Interferometric Monitoring of Gamma-ray Bright AGNs: Exploring the Variability of the Flat Spectrum Radio Source 1633+382

J. C. Algaba, B. Rani and the iMOGABA collaboration

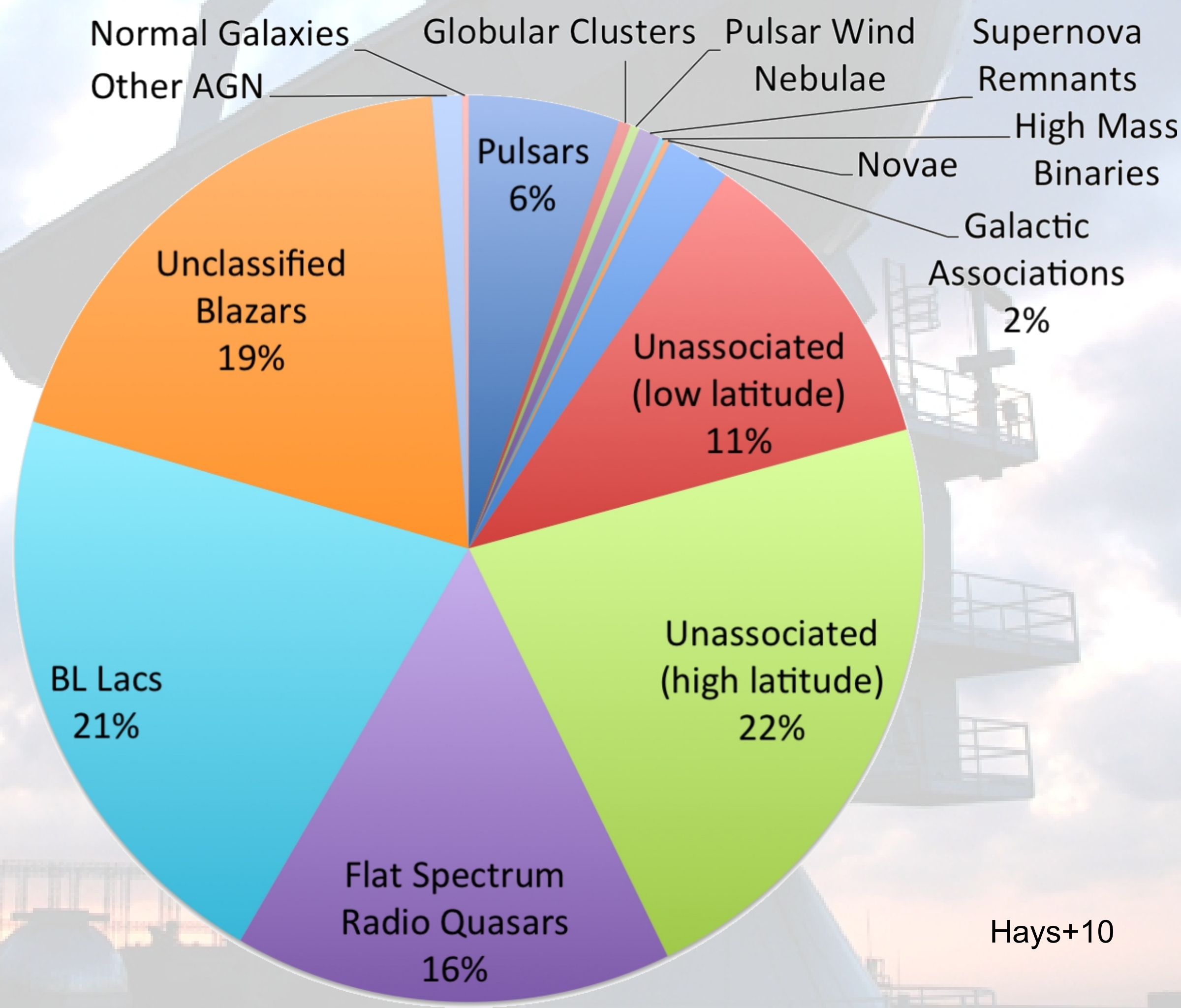
ASIAA Colloquium, July 28th 2017

Contents

- Gamma Rays
- iMOGABA
- 1633+382
- Correlations
- Shock-in-jet?
- Summary

Gamma-Rays

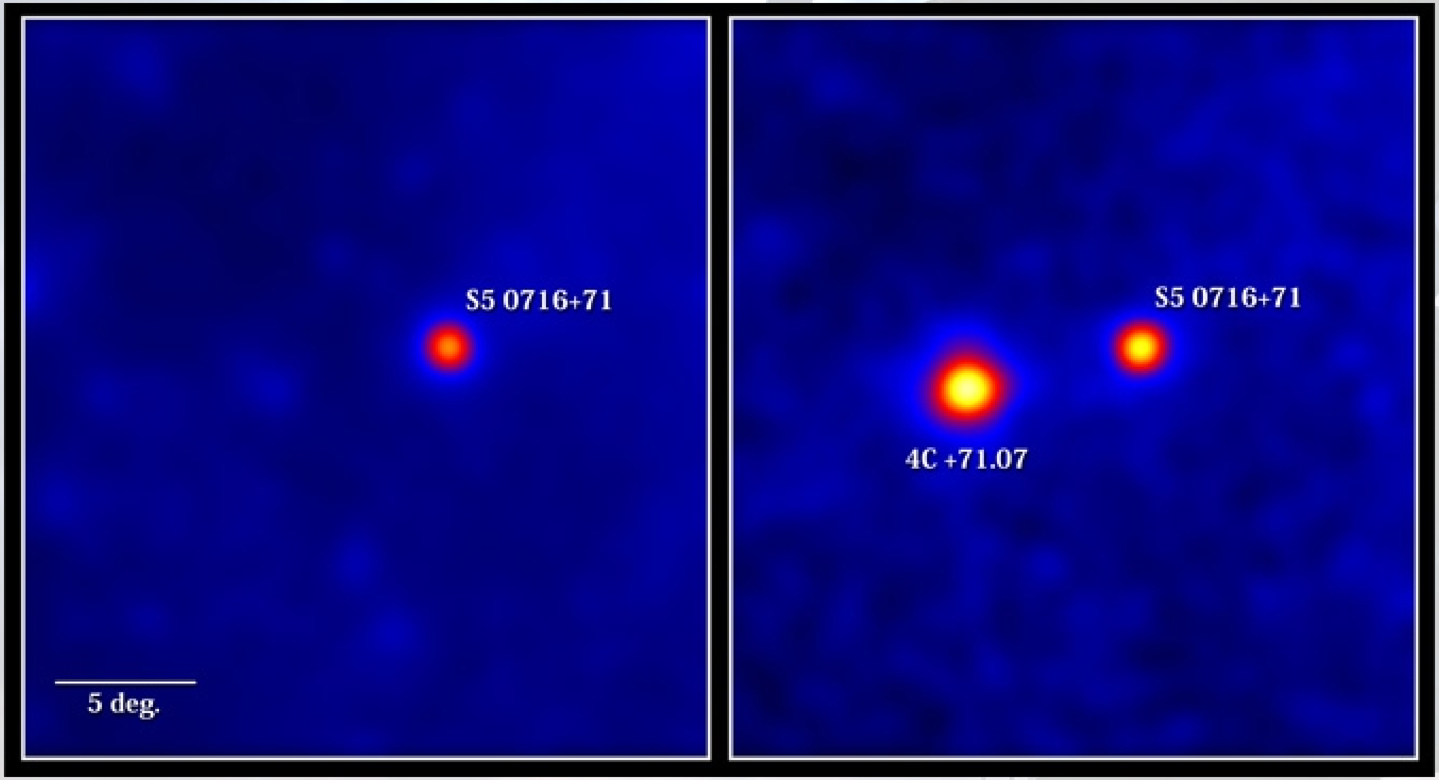
- *Fermi*-LAT observes the gamma-rays sky
  - All sky survey in 2 orbits (~3 hours)
  - 4 years of data released in their 3FGL catalog (Acero+15)
  - Most of the sources are AGNs
- Where does the high energy flux come from?
  - Poor Fermi resolution
  - Only <50 sources show extended structure (out of >3000)
- Synergy with other programs
  - Multi-frequency analysis
  - High-resolution VLBI



Hays+10

Gamma-Rays

- Gamma-ray flares are common!
  - Left: 4 years of observations
  - Right: 10 weeks of activity in late 2011



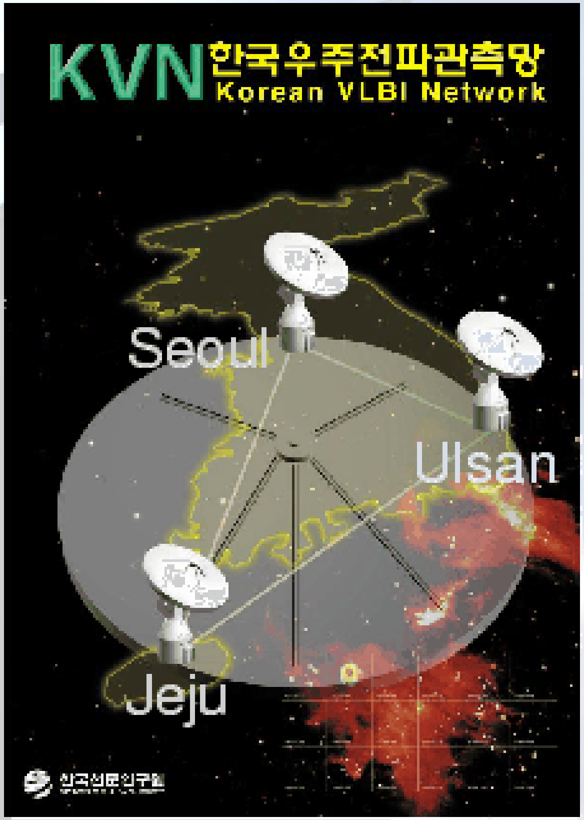
Credit: NASA/DOE/Fermi LAT Collaboration

Gamma-Rays

- What is the location of the gamma-ray flares?
  - Downstream the jet
  - Near to the central engine, around BLR
  - (Both...?)
- What is the cause of the gamma-ray flares in AGNs?
  - Relativistic Jet of High Energy Plasma
  - Doppler boosting of Synchrotron radiation
  - Inverse Compton Scattering

iMOGABA

- Key Science Project for KVN
  - Interferometric Monitoring of Gamma-ray bright AGNs
  - Milliarcsecond scales
  - Monthly observations started on December 2012
  - Sample of ~30 sources
  - Simultaneous @ 22, 43, 86, 129 GHz
- Synergy with other monitoring programs
  - e.g., MOGABA, BU 43 GHz Monitoring, MOJAVE,…
- Unique in its simultaneous high frequency observations
- No other VLBI program above 43 GHz
  - Excel to probe innermost, optically thin regions of AGNs
- Science Case: Study the origin of Gamma-ray flares



Interferometric Monitoring of Gamn ×

radio.kasi.re.kr/kvn/sslee/ 90% Search

Monitoring of Gamma-ray Bright AGNs

Home
MOGABA
iMOGABA
Publications
KVN

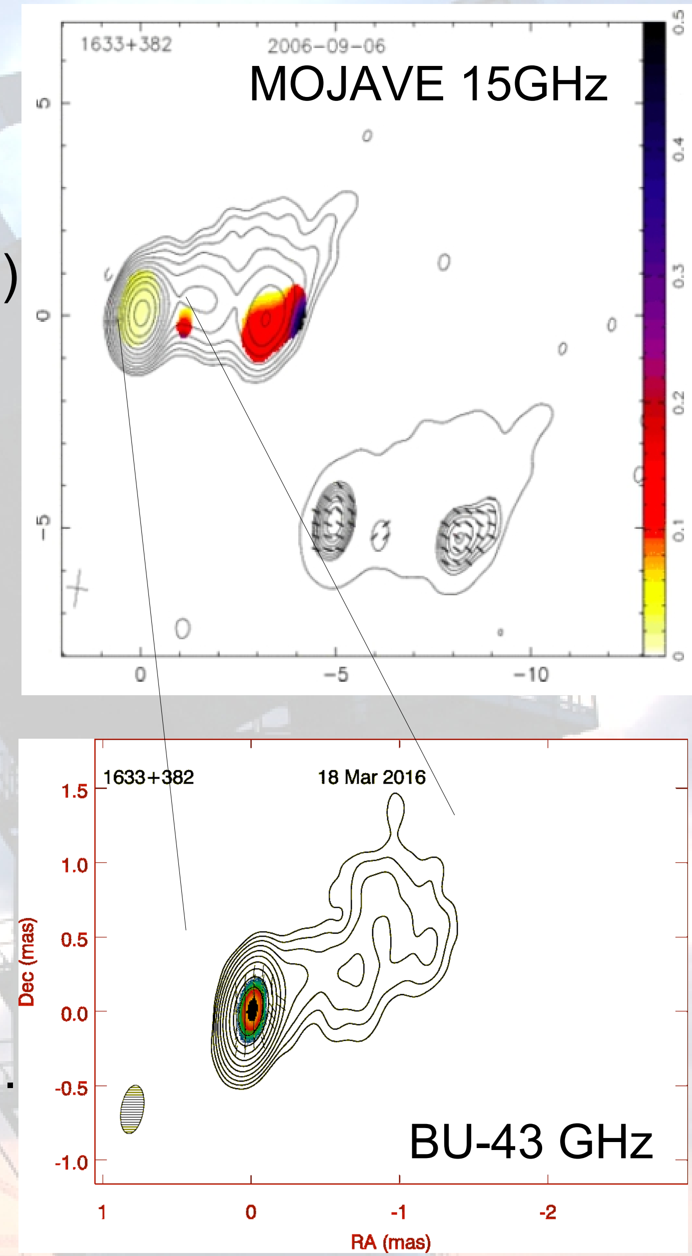
Interferometric Monitoring of Gamma-ray Bright AGNs

Images of the Gamma-ray Bright AGNs taken with Korean VLBI Network

Obs Name	imogaba20	imogaba19	imogaba18	imogaba17	imogaba16	imogaba15	imogaba14	imogaba13	imogaba12	imogaba11	imogaba10	imogaba9
Obs Date	2014-12-25	2014-11-28	2014-10-29	2014-09-27	2014-09-01	2014-06-13	2014-04-22	2014-03-22	2014-02-28	2014-01-27	2013-12-24	2013-11-19
	MJD=57017	MJD=56990	MJD=56960	MJD=56928	MJD=56902	MJD=56822	MJD=56769	MJD=56738	MJD=56716	MJD=56684	MJD=56650	MJD=56615
BLLAC									KQWD	KQ	KQWD	KQWD
CTA102									KQWD	KQ	KQWD	KQWD
J0730-1141										KQ	KQWD	KQWD
M87									KQ	KQ	KQWD	KQWD
MRK421										KQ	KQ	KQWD
OJ287										KQ	KQWD	KQWD
NRAO530									KQW	KQ		
SGRA									KQ	KQ		
3C111										KQ	KQWD	KQWD
3C273B									K	KQ	KQWD	KQWD
3C279								KQWD	KQW	KQ	KQWD	KQWD
3C286									K	K	K	K
3C345									KQ	KQ	KQWD	KQWD
3C446											KQW	KQW
3C454.3										KQ	KQWD	KQWD
3C84									KQWD	KQ	KQWD	KQWD
4C28.07									KQW	KQ	KQWD	KQWD
4C38.41									KQW	KQ	KQWD	KQWD
4C39.25									KQW	KQ	KQWD	KQWD
0235+164										KQ	KQW	KQ
0218+35A										KQ	KQ	
0420-014										KQ	KQWD	KQWD
0528+134										KQ	KQW	KQW
0716+71										KQ	KQWD	KQWD
0735+178										KQ	KQW	KQW
0827+243											KQ	KQ
0836+710										KQ	KQW	KQW
1044+719										KQ		

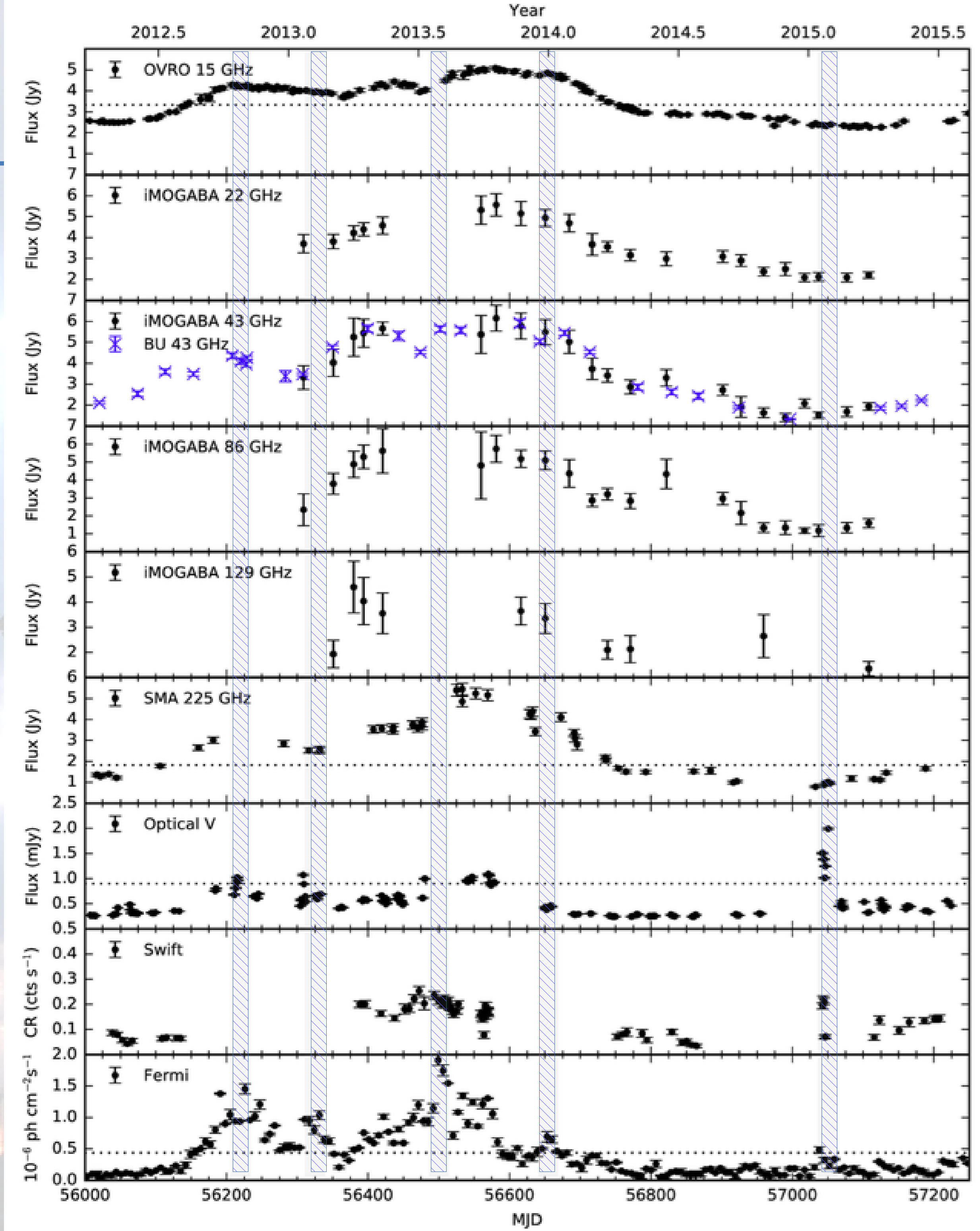
1633+382

- 1633+382, Aka 4C 38.41
  - OVV, HPQ Flat radio spectrum
  - z=1.813, ~14 Gpc, 8.54 pc/mas
  - Relatively bright in radio (Flux 2-4 Jy @15GHz)
  - γ-ray bright source
- Very popular source in various programs
  - BU-VLBA, iMOGABA, SMA, OVRO,...
  - Observational synergy
- Ideal target to study variability & γ-ray flares
- Target of iMOGABA
- Flared period between 2013-2015
  - Observations and Data collection
  - OVRO, iMOGABA, SMA, Optical, Swift, Fermi..



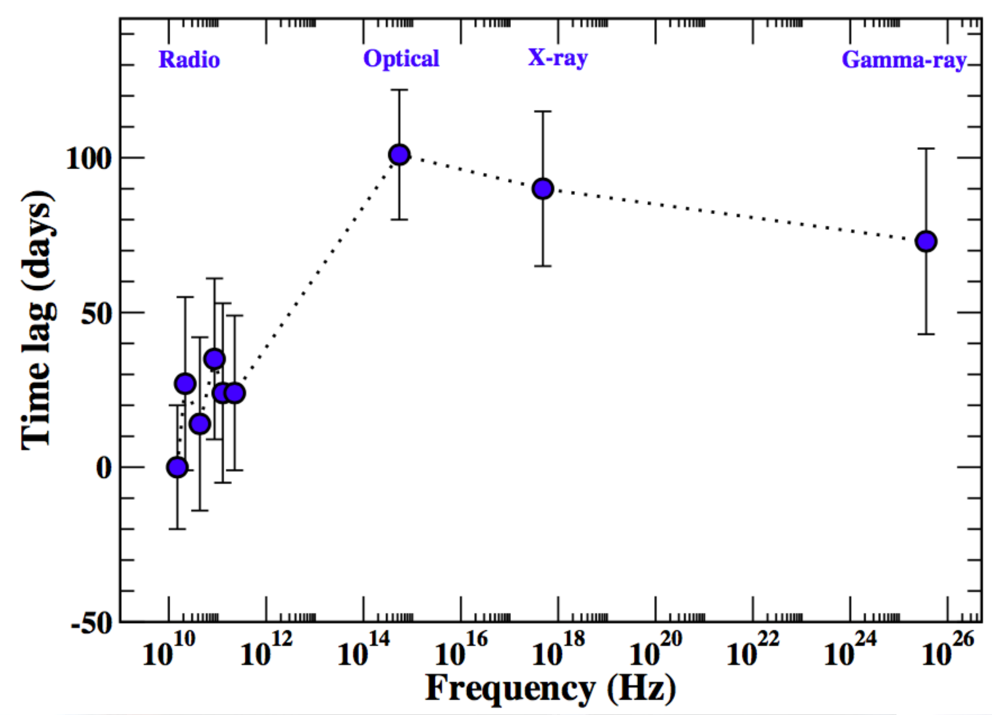
Light Curve

- Follow-up
  - 2012 Mar – 2015 Aug
- iMOGABA didn't observe all
  - beginning of the flares
  - Maintenance seasons
    - Gaps covered by BU 43 GHz data
- Multi-frequency comparison
  - Correlation with other frequencies
  - Other flares in high freq. bands



Correlations

- Time lags
  - Radio - Radio correlations
    - Compatible w/ zero time lag
    - Possible trend? But too large uncertainties
  - Radio - Optical correlations
    - Weak correlation
    - If any, large time lag
  - Radio - γ-rays correlation
    - Significant time lag



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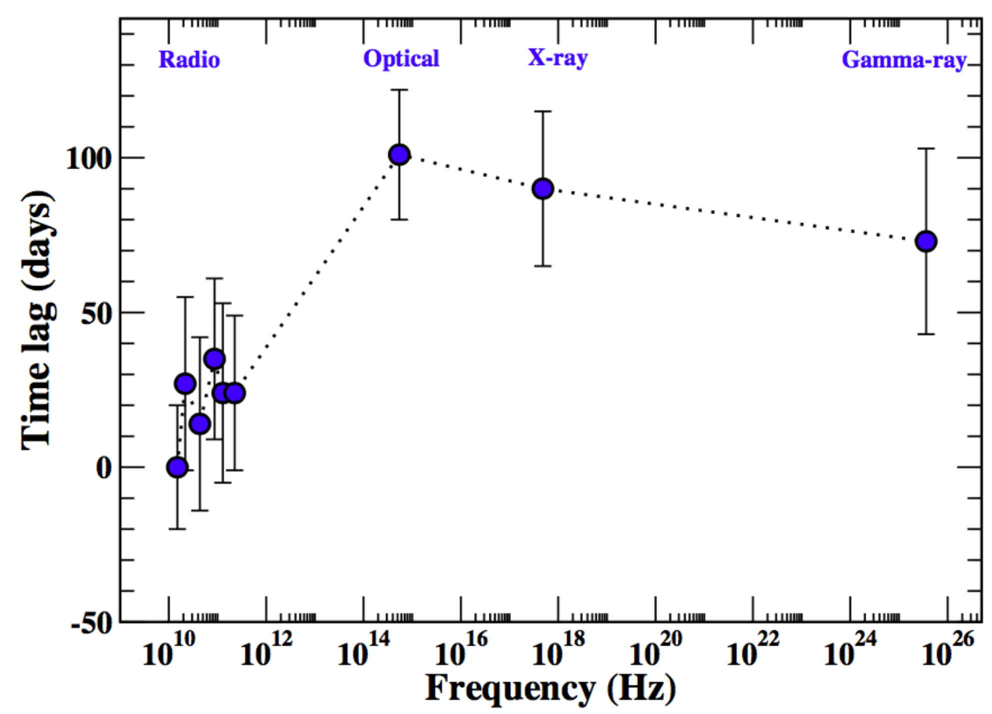
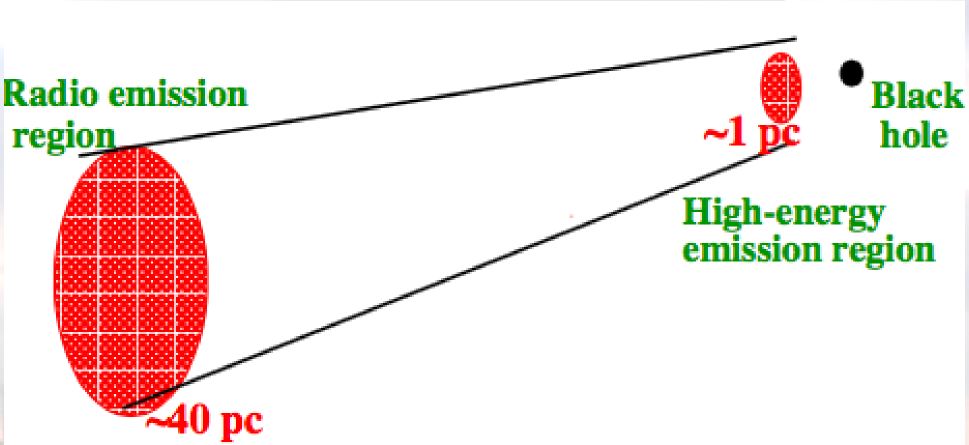
- Indications of different emitting regions at high energies / radio?





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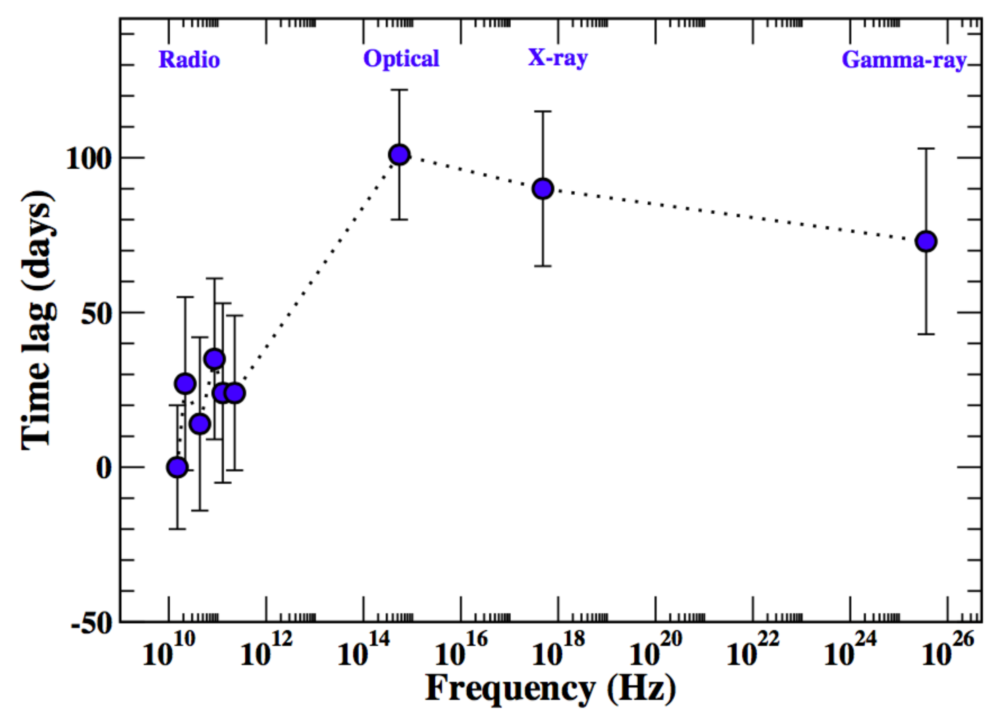
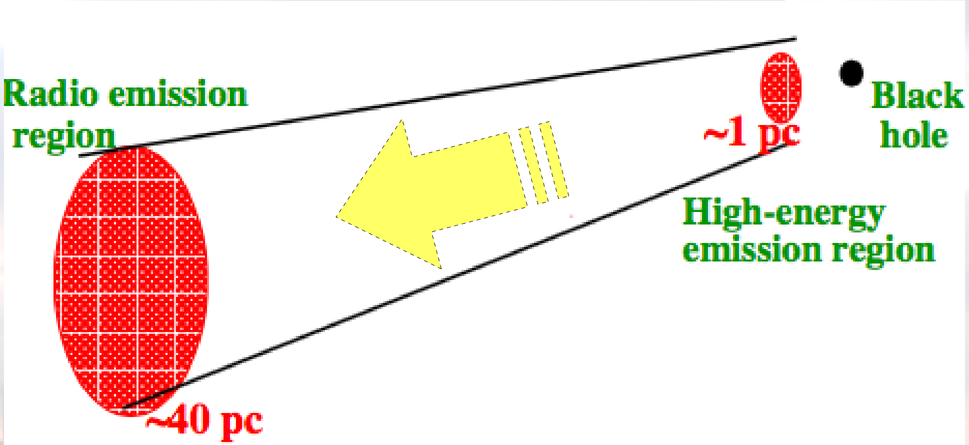
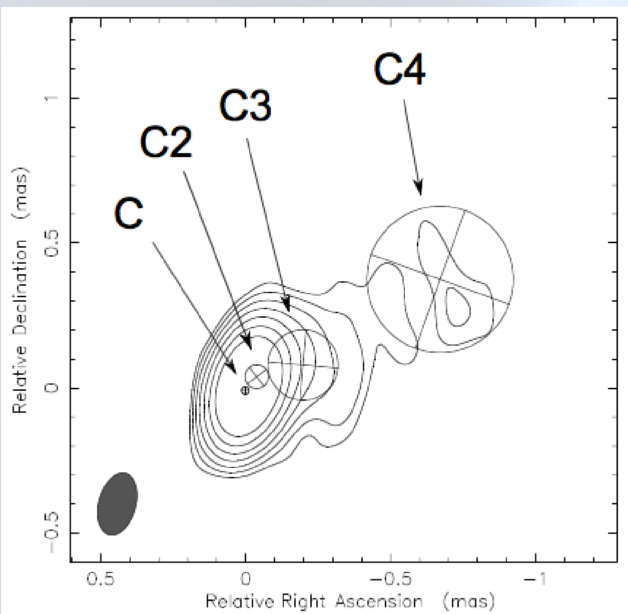
- Indications of different emitting regions at high energies / radio?
  - Shock-in-jet model?

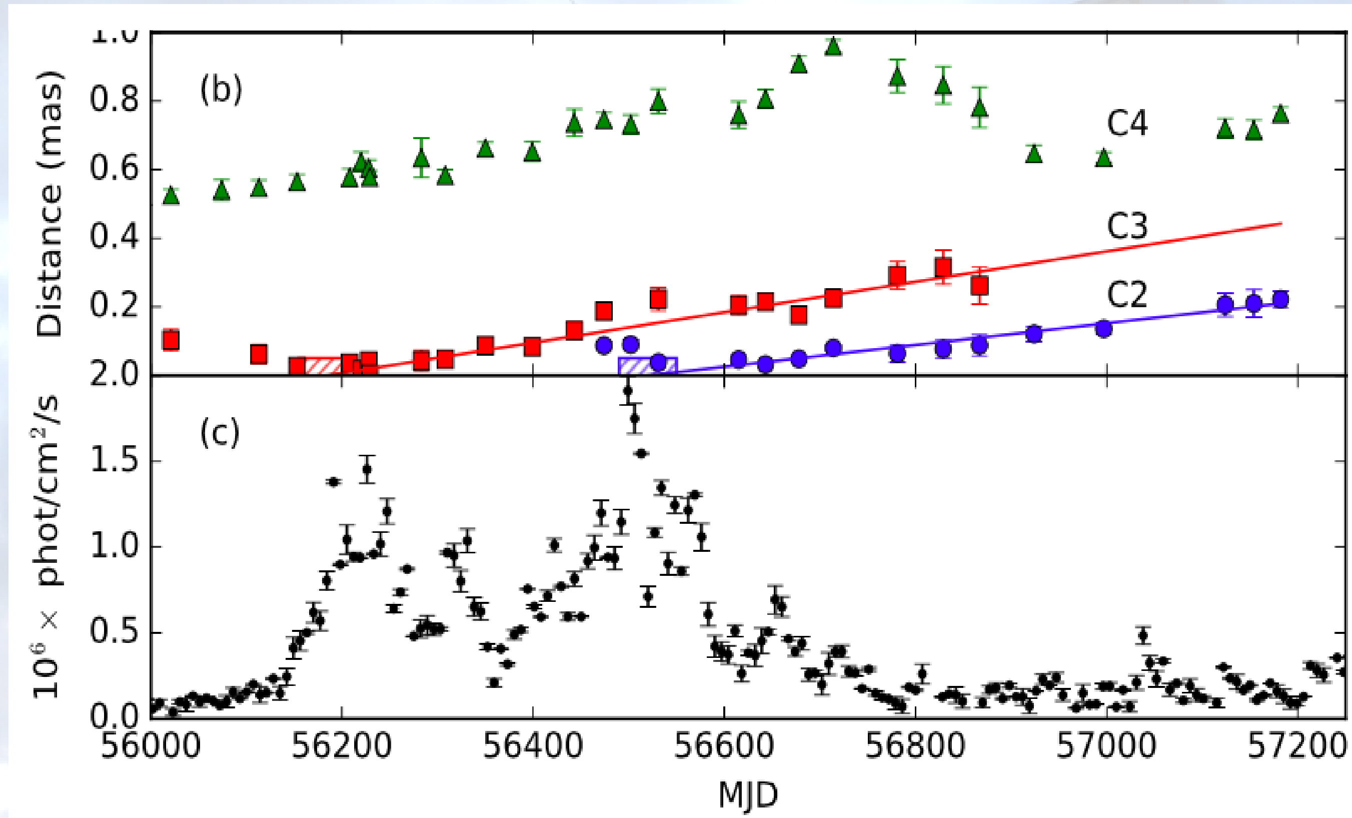




Shock-in-jet?

- Structure analysis
  - Jet components
  - Core size



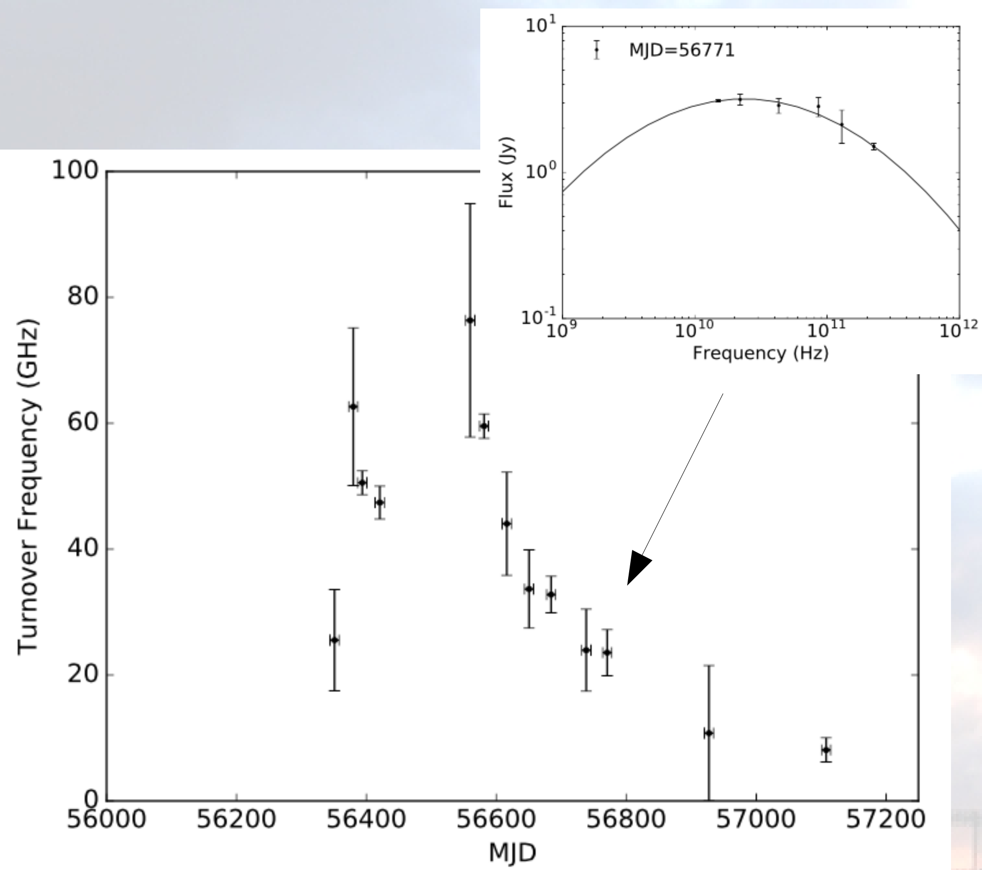


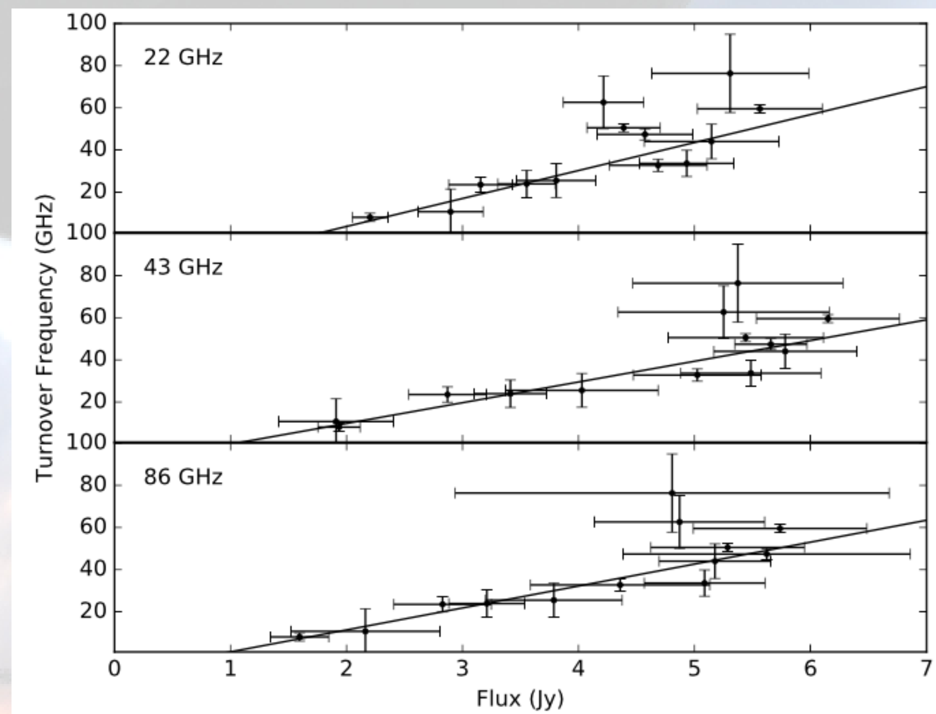
- New VLBI component ejection near brightest γ-ray flares
  - v(C2) = 9.4±0.8c
  - v(C3) = 12.5±0.8c

} Γ~12-14; δ~19-21 for θ~2.5°, in agreement with Hovatta+09

Shock-in-jet?

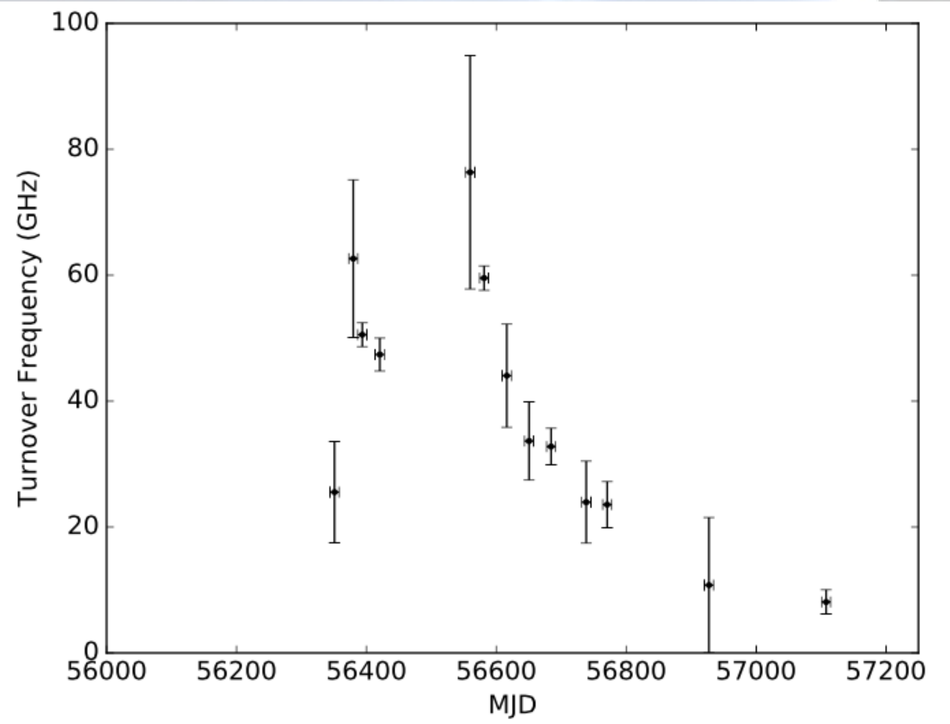
- Turnover Frequency
  - IMOGABA (22, 43, 86, 129) + OVRO + SMA
- Relation between flux density and turnover frequency

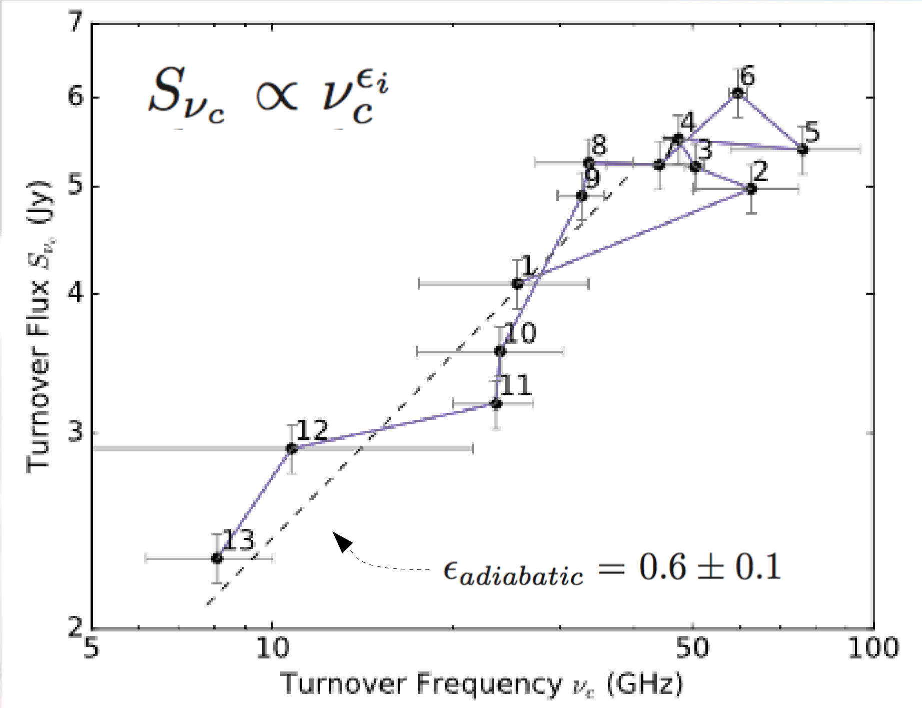




Shock-in-jet?

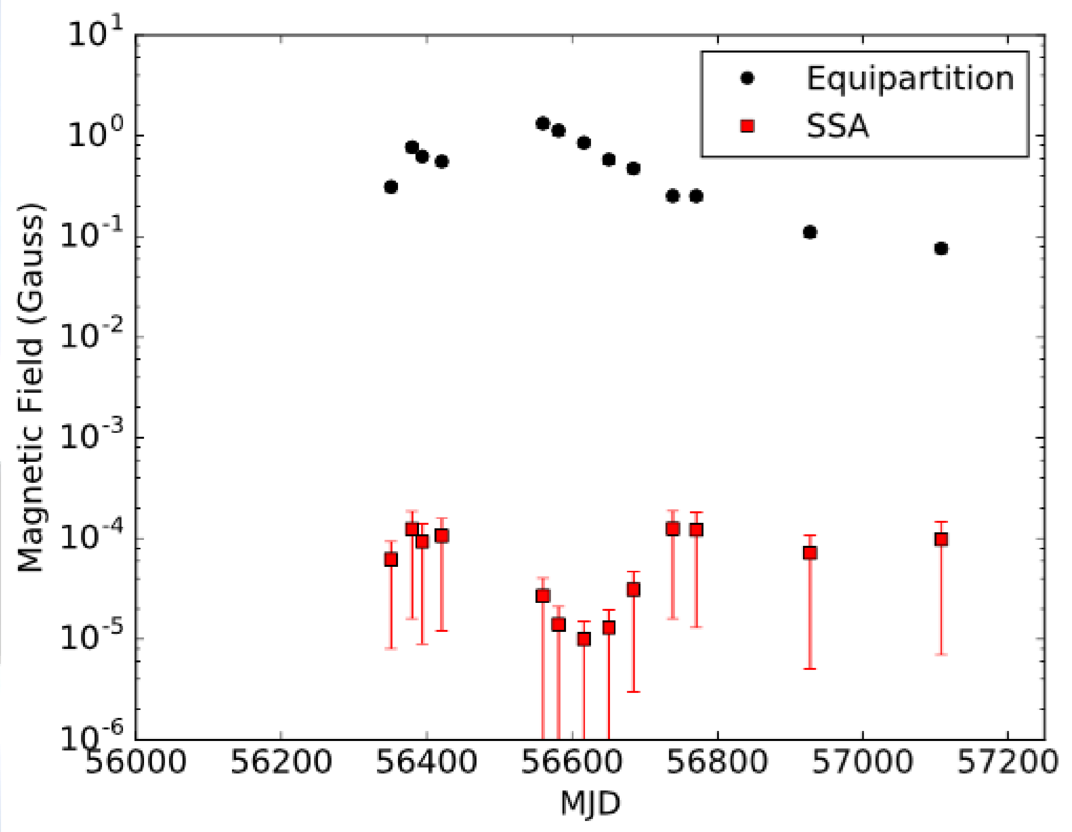
- Turnover Frequency
  - IMOGABA (22, 43, 86, 129) + OVRO + SMA
- Relation between flux density and turnover frequency
  - In the Shock in jet model, three stages: Compton, Synchrotron, Adiabatic
  - Data compatible with small-θ ϵ_{syn} followed by ϵ_{adiab}.





Shock-in-jet?

- Magnetic Fields
  - Synchrotron Self Absorption
  - Equipartition
- Characteristics
  - Constant over the whole period
  - $B_{SSA} << B_{eq}$
- Implications
  - B may not play an important role in the flares/component ejection
  - Flares associated with particle dominated regions



Conclusions

- Remember the two questions raised at the beginning
  - What is the location of the gamma-ray flares?
  - What is the cause of the gamma-ray flares?

Conclusions

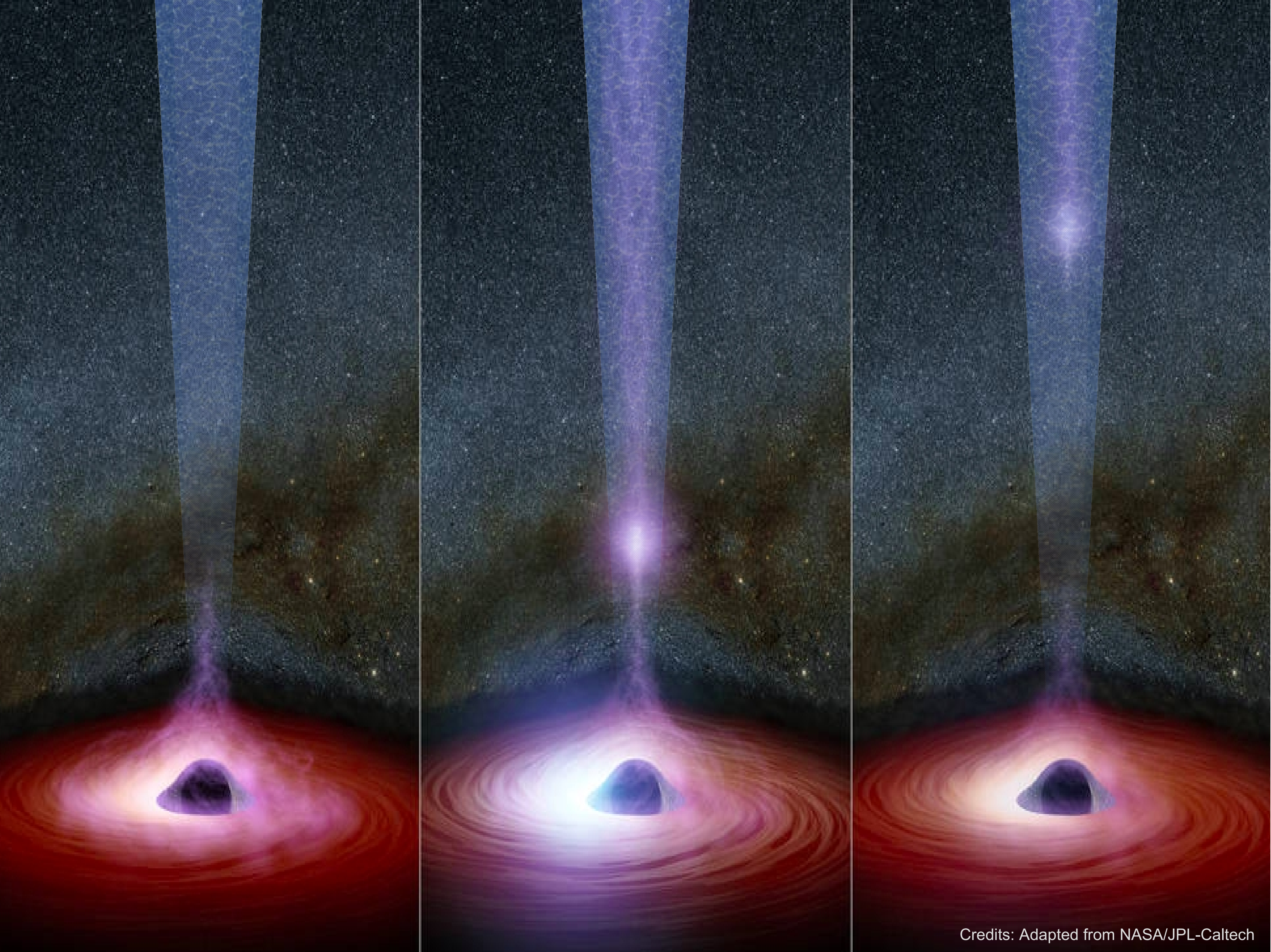
- Remember the two questions raised at the beginning
  - What is the location of the gamma-ray flares?
    - Pinpointed their origin at around 1pc from the central engine
  - What is the cause of the gamma-ray flares?
    - A new ejected component due to particle injection traveling through the jet

Conclusions

- Remember the two questions raised at the beginning
  - What is the location of the gamma-ray flares?
    - Pinpointed their origin at around 1pc from the central engine
  - What is the cause of the gamma-ray flares?
    - A new ejected component due to particle injection traveling through the jet
- Question: Is it the same for all sources?
  - More investigation needed
  - MOGABA has a good sample of sources to investigate
    - 1633+382 (Algaba+17)
    - 0716+714 (J. W. Lee+17)
    - 3C84 (Hodgson+16,17)
    - BL Lac (D. W. Kim+17)
    - M87 (J. W. Kim+17)
    - ...and more to come!

Thanks

Credits: Adapted from NASA/JPL-Caltech



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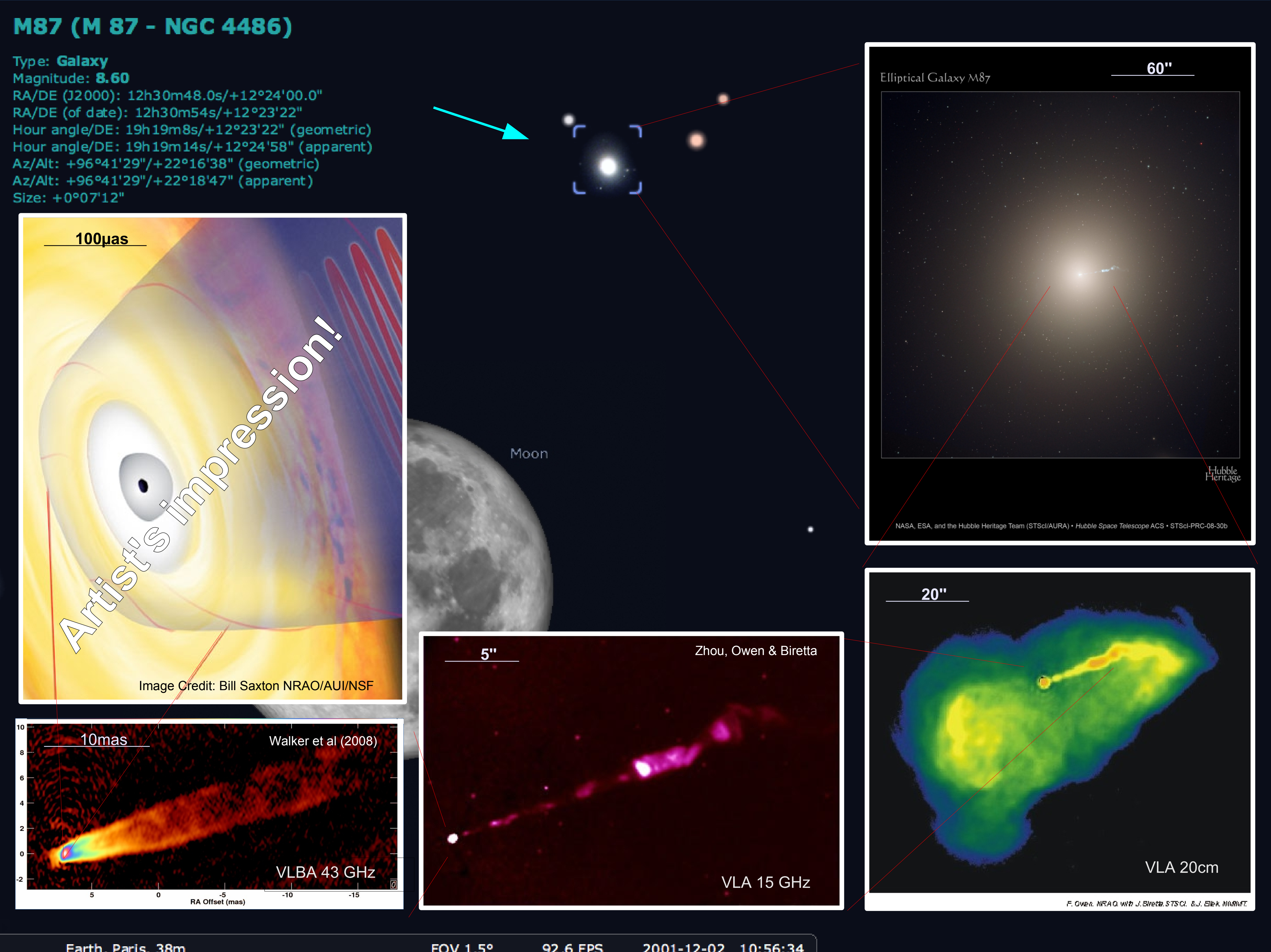
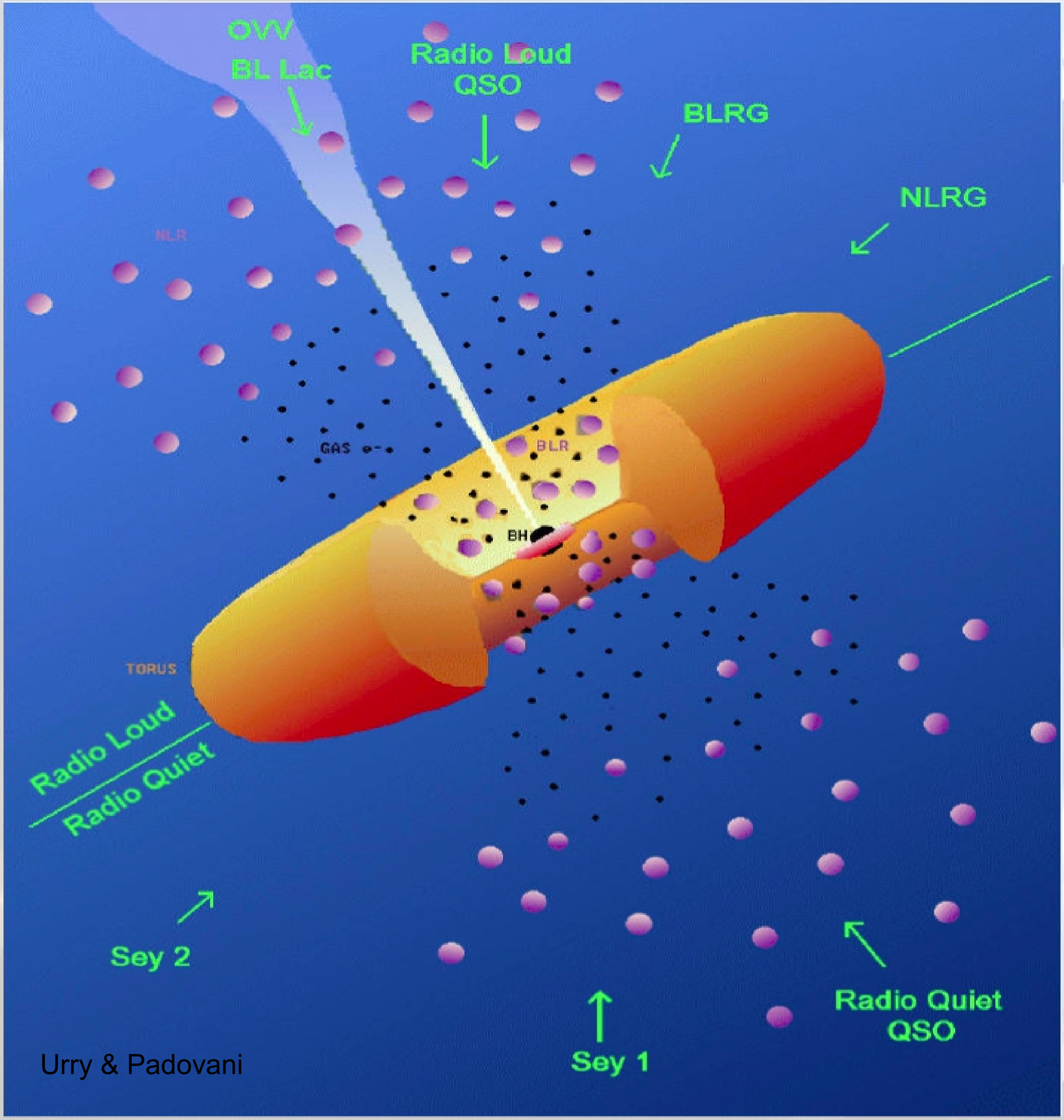


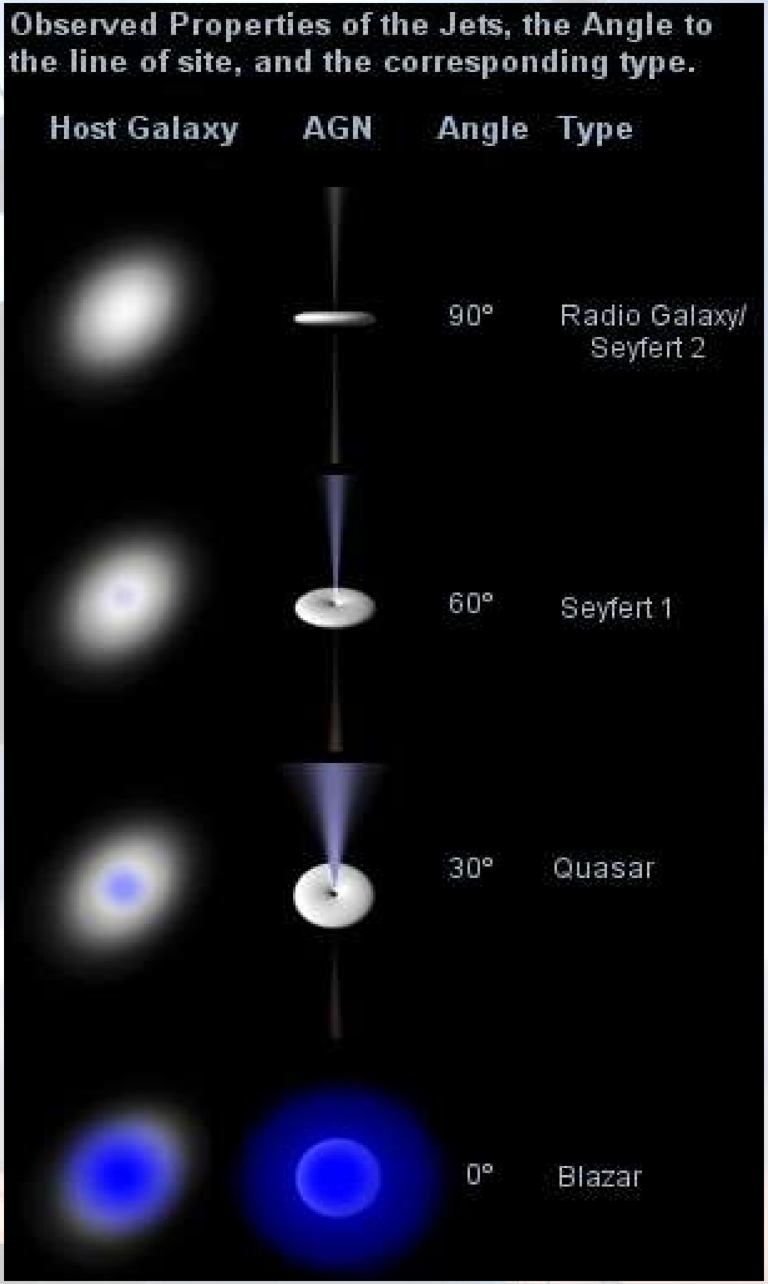
M87 (M 87 - NGC 4486)
Type: Galaxy
Magnitude: 8.60
RA/DE (J2000): 12h30m48.0s/+12°24'00.0"
RA/DE (of date): 12h30m54s/+12°23'22"
Hour angle/DE: 19h19m8s/+12°23'22" (geometric)
Hour angle/DE: 19h19m14s/+12°24'58" (apparent)
Az/Alt: +96°41'29"/+22°16'38" (geometric)
Az/Alt: +96°41'29"/+22°18'47" (apparent)
Size: +0°07'12"
Moon
Elliptical Galaxy M87
60"
Hubble Heritage
NASA, ESA, and the Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC-08-30b
100µas
Artist's impression!
Image Credit: Bill Saxton NRAO/AUI/NSF
20"
VLA 20cm
F. Owen, NRAO with J. Biretta, STScI, & J. Eilek, NMIMT
5"
Zhou, Owen & Biretta
VLA 15 GHz
10mas
Walker et al (2008)
VLBA 43 GHz
RA Offset (mas)
Earth, Paris, 38m
FOV 1.5°
92.6 FPS
2001-12-02 10:56:34

Active Galactic Nuclei

- Quick summary of AGNs
  - Compact region in the center of the galaxy
  - Excess of luminosity that cannot com from stars
  - Curtiss (1918) “A curious straight ray apparently connected with the nucleus...”
- Some of the most energetic objects
  - Power about > 10^{41} erg/s
  - Radiating at most bands from radio to γ-rays
- Come in different flavors
  - Radio Galaxies
    - FR1, FR2
  - Blazars (BL Lacs + Quasars) beamed counterparts of radio galaxies
    - FSRQ: strong lines in optical spectra, prominent accretion disk signature, high radio and bolometric luminosity (FR2 counterparts), “red” SEDs
    - BLL: weak or no lines, radiatively inefficient accretion disk, low luminosity (FR1 counterparts), “blue” SEDs

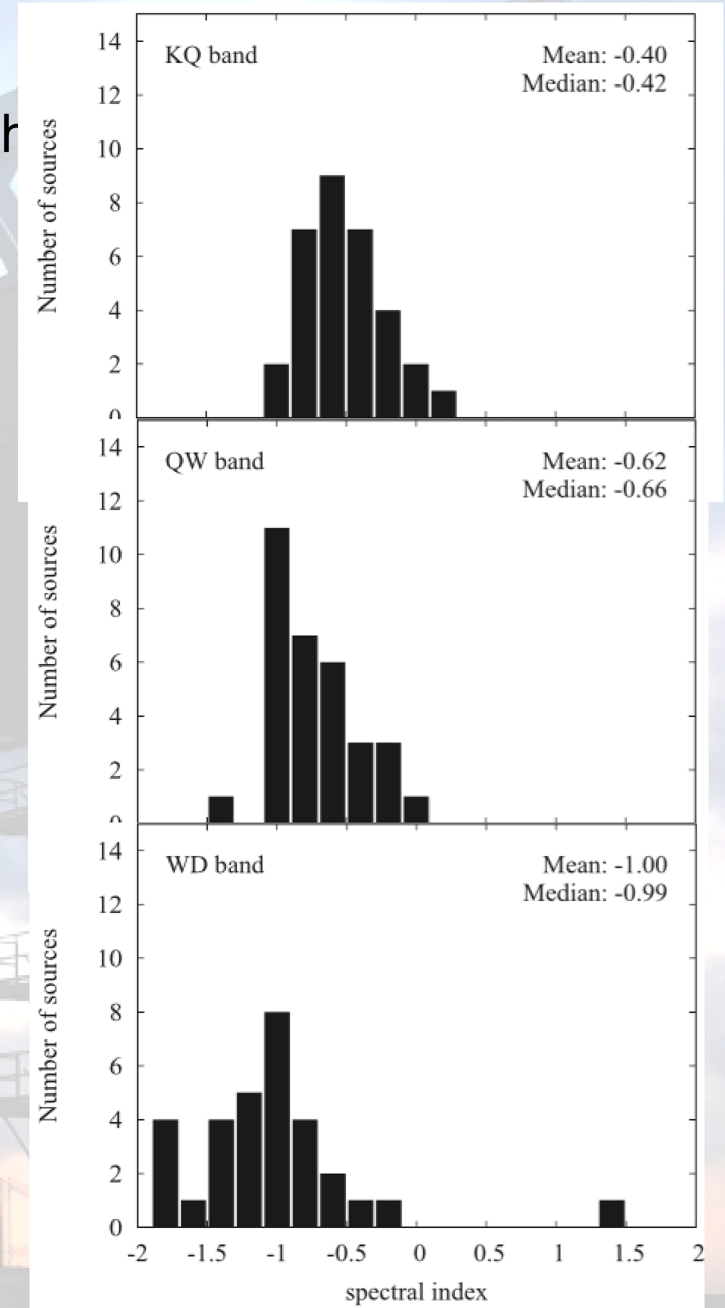
Active Galactic Nuclei





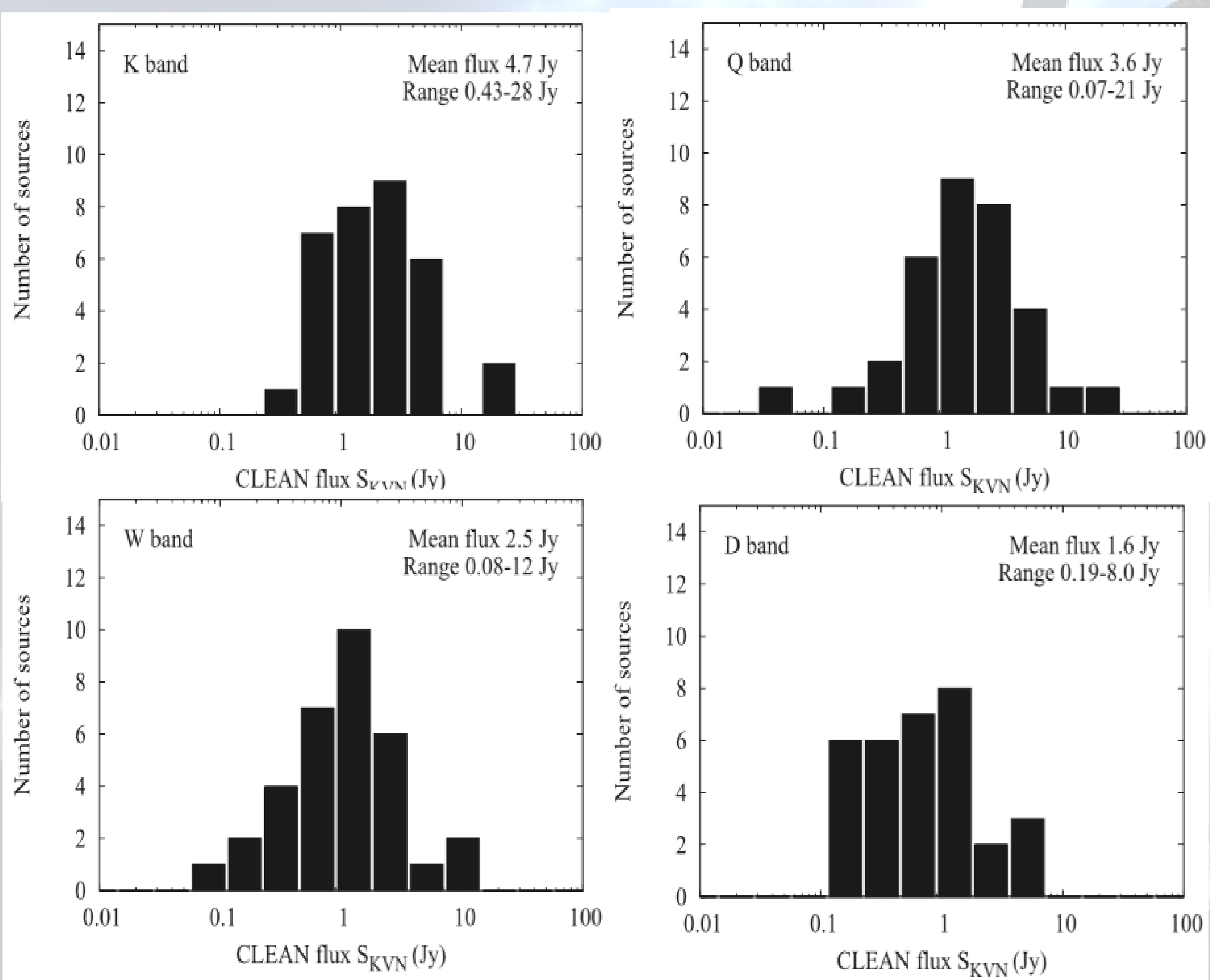
iMOGABA

- Spectral index
  - Interferometric Monitoring of Gamma-ray brigh
  - Milliarcsecond scales



iMOGABA

- Statistical Properties
  - CLEAN flux



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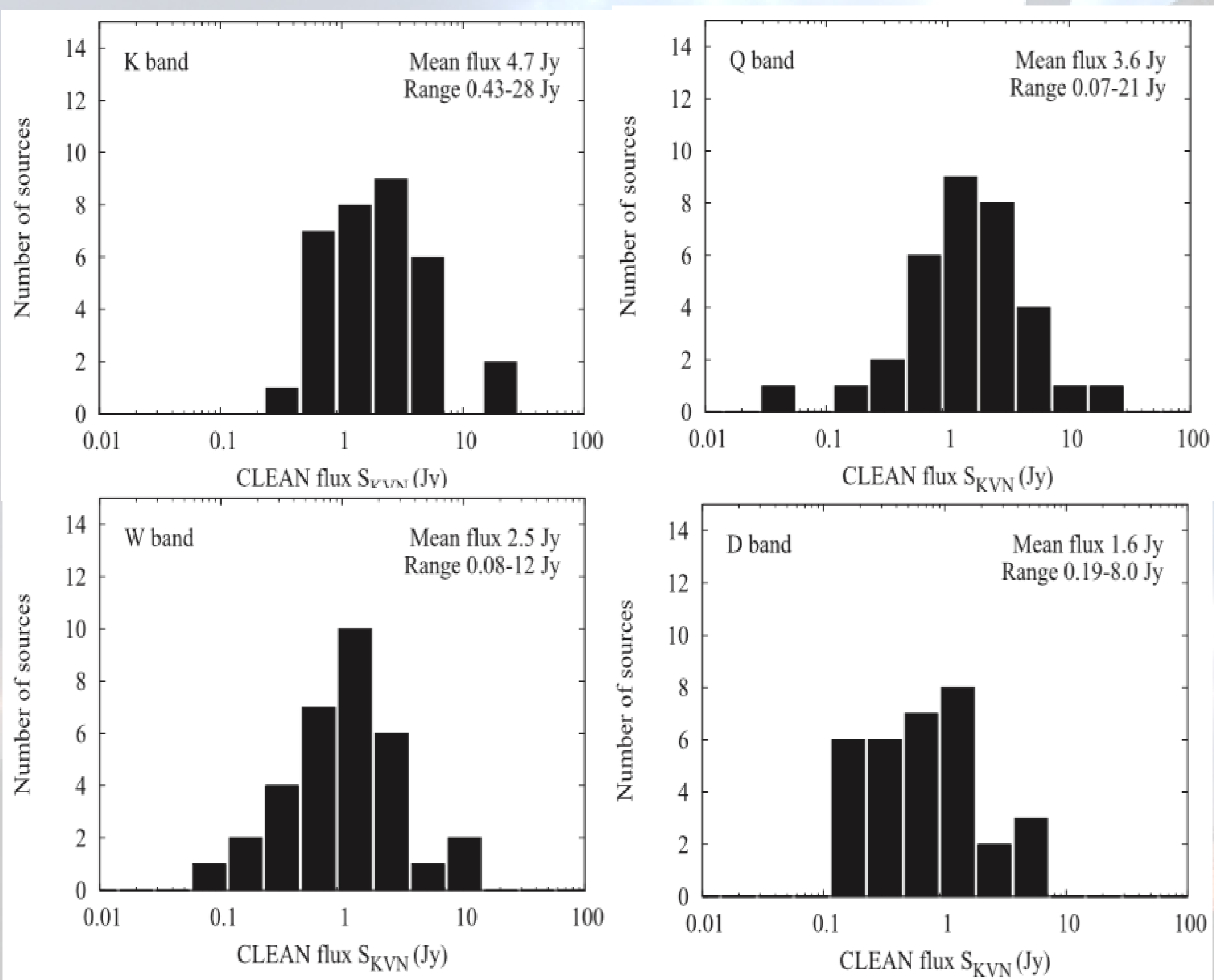
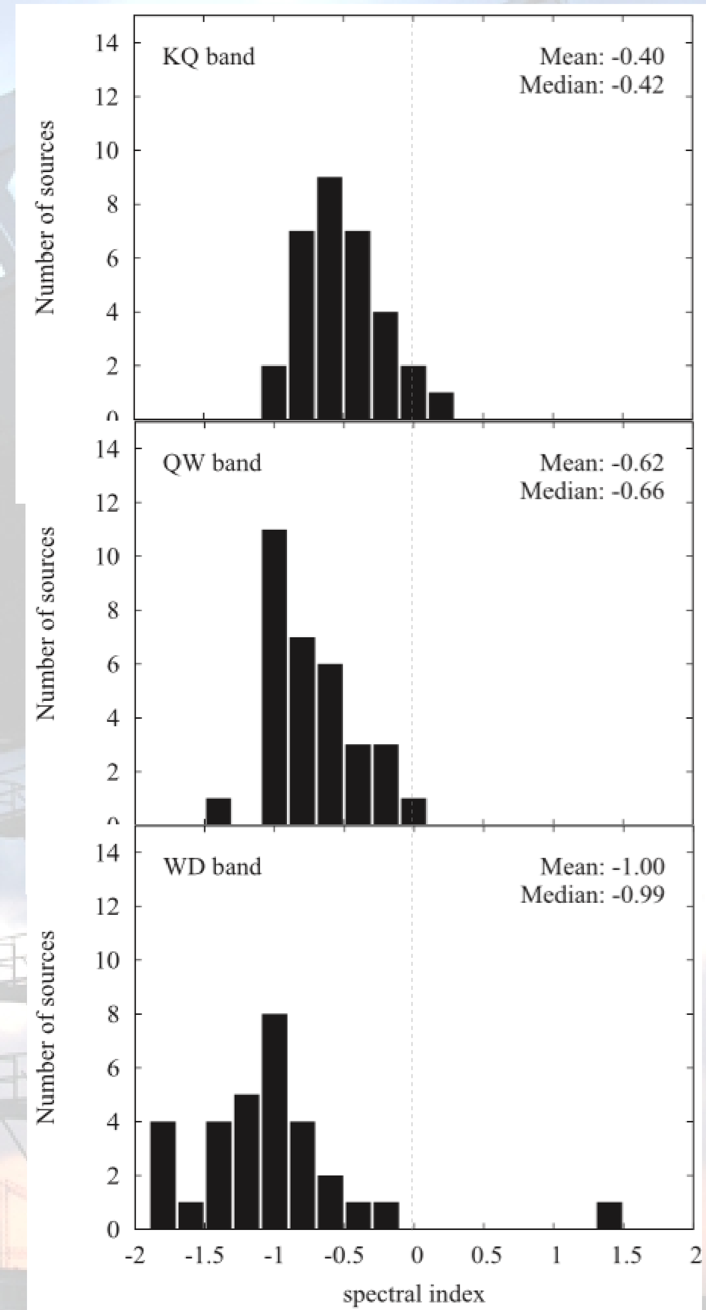
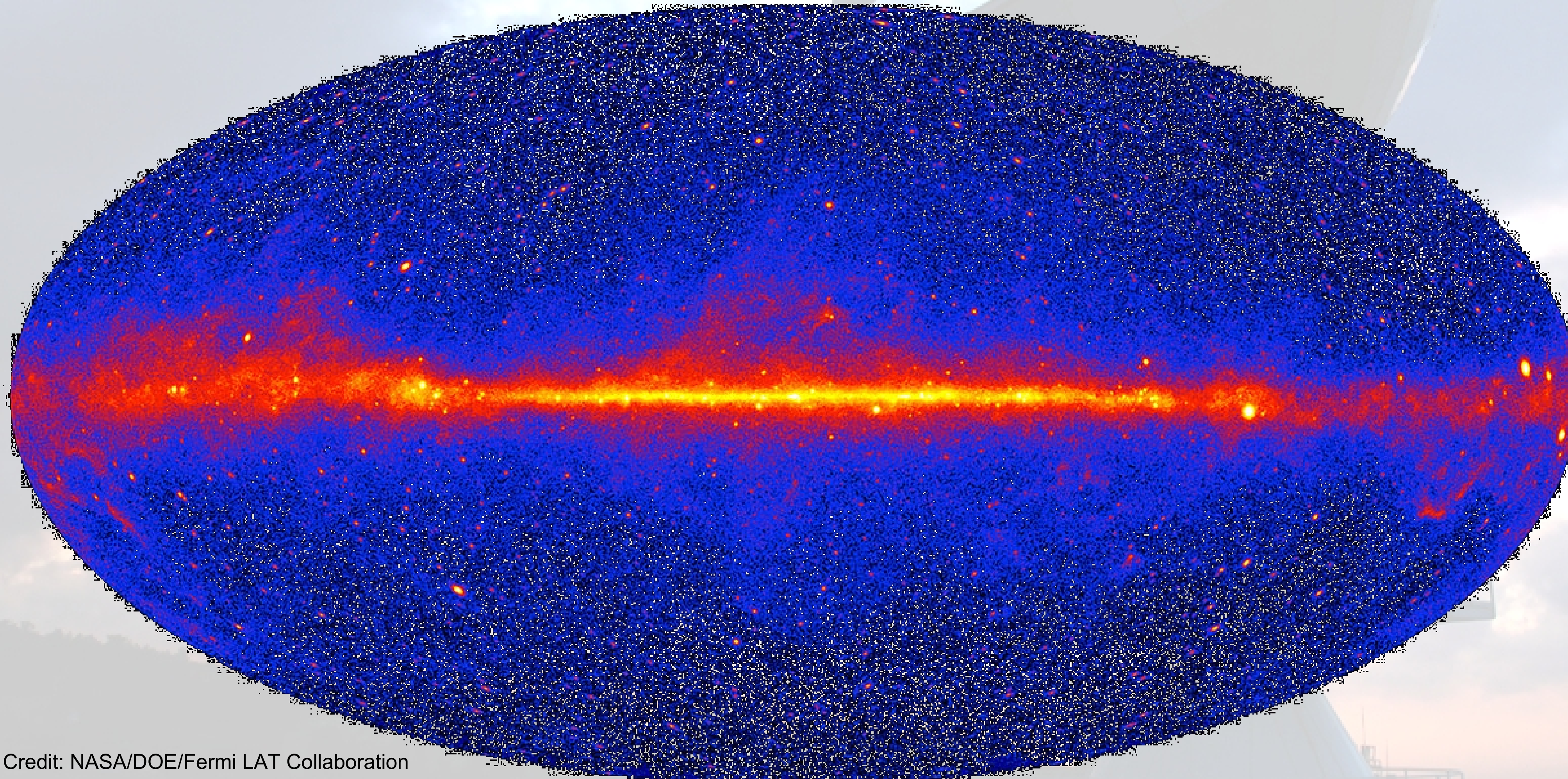




Gamma-Rays

- *Fermi*-LAT observes the gamma-rays sky
  - All sky survey in 2 orbits (~3 hours)
  - 4 years of data released in their 3FGL catalog (Acero+15)
  - Most of the sources are AGN



Credit: NASA/DOE/Fermi LAT Collaboration

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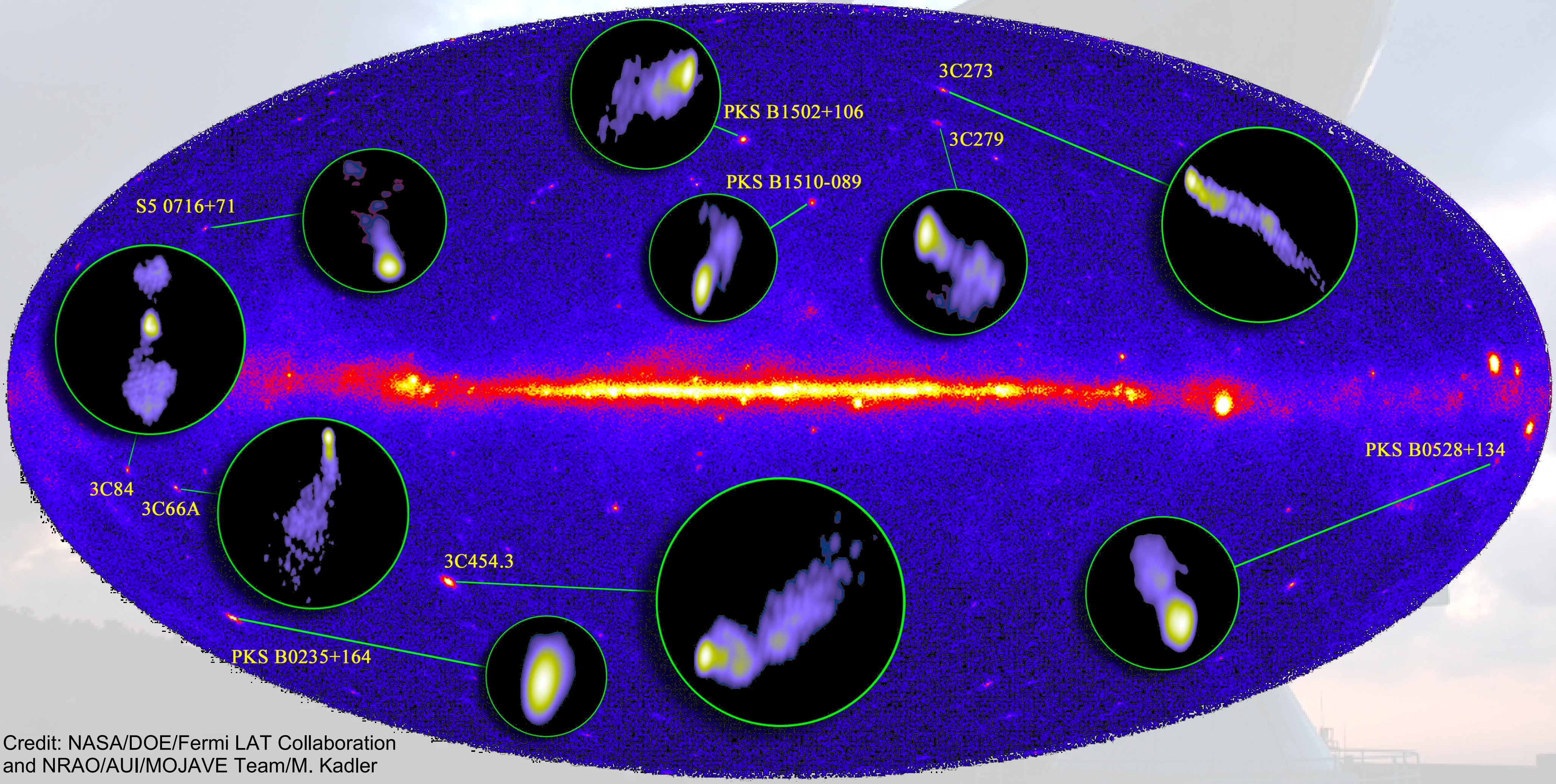


Credit: NASA/DOE/Fermi LAT Collaboration and NRAO/AUI/MOJAVE Team/M. Kadler

Gamma-Rays

- Gamma-ray flares are common!

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

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

... observation of ongoing GeV activity ... 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)

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

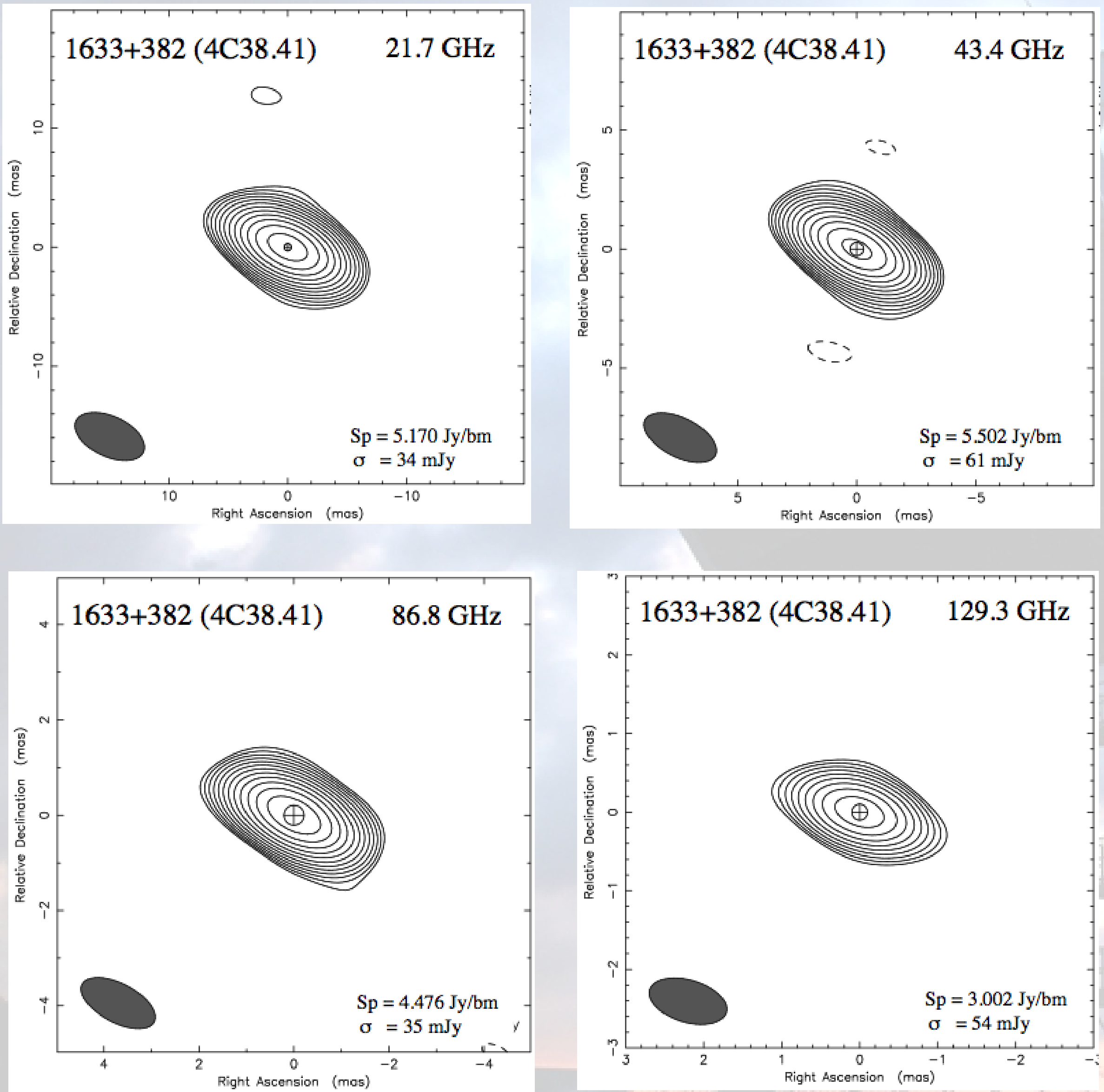
Fermi LAT detection of renewed GeV gamma-ray activity from the gravitationally lensed blazar PKS 1830-211

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)

1633+382


1633+382 (4C38.41) 21.7 GHz
Sp = 5.170 Jy/bm
σ = 34 mJy
1633+382 (4C38.41) 43.4 GHz
Sp = 5.502 Jy/bm
σ = 61 mJy
1633+382 (4C38.41) 86.8 GHz
Sp = 4.476 Jy/bm
σ = 35 mJy
1633+382 (4C38.41) 129.3 GHz
Sp = 3.002 Jy/bm
σ = 54 mJy
Relative Declination (mas)
Right Ascension (mas)

1633+382

1633+382 (4C38.41)
21.7 GHz
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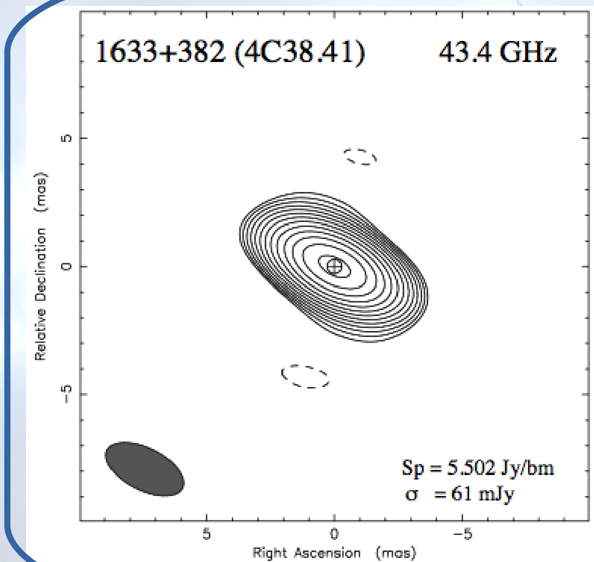
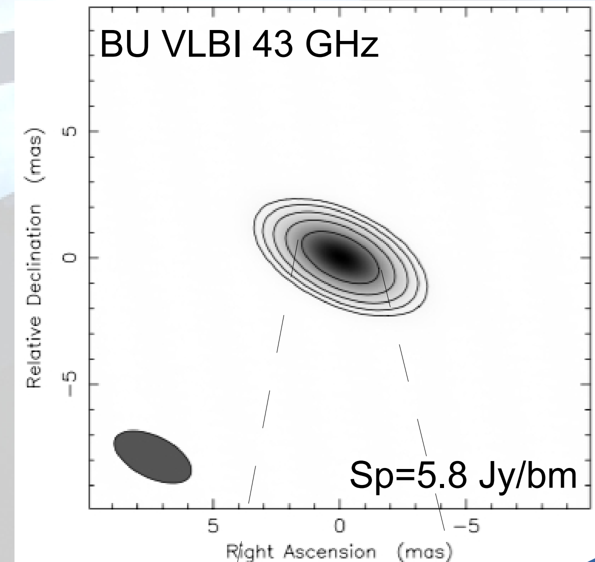

1633+382 (4C38.41)
43.4 GHz
Sp = 5.502 Jy/bm
σ = 61 mJy
Relative Declination (mas)
Right Ascension (mas)


BU VLBI 43 GHz
Sp=5.8 Jy/bm
Relative Declination (mas)
Right Ascension (mas)

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86.8 GHz
Sp = 4.476 Jy/bm
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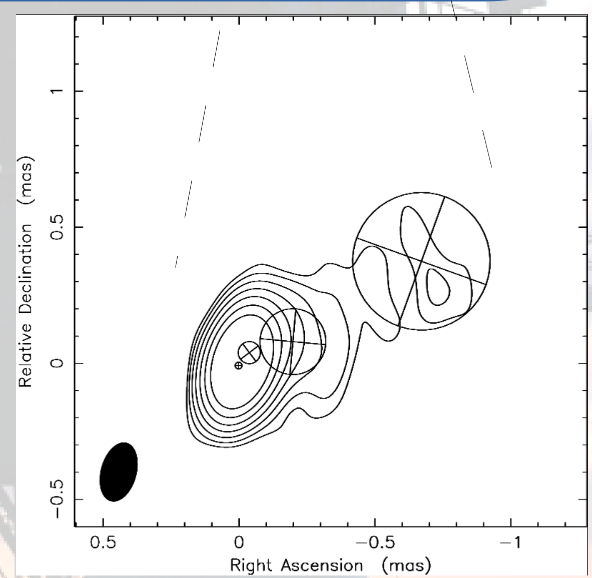
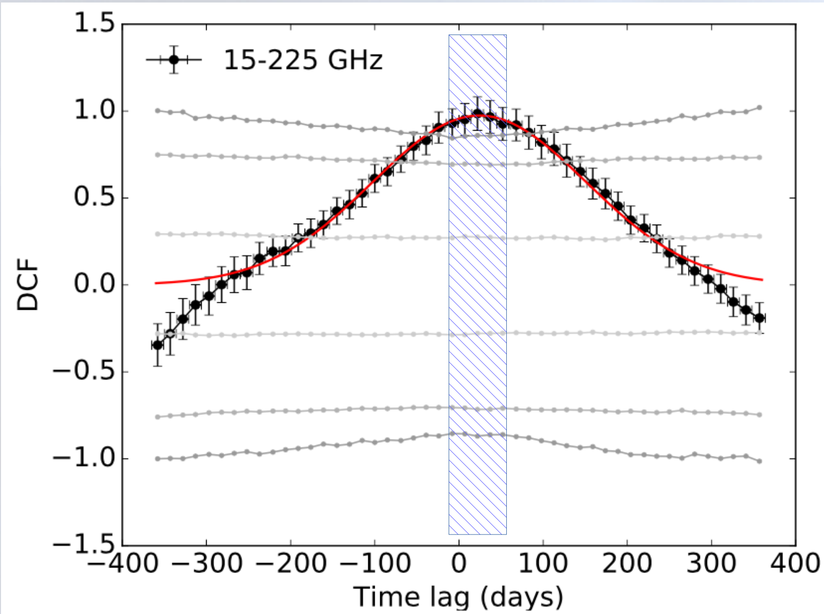
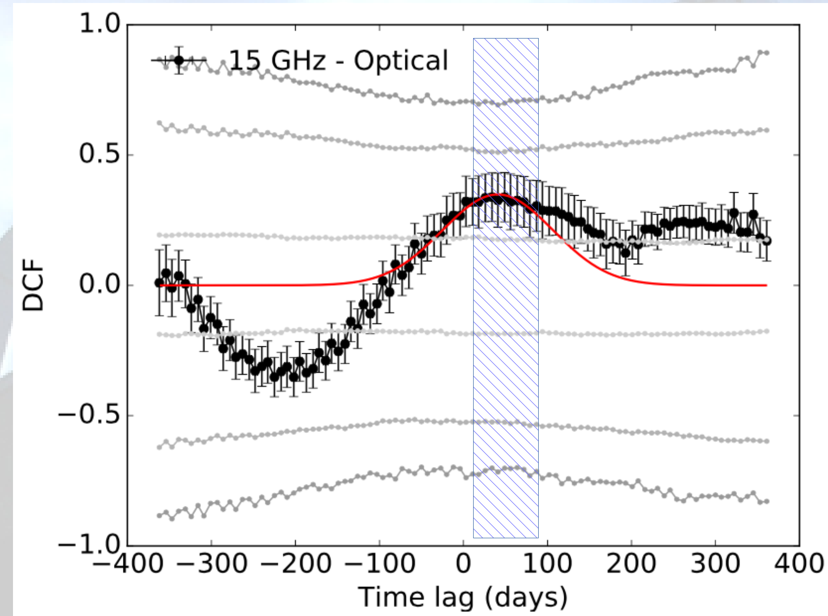
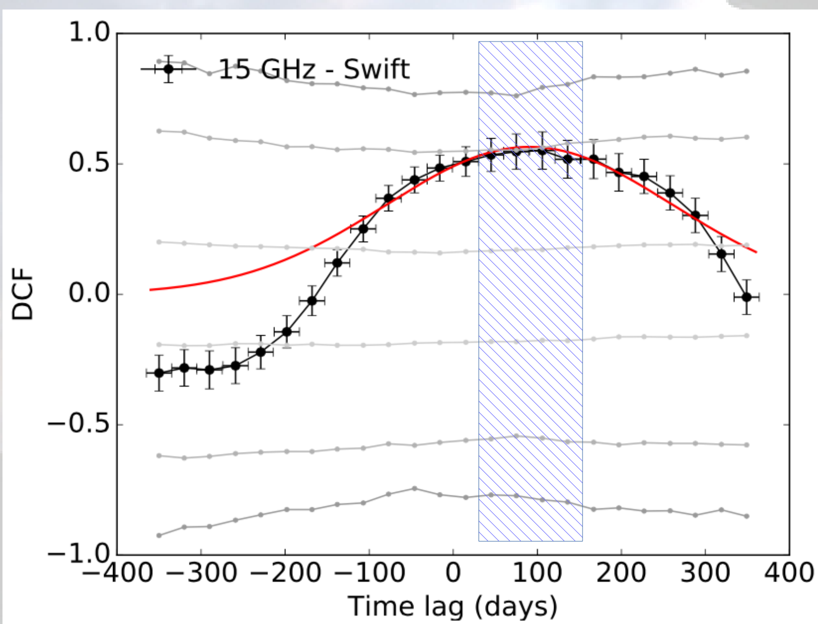
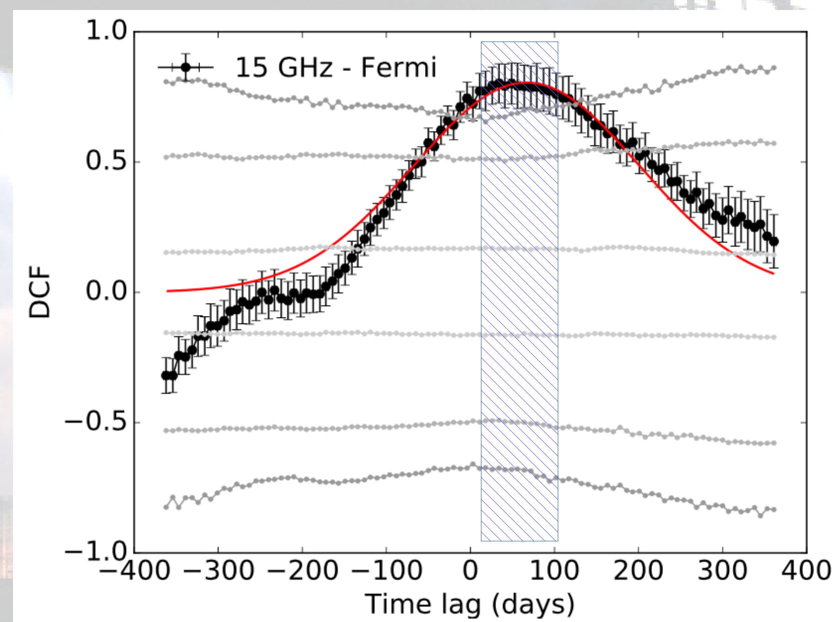

Relative Declination (mas)
Right Ascension (mas)

Correlations



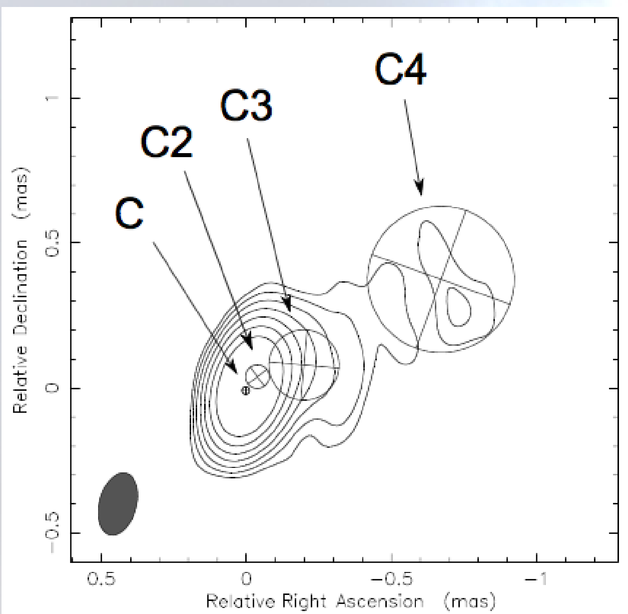


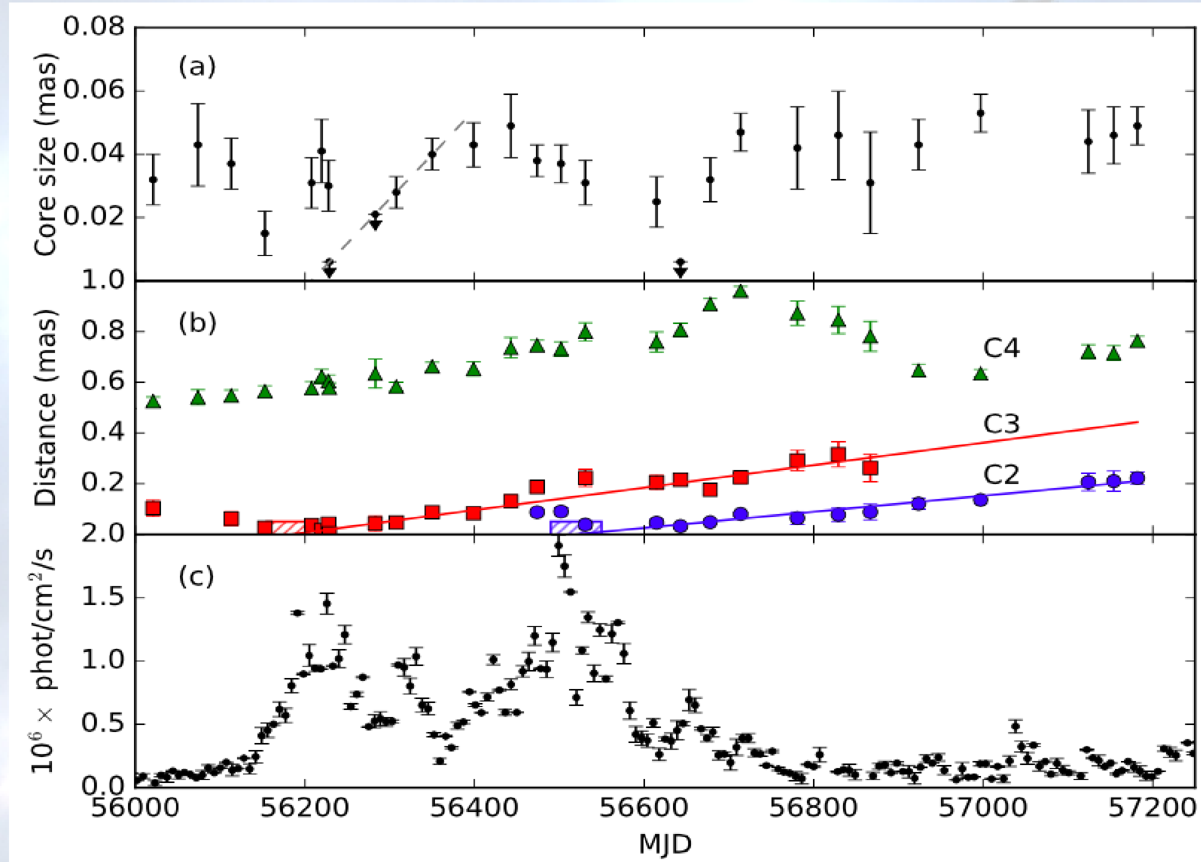




Shock-in-jet?

- Structure analysis
  - Jet components
  - Core size





- New VLBI component ejection near brightest γ-ray flares
  - v(C2) = 9.4±0.8c
  - v(C3) = 12.5±0.8c

  } Γ~12-14; δ~19-21 for θ~2.5°, in agreement with Hovatta+09

- Core size may show indications of physics also happening
  - v(Core) ~ 7.8c

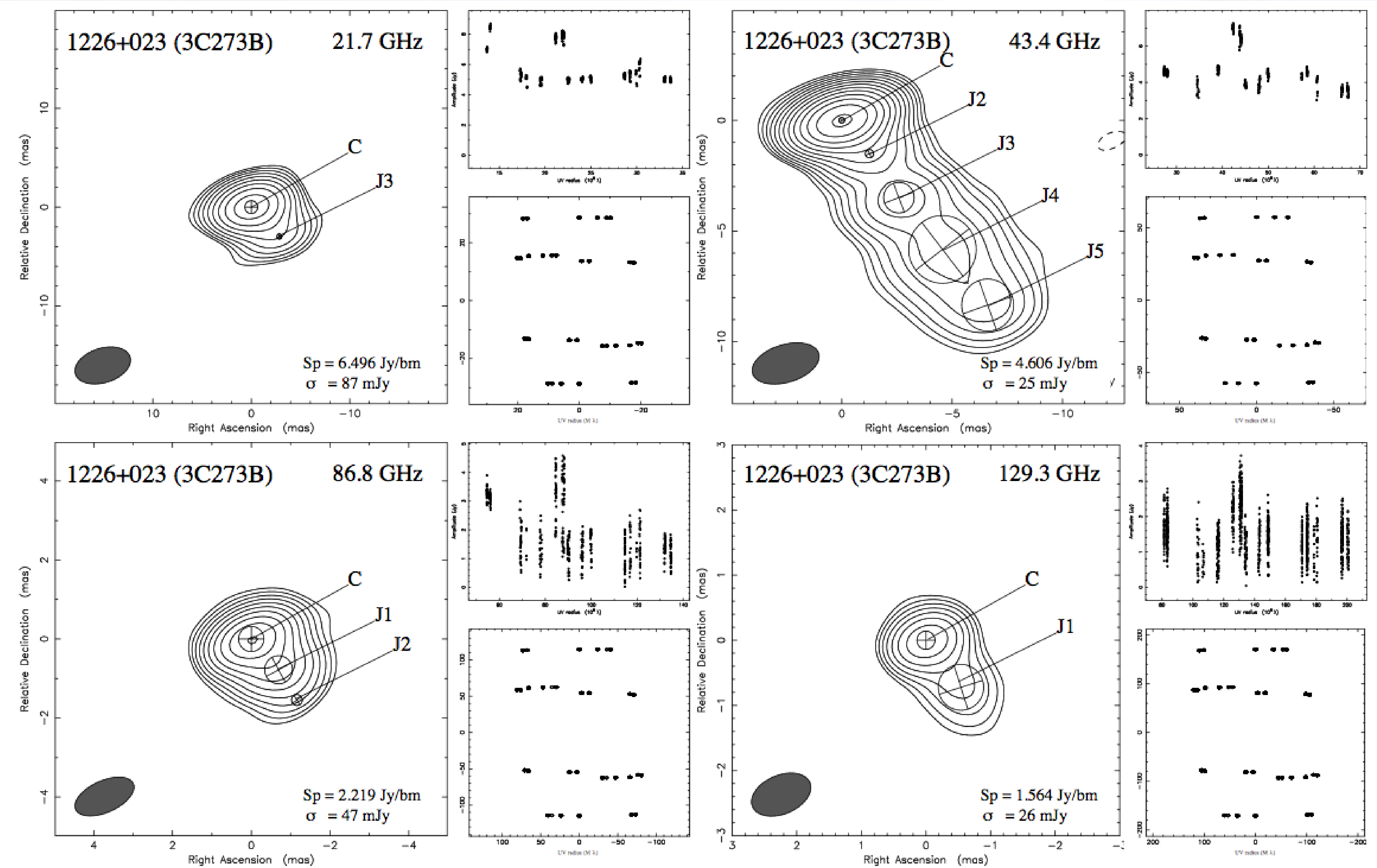
Monitoring of Gamma-ray Bright AGNs

Interferometric Monitoring of Gamma-ray Bright AGNs

Images of the Gamma-ray Bright AGNs taken with Korean VLBI Network

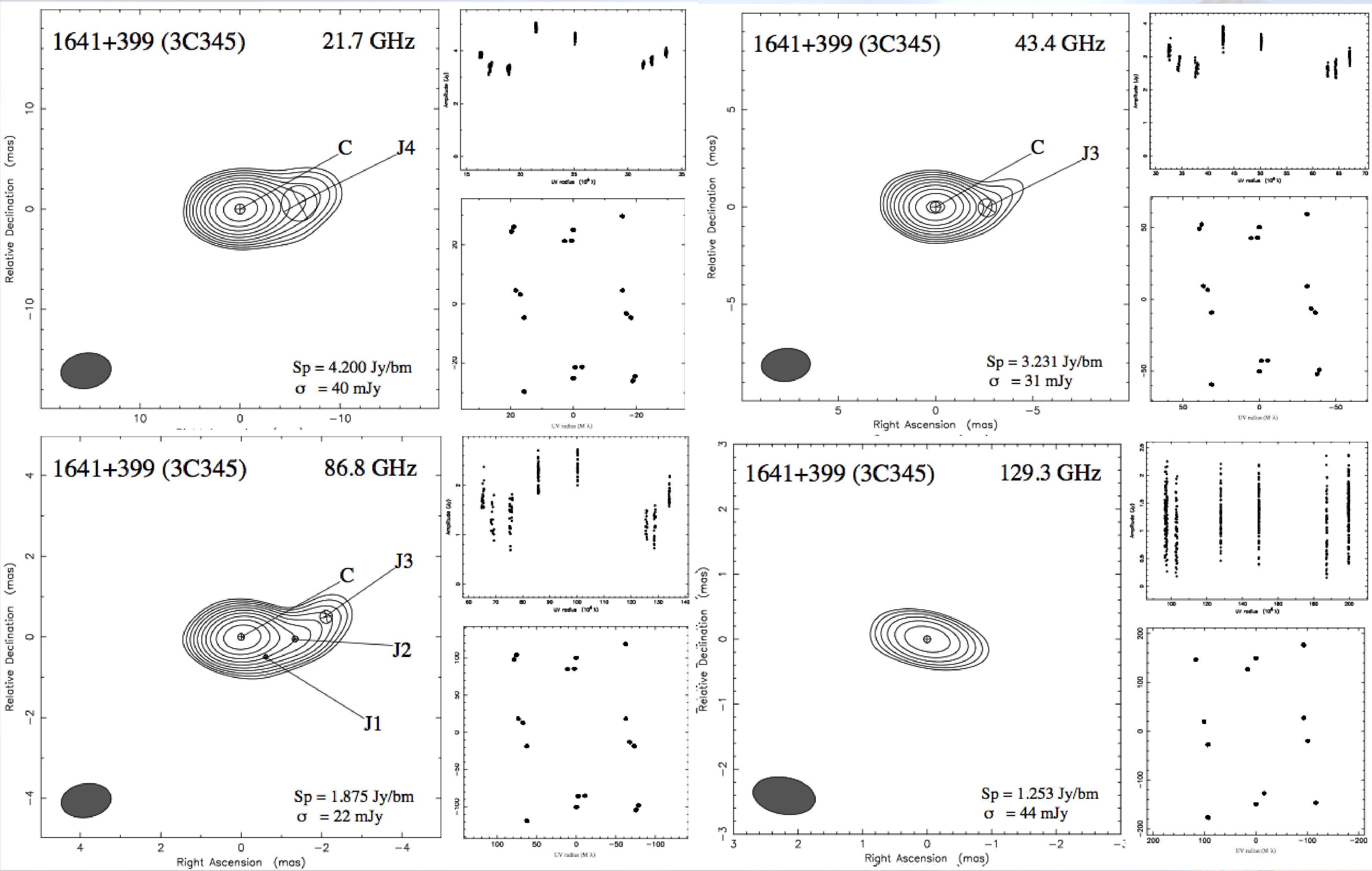
Obs Name	imogaba20	imogaba19	imogaba18	imogaba17	imogaba16	imogaba15	imogaba14	imogaba13	imogaba12	imogaba11	imogaba10	imogaba9
Obs Date	2014-12-25	2014-11-28	2014-10-29	2014-09-27	2014-09-01	2014-06-13	2014-04-22	2014-03-22	2014-02-28	2014-01-27	2013-12-24	2013-11-19
	MJD=57017	MJD=56990	MJD=56960	MJD=56928	MJD=56902	MJD=56822	MJD=56769	MJD=56738	MJD=56716	MJD=56684	MJD=56650	MJD=56615
BLLAC									KQWD	KQ	KQWD	KQWD
CTA102									KQWD	KQ	KQWD	KQWD
J0730-1141										KQ	KQWD	KQWD
M87									KQ	KQ	KQWD	KQWD
MRK421										KQ	KQ	KQWD
OJ287										KQ	KQWD	KQWD
NRAO530									KQW	KQ		
SGRA									KQ	KQ		
3C111										KQ	KQWD	KQWD
3C273B									K	KQ	KQWD	KQWD
3C279								KQWD	KQW	KQ	KQWD	KQWD
3C286									K	K	K	K
3C345									KQ	KQ	KQWD	KQWD
3C446											KQW	KQW
3C454.3										KQ	KQWD	KQWD
3C84									KQWD	KQ	KQWD	KQWD
4C28.07									KQW	KQ	KQWD	KQWD
4C38.41									KQW	KQ	KQWD	KQWD
4C39.25									KQW	KQ	KQWD	KQWD
0235+164										KQ	KQW	KQ
0218+35A										KQ	KQ	
0420-014										KQ	KQWD	KQWD
0528+134										KQ	KQW	KQW
0716+71										KQ	KQWD	KQWD
0735+178										KQ	KQW	KQW
0827+243											KQ	KQ
0836+710										KQ	KQW	KQW
1044+719										KQ	[illegible]	[illegible]

iMOGABA



Lee,...,Algaba,+16

iMOGABA



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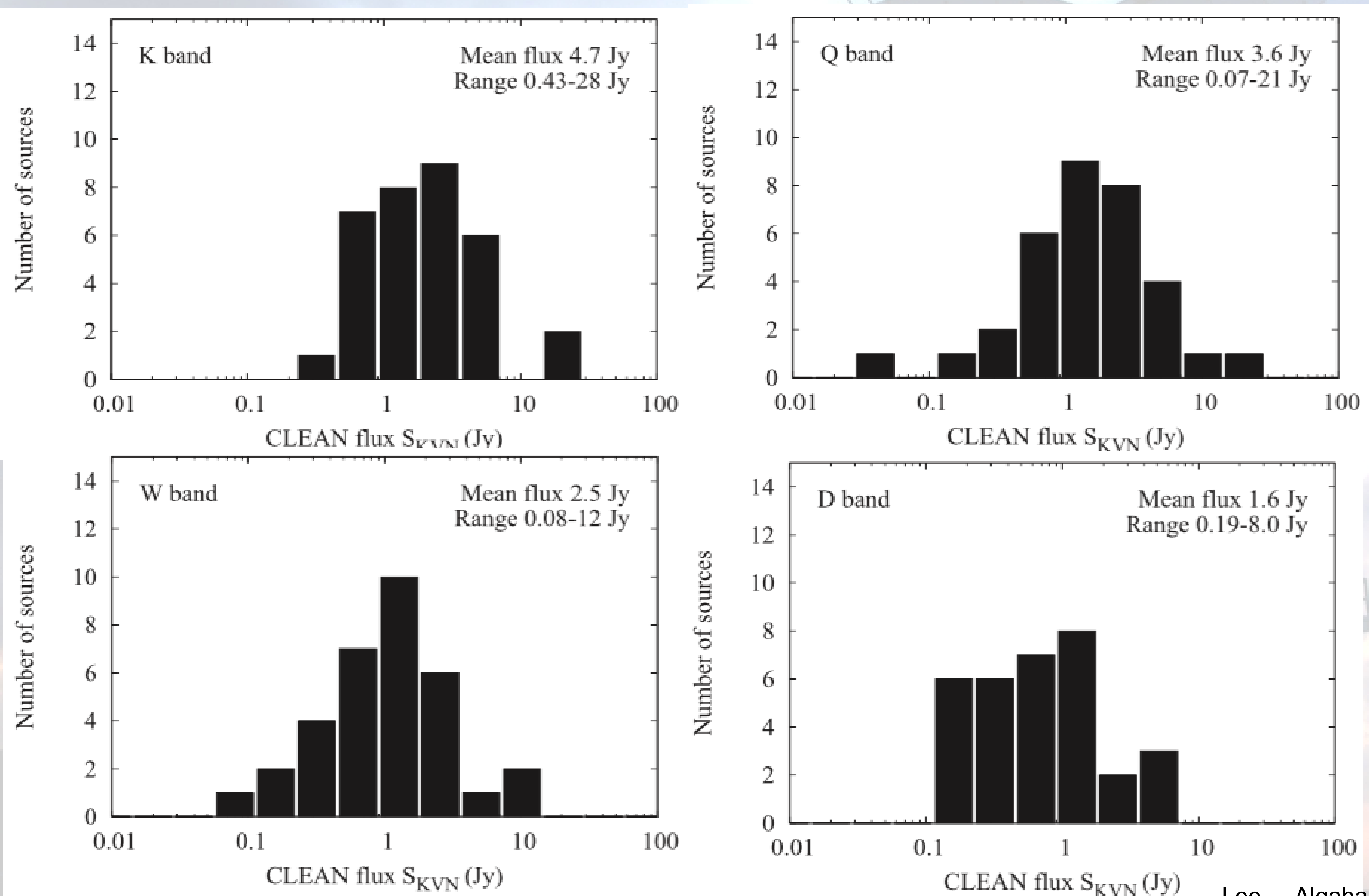
- CLEAN flux



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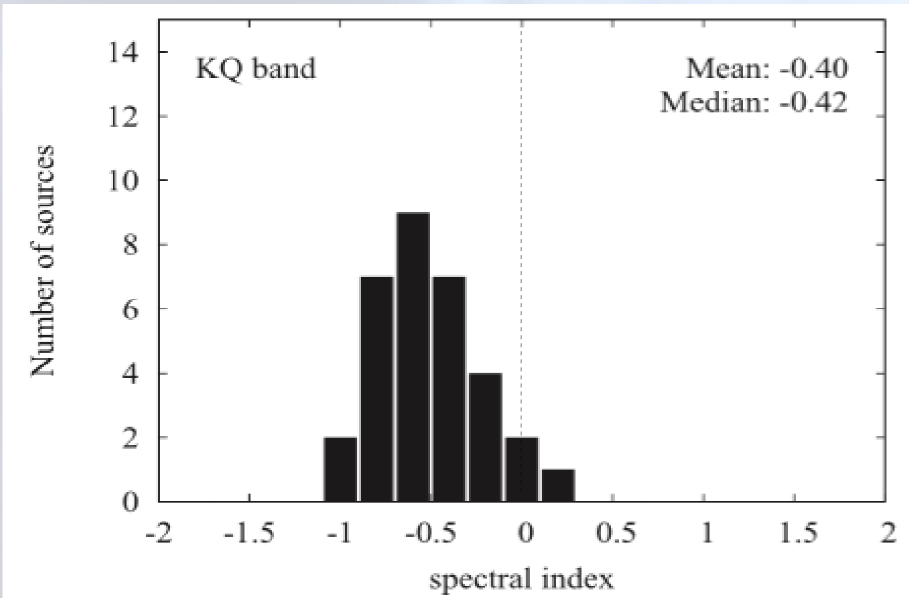
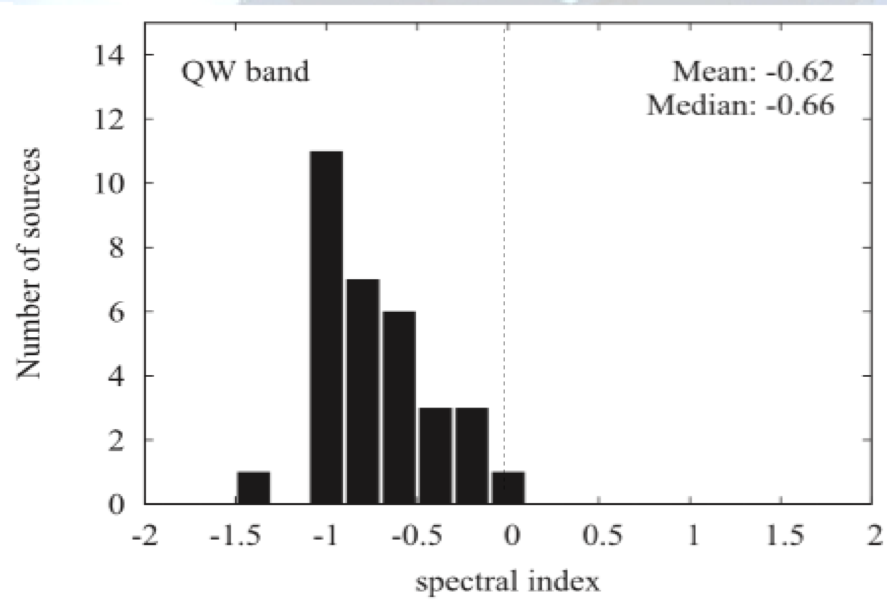
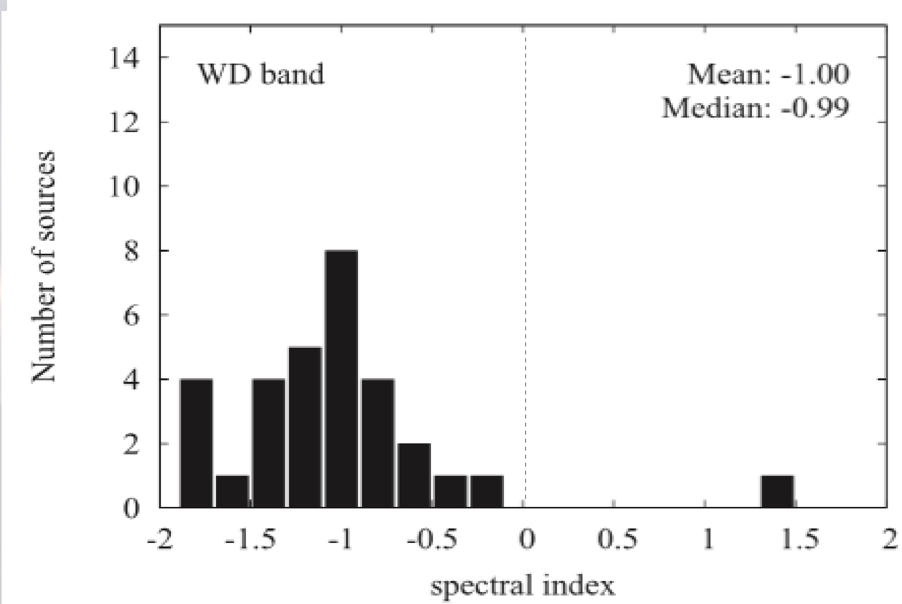
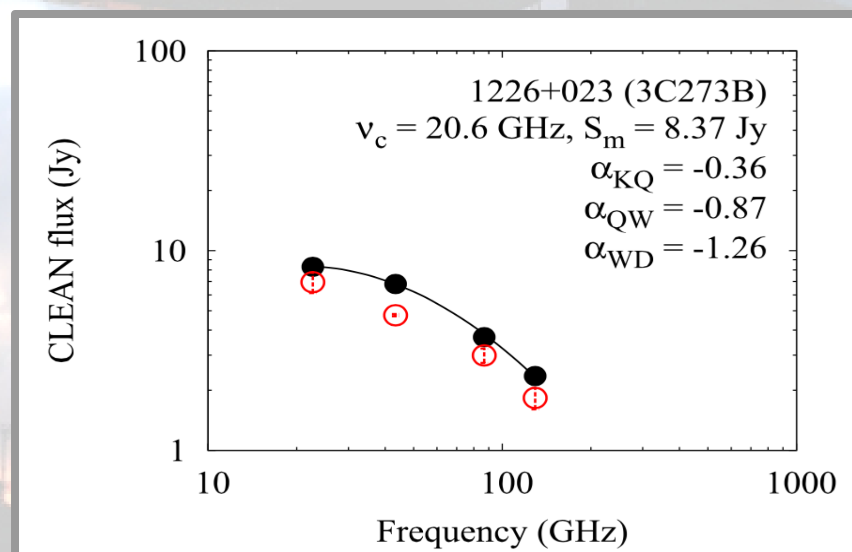
- Spectral index









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