Sub kpc -pcスケールでの質量降着に関して

和田 桂一
鹿児島大学

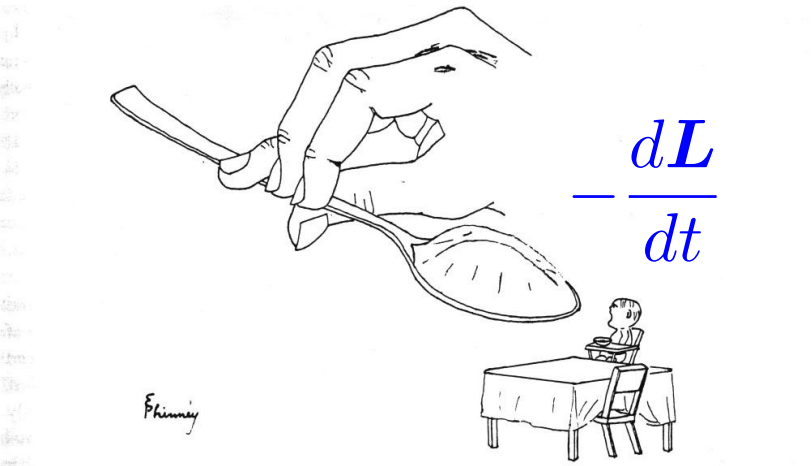


Fig. 1—The problem of feeding the monster: a large (angular momentum) spoon and a small (angular momentum) mouth. Hands and teeth (gravitational and magnetic forces, viscosity, ...) are needed to guide and divide the food into morsels that can be metabolized during activity.

Phinney (1994) in "Mass-transfer induced activity in galaxies"

$$\frac{d\boldsymbol{L}}{dt} = \sum_i (\boldsymbol{r}_i \times \boldsymbol{F}_i)$$

$\boldsymbol{F}_i$:
- gravity
- (turbulent) viscosity
- magnetic force

$$L^j = I^j_{\ k}\ \omega^k$$

$d\omega^k/dt$:
- oblique shock (e.g. spiral shock)
- pressure gradient
- cloud-cloud collision

dI^j_k/dt :
- merger
- outflow, star formation

angular momentum transfer (exchange)

Fueling Problem: origins of torques/viscosity

- kpc scale
  - ✔ Galaxy interactions, major/minor mergers (Taniguchi, KW 1996, Saitoh et al. 2004)
  - –Dynamical friction between stars and gases
  - ✔ Stellar bar/double bar (KW 1992,95)
  - ✔ Spiral shock driven turbulence (KW, Koda 2003)
- 100 pc scale
  - –Collision between dense clumps, dynamical friction
  - ✔ Gravity-driven turbulence (KW, Meurer, Norman 2002)
  - ✔ SN-driven turbulence in a molecular torus (KW, Norman 2002)
  - ✔ Radiation drag (Kawakatu, Saitoh, KW 2004)
- pc and sub-pc scales
  - –MHD turbulence
  - –Radiative avalanche
  - ✔ Radiation-driven fountain (KW 2012, 2015)

from kpc to pc: four possible mechanisms

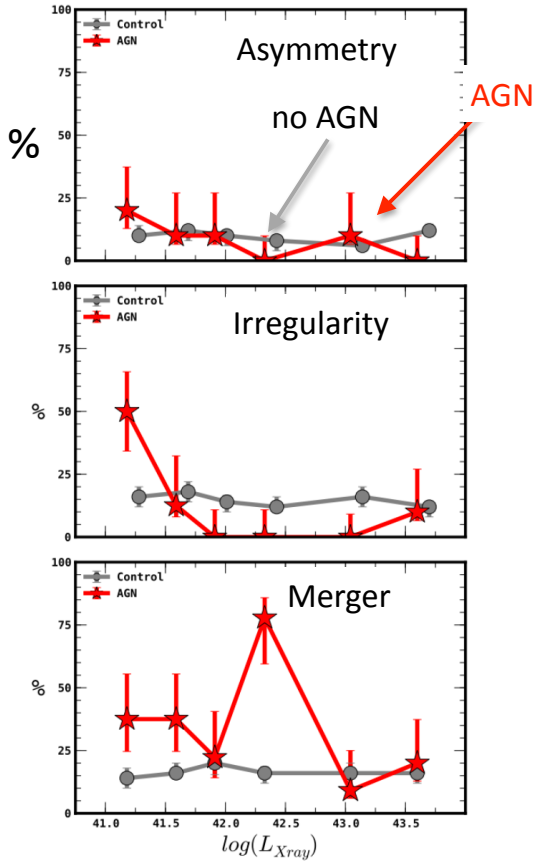
- majer merger
- minor merger
- external accretion (gas streamer)
- secular evolution (bar, spiral)

from kpc to pc: four possible mechanisms

Villforth+2014
z < 0.7 AGNのhost

- majer merger

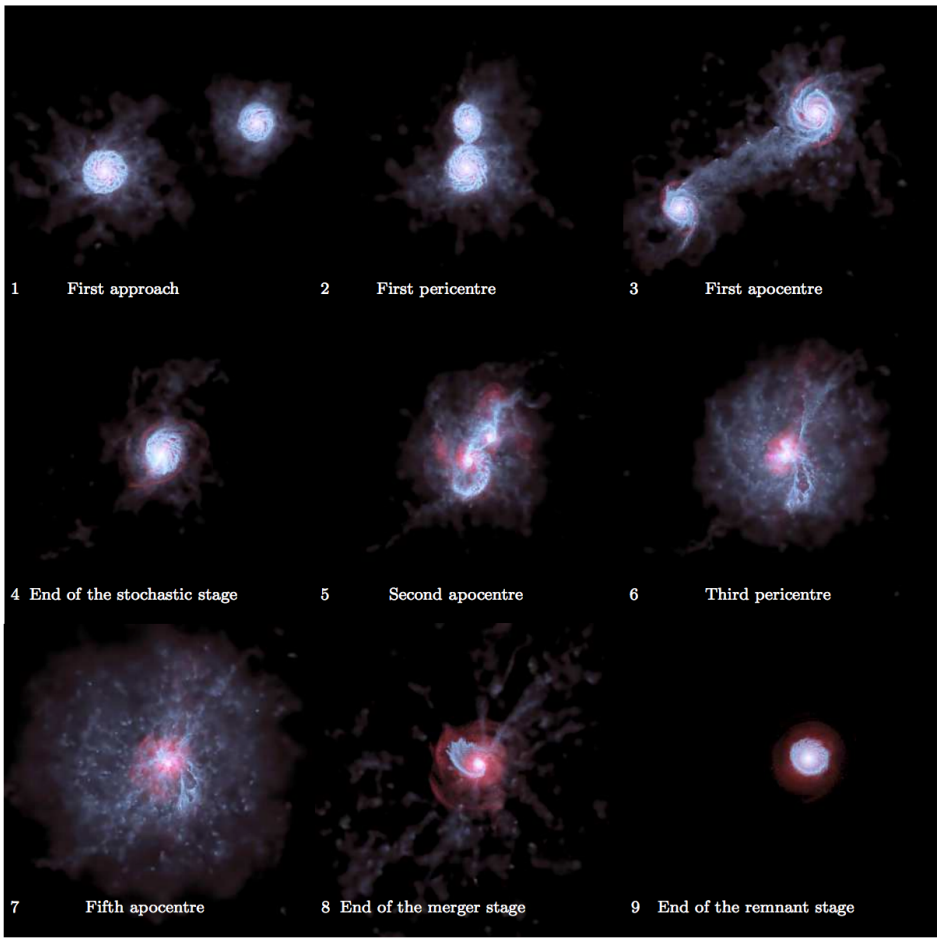
minor effect for triggering AGN?



cf. **Karouzos+ 2014**
Radio loud AGNsとnon-AGNは
環境には違いはないが、close-pairに
AGNがassociateしているものも

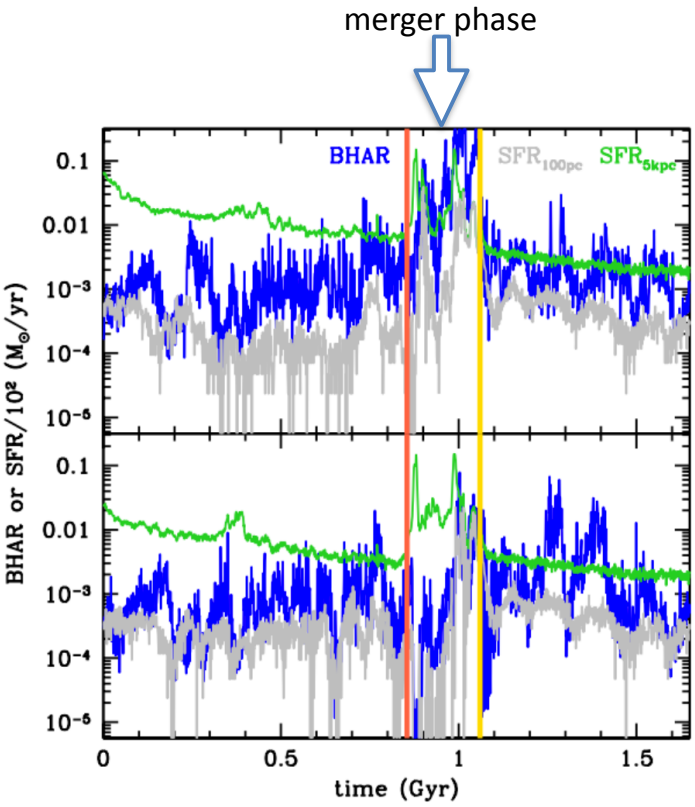
merger simulation

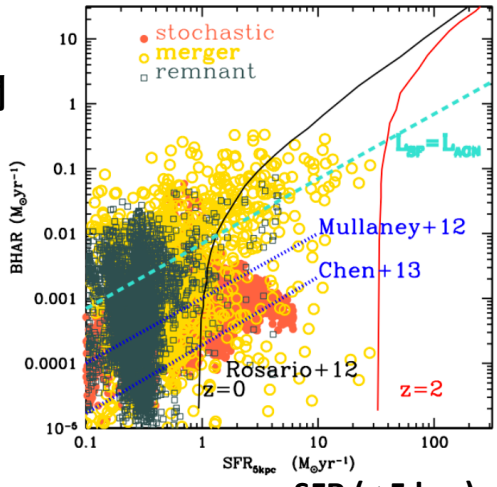
Volonteri+2015



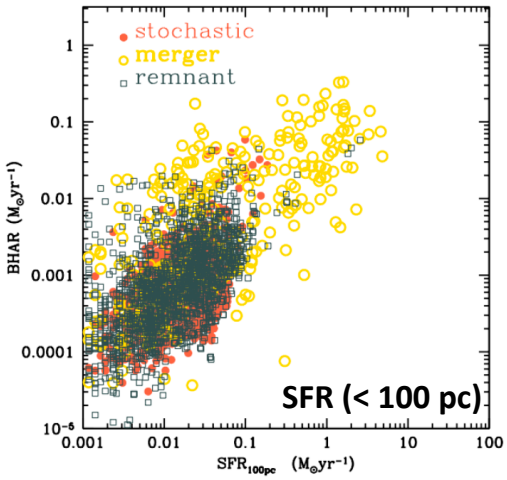
Volonteri+2015

SFR (< 100 pc)とBH accretion rate (<5 pc)は相関





SFR (< 5 kpc)



SFR (< 100 pc)

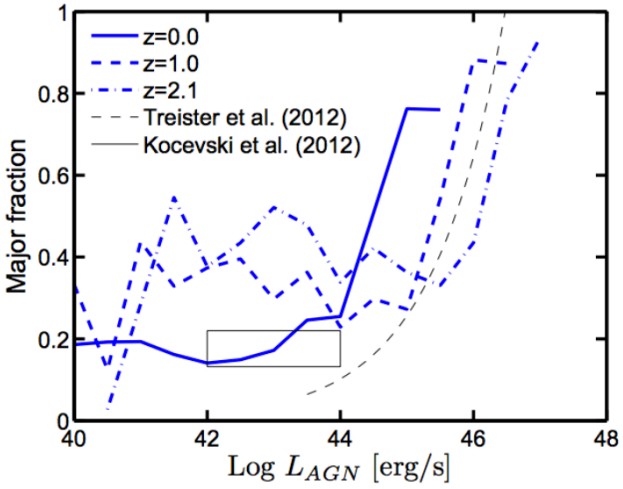
from kpc to pc: four possible mechanisms

- **major merger**
- **minor merger**

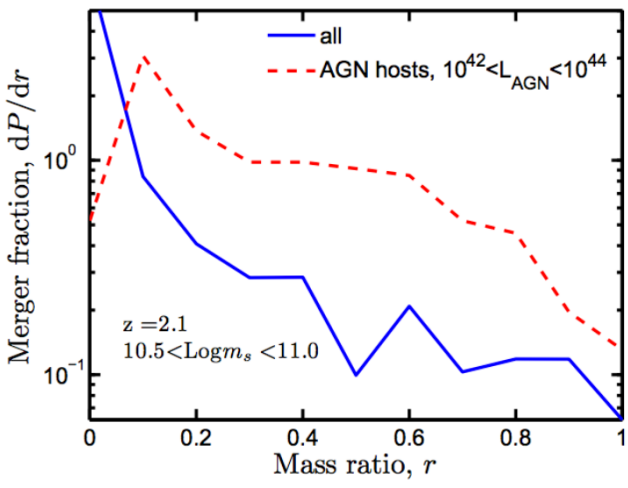
Neistein, Netzer (2015) Semi-Analytic Model

※ accretion rateをSFRと連動させるというモデル

more major mergers in luminous AGN

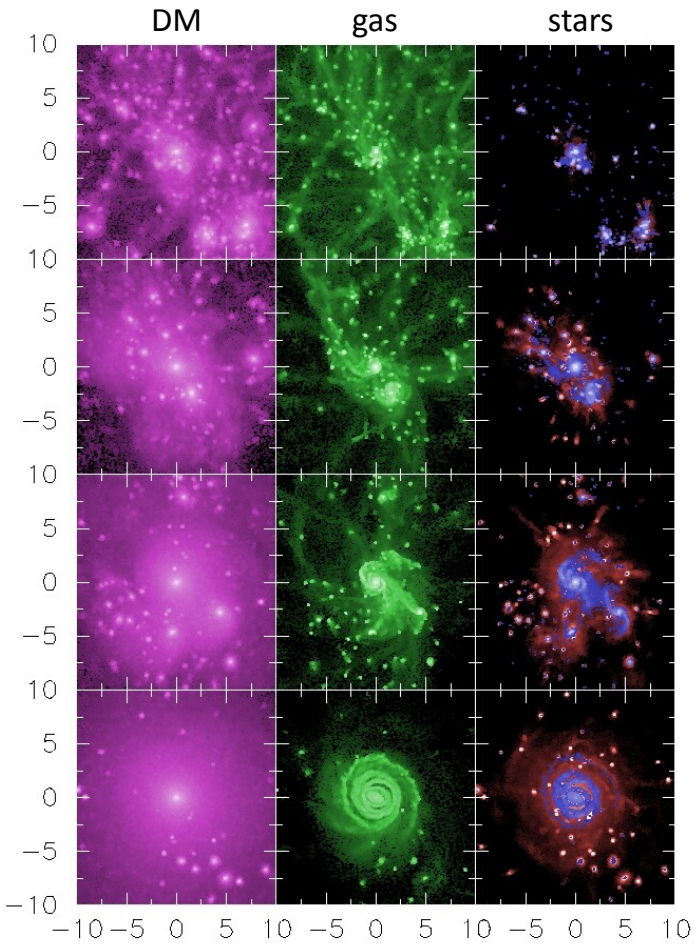


merger fraction is larger in AGN hosts



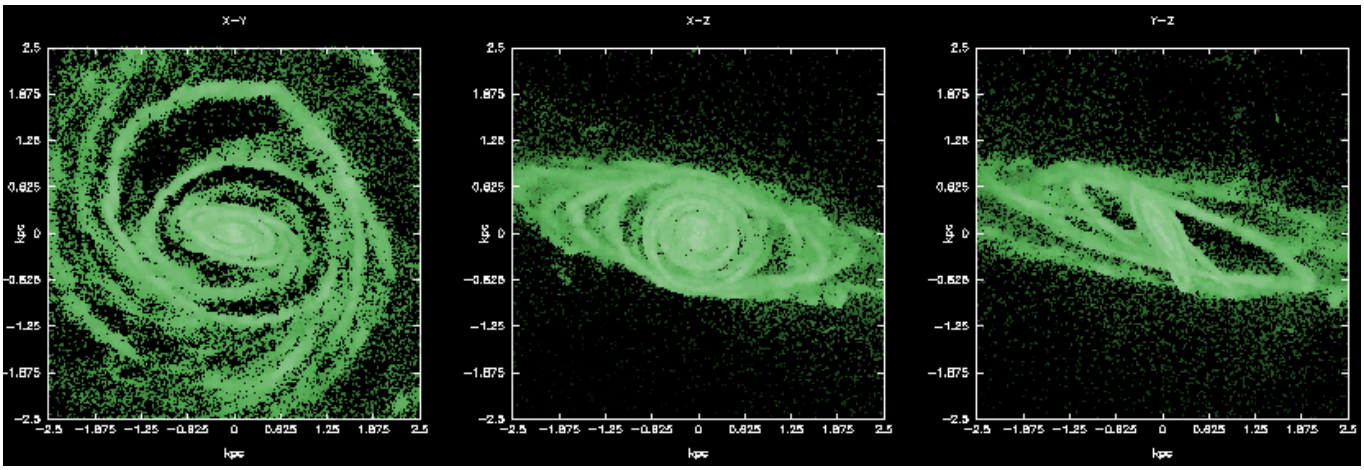
Formation of a small spiral galaxy

Saitoh et al. (2004)



3-D structure of the inner gas disk

z=2.1

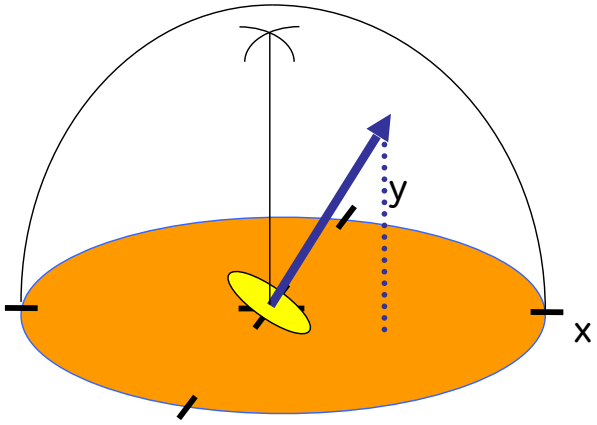


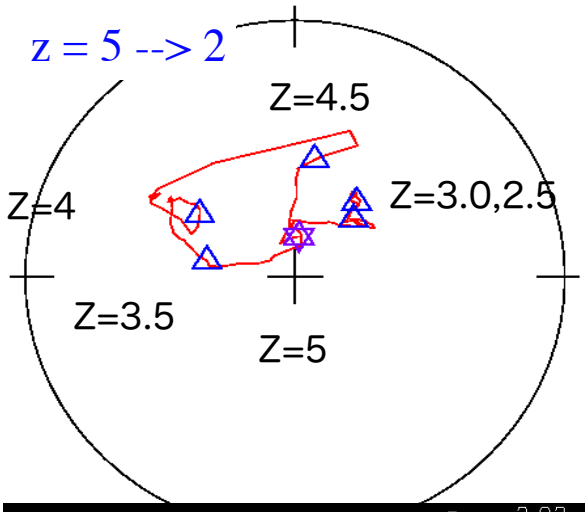
The disk is formed from many 'rings', which are remnants of past mergers.

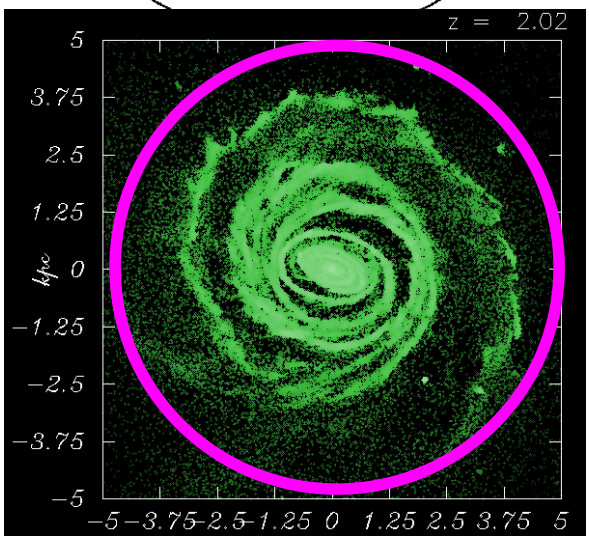
Saitoh et al. (2004)

Evolution of Spin vector of the gas (R< 5kpc)

Saitoh et al. (2004)

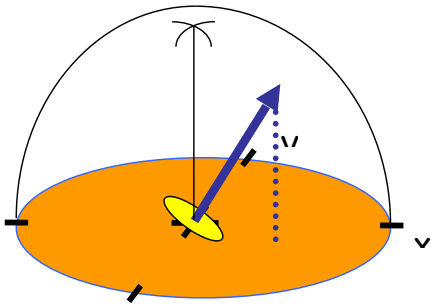


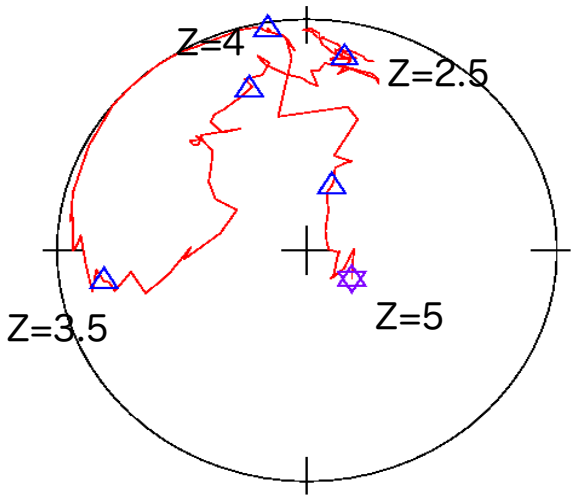


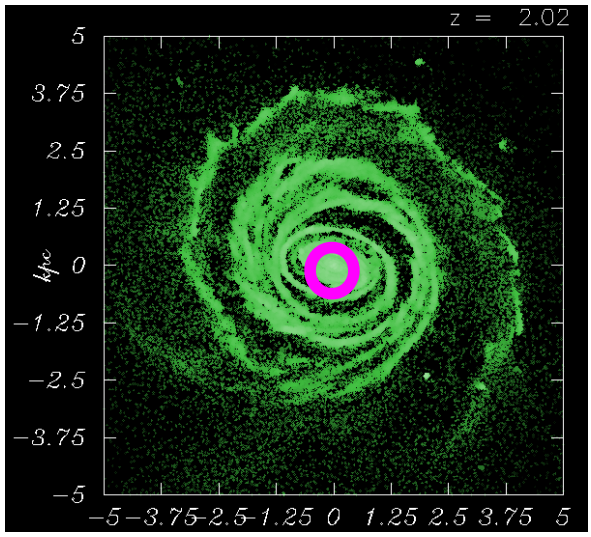


Angular momentum does not change significantly during evolution.

Evolution of A.M. vector of the core
R < 0.5 kpc





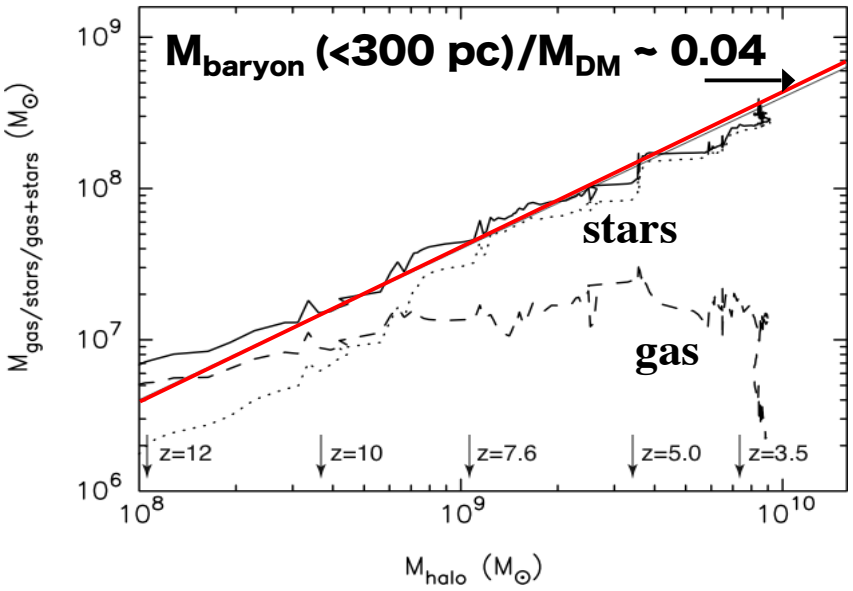


Spin axis of the core changes its direction often during the formation process.

The central part has been affected by mergers w/ different A.M.

Saitoh et al. (2004)

Mass accretion to sub kpc is correlated with merger process of halos



N-body/SPH

Saitoh & Wada (2004)
Saitoh et al. 2008

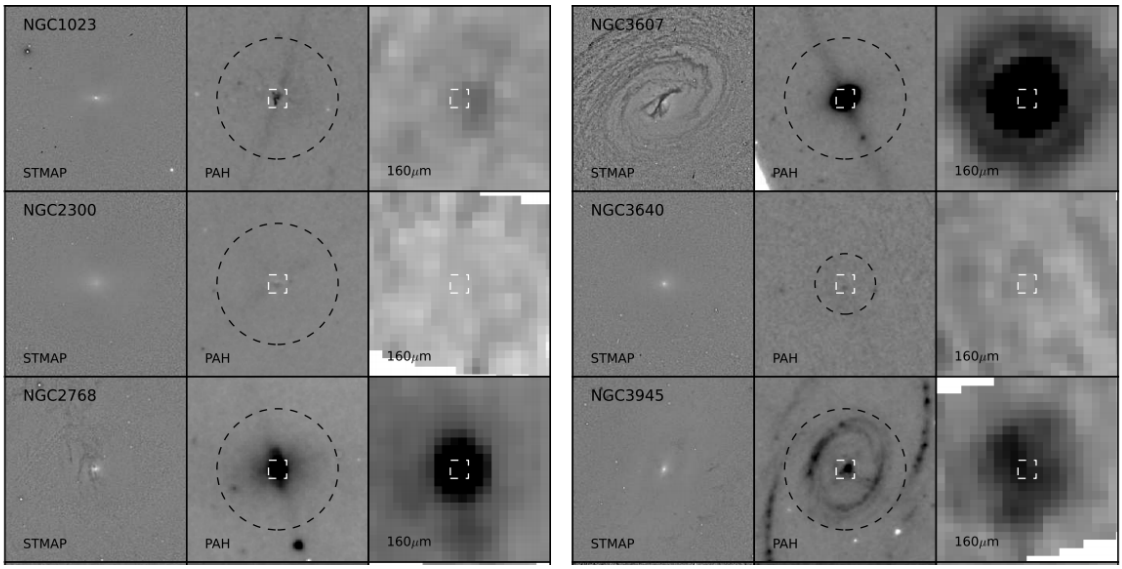
tidal force due to mergers drives the gas into 100 pc region

from kpc to pc: four possible mechanisms

- minor merger

Martini+ 2013

dust in Early type galaxies: external origin? How? (satellite merger?)

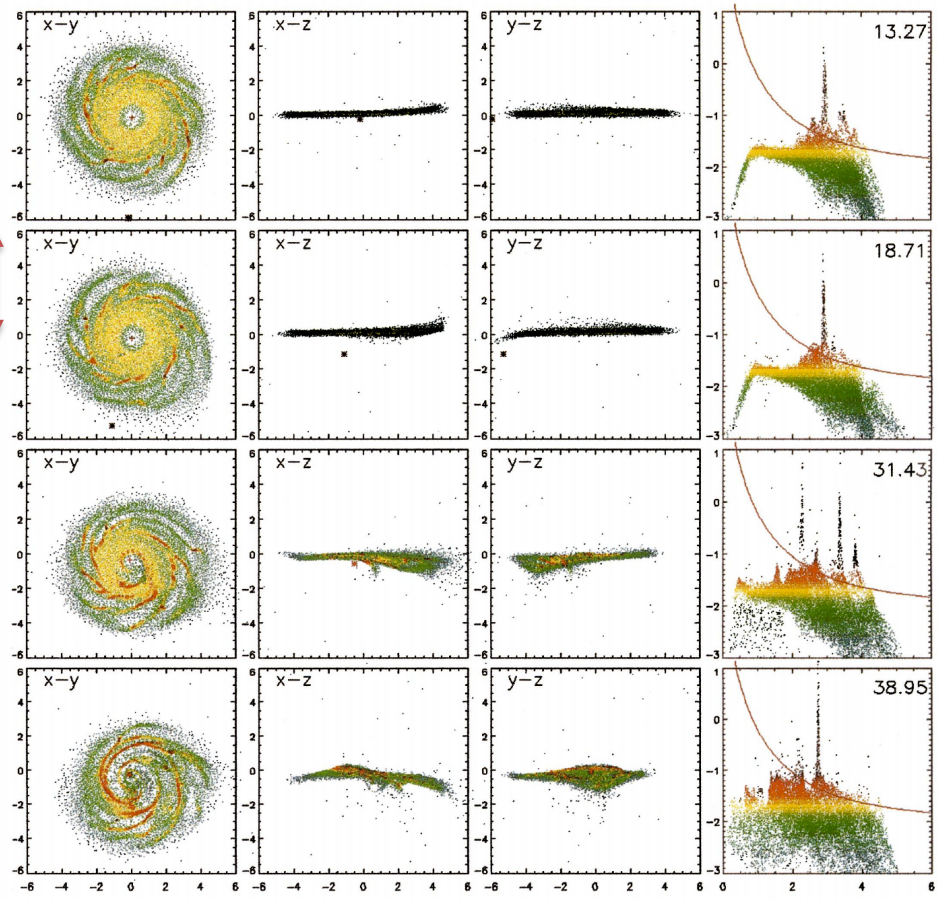


“minor-merger” driven starburst and fueling

Taniguchi, KW (1996)

satellite のBHが落ちてくる

density



6 kpc

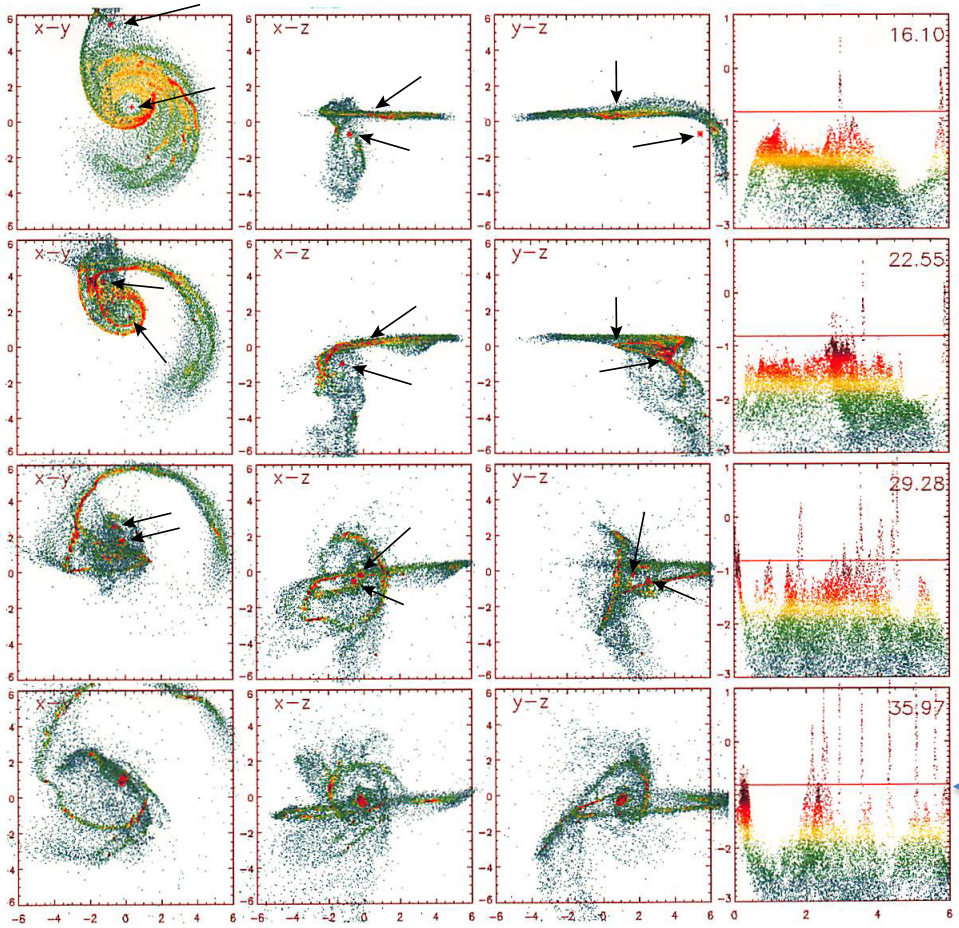
BH mass ratio:

Ms/Mp = 0.1

← 重力不安定

“minor-merger” driven starburst and fueling

Taniguchi, KW (1996)



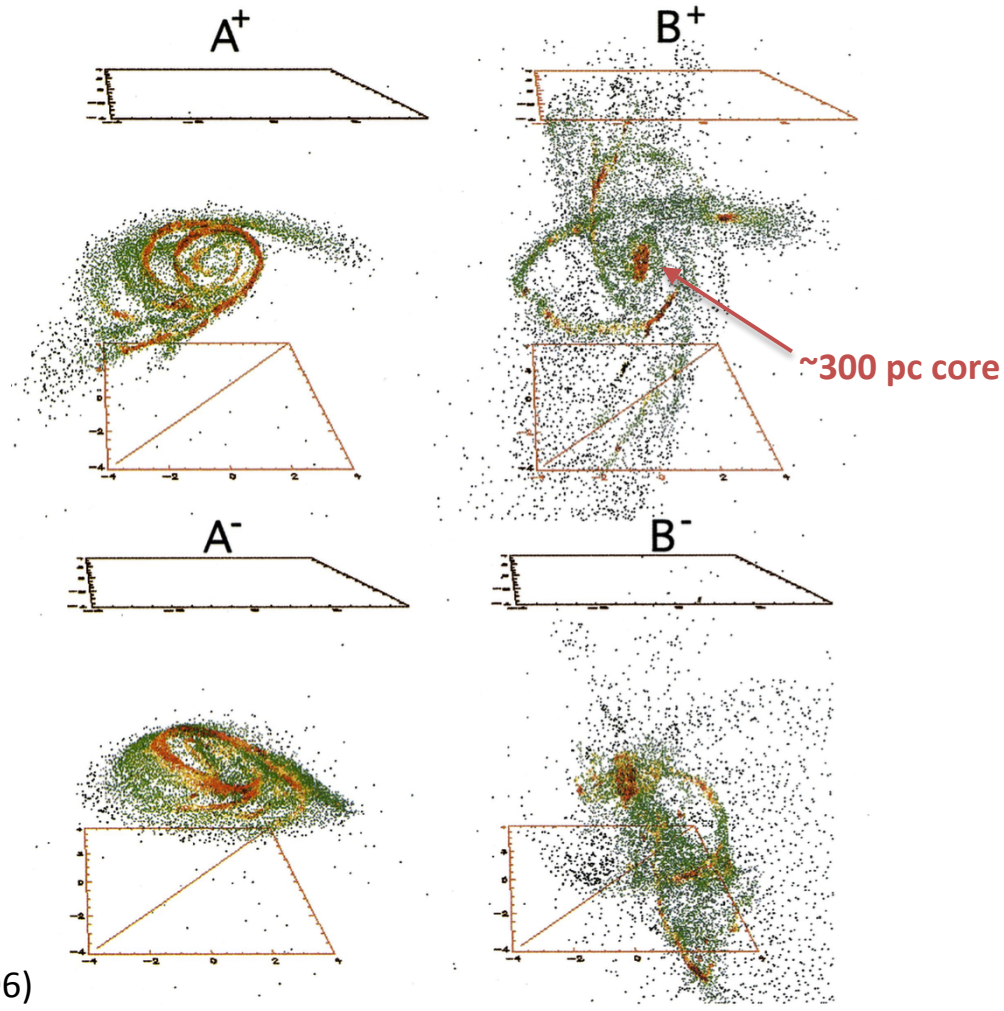
6 kpc

Ms/Mp = 0.5

← 重力不安定

minor merger
⇒ disk 不安定
or core形成

prograde



retrograde

Taniguchi, KW (1996)

from kpc to pc: four possible mechanisms

- secular evolution

Do bars contribute to the nuclear activity?

- no correlation in bar-strength and X-ray luminosity:

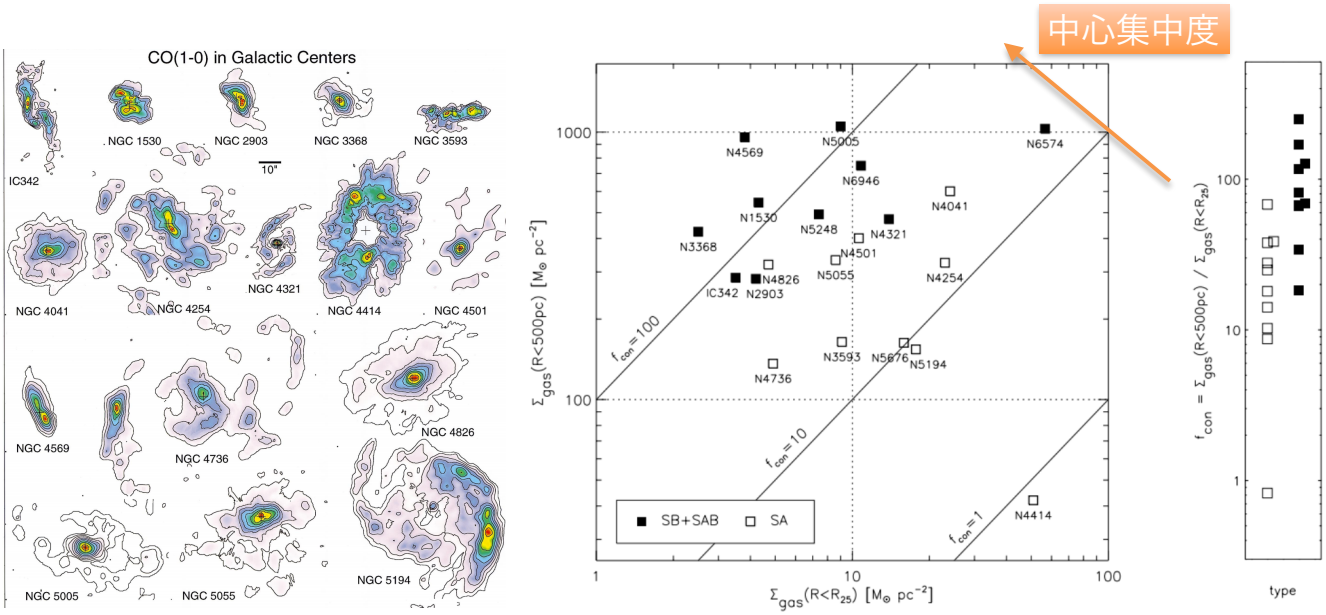
e.g. Cisternas+2013

- molecular gas is concentrated in barred galaxies

e.g. Sakamoto+1999

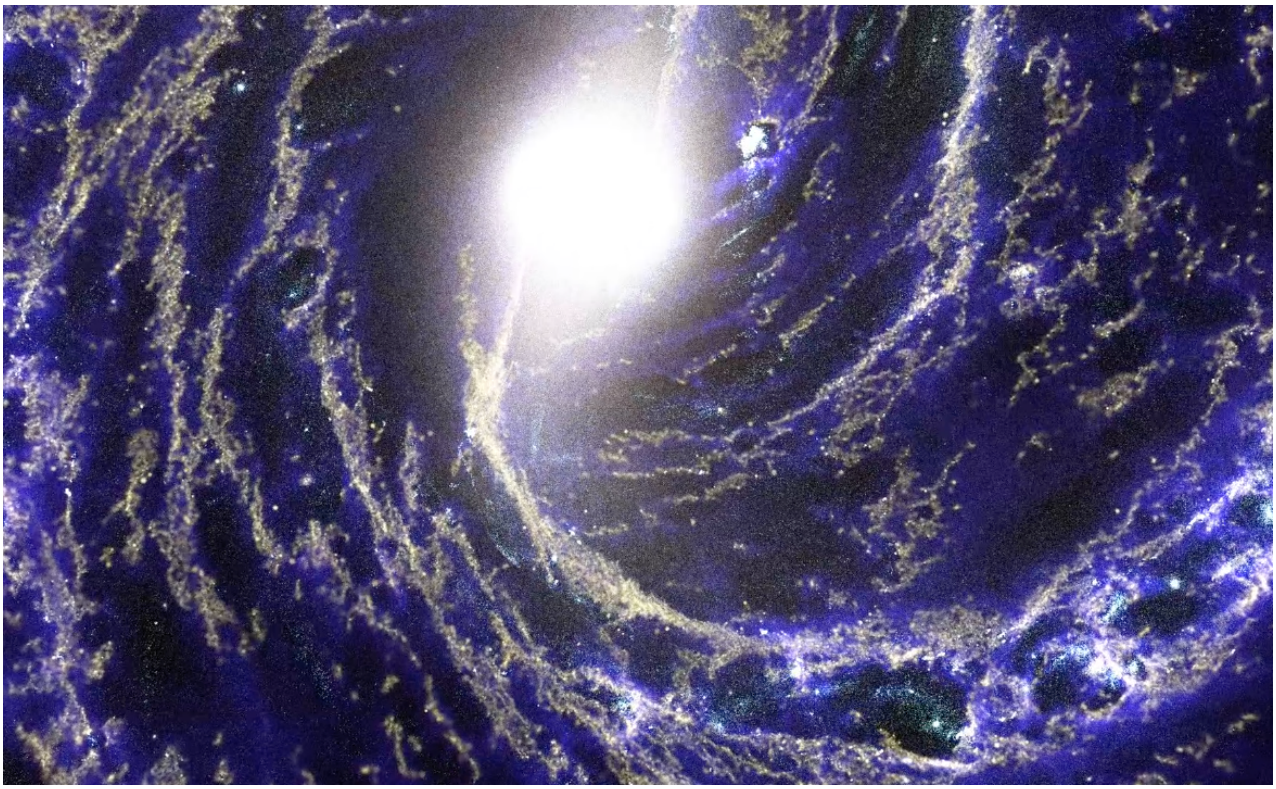
from kpc to pc: four possible mechanisms

- secular evolution by bar



Sakamoto+1999

Bar&spiral-driven fueling (Baba 2015)



visualized by T. Takeda

Bars-within-bars: a mechanism for fueling active galactic nuclei

Shlosman, Frank, Begelman (1989) Nature 338, 45

- **Citation数 545**の有名論文
  - でも、ちゃんと読んでいる人、たぶん少数

- 回転するgaseous/stellar disk/sphereには、 **bar-mode 不安定** （**global不安定**）がある
  - 例） Maclaurin spheroid
    - $T_{rot}/|W| > 0.2738$で不安定
  - 例）stellar disk (Ostriker-Peebles criterion)
    - $T_{rot}/|W| > 0.14$で不安定

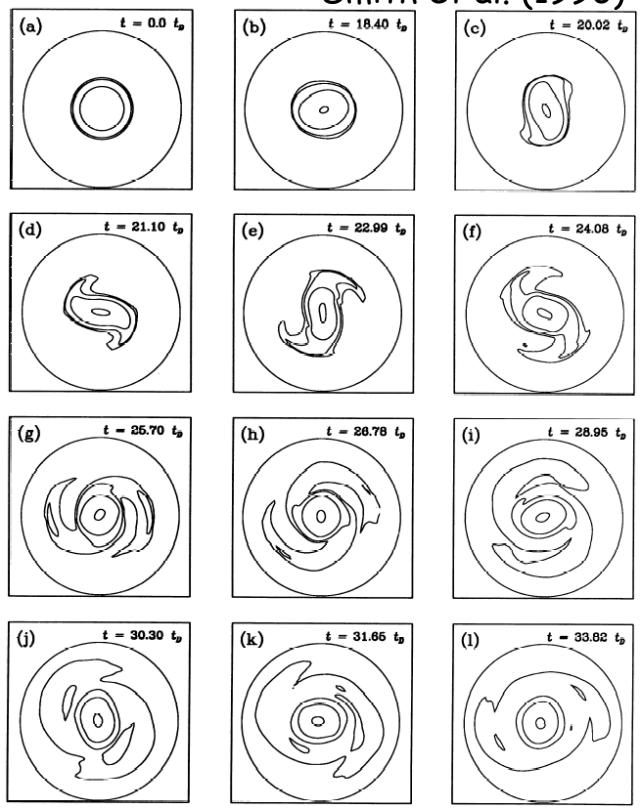
Bars-within-Bars model Shlosman et al. (1989)

- Bar不安定の条件 $T_{rot}/|W| > t_{crit}$ を、書き換えて、
  $a_{star}/a_{gas} > C(t_{crit}) / g^2$, $g=M_{gas}/M_{total}$
- g, t_{crit} を与えたとき、どれだけgas diskがshrinkすると、bar不安定になるか
  - e.g. $g=0.2$, $t_{crit} = 0.14$ **$a_{star}/a_{gas} > 10$ なら、bar不安定を起こす**
- a_{star}=1 kpc の銀河で、stellar bar-driven fueling ⇒ gasが中心集中 ⇒ a_{gas} = 100pc ⇒ bar不安定になる
- **質量、角運動量の再分配が起こり、一部のgasが中心に落ち、coreを形成**
- coreが、 $a_{star}/a_{gas} > C(t_{crit}) / g^2$を満たせば、bar不安定を起こす

結局、角運動量輸送しないとループが完成しない

bar instability of rotating gas sphere

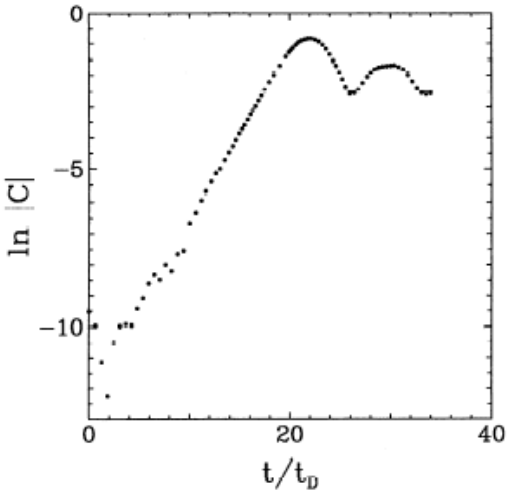
Smith et al. (1996)



T/W= 0.24

２度目以降のbar不安定は非常に弱い

bar-within-bar ループは完成しない



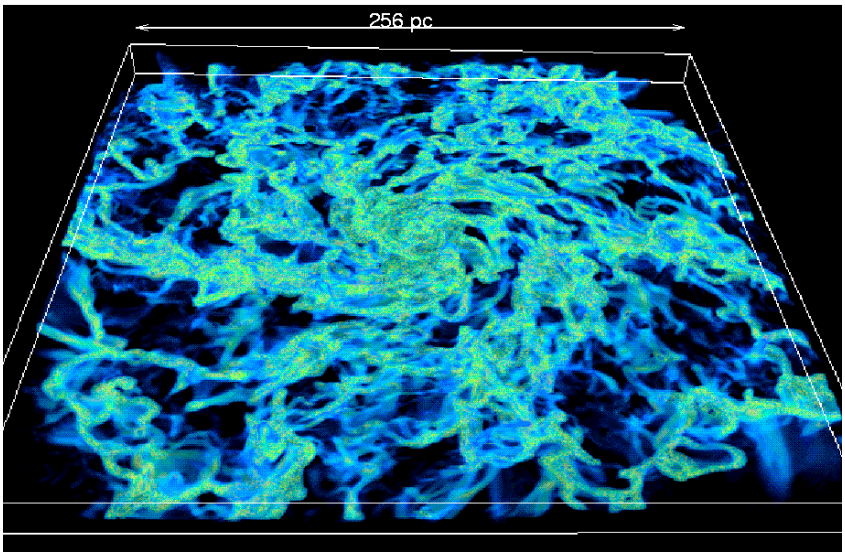
Bar mode amplitudeの成長

3D structure of the nuclear massive disk

512^2 x 32 grid points (0.5 pc/grid)

Wada (2001)

Due to radiative cooling,
local instability dominates the bar instability



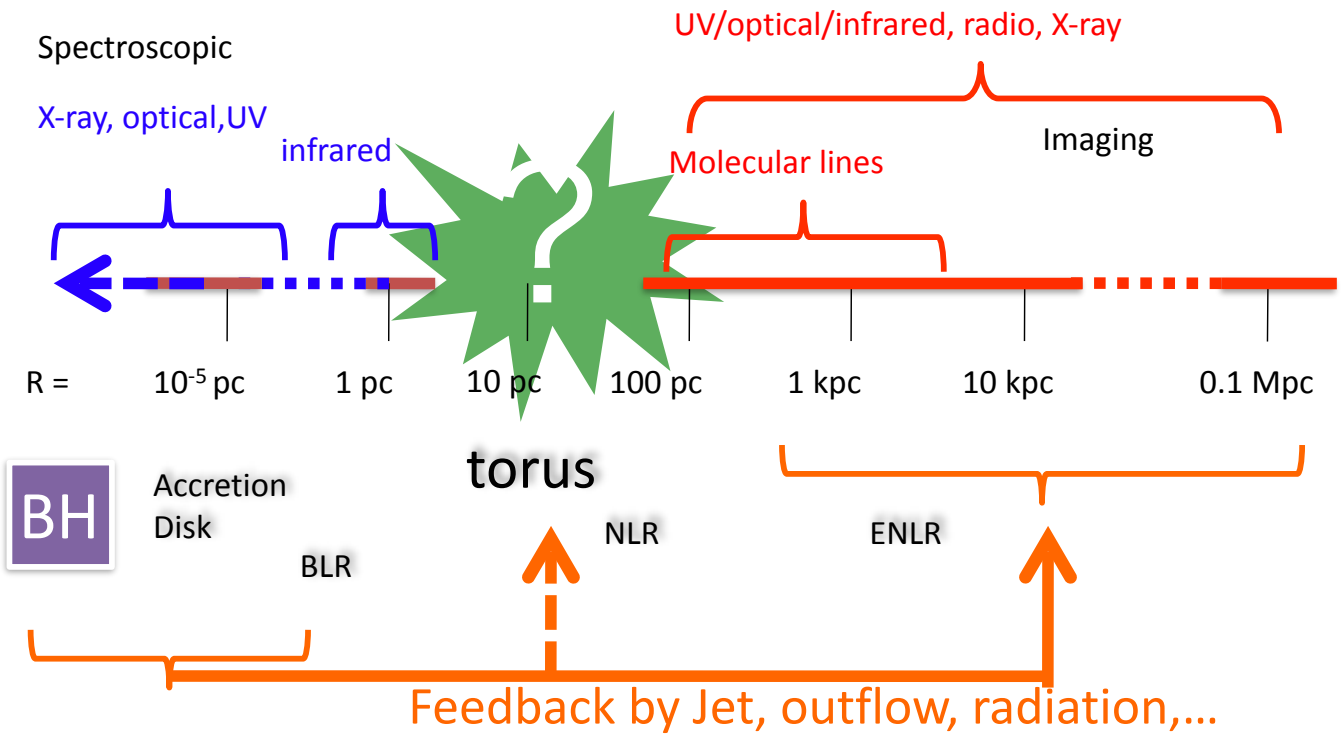
128 pc

Angular momemtum change by

- **torque by spiral arms**
- **turbulent viscosity**

AGN進化　　２つの重要な物理過程：Feeding/Feedback

R = pc-数10 pc領域（ダークドメイン）は未解明

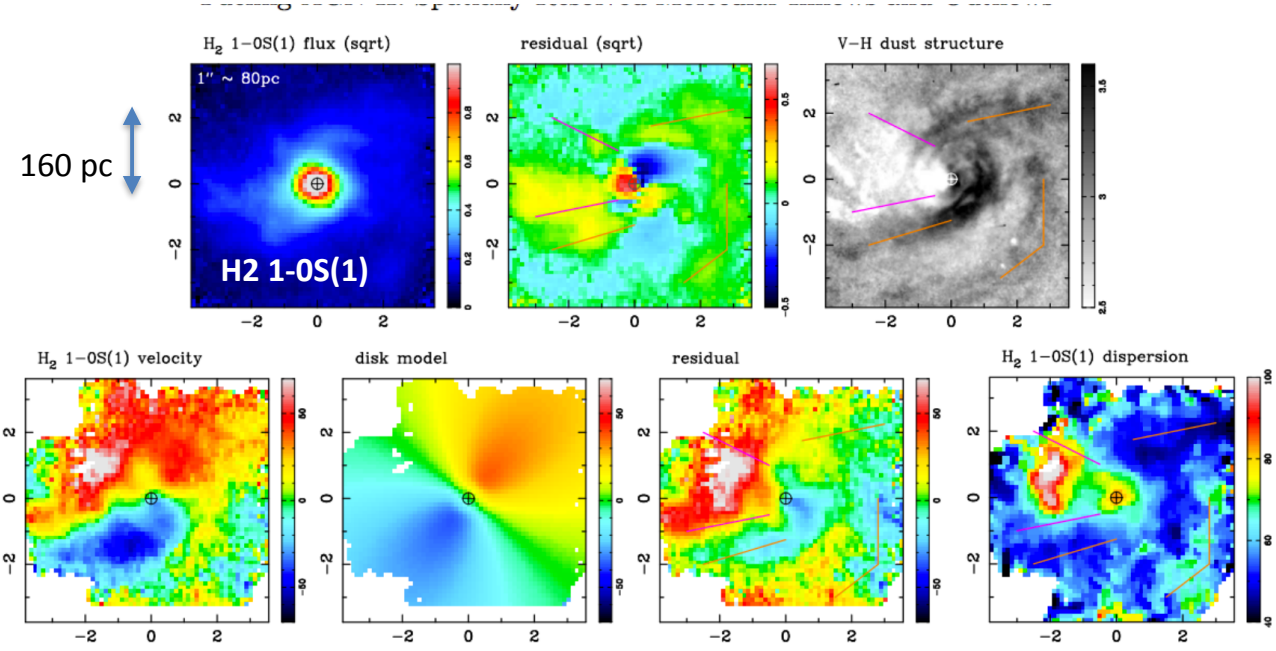


”Dark domain" で何が起こっているか？

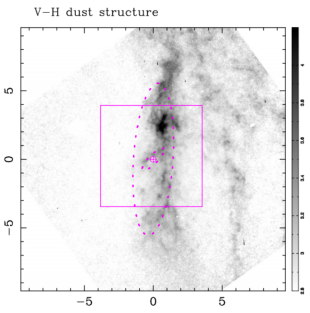
Davies+2014　　VLT/SINFONI

- velocity field, warm H2 (2μm) in central 100 pc of 10 AGNs
- CMD in all 5 active AGNs

NGC 5643 (Seyfert 2)



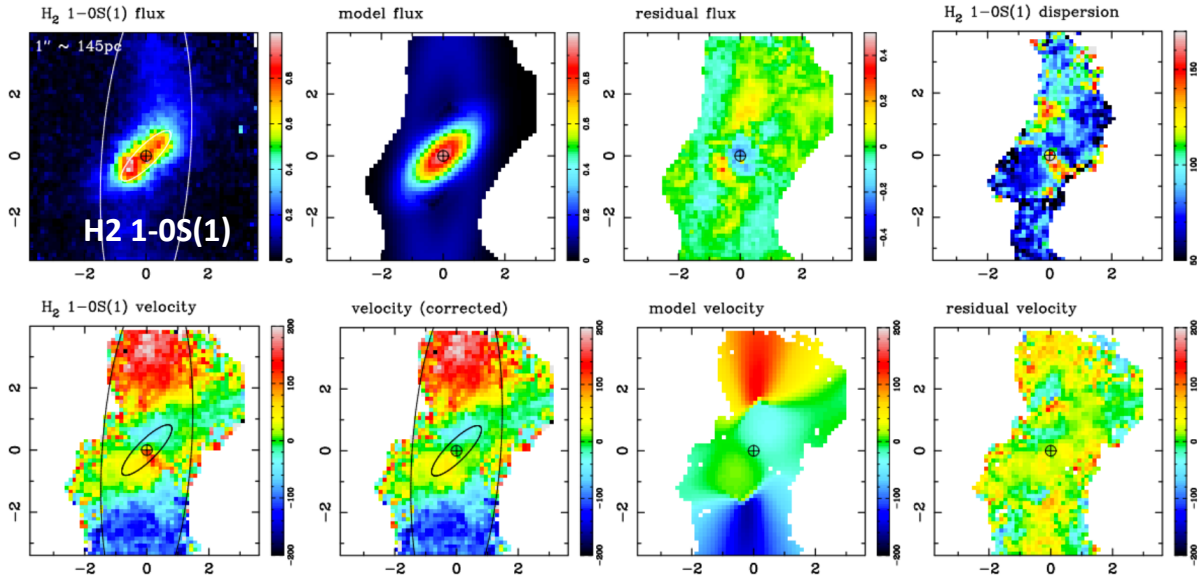
IC 5267 (inactive)



Davies+2014

H2 1-0S(1)

300 pc



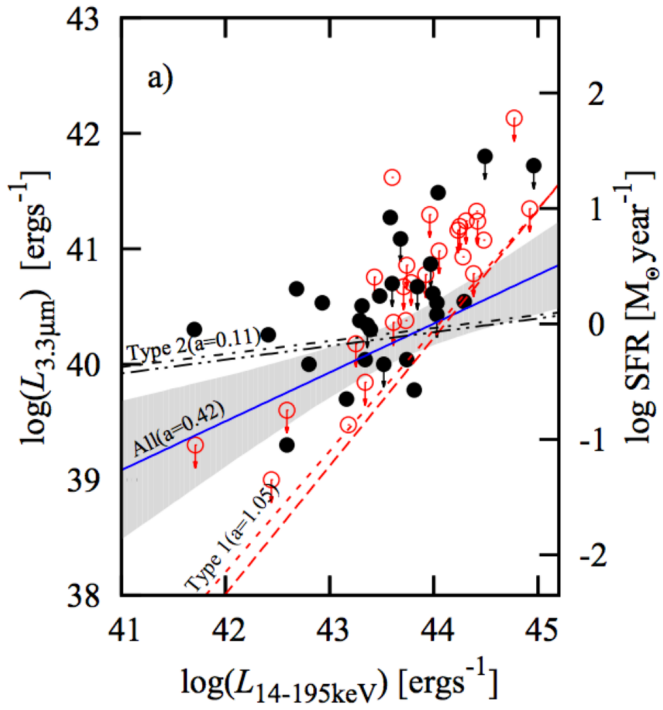
counter rotating gas disk. "pre-AGN" phase?

Davies+2014 VLT/SINFONI

- velocity field, warm H2 in central 100 pc of 10 AGNs
  - CMD in all 5 active AGNs
  - lack of gas in inactive galaxies
  - no on-going SF in both active and inactive
  - molecular outflows (~150 km/s) observed in 4/5 active galaxies, not in inactive ones
- **two accretion process?**
  - **long, continuous, internal supply**
    - circum-nuclear spirals
  - **short, stochastic, external supply**
    - counter rotating gas
    - HI inter-galactic filaments in group

mismatch in time-scale
AGN duty-cycle vs. accretion time scale

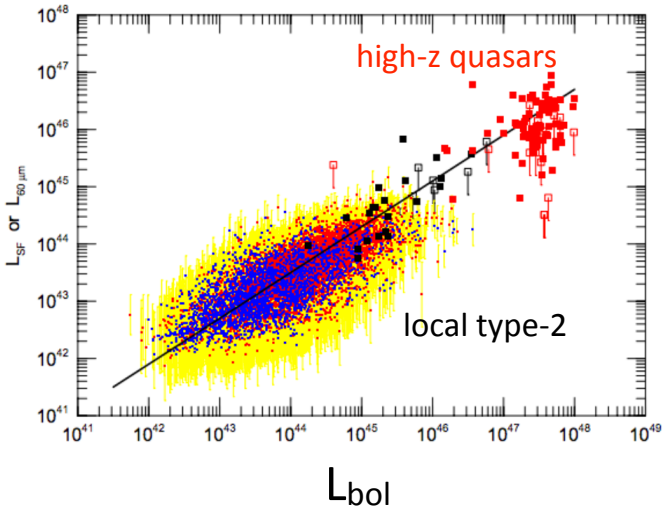
starburst-AGN connection



Castro et al. 2015

Akari

Netzer 2009



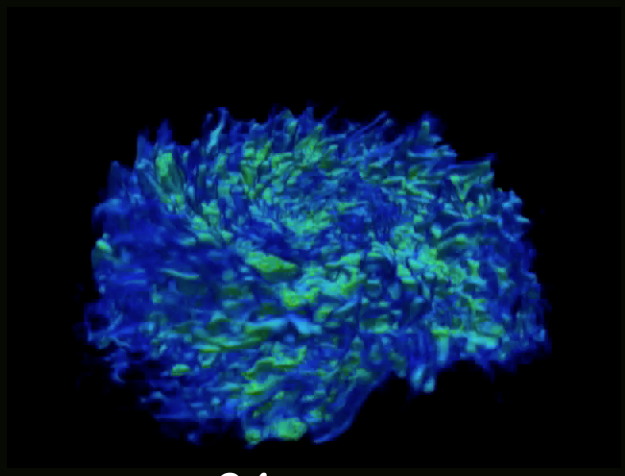
Wada & Norman (2002) ApJ 566, L21

Obscuring "torus" around a supermassive BH with nuclear starburst

256^2 x 128, uniform grid, 0.25pc/grid

Radiative cooling (5-10^8 K), SN feedback, selfgravity

$M_{BH} = 10^8\ M_{sun}$, $M_{gas} = 10^7\ M_{sun}$, SNR = 0.8 yr^{-1}

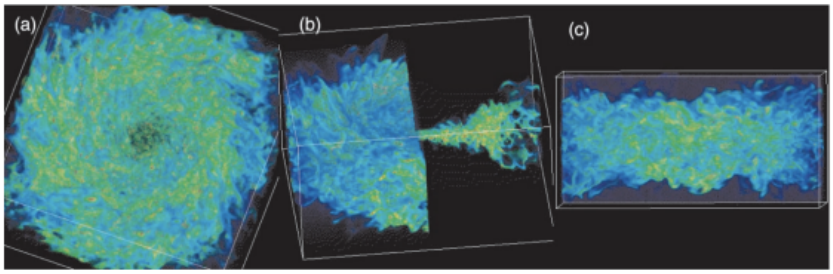


64 pc

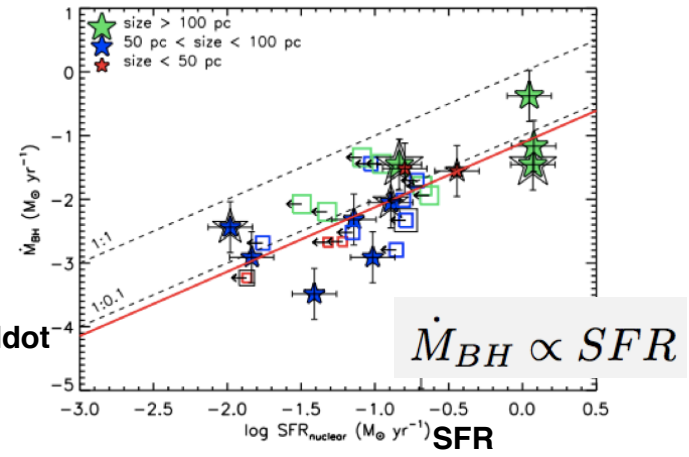
Modeling the ISM in a galactic center: Progress for the last decade

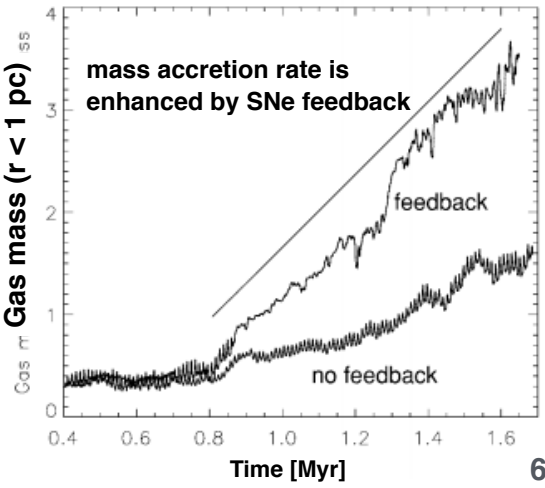
- 64^2 pc x 32 pc
- self-gravity
- radiative cooling
- SNe
- BH

Wada & Norman 2002



Esquej+2014





from kpc to sub-pc: 課題

・major merger, minor merger, accretion, secular evolutionの相対的重要性(どういう状況で何が効いているのか)

・r < 数10 pc

- nuclear SF とfuelingの因果関係
- AGN feedbackとfuelingの関係（positive or negative?)

・r < r_dust (sub pc)

- 外側のaccretion rateとの関係 $\dot{M}(R)$

・AGN構造（accretion disk, BLR, NLR, torus, jet)とaccretionの関係、そのredshift進化