Near-IR View of Accretion Disks in Super-Eddington Active Galactic Nuclei

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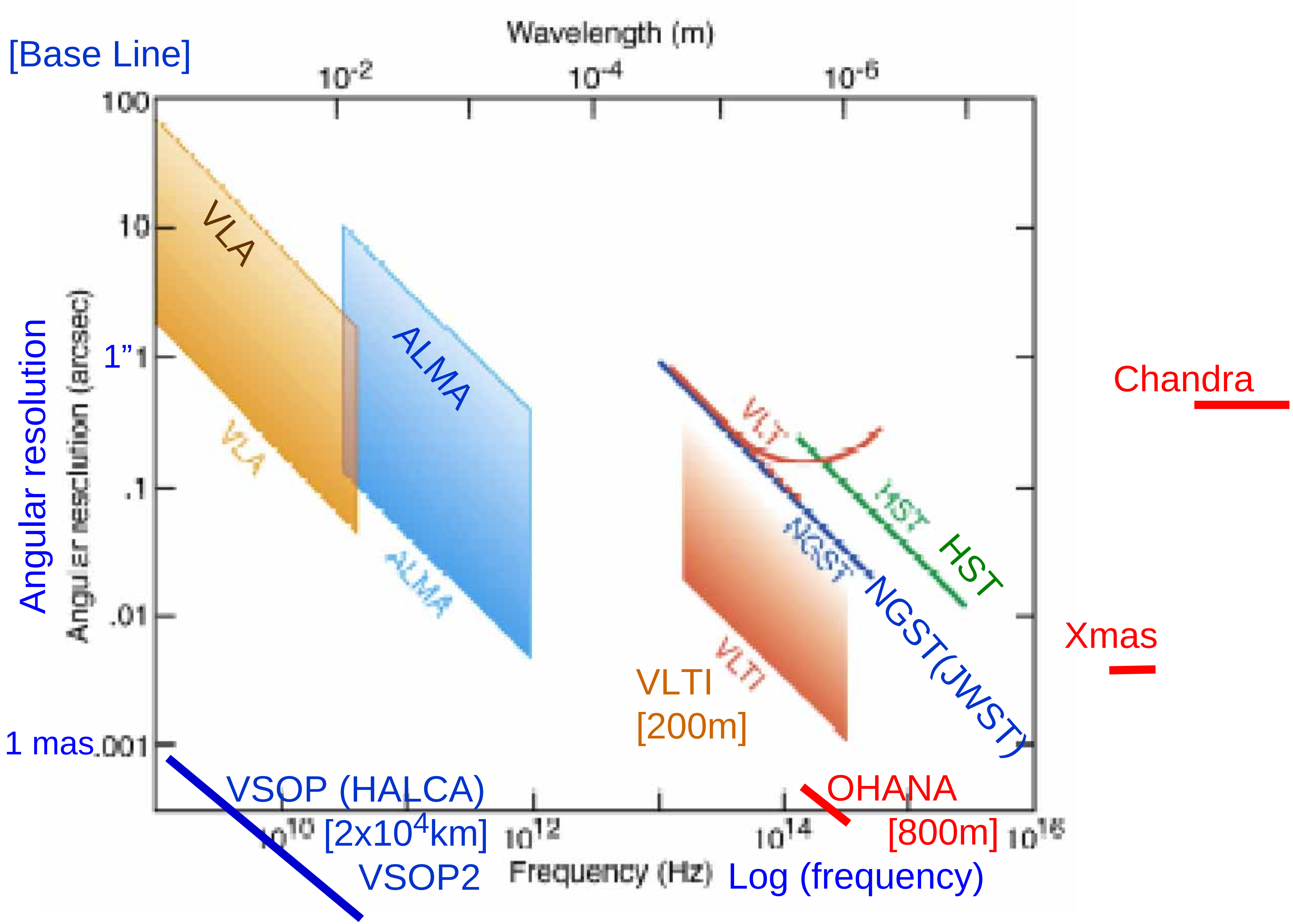
   円盤自己重力 (**中心**BH**から 約**10^4 R_{Sch})
2. **原始惑星系円盤の、(自己重力起源らしき)渦状構造に学ぶ**:
   OHANA**や**VLTI (**近赤外線干渉計(計画))の空間分解能で、**
   AGN**降着円盤の渦模様は見えるか？ どれだけ足らないか？**



ESO report; VLTI strategy upto 2020

0. Candidates for Super-Eddington Accretion sources

- Narrow-Line Seyfert 1 galaxies (NLS1s):

Black Hole (BH) mass: $M_{BH} \sim 10^{(6-7)} M_{sun}$,
Bolometric Luminosity $\gtrsim$ Eddington Limit (L_{Edd})

- Narrower “Broad Lines”: line width ~ virial velocity at broad-line region
- Rapid X-ray variability : smaller emitting region
- Hotter “Big Blue Bump” (optical--X-ray): smaller volume (cf. X-ray binaries)

(cf. quasar: $M_{BH} \sim 10^9 M_{sun}$, $L \sim (0.01 -- 0.1) L_{Edd}$)
(**言い換えると、**accretion rate ($\dot{M}$) / M_{BH} **比が他の**AGN**に比べ大きい。**)

NLS1**の関連する研究分野**(**今日の発表には関係ないです**)

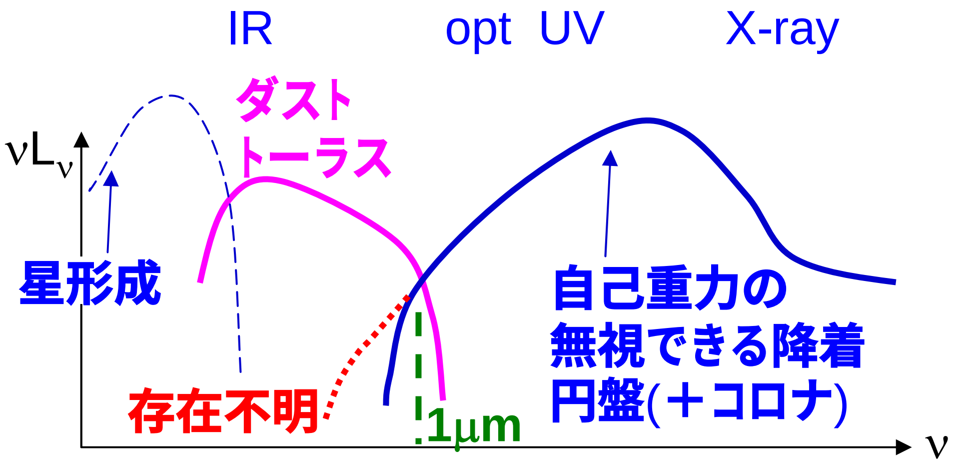
- Rapid (~ $M_{BH}/\dot{M}$) and major phase of BH growth (Kawaguchi et al. 2004b)
- Elapsed time from the beginning of BH growth (~ $M_{BH}/\dot{M}$) seems shorter.

(Our spectroscopic and imaging observations are underway.)

- Contribution to Extreme-UV (EUV) background radiation : → Re-ionization
- Laboratories for accretion disk theory (Kawaguchi 03; Kawaguchi et al. 04a)

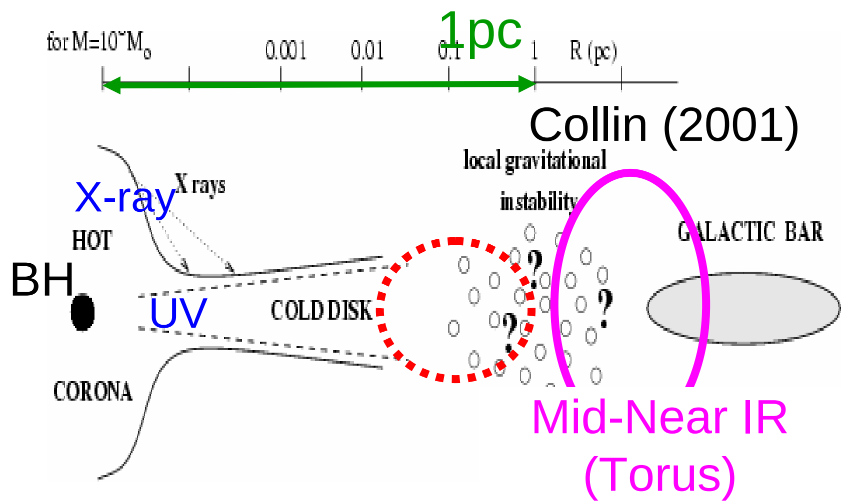
1-1. : self-gravity in AGN accretion disk

- Sub-Eddington AGNs

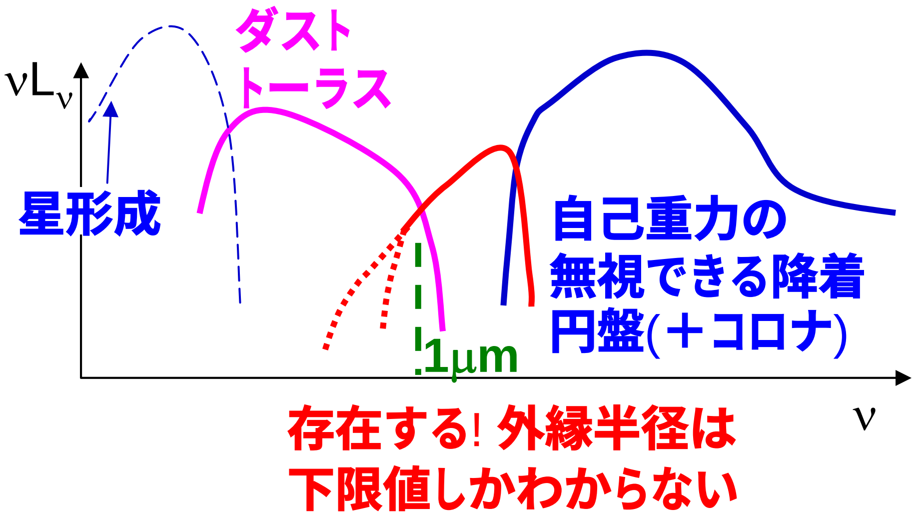


Before …

Self-gravitating part of the accretion disk can not be observed.
(i.e. not testable)



- Super-Eddington AGNs



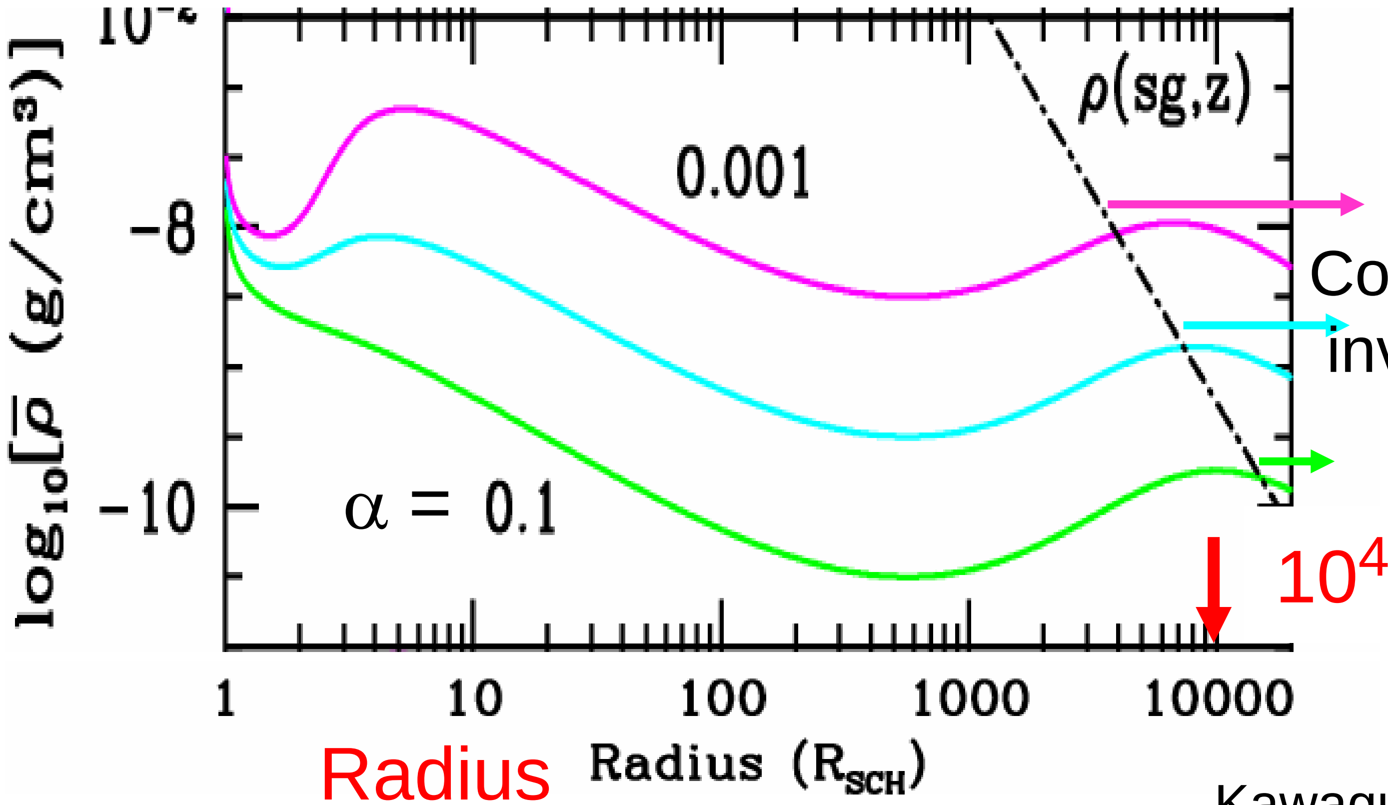
Now …

Self-gravitating part of accretion disks (in super-Eddington AGNs) exists, and does emit optical continuum radiation (Kawaguchi 03; Kawaguchi et al. 04a).
(Systematic M_{BH} overestimation)

1-2. Self-gravity in AGN accretion disks: Discovery (1/2)

If $\rho > \rho(\mathrm{sg})$ → (Vertical) self-gravity onsets

$\dot{M}$dot = 1000 L_{Edd}/c^2



Density

Computations invalid

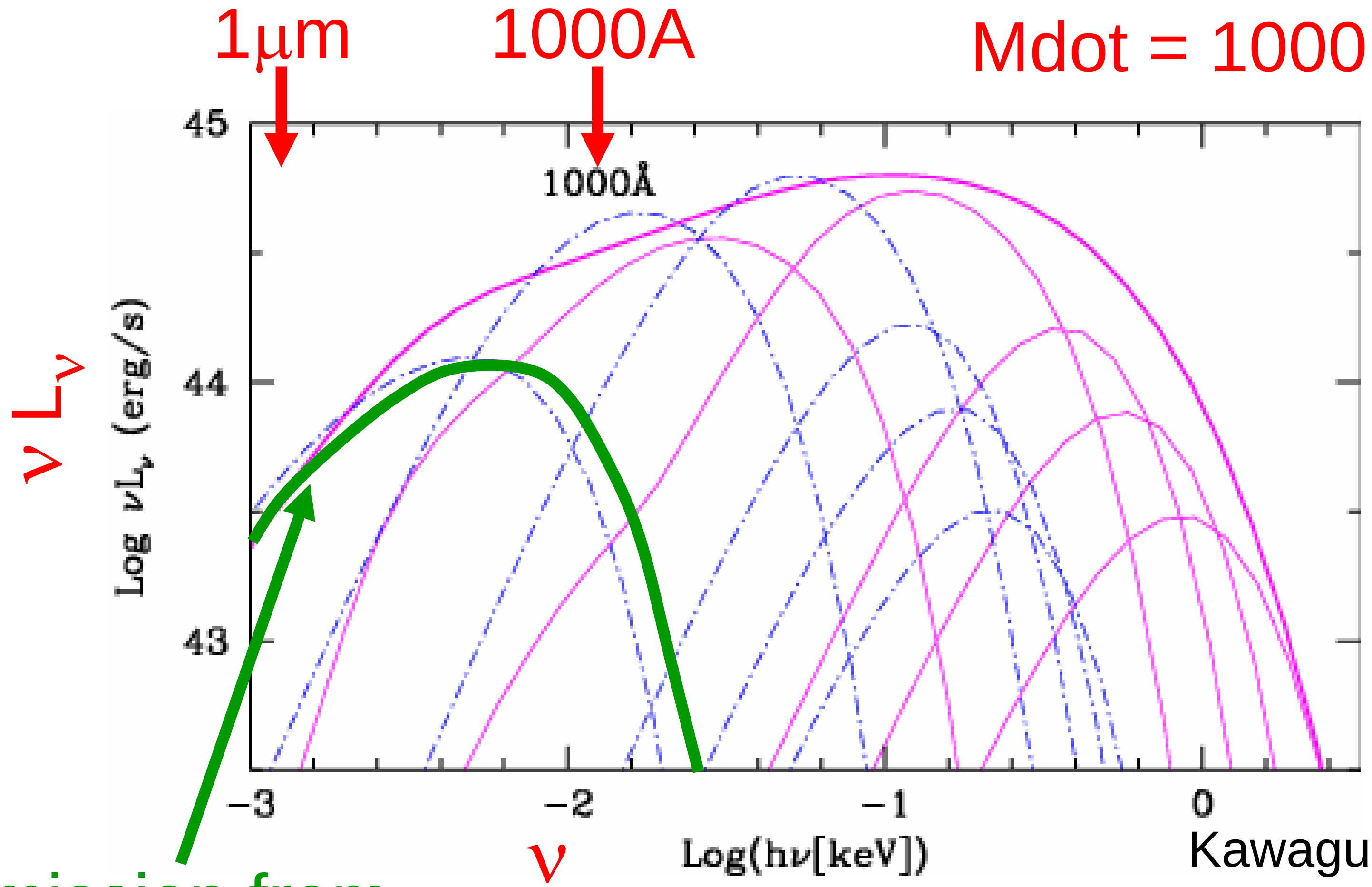
$10^4\ R_{\mathrm{Sch}}$

Radius

Kawaguchi (2003)

1-2. Self-gravity in AGN accretion disks: Discovery (2/2)

Mdot = 1000 L_{Edd}/c^2



Kawaguchi (2003)

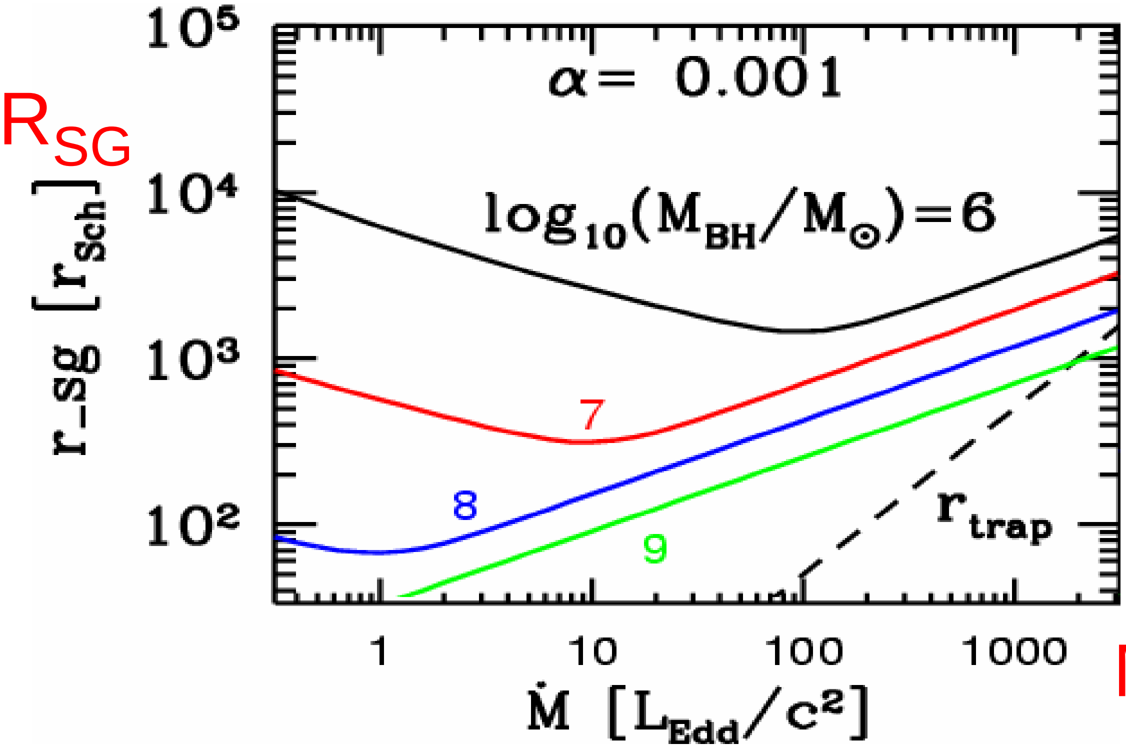
Emission from
10^3 – 2 x 10^4 R_{Sch} appears at optical band

3-3. Outer edge of non self-gravitating disk (1/3): Radius

R_{SG}: the radius where $\rho = \rho\ (\text{sg}) = \boldsymbol{\Omega}^2 / (4\pi G)$

At $R > R_{SG}$, self-gravity plays a role.

R_{SG}



(Kawaguchi, Pierens, Hure 2004)

(see also Hure 98 etc)

Mdot

Sub-Eddington

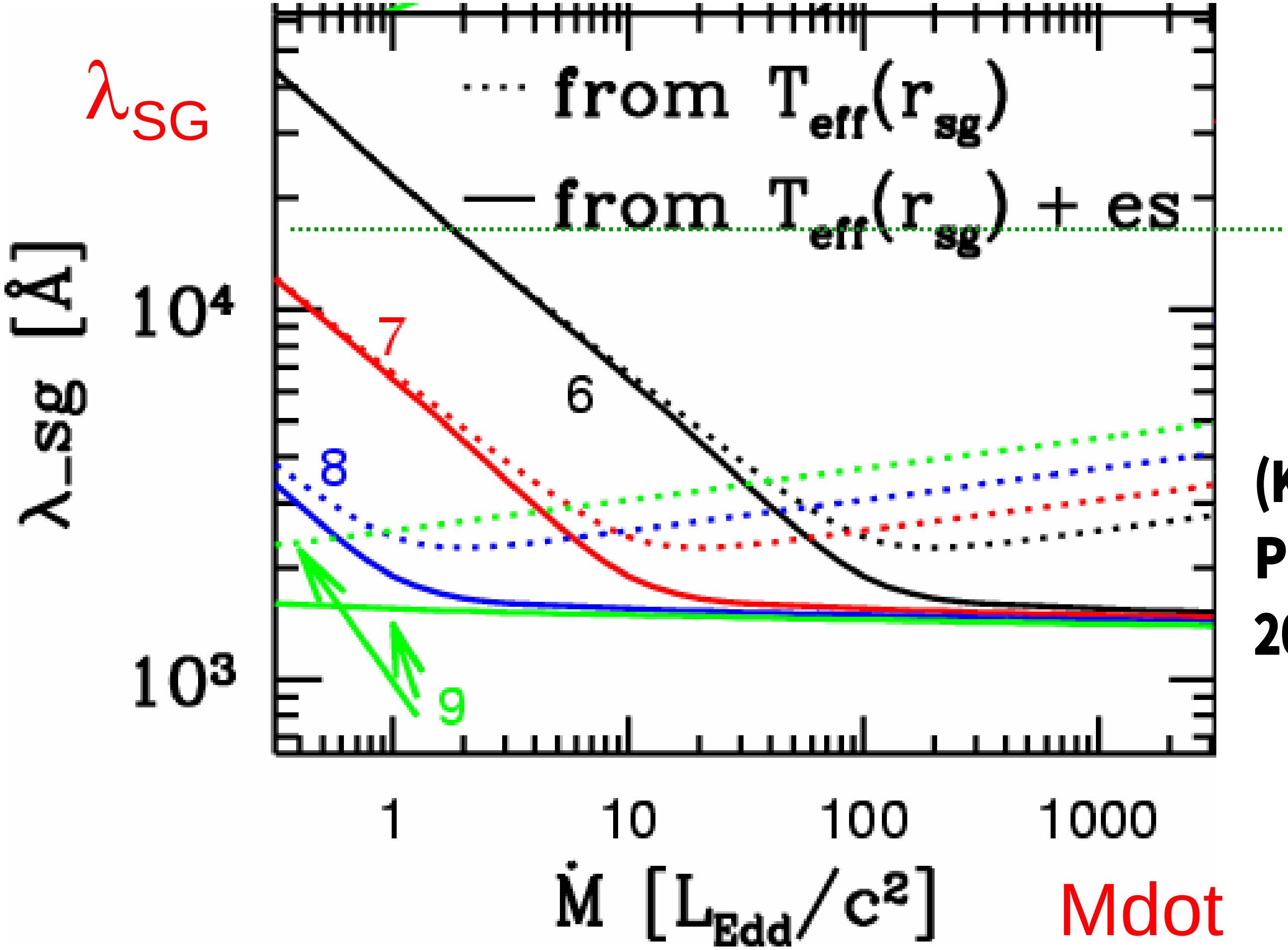
Supper-Eddington

$R_{trap} > R_{SG}$

self-gravitating, optically-thick, advection-dominated disk

3-3. Outer edge of non self-gravitating disk (2/3): Wavelength-1

λ_{SG}: wavelength corresponding to emission from R_{SG}



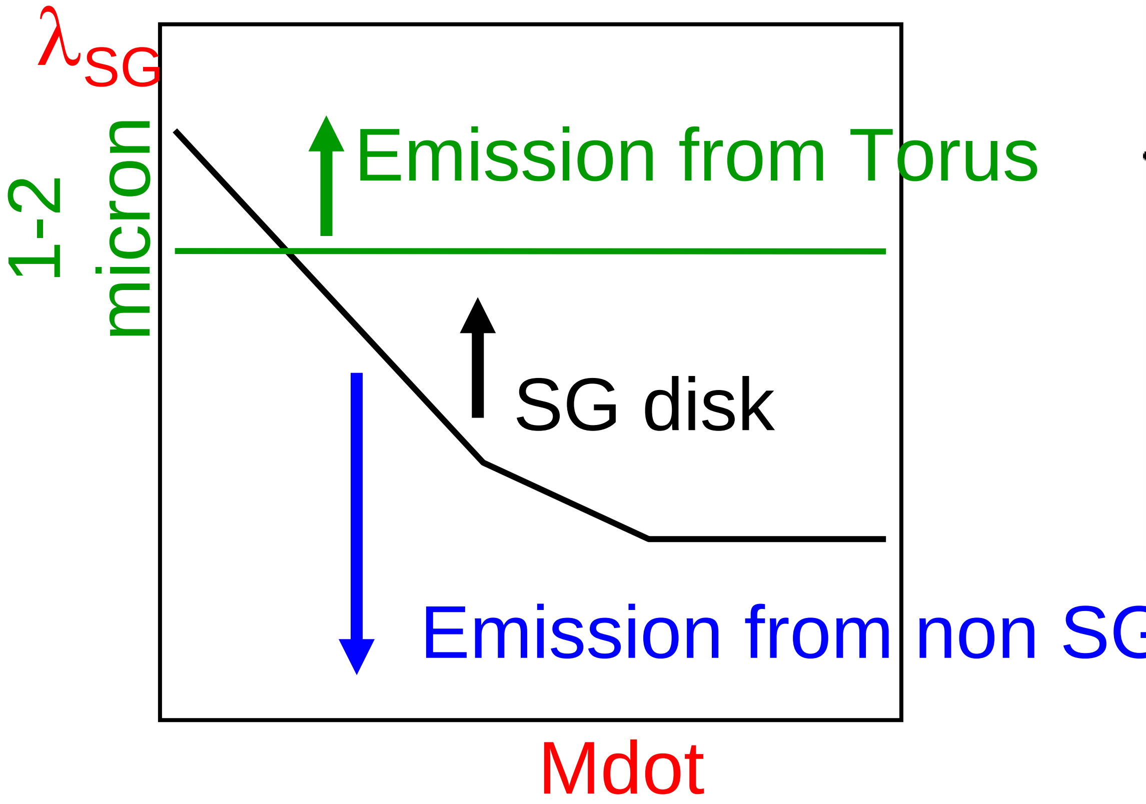
λ_{SG}

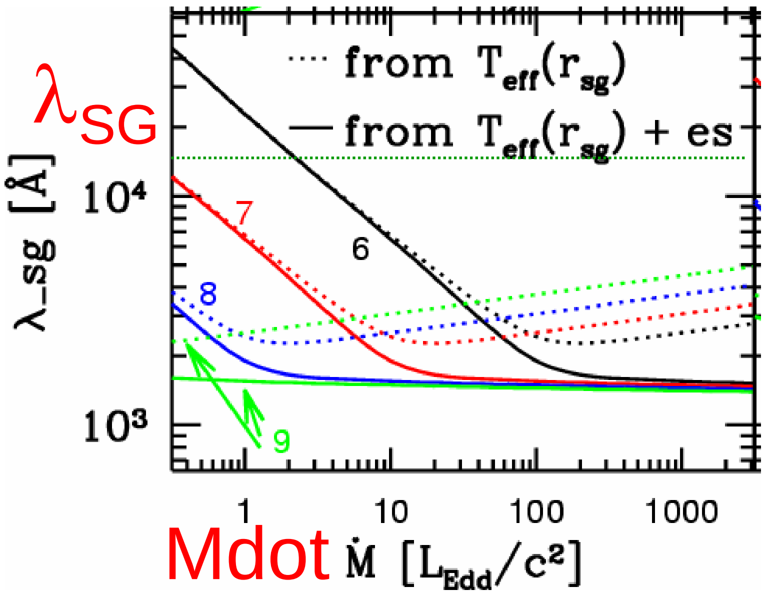
1-2 micron

Mdot

(Kawaguchi, Pierens, Hure 2004)

3-3. Outer edge of non self-gravitating disk (3/3):Wavelength-2

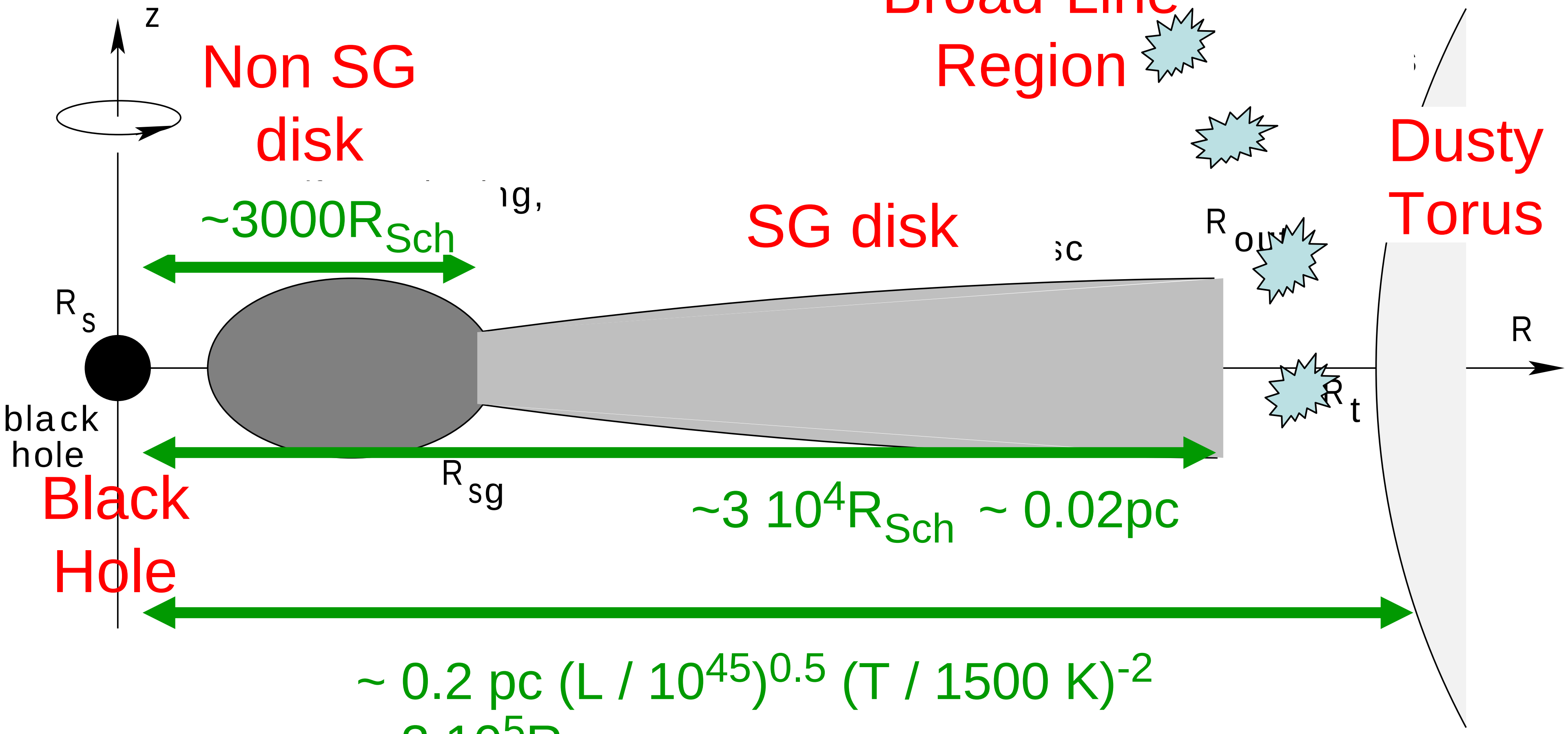




“λ_{SG} < 1 micron” indicates that
we CAN observe self-gravitating part of accretion disks.
“Spectral Window to Observe Self-Gravity”

4-3. Ton S 180: Configuration

(R_{Sch} ~ 1.9 10^{12} cm)



Broad-Line Region

Non SG disk

Dusty Torus

~3000R_{Sch}

SG disk

Black Hole

~3 $10^4 R_{Sch}$ ~ 0.02pc

~ 0.2 pc (L / 10^{45})$^{0.5}$ (T / 1500 K)$^{-2}$

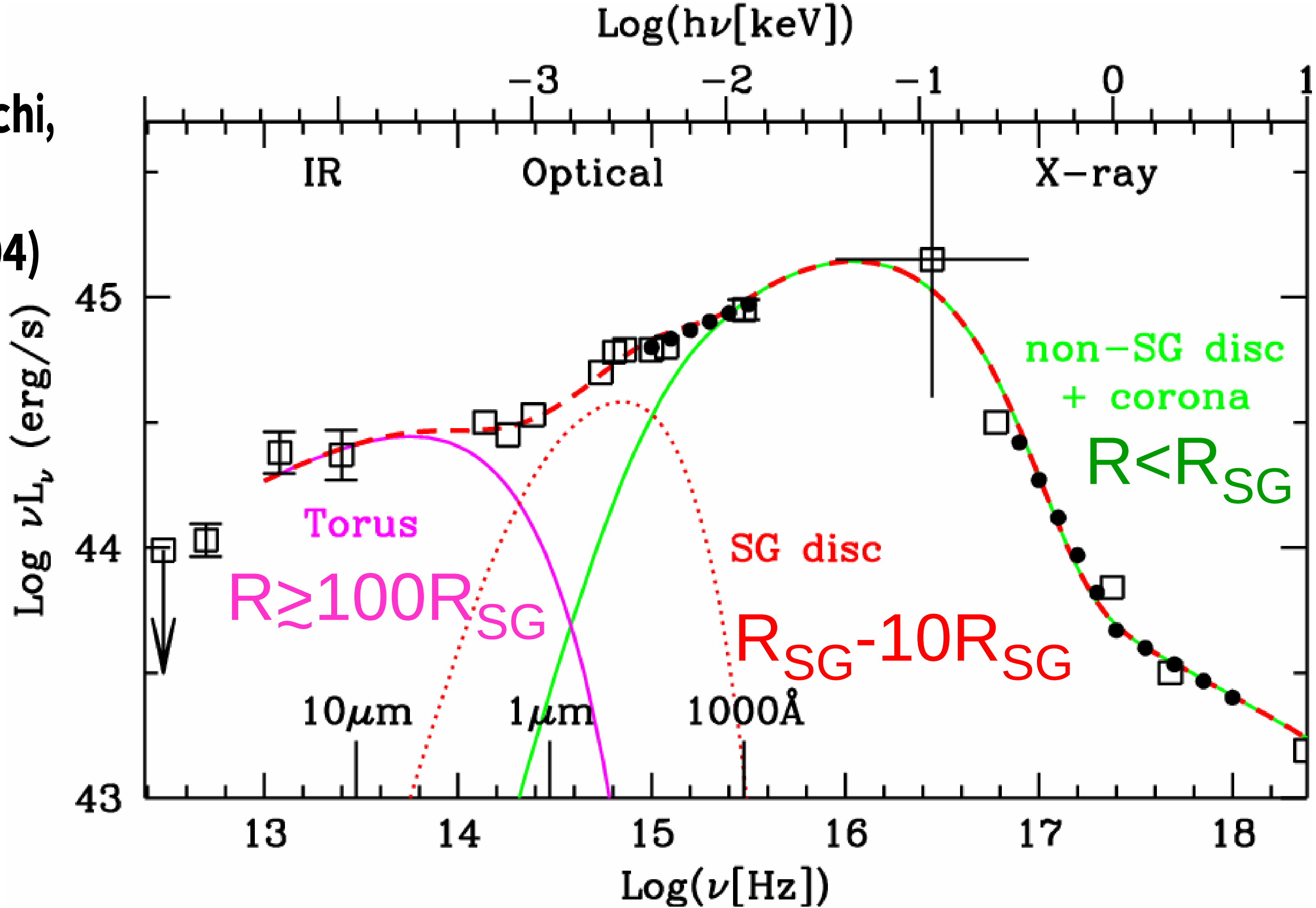
~ 3 $10^5 R_{Sch}$

Distance of Broad Line Region from central BH (Kaspi et al. 2000)

~ 0.085 pc ~ 1.4 $10^5 R_{Sch}$

4-8. Ton S 180: Self-Gravitating Disk-1

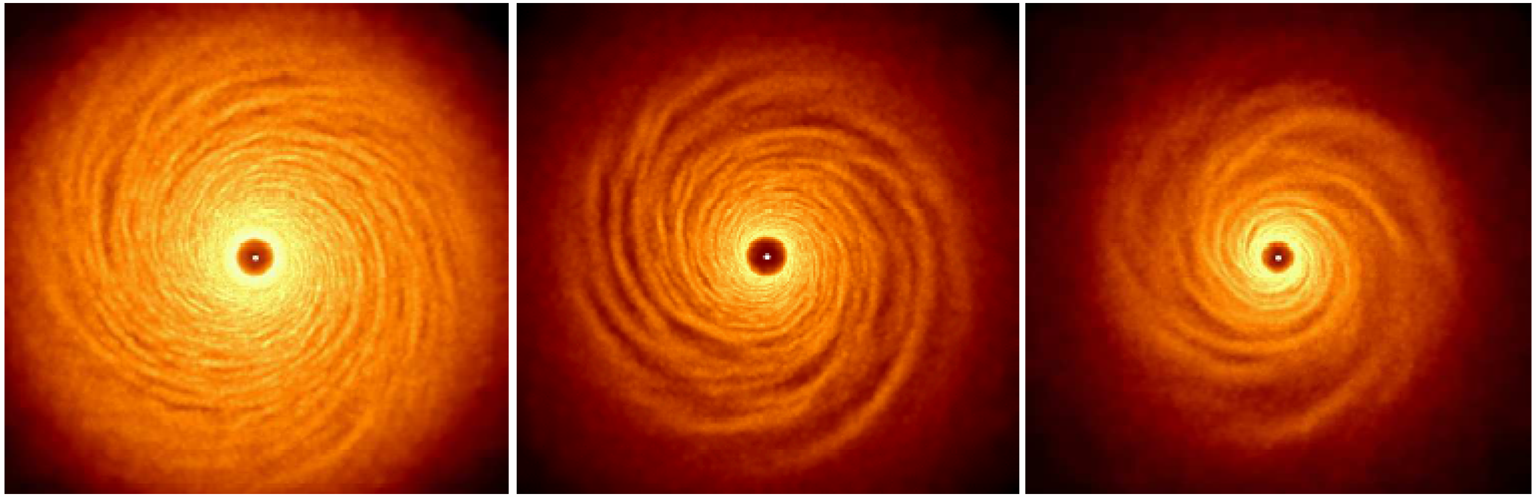
(Kawaguchi, Pierens, Hure 2004)

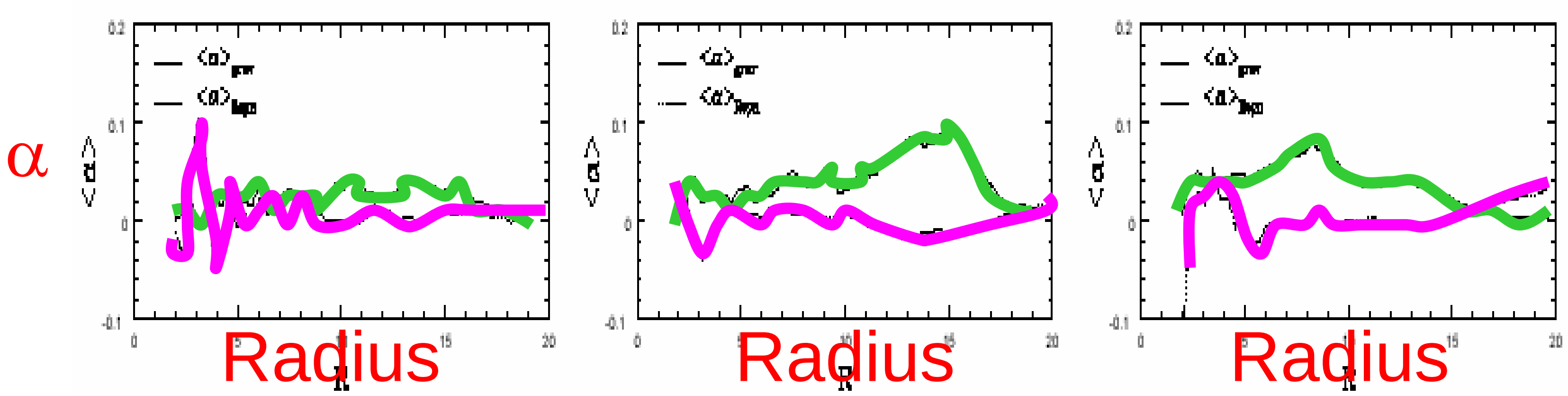


- Assumptions; $\Sigma \sim R^{\gamma}$, $H \sim R^{\beta}$ ($\beta \sim 1$)
- Inner boundary conditions; $\Sigma(R_{SG})$ and $H(R_{SG})$
- Outer most radius is chosen to be 10 R_{SG}

4-9. Ton S 180: Self-Gravitating Disk-2
Heating at SG disk

$M_{disc}=0.05M_{BH}$ $0.1M_{BH}$ $0.25M_{BH}$



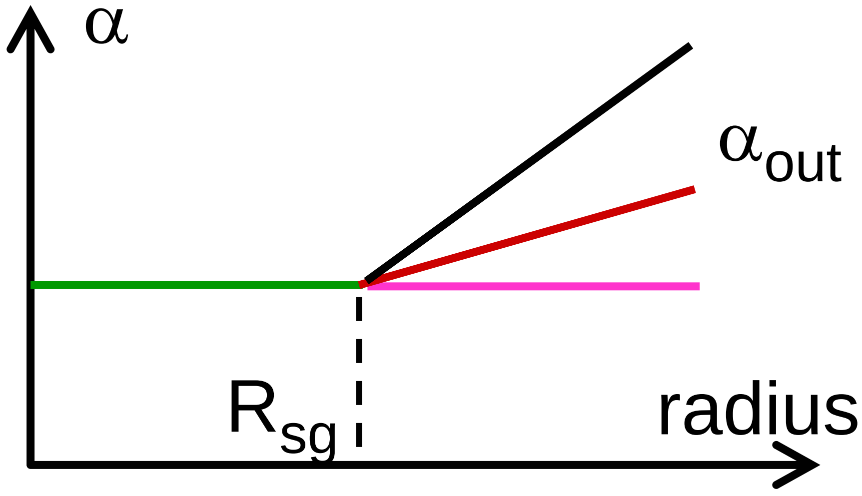


SPH simulation by Lodato & Rice (2004): Note a priori cooling timescale.

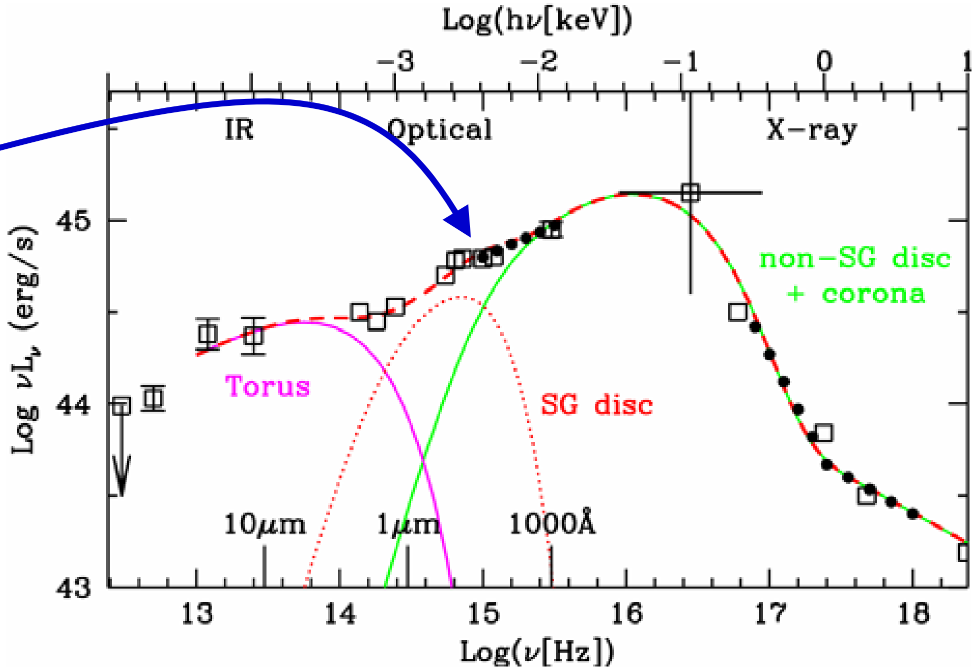
α(grav. Instabilites) > α(viscous), if disc mass is large.

4-10. Ton S 180: Self-Gravitating Disk-3

Three solutions below fit the observed spectrum equally.



α_{out}	γ ($\Sigma \sim r^{\gamma}$)
0.002	0.3
(i.e. constant α)	
0.02	-0.6
0.1	-1.5



Further understanding of α_{grav} is necessary

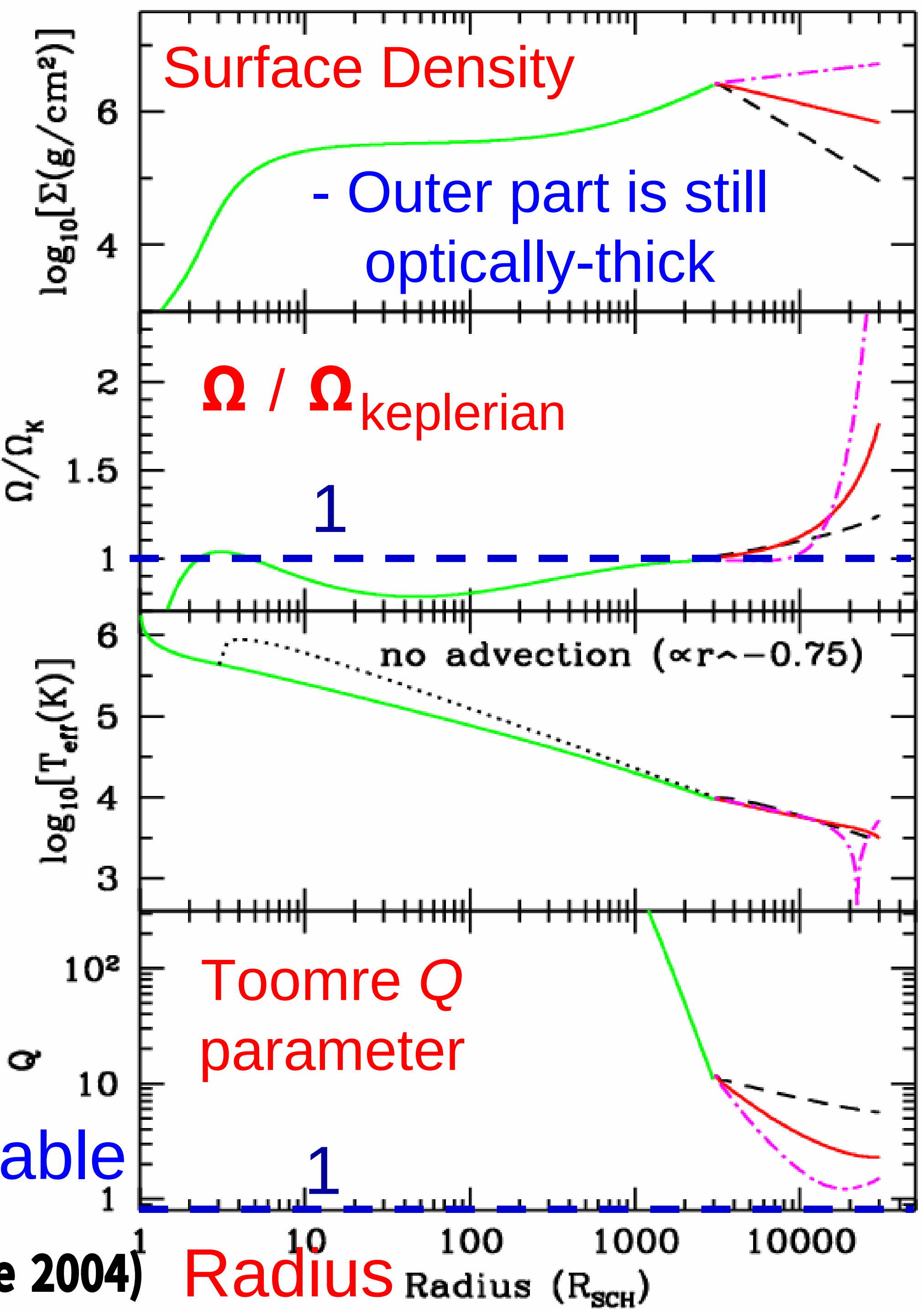
4-11.TonS180: Physical Quantities

- Super-Keplerian rotation at R > R_{SG}

Effective Temperature

- Q parameter is always greater than 1, i.e. (at least marginally) stable

- Outer part is still optically-thick

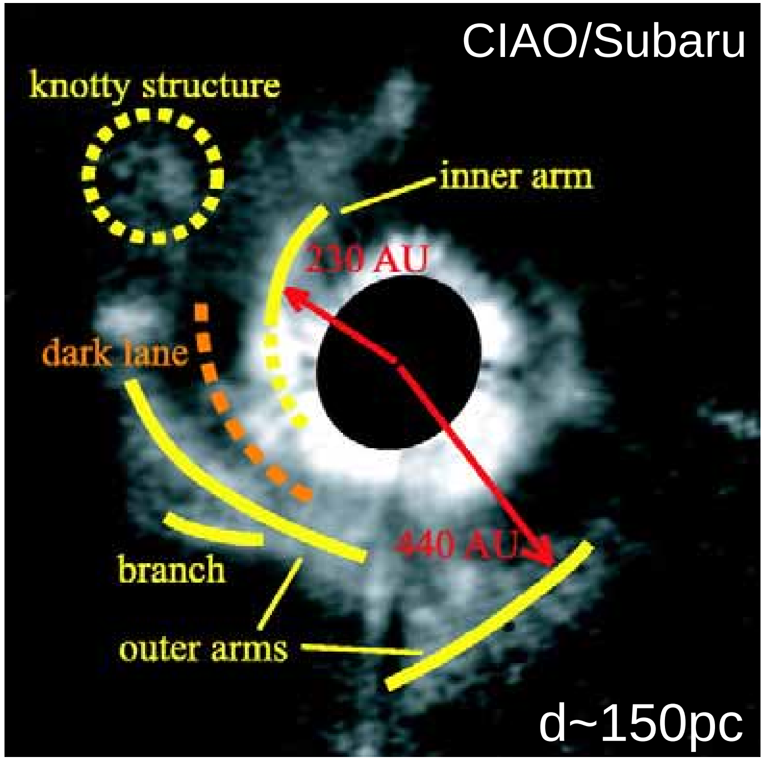


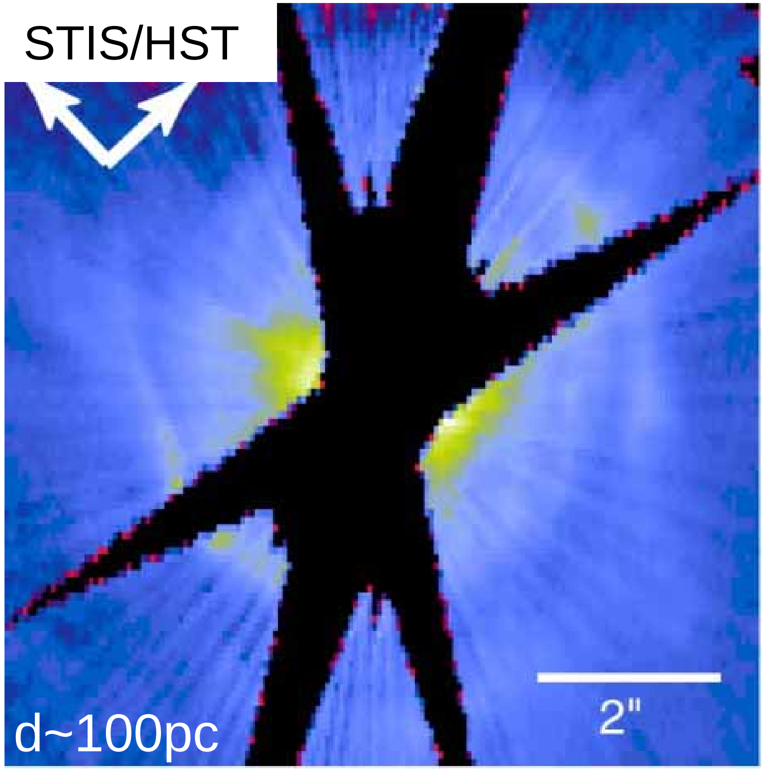
(Kawaguchi, Pierens, Hure 2004)

2-1. Is spiral structure in AGN disk observable?

Spiral structure in proto-planetary disks: “face-on” view

(Fukagawa ++04) (中心星＋降着円盤内縁部)光のダスト散乱 (Grady ++01)





~2” (~300AU ~ 6 x $10^9 R_{Sch}$)

$M_{\star}$~2.4M_{sun},
M’~$10^{-8}M_{sun}$/yr (~1.9 L_{Edd}/c^2)

$M_{\star}$~4M_{sun}, M’~$10^{-?}M_{sun}$/yr

R_{SG}~20AU for a dust opacity-dominated disk around 1 M_{sun} (Hure 2000)

$R_{SG} \propto M_{\star}^{1/3}$ なので、R_{SG} (for 2.4 M_{sun}) ~ 30AU.

結論：渦模様は、5R_{SG} – 15R_{SG}の範囲に出現。(5R_{SG}**以内の模様の存否は不明**)

2-2. Near-IR Interferometer

VLT Interferometer (VLTI)

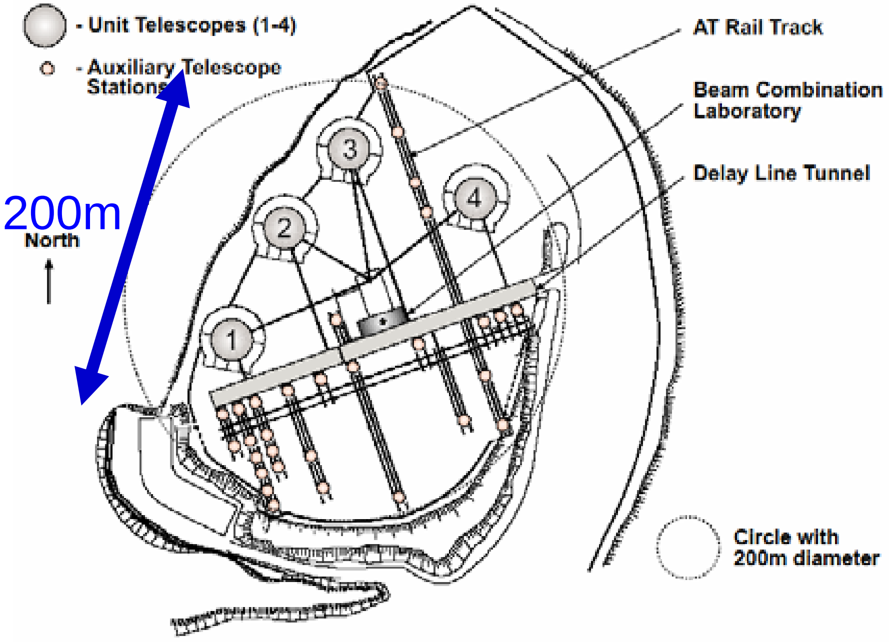
resolution ~ 1--20 mas at 1—20 μm

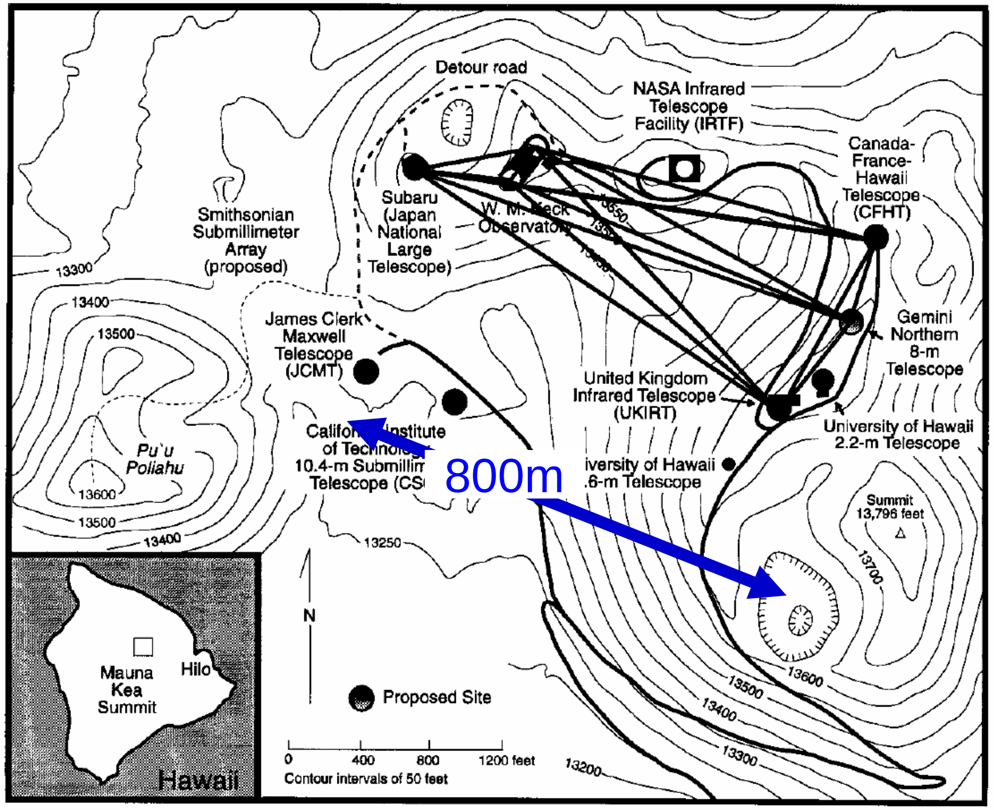
excellent uv coverage

OHANA (Mariotti ++96, Perrin ++00)

resolution ~ 0.25--0.5 mas at 1--2 μm

0.1pc at 1μm @ 100Mpc(z~0.025)





2-3. Is spiral structure in AGN disk observable?

イ) **原始惑星系円盤の場合、渦模様は、**5R_{SG} – 15R_{SG}**の範囲に出現。**

ロ) OHANA: resolution ~ 0.25--0.5 mas at 1--2 μm

0.1pc at 1μm @ 100Mpc(z~0.025)**に相当。**

-5R_{SG}(~0.01pc)**の分解能で、**BH**から**10-15R_{SG}**離れた領域での渦模様を狙うとする。**

→ d < 10Mpc (z<0.0025)

→ 5-10**倍くらい空間分解能が足らない** for nearby NLS1s (in N-hemi).

→ optical**版**OHANA(resolution 2**倍くらいに**)**があっても足らない。**

- **もし自己重力が効いた降着円盤が、ダストトーラスの内縁付近**(~100R_{SG})**まで広がっていて、かつ近赤外線を多少は出しているとする。**25R_{SG}(0.05pc)**の分解能で済むのなら、**d<50Mpc**から候補天体を選べるので、模様が見える可能性有り。**

- **短い波長域：例えば、紫外線スペース干渉計**@2000A with 800m base line **だと、分解能の点は**OK. **ただし、自己重力が効く領域は、**(**近**)**赤外線**-**可視光で光る為、おそらく紫外線では写らないのでは。**BH**により近い、紫外線を出す様な領域は、円盤自己重力は完全に無視できて、たぶん模様の無いのっぺりした絵。**

3. Summary

1. R_{SG}: 円盤自己重力が効き始める、BHからの距離

   λ_{SG}: R_{SG}からの放射波長

   M’がsuper-Eddington(>>L_{Edd}/C^2)になると、

   λ_{SG}が数千Åまで小さくなる事がわかった。

   (R_{SG}~0.002pc) (Kawaguchi 03; Kawaguchi ++ 04a)

   つまり、super-Eddington AGNの可視光連続光は、

   自己重力領域からの放射だった。

2. 原始惑星系円盤の渦状構造が何R_{SG}での構造か計算してみた。

   結果、約5—15 R_{SG}。

3. super-AGNの降着円盤の渦状構造が、5—15R_{SG}にわたって

   存在していたら、OHANAで見えるか？　無理。5-10倍足りない。

   もし、ダストトーラスの内縁ぎりぎり(約100R_{SG})まで、広がって

   いたら、見えるかも。　南天の近傍NLS1も確認すること。