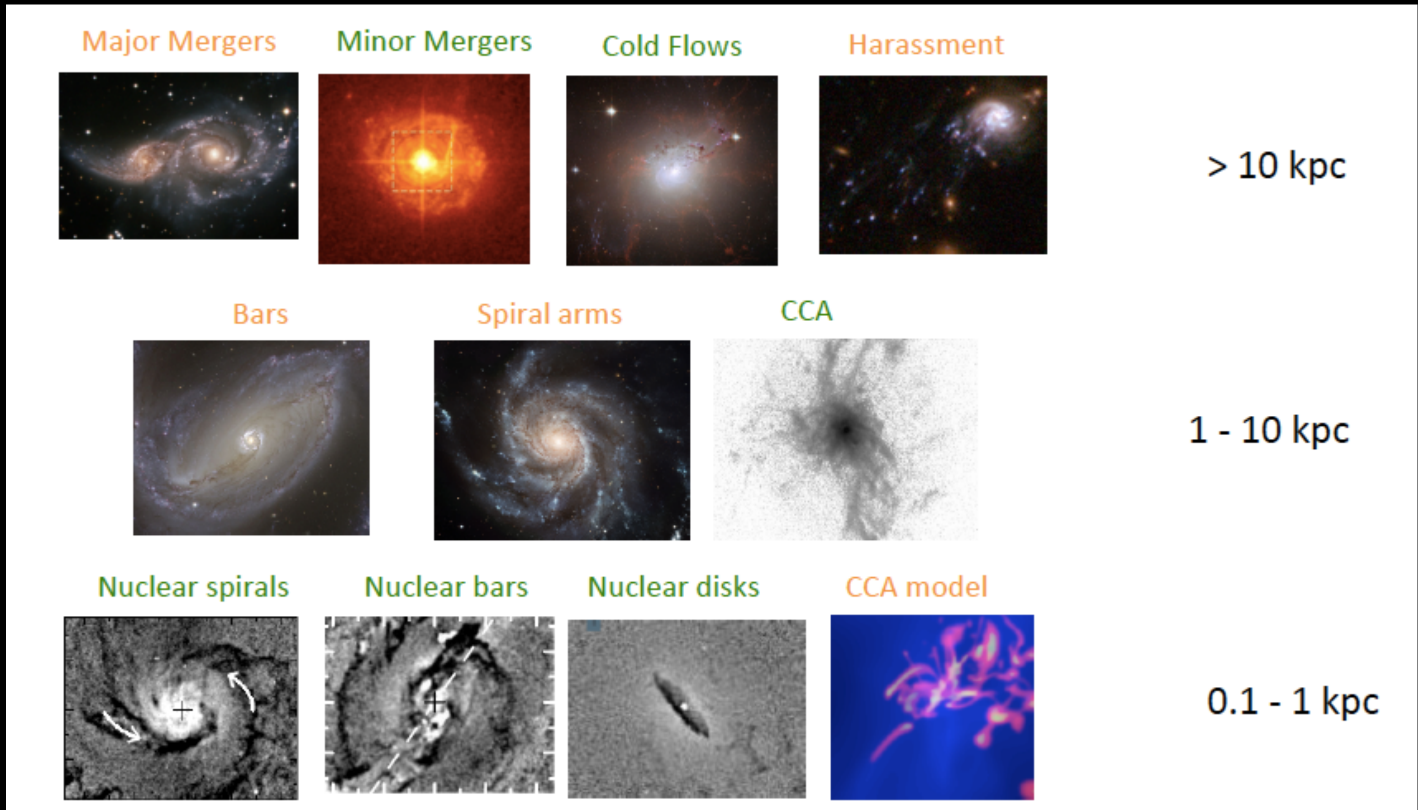

The feeding of Supermassive Black Holes

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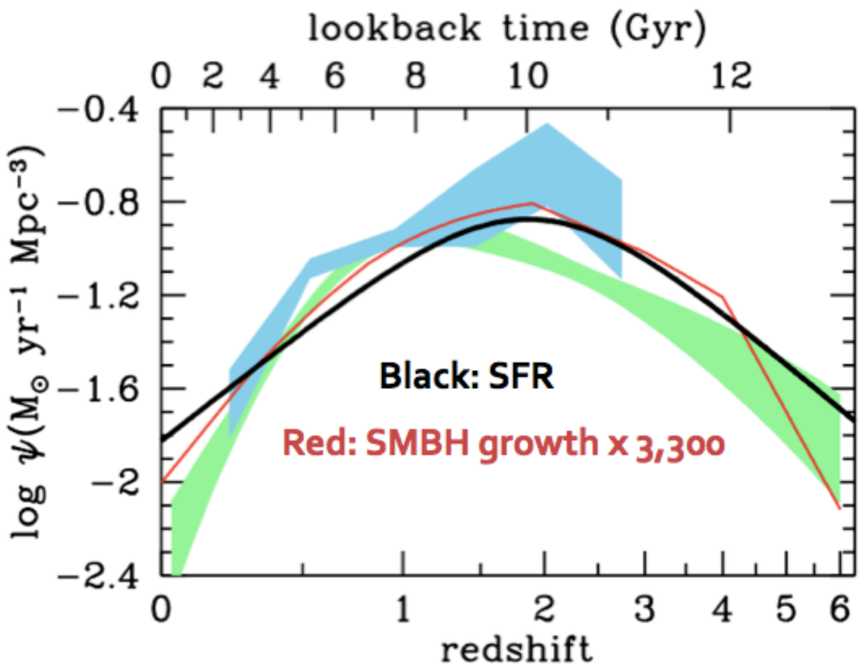
Overview

- Why AGN are important?
- What is necessary: gas
- How AGN get their gas?
  - Extragalactic scales: major and minor mergers, CCA
  - 100 pc – 1 kpc scales: nuclear spirals, bars and disks
- Summary

Are AGN important?

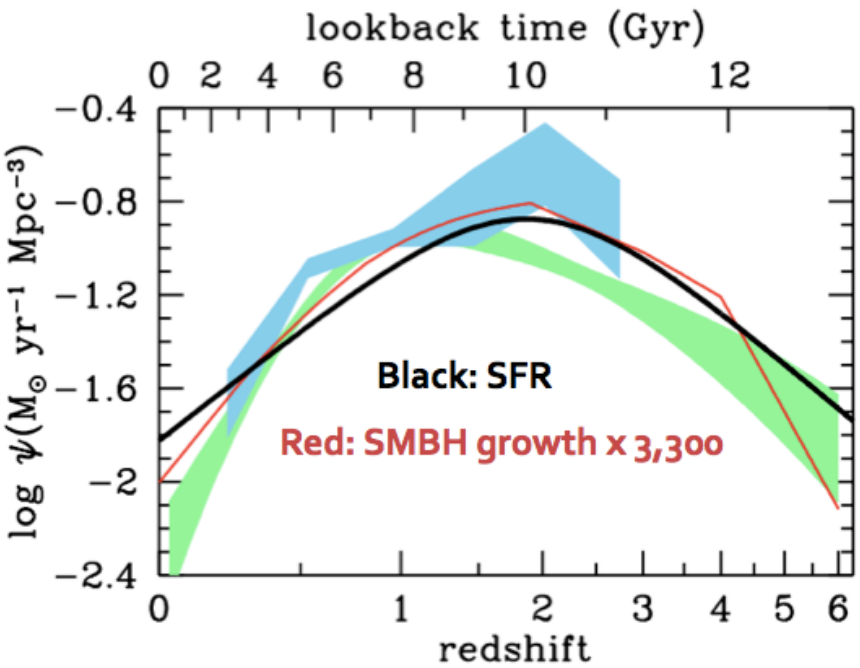
Madau & Dickinson 2014:

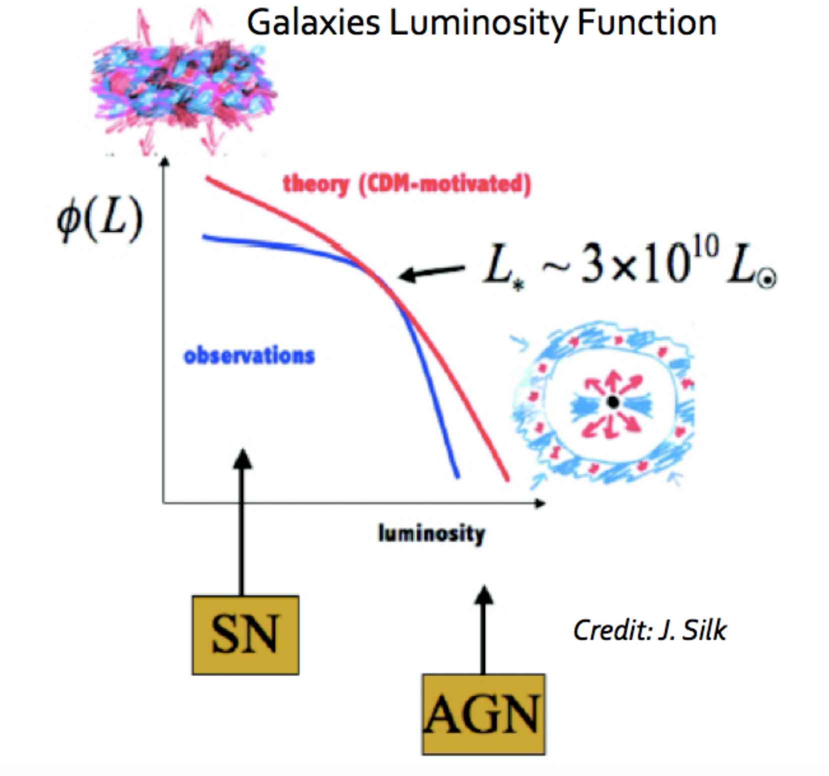


They are there, making SMBHs grow
"in tandem" with the host galaxies

Are AGN important?

Madau & Dickinson 2014:

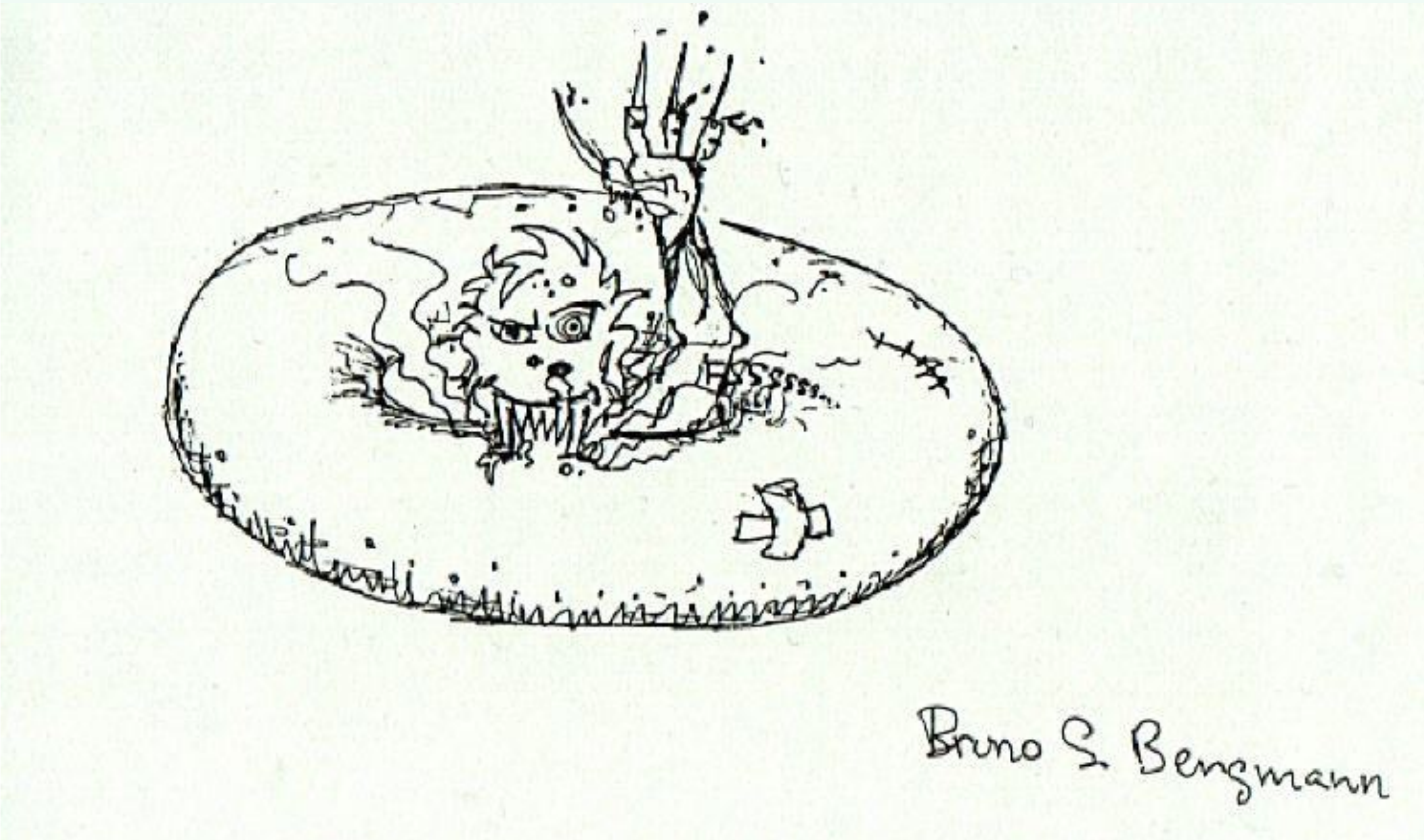




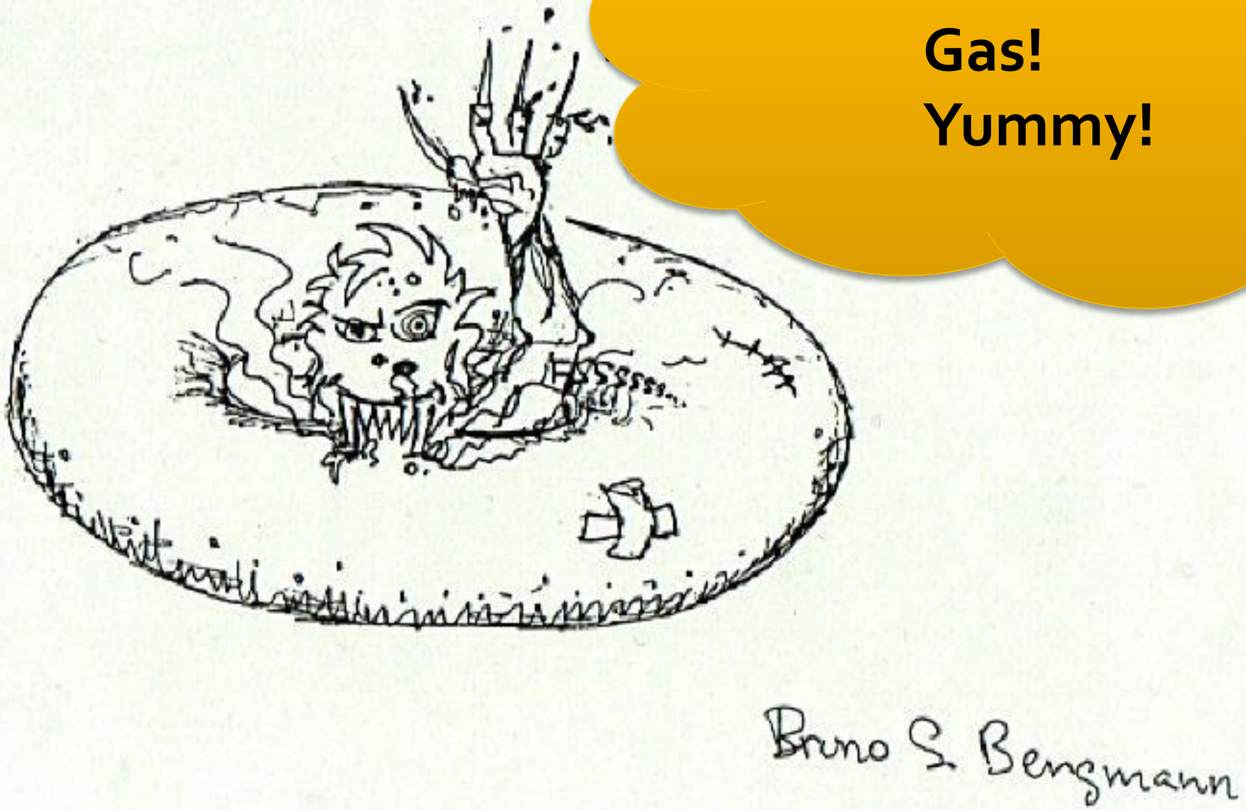
They are out there, with SMBHs growing "in tandem" with host galaxies

Their feedback necessary in models to reproduce galaxy Luminosity Function

What is necessary?

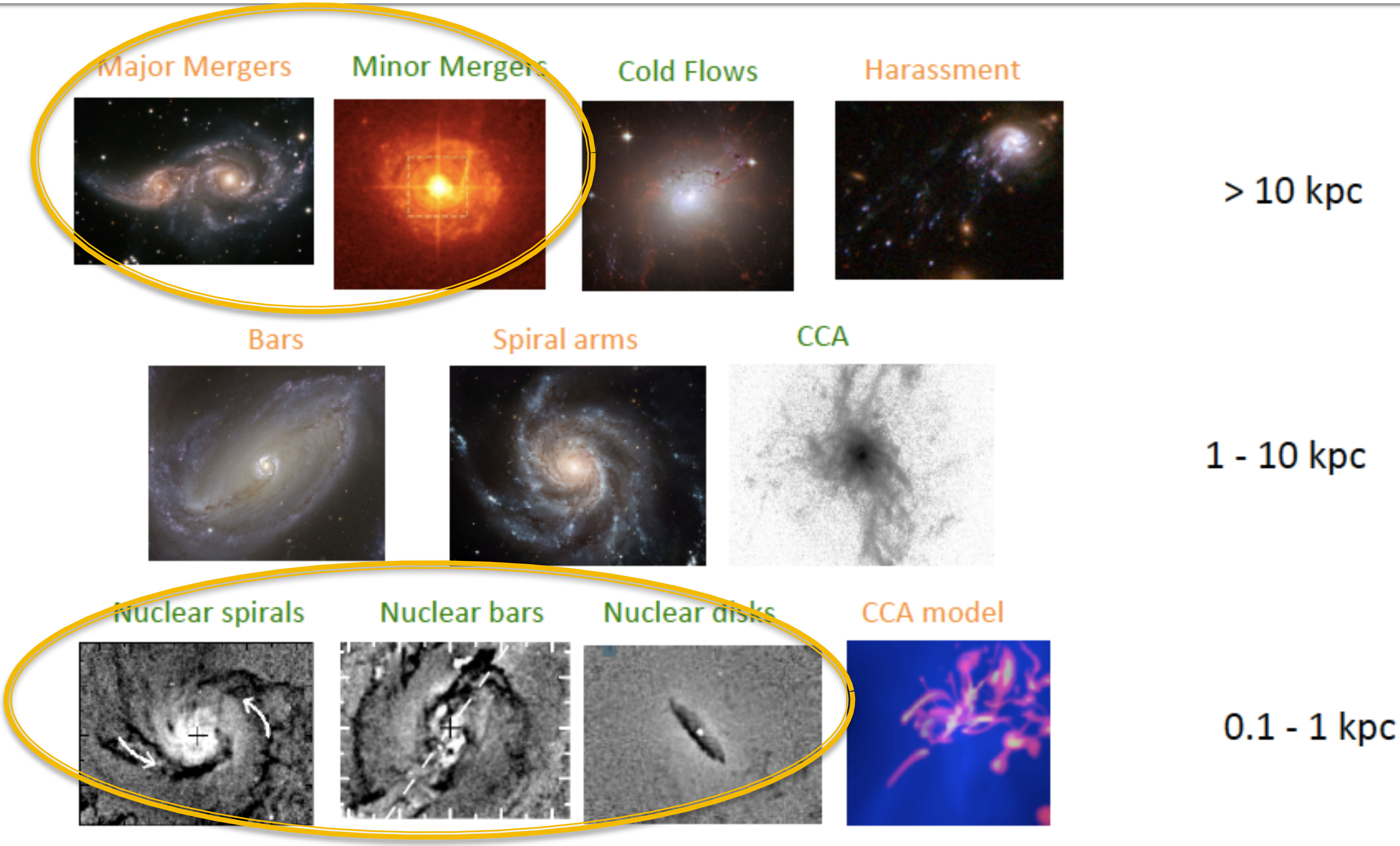


What is necessary? Feed the monster!



Gas!
Yummy!

How to get the necessary gas?
(Storchi-Bergmann+Schnorr-Müller 18)

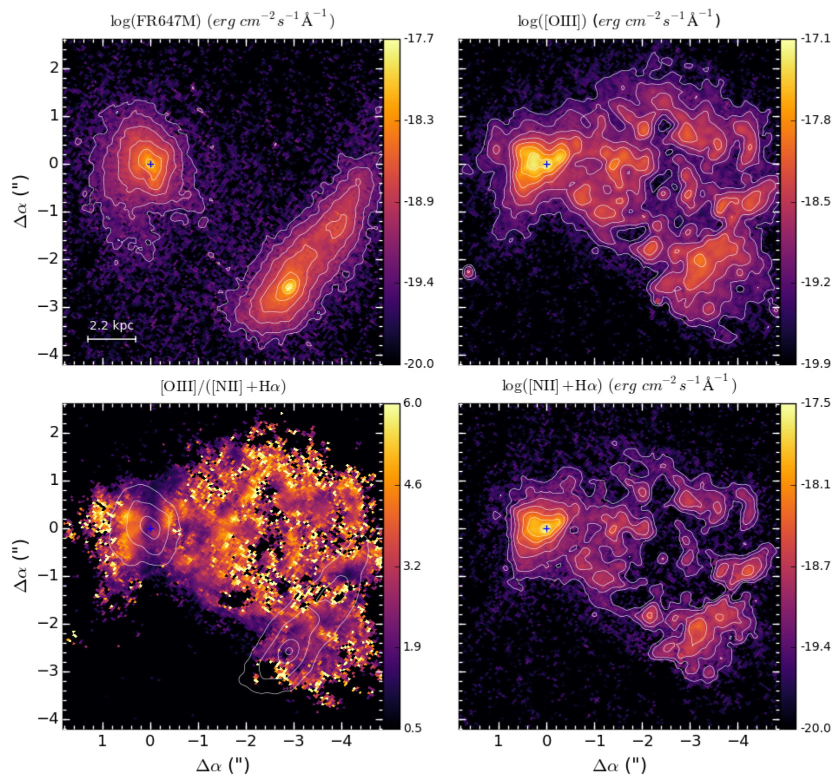


Major mergers and galaxy pairs

Simulations: mergers for high SMBH masses (e.g. menci+14,hopkins+14, gatti+14)

Observations:

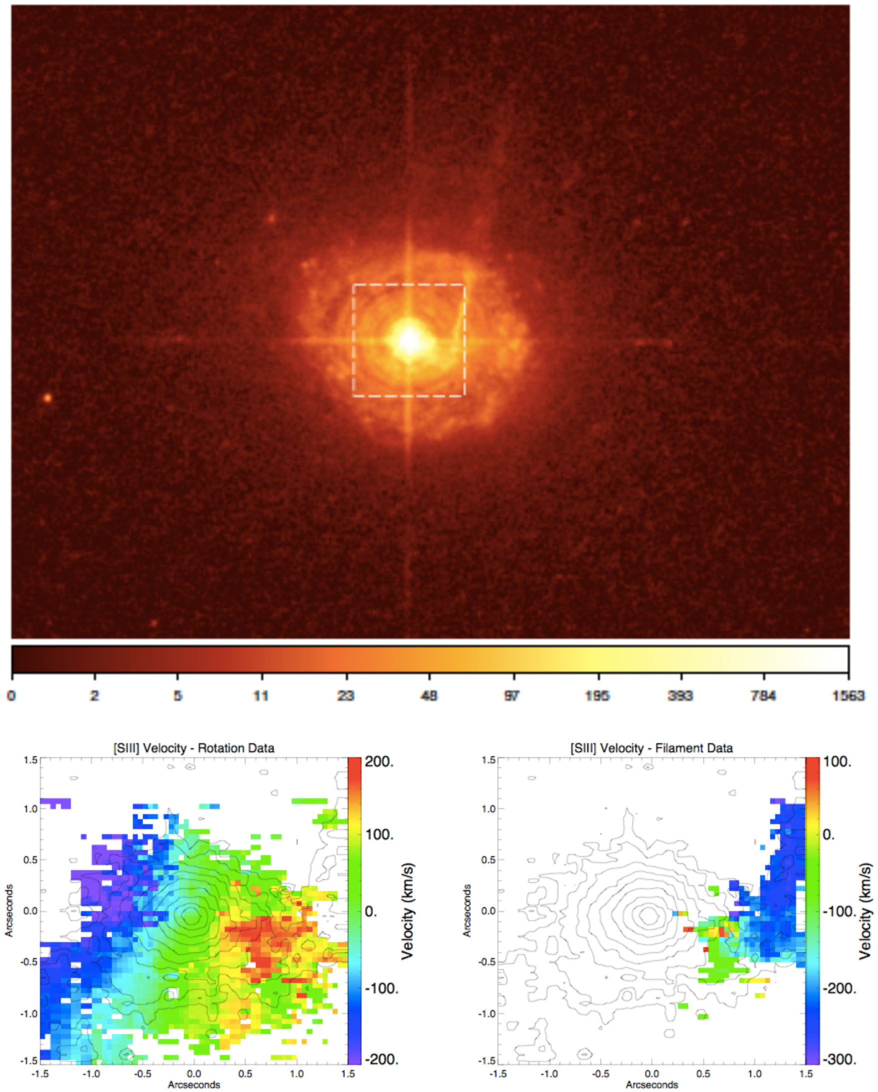
- Most luminous AGN (L>10^{46} erg/s), ULIRGS, hosted by mergers (urrutia+08, treister+12, glickman+15, fan+16, goulding+17)
- Intermediate luminosities (L~10^{44} erg/s) in close galaxy pairs (silverman+11, ellison +11,+13,satyapal+14)
- Some negative results when compared to control samples (cisternas+11, kocevski+12, villforth+14, karouzos+14, mechtley+16,villforth+17)



Storchi-Bergmann+18: most high-luminosity AGN have companions or signature of interactions

Minor mergers

- In early-type, gas starving galaxies, in low to moderately luminous AGN
- Theory: neistein+14
- Observations: simões-lopes +07, martini+13, davies+14
  poster by Davies, on LLAMA sample

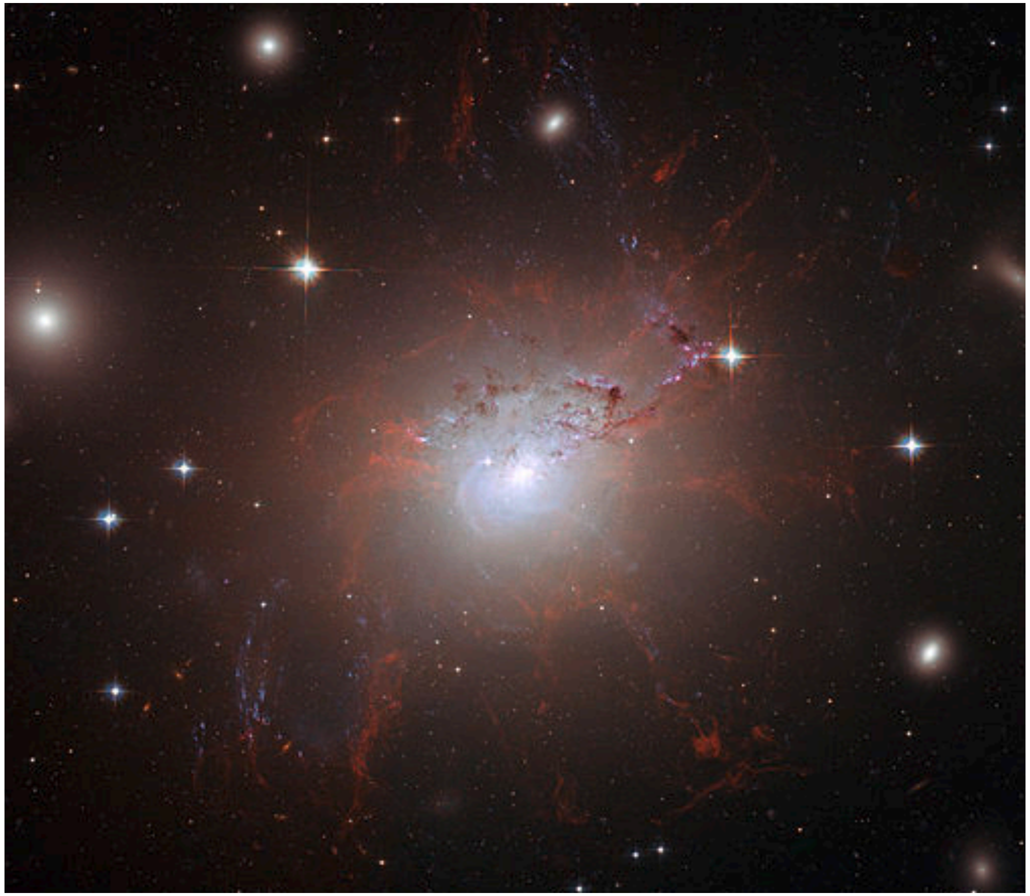


Fischer+15: Mrk 509

Cooling flows; Chaotic Cold Accretion

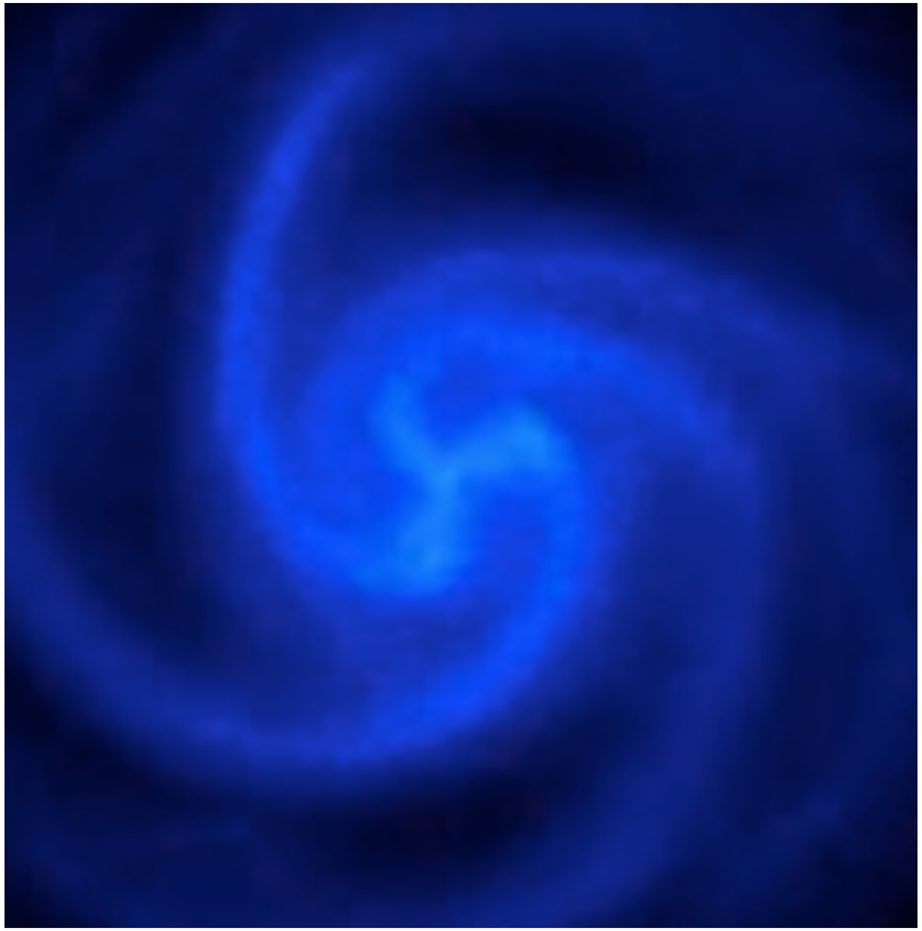
In radio galaxies, center of galaxy clusters: fuelling of radio-mode AGN, filaments and cold clouds leading to low mass accretion rate: e.g. gaspari+17,+18

ALMA: plenty molecular gas on such clusters, consistent with products of gas cooling (e.g. pasquale+18)



NGC1275, Perseus A, HST

Inner kpc: resolved in nearby AGN



Inner kpc: resolved in nearby AGN

- Most nearby AGN have accretion rates ~ 10^{-3} $M_{\odot} yr^{-1}$

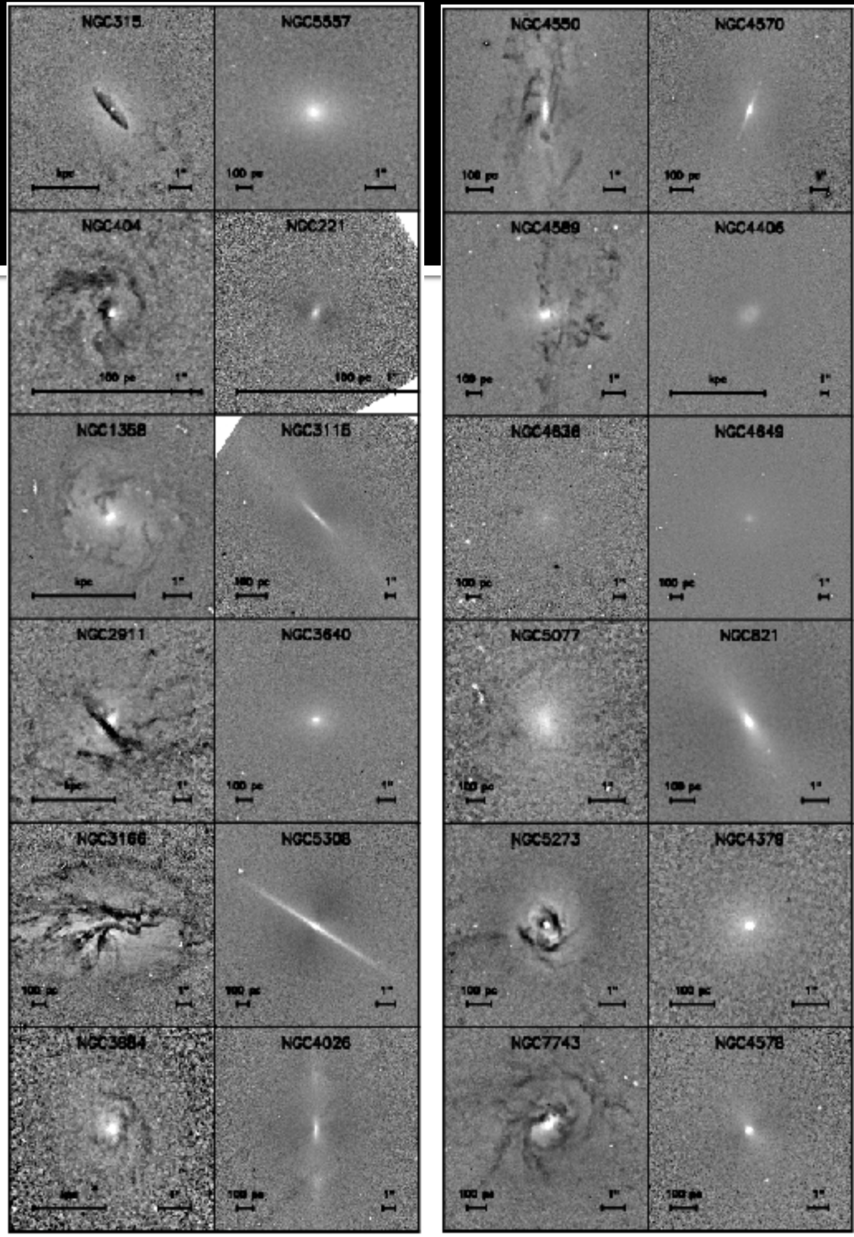
- Could be provided by mere mass loss of bulge stars (e.g. Ho+08,+13, Davies+14)

- Yet in the inner kpc of nearby AGN …

AGN in early-type hosts

HST F606W images of inner kpc (Simões Lopes+07, Malkan+98) :

- Dusty nuclear spirals in all **early-type** AGN;
- But in only 25% of control sample;



Early-type active control active control

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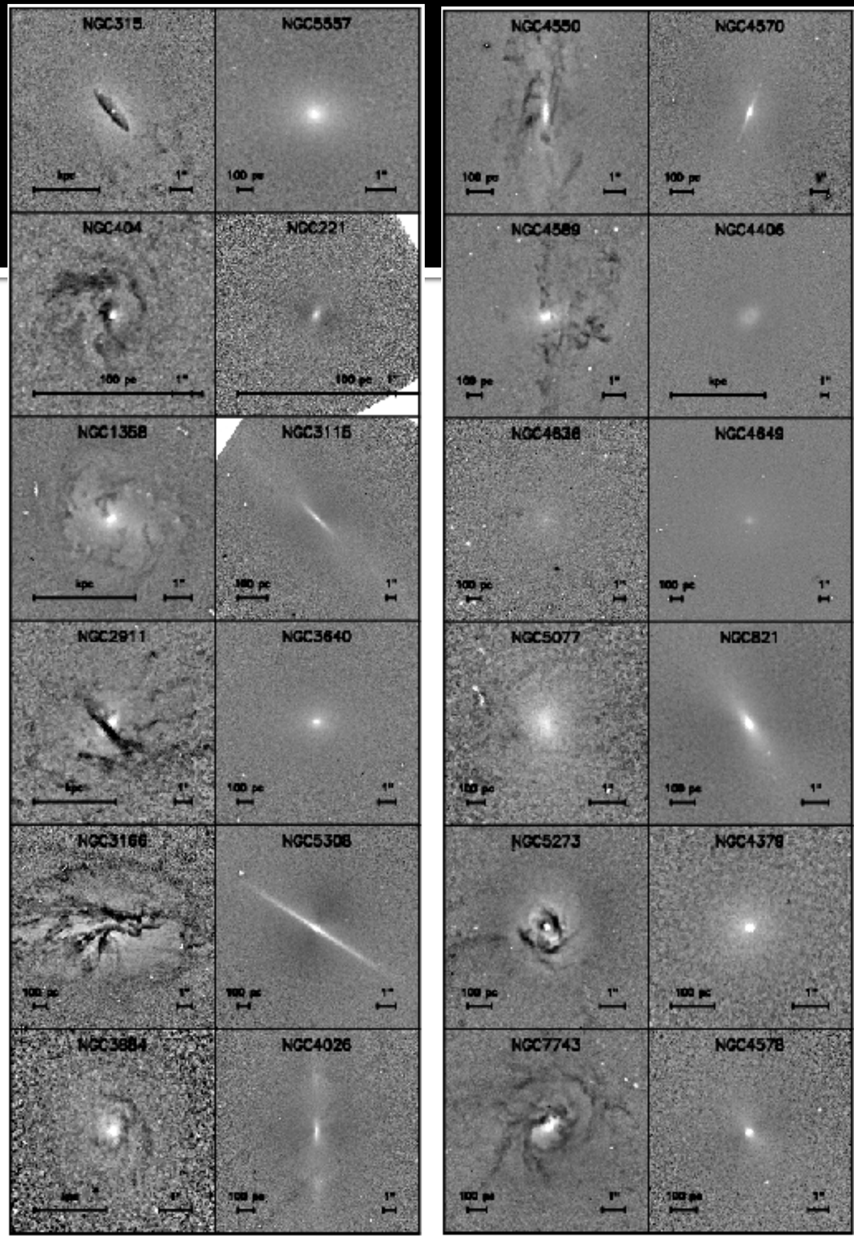
-> Excess cold gas in AGN, confirmed by Spitzer – martini+13 **(see also poster by Davies)**



Early-type active control active control

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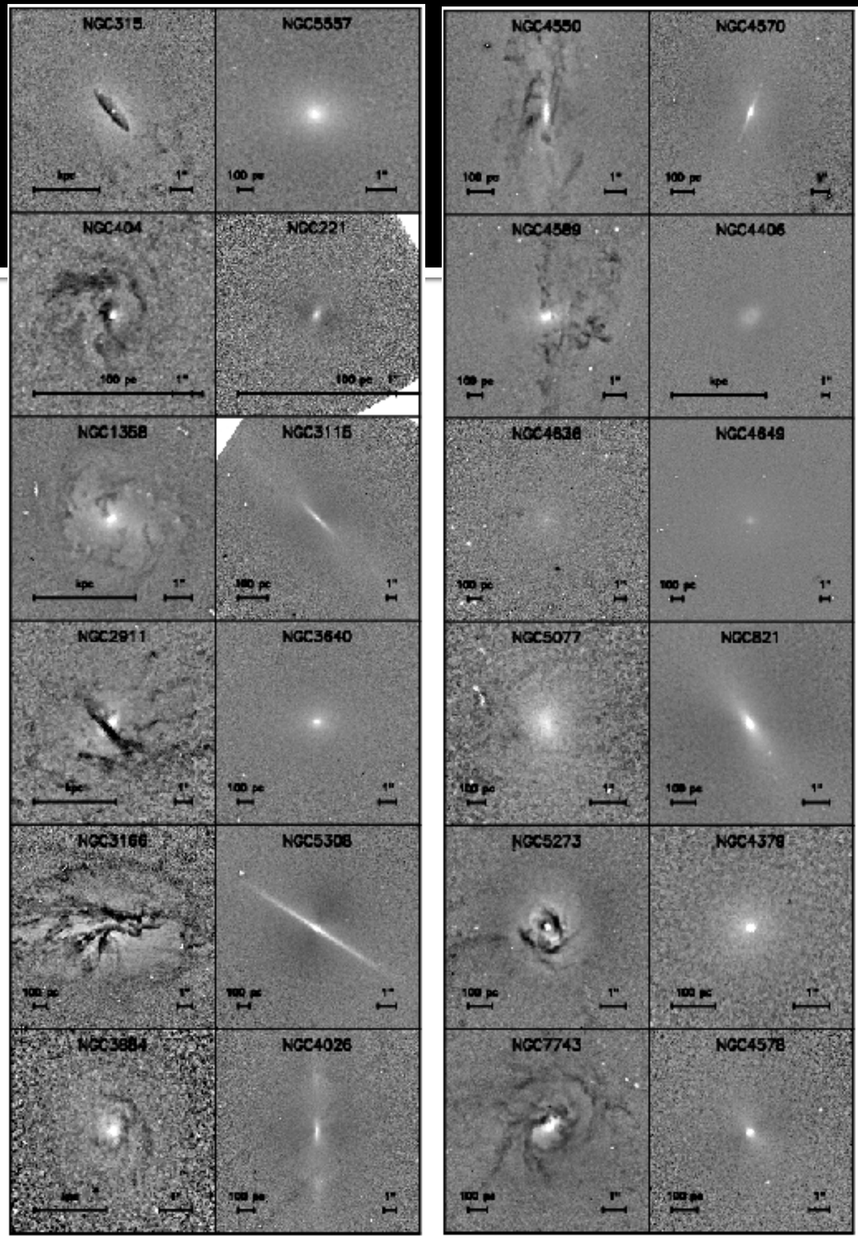
- Dusty nuclear spirals in all **early-type** AGN;
- But in only 25% of control sample;

-> Excess cold gas in AGN, confirmed by Spitzer – martini+13 **(see also poster by Davies)**

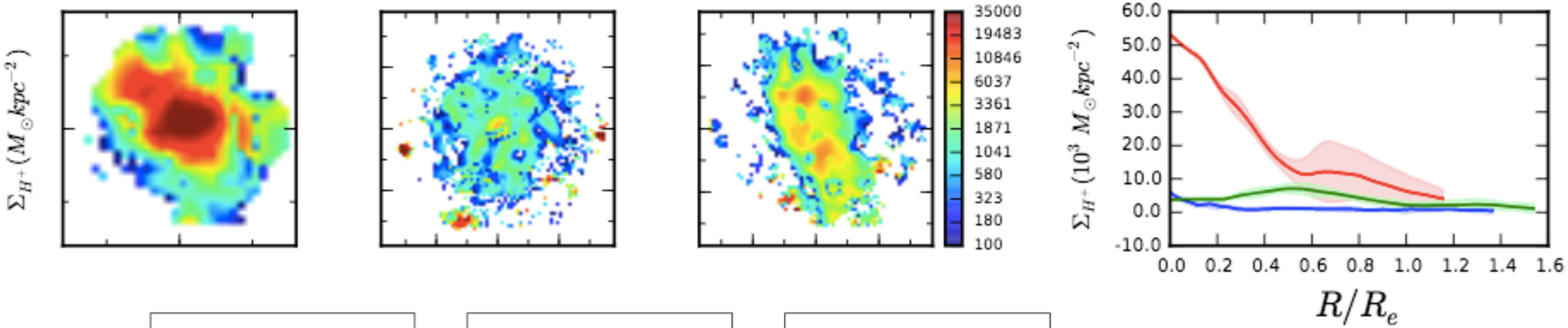
-> Nuclear spirals: channels to feed SMBH (Maciejewski 04, van de Ven & Fathi 10; Piñol-Ferrer+12; Hopkins & Quataert 10)

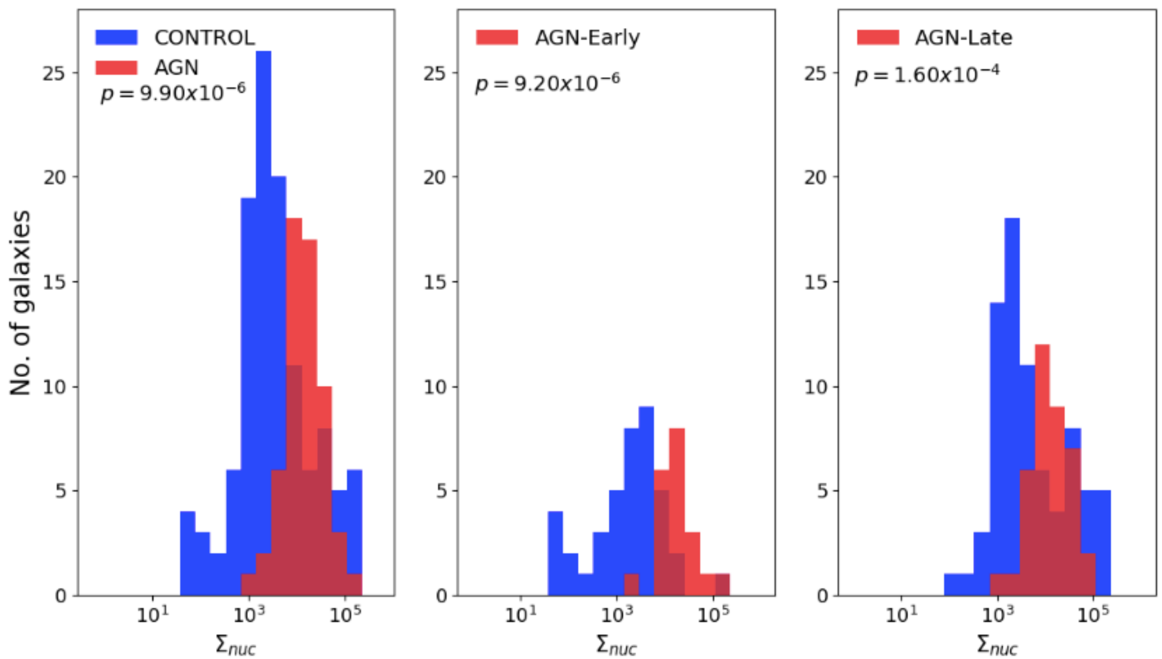


Early-type active control active control

AGN: higher ionised gas surface density

Σ_{nuc} (within inner 0.2 R_e: Nascimento+18)





62 MaNGA AGN

112 controls

Inner (0.2 Re) gas surface mass density in $M_\odot\ yr^{-1}$

AGNIFS (AGN Integral Field Spectroscopy) team

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Jaderson Schimoia
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Allan Schnorr Müller
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Astor Schönell Jr.
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Hekateline Carpes
Izabel Freitas
Natacha Z. Dametto
Fausto K. B. Barbosa
Bruno Dall'Agnol de Oliveira
Marina Bianchin
Nicolas D. Mallmann
Janaína Nascimento
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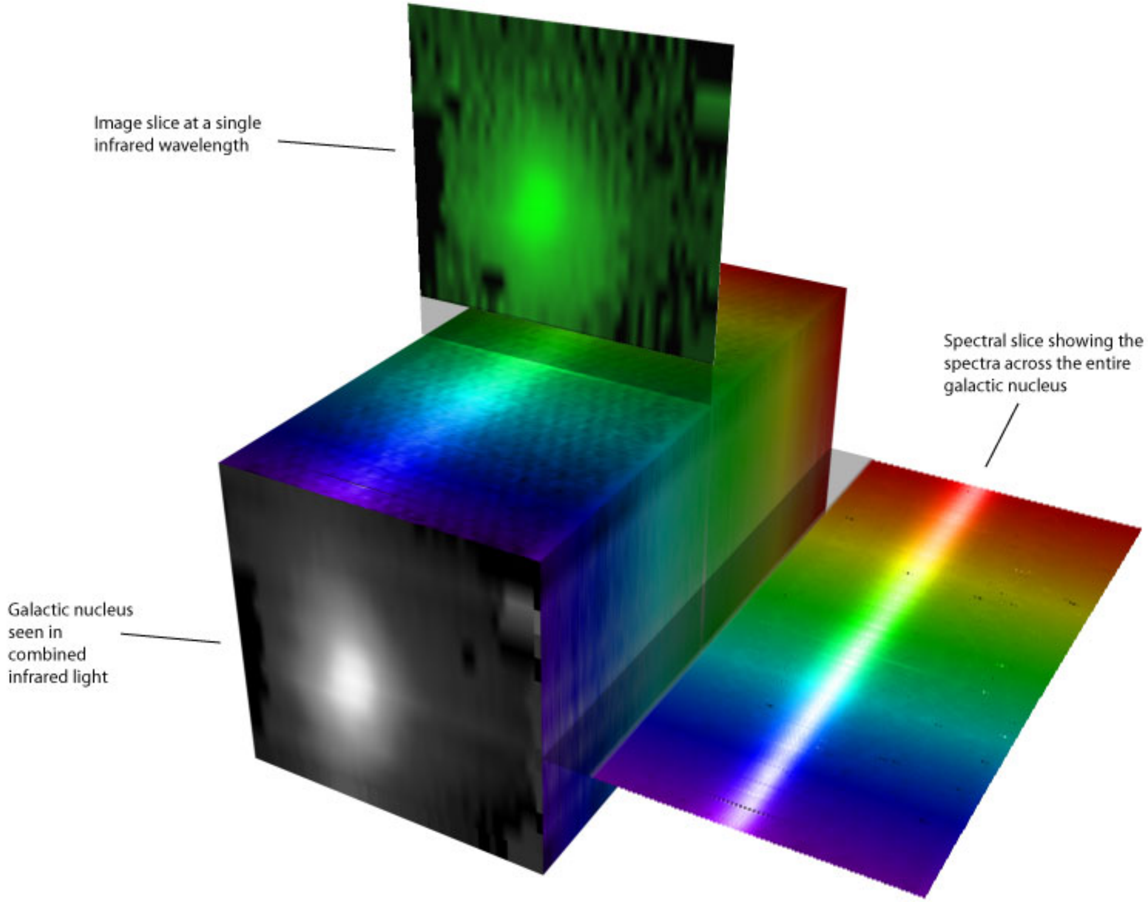
Johan Marques
+ COLABS
L. Colina, R. Davies,
L. Burtschner, D. Rosario,
A. Robinson, D. Lena, N. Nagar,
H. Schmitt, M. Crenshaw,
S. Kraemer, T. Fischer, M. Elvis...

Data cubes from Gemini and MaNGA

Near-IR: NIFS + ALTAIR (adaptative optics)
- FOV: 3" x 3"
- Sampling: 0.04"×0.1"
- PSF ~ 0.1"
- R~5500, Z, J, H, K

Optical: GMOS IFU
- FOV: 3.5"x5" or 5"x7"
- Sampling 0.2"
- PSF ~ 0.6"
- R~2500

Optical: MaNGA-SDSS-IV
- FOV: 12"x 12" to 32"x32"
- Sampling 2"
- R~2000



Three main projects

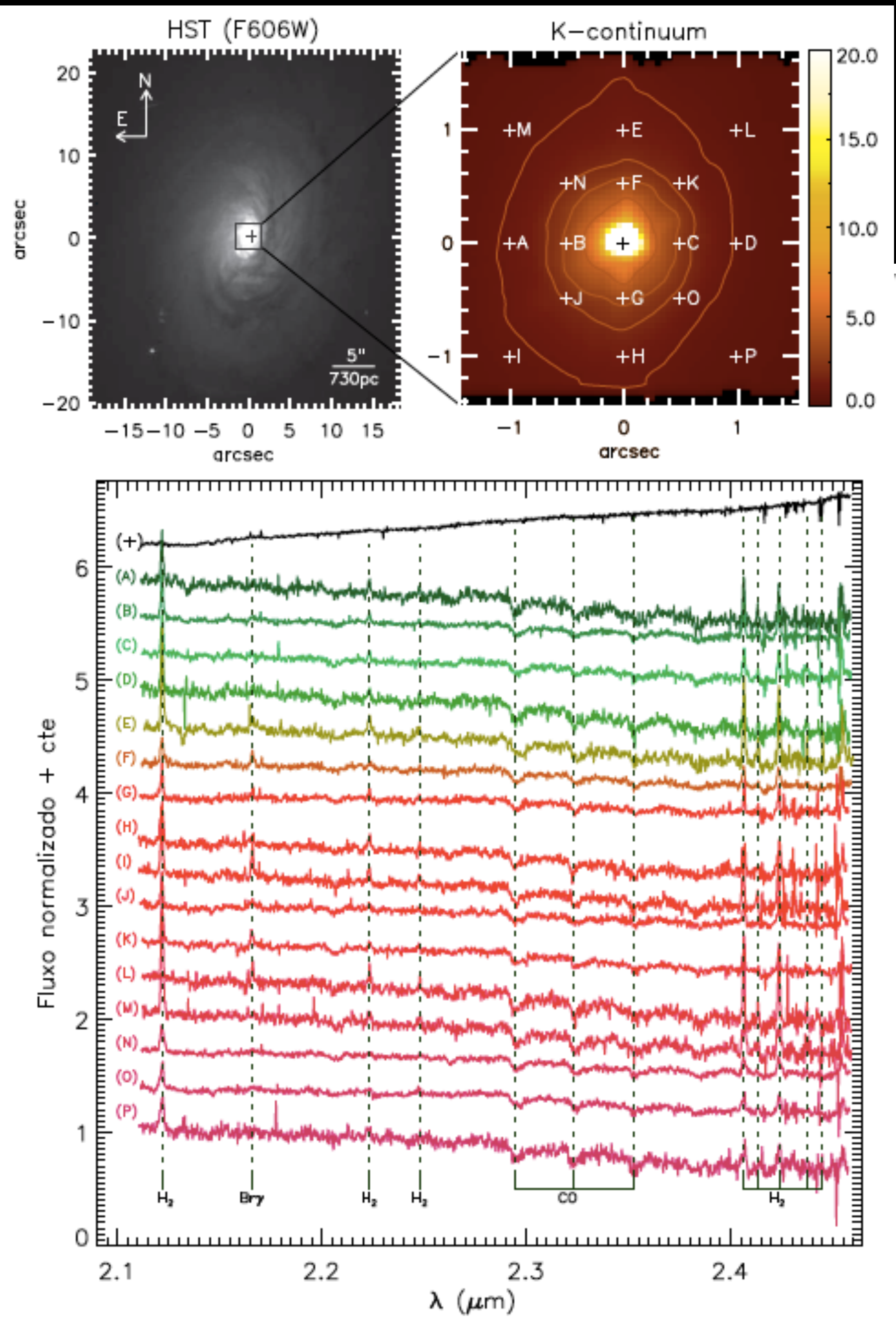
- ***Near-IR: Gemini NIFS survey of feeding and feedback of nearby active galaxies***: Brazilian LLP2 (Riffel+17,+18); ***LLAMA collaboration*** **(Davies, Rosario, Hicks, Burtscher)*;***

- ***Optical: Ionised gas kinematics in active galaxies using GMOS-IFU:*** local sample of 24 AGN (Ruschel-Dutra+18); sample of 9 luminous AGN (L[OIII]>10^{42} erg/s);

- ***MaNGA SDSS-IV AGN + control sample*** (Riffel+18, Wylezalek+17, Nascimento+17): **Posters by Riffel, Rogemar and Riffel, Rogério** (yes, two different people!)

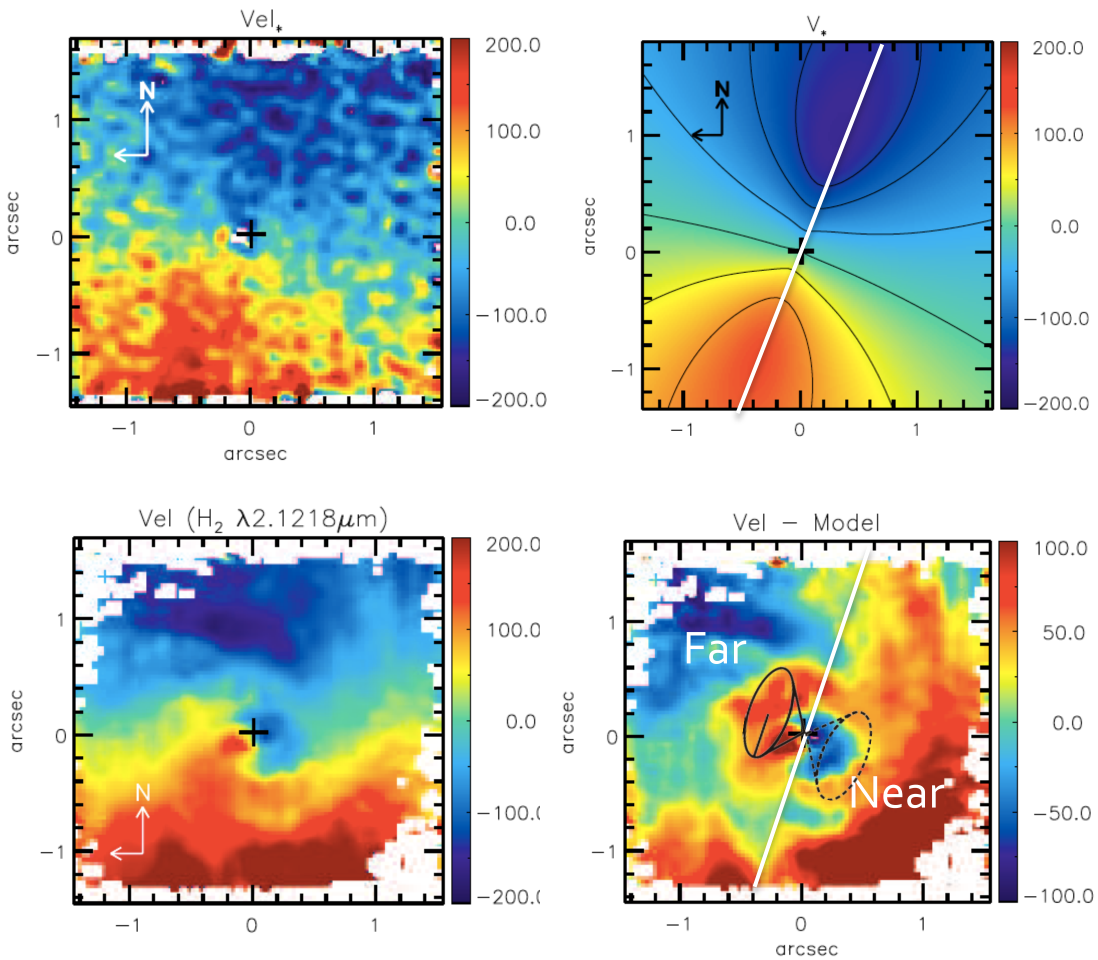
NGC2110, NIFS

(Diniz+15)



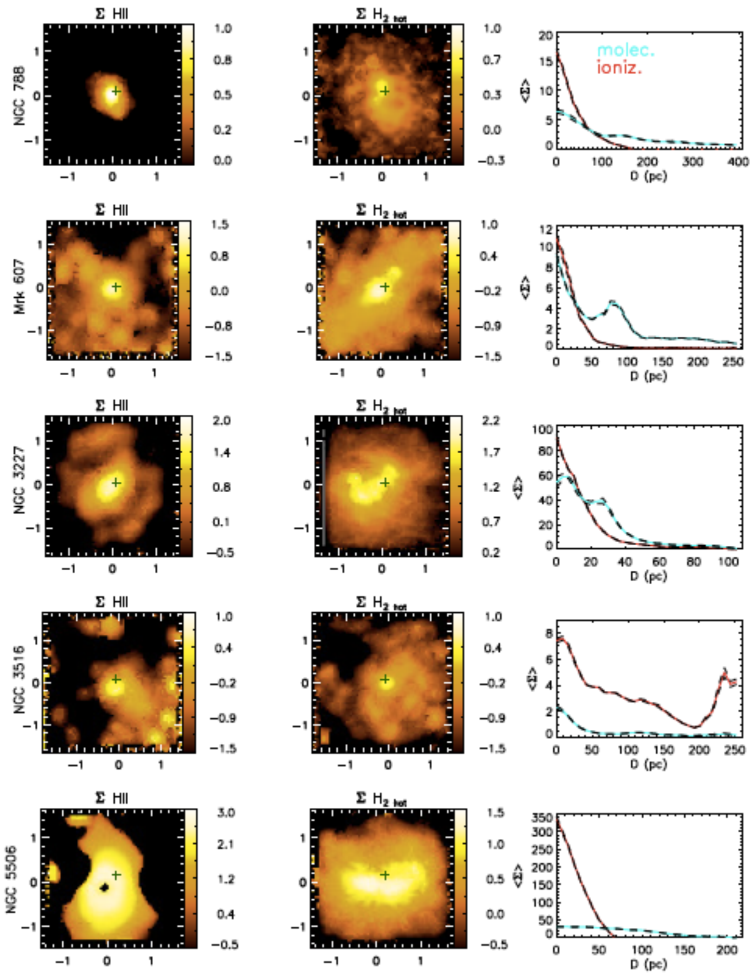
- SO, Sy 2
- FOV= 450 pc x 450 pc
- 0.1"=15 pc
- NIFS, K band
- Stellar (CO) and warm H2 kinematics

NGC2110: centroid velocity



- Stellar velocity field: rotation
- H2 velocity field: rotation + distortions at ~200 pc spiral arms
- Closer to the center: outflow
- Hot (2000K) H2 mass ≈ 1400 $M_{\odot}$

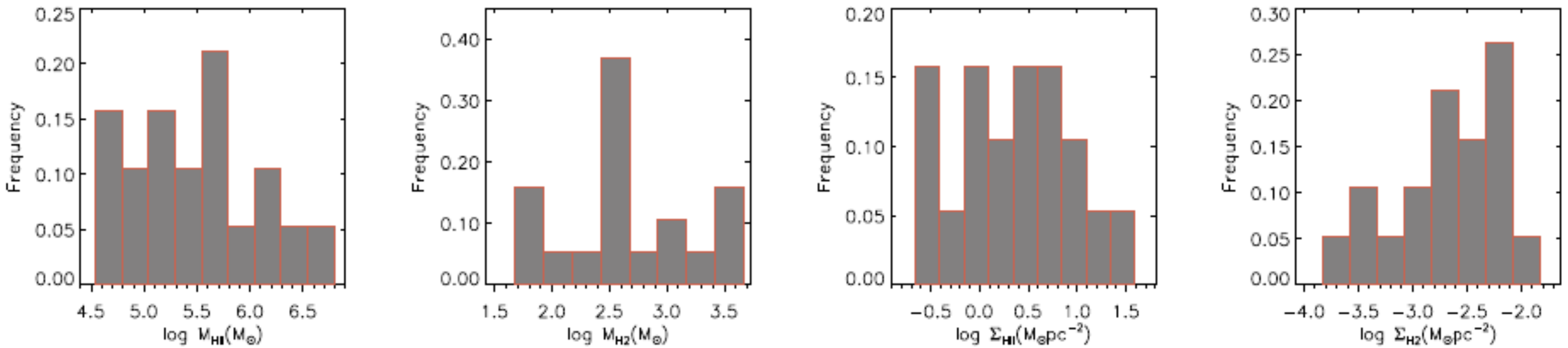
Global results – LLP2 (Schoenell +18, Riffel, R. A. +18): HII and warm H2, inner kpc



Surface mass densities: $\Sigma_{HII} \sim M_\odot\ pc^{-2}$ more concentrated than $\Sigma_{H_2} \sim 10^{-3}\ M_\odot\ pc^{-2}$:

- HII: HI rapidly absorbs ionizing photons -> HII concentrates near the nucleus and along ionization axis;
- Warm H_2: X-rays penetrate the galactic plane in all directions -> heat molecular gas -> more uniform and extended.
- Total HII mass: few $10^6\ M_\odot$
- Total warm H2 mass: few $10^3\ M_\odot$

Global results – LLP2 (Riffel+18)

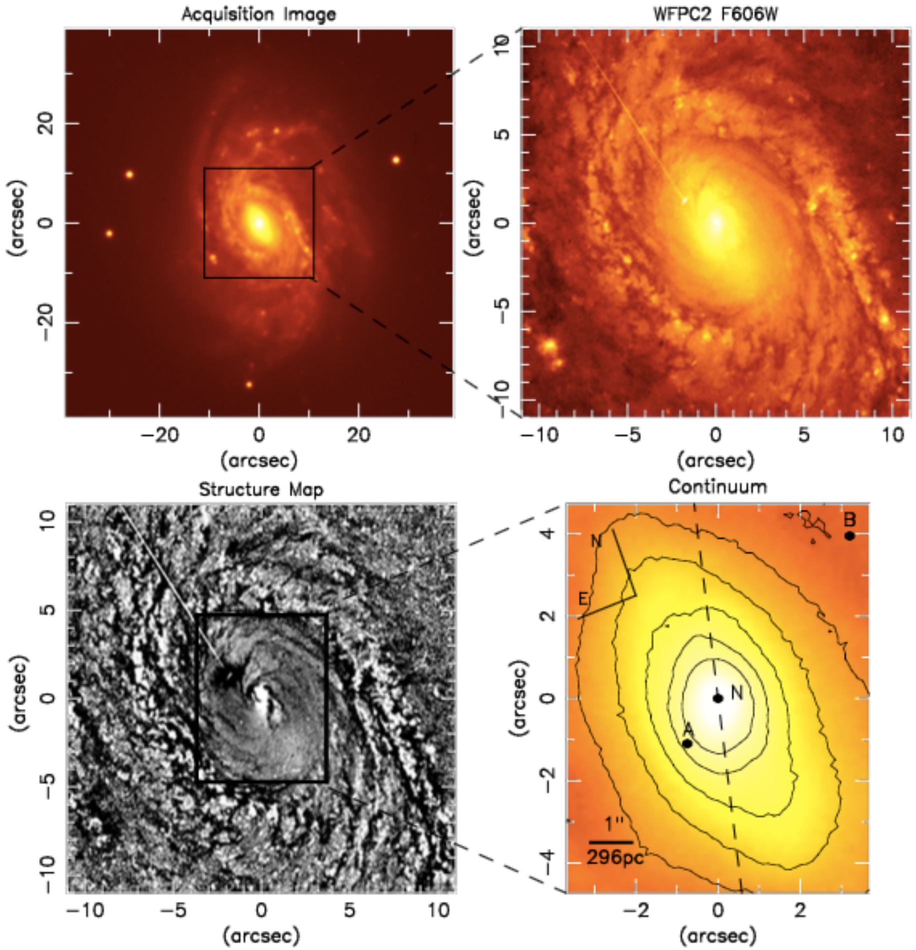


Inner kpc	M_{HII} ($M_\odot$)	M_{H2} ($M_\odot$)	Σ_{HII} ($M_\odot$ pc^{-2})	Σ_{H2} ($M_\odot$ pc^{-2})	*dm/dt* ($M_\odot$ yr^{-2})	*dM/dt* ($M_\odot$ yr^{-2})
Ionized Warm	$(0.03\text{-}4.4)\times10^6$	$(0.05\text{-}3)\times10^3$	0.2-36	$(0.2\text{-}14)\times10^{-3}$	$10^{-3}\text{-}10^{-2}$	$10^{-5}\text{-}10^{-3}$
Cold		x ~10^6 (*)		x ~10^6 (*)?		x 10^6 (*)?

*Dale+05, Mazzalay+12: Masses of cold molecular gas may reach ~$10^{7\text{-}9}$ $M_\odot$ (observed with ALMA)

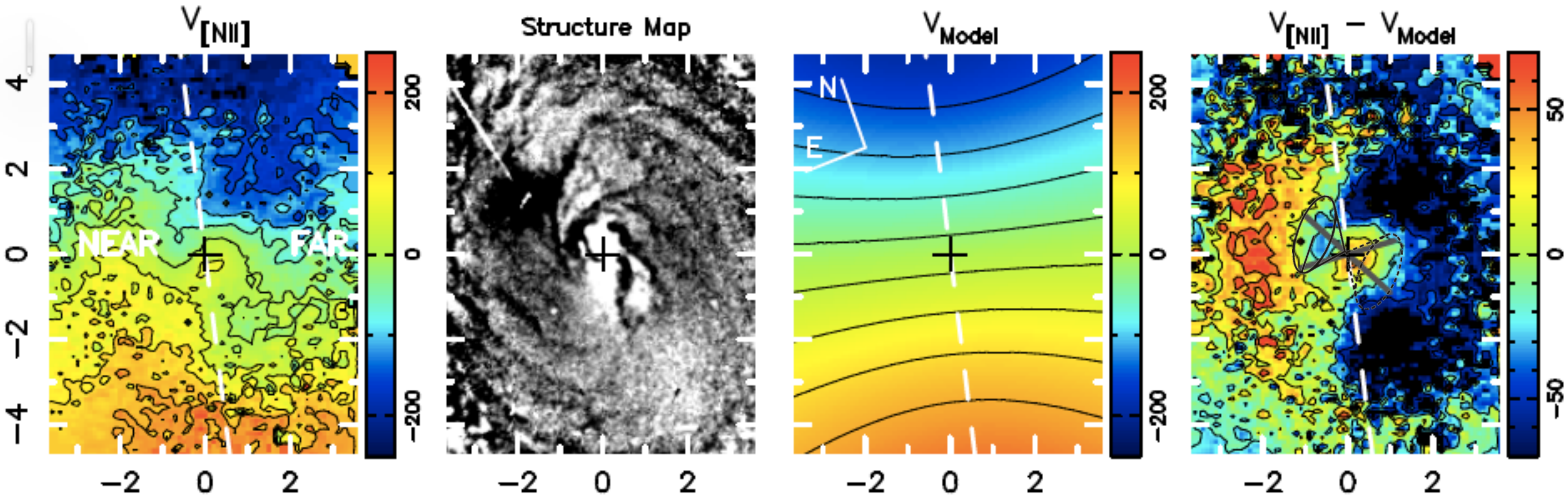
$\Sigma_{H2,cold}$ could reach 100 – 7000 $M_\odot pc^{-2}$; *dM/dt (inflow rate)* probably higher than ~1 $M_\odot yr^{-2}$

Inflows in NGC1667, GMOS-IFU (Schnorr-Müller+17)



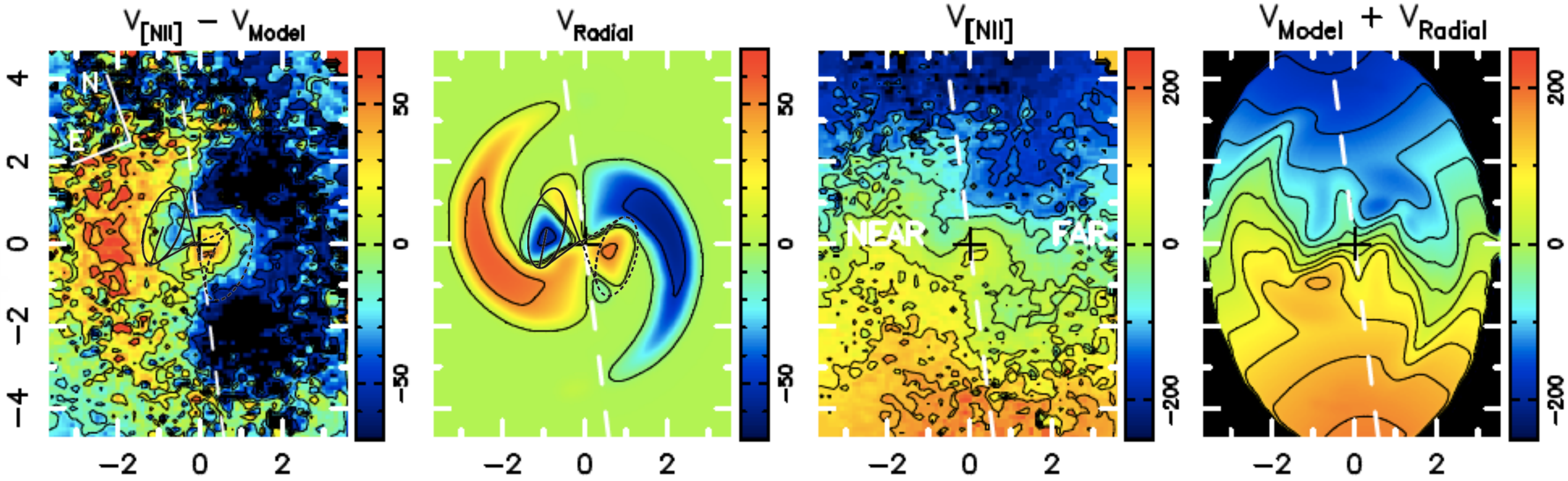
- SAB(r)c, Seyfert 2
- GMOS-IFU
- 1.8 kpc x 2.4 kpc
- Nuclear spiral
- 0.6"= 180 pc

Inflows in NGC1667 (Schnorr-Müller+17)



- Gas velocity field: rotation + distortions in spiral arms
- Model of stellar kinematics subtracted from gas velocity field

Inflows in NGC1667 (Schnorr-Müller+17)



- Comparison with toy model: Shape (Steffen+14): rotation + radial inflow in spiral at 80 km/s; center: outflow
- Mass inflow rate: ~ 2.4 $M_{\odot} yr^{-1}$

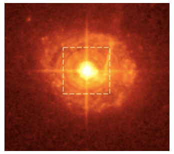
Summary: feeding within inner kpc

- Inflows in nuclear spirals, bars and disks, capture of dwarf companion; observed in HII and H2;
- Inflow velocities ~ 100 km/s;
- Mass inflow rates ~0.1 – few $M_{\odot} yr^{-1}$: 10^2-10^3 times the AGN accretion rate -> formation of new stars, galaxy co-evolution
- Estimated total gas masses in ionized gas: ~ 10^6 - 10^8 $M_{\odot}$
- In warm molecular gas ~ 10^3 $M_{\odot}$: "hot skin" of cold molecular gas; ALMA ~10^8 $M_{\odot}$

Global summary (review for Nature Astronomy)

Major Mergers

Minor Mergers



Cold Flows

Harassment

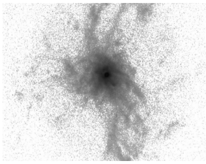
> 10 kpc

Extragalactic

Bars

Spiral arms

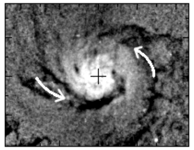
CCA



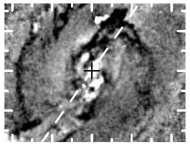
1 - 10 kpc

Galactic: ??? Secular processes, AGN intermittency

Nuclear spirals

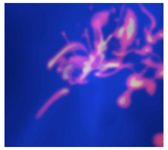


Nuclear bars



Nuclear disks

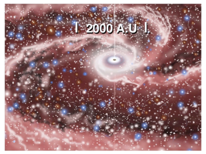
CCA model



0.1 - 1 kpc

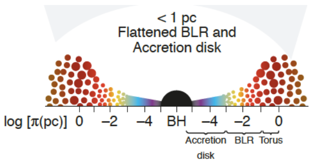
Inner few 100 pc

Do nuclear disks and spirals go all the way to torus/accretion disk?



1- 10 pc

Flattened BLR
+
Accretion disk



< 1 pc

New results coming: ALMA, EHT