VLBA (VIPS) and optical/ir studies of GLAST Blazars
and the
Owens Valley Radio Observatory
40 Meter Telescope Program of Monitoring GLAST Blazars at 15 GHz: The Northern CGRaBS Sources

Tony Readhead
California Institute of Technology

VLBI in the GLAST Era

Washington DC, 23-24 April 2007

Thanks to Steve Ritz and Neil Gehrels for providing funds to bring the 40 M out of mothballs!

GLAST Blazars: Studies of Astrophysical Jets
GLAST, Radio Monitoring, VIPS, Optical, X-ray

Stanford:
Roger Blandford
Jennifer Carson
Jim Chang
Teddy Cheung
Persis Drell
Richard Dubois
Stefan Funk
Steve Healey
Marieangela Lisanti
Greg Madejski
Peter Michelson
David Paneque
Anita Reimer
Olaf Reimer
Roger Romani
Lukasz Stawarz
Chen Zheng

Caltech:
Russ Keeney
Tim Pearson
Sterl Phinney
Tony Readhead
Joey Richards
Matthew Stevenson
Larry Weintraub

UNM:
Greg Taylor
Steve Tremblay

GSFC:
Neil Gehrels

MPIfR:
Manolis Angelakis
Lars Fuhrmann
Thomas Krichbaum
Anton Zensus

NRL:
Joe Helmboldt

Oxford:
Garret Cotter

UCD:
Chris Fassnacht

Manchester:
Ian Browne
Peter Wilkinson

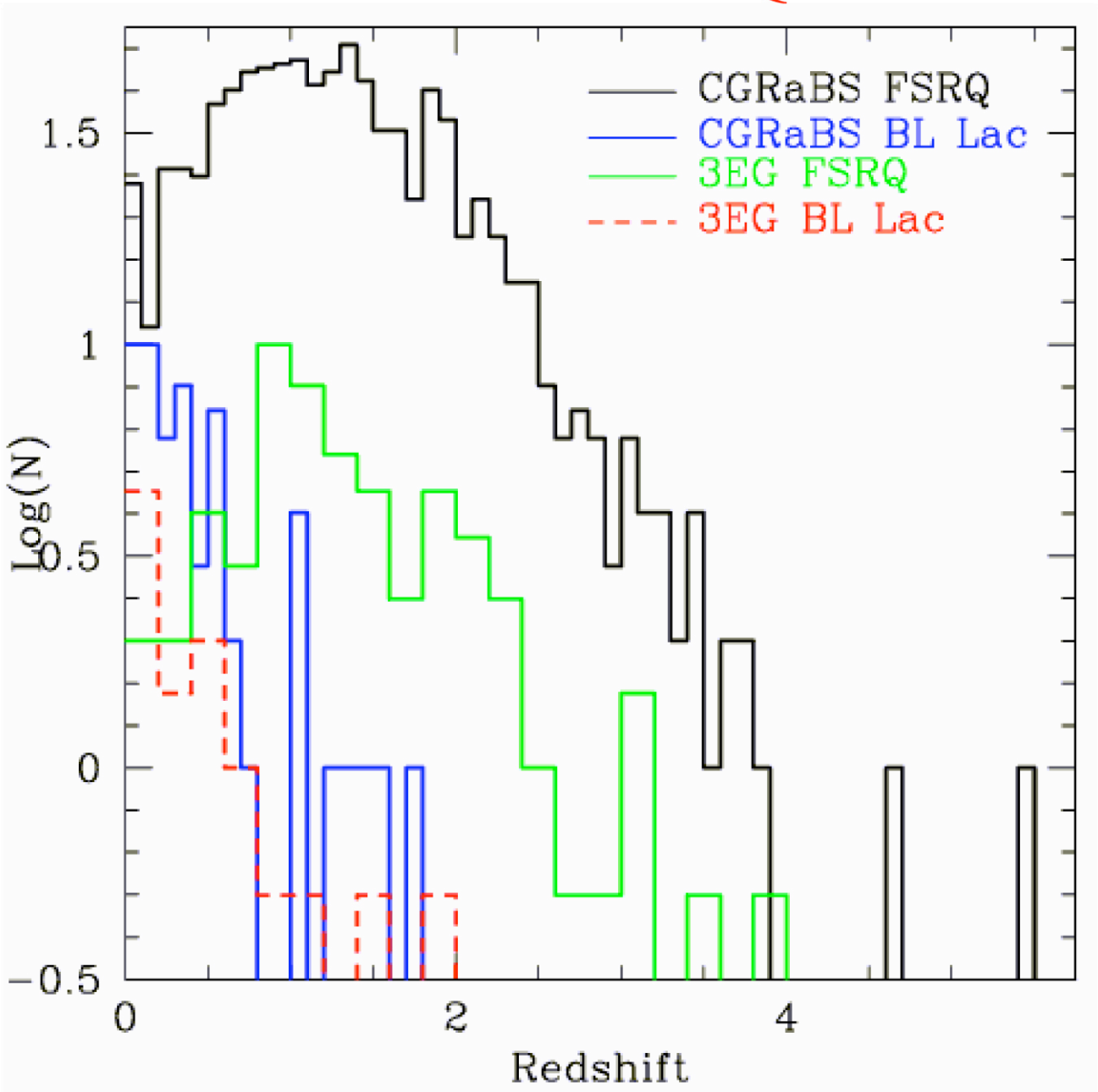
Torun:
Andrzej Kus

Concepcion:
Ricardo Bustos

NRAO:
Myers
Lorant Sjouwerman
Craig Walker

Redshift Distribution – FSRQ/BLL

- High-z tail…
- 3EG
  - 9 z>2.5
  - 5 z>3
- CGRaBS
  - 86 z>2.5
  - 30 z>3



It is 99 years since Curtis discovered the jet in M87. This was the birth of the study of active galaxies and relativistic jets. The LAT on GLAST will make it possible *for the first time* to study nature's high energy particle accelerators in blazars in sufficient numbers at γ-ray energies to address a number of key problems associated with the origin and evolution of relativistic jets in active galaxies, including their formation, collimation and propagation.

The jet phenomenon is no respecter of mass scales and is common in X-ray binaries and γ-ray bursters as well as protostars.

In spite of all the beautiful work that has been done on active galaxies at radio, infra-red, optical, uv and X-ray wavelengths, there is still no unique, accepted model for:

(i) the acceleration of jets near the inner parts of the accretion disk

(ii) the composition of the jets

(iii) jet confinement, and

(iv) particle acceleration and magnetic field production and, consequently, non-thermal emission.

(1) How many types of γ-ray blazars are there? Are they all basically produced by the same mechanism, differing only in energy?

(2) Where is the γ-ray emission in blazars produced?
There is a lower bound on the radius of the γ-ray emission (roughly 10^9-10^{11}m) set by the requirement that the GeV γ-rays be able to escape pair production on the soft X-ray background, but theories of where the emission arises range over 6 orders of magnitude.

(3) What is the relationship between the γ-ray emission and emission in other wavebands? Does the γ-ray emission occur before, coincident with, or after, the radio emission, or possibly all three?

(4) Can we develop a self-consistent model for the emission from blazars, which encompasses the emission from the regions in and around the accretion disk, the relativistic jet, and its interaction with the environment? GLAST+VLBI+monitoring provides us with by far the best opportunity yet of answering these questions.

THE ASTROPHYSICAL JOURNAL, 441:79–95, 1995 March 1

PAIR CASCADES IN EXTRAGALACTIC JETS. I. GAMMA RAYS

R. D. BLANDFORD AND A. LEVINSON
Theoretical Astrophysics 130-33, Caltech, Pasadena, CA 91125
Received 1994 February 11; accepted 1991 September 9

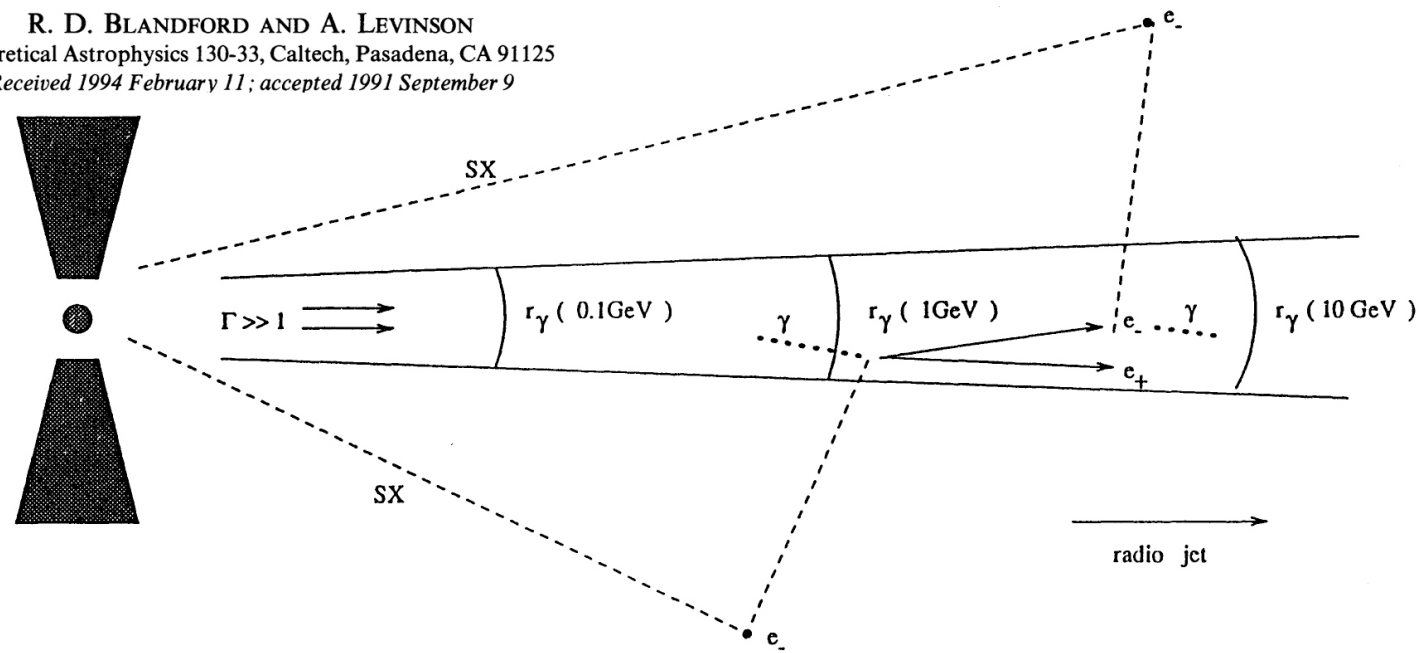
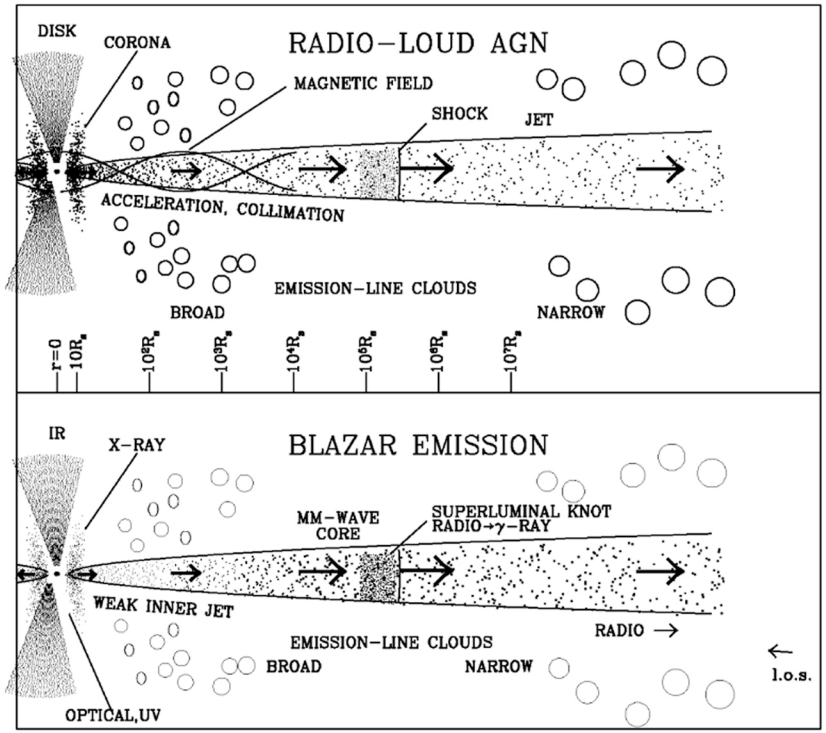
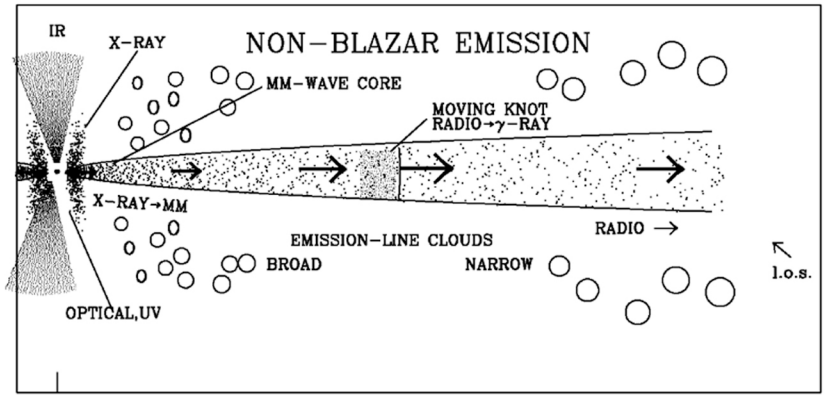


FIG. 6.—Schematic representation of the pair cascade model. A relativistic jet is formed parallel to the spin of a massive black hole orbited by a thick accretion disk. Soft X-ray photons denoted SX emitted near the black hole may be Thomson-scattered into the jet. There they can both combine with γ-rays to form electrons and positrons and be inverse Compton scattered by electrons and positrons to form γ-rays. In this way a pair cascade can develop. Also shown are the γ-spheres for $E_\gamma = 0.1, 1, 10$ GeV.

Jorstad, Marscher, et al. Ap.J. 556, 738, 2001





Quote from Abstract: "Our analysis . . . suggests that the γ-ray events occur in the superluminal radio knots. This implies that the γ-ray flares are caused by inverse Compton scattering by relativistic electrons in the parsec-scale regions of the jet rather than closer to the central engine."

Fig. 1 Rough sketch of the structure and emission regions of a radio-loud active galaxy with a relativistic jet. Note the logarithmic scale on the bottom for the distance down the jet. In the two emission panels—one for jets viewed almost end-on (a blazar) and the other for those seen at a wider angle (a typical radio galaxy)—the likely waveband of photons that can be emitted at each site is indicated. If the jet accelerates out to parsec scales, the inner jet between the mm-wave core and the black hole may be essentially invisible in blazars, while in radio galaxies bright emission might extend down to the base of the jet. (Adapted from Marscher 2005.)

Candidate Gamma-Ray Blazar Survey
"CGRaBS"

Romani, Healey, Michelson, Cotter, Giommi, Grenier, Murphy, Pearson, Readhead, Ricardo, Sadler, Sowards-Emmerd, Taylor, Ulvestad, Weintraub, Zensus . . . .

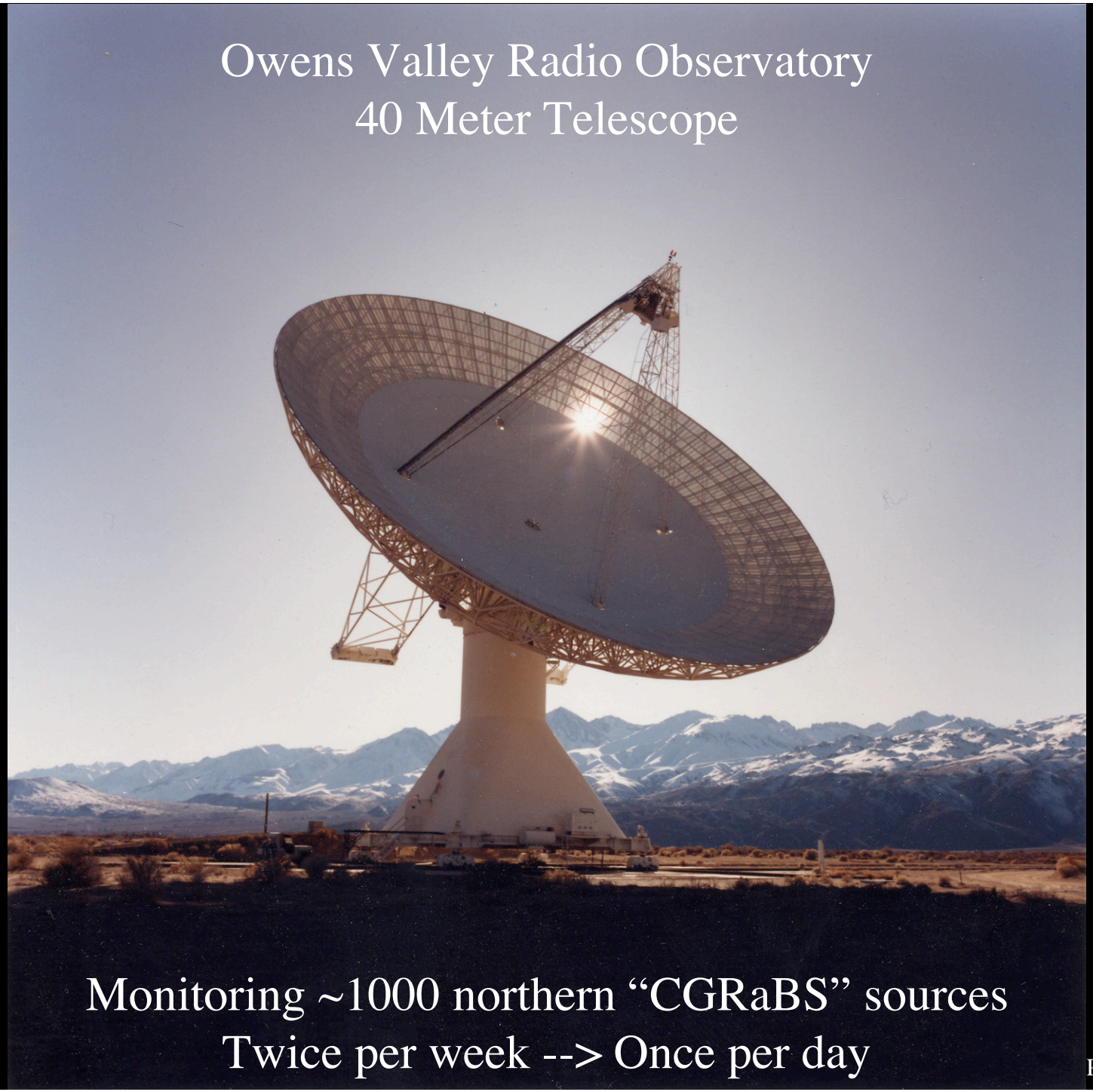
CGRaBS Selection criteria: NVSS/SUMSS+CLASS/new VLA/ATCA 8 GHz <1″

$S_{8GHz} > 85$ mJy, $|b| > 10^o$, $\alpha > -0.5$, so we expect $S_{15GHz} > 62$ mJy

Figure of Merit based on S_{8GHz}, α, S_X --- 1520 objects selected (all sky)

Optical spectra almost complete: 10% are BL Lacs, almost all the rest are FSRQs

Choice of frequency for OVRO monitoring: 15 GHz is well-chosen for Intra-Day Variable sources (IDVs), since IDV is now thought to be about half intrinsic and half propagation. It is also the highest frequency at which the 40 M telescope can operate at efficiency ~40%.


Owens Valley Radio Observatory
40 Meter Telescope
Monitoring ~1000 northern “CGRaBS” sources
Twice per week --> Once per day
Photo: D. Woody

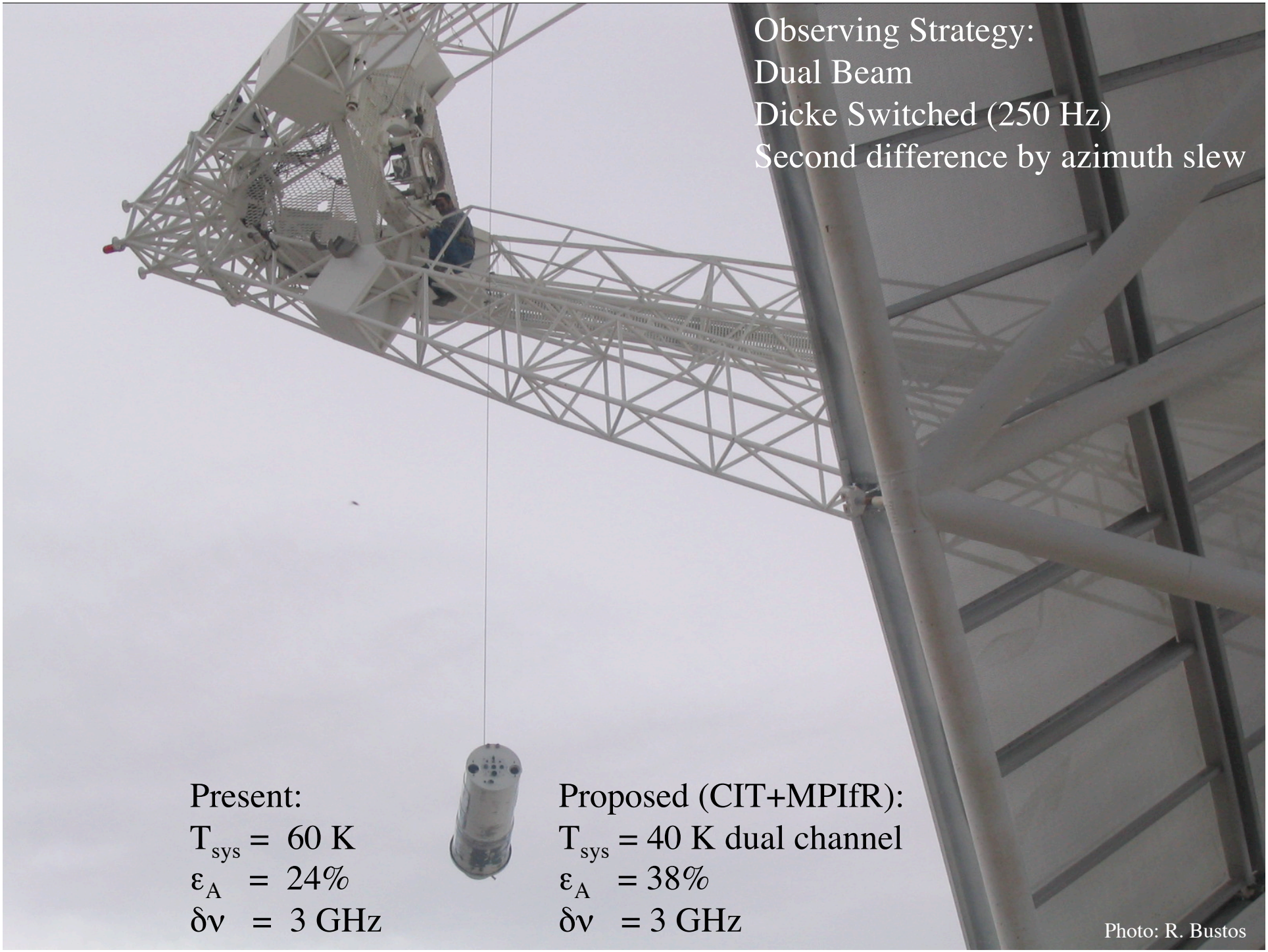
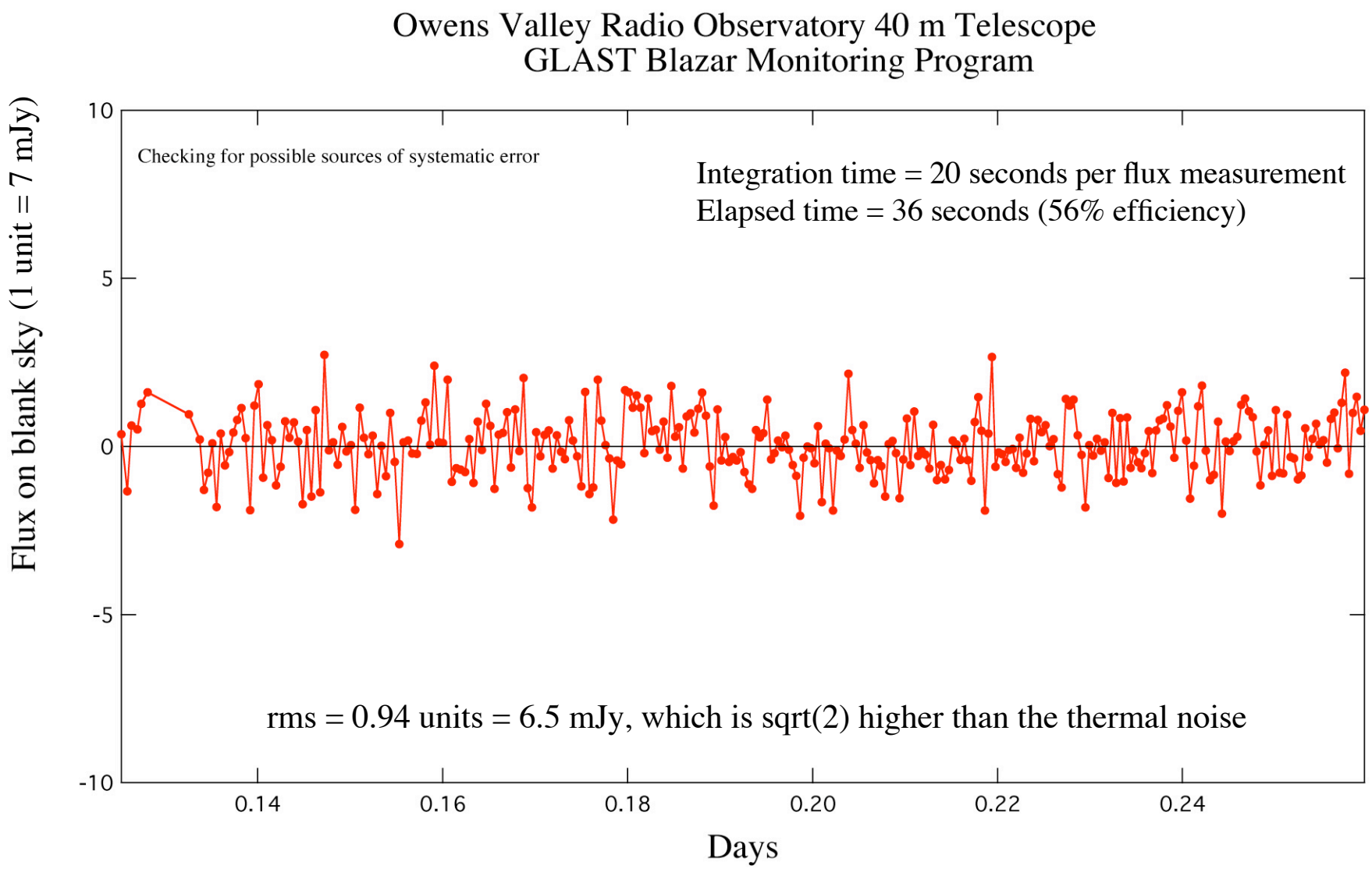
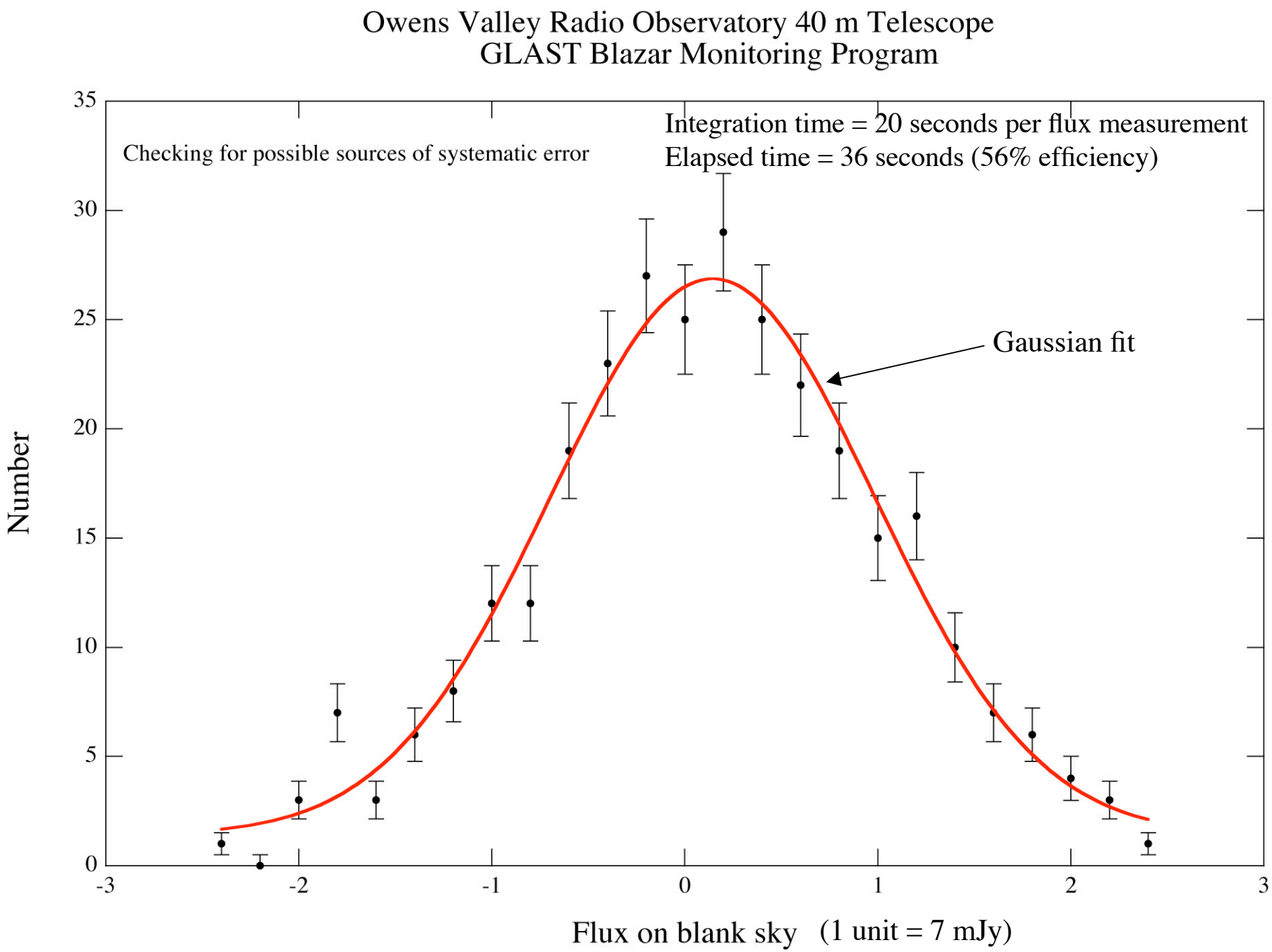
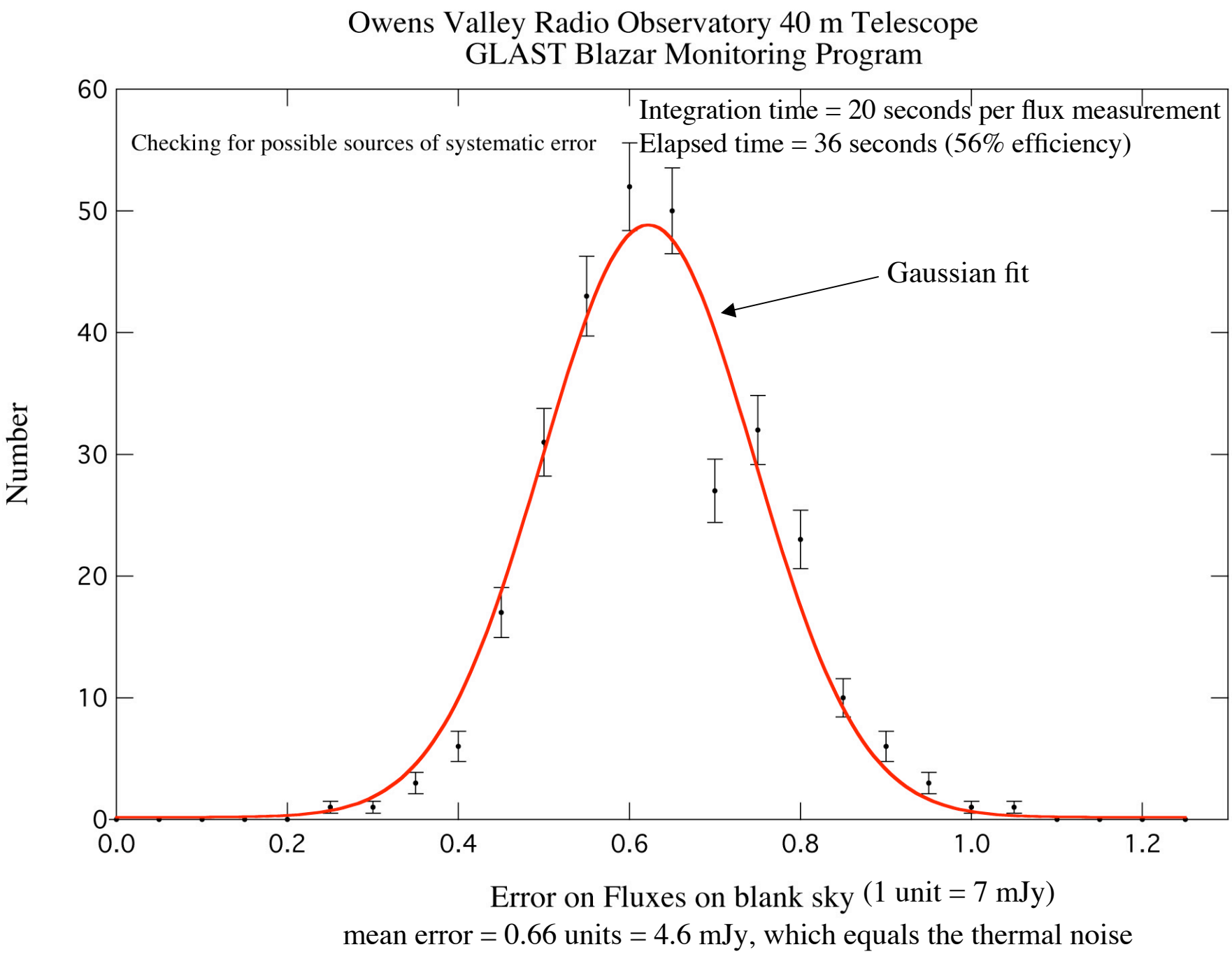

Observing Strategy:
Dual Beam
Dicke Switched (250 Hz)
Second difference by azimuth slew
Present:
T_{sys} = 60 K
ε_A = 24%
$\delta\nu$ = 3 GHz
Proposed (CIT+MPIfR):
T_{sys} = 40 K dual channel
ε_A = 38%
$\delta\nu$ = 3 GHz
Photo: R. Bustos

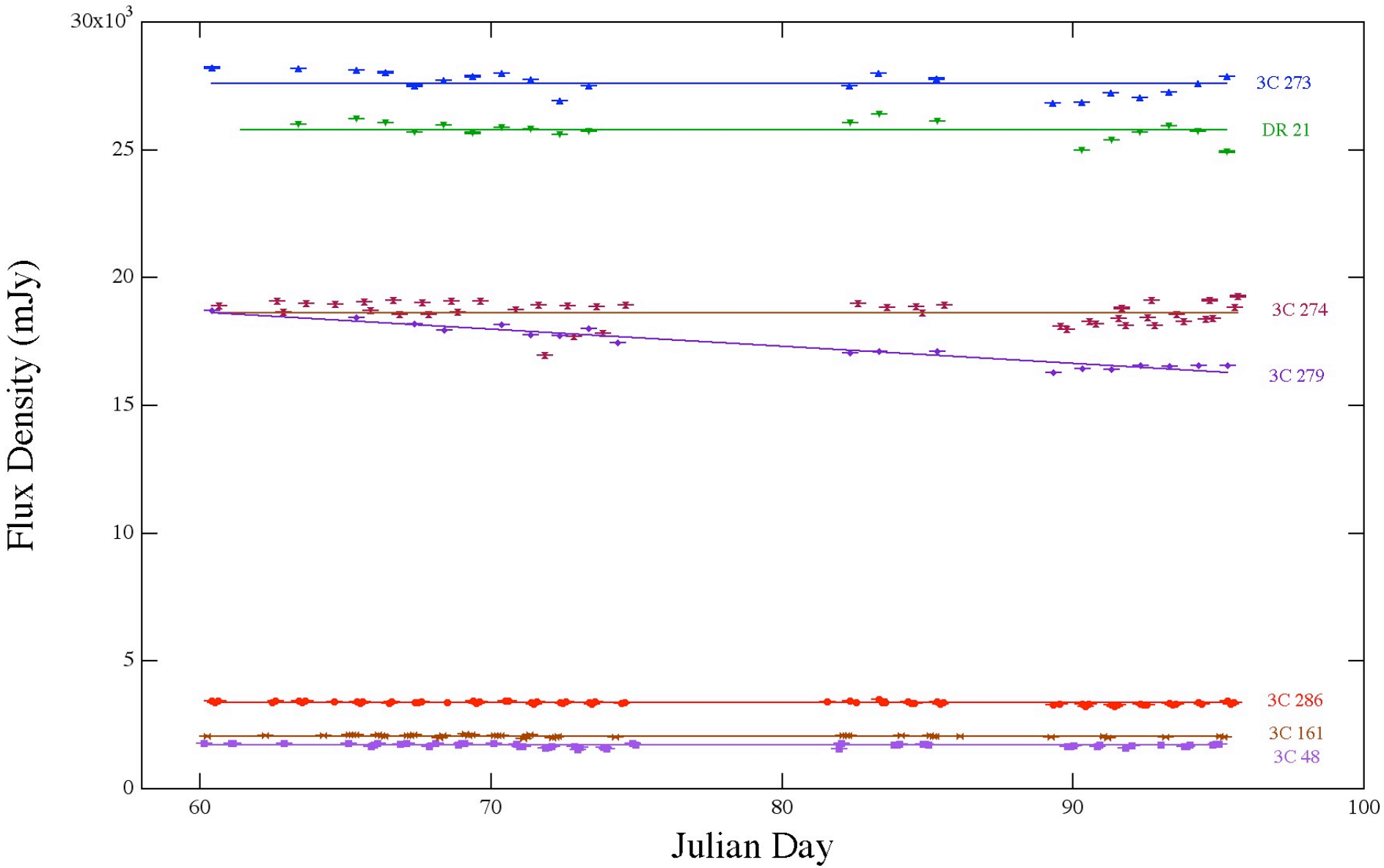
Photo: R. Bustos

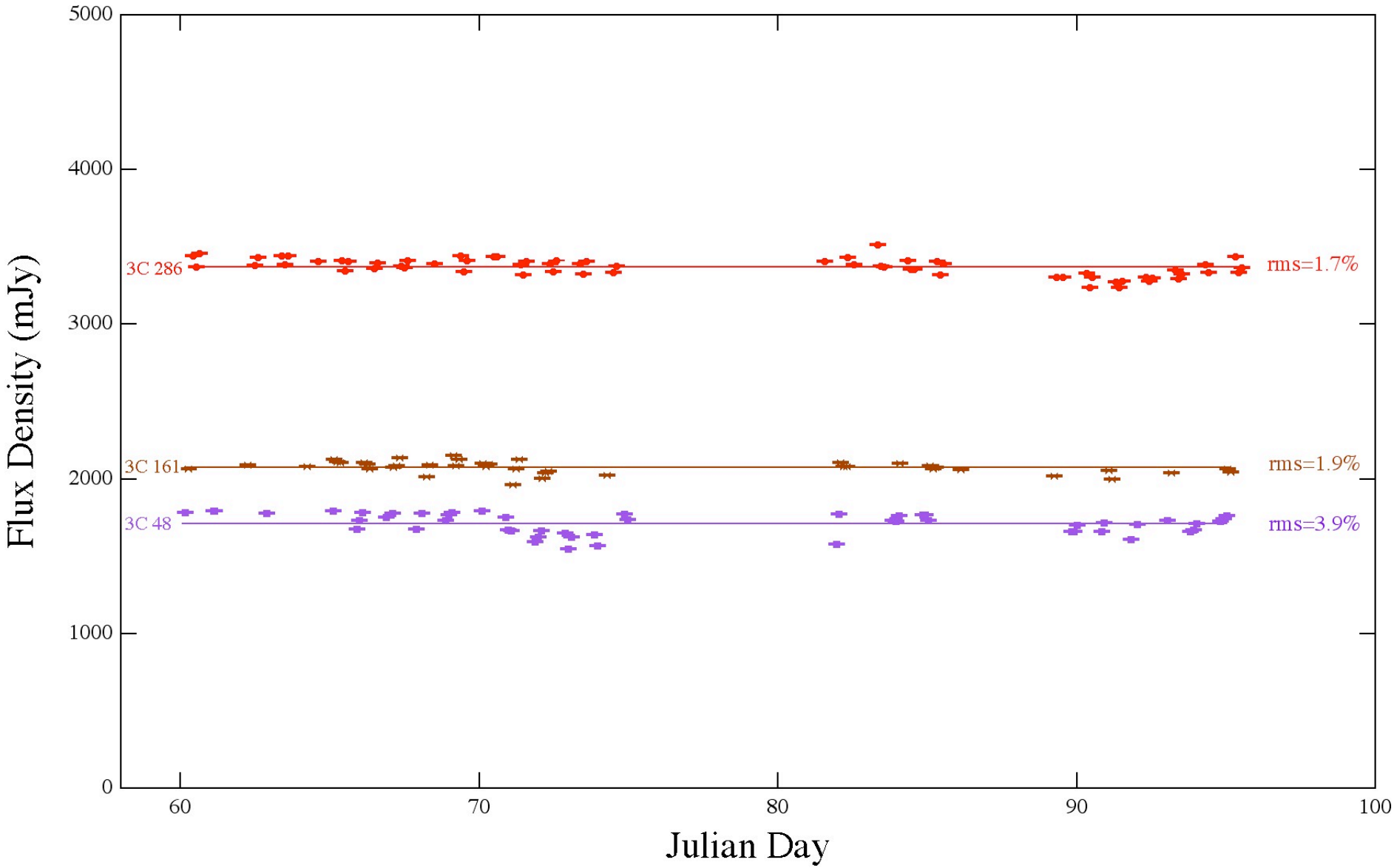

Photo: R. Bustos

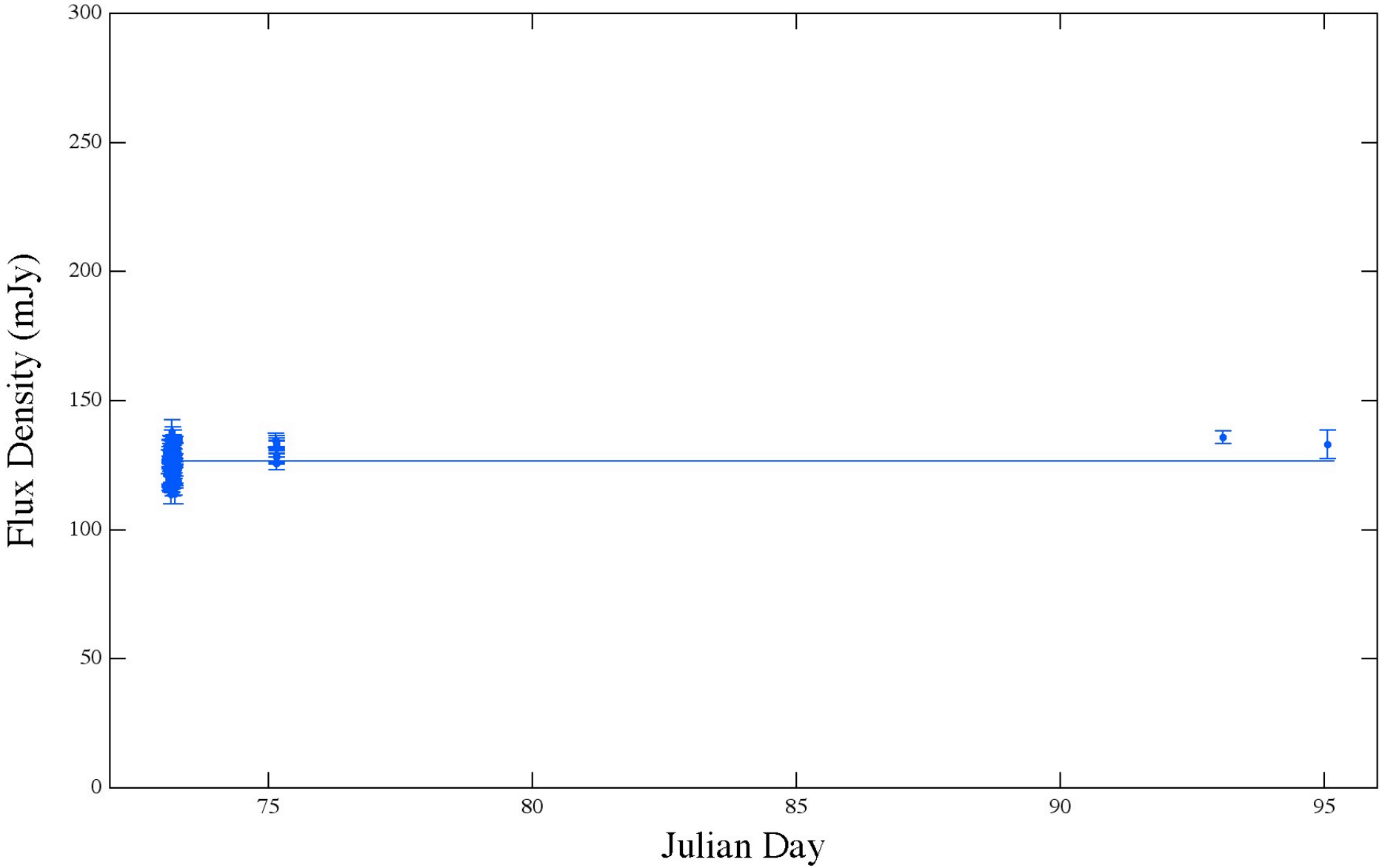

Owens Valley Radio Observatory 40 m Telescope
GLAST Blazar Monitoring Program
Checking for possible sources of systematic error
Integration time = 20 seconds per flux measurement
Elapsed time = 36 seconds (56% efficiency)
rms = 0.94 units = 6.5 mJy, which is sqrt(2) higher than the thermal noise
Flux on blank sky (1 unit = 7 mJy)
10
5
0
-5
-10
0.14
0.16
0.18
0.20
0.22
0.24
Days

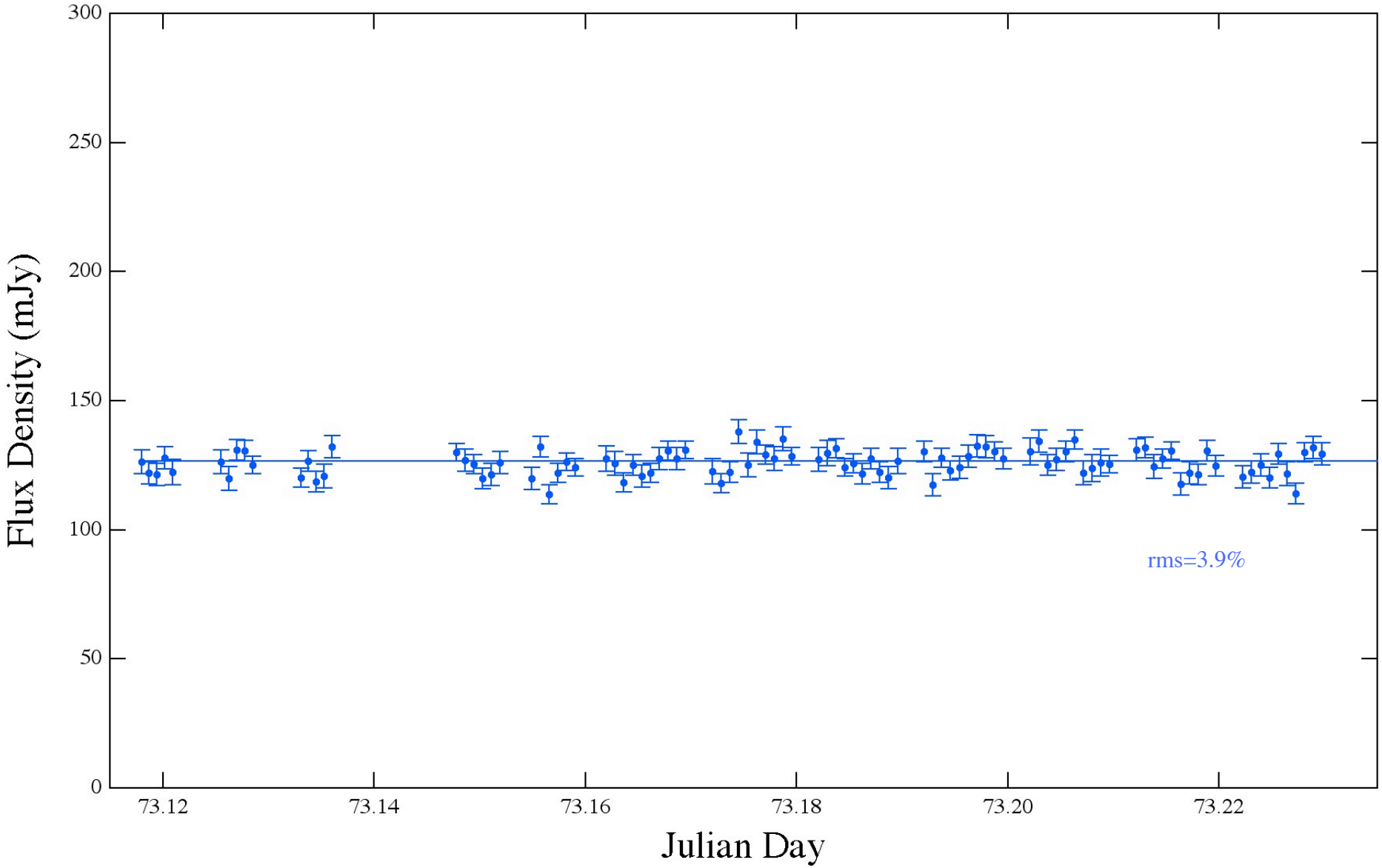

Owens Valley Radio Observatory 40 m Telescope
GLAST Blazar Monitoring Program
Checking for possible sources of systematic error
Integration time = 20 seconds per flux measurement
Elapsed time = 36 seconds (56% efficiency)
Gaussian fit
Number
Flux on blank sky (1 unit = 7 mJy)
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
3


Owens Valley Radio Observatory 40 m Telescope
GLAST Blazar Monitoring Program
Checking for possible sources of systematic error
Integration time = 20 seconds per flux measurement
Elapsed time = 36 seconds (56% efficiency)
Gaussian fit
Number
0
10
20
30
40
50
60
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Error on Fluxes on blank sky (1 unit = 7 mJy)
mean error = 0.66 units = 4.6 mJy, which equals the thermal noise


30x10^3
25
20
15
10
5
0
Flux Density (mJy)
60
70
80
90
100
Julian Day
3C 273
DR 21
3C 274
3C 279
3C 286
3C 161
3C 48


5000
4000
3000
2000
1000
0
Flux Density (mJy)
3C 286
3C 161
3C 48
rms=1.7%
rms=1.9%
rms=3.9%
60
70
80
90
100
Julian Day


300
250
200
150
100
50
0
Flux Density (mJy)
75
80
85
90
95
Julian Day


300
250
200
150
100
50
0
Flux Density (mJy)
73.12
73.14
73.16
73.18
73.20
73.22
Julian Day
rms=3.9%

At present the systematic errors are limiting the sensitivity on bright sources to 5% in the worst cases, and 3% - 4% in typical cases. These scale with flux density. We expect to be able to reduce these systematic errors to the level of 2% - 3%, so we are looking for about a factor 2 reduction in the level of systematic errors. Sources fainter than 50 mJy are limited by thermal noise.

Propose to begin continuous monitoring in September (3 months ahead of launch)

Prior to the continuous monitoring we will be observing selected SWIFT, CGRaBS, and VERITAS objects.

We will begin by daily monitoring of at least 300 CGRaBS sources at 15 GHz on the OVRO 40 M Telescope per day, covering the 1000 sources in our sample twice/week.

We will also coordinate with GLAST schedule to monitor the same area of sky as the GLAST pointings, when the observatory is not in sky suvey mode in order to get as close to simultaneous radio+GLAST measurements as possible

Our target will be to monitor all 1000 sources in our sample each day, and to make the results, including structure functions and fluctuation indices available on the web. We will also monitor a subset of sources monthly at 30 GHz on the Torun 32 M Telescope

The OVRO program is complementary to other monitoring programs since it will cover a large number of sources with a high duty cycle at 15 GHz. This complements other monitoring programs, which will cover a significantly smaller number of sources at multiple frequencies. The Torun program will provide complementary backup to the OVRO and other monitoring efforts.