Physics 205

Opportunities with the
Fermi
Gamma-ray Space Telescope

W.B. Atwood, R. Johnson, and S. Ritz
UCSC and SCIPP

Physics 205

Opportunities with the
Large Synoptic Survey Telescope (LSST)

S. Ritz, C. Rockosi, R. Johnson
UCSC and SCIPP

See http://www-glast.stanford.edu/ and links therein

See http://lsstcorp.org/
Intro and Overview

Much more at http://scipp.ucsc.edu/news.html
SCIPP Overview

• UCSC Organized Research Unit
  – Includes faculty from Physics, Astronomy and Astrophysics, and SCIPP appointments.
  – 14 post-docs and research physicists, 8 technical staff, 29 graduate students, >50 undergrads, plus visitors, administrative staff

• Primary focus is experimental and theoretical particle physics, including the development of technologies needed to advance that research.

• Also pursuing the application of those technologies to other scientific fields such as neurophysiology and biomedicine.

• A great strength is the close interplay between theory and experiment.

• Very strong support from the University.

• SCIPP is constantly evolving.
Many Ongoing and New Activities

• Active areas of research include
  – Energy frontier (ATLAS at the LHC). Data analysis and upgrades.
  – Future collider detector development
  – Fermi Gamma-ray Space Telescope operation and data analysis; VERITAS and CTA; involvement also with HAWC; NuSTAR, ADELE, BARREL, RHESSI.
  – Dark Energy Survey (DES); Baryon Oscillation Spectroscopic Survey (BOSS); Large Synoptic Survey Telescope (LSST)
  – NeuroProject; Medical applications (pCT)
  – Heavy Photon Search (HPS)
  – Theoretical Astrophysics and Cosmology. Close connections to HIPACC and UCO.
  – Theoretical Particle Physics
Recent Community Service (a lot!)

- Snowmass Leadership:
  - Cosmic Frontier (Ritz)
  - Dark Matter Indirect Detection (Profumo)
  - Theory (Dine)
  - Future Colliders (Battaglia)
  - Instrumentation (Seiden)

- Recent Reviews and Panels:
  - COV (Dine)
  - DOE Comparative Review University Program (Dine)
  - NSF PFC Review Panel (Profumo)
  - DOE Comparative Review of Labs (Ritz)
  - FNAL PAC (Ritz, chair)
  - LBNL Physics Division DOE Review (Ritz)
  - SLAC/SU KIPAC Visiting Committee (Ritz, chair)
  - P5 Chair (Ritz)

- DPF Officer (Haber)

- DPF MEETING @ UCSC (Seiden lead organizer)

- Outreach:
  - QuarkNet Center
    - High School Student Summer Program (Ritz)
    - Balloonfest (Schalk, Sadrozinski)
  - Public Talks:
    - "All you wanted to know about the Higgs but were afraid to ask" (Schumm)
    - Monterey Bay Physics Teachers’ Alliance talk about Higgs and LHC (Nielsen)
    - Scotts Valley High School Keynote (Ritz)
    - FACULTY RESEARCH LECTURE 2014: Seiden and Haber, Higgs Discovery
  - “Particle Fever” Santa Cruz screening event 2014
Some History

SCIIPP personnel have been at the core of Fermi (originally called GLAST) since inception. Bill Atwood, together with Peter Michelson (Stanford), originated the mission in the early 1990s. Robert Johnson soon joined, and he became the leader of the LAT Tracker subsystem. Steve Ritz joined in 1996 and contributed to many aspects of the instrument, especially those crossing subsystem boundaries, and soon became the LAT Instrument Scientist and LAT Deputy PI, as well as the overall Mission Project Scientist.

SCIIPP members have been deeply involved in all aspects of the project, from detailed hardware design, construction, testing, and operation, through reconstruction software and physics analysis. The SCIPP group is a leading DOE-funded university group on Fermi.
Gamma rays from cosmic ray particles smashing into the tenuous gas between the stars. DM clumps and other signals of new physics possible.

Pulsars – rapidly spinning neutron stars with enormous magnetic and electric fields.

Blazars – supermassive black holes with huge jets of TeV particles and radiation pointed at us. Probe cosmological distances.

The Unknown – hundreds of sources yet unassociated.

Gamma-ray bursts – extreme exploding stars or merging black holes or neutron stars. Tools for new physics searches.
Gamma rays expected from Dark Matter Annihilation
Fermi Large Area Telescope 2FGL catalog

- AGN
- AGN-Blazar
- AGN-Non Blazar
- Galaxy
- Starburst Galaxy
- Radio Galaxy
- Seyfert Galaxy
- Nova
- PWN
- PSR
- PSR wi/PWN
- SNR
- Globular Cluster
- HMB

Credit: Fermi Large Area Telescope Collaboration
Understanding the Gamma-ray Sky

data = sources + galactic diffuse + isotropic diffuse

+ dark matter?? + ??

Bootstrapped, iterative process
### 2FGL Sources

**Red symbols:** Identified sources  
**Blue symbols:** Associated sources

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Identified</th>
<th>Associated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsar, identified by pulsations</td>
<td>83</td>
<td>-</td>
</tr>
<tr>
<td>Pulsar, no pulsations seen in LAT yet</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>Pulsar wind nebula</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Supernova remnant</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Supernova remnant / Pulsar wind nebula</td>
<td>-</td>
<td>58</td>
</tr>
<tr>
<td>Globular cluster</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>High-mass binary</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Nova</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>BL Lac type of blazar</td>
<td>7</td>
<td>428</td>
</tr>
<tr>
<td>FSRQ type of blazar</td>
<td>17</td>
<td>353</td>
</tr>
<tr>
<td>Non-blazar active galaxy</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Radio galaxy</td>
<td>2</td>
<td>10</td>
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<tr>
<td>Seyfert galaxy</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Active galaxy of uncertain type</td>
<td>0</td>
<td>257</td>
</tr>
<tr>
<td>Normal galaxy (or part)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Starburst galaxy</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Class uncertain</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td><strong>Unassociated</strong></td>
<td>-</td>
<td><strong>576</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>127</strong></td>
<td><strong>1746</strong></td>
</tr>
</tbody>
</table>
Expanding Classes of Fermi-LAT Sources

- GRBs
- Fermi Bubbles
- Blazars (782)
- Radio Galaxies (12)
- Starburst Galaxies (4)
- LMC & SMC
- Globular Clusters (11)
- Novae
- SNR & PWN (68)
- γ-ray binaries (6)
- Pulsars: young & millisecond (MSP) (117+)
- Sun: flares & CR interactions
- Terrestrial Gamma-ray Flashes
- Unidentified Sources (~600/1873)

e^+e^- spectrum

Extragalactic

Galactic

Local
Huge Dynamic Ranges

- Galactic Diffuse
- Isotropic Diffuse & Dark Matter
- Point Sources
- Solar Flare/GRBs
- TGFs

Rate [Hz]

Energy [MeV]

Trigger request
Trigger accept
Onboard filter
P7TRANSIENT
P7SOURCE
P7SOURCE [E<100]

arXiv:1206.1896
The Variable Gamma-ray Sky

36 months
$E > 100$ MeV

many transients in the $\gamma$-ray sky

with time, deeper exposure has revealed many new sources and new source classes
Example of all-sky payoff: 3C454.3

- Well-known radio source at $z = 0.859$; also detected by EGRET, AGILE
3C454.3

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/

Also see arXiv:1102.0277
HE Gamma-ray Experiment Techniques

- **Space-based:**
  - use pair-conversion technique

- **Ground-Based:**
  - **Atmospheric Cerenkov Telescopes (ACTs)**
    - image the Cerenkov nin from showers induced in the atmosphere. Examples: VERITAS, MAGIC, HESS; CTA.
  - **Extensive Air Shower Arrays (EAS)**
    - Directly detect particles from the showers induced in the atmosphere. Example: Milagro; HAWC,
Why Space?

Atmosphere:

\[ \gamma \]

~30 km

\[ \sim 10^3 \text{ g cm}^{-2} \]

Photon interaction mechanisms:

To detect these gamma rays, must have an instrument above the atmosphere.

[Note, for very high-energy gamma rays, \( > \sim 100 \text{ GeV} \), information from showers penetrates to the ground.]

Fig. 2: Photon cross-section \( \sigma \) in lead as a function of photon energy. The intensity of photons can be expressed as \( I = I_0 \exp(-\sigma x) \), where \( x \) is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).
The Accelerator
The Observatory, Spring 2008

Spacecraft Partner: SpectrumAstro/General Dynamics/Orbital

Large Area Telescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES
• Huge field of view
  - LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours.
  - GBM: whole unocculted sky at any time.
• Huge energy range, including largely unexplored band 10 GeV - 100 GeV. Total of >7 energy decades!
• Large leap in all key capabilities. Great discovery potential.
Launch!

- Launch from Cape Canaveral Air Station on 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.
A moment later…
... and then ...
… on its way!
LAT Overview

• Precision Si-strip Tracker (TKR) Measure the photon direction; gamma ID.
• Hodoscopic CsI Calorimeter (CAL) Measure the photon energy; image the shower.
• Segmented Anticoincidence Detector (ACD) Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
• Electronics System Includes flexible, robust hardware trigger and software filters.

Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.
Different event classes trade background rejection and PSF against effective area.
Data/MC Comparisons

FIG. 1: Comparison of beam test data (solid line) and Monte Carlo simulations (dashed line) for two fundamental tracker variables used in the electron selection: the number of clusters in a cone of 10 mrad radius around the main track (left panel) and the average time over threshold (right panel). Both variables are shown for an electron and a proton beam.

FIG. 4: Comparison of Beam test data and Monte Carlo simulations for the longitudinal shower profiles for electron beams entering the CU at 0° and 30° and energies of 20 and 282 GeV.

FIG. 3: Comparison of beam test data (triangles) and Monte Carlo simulations (squares) for the energy resolution for electron beams entering the CU at 0° and 60° and energies from 10 to 282 GeV. Lines are to guide an eye.

Many thanks to CERN, GSI, and SLAC!!

arXiv:1008.3999v1, PRD 82
LAT Collaboration

- France
  - CNRS/IN2P3, CEA/Saclay
- Italy
  - INFN, ASI, INAF
- Japan
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology
- Sweden
  - Royal Institute of Technology (KTH)
  - Stockholm University
- United States
  - Stanford University (SLAC and HEPL/Physics)
  - University of California, Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - The Ohio State University
  - University of Washington

PI: Peter Michelson (Stanford)

~400 Scientific Members (including 97 Affiliated Scientists, plus 71 Postdocs and 123 Students)

Cooperation between NASA and DOE, with key international contributions from France, Italy, Japan and Sweden.

Project managed at SLAC.
Operating modes

• Primary observing mode is Sky Survey
  – Full sky every 2 orbits (3 hours)
  – Uniform exposure, with each region viewed for ~30 minutes every 2 orbits
  – Best serves majority of science, facilitates multiwavelength observation planning
  – Exposure intervals commensurate with typical instrument integration times for sources
  – EGRET sensitivity reached in days

• Pointed observations when appropriate (limited fraction, and selected by peer review) with automatic earth avoidance selectable. Target of Opportunity pointing.
• Autonomous repoints for onboard GRB detections in any mode.
Overall Timeline

- Science operations start: 4 August 2008
- Plan: Five-year mission with a ten-year goal
  - with reviews to assess productivity in extended phase
- Mission extended by NASA to at least 2016, based on most recent Senior Review:
  - “The first three years of Fermi have been very productive, and the committee believes we have yet to see the peak of Fermi’s science output”
  - The report recommended “…funding at the desired level of augmentation to provide for full operations through FY14. We recommend an extension through 2016 with a review in 2014.”
- LAT international partners (agencies funding particle physics and astrophysics) are also planning continued support of the experiment.
- In the second Senior Review cycle right now.
Some LAT Highlights

• Discovery and study of >117 gamma-ray pulsars, 36 of which are seen to pulse only in gamma rays. 40 are ms pulsars.
  – 43 new ms radio pulsars discovered thanks to LAT data!
• Remarkable high-energy emission from gamma-ray bursts
  – Starting to see what was missing
  – w/GBM, provides interesting limits on photon velocity dispersion
• Very high statistics measurement of the cosmic e+e- flux to 1 TeV
• Nailing down the diffuse galactic GeV emission
• LAT determination of the isotropic diffuse flux
• Searches for Dark Matter signatures in different kinds of sources
• Many new results on supermassive black hole systems (AGN), including sources never seen in the GeV range
• More cosmic accelerators: Galactic X-ray binaries, supernova remnants, PWNe. Probing the cosmic-ray distributions in other galaxies; LMC and SMC.
• Extragalactic Background Light measurements
• New limits on large extra dimensions
• Crab short flares
• 2nd catalog: 1873 sources
>270 LAT Team papers out...

ADS: LAT 2nd Catalog most highly cited paper of 2012 in Astronomy

...with many more in the pipeline...and many hundreds more more using public LAT data.

http://www-glast.stanford.edu/cgi-bin/pubpub
Every Workout Ends With Dark Matter

Sports nutrition experts and bodybuilders have long known that the most critical time to stimulate muscle growth through nutritional interfusion is post-workout. They refer to the 1-hour period immediately after training as the “Anabolic Window.” Over the years, supplements have been developed in an attempt to optimize this short muscle building opportunity. While some innovations and developments have been made, researchers concluded that still, NO product on the market was fully optimizing this window of muscle growth opportunity. The direct short explanation why is simple. None of these products work fast enough and none of them had the right micronutrient timing at the Anabolic Axis!

Now, through the development of DARK MATTER, bodybuilders are finally maximizing this muscle building opportunity and packing on pounds of new muscle. Victor Martinez credits DARK MATTER for adding 12 pounds of extra muscle to his already monstrous physique.

CLICK HERE TO READ ABOUT THE SCIENCE BEHIND DARK MATTER!
The Dark Matter Problem

Observe rotation curves for galaxies:

For large $r$, expect:

$$G \frac{M}{r^2} = \frac{v^2(r)}{r} \quad v(r) \sim \frac{1}{\sqrt{r}}$$

see: flat or rising rotation curves

Hypothesized Solution: the visible galaxy is embedded in a much larger halo of dark matter.
Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of cosmic particles ("indirect detection").

Anomalous gamma ray spectra and/or $\gamma\gamma$ or $Z\gamma$ "lines" and/or anomalous charged cosmic rays and/or neutrinos?

- If particles are stable: rate $\sim (\text{DM density})^2$
- If particles unstable: rate $\sim (\text{DM density})$

Key interplay of techniques:
- colliders (TeVatron, LHC)
- direct detection experiments underground
- indirect detection (most straightforward: gamma rays and neutrinos)
  - Full sky coverage look for clumping throughout galactic halo, including off the galactic plane (if found, point the way for ground-based facilities)
  - Intensity highly model-dependent
  - Challenge is to separate signals from astrophysical backgrounds

Just an example of what might be waiting for us to find!
Gamma rays from Dark Matter annihilation

Secondary from $\pi^0$ decays

Prompt lepton pair production

+ “lines” from 2-body final states

$$\Phi_{WIMP}(E, \Psi) = J(\Psi) \times \Phi^{PP}(E)$$

Astrophysical factor

$$J(\Psi) = \int dl(\Psi) \rho^2(l)$$

Particle physics factor

$$\Phi^{PP}(E) = \frac{1}{2} \frac{\langle \sigma v \rangle}{m_{WIMP}^2} \sum_f \frac{dN_f}{dE} B_f$$
Dark Matter: Many Places to Look!

**Satellites**
Low background and good source id, but low statistics, in some cases astrophysical background

- JCAP 1204 (2012) 016
- JCAP 01 (2010) 031

All-sky map of gamma rays from DM annihilation arXiv:0908.0195 (based on Via Lactea II simulation)

**Galactic Center**
Good Statistics but source confusion/diffuse background

**Milky Way Halo**
Large statistics but diffuse background

- And anomalous charged cosmic rays (little/no directional information, trapping times, etc.)

- Phys. Rev. D84, 032007 (2011)
- Phys. Rev. D82, 092003 (2010)
- PRL 108 (2012)

**Spectral Lines**
No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR


**Extragalactic**
Large statistics, but astrophysics, galactic diffuse background

- JCAP 04 (2010) 014

**Galaxy Clusters**
Low background, but low statistics

- JCAP 05 (2010) 025
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arXiv:1205.6474

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Low background, but low statistics
- JCAP 05 (2010) 025
Combining dSph Limits

Now getting to very interesting sensitivity ranges!

PRL 107(2011)  
arXiv:1108.3546v2
DM: A Look Forward

- Much more to do in all areas:
  - future DM limits from dSph projected to improve due to increased observation time, discovery of new dwarfs
  - Lines: more data, improved analysis of high-energy events, optimization of regions, checks!
  - Halo: more detailed accounting of uncertainties in limits
  - Galactic Center

- Additional results:
  - Anisotropy analyses
  - Clusters
  - Satellites
  - ...

More data needed!
- Altered observing strategy for increased exposure of the Galactic center
- Push WIMP sensitivity (see above) to O(100) GeV.
UCSC LAT Collaboration Members

- **Full members**
  - Atwood, Johnson, Ritz, Sadrozinski, Saz-Parkinson, Schalk
  - Wells, plus undergrads, plus new students…

- **Affiliated members**
  - Jeltema, Primack, Williams, Ramirez-Ruiz, Smith

- Graduate student Zalewski defended his thesis in 2013.

- A new post-doc, Regina Caputo, will join the group in May.

- The group is looking for 2 additional graduate students.
Current/Upcoming Projects

- Students are encouraged to define their own projects, but we also are happy to suggest directions of mutual interest.
- Some ongoing projects:
  - Several on dark matter, including combining information from various sources as we continue to collect more data
  - Final great leap in instrument performance: “Pass8”
  - Pair halos of distant objects, diagnostic of intergalactic magnetic fields and EBL
- Start ups (and restart ups) include:
  - Several studies related to dark matter
  - Better use of single-photon error information
  - The highest energy Fermi sky
  - Novel uses of AGN light curves
  - Intermediate timescale transients
  - Your idea here!
Discussion

• How the group functions
  – encourage students to work with people both at UCSC and within the international collaboration

• Path is largely up to the student
  – goal is for you to learn over time how to define your own research problems.
  – we suggest topics, but free to pursue others. we will help you stay on track.
  – we emphasize understanding of the instrument and the details of the data analysis. we will also try to create hardware opportunities

• Great return on hard work!
Tools for Your 205 Proposals

• All the LAT papers can be found here, sorted by topic: http://www-glast.stanford.edu/cgi-bin/pubpub

• The LAT gamma-ray data and a set of software tools are public.
  – See http://fermi.gsfc.nasa.gov/ssc/data/

• There is also public documentation and tutorials on how to do an analysis with the public data
  – See http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/

• Come by to chat. Ask us questions!
Looking forward to more great Fermi results and Birthday celebrations!
LSST Overview

**LSST in a Nutshell**

- The LSST is an integrated survey system designed to conduct a decade-long, deep, wide, fast time-domain survey of the optical sky. It consists of an 8-meter class wide-field ground based telescope, a 3.2 Gpix camera, and an automated data processing system.

- Over a decade of operations the LSST survey will acquire, process, and make available a collection of over 5 million images and catalogs with more than 37 billion objects and 7 trillion sources. Tens of billions of time-domain events will be detect and alerted on in real-time.

- The LSST will enable a wide variety of complementary scientific investigations, utilizing a common database and alert stream. These range from searches for small bodies in the Solar System to precision astrometry of the outer regions of the Galaxy to systematic monitoring for transient phenomena in the optical sky. LSST will also provide crucial constraints on our understanding of the nature of dark energy and dark matter.

### Summary of High Level Requirements

<table>
<thead>
<tr>
<th>Survey Property</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Survey Area</td>
<td>18000 sq. deg.</td>
</tr>
<tr>
<td>Total visits per sky patch</td>
<td>825</td>
</tr>
<tr>
<td>Filter set</td>
<td>6 filters (ugrizy) from 320 to 1050nm</td>
</tr>
<tr>
<td>Single visit</td>
<td>2 x 15 second exposures</td>
</tr>
<tr>
<td>Single Visit Limiting Magnitude</td>
<td>u = 23.5; g = 24.8; r = 24.4; i = 23.9; z = 23.3; y = 22.1</td>
</tr>
<tr>
<td>Photometric calibration</td>
<td>2% absolute, 0.5% repeatability &amp; colors</td>
</tr>
<tr>
<td>Median delivered image quality</td>
<td>~ 0.7 arcsec. FWHM</td>
</tr>
<tr>
<td>Transient processing latency</td>
<td>60 sec after last visit exposure</td>
</tr>
<tr>
<td>Data release</td>
<td>Full reprocessing of survey data annually</td>
</tr>
</tbody>
</table>

**LSST Will be Sited in Central Chile**

- Points to new positions in the sky every 39 seconds
- Tracks during exposures and slews 3.5 to adjacent fields in ~ 4 seconds
Key staff have been identified.

Major recent/upcoming milestones

- Oct 2013 – Release sensor RFP package vendors
- Oct 2013 – CABAC1 Design Review
- Oct 2013 – Award AR broadband coat study
- Oct 2013 – Prototype ITL sensors delivered, partial for early testing
- Nov 2013 – Release L1-L2 RFP package to vendors
- Nov 2013 – Filter Exchange System Review
- Nov 2013 – Camera Optical Alignment Review
- Dec 2013 – NSF Final Design Review
- Jan 2014 – Award L1-L2 Design-Manufacture Contract
- Jan 2014 – DAQ & CCS Preliminary Design Review
- Jan 2014 – Wavefront Sensor Review
- Feb 2014 – Shutter & Camera Body Review
- Feb 2014 – SLAC Director’s Review for CD3a
- Mar 2014 – DOE CD-3a Review (start construction for long lead items)
- May 2014 – Award 1st Article Sensor Contract (waiting for funding)
- Apr 2014 – Cryostat Review
- Apr 2014 – Refrigeration Review
- Apr 2014 – L3 Optics Review

The Large Synoptic Survey Telescope Wallet Card

- Three Mirror Anastigmat (TMA) optical design.
  - 8.4 meter primary, 6.5 meter effective aperture
  - 3.4 meter diameter secondary
  - 5 m tertiary is being fabricated in same substrate as primary mirror
  - three-element refractive corrector
  - f/1.2 beam delivered to camera
  - 9.6 square degree field (on science imaging pixels)
  - optics deliver < 0.2 arcsec FWHM spot diagram.
  - 6 filters: ugrizy: 320 nm to 1050 nm (UV atmospheric cutoff to Si bandgap)

- 3.0 Gpixel camera
  - 10 micron pixels, 0.2 arcsec/pixel
  - Deep depletion (100 µm), high-resistivity CCDs for NIR response
  - Dual 15 second exposures (to avoid trailing of solar system objects)
    - 2 second readout (trade between noise and imaging efficiency)
    - 550 kpix/sec through 16 ampere/CCD x 189 CCDs = 3024 channels
    - 12 GBytes per image (as floating point numbers), 20 TBytes/night.

- Real-time frame subtraction for time domain alerts, ~850 visits for each patch of sky, allows co-adds to r ~ 27 (AB), over 18,000 square degrees.
The LSST Science Book

Contents:
- Introduction
- LSST System Design
- System Performance
- Education and Public Outreach
- The Solar System
- Stellar Populations
- Milky Way and Local Volume Structure
- The Transient and Variable Universe
- Galaxies
- Active Galactic Nuclei
- Supernovae
- Strong Lenses
- Large-Scale Structure
- Weak Lensing
- Cosmological Physics

Main UCSC interests: testing $\Lambda$CDM
Plans for the coming year

- **Weak Lensing instrumental systematics:**
  - push development of test objects for existing imager systems (with K. Gilmore at SLAC and T. Tyson UC Davis) using LSST CCDs to check systematic effects on shape measurements using hundreds of exposures – verify averaging down precision – and detailed comparisons with MC simulation. Ritz and Rockosi

- Continue consultations as needed on camera electronics system. Johnson

- Ramp up DESC work on Weak Lensing (Ritz), Clusters (Jeltema), and Dark Matter (Rockosi)

- Additional opportunities for science-prep studies, particularly connected with hardware development, likely.
Personnel Summary

• Who:
  – Terry Schalk: early SCIPP efforts on Camera Controls System
  – Steve Ritz: transitioning earlier from Fermi toward LSST
    • Camera Project Scientist (as of 5/2013)
    • Starting work on instrumental systematics affecting Weak Lensing
  – Connie Rockosi
    • LSST Board Member
    • Ramping up work over the next 6 months (instrumental systematics, commissioning camera)
  – Robert Johnson
    • Consultation on camera electronics system, will ramp up over the next few years
  – Tesla Jeltema
    • Dark Energy Science Collaboration (DESC) Cluster work (also working on DES)

Great opportunities for students to analyze Fermi LAT data while getting involved in LSST hardware development and science preparation.