IGM@50

Is the Intergalactic Medium driving Star Formation?

Scientific Organizing Committee

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www.arcetri.astro.it/igm50

Summary talk
by Edvige Corbelli

92 Participants

Australia (3)
Austria (1)
Brazil (2)
Cech Rep. (1)
Denmark (1)
France (10)
Germany (12)
Israel (5)
Italy (14)
Spain (5)
South Africa (1)
Switzerland (4)
The Netherland (3)
United Kingdom (3)
USA (27)

72 talks – 20 posters – 3 discussions

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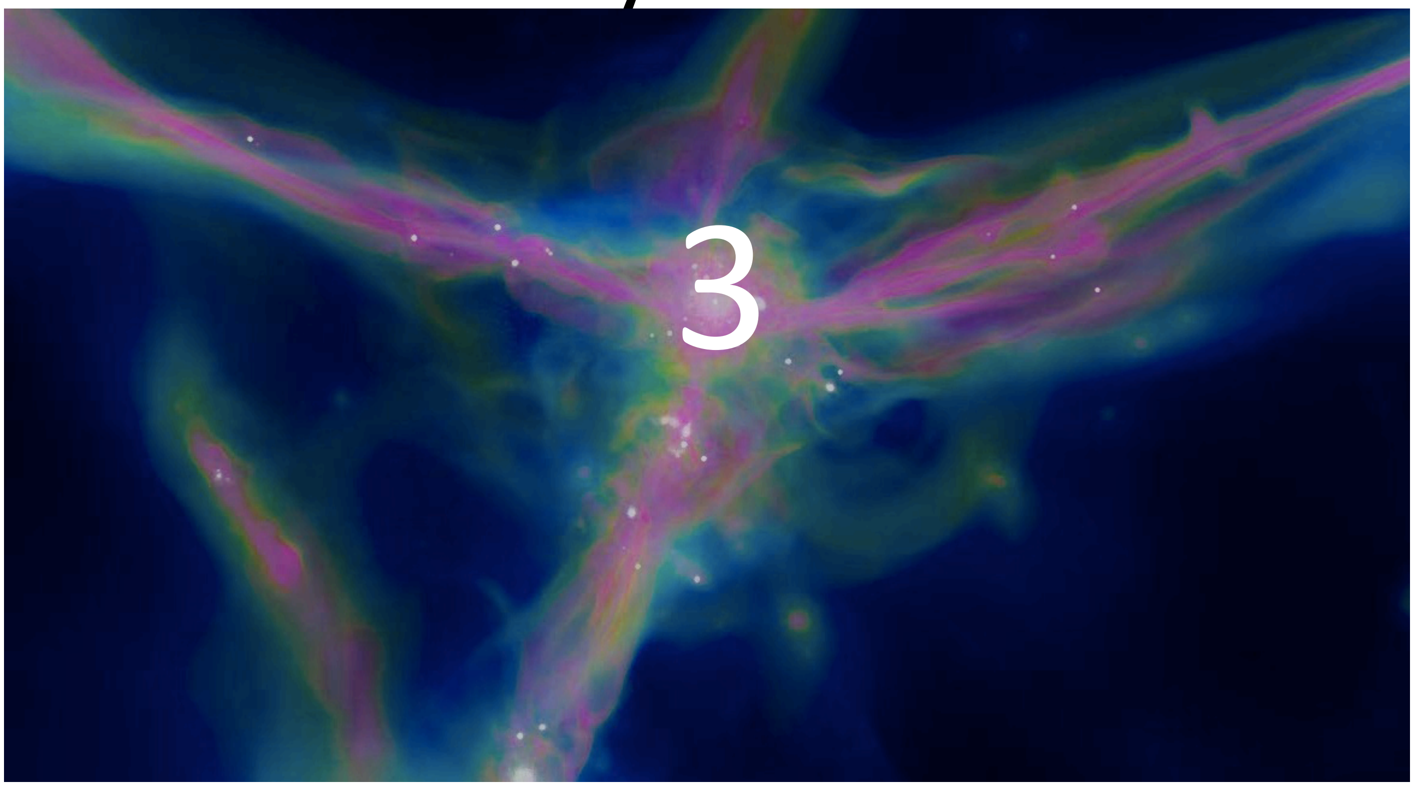
Key word 1 - **Streams**

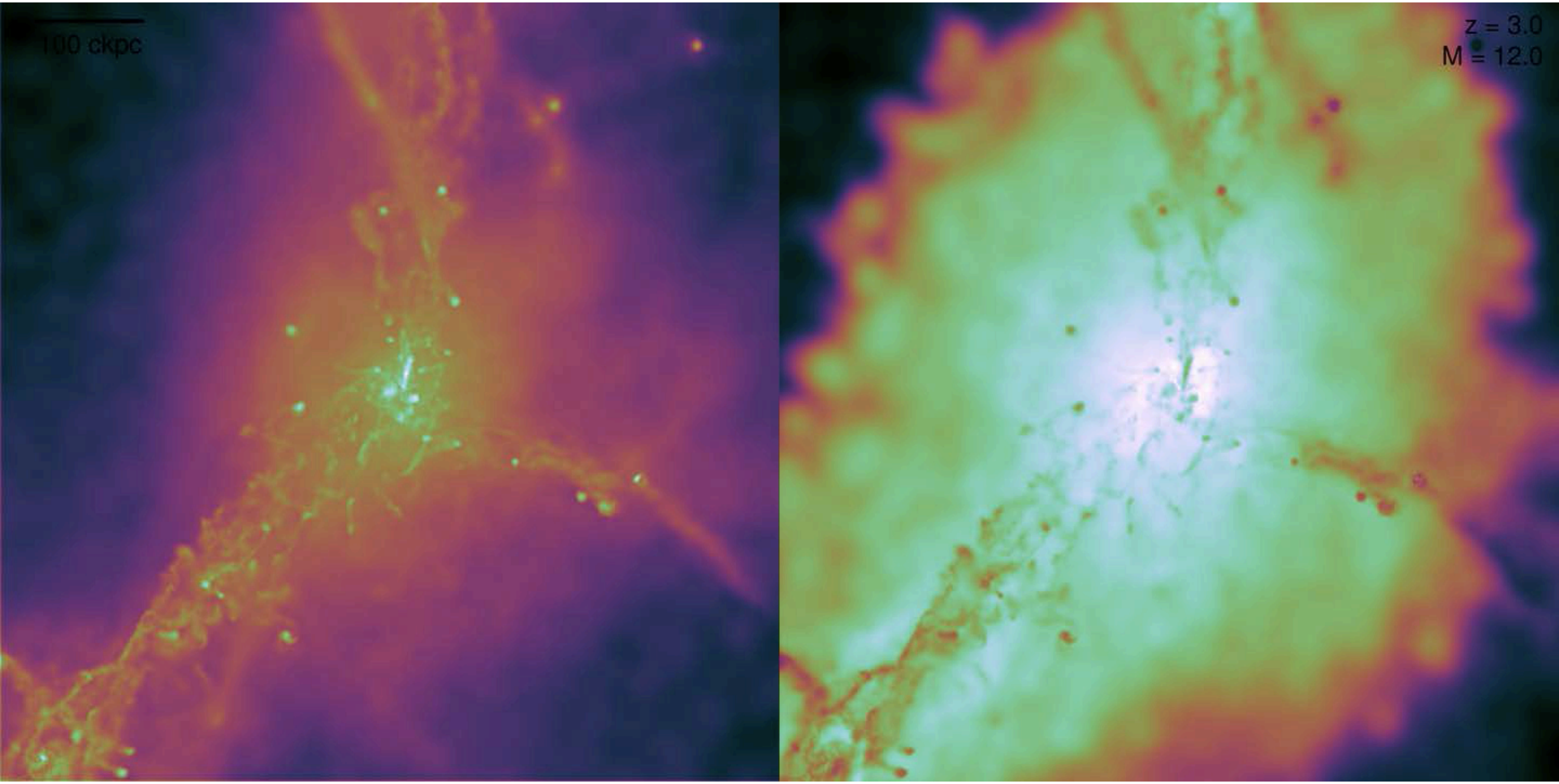
how many cold streams?



Influx in the streams: 55% in 1 stream, 90% in 3 streams

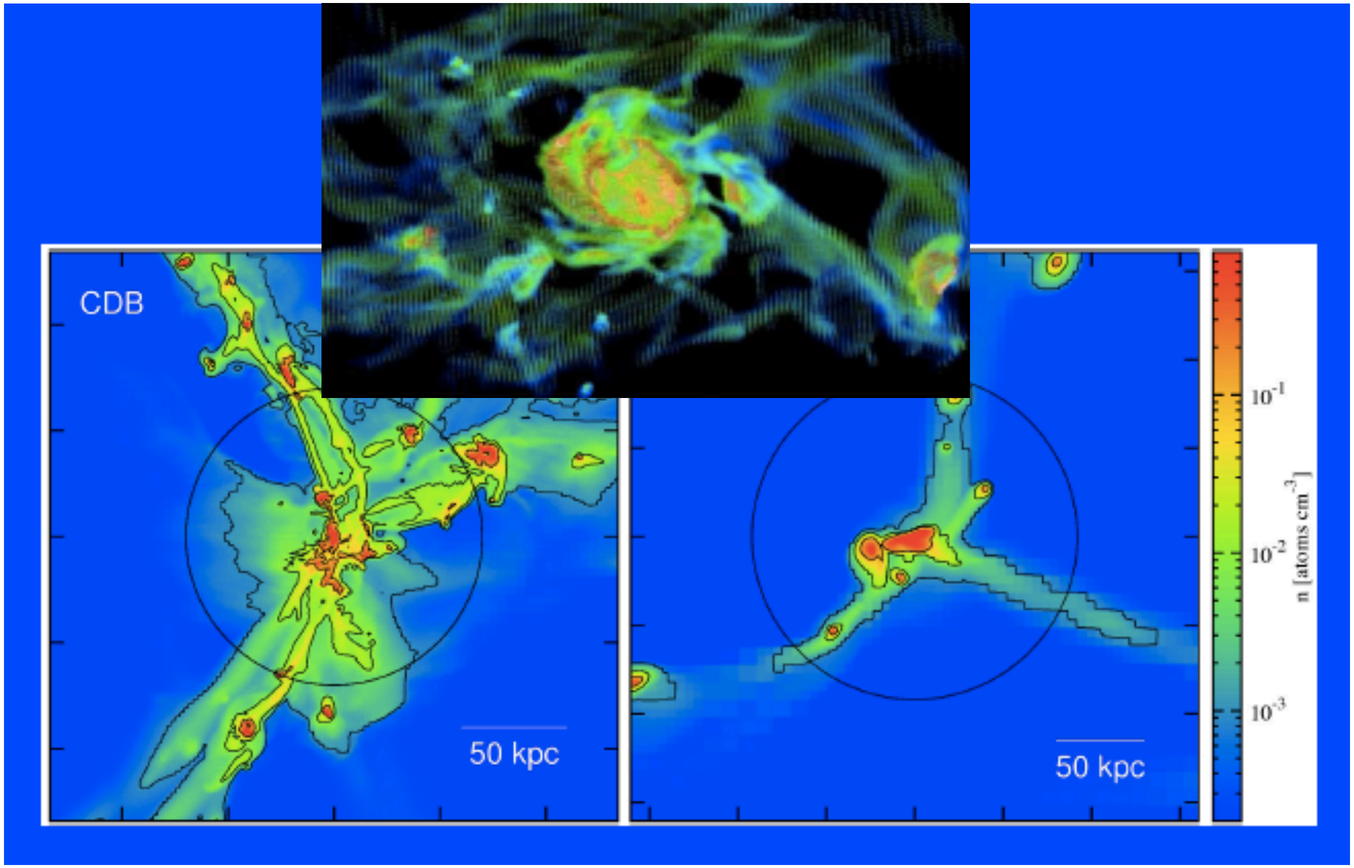
Influx at R_{vir}: 70% in streams, 20% in pancakes

They are narrow with clumps



..and break up in massive halos due to instabilities
Baryon and DM: in outer regions grow together,in inner don't, take into account pseudoevolution…

Streams join the disk via extended rings

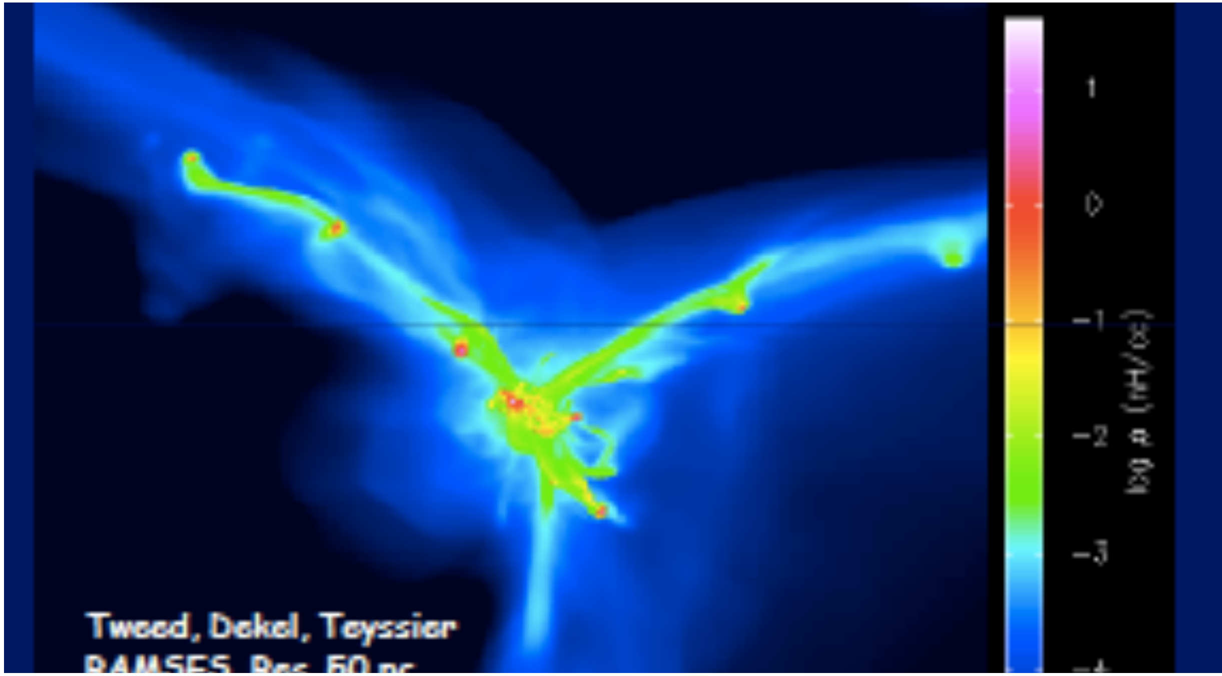


Inflow velocity is constant at all R, increases with z, it is not related to mass

High z: filaments are dominated by small scale structures
At z=0: small scale structures in filaments are mostly gone

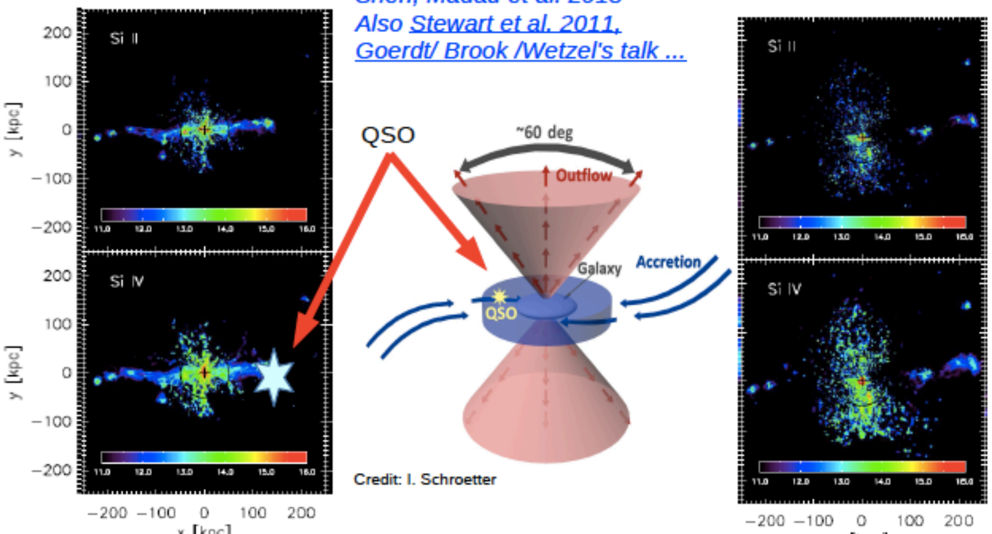
By the way.....Coma cluster has also 3 filaments... and we do have 3 meals per day!

-Gas Inflow penetrate efficiently to 0.2Rvi, recycling at smaller R
-Out of plane gas at high-z; low angular momentum material is accreted first
-radial direction later on
-In Dwarfs: not much difference inplane/outplane
-Outflows removes angular momentum, stronger in low mass galaxies but Recycling is more rapid in high mass galaxies



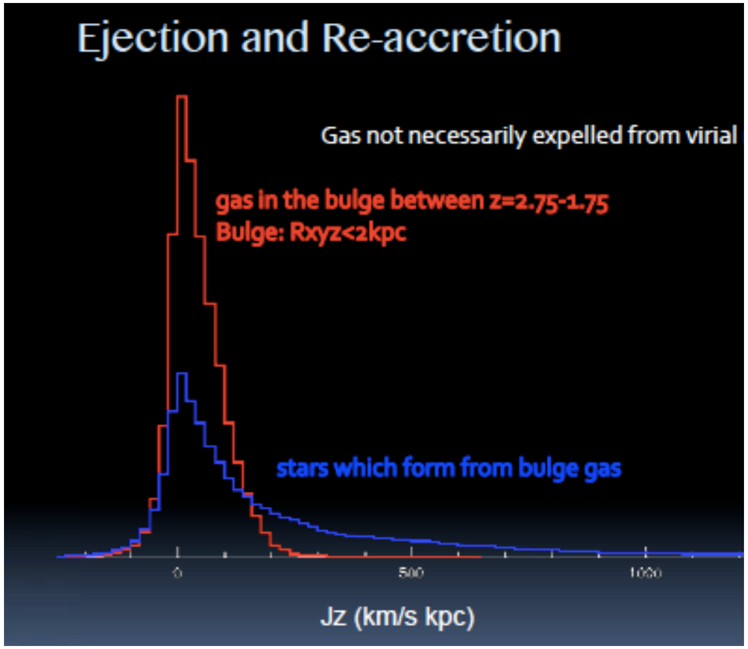
Inflows/Outflows are not co-spatial

Shen, Madau et al. 2013
Also Stewart et al. 2011,
Goerdt/ Brook /Wetzel's talk ...

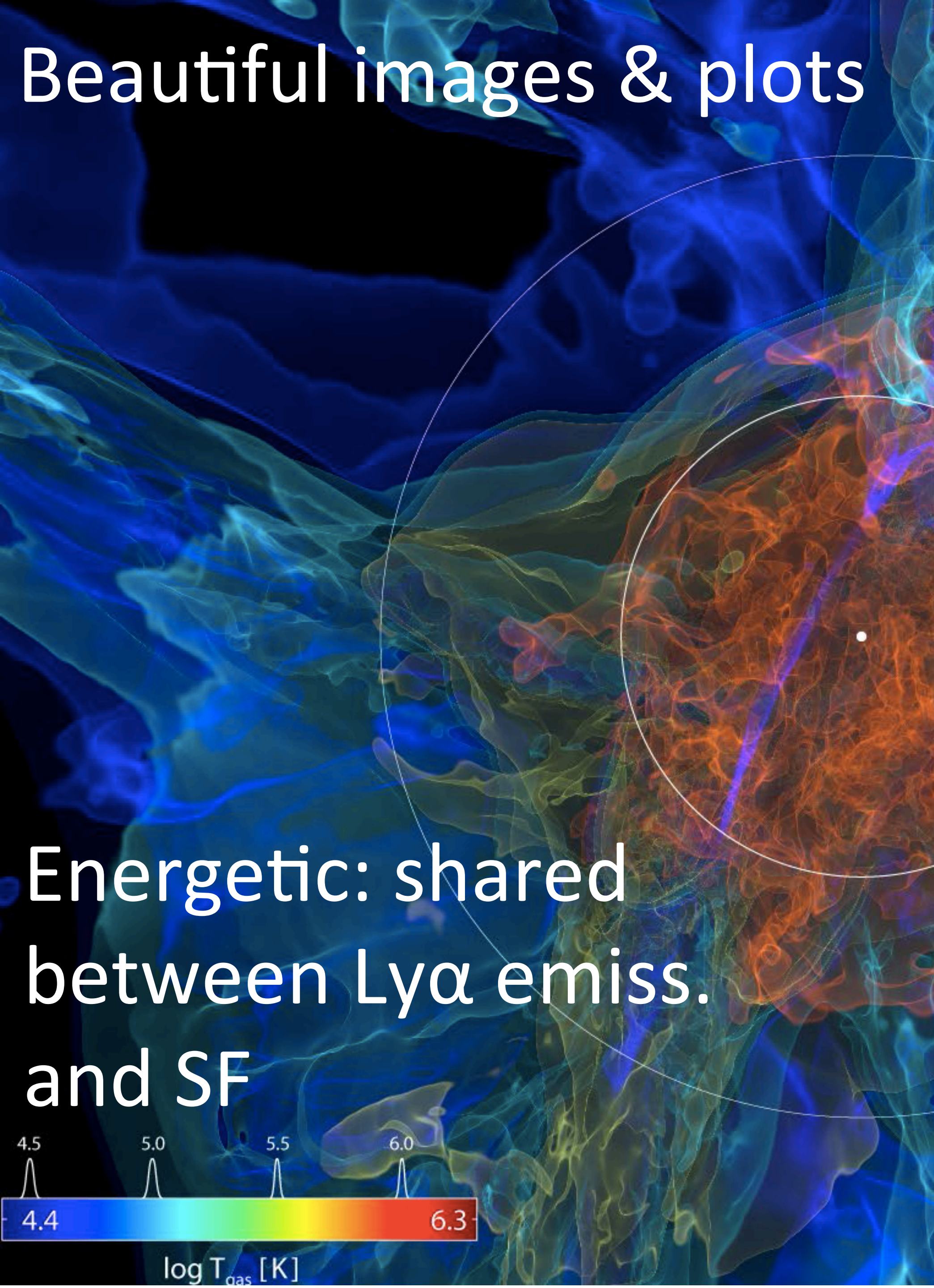


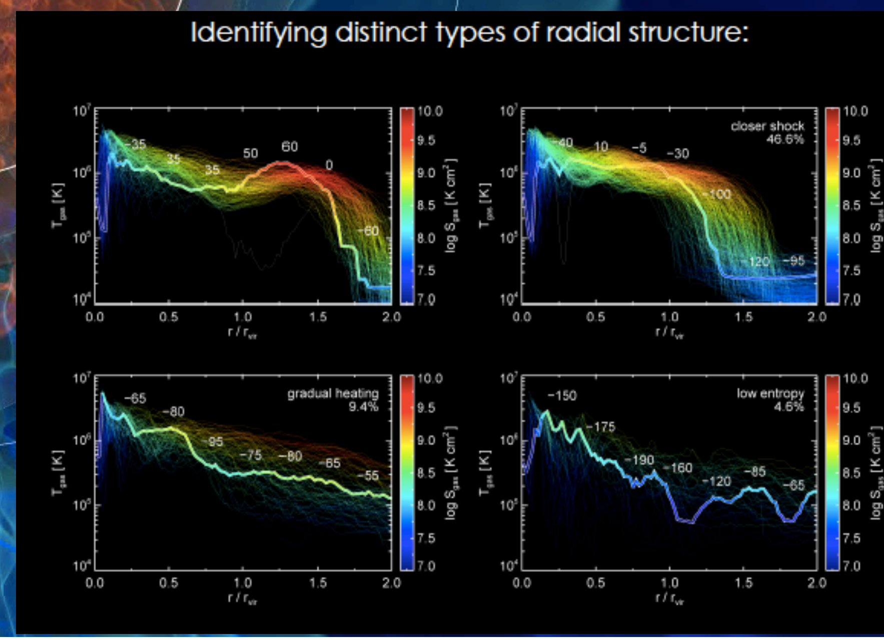
Inflowing particles

Outflowing particles



Beautiful images & plots

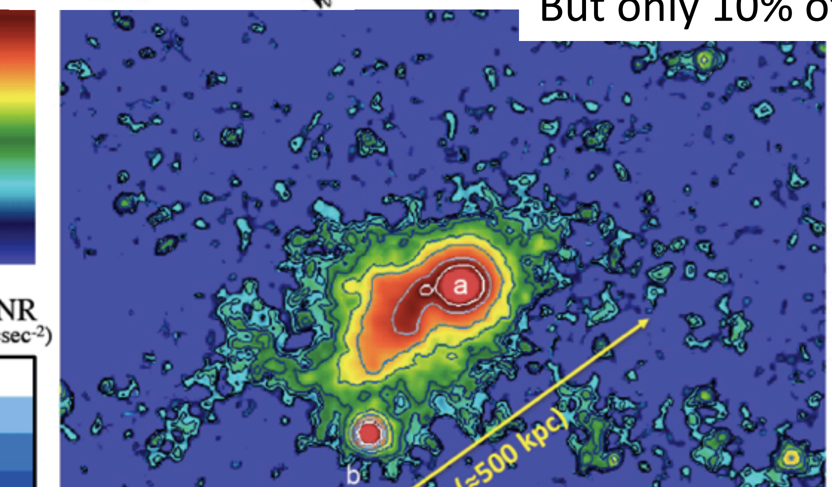


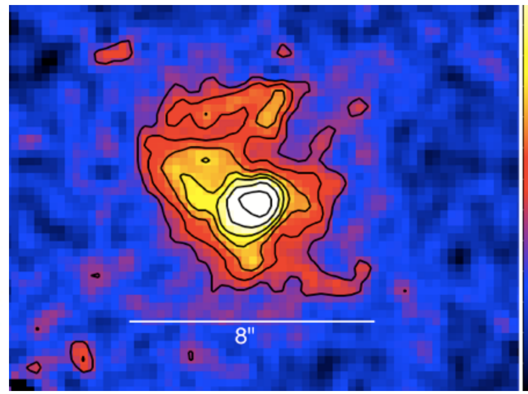


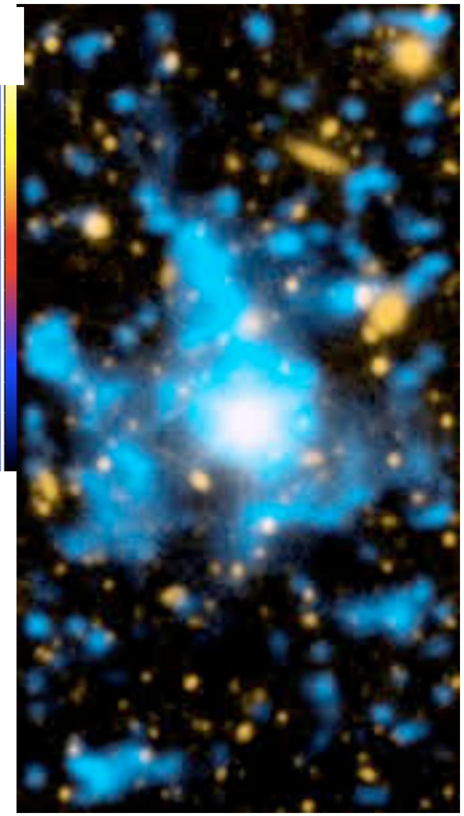
Energetic: shared between Lyα emiss. and SF

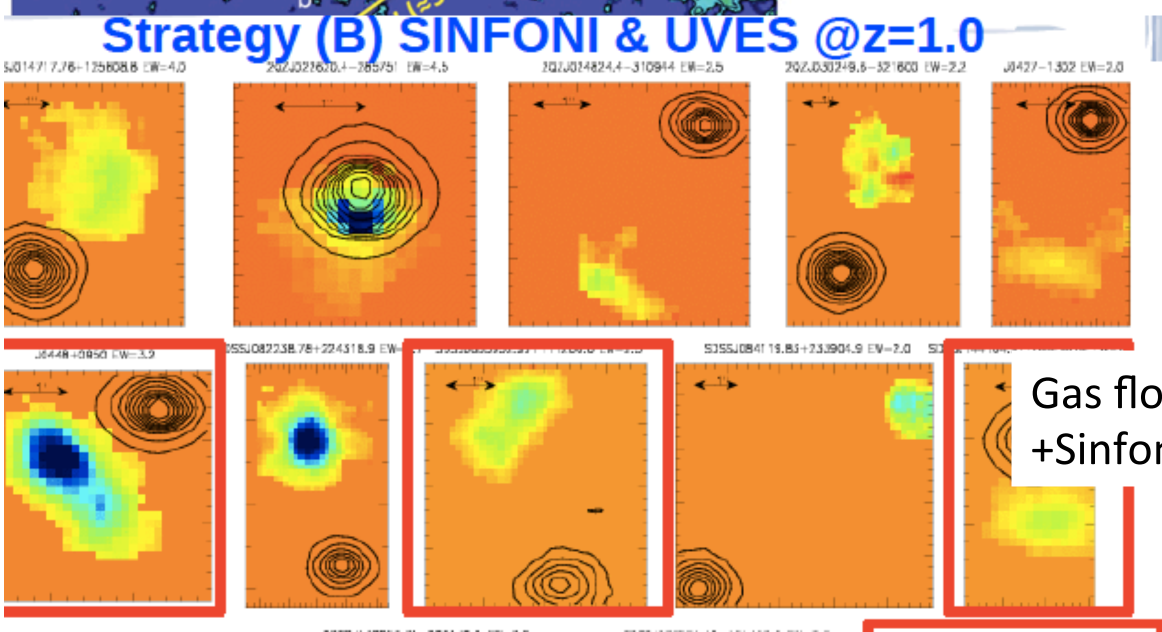
Flashlight: clumps&filaments in quasar induced Lyα, fluorescence

But only 10% of QSOs show giant nebulae



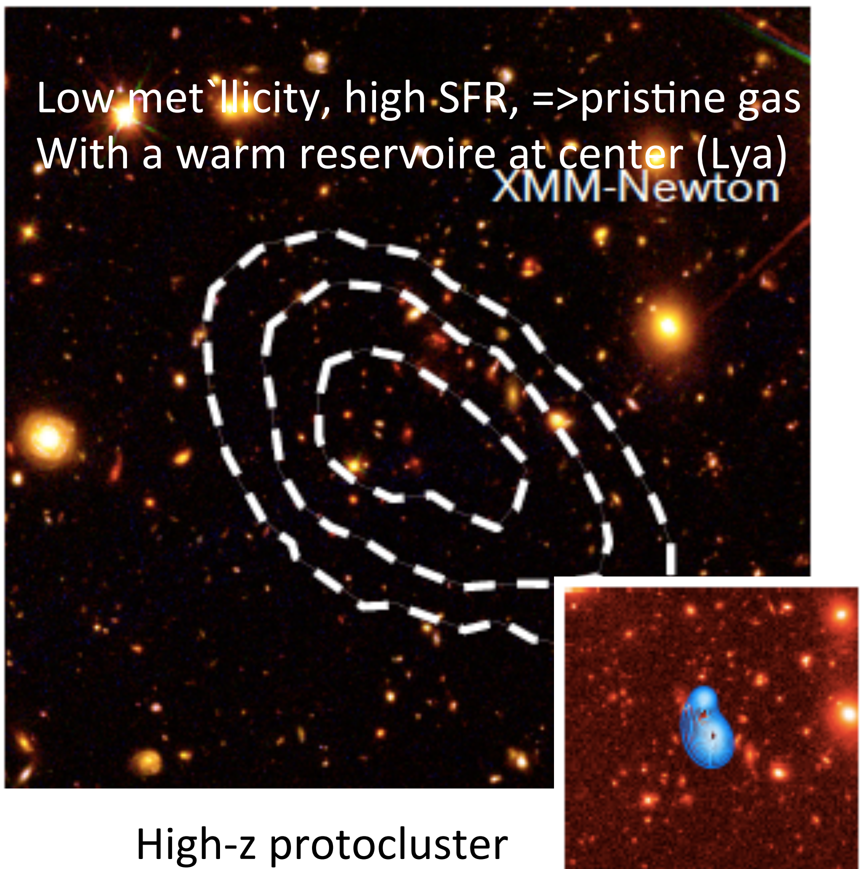




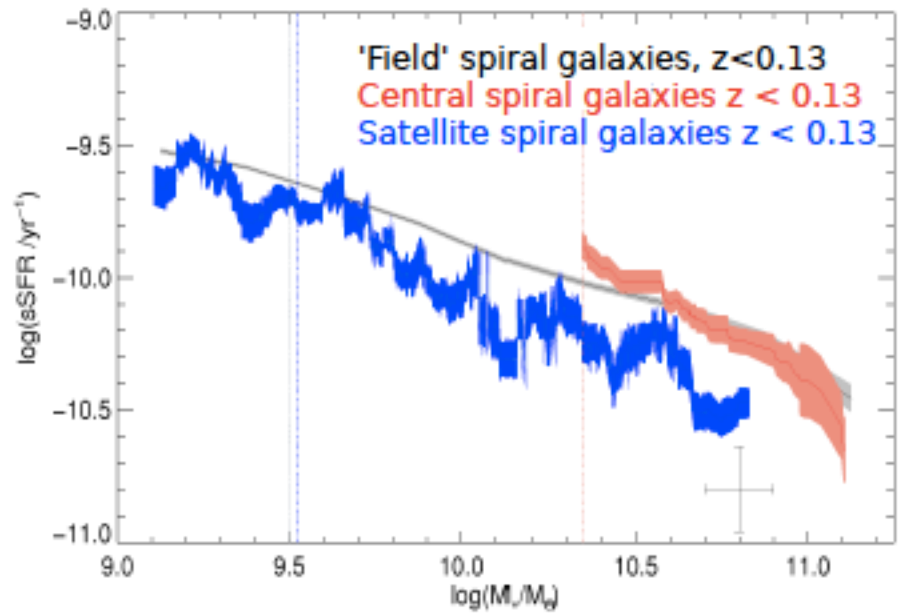


Gas flows from MgII absorber sel. Sample +Sinfoni maps

Density →

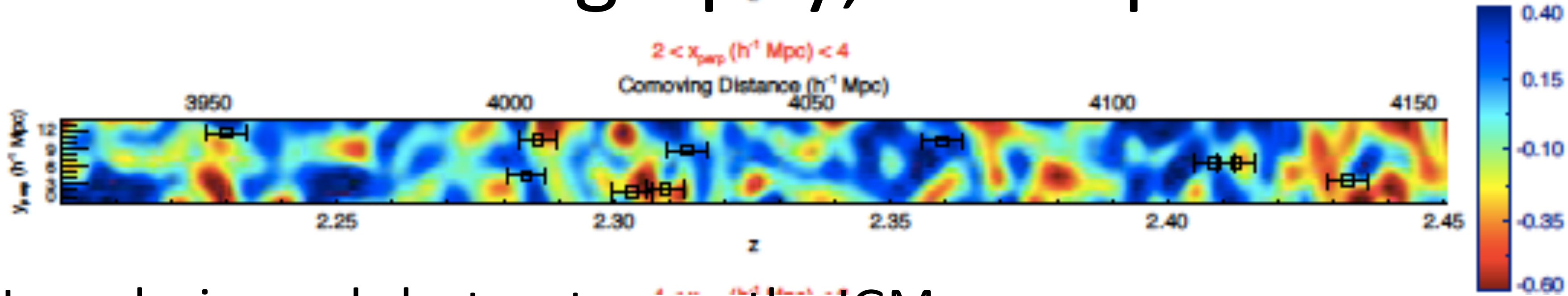


High-z protocluster

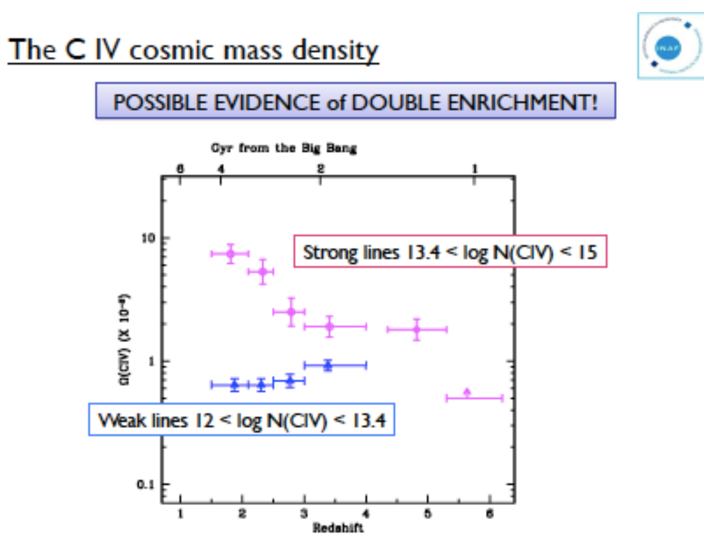


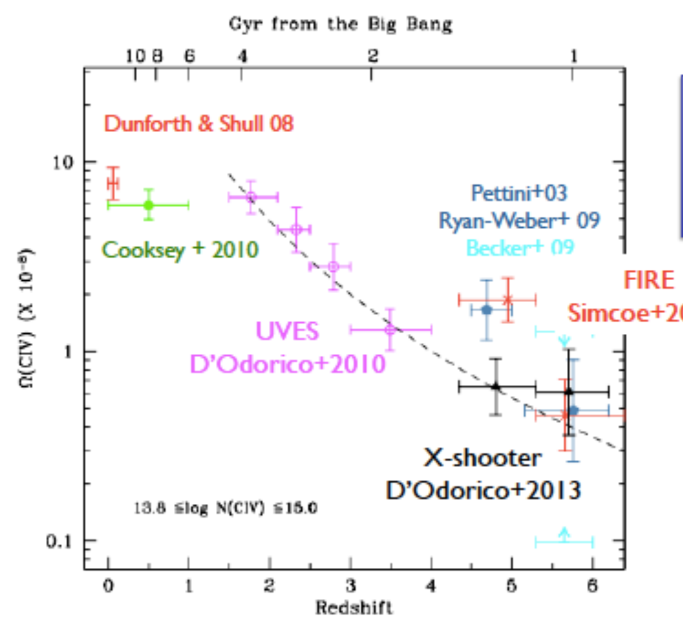
-Low-z group accretion
-Filaments accretion in group halo helps explaining on-going SF in satellites

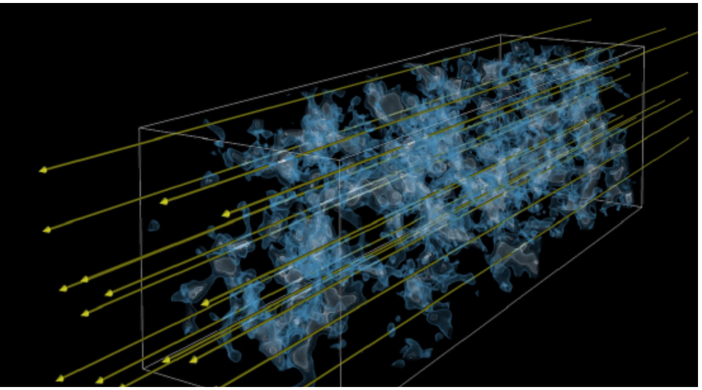
IGM:tomography,3D-maps



- -Use galaxies and clusters to map the IGM
- -Metal mixing, metal filling factor
- -Metal lines at low column densities
- -Origin of metallicity: popIII-popII ?
- -Pristine flow or recycling

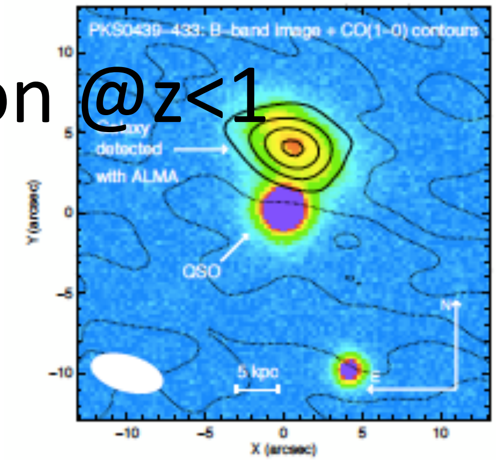






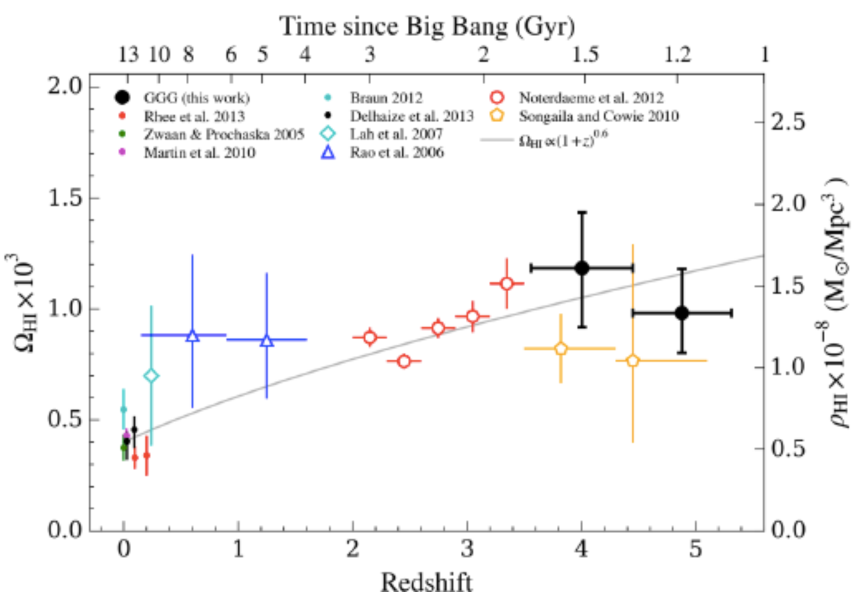
DLA: HI Tomography

CO emission @z<1



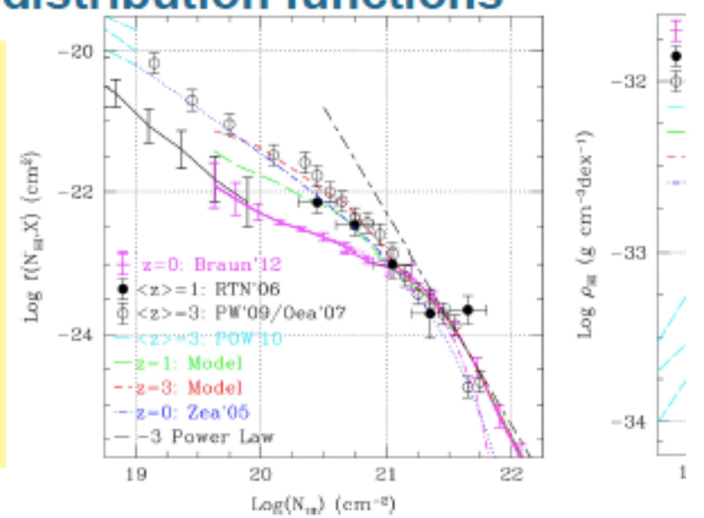
DLA: Very large sizes (10-50 kpc) , faint galaxies!

- SFR efficiency of HI gas is a factor of >10 lower at z~1-3 than in normal galaxies at low redshift
- Need to test the possibility of DLAs consisting of low-mass dwarf galaxies in more massive halos. HST + MUSE

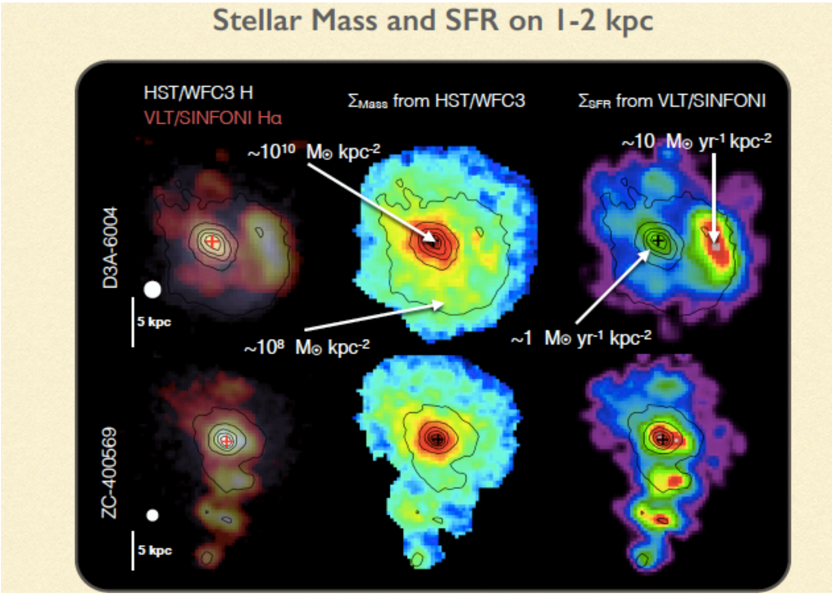


HI is a short-lived buffer, not a large reservoir! Dense HI phase is also Short lived

HI column density and mass distribution functions



Star formation and scaling relations

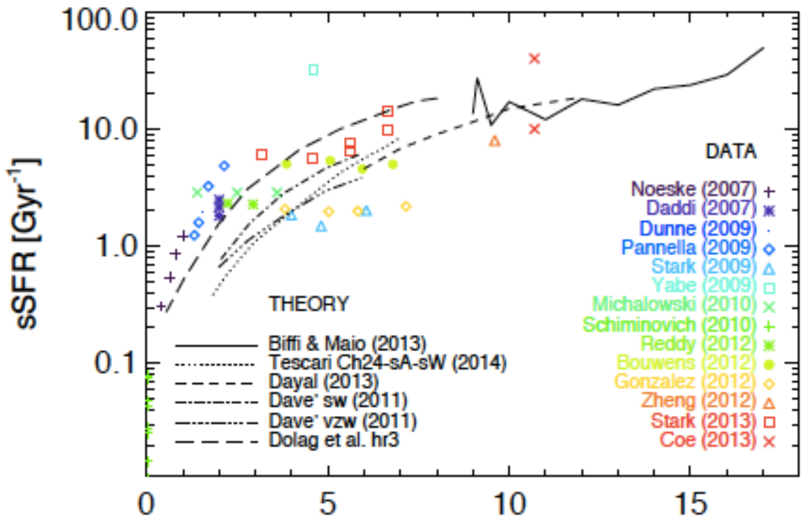


SFR-M* relation:
-steepening with z
-2 peak distribution due to starburst at z=2
-gas fractions from CO 3-2 & dust as function of z: steeper relation than HI in DLA
-depletion time decrease with z and sSFR
K-S relation is superlinear if a wide range of SFR is considered

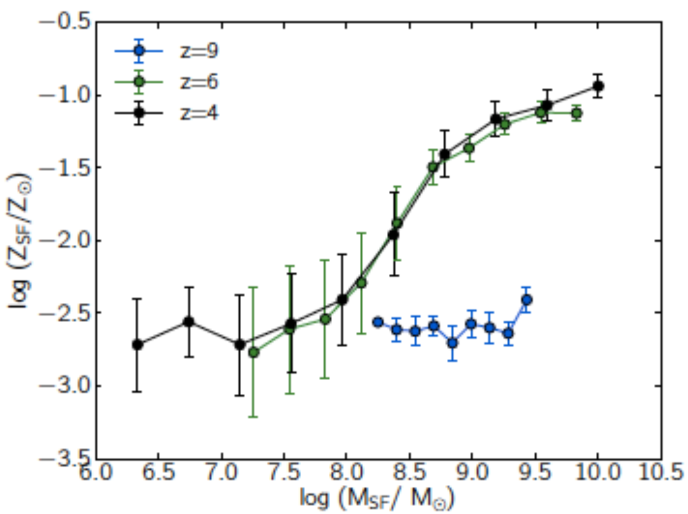
Beautiful images with Galaxy Morphologies z~1-3 SFG-
Bulge formation happens during SF phase as soon as log M*~11
Q>>1 in the center => morphological quencing
Halos at high-z are not so concentrated and too much baryonic matter in center because of dissipation => outflows which increase with mass

Depletion time might depend on the scale we sample
=>IGM is driving SF on galactic scale but not at parsec scale

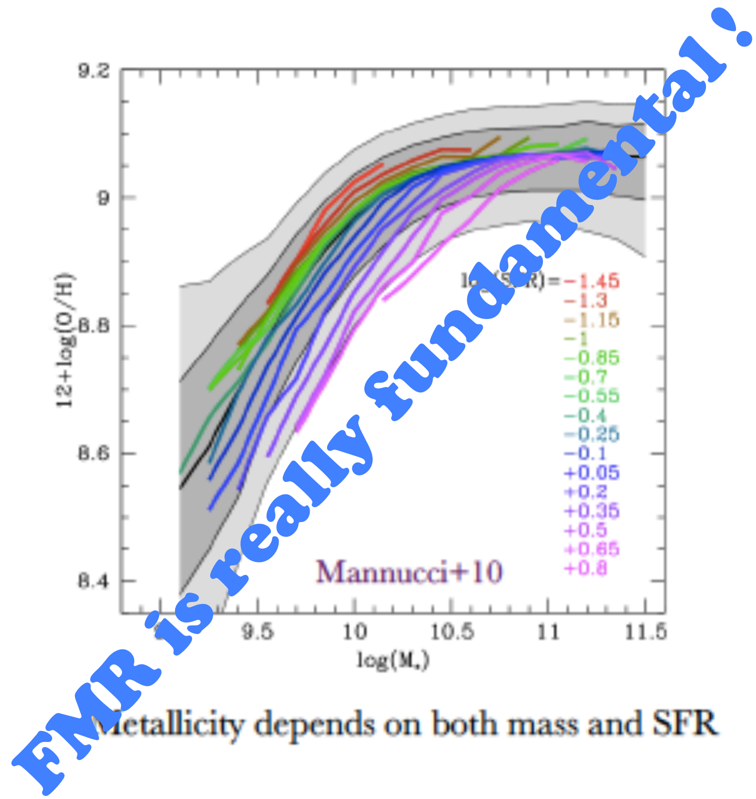
sSFR – early bursty Universe



ALMA observations can Detect important ISM signature at z>5 objects



Mass-metallicity relation established by z=6

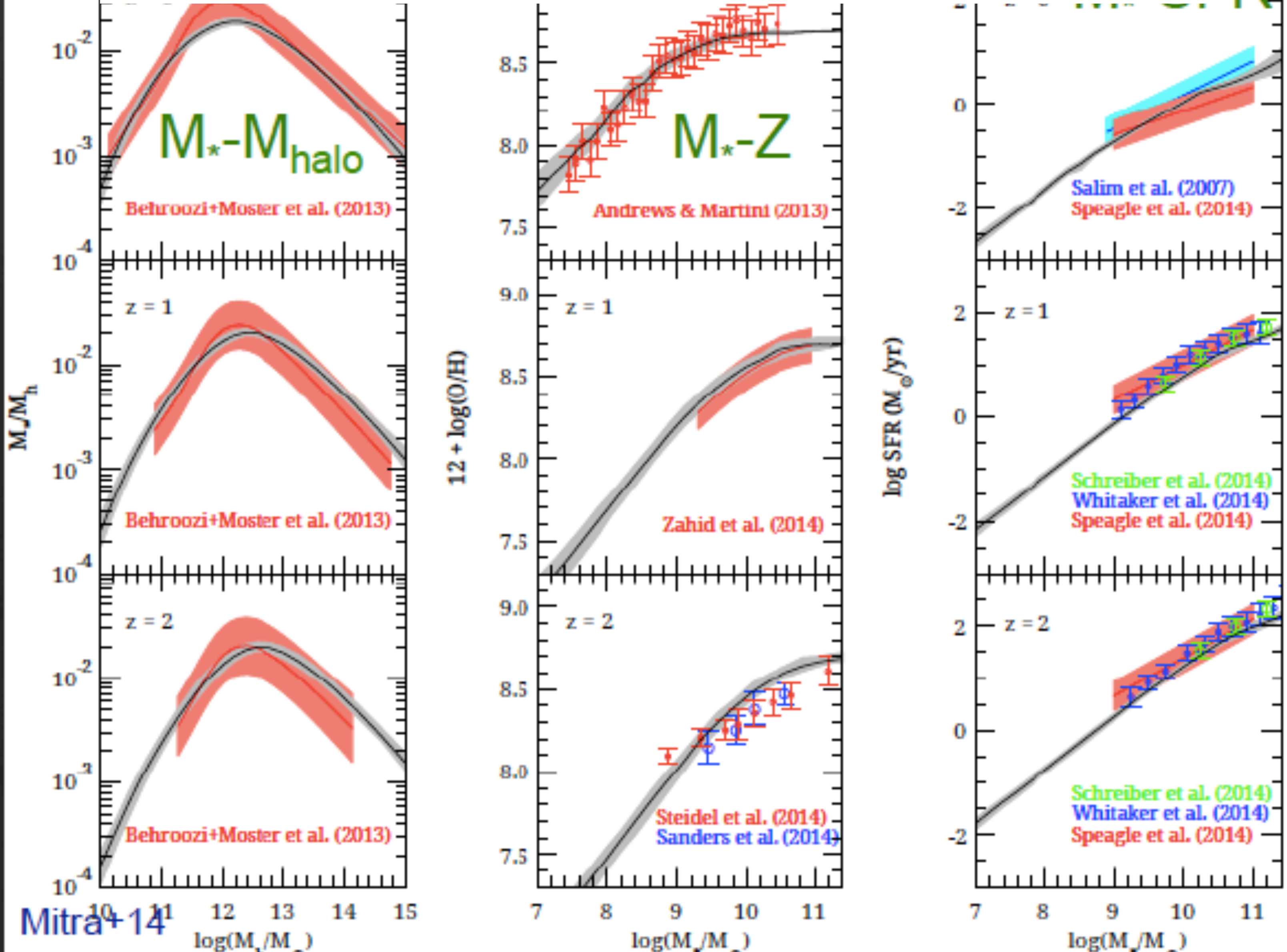


Metallicity depends on both mass and SFR

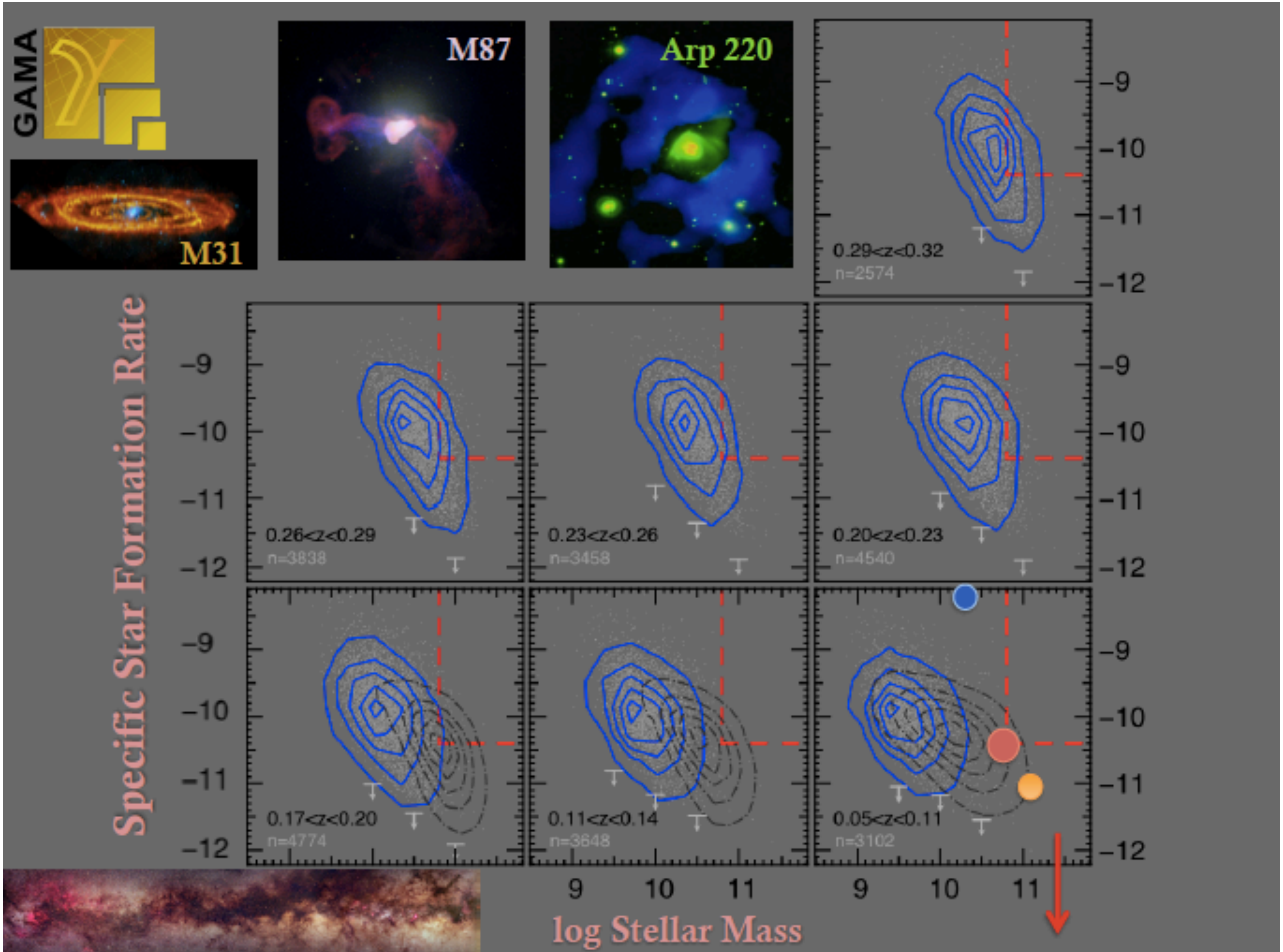
Equil… (z~1.6)

Observed sSFR at z>2 higher than in simulations???

Observed SFR (M*) lower than models?



Mitra+14



GAMA
M31
M87
Arp 220
Specific Star Formation Rate
log Stellar Mass
0.29<z<0.32
n=2574
0.26<z<0.29
n=3838
0.23<z<0.26
n=3458
0.20<z<0.23
n=4540
0.17<z<0.20
n=4774
0.11<z<0.14
n=3648
0.05<z<0.11
n=3102

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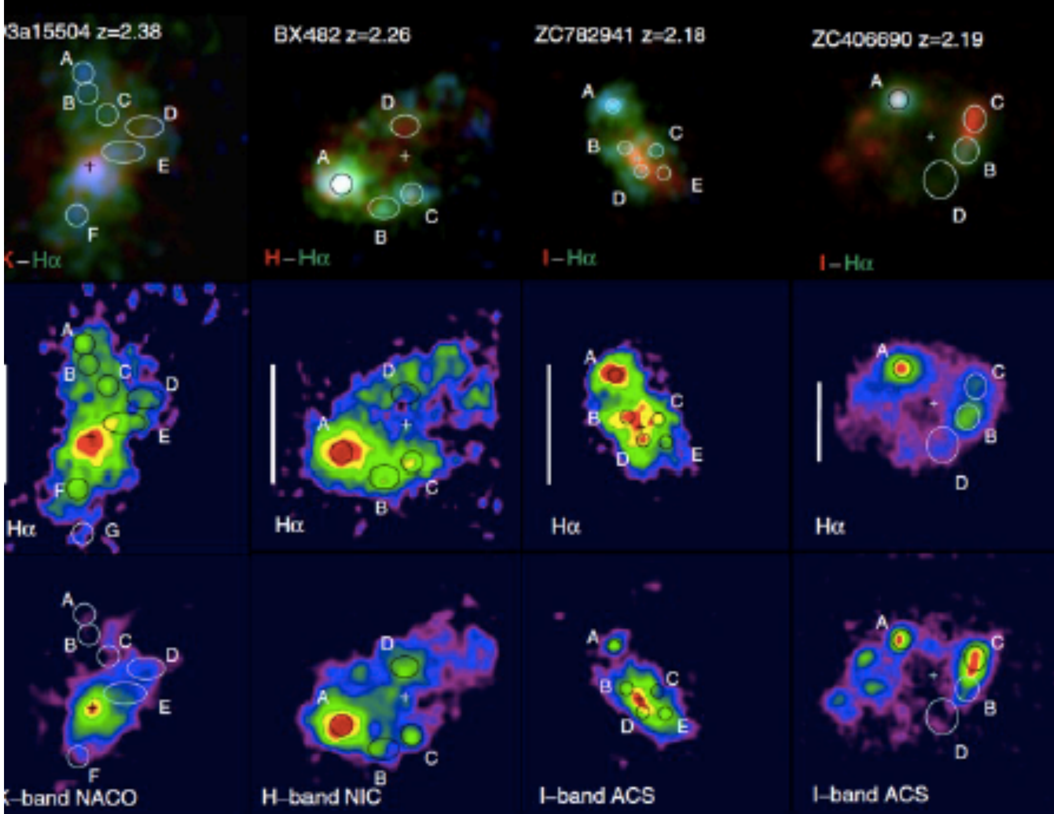
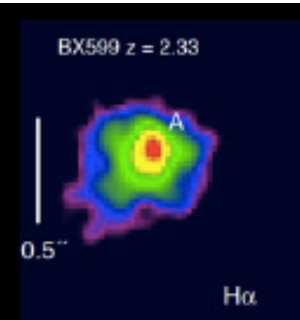
Key word 2 – **Clumps**

how big? @high/low-z   in spirals/dwarfs



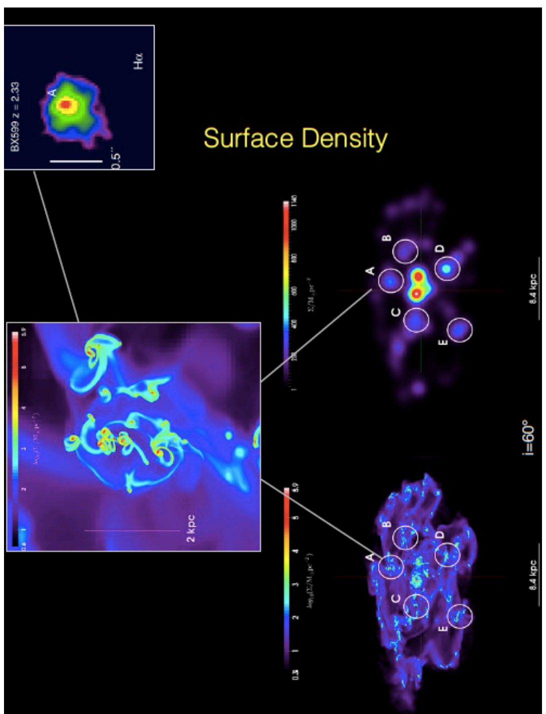


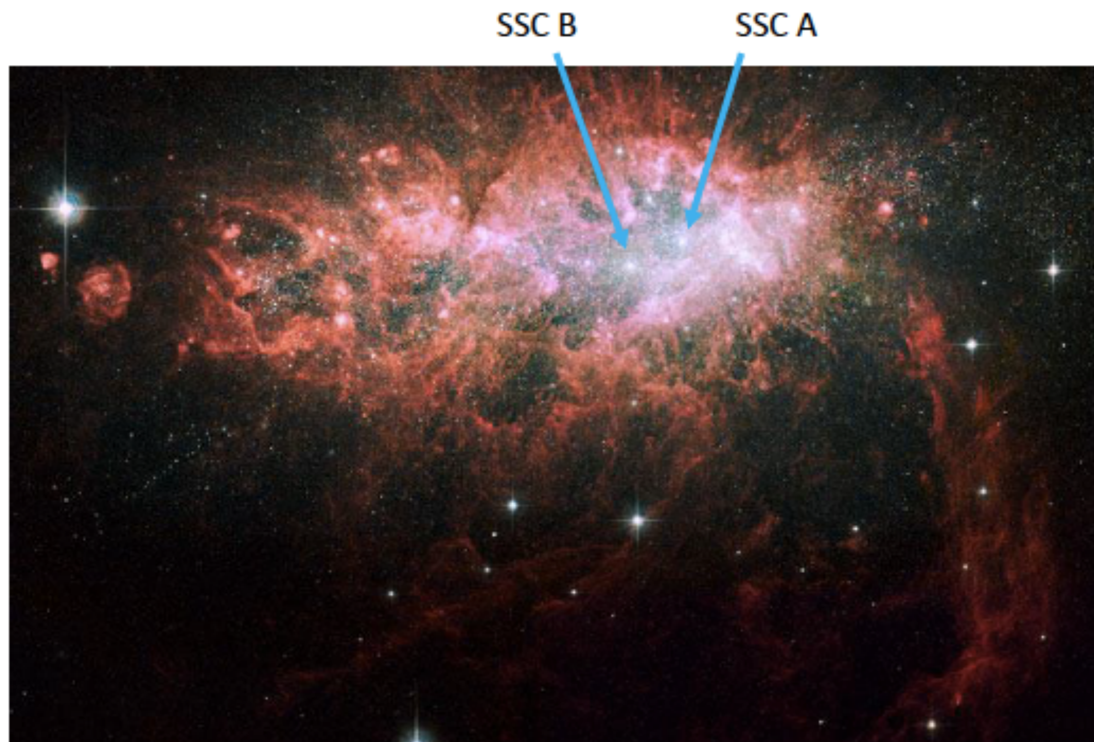
- structure + kinematics
- star formation + IMF
- outflow + mass loss
- nucleosynthesis

- globular clusters
- seed black holes
- bulge formation

Toomre Instability: yes in spirals, not in dwarfs 3D-but don't make it too thick

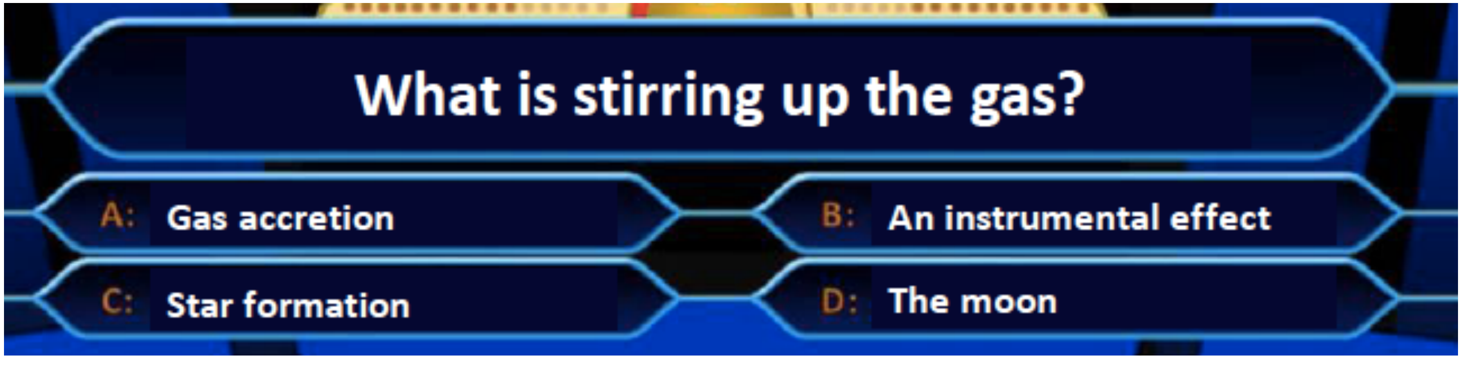
- Resolved scale height, ring formation to larger and larger radii, constant clump number, clump clusters. Merging? Resolution ?
- Turbulence, Two Fluid Instability, Stable Thick disks, No accretion needed in outer parts, flaring, slow SF



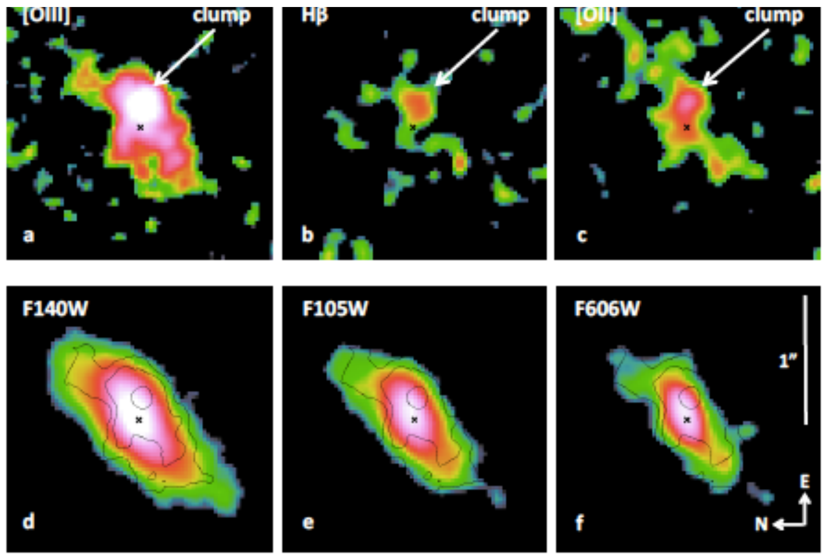


Simulation on pc scale for high-z disks Gravity+hydro drive clump formation

- Turbulent cascade => Clumps with 10^8-9 Msun
- Gas is 50% of baryonic reservoire
- Clump migration
- Slight or no α_{CO}(SFR) dependence
- Frangmentation drives the α_{CO} morph. dep. Which is higher for spirals
- SN+HII radiation pressure =>outflow rate close to SFR



Do massive clumps exist?

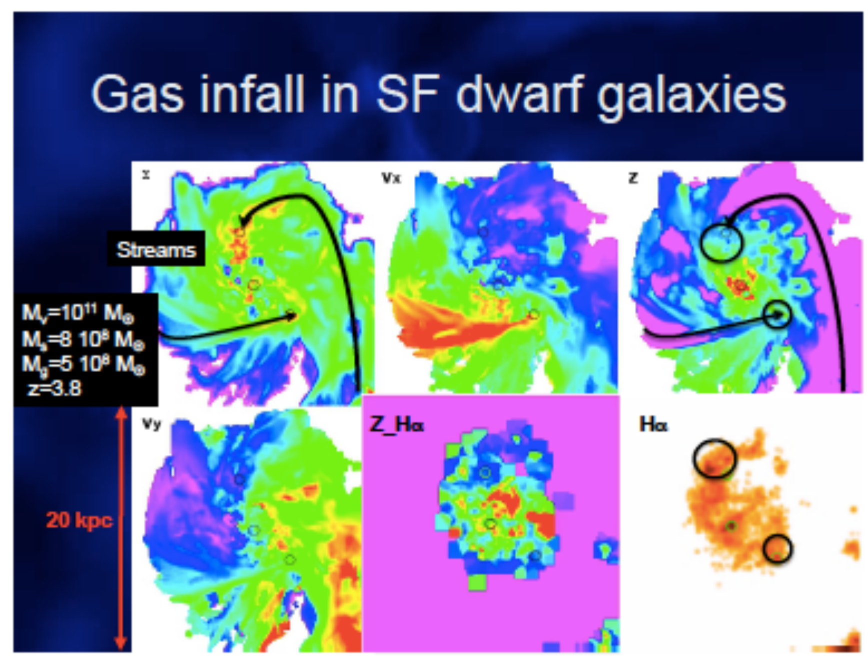


GALFIT decomposition: diffuse **disk** + off-nuclear **clump**

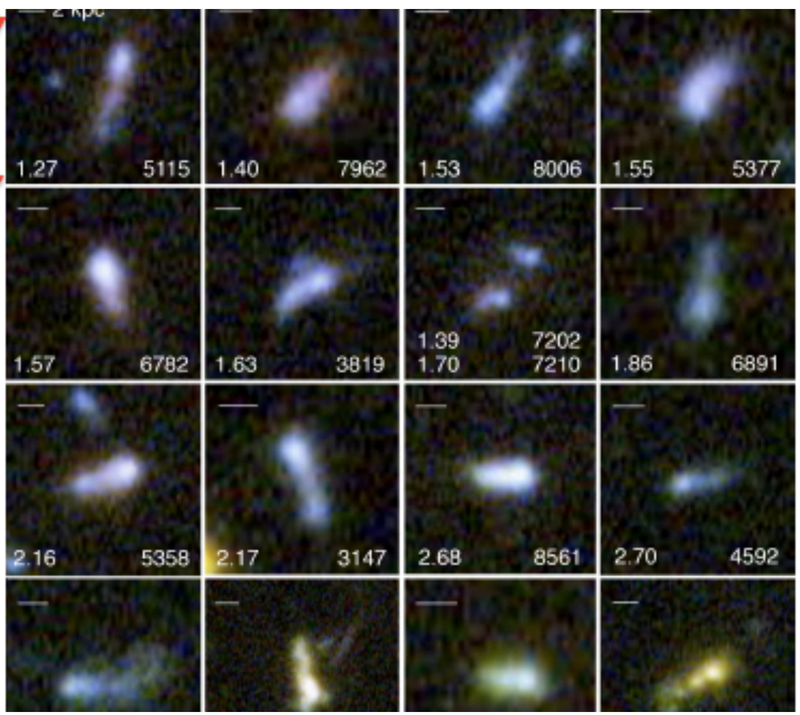
A young (<10 Myr) SF clump @ high-z lasting 500 Myr

How many? 2.5 clumps/ galaxy/Myrs

Dwarf galaxies are clumpy at any z
OFF-center/central clumps
More metallicity than kinematical signes,
No stellar signature => IGM accretion



Local and high(more common)-z tadpoles:
Rotating and with low metallicities =>cosmic accretion

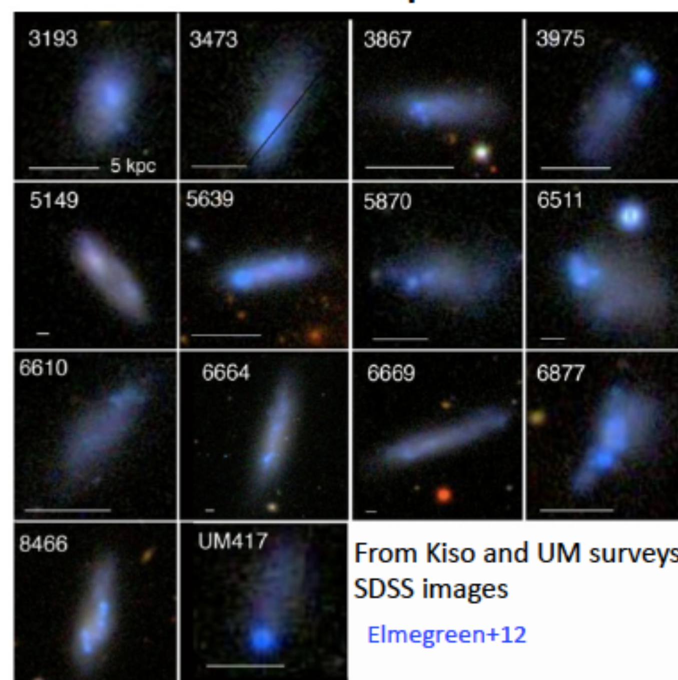


~10% of resolved UDF galaxies are tadpoles;

30% of clumpy galaxies are tadpoles

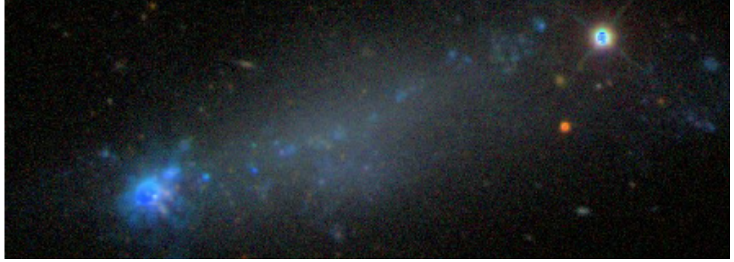
Elmegreen +07 10

Local tadpoles



From Kiso and UM surveys; SDSS images

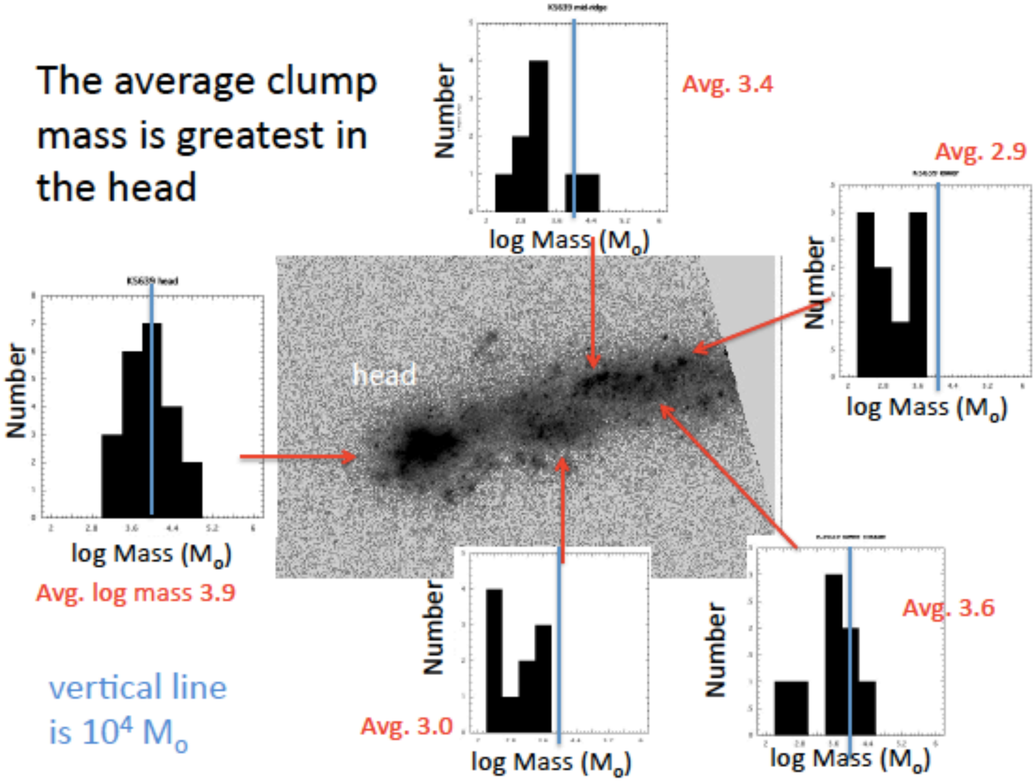
Elmegreen+12

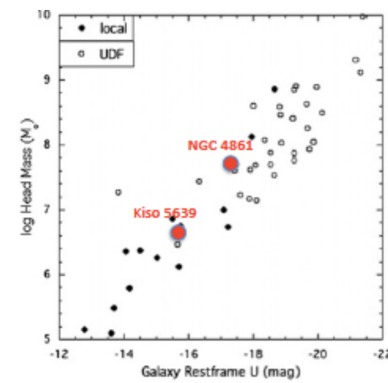


The average clump SFR is highest in the head

Comparison of clump masses in head, tail

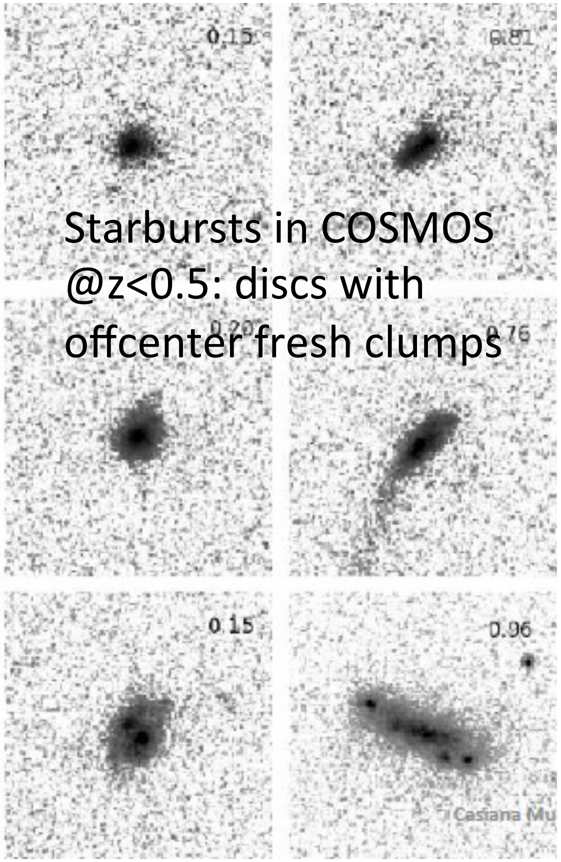
The average clump mass is greatest in the head





The clump mass distributions are consistent with the head masses scaling with galaxy brightness

Local tadpoles have lower SFR and SFR/area than high z tadpoles, consistent with less accretion



Starbursts in COSMOS @z<0.5: discs with offcenter fresh clumps

Local Analogs to High-z SFGs

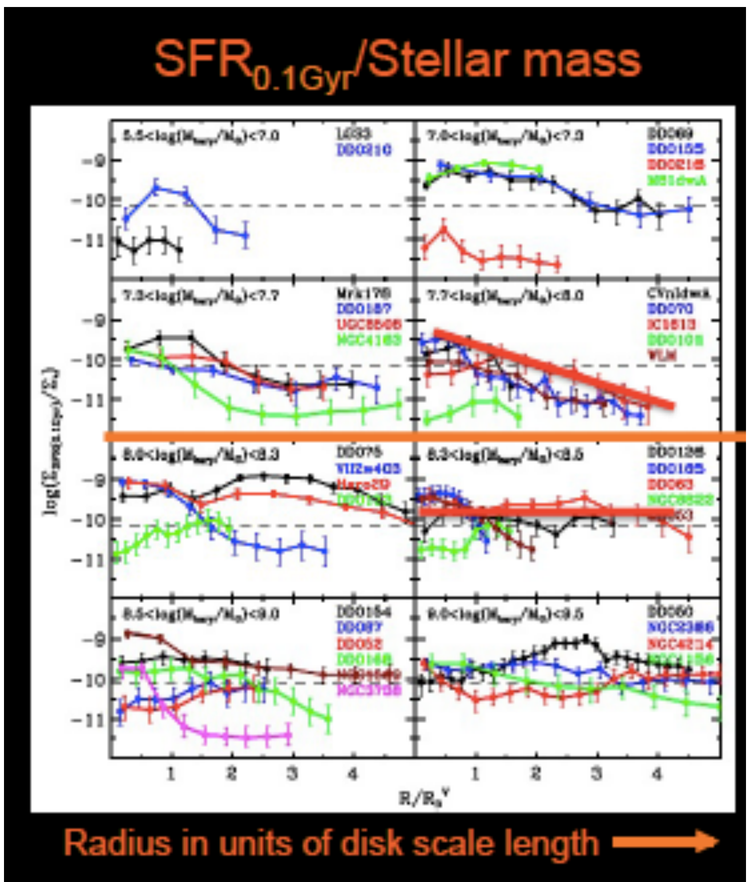
EXtremely Metal Poor galaxies (XMPs)

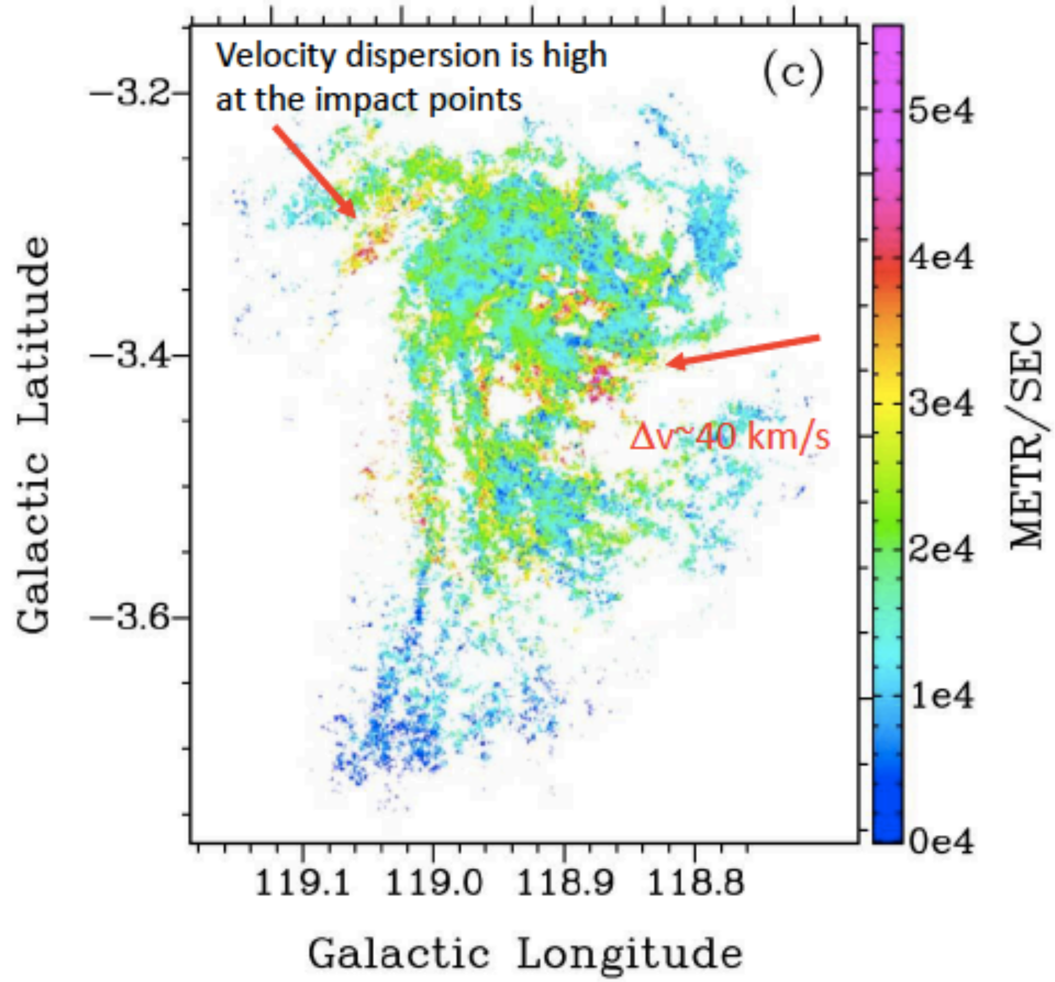
The time-scale for gas mixing in a turbulent disk is very short; of the order of the rotational period or shorter (say 200 Myr; Yang&Krumholz 12).

So, XMPs seem to be faint solar-metallicity turbulent disks with one (or more) off-centered starburst of low metallicity

Clumps+turbulence: sign of gas accretion

- Feed starburst
- Trigger SF sites
- Dwarfs seem to follow an Outsite-in growth



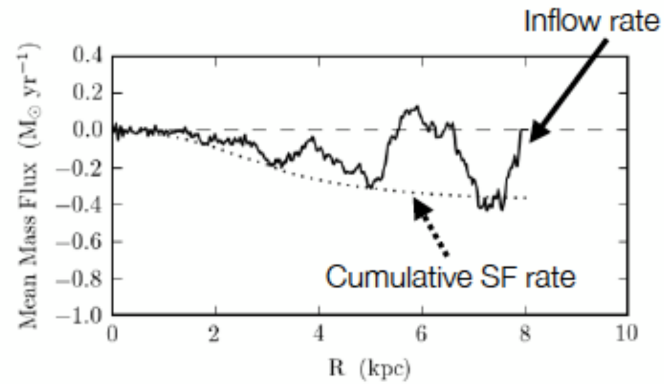


GALAXIES are NOT points!

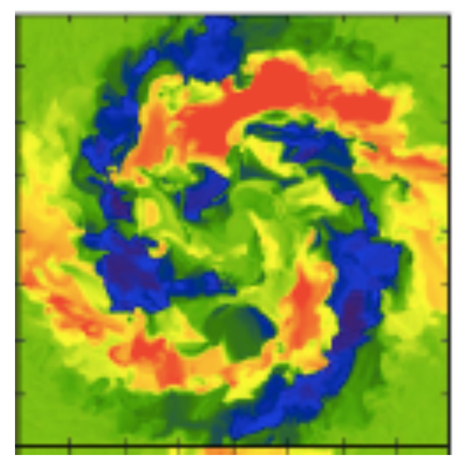
Solution: Transport in Galactic Disks

- Galactic disks are accretion disks: turbulence transports angular momentum outward, mass inward
- Dominant driver of turbulence: gravity!

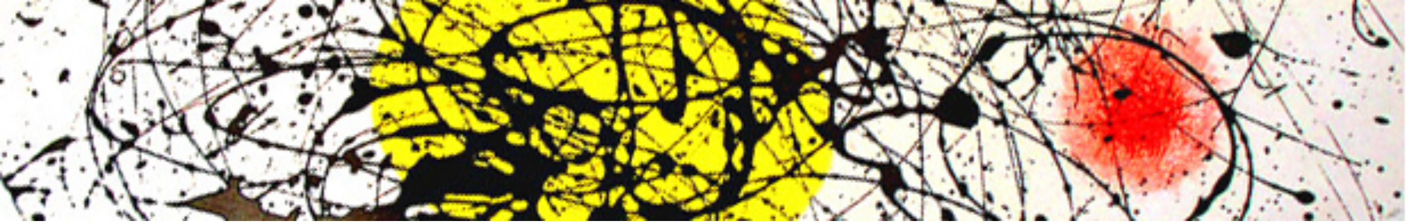
- Energy balance: decay of turbulence lowers σ and Q, transport of mass inward raises them
- SNe can also raise Q, but are unimportant at large radii, where σ and Q are also high — too little SF to matter



Metals Are Transported Too



Disk Stabilizes at Q ~ 1



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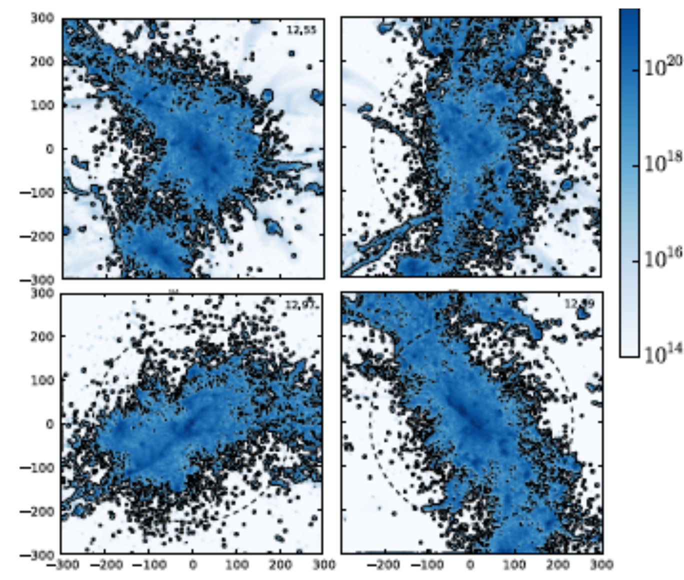
Key word 3 - The CGM

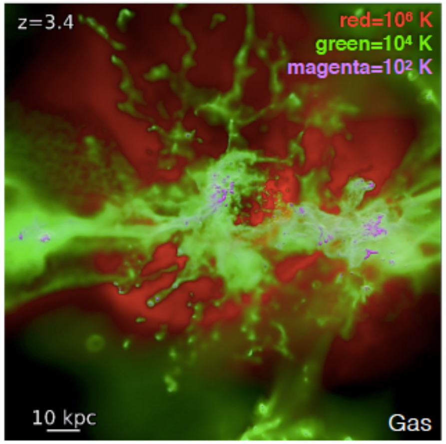
- CGM is associated to LLS, then to massive galaxies, correlation length has been measured
- Clustering of LLS, low metallicity clouds
- It is possible to associate LLS to cold accretion
- Stellar feedback puffing up inflowing filaments, helps explain large LLS coverings in QSO halos

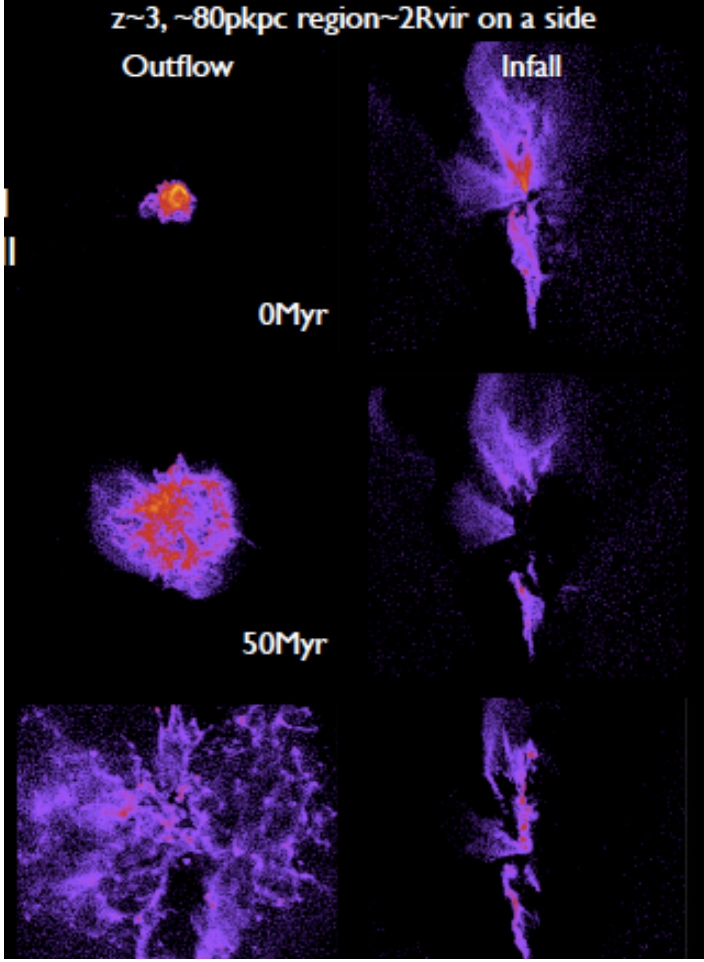
IX

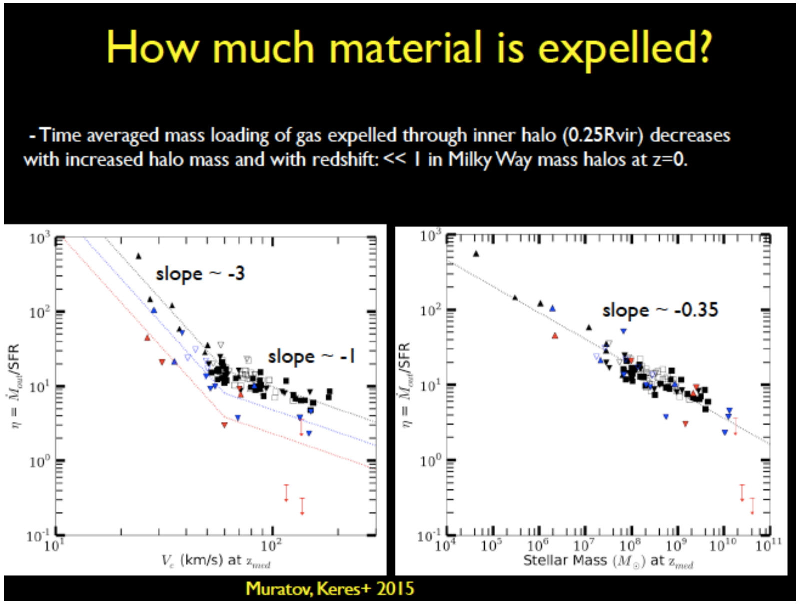


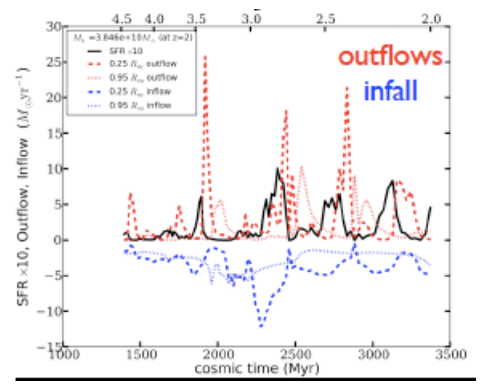
INFLOW-OUTFLOWs

Outflows are intermittent,fast,absent at low-z, may stop inner halo infall,large fraction in halo

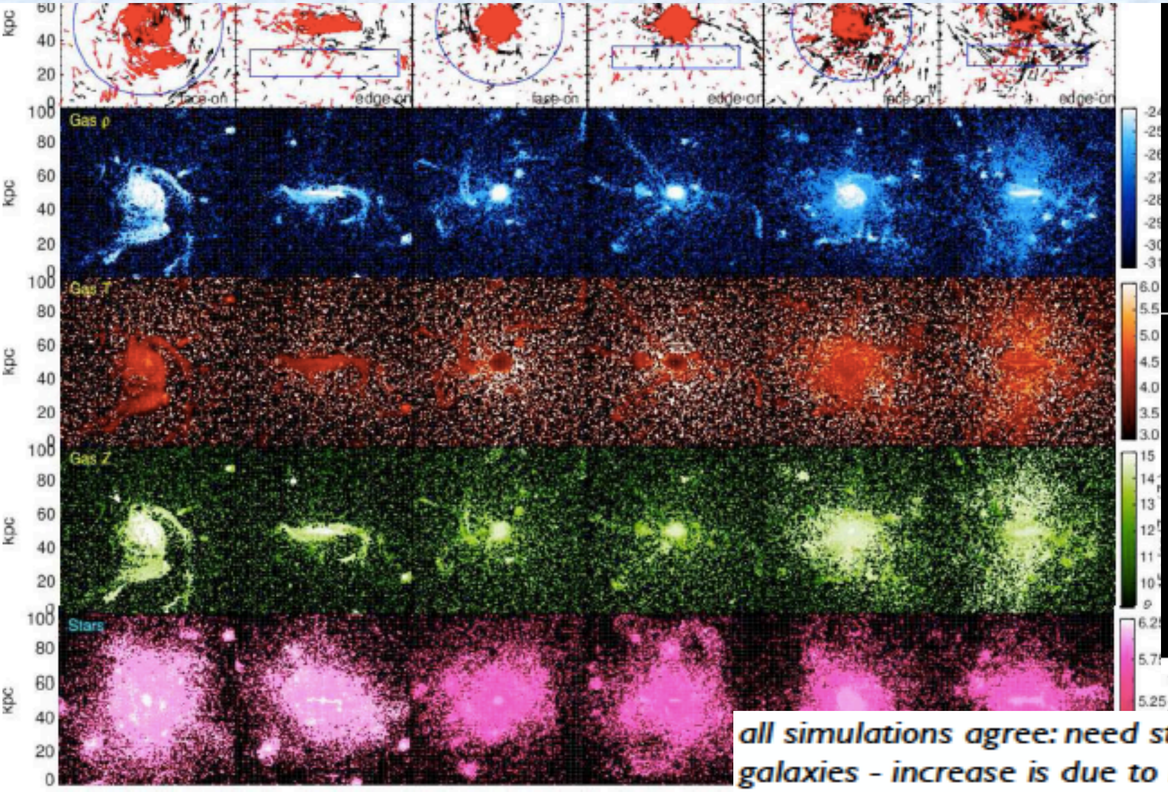


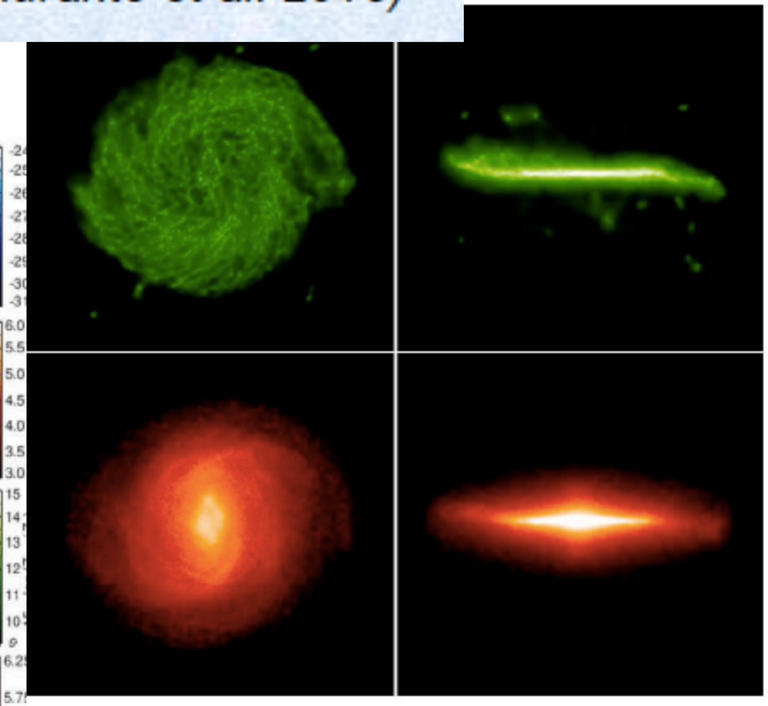






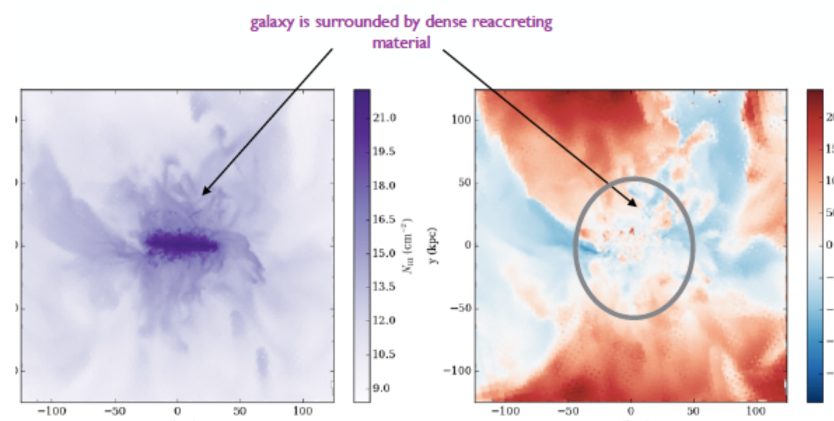
SN Energy Feedback in MUPPI *(Murante et al. 2015)*

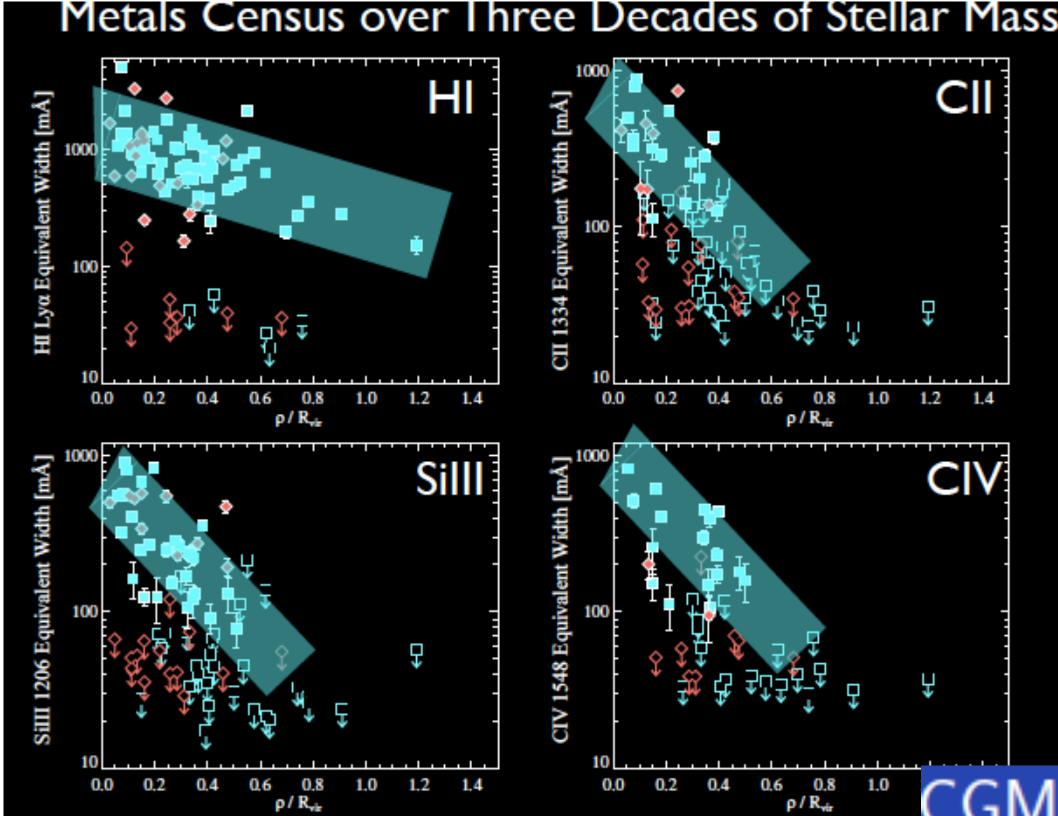




all simulations agree: need strong FB to account for HI abundance around galaxies - increase is due to reaccretion of old outflows

- **Dwarf galaxies are inefficient at forming stars**
- The most popular way to explain this is with strong feedback from SNe.
- We are running simulations with well-resolved SNe feedback to verify or reject this scenario.
- So far we find that grain photoelectric heating has a stronger effect.

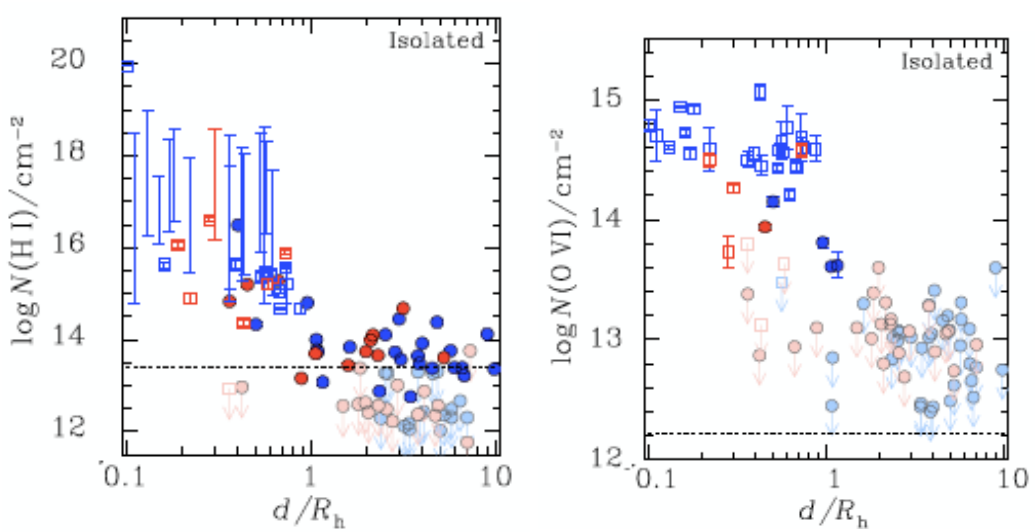




Feedback affect SF in dwarf galaxies

The CGM around dwarf galaxies: tight relation between eq.width and M*

CGM dependence on environment



Feedback: energetic,structure

- SN
- Photoionization +CIE: not right line ratio?

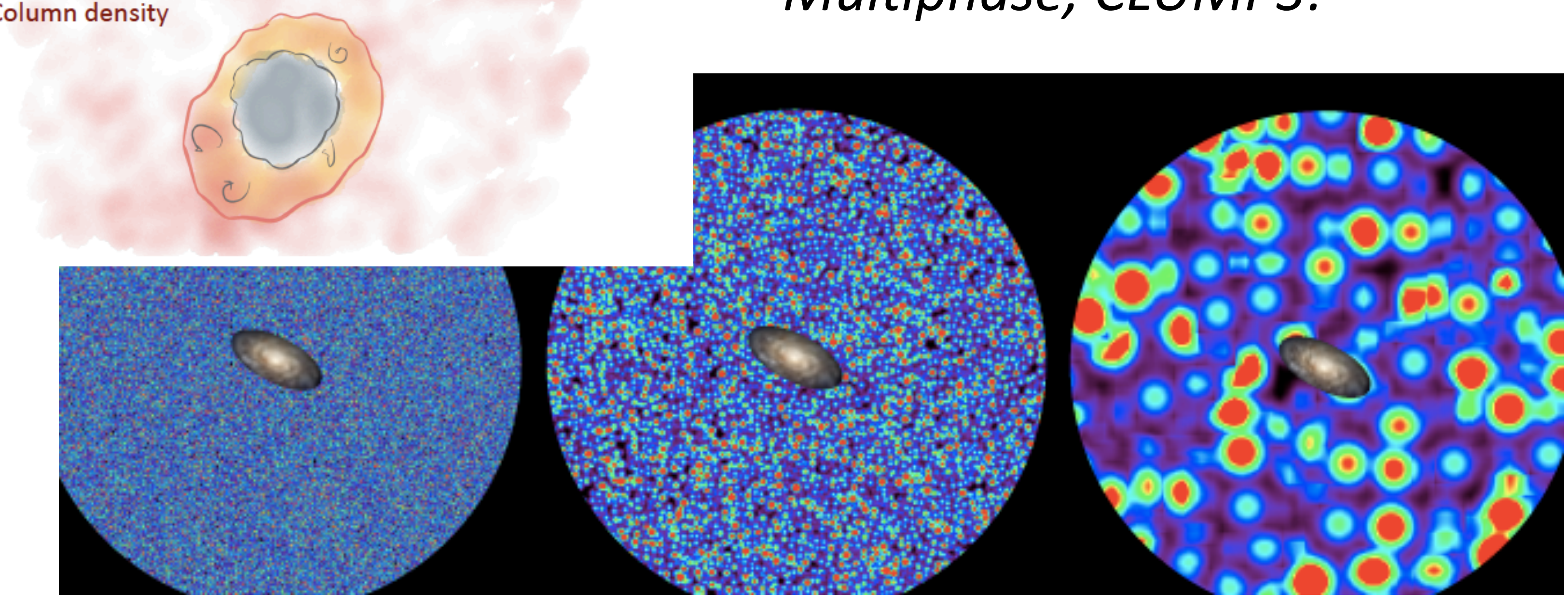
Other Non-Equilibrium Models

- Shock Ionization (Dopita 96; Gnat+09): Not enough SiIV
- Radiative cooling in a moving flow (Edgar+86; Shapiro+91): Correct Ratios; Column densities?
- Turbulent Mixing Layers (Begelman+90; Slavin+93): Wrong Ratios; Wrong Column densities
- Conductive Interfaces (Borkowski+90; Gnat+10): Low Total OVI Column density

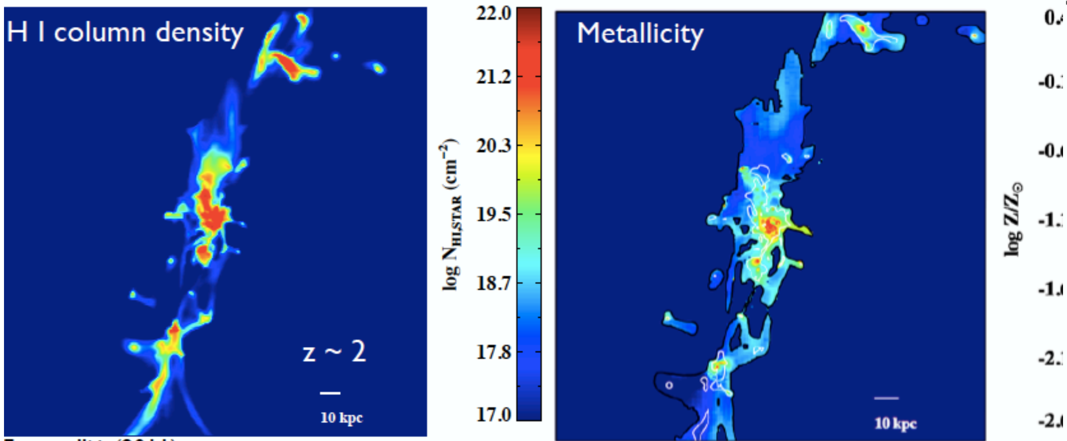
-OVI probes outflow phase

-MgII, FeII probe halo clouds: coherent over >1kpc scale

-Multiphase, CLUMPS!

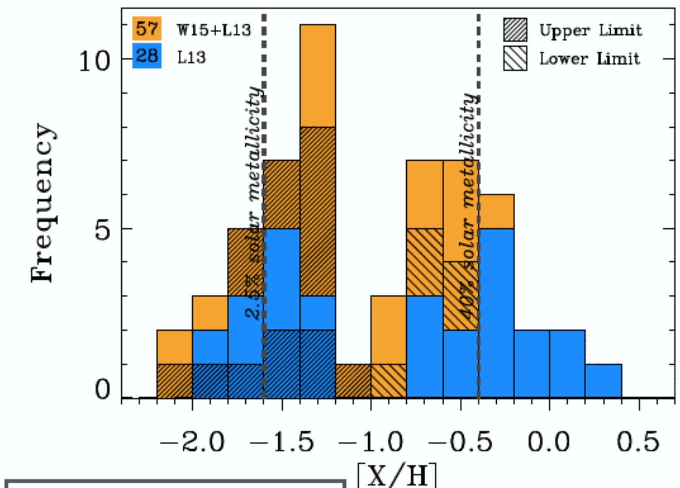


Feedback: spectral signatures probing inflow & outflow – use HI & X/H – use IFU & abs lines



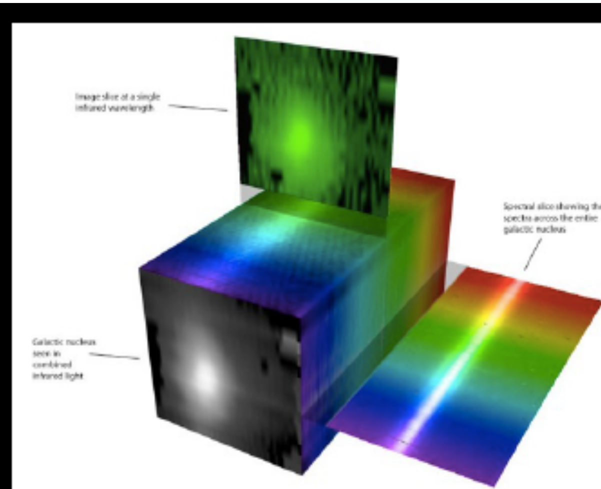
Fumagalli+ (2011)

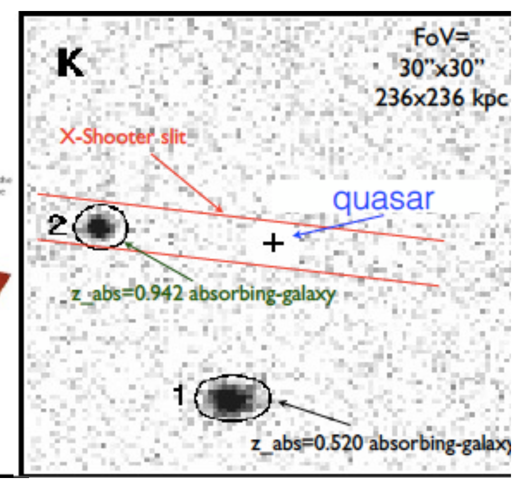
MDF of the combined sample of LLSs at z<1



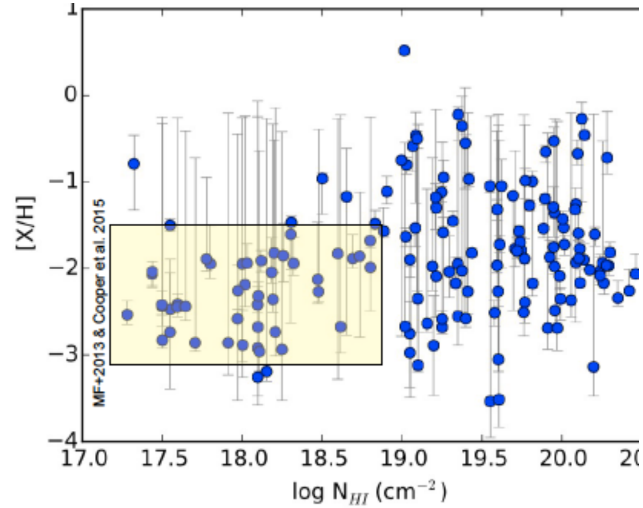
The MDF of the LLSs is bimodal and unique to the LLSs.

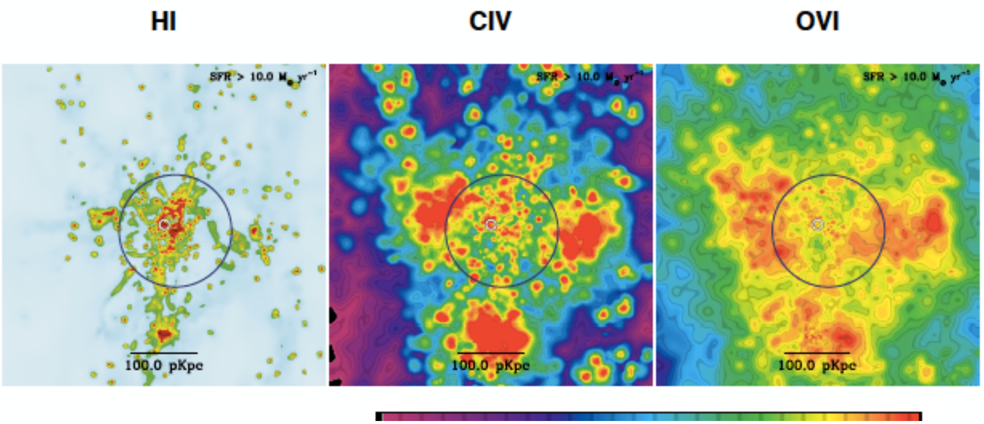
- search for stellar content of absorbers with **known N(HI)**
- IFU allows to remove signature of background quasar



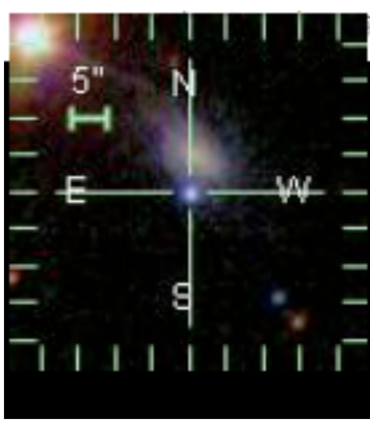


LLS metallicity distribution





- EAGLE reproduces the cosmic distribution of HI and metal absorbers and the observed HI covering fractions around LBGs and QSOs at z ~ 2-3
- Most strong HI and metal absorbers are associated with tiny galaxies

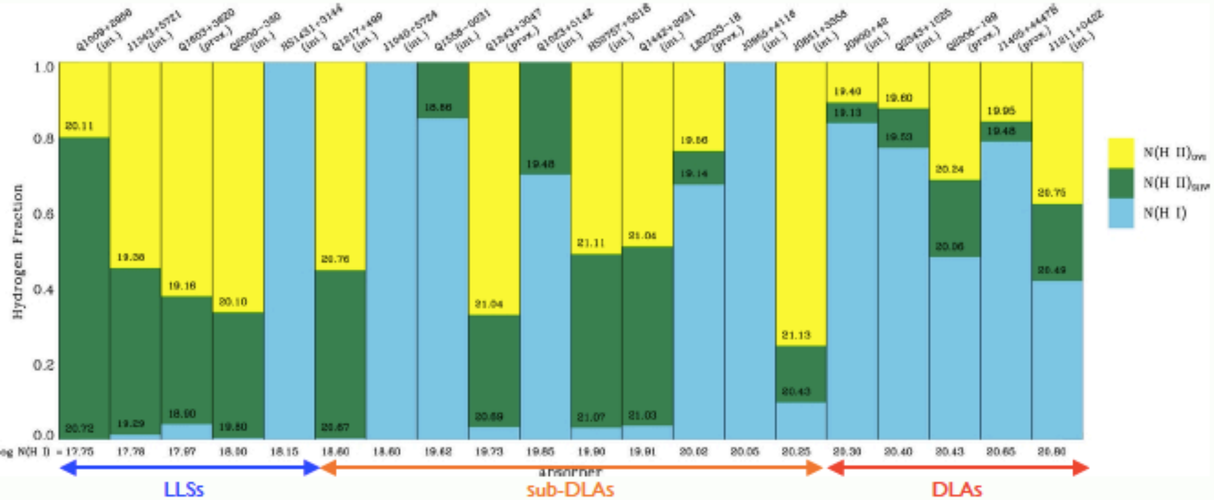


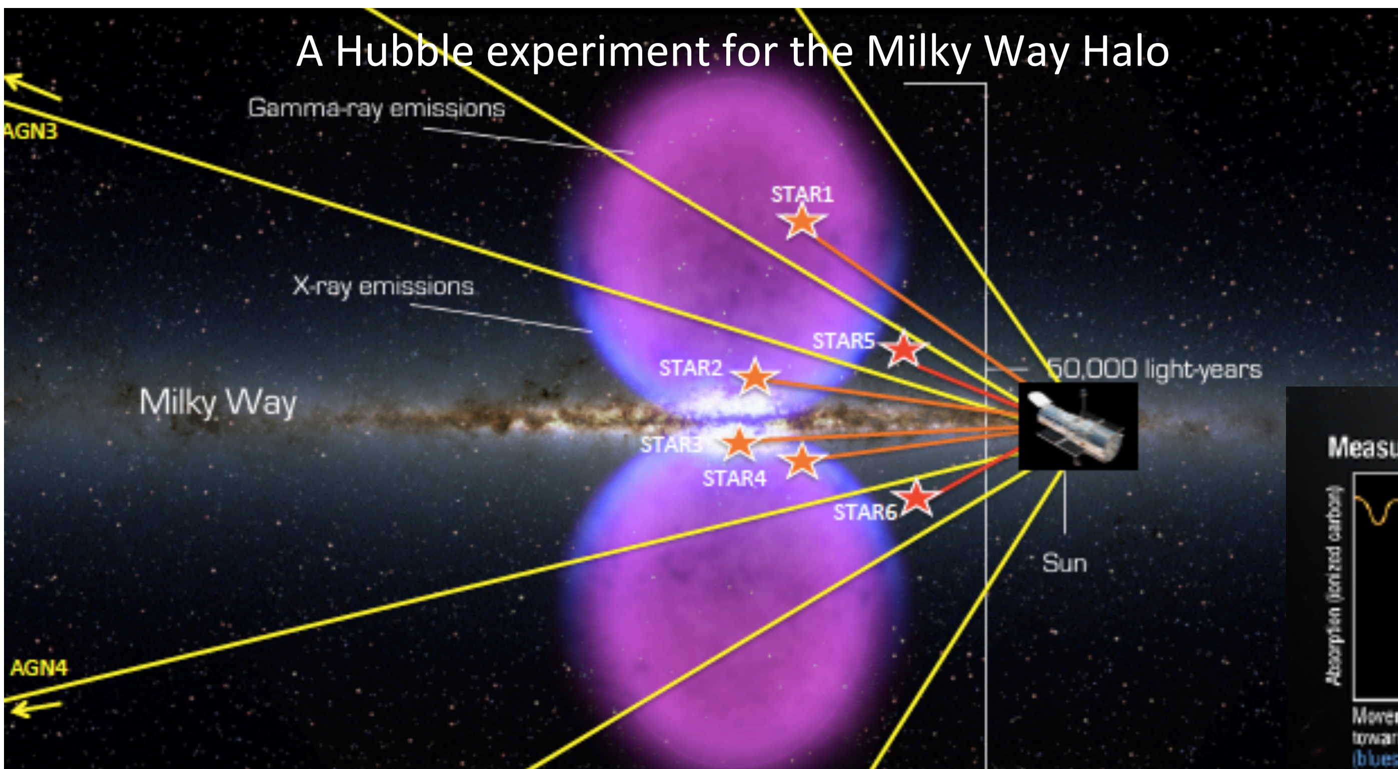
GOTOQs: low-z Quasar-galaxy pairs

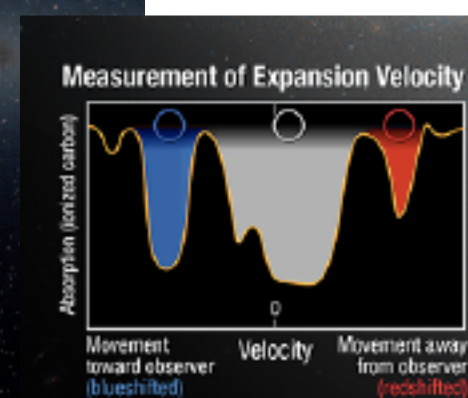
z(em)=0.046

- GOTOQs selected by emission are primarily isolated late-type galaxies with low SFR

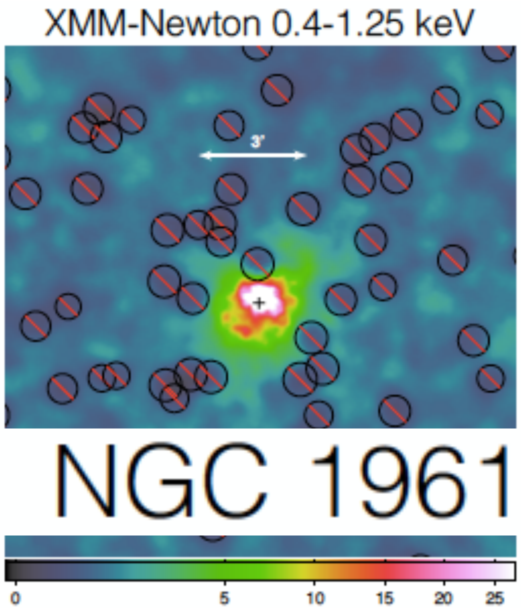
CGM baryons are substantial at z~2-3

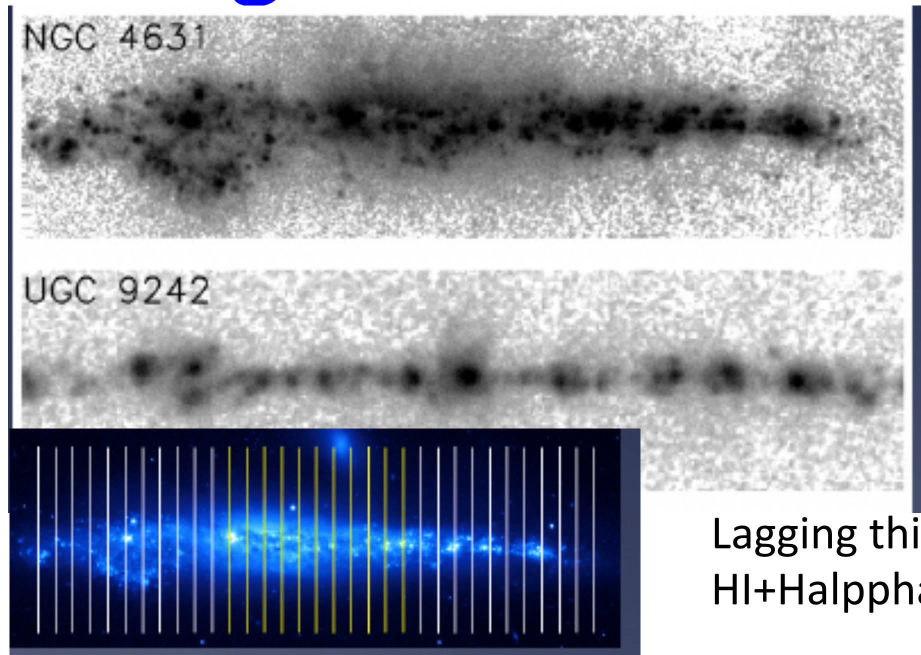




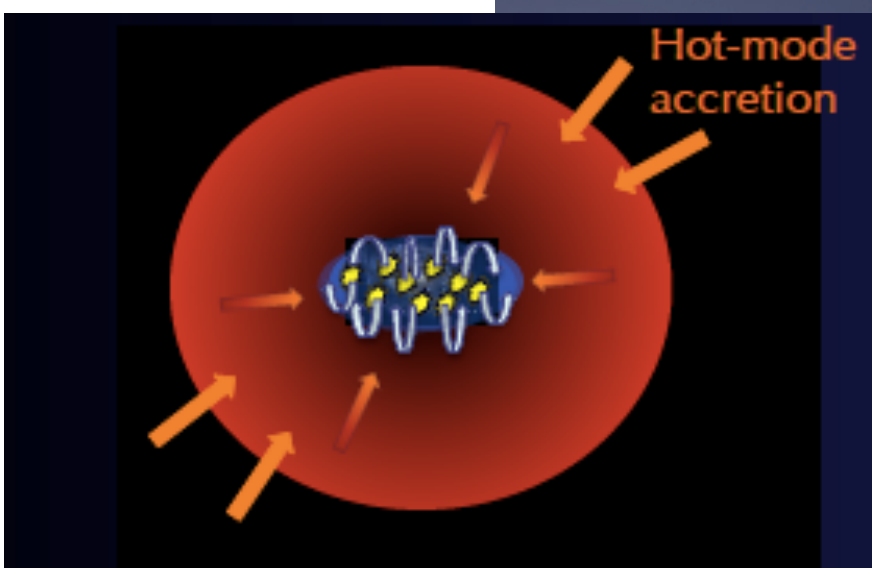


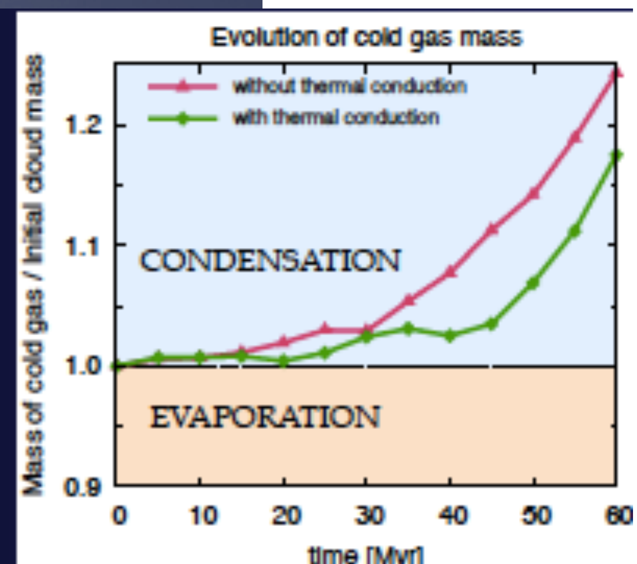
Extraplanar gas@low-z: does a hot corona/ fountain regulate accretion?





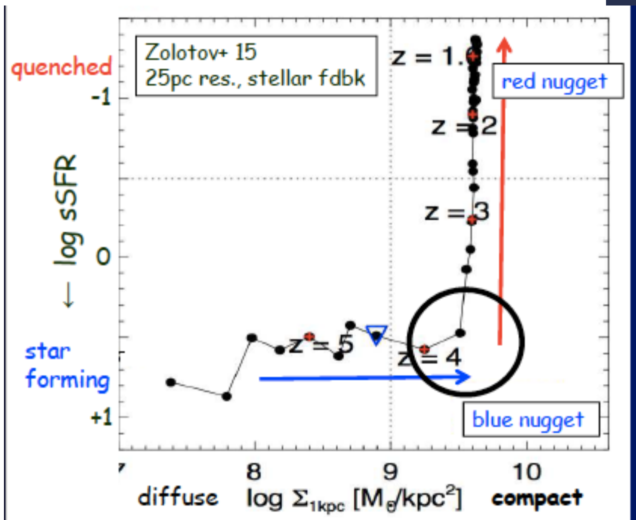
Lagging thick disk:
HI+Halppha





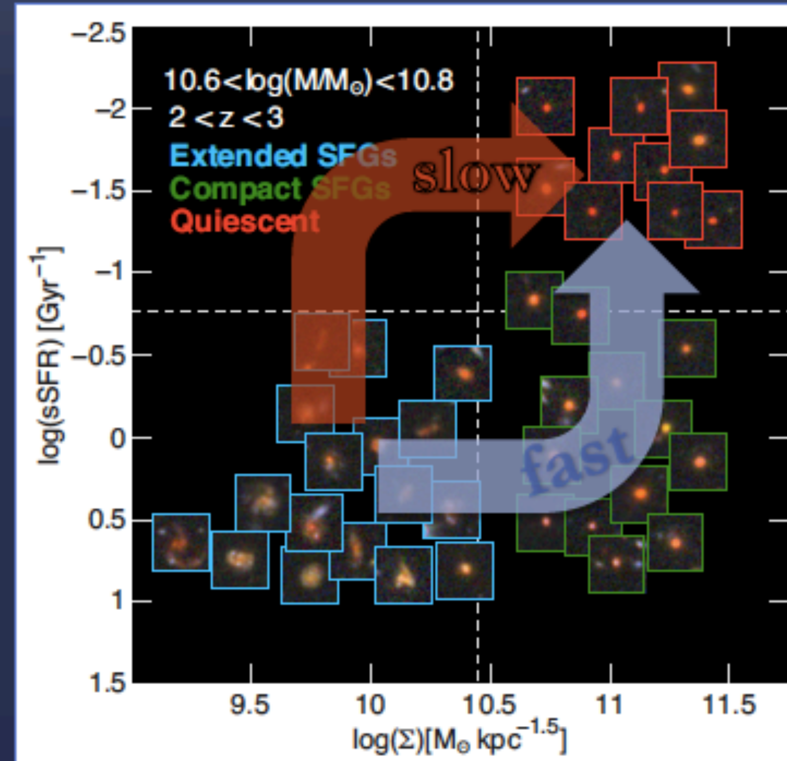
QUENCHING

GALAXY EVOLUTION REVEALED BY STRUCTURAL CHANGES



- "Compaction" and quenching
- Extended red galaxies possibly trace a slower quenching pathway.

Low mass are more Hesitant in quencing

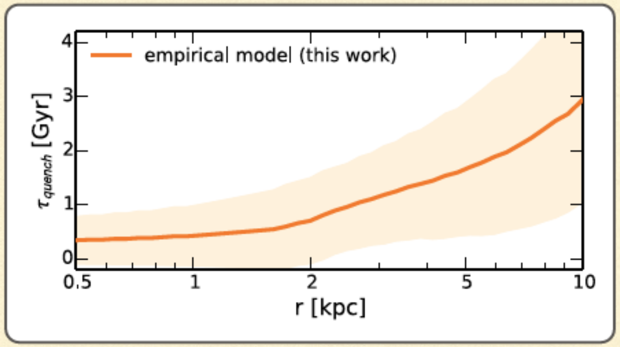


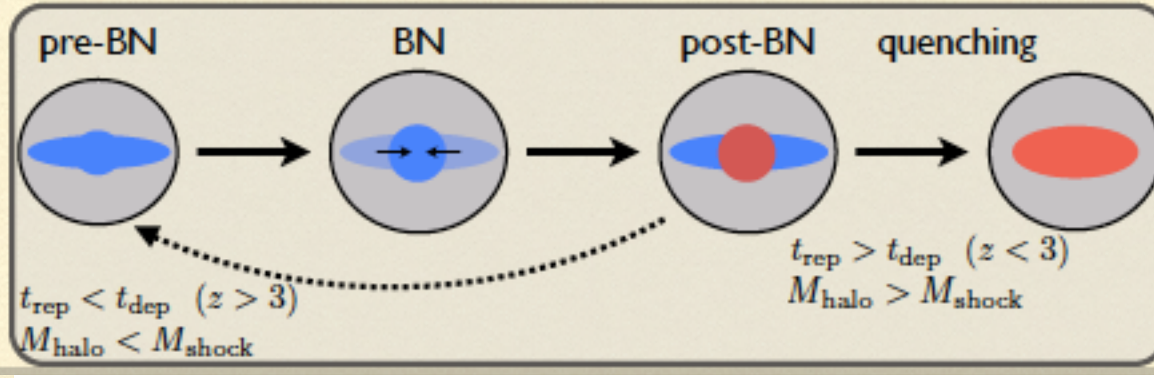
Barro et al. (2014)

- Massive quiescent disks are common at high-z.
- Mechanism other than major merging is required to build up early massive disks. Cold streams are one likely possibility.

- Violent disk instabilities + AGN feedback? (Can VDI funnel enough gas to the center to feed an AGN without compactifying and/ or building too much bulge?)
- Possibly slower processes like morphological quenching and hal quenching?

-Later mergers make morphological transformation of quiescent disks.
-In bulges stars are born in situ but this is a short lived bulge phase.



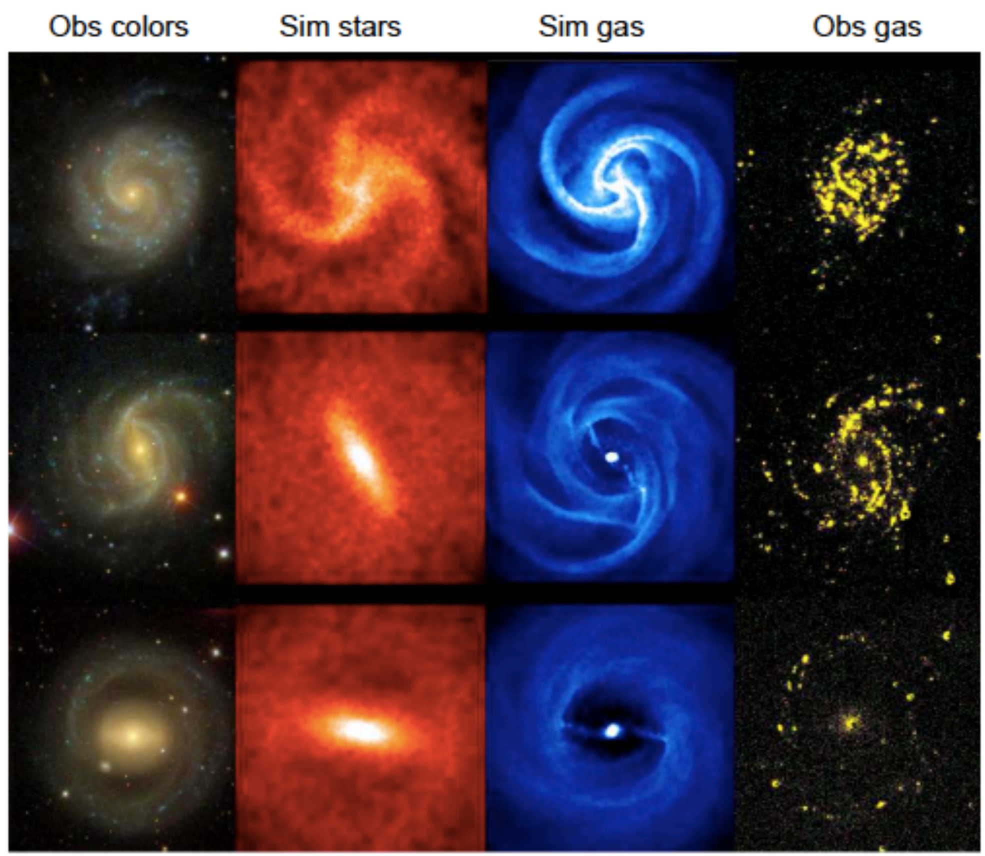


➜ infer how quenching progresses with radius:

inside-out quenching!

AGN?
Gas supply cut-off?
morphological Q?

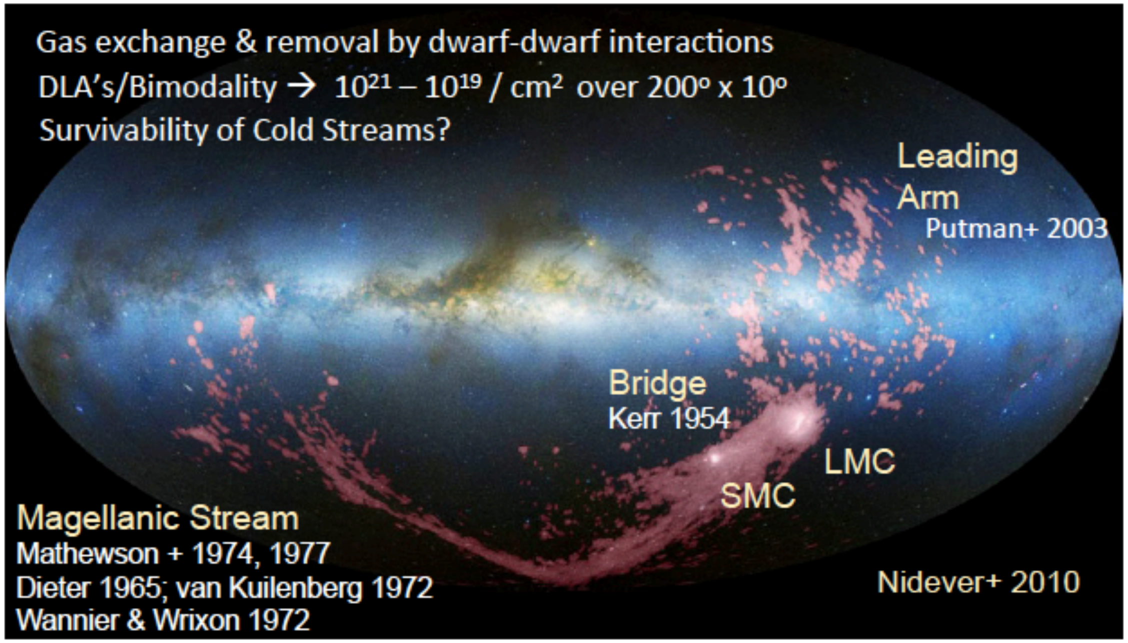
INSTABILITIES trigger Red→blue transition
-BAR? Low gas fraction trigger it?
-VIOLENT INSTAB. Timescale for gas deposition increases
-Central BH fast growing due to clumpy accretion

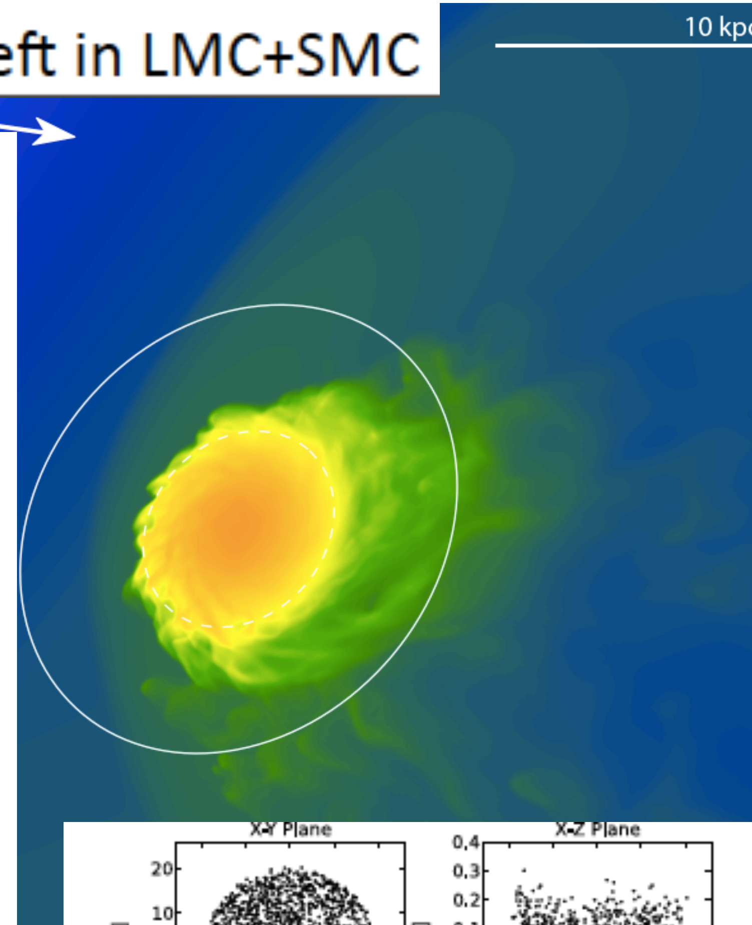


Barred galaxies are red within corotation radius

Stream contains more gas mass than is left in LMC+SMC

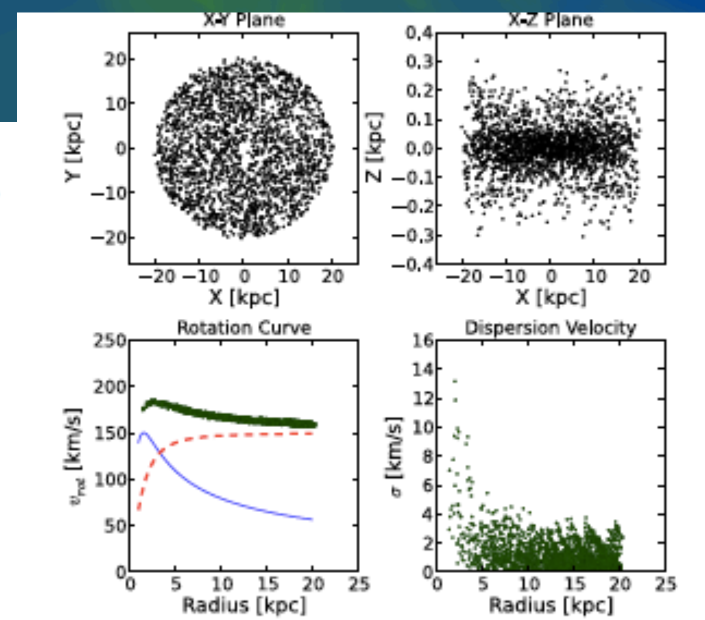
The Magellanic System



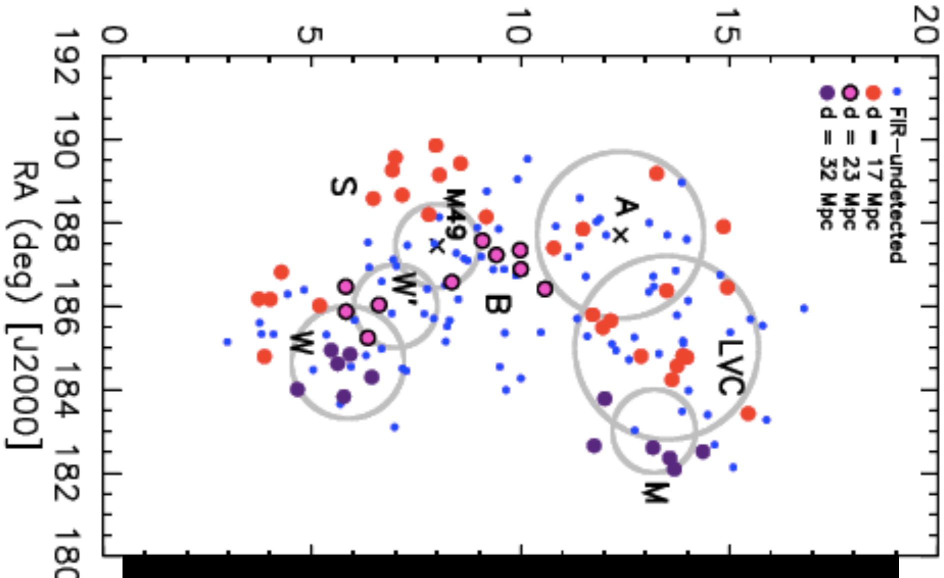


$M_{\text{Gas outside}}$ ~ **2 x10^9 M$_\odot$**(d/55 kpc)^2 > 2 x $M_{\text{Gas LMC+SMC}}$ **Fox+ 2014**

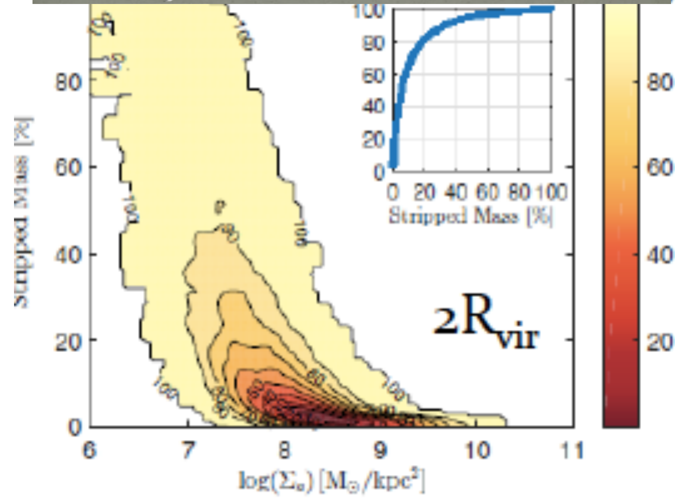
$$n_{\text{MWHalo}}(R = 48.2 \pm 2.5\ \text{kpc}) = 1.1^{+.44}_{-.45} \times 10^{-4}\ \text{cm}^{-3}$$



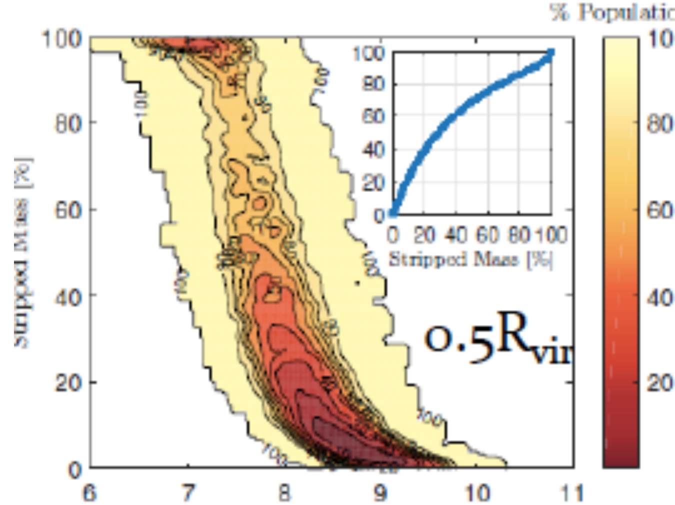
Slow Quenching of Satellite Galaxies at the Outskirts of Galaxy Clusters



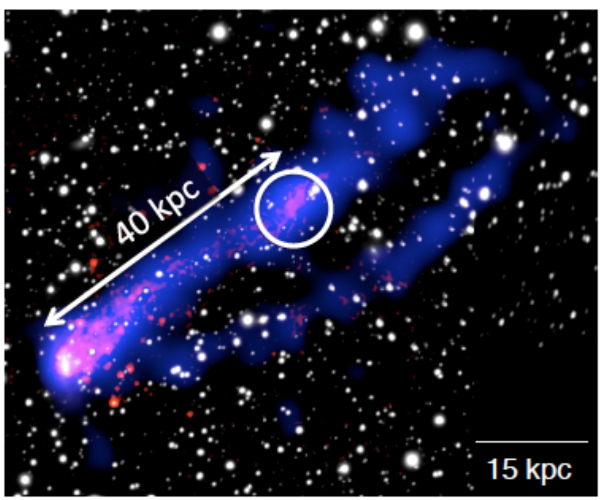
As expected, dusty SF dwarf galaxies, tend to avoid the densest regions (cluster A and B)



(a) $r = 2R_c$



Different gas phases in stripped tails



Halo gas reservoir can be effectively removed well before the satellite reaches R_{vir}.

Key names

- CLAMATO,EXPRESS, AREPO,ILLUSTRIS,EAGLES,RADAMESH
- GADGET ,MUSE, FLASHLIGHT,FIREBALL,ISTO,VELA,FIRE
- SAMI,GAMA,ZFOURGE,RAMSES,GOTOQS,GIDGET,PHIBSS
- ENZO,AGORA,COLDGASS,MOSFIRE,LUCI,MUPPI,KODIAQ
- PRIMUS,HALOGAS……………………..

Pretty Posters

- Corlies L. (Best Colours)
- Del Olmo A. (Nicest simulation picture)
- Schneider E. (Nicest observational picture)

Thank you SOC !!!

Best Chair & email resp.(ON time):Debra & Bruce

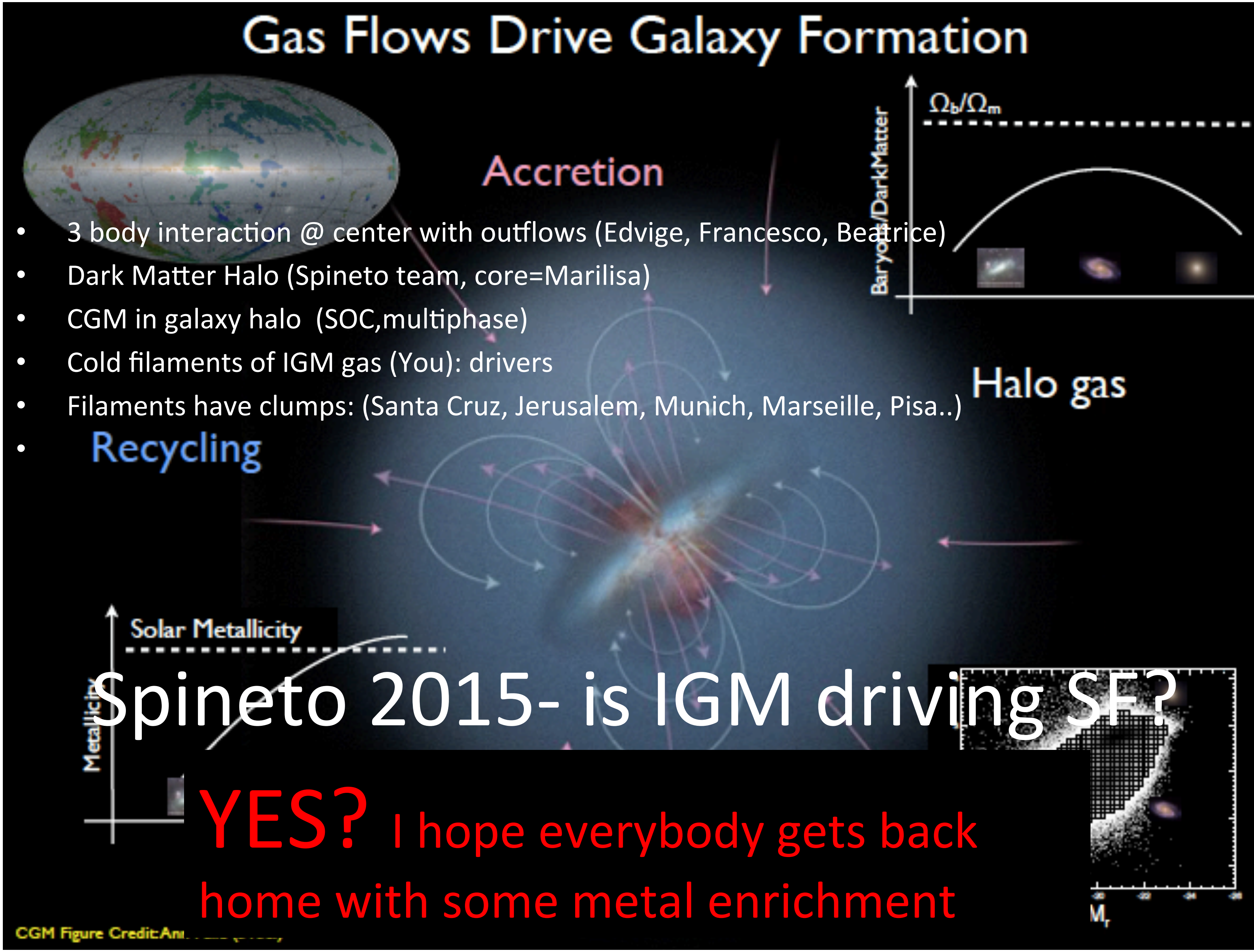
Title input: Avishai

Hystorical Expert: Xavier

Trigger for Spineto 2015: Andi

SOS

- Wild pigs while running
- Lizard in bathroom @Cerchiaia
- Scorpio @Cerchiaia
- Scorpio @Poderuccio
- Flies eating Poderuccio
- Fload @Il Piano
- Loud night UFOs @La Sorgente
- Intermittent Internet & phones
- Weather forecast on Wednesday
- Unavailable pool/hot water in Sasseto
- ………………….


Gas Flows Drive Galaxy Formation
Accretion
Ω_b/Ω_m
Baryons/DarkMatter
• 3 body interaction @ center with outflows (Edvige, Francesco, Beatrice)
• Dark Matter Halo (Spineto team, core=Marilisa)
• CGM in galaxy halo (SOC,multiphase)
• Cold filaments of IGM gas (You): drivers
• Filaments have clumps: (Santa Cruz, Jerusalem, Munich, Marseille, Pisa..)
• Recycling
Halo gas
Solar Metallicity
Metallicity
Spineto 2015- is IGM driving SF?
YES? I hope everybody gets back home with some metal enrichment
M_r