Globular Clusters and Low-Mass X-Ray Binaries in M87

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Sinan Alis, Genoveva Micheva
Tutor: Andrés Jordán

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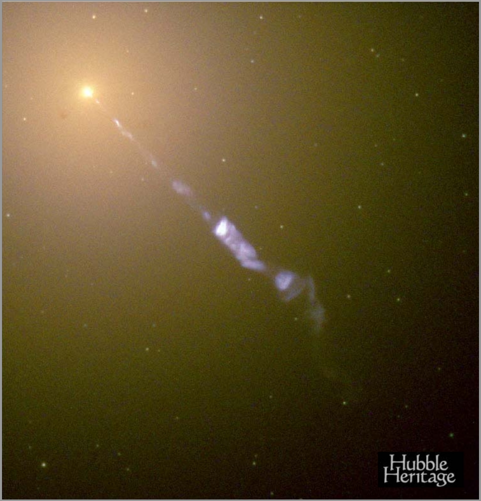
Outline

1. Introduction
   - Motivation
   - Globular Clusters
   - Low-Mass X-Ray Binaries
   - Instrument introduction
2. Data Analysis
   - HST Data
   - Chandra Data
3. Results and Conclusions
   - Discussion
   - Results

Motivation



- In Milky Way globular clusters form LMXBs efficiently
  - Small sample!
  - → Look at M87
- M87 richest globular cluster system in local universe
- → Increased GC sample of ~ 14000
- → Study properties of GCs hosting LMXBs

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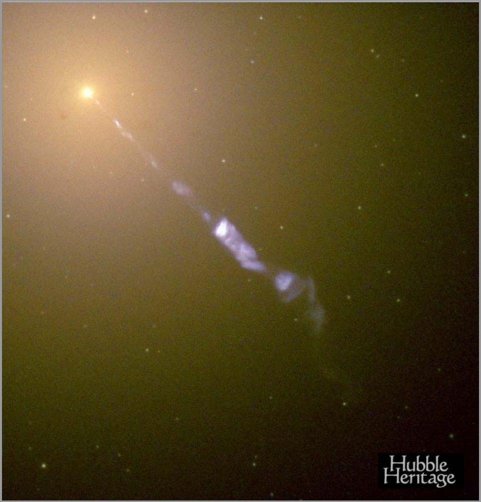

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  - $\longrightarrow$ Look at M87
- M87 richest globular cluster system in local universe

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Globular Clusters

- Spherical collection of stars orbiting a galaxy
  - Small and dense
  - Dust and gas free
  - Diameter independent of mass
- Old systems, mainly population II stars
- Luminosity Function used as standard candle

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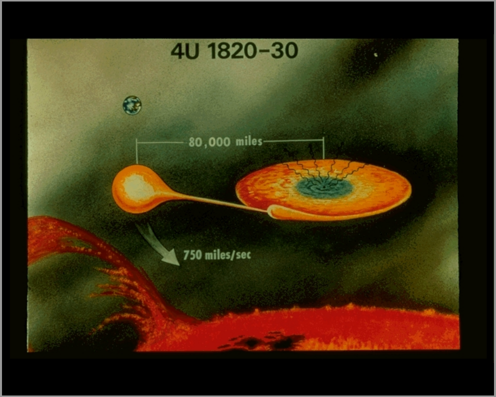
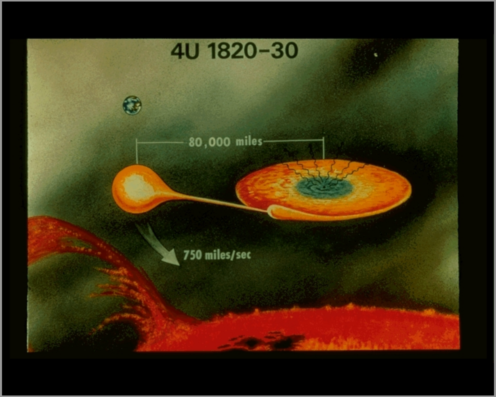
Low-Mass X-Ray Binaries



- Binary Systems
  - Neutron star or blackhole primary
  - Late-type secondary $M \lesssim 2.0 M_\odot$
- Mass overflow (Roche lobe filling)
- $L \sim 10^{35} - 10^{39}$ erg/s
- Older than 10^9yr
- Possible formation
  - Direct formation
  - Tidal capture
  - Binary exchange processes

Low-Mass X-Ray Binaries



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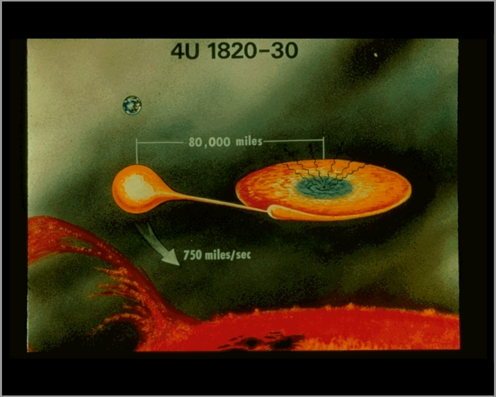

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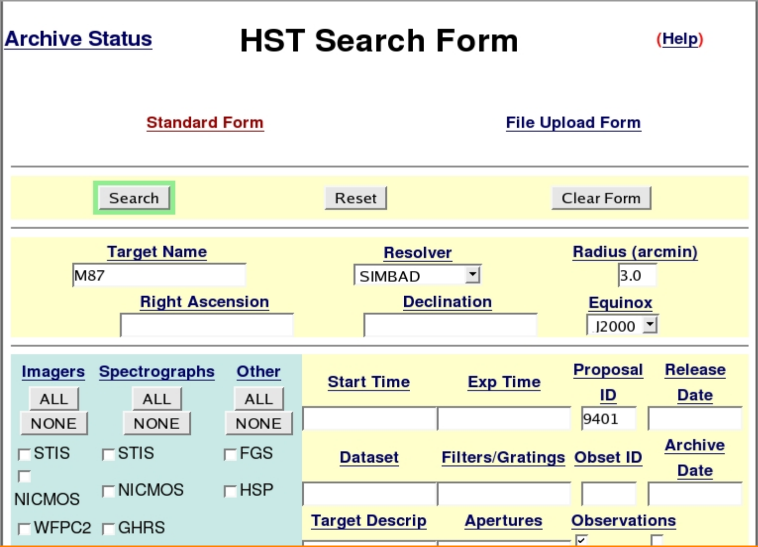
Optical and X-Ray data

ACS Wide Field Camera
202”×202” FoV
2×560s + 90s F850LP ($\simeq z$ band)
2×375s F475W ($\simeq g$ band)

ACIS Imaging mode
8’×8’ FoV (S3)
105 ks exposure time

Obtaining optical data



Archive Status

HST Search Form

(Help)

Standard Form

File Upload Form

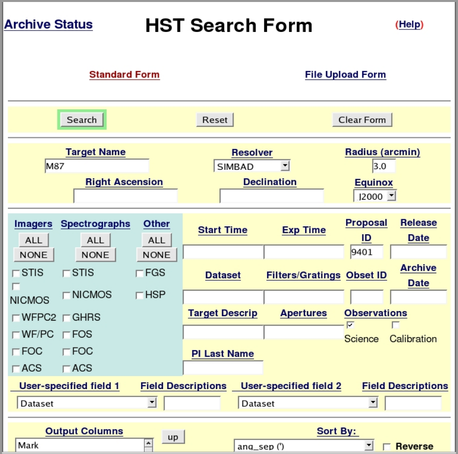
Search | Reset | Clear Form

Target Name: M87
Resolver: SIMBAD
Radius (arcmin): 3.0
Right Ascension
Declination
Equinox: J2000

Imagers: ALL NONE — STIS, NICMOS, WFPC2
Spectrographs: ALL NONE — STIS, NICMOS, GHRS
Other: ALL NONE — FGS, HSP

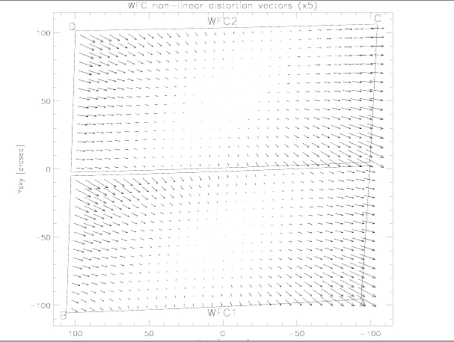
Start Time | Exp Time | Proposal ID: 9401 | Release Date
Dataset | Filters/Gratings | Obset ID | Archive Date
Target Descrip | Apertures | Observations

Obtaining optical data



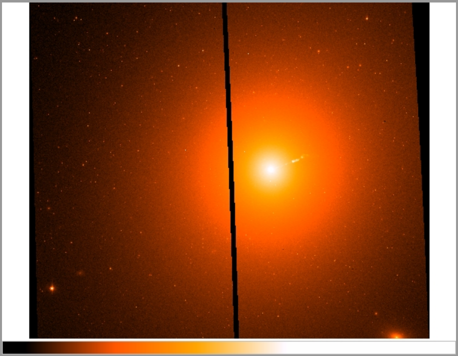
- Obtain data from **http://archive.stsci.edu/hst**
- Program ID: GO-9401
- Program PI: Patrick Côté

Processing optical data



- Software: PyRAF
- Necessity of drizzling with *multidrizzle* (calibration files)
    - corrects for built-in geometric distortion (off-axis location of instrument)
    - restores information lost due to undersampling
    - combines dithered images
    - filters cosmic rays

Processing optical data



- Software: SExtractor
- Source extracting in both bands
  - DETECT_MINAREA 5
  - DETECT_THRESH 3
  - PHOT_APERTURES 4 8 10 16
  - SATUR_LEVEL 65000
  - MAG_ZEROPOINT 26.068 (F475W, AB)
  - MAG_ZEROPOINT 24.862 (F850LP, AB)
  - PIXEL_SCALE 0.049
  - SEEING_FWHM 0.098
  - BACK_SIZE 32

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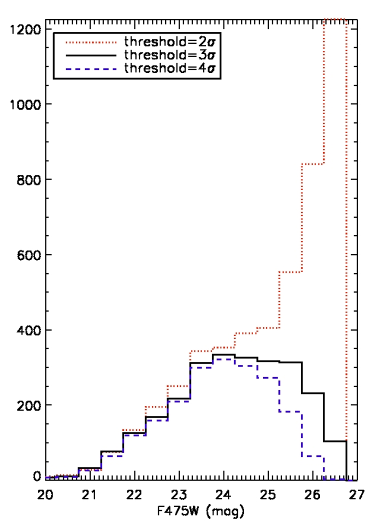

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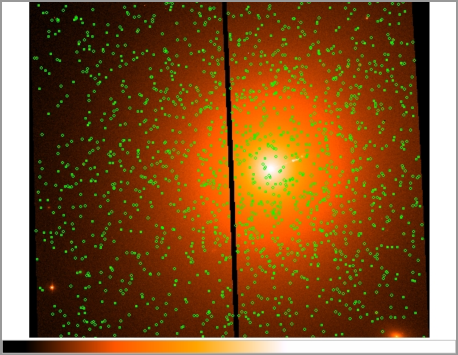
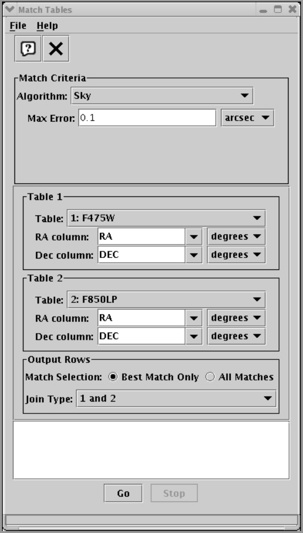


- 2608 sources (F475W)
- 2372 sources (F850LP)
- 1911 sources (cross-matched) with TOPCAT

Processing optical data



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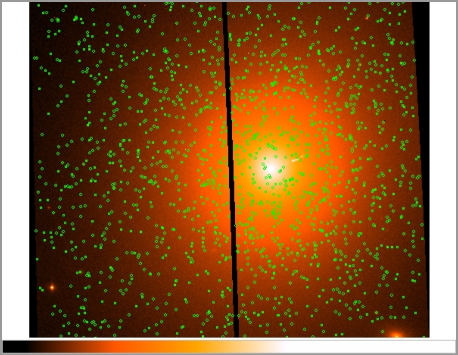
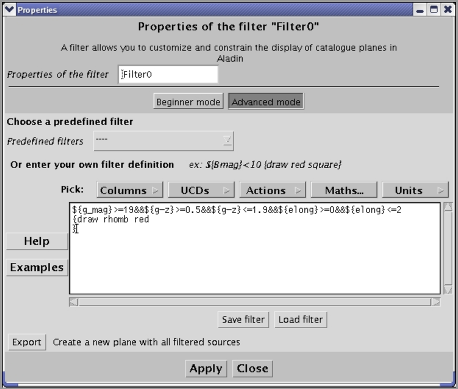
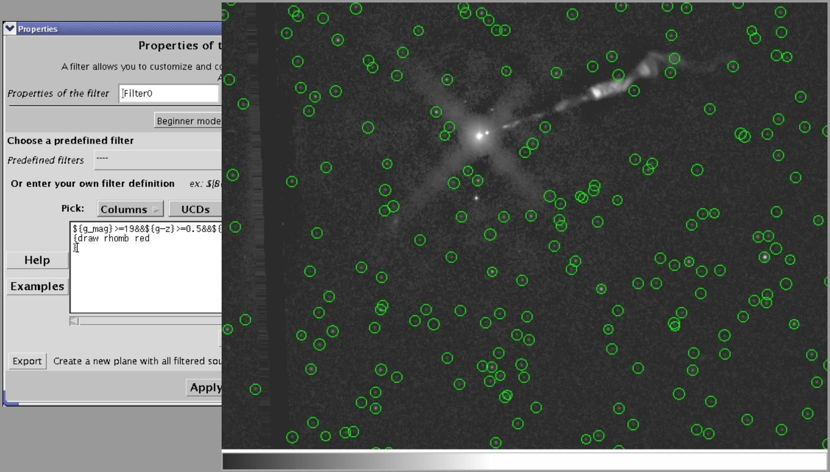


Filtering optical data



- Aladin filter applied to cross-matched catalog
  - $0.5 \leq$ g-z≤ 1.9
  - $m_z > 19$
  - $m_g > 19$
  - $0 <$ elongation < 2

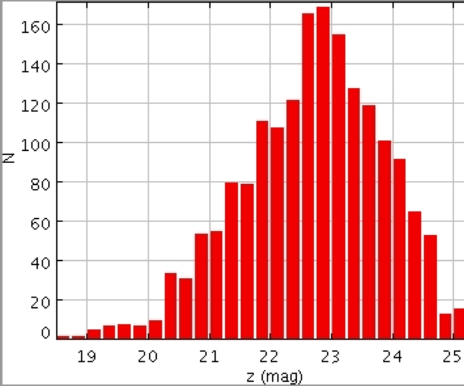
Filtering optical data



Analyzing optical data

- Calculate distance
  - $m_z - M_z = 5\log d - 5 + A_z$
  - $E(B-V) = 0.022$ (taken from NED database)
  - $A_z = 1.485 \times E(B-V)$ (from Jordán et al., 2004)
  - $m_{peak} \simeq 22.8$ (for the z band)
  - $(M_{peak}/L_{peak})_z \sim 1.5 \times (M_\odot/L_\odot)$ (from PÉGASE models)
  - $M_{peak} - M_\odot = 2.5\log(L_\odot/L_{peak})$

  Where m, M, A_z are apparent and absolute magnitudes and extinction, resp.



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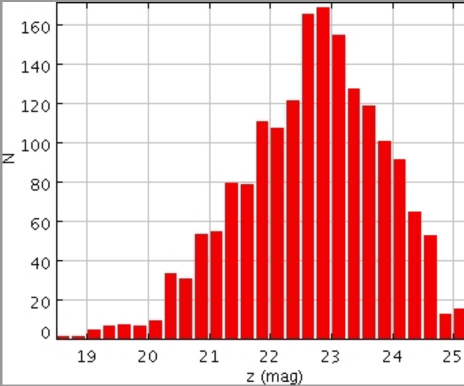
$\boxed{16.1 \text{ Mpc}}$



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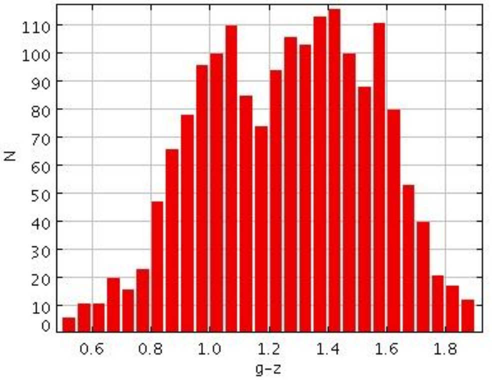
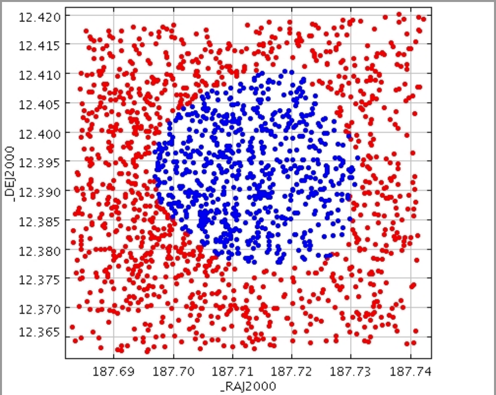


- Two distinct populations
  - $g - z < 1.2$
  - $g - z > 1.2$

  Two different mean metallicities

Analyzing optical data



- Comparison between inner and outer part of the population
  - Define two regions
  - No significant shift of the peaks
  - BUT: More metal-rich in inner part

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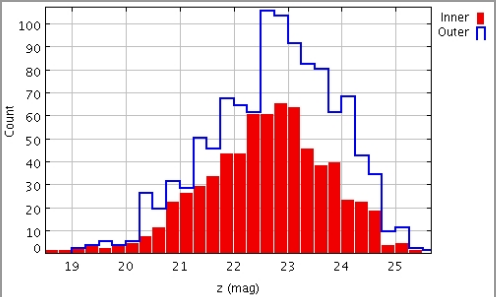

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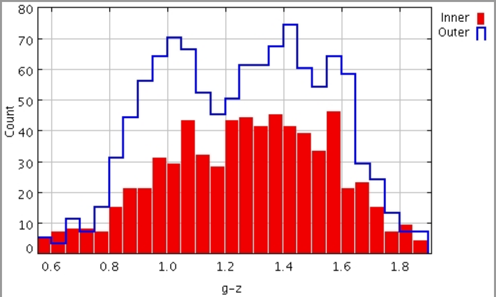

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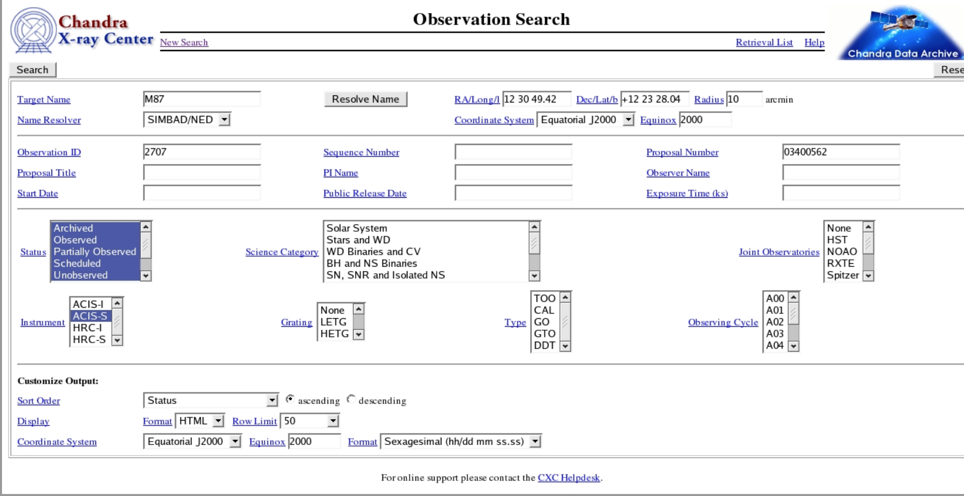
Obtaining X-ray data



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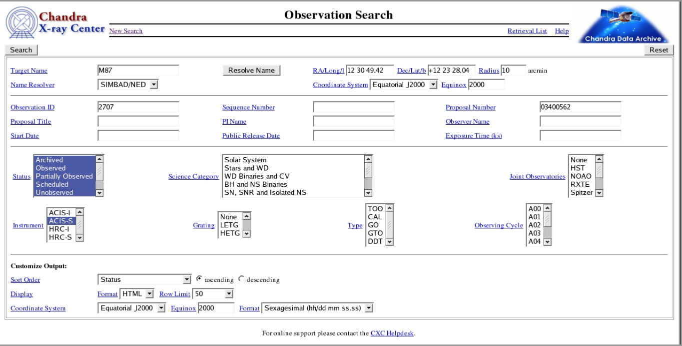
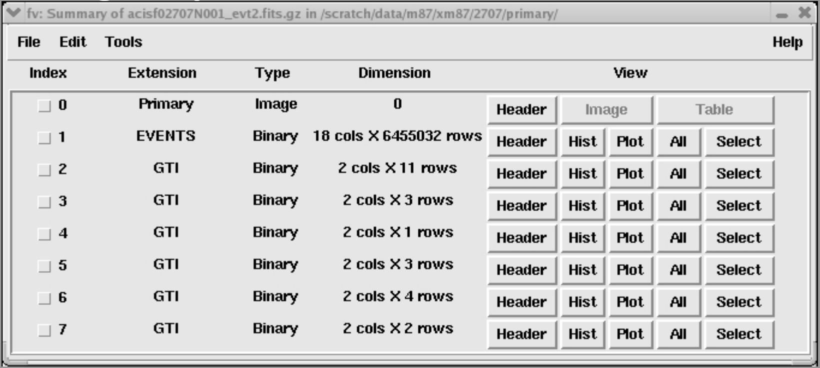


- Obtain data from **http://cda.harvard.edu/chaser/dispatchOcat.do**
- Obs ID: 2707
- Program PI: Patrick Côté

Processing X-ray data


fv: Summary of acisf02707N001_evt2.fits.gz in /scratch/data/m87/xm87/2707/primary/

File Edit Tools Help

Index	Extension	Type	Dimension	View				
0	Primary	Image	0	Header	Image		Table	
1	EVENTS	Binary	18 cols X 6455032 rows	Header	Hist	Plot	All	Select
2	GTI	Binary	2 cols X 11 rows	Header	Hist	Plot	All	Select
3	GTI	Binary	2 cols X 3 rows	Header	Hist	Plot	All	Select
4	GTI	Binary	2 cols X 1 rows	Header	Hist	Plot	All	Select
5	GTI	Binary	2 cols X 3 rows	Header	Hist	Plot	All	Select
6	GTI	Binary	2 cols X 4 rows	Header	Hist	Plot	All	Select
7	GTI	Binary	2 cols X 2 rows	Header	Hist	Plot	All	Select

- One event per photon
- Photon energy, position & time of arrival stored

→ Possibility of obtaining spectra and images

Processing X-ray data

fv: Binary Table of acisf02707N001_evt2.fits.gz[1] in /scratch/data/m87/xm87/2707/primary/

File Edit Tools Help

Select	time	ccd_id	node_id	expno	chipx	chipy	tdetx	tdety	detx	dety	x	y
	1D	1I	1I	1J	1I	1I	1I	1I	1E	1E	1E	1E
All	s				pixel	pixel	pixel	pixel	pixel	pixel	pixel	pixel
Invert												
1	1.423799869622E+08	2	0	3	54	63	3124	4032	3.089413E+03	2.285412E+03	6.096516E+03	3.619580E+03
2	1.423799869622E+08	2	3	3	824	84	3145	3262	3.112983E+03	3.053402E+03	5.350648E+03	3.435065E+03
3	1.423799869622E+08	2	3	3	882	280	3341	3204	3.308089E+03	3.111021E+03	5.242524E+03	3.607390E+03
4	1.423799869622E+08	2	0	3	51	388	3449	4035	3.414205E+03	2.282513E+03	6.011675E+03	3.933110E+03
5	1.423799869622E+08	2	3	3	887	431	3492	3199	3.459158E+03	3.116515E+03	5.196474E+03	3.751373E+03
6	1.423799869622E+08	2	1	3	400	542	3603	3686	3.568831E+03	2.630400E+03	5.634971E+03	3.988138E+03
7	1.423799869622E+08	2	3	3	799	623	3684	3287	3.650570E+03	3.028932E+03	5.229164E+03	3.959317E+03
8	1.423799869622E+08	2	1	3	327	727	3788	3759	3.752404E+03	2.558263E+03	5.654902E+03	4.184366E+03
9	1.423799869622E+08	2	1	3	377	952	4013	3709	3.977418E+03	2.607432E+03	5.546846E+03	4.387768E+03
10	1.423799870032E+08	7	3	3	881	10	4798	1712	4.761073E+03	4.602163E+03	3.414655E+03	4.604163E+03
11	1.423799870032E+08	7	2	3	671	12	4588	1714	4.551036E+03	4.600621E+03	3.472810E+03	4.402331E+03
12	1.423799870032E+08	7	0	3	74	18	3991	1720	3.955225E+03	4.595276E+03	3.638712E+03	3.830059E+03
13	1.423799870032E+08	7	2	3	686	22	4603	1724	4.566297E+03	4.590324E+03	3.478607E+03	4.419804E+03
14	1.423799870032E+08	7	0	3	85	28	4002	1730	3.966067E+03	4.585139E+03	3.645548E+03	3.843234E+03
15	1.423799870032E+08	7	2	3	665	44	4582	1746	4.545069E+03	4.568715E+03	3.505142E+03	4.405194E+03
16	1.423799870032E+08	7	0	3	248	47	4165	1749	4.128573E+03	4.566060E+03	3.620073E+03	4.004861E+03
17	1.423799870032E+08	7	0	3	24	52	3941	1754	3.905077E+03	4.561281E+03	3.684976E+03	3.790943E+03
18	1.423799870032E+08	7	0	3	118	55	4035	1757	3.998686E+03	4.557890E+03	3.662985E+03	3.881995E+03
19	1.423799870032E+08	7	0	3	206	61	4123	1763	4.087201E+03	4.551770E+03	3.644996E+03	3.968879E+03
20	1.423799870032E+08	7	0	3	176	71	4093	1773	4.056795E+03	4.541694E+03	3.662902E+03	3.942319E+03

Go to: Edit cell:

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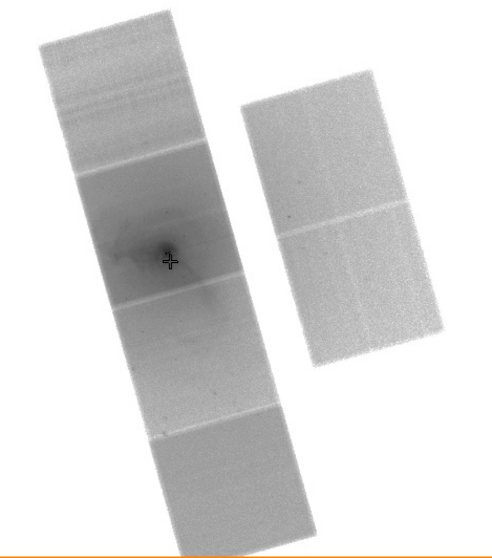
→ Possibility of obtaining spectra and images

Processing X-ray data



- 6 ACIS chips
- Using Software CIAO to:
  - Cut to S3
  - Restrict the image to HST FoV
  - Construct the background light curve (S1)
  - No background flares

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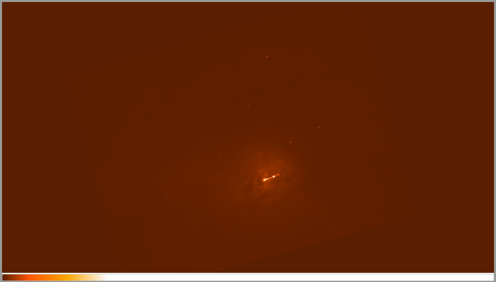

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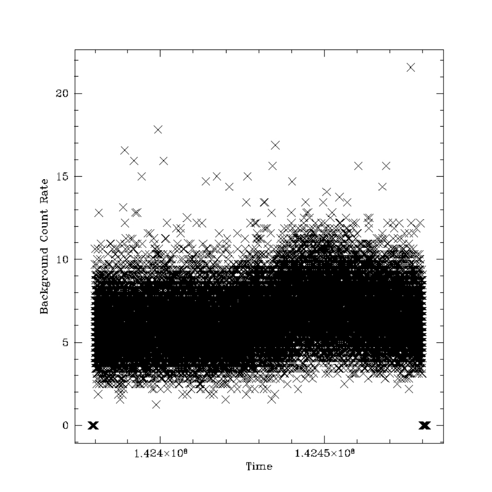

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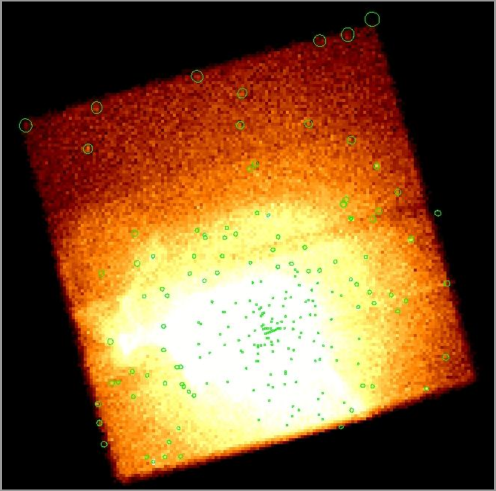

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- Manual removal of problematic regions

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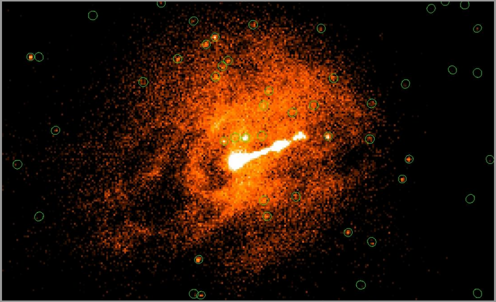

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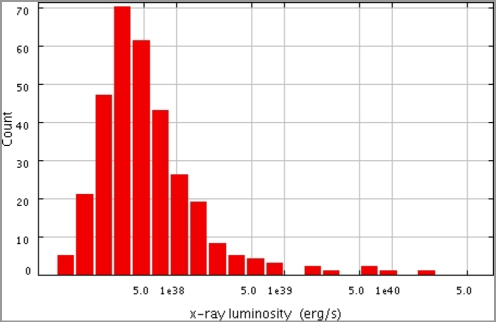
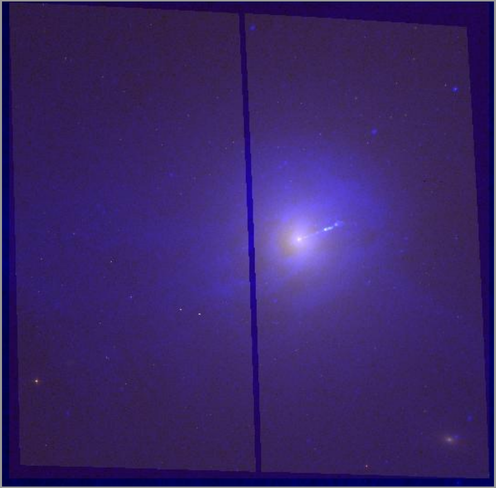
Analyzing X-ray data



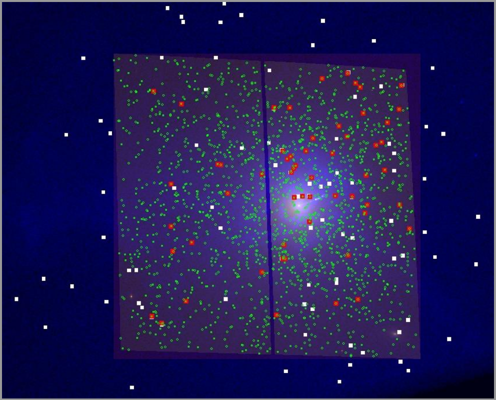
- LF shape compatible with LMXB population, peak artificial
- Higher luminosities suggest possible BH presence

Cross-matching optical & X-rays



- RGB image (ds9)
  - Red: F850LP ($\simeq$ Sloan z)
  - Green: F475W ($\simeq$ Sloan g)
  - Blue: X-ray
- Cross-matching the catalogues
  - Green: Optical catalogue
  - White: X-ray catalogue
  - Red: Cross-matched

Cross-matching optical & X-rays



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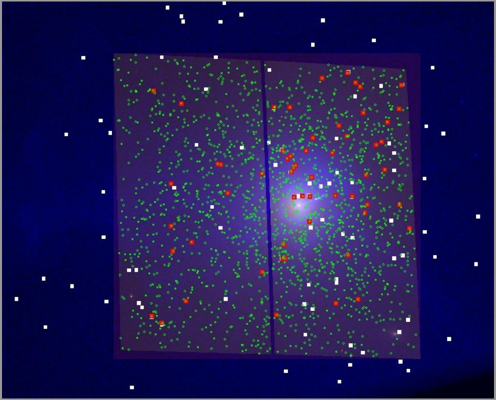
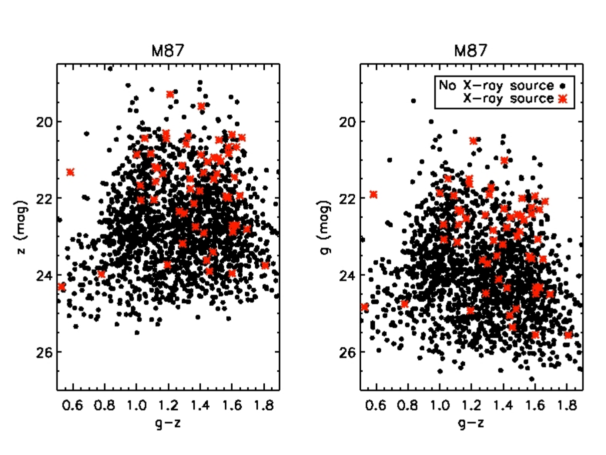


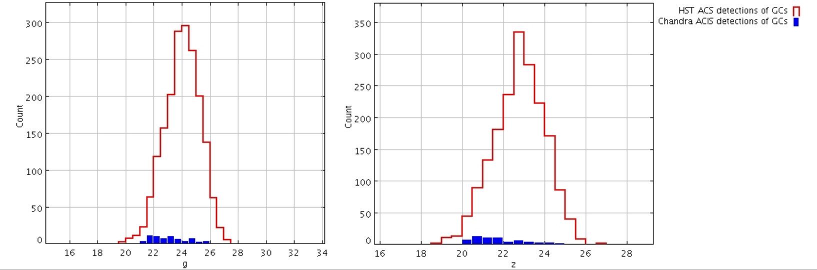
- Cross-match performed with TOPCAT
- Using RA & DEC for matching (0.1" threshold)
    - 1769 optical sources
    - 179 X-ray sources
    - 57 cross-matches

Properties of optical counterparts



- Redder in color
- Brighter in g & z mag
- ∼ 2 times more frequent in the red peak

Properties of optical counterparts



- Different behaviour of two populations
  - GCs containing LMXBs are brighter
- Higher density favours LMXB formation

THANK YOU!