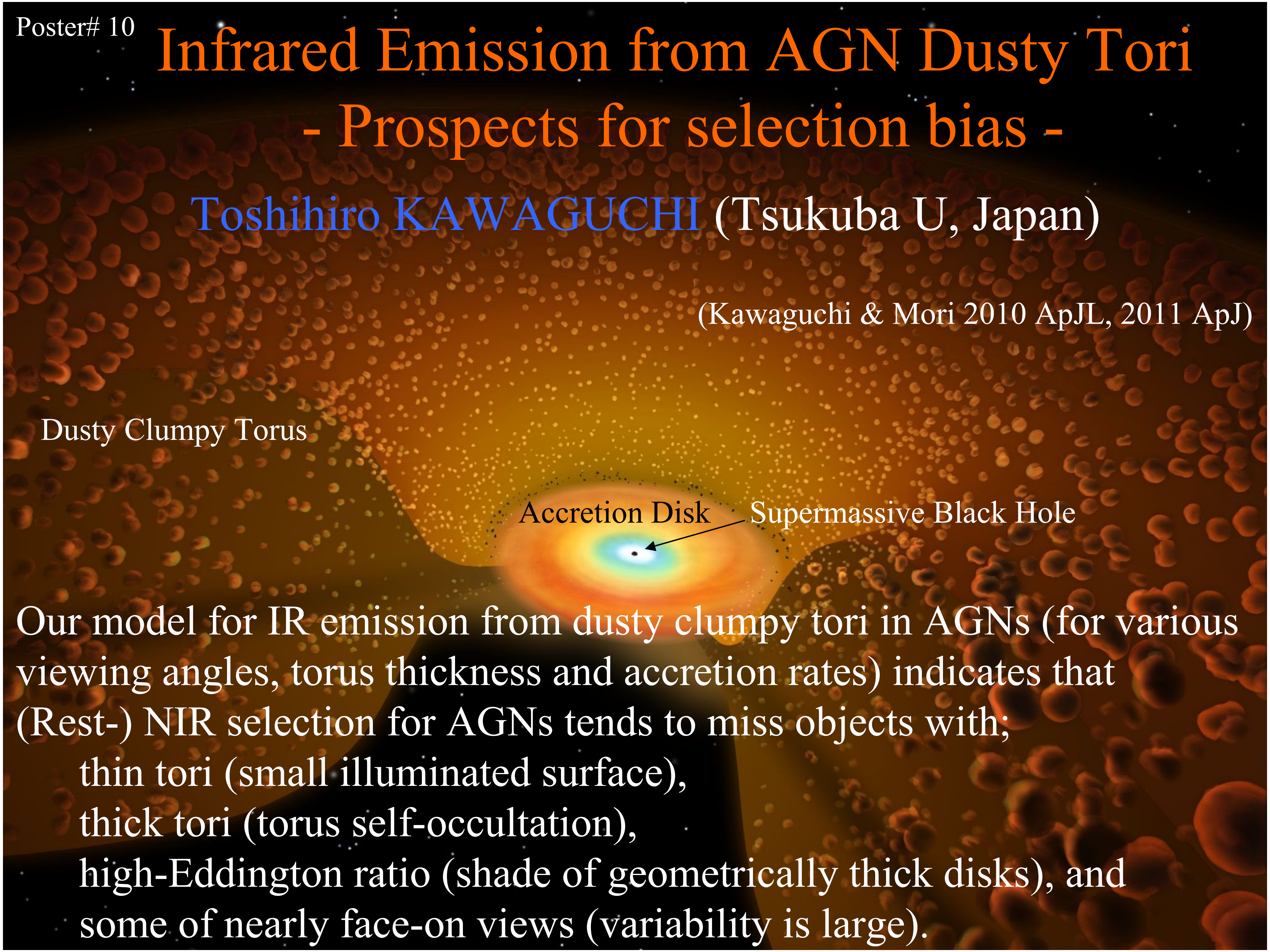
Poster# 10

Infrared Emission from AGN Dusty Tori

- Prospects for selection bias -

Toshihiro KAWAGUCHI (Tsukuba U, Japan)

(Kawaguchi & Mori 2010 ApJL, 2011 ApJ)



Our model for IR emission from dusty clumpy tori in AGNs (for various viewing angles, torus thickness and accretion rates) indicates that (Rest-) NIR selection for AGNs tends to miss objects with;

thin tori (small illuminated surface),
thick tori (torus self-occultation),
high-Eddington ratio (shade of geometrically thick disks), and
some of nearly face-on views (variability is large).

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Summary

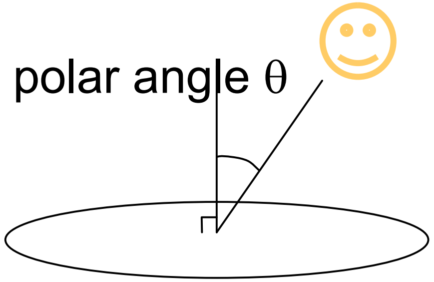
The accretion disk and black hole in AGNs are surrounded by a dusty clumpy torus. We have developed a model for the Near-IR (NIR) emission and its time variabiity from the torus, taking into account the anisotropic illumination from the disk, the waning effect of each clump and the torus self-occultation. We present some results that would affect AGN surveys via rest-NIR emission. For instance,

* both a thick & thin tori display the weaker NIR emission.
* Objects with high Eddington ratios are also expected to be NIR weak. Thus, NIR-selected AGNs tend to possess moderately thick tori (with the opening angle ~ 45deg) with sub-Eddington accretion rates.
* A small inclination angle (closer to a face-on view) leads to a large rest-NIR variability. Inclined angles (e.g. type 1.5) show intrinsically red optical-NIR color.

1-1. Our model for AGN dusty clumpy torus

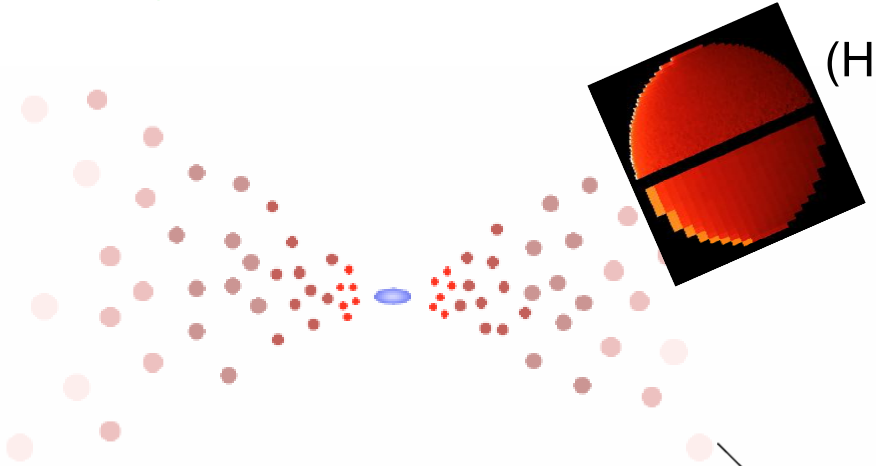
Motivation :

Earlier models presumed an isotropic illumination.
However, emission from optically-thick disk is inevitably anisotropic.



Flux to θ $\propto \underline{\cos\theta}\ \underline{(1 + 2\cos\theta)}$

projection and limb darkening

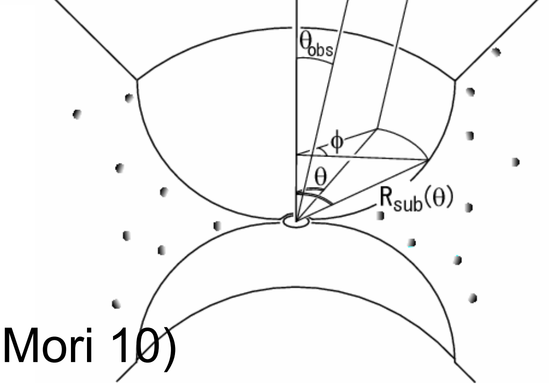

(Honig et al. 2006)

Assumptions :

At inner radius,
clump temperature
= 1500K

Resultant inner shape:

- closer to the central BH
- concave/hollow
- connected to the disk outermost radius
  i.e. no gap between disk and torus.



(TK & Mori 10)

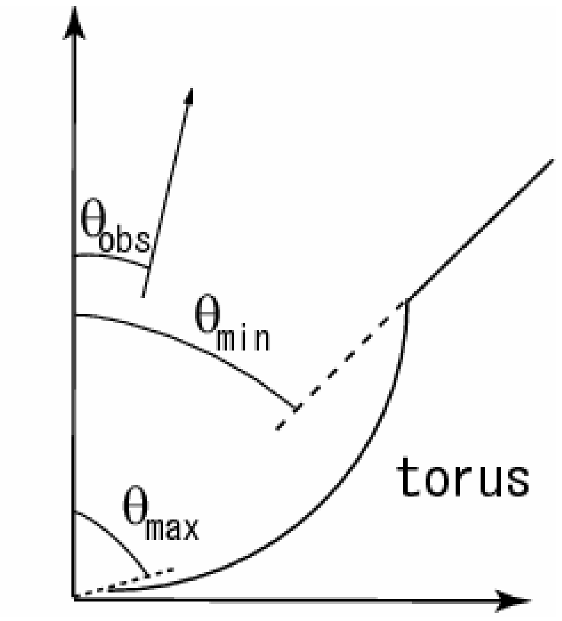
1-2. NIR time variability in response to optical/UV flash $\Psi(t)$ ②

- We calculate the time variation (transfer function) $\Psi(t)$ of the NIR emission from the torus, in response to a flash of UV/optical illumination from the accretion disk.

$\Psi(t)$ shape: NIR time variation profile
centroid: optical--NIR time lag
integration: NIR luminosity

- Ingredients to compute $\Psi(t)$

1. light pass difference (θ, φ; θ_{obs})
2. NIR emissivity
3. Anisotropic emission from each clump
   (How extent each clump faces their illuminated surface to the observer)
4. Torus self-occultation



- Input parameters: viewing angle, torus thickness, disk thickness

1-3. Torus inner radius：our model solved the conflict.

③

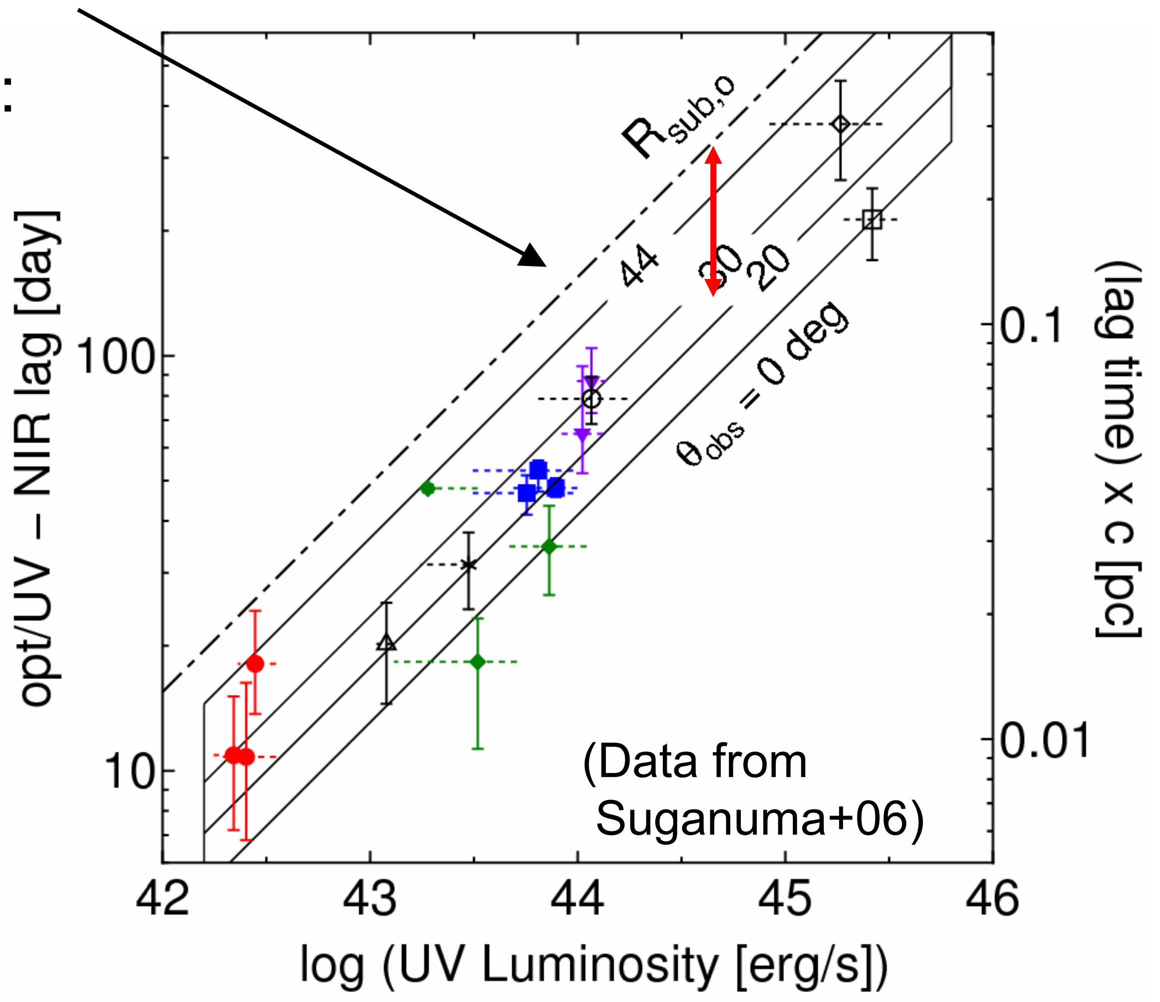
- Earlier theoretical prediction (dot dashed = sublimation radius)

$$R_{\rm sub} = 1.3 \left(\frac{L_{\rm UV}}{10^{46}\ {\rm erg/s}}\right)^{1/2} \left(\frac{T_{\rm sub}}{1500\ {\rm K}}\right)^{-2.8} \left(\frac{a}{0.05\ \mu{\rm m}}\right)^{-1/2} {\rm pc}$$

(Barvainis 1987)

- Observed radius (points): systematically smaller by ~1/3

(Oknyanskij+Horne 01; Kishimoto+07; Nenkova+08)

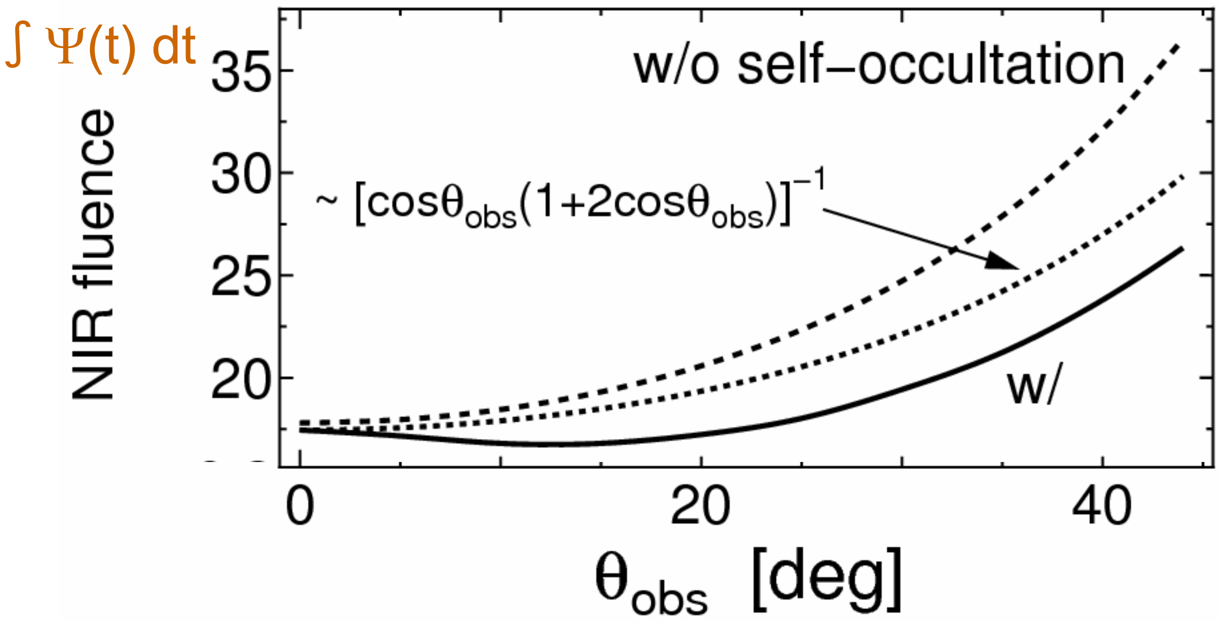


(Data from Suganuma+06)

- Our model (loci) well covers the observed data!

2-1. Viewing angle θ_{obs} dependency: NIR luminosity, opt-NIR color

④



Normalization:
If torus NIR emission is ...
* anisotropic as the disk,
then a horizontal line.
* isotropic, then dotted line.

Computed torus emission:

◆ Solid line is below the dotted line.

➔ NIR is weaker when viewed at an inclined angle.

◆ Solid line increases at larger θ_{obs}.

➔ Torus anisotropy is weaker than that of the disk.

In other words, the intrinsic optical-NIR color is redder for type 1.*.

[We are computing for the same $4\pi d^2$ x optical flux [L_{iso}(opt)] (same $R_{sub,0}$)]

2-2. Viewing angle θ_{obs} dependency: NIR variability amplitude ⑤

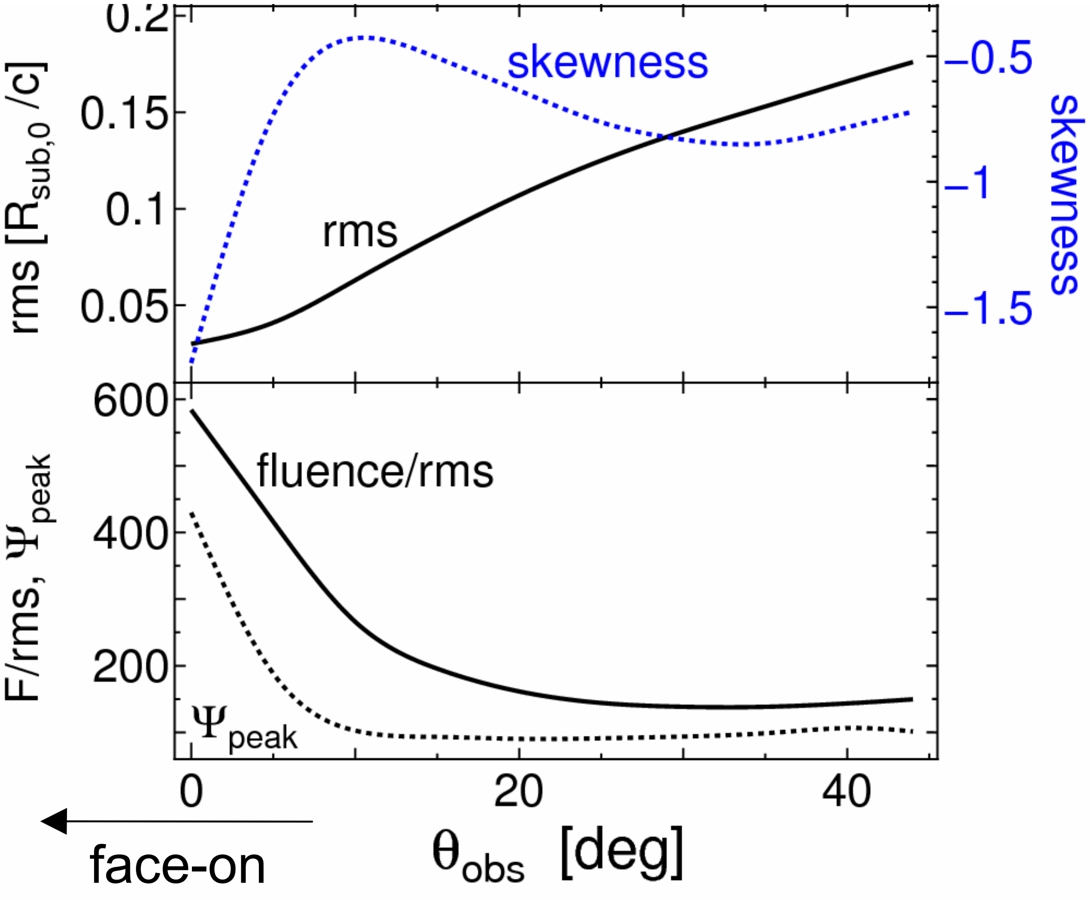
Closer to face-on, the NIR variability amplitude is expected to be larger.

Width (rms) of the NIR time response:

NIR variation is large for small rms.

NIR fluence/rms ratio (solid and peak value of NIR time response (dotted):

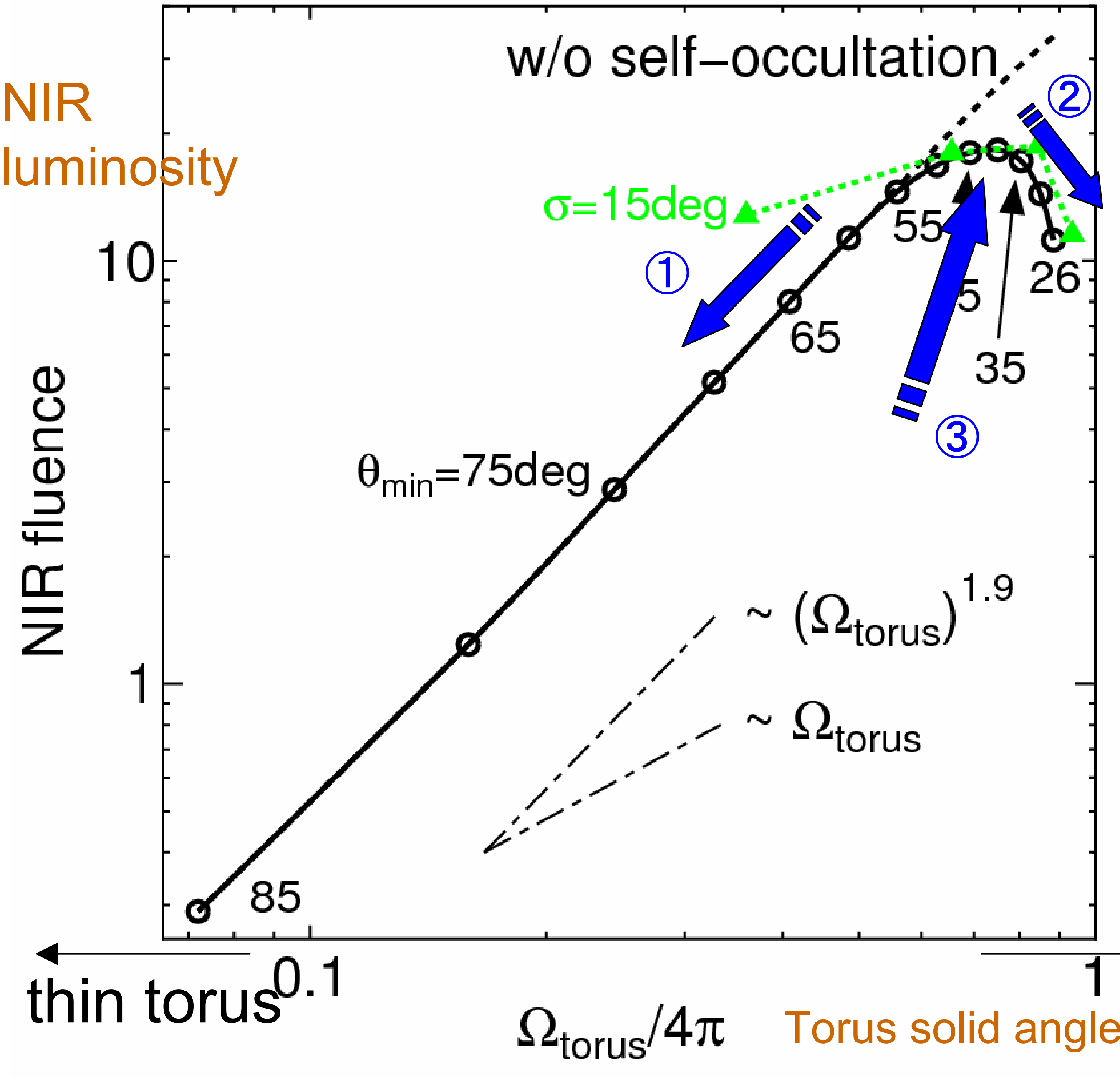
If they are large, then large NIR variation is expected.



3 Torus thickness θ_{min} dependency: NIR luminosity (1/2)

⑥

NIR luminosity



Nenkova+08
R_{sub}= const.
(isotropic illumination)

cf. R_{sub} is a function of θ in our calculations

thin torus ← → thick

Torus solid angle seen from the center

3 Torus thickness θ_{min} dependency: NIR luminosity (2/2)

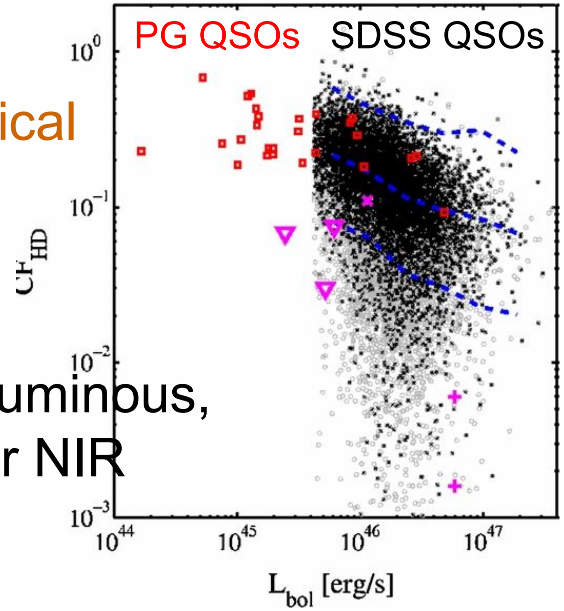
① Thin tori are weak NIR emitter:

qualitatively, trivial (smaller illuminated surface).

➔ Thin tori (quasars) show redder opt-NIR color,

consistent with observed trend

(e.g. Mor+Trakhtenbrot 11).



NIR/optical

More luminous,
weaker NIR

② Thick torus also shows weaker NIR due to torus self-occultation.

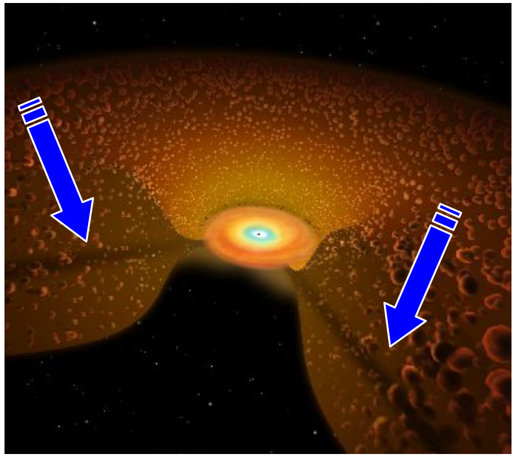
(cf. dashed line = torus self-occultation off)

③ Modestly thick torus is the strongest NIR emitter:

➔ Selection bias: NIR selected AGNs tend to show modest thickness for their tori.

4. Accretion rate dependency: shade of disk (disk self-occultation)

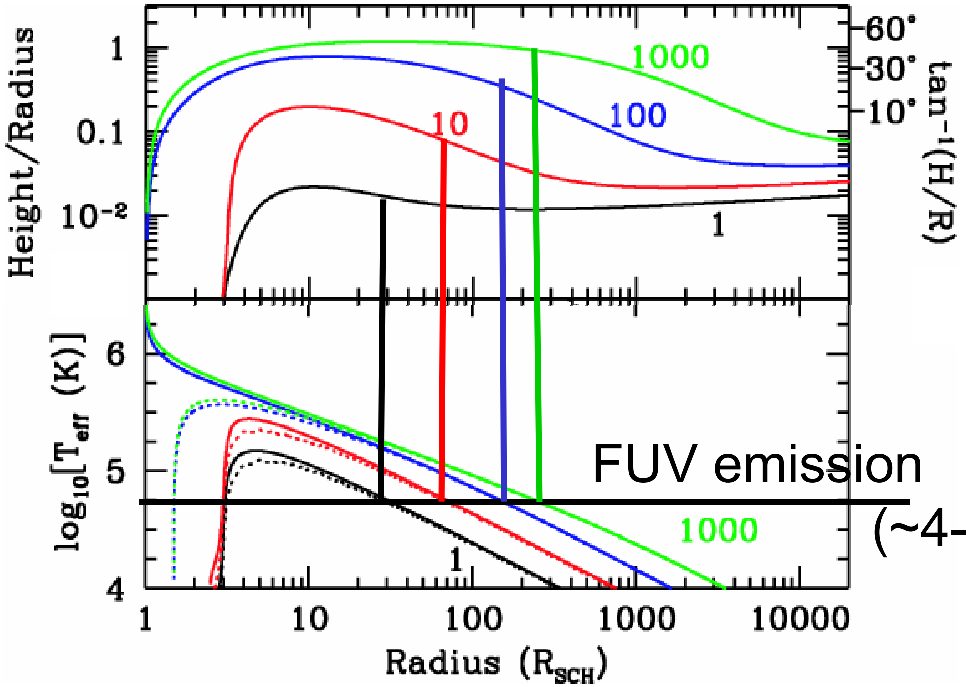
The disk becomes geometrically thick when the accretion rate gets super-Eddington rate.



$\dot{M}/(L_{Edd}/c^2) = \underline{1, 10}, \underline{100, 1000}$

Sub-Eddington accretion
(standard accretion disk)

Super-Eddington



FUV emission

$(\sim 4\text{-}5\ 10^4\ \mathrm{K})$

distance from BH (r_{Sch})

(TK 2003)

angular thickness $(=90^\circ - \theta_{max})$

1°
4°
17°
39°

shade negligible

huge shage

4. Disk thickness (accretion rate) dependency

When the accretion rate becomes super-Eddington, large shade of the disk (less illumination to torus) reduces the NIR emission. Moreover, disk self-gravity makes the disk truncated, leading to no disk contribution at NIR (TK03; TK+04a).

➔ Rest-NIR selection tends to miss super-Eddington accretors.