The Star Formation Efficiencies of High-z Galaxies

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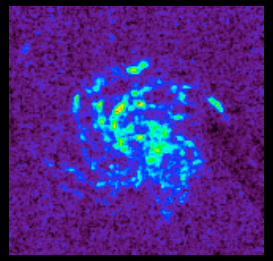
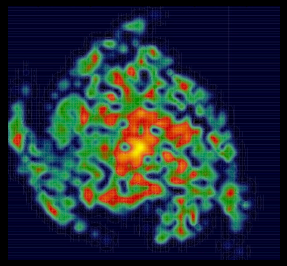
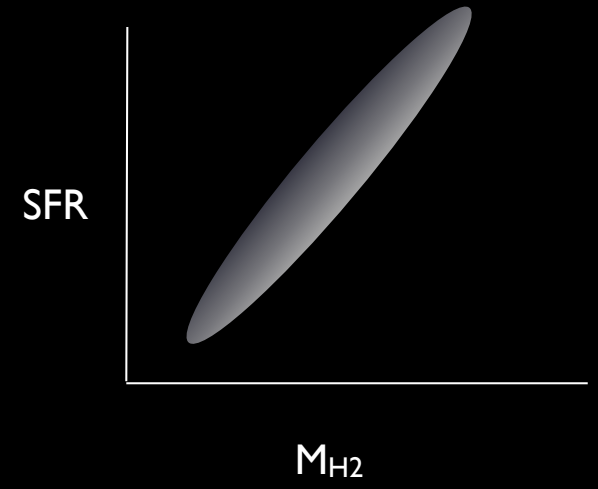
With: Mark Krumholz, Eve Ostriker, Lars Hernquist, Chris Hayward and others





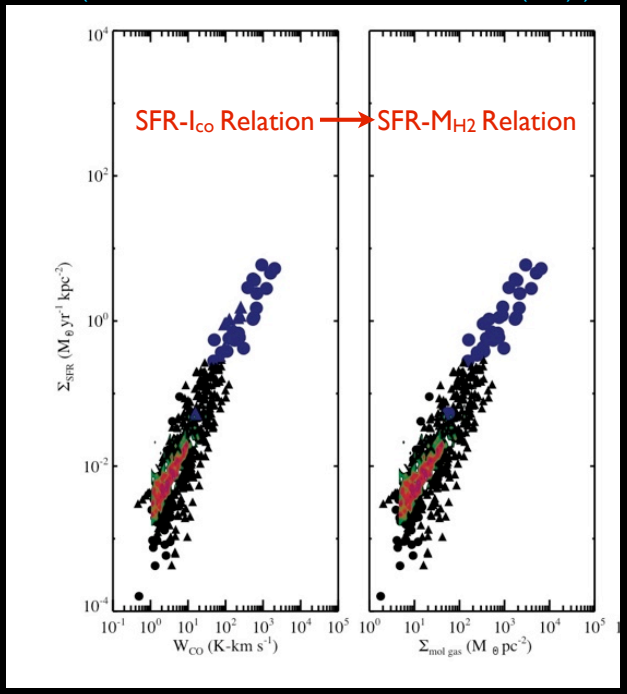
What does an SFE in a galaxy mean?
SFR/M_{H2}



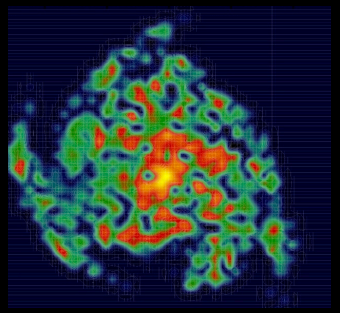
aka a "Kennicutt-Schmidt" Relation

constant SFE (SFR/M_{H2})

(if constant $CO\text{-}H_2$ conversion factor (X_{co}))

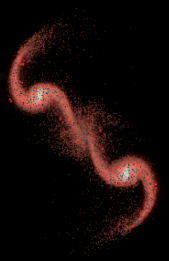


Kennicutt et al. 1998, Bigiel et al. 2008, Daddi et al 2010, Genzel et al. 2010



"Disk Value"

$X_{CO} \sim 2 \times 10^{20}$ cm^{-2}/K km s^{-1}



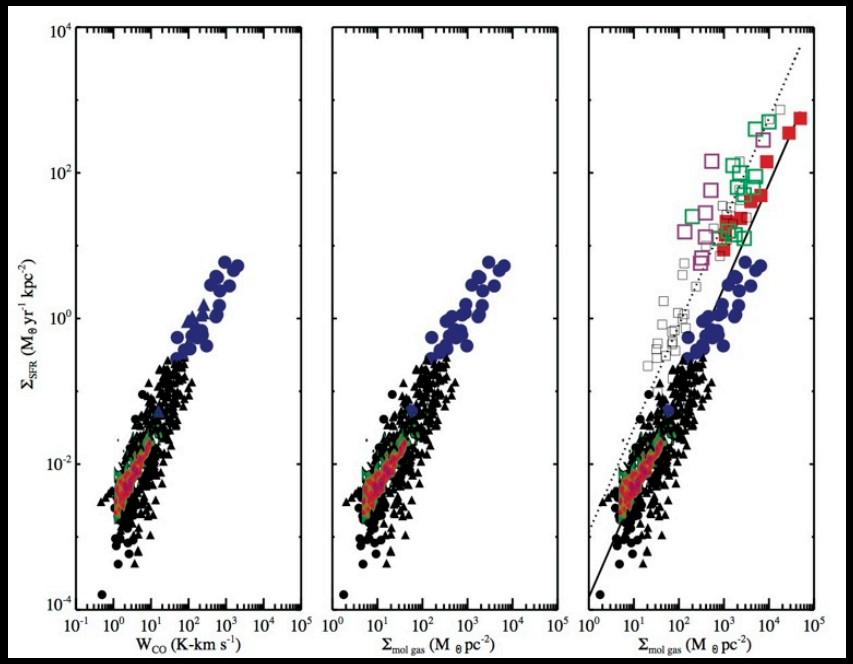
"Merger Value"

$X_{CO} \sim$ few $\times 10^{19}$ cm^{-2}/K km s^{-1}

In the last decade of literature, this is used bimodally

constant SFE (SFR/M_{H2})
(constant X_{co})

enhanced SFE in mergers
(bimodal X_{co})



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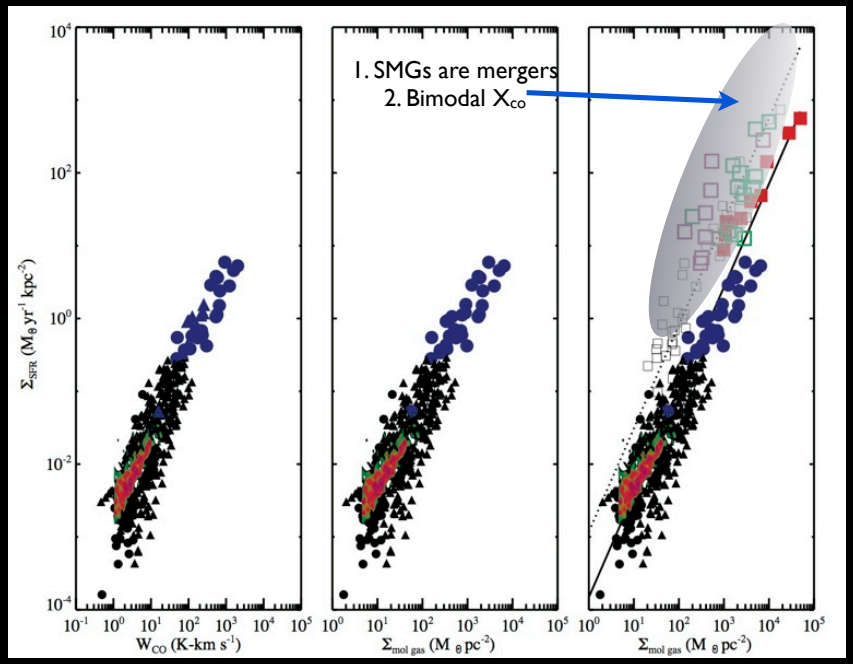
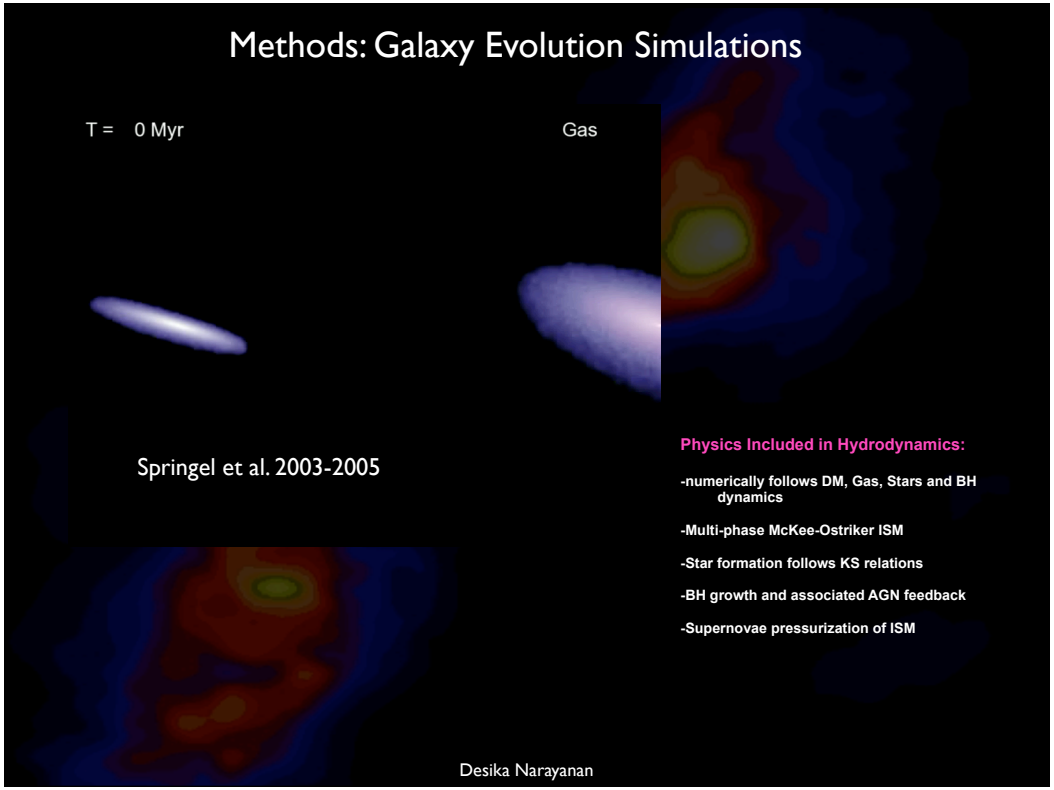


Kennicutt et al. 1998, Bigiel et al. 2008, Daddi et al 2010, Genzel et al. 2010

Methods: Galaxy Evolution Simulations



Springel et al. 2003-2005

Physics Included in Hydrodynamics:

- -numerically follows DM, Gas, Stars and BH dynamics
- -Multi-phase McKee-Ostriker ISM
- -Star formation follows KS relations
- -BH growth and associated AGN feedback
- -Supernovae pressurization of ISM

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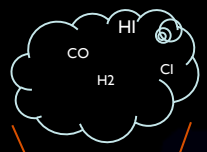
What do the molecules look like?



70 pc

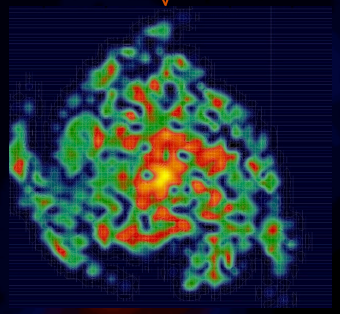
-H2-HI balance calculated by balancing growth of H2 on grains with LW band photodissociation (Krumholz, McKee, Tumlinson 2010)

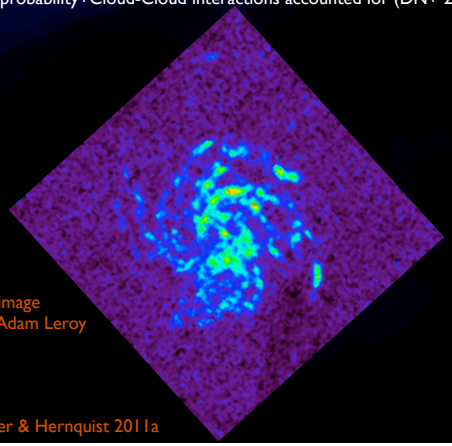
-CO-CI balance function of ISRF, Z (Wolfire et al. 2010)

-Temp calculated by balancing PE, CR heating, line cooling and thermal exchange with dust (Krumholz, Leroy, McKee 2011)

-Monte Carlo code: Calculates full statistical equilibrium of level populations in a 3D velocity, temp, density field (DN + 2006, 2008)

-Cloud Escape probability+Cloud-Cloud interactions accounted for (DN+ 2011)

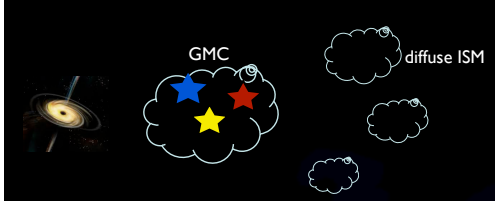


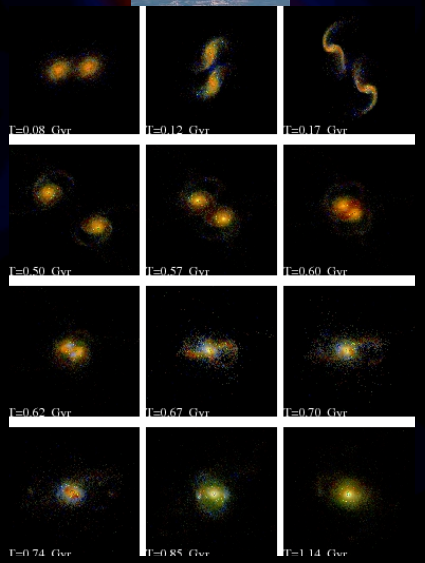


M101 image
provided by Adam Leroy

Narayanan, Krumholz, Ostriker & Hernquist 2011a

What do the Broadband Colors of the Galaxies look like?





Physics Included in Monte Carlo Dust RT

-Radiative Transfer of stellar and AGN spectrum
(starburst99 for stars and Hopkins+07 template for AGN)

-Dust radiative equilibrium

-Kroupa IMF, MW Dust to metals

Jonsson, Groves & Cox 2009

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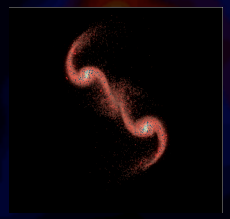
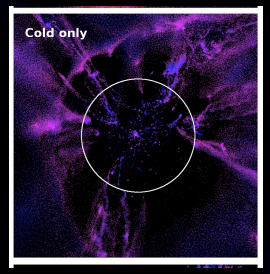
What Galaxies at High-z are Mergers? What are Disks? SMG formation as an example....

Baugh et al. 2005:
SMGs are mostly major and minor mergers with a flat IMF



Davé et al. 2010
SMGs are mostly discs fed by cold-flows with a "bottom light" IMF



(figure from Dusan Keres)

(more [hopefully] in Somerville's talk, Benson's talk)

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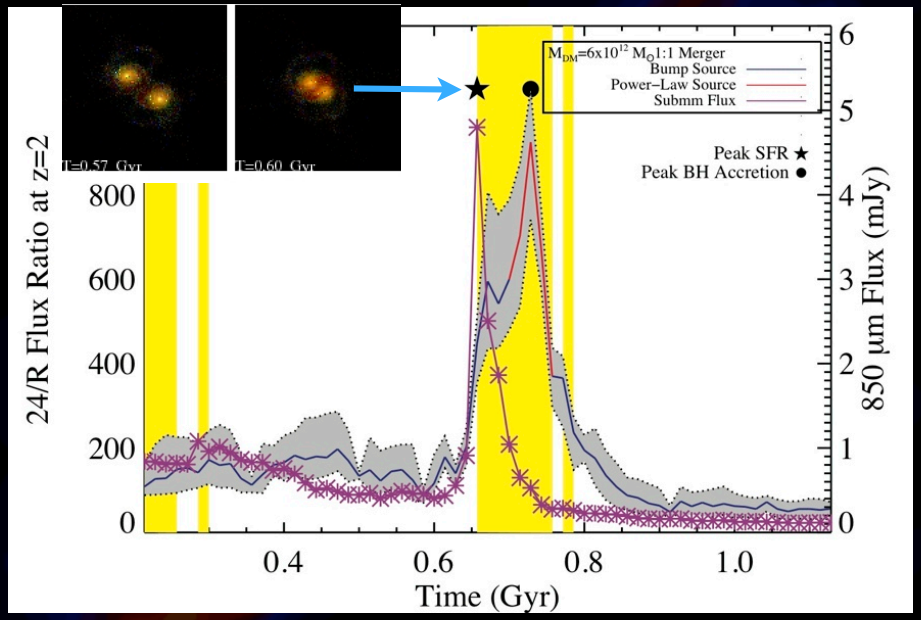
Submillimeter Galaxies are Major Mergers (in our model)



Narayanan et al. 2010
Hayward et al. 2011

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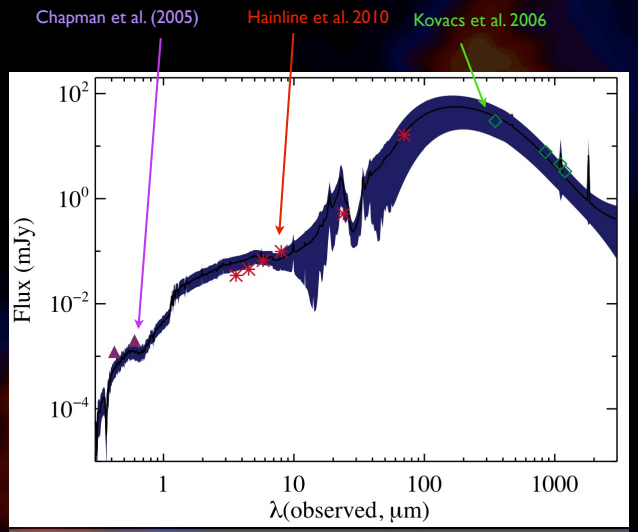
Merger Based Model for SMG Formation



Narayanan, Hayward, Cox et al. 2009
Narayanan, Cox, Hayward et al. 2010
Hayward, DN et al. in prep.

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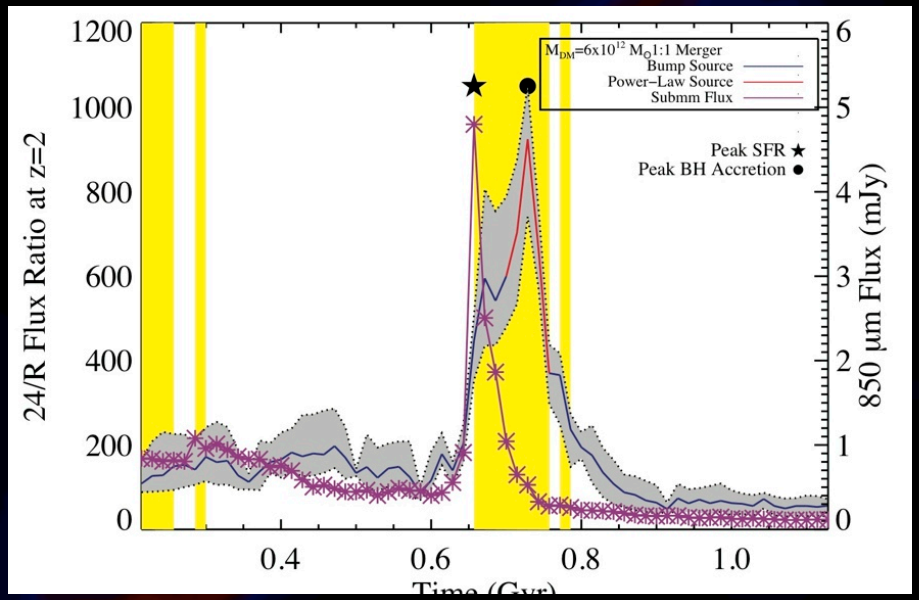
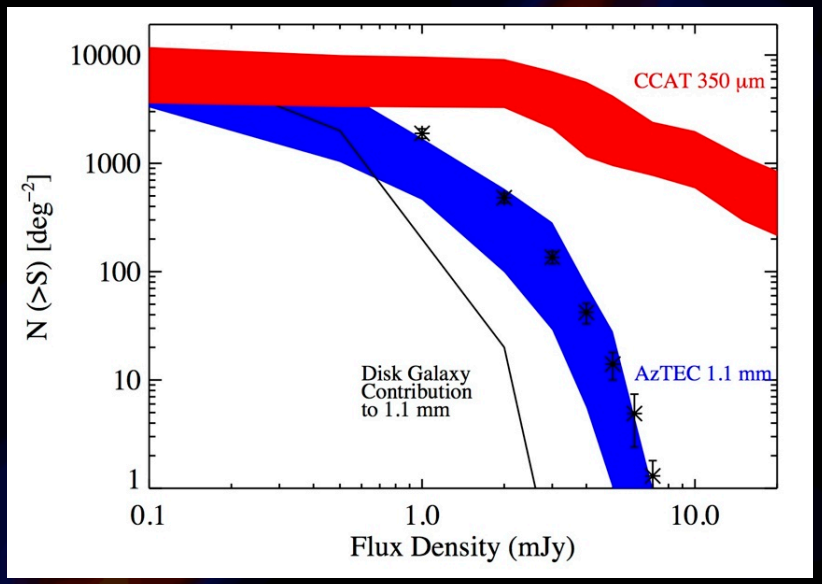
SMGs and 24μm sources in Evolution



Narayanan, Dey et al. 2010

Merger Based Model for SMG Formation Matches Number Counts



Hayward, Narayanan et al. in prep.

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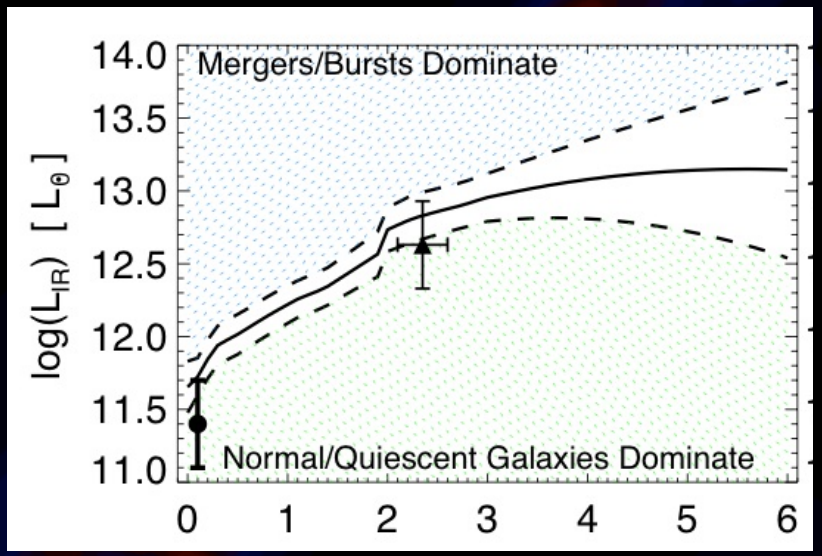
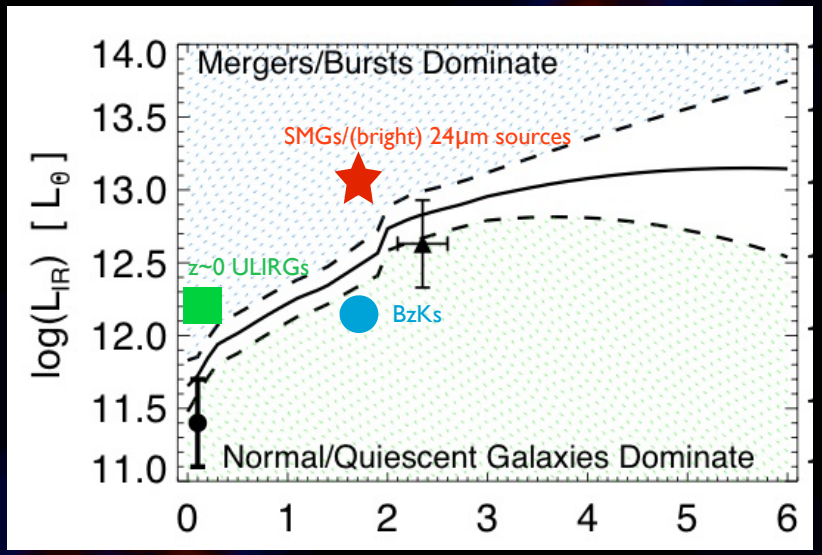
More Generally: When are galaxies at high-z mergers?



Hopkins, Younger, Hayward, DN, Hernquist 2010

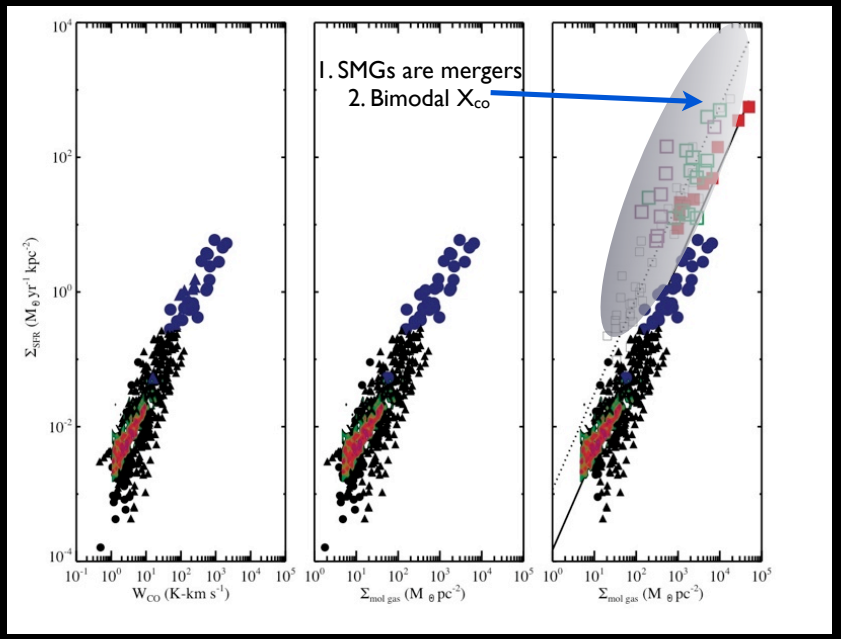
More Generally: When are galaxies at high-z mergers?



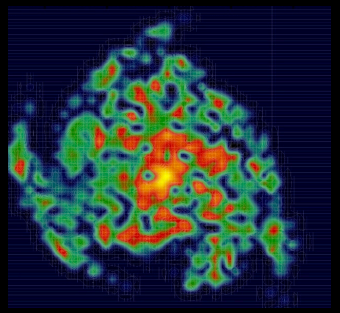
Hopkins, Younger, Hayward, DN, Hernquist 2010

constant SFE (SFR/M_{H2}) (constant X_{co})

enhanced SFE in mergers (bimodal X_{co})

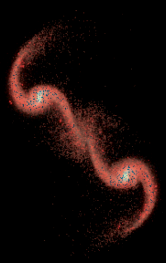


Kennicutt et al. 1998, Bigiel et al. 2008, Daddi et al 2010, Genzel et al. 2010



"Disk Value"

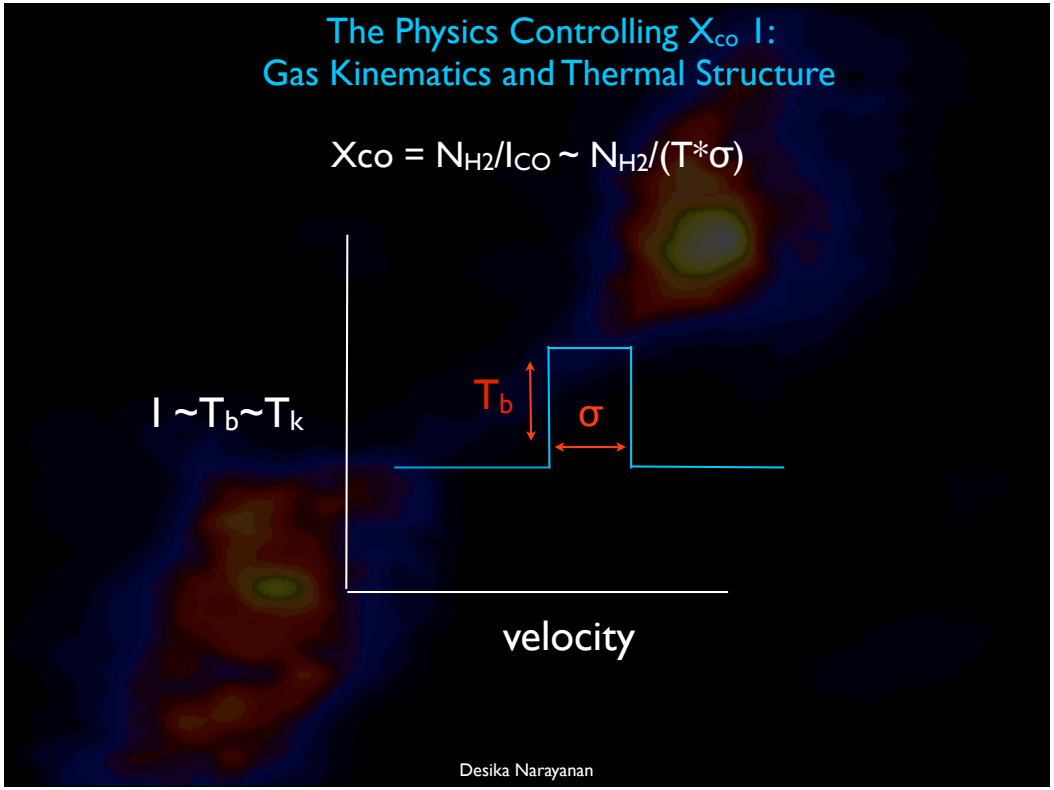
$X_{CO} \sim 2 \times 10^{20}$ cm^{-2}/K km s^{-1}



"Merger Value"

$X_{CO} \sim$ few $\times 10^{19}$ cm^{-2}/K km s^{-1}

(see poster and upcoming paper by Jonathan Armour)


The Physics Controlling Xco I:
Gas Kinematics and Thermal Structure
Xco = NH2/ICO ~ NH2/(T*σ)
I ~Tb~Tk
Tb
σ
velocity
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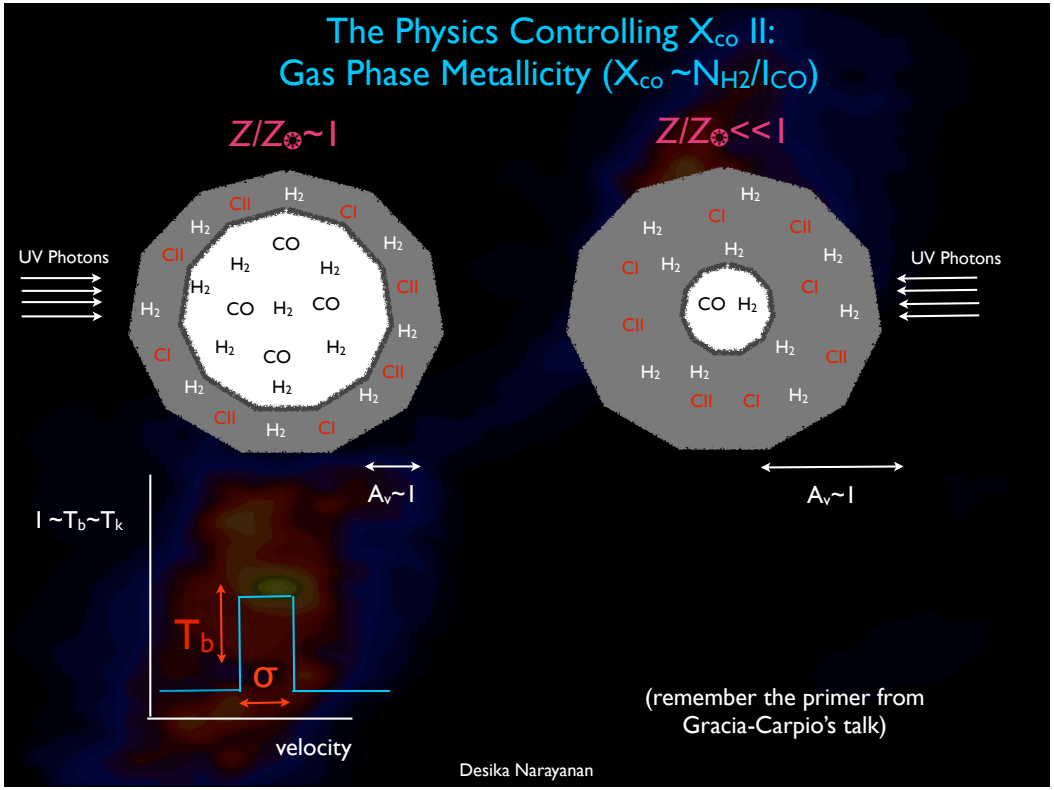
The Physics Controlling X_{co} II:
Gas Phase Metallicity (X_{co} ~N_{H2}/I_{CO})
$Z/Z_\odot$~1
$Z/Z_\odot$<<1
UV Photons
UV Photons
CII
CI
H_2
CO
A_v~1
A_v~1
I ~T_b~T_k
T_b
σ
velocity
(remember the primer from Gracia-Carpio's talk)
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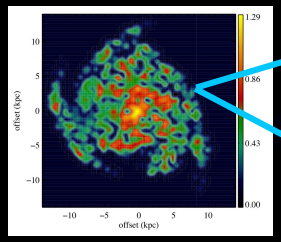
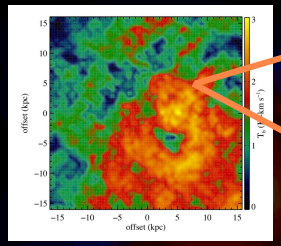
$X_{CO} = N_{H2}/I_{CO} \sim N_{H2}/(T*\sigma)$



$N_{H2} \sim 10^{22}$ cm^{-2}
T~ 10 K
σ ~ 5 km/s

Virialized GMCs unaffected by galactic environment

$X_{CO} \sim 2 \times 10^{20}$ cm^{-2}/K km s^{-1}

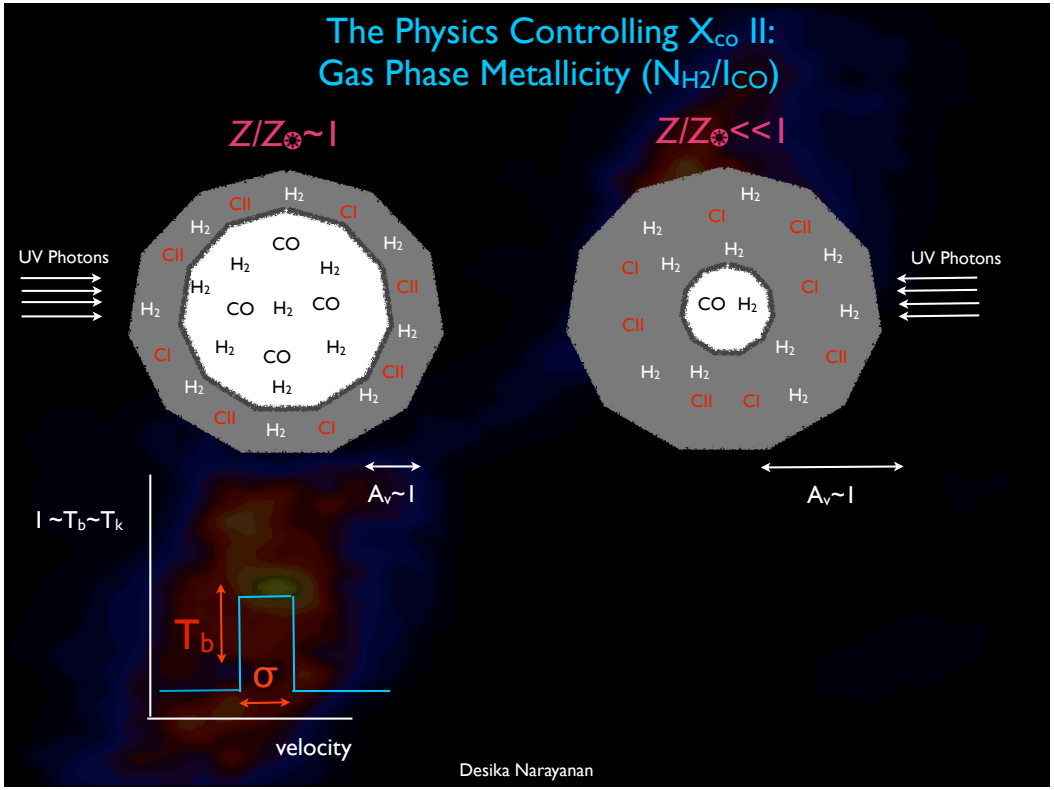


$N_{H2} \sim 10^{23}$ cm^{-2}
T~ 50 K
σ ~ 50 km/s

non-virialized GMCs strongly affected by galactic environment

$X_{CO} \sim$ few $\times 10^{19}$ cm^{-2}/K km s^{-1}

Narayanan, Krumholz, Ostriker & Hernquist 2011a


The Physics Controlling X_{co} II:
Gas Phase Metallicity (N_{H2}/I_{CO})
$Z/Z_\odot$~1
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UV Photons
UV Photons
CII
CI
H_2
CO
A_v~1
A_v~1
I ~T_b~T_k
T_b
σ
velocity
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This results in a relation between $X_{\rm CO}$, Z', and $\langle W_{\rm CO} \rangle$:

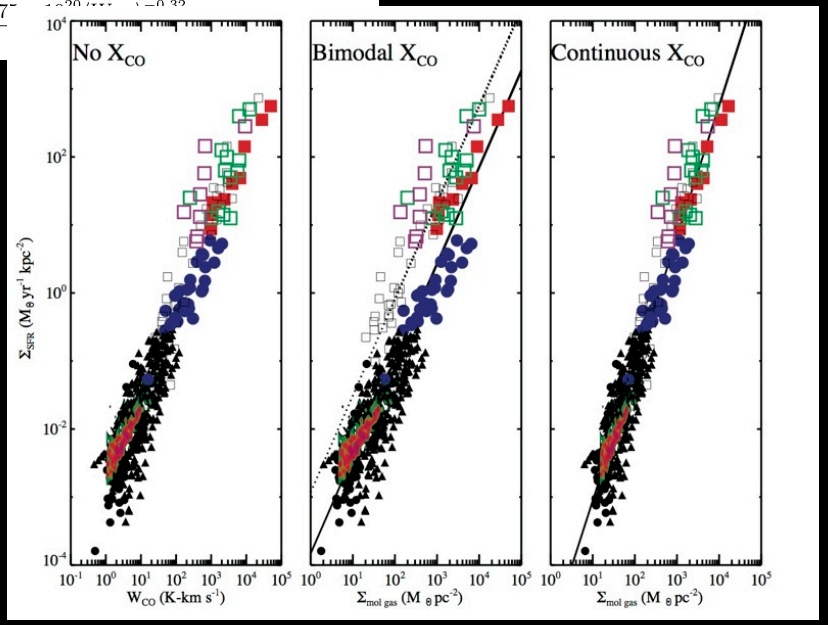
$$X_{\rm CO} = \frac{6.75 \times 10^{20} \langle W_{\rm CO} \rangle^{-0.32}}{Z'^{0.65}}$$

Narayanan, Krumholz, Ostriker, Hernquist 2011b...on astro-ph next week

This results in a relation between $X_{\rm CO}$, Z', and $\langle W_{\rm CO} \rangle$:

$$X_{\rm CO} = \frac{6.7}{}$$

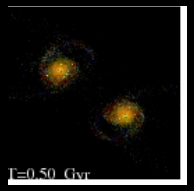
Narayanan, Krumholz, Ostriker, Hernquist 2011b

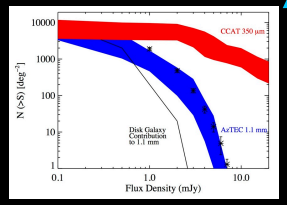


$\Sigma_{SFR} \sim \Sigma_{H2}^2$ unimodally

Summary

I.





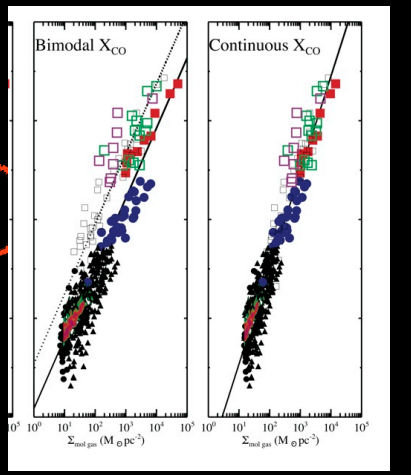
Merger-Driven Model for SMG formation works reasonably well

General model suggests that at z=2, mergers dominate Lum. function >10^{13} L

II.

$$X_{\rm CO} = \frac{6.75 \times 10^{20} \langle W_{\rm CO} \rangle^{-0.32}}{Z'^{0.65}}$$

Xco depends on galactic environment, though is not bimodal: no "merger" value and "disk" value



III.

On average, mergers form stars more efficiently than disks, though for a given set of physical conditions, they are no different