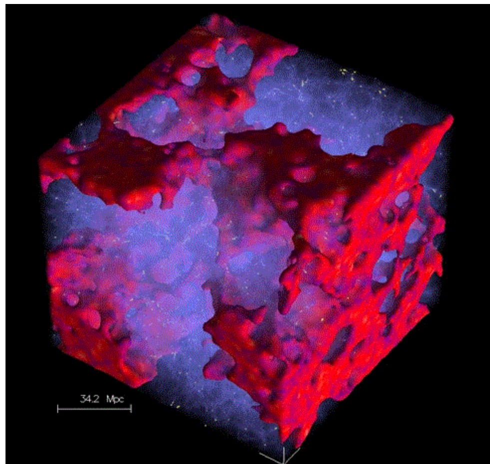
AGN in Galaxy evolution

Action Incitative Hautes Energies
Feb 11th, 2022

Philippe Salomé
LERMA, Observatoire de Paris

Quasars at epoch of re-ionization and cosmic dawn : observations / simulations

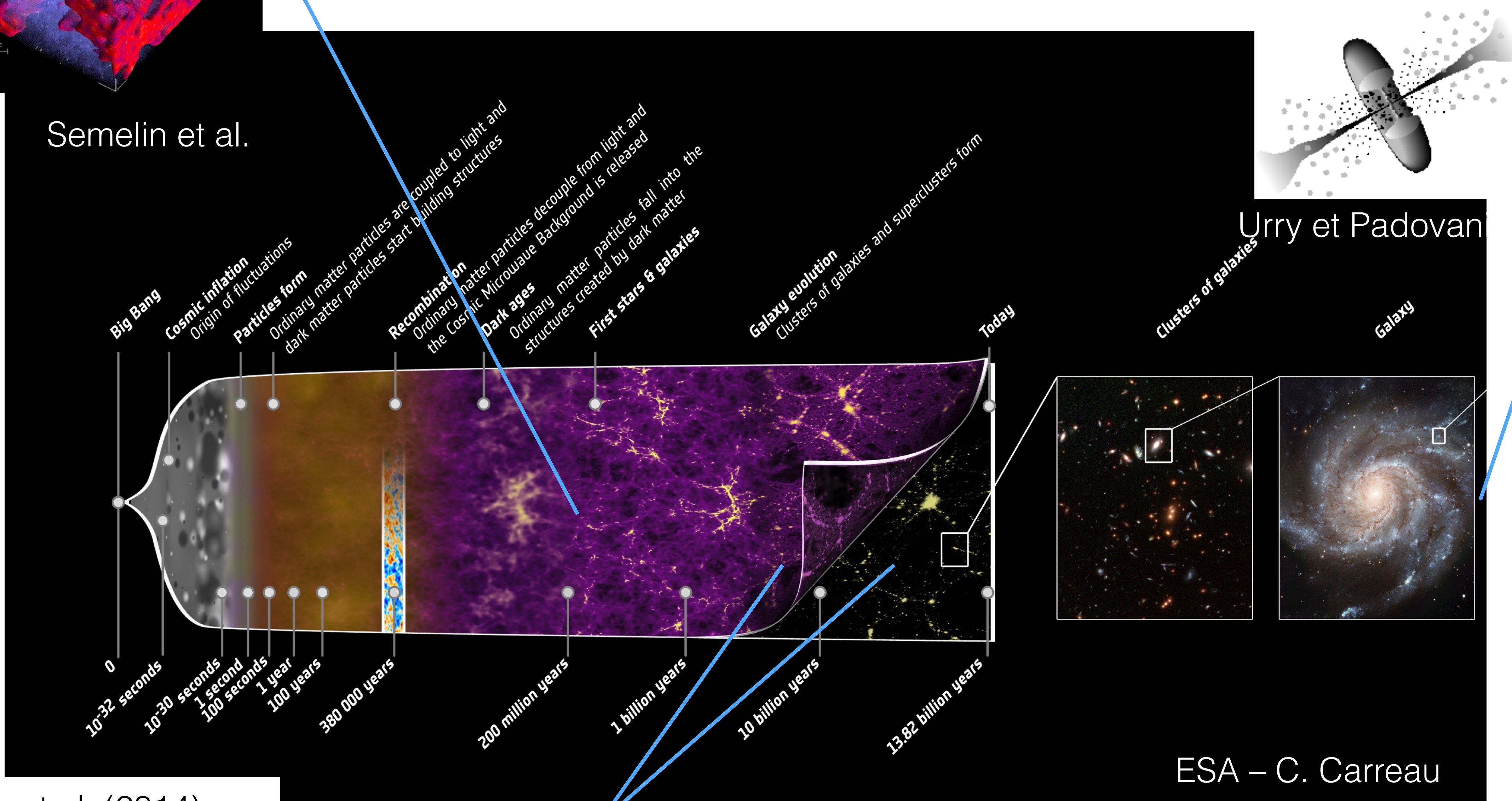


Semelin et al.

Molecular Tori in nearby AGN

Combes et al.

Urry et Padovani

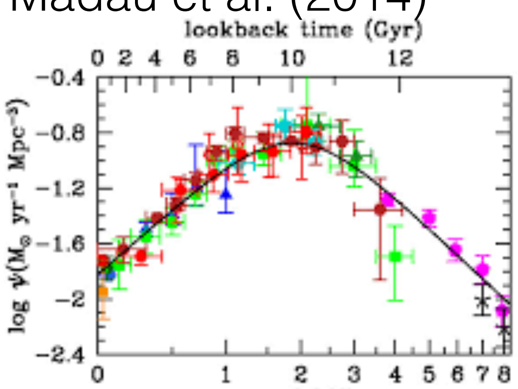


ESA – C. Carreau

M31 - Fermi Bubble ?

Melchior et al.

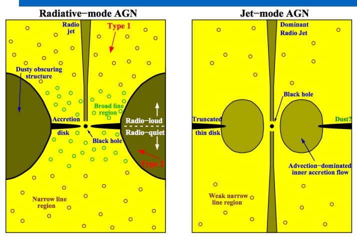
Madau et al. (2014)



AGN-Feedback (negative / positive) - SF regulation in galaxies

Salomé et al.;
Combes et al.
Melchior et al.

Small Scales
< 1 pc



Feeding the BH - Fate of the Gas Accretion / Removal

Effect of feedback on the inner region (self-regulated, duty cycle, intermittent phases)

Observations : High angular resolution, warm / excited gas tracers

Probes : Morphology and kinematics of the inner region. AGN theory

- Gas / Dust Torus
- Gas accretion pattern (disk, bar, torques)

UFO, ADAF

No High-z (yet)

Intermediate Scales
~ kpc

Impact (effect) of the feedback (interaction) wrt SFR :

- negative (quenching)
- positive (triggering) Interaction with interstellar gas (ISM of galaxies)

Observations :

- **Outflows (rate, efficiency)**
- **Gas Excitation : Heating / Ionisation**
- **Overpressure (HI —> H2)**

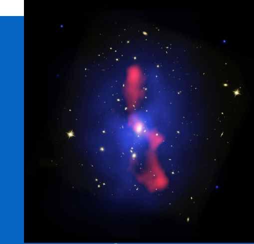
Probes : Mechanical vs Radiative feedback (AGN-related) ?

Probes : Efficiency of the feedback vs SFR

- to prevent cooling if negative
- to form stars if positive

(**Environment related** - distance, gas properties…)

High-z examples



Large scales
> 10 kpc

Large scale cooling / accretion vs outflows / fountains - gas resplenishment

Observations :

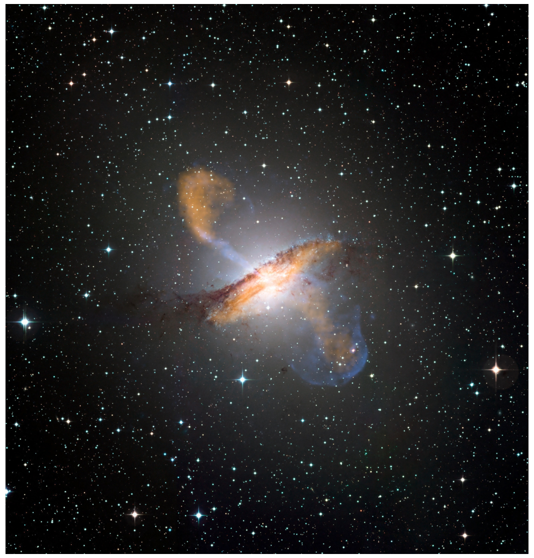
- **Ionised / molecular Filaments around cool core BCGs**
- **AGN / ICM cavities in local clusters (radio + X-rays)**
- **Absorption halo lines in front of background sources (mostly optical, UV)**

Probes: properties/Content of

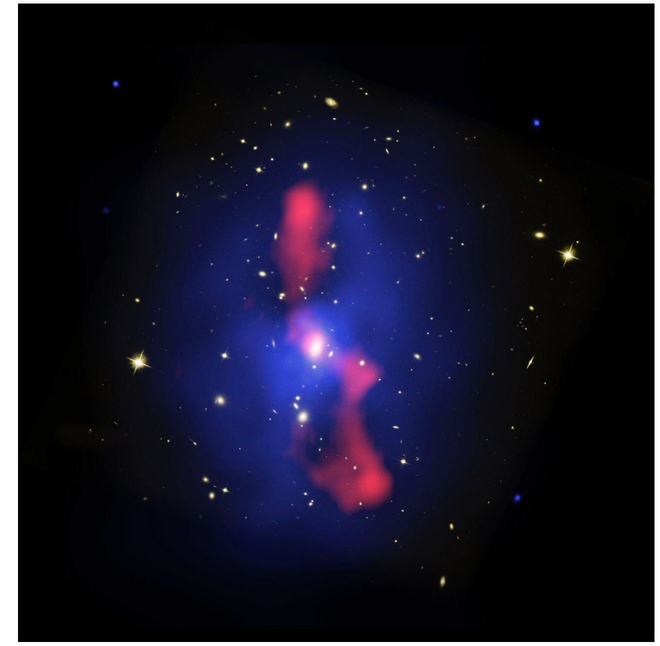
- **Circum-galactic (Haloes)**
- **Intergalactic (Enrichment, ionisation)**

Built-up on longer timescales

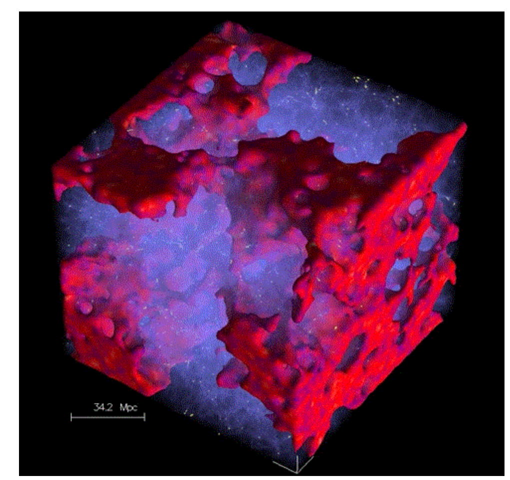
High-z examples
Role of AGN along redshift (mode-dependent), in particular at very high-z (re-ionisation)



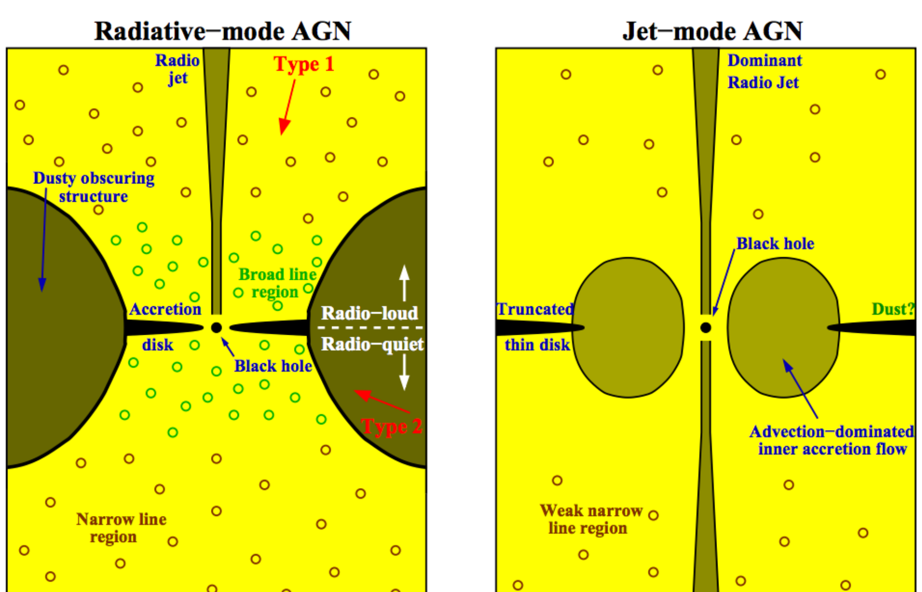
> 10 kpc



~ kpc



< 1pc



Very large Scales

Very Large Scales

Re-ionisation

A simple **model of the quasar population** that matches current observations at z<6. Study the impact of this modelling on the 21-cm model through all four radiation types (ionizing UV, X-rays, Lyman band, and radio)

Model ionisation mechanisms

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **478,** 5564–5578 (2018)
doi:10.1093/mnras/sty1293
Advance Access publication 2018 May 18

Imprints of quasar duty cycle on the 21-cm signal from the Epoch of Reionization

Florian Bolgar,[1★] Evan Eames,[1] Clément Hottier[2] and Benoit Semelin[1]

[1]*LERMA, Observatoire de Paris, Sorbonne Université, PSL research university, CNRS, F-75014 Paris*
[2]*GEPI, Observatoire de Paris, Université PSL, CNRS, 5 Place Jules Janssen, F-92190 Meudon, France*

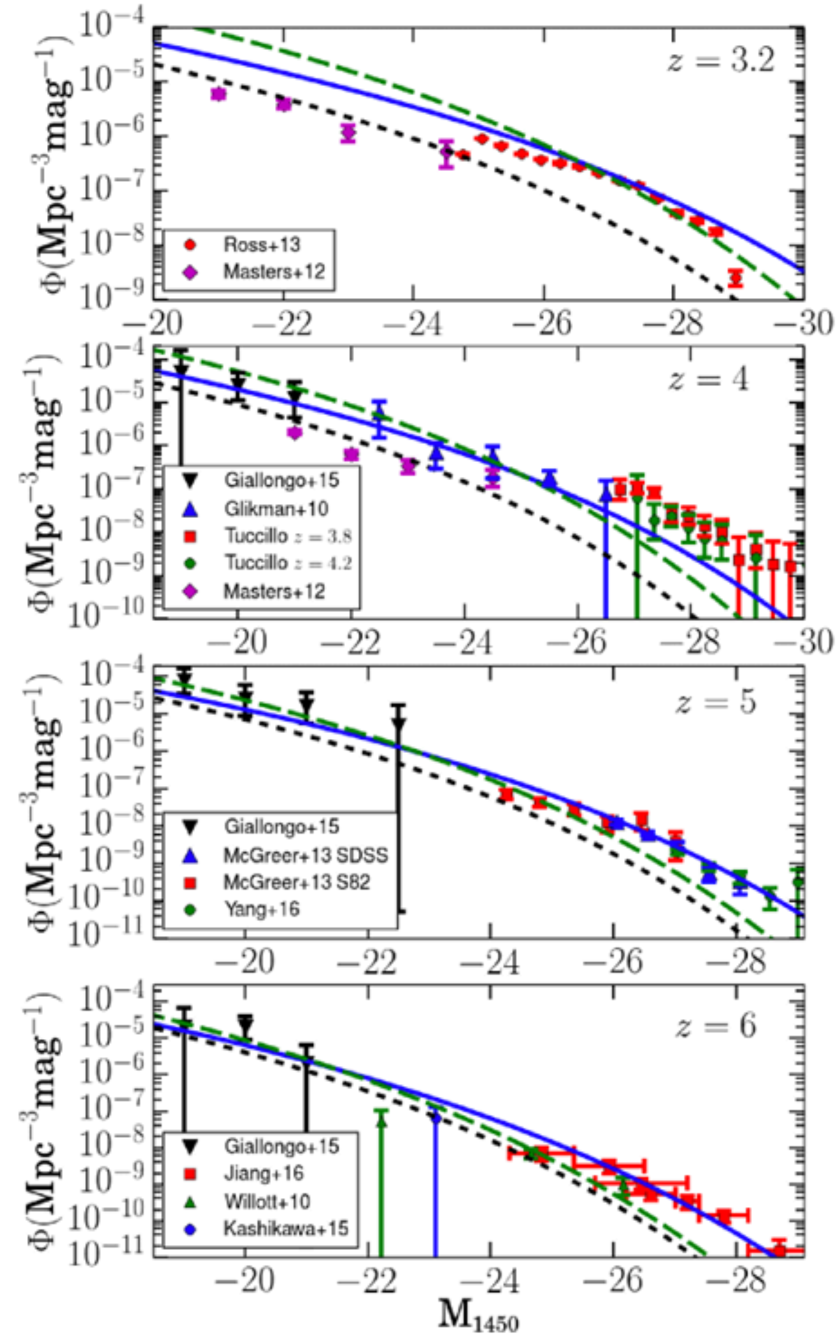


Figure 1. Quasar luminosity functions for the 1450 Å absolute magnitude M_{1450}. The blue solid line represent our fiducial model with $f_{duty} = 0.02$ and $f_{corr} = 1$, the long dashes green line represent our model with $f_{duty} = 0.2$ and $f_{corr} = 0.2$ and the short dashed black line is the model of Haiman et al. (2004). From top to bottom: theoretical curves generated at $z = 3.25$, $z = 4$, $z = 5$ and $z = 6$. The data points are taken from Glikman et al. (2010), Willott et al. (2010), Masters et al. (2012), Ross et al. (2013), McGreer et al. (2013), Giallongo et al. (2015), Kashikawa et al. (2015), Tuccillo et al. (2015), Yang et al. (2016), Jiang et al. (2016).

Re-ionisation

- A radio-loud quasar can leave the imprint of its **duty cycle** on the 21-cm tomography.
- Cosmological simulations conclude that the effect of typical **radio-loud quasars is most likely negligible** in an Square Kilometer Array **(SKA)** field of view. For a ~10-mJy quasar the effect is stronger though hardly observable at SKA resolution.
- The contribution of the **Lyman-band** (Ly α to Ly β) emission of quasars is n**ot negligible : a distinctive pattern around the brightest quasars in an SKA field** of view may be observable in the tomography, encoding the duration of their duty cycle.
- This pattern has a high signal-to-noise ratio for the brightest quasar in a typical SKA shallow survey

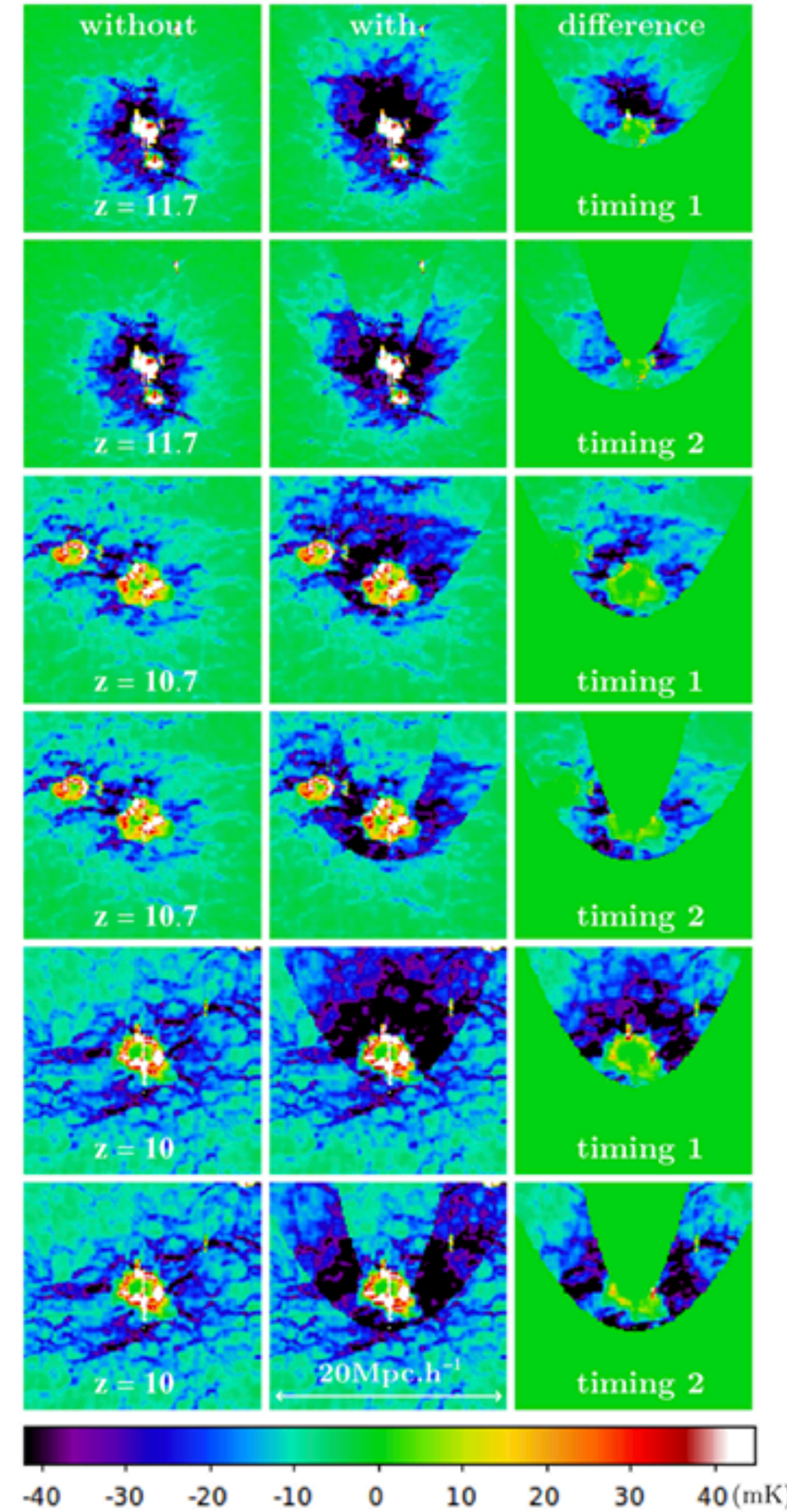


Figure 7. Effect of the Lyman continuum emission of three of the biggest quasars expected in a typical SKA field on the 21-cm signal, at different redshifts and for different timings of the duty cycle. From left to right: δT_b (in mK) without a quasar, with a standard quasar, and the difference between the third image and the first (that is, the net contribution of the quasar). These are slices of the 3D lightcone of δT_b along the direction of the line of sight: The vertical axis corresponds to the frequency direction, converted in comoving distance, while the horizontal axis corresponds to one of the transverse directions.

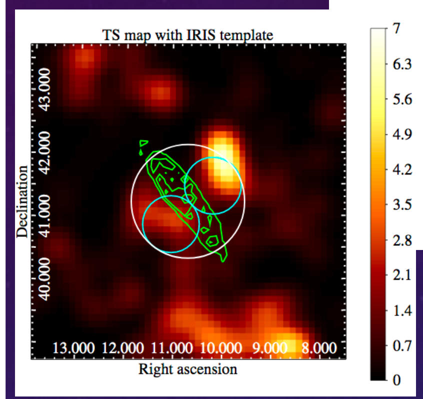
Intermediate Scales

FERMI BUBBLES IN M31?

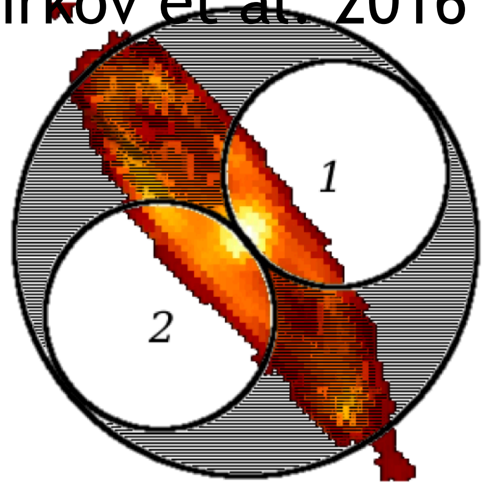
Gamma-ray haloes can exist around galaxies due to the interaction of escaping galactic cosmic rays with the surrounding gas. We have searched for such a halo around the nearby giant spiral Andromeda galaxy M31 using almost 7 yr of Fermi LAT data at energies above 300 MeV.

GAMMA DATA

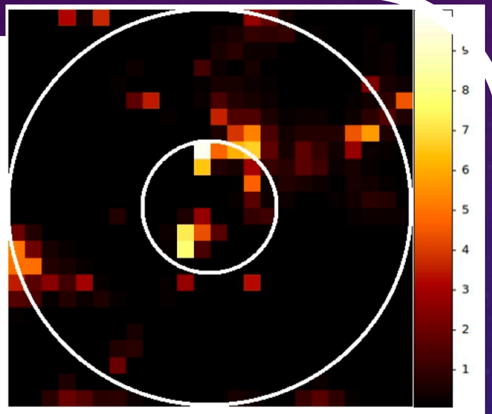
Li et al. 2016

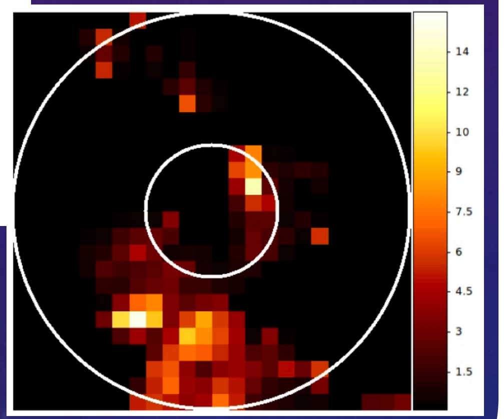


Pshirkov et al. 2016



→ Excess of milli-second pulsars?
Ackermann et al 2017, Eckner et al. 2018, See also Feng et al. 2018, Karwin et al. 2019, Fragione et al. 2019



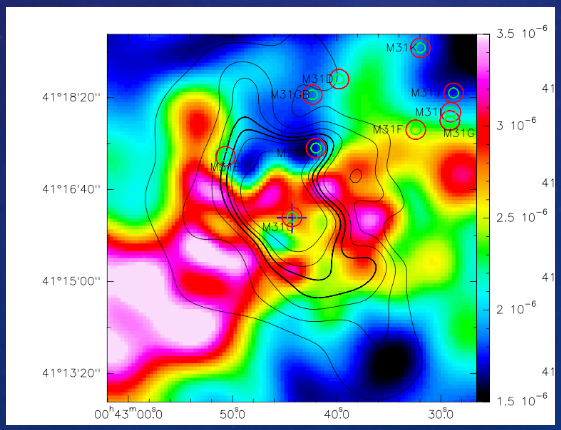


Fermi LAT : Residual excess emission from the direction of M31 if only the galactic disk as traced by the far infrared emission is considered.

- Adding a point-like source will improve the fitting effectively,
- Additional slight improvements can be found if an extended component such as a uniform disk or two bubbles is added instead.

X-RAY OUTFLOW

Bogdan & Gilfanov (2008)
See also Li & Wang 2007

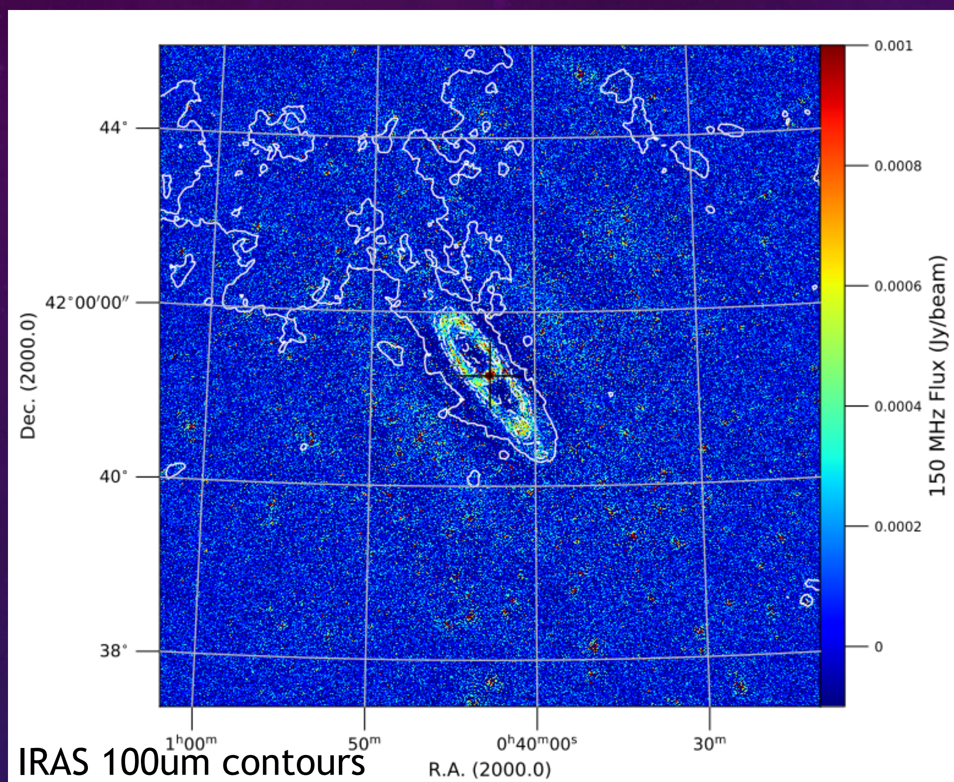


Unresolved X-ray emission from the bulge of M31 based on archival Chandra and XMM–Newton observations. 3 different components

(i) Broad-band emission from a large number of faint sources : white dwarfs and active binaries
(ii) Soft emission from ionized gas with a temperature of about ~300eV and a mass of~2×106 Msun. The gas distribution is significantly extended along the minor axis of the galaxy (outflowing in the direction perpendicular to the galactic disc). Type Ia supernovae is sufficient to sustain the outflow
(iii) Hard extended emission from spiral arms, most likely associated with young stellar objects

FERMI BUBBLES IN M31?

A.-L. Melchior, F. Combes, C. Tasse et al., in prep.



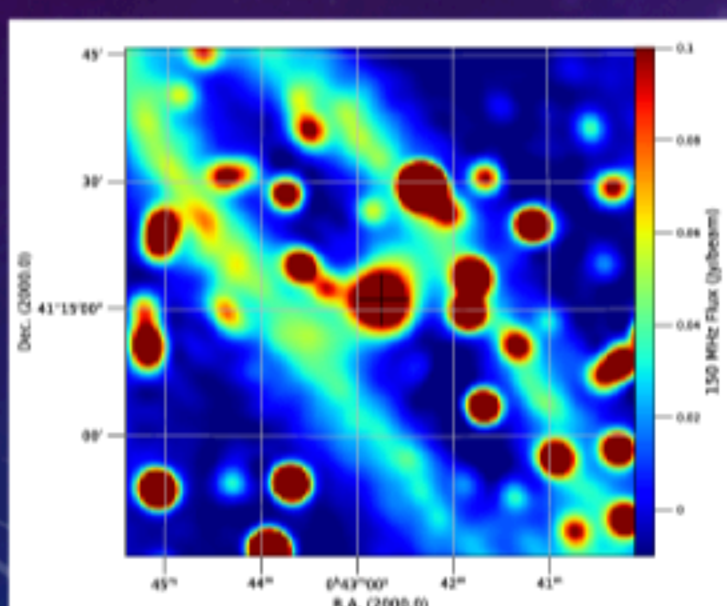
LOFAR (150 MHz) OBSERVATIONS

- 1.4 arcmin resolution
- 8 deg x 8 deg map

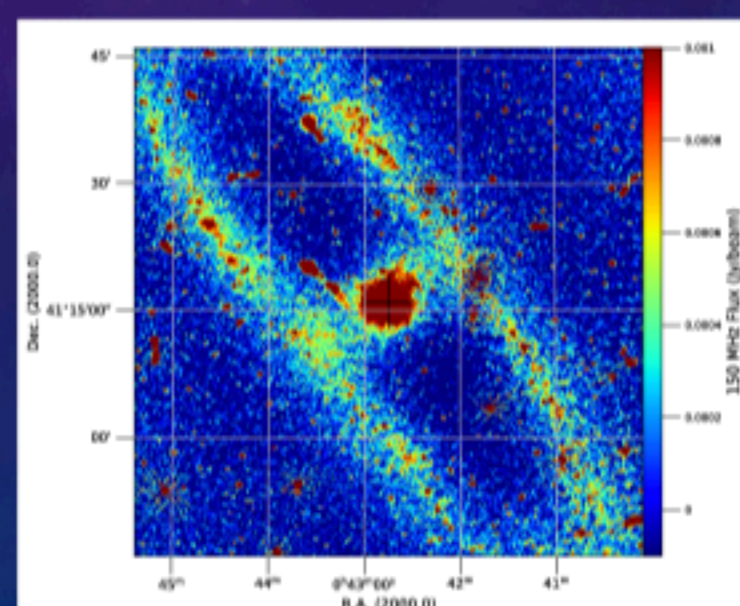
- Good correlation with the SF 10kpc-ring
- The Bulge (with no SF is much stronger than the ring
  —> different excitation in the 2 regions

- No 150 MHz counterpart of the FERMI excess

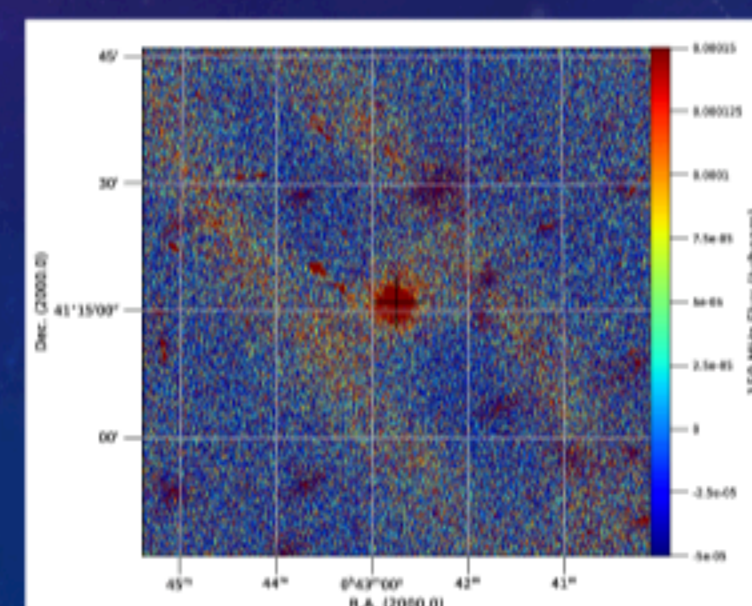
Very low resolution (1.4 arcmin)



Low resolution (20 arcsec)



High resolution (5 arcsec)



DOUBLE-PEAK EMISSION-LINE GALAXIES

CONFRONTING GALMER SIMULATIONS OF MINOR MERGERS

Double-peak narrow emission line galaxies have been studied extensively in the past years, in the hope of discovering late stages of mergers. It is difficult to disentangle this phenomenon from disc rotations and gas outflows

Role of minor mergers in Galaxy growth - Emission line probes of recent mergers

Search for 2 cores / counter parts to build samples

Maschmann et al., 2020, 2021

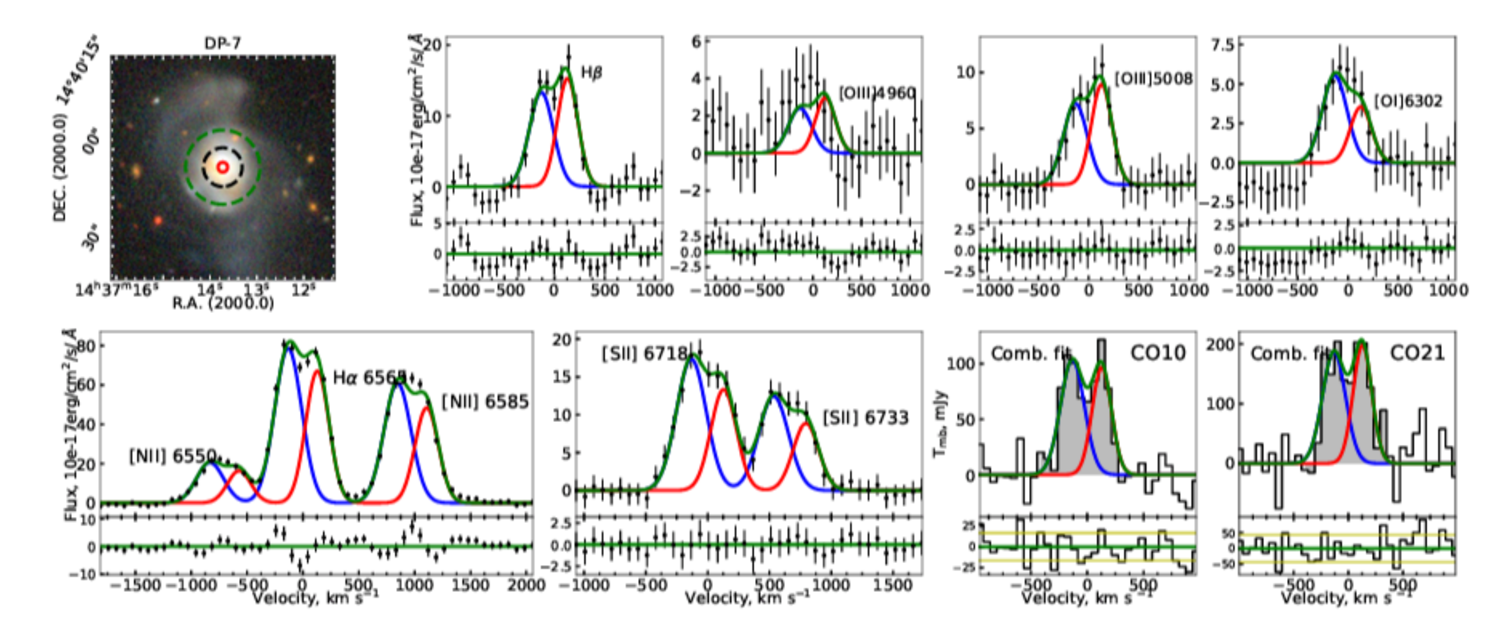


Fig. 2. Example of combined emission line fit for DP-7. We show the Legacy survey snapshot on top left and mark the position and size of the SDSS 3″ fibre in red and with green (resp. black) dashed lines the FWHM of the CO(1-0) (resp. CO(2-1)) beam of the IRAM 30m telescope. The top row displays next to the snapshot the Hβ, [OIII]λ4960, [OIII]λ5008 and [OI]λ6302 emission lines and in the bottom panels the [NII]λ6550, Hα, [NII]λ6585, [SII]λ6718, [SII]λ6733 and the CO(1-0) and CO(2-1) lines. We show the double Gaussian fit with the blueshifted (resp. redshifted) component in blue (resp. red) and the total fitted function in green. Tick marks indicate the line position, deviating sometimes from the expected redshift. For the Hα, [NII]λ6550, 6585 doublet we display the lines with respect to the expected Hα line velocity and the [SII]λ6718, 6733 with respect to the [SII]λ6718 line velocity. Residuals are plotted below each emission line fit.

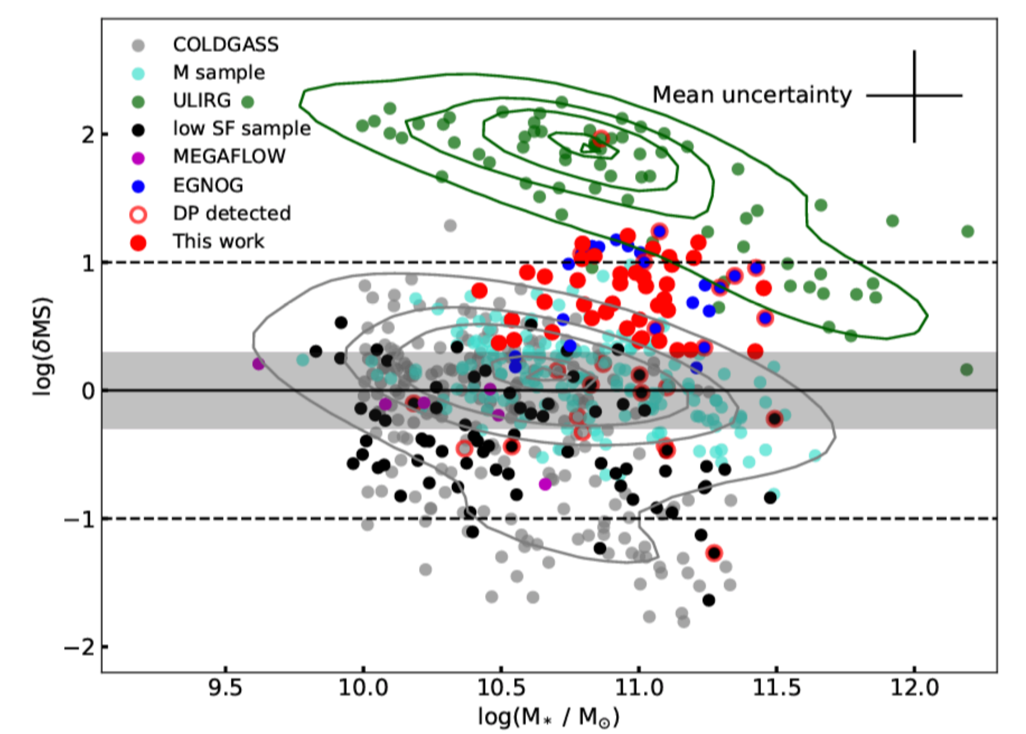


Fig. 3. Offset from the MS as in Fig. 1. We show the DP sample with red dots, the EGNOG sample with blue dots, the COLD GASS sample with grey dots, the low SF sample as black dots, the ULIRG as green dots, the M sample with turquoise dots and the MEGAFLOW sample with magenta dots. The literature samples are introduced in Sect. 2.5.1-2.5.6 and a detailed description of the MS is done in Sect. 2.6.1. We mark galaxies from other samples which were identified to exhibit a DP emission line with red circles. We show contour lines for ULIRG in green and for the COLD GASS sample combined with the M sample in grey. In the top right we show the mean uncertainties of all samples and discuss the individual uncertainties for each sample in the text.

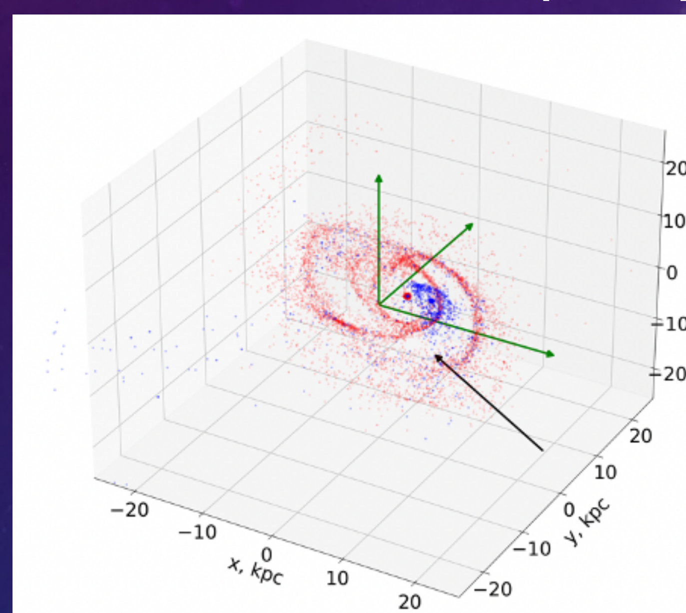
KINEMATIC DECOMPOSITION OF A MINOR MERGER

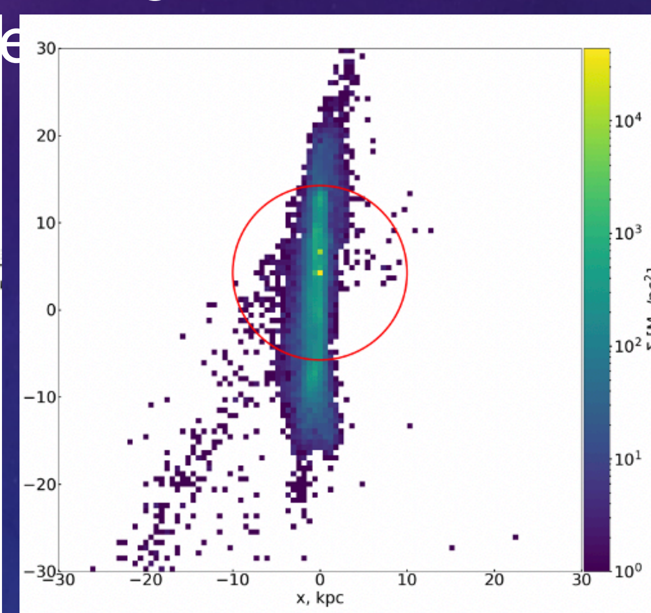
Double-peak narrow emission line galaxies have been studied extensively in the past years, in the hope of discovering late stages of mergers. It is difficult to disentangle this phenomenon from disc rotations and gas outflows

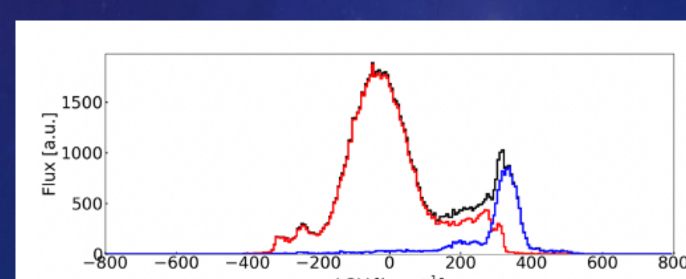
Role of minor mergers in Galaxy growth - Emission line probes of recent mergers

D. Maschmann, A. Hallé et al., in prep.

First peri-passage --



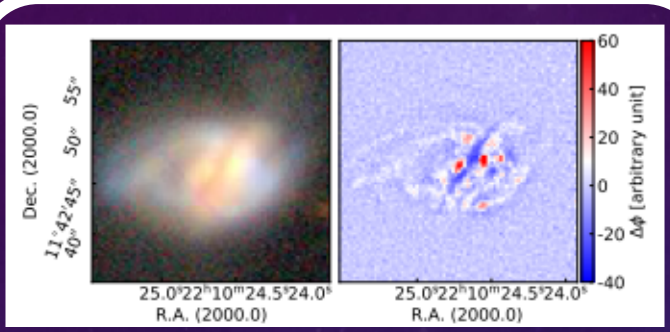




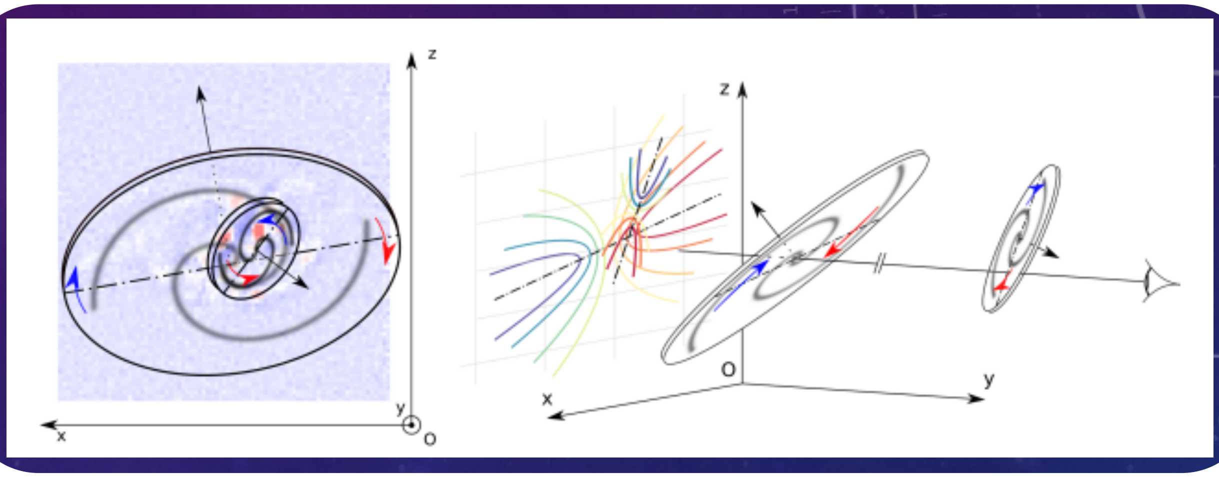
KINEMATIC DECOMPOSITION OF A MINOR MERGER

Mazzilli-Ciraulo et al., 2021, A&A, 653, 47

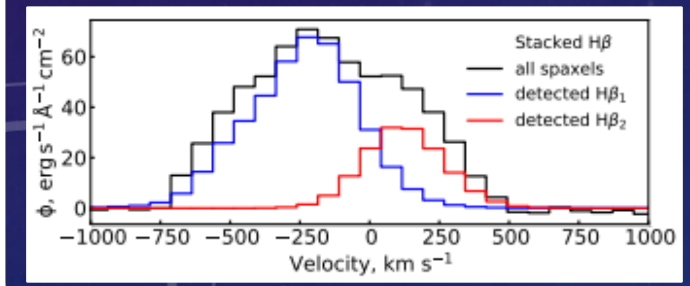
Role of minor mergers in Galaxy growth - Emission line probes of recent mergers

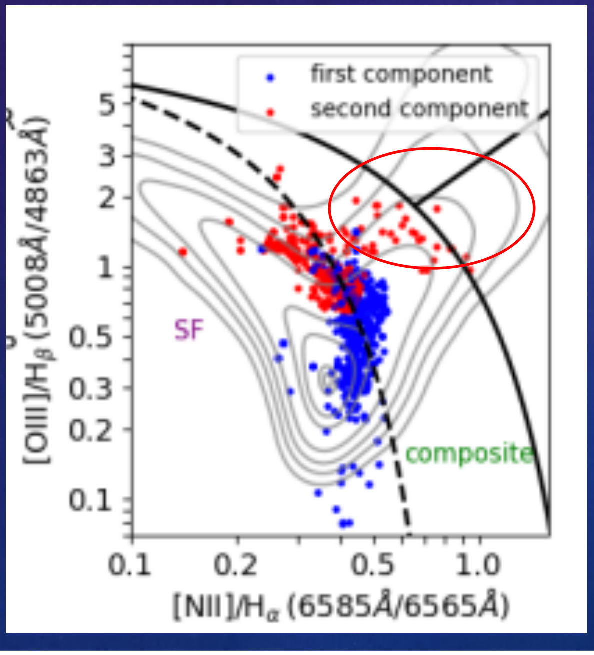


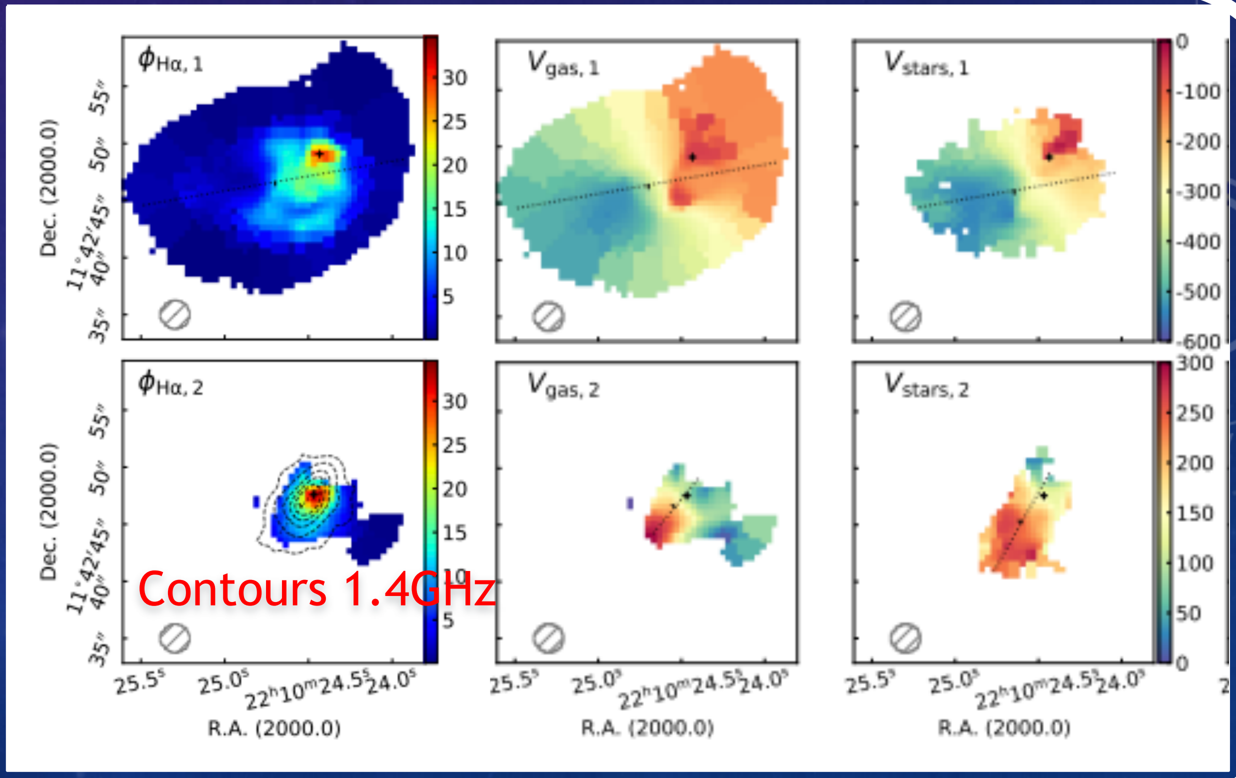
Mass ratio:
9+1



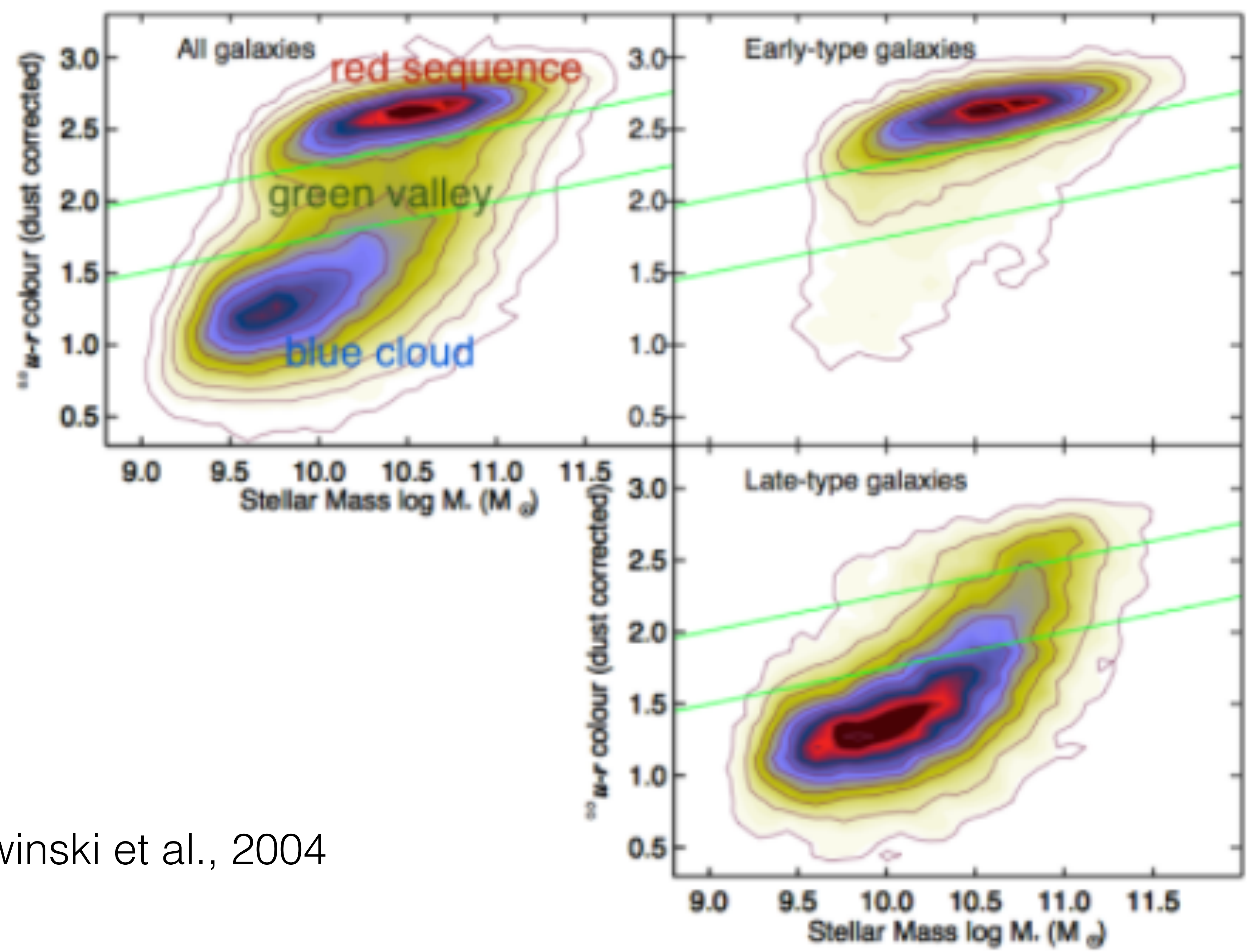
Excitation de type AGN/
LINER-type excitation for the second component+ radio continuum excess







Main Sequence of Star formation



Schawinski et al., 2004

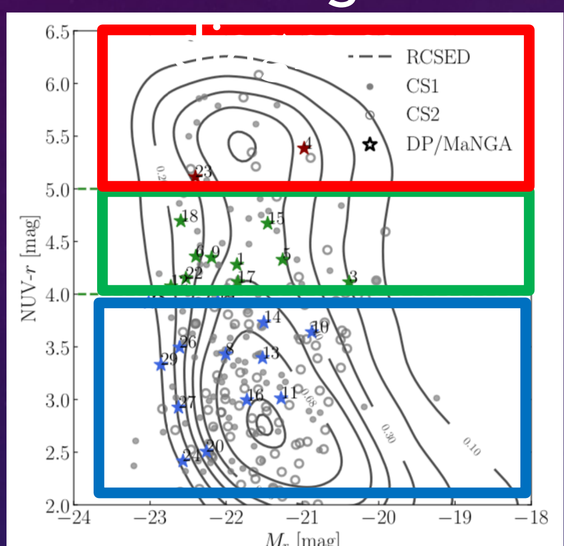
QUENCHING IN THE CENTRE OF GREEN VALLEE GALAXIES LINKED TO A WEAK AGN ACTIVITY?

Spatial separation : stellar population / gas SFR tracers / AGN-dominated regions

Probe LINERs population (more common)

Mazzilli-Ciraulo et al., 2022, A&A submitted

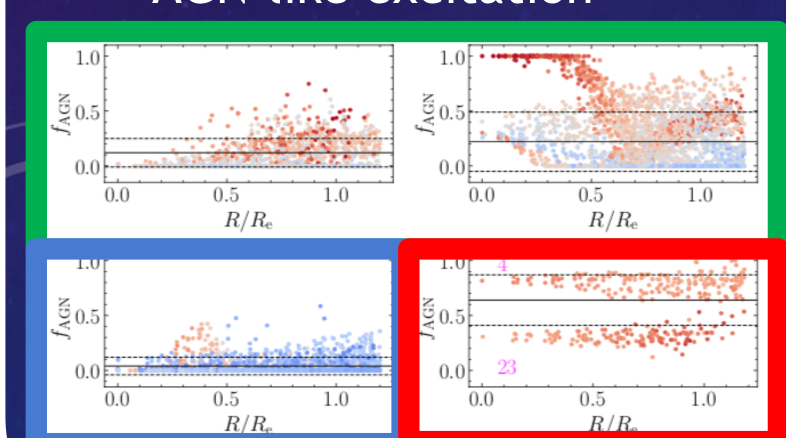
Colour-magnitude



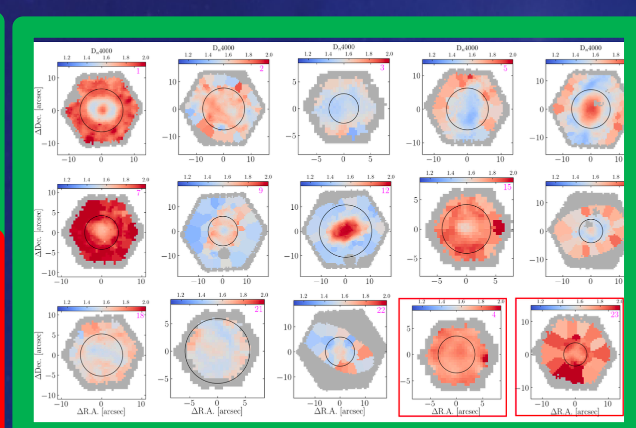
MaNGA, RCSED data

Observations of the sample (29 galaxies) at IRAM-30m and Nançay, in prep.

Fraction of *spaxels* with an AGN-like excitation



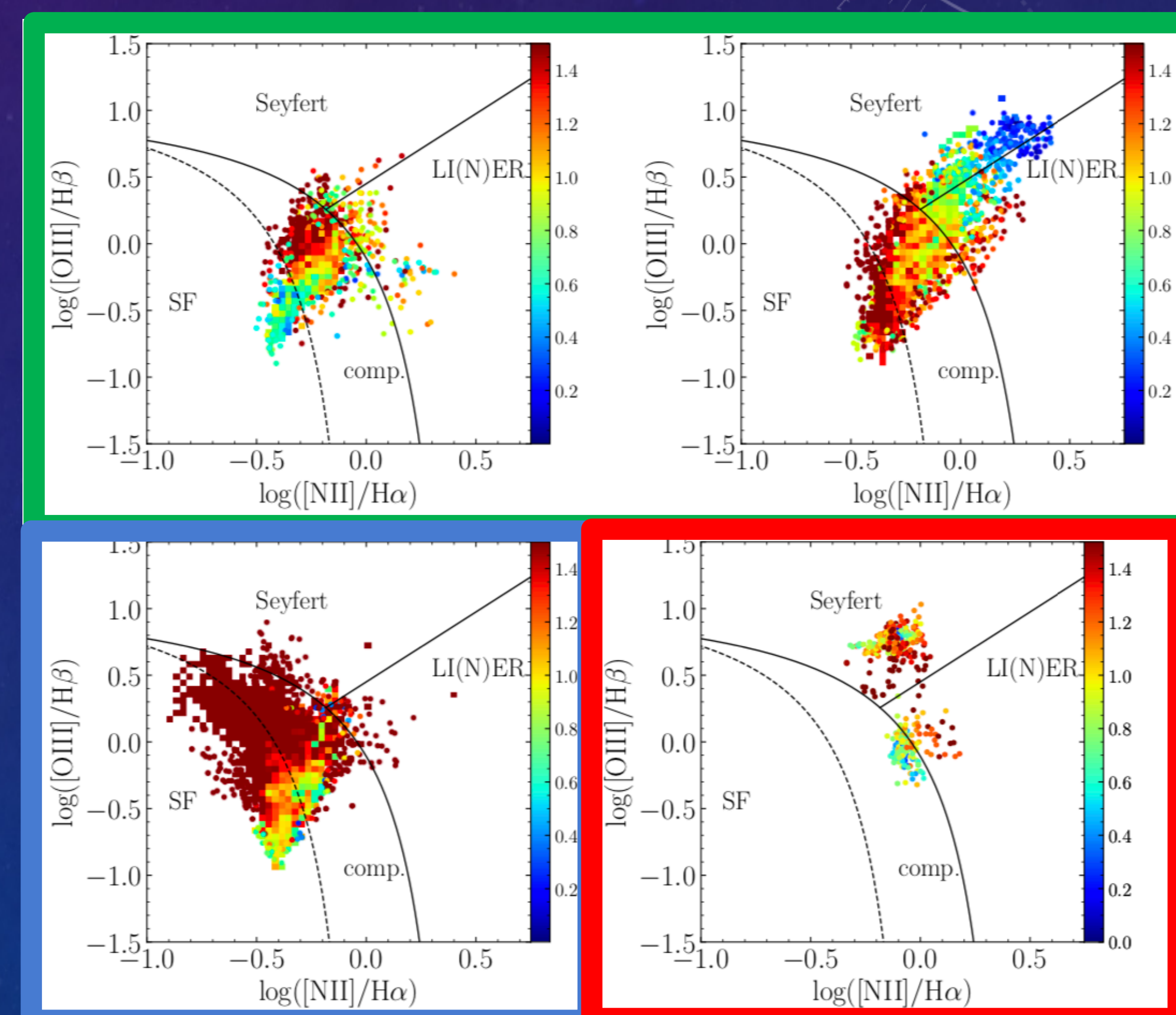
Stellar populations (D4000) young (blue) VS old (red)



BPT diagrams

SF inside, quenched outside

SF outside, quenched inside



Feedback

Colour composite image of **Centaurus A**, revealing the lobes and jets emanating from the active galaxy's central black hole. The 870-micron submillimetre data, from LABOCA on APEX in orange. X-ray from the Chandra in blue. Visible light data from the Wide Field Imager (WFI) on the MPG/ESO 2.2 m La Silla,, show the background stars and the dust lane

NGC 4258 : X-rays from Chandra (blue), radio waves from the VLA (purple), optical data from Hubble (yellow and blue), and infrared with Spitzer (red).

What controls galactic scale mass budget (inflows vs outflows) ?

1. What is the **mode of feedback** (radiative vs mechanical) ?
2. How does the feedback affect Star Formation **(positive vs negative)** ?

AGN episodes **(short timescales)** along the life of the BHs affect **(on average)** the surrounding gas and influence SF and galaxy growth ? —> **need for statistics ?**

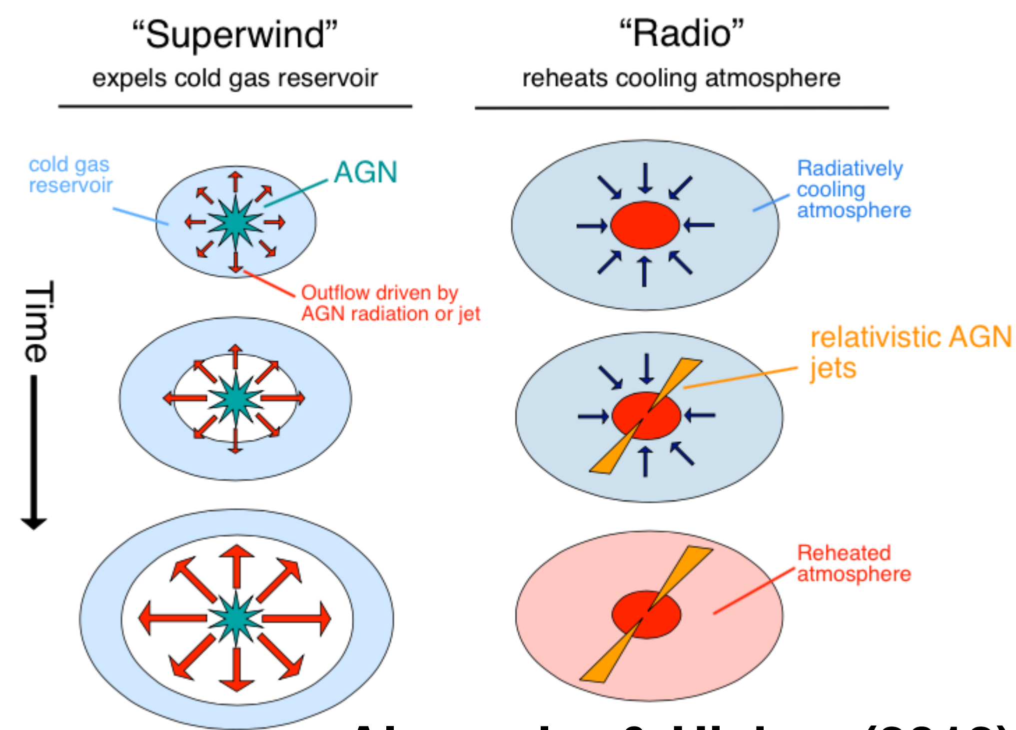
Feedback

i.e. **Review by Fabian (2012)**

Radiative-mode, Quasar-mode, Energy-driven

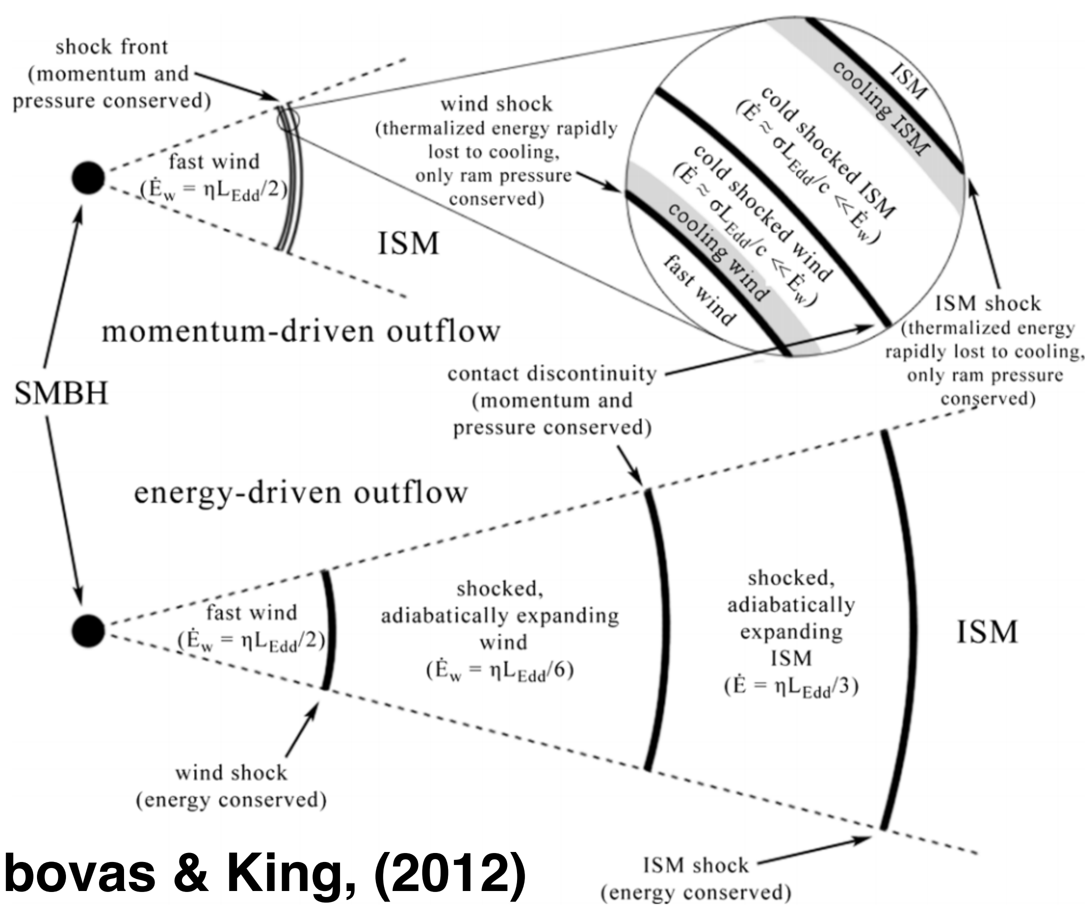
Kinetic (mechanical)-mode, Radio-mode, Momentum-driven

Radiative mode	Mechanical (kinetic) mode
Quasar mode	Radio-mode
wind	wind / jets
< 1 kpc	> 1 kpc
QSO, Seyfert	Liners
HI abs, ionised, molecular	molecular outflows ?
High luminosity AGN	Low luminosity AGN



Alexander & Hickox (2012)

Figure 7: Schematic diagrams to illustrate the two main modes of AGN outflows: “superwind”-mode outflows such as those found in luminous AGNs and “radio”-mode outflows such as those found in low-excitation radio-loud AGNs.



Zubovas & King, (2012)

Review by Alexander & Hickox (2012)
Review by Heckman & Best (2014)
Review by King & Pounds (2015)
Review by Harrison (2018)
Review by Hickox & Alexander (2018)

Feedback

	$L/L_{Edd} \lesssim 0.01$	$L/L_{Edd} \gtrsim 0.01$	
	Jet mode	**Radiative mode**	
		Type 2	**Type 1**
Radio Loud	**Low–excitation radio source** * Very massive early–type galaxy * Very massive black hole * Old stellar population; little SF * Moderate radio luminosity * FR1 or FR2 radio morphology * Weak (or absent) narrow, low ionisation emission lines	**High–excitation radio source** * Massive early–type galaxy * Massive black hole * Old stellar population with some on–going star formation * High radio luminosity * Mostly FR2 morphology * Strong high–ionisation narrow lines	**Radio–loud QSO** Host galaxy properties like high–excitation radio source, but with addition of: * Direct AGN light * Broad permitted emission lines * Sometimes, beamed radio emission
Radio Quiet	**AGN LINER** * Massive early–type galaxy * Massive black hole * Old stellar population; little SF * Weak, small–scale radio jets * Moderate strength, low–ionisation narrow emission lines	**Type 2 QSO / Seyfert 2** * Moderately massive early–type disk galaxy with pseudo–bulge * Moderate mass black hole * Significant central star–formation * Weak or no radio jets * Strong high–ionisation narrow lines * QSOs more luminous than Seyferts	**Radio Quiet QSO / Seyfert 1** Host galaxy properties like Type–2 QSO and Seyfert 2, respectively, but with addition of: * Direct AGN light * Broad permitted emission lines * Bias towards face–on orientation
	Light dominated by host galaxy		Direct AGN light

Heckman & Best, (2014)

Fig. 4.— The categorisation of the local AGN population adopted throughout this review. The blue text describes *typical* properties of each AGN class. These, together with the spread of properties for each class, will be justified throughout the review.

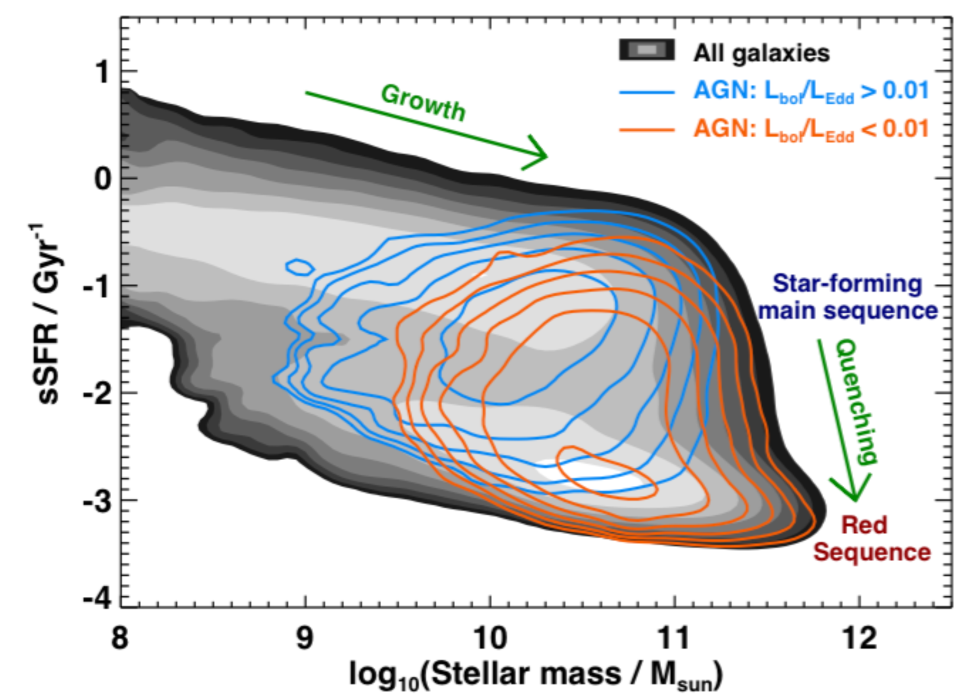
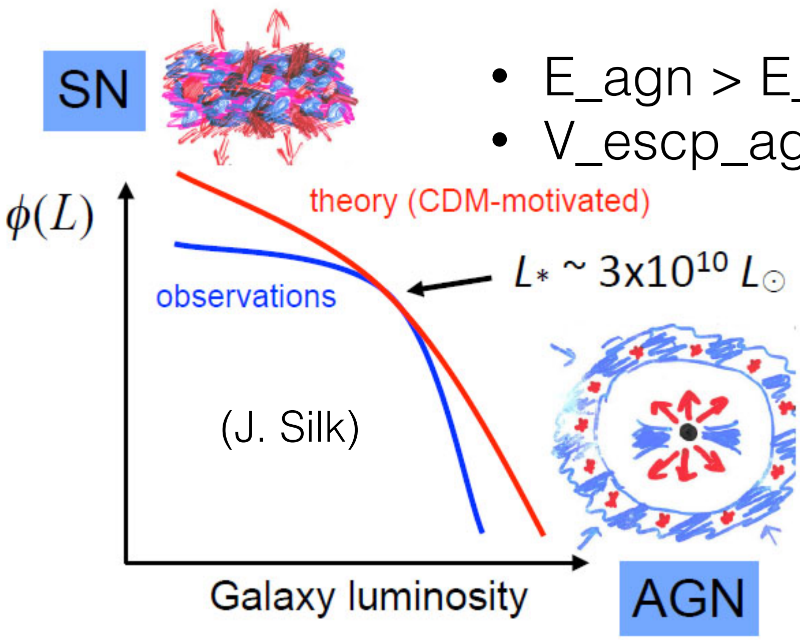


Fig. 2.— The distribution of galaxies in the SDSS main galaxy sample on the plane of stellar mass *vs.* specific star formation rate (sSFR = SFR/M_*). The greyscale indicates the volume-weighted distribution of all galaxies, with each lighter color band indicating a factor of two increase. Galaxies predominantly fall within two regions: a 'main sequence' of star-forming galaxies, and a red sequence of 'quenched' galaxies. The blue and red contours show the volume-weighted distributions of high (>1%; mostly radiative-mode) and low (< 1%; mostly jet-mode) Eddington-fraction AGN, with contours spaced by a factor of two.

Galaxies Formation and Feedback
and Molecular gas

Models without feedback fail reproducing observations



- E_agn > E_SN
- V_escp_agn >> V_escp_SN

Possible quenching mechanisms

- Gas removal
  - **outflowing winds by star formation or AGN**

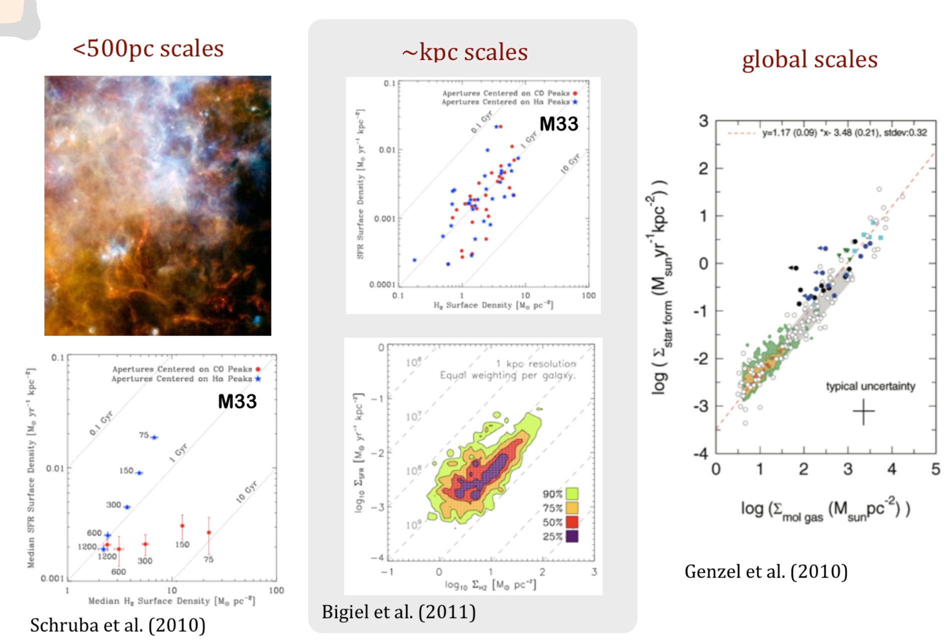
but also :
- Gas supply shutdown: strangulation (subhalos tidal stripping, shocks)
- Environmental effects: ram-pressure stripping…

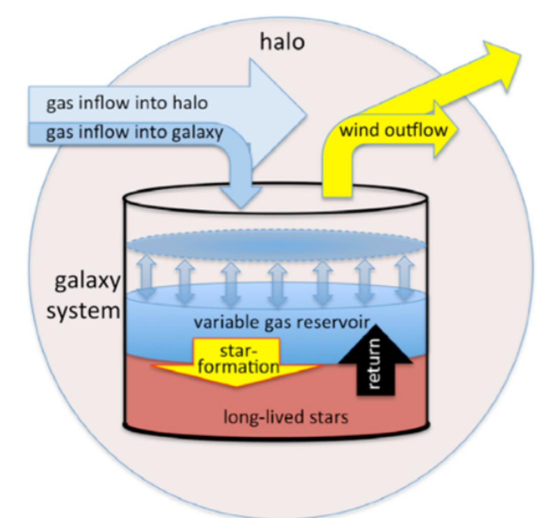
Numerical simulations (ie Di Matteo et al. 2005, Croton et al.2006, Bower 2006, Dubois et al. 2010)

Molecular gas and Star Formation

What regulates the star formation process in galaxies ?

- need to form **molecular gas (reservoir for star formation)**
- need to efficiently convert this gas into stars (efficient gas consumption: major mergers…)





Lilly et al. (2013), see also, e.g. Genel et al. (2008), Bouché et al. (2010), Davé et al. (2011,2012), Krumholz & Dekel (2012)

Molecular outflows (Mkr231) ~10yrs ago

- Giant molecular outflow of about **~700 Msun/year, far larger** than the ongoing star-formation rate (~200 M/year) **(Feruglio et al. 2010, 2015)**
- Mrk 231 : wind-driven molecular **kpc-outflow** (**Feruglio et al. 2010, 2015**). Nearest quasar, with a nuclear **UFO in X-ray** (velocity 20000 km/s)
- Sub-kpc scale **HI outflow** of ~1300 km/s (**Morganti et al. 2016**)
- Mrk 231 contains a **radio plasma jet and radio lobes** but the jet power does not seem to drive and sustain the outflow
- **Multi-scale** observed outflow where most of the UFO kinetic energy is transferred to mechanical energy of the kpc-scale outflow (**Feruglio et al. 2015**).

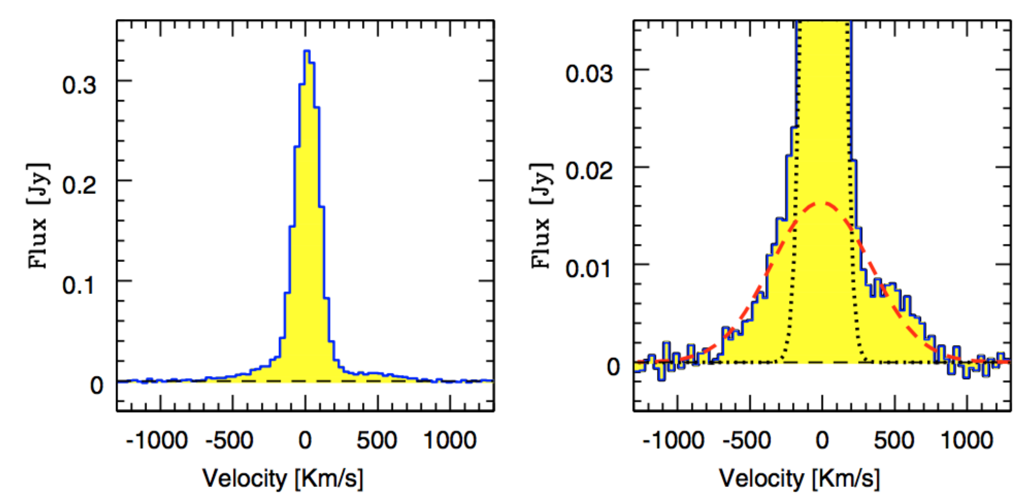


Fig. 1. Continuum-subtracted spectrum of the CO(1–0) transition in Mrk 231. The spectrum was extracted from a region twice the beam size (full width at half maximum, *FWHM*), and the level of the underlying continuum emission was estimated from the region with $v > 800$ km s^{-1} and $v < -800$ km s^{-1}. *Left panel*: full flux scale. *Right panel*: expanded flux scale to highlight the broad wings. The line profile has been fitted with a Gaussian narrow core (black dotted line) and a Gaussian broad component (long-dashed line). The *FWHM* of the core component is 180 km s^{-1} while the *FWHM* of the broad component is 870 km s^{-1}, and reaches a Full Width Zero Intensity (FWZI) of 1500 km s^{-1}.

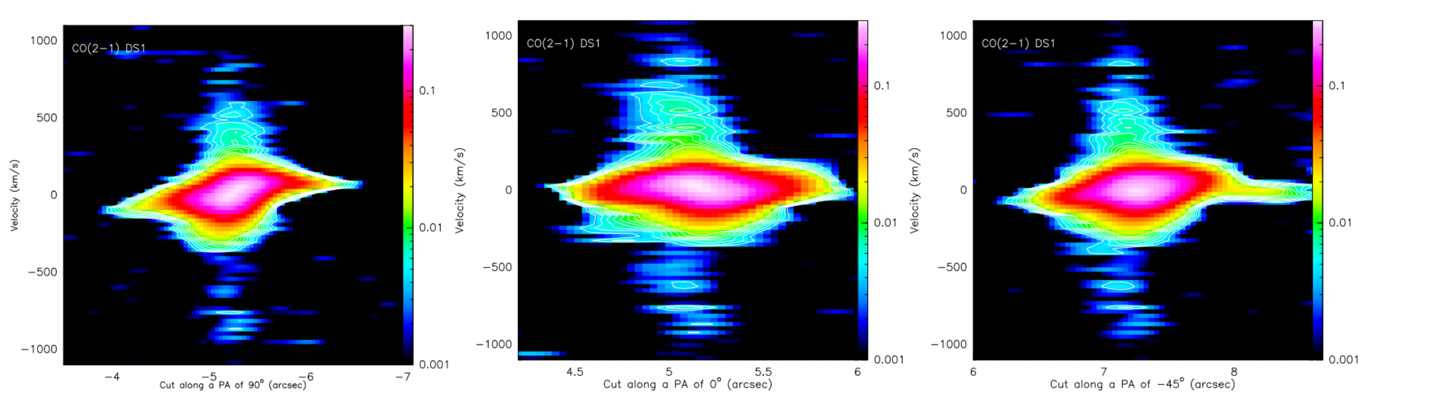
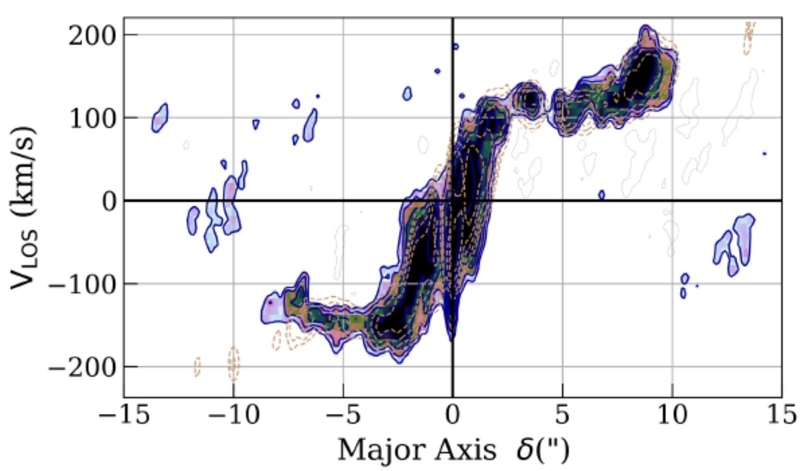


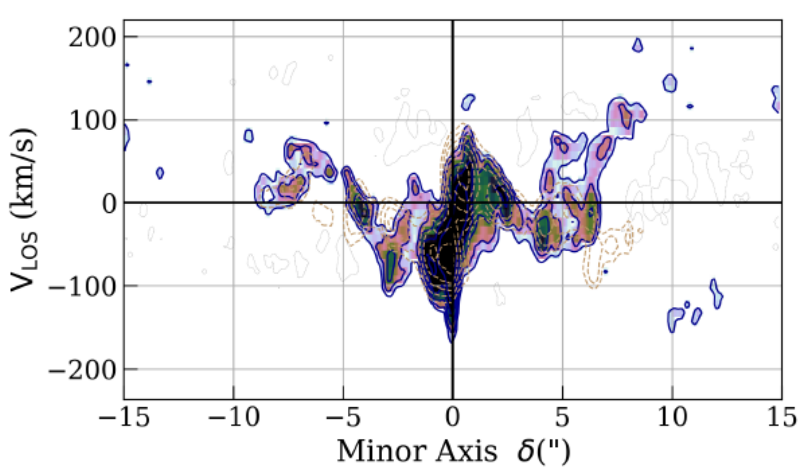
Fig. 6. Position-velocity plots with east-west (left panel, left to right), south-north (middle panel, left to right) and PA -45 deg, south-west to north-east (right panel, left to right) cuts, through the CO(2-1) peak from DS1. Contours levels are 3 to 15σ, 1σ =1.3 mJy/20 MHz.

NGC 1808-Sy2

No outflow in CO close to the center

But outflow at larger scale

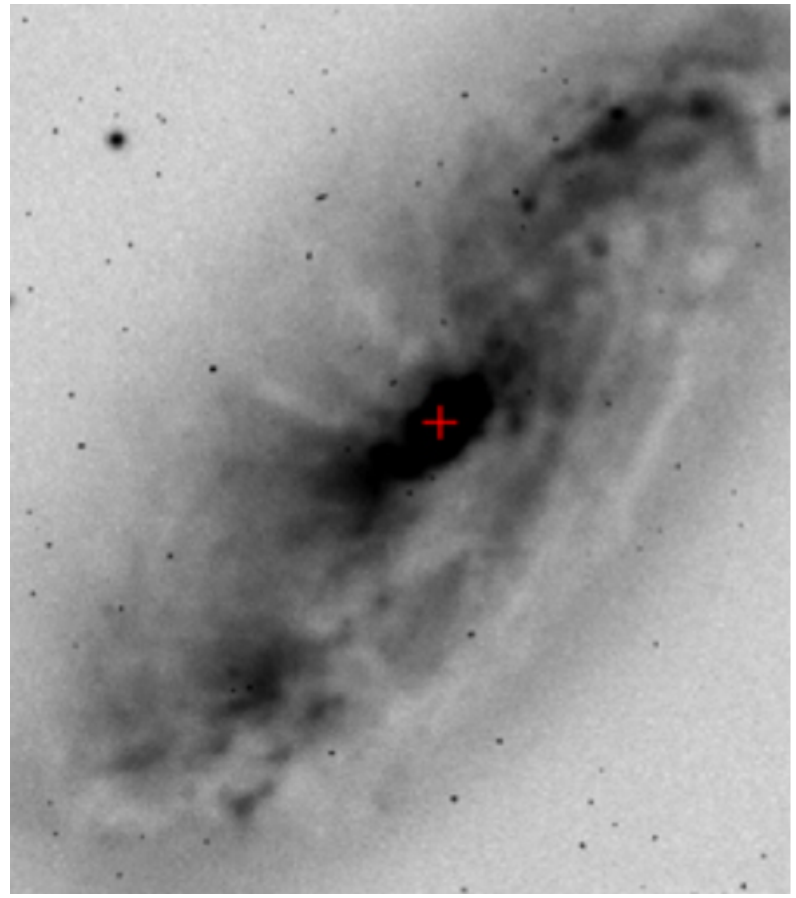




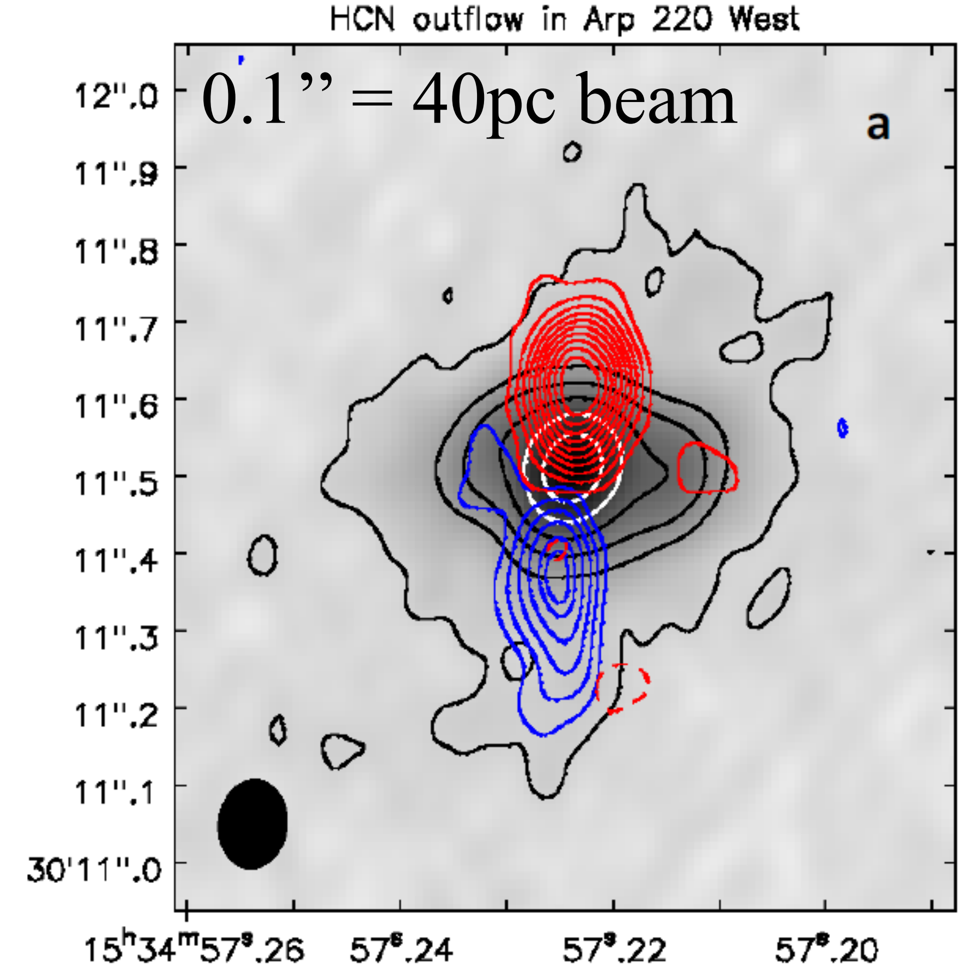
CO(3-2)

Audibert et al 2021

Arp 220



➔ Due to starburst



Collimated HCN outflow

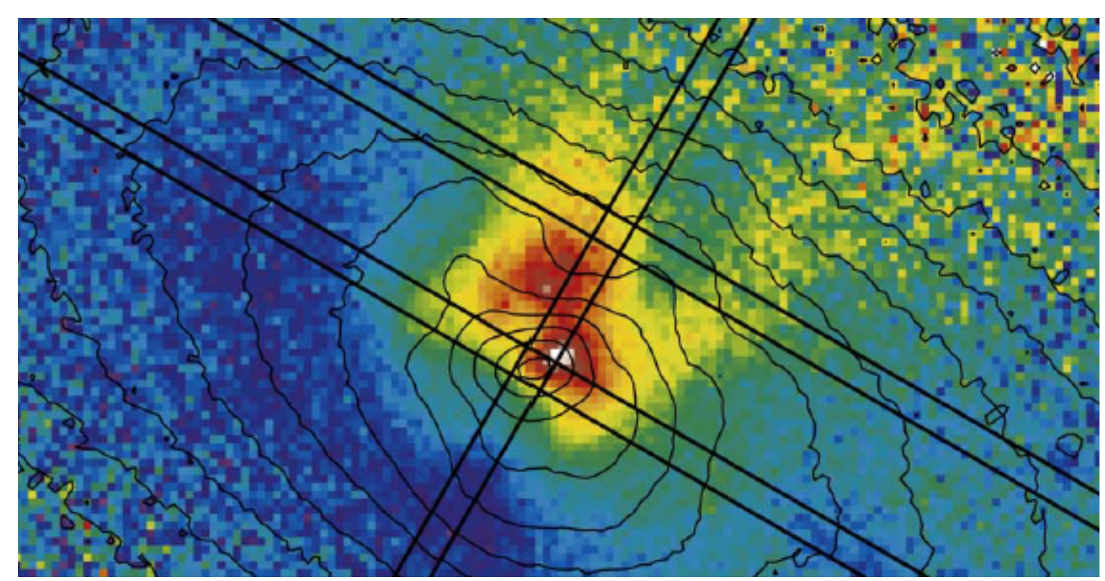
→SN + AGN contribution

Barcos-Munoz et al 2018

N4418 Sy2

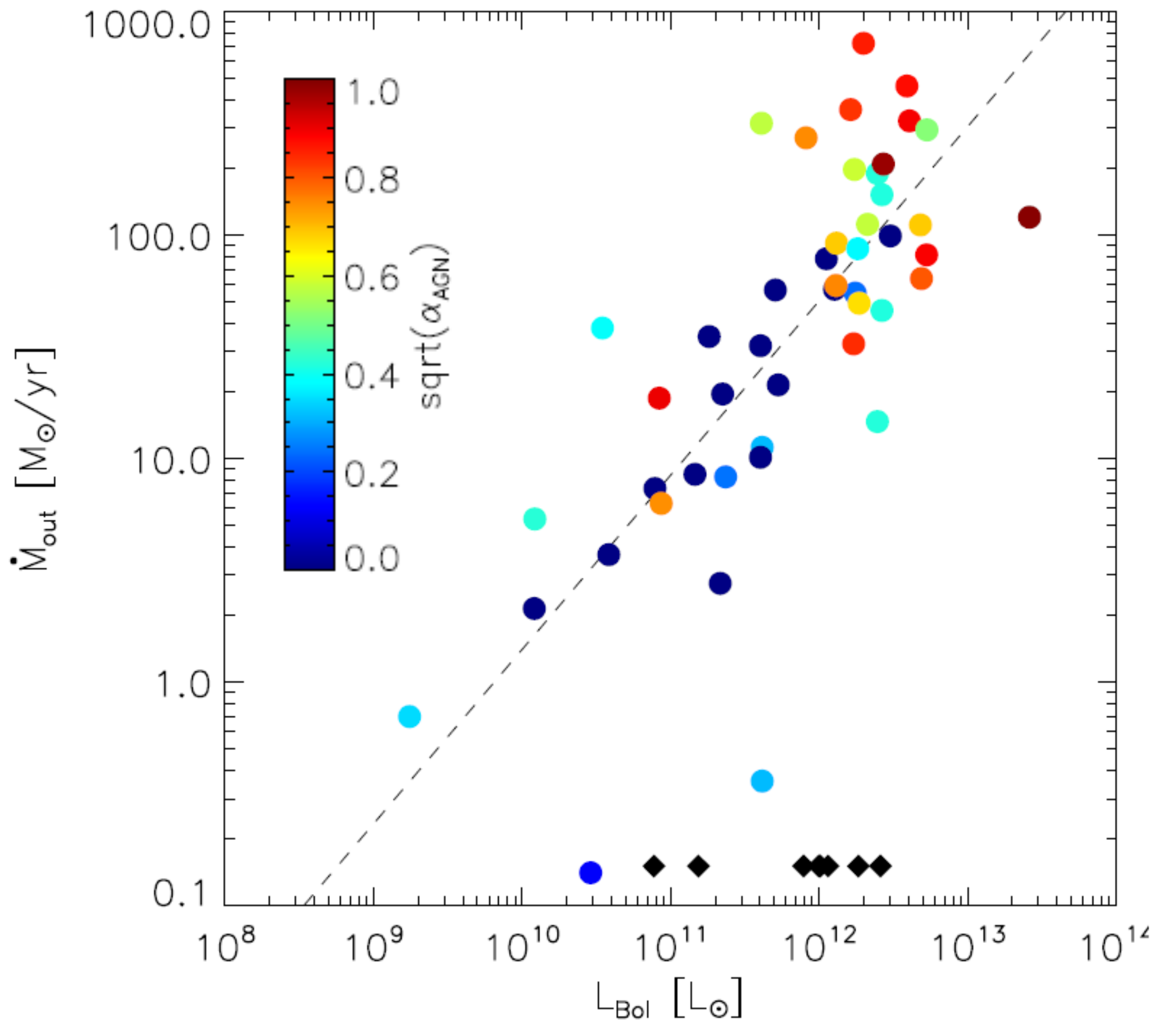
Dust outflow

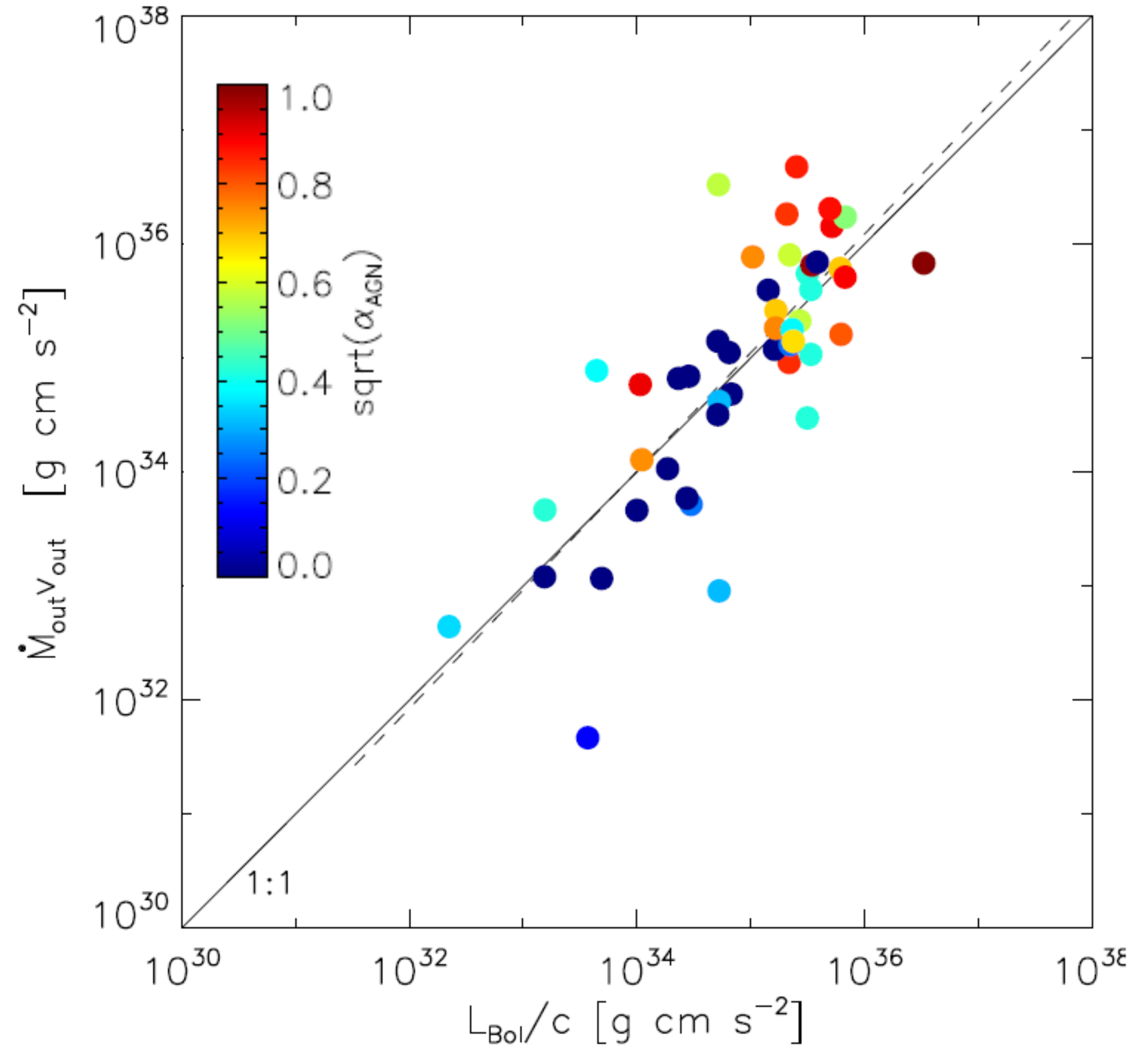
Ohyama-19



ULIRGS outflows

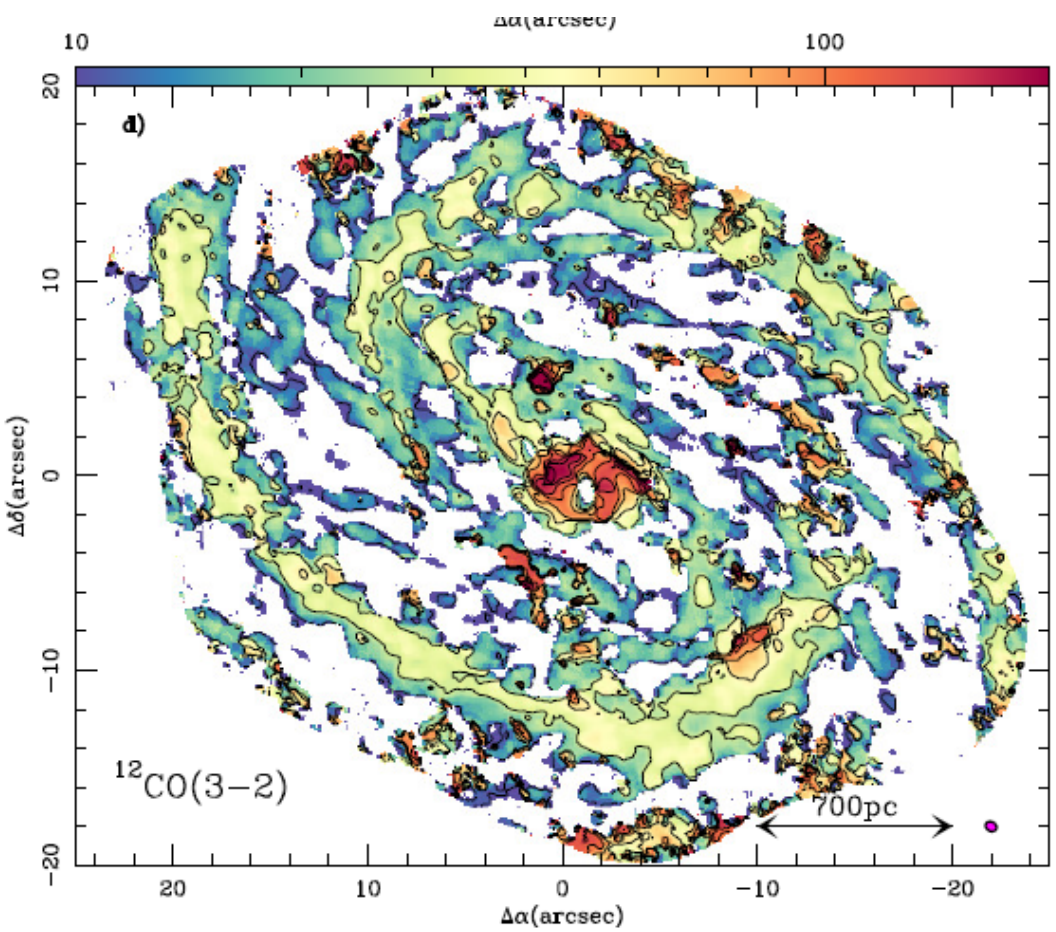
12 ULIRGS: OH outflows with Herschel *(Gonzalez-Alfonso et al 2017)*
More powerful with AGN, Appear momentum-driven

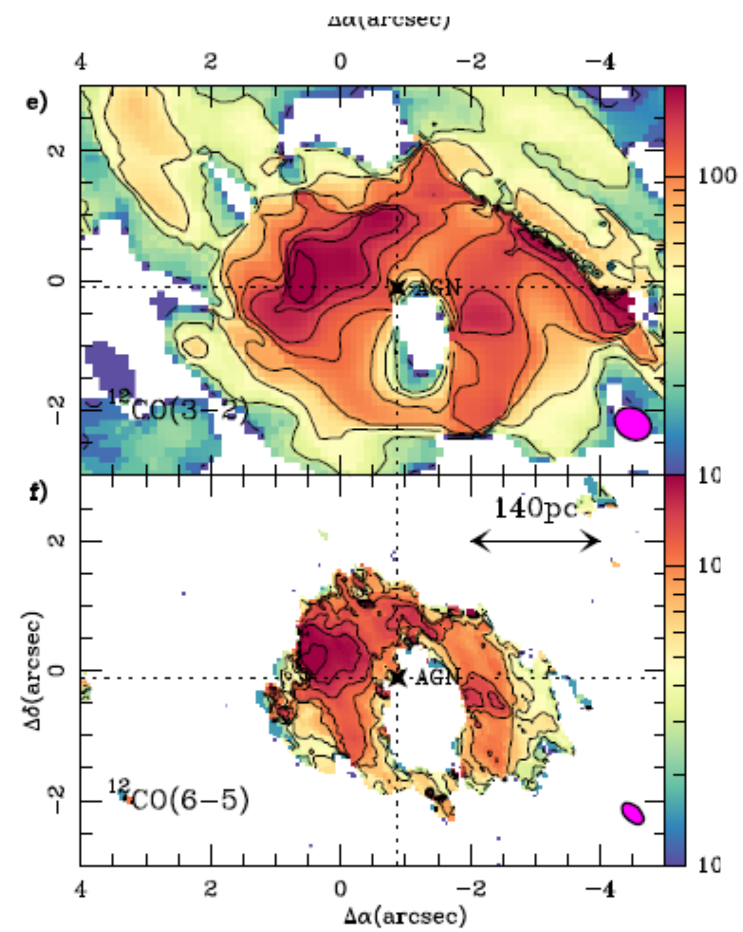




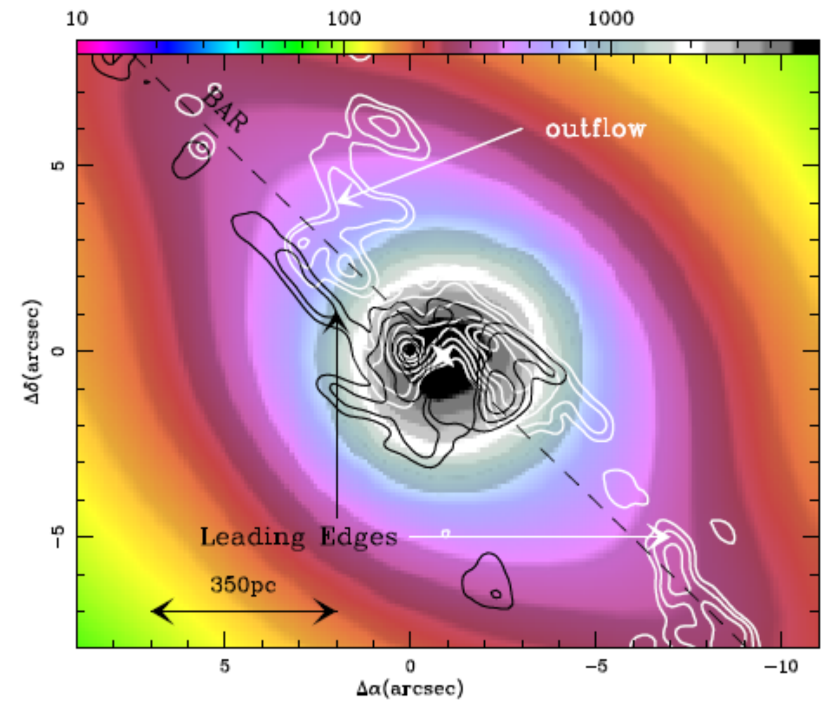
Lutz et al 2020

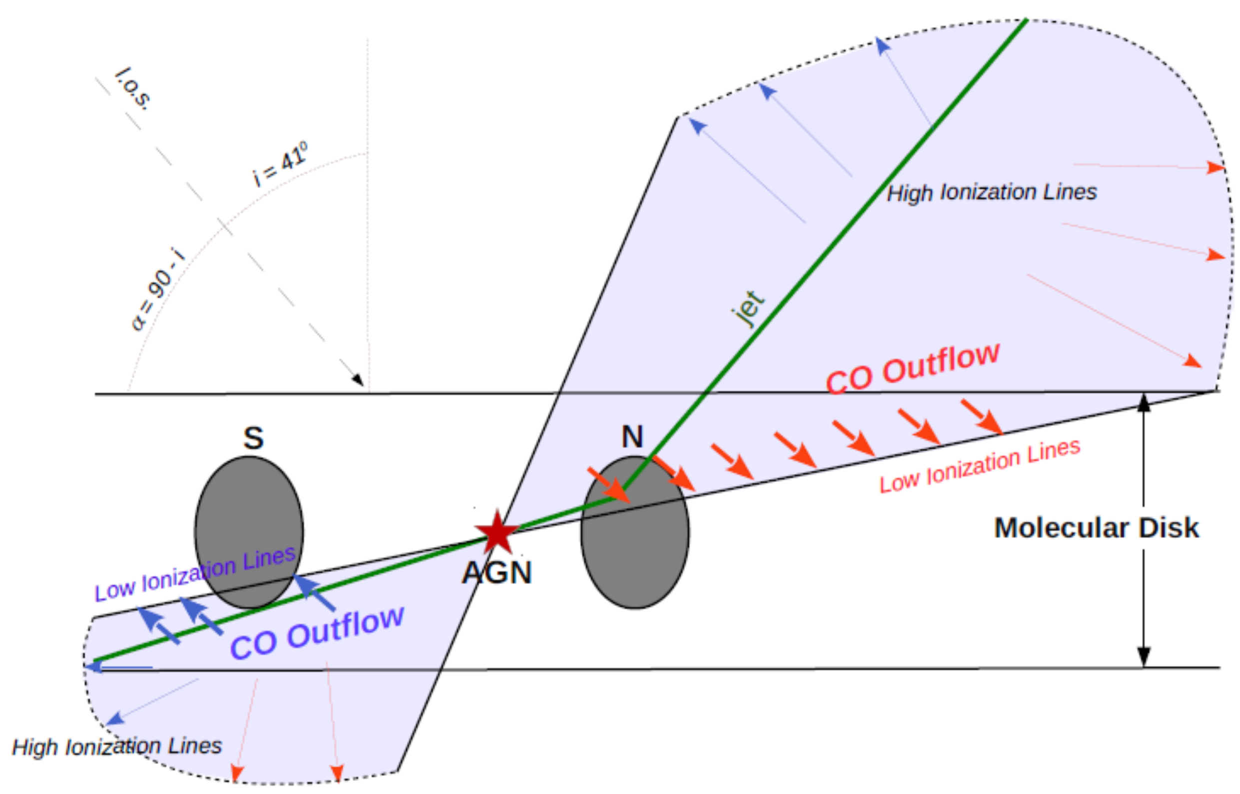
Offcentered nucleus and outflow in NGC1068





Black V=-50km/s
White V=50km/s





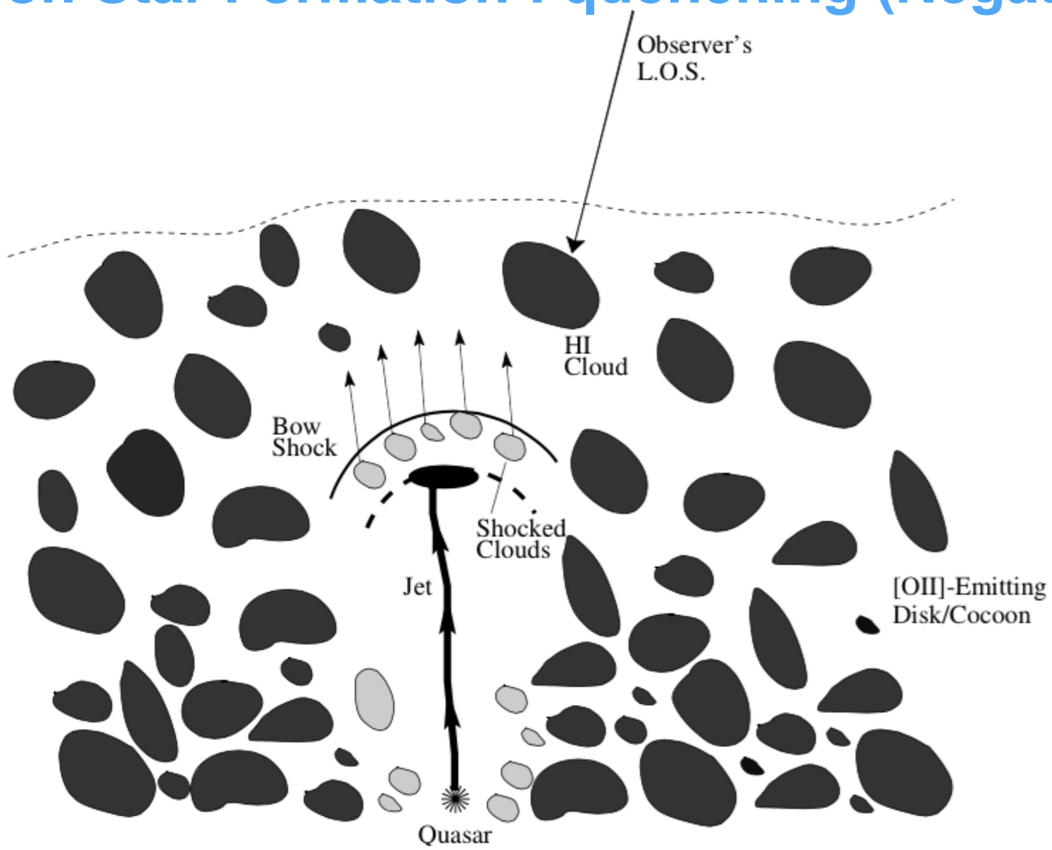
Outflow of 63M$_{\odot}$/yr

10x the star formation rate in this region

Garcia-Burillo, Combes, Usero et al 2014

Positive vs Negative Feedback

Effect on Star Formation : quenching (Negative Feedback) vs triggering (Positive Feedback) ?



Schematic showing a young radio source expanding through the natal cocoon of dense gas in the near-nuclear regions of the host galaxy. It is expected that jet-cloud interactions will be particular strong at this early stage of radio source evolution (from **Tadhunter 2016**)

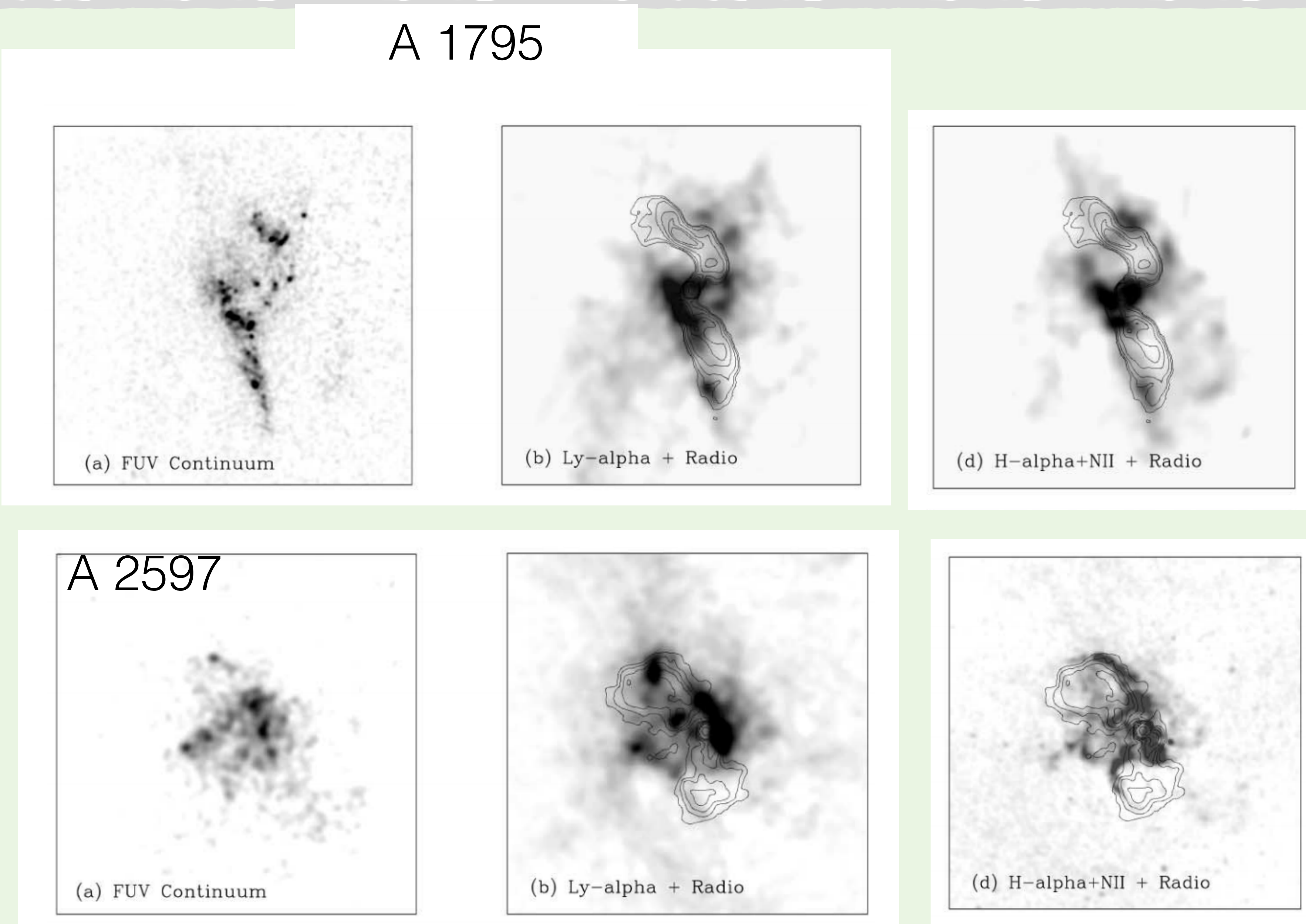
AGN Negative-feedback (quenching SF):

- No : do not affect on the SF in disk **(Gabor et al. 2014)** since little effect on the dense gas fraction where the star from
- Yes / No : remove some gas that may cool later and reform molecules in situ —> delay SF

AGN Positive-feedback (triggering SF) :

- Yes : **Overpressure the ISM** **(Rees 1989)** : more efficient than ablation and KH instabilities at the surface of the clouds **(Wagner et al., 2016**). **More efficient in larger clumps** —> modified PDF / truncated Larson Law ?
- No : if clouds are too small (destroyed) —> very much **dependent on the ISM properties / cloud distribution** (**Wagner et al., 2016** and references therein).

Observational (rare) Evidences



(i) Local BCGs

- **Abell 1795, Abell 2597** **(McNamara et al., 1996, O'Dea et al., 2004…)**

(i) Higher-z

- **4C41.17**@ z=3.9 **(Bicknell et al., 2000, deBreuck et al., 2005)**
- **CO vs radio-jet alignment @ z=2.6** **Nesvadba et al. (2009)**, 13 sources @ 1.4 < z < 2.8 : **Emonts et al. (2014)**
- QSO at higher-z **: BR1202-0725 @ z=4.7 (Klamer et al., 2004)** vs protocluster / merger

Observational (rare) Evidences (ii) : Local radio-sources Minkowski Object, HE450-2958, 3C285, Centaurus A

- **Minkowski Object (ie Van Breugel et al., 1985, Croft et al., 2006, Salomé et al., 2015, Lacy et al., 2017)**

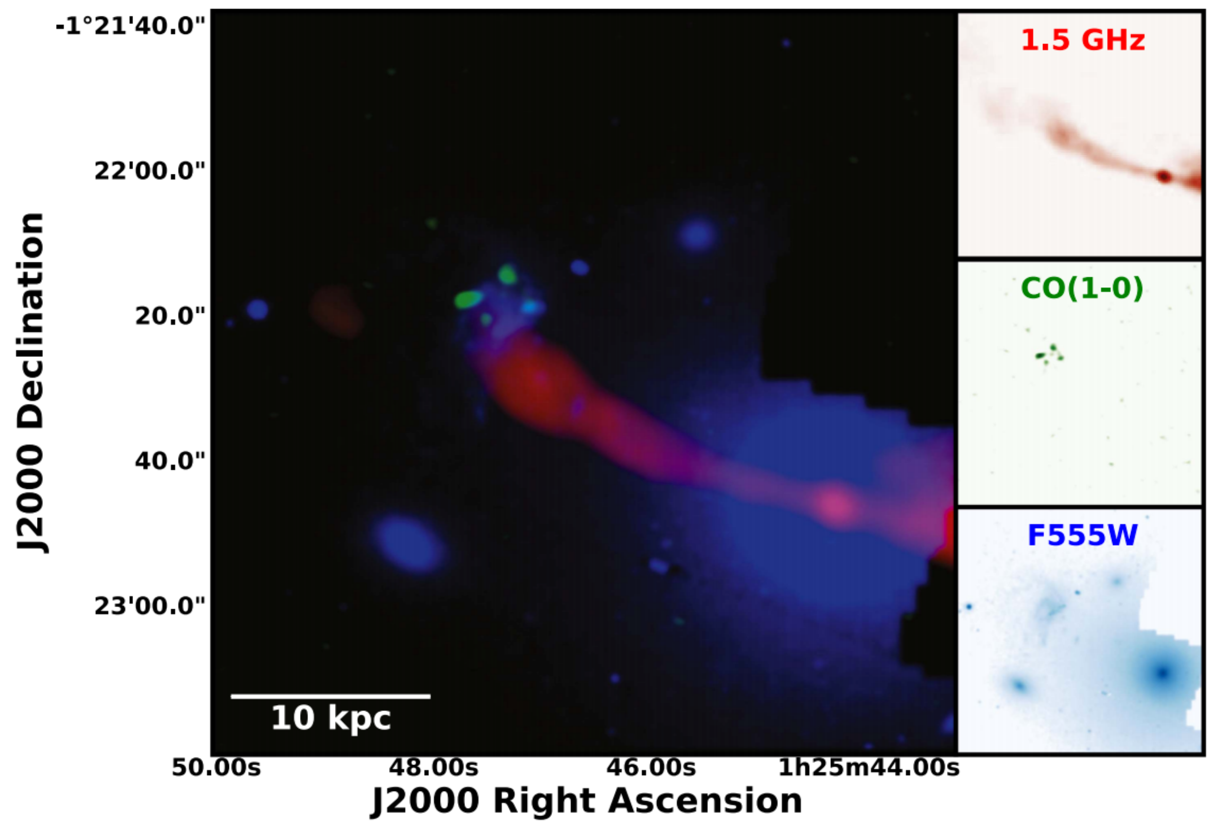
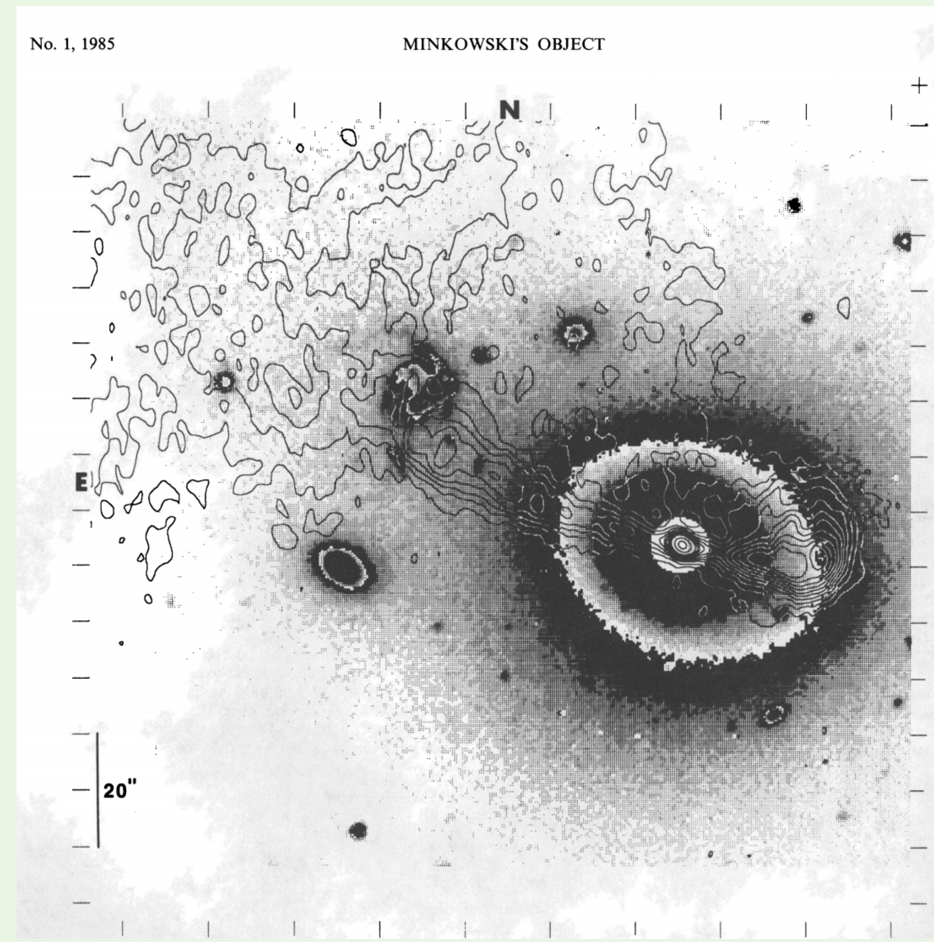


Figure 1. Overview of the VLA, *HST*, and ALMA imaging of Minkowski's Object. The 1.5 GHz VLA image of the radio jet is shown in red, the *HST* F555W image is shown in blue, and the CO(1-0) moment 0 map from our new ALMA spectral line observations is shown in green. The large image is a three-color rgb composite image, while the smaller images on the right highlight each band individually.



- **HE450-2958 (Elbaz et al, 2009, Molnár et al., 2017)**
- **Centaurus A (Graham 1998; Fassett & Graham 2000; Mould et al., 2000; Rejkuba et al. 2002; Oosterloo & Morganti 2005; Crockett et al. 2012, Hamer et al., 2015, Santoro et al., 2015, Salomé et al., 2015)**
- **100s of AGN in the Chandra Deep Field South** : AGN with pronounced **radio jets** exhibit a much higher star formation rate than purely X-ray **(Zinn et al., 2013)**

NGC 5128
(Centaurus A)

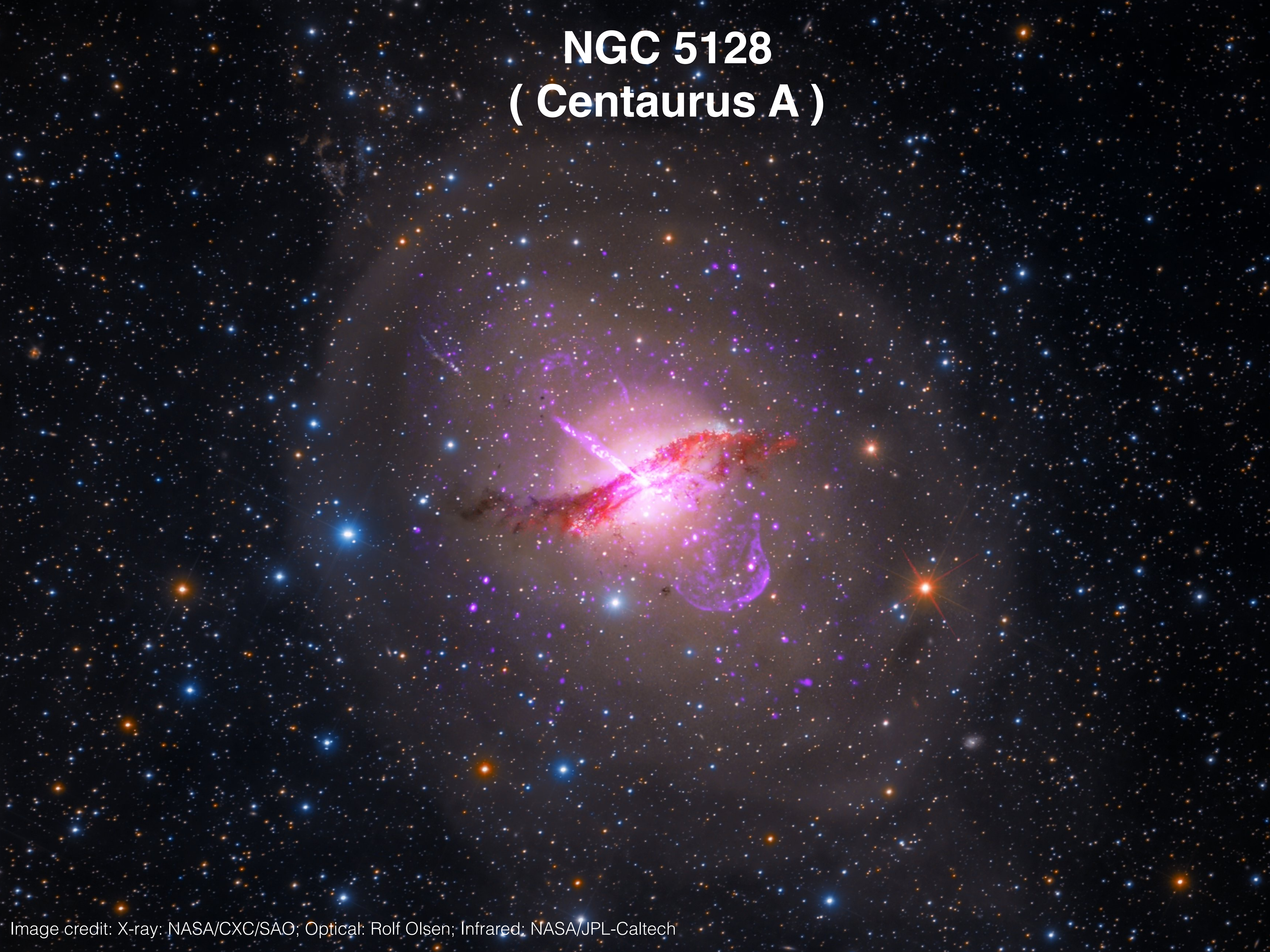
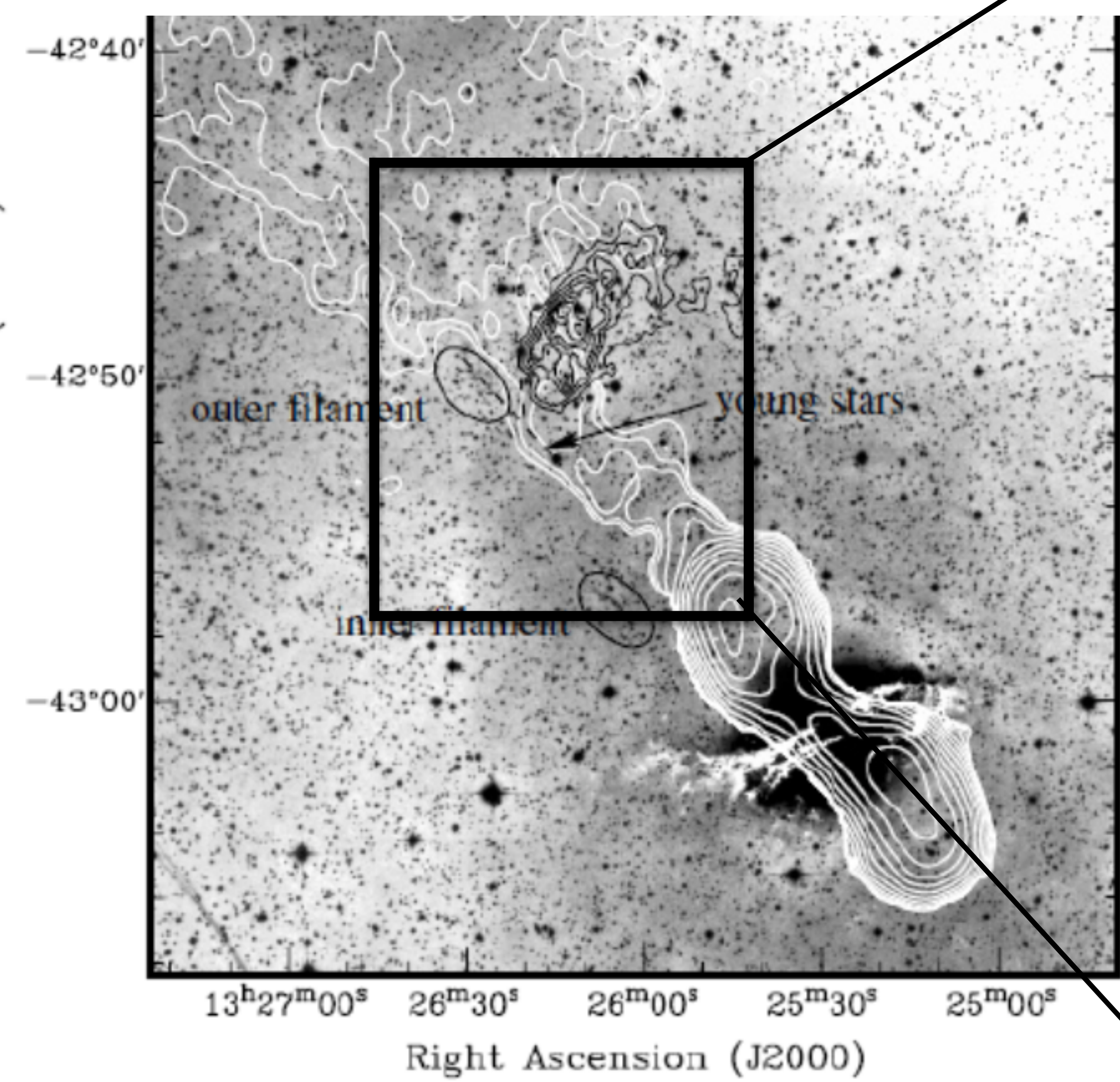


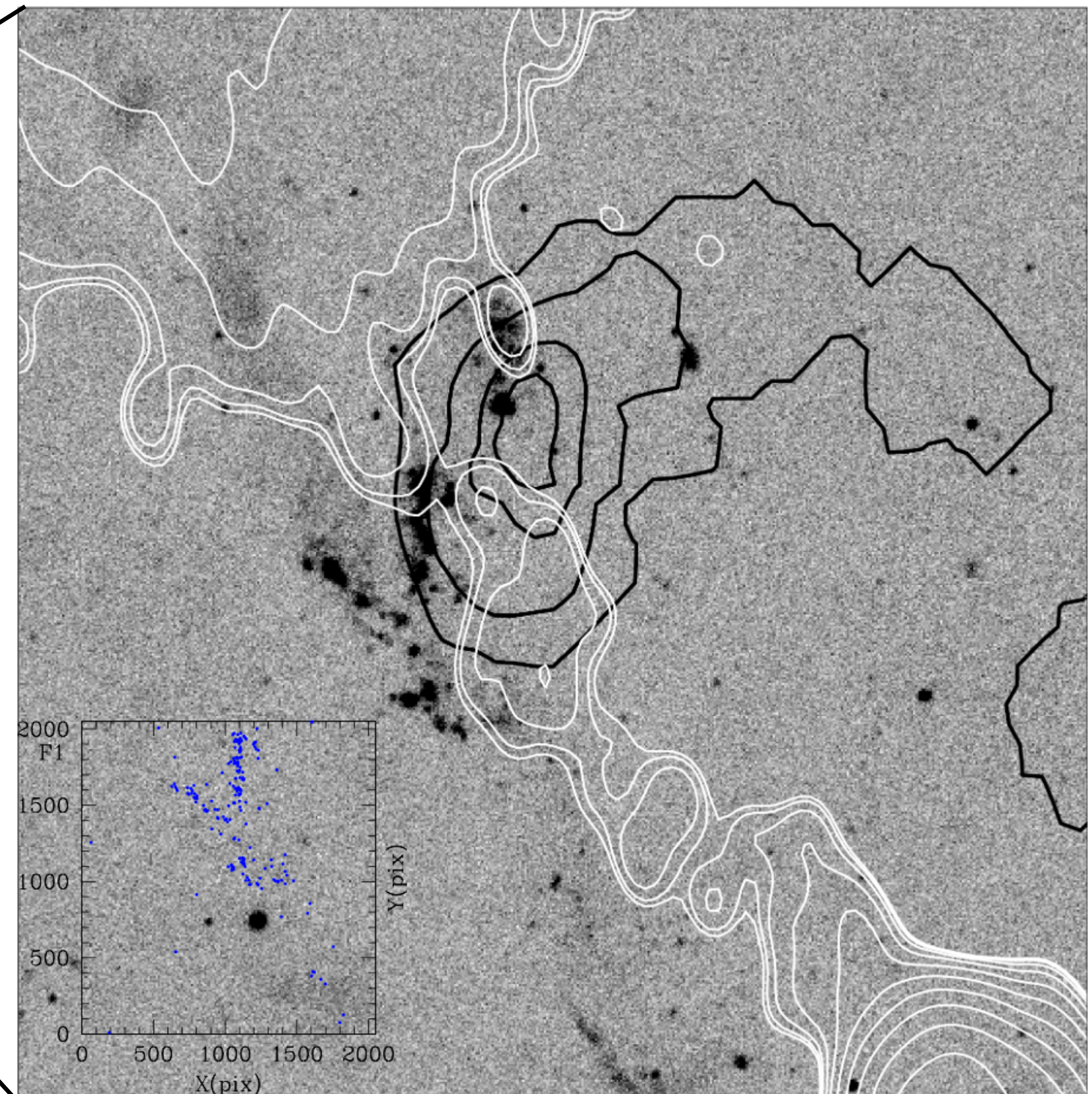
Image credit: X-ray: NASA/CXC/SAO; Optical: Rolf Olsen; Infrared: NASA/JPL-Caltech

Star formation along the jet



Osterloo et Morganti (2005)

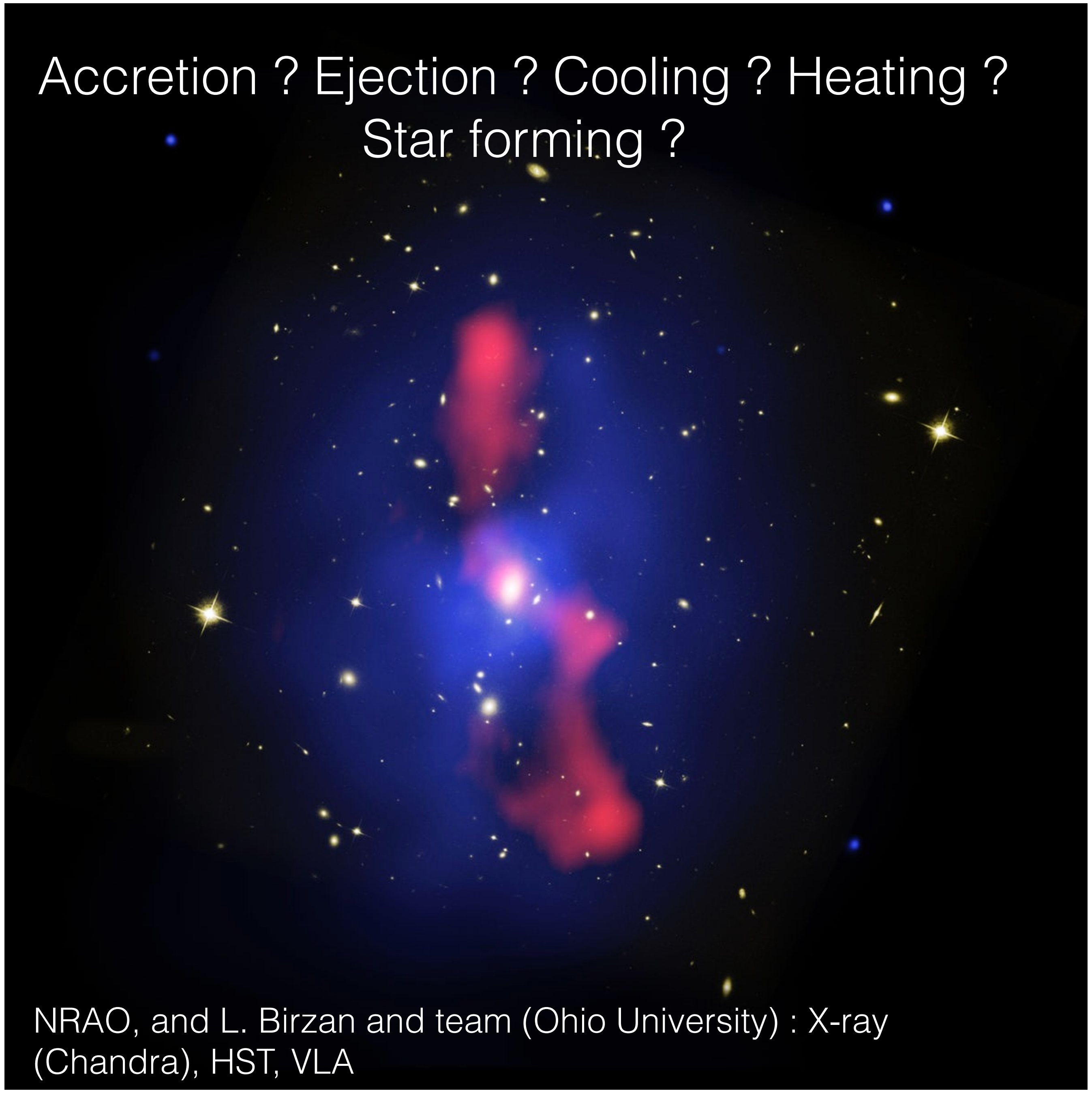
GALEX (UV) + HI (black contours) + Radio-jet (white contours)



Blue : Rejkuba et al., (2001)

Large Scales

Large Scales



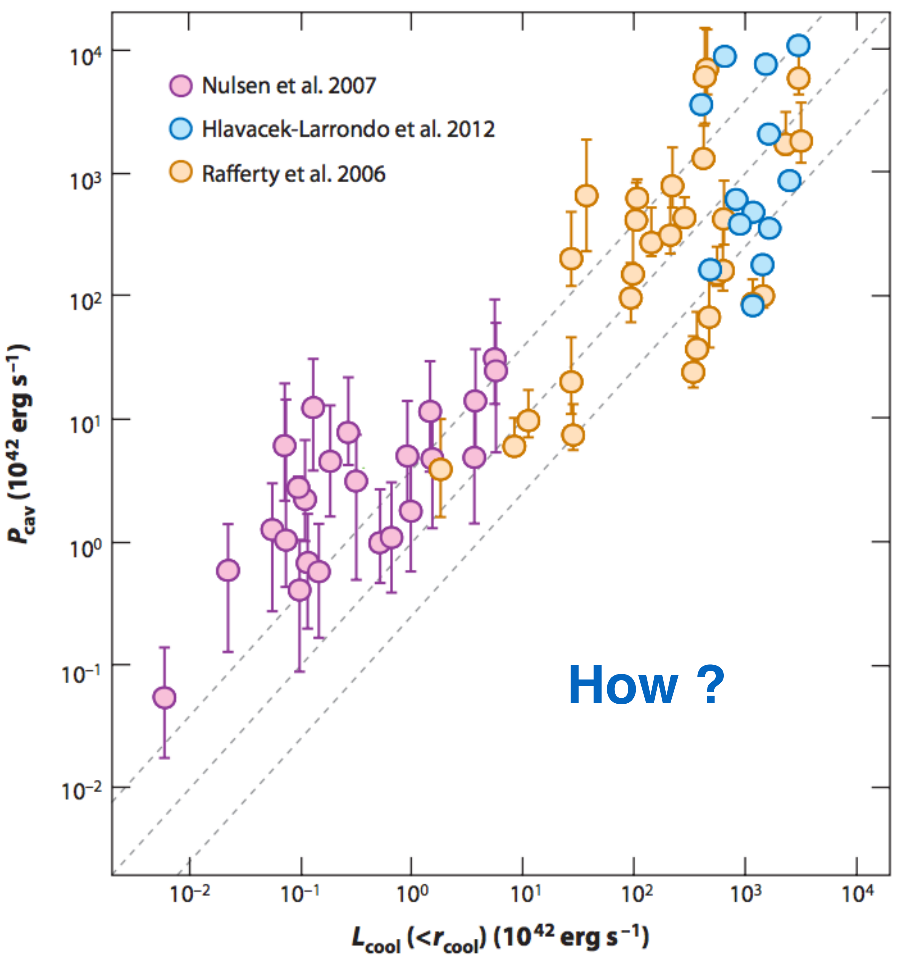
- **Does the presence of an AGN affect the large scale (> 10-100 kpc)** environments of galaxies (molecular gas content, star formation outside disks, halo metallicities) ?
- Does it **helps gas accretion and cooling** hot ICM onto galaxies ?

Review by McNamara & Nulsen (2012)

AGN controls cooling flows (Cool Core Clusters) around local Brightest Cluster Galaxies by **heating the ICM and driving local cooling**.

BCGs

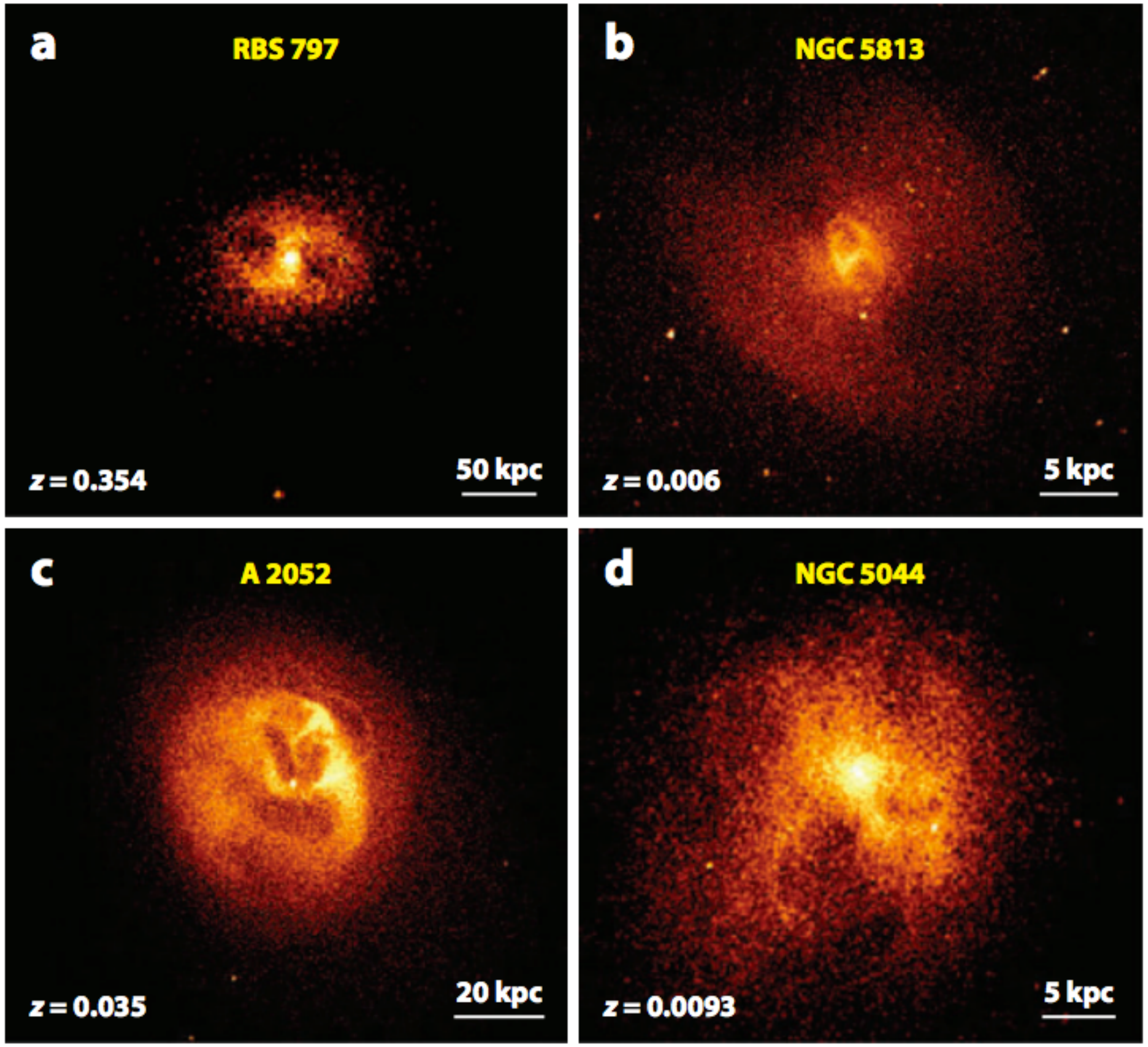
Radio-feedback in BCGs



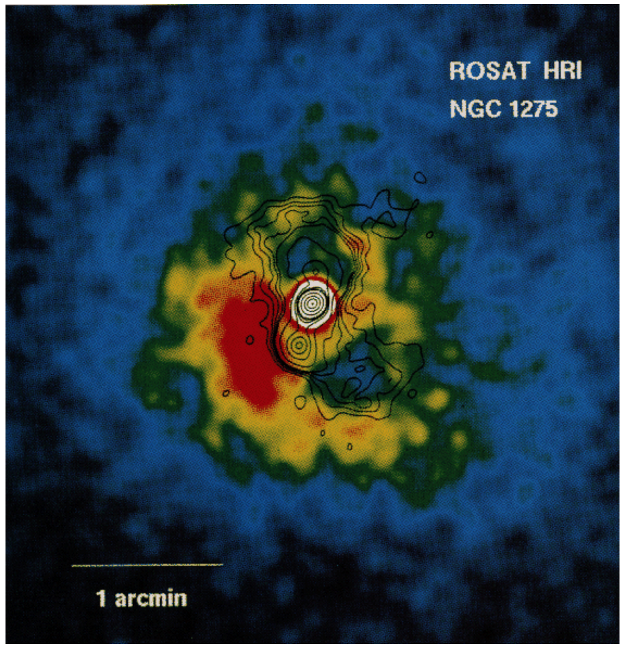
Power inferred from the cavities vs luminosity within the cooling region (**Hlavacek-Larrondo, Fabian et al., 2012, Cavagnolo et al., 2010)**

Shin et al., (2016) X-ray cavities for 133 targets : 148 X-ray cavities from 69 targets and measure their properties, (cavity size, angle, and distance)

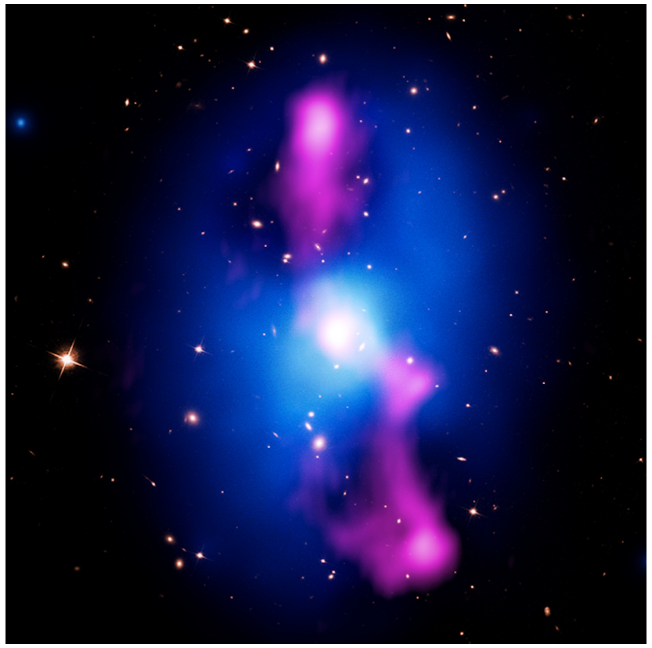
IGM vs Radio-Lobe interaction



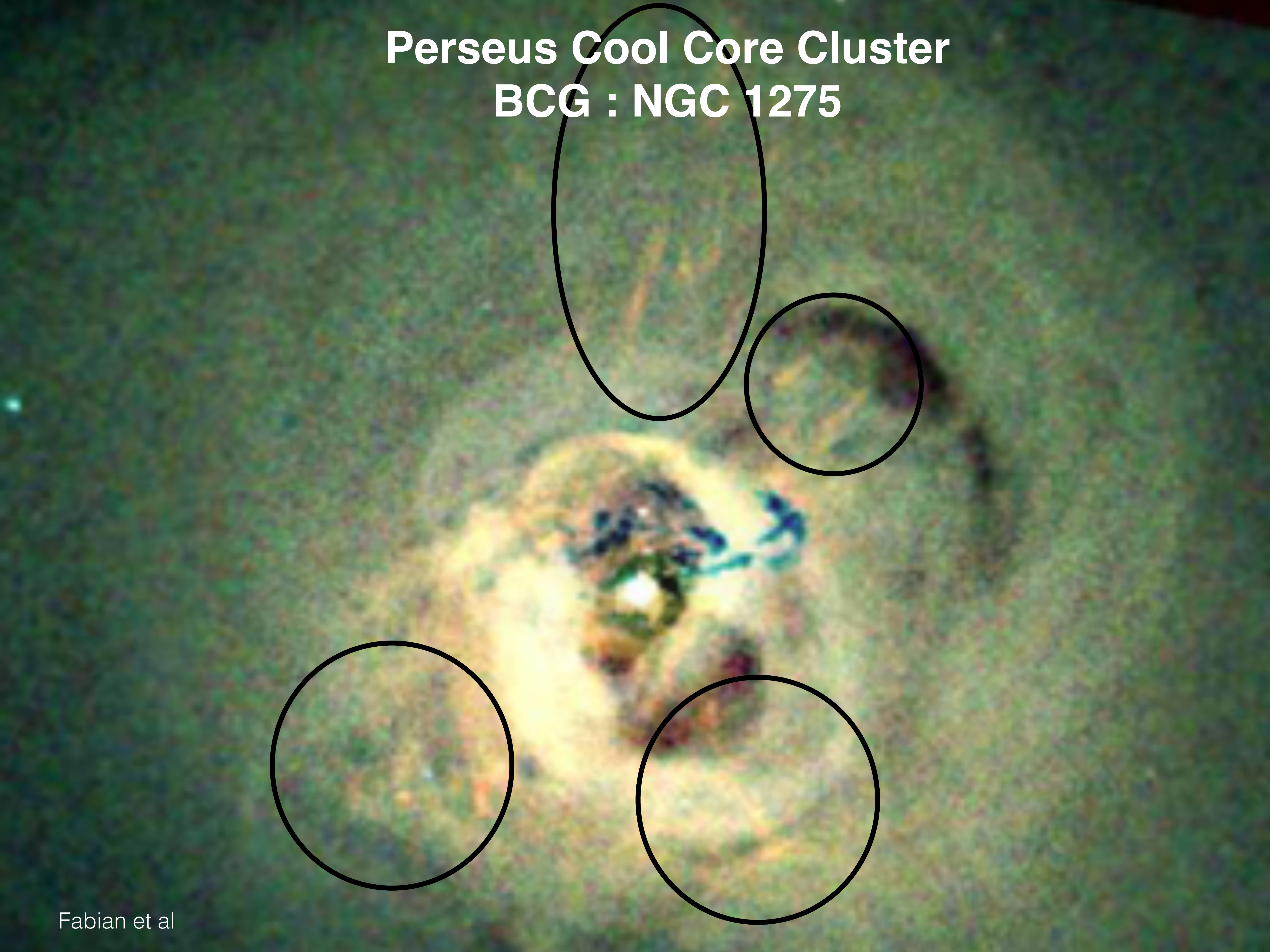
Fabian et al., (2012) - Review

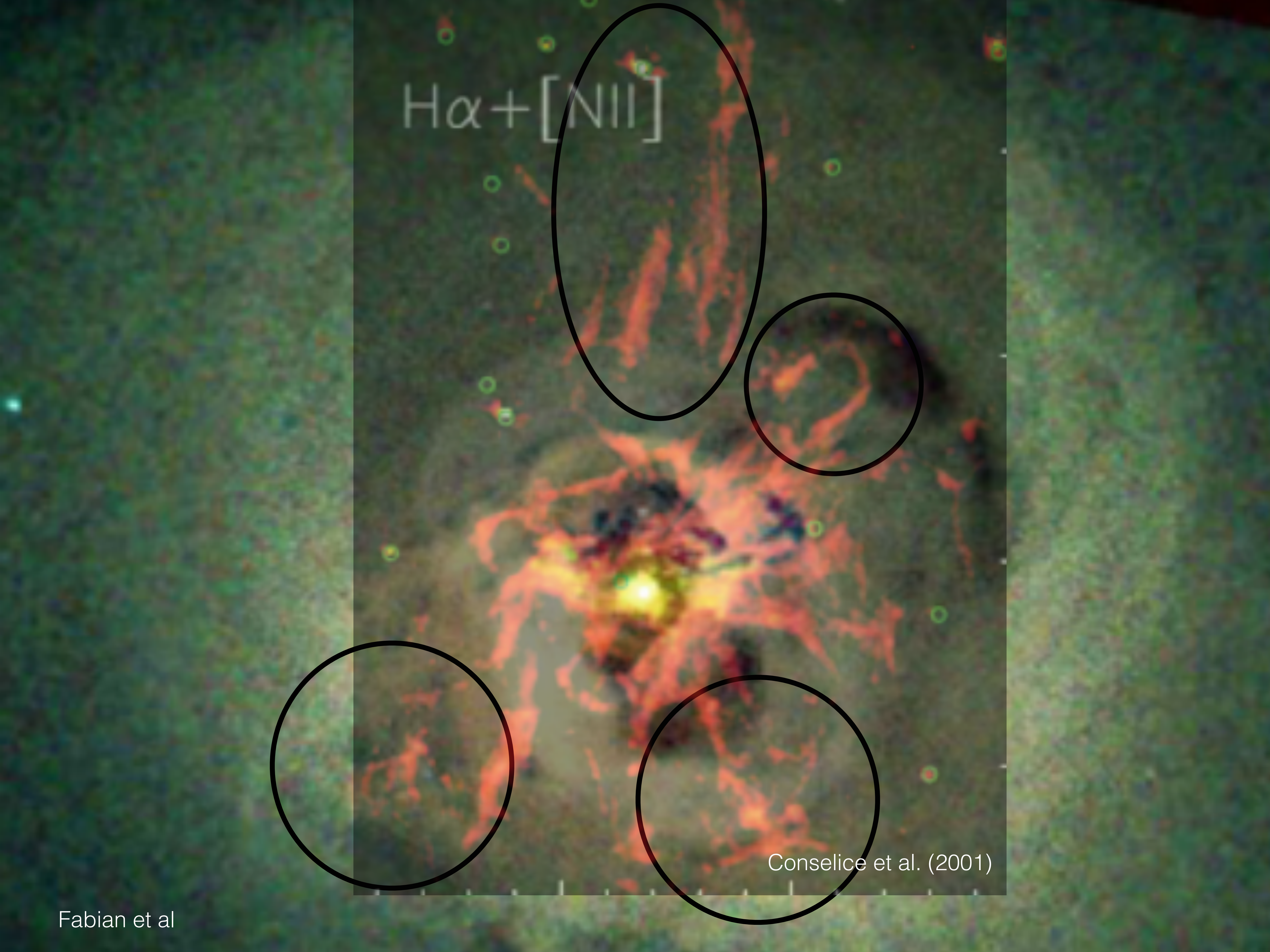


(Boeringer et al., 1993)



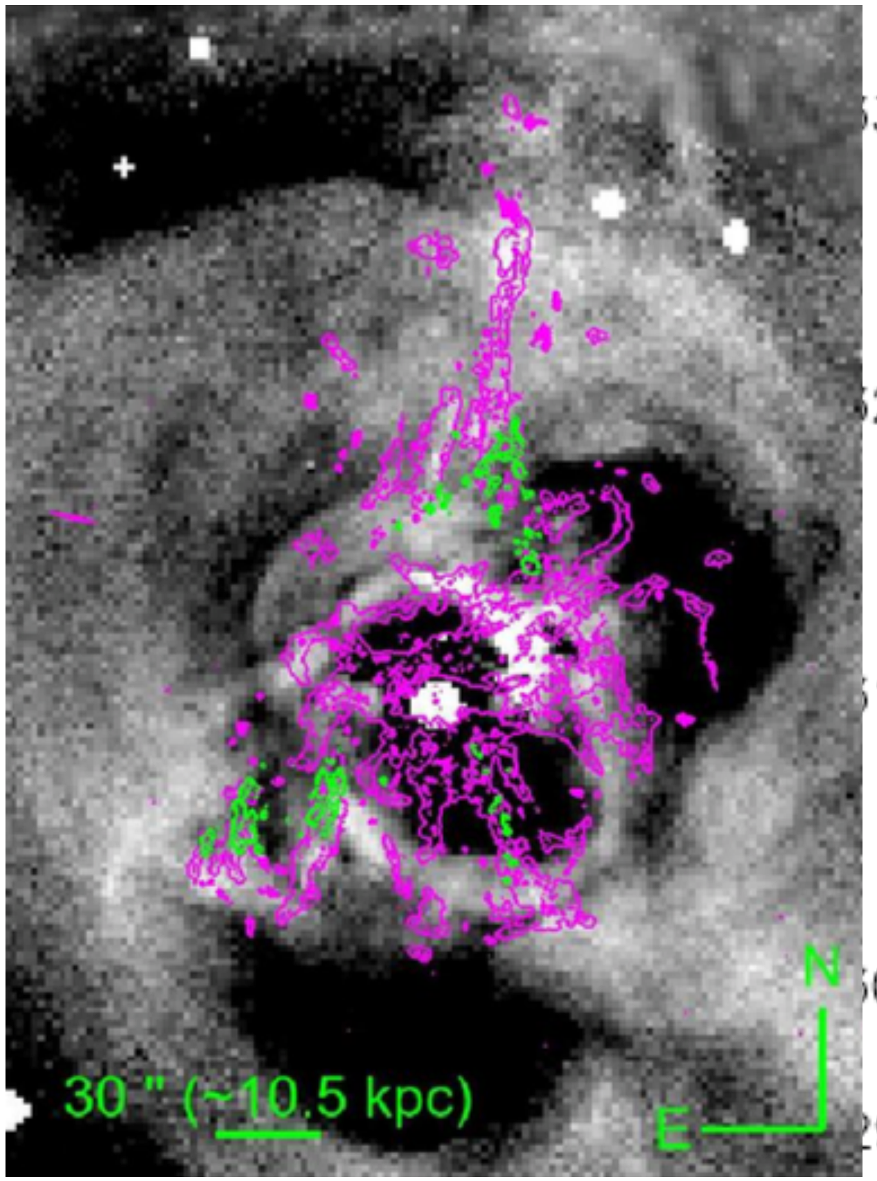
(McNamara et al. 2009)


Perseus Cool Core Cluster
BCG : NGC 1275
Fabian et al

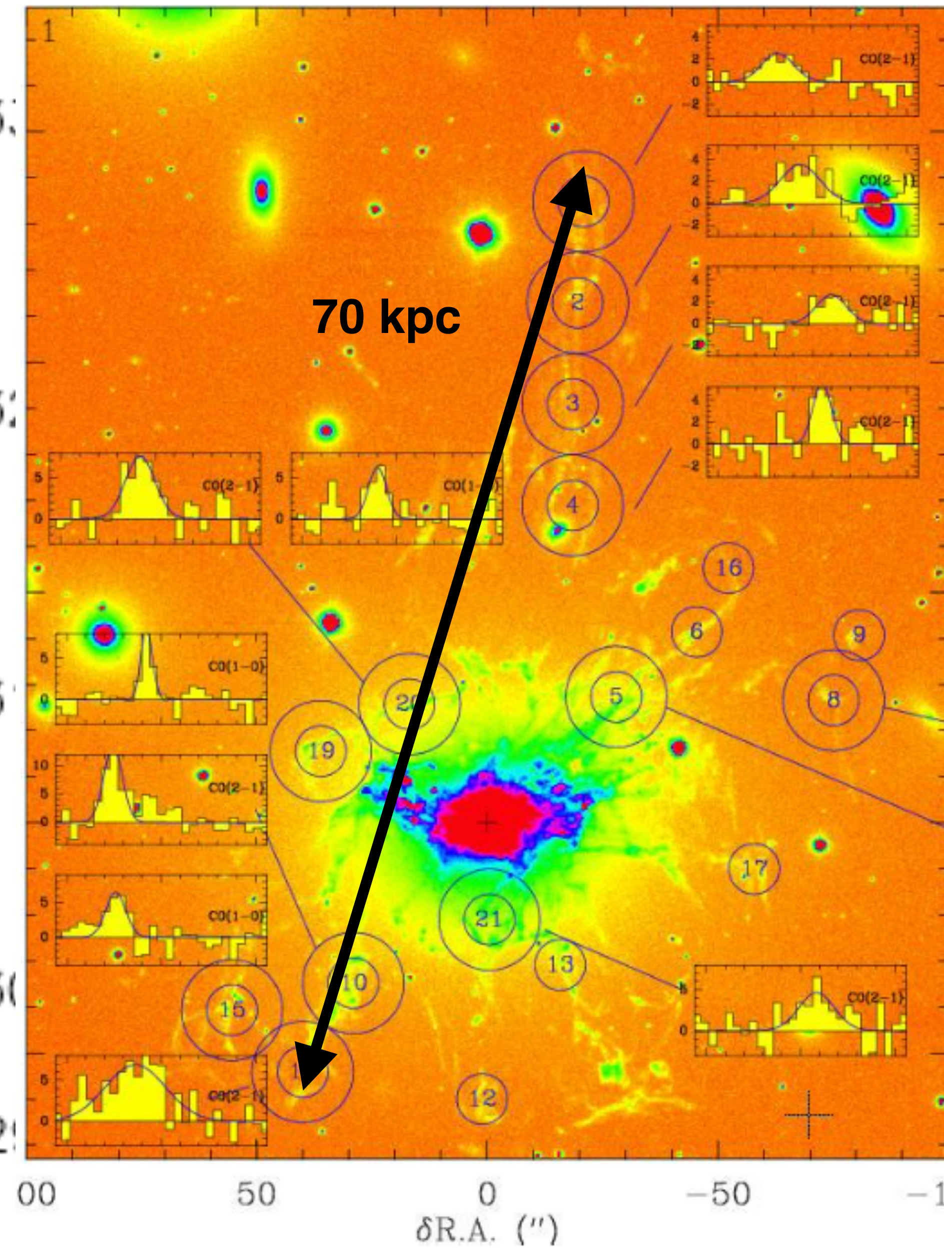

Hα+[NII]
Conselice et al. (2001)
Fabian et al

Molecular filaments

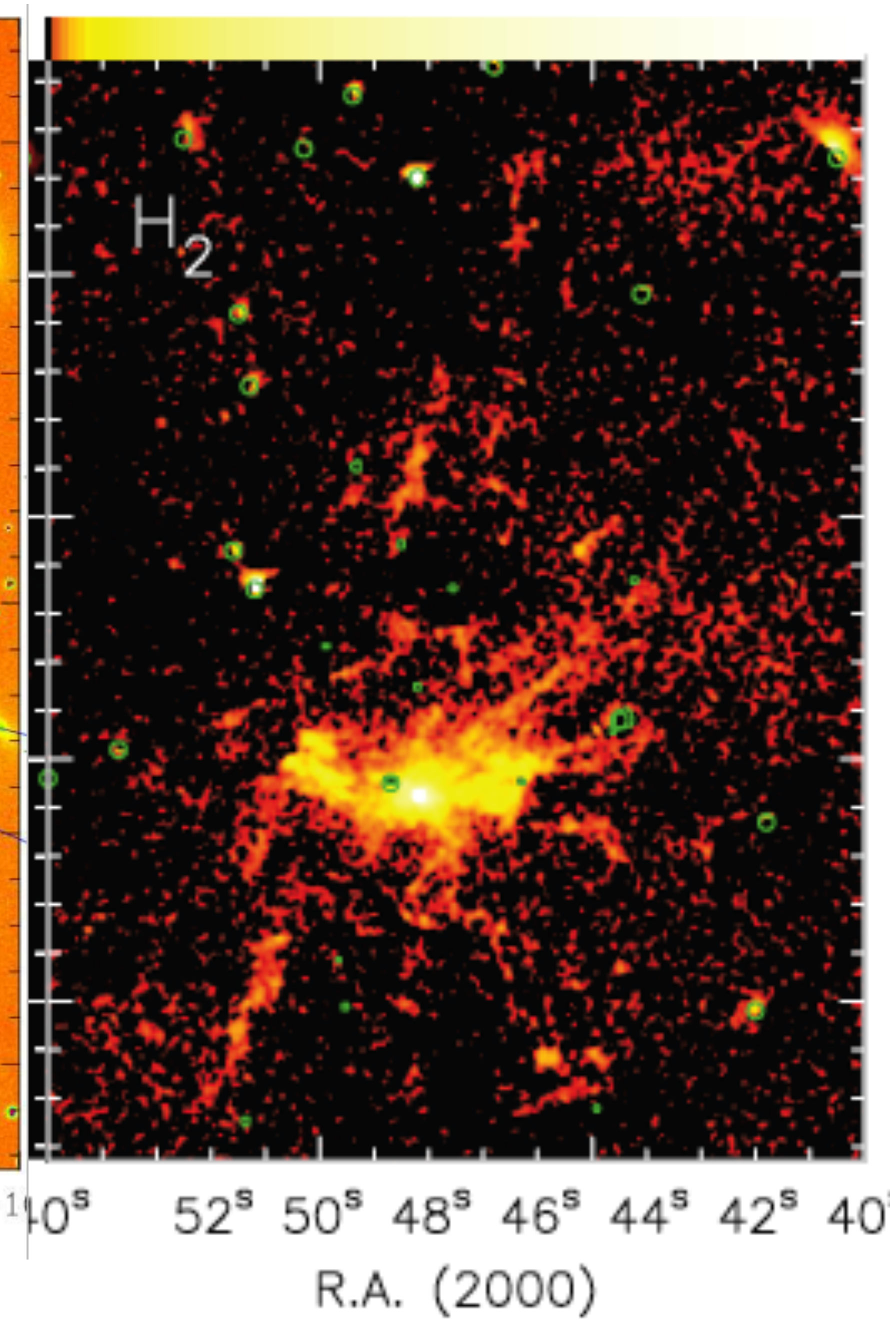
…and star formation



Chandra X-ray surface brightness image from (**Fabian et al. 2011b**) overlaid with contours of Hα emission (magenta; **Conselice et al. 2001**) and young star-forming regions (from HST, **Canning et al., 2014**).



Molecular gas CO(1-0) and CO(2-1) from the **IRAM 30m-telescope** (**Salomé et al., 2012**)

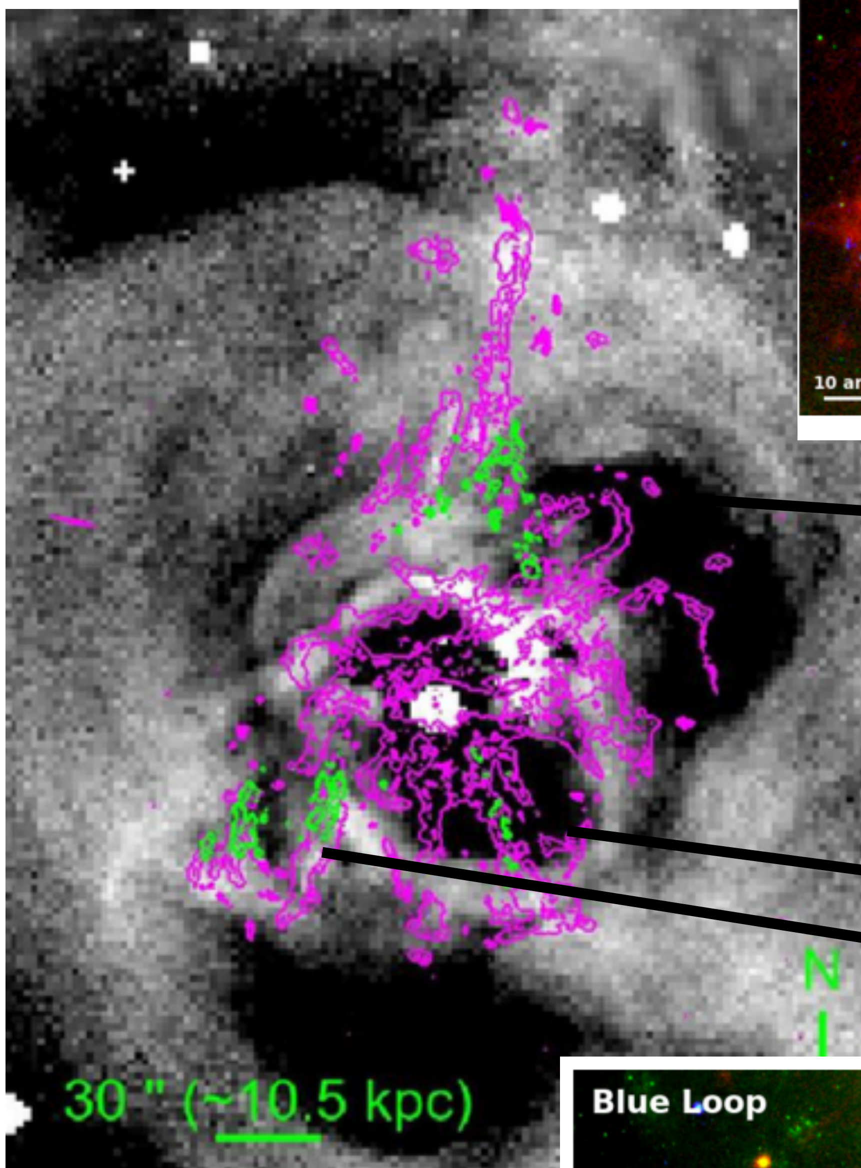


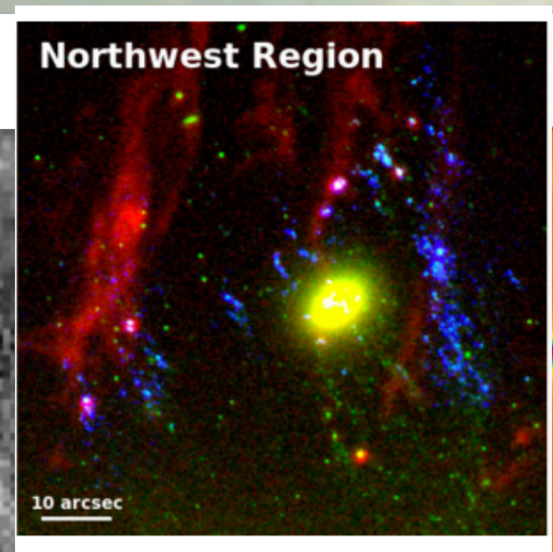
Warm H2 **(Lim et al., 20012)** @ 2.12um from CHFT

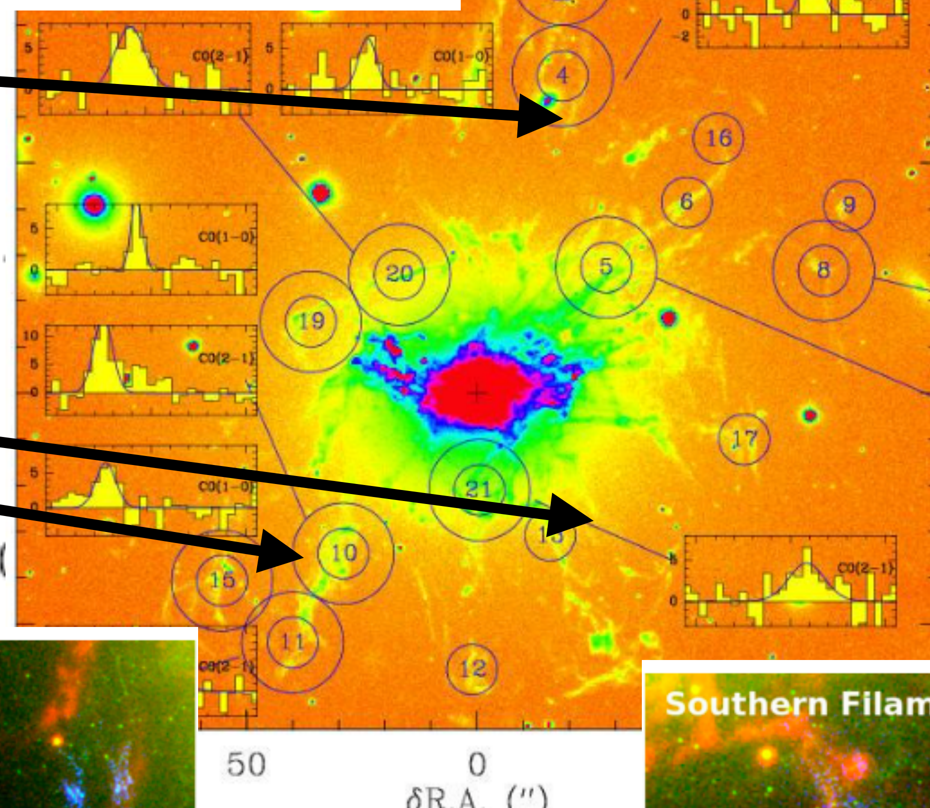
Molecular filaments

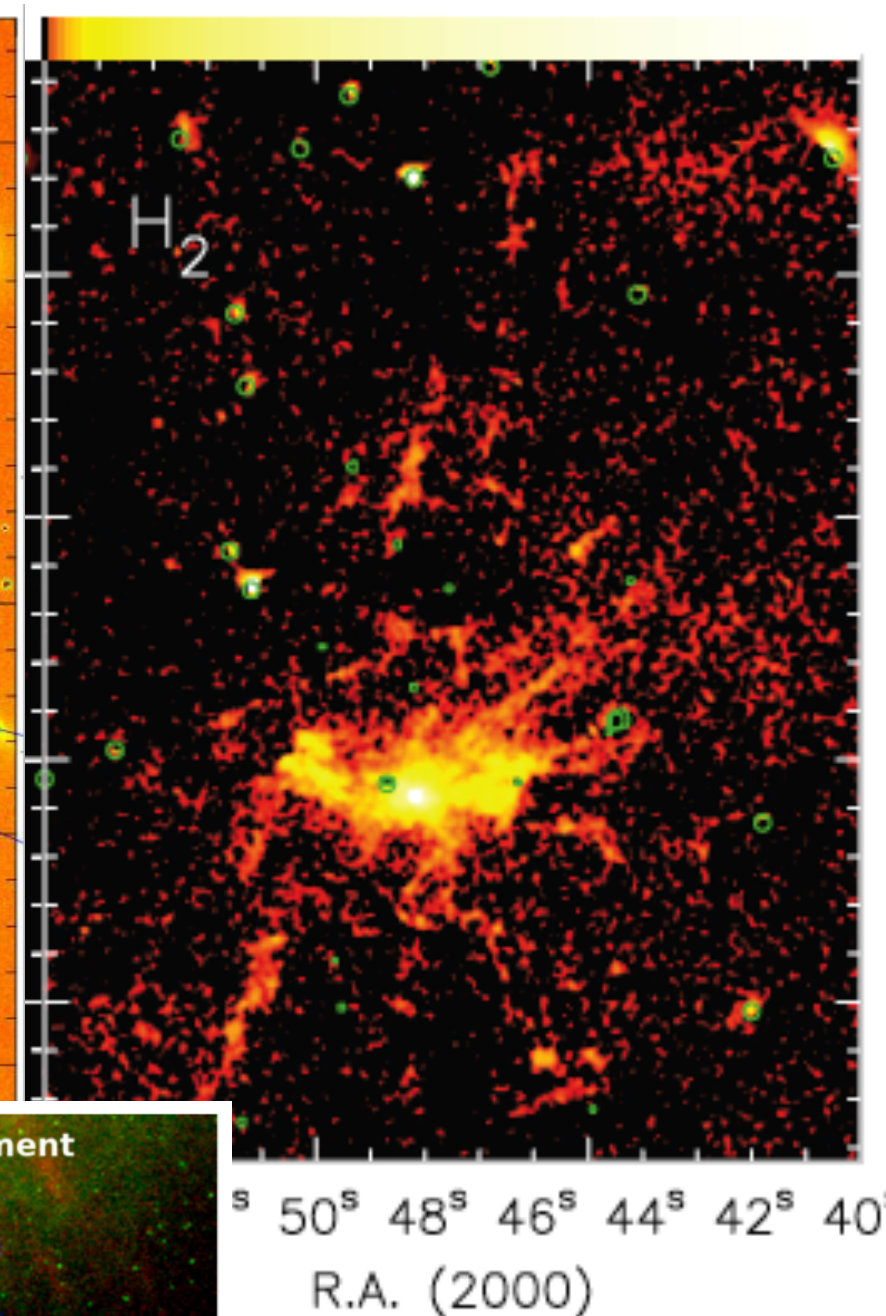
…and star formation

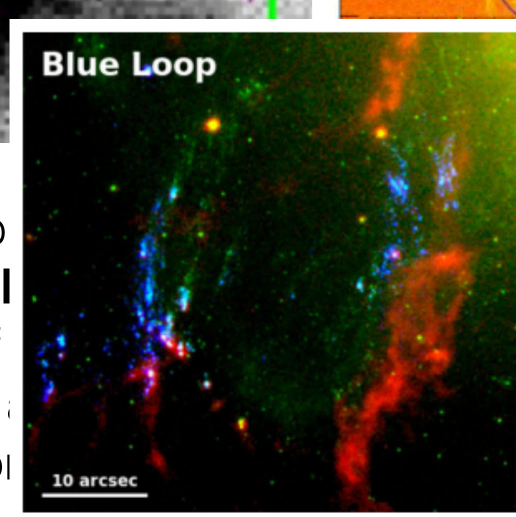
~1E7 Msun each spectrum

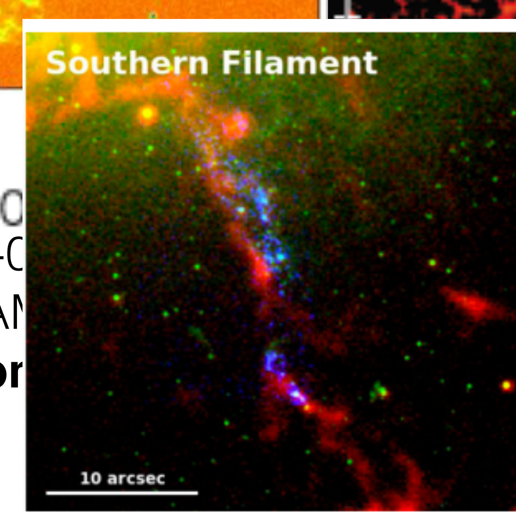












Chandra X-ray surface b
image from (**Fabian et al**
overlaid with contours of
(magenta; **Conselice et**
young star-forming regio
Canning et al., 2014).

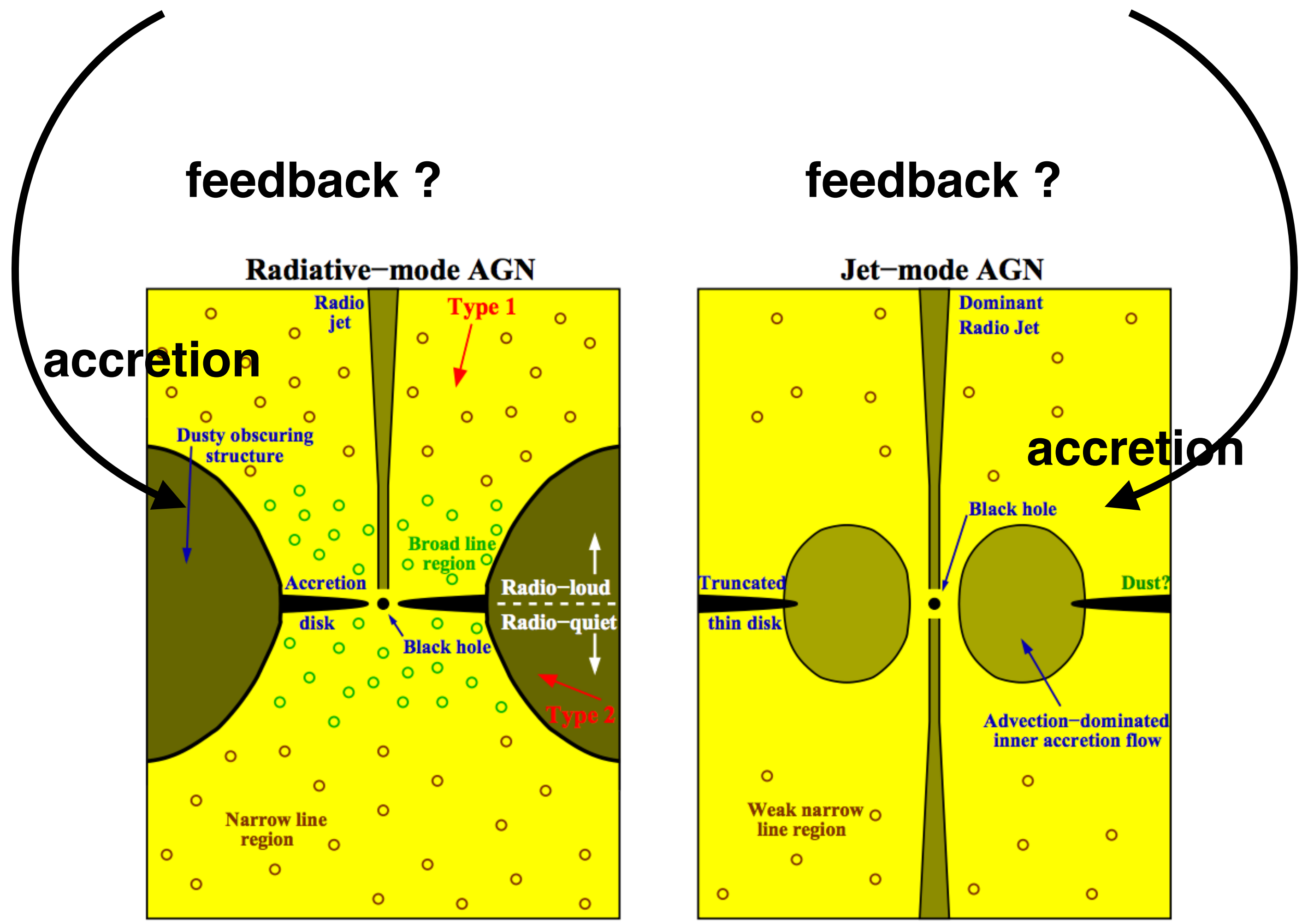
Molecular gas CO(1-0
CO(2-1) from the IRAM
30m-telescope (**Salor**
2012)

arm H2 **(Lim et al., 2008)** @
12um from CHFT

Small Scales

Small Scales

- What controls **sub-galactic scale accretion and BH fueling** ?
- How to drive gas near the BH (**Angular momentum**) ?
- Can the **AGN wind / jet regulate** or stop the fueling in the **very inner** region ?

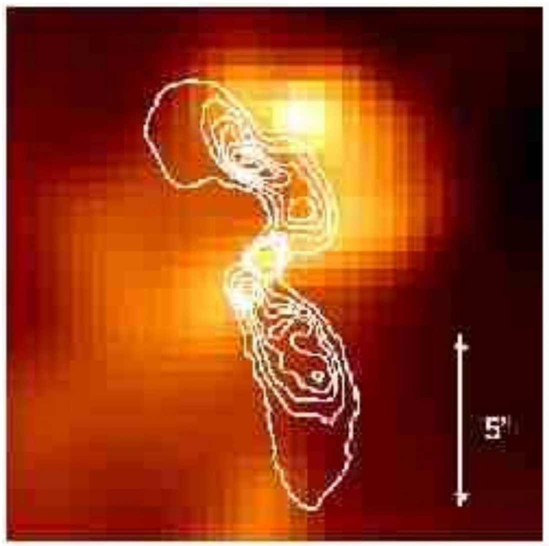


Heckman & Best (2014)

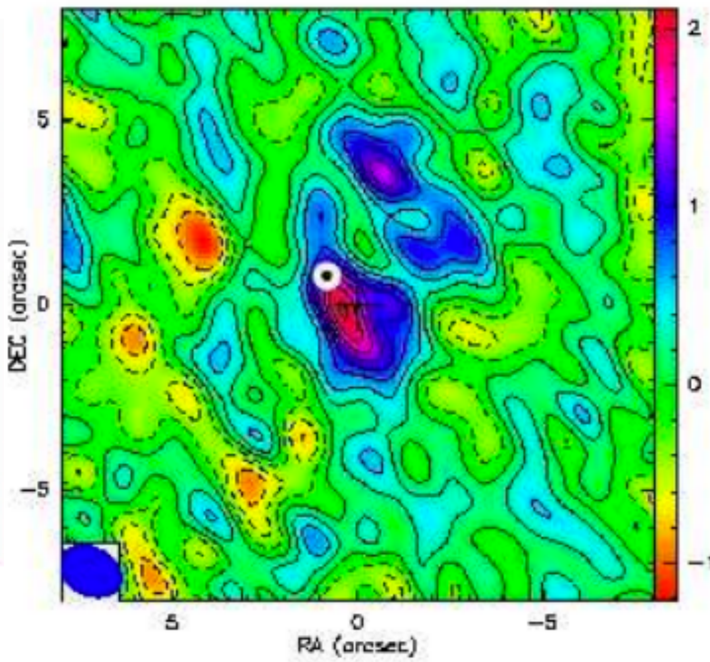
The mass-growth of the supermassive black holes is related to
(i) accretion driven process (inflows vs outflows; Violent Instabilities)
(ii) The growth of the inner region of the host galaxy (bulge)

Abell 1795 - Cool Core Cluster BCG

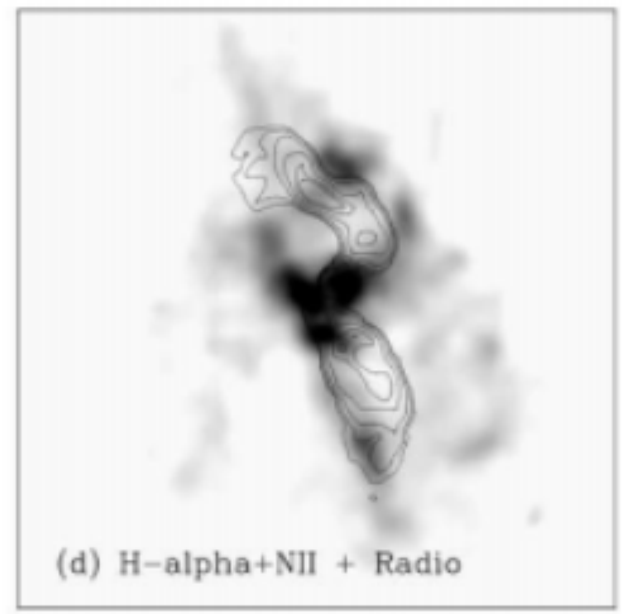
- Molecular gas is found along radio-lobes
- Molecular is found in star forming regions

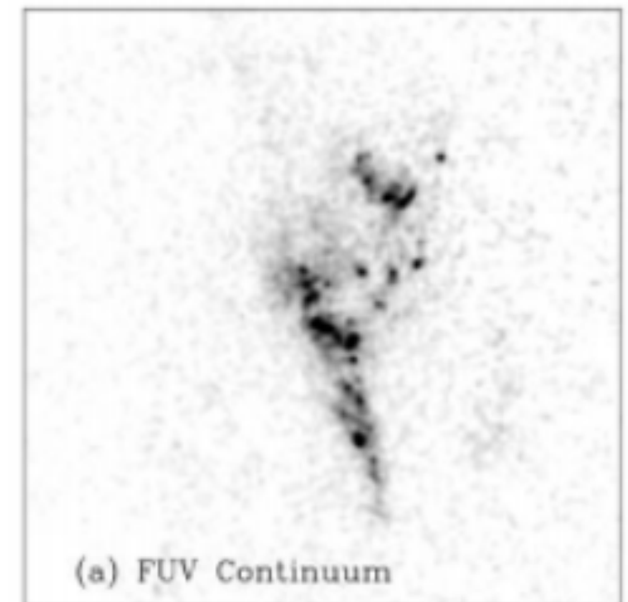


X-rays - Chandra



CO(2-1) molecular gas emission IRAM-PdB (Salomé et al., 2004). ~5 E9 Msun

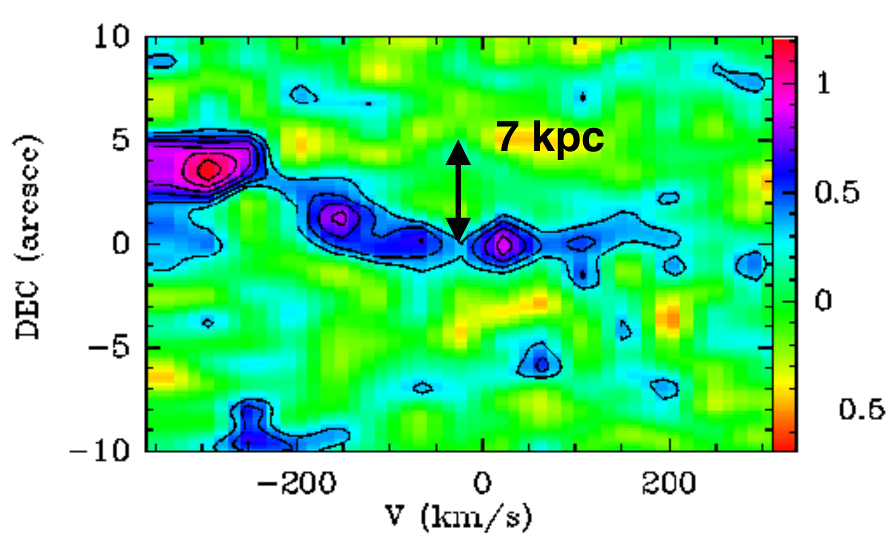




Star Formation rate of the order of 10 Msun / yr
Montage of HST images and VLA 8.4 GHz image (O'Dea et al., 2004)

Origin of the molecular gas
- outflow/uplifted
- infalling cooled gas ?

Fate of the gas :
- feeding the central BH ?
- forming stars in the halo



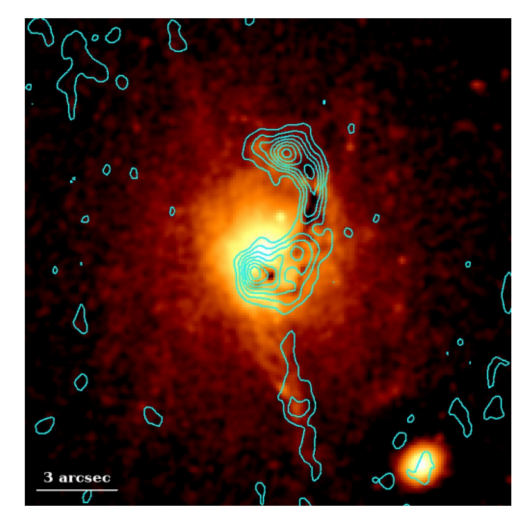
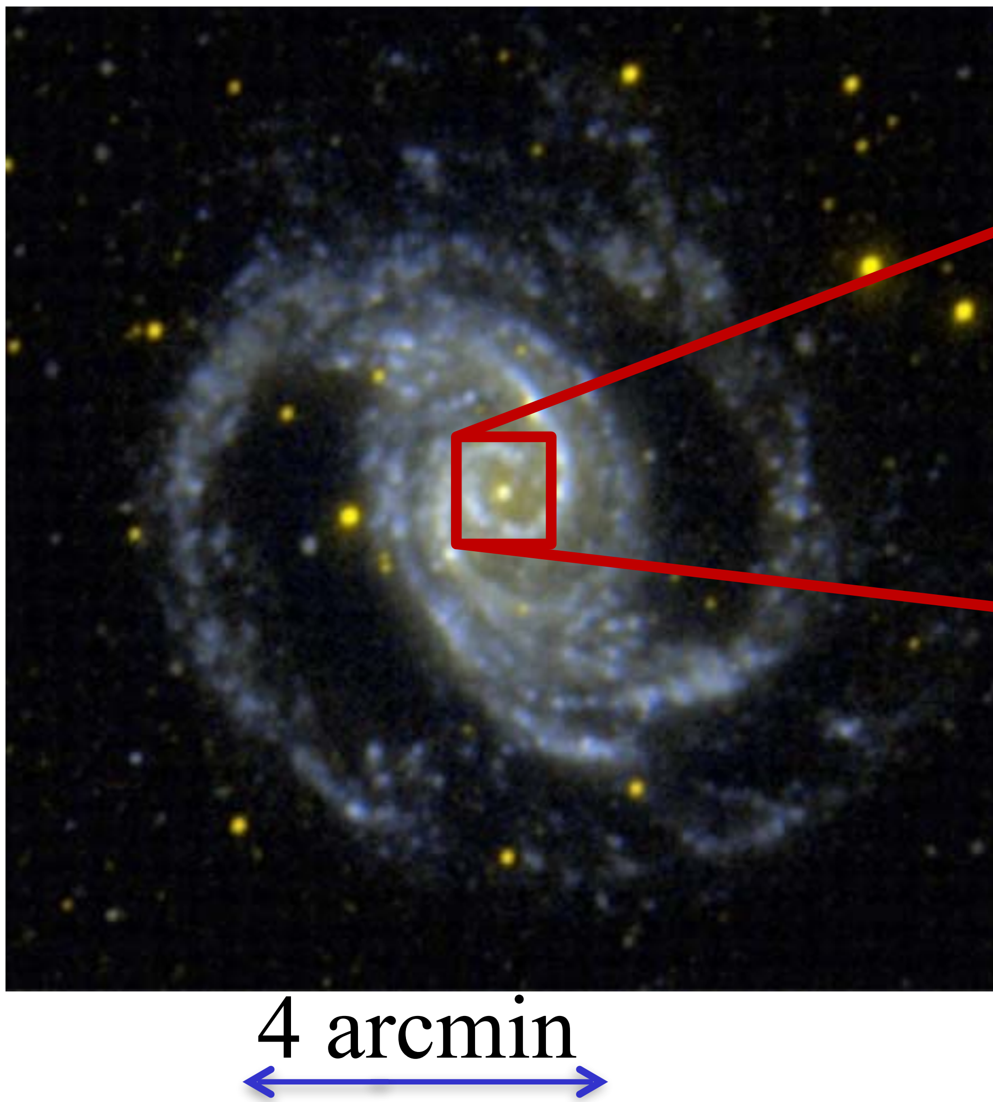


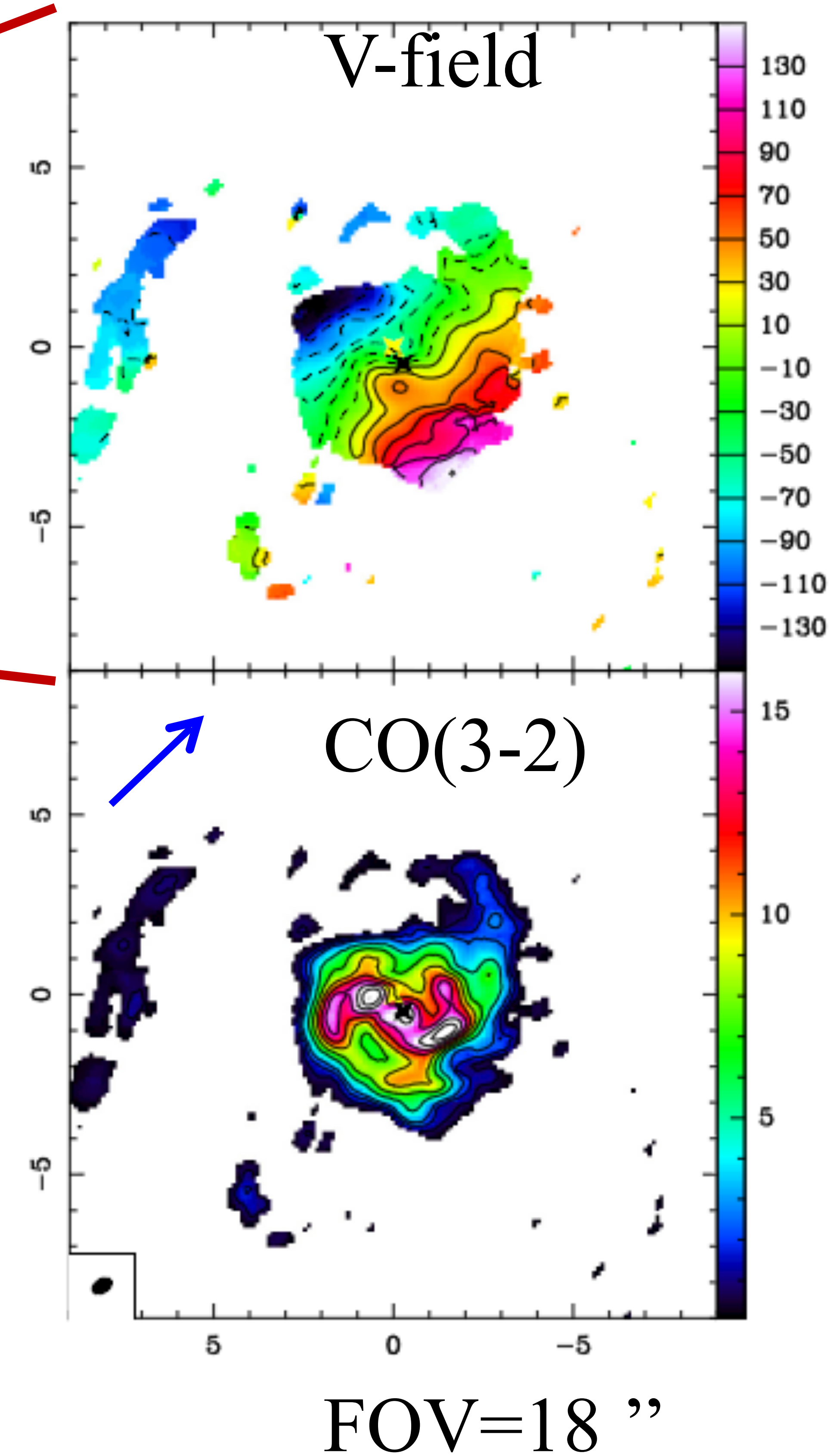
Figure 8. HST F702W image with a smoothed model subtracted to highlight the dust lane. The contours show the CO(2-1) integrated emission (see Fig. 1).

Mechanisms in obscured nuclei

1- **Feeding** :AM transfer through gravity torques
Dynamical features: nuclear bars & spirals
➔Accumulation in a molecular torus

The NGC1566 barred Sy1-2: feeding phase

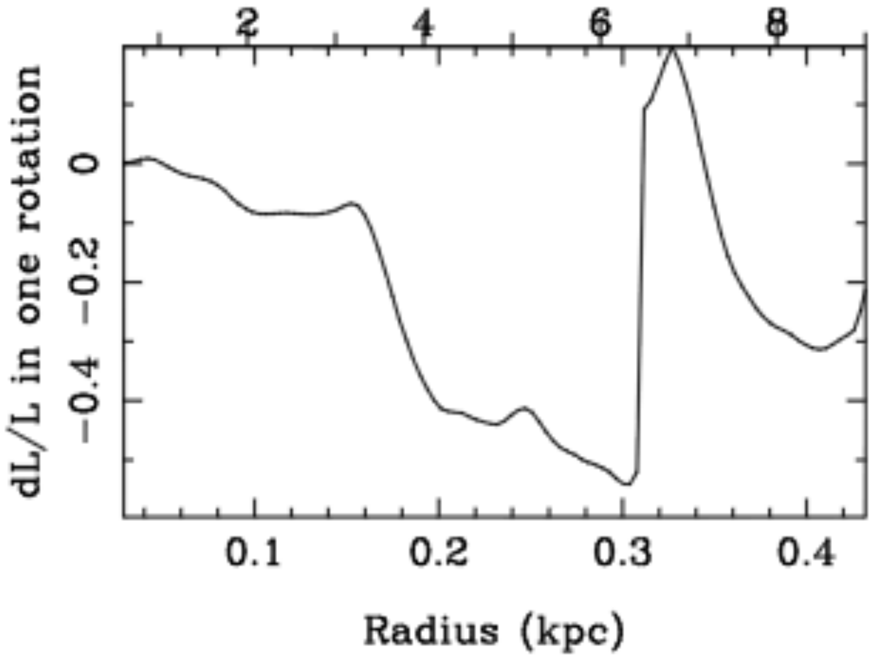




ALMA: mapping inside the nuclear ring

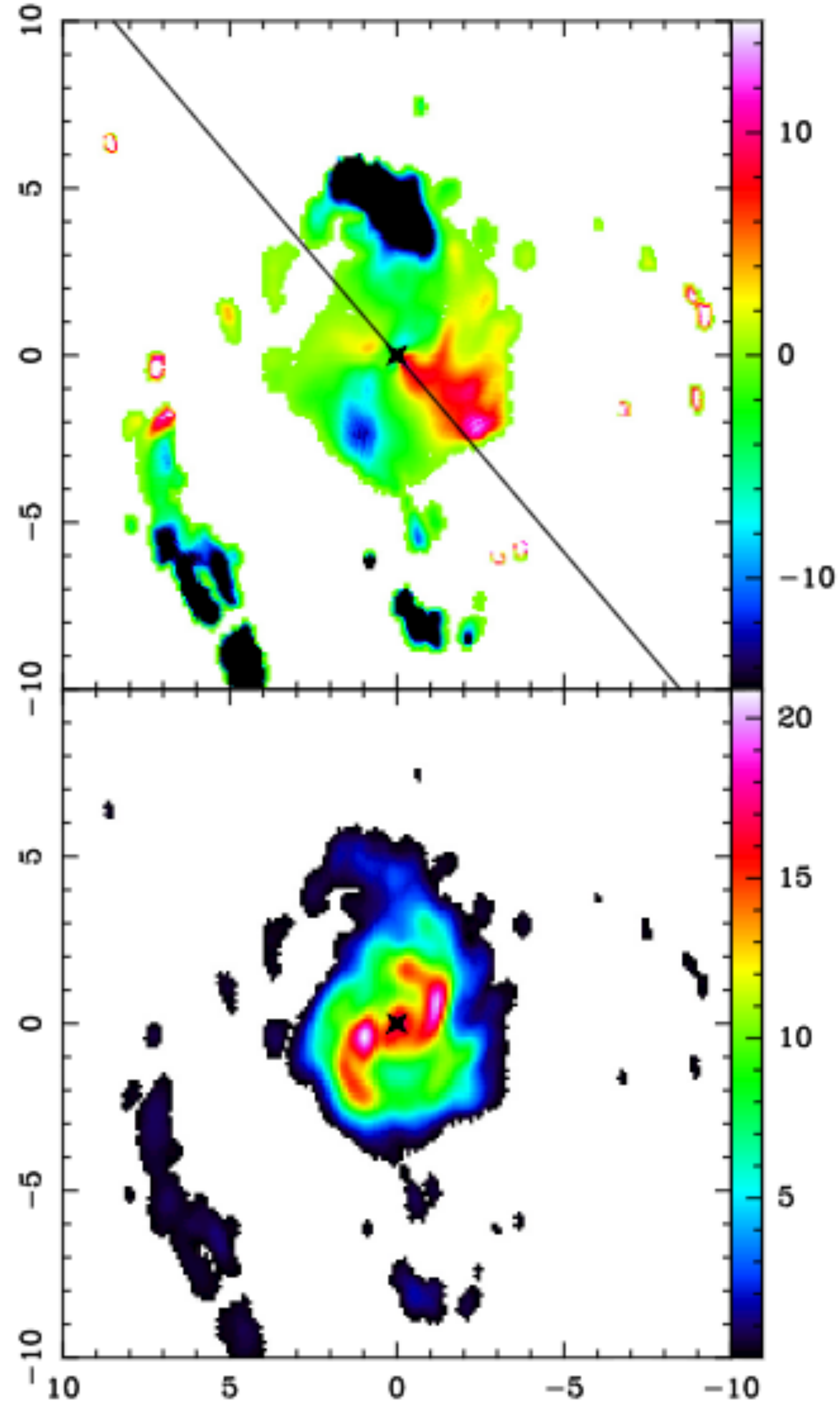
Combes et al 2014

NGC1566: gravitational torques



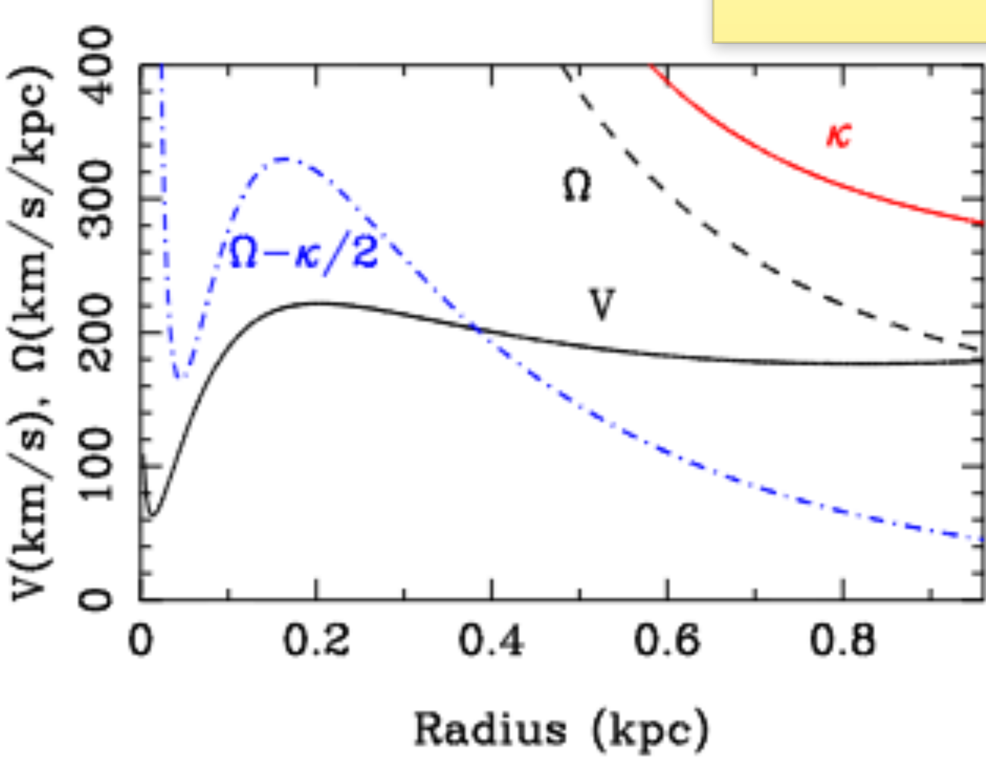
Gas is driven inwards

Torques on deprojected image



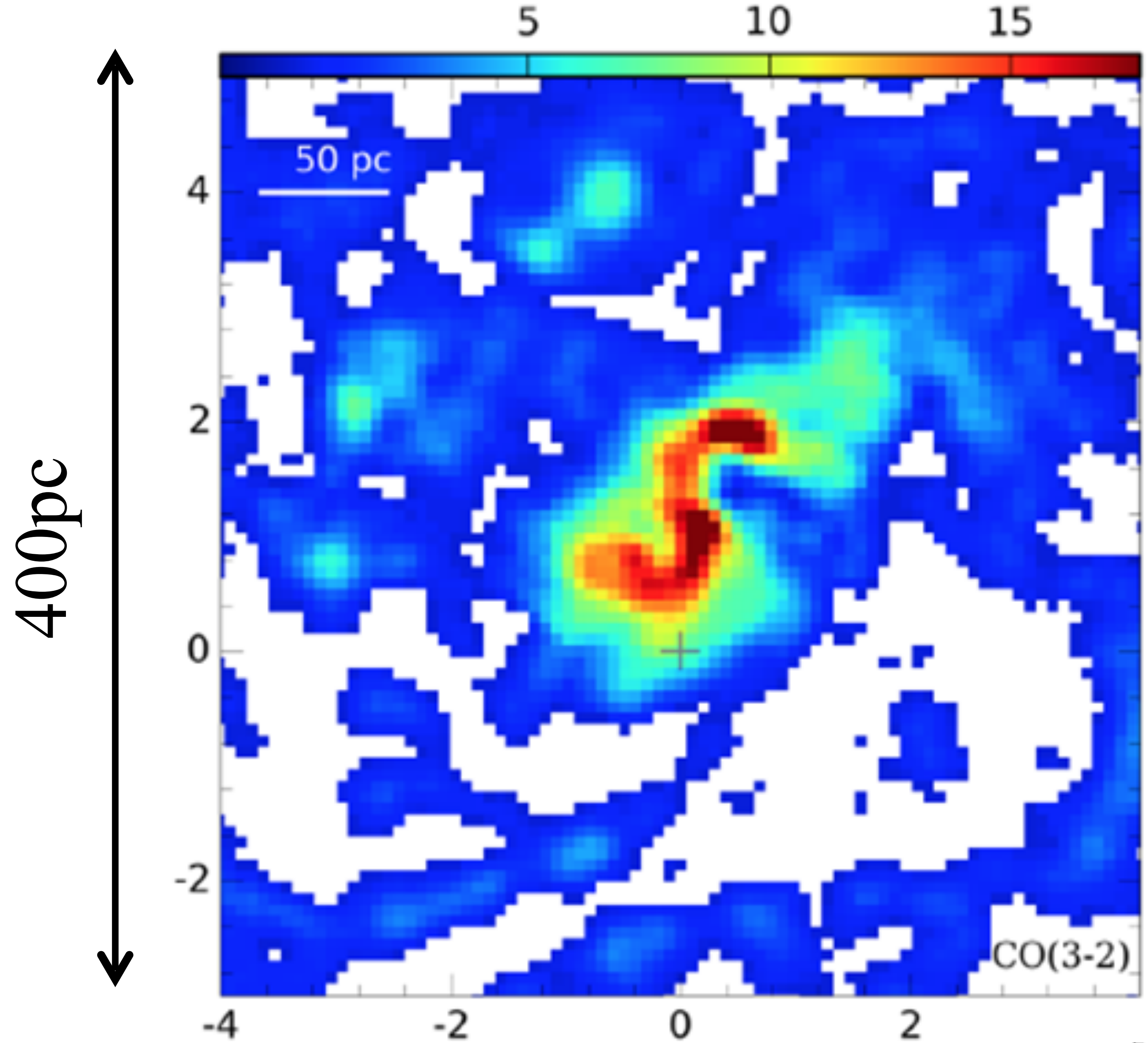
Trailing spiral inside the ILI

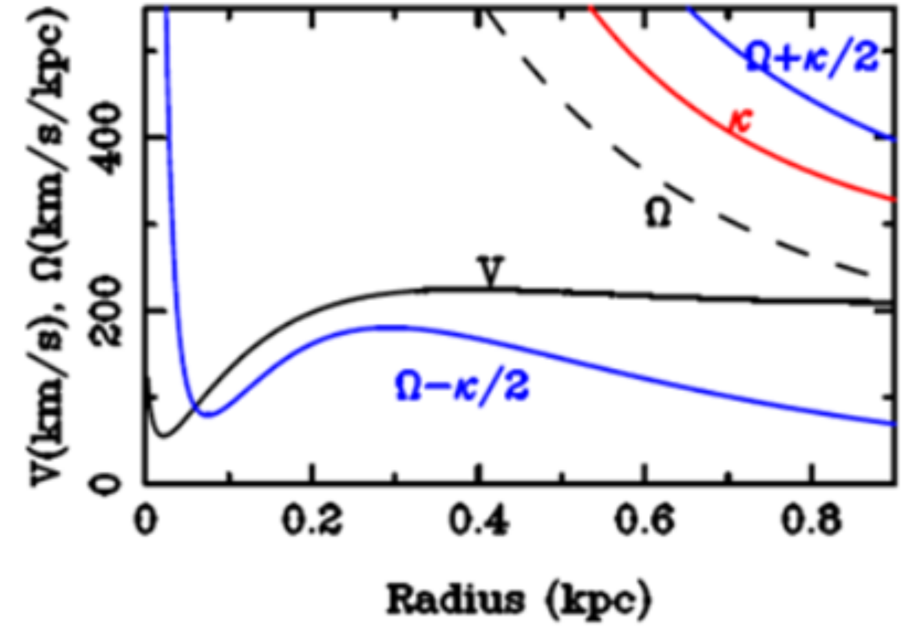
➔ BH influence on the dy

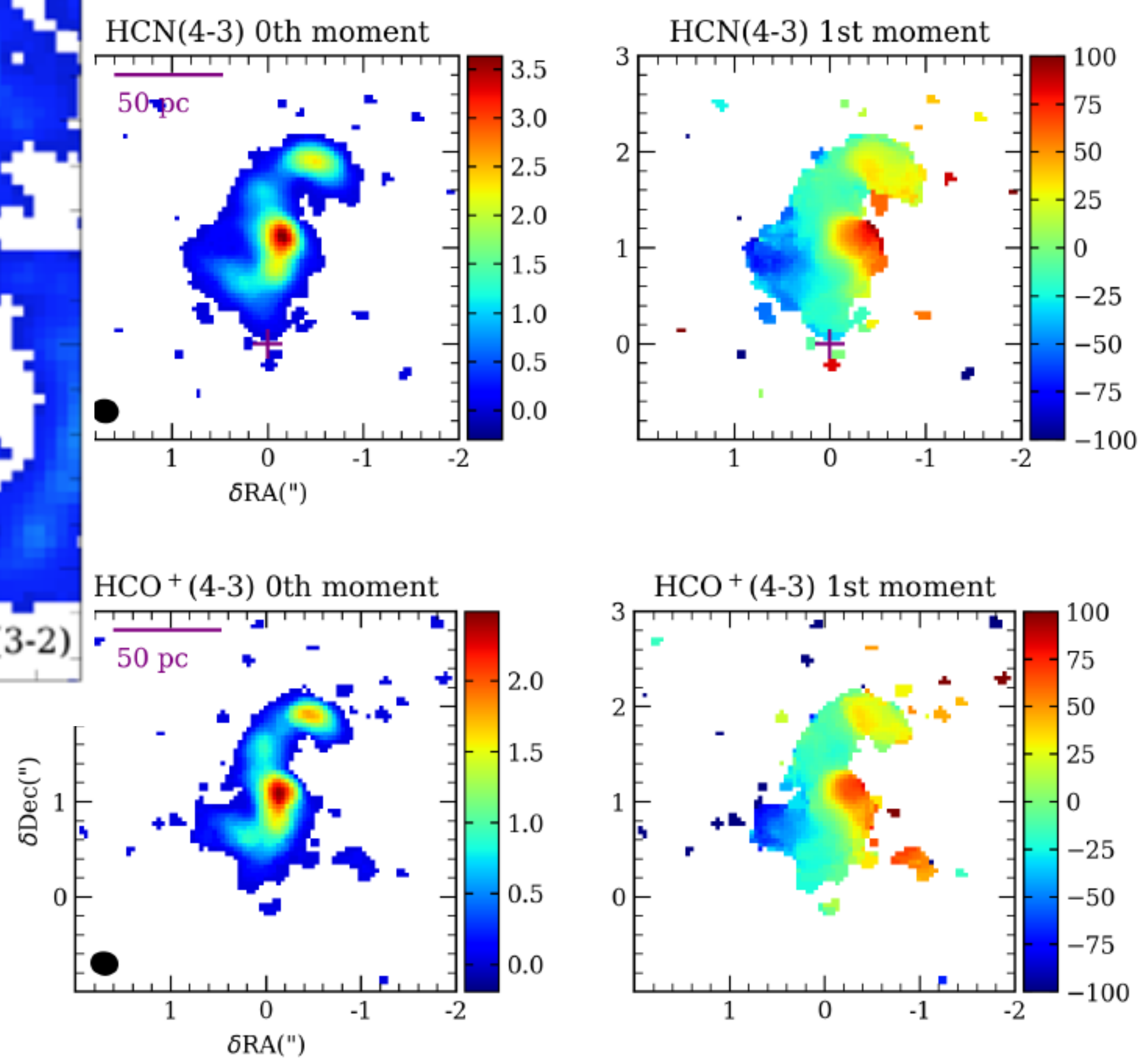


also in N613, N1808

Audibert et al 2021





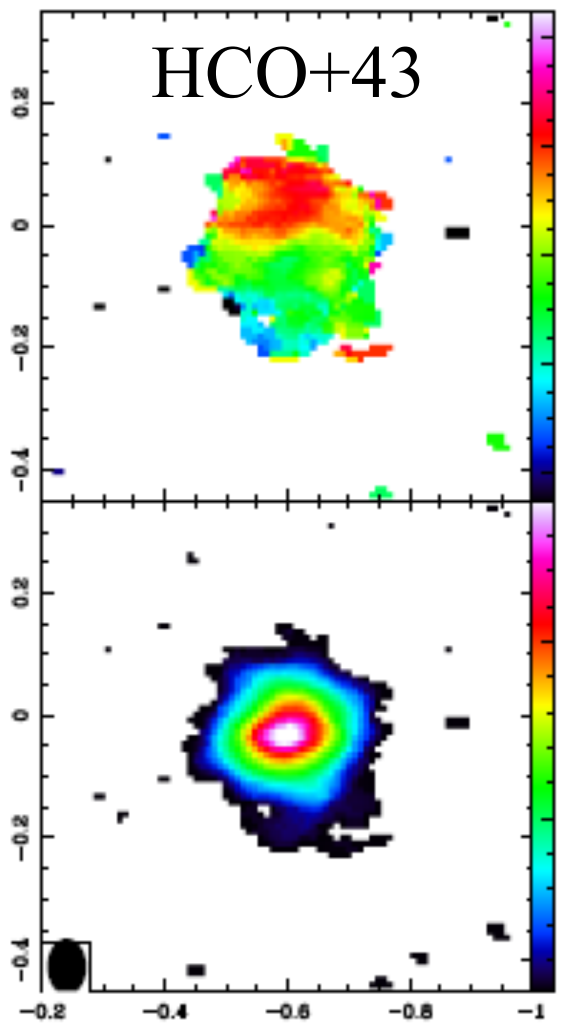


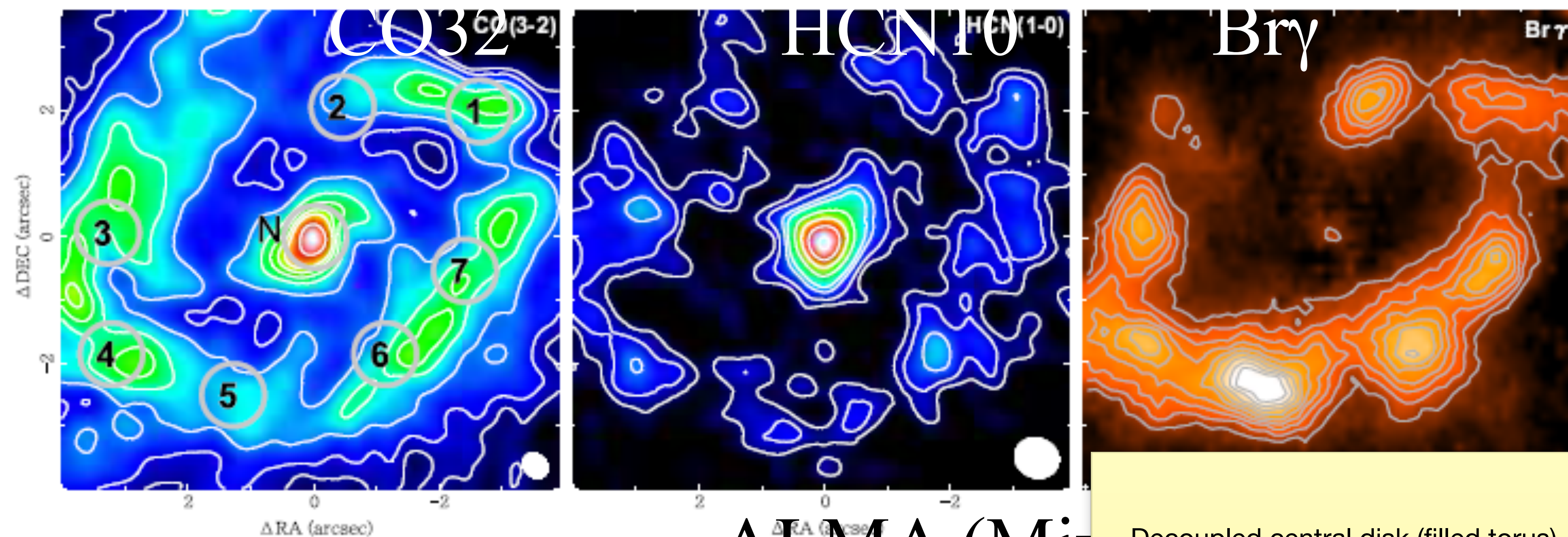
Trailing nuclear spiral in N1808

➔ Fueling the BH

Beam 0.08" =4pc

0.6” 50pc



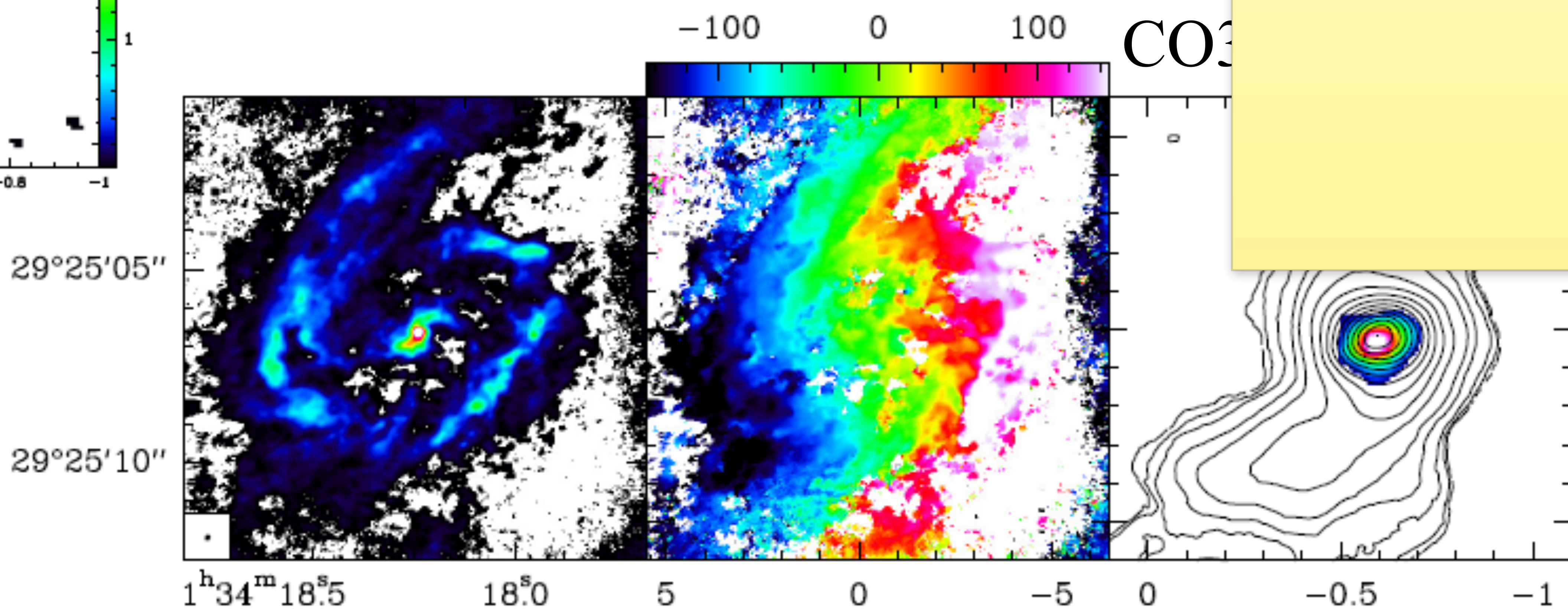


ALMA (Mi

Decoupled central disk (filled torus). So
spirals fuels it. Black hole mass measu
high resolution catch the BH sphere of
Sometimes high velocities tracing outfl

NGC613

CO3



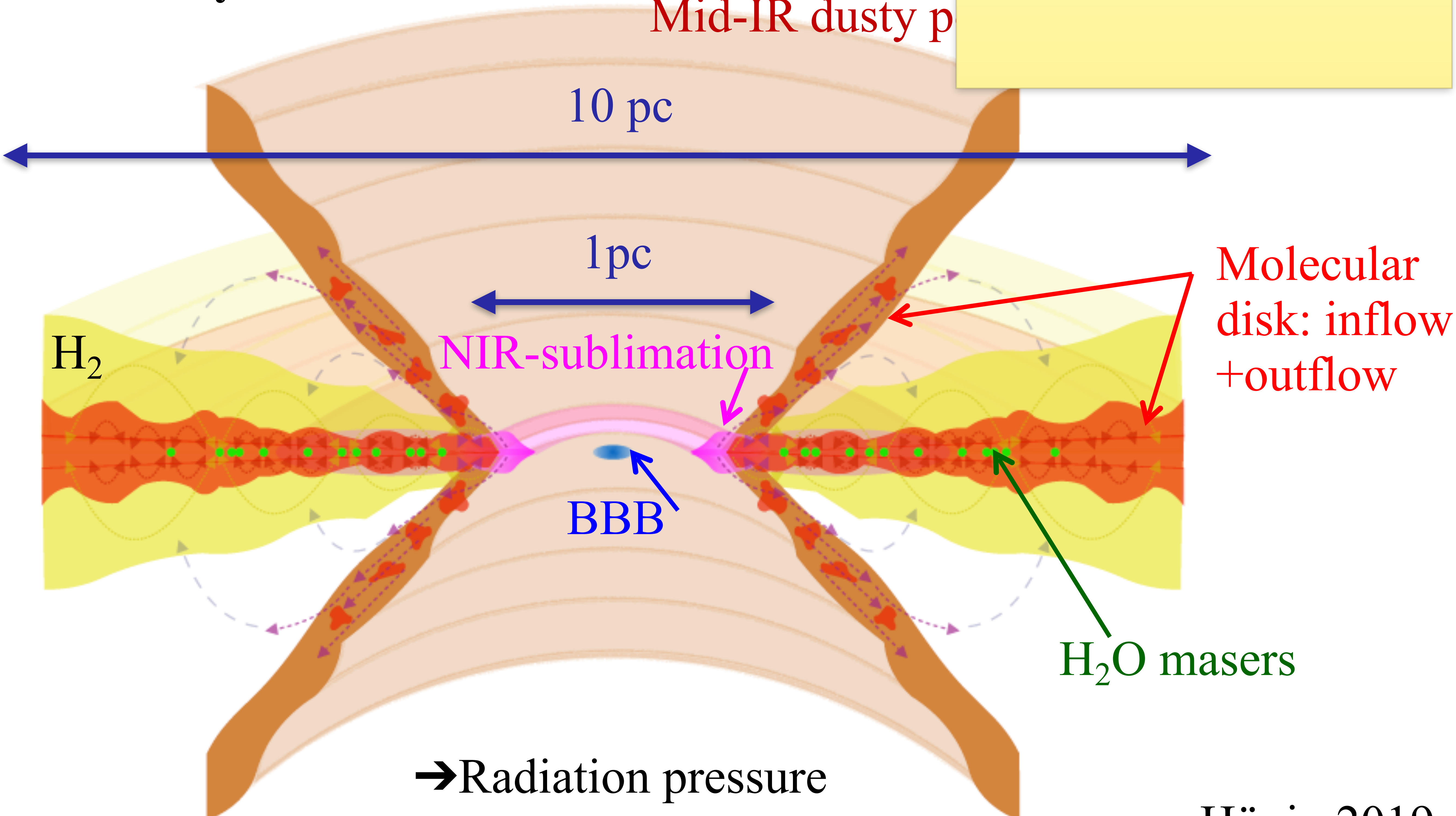
With 0.09” x 0.06” resolution (5pc): nuclear spiral +torus

Combes et al 2019

observed. Signs of outflow too.

Schematic vision: Infl

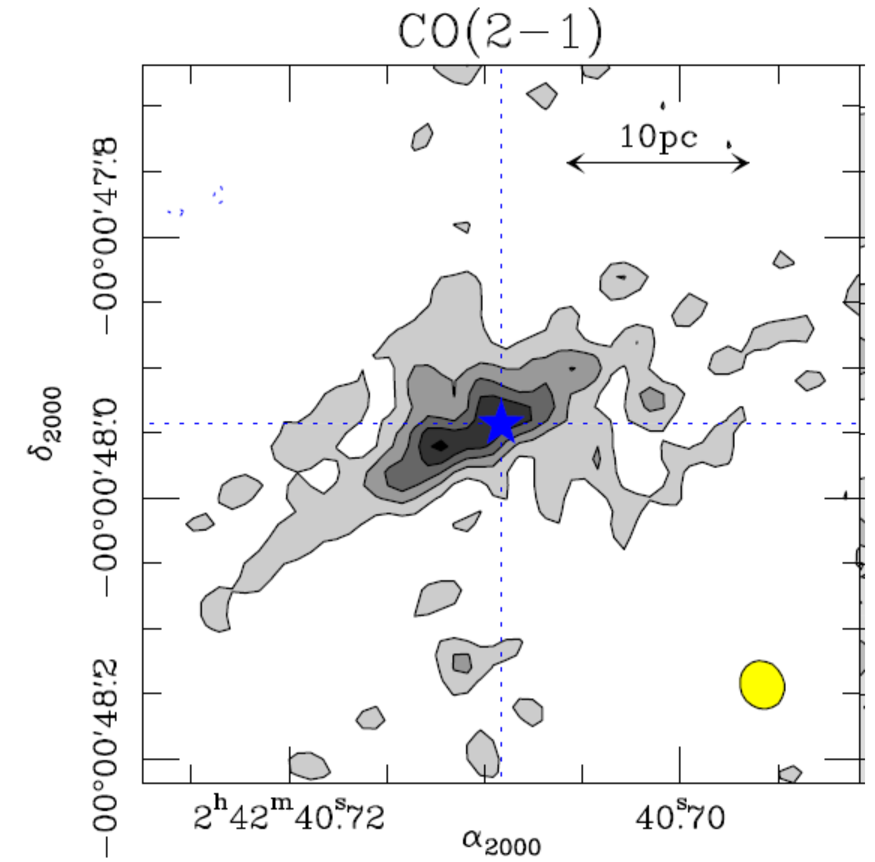
Parsec scale:
« The dusty torus »



Hönig 2019

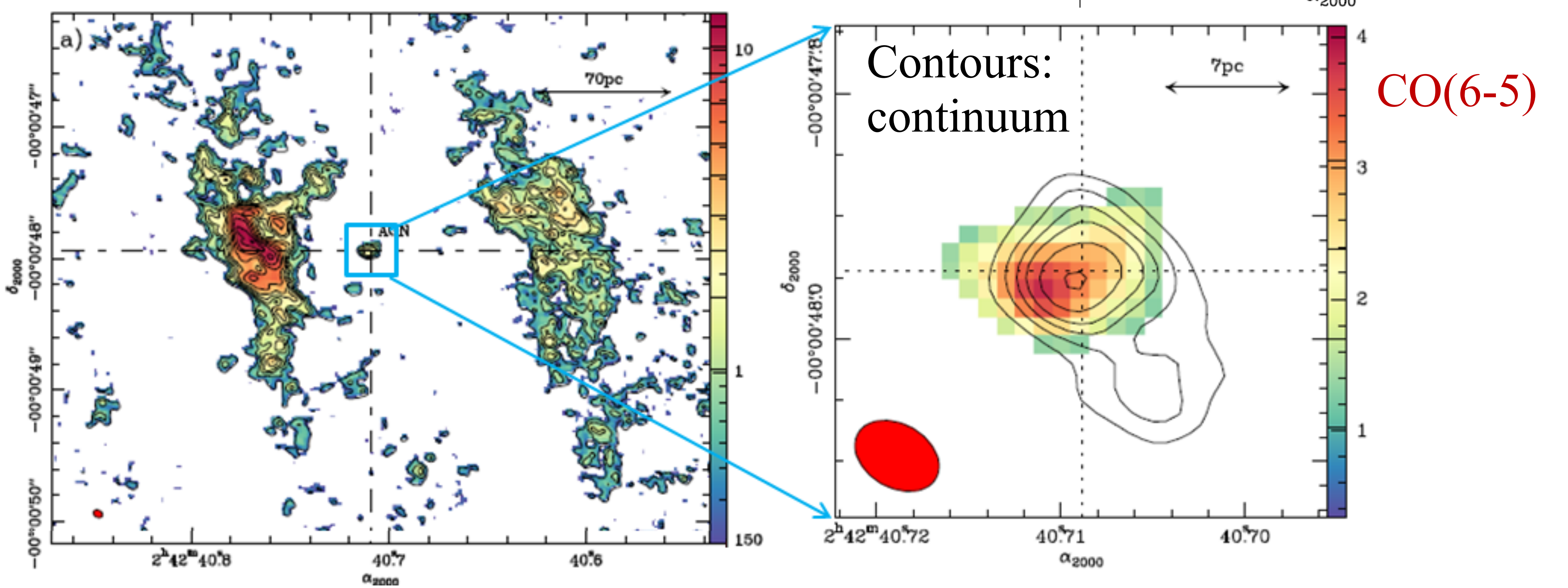
Detection of molecular tori

Garcia-Burillo et al 2019



ALMA CO(6-5) and 432μm dust emission
→Torus of 7-10pc in diameter in NGC1068

More inclined than the H_2O maser disk



Garcia-Burillo, Combes, Ramos-Almeida et al 2016, **R=3.5pc torus**

Concluding Remarks

Small scales :

- mechanisms to drive the gas in (10pc) - **angular momentum pb**
- Even higher resolution ? Kinematics of the torus ? **Effect (feedback) at small scales** of the AGN winds / jets ? …

Intermediate scales :

- clear evidence of feedback : molecular outflows / X-ray cavities
- **impact of the feedback debated** (how does it affect the SFR —> how does it affect the molecular gas). v_outflow vs v_escape ? warm gas fraction ? total outflow mass (opt. thin) ? Effect on disks ? Forming stars ? Jet vs Wind, Epoch ?
- Need to **study the properties of molecular gas** expelled / re-formed ? Overpressured ? HI to H2 transition ? Physical state (CR, shock heated, PDF) ? …

Large scales :

- **Filamentary structures in ICM** of local clusters **radio-jets**. Role of the AGN if any ? Rapid evolution of modeling technics (ie CCA). Maintenance mode when radio-source on…
- GRGs
- Evidence of early halos enrichment

Very large scales :

- Impact of QSO on the re-ionisation