Disk Galaxy Formation Models

Ortwin Gerhard, Markus Samland, Andi Immeli

Astronomical Institute, University of Basel, Switzerland
gerhard@astro.unibas.ch, www.astro.unibas.ch

What we want to talk learn and how: Multi-Phase Models for Galaxy Formation and Evolution

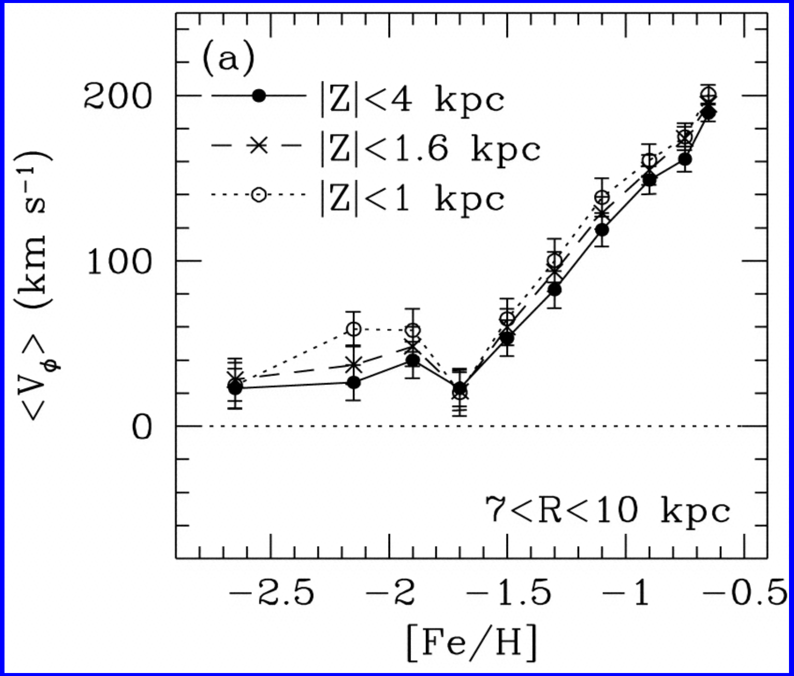
- Gas-rich Disks and High-z Morphology
- Assembly of a Massive Disk Galaxy
- Stellar Populations and Origin of the Galactic Halo

Swiss National Science Foundation CSCS Large User Project

Young Galaxies to Today´s Galaxies

HDF 4-105

(van den Bergh et al., 1996)



Halo Star Rotation Velocities
Versus Metallicity

(Data fromChiba & Beers 2000)

Aim of the Project

Consistent evolution models for disk galaxies, to connect:

- Observables from the Milky Way and local galaxies (kinematical and chemical history of individual stars and stellar populations), with
- Observations of local and high-redshift galaxies (morphology, gas-phase metallicities, dynamics)

to constrain these models, and learn about galaxy formation in general.

Study global star formation history, chemical enrichment, feedback from galaxies of different masses

Multi-Phase Models for Galaxy Formation and Evolution

Dynamical evolution, involving diffuse and condensed gas, stars and dark matter;

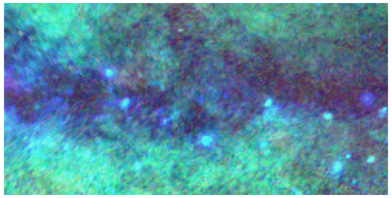
Star formation;

Thermal evolution, affecting the gas components;

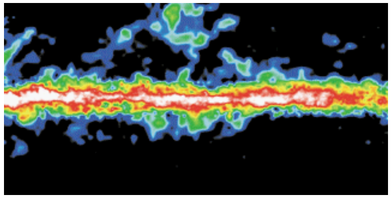
Chemical evolution, origin and distribution of nuclear species in stars and gas.

The Multi-Phase (Chemo-)Dynamical Model

gas

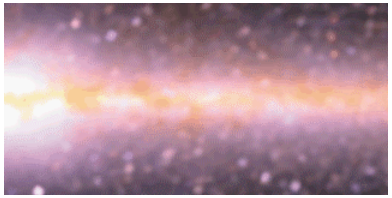


clouds



hydrodynamical grid code

stars



particle mesh

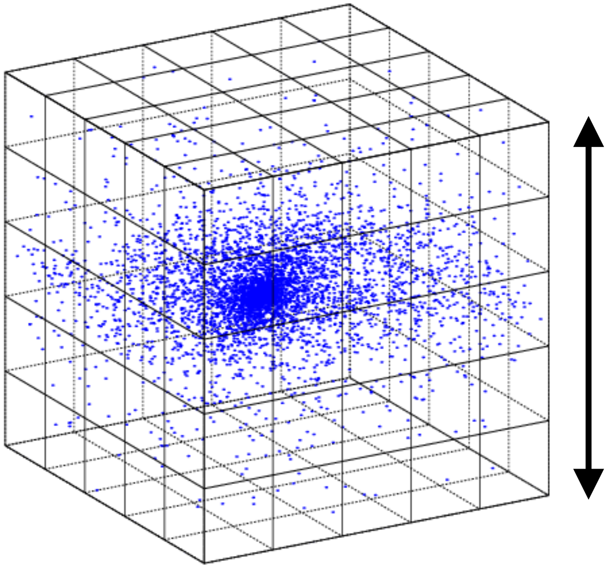
dark matter

from cosm.sim.

interaction network + gravitation

<u>3D-hybrid code</u>

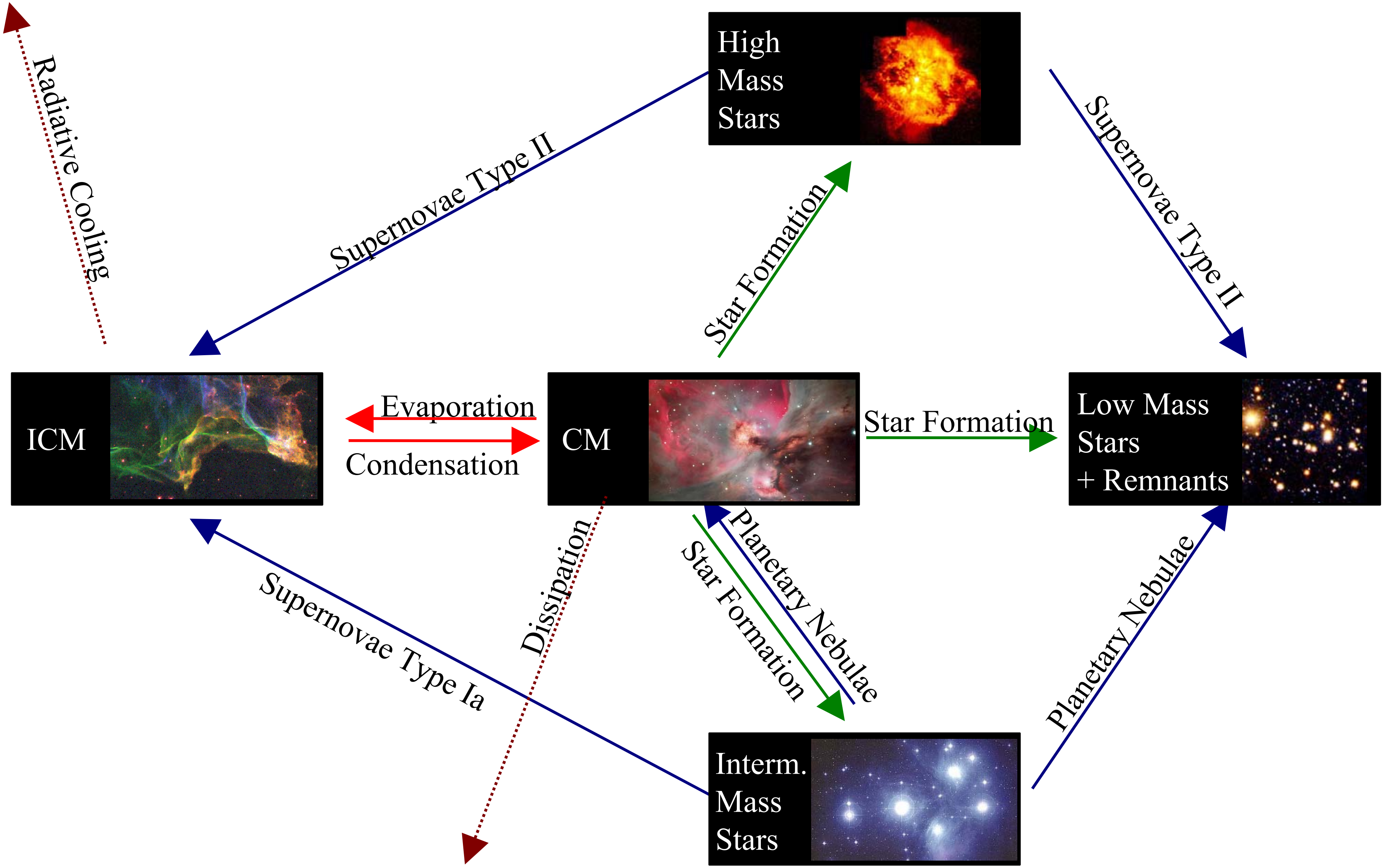
2 000 000 grid cells
650 000 particles



1000000 light years

Interaction Network

Samland etal. 1997, Samland 1999,
Samland & Gerhard 2003



High Mass Stars

Low Mass Stars + Remnants

ICM

CM

Interm. Mass Stars

Radiative Cooling

Supernovae Type II

Supernovae Type II

Star Formation

Evaporation

Condensation

Star Formation

Dissipation

Star Formation

Planetary Nebulae

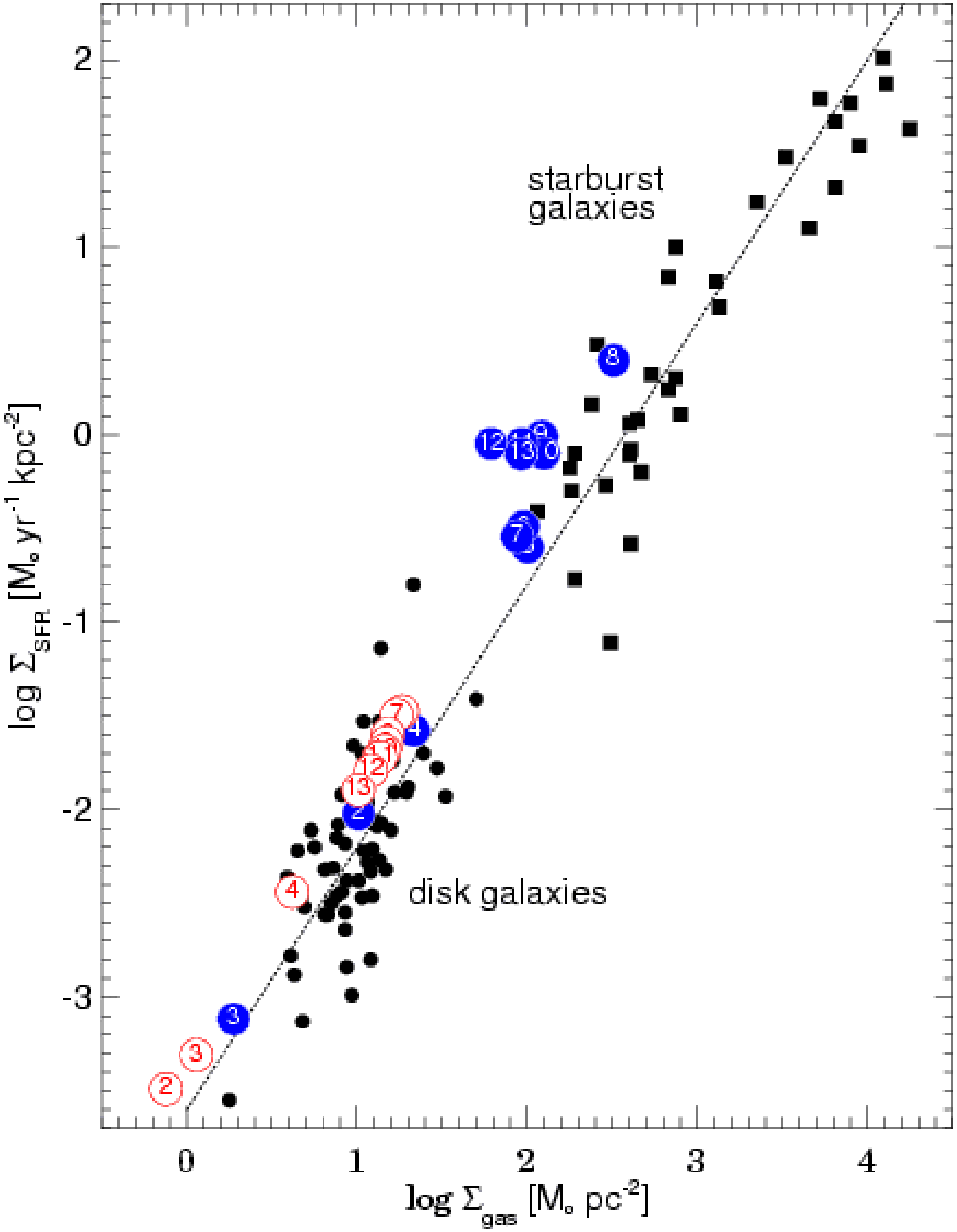
Planetary Nebulae

Supernovae Type Ia

The galactic star formation rate

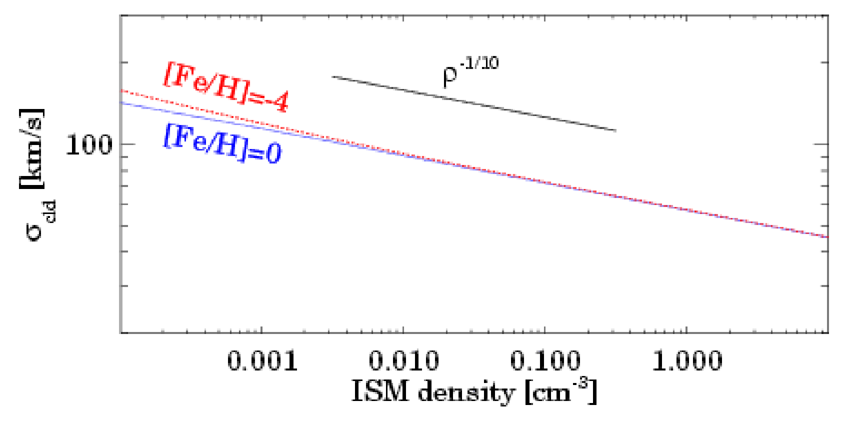
Data points and line from Kennicutt 1998, ApJ, 498, 541

Mean (red) and most active (blue) region SFR in the model at age/Gyrs

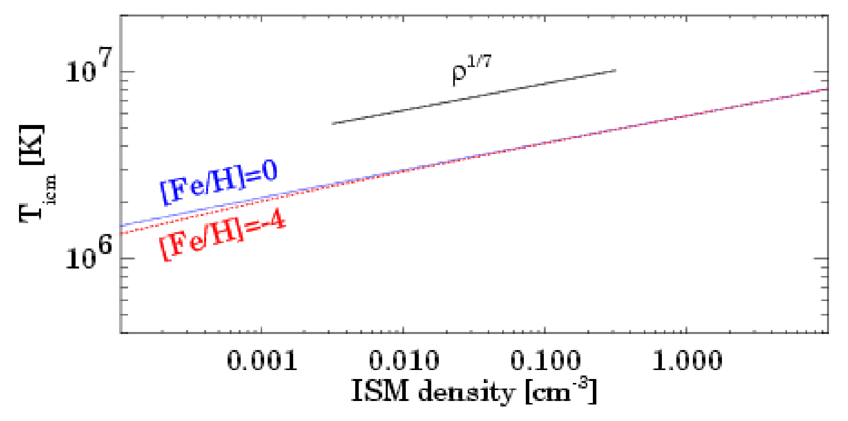


Self-regulating character of the 2-phase medium

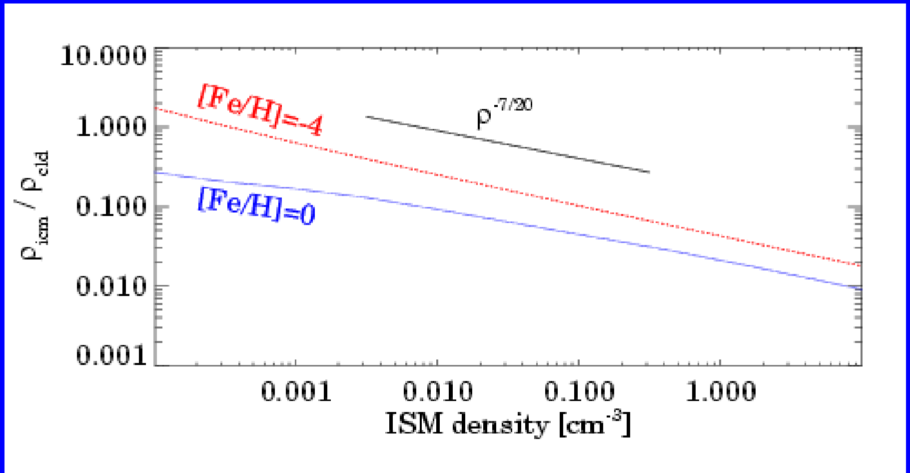
Velocity dispersion of the cloudy medium



Temperature of hot gas



Gas-to-cloud mass fraction

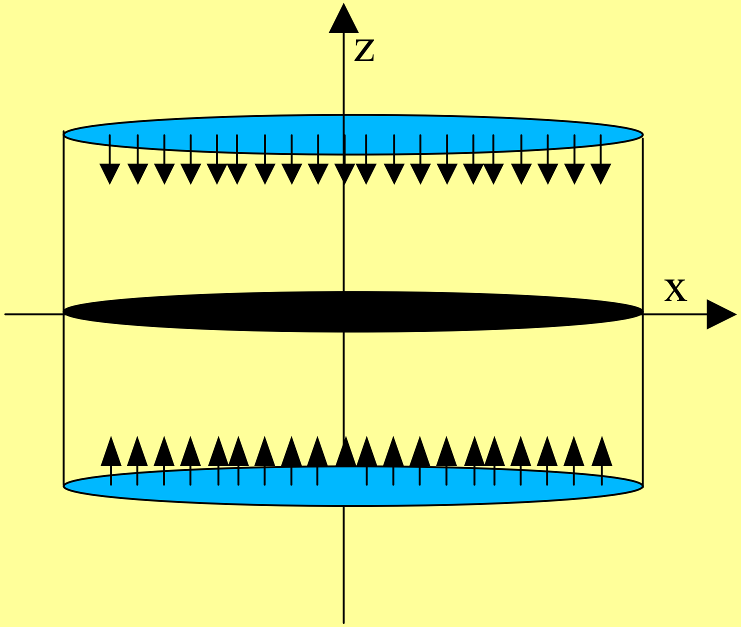


Although the gas density varies over 5 orders of magnitude, quantities like temperature, velocity dispersion or gas-to-cloud mass fraction do not vary more than a factor of 10.
(Samland & Gerhard, 2003,
. A&A, 399, 691)

1. Gas-rich Disks and High-z Morphology

Immeli, Samland, Gerhard, 2003

Disk Infall with Varying Dissipation Rate



Grid Resolution: 129^3

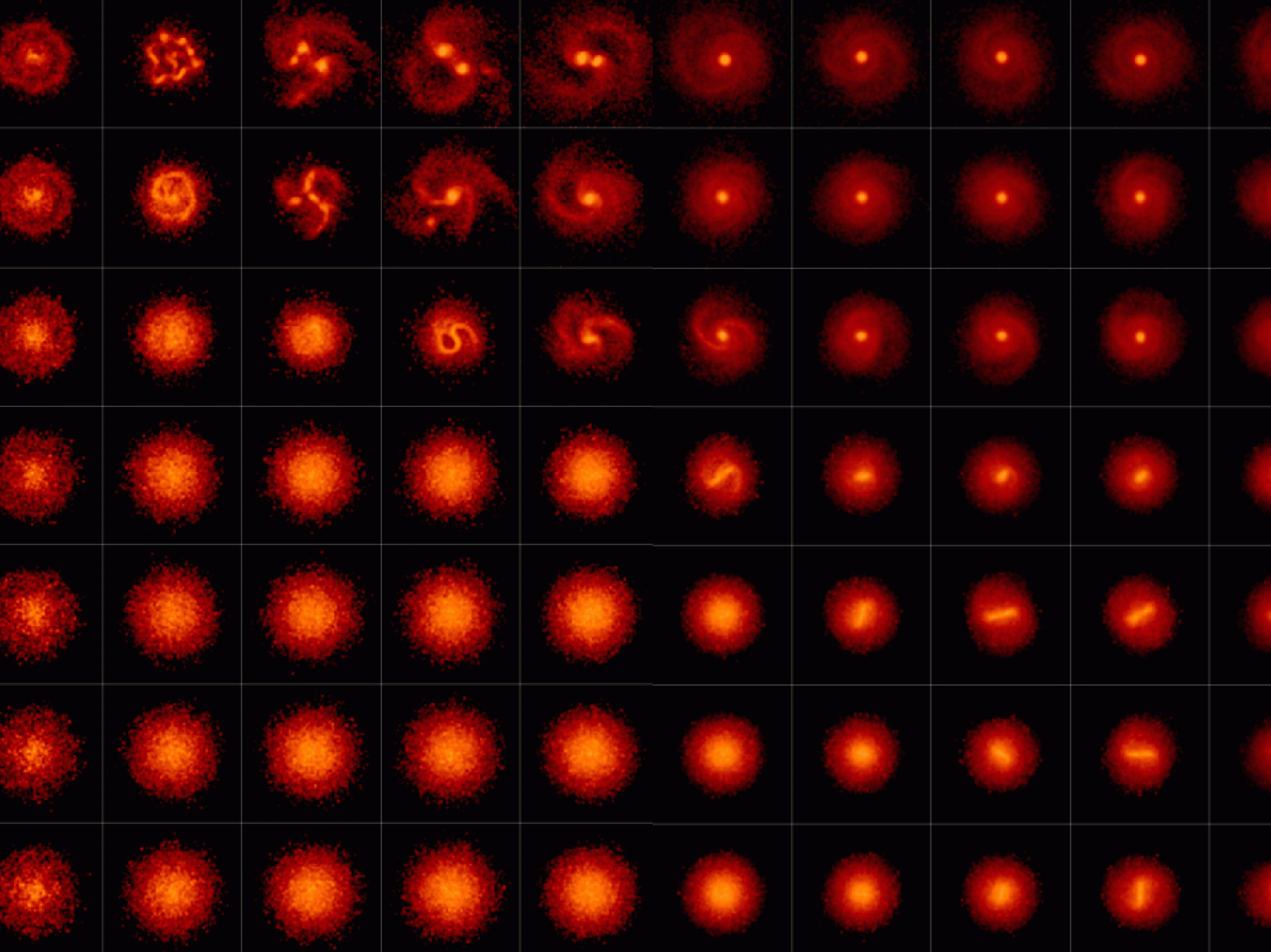
spacial resolution: 295pc, 120pc

Dark matter halo (NFW), static

Infall of gas along z-axis
- uniformly distributed
- primordial abundances
- circular velocity at infall point

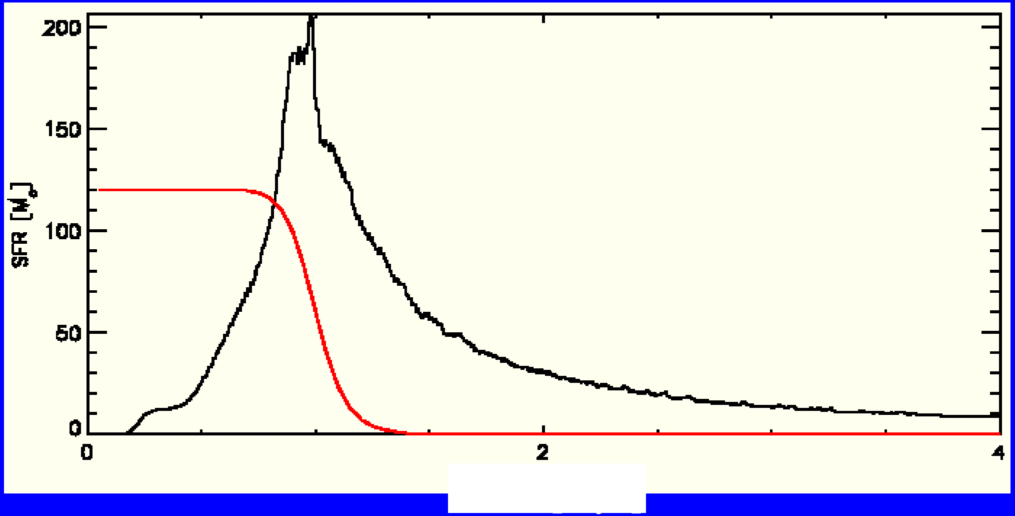
Varying cloud energy dissipation rate (yields cloud velocity dispersion from lower to upper end of the observations)

→ leads to the formation of a gaseous disk, which subsequently fragments, or stellar disk that forms a bar.



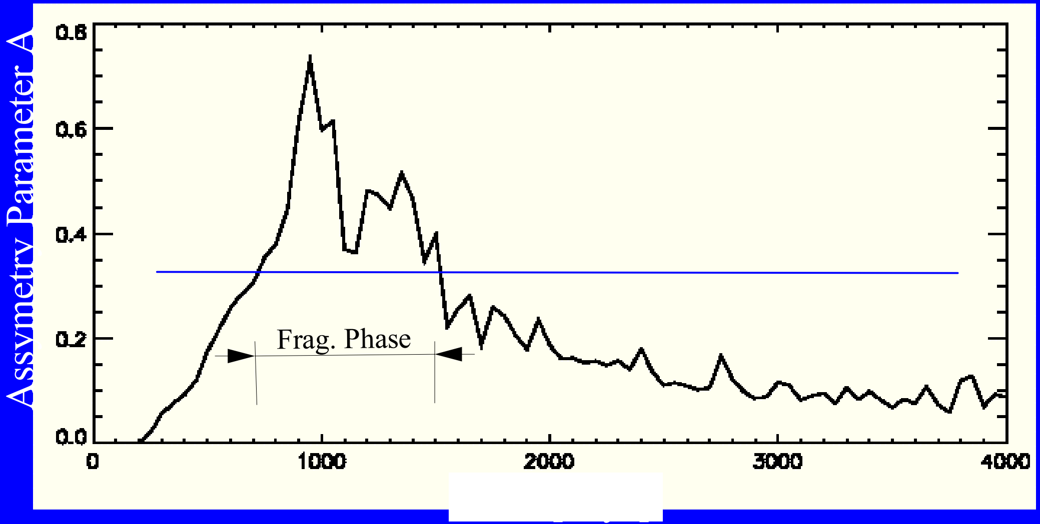
Star Formation During Fragmentation

Star formation rate and
infall rate



Asymmetry parameter
(Abraham et al, 1996)
as a measure for
fragmentation

Fragmentation phase
from ~0.7 to 1.5 Gyr



The star formation rises steeply when the fragmentation gets under way

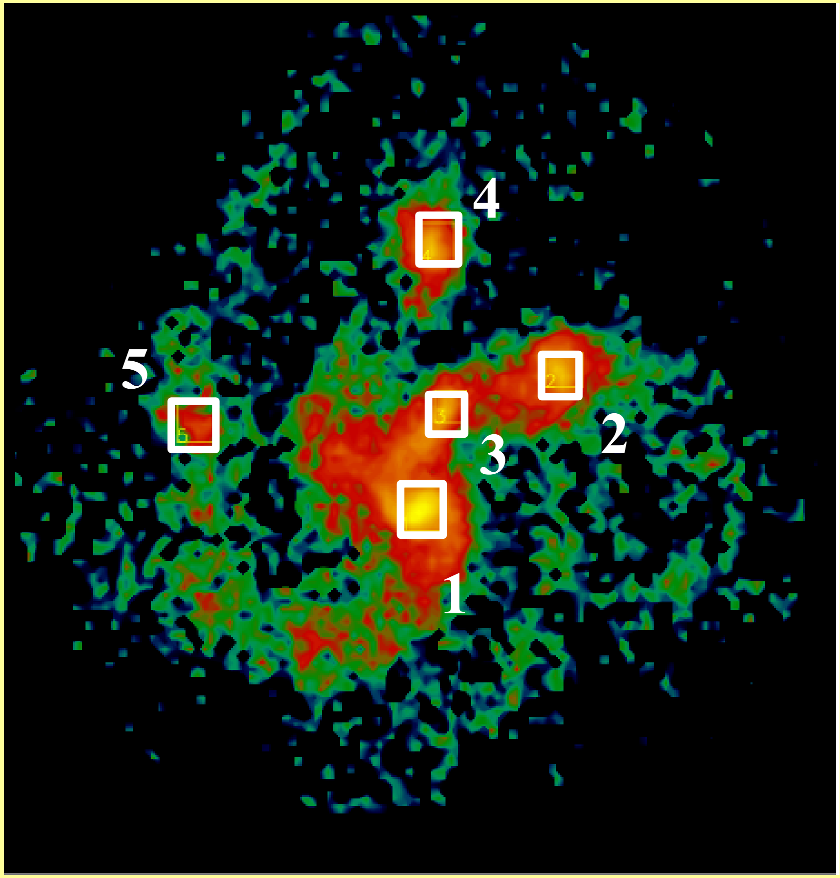
Metallicities of Individual Clumps

Properties of the individual clumps:

Clump	Mass (1e9 M_o)	[O/H]	[Fe/H]	[O/Fe]
1	7.96	-0.32	-0.72	0.40
2	4.10	-0.38	-0.77	0.39
3	2.02	-0.44	-0.84	0.40
4	2.39	-0.42	-0.82	0.40
5	0.64	-0.59	-0.98	0.39

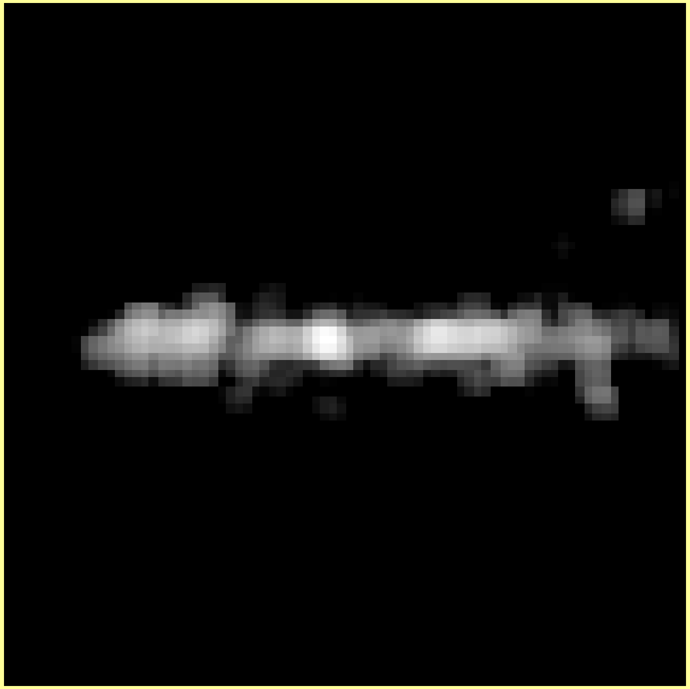
There exist metallicity differences of ~0.25 dex between the clumps.

[O/Fe] is enhanced due to the short timescale of the starburst taking place in the clumps.

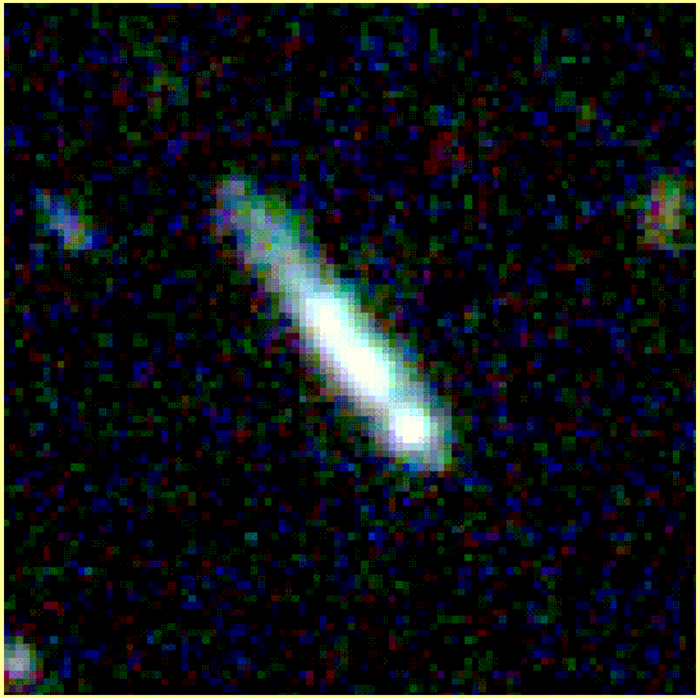


Stellar mass surface density of the model at 1.2 Gyr used to select the clumps.

Comparision to Observations: Chain Galaxies



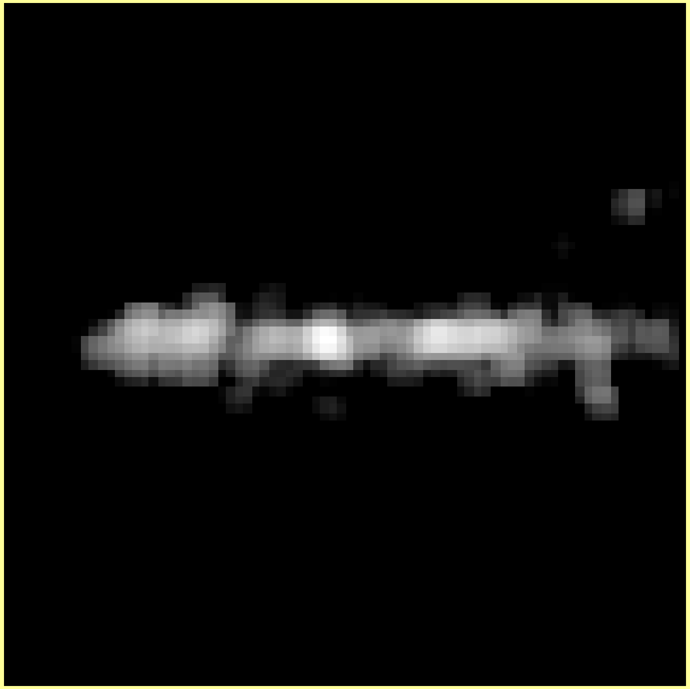
Model galaxy edge on at 1.15 Gyr.

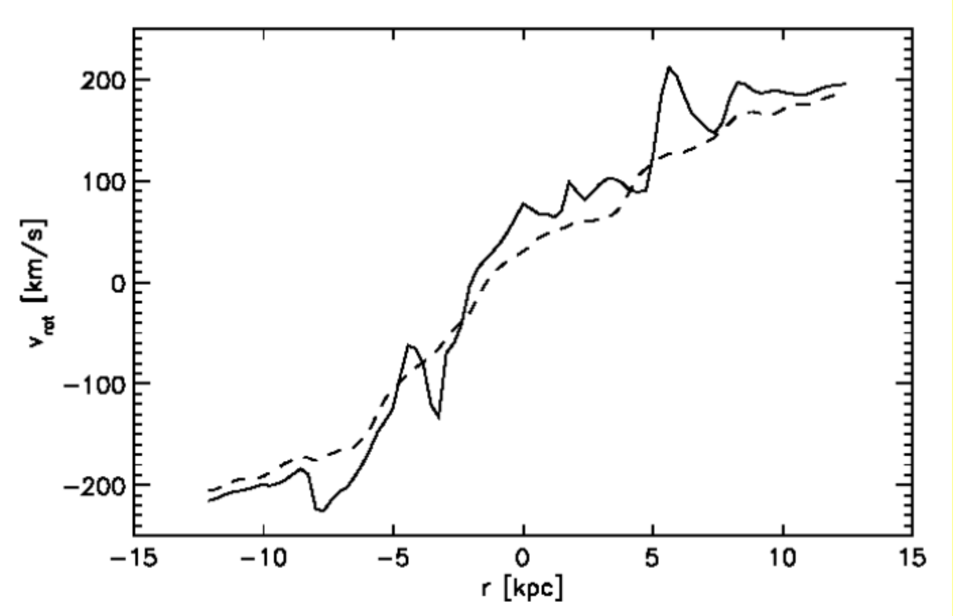


HDF 3-531.Chain galaxies, first reported by Cowie et al. (1995), image from van den Bergh et al. (1996)

Observational tests for the nature of chain galaxies: measurement of rotation,
metallicities of clumps

Chain Galaxies – Rotation Signature

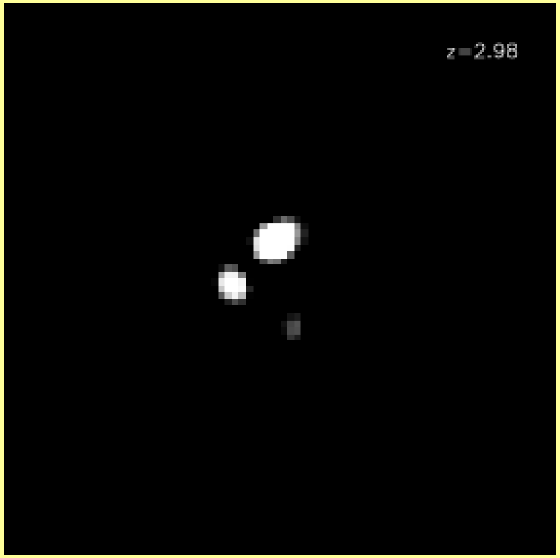


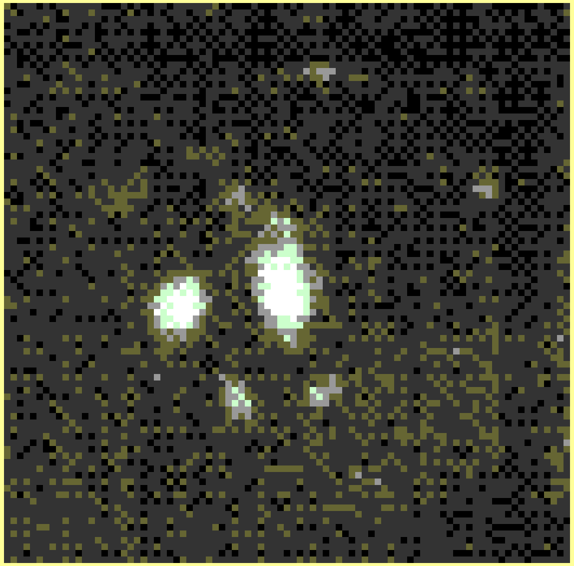


Model galaxy edge on at 1.15 Gyr.

Observational test for the nature of chain galaxies: measurement of rotation.
If chain galaxies are edge-on fragmented disks, predict basic rotation signature with superposed bumps of up to 100 km/s for a massive disk.

Comparision to Observations: Knots

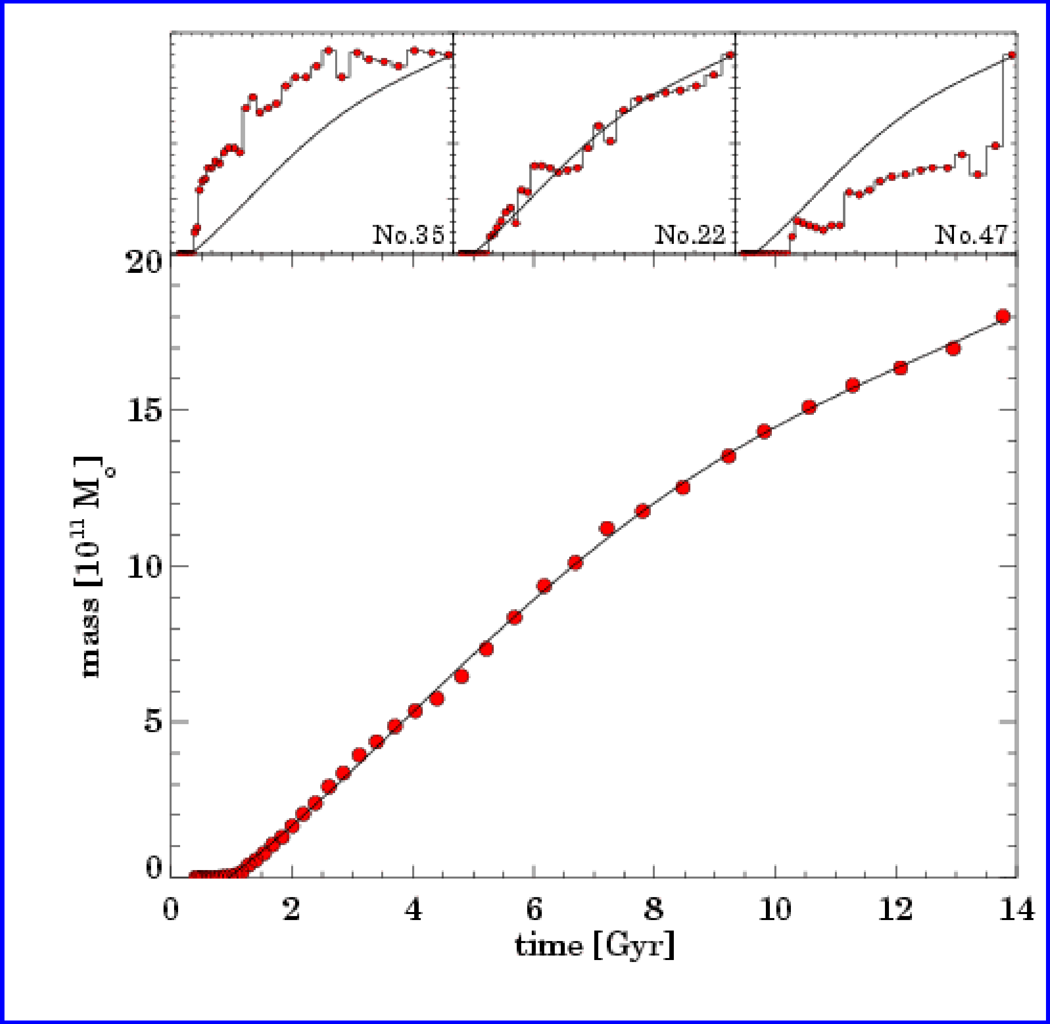




Observed F606W surface brightness
of the model at 1.3 Gyr

2. Assembly of a Massive Disk Galaxy

Dark Halo Formation History



Halo formation history from cosmological simulations. VIRGO-GIF project data, Diaferio etal. 1999, MN, 307, 537

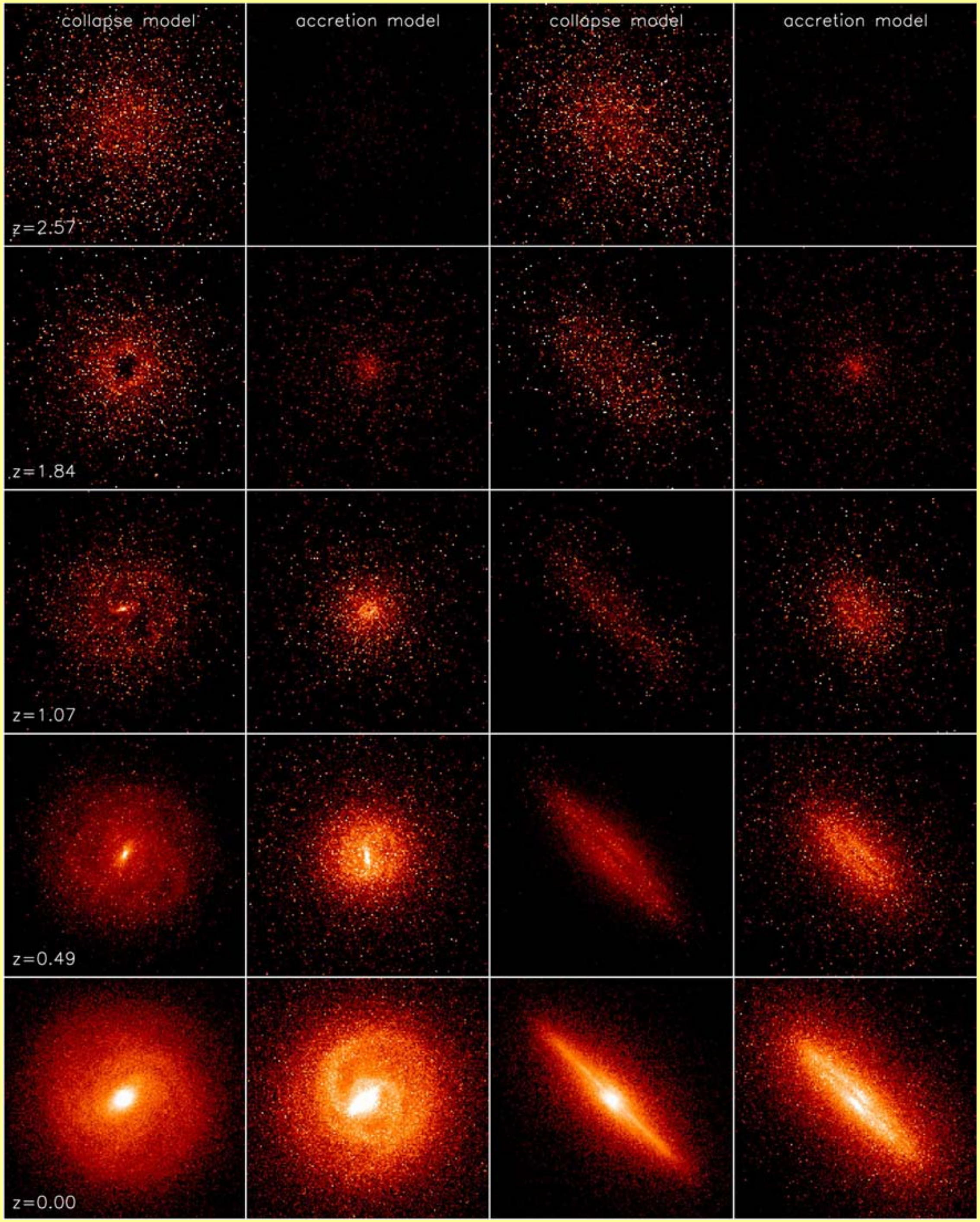
Λ = 0.7
Ω(dark) = 0.25
Ω(bary) = 0.05
h = 0.7

Spin parameter: λ = 0.05
Universal angular momentum distribution, approx. v=const., Bullock etal. 2001, ApJ, 555, 245

Total mass: 1.8E12 solar mass

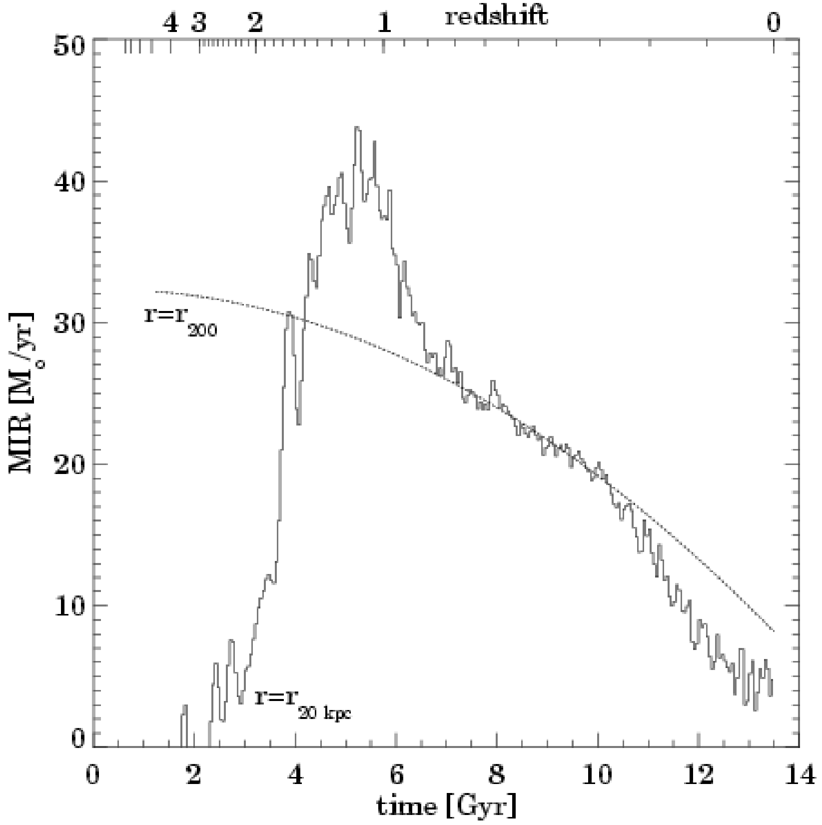
V-Band Images

redshifted spectra including dust absorption (constant dust-to-metal density ratio).

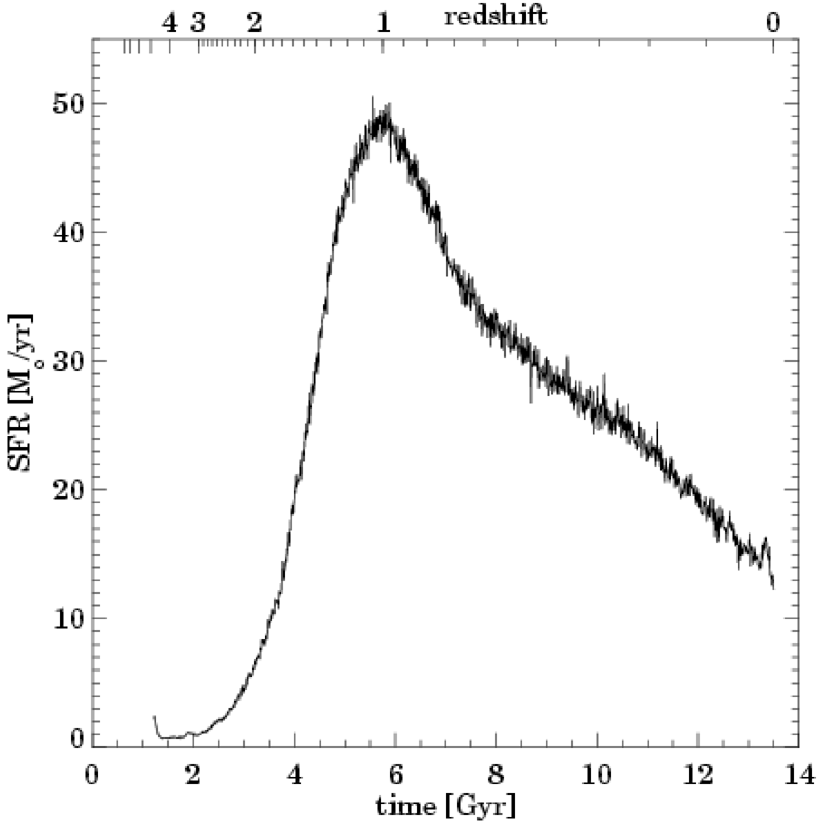


Westera et al., 2002, A&A 389,761

Mass Infall Rate



Star Formation Rate

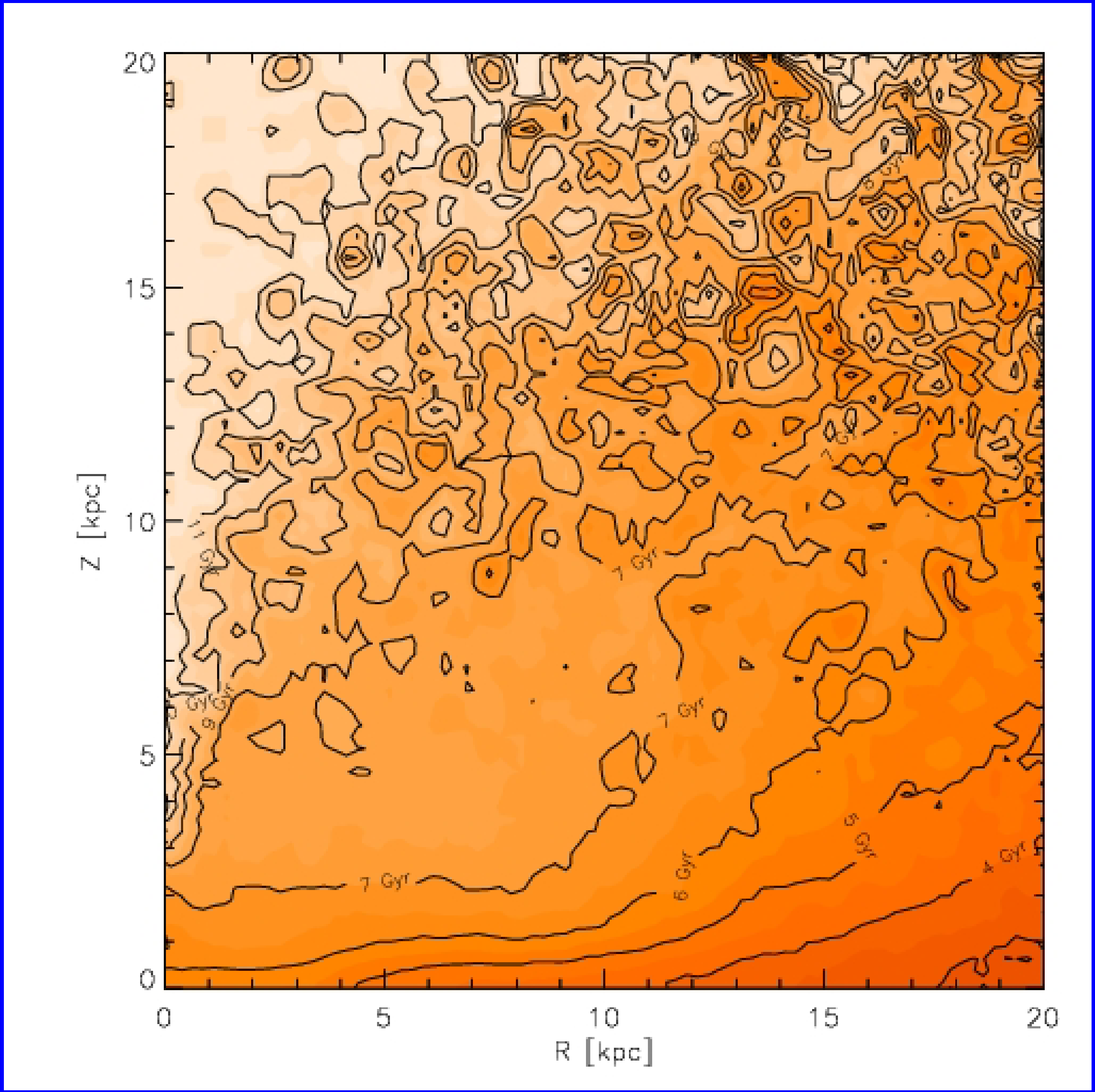


Feedback from SN and massive stars prevents a rapid collapse. Main galaxy „formation“ at approx. z=1. At z=0.3, stellar mass return exceeds infall.

Average stellar ages

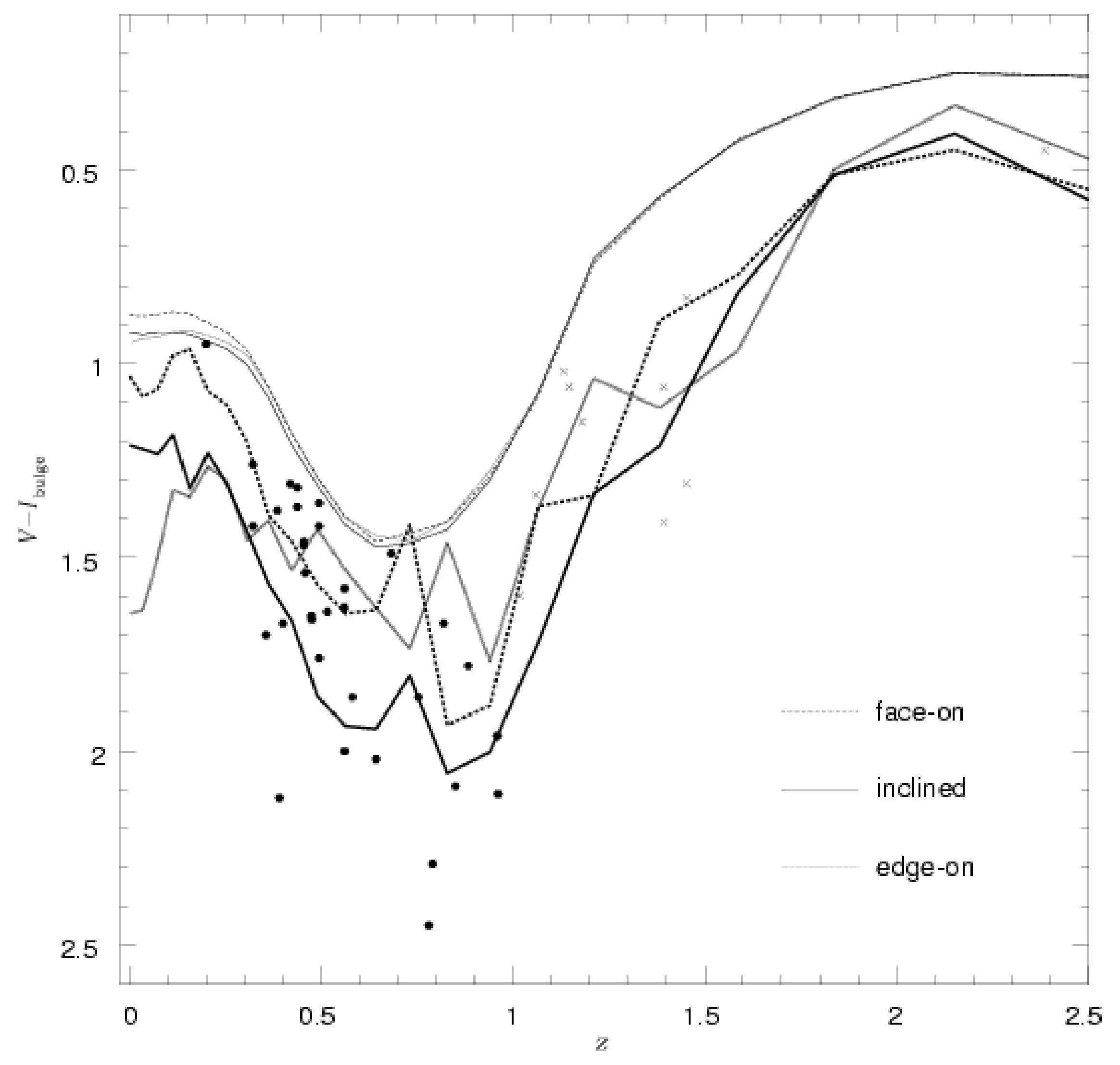
The model galaxy forms from inside-out and top-to-bottom;

inner bulge and halo first, outer disk last.



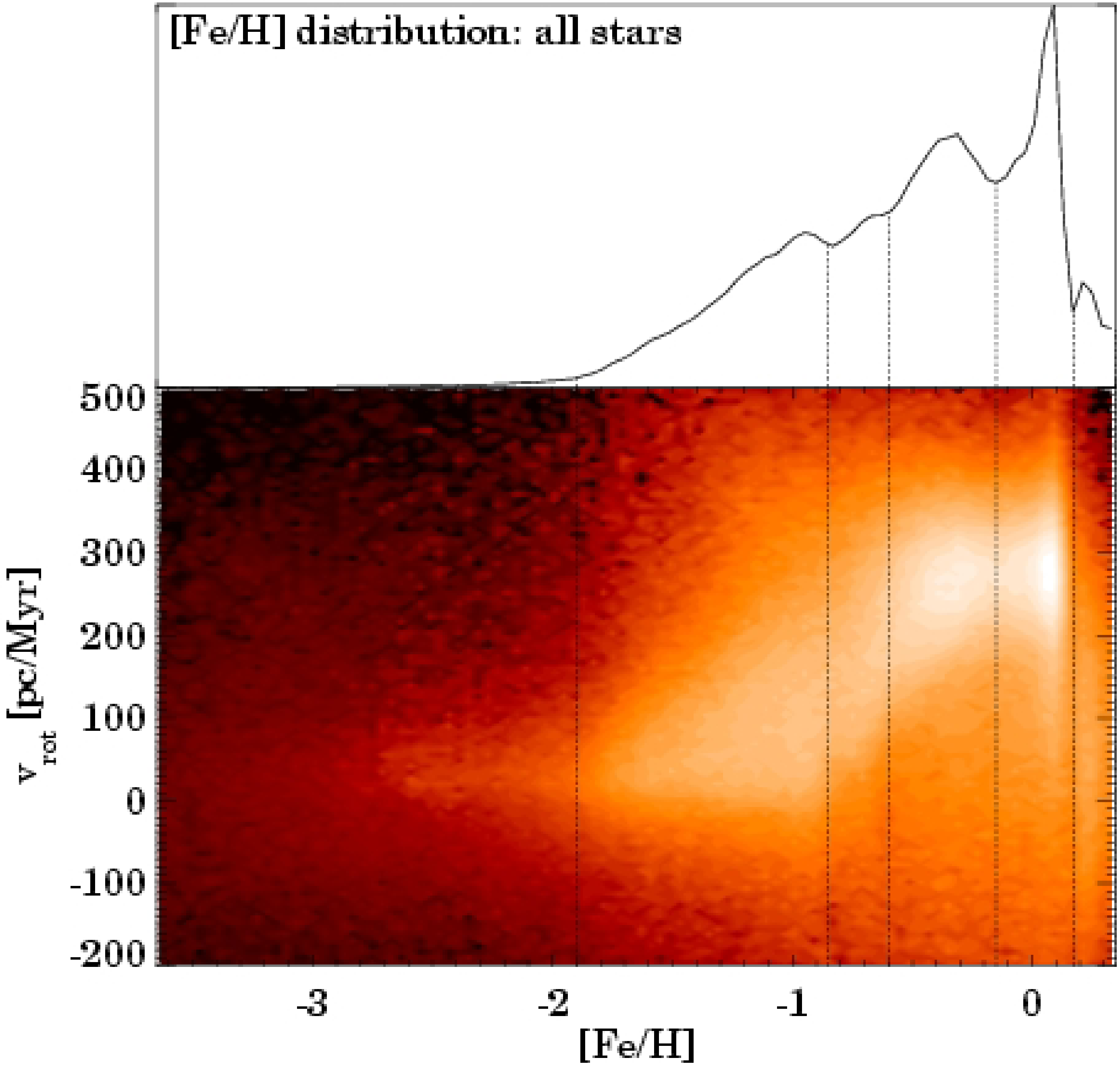
Comparison with Bulge Colours in HDF

HDF colours from
Ellis et al. 2001,
transformed to
standard V, I



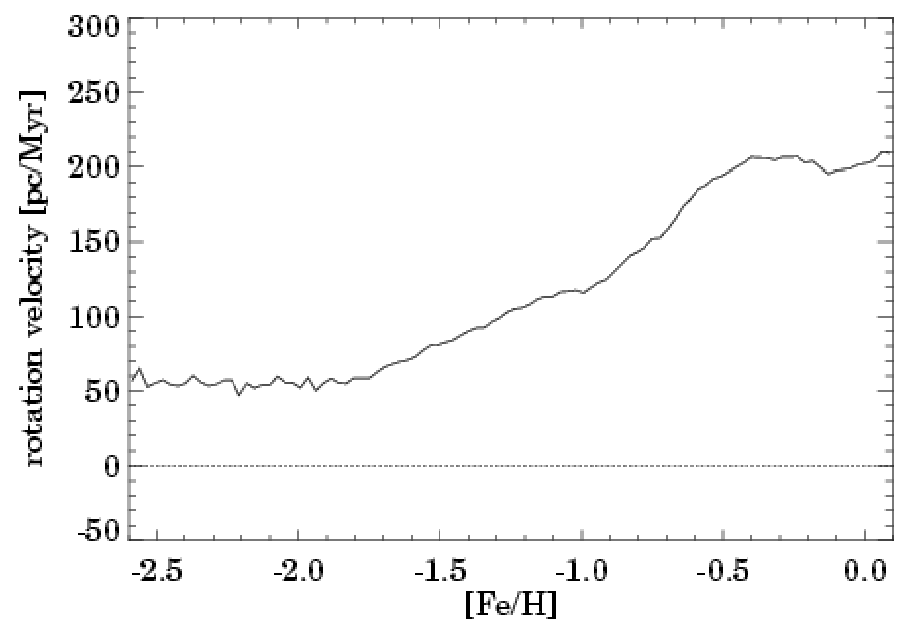
3. Stellar Populations and the Origin of the Galactic Halo

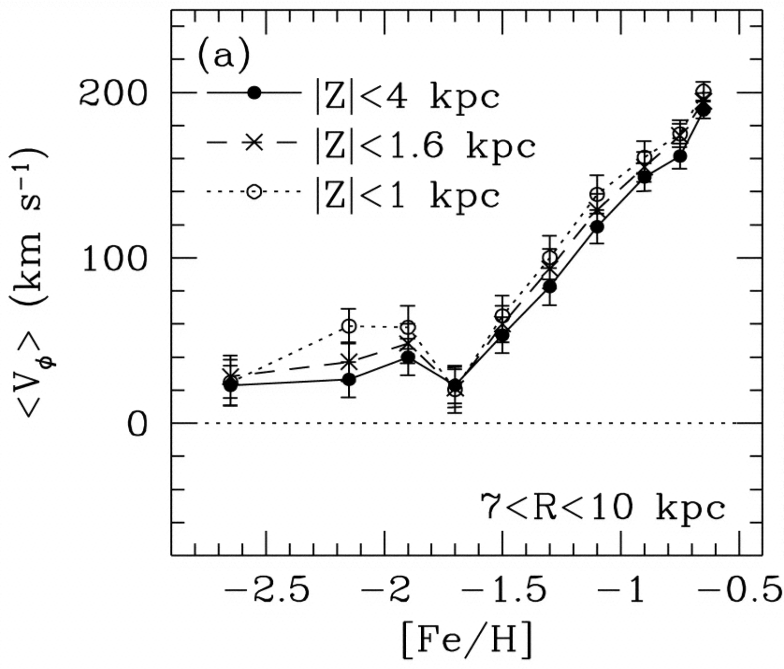
Rotation and Metallicity



Mean Stellar Rotation Velocity - [Fe/H]

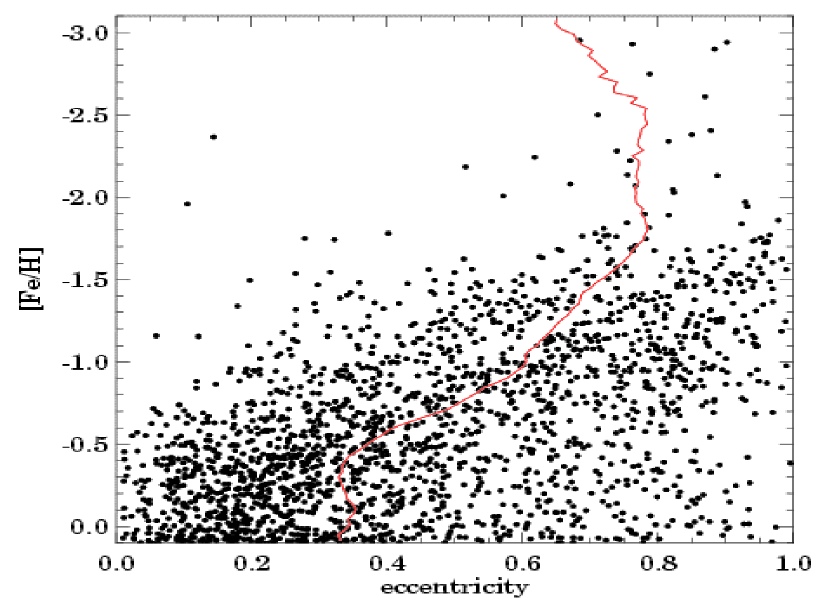
Multiphase Model
(Samland & Gerhard 2003)



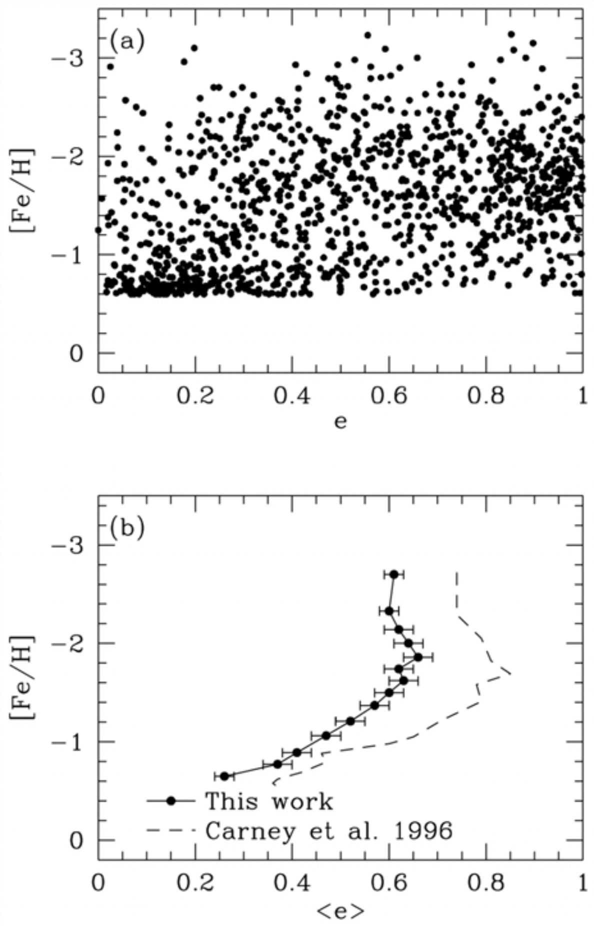


Milky Way Data
(Chiba & Beers 2000)

Stellar Orbital Eccentricities as a Function of Metallicity



Multiphase Model
(Samland & Gerhard 2003)



Milky Way Data
(Chiba & Beers 2000)

Results and Conclusions

- Interpreted chain galaxies and other unusual high-z morphologies as due to fragmenting highly dissipative, gas-rich, star-forming disks. Clump formation and merging to form central bulge.
- At lower cloud dissipation rate: more gradual build-up of stellar disk, bar instability after several Gyr, forming bulge from disk.
- Realistic disk galaxies can be formed. These grow from inside-out and from halo to disk. Sequence halo-bulge-thick disk-thin disk
- Predicted colours of the bulges consistent with HDF data. Predicted metal enrichment history broadly consistent with [Zn/H] in damped Lyα systems and metallicity distribution of Milky Way low mass stars.
- SN feedback important and delays collapse and maximum SFR to z=1. Inflow of cold gas and outflow of hot medium can spatially coexist.
- Dissipative collapse much more complicated than in simple monolithic scenarios (halo kinematics, preenrichment of the galactic disk, large-scale gas flows, feedback-delayed collapse)
- Modified interpretation of Galactic halo kinematics: most of the halo may have formed in a lumpy dissipative collapse, with only of order 10% added by late accretion of satellites

Future Work

Multiphase models as tool to simulate the dissipative formation of disk galaxies, to investigate kinematical, chemical and spectral properties, star formation history, gas, dust, wind outflows, morphology and photometric evolution as f(z), including Milky Way and others at z=0.

- Cosmological initial conditions, effects of small-scale structure
- Disk galaxy models of different mass and j(R)
- Comparison with galaxy observations at different z