AGN & SN feedback: from galaxy evolution to the epoch of reionisation

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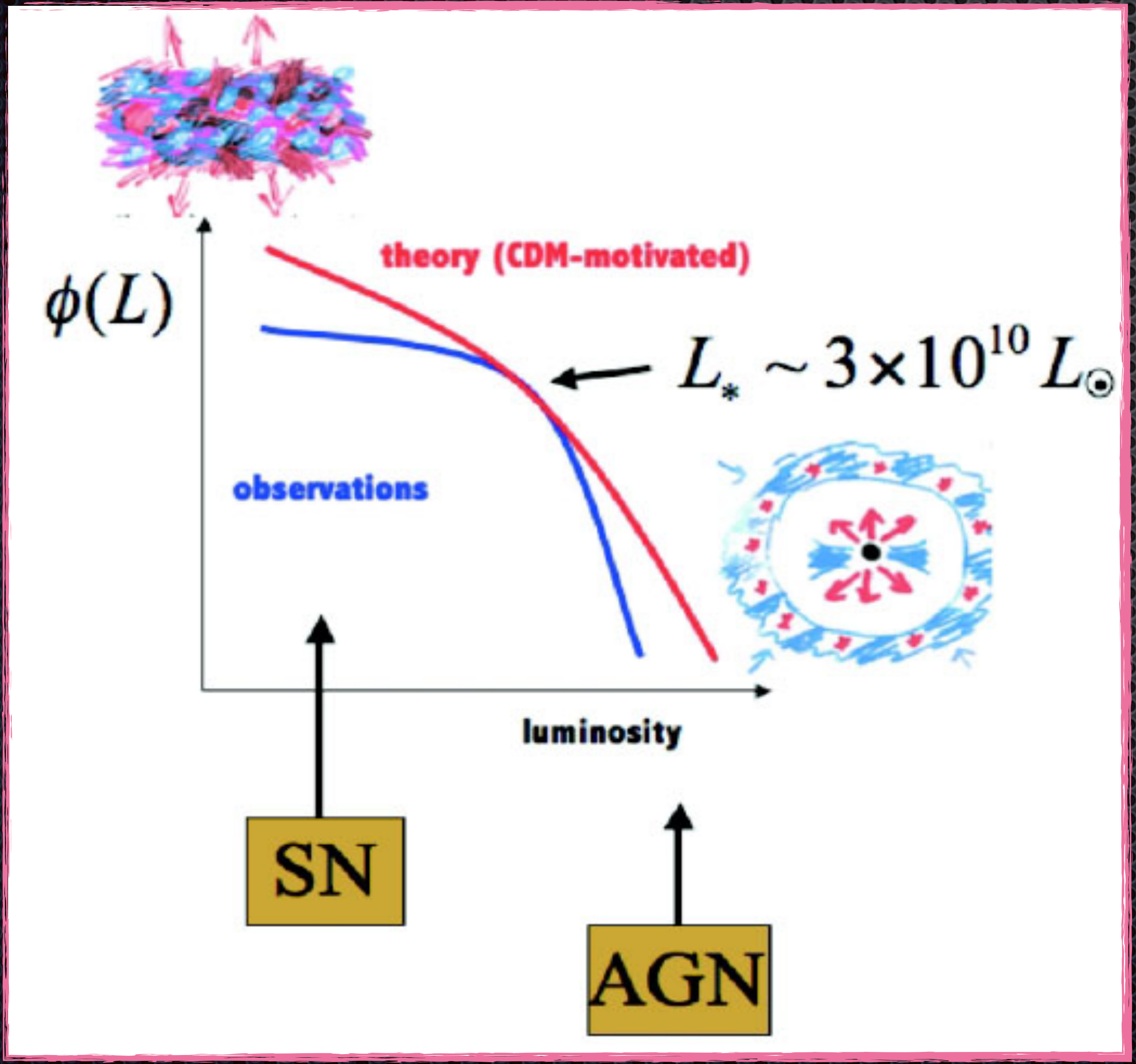
Super winds and galaxy evolution

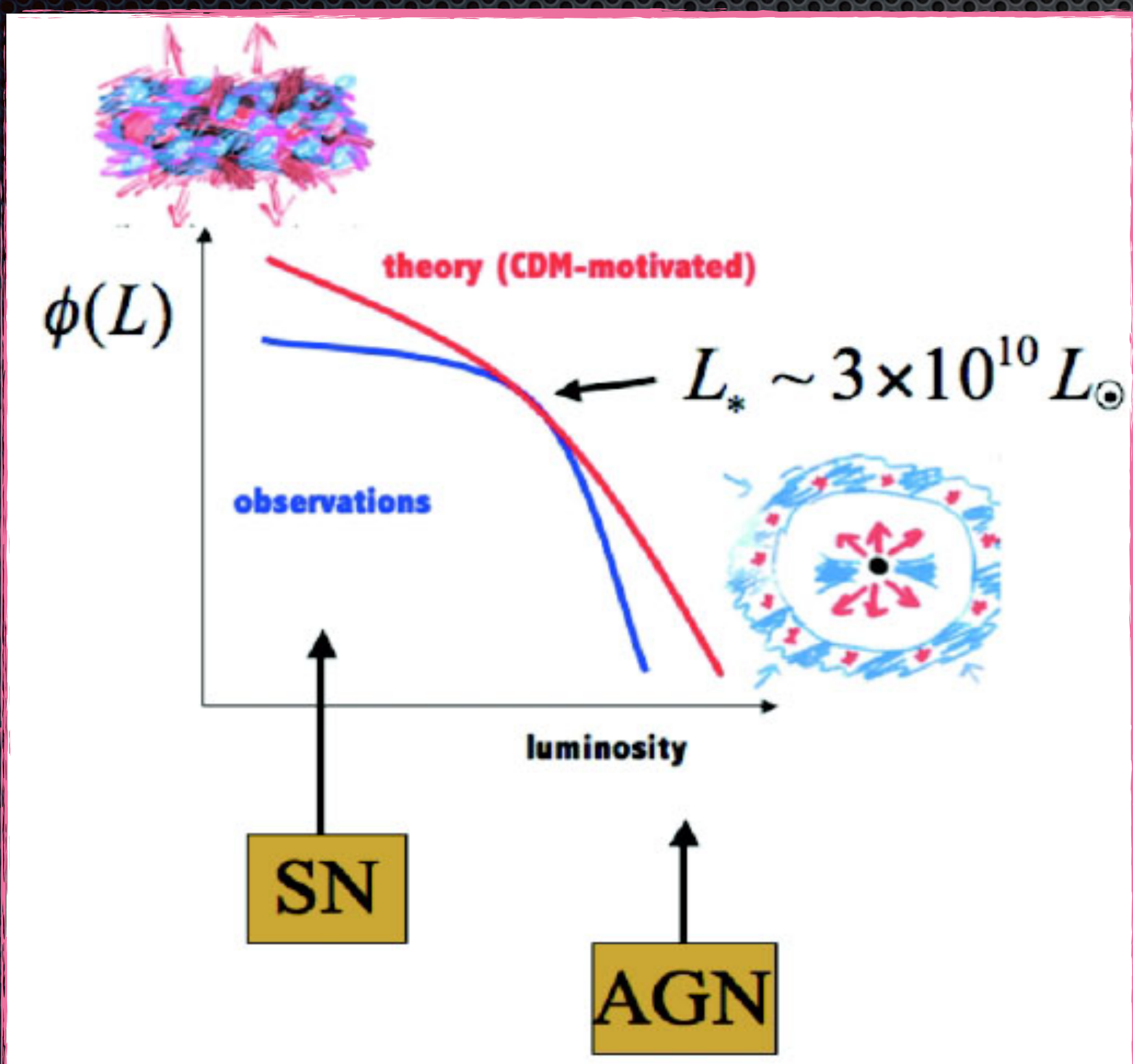
Super winds and galaxy evolution

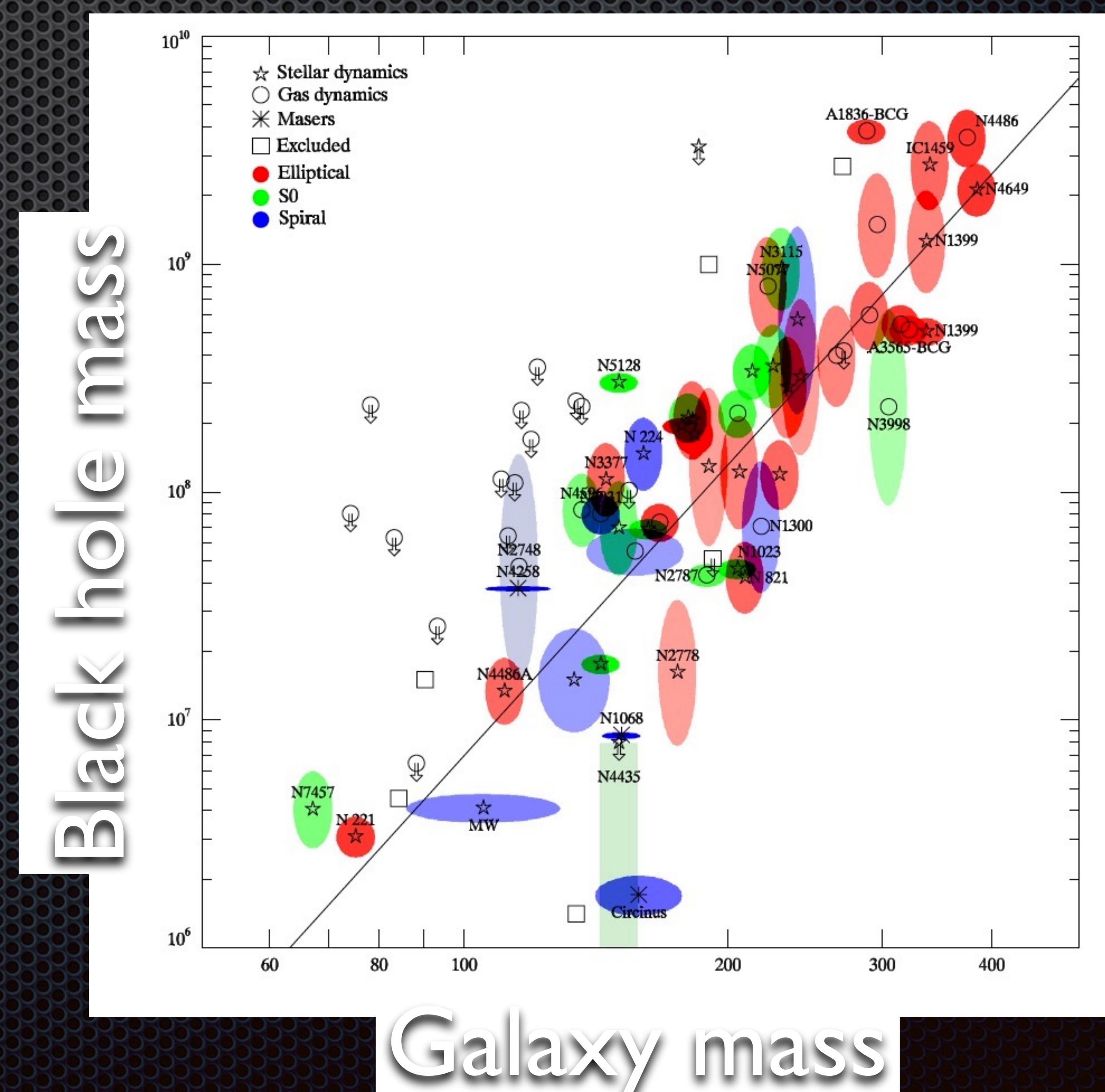
- Star formation is suppressed in galaxies. Why?



Super winds and galaxy evolution

- Star formation is suppressed in galaxies. Why?
- The evolution of galaxies and nuclear black holes is linked. Why?



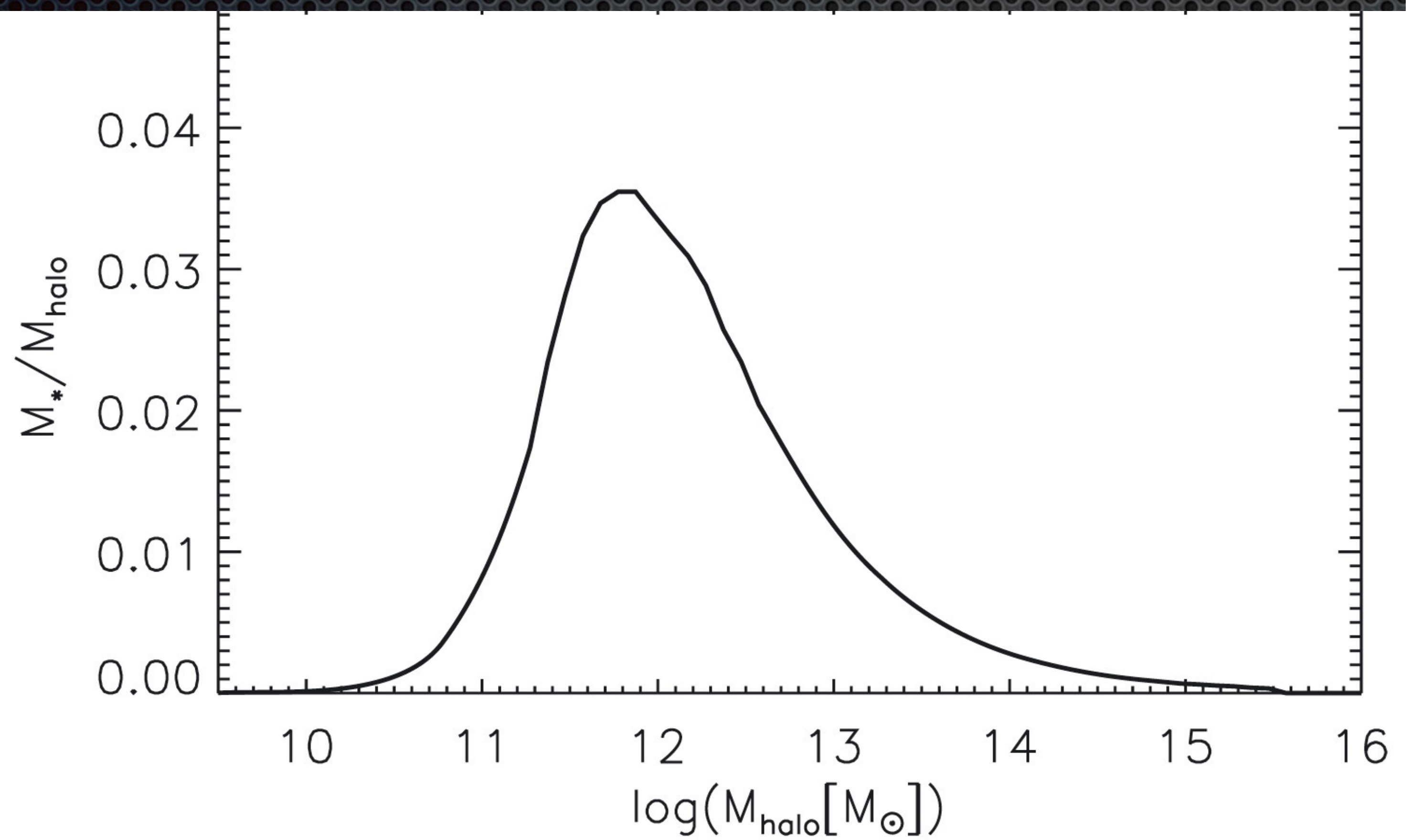


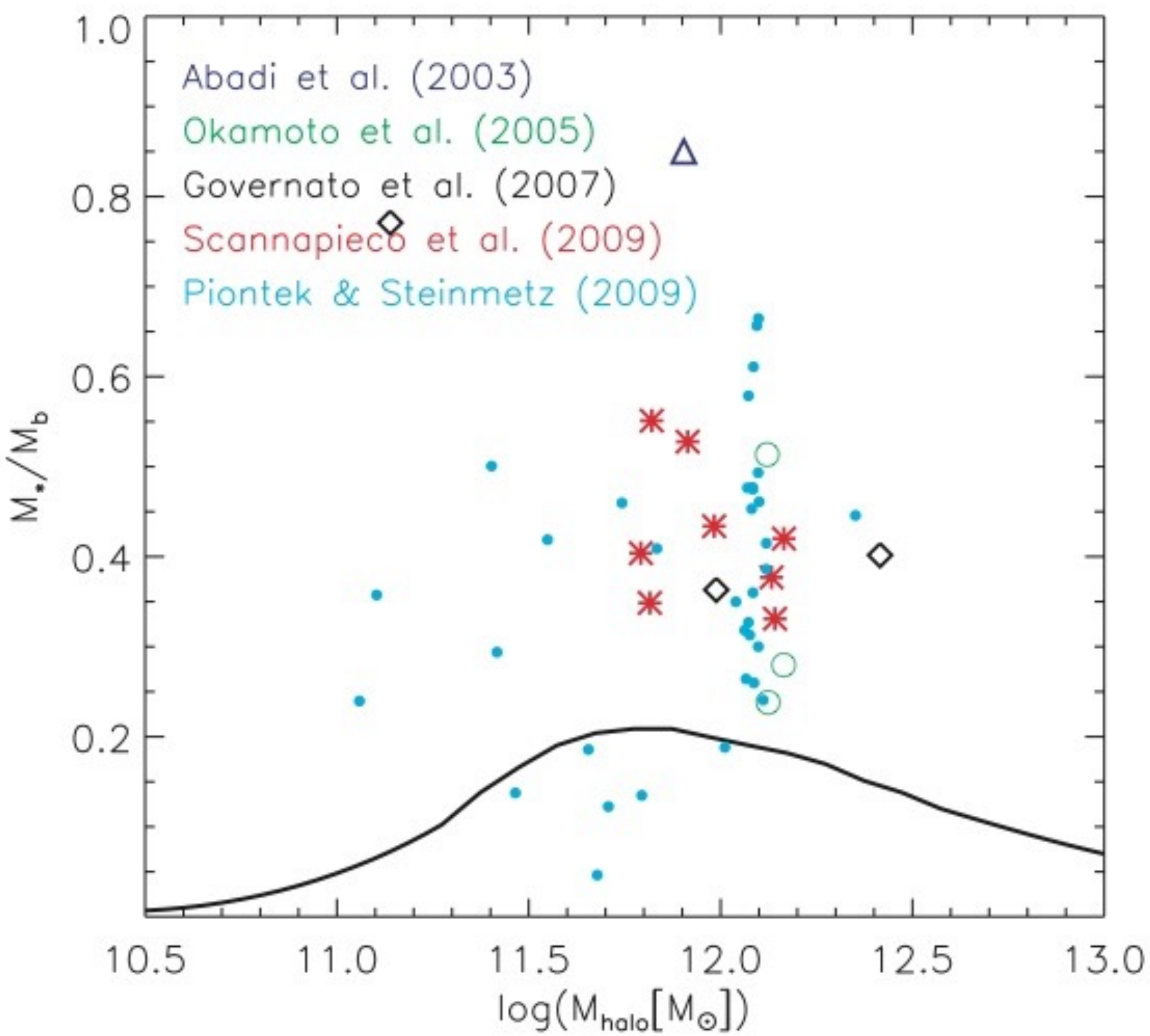
Super Winds

Efficiency of galaxy formation

$$\text{Efficiency} = \frac{M_*}{M_{\rm halo}} \times \frac{\Omega_{\rm m}}{\Omega_{\rm b}} = 0.17 \times \frac{M_*}{M_{\rm halo}}.$$

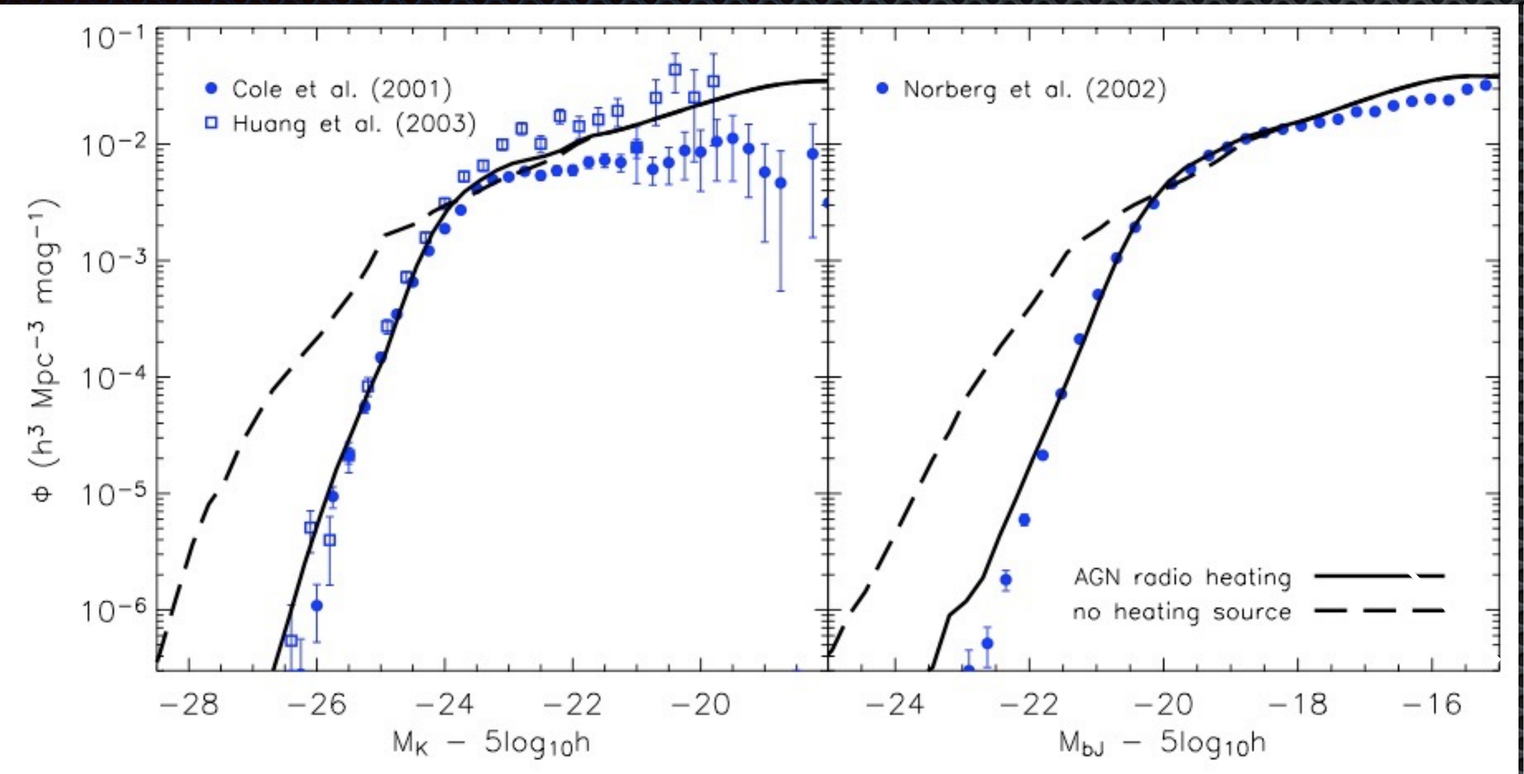
Guo+ 2010

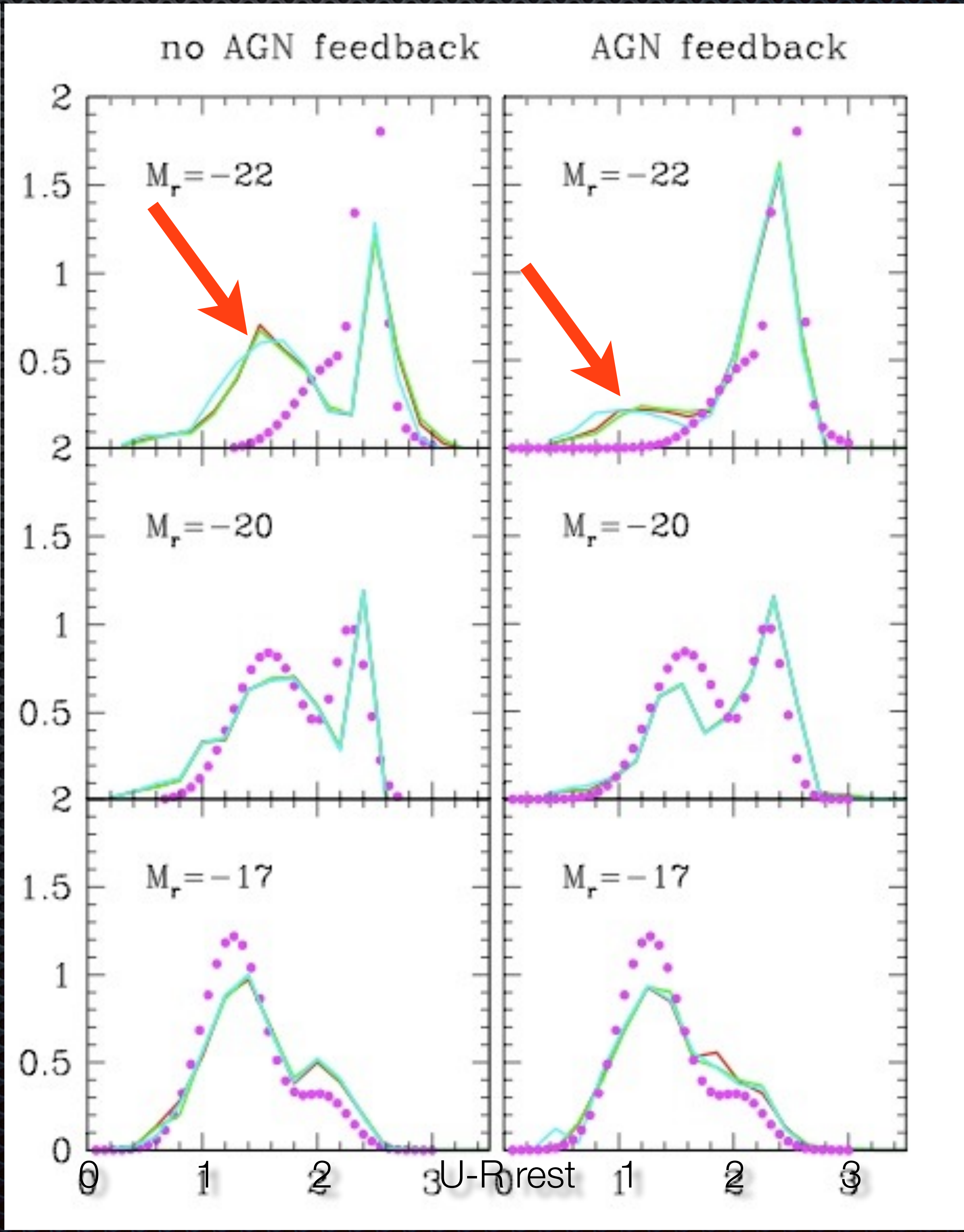




Massive galaxy density and colors: AGN feedback!

Menci+ 2006 Croton+2006





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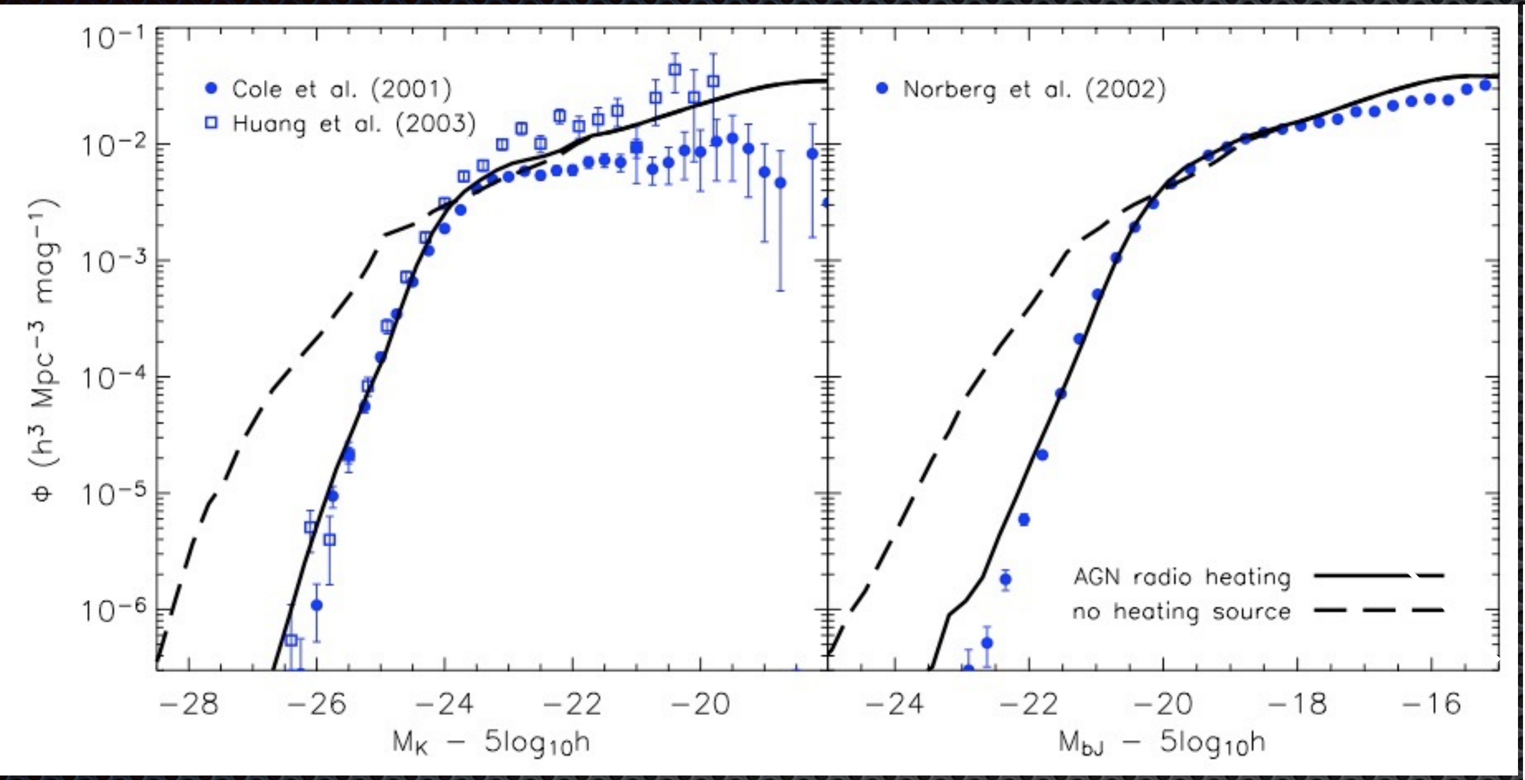

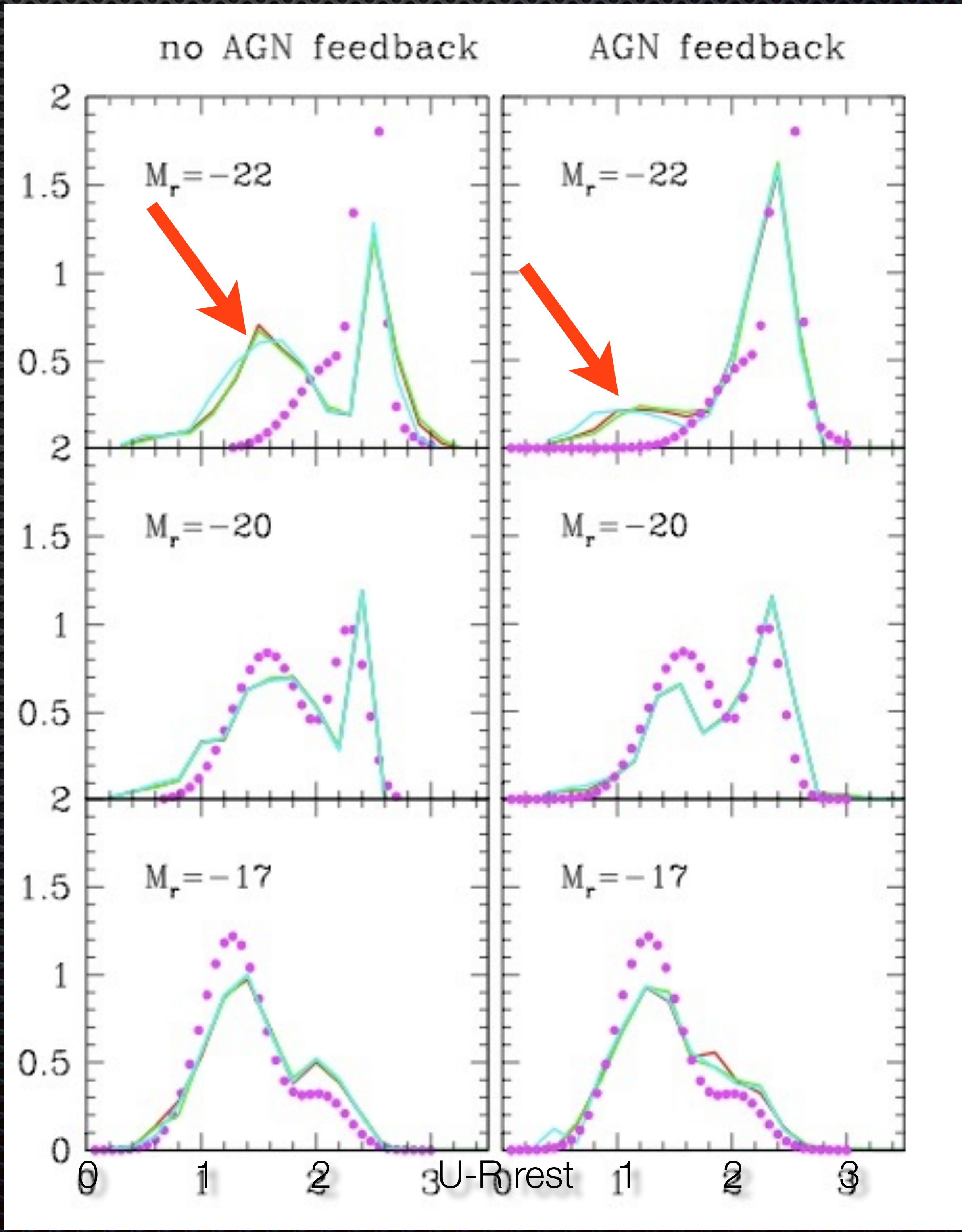

Without AGN heating SAMs:

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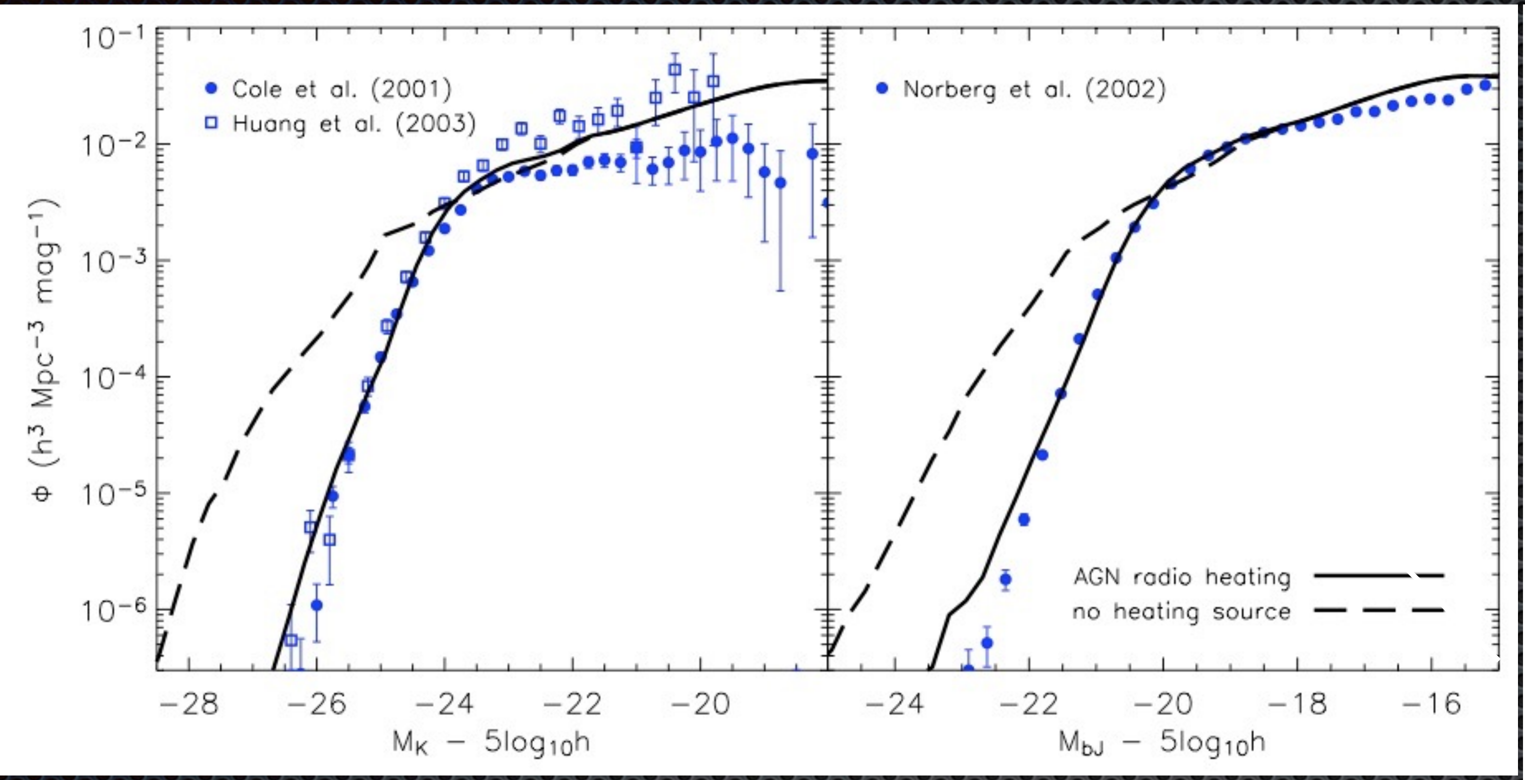

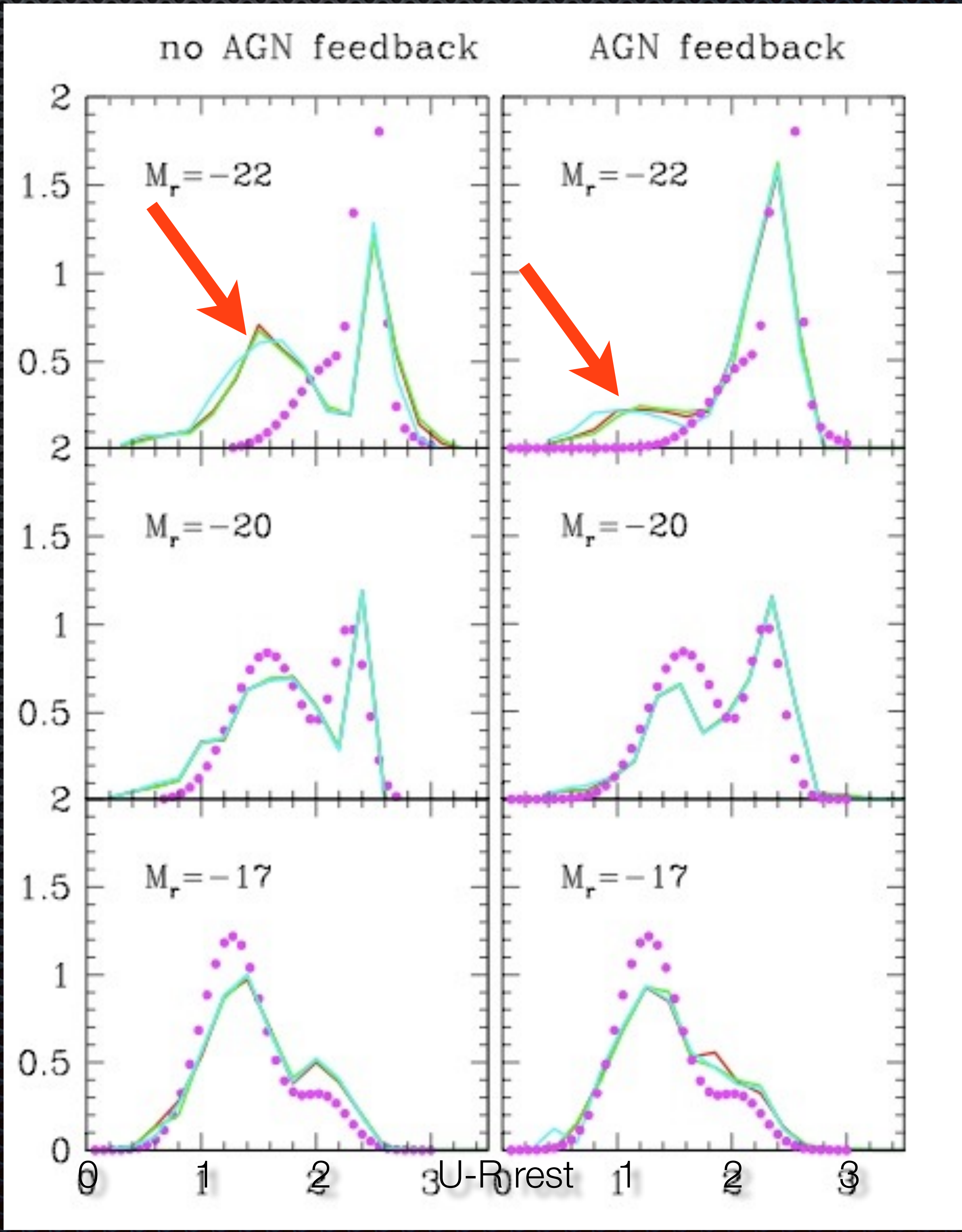

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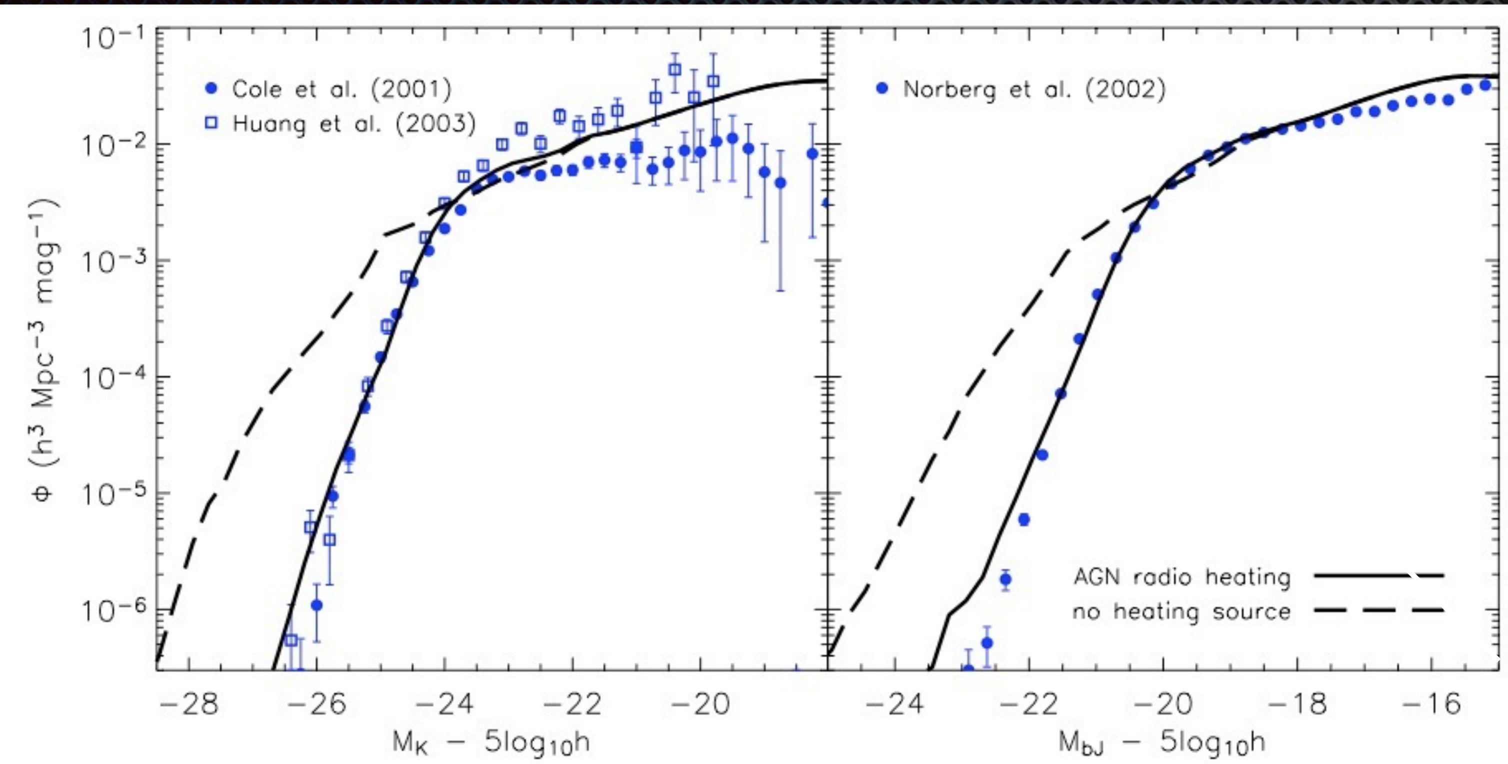

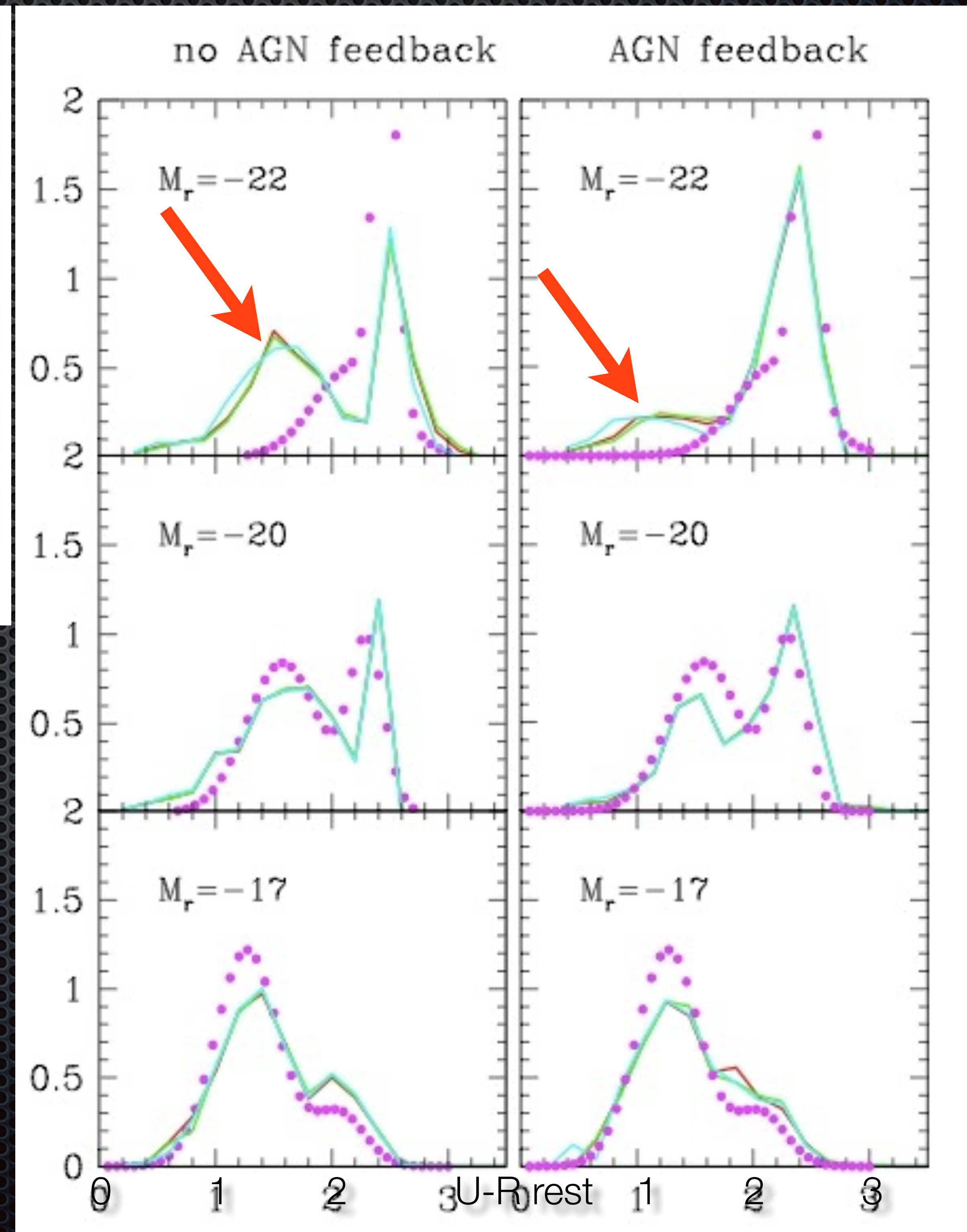

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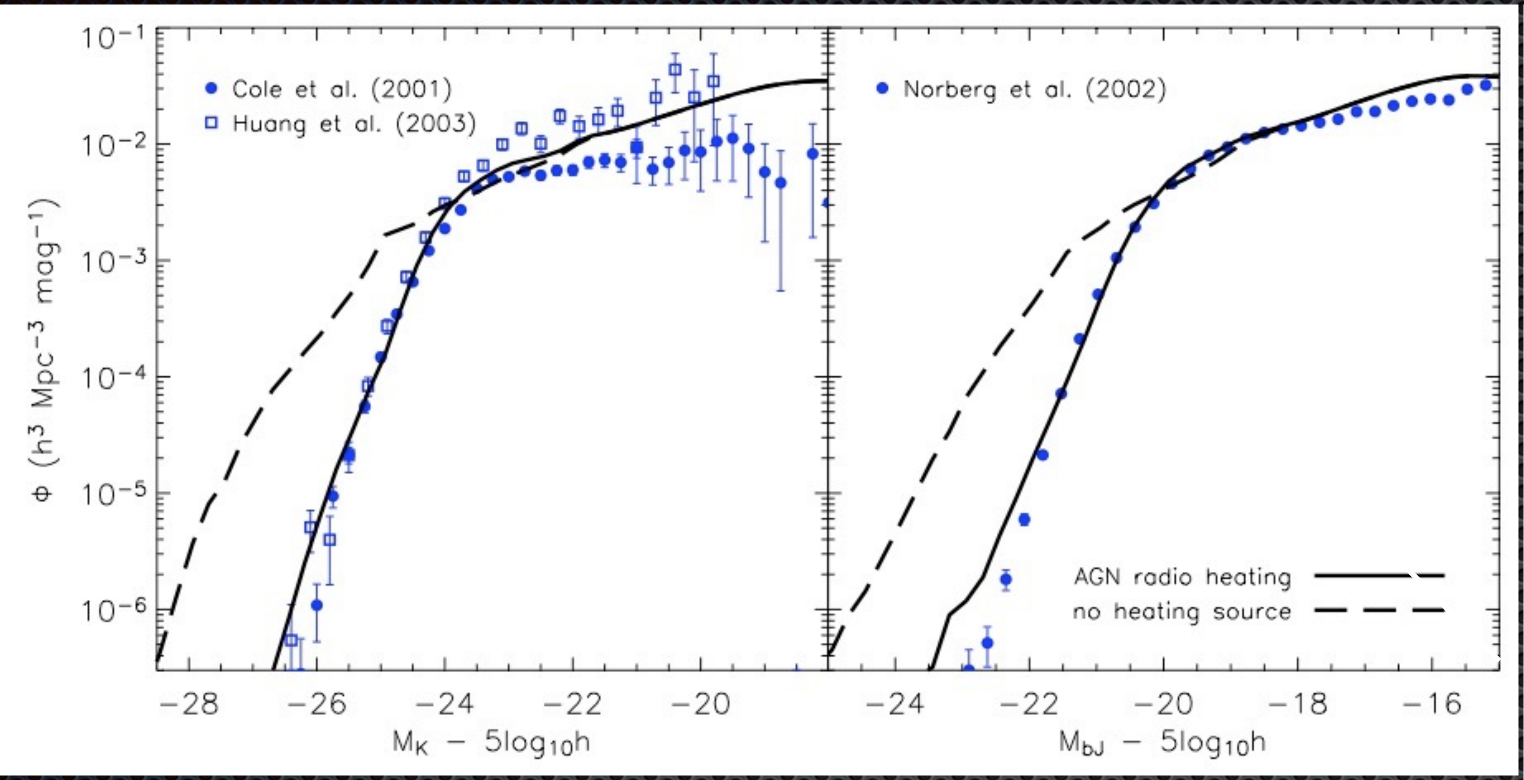

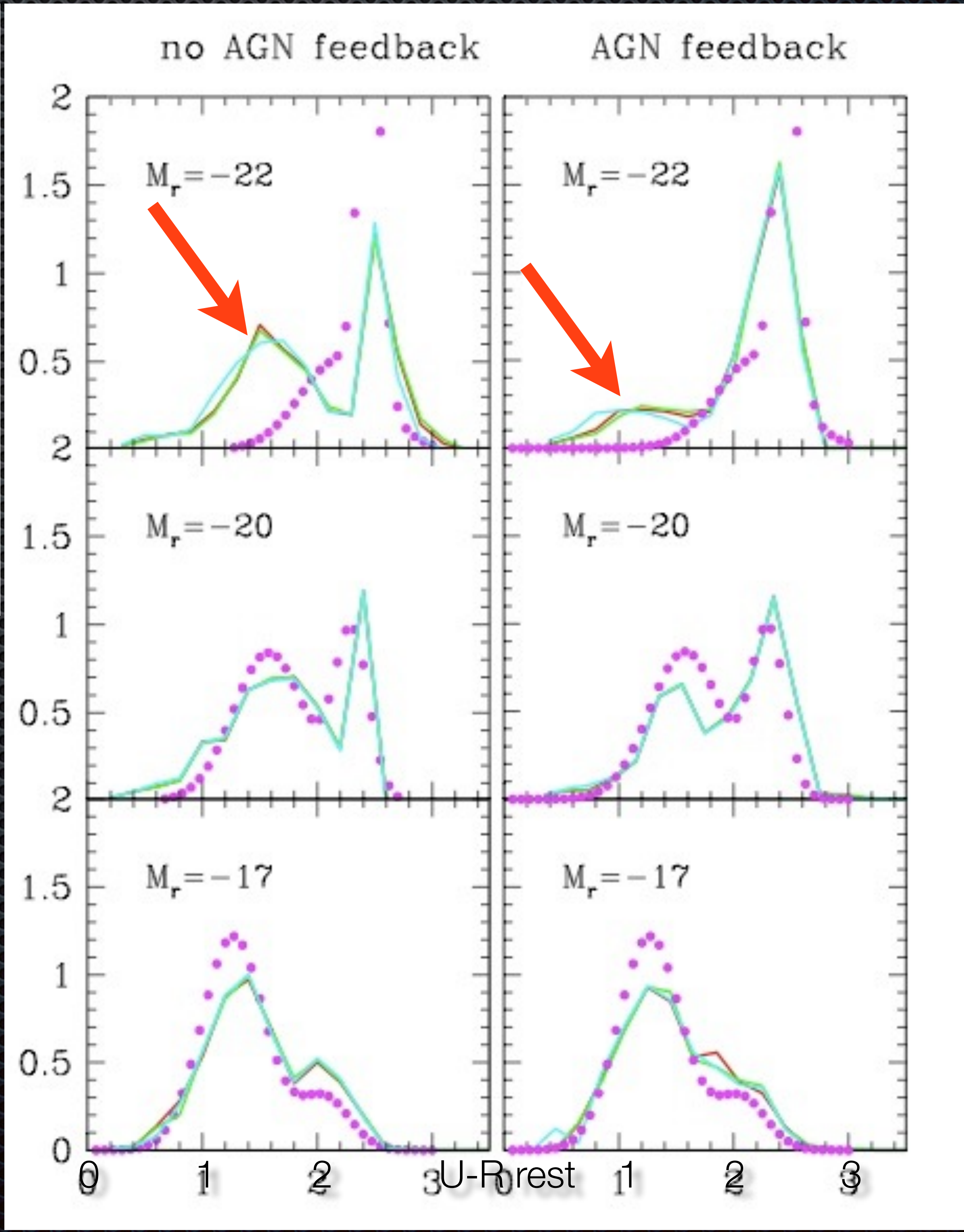

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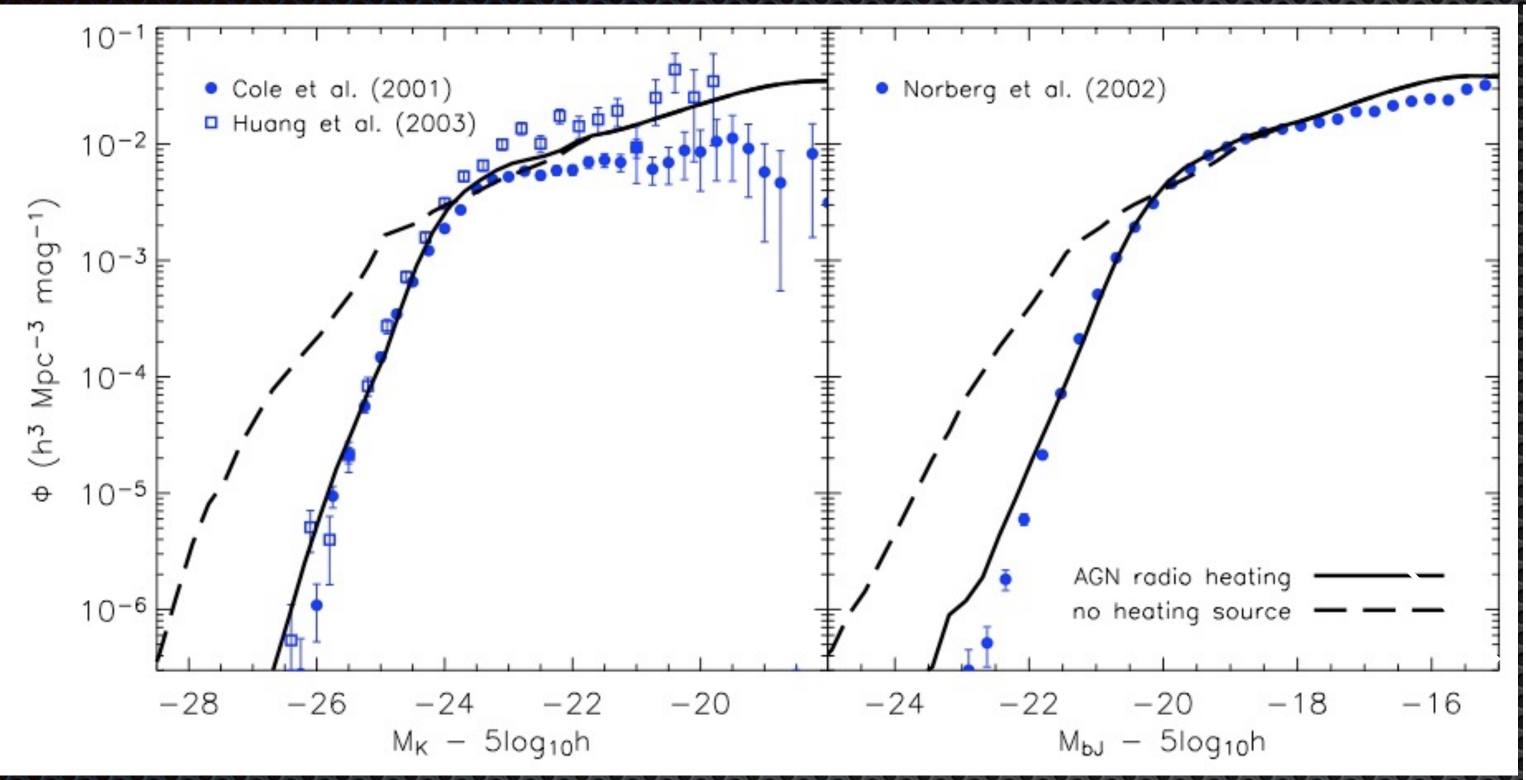

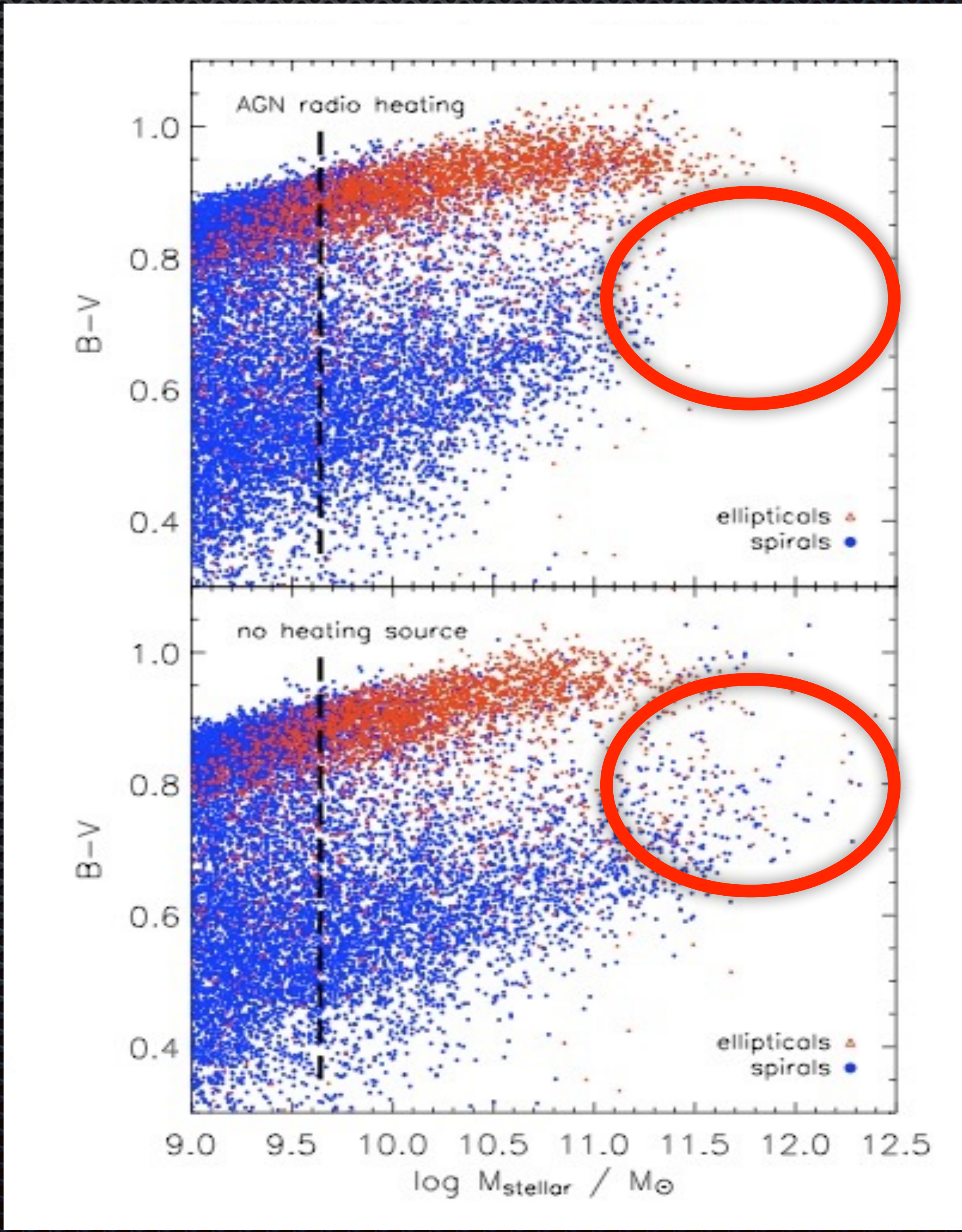

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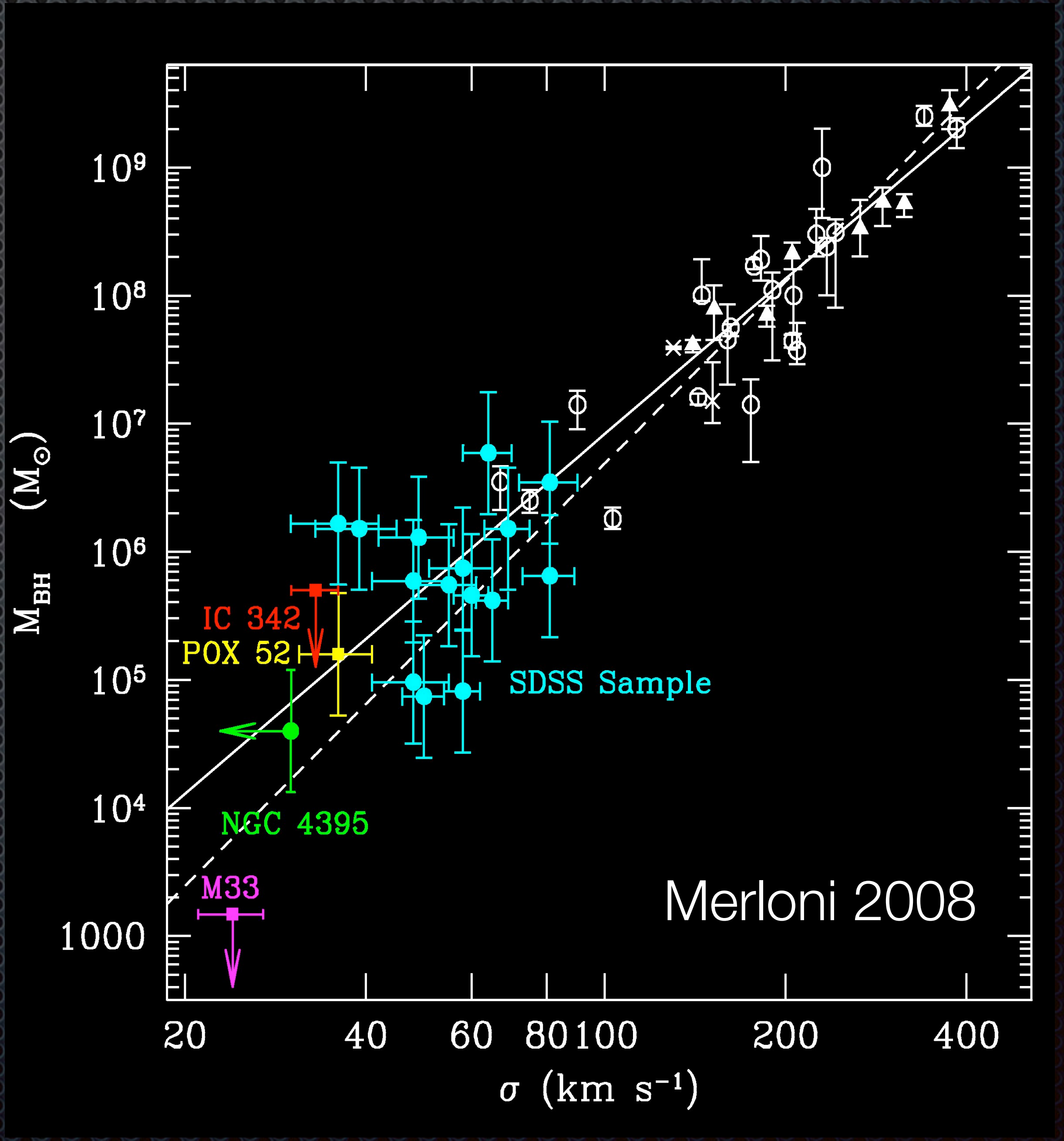
The starting point: SMBH and stellar mass growth



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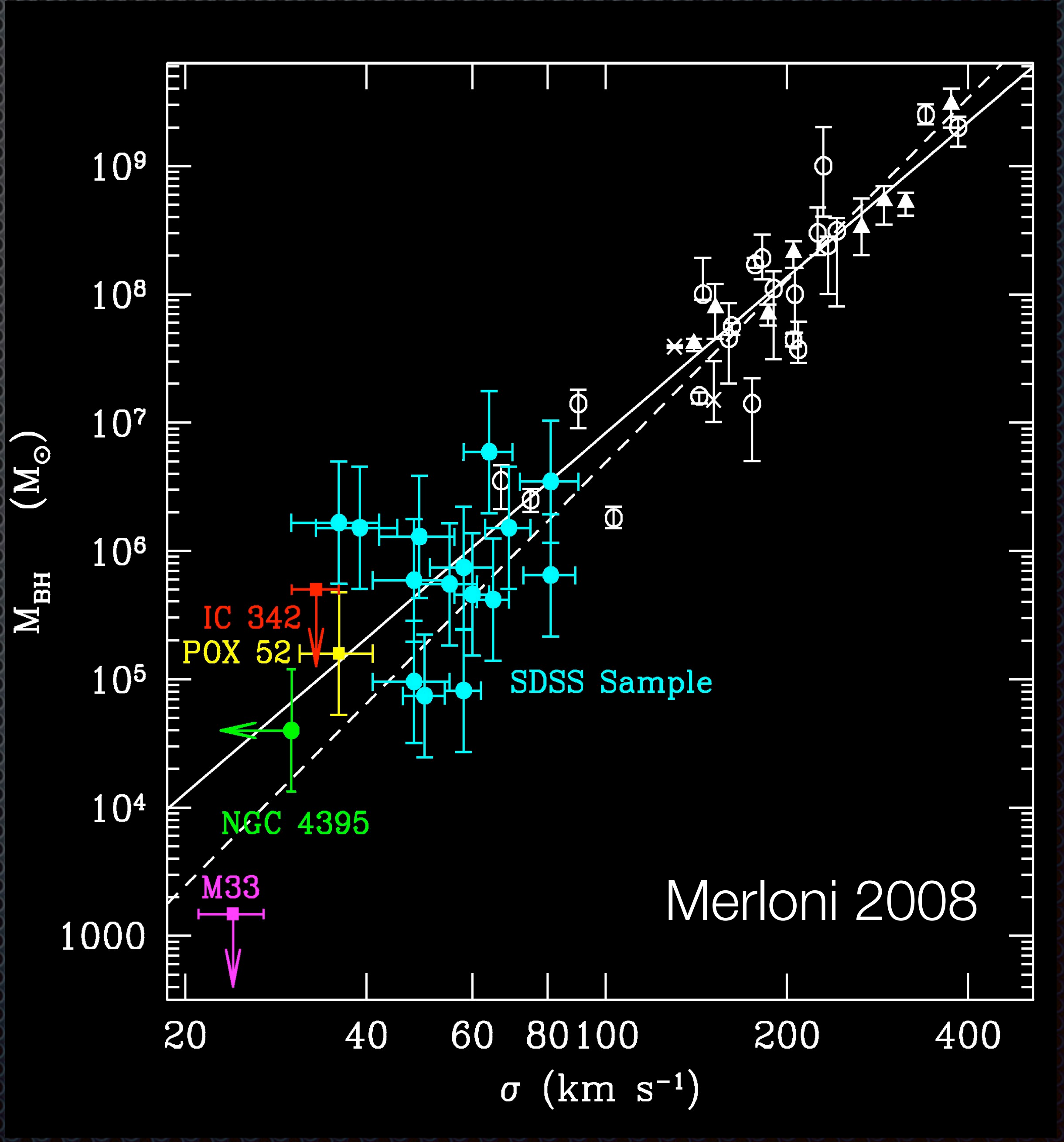
The discovery of SMBH in the most local bulges; **tight correlation** between M_{BH} and bulge properties (*e.g. Richstone+ 1998)*



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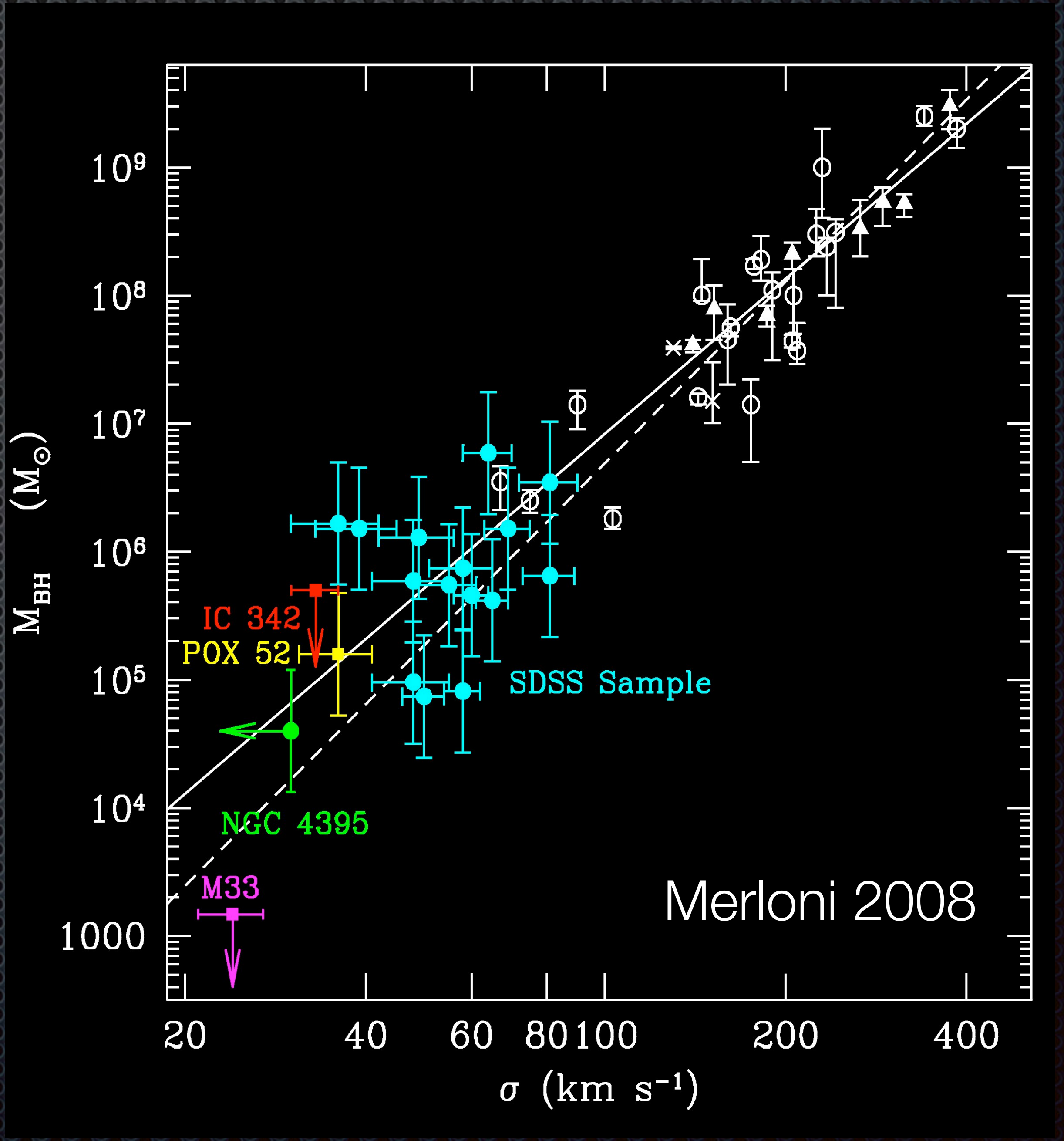

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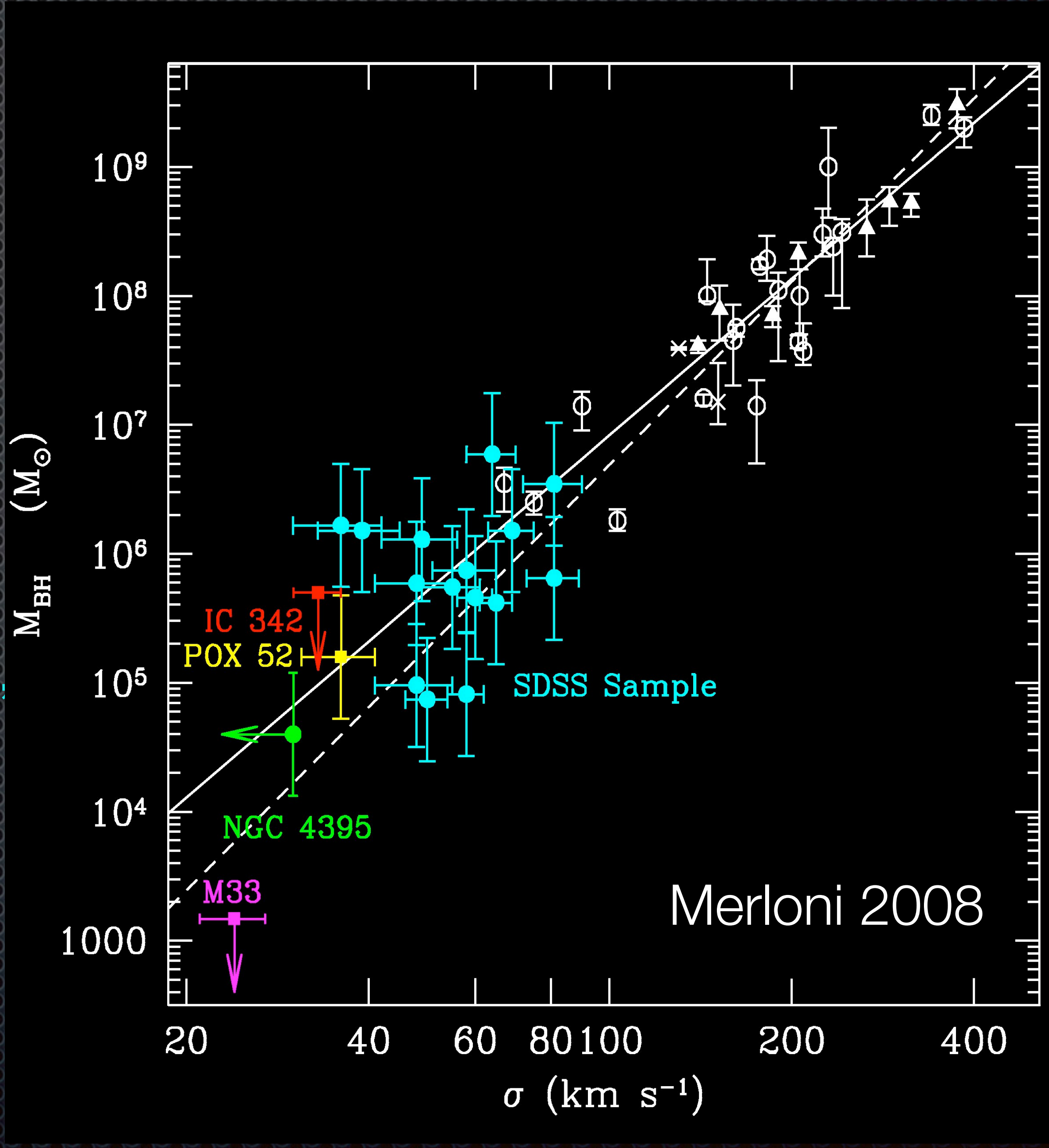

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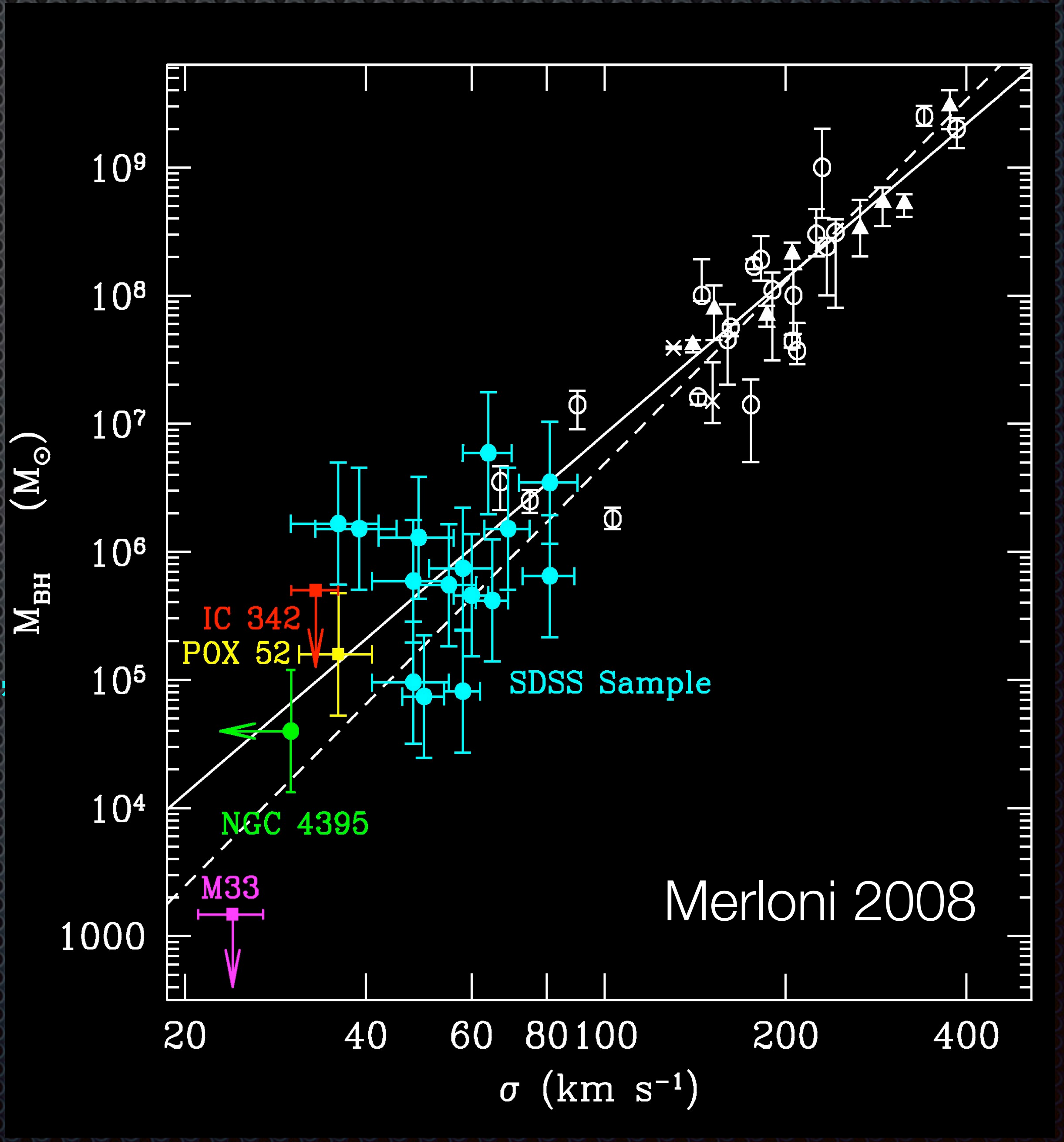
Outflows affect large fraction of baryon in the Universe!!



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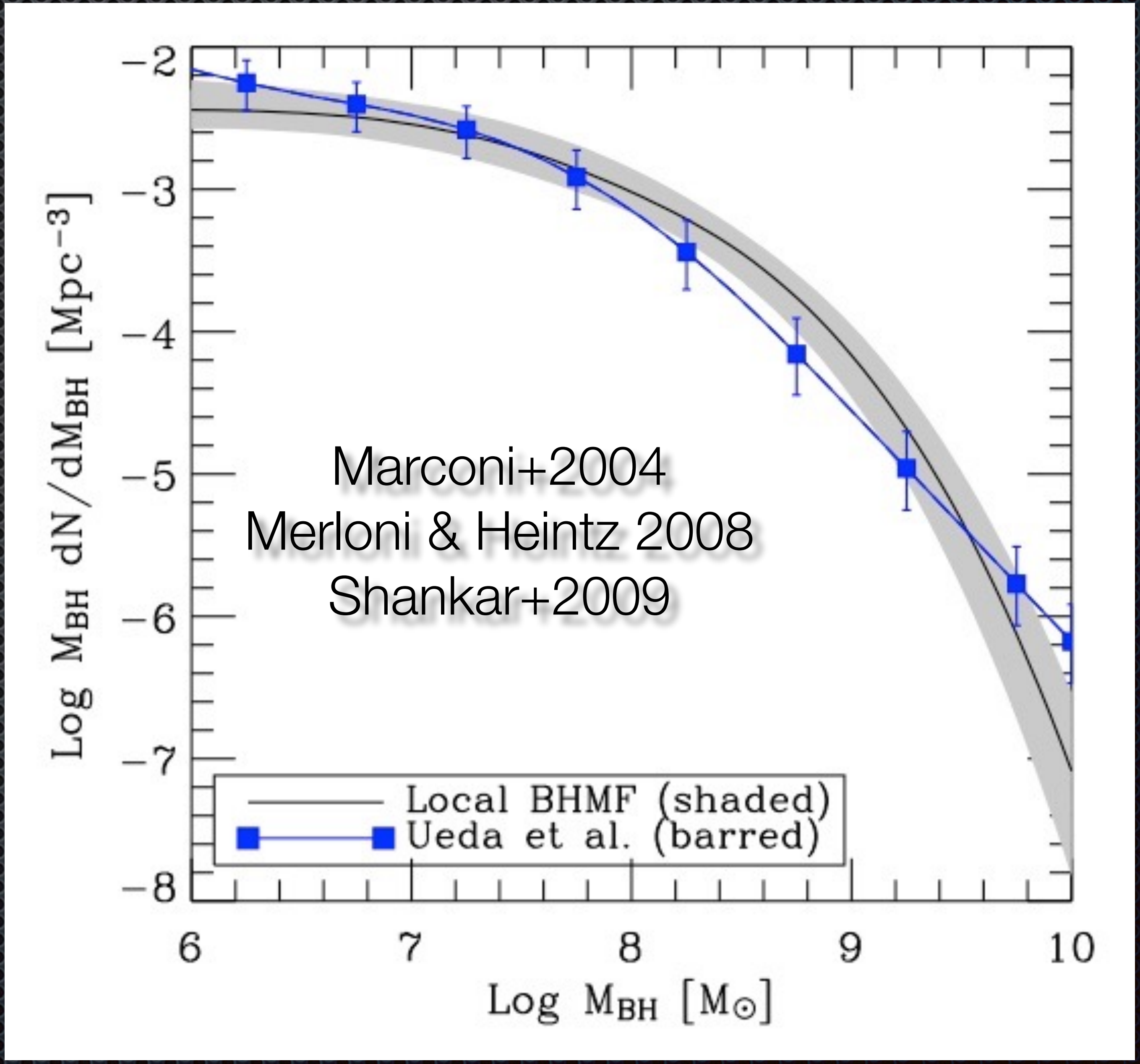

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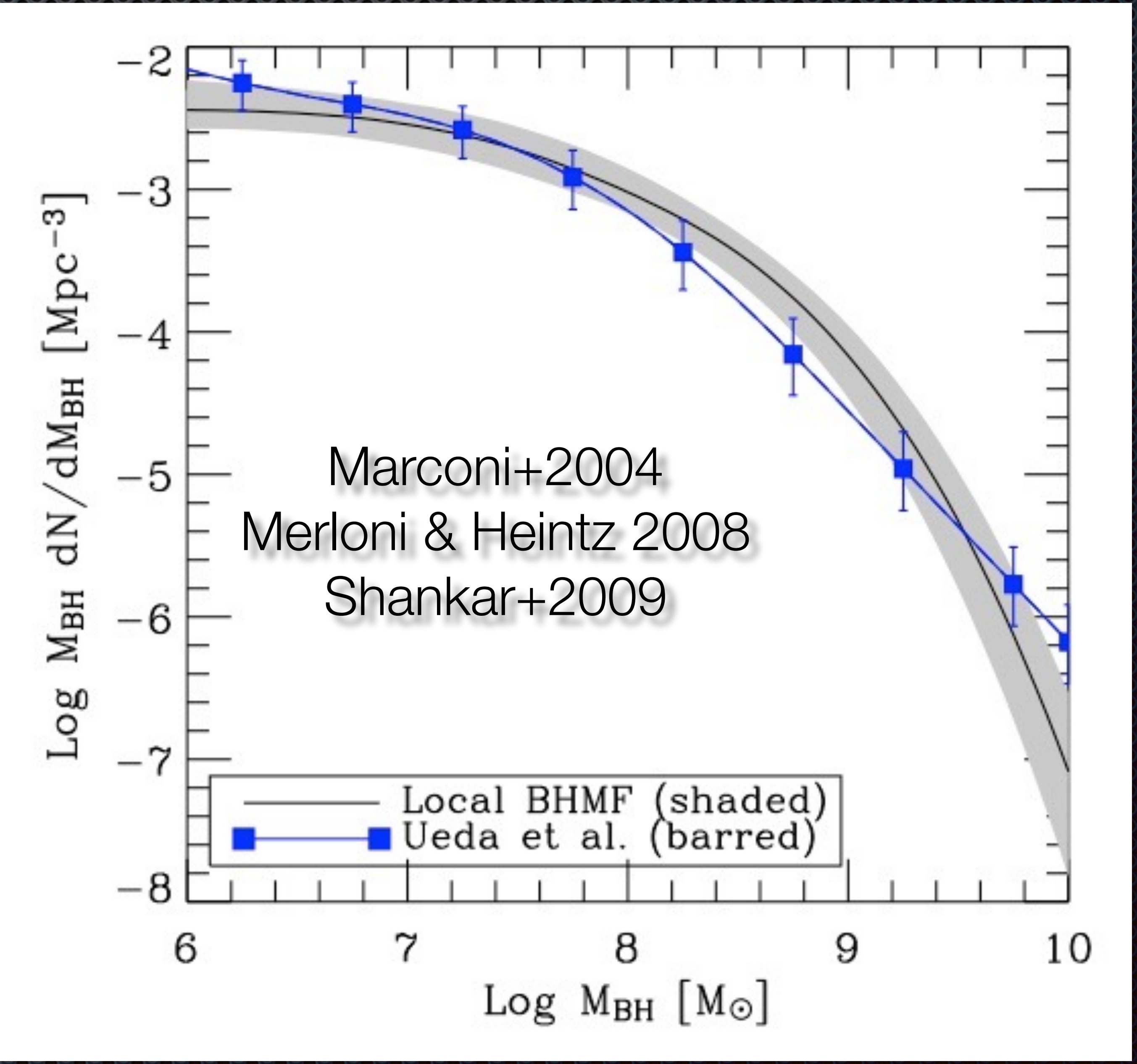
The BH mass density obtained integrating the AGN L.-F. and the CXB ~ that obtained from local bulges



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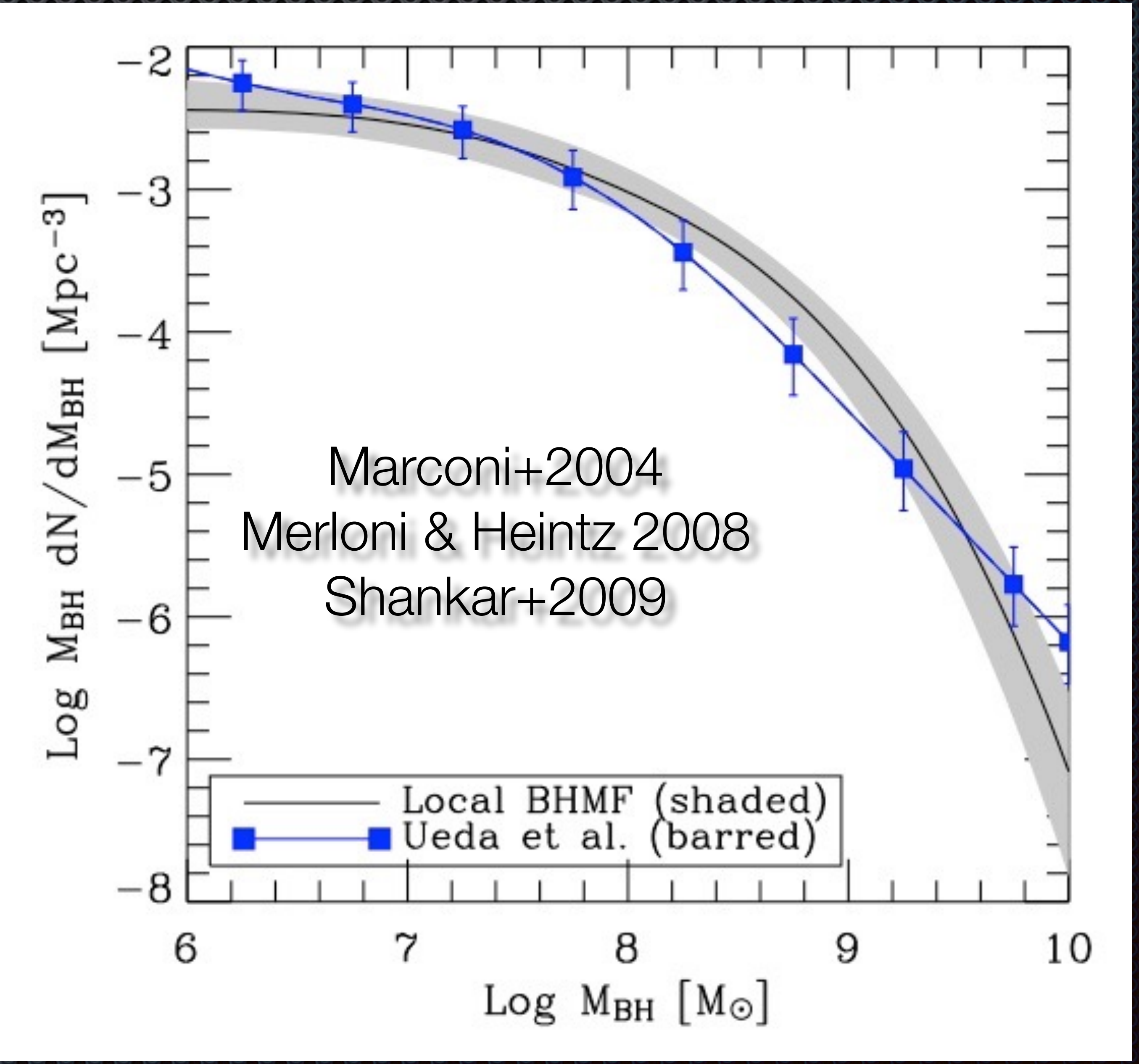

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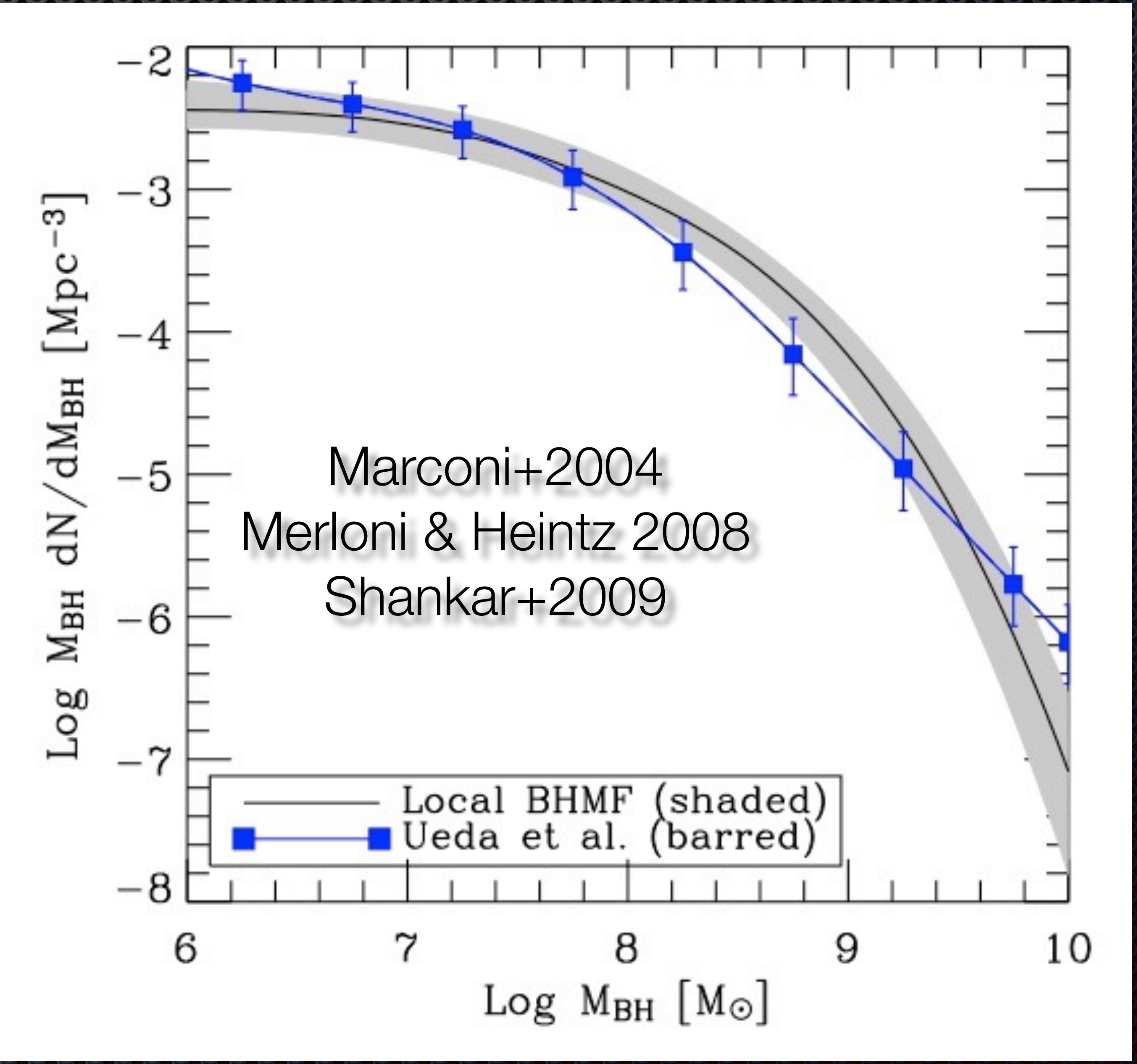

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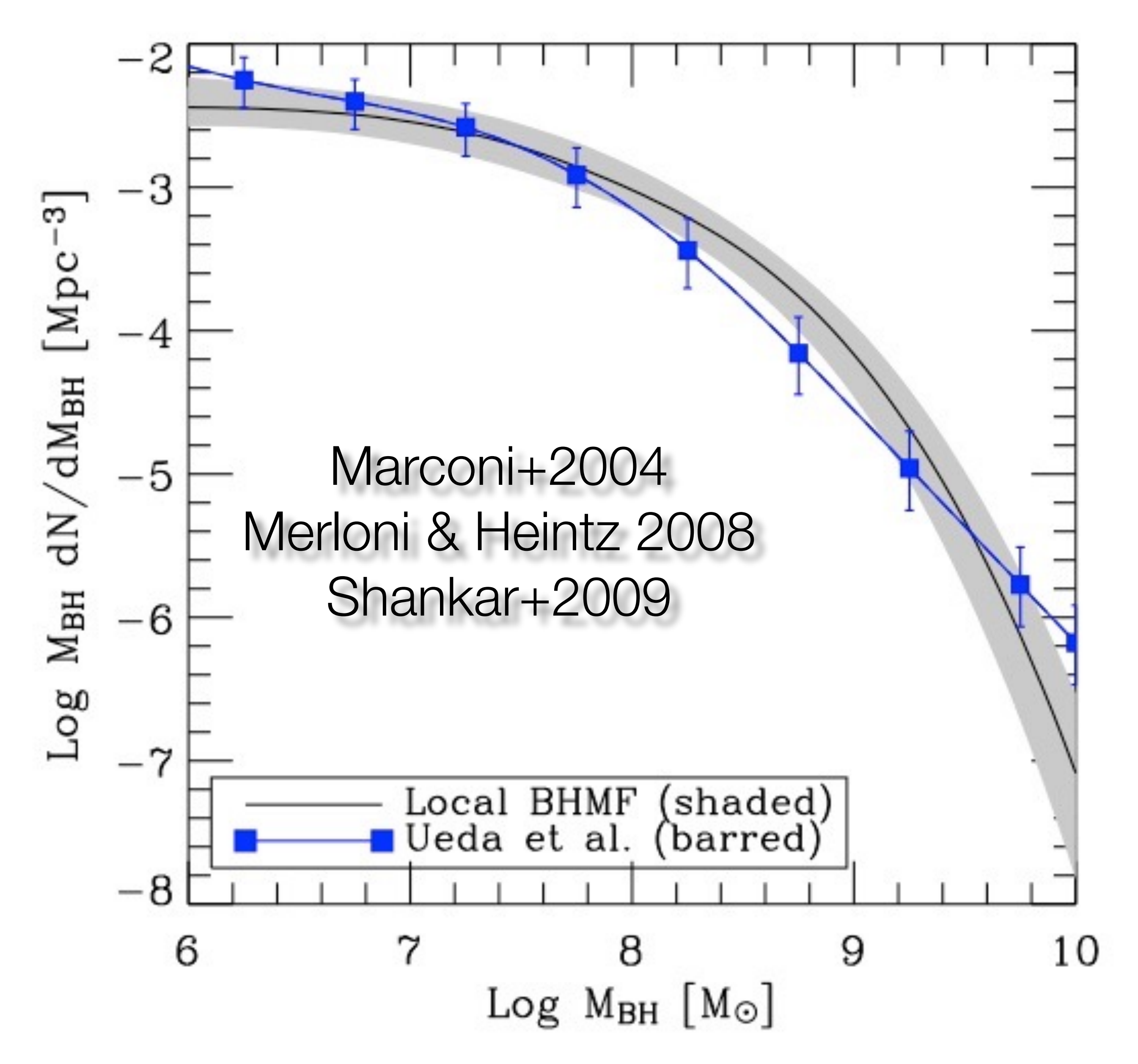

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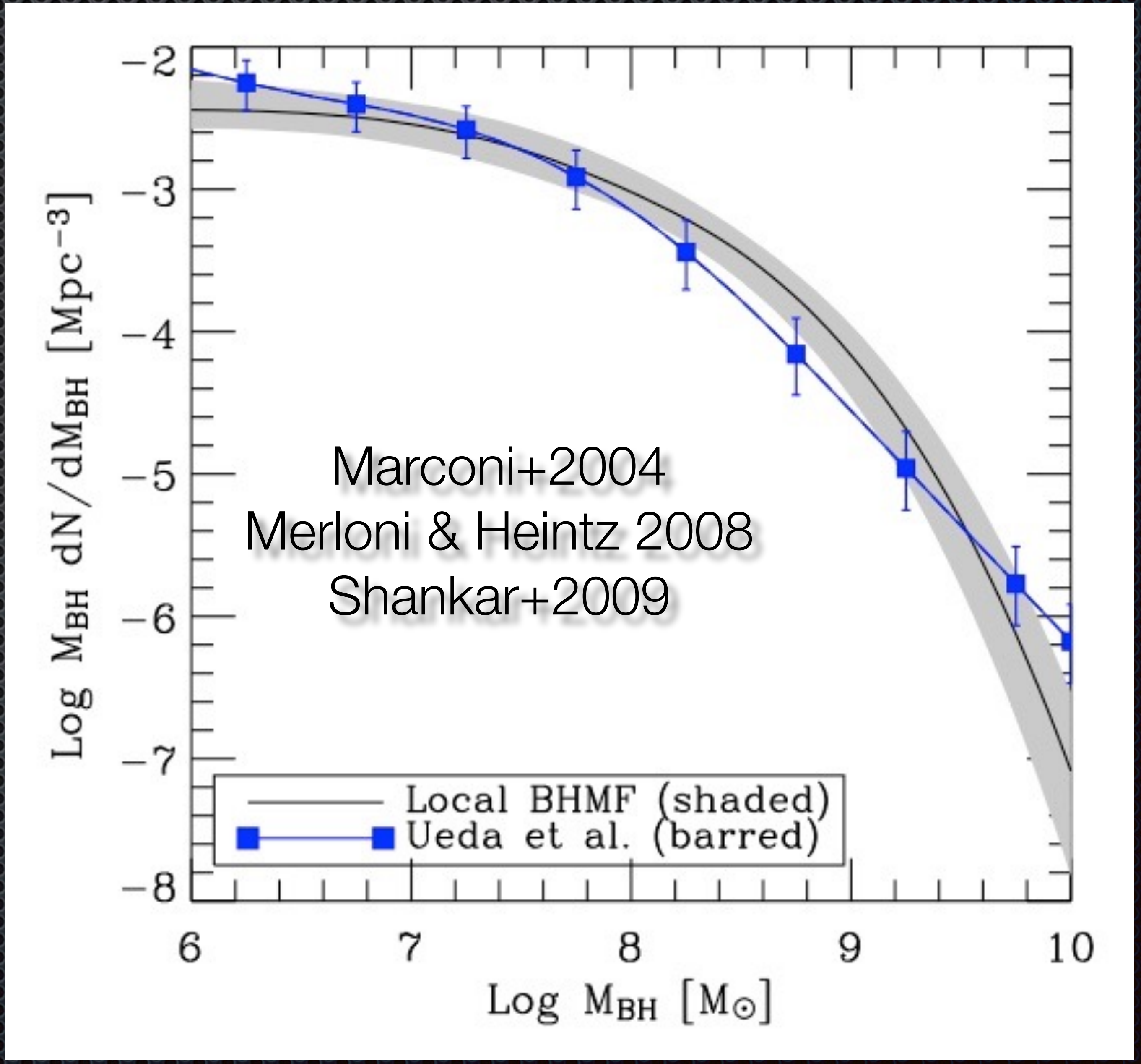
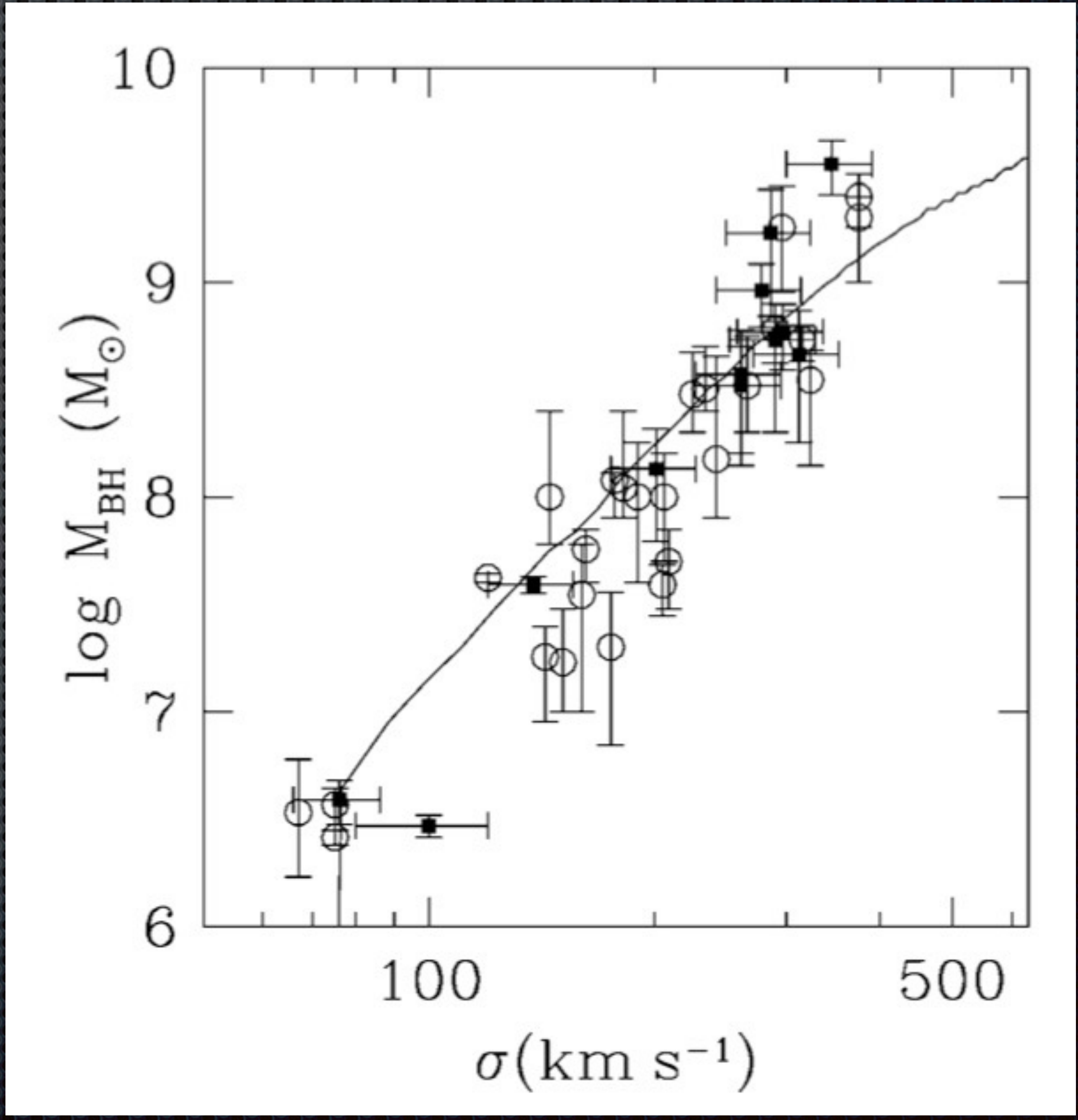


SMBH and stellar mass growth

Expectation of hierarchical galaxy formation models



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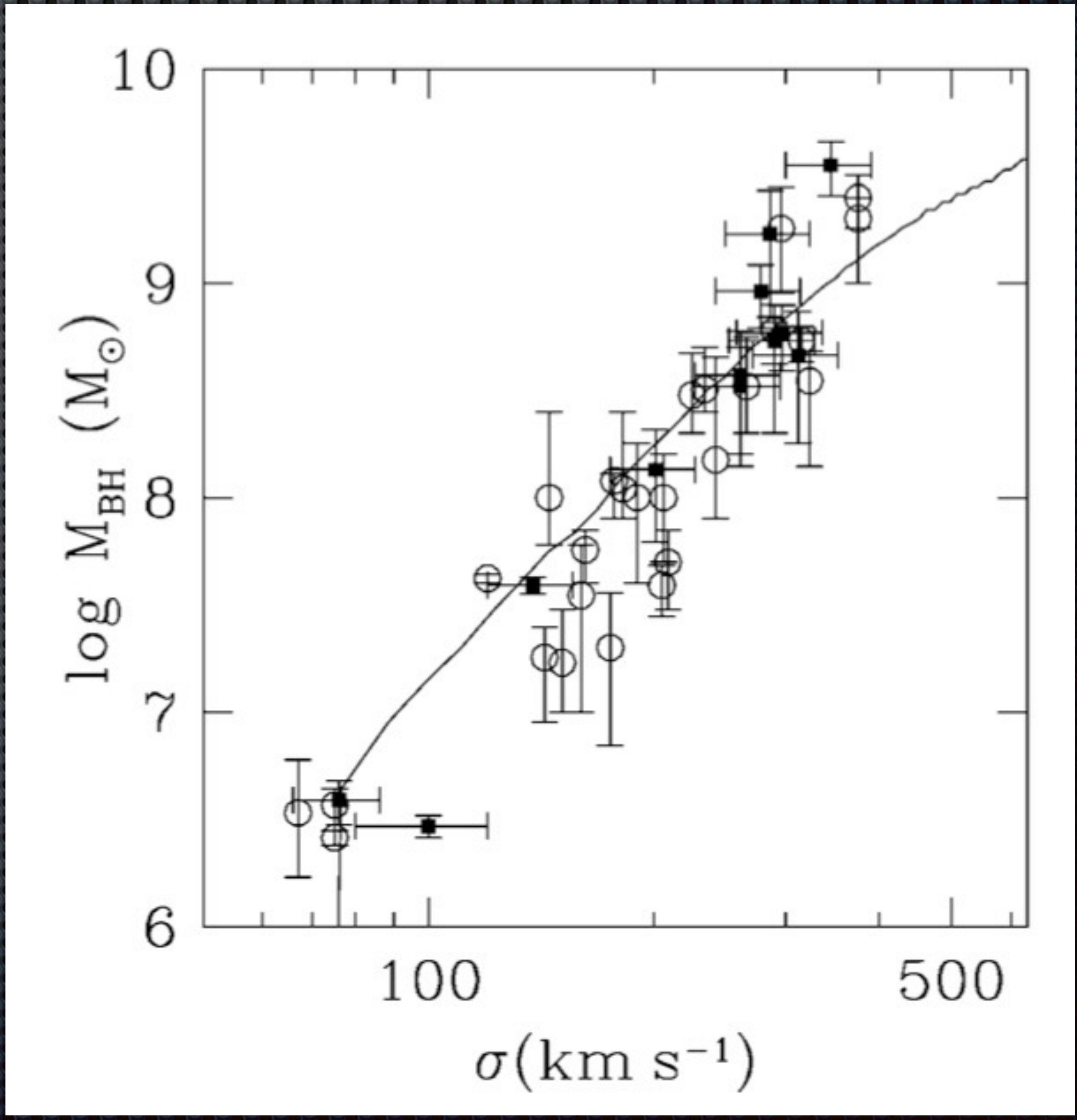

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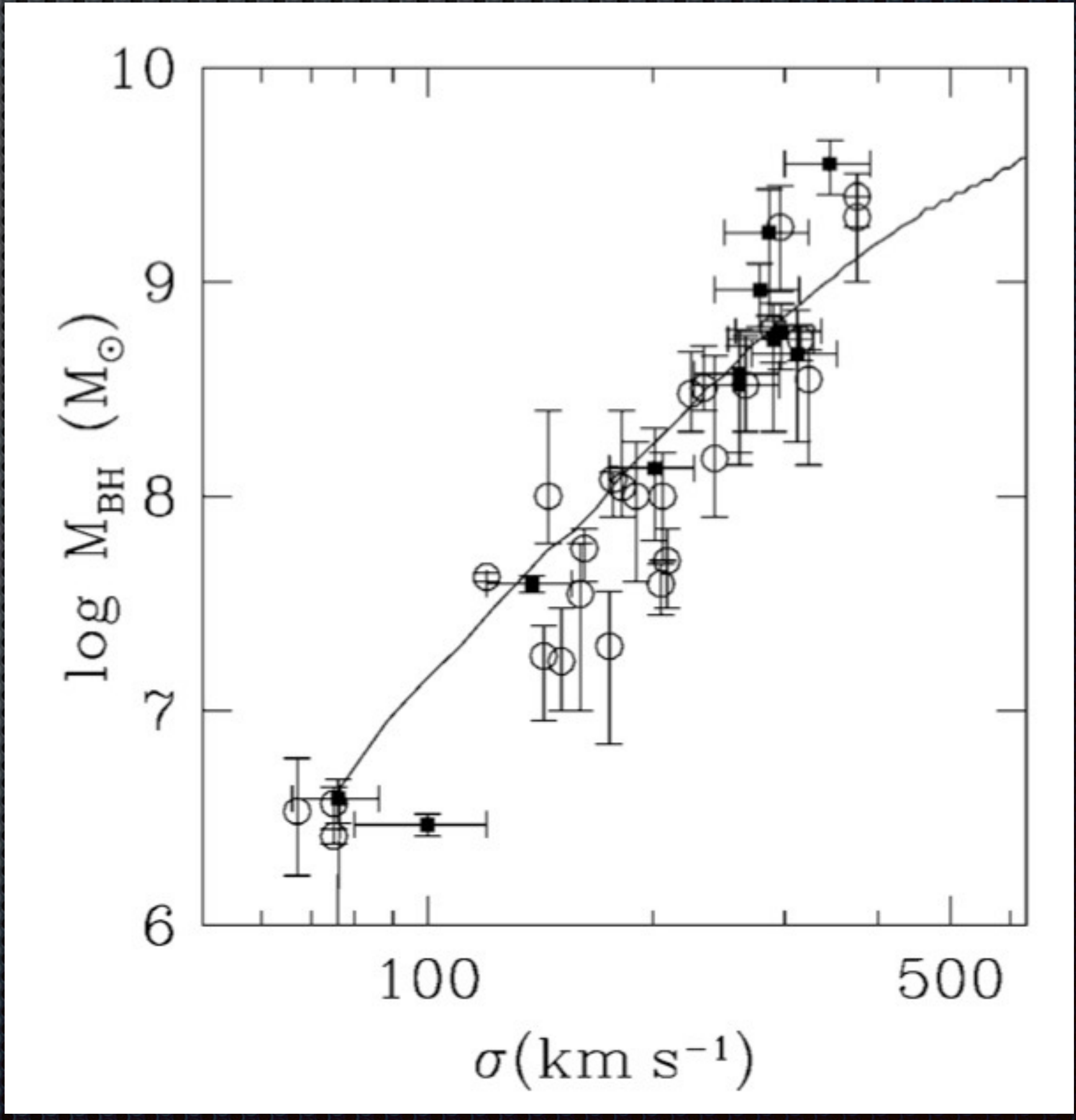

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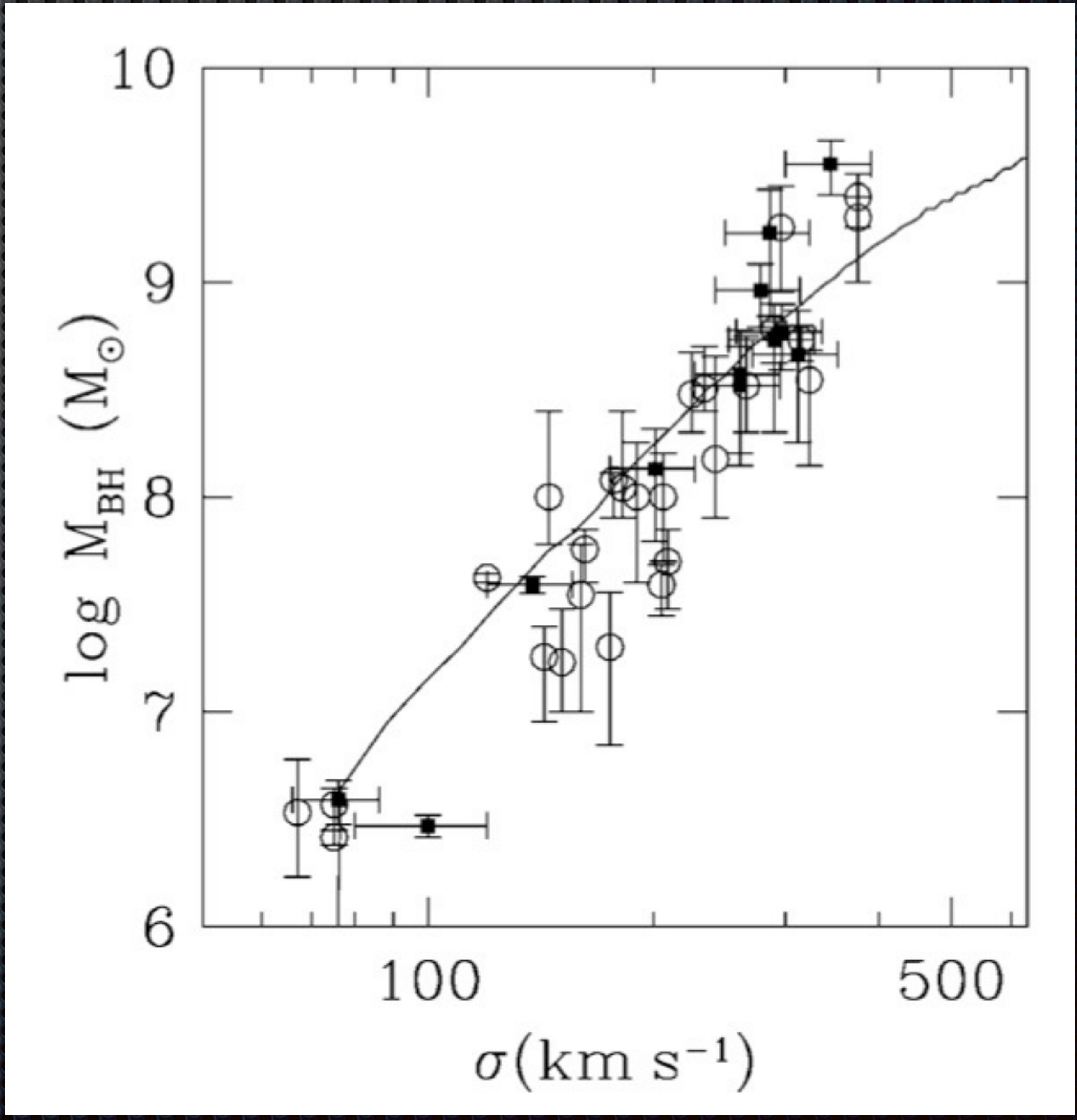

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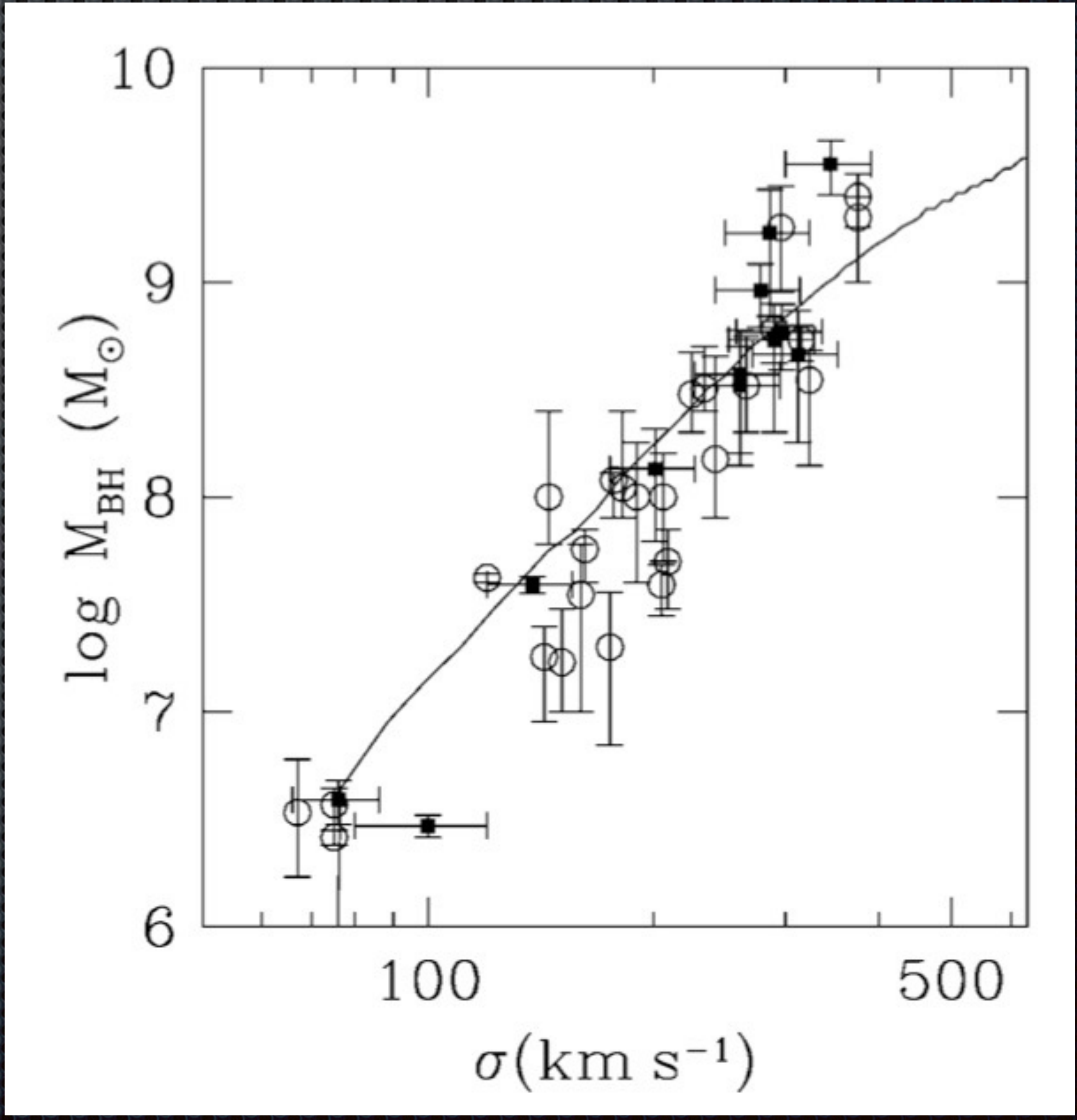

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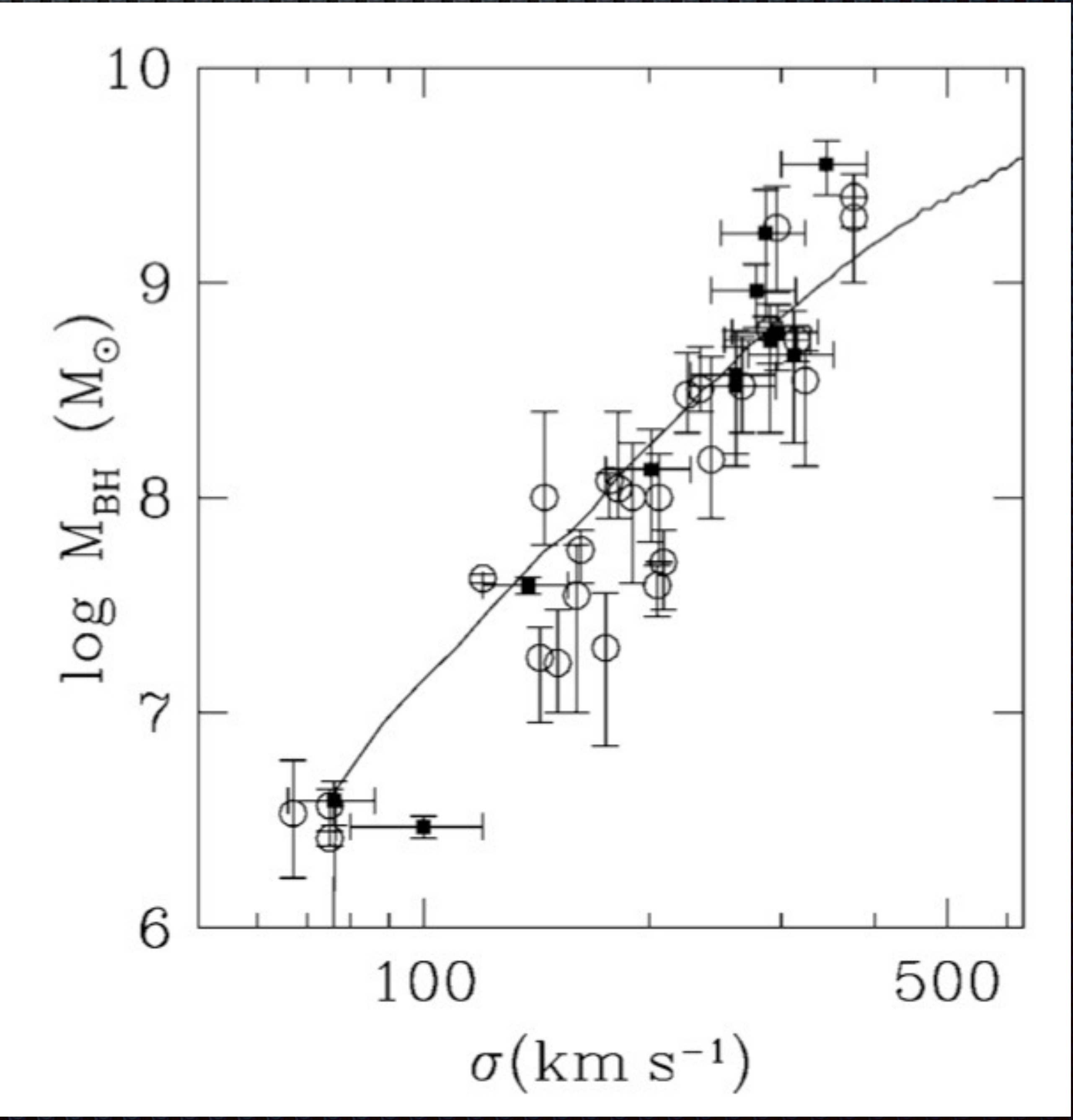

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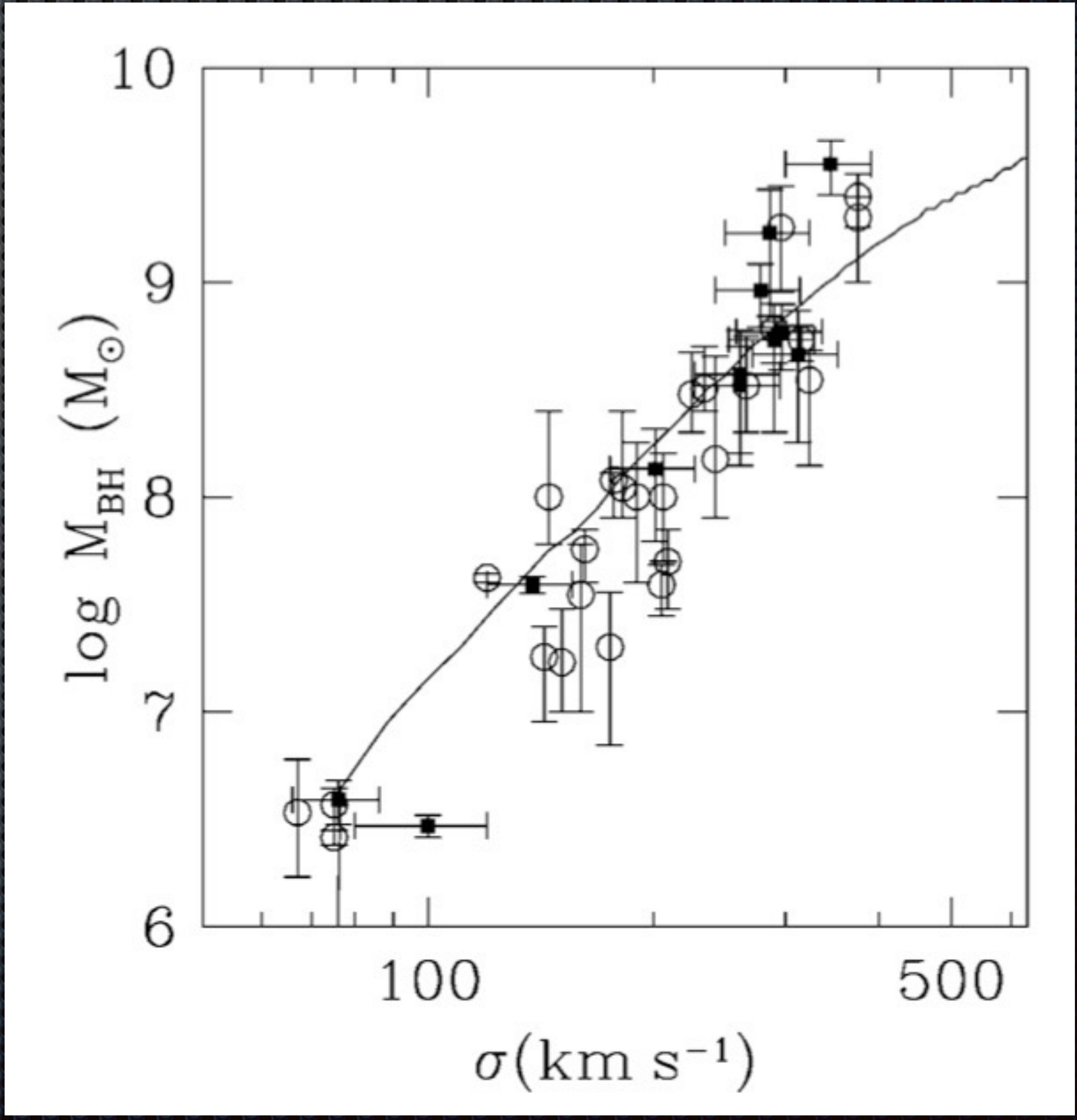

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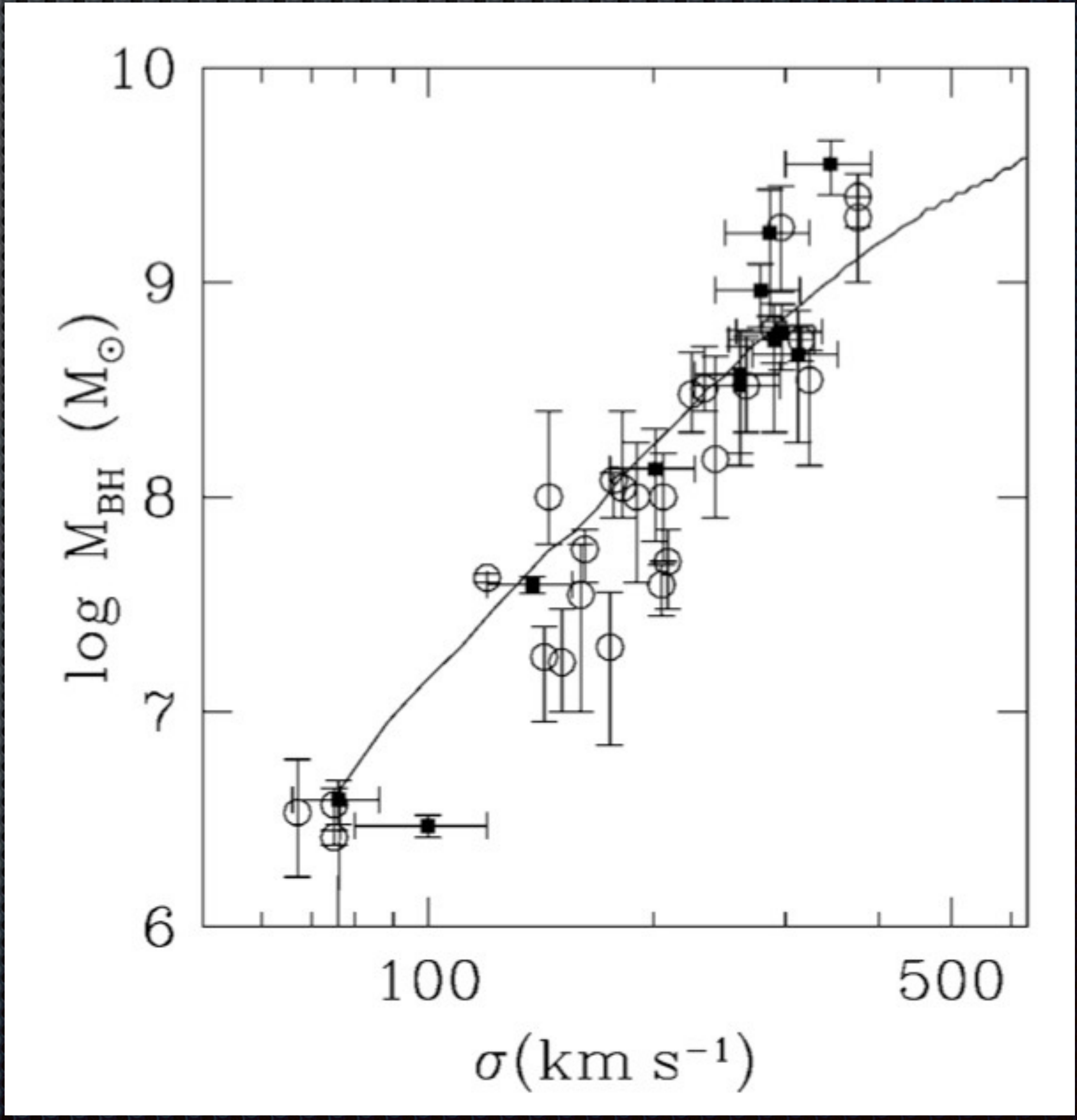

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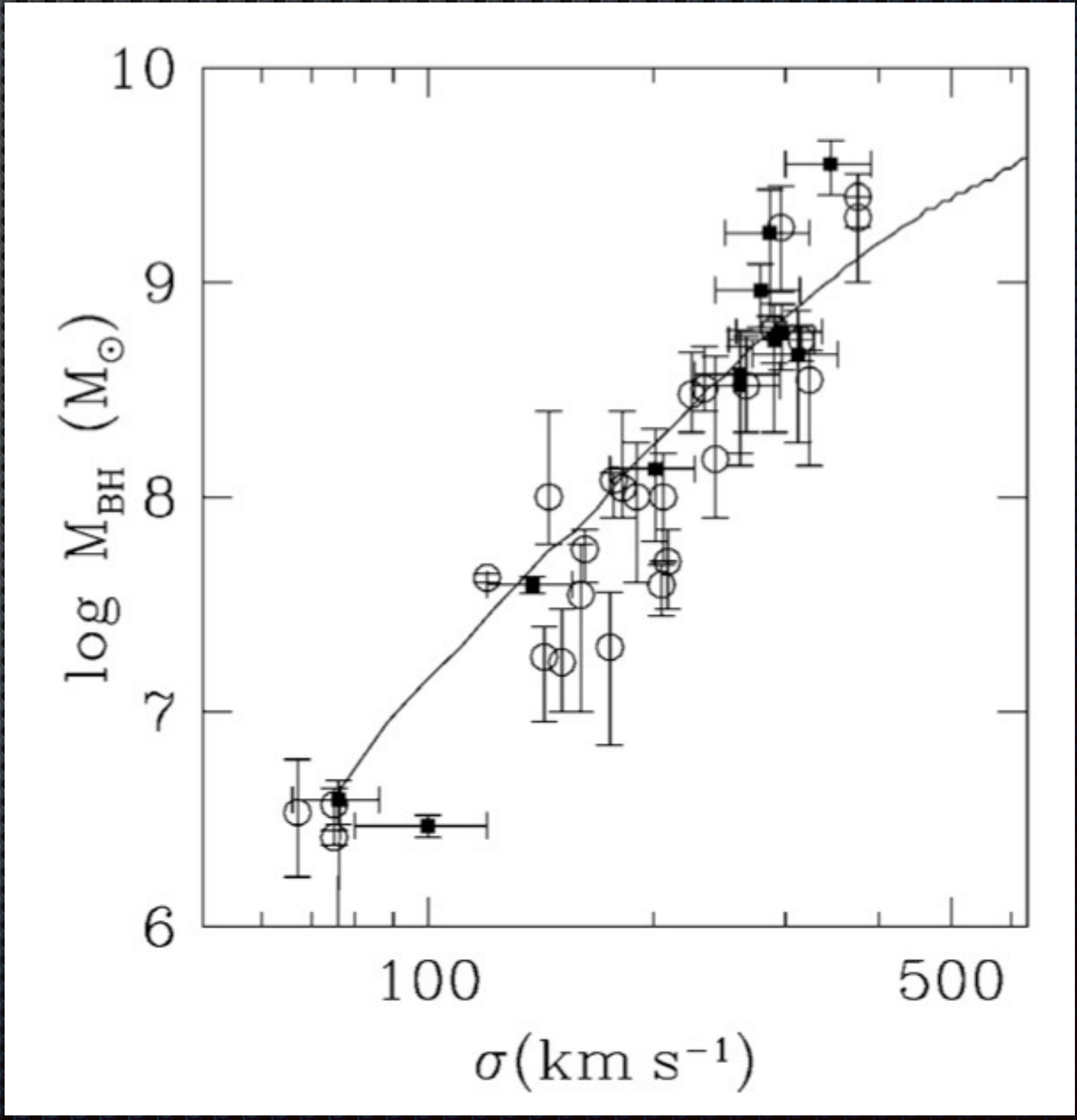

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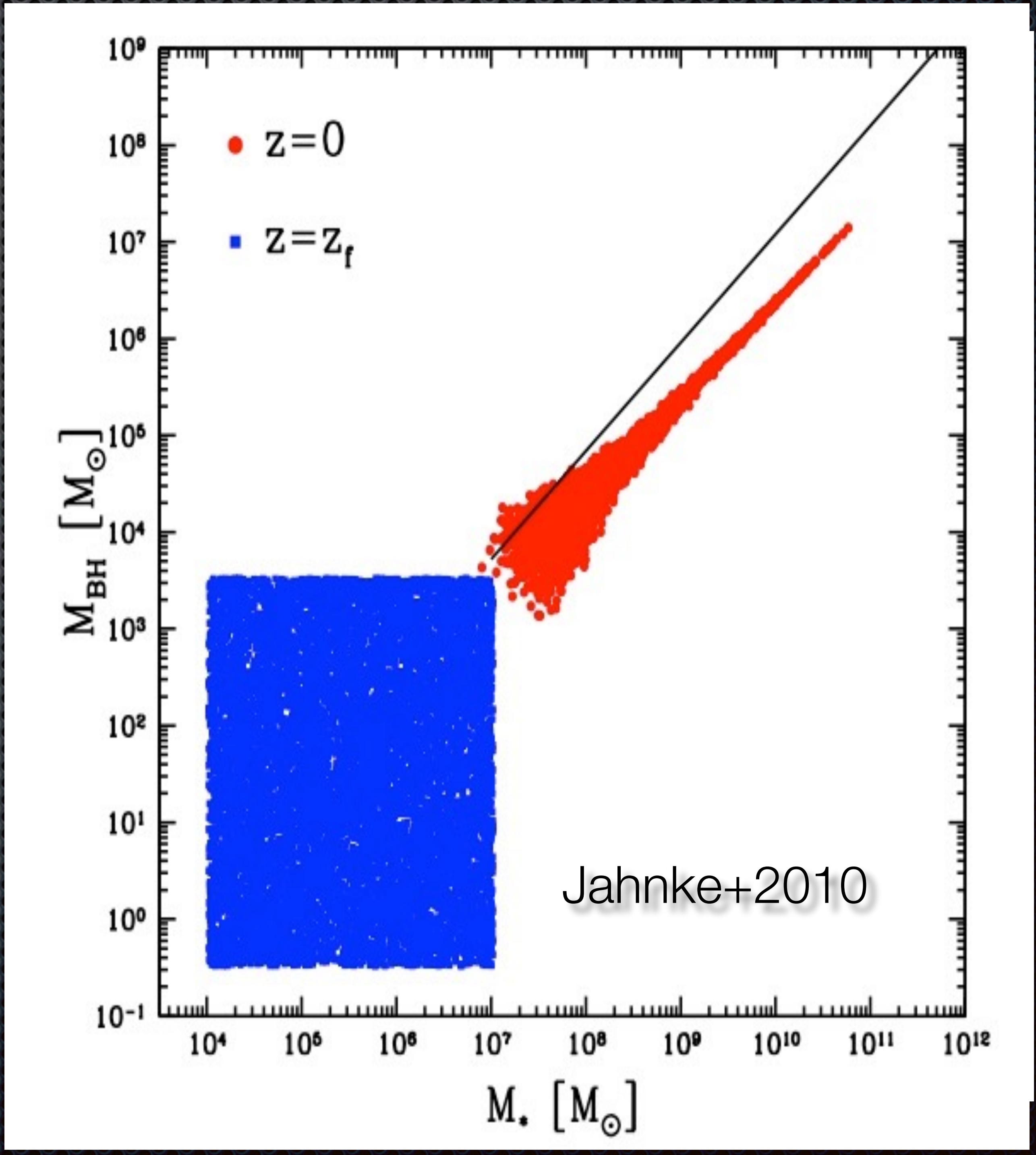

AGN Feedback &
AGN accretion mode

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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

Somerville+2003

Menci+ 2003,2004,2006,2008

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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

Radio-mode *feedback*

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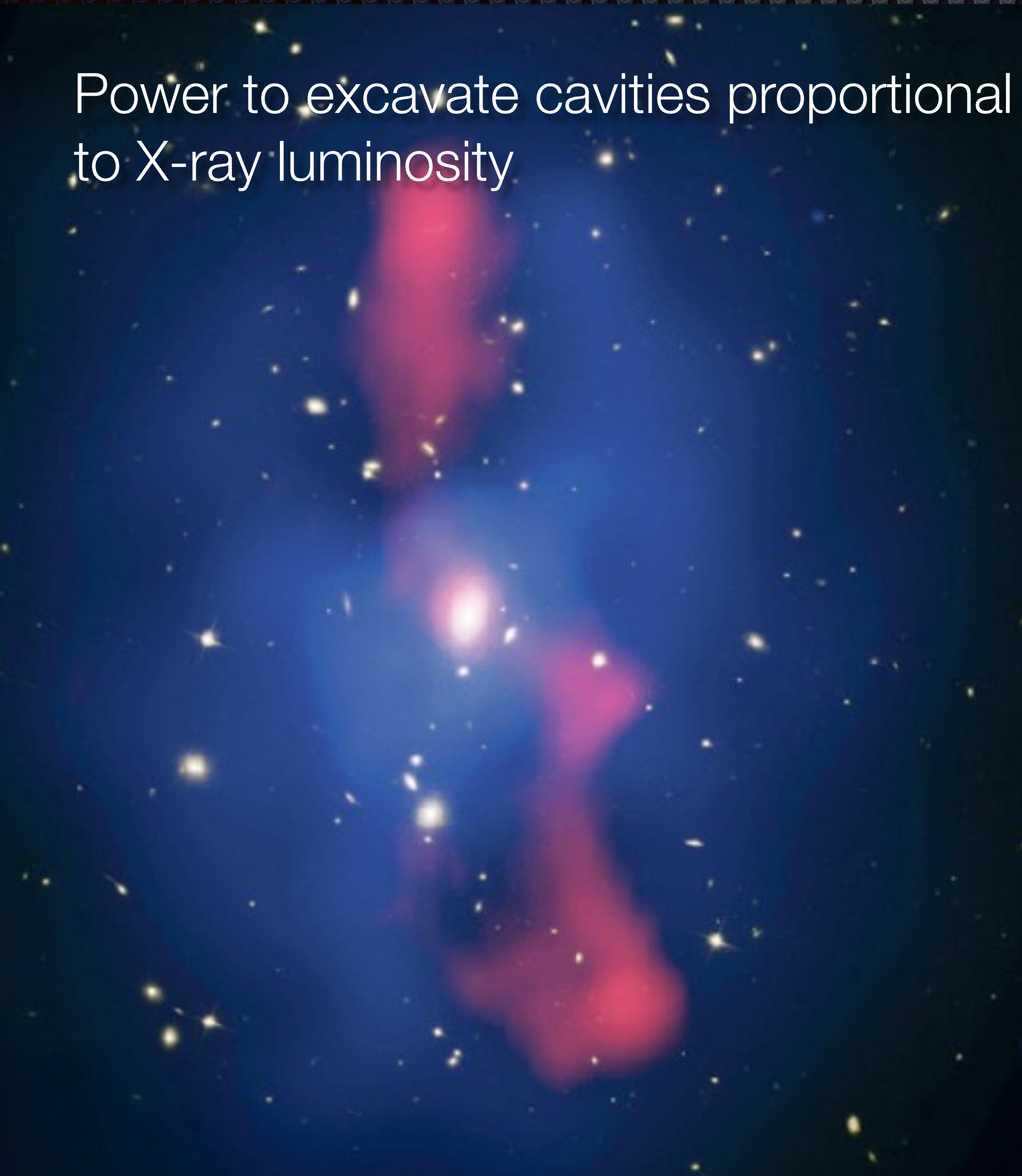
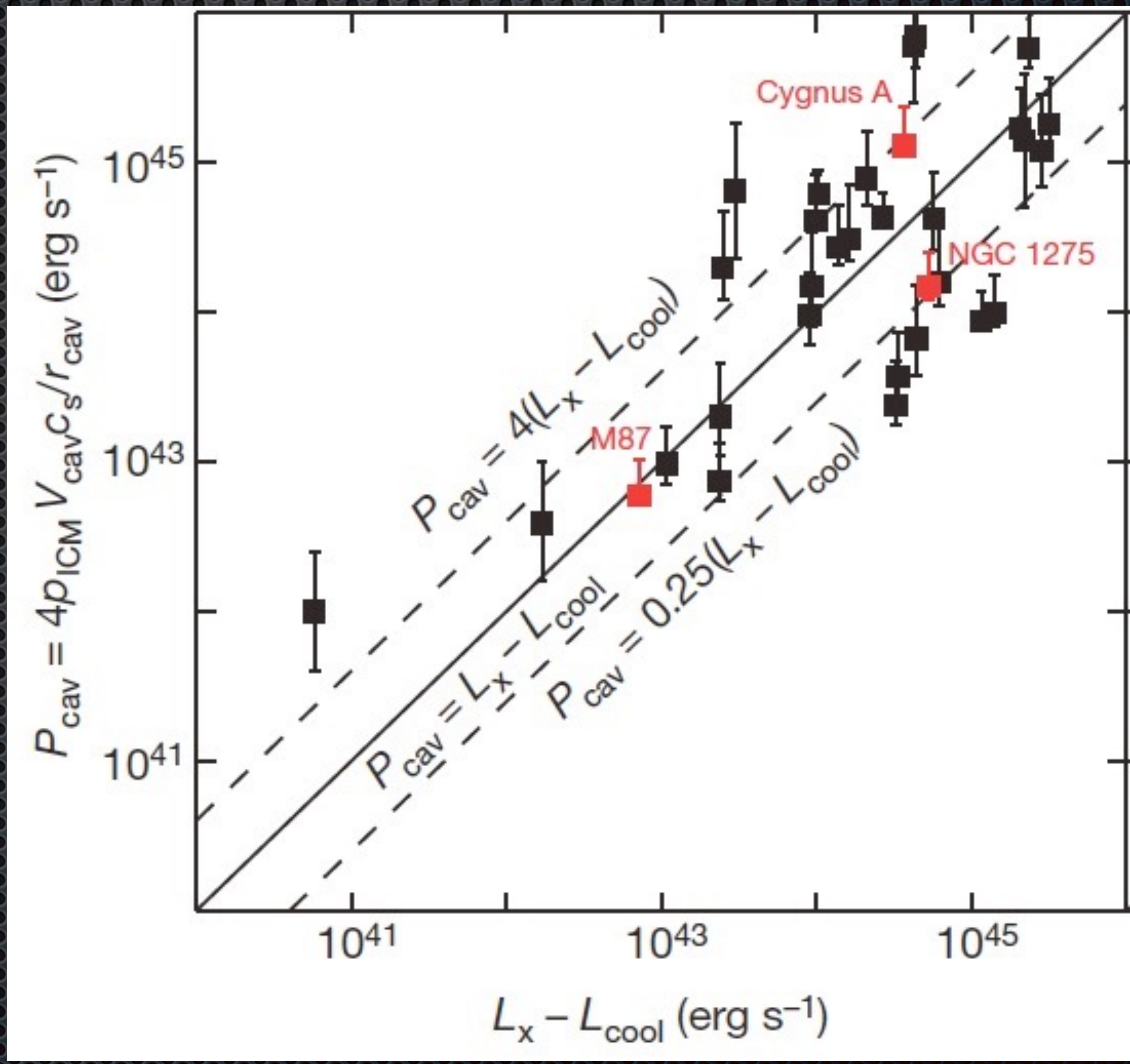
Power to excavate cavities proportional to X-ray luminosity





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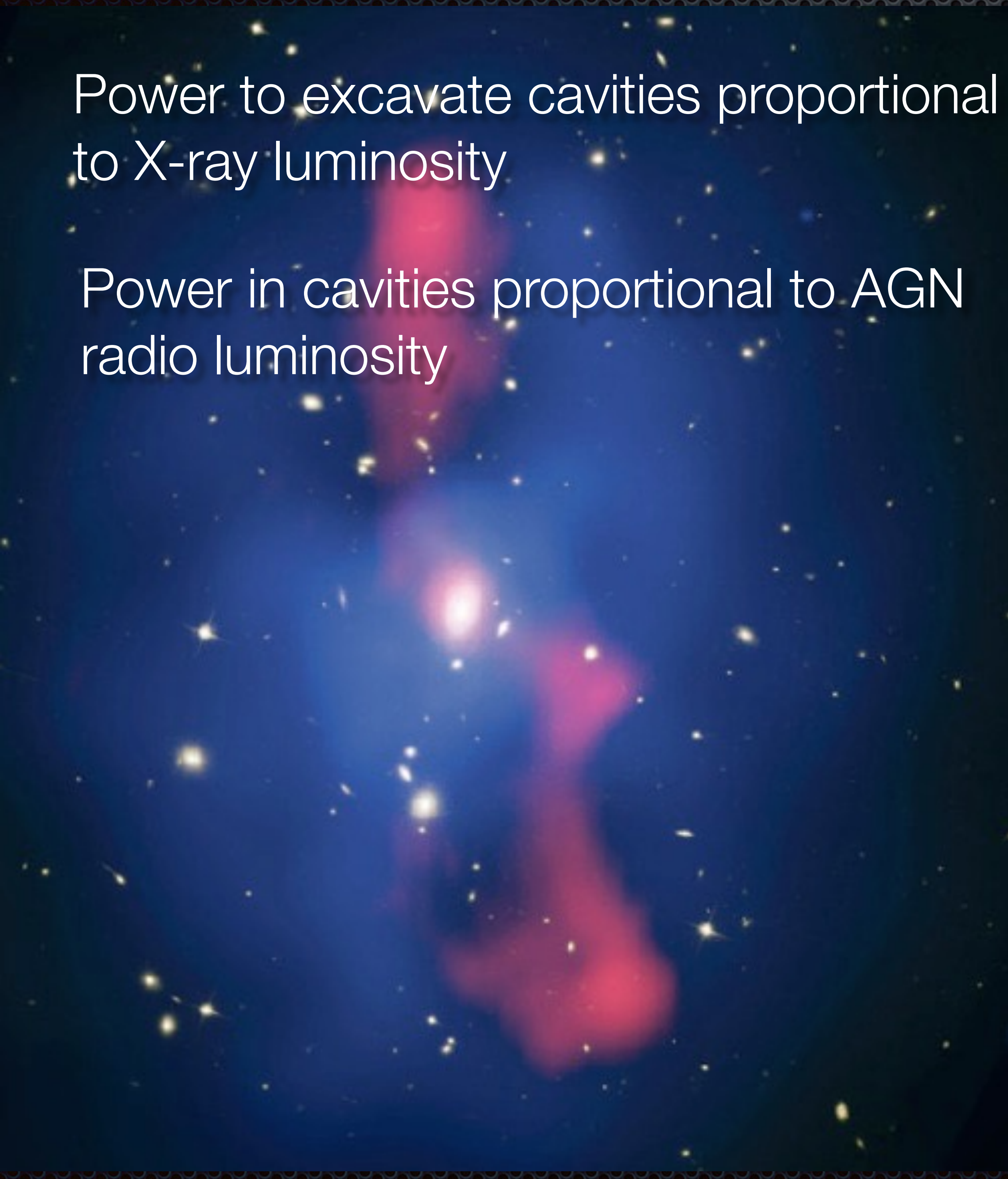

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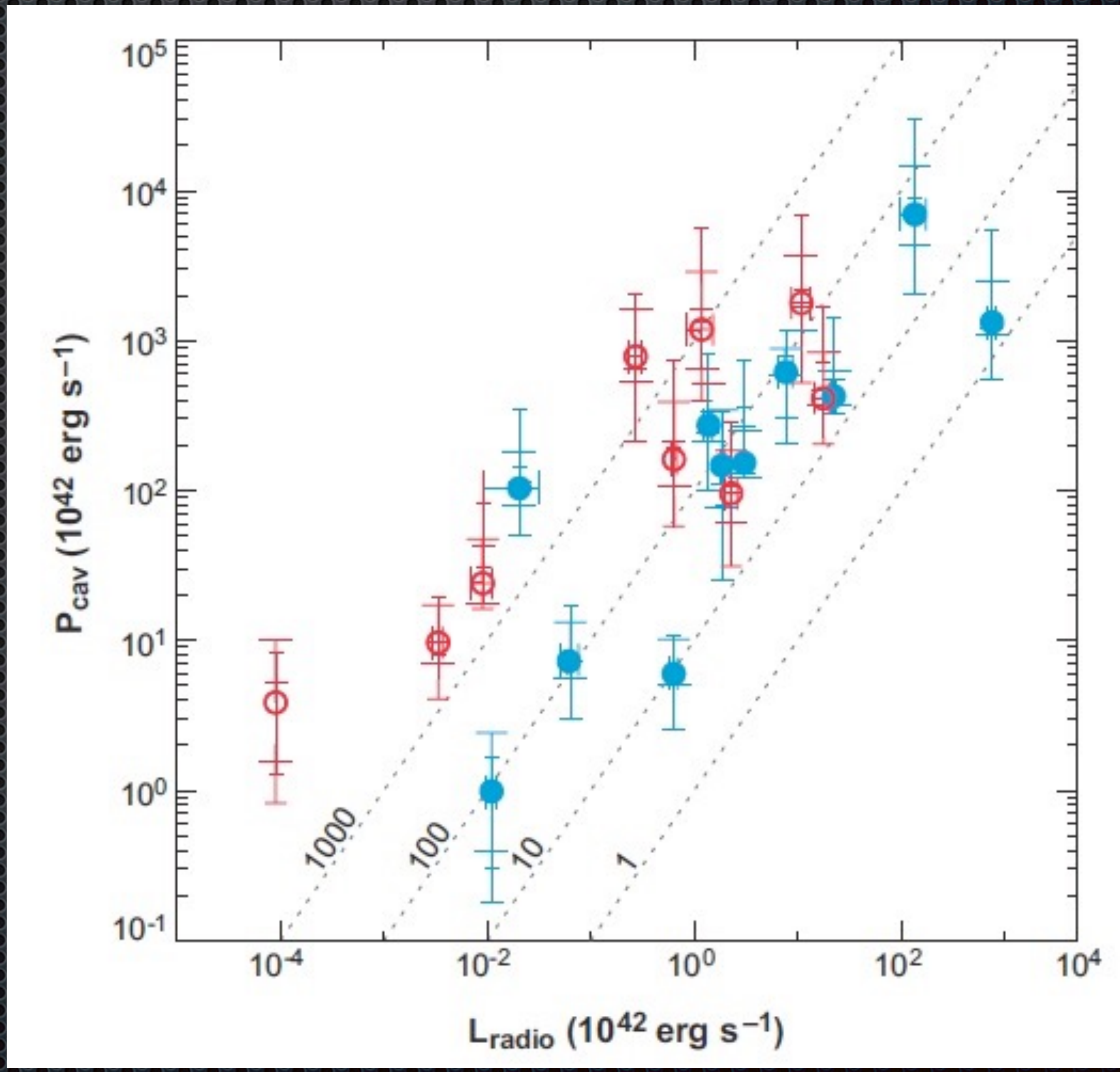

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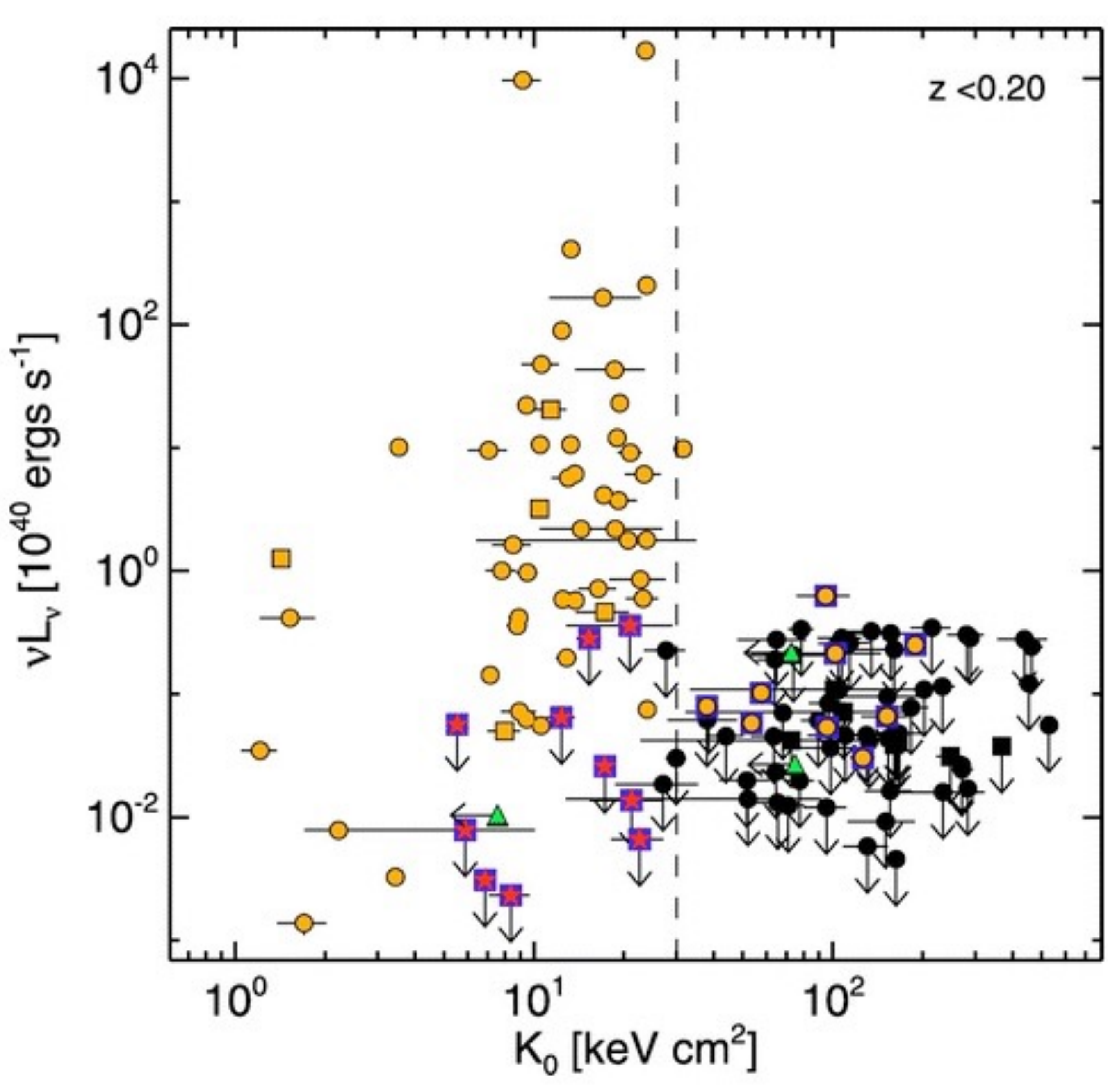

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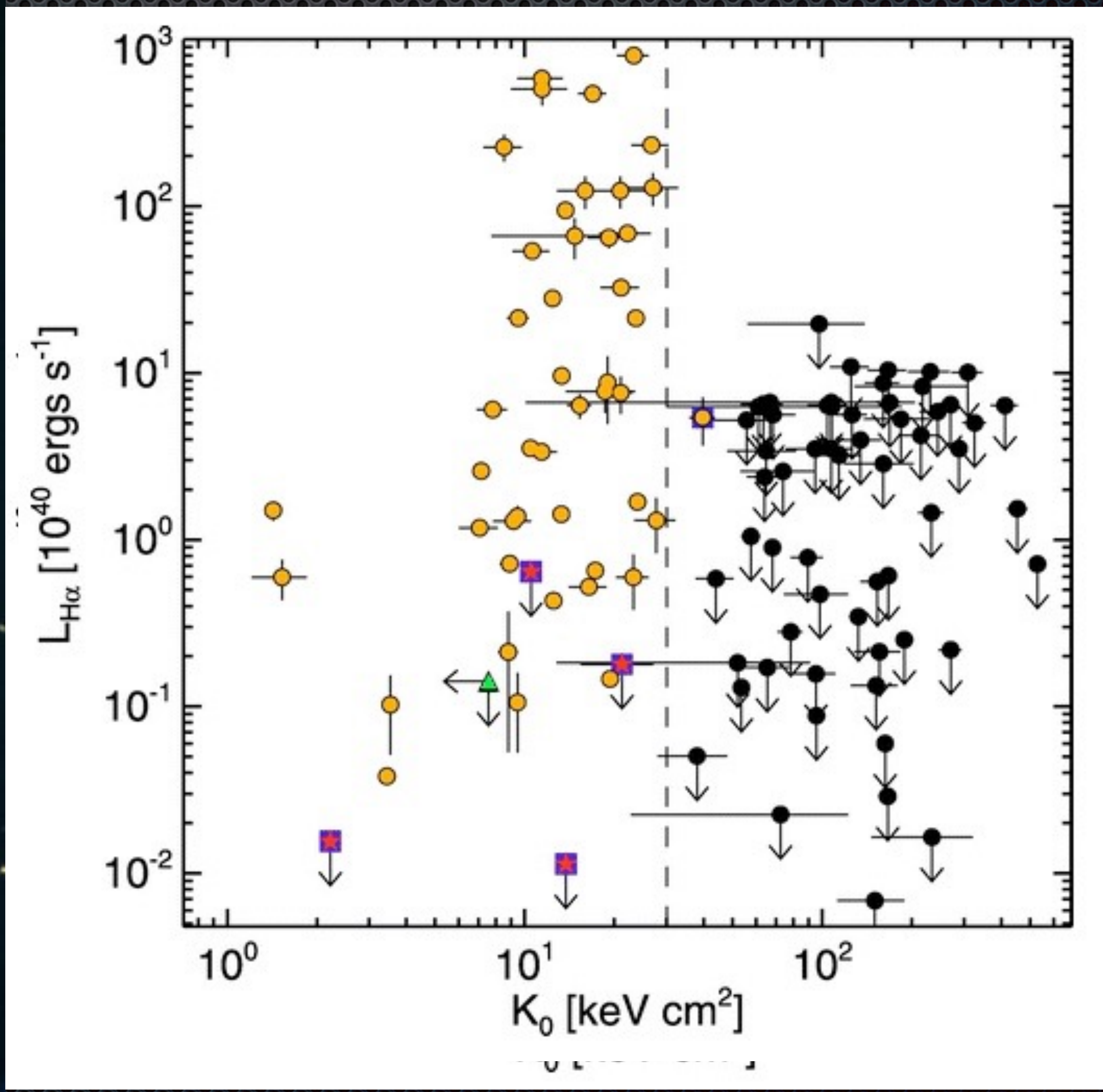
..and only BCG with low inner entropy ***and*** an active nucleus are **actively forming stars!**

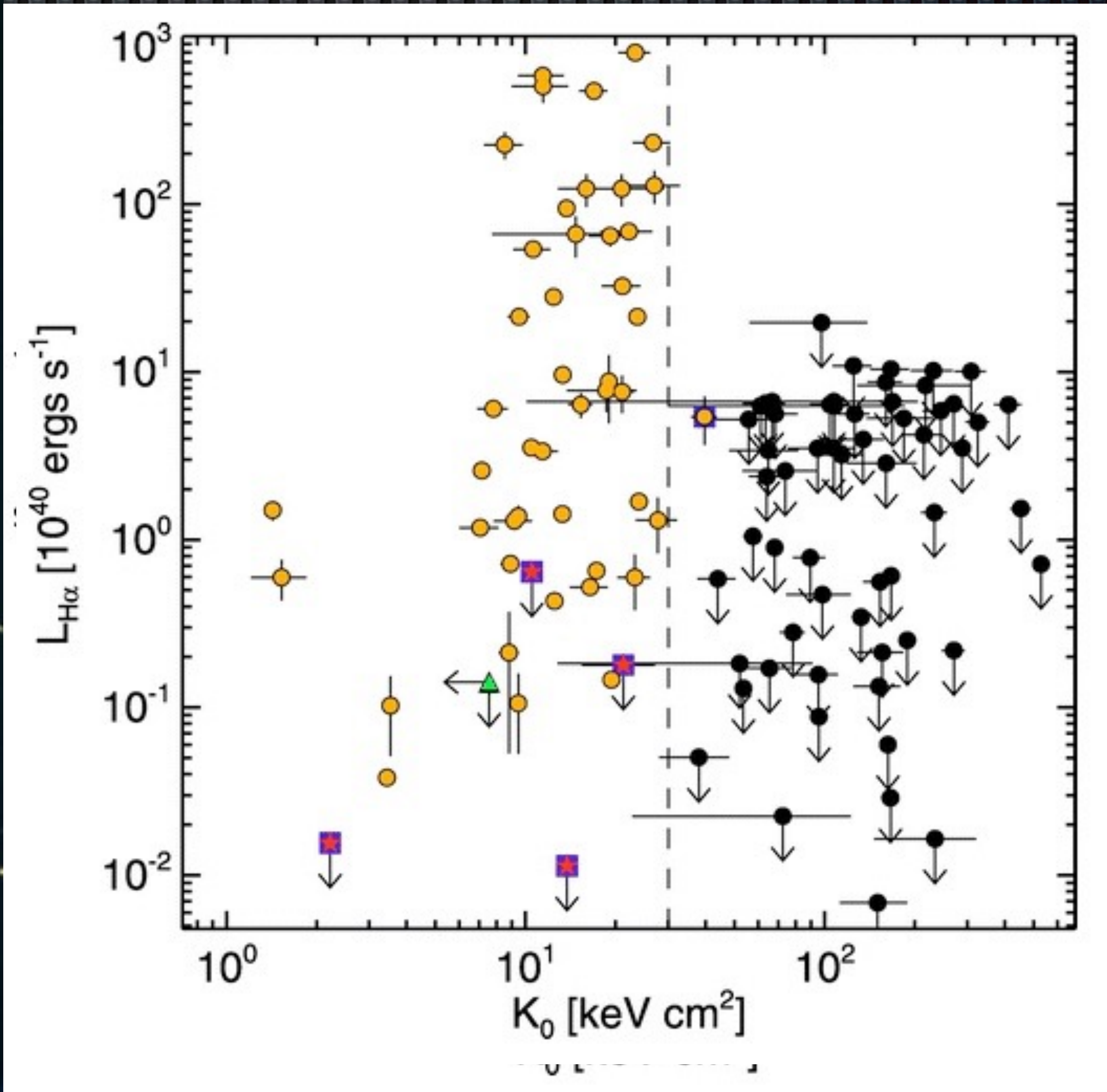


Radio-mode *feedback*

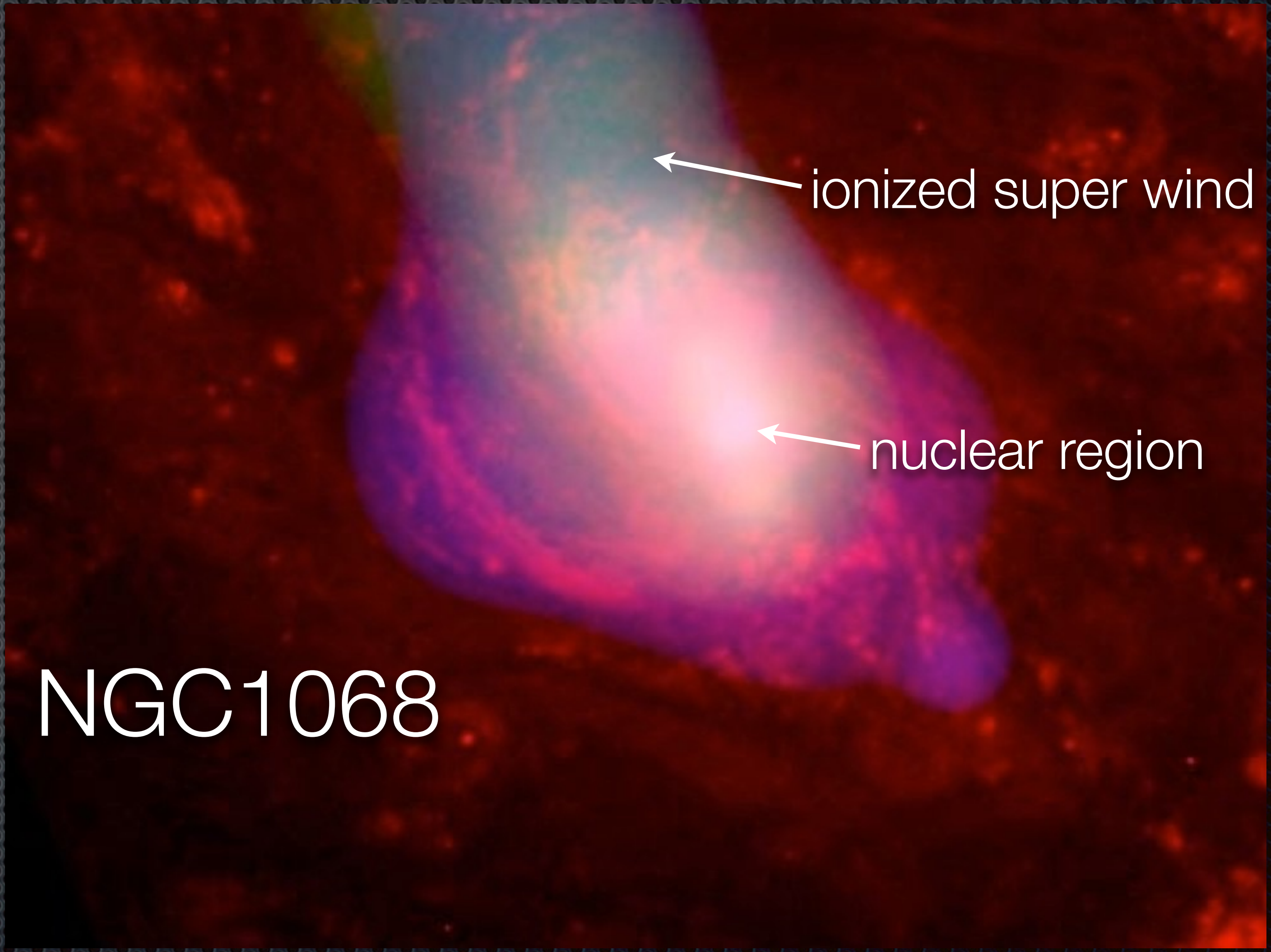
A delicate feedback mechanism:

AGN input energy *regulates* the gas entropy and, in turn, further gas accretion and SF (stars can form from low entropy, cold and dense gas only).

Voit & Donahue 2014



AGN winds are ubiquitous



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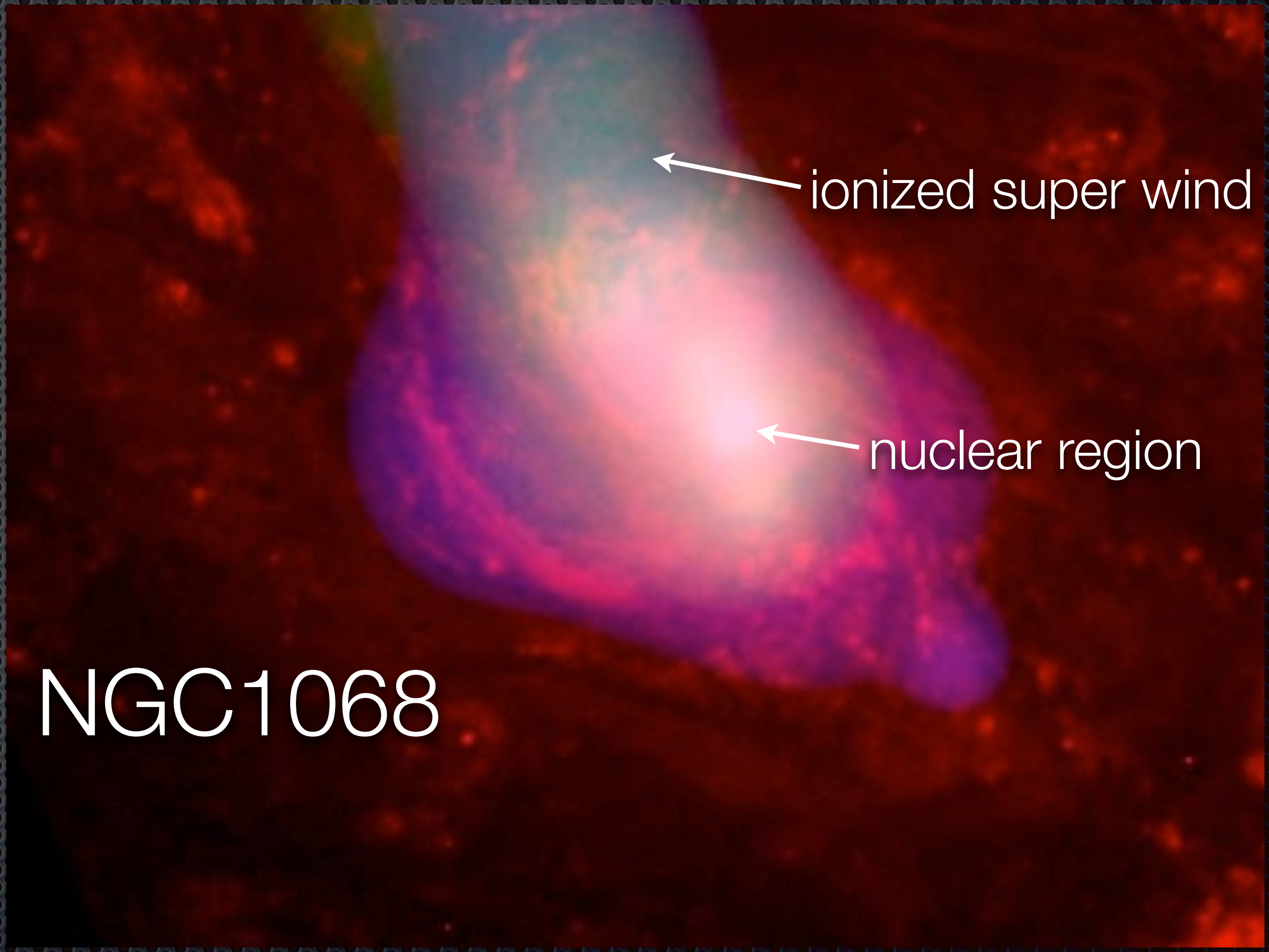

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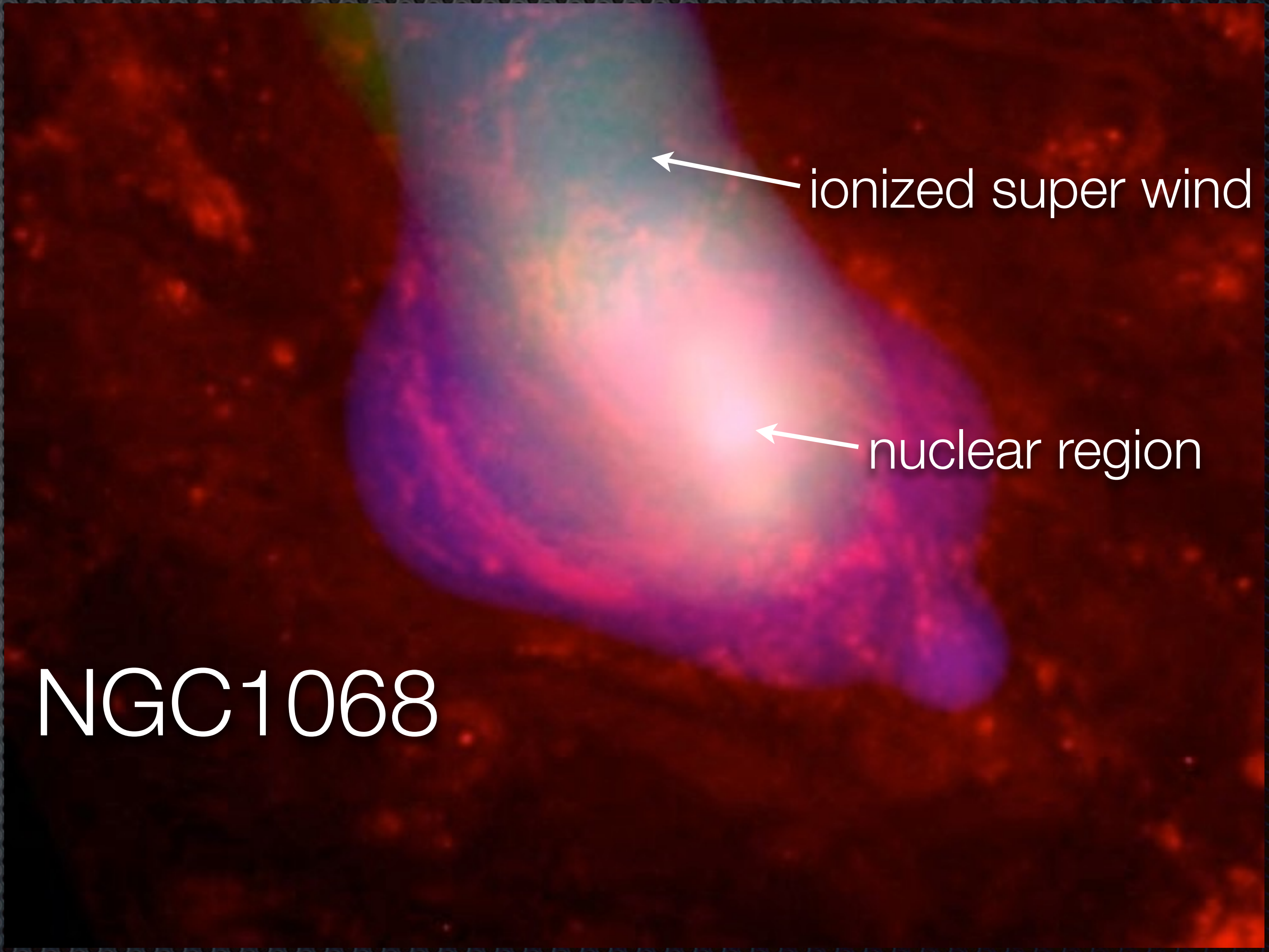

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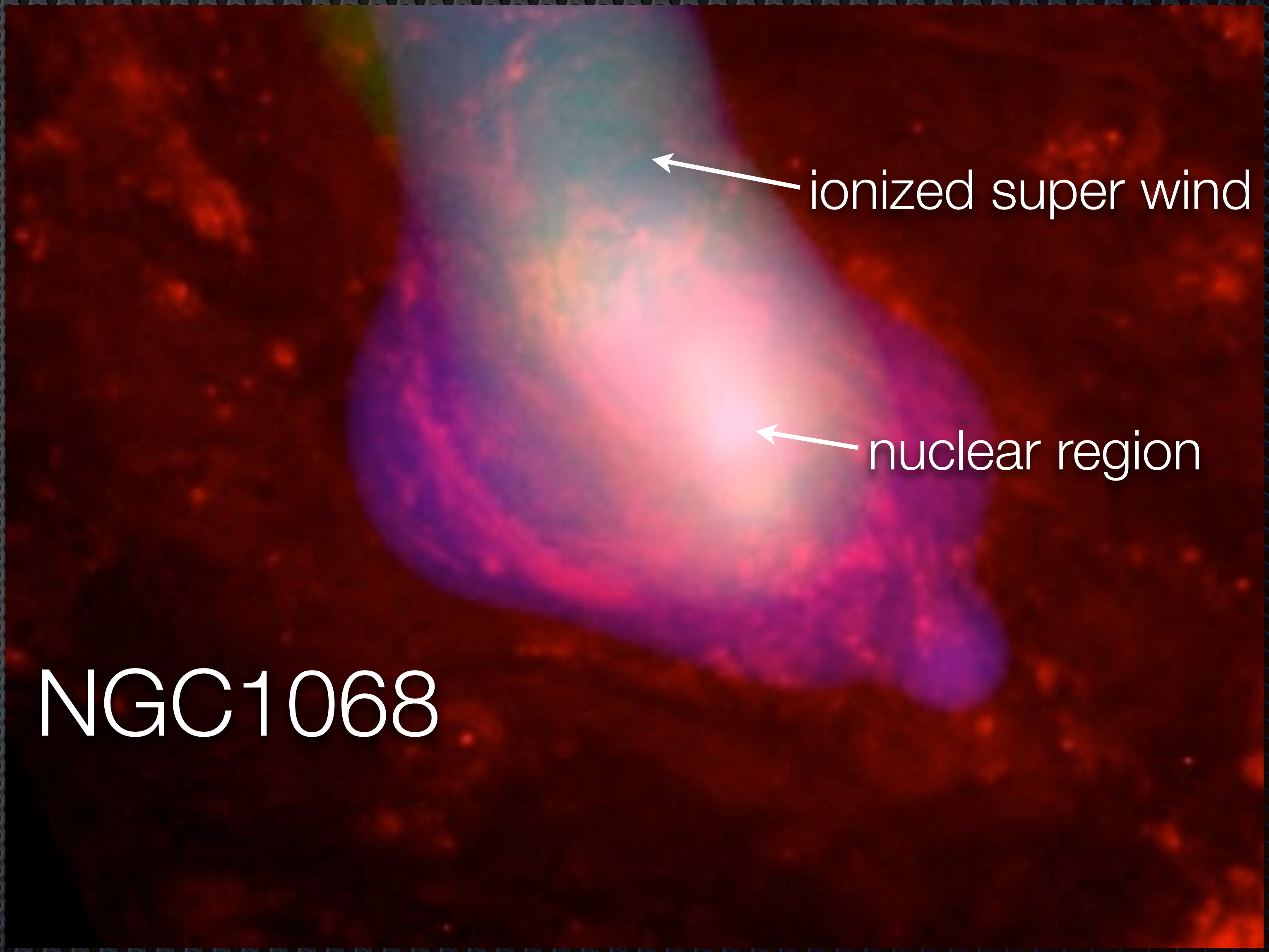

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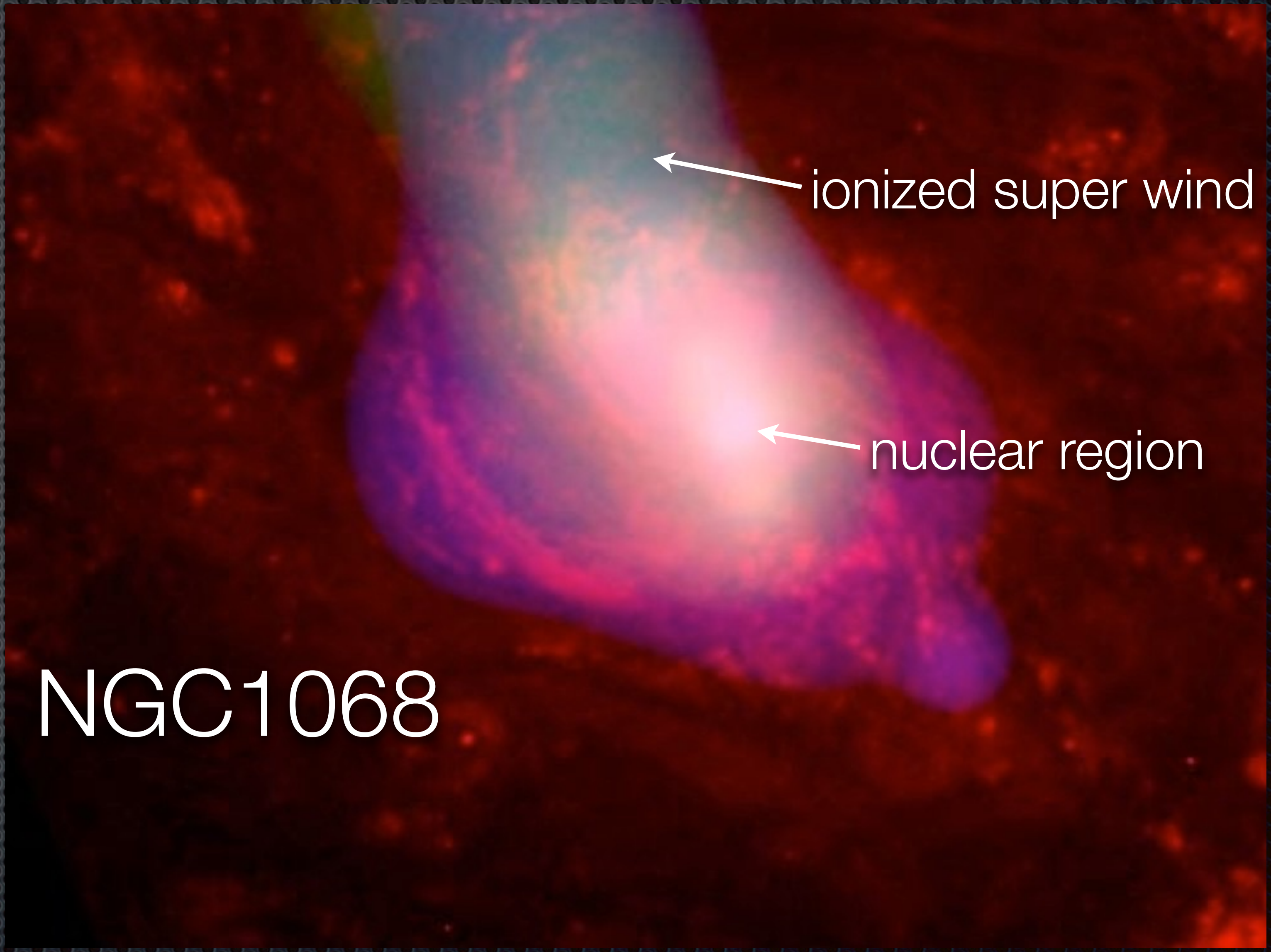

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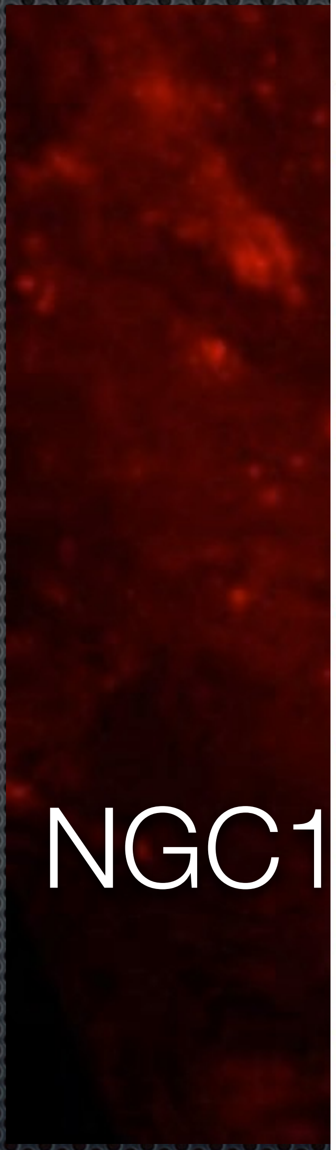
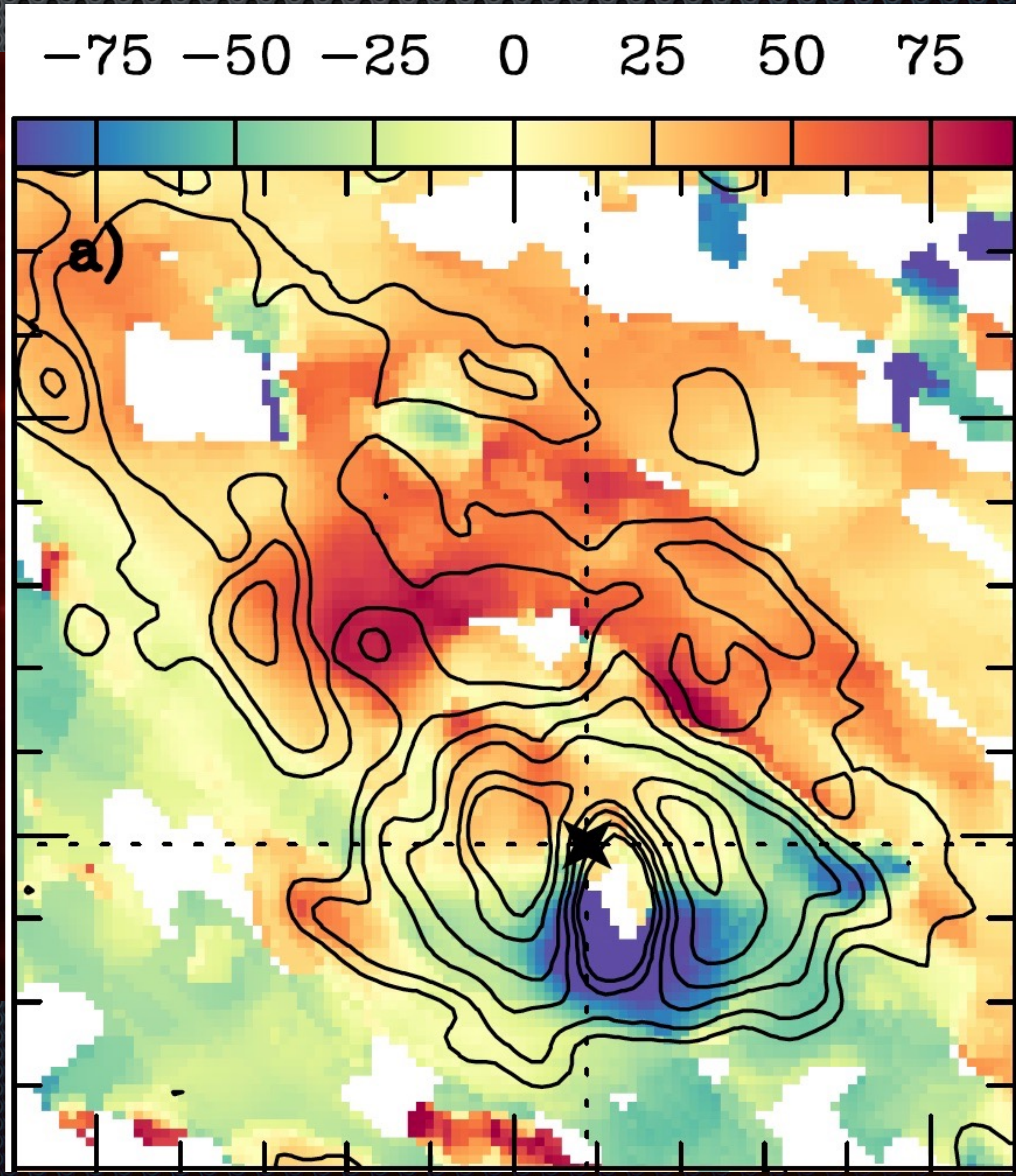
- molecular gas outflows (OH, CO, HCN, v~100-2000 km/s)

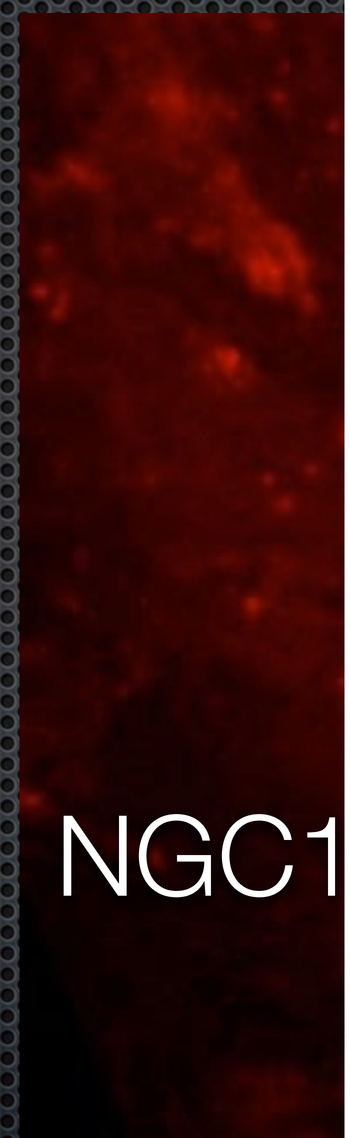


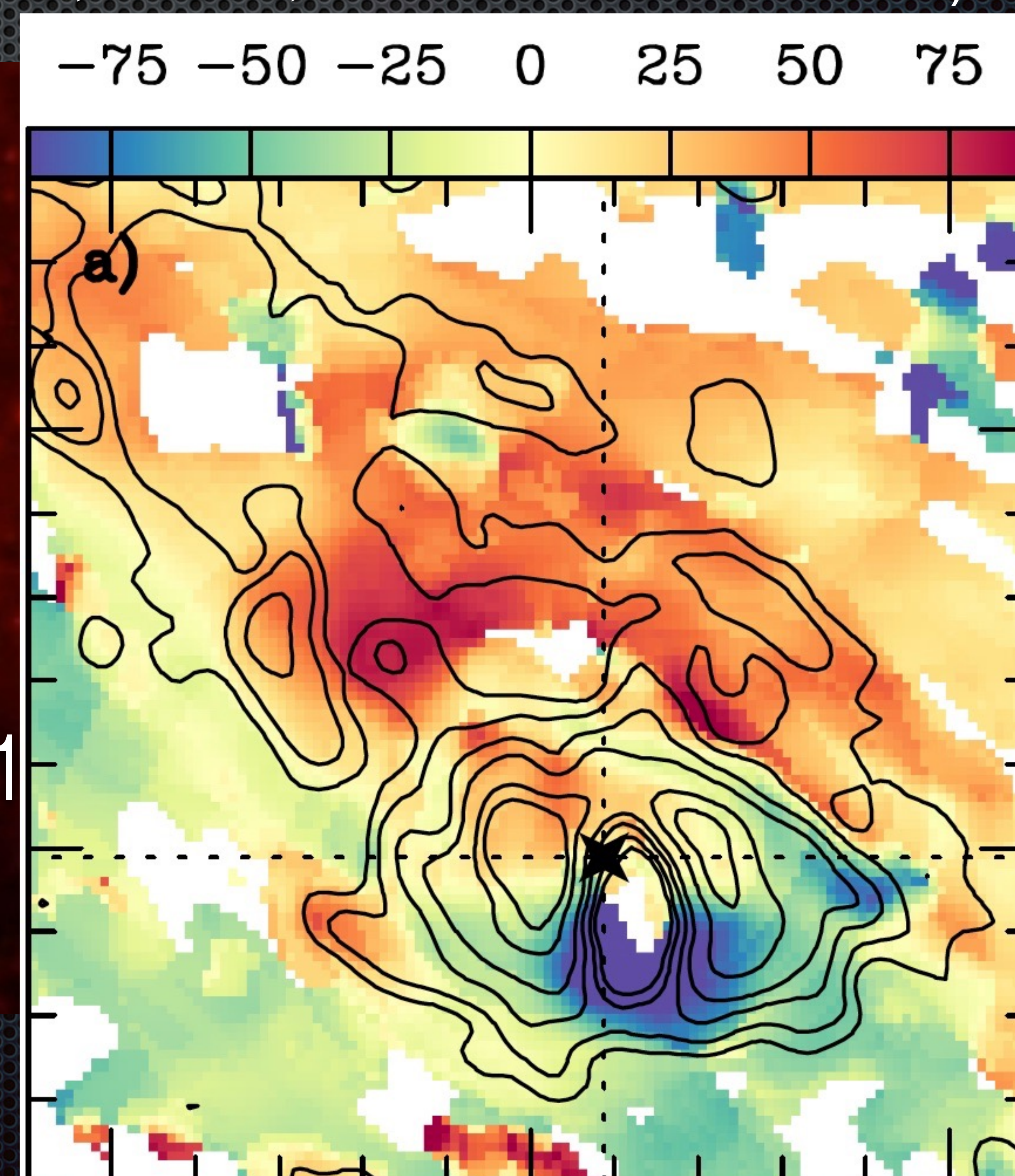


AGN winds are ubiquitous

All carry significant amount of AGN L_{bol} ie~a few%

- X-ray winds (warm absorbers, thousands km/s, UFO, moderately relativistic,)
- ionized gas outflows (BAL, NAL, [OIII], Ha, v~1000-30000 km/s)
- atomic gas outflows (NaI, HI, v~100-1000 km/s)





AGN winds are ubiquitous

***Feedback* observations are difficult**

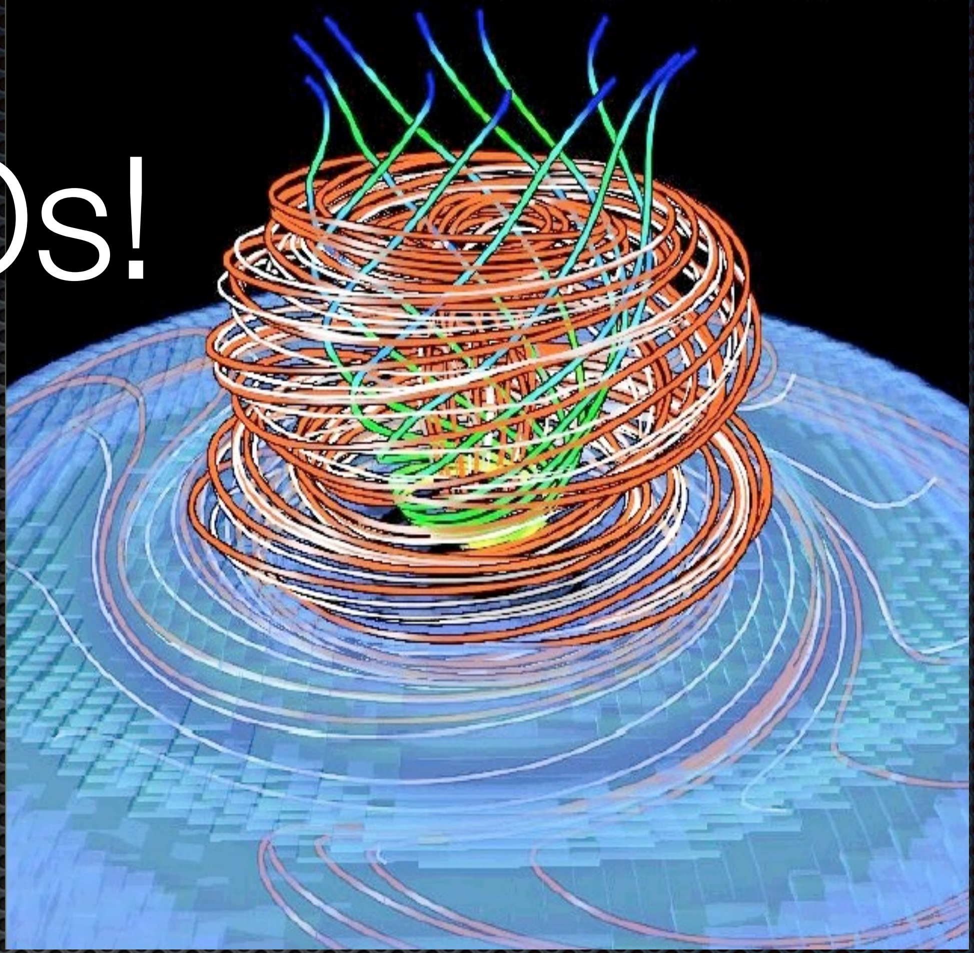
Radio-mode (jet driven) *feedback* observed frequently, joining X-ray and radio observations (X-ray cavities in cool core clusters, filled with radio plasma)

Quasar-mode *feedback* observations are rare. Systematic investigation of super winds impact on galaxy evolution still missing

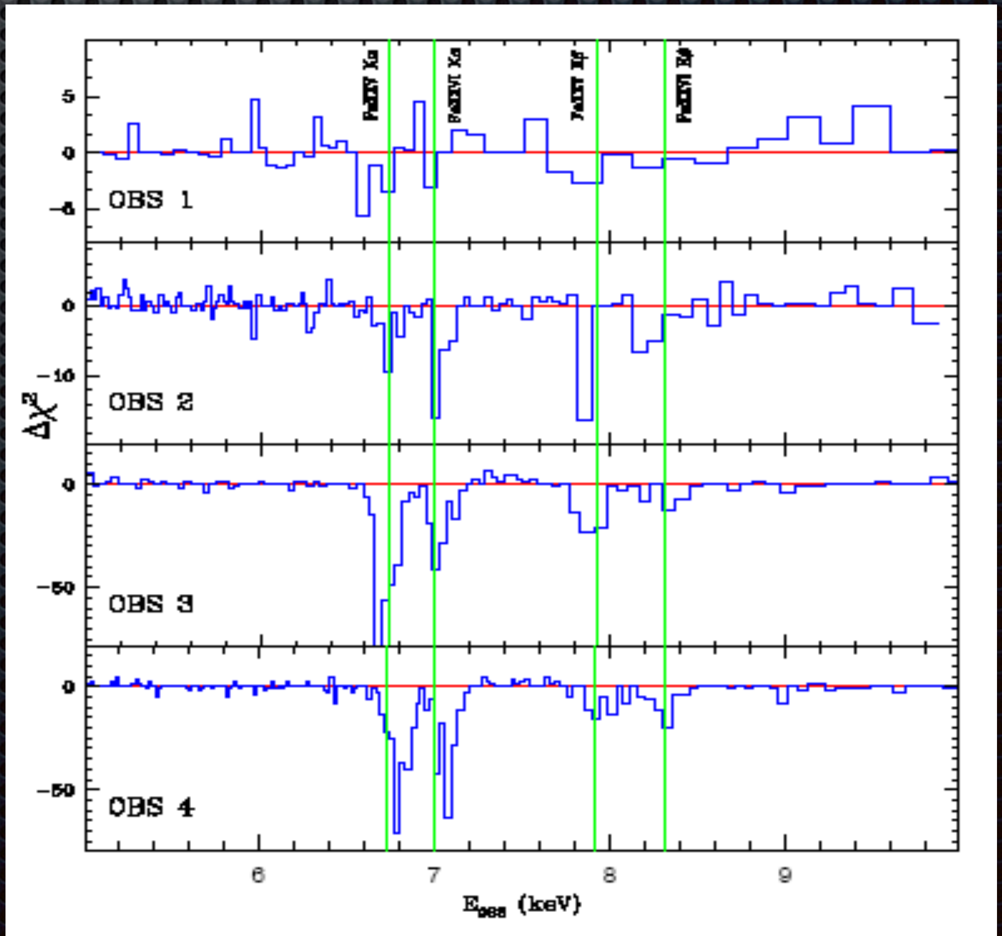
Ultra fast outflows: UFOs!

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. Highly ionized, H-like He-like Fe

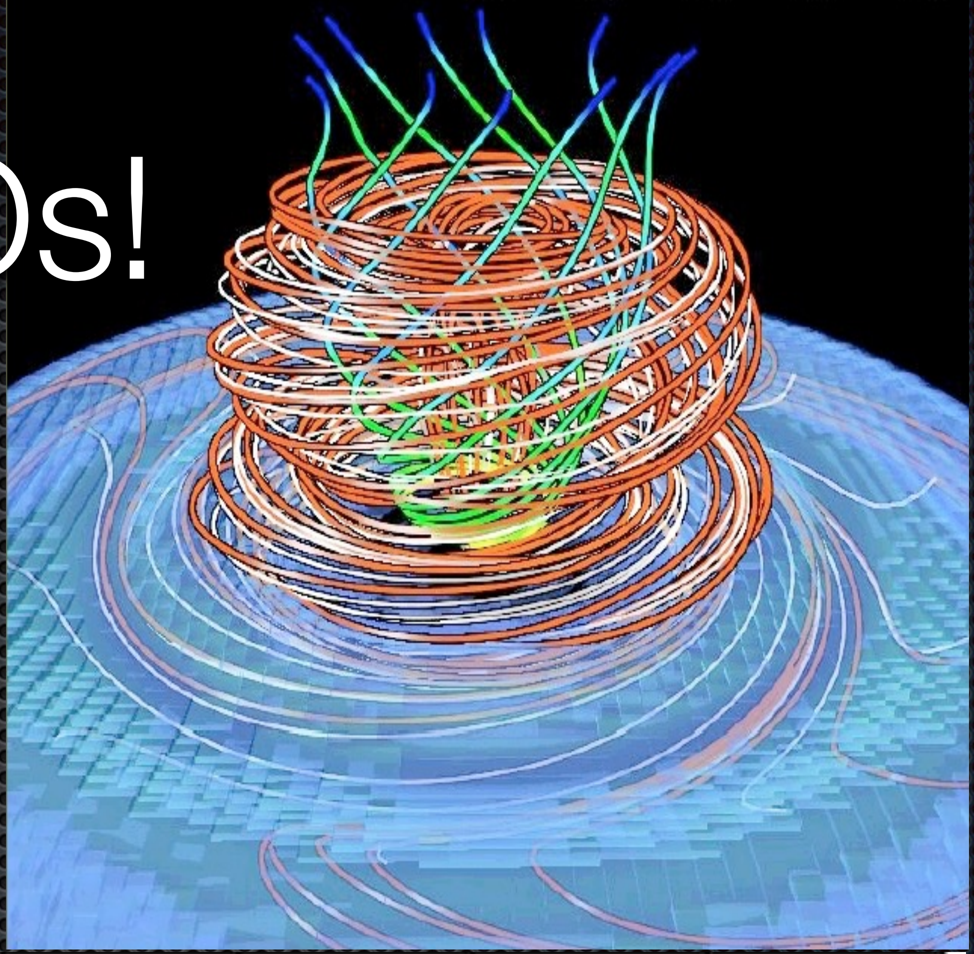
Crenshaw+03, Pounds+03, Reeves+09, Moe+09, Tombesi+12



NGC1365 Risaliti+ 2005



Ultra fast outflows: UFOs!



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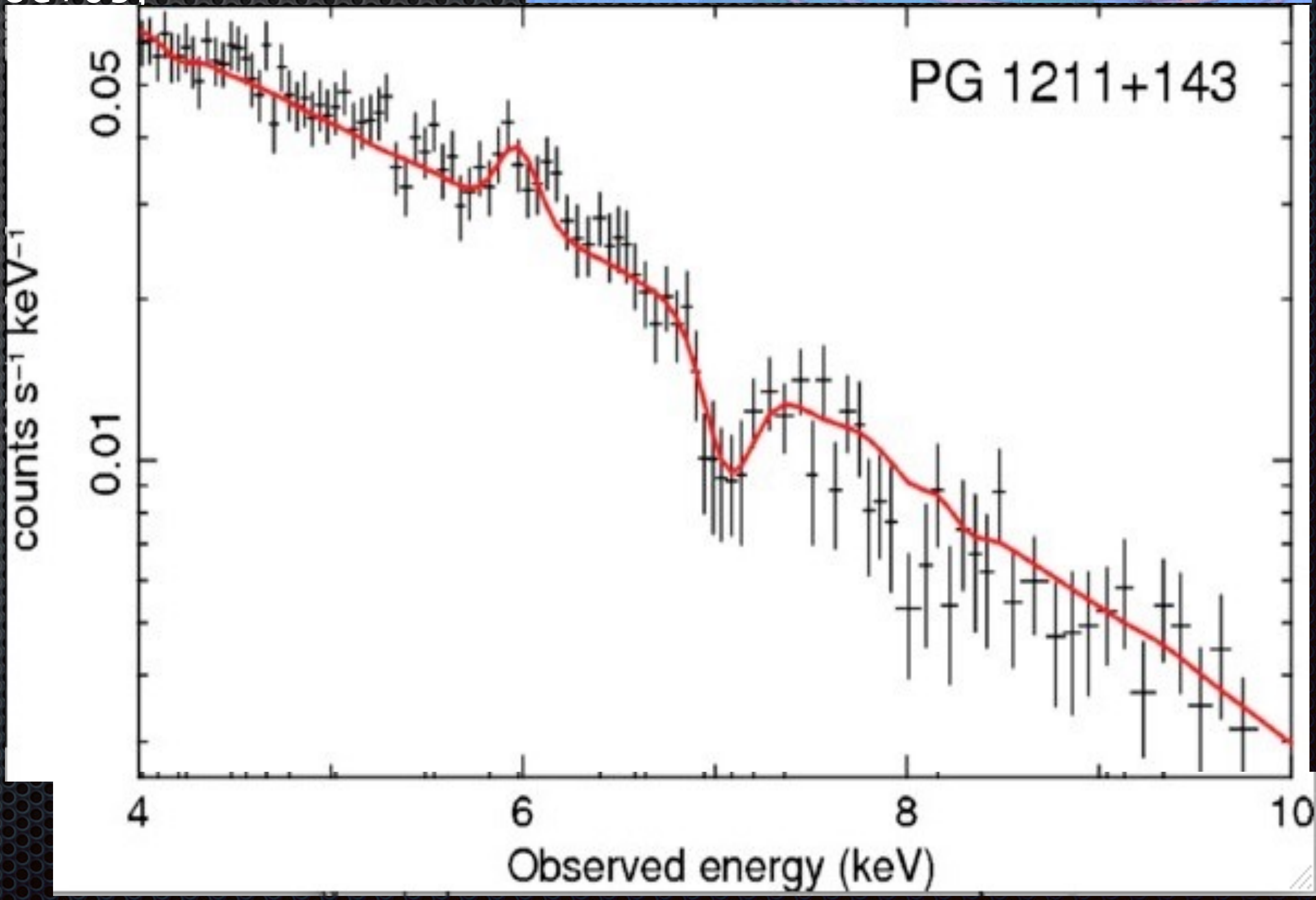
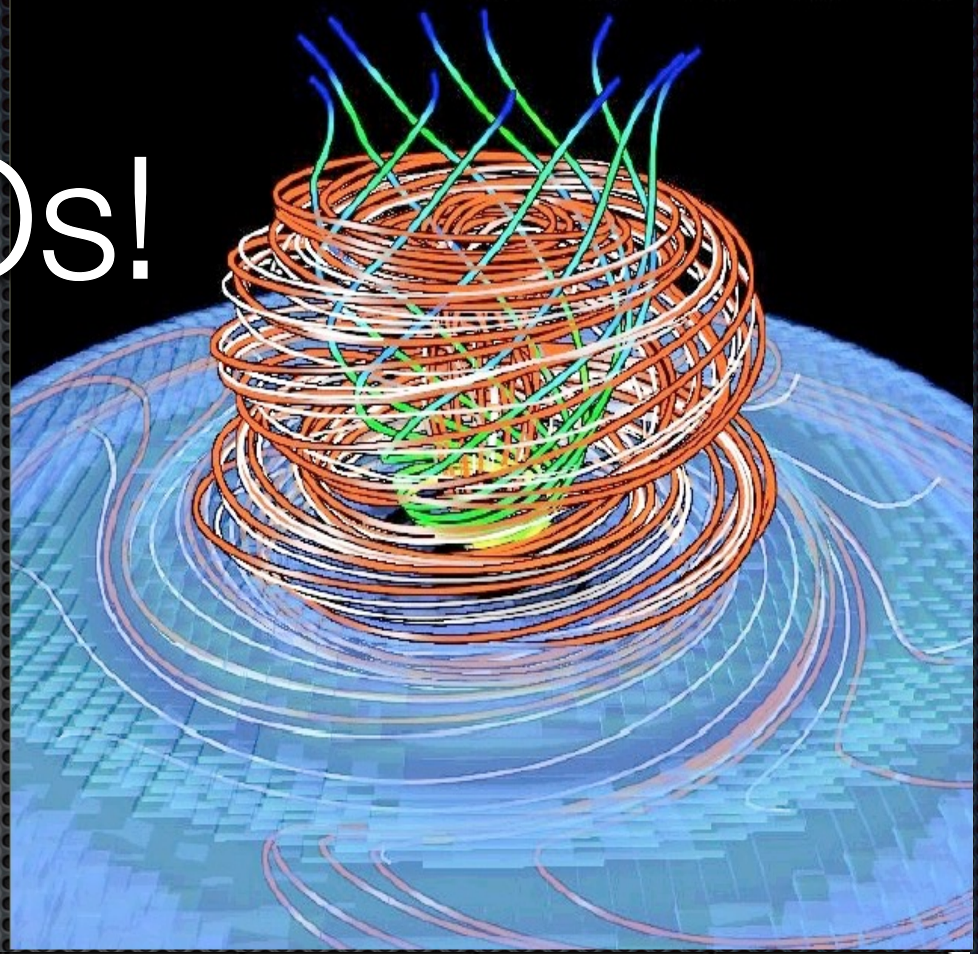


Ultra fast outflows: UFOs!



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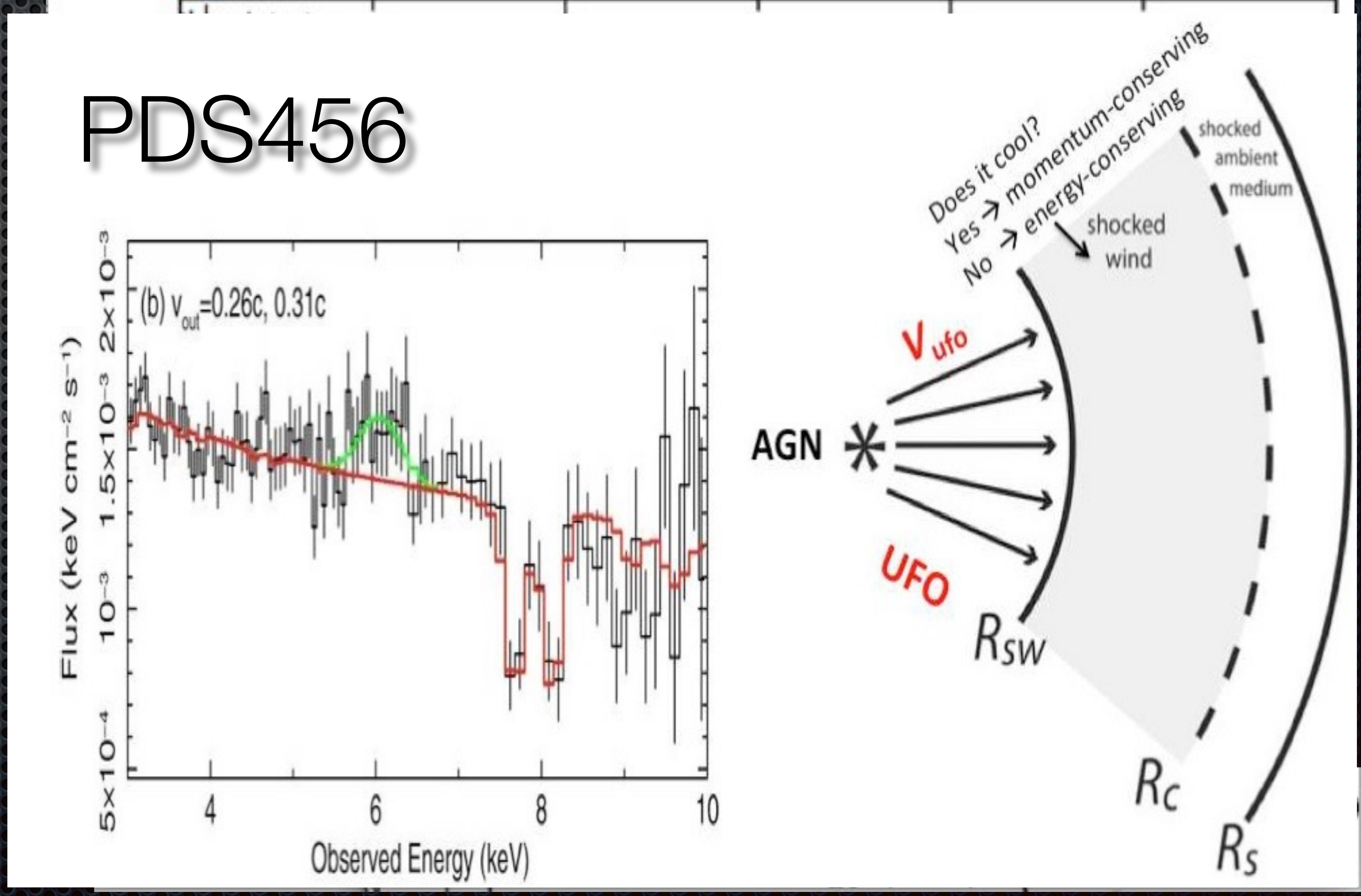
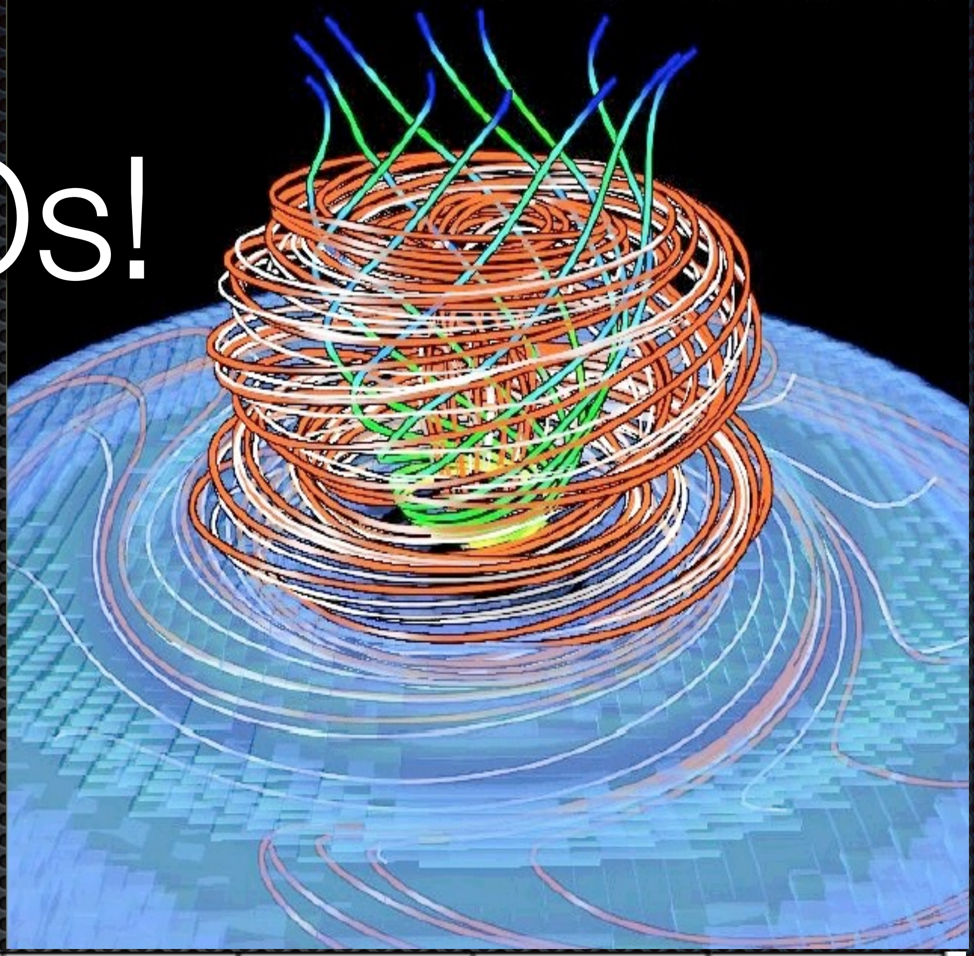


Ultra fast outflows: UFOs!



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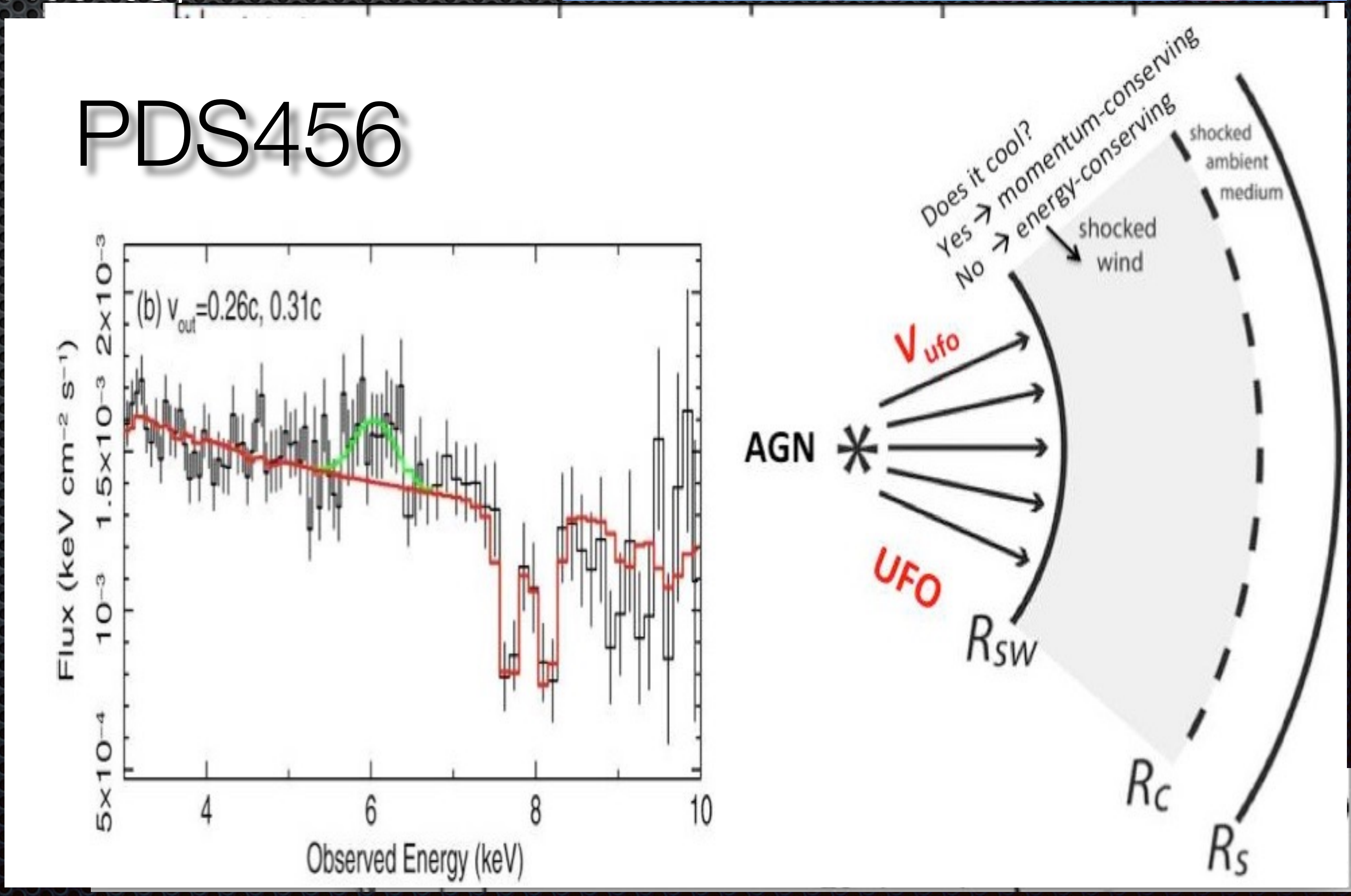
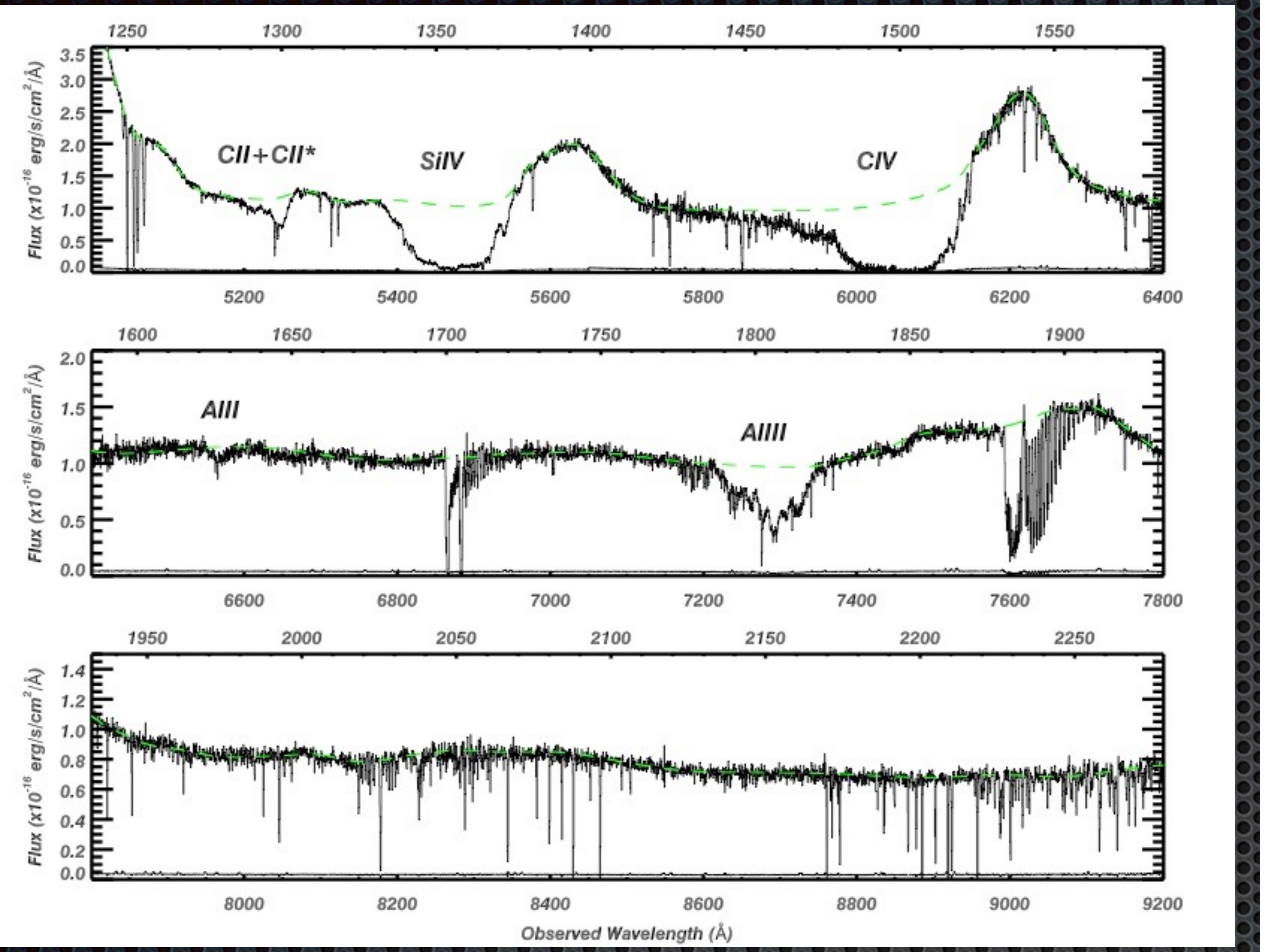
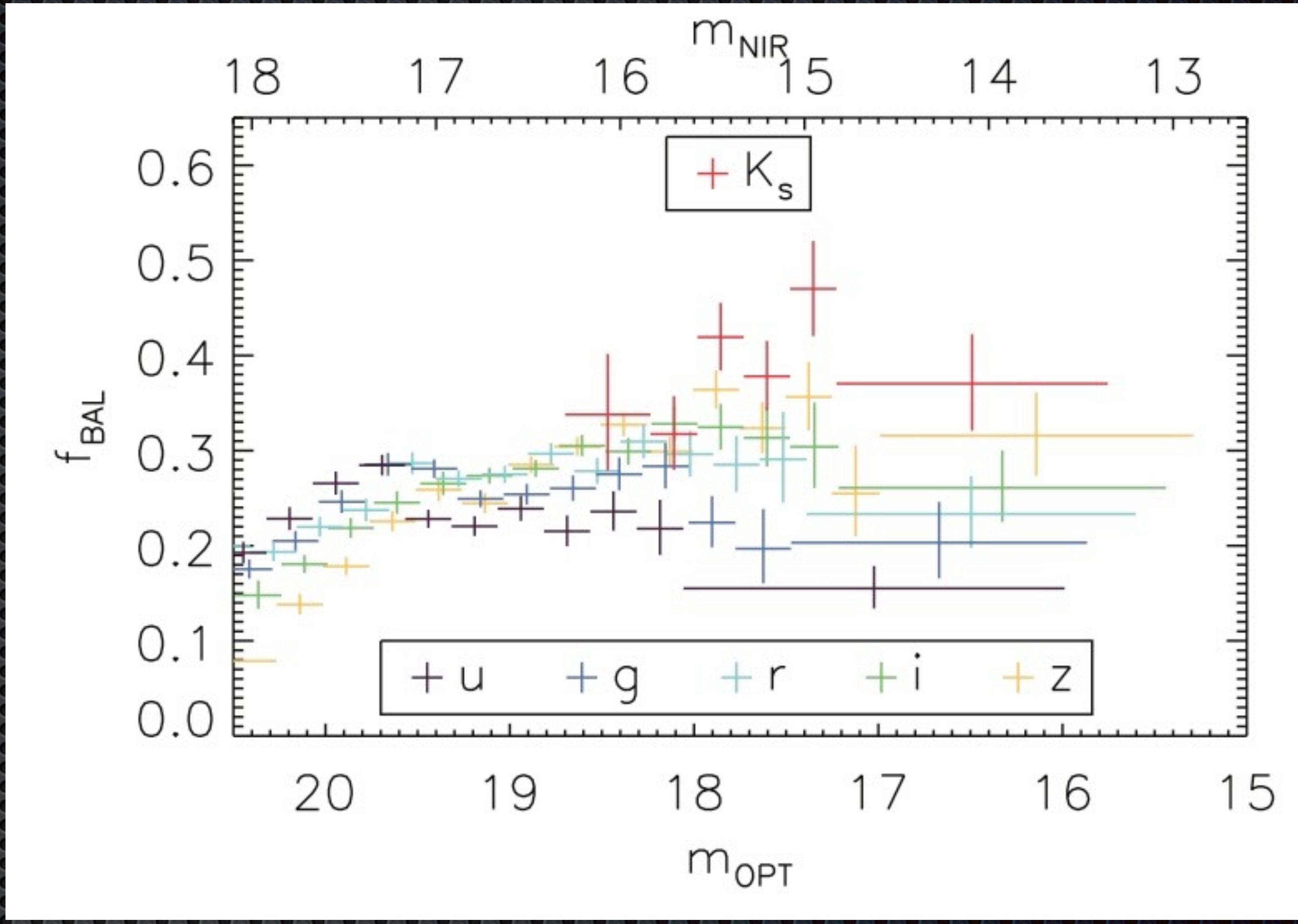
Crenshaw+03, Pounds+03, Reeves+09, Moe+09, Tombesi+12

$\log\xi \sim 3$-6
$\log N_H \sim 22$-24
$v_{out} \sim 0.03$-$0.3\ c$
$r_{max} < L_{ion}/N_H\xi \sim 0.03pc$
ionization par.
$r_{min} < 2GM_{BH}/v^2_{out} \sim 0.003pc$
escape vel.
$M_{out} \approx m_p N_H r v_{out} \sim 0.01$-$1 M_\odot/yr$
Mass outflow rate



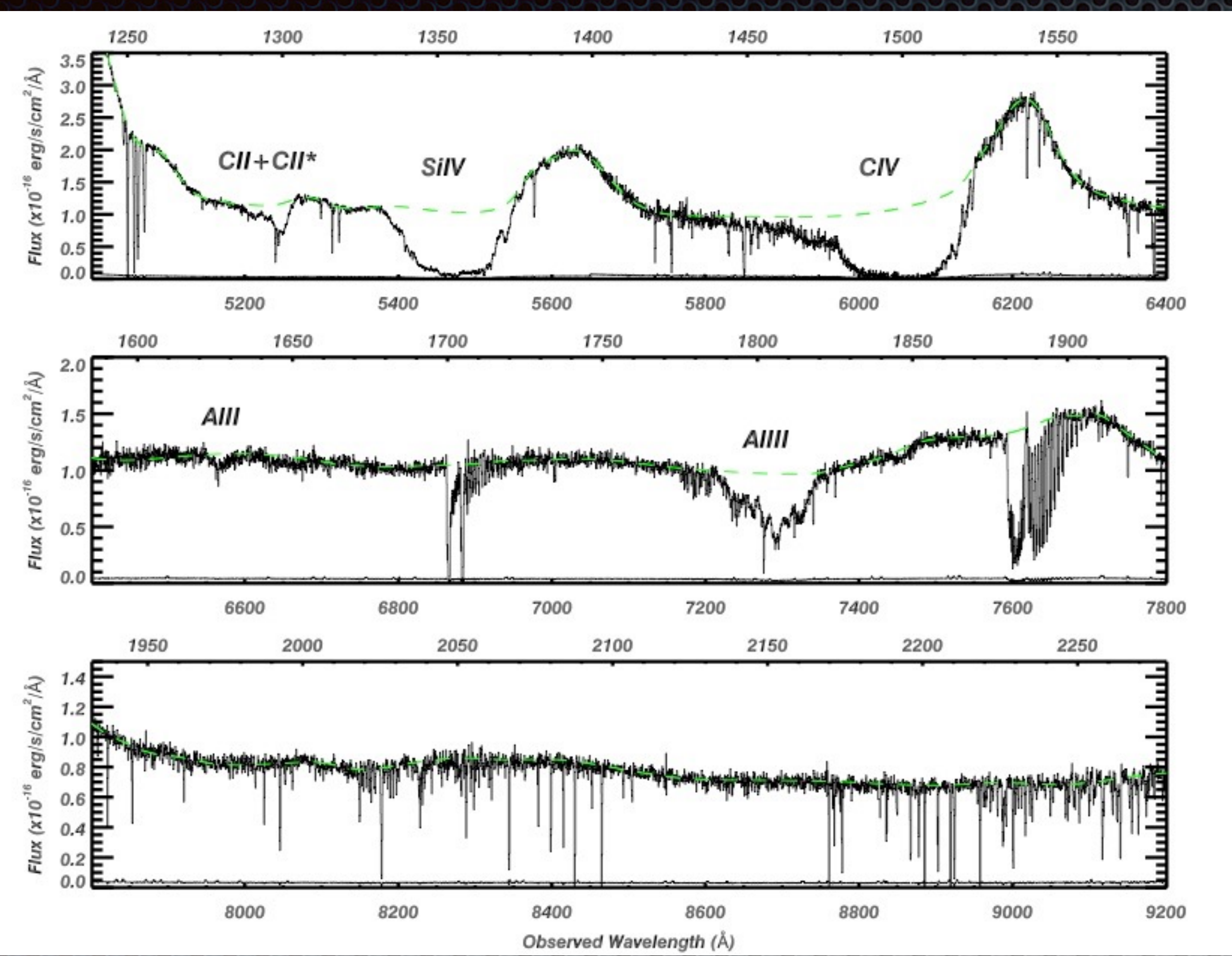
Broad Absorption Line QSOs

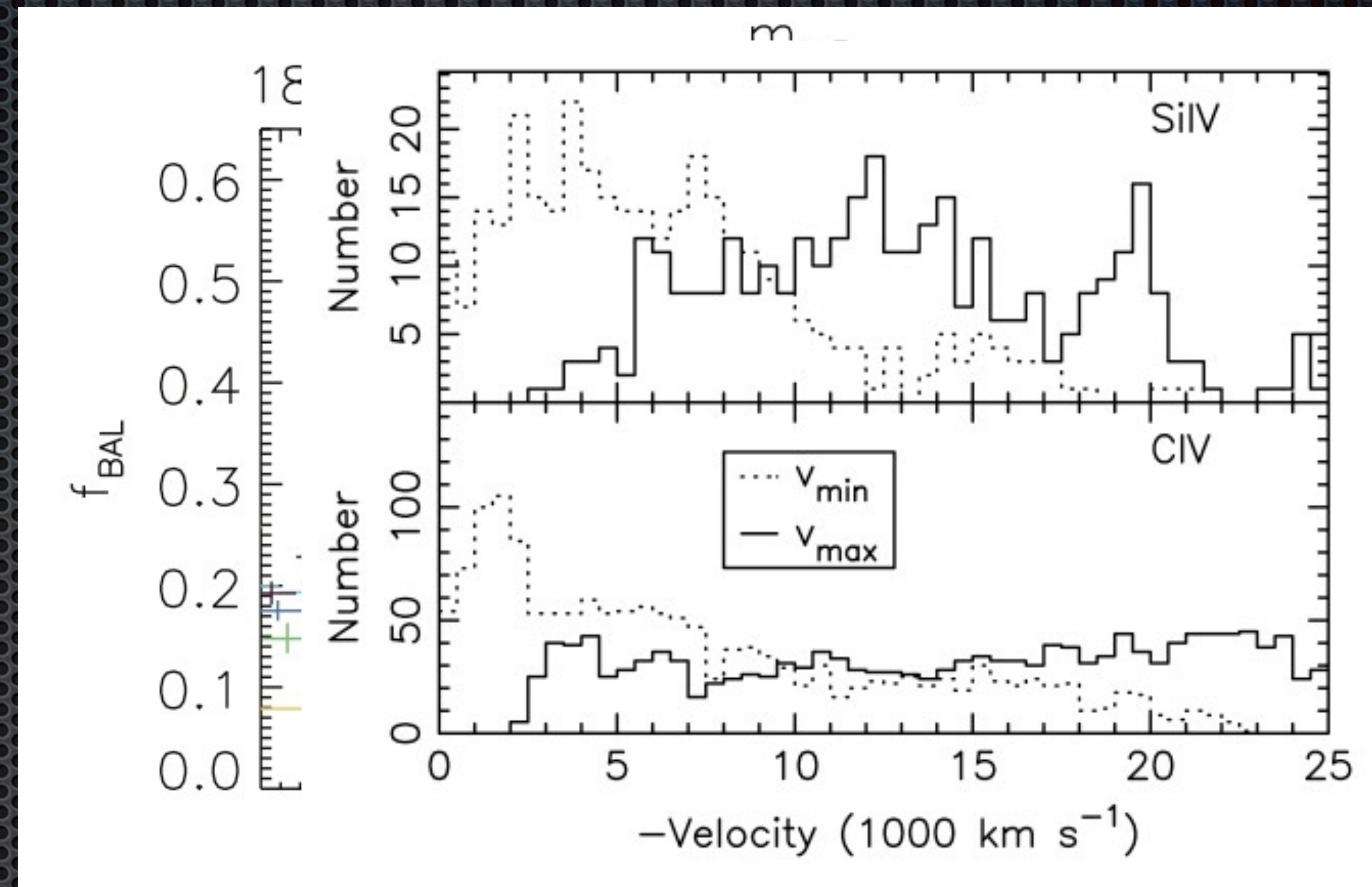


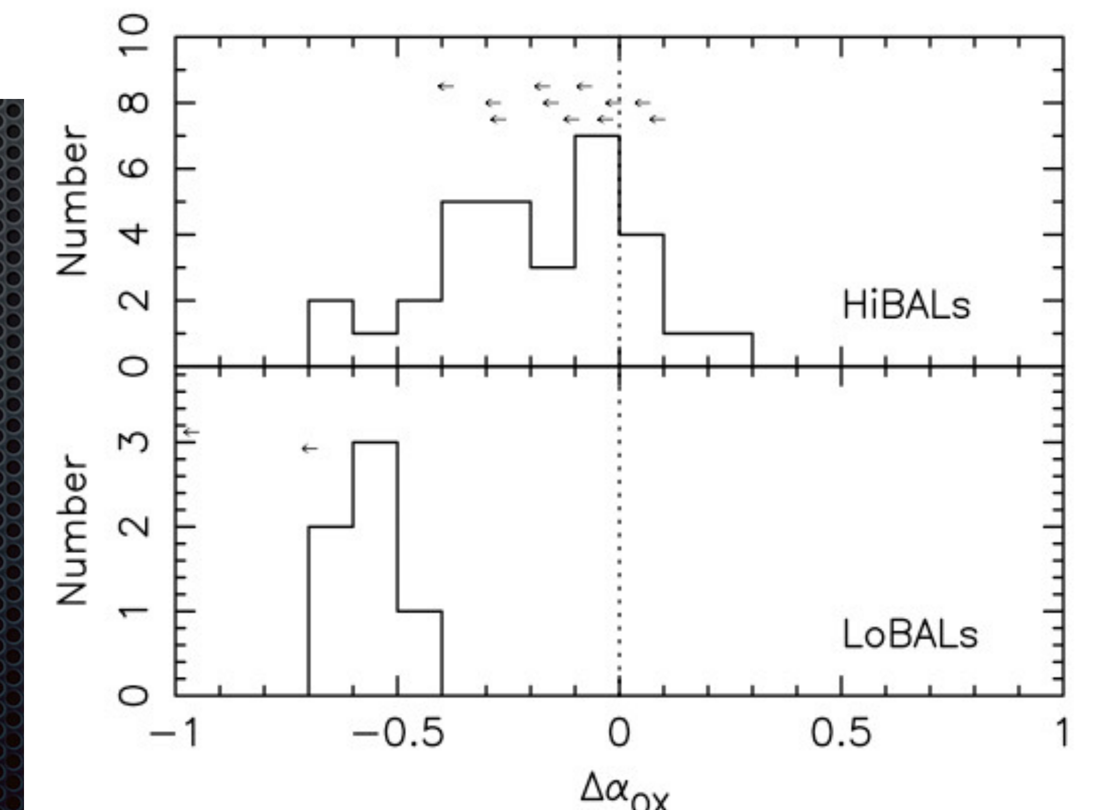


Borguet+2013 Gibson+2010 Dai+2008

Broad Absorption Line QSOs







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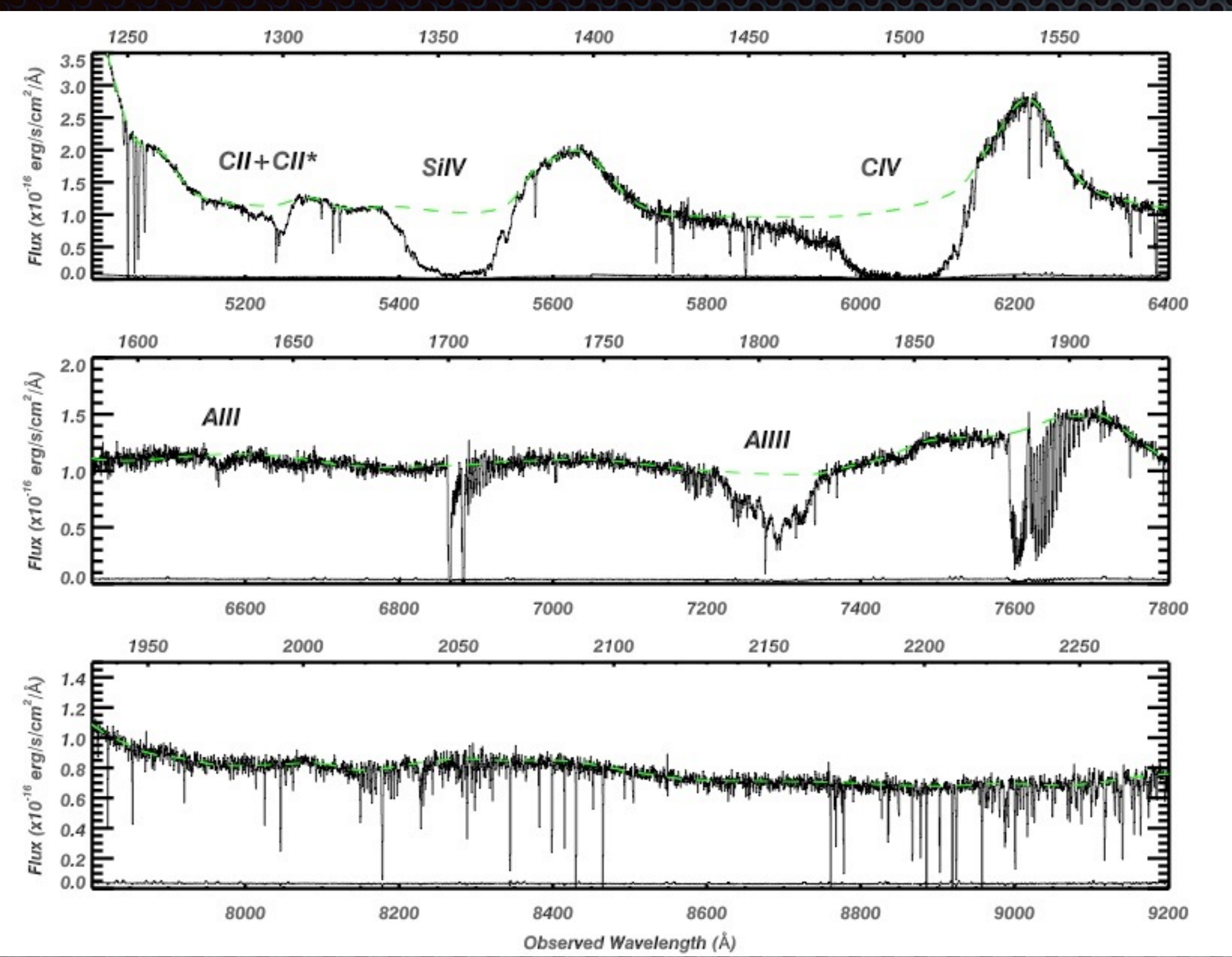
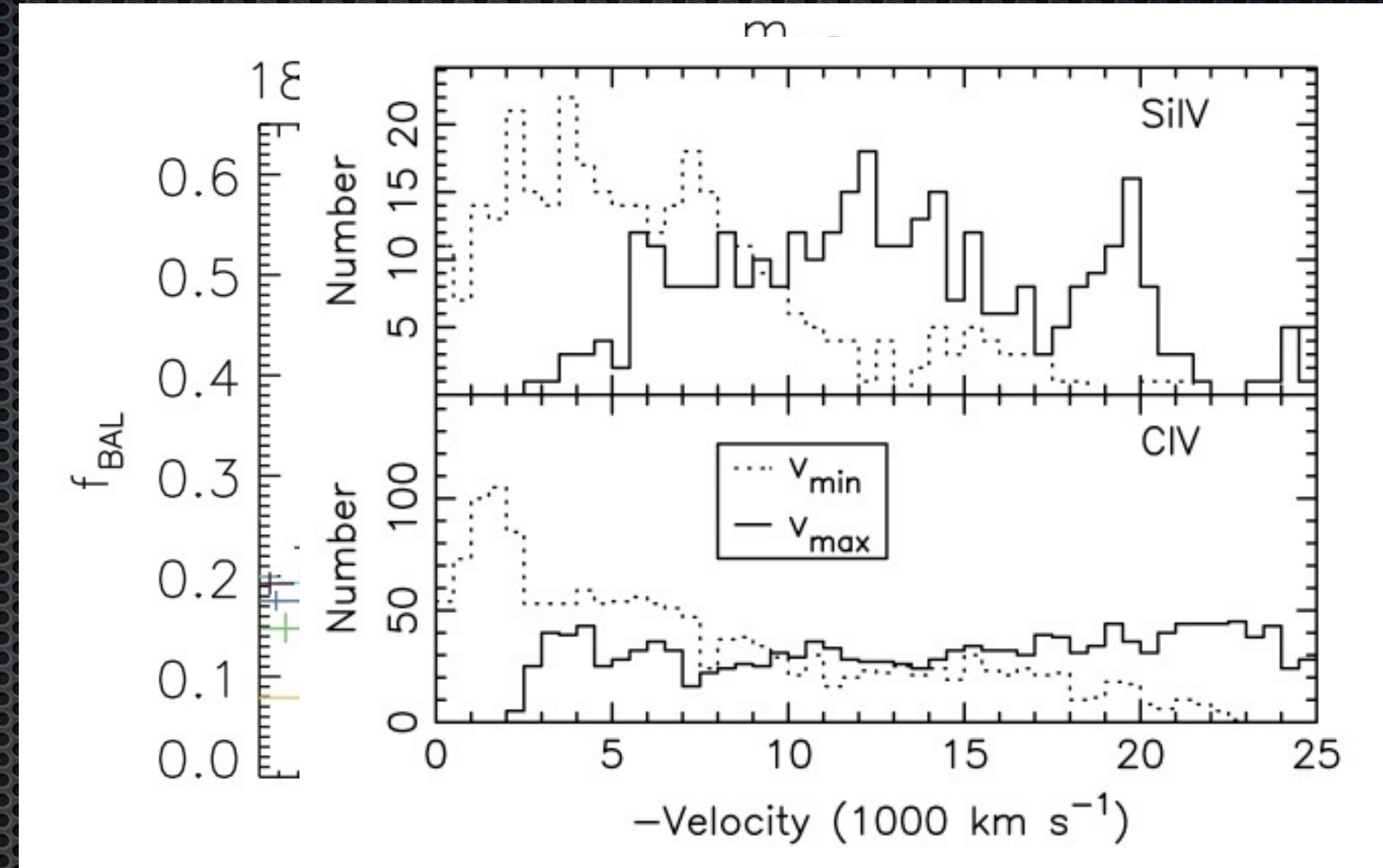




Borguet+2013 Gibson+2010 Dai+2008

logU~ -1 ÷ 1 $\quad$ $\log N_H$~21-23

v_{out}~1000-30000 km/s

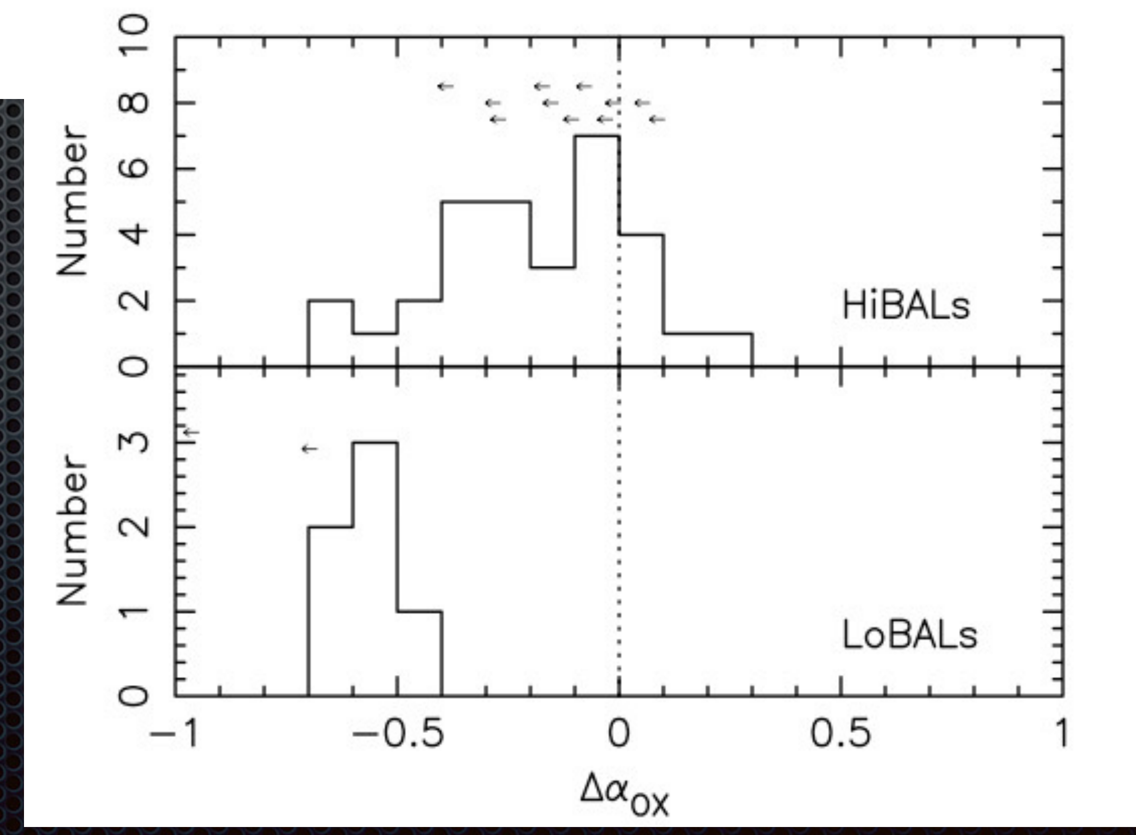
$\log n_H$=3-4 $\quad$ from SIV*/SIV

$U=Q/4\pi r^2 c n_H$ $\quad$ ionization par.

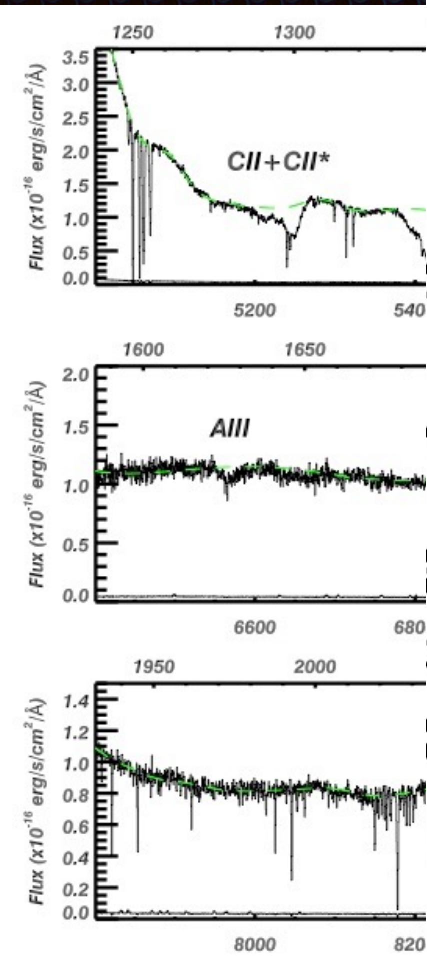
r~0.1-1kpc

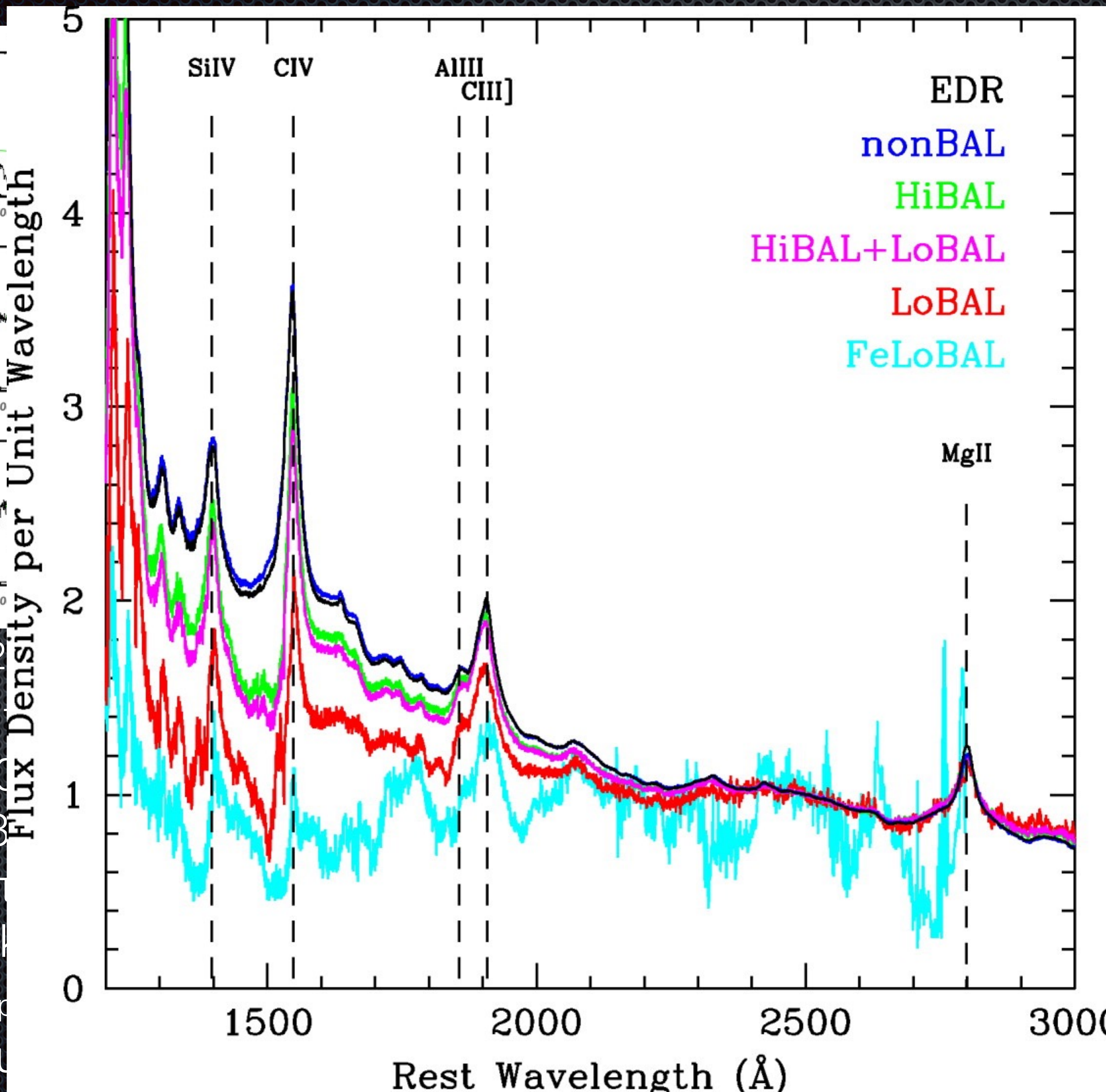
$M_{out} \approx m_p N_H r v_{out}$~10-1000$M_\otimes$/yr

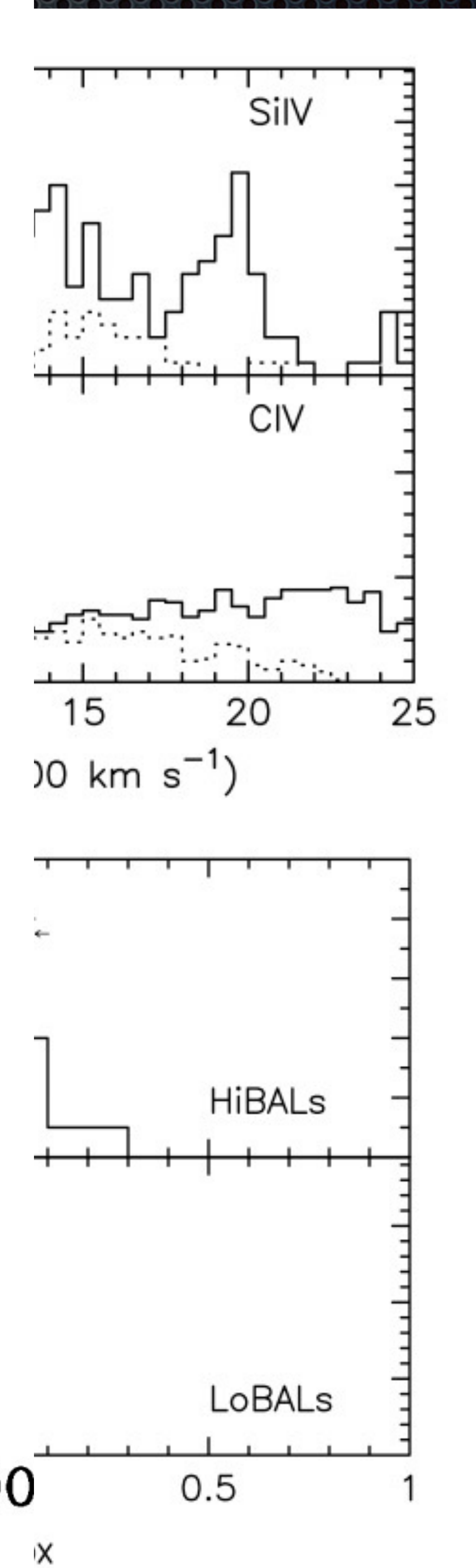
Mass outflow rate



Broad Absorption Line QSOs







Borguet+2

$\log U \sim -$

$v_{out} \sim 100$

$\log n_H = 3$

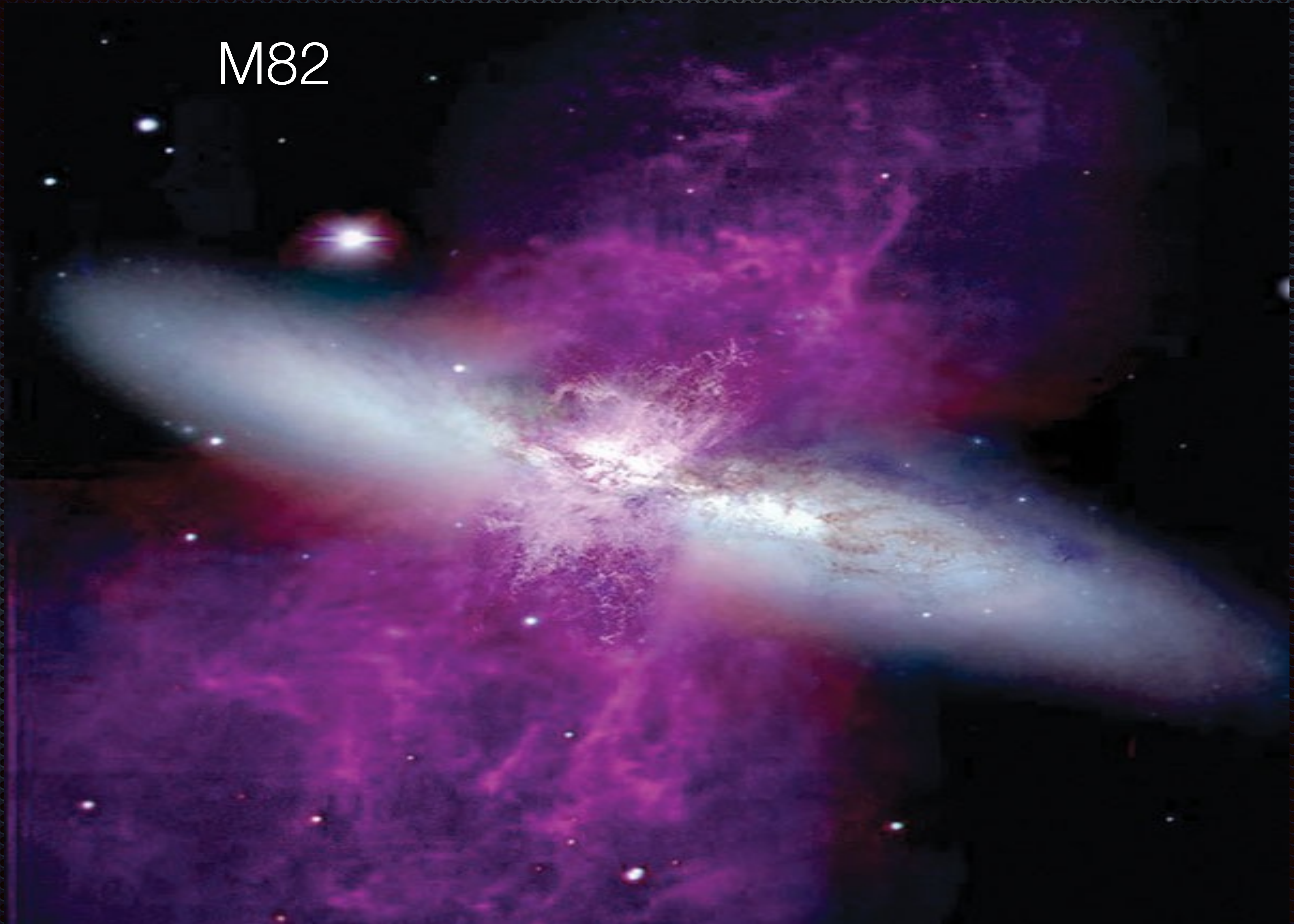
$U = Q/4\pi$

r~0.1-1k

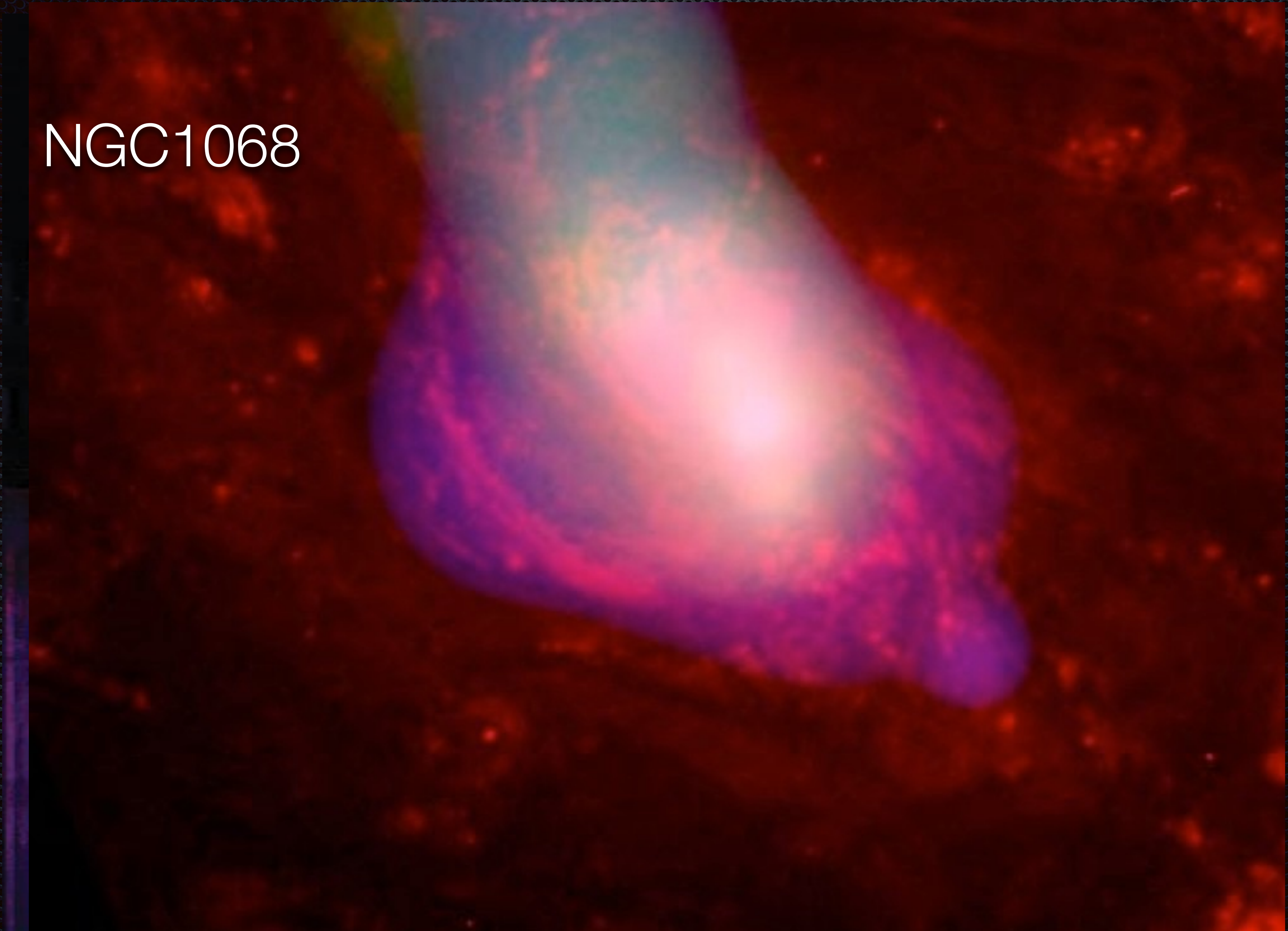
$M_{out} \approx m_p$

Mass ou

Local superwinds

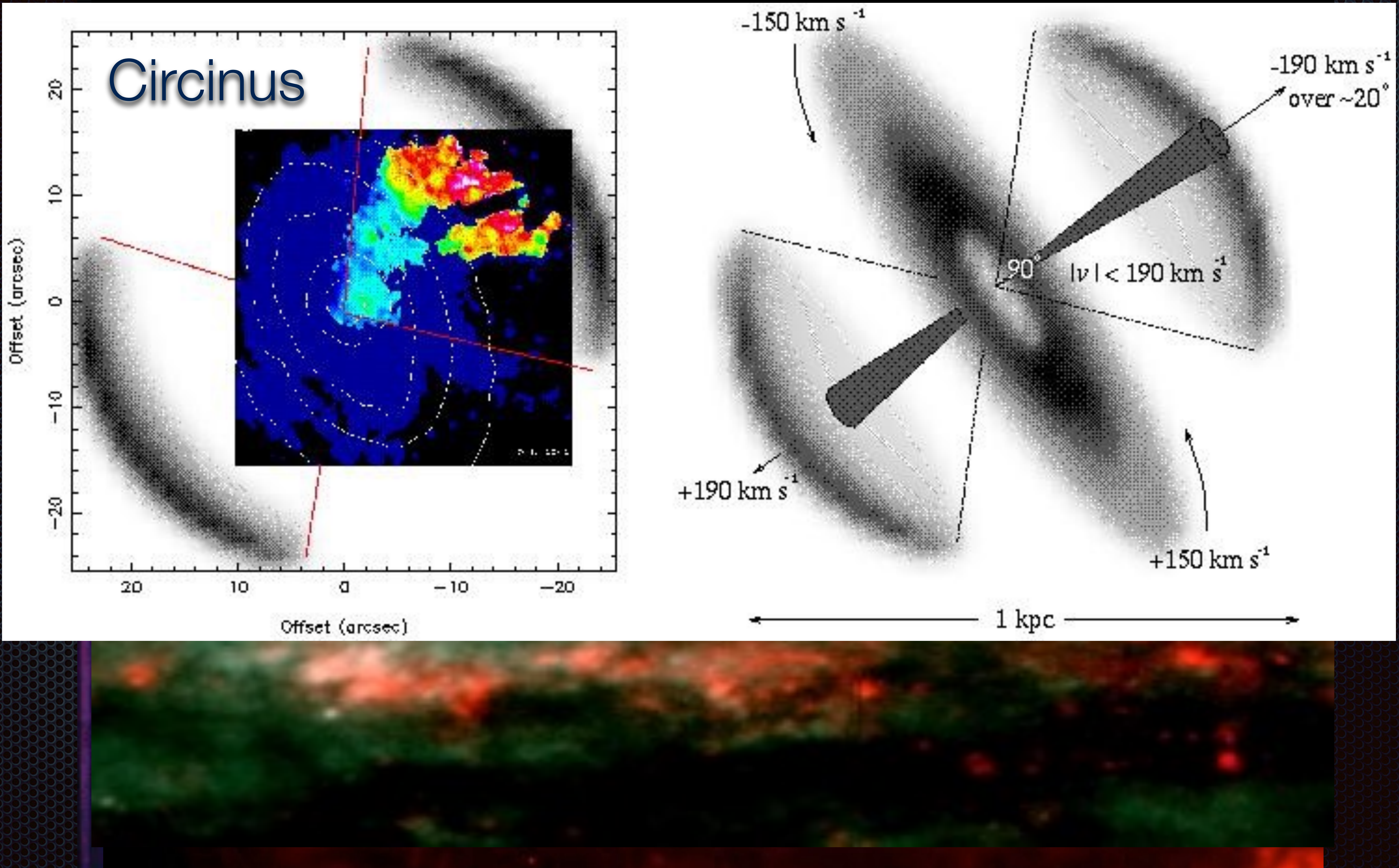


Local superwinds

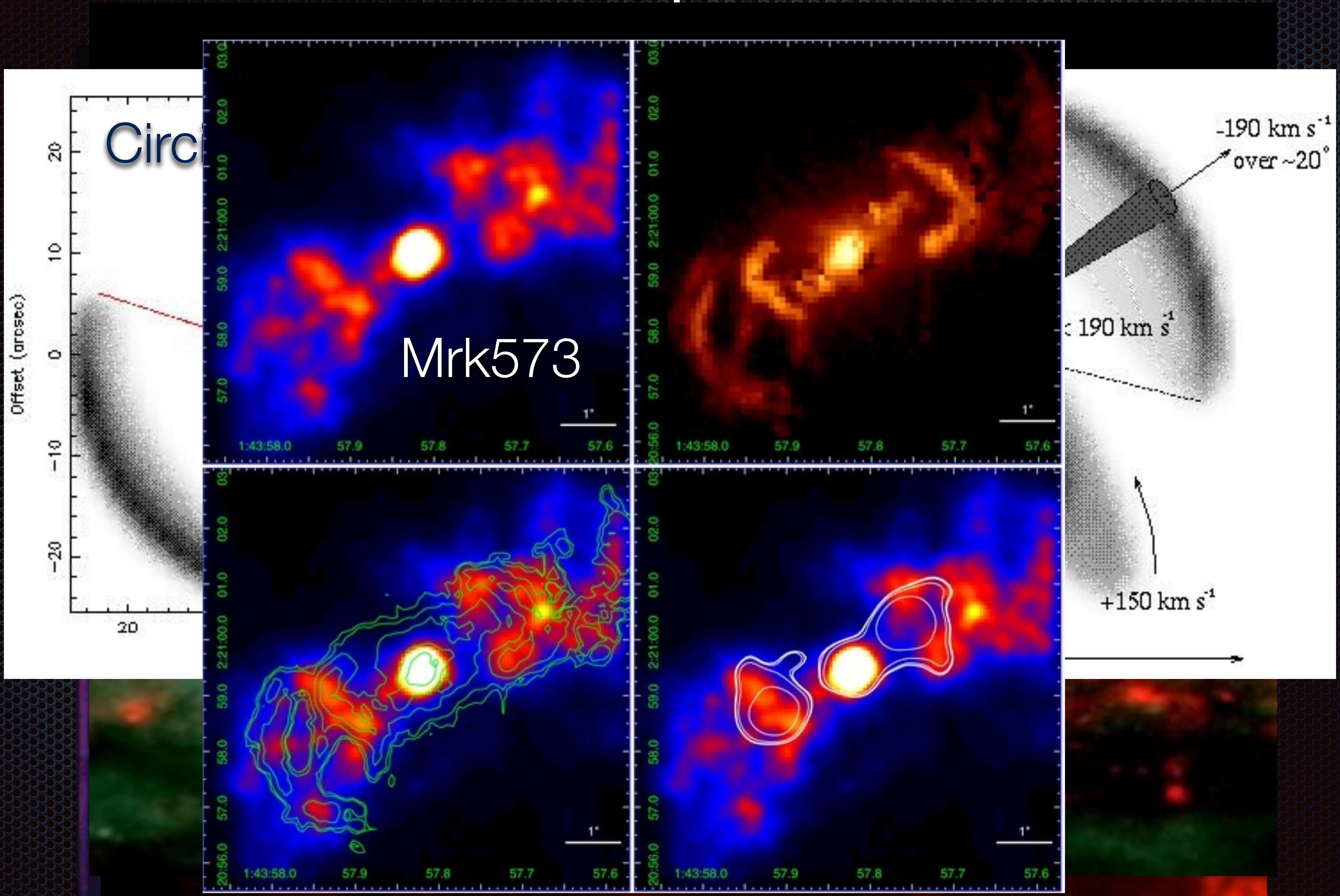


Local superwinds

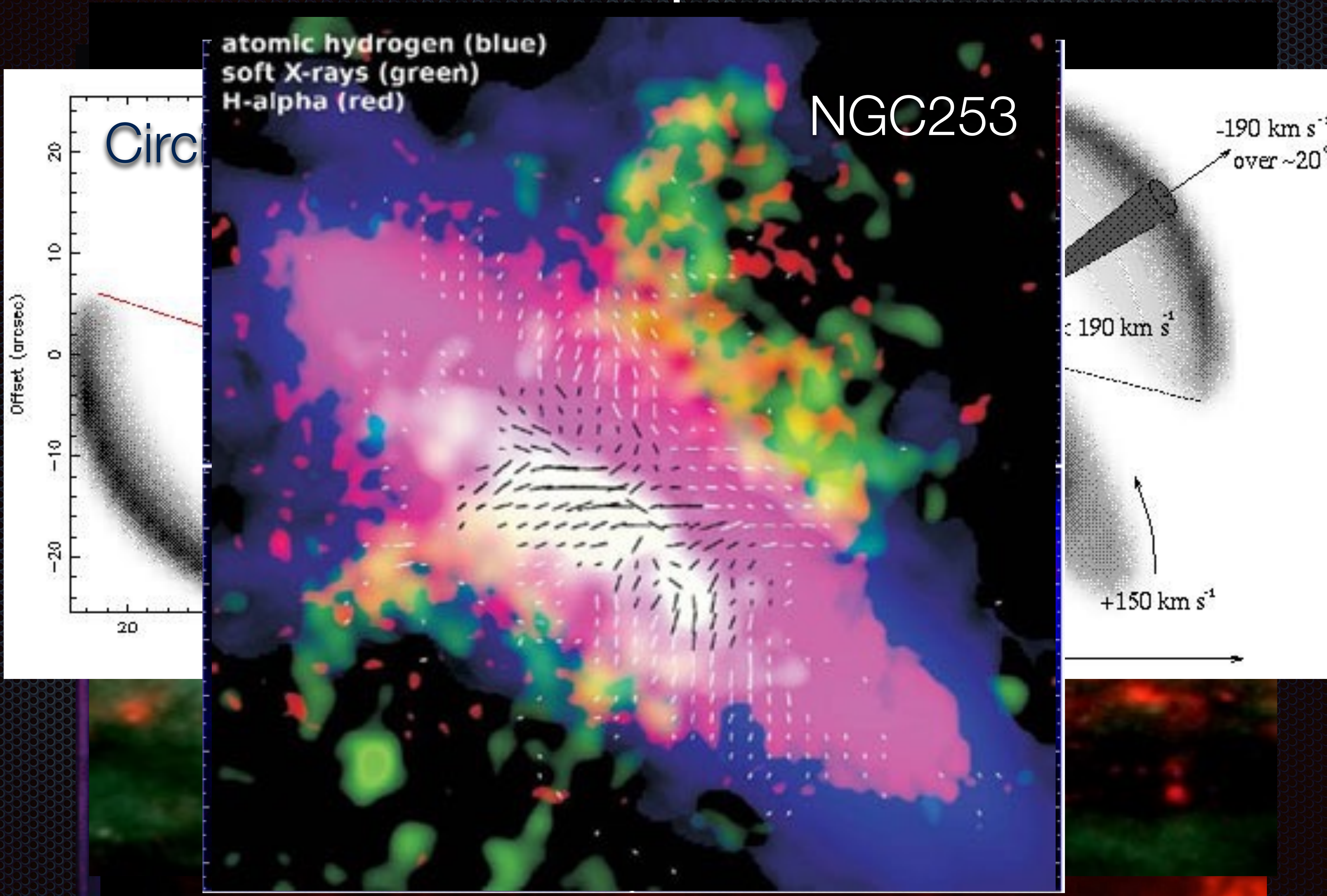
Local superwinds



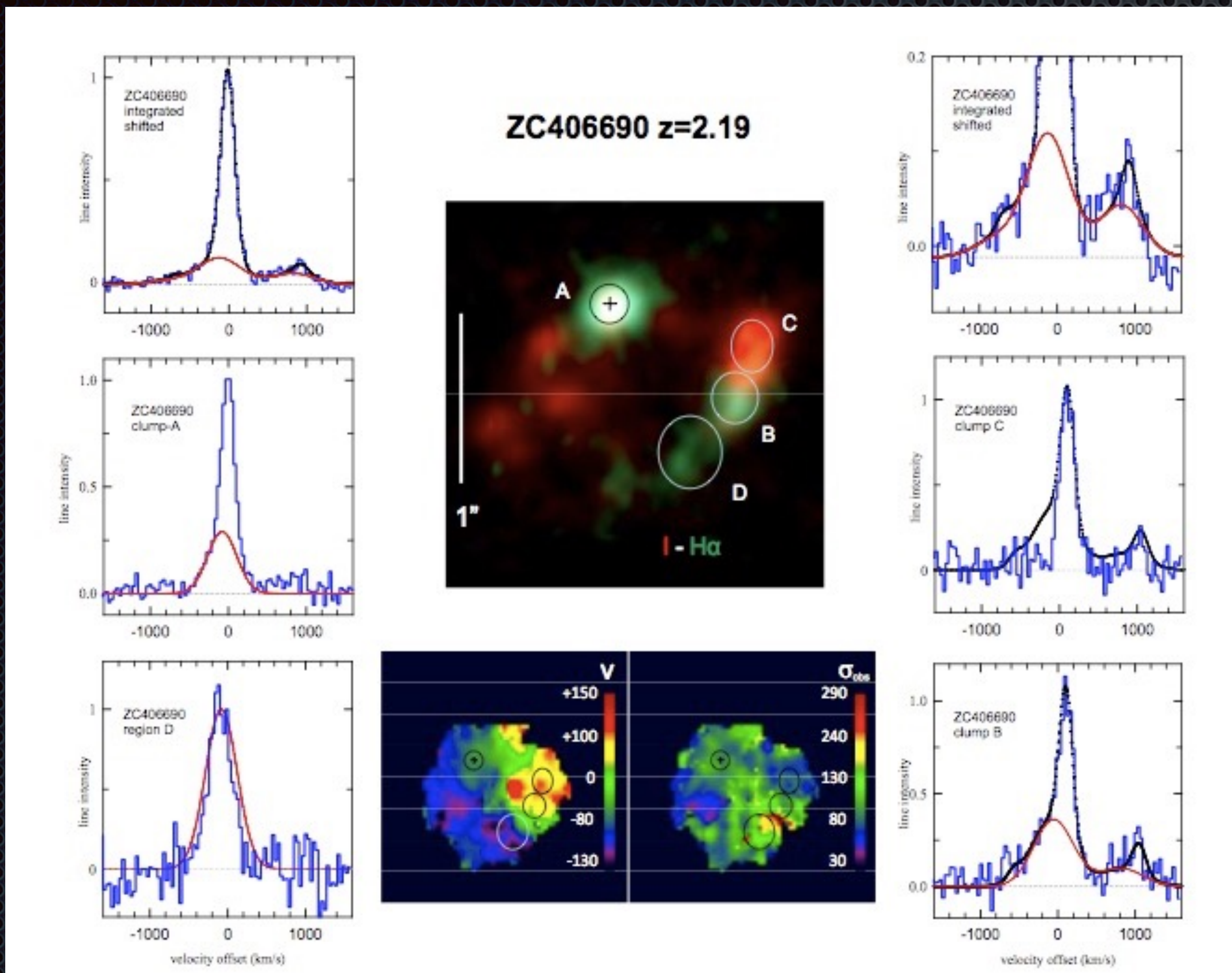
Local superwinds



Local superwinds



[OIII], [FeII], Hα winds



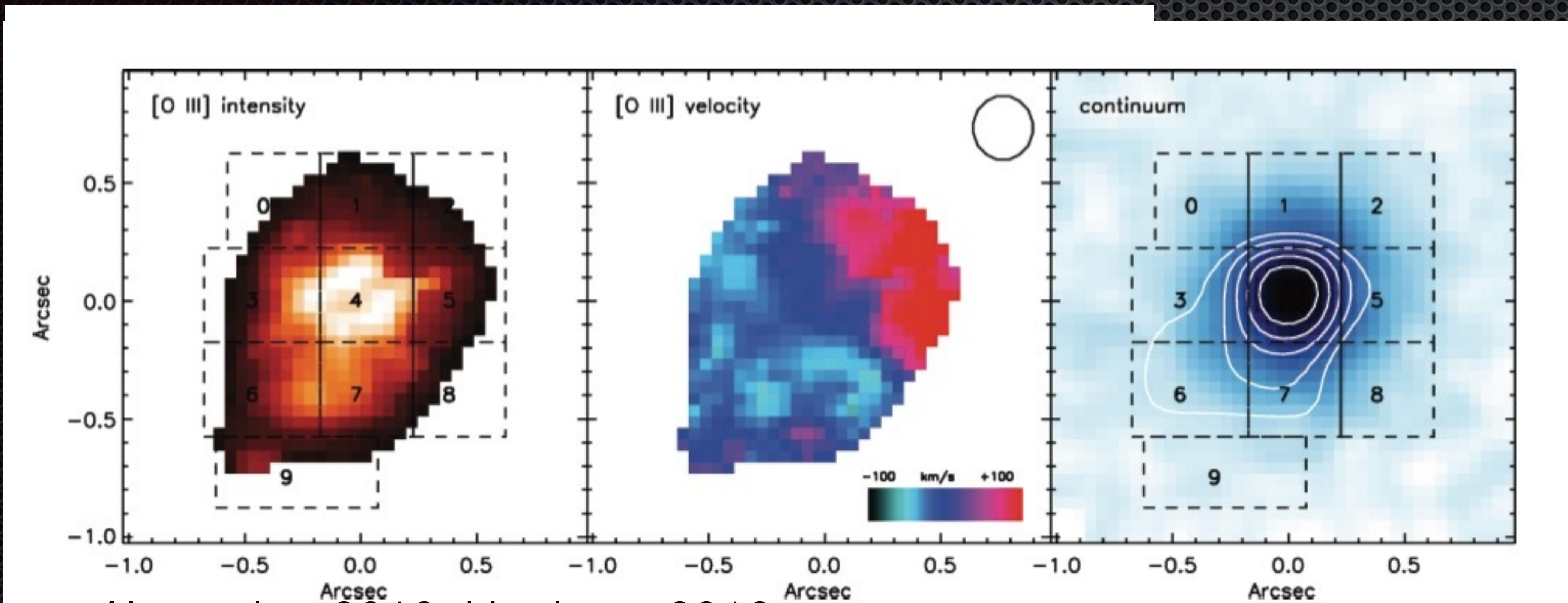
Genzel+2008 Forster Schreiber +2014

$$M_{out}^{ion} = 5.33 \times 10^7 \, \frac{C \, L_{44}([\mathrm{OIII}])}{\langle n_{e3} \rangle \, 10^{[\mathrm{O/H}]}} \, M_\odot$$

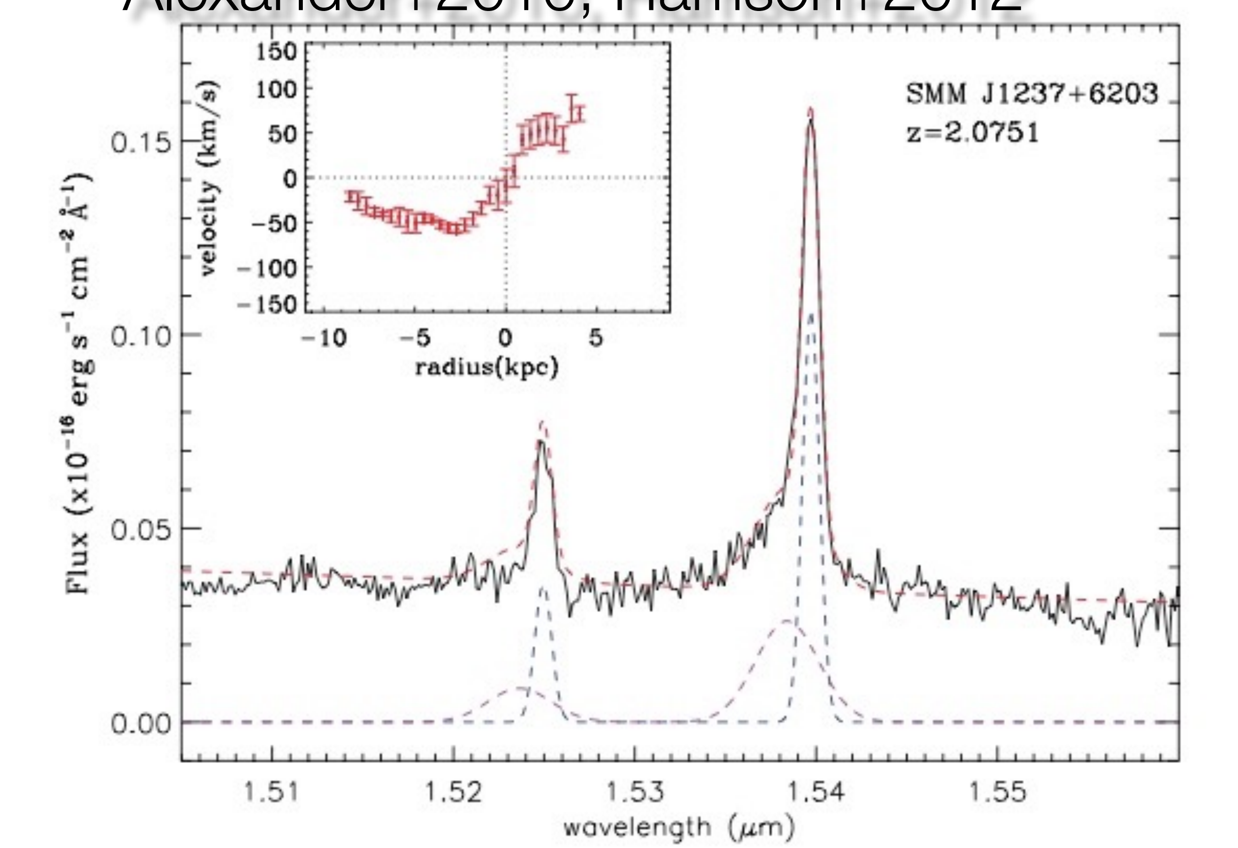
$$\dot{M}_{out}^{ion} = \langle \rho \rangle_V \, v \, \Omega R^2$$

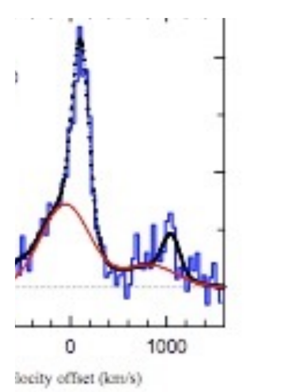
$$\dot{M}_{out}^{ion} = 164 \, \frac{C \, L_{44}([\mathrm{OIII}]) \, v_3}{\langle n_{e3} \rangle \, 10^{[\mathrm{O/H}]} \, R_{\mathrm{kpc}}} \, M_\odot \, \mathrm{yr}^{-1}$$

[OIII], [FeII], Hα winds



Alexander+2010, Harrison+2012



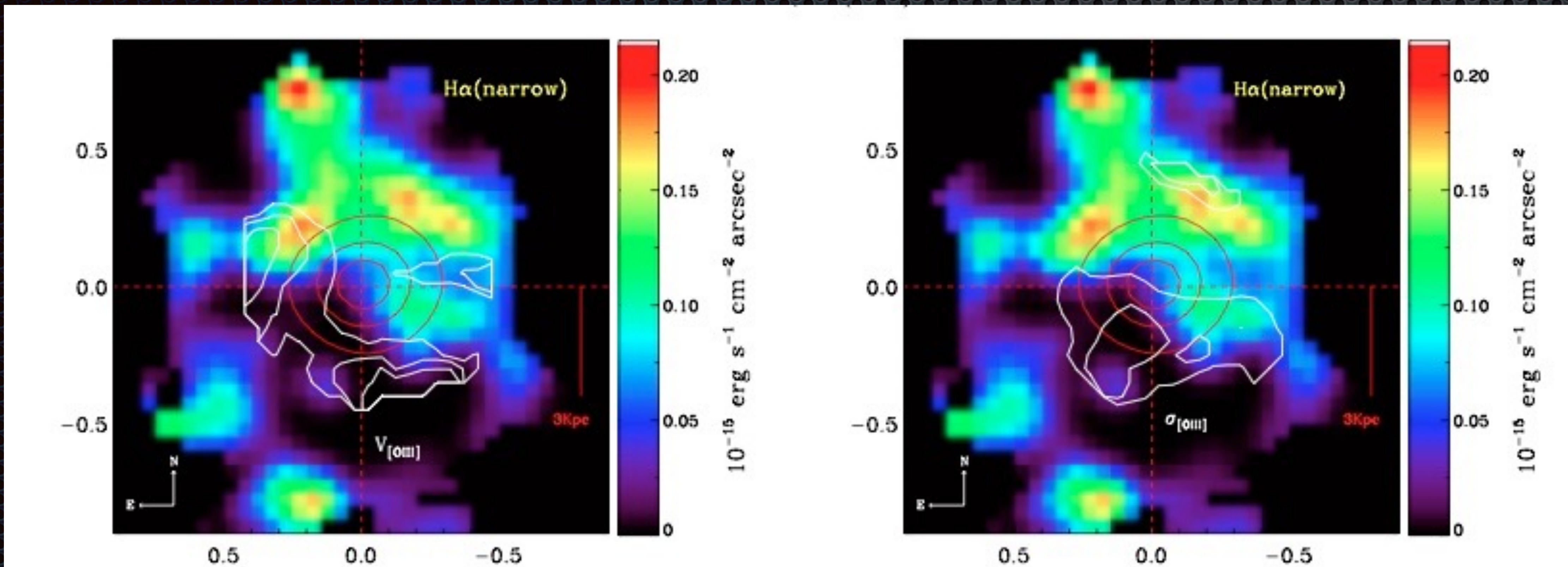


$$M_{\rm out}^{\rm ion} = 5.33 \times 10^7 \frac{C\, L_{44}([\rm OIII])}{\langle n_{e3} \rangle\, 10^{[\rm O/H]}} M_\odot$$

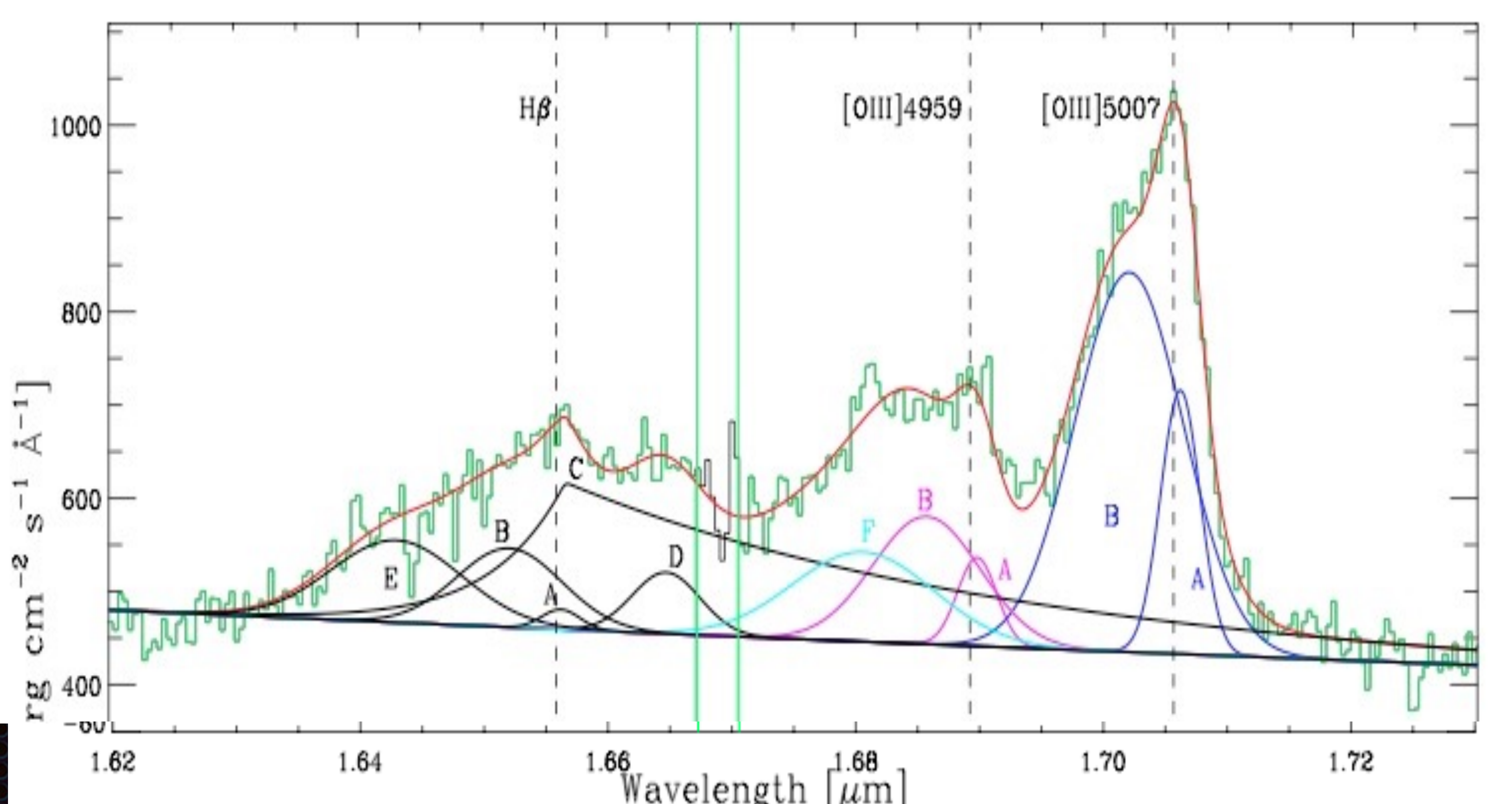
$$\dot{M}_{\rm out}^{\rm ion} = \langle \rho \rangle_V\, v\, \Omega R^2$$

$$\dot{M}_{\rm out}^{\rm ion} = 164 \frac{C\, L_{44}([\rm OIII])\, v_3}{\langle n_{e3} \rangle\, 10^{[\rm O/H]}\, R_{\rm kpc}} M_\odot\, {\rm yr}^{-1}$$

[OIII], [FeII], Hα winds



Cano-Diaz+2012



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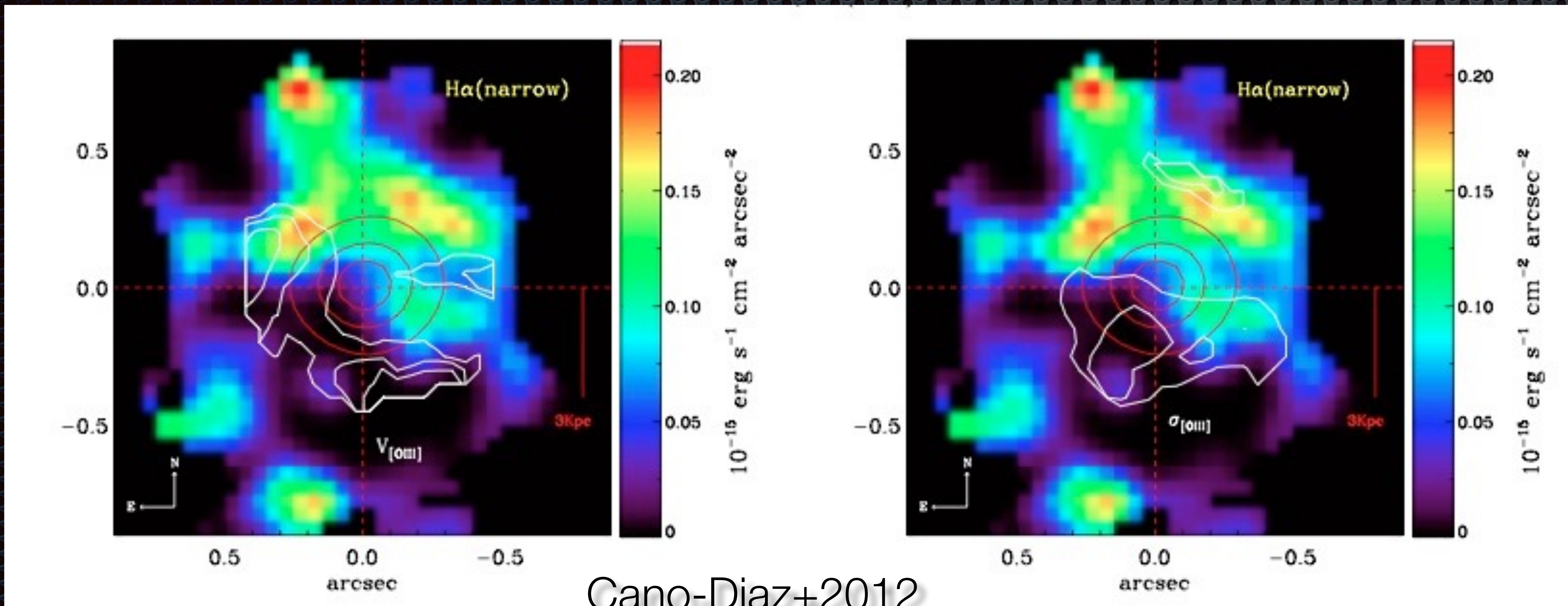
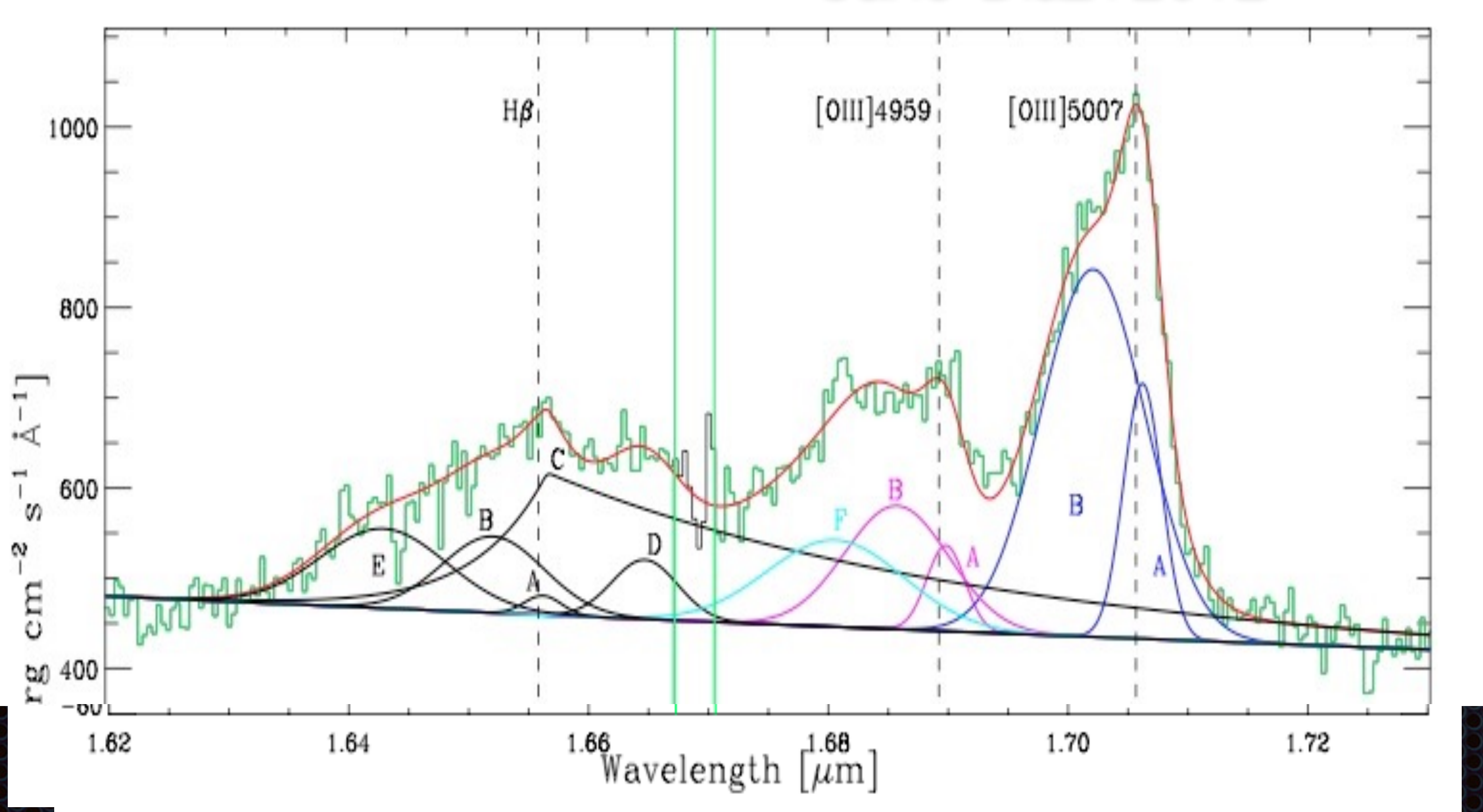
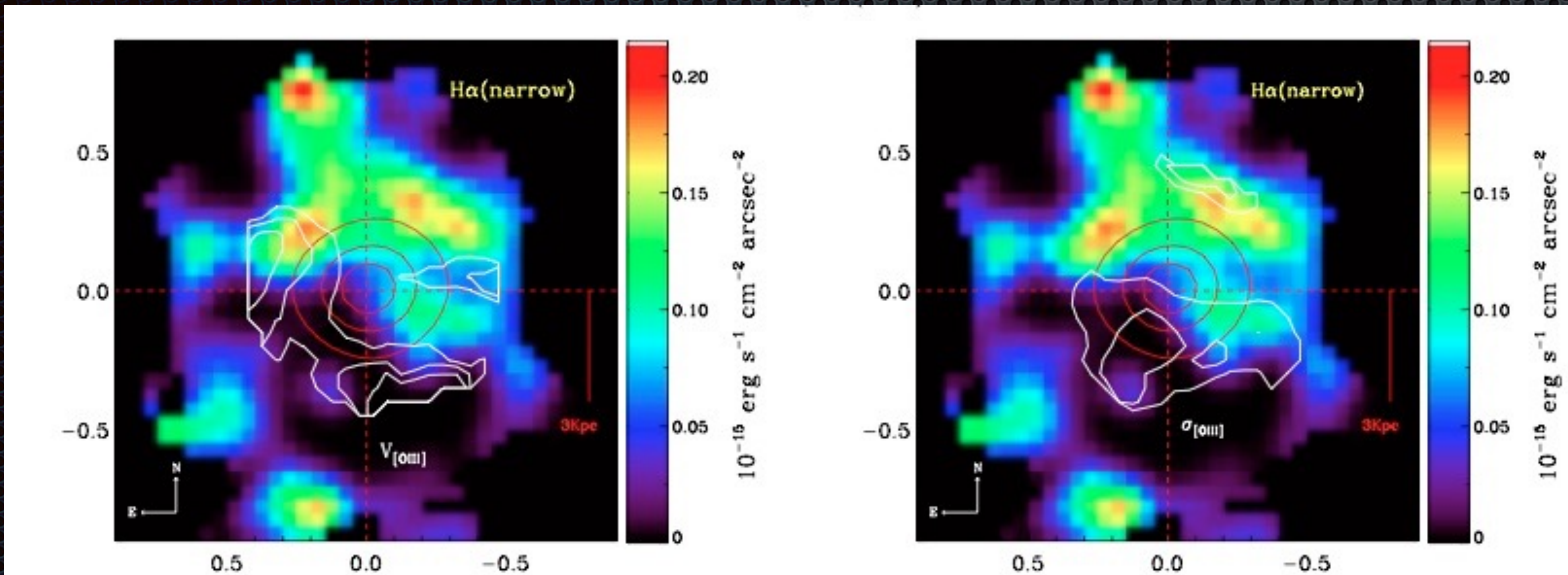
[OIII], [FeII], Hα winds



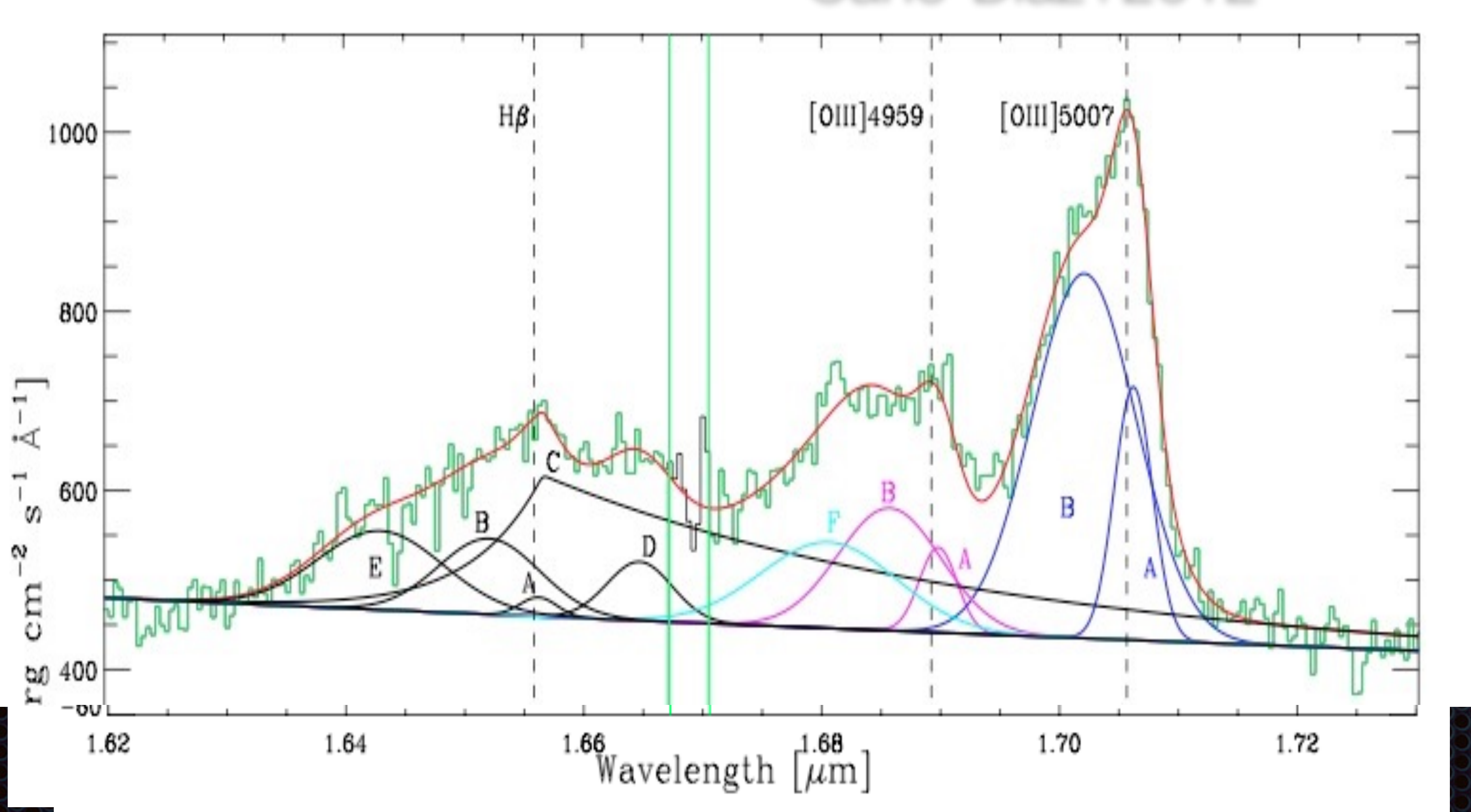
Cano-Diaz+2012



[OIII], [FeII], Hα winds

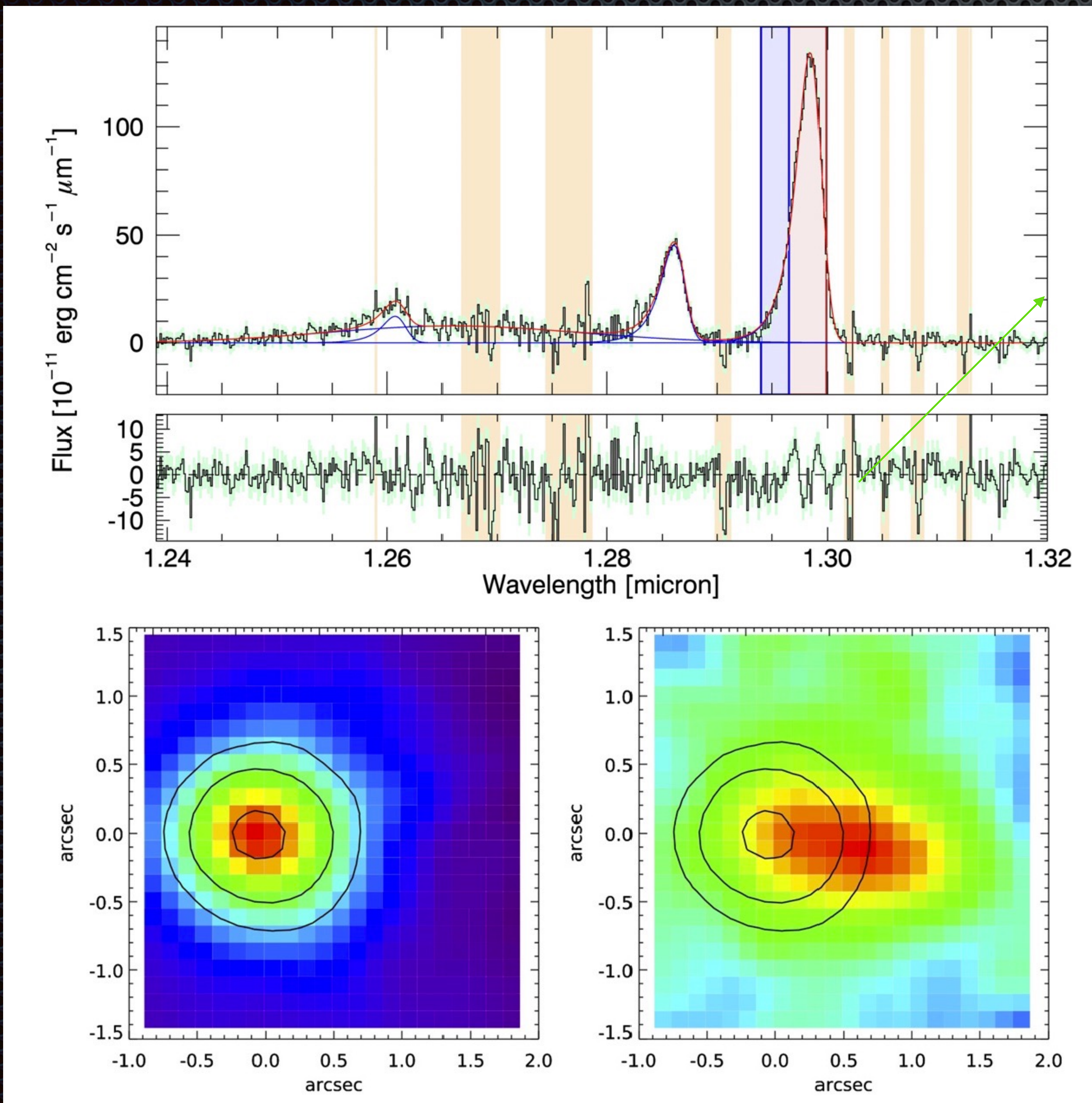


Cano-Diaz+2012



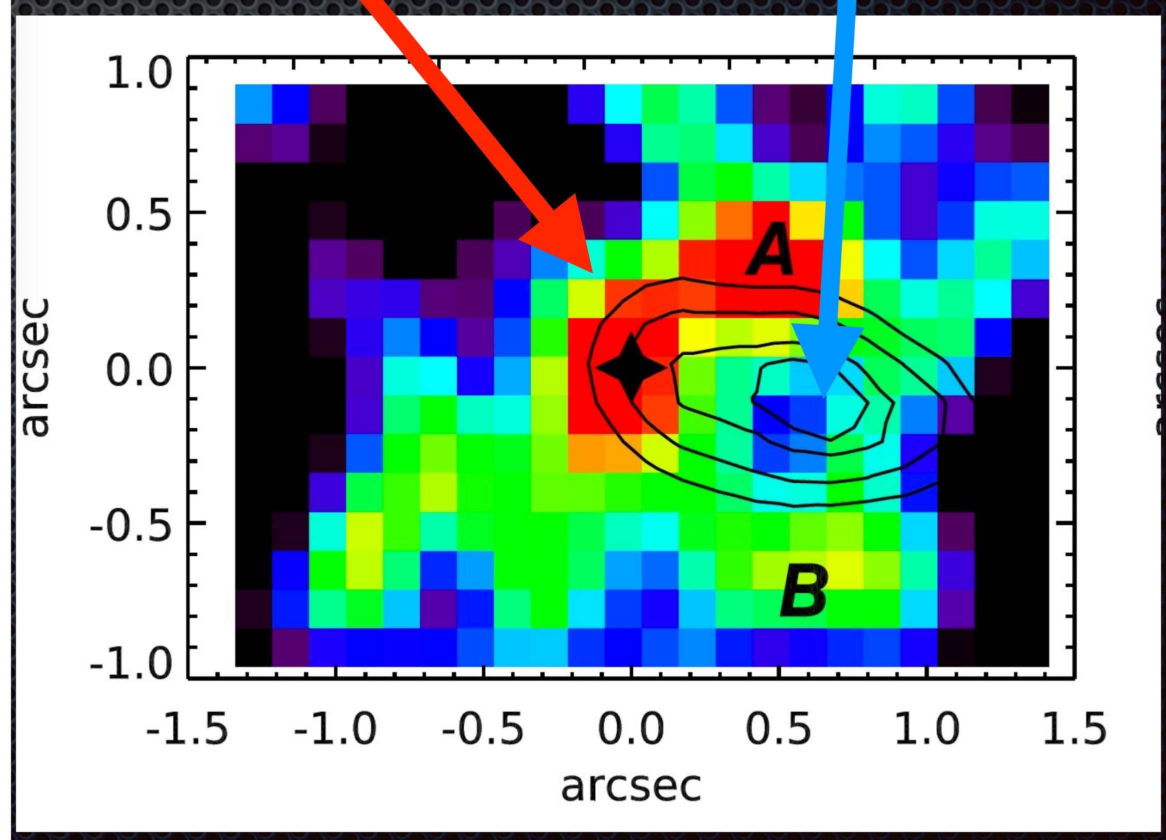
v_{out}~1000-10000 km/s
logL[OIII]=42-44 ergs/s
logn_H=3-4 NELR
r~1-10kpc
M_{out}~10-1000$M_{\odot}$/yr
Mass outflow rate

[OIII], [FeII], Hα winds

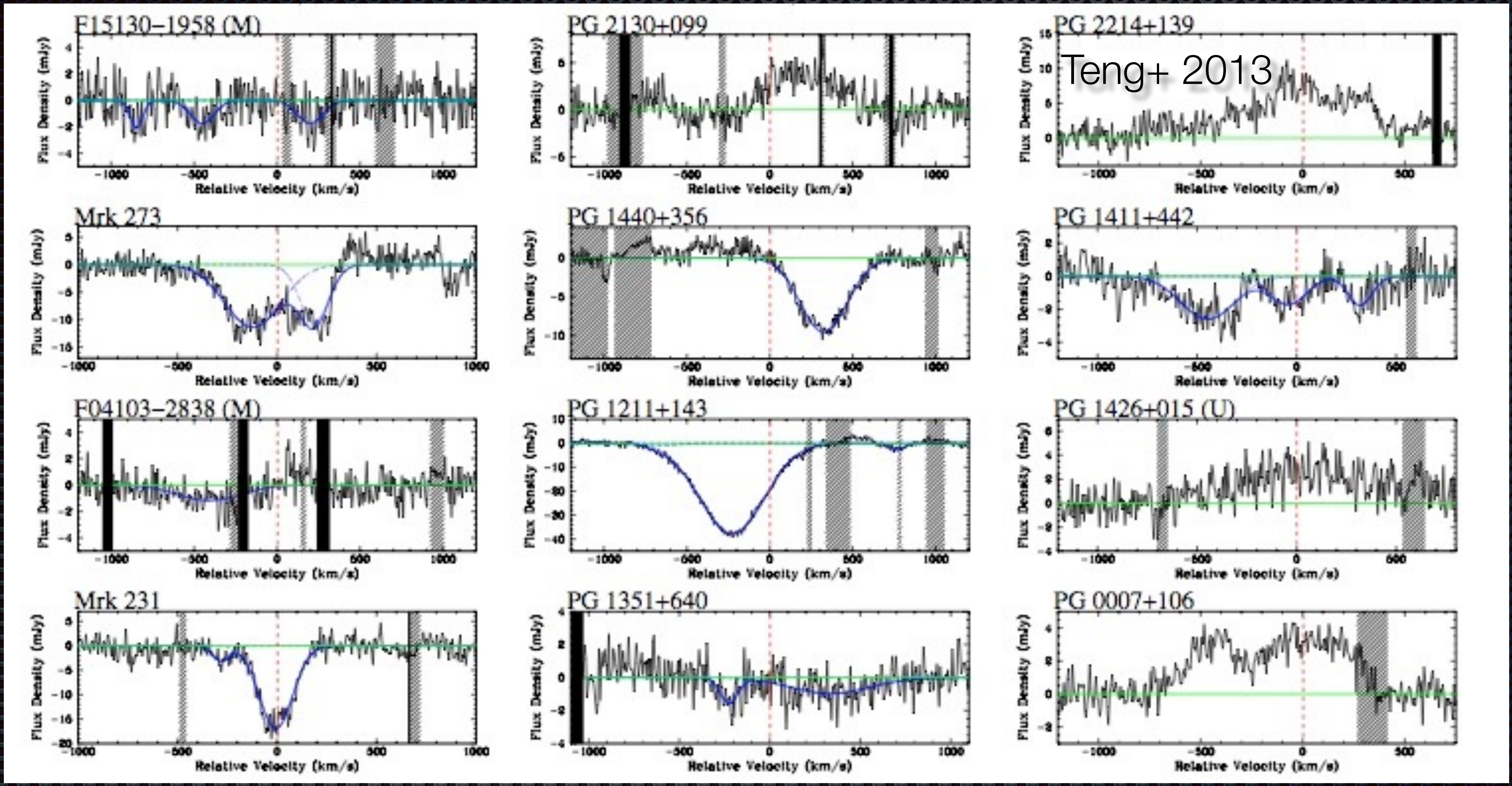


Cresci+2015

Hα [OIII]broad



Cold atomic gas winds



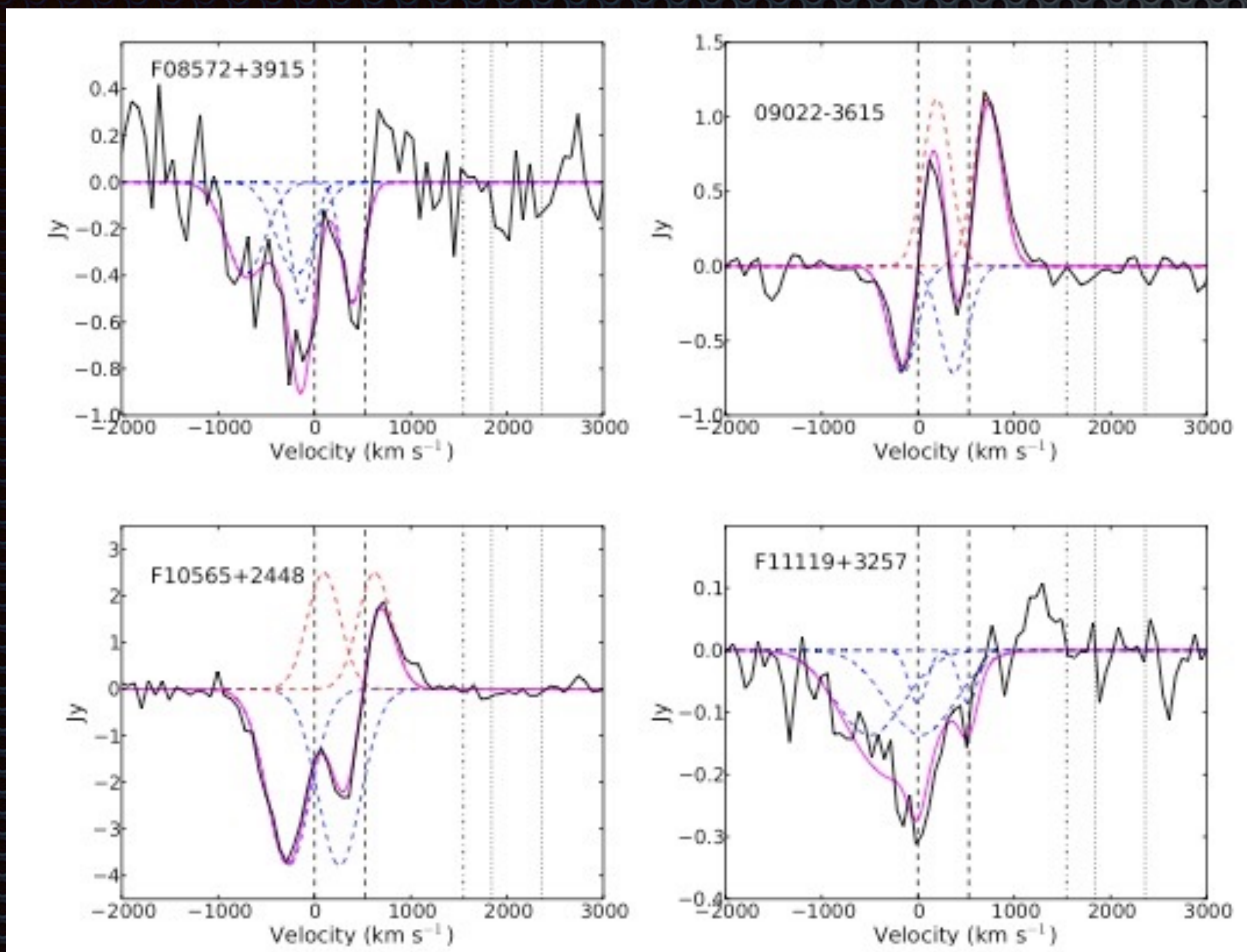
v_{max}=300-2000 km/s $\log N_H$=21-24

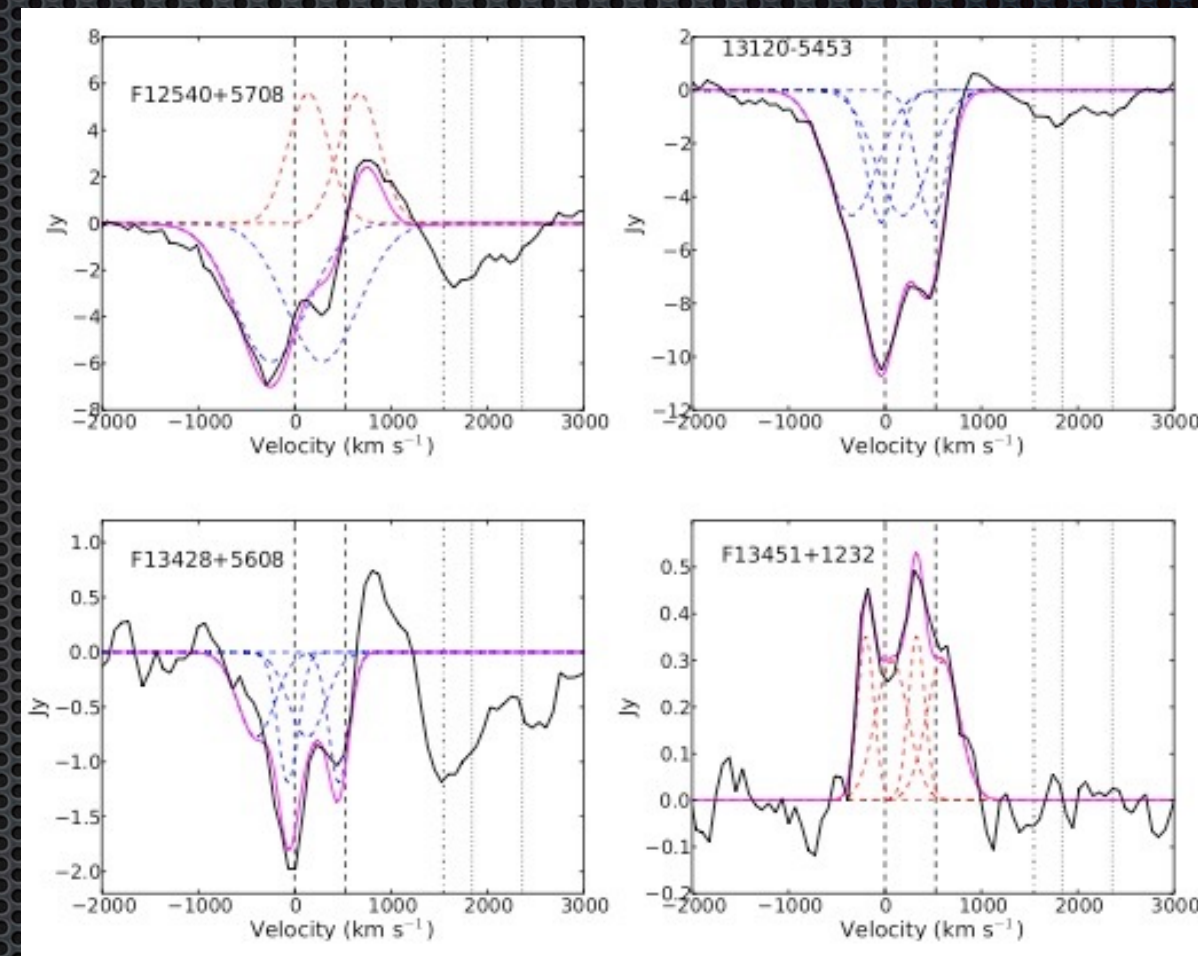
assuming $\Omega=\pi$ and r=1kpc

M_{out}=10-10000 $M_{\odot}$/yr   Mass outflow rate

Molecular gas winds

OH 79um, 119um absorption/emission lines: Sturm+2011 Veilleux+2013





$$\dot{M} \sim M_{\rm gas}/t_{\rm dyn} \sim 4\pi \times n({\rm OH})_{\rm in}/\chi({\rm OH}) \times m_{\rm H_2} \times R_{\rm in}^2 \times f \times g \times v$$

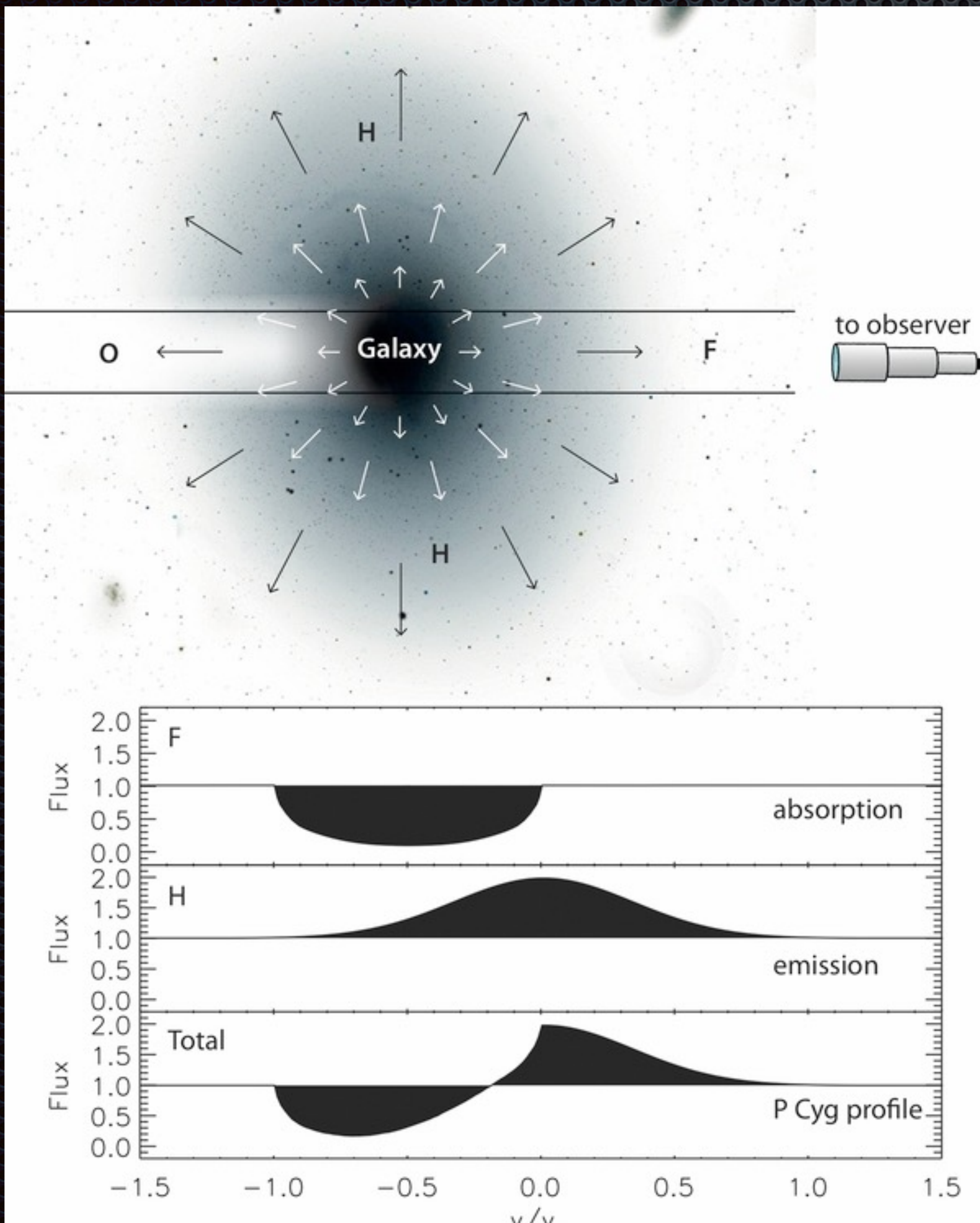
$\chi(\rm OH) = 5 \times 10^{-6}$ is the OH abundance $\quad t_{\rm dyn} \sim R/v$

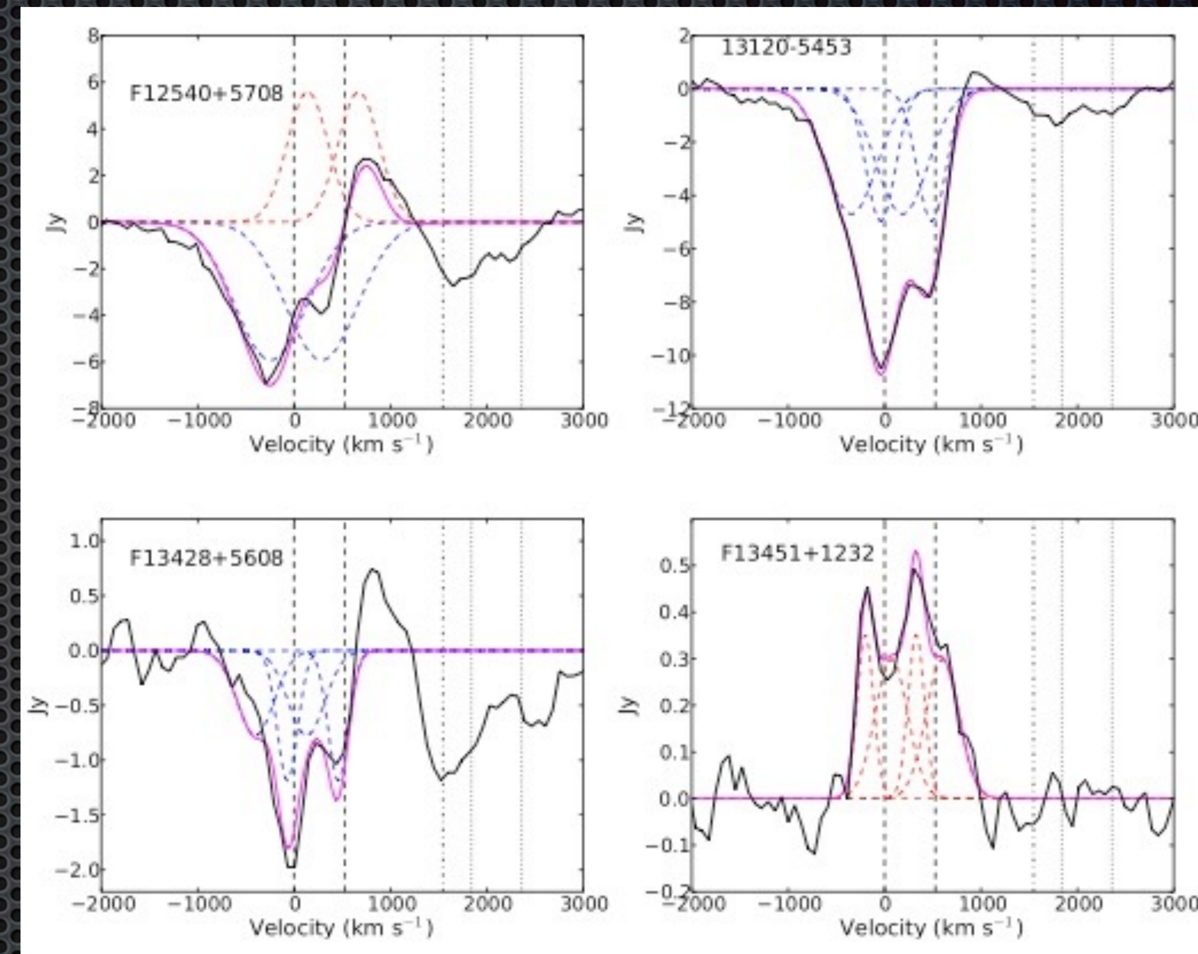
Rin~100pc n(OH)~10^{-4} - 10^{-5} f=0.2-1 M_{out}=100-1000 $M_{\otimes}$/yr

by fitting line profiles with a radiative transfer code

Molecular gas winds

OH 79um, 119um absorption/emission lines: Sturm+2011 Veilleux+2013





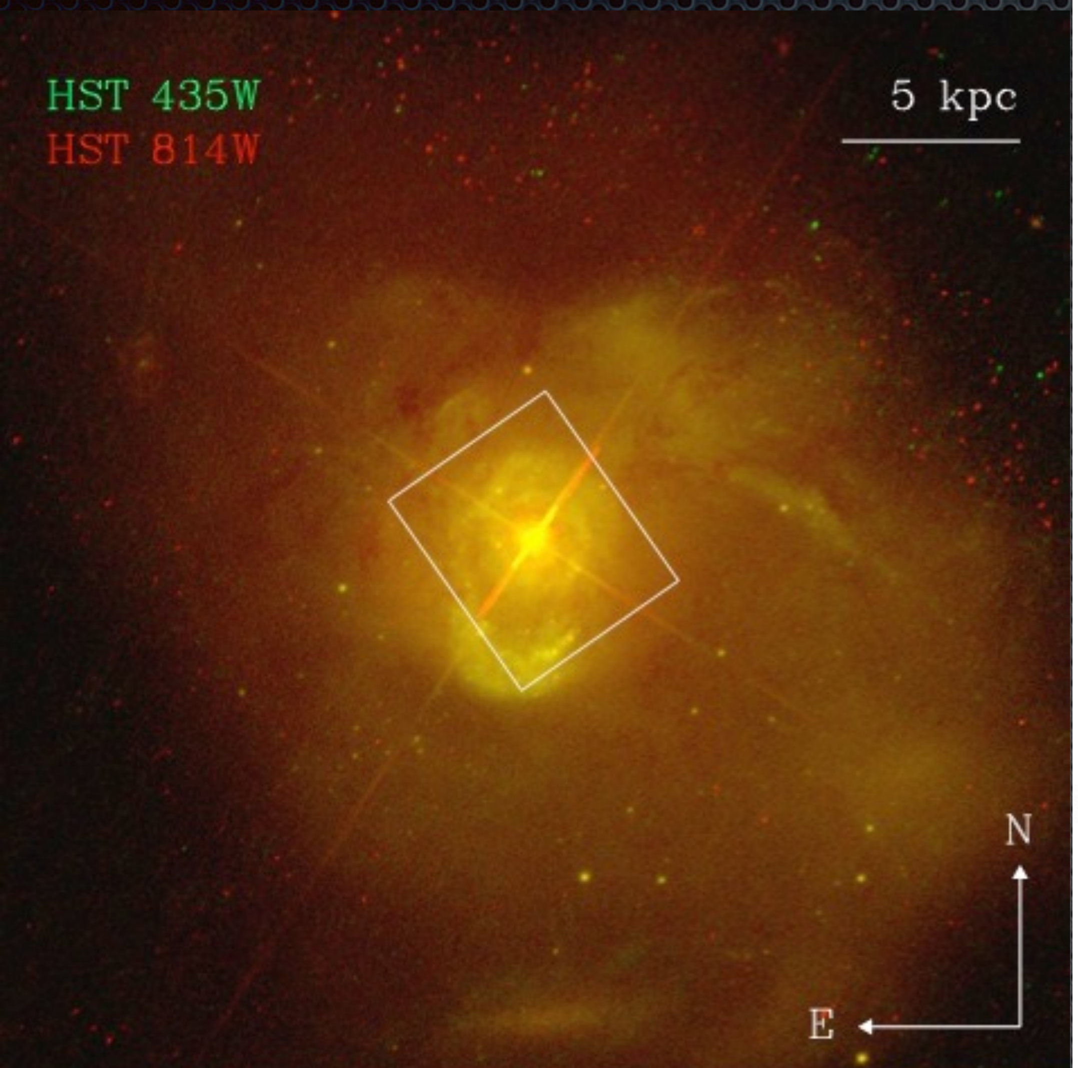
$$/\chi(\mathrm{OH}) \times m_{\mathrm{H_2}} \times R_{\mathrm{in}}^2 \times f \times g \times v$$

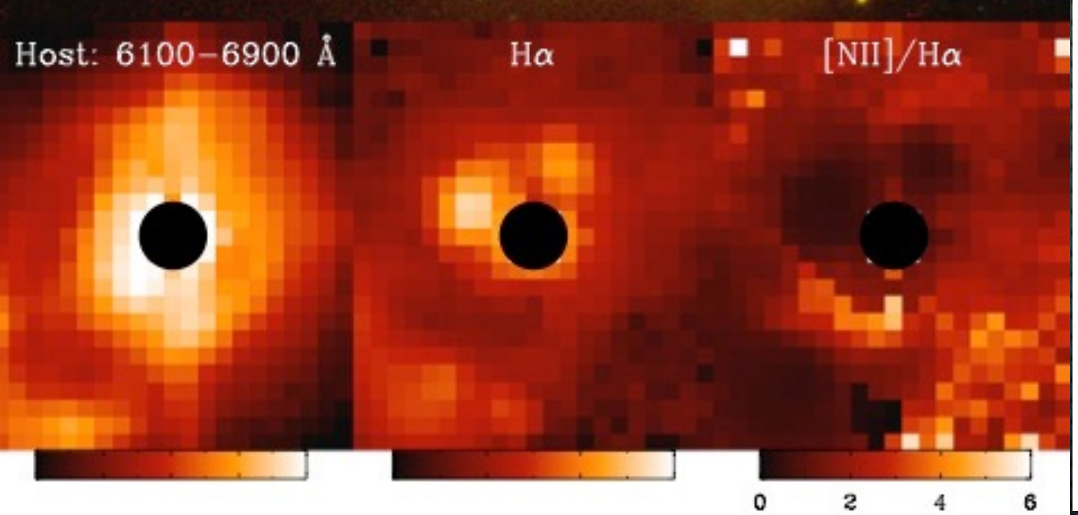
undance $\quad t_{\mathrm{dyn}} \sim R/v$

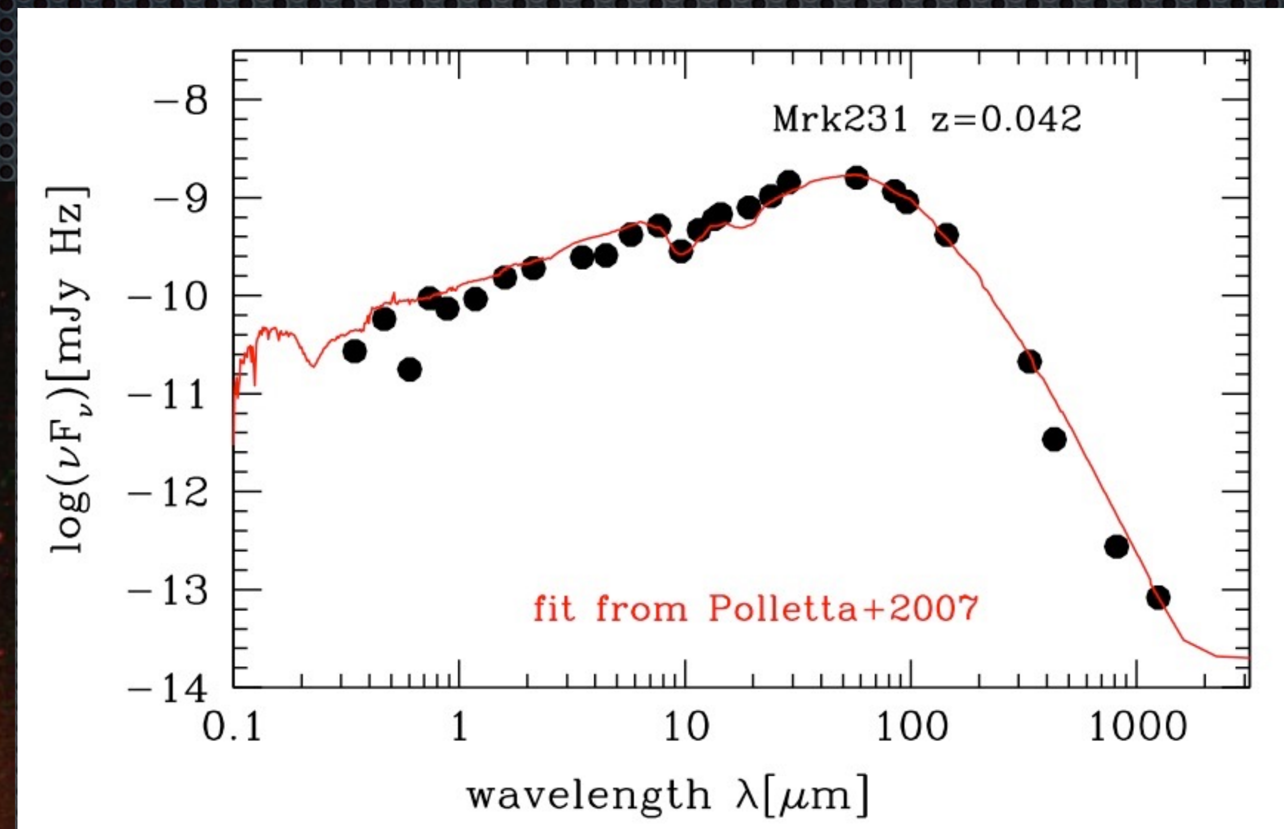
.2-1 M_{out}=100-1000 $M_{\otimes}$/yr

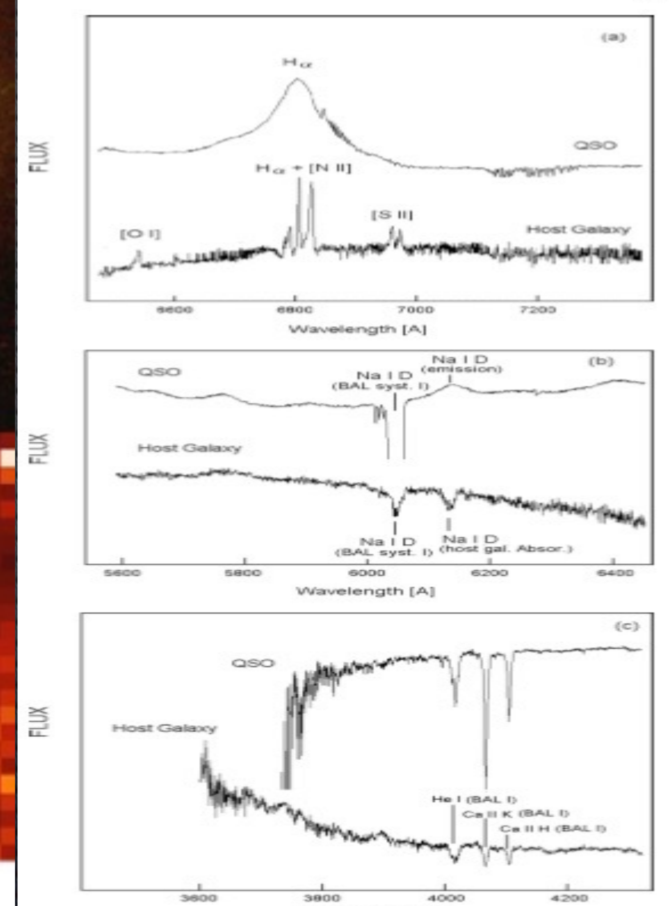
ve transfer code

The case of Markarian 231

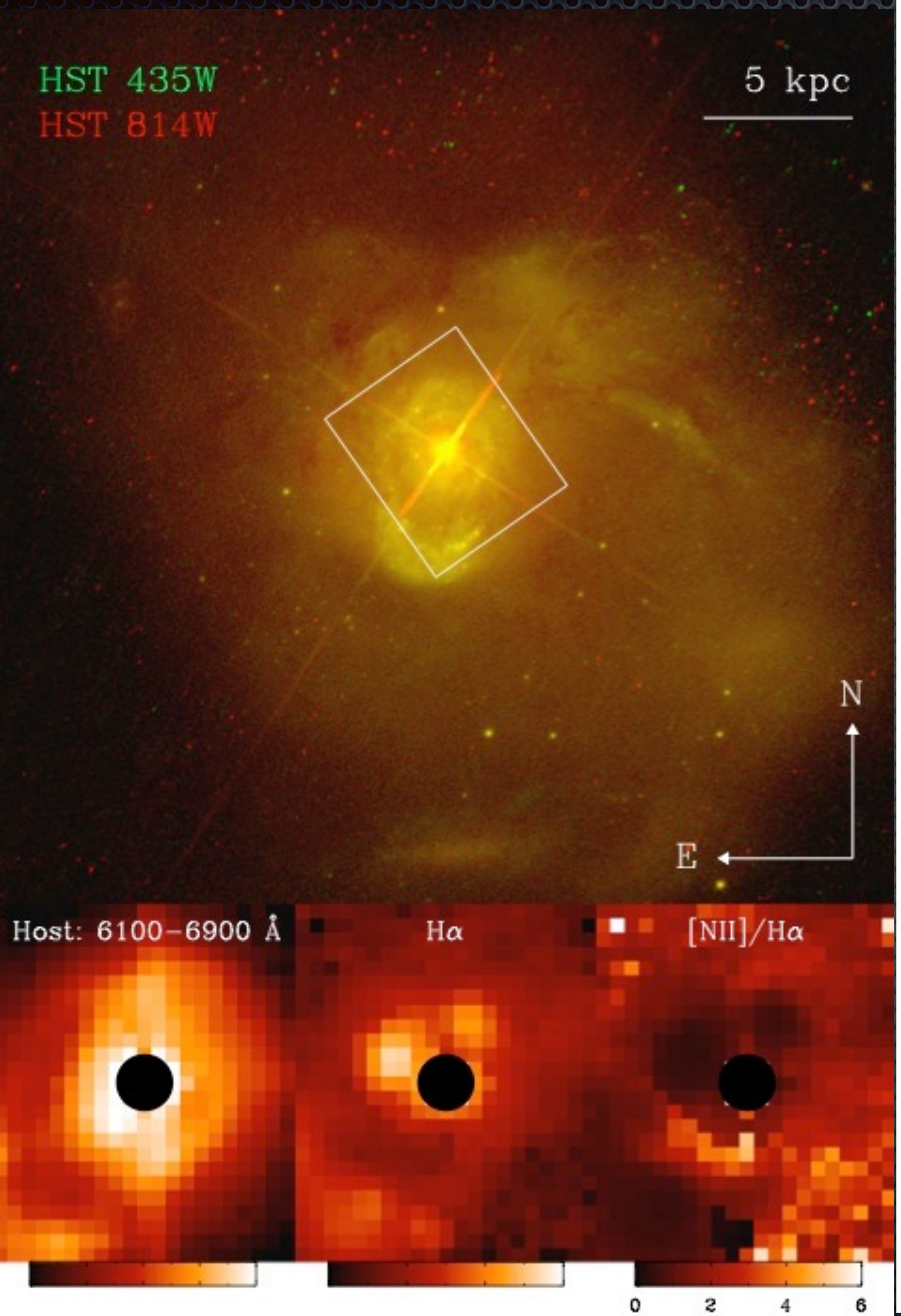


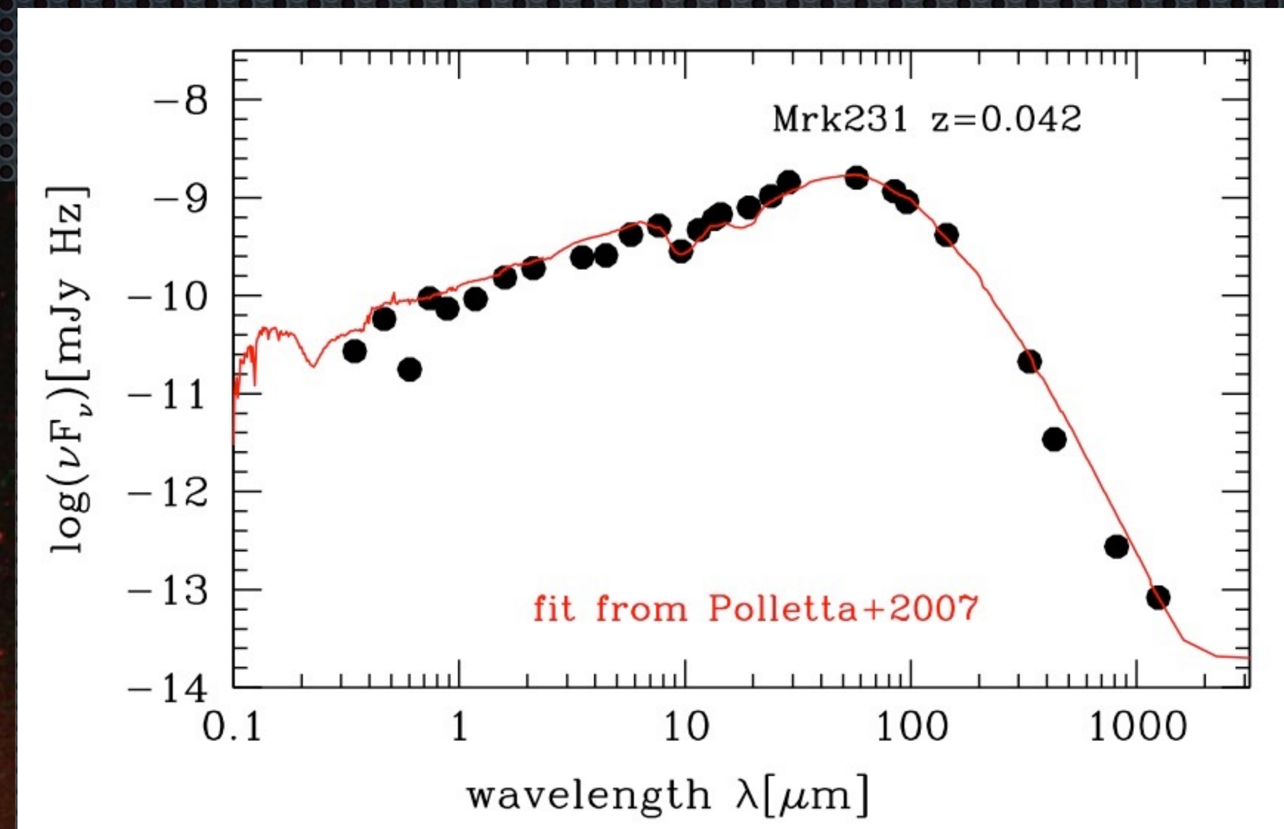


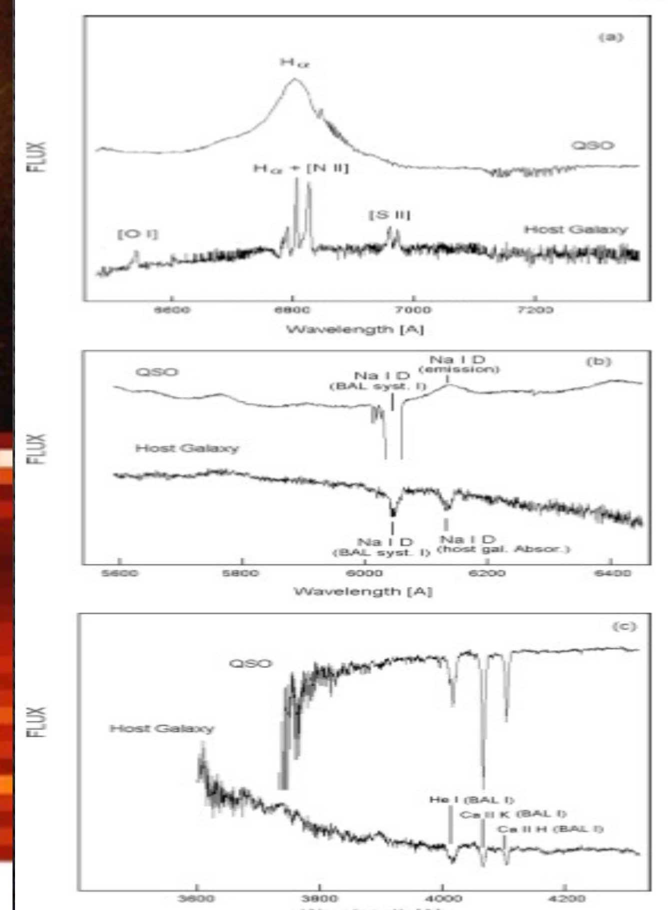




The case of Markarian 231

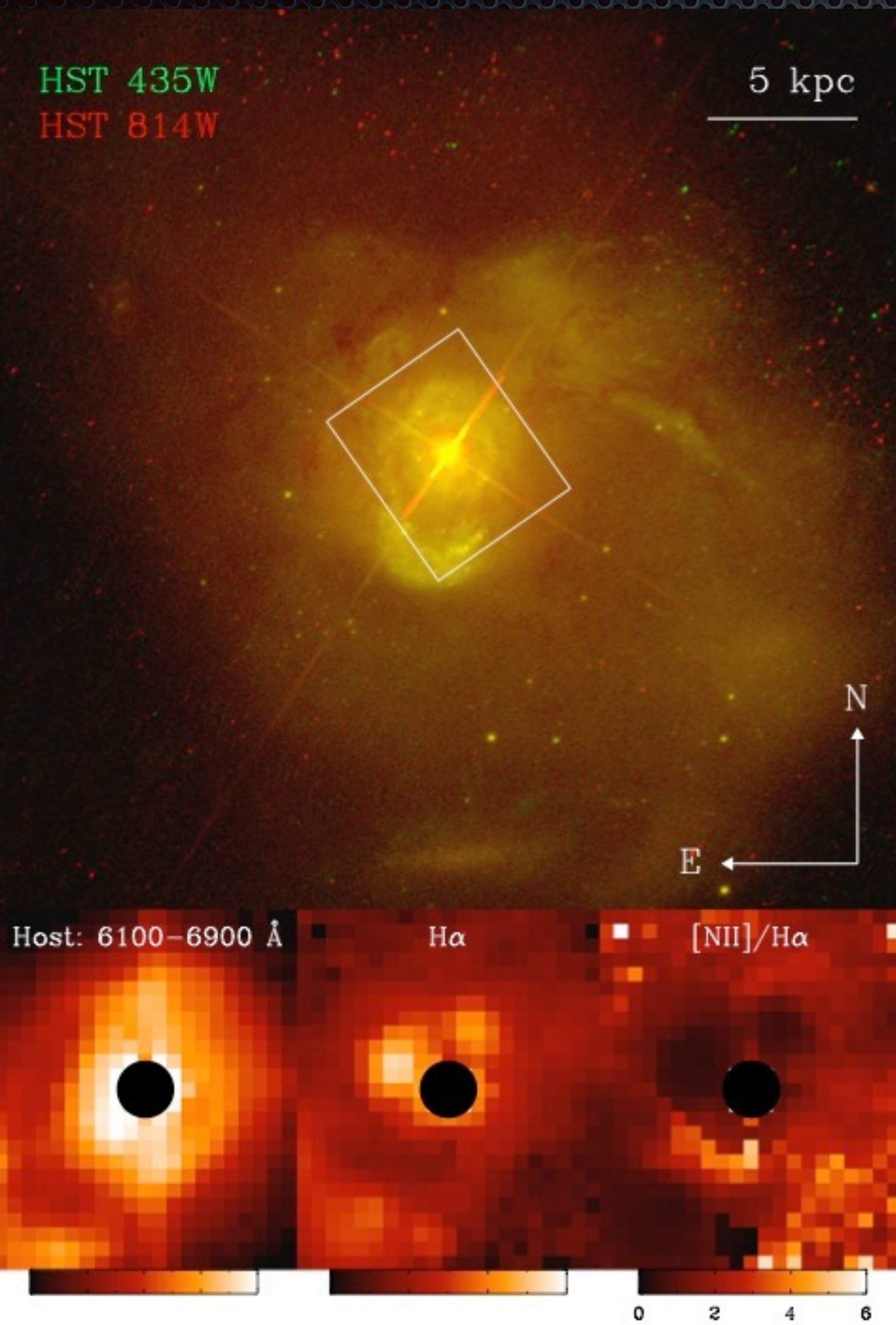


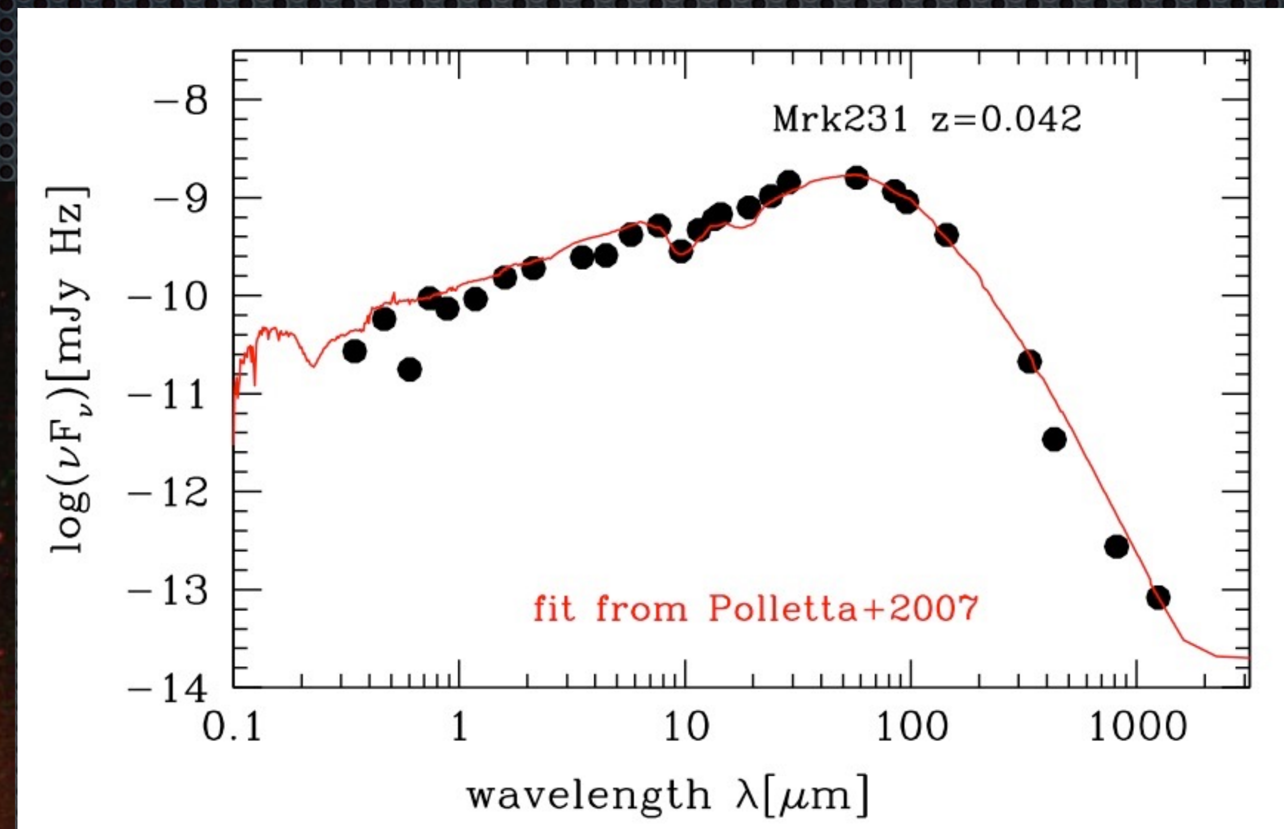


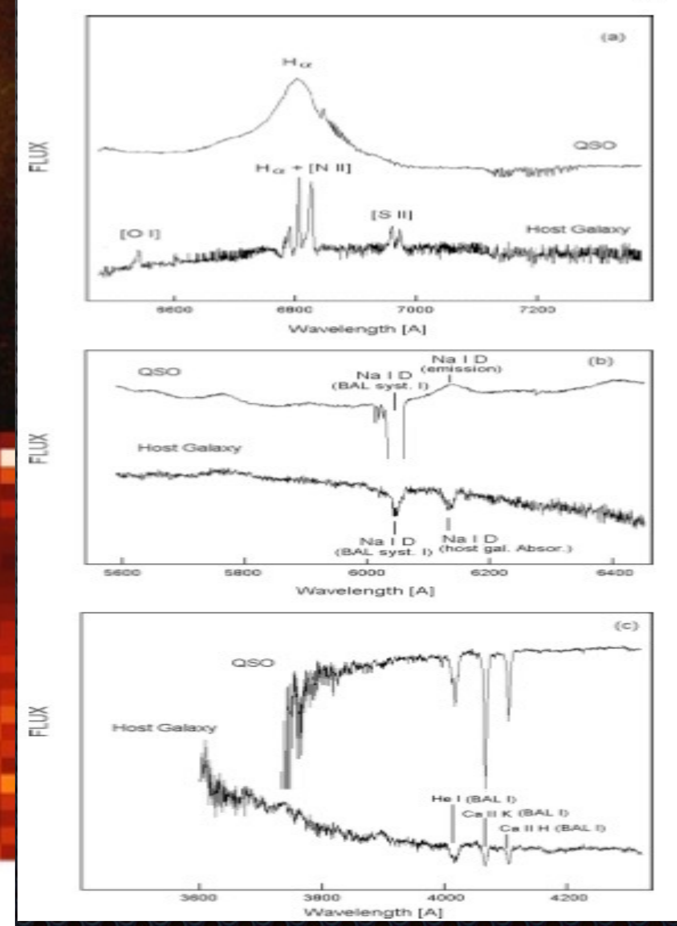


- Nearby z=0.042, 187Mpc

The case of Markarian 231

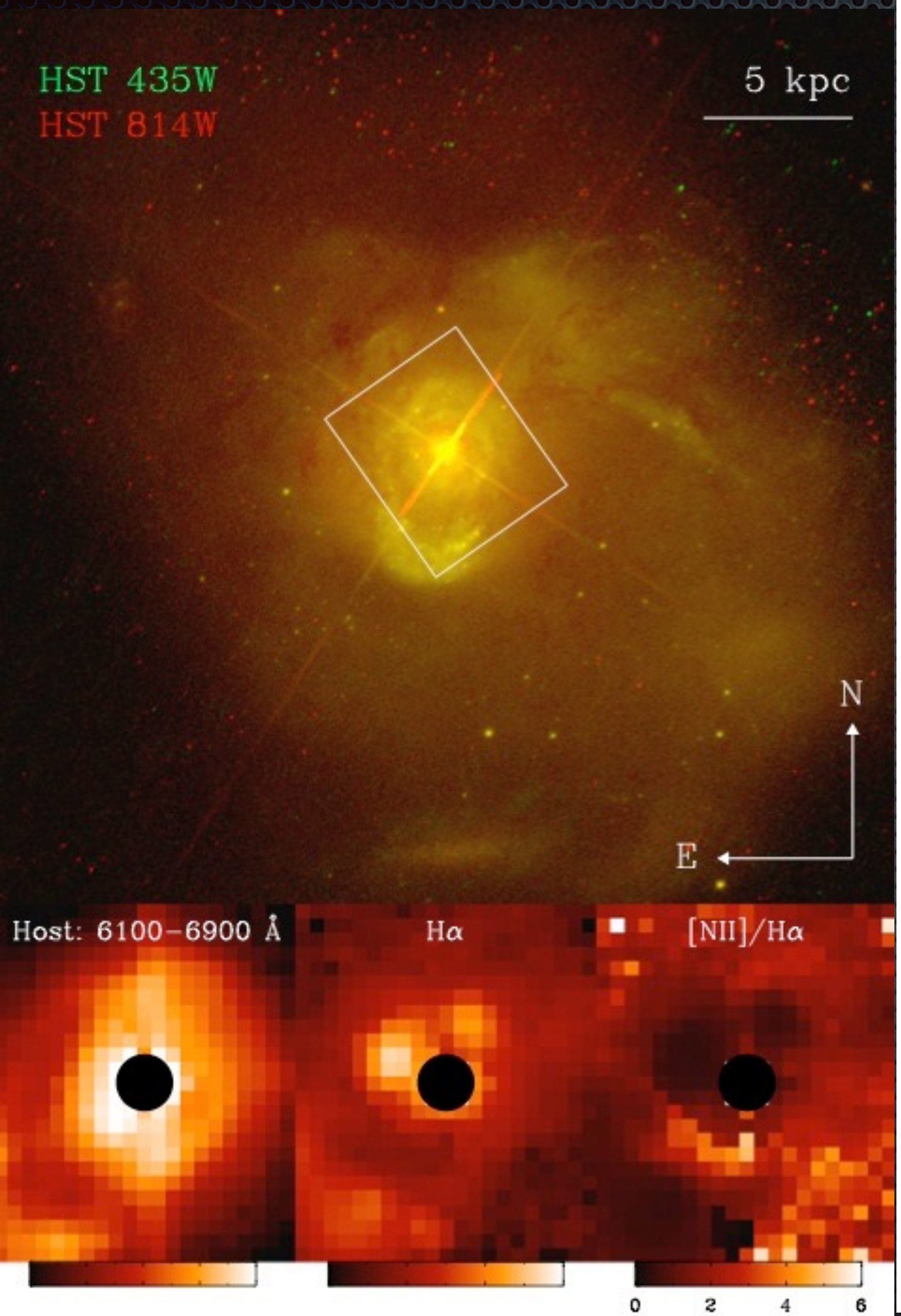


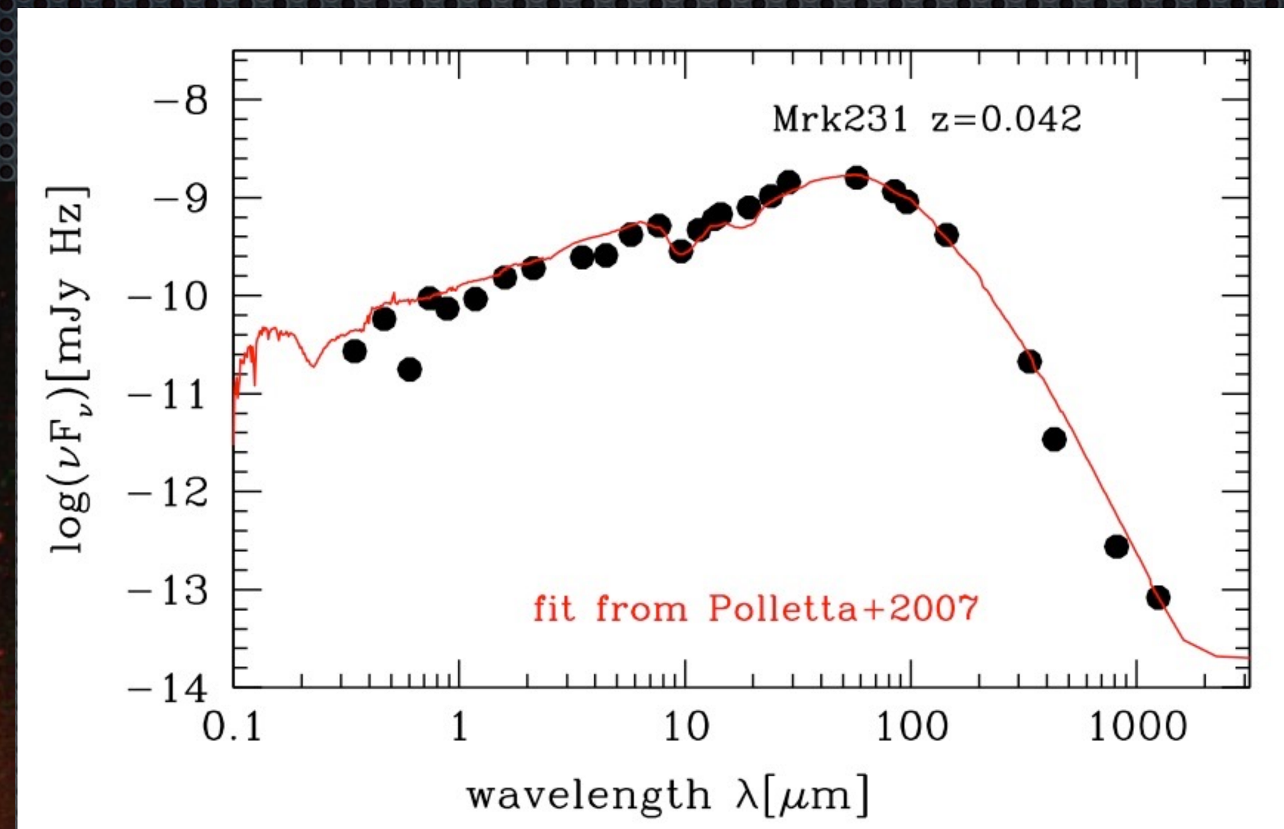


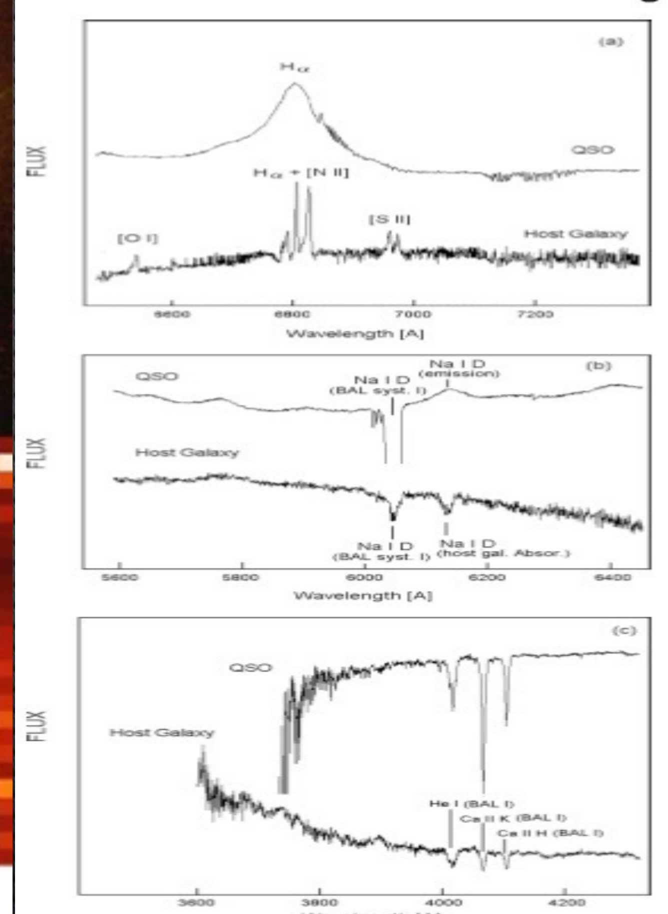


- Nearby z=0.042, 187Mpc
- Merger system

The case of Markarian 231

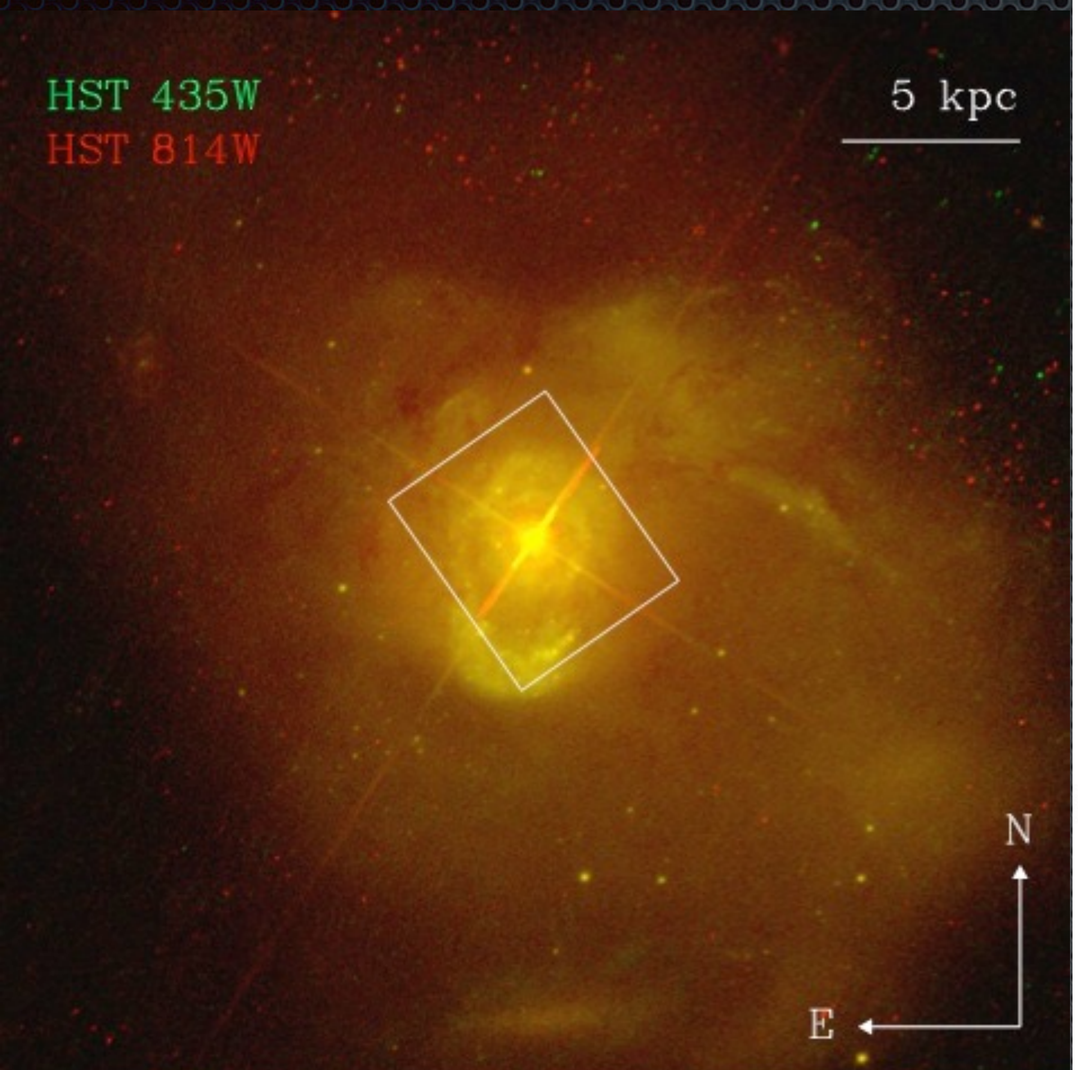


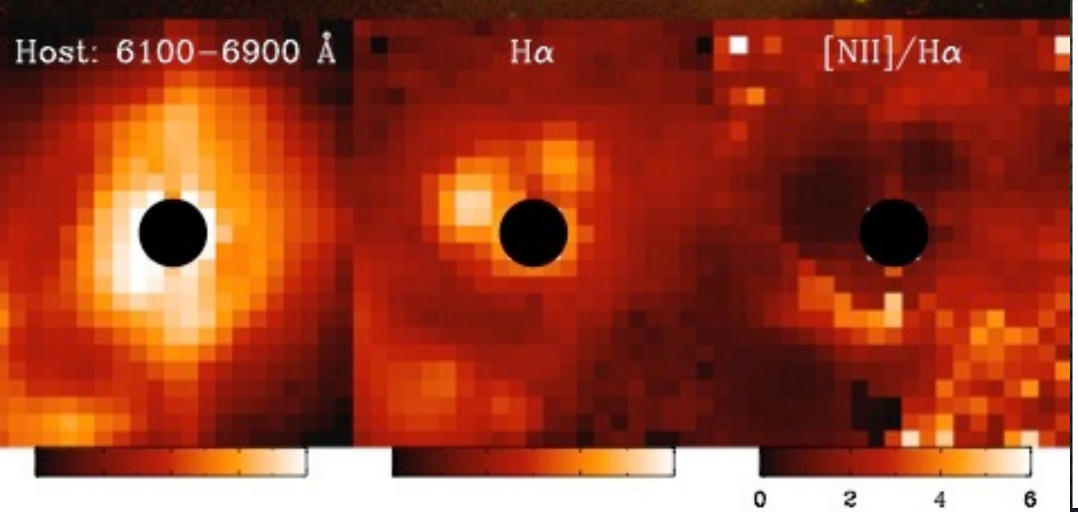


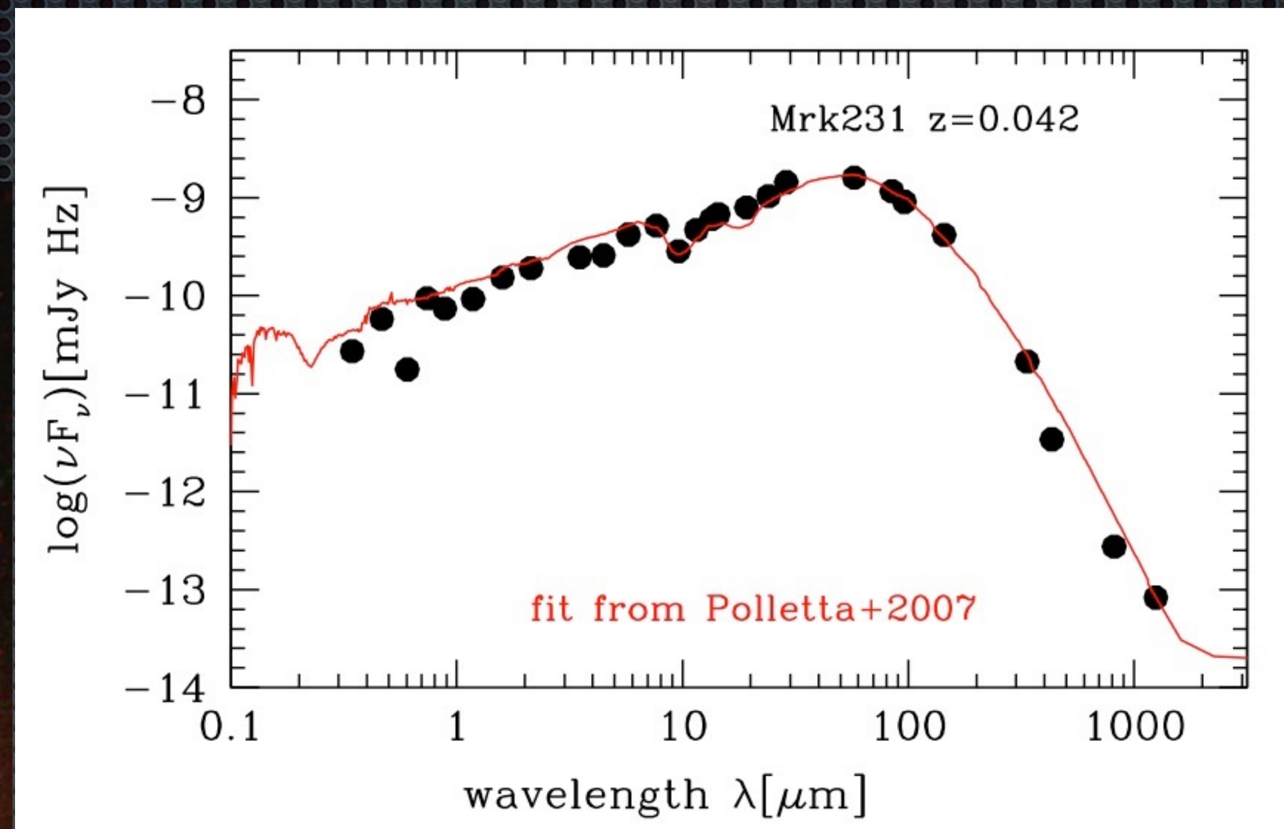


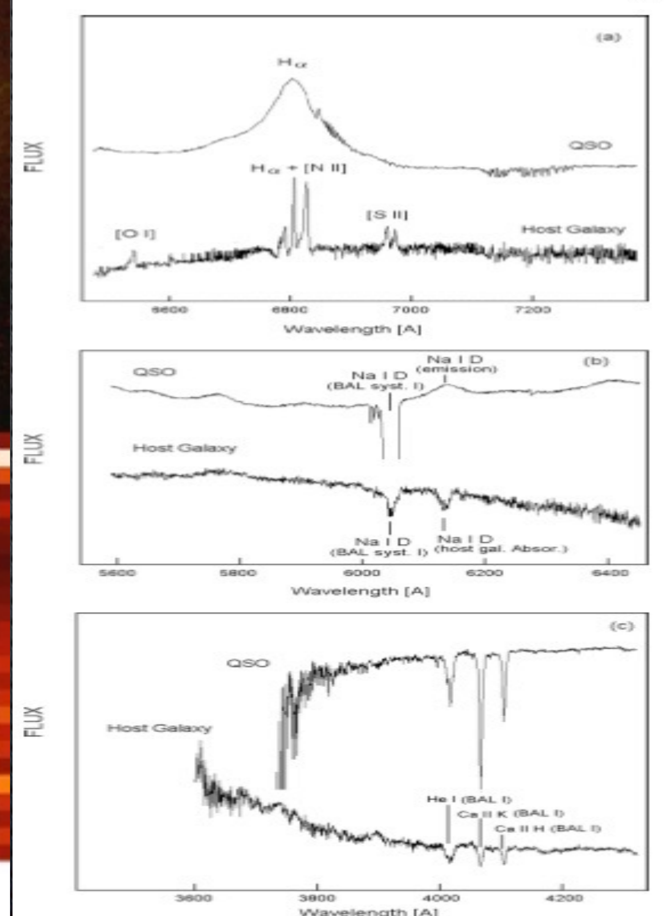
- Nearby z=0.042, 187Mpc
- Merger system
- High luminosity (L_{bol}~10^{46} erg/s), highly obscured (N_H~10^{24} cm^{-2}) BALQSO.

The case of Markarian 231



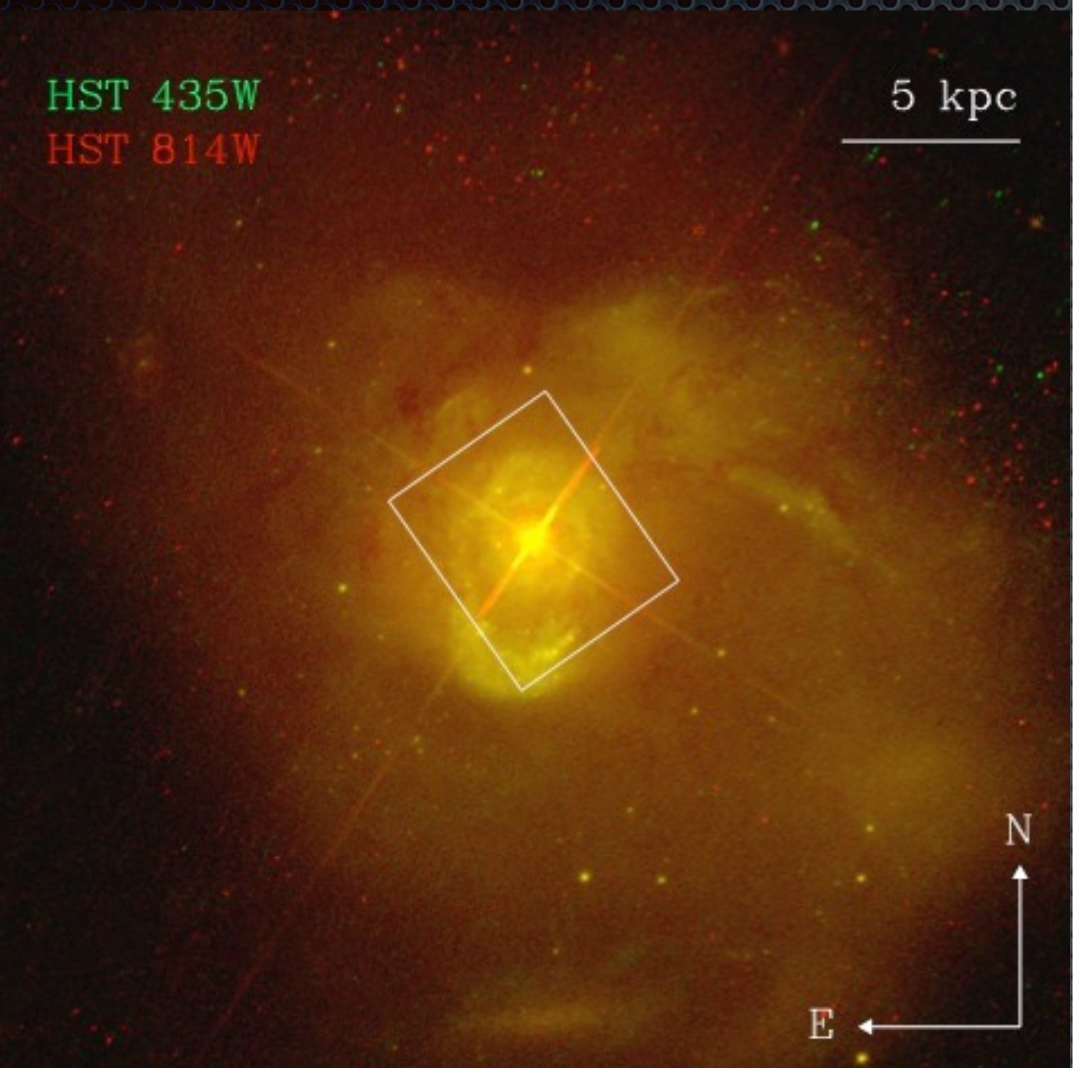


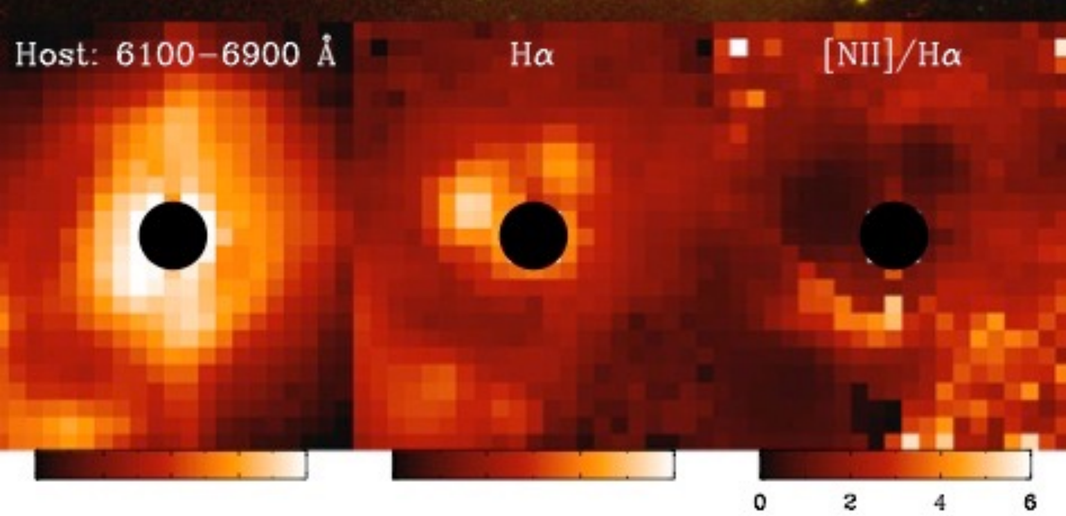


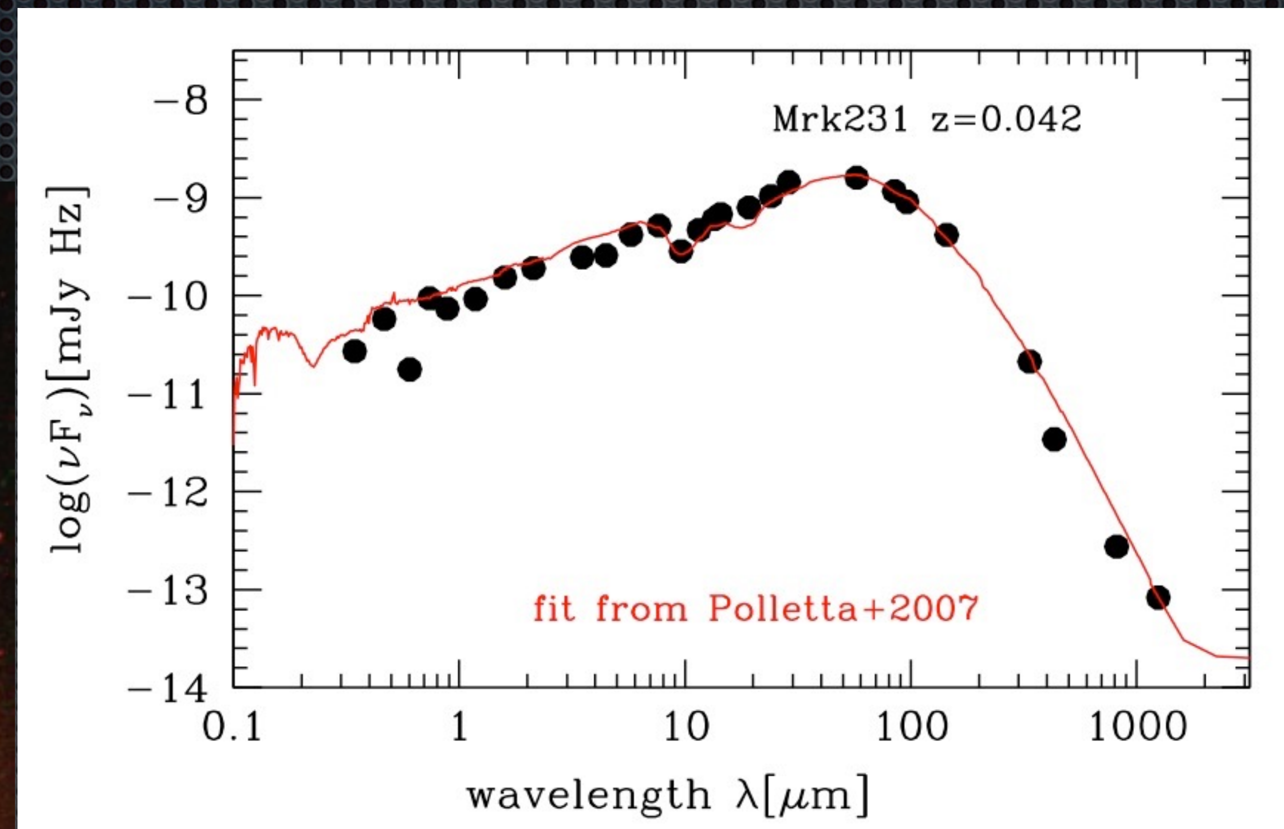


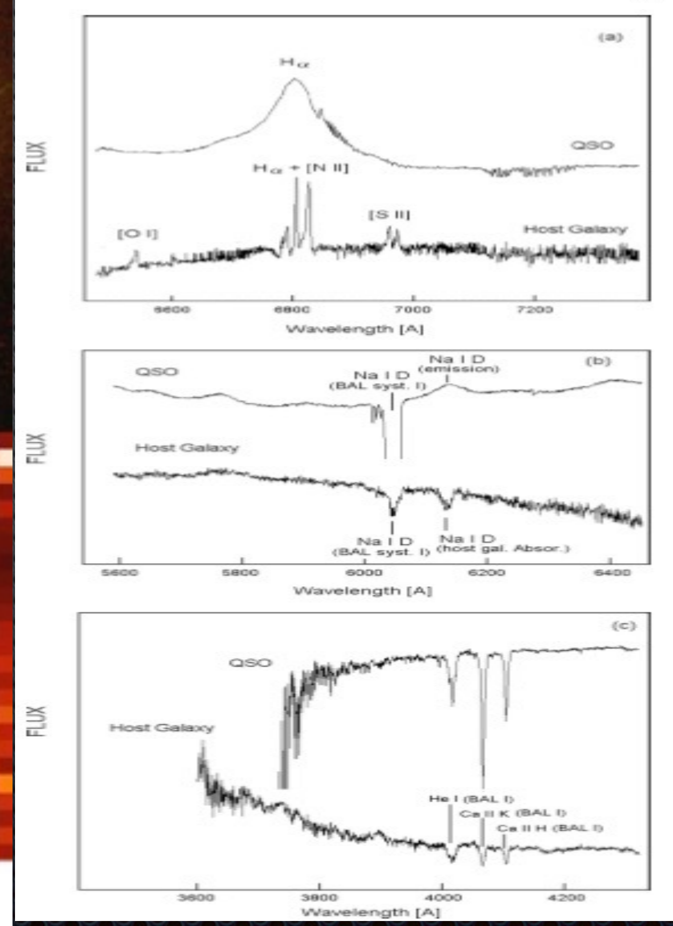
- Nearby z=0.042, 187Mpc
- Merger system
- High luminosity (L_{bol}~10^{46} erg/s), highly obscured (N_H~10^{24} cm^{-2}) BALQSO.
- SFR=200 M_{Sun}/yr

The case of Markarian 231









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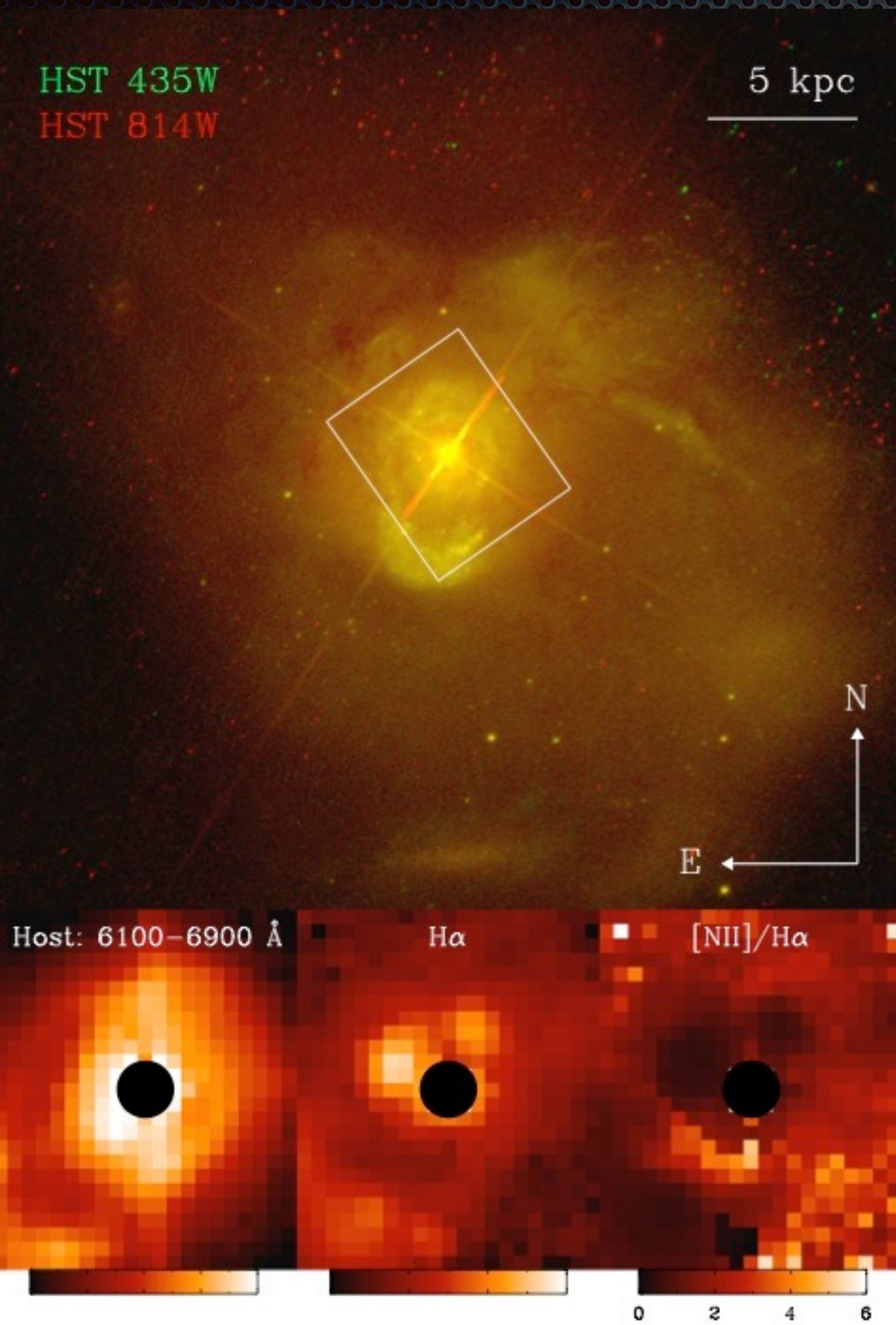

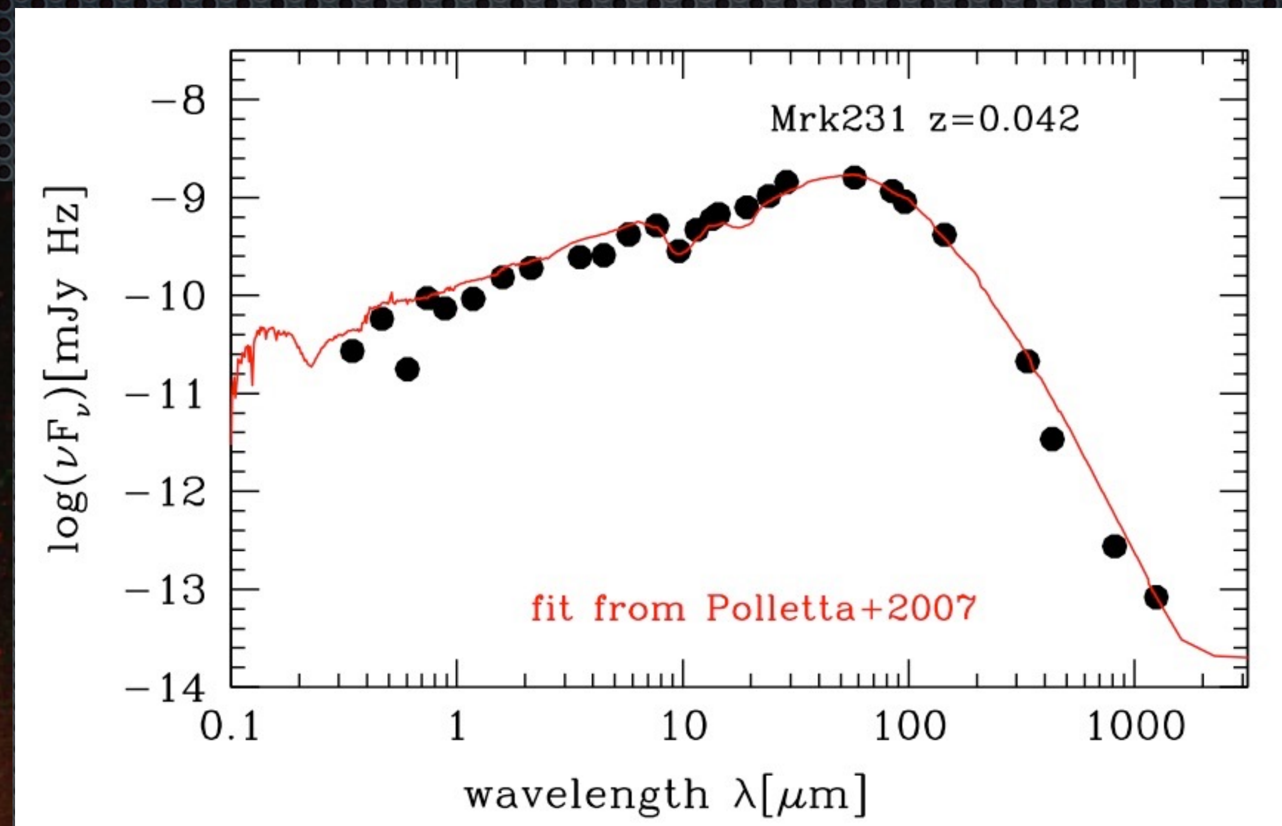

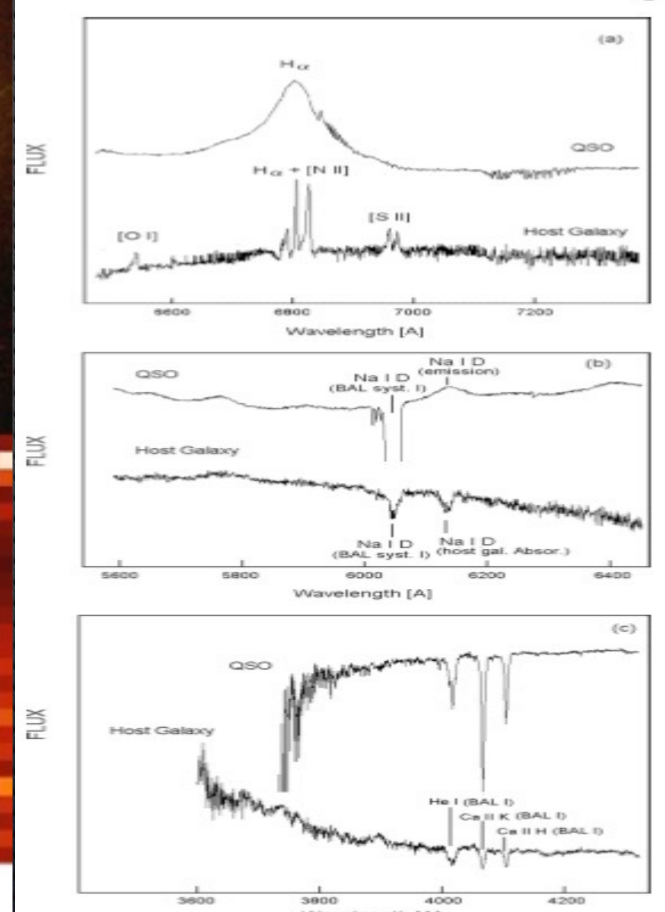

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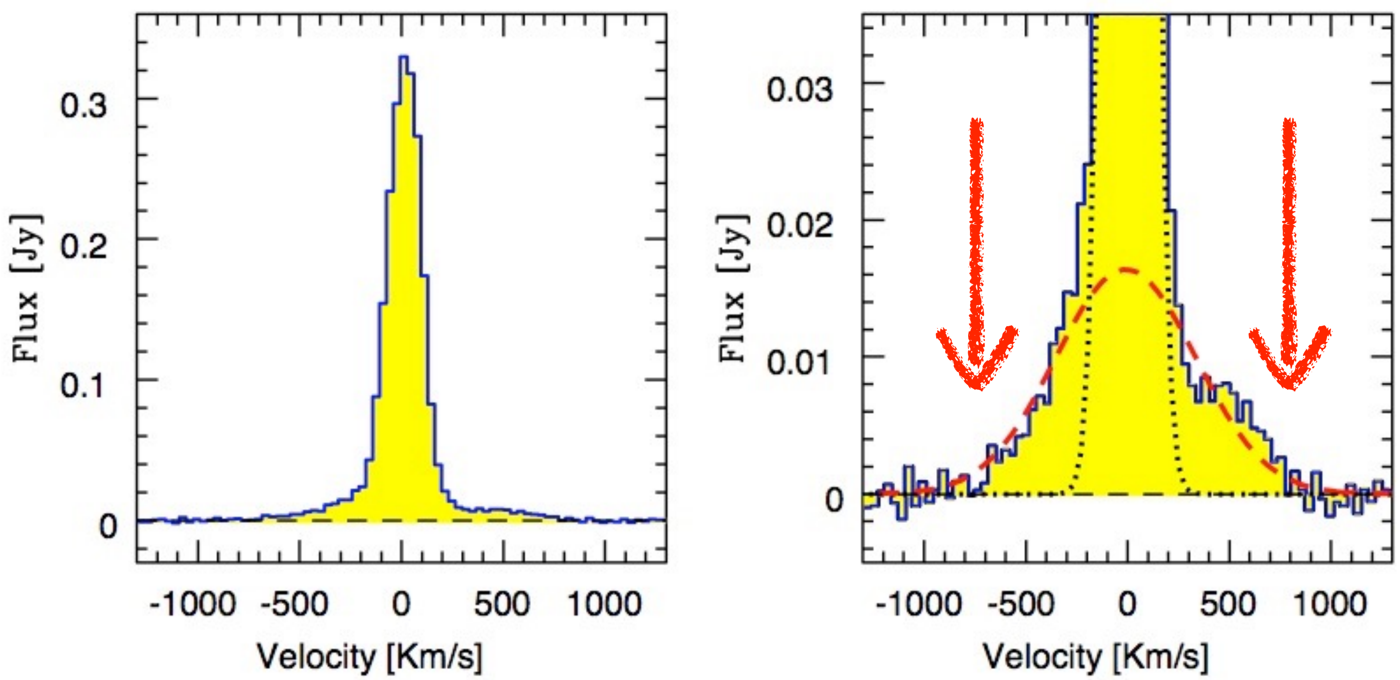
Dust enshrouded AGN/ star-forming galaxy

Markarian 231

CO(1-0) emission line at 112 GHz



Fast cold gas (~100 K, up to +-1000 km/s) was detected on scales of ~1 kpc
based on visibility fit

- **too fast to be disk rotation or inflow**
- **too extended to be BLR**

OUTFLOW

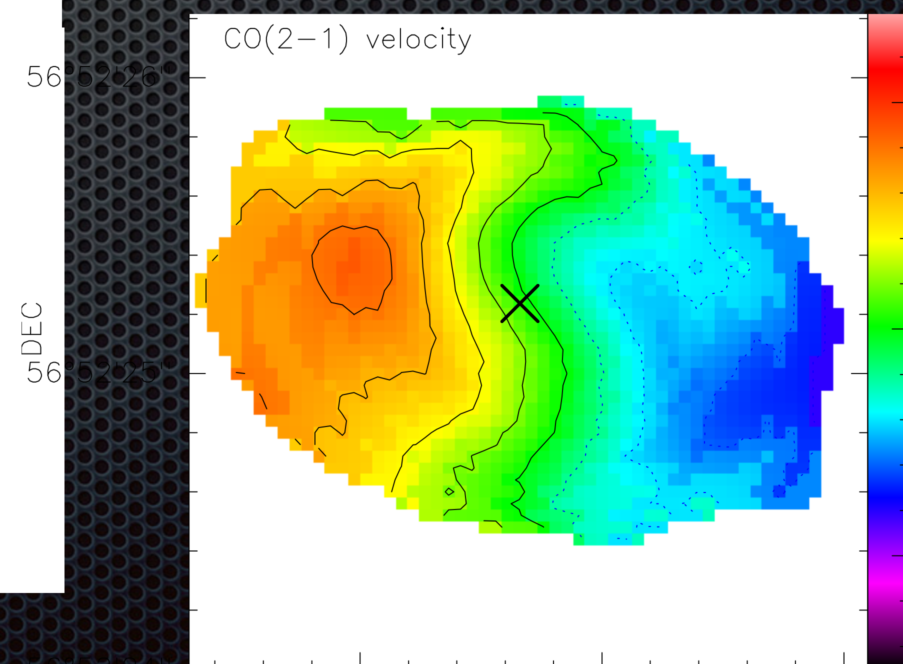
$L_{bol} \sim 5 \times 10^{45}$ ergs/s

$M_{H2,\,of} \sim 7 \times 10^{7}\, M_{sun}$

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

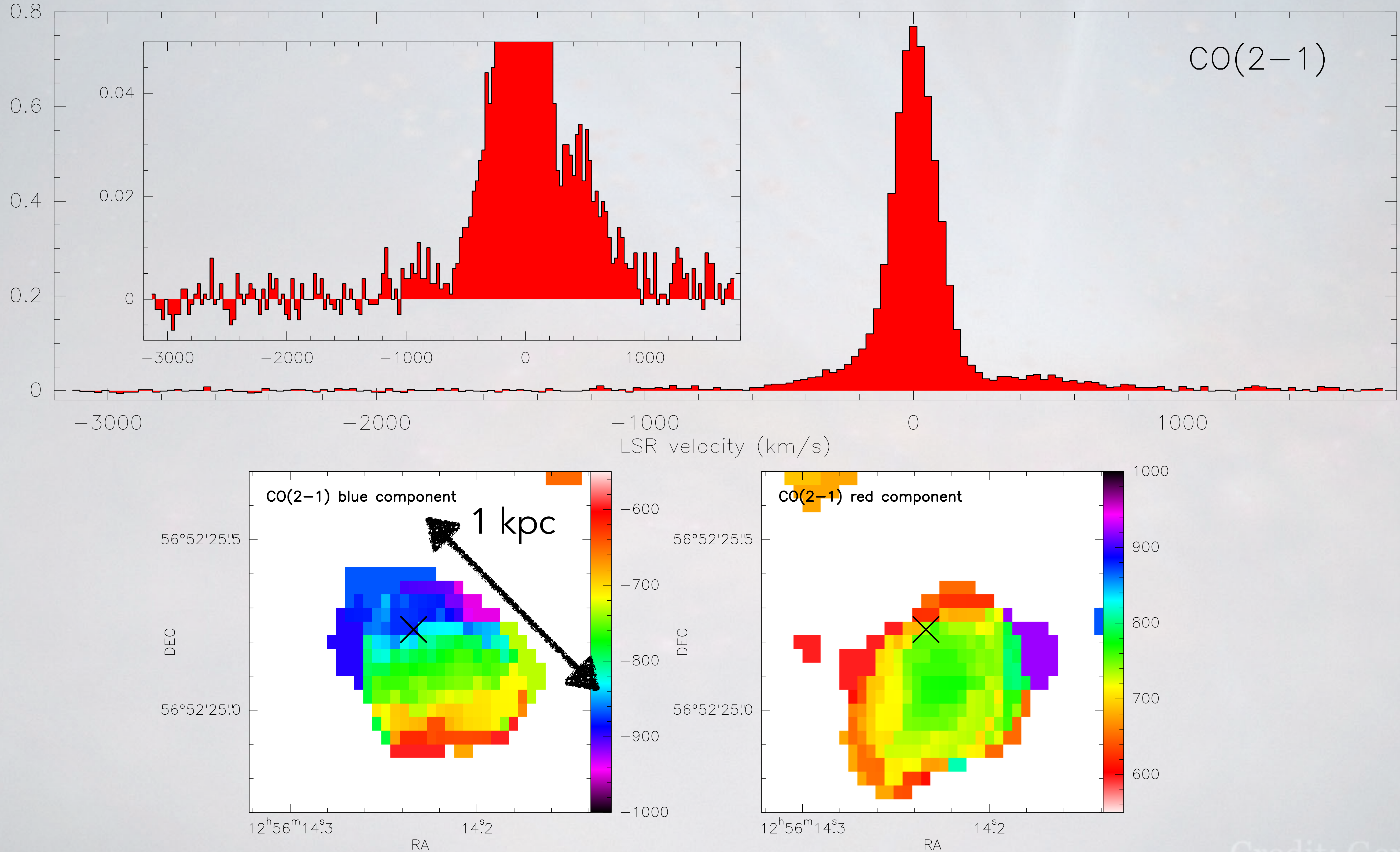
$M_{of} \sim 700\, M_{Sun}/yr$

$L_{bol}/M_{out} \sim 7 \times 10^{42}$ erg/s / M_{Sun}/yr



Outwards: cold outflow mapped

Feruglio+2015, A&A in press

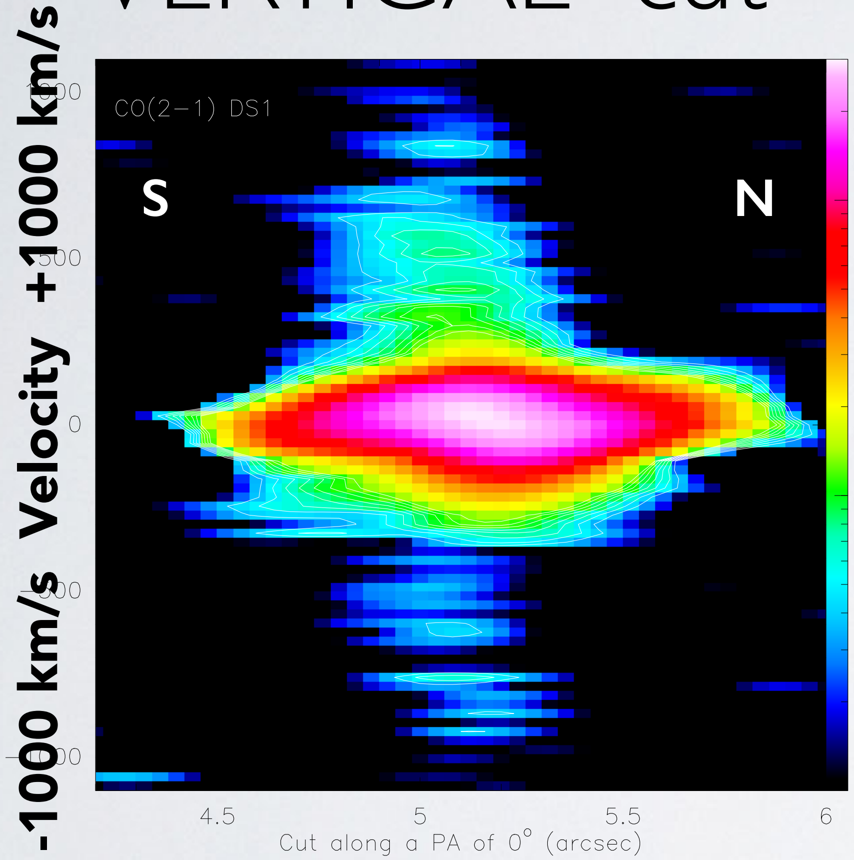


Cold outflow mapped: position-velocity plots

Feruglio+2015, A&A in press

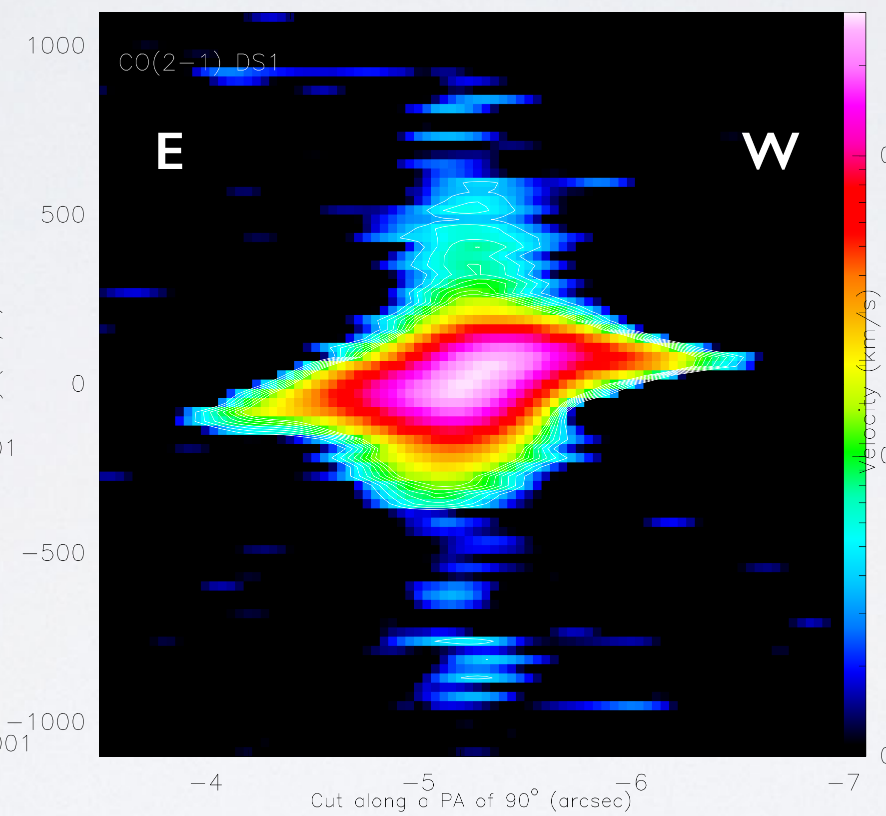
CO(2-1) cuts through peak of emission (=AGN)

VERTICAL cut



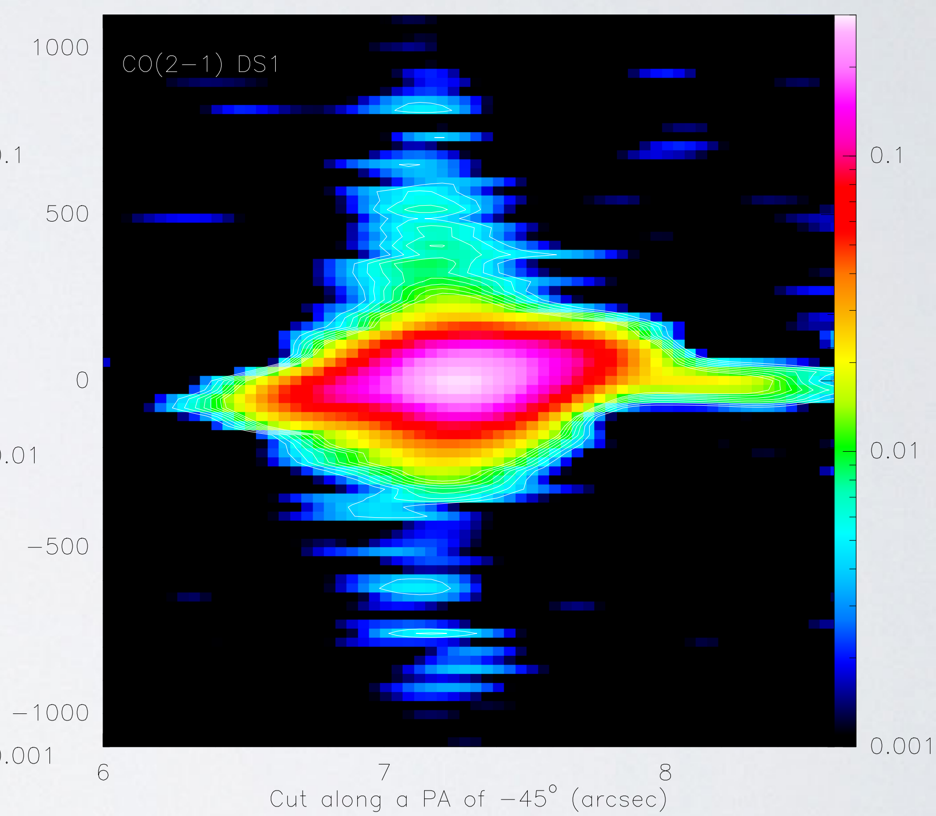
arcsec

HORIZONTAL



arcsec

-45 degrees



arcsec

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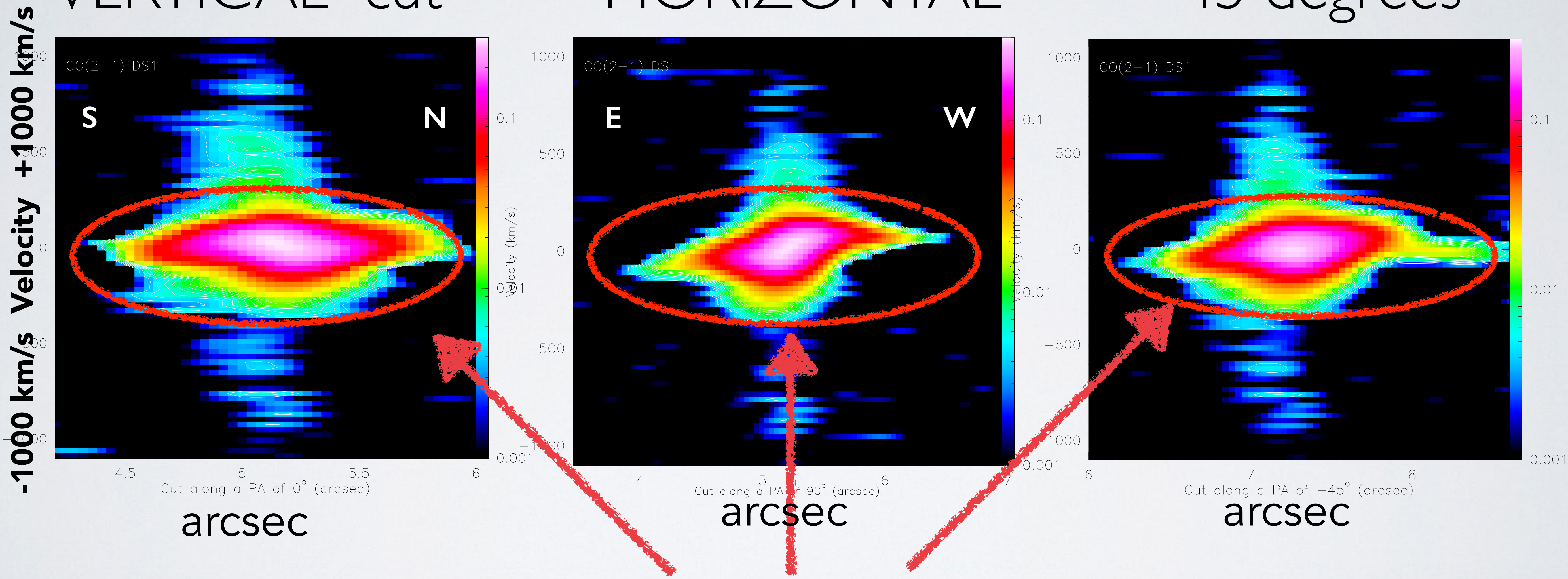
Feruglio+2015, A&A in press

CO(2-1) cuts through peak of emission (=AGN)

VERTICAL cut HORIZONTAL -45 degrees



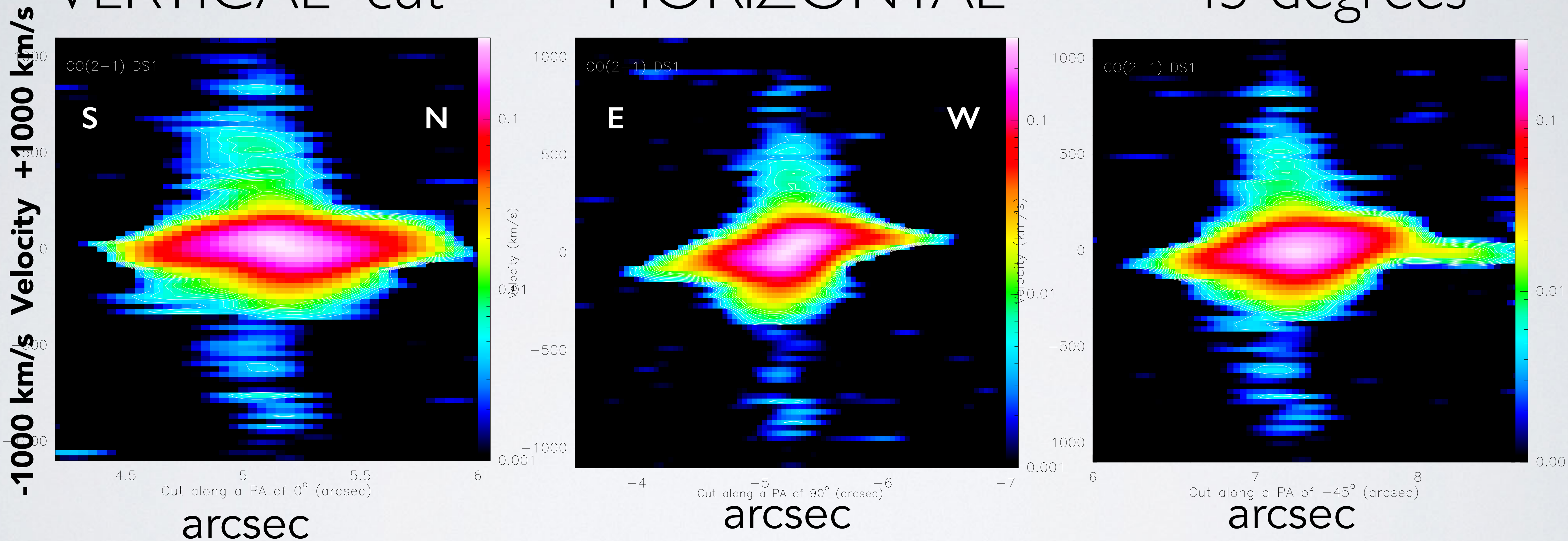
Rotating molecular disk

Cold outflow mapped: position-velocity plots

Feruglio+2015, A&A in press

CO(2-1) cuts through peak of emission (=AGN)

VERTICAL cut HORIZONTAL -45 degrees



Cold outflow mapped: position-velocity plots

Feruglio+2015, A&A in press

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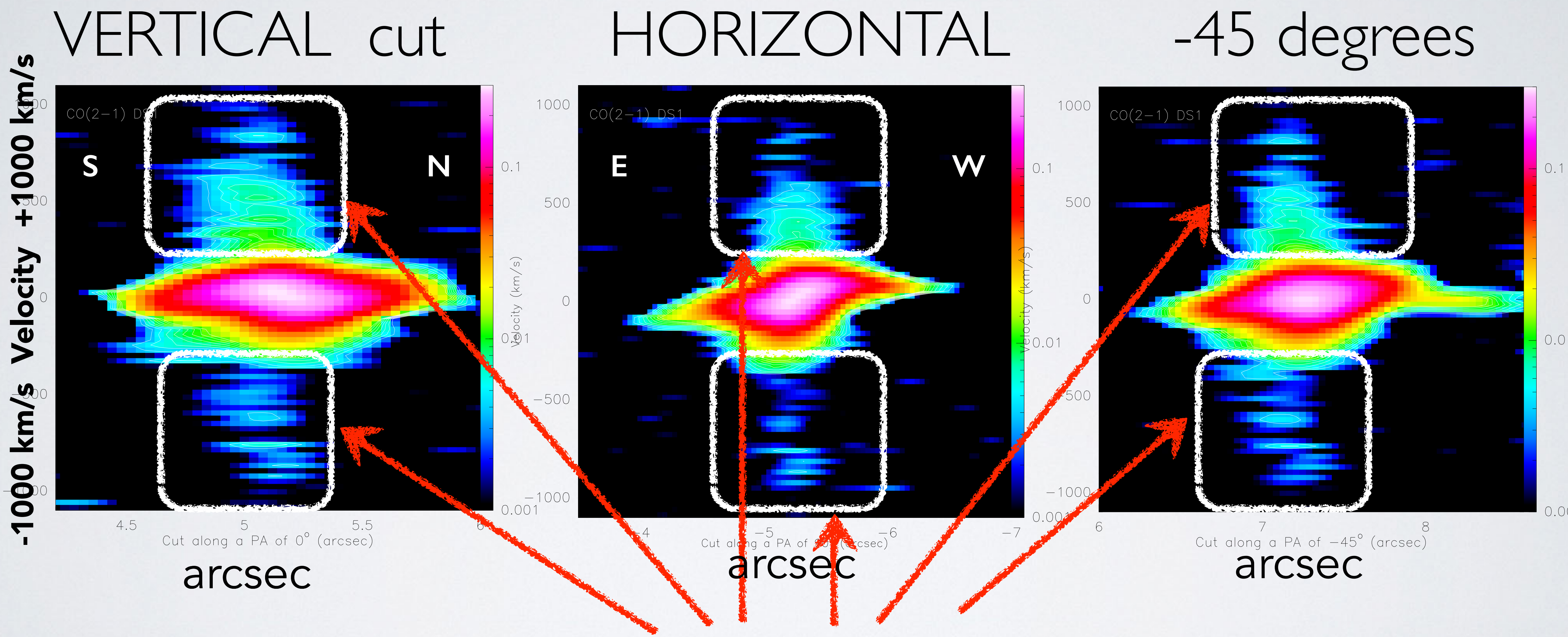
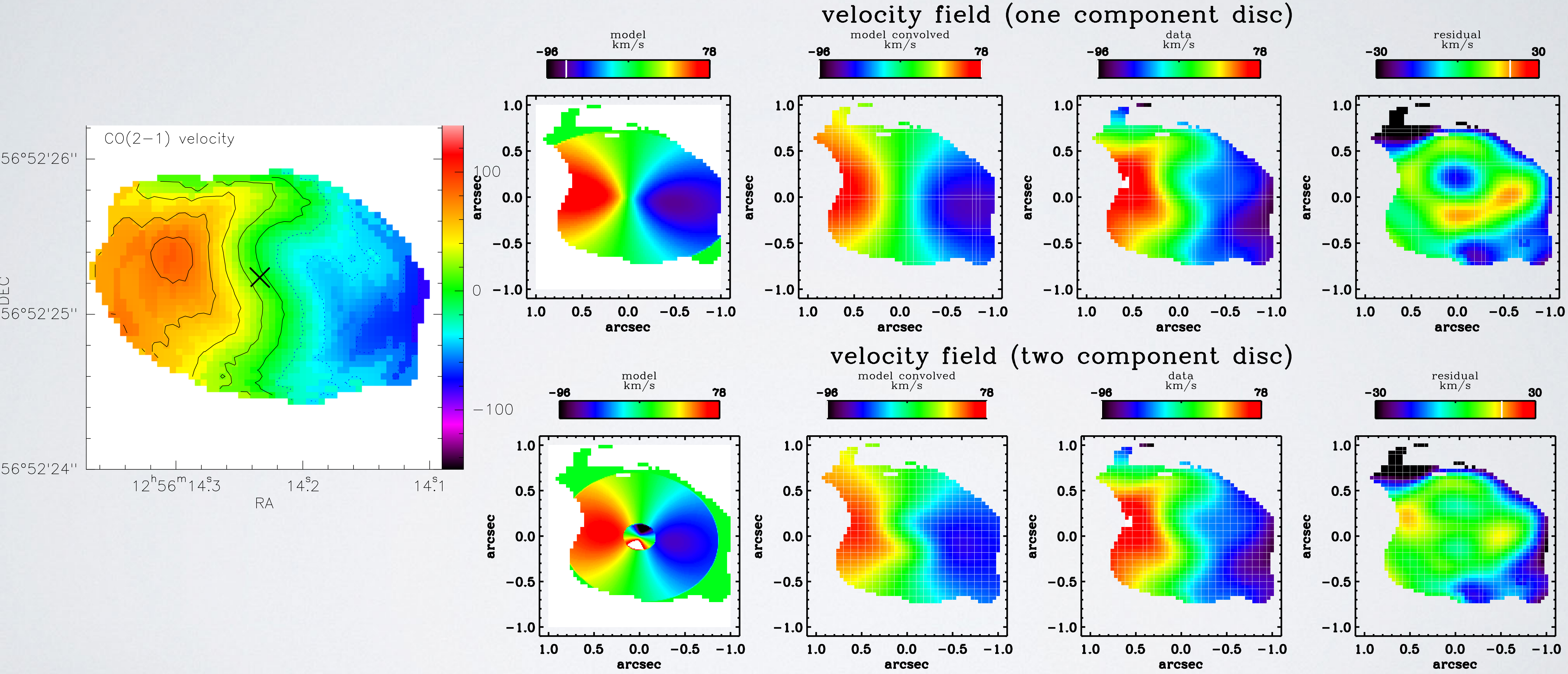


Molecular outflow with wide opening angle

Warped molecular disk

Outer rotating molecular disk seen face on +
Inner warped disk with radius 80-100 pc, 60 deg inclined on l.o.s.

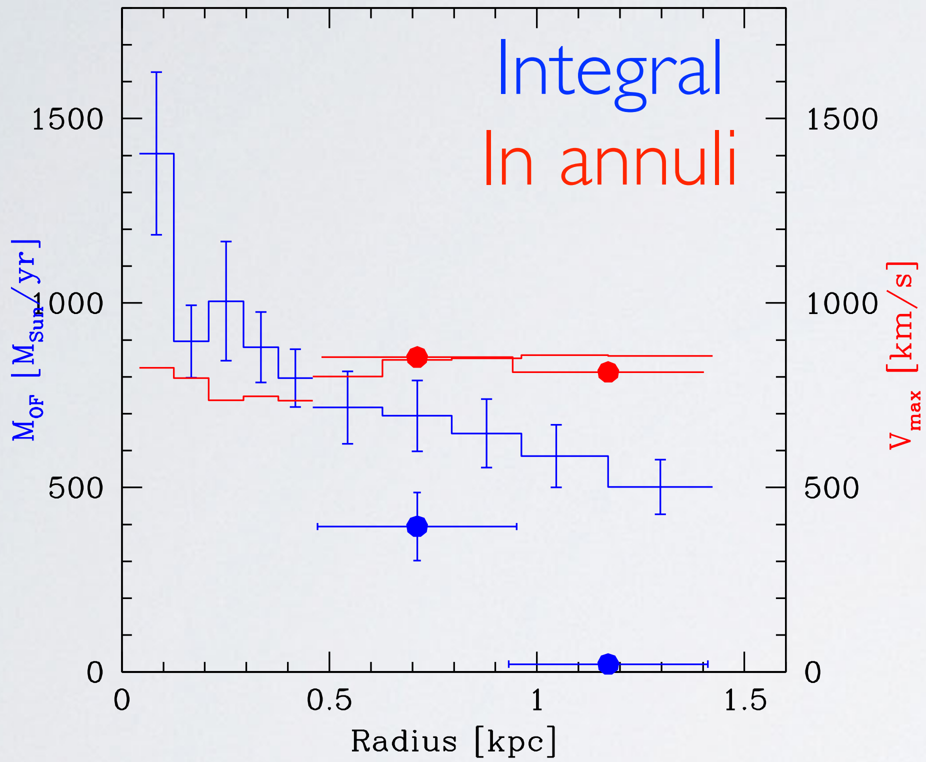


seen also in HCN vibrational transition Aalto+2014

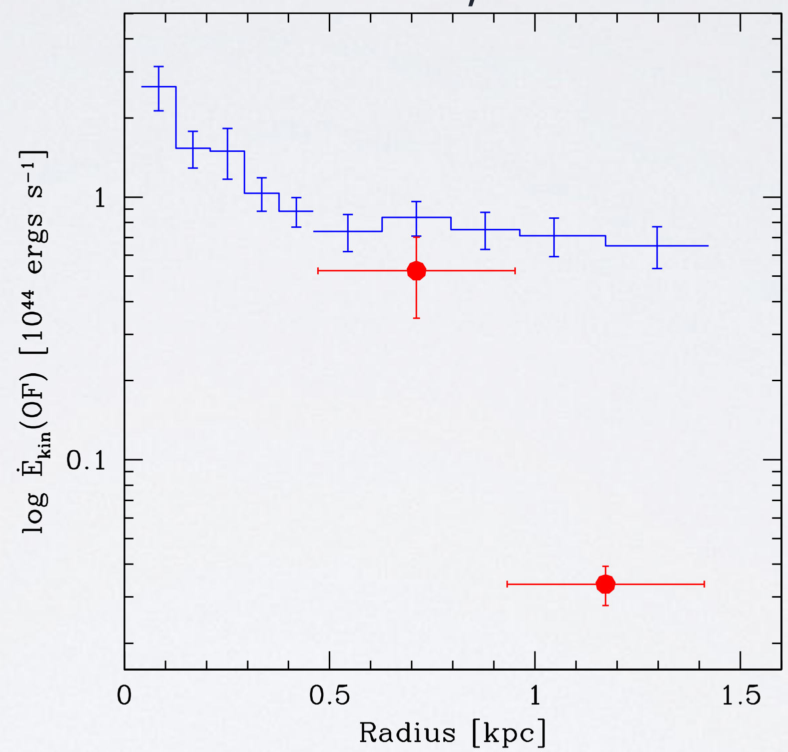
$\dot{M}_{OF}$, $\dot{E}_{kin,OF}$ and M_{OF}/M_{disk} radial profiles

Spectra from regions centered on the nucleus and with increasing sides, Gaussian fit to model rotating disk and outflow components, vmax = v98% = velocity shiftbroad + 2σbroad , $\dot{M}_{OF} = 3 \times v_{max} \times M_{OF}/R_{OF}$

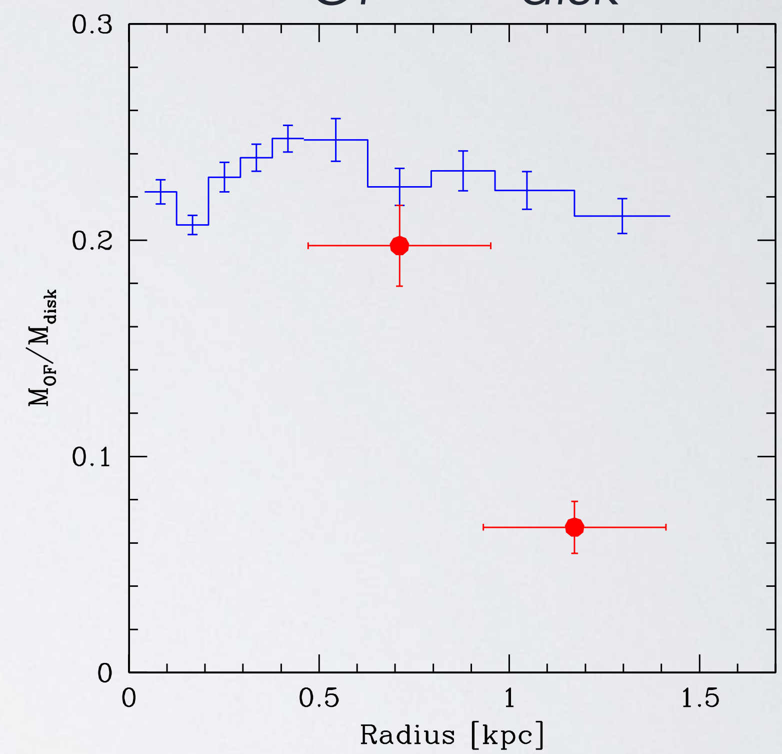
$\dot{M}_{OF}$



$\dot{E}_{kin,OF}$



M_{OF}/M_{disk}



$\dot{M}_{OF} = [500 - 1000]\ M_{\odot}\ yr^{-1}$ $\dot{E}_{kin,OF} = [7 - 10] \times 10^{43}$ erg s^{-1} OF mass ~ 20% disk mass

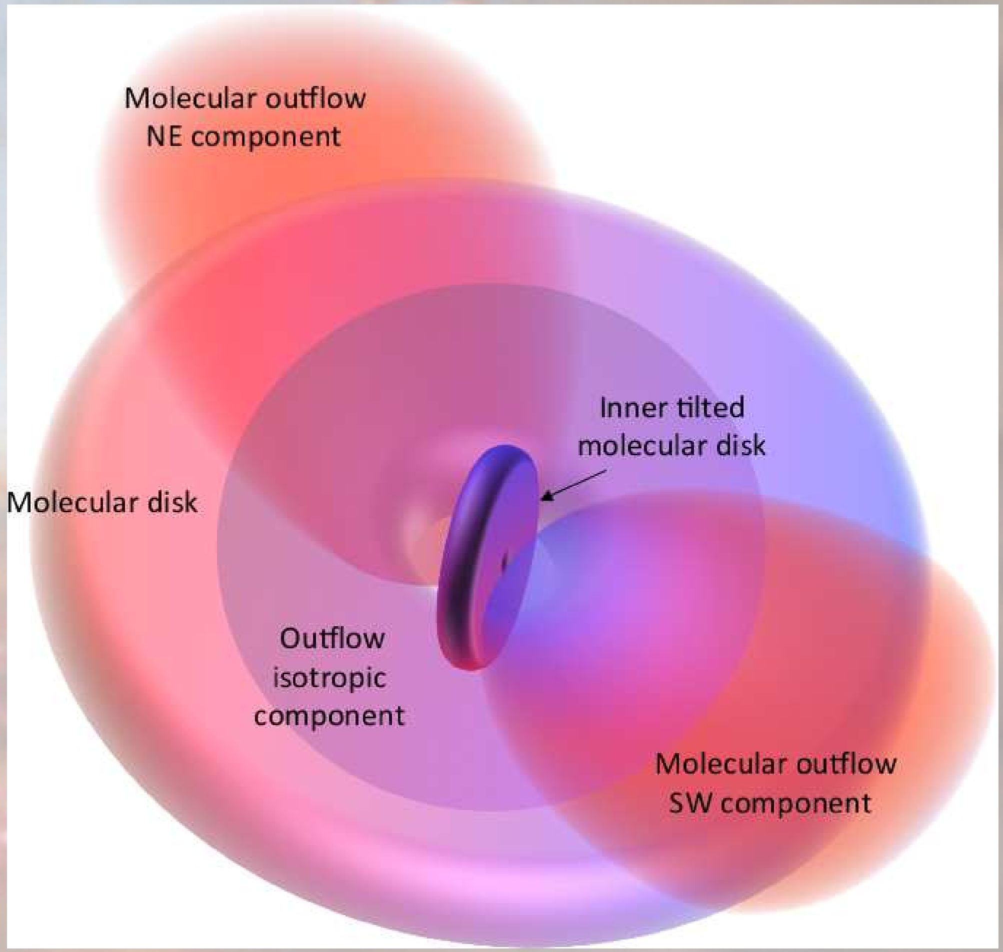
v_{max} ~ constant out to ~1 kpc

Implies OF density decrease from the nucleus outwards as ~ r^{-2} : either a large part of the gas leaves the flow during expansion, or bulk of the OF not yet reached 1 kpc (limiting age of 1 Myr)

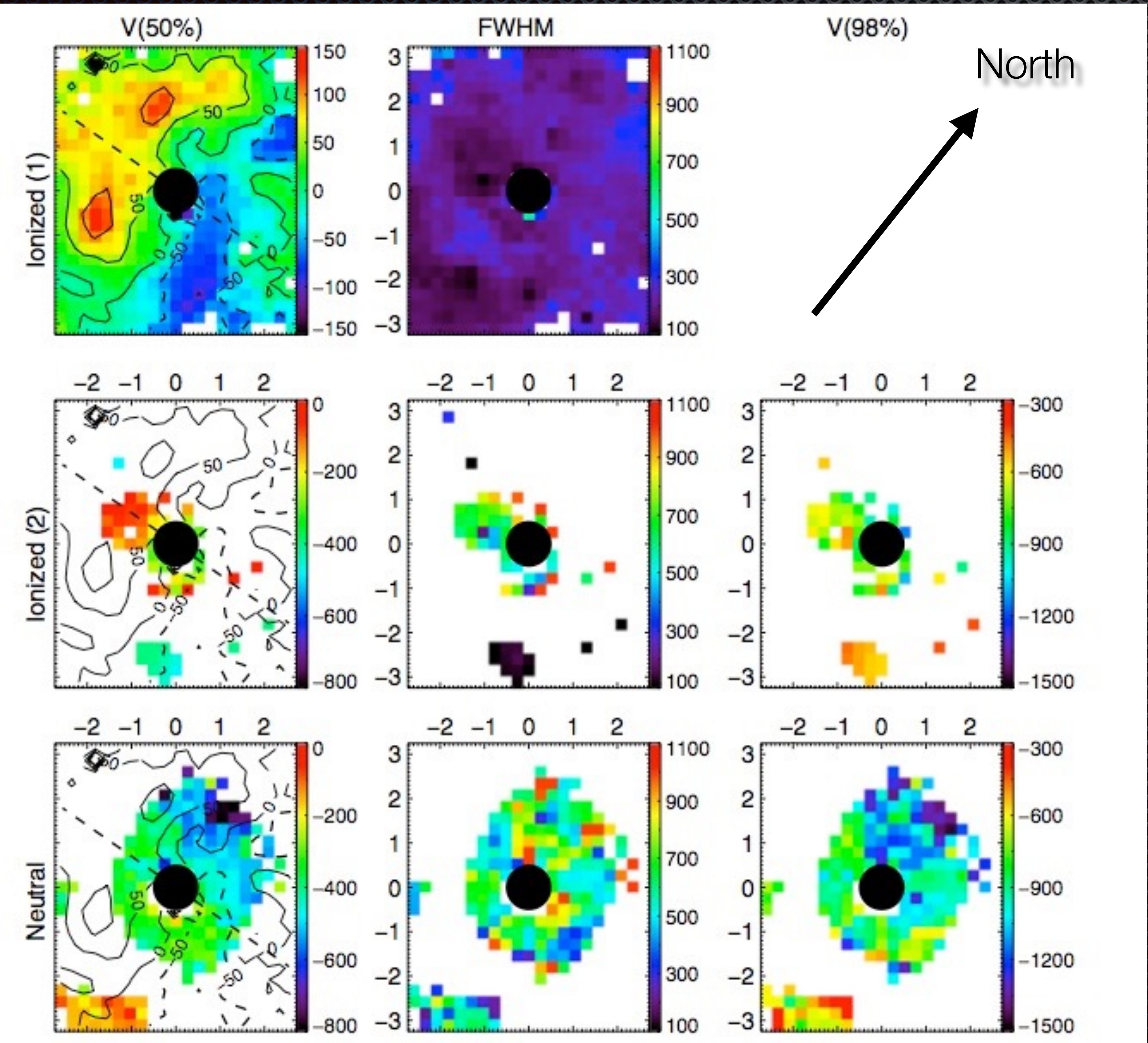
Markarian 231 Summary

- Complex kinematics (2 component disk+ outflow)
- Cold outflow out to ~ 1kpc
  + nuclear semi relativistic wind
- Energy-conserving outflow
- What fate for the fast cold gas?

Energy is large enough to leave the halo
but size <~ 1 kpc.
If density decreases as $\sim r^{-2}$
molecular clouds dissolve
but outflow may be visible in atomic ionized phase

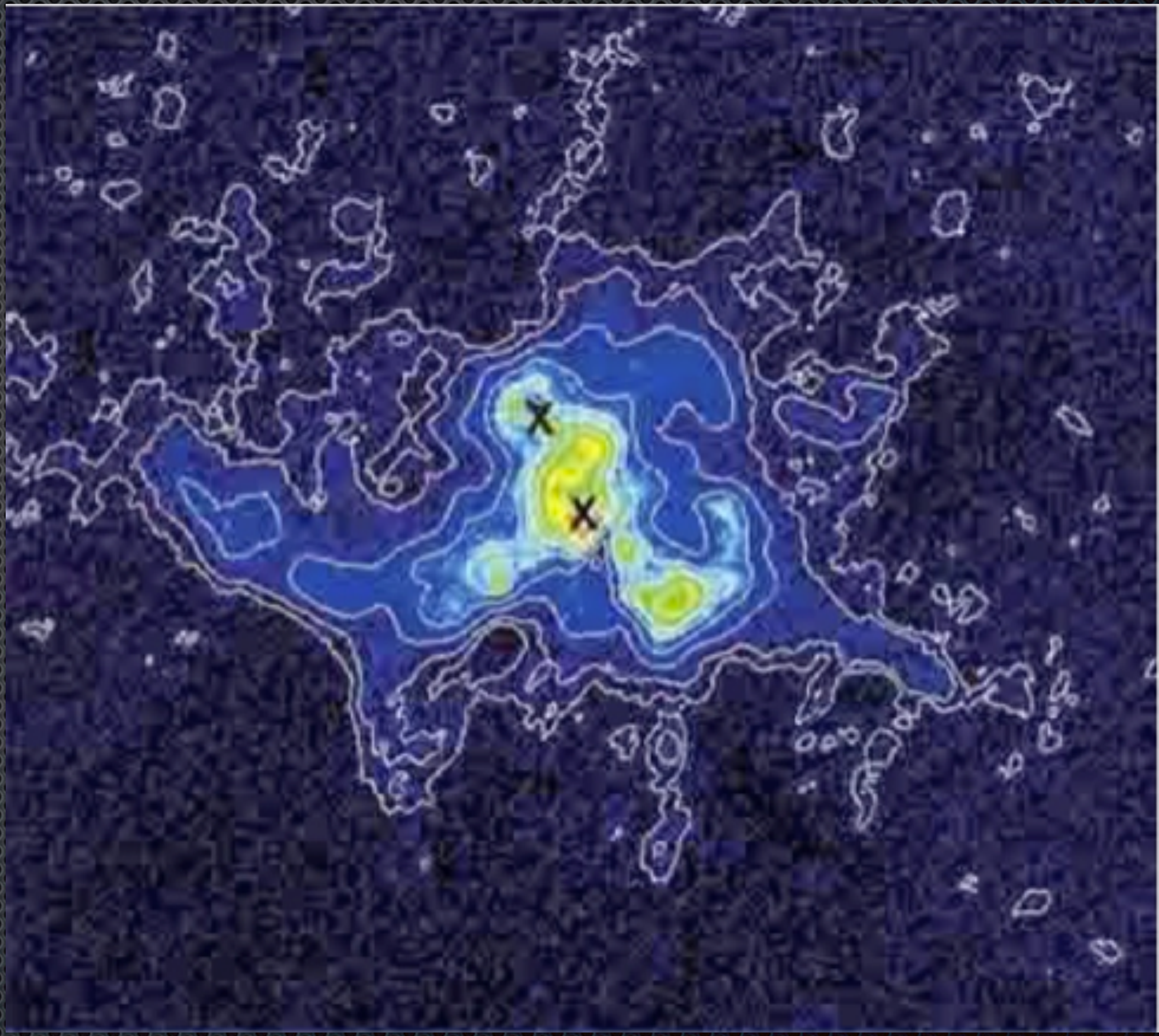


Mark 231 atomic gas outflow



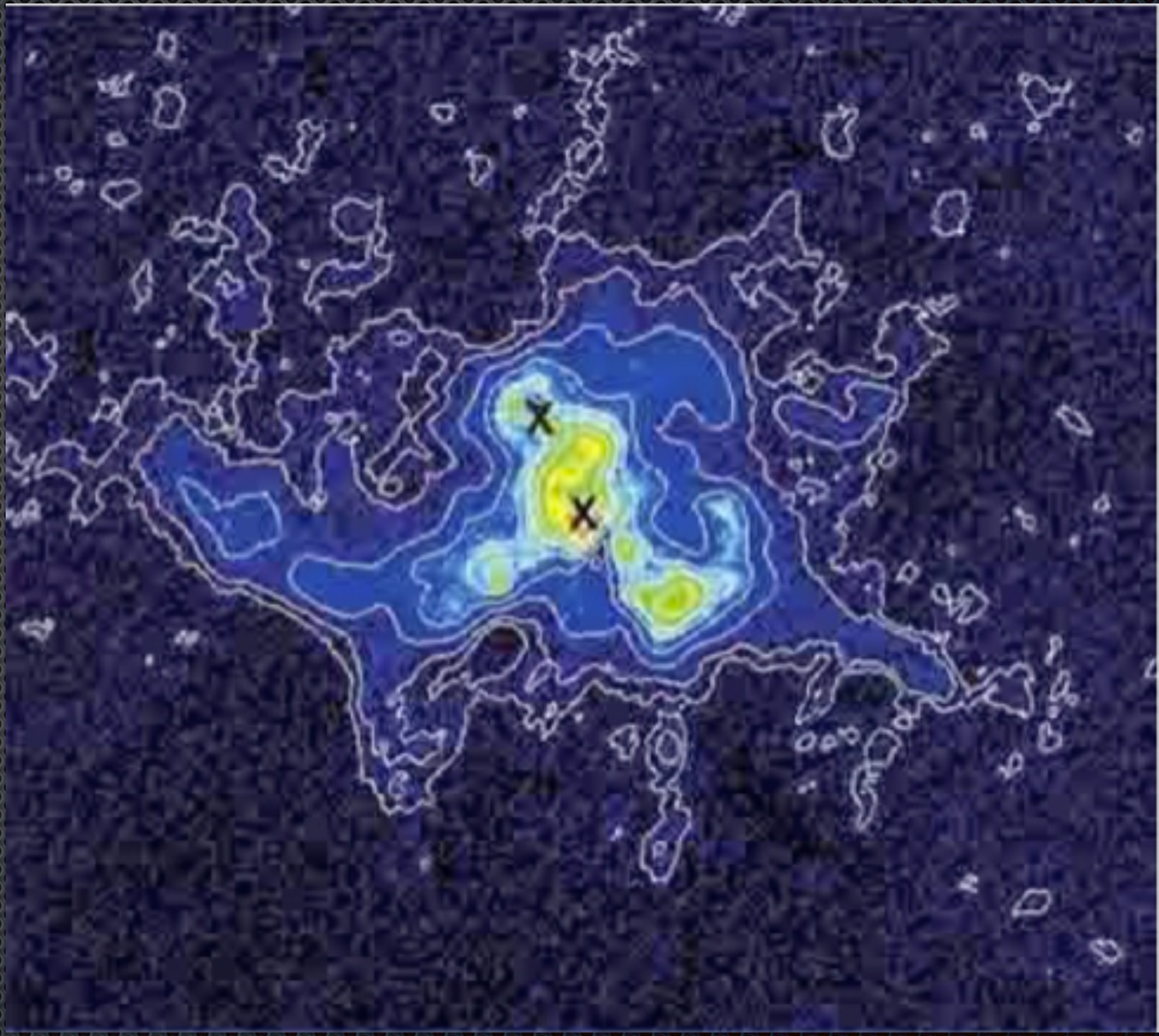
- Narrow ionized lines=disk
- Broad ionized lines=outflow
- Neutral gas, NaI absorption = outflow
- Rupke&Veilleux 2011,2013

The case of NGC 6240



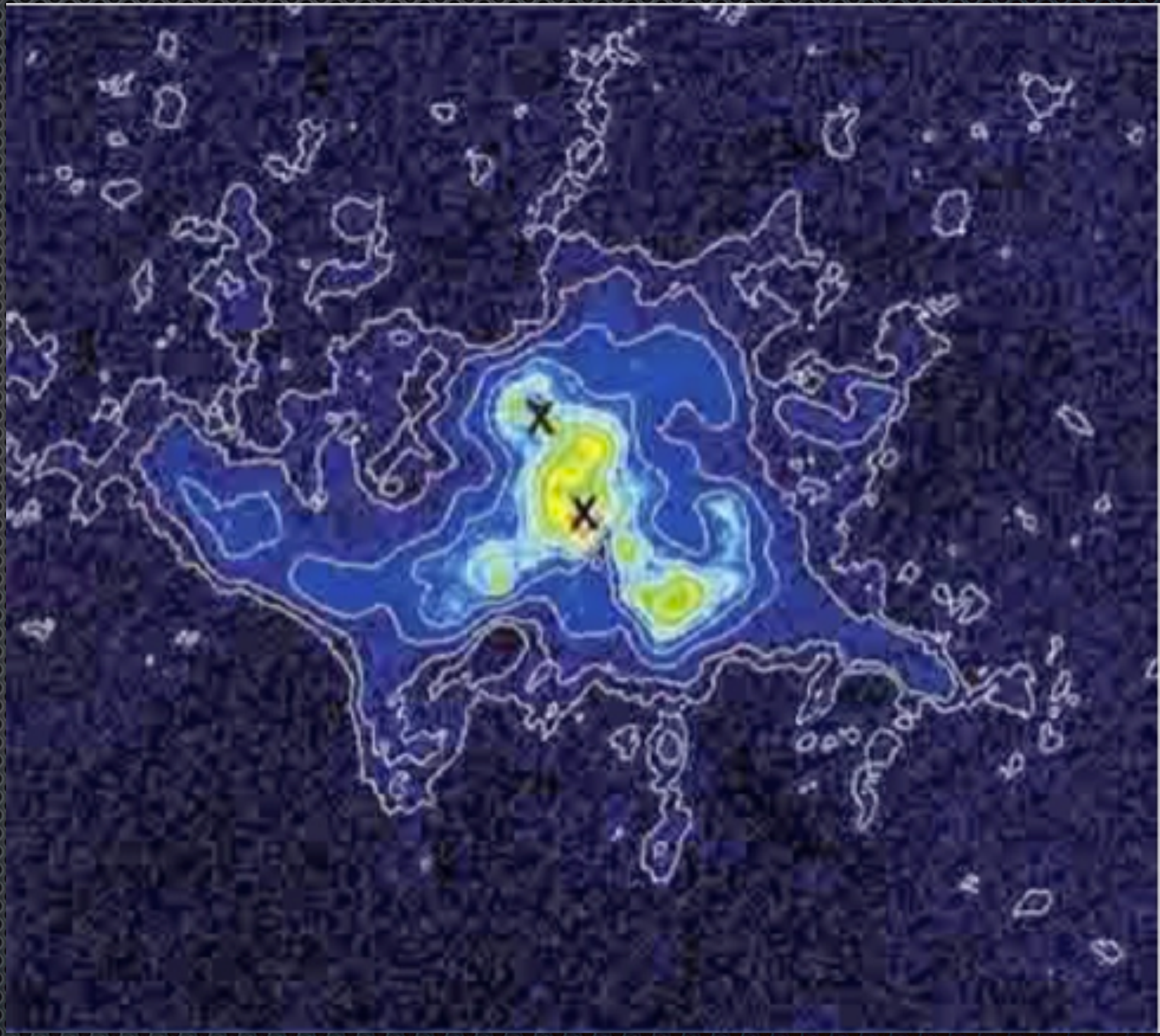
The case of NGC 6240

Major merger in early stage,



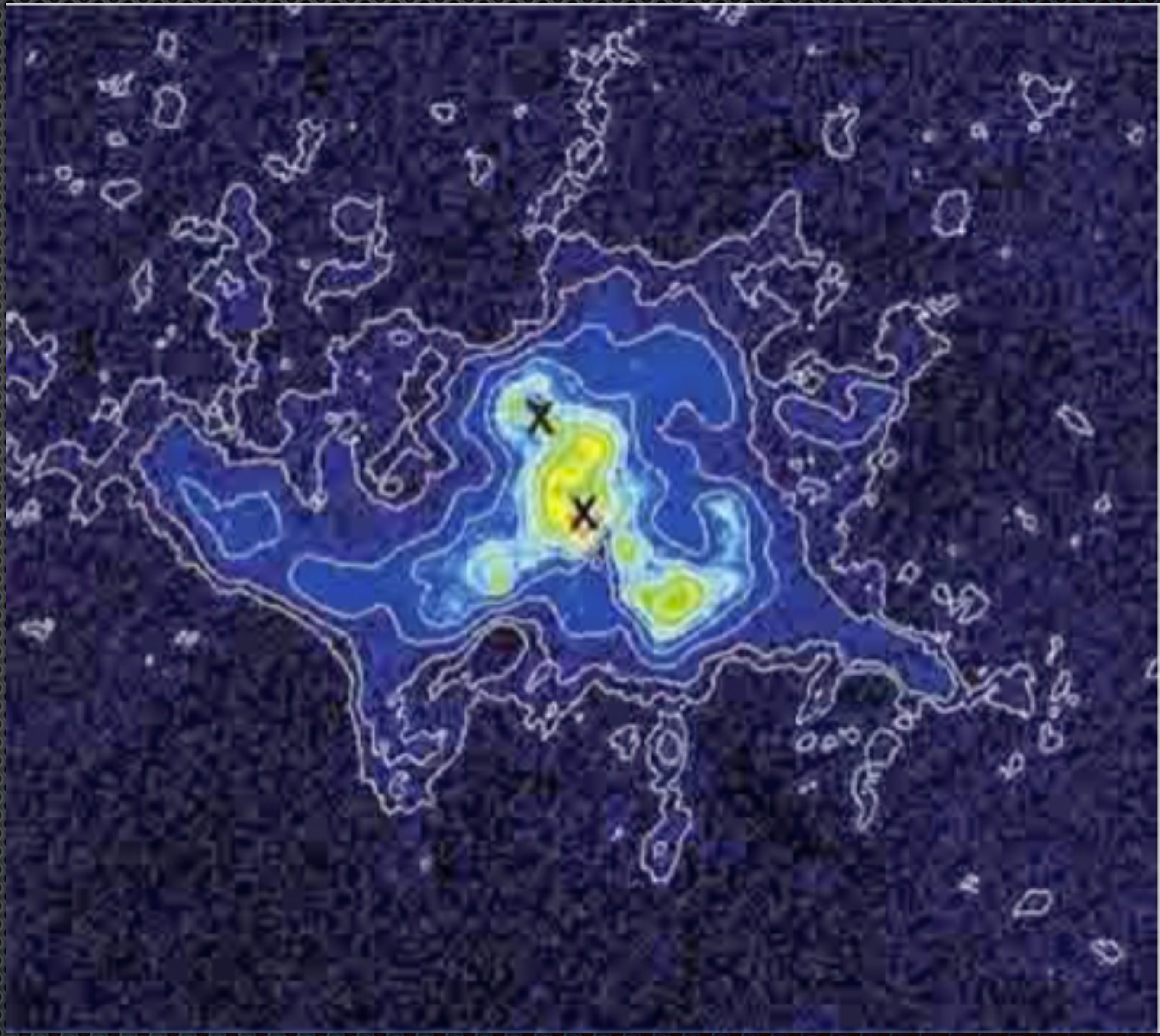
The case of NGC 6240

Major merger in early stage,
with complex morphology,



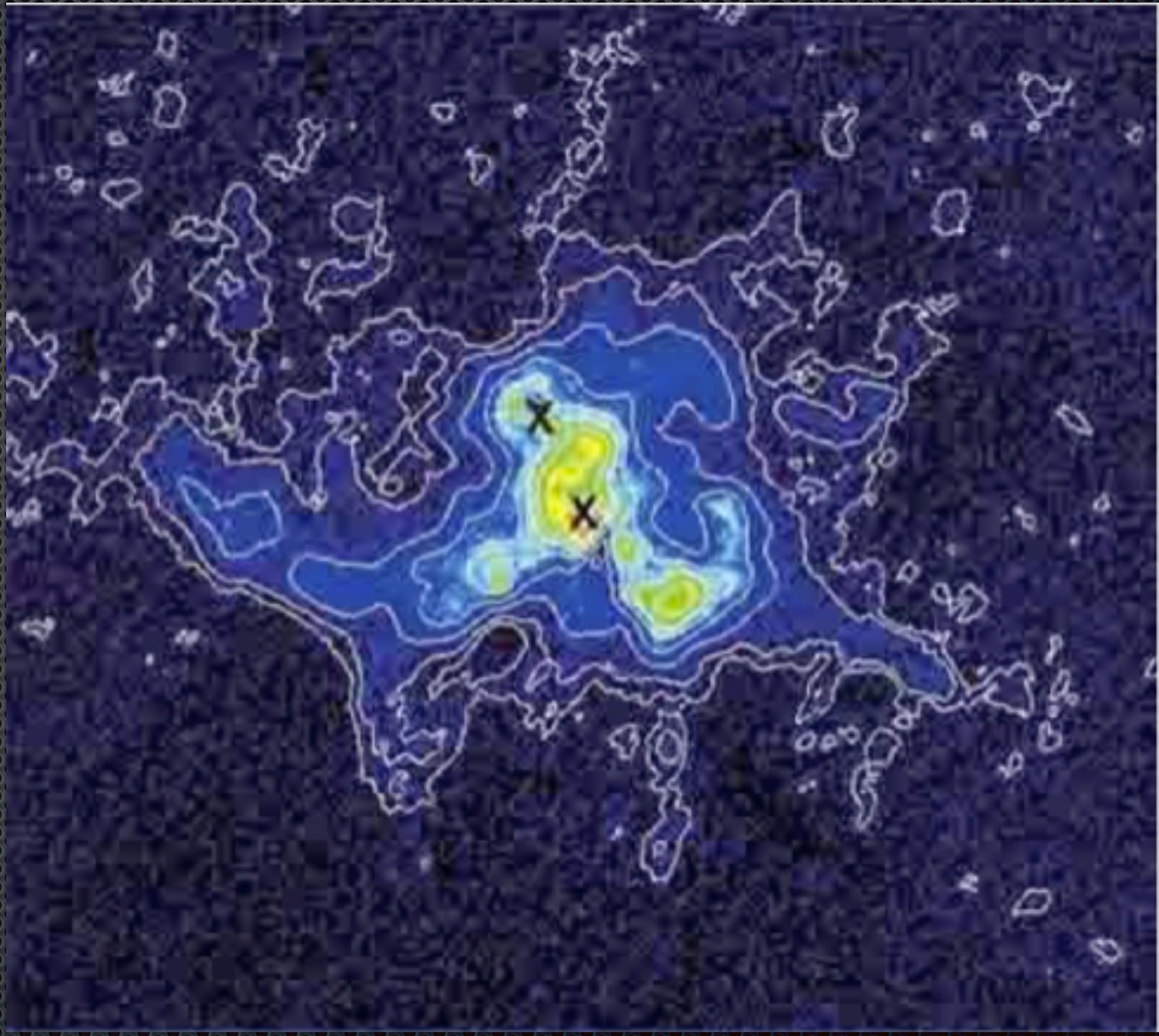
The case of NGC 6240

Major merger in early stage, with complex morphology, streamers, tidal tails,



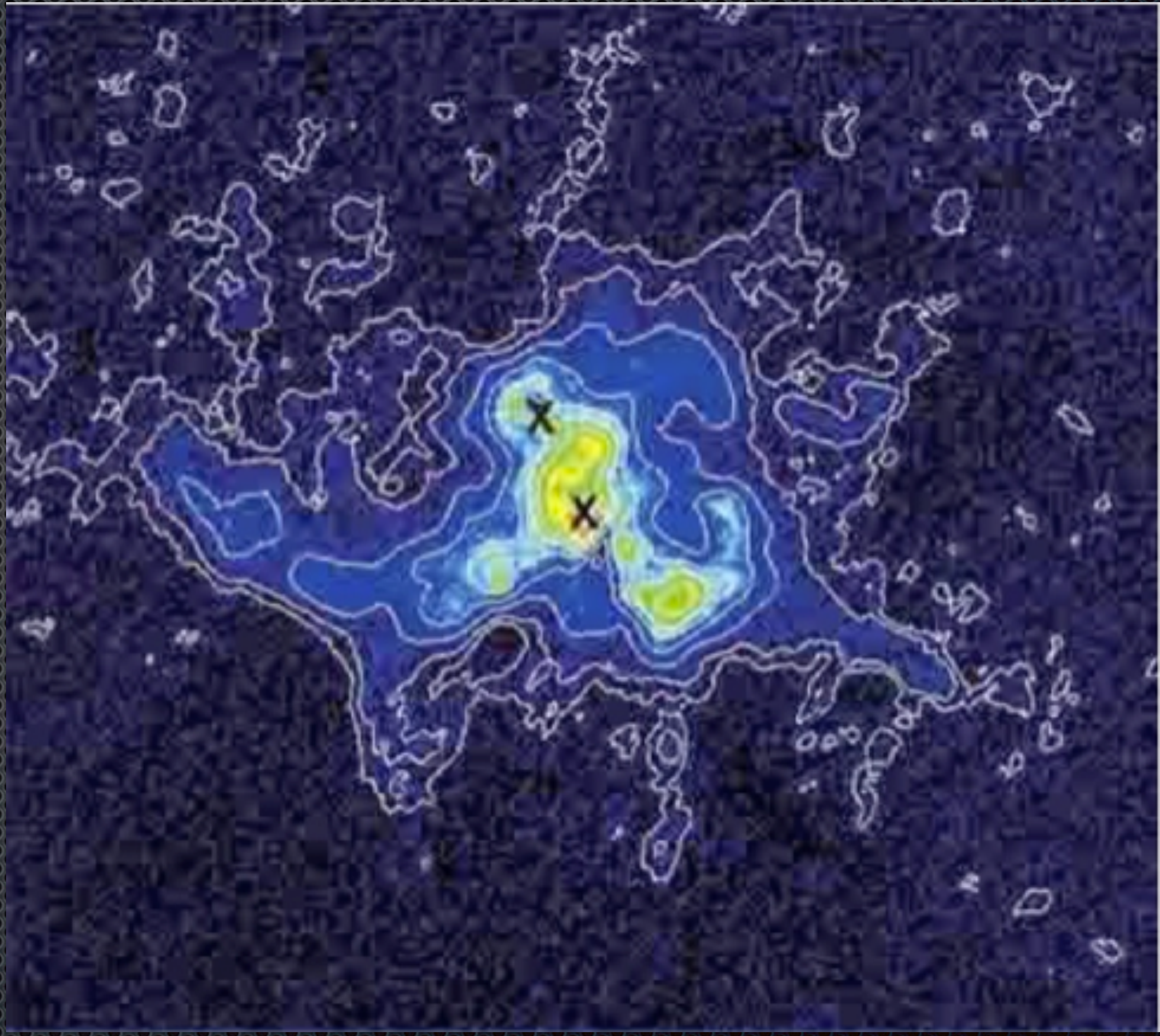
The case of NGC 6240

Major merger in early stage, with complex morphology, streamers, tidal tails, and 2 AGN nuclei



The case of NGC 6240

Major merger in early stage,
with complex morphology,
streamers, tidal tails,
and 2 AGN nuclei
both heavily obscured,



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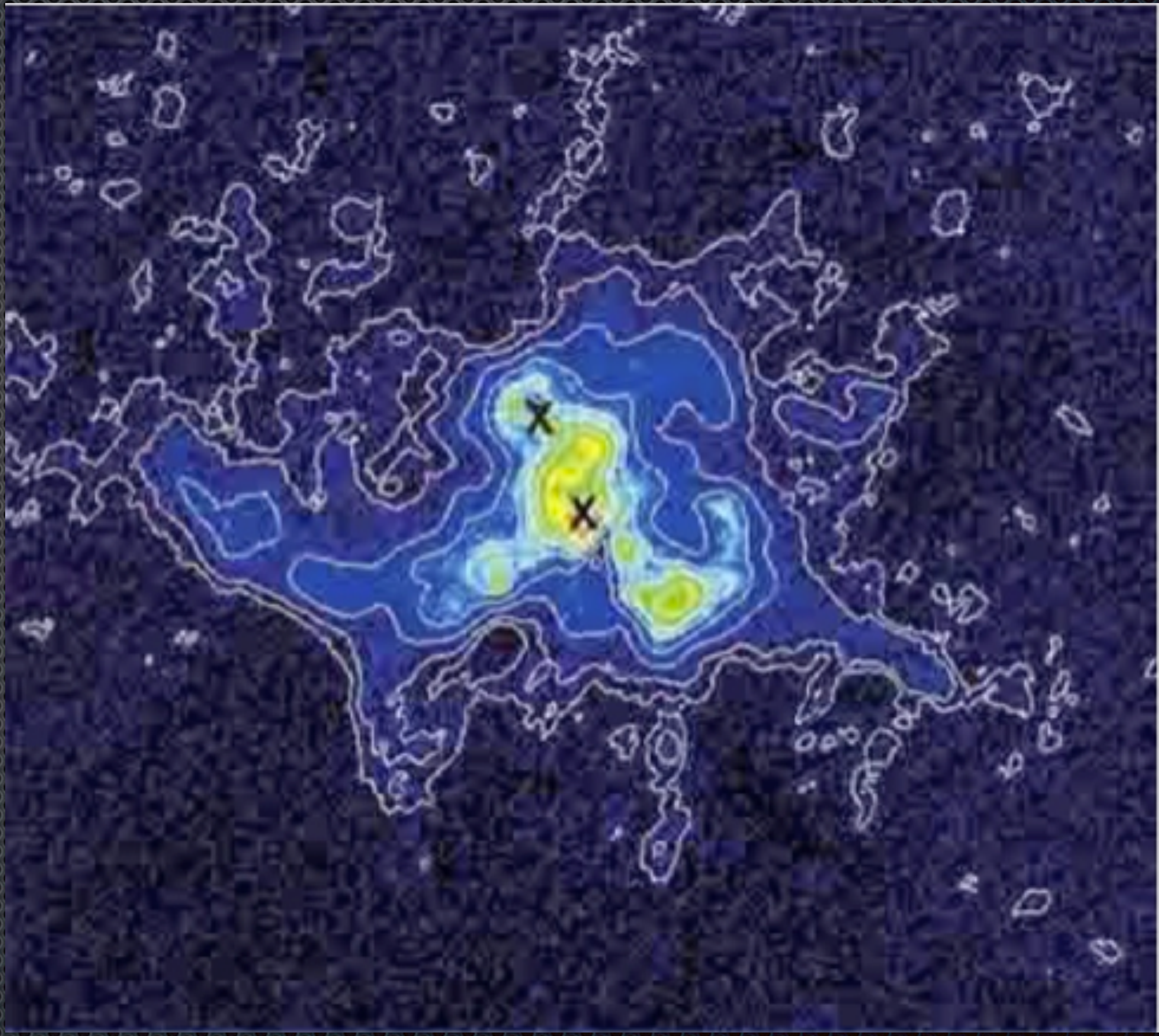
with L(2-10) keV > 10^{44} erg/s
and MBH > 10^8 $M_\odot$



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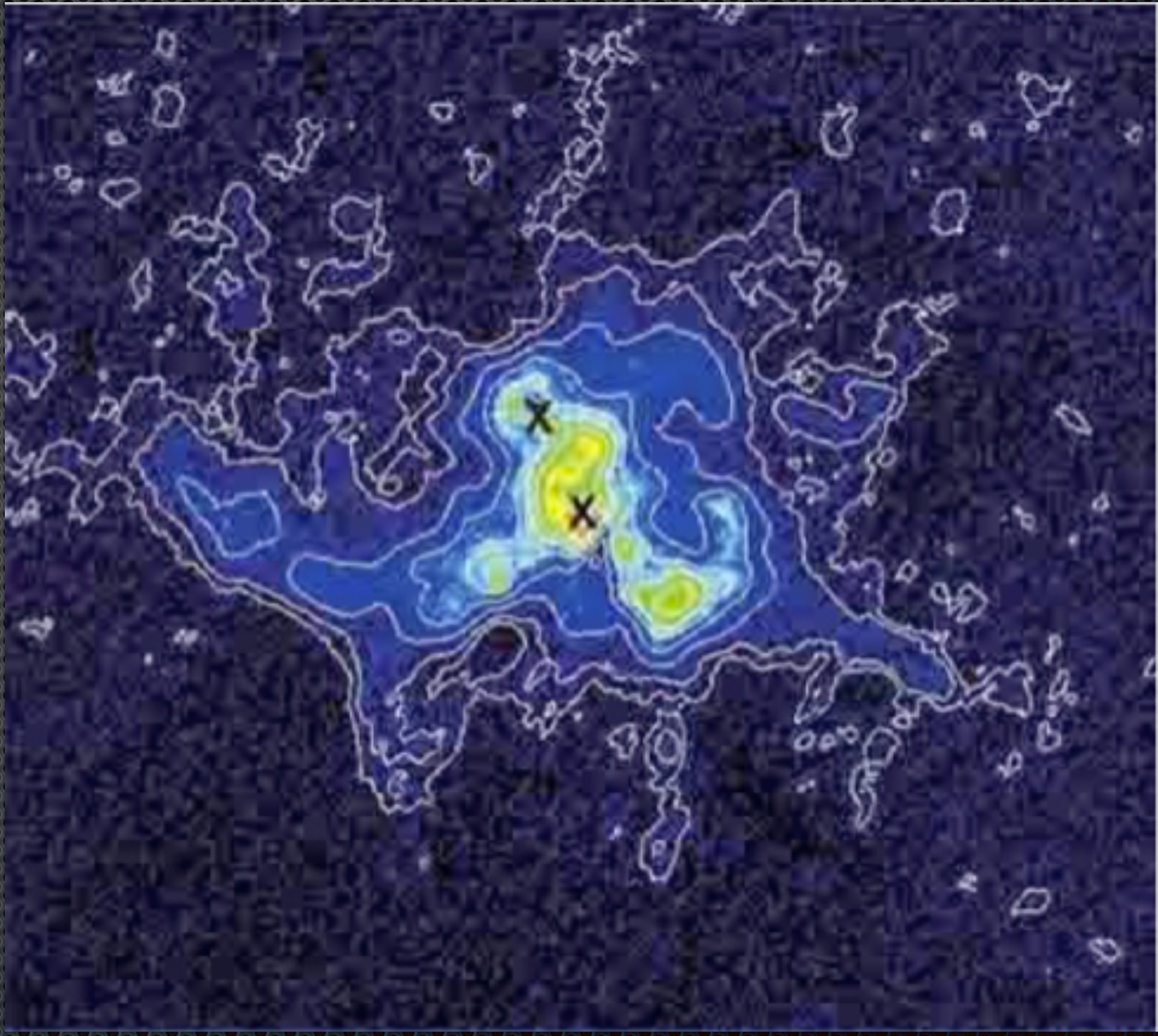
SEVERAL MECHANISMS in ACTION !!



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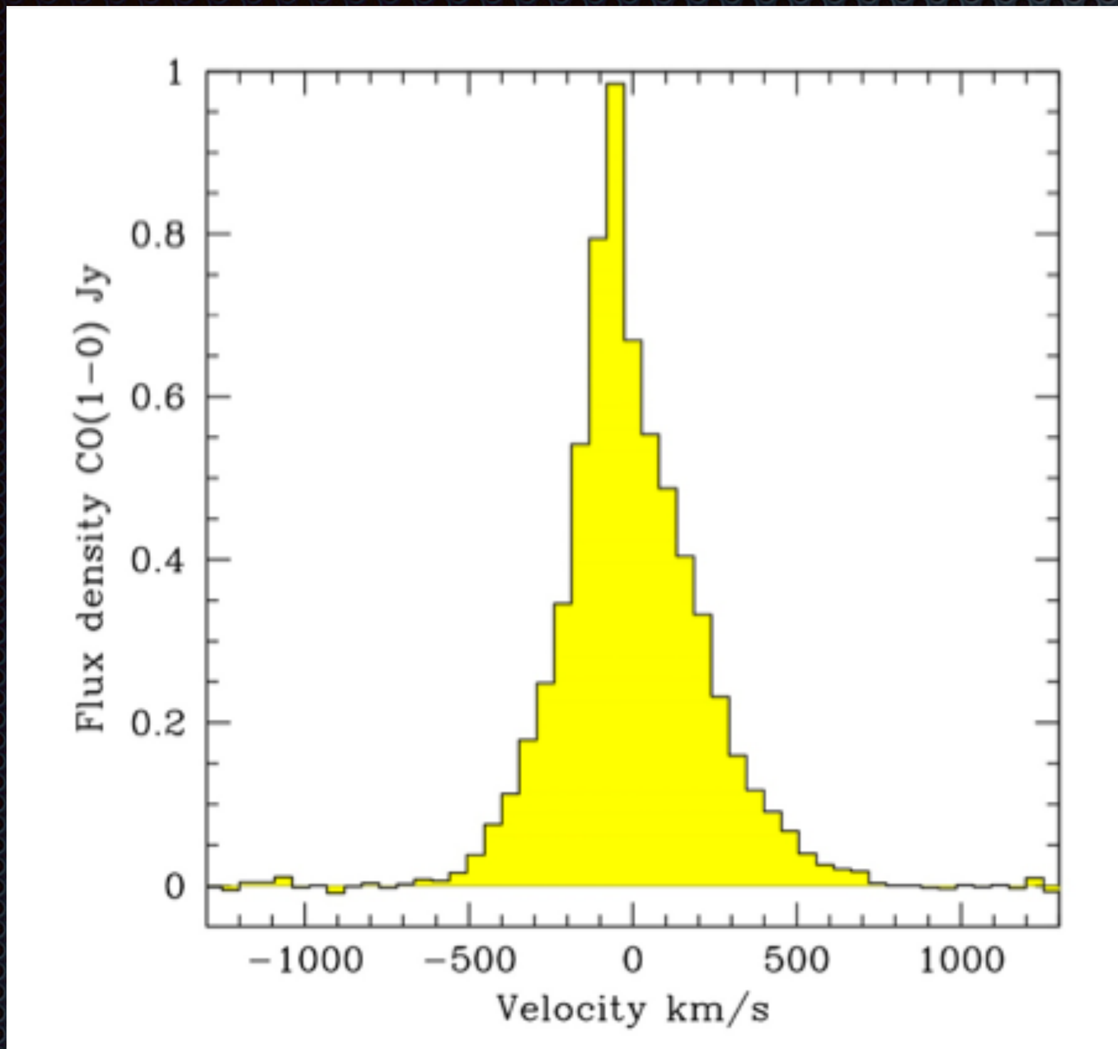

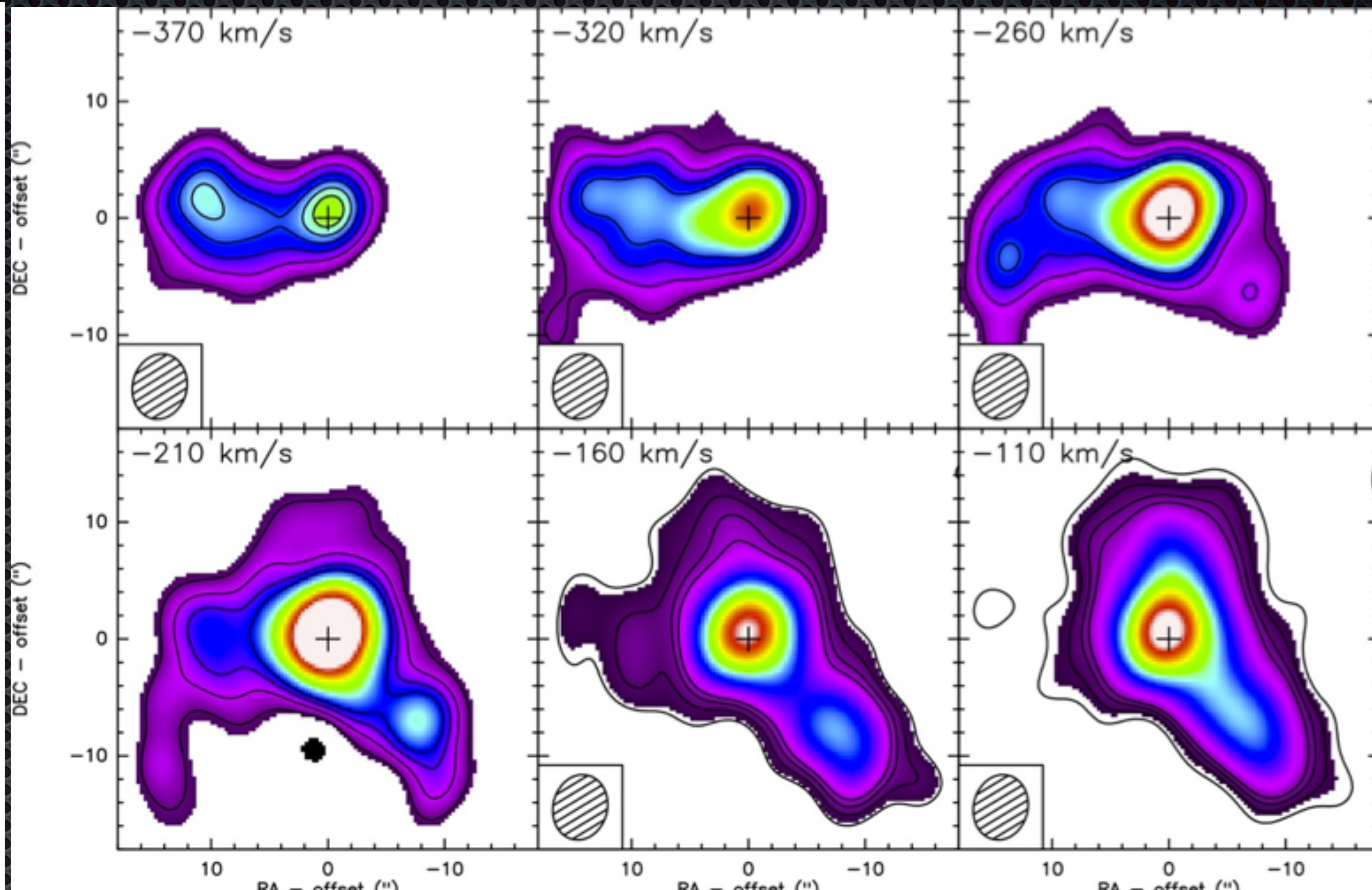

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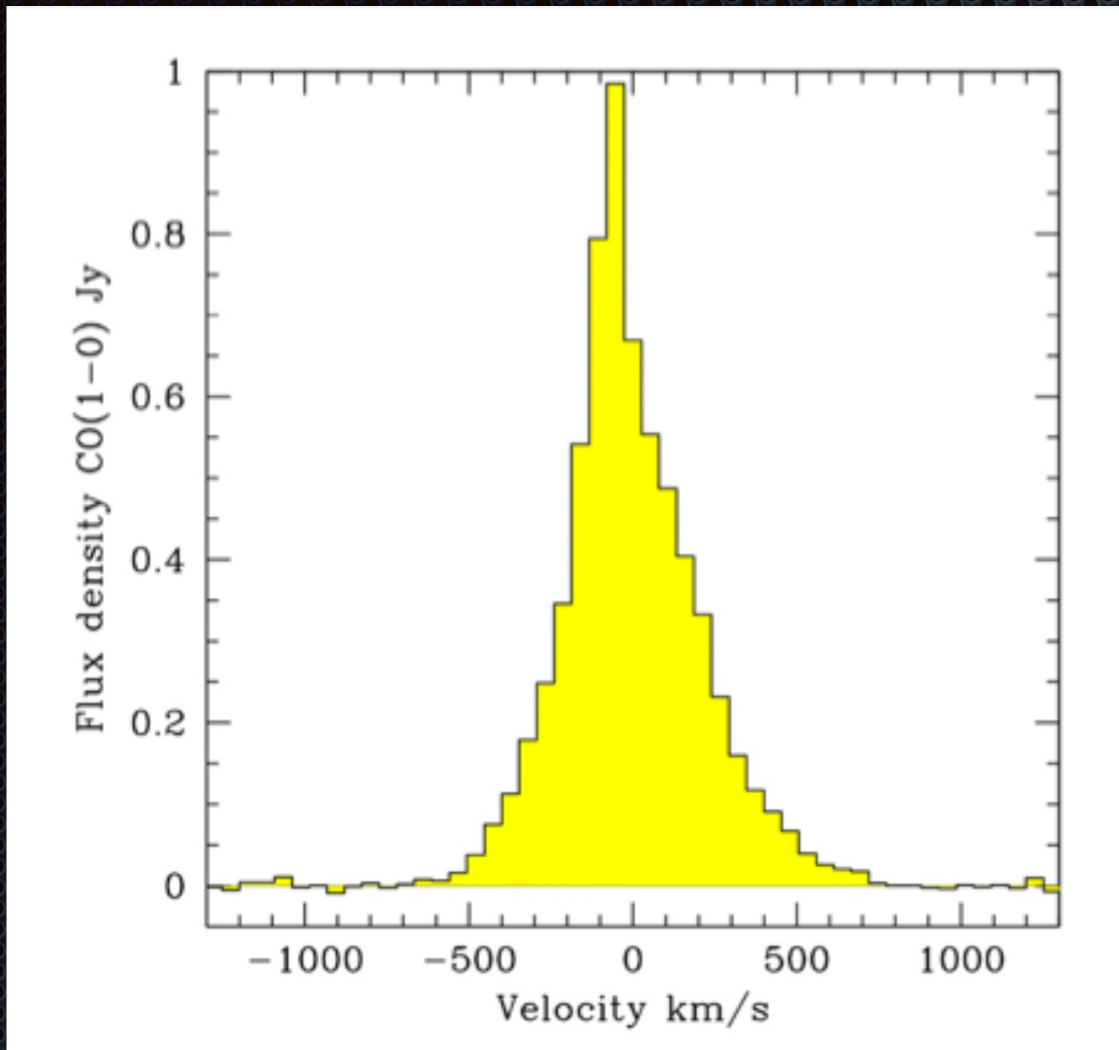
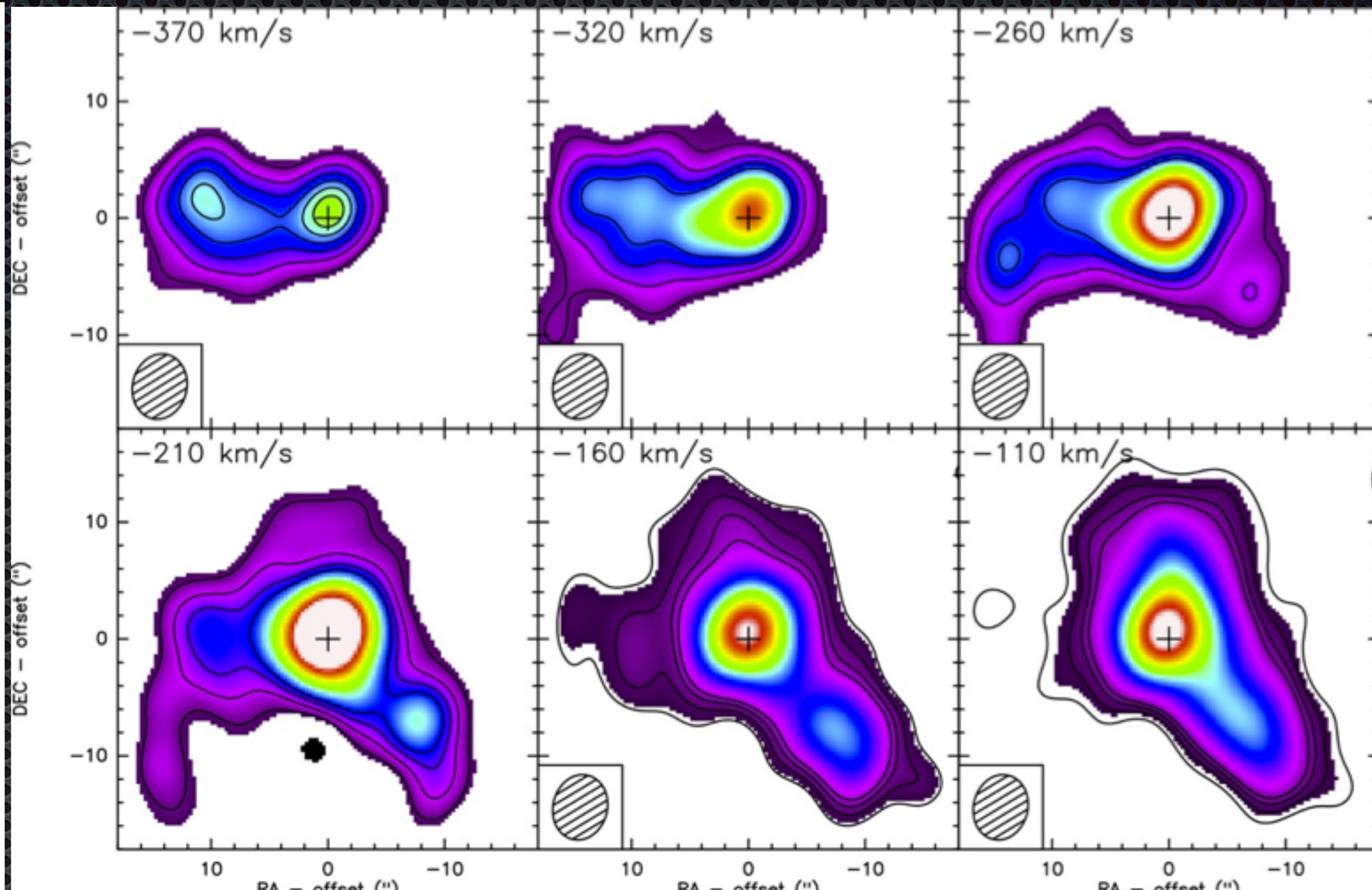
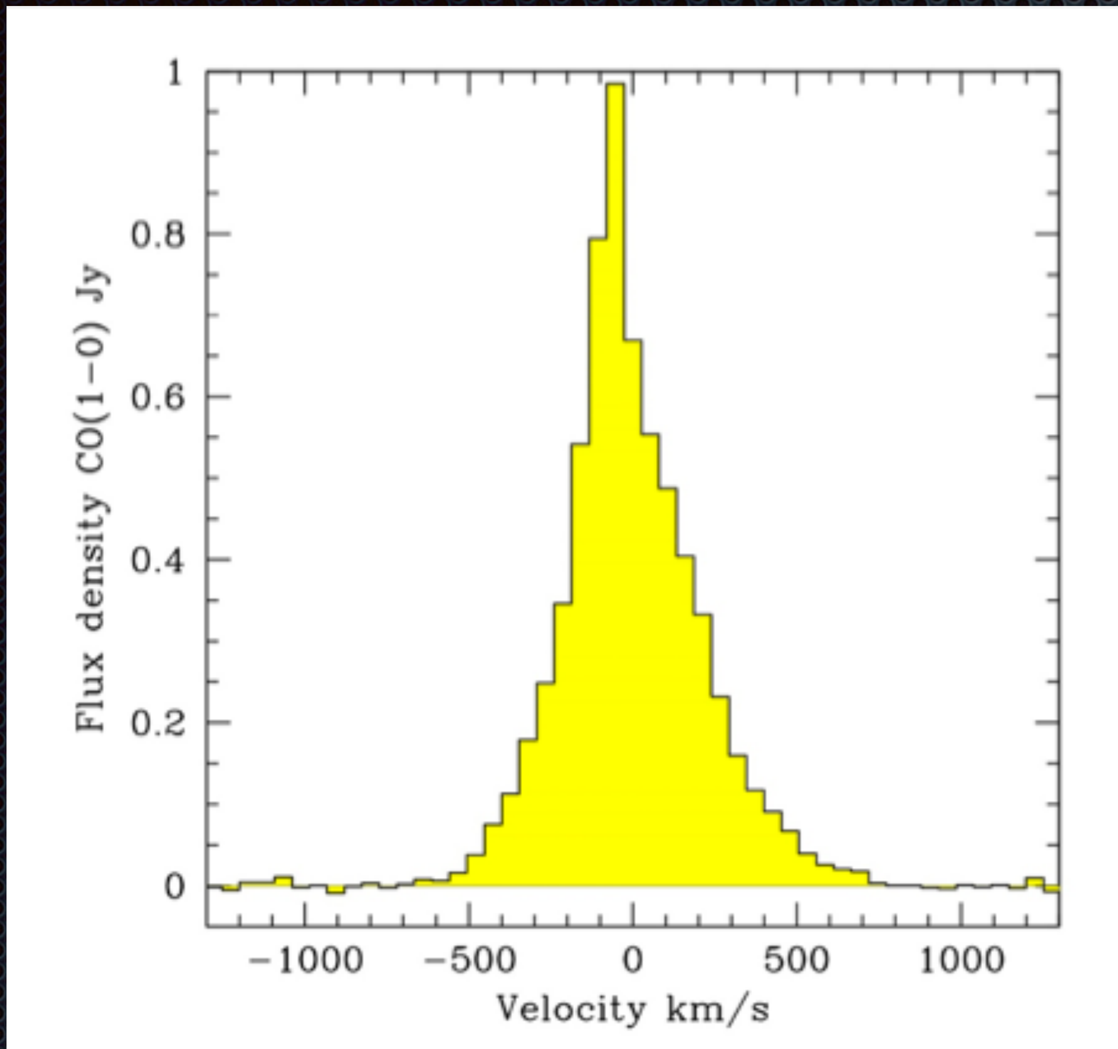
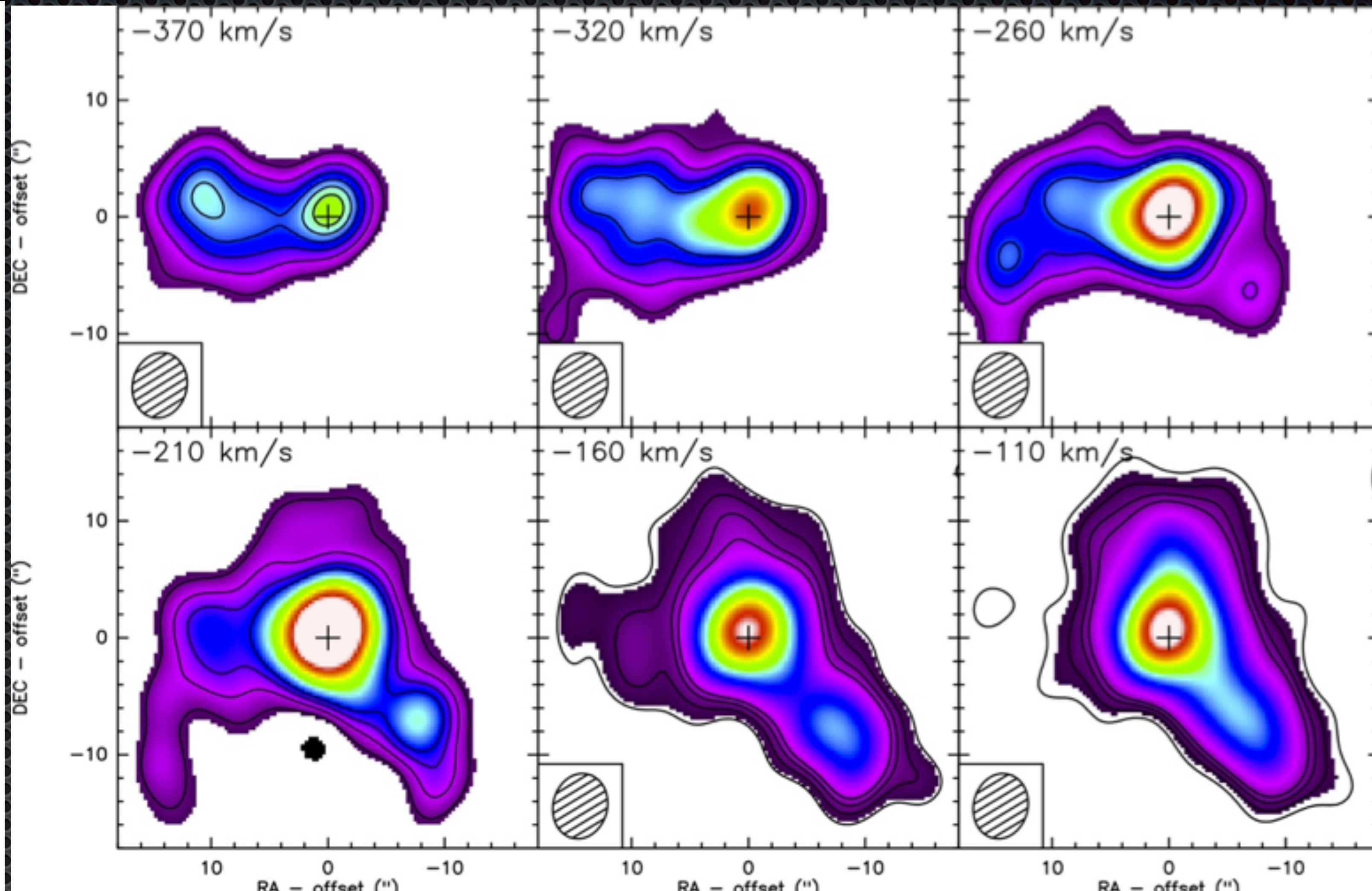




New sensitive PdBI observations of CO(1-0):

The case of NGC 6240





New sensitive PdBI observations of CO(1-0):

Broad CO(1-0) detected out to +- 800 km/s

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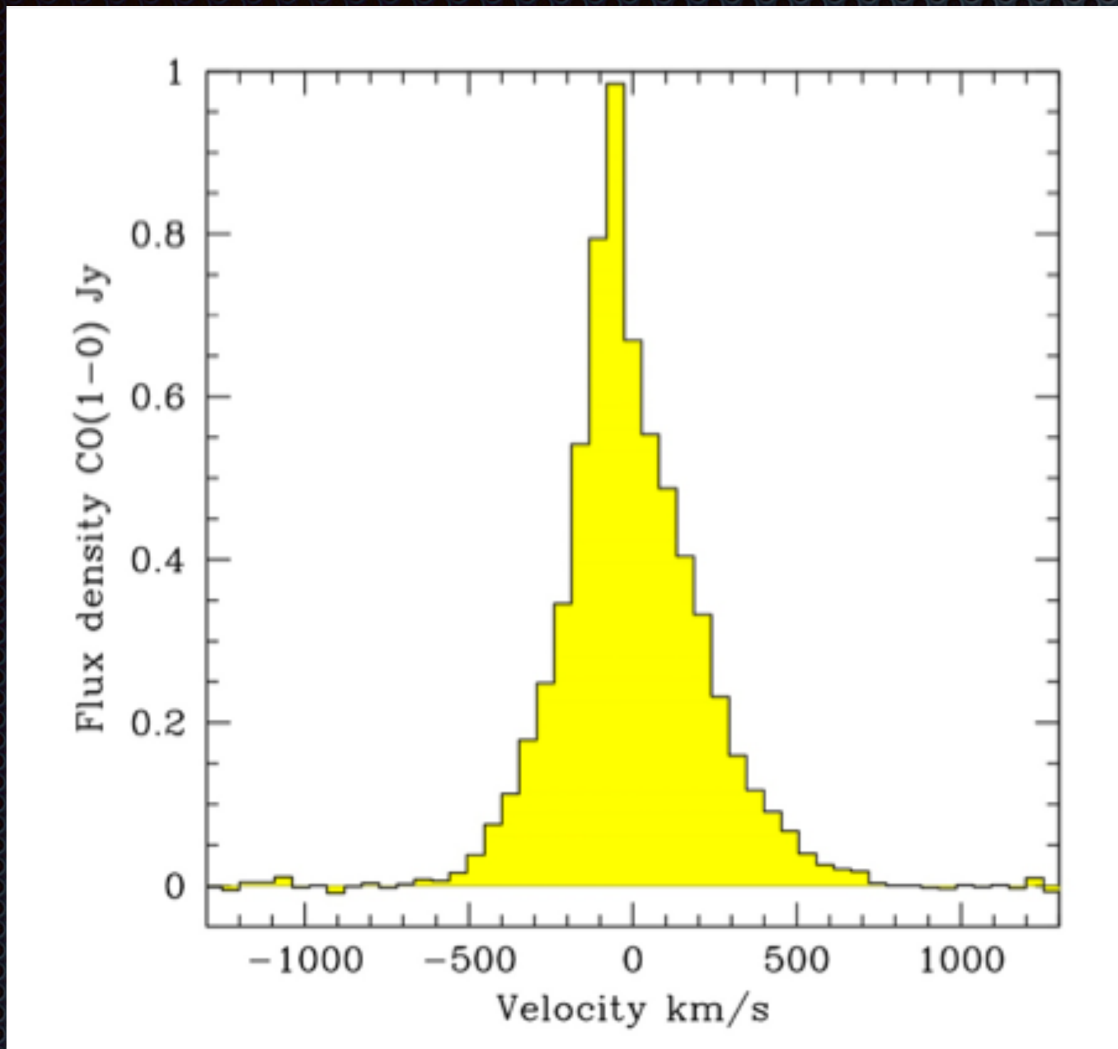

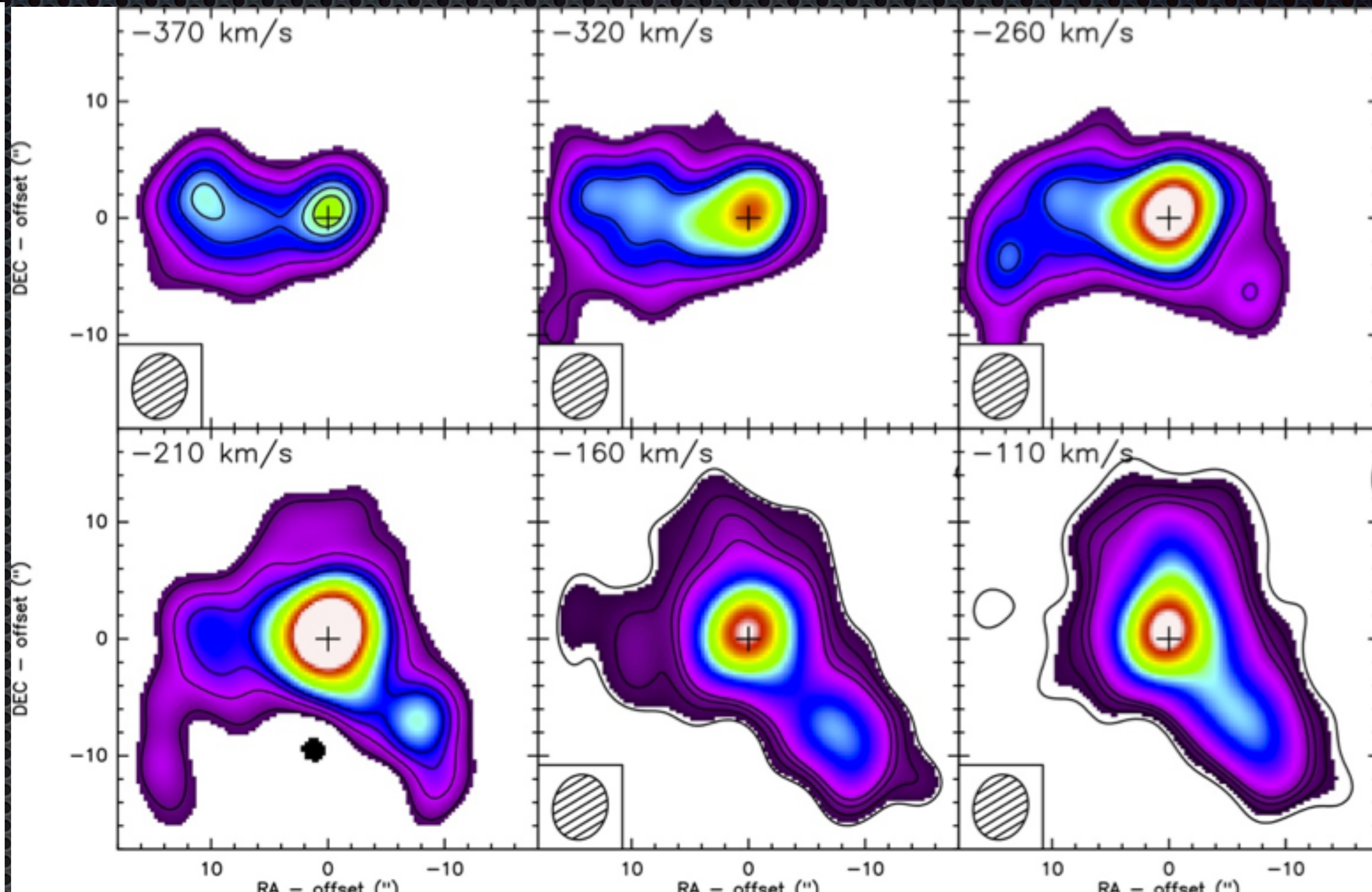

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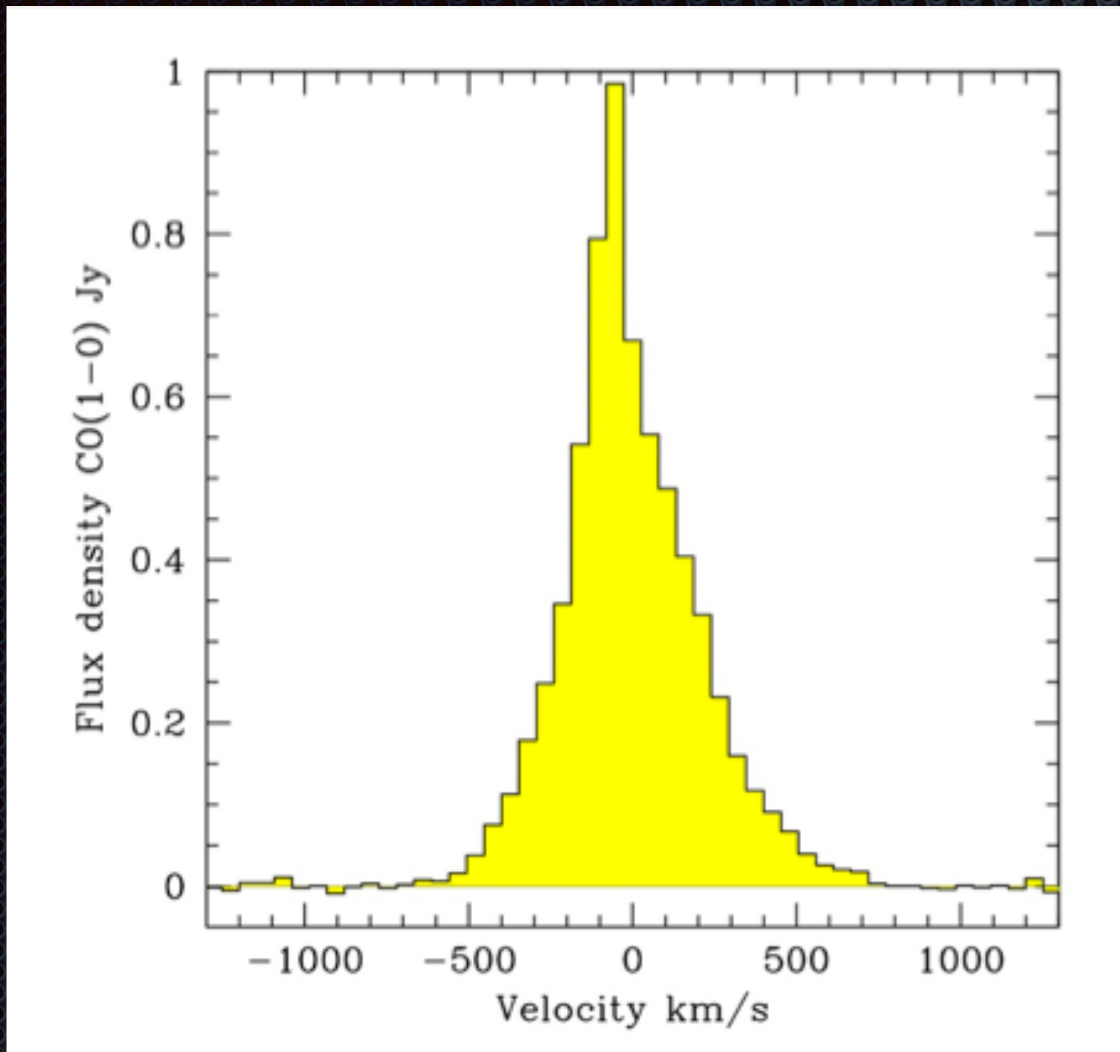
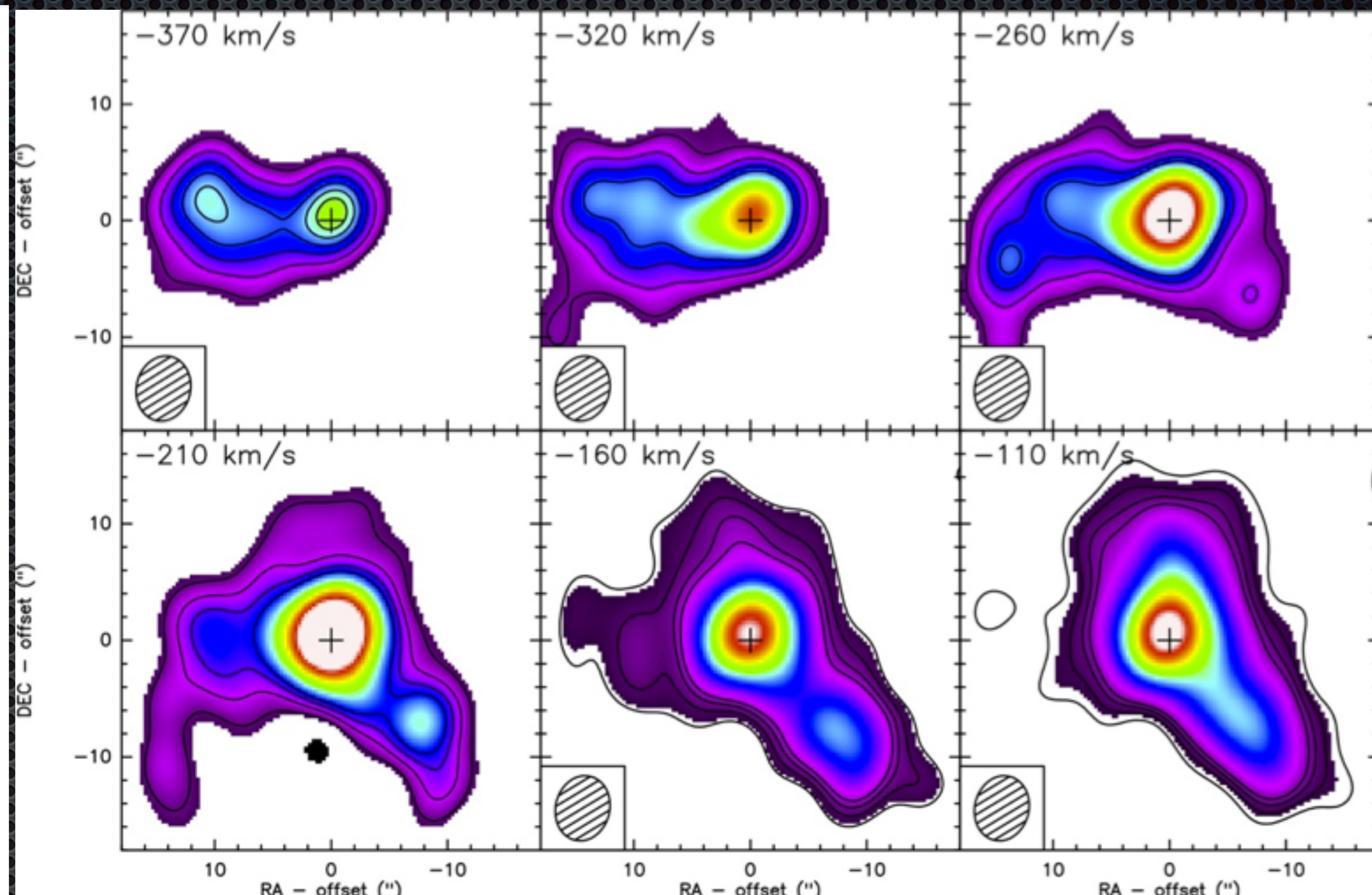
Low surface-brightness structures

The case of NGC 6240





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blue-shifted (-300-400 km/s) extended structure up to scales of 7 kpc East

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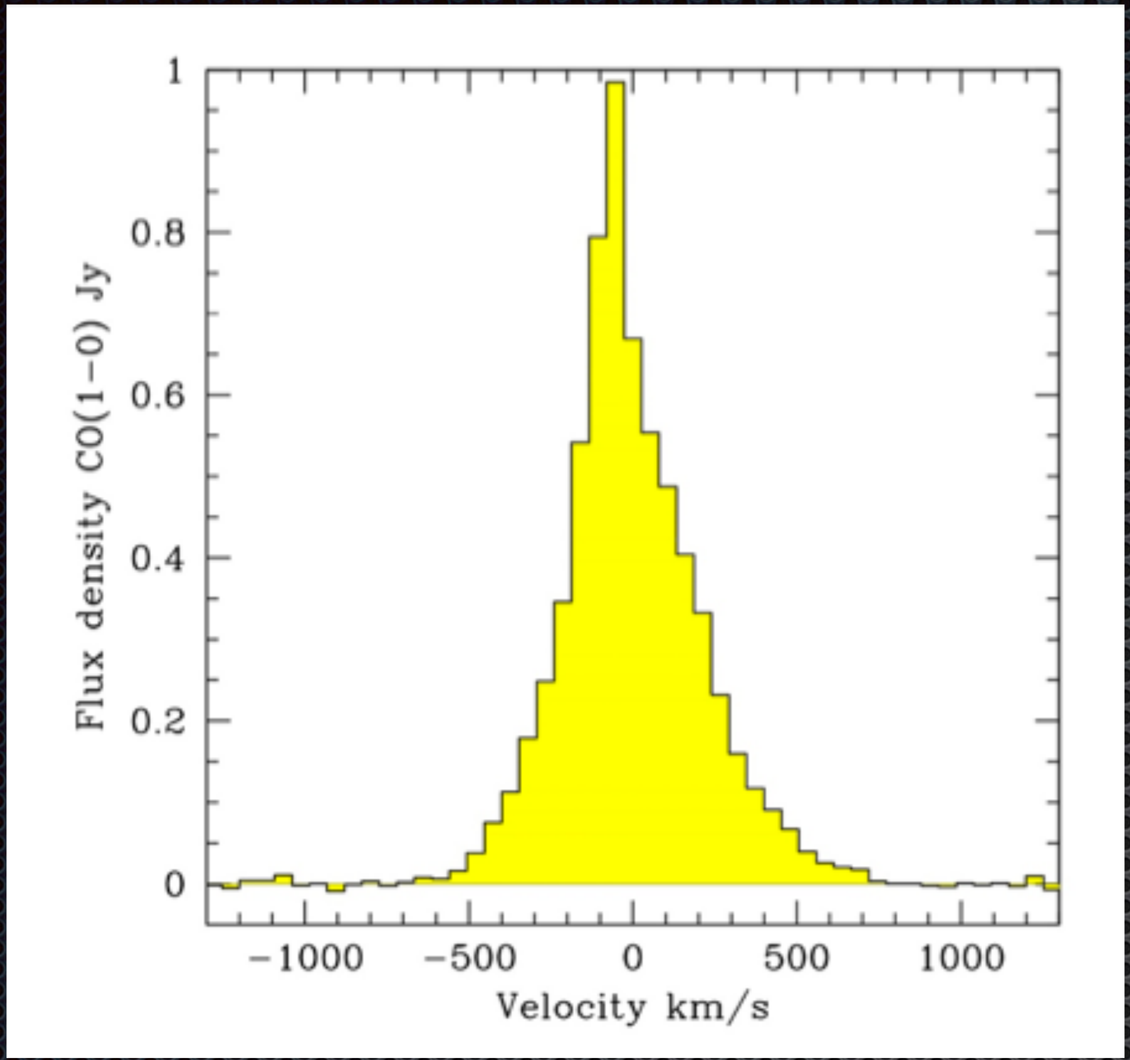

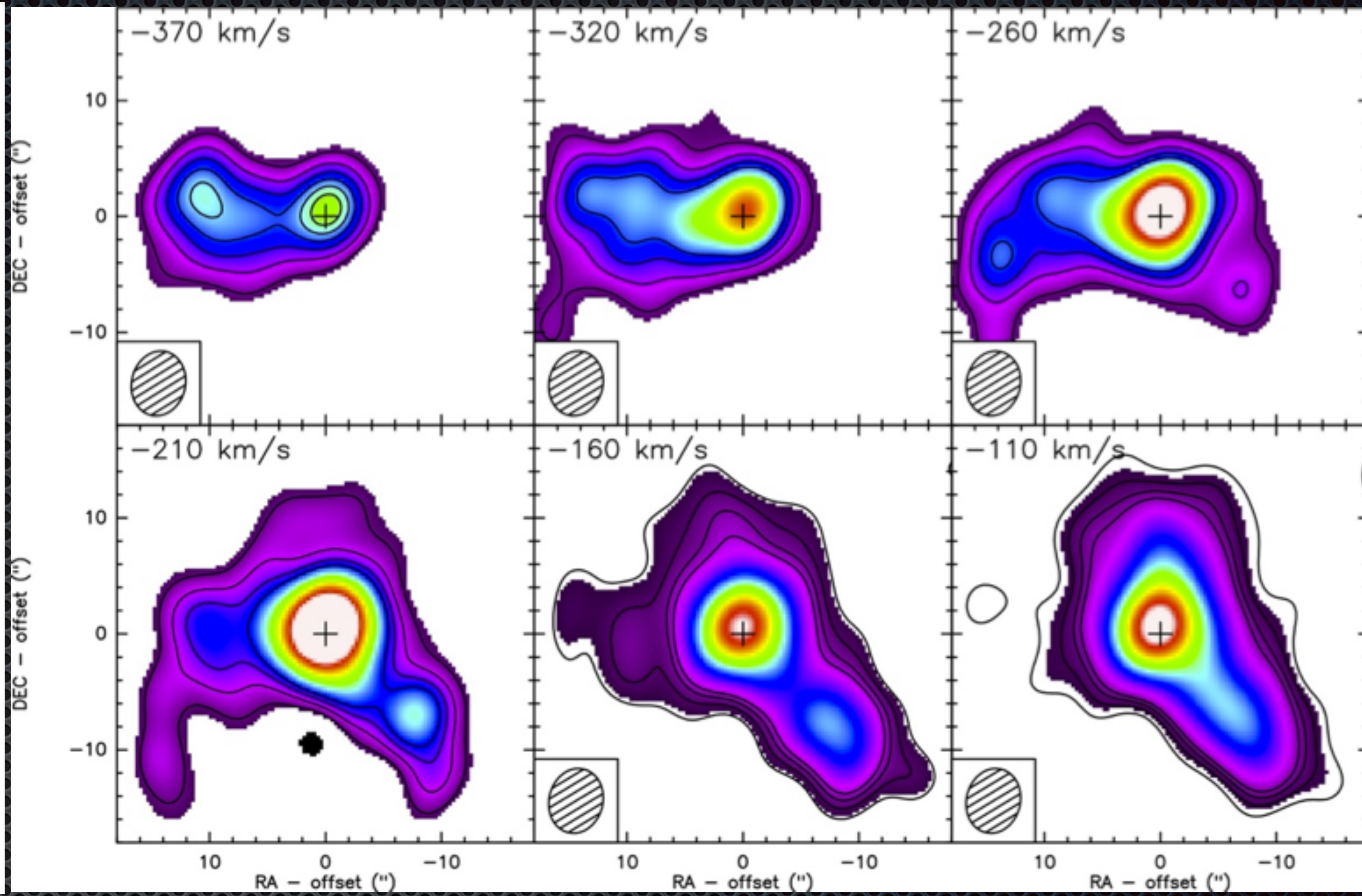

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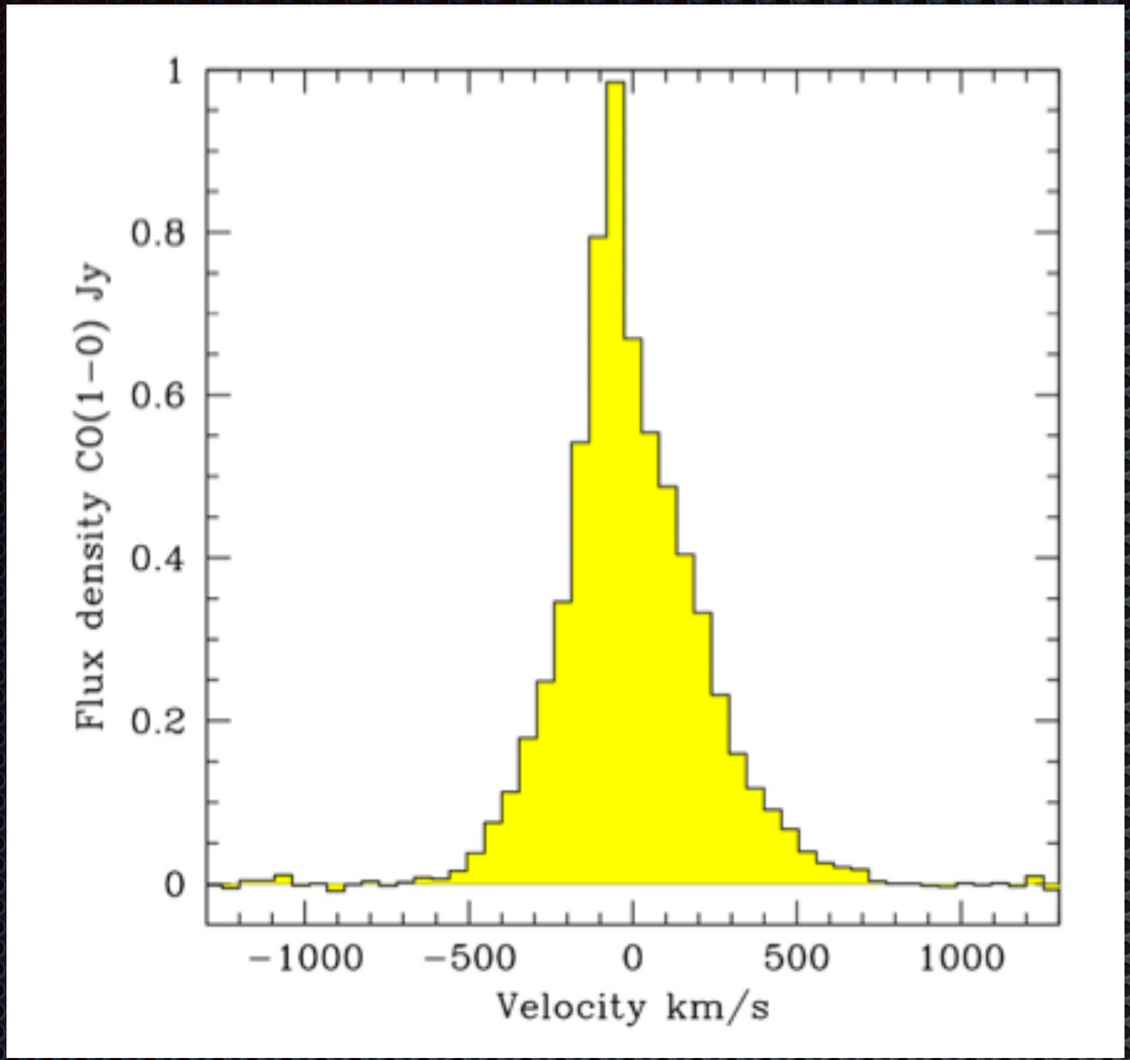
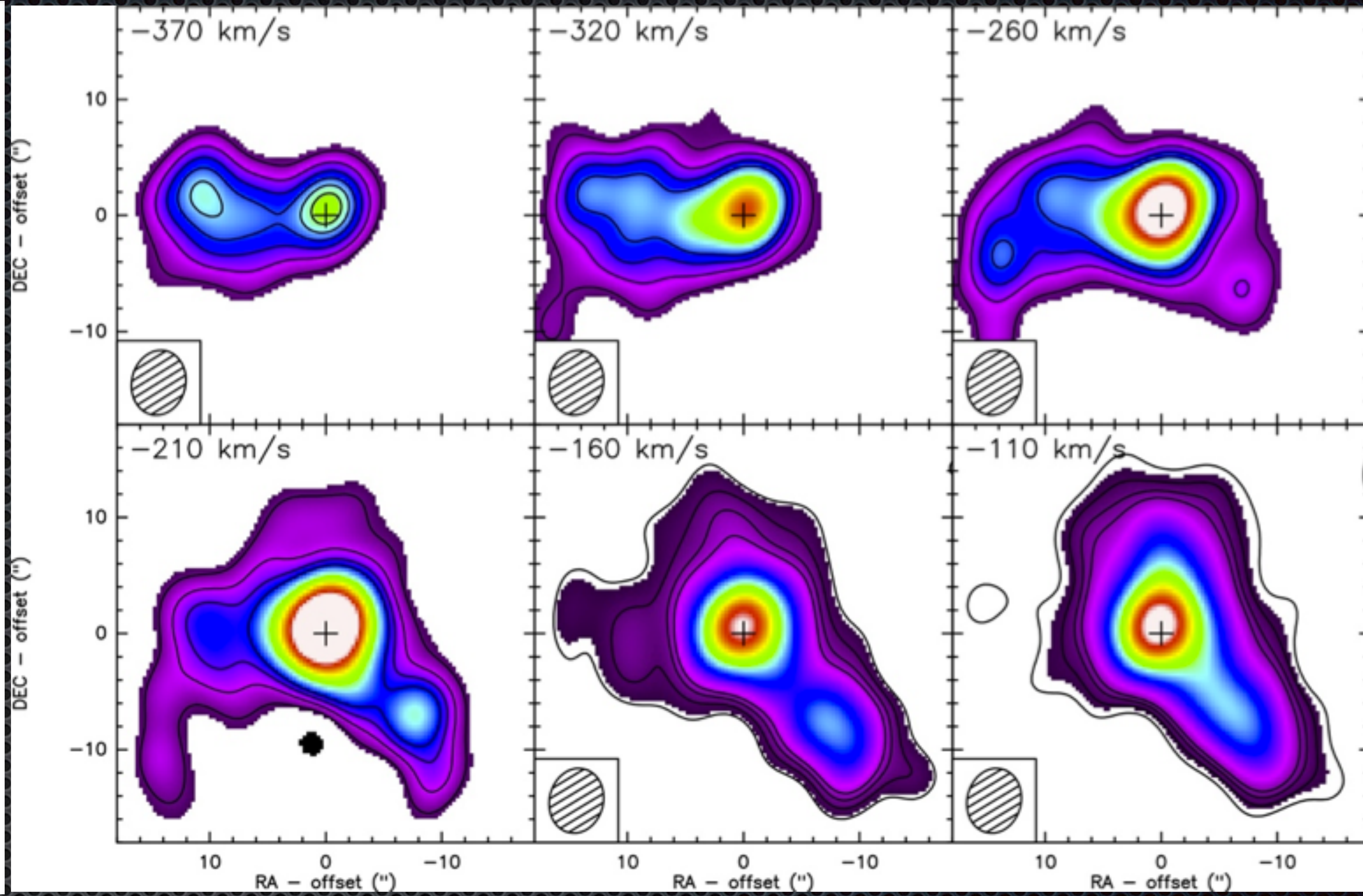
The case of NGC 6240





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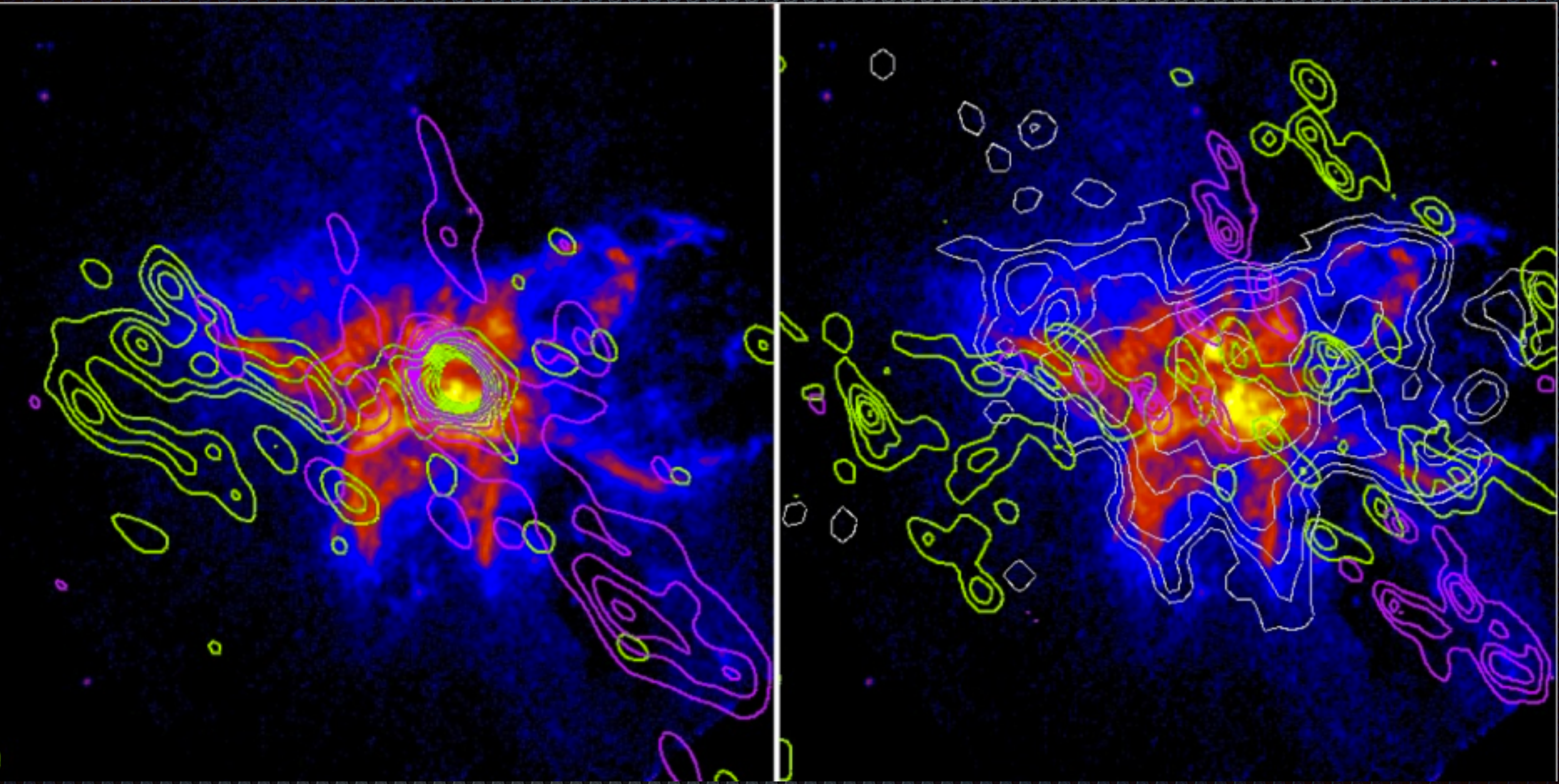
Feruglio+ 2013a

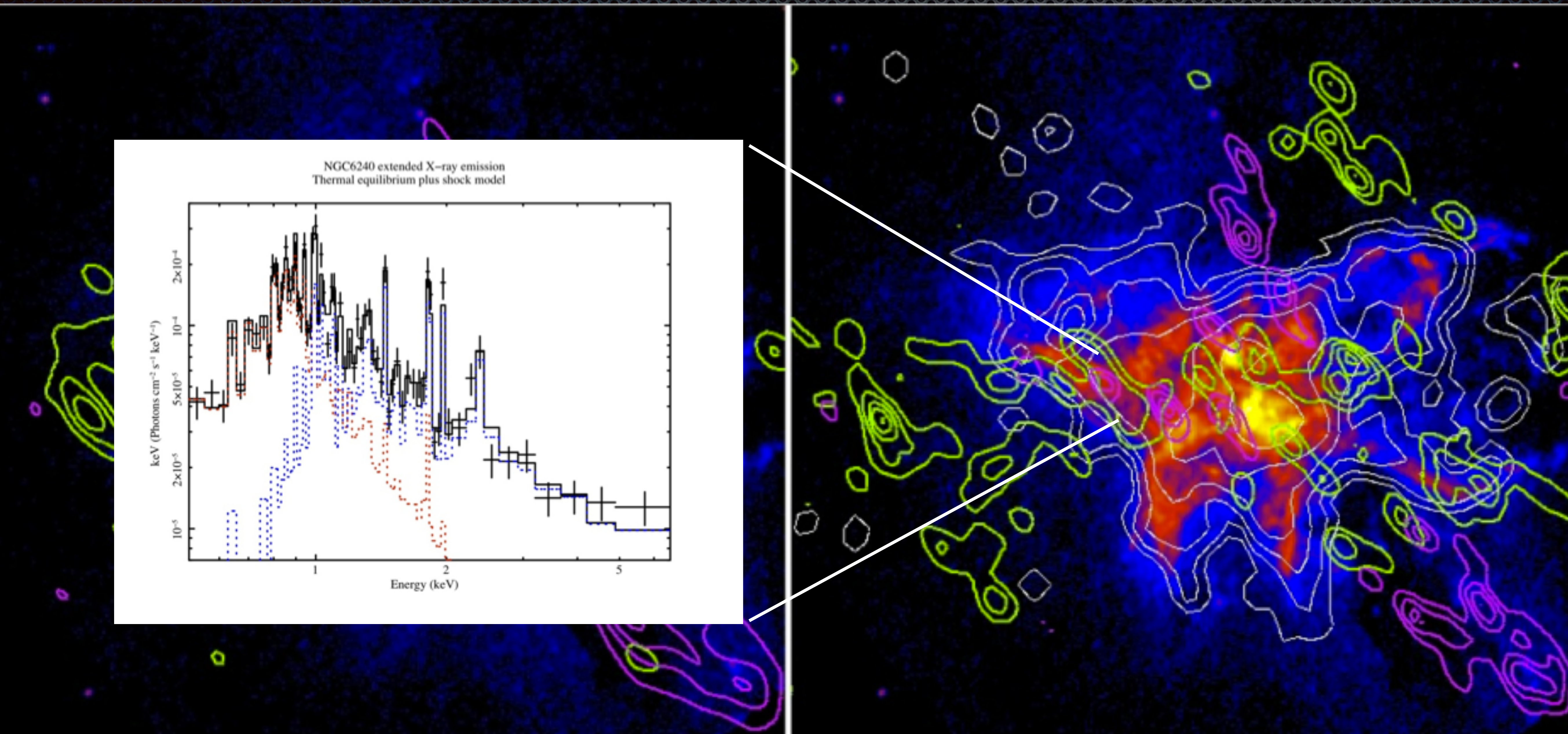
The case of NGC 6240



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

The case of NGC 6240



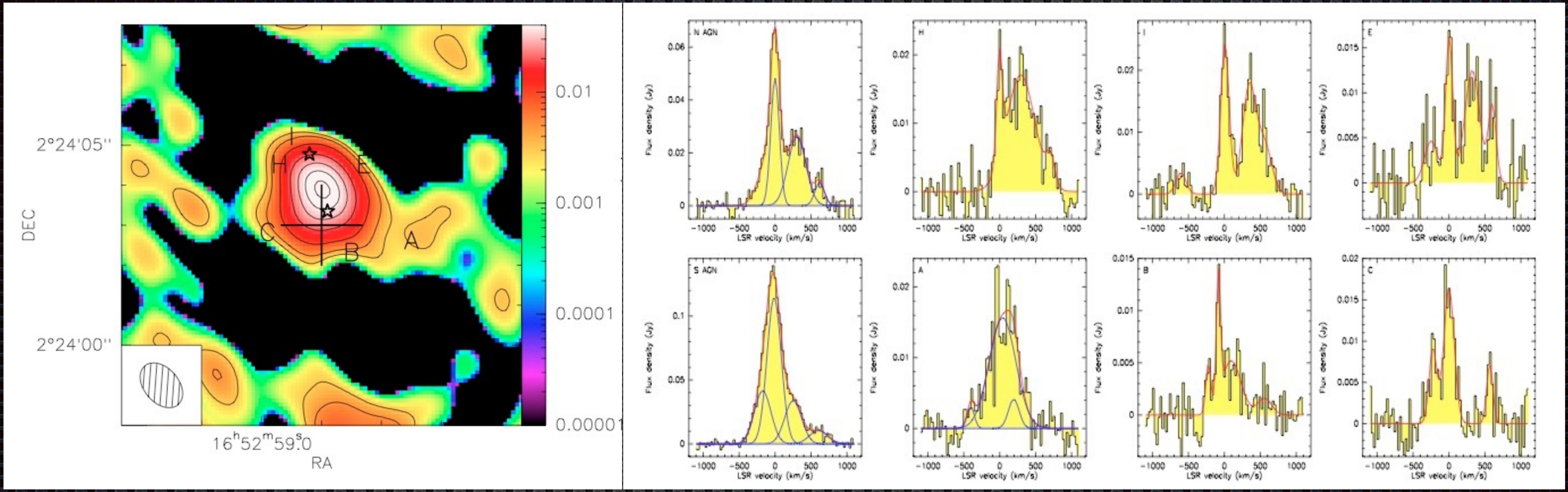
CO at -100 km/s coincides with the dust lane seen in HST image in the SW region

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

The case of NGC 6240

High resolution CO(1-0) mapping (0.5kpc) Feruglio et al. 2013b



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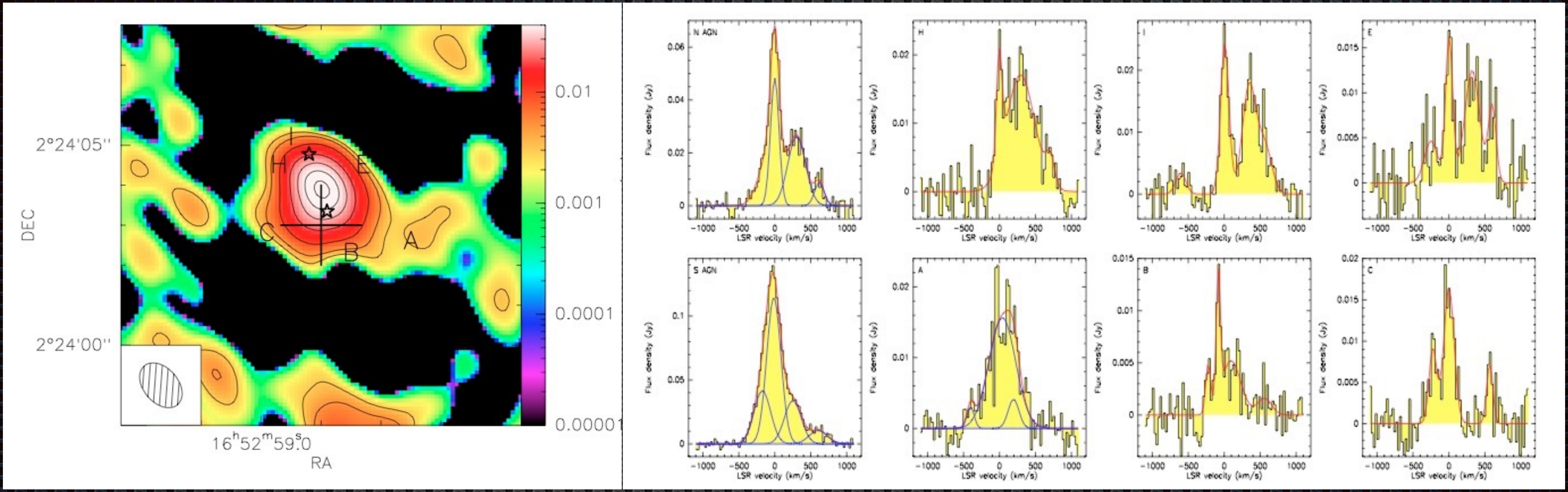

Complex nuclear flow.

The case of NGC 6240

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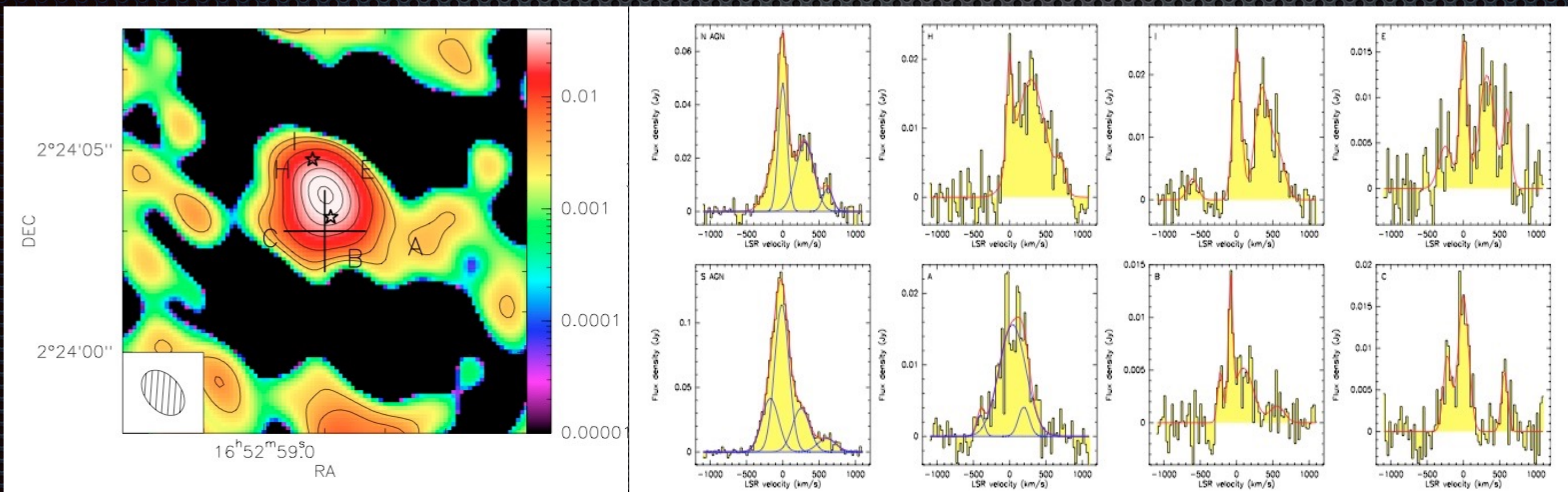
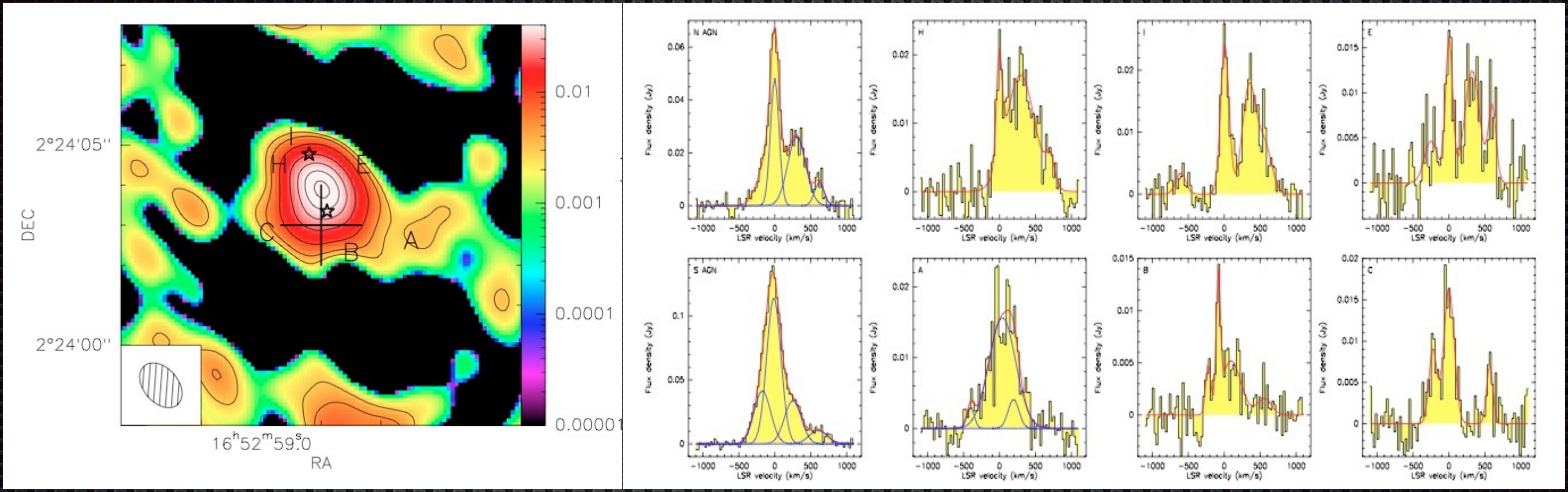


Complex nuclear flow.

Velocity component width ~100km/s, as in merger models

The case of NGC 6240

High resolution CO(1-0) mapping (0.5kpc) Feruglio et al. 2013b



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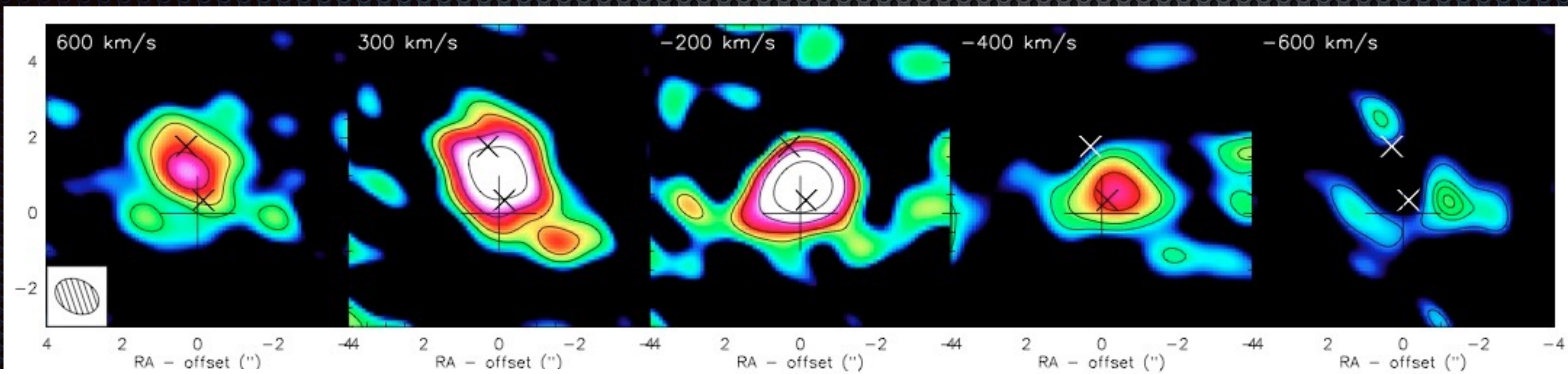
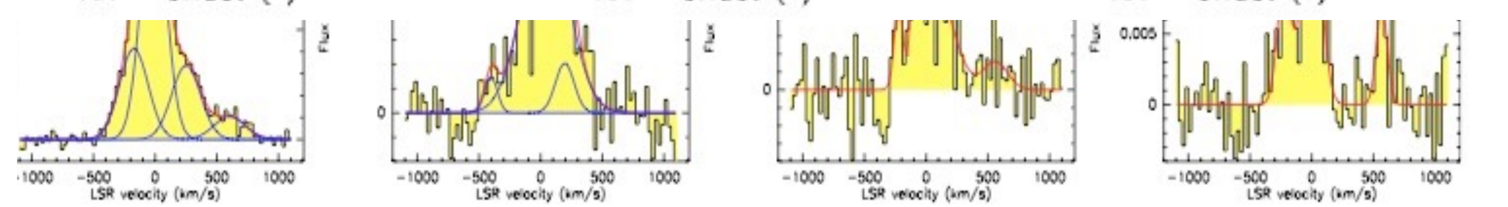
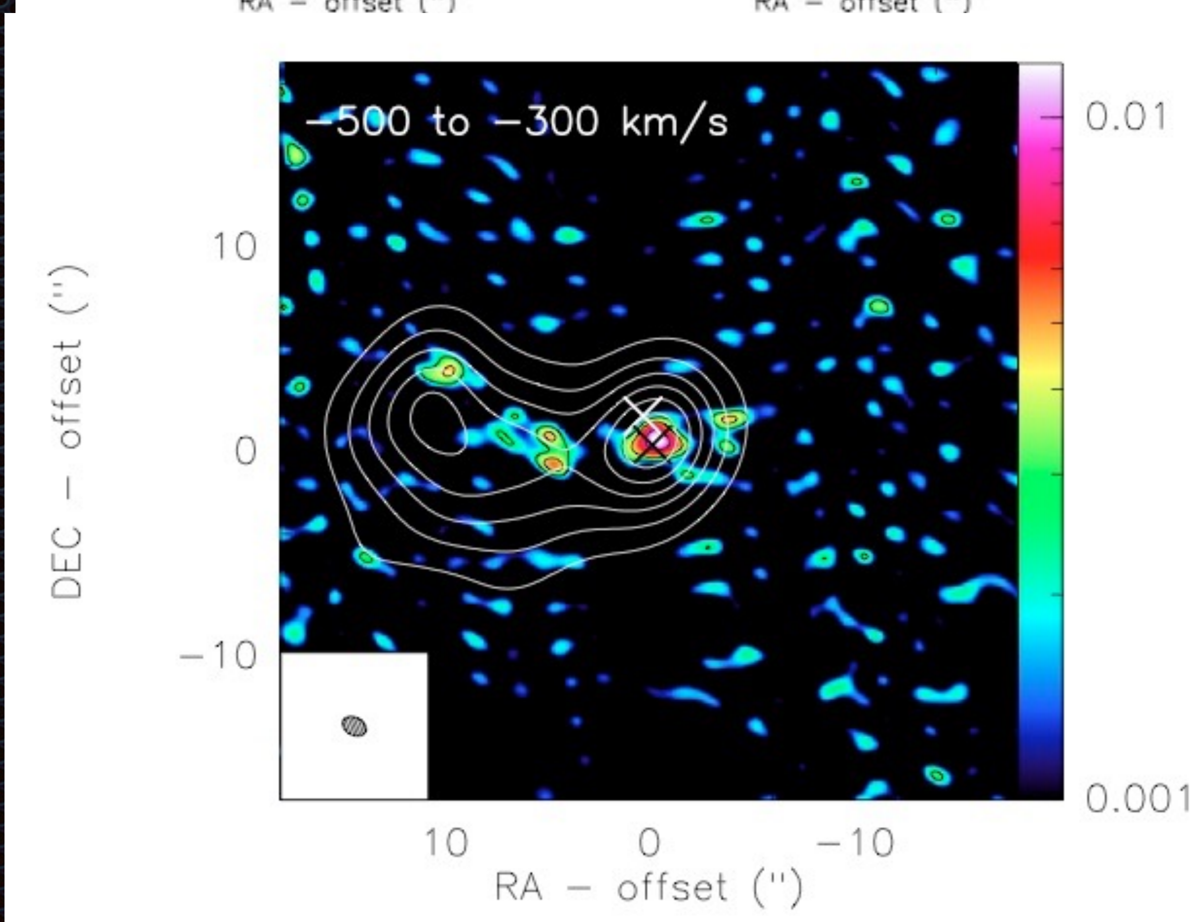






The blueshifted -400km/s component originates from the souther nucleus!

Wind physical quantities

Measure:

- projected velocities
- line luminosities (1D spectra, 2D maps)

Want to estimate

- Wind velocity
- Wind size and geometry
- Mass outflow rate, kinetic energy
- Distribution of Mass outflow rate

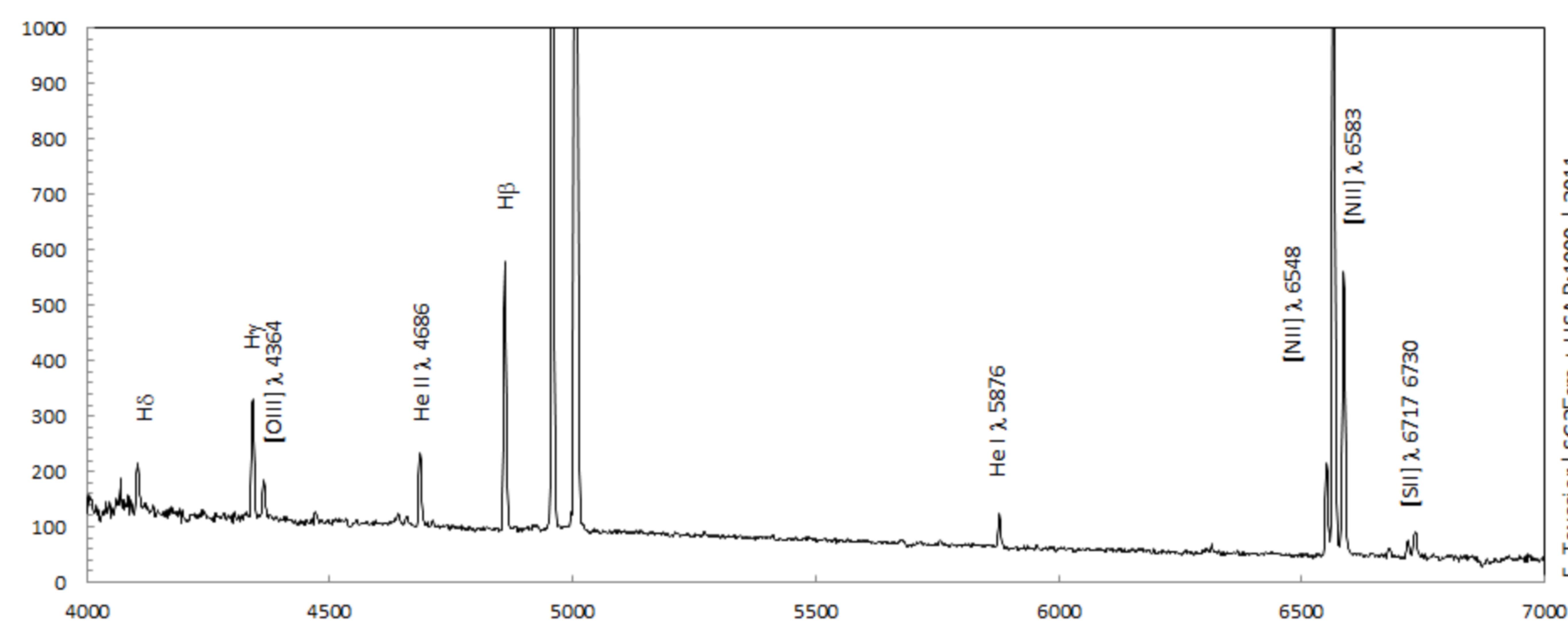
$$\dot{\mathrm{M}}_{\mathrm{OF}} = \Omega \ \mathrm{R}^2_{\mathrm{OF}} \ \rho_{\mathrm{OF}} \ \mathrm{v}_{\mathrm{max}}$$

$$\dot{M}_{OF} = 3 \times v_{max} \times M_{OF}/R_{OF}$$

$$M_{[OIII]} = 4.0{\times}10^7 M_{\odot} (\frac{C}{10^{O/H}})(\frac{L_{[OIII]}}{10^{44}})(\frac{< n_e >}{10^3})^{-1}$$

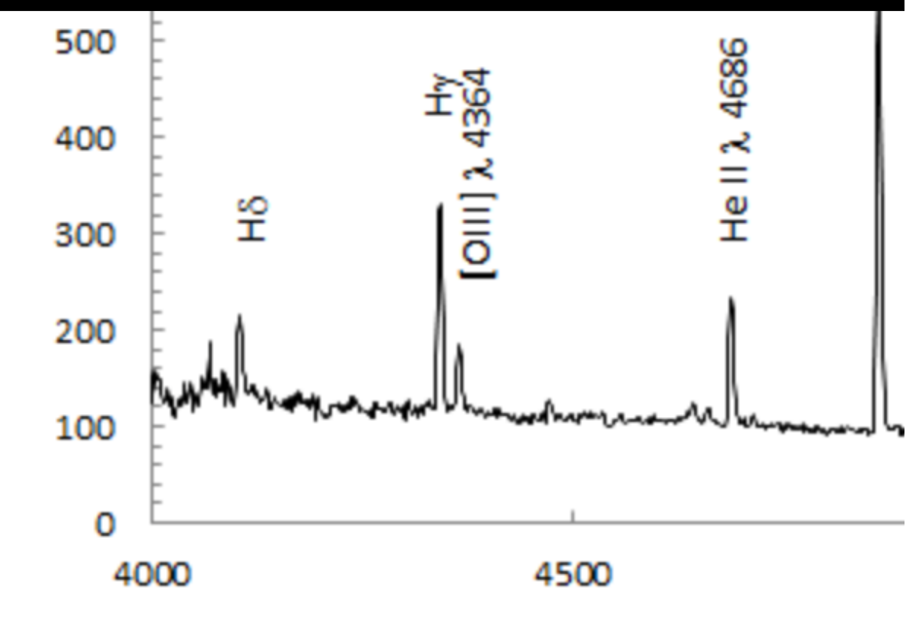
$$M_{H\beta} = 7.8 \times 10^8 C (\frac{L_{H\beta}}{10^{44}})(\frac{< n_e >}{10^3})^{-1}$$

Wind physical quantities



Wind physical quantities

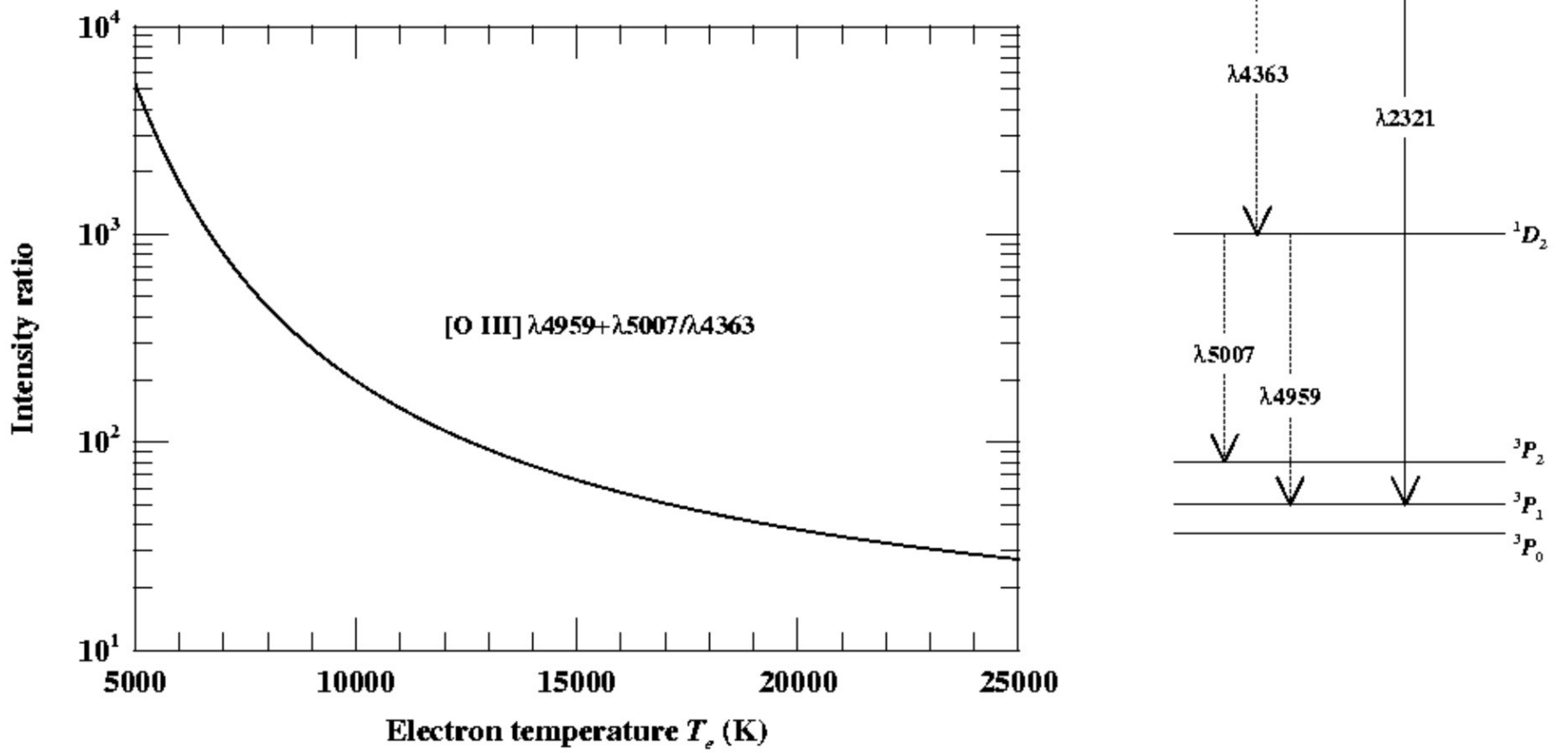
Hβ emissivity ∝ 1/T; [OIII] emissivity nearly constant (for T ≈ 10^4K)



Narrow Line Region: electron temperatures

- As temperature increases, [O III]4363 increases in strength relative to [O III]4959, 5007 because of increasing collisional excitation rate of the $1S_0$ level relative to the $1D_2$ level.

(also used e.g., [N II] 6548+6583/5755)

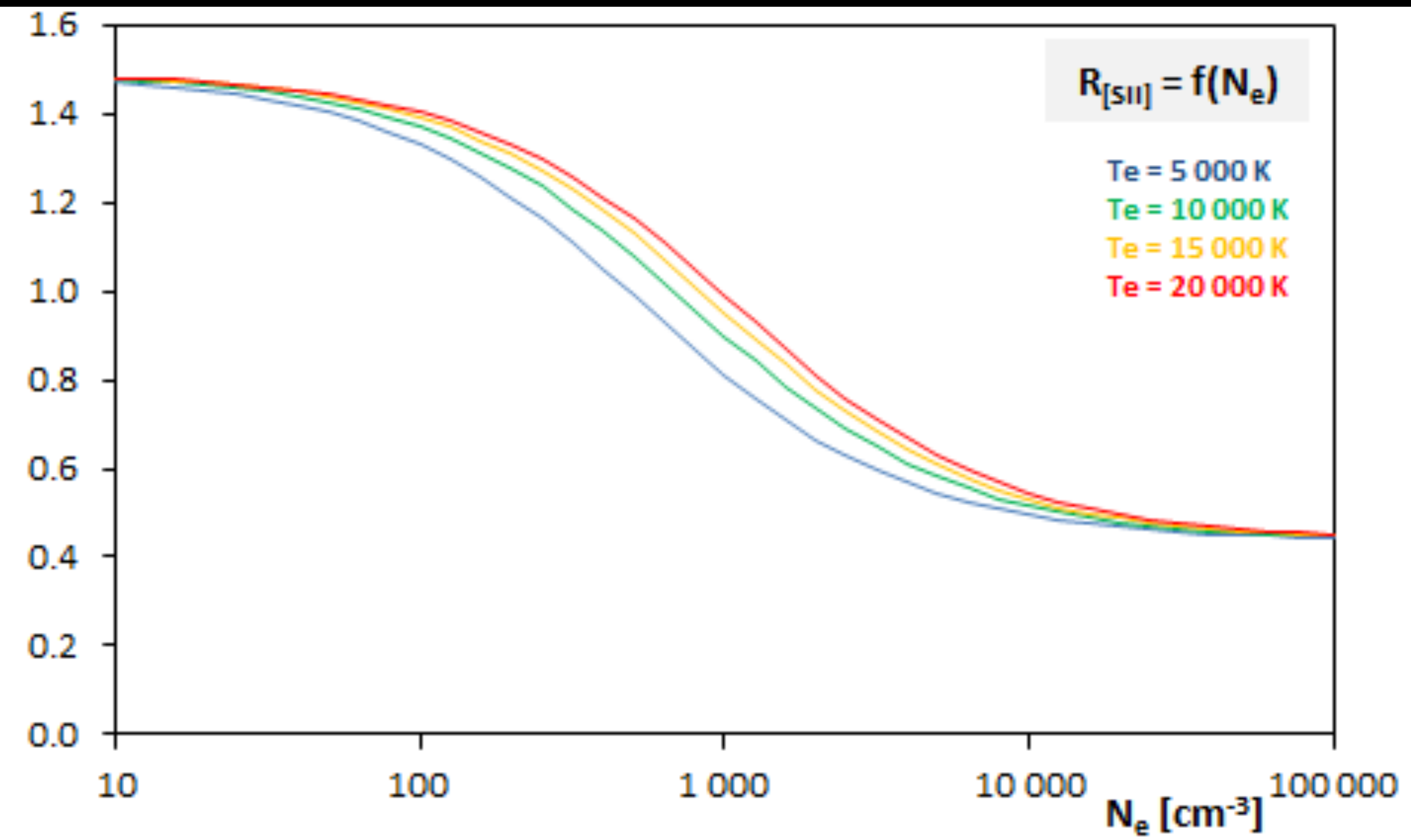


Wind physical quantities

NLR: density

- Low density case: radiative de-excitation dominates, emissivity $\sim n_e^2$
- High density case: collisional de-excitation dominates; emissivity $\sim n_e$
- *critical density n_{crit}* where radiative de-excitation rate = collisional de-excitation rate, e.g.,
  – n_{crit}([S II] 6716) = 1.5×10^3 cm^{-3}
  – n_{crit}([S II] 6731) = 3.9×10^3 cm^{-3}

=> density dependence of line ratio (also e.g., [O II] 3729/3726)



SuperWinds
Summary from yesterday

- High level science motivations
  - Efficiency of galaxy formation and quenching
  - BH-Bulge correlations
- SuperWind observations (multi-wavelength)
- Feedback observations
- From observed quantities to wind physical quantities

Launching a wind

1) Thermal wind arising from the accretion disk. If nH<10^{12} cm-3 and logT<5K ionization heating is balanced by line cooling and recombination. If U is high line cooling is suppressed and gas reaches a hot phase in which Compton heating is balanced by inverse Compton cooling at an equilibrium T

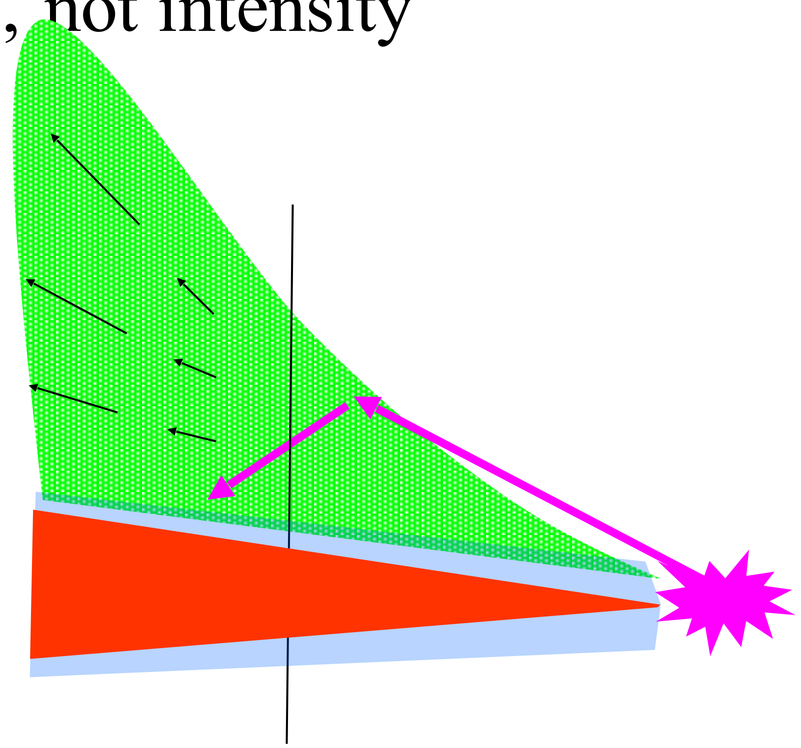
$$\text{Compton temperature } kT_{IC} = 1/4\langle\varepsilon\rangle;\ \langle\varepsilon\rangle = L^{-1}\int_0^\infty h\nu L_\nu\, d\nu$$

$$\text{if } C_s < v_{esc} \Rightarrow \text{ a corona will form}$$

$$\text{if } C_s > v_{esc}; T_{esc} = \frac{GMm_p}{R_o k} < T_{IC} \Rightarrow \text{a thermal wind will arise}$$

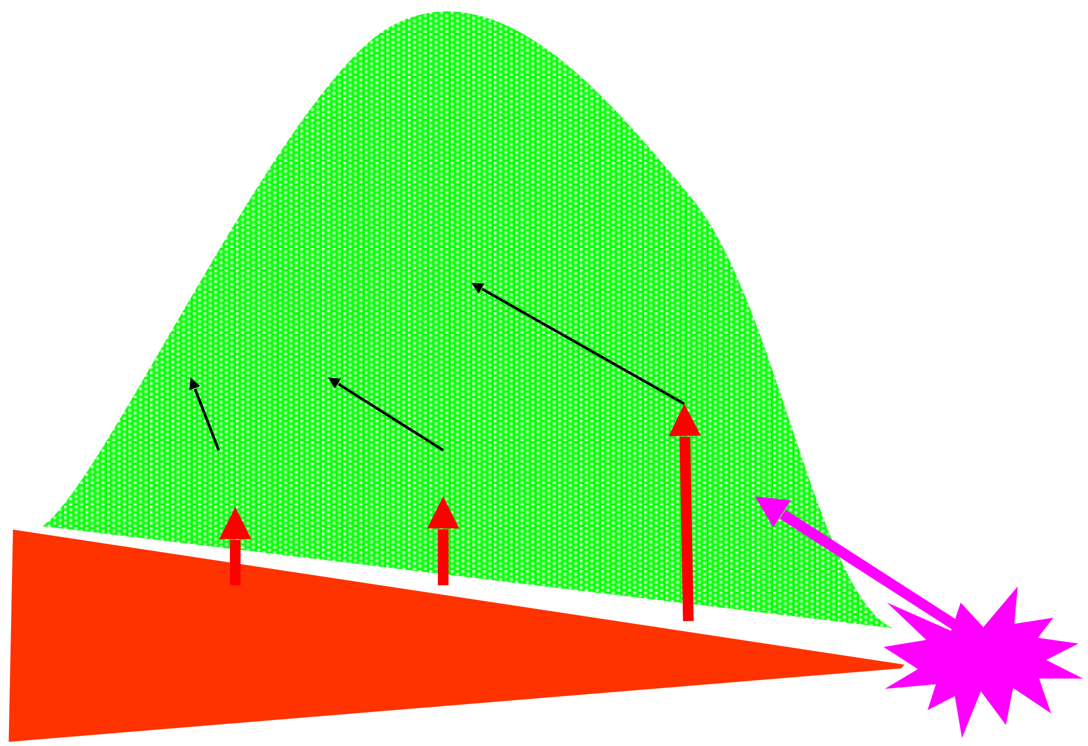
v_{esc} decrease with R; T_{IC} and v_{esc} function of SED, not intensity

$$\Rightarrow \text{ winds starts at } R \geq \frac{GMm_p}{kT_{IC}}$$



2: Continuum radiation driven Wind

- But any material above disc is also illuminated by the continuum source
- Effective gravity is $(1 - \tau/\tau_{es}\ L/L_{Edd})$ GM/R NOT simply GM/R
- If just electron scattering $= (1 - L/L_{Edd})$ GM/R continuum driven wind
- Exceeds L_{edd} in central regions of disc so wind from inner disc!



Winds, dynamical models
3) line driven and dust driven winds

equation of motion: $v\frac{dv}{dr} = \frac{kL}{4\pi r^2 c} - \frac{GM}{r^2}$

asymptotic velocity: $v_\infty = \left[\frac{2}{r_0}\left(\frac{kL}{4\pi c} - GM\right)\right]^{1/2}$

k is the absorption cross section per unit mass which depends on the source of opacity.

$$\frac{\text{Dust opacity}}{\text{Thompson opacity}} \sim 100 - 1000$$

Dust; $r_{\min} \approx 1.3 L_{46} T_{1500}^{-2.8}\, pc$

Line opacity; efficiency $\eta = \frac{\text{line scattering}}{\text{electron scattering}}$

Force multiplier = ratio of line acceleration to that due to Thomson scattering $M_L(U)$

$U\uparrow \eta \downarrow$

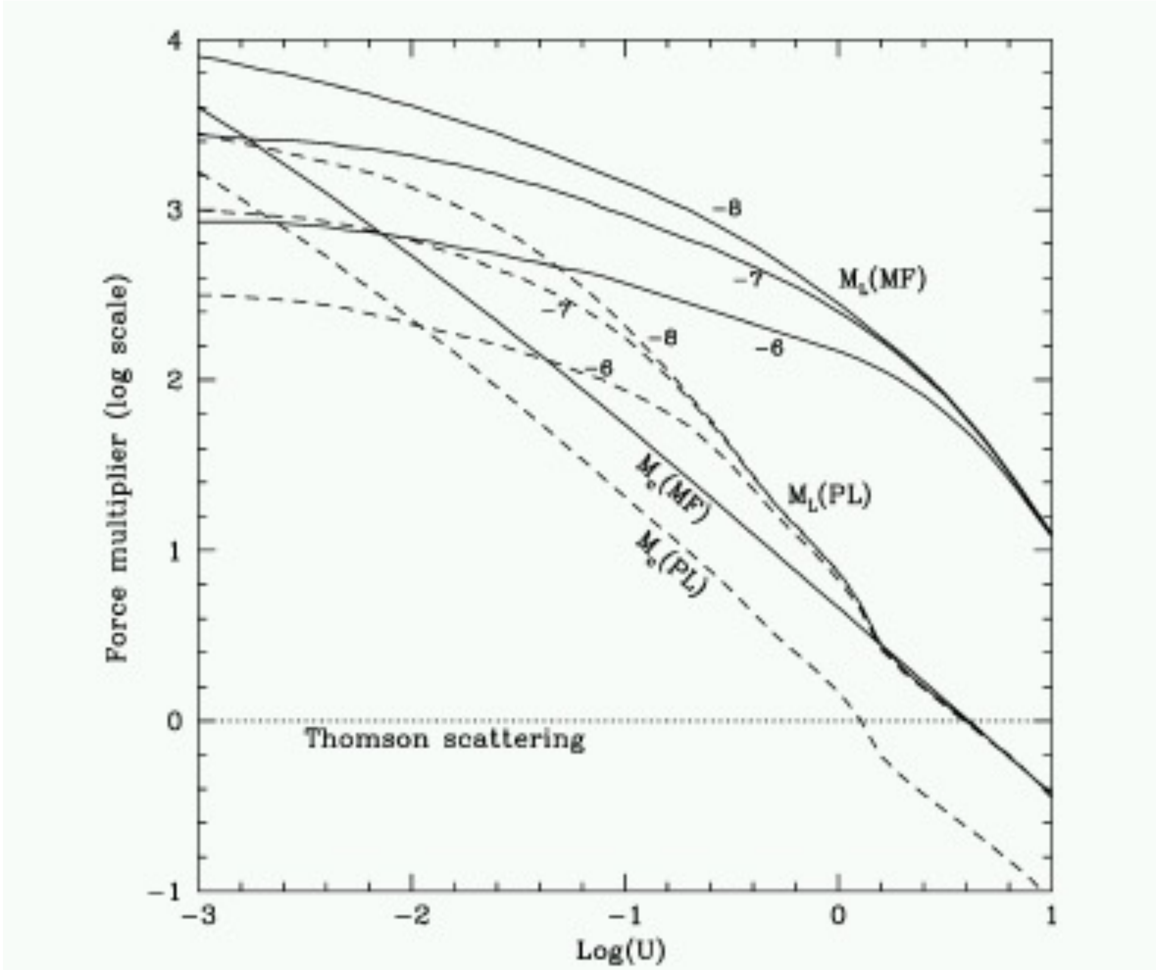
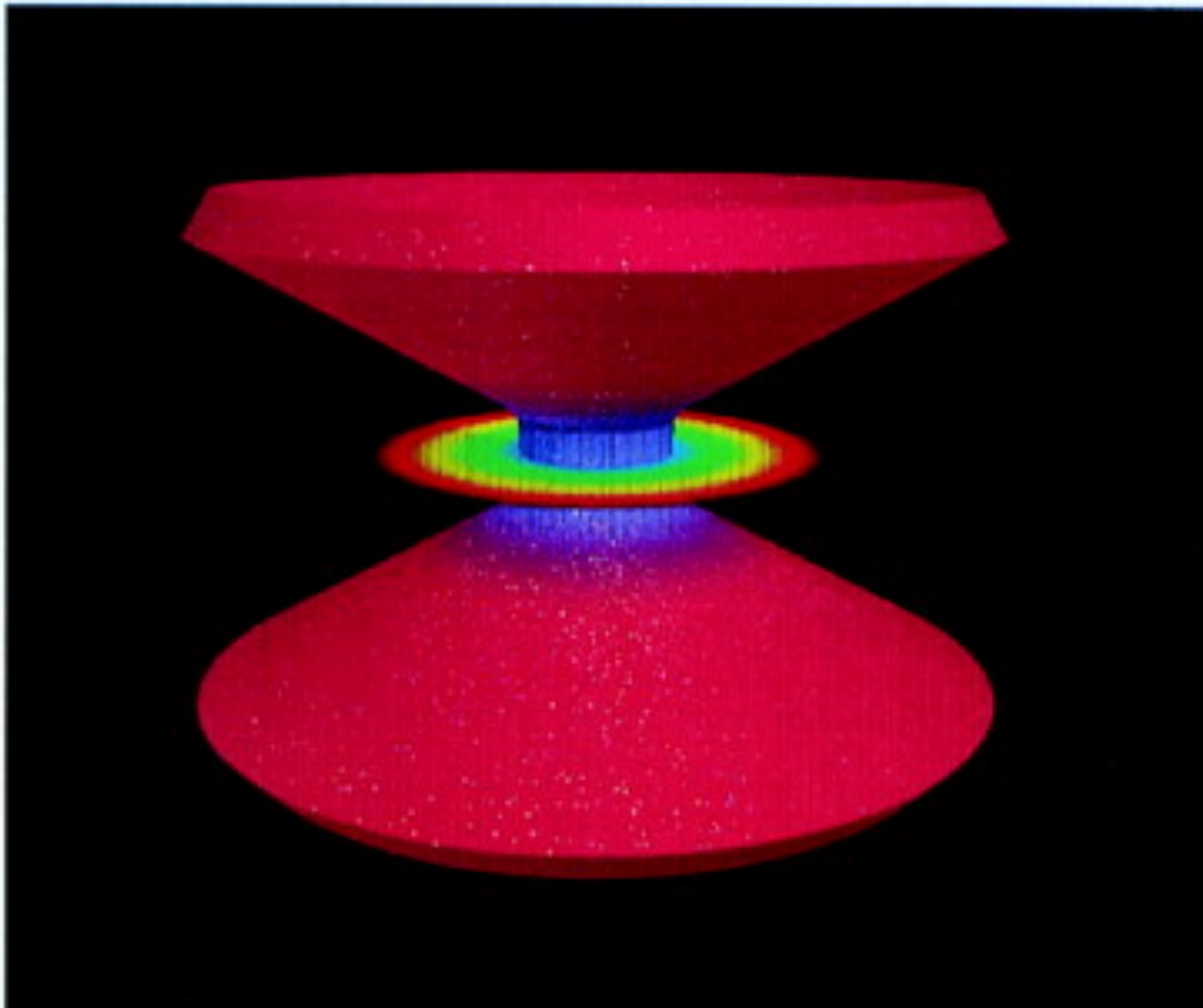


Figure 9 Force multipliers, M_L and M_e, as functions of U, for different ionizing continua (from Arav et al. 1994). MF stands for the Mathews & Ferland (1987) SED, and PL for a simple power-law SED, with $L_\nu \propto \nu^{-1}$. The three different curves are for different values of log(t) = −6, −7, and −8.

Wind models



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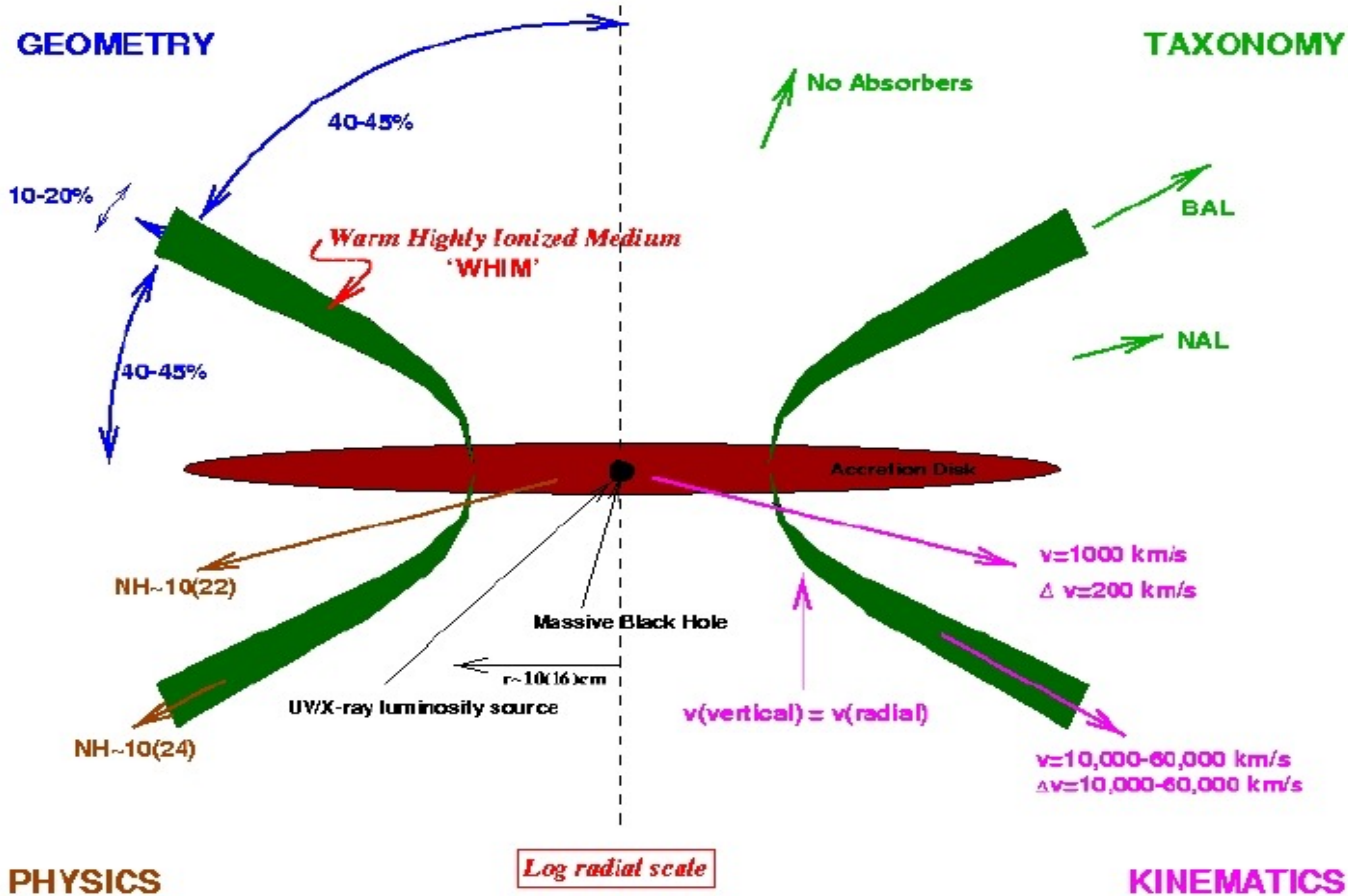
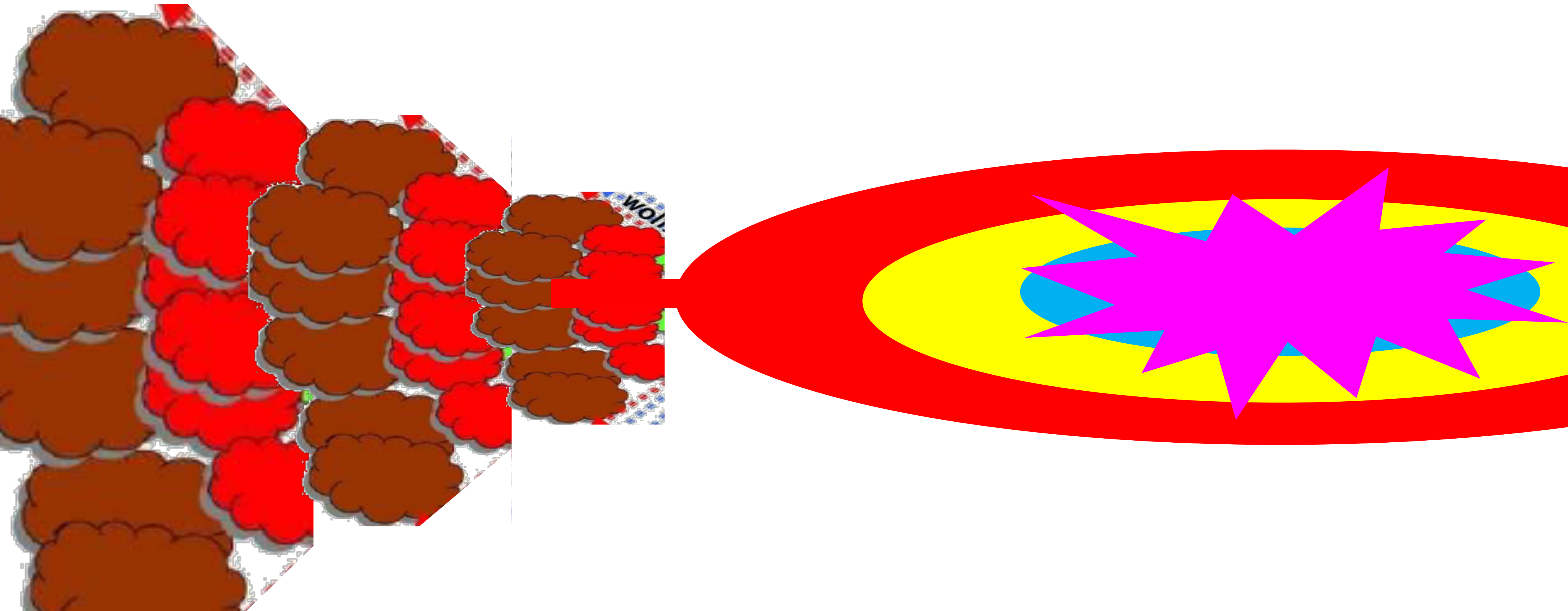


Elvis 2000-2003

Which wind goes where? L~0.1LEdd

Courtesy by Chris Done



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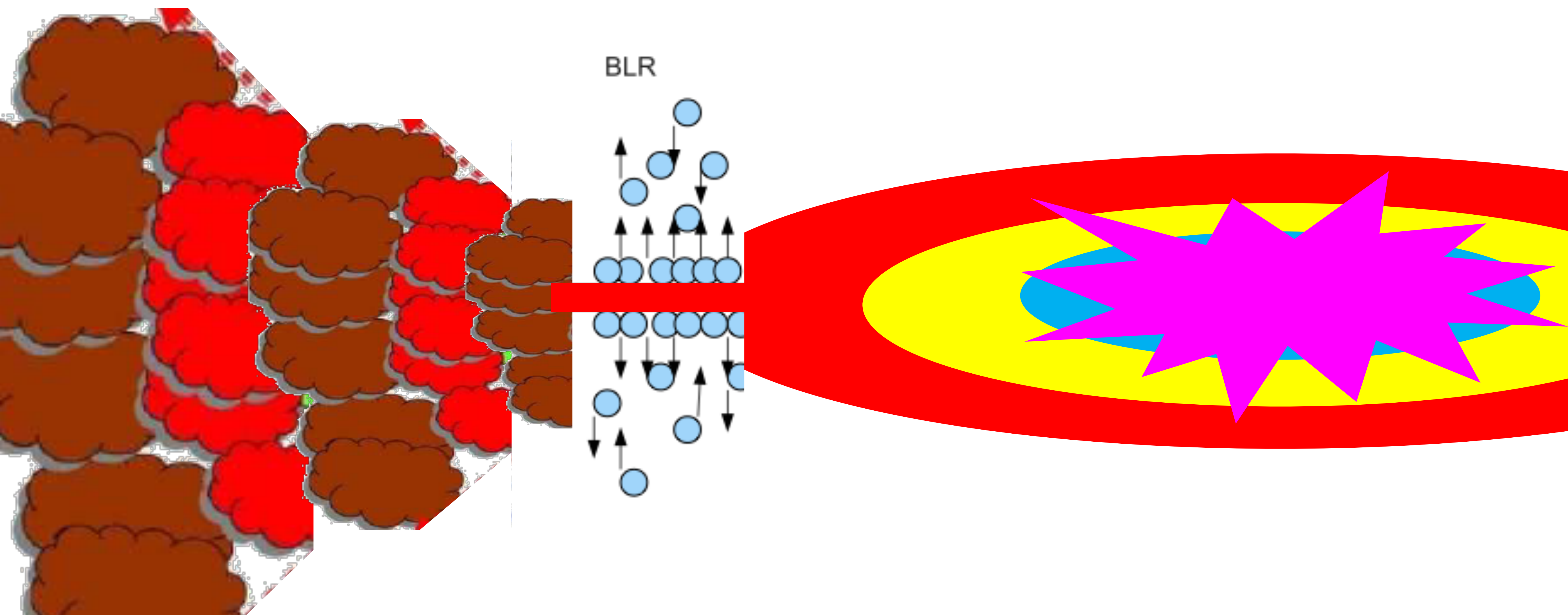
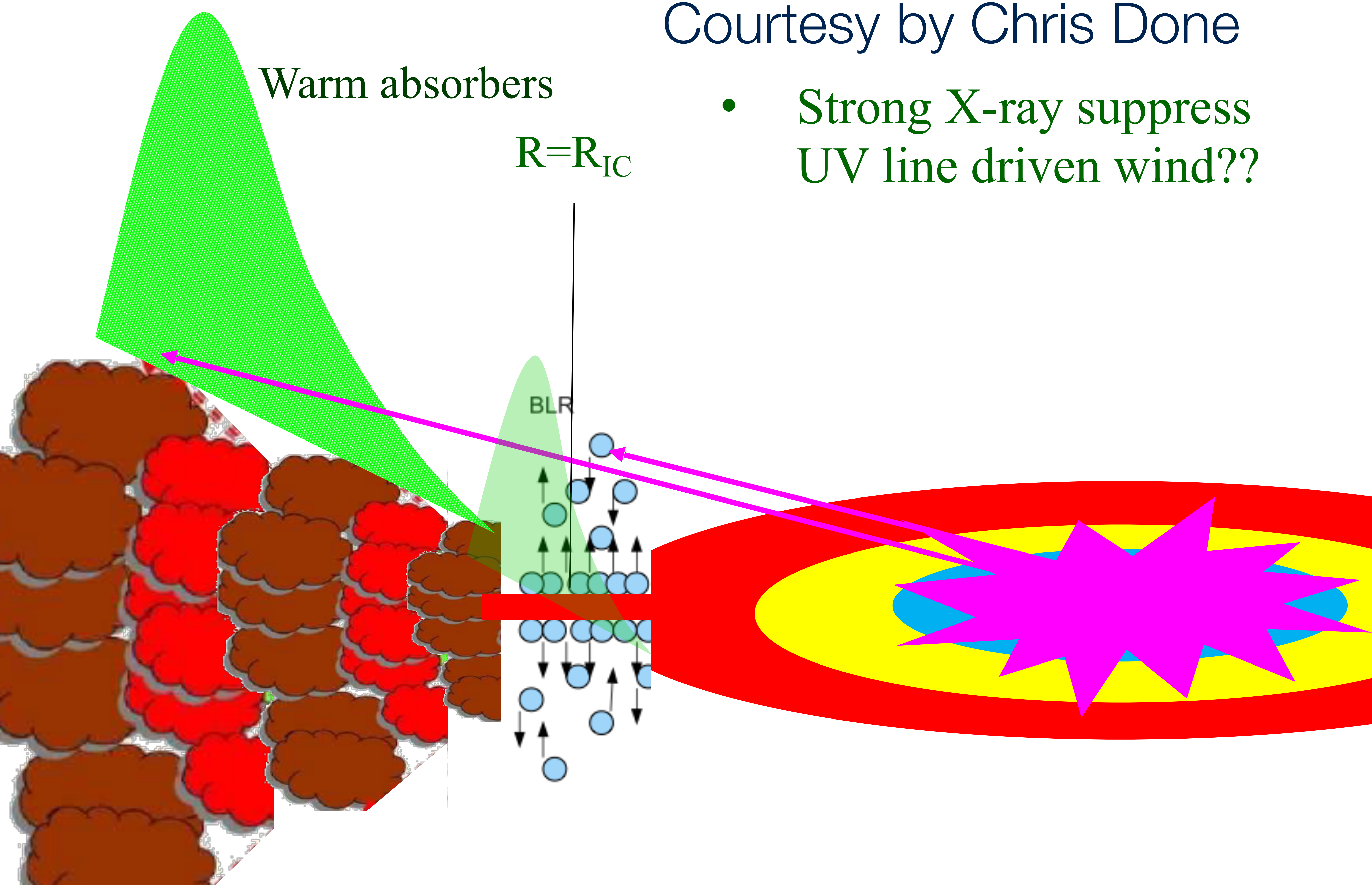


Which wind goes where? L~0.1LEdd

Courtesy by Chris Done

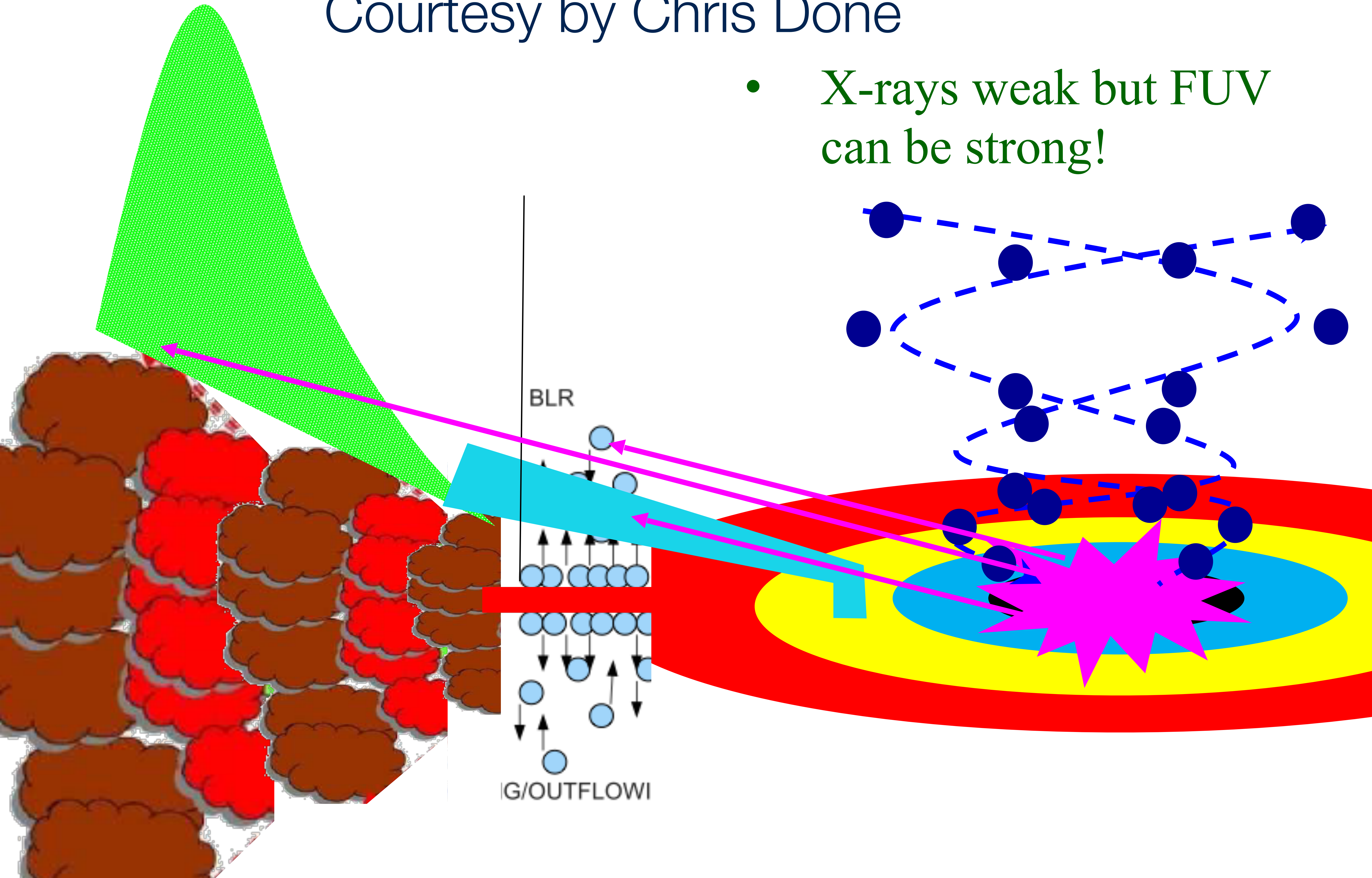
- Strong X-ray suppress UV line driven wind??



Which wind goes where? L~LEdd

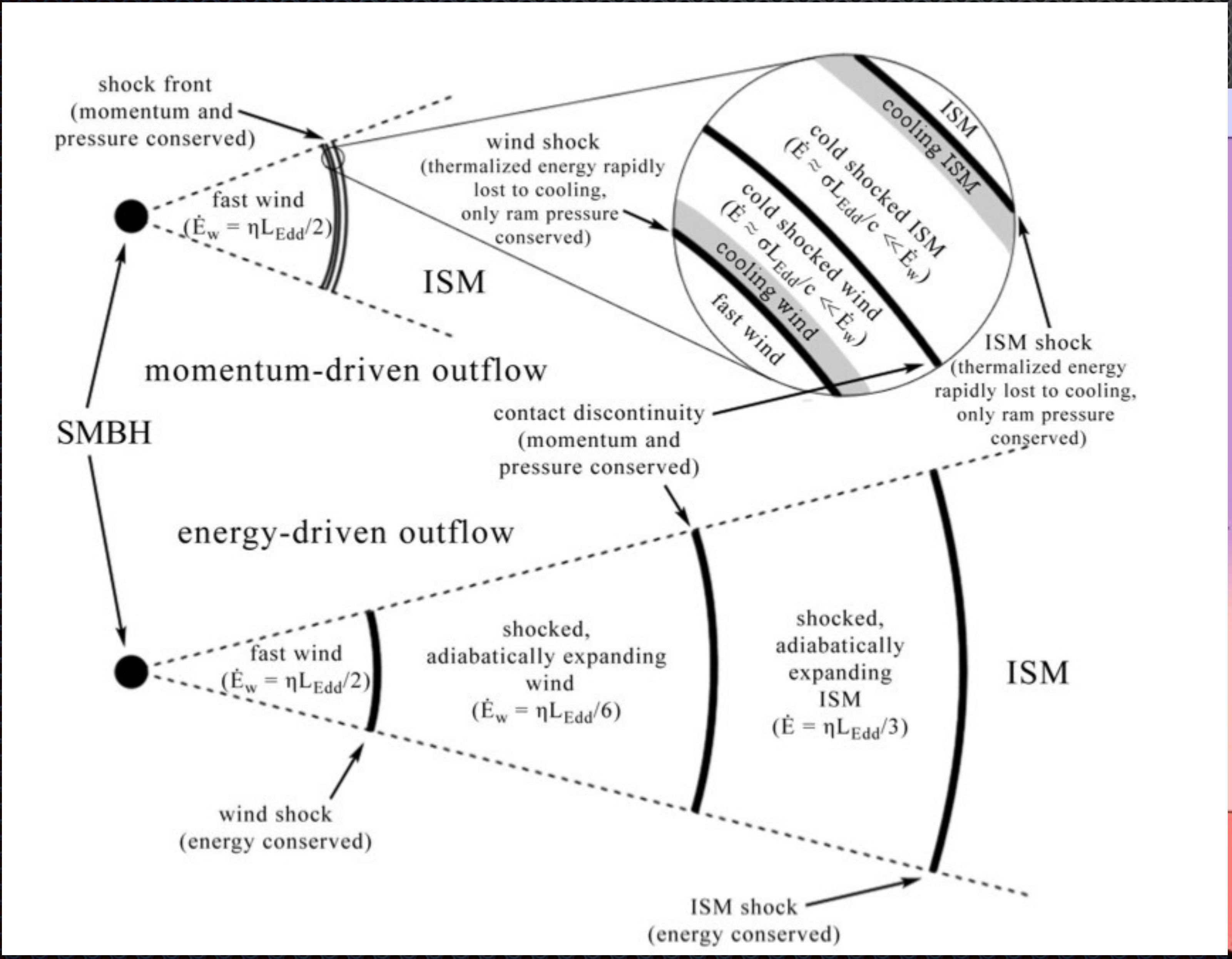
Courtesy by Chris Done

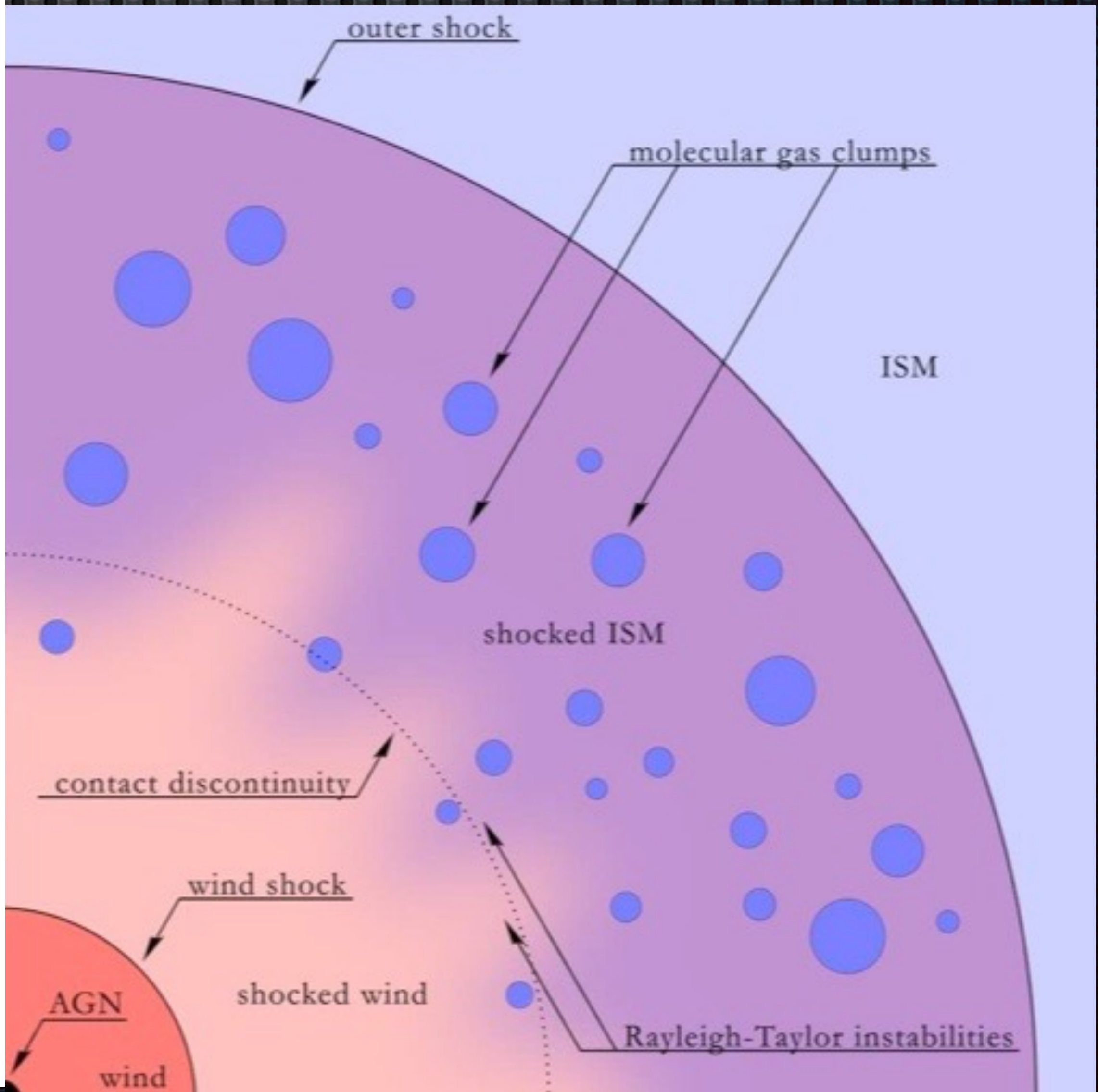
- X-rays weak but FUV can be strong!



Wind scenarios/models

Zubovas&King2012-2014





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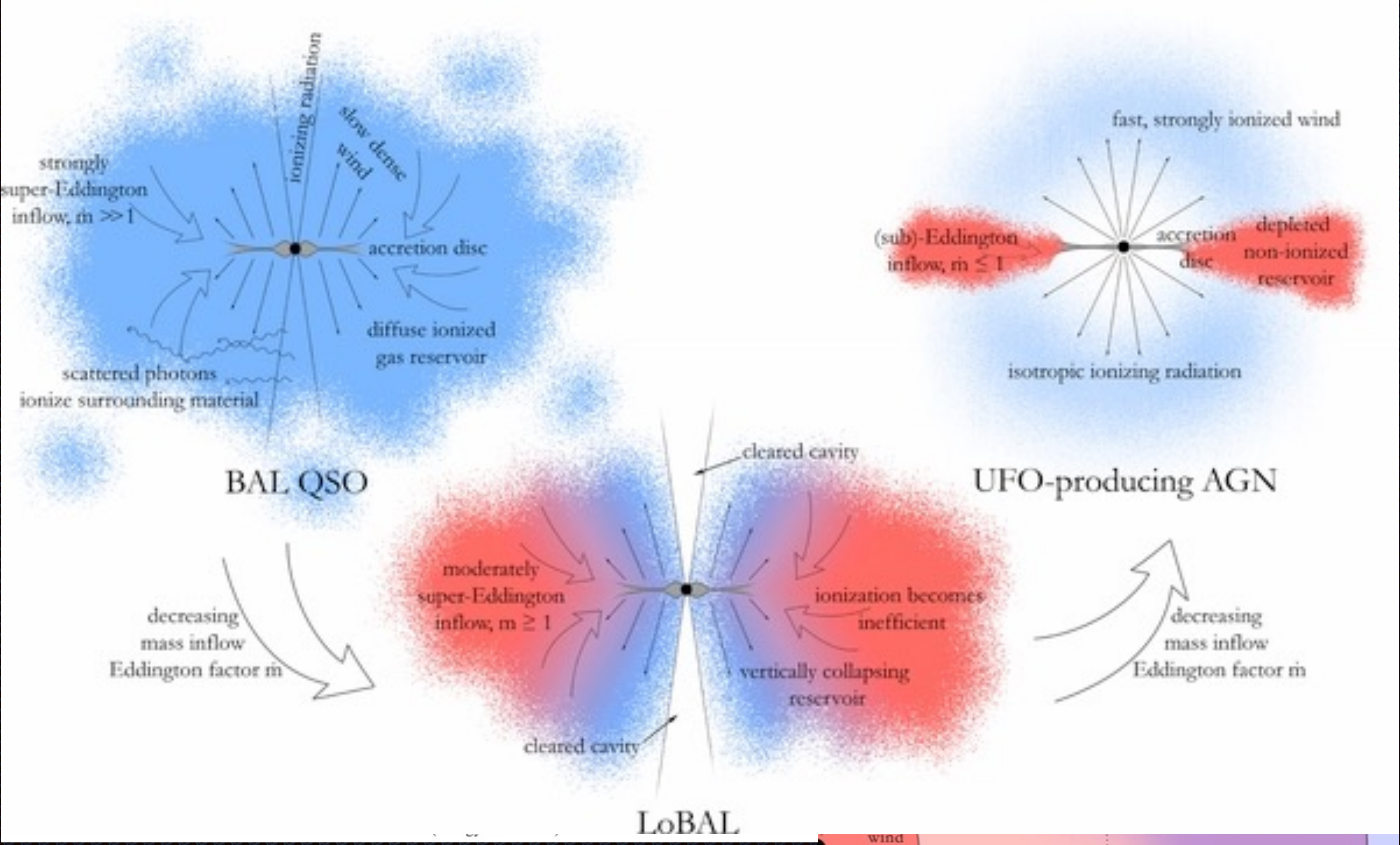

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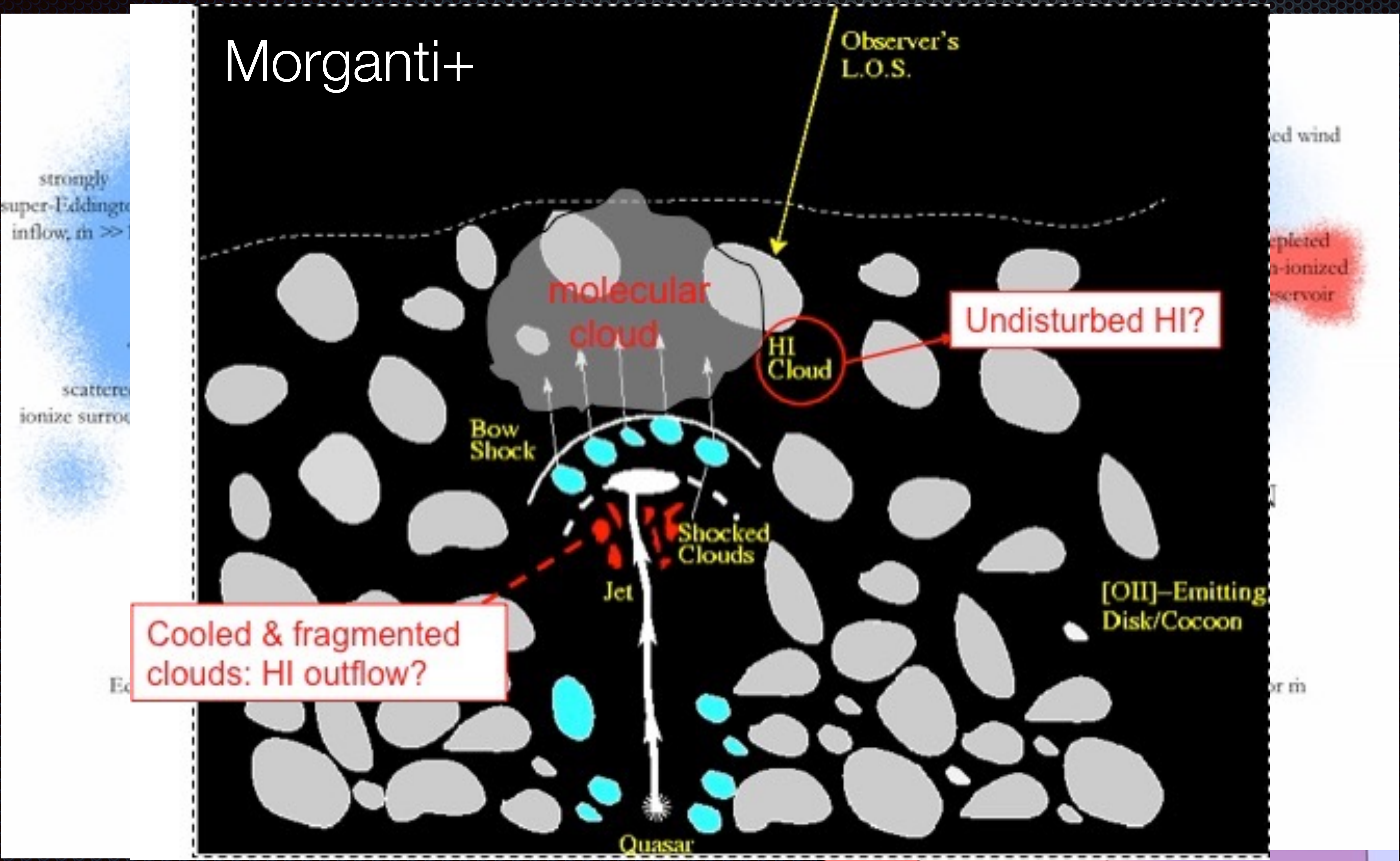

Wind scenarios/models

A few open problems:

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Wind scenarios/models

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  - If yes, this may imply a cooling sequence, X-ray, UV, molecular gas
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Statistical studies

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- Next generation surveys ***must target blind samples*** (a la SUPER, PHIBBS2, etc.) to constrain wind demographics
- In the meantime… collections of ***all winds in AGN*** published so far
  - 18 molecular winds (Mrk231, N6240, N1068, ULIRGs, etc)
  - 36 ionized gas winds (local SDSS type 2 AGN, z~2 QSOs and radio galaxies, z~3 hyper-luminous QSOs)
  - 6 BAL with spatial info available
  - 30 X-ray winds (UFOs, warm absorbers)

Three main sets of relationships

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1. Wind mass outflow rate, kinetic energy, AGN L_{bol}

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1. Wind mass outflow rate, kinetic energy, AGN L_{bol}
2. Wind mass outflow rate, kinetic energy, SFR

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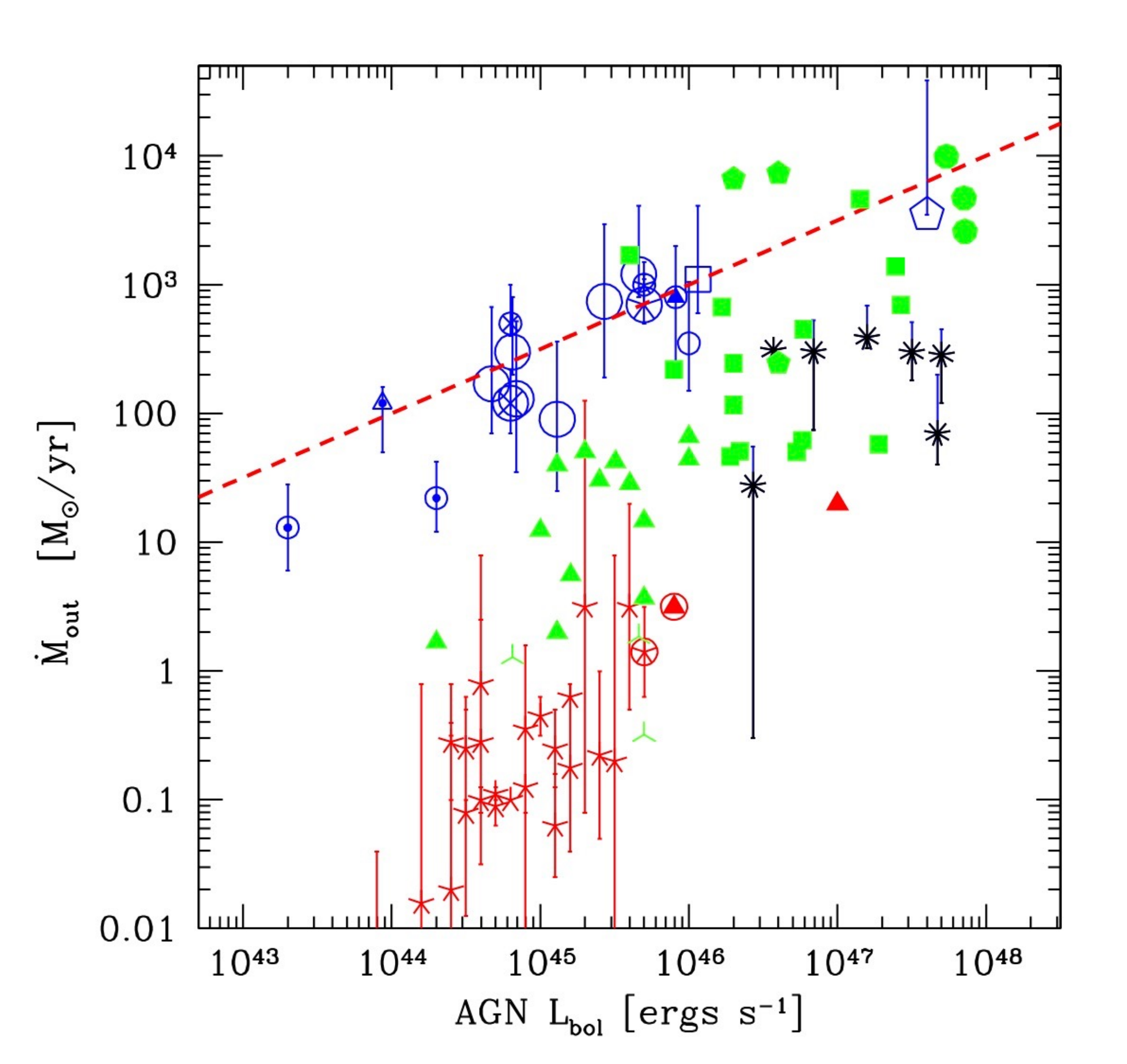
1. Wind mass outflow rate, kinetic energy, AGN L_{bol}

2. Wind mass outflow rate, kinetic energy, SFR

3. Wind properties vs. SFG scaling relations (t_{dep} gas fraction)

Super Winds & AGN L_{bol}

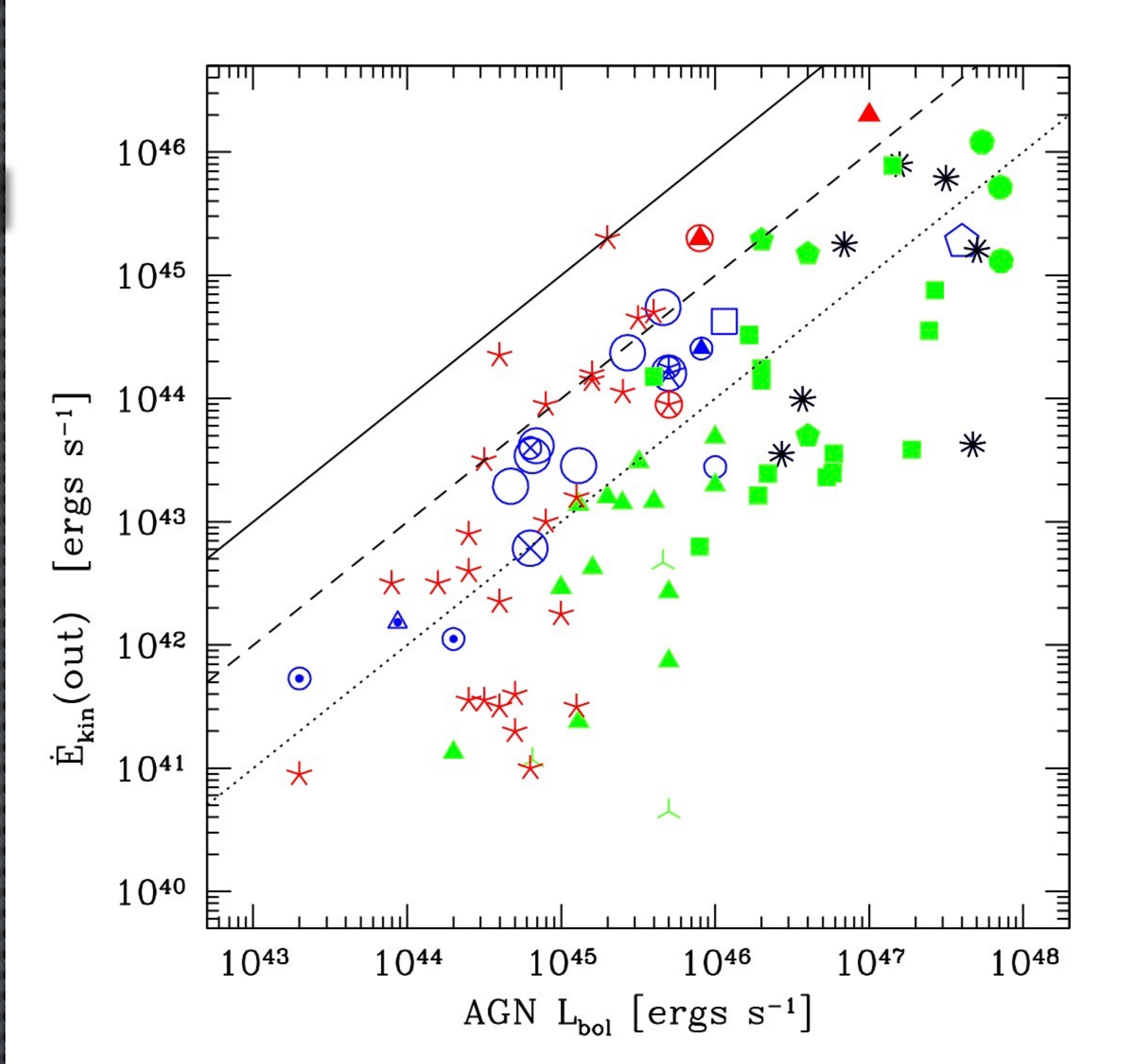


Molecular
small=nucl
large=gal.

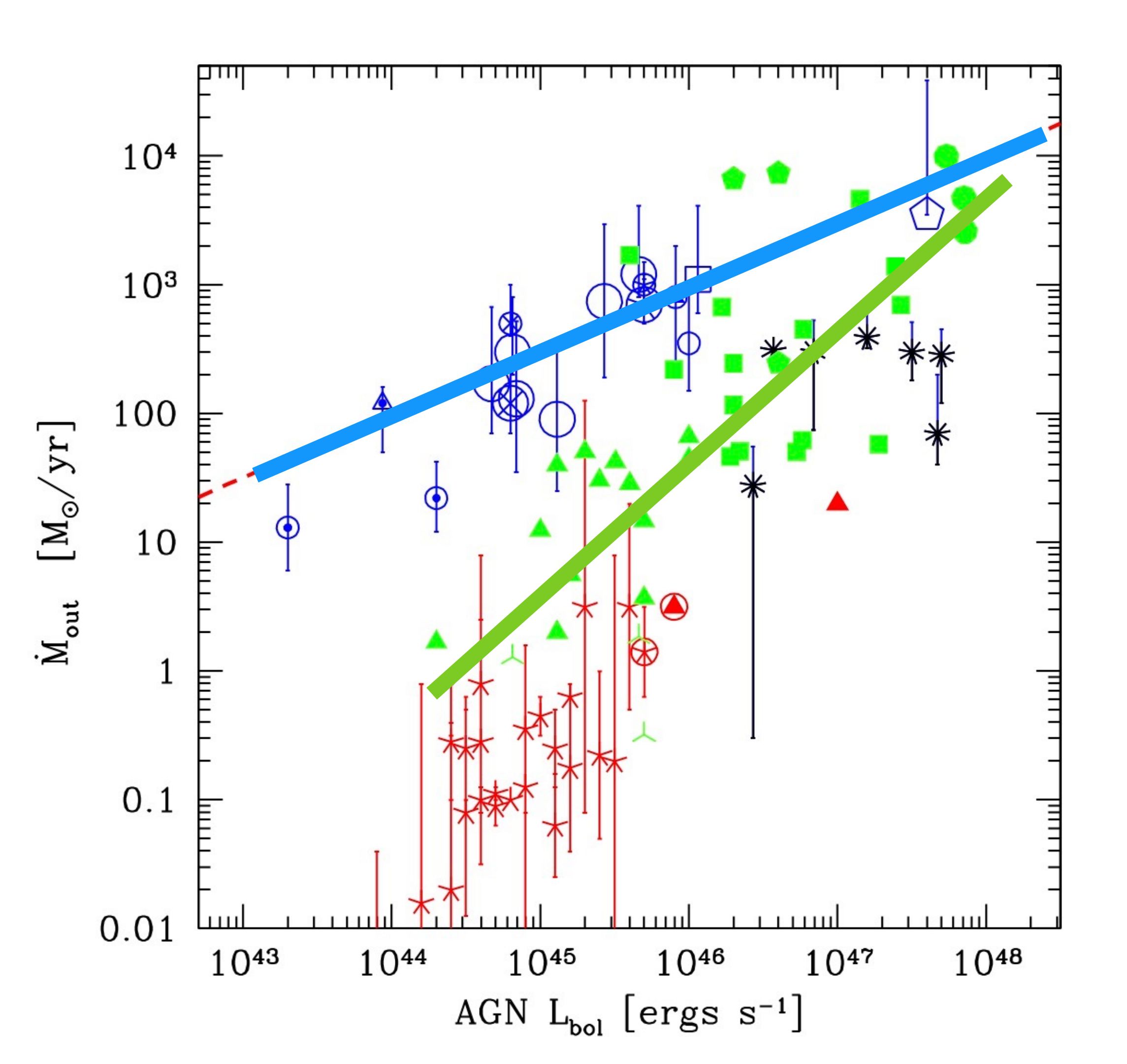
Ionized

BAL

X-ray



Super Winds & AGN L_{bol}



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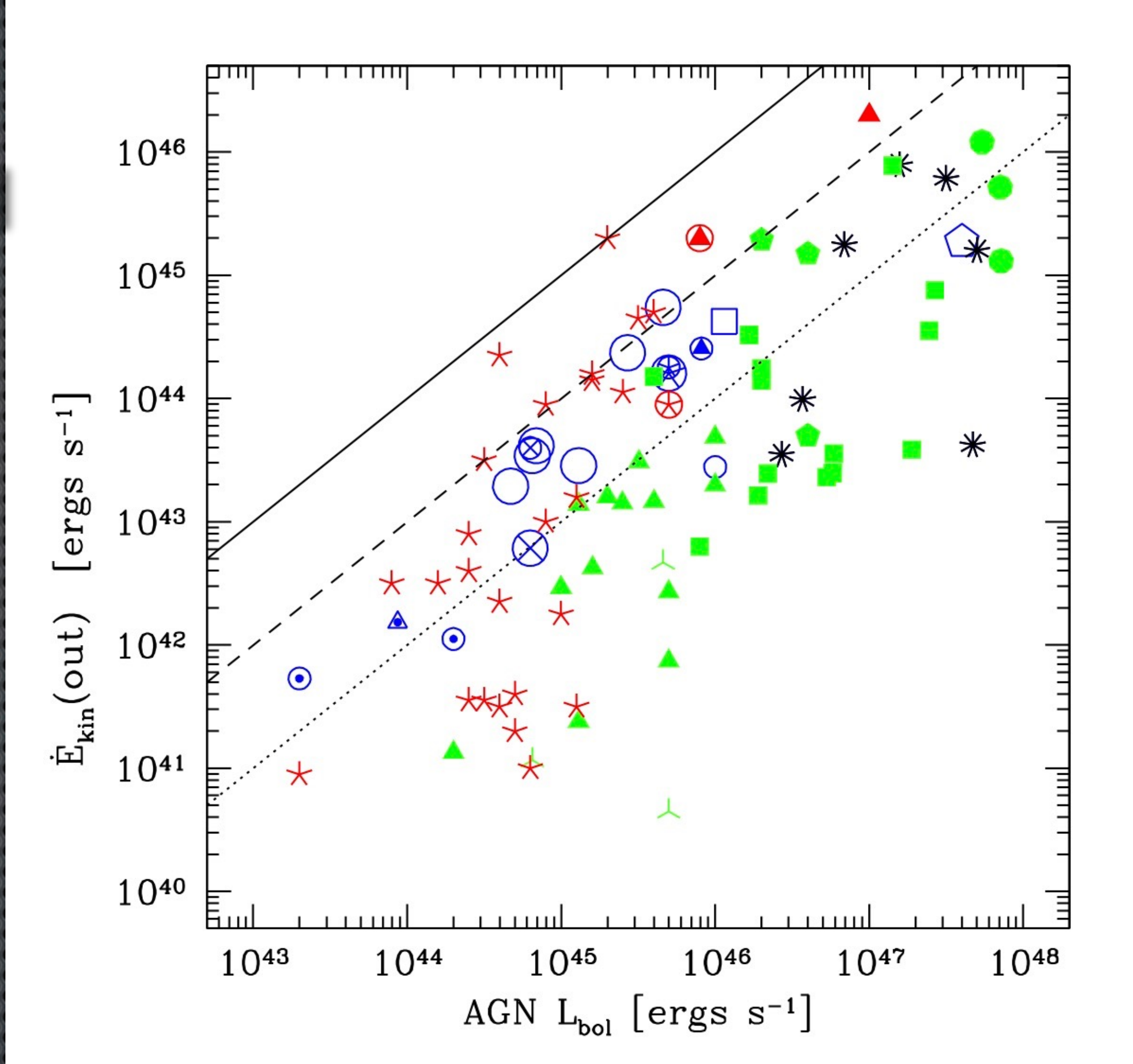
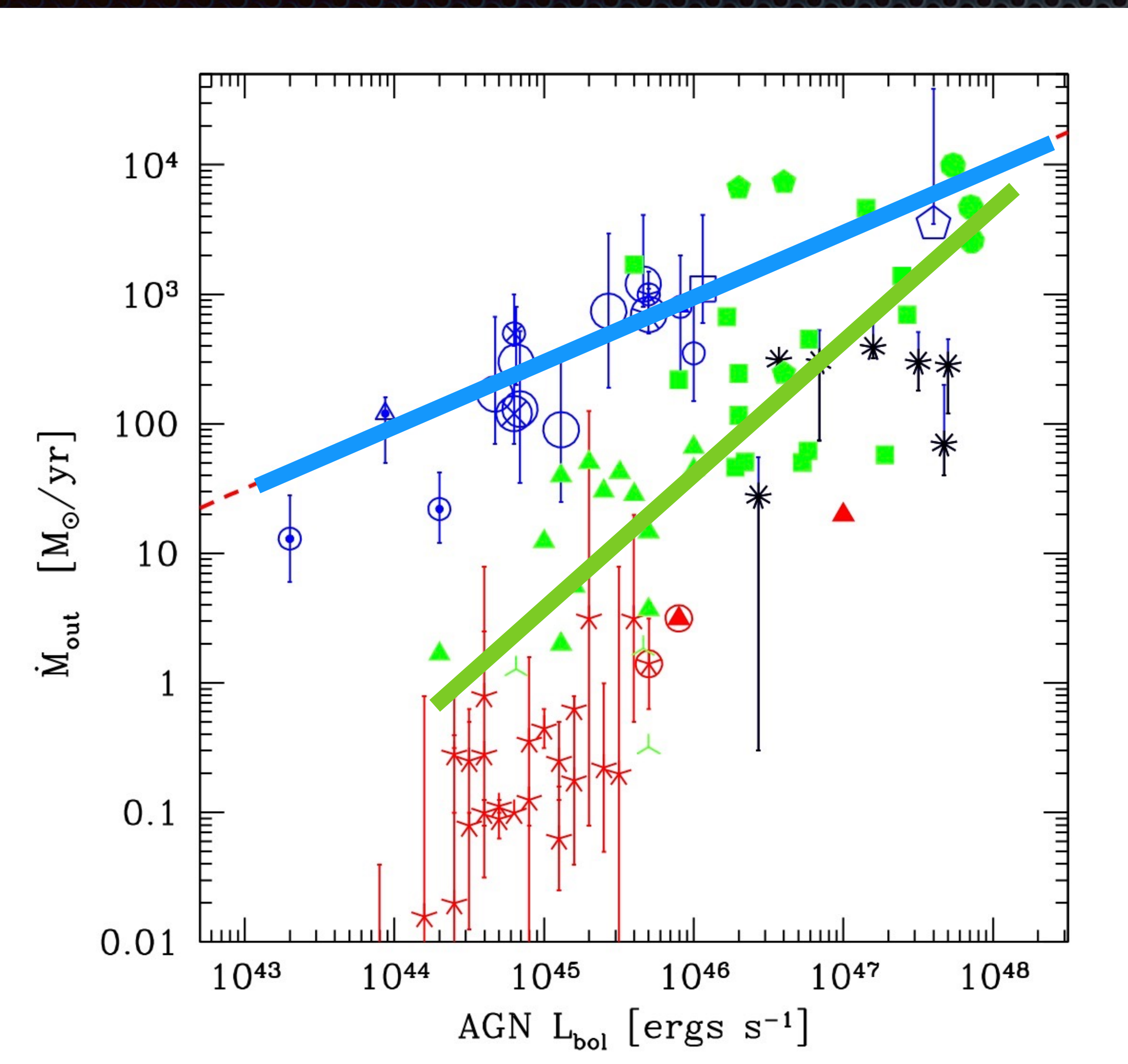


Remarkable correlation between wind mass outflow rate and AGN bolometric luminosity: $M_{out} \sim L_{bol}^{0.5}$ for molecular winds $M_{out} \sim L_{bol}$ for ionized winds

Super Winds & AGN L_{bol}



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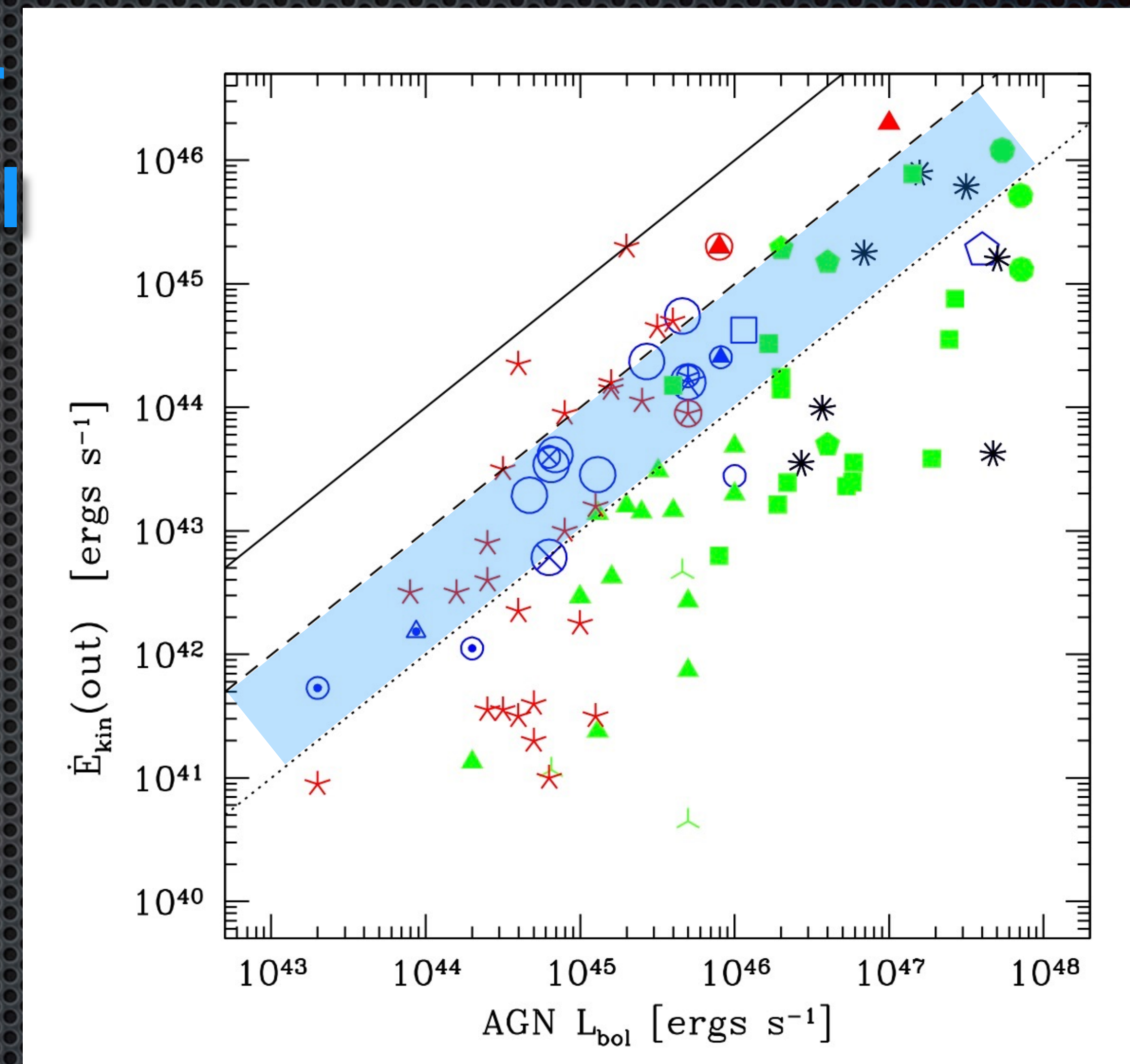

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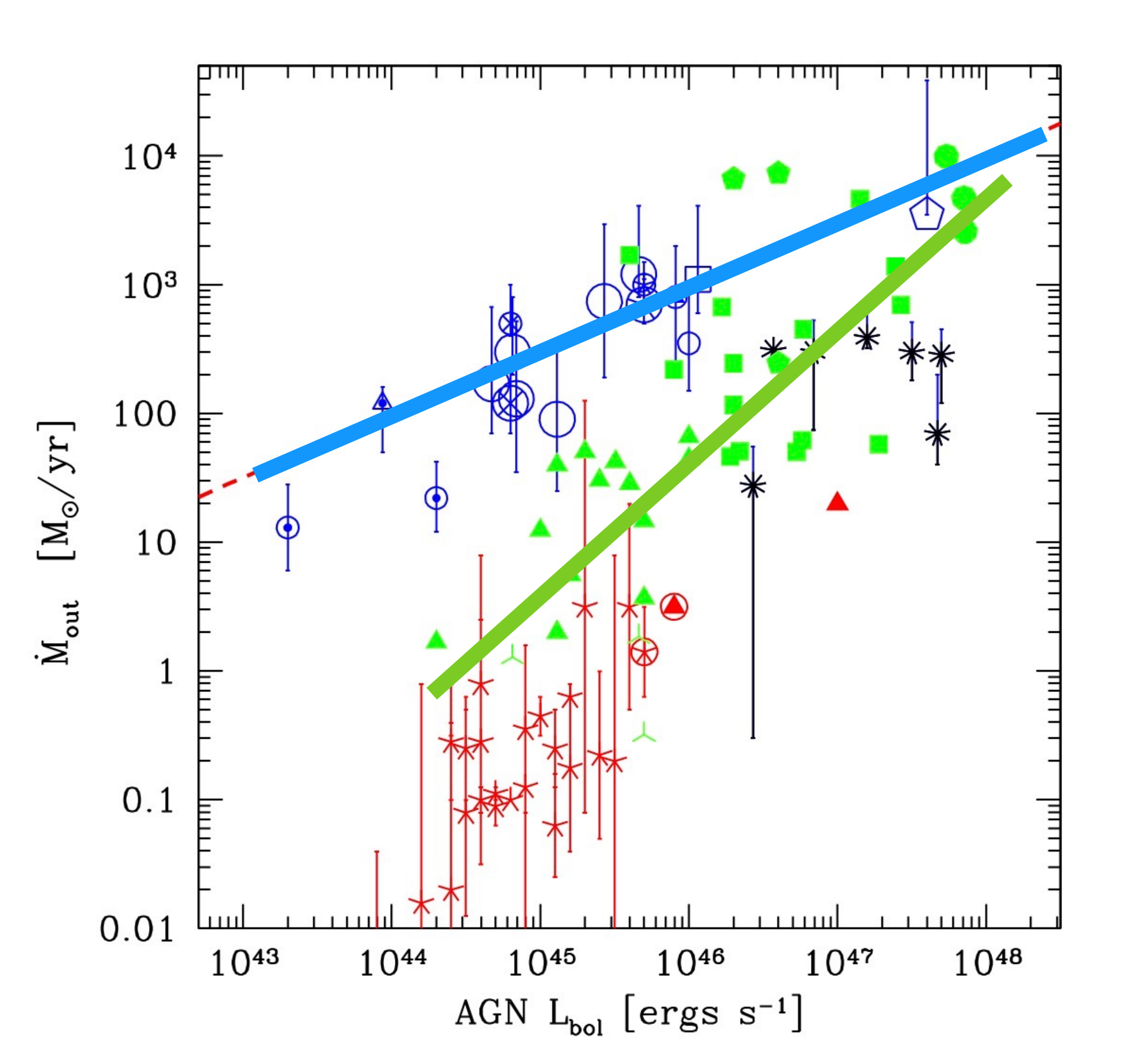
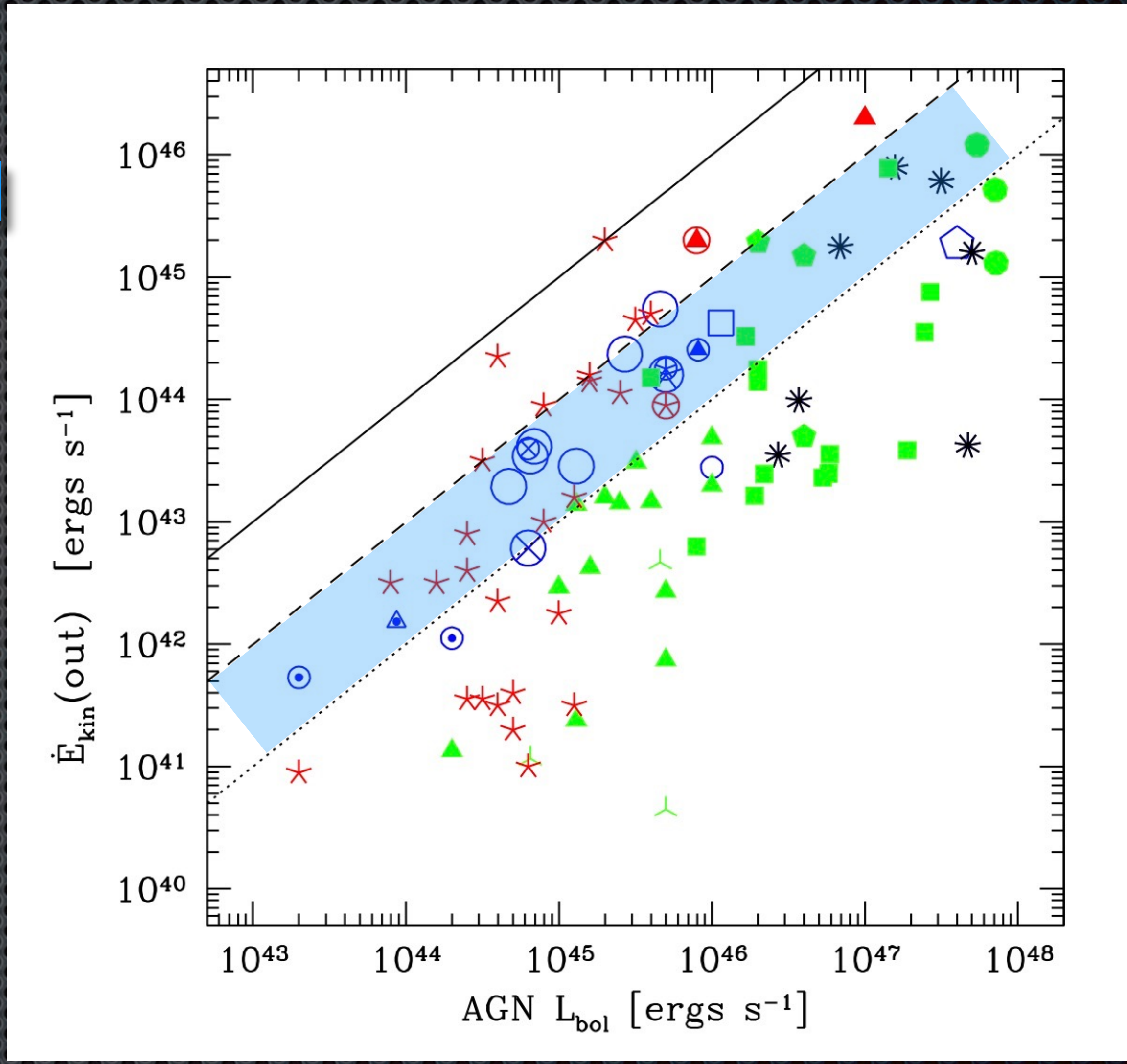
E_{kin}(out) = 1-10% L_{bol} (molecular)

Super Winds & AGN L_{bol}





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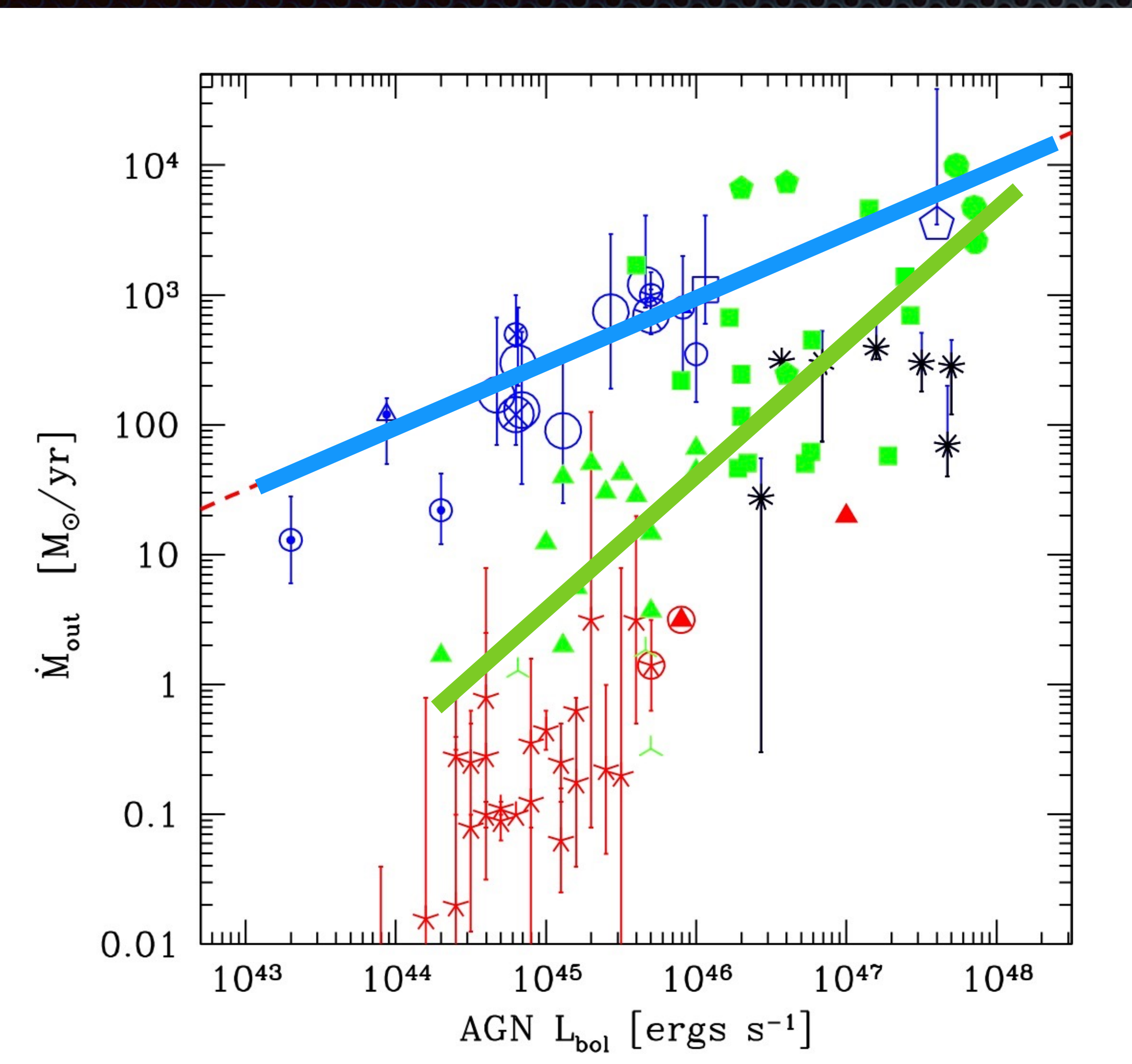
Super Winds & AGN L_{bol}



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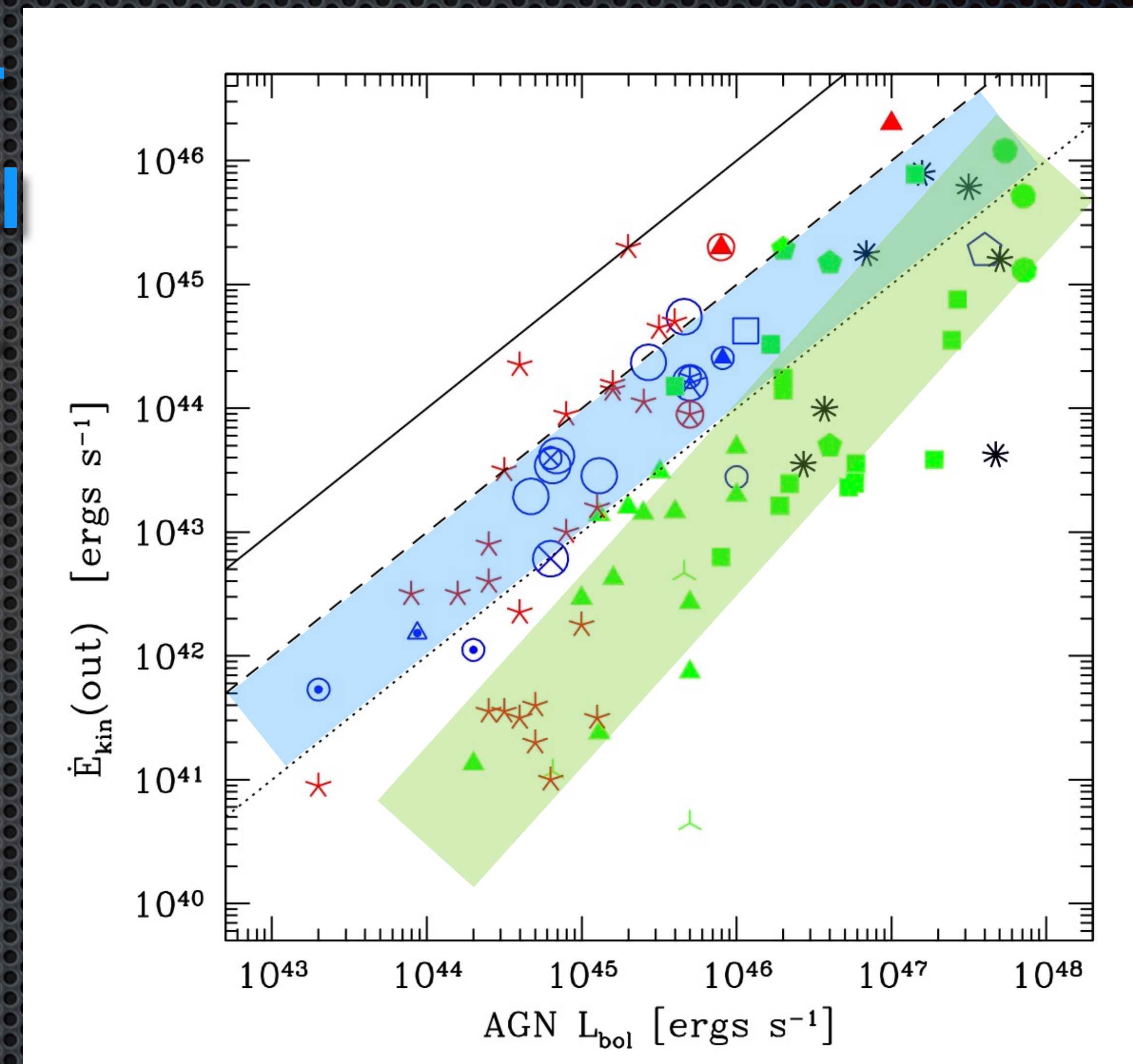
BAL

X-ray



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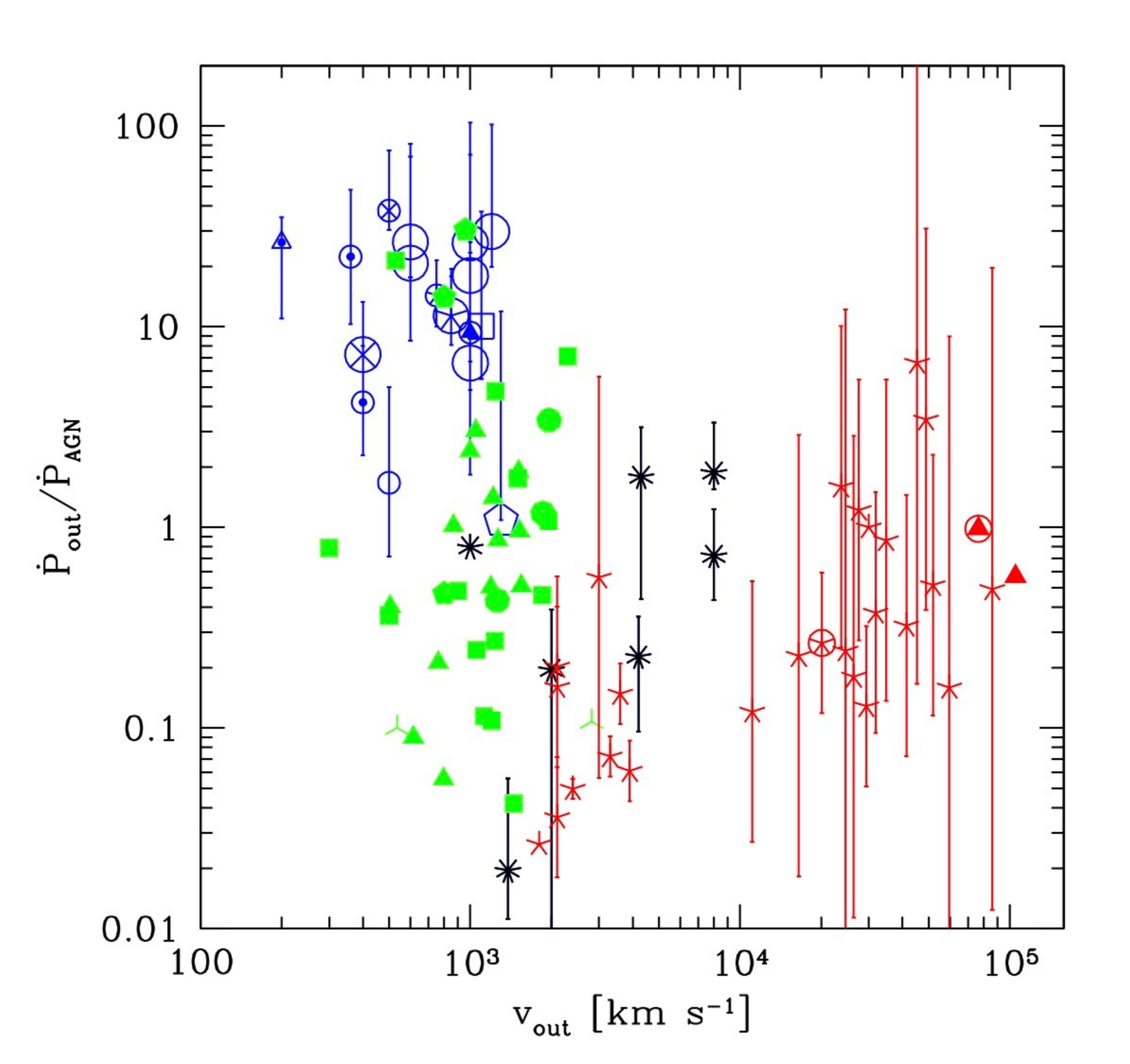
E_{kin}(out) = 0.1-1% (ionized low L_{bol}) = 1-10 % (ionized high L_{bol})

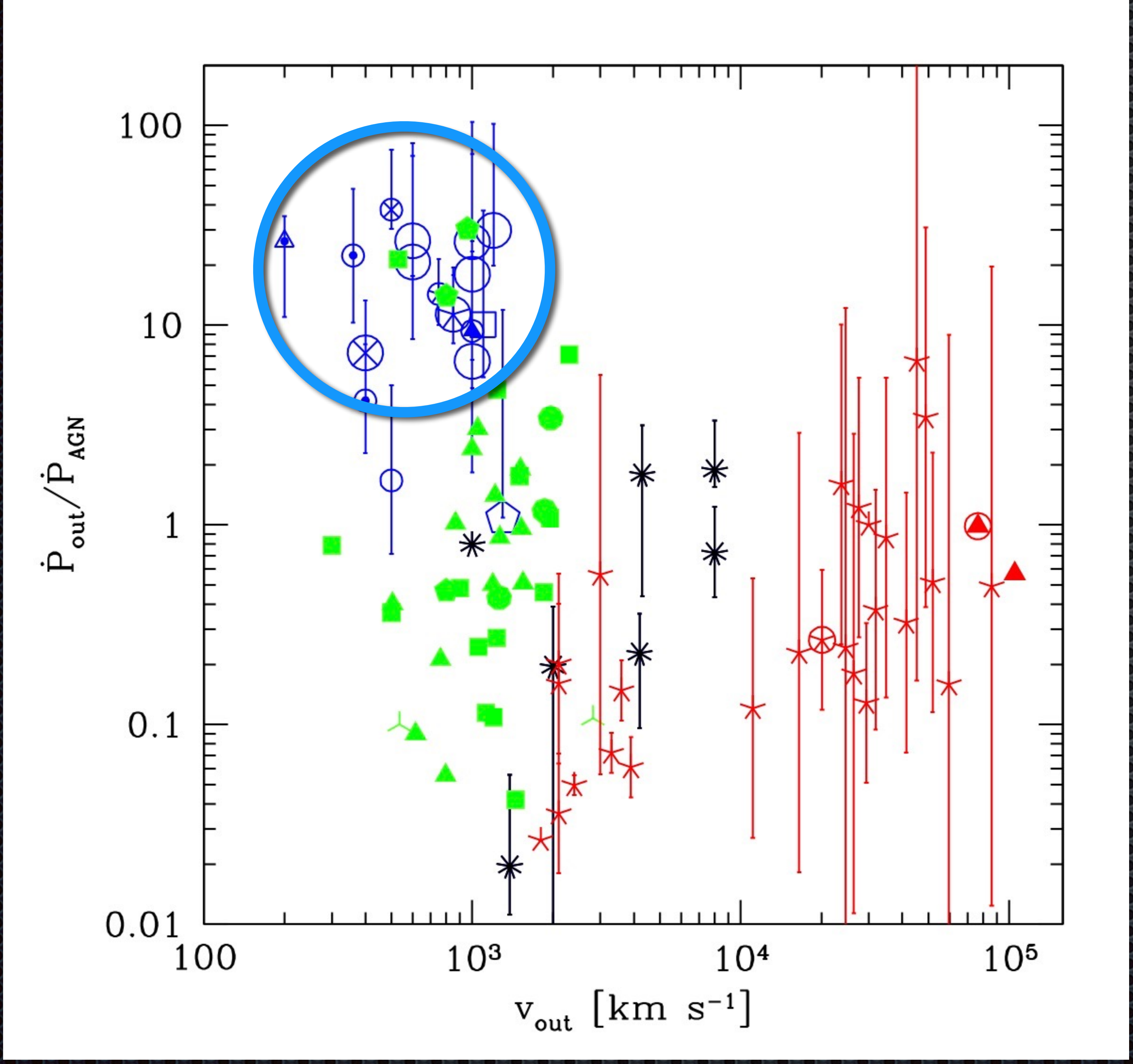
Super Winds & AGN L_{bol}

Molecular, **Ionized**, **BAL**, **X-ray**



Super Winds & AGN L_{bol}

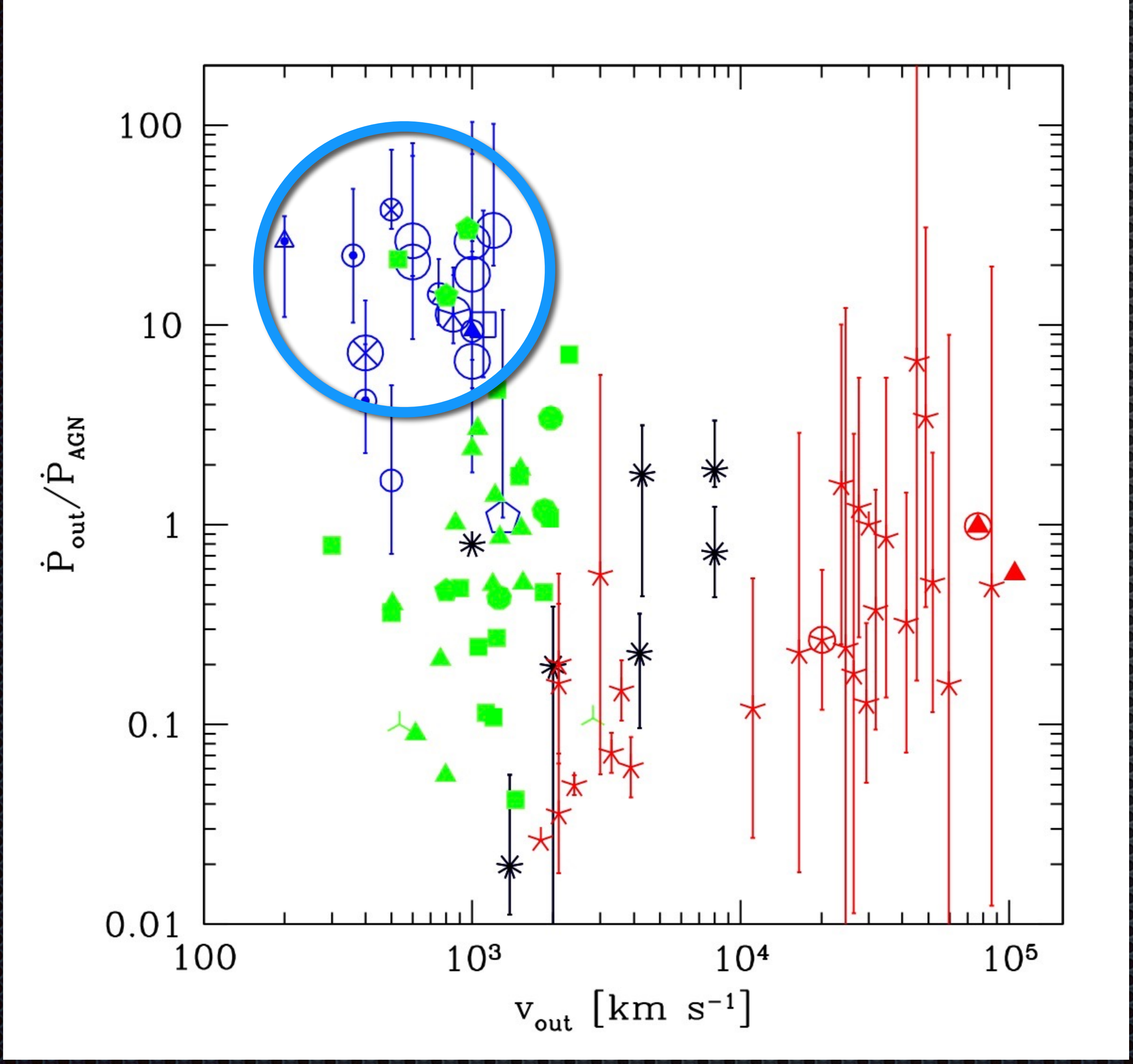
Molecular, Ionized, BAL, X-ray



AGN outflow momentum rate
>>
AGN radiation momentum rate

Super Winds & AGN L_{bol}

Molecular, **Ionized**, **BAL**, **X-ray**

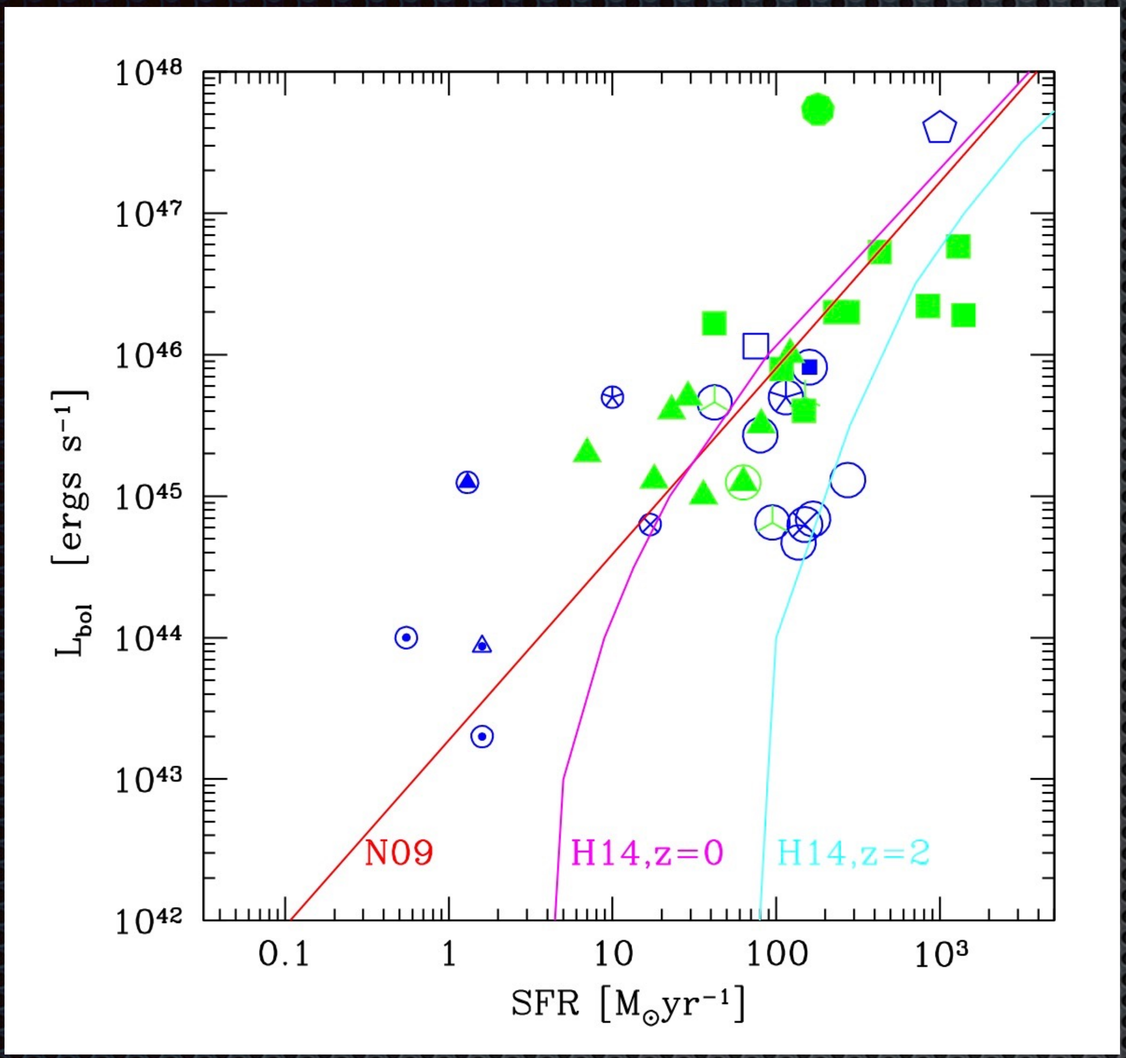


AGN outflow momentum rate
>>
AGN radiation momentum rate

Most molecular winds and several ionised winds are energy-conserving

(but uncertainties are LARGE)

Super Winds & SFR



Molecular
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BAL

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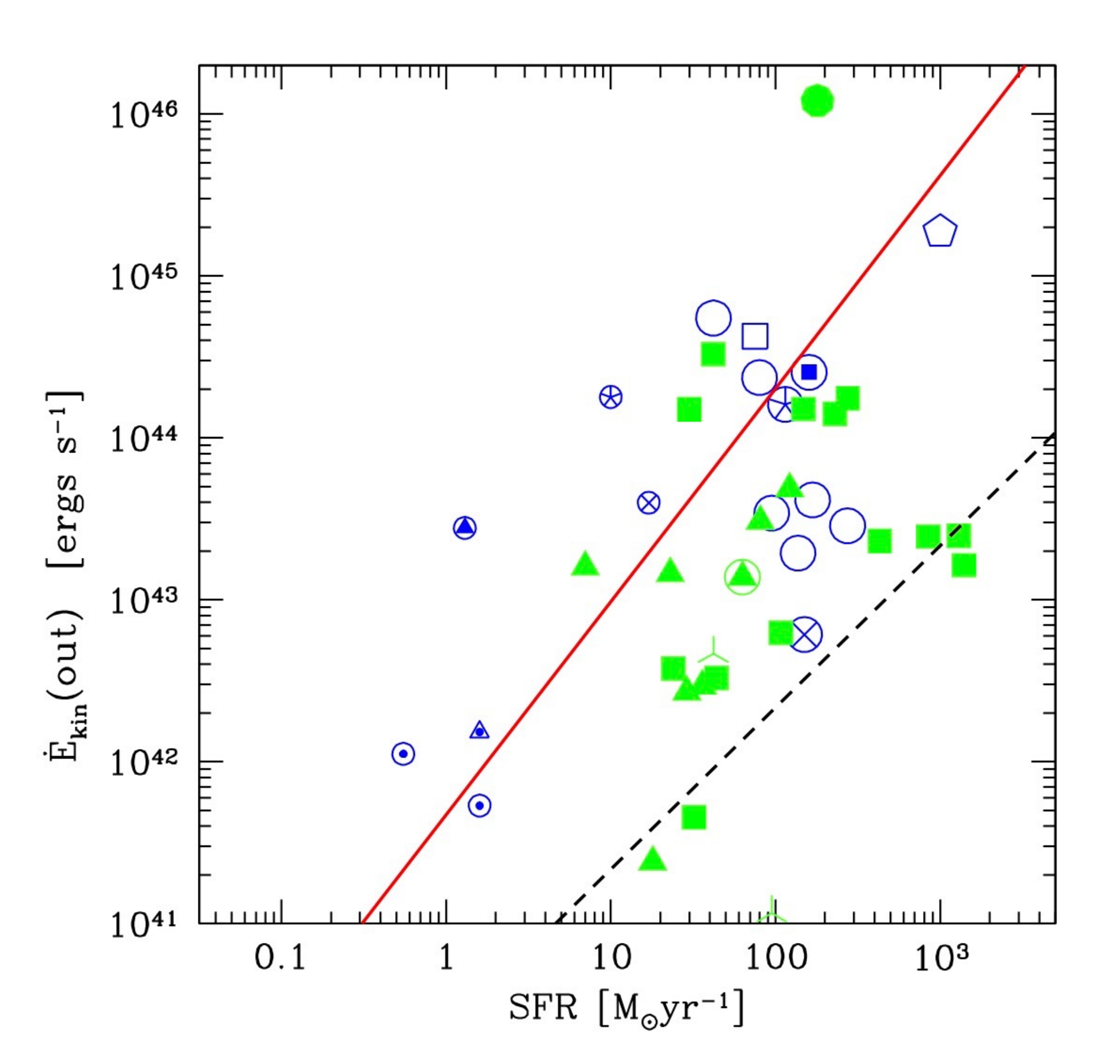
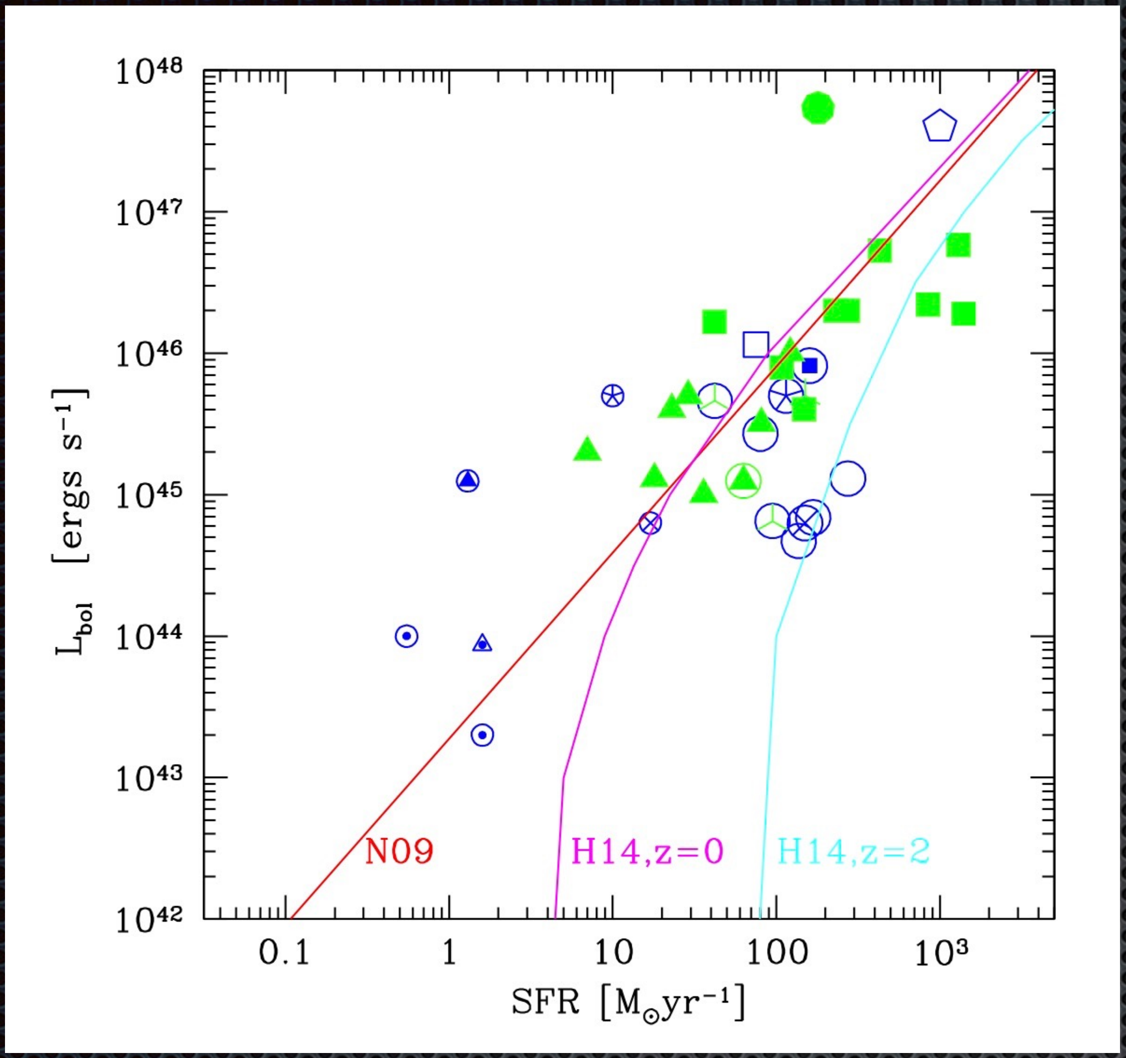


Super Winds & SFR



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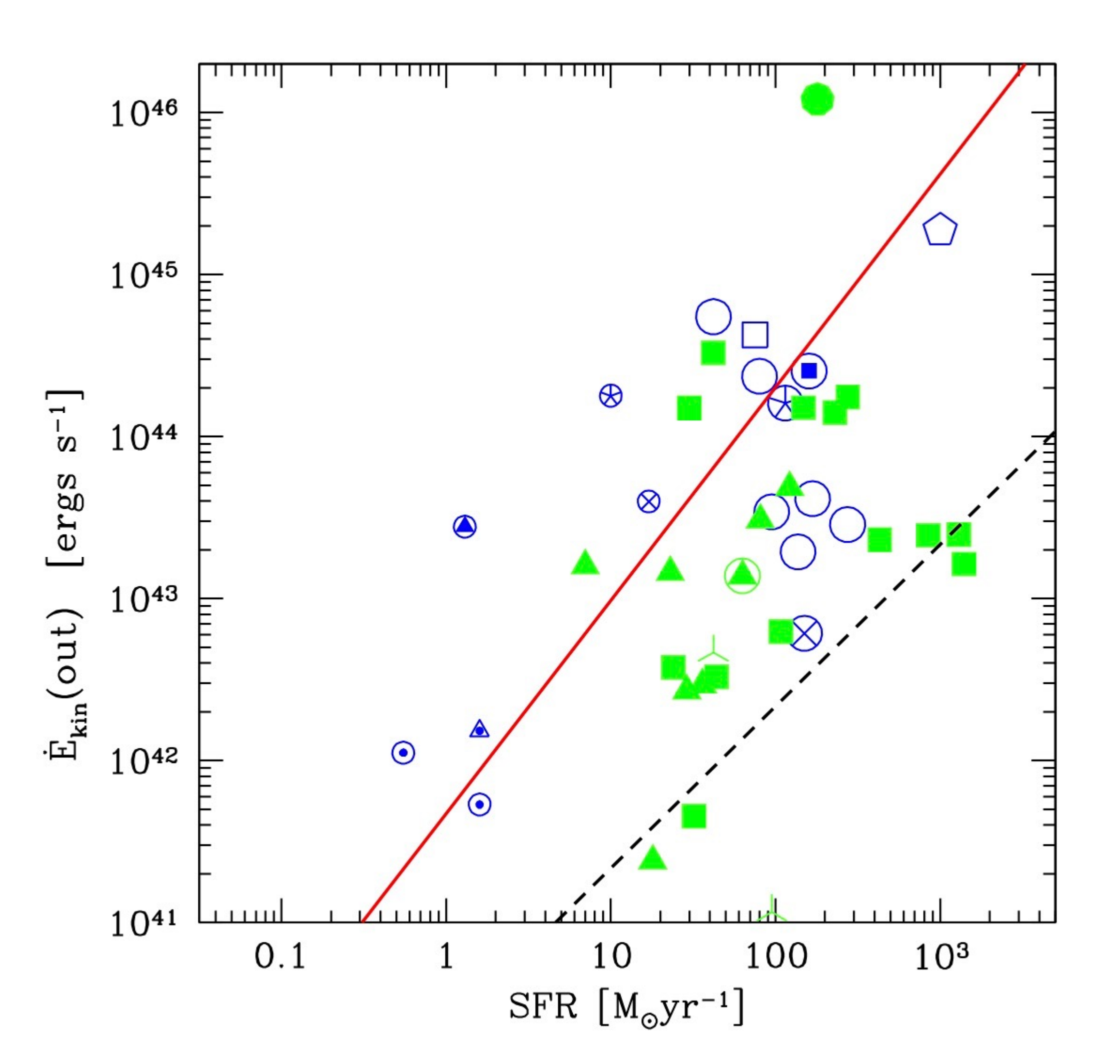
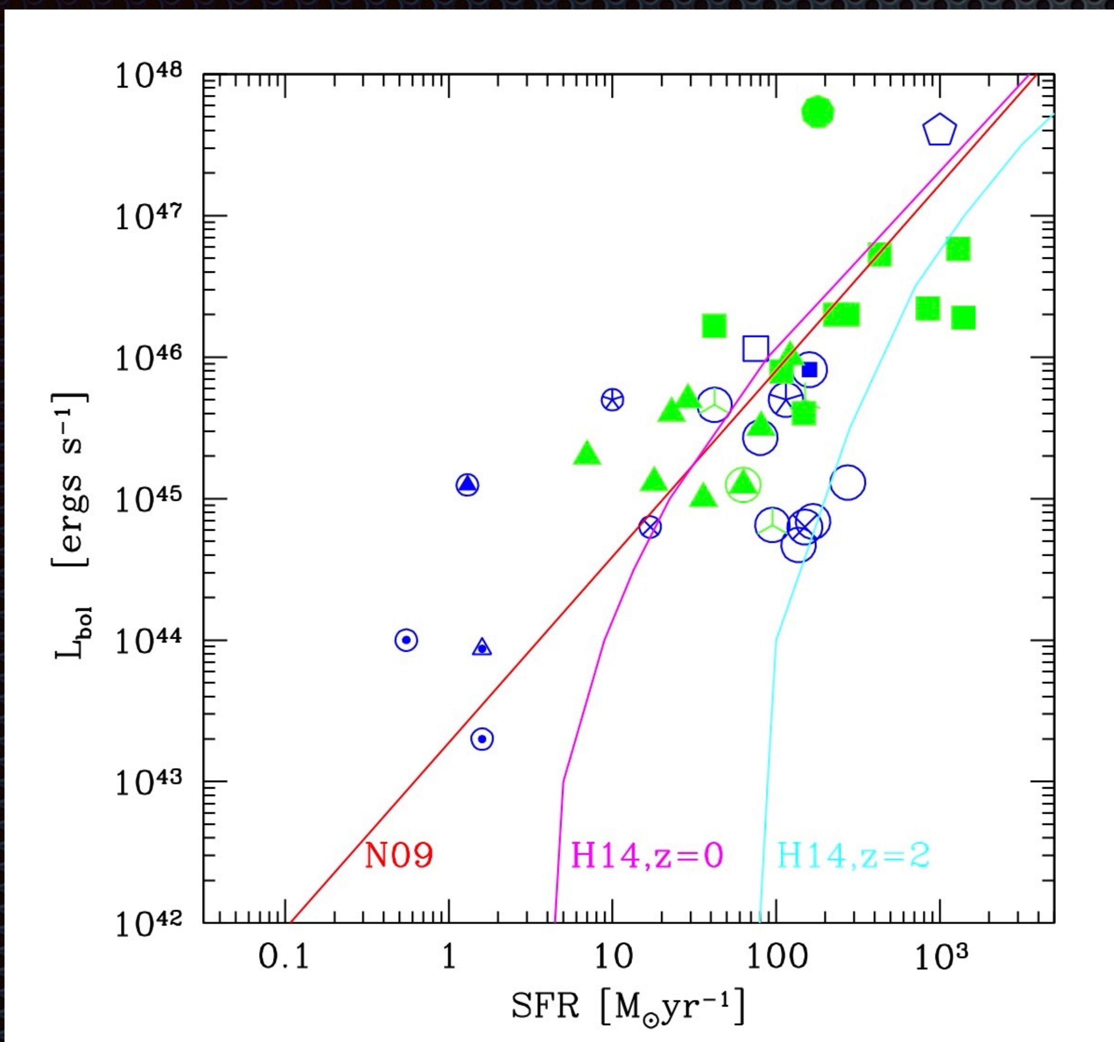


Coarse correlation between L_{bol} and SFR, coarse correlation between Ekin(out) and SFR

Super Winds & SFR



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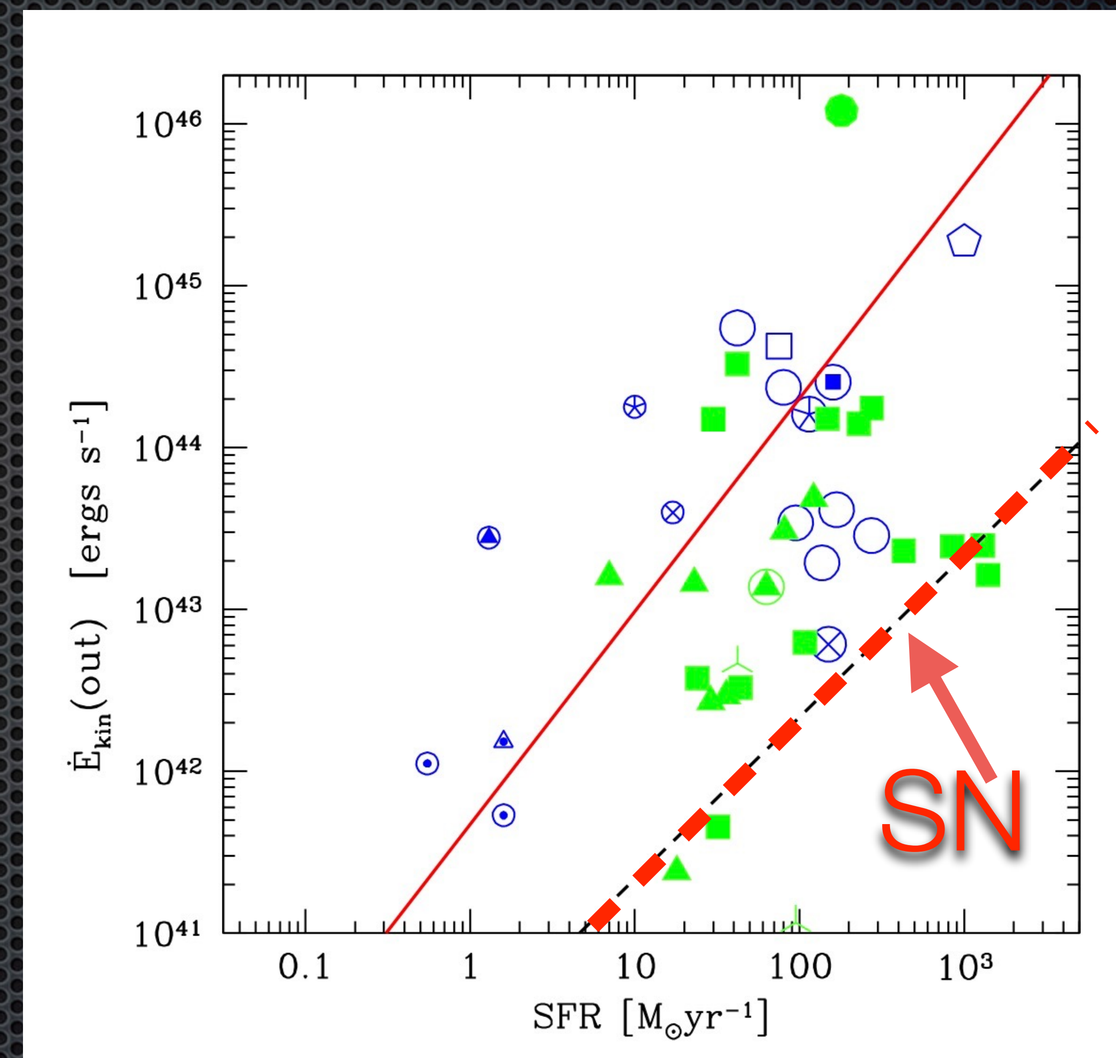
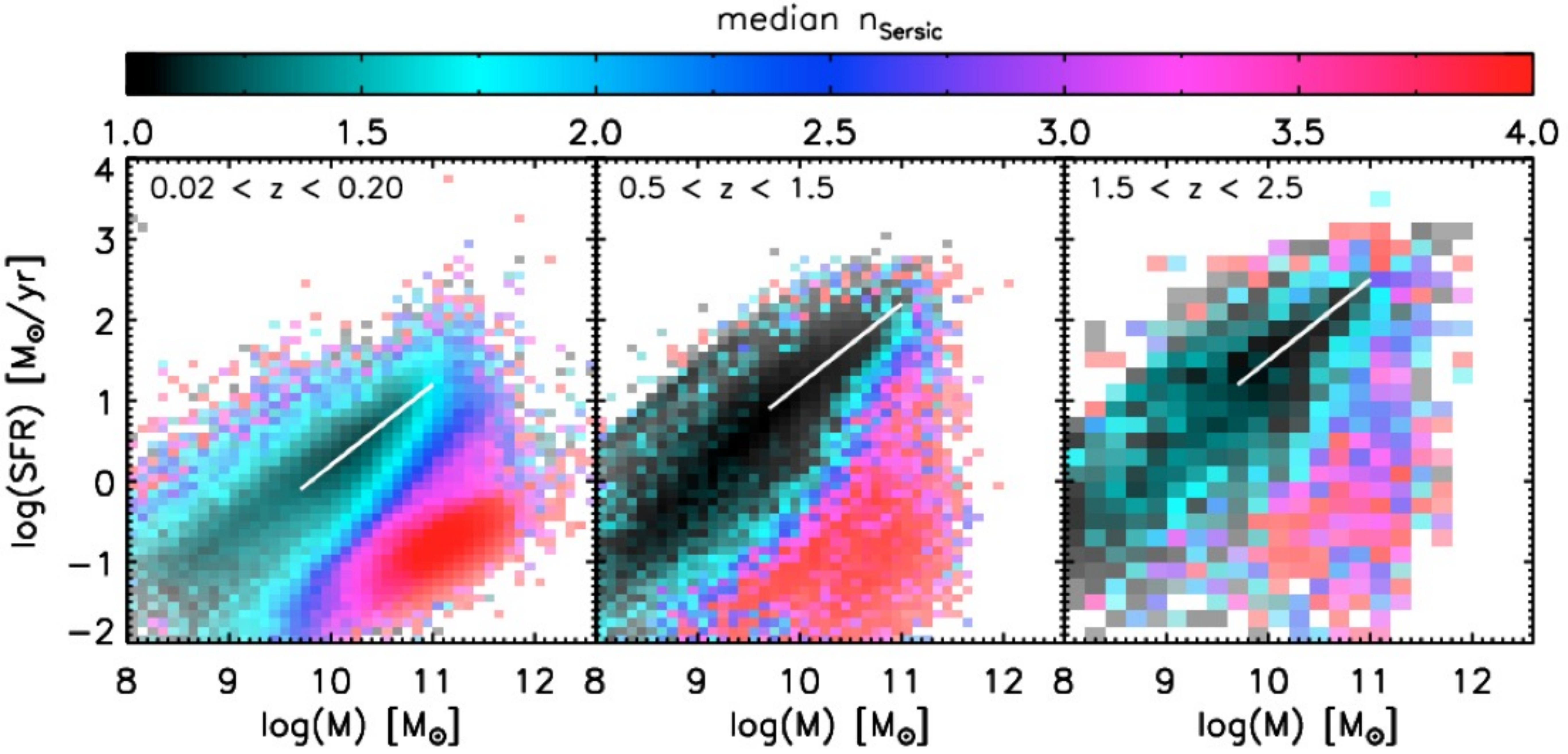


Coarse correlation between L_{bol} and SFR, coarse correlation between Ekin(out) and SFR

Most molecular and ionised winds are too powerful to be powered by SN
They are most likely AGN driven

Molecular/ionized winds scaling relations: Galaxy main sequence



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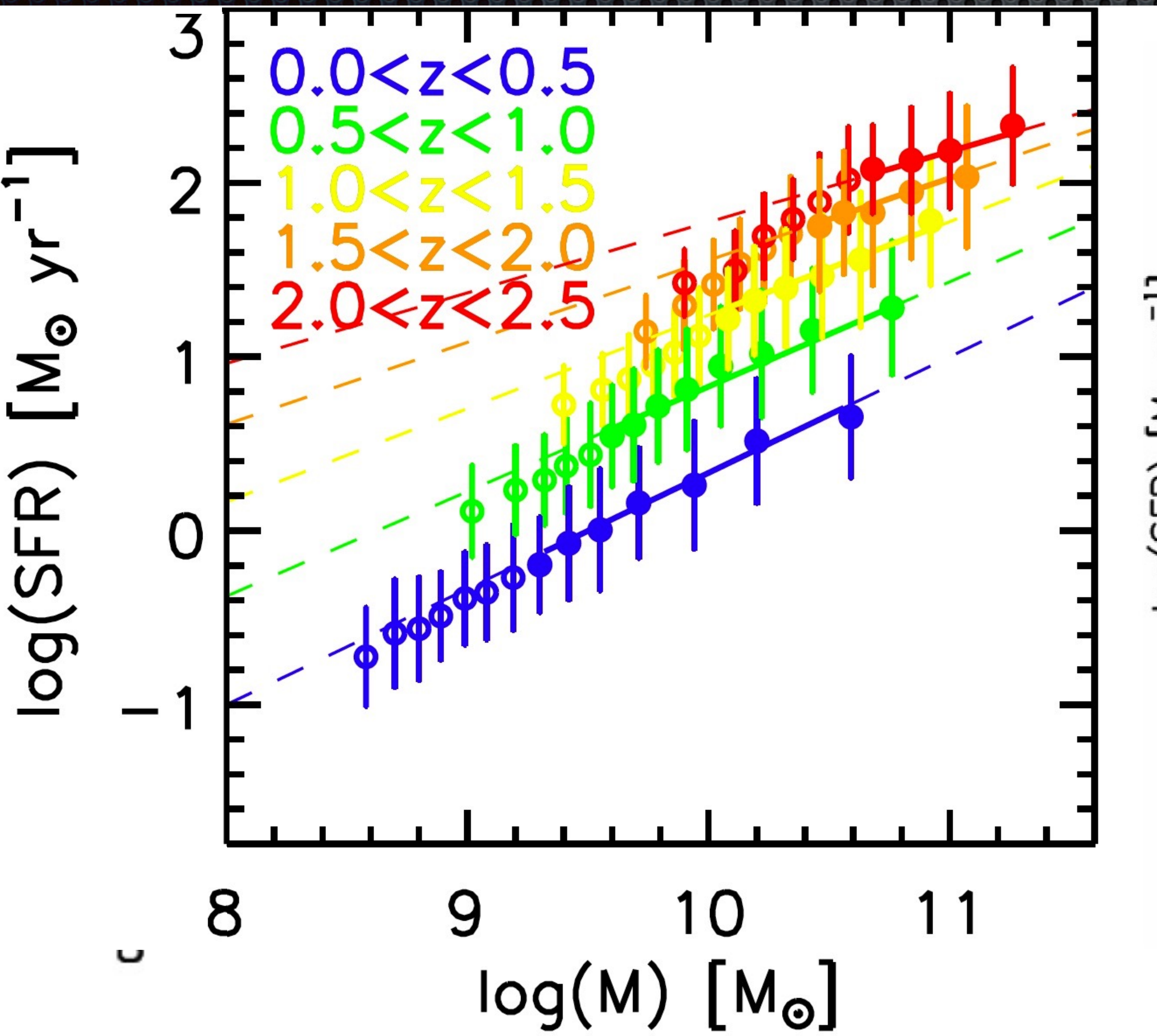

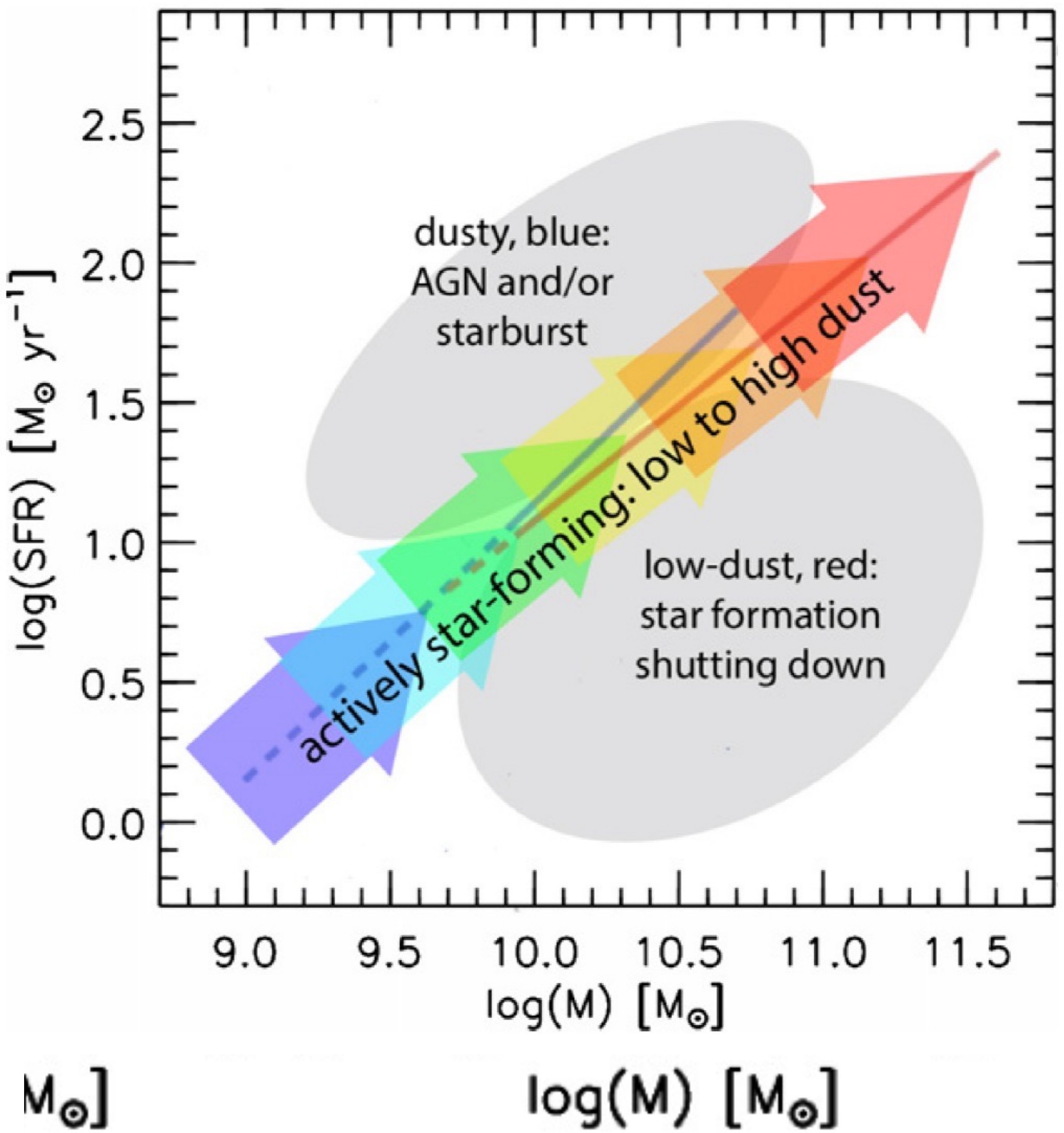

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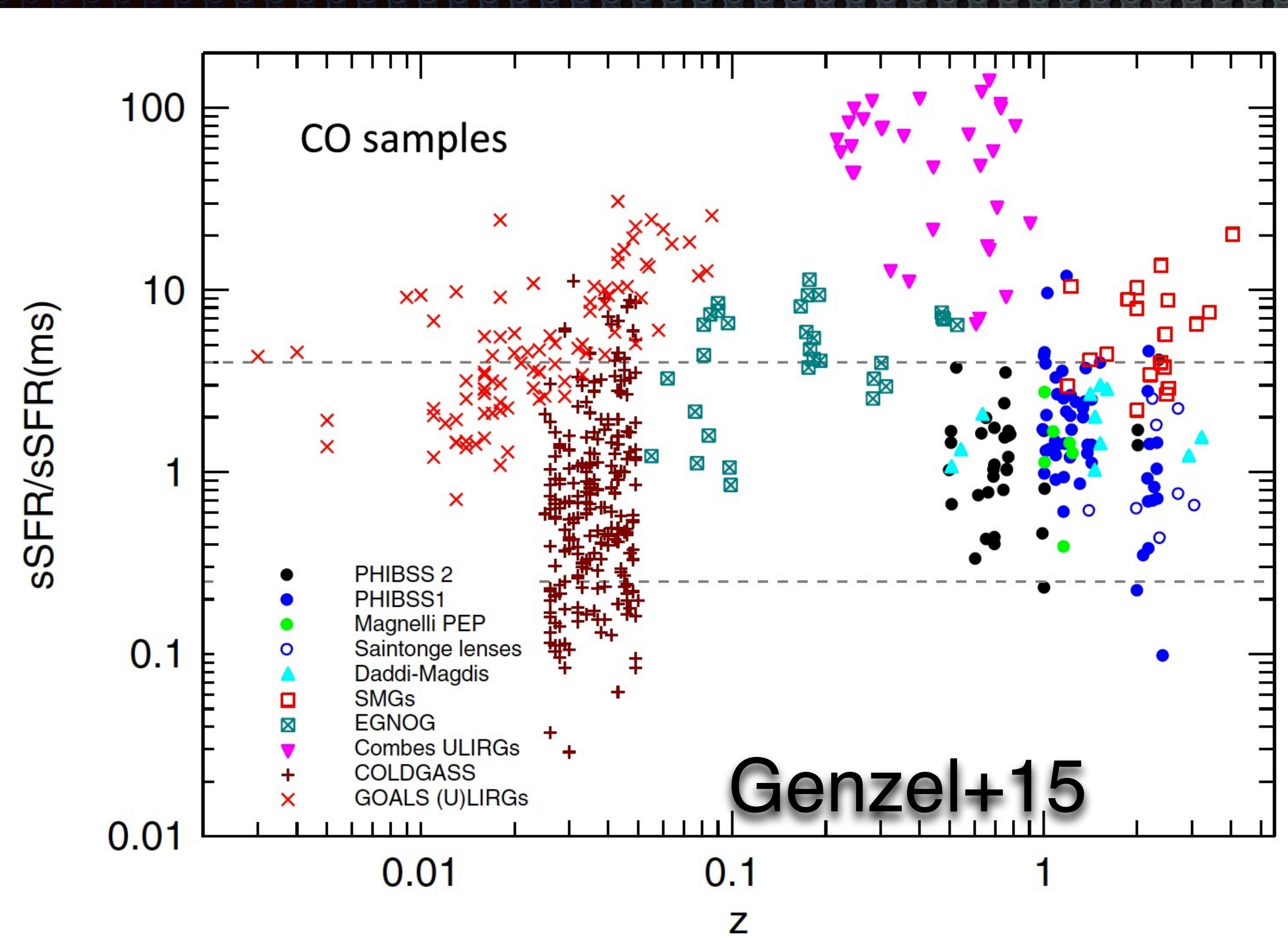
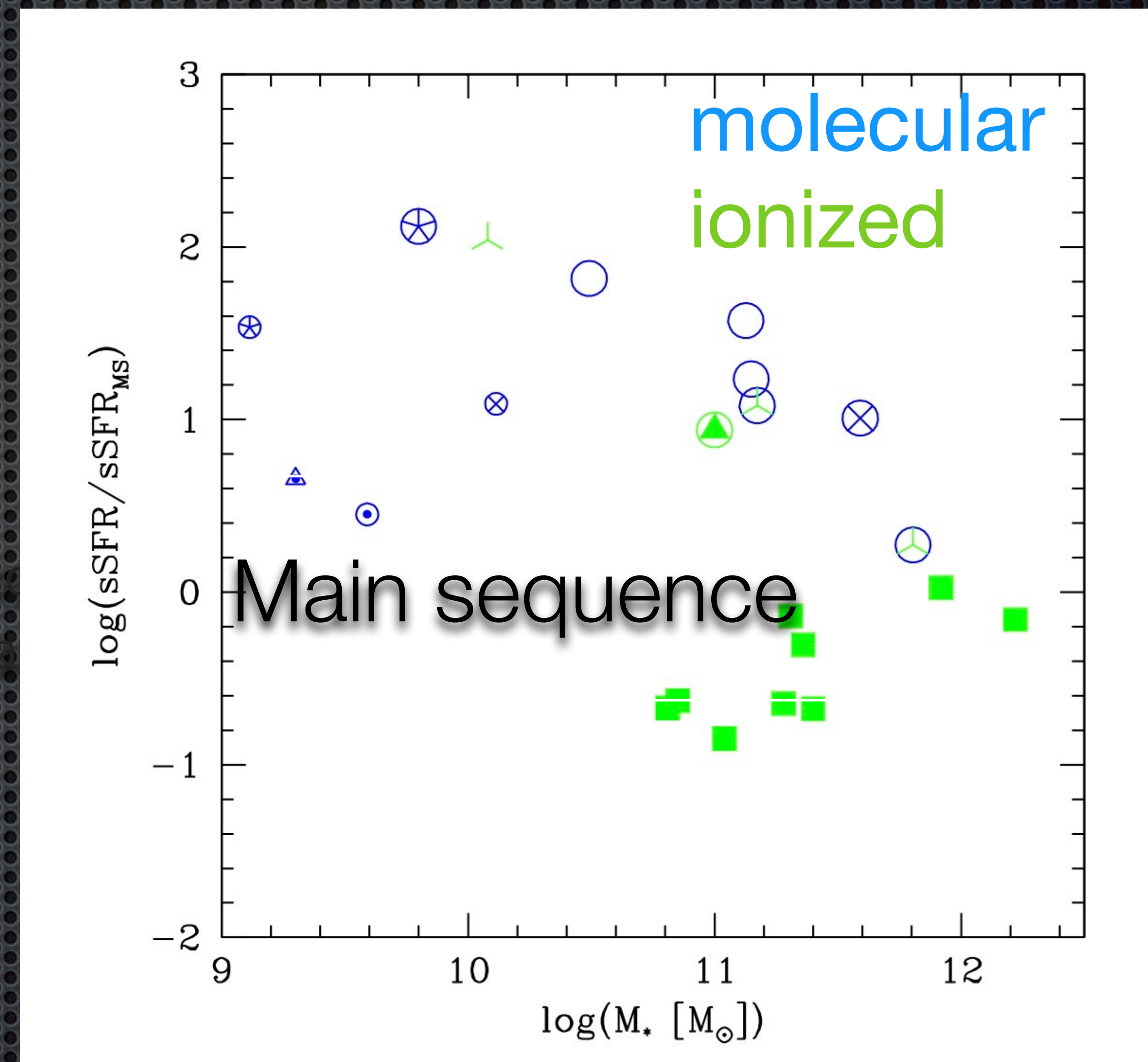


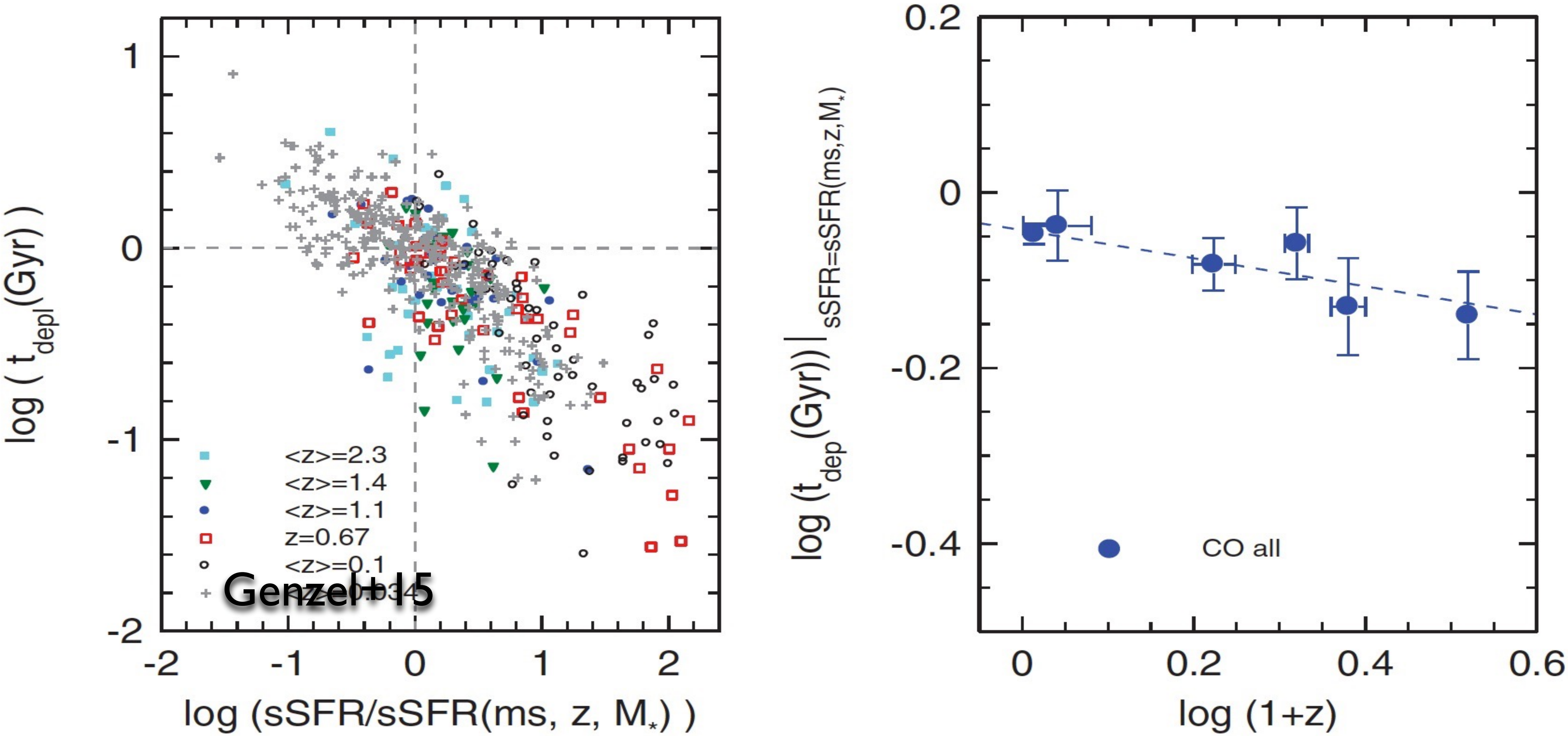


Heterogeneous sample:

Molecular winds in local (U)LIRGs and nearby Seyfert galaxies.

Most ionized winds in z~2 AGN

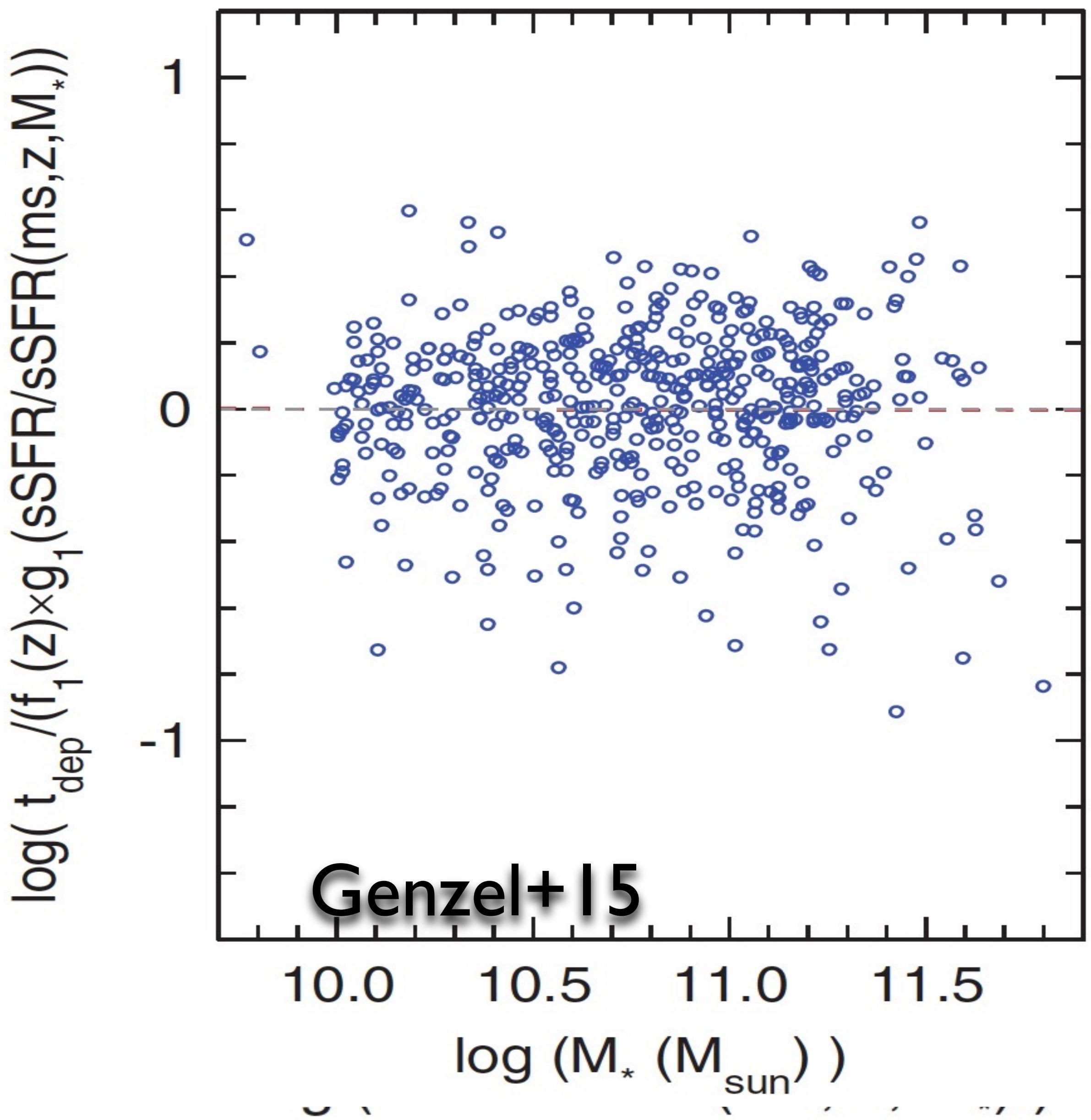
Molecular/ionized wind scaling relations

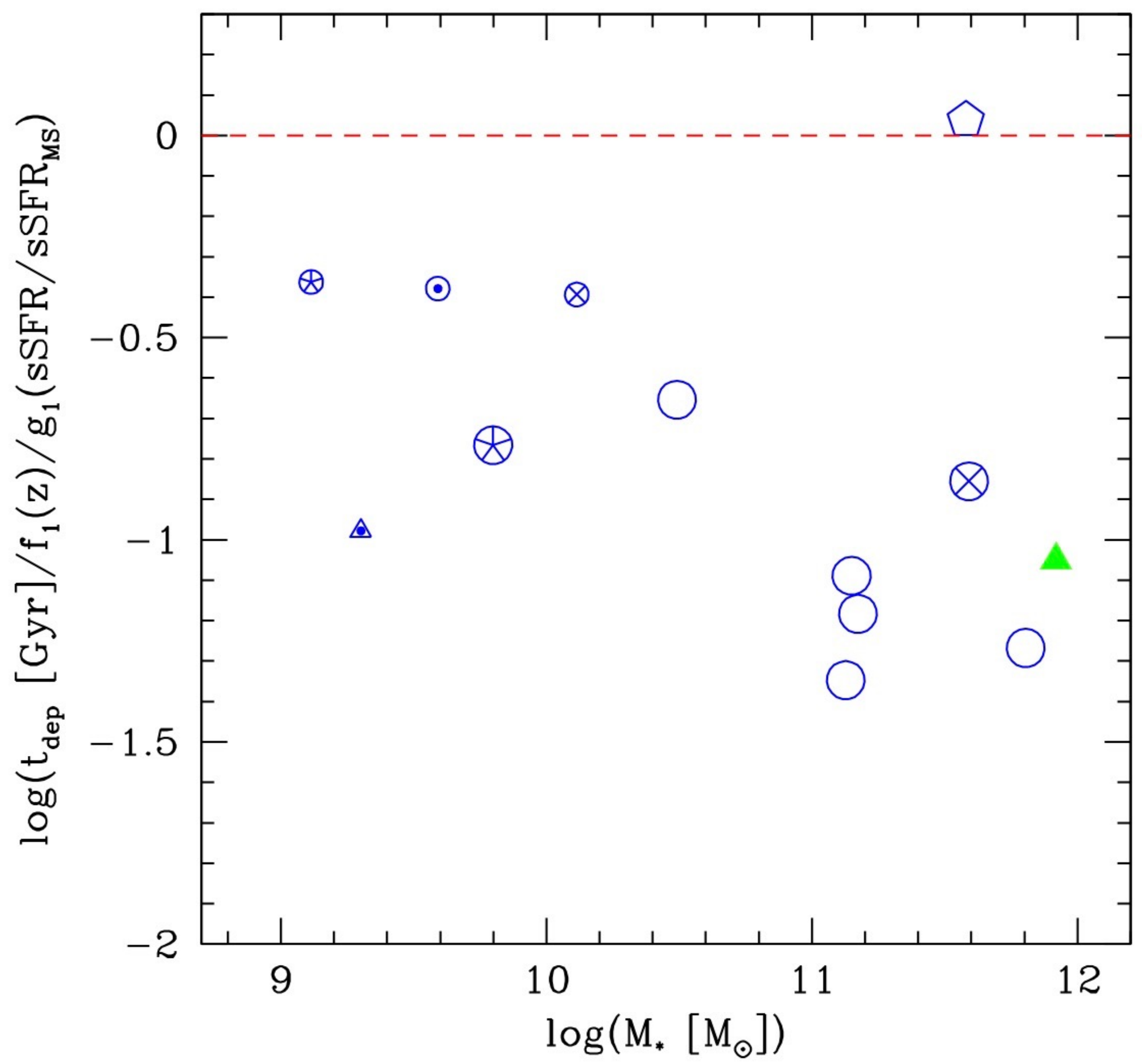


Gas depletion timescale (M_{gas}/SFR) normalised for trends with z and offset from galaxy main sequence

F, F+15

Molecular/ionized wind scaling relations





Gas depletion timescale (M_{gas}/SFR) normalised for trends with z and offset from galaxy main sequence

F, F+15

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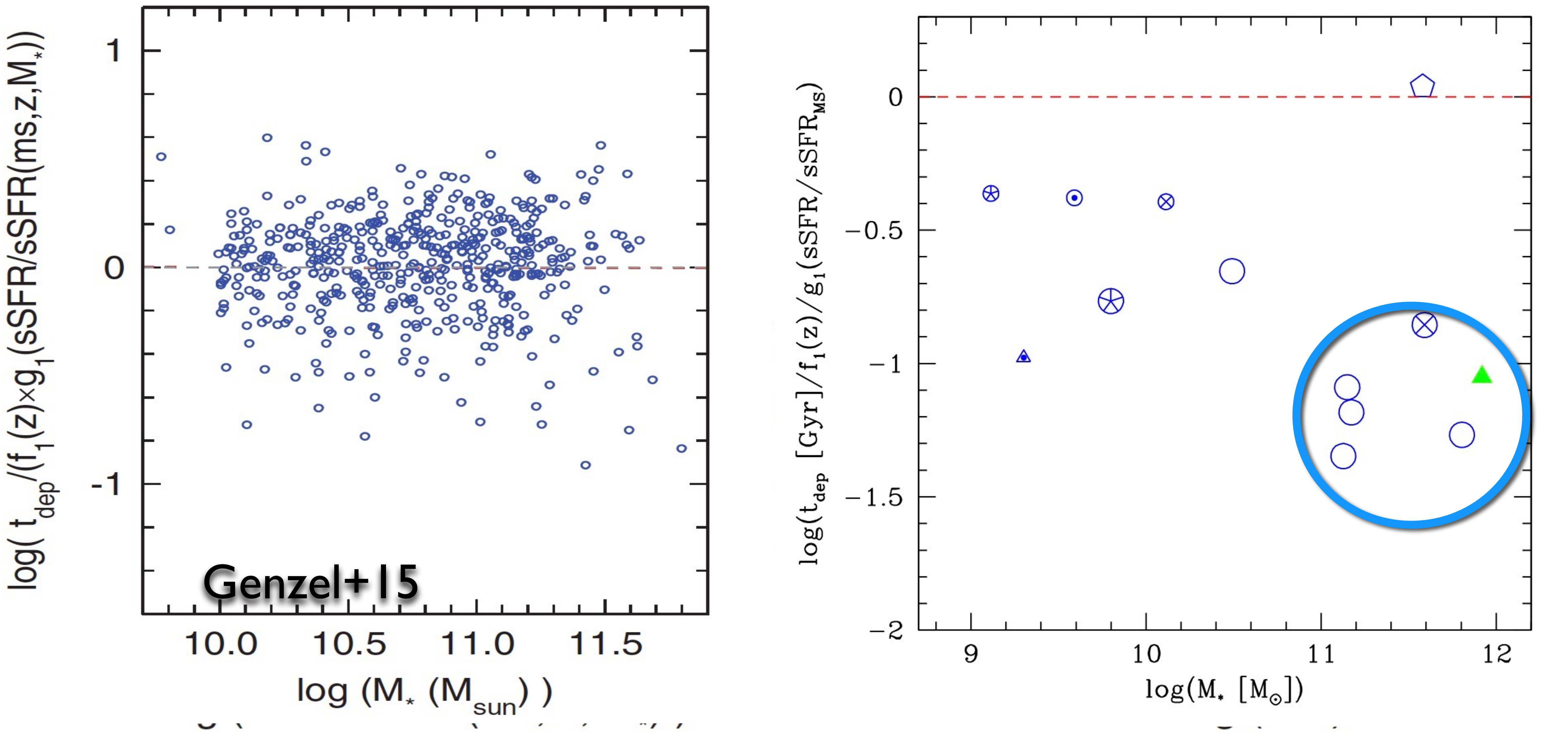
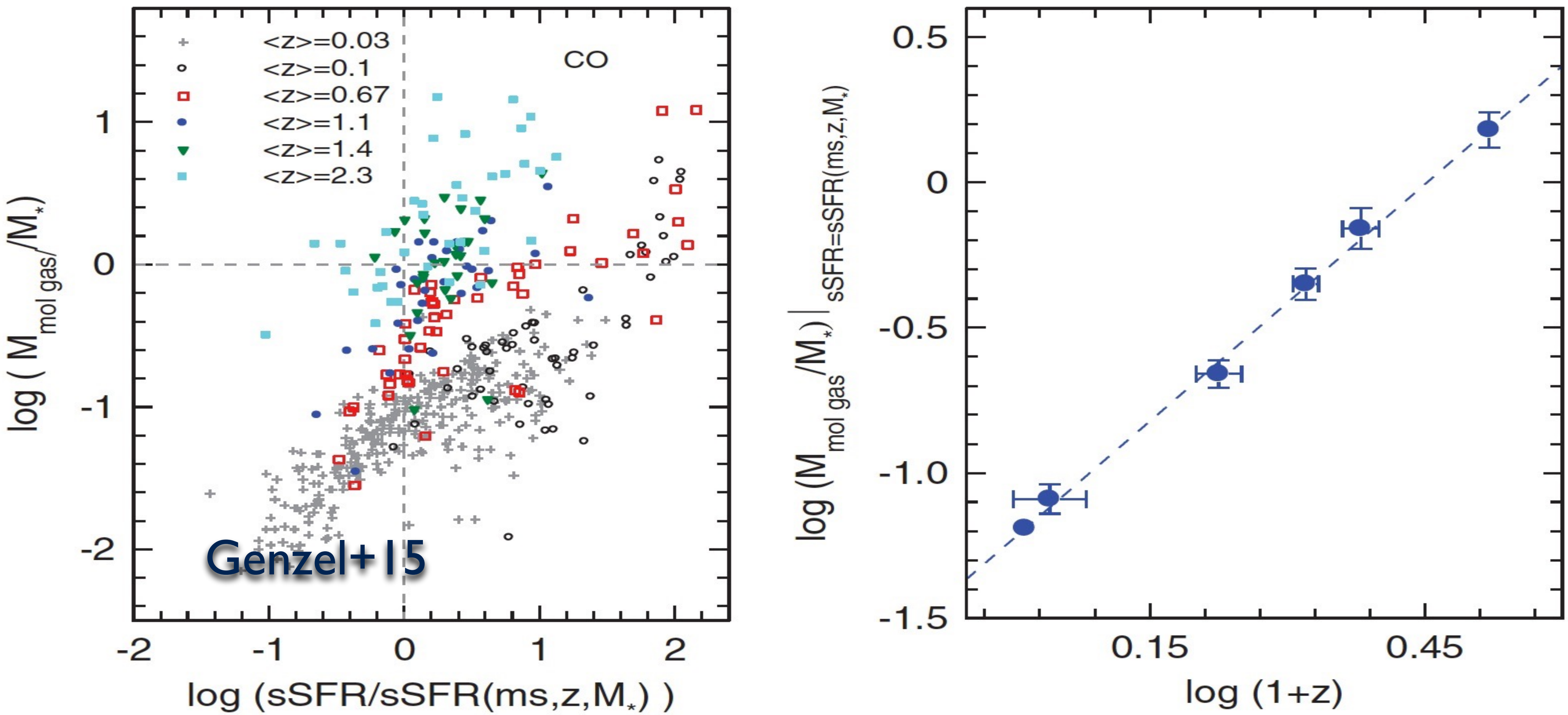


Gas depletion timescale (M_{gas}/SFR) normalised for trends with z and offset from galaxy main sequence

t_{dep} ~10-30 times shorter than average at high M_* F, F+15

Molecular/ionized wind scaling relations



Gas fraction (Mgas/M*) normalised for trends with z and offset from galaxy main sequence

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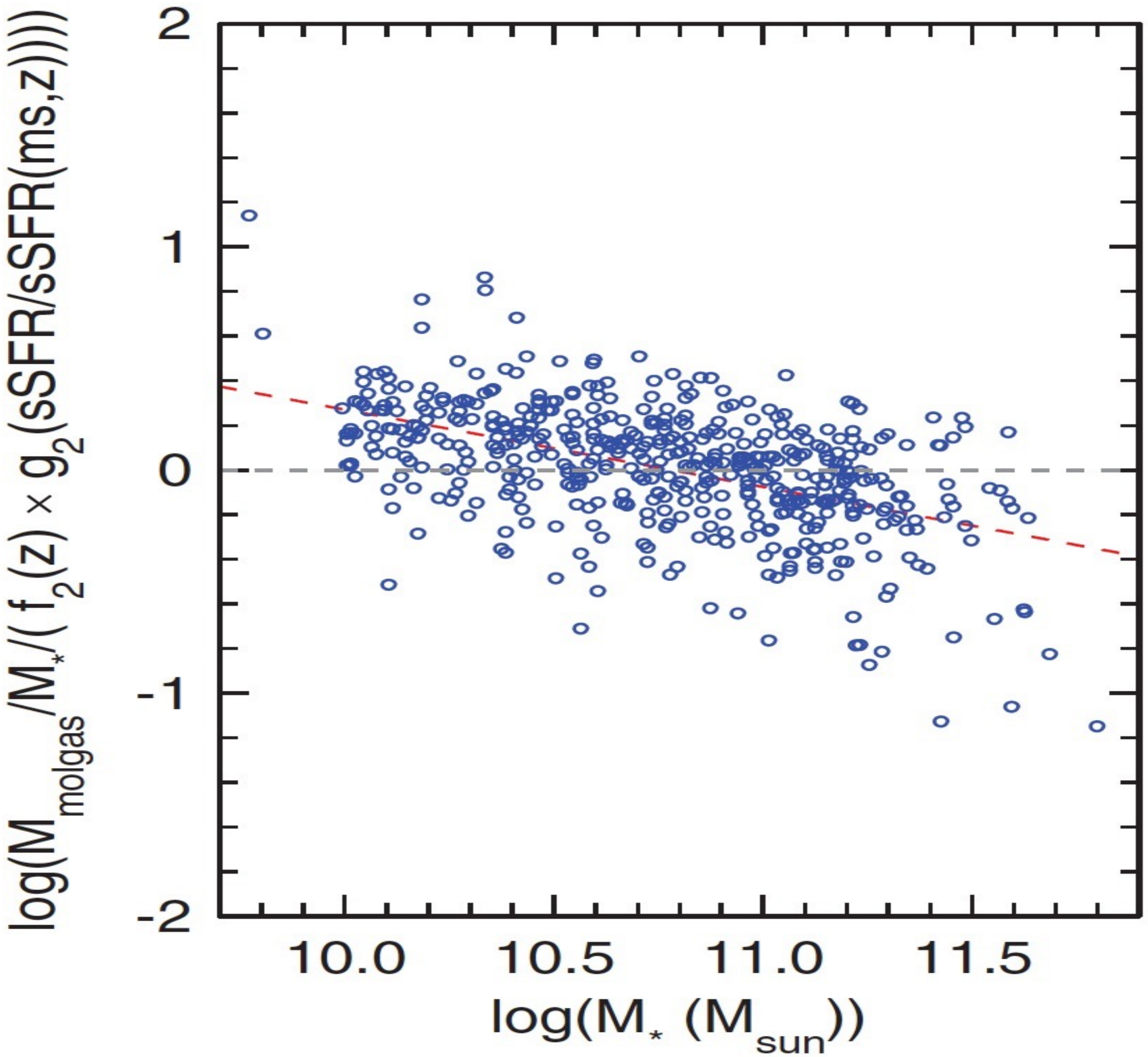

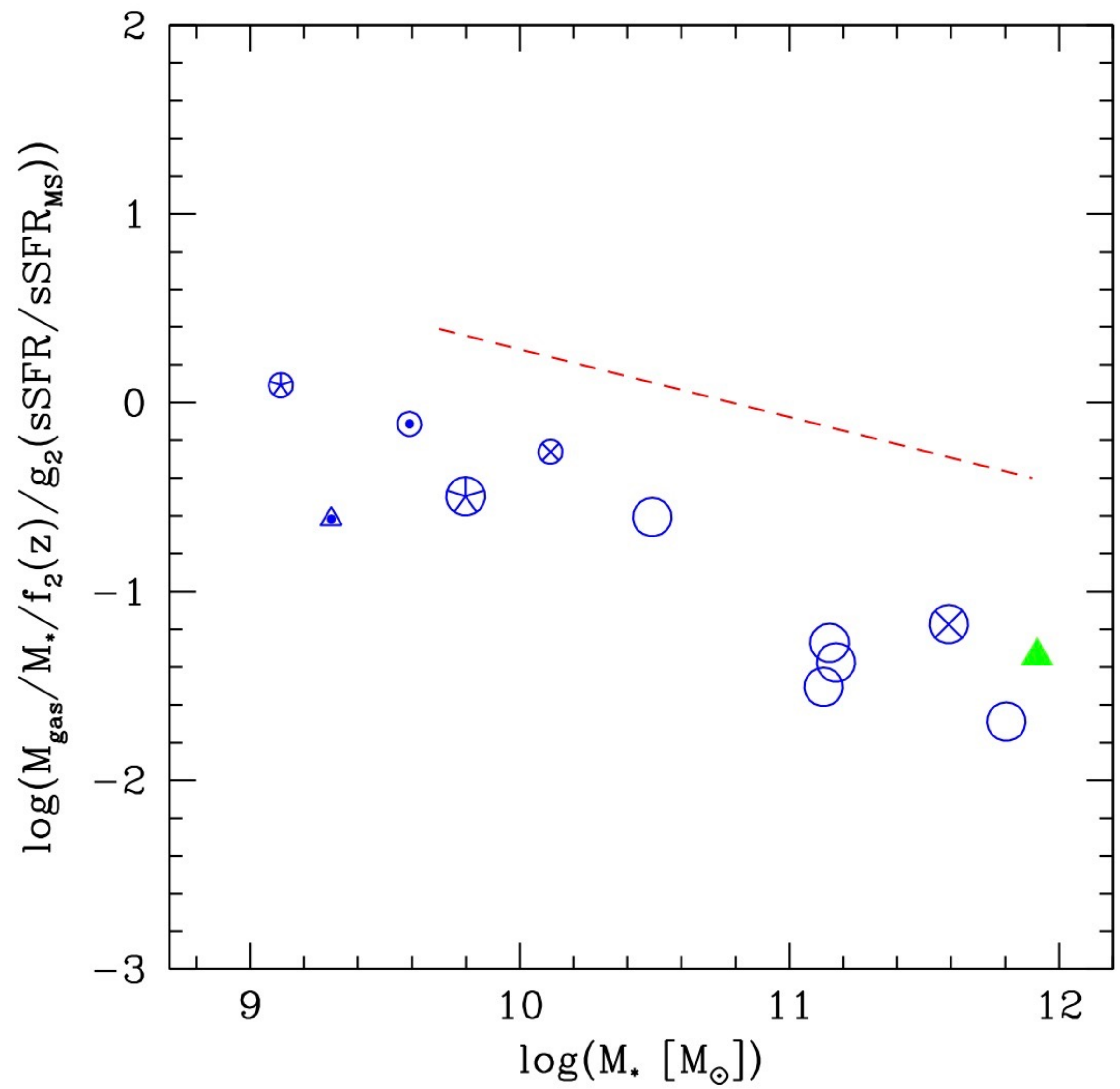

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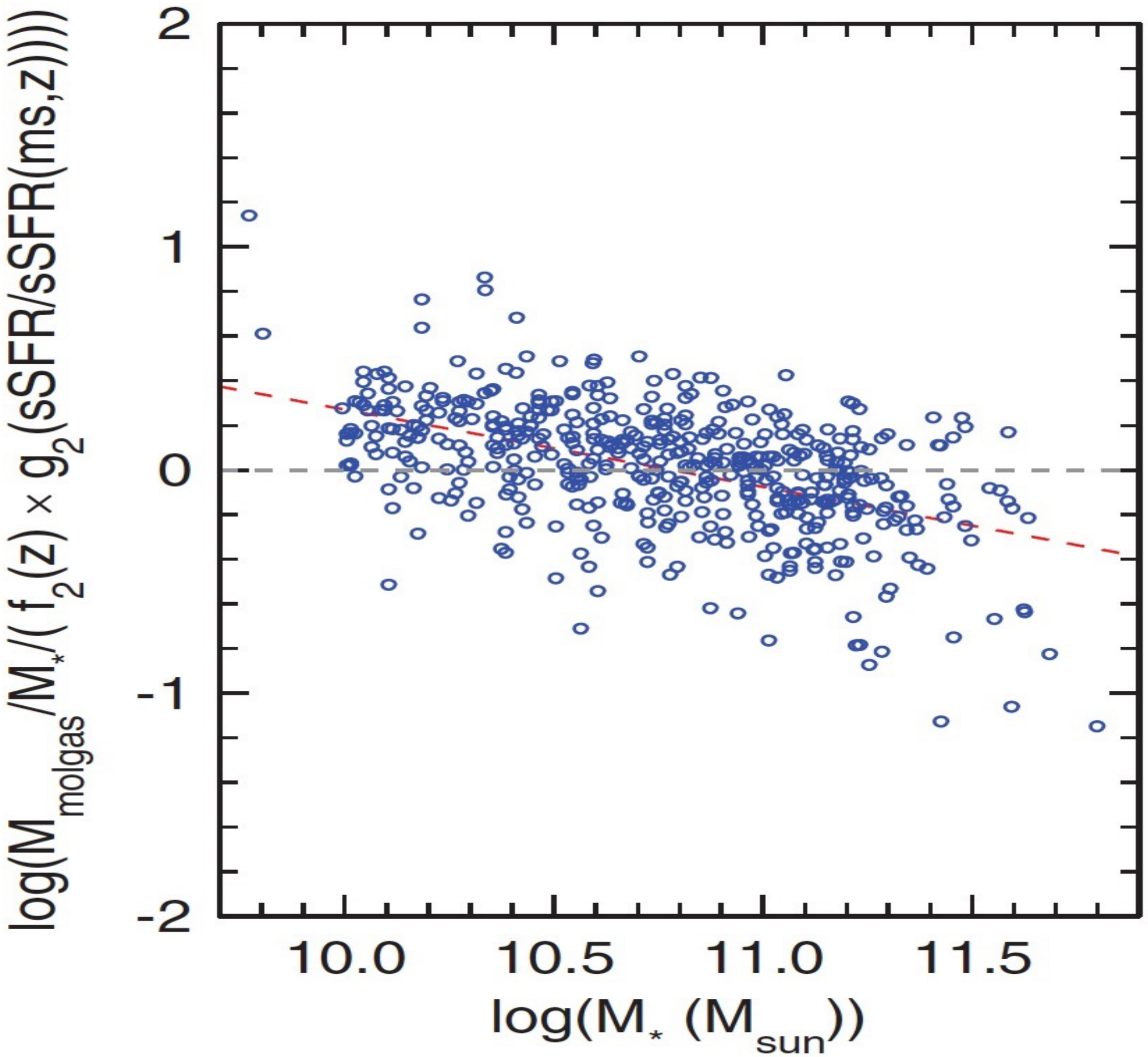

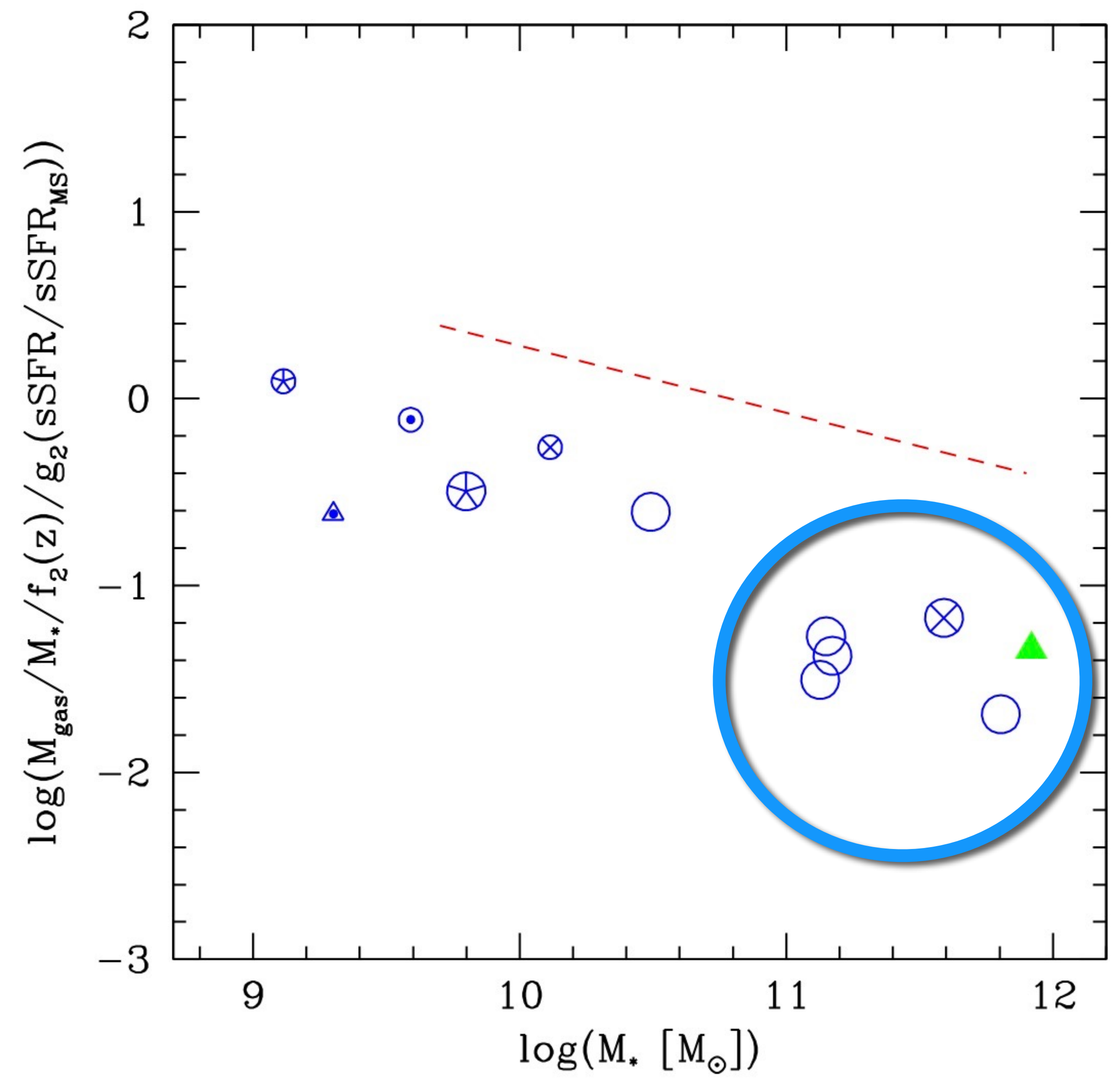

Gas fraction (Mgas/M*) normalised for trends with z and offset from galaxy main sequence

Gas fraction 10-20 times smaller than average at high M*

F, F+15

Summary

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speculation: 1+2 molecule in massive galaxies hosting powerful AGN are gradually destroyed, most gas is in atomic and ionized fase

Summary 2

- Most molecular winds some ionised winds and are energy conserving
- Most molecular winds are AGN driven, some ionised wind may be SN driven

however…

results are based on strongly biased samples!!!!!
we need to test them on blind/unbiased samples

Summary 3

First step

PHIBBS2: IRAM/NOEMA Legacy program (PI Genzel, 2000hr) to study gas in 100 SFG

SUPER: VLT/SINFONI Large program (PI Mainieri, 280hr) to study 41 z~2 AGN

Next steps

ALMA/NOEMA surveys of 50-100 galaxies from z=0 to z=3 to definitely constrain molecular Super Wind demographics and physics

ELT/IFU/MOS NIR surveys of z=1-3 galaxies to definitely constrain ionised Super Wind demographics and physics at cosmic noon

8m/MOS, ELT/MOS optical surveys of z=0-1 galaxies to definitely constrain ionised Super Wind demographics and physics of galaxies from the local Universe to cosmic noon

Super winds effects on the formation of the first galaxies/AGN at the end of re-ionisation (z>6):

ALMA (cold gas)

E-ELT/MOS (warm gas)

SKA and precursors (neutral gas)

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