# Observation of a new rotational band in $^{104}$Nb nucleus*

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**Abstract** The high spin states in neutron-rich $^{104}$Nb have been investigated from study of prompt γ-rays in spontaneous fission of $^{252}$Cf with the Gammasphere detector array. A new rotational band has been identified for the first time. This band is proposed as a semi-decoupled band based on the configuration $\pi 5/2^-[303]\otimes\nu 1/2^-[541]$.

**Key words** high spin states, spontaneous fission, neutron-rich nucleus, semi-decoupled band

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## 1 Introduction

The neutron-rich nuclei with $Z \simeq 40$ and $A \simeq 100$ have some interesting characteristics. In this region, the Sr and Zr isotopes have axial symmetry shape and show the sudden onset of the large quadrupole deformation with the deformed parameter $\beta_2 = 0.3 \sim 0.4$ at $N \simeq 60$[1, 2], and the Mo, Ru and Tc nuclei have the triaxial deformation[3, 4]. Shape transition from the prolate to the triaxial has been observed in this nuclear region[2, 5]. And the shape coexistence, superdeformed ground states and identical bands were also observed[2, 6]. These unusual phenomena attract considerable attention. However, in this nuclear region, the data of the odd-odd nuclei are still scarce.

The Nb ($Z$=41) isotopes lie between Zr($Z$=40) and Mo($Z$=42) isotopes. Study of their high spin states is an important work for enriching our knowledge in $A = 100$ neutron-rich nuclei. In the previous reports, the high spin states of odd-$A$ $^{101,103,105}$Nb nuclei have been studied carefully and some collective bands have been established[4, 7]. For the odd-odd Nb nuclei, only the higher spin levels of $^{102}$Nb were investigated earlier by our group[7, 8], but not in other odd-odd Nb nuclei yet. As to the $^{104}$Nb nucleus, in previous β-decay studies[9], some low spin levels of have been identified and a "pairing free" $K^\pi = 1^+$ band was proposed[10], but no information about the high spin states and collective bands was reported. In this work, we report on investigation of the higher spin states in $^{104}$Nb. Some new transitions are identified and a new collective band is established.

## 2 Experiment and results

In the present work, the level structure of $^{104}$Nb has been investigated by measuring the prompt γ-rays emitted from the fragments produced in the spontaneous fission of $^{252}$Cf. The experiment was carried out at the Lawrence Berkeley National Laboratory. A $^{252}$Cf source of strength ~60 μCi was sandwiched between two Fe foils of thickness of 10 mg/cm$^2$. The source then was placed at the center of the Gammasphere detector array which consisted of 102 Compton-suppressed Ge detectors. A total of $5.7\times10^{11}$ triple- and higher-fold γ-coincidence events were collected. The coincidence data were analyzed with the RADWARE software package[11].

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From our experimental data, we did not find any $\gamma$-transition in $^{104}$Nb reported in the previous β-decay measurements[9]. However, we can use the known partner transitions to identify its new $\gamma$-transitions. In spontaneous fission, a pair of correlated partners is produced. By double gating on known γ-rays in a partner isotope, one can identify the γ-transitions in its correlated partner. So by double gating on the 291.5 and 498.3 keV transitions in $^{143}$La[12], and 314.3 and 460.2 keV transitions in $^{145}$La[13, 14], respectively, as shown in Fig. 1, one can see two new $\gamma$-transitions at 157.0 and 185.5 keV which are considered as the transitions of $^{104}$Nb.

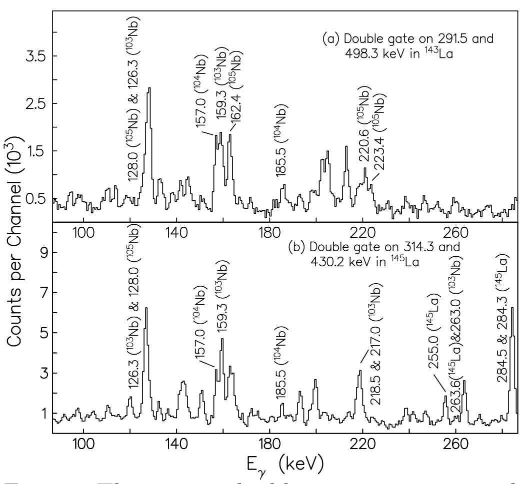


Fig. 1. The spectra double gating on 291.5 and 498.3 keV transitions in $^{143}$La (a), and 314.3 and 430.2 keV transitions in $^{145}$La (b).

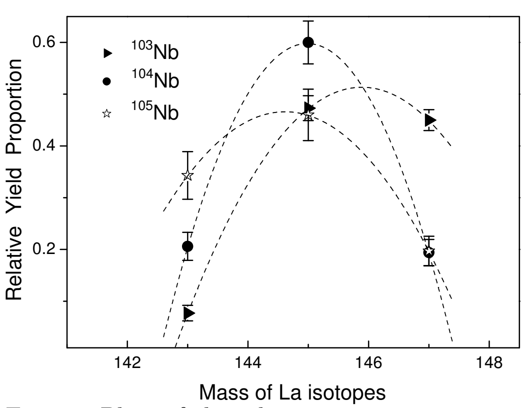


Fig. 2. Plots of the relative intensities against the mass of La isotopes for different Nb isotopes.

In order to confirm our assignment, we carried out data analysis of the relative yield distributions of correlated fission fragment pairs of Nb-La isotopes. By double gating on the transitions of different Nb isotopes, we can calculate the relative intensities of the 291.5, 172.0 and 212.2 keV transitions in $^{143}$La[12], $^{145}$La and $^{147}$La[13, 14], respectively, which are used to represent the yields of the odd-$A$ La isotopes. The relative intensities against the mass of La nuclei for $^{103,104,105}$Nb isotopes observed in the present work are shown in Fig. 2. One can see that the mass of its La isotope with largest yield decreases with increasing of neutron number of the Nb isotopes. The peak of the curve of $^{104}$Nb is situated between those of $^{103}$Nb and $^{105}$Nb. So the two new transitions at 157.0 and 185.5 keV belong to $^{104}$Nb nuclei.

Based on two new $\gamma$-transitions at 157.0 and 185.5 keV, and by the γ-γ-γ coincidence and $\gamma$-transition intensity analysis, a new band to higher spin for $^{104}$Nb has been established, as shown in Fig. 3. In this figure, a collective band labeled (1) above the scheme is newly established, whereas a group of levels labeled (2) were observed in previous $\beta$-decay measurements[9, 10] but are not observed in present work. Thus band (1) sits at an unknown energy $x$ above the ground state. The values in the parenthesis are the relative transition intensities which are normalized to that of 157.0 keV $\gamma$-transition.

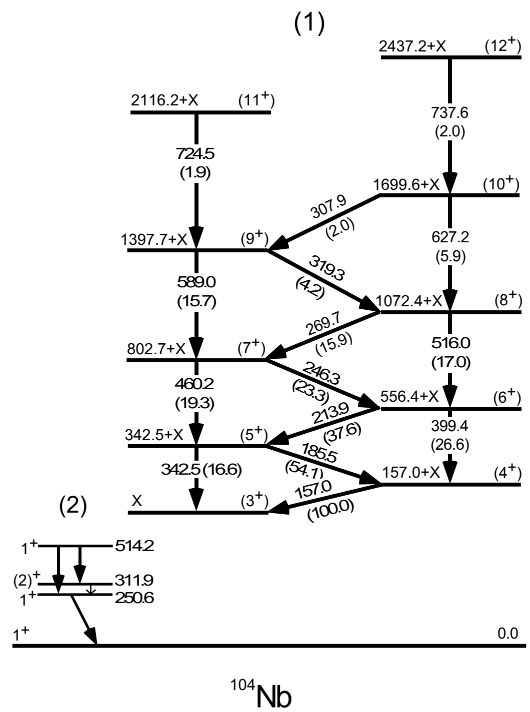


Fig. 3. The new level scheme of $^{104}$Nb.

## 3 Discussion

The characteristic of the new identified band (1) in $^{104}$Nb is similar with that of band (3) of the odd-odd $^{102}$Nb nucleus, and they should have same configuration. The band (3) in $^{102}$Nb was proposed as one of the semi-decoupled doublet bands with the configuration $\pi 1/2^+[431]\otimes\nu 5/2^-[532]$[8]. Based on the newly

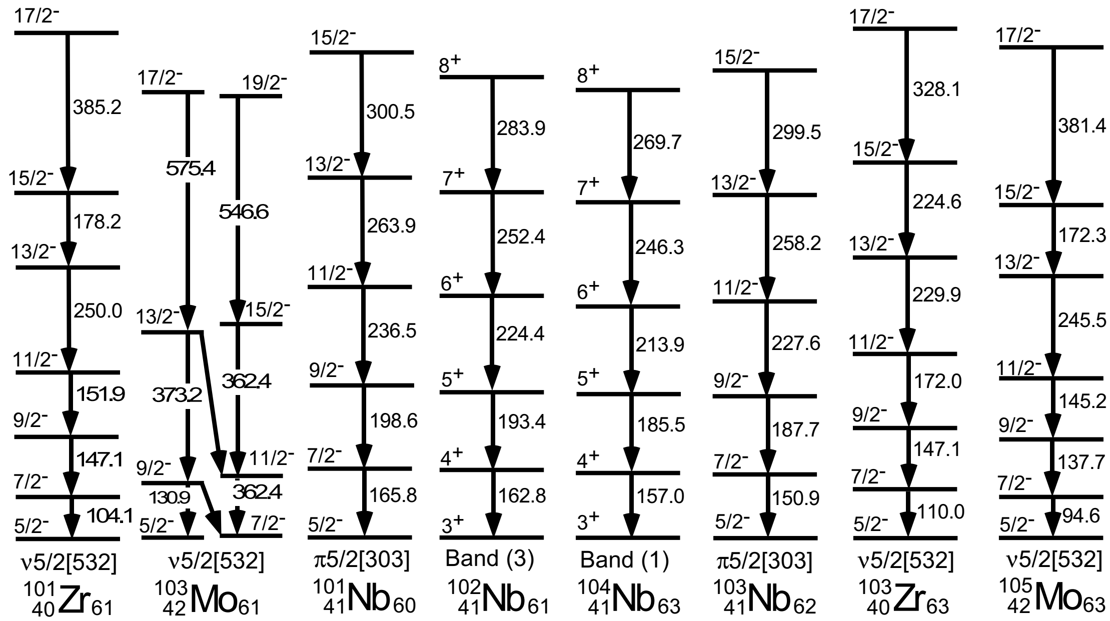


Fig. 4. Systematic comparison for the levels of the $^{101-104}$Nb, $^{101,103}$Zr and $^{103,105}$Mo.

identified data in the neighboring nuclei, here we should reassign this configuration for band (3) in $^{102}$Nb. As indicated in Refs. [15, 16], the level structure of $K = \Omega + \frac{1}{2}$ band of semi-decoupled doublet bands should be similar to the corresponding $K = \Omega$ bands of the neighboring odd-$A$ nuclei. Thus, through comparison with the level structures of the neighboring odd-$A$ Zr[17] and Mo[17, 18] nuclei, shown in Fig. 4, one can see that band (3) in $^{102}$Nb and band (1) in $^{104}$Nb are much more similar to the $5/2^-[303]$ bands of $^{101}$Nb and $^{103}$Nb, but different from the $5/2^+[532]$ bands of $^{101,103}$Zr and $^{103,105}$Mo. So the proton may occupy $5/2^-[303]$ orbit, and the neutron may occupy $\Omega = \frac{1}{2}$ orbit. Around the $N = 63$ Fermi surface, the neutron orbits with $\Omega = \frac{1}{2}$ either $1/2^+[411]$ or the intruder orbit $1/2^-[541]$. The intruder orbit $1/2^-[541]$ which is strongly prolate-driving can cause excited bands to have much larger deformation than the ground state. This can support the lack of transitions connecting the excited bands to the ground state as discuss in Ref. [8]. So we propose that the configurations of the band (3) in $^{102}$Nb and the band (1) in $^{104}$Nb should be $\pi 5/2^-[303] \otimes \nu 1/2^-[541]$ with $I^\pi = 3^+$ for the bandhead level. According to the regular level spacing, the $I^\pi$'s of the other levels in $^{104}$Nb are assigned as shown in Fig. 3.

## 4 Summary and concluding remarks

In summary, the higher spin states in $^{104}$Nb have been investigated. A new collective band has been established. This band is proposed as a semi-decoupled band based on $\pi 5/2^-[303] \otimes \nu 1/2^-[541]$ configuration.

### References

1 Cheifetz E et al. Phys. Rev. Lett., 1970, **25**: 38
2 Hamilton J H. Prog. Part. Nucl. Phys., 1985, **15**: 107; Treatise on Heavy Ion Science, Allan Bromley et al. (Plenum, NY, 1989) p.2
3 Shizuma K et al. Z. Phys. A, 1983, **311**: 71
4 LUO Y X et al. J. Phys. G: Nucl. Part. Phys., 2005, **31**: 1303
5 Skalski J et al. Nucl. Phys. A, 1997, **617**: 282
6 Hamilton J H et al. Prog. Part. Nucl. Phys., 1995, **35**: 635
7 Hwang J K et al. Phys. Rev. C, 1998, **58**: 3252
8 Hwang J K et al. J. Phys. G: Nucl. Part. Phys., 2001, **27**: L9
9 Firestone R B et al. Table of Isotopes, 8th ed. Wiley, New York, 1998
10 Peker L K et al. Phys. Lett. B, 1986, **169**: 323
11 Radford D C. Nucl. Instrum. Methods Phys. Res. A, 1995, **361**: 297
12 WANG J G et al. Phys. Rev. C, 2007, **75**: 064301
13 ZHU S J et al. Phys. Rev. C, 1999, **59**: 1316
14 Urban W et al. Phys. Rev. C, 1996, **54**: 945
15 Kreiner A J et al. Phys. Rev. C, 1987, **36**: 2309
16 Kreiner A J. Phys. Rev. C, 1988, **38**: 2486
17 Hua H et al. Phys. Rev. C, 2004, **69**: 014317
18 DING H B et al. Phys. Rev. C, 2006, **74**: 054301