1st FISICA Workshop

Science Goals of a Sub-arcsecond

Far-infrared Space Observatory

Probing the early evolution of supermassive black holes in proto spheroids at z > 1.5

Observatory of Padova

Presented by **Mattia Negrello**

INAF - Osservatorio Astronomico di Padova, Italy

ma per seguir virtute e canoscenza

SISSA

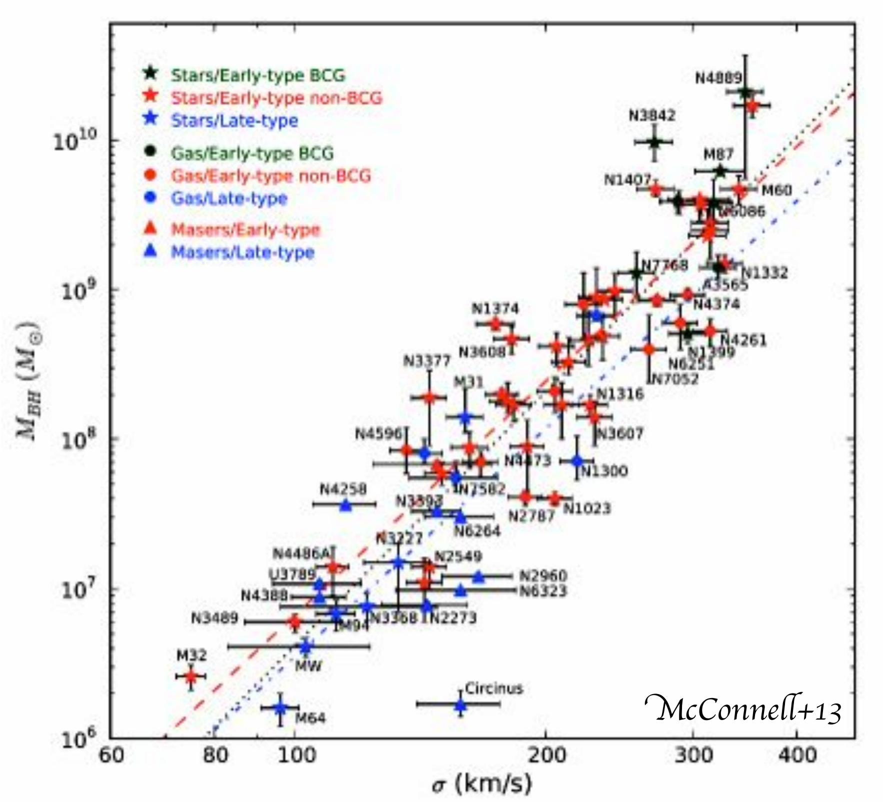
On behalf of **A. Lapi, Z.-Y. Cai, G. De Zotti, L. Danese**

Outline

- SF/AGN co-evolution
- Torus formation in proto-spheroids @ z>1.5
- Studying the torus with gravitational lensing
- Conclusions

The spheroid – AGN connection

- Relation between the properties of **SMBHs** and the **host spheroids**
  - **M_{BH} – $L_\star$**
  - **M_{BH} – M_{sph}**
  - **M_{BH} – $\sigma_\star$**



The spheroid – AGN connection

- Relation between the properties of **SMBHs** and the **host spheroids**
  - $\mathbf{M_{BH} - L_{\star}}$
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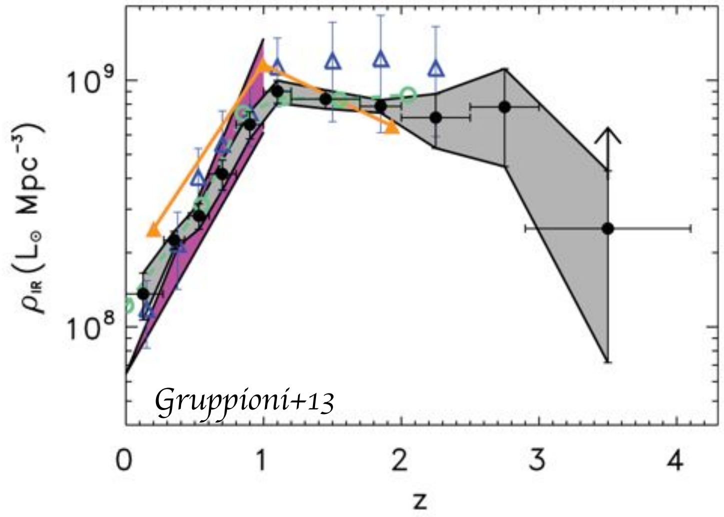
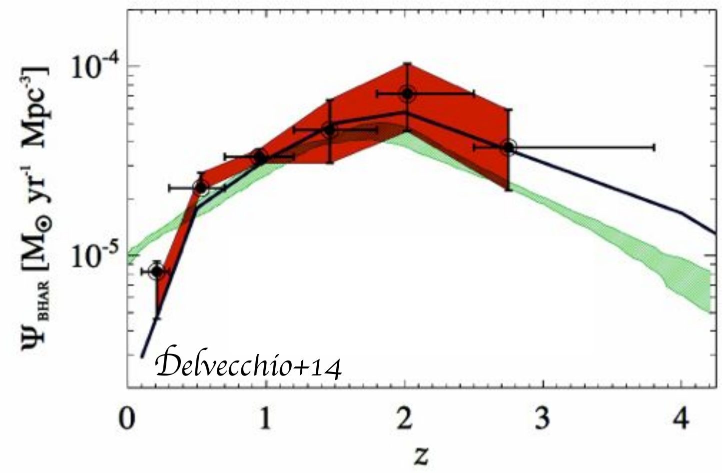
  - $\mathbf{M_{BH} - \sigma_{\star}}$

- **Similar redshift (z~2)** for the peak of the **star formation** and the **nuclear activity**

STAR FORMATION



BH ACCREATION



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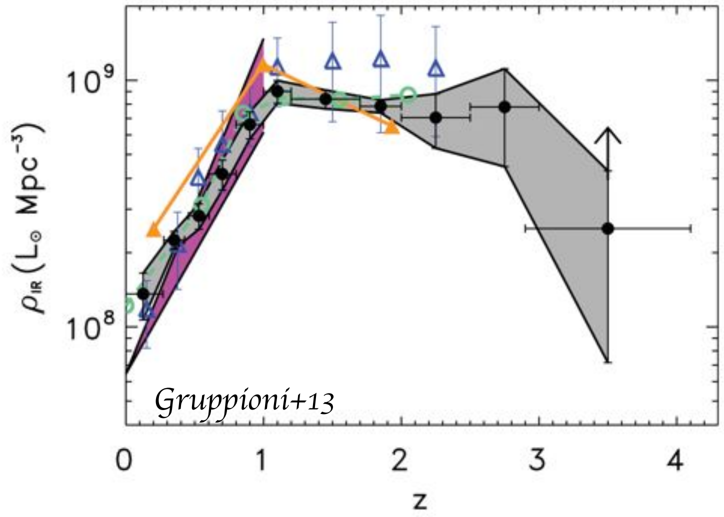
- **Similar redshift (z~2)** for the peak of the **star formation** and the **nuclear activity**

SF/BH co-evolution and mutual influence !

STAR FORMATION



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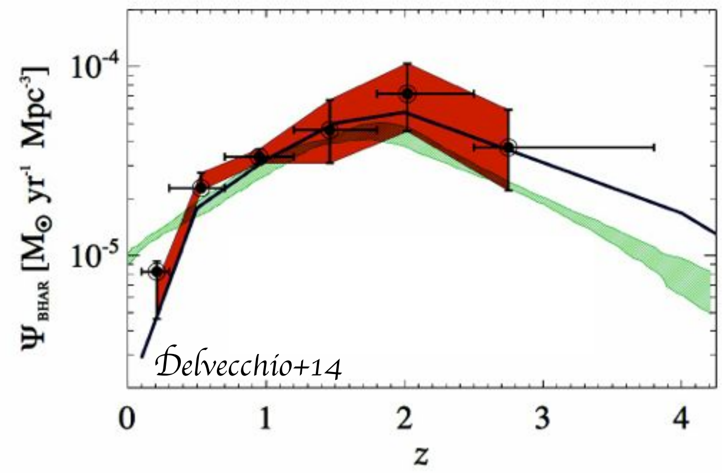
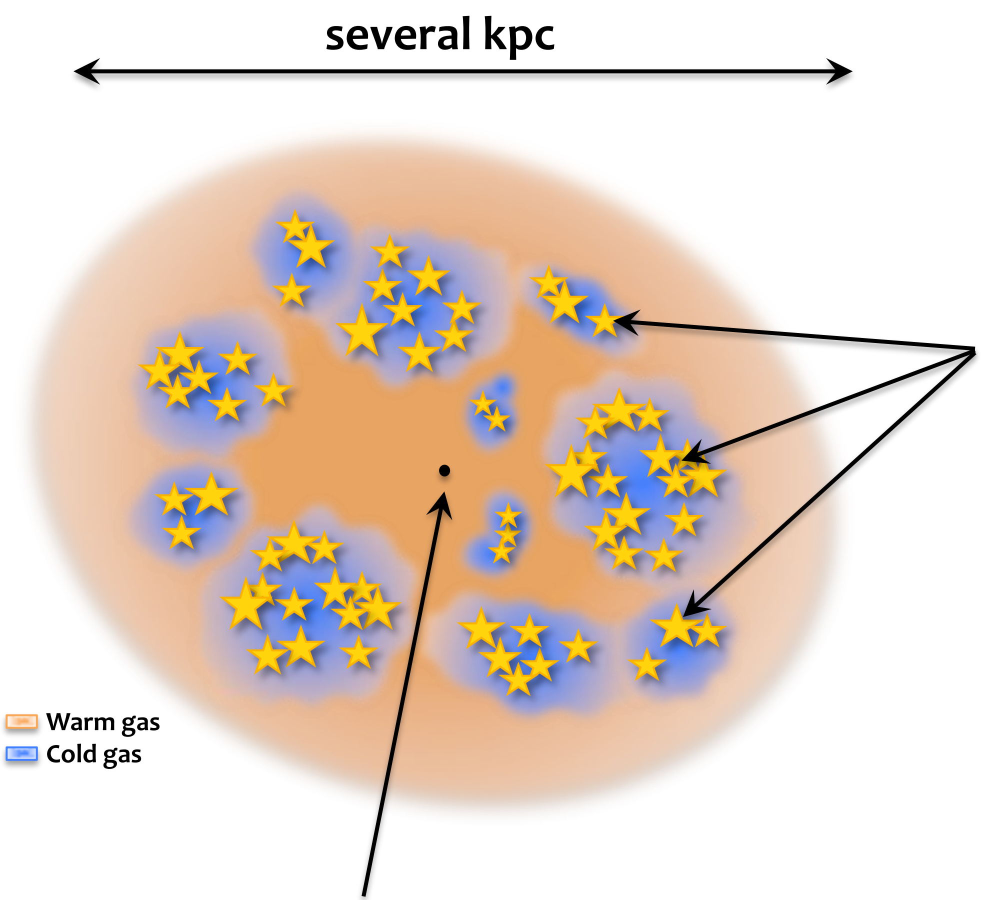


The spheroid – AGN connection



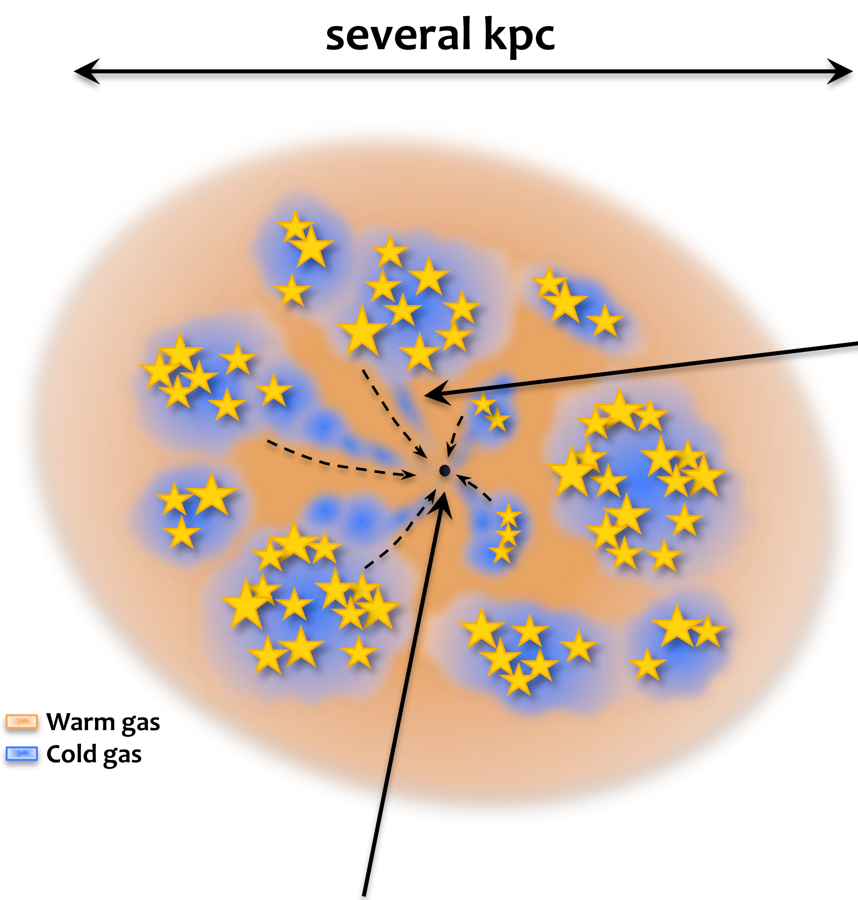
Proto-spheroid @ **z ~> 1.5**

Clumps of **cold gas** where **star formation** can occur

Seed BH

$M_{\rm seed} = 10^2 - 10^3\, M_{\odot}$

The spheroid – AGN connection



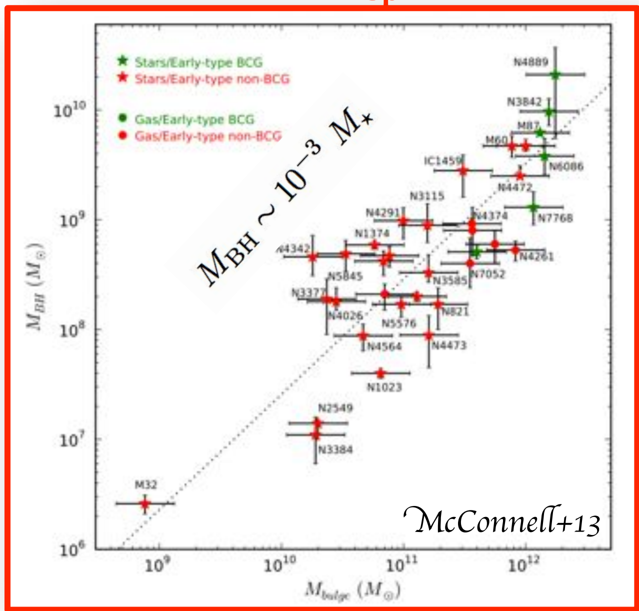
Seed BH

$$M_{\rm seed} = 10^2 - 10^3\ M_\odot$$

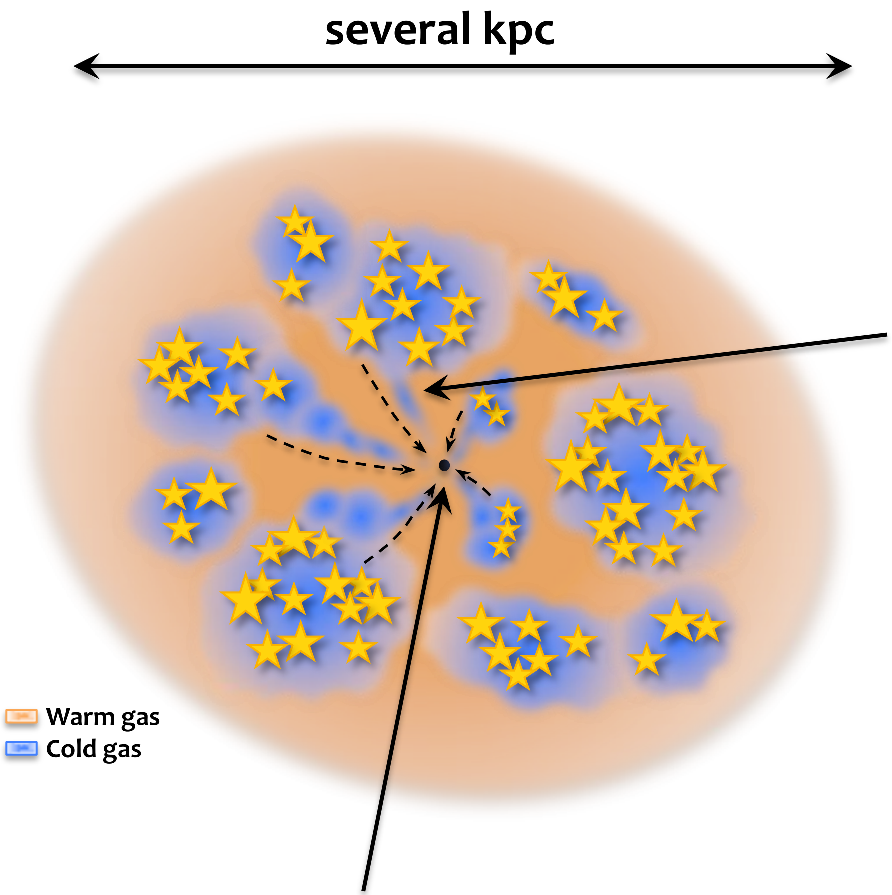
The **cold gas** inflows from **galactic scales (several kpc)** to the **central regions (< 100 pc)** at a rate **proportional to the SFR**

$$\dot{M}_{\rm inflow} = \alpha_{\rm res} \times 10^{-3}\ \dot{M}_\star$$

⇒ local $\mathbf{M_{BH}}$- $\mathbf{M_{sph}}$ relation



The spheroid – AGN connection



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$$\dot{M}_{\rm inflow} = \alpha_{\rm res} \times 10^{-3}\ \dot{M}_\star$$

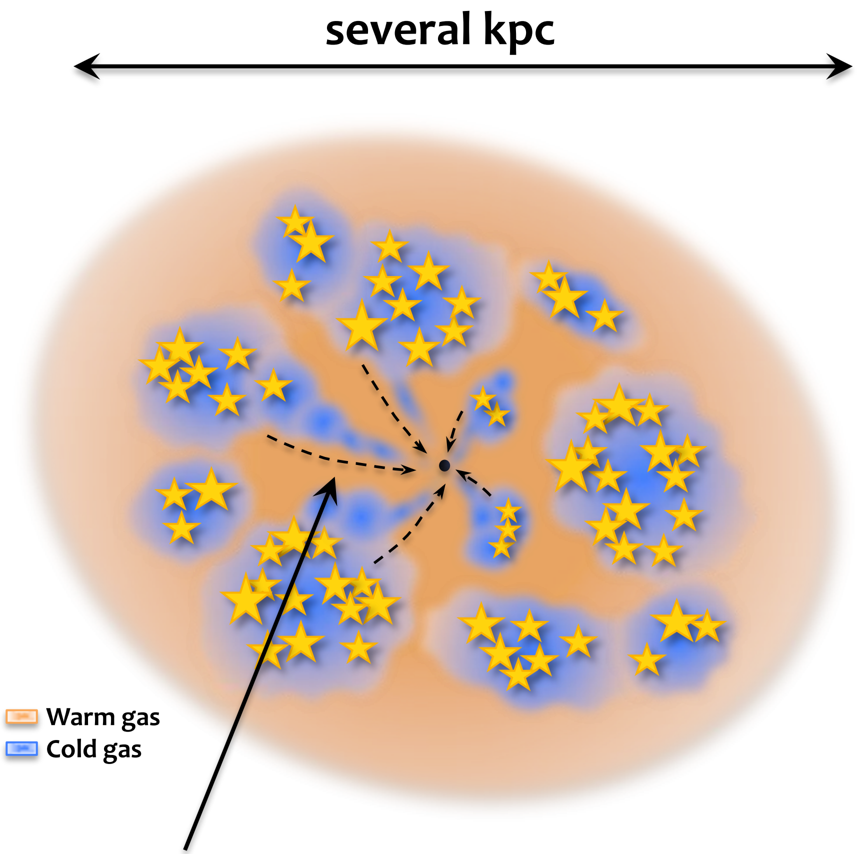
Depends on the process considered for the gas to lose its angular momentum on large scales (see e.g. *Granato+04, Lapi+06*):

- radiation drag
- dynamical friction
- tidal fields
- spiral waves
- turbulence
- ...

$\alpha_{\rm res} \sim 2$

with $\sim 0.4\,{\rm dex}$ scatter

The spheroid – AGN connection



Black Hole accretion

$$\epsilon \, c^2 \, \dot{M}_{\rm accr} = L_{\rm AGN}$$

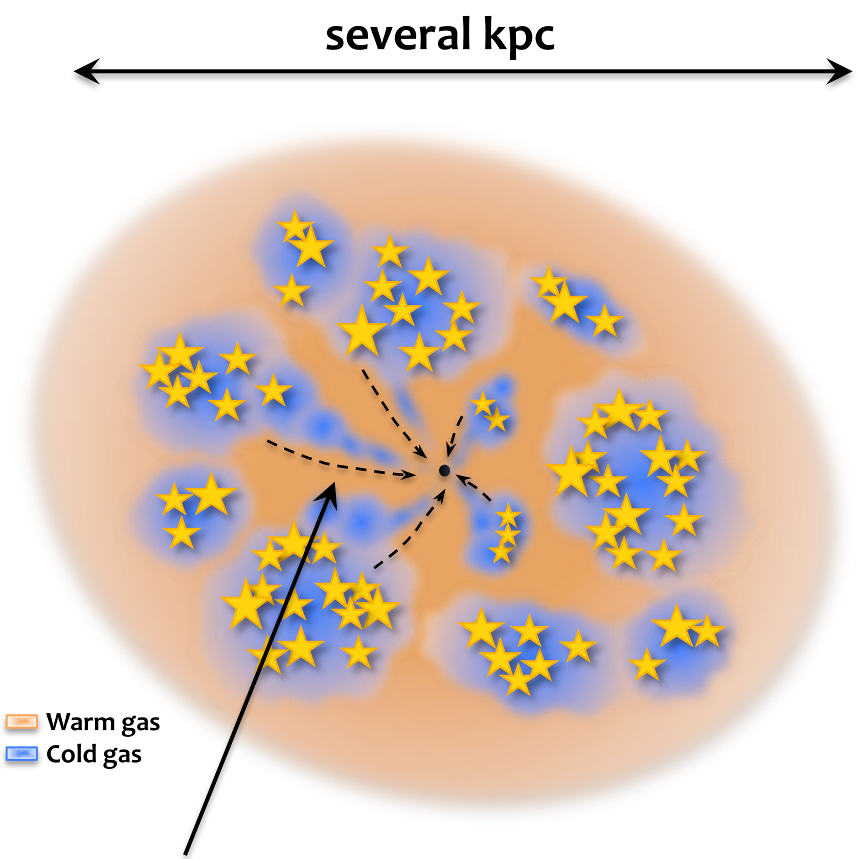
Mass to radiation conversion efficiency

$0.06 \lesssim \epsilon \lesssim 0.3$

Gas infall

$$\dot{M}_{\rm inflow} = \alpha_{\rm res} \times 10^{-3} \; \dot{M}_{\star}$$

The spheroid – AGN connection



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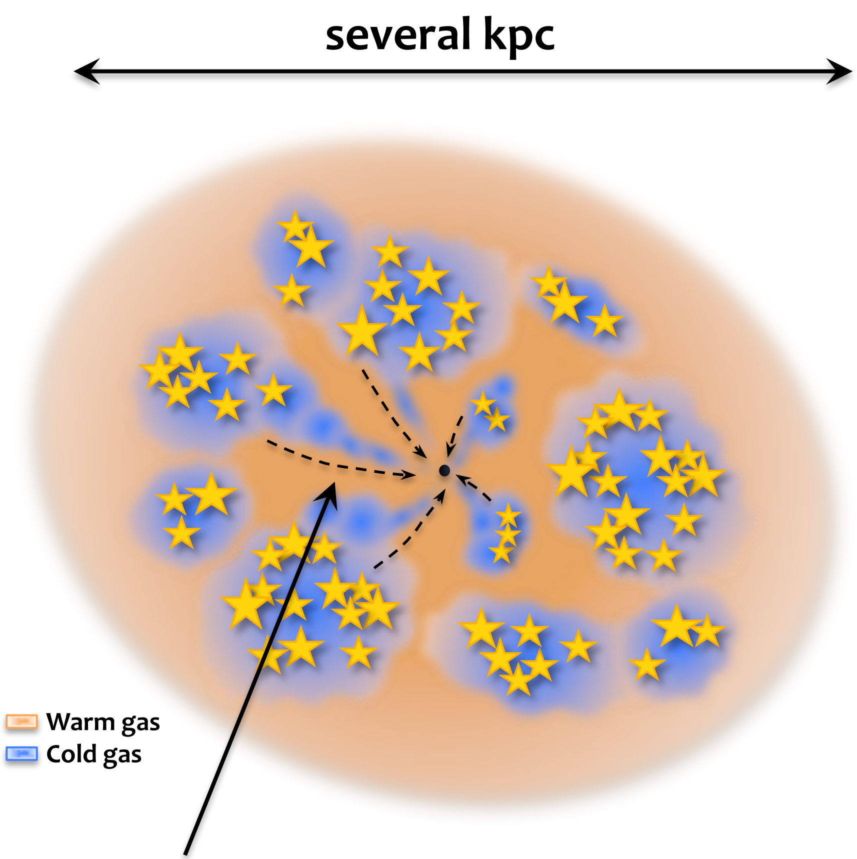
$$\epsilon\, c^2\, \dot{M}_{\rm accr} = L_{\rm AGN} = \lambda L_{\rm Edd}$$

Mass to radiation conversion efficiency $0.06 \lesssim \epsilon \lesssim 0.3$

$\lambda(z) = -1.15 + 0.75(1+z)$ for $1.5 \lesssim z \lesssim 6$ (*Lapi+06*)

The spheroid – AGN connection



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for $1.5 \lesssim z \lesssim 6$ (*Lapi+06*)

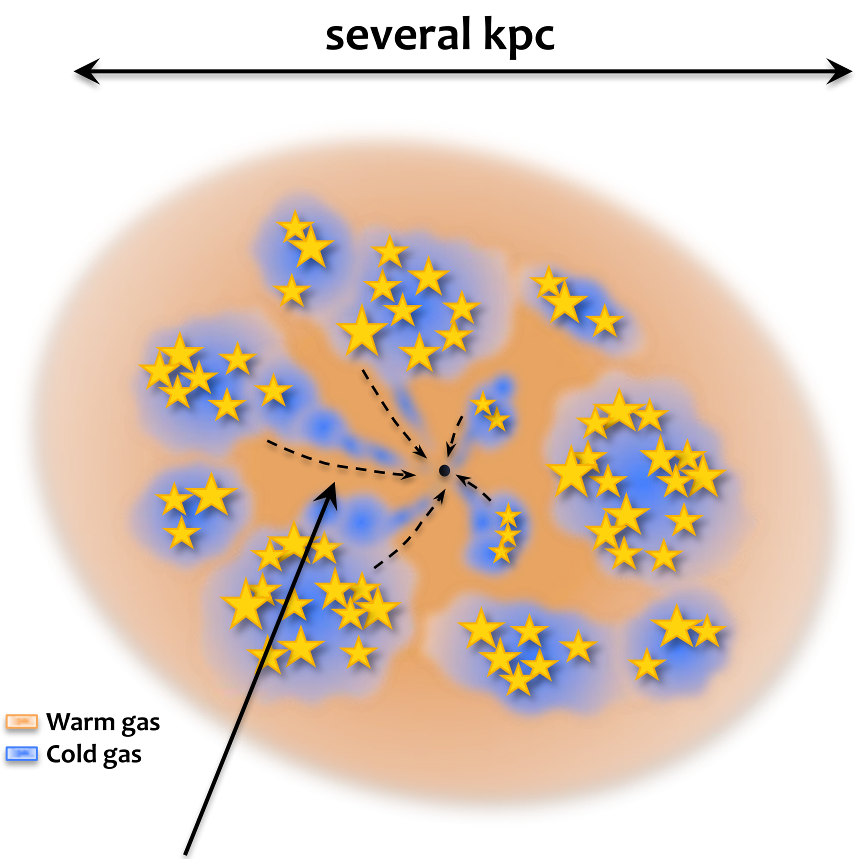
$\epsilon = {\rm const}$

$\lambda = {\rm const}$

$$M_{\rm BH}(t) = M_{\rm seed} \times e^{\frac{t}{\tau_{\rm ef}}}$$

$$\tau_{\rm ef} = \frac{\epsilon}{\lambda(1-\epsilon)}\tau_{\rm Edd} \overset{\epsilon=0.15,\ z=2}{=} 7.2 \times 10^7\ {\rm yr}$$

The spheroid – AGN connection



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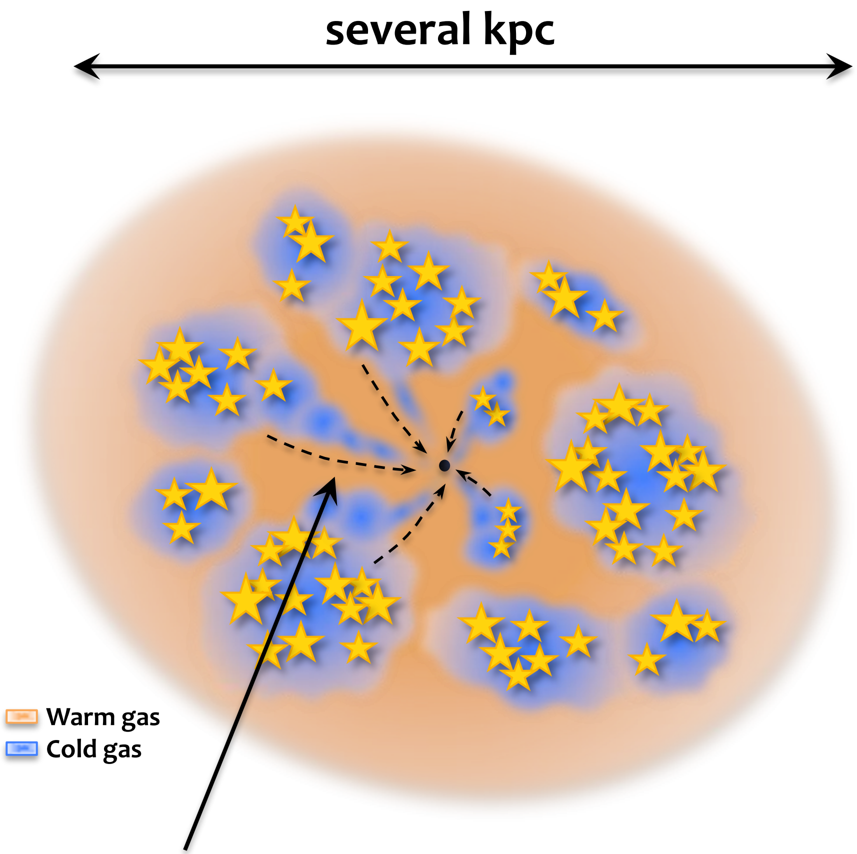

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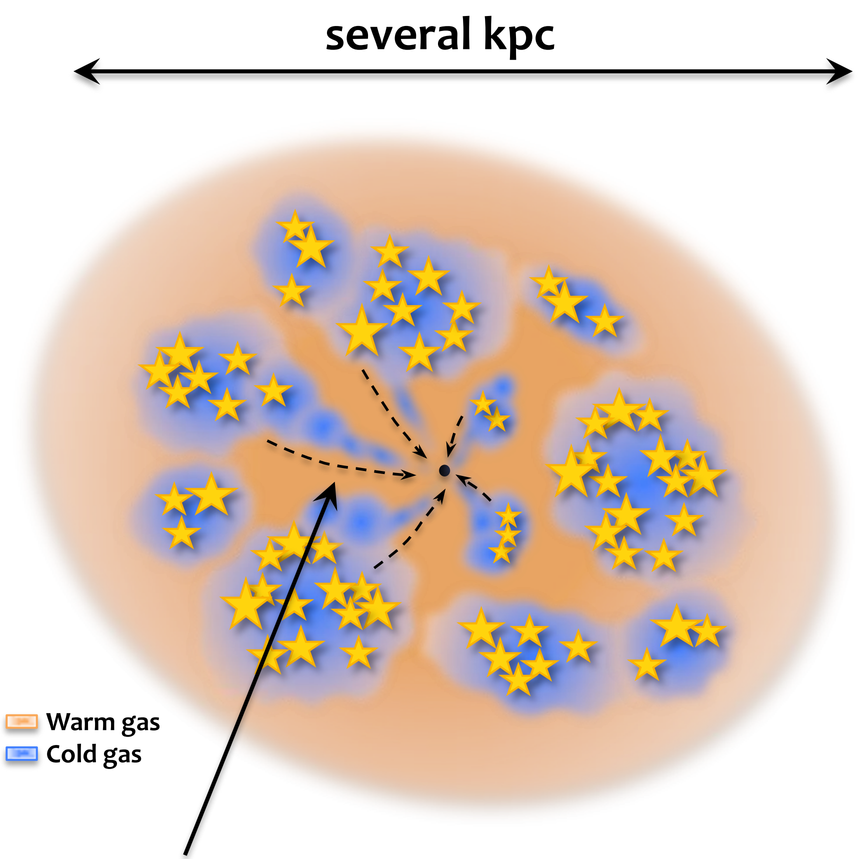

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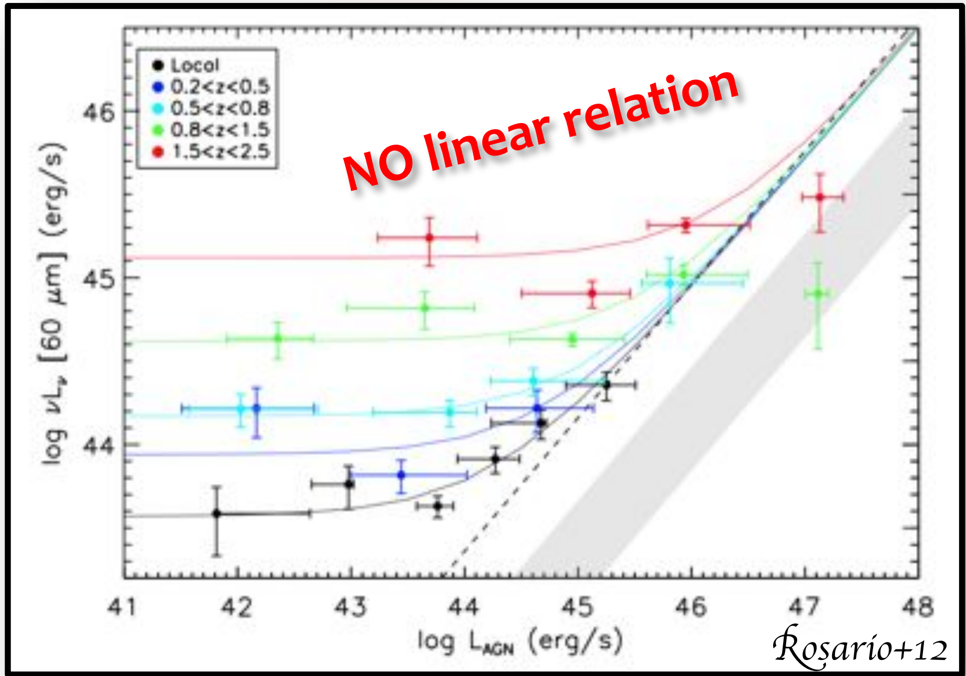
$$\dot{M}_{\rm accr} = \dot{M}_{\rm inflow}\ ?$$

If so ...

- $L_{\rm AGN} \propto \dot{M}_{\star} \propto L_{\rm IR}$

(e.g. *Cole+00; Baugh+05; Fanidakis+12*)

The spheroid – AGN connection



Black Hole accretion

$$\epsilon \, c^2 \, \dot{M}_{\mathrm{accr}} = L_{\mathrm{AGN}} = \lambda L_{\mathrm{Edd}}$$

$$\dot{M}_{\mathrm{accr}} = \dot{M}_{\mathrm{inflow}} \; ?$$

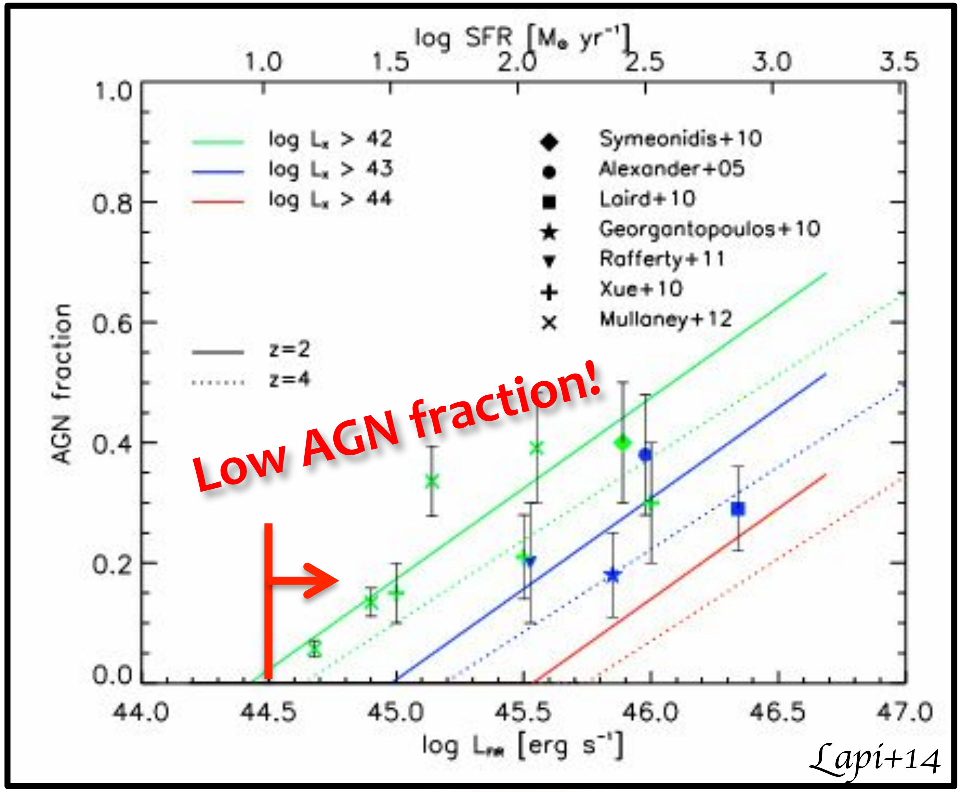
If so …

- $L_{\mathrm{AGN}} \propto \dot{M}_{\star} \propto L_{\mathrm{IR}}$

Gas infall

$$\dot{M}_{\mathrm{inflow}} = \alpha_{\mathrm{res}} \times 10^{-3} \; \dot{M}_{\star}$$

The spheroid – AGN connection



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- $L_{\rm AGN} \propto \dot{M}_\star \propto L_{\rm IR}$
- detected nuclear activity in all galaxies with L_{FIR} >~ 3 ×10^{44} erg/s

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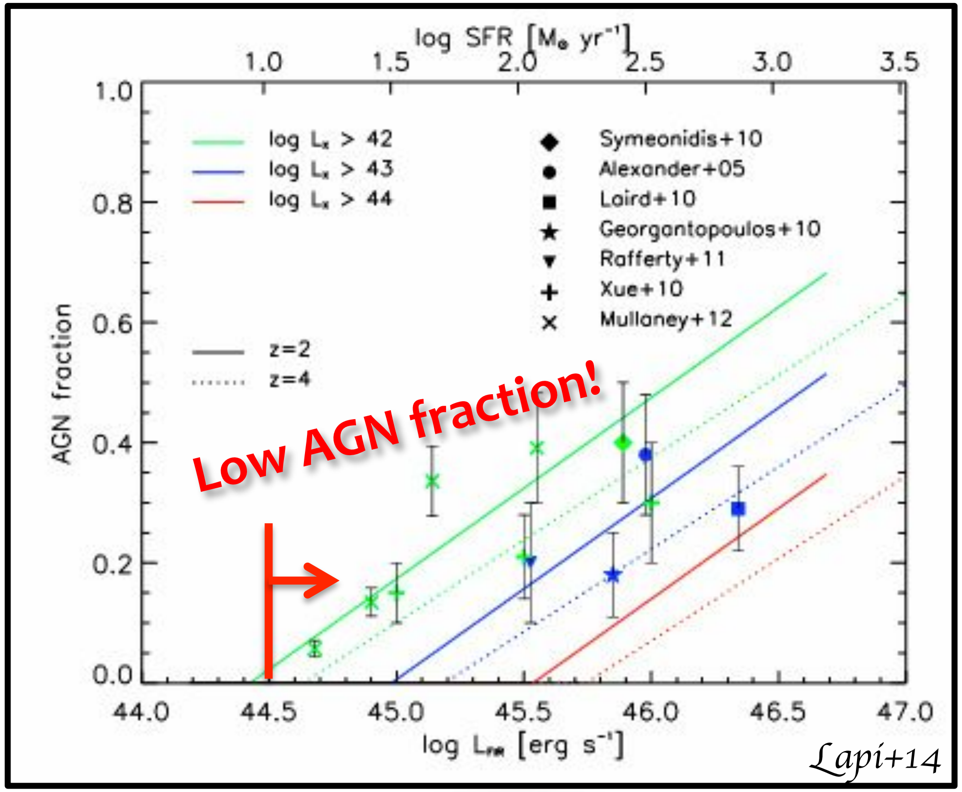

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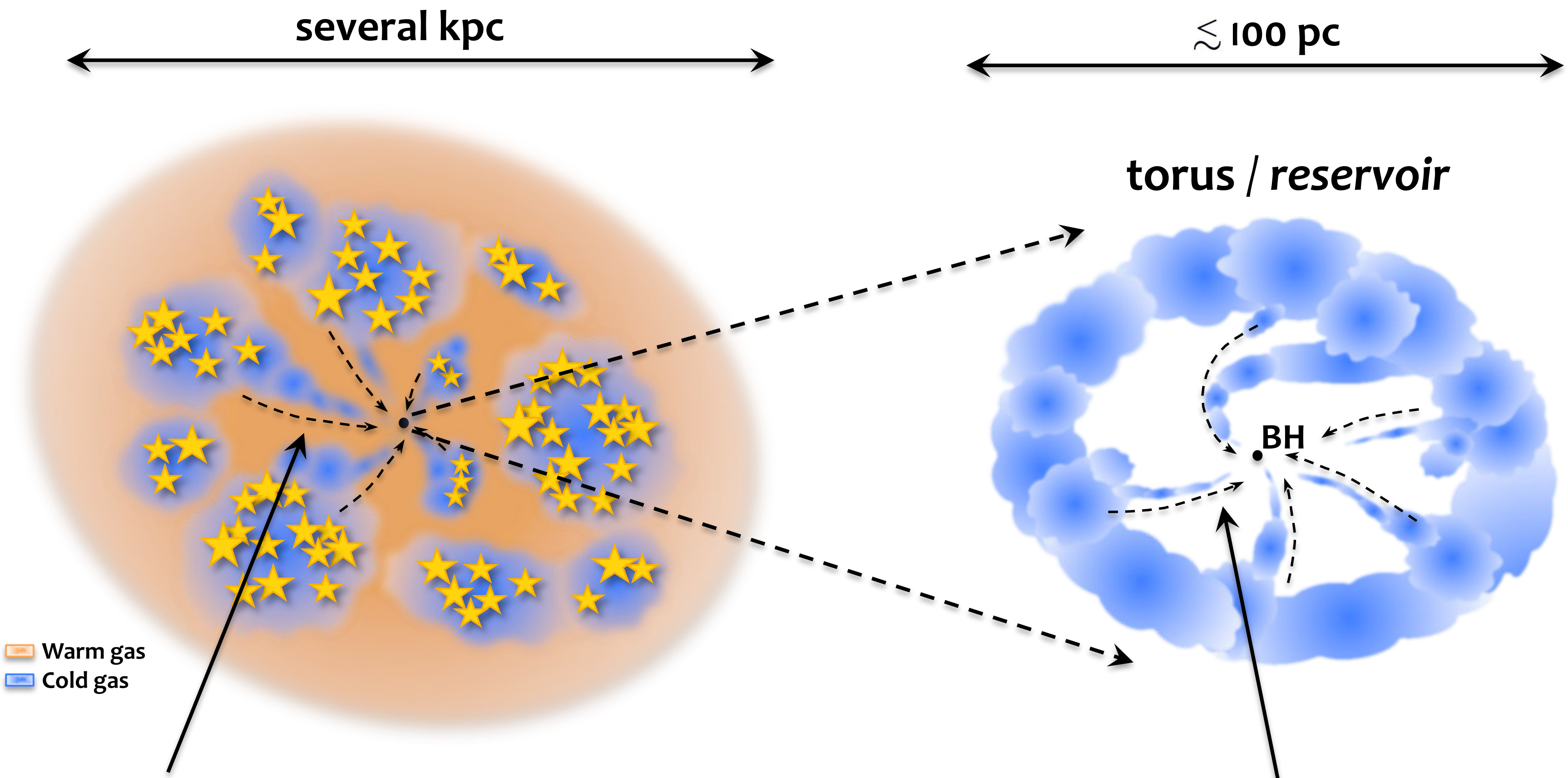

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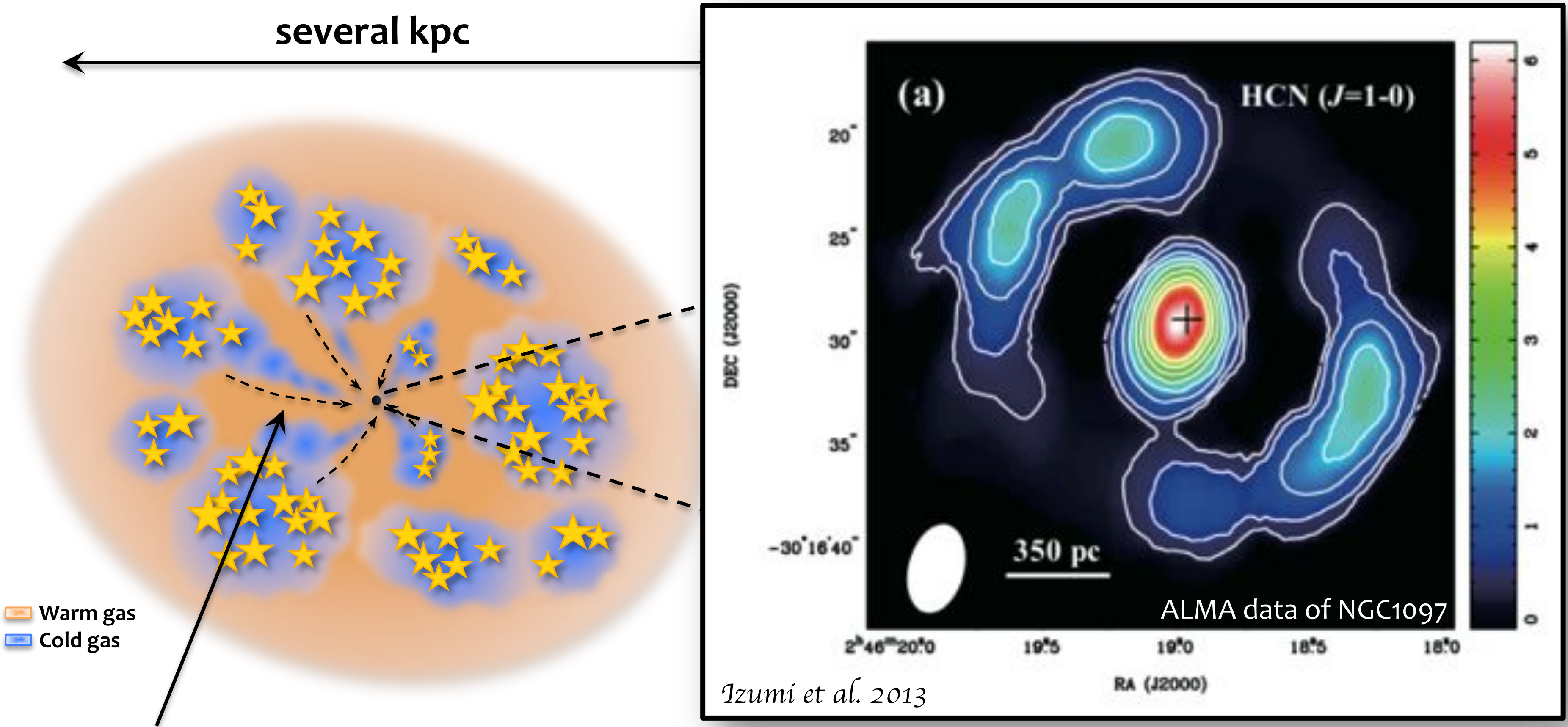

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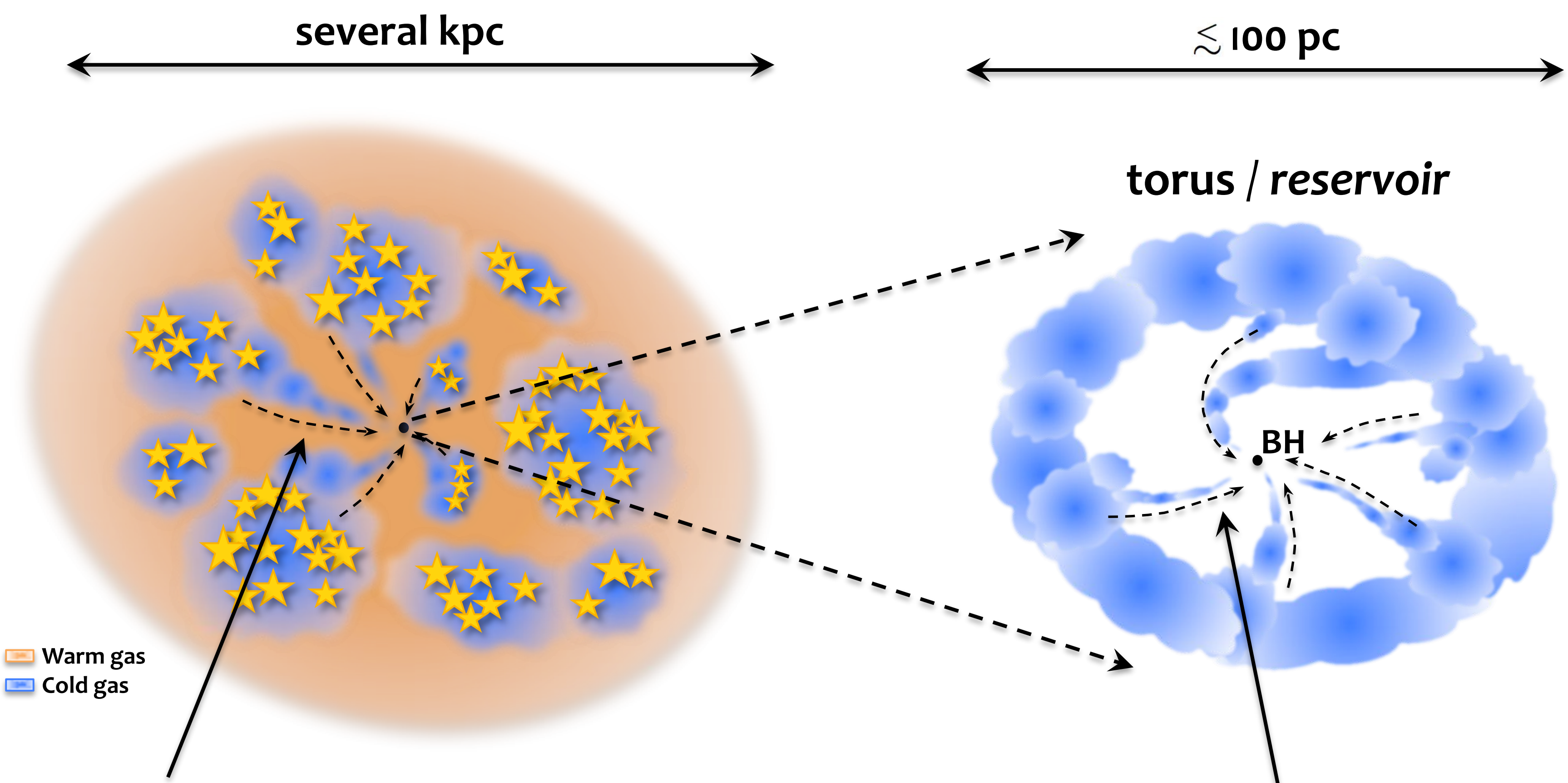

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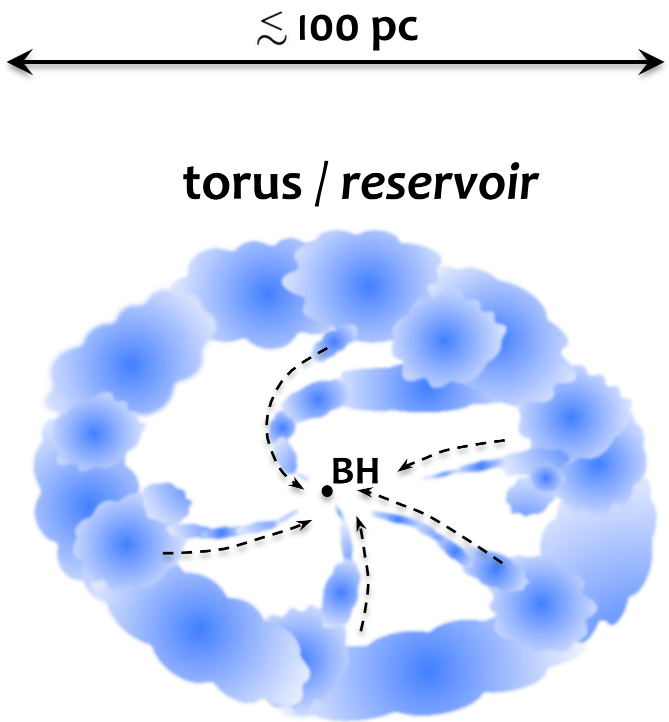
Reservoir

$$\dot{M}_{\rm res} \quad = \quad \dot{M}_{\rm inflow} - \dot{M}_{\rm accr}$$



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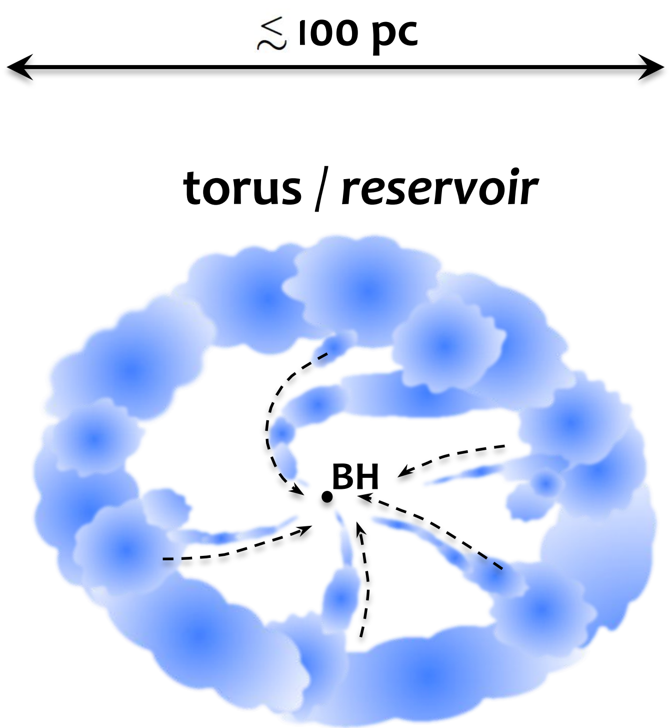
Reservoir

$$\dot{M}_{\rm res} = \dot{M}_{\rm inflow} - \dot{M}_{\rm accr}$$

$$= \alpha_{\rm res} \times 10^{-3}\ \dot{M}_\star - \frac{\lambda}{\epsilon}\frac{L_{\rm Edd}}{c^2}$$

$$= \alpha_{\rm res} \times 10^{-3}\ \dot{M}_\star - \frac{M_{\rm seed}}{(1-\epsilon)\tau_{\rm ef}} e^{\frac{t}{\tau_{\rm ef}}}$$



> 0 for many *e*-folding times if

- $\dot{M} \gtrsim 10^2\ M_\odot\ {\rm yr}^{-1}$
- $M_{\rm seed} = 10^2 - 10^3\ M_\odot$

The spheroid – AGN connection

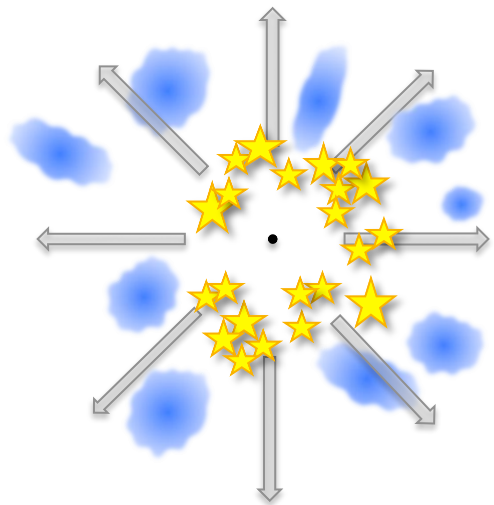
Feedback from **nuclear activity**

$\Rightarrow$ **ISM is removed**

$\Rightarrow$ **SF and fueling of the reservoir are stopped**

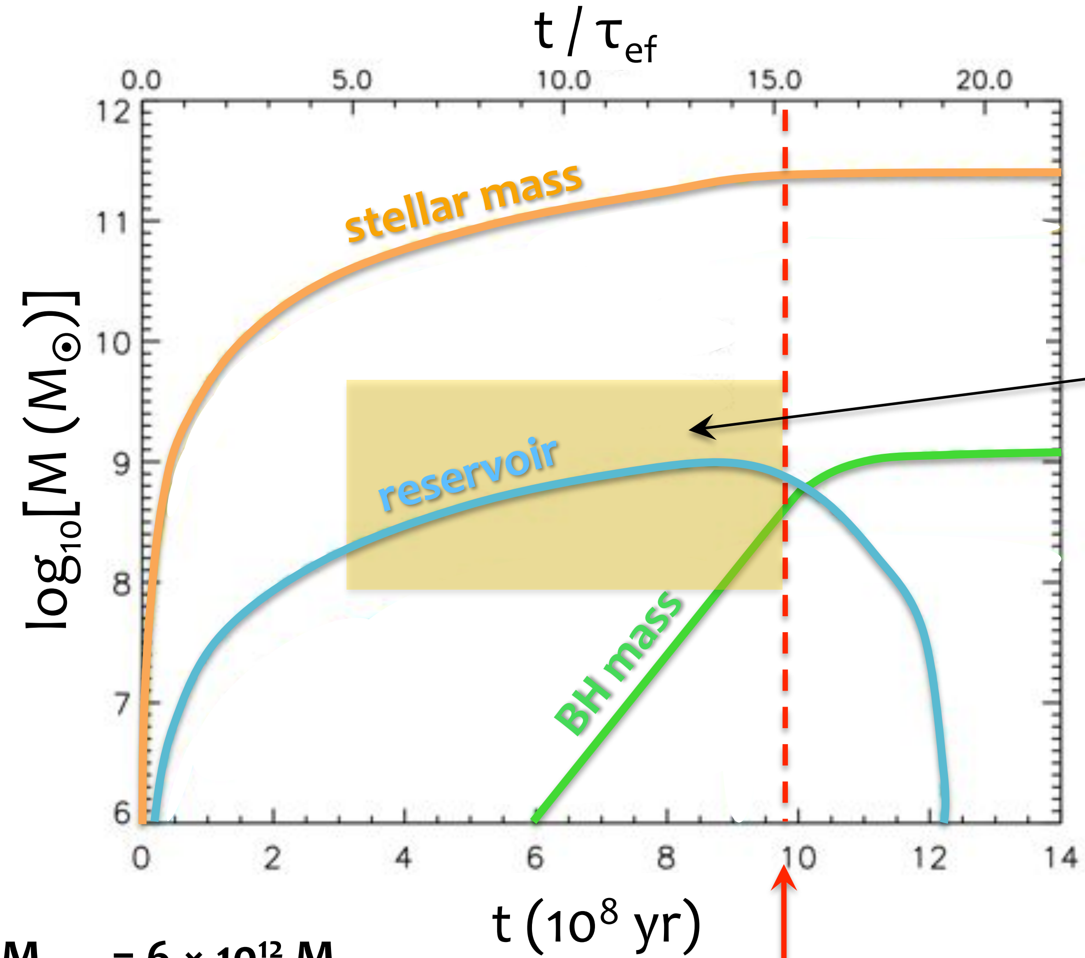
$\Rightarrow$ **supply-limited accretion**

$$\dot{M}_{\rm res} = \xcancel{\dot{M}_{\rm inflow}} - \dot{M}_{\rm accr}$$



The spheroid – AGN connection

Reference: *Lapi et al. 2014, ApJ, 782, 69*



The main star burst lasts for **~ 0.5 – 1 Gyr**

Growth of the *reservoir*

AGN feedback

M_{halo} = 6 × 10^{12} $M_\odot$
@ z = 2

The spheroid – AGN connection

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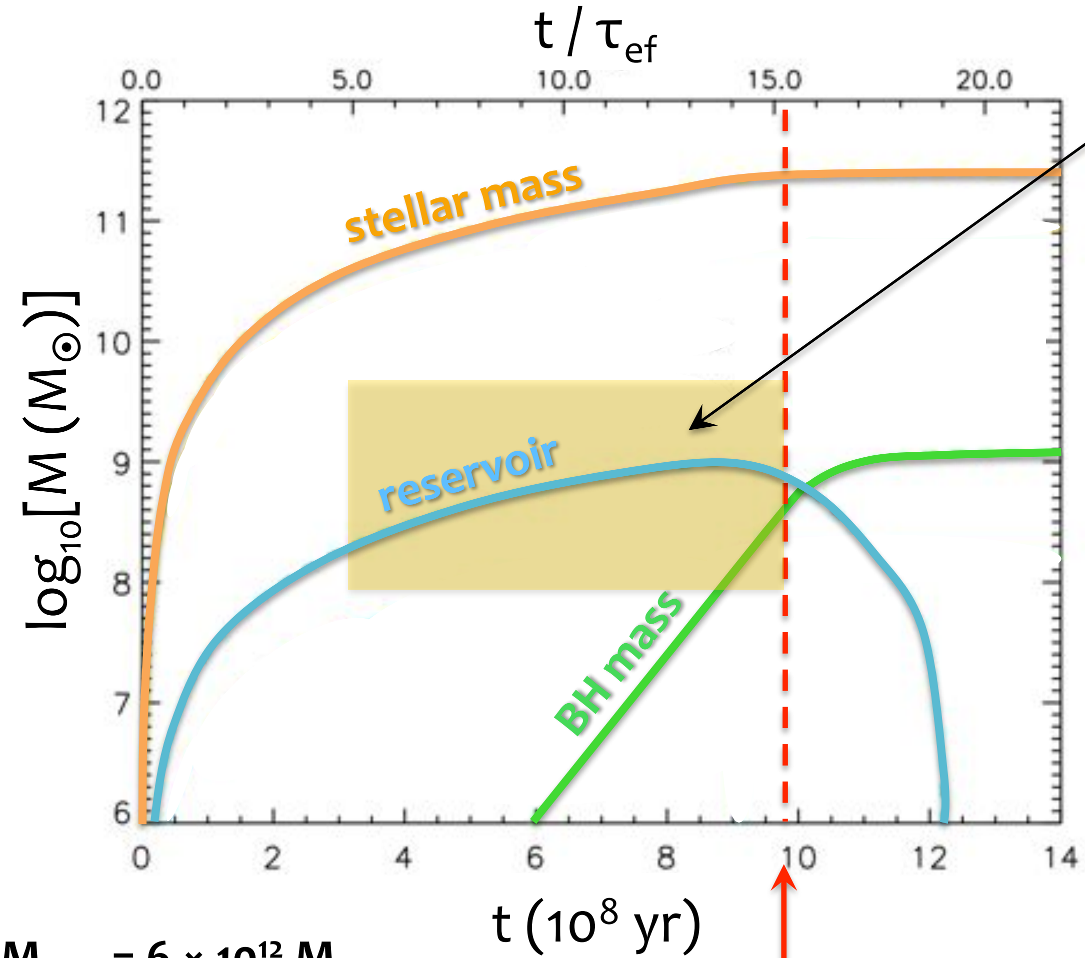

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AGN feedback

MID/FAR-IR SELECTION

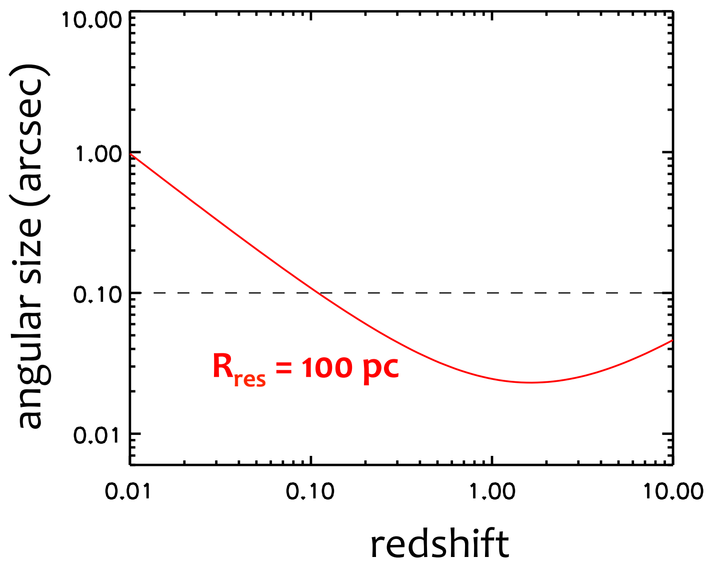
The emission from the **dusty torus/reservoir** peaks in the **mid-IR**

Can we resolve the torus/reservoir?

Imaging of the *reservoir*

Typical size $\mathbf{R_{res}} \lesssim$ **100 pc**

$\Rightarrow$ $\boldsymbol{\theta_{res}}$ **< 0.1 arcsec @ z > 0.1**



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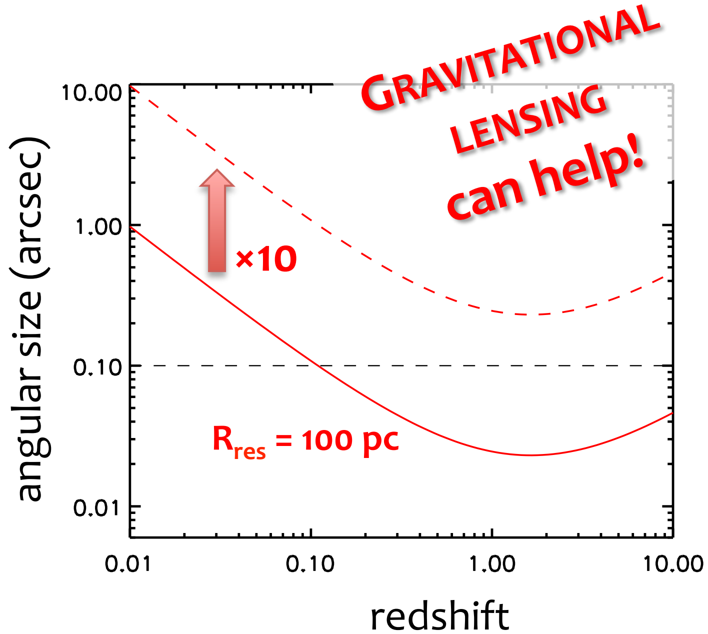

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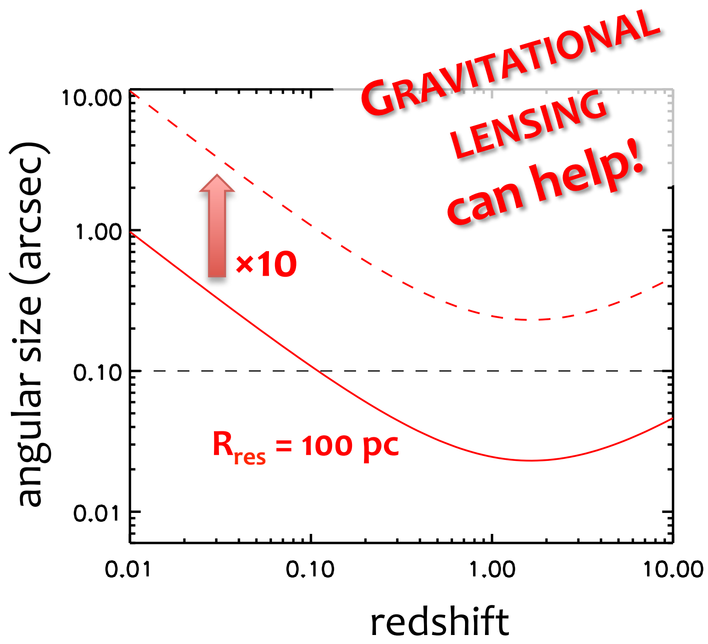

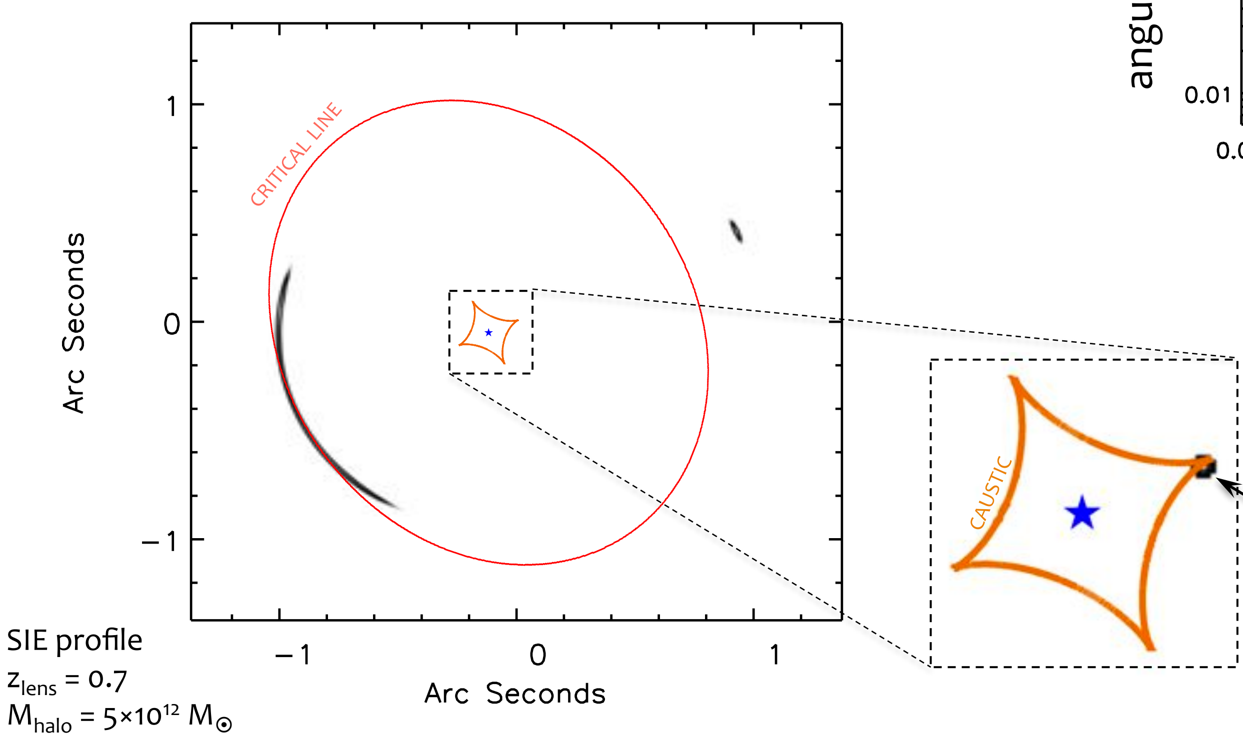

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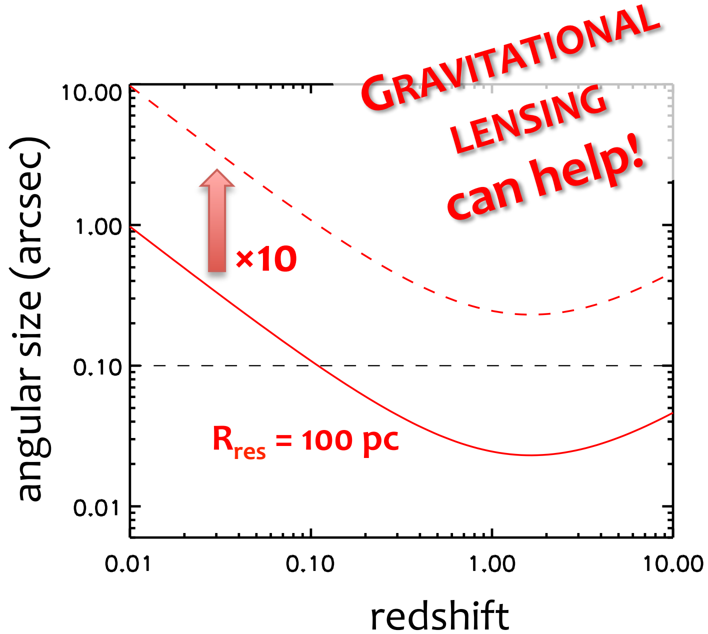
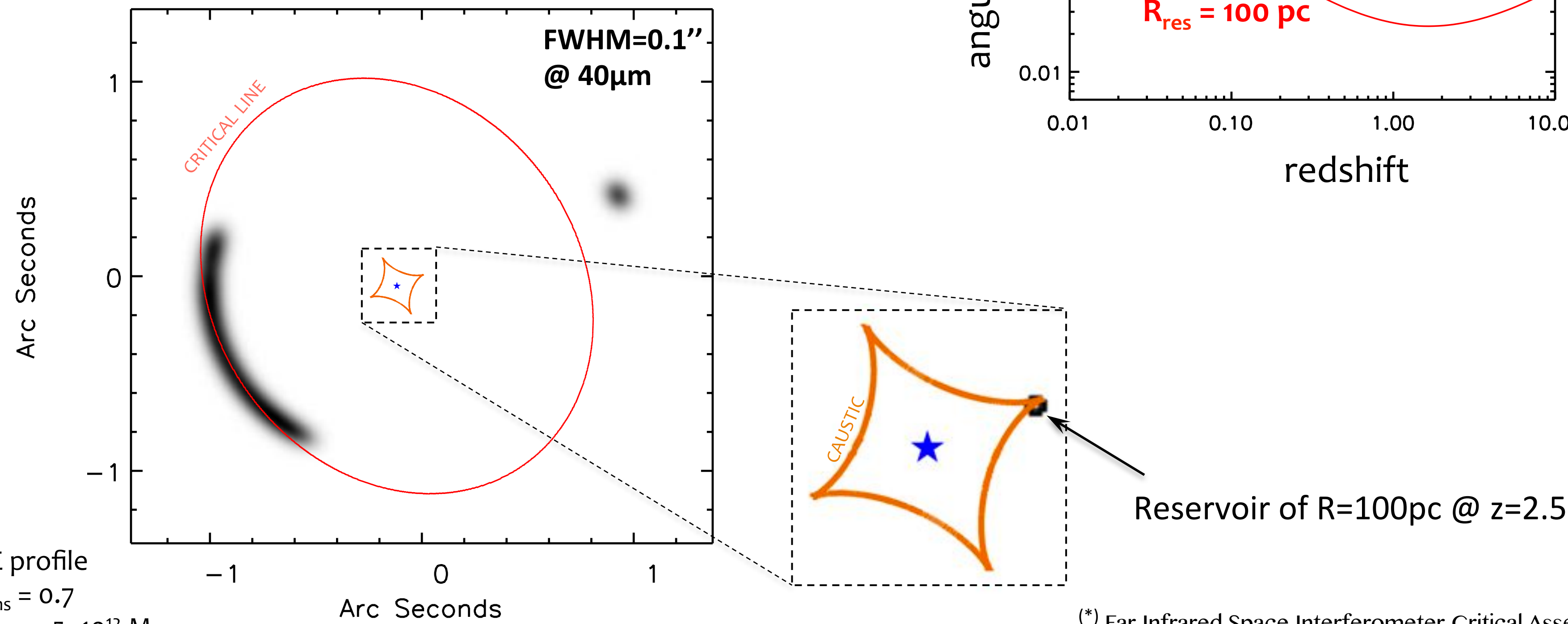


(*)

FIRI: 100m baseline	@30μm	@40μm	@100μm	@200μm
diffraction limit(FWHM) #:	0.07 arcsec	0.1 arcsec	0.25 arcsec	0.5 arcsec



SIE profile
$z_{lens} = 0.7$
$M_{halo} = 5{\times}10^{12}\ M_\odot$

(*) Far Infrared Space Interferometer Critical Assessment V2.0, 20.12.2013, by Spinoglio

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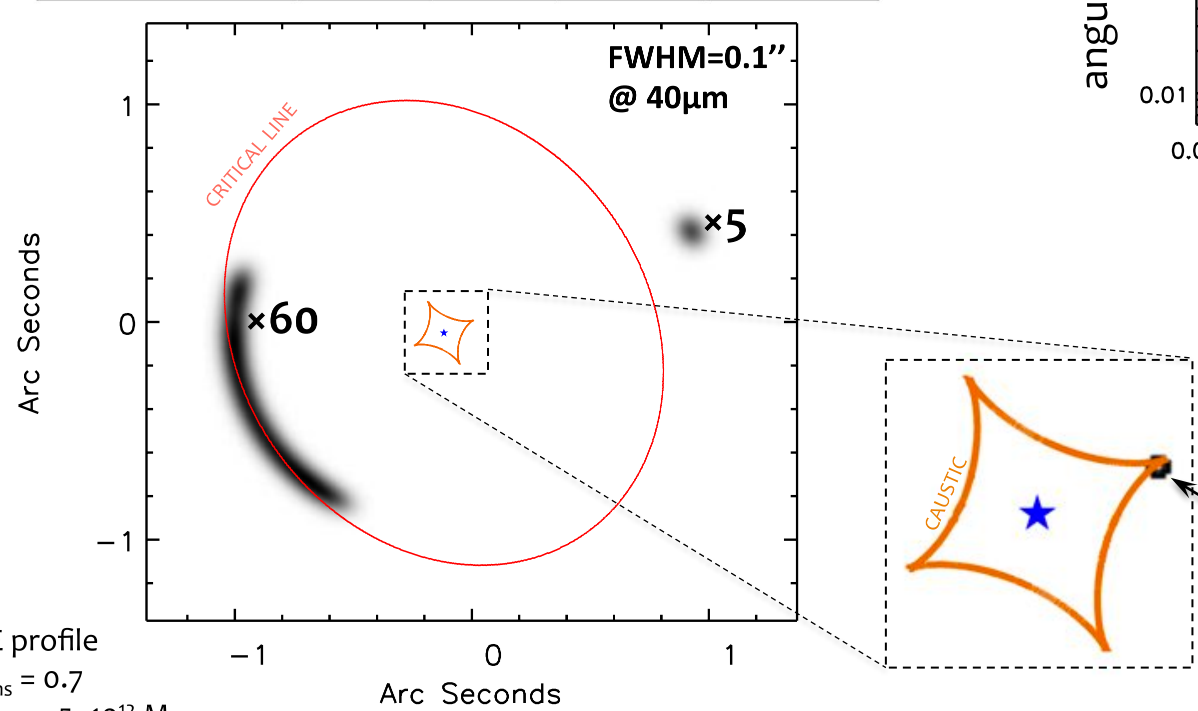

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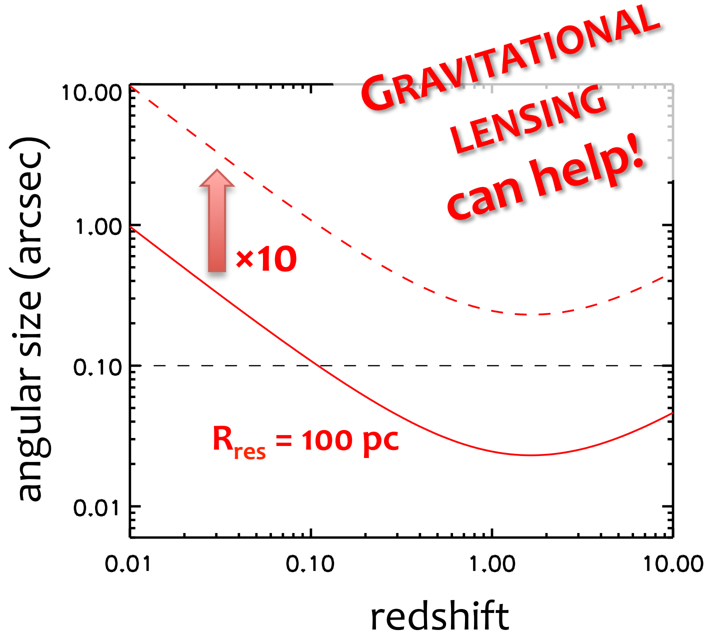

Small size
$\Rightarrow$ high magnification

Reservoir of R=100pc @ z=2.5

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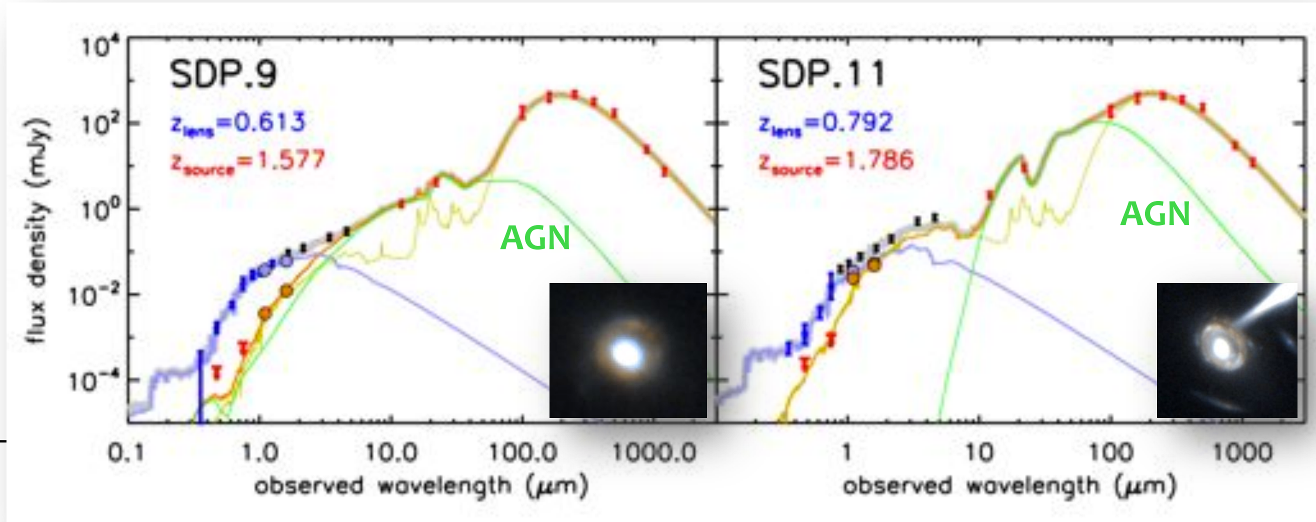
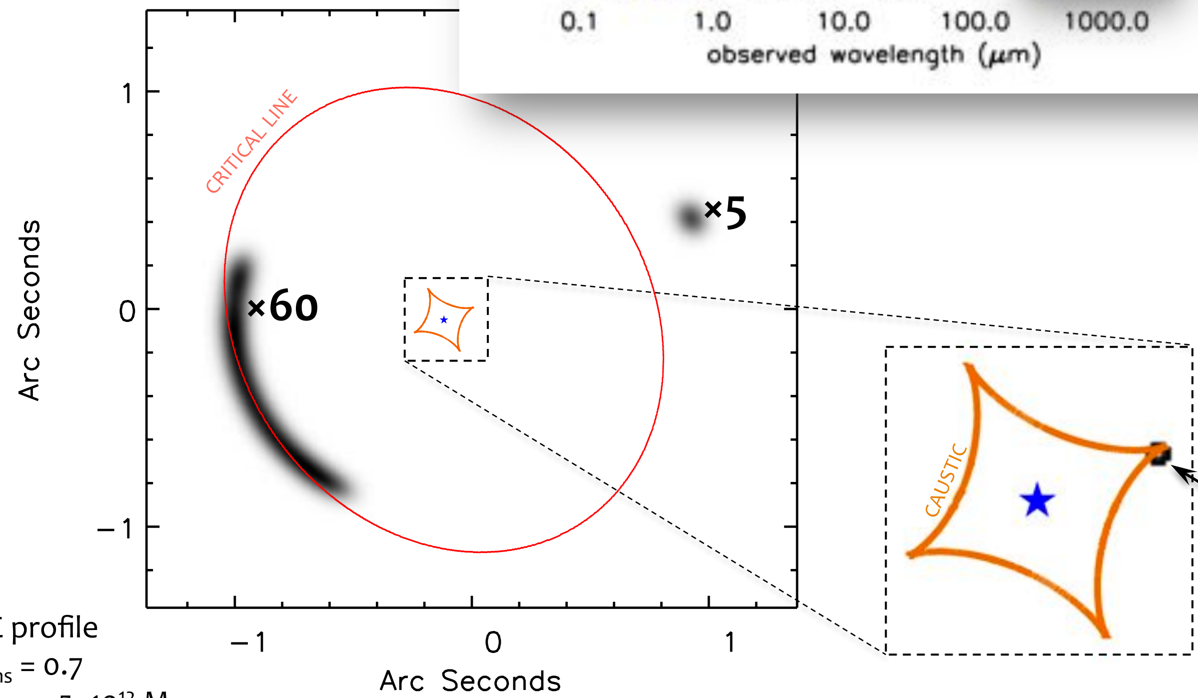
Imaging of the *reservoir*

sub-mm selected lensed galaxies

(Negrello+14)





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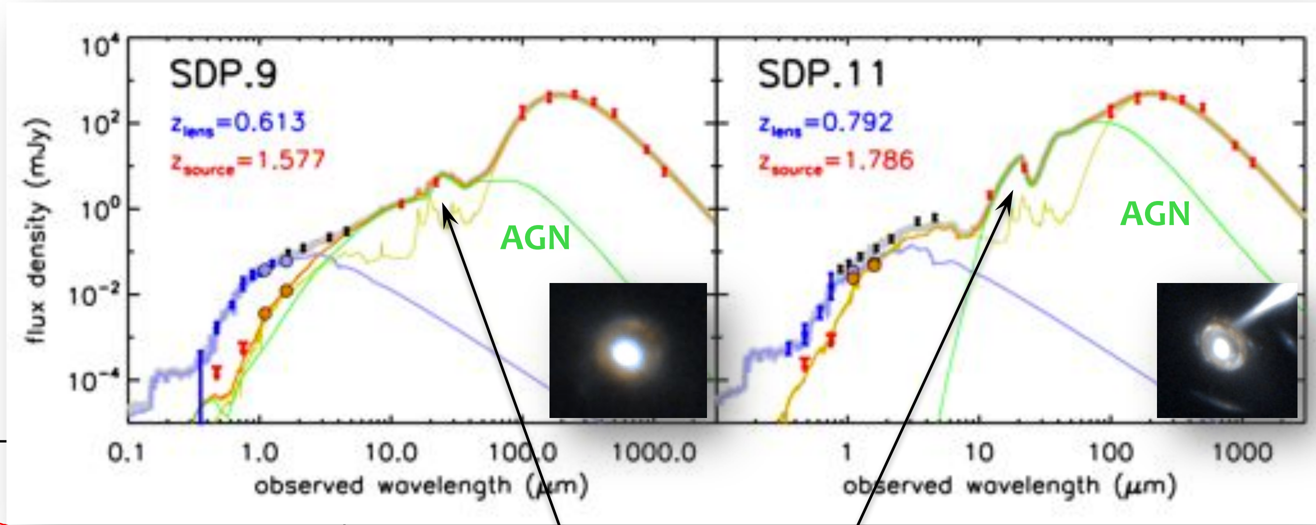
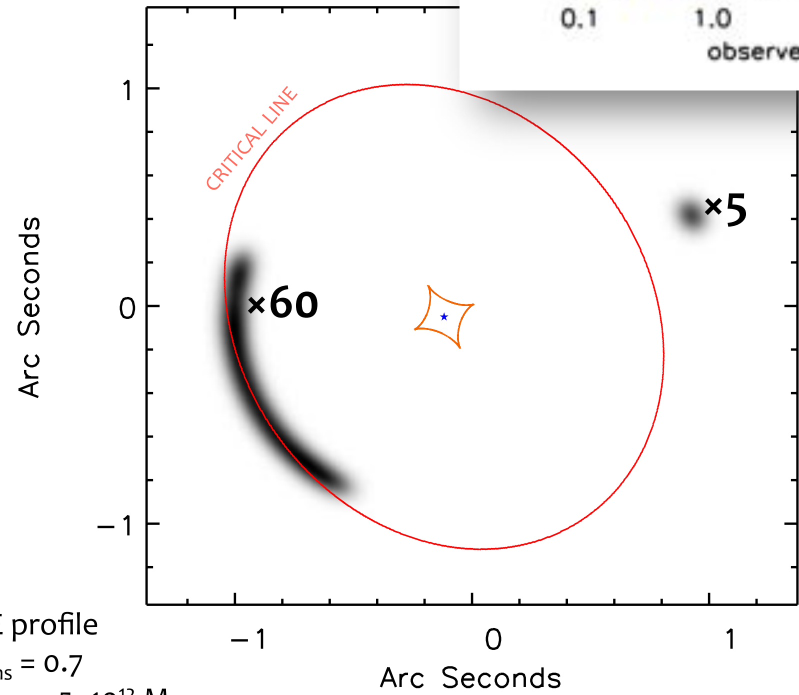


$\gtrsim$ 5 mJy @ 22 μm (WISE)

Expected sensitivity(*) (5σ in 24hrs)

3.5 – 5 mJy @ 35 – 70 μm



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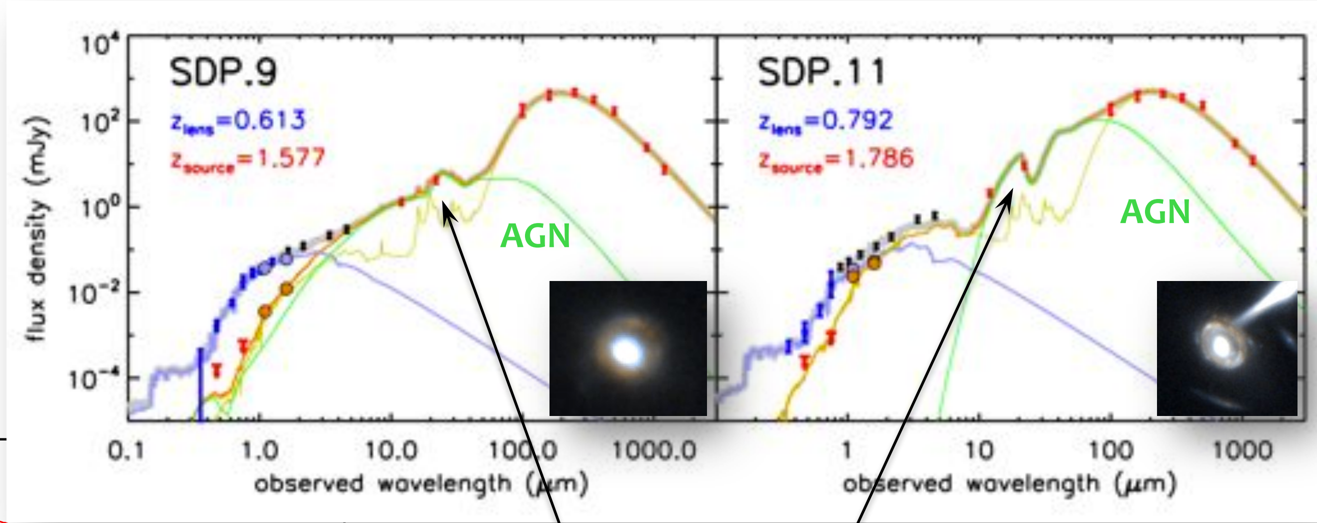

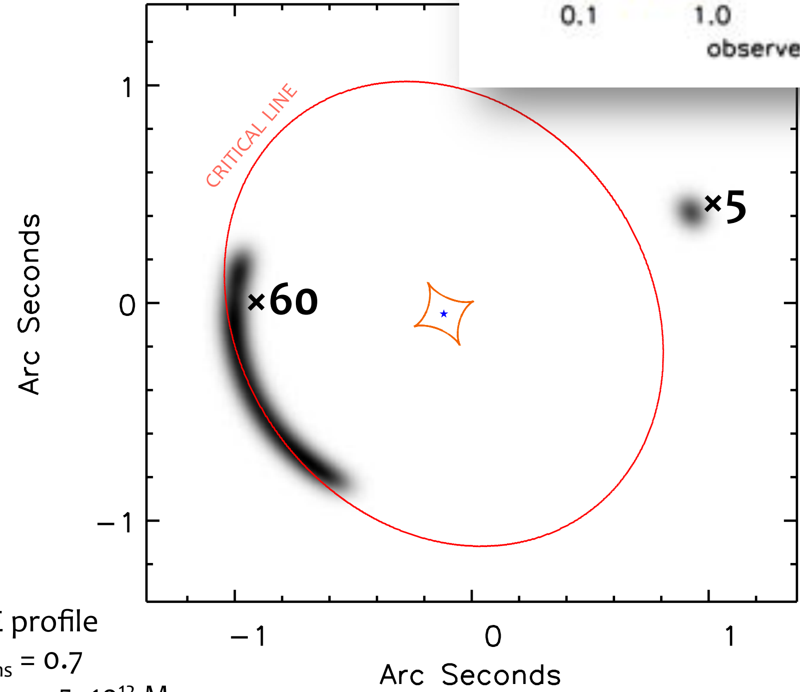

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⇒ **Need longer integration on-source**

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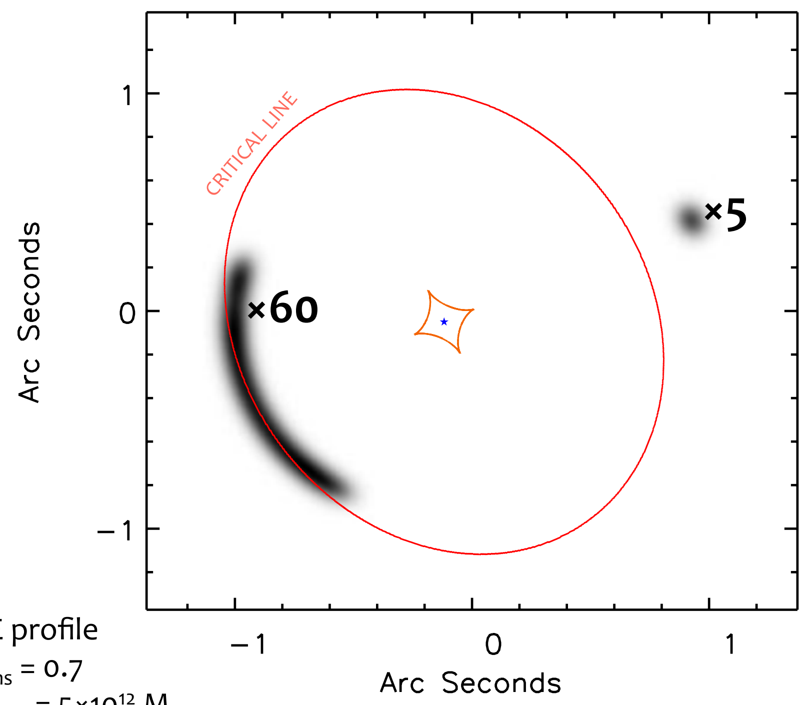
Spectroscopy

Expected line sensitivity(*)

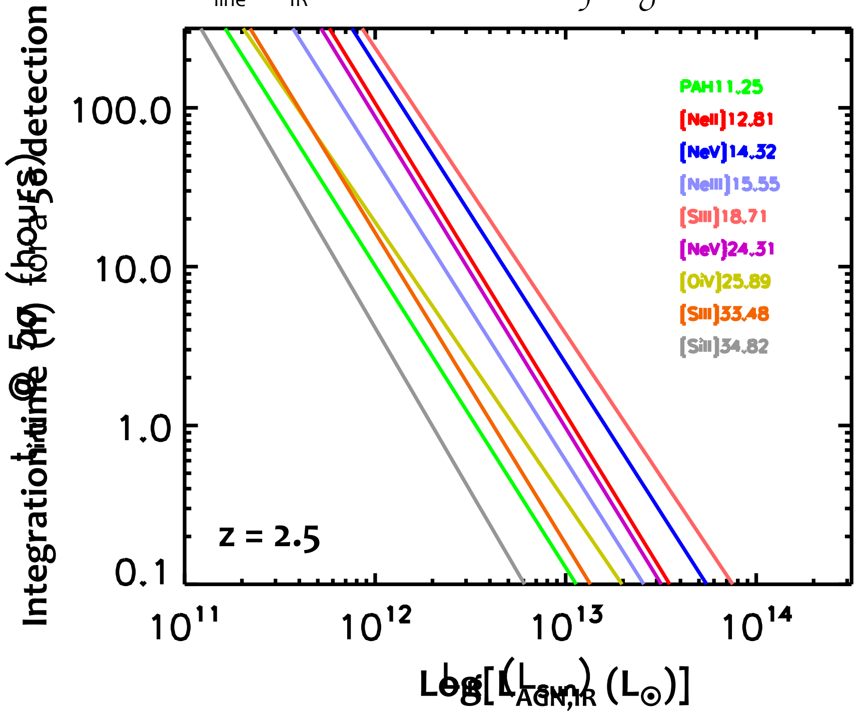
5σ in 24hrs: **(0.7 – 0.3) × 10^{-19} W/m² @ 35 – 280 μm**

(*) Far Infrared Space Interferometer Critical Assessment V2.0, 20.12.2013, by Spinoglio



SIE profile
z_{lens} = 0.7
$M_{halo} = 5\times10^{12}\ M_\odot$

$L_{line} - L_{IR}$ calibrations from *Spinoglio+12*



Conclusions

The **growth of the SMBH** in proto-spheroids @ z>1.5 is associated with the formation of a **reservoir of gas and dust**

We propose to follow-up **sub-mm/mm strongly lensed galaxies** that show a **WISE 12/22 μm "excess"** in order to resolve the reservoir and to study the AGN line emission