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17-V-2006

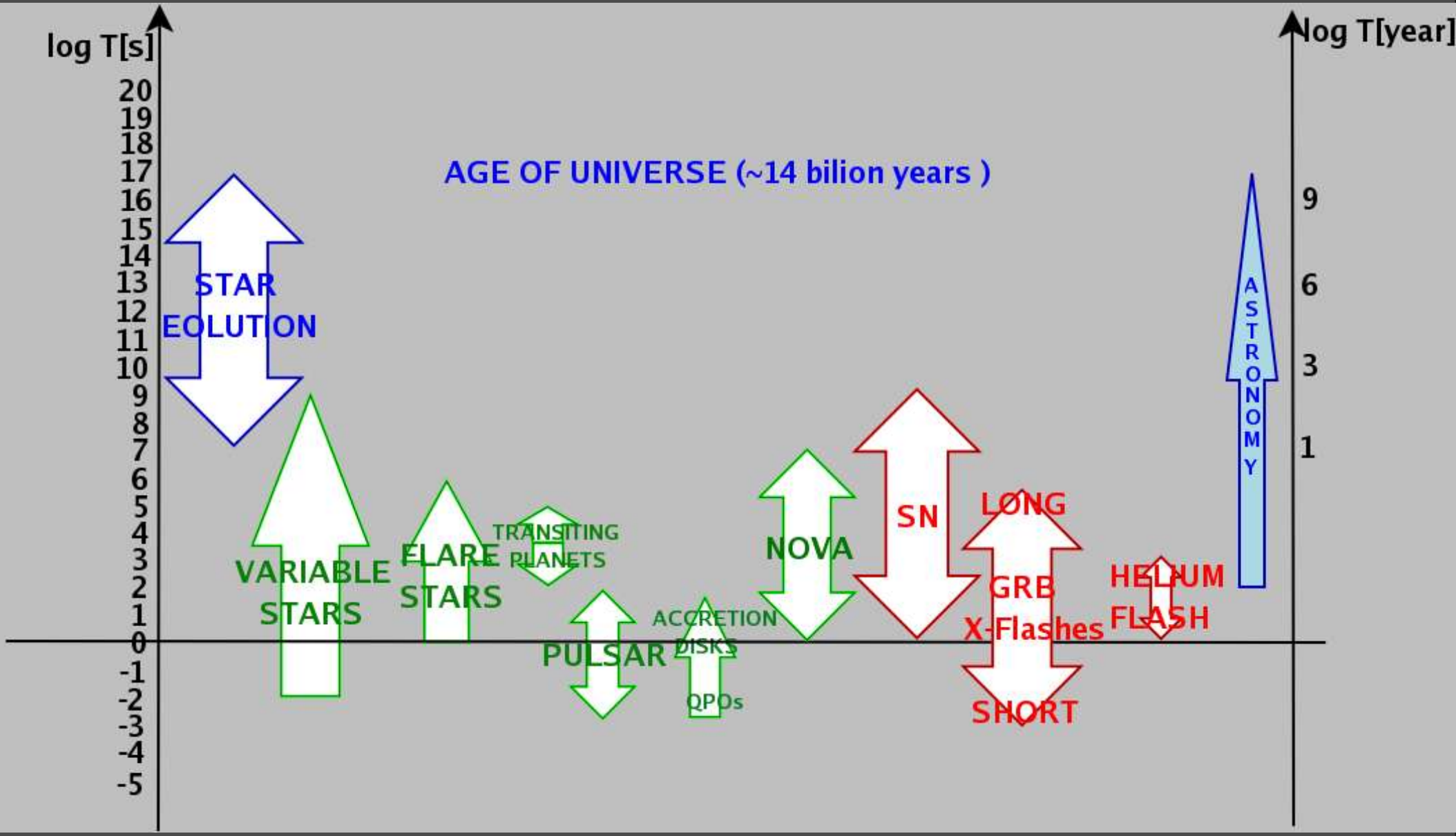
Observation of short timescale astrophysical phenomena in the ,,Pi of the Sky'' experiment

Workshop : Physics at future colliders

Agenda

- timescales of astrophysical processes
- “Pi of the Sky” experiment
- data analysis in π
- results
- summary

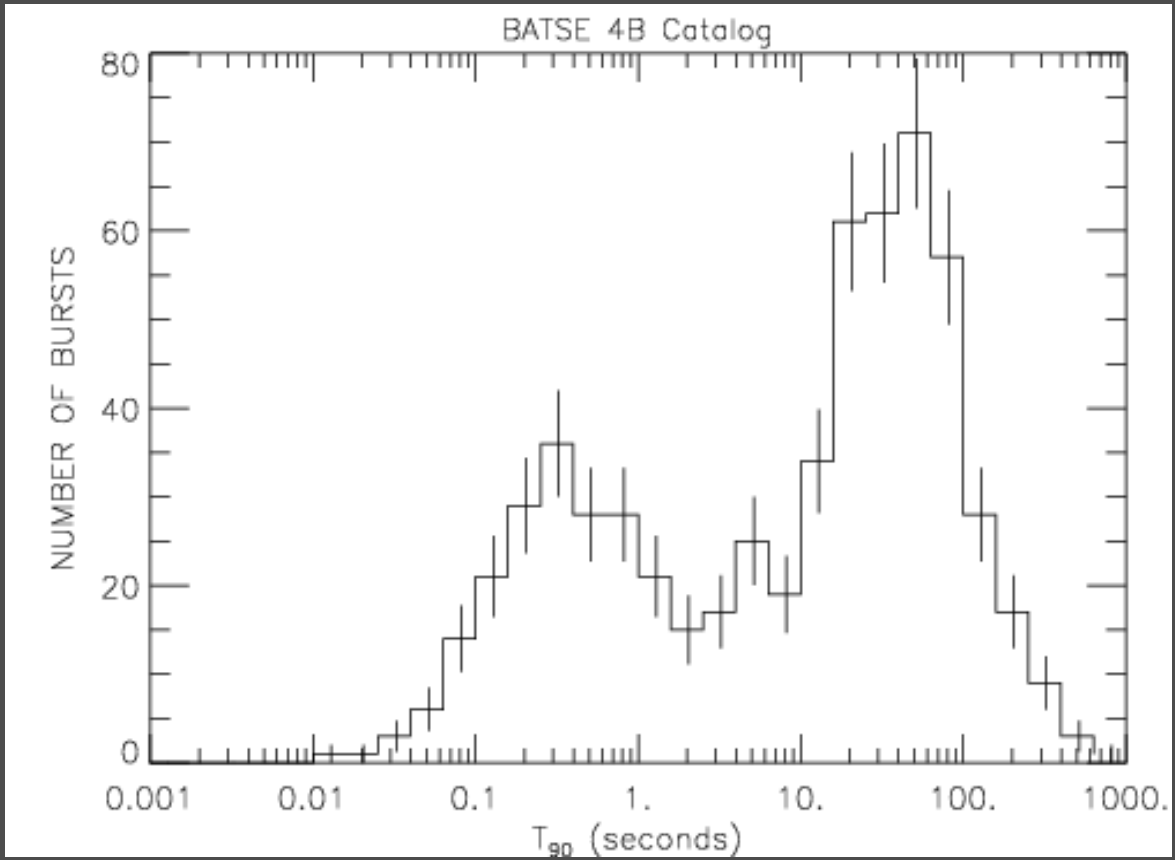
Astrophysical timescales



Gamma Ray Bursts (GRB)

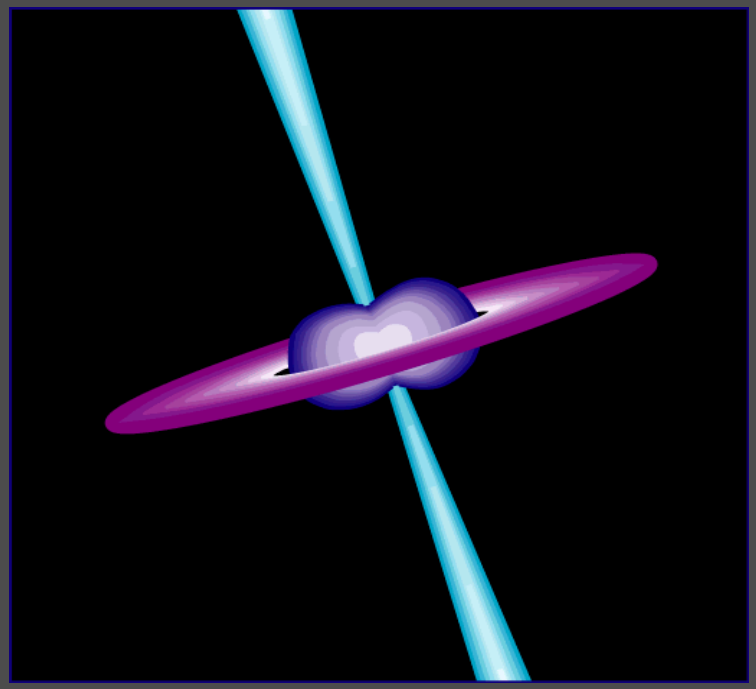
- short pulses (0.1 – 100 s) of gamma radiation coming from point sources on the sky
- gamma observation only from outside atmosphere – satellites, information is passed through GCN
- about 3 daily occur, over a dozen per month are detected by satellites
- extragalactic origin and huge energies : 10^{51} ergs (collimated) Sun emits 10^{33} erg / s , it means billion years of Sun shine !
- genesis still remains unclear , long bursts due to death of massive star , short ones collision of two neutron stars in binary system
- they may be accompanied by optical flash - **afterglow**
- important information is the observation of optical afterglow in early time – even before gamma emission itself , it cannot be realized by classical robotic telescopes
- significant neutrino emission (also UHE) is theoretically predicted

GRB – durations

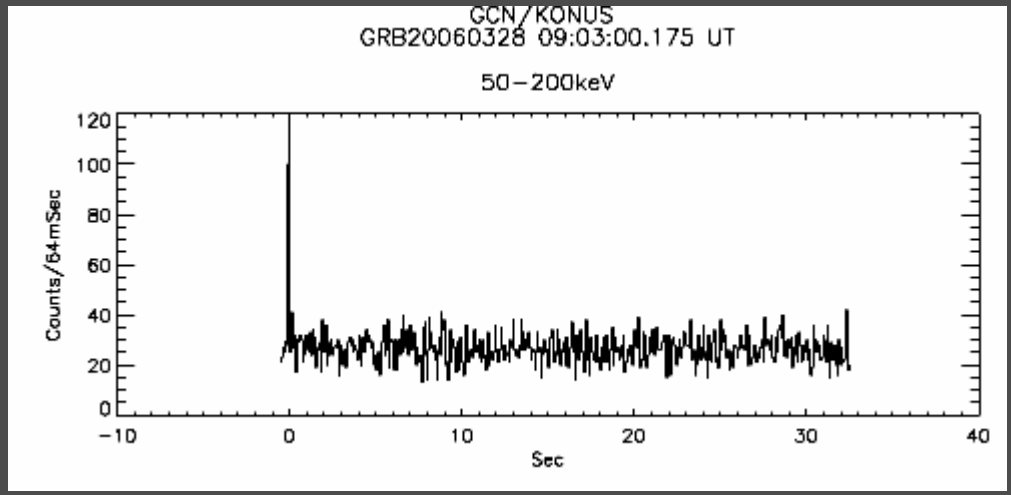


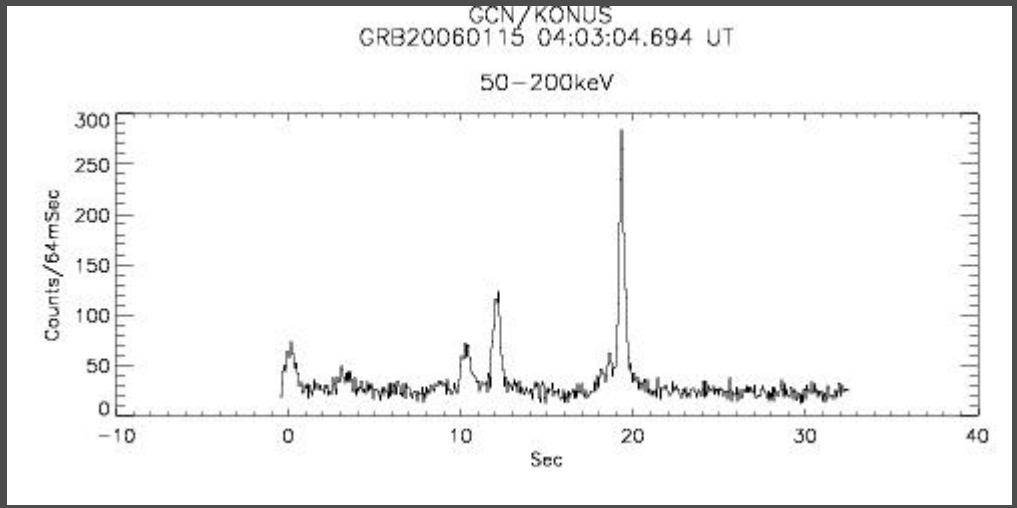
GRB – short and long

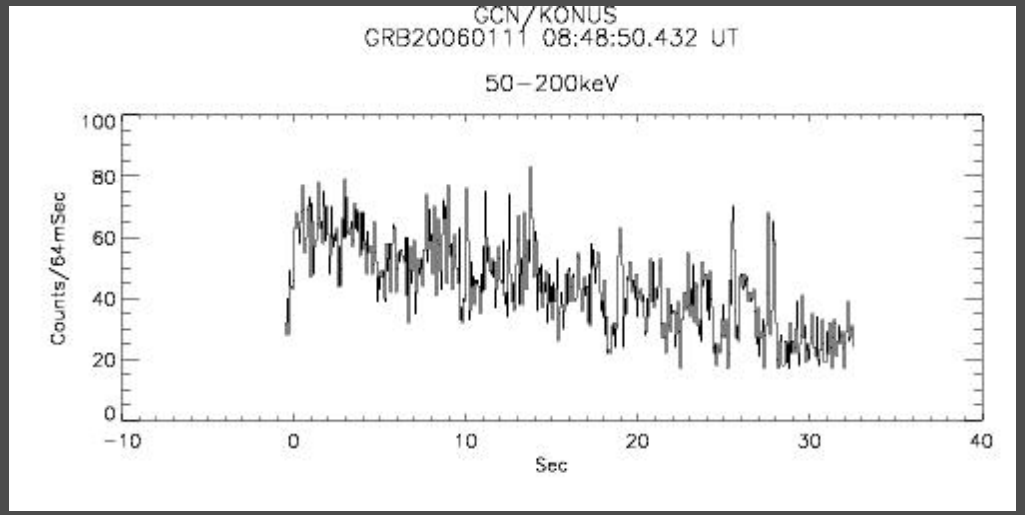
NS-NS Collision



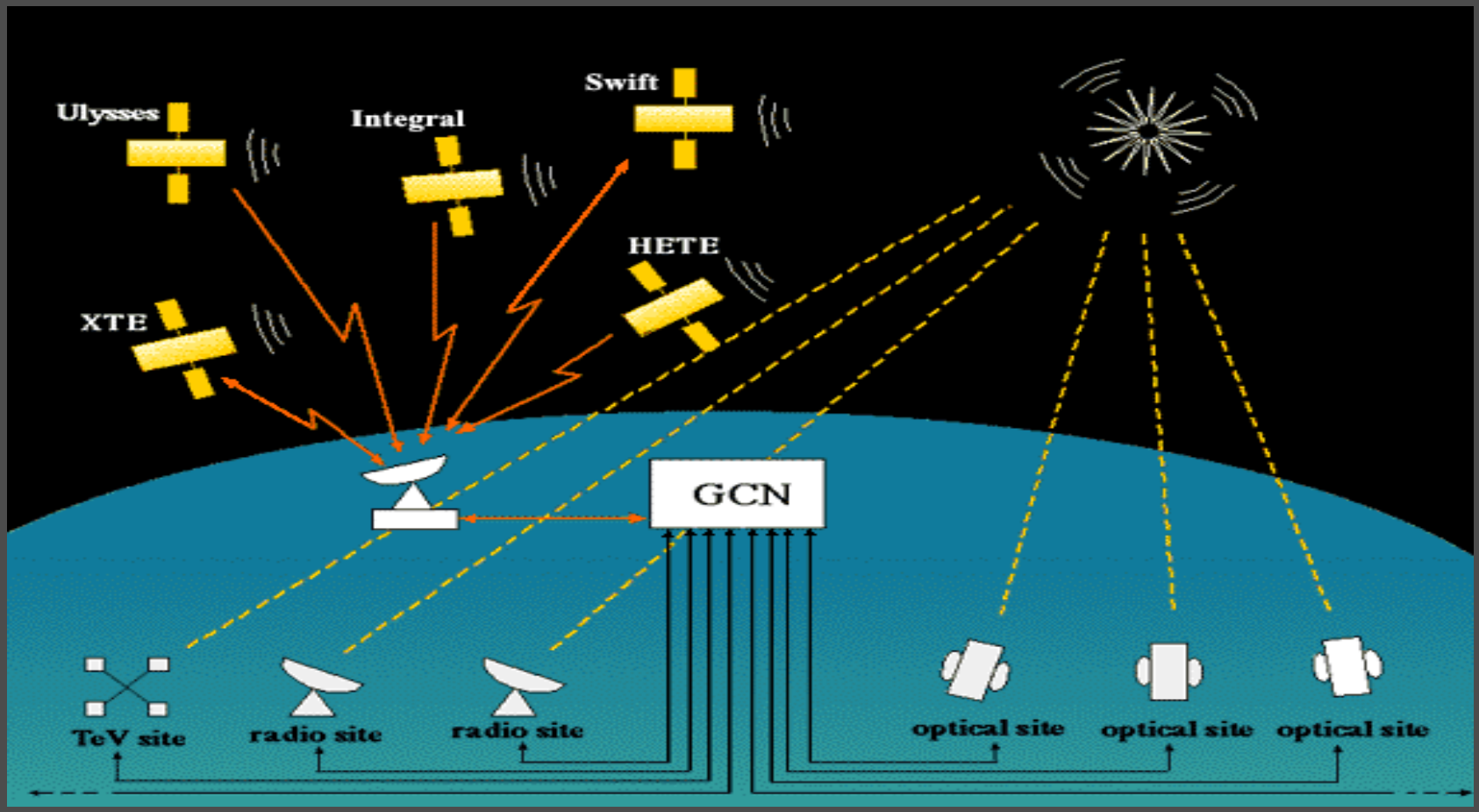
GRB lightcurve examples







GCN Network

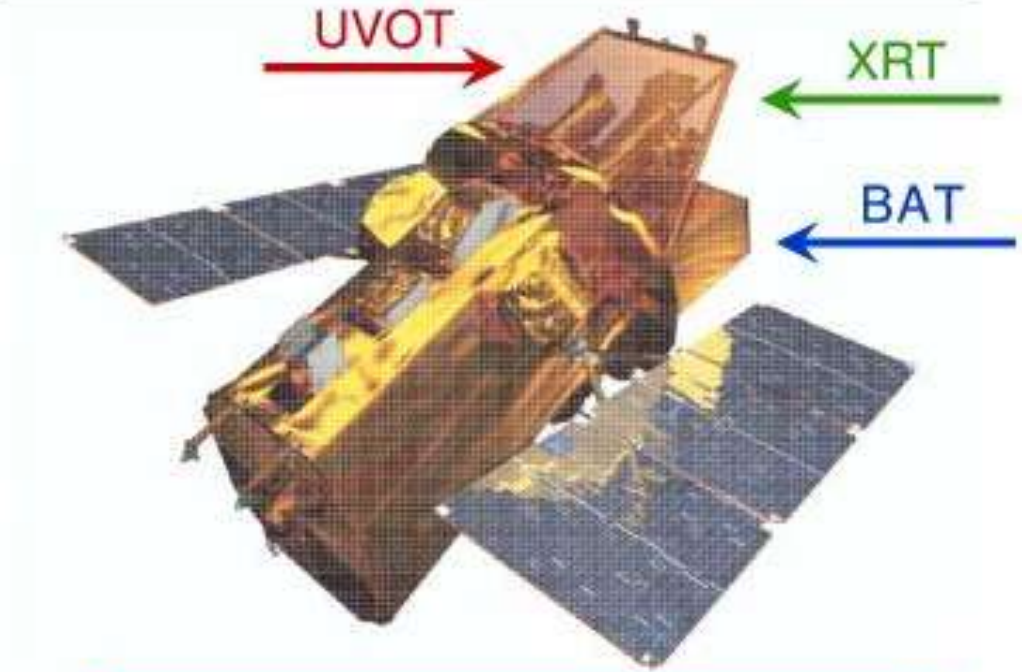


limitations :

- time of signal propagation from satellite to ground telescope
- inertia of telescope
- only in few cases observation seconds after gamma detection

<N> ~ 6 GRB /month

The *Swift* satellite



BURST ALERT TELESCOPE

* Imaging: 15-150 keV
* Precision: 2-3 arcmin
* Field of view: 1/6 of sky

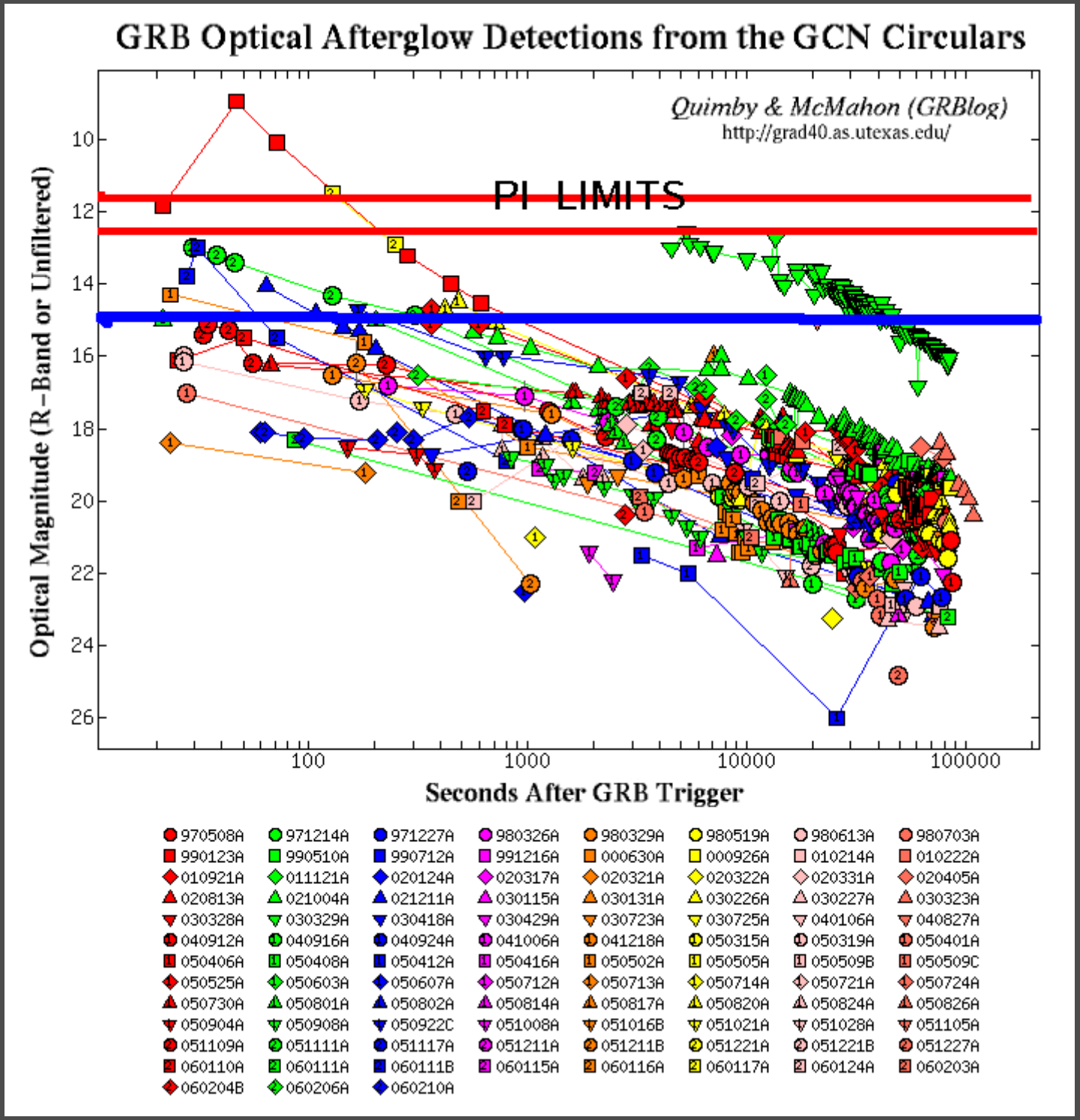
UV/OPTICAL TELESCOPE

* Imaging: 1700 – 6500 Å
* Precision: 0.5 arcsec
* Sensitivity: $V = 20$

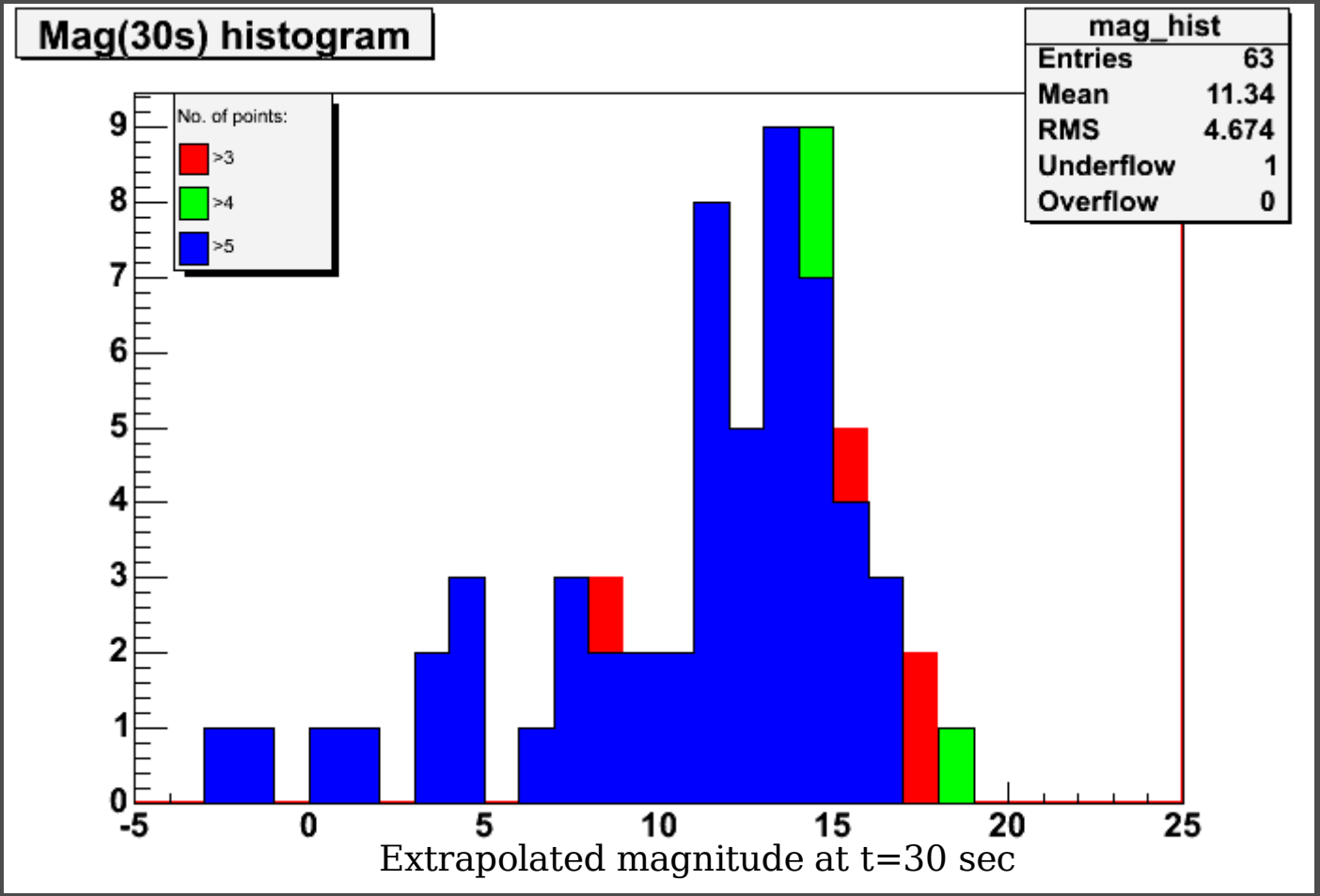
X-RAY TELESCOPE

* Imaging in 0.2–10 keV
* Precision: 3 arcsec
* Sensitivity: 2×10^{-14} cgs

Optical afterglows of long GRBs



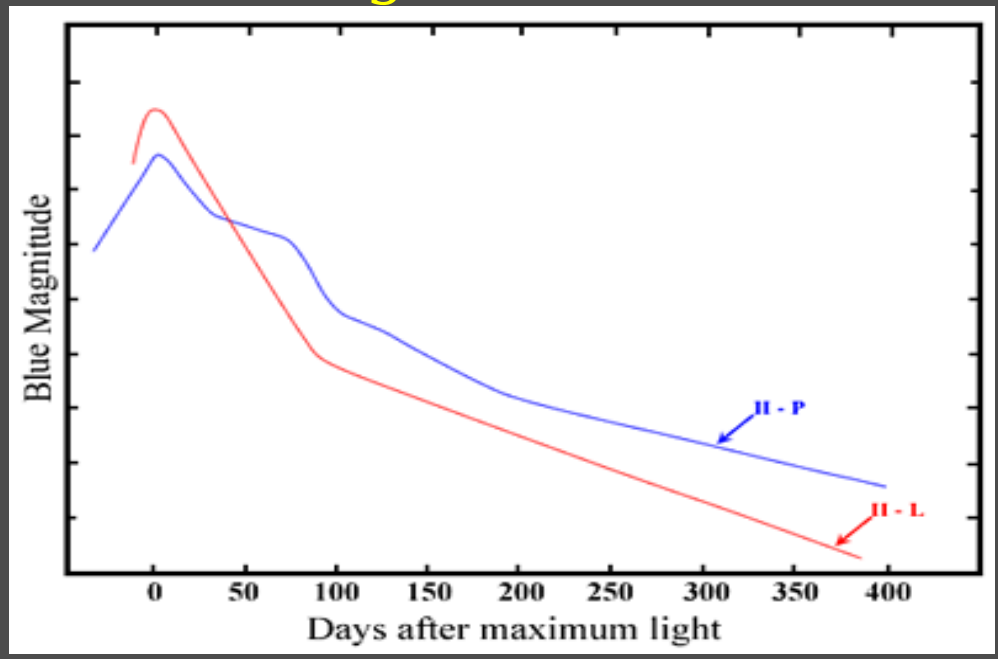
Distribution of extrapolated magnitude at t=30 sec (only well fitted lightcurves used)



SuperNova

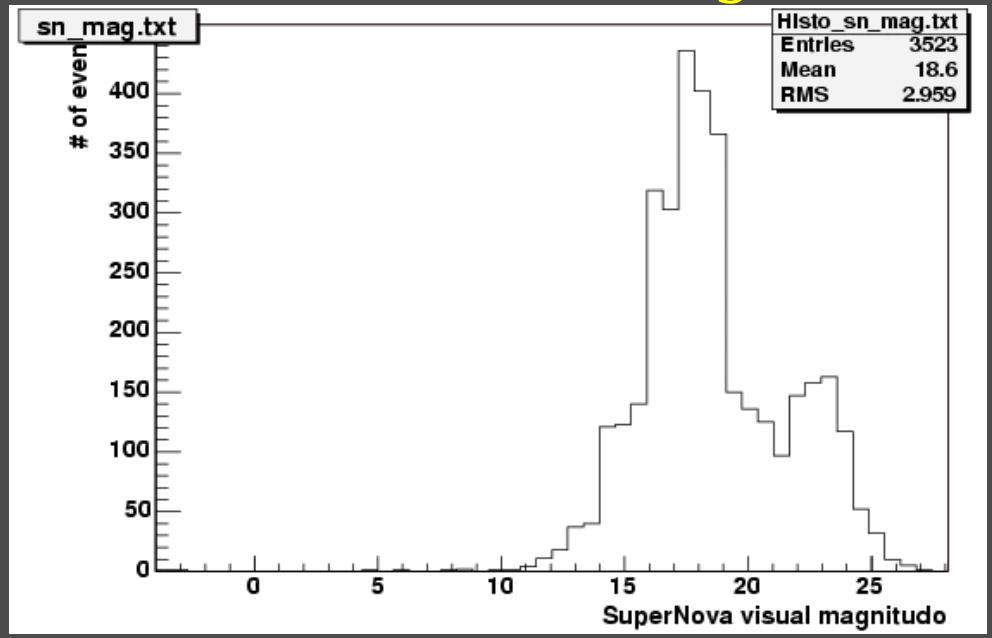
Artist's view

Lightcurve

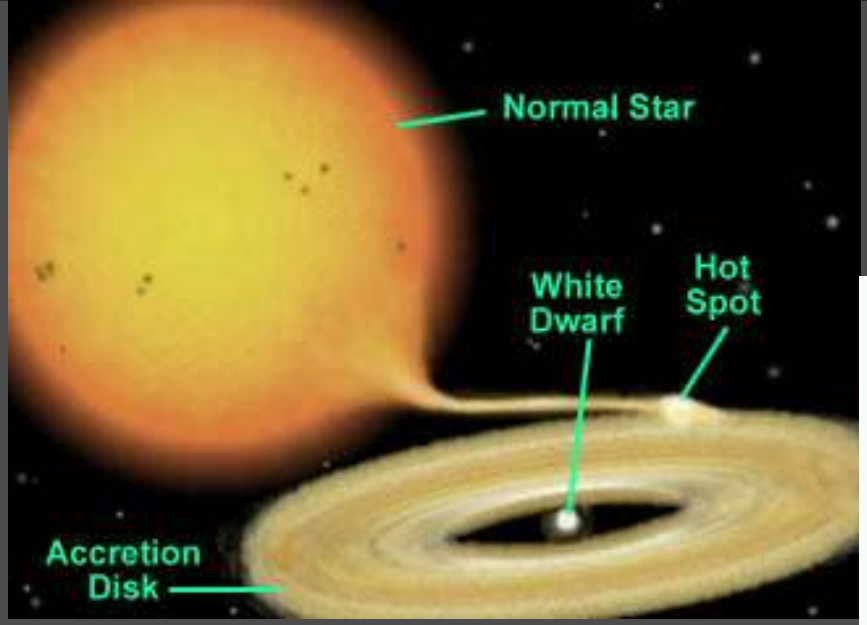


SNR – Crab Nebula in X-ray

Distribution of SN magnitudes



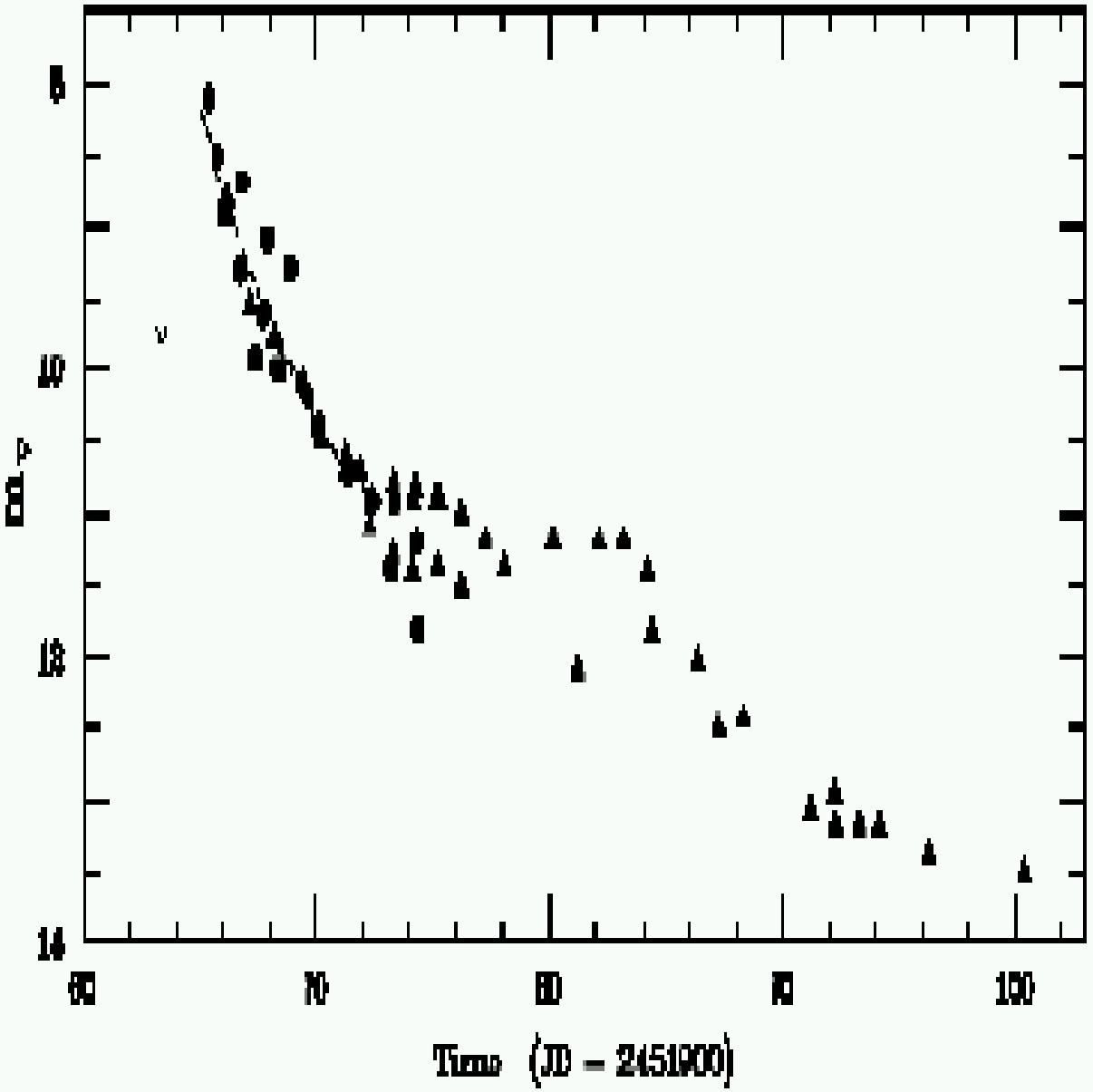
Nova_



Artist's view

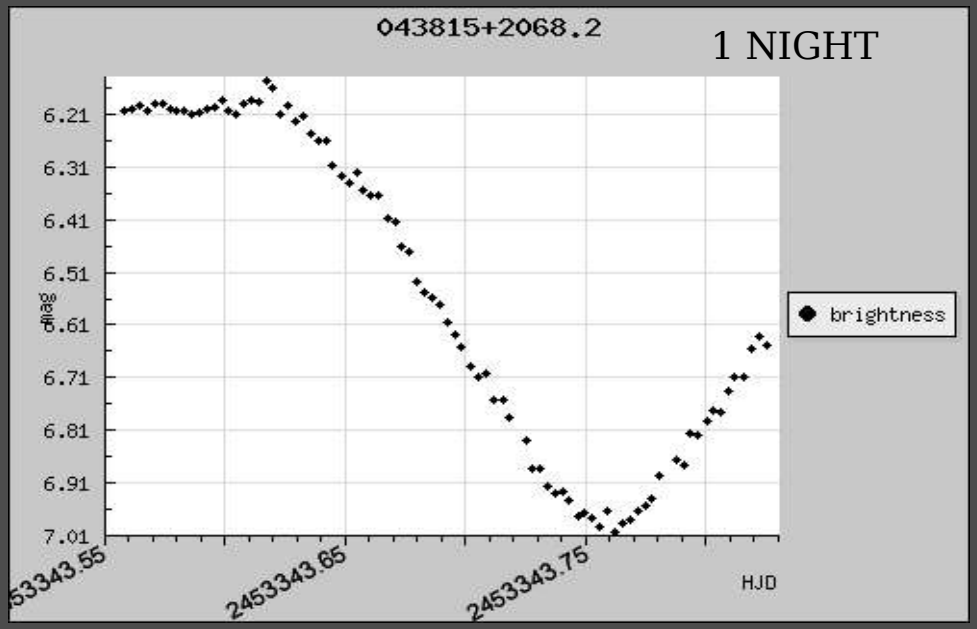
Thermonuclear explosion of matter accreted on White Dwarf from companion star

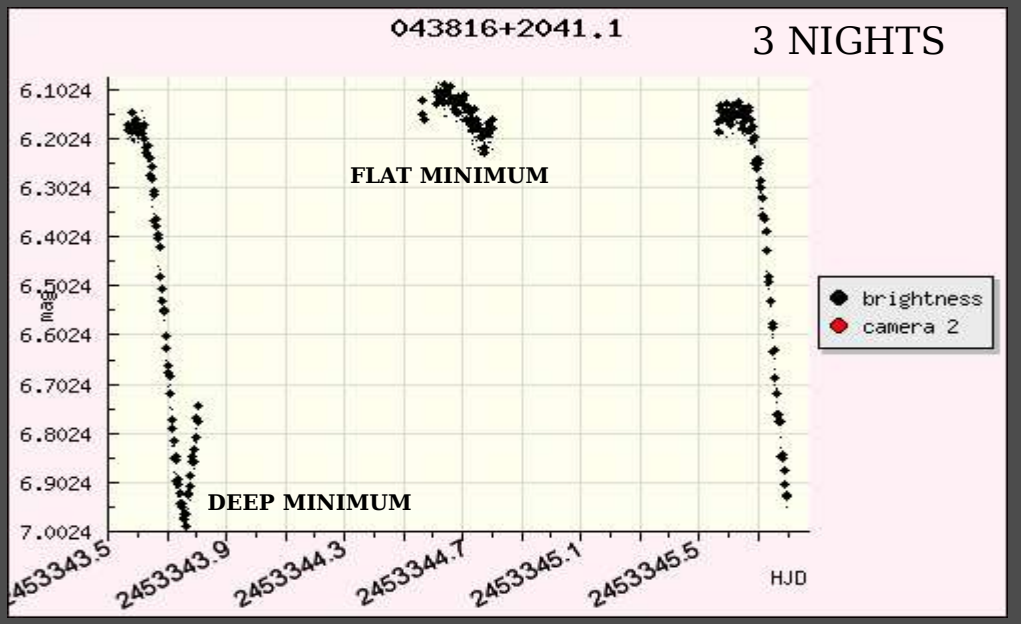
Lightcurve



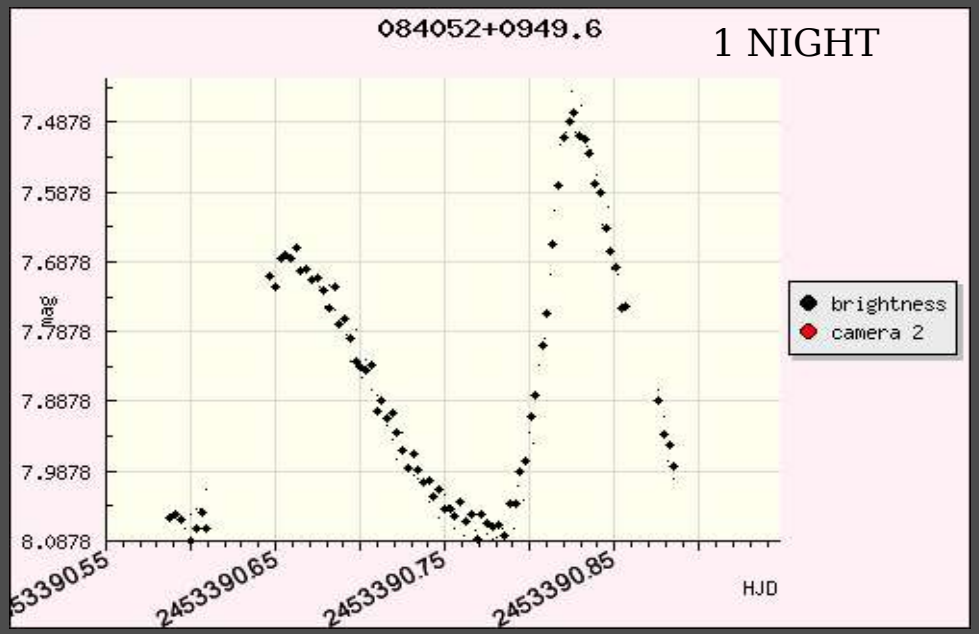
Variable Stars

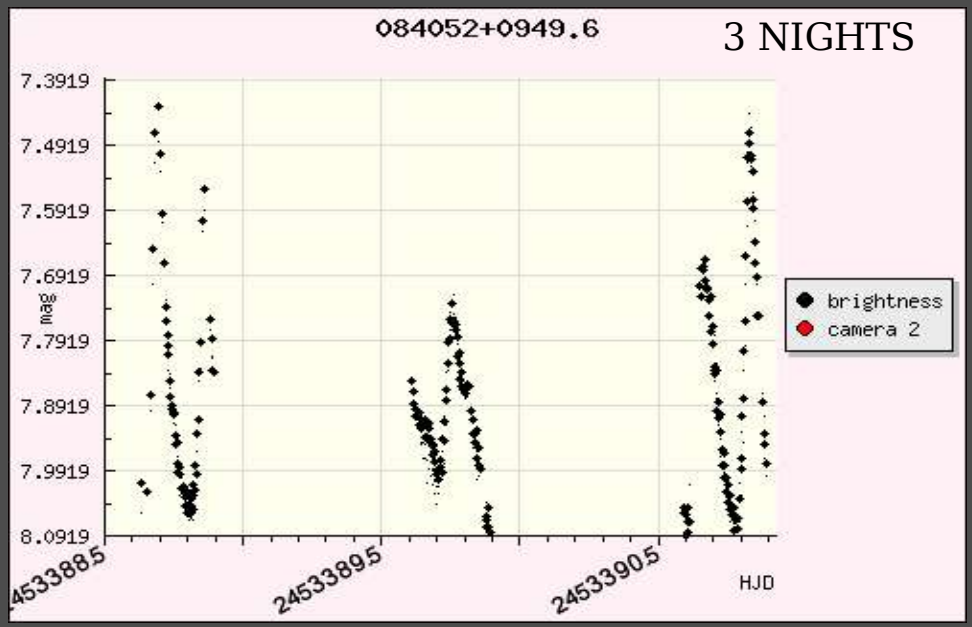
HD 29365 – eclipsing binary of ALGOL type





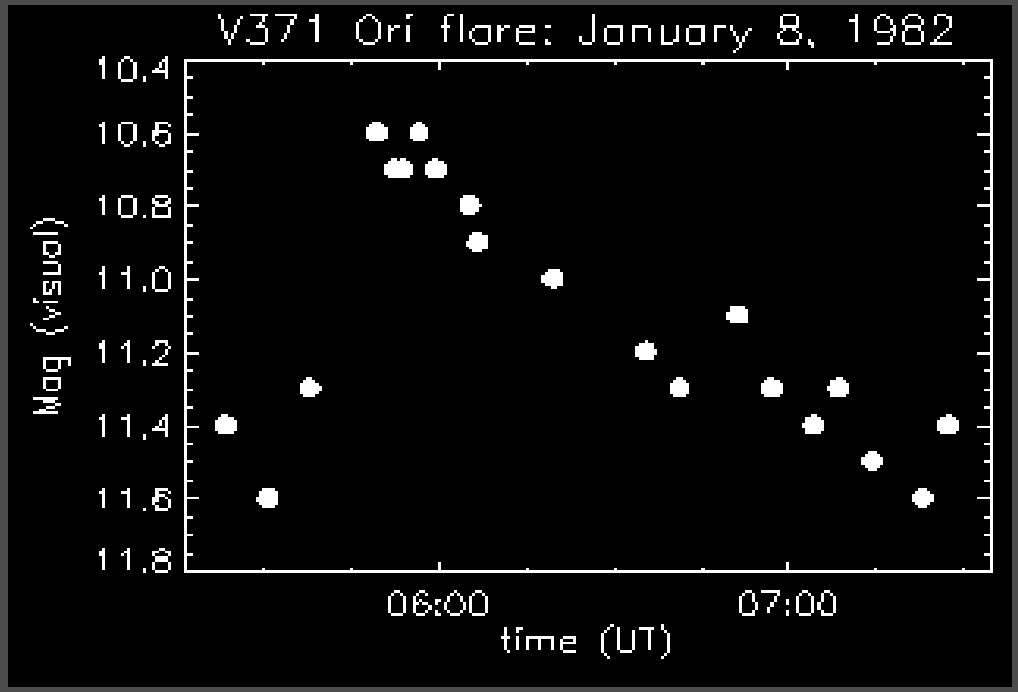
HD 73857 – pulsating star of RR Lyr type





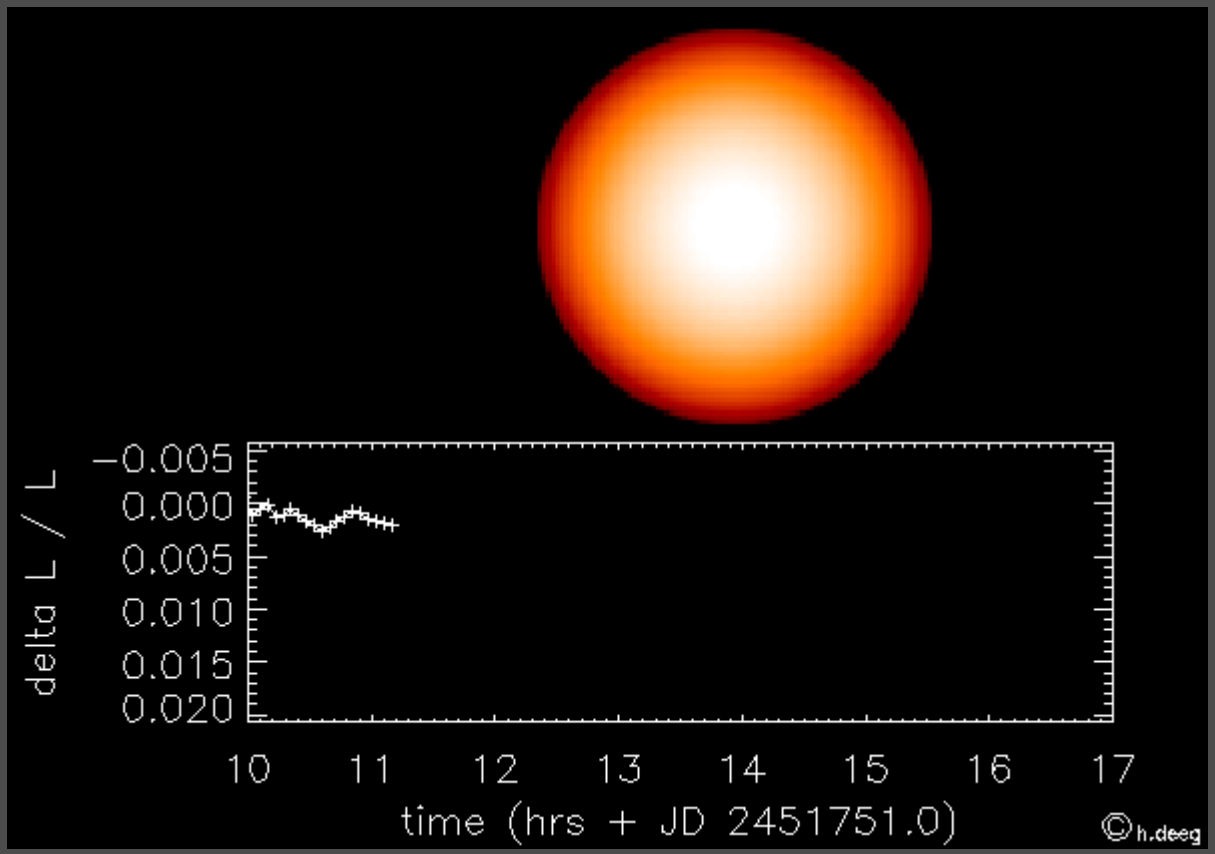
FLARE STARS

Main sequence stars with characteristic short (seconds / minutes) explosions of amplitude 1-6 mag and longer exponential decay. Explosions are related to release of magnetic field energy near surface of the star

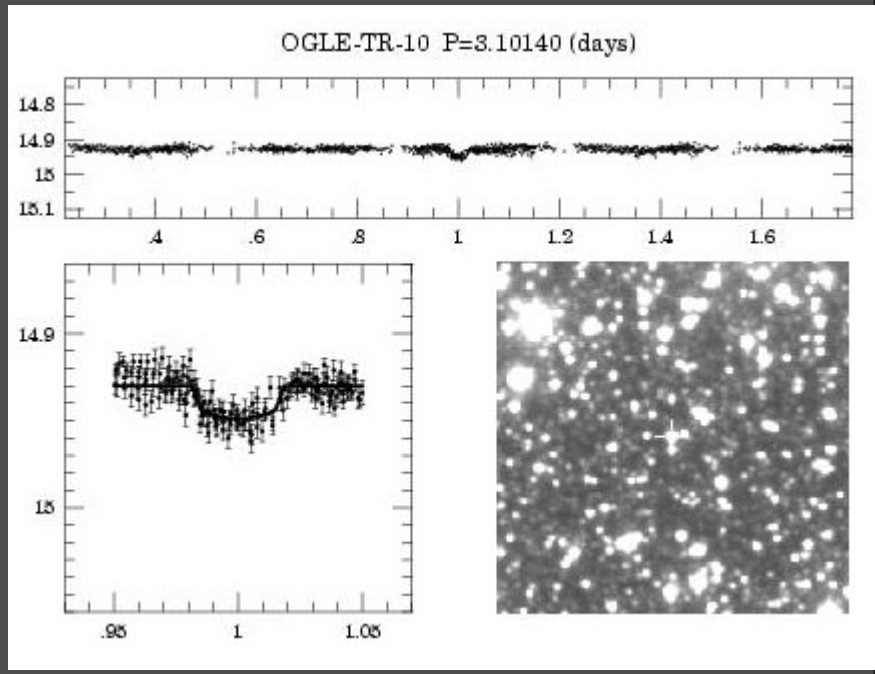


EXTRASOLAR PLANETS

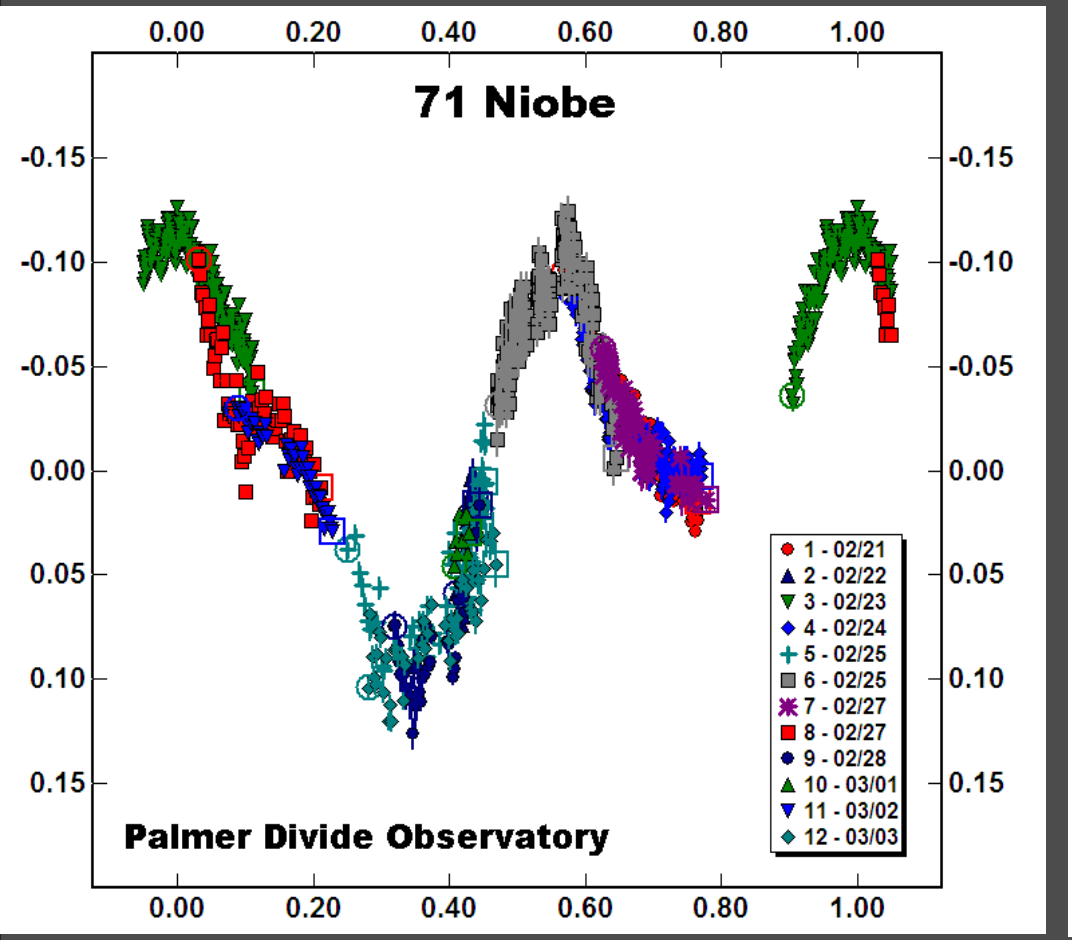
ANIMATION

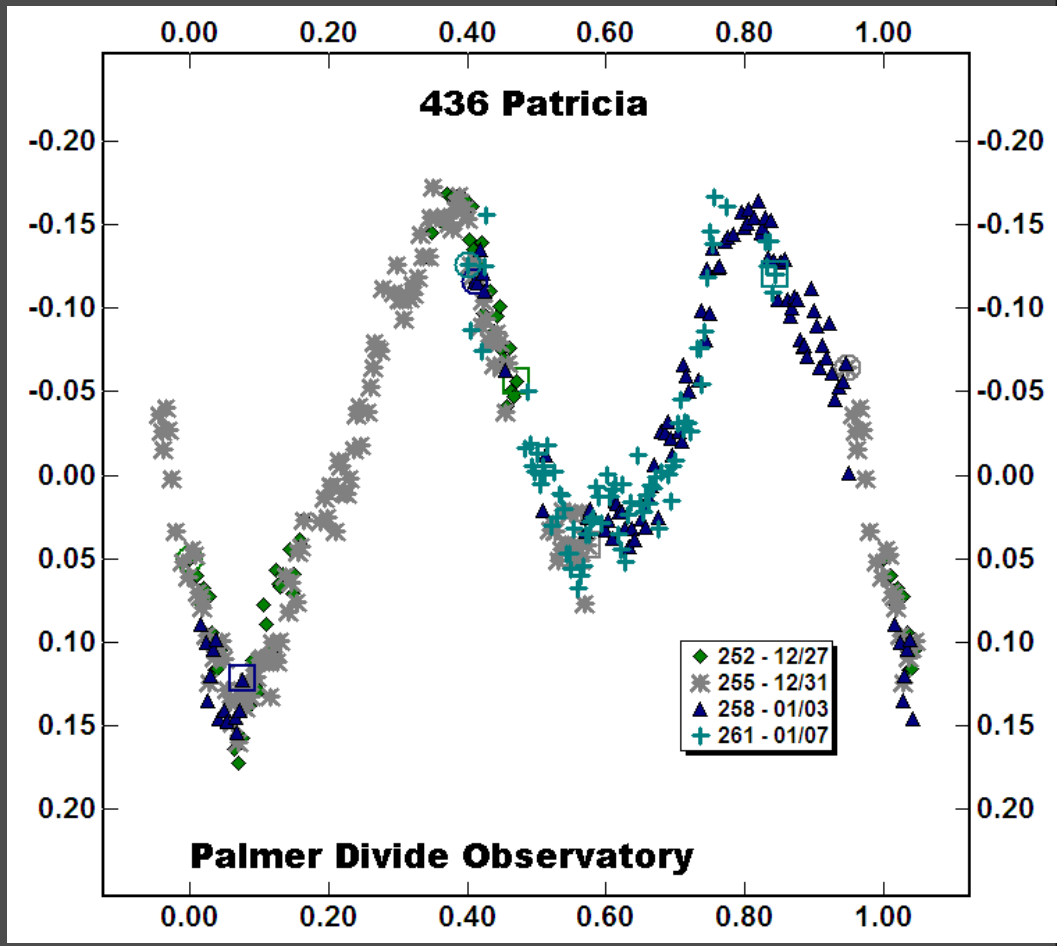


OGLE-TR-10



ASTEROIDs, PLANETOIDs, COMETS





“Pi of the Sky” Collaboration

- **The Andrzej Sołtan Institute for Nuclear Studies**

  G.Wrochna, K.Nawrocki, M. Sokołowski, J.Mrowca-Ciułacz , P.Sitek

- **Center for Theoretical Physics, Polish Academy of Science**

  L.Mankiewicz , A.Majcher

- **Warsaw University**
  - **Institute of Experimental Physics**

    A.F. Żarnecki, L.W.Piotrowski, M.Biskup, M.Ćwiok,H.Czyrkowski, R.Dąbrowski, W.Dominik

- **Warsaw University of Technology**
  - **Faculty of Electronics**

    A.Burd, M.Grajda, K.Poźniak, R.Romaniuk, G.Kasprowicz,S.Stankiewicz
  - **Faculty of Physics**

    J.Użycki, M.Molak

- **Cardinal Wyszyński University**

  K.Krupska

- **In cooperation with :**

professor B.Paczyński PRINCETON and G.Pojmański Warsaw University (ASAS)

PROTOTYPE OF DETECTOR

- Paralactic mount, step engines
  5 steps / arc sec

- Two cameras of special design:
  - low noise (16 e)
  - Peltier cooling
  - fast readout 2MHz / pixel
  - mechanical shutter 10 mln cycles
  - objective of focal length :
    f = 50 mm , f/d = 1.4
  - 2000x2000 CCD chip of pixel size
    15μm
  - field of view (FOV)
    33° x 33°
  - limiting magnitude **11**^{m} (on 10s),
    and **12-13**^{m} for 20 averaged image

- Currently installed at
  Las Campanas Observatory
  (Chile), very good conditions
  90% of observing nights


Las Campanas Observatory (Chile)

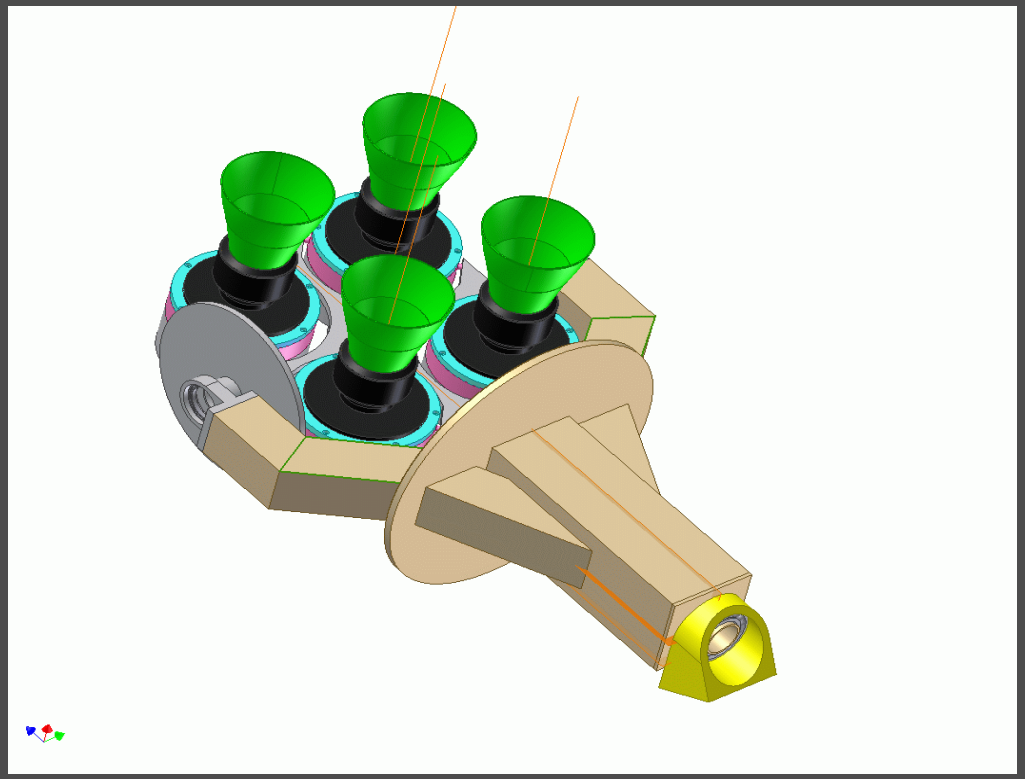
Pi apparatus in ASAS dome

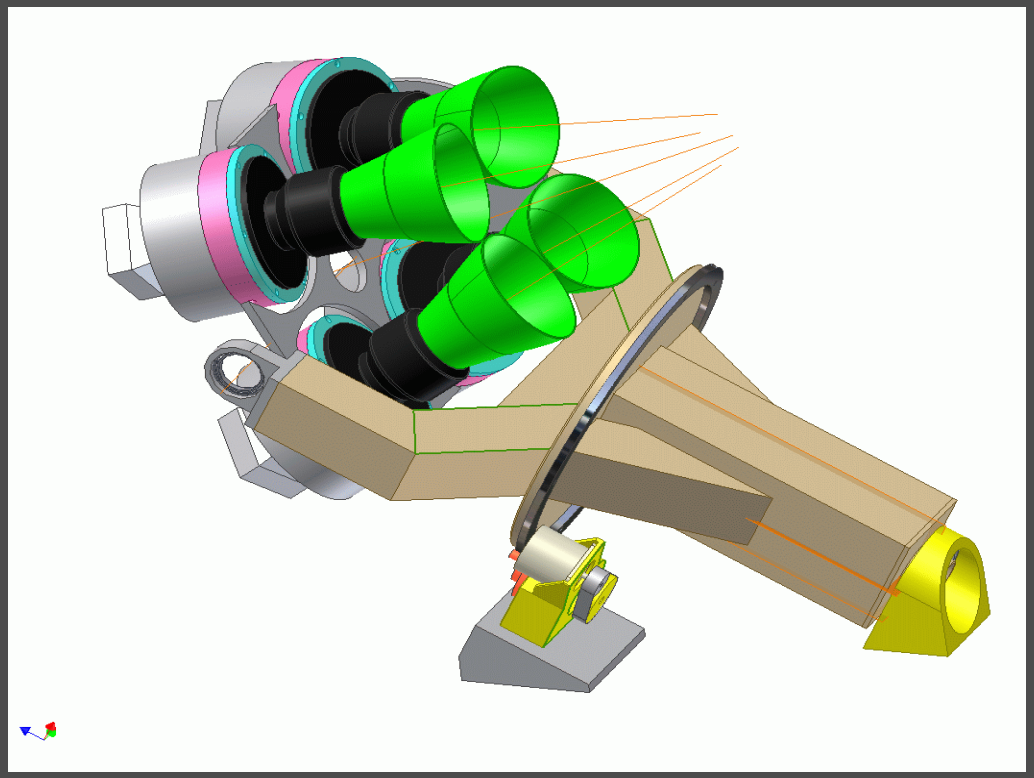
Observation strategy

- follow the field of view of satellite INTEGRAL or HETE in order to have “images of GRB” before, during and after the gamma detection
- 10 s exposures are taken, with 2 sec break
- on-line flash identification algorithm looks for optical transients coinciding on two cameras
- in case of GCN alert from other satellite arvies move to that position and remain there for ½ h
- 2 times a night scan of whole celestial sphere is performed
- collected images are used in standard photometrical analysis concerned on variable stars

Automation of the system

- system controlled by 2 PCs is fully automatic and does not require human attention during normal work
- remotely controlled, only sporadic local support was needed (remote power control , Boot On LAN, Wake On LAN)
- every night special script is generated according to satellite pointing information from WWW and is realized by system
- common problems are handled by system itself
- in case of major problem information is sent by e-mail or sms
- identified flashes are automatically placed on WWW page to be easily accessible for further validation





FULL VERSION OF THE DETECTOR

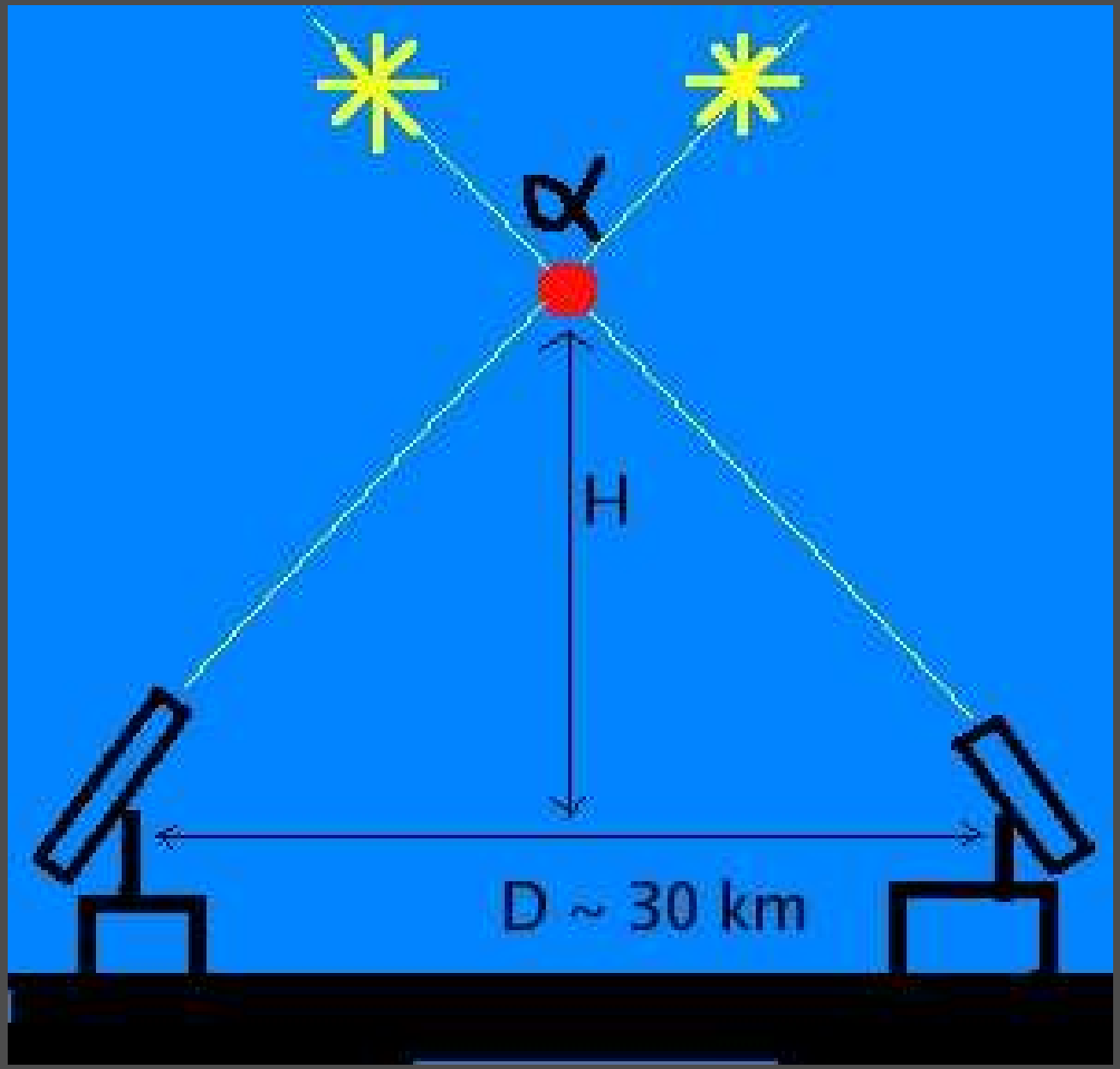
- 2 x 16 cameras on paralactic mounts, covering big fraction (~ 2 srad) of sky

- 2 in distance of ~ 50 km

- camera :
  - lenses :
    f = 85 mm , f/d = 1.2
  - Field Of View (FOV)
    20° x 20°
  - CCD chip of pixel size 18μm
  - limiting magnitude **12.5 m** (10s exposure) and **14-15 m** for 20 averaged frames

- localization – Canary Islands : Teneryfa/La Palma

Parallax will allow to reject planes and satellites



Data analysis

On-line

- Fast flash recognition algorithm, comparing new image with series of previous images and looking for new objects on image with ~15000 stars

- Rejection of background coming from cosmic rays, flashing artificial satellites, constant stars, clouds, meteorites etc

Off-line

- Catalog of objects on images : photometry, astrometry, save of stars and their magnitude measurements to the database of structure :

  084052+0949.6 <-- (2453361.68387436,7.98)
  (2453361.68687233,8.01)
  (2453361.68983538,8.01)
  ...

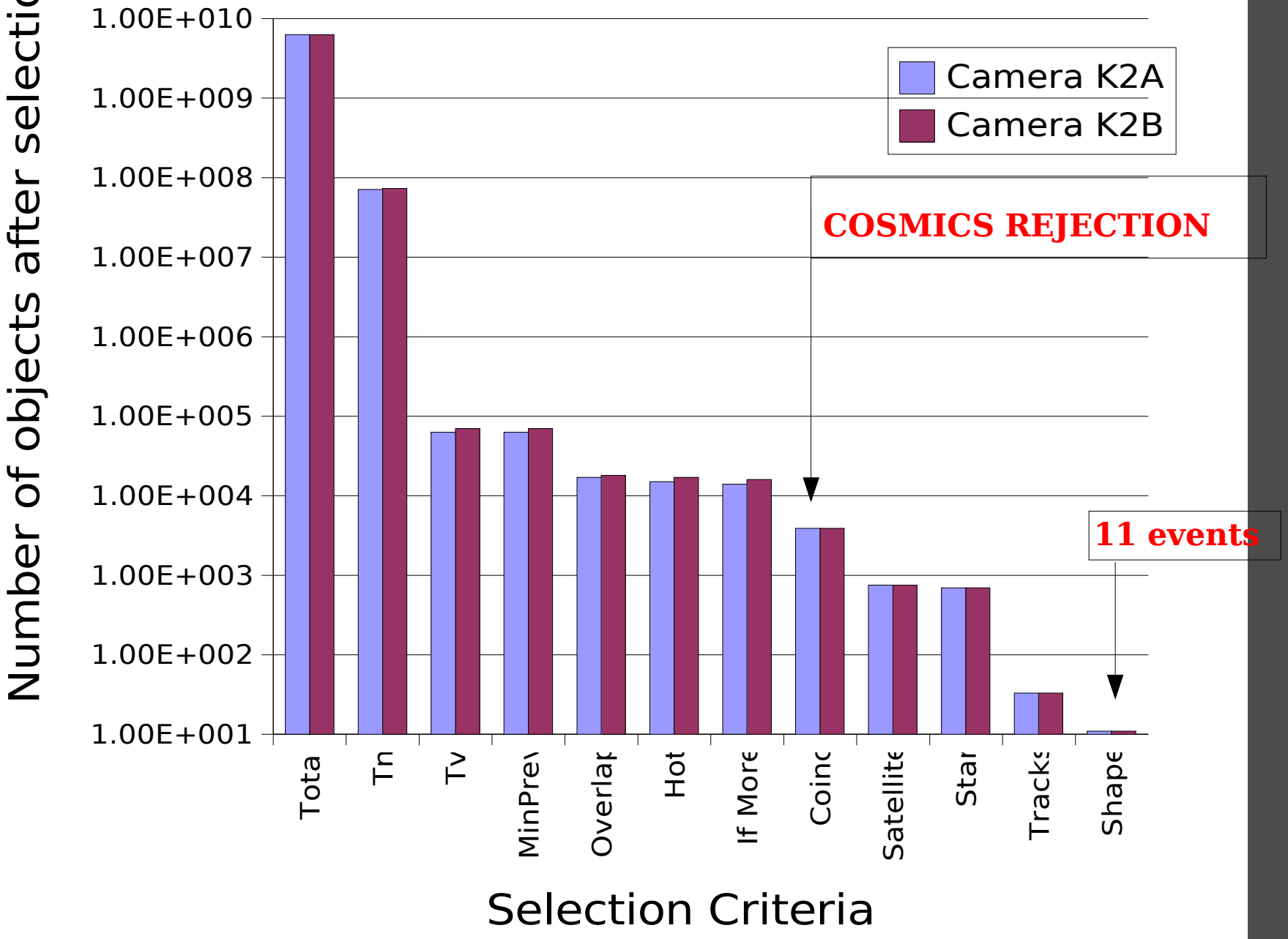
  Number of stars :
  - averages of 20 images : star# ~ 4,1 mln , measurements# ~ 790 mln
  - single frames : 8 mln – (probably a lot of fluctuations)
  - scan of whole sky (average of 3 images) : star# ~ 5 mln, measure# ~ 170 mln

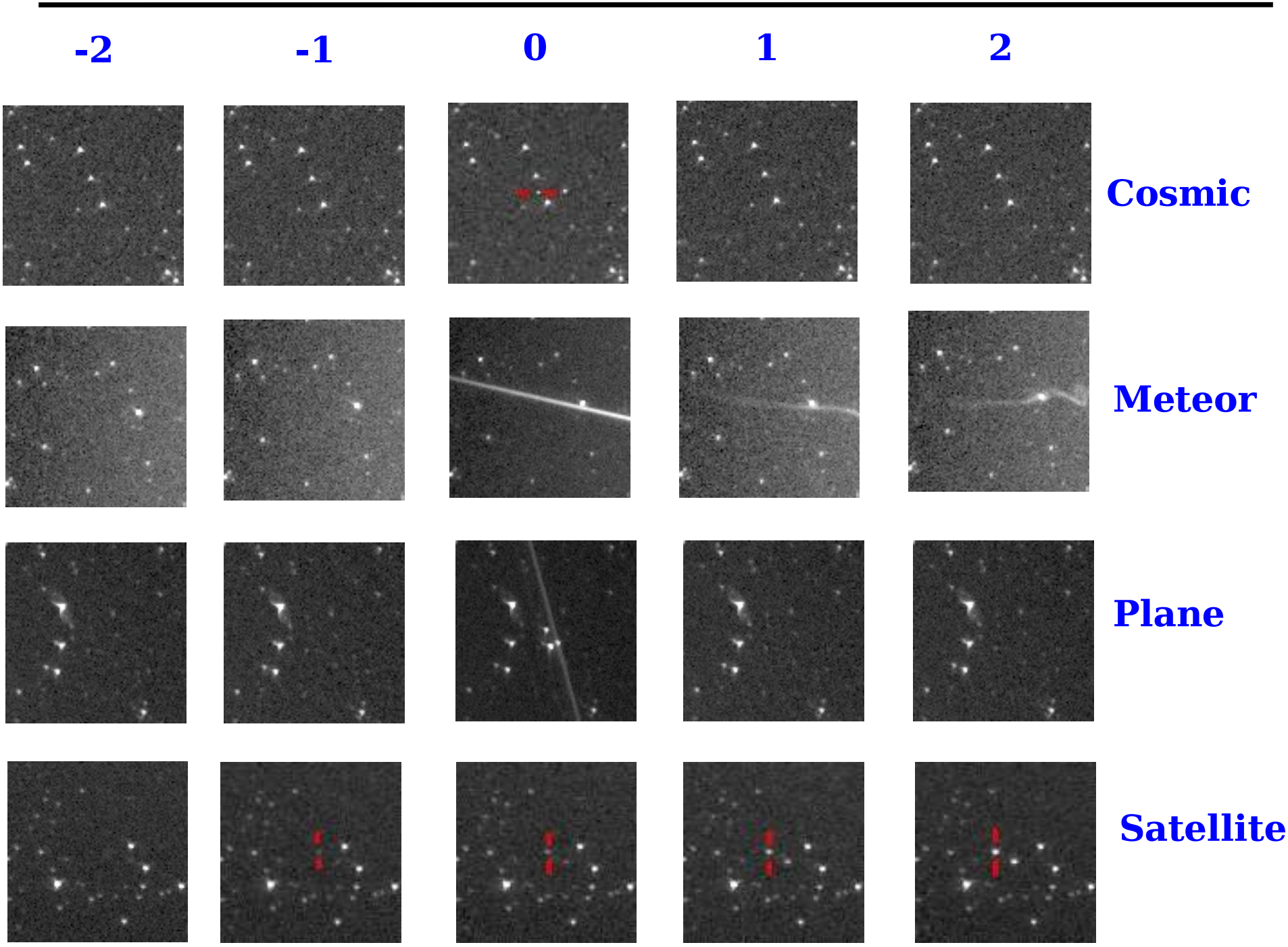
- Lightcurves of stars

- Identification of star brightness increase, appearance of new objects (night + scan) , variable stars analysis, finding new variable stars, lightcurves of planetoids

- Database is public, everybody can look at lightcurve of any star observed by Pi (currently only Southern Sky)

Background Reduction




-2
-1
0
1
2
Cosmic
Meteor
Plane
Satellite

GRB Afterglow results

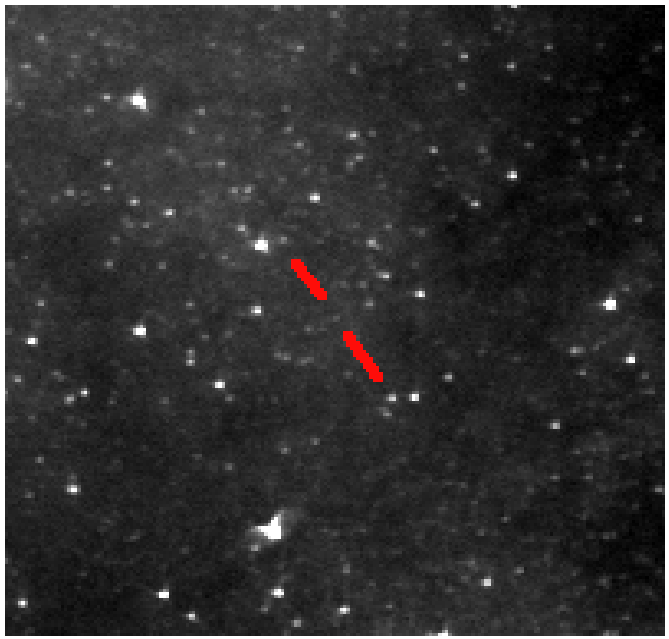
GRB	before GRB	during GRB	after GRB	GCN
X 050509C	**-**	**outside FOV**	**>+28min >13^{m}**	
G 050412	**>11.5^{m}**	**>11.0^{m}**	**>11.5^{m}**	**3240**
G 050326	<-33min: >11^{m}	outside FOV		3146
G 050219B	<-20.5h: >12^{m}	daytime	>+3.7h: >10^{m}	
G 050219	<-3.7h: >11.5^{m}	daytime		
G 050128	<-19.7h: >11^{m}	outside FOV	>+4.3h: >12^{m}	
G 050123	<-1.8h: >12^{m}	daytime		2970
G 041217	**-**	**outside FOV**	**>+30min:>11.5^{m}**	**2862**
G 041211	<-4.7h: >11^{m}	daytime		
G 040924	<-3h: >11^{m}	daytime		
X 040916	**<-13h: >12^{m}**	**outside FOV**	**>+17min: >13^{m}**	**2725**
X 040912	<-4.7h: >12^{m}	daytime	>+19h: >10^{m}	
X 040903	<-18h: >10^{m}	daytime		
G 040827		daytime	>+12h: >10^{m}	
X 040825B	<-6.7h: >10^{m}	daytime	>+17h: >10^{m}	
G 040825A	**<-11s: > 10^{m}**	**> 10^{m}**	**>+7s: > 9.5^{m}**	**2677**
G 040812	**-**	**outside FOV**	**>+20min: >12^{m}**	

Observation of Nova V 5115 Sgr

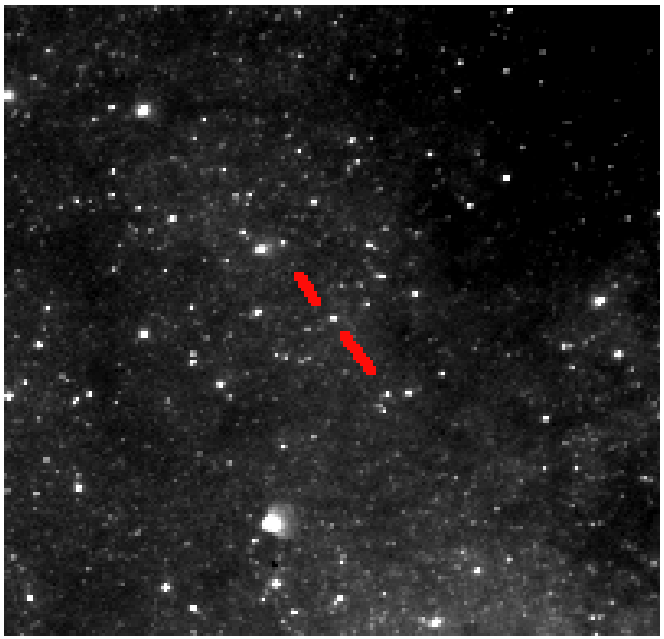
Discovered by :
2005.03.28.779 UT (Nishimura) 8.7m
2005.03.28.796 UT (Sakurai) 9.1m

2005.03.27.3918 >11m
nova not visible

2005.03.28.3955 10.0m
9.2h before discovery:

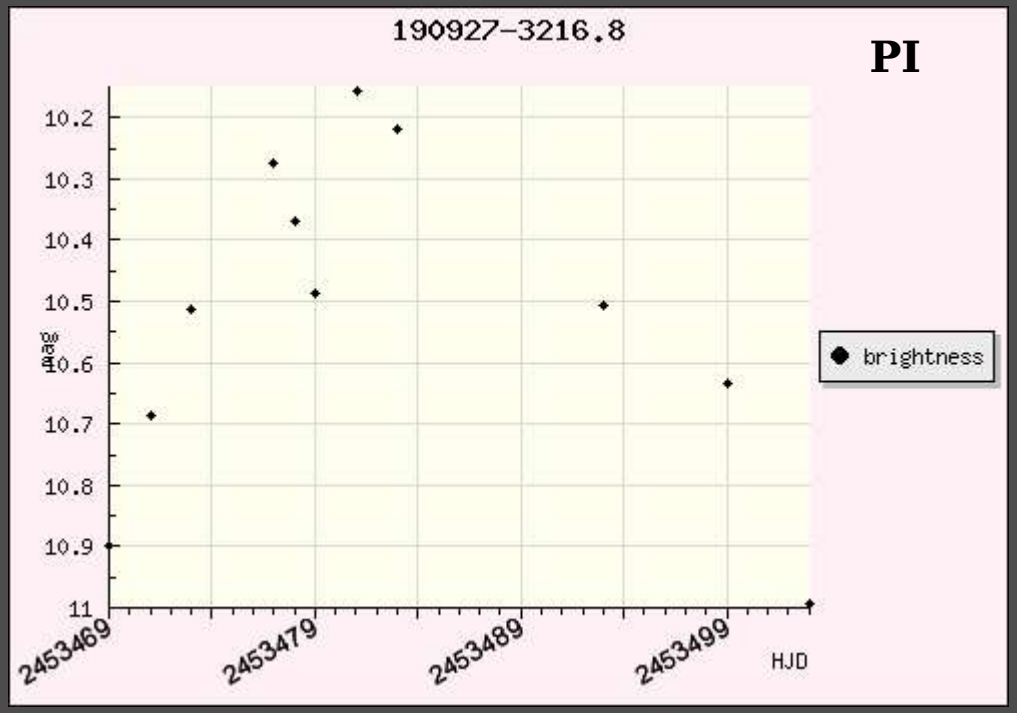


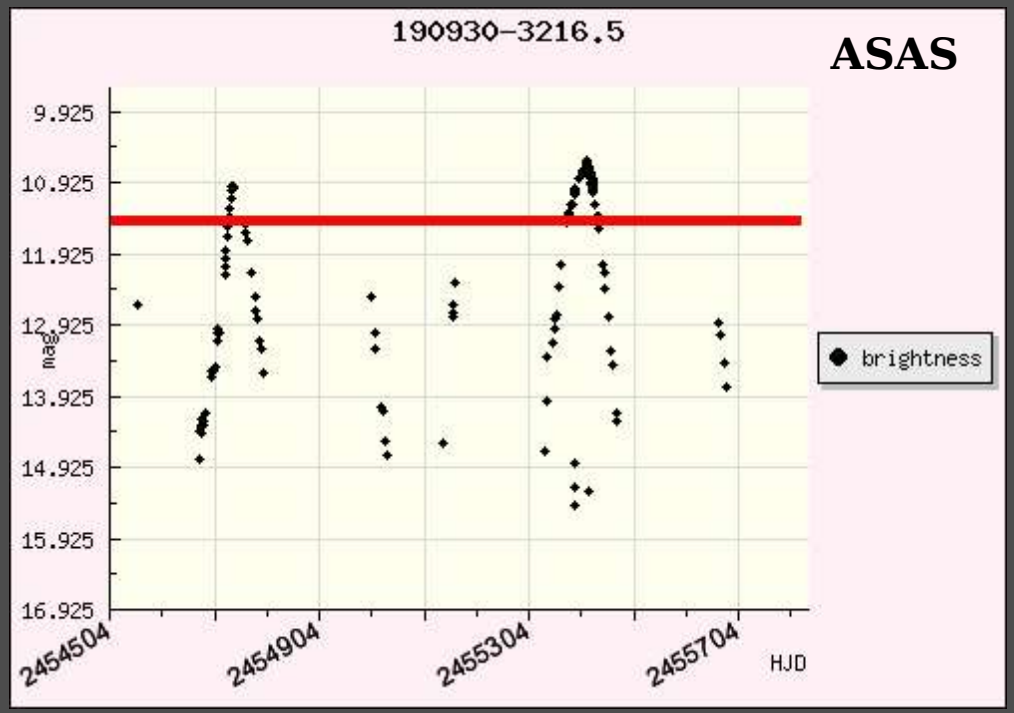
2005.03.29.3914 8.0m
Bight Nova in the center



Nova searching algorithm

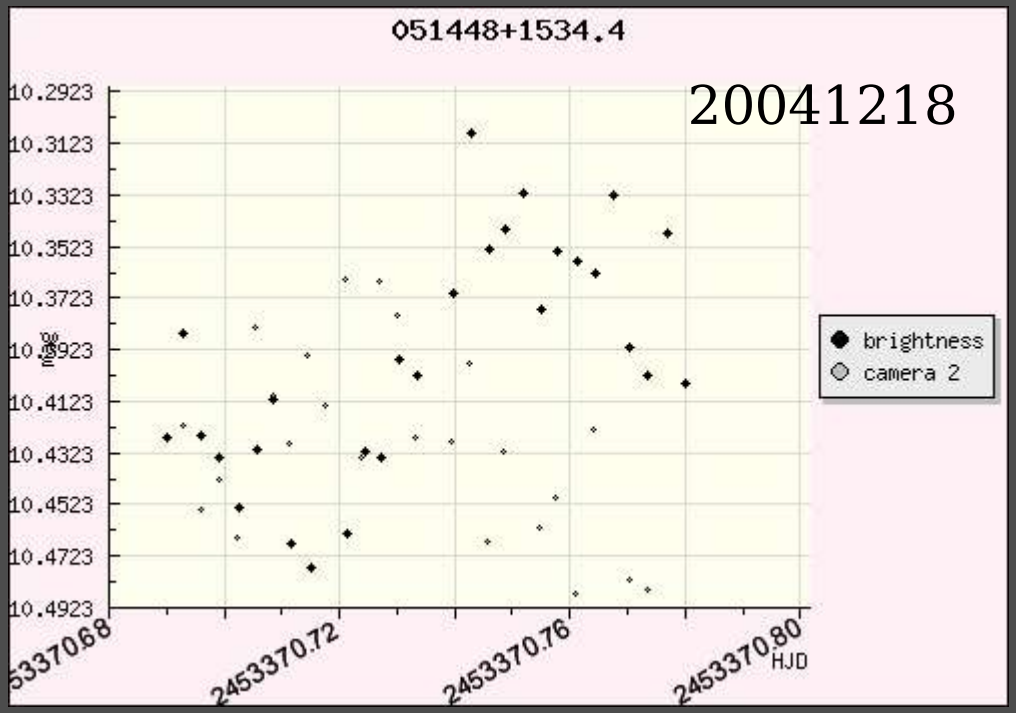
- cataloging program flags first observation of the star in the database
  algorithm looks for objects marked as new on analyzed night
- additional criteria : objects visible during several next observation of this field
- algorithm identified known Nova, moving objects (like Neptune) and variable stars
  with long period and big amplitude

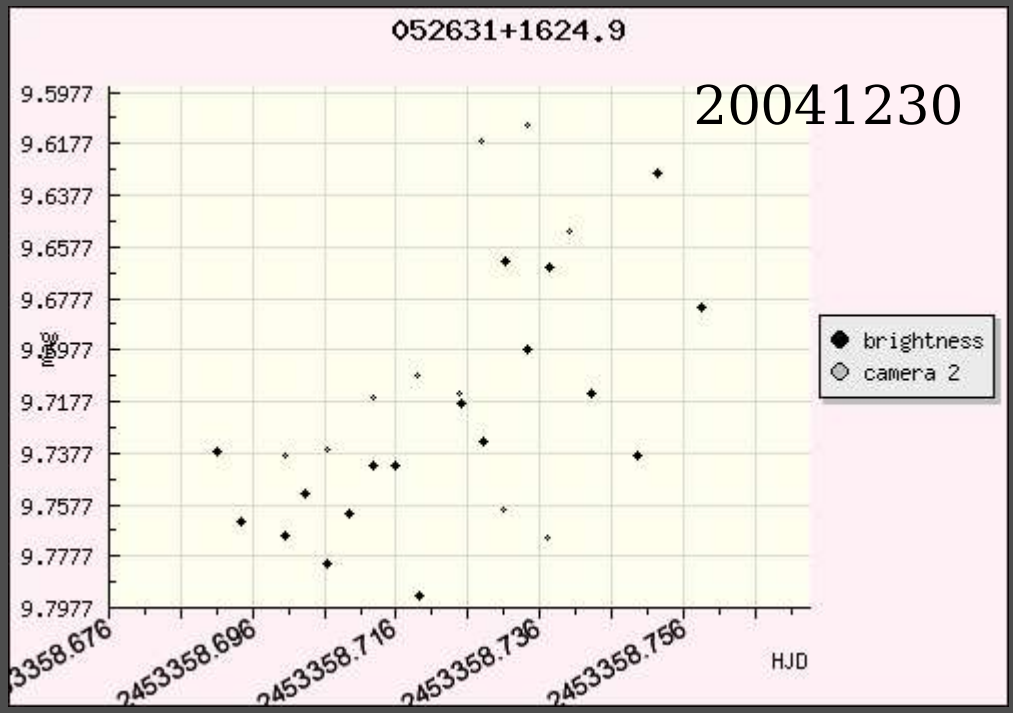




… also planetoids

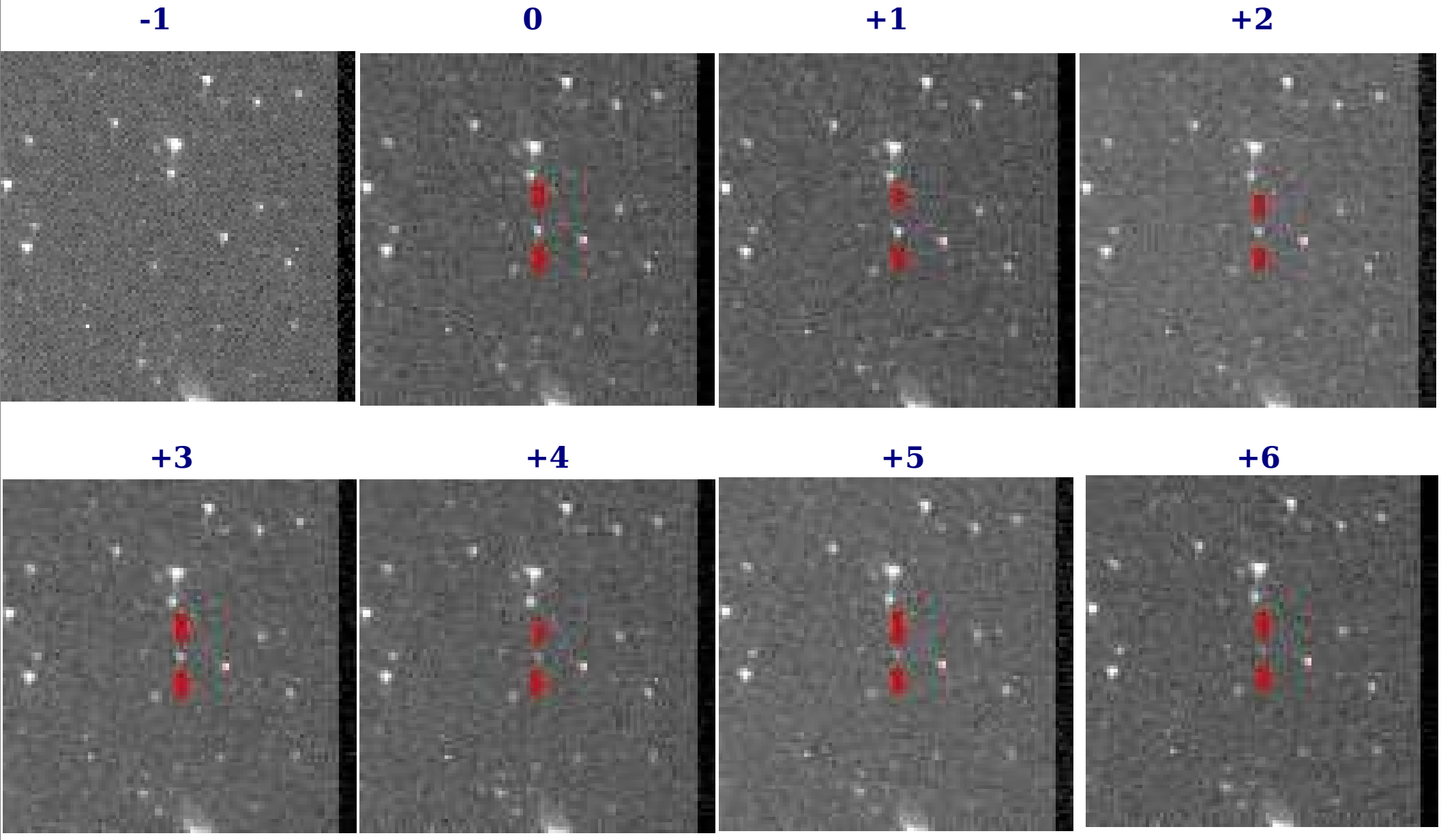
(230) Athamantis





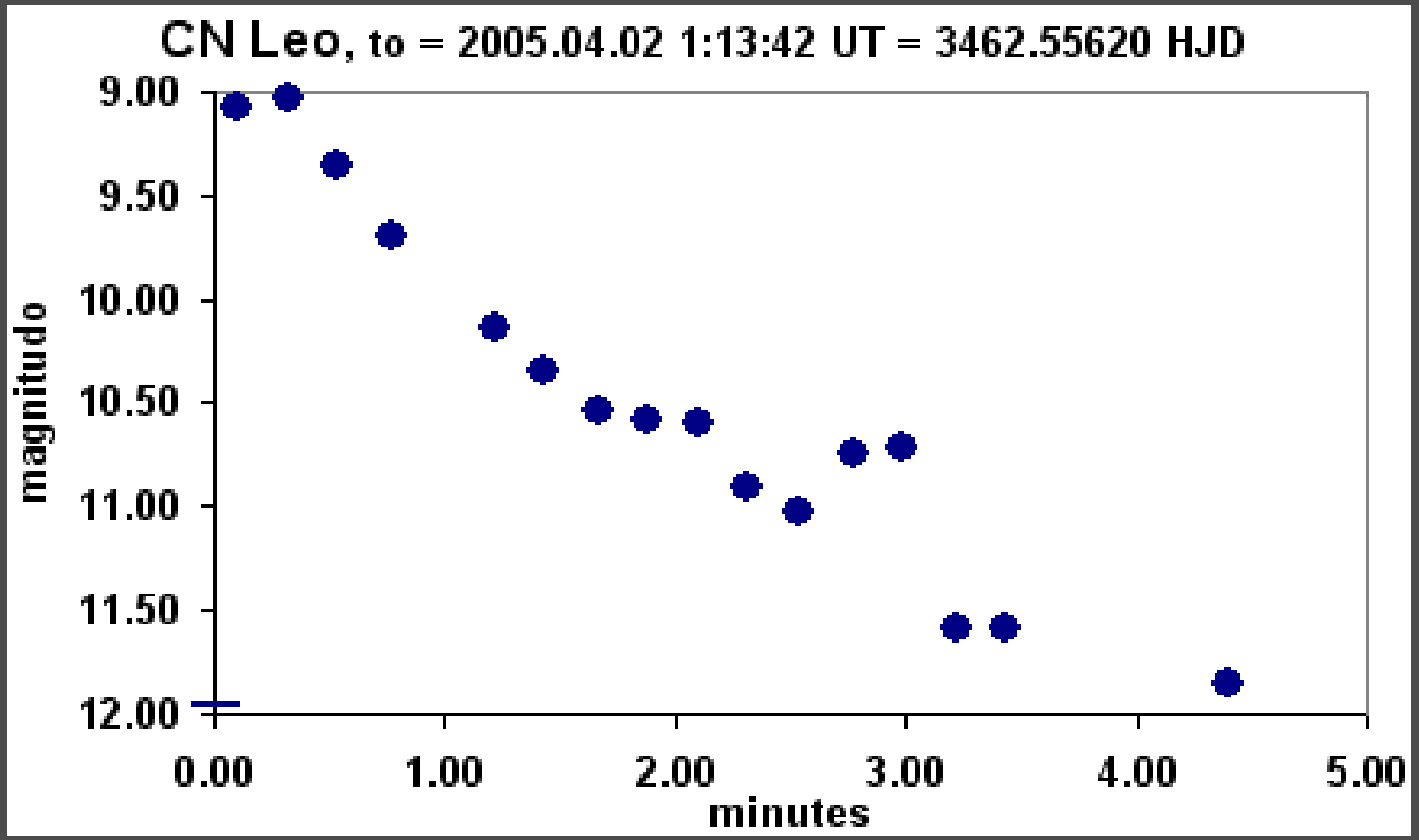
Planetoids move on celestial sphere so nova recognition algorithm finds few such objects which are in slightly different position every night

Flare Star V* CN Leo : 20050402



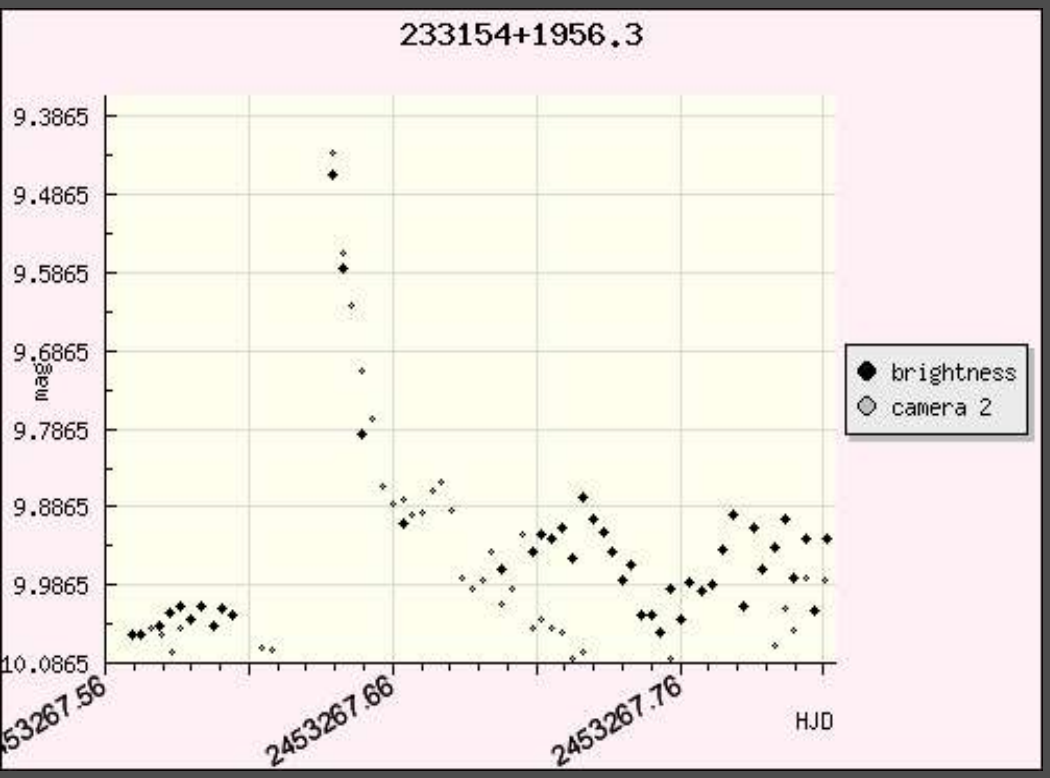
Flare Star V* CN Leo : 20050402

Brightness increase from 13.5m to 9.0m , Δm=4.5m , luminosity of star suddenly increased about 100 times

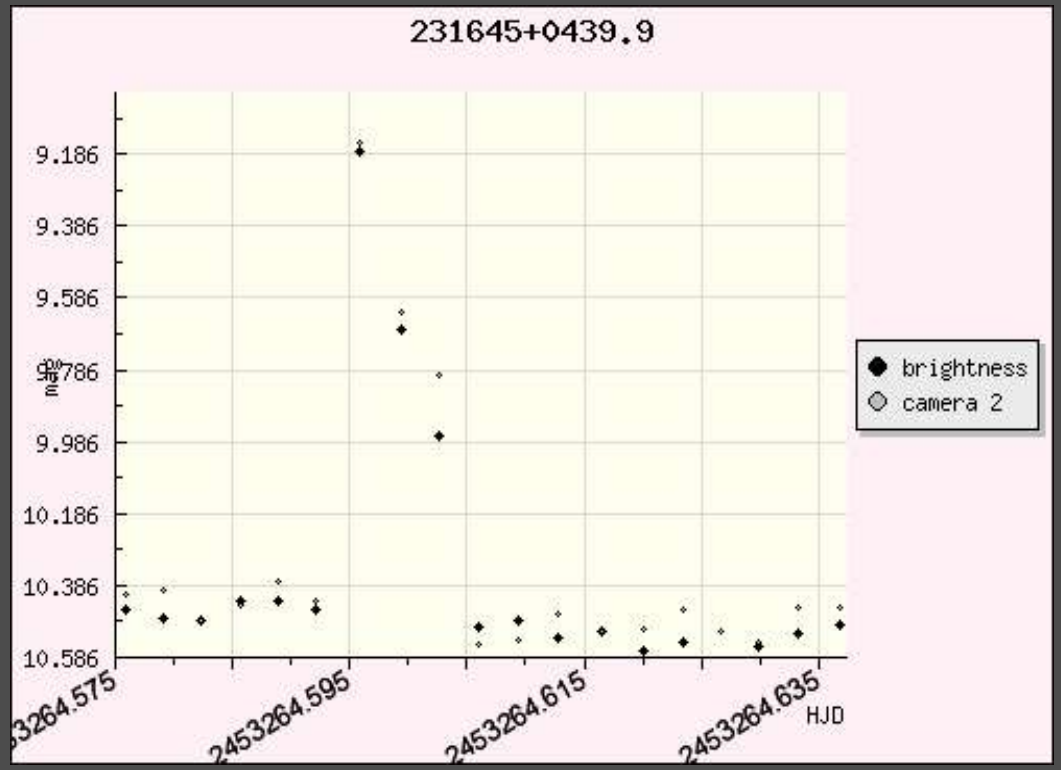


Off-line analysis acting on database

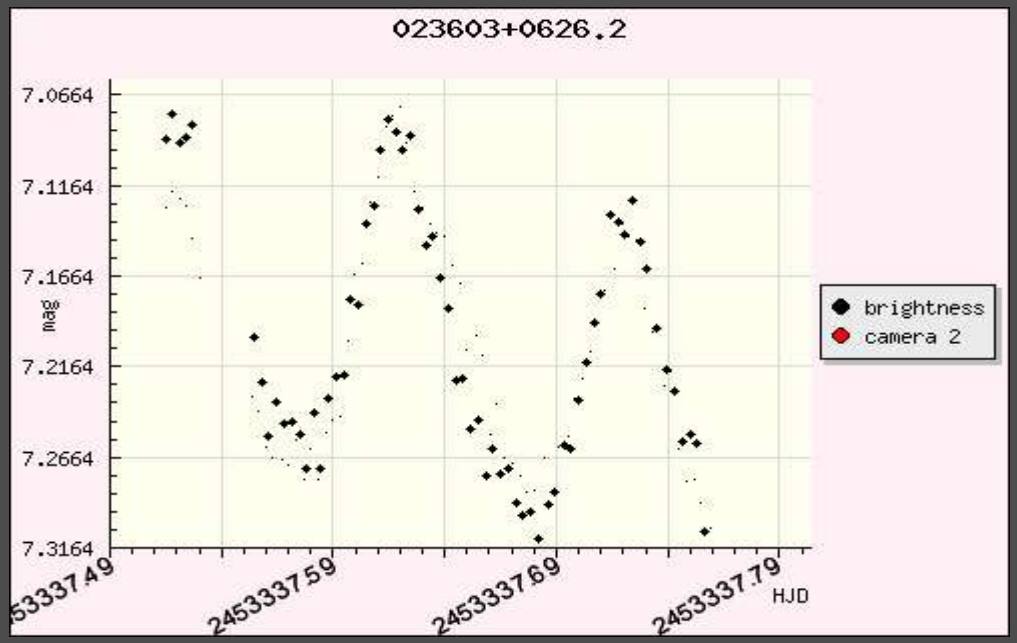
Known Flare Star V* EQ Peg



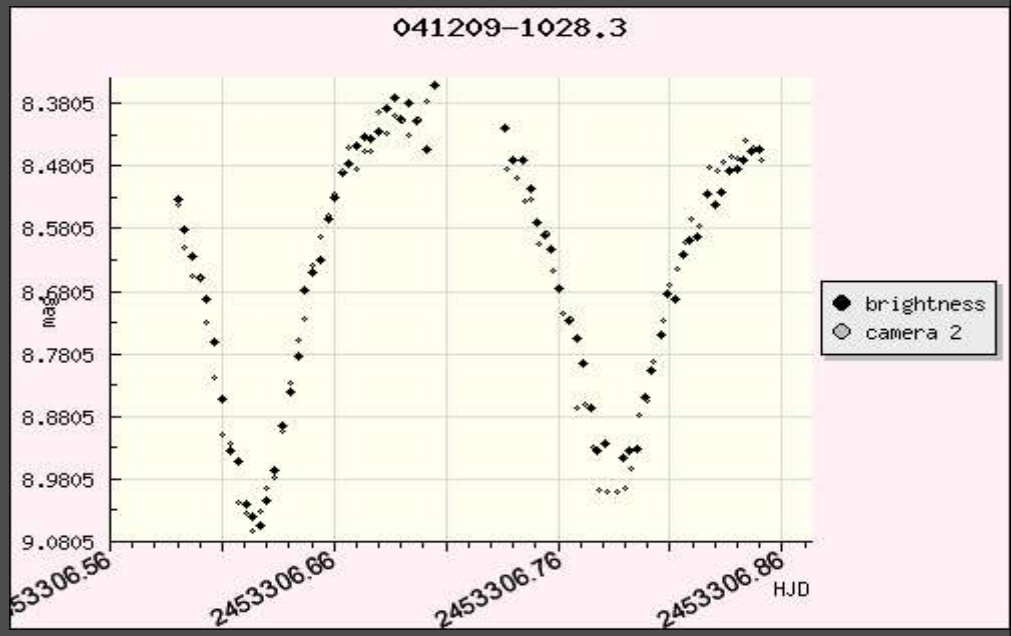
Interesting event found by algorithm



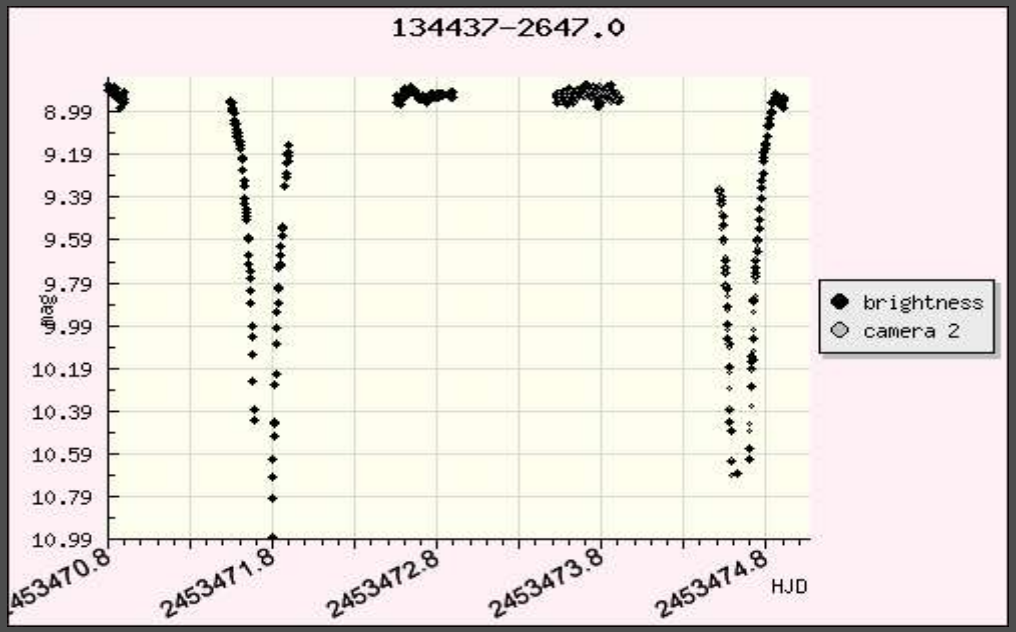
HD 16189 – variable star



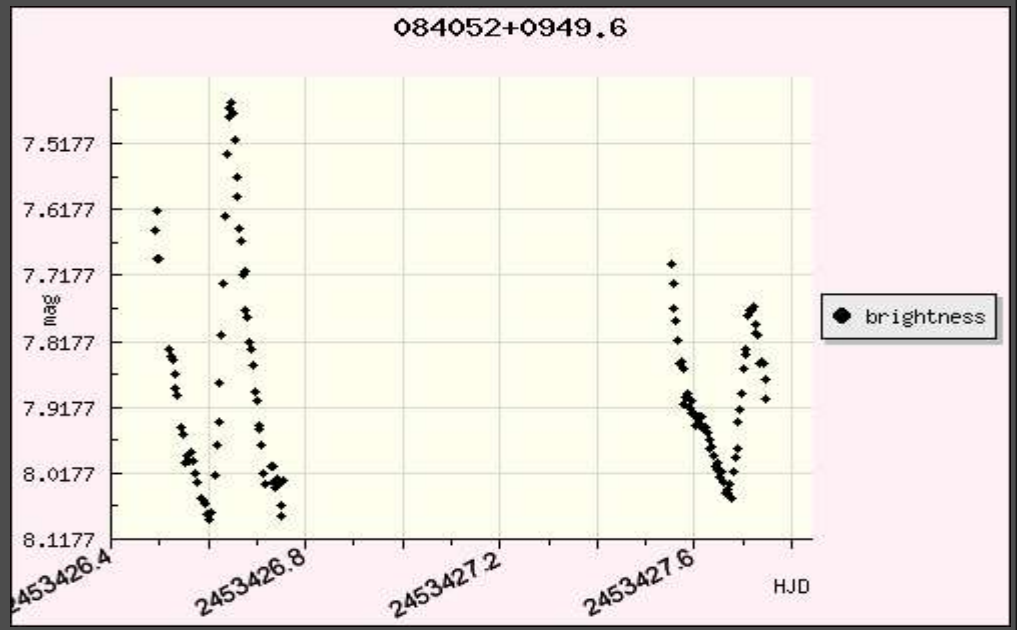
HD 26609 – double binary of W UMa type



HD 119592 – double binary of Algol type



HD 73857 – variable star of RR Lyr type



We are working on algorithm for automatic identification and classification of variable stars , possibly neural network algorithm will be used for this purpose

Summary of observed flashes :

- **Outburst of flare star CN Leo**

- 92 flashes of unknown origin visible on both cameras, but on single 10 s image
- 7 flashes visible on 2 consecutive frames
- 3 increases of star brightness was detected
- novae star explosions have been observed
- no correlation of our flashes with GRB events was found
- interesting background events : bolid explosion

Summary of algorithms :

On-Line:

- on-line flash recognition algorithms :
  - acting on single frame
  - acting on several (8) averaged images

  in 2 versions – coincidence and confirmation on next image

Off-line :

- star catalog based algorithms :
  - new objects finding (scan, 20 averaged)
  - brightness increase finding

- future algorithms :
  - variable star identification, classification (neural network ?)

Summary

- there is wide range of astrophysical phenomena in short timescales a lot of this processes is unpredictable thus difficult to study for ordinary telescopes
- In order to study such processes specially designed telescope with good time resolution and wide FOV must be used
- prototype of “Pi of the Sky” detector shows that this can be a good tool for such kind of studies
- Full version of the detector will allow to monitor big fraction of the sky searching for flashes and other short timescale phenomena, it can be trigger system for future “colliders” ...
- More info : **grb.fuw.edu.pl**

PROCESS	TIMESCALE	REQUIREMENT	MAG	FREQUENCY
GRB	milisec - days	FOV, limiting magnitude	>10	3 / day on whole sky
SN	hours - days	FOV, limiting magnitude	>15	1/25-100 lat in the Galaxy m<15 -> ~11/day m<20 -> ~7000 / day obs : 400 / year
NOVA	hours - days	FOV, limiting magnitude	>12	?
VARIABLE STARS	seconds - years	FOV, limiting magnitude	>12	1% of stars
FLARE STARS	seconds - days	FOV, limiting magnitude	>12	?
EXOPLANETS	hours	FOV, precision of magnitude measurements	>12	?
PLANETOIDY	hours - days	FOV, limiting magnitude	>12	?