Deep VLA Observations of M31* and M32*: Whisper of The Hidden Monster

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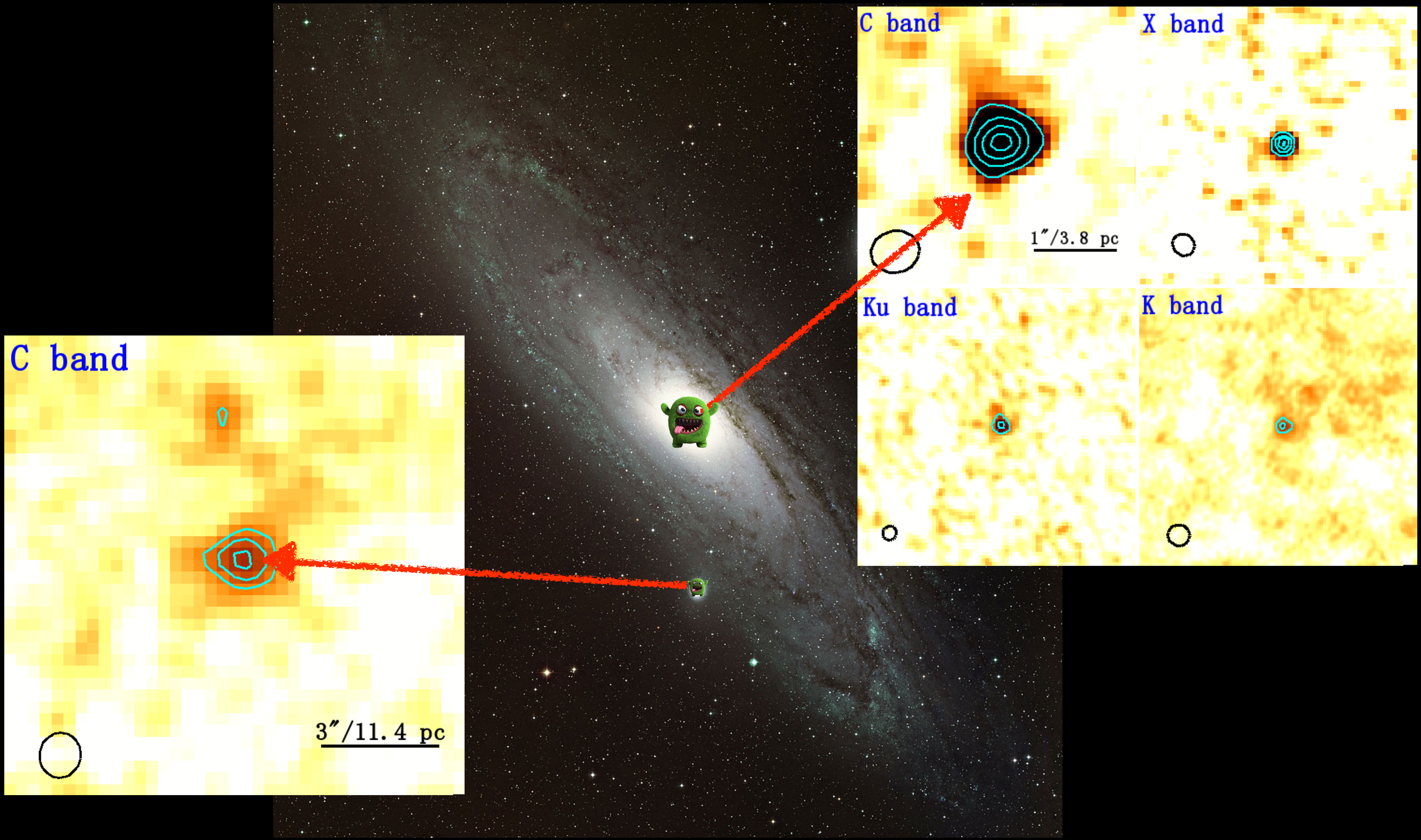
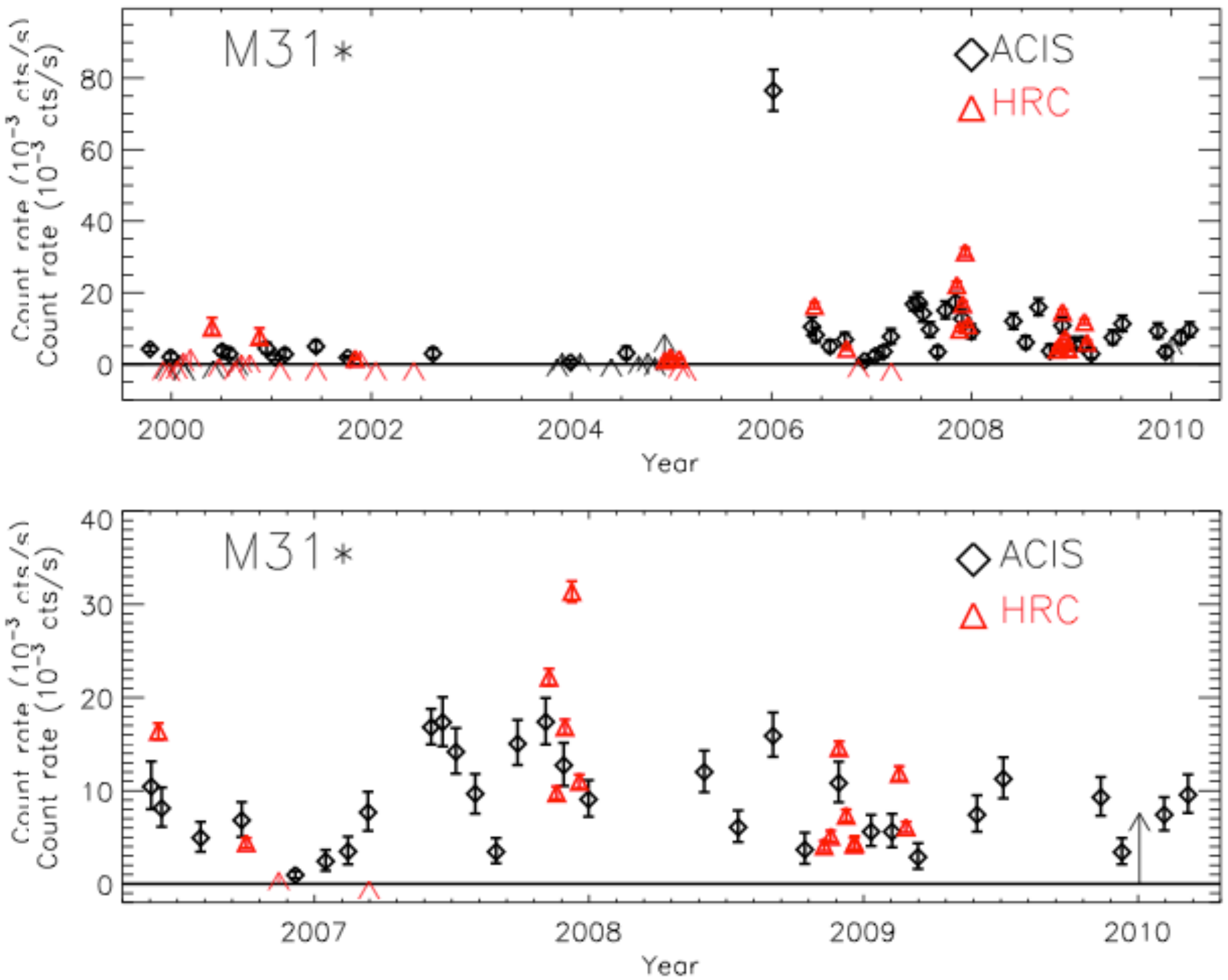


Background

- Low luminosity AGN: $L_{bol}/L_{Edd} \leq 10^{-2}$
- In local universe, most SMBHs are radiatively quiescent, LLAGN, such as Sgr A*, M31* and M32*.
- Before 2010, Sgr A* has remained the only LLAGN found to exhibit flares.
- Li et al. 2011 reported M31* shows similar X-ray flares since 2006.



- Outburst is ~100 times the quiescent level; the long-term average flux ~10 times after the outburst.
- Outburst in M31* and Sgr A* are >100 times the quiescent level.
- Same physical origin with the Sgr A* flares?

- A comparative study of the two SMBHs should yield important constraints to the flare modeling.

	M31*	M32*	S
Mass	$1.4^{+0.9}_{-0.3}\times10^{8}M_{\odot}$	$2.5\times10^{6}M_{\odot}$	$4.1\times10^{6}M$
Distance	780 Kpc	780 Kpc	8.6 Kpc
Flare	Exhibit in X-ray	Null	Exhibit in
L_X	$\sim 4.8\times10^{36} erg\ s^{-1}$(0.5-8 keV)	$\sim 9.4\times10^{35}\ ergs^{-1}$(2-10 keV)	2.2×10^{33}e
L_R(5-6 GHz)	16uJy	7.4uJy	0.71 Jy
L_{bol}/L_{Edd}	$\sim 3\times10^{-9}$	$\sim 3\times10^{-8}$	$\sim 3\times10^{-}$

VLA observations of M31* and M32*

PI: Li Zhiyuan, Lorant Sjouwerman

- Based on deep, multi-band EVLA to observe M31* in 19 epoch in 2011 and 2012.
- Each epoch at two frequencies (except two epochs) to get its simultaneous spectral index over the range of 5 to 20 GHz (C, X, Ku, K band).
- First time to observe M31* at Ku and K band.
- First time to get the simultaneous spectral index.

~50 h

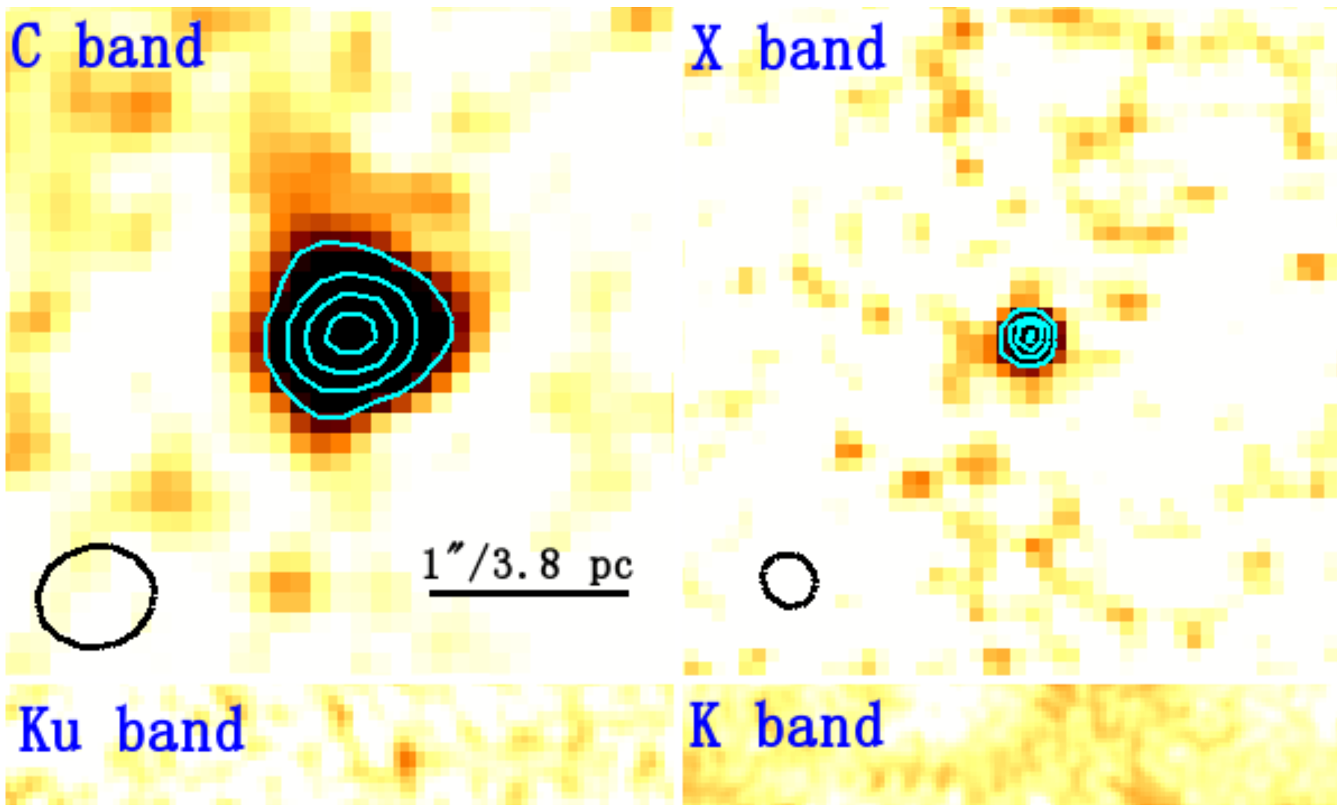
M31*

- Based on deep EVLA to detect M32* for 3 epochs at C band (6 GHz) in B configuration.

M32*

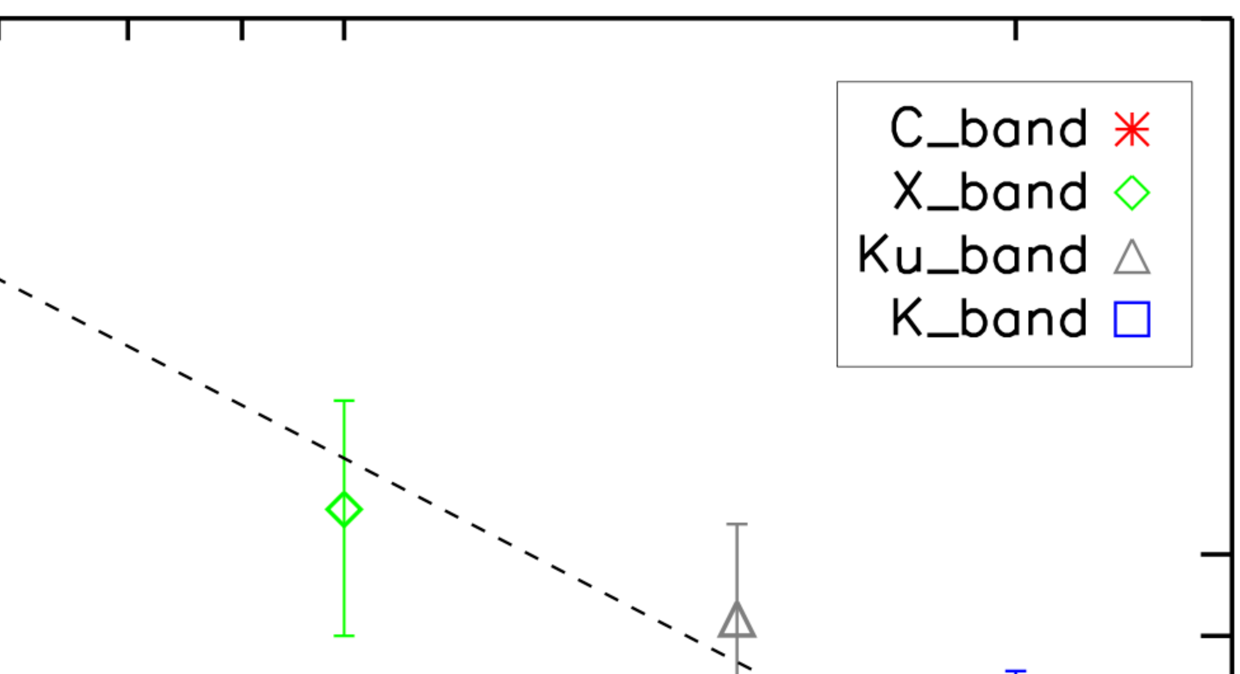
~18 h

Results of monitoring M31*

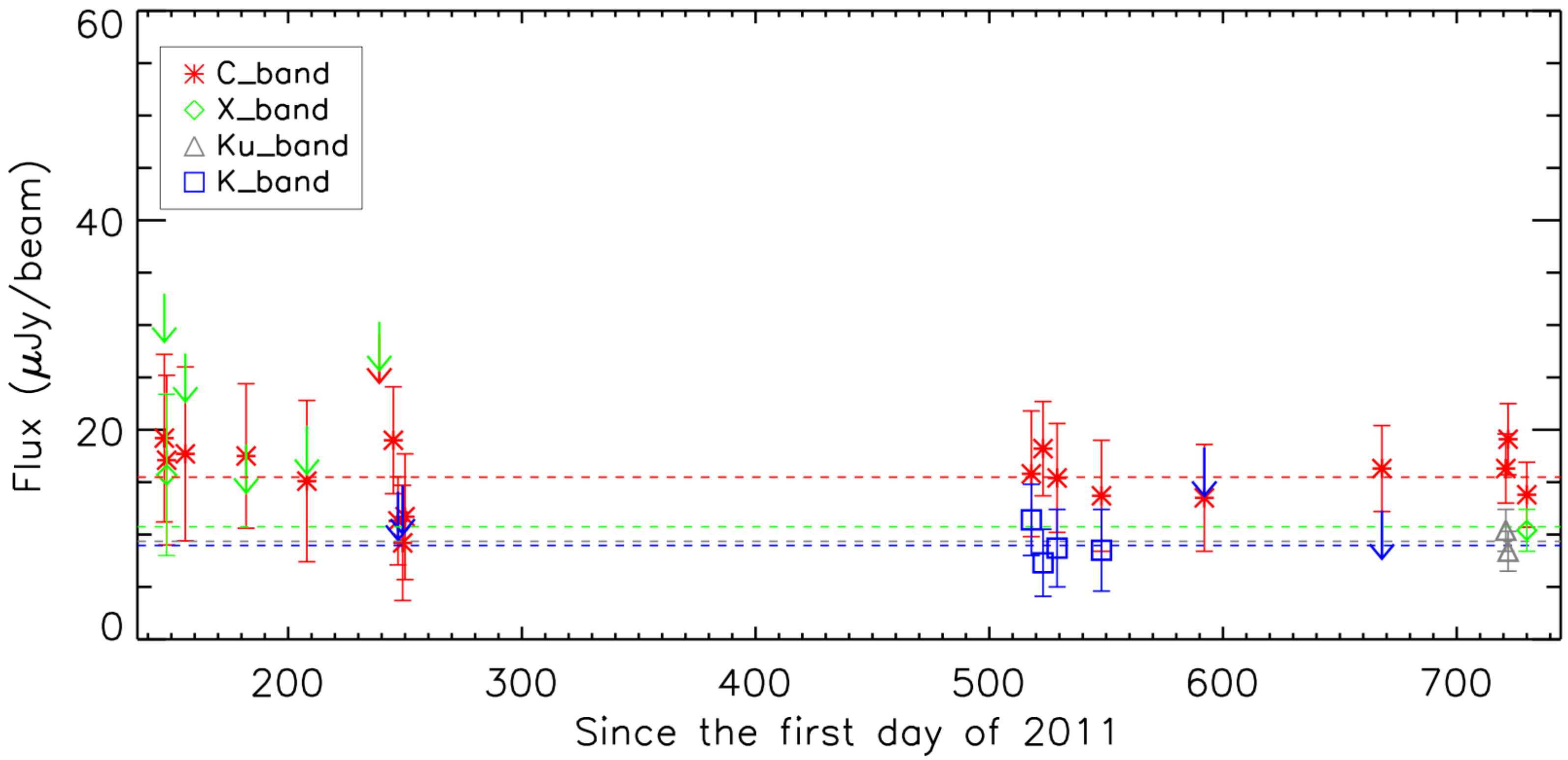


	Freq (GHz)	Flux (μJy/beam)	Flux err(μJy/beam)
C band	6.0	15.9	1.3
X band	10	10.6	1.6
Ku band	15	9.2	1.2
K band	20	6.8	1.8

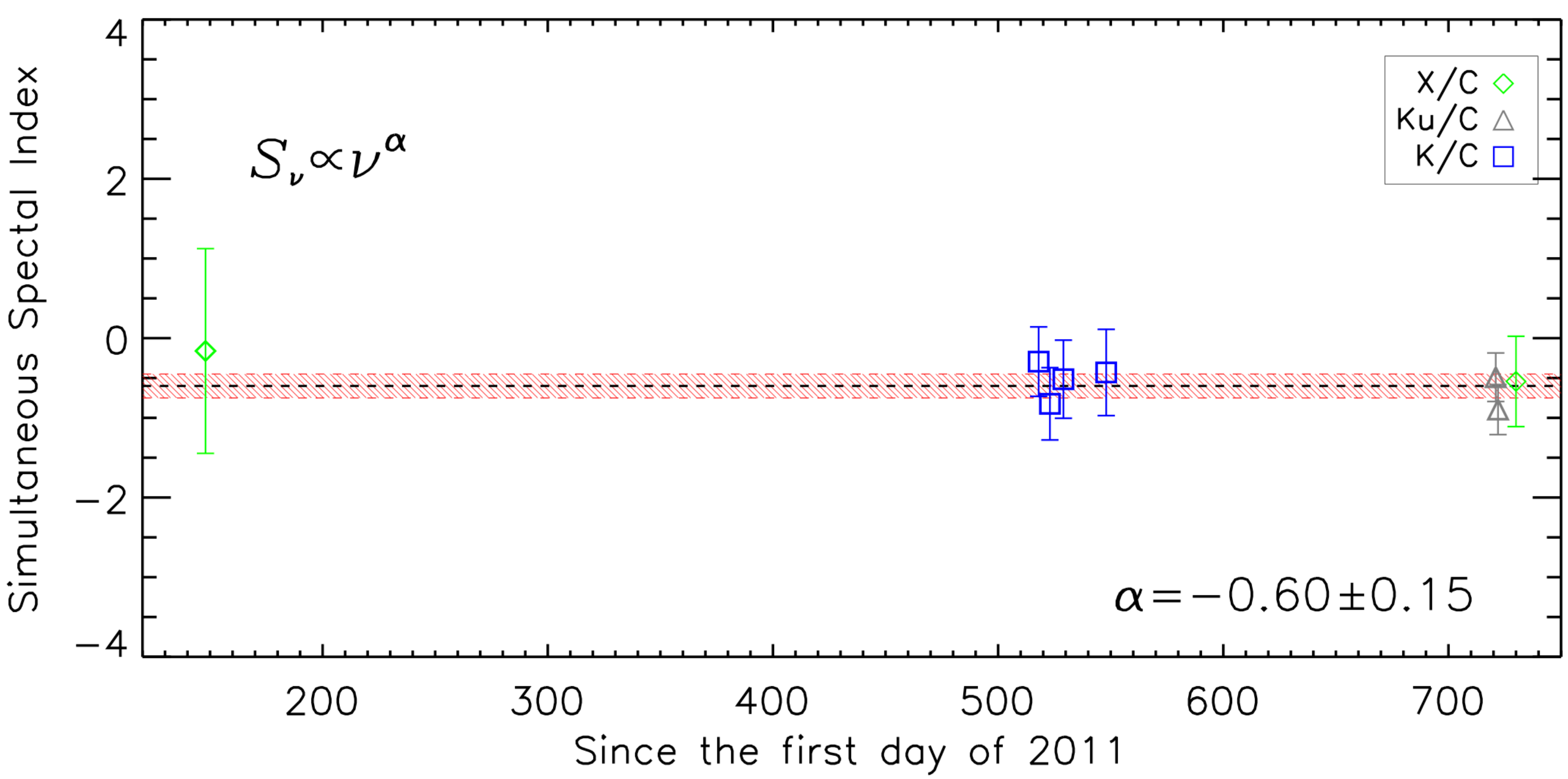
- Pointlike and no sign of jet.
- The average C band flux density between 2002-2005 (Garcia et al. 2010) is ~ 3 times higher than between 2011-2012.
- Li et al. 2011 reported M31* has an X-ray flux increase since 2006; associated with the radio flux decrease?



Results of monitoring M31*

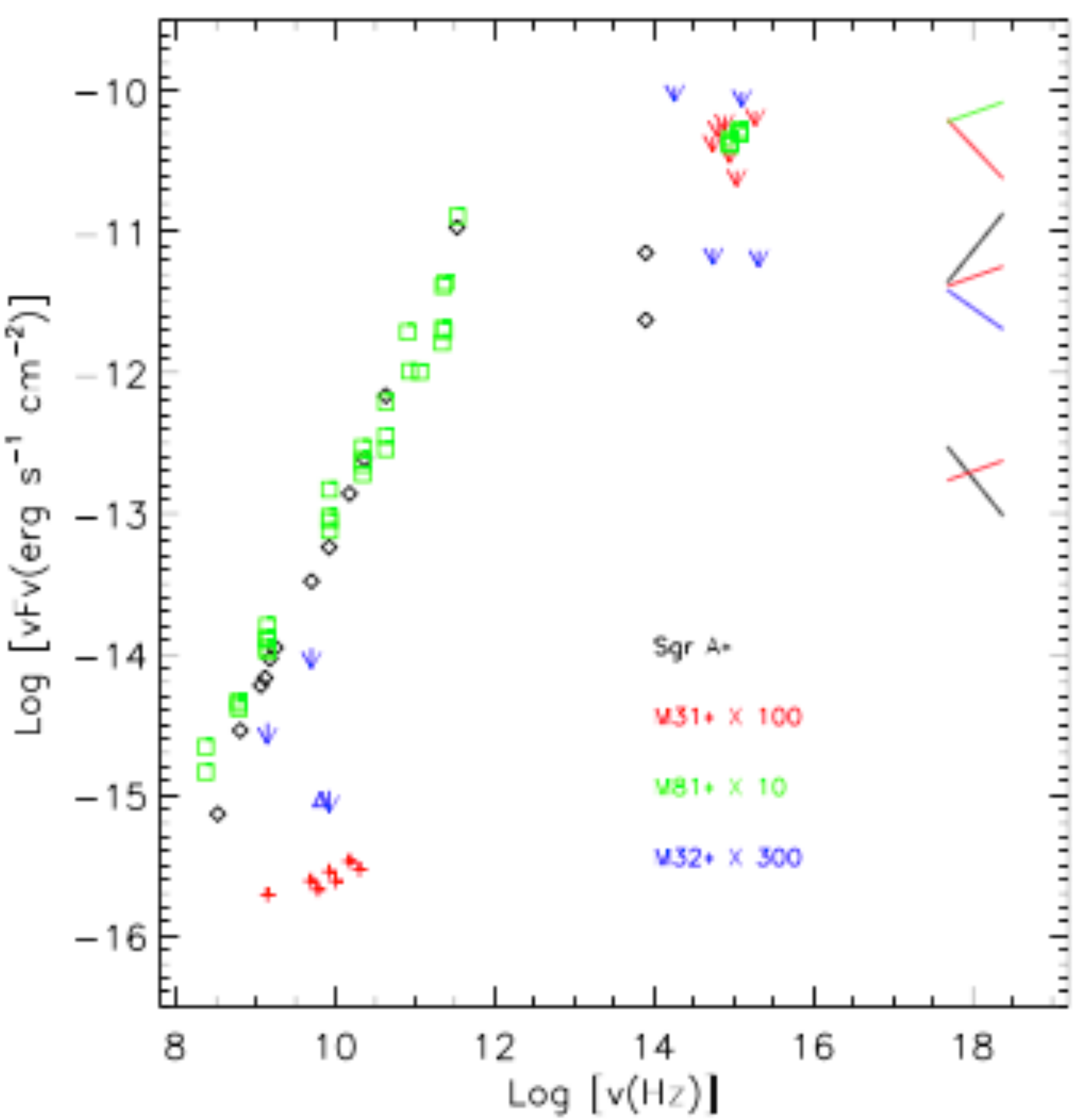


- Show no significant variability between 2011-2012.



- Average simultaneous spectral index ~ -0.60 ± 0.15.

VLBA+TM65 proposal



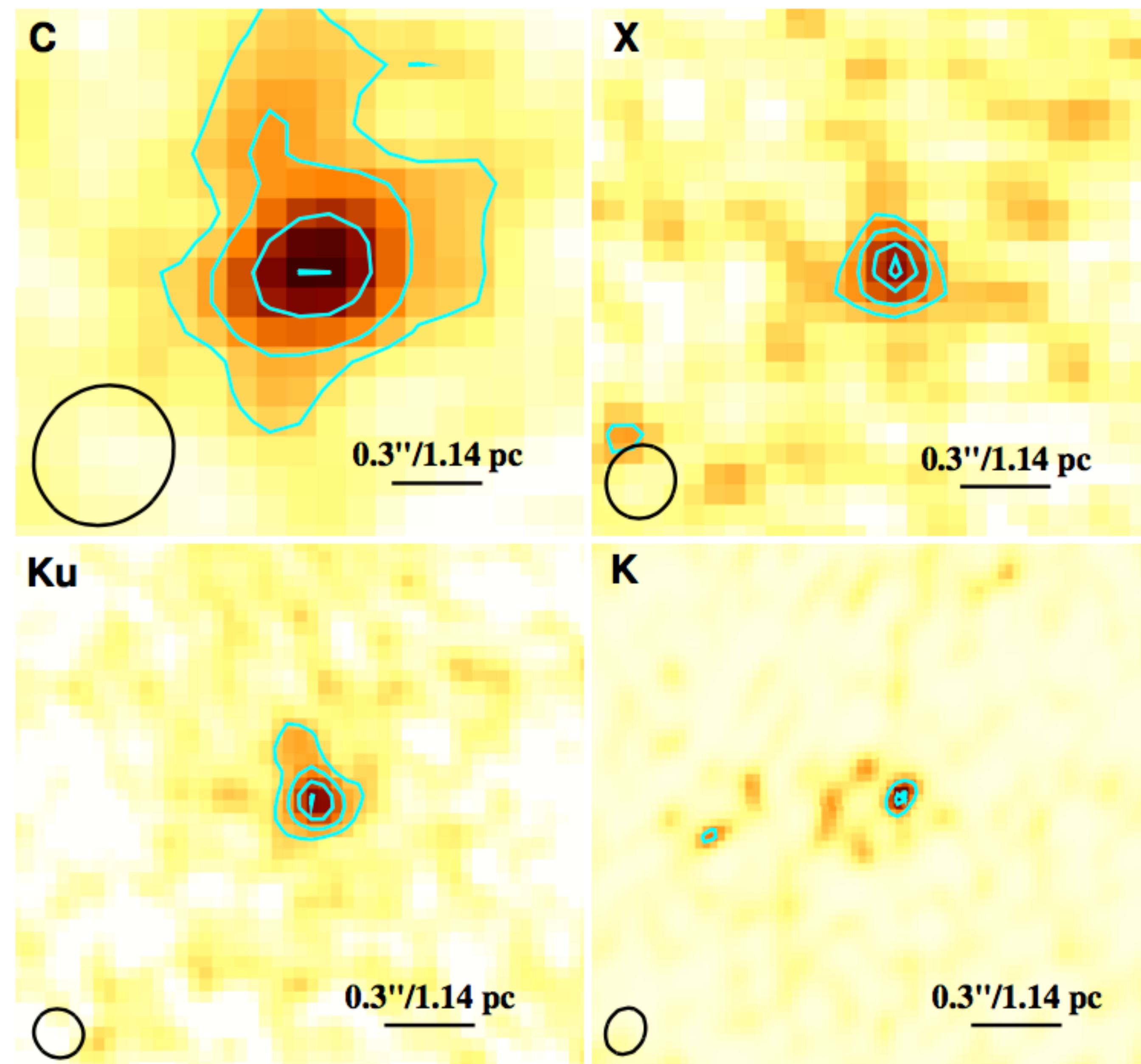
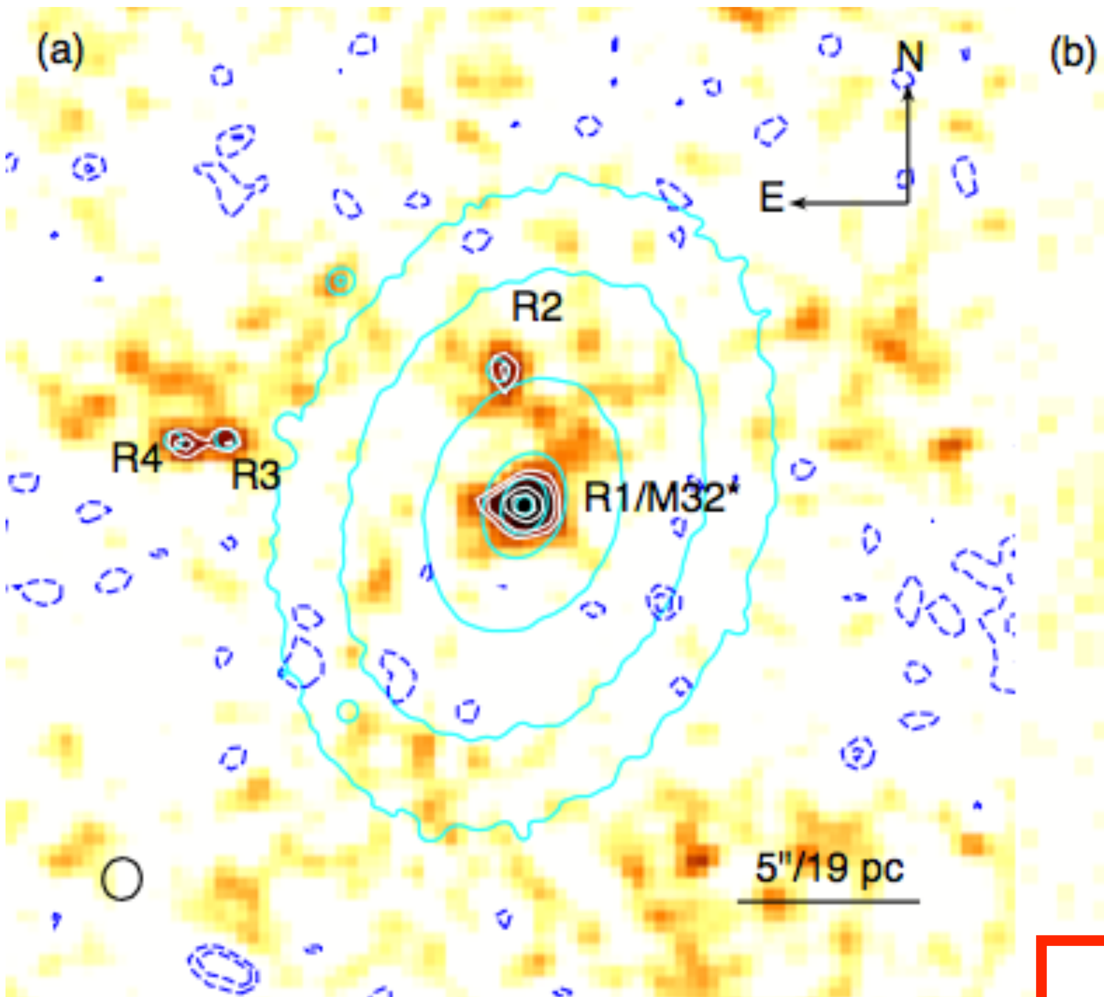


Figure 2: VLA images of M31* in the C, X, Ku and K bands. Contour levels are at [3, 5, 10, 16] × RMS, [3, 5, 8, 10] × RMS, [3, 5, 8, 11] × RMS, [3, 4] × RMS (RMS are 1.6, 2.0, 1.4 and 4.1 μJy/beam in the four bands, respectively). M31* appears a compact source at all frequencies, although there is some hint of a weak plume extending toward a position angle of ∼20 degree (east from north), in particular in the C and Ku bands.

Results of monitoring M32*



- First detection of a faint radio source coincident with the nucleus of M32. contours level at [-3,-2,4,5,7,8] x rms.
- Extended, $S_{6.6GHz}$ = 47.3 ± 6.1 uJy (IMFIT R1 FWHM ≈ 2.8×1.8 and a PA of 130.1 ±1.9).
- First detection of three planetary nebulae's radio counterparts.

47.3±6.1

Source (1)	RA (2)	(3)	(4)	(5)	$L_{6.6}$ (6)	$L_{[OIII]}$ (7)
R1	$00^h42^m41\overset{s}{.}838$	$+40°51'54\overset{''}{.}98$	10.7±1.2	47.3±6.1	22.7	< 4.3
R2	$00^h42^m41\overset{s}{.}891$	$+40°51'58\overset{''}{.}41$	6.6±1.2	3.5±1.2	1.7	11.1
R3	$00^h42^m42\overset{s}{.}563$	$+40°51'56\overset{''}{.}52$	6.6±1.2	3.4±1.2	1.6	7.0
R4	$00^h42^m42\overset{s}{.}659$	$+40°51'56\overset{''}{.}41$	6.8±1.2	3.5±1.2	1.7	5.6

What's the Nature of this radio source

- Core-collapse supernovae? no on-going star formation.
- Type Ia supernovae? expected rate is too low. $\lesssim 10^{-8}\ \mathrm{yr}^{-1}$
- SF activities? upper limit is lower than observed.

Caplan & Del $\lesssim 2 \times 10^{36}\ \mathrm{erg\ s}^{-1}$

$$\left[\frac{F(\mathrm{H}\alpha)}{10^{-12}\ \mathrm{erg\ cm^{-2}\,s^{-1}}}\right] \sim 0.8 \left(\frac{T_e}{10^4 \mathrm{K}}\right)^{-0.52} \left(\frac{\nu}{\mathrm{GHz}}\right)^{0.1} \left(\frac{S_{\mathrm{ff}}}{\mathrm{mJy}}\right)$$

$$S_{\mathrm{ff,\,6.6\,GHz}} < 28.4\ \mu\mathrm{Jy}.$$

v.s. obs $S_{\mathrm{ff,6.6\ GHz}}$=47.3 μJy

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- SF activities? upper limit is lower than observed.
- BHBs? if so,
    - should be in low/hard state, (L_X~10^{36} erg s^{-1})
    - but inconsistent X-ray photon index (2.4 v.s. 1.5-2.0)
    - inconsistent with the “fundamental plane of BH activity” (Gueltekin et al., 2009)

$$\log L_{\mathrm{R}} = (4.80 \pm 0.24) + (0.78 \pm 0.27) \log M_{\mathrm{BH}} + (0.67 \pm 0.12) \log L_{\mathrm{X}}$$

$$L_{5\mathrm{GHz}} \sim 5\times 10^{29}\ \mathrm{erg\ s}^{6}\ \text{v.s. obs}\ L_{6.6\mathrm{GHz}} = 2.3\times 10^{31}\ \mathrm{erg\ s}^{-1}$$

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- Type Ia supernovae? expected rate is too low. $\lesssim 10^{-8}\ \mathrm{yr}^{-1}$
- SF activities? upper limit is lower than observed.
- BHBs? unlikely a stellar BH
- SMBH!

  $$M_{\mathrm{BH}} = 2.5 \times 10^{6}\ M_{\odot}$$

  - Fundamental Plane for LLAGN (Yuan et al. 20[illegible]):

$$\log L_{\mathrm{R}} = 1.29(\pm 0.03) \log L_{\mathrm{X}} + 0.11(\pm 0.04) \log M_{\mathrm{BH}} - 14.1$$

$$L_{5\mathrm{GHz}} \sim 1.1 \times 10^{33}\ \mathrm{erg\ s}^{6}\ \text{ v.s. obs } L_{6.6\mathrm{GHz}} = 2.3 \times 10^{32}\ \mathrm{erg\ s}^{-1}$$

Summary

- M31* show no significant variability between 2011-2012.
- The average C band flux density between 2002-2005 (Garcia et al. 2010) is ~ 3 times higher than between 2011-2012.
- The average C band flux density between 2002-2005 is ~ 3 times higher than between 2011-2012.
- We get an average simultaneous spectral index ~ -0.60 ± 0.15.
- A probable radio counterpart of M32* is detected for the first time
- First detection of three planetary nebulae's radio counterparts.

Thank you