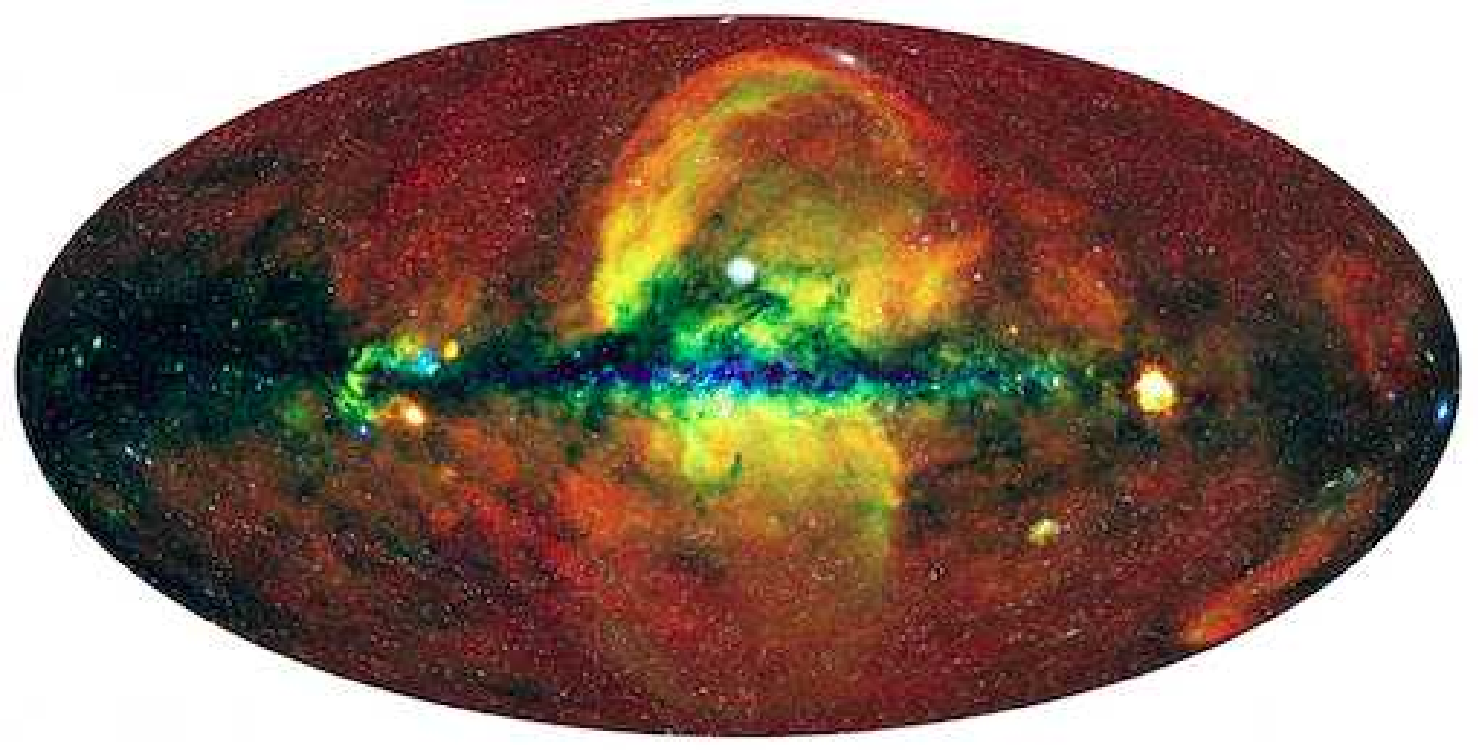
A problem of classification the eROSITA Tidal disruption events among other variable X-ray sources

Georgiy Khorunzhev, Prof. Marat Gilfanov, Prof. Sergey Sazonov
(IKI RAS) Space Research instutute of the Russian academy of sciences

The talk presents results from the SRG/eROSITA Russian consortium of following scientific collaboration groups:
The SRG/eROSITA X-ray catalog
The SRG/eROSITA Active galactic nuclei, QSO/TDE
The ground optical support of the SRG



High Energy Astrophysics and Cosmology in the era of all-sky surveys, Yerevan, 2024

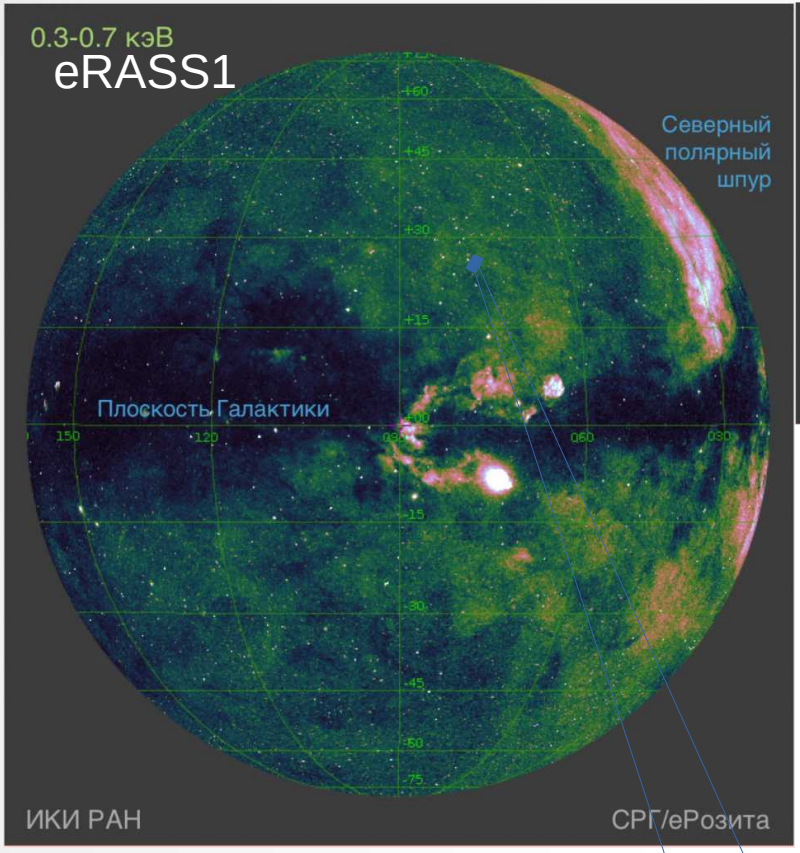
Talk plan

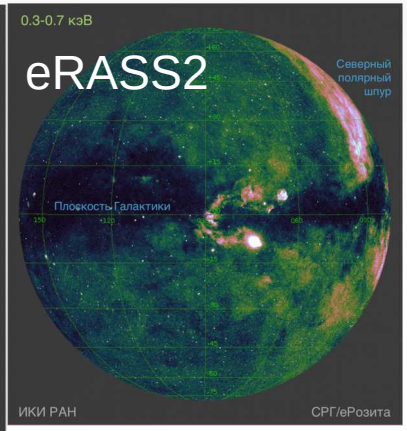
- **Introduction**
- Half-year SRG/eROSITA X-ray surveys
  A constellation of ground telescopes
  The Tidal Disruption events in X-ray data [Sazonov+2021]
- **Classification for the SRG/eROSITA TDE**
- Problem to distinguish AGN and TDE among X-ray variable sources [Khorunzhev+2022]
- The LX/L[OIII] relation helps catch TDE even for archive

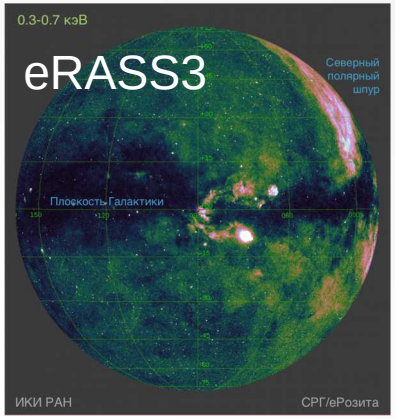
Optical classification for the extreme variable SRG/eROSITA soruces

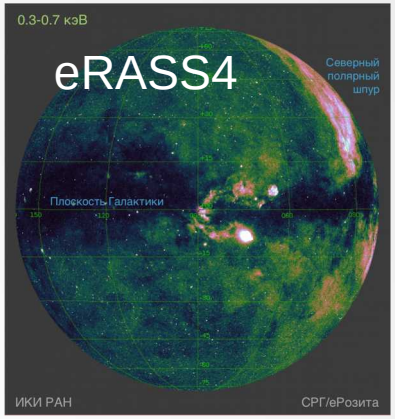
- The most challenging sources are always missed in archive [Medvedev+2022]
- Optical classification of missed sources [Khorunhzev+2024 in press]
- Validation the LX/L[OIII] method for extreme variable AGN

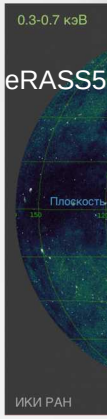
The SRG/eROSITA X-ray sky
Half-year surveys











SRG/eROSITA X-ray sky snapshot of the first half-year all sky survey (Part of Russian consortium)
SRG/eROSITA covered all sky 4.37 times.

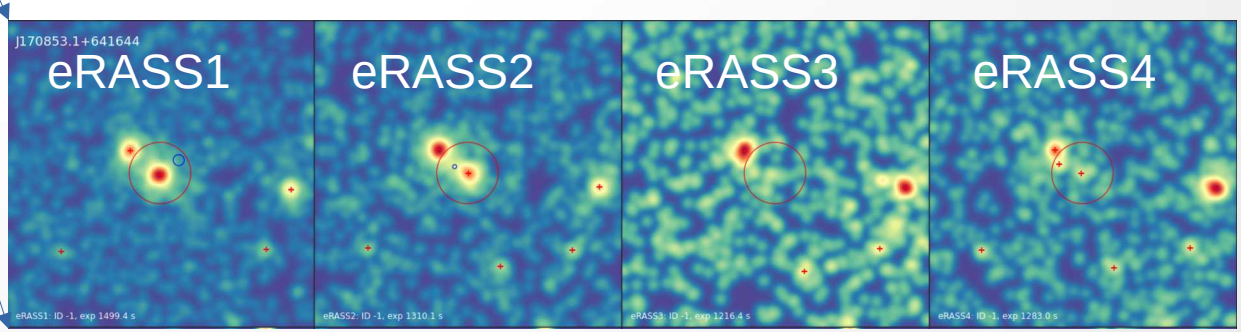
Mean source gets in the eROSITA FOV six times for 40s every half-year

The Russian consortium has an X-ray sample for ~1300 extragalactic sources that have changed X-ray flux more than 10-times between the half years surveys.

Approximately 400 souces had no spectroscopic redshifts and did not have astrometry classification of the GAIA
The sources could appeared AGN, TDE, weak stars (CV, M-type)

49 extragalactic sources was detected in all surveys in high and low flux state(Medvedev+2022)

Example of stable and variable sources:



Russian telescopes provide a ground support for the SRG

Telescope	Instrument	Typical task for SRG
BTA 6-м SAO RAS Cauqasus	Spectrographs Scorpio-2 Scorpio-I	Spectroscopy in the range of 3500-10000 A r~21.5 mag S/N~5 texp=1 hour Deep photometry g,r,i,z down to r~25 mag
RC2500 CMO GAISH MSU	Spectrograph TDS (Medium Resolution)	Spectroscopy in the range of 3000-7200 A
	Infrared spectrograph and photometer ASTRONIRCAM	IR photometry of Z,Y,J,H,K bands

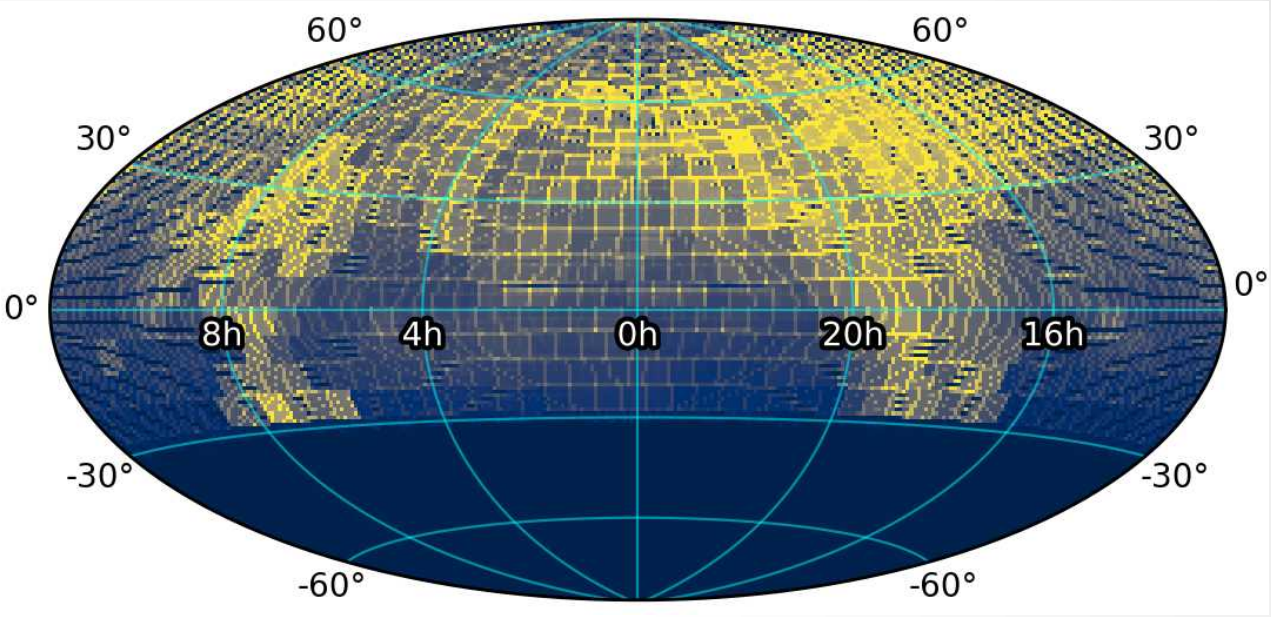
Telescope	Instrument	Typical task for SRG
AZT-33IR 1.6-м Sayan Observatory Siberia	Spectrograph ADAM (Low resolution)	Spectroscopy in the range of 4200-9800 A r~20 mag S/N~5 t=1 h
	Andor IKON-M Imager	Photometry in the bands g,r,i,z z~21 T=3600
RTT-150 1.5-м TUG observatory, Antalya	Spectrograph TFOSC (Low and Medium resolution)	Spectroscopy 4200-9500 A r~19.5 mag S/N~5 t=1 h

Systematic Search for TDE in the optical band

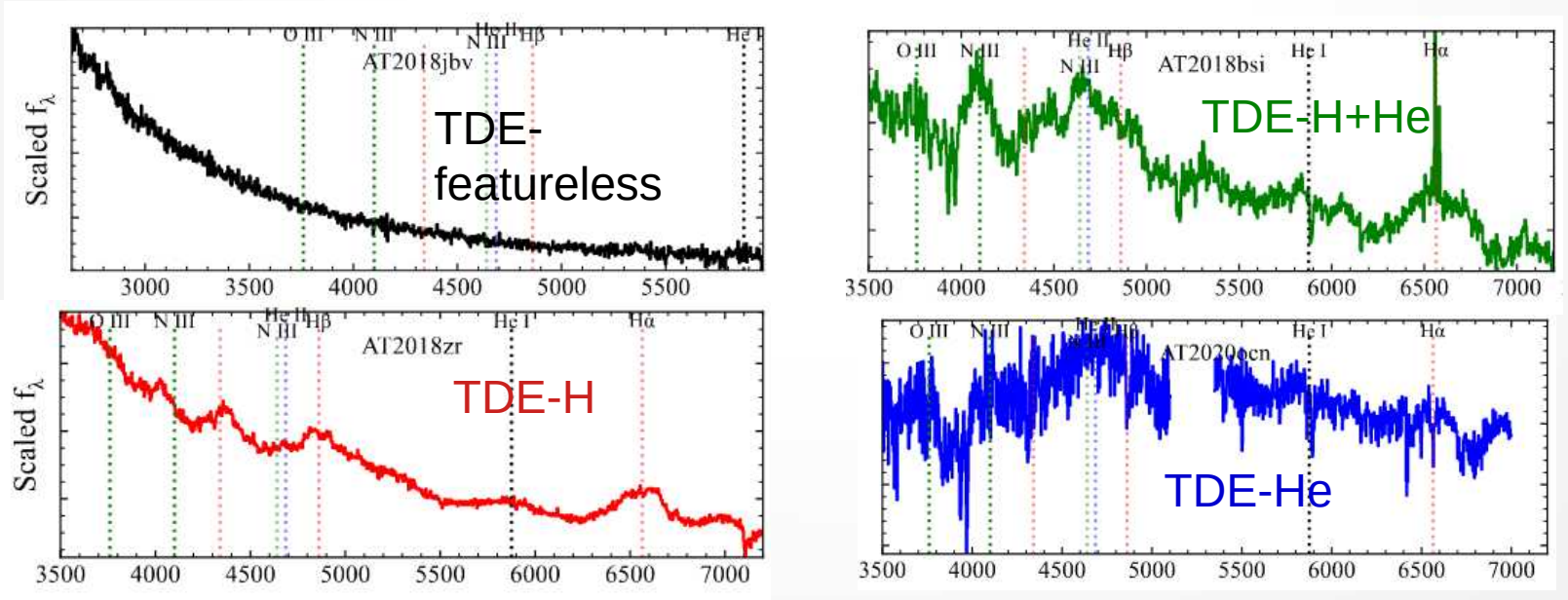
Zwicky Transient Facility Phase-I
(March 2018 – September 2022)

48-inch telescope with FOV=47 sq.d
makes sky survey each 3 night down to sensitivity r~20.5
Whole coverage around 25000 sq.d

30 TDE was discovered at ZTF-I
14/30 has detected by SWIFT

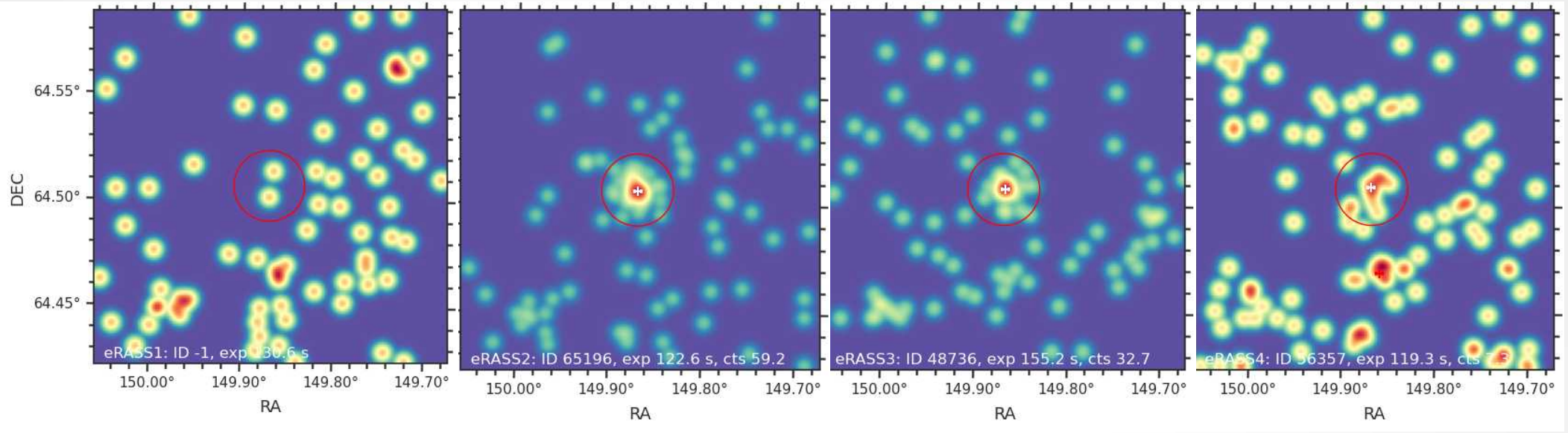


A spectral classification of optical TDE near optical peak (Hammerstein+2023):



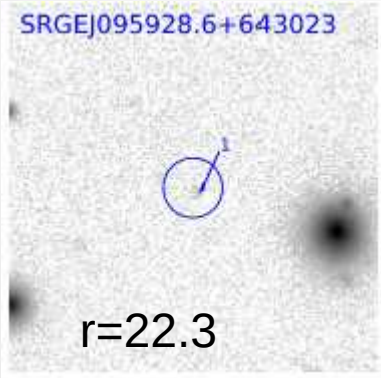
Systematic Search for TDE in the SRG/eROSITa ½-year surveys

Sazonov+2021 obtained 13 X-ray selected TDE from 2-d eRASS survey.
Most X-ray TDE have no optical flares. Optical spectrum is quiet galaxy. New class TDE-host.



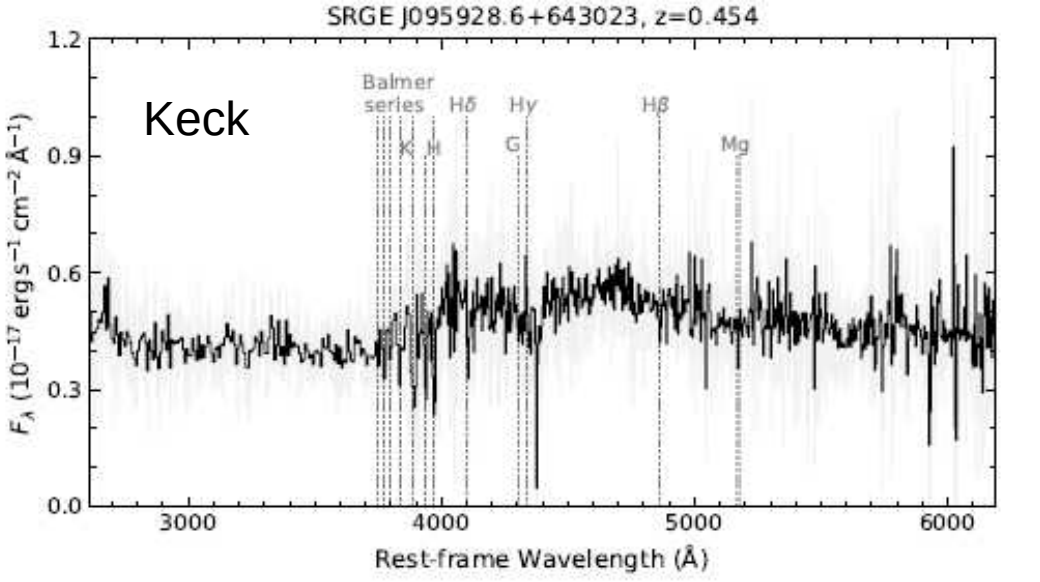
Absorbed power-law model: TBABS*ZPHABS*ZPOWERLW

Object (SRGE)	N_H 10^{21} cm^{-2}	K^a_{1keV}	Γ	cstat/ d.o.f
J095928.6+643023	$2.4^{+21.2}_{-2.4}$	$4.6^{+148.4}_{-2.3} \times 10^{-4}$	$5.7^{+8.9}_{-2.1}$	18.6/17



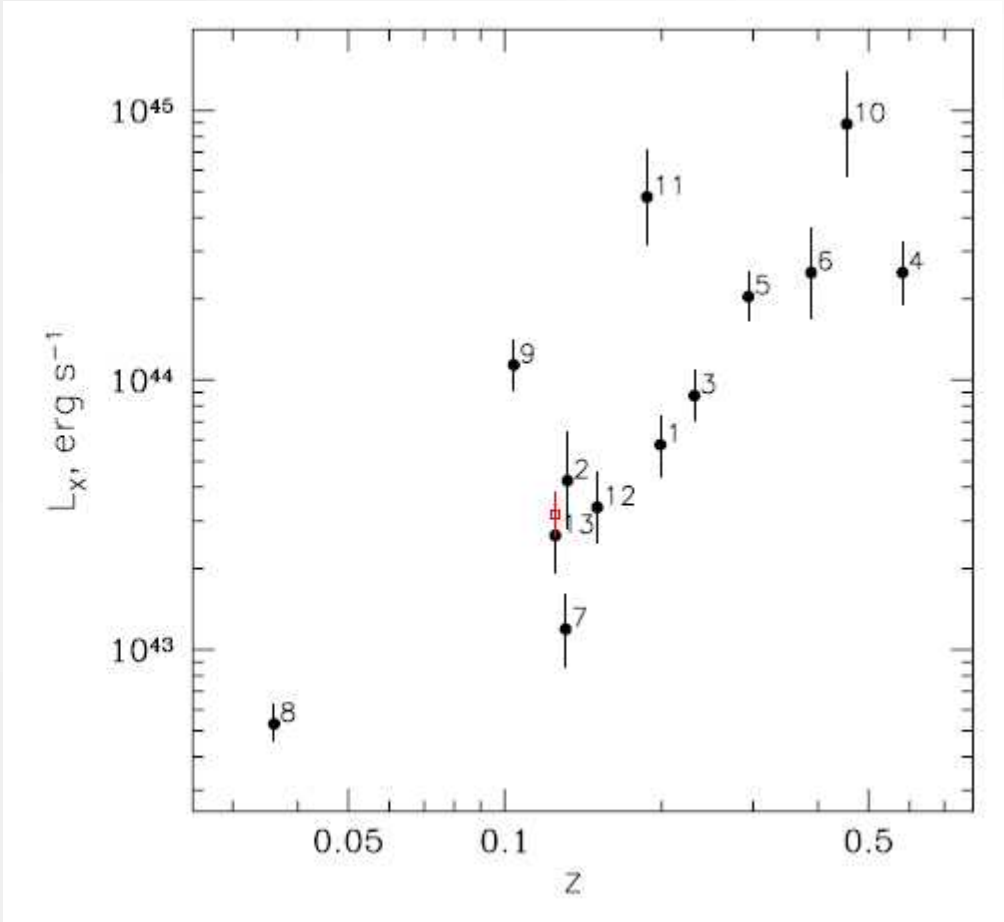
FXmax = 4E-13 erg/s/cm2
LXmax = 9E44 erg/s

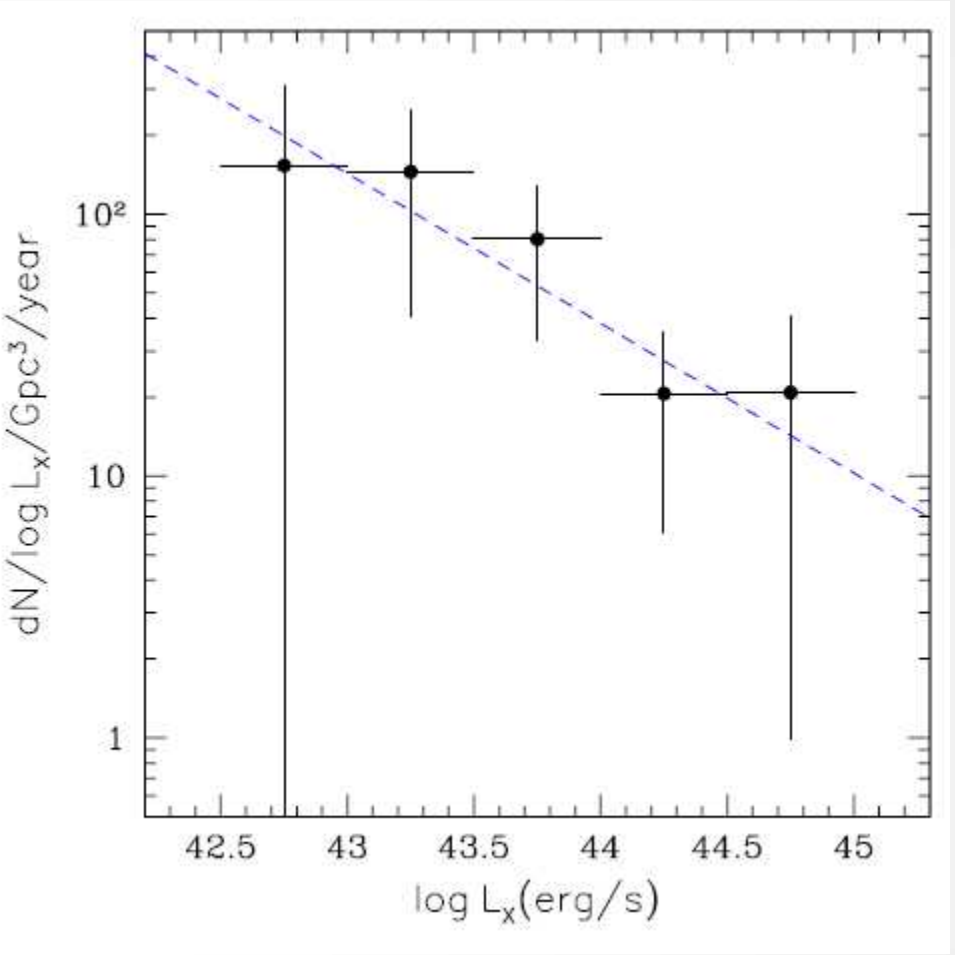
TDE-host class



Systematic Search for TDE in the SRG/eROSITa ½-year surveys

The X-ray luminosity function for TDE was constructed first time in Sazonov+2021





The median redshifts for the eROSITA X-ray selected TDE (Sazonov+2021) are higher <z>=0.2 than optical selected TDE <z>=0.1 (Hammerstein+2023)
More luminous optical TDEs are brighter in the X-ray (Hammerstein+2023)
An X-ray sample extends a range of TDE to lower luminosites and higher redshifts

Strategy for search TDE among X-ray data of SRG/eROSITA

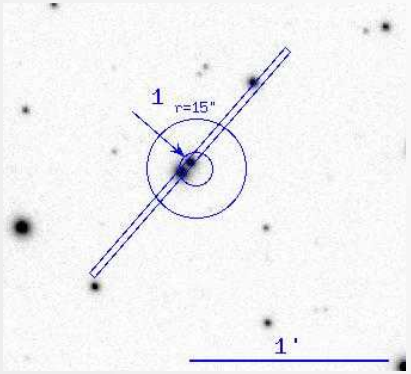
For the SRG 1/2-y X-ray surveys there is no clear difference between flare in AGN and TDE.

Soft X-ray flares can be produced by AGN and the ½ year scale too long to fix flux drop according logt=-5/3 for weak TDE. Or the fall according log t=-5/3 may not appear.
Both weak AGN and TDE host galaxy can have moderate WISE color W1-W2<0.6.

Only optical spectroscopy can provide the final answer about the source nature.
Unfortunatelly, a spectroscopy of TDE candidates could be done a few month after trigger

Selection for spectroscopy at Sazonov et al. (2021):

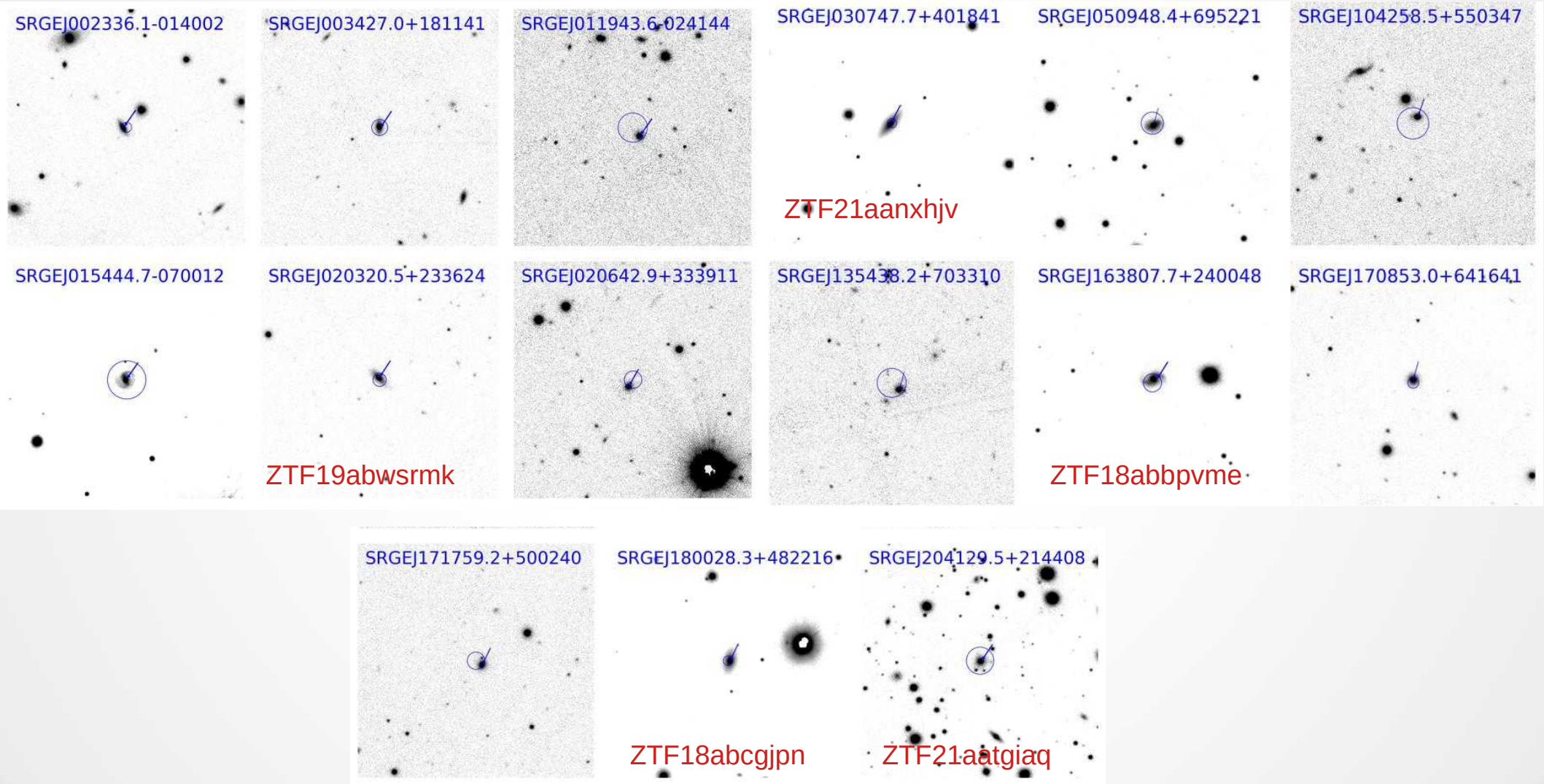
STAR	AGN	TDE
All sources in R98 localization radius appear GAIA stars according parallax or proper motion.	Color WISE W1-W2>0.8 (Assef+2012)	Not GAIA star and not AGN (W1-W2<0.8)
	Archive AGN spectrum	Archive galactic spectrum
	~~Weak X-ray flux observed in previous half-year surveys~~	~~ZTF signal occurs after SRG Launch~~
	~~Has hard X-ray spectrum~~	~~Has soft X-ray spectrum~~



Developing a classification for TDE using optical spectrum

The sample of 15 observed by the russian telescopes had been studied by Khorunzhev+2023
The sources was selected among 400 X-ray spectroscopicaly observed variable sources and shown features may associated both to AGN or TDE activity.

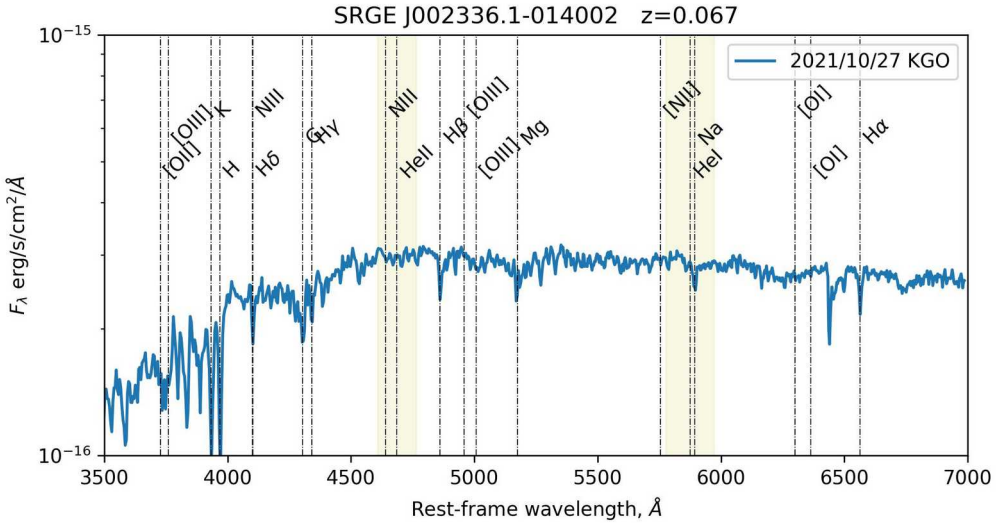
Only 1/3 sample had ZTF optical flare



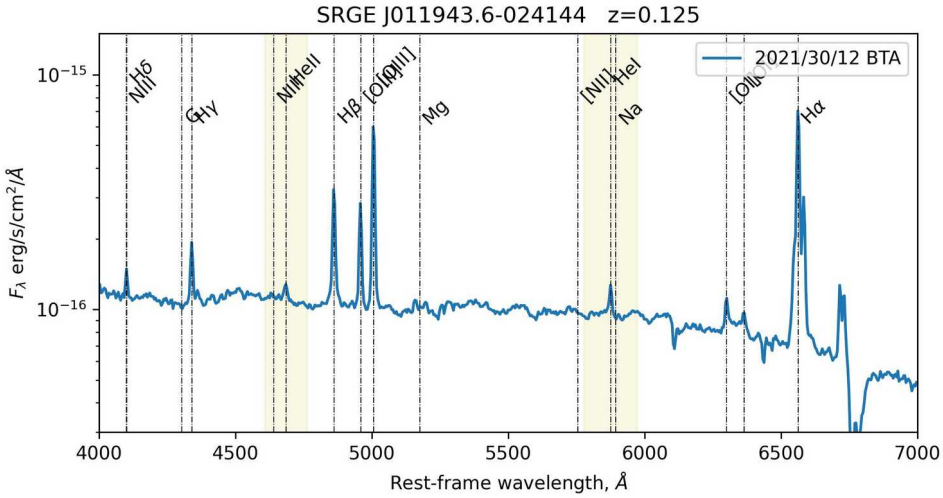
Developing a classification for TDE using optical spectrum

AGN Features: strong emission lines [OIII], [NII], broad H balmer line
TDE Features: broad H and He lines, or no any emission line.

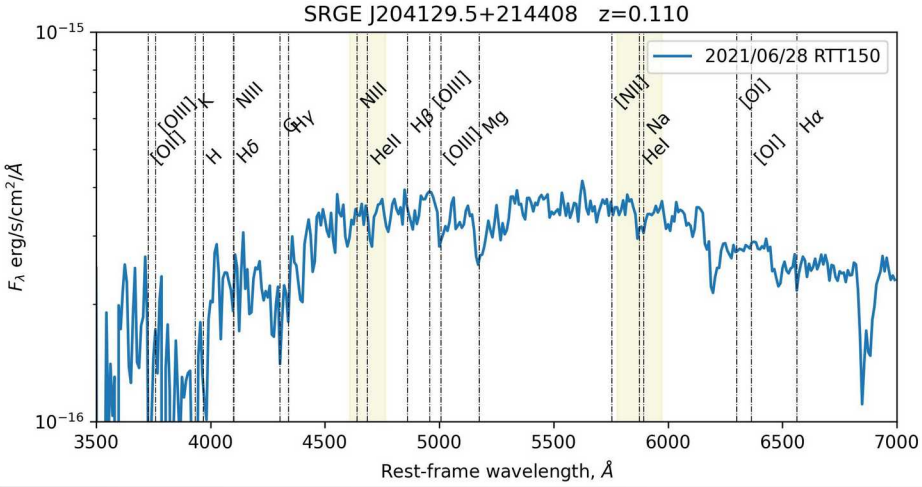
Some X-ray sources have no emission lines:

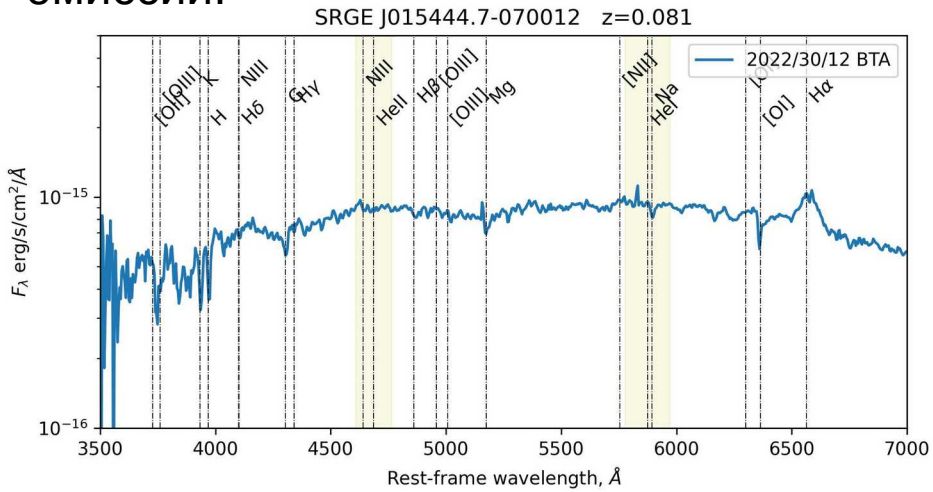


Some X-ray sources have narrow or/and broad lines



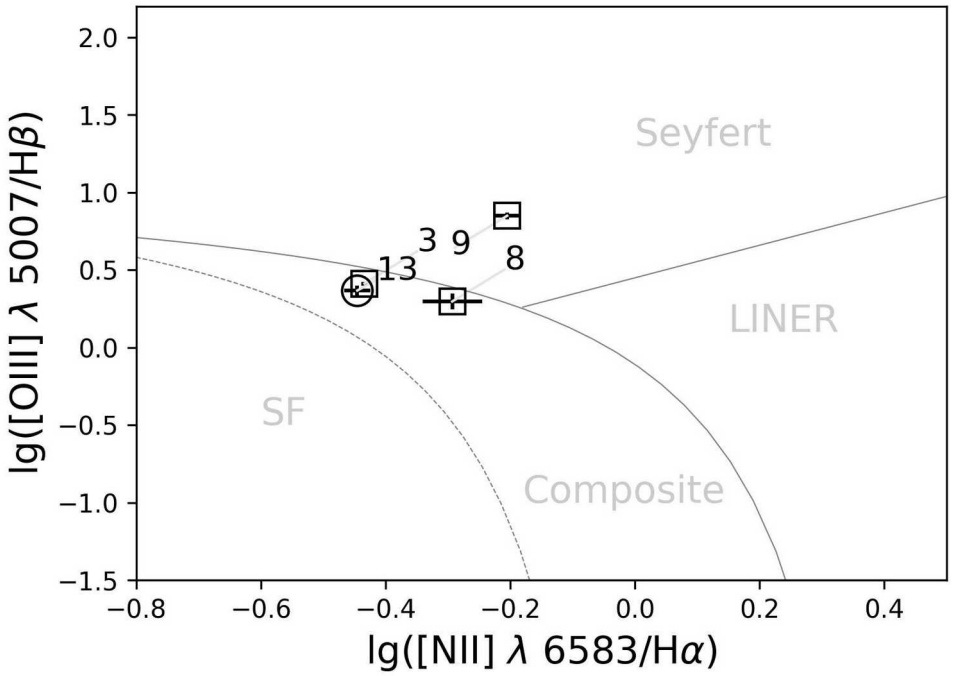
В спектрах наблюдаются широкие линии эмиссии:



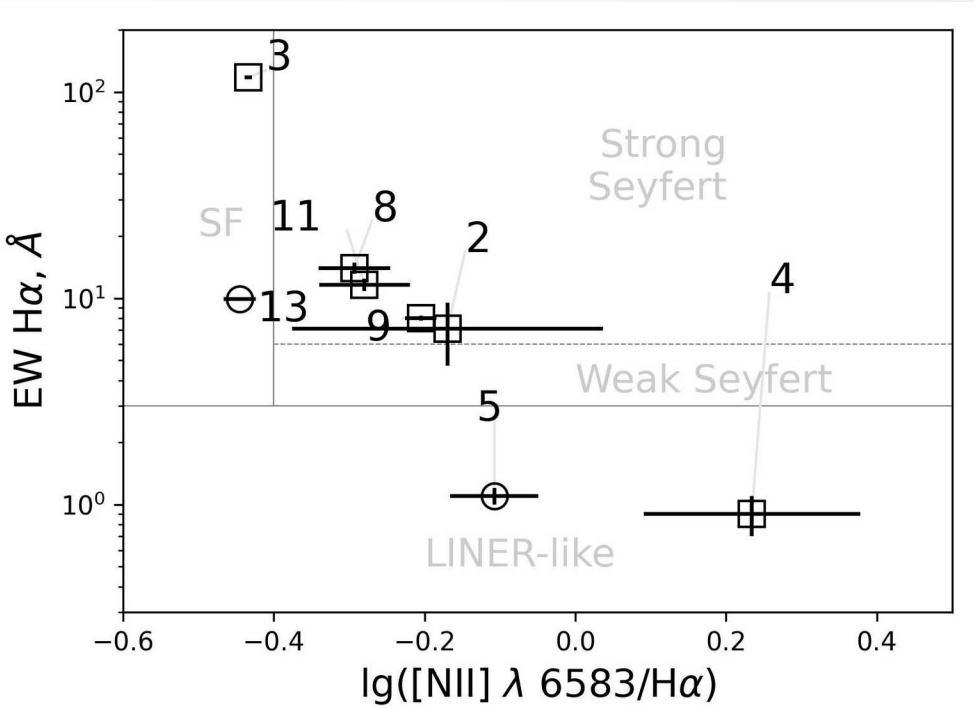


Developing a classification for TDE using optical spectrum

BPT diagramm
Baldwin,Phillips&Terlevich (1981)



WHAN diagramm Cid Fernandes+(2010)

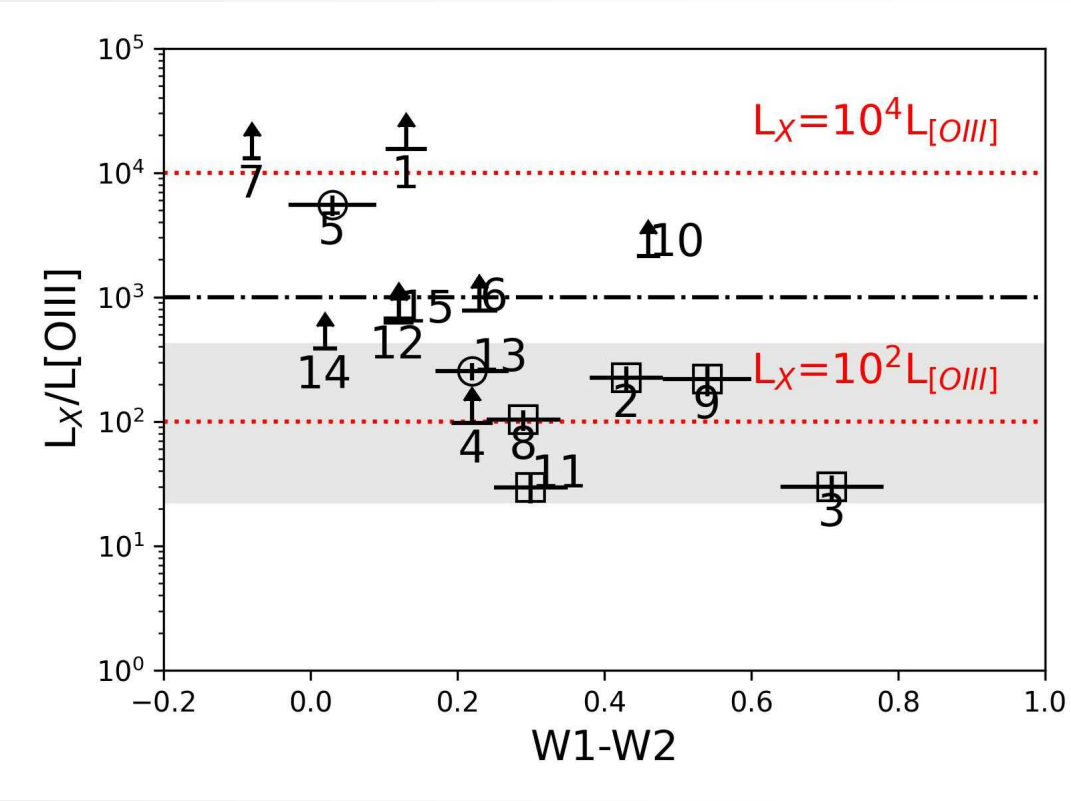


Objects with broad line are shown squares. Objects with narrow lines only shown circles

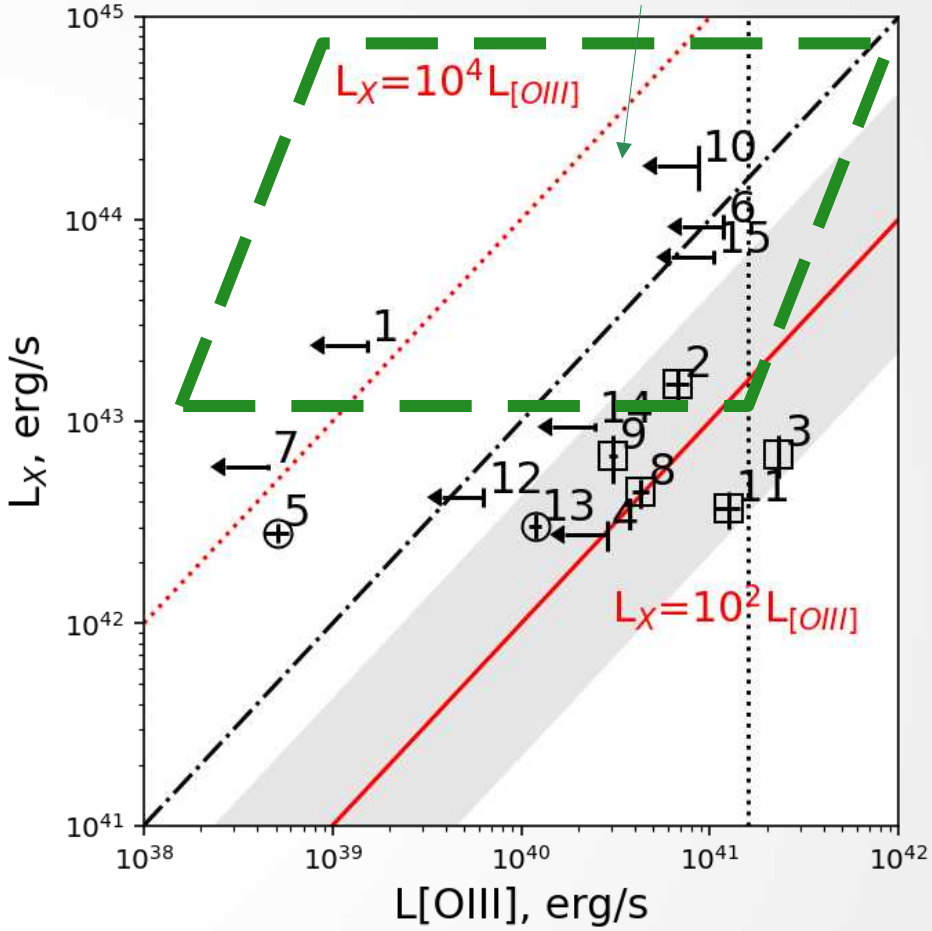
BPT diagram works only for spectrum with complete set of emission lines.
Many sources appear in a composite region. WHAN diagram appropriate for sources with low intensity of H-beta and [OIII] lines. But when H-alpha broad line floods narrow lines it doesn't work

Developing a classification for TDE using optical spectrum

The standing alone [OIII] (5007A) emission line is widely known feature of AGN Activity.
We can use the relation LX/L[OIII] to say may
X-ray emission originates regular AGN activity or not



Sazonov et al. 2021



The most of AGN should be placed in grey area around Lx=100L[OIII] (Ueda+2015, complete sample of SWIFT/BAT AGN at z<0.1)

Sources with LX/LOIII>1000 can be regarded as TDE candidates

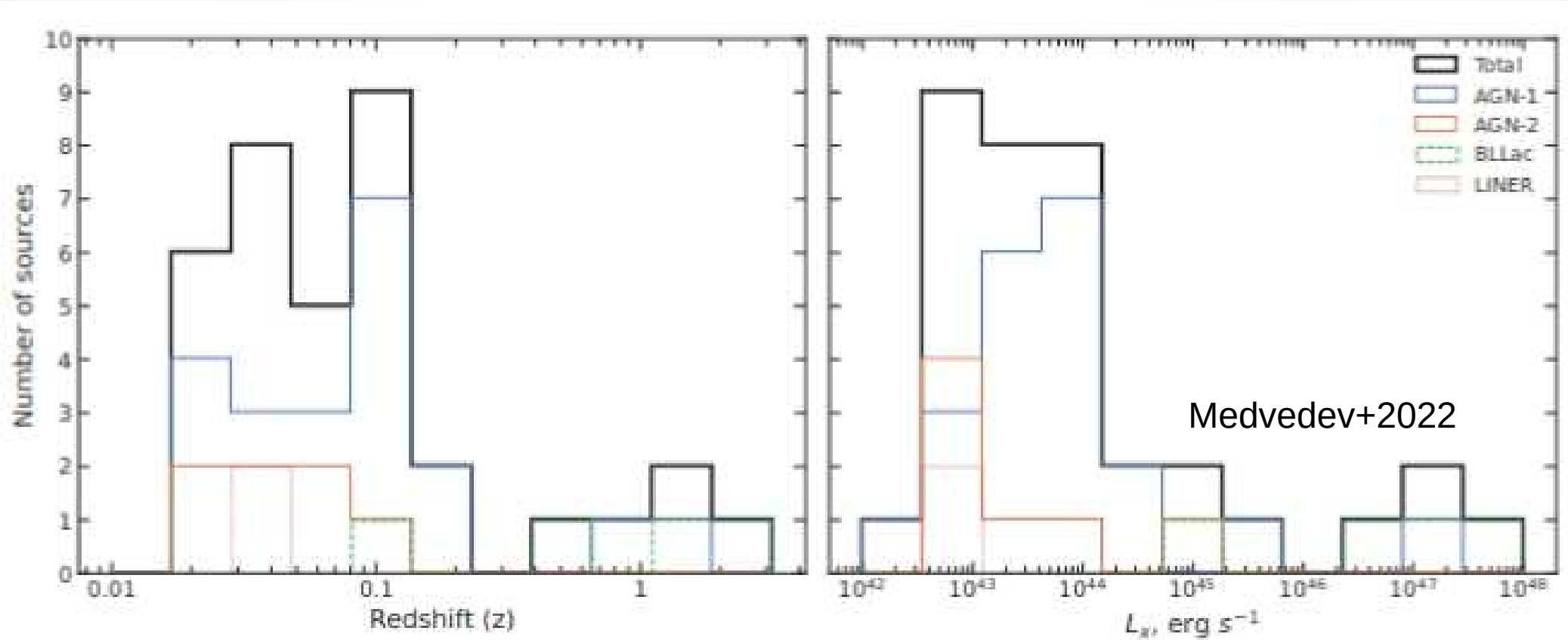
Developing a classification using optical spectrum

- The [OIII] 5007A spectral line (or upper limit) is easy measurable for ground optical telescopes up to redshifts z<0.8
- The relation LX/L[OIII] works for sources with spectra obtained for faded TDE or for archive data
- SRG X-ray data can recover more distant TDE and less luminous TDE than optical surveys give
- A complex view at X-ray and optical data are important for final classification source as TDE
- Among 15 the extragalactic transients we classified 5 new and 1 known TDE (№7, Yao+2022) using LX/L[OIII] criterion. Two sources are still unknown. Other sources are AGN.
- It is interesting to check could the LX/L[OIII] fails for extremely variable AGN (e.g. Medvedev+2022)

Optical classification extreme variable soruces SRG detected in low state

The sample of 49 SRG/eROSITA X-ray sources, that change X-ray flux more than 10 times (R>10) between a half-year surveys and detected in all eRASS surveys both soft and bright X-ray flux states (Medvedev+2022).
They change X-ray flux from 20 to 80 times at half-year scale.

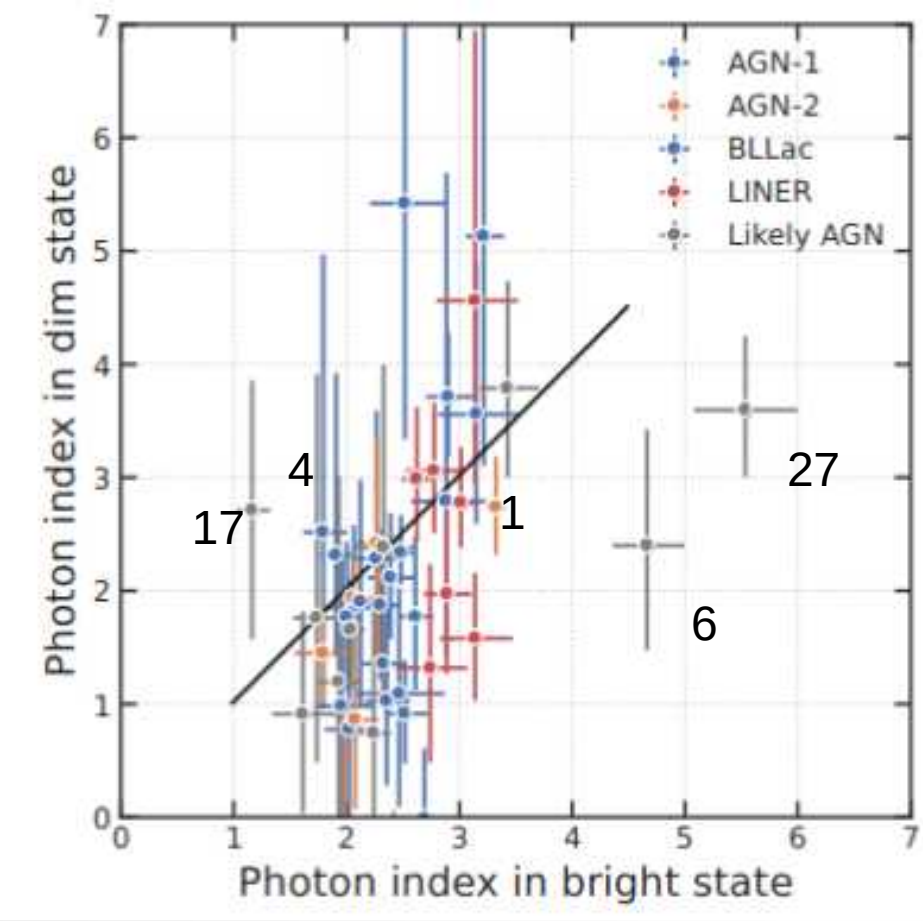
13 sources have no known spectroscopic redshifts. We have obtained its spectrum and provided classification (Khorunzhev+2024 in prep.)



Optical classification for extreme variable soruces SRG detected in low state

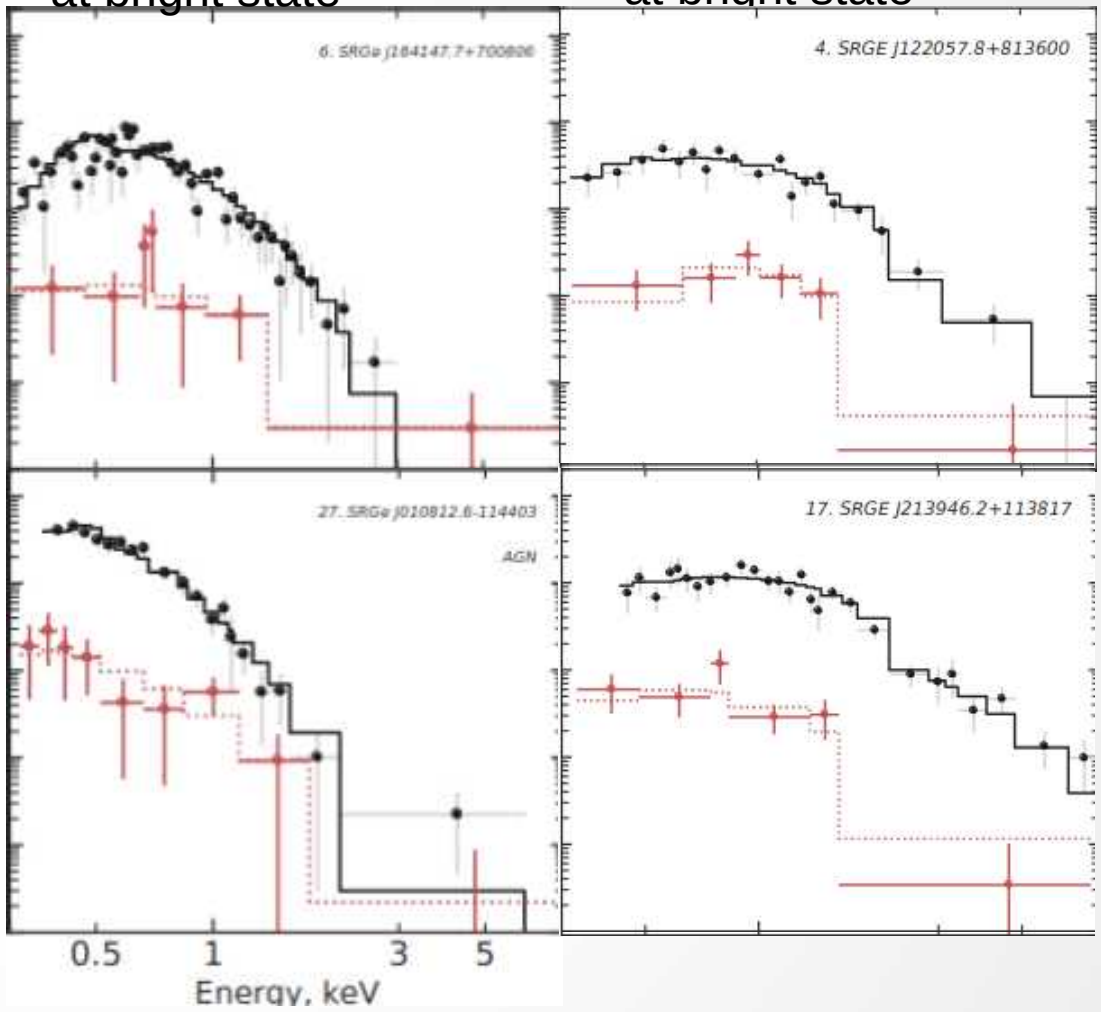
The most interesting sources have no known redshift

X-ray spectral slopes Γ:



Soft X-ray spectrum at bright state

Hard X-ray spectrum at bright state

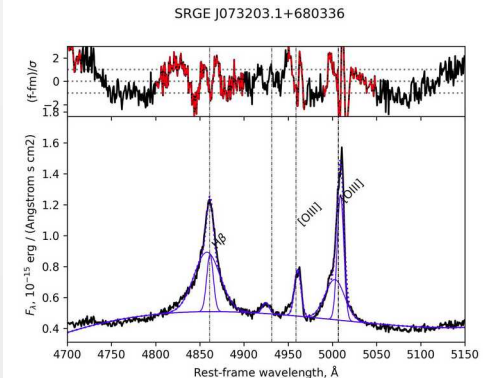


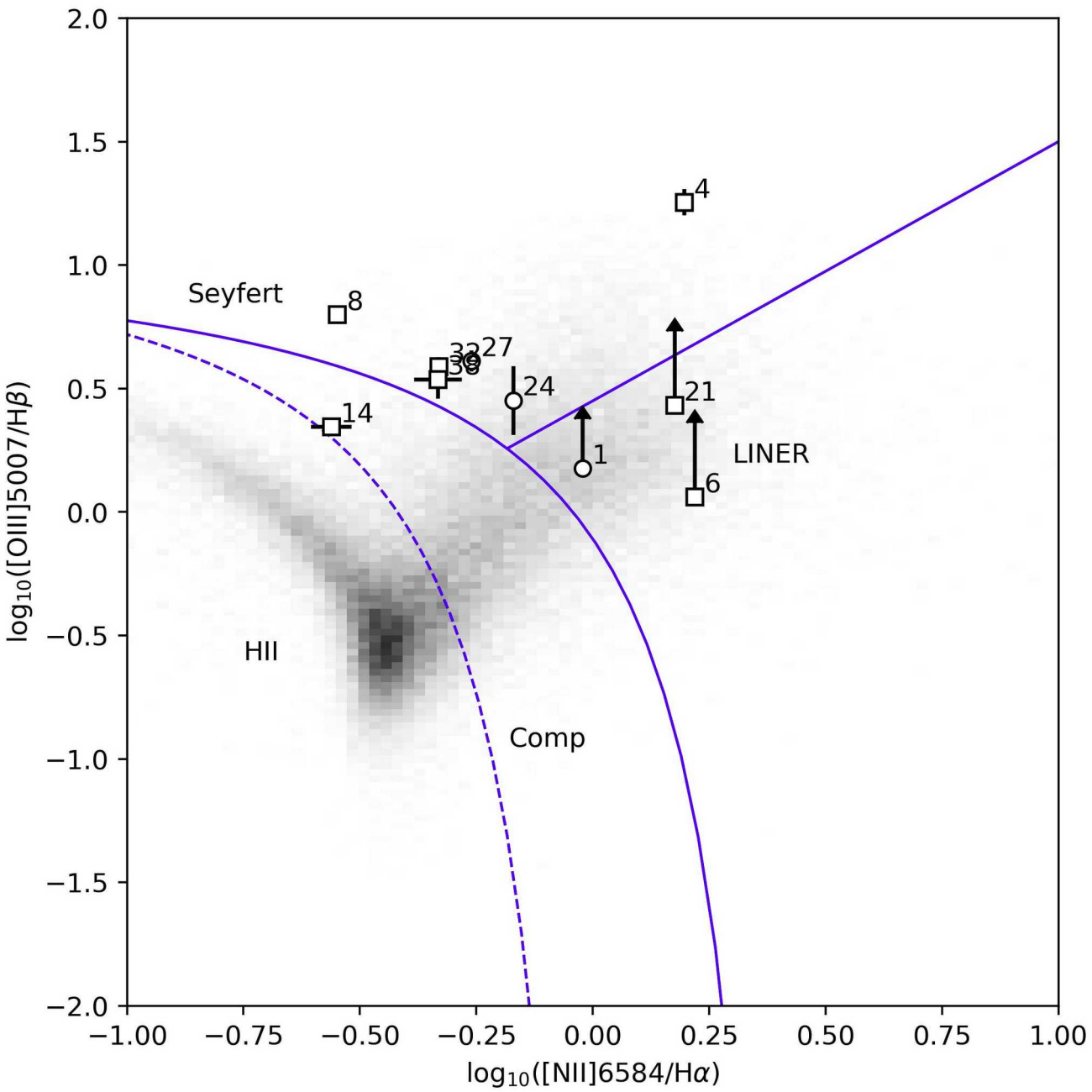
Medvedev+2022

Optical classification for extreme variable soruces SRG detected in low state

Classification scheme for AGN (Mikaelian+2022)

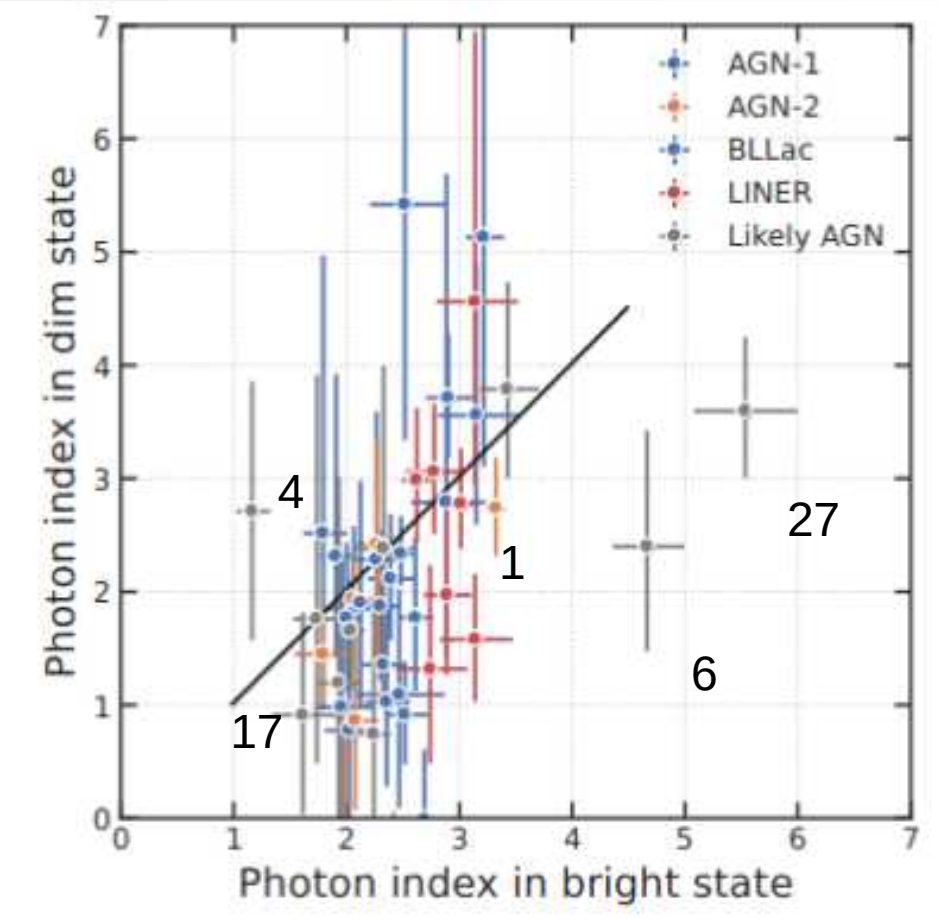
№	z	class
1	0.099	TDE/LINER
4	0.035	Sy1.9
6	0.077	LINER/Sy1.9
8	0.097	Sy1
10	0.523	Sy1/NLSy1
14	0.338	Sy1
17	0	CV
21	0.0945	LINER/Sy1.9
24	0.057	Sy2
27	0.074	Sy2
32	0.208	Sy1.8
38	0.0623	Sy1
39	—	Blazar





The most interesting sources

X-ray spectral slopes Γ:



Source №1
Rx=83 is TDE in LINER galaxy
(ATel Khabibullin+2020 #13494,
Brightman+2021)

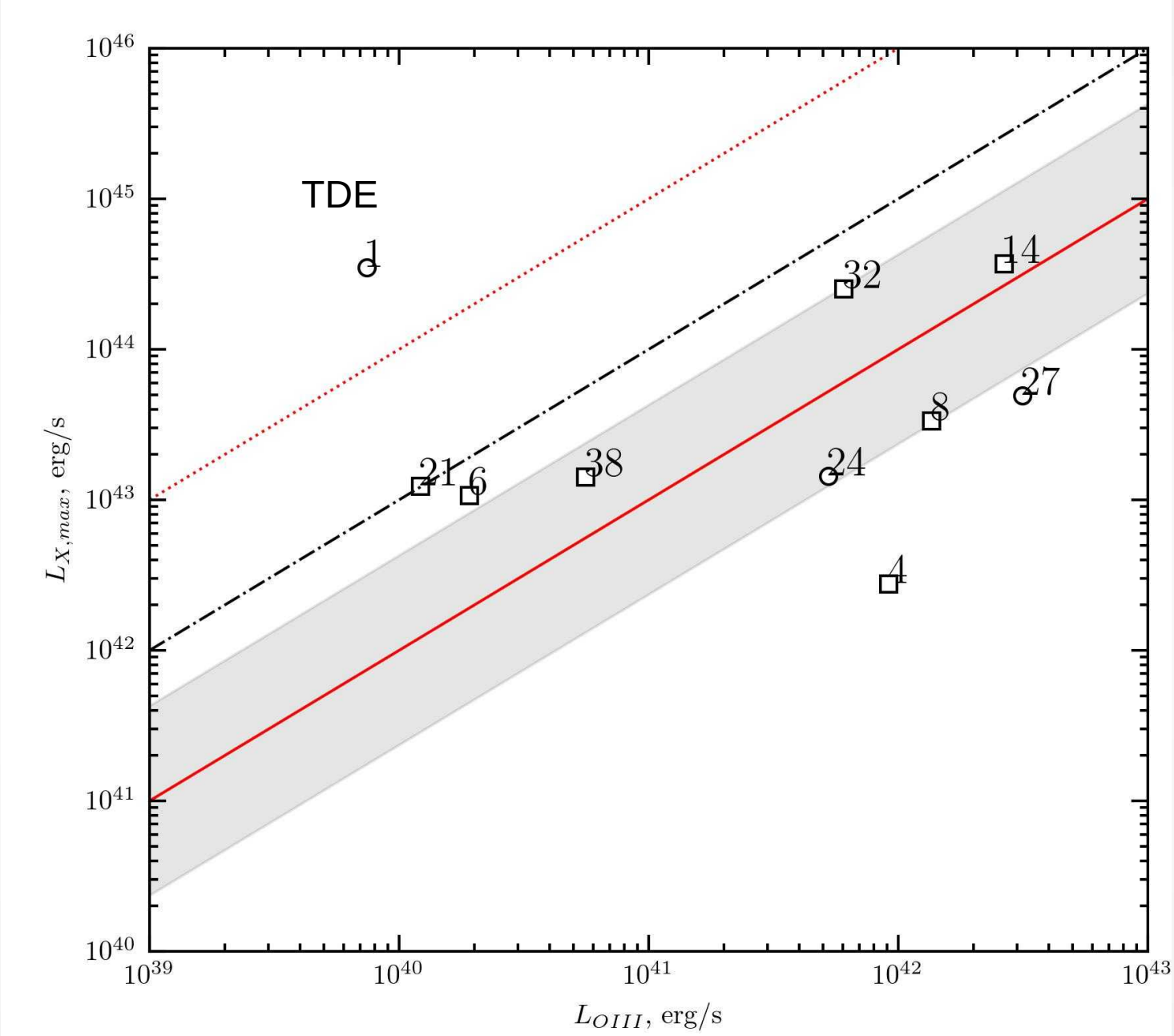
Source №4:
Rx=47 Sy1.9 changes X-ray NH and width of H-alpha FWHM 1000 → 2000 km/s and flux of Ha increases 5 times.
Possibly source is near Eddington limit

Source №6:
Rx=41 Liner/Sy1.9 with extremely soft X-ray (Surprisingly)

Source №17: STAR CV

Source №27:
Rx=24 Sy2 with extremely soft X-ray (Surprisingly)

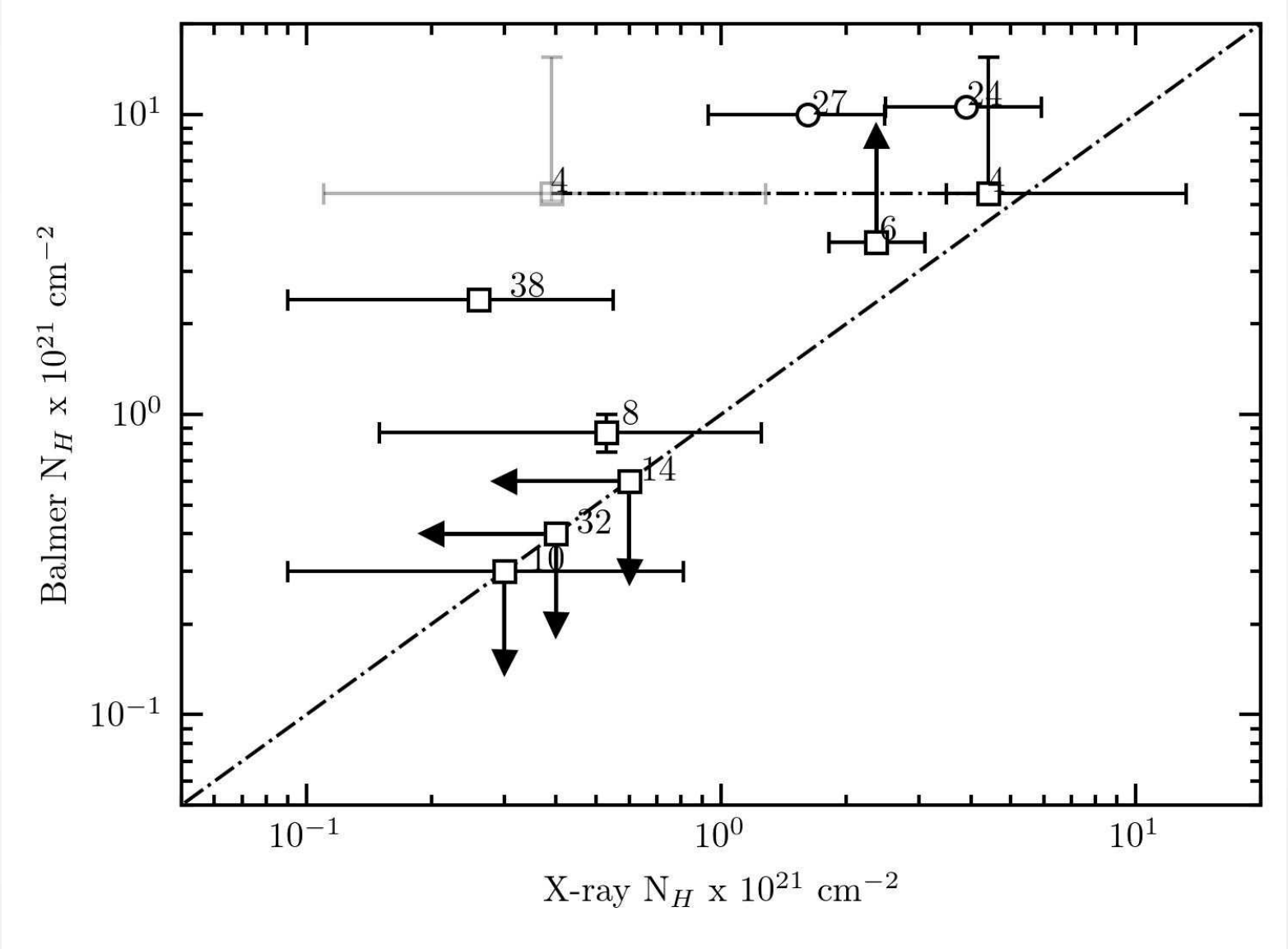
Optical classification for extreme variable soruces SRG detected in low state



Absorption column density measurements from the X-ray and optical

$$N_H(cm^{-2}) = (2.21 \pm 0.09) \times 10^{21} \; A_V(\mathrm{mag}).$$

Guver, Ozel (2009)



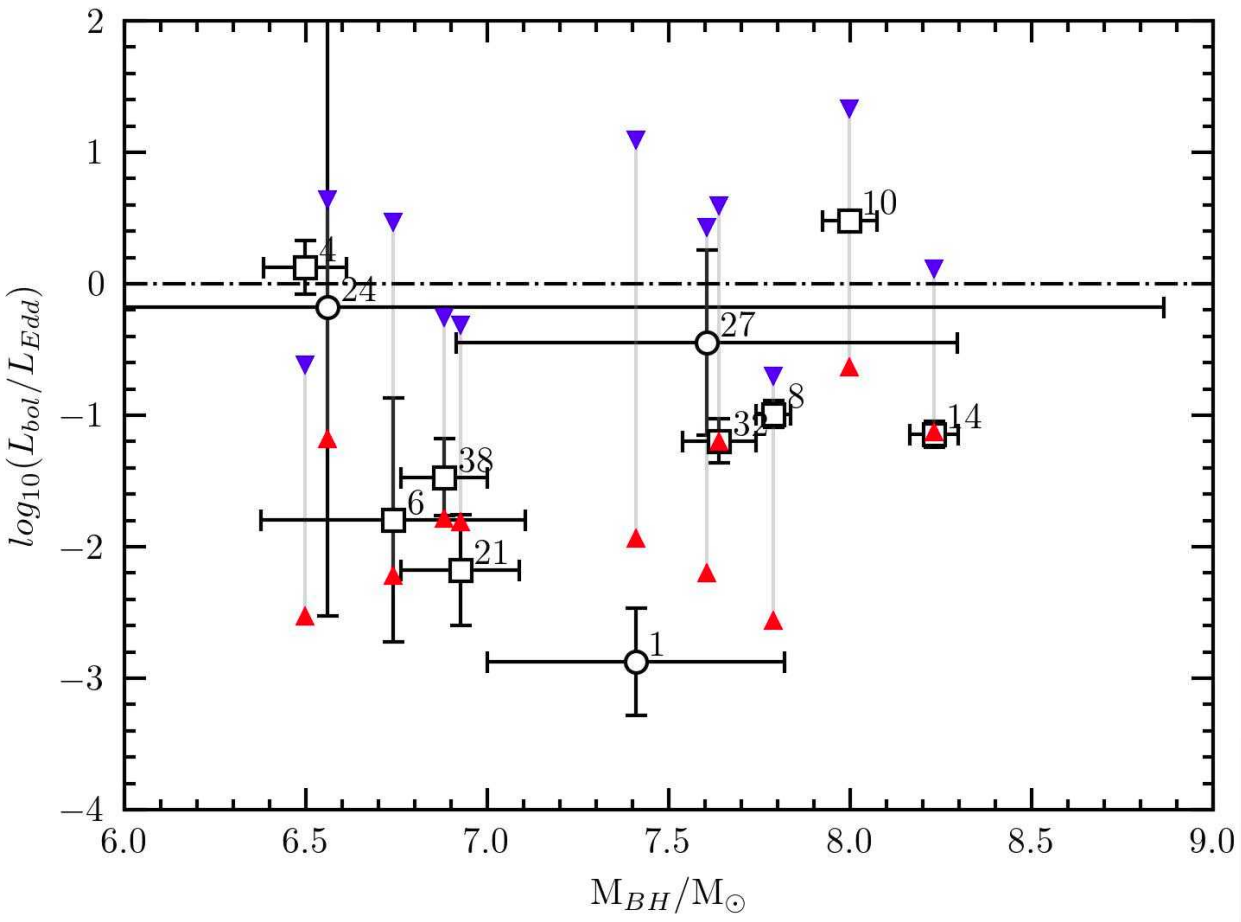
The Black hole mass and Eddington ratios

L[OIII] bolometric luminosity is related with long-time AGN activity:

$$L_{bol} = 600 L([OIII])$$ Kauffmann&Heckman (2009)

X-ray bolometric luminosity is related with instant AGN activity

$$log_{10}(L_{bol,X}) = 1.3\, log_{10}(L_X) - 11.76$$ Netzer (2009)



Greene&Ho (2005) for sources with broad Halpha:

$$M_{BH} = (2.0^{+0.4}_{-0.3}) \times 10^6 \times \times \left(\frac{L_{H\alpha}}{10^{42} erg/s}\right)^{0.55\pm0.02} \left(\frac{FWHM(H\alpha)}{10^3 km/s}\right)^{2.06\pm0.06}$$

Approach of Baron, Menard+2019 for Sy2:

$$log_{10}\frac{L([OIII])}{L(H\beta)} = (0.58 \pm 0.07) log_{10}\frac{FWHM(H\alpha^{Broad})}{km/s} - (1.38 \pm 0.38)$$

№1 Mbh=7.4 Brightman+2021

Lbol via High X-ray flux

Lbol via Low X-ray flux

Lbol via [OIII] flux

Results

- LX/L[OIII]~1000 criterion selects TDE and rids out X-ray variable AGN quite good
- Only LINERs may interfere with TDE (We cannot exclude actually that it’s real TDE)
- Soft X-ray flares may occur in a Sy2 galaxies
- An empirical border between absorbed and unabsorbed variable AGN are approximately same NH~10^{22} cm^{-2} . X-ray and Optical classification are in agreement
- A complete spectroscopic sample of 48 extreme variable AGN detected in low state (Medvedev+2022) have obtained