Introduction

This document presents the scientific topics regarding Blazars and Radio Galaxies that will be addressed with the LAT data. Its aim is to serve as a guiding document intended to both the LAT Blazar Science Working Group and the community at large working in the field of Blazar Science and interested in collaborating with the LAT collaboration members. It is based on the rationale that all observations should be science-driven. In particular, well-defined scientific objectives must thus be identified a priori to justify extensive simultaneous/contemporaneous campaigns involving observatories spreading across many wavelength bands.

This document is intended to be a living document, evolving until the GLAST launch, scheduled in October 2007, and possibly beyond. The initial draft has been written up by Anita Reimer and Greg Madejski with significant contributions from Chuck Dermer.

Further information concerning the preparation of Multiwavelength activities associated with the LAT can be found on the page of the Multiwavelenghth Coordinating Group led by Dave Thompson (djt@egret.gsfc.nasa.gov):
http://confluence.slac.stanford.edu/display/GLAMCOG/GLAST+LAT+Multiwavelength+Coordinating+Group.

A few technicalities concerning the LAT

The LAT (Large Area Telescope), will detect gamma rays with energies between 30 MeV and 300 GeV. Thanks to its large effective area (10000 cm2 at 1 GeV) and large field of view, FOV, (2.4 sr), the one-year LAT sensitivity at high galactic latitude is estimated to be 4 10^{-9} ph (E> 100 MeV) cm^{-2} s^{-1}, a factor 25 better than the Third EGRET Catalog sensitivity. The satellite will orbit the Earth at an altitude of 565 km with an inclination of 28.5 deg. In the first year of operation, the observatory will operate in survey mode, by rocking alternatively by 35 deg with respect to the direction opposite to the Earth every second orbit. The sky will thus be totally covered in two orbits, about 3 hours, the exposure being very uniform over the sky. This feature will enable the continuous monitoring of many blazars, over time scales of about one hour for the brightest ones. The mission expected livetime is 5 years. Up-to-date details concerning the LAT performance can be found at:
http://wwwglast.slac.stanford.edu/software/IS/glast_lat_performance.htm

Other information

Depending on the models, the LAT should detect between one thousand and several thousands gamma-ray blazars. To prepare for the identification of these blazars, an all-sky optical/radio survey (Candidate Glast gamma-Ray Blazar Survey, CGraBS) ultimately including about 1500 blazar candidates is currently underway.
During the first year, some data (flux + spectral index) will be released on a regular basis for a number (about 20) of selected sources.

OUR ULTIMATE GOALS

The overarching goal is to understand the phenomenon of an active galaxy and the associated jet. We are working within the paradigm where an AGN is ultimately powered by the release of gravitational energy via flow of material onto a black hole.

We envision that our work will have broad implications for understanding of:

* formation and evolution of black holes
* formation, structure and evolution of relativistic jets, and the connection between the jet and the black hole
* basic physics of particle - particle and particle - field interactions, in particular under extreme environments (ultra-high energy particles and radiation)
* particle acceleration processes
* origin of the cosmic rays
* implications for the evolution of structure in the Universe

Our approach here is akin to "peeling an onion":

- we study AGN via the "messengers" - photons – to infer first the emission mechanisms, leading to the physical setting and energization mechanisms of the particles that emit the radiation, then leading to the ultimate source of power

- We divide the study into three parts:
- (A) AGN as a population and the blazar phenomenon
- (B) Physics of the gamma-ray emission in AGN
- (C) AGN as tools for other investigations

Importantly, we identify data in other bands (non-γ-ray) needed to accomplish our goals

A. AGN as a population and the blazar phenomenon

The estimated number of blazars that GLAST will detect ranges from a thousand (Dermer 2006) to several thousand (Stecker & Salamon, 1996; Chiang & Mukherjee 1998; Mücke & Pohl 2000). Such a large and homogeneous sample will greatly improve our understanding of blazars and radio galaxies and will be used to perform detailed population studies and to carry out spectral and temporal analyses on a large number of bright objects. In particular, the very good statistics will allow us to

a) extend the LogN-LogS curve to fluxes about 25 times fainter than EGRET

b) estimate the luminosity function and its cosmological evolution

c) calculate the contribution of blazars and radio galaxies to the extragalactic gamma-ray background.

These observations will chart the evolution and growth of supermassive black holes from high-redshifts to the present epoch, probe the evolutionary connection between BL Lacs and FSRQs, verify the unified model for radio galaxies and blazars (Urry and Padovani 1995), and test the "blazar sequence" (Fossati et al. 1998). Finally, LAT blazar detections will be essential in determining if a truly diffuse component of extragalactic gamma-ray emission is required, or if such background can be accounted for by a superposition of various classes of discrete objects.

B. PHYSICS OF GAMMA-RAY EMITTING AGN

This is about how gamma-ray emitting radio-loud AGN work, including the jet structure, content, and radiative processes.

We are considering the two leading candidate processes for radiation emission mechanisms. Those are (1) leptonic processes, where the low energy "peak" is produced by synchrotron mechanism by a non-thermal population of relativistic electrons/positrons, and the high energy peak is produced by inverse Compton mechanism by the same particles, where the seed photons are the internal synchrotron radiation, or on the external circum-nuclear radiation; or (2) hadronic processes, where the low energy component is also produced by synchrotron radiation, while meson production (via the interaction of highly relativistic protons and photons), and subsequent cascading is involved in the production of the high energy component. Such cascades are initiated by the photons resulting from the decay of π^0 (produced via proton-photon interaction), or by synchrotron photons from the secondary pairs, Those are then reprocessed to lower energies where they can escape the emission region. Hence, additional components may include synchrotron radiation of the photoproduced charged particles and protons and their reprocessed radiation. The target photon field for photomeson production and cascading may encompass the same internal and external photons fields as in the leptonic model.

B.1 WHAT is the structure (ingredients/content) of jets in quasars and radio galaxies?

* *B.1.(a) the content of innermost part of the jet (ionic, e+e-, Poynting flux; baryon loading?)*

  *** Approach:** Is there a substantial e+/e- component to those? Are they most likely Poynting flux dominated? --> search for soft X-ray "precursors" to gamma-ray flares and determine the time delay; presumably if jets are particle dominated to begin with, one should see "bulk-Compton" radiation prior to dissipation events - the intensity of the "precursors" should reveal the total e+ /e- content of the jet. *Note that a different temporal behavior is predicted by some specific hadronic models (e.g. blast-wave model) which predict in general the X-ray flare to follow (lag) the gamma-ray flare; this is because the X-ray component in this model is produced by synchrotron radiation by the pair cascades from charged pions that are produced in proton-photon interactions whereas the gamma-ray flare is dominated by the photons from pi^0-decays.*

  Targets: Bright blazars in flaring states: 3C279, 1622+398, PKS 0528+134
  Other data needed: Good coverage in soft X-rays during pre-flare, flare, and post-flare state; time lag information. Needed duration: 2 weeks; sampling: every 3 hours if feasible since little is known regarding the location of particle acceleration region from the central engine (although this can't be too close, or Compton drag prevents the jet to survive: the jet would then become photon dominated).

** B.1.(b) composition/structure of gamma ray emitting part of jet (e+/e-, p/e or UHECRs, B field)*

*** Approach 1:** Test simple, 1-zone leptonic models: To first order, no lags (or at most, small lags) between the synchrotron and Compton components are expected. Non-expected behavior calls for alternative model solutions which may be linked with the need for hadronic jet components (see ``orphan flares`` - occurring only in one component; low-E component lagging high-E component, etc.)

Examples: are single-zone SSC models already in trouble for the HBL-type blazars? SSC model precludes flares that are seen only in one, but not in the other component: "orphan" flares seen via X-ray + TeV campaigns pose substantial problem to SSC models; a few were reported in previous data, but no clear consensus

Targets: HBL blazars Mkn 421, Mkn 501, 1ES1959+65
Other data needed: good coverage in soft X-rays and in the TeV band

** B.1.(b) composition/structure of gamma ray emitting part of jet (e+/e-, p/e or UHECRs, B field) (continued)*

*** Approach 2:** Identify dominant general scenario: (a) leptonic, (b) hadronic (protons interacting with protons, photons or fields) at gamma-ray energies. Apart from (non-available) polarization data in the gamma-ray band, this goal can be approached through detailed broad-band modeling (including simultaneous broadband data and variability information) using competing blazar emission models. E.g., leptonic models predict significantly sharper cutoff at high energies for the LBL objects than the hadronic models which predict more gradual spectral decline in the (sub-) TeV range. This is because in blazars with denser target photon fields (such as LBLs) components from charged muon/pion synchrotron radiation may produce additional flux in the sub-TeV range.

Targets: nearby strong emission line LBLs (BL Lacertae, W Comae), but potentially also FSRQs (3C273, 3C279, 3C454.3, PKS 0528+134) – but for those, one must consider complications associated with the gamma-UV pair production as well as Klein-Nishina effects.

Other data needed: For unambiguous model fits both simultaneous broad-band SEDs plus variability information (light curves, hysteresis...) are required in energetically equally distributed energy bands.

** B.1.(b) continued: composition/structure of gamma ray emitting part of jet*

*** Approach 3:** Derive a measurement or UPPER limit on B field strength in the gamma-ray emitting region; useful tools may be: equipartition arguments using low-E peak flux, width of variability correlation functions, multi-lambda leads/lags including optical + X-ray + GLAST data, information on the total kinetic luminosity of the jet (total energetics of flares, radio lobes)

Targets: nearby, bright blazars (both HBL, TeV – emitting objects, and LBL objects)
Other data needed: broadband long continuous data trains, very short sampling time scale

*** Approach 4:** Determine the relative importance of adiabatic vs. radiative losses, via study of the flare profiles (symmetric vs. not symmetric); non-symmetric flare profiles are a tell-tale of radiative processes dominating. Time-dependent hadronic models?

Targets: same as above

* **Approach 5:** Derive an unbiased estimate for the total jet luminosity / total charged particle content / kinetic energy of the blazar jet. Need to do this in the HE component since the LE component might be contaminated by emission from much larger volume and/or affected by synchrotron self-absorption

Targets: should yield inferences about the particle content from modeling of the Compton component - presumably the "low end" of the distribution is due to less energetic but much more numerous particles -> bright sources with hard X-ray spectra are best, such as BL Lacertae, PKS 1510-089

Other data needed: Hard X-ray/soft γ-ray band regimes are most important, besides GLAST

Note that the very hard spectra in the 10-100 keV regime may challenge hadronic models

* **Approach 6:** Search for gamma-ray emission from blazars that display spectra consistent with neutron-decay and hadronic cascade origins for synchrotron and Compton components (cf. Atoyan & Dermer 2003 etc.).

Targets: 3C 279, PKS 0528+135, Mrk 421, Cygnus A, Pictor A, others
Other data needed: Multi-wavelength coverage of blazars at energies of most highly variable synchrotron flares.

** B.2 WHERE are the X-rays/gamma-rays produced ?*

** B.2.(a) photon production sites of low & high energy component*

* **Approach:** Is an one-zone model sufficient? If the flares are indeed produced by the same co-spatial electron population, the light curves for the synchrotron and Compton component flares should be strictly simultaneous, meaning no measurable leads or lags of the IR/opt/UV and gamma-ray flares

Targets: HBL blazars Mkn 421, Mkn 501, 1ES1959+65
Other data needed: Simultaneous monitoring in the IR/opt/UV bands, at a cadence allowing to temporally resolve the flares (implied by the GLAST data)

** B.2.(b) energization sites*

* **Approach:** Use the “gamma-gamma attenuation within a jet” arguments to place a minimum limit on the bulk relativistic Lorentz factor of blazar jets, and to set minimum distances of the location of the emitting jets from the central supermassive black holes. Correlate Lorentz factors with blazar types.

Targets: 3C 279, CTA 102, PKS 1622+398, others
Other data needed: Correlated X-ray observations

** B.3 HOW are the X-/gamma-ray flares produced in blazars and radio galaxies?*

** B.3.(a) Importance of external photon fields (BLR, accretion disk, CMB, ...) for X- & gamma-ray production*

**** Blazars:***

*** Approach 1:** Is Self-Compton or External Compton more applicable for objects with strong emission lines? Gamma-ray flares (presumably Compton) should obey the simple quadratic (for SSC) or linear (for ERC) relationship against the amplitudes of the IR/Opt/UV flares (presumably synchrotron component) if the low and HE component are co-spatially produced (which is in doubt considering the most recent MWL results). In this case correlated variability between optical and 100 MeV - GeV emission, and X-ray and >>GeV – TeV emission should be examined as evidence for SSC, EC or other (e.g. proton synchrotron?) processes by comparing with model expectations.

For HBLs, is the HE component indeed a single component, or does it consist of many parts? Is the TeV spectrum a smooth continuation of the GeV spectrum? EGRET data were only marginal for HBLs.

* **Approach 2:** via direct verification of the strength of the putative external target photon fields (e.g. BLR, accretion disk through emission line measurements, etc.)

Target(s): Bright blazars in flaring states: 3C279, 1622+398, PKS 0528+134

Other data needed: Simultaneous monitoring in the IR/opt/UV/X-ray bands, at a cadence allowing to temporally resolve the flares (implied by the GLAST data); BLR emission line strengths around times of gamma-ray activity

** B.3.(a) continued: Importance of external photon fields (BLR, accretion disk, CMB, ...) for X- & gamma-ray production*

**** Radiogalaxies/large scale jet structures:***

*** Approach:** Tests of the Compton-scattered CMBR interpretation of extended X-ray (Chandra) jets; Highly relativistic motions on hundred kpc scale is required to explain X-ray knot emission in Chandra jets through Compton-scattering of the CMBR, with definite predictions for GLAST.

Targets: PKS 0637-752, Cen A?
Other data needed: Measurements of the minimum non-variable flux of PKS 0627-752 will test this model. IR data important.

** B.3.(b) Relation between flares and dissipation of magnetic energy*

* **Approach:** Are gamma-ray flares related to dissipation of magnetic energy? This can be accomplished via monitoring of the IR/optical polarization near the peak of the synchrotron component, and correlation of polarization direction changes with gamma-ray flares

Targets: BL Lacertae, AO 0235+164, 3C454.3, others; preferred sources are those with the peak in the optical / IR band
Other data needed: good optical polarization coverage, at good (< hour) temporal resolution

B.4 Testing of predicted features of various hadronic models

* **Approach:** Assess various classes of hadronic models, and evaluate the consequences that might be potentially observable via multi-wavelength data

Targets:
Other data needed:

Much more work is needed here… Especially development of time-dependent hadronic models.

C. AGN as a tool

- This includes two main topics, related to the host galaxy, and the intervening medium.

The list below is only preliminary, needs elaboration:

C0. Study of the matter content of the circum-nuclear region at intermediate – to large distances from the black hole: probing the baryonic Compton-thick material in the AGN's vicinity, host galaxy, and in the intergalactic space.

C1. Study of the attenuation of -ray blazars by the Extragalactic Background Light (EBL)

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Motivation.

The Extragalactic Background Light (EBL) is the accumulated electromagnetic radiation (at IR-optical-UV wavelengths) resulting from the formation and evolution of structure in the universe. The main contributors to the EBL are: i) starlight at the optical- UV, and ii) re-processing of starlight by dust at the IR(see Hauser & Dwek 2001, Kashlinsky 2006 for a review). Measurement of the EBL density provides therefore a fundamental insight into the history of the universe. In particular, the UV-optical EBL flux (to which GLAST is sensitive) contains information about the star formation rate and dust-extinction process at high redshifts. Unfortunately, direct measurements of the EBL intensity are extremely difficult due to the bright foreground from nearby sources (interplanetary dust, stars and gas in the Milky Way, etc.)

The EBL is strongly connected to gamma-ray astrophysics because γ-rays emitted by blazars (or any other extragalactic source) are subject to absorption due to pair-production with EBL photons. One positive consequence of this effect is that the magnitude of this absorption can then be used to measure -or at least constrain- the column density of background photons between the source and the observer (Stecker, de Jager, Salamon 1992). Gamma-rays detected by ground-based telescopes (with energy E > ~200 GeV) are subject to strong attenuation by the *near- and mid- infrared* part of the EBL, limiting (sub-)TeV probes of the EBL to low redshifts. GLAST, on the other hand, is sensitive to the less drastic attenuation of multi-GeV photons by the *UV-optical* part of the EBL, with no attenuation expected (at any redshift) for photons with energy below 10 GeV. Thus, EBL attenuation will not limit GLAST's ability to detect blazars. Depending on the blazar luminosity function (something that GLAST itself will measure), GLAST is expected to detect a large number of blazars (about one thousand or more ; Dermer 2006, Stecker & Salamon 1996, Chiang & Mukherjee 1998) with redshifts up to z~5. How many of these sources are suitable for EBL studies is something that GLAST will answer. Nevertheless, the energy range of GLAST is ideal for probing the EBL to cosmological distances.

The goal of GLAST concerning EBL is to answer the following questions:

C1.1. Is there evidence of EBL attenuation in the LAT energy range? If yes, what is the optical depth $\tau(E; z)$ due to EBL?

Approach 1) Individual Behavior:
Use blazar emission models combined with multiwavelength observations to predict the *unattenuated* spectrum of bright, hard blazars. Compare to observed spectrum.

- Are the differences statistically significant?
- How robust are the models?
- Do the models consider opacity due to intrinsic absorption?
- Do we get the same answer during different flaring states?

Targets: (see table below)

Approach 2) Collective Behavior: Do blazars at similar redshifts present similar spectrum steepening, or cut-offs at the same energy?

i) Flux-ratio method (Chen et al. 2004)
ii) spectrum fitting with parametric attenuation functions
(as described in http://glue.umd.edu/~lreyes/glast/dc2_closeout.pdf).

- Can the large number of sources be used to address the systematic uncertainty introduced by not knowing the detailed intrinsic spectrum of the individual sources?
- What is the usable distribution (luminosity function and intrinsic spectrum) of blazars?
- How many blazars will have known redshift?
- Can we explain outliers?
- What is the spread caused by internal absorption?

Note: Observations by GLAST of nearby blazars (z<~0.5) are not expected to be affected by the EBL. We should use this (almost entirely new) population as a control sample to re-educate ourselves about what is "usual" and "unusual" for blazar spectra. There is a big caveat: nearby sources could be intrinsically different from distant ones due to blazar evolution (another aspect to be addressed by GLAST observations).

C1.2. What is the evolution of the EBL as a function of redshift?

The optical depth that GLAST will measure (given the right conditions) is an integral of the EBL density ($n_{EBL}(E,z)$) over the line path between the source and the observer:

$$\tau(E_\gamma, z) \propto \int_0^z \int_{\epsilon_{th}}^{\infty} dz' d\epsilon \, \frac{dl}{dz'} \, \sigma\left(E(z'), \epsilon\right) n_{EBL}\left(\epsilon, z'\right)$$

where E_γ is the observed γ-ray energy (at z=0), ε is the soft-photon energy, ε_{th} is the threshold energy for pair-production with a γ-ray with energy E(1 + z'), and σ is the cross section for pair-production.

Measuring τ(E,z) is important, but our ultimate goal should be to measure (or constrain) *$n_{EBL}(E,z)$*.

Note: For EBL analysis of (sub-)TeV observations (like Aharonian et al. 2006), the approximation was made that the EBL density is constant over the probed redshift (z<0.2), which allowed them to calculate limits to $n_{EBL}(E,z)$ in a straightforward way. GLAST observations, in the other hand, are sensitive to EBL evolution. Using GLAST data to say something about $n_{EBL}(E,z)$ will not be trivial. This is both exciting and challenging!

Approach 1: At the very least, GLAST measurements of $\tau(E,z)$ will validate (or refute) EBL evolution models from the literature (Stecker et al., Primack et al., Kneiske et al.)
Approach 2: Forward folding of GLAST data to model the EBL density with special emphasis on the relevant physical parameters at optical-UV wavelengths (star formation rate, stellar synthesis models, effects of dust extinction). (A lot of work needed here!).

C1.3. What are the effects of EBL attenuation on the extragalactic γ-ray diffuse background?
C1.3. a) Is there an EBL attenuation effect on the diffuse extragalactic background?
If a significant fraction of the diffuse γ-ray background is originated farther away than z>~1 (by blazars for example), the EBL absorption will steepen the spectrum of the extragalactic diffuse at energies above 10-100 GeV (Salamon & Stecker 1998).
C1.3. b) Is there a bump starting at 10 GeV in the extragalactic -ray diffuse due to VHE -rays cascading down in energy?
Cascade effect: The electron and positron produced by the γ-γ "annihilation" are highly energetic particles that will produce secondary γ-rays by inverse Compton scattering of soft photons (CMB, EBL). Each secondary γ carries roughly half of the original energy and is likely to interact again with the EBL. This cascade reaction will stop when the energy of the *nth* γ-ray E_n is such that $\tau(E_n,z) < 1$, i.e. the energy is below the threshold for effective pair production with EBL photons (Aharonian, Coppi & Völk, 1994).

Preliminary table of useful sources for EBL studies

Name	Redshift	Observations
4C+71.07	2.17	FSRQ with strong IC emission
PKS0528+134	2.07	FSRQ with strong IC emission
Q0906+693	5.48	
3EG J0450+1105	1.207	
3EG J0500-0159	2.286	
3EG J0530+1323	2.06	
3EG J0531-2940	3.11	
3EG J0808+4844	1.43	
3EG J0812-0646	1.84	
3EG J0829+2413	2.05	
3EG J0917+4427	2.18	
3EG J1409-0745	1.49	
3EG J1635+3813	1.81	
2052-474	1.49	
CTA 102	1.04	
3C 454.3	0.86	
2356+196	1.066	
A0 0235-164	0.94	BL Lac
PKS 0537-441	0.89	BL Lac