Ignition and launching the galactic winds

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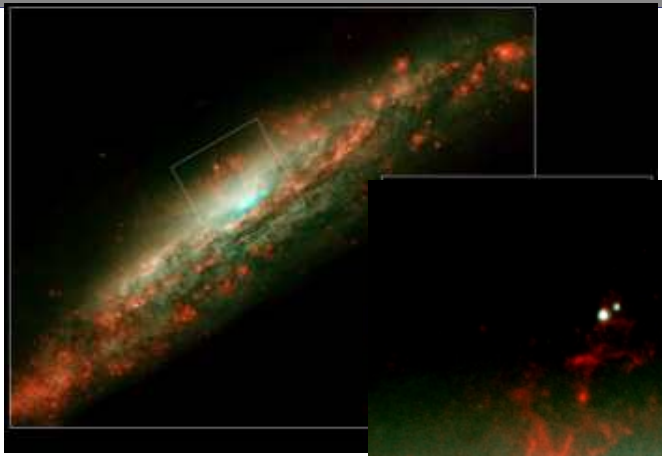
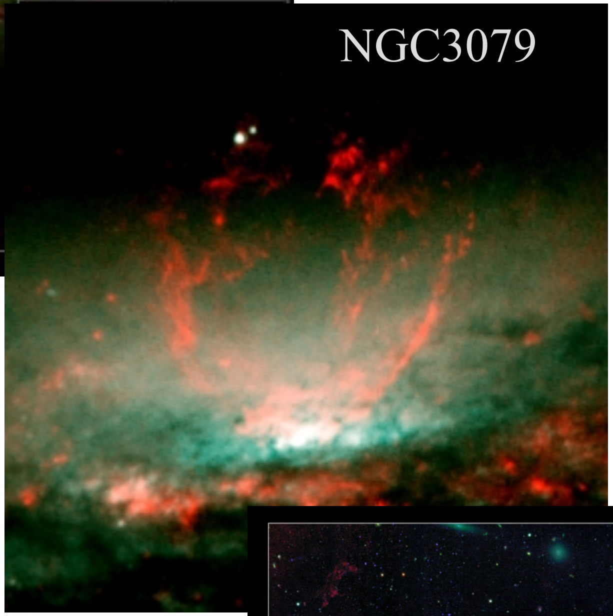
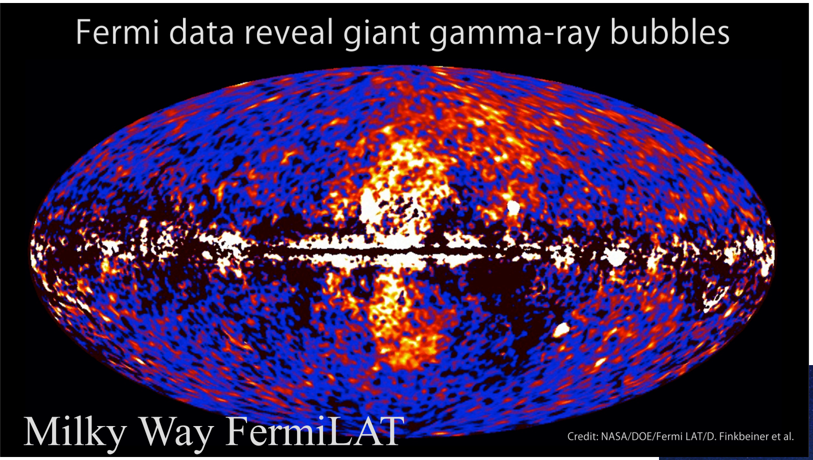
Galactic winds from NASA & *Subaru*

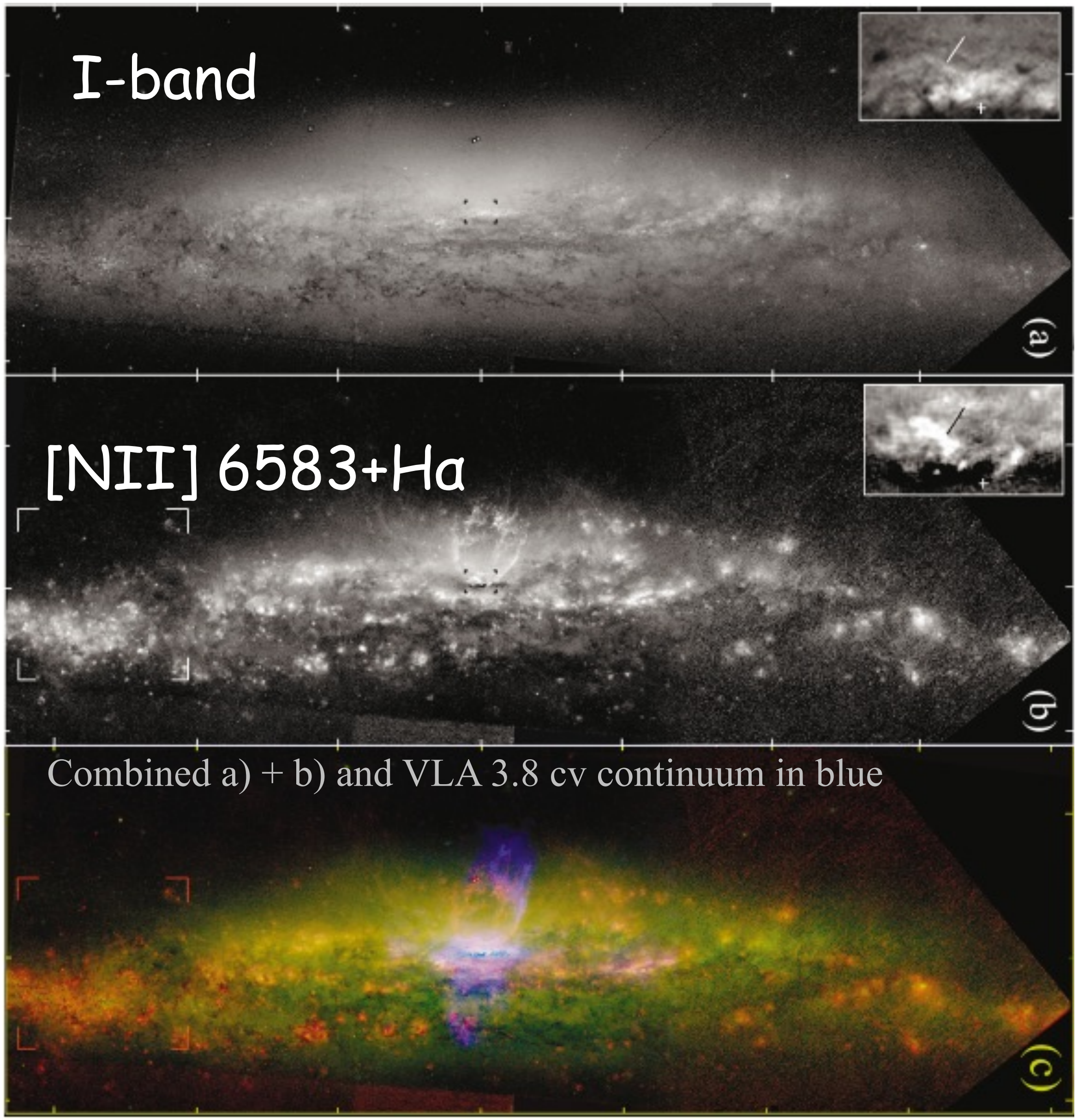






GW as it looks like

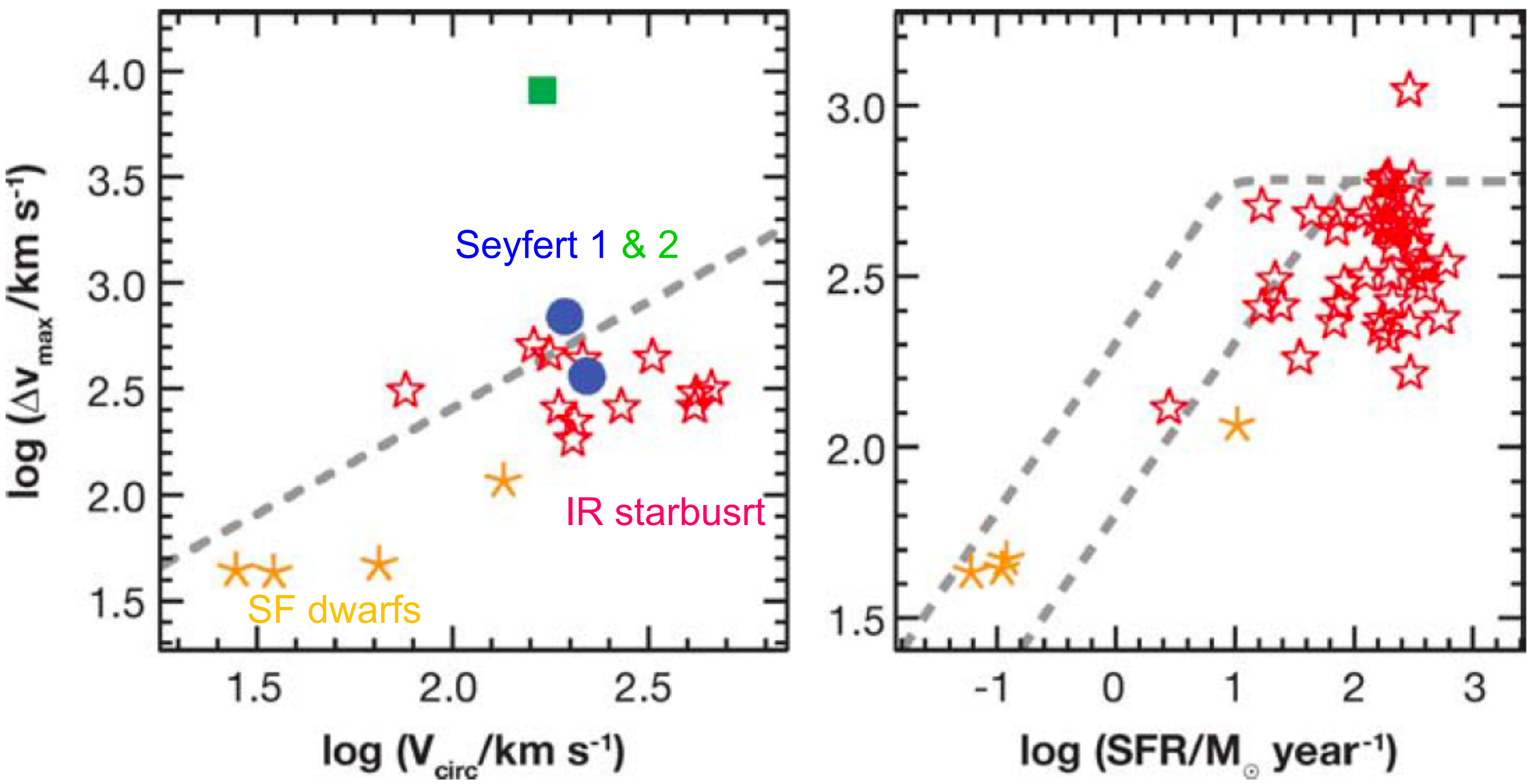
Галактический ветер



NGC3079

Cecil et al 2001

SF as a driving mechanism



Wind-SF correlation

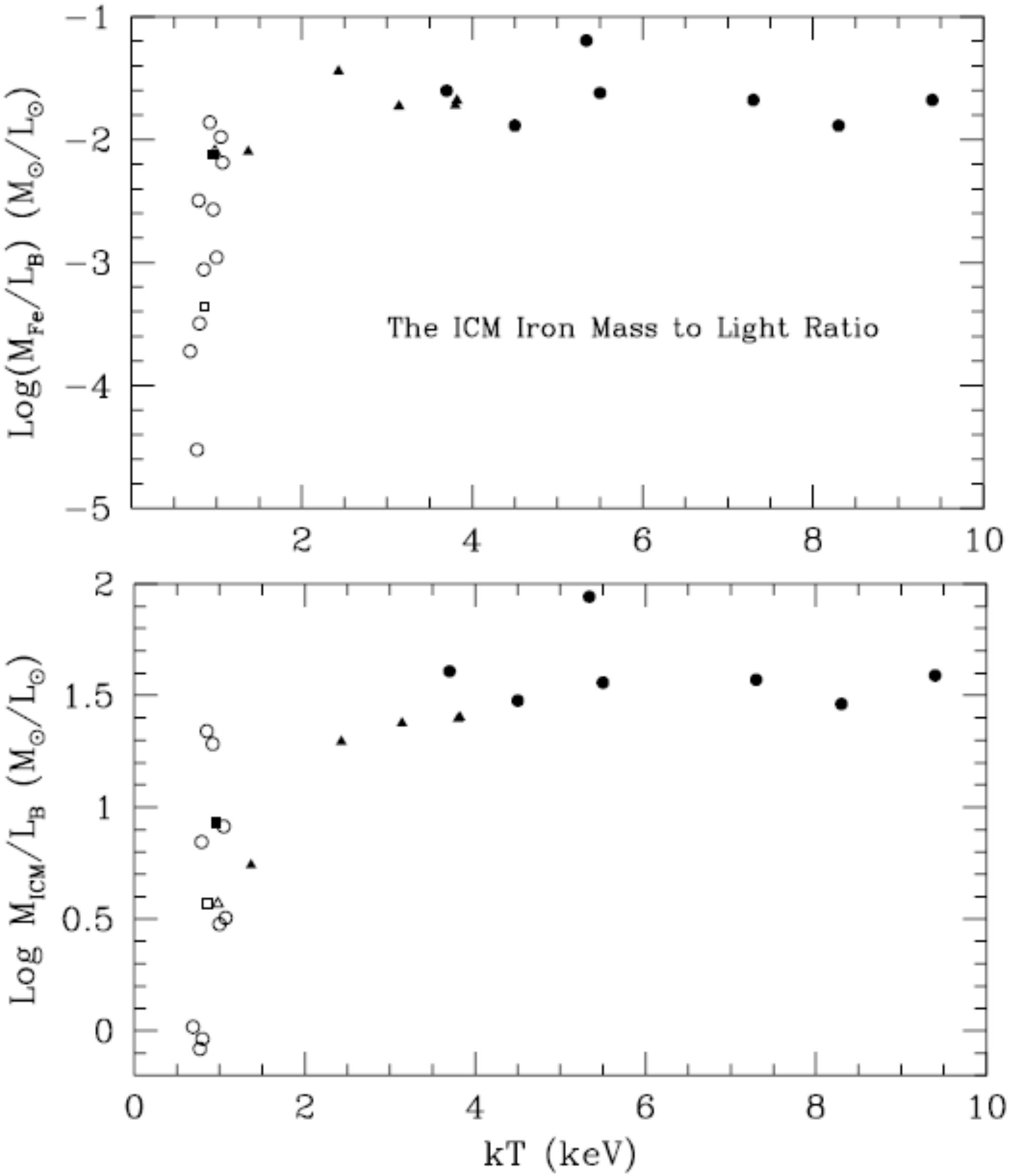
Renzini 1997, 2003

Intracluster gas

- Enrichment at nearly the same epoch (very likely at $z \approx 3$); Ellis + 1996
- Iron mass in ICM ~2 of iron mass in galaxies;
- Required mass-loss rate for a Coma-like cluster

$$\dot{M} \gtrsim \frac{M_{\rm Fe}}{Z_e t_H} \sim 2 \times 10^3 Z_e^{-1} h^{-1} \frac{M_\odot}{\rm yr}$$

$$\dot{M}_{\rm wind} \sim 2 Z_e^{-1} h^{-1} \frac{M_\odot}{\rm yr}$$ per galaxy



Extended galactic halos in local Universe

- Extended circumgalactic halos

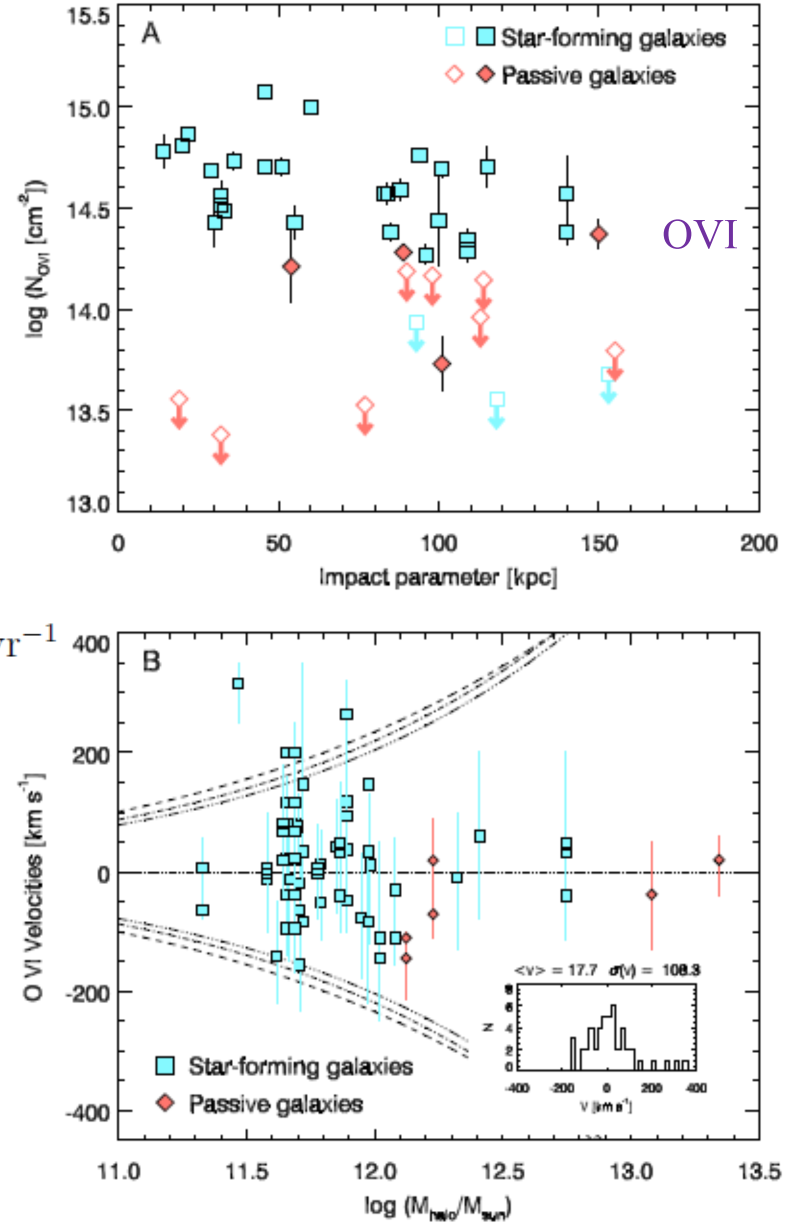
Tumlinson etal 2011

42 glxs, z =0.1-0.36 Absorptions in OVI

$$M_{\rm gas} = 177 \left(\frac{Z_\odot}{Z}\right) M_{\rm O} = 2 \times 10^9 \left(\frac{Z_\odot}{Z}\right) \left(\frac{0.2}{f_{\rm OVI}}\right) M_\odot \,,$$

most plausible $Z = 0.1\ Z_\odot$

$f_{OVI} = 0.02$ → $\dot{M}_{\rm wind} \sim 10 - 20\ M_\odot\ {\rm yr}^{-1}$

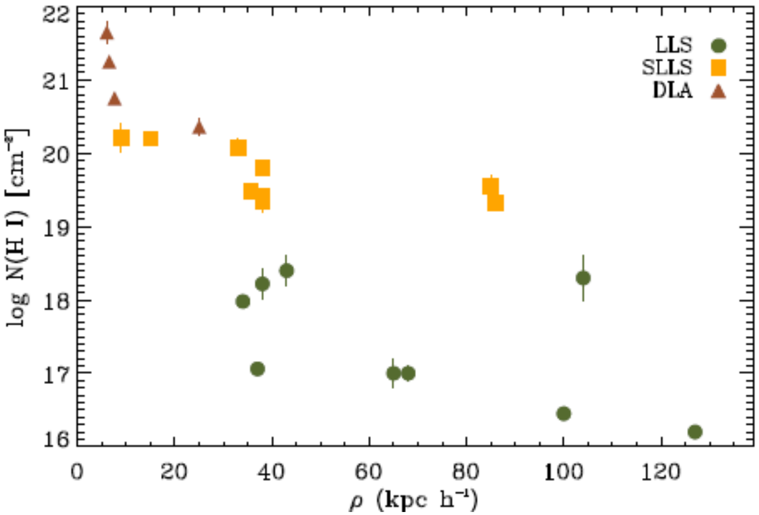


Tracing galactic wind at high redshifts

Simcoe etal 2006

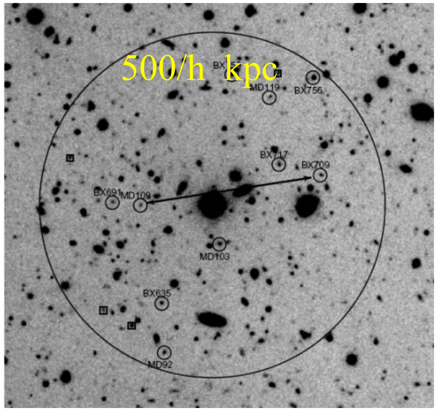
- Extended circumgalactic halos

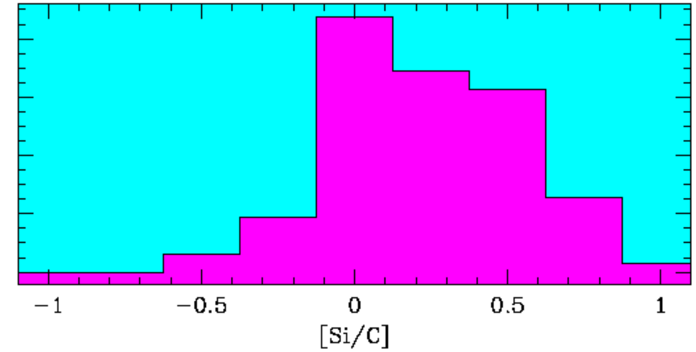
Lehner + 2013

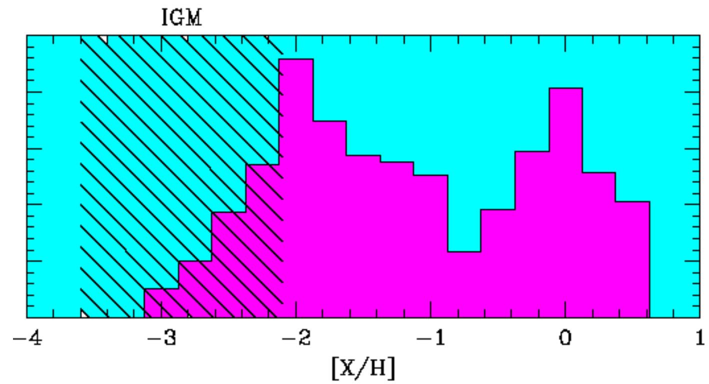


Name	z_{abs}	[X/H]	ρ (kpc h^{-1})
PG1630+377	0.2740	-1.71 ± 0.06	37
TON153	0.6610	-1.69 ± 0.37	104
PKS1302-102	0.0985	< -1.60	65
PKS0312-77	0.2026	-0.60 ± 0.15	38
PG1116+215	0.1385	-0.50 :	127
J1009+0713	0.3588	-0.40 ± 0.20	43
PHL1811	0.0810	-0.19 ± 0.08	34
PKS0405-123	0.1672	$+0.10$:	100
PG1206+459	0.9270	$+0.30$:	68

z=2.73

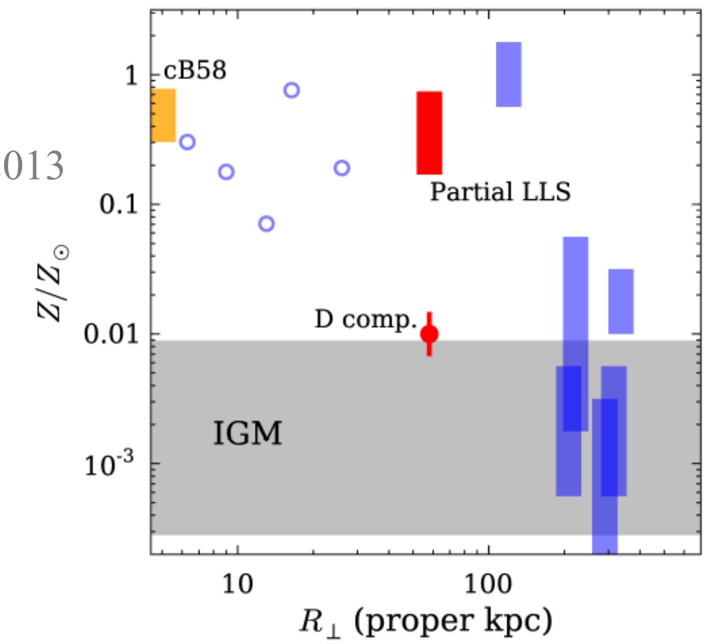






- a star-forming galaxy at $z \simeq 2.5$

Crighton + 2013



$$N_{\rm HI} \simeq 10^{19.5}\ {\rm cm}^{-2}$$

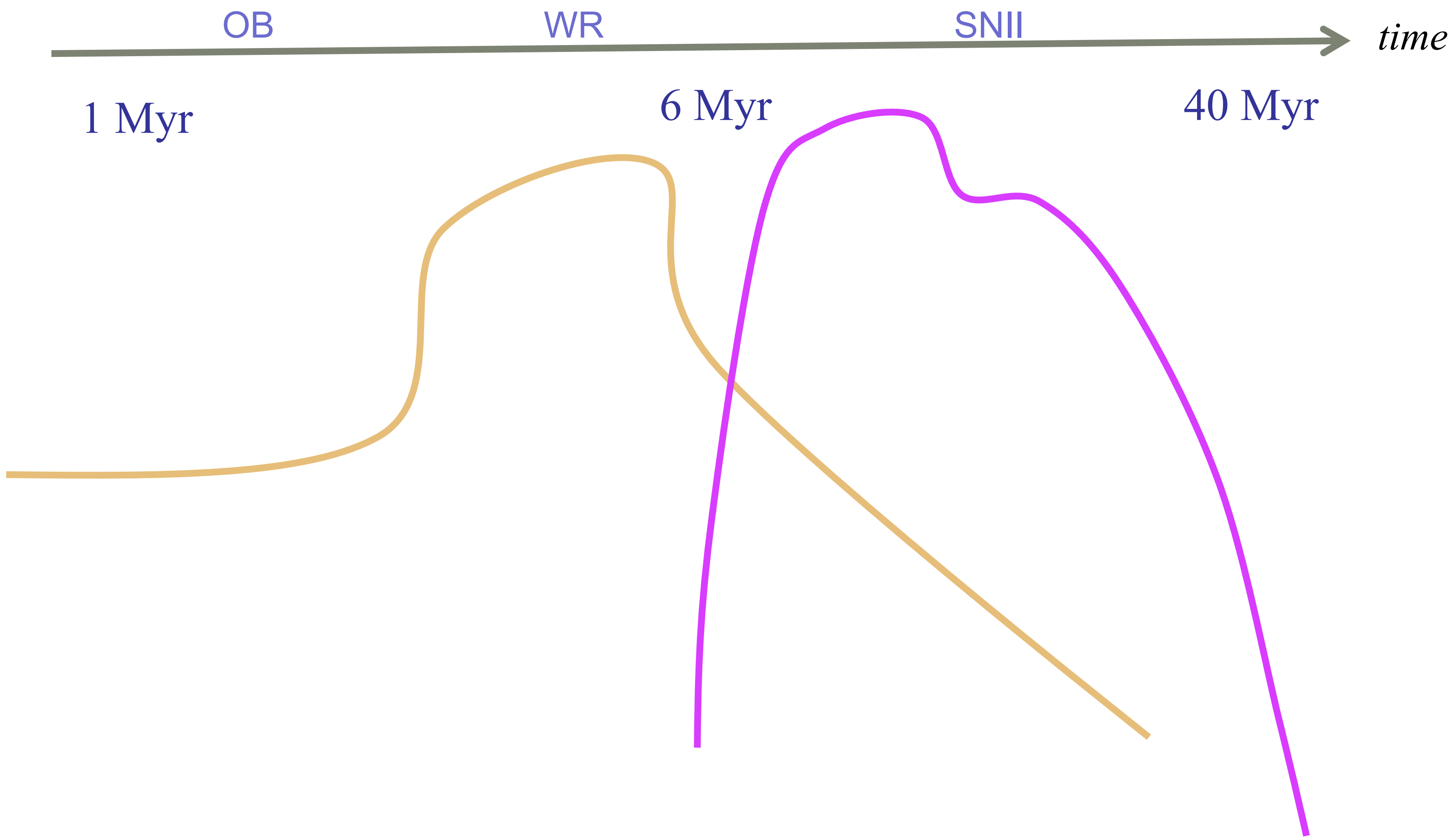
$$M_Z \simeq 2 \times 10^8\ M_\odot$$

$$\dot{M}_Z^{ej} \geq \frac{M_Z}{t_H(z)} \sim 0.1\ \frac{M_\odot}{\rm yr} \Rightarrow \dot{M}_{\rm HI}^{ej} \sim 6\ \frac{M_\odot}{\rm yr}$$

$$\dot{M}_* \simeq 24 M_\odot\ {\rm yr}^{-1}$$

- Stellar activity: SNe explosions, stellar radiation..

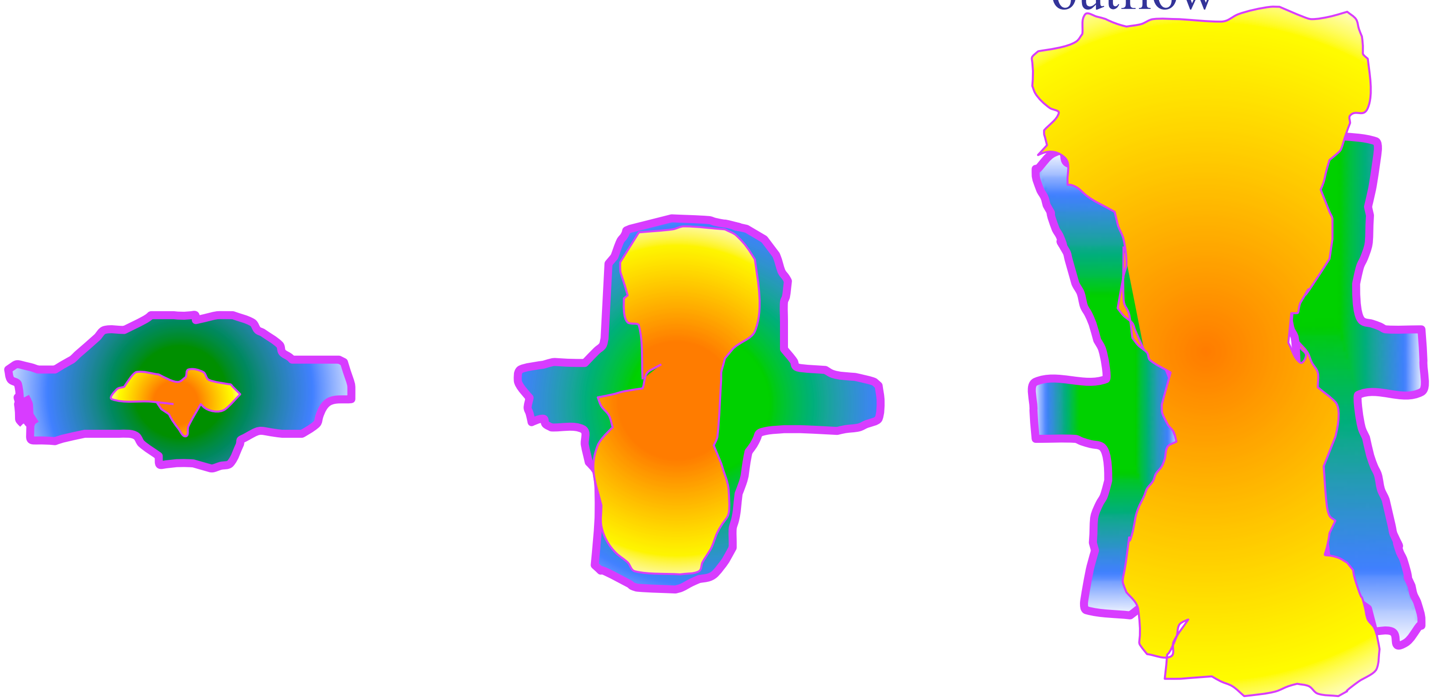
Leitherer + 1999



- Ignition → Launching → Advanced wind

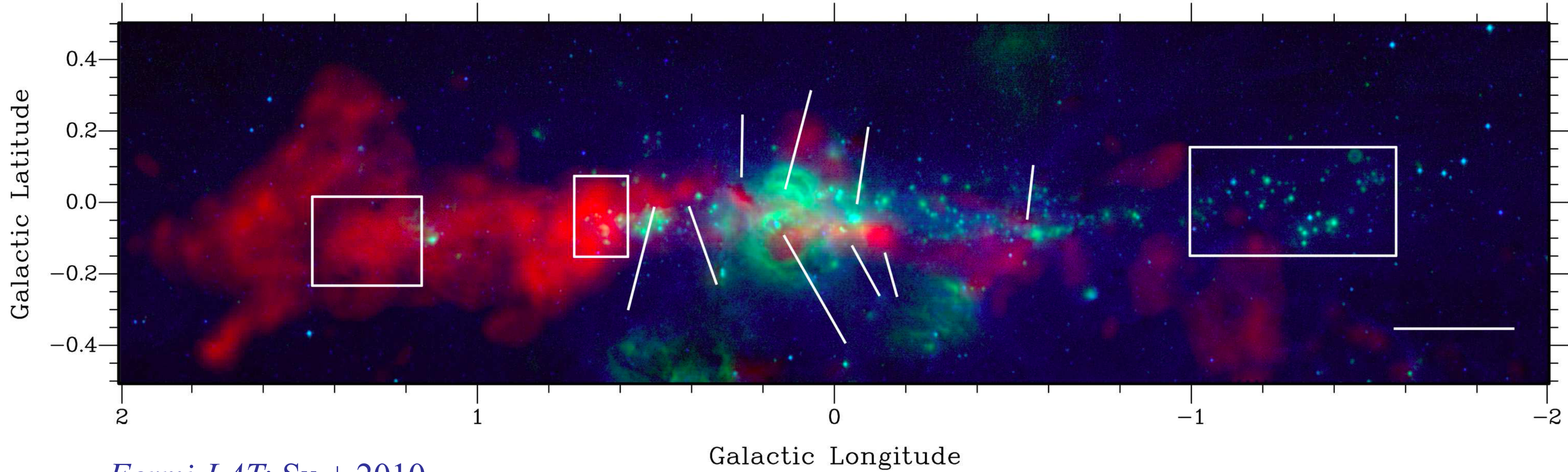
Myr

~ 10-30	~ 30-50	~ 100-300
Starburst	Breakthrough of the ISM gas layer	Quasi-steady large scale collimated outflow

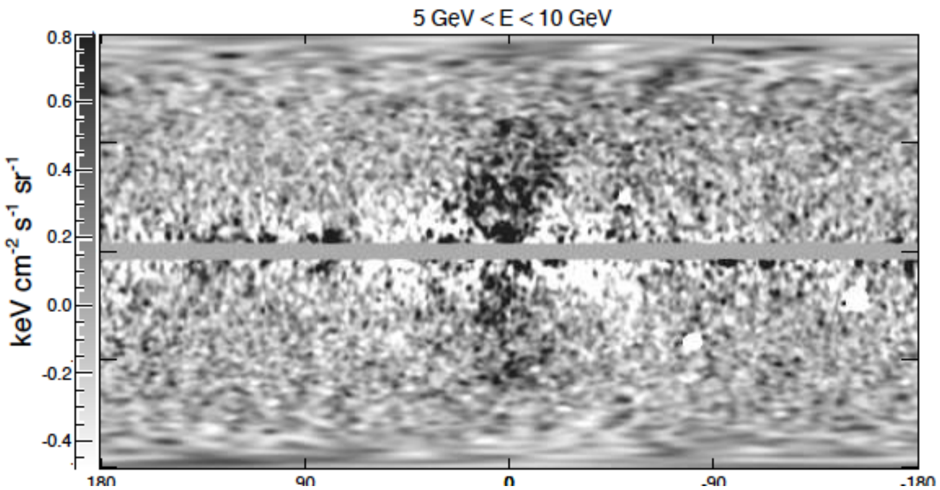


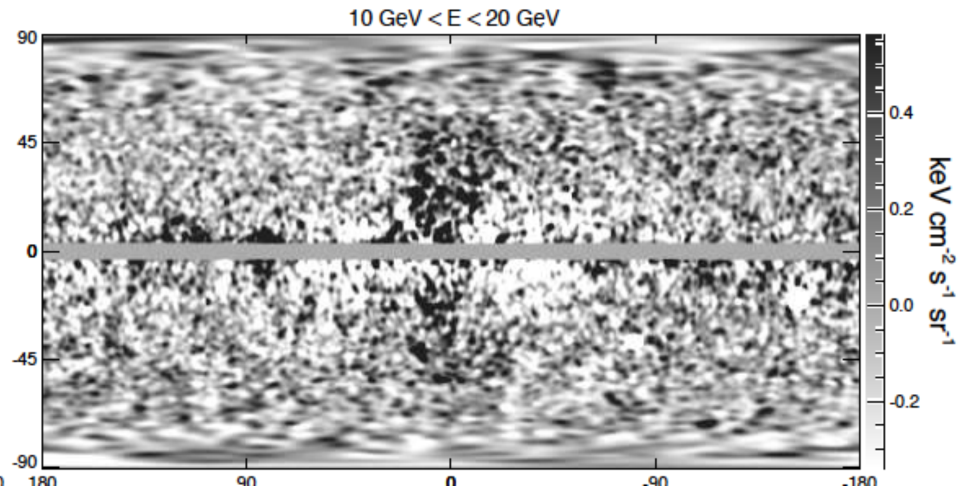
Quasi-steady phase: MW center & bubble

Kruijsen + 2012



Fermi-LAT: Su + 2010





- Coherency:

Roy + 2013

$$f_v(t) = \frac{V_{SNR}(t)}{V} \gtrsim 1$$

$\rightarrow$ $L = E_{\rm SN} \mathcal{R}_{\rm SN}$ erg s^{-1}

✔ • Mass & energy injection rate:

$$\dot{E}_{SN} > \dot{E}_w$$

$$\dot{M}_{SN} > \dot{M}_w$$

✔ • Critical mechanical (energy) luminosity to launch:

$$E_{\rm min} \sim 100\rho_0 z_0^3 c_s^2 \sim 10^{53} \text{ erg} \Rightarrow 100 \text{ SNe}$$

Quasi-steady phase: necessary conditions

- Coherency:

Roy + 2013

$$f_v(t) = \frac{V_{SNR}(t)}{V} \gtrsim 1$$

→ $L = E_{\rm SN}\mathcal{R}_{\rm SN}$ erg s^{-1}

✔ - Mass & energy injection rate:

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✔ - Critical mechanical (energy) luminosity to launch:

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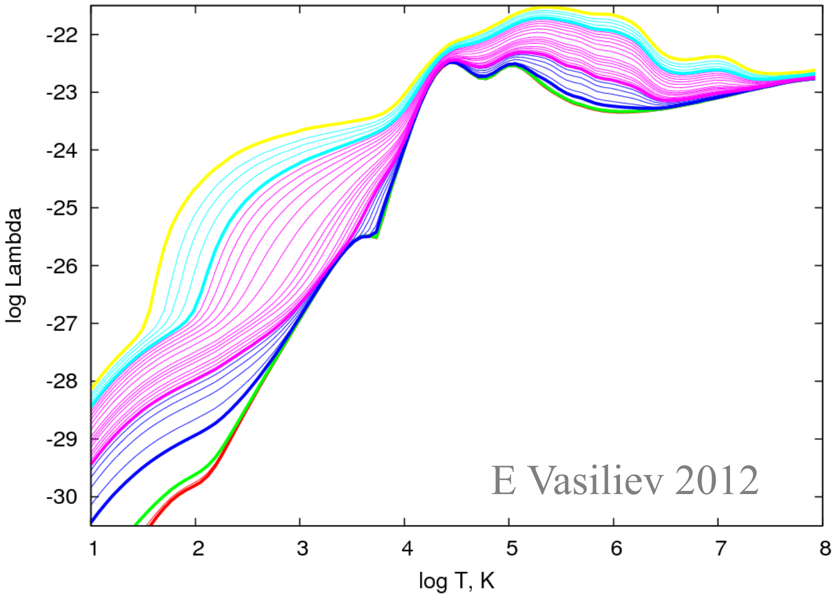
- Energy conservation → momentum conservation

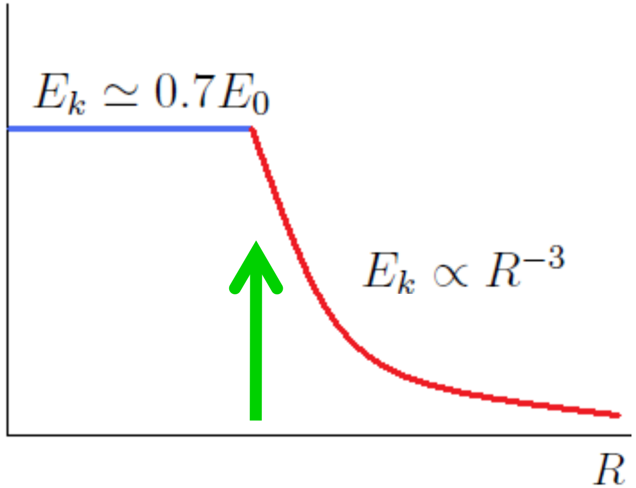


It begins when

Cooling time — Dynamical time

$$t_d = \frac{kT}{4\Lambda n} < \frac{z_0}{3c_s}$$

$$\frac{10^{10}}{n}\ \mathrm{s} < 10^{15}\ \mathrm{s}$$



- Coherency:

$$f(t_c) \sim \frac{4\pi}{3}\nu_{SN} r_c^3 t_c \gtrsim 1$$

$$\frac{d\dot{E}}{dS} = \frac{\nu_{\rm SN} E}{\pi R^2} \sim 10^{-3} n \frac{z_0}{R_c} \frac{\rm erg}{\rm cm^2\ s}$$

Superwinds:	$\sim (3-5)\times 10^{-2}\ {\rm cm^{-3}\ s^{-1}}$	Heckman 2002
Edge-ons:	$\geq 6 \times 10^{-2}\ {\rm cm^{-3}\ s^{-1}}$	Tüllmann etal 2006

$$t_c \quad \Rightarrow \quad v_c(t_c) = 100\ {\rm km/s}$$

$$r_c^3 \propto n^{-1}$$

$$t_c \propto n^{-1/3}$$

$$f(t_c) \propto n^{-4/3}$$

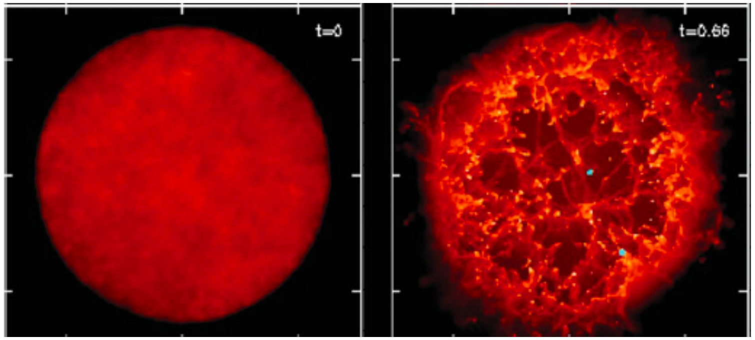
- Coherency:

$$f(t_c) \sim \frac{4\pi}{3} \nu_{SN} r_c^3 t_c$$

- Homogeneous (averaged) cloud $f(t_c) \sim 0.2$
- Puffed by stars (ionizing + pushing dust) cloud $f(t_c) \sim 1$

Walch + 2012, 13

Murray + 2010



$$\dot{M}_{inj} \sim \eta \mathrm{SFR}$$

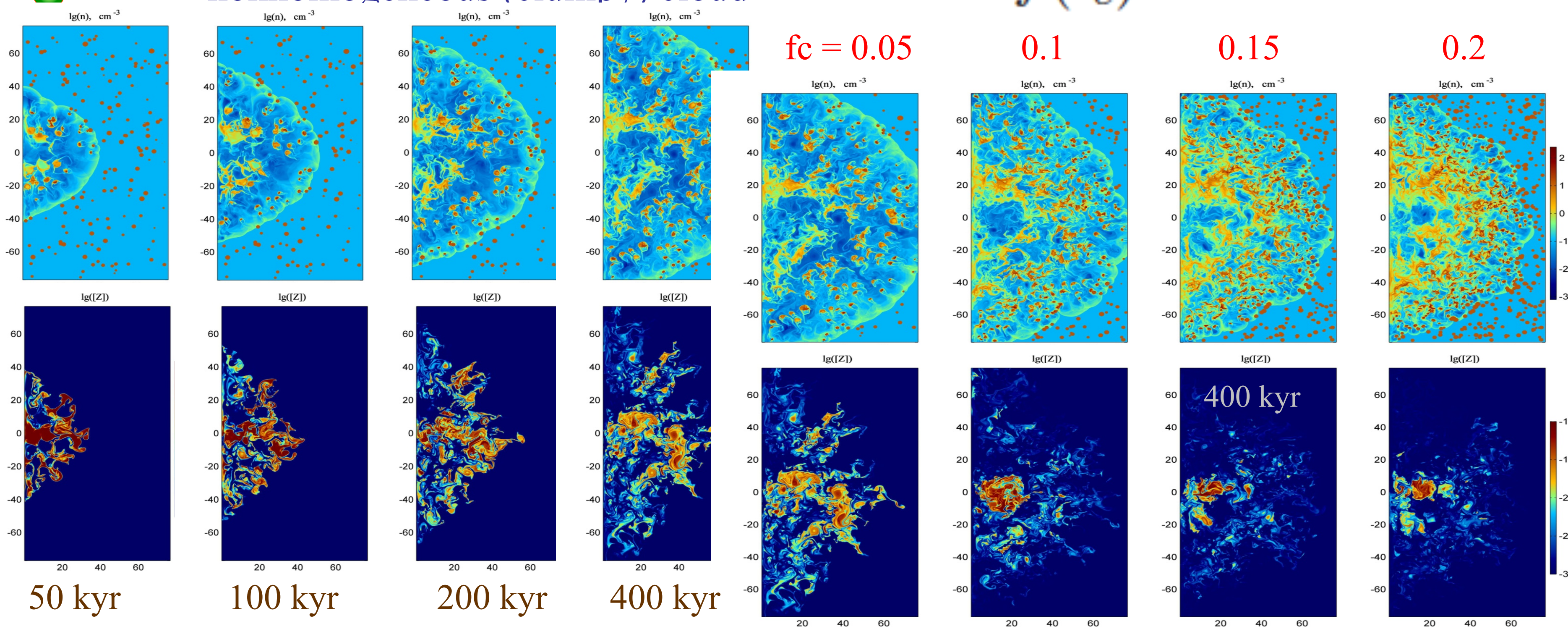
$$\eta = \eta(f_c) \lesssim 1$$

- Coherency:

$$f(t_c) \sim \frac{4\pi}{3} \nu_{SN} r_c^3 t_c$$

- nonhomogeneous (clumpy) cloud

$$f(t_c) \sim 0.2$$



- Coherency:

$$f(t_c) \sim \frac{4\pi}{3}\nu_{SN} r_c^3 t_c$$

- Homogeneous (averaged) $f(t_c) \sim 0.04$
- Puffed by stars (ionizing + pushing dust) $f(t_c) \sim 0.2$

$$\dot{M}_{inj} \sim 0.02 \times \mathrm{SFR} \ll \dot{\mathrm{M}}_{\mathrm{w}}$$

!

- Critical mechanical (energy) luminosity to launch:

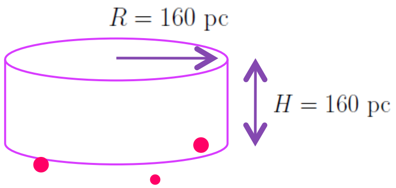
- $L = L_{\rm cr} \simeq 2 \times 10^{39}$ erg s^{-1} $\Rightarrow$ $f(t_c) \sim 2 \times 10^{-5}$
- $f(t_c) \sim 1 \Rightarrow L \sim 10^{43}$ erg s^{-1}

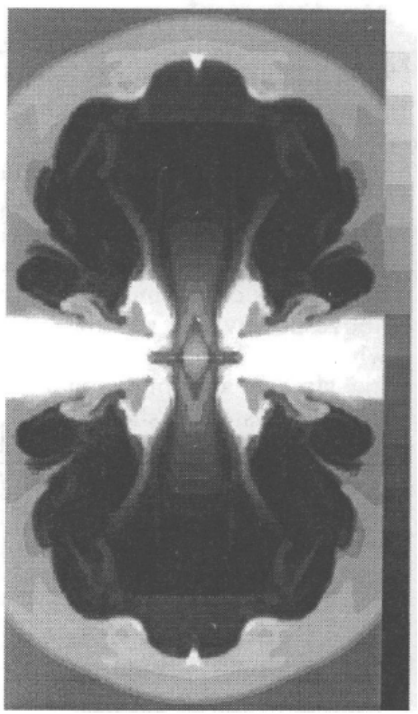
!

- Suchkov + 1994, 1996: Numerical model for M82

$$\sum \dot{E}_{\rm SN} \sim 5 \times 10^{41} \text{ erg/s}$$

$$f_v = \frac{\nu_{\rm SN} V_{\rm SN} t_c}{\pi R^2 H} \sim 10^{-3}$$



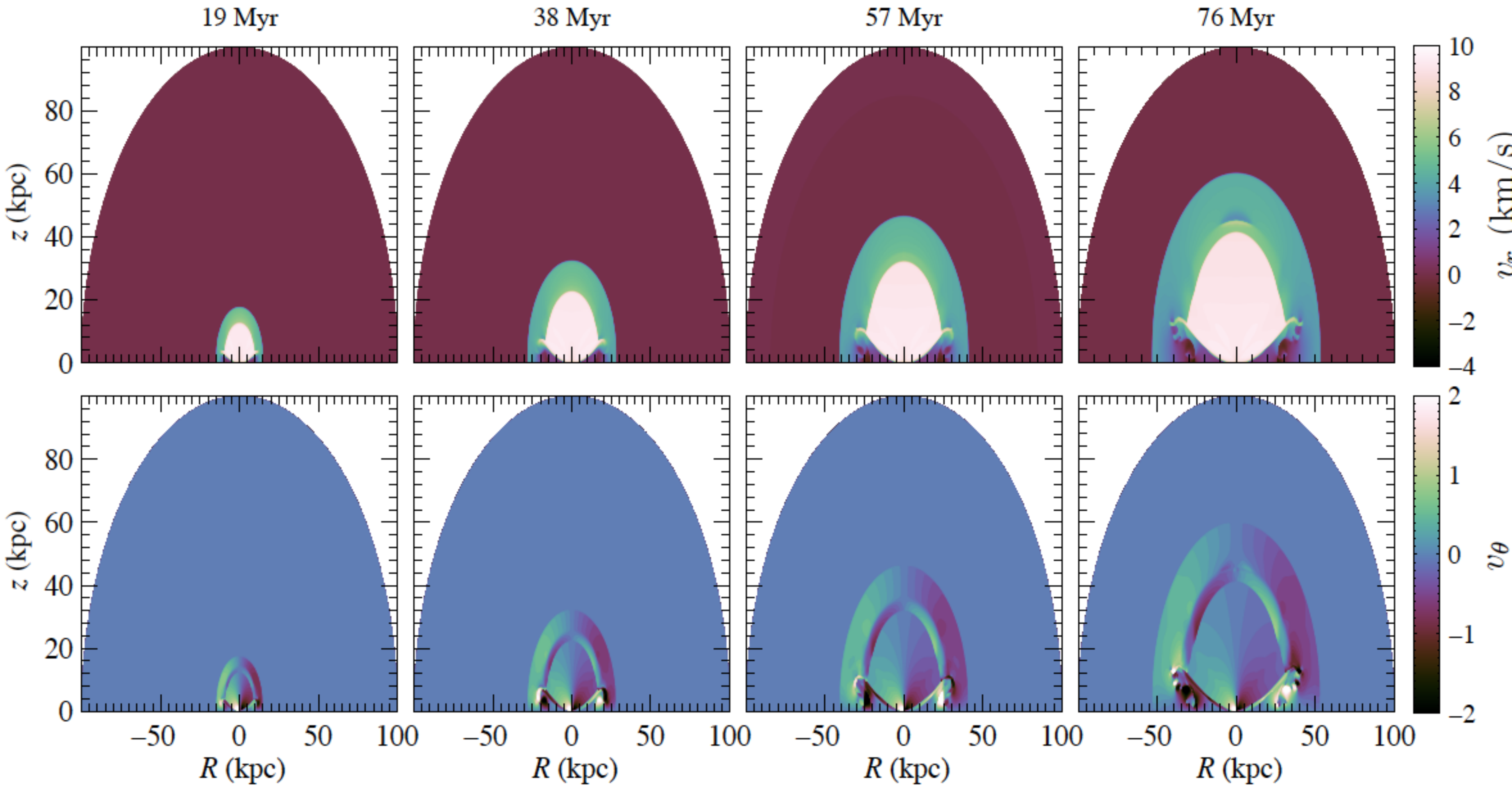


Still weak points: M82..

- X-ray emission needs mass loading (Suchkov + 1996)
- Mass loading needs thermolization → very hot (hudnred of millions K) wind gas → enhances radiation losses (Strickland & Heckman 2009)
- Little mass is ejected (Mac Low & Ferrara 1999): Arp 220 galaxy

Mass outflow

M Sharma + 2013



Mass outflow

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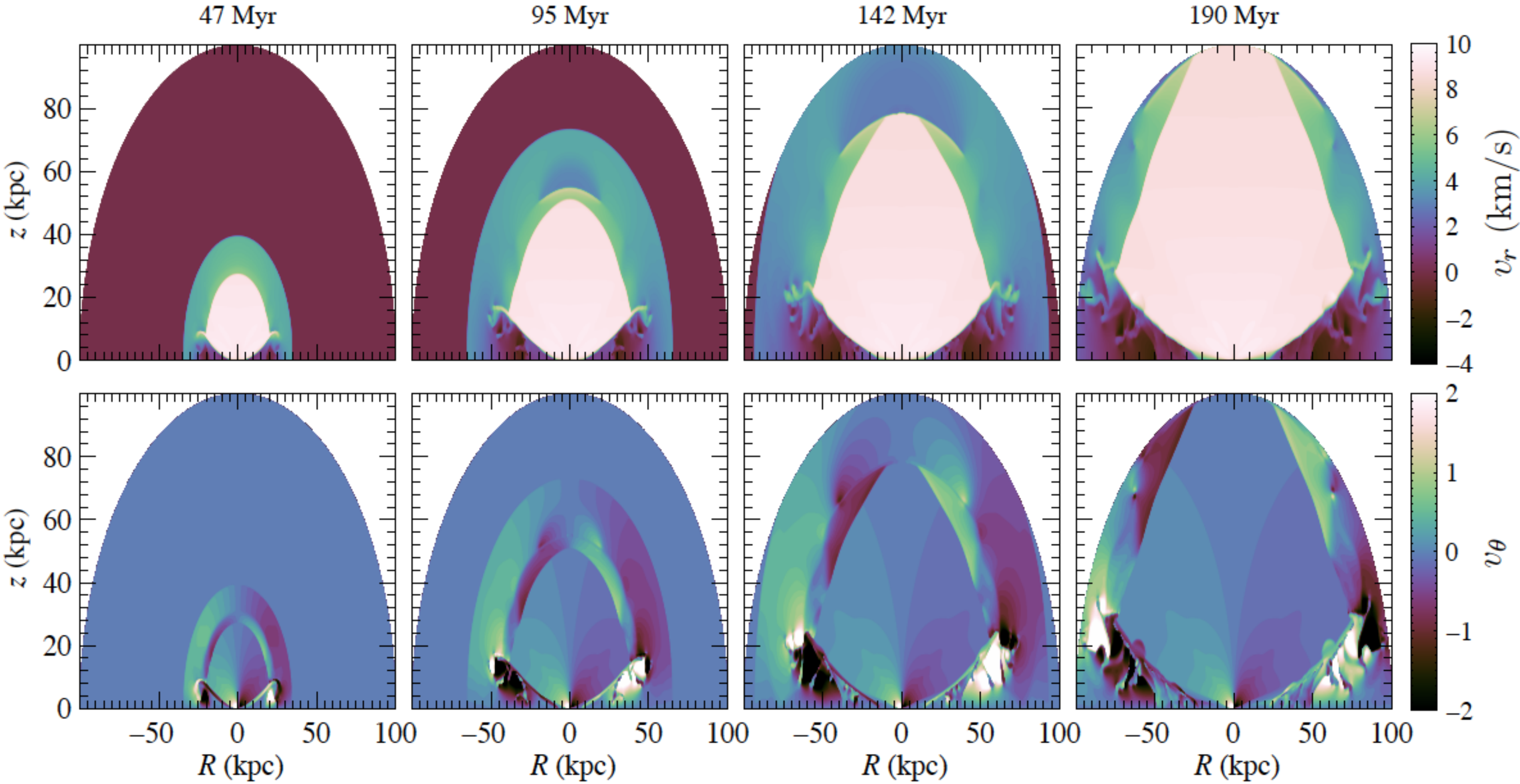
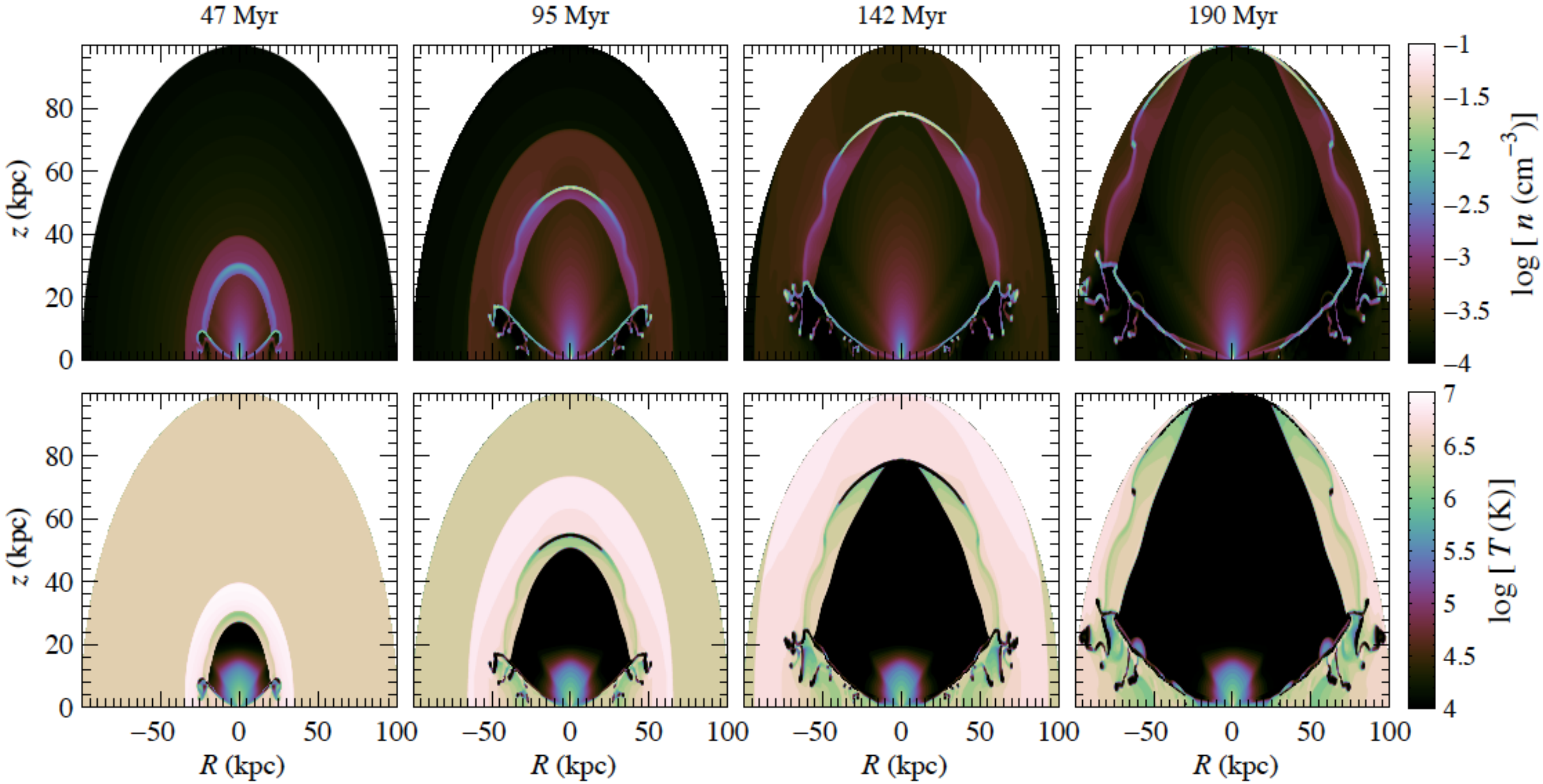


- Top shell formation

M Sharma + 2013



Arp 220 galaxy

Radiation pressure as a driver of GWs

- Dust driven wind

Nuclear luminosity

$$N_{HI} \lesssim \frac{L}{4Gc\mu m_p M} \leq 2 \times 10^{19} \left(\frac{L}{M}\right)_{\odot} \ \mathrm{cm}^{-2}$$

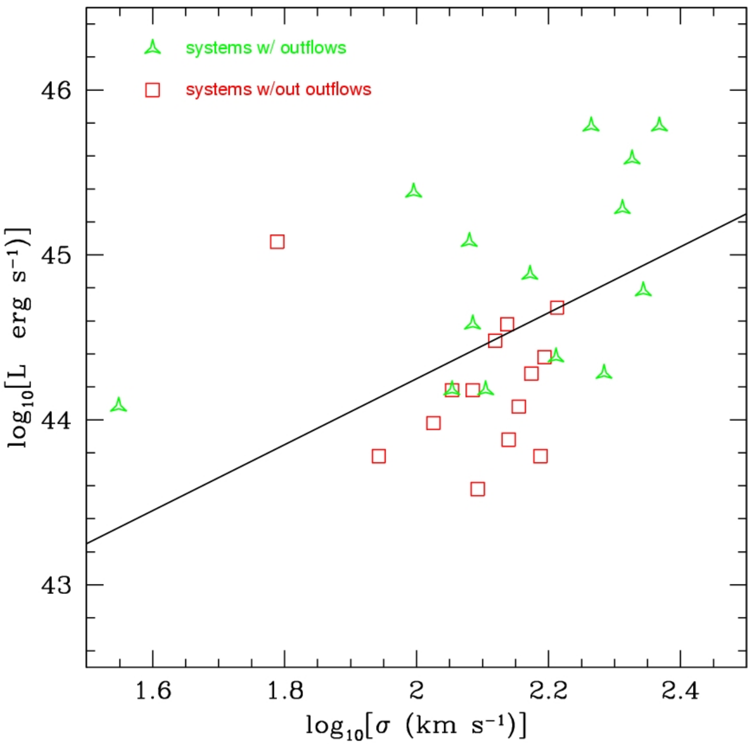
Total galactic mass

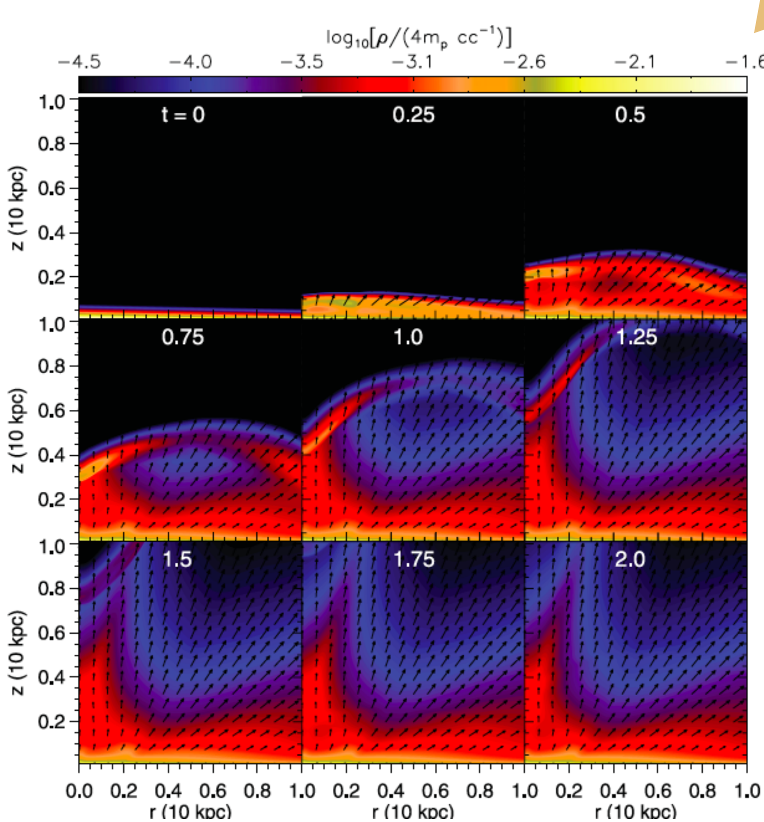
Murray + 2005

Nath & Silk 2009

M Sharma + 2011

Chattopadhyay + 2012





Radiation driven advantages & disadvantages

- Advantages
- Coherent flux as all stellar population does work continuously

  Supports superbubble shell against slipping down

- Disadvantages: Photon to gas kinetic energy conversion
- M82 case:

$$L_{kin} \sim \frac{v}{c} L_{UV} \sim 10^{-4} L_{UV}$$

$$L_X \simeq 10^{41} \text{ erg s}^{-1}$$

- $$L_{IR} \simeq 3 \times 10^{10} L_\odot$$

Speculations: Energy driven vs radiation driven: confront or complement

- Basically they are complementary
- Perhaps their relative contributions detemine diversity of the wind
- Magnetic field enhances troubles
- Observations & numerical simulations

Speculations: Energy driven vs radiation driven: confront or complement

- Basically they are complementary
- Perhaps their relative contributions detemine diversity of the wind
- Magnetic field enhances troubles
- Observations & numerical simulations
- Our future is bright, interesting and happy..