Galaxies, their environment and feedback...

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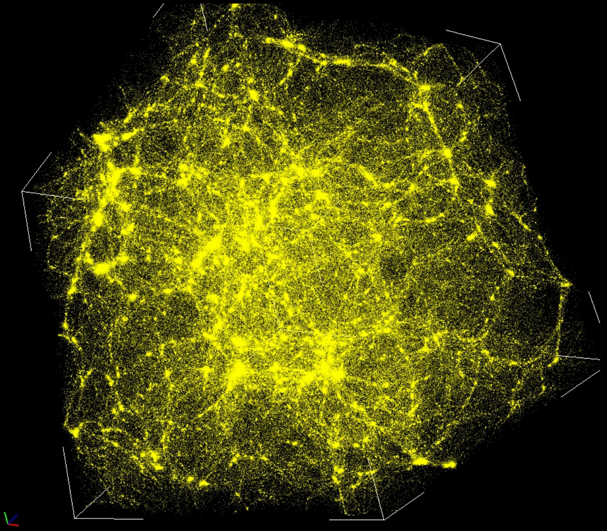


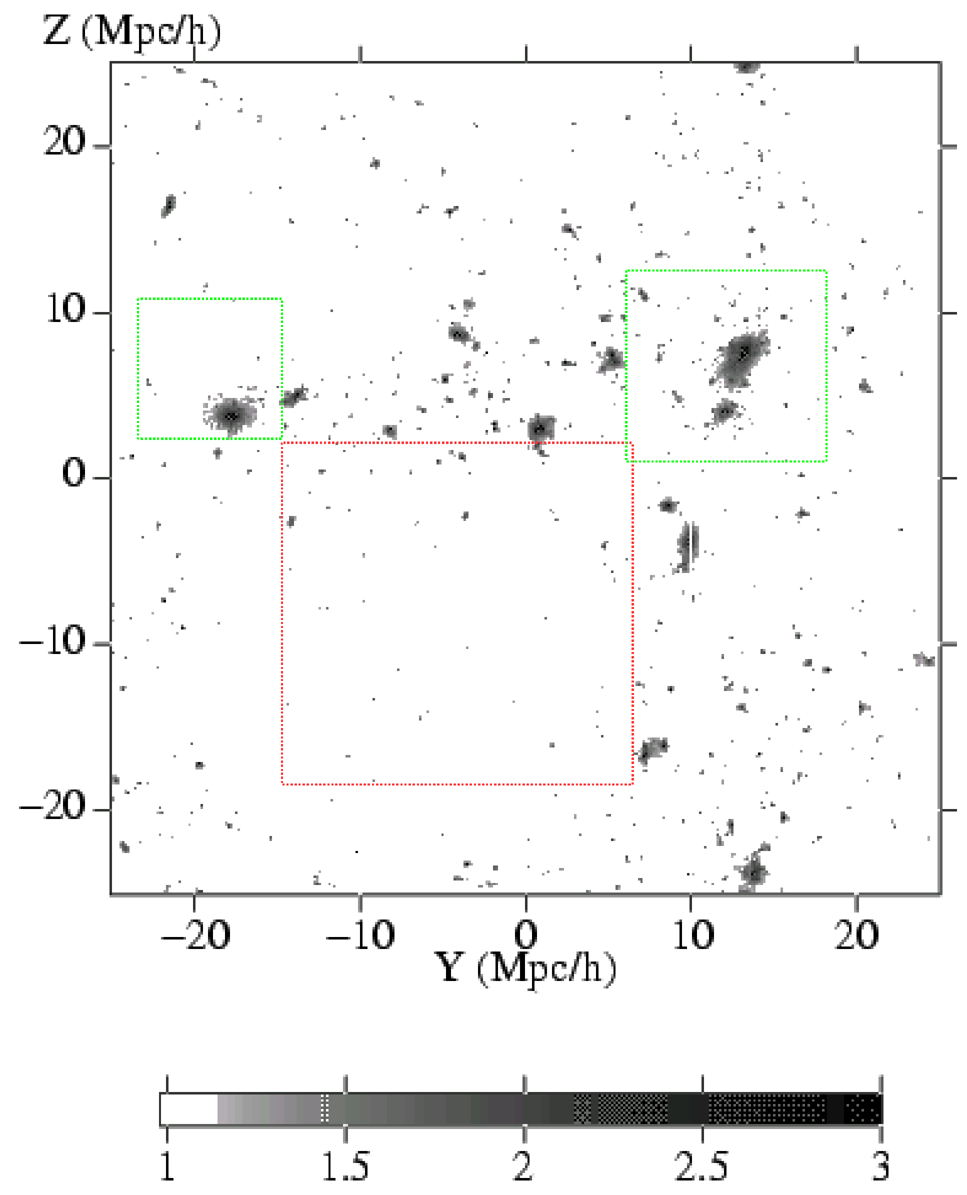
⇒

- $n(M_{DM},z)$: probing (only) systematics?
- Direct simulations of AGN feebdack

Outline

- High resolution mass functions and the origin of spin (Environment)
- ~~Galaxies in (true) Voids (Environment)~~
- Physical models of AGN feedback (Evolution)

Prehistory: the '50s of N-body simulations.....



- 2001: 256^3 ~16 million bodies , 70 Mpc/h, $m_p = 1.37 \times 10^{11}\ M_{SUN}$
- 3 cubic volumes – appr. same # of halos in each

DOUBLE: 827 (912) halos

SINGLE: 768 (796) halos

VOID: 815 halos

- SKID: grav. Bound halos
- $l_{group} = 100\ h^{-1}$ Kpc

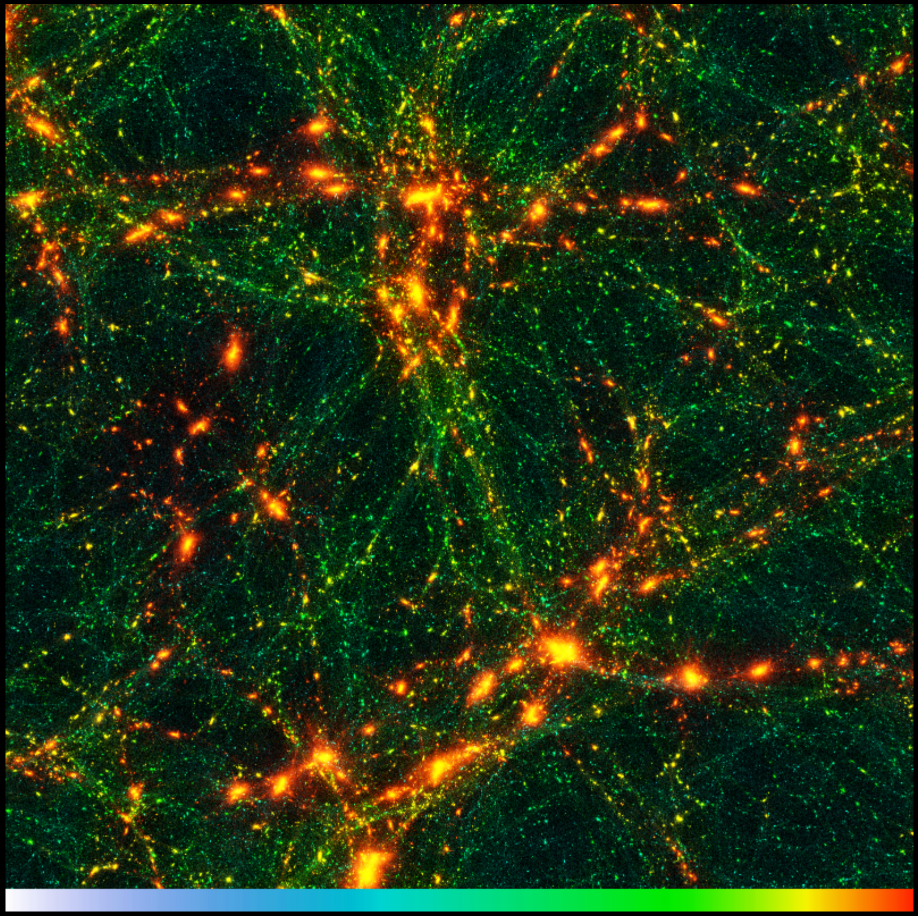
2009.....

FLY @ Trigrid

- $1000^3 = 10^9$ bodies , 85 Mpc/h, $m_p = 4.37*10^9\ M_{SUN}$
- >149.000 halos identified by AHF

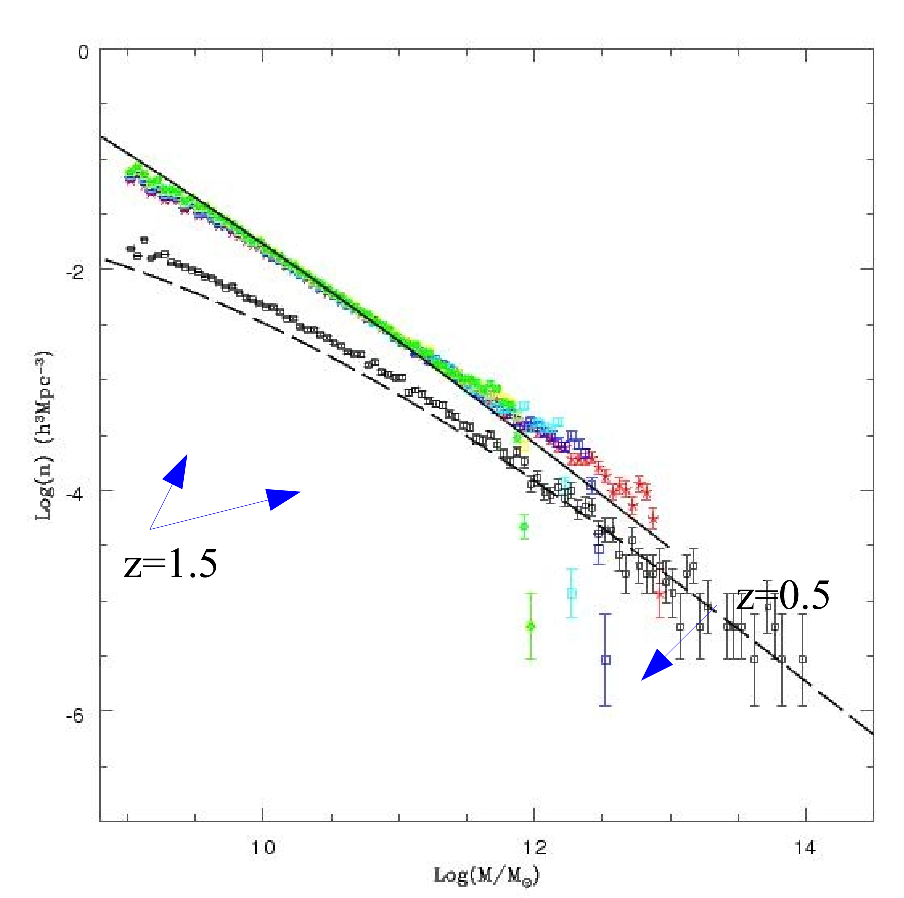
- n(M,z) can now be studied with very little statistical uncertainty
(Reed et al., 2005; Tinker et al., 2008; Warren et al., 2008,.....)

NOTE: These simulations are done with Parallel Treecodes, using comparatively small # CPUs (248)



> $70*10^9$ bodies using PM (Lbox > 150-200 Mpc/h (Teyssier et al., 2007)

MF of galactic-sized DM halos: we now only probing systematics?



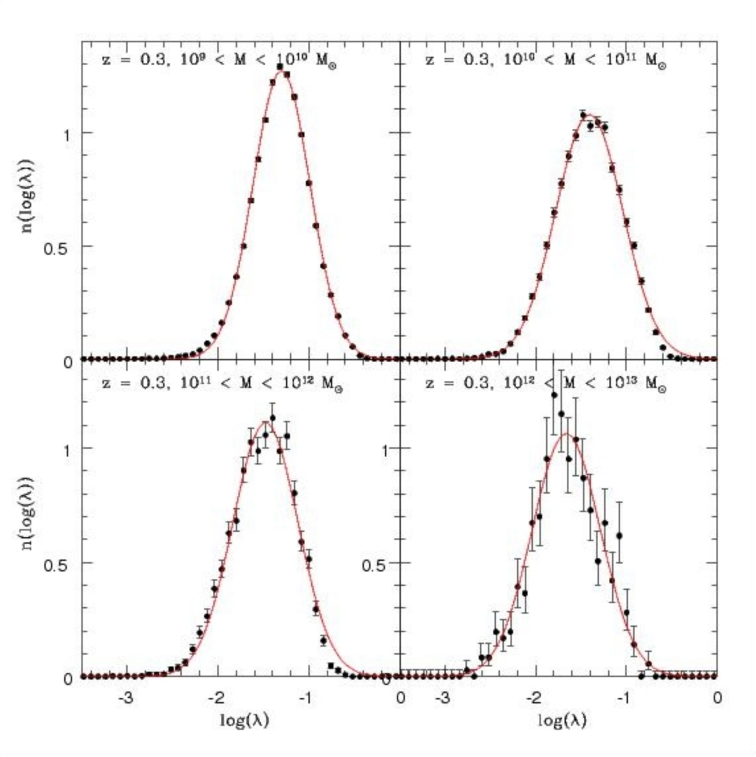
Red: z=0.1
Blue: z=0.3
Cyan: z=0.5
Yellow: z=0.9
Green: z=1.0
Black: z=1.5

Fits: Tinker et al. (2008), for z=0.5 and 1.5

~40.000 halos with > 100 particles

- FOF selected halos provide Mfs which are systematically Sheth-Tormen...
- Why AHF/SKID halos result in a different MF ?

What about spin/angular momentum?

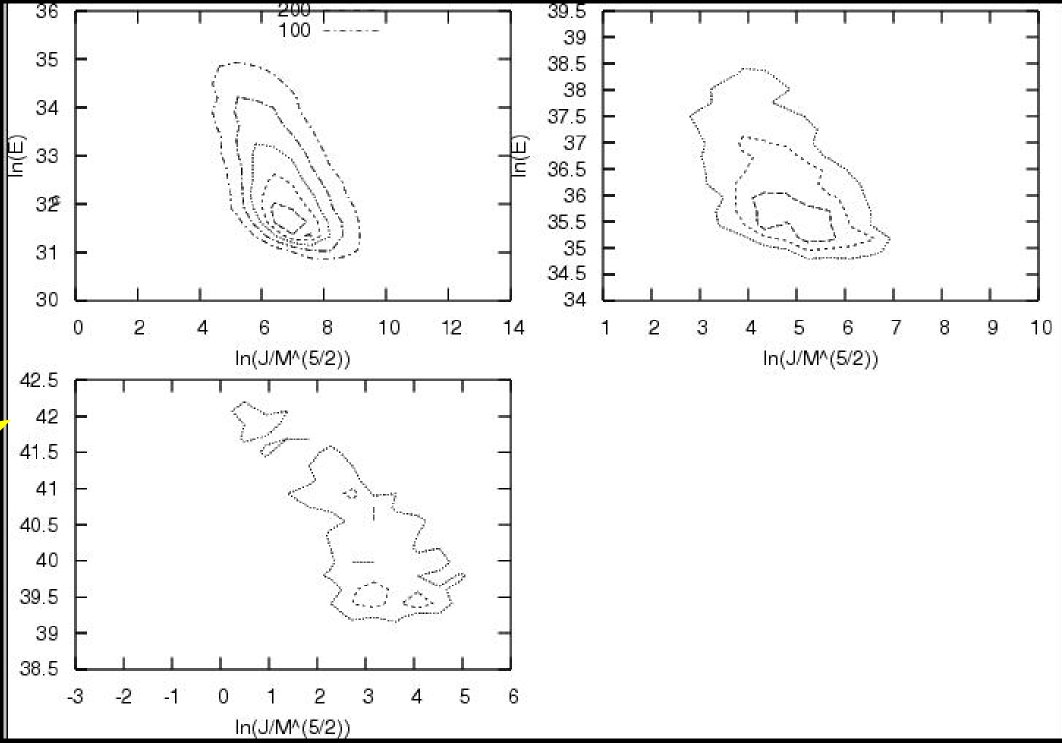


- Spin (Peebles, 1980):

$$\lambda = J|E|^{1/2}/GM^{5/2}$$

lognormally distributed (?)

- Excess at low-λ, deficit at high λ beyond statistical uncertainty
- *Cramer Theorem*: deviations from lognormal arise from correls.: $\ln(J/M^{5/2})$ and $\ln(|E|)$



FLY4: A distributed N-body code

- Treecode (Barnes & Hut, 1990):

Parallel ⇒ particles are divided among the processors, and the tree is partially replicated on the remote CPUs

Distributed ⇒ only one single tree – particles are cyclically migrated to remote CPUs

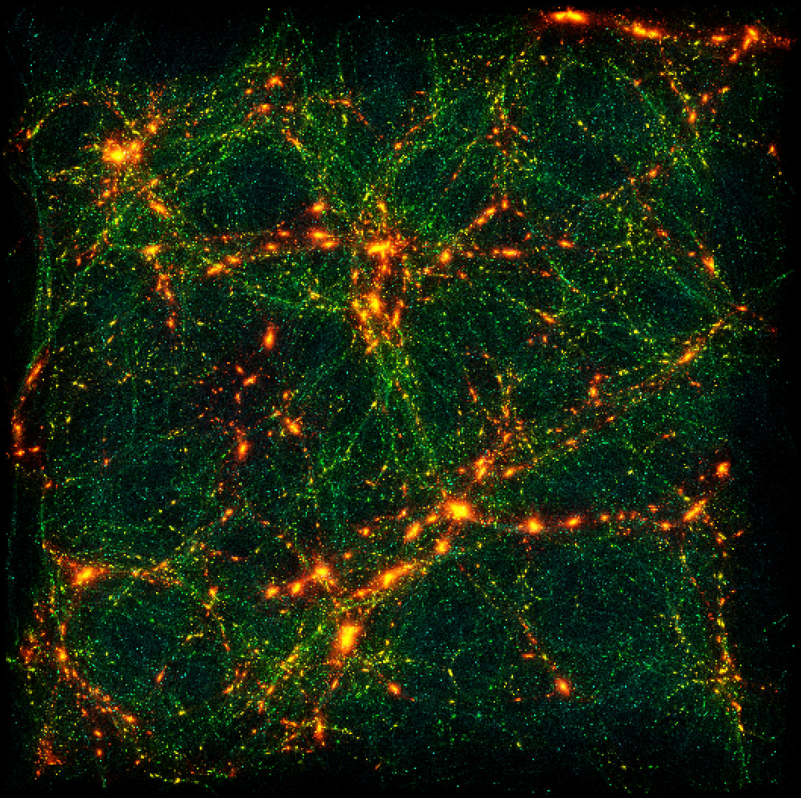
Advantages: Less memory occupation (⇒ bigger runs), higher numerical precision,

Con's: constant workload (n times more CPUs – same t_{cpu} , no scaling)

NOTE: These simulations are done with Parallel Treecodes, using comparatively small # CPUs (248)

Becciani et al., Comp. Phys. Comms. 136, 54 (2001), ...

85 Mpc h^{-1}, mp=4.29*10^7 M_{sun} h^{-1}



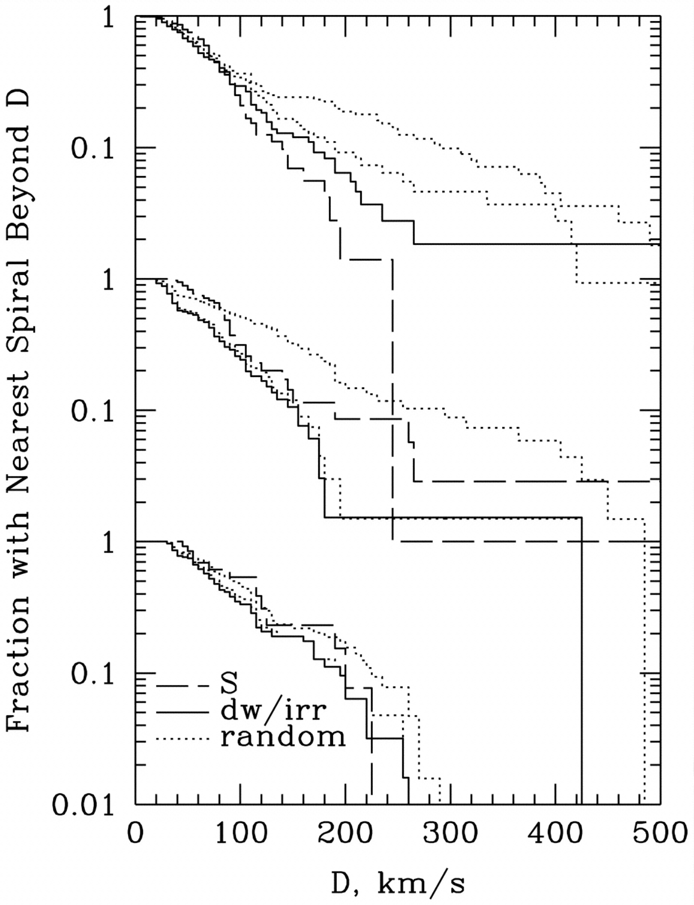
Galaxies in (true) Voids

(*Sorrentino, V.A.-D. And Rifatto, A&A 460, 673, 2006*)

Previous and subsequent work *(using 2dF or SDSS*):
Goto et al., 2003; Balogh et al., 2004a,b; Rojas et al. 2004, 2005 [2dF in Voids]; Hoyle et al., 2005; Blanton et al., 2005; Croton et al., 2005, Tanaka et al., 2005; Weinamnn et al., 2006; Deng et al, astro-ph/0609601; Park et al., astro-ph/0611610

- Our work: look only at (u-r) statistics and use a 3D selection criterion to extract a subsample of *genuine Void galaxies* (lying far from Void boundaries)

- Peebles (2001), *Void phenomenon*: HC scenarios *suggest A sudden transition in galaxy properties with environment*
- *Not seen in clustering statistics*
- *Larger statistical samples made available with 2dF and SDSS*



DM Halos in voids: no galaxy-galaxy inter. (*tidal fields)*
→ spherical collapse should apply

Observations <u>before</u> 2dF and SDSS

- *Elsässer, Popescu et al. (1996,1997)*: Void galaxies

trace filaments

- *Grogin & Geller (2000)*: Cfa2, 15R and CS: $-22 \leq R \leq -18$,

complete in redshift

- *Galaxies in Voids are a subset of galaxies in low density environments*

Selection:

a) $0.05 \leq z \leq 0.095$ *median*: $z = 0.061$

b) $M_r \leq M_r^* + 1.45\ (-20)$

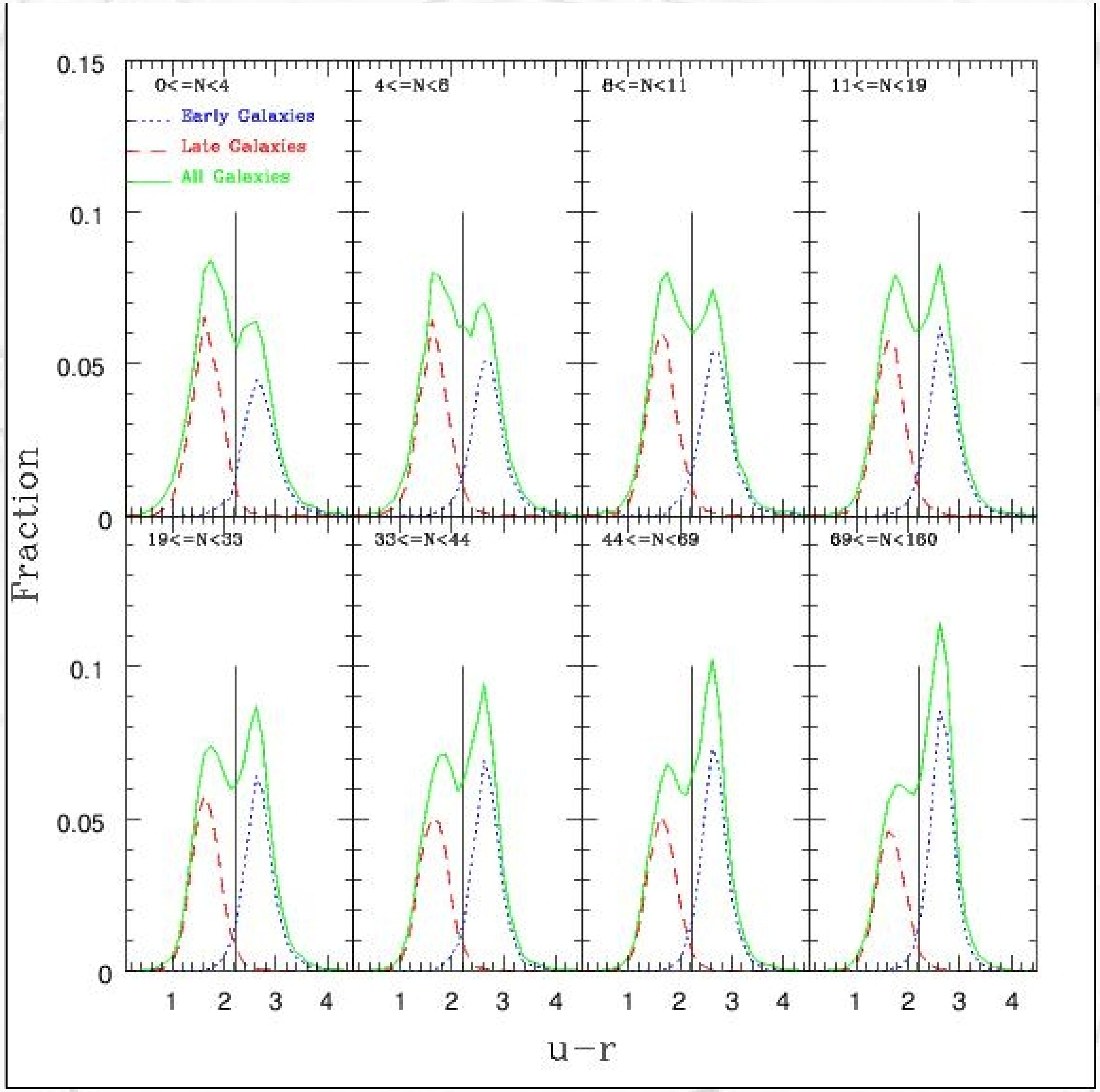
c) Neighbouring galaxies: $D_{ij} \leq D_{max}$ (=5 Mpc) & $|z_i - z_j| \leq 10^3$ Km/sec

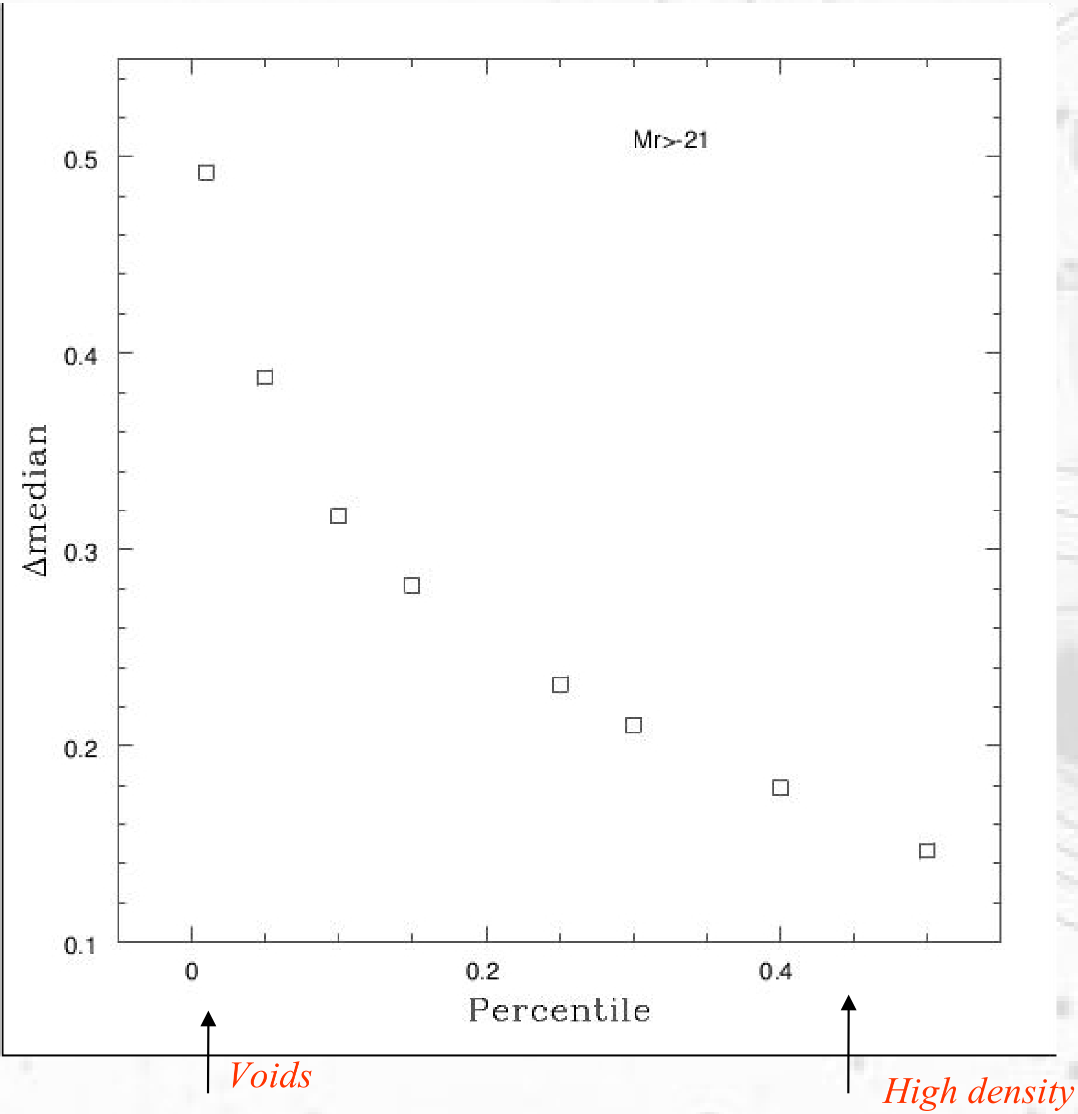
- *Local gal. density*: *2. + 3. above*

- Distributions almost insensitive to D_{max} up to Dmax ~ 10 Mpc

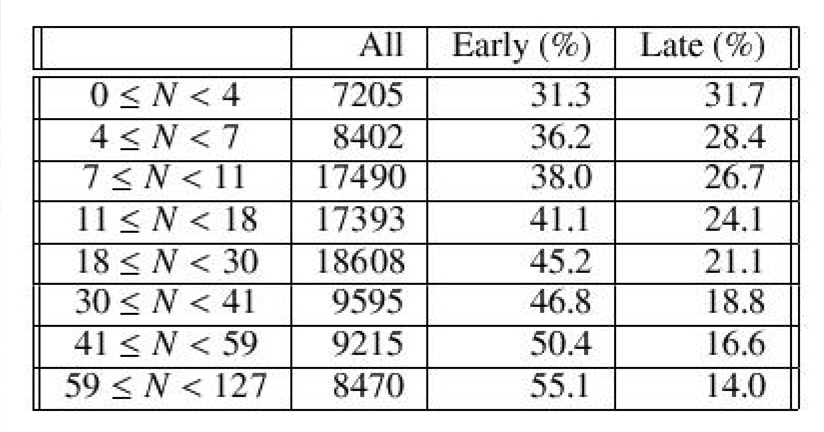
Used DR4: 1.)-3.) results in 91566 gals.

- The *environmental* transition happens at almost the same (u-r)
- NOTE: we apply K-correction to each galaxy in our sample



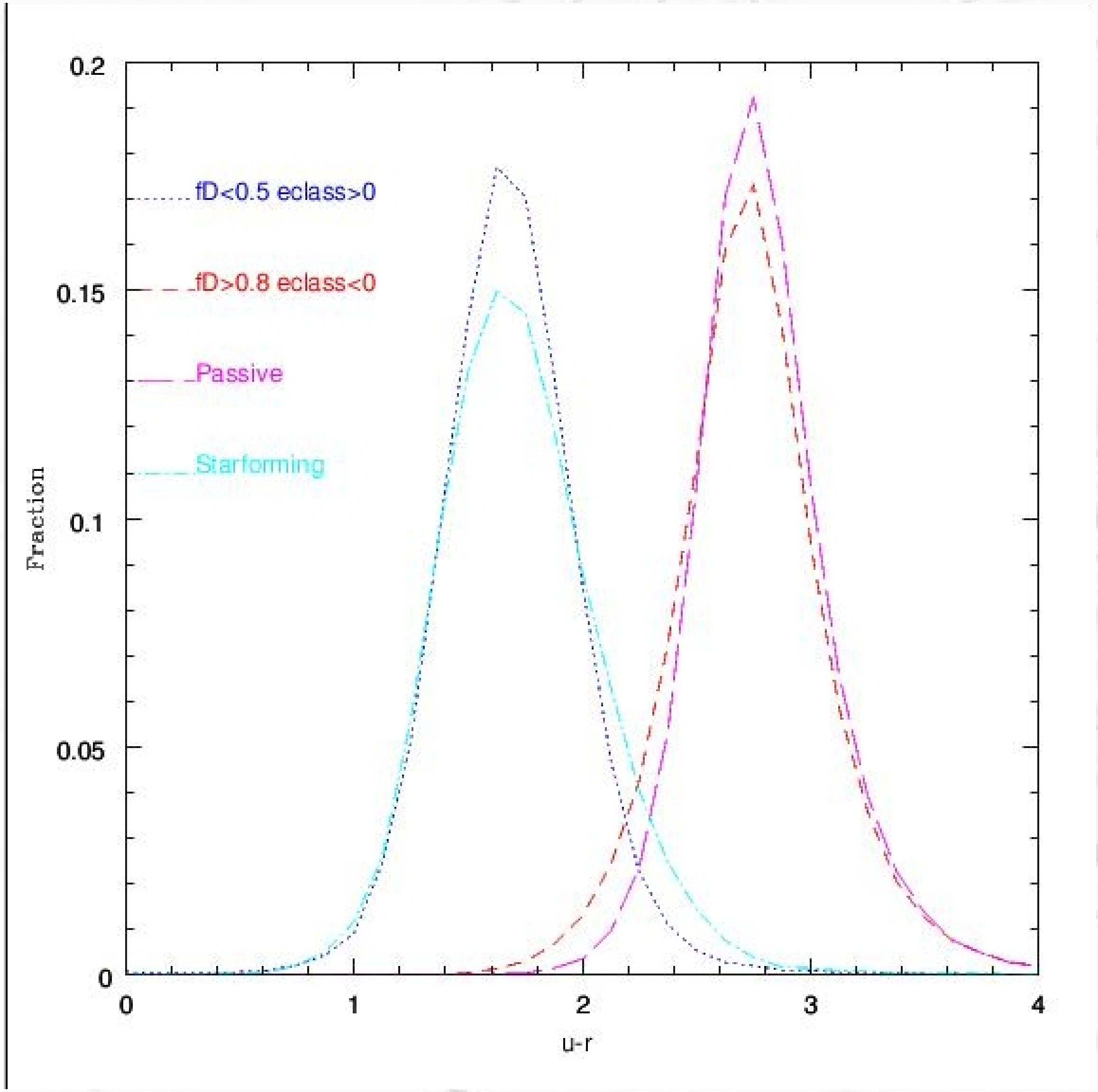


- More interesting, the transition is *continuous* – no evident transition, no “void” galaxy *<u>mix</u>* of populations



	All	Early (%)	Late (%)
$0 \leq N < 4$	7205	31.3	31.7
$4 \leq N < 7$	8402	36.2	28.4
$7 \leq N < 11$	17490	38.0	26.7
$11 \leq N < 18$	17393	41.1	24.1
$18 \leq N < 30$	18608	45.2	21.1
$30 \leq N < 41$	9595	46.8	18.8
$41 \leq N < 59$	9215	50.4	16.6
$59 \leq N < 127$	8470	55.1	14.0

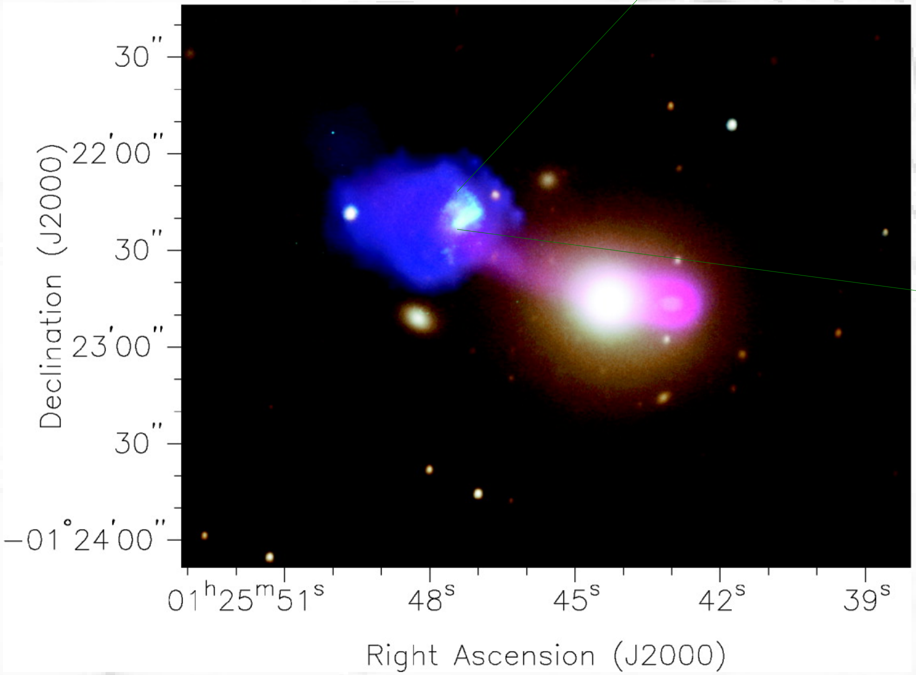
- Δmedian = $(u\text{-}r)_{N<20th}$ - $(u\text{-}r)_{N>80th}$



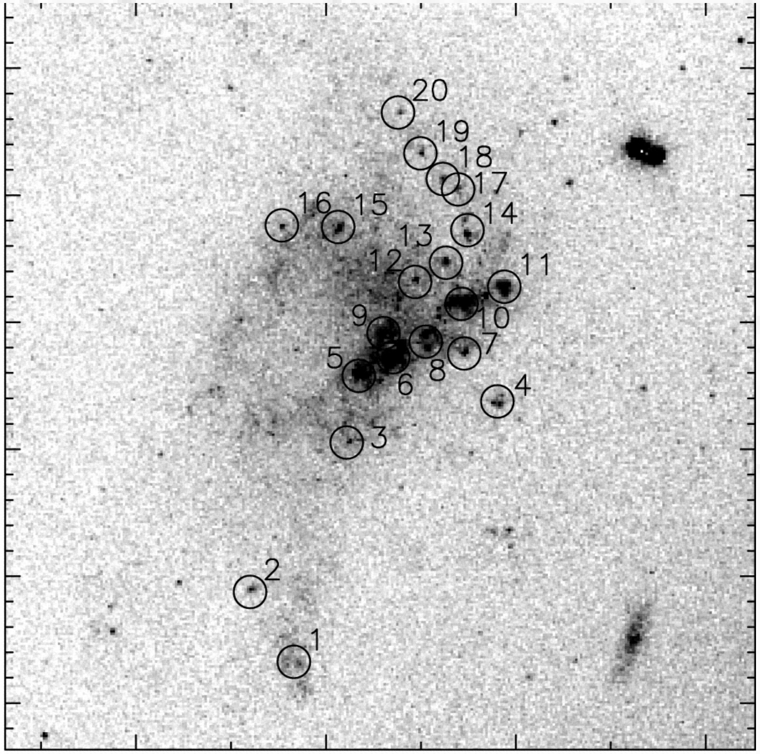
- Using SDSS *morphol.* indicator instead of spectroscopical ones gives the same color distribution → environmental uniformity is evident in the SF activity

AGN positive feedback at $z \approx 0$: Minkowski object

- $L = 18\ h^{-1}$ kpc from NGC 541
- GALEX: UV colors
- $t_* \approx 7.5$ Myr, $M_* \approx 1.9\text{x}10^7\ M_{sun}$, SFR $\approx 0.52\ M_{sun}$/yr



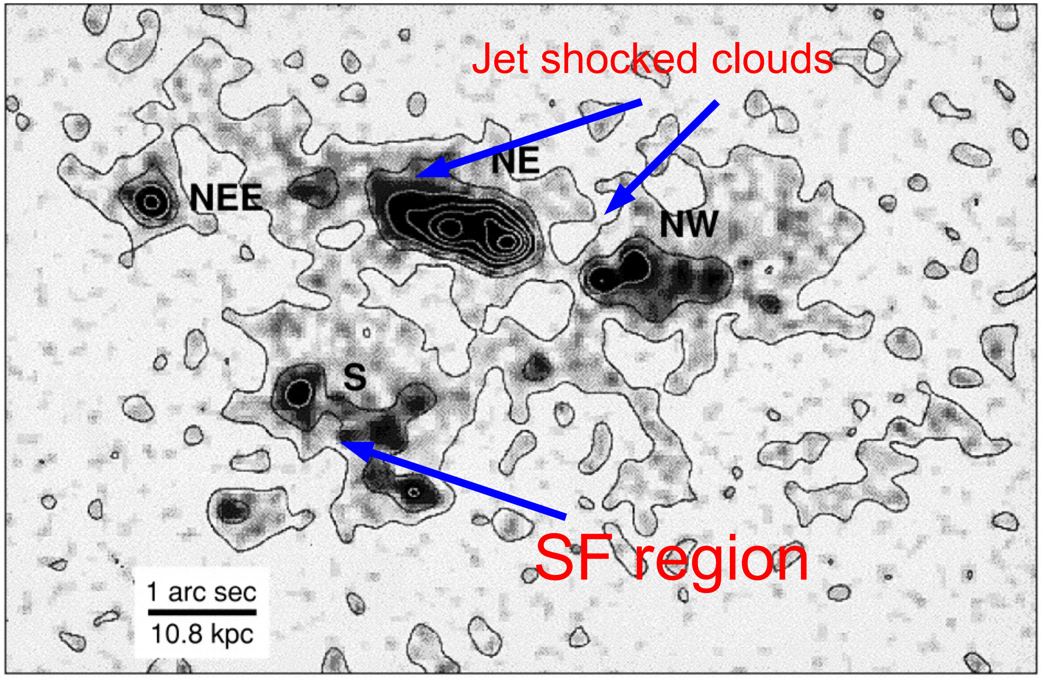
F555W (HST)



Croft, v. Bruegel et al., 2006)

…More positive fbck, at $z \approx 3.18$: 4C 41.17

- $W_{jet} \approx 2\text{x}10^{46}$ ergs s^{-1}
- $M_* \approx 8\text{x}10^{10}\ M_{sun}$
- Enhanced SF region detected far from the jet (*cocoon* ?)



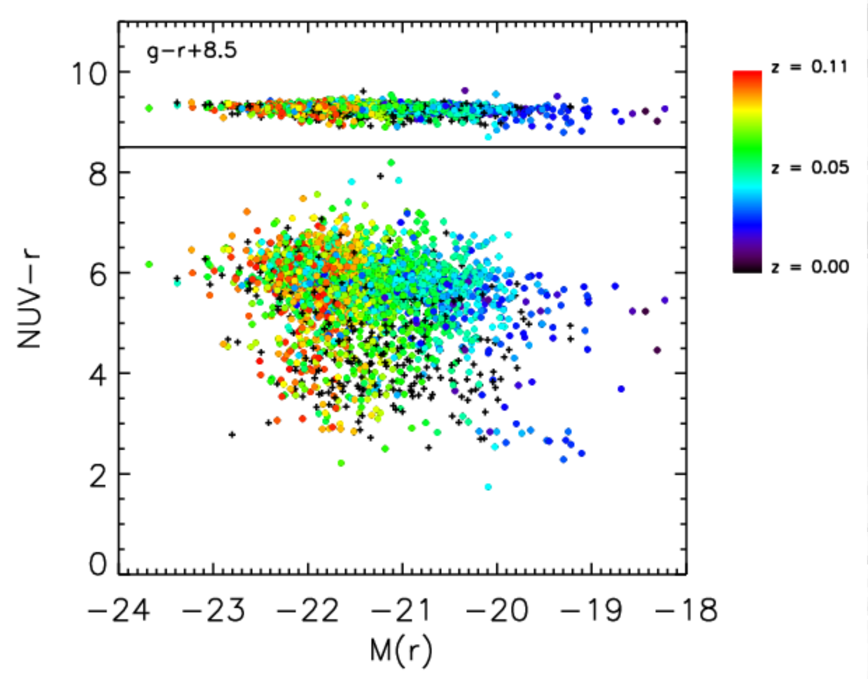
HST F702W, Bicknell et al., ApJ 540, 678 (2000)

Region S: SFR ≈ 110 M_{sun}/yr

Region NE+NEE: SFR ≈ 220+30 M_{sun}/yr

Recent star formation in early-type galaxies

GALEX results in the nearby Universe



Kaviraj et al., ApJ (Dec 2007), astro-ph/0601029
Yi et al., ApJ, 619, L111 (2005)
Schawinski et al., ApJ (Dec 2007), astro-ph/0601036

- Early-types have red optical colours with small scatter
- But their UV colours show spread of 6 mags
- Signatures of widespread recent star formation

AMR jet simulations:

setup

- FLASH v. 2.5 with cooling function (up to $T \sim 10^{11}$ K)
- 6 ref. Levels, 20 in. mesh cells, 40 kpc h^{-1} box $\rightarrow l_{min} = 7.85$ pc h^{-1}
- Isoth. equil. ISM embedded in NFW DM halo (→ inhom.)
- 9 2D + 3 3D sims.: $100 < \sigma_v < 300$ km/sec
- Used ***scaling relations*** between $\sigma_v - \rho_{c,ISM}$, $\sigma_v - M_{BH}$, $\sigma_v - M_{bulge}$, $M_{bulge} - P_{jet}$ for init. configur.
- $10^7 < M_{BH} < 5.5 \times 10^8 < M_{sun}$, $2 \times 10^{44} < P_{jet} < 7.2 \times 10^{45} <$ erg sec^{-1}

AMR jet simulations

crucial points

Adaptivity: Spatial resolution: 7.5 pc/L_{box} = 40 kpc

- Large (~ 10-40 kpc) scale: feedback on SFR

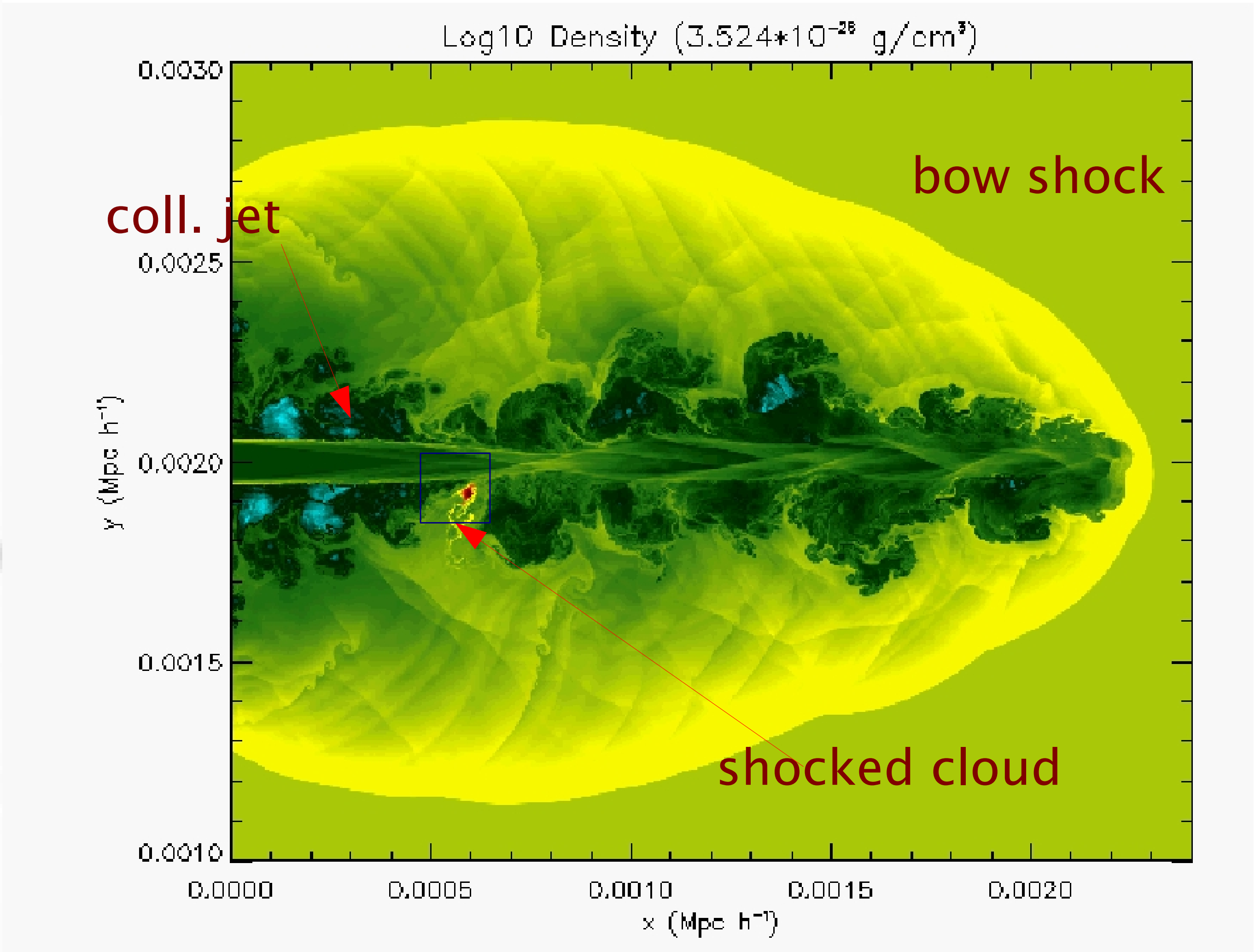
- Small (20-50 pc) scale: backflow feeds the circumnuclear region (V.A.-D. & Silk, 2009)

Simulating Jet-ISM interactions

(V.A.-D. & Silk, 2008, 2009; Tortora et al., 2009a, b, Kaviraj, V. A.-D. And Silk, 2010)

$n_{env} = 1\ \mathrm{cm}^{-3}$, $T_{env} = 10^{7}$ K, $t_{max} = 8.4\mathrm{x}10^{4}\ h^{-1}$ yrs

$W_{jet} = 10^{46}$ erg sec^{-1}, $d_{jet} = 100\ h^{-1}$ pc

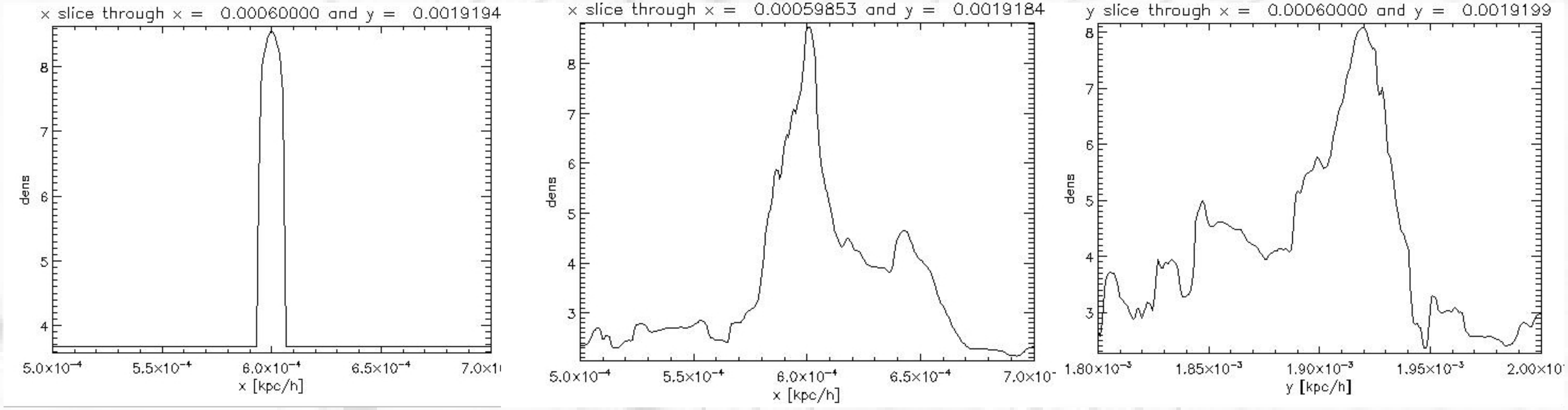


bow shock

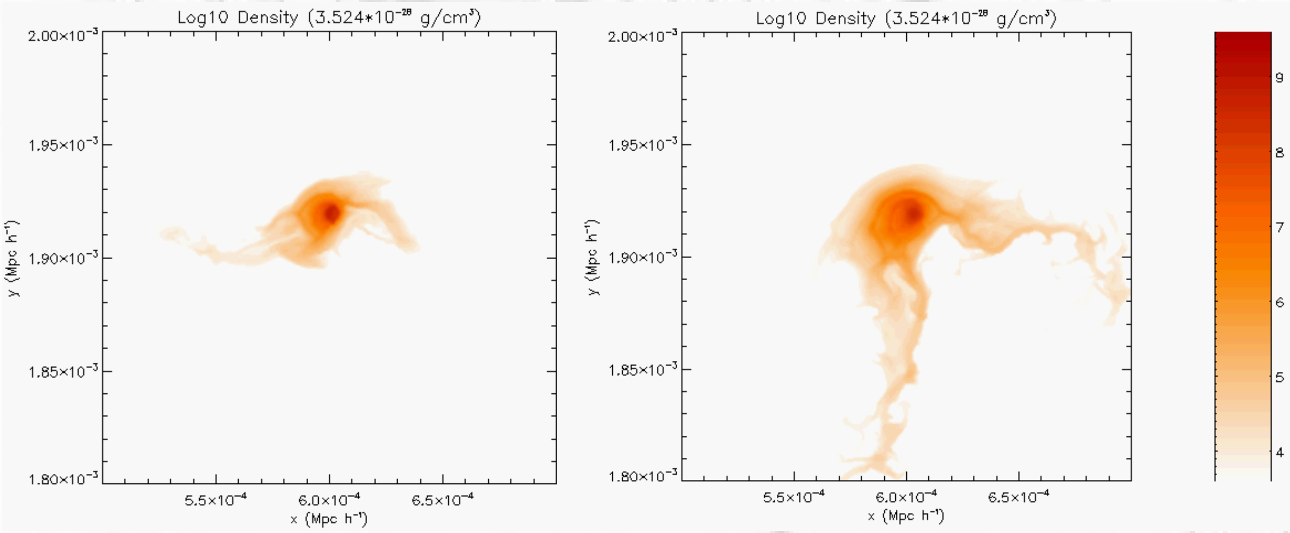
coll. jet

shocked cloud

Cloud's density evolution

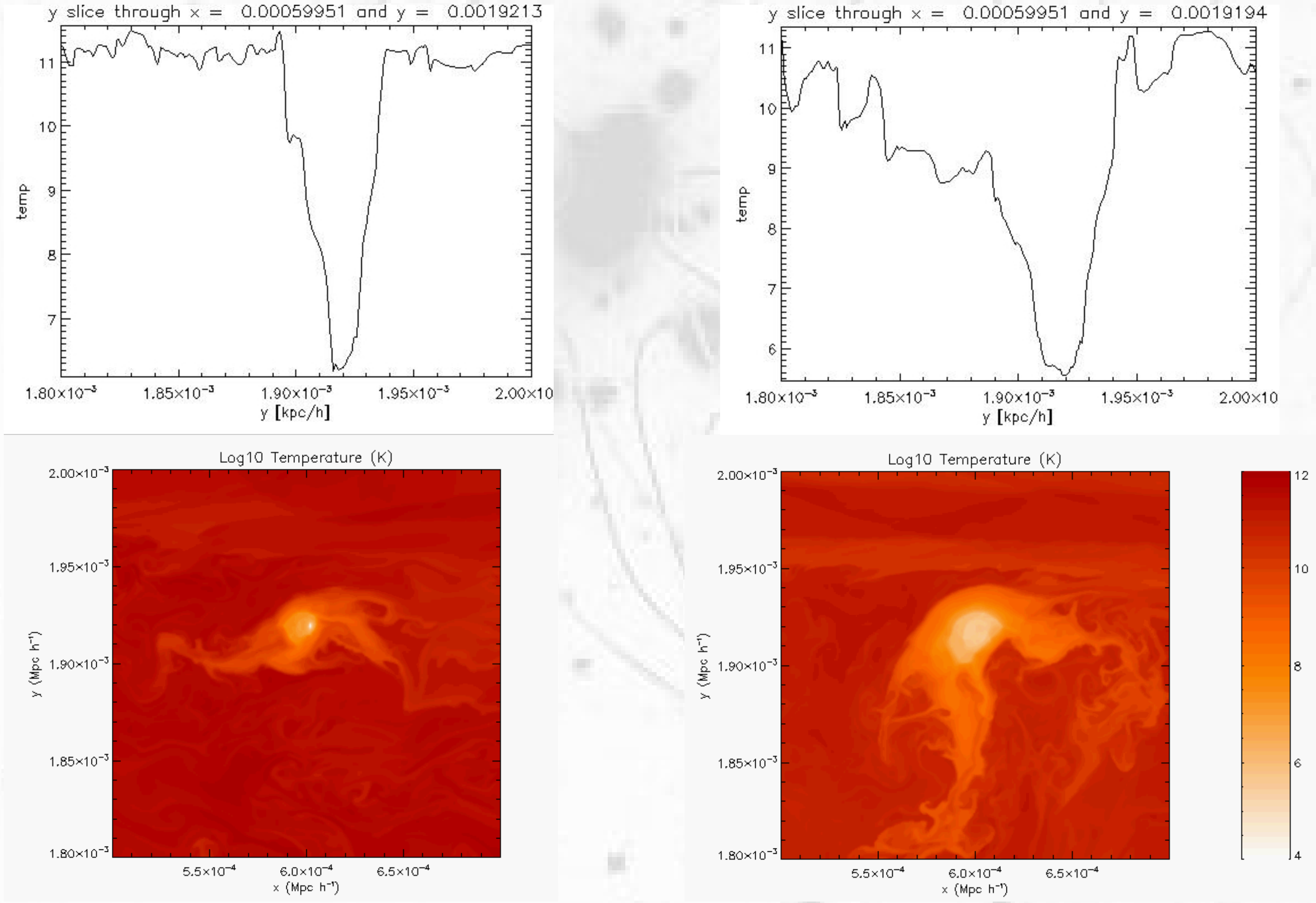


- $W_{mech} / (W_{sh} + \Lambda_c) \approx 10^{-1}$
- Shear ⇒ expansion ⇒ filaments ⇒ shock compression



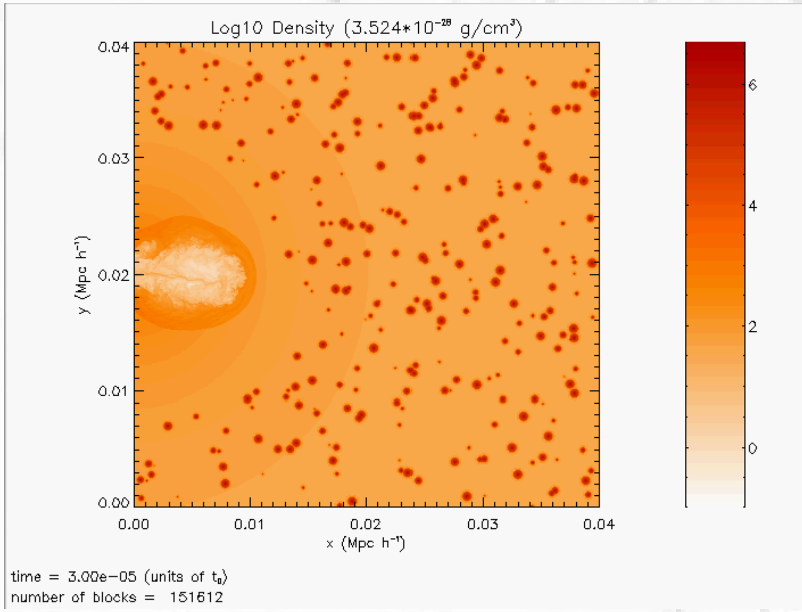
- $t \gg t_{cc} = (n_{cl}/n_{jet})^{1/2} r_{cl}/v_{sh}$ never totally destroyed

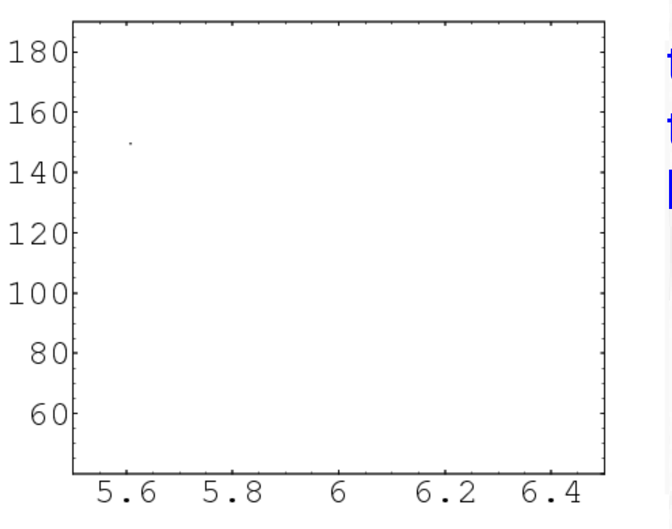
Cloud's temperature evolution



- Cooling ⇒ thermal instability ⇒ filaments

- Positive feedback: $\Delta t \simeq 1.87*10^5\ h^{-1}$ yrs., @ $W_{jet} = 10^{46}$

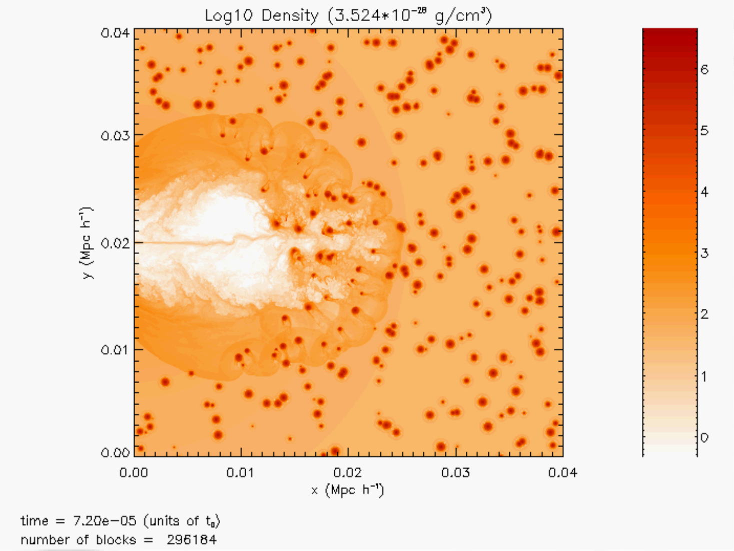


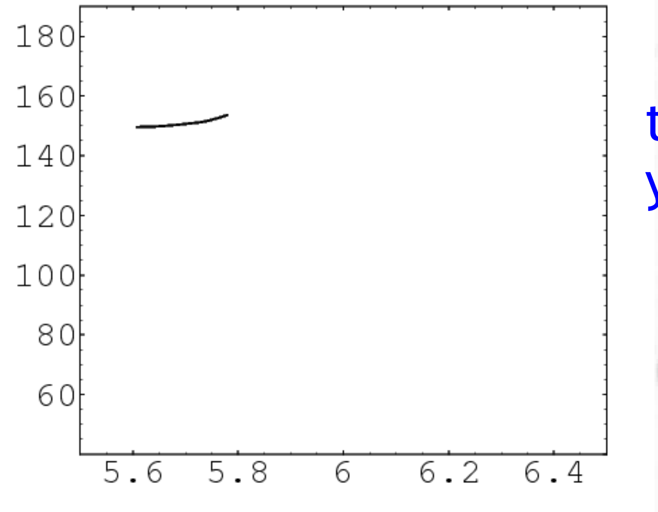


$t = 3*10^{-5}$

$t0 \simeq 3.6*10^5$

h^{-1} yrs.

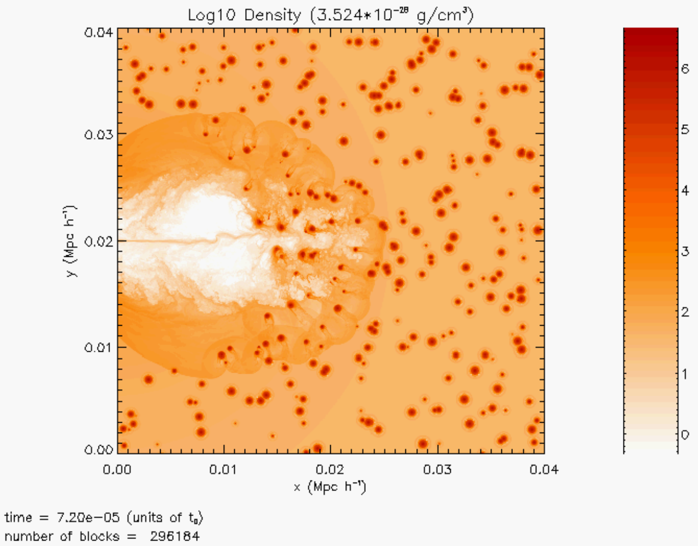


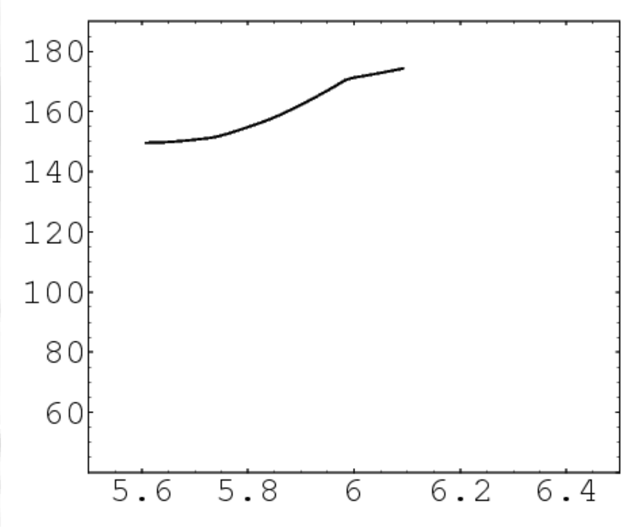


$t \simeq 5.4*10^5\ h^{-1}$

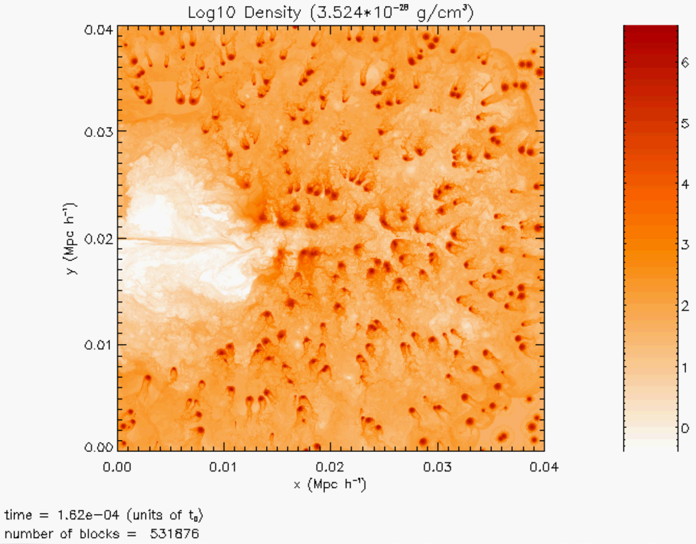
yrs.

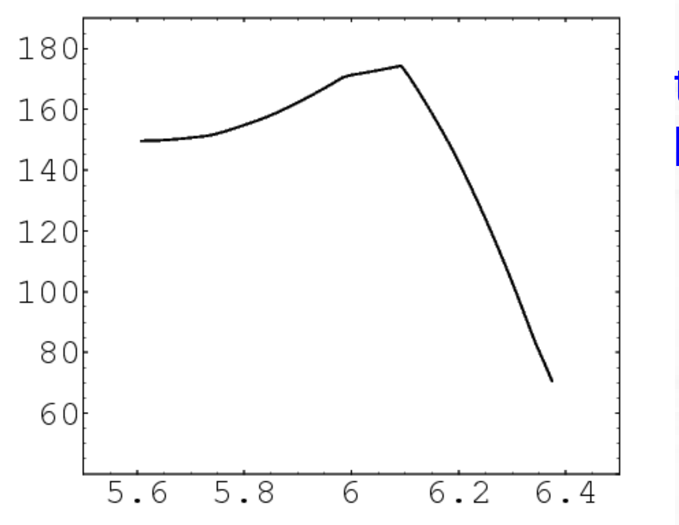
- Positive/Negative feedback: $\Delta M_*/M_* \simeq 1.27/0.42$



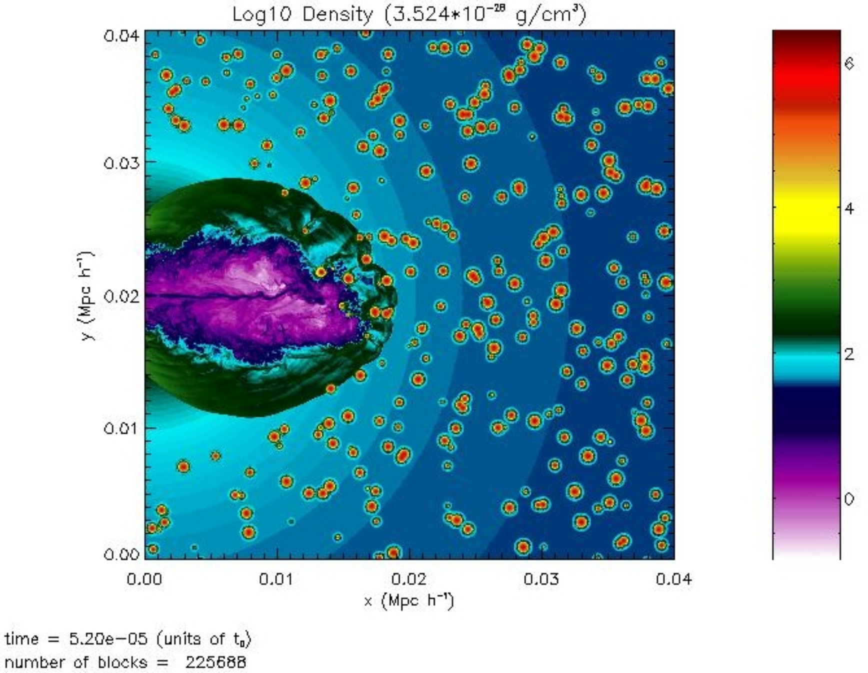


$t \simeq 8.64*10^5$ h^{-1} yrs.





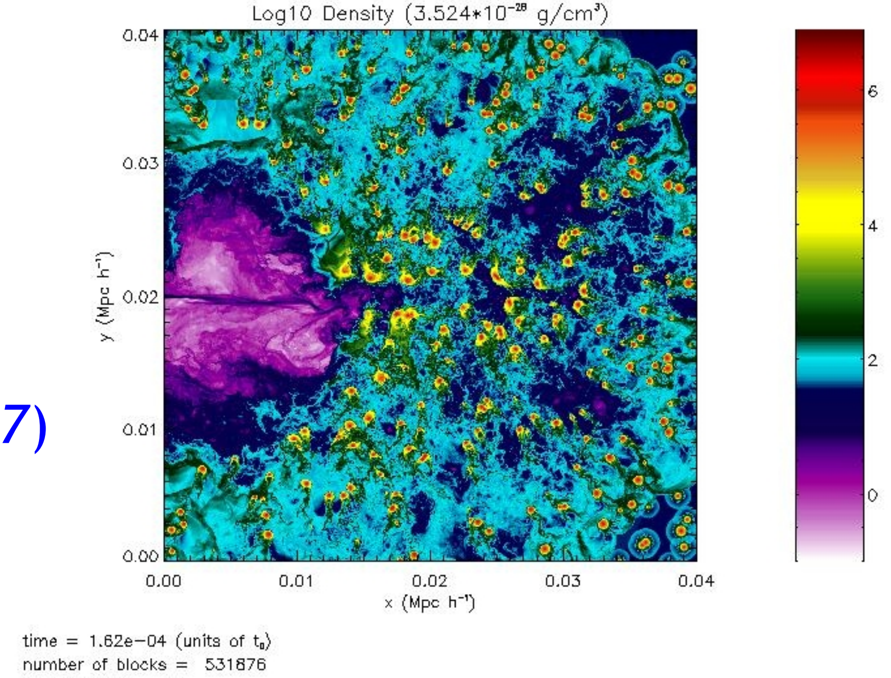
$t \simeq 1.944*10^6$ h^{-1} yrs.



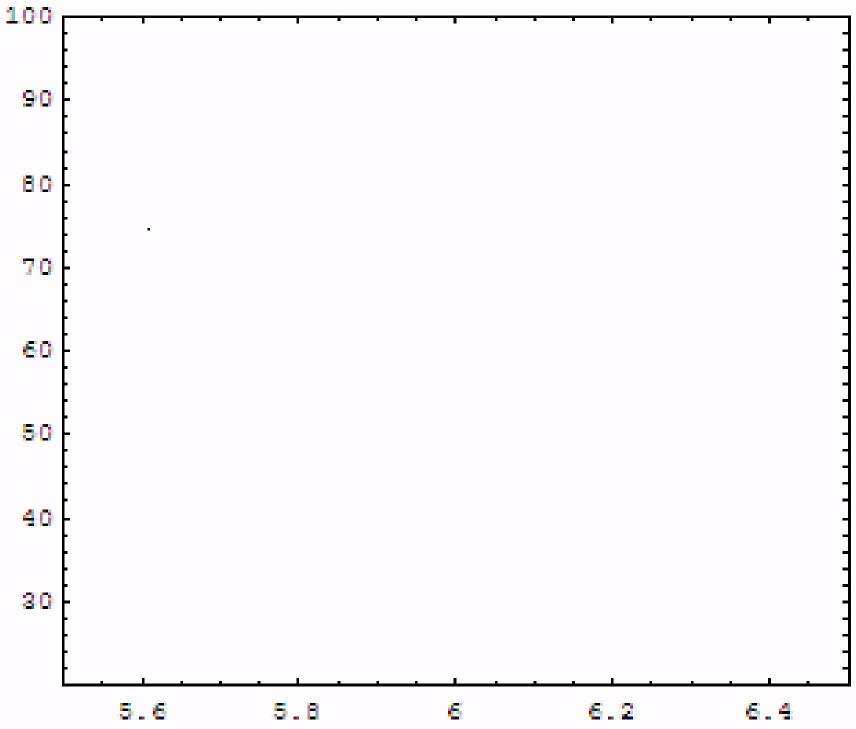
- Positive feedback from <u>pre-shocks</u> propagating before the cocoon
-
- Compression → *positive feedb.*

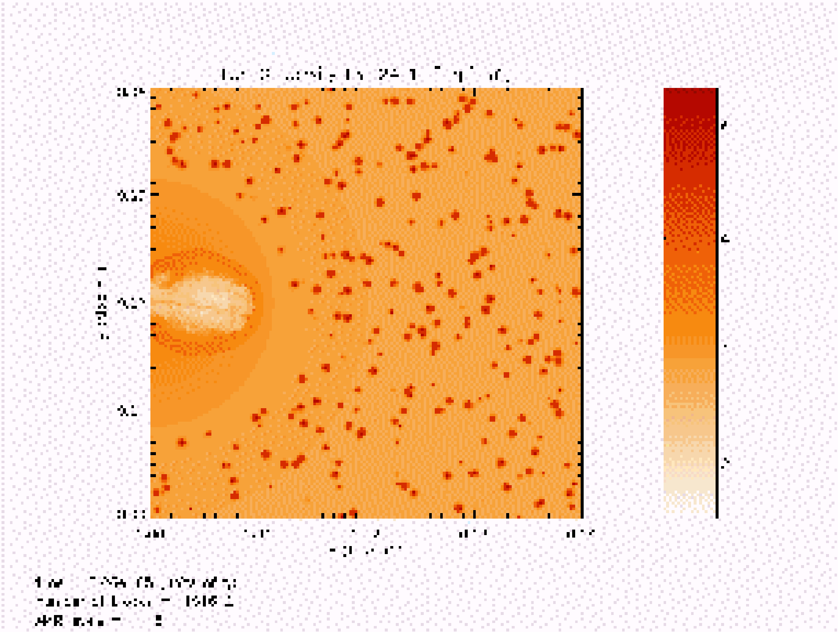
- Negative feedback arises from <u>evaporation</u>+KH instabilities

- $\tau_{Ev} \simeq 3.3*10^{20} n_c R_c^{2} T_{env}^{-5/2} \ln(\Lambda)/30 \simeq 3.16*10^{7}$ yrs. (*Cowie & McKee, 1997*)



- Global time evolution: a *moderate* amount of positive feedback followed ($t > t_{shock}$) by a significant negative feedback





- Only ISM clouds within $r \le r_{max,coc}(t|W_{jet},n_{ISM},T_{ISM})$ are affected by pos. feedback

Negative feedback dominates for $W_{jet} > 2.7*10^{41}$ ergs sec^{-1}

E's sample selection criteria

(*Kaviraj et al., 2007*)

SDSS $\cap$ GALEX | {morph. + spectral criteria}

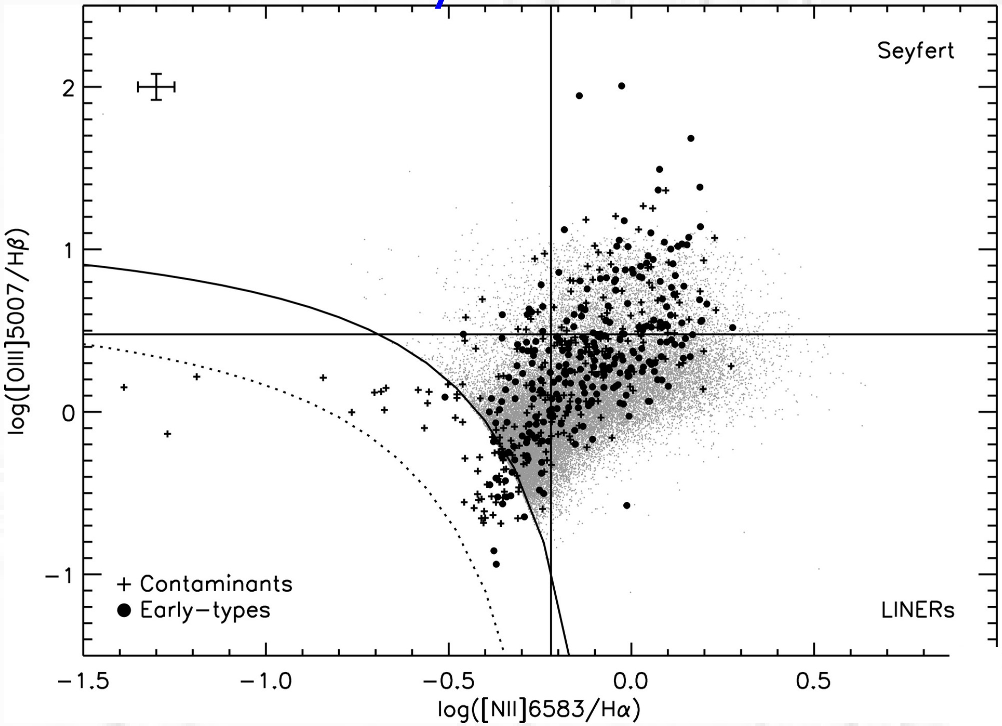
- Morphology: **fracDev > 0.95** (g,r,i) ~ 90% successful

- $m_r < 16.8$ (matching morph. from vis. comp. to COMBO-17), $z < 0.1$

- Cross match with 595 GALEX detections ($l_s < 4''$), no multiple objects

- Type 1 AGN = "QSO" SDSS flag
  Type 2 AGN: BPT (1981) indices (as in Kauffmann et al., 2003), [OIII/Hβ], [NII/Hα]

- Statistically corrected for abs. In UV

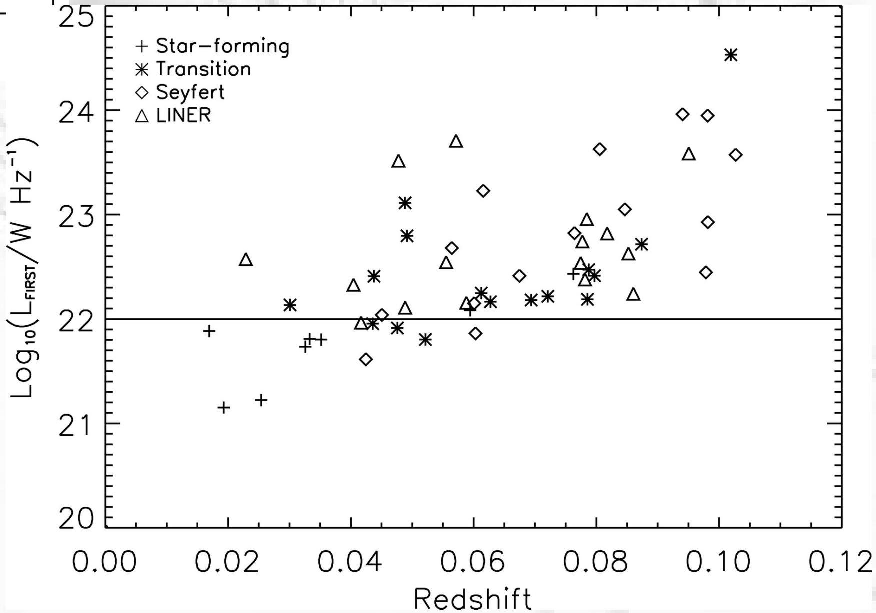


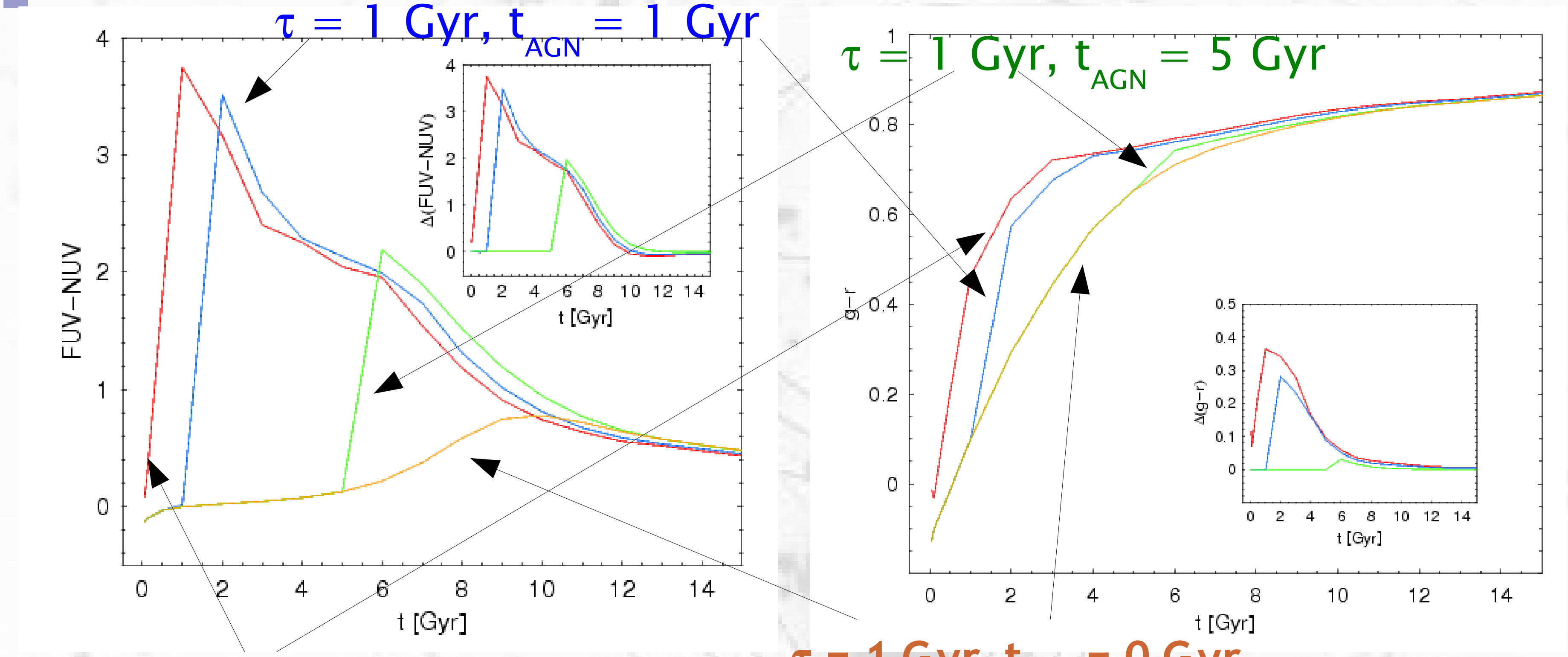
- ~ 25% of type 2 AGNs

- Grey 'cloud': Kauffmann 03 type 2 AGNs

- For AGNs having S/N ≤ 3 use 20cm FIRST gals. with W > 10^{22} W Hz^{-1}

- Rules out further ~ 3% of gals. not excluded by line analysis





τ = 1 Gyr, t_{AGN} = 1 Gyr

τ = 1 Gyr, t_{AGN} = 5 Gyr

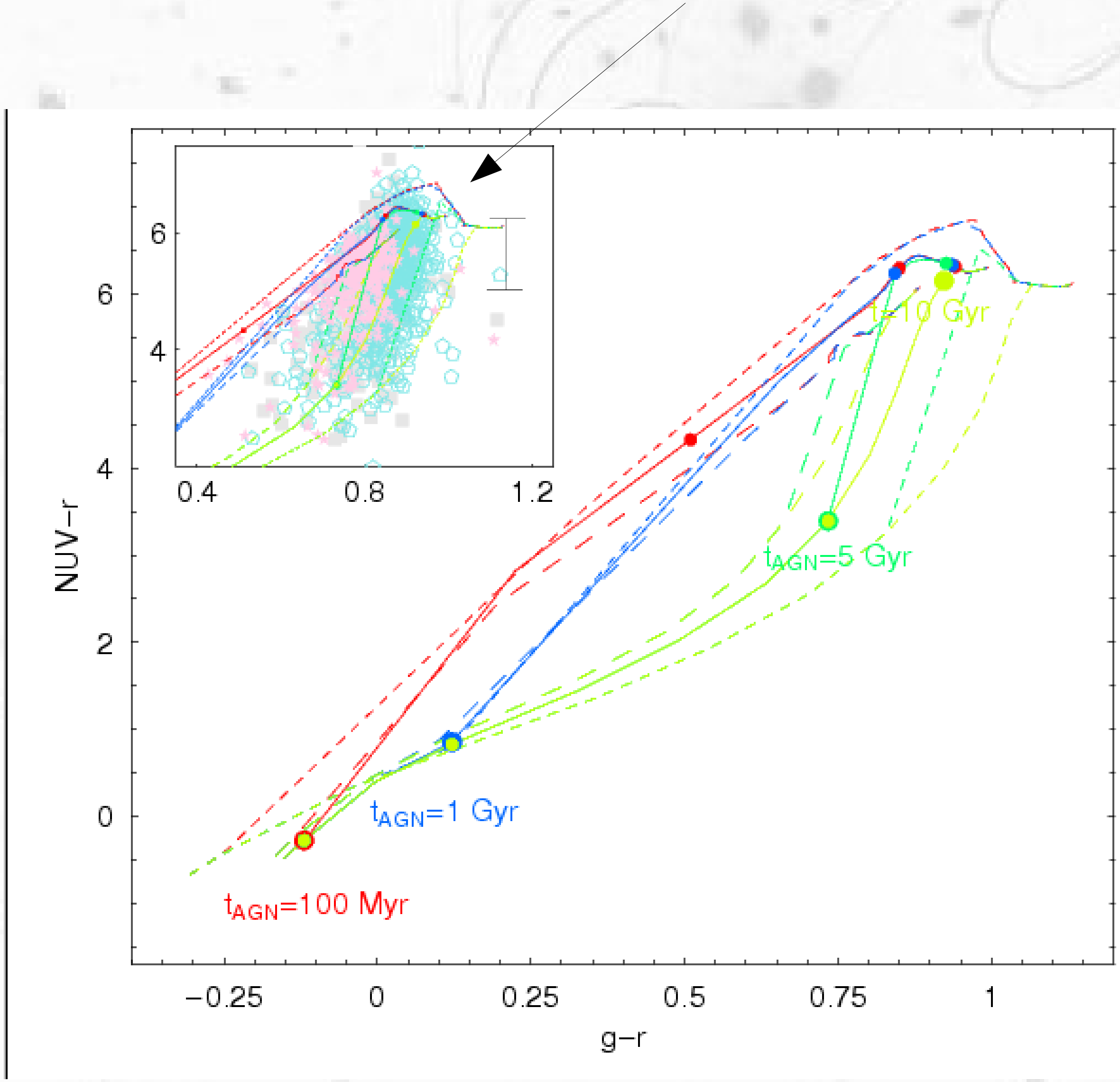
τ = 1 Gyr, t_{AGN} = 0 Gyr

τ = 0

- Colour evolution in (F,N)UV is much more evident than in g, r

- Δ(FUV-NUV) mostly concentrated in 1-2 Gyrs. → timescale of transit in the **green valley** of the (u−r,g−r) diagram

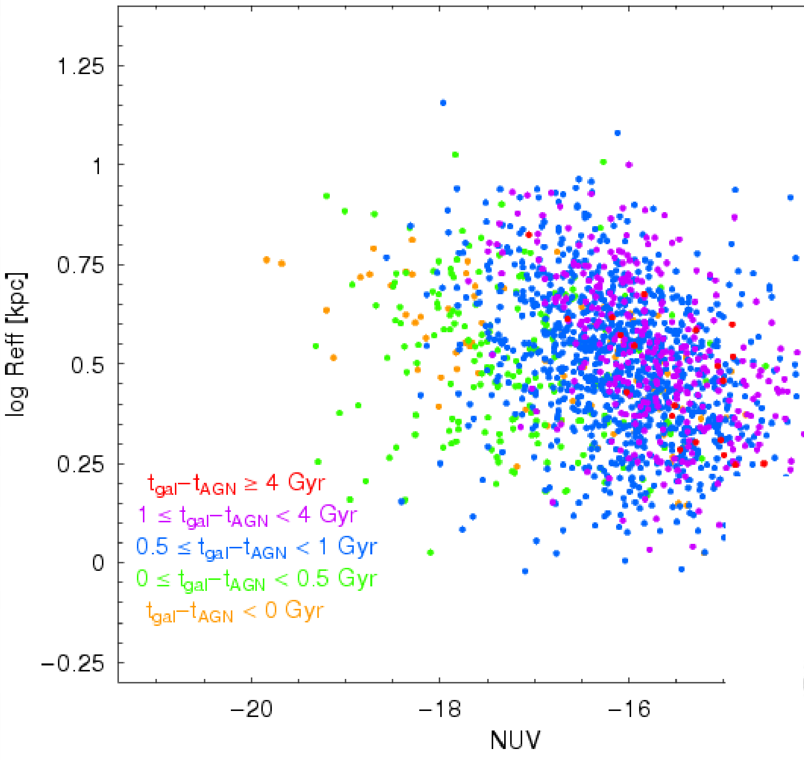
Observed points are embedded into the envelope of the predicted evol. tracks



- NUV/optical evolutionary tracks for Z = (0.008, 0.02[solar], 0.05)/(-- --, -, - -)
- Red: t_{AGN} = 0.1 Gyr
  Blue: t_{AGN} = 1 Gyr
  Green: t_{AGN} = 5 Gyr
  Yellow: t_{AGN} = 10 Gyr

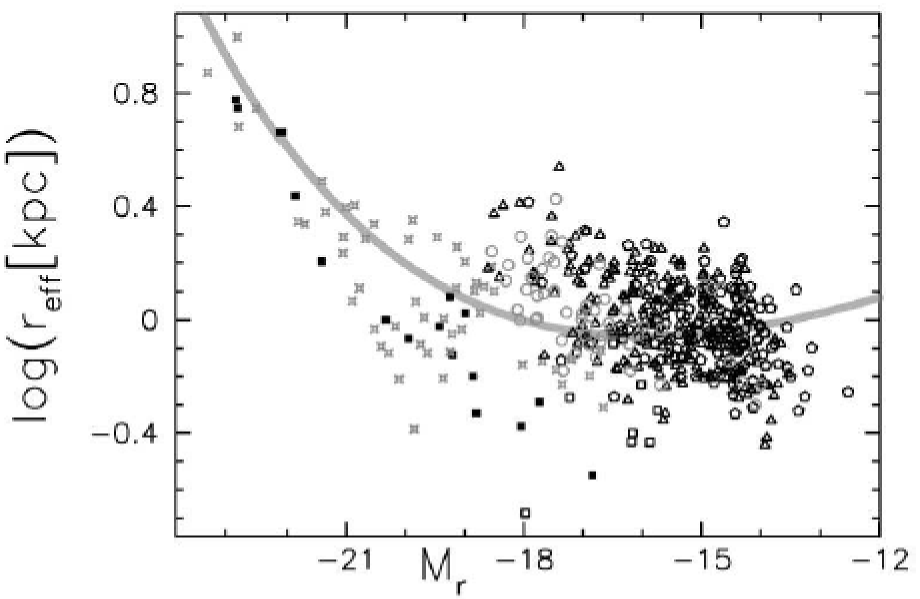
- Median. syst. scatter in (NUV−r) : 0.65 → smaller than obs. dispersion

A significant evolution is also observed in galaxy r-band sizes

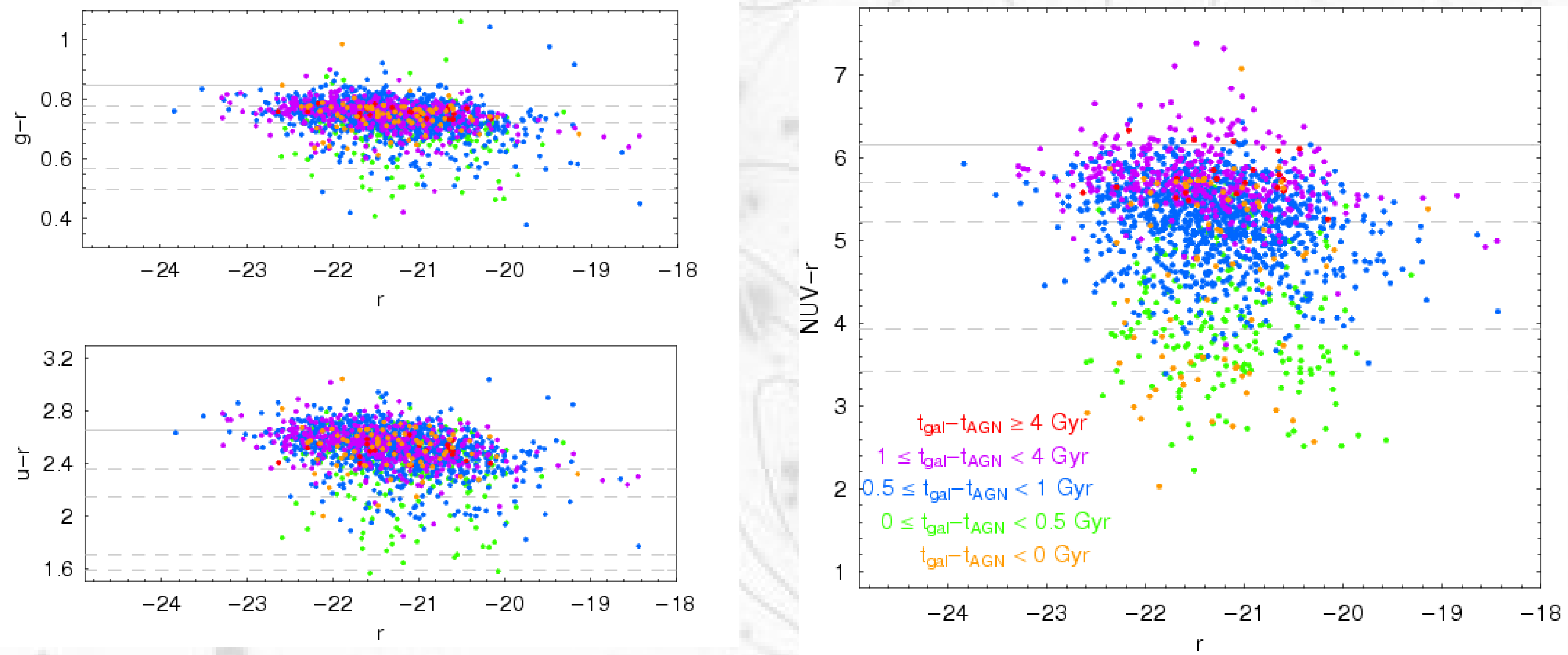


- Compare with Lisker and Janz (arxiv:0810:2999)
 Note: we are not restricted to dEs' → a larger range in R_{eff}

- A weak correlation between t_{AGN} and NUV is seen



The jump in (NUV−r) is age−dependent

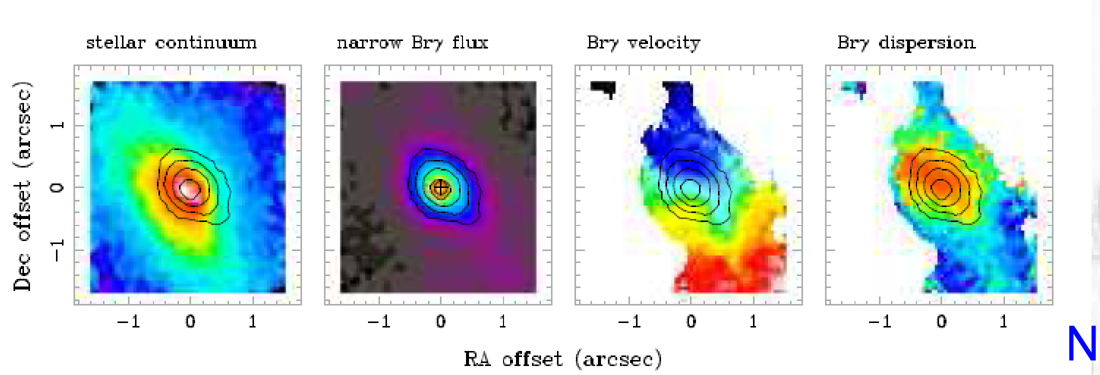


- Hor. lines: SSPs at $z_f=3$, observed at $z=0$, for $Z = 10^{-4}$, $4*10^{-4}$, $4*10^{-3}$, $8*10^{-3}$ (top to bottom)
- Optical colours are much lesser pronounced and age-sensitive
- The large scatter is intrinsic (UV upturn)

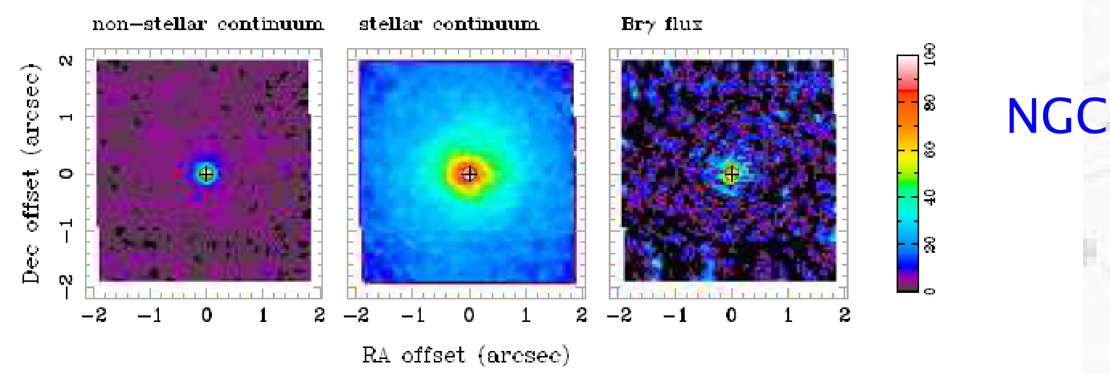
Backflow → Circumnuclear Starburst

(V. A.-D. & Silk, 2008)

- Nuclear star forming rings AGN act. (e.g. Davies et al., SIMFONI obs., l_s = 0.085" ~ 10 pc)



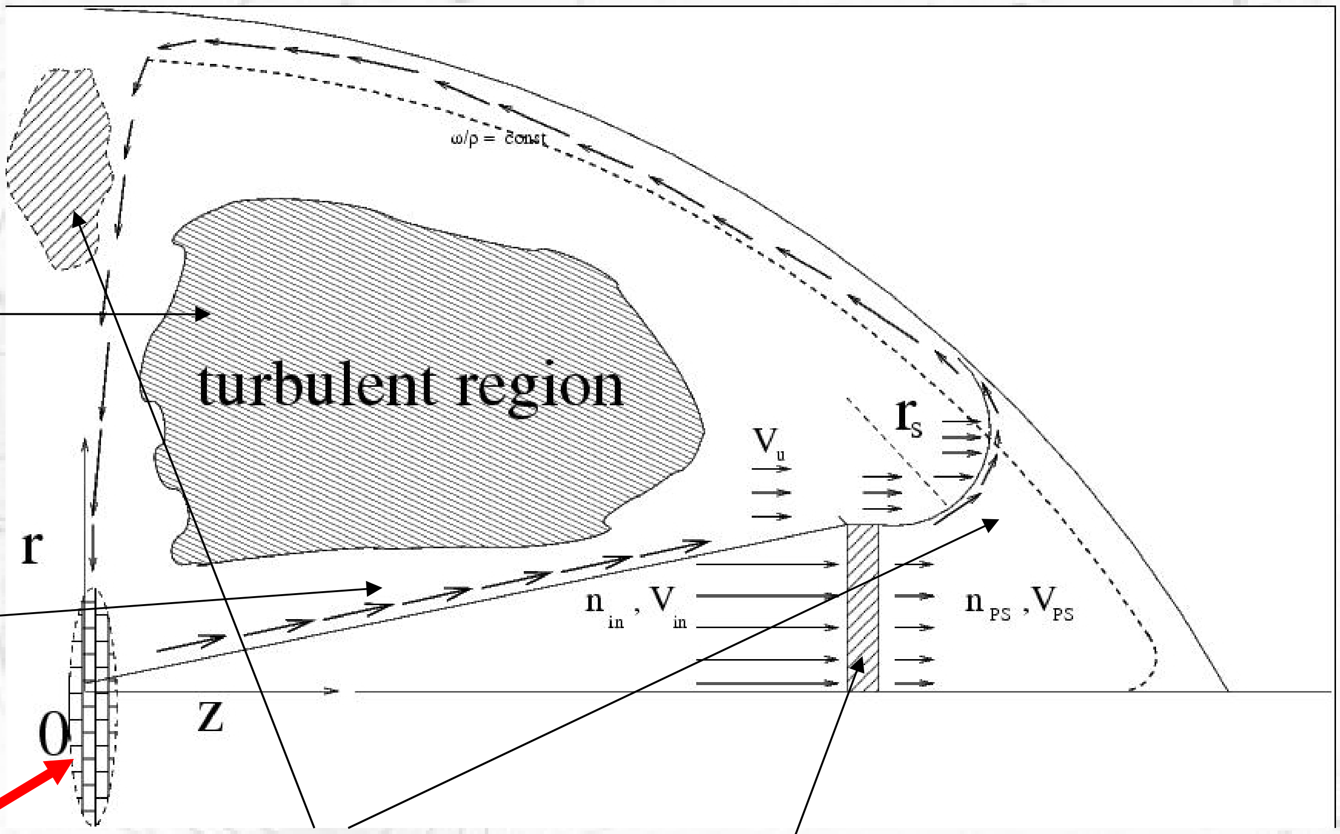
NGC 2992, 1" = 160pc



NGC 1097, 1" = 80pc

- Sugg.: nucl. Ring SF is directly activated by jet dynamics → it follows after Δt ~ 10^5 yrs jet's expn. And onset of UV/activity within ~ 10–25 kpc

Internal flow within the cocoon: Model



Cocoon

Shear flow

Circumn.-accr.

disc

High density regions

Recollimation shock

Crocco theorem (1937)

- Origin of circulation: gradients of stagnation enthalpy

$$(\vec{v}\nabla)\vec{v} = -\frac{1}{\rho}\nabla p$$

- (Quasi-)stationary flows ($\partial/\partial t = 0$):

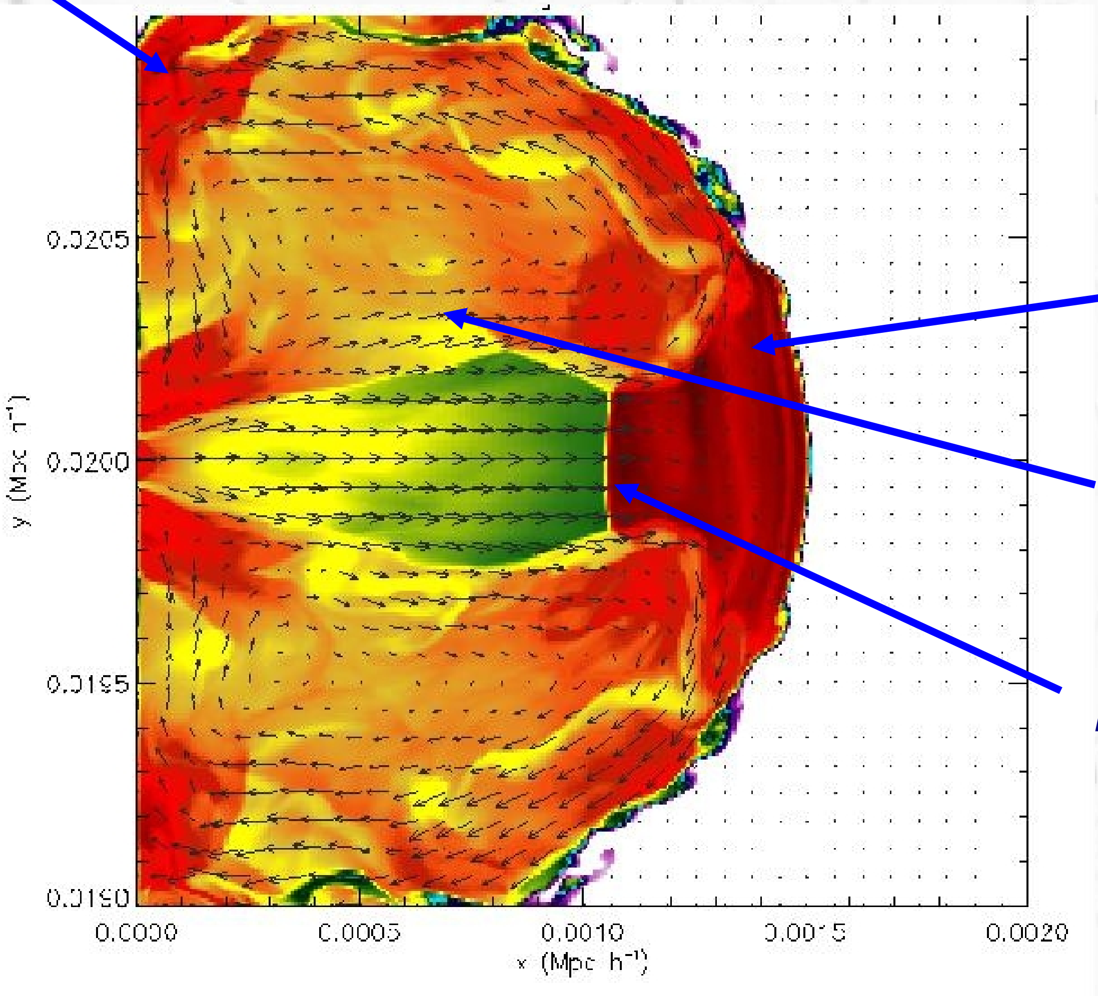
- Main formulation: $\vec{v} \times \mathrm{curl}\,\vec{v} = \nabla h - T\nabla S.$

$$h = U + \frac{p}{\rho} + \frac{1}{2}v^2$$

Stagnation enthalpy

  - $\nabla S = 0$ across an ideal shock → circulation arises only from $\nabla h \neq 0$

σ_v = 100, t=6.8x10^6 yrs.



∇h_0

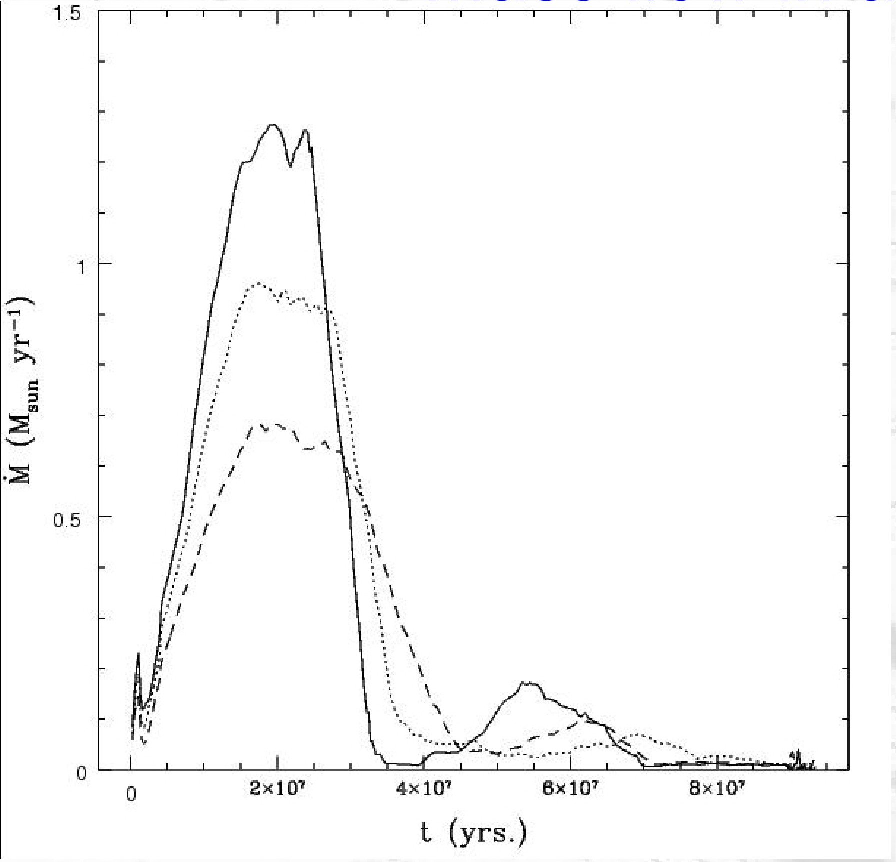
∇h_0

lateral flow

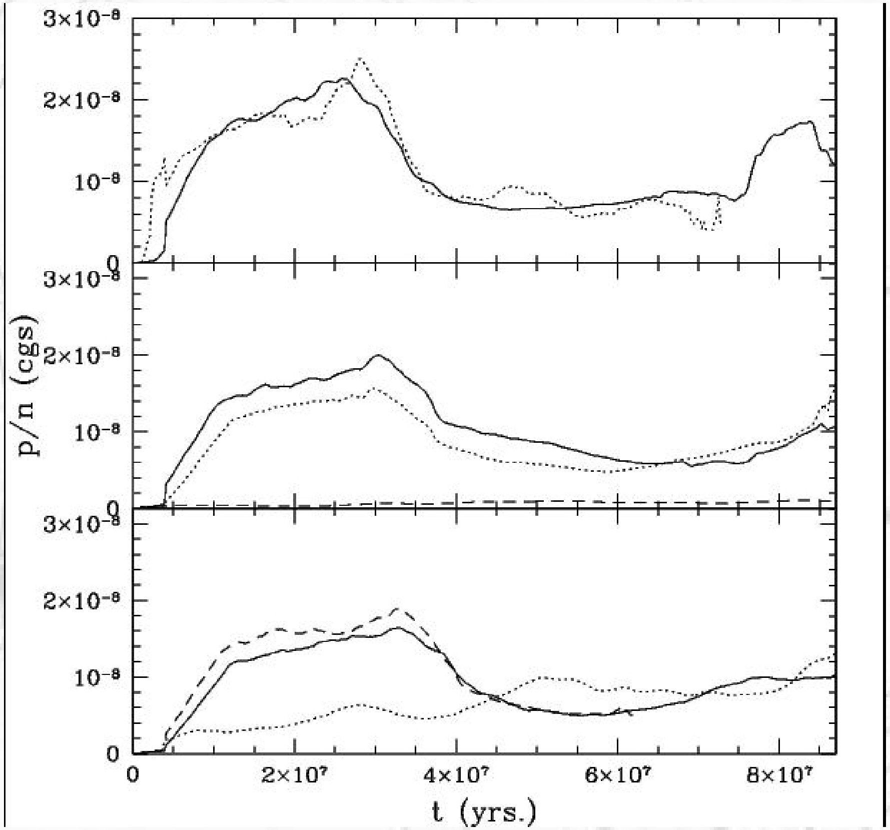
recoll. shock

- Main features of the model are reproduced in simulations

Mass flow in a circumnuclear region

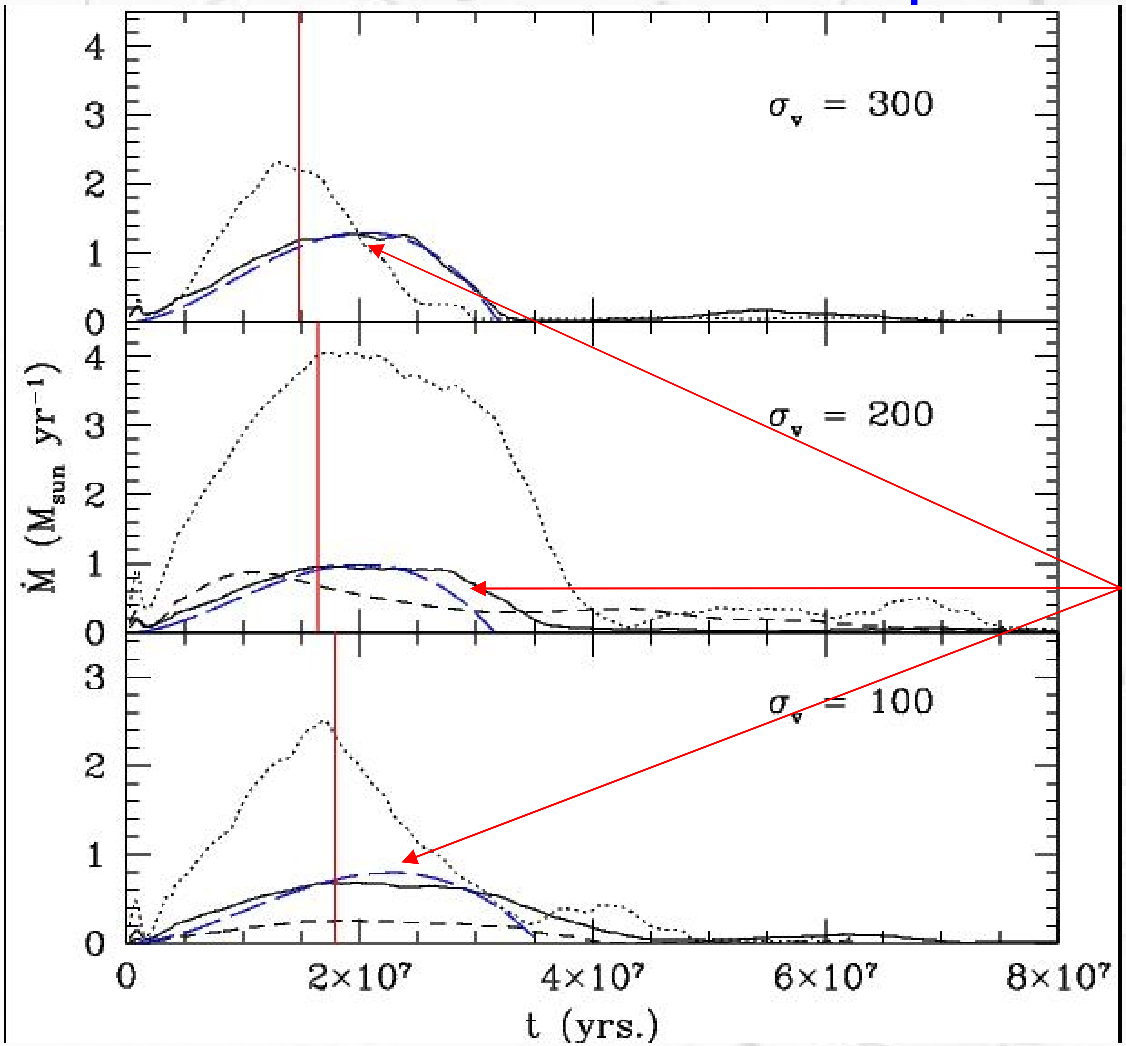


- In all 3 cases, peaks at t ~ 1.9×10^7 yrs., with aver. values 0.32 – 0.76 M_{sun}/yr.,



- All this gas has no ang. mom. - $\langle \rho v^2 \rangle \sim \langle \rho T \rangle \sim p_{disc}$ compression → starburst

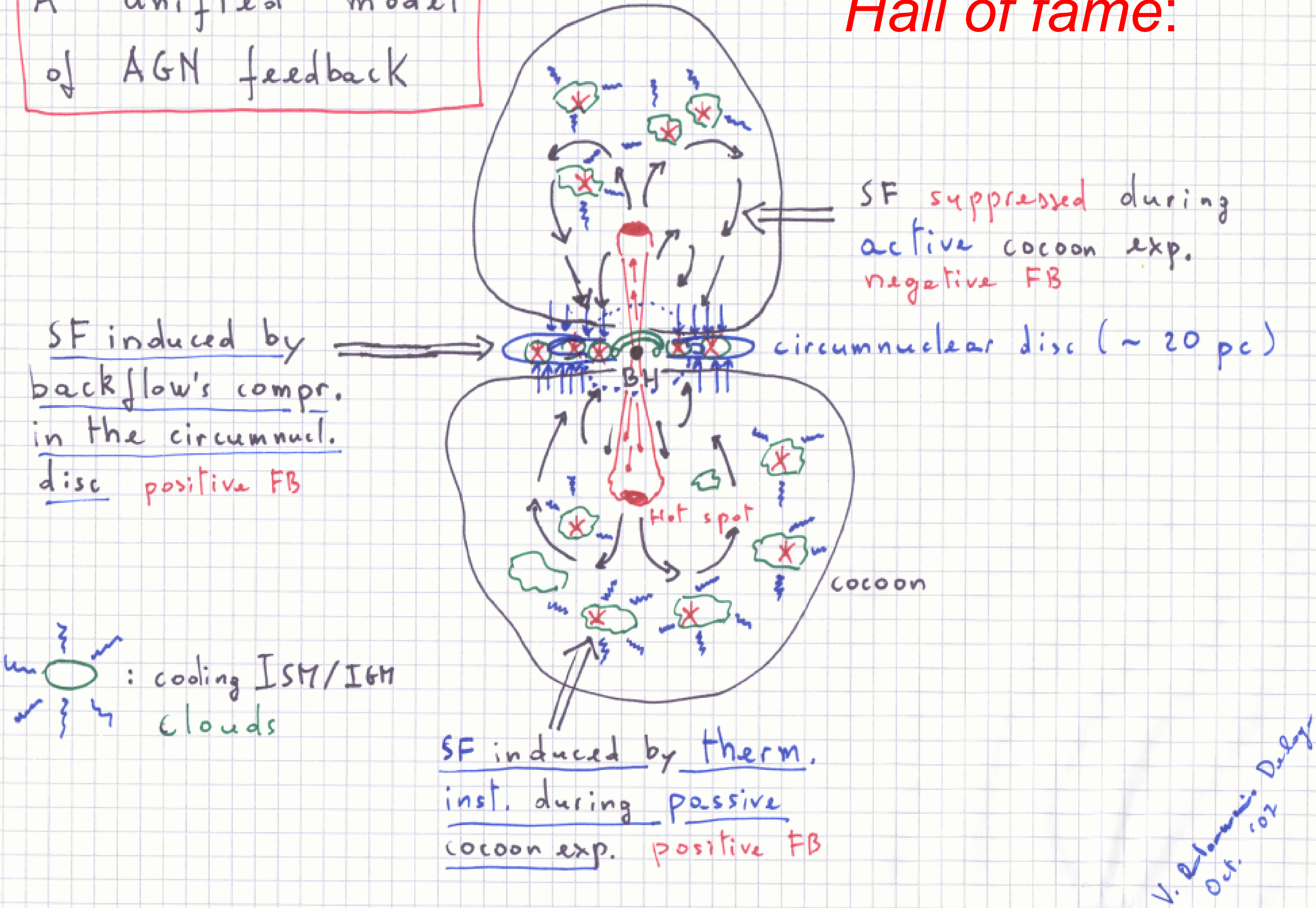
Model predictions



- For each snapshot, determine M_n and ρ_{BS} directly from simulation , then apply the 3-steps circ. model.
- Blue dashed curves. model predictions
- Mass and press. flows predicted by the model are in excellent agreement with simulations, before the destruct. of the recoll. shock

Hall of fame:

A "unified" model of AGN feedback

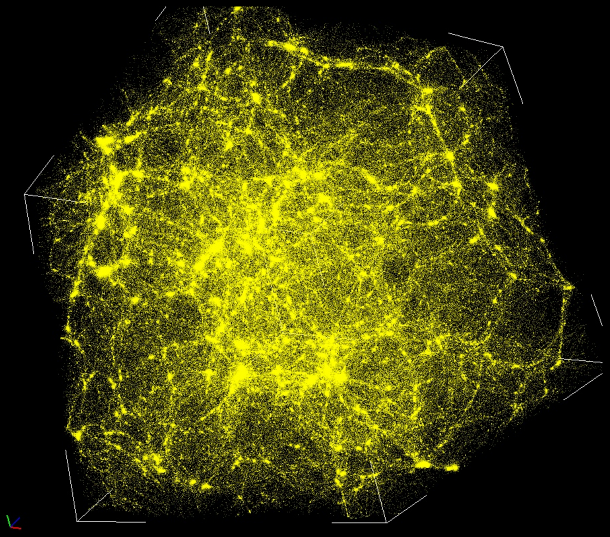


The final question:

Mass Functions are the most secure predictions one can get from state-of-the-art N-body simulations

How much statistical nonlinearity is hidden in going from halos to light?

¿ ¿



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