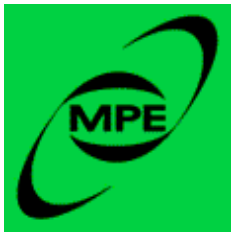
A Connection between AGN Activity and Nuclear Star Formation in Seyfert Galaxies



R. Davies[1], R. Genzel[1], L. Tacconi[1], E. Hicks[1], F. Mueller Sánchez[1], S. Friedrich[1], A. Sternberg[2]

[1] *Max Planck Institute for Extraterrestrial Physics*
[2] *University of Tel Aviv, Israel*

- black hole mass from stellar dynamics to test reverberation masses (BLR geometry) & M_{BH}-σ relation
- distribution & kinematics of molecular gas, and relation to obscuring material
- extent, intensity, & history of recent star formation and relation to AGN

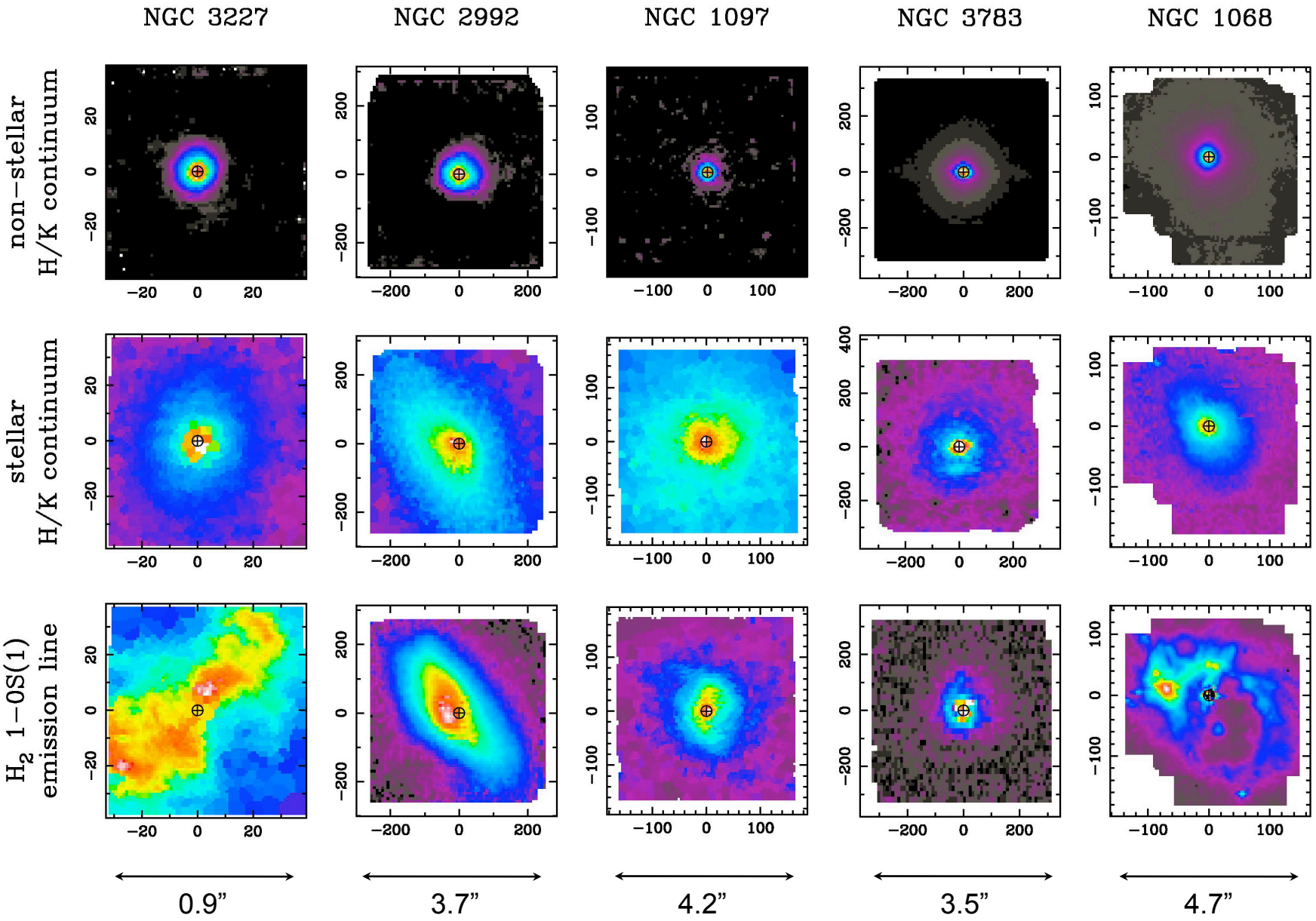
Adaptive Optics Observations of AGN with Keck & VLT

object	*type*	*Mpc*	*resolution*		
Mkn 231	ULIRG, Sy1, QSO	170	0.176”	145pc	ApJ 613, 78
IRAS 05189–2524	ULIRG, Sy1	170	0.12”	100pc	
NGC 2992	Sy1	33	0.30”	48pc	Friedrich+ in prep
NGC 3783	Sy1	42	0.18”	37pc	
NGC 7469	Sy1	66	0.085”	27pc	ApJ, 602, 148
NGC 1097	LINER, Sy1	18	0.245”	21pc	
NGC 3227	Sy1	17	0.085”	7pc	ApJ, 646, 754
NGC 1068	Sy2	14	0.085”	6pc	Mueller Sanchez+ in prep
Circinus	Sy2	4	0.22”	4pc	A&A, 454, 481

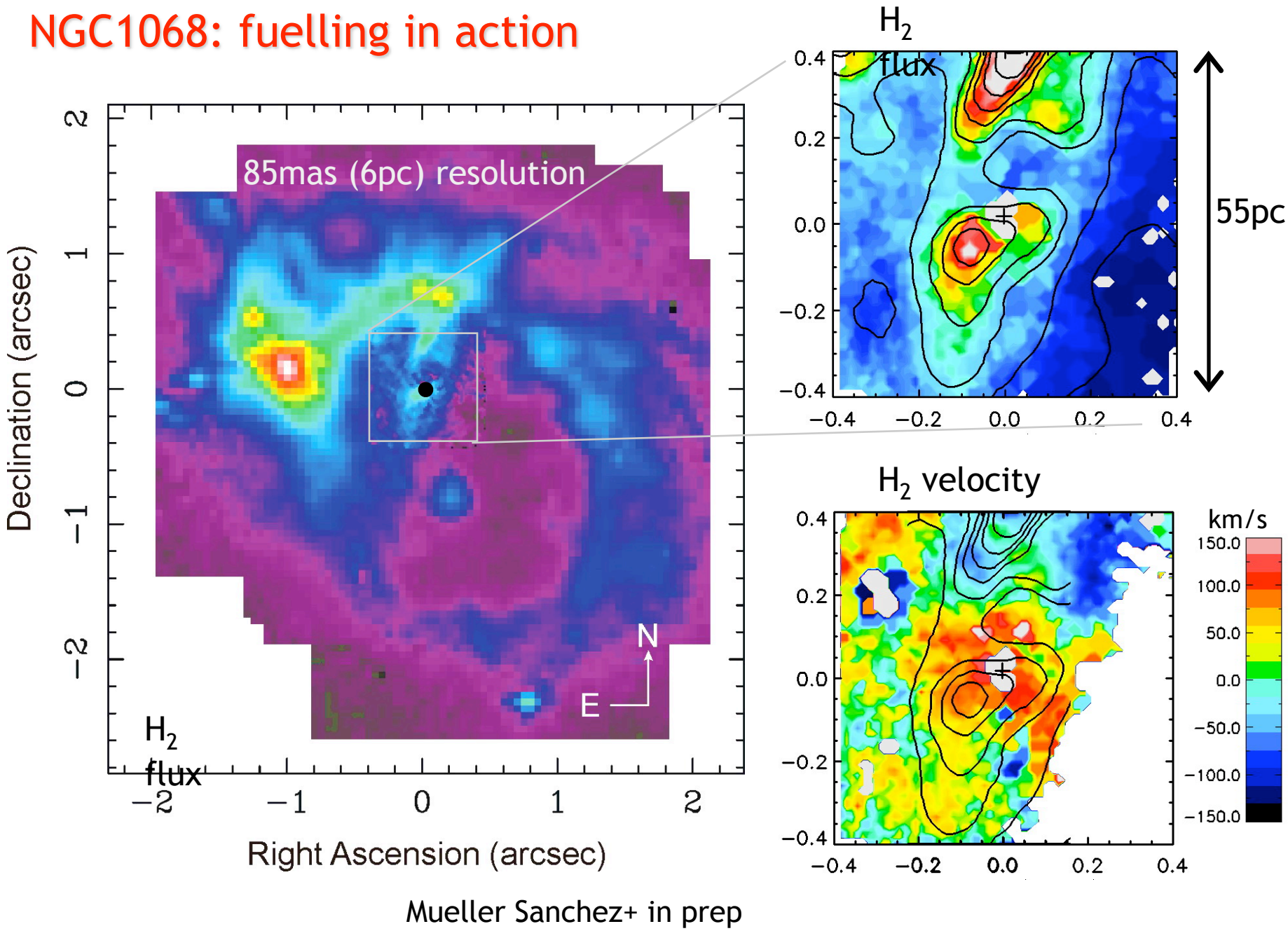
star formation: Davies+ (astroph 0704.1374)

molecular gas: Hicks+ in prep

examples of SINFONI data



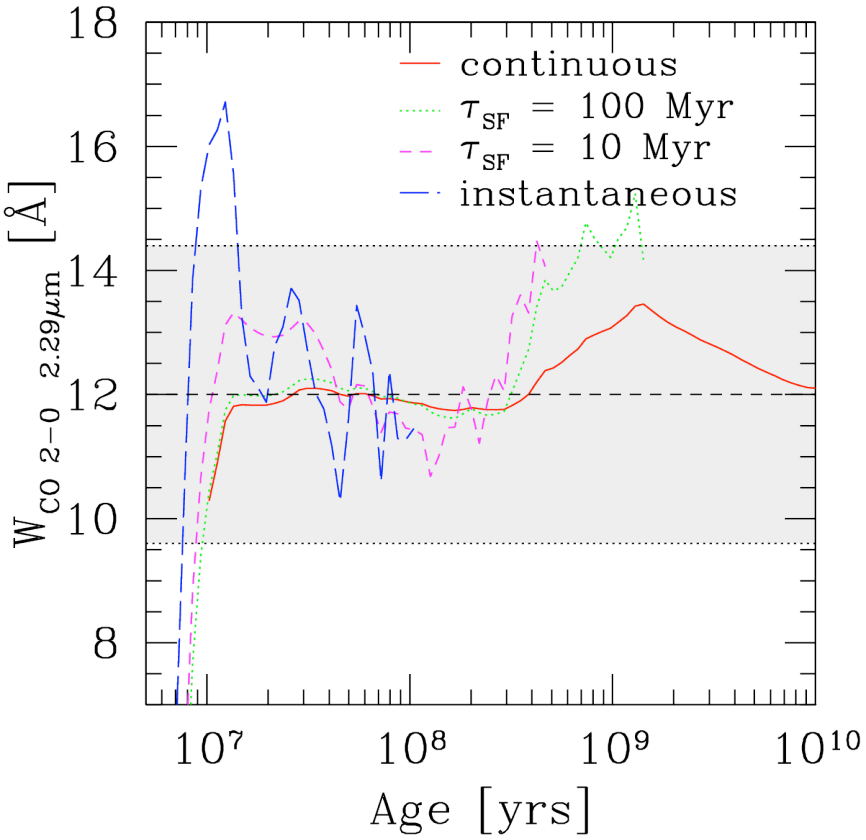
NGC1068: fuelling in action



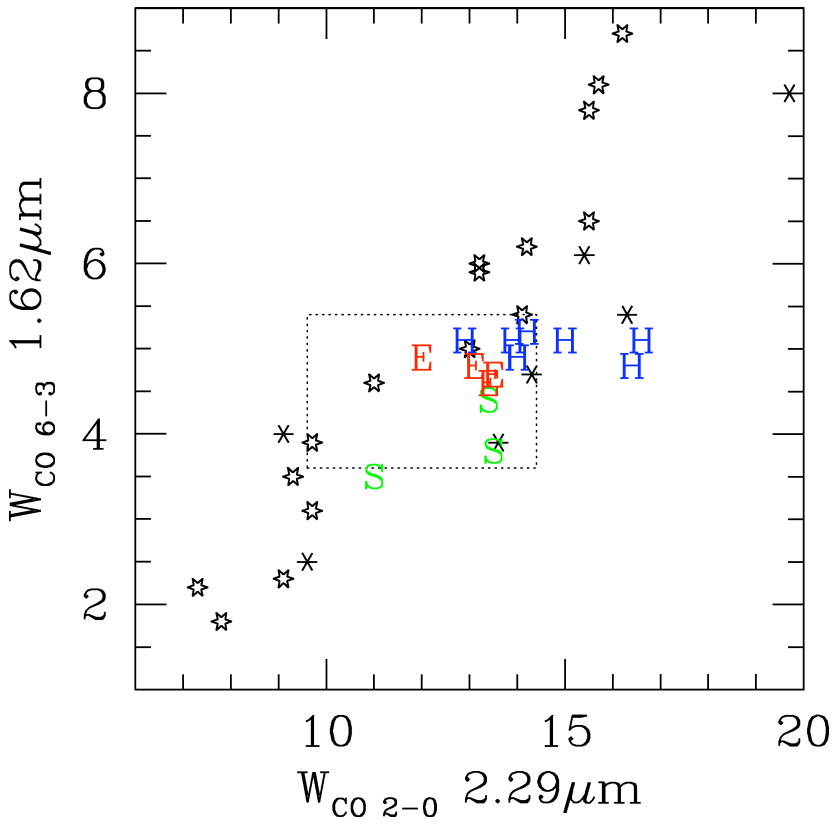
Mueller Sanchez+ in prep

CO equivalent width: stellar vs non-stellar continuum

It is possible to correct for dilution by AGN & estimate stellar continuum without knowing anything about the stellar population



STARS stellar cluster models
W_{CO6-3} ~ 4.5Å & W_{CO2-0} ~ 12Å

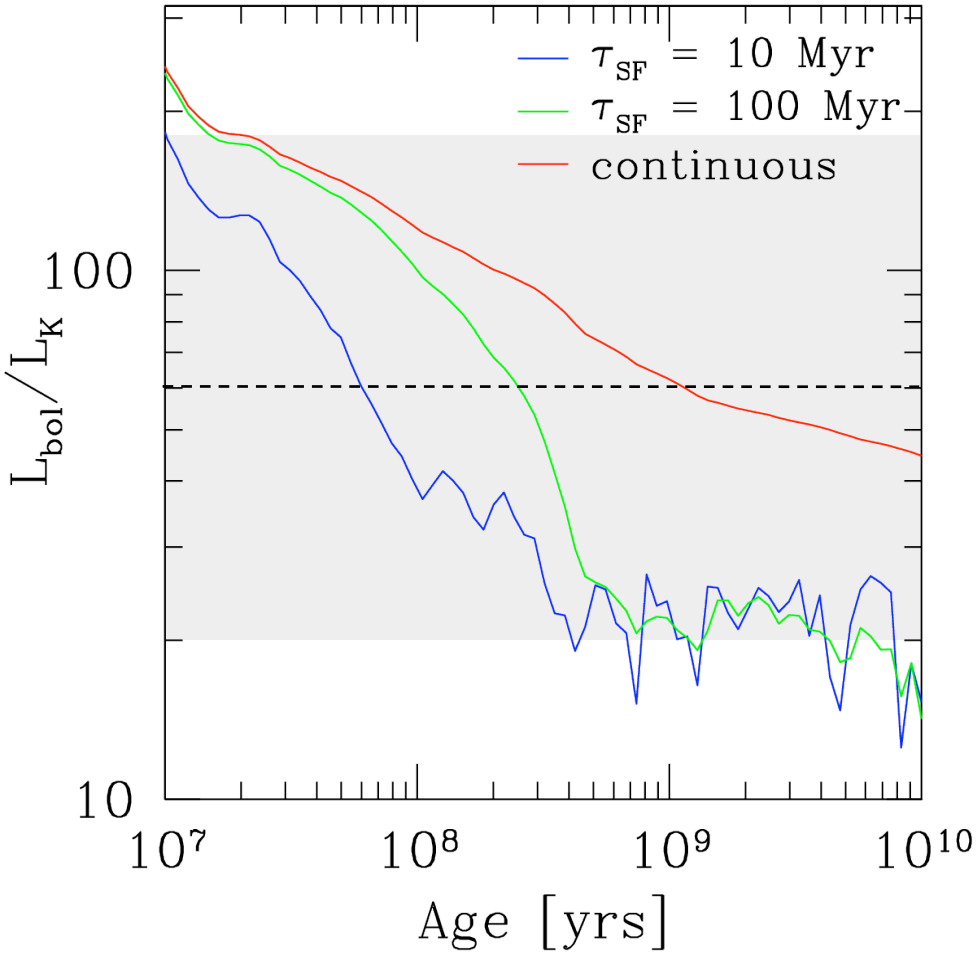


adapted from Oliva et al. 1995

Stellar Bolometric Luminosity

Estimating stellar bolometric luminosity is simple and robust

For the stellar continuum, it is possible to estimate L_{bol} from L_K to within a factor of 3 without knowing anything about the star formation history



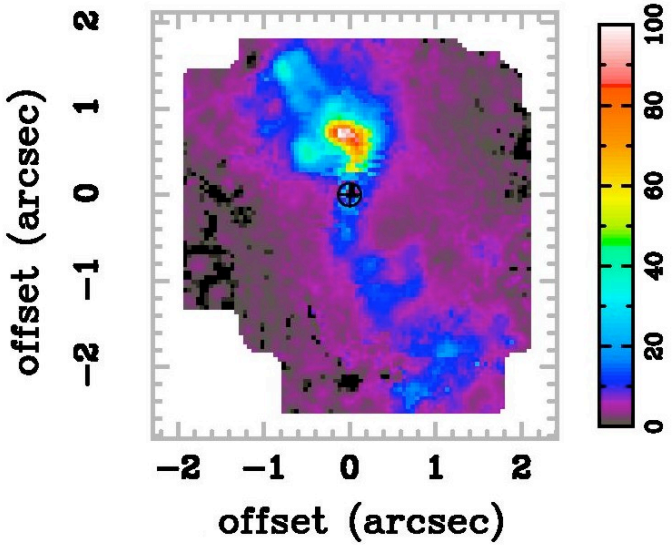
STARS stellar cluster models

Star Formation Diagnostics

Brγ equivalent width

- correct Brγ for AGN contribution (e.g. NLR, jet) through morphology & kinematics
- ratio to *stellar* continuum

NGC1068 **Brγ equivalent width**

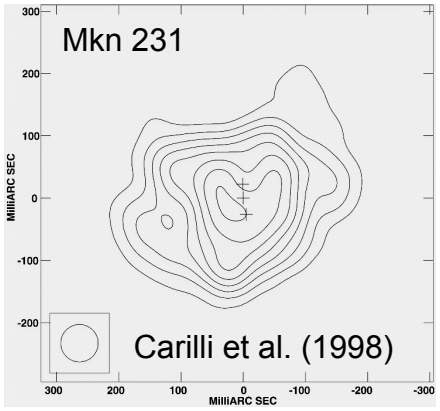


mass-to-light ratio

- use spatially resolved kinematics (V_{rot} & σ) to estimate dynamical mass
- correct L_K for non-stellar continuum
- gives upper limit to M/L_K for most recent star formation

radio continuum (supernova rate)

- resolved continuum with low T_B probably star formation
- correct flux for unresolved point source associated with AGN, and also for any jet contribution
- estimate supernova rate



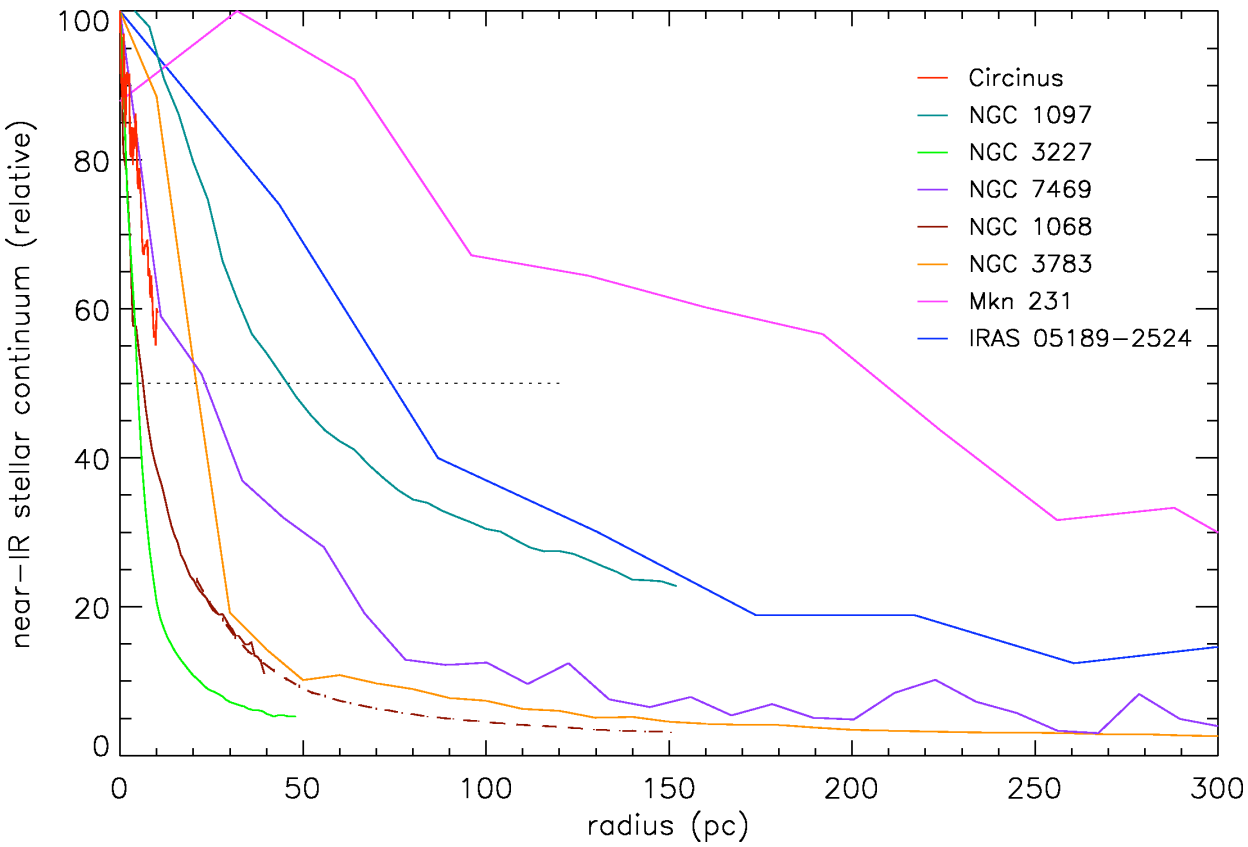
0.06” beam
source size 0.44×0.31”

Star Formation Size & Age

nuclear stellar continuum resolved in all cases

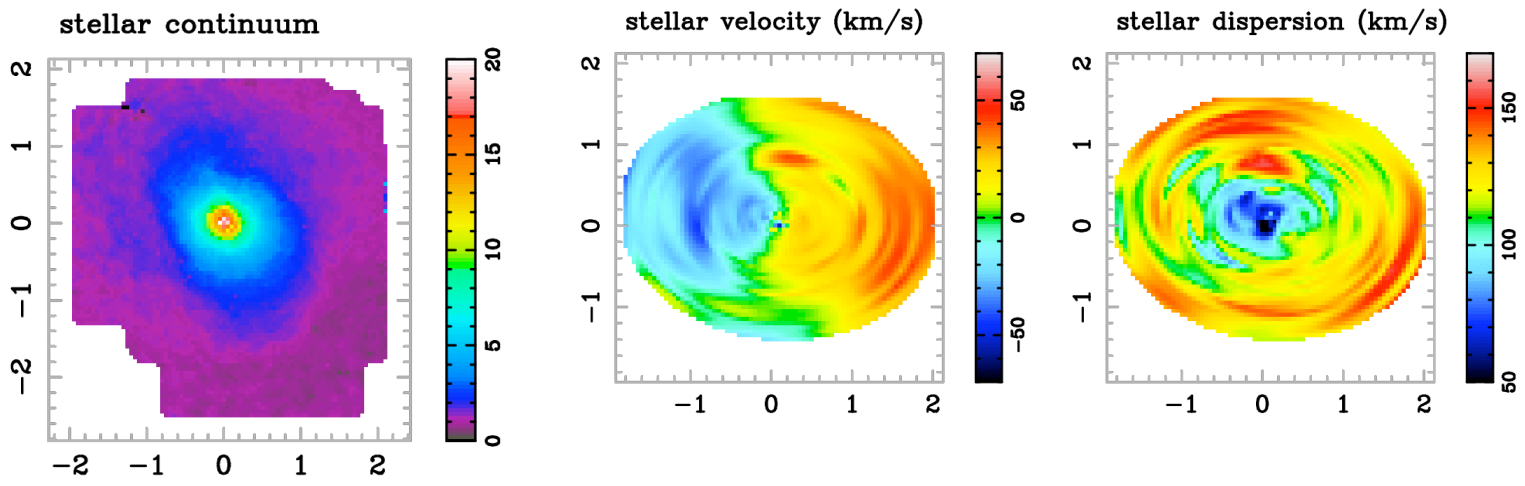
age is 10-300 Myr

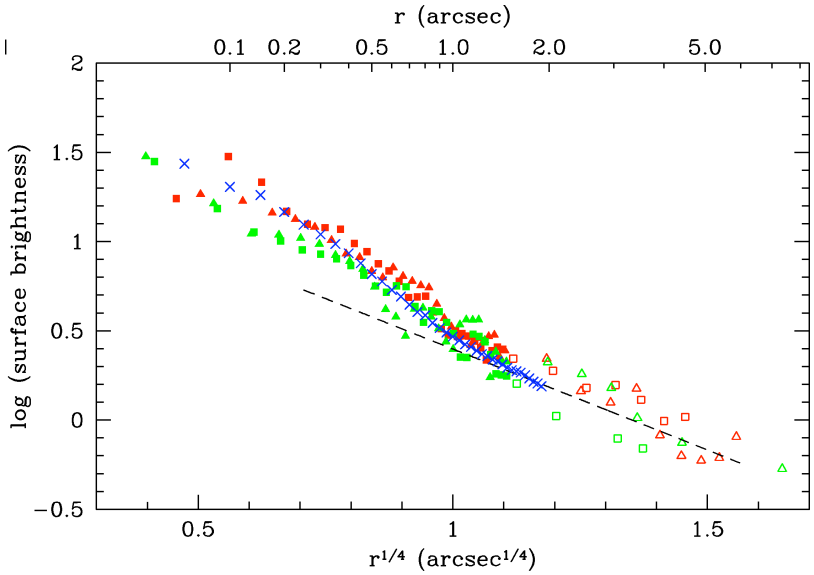
but low $W_{Br\gamma}$ means star formation is no longer active



Cid Fernandes+ 04: central ~200pc of 79 nearby Seyfert 2s; 1/3-1/2 have experienced significant star formation in last few hundred Myr

Star Formation occurs in Nuclear Disks





nuclear disk in NGC1068:

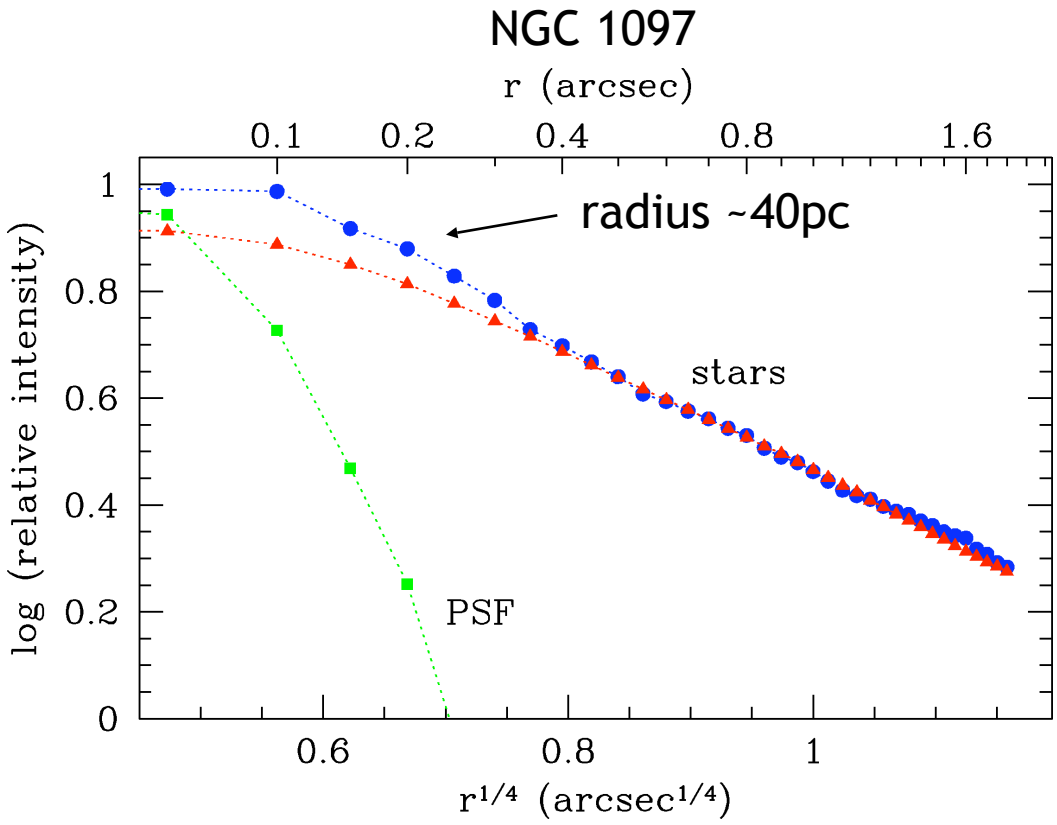
detected to	~70 pc
mass	~1.2×10^8 M_{sun}
scale height	~6 pc

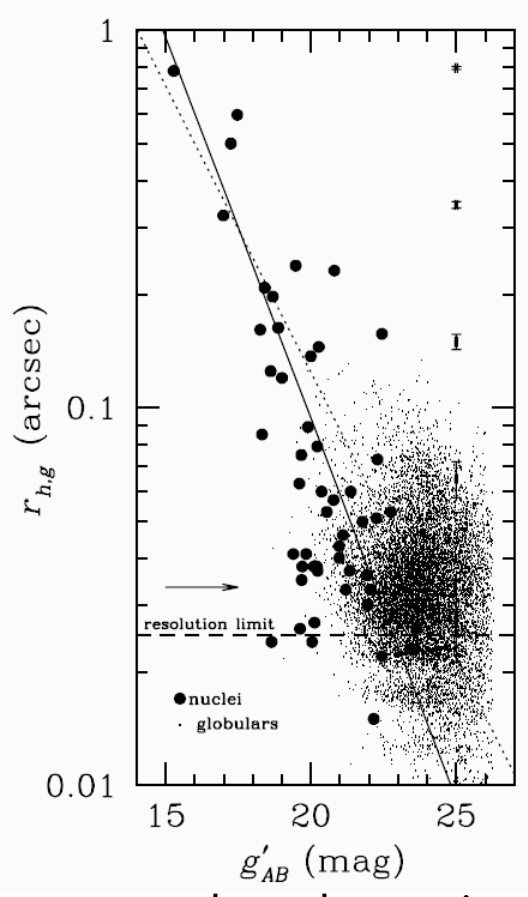
Kinematic evidence (σ-drops) for nuclear disks is seen in ~30% of spiral galaxies (Ganda+06, Emsellem 07)

Are Nuclear Disks related to Nuclear Clusters?

Nuclear Clusters seen with HST in 70%-90% of all galaxies, with sizes 2-60pc
(Carollo+98, Böker+02, Graham+03, Lotz+04, Grant+05, Ferrarese+07)

ages 10Myr to 10Gyr, masses 10^5-$10^8 M_{sun}$
(Walcher+05,06 Rossa+06)





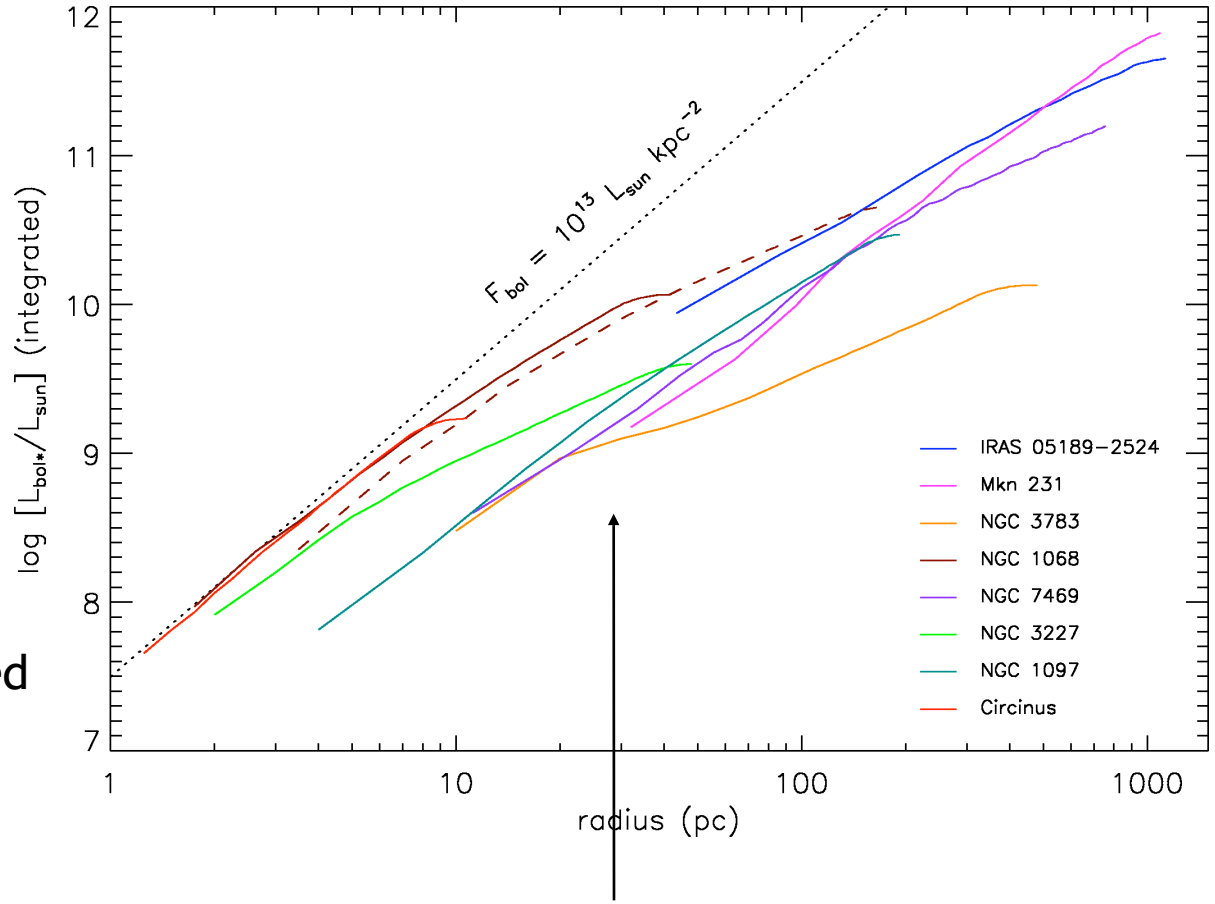
nuclear clusters in early type galaxies (Ferrarese+ 07)

Stellar Bolometric Luminosity

starbursts are close to being Eddington limited

e.g. M51 star clusters and Arp 220 (Scoville 03)

e.g. radiatively supported starburst models (Thompson et al. 05)

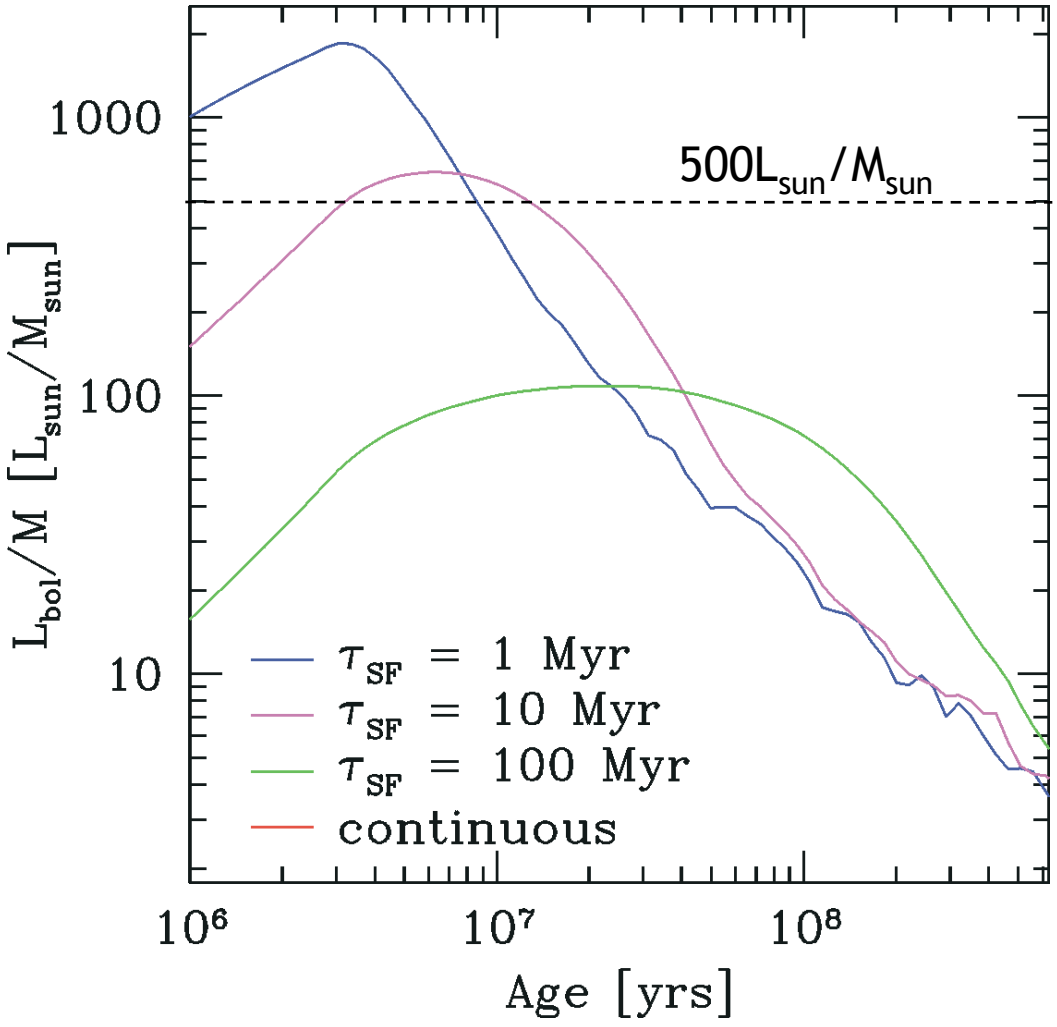


note: $500L_{sun}/M_{sun} \sim 10^{13}L_{sun}/kpc^2$ for $\Sigma=2\times10^4 M_{sun}/pc^2$

What does it take for a starburst to be Eddington limited?

If gas is present at the beginning, then star formation time scale must be of order ~10Myr

this is consistent with the star forming timescales implied by the data

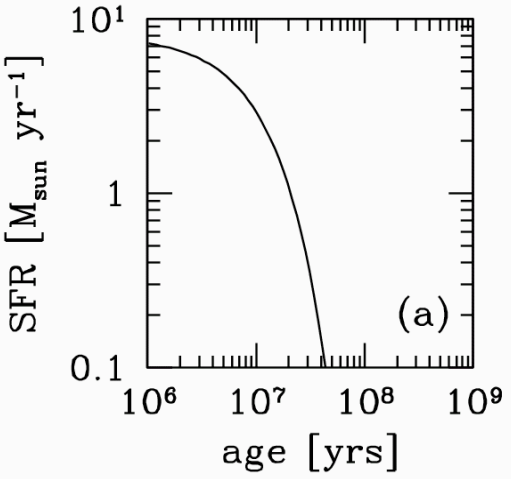


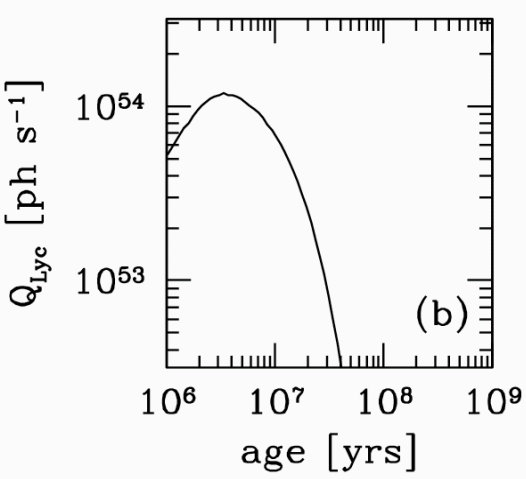
STARS stellar cluster models

How much higher was the stellar luminosity?

STARS illustrative stellar cluster model:
for recent star formation which is no longer active, the luminosity was of order 10 times higher in the past

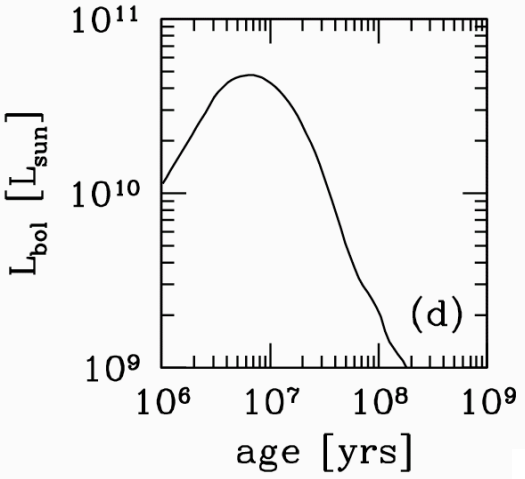
exponentially decaying star formation rate, τ_{SF}=10Myr

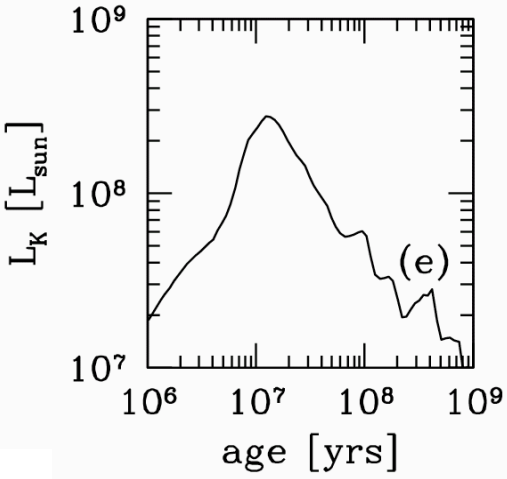




Brγ flux drops rapidly

normalisation set by L_{bol} =2×10^9L_{sun} at 100Myr





L_K similar to L_{bol}

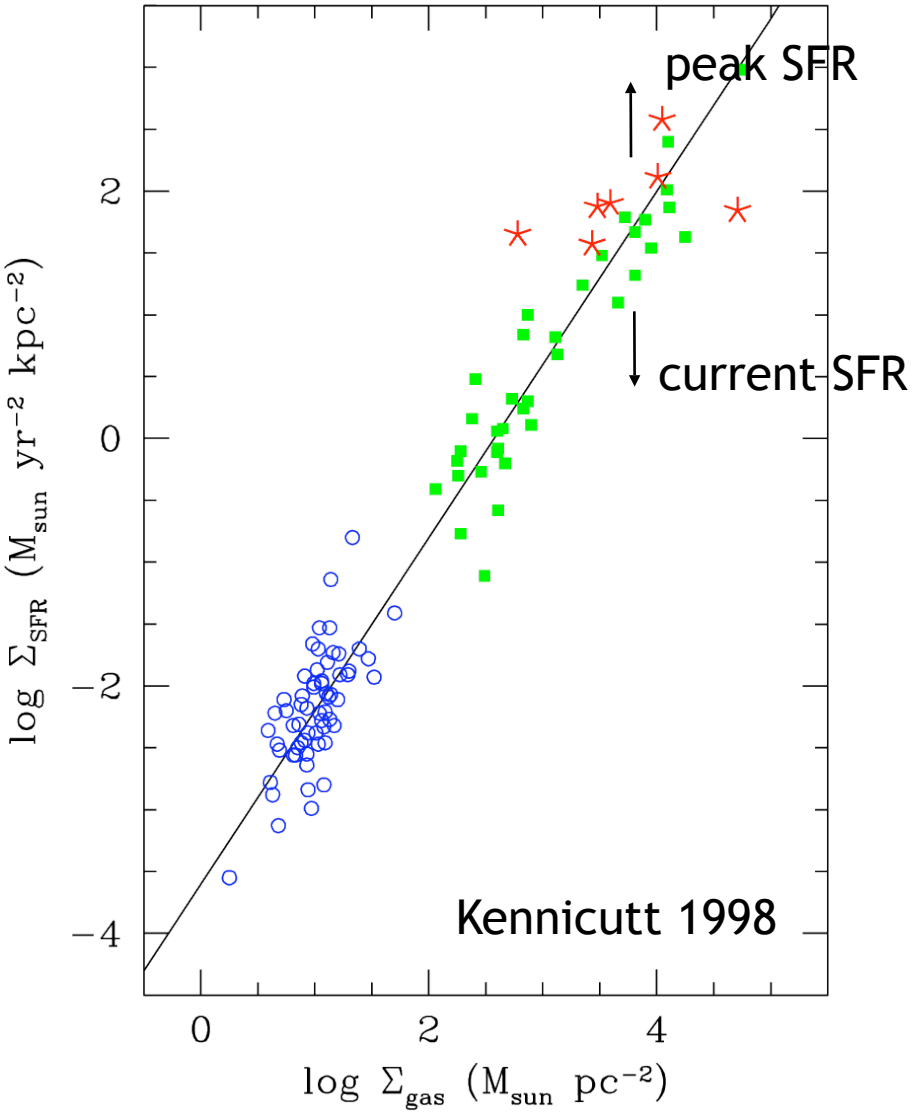
Why should the Star Formation Rate be so High?

Nuclear starbursts lie on the Kennicutt Schmidt law

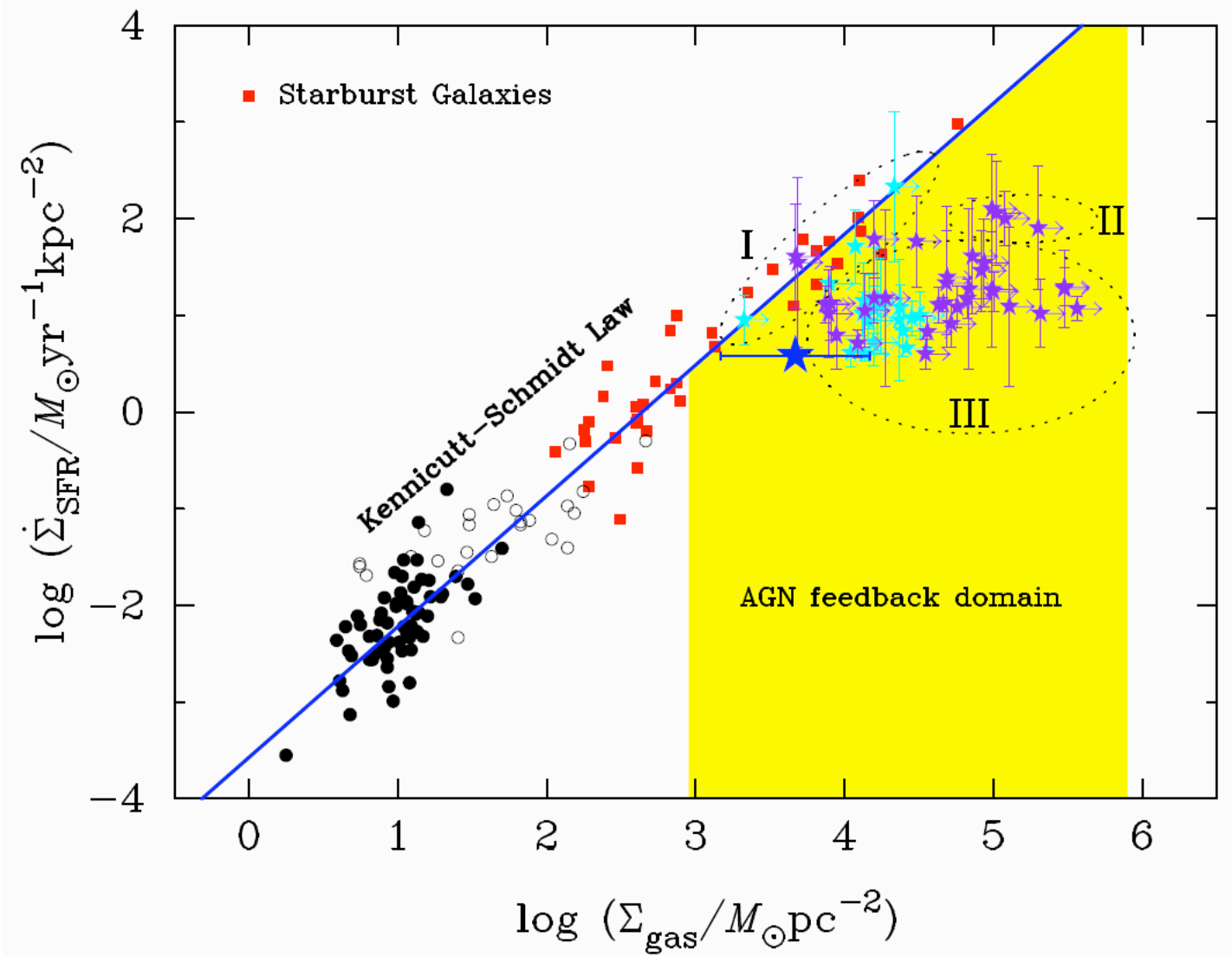
$\Sigma_{SFR} = 2.5\times10^{-4}\ \Sigma_{gas}^{1.4}$

when SFR is time averaged and 30% of dynamical mass is attributed to gas.

SFR is high because the gas surface mass density is high. As a result the star forming efficiency is also high.



Why should the Star Formation Rate be so High?



Wang et al. 2007

‘Galaxies in Zone III are undergoing suppressed star formation’

A Scenario for Star Formation around AGN

- Gas accumulates in central 100pc
- Region cannot form stars due to high turbulence (Toomre criterion, $Q=\sigma\kappa/\pi G\Sigma$) [Erin Hicks, short talk]
- Eventually, the high gas density leads to a high star formation rate
- Starburst is Eddington limited, generating a huge radiation pressure
- Because the efficiency is high, the starburst is short lived
- Starburst fades and is then dormant until gas is replenished

… but how is star formation related to the torus & the AGN?

Relation of Star Formation to Molecular Gas

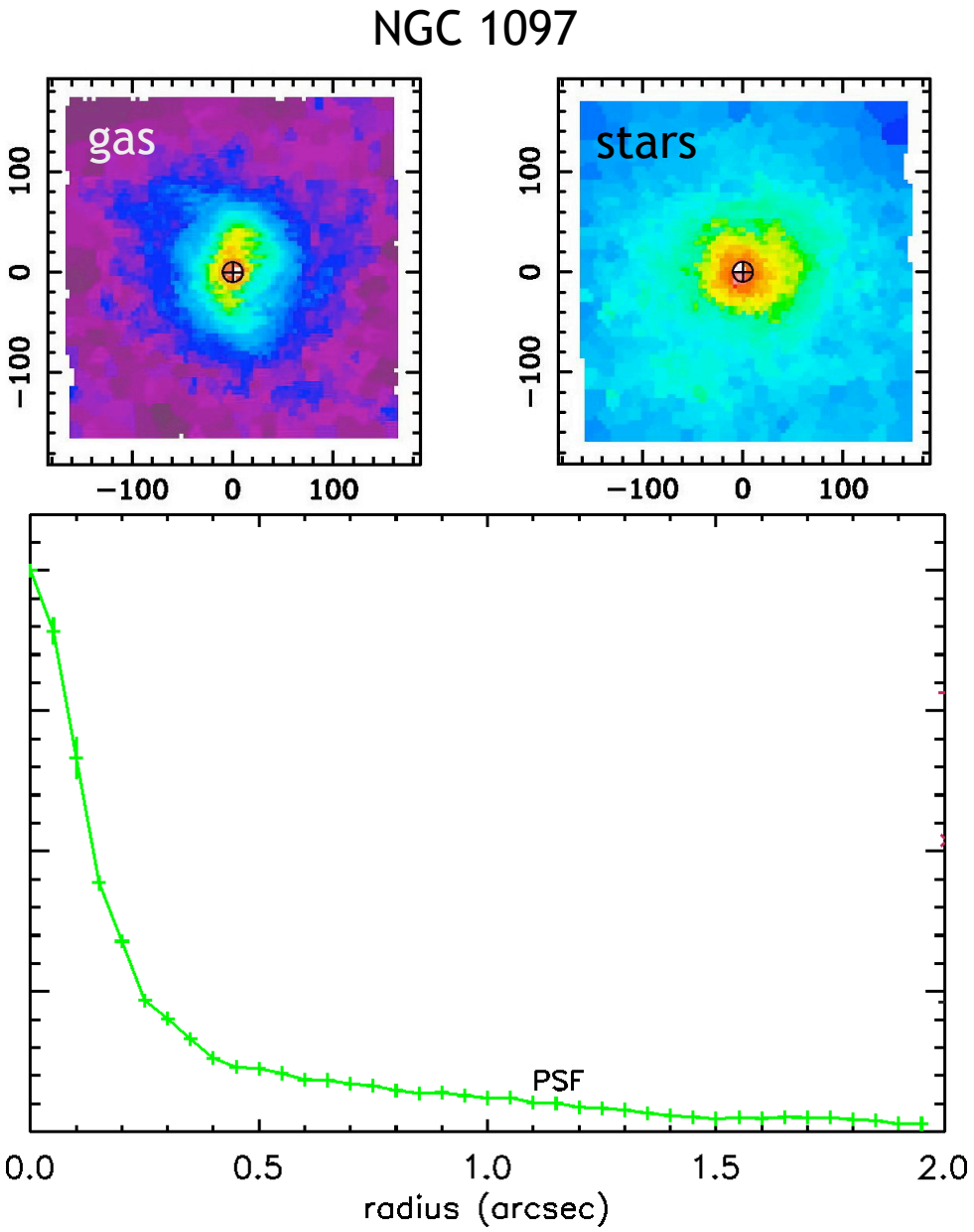
(Erin Hicks, short talk)

in general, gas
- is centrally concentrated
- has high dispersion (vertically extended)
- has high column density

these are the properties of an obscuring torus

kinematics of stars & gas are similar at r<0.5”

i.e. gas & stars are mixed



Relation of Star Formation to Molecular Gas

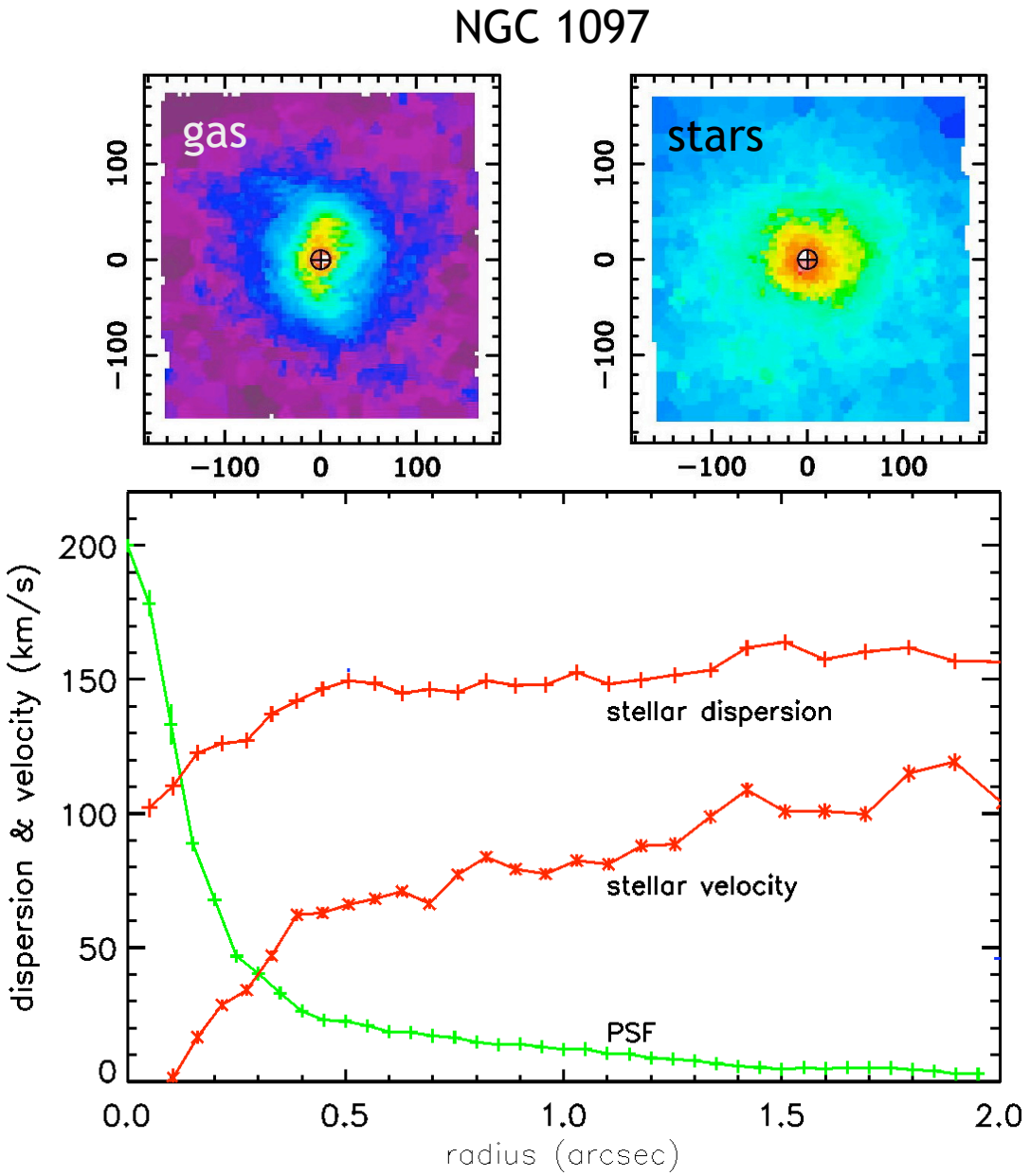
(Erin Hicks, short talk)

in general, gas
- is centrally concentrated
- has high dispersion (vertically extended)
- has high column density

these are the properties of an obscuring torus

kinematics of stars & gas are similar at r<0.5”

i.e. gas & stars are mixed



Relation of Star Formation to Molecular Gas

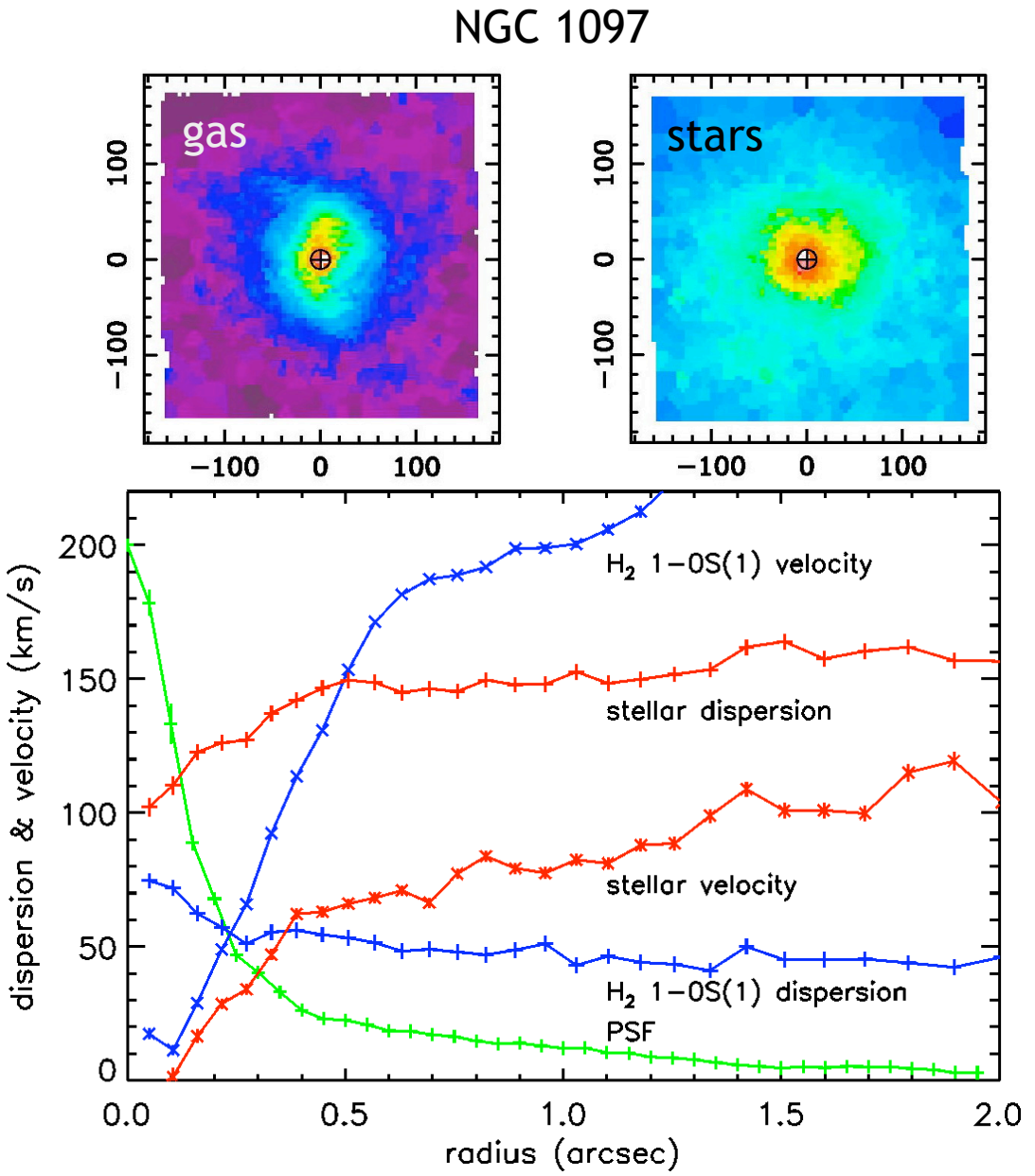
(Erin Hicks, short talk)

in general, gas
- is centrally concentrated
- has high dispersion (vertically extended)
- has high column density

these are the properties of an obscuring torus

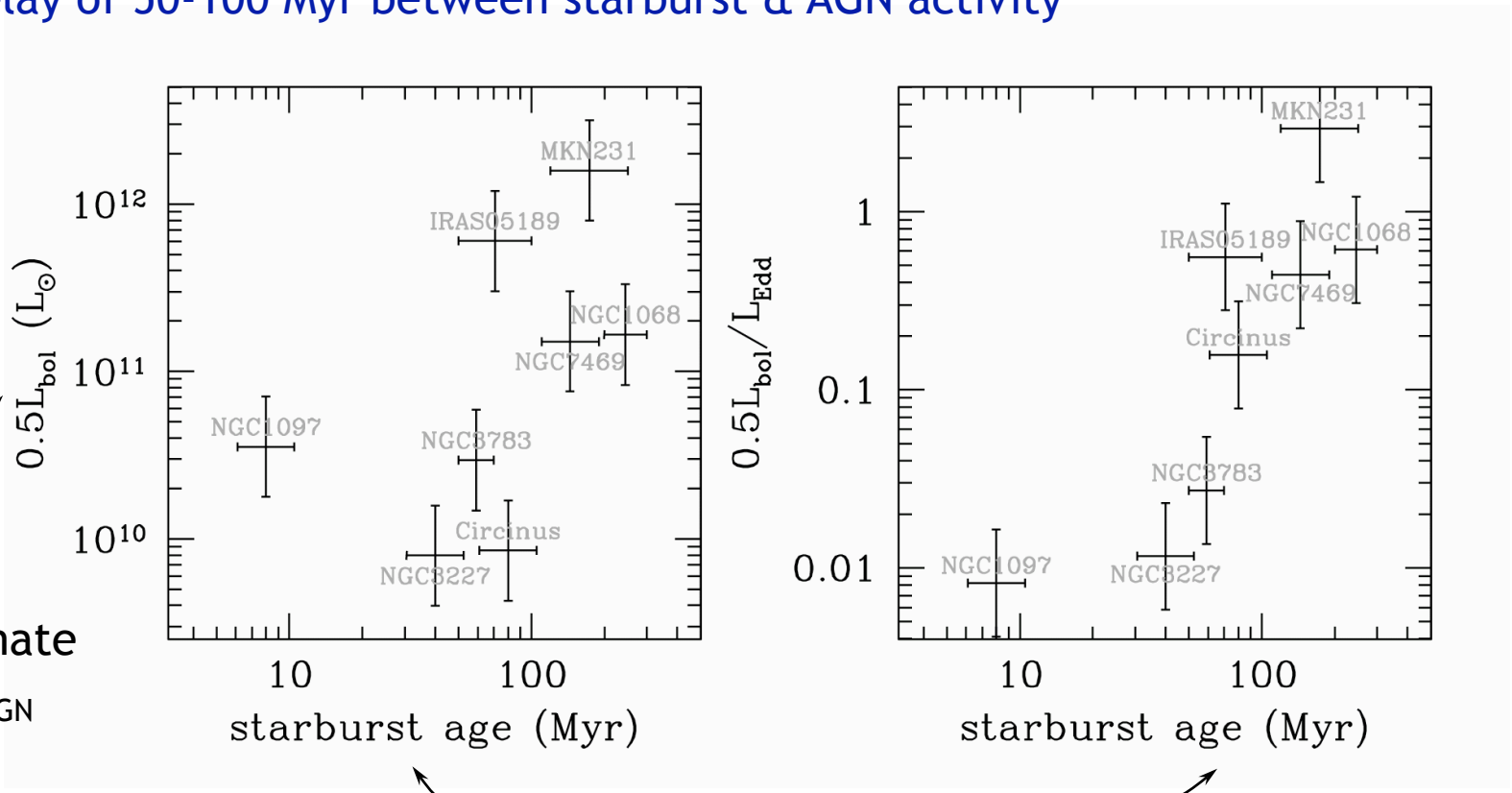
kinematics of stars & gas are similar at r<0.5”

i.e. gas & stars are mixed



Starburst – AGN connection

Delay of 50-100 Myr between starburst & AGN activity



estimate of L_{AGN}

best estimate of time since most recent star forming episode began

Starburst – AGN connection

What role do stellar ejecta play in fuelling the black hole?

OB stars

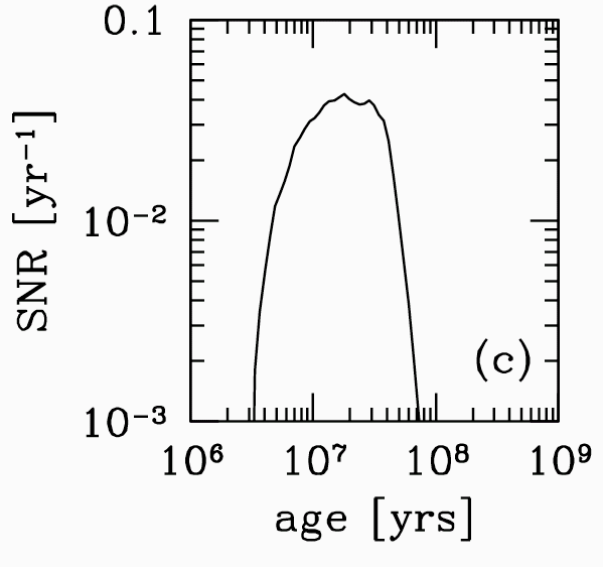
significant mass loss, but at speeds of ~1000km/s and only for a short time;

in Galactic Centre, winds are partially responsible for stopping accretion (Ozernoy+96,97, Cuadra+06)

supernovae

~10^6 SNe, each ejecting ~$5M_{sun}$ at ~5000km/s;

most likely outcome is a superwind rather than accretion



SNe occur at starburst ages of 10-50Myr, and probably play a role in delaying the fuelling of the black hole

STARS illustrative stellar cluster model

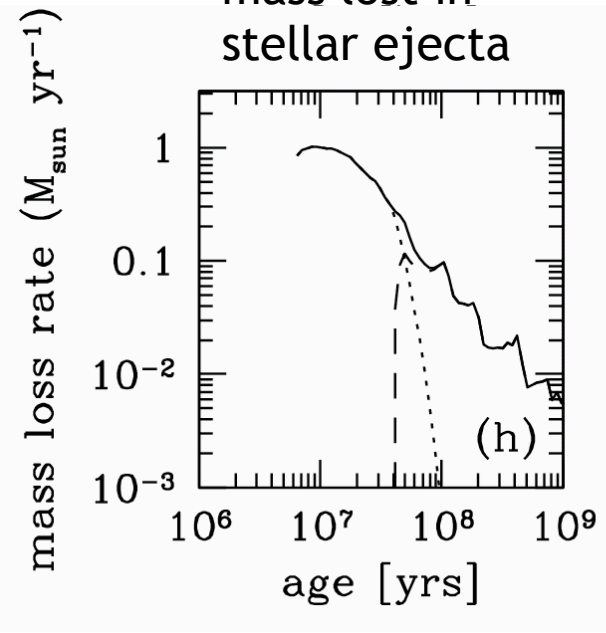
Starburst – AGN connection

What role do stellar ejecta play in fuelling the black hole?

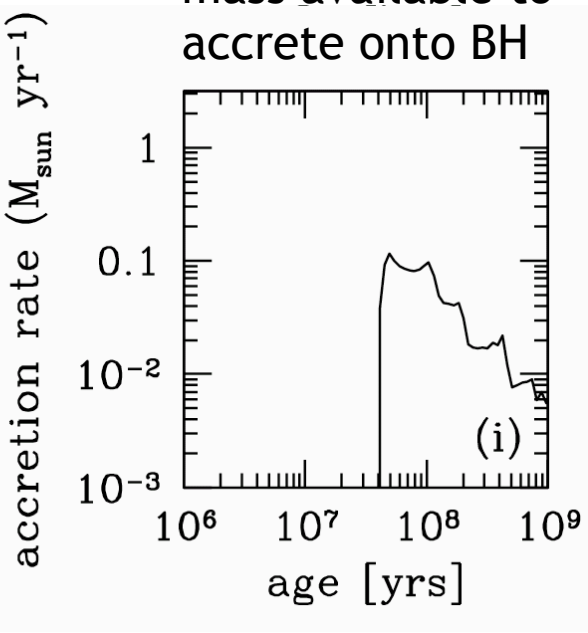
AGB stars

stars of 1-8M_{sun} reach AGB phase after ~50Myr;
winds have speeds of 10-30km/s and remain bound;
mass available >0.02M_{sun}/yr over timescale of 50-200Myr;
total mass ~2×$10^7 M_{sun}$ over 1Gyr

mass lost in stellar ejecta



mass available to accrete onto BH



STARS illustrative stellar cluster model

Summary

- adaptive optics integral field spectroscopy of AGN,
  with spatial resolution to better than 10pc
- detailed morphologies & kinematics of molecular gas and stars
- star formation:
  - recent, intense, short lived starbursts in central few 10s of pc
  - stars & gas are mixed – starburst occurs in the molecular torus
  - delay between starburst activity & AGN activity
  - AGN accretion probably delayed by supernovae and fuelled by winds from AGB stars