The life-cycle of galaxies:
feedbacks in galaxy evolution

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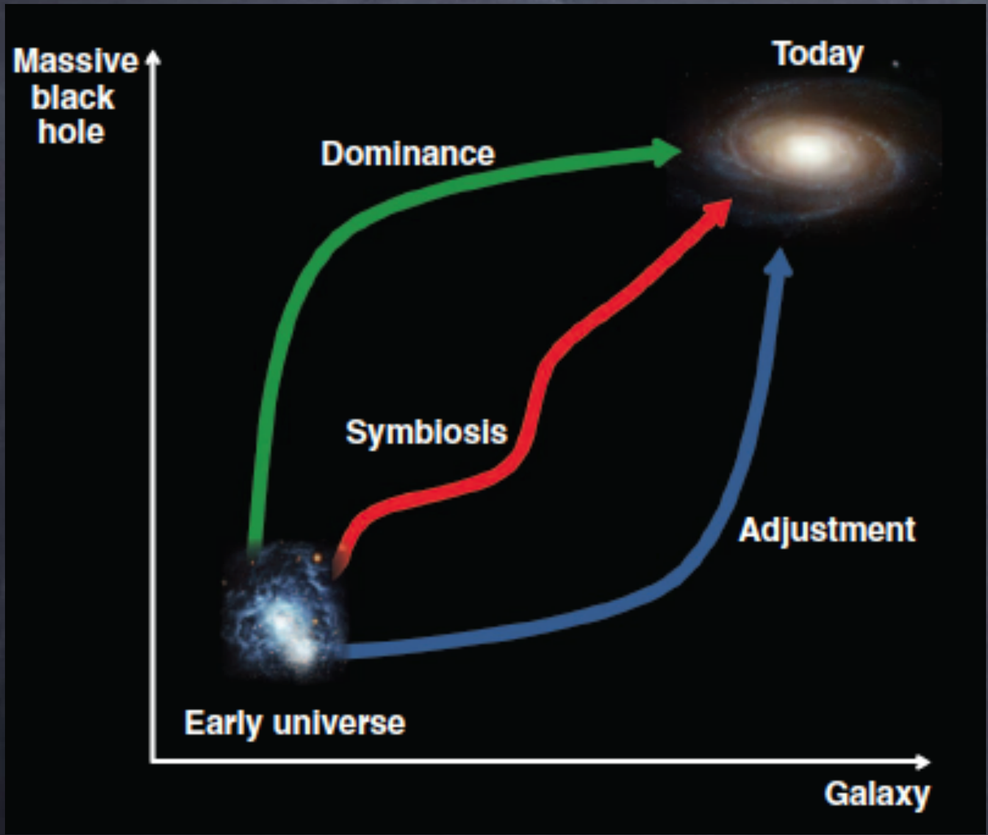
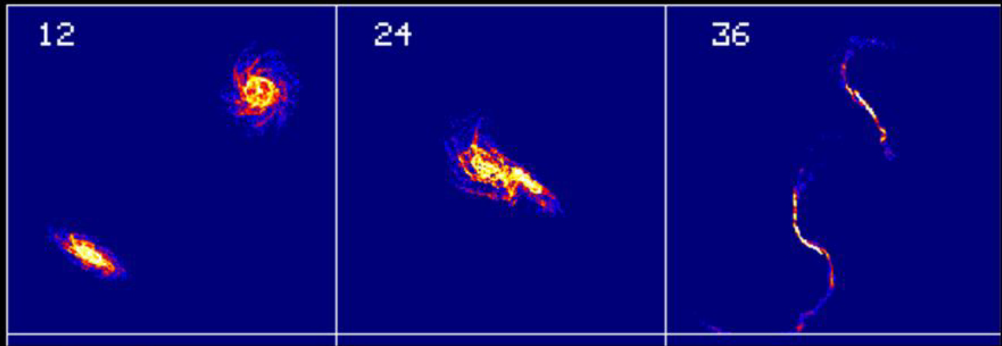
The AGN/galaxy coevolution



- Collapse
  - Galaxy Formation
  - MBH Formation
  - Accretion
- Merging
  - Galaxy
  - MBH
- Feedback
  - Stellar / SN
  - AGN

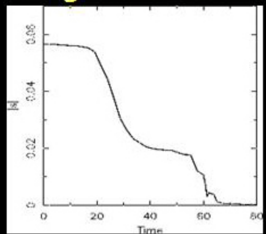
Galaxy encounters



Mihos & Hernquist 1996
See also Noguchi 1987
Barnes & Hernquist 1991

"'tidal forces during encounters cause otherwise stable disks to develop bars, and the gas in such barred disks, subjected to strong gravitational torques, flows toward the central regions "

Gas Angular Momentum



Part of the available galactic cold gas is detabilized and funnelled toward the centre

$$f(v,V) = \frac{1}{2}\left|\frac{\Delta j}{j}\right| \approx \frac{1}{2}\left\langle \frac{m' r_d v_d}{mbV} \right\rangle$$

Cavaliere Vittorini 2000

(Sanders & Mirabel 96)

1/4 feeds the central BH

3/4 feeds circumnuclear starbursts

This occurs at a rate:

$$\tau^{-1}_{FlyBy} \propto n(\pi r^2_{tidal}) V_{rel}$$

It is averaged over all merging partners (m') in the same group/cluster (with relat. velocity V) at inpact param. b. These quantities + the cold available gas mcold are obtained from the SAM (NM et al. 2002)

QSO Properties

$$\dot{m}_{acc}(v,t) = \frac{1}{4}\left\langle \frac{f\, m_{cold}}{\tau_r} \right\rangle$$

$$L(v,t) = \frac{\eta c^2 \Delta m_{acc}}{\tau}$$

$$m_{BH} = (1-\eta)\int_0^t \dot{m}_{acc}(v,t')\, dt'$$

Starbursts Properties

$$\Delta \dot{m}_*(v,t) = \frac{3}{4}\left\langle \frac{f\, m_{cold}}{\tau_r} \right\rangle$$

$$\Delta S_\lambda = \int_0^t \Delta \dot{m}_*(t-t')\, \Phi_\lambda(t')\, dt'$$

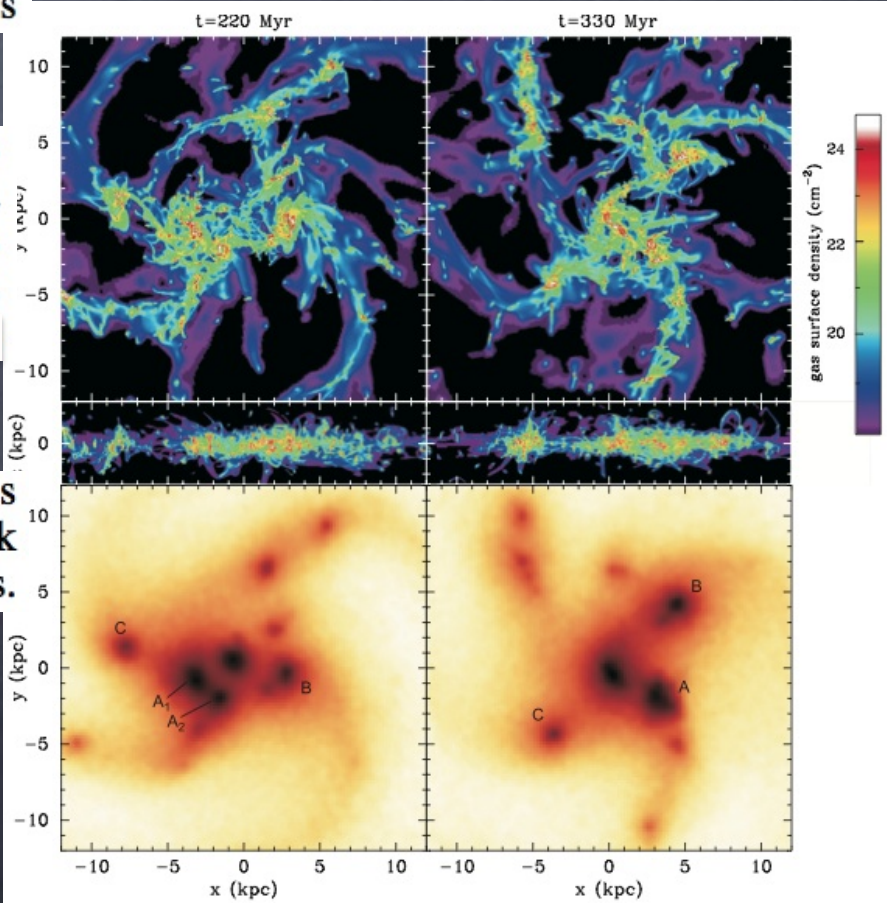
Galaxy dinamycs

The corresponding bolometric luminosity is 2×10^{44} erg s^{-1}. With typically 1%–5% in X-rays, we estimate on average $L_X \sim 10^{42}$–10^{43} erg s^{-1}, scaling with galaxy mass and with $(1+z)^{2.5}$. While the average luminosity would be modest, short episodes of higher accretion rate, possibly up to the Eddington level, occur during the central coalescence of migrating giant clumps—which could also bring with them seed BHs

Cold flows (similar to minor mergers)

Dekel+ 2009, Bournaud+ 2011

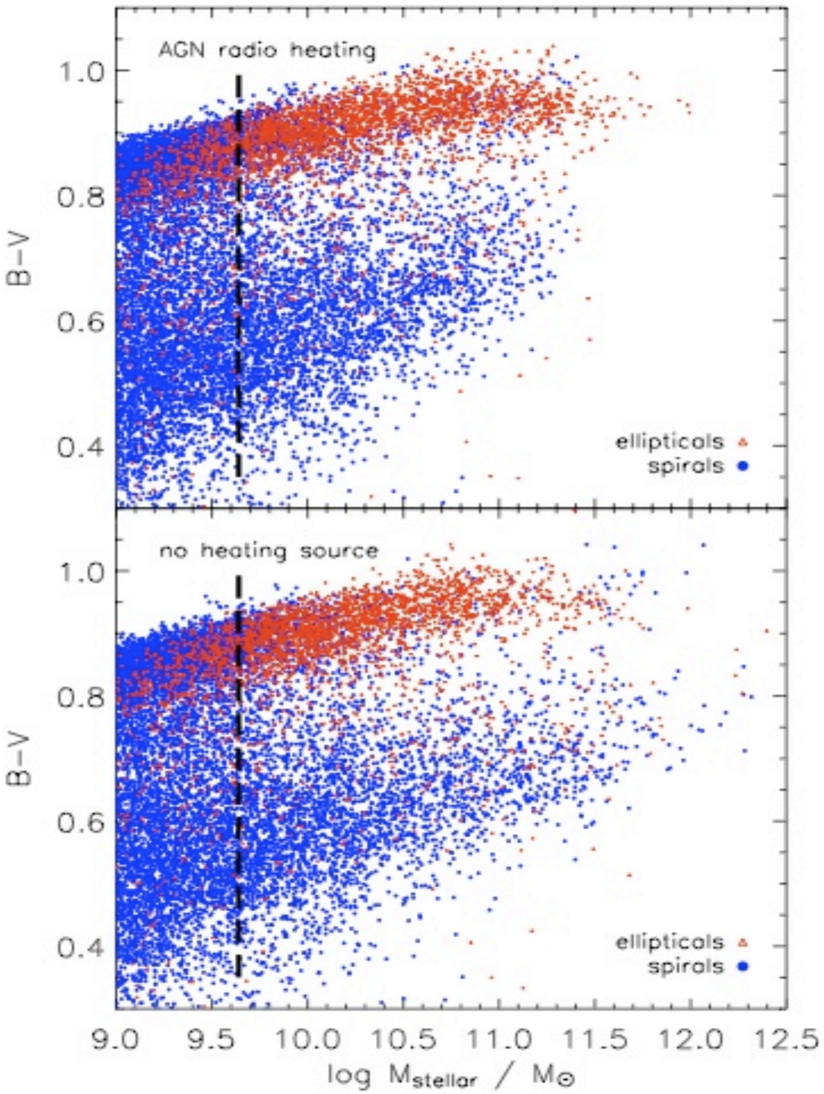
Disk instability at $z \sim 2$ can thus funnel half of the disk gas toward the center in 2 Gyr. This is similar to the mass inflow in a major merger (Hopkins et al. 2006), but spread over a 10 times longer period, resulting in a lower average AGN luminosity, with higher duty cycle, and high obscuration.



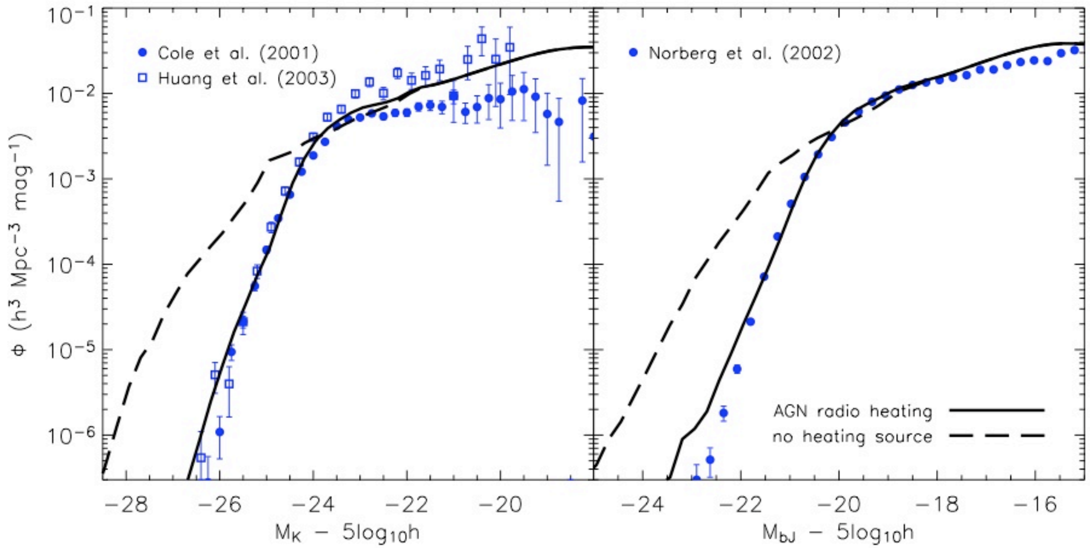
The main prediction is thus that many high-z AGNs should be hosted by star-forming disk galaxies, composed of clumpy disks and growing spheroids.

Massive galaxy density and colors: AGN feedback!

Menci+ 2006



Croton+2006



Without AGN heating SAMs:

1. overpredict luminosities of massive galaxies by ~2 mags

and/or

2. predict a number of massive blue galaxies higher than observed

AGN Feedback & AGN accretion mode

- Quasar mode
  - Major mergers
  - Minor mergers
  - Galaxy encounters
  - Activity periods are strong, short and recurrent
- AGN density decrease at z<2 is due to:
  - decrease with time of galaxy merging rate
  - Decrease with time of encounters rate
  - Decrease with time of galactic cold gas left available for accretion
- Feedback is driven by AGN radiation

Menci+ 2003,2004,2006,2008

- Radio mode
- Low accretion-rate systems tend to be radiatively inefficient and jet-dominated
- Feedback from low luminosity AGN dominated by kinetic energy
- Low level activity can be ~continuous

Croton+ 2006

AGN feedback & AGN obscuration

Lapi Cavaliere & Menci 2005 ***Blast wave model:*** a way to solve the problem of the transport of energy: central highly supersonic outflows compress the gas into a blast wave terminated by a shock front, which moves outwards at supersonic speed and sweeps out the surrounding medium

Recipe plugged in the Menci et al. SAMs

$$R_S(t) \propto Mach\ t \propto \left(\frac{\Delta E}{E}\right)^{1/2} t$$

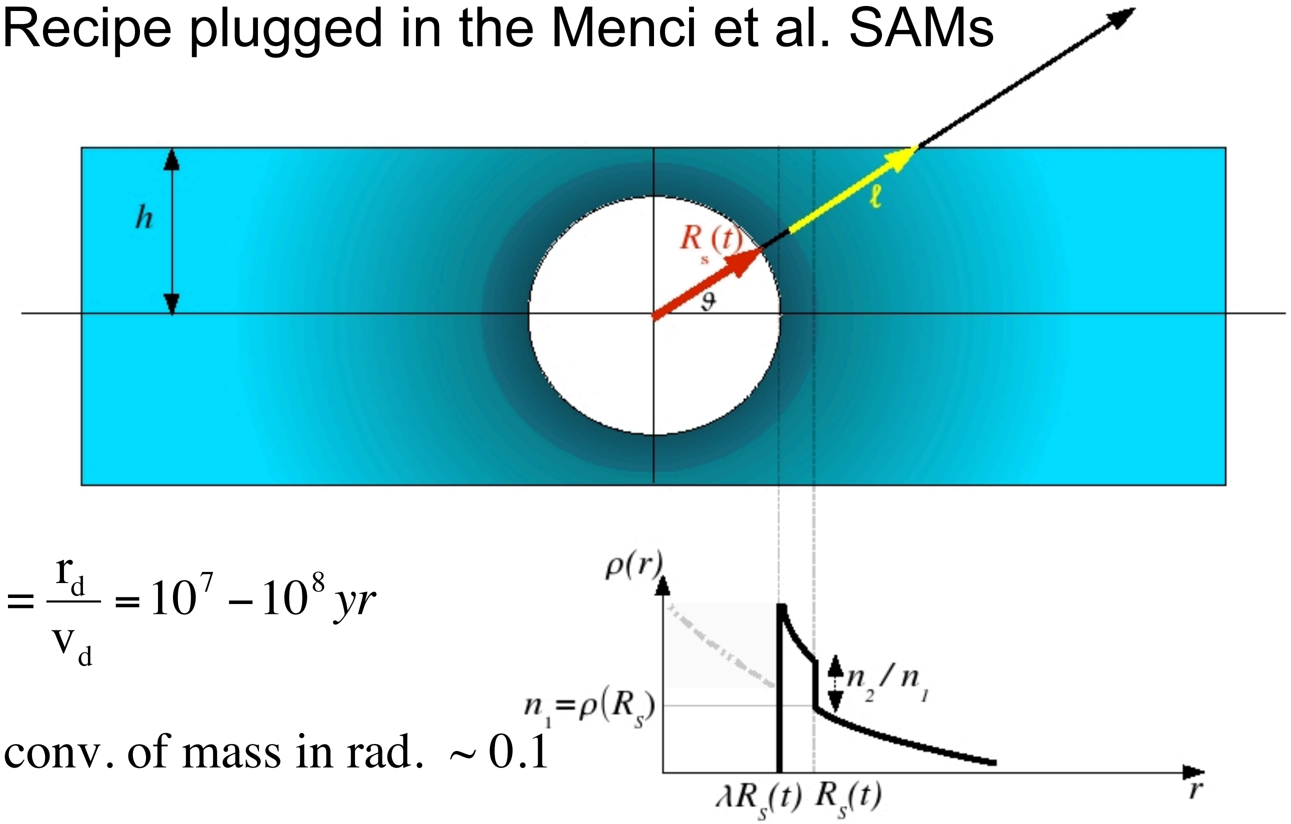
$$Mach \sim \left(\frac{\Delta E}{E}\right)^{1/2} \sim 40$$

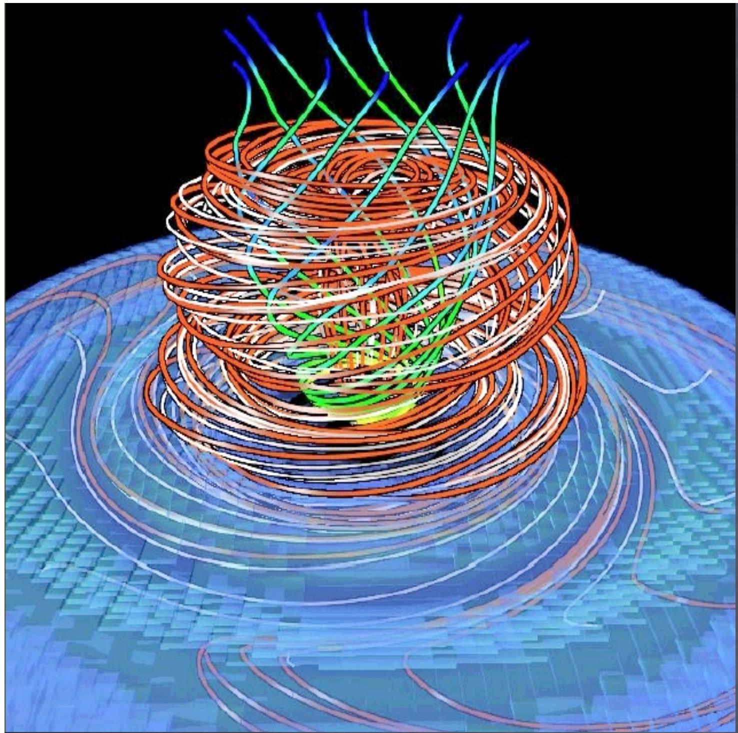
$$\Delta E = \varepsilon L \tau$$

$$\varepsilon \sim \frac{v_w}{2c} \sim 0.05 \text{ if } v_w \sim 0.1$$

$$\tau = \text{ timescale of AGN activity } = \frac{r_d}{v_d} = 10^7 - 10^8\, yr$$

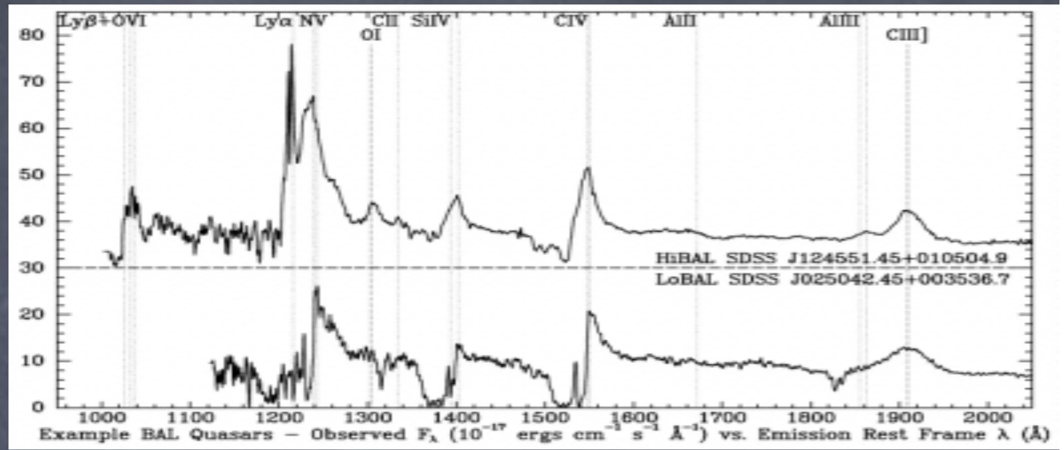
$$L = \frac{\eta c^2 \Delta m_{acc}}{\tau} \quad \eta = \text{efficiency of conv. of mass in rad. } \sim 0.1$$





AGN winds and outflows

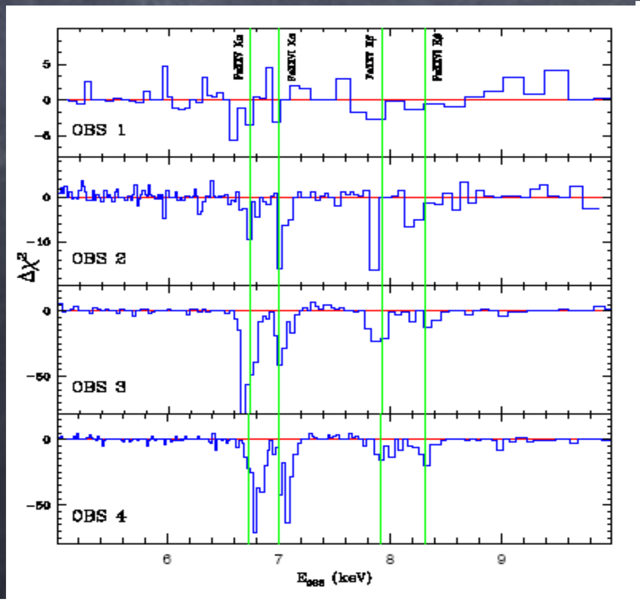
BAL QSOs (10-40% of all QSOs)



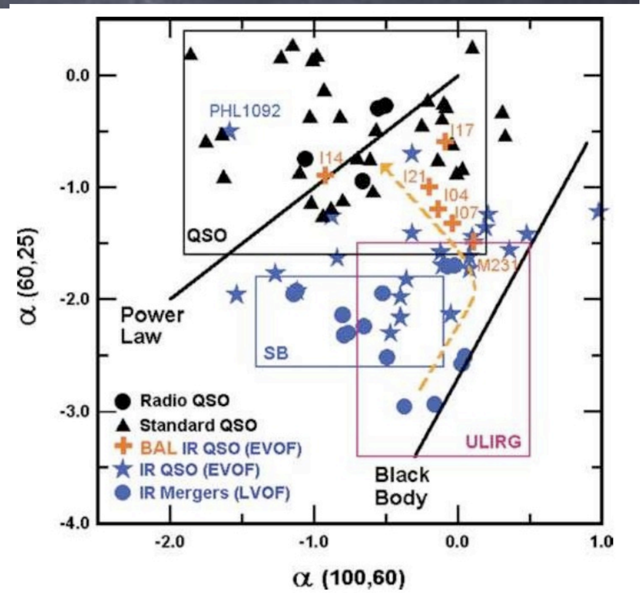
Fast winds with velocity up to a fraction of c are observed in the central regions of AGNs; they likely originate from the acceleration of disk outflows by the AGN radiation field.

Crenshaw+03, Pounds+03, Reeves+09, Moe+09

NGC1365 Risaliti+ 2005



BAL sequence Lipari+ 2006



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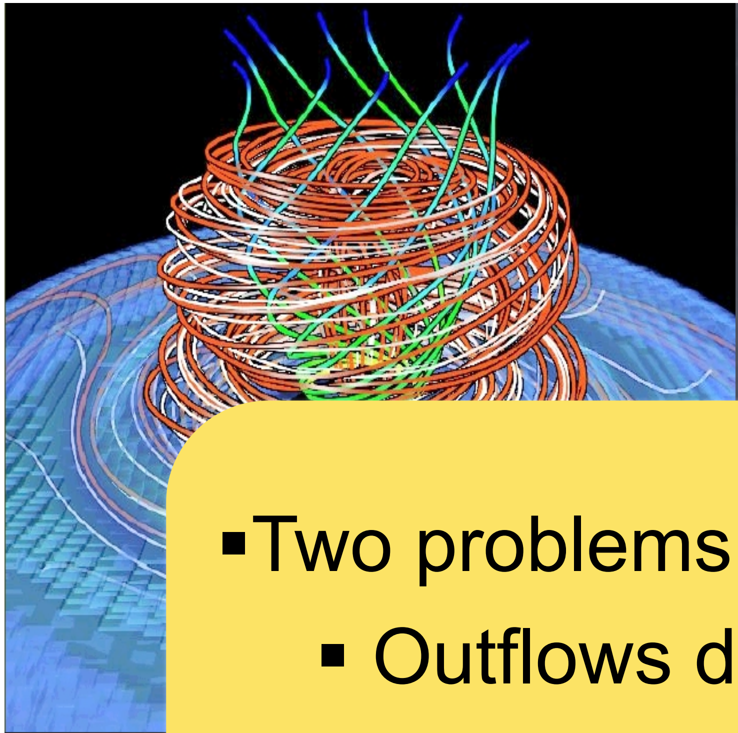

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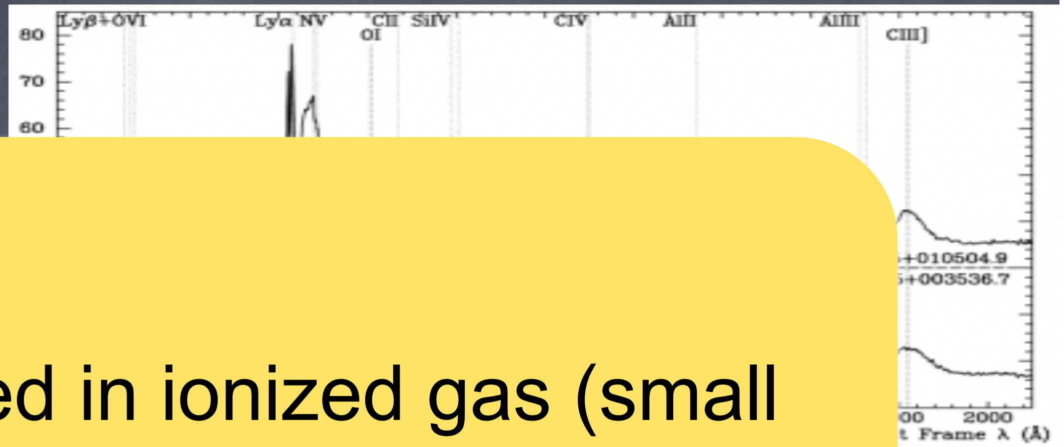

- Two problems:
  - Outflows detected in ionized gas (small fraction of all galaxy gas)
  - Physical scale unknown or small (nuclear)

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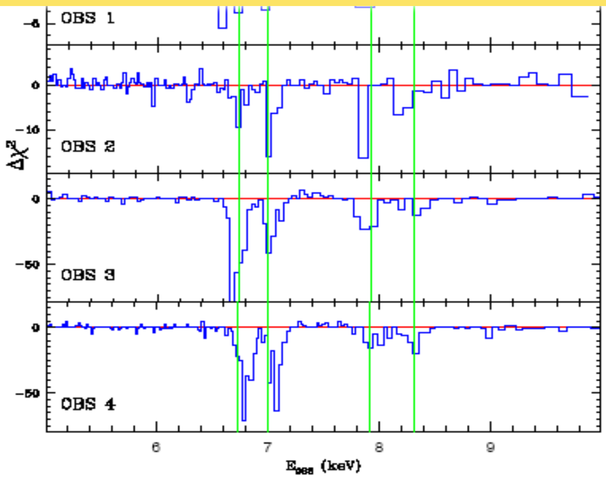
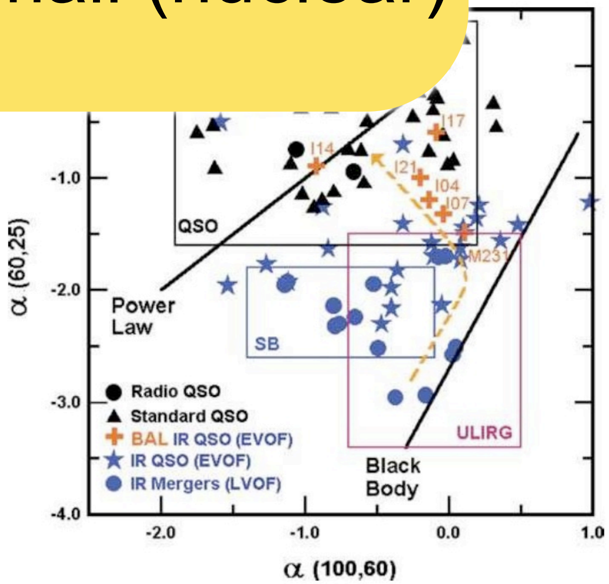
+ 2006





Galaxy scale ionized outflows

- IFU observations of [OIII] emission of radio galaxies, up to z=2.5 (Nesvabda+ 2006, Swinbank+ 2005,2006)
  - Extent of broad [OIII] similar to radio emission
  - Ekin~1-40% Ejet
- SMMJ1237, a QSO in a z~2 ULIRG (Alexander+ 2010)
  - Extent of broad [OIII] ~4-8kpc
  - E_{kin}~10^{59} ergs over 30Myr ~ binding energy of galaxy spheroid
- Giant SF clumps at z~2 (Genzel +2011)
  - Broad Hα wings, mass outflow rate > SFR

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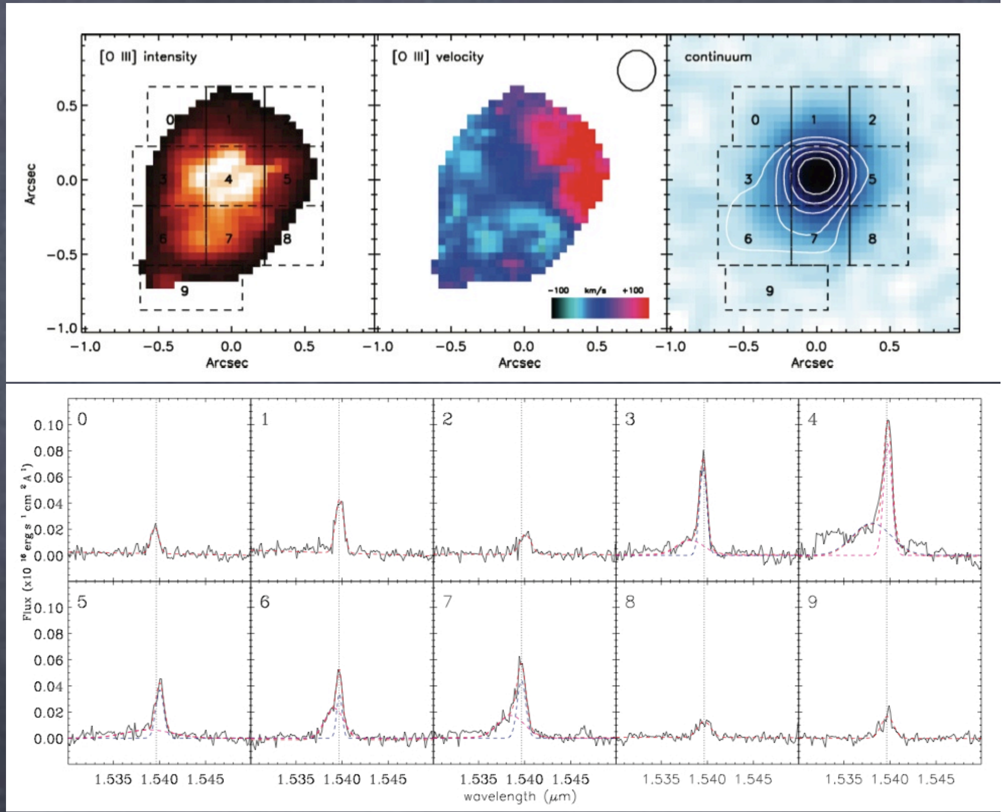

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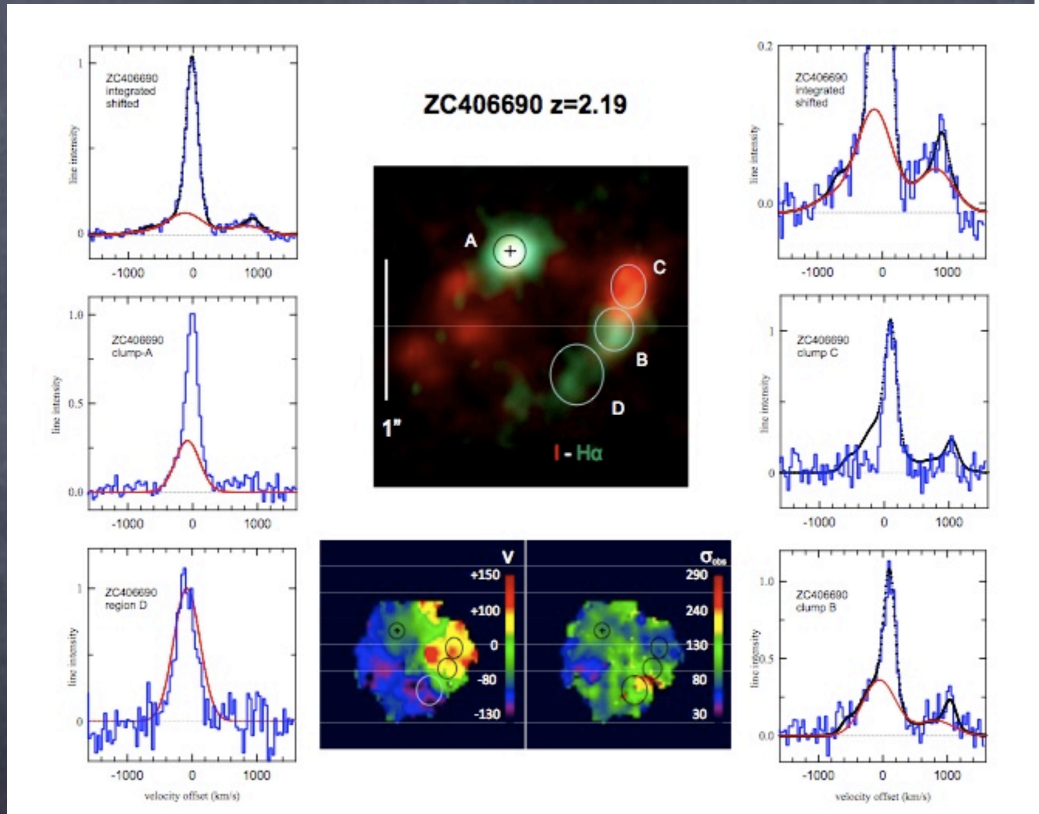

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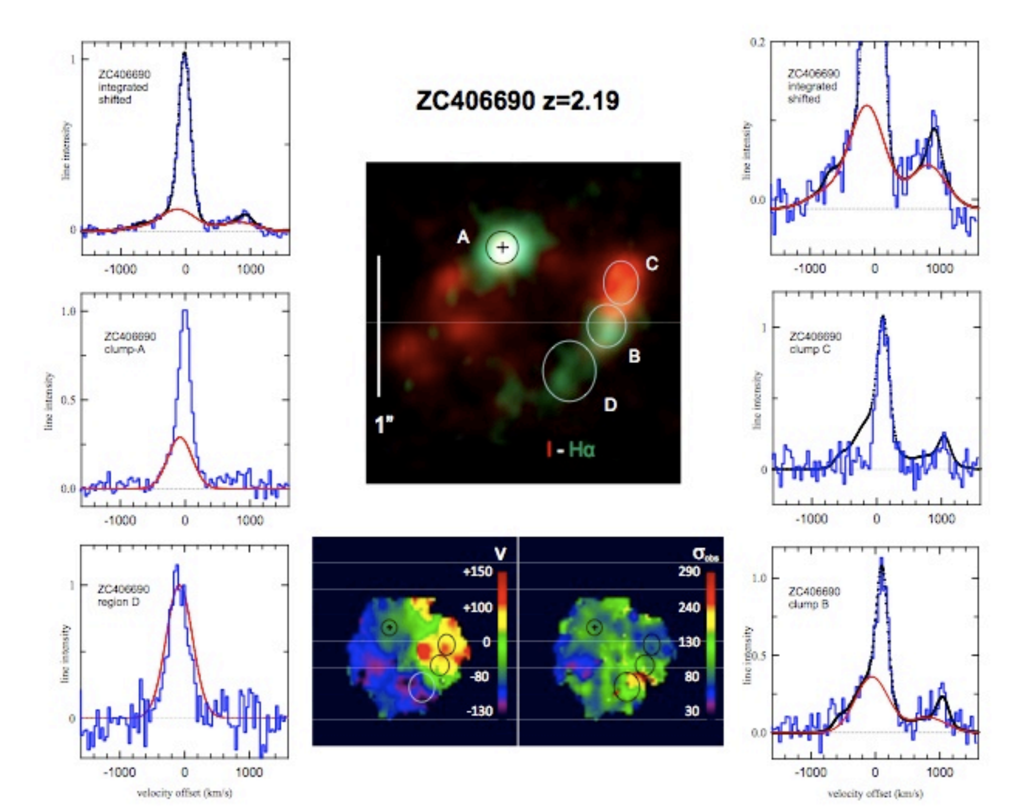


Mid-IR & Far-IR lines revealing AGN-driven outflows:

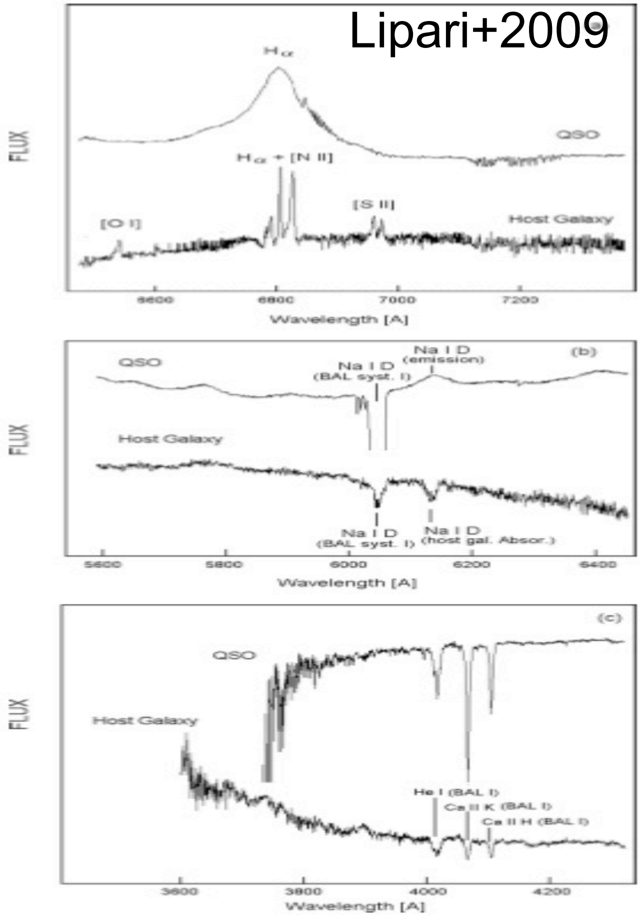
(I) Molecular gas
(II) Ionized gas

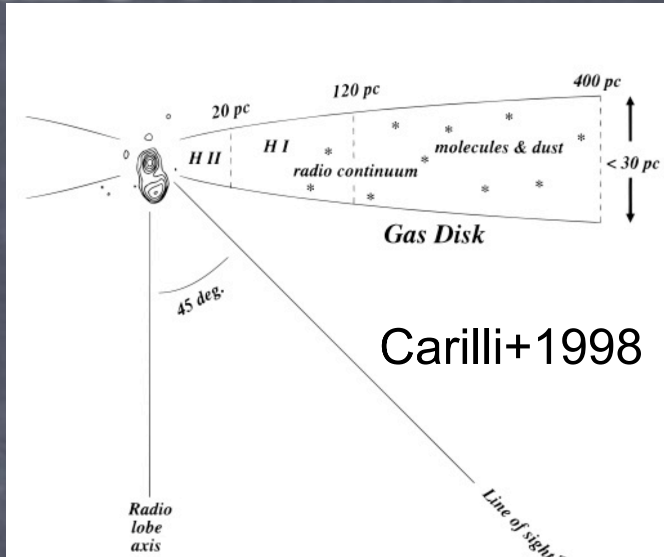
- Three science cases for testing the role of AGN feedback by a detailed kinematic study of the outflowing gas

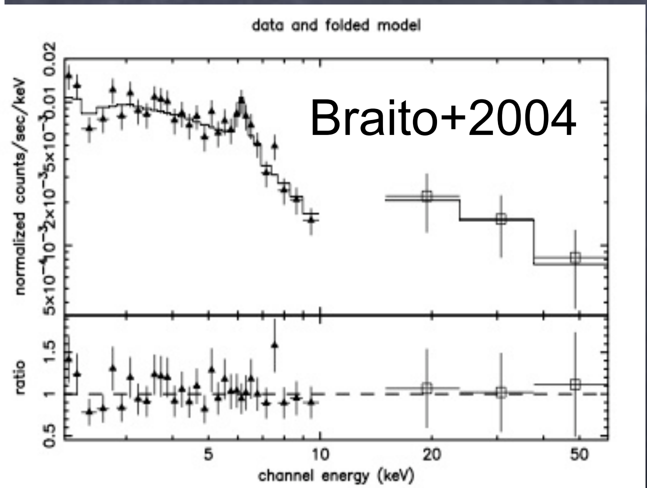
◆ Massive CO, OH outflows (Feruglio+2010, Sturm+ 2011)
◆ Warm H2 gas (Dasyra & Combes 2011)
◆ Blueshifted [Ne III] + [Ne V] lines (Spoon & Holt 2009)

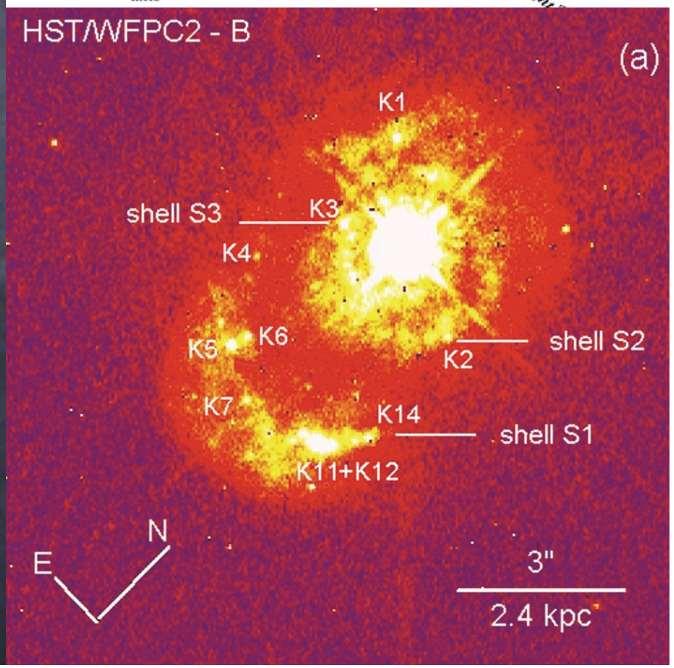
Galaxy scale molecular outflows: the case of Mrk231

- The nearest (z=0.042, 187Mpc), high luminosity (L_{bol}~10^{46} erg/s), highly obscured (N_H~10^{24} cm^{-2}) (BAL)QSO.









AGN outflows vs star formation

Mark231 broad CO line wings Feruglio+2010

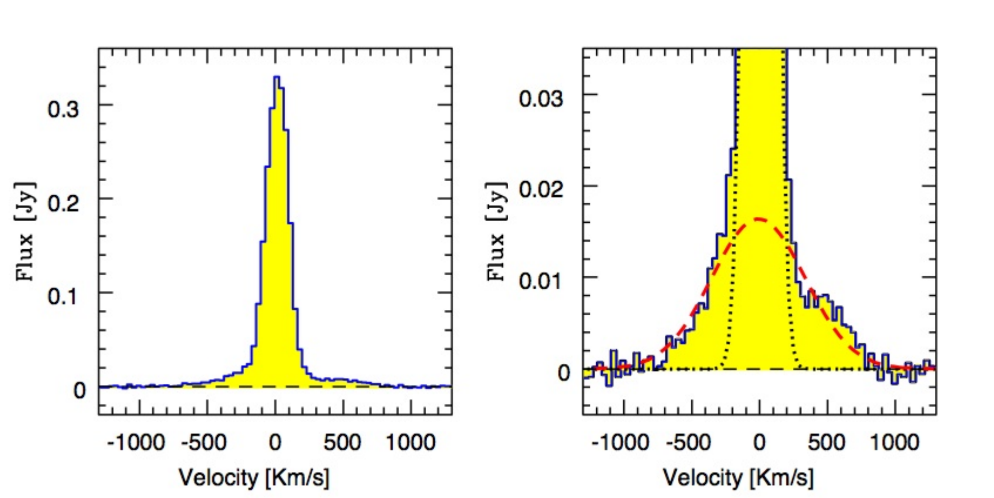
L_{bol}~5×10^{45} ergs/s

M_{H2}~7×10^{7} M_{sun}

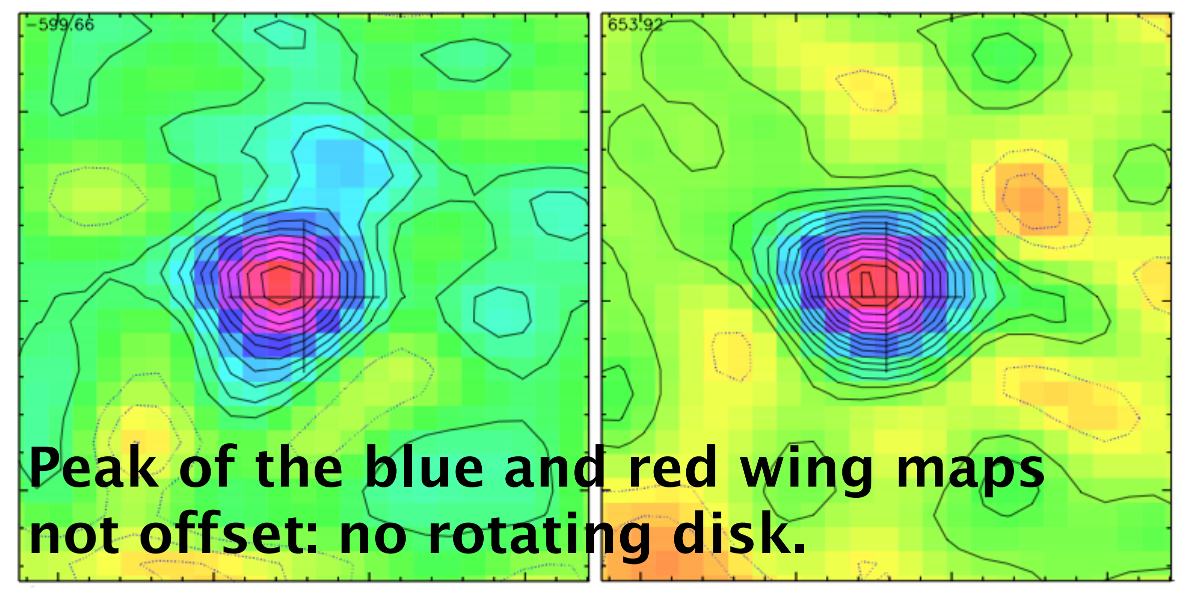
(uncertain conversion L'CO to M_{H2})

M_{out}~700 M_{Sun}/yr, SFR~200M_{sun}/yr:

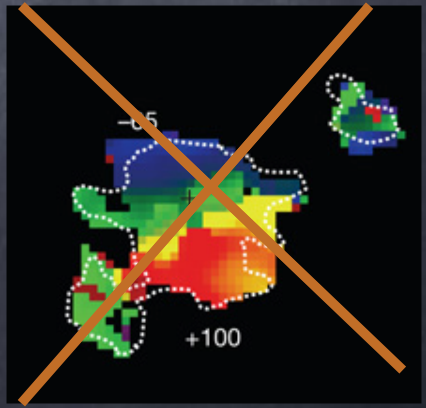
L_{bol}/M_{out}~7×10^{42} erg/s / M_{Sun}/yr



Wings are spatially resolved and extended on **1.2 kpc scales.**



Peak of the blue and red wing maps not offset: no rotating disk.

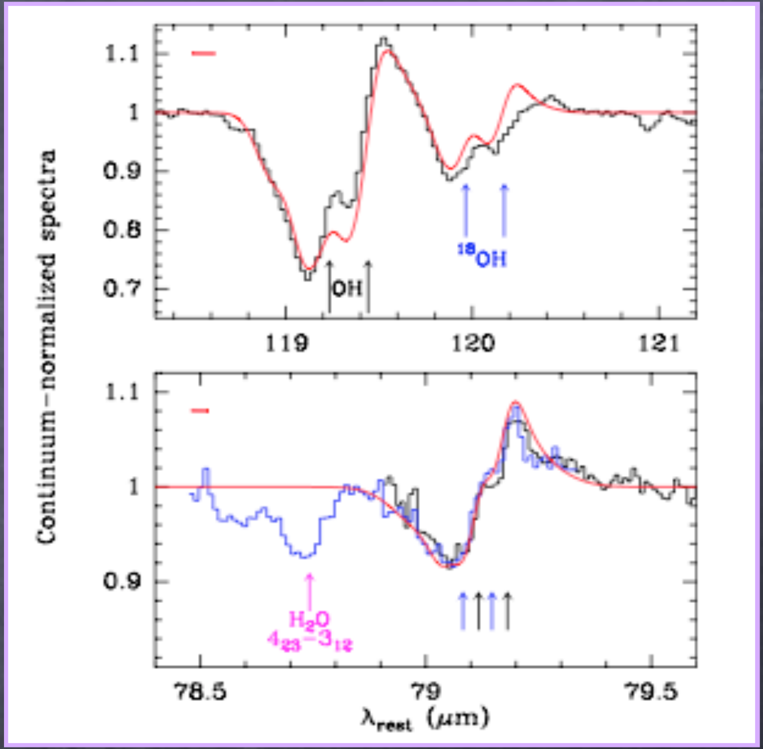


OUTFLOW!!!

AGN outflows: Herschel spectroscopy

P-cygni profile in OH, Herschel PACS spectra

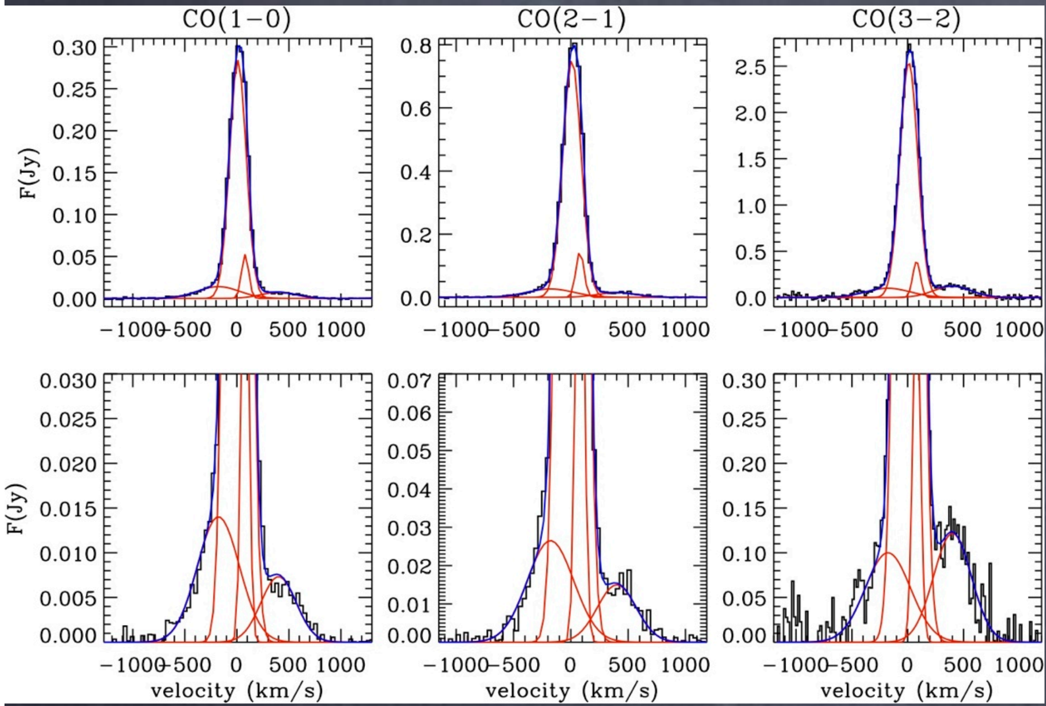
Fisher+2012

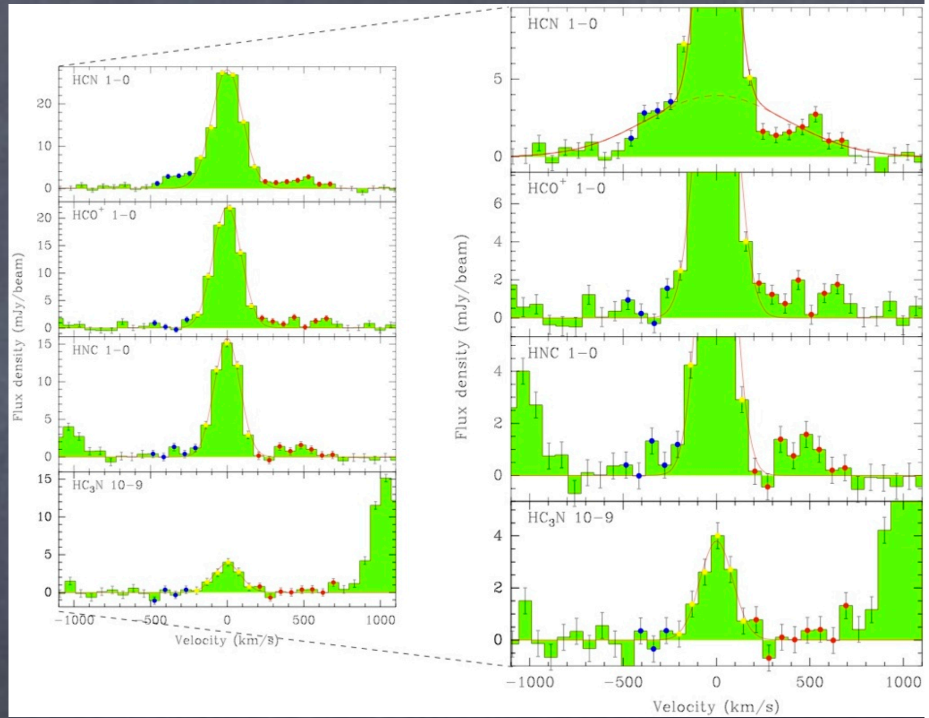


- Mass loss rate larger than the SFR: gas depletion time of the order 10^7-10^8 yr
- No stellar populations younger than 10^6 years in the central kpc (Lipari+2009)

The prototype Massive Outflow: Mrk 231

Broad wings detected in several other molecular transitions (Aalto+ 2012, Cicone+ 2012)





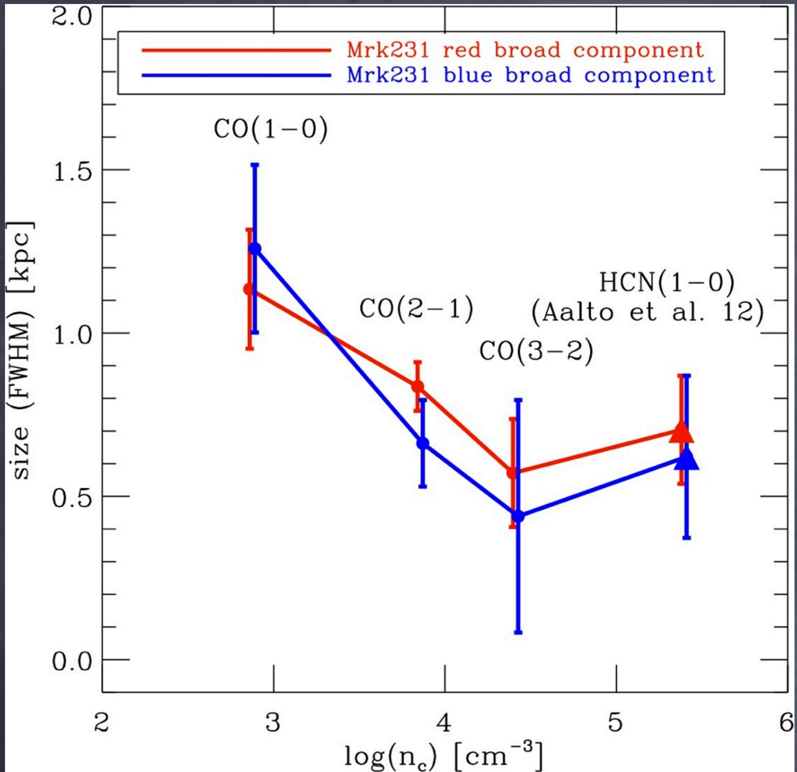
CO transitions

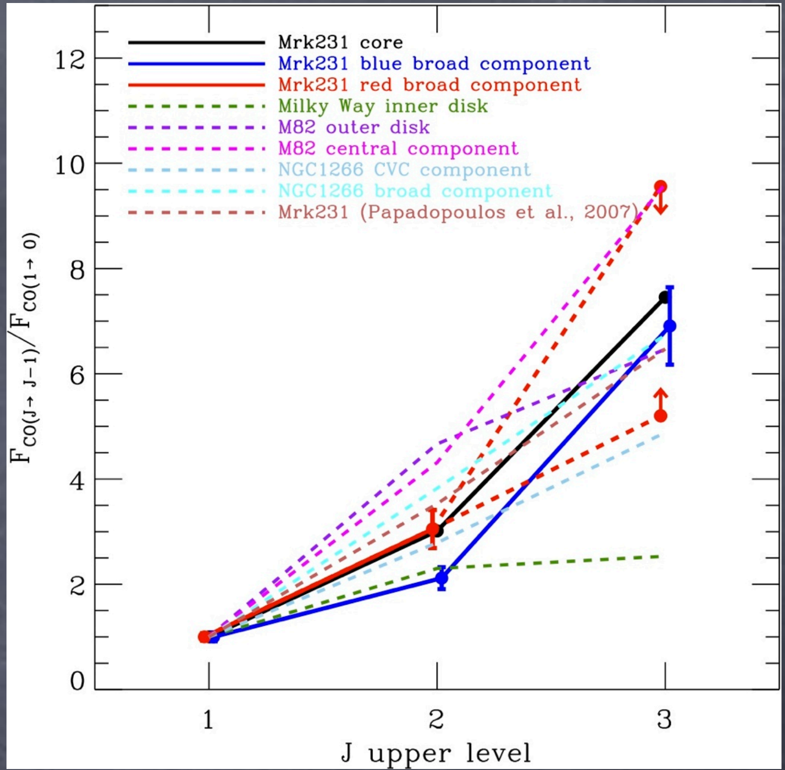
HCN HCO+ tracing dense clumps

Kinetic energy of outflowing gas: E =1.2×10^{44} erg/s = a few % L_{Bol} (5×10^{45} erg/s) of the AGN

compatible with models of AGN-driven outflow through a shock wave.

The prototype Massive Outflow: Mrk 231





Size is anti-correlated with the critical density: denser outflowing gas has more compact morphology

No difference in excitation of CO transitions in the high-v vs low-v gas.

Large uncertainties, CO(4-3) red wing may be blended with H13CN(4-3)

Agrees with King & Zubovas 2012: dense outflowing clouds embedded in a atomic outflow are not excited by shocks.

Cicone+ 2012

The prototype Massive Outflow: Mrk 231

Rupke+ 2011

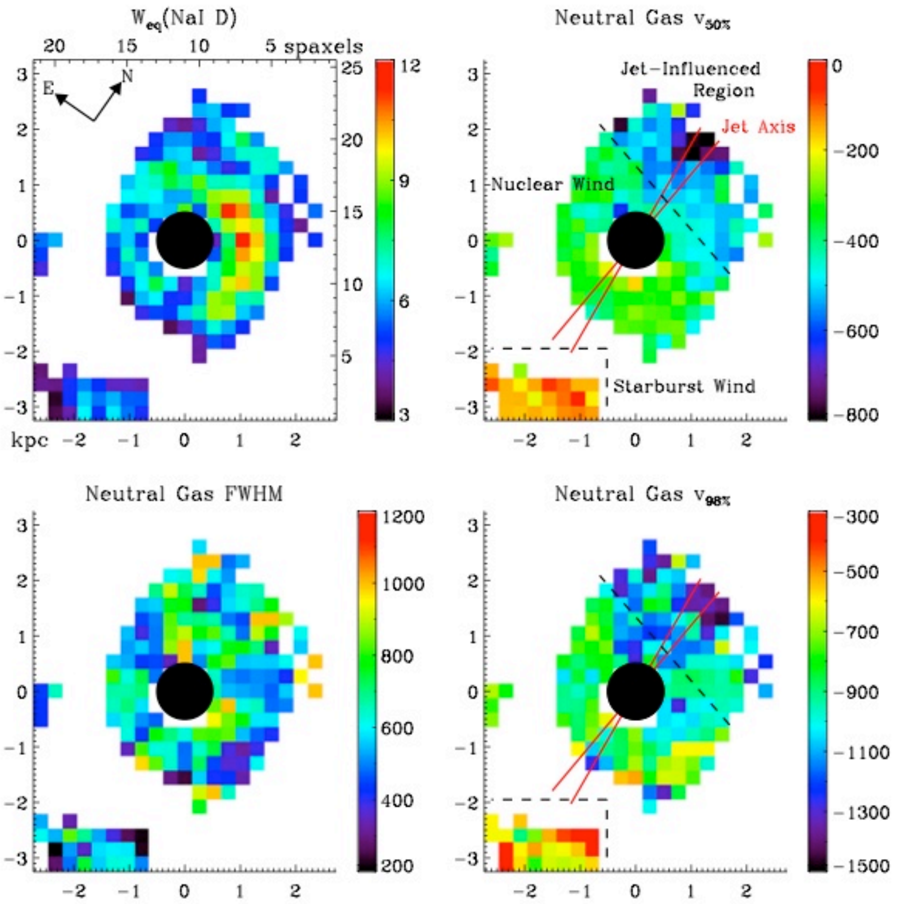


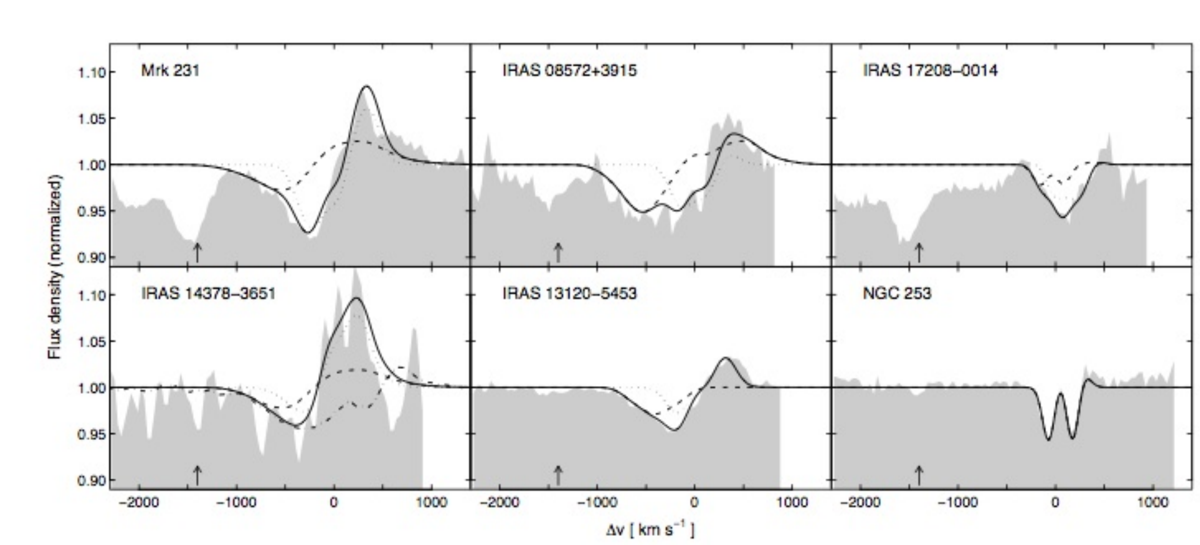
Figure 4. Equivalent width, central velocity, FWHM, and $v_{98\%}$ maps of Na I D. A nuclear outflow extends from the nucleus up to 2–3 kpc in all directions (as projected in the plane of the sky). The high velocities suggest that the AGN powers the nuclear wind. The northern quadrant of the nuclear wind is further accelerated by the radio jet. A lower-velocity starburst-driven outflow is present in the south.

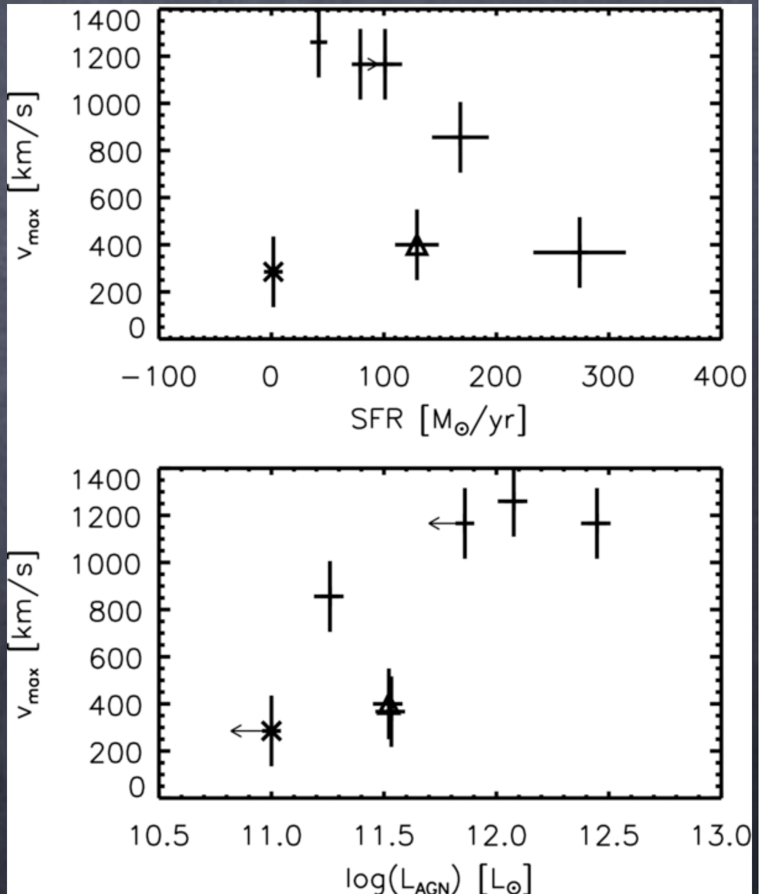
Extended outflow detected in IFU IR observations of neutral gas as well

Also a blu-shifted HII region, probably outflow powered by star-formation. Showing the complex nature of Mrk 231 :OUTFLOWS from AGN and SF acting at the same time

AGN outflows vs star formation

Sturm+2011 Herschel PACS BAL spectra composite sample of both AGN and SF-dominated ULIRGS. Outflows detected through P-cygni profiles of OH. Mass loss rate depends on the OH abundance but > several hundreds M_{Sun}/yr





What is powering the outflows?

Terminal velocity vmax correlated with LAGN --> powered mainly by the AGN

Terminal velocities > 1000 km/s in AGN-dominated objects

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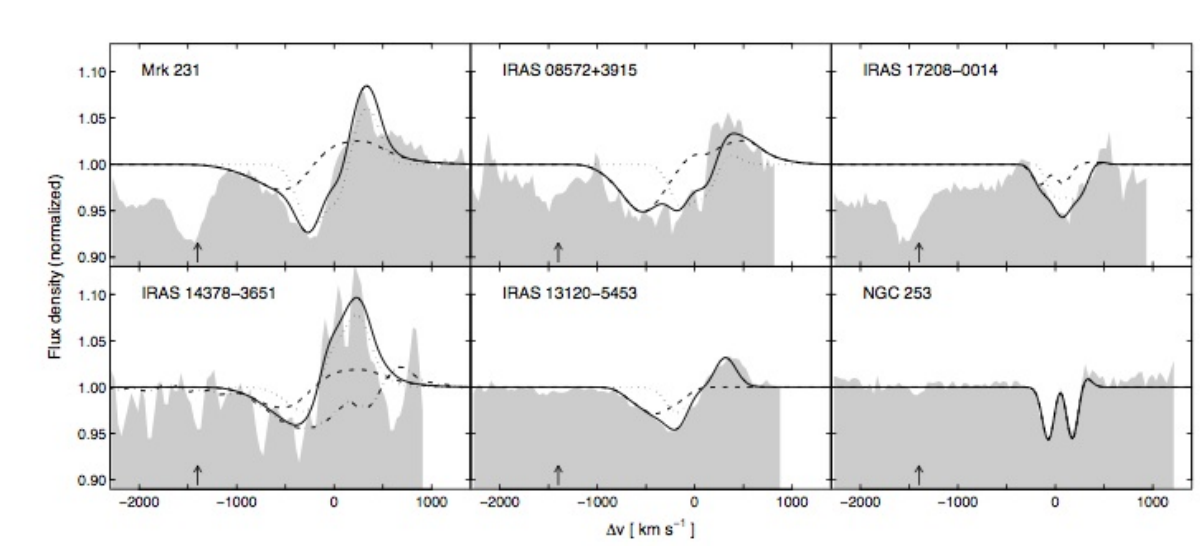

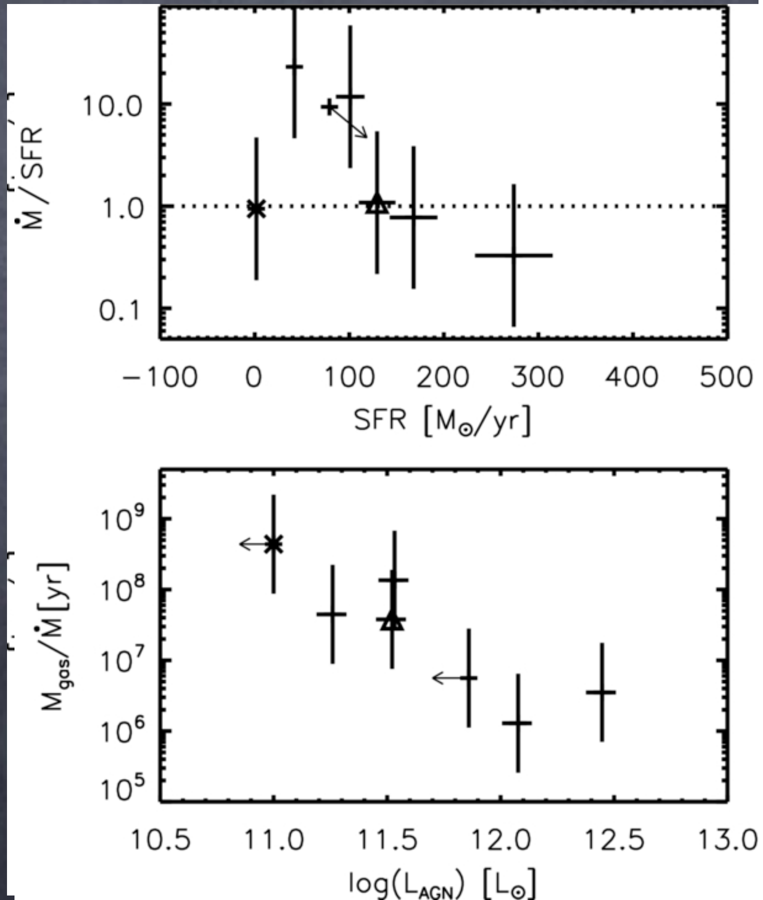

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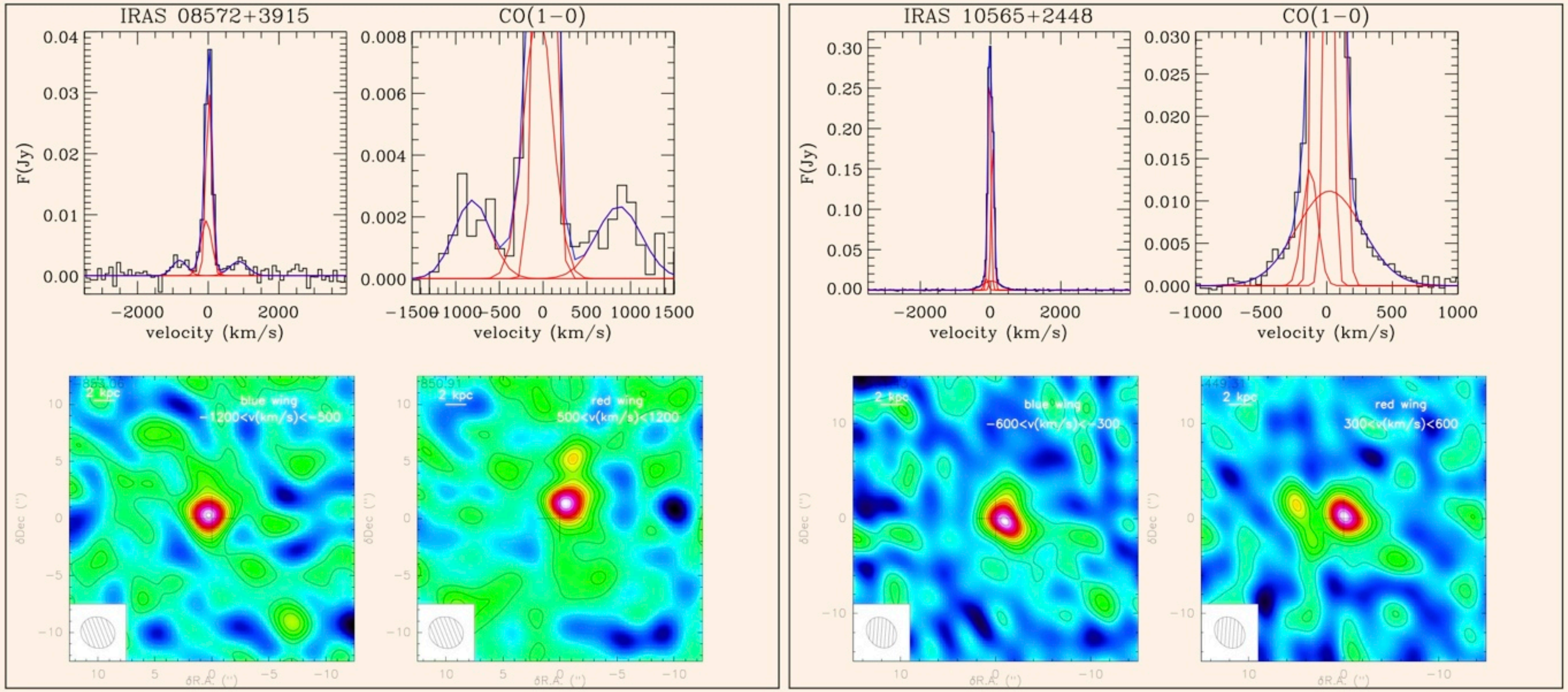
OUTFLOWS COMMON IN ULIRG/QSO?

On-going follow up with the PdBI to constrain sizes and mass loss rate

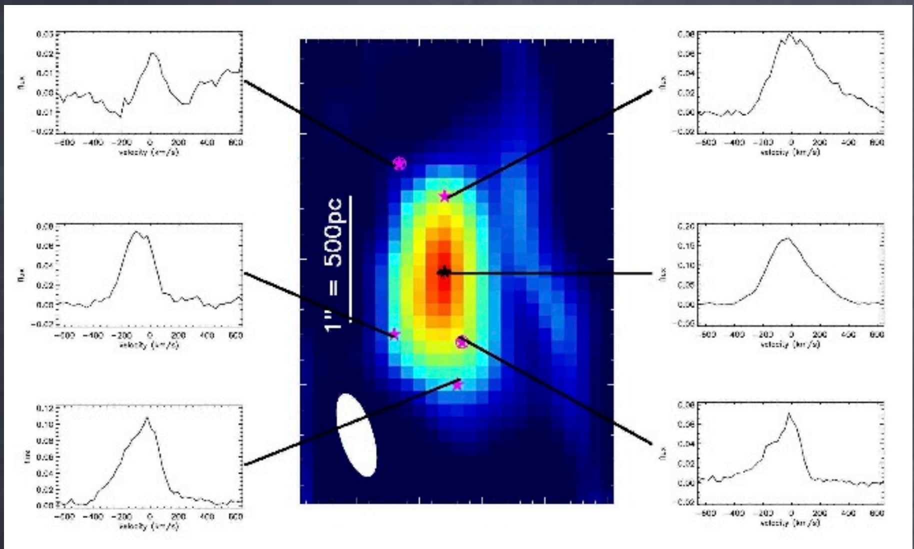
Broad wings detected, and resolved. Maps also show substructures (clumps)

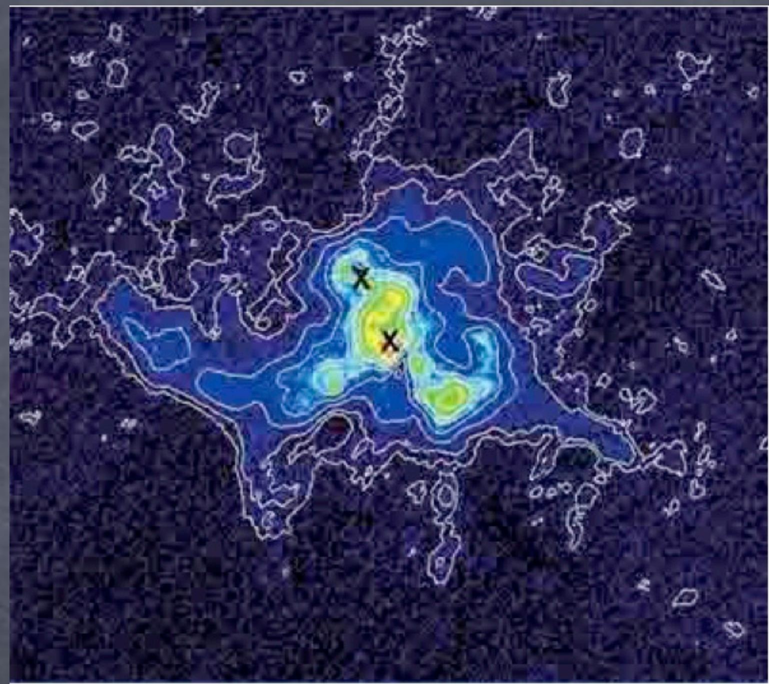
Mass loss rate > 600 M☉/yr   and above 1000 M☉/yr in AGN-dominated objects



Source	$\log(L_{AGN})$ [$L_\odot$]	SFR [$M_\odot$ yr^{-1}]	$v_{OF,max}$ [km/s]	FWHM (CO(1-0)) [kpc]	OF rate [$M_\odot$ yr^{-1}]
Mrk 231	12.45	200	~1000	1.2	~700-1000
IRAS 08572+3915	12.08	42	~1500	2.5	~1400
IRAS 10565+2448	11.38	84	~600	2.4	~600

NGC 6240
a complex system with broad CO





Major merger in early stage, with complex morphology, streamers, tidal tails, and 2 AGN nuclei both heavily obscured, with L(2-10) keV > 10^{44} erg/s and MBH > 10^8 M☉

SEVERAL MECHANISMS in ACTION !!

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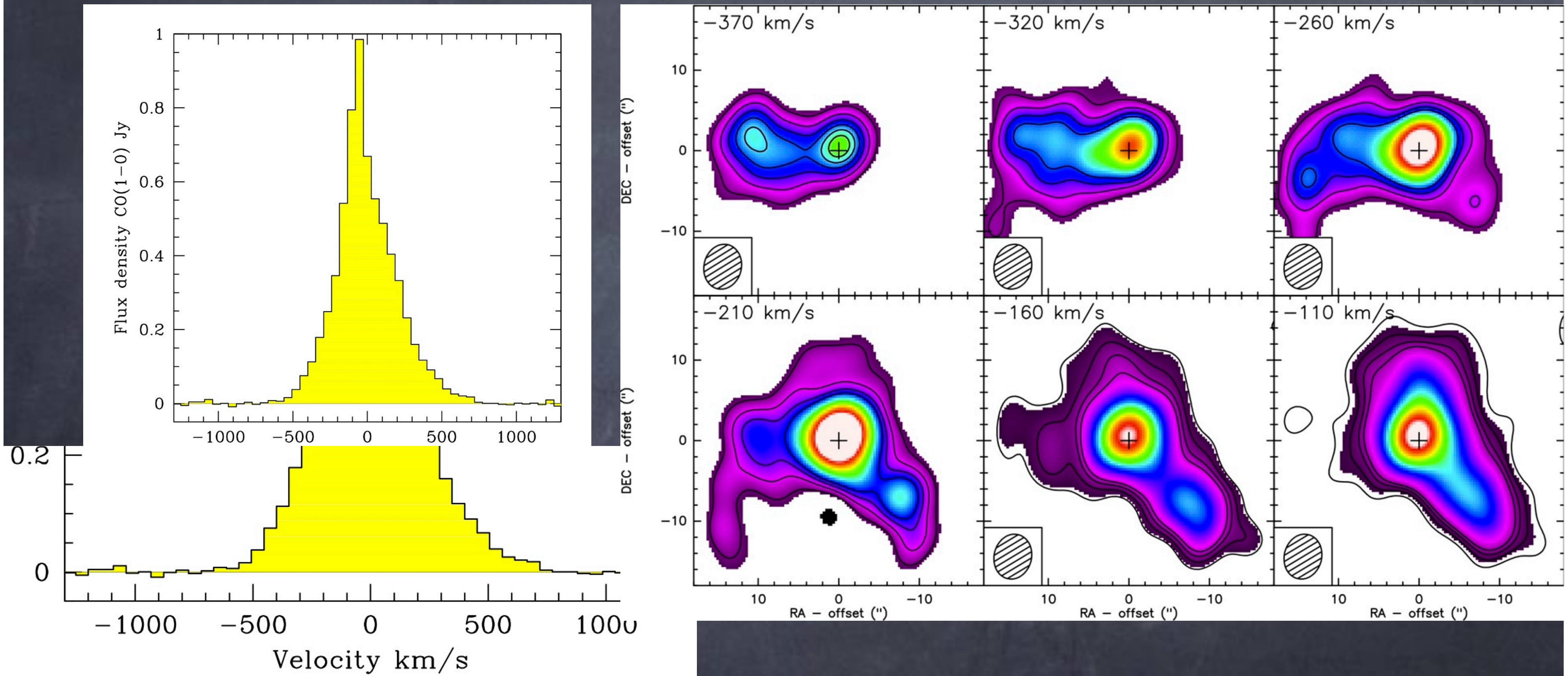

New sensitive PdBI observations of CO(1-0): Broad CO(1-0) detected out to +- 800 km/s and a blue-shifted extended structure on scales of 7 kpc

Feruglio+ 2012

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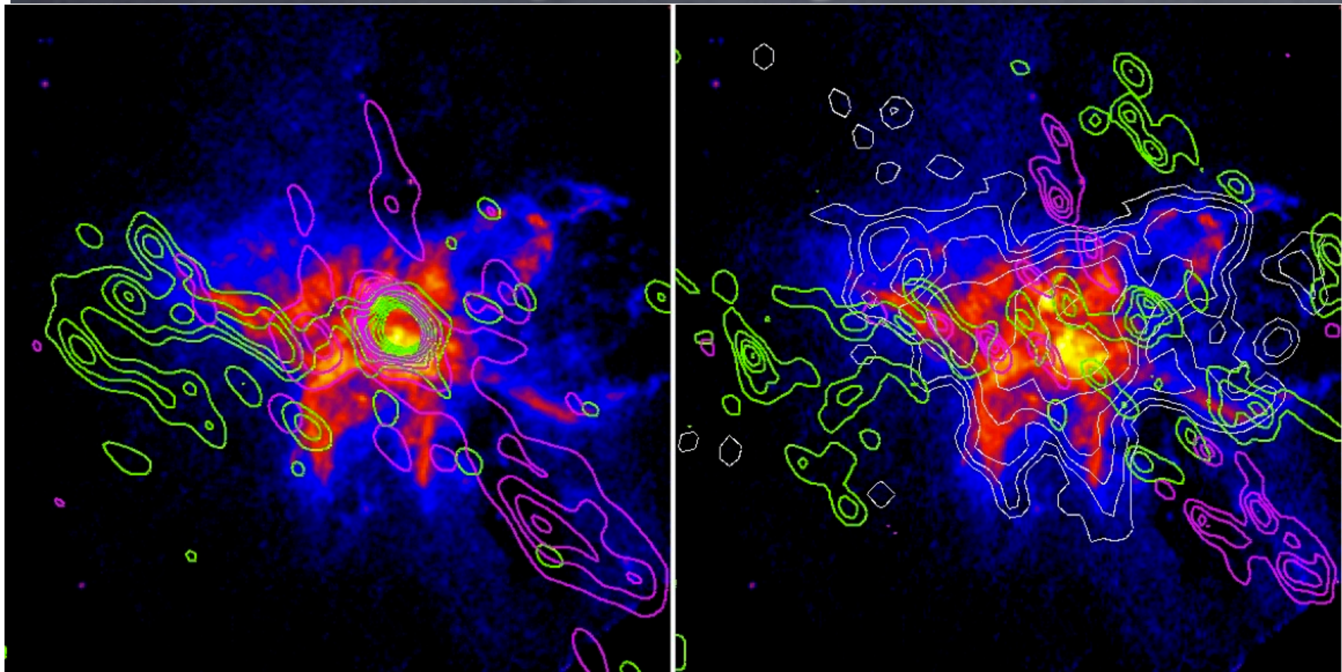
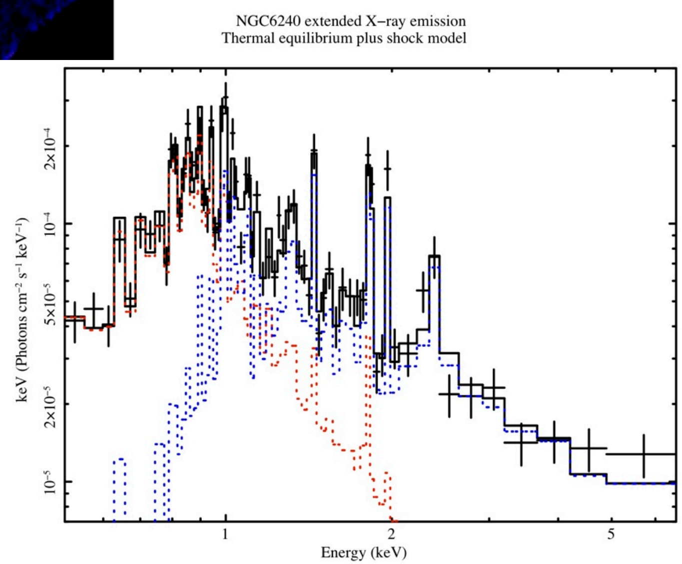
a complex system with broad CO



CO at -100 km/s coincides with the dust lane seen in HST image in the SW region

CO with -400 km/s coincident with Hα filaments in the Eastern region



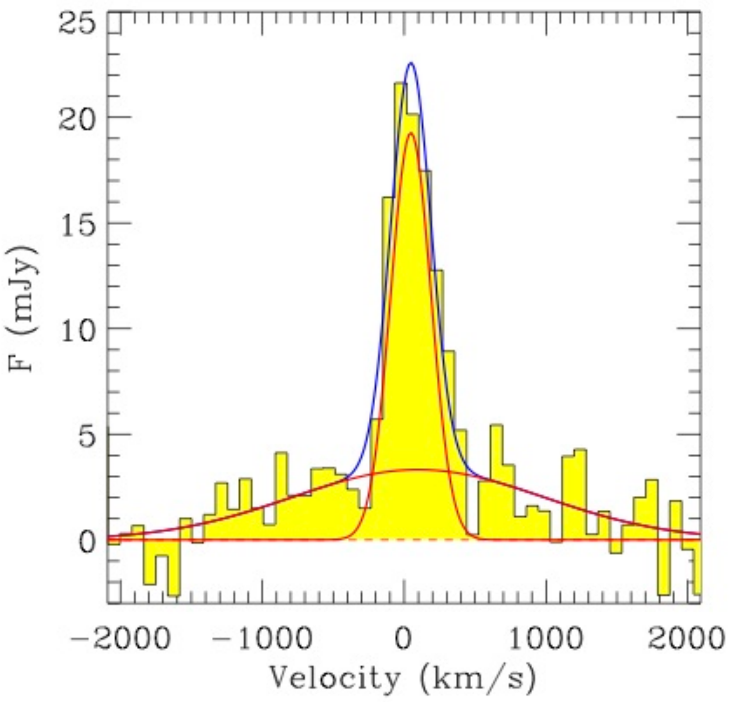
Chandra spectra provide evidence for shocked gas at the position of the Hα emission, and suggests that a shock is propagating eastward and it is compressing the molecular gas, while crossing it. If CO outflow proceeds from the southern nucleus, as it is the case for Hα, it carries several 100 M☉/yr

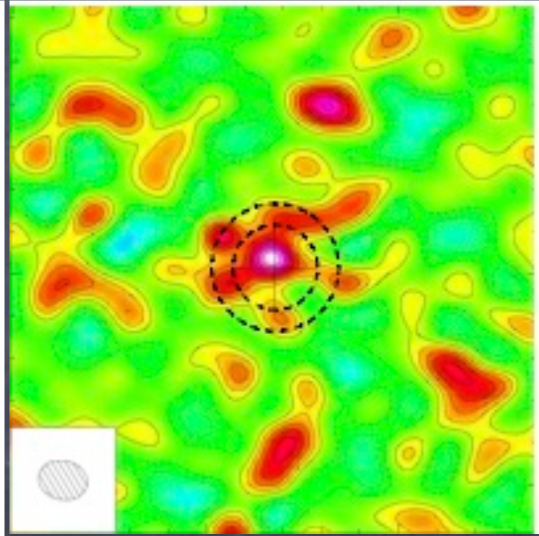
Outflows in the distant Universe

Extremely luminous QSO SDSS J1148 at z=6.4. Host galaxy SFR ~ 3000 $M_\odot$/yr and M_{H2} ~ 2×10^{10} $M_\odot$

Broad wings detected in [CII]158um with FWHM=2000 km/s Maiolino+2012

Vmax = 1300 km/s already points towards AGN-driven outflow and shocks





Mout>7×10^9 $M_\odot$ <u>under conservative assumptions</u>

Broad component concentrated in the center but extended on scales of 16 kpc

mass loss rate

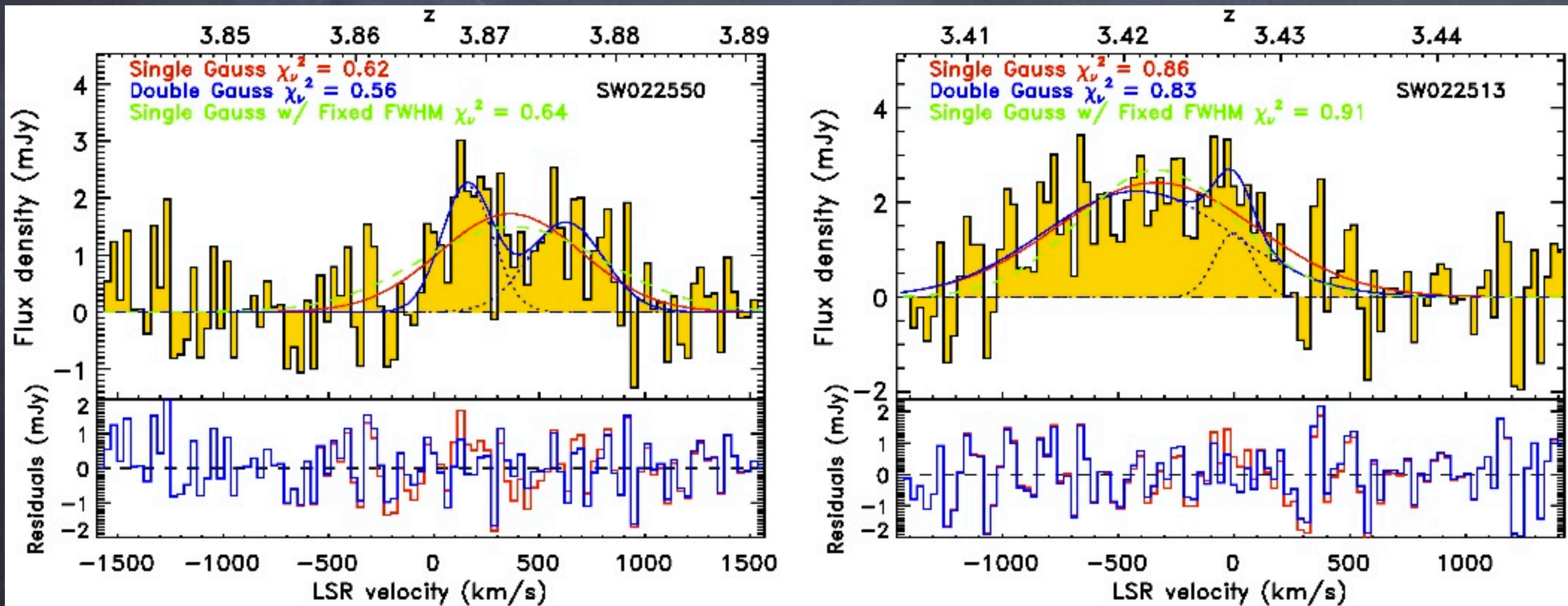
dM/dt > 3500 $M_\odot$/yr !!!

kinetic power Pkin>2×10^{45} erg/s < 1% of the AGN Lbol, well above the power injected by SNa = η × SFR ×7×10^{41} (η ~ 0.1)

Outflows at z=3=4

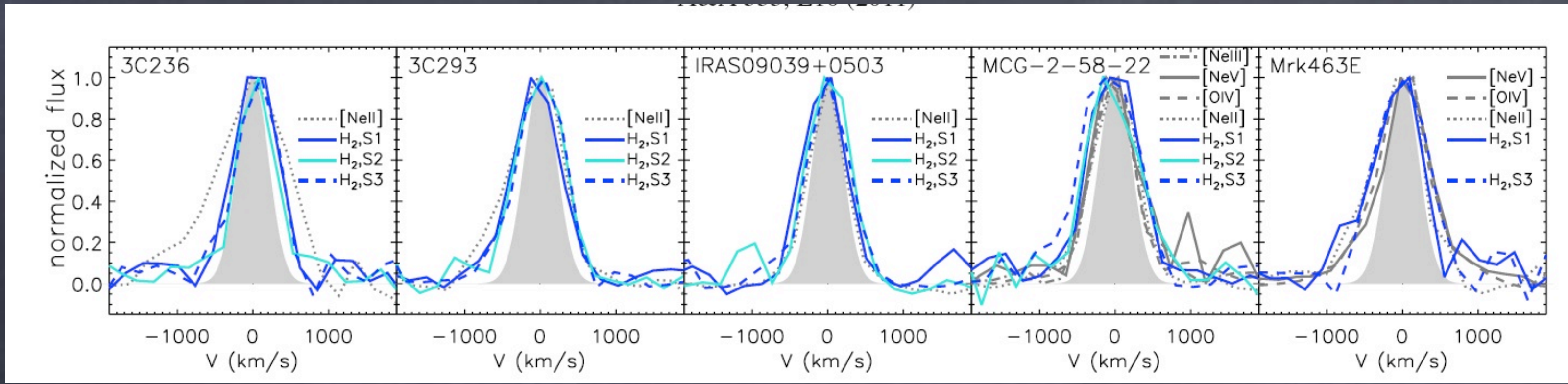
2 highly obscured QSOs at z>~3.4 with with Lbol (AGN) ~ 10^{47} erg/s

ULIRGs with SFR =500-3000 $M_\odot$/yr Polletta+ 2011

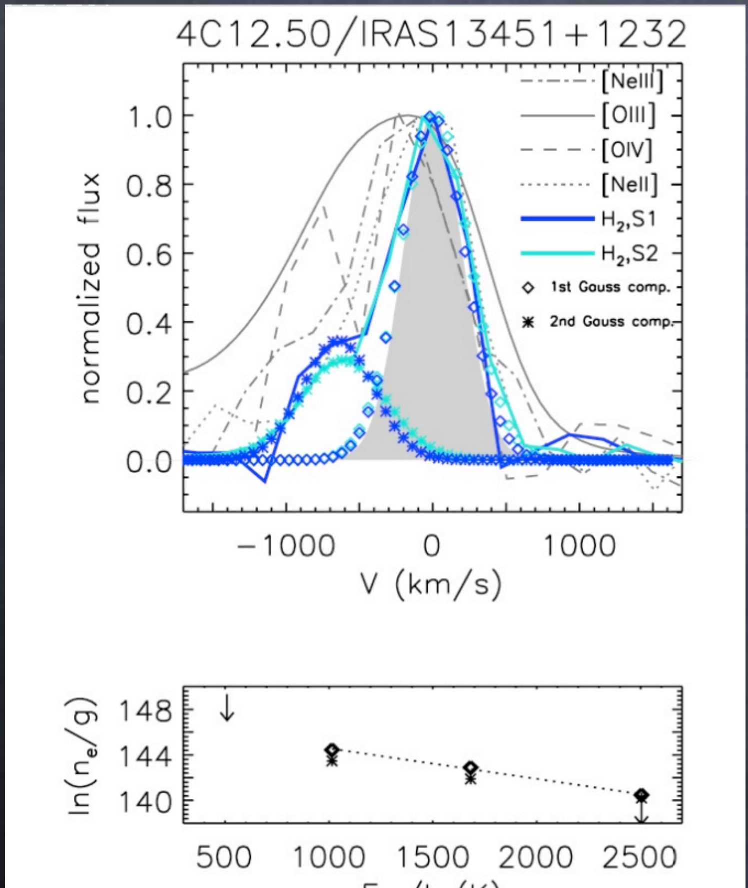


Very broad lines detected but unclear origin: merger or outflow?

Need high-resolution maps and sensitive observations to constrain morphology and gas dynamics.



Dasyra & Combes 2011



Warm H2

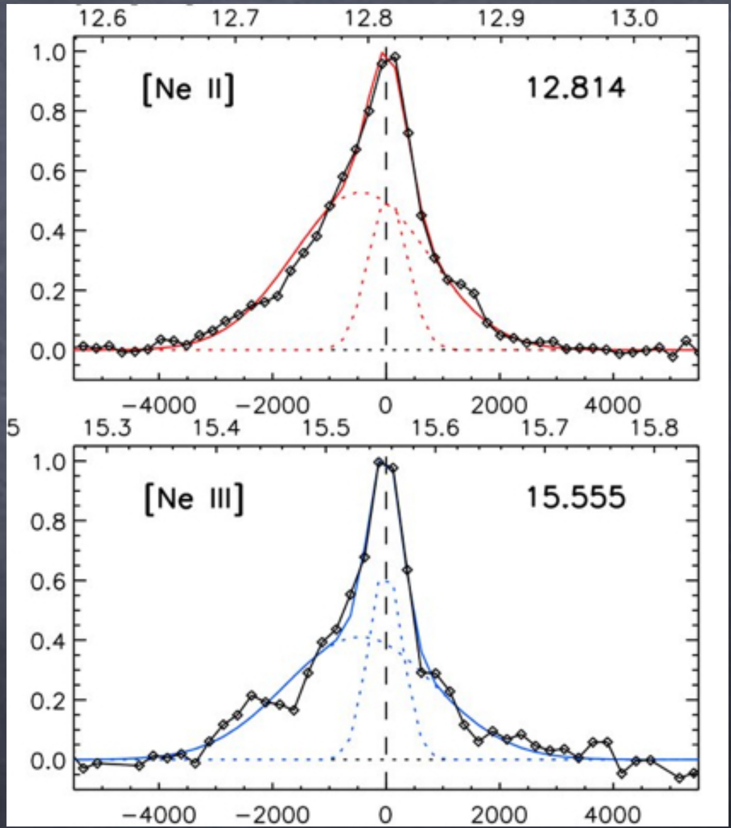
If combined with CO observations:

Warm to cold H2 ratio in wings and core

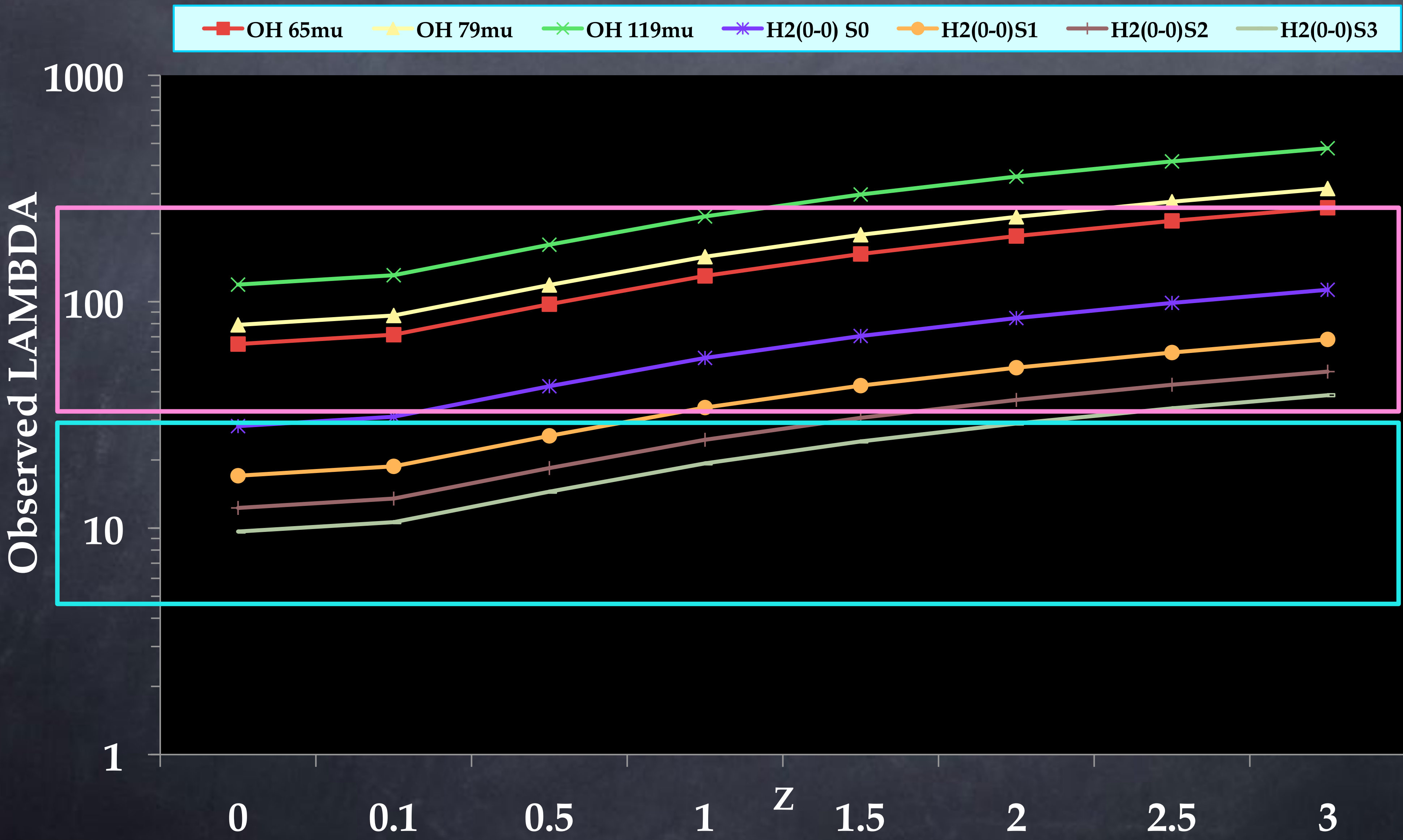
Is the outflow warming up the gas?

Outflows in ionized gas

IRAS F00183-7111 with R~600
Spoon et al.09



Molecular Lines



Ionized Gas

[O IV] 25.89mu
[Ne III] 15.56mu
[NeV] 14.32mu
Observed LAMBDA
180
160
140
120
100
80
60
40
20
0
0
0.1
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Redshift

Absorption line spectroscopy

Absorption troughs = 5-10%

Abs. Width = 500-1000km/s R=600-300

Continuum at 10-20σ on

Δλ~0.5-0.25um

PACS continuum sensitivity:

100mJy 1hr 5σ

Safari <10mJy 1hr 5σ

L(Mark231)~10^{46} ergs/s

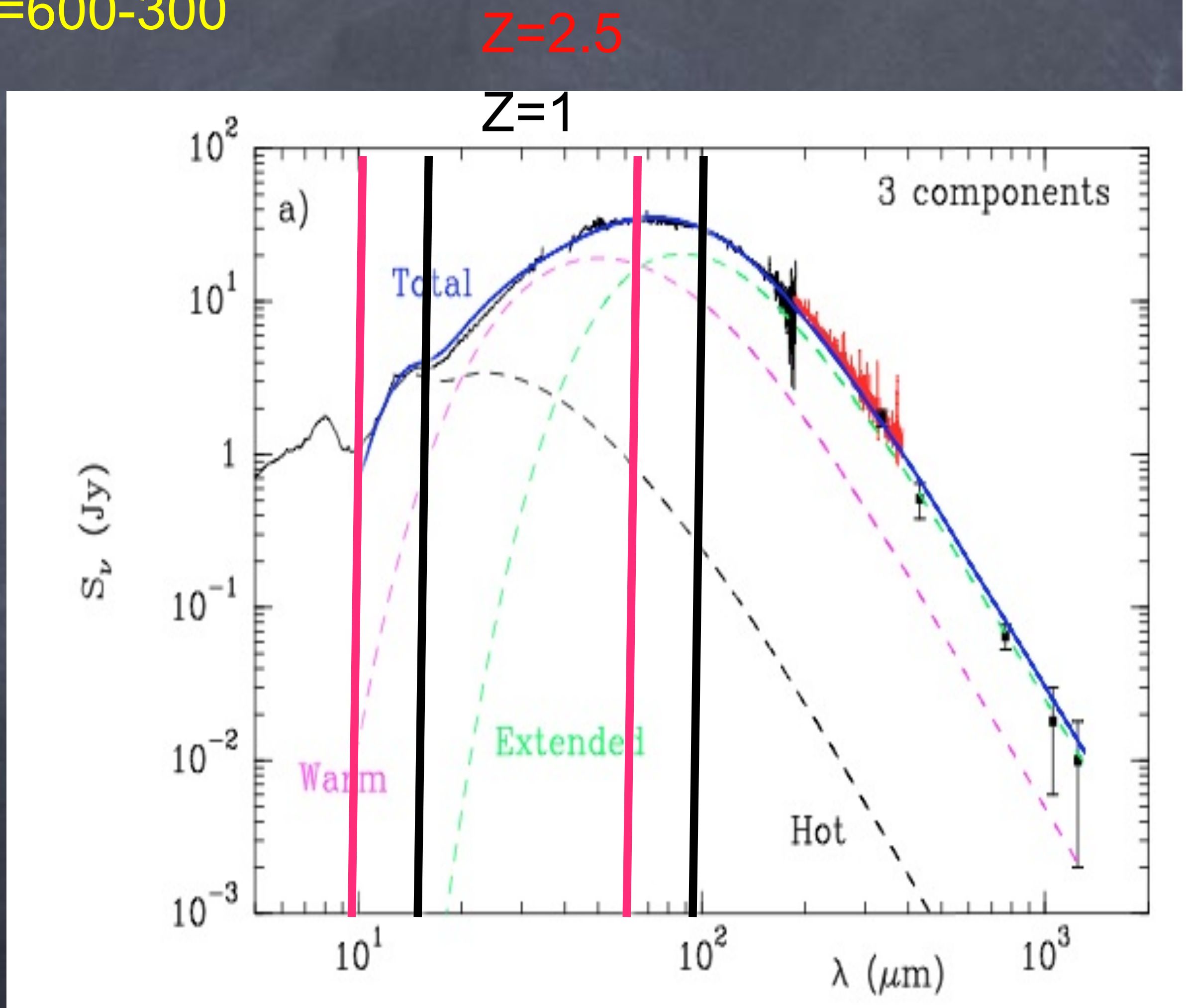
F(Mark231)~10-30 Jy

F(z=1)/F(z=0.042)=10^{-3}

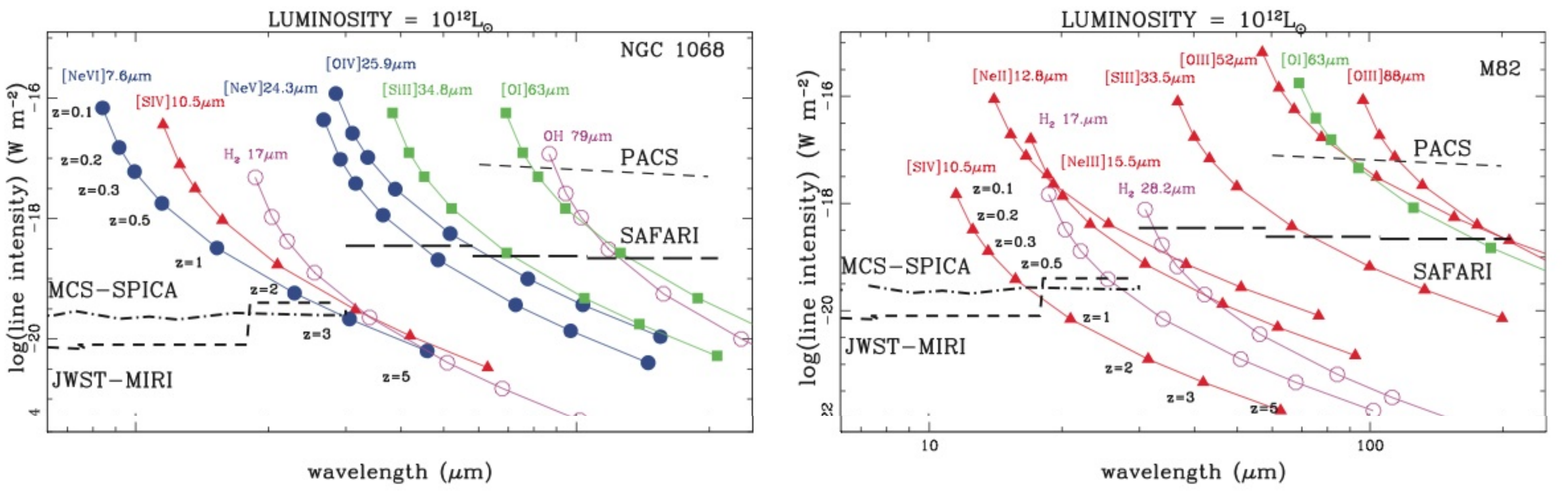
F(z=2.5)/F(z=0.042)=10^{-4}

F(Mark231 z=1)=3-30mJy

F(Mark231 z=2.5)=1-30mJy



Emission line spectroscopy



Spinoglio + 2012

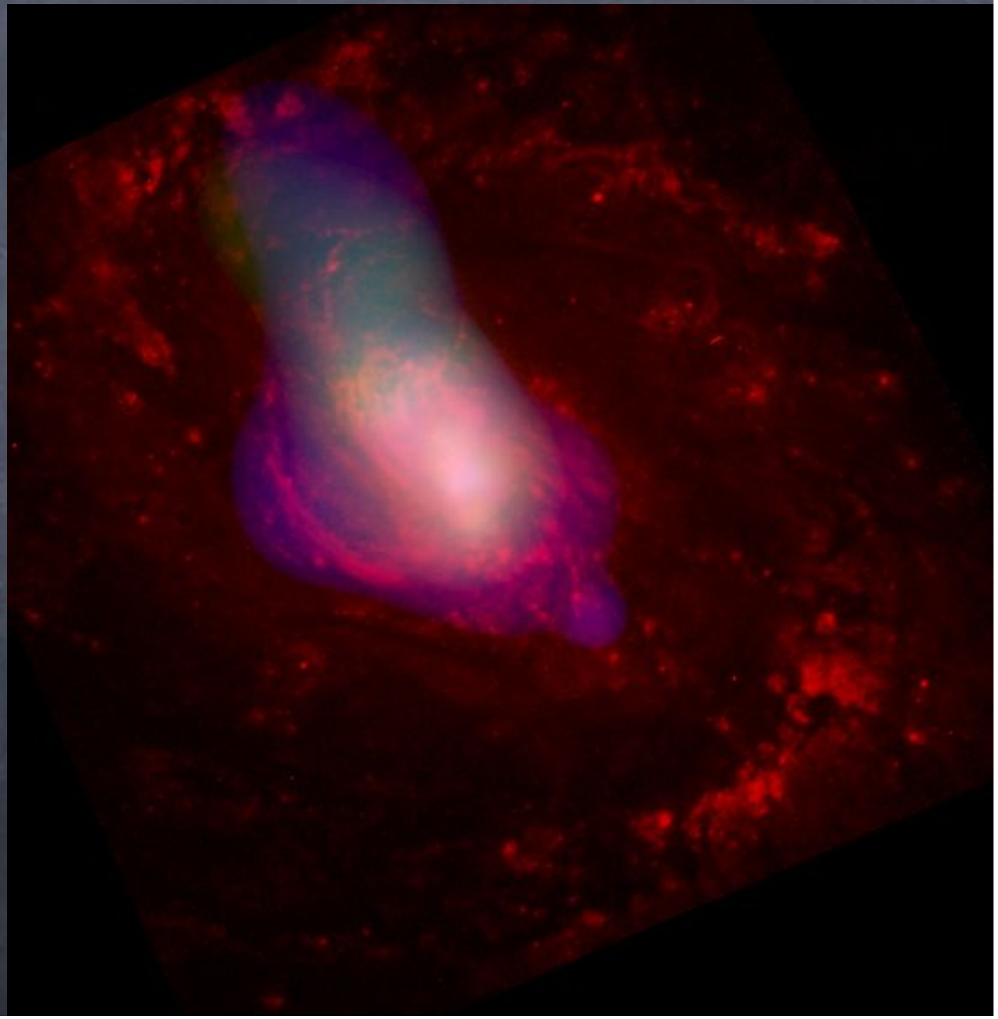
Mapping of local galaxies

M82 Blue=X-rays,Red=MIR

14 pc/arcsec

NGC1068 Blu=X-ray, red=optical

77pc/arcsec

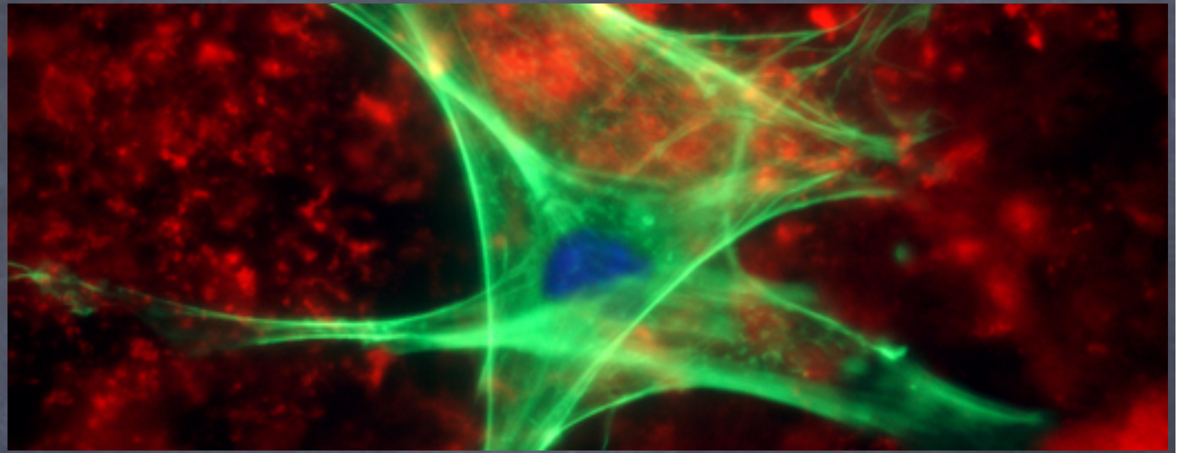


A change in perspective

Universe island →

A change in perspective

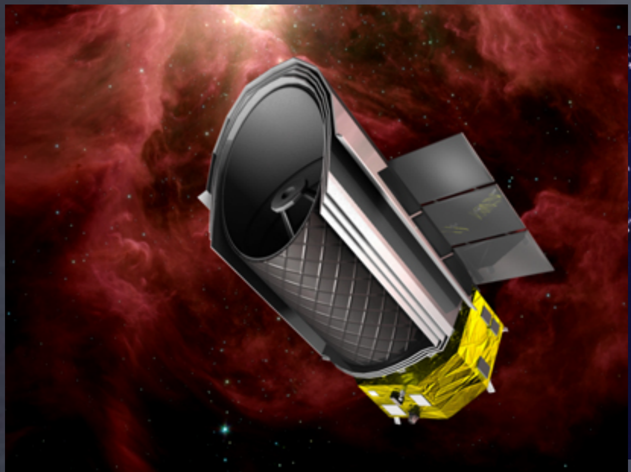
Universe island → Bio cells



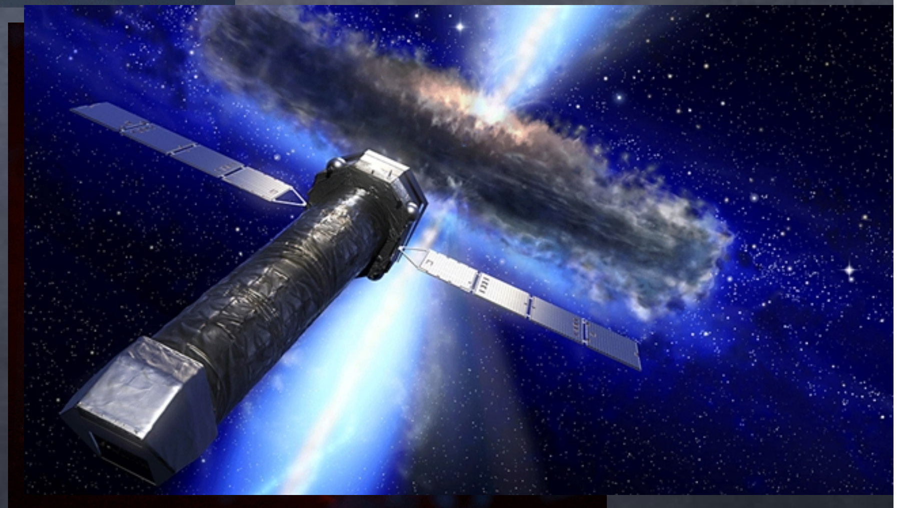
Organisms exchanging energy and matter with the environment throughout a network of interactions: ***The life cycle of galaxies***

A change in perspective

Universe island → Bio cells







Organisms exchanging energy and matter with the environment throughout a network of interactions: ***The life cycle of galaxies***