0.700865  | 1.65273  |
| Gaia19dmu | 84.02774  | -6.53810  | "YSO"                                                                         | "YSO V823 Ori dims ~ 1 mag"                                                       |                  | J053606.5-063216 | 84.0277  | -6.53810 | 1.29337   | 1.67677  |
| Gaia19dnu | 204.41574 | -12.95685 | "QSO"                                                                         | "Blazar MLS150321:133740-125725 brightens by 1 mag in <2 months"                  |                  | J133739.7-125724 | 204.416  | -12.9568 | 0.180558  | 0.710046 |
| Gaia19dfp | 344.32212 | 7.72009   | "QSO"                                                                         | "QSO brightens 1 mag"                                                             |                  | J225717.2+074312 | 344.322  | 7.72009  | 0.271016  | 0.710551 |
| Gaia19cyi | 295.37182 | 40.19005  | "CV"                                                                          | "Gaia source brightens by ~3mags, coincident with known CV"                       |                  | J194129.2+401124 | 295.372  | 40.1900  | 0.189668  | 0.724690 |
| Gaia19cql | 35.76983  | 1.54353   | "QSO"                                                                         | "long-term rise in known QSO"                                                     |                  | J022304.7+013236 | 35.7698  | 1.54353  | 0.653822  | 1.52188  |
| Gaia19cpm | 195.17032 | 46.62363  | "QSO"                                                                         | "slow 0.7 mag rise in QSO SDSS J130040.87+463725.0"                               |                  | J130041.0+463725 | 195.170  | 46.6236  | 1.52089   | 2.92940  |
| Gaia19cjh | 139.45177 | 59.44903  | "QSO"                                                                         | "Known z=1.09QSO SDSSJ091748.42+592656.4 brightens by 1 mag over 4.5years"        |                  | J091748.4+592656 | 139.452  | 59.449   | 0.451179  | 2.93765  |
| Gaia19cjb | 155.01593 | 47.67201  | "QSO"                                                                         | "QSO brightens by 1.5 mag in 4 years"                                             |                  | J102003.9+474019 | 155.016  | 47.6720  | 1.71763   | 5.42176  |
| Gaia19byn | 105.92984 | -11.55170 | "YSO"                                                                         | "known YSO Z CMa brightens by 2 mag"                                              |                  | J070343.1-113306 | 105.930  | -11.5517 | 0.0906577 | 0.716232 |
| Gaia19bpb | 324.19646 | 57.49790  | "unknown"                                                                     | "variable source in nebula brightens by more than 1 mag, cand YSO"                |                  | J213647.1+572952 | 324.196  | 57.4979  | 0.268389  | 0.796600 |
| Gaia19bjg | 93.19016  | 17.94951  | "YSO"                                                                         | "known YSO 2MASS J06124564+1756583 fades by 0.4 mag"                              |                  | J061245.6+175657 | 93.1902  | 17.9495  | 0.293266  | 0.925655 |
| Gaia19bgg | 67.34892  | 24.54993  | "YSO"                                                                         | "YSO GV Tau brightens by 1.4 mags over 7 months"                                  |                  | J042923.7+243300 | 67.3489  | 24.5499  | 0.594991  | 0.720021 |
| Gaia19bgm | 246.65344 | -24.26455 | "YSO"                                                                         | "YSO brightens by 1.4 mag"                                                        |                  | J162636.8-241552 | 246.653  | -24.2645 | 0.335387  | 0.767438 |
| Gaia19bby | 156.80201 | -58.43518 | "unknown"                                                                     | "blue source fades by 3 mag over 5 months then brightens by 1 mag, cand R CrB"    |                  | J102712.7-582608 | 156.802  | -58.4352 | 2.95749   | 8.06233  |
| Gaia19axl | 83.85629  | -5.76245  | "unknown"                                                                     | "YSO NR Ori dims by 1.7 mag"                                                      |                  | J053525.4-054544 | 83.8563  | -5.76245 | 0.555486  | 1.47588  |
| Gaia19awk | 83.53320  | -5.60476  | "YSO"                                                                         | "YSO V396 Ori dims by >1.5 mag"                                                   |                  | J053407.9-053616 | 83.5332  | -5.60476 | 0.670211  | 1.97094  |
| Gaia19auy | 250.74506 | 39.81031  | "QSO"                                                                         | "QSO brightens by 0.8 mag over 4 months, previous event seen"                     |                  | J164258.8+394837 | 250.745  | 39.8103  | 0.235124  | 0.709886 |
| Gaia19aum | 324.30123 | -54.60881 | "unknown"                                                                     | "AGN candidate 2XMMJ213712.2-543630 fades by 1 mag in 14 months"                  |                  | J213712.3-543631 | 324.301  | -54.6088 | 0.0570065 | 0.831927 |
| Gaia19aso | 109.46604 | 45.63423  | "QSO"                                                                         | "long term brightening of QSO 7C 071413.19+454336.00"                             |                  | J071752.0+453801 | 109.466  | 45.6342  | 2.51823   | 3.43084  |
| Gaia19aso | 109.46604 | 45.63423  | "QSO"                                                                         | "long term brightening of QSO 7C 071413.19+454336.00"                             |                  | J071751.8+453803 | 109.466  | 45.6342  | 2.717118  | 0.710445 |
| Gaia19apd | 242.09364 | -39.07970 | "YSO"                                                                         | "YSO dims by almost 3 mags"                                                       |                  | J160822.4-390446 | 242.094  | -39.0797 | 0.303383  | 0.710917 |
| Gaia19ank | 83.76317  | -5.30834  | "YSO"                                                                         | "YSO V2128 Ori dims by 2 mag"                                                     |                  | J053503.1-051829 | 83.7632  | -5.30834 | 0.446697  | 0.717623 |
| Gaia19amy | 84.03455  | -6.81008  | "YSO"                                                                         | "YSO AY Ori brightens by 2 mag"                                                   |                  | J053608.2-064836 | 84.0345  | -6.81008 | 0.162987  | 0.805697 |
| Gaia19ahk | 357.01086 | -16.52000 | "QSO"                                                                         | "long term brightening of variable QSO B2345-167"                                 |                  | J234802.6-163111 | 357.011  | -16.5200 | 0.241682  | 0.709999 |
| Gaia18dzf | 343.50433 | 62.58926  | "YSO"                                                                         | "YSO dims by 1.5 mag"                                                             |                  | J225400.9+623521 | 343.504  | 62.5893  | 0.545836  | 1.19423  |
| Gaia18dvh | 38.14334  | -7.51765  | "QSO"                                                                         | "0.3 mag slow rise in QSO [VV2006] J023234.4-073104"                              |                  | J023234.3-073105 | 38.1433  | -7.51765 | 1.56576   | 5.39371  |
| Gaia18dlf | 314.26398 | 43.69568  | "YSO"                                                                         | "Long term brightening in Gaia source coincident with YSO 2MASSJ20570334+4341444" |                  | J205703.3+434144 | 314.26   | 43.6957  | 0.650846  | 0.904126 |
| Gaia18czv | 155.66286 | 34.79221  | "unknown"                                                                     | "Gaia source brightens by almost 2 mags over more than 2 years"                   |                  | J102239.1+344731 | 155.663  | 34.7922  | 0.453997  | 0.714522 |
| Gaia18cvt | 258.09947 | -38.48402 | "unknown"                                                                     | "1 mag brightening of red Gaia source, candidate YSO"                             |                  | J171223.8-382902 | 258.099  | -38.4840 | 0.269724  | 0.734929 |
| Gaia18csq | 183.76474 | -65.48969 | "unknown"                                                                     | "Apparently hostless Galactic plane transient"                                    |                  | J121503.5-652923 | 183.765  | -65.4897 | 0.262445  | 0.713470 |
| Gaia18cox | 85.43330  | -1.97933  | "YSO"                                                                         | "long-term increase in brightness (~2 mags) in YSO"                               |                  | J054143.9-015845 | 85.4333  | -1.97933 | 0.180139  | 0.808681 |
| Gaia18cos | 39.46837  | 28.80250  | "BL Lac"                                                                      | "Long term brightness increase on blazar CSS111018:023752+284809"                 |                  | J023752.3+284808 | 39.4684  | 28.8025  | 0.178321  | 0.710325 |
| Gaia18cnd | 100.27139 | 9.89670   | "YSO"                                                                         | "YSO brightens by 1.5 mag over 5 months"                                          |                  | J064105.1+095348 | 100.271  | 9.89670  | 0.574711  | 2.01164  |
| Gaia18cgq | 271.04164 | -24.32494 | "YSO"                                                                         | "Brightening in Gaia source coincident with YSO 2MASSJ18040998-2419298"           |                  | J180410.0-241930 | 271.042  | -24.325  | 0.314108  | 0.984575 |
| Gaia18cfg | 32.69251  | -51.01720 | "BL Lac"                                                                      | "BL Lac QSO B0208-512 brightens by >2 mag over 4 months"                          |                  | J021046.1-510101 | 32.6925  | -51.0172 | 0.0936309 | 0.709893 |
| Gaia18caj | 9.37029   | -33.74512 | "unknown"                                                                     | "~1.5 mag increase on AGN candidate 2XMM J003728.9-334442"                        |                  | J003728.8-334442 | 9.37029  | -33.7451 | 0.0920537 | 0.710804 |
| Gaia18hwi | 343.39782 | 62.61233  | "YSO"                                                                         | "Gaia source coincident with YSO 2MASSJ22533547+6236445 dims by ~1mag"            |                  | J225335.4+623644 | 343.398  | 62.6123  | 0.487510  | 0.812975 |

# Conclusions

- It was created software for search alert companions in some catalogues (if we want to add new catalog we need to develop only special read driver)
- It has been found that about 1% Gaia alerts have analogues in the Chandra catalogue and about 2% in the radio FIRST catalogue
- If assume that the probability to find pair is the same over the sky than we can estimate that 30-40% alerts can be associated with X-ray sources and 20% with radio sources