University of Leicester

DEPARTMENT OF PHYSICS AND ASTRONOMY
THEORETICAL ASTROPHYSICS GROUP

TIME-DEPENDENT MODELS OF STAR FORMATION IN AGN ACCRETION DISCS

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AGN feeding difficulties: angular momentum transport

How does AGN feeding work?

Large scale

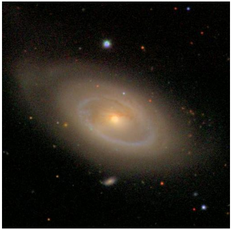
Mergers, global gravitational instabilities bring gas down to $\sim$ 1 *kpc* [Hopkins et al 2009]

See Chris Power's Talk

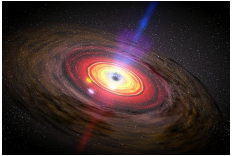
Small scale

Steady α–disc theory below self–gravity radius

[Shakura & Sunyaev 1973, Pringle 1981, Balbus & Hawley 1991]



Credit: SDSS



Credit: NASA/Dana Berry, SkyWorks Digital

AGN feeding difficulties: star formation

Extended accretion discs framework

$$R \gtrsim R_{\rm sg} \sim 0.01 - 0.1\, pc$$

[Toomre 1964, Paczynscky 1978, Kolykhalov & Sunyaev 1980, Collin & Zahn 1999, Goodman 2003]

massive and cold discs

$\Downarrow$

Gravitational instability

$\Downarrow$

Star formation

- Star formation consumes gas.
- Young massive stars rings around Sgr A* [Paumard et al. 2006]

AGN feeding difficulties: star formation

CAN STAR FORMATION STARVE SMBH?

Accounting of Stellar feedback

Energy and Momentum injection

- ⋆ Protostellar accretion
- ⋆ Massive stars (radiation, winds)
- ⋆ Supernovae

NEGATIVE FEEDBACK!

Steady–state models [Thompson et. al. 2005]

Extended steady-state accretion discs

- Global torques action (spiral waves) [Goodman 2003]
- Continuous external inflow of gas
- Instantaneous stellar feedback with a global stellar efficiency $\varepsilon = 10^{-3}$ of $M_{\star}c^2$ [Salpeter 1955, Leitherer 1992]

⋆ **Critical external inflow rate** $\dot{M}_{\mathbf{ext}} > 220\, M_{\odot}/$**yr at** $\sim 100\, pc$

⋆ **Accretion rates** $\sim 4\, M_{\odot}/\mathrm{yr}$**, enough to power AGN**

⋆ **High SF rates within 0.1-10 pc**

Time–dependent model: motivations

Time–scales

Gravitational collapse $t_{\rm dyn} = 1/\Omega \sim 10^3 r_{\rm pc}^{3/2} m_8^{-1/2}\, y.$

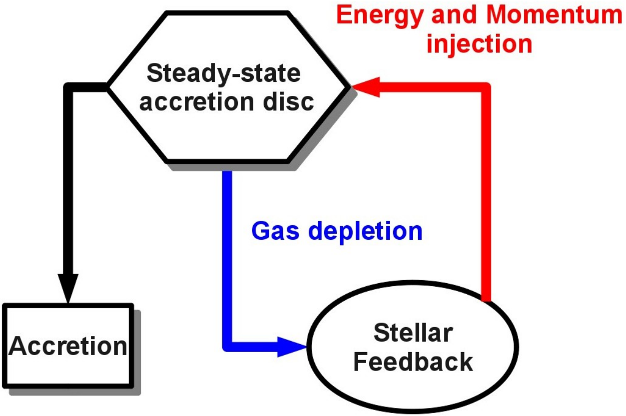
Star formation $t_\star = t_{\rm dyn}/\eta \sim 5 \times 10^4 r_{\rm pc}^{3/2} m_8^{-1/2}\, y$, $\eta \sim 0.02$ [Kennicutt, 1998]

Viscous accretion $t_{\rm visc} \sim \alpha^{-1} (R/H)^2 t_{\rm dyn} \sim 3 \times 10^7 / h_{-2} \alpha_{0.3}\, y$

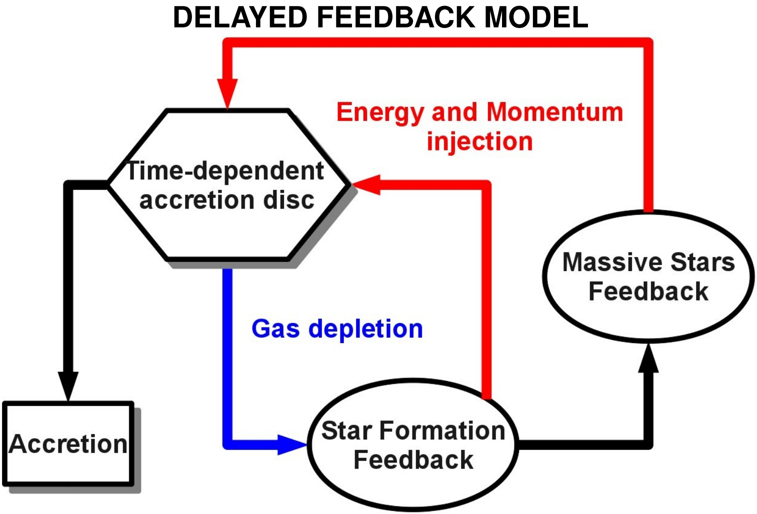
- SF feedback is less efficient (more SF).
- Massive stars feedback is different from SF feedback.
- Local thermodynamical balance may be not appropriate

Comparing Models

INSTANTANEOUS FEEDBACK MODEL



Comparing Models



Master equations

Evolution of the disc surface density

[Lynden-Bell & Pringle 1974, Pringle 1981, Frank et al. 2002]

$$\underbrace{\frac{\partial \Sigma}{\partial t}}_{\text{Rate}} = \underbrace{\frac{3}{R}\frac{\partial}{\partial R}\left[R^{1/2}\frac{\partial}{\partial R}\left(R^{1/2}\nu\Sigma\right)\right]}_{\text{Viscous diffusion}} + \underbrace{\frac{\partial \dot{M}}{2\pi R \partial R}}_{\text{Supply}} - \underbrace{\dot{\Sigma}_\star}_{\text{SF rate}}$$

Evolution of the disc temperature.

As in [Nayakshin et al., 2000, Abramowicz et al., 1995]

$$\underbrace{Q_c \frac{d \ln T}{dt}}_{\text{Rate}} = \underbrace{\frac{2}{R}\frac{\partial}{\partial R}\left(R F_R H\right)}_{\text{Radial heat transport}} + \underbrace{F^+}_{\text{Heating}} - \underbrace{F^-}_{\text{Cooling}}$$

Ring tests

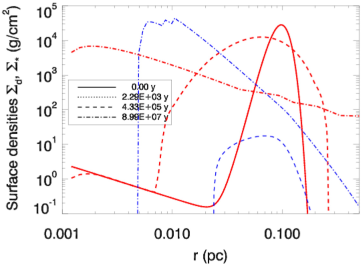
Initial ring of gas around SMBH

- No external gravitational torques
- No external mass supply

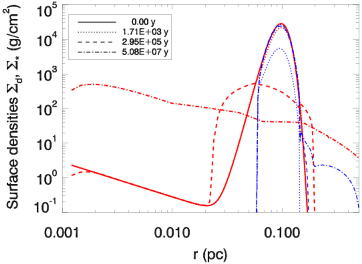
- SMBH mass $M_{bh} = 10^7\ M_\odot$
- Disc mass $M_d = 3 \times 10^6\ M_\odot$
- Initial gaussian density profile
- Ring center $R_{peak} = 0.1\ pc$
- Ring width $R_{width} = 0.02\ pc$

Ring tests results: surfaces densities

Instantaneous Feedback



Delayed Feedback

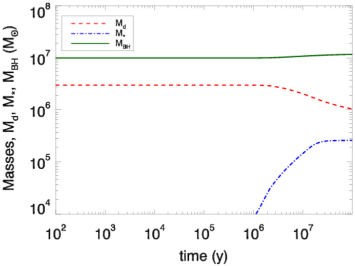


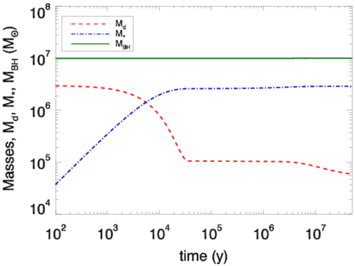
Initial ring setting. Gas (*thick red lines*) and stellar surface densities (*thin blue lines*). The different lines styles are snapshots at different times specified in the label. Left) Calculation with istantaneous stellar feedback. Right) Calculation with delayed stellar feedback.

Ring tests results: evolution of masses

Instantaneous Feedback

Delayed Feedback

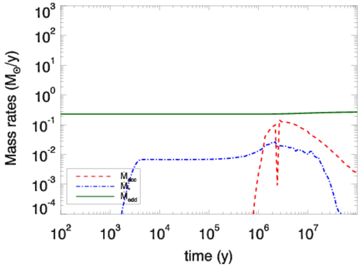




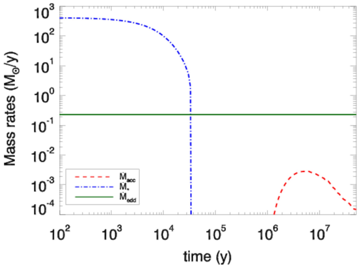
Initial ring setting. Evolution of the gas (red dashed line) and of the global stellar (blue dot-dashed line) masses. The green line is the mass of the SMBH . Left) Calculation with istantaneous stellar feedback. Right) Calculation with delayed stellar feedback.

Ring tests results: mass rates

Instantaneous Feedback



Delayed Feedback



Initial ring setting. Evolution of accretion and star formation rates. The green line is the Eddington accretion rate for the relative SMBH mass. Left) Calculation with istantaneous stellar feedback. Right) Calculation with delayed stellar feedback

Global torque driven accretion disc tests

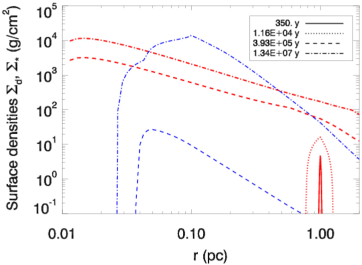
External deposition of matter around the SMBH

- Initial empty area
- External gravitational torques
- External mass supply

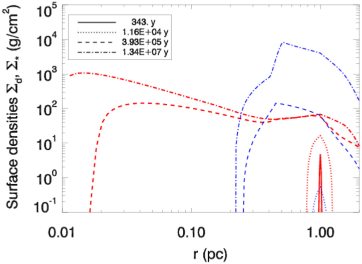
- SMBH mass $M_{bh} = 10^7\, M_\odot$
- Deposition radius $R_{peak} = 1\, pc$
- External mass supply rate $\dot{M} = 10\, M_\odot / y$

GTA results: surface densities

Instantaneous Feedback



Delayed Feedback



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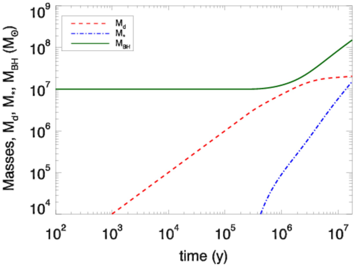
GTA results: evolution of masses

Instantaneous Feedback



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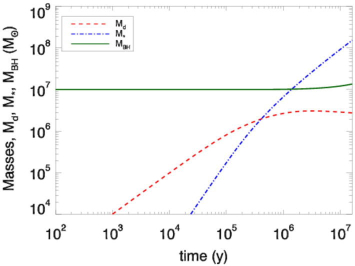

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GTA results: mass rates

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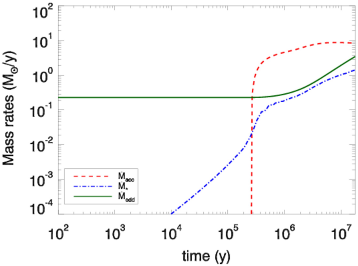

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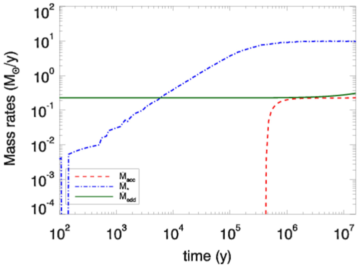

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Conclusions

- The delayed feedback model results are very different from instantaneous feedback model.
- SF is not quenched by feedback, but it is the dominant process.
- SF consumes almost all the gas supplied.

? Missing feedback physics?

? Different feeding mechanism?

! To do: test with Sgr A* parameters