Mid-infrared Monitoring Observations of Circumstellar Disks with TAO/MIMIZUKU

The University of Tokyo Atacama Observatory (TAO) Project

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Abstract

Mid-infrared variabilities of dust continuum and features in time scale of days to years have been found in circumstellar disks around YSOs and debris disks by multi-epoch studies with recent space missions such as AKARI, WISE, Spitzer, and Herschel (e.g., Dahm+09, Espaillat+11, Flaherty+12, Melis+12). However, physical mechanisms leading to the rapid MIR variabilities are still unclear because of sparse data sampling. More frequent and long-term observations with ground-based MIR instruments are required. Meanwhile, fast fluctuation of atmospheric water vapor affects photometric accuracy in the MIR observations from the ground. In order to monitor the variabilities of a few percent level as detected by the space telescopes, improvements of observation methods are needed.

We have been developing a new MIR instrument MIMIZUKU (Kamizuka+12, Miyata+10) mounted on 6.5-m TAO telescope (Yoshii+10), which will be constructed at a 5,640-m altitude site in Atacama, Chile, and 8.2-m Subaru telescope in Hawaii. The MIMIZUKU has unique equipment called Field Stacker which enables simultaneous observations of target and reference objects owing to focusing two separated field-of-views on a same detector. The simultaneity improves the photometric accuracy and realizes stable long-term monitoring. We will carry out MIR monitoring observations of dust emission from the circumstellar disks and the debris disks with the imaging and low-resolution spectroscopic modes of the MIMIZUKU. The time-variable emissions from the YSOs could allow us to reveal formation and destruction mechanism of dust grains in the inner disk region. In observations of debris disks, fresh dust formed by large collisions in a planetary disk is expected to be detected.

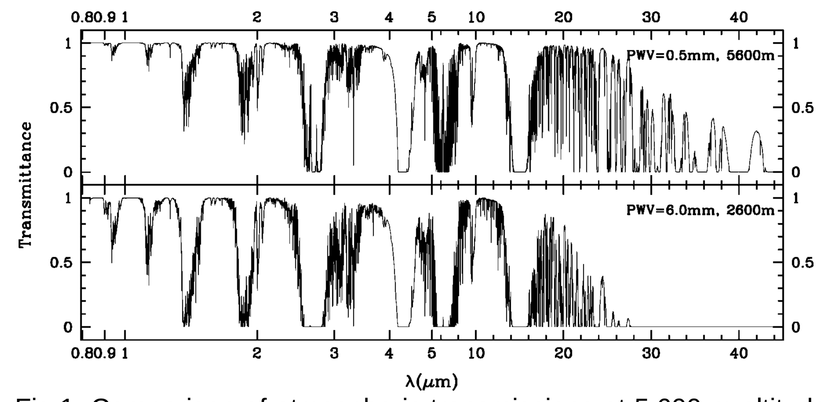

Fig.1. Comparison of atmospheric transmissions at 5,600 m altitude (a model for Chajnantor) and 2,600 m (for Paranal). At Chajnantor, new atmospheric windows beyond a wavelength of 25 μm appear.

What's TAO and MIMIZUKU

The University of Tokyo Atacama Observatory (**TAO**) is a project to construct a 6.5-m infrared-optimized telescope at the summit of Co. Chajnantor, 5,640 m altitude, in the northern Chile (P.I. Y. Yoshii). It is lead by Institute of Astronomy, the University of Tokyo. Thanks to the high altitude and low water vapor, continuous window from 0.9 to 2.5 μm as well as new windows at wavelength longer than 25 μm appears as shown in Fig. 1. The 6.5-m telescope is now at a construction phase, and will be completed in 2017.

The **MIMIZUKU** (Mid-infrared Multi-field Imager for gaZing at unKnown Universe) is a mid-infrared camera and spectrograph developed for the 6.5-m TAO telescope (Figs. 2 and 3). The MIMIZUKU has unique equipment called **Field Stacker** which enables simultaneous observations of target and reference objects owing to focusing two separated field-of-views on a same detector. The simultaneity improves the photometric accuracy and realizes stable long-term monitoring. High-resolution capability with wide-band coverage from NIR to MIR up to 38μm is also noteworthy features of the MIMIZUKU. The MIMIZUKU will be attached on the 8.2-m Subaru telescope in 2014 and conduct scientific observations before the completion of the 6.5-m TAO telescope.

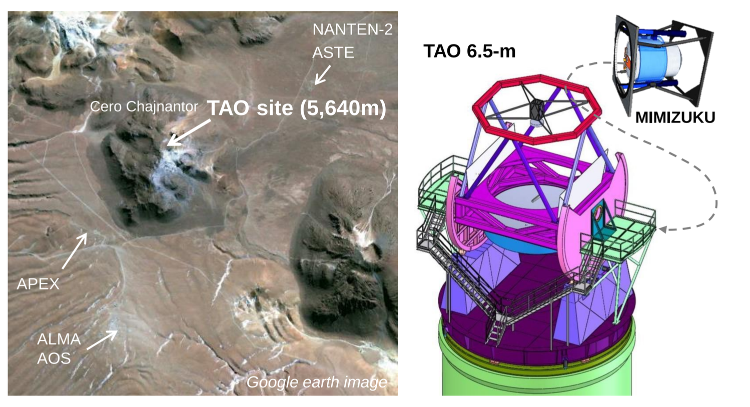

Fig.2. (left) Overview of the TAO site, the highest observatory in the world. (right) Design of the TAO 6.5-m telescope. The MIMIZUKU is installed at a Nasmyth focus.

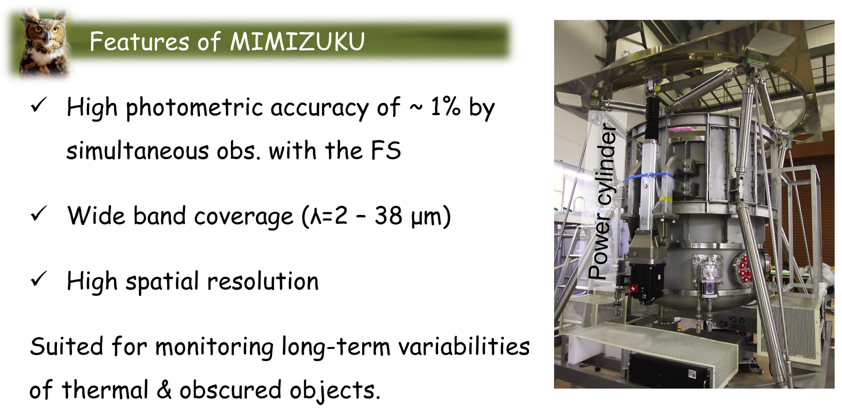

Fig.3. Fabricated dewar of MIMIZUKU (2-m cubic, 2.3-ton). Details are described on *http://www.ioa.s.u-tokyo.ac.jp/TAO/mimizuku/pub/*. 'MIMIZUKU' means 'owl with long ears' in Japanese.

1. Field Stacker (FS)

Fast fluctuation of atmospheric water vapor affects photometric accuracy in the MIR observations from the ground. The photometric accuracy depends on a time-separation alternately observing a target and standards. Usually it is expected to be up to 10-%. The MIMIZUKU will improve the accuracy to about 1-% with the Field Stacker (FS) equipped on the focal plane at room temperature (Fig. 4). It consists of 2 pick-up (PU) mirrors and 1 triangle-prism-shape mirror. The mirrors combine the images of two fields, separated by < 25' / 5' for TAO / Subaru, onto 1 detector. The FS system realizes **simultaneous imaging and spectroscopic observations** of the targets and the reference objects, and allows us to conduct monitoring observations of long-term viabilities with small amplitudes (Fig. 5 and Table 1).

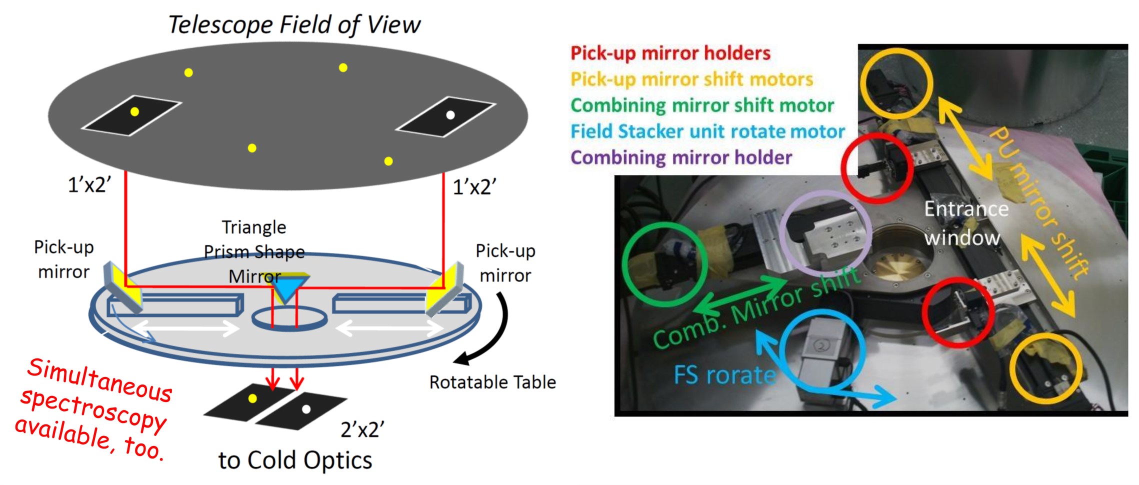

Fig.4 (left) Schematic view of the FS. (right) FS components around the entrance window of the dewar. These motions enable free field pick-up.; Two power cylinders are attached to the sides of the dewar as shown in Fig. 3. They move the dewar up-and-down to cancel out variation of optical path-length caused by PU-mirror shifts.

Telescope	FoV of the telescope	9 μm		18 μm	
		> 50 mJy	> 300 mJy	> 130 mJy	> 1000 mJy
TAO 6.5-m	ϕ 25 arcmin	55 %	51 %	51 %	15 %
Subaru 8.2-m	ϕ 5 arcmin	51 %	10 %	41 %	0.3 %

Table1. Probability of finding a reference object in a selectable field of the FS.

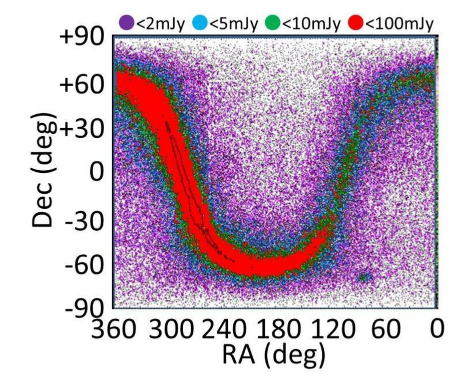

Fig. 5. Distribution of mid-infrared sources detected by the AKARI all-sky survey. The FS will work well especially for objects near the galactic plane.

2. Wide Band Coverage

The MIMIZUKU covers the wavelengths of 2 – 38 μm with three modules, NIR, MIR-S, and MIR-L as shown in Fig. 6. The range in 24 – 38 μm is an unique and strong tool to investigate cool dust. This observation mode is available only at > 5,000 m altitude where the TAO site is located. The NIR capability enables us to conduct quasi-simultaneous observations from NIR to long-MIR without changing the instruments. It is useful to monitor illuminating sources as well as illuminated dust, and suits for revealing grain formation / destruction / variation induced by variable light sources, YSOs, AGBs, AGNs, Novae, etc.

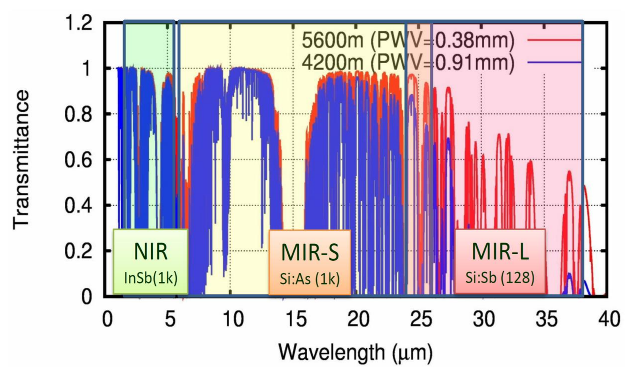

Fig. 6. Atmospheric transmittance and band coverage of the MIMIZUKU.

3. Specification summary

The MIMIZUKU has capabilities of wide-field and high-angular-resolution imaging and spectroscopy in the wide band from NIR to long-MIR (Table 2). Especially in 25 – 38 μm, the MIMIZUKU has the highest angular-resolution in all MIR instruments including future missions (Fig. 7). The resolution at 38 μm on TAO, 1.5", corresponds to resolving a cold disk of 230-AU diameter at 150-pc distance. Estimated sensitivities are high enough to detect thermal emission from extragalactic objects in 38 μm band (Fig. 8). These features and the long-term monitoring capabilities are complementary with next-generation space missions like SPICA and JWST.

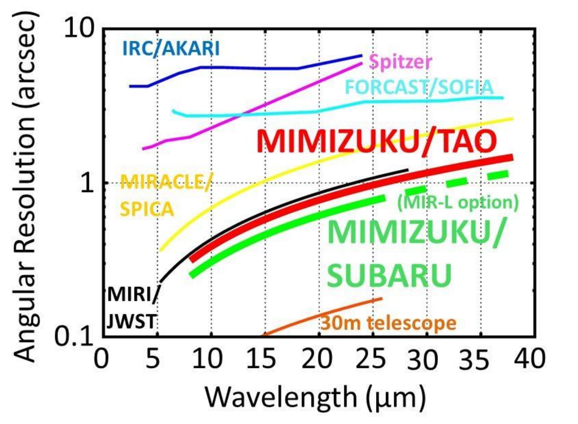

Fig. 7. Comparison of angular resolution between the MIMIZUKU and recent/future MIR instruments.

		NIR-ch	MIR-S ch	MIR-L ch
Wavelength		2 - 5.6μm	6 - 26μm	24 - 38μm
Detector		HAWAII1RG 1024 x 1024	Si:As AQUARIUS 1024 x 1024	Si:Sb DRS MF-128 128 x 128
Pixel Scale		0.07 "/pix	0.11 "/pix	0.18 "/pix
Field of View	w/o FS	1.2 ' x 1.2 '	2 ' x 2 '	23 " x 23 "
	w/ FS	0.6' x 1.2' x 2-fields	1' x 2' x 2-fields	23" x 11" x 2-fields
Imaging Filters		K, L', M (J, H option)	Med-band filters (Δλ ~ 1 μm) Narrow-band filters (Δλ ~ 0.2 μm)	Med-band filters (Δλ ~ 3 μm)
Spectroscopic resolution		R~180 @2.8 - 5.5 μm	R~230 @7.5 - 13.5 μm R~160 @16.5 - 25.5 μm	R~60 @26 – 38 μm (option)
Slit width, length		0.6 " x 60 "	0.3 " / 0.6 " x 60 "	1.2 " x 50 "

Table 2. Specification of the MIMIZUKU

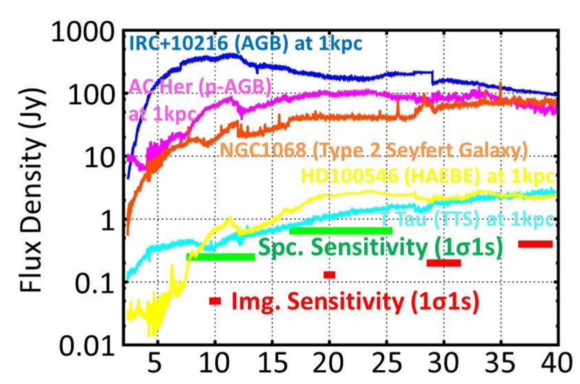

Fig. 8. Estimated sensitivity of the MIMIZUKU and some scaled spectra of interesting objects

MIR Monitoring of Disks with MIMIZUKU

The simultaneous observations with the MIMIZUKU realize stable long-term monitoring in NIR to MIR.

- **Simultaneous imaging** → **Precious photometric accuracy of ~ 1 %**
- **Simultaneous spectroscopy** → **Precious cancellation of atmospheric absorption lines**

We will carry out imaging and spectroscopic monitoring observations of dust emission from the circumstellar disks and the debris disks with the MIMIZUKU on Subaru and TAO telescopes. In **Subaru**, from 2014, MIR variabilities **up to λ=25 μm** with time-scale of **months to hours** will be focused on. In **TAO**, from 2018, observation targets will be expanded to long-MIR variations **up to λ=38 μm** with time-scale of **years to hours**. Main scientific topics we are planning are described below.

1. Dust Streams in Protoplanetary Disks

Discrepancy between theory and measurement

Theory: Silicate is crystallized on inner disk surface at < 0.1 AU, ~1,500K.
Observation: Crystallized silicate is found in interplanetary space around the earth, ~1AU, and in virgin comets formed in cold region in > 10 AU. Crystallized silicate features are appeared just after stellar outburst (Fig. 9)

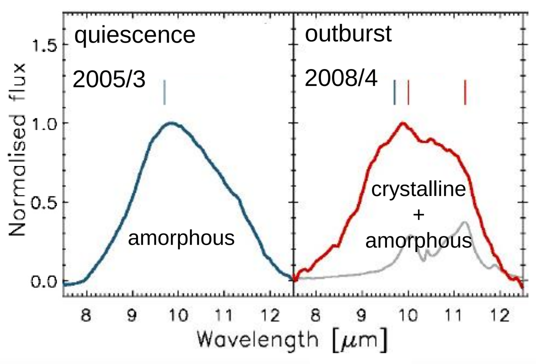

Fig.9. Crystalline features appeared just after a stellar outburst of EX Lupi (Abraham+09).

Hypothesis of dust stream

- Dust stream driven by stellar radiation and/or outflow exists? (Fig. 10)
- How is it transported outward?

Monitoring of dust disk around YSOs with outburst

Trace fresh crystalline dust processed by transient outburst.

(1) Stellar outburst
(2) Crystallization inside of 0.1 AU (hot crystalline features appeared)
(3) Migration outward (dust temperature decreased)

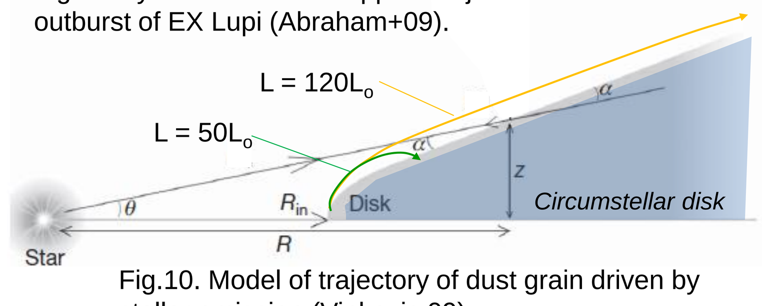

Fig.10. Model of trajectory of dust grain driven by stellar emission (Vinkovic 09).

MIMIZUKU's advantages

- High-accuracy long-term monitoring
- High-accuracy correction to atmospheric absorption bands around 10 μm.

2. Signatures of Giant Impacts on Young Exoplanets

Giant hypervelocity impact

- Collision between rocky planetesimals with >10 km/s (Fig. 11)
- Lunar forming giant impact in our solar system is similar phenomenon.

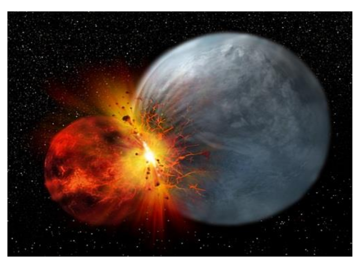

Fig.11. Artistic illustration of a giant hypervelocity impact (spaceref.com).

Peculiar hot silica features from old debris disks

- Dust emission is not luminous in typical old-debris disk of > 20 Myrs.
- Temperature is ~200 K, which suggests the debris is produced in outer cold region.

But, rarely, **hot luminous dust emission with Silica features** is seen in old debris disks, as HD172555 in Fig. 12.

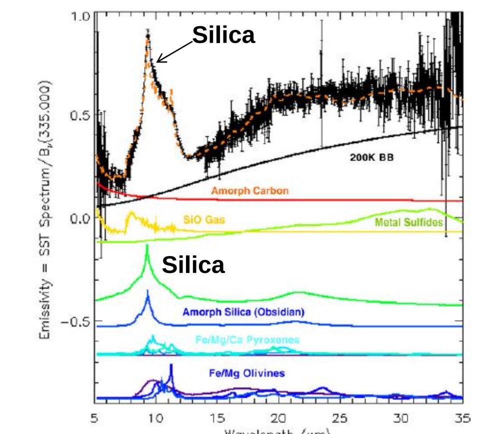

Fig.12. Silica features found in a MIR spectrum of HD172555 surrounded by an old debris disk (Lisse +09).

Spectroscopic and Monitoring observations of Silica features

Where is silica dust from?

- Silica(SiO_2) is not seen in interstellar dust.
- Silica is formed under high-temperature and high-pressure such as magma and giant impact events.

→ Silica features indicate signatures of Giant Impact, Magma Ocean and/or Giant Volcanos on rocky planets, or not?

MIMIZUKU' advantages

- High-accuracy correction to atmospheric Ozone around silica features.
- High-accuracy long-term monitoring for time decay of the silica emission.

3. Pulsations of Massive-YSOs (MYSOs)

Problems of massive star formation

- High accretion rate is needed for overcoming radiation pressure feedback from a massive protostar.
- Spatial resolution is not enough to observe the heavily obscured inner-region of < 1,000 AU radius.

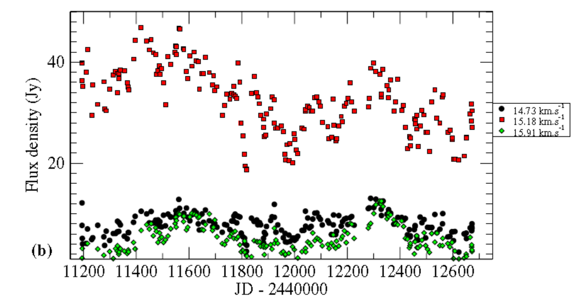

Fig.13. Time-series of 6.7 GHz methanol maser from MYSO G196.45-1.68 (Goedhart+04).

Periodic bursts of methanol masers in MYSOs

- Recently, periodic flux variations of methanol masers over several 10-100 days are reported as shown in Fig. 13 (Goedhart+04, 09).
- Could be explained by pulsation of massive protostars growing under rapid mass accretion (Inayoshi+13)

MIR monitoring of MYSOs with periodic maser variations

- If the periodic maser variations are induced by the pulsation of the protostar, thermal emission from the inner (disk?) structure could be synthesized with the variations (Fig. 14).

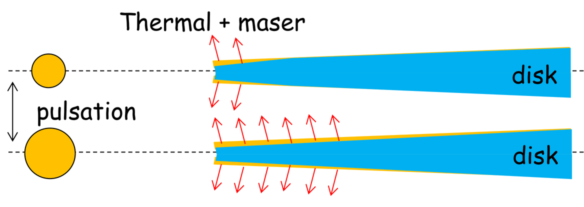

Fig.14. Schematic view of synthesized variation of thermal and maser emissions when a thin-disk exists around the protostar.

MIMIZUKU' advantages

- High-accuracy long-term monitoring
- Sensitivity in long-MIR up to 38 μm.

Related paper on MYSO is at 1B056 (Uchiyama+)

4. Follow-ups of Interest Variabilities Detected in Disks

Example of an interest variability

Rapid disappearance of warm debris disk around TY8241 2652 1

- Infrared flux from a debris disk decreased drastically, by about 1/30, over a period of < 2 years (Melis+12, Fig.15).
- Such rapid evolution is not previously predicted or observed.
- No currently available physical model satisfactorily explains the observations

Continuous long-term follow-up observations are required.

→ **The MIMIZUKU is a suitable instrument for follow-ups of the peculiar phenomenon of TY8241 2652 1.**

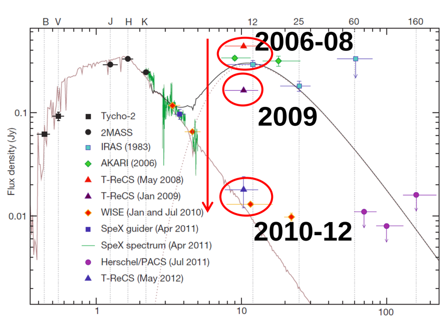

Fig.15. SED of TY8241 2652 1 (Melis+12). Infrared excess around 10 μm is decreased drastically, by about 1/30, in < 2 years.

MIMIZUKU

Collaborations are very welcome. Please contact us, if you have any interests in TAO and MIMIZUKU projects. E-mail: sako@ioa.s.u-tokyo.ac.jp (Shigeyuki Sako)

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