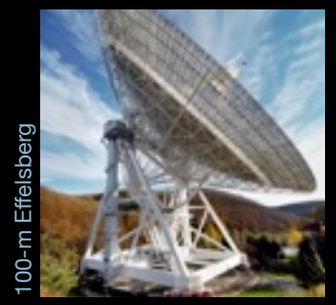


F-GAMMA program - review and recent findings: Unification and physical interpretation of the radio spectra variability patterns in Fermi blazars and jet emission from NLSy1s

E. Angelakis

and L. Fuhrmann[1] **(PI)**, I. Nestoras[1], R. Schmidt[1], J. A. Zensus[1], N. Marchili[1], T. P. Krichbaum[1], and H. Ungerechts[2], A. Sievers[2], D. Riquelme[2], C. M. Fromm[1], M. Perucho-Pla[4], L. Foschini[5], G. Ghisellini[5], G. Ghirlanda[5], G. Tagliaferri[5], F. Tavecchio[5], L. Maraschi[5], M. Giroletti[6], G. Calderone[7], M. Colpi[7], R. Decarli[8]

1 Max-Planck-Institut für Radioastronomie, Auf dem Hgel 69, Bonn 53121, Germany
2 Instituto de Radio Astronomía Milimétrica (IRAM), Avenida Divina Pastora 7, Local 20, E 18012 Granada, Spain
4 Departament d'Astronomia i Astrof´ısica. Universitat de Valencia. C/Dr. Moliner 50, 46100 Burjassot (Valencia), Spain
5 INAF - Osservatorio Astronomico di Brera, Italy
6 INAF - Istituto di Radioastronomia, Bologna, Italy
7 Universita' di Milano-Bicocca, Dipartimento di Fisica, Milano, Italy
8 Max-Planck-Institut für Astronomie, Heidelberg, Germany

F-GAMMA PROJECT

- monthly monitoring program for ~60 Fermi-GST blazars since January 2007
- all light curves and spectra available online
- at 2.6 - 345 GHz at 12 frequencies, optical and gamma-rays
- optical polarimetry (expected 2012)
- **Linear** and **Circular** Polarization of the Effelsberg data:
  - e.g. 3C454.3 at 4.85 GHz: we detect ~ 0.82 % CP *(Miserlis, Angelakis, Kraus)*

www.mpifr.de/div/vlbi/fgamma

100-m Effelsberg

- Monthly monitoring of ~60 sources
- 2.64 - 43 GHz at 8 frequency steps
- Simultaneous spectra within 40 minutes

L. Furhmann, E. Angelakis, I. Nestoras, J. A. Zensus, N. Marchili, T. P. Krichbaum

30-m IRAM

- Monthly monitoring of ~60 sources
- 86, 142 and 228 GHz
- Simultaneous spectra within 2 minutes

H. Ungerechts, A. Sievers, D. Riquelme

12-m APEX

- Irregular “filler” monitoring
- 345 GHz
- accuracy <15%

S. Larson, A. Weiss

Max-Planck-Institut für Radioastronomie: E. Angelakis

70-cm meniscus and 125-cm Ritchey-Chretien telescopes. Abastumani Observatory

- Monthly monitoring of ~90 sources

Omar Kurtanidze, Maria Nikolashvili, Givi Kimeridze, Lorand Sigua, Revaz Chigladze

1.3 m Skinakas telescope, Greece

- polarimetry (Expected Spring 2012)

I. Papadakis, Papamastorakis, Caltech, MPIFR

40-m OVRO telescope (Caltech)

- ~1200 blazars at least 2–3 times per week (Richards et al. in prep.)
- 15 GHz

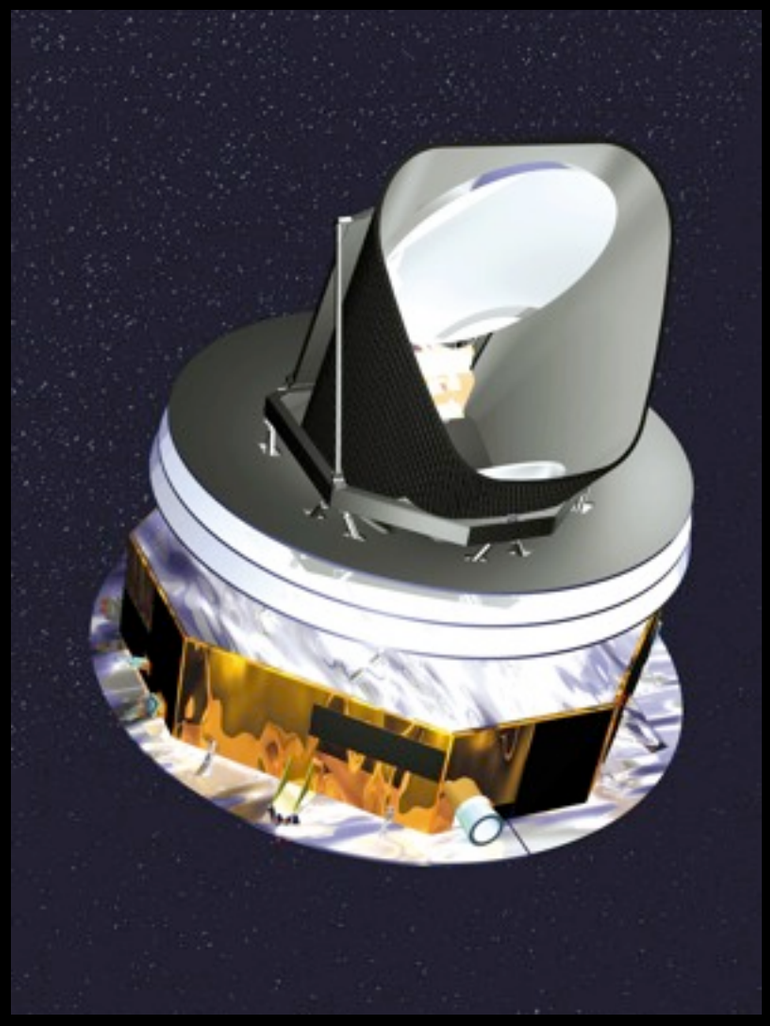
A. C. S. Readhead, V. Pavlidou, J. Richards, W. Max-Moerbeck, T. Pearson

Korean VLBI Network 21-m radio telescope Korea Astronomy and Space Science Institute

- Monthly monitoring of ~90 sources
- 13 , 7 mm

Bong Won Sohn, Pulun Park, Sang-Sung Lee, Do-Young Byun, Jee Won Lee, Jung Hwan Oh

Max-Planck-Institut für Radioastronomie: E. Angelakis



The Planck satellite

- Occasional monitoring of ~20 sources
- 30-857 GHz

J. P. Rachen et al.

Fermi-GST

- 4π / 3 hours
- 20 MeV to 300 GeV

L. Fuhrmann, J. A. Zensus, I. Nestoras

Max-Planck-Institut für Radioastronomie: E. Angelakis

J2347+5142 (1ES2344+514)
J1354-1041 (PKS1352-)
J1224+2122 (4C21.35)
J2348-1631 (PKS2345-16)
J1159+2914 (TON599)
J1504+1029 (1502+106)
J1310+3220 (OP313)
J1408-0752 (PKS1406-076)
J1229+0203 (3C273)
J0217+0144 (PKS0215+015)
J0818+4222 (TXS0814+425)
J1540+8155 (1ES1544+820)
J1635+3808 (4C38.41)
J1824+5651 (4C56.27)
J2025-0735 (J2025-07)
3C48
J0958+6533 (S40954+65)
J2225-0457 (3C446)
J0418+3801 (3C111)
J1542+6129 (J1542+61)
J0841+7053 (S50836+71)
J1642+3948 (3C345)
J1848+3219 (J1848+32)
J2147+0929 (J2147+09)
3C295
J0654+4514 (J0654+45)
J2229-0832 (J2229)
J1332-0509 (J1332-05)
J0237+2848 (4C28.07)
J1553+1256 (1551+130)
J1733-1304 (NRAO530)
J1849+6705 (S41849+6)
J1130-1449 (PKS1127-14)
J1653+3945 (Mkn501)
J0006-0623 (0003-066)
J0507+6737 (1ES0502+675)
J2232+1143 (CTA1)
J1345+4452 (1343+451)
J0854+2006 (OJ287)
J1555+1111 (1ES1553+113)
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J1959+6508 (1ES1959+650)
J0221+3556 (0221+355)
J1217+3007 (J1217+30)
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J0359+5057 (NRAO150)
J1613+3412 (OS319)
J1800+7828 (S51803+78)
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J2158-1501 (PKS2155-152)
J2143+1743 (J2143+17)
J0050-0929 (J0050-09)
J1221+2813 (WCom)
3C286
J0241-0815 (NGC1052)
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J1806+6949 (3C371)
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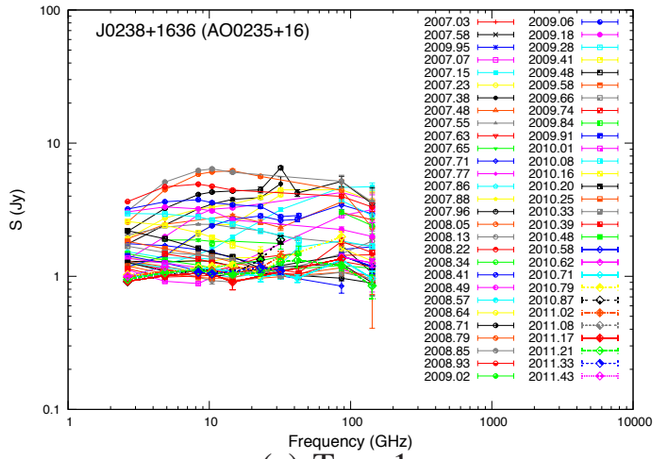
J1959+4044 (Cygn
J0423-0120 (PKS0420-01)
J1104+3812 (Mkn421)
J0136+4751 (0136+475)
J1136+7009 (Mkn180)
J0238+1636 (AO0235+16)
J2327+0940 (J232
J1505+0326 (PKS1502+036)
J1428+4240 (H1426+428)
J1512-0905 (PKS1510-08)
J1522+3144 (1522+314)
J0319+4130 (3C84)

Max-Planck-Institut für Radioastronomie: E. Angelakis

Thursday, November 10, 2011



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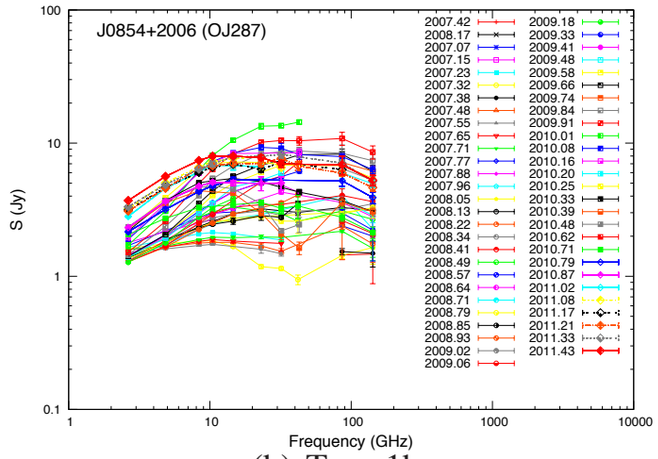

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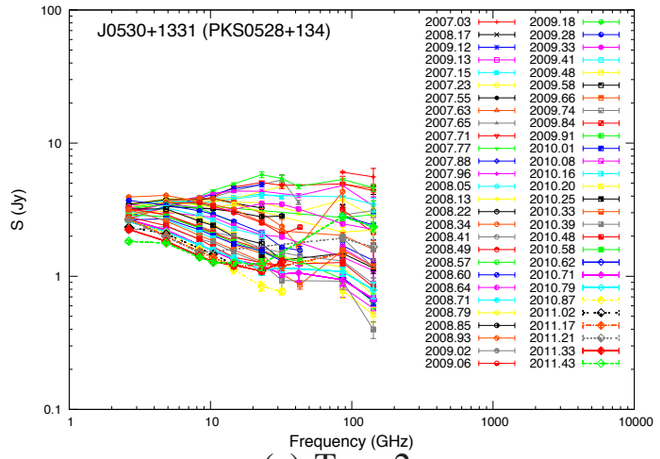

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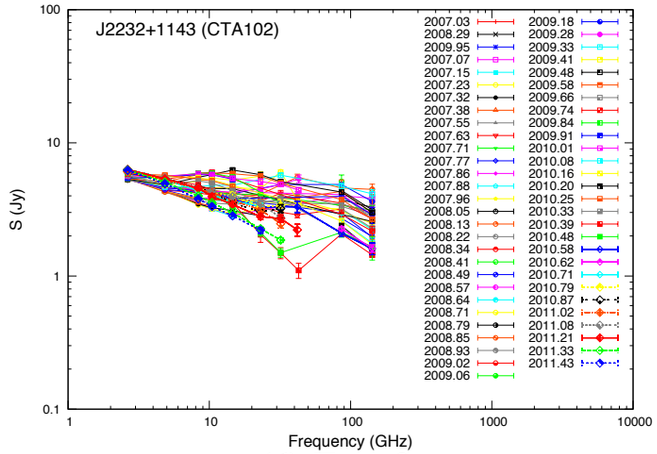

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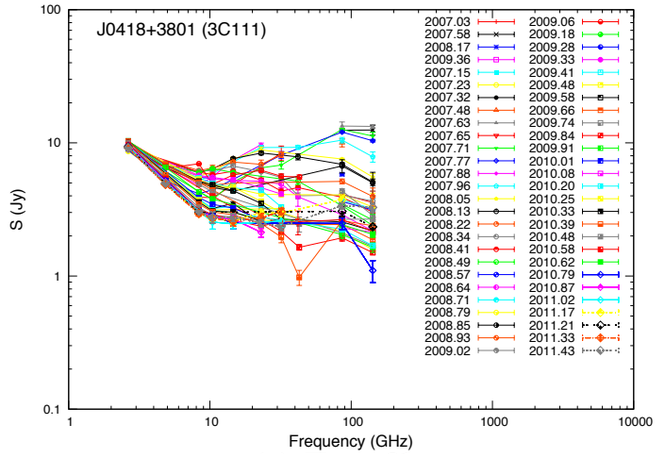

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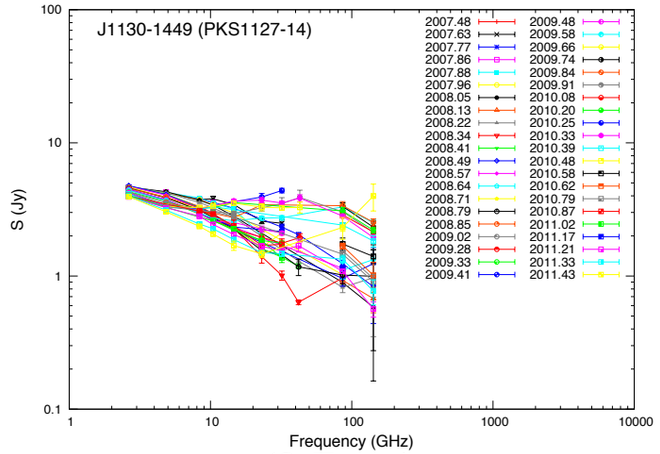

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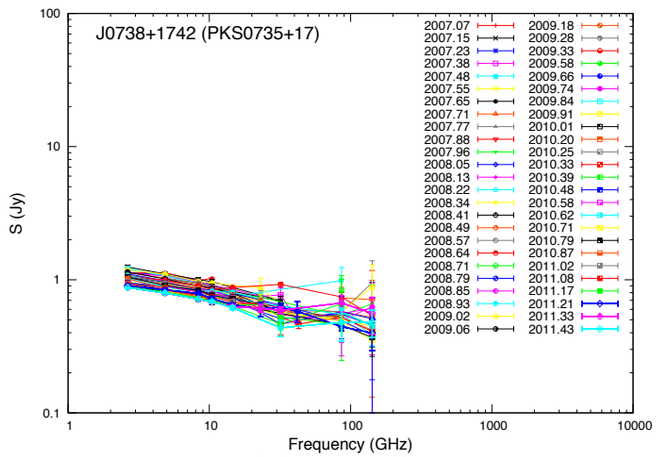

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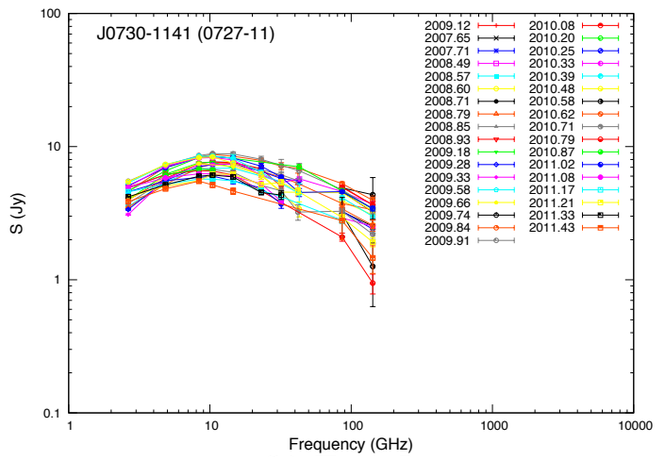
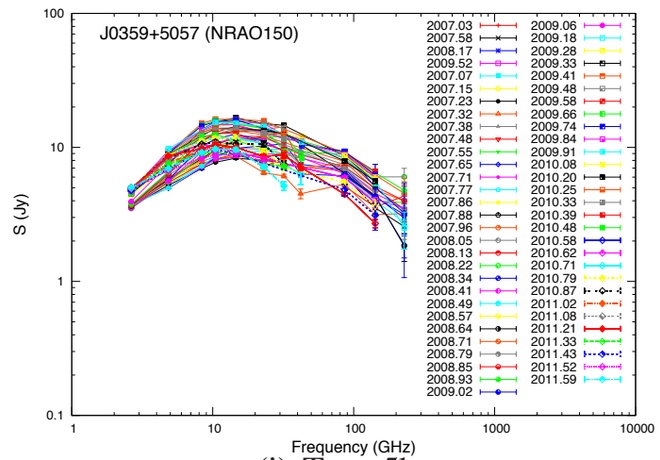


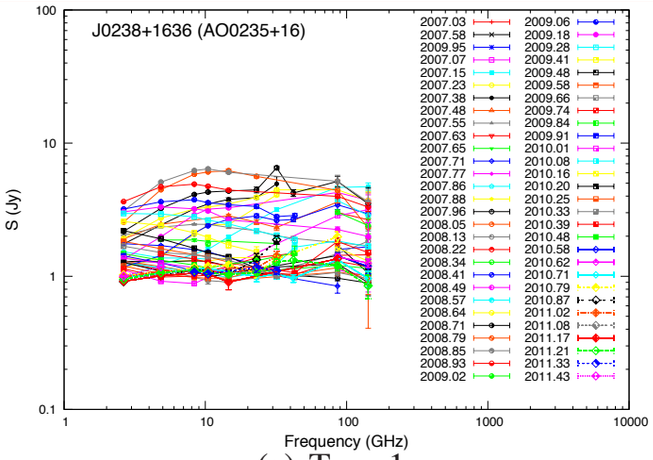
(h) Type 5



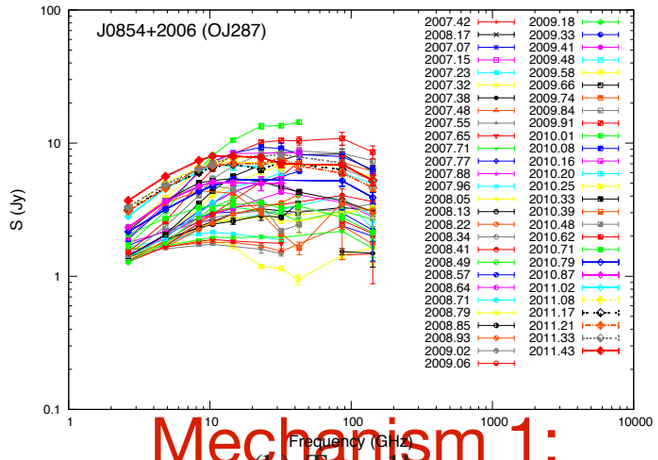
(i) Type 5b

Angelakis et al. in prep.

Mechanism 1: Spectral Evolution



(a) Type 1



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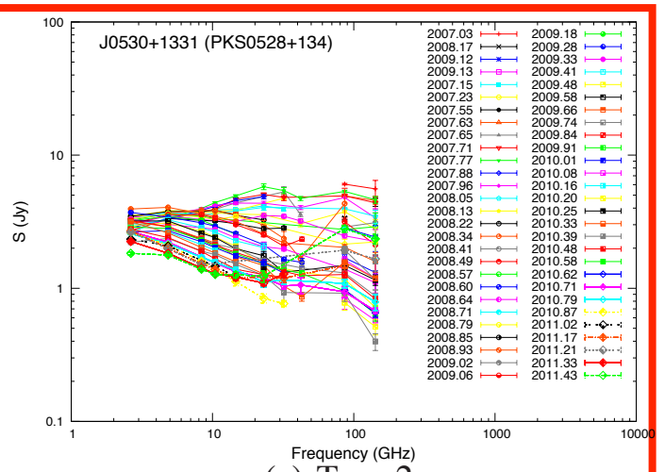

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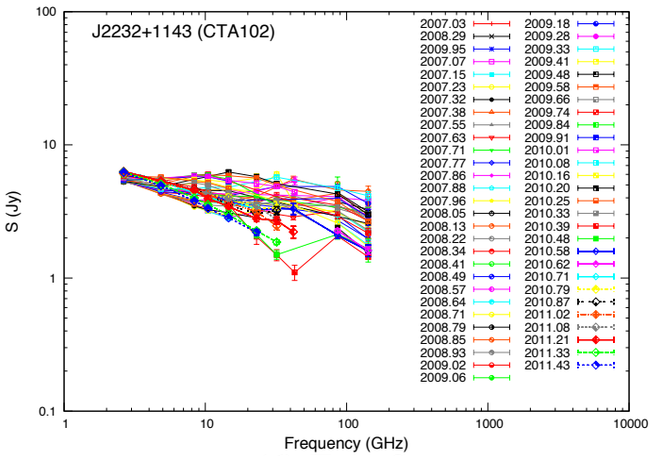

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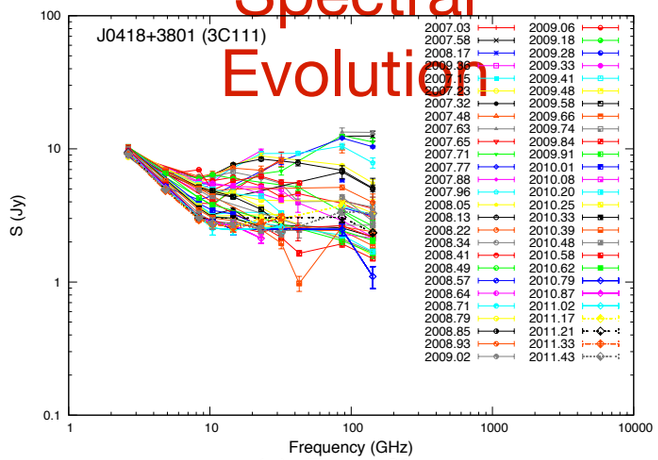

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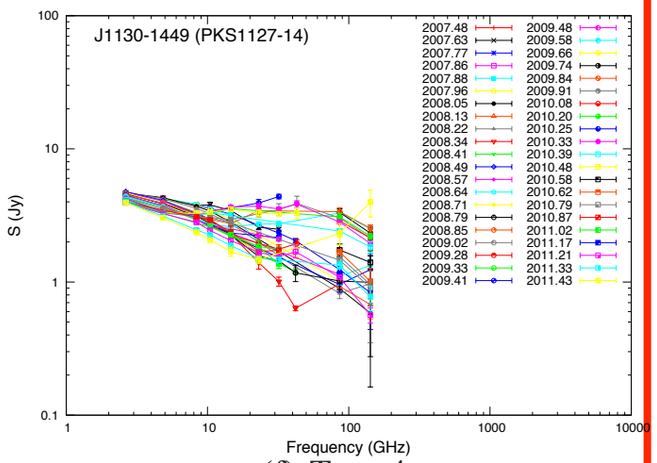

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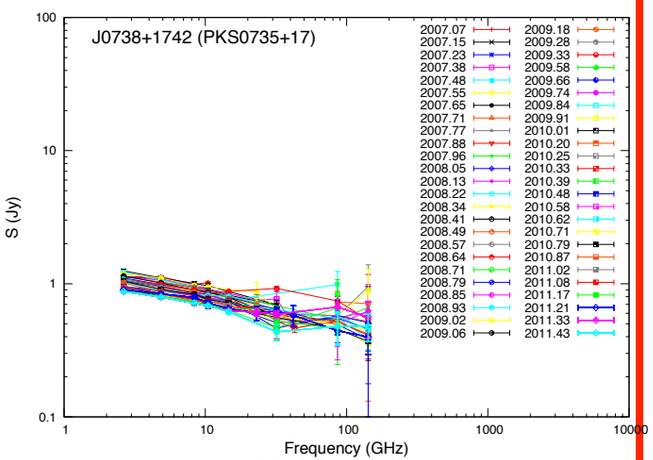

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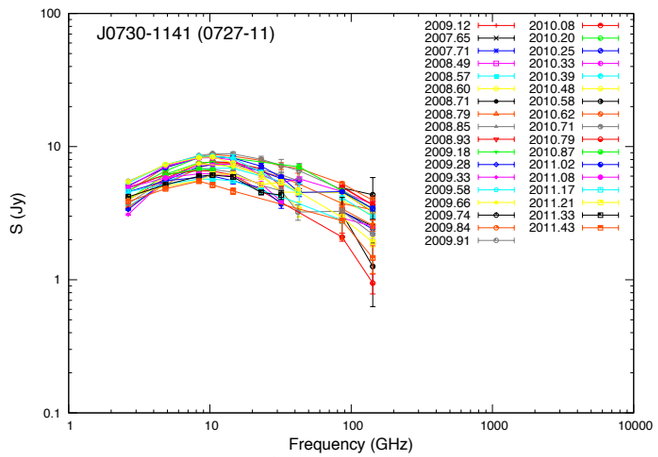

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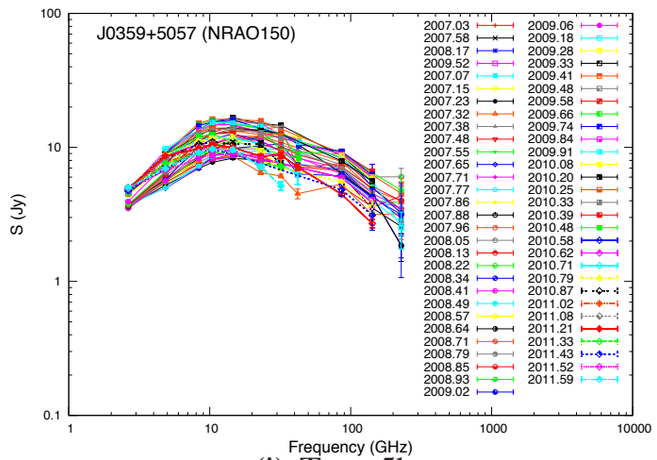

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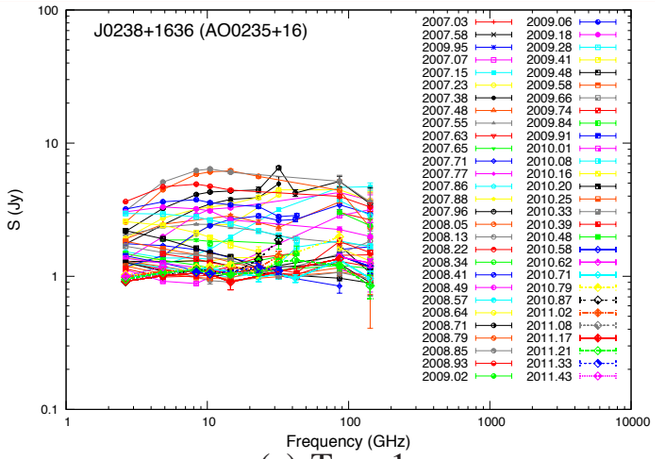
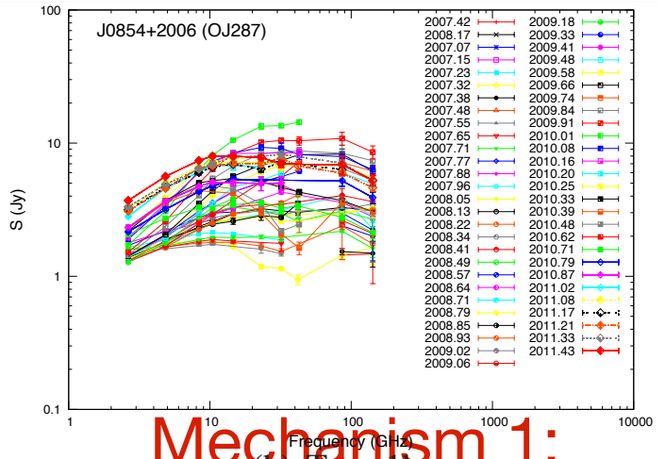
Angelakis et al. in prep.



(a) Type 1



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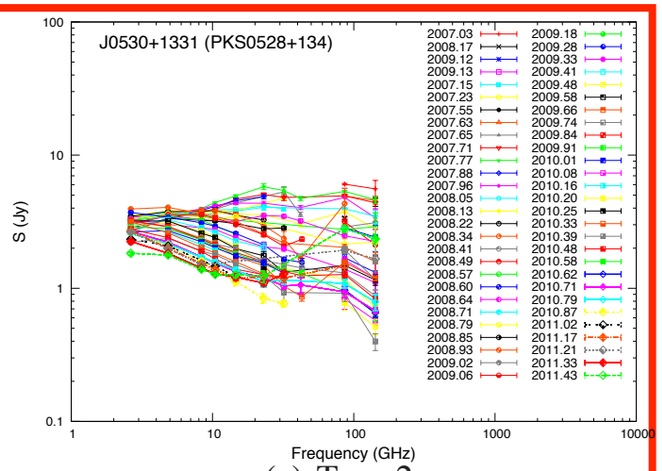

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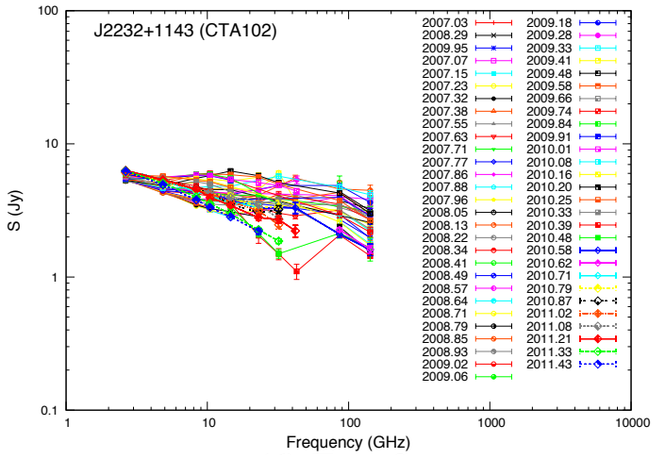
Mechanism 1: Spectral Evolution



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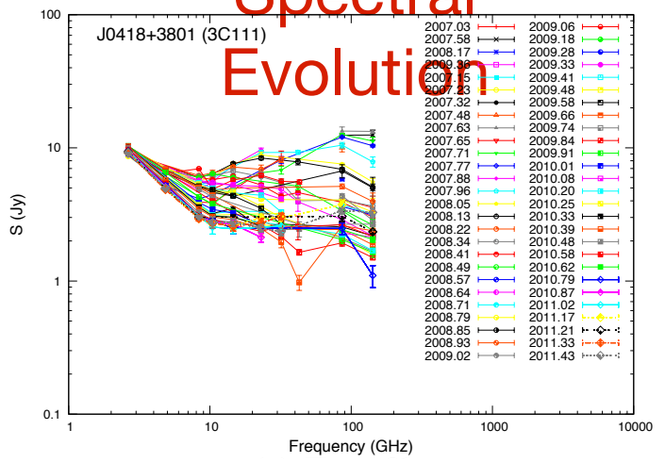

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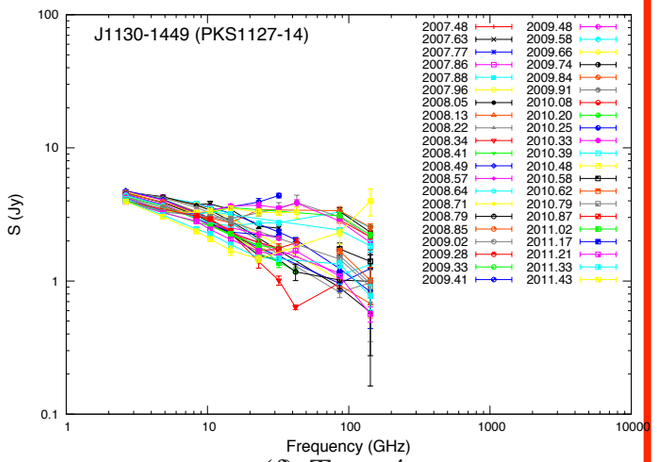

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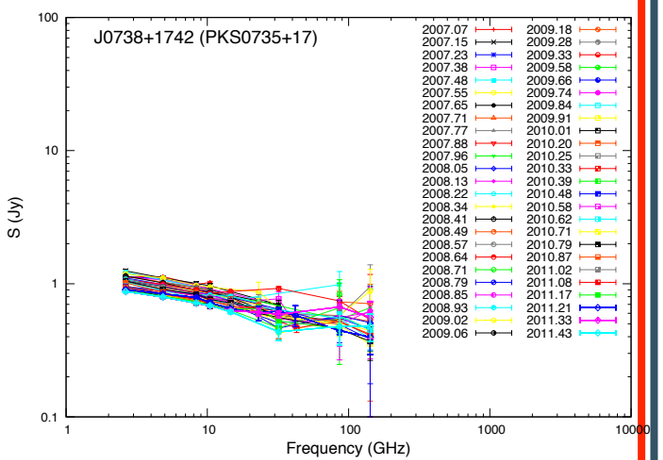

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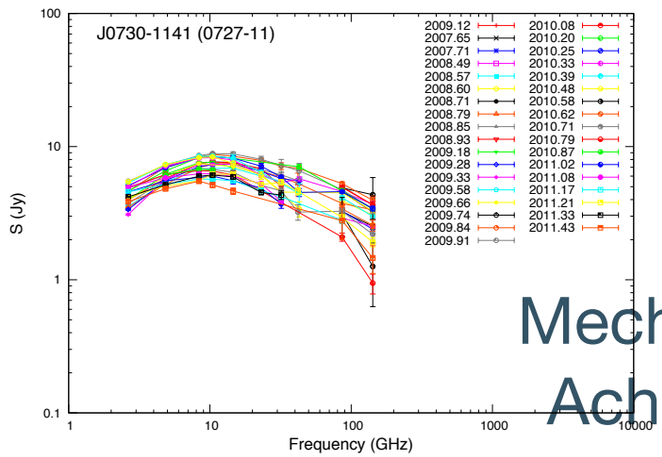

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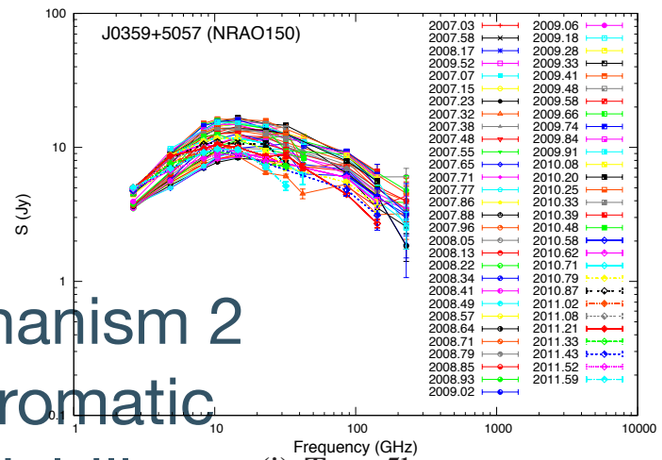

(i) Type 5b

Mechanism 2 Achromatic variability

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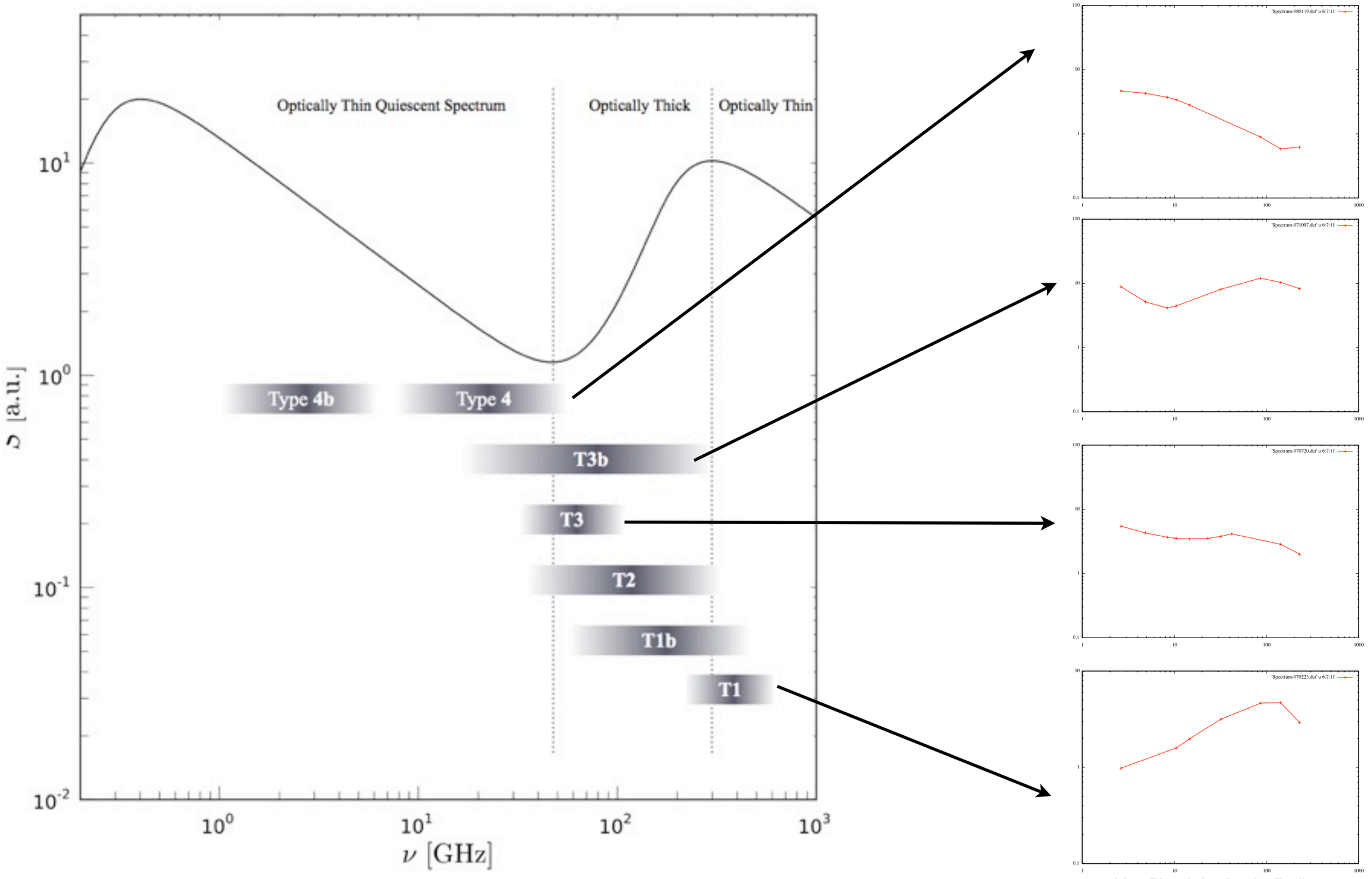
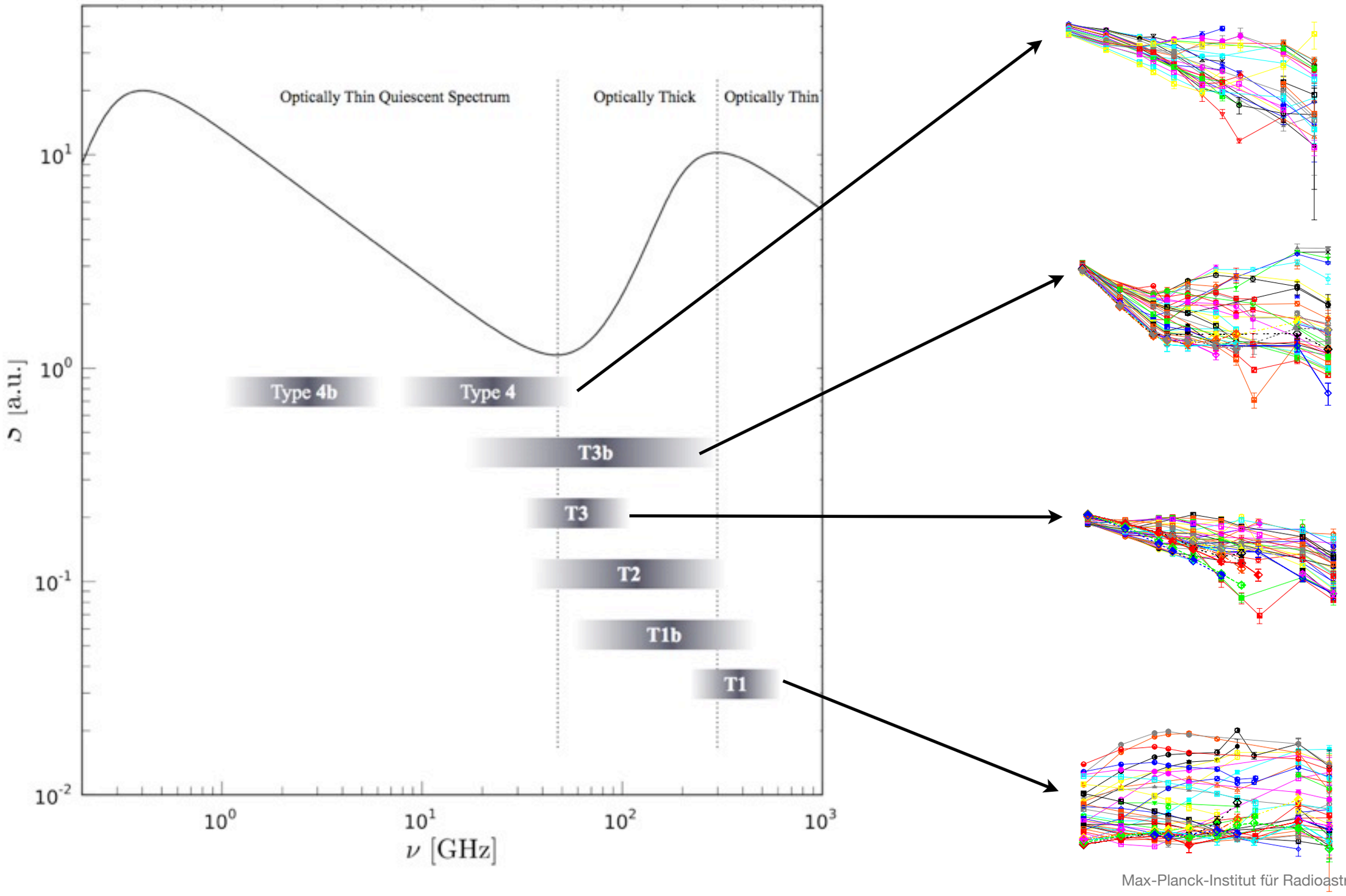
reproducing the observed variability pattern



reproducing the observed variability pattern



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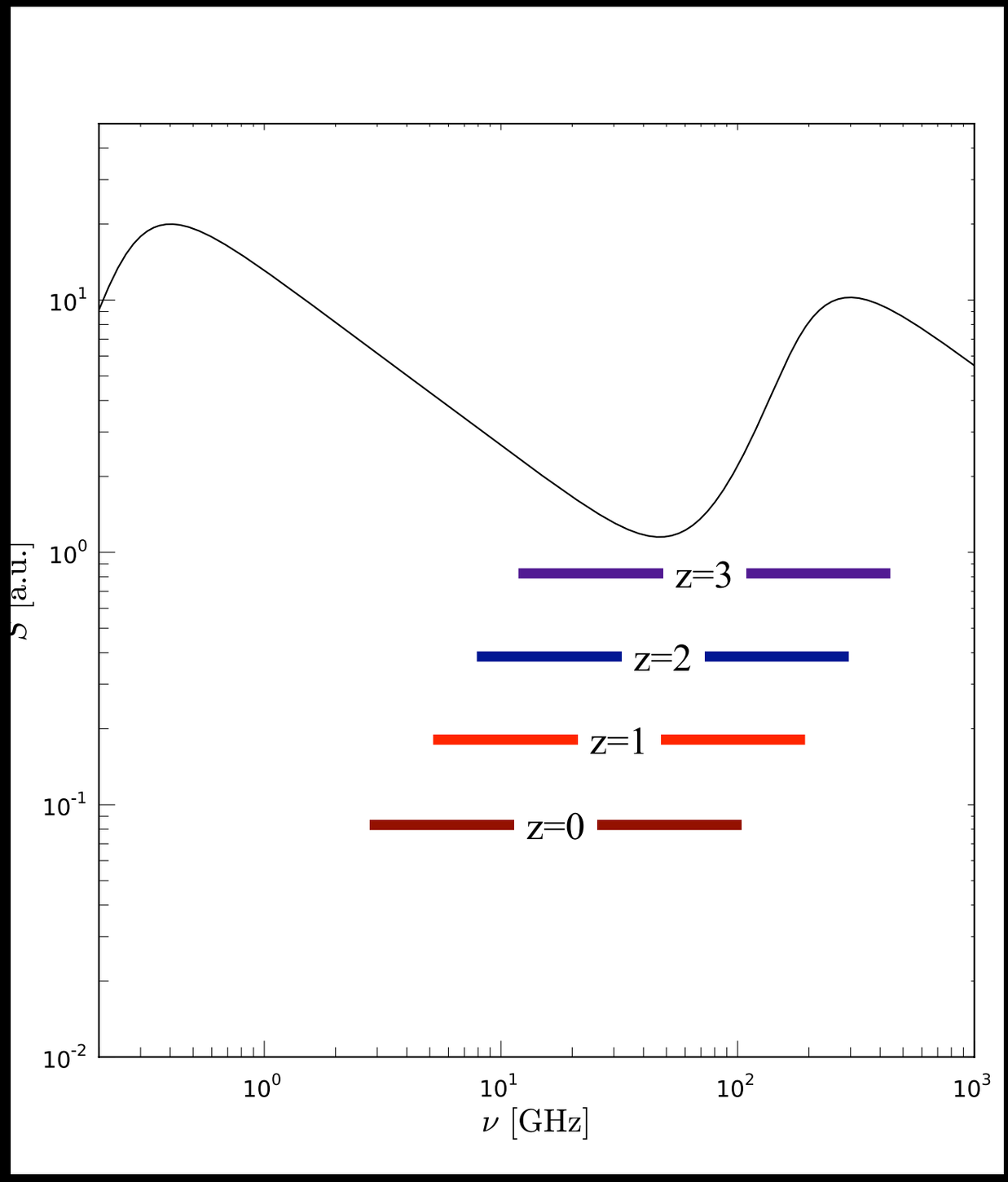
reproducing the observed variability pattern

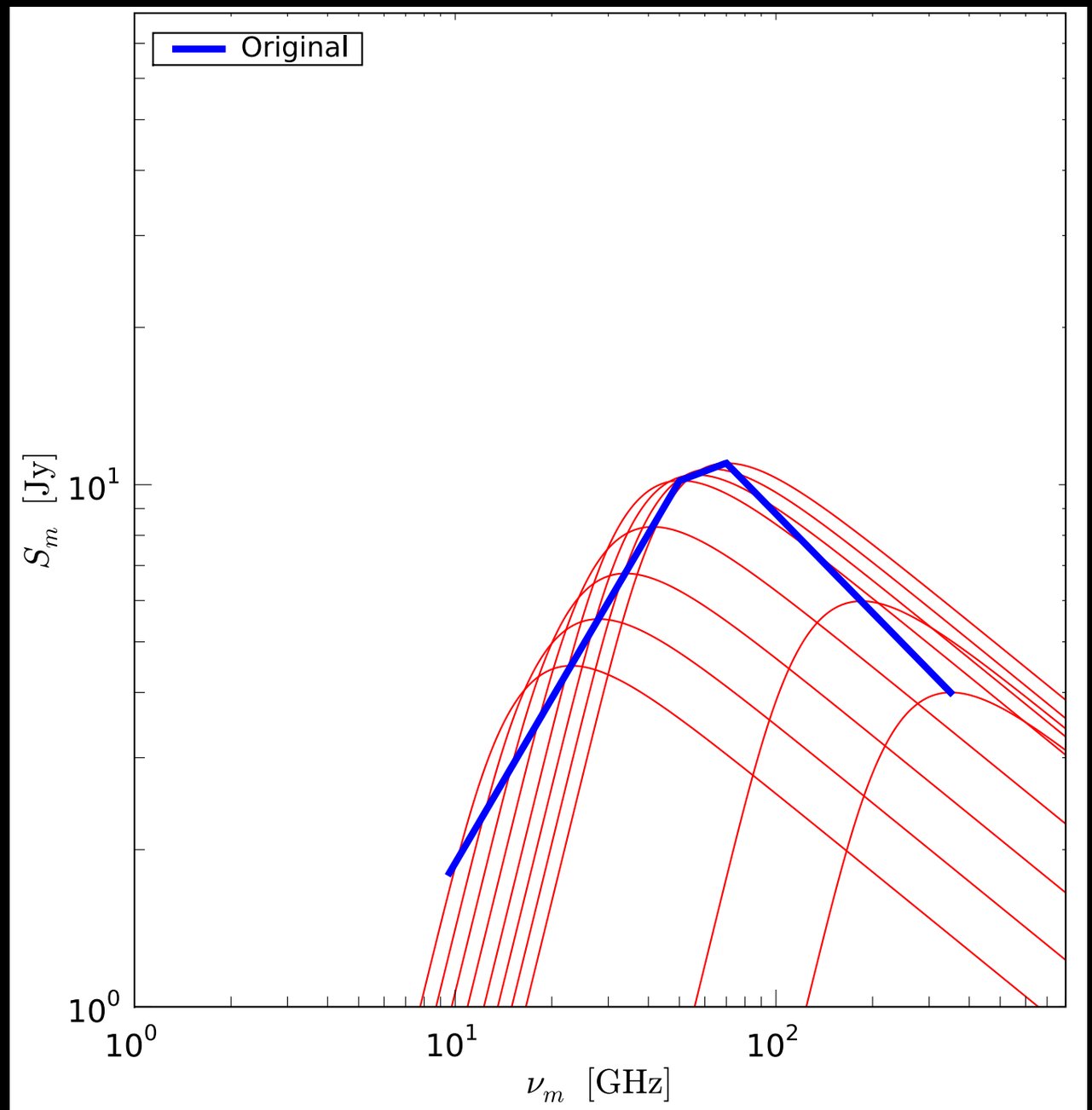
the toy model accounts for:

- source redshift
- source intrinsic properties:
  - peak frequency of the SSA spectrum
  - outburst excess relative to the quiescence spectrum
  - broadness of the SSA spectrum of the outburst and
  - broadness of the valley
- spectral evolution



reproducing the observed variability pattern

- parameter “b”: evolution of the magnetic field
- parameter “d”: evolution of the Doppler factor
- parameter “r”: jet opening angle
- parameter “s”: spectral index (estimated from quiescent spec.)
- parameter “k”: normalization parameter



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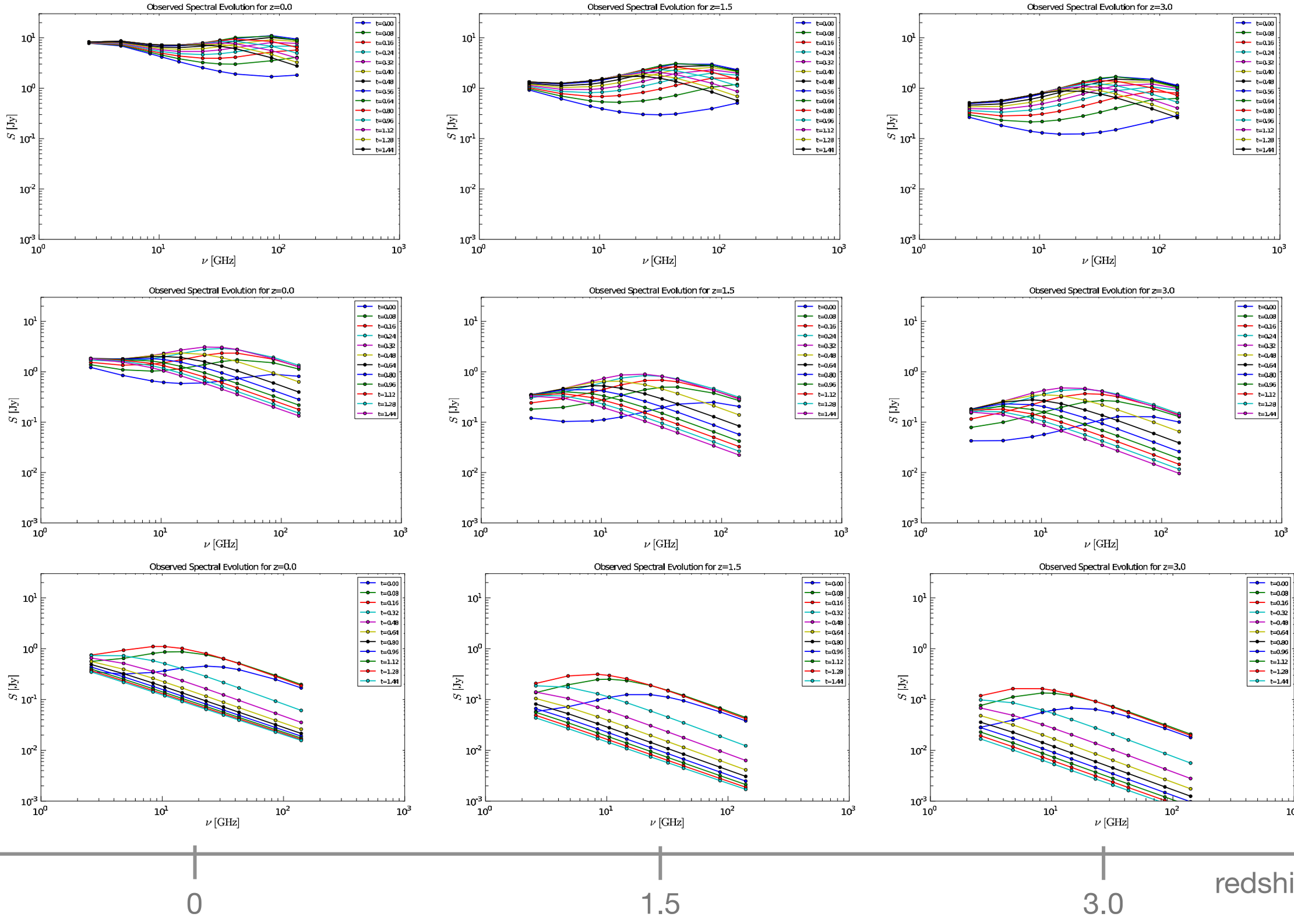
intrinsic power



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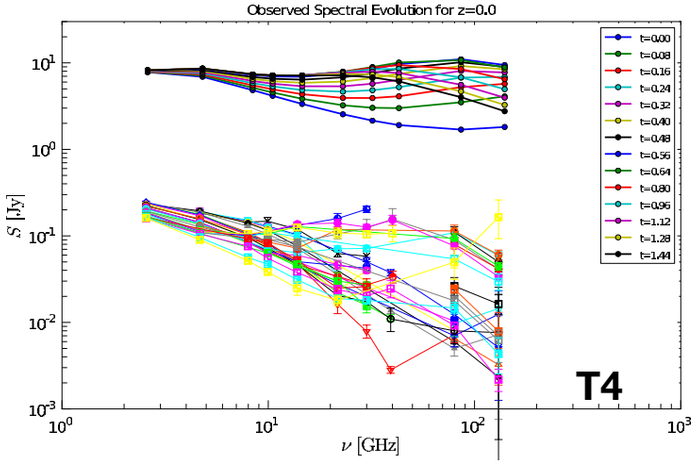
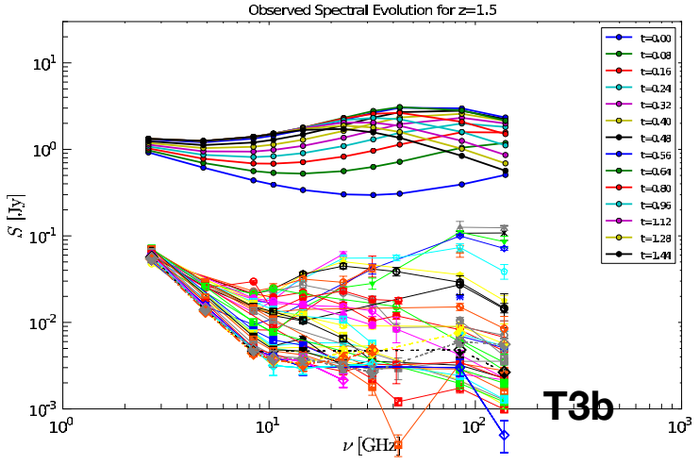
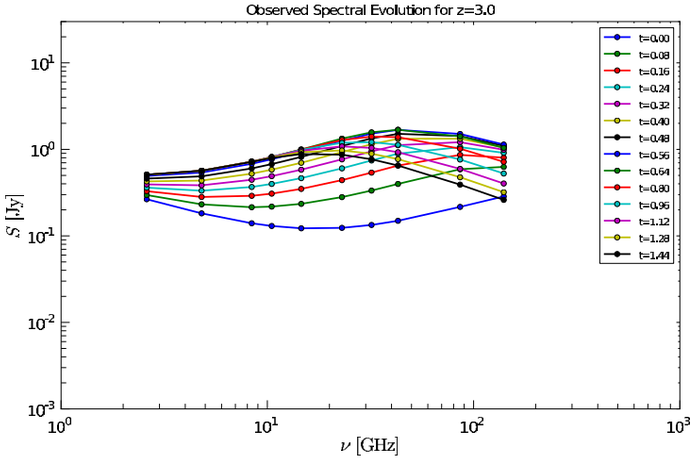
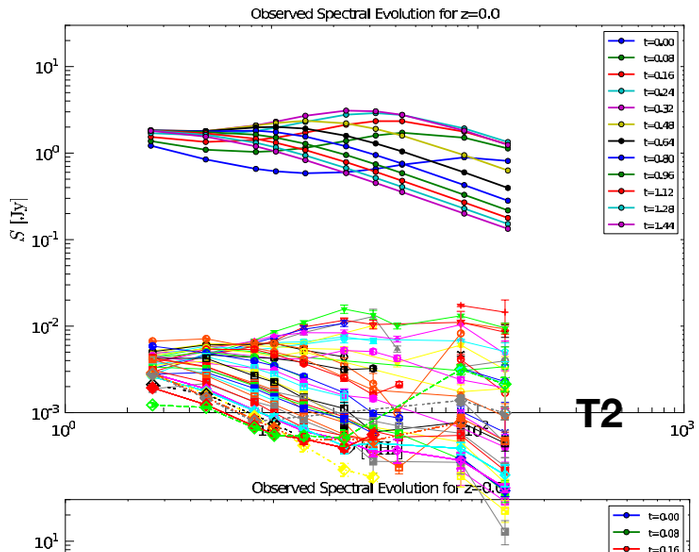
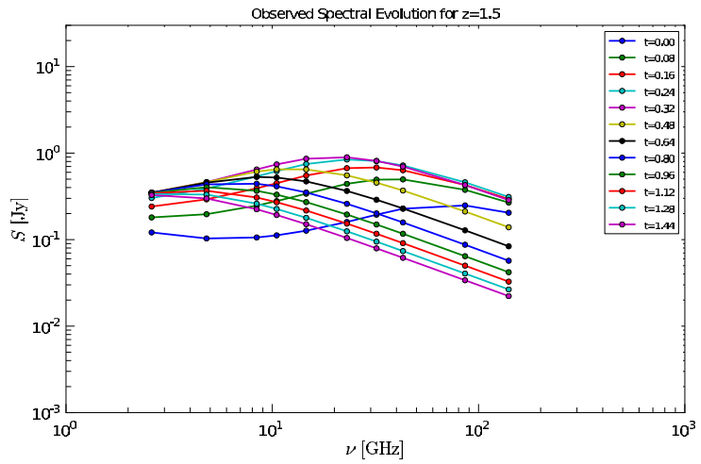
intrinsic power

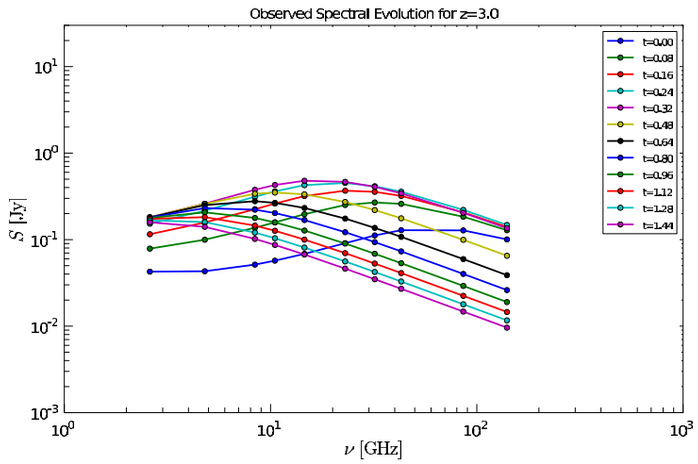


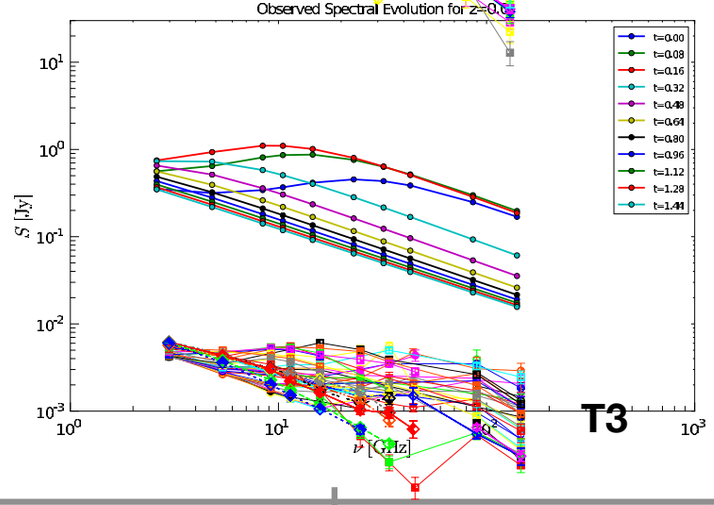


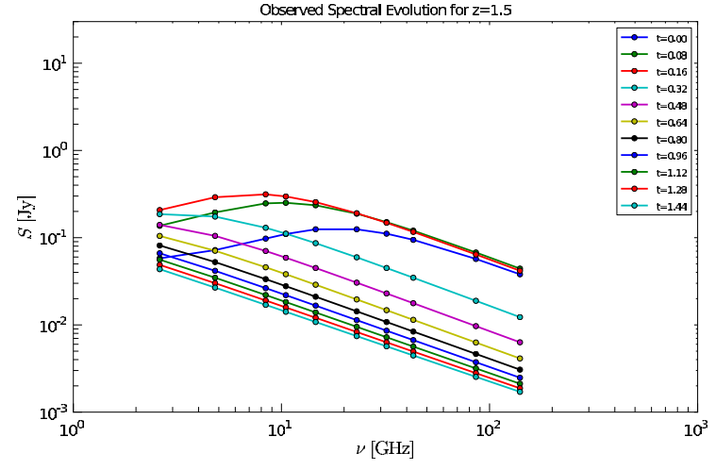


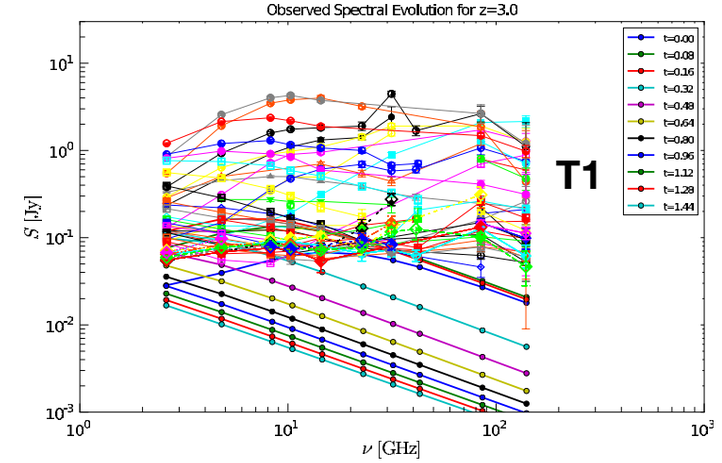










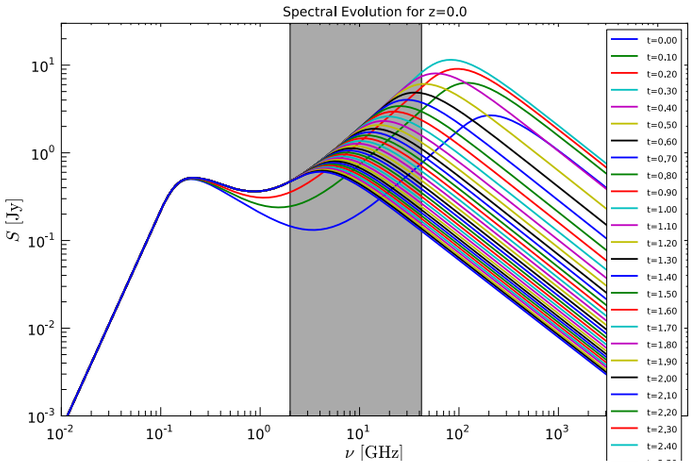


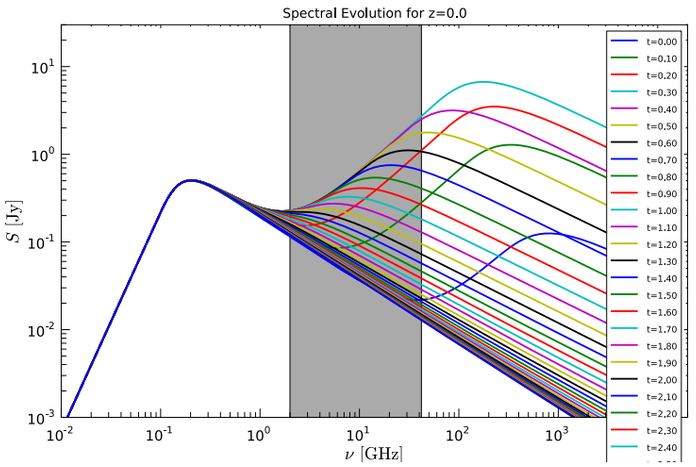
0

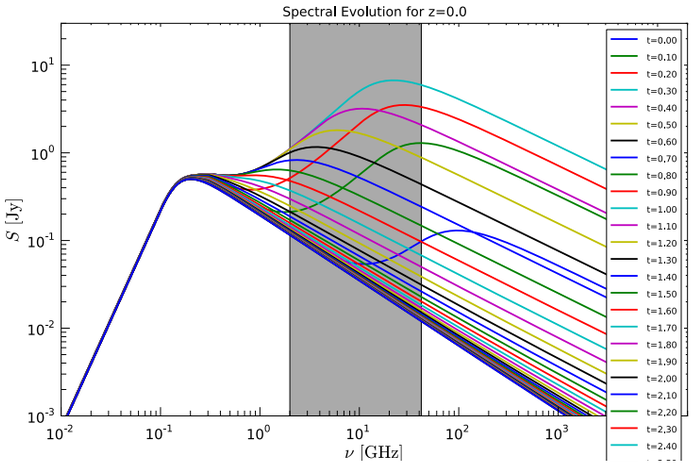
1.5

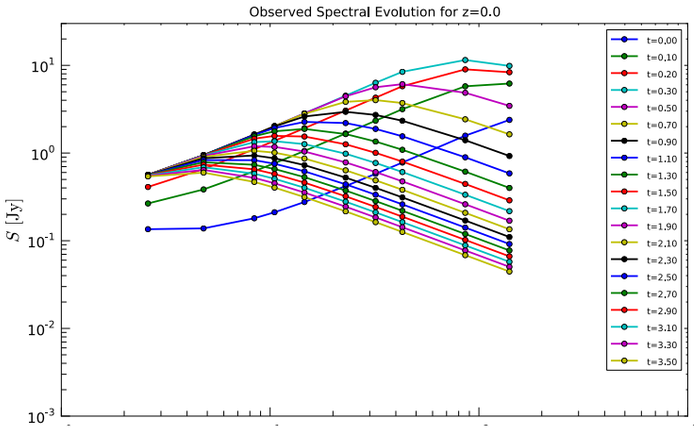
3.0

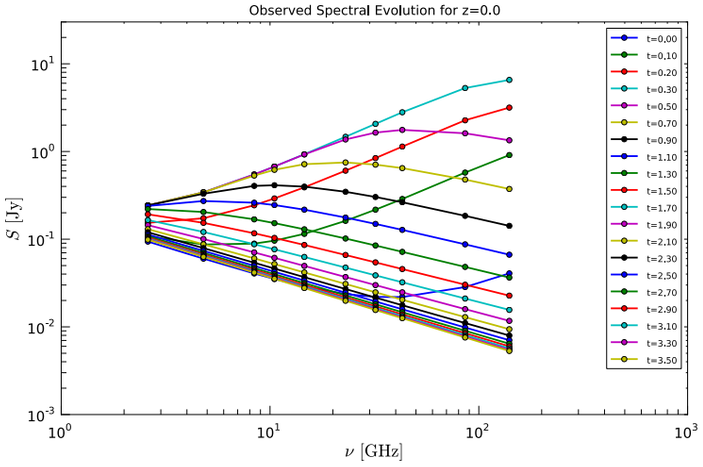
redshift

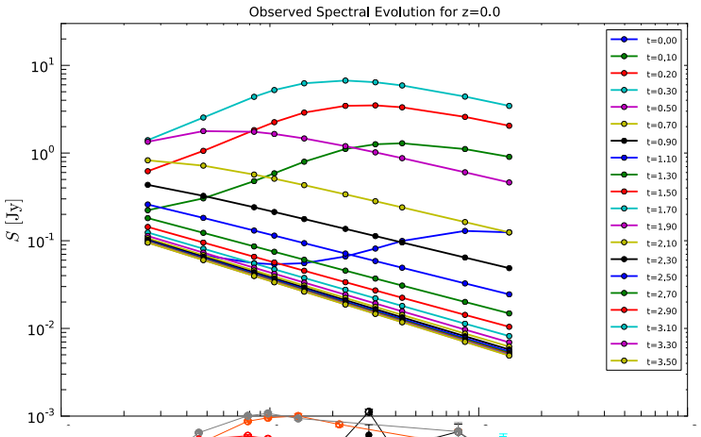

Spectral Evolution for z=0.0
S [Jy]
ν [GHz]

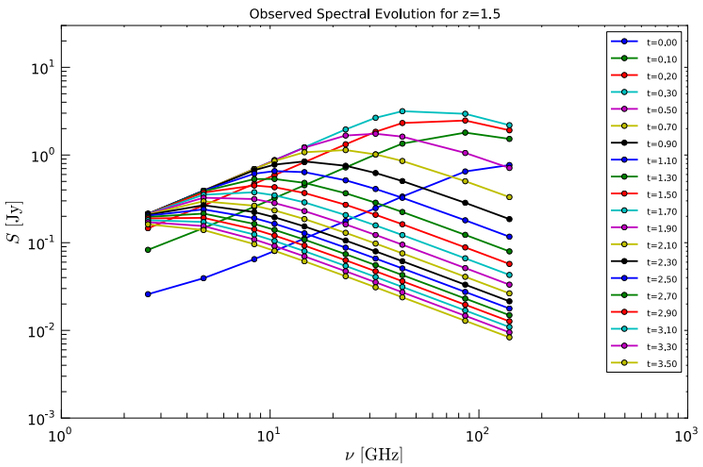

Spectral Evolution for z=0.0
S [Jy]
ν [GHz]

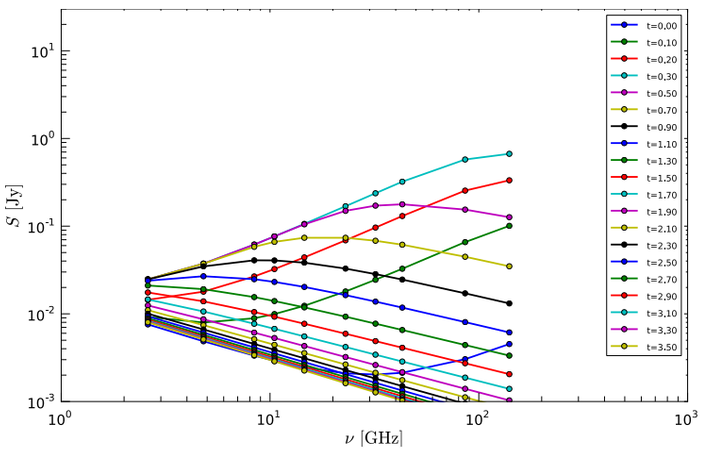

Spectral Evolution for z=0.0
S [Jy]
ν [GHz]

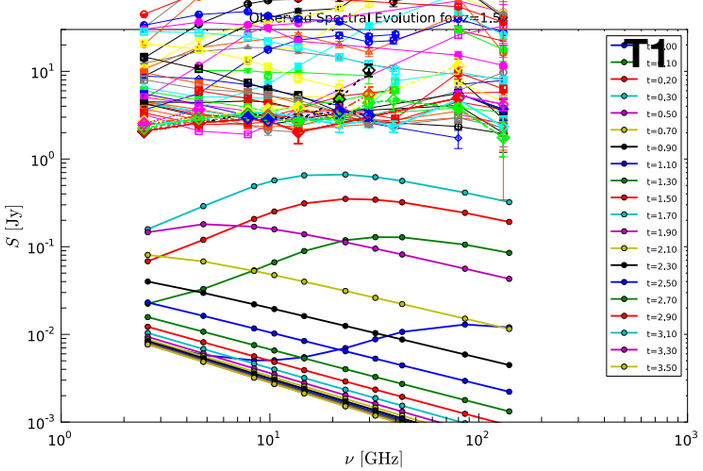

Observed Spectral Evolution for z=0.0
S [Jy]

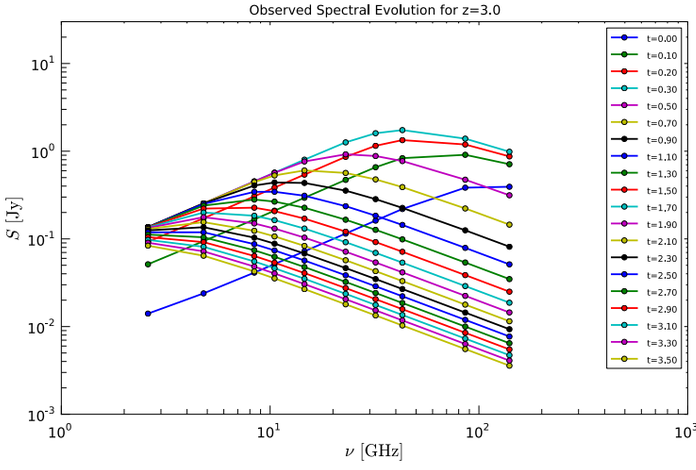

Observed Spectral Evolution for z=0.0
S [Jy]
ν [GHz]

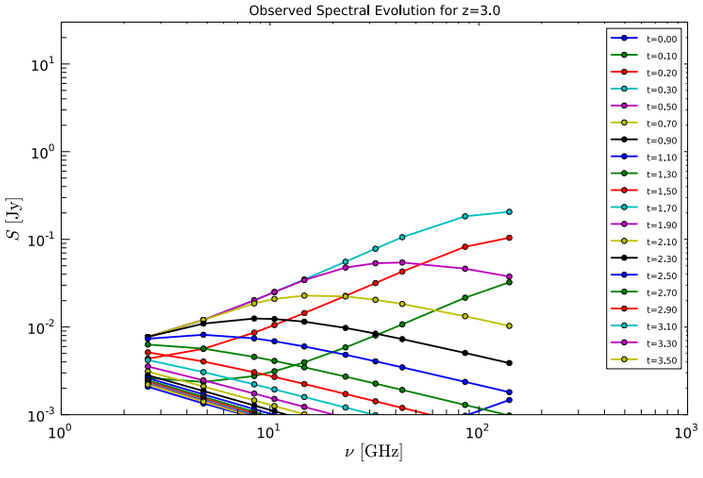

Observed Spectral Evolution for z=0.0
S [Jy]

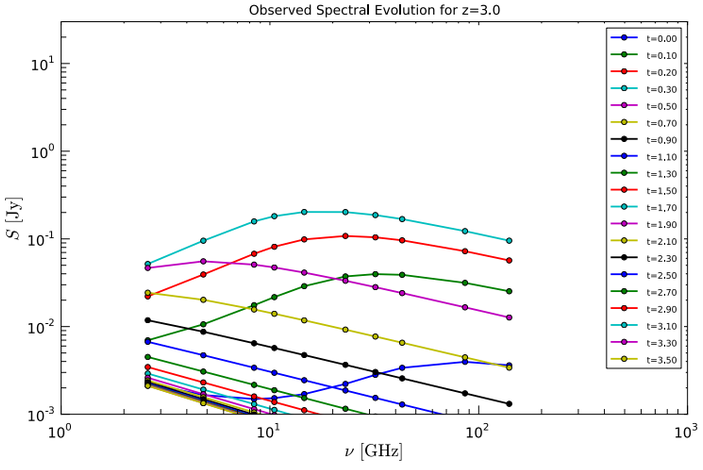

Observed Spectral Evolution for z=1.5
S [Jy]
ν [GHz]


S [Jy]
ν [GHz]


Observed Spectral Evolution for z=1.5
S [Jy]
ν [GHz]


Observed Spectral Evolution for z=3.0
S [Jy]
ν [GHz]

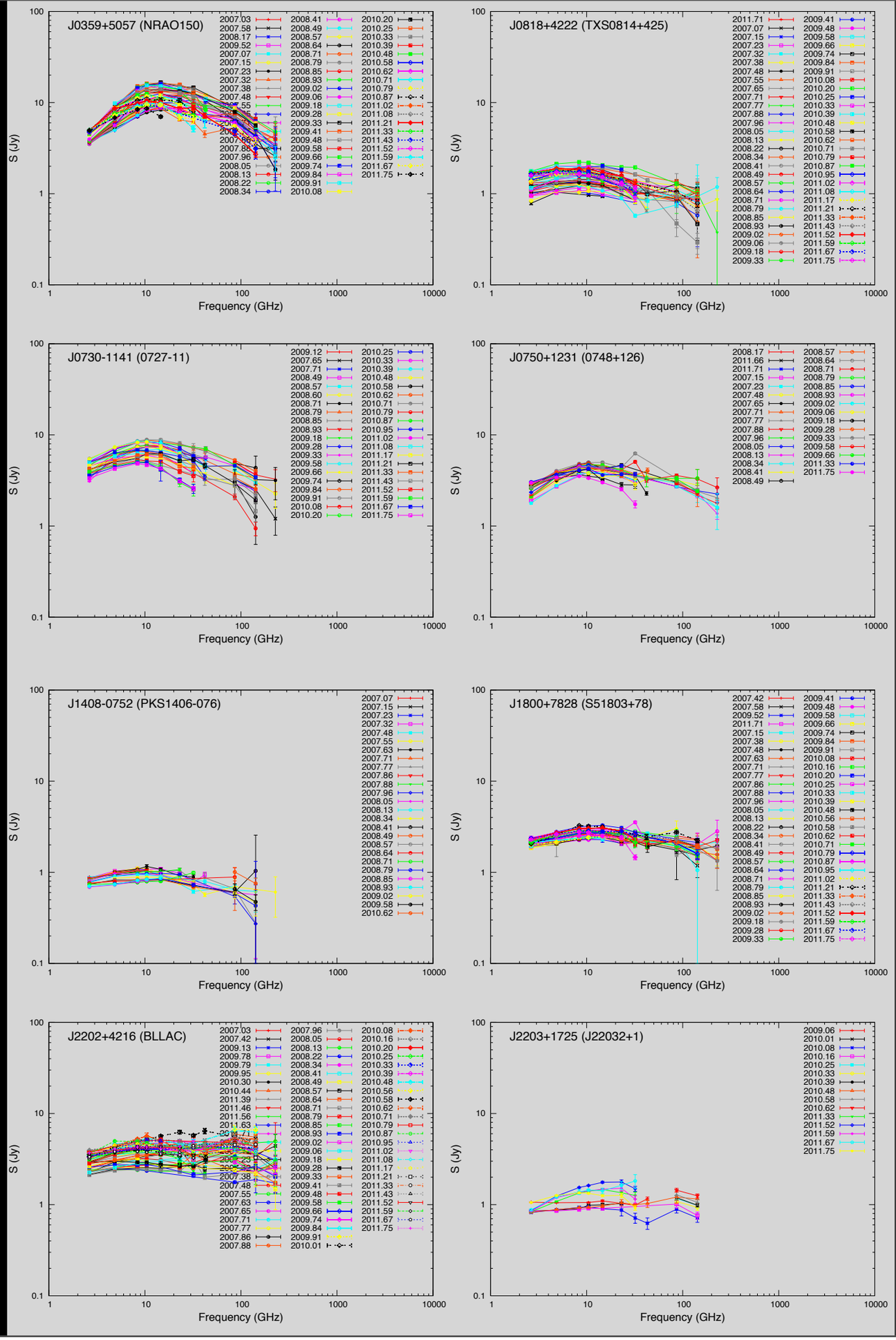

Observed Spectral Evolution for z=3.0
S [Jy]
ν [GHz]


Observed Spectral Evolution for z=3.0
S [Jy]
ν [GHz]

T1

Achromatic variability

- spectrum changing self-similarly with possibly a mild shift of the peak towards low frequencies as the flux increases
  - geometry?
  - changes in the B topology?
  - changes in D?
  - opacity effects?



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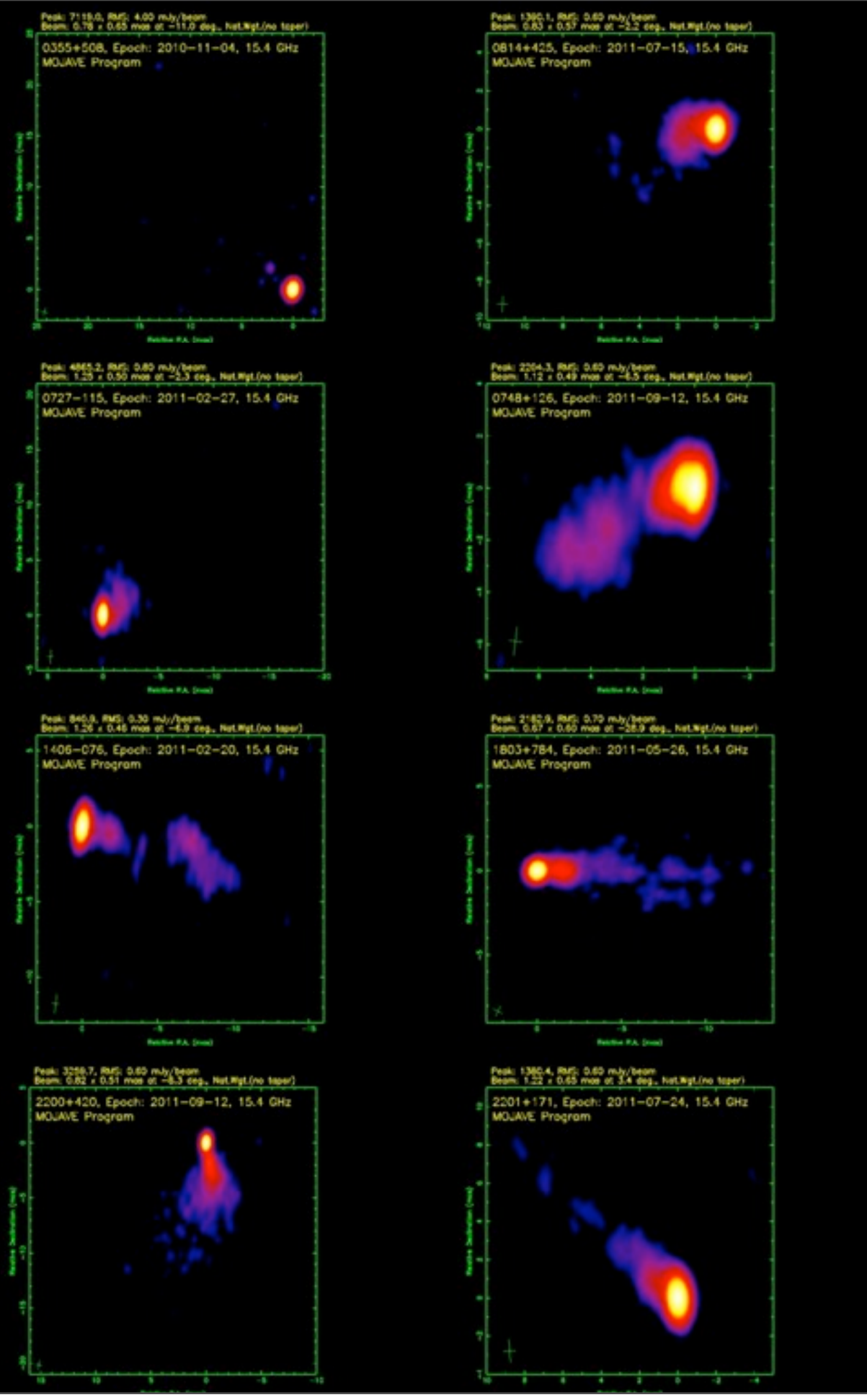
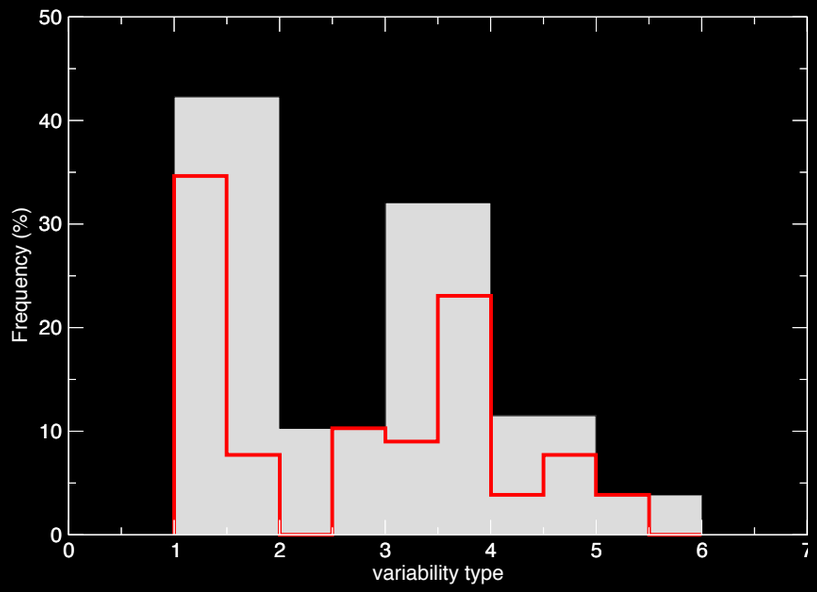
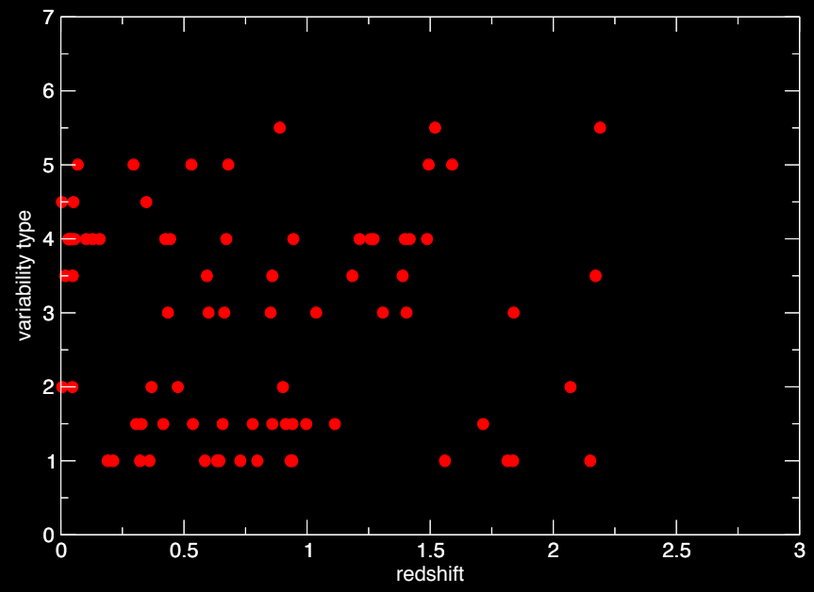
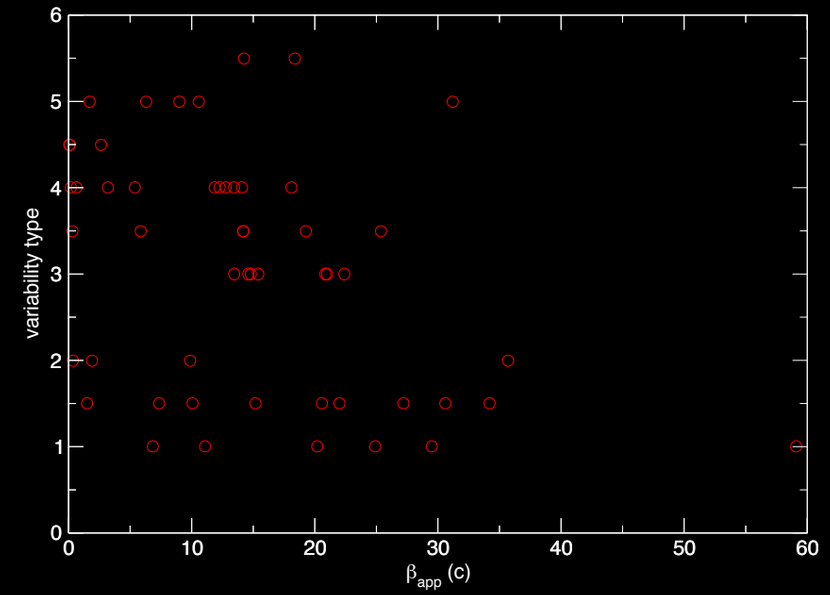
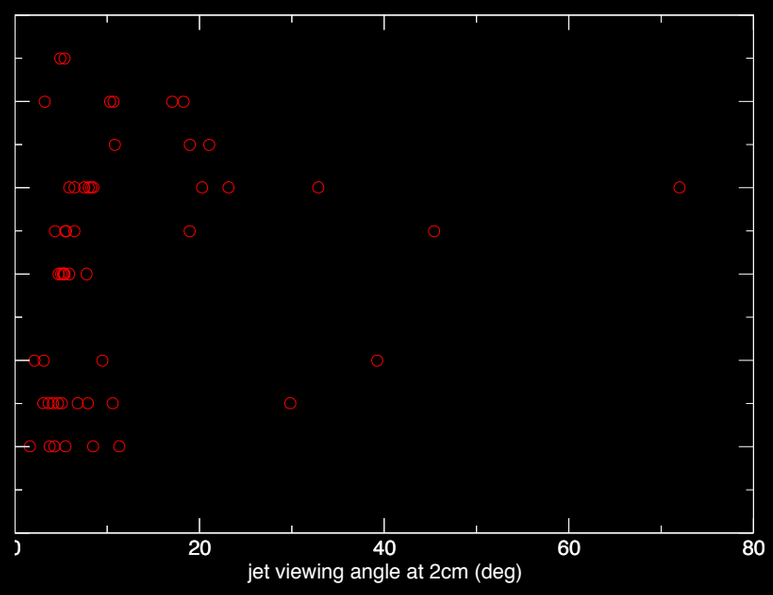
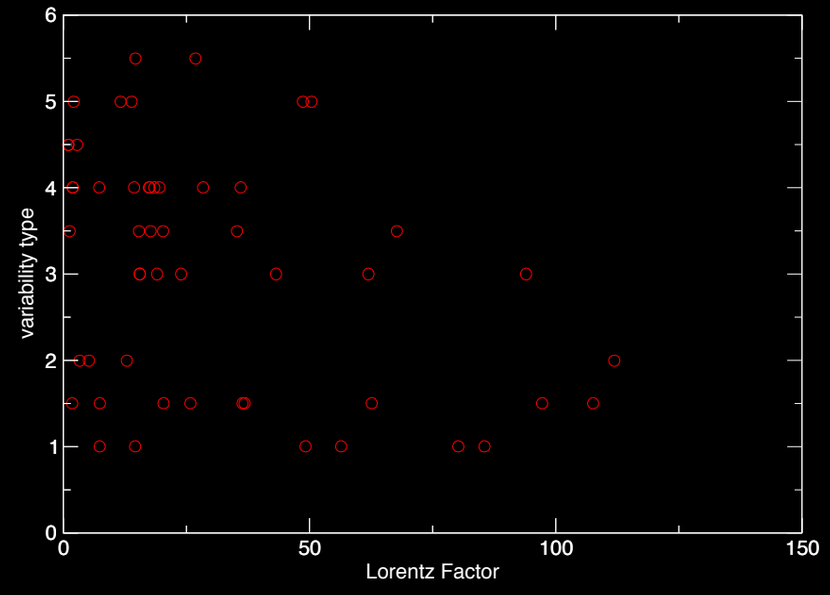


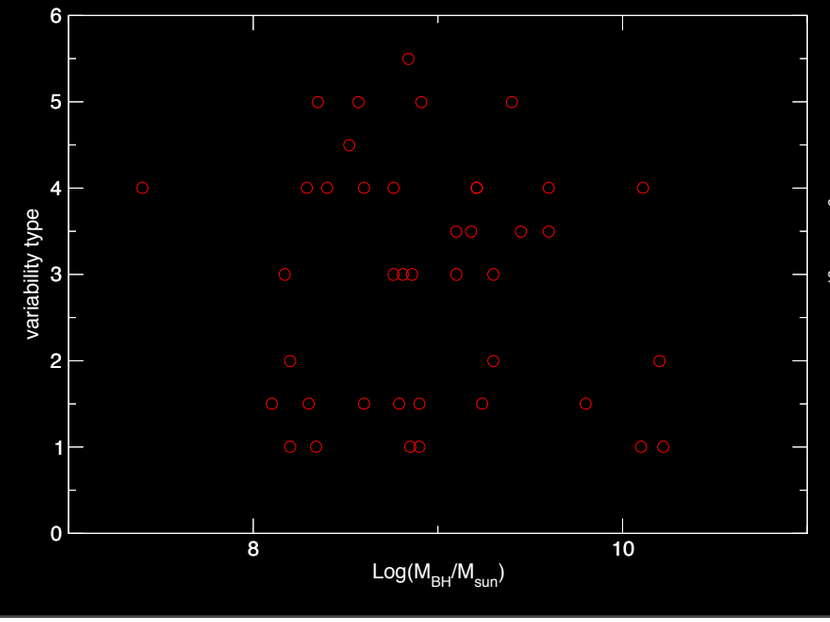


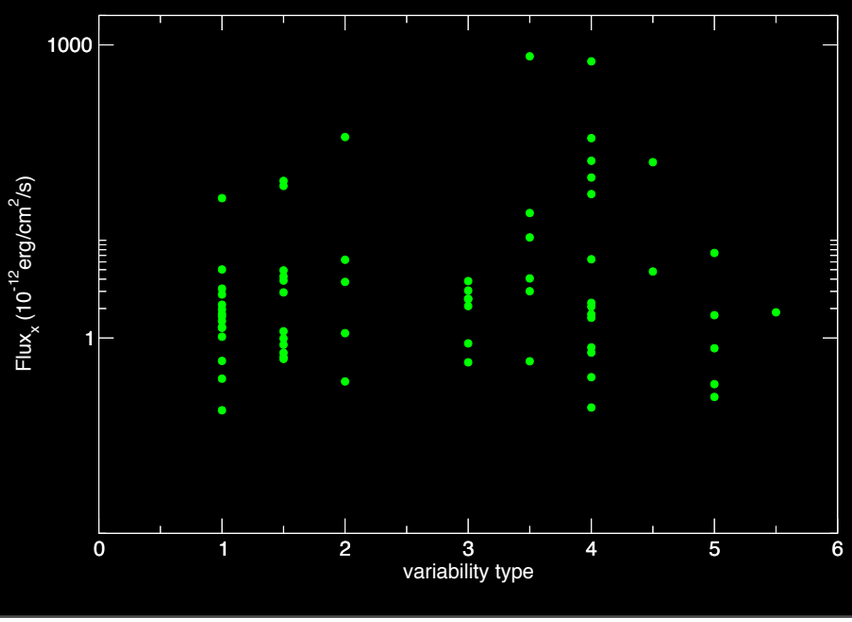












Conclusions

- it seems that only two distinct mechanisms produce variability:
  - achromatic variability
  - spectral evolution dominated
- no type switch observed, suggesting that:
  - either the mechanism is a source fingerprint
  - determined by source intrinsic properties that stay invariant or change with pace slower than we can sample

Conclusions

- the spectral evolution monitoring method is probing smallest spatial scales (uniform clouds of emitting particles), otherwise unaccessible to current observing apparatus
- our toy model provides a tool to calculate the physical parameters
- it is very unclear what mechanism produces achromatic variability: changes in the topology of B that would imply changes in the doppler factor D, do not seem to be the case. further investigation needed

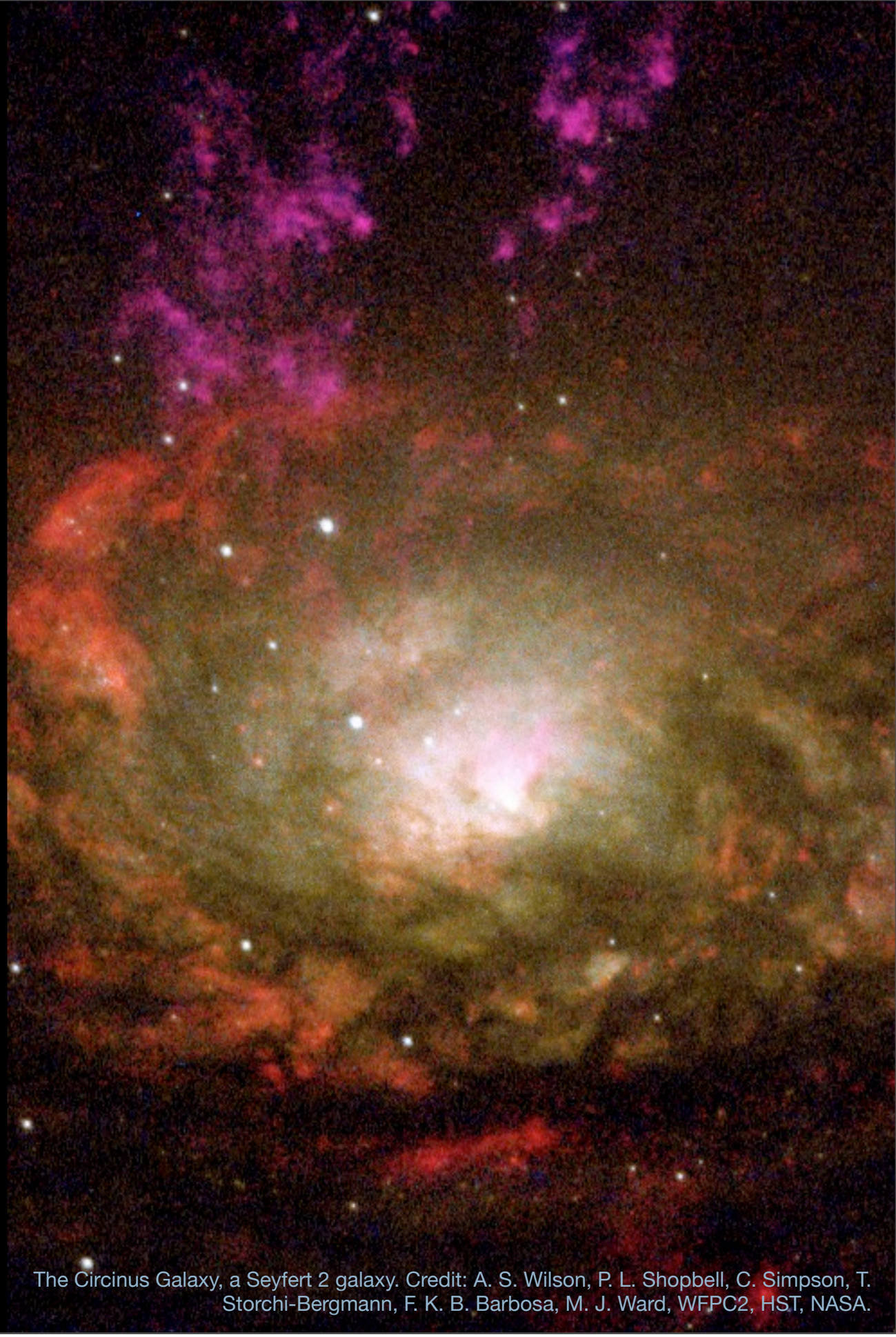
Narrow Line Seyfert 1

- permitted lines from the BLR, BUT much narrower than typically those seen in Seyfert 1 or blazars (FWHM (Hβ) < 2000 km s–1)

- in spiral galaxies

- appear to accrete with high Eddington ratios having low black-hole masses *(e.g. Grupe & Mathur, 2004)*

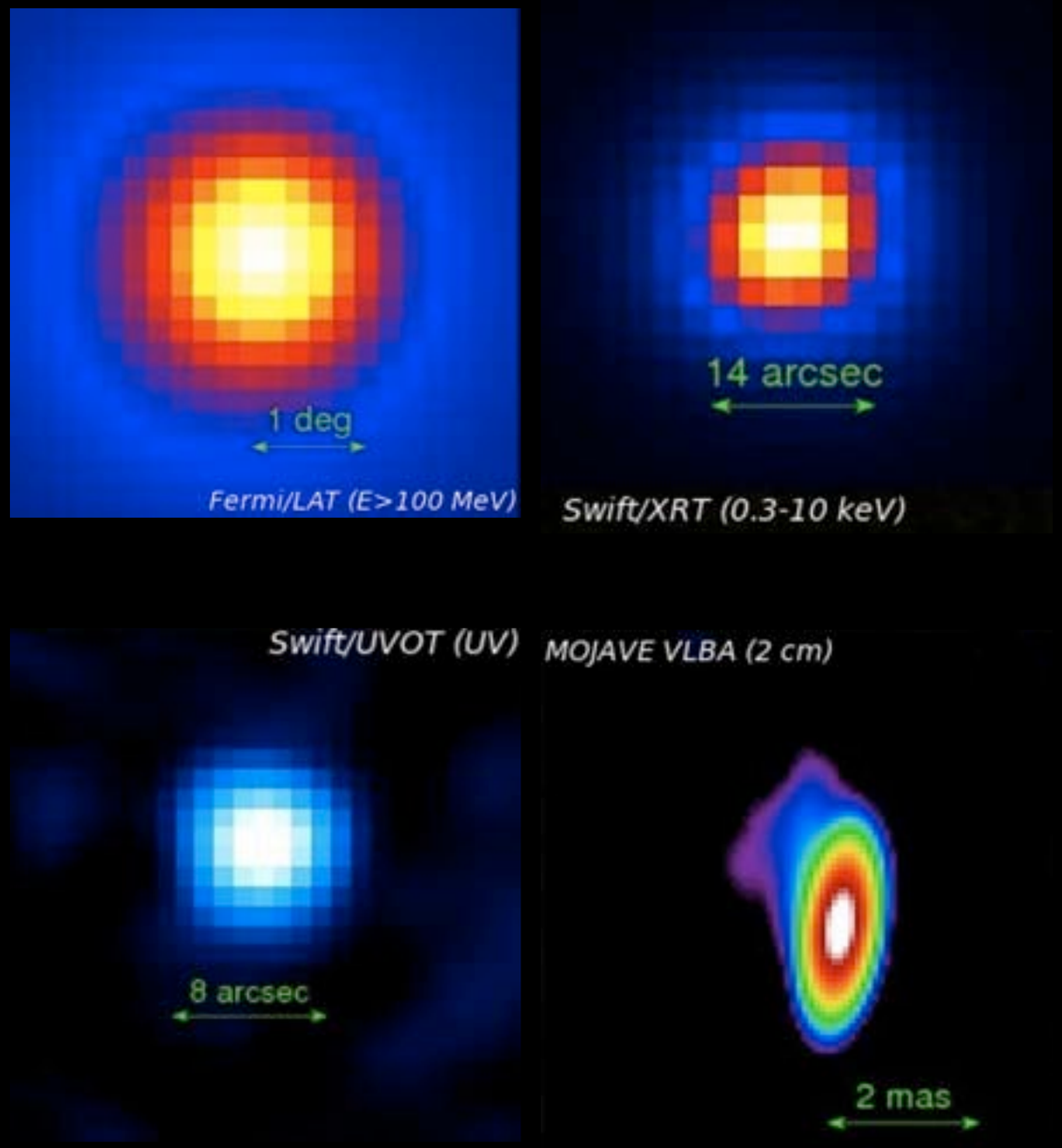
- typically RQ *(Komossa, S., et al. 2006, AJ, 132, 531)*



The Circinus Galaxy, a Seyfert 2 galaxy. Credit: A. S. Wilson, P. L. Shopbell, C. Simpson, T. Storchi-Bergmann, F. K. B. Barbosa, M. J. Ward, WFPC2, HST, NASA.

Fermi-GST detection of NLSy1s

- Fermi-GST detects 4 radio loud NLSy1 galaxies *(Abdo et al. 2009)*:
  - PKS1502+036 (z = 0.409)
  - 1H0323+342 (z = 0.061)
  - PKS2004-447 (z = 0.24)
  - PMNJ0948+0022 (z = 0.585)



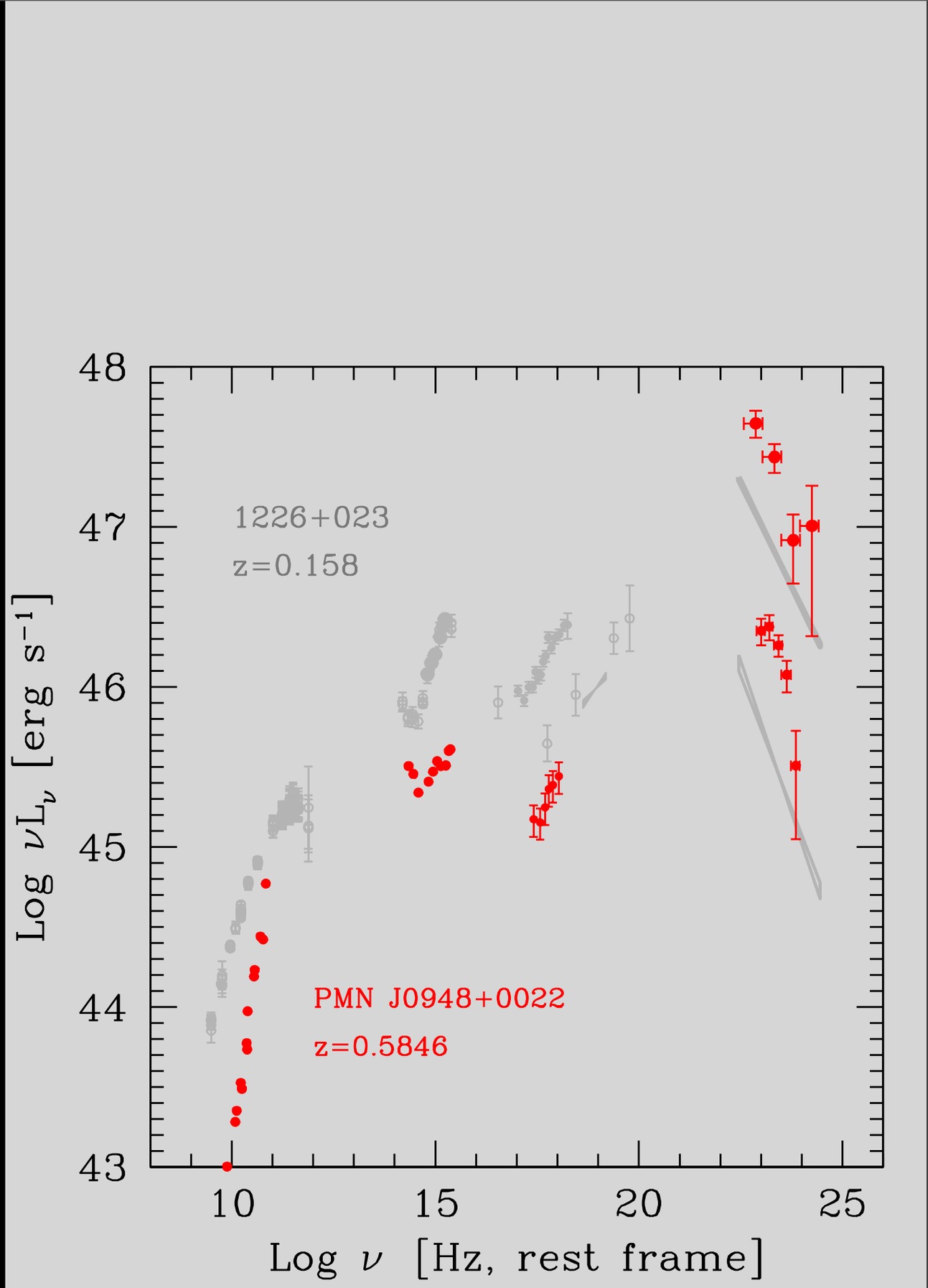
PMNJ0948+0022 for the July 2010 outburst, image compilation by L. Foschini

Foschini et al. 2010

PMN J0948+0022

- Lγ ~ 10^{48} erg s^{-1} at 0.1–100 GeV (first time that such a power is measured from a NLS1)

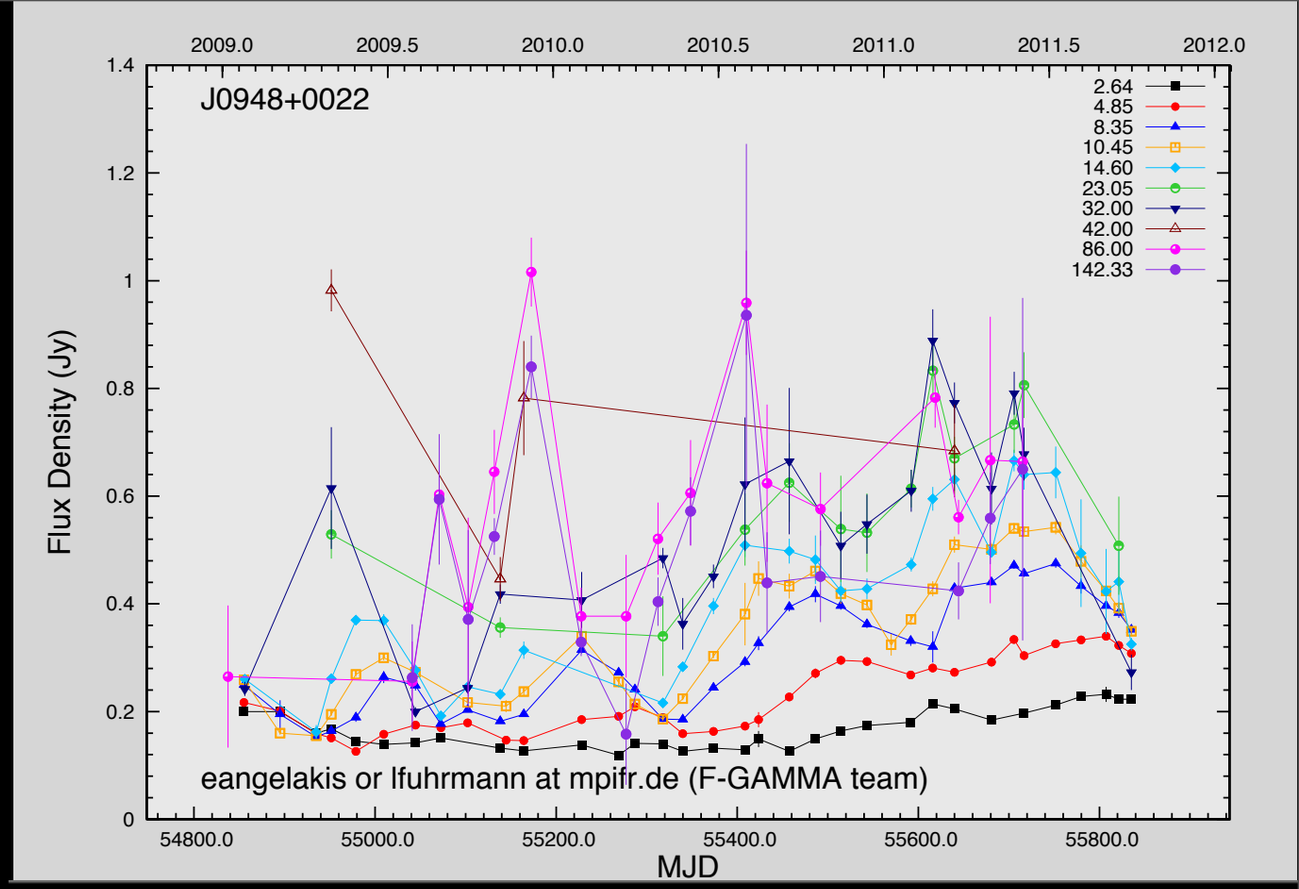
- confirms, that NLS1s can host relativistic jets as powerful as those in blazars and radio galaxies, despite the relatively low mass (1.5 × 10^{8} M⊙)

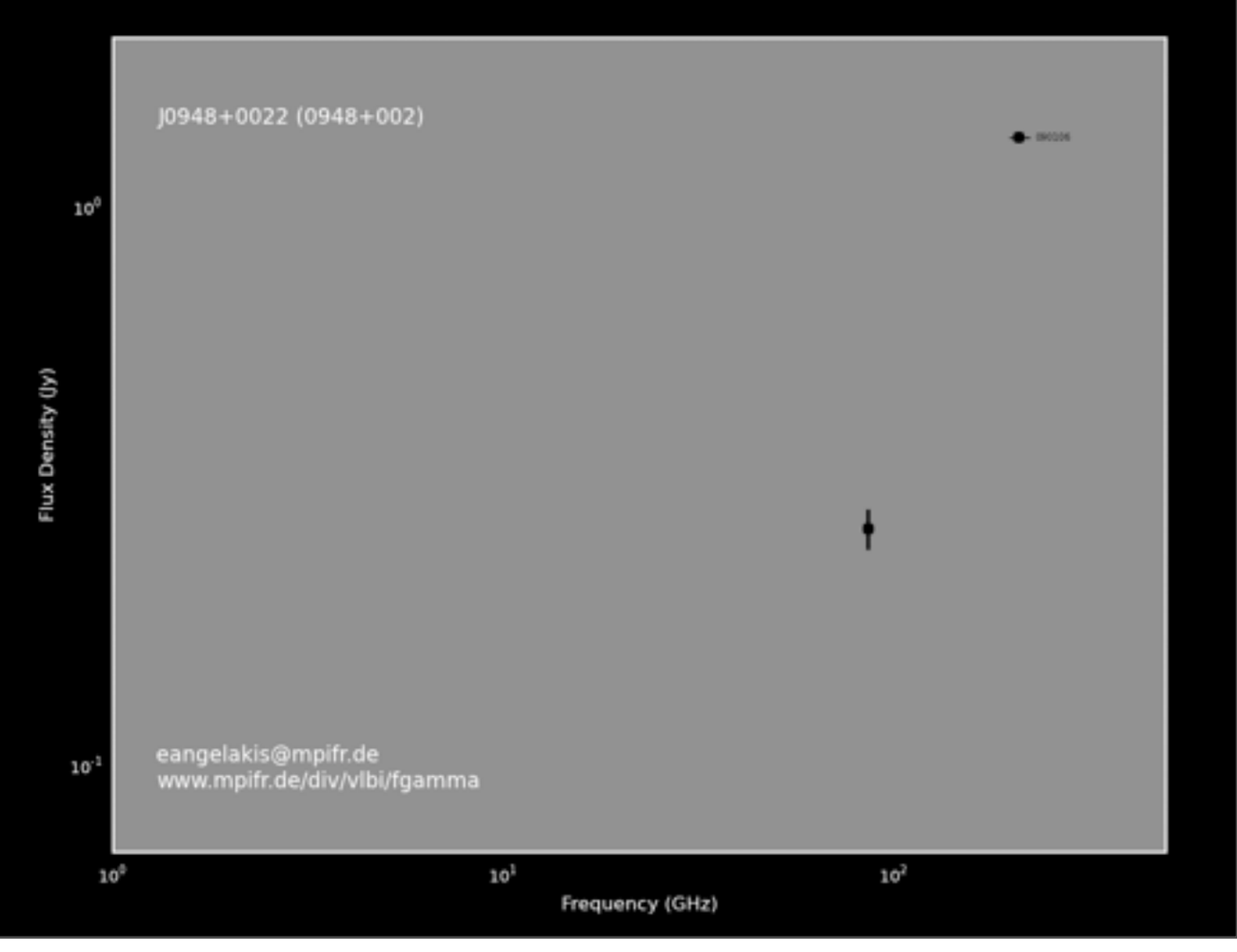


Foschini et al. 2010

gamma-ray loud NLSy1s in radio

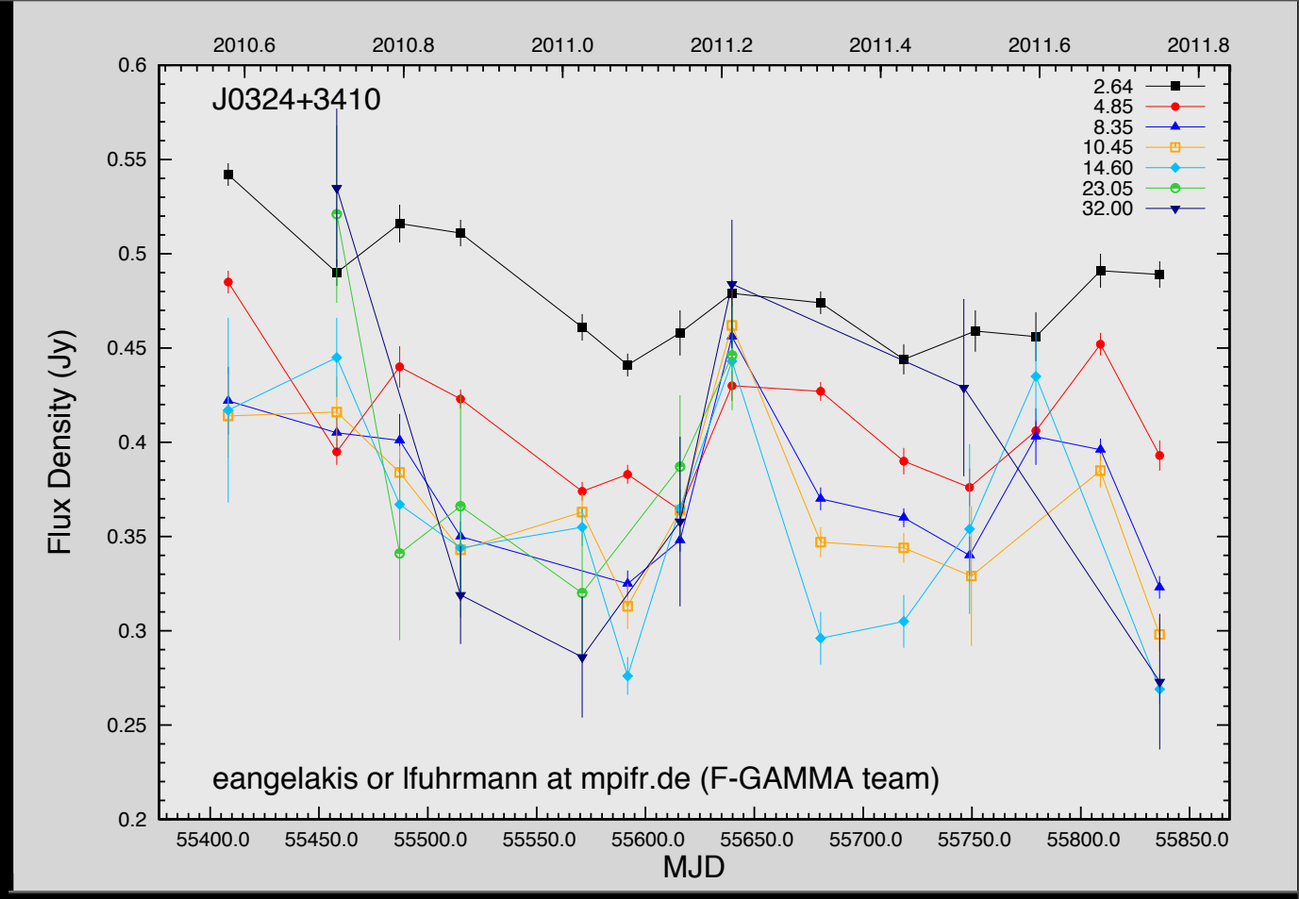
- J0948+0022:
  - blazar-like, relativistic-jet-like behavior, rapid spectral variability (weeks to month)!
  - intense spectral evolution present
  - SF analysis:
    - **15 GHz:** $\mathrm{Log}(T_B) \sim 2 \cdot 10^{11} \Longrightarrow \delta \sim 2$

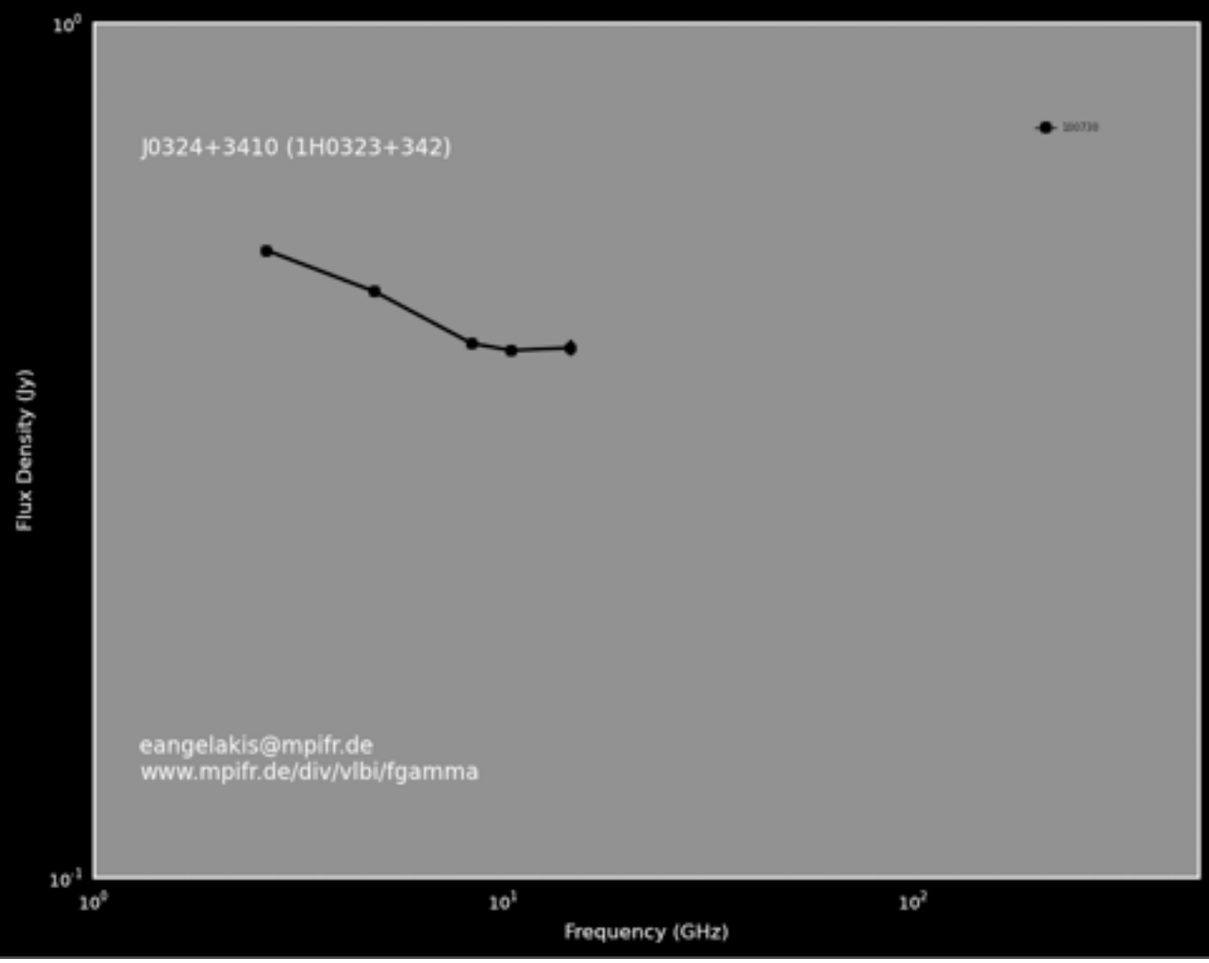




gamma-ray loud NLSy1s in radio

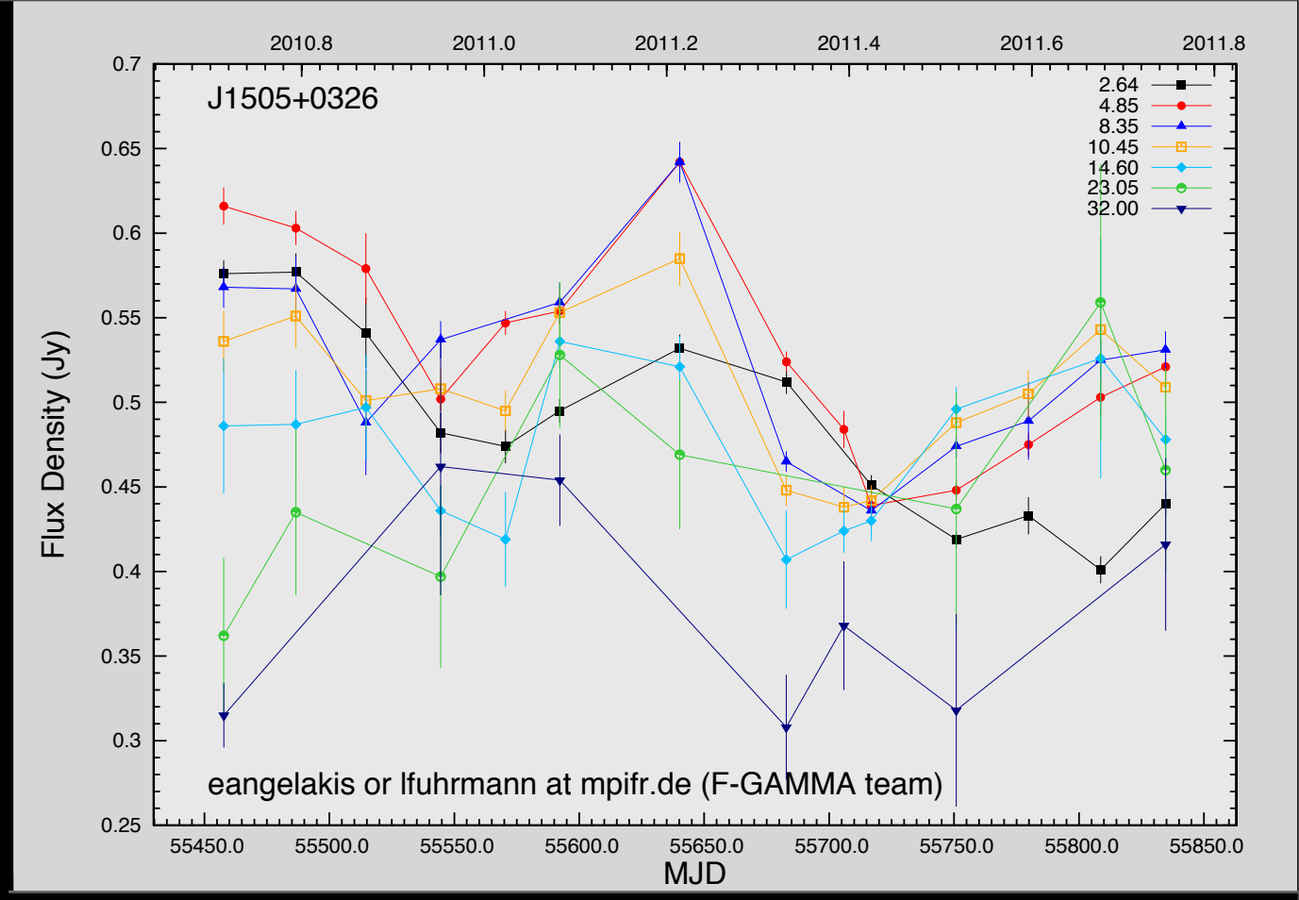
- J0324+3410:
  - blazar-like, relativistic-jet-like
  - intense spectral evolution present
  - rapid spectral variability
  - SF analysis:
    - $t_{var,15GHz}$ ~210 days, ΔS ~ 25%
    - $t_{var,15GHz}$ ~ 60 days, ΔS ~ 60%
    - **15 GHz:** $\mathrm{Log}(T_B) \sim 2 \cdot 10^{11} \Longrightarrow \delta \sim 2$



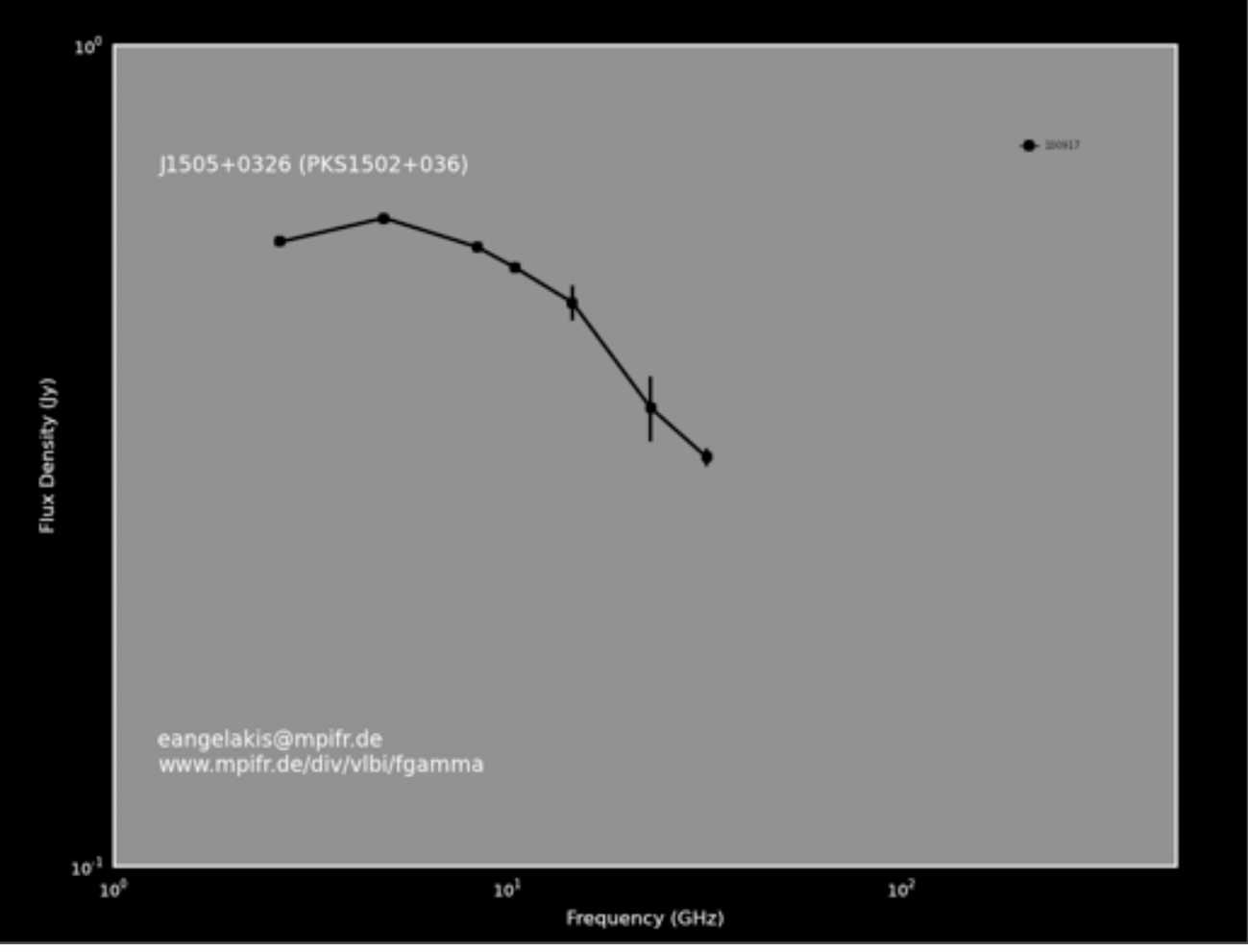


gamma-ray loud NLSy1s in radio

- J1505+0326:
  - similarly, blazar-like, relativistic-jet-like, intense spectral evolution present, rapid spectral variability

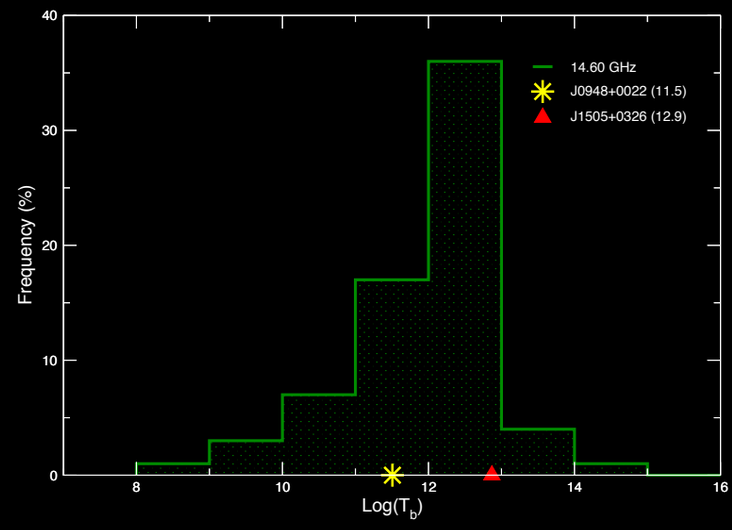


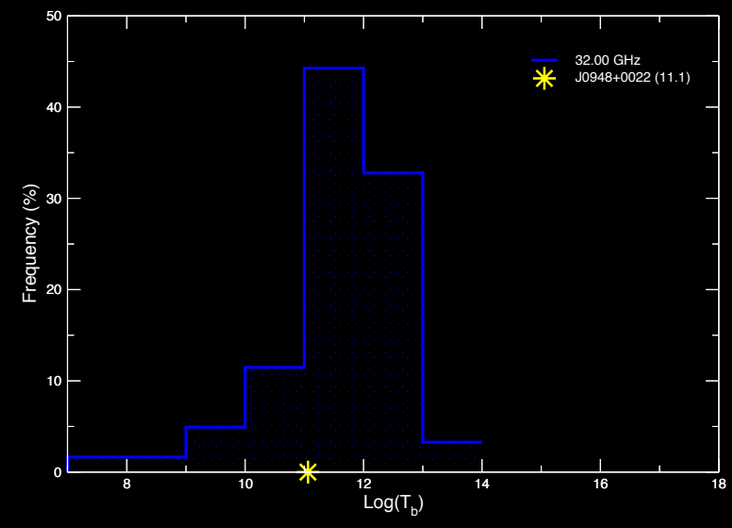
- SF analysis:
  - **15 GHz:** $\mathrm{Log}(T_B) \sim 7.4 \cdot 10^{12}$ $\Longrightarrow \delta \sim 5.4$

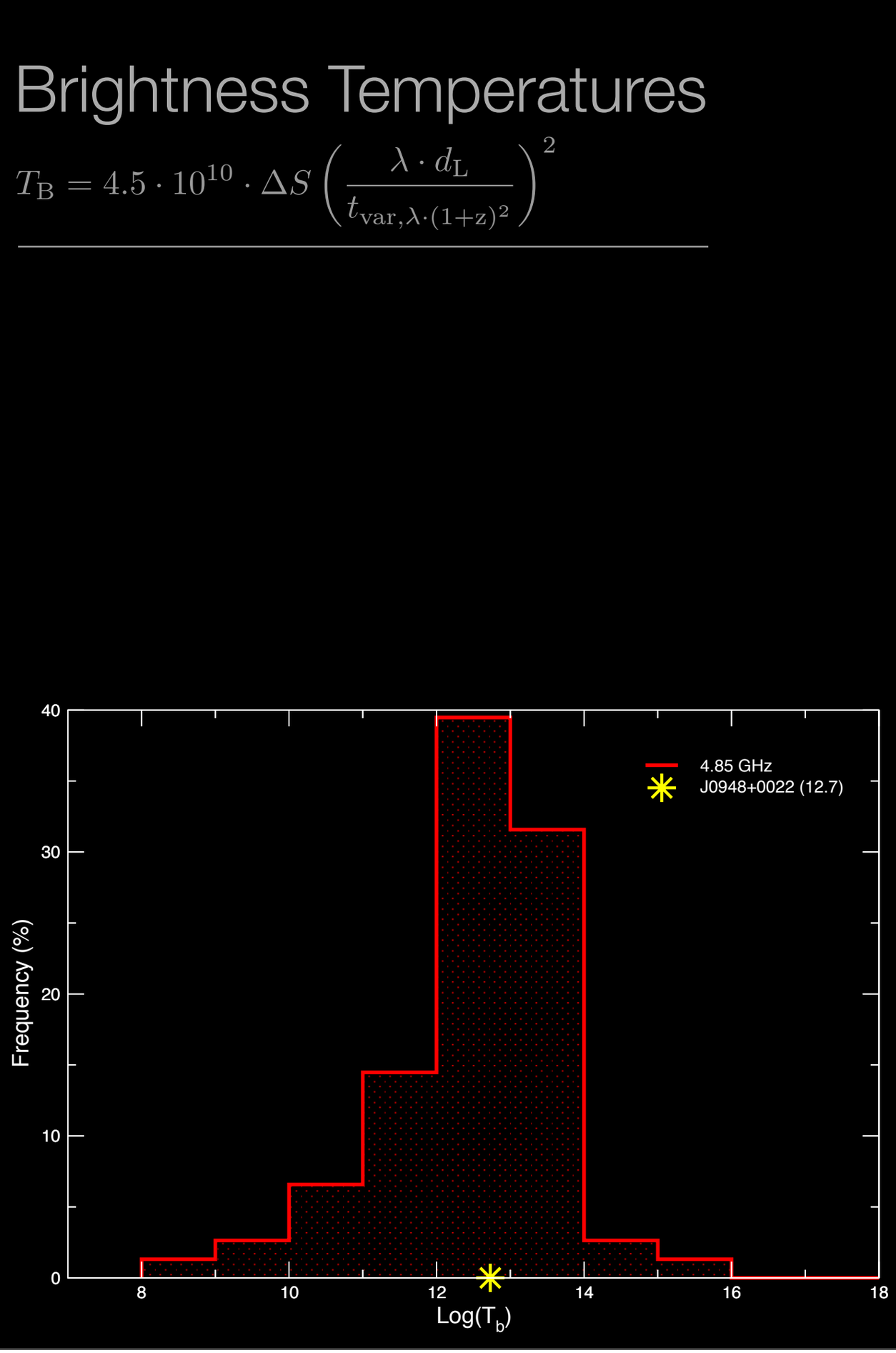


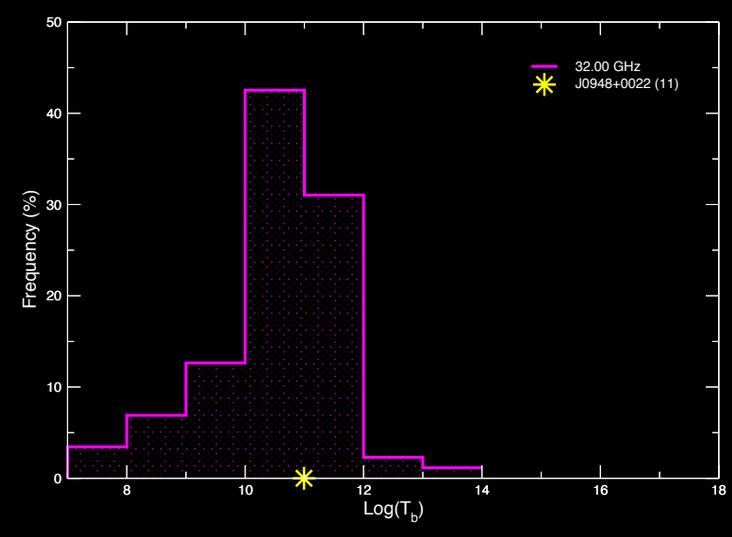
Brightness Temperatures

$$T_{\mathrm{B}} = 4.5 \cdot 10^{10} \cdot \Delta S \left(\frac{\lambda \cdot d_{\mathrm{L}}}{t_{\mathrm{var},\lambda \cdot (1+\mathrm{z})^2}} \right)^2$$









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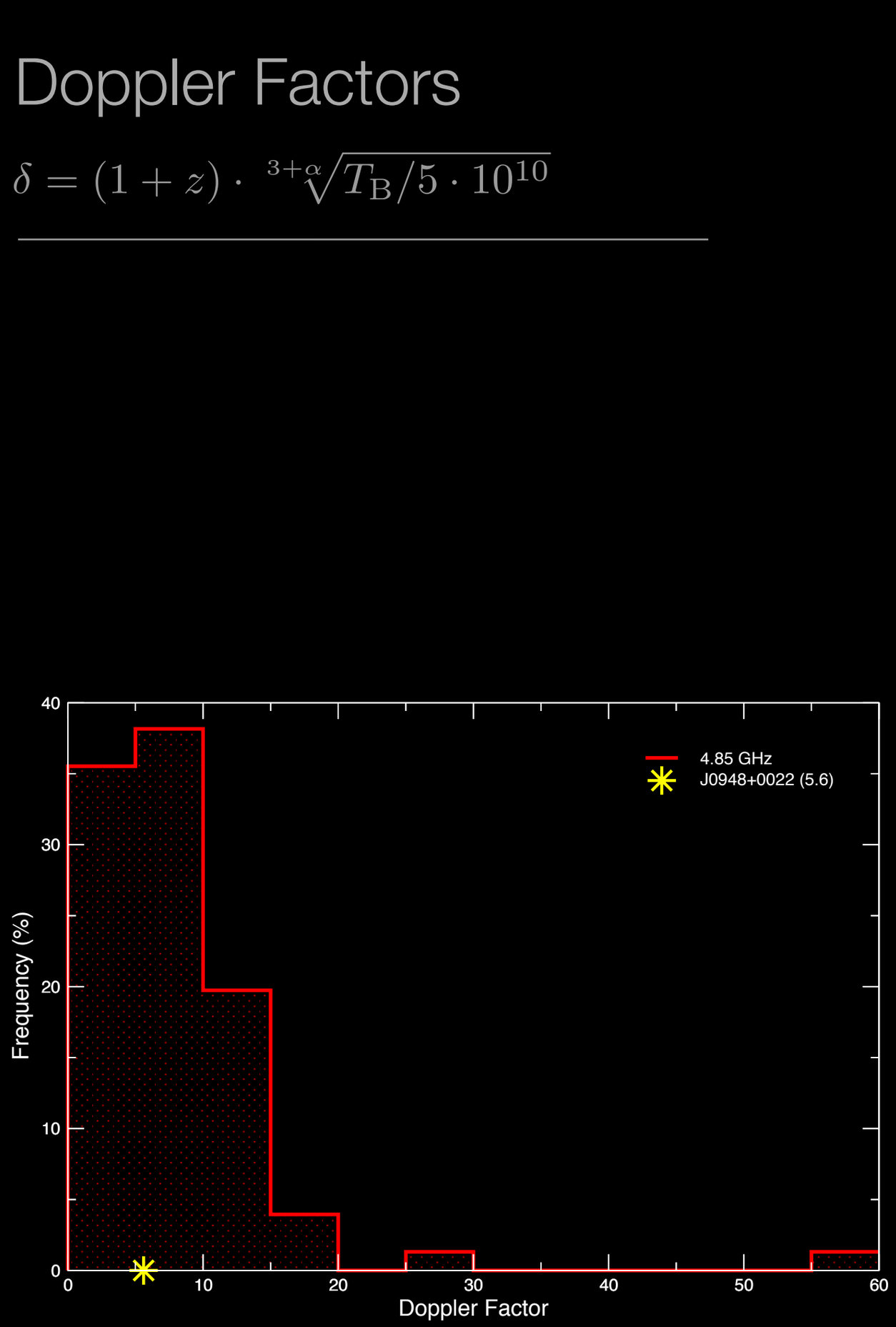
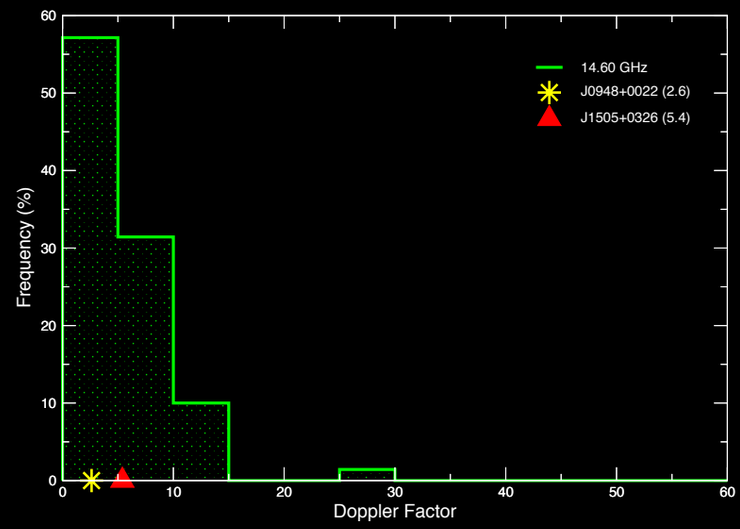
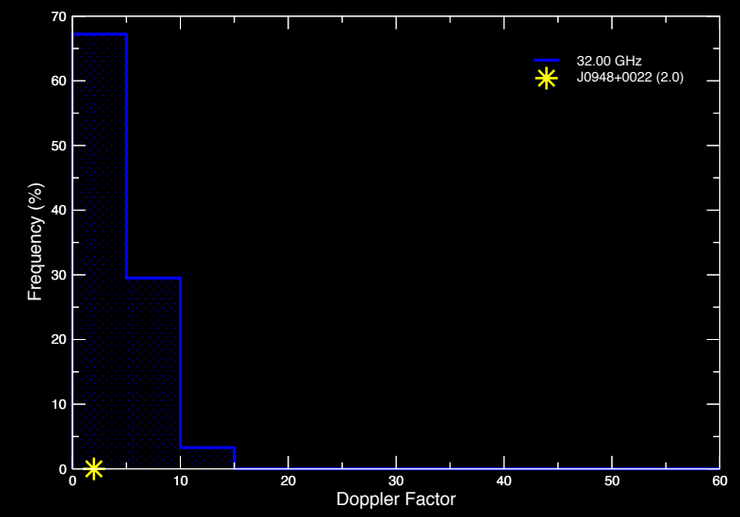
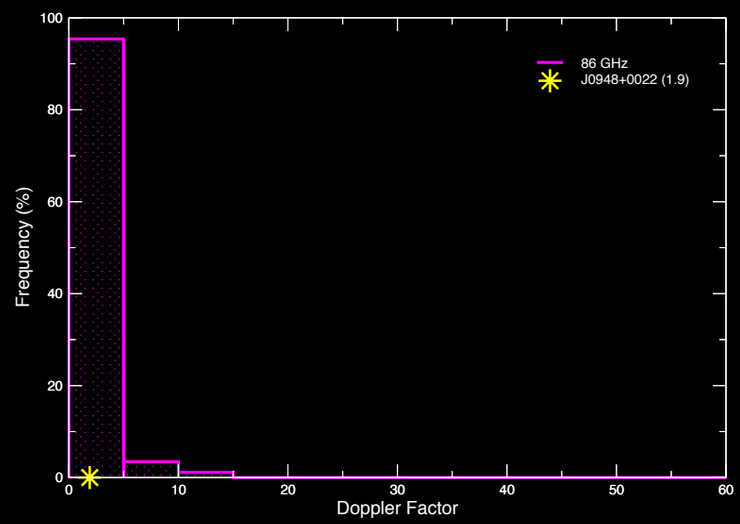
Doppler Factors

$$\delta = (1+z)\cdot \sqrt[3+\alpha]{T_{\mathrm{B}}/5\cdot 10^{10}}$$









Conclusions

- particularly fast variability at radio bands
- intense spectral evolution: with peculiar characteristics (e.g. very inverted or very steep spectra)
- blazar like behavior
- J0948 and J0324 show low Doppler factors while J1505 appears at the high end tail of the distribution
- MW campaigns (e.g. Foschini et al.) are in progress and 3 Effelsberg proposals

Thank you!

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