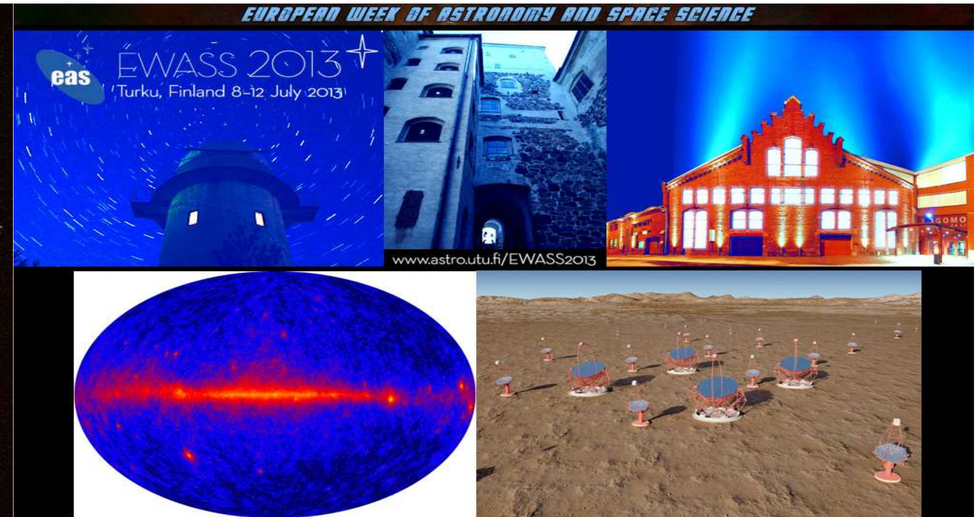


THE GAMMA-RAY SKY IN THE ERA OF FERMI AND CHERENKOV TELESCOPES

Gamma-ray flaring activity from the gravitationally lensed blazar PKS 1830-211 observed by Fermi LAT

Stefano Ciprini

1. ASI Science Data Center, Rome, Italy
2. INAF Observatory of Rome, Italy

On behalf of the Fermi Large Area Telescope collaboration

Collaboration for this work:

S. Buson, J. Finke, F. D'Ammando, S. Larsson, T. Cheung, A. Abdo, L. Reyes

asdc ASI Science Data Center

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

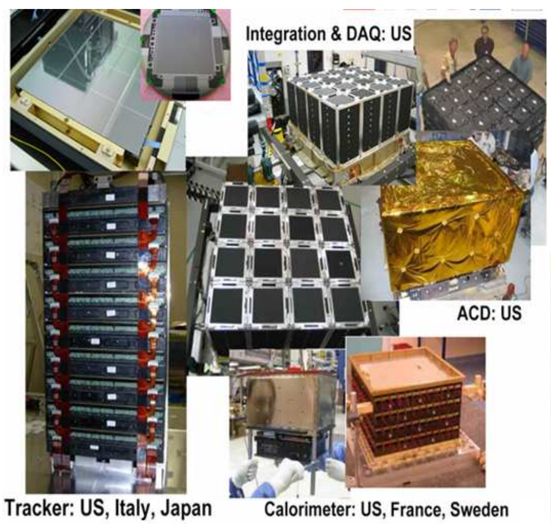
asi agenzia spaziale italiana Italian Space Agency

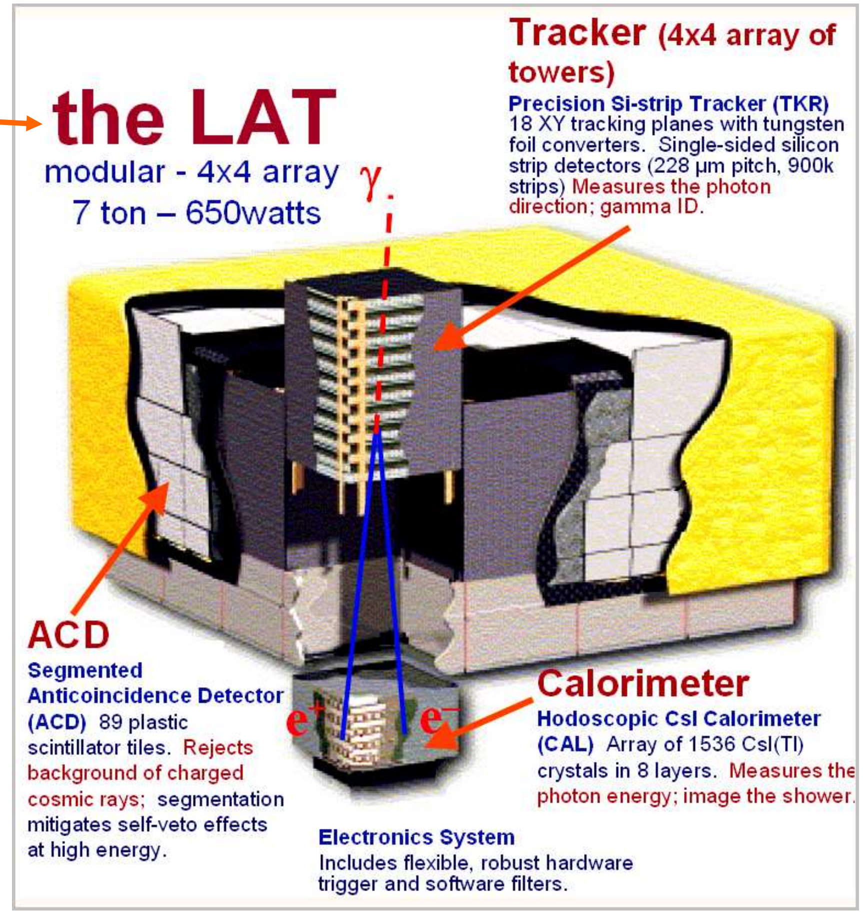
Fermi Gamma-ray Space Telescope

Fermi (formerly GLAST): two Instruments

The Large Area Telescope (LAT)
20 MeV - 300 GeV
>2.5 sr FoV

The Burst Monitor (GBM)
8 keV – 40 MeV
9.5 sr FoV





Gamma-ray flares from gravitationally lensed quasars: PKS 1830-211 and S3 0218+35

ATel#2943

Fermi LAT detection of an intense GeV flare from the high-redshift and gravitationally lensed blazar PKS 1830-211

ATel #2943; *S. Ciprini (Perugia Univ. / ASI-INAF, Italy), on behalf of the Fermi Large Area Telescope Collaboration*
on ***15 Oct 2010; 16:52 UT***
Distributed as an Instant Email Notice Request For Observations
Credential Certification: Stefano Ciprini (stefano.ciprini@pg.infn.it)

Subjects: Gamma Ray, >GeV, Request for Observations, AGN, Blazar, Quasar

Referred to by ATel #: 2950, 4158

The Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed a rapidly increasing gamma-ray flux from a source positionally consistent with PKS 1830-21 (also known as 3EG J1832-2110, RA: 18h 33m 39.9s, Dec -21d 03m 40s, J2000, van Ommen et al., 1995, ApJ, 444, 561).

PKS 1830-211 (z=2.507, Lovell et al. 1998, ApJ, 508, L51) is a distant and peculiar flat spectrum radio quasar located behind the southern Galactic Bulge with gravitational magnification and absorption features. It is gravitationally lensed by a galaxy at z=0.886 (Wiklind & Combes 1996, Nature, 379, 11). In addition to being the brightest radio source of any gravitational lens, it has an intervening absorption system and showed a large gamma-ray inverse Compton dominance during the EGRET era. This source was well observed in the past by hard-X-ray and soft-gamma-ray instruments like COMPTEL, Swift-BAT, INTEGRAL (Zhang et al. 2008, ApJ, 683, 400).

Preliminary analysis indicates that the source on October 14, 2010 showed a bright gamma-ray outburst with a daily flux (E>100MeV) of (5.2+/-1.1) x10^-6 ph cm^-2 s^-1 (errors are statistical only), more than a factor of 12 greater than reported in the Fermi-LAT 1st year catalog (1FGL J1833.6-2103, Abdo et al. 2010, ApJS 188, 405). A peak flux (E>100MeV) of (14+/-5) x 10^-6 photons cm^-2 s^-1 (statistical only) was reached between 06:00 and 11:17 UT.

The Fermi-LAT contact people for this source are L. C. Reyes (lreyes@kicp.uchicago.edu), A. Tramacere (Andrea.Tramacere@unige.ch) and S. Ciprini (stefano.ciprini@pg.infn.it) . Because Fermi operates in an all-sky scanning mode, regular gamma-ray monitoring of this source will continue. In consideration of the ongoing activity of this source we strongly encourage multiwavelength observations.

The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

ATel#4343

Fermi LAT detection of a GeV flare from the gravitationally lensed blazar S3 0218+35

ATel #4343; *S. Ciprini (ASI ASDC & INAF OAR, Rome), on behalf of the Fermi Large Area Telescope Collaboration*
on ***28 Aug 2012; 20:45 UT***
Credential Certification: Stefano Ciprini (stefano.ciprini@asdc.asi.it)

Subjects: Gamma Ray, >GeV, Request for Observations, AGN, Blazar, Quasar

Referred to by ATel #: 4351, 4361, 4371, 4411

The Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed gamma-ray flaring activity from a source positionally consistent with the blazar S3 0218+35 (also known as 2FGL J0221.0+3555, Nolan et al. 2012, ApJS, 199, 31, and B2 0218+35, OD 330, lens B0218+357) placed at radio coordinates R.A.: 35.27279 deg, Dec: +35.93715 deg (J2000, Patnaik et al. 1992, MNRAS, 254, 655).

S3 0218+35 is a gravitationally lensed blazar (Patnaik et al. 1993, MNRAS, 261, 435; Browne et al. 1993, MNRAS, 263, 32; Lehar et al. 2000, ApJ, 536, 584; Cohen et al. 2003, ApJ, 583, 67) with source redshift z=0.944+/-0.002 (Cohen et al. 2003, ApJ, 583, 67) while the intervening and lensing spiral galaxy has redshift z = 0.6846 (Zeiger et al. 2010, ApJ, 709, 386). S3 0218+35 is a small separation optical lens (335 mas separation, Biggs et al. 1999, MNRAS, 304, 349) possessing one of the smallest Einstein rings in the radio band (0".33 diameter, Heidt et al. 2004, A&A, 418, 813; Cohen et al. 2003, ApJ, 583, 67; Oguri 2007, ApJ, 660, 1) and it represents an important object for studies of gravitational lensing, Hubble constant value and individual molecular clouds at high redshifts (Jethava et al. 2007, A&A, 472, 435; Zeiger et al. 2010, ApJ, 709, 386). The time delay between the variations in the two compact radio source images is 10.5+/-0.4 days (Biggs et al. 1999, MNRAS, 304, 349).

Preliminary analysis indicates that on 2012 August 26, S3 0218+35 was in a high state with an average daily gamma-ray flux (E>100MeV) of (1.6 +/- 0.3) x 10^-6 photons cm^-2 s^-1 (errors are statistical only), about 16 times greater than the average flux reported in the second Fermi LAT catalog (2FGL). A bright daily flux level around 1 x 10^-6 photons cm^-2 s^-1 was already detected on 2012 August 22 and 25 as well.

Because Fermi operates in an all-sky scanning mode, regular gamma-ray monitoring of this source will continue. In consideration of the ongoing activity of this source we encourage multiwavelength observations. For this source the Fermi LAT contact person is C. C. Teddy Cheung (ccheung@milkyway.gsfc.nasa.gov).

The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

LAT flare discovery and first ATel on GB 1310+487. Other following-up ATels

Fermi LAT detection of a GeV flare from GB6 B1310+4844

ATel #2306; *K. V. Sokolovsky (MPIfR/ASC Lebedev), S. E. Healey (Stanford/KIPAC), F. Schinzel (MPIfR); on behalf of the Fermi Large Area Telescope Collaboration, and Y. Y. Kovalev (ASC Lebedev/MPIfR)*
on 21 Nov 2009; 01:33 UT
Distributed as an Instant Email Notice Request For Observations
Credential Certification: Teddy Cheung (ccheung@milkyway.gsfc.nasa.gov)

Subjects: Gamma Ray, >GeV, Transient

Referred to by ATel #: 2310, 2316

The Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed an increasing gamma-ray flux from a source positionally consistent with the flat spectrum radio quasar GB6 B1310+4844 (VLBI position: R.A. = 13:12:43.354, Dec. = +48:28:30.94, J2000, Beasley et al. 2002, ApJS, 141, 13). Preliminary analysis indicates that the source on November 18, 2009 was in a high state with a gamma-ray flux (photon energy E>100MeV) of (1.0 +/-0.2) x 10^-6 photons cm^-2 s^-1 (errors are statistical only), which represents an increase of a factor of about 40 with respect to the average source flux level during the first 11 months of the Fermi mission.

An optical spectrum obtained with the Hobby-Eberly Telescopes indicates a redshift z=0.501 (CGRaBS J1312+4828; Healey at al. 2008, ApJS, 175, 97) -- see the linked spectrum below. Note that the previously reported value (z=0.313) by Falco et al. (1998, ApJ, 494, 47) was indicated as a "marginal measurement."

Radio observations conducted with RATAN-600 in June 2003 show a flat radio spectrum on the level of about 0.2 Jy. Existing VLBA images from July 17, 2006 at 4.8 GHz (Helmboldt et al. 2007 ApJ, 658, 203) and August 10, 1996 at 2.3 and 8.4 GHz (http://astrogeo.org/vcs/), show an isolated, compact radio core which is expected for a faint blazar (extended structure, if present, would not be detected during short VLBA observations).

Because Fermi operates in an all-sky scanning mode, regular gamma-ray monitoring of this source will continue. In consideration of the ongoing activity of this source we strongly encourage multiwavelength observations. For this source the Fermi LAT contact person is K. Sokolovsky (ksokolov[at]mpifr-bonn.mpg.de).

The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

ATel#2306

ATel#2316, ATel#4158, ATel#4371

Fermi LAT observation of ongoing GeV activity from spectrally hard blazar GB6 B1310+4844 (GB1 1310+487)

ATel #2316; *E. Hays (NASA/GSFC), L. Escande (CNRS/IN2P3 Bordeaux) on behalf of the Fermi Large Area Telescope Collaboration*
on 28 Nov 2009; 00:29 UT
Credential Certification: Elizabeth Hays (elizabeth.a.hays@nasa.gov)

Fermi LAT detection of renewed GeV gamma-ray activity from the gravitationally lensed blazar PKS 1830-211

ATel #4158; *Stefano Ciprini (ASI Science Data Center and INAF Rome, Italy), on behalf of the Fermi Large Area Telescope Collaboration*
on 7 Jun 2012; 21:53 UT
Credential Certification: Stefano Ciprini (stefano.ciprini@asdc.asi.it)

Fermi LAT detection of a potential echo gamma-ray flare from gravitational lens S3 0218+35

ATel #4371; *M. Giroletti (INAF-IRA Bologna), M. Orienti (Univ. Bologna, INAF-IRA Bologna), C. C. Cheung (NRC/NRL); on behalf of the Fermi Large Area Telescope Collaboration*
on 11 Sep 2012; 20:42 UT
Credential Certification: Teddy Cheung (ccheung@milkyway.gsfc.nasa.gov)

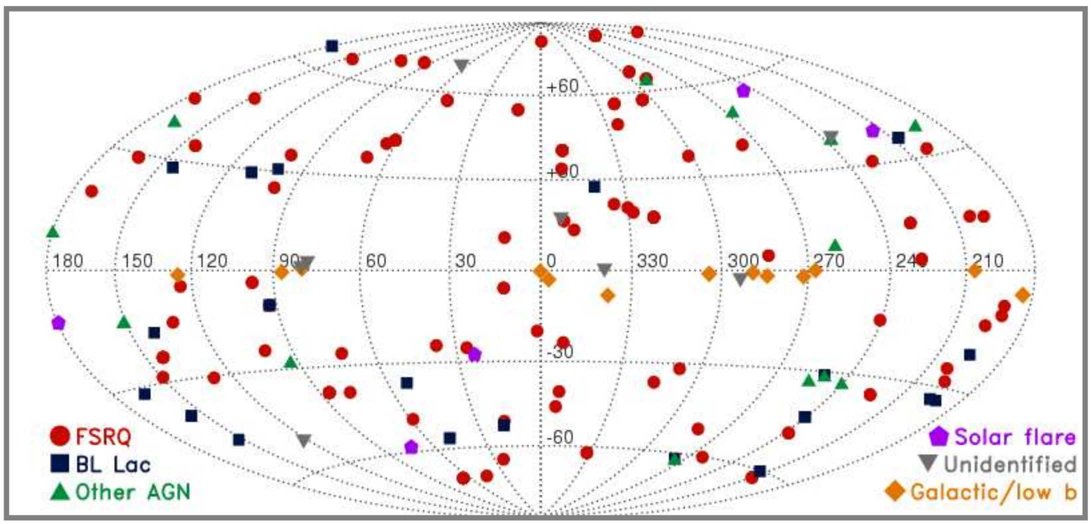
Fermi LAT Flare Advocate Service

Discovery of gamma-ray outbursts in gravitationally lensed blazars: PKS 1830-211 (FSRQ at z=2.507), S3 0218+35 (BL Lac object at z=0.944), GB 1310+487 (NL-Sy1 at z=0.638, preliminary) followed from the Fermi LAT all-sky survey and the Fermi LAT Flare Advocate service.

FA-GSW is a twofold service:

❑ Flare Advocate (FA): look for flares, transients, sources wit daily flux >1E-6 ph/cm2/s; publish ATels, internal emails to science groups, ToO requests (ex. to Swift), MW campaigns, papers on flares and MW simultaneous data.

❑ Gamma-ray Sky Watcher (GSW): look at daily / 6hour all sky maps, revise Automatic Science Processing results and check source detections, day-by-day internal report; weekly summary for the Fermi Gamma-ray Sky Blog; look for new sources (not published in LAT Catalogs), first-guess for source associations.

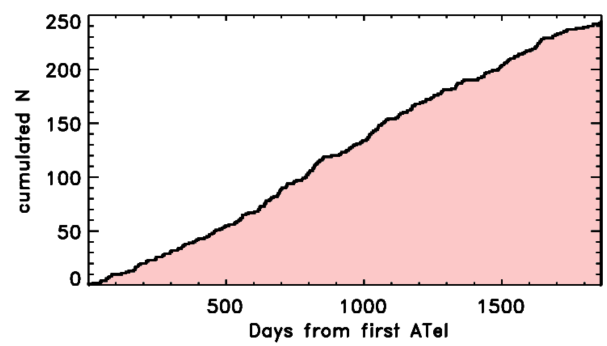


Outline of the all-sky map distribution of new gamma-ray sources, flares and transients found by *Fermi* LAT and announced through Astronomer's Telegrams (ATels).

First ~5 years of Fermi all-sky survey mission:

❑ 271 weekly reports in Fermi Sky Blog.

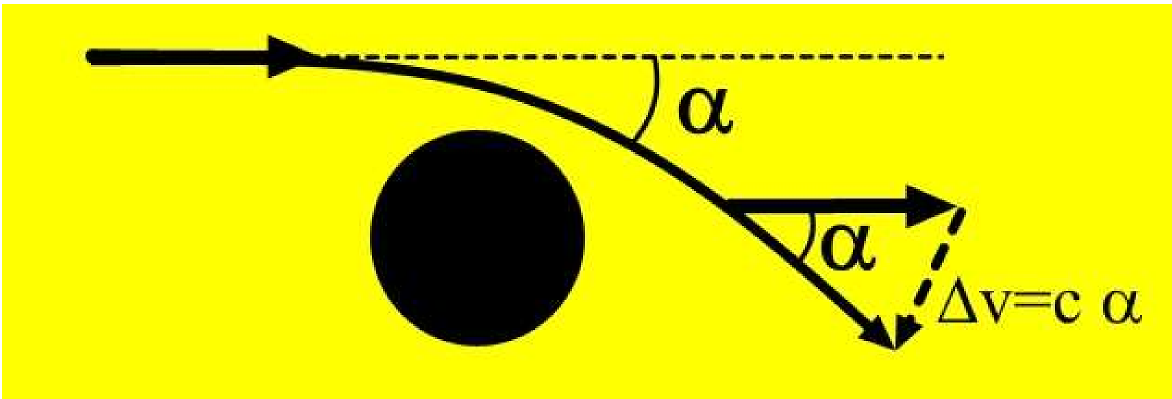
❑ 245 ATels posted.



- **fermisky.blogspot.com**
- **www-glast.stanford.edu/cgi-bin/pub_rapid**
- **www.asdc.asi.it/feratel/**

A primer in gravitational lensing

Sir HENRY CAVENDISH (1784)



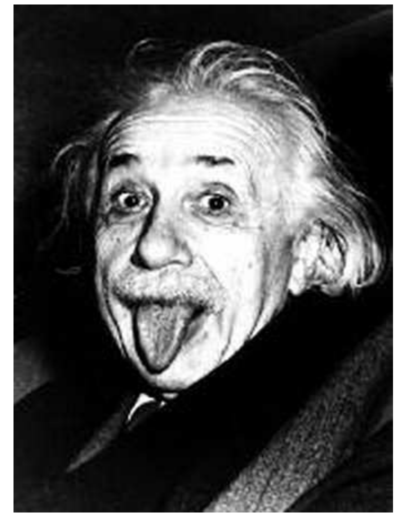
$$\frac{dv}{dt} = \frac{GM}{r^2}$$

$$\int dv = GM \int \frac{dt}{r^2}$$

$$\alpha = \frac{2GM}{c^2 R}$$

$$\alpha_\odot = \frac{2GM_\odot}{c^2 R_\odot} \approx 0.85\ arcsec$$

ALBERT EINSTEIN (1915)



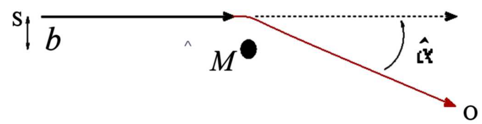
$$\alpha_{rel} = \frac{4GM}{c^2 R}$$

$$\alpha_{rel\,\odot} \approx 1.7\ arcsec$$

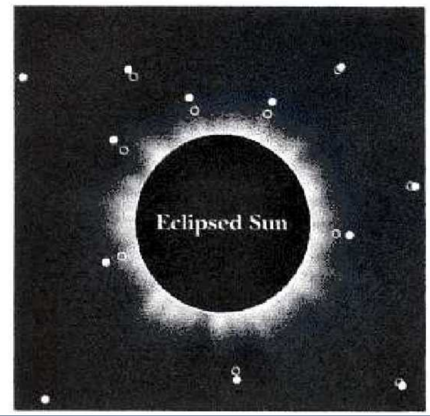
A primer in gravitational lensing

- Newton's rhetorical question: *"Do not Bodies act upon Light at a distance, and by their action bend its Rays; and is not this action strongest at the least distance?"* Evident positive answer.
- In Newtonian gravitational theory the deviation angle was calculated by Soldner (1801), with an answer $\alpha = 2GM/(c^2 b)$ (b impact parameter, α deflection angle).
- General Relativity (Einstein 1915) predicts that a light ray which passes by a spherical body of mass M with impact parameter b, is deflected by the Einstein angle:

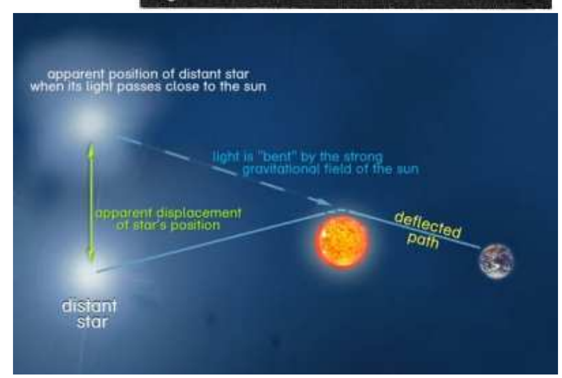
$$\hat{\alpha} = \frac{4GM}{c^2 b} = \frac{2R_s}{b}$$



provided b >> Schwarzschild radius R_s.



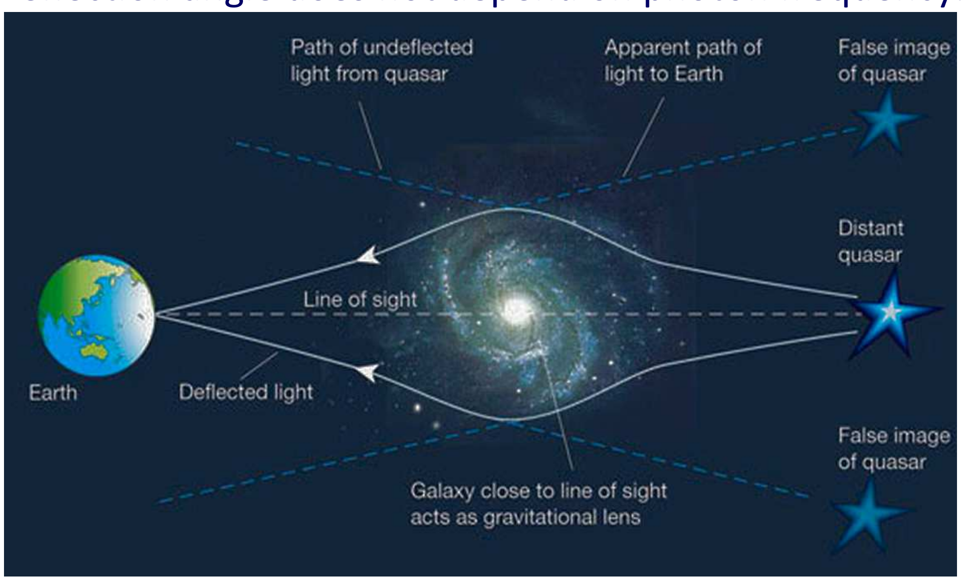
- For the light deviation by the Sun, Einstein theory gave value of deviation angle 1.75''. To check these predictions expedition was led by A. Eddington, to measure the positions Hyades stars around the Sun during the solar eclipse of 29 May 1919. Einstein result confirmed, (Dyson et al. 1920), together with the precession of the Mercury orbit, and measurements of the redshift. These were the 3 proofs of validity of General Relativity.



- Lodge (1919) invented the term "gravitational lens", Eddington (1920) showed the possibility of observations of multiple images of one lensed source, Chwolson (1924) found that a lensed image may have a circular form (ring), when the source, lens and observer are on the same line. Magnification of a lensed image (Tihov 1937), (Zwicky 1937): gravitational lensing on massive extragalactic "nebulae" (present galaxies or galaxy clusters) much more effective than on stars. (Zwicky 1937) probability that nebulae which act as gravitational lenses will become a certainty.

A primer in gravitational lensing

- Theory of gravitational lensing developed by Klimov (1963), Liebes (1964), Refsdal (1964), Ingel' (1974).
- Discovery of the first gravitational lens (Walsh et al. 1979): observation of the quasar with two images (twin quasar) TXS 0957+561 (SBS 0957+561, z=1.4141). Quasars emerged as ideal sources for search of strong and evident gravitational macrolensing.
- Microlensing and calculations of light curves done by Byalko (1969). Observations of microlensing
- events started in 1991 (first event discovered by Alcock, et al. 1993) and Aubourg, et al. 1993, in Large Magellanic Cloud, and the Galactic halo, respectively).
- Most astrophysical situations: gravitational lensing vacuum approximation of weak deflection (b >> R_s) is well satisfied. Deflection angle does not depend on photon frequency.



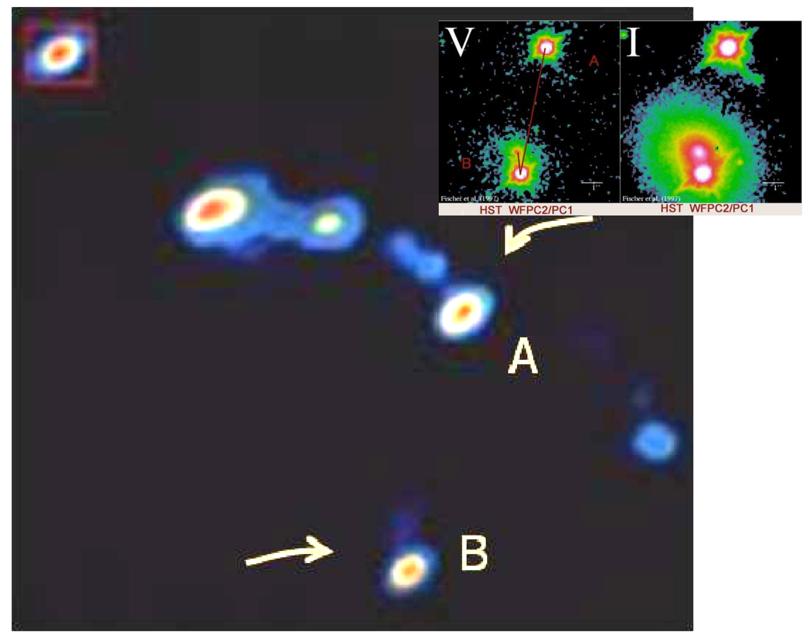
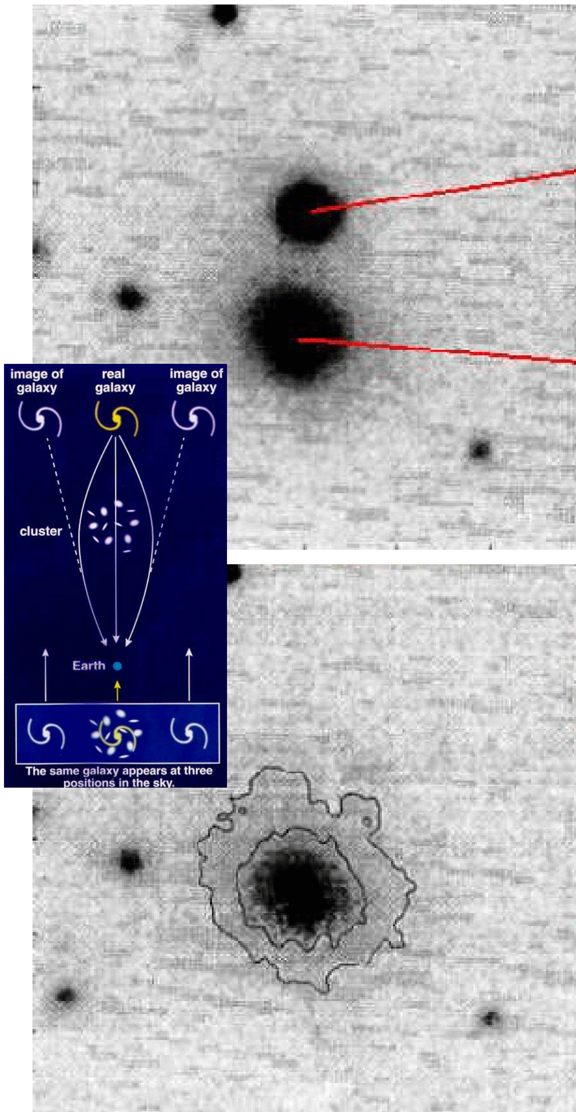
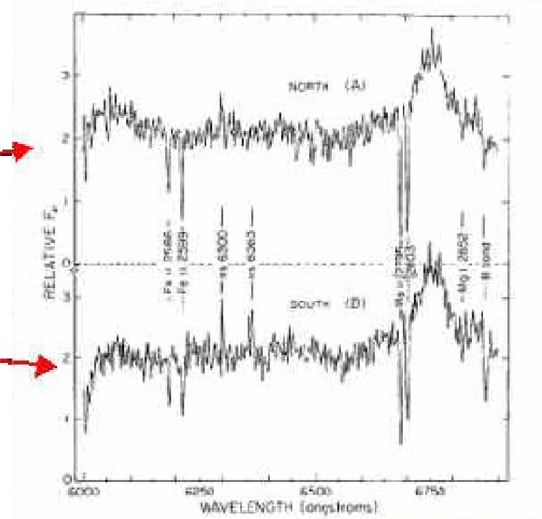
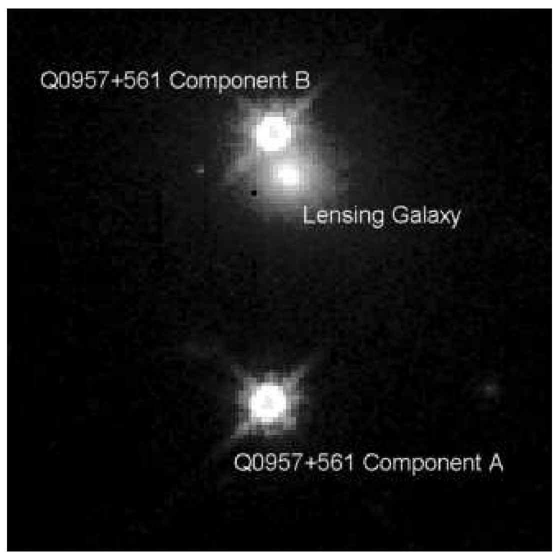


Fig. 2. The first observed lense (1981): QSO 0957+561, maximum separation - 6.1 arcsec, Image redshift - 1.41, Lens redshift - 0.36, B/A = 2/3. Radio map of the double quasar (0957+561), at 6 cm wavelength, taken with the Very Large Array (VLA) radio telescope, New Mexico. These two images of a single distant quasar are the result of the gravitational bending of light from the quasar by an intervening body. Image A is the bright point source (top) emitting radio jets on either side. Image B is the bright point-like object below A; the jets have not been doubly imaged. The weak image just above B coincides with the center of a large galaxy observed in the optical, which, along with the rich cluster of galaxies it lies in, is believed to be acting as the gravitational lens.

Strong gravitational lensing







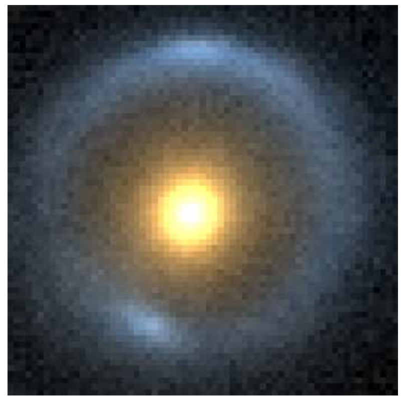
The first (strong/macro) gravitationally lensed object ever discovered, TXS 0957+561 (SBS 0957+561, z=1.4141). is a quasar whose image is split into two by the gravity of a foreground galaxy. In this image, the two star like objects are the split images of the quasar. The fuzzy object near top quasar image is the foreground galaxy. The quasar lies at a redshift of 1.41. The foreground galaxy lies at a redshift of 0.39. In optical light, Q0957+561 appears as two point images of roughly 17 mag separated by 6.1 arcseconds.

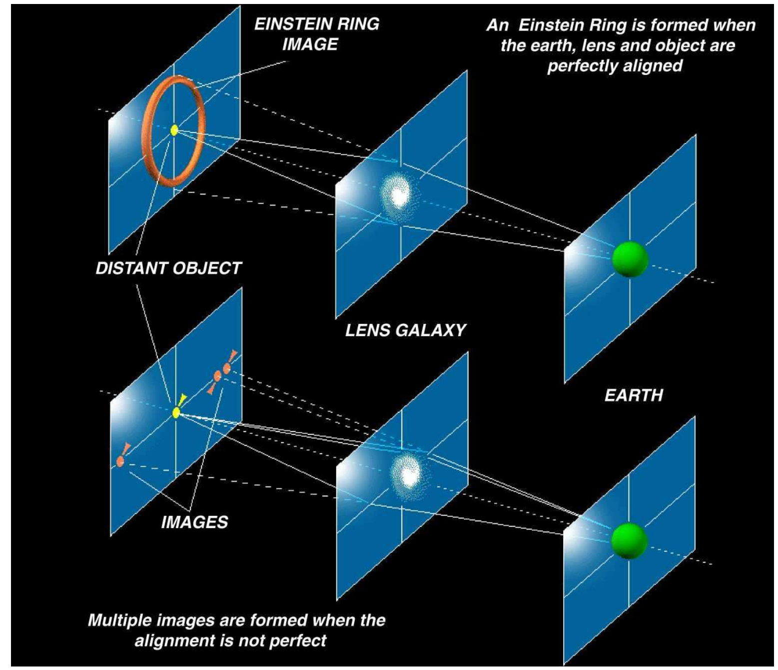
*** Image credit : Walsh, D. and Carswell, R.F. and Weyman, R.J. 1979, "0957+561 A,B: twin quasistellar objects or gravitational lens?" *Nature*, **279**, 381

Strong gravitational lensing

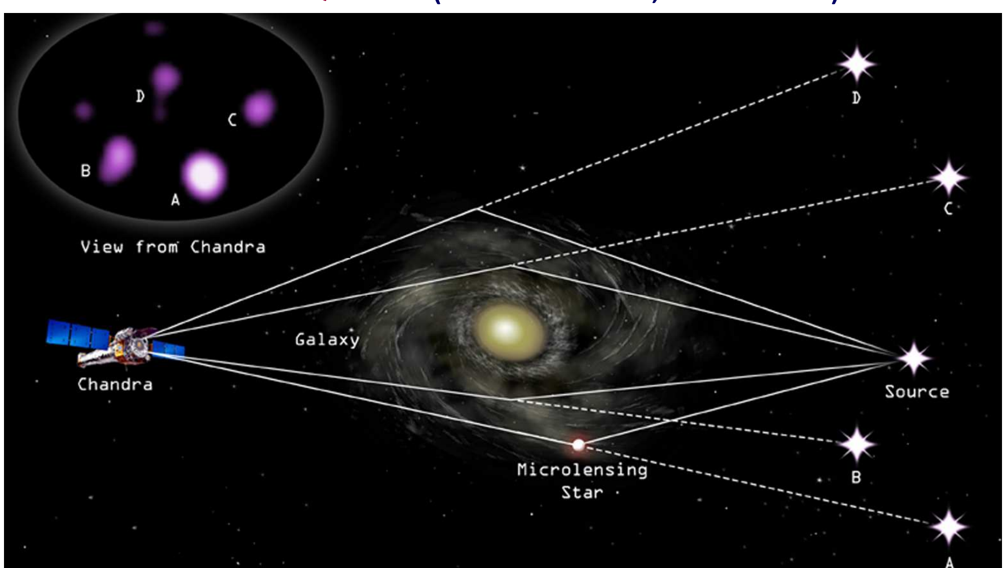
The most picturesque gravitational lens have their own names.

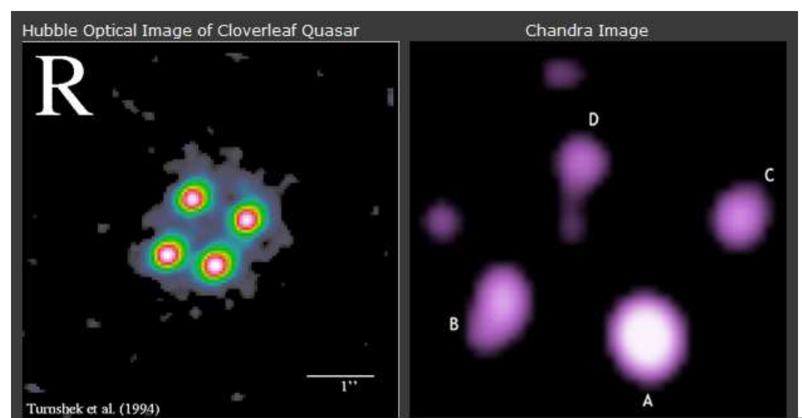
❑ 1. Einstein Ring (1'' diameter) in the gravitational lens system TXS 1938+666 (z=0.8809)





❑ 2. The Cloverleaf Quasar (H 1413+117, z=2.5582).

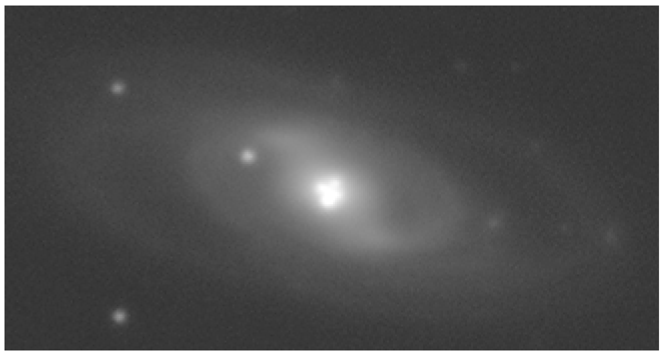


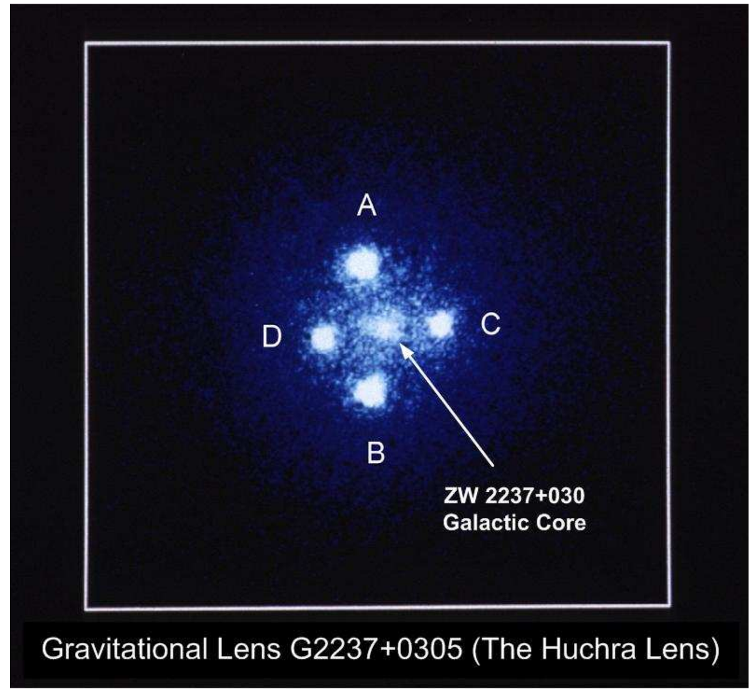


Strong gravitational lensing

The most picturesque gravitational lens have their own names.

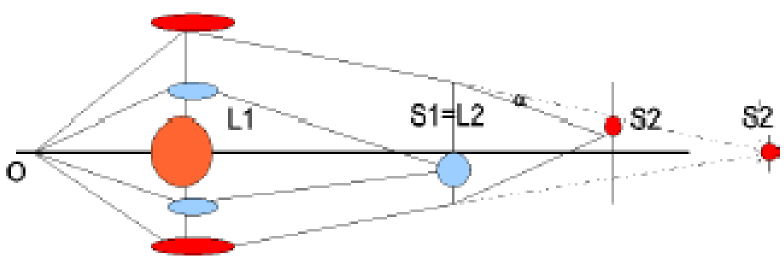
❑ 3. Einstein Cross quasar [HB89] 2237+030 (z= 1.695, lensed into four images by a z=0.04 galaxy).

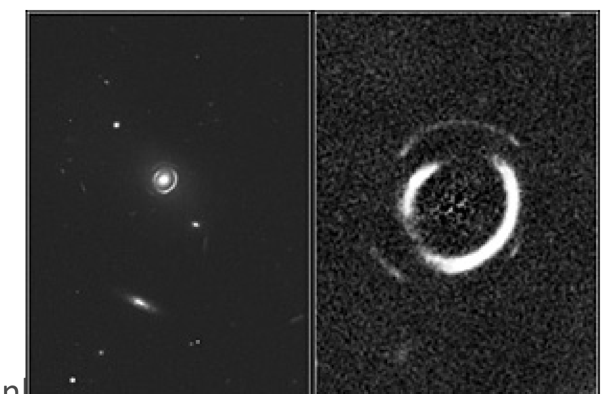




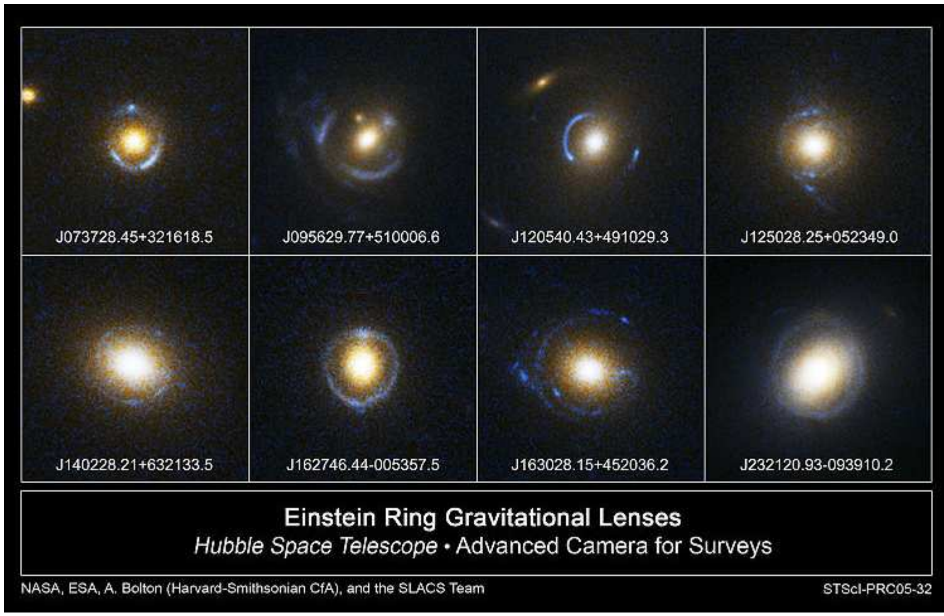
Gravitational Lens G2237+0305 (The Huchra Lens)

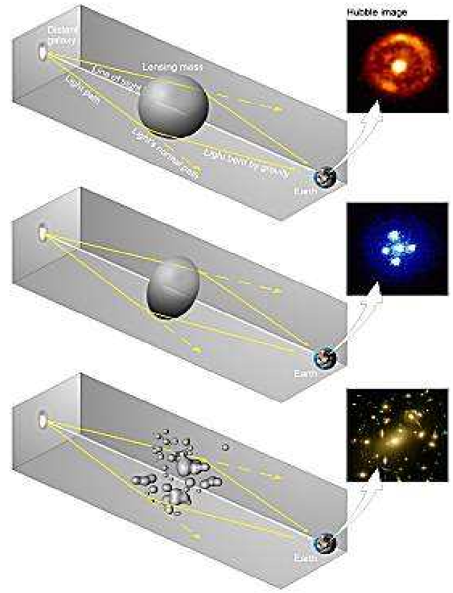
❑ 4. Double Einstein Ring around the gravitational lens SDSS J0946+1006 (main lens at z=0.222, inner ring at z=0.609).

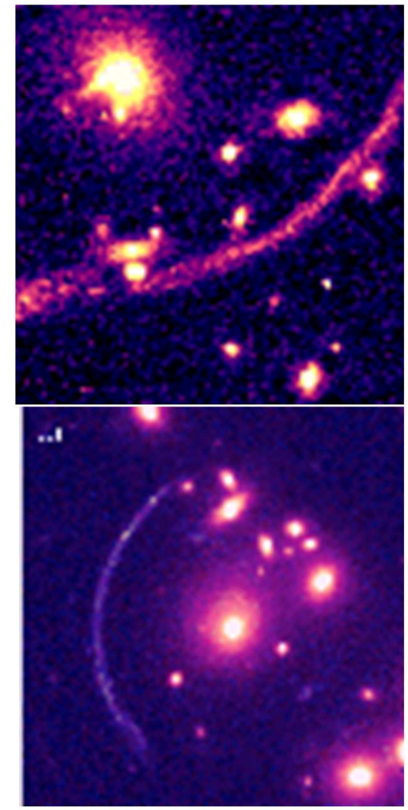


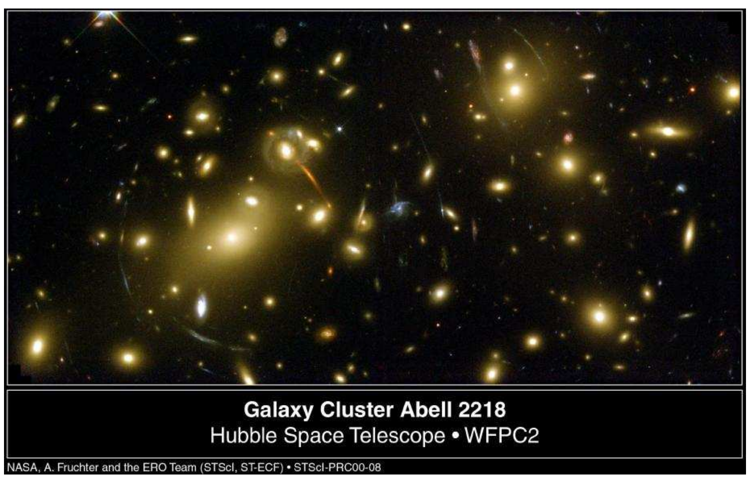


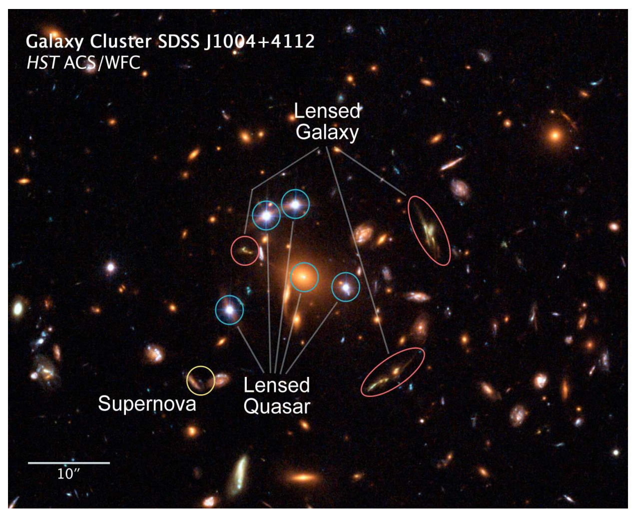
Strong gravitational lensing







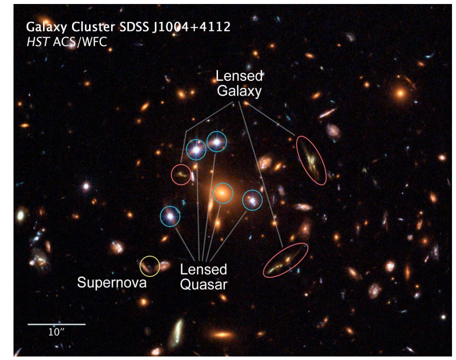


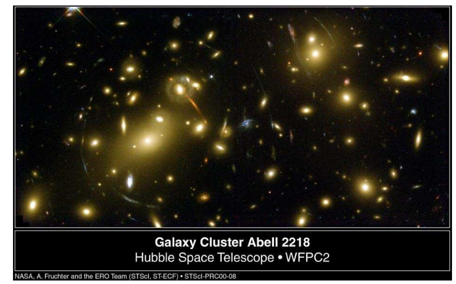


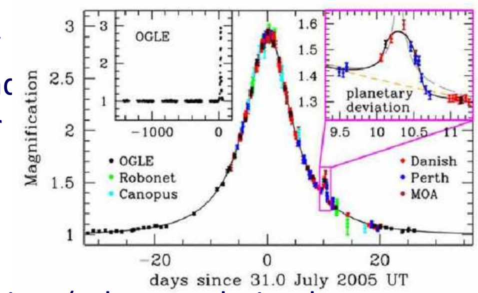
- Mysterious 'Giant arcs' in A370,Cl224. Paczynski suggests lensing. 1987 Fort et al. confirm. Spectroscopy. Clusters are more massive than expected.

Gravitational lensing

Observational point of view: 3 types of the gravitational lensing.



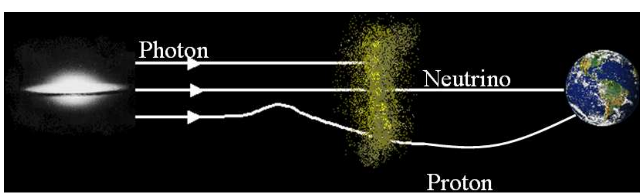




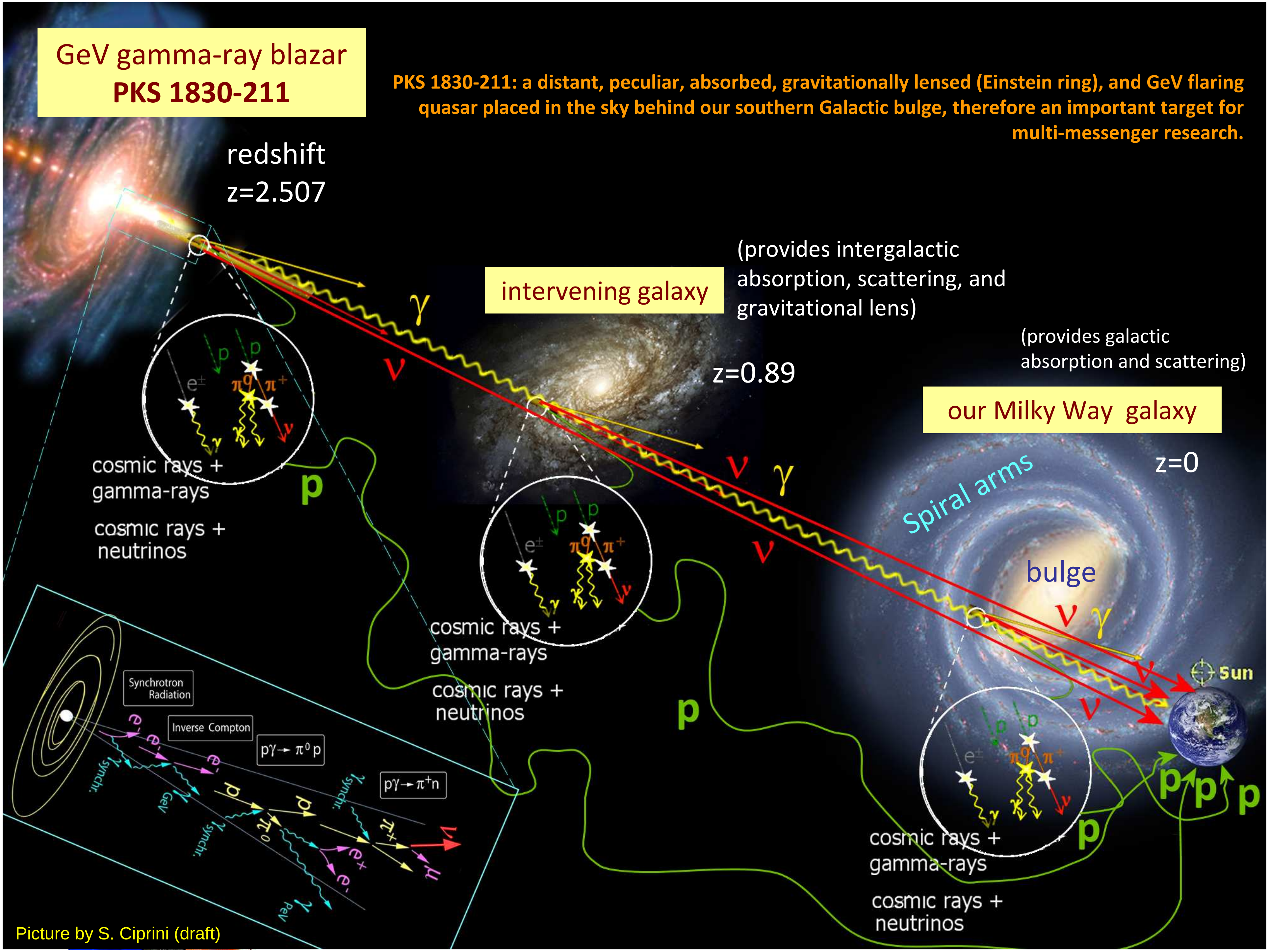
❑**STRONG LENSING**: Where there are easily visible distortions of light such as Einstein Rings, arcs and multiple images. This type of lensing is characterized by multiple images that, together with spectral and time variation properties of the images, allows to obtain a clear conclusion about the presence of the gravitational lens. All four previous examples belong to "strong macro-lensing" cases.

❑**WEAK LENSING**: Where the distortions of background sources are much smaller and can only be detected by analyzing large numbers of sources to find coherent distortions of only a few percent. Those cannot be identified in individual sources, but only in a statistical way. The example of a weak lensing is cluster Abell 1703. Observations of many distorted images of galaxies give a possibility to reconstruct the mass distribution (also dark matter mass) in the gravitational lens.

❑**MICROLENSING**: no distortion in shape but the amount of light received from a background object changes over time. A version of strong lensing in which the image separation is too small to be resolved. A single star (~ solar mass) can lead to images split into micro-images separated by mas. Example is microlensing on planets. Data from a microlensing event indicate a smooth, symmetric flux magnification curve as a lens star moves between a source star and an observatory on Earth. Short spike in magnification is caused by a planet orbiting (estimations of planet mass and orbit). Another example are MACHOs, kind of body that might explain the presence of dark matter in galaxy halos (detected when it passes in front of a star causing brightnening.

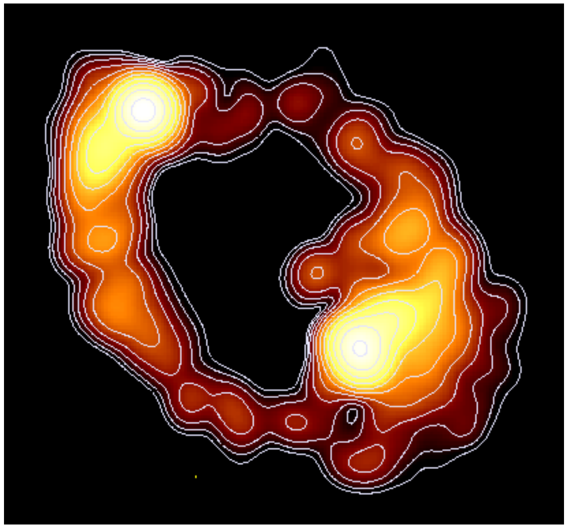


Gravitational lensing and neutrinos. Conservative view (take correlation between photons and neutrino). 1) Electromagnetic information for potential neutrino sources; 2) Easier to motivate (flux limits on sources); 3) Favorite candidates: nearby blazar, gamma-ray blazars, sources with large magnification ratios.


GeV gamma-ray blazar
PKS 1830-211
PKS 1830-211: a distant, peculiar, absorbed, gravitationally lensed (Einstein ring), and GeV flaring quasar placed in the sky behind our southern Galactic bulge, therefore an important target for multi-messenger research.
redshift
z=2.507
intervening galaxy
(provides intergalactic absorption, scattering, and gravitational lens)
z=0.89
(provides galactic absorption and scattering)
our Milky Way galaxy
z=0
Spiral arms
bulge
Sun
cosmic rays + gamma-rays
cosmic rays + neutrinos
cosmic rays + gamma-rays
cosmic rays + neutrinos
cosmic rays + gamma-rays
cosmic rays + neutrinos
γ
ν
p
Synchrotron Radiation
Inverse Compton
pγ→ π⁰ p
pγ→ π⁺n
Picture by S. Ciprini (draft)

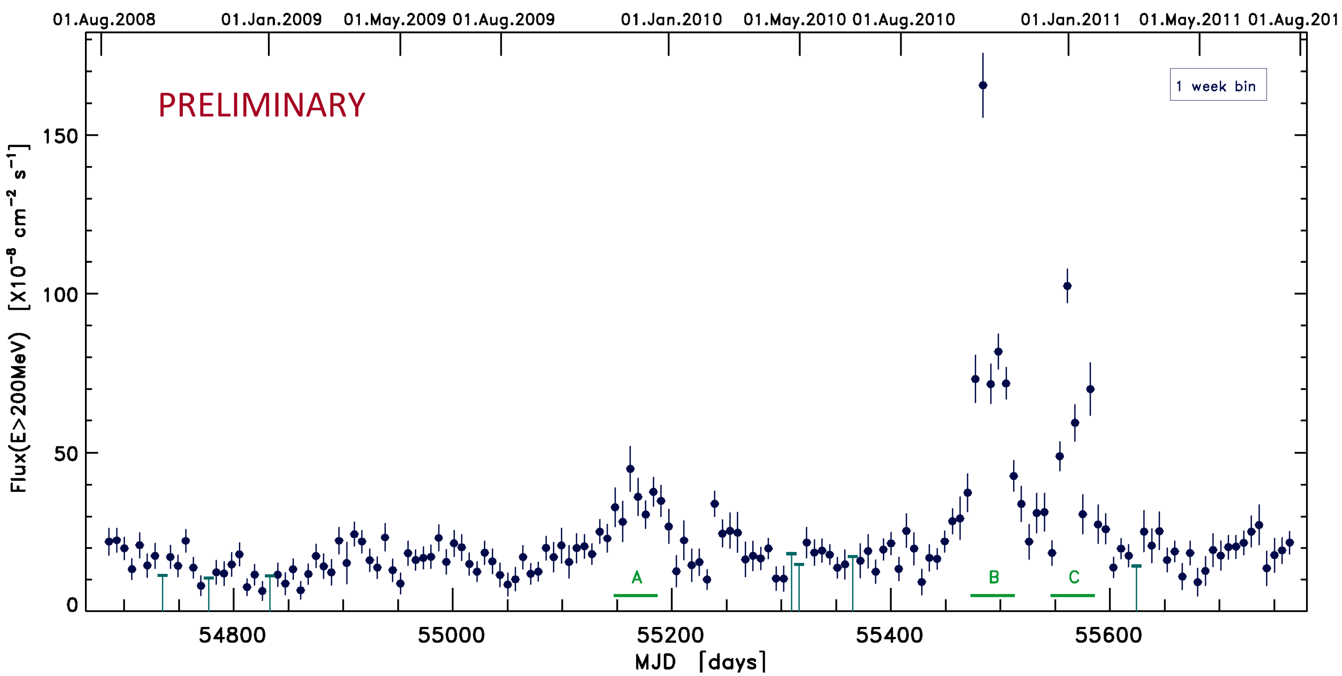
PKS 1830-211

- Flat spectrum radio quasar (FSRQ) PKS 1830-211 (a.k.a. TXS 1830-210, RX J1833.6-210, MRC 1830-211) clearly a strong gravitationally lensed source. Discovered as single source in Parkes (PKS, in 1969) catalog. VLA and ATCA clearly revealed two sources (NE and SW, separated by 0.98'' and connected by an Einstein ring). NE radio image a flux about 1.5 times as bright as the SW image.
- For the first time point source neutrino flux upper limits calculations (after the LAT ATel issue) are obtained for PKS 1830-211 with the IceCube telescope.
- Molecular absorption lines revealed lensing galaxies at z = 0.886, and z = 0.19. Optical imaging shows the same lens separation from the core (0.98'') and an unusually strong radio Einstein ring (confirmed by Gemini and HST). Further galaxies identified in the field of the source. Detailed exploration hampered in the optical by its proximity to the Galactic plane (dust extinction).
- Different paths to reach us → time delay between the photons which arrive from the two main images. Time delayed variability and flares expected. The system appears too much complex anyway to be used to measure H0.
- Radio time delays claimed: 26+/-5 days, 24+/-5 days, and a different value of 44+/-9 days (van Ommen et al. 1995 do not correctly accounting the contribution of the ring).
- PKS 1830-211 is highly variable (Fermi LAT flares, radio flares) and is also bright at hard X-rays and MeV energies (Chandra, XMM-Newton, INTEGRAL, Comptel detections, and X-ray photon index about 1). An EGRET source, AGILE source, 1FGL/2FGL LAT source too.



In 1991 the source PKS 1830-211 was identified as an unusually strong radio-band emitter and radio Einstein ring (gravitational lens). But it now appears that there may be two separate lensing galaxies, intervening in our line of sight, involved, not one (!). This would make PKS 1830-211 the first compound gravitational lens. Moreover PKS 1830-211 lies in a crowded and obscured sky field close to the Milky Way Galactic Centre.

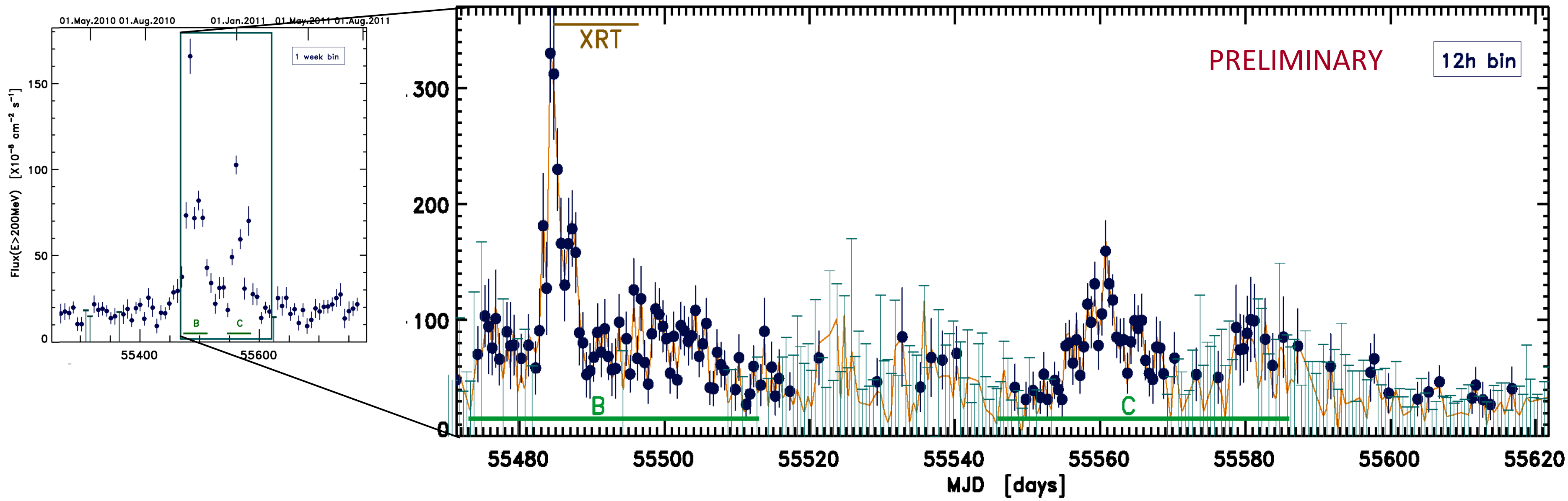
Gamma-ray flux light curve



- 3-year (1085 days, 2008 August 4 to 2011 July 25) LAT gamma-ray light curve of PKS 1830-211 in weekly bins, from 2008 August 4 to 2011 July 25 (MJD 54682.65 to 55767.65). Vertical lines refer to 2-sigma upper limits on the source flux. ULs have been computed for bins where TS<4, Npred<3, or ΔF>F/2.

- Energy range: 200 MeV - 100 GeV (E_min cuts some diffuse emission from nearby Galactic plane).
- Likelihood model accounted neighboring sources and diffuse emission. PSR J1809-2332 modeled with exponentially cutoff power law. PKS 1830-211 modeled with power law. PL fit over the entire period: Flux(0.2-100 GeV) = (20.43 +/- 0.44)E-8, ph.index 2.55 +/- 0.02
- Light curves: fixed photon index within the bins, weekly bin over 36 months time range, 12-hour bin on a 150-day long (2010 October 2 to 2011 March 1 active phase containing ``B'' and ``C'' flare intervals) . 2-day bin LC also produced and analyzed for comparison with Barnacka et al. (2011).

Gamma-ray flux light curve

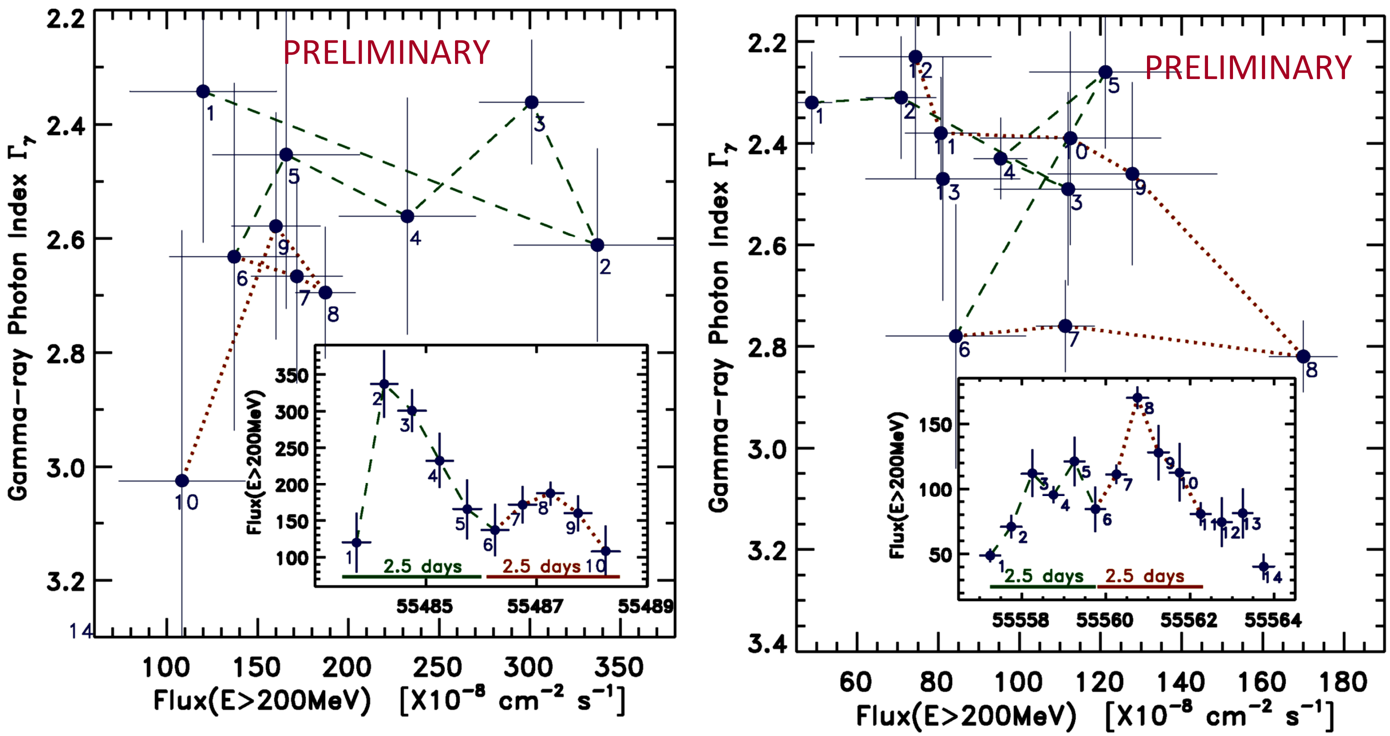


❑150-day range (2010 October 2 to 2011, March 1) flux light curve extracted with 12-hour bins and containing the "B" and "C" intervals when the main outburst of 2010 Oct. and the second largest, and double-peaked, flare of 2010 Dec.-2011 Jan. occurred.

❑12 hours are about 8 Fermi orbits → exposures from bin to bin are roughly the same.

❑ 2010 Oct. outburst is characterized by a rapid increase of a factor of about 2.6 in flux in 12 hours between 2010 Oct.14 and 15, and a Fpeak(>200MeV) = (330 +/- 42)X10^-8 phot/cm^2/s , yet taking about 48 hours to fall, resulting in an asymmetric temporal shape. The total peak lasts about 2.5 days, and seems to be followed by another weaker peak also lasting 2.5 days.

Gamma-ray flux light curve

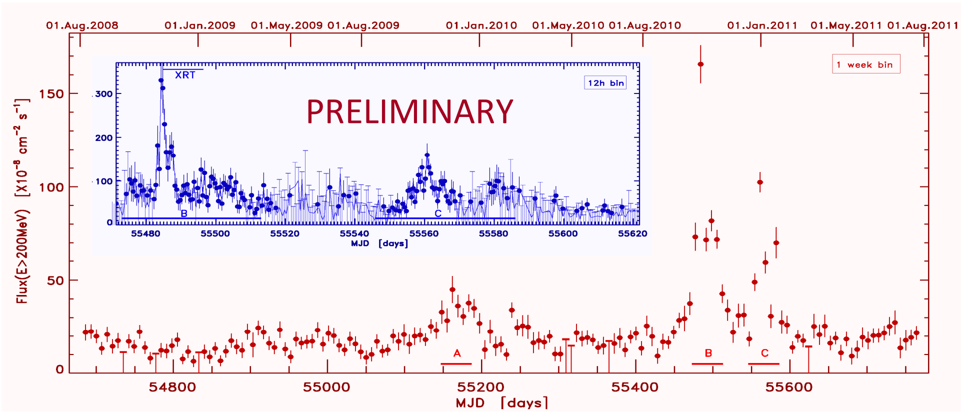


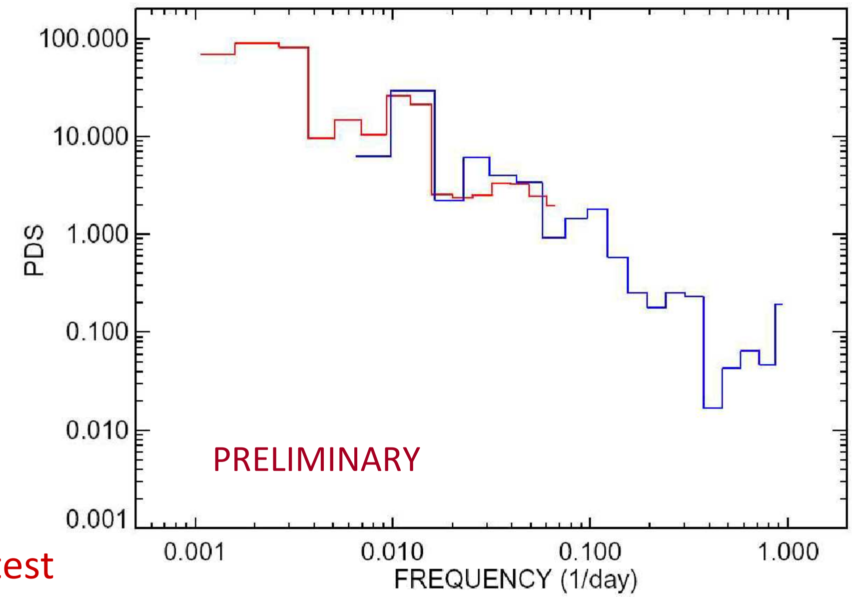
Evolution of the gamma-ray photon energy index as a function of the gamma-ray flux resolved by the LAT in 12-hour time bins during the peak of the 2010 Oct. outburst and the flaring event of 2010 Dec. - 2011 Jan. In this case, the photon index was left free in the gtlike fit analysis.

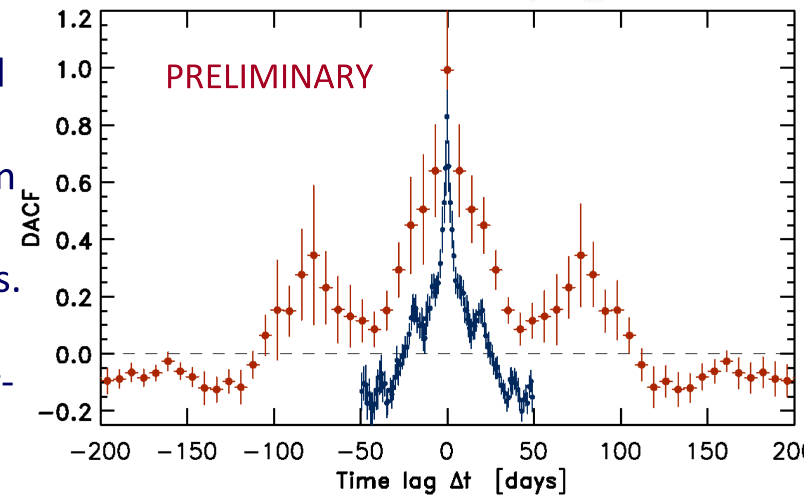
❑ Both flare events peaks do not show significant rotation in the ph.index-flux hysteresis diagram, (statistically constant photon index and relatively large errors on flux / ph.index w.r.t. variations.

❑ The 2010 Dec. 25 - 2011 Jan. 6 (right panel), displays two temporal peaks of about 2.5 days duration each. The firstpeak shows hints of a plateau while the second peak of about 2.5-day duration, reaches a flux value of (159+/- 27)X 10^-8 phot/cm^2/s, roughly half of the peak flux of the 2010 Oct. outburst.

Gamma-ray time variability properties







❑ AGILE ATel on 2009 Oct. 12-13 bright activity (occurred some weeks before the ``A'' phase we identified).

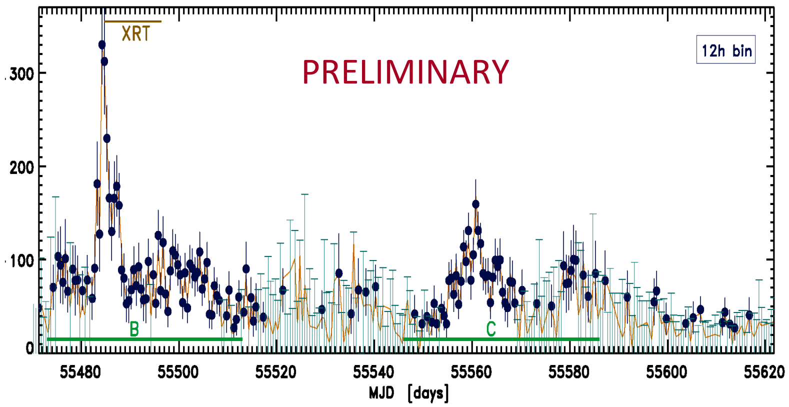
❑ Main LAT outburst epoch (Oct.2010): ``B''. Second brightest flare epoch (Dec.2010-Jan.2011): ``C''.

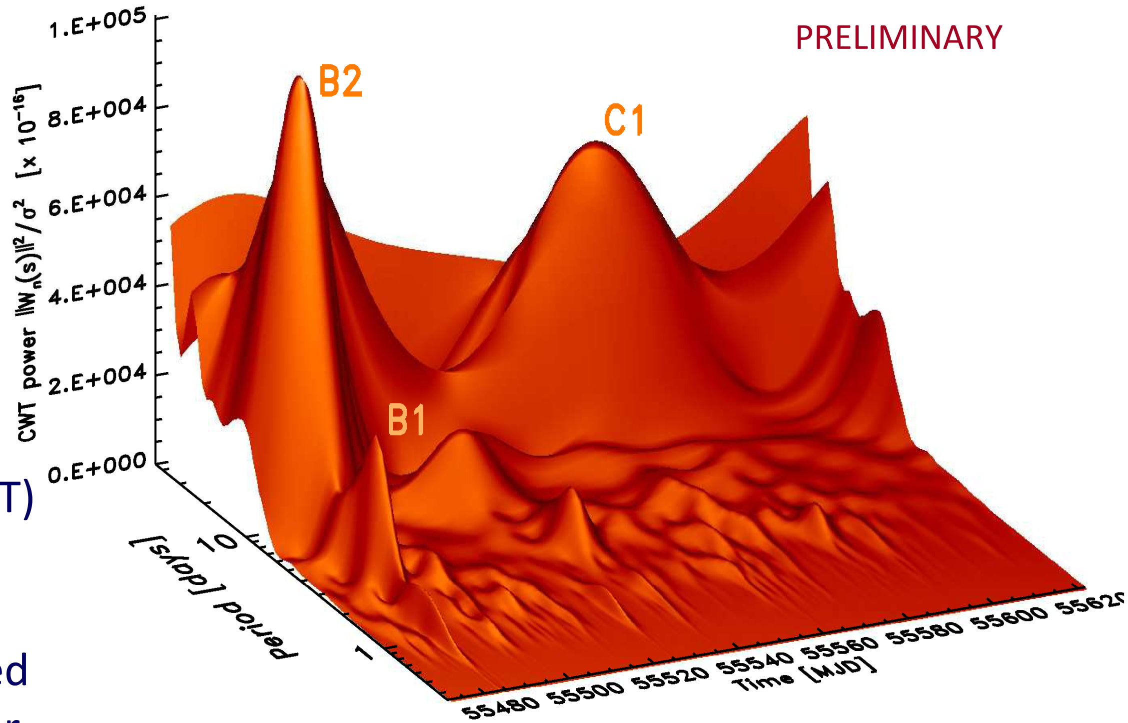
❑ Main composite outburst: first peak asymmetric, temporal structure characterized by two 2.5-day peaks.

❑ Power Density Spectra (PDS) and Discrete Auto-Correlation Function (DACF) extracted for both the 3-year (weekly bin, red line), and 150-day (12-hour bin, blue line) LAT light curves.

❑ PDS and DACF result in variability behavior closer to a ``flickering'' (red noise) than to shot (Brownian) noise (power-law index for PSD is about 1.2). DACF 20-day time peak.

Gamma-ray time variability properties

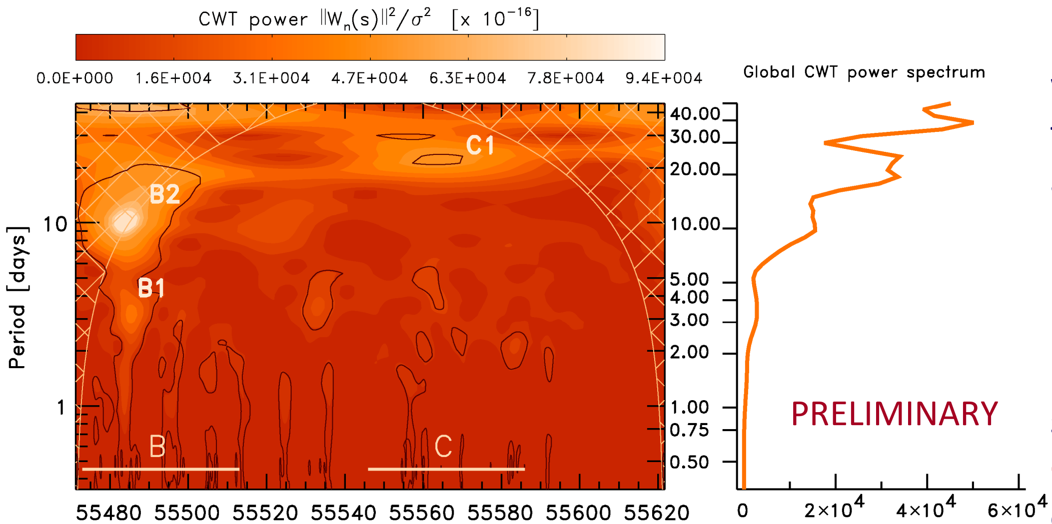




- ❑ Continuous Wavelet Transform (CWT) scalogram (3D plot of the 2D CWT transform power density spectrum for the 12-hour bin LAT light curve obtained using a Morlet, complex valued, mother function.
- ❑ The B epoch outburst (Oct.2011) well decomposed in two main temporal-localized components, C flare is identified with longer characteristic timescale.

3D pictorial version of the CWT scalogram for the 150-day 12-hour bin LAT (E>200MeV) light curve.

Gamma-ray time variability properties



❑ Most of the CWT power (out of edge effects) is within characteristic scales (y-axis, timescales 1/f, f=frequency) from 8 to 30 days. Appreciable power at longer periods (40-50 days, falling in cone of influence).

❑ Below timescales of 2 days there are not localized signal power peaks.

❑ Bulk of the flux power is localized along the time series (x-axis) and released between about 2010 October 6 - 26 (peak October 15). Corresponding characteristic scale of this outburst is 10 day.

❑ Resolved component of 3 days at Oct.17. Agreement with 2.5-day sub-peaks observed in the light curve.

❑ Second brightest flare identified by well-defined power peak, characteristic timescale of about 21 days, between about 2010 Dec. 30 and 2011 Jan. 4.

❑ Slight shift from a characteristic timescale for the outburst event duration of about 10 days (B2 peak in the CWT), to a timescale of about 20 days (C1 peak in the CWT). Later flare has twice the duration of the first ourburst, yet is approximately half as bright in emitted flux.

❑ No evidence for a detection of signal of delayed flares (induced by the second image of the gravitational lens system in PKS 1830-211) and following one of these two main flare events. The supposed delayed flares would appear as independent, power peaks separated by about 25 days (x-axis). No evidence for that.

❑Flare events connected by a regular delay would provide a clear structure in the CWT. The global CWT spectrum (left panel) does not show well defined peaks, meaning no periodicity or "recurrent" time scales.

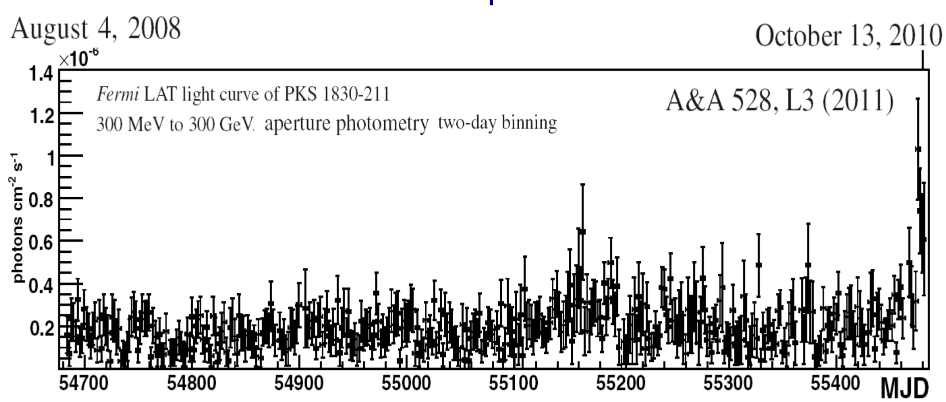
No clear evidence of time-delayed events produced by lensing

- **A clear evidence lensing-induced following-up flares is ruled out.** No following-up gamma-ray flares from the second lens image for both the ``B'' outburst and the ``C'' second brightest flare found. Gtlike flux (bin x bin spectral fit) light curve (12-hour, 2-day and 1-week binnings over 3 years) extracted using the same event class (Pass-6) and analyzed with different methods (PDS, DACF, WT). Minor variability on longer timescales (weeks/months) also found.

- Time delay of 26^{+5}_{-4} days (Lovell98), 24^{+5}_{-4} days (Wiklind01), the main outburst peak of 2010 Oct. 14-15 showed no delayed event. The same for the 44+/-9 days time delay (by VanOmmen95). Magnification ratio in radio bands is 1.5.

- Delayed flare does not exist in gamma-rays or magnification ratio in gamma-rays is much smaller, or there is a time or energy variable magnification ratio too given by the complex lens system and ambient.

- Barnacka et al. (2011) claimed a 27.1+/-0.6 days time delayed signal (using 2-day bin flux LC extracted through *"aperture photometry"* using Pass-6 events and IRFs. We used the same photons event classification and IRFSs.



- Aperture photometry technique and LAT data selection differs from that used for our maximum likelihood analysis.
- In addiction they used different E>300 MeV selection, a reduced time range (the LC stops at 2010 October 13, i.e. two days before the gamma-ray flare peak). A relevant portion of the main outburst and claimed delayed flare epoch are not taken in account.

No clear evidence of time-delayed events produced by lensing

❑ Signal feature at 53.4-day timescale: precession period of the spacecraft orbit → systematics by effective area variation not completely taken into account in Pass-6 data and IRFs. Incidentally the 27.1+/-0.5 day delay claimed is the first harmonic of that.

❑ LAT observing configuration affected also by moon gamma-ray emission (sidereal period of 27.32 days). A contribution to flux-modulation in aperture photometry method is possible, especially when the source was in a lower emission state (basically before October 2010).

NOTE:

❑ Other issues of aperture photometry with LAT data: 1) gamma-ray background not well measured and photon events are not background substracted (PKS 1830-211 close to Galactic plane); 2) contamination of the extracted light curve from other nearby sources (severe problem for spectral fit and count rate /flux estimation in case other nearby sources are variable); 3) the method potentially uses also less gamma-ray photons from the source since analyzes a smaller aperture area than the likelihood; 4) detailed physical spectral models cannot be applied (PKS 1830-211 has several gamma-ray sources within 10deg, including pulsar PSR J1809-2332 that needs to be modeled separately; 5) calculation affected by spurious fluctuations/modulations and systematic errors correlated to the particle background rate along the Fermi spacecraft orbit (precession period 53.4 day).

❑ Aperture photometry with LAT data is mostly used for very short bins (< 600s, rate curves with cumulated events and folding technique for very bright, Galactic, gamma-ray sources).

❑ Standard likelihood fit, time bin per time bin, is recommended for blazar sources (flaring, irregularly variable, fainter sources). Binning can be adapted (significant flux estimations, no ULs). This lead to 1) greater sensitivity, 2) more accurate bin flux measurements, 3) less spurious fluctuations, 4) correct backgrounds estimation, 5) correct flux calculation from spectral fit modeling.

Swift simultaneous observations

10 ToO Swift (XRT, UVOT) observations of PKS 1830-211 between 2010 October 15 and 24 through a GI program (PI: L. Reyes) triggered by the LAT outburst.

• BAT: BAT 58-month catalog 8-channel spectrum (HEASARC). 14-195 keV spectrum with ph. index 1.50+/-0.13

• XRT: previous soft X-ray observations revealed a hard spectrum (ph.index about 1) and absorption in excess (lensing galaxy at z=0.886). Individual XRT spectra of 2010 October fitted with absorbed power law (neutral hydrogen column + extra absorption by lensing galaxy). 0.3--10 keV X-ray flux only slightly higher than past XMM and Chandra measurements.

• Joint fit XRT+BAT: absorbed broken power law about 1.0 and 1.5 ph.indexes

• UVOT: due to high extinction (south galactic bulge region) PKS 1830-211 not detected above 3sigma in any filter

Table 1: Summary of the *Swift*/XRT analysis of PKS 1830-211.

			Power law Model			
Exp[a]	N_H[b]	$\Gamma_{X1)}$	E_{break}	Γ_{X2}	Flux (0.3–10)[c]	χ^2_{red}/d.o.f.
20.3	1.94 (fix)	1.20 ± 0.06	–	–	1.64 ± 0.11	1.19/129
20.3	$2.09^{+0.54}_{-0.36}$	$1.23^{+0.11}_{-0.08}$	–	–	$1.65^{+0.27}_{-0.18}$	1.19/128
			Broken Power law Model			
Exp[a]	N_H[b]	Γ_{X1}	E_{break}	Γ_{X2}	Flux (0.3–10)[c]	χ^2_{red}/d.o.f.
20.3	1.94 (fix)	1.05 ± 0.10	$3.65^{+1.35}_{-0.60}$	$1.56^{+0.39}_{-0.20}$	$1.53^{+0.14}_{-0.11}$	1.13/127

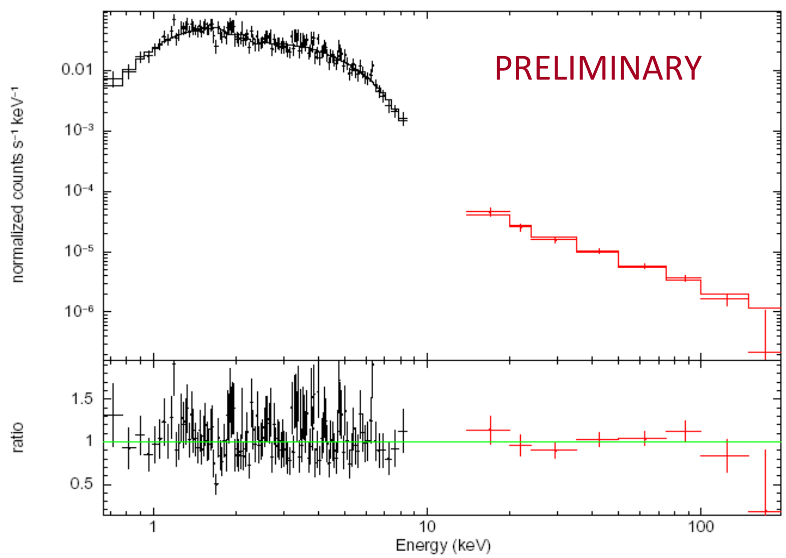
a Net exposure in kiloseconds adding the single XRT observations performed between 2010 October 15 and 24.

b Column density of the extragalactic absorber at redshift z=0.886 in units of 10^{22} cm^{-2}. A Galactic absorption of 2.05×10^{21} cm^{-2} (Kalberla et al. 2005) is added.

c Unabsorbed flux in the $0.3 - -10$ keV energy band.

Swift simultaneous observations

- 0.3-10 keV X-ray flux showed no significant activity in soft X-ray during the gamma-ray outburst is detected by LAT.
- No cross-correlation.



XRT and BAT joined spectral fit.

Fig. 5.— Joined *Swift* XRT spectrum from the accumulated data obtained during the multiwavelength campaign from 2010, October 15 to 24, and *Swift* BAT spectrum from all the accumulated archival data (58-month observations, 2004 November – 2009 August).

XRT and LAT simultaneous light curves

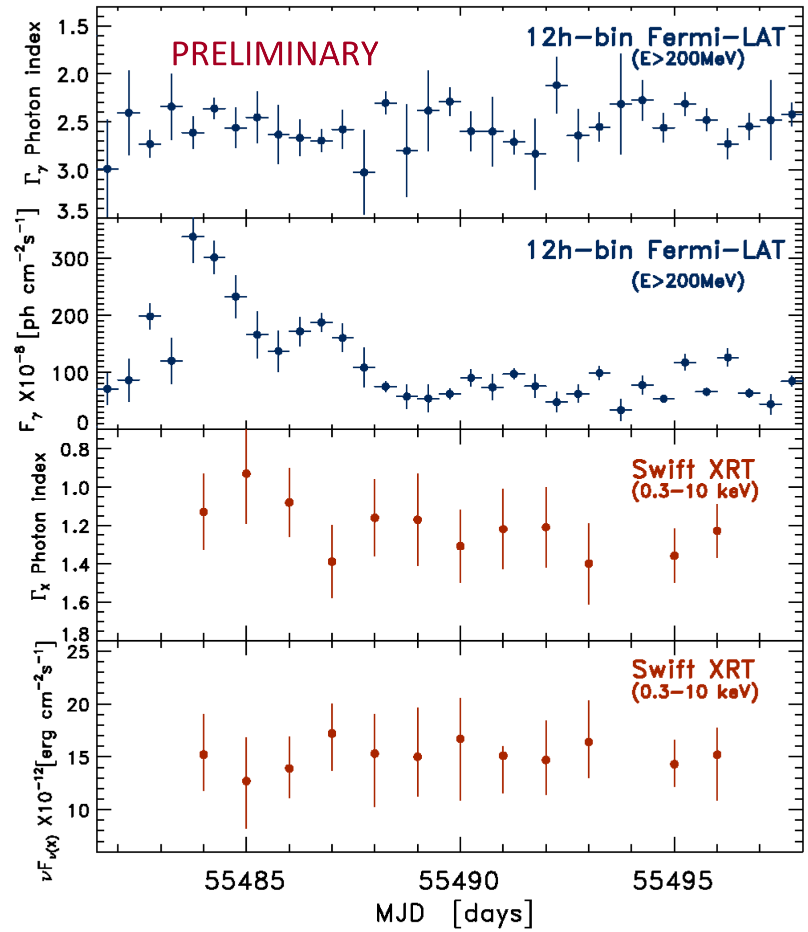
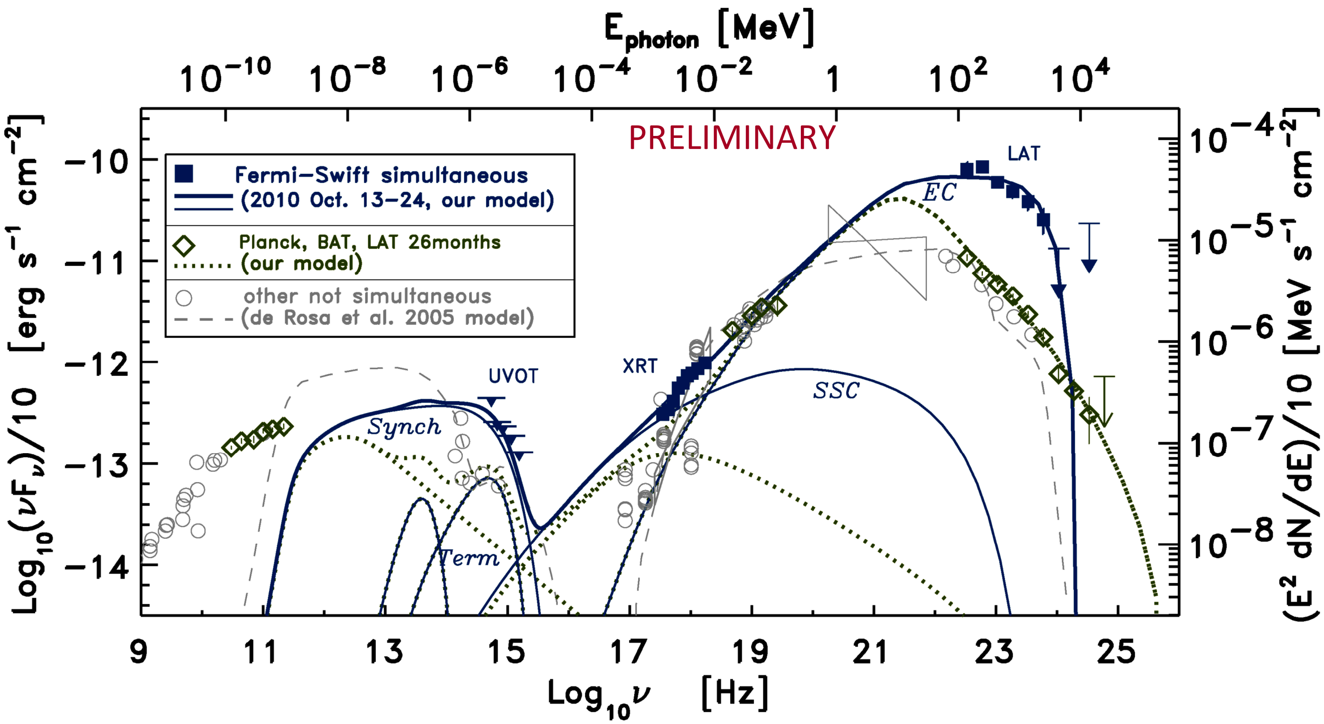


Fig. 4.— Multi-panel plot with simultaneous *Fermi* LAT and Swift XRT flux and photon index light curves.

Radio to gamma-ray SED



The SED of PKS 1830-211. Simultaneous Fermi-LAT, Swift XRT and UVOT (upper limits here) data, averaged over the 2010 October 13-24 campaign and corresponding to the gamma-ray outburst (blue square symbols). Non-simultaneous 26-month LAT spectrum, 58-month BAT spectrum, Planck ERCSC spectrum are all plotted as green open diamond symbols). Archival data (radio/mm, Gemini-N, HST, Chandra, INTEGRAL-IBIS, Comptel, EGRET plotted in light grey). All data are corrected for a factor of 10 magnification (although note that the magnification may not be the same for all frequencies. Plotted "strawman" fits with a synchrotron/SSC/ERC model to the flaring state and lower-brightness state are reported. Ambient dust and disk emission are the same for both models. Low state green data can be fitted with model parameters similar to the flaring (blue data) model, only changing two parameters: p_3 = 4, and gamma_max=10^5.

Radio to gamma-ray SED

- ❑ Data de-magnified by factor of 10 following Nair1993 Mathur1997.
- ❑ As an FSRQ, is unlikely that a pure synchrotron/SSC can explain the entire SED, ERC component needed (as already emerged from previous models, DeRosa2005, Foschini2006).
- ❑ Soft X-ray photons originated in the low-energy tail of the same electron distribution.
- ❑ Emitting region outside the BLR, primary seed IR photons from a dust torus
- ❑Emitting region size scale chosen consistent with minimal variability time scale resolved in main outburst (``B'') of 12 hours.
- ❑ Electron distribution with two spectral breaks.
- ❑ Due to simultaneous non-detection at UV/optical wavelengths, model not strongly constrained.
- ❑ For outburst ``B'' SED fit: total jet power about 3.3E45 erg s-1
- ❑ ``Quiescent state'' SED also built (non-simultaneous 58-month BAT spectrum, Planck ERC spectrum, 26-month LAT spectrum). Quiescent state SED can be reproduced by varying 2 parameters from the high state SED.

MODEL FIT PARAMETERS

Parameter	Symbol	2010 Oct 13–24 fit	Quiescent fit
Bulk Lorentz Factor	Γ	25	25
Doppler Factor	δ_D	25	25
Magnetic Field	B	1 G	1 G
Variability Timescale	t_v	12 hours	12 hours
Comoving Blob radius	R'_b	7.4×10^{15} cm	7.4×10^{15} cm
Jet Height	r	10^{19} cm	10^{19} cm
Low-Energy Electron Spectral Index	p_1	1.0	1.0
Medium-Energy Electron Spectral Index	p_2	1.8	1.8
High-Energy Electron Spectral Index	p_3	2.8	4.0
Minimum Electron Lorentz Factor	γ'_{min}	10	10
First Break Electron Lorentz Factor	γ'_{brk1}	30	30
Second Break Electron Lorentz Factor	γ'_{brk2}	300	300
Maximum Electron Lorentz Factor	γ'_{max}	6×10^3	1×10^5
Dust torus temperature	T_{dust}	1.1×10^3 K	1.1×10^3 K
Dust torus radius	r_{dust}	2×10^{18} cm	2×10^{18} cm
Dust torus luminosity	L_{dust}	1.7×10^{45} erg s^{-1}	1.7×10^{45} erg s^{-1}
Jet Power in Magnetic Field	$L_{j,B}$	7.5×10^{43} erg s^{-1}	7.5×10^{43} erg s^{-1}
Jet Power in Electrons	$L_{j,e}$	5.4×10^{45} erg s^{-1}	5.4×10^{45} erg s^{-1}
Total Jet Power	$L_{j,tot}$	5.5×10^{45} erg s^{-1}	5.5×10^{45} erg s^{-1}

PKS 1830-211: conclusions (1)

- LAT routinely detected highly dust absorbed, reddened and MeV-peaked flat spectrum radio quasar (FSRQ) PKS 1830-211 (z=2.507). This is the third most distant object detected in flaring activity by Fermi-LAT behind TXS 0536+145 and B3 1343+451

- Averaged apparent isotropic gamma-ray luminosity about 10^49 erg s^-1 (among the brightest high-redshift Fermi blazars). During the main LAT outburst a value of 1.9X10^50 erg s^-1 was detected.

- Peak flux F(0.2-100GeV) of 2010 October 14-15 was about 300x10^-8 ph cm-2 s-1 (factor 17 greater than the average 3-year flux).

- A gravitationally lensed bright gamma-ray blazar. Contrary to previous published claims we find no substantial evidence for a such a time delayed event from the second lens image in the LAT gamma-ray light curves (the expected delay of about 27 days with a flux magnification ratio of about 1.5 was not detected by the LAT).

- The flux ratio between the source and the image for gamma rays must be significantly greater than 6. Magnification ratio could be different for radio and gamma-ray emission.

- Although macrolensing is achromatic, different magnification ratios are found in other lensed quasars (Blackburne2006, Chen2011}, caused by microlensing substructure and complex multi-lensing system like PKS 1830-211 should be.

PKS 1830-211: conclusions (2)

- Peculiarly asymmetric peak (fast rise, slower decay) for the gamma-ray outburst with a rise of a factor 2.6 in flux in 12h. Asymmetry of the main outburst might imply particle acceleration and cooling times that are greater than the light crossing time, or be evidence for a dominant contribution by ERC radiation. A 2.5-day flux peak timescale appears to characterize the main outburst and the 2011 January second brightest flare.

- PDS spectrum has power law index 1.2, behavior closer to flickering fluctuations.

- ToO Swift observations. Hard X-ray spectrum (ph.index 1.2), no evidence for variability. No correlated X-ray and gamma-ray variability is somewhat typical for FSRQs.

- Mechanism producing gamma-ray flare not influenced the X-ray spectrum. The hard and soft X-rays are thought to be a combination of the contributions from SSC and ERC processes.

- SED modeling: gamma-rays originate primarily from dust-torus ERC process. Energy dissipation occurred far from the BLR.

- The gamma-ray behavior over the first 3 years of Fermi LAT operations can be attributed to intrinsic variability within the source, with no evident events caused by strong (macro) gravitational lensing.

Appendix:
flare of lensend blazar S3 0218+35

Flare and ATel#4343 on S3 0218+35

Fermi LAT detection of a GeV flare from the gravitationally lensed blazar S3 0218+35

ATel #4343; *S. Ciprini (ASI ASDC & INAF OAR, Rome), on behalf of the Fermi Large Area Telescope Collaboration*
on 28 Aug 2012; 20:45 UT
Credential Certification: Stefano Ciprini (stefano.ciprini@asdc.asi.it)

Subjects: Gamma Ray, >GeV, Request for Observations, AGN, Blazar, Quasar

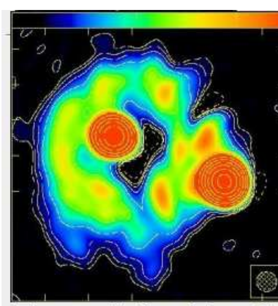
Referred to by ATel #: 4351, 4361, 4371, 4411

The Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed gamma-ray flaring activity from a source positionally consistent with the blazar S3 0218+35 (also known as 2FGL J0221.0+3555, Nolan et al. 2012, ApJS, 199, 31, and B2 0218+35, OD 330, lens B0218+357) placed at radio coordinates R.A.: 35.27279 deg, Dec: +35.93715 deg (J2000, Patnaik et al. 1992, MNRAS, 254, 655).

S3 0218+35 is a gravitationally lensed blazar (Patnaik et al. 1993, MNRAS, 261, 435; Browne et al. 1993, MNRAS, 263, 32; Lehar et al. 2000, ApJ, 536, 584; Cohen et al. 2003, ApJ, 583, 67) with source redshift z=0.944+/-0.002 (Cohen et al. 2003, ApJ, 583, 67) while the intervening and lensing spiral galaxy has redshift z = 0.6846 (Zeiger et al. 2010, ApJ, 709, 386). S3 0218+35 is a small separation optical lens (335 mas separation, Biggs et al. 1999, MNRAS, 304, 349) possessing one of the smallest Einstein rings in the radio band (0".33 diameter, Heidt et al. 2004, A&A, 418, 813; Cohen et al. 2003, ApJ, 583, 67; Oguri 2007, ApJ, 660, 1) and it represents an important object for studies of gravitational lensing, Hubble constant value and individual molecular clouds at high redshifts (Jethava et al. 2007, A&A, 472, 435; Zeiger et al. 2010, ApJ, 709, 386). The time delay between the variations in the two compact radio source images is 10.5+/-0.4 days (Biggs et al. 1999, MNRAS, 304, 349).

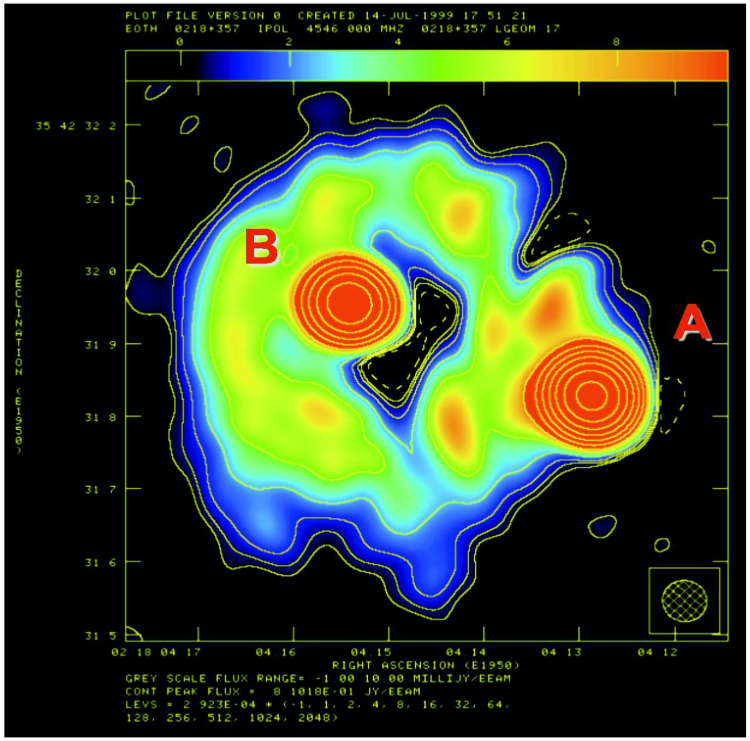
Preliminary analysis indicates that on 2012 August 26, S3 0218+35 was in a high state with an average daily gamma-ray flux (E>100MeV) of (1.6 +/- 0.3) x 10^-6 photons cm^-2 s^-1 (errors are statistical only), about 16 times greater than the average flux reported in the second Fermi LAT catalog (2FGL). A bright daily flux level around 1 x 10^-6 photons cm^-2 s^-1 was already detected on 2012 August 22 and 25 as well.

- Beginning around 2012 July, the Fermi LAT observed increased gamma-ray activity from the radio double-imaged gravitationally lensed blazar S3 0218+35 (z=0.944).
- Flare Advocate ATel issued at the end of Aug.2012.
- A simpler strong gravitational lens → more promising for time delayed event identification in gamma-rays!. LAT Coll. paper in preparation (T. Cheung et al.)
- Sustained and bright gamma-ray flaring activity in late Aug.2012 through Sept.2012. Unique opportunity to identify and measure the expected gravitationally lensed delayed flare emission for the first time in gamma-rays.



The gravitational lens CLASS B0218+357.
(Biggs et al., 2001, MNRAS, 322, 821

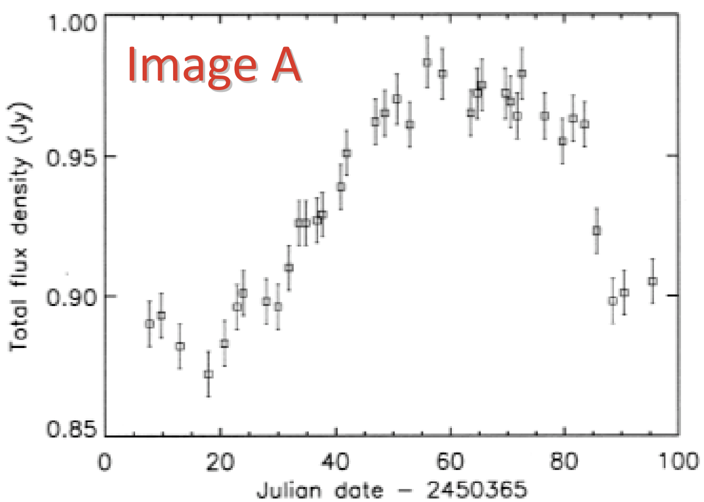
S3 0218+35

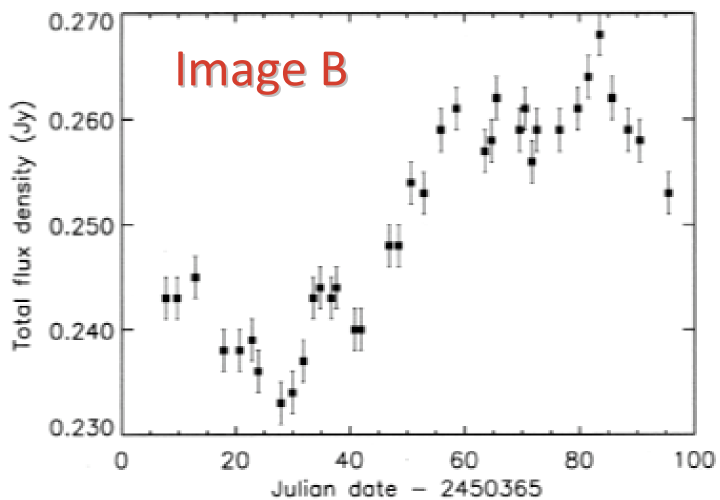


S3 0218+35 discovered with the NRAO 140-ft telescope (strong source survey 3, Pauliny-Toth & Kellermann 1972) with a 5 GHz flux density of 1 Jy. Subsequent radio imaging revealed it to be a gravitationally lensed double-image blazar with a separation of 335 milli-arcseconds (the smallest known) and an Einstein ring with a similar angular extent (O'Dea et al. 1992; Patnaik et al. 1993). The blazar is at a redshift, z = 0.944 ± 0.002 (Cohen et al. 2003), and the lensing galaxy is at z = 0.6847 (Browne et al. 1993).

- ❑ Smallest separation CLASS lens (0.335"); also in this case there is an Einstein ring
- ❑ Delay 10.5 +/- 0.4 day (95% CL); Biggs et al. 1999
- ❑ Bright radio source (1.2 Jy at 8 GHz)
- ❑ Associated 0FGL J0220.9+3607, 1FGL J0221.0+3555, and 2FGL J0221.0+3555
- ❑ Beginning mid-2012, increased gamma-ray activity from S3 0218+35 observed by the LAT. Sustained flaring with daily fluxes greater than 10x the source's nominal level, and simpler lens system wit respect to the previous case showed. → opportunity to uniquely measure the expected gravitational lens delayed flare event in gamma rays (C. C. Cheung , J. Scargle , R. Corbet, D. Wood in preparation).
- ❑ Fermi-LAT pointed observations for the anticipated delayed emission epoch.
- ❑ Brightest flares with peaks ~60x its nominal flux at the end of September 2012.
- ❑ Constrain the gamma-ray magnification ratio between the images.

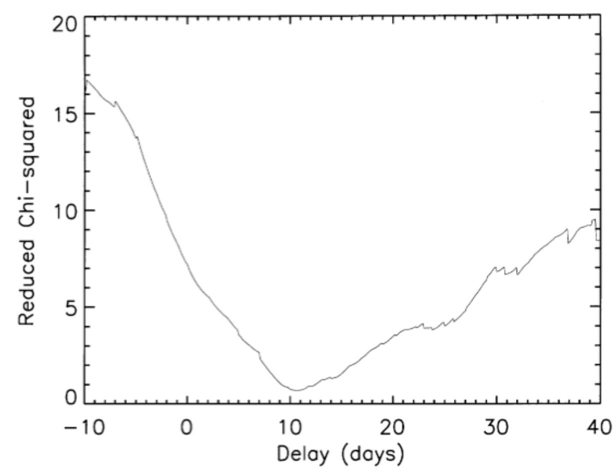
S3 0218+35 delay in radio light curves





- Radio-band delay 10.5 +/- 0.4 day (95% CL), Biggs et al. 1999 from chi-sq minimization in 0.1 day step sliding window; error from Monte-Carlo, consistent with cross-correlation function and discrete correlation function (Edelson-Krolik).

- Radio interferometric monitoring observations that spatially separated the double --> radio time delay (Refsdal 1964) between the brighter A (western) and B (eastern) images has been determined. Different analysis assumptions and techniques: best-fit values ranged from about 10 to 12 days.
- Independent (but contemporaneous) VLA measurements: Biggs et al. (1999) 10.5±0.4 day delay; Cohen et al. (2000) 10.1+1.5−1.6 day delay. Results consistent with 12±3 day delay previously determined from less detailed lightcurves (Corbett et al. 1996).
- Eulaers & Magain (2011) using measurements of Cohen et al. (2000) derived two possible delays (9.9+4.0 days, and 11.8±2.3 days).



LAT light curve: 1-day bins

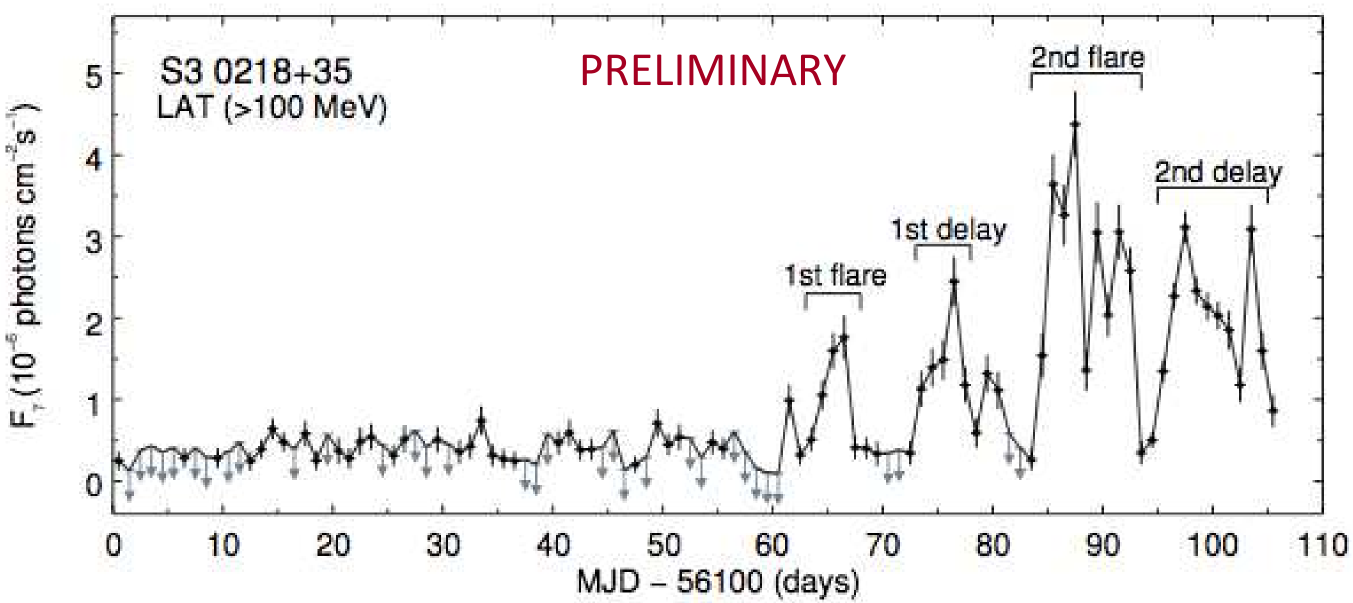
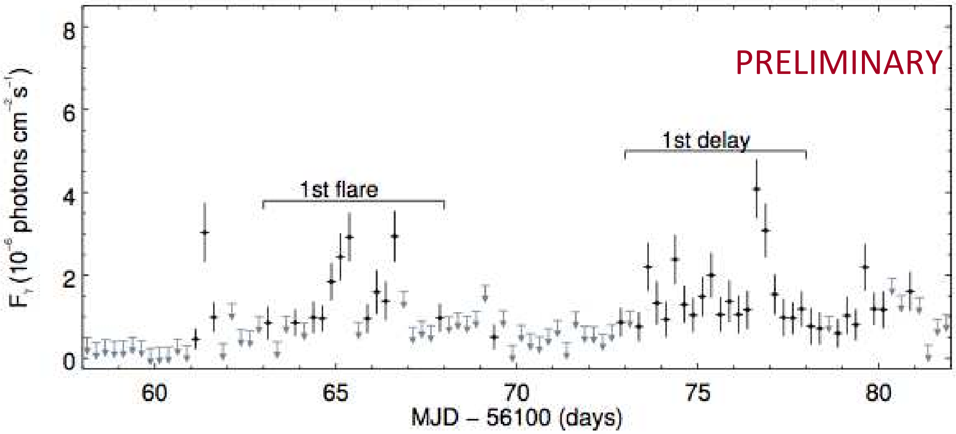
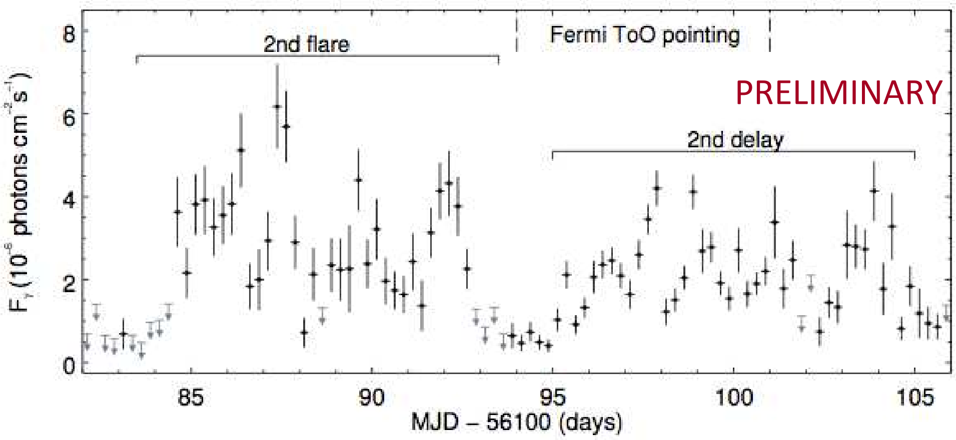


Fig. 2.— LAT lightcurve in 1-day bins for a 106 day interval surrounding the recent active period starting at MJD 56100 (see text and Figure 1). Fluxes are shown for days with $TS > 9$ as detections; 2σ upper limits on the fluxes are indicated for days with $TS < 9$.

In 2012, first flare detected in late August (ATel#4343) followed by first delay (ATel#4361, ATel#4371). Second flare observed late September (ATel#4411) with a Fermi target-of-opportunity observation aimed at the second delay. (C. C. Cheung , J. Scargle , R. Corbet, D. Wood in preparation).

LAT light curve: 6-hr bins and orbit by orbit (1.5-hr) bins around bright flares





3.— LAT lightcurve in 6-hr bins with the photon index fixed at $\Gamma = 2.3$.

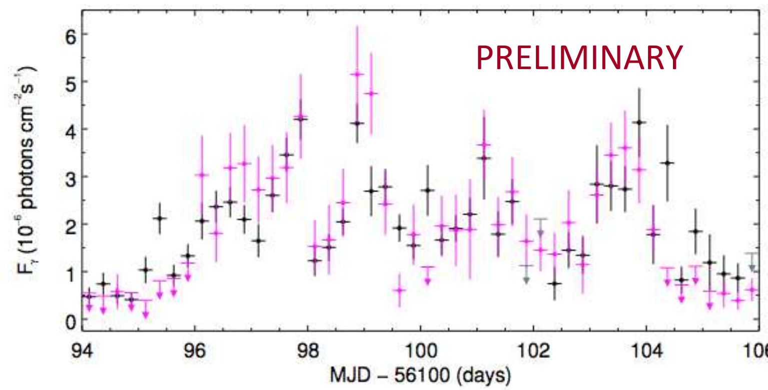


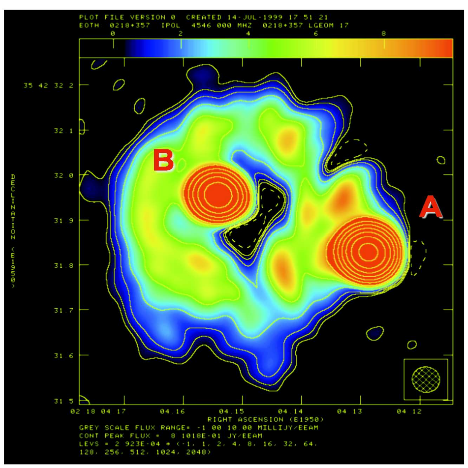
Fig. 4.— As in the bottom panel of Figure 3 but with the flare emission (magenta) divided by the observed flux ratio of 1.16 and shifted by +11.5 days (to the right) to match the delayed emission. Note the excess at day 104-105.

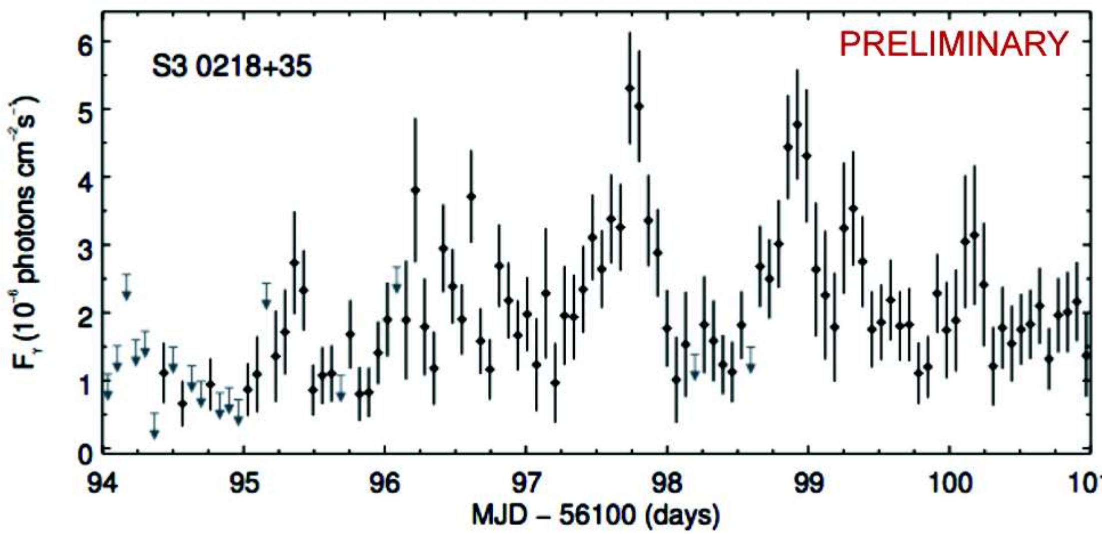
- LAT gamma-ray flux ratio = 1.16 +/- 0.07;
- LAT gamma-ray magnification ratio = 1.32 +/- 0.09

- Autocorrelation function and wavelet analysis identified a delay compatible with about 10-11 days (PRELIMINARY), consistent with previously determined radio values.
- Fermi pointed observation and revealed factors of two changes in gamma-ray flux rising and decay timescales of 3-4.5 hours.

S3 0218+35: conclusions

- ❑ Multiple radio delays published for this system with independent datasets & analysis methods giving: 12 +/- 3 day (Corbett et al. 1996) 10.5 +/- 0.4 day (Biggs et al. 1999), 10.1 (+1.5/-1.6) day (Cohen et al. 2000); reanalysis of Cohen+ data: 9.9 (+4.0/-0.9) or 11.8 (+/-2.3) day (Eulaers & Magain 2011).
- ❑ Independent gamma-ray measurement of gravitational lens delay.
- ❑ In radio, image A (brighter) leads image B (fainter) with A/B flux ratio ~3.7.
- ❑ In gamma-rays, we observed smaller flux ratio A/B ~1.2 .





LAT lightcurve in orbit-by-orbit bins over the 7-day interval of the *Fermi* ToO observation.

Summary and prospects

- **PKS 1830-211**: strong gamma-ray blazar; two major flares in first 3 years of Fermi survey; asymmetric outburst peak; no X-ray gamma-ray correlation, dust-torus (far from BLR) external Compton radiation (ERC) process; no substantial evidence for time delayed event caused by lensing; complex lensing system; flux ratio between the the image for gamma rays significantly greater than 6.
- **S3 0218+35**: smallest separation CLASS lens; simpler lens system; multiple radio delays published; independent gamma-ray measurement of gravitational lens delay; gamma-ray flux ratio 1.16 +/- 0.07; gamma-ray magnification ratio 1.32 +/- 0.09.
- **GB 1310+487** might be the third gravitationally lensed AGN discovered in flaring state in gamma-rays by Fermi LAT.

Prospects for Fermi LAT studies of lensed gamma-ray AGN/blazars

- Just under about 30 known lenses from JVAS/CLASS flat-spectrum radio source survey (16,500 objects). A fraction (~1/2) are doubles. Delays from radio measured for ~5 with varying uncertainty.
  - Gamma-ray flares more pronounced with 1-day flares of ~4-10x common (compare to few-10% increases in radio).
  - LAT can provide independent and new delay measurements.
- LAT can discovery new gravitational lens via gamma-ray temporal analysis
  - smaller separation ones than resolvable in CLASS 0.2” finding images
  - yet unidentified southern hemisphere sources
  - and maybe radio-faint objects in unidentified LAT point sources (different magnification ratios at radio and gamma-rays)?