Star Formation and Accretion Power of Supermassive Black Holes in Circumnuclear Disks

Wara Chamani, Dominik Schleicher and Stephanie Dörschner

Institute for Astrophysics, University of Göttingen, Germany

1. Motivation

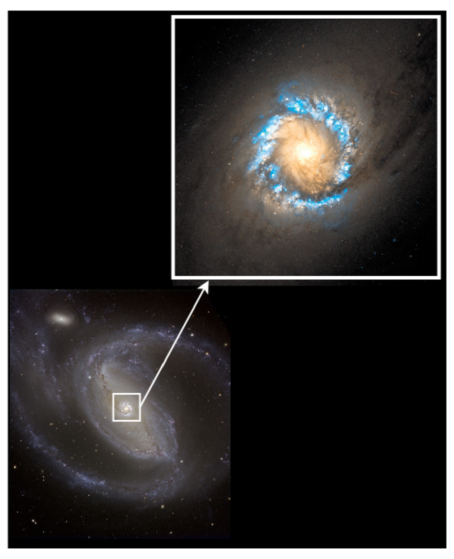

Fig.1. Circumnuclear ring of star formation in NGC 1097.

To understand and explain the physical processes that regulate the co-evolution between supermassive black holes (SMBHs) and the star formation (SF) in the circumnuclear disk (CND) in active galaxies.

Method: to combine two models; the accretion processes and star formation rate for the evolution of the SMBH in the CND (Kawakatu & Wada 2008: Wutschik et al., 2013) and other star formation frameworks (Krumholz et al., 2008) that also gives an analytic prediction of the turbulence-regulated star formation rate in molecular clouds.

2. Model for Star Formation

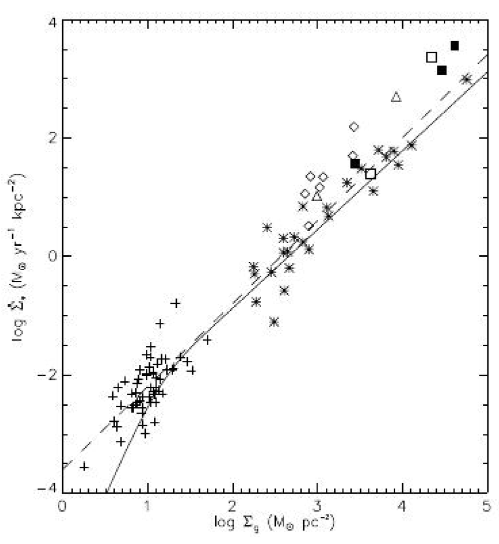

Fig.2. Predicted star formation rate versus Σ_g (solid line), Kennicutt law (dashed line). The data points ranges from normal disks to ULIRGs, Krumholz & McKee, 2005.

According to the model proposed by Wutschik, et al 2013, the star formation rate $\dot{\Sigma}_*$ in the CND can be non-regulated ($\epsilon = 0$) and regulated ($\epsilon = 1$) by an increased turbulence velocity based on a previous models suggested by Kawakatu & Wada(2008) and Elmegreen & Burkert(2010), given as:

$$\dot{\Sigma}_* = \Psi(\Sigma_{gas}(r))^{\theta}(v_{turb}(r))^{-\epsilon} \tag{1}$$

where Ψ is a normalization constant, $0 \leq \theta \leq 2$ and $0 \leq \epsilon \leq 1$ are free parameters. The non-linear dependence of the star formation rate on the gas surface density Σ_{gas} and on the turbulence velocity v_{turb} influences the evolution of the black hole mass and the star formation rate. The turbulence regulated star formation model (Krumholz, M.R., McKee, C.F. 2005,) considers the collapse of virialized molecular clouds, and is described as follows:

$$\dot{\Sigma}_* \approx M^{-0.32}\phi_\rho^{1/2}Q_{1.5}^{-1}f_{GMC}\Omega_g\Sigma_{gas} \tag{2}$$

where M is the mach number, ϕ_ρ and Q are both free parameters, Ω the angular velocity.

3. Model of Gas Accretion in a Circumnuclear Disk

The model of the evolution of a SMBH centered in a circumnuclear disk considers constant mass supply from the host galaxy and the physical states of the CND are regulated by the injection of supernova-driven turbulence.

- Mass conservation: $M_{gas} + M_{BH} + M_{disk} = M_{supply}$
- Mass accretion rate in a viscous accretion disk:

$$\dot{M}(r,t) = 2\pi\nu\Sigma_g(r)\frac{d\ln\Omega(r)}{d\ln r} \tag{3}$$

- The time evolution of the mass gas in the disk:

$$M_g(t) = \int_0^t [\dot{M}_{sup}(t') - \dot{M}_*(t') - \dot{M}_{BH}(t')]\, dt' \tag{4}$$

- The surface density of the disk:

$$\Sigma_{disk}(r) = \Sigma_{disk,0}\left(\frac{r}{r_{out}}\right)^{-\gamma} \tag{5}$$

$$= \Sigma_{gas} + \Sigma_{stars} \tag{6}$$

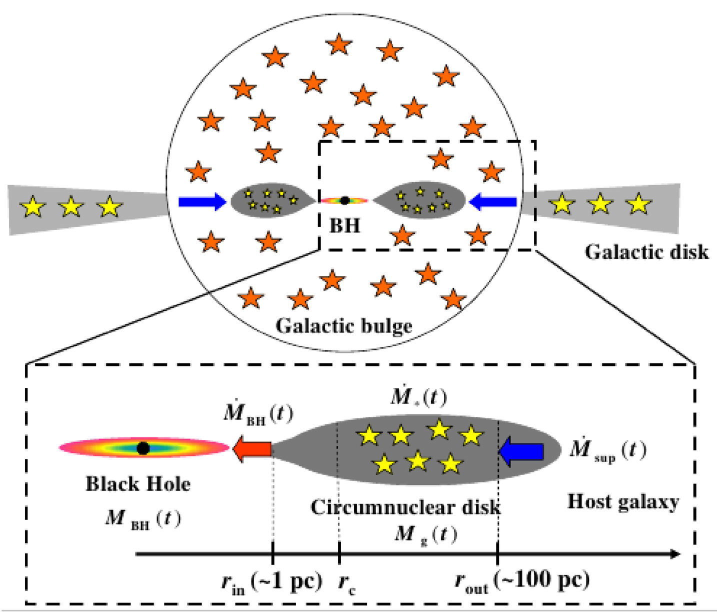

Fig. 3. Supply of gas from the host galaxy for feeding the SMBH, Kawakatu & Wada 2008.

Two modes of gas accretion:

i) Circumnuclear disk is fully gravitationally unstable,

- $r_c < r_{out}$ and $\Sigma_g > \Sigma_{crit}$
- Disk geometrically thick due to stellar energy feedback.
- Dominated by turbulence pressure of the gas, $P_g = \rho_g v_t^2$.
- Large accretion disk.
- $\nu_t = v_t(r)h(r)$, turbulent viscosity.

ii) Circumnuclear disk is fully gravitationally stable,

- $r_c > r_{out}$ and $\Sigma_g < \Sigma_{crit}$
- Dominated by thermal pressure of the gas, $P_g = \rho_g c_s^2$.
- Accretion is less efficient.
- $v_t < c_s$

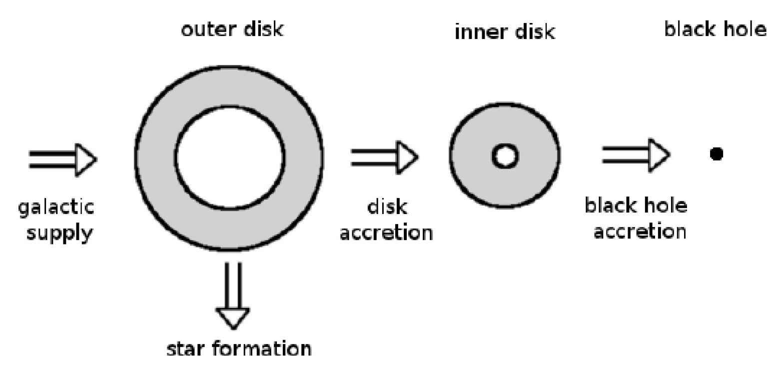

Fig.4. The extension of Kawakatu's model treats the accretion disk as composed by two disks. The gas is first accreted by the outer disk, where the stars form and then the rest is transfered to the inner disk for feeding the SMBH, Wutschik et al., 2013.

5. Results

Two phases of SMBH growth

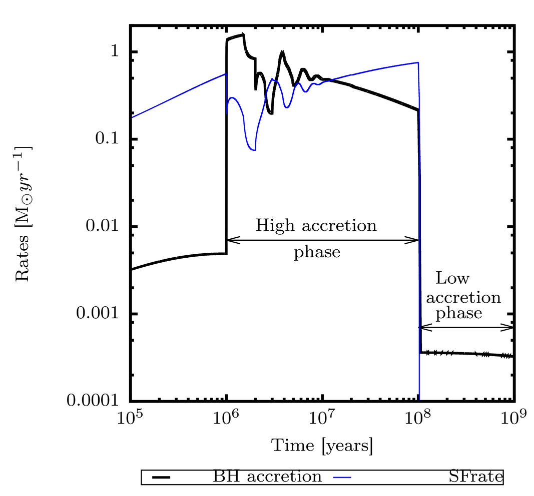

Fig.5. Rates vs Time

Black hole, Stellar and Gas masses

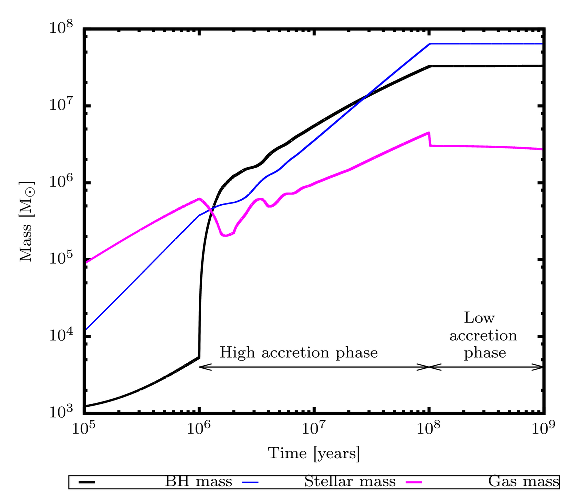

Fig.6. Mass vs Time

Turbulent gas in the different gravitational fields

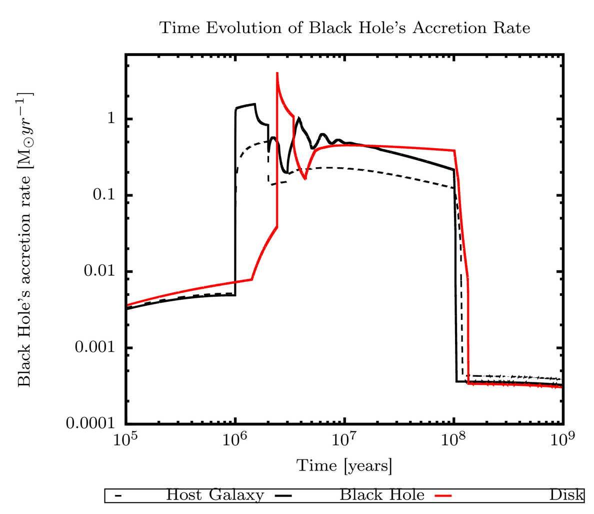

Fig.7. Black hole's accretion rate vs Time

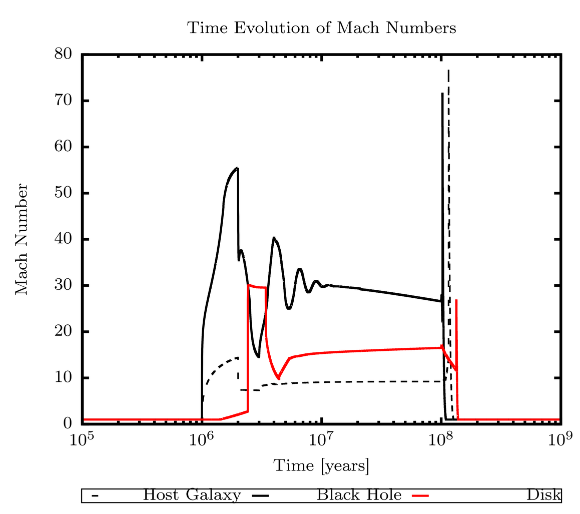

Fig.8. Mach numbers vs Time

SF models regulated by turbulence

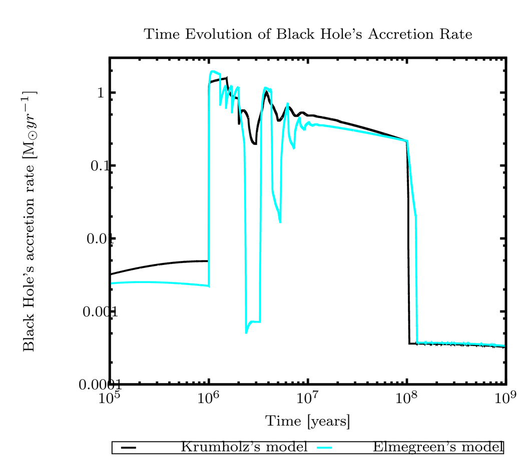

Fig.9. Black hole's accretion rate vs Time

Influence of the Mass Supply Rate

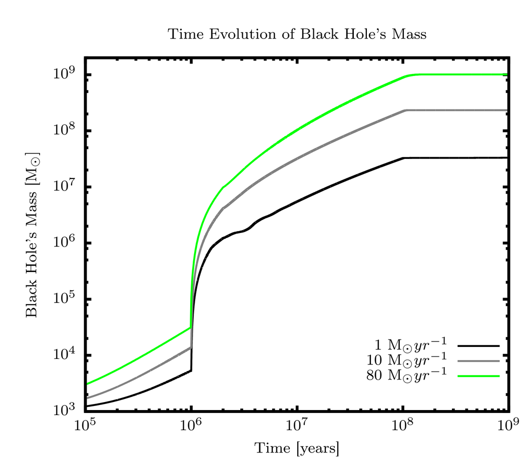

Fig.10. Black hole's mass vs Time

6. Comparisons with observations

a) Starburst Ring on the Milky Way

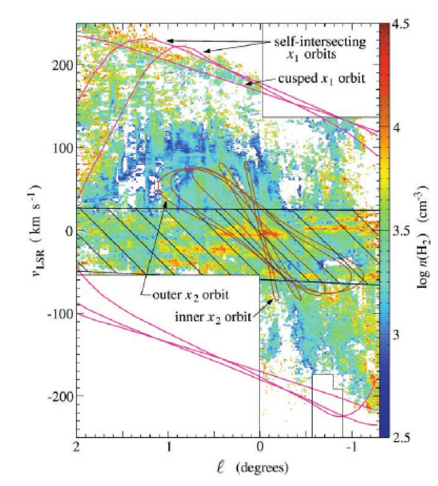

Fig.9. x_2 orbit of gas; an inner starburst region on the Milky Way, Stark et al., 2004.

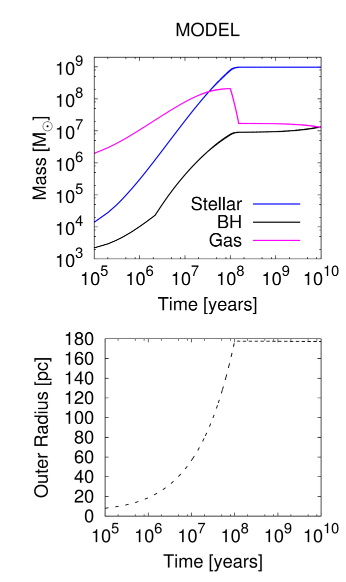

Fig.10. Simulation of the BH mass, gas mass and radius of the ring on the Milky Way.

b) Star Formation Ring in NGC 6951

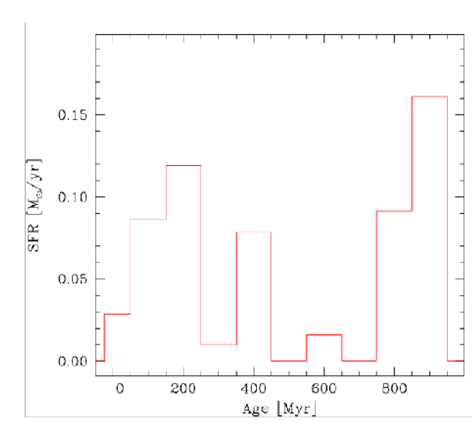

Fig.11. Star formation history in the circumnuclear ring of NGC 6951,(van der Laan et al., 2013).

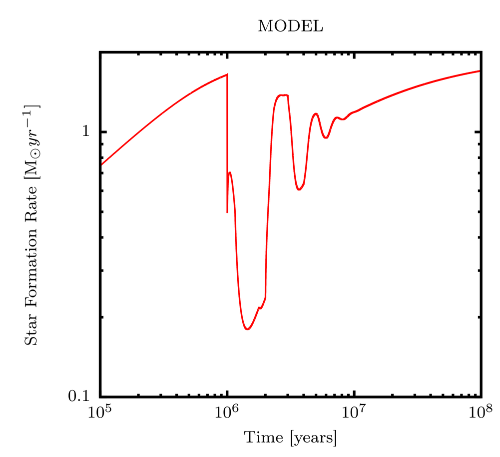

Fig.12. Simulation of the star formation rate evolution in the star formation ring of NGC 6951 .

7. References

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[2] Kawakatu, N.,& Wada,K. 2008, ApJ, 617,214.
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