

Using Time Domain Astronomy to Explore AGN

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Collaborators: Mark Gurwell, Svetlana Jorstad, Alan Marscher,
Dirk Grupe

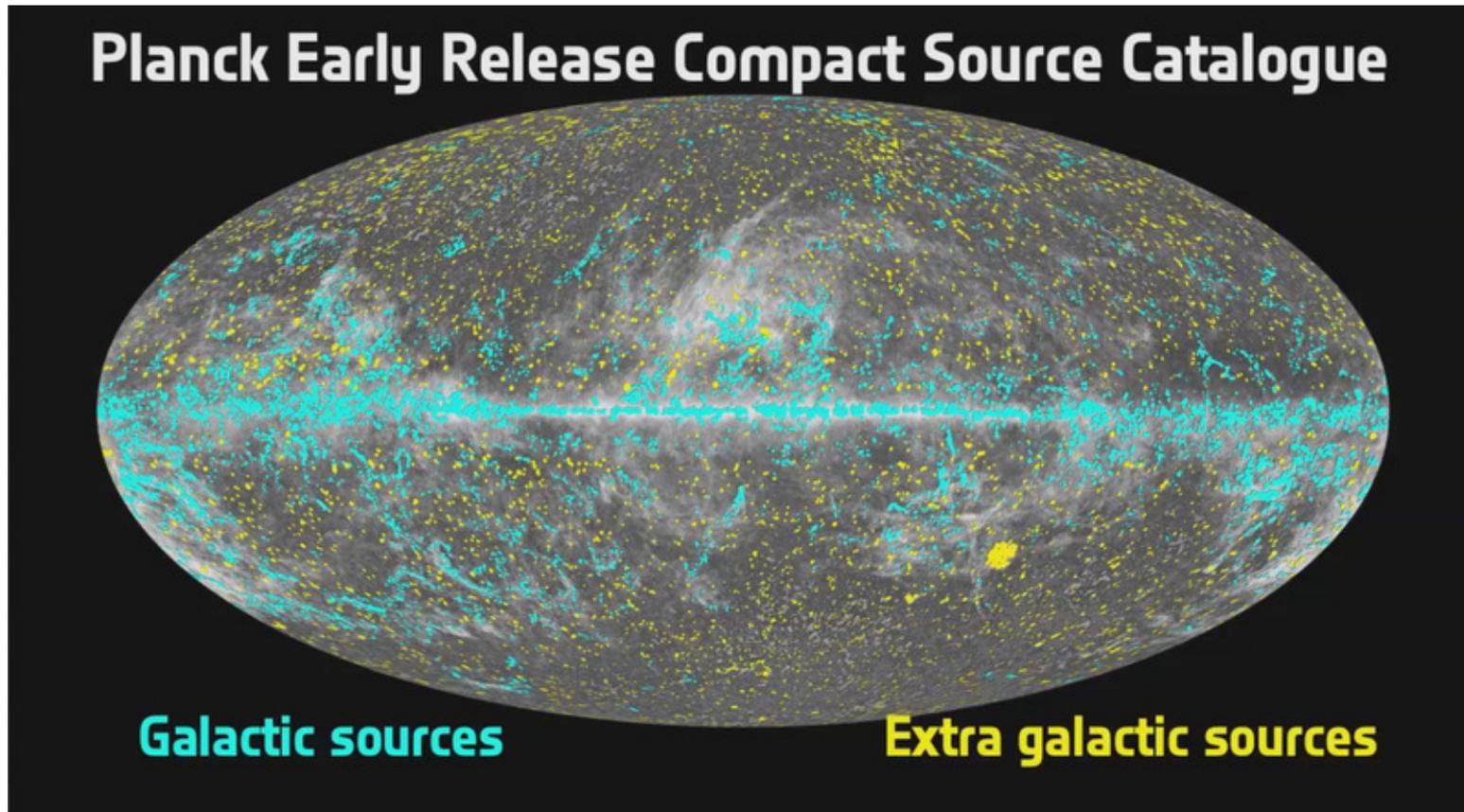
Fermi LAT Team, NuSTAR Team

GASP Collaboration (Claudia Raiteri, Massimo Villata)
and many others

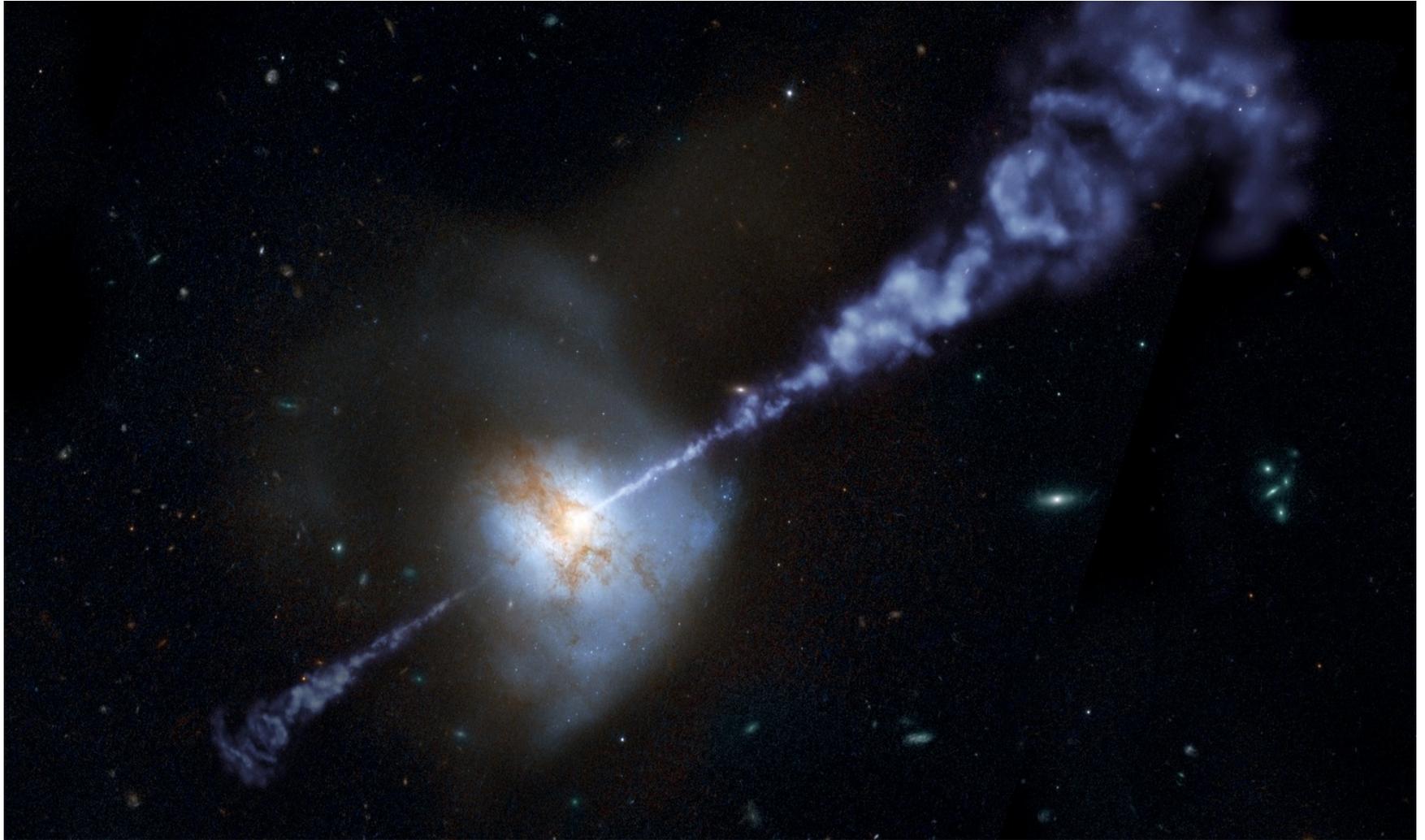


SMA: The First Decade of Discovery, Cambridge, MA, 9-10 June 2014

- New all-sky surveys -most variable objects - AGN and exotic types of stars (SNe, CVs, pulsars, etc.)



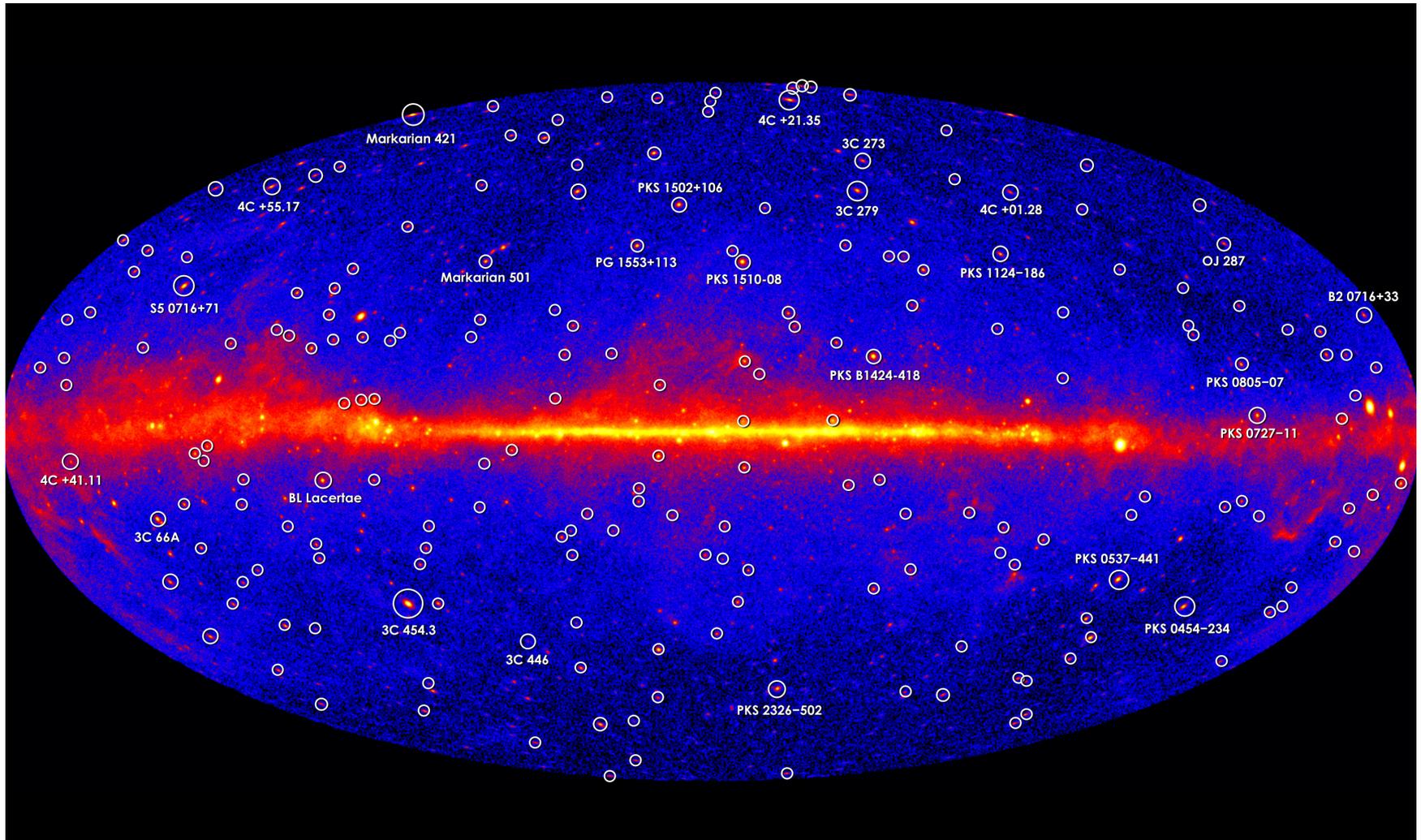
Radio Loud AGN Contain Relativistic Jets- Strongly Variable on Timescales of Days-Months



Blazars- looking directly down the jet

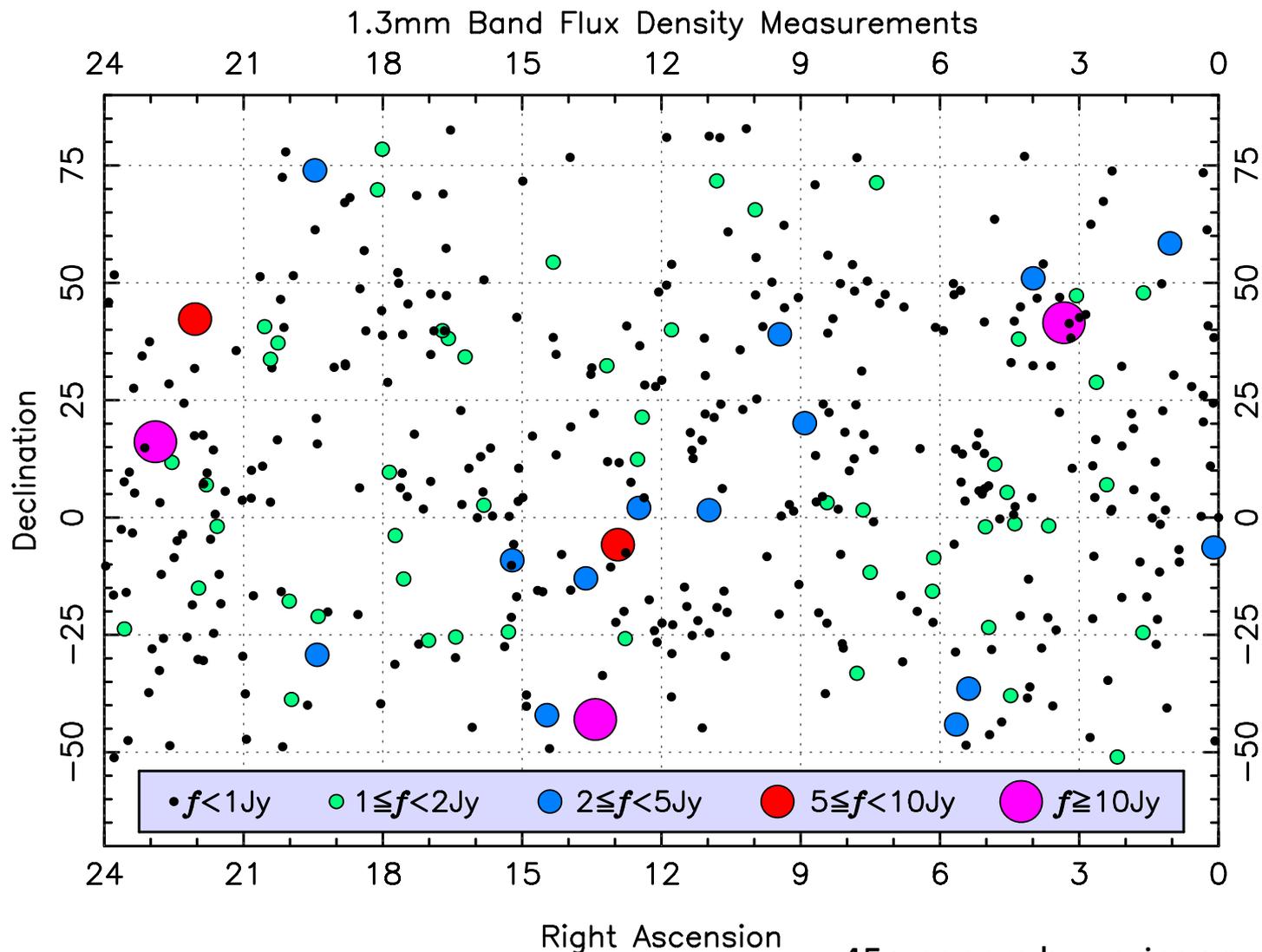
Ann E. Wehrle, SMA: First Decade of Discovery, 9-10 June 2014

Fermi Blazars =SMA Calibrators



Fermi LAT Team- 5 year sky, two strong blazar flares per month, duty cycles vary
Ann E. Wehrle, SMA: First Decade of Discovery, 9-10 June 2014

Brightest AGN at 230 GHz

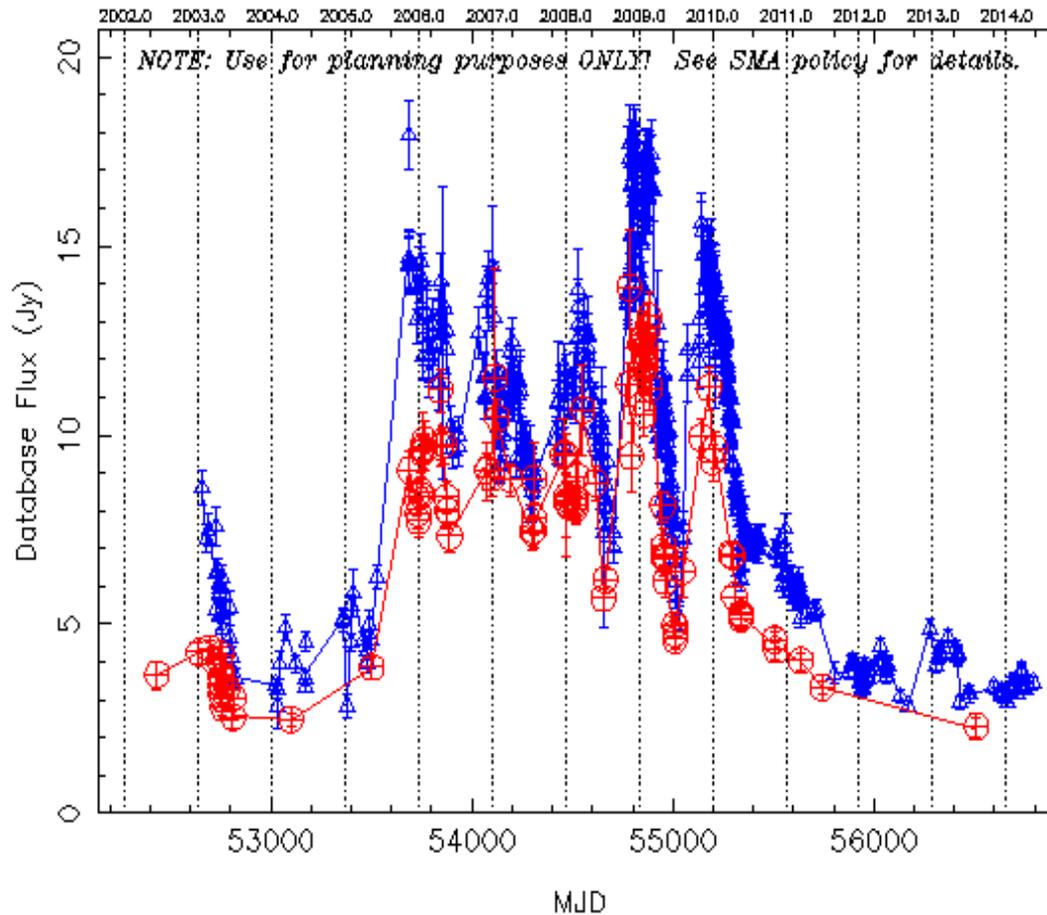


M. Gurwell, CfA/SAO (see his poster)

45+ papers by various groups

Flaring AGN

B1226+023 J1229+020 3c273 \triangle 1.4–1.1mm SMA \oplus 870 μ m SMA



What does variability tell us about AGN physics?

1. Rise-fall: Physical scale (mod. Doppler factors), shock conditions
2. Time delays: relative locations
3. Amplitude: (+ modelling) changes in magnetic field, number of electrons and energy distribution, blob size, distance
4. Brightness correlated with image changes: location
5. Monitoring: PSD of fluctuations could be function(activity level, jet, corona, disk); turbulence
 - A. break timescale implies physical scale;
 - B. relaxation timescale implies “corporate memory”

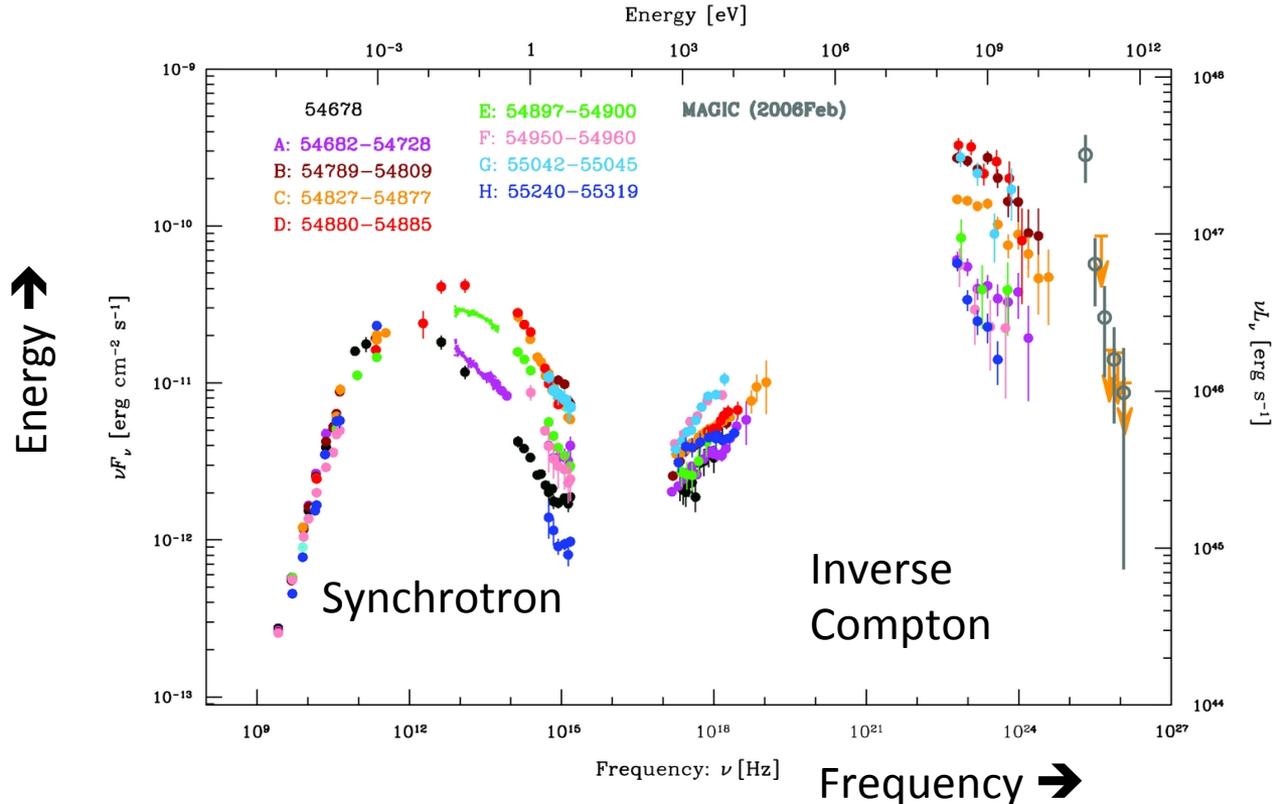
AGN Jet Questions

1. What is the parsec-scale structure at various wavebands?
2. What are the physical characteristics of the jet?
3. Are all flaring events the same?

Strategy #1

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1. Predetermined targets for dedicated study, often multiwavelength campaigns, or single-telescope monitoring for months to years (e.g., 3C279, Hayashida et al. 2012 ApJ 754, 117)

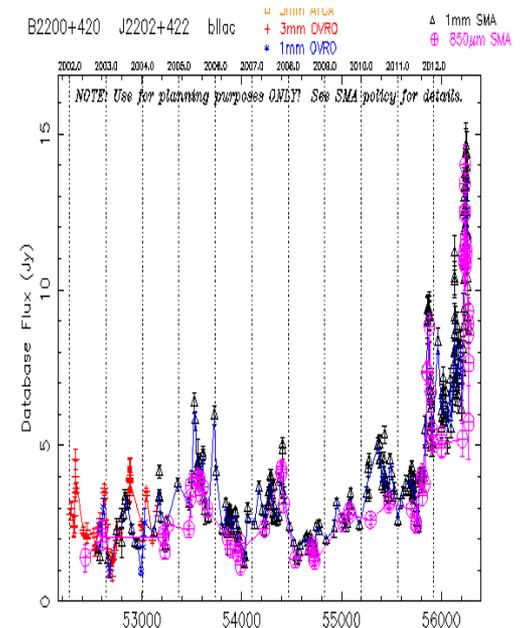
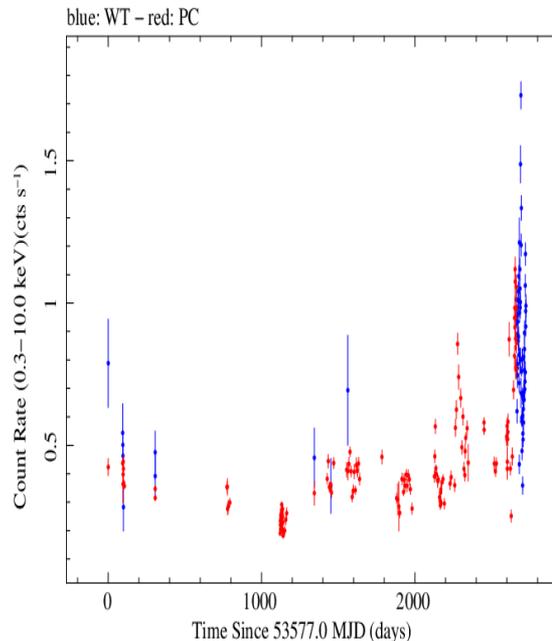
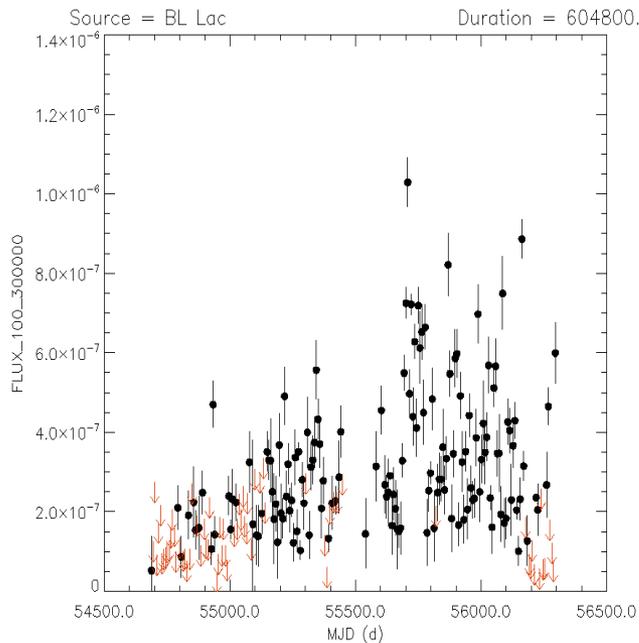


Strategy #2

2. Targets of Opportunity triggered by unusual behavior such as historical brightening (fading) or lack of identified counterpart,

e.g., **Gamma-Ray Blazar BL Lacertae at historic high brightness in millimeter, X-ray and far-infrared bands**

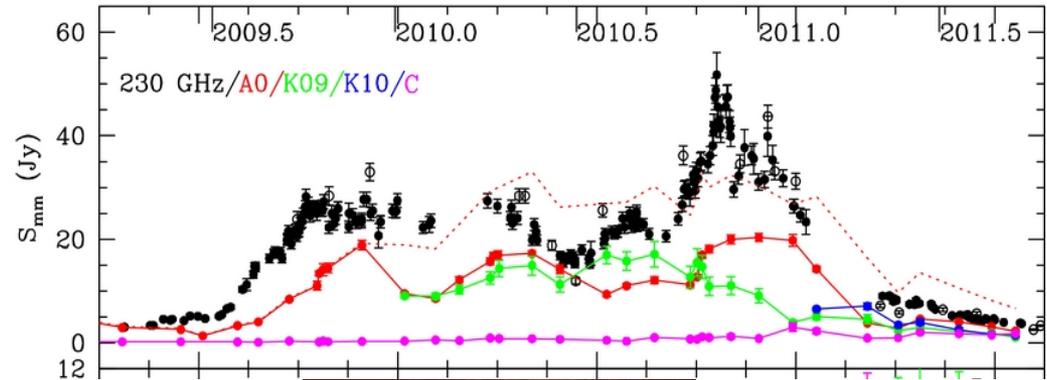
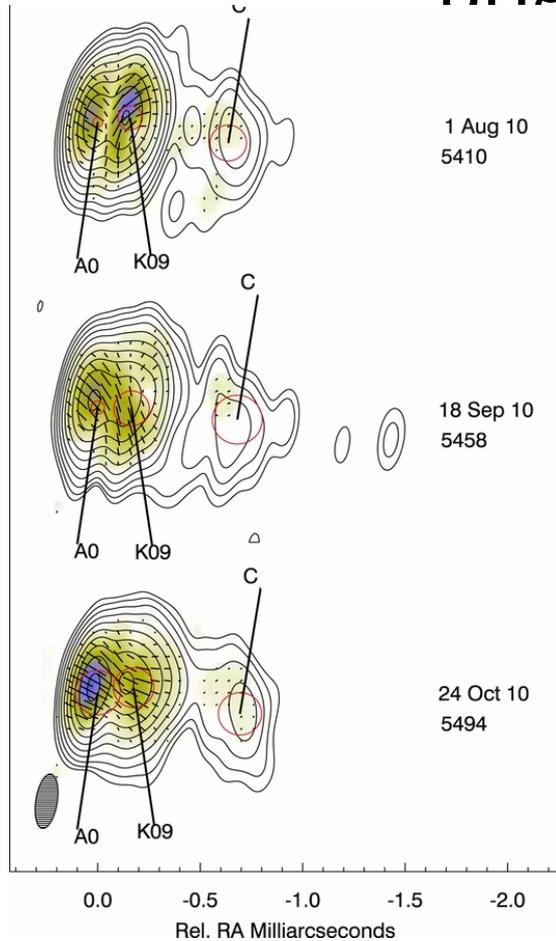
ATel #4557; *Ann E. Wehrle (Space Science Institute), Dirk Grupe (Penn State), Mark Gurwell (CfA), Svetlana Jorstad (Boston University), Alan Marscher (Boston University)*
on 8 Nov 2012; 19:32 UT



Sample Time Domain Techniques

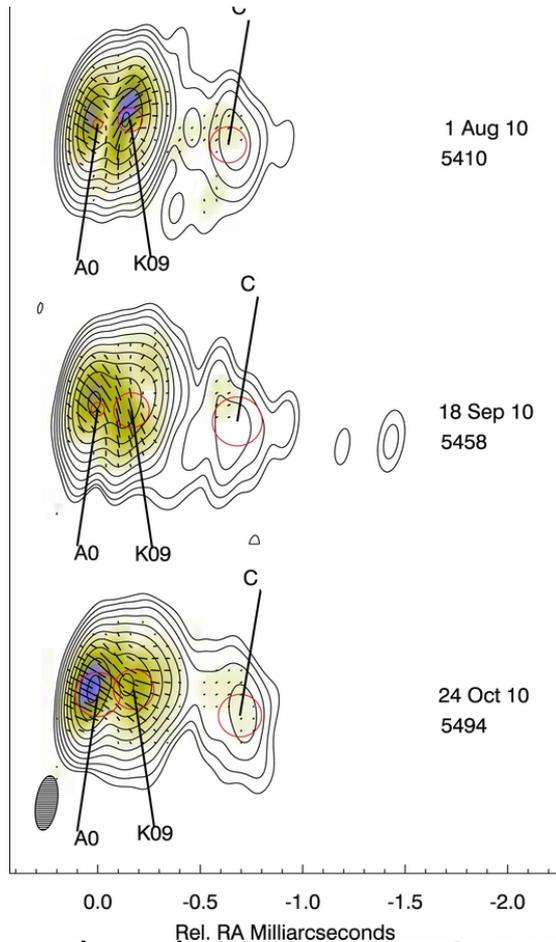
- Optical, near-IR and radio monitoring- (1-2 m optical telescopes, mm and cm band radio telescopes)
- BLR monitoring (e.g., Peterson et al., Bentz et al) – “reverberation mapping”
- VLBI imaging
- Multiwavelength campaigns (e.g., with survey missions WISE, Planck, Fermi,) and pointed observations (SMA, Herschel, Spitzer, Swift, Chandra, NuSTAR, AGILE)

Correlation with Changes in Images: When 230 GHz flux increases, 43 GHz VLBI core or first blob brighten in 3C454.3

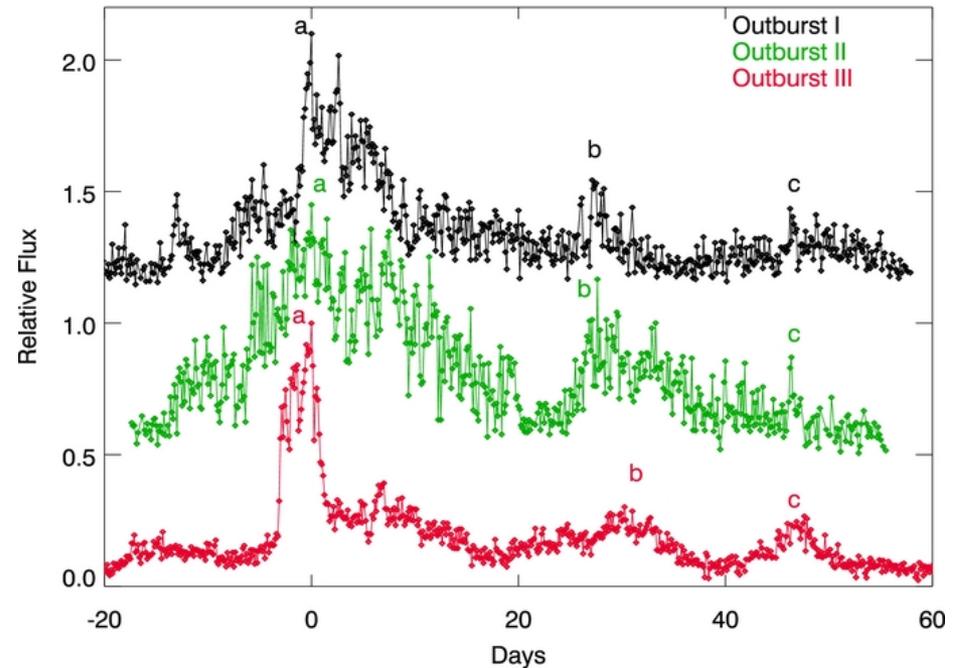


Jorstad et al. 2013 ApJ 773, 147

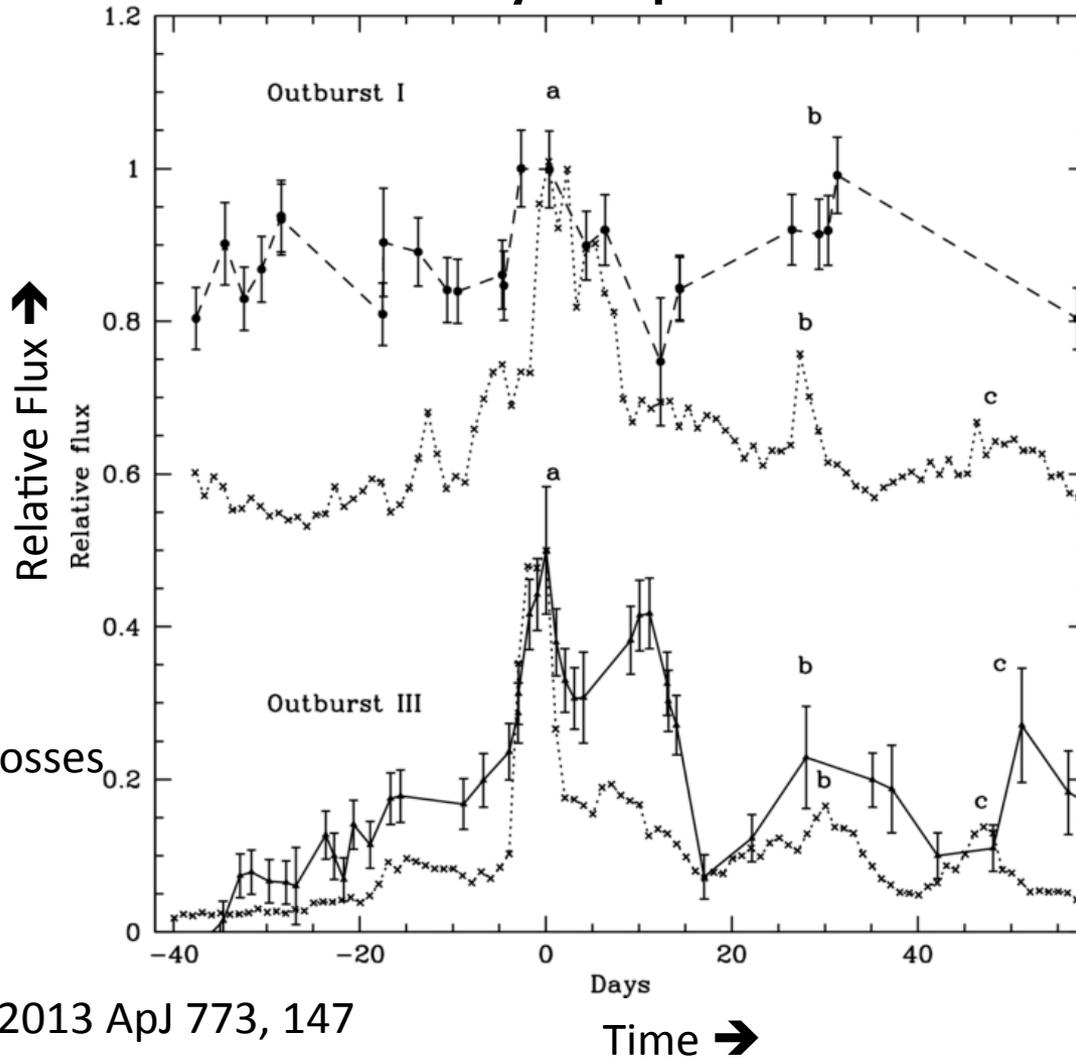
Correlation with Changes in Images: When moving blob hits certain areas within the 43 GHz “core AO” area (< 1 pc from SMBH) , the gamma-ray jet lights up



Jorstad et al. 2013 ApJ 773, 147



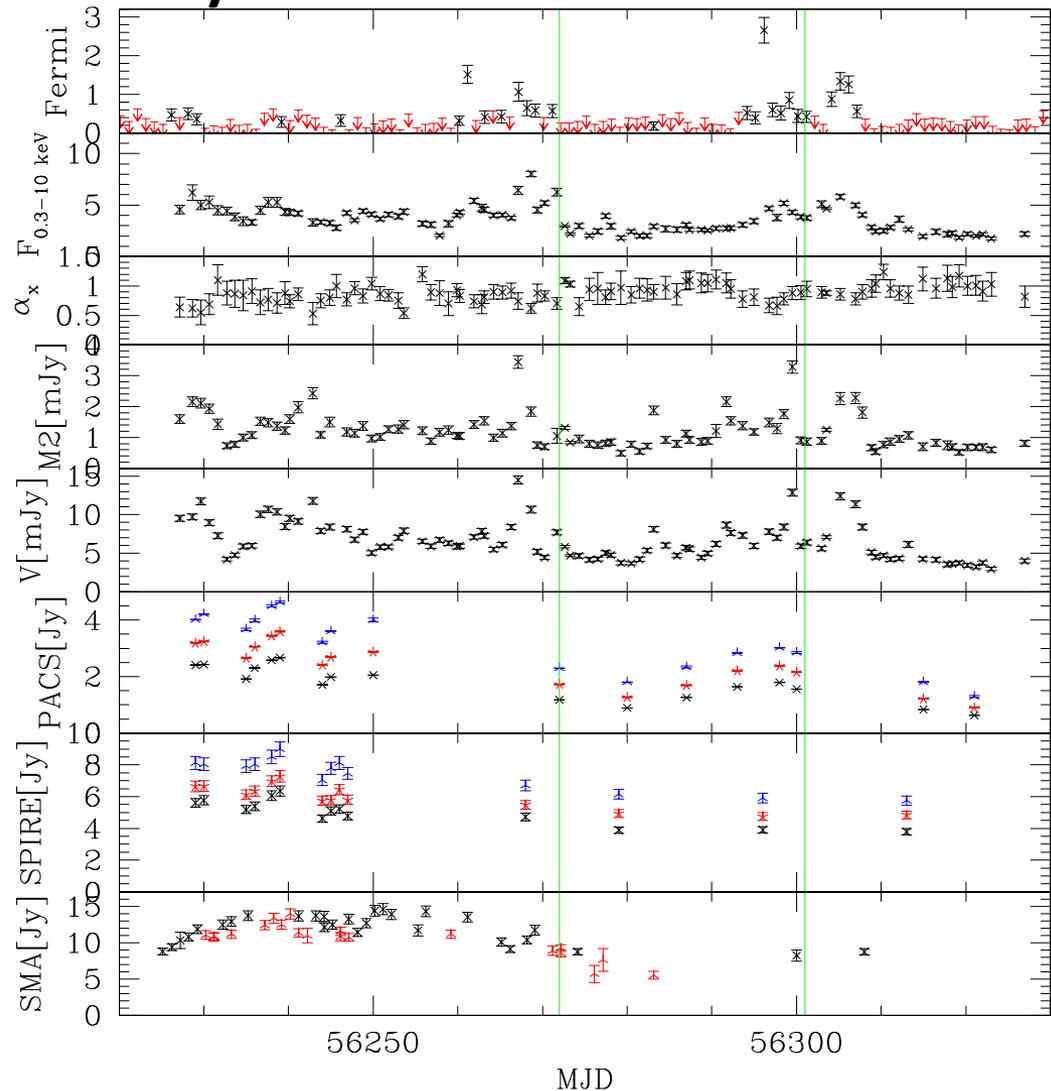
3C454.3 Time delay info: 1.3mm and Gamma-ray light curves' similarity implies same location in jet



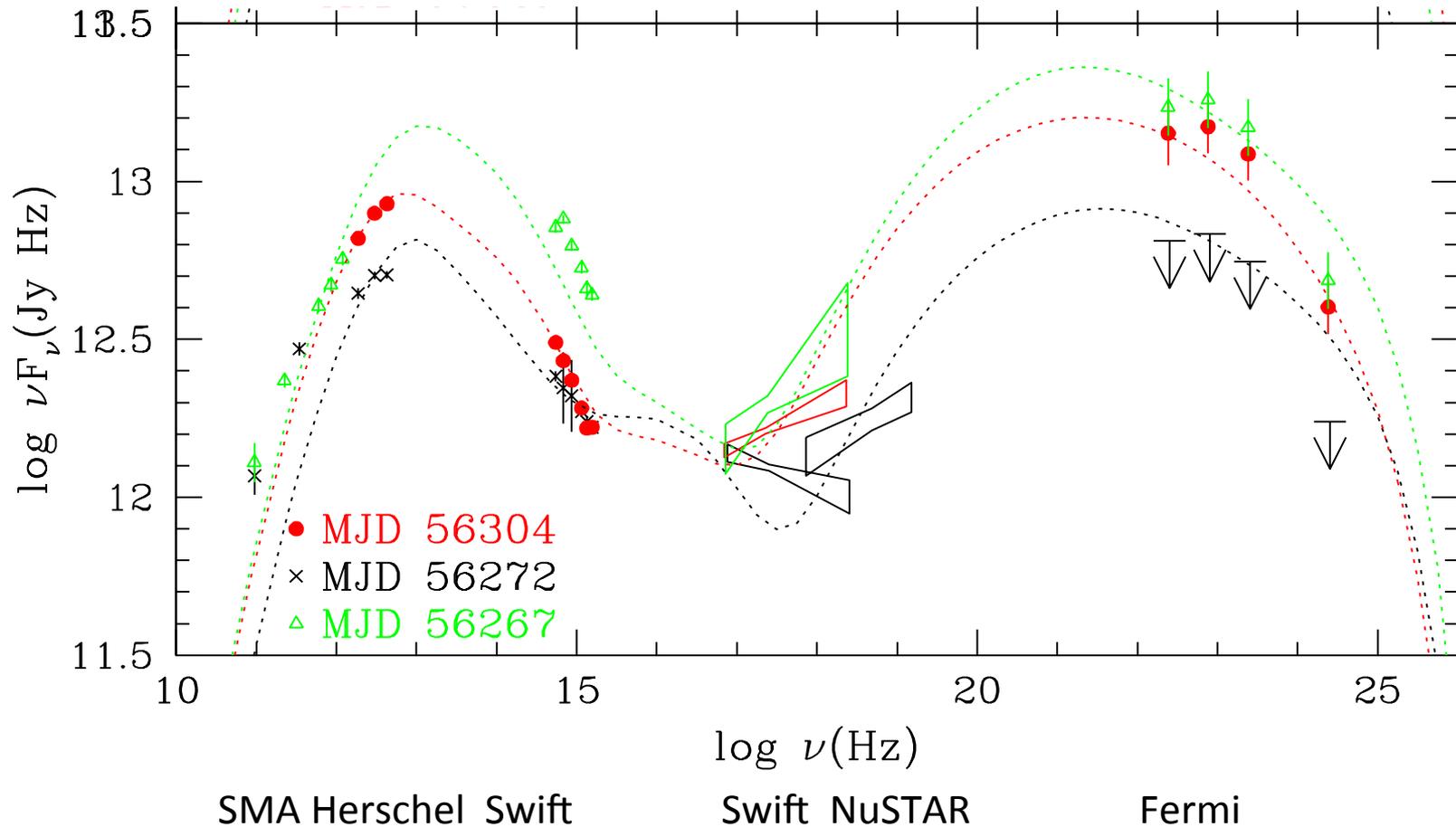
Jorstad et al. 2013 ApJ 773, 147

BL Lac: Time Delay between Wavebands

- BL Lac (Wehrle et al. in prep.)
- Very high activity shows up at all wavebands
- 1.3mm flares are delayed ~ 140 days after gamma rays
- “Orphan flares” imply *multiple* locations for flaring in jets where different physical conditions operate (n_e , B)



New SEDs of BL Lac (3 of ~200)



TEMZ models by A. Marscher; see poster

What we learn from multiwavelength SED of BL Lac: why do we need all these telescopes?

- SMA, VLBA and Fermi LAT define location of flares
- Herschel shows us the electron energy distribution that generates the synchrotron emission at the transition valley between two peaks in SED
- Swift and NuSTAR intersection pinpoints the synchrotron to inverse Compton transition
- Fermi LAT shows spectrum of inverse Compton scattering

AGN Jet Questions

1. What is the parsec-scale structure at various wavebands?

Answer: For 3C454.3, 1.3mm and gamma ray emission come from the same location in the core, as disturbance passes through, but For BL Lac, some 1.3 mm flares are simultaneous and some delayed wrt gamma ray flares .

2. What are the physical characteristics of the parsec-scale jet?

Answer: Magnetic field 0.1-1 Gauss, $n_e \sim 10^4 / \text{cm}^3$, $100 < \gamma < 10^6$, jet is turbulent (leptonic jet modelling)

3. Are all flaring events the same?

Answer: *Major* events look very similar at most wavebands but there are small isolated “orphan” flares that have no counterparts at other wavebands.

Designs on the Future

- Comprehensive analyses of samples 25-1000 objects: characterize range of activity, duty cycles, evolution of activity?
- Detailed studies of single objects based on historical flaring or fading: how universal are quantities such as magnetic fields, turbulence power spectra, sources of seed photons are in jets?
- *SMA TOOs- Investigate objects discovered in data mining of new synoptic survey triggers such as optical outliers, short transient radio flares, X-Ray flares, and TeV flares.*

Current Synoptic Surveys- Optical

- Catalina Real Time Transient Survey (public)
- Palomar Transient Factory, iPTF
- PanSTARRS
- Dark Energy Survey
- Kepler extended as “K2” mission (public)



Current Synoptic Surveys- Radio

- LOFAR
- Murchison Widefield Array



Future of SMA TOO Triggers- Example: Catalina Real Time Transient Survey **CRTS Event Detections as of May 2013**

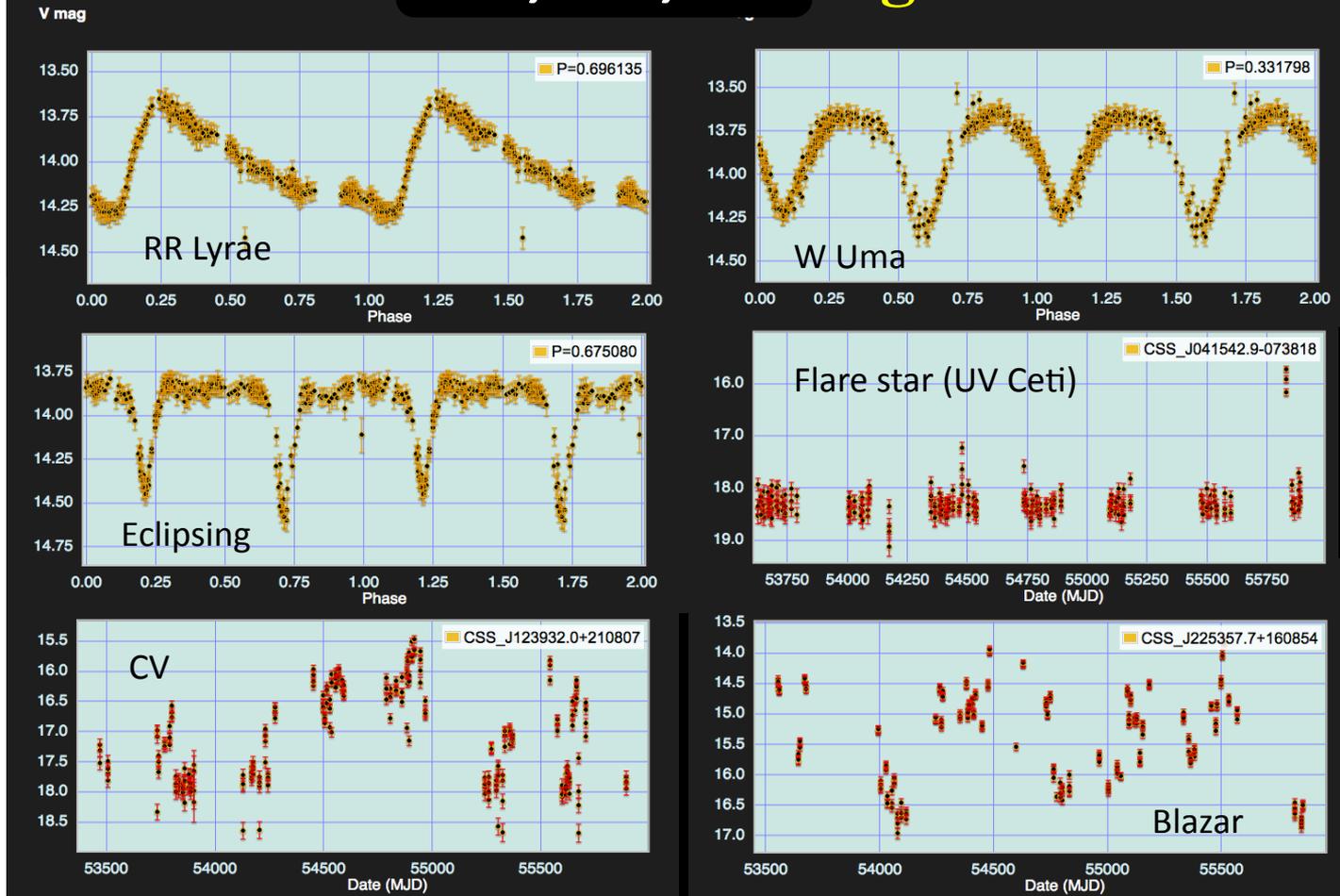
Telescope	All OTs	SNe	CVs	Blazars	Flare	CV/SN?	AGN	Other
CSS	3385	1003	675	215	269	436	437	436
MLS	3387	479	69	75	225	600	1597	522
SSS	680	99	251	17	11	108	32	167
SNhunt	186	186	0	0	0	0	0	0
Total	7638	1767	995	307	505	1144	2066	1125

- Threshold set deliberately very high ($\sim 1 - 2$ mag, $>5 \sigma$), so only the most dramatic transients are pulled out in the real time
- • About 1 strong transient per 10^6 source detections
- The rate of significant transients/variables is at least an order of magnitude higher; available for an archival study
- Many events are re-detected repeatedly (not counted above)
 - Many also detected independently by PTF, PS1

Slide courtesy of S. Djorgovski et al. 2013

Catalina Real Time Transient Survey

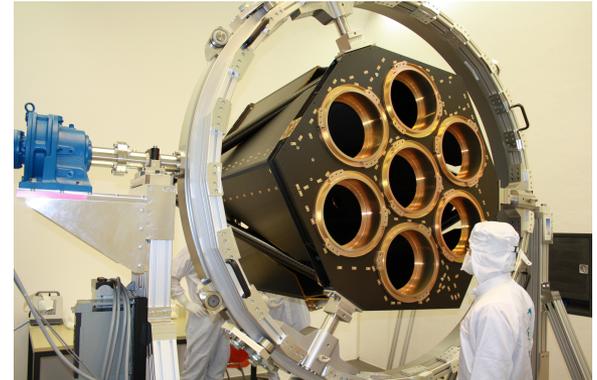
Released 500,000,000 Light Curves



Slide courtesy of S. Djorgovski et al. 2013

Future Synoptic Surveys

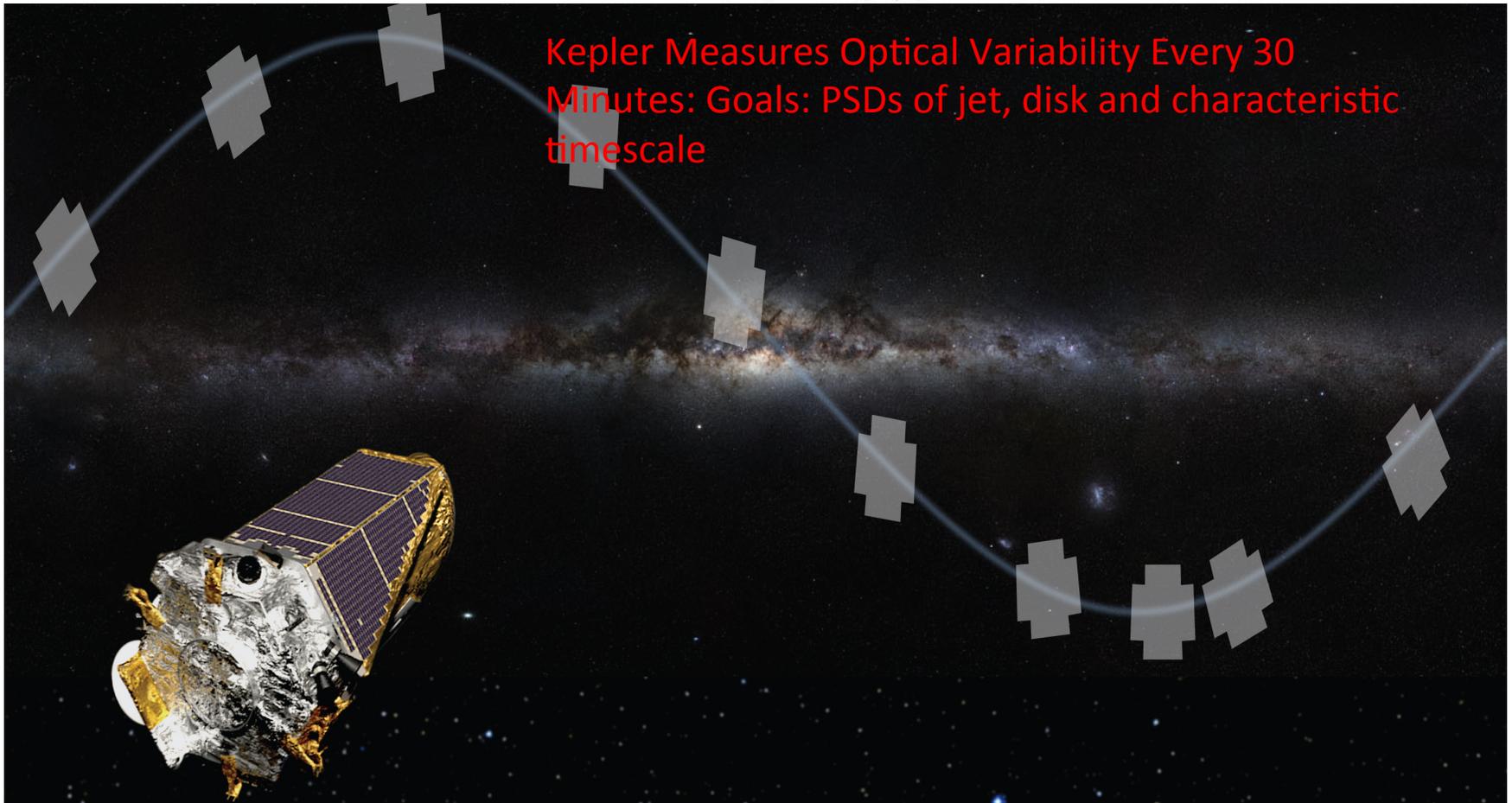
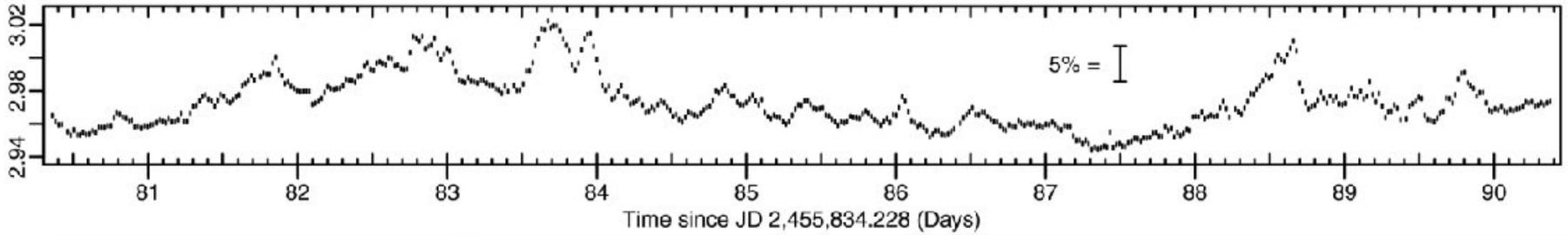
- High-Altitude Water Cherenkov Observatory (2014)
- Large Synoptic Survey Telescope (~2022, 10 year)
- eROSITA X-Ray mission (2015, 4 year)
- Square Kilometer Array (precursors completed, arrays in development)



Conclusions

1. Time domain studies with SMA reveal physical conditions in AGN jets (e.g., magnetic field, turbulence, particle populations).
2. Time domain is the wave of the future with panoramic, synoptic surveys coming online, providing new triggers for SMA observations, including previously unknown objects.
3. Keys to new variable AGN physics with SMA are open access, rapid TOO scheduling, new technical capabilities, persistence in long term monitoring, and willingness to take risks for high risk/high payoff science.

Back up Slides



Corona and Accretion Disk: turbulence and QPO's

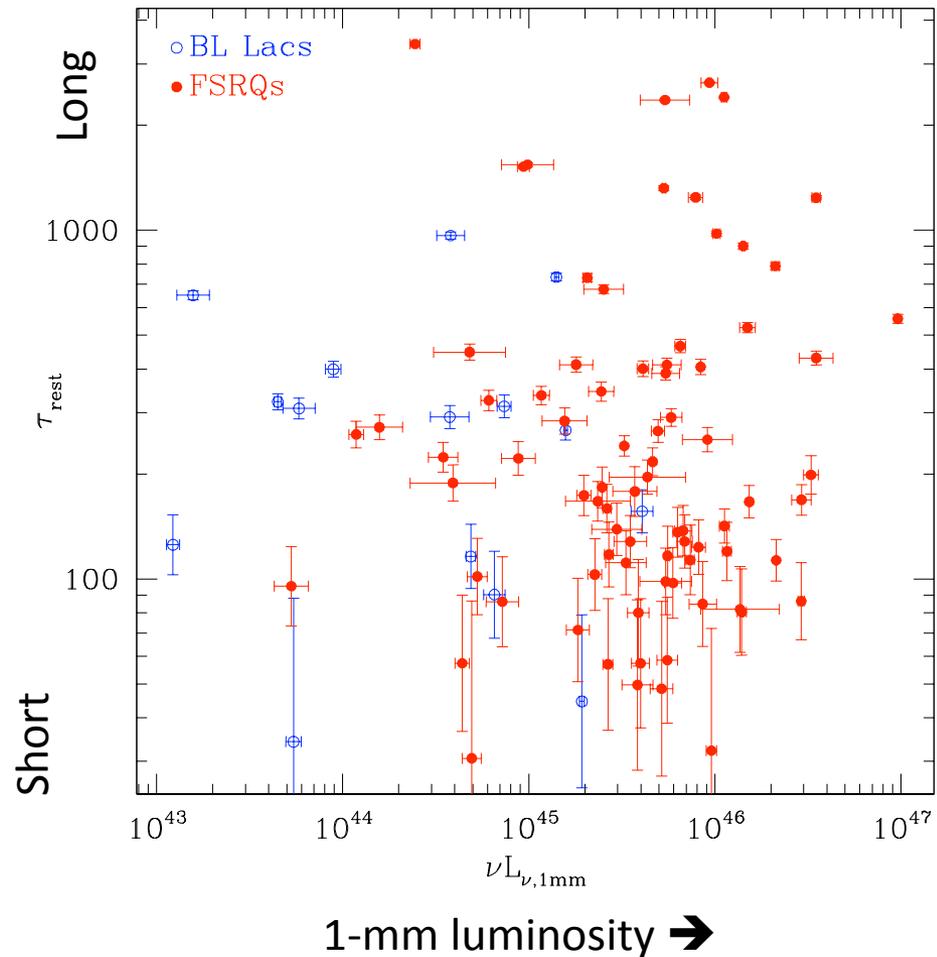


γ -ray Blazar Relaxation Timescale ~ 100 - 1000 days

SMA light curves were modelled as continuous autoregressive process, using method of Kelly et al. 2009.

Characteristic "relaxation timescales" of BL Lac and FSRQ (blazars whose SEDs peak at high and low energies) look very similar over years of SMA observations.

Source "forgets" about events on timescale of VLBI blob ejection.



Strom et al. 2009 Fermi Symposium