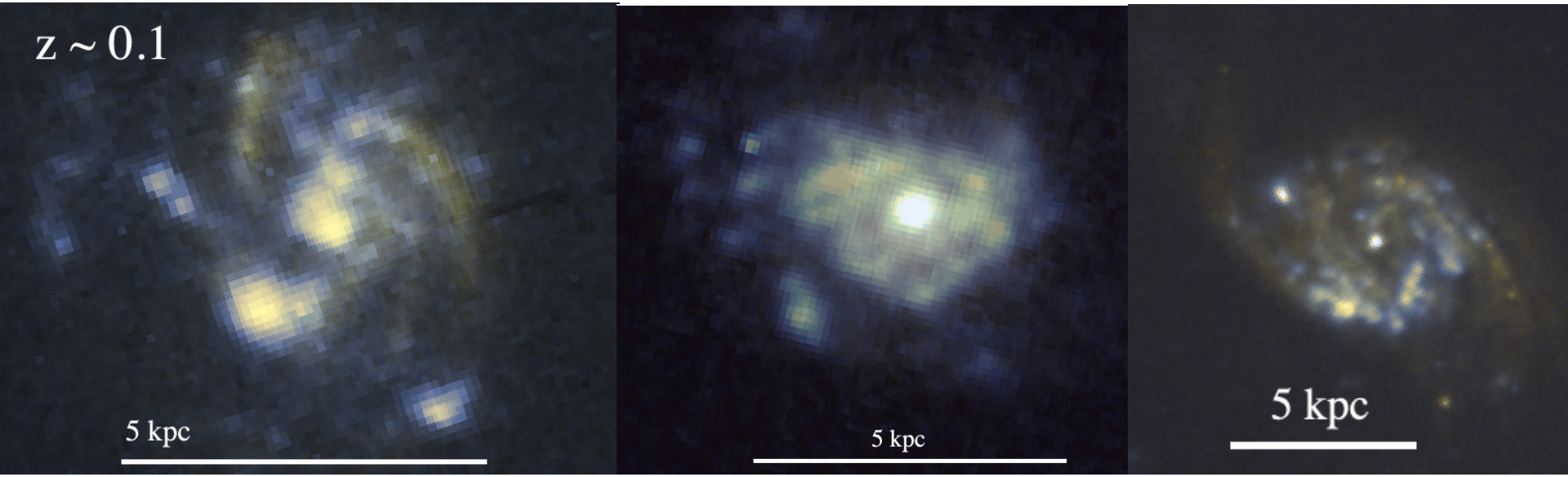
DYNAMO:
An up-close view of turbulent, clumpy galaxies

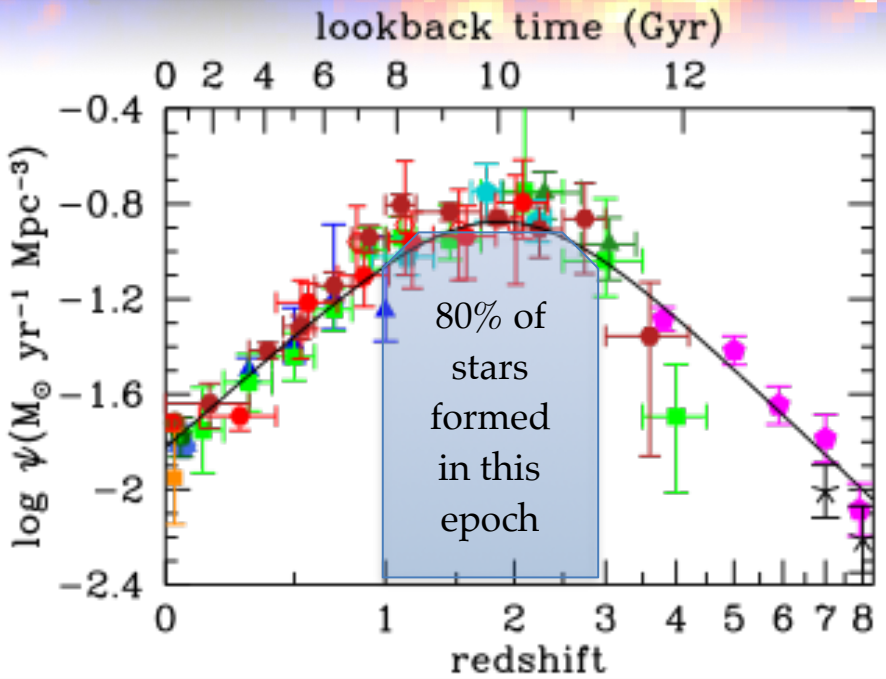


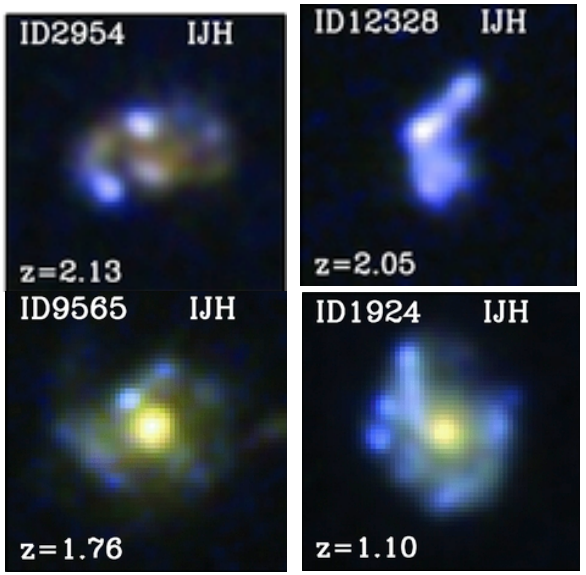
Deanne B Fisher

Swinburne University of Technology

Alberto Bolatto, Karl Glazebrook, Heidi White, Laura Lenkic, Isabella Lamperti, Liyu Tilahun, Ivana Damjanov, Emily Wisnioski, Rob Bassett, Andy Green, Bob Abraham, Danail Obreschkow,

Most galaxies at the peak of star formation are VERY clumpy, turbulent disks.



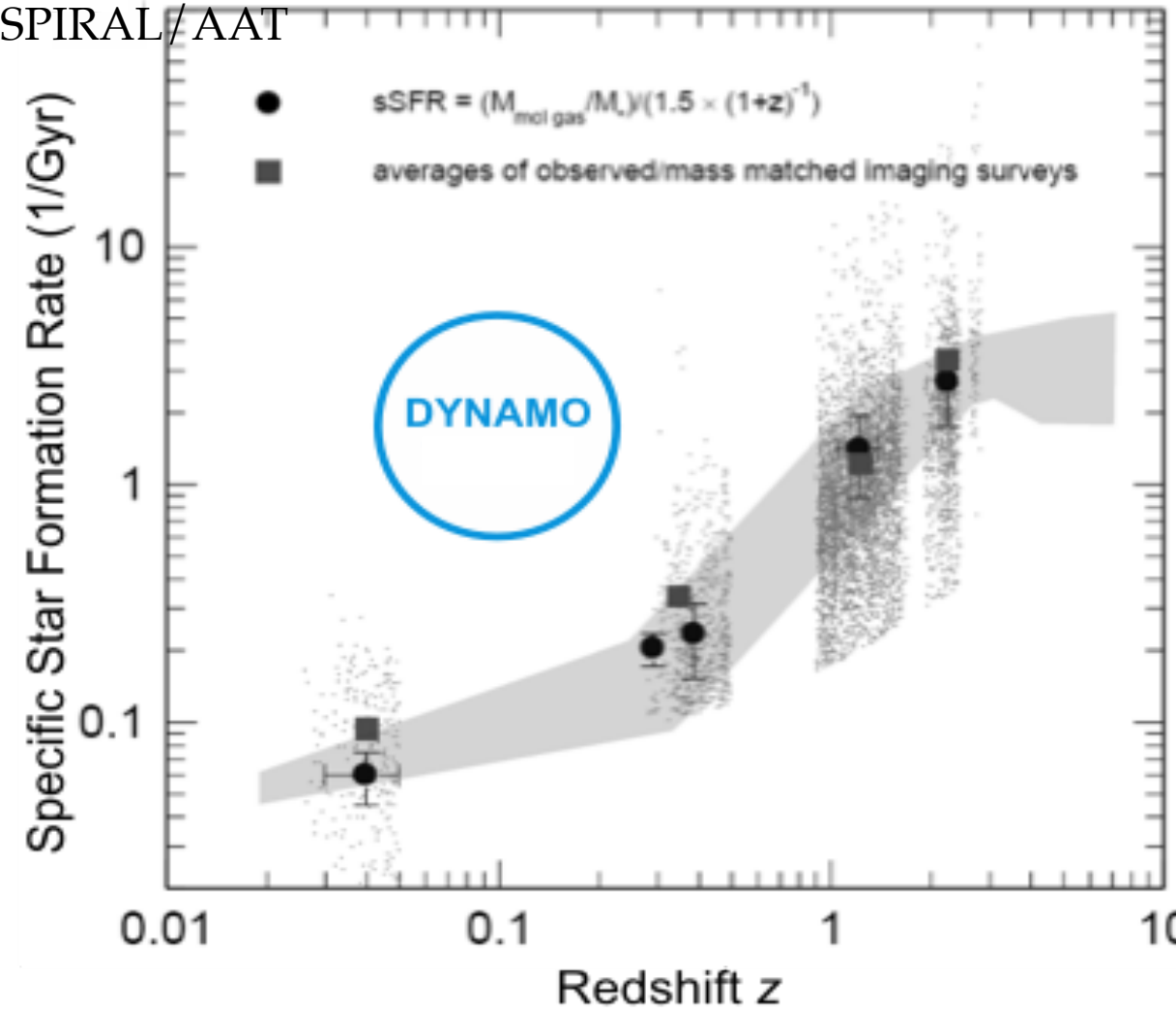


This means we have a problem, because the properties of individual clumps are very difficult to observe at this distance.

Genzel et al. 2011, Jones et al 2010, Elmegreen & Elmegreen 2005, Wisnioski et al. 2012, Swinbank et al 2012, Livermore et al 2012,2015, Forster-Schreiber et al 2009, Guo et al 2012,2015,2018, …

DYNAMO galaxies are similar to z≈1 main-sequence galaxies

Green et al (2010,2014): ~100 galaxies with IFS Hα data from WiFES/2.3-m and SPIRAL/AAT



Turbulent gas: σ=20-80 km/s

Gas Rich: f_{gas}=10-70%

Star Forming: 10-100 $M_{\odot}yr^{-1}$

Massive: M_*~ $3x10^{10}$ $M_{\odot}$

Compact: $R_{1/2}$= 1-3 kpc

Disks: Rotating & Exponential

T_{dust}=20-30 K

DYNAMO Galaxies Resemble Turbulent Disks

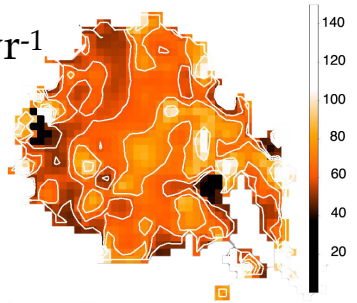
Keck OSIRIS Pa α

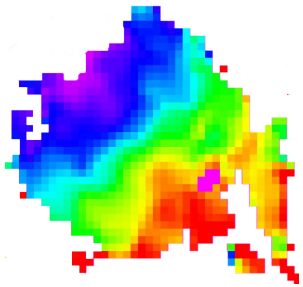
Dispersion

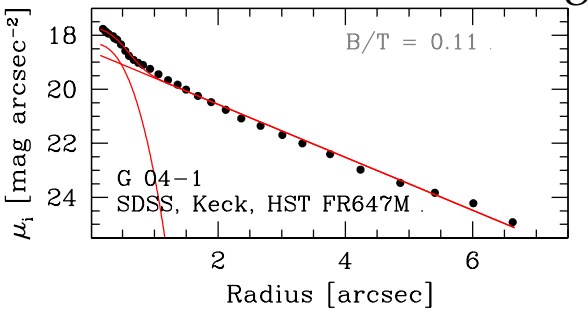
Rotation

Stellar Surface Brightness

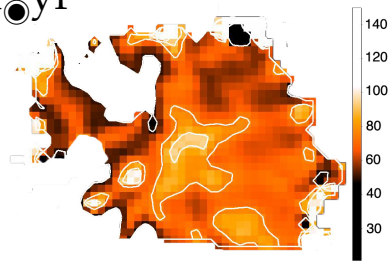
SFR≈ 40 $M_\odot yr^{-1}$

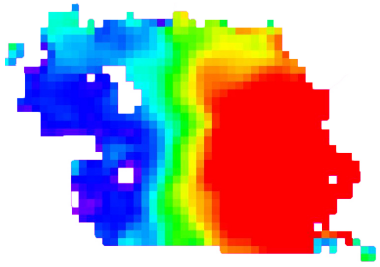


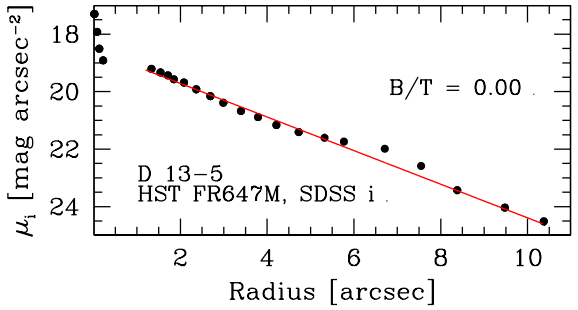




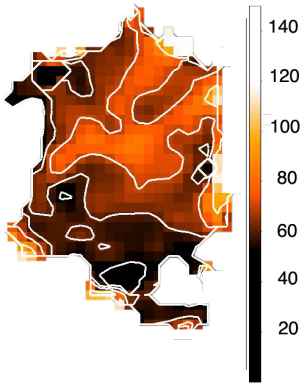
SFR≈ 22 $M_\odot yr^{-1}$

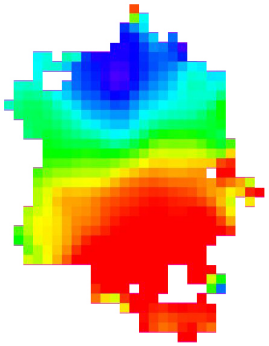


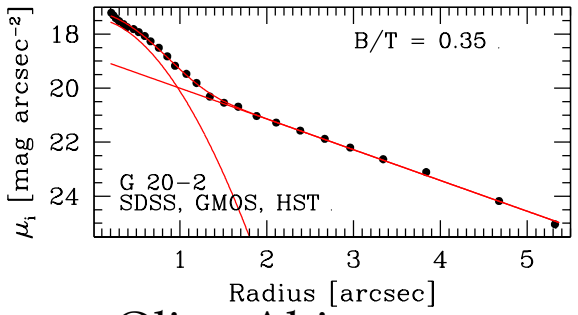




SFR≈ 18 $M_\odot yr^{-1}$

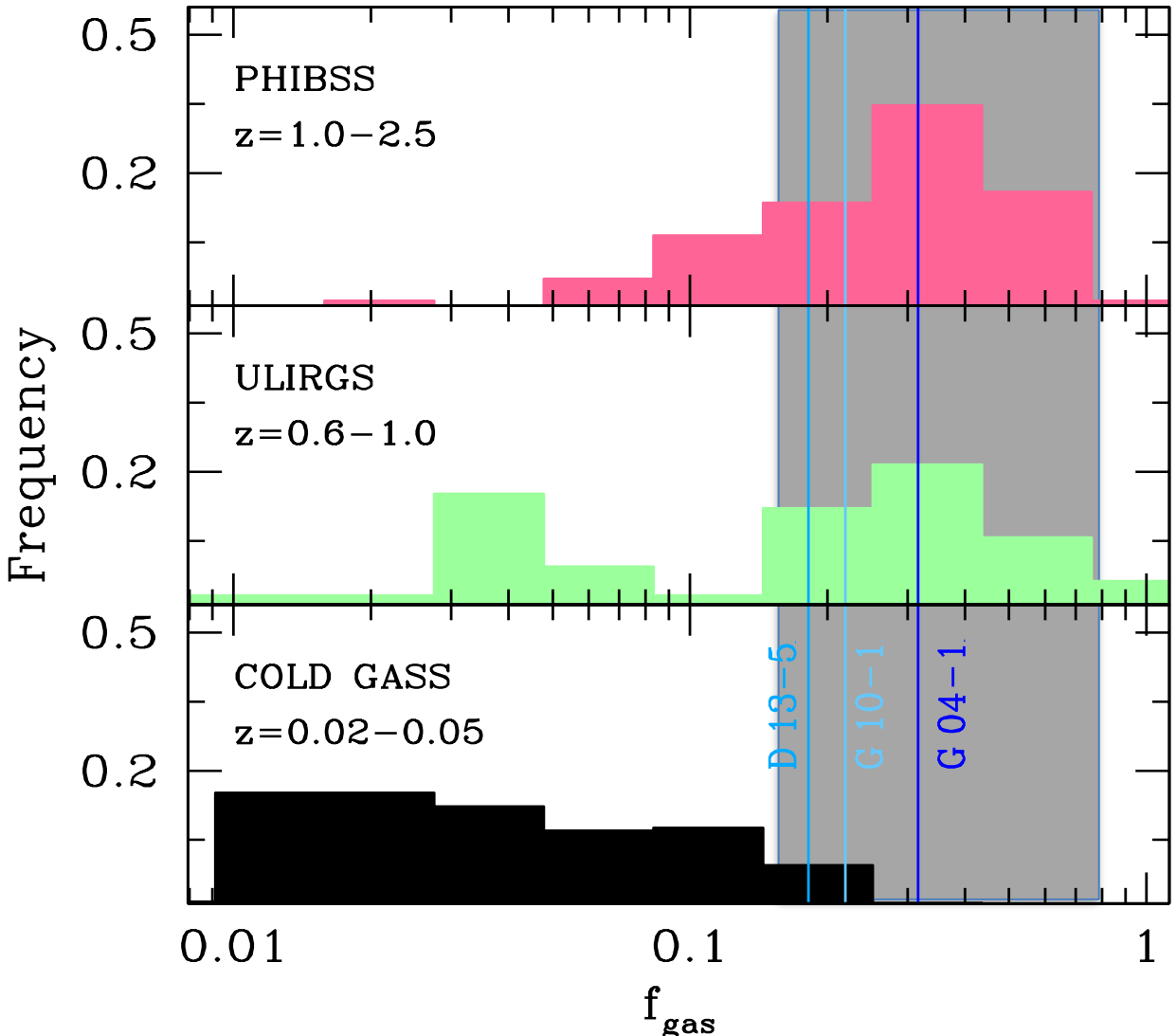






Oliva-Altimarano et al (2018)

DYNAMO galaxies are very gas rich



Fisher et al. 2014; White et al 2017

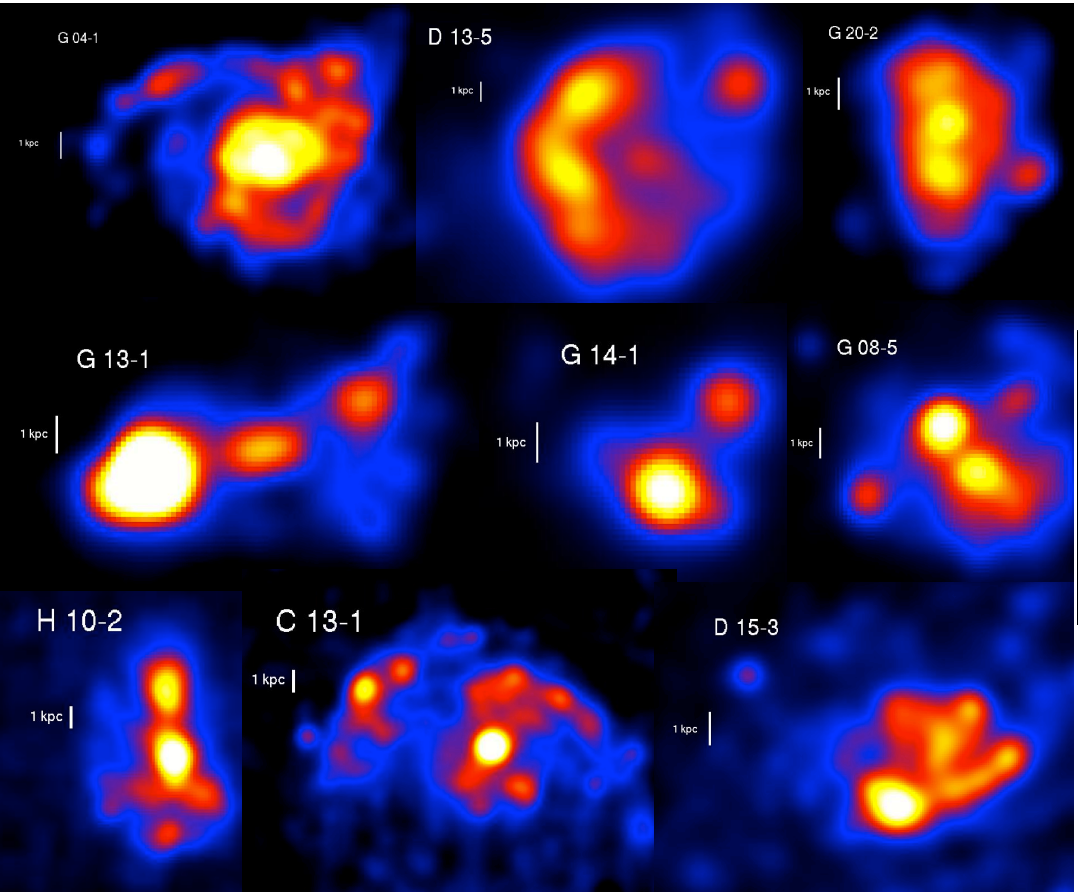
CO(1-0) & Hercschel: **f_{gas}=15-80%.**

Herschel Observations: **T_{dust}=20-30 K**

Recent ALMA Data: **R_{31}= 0.4-1.0**

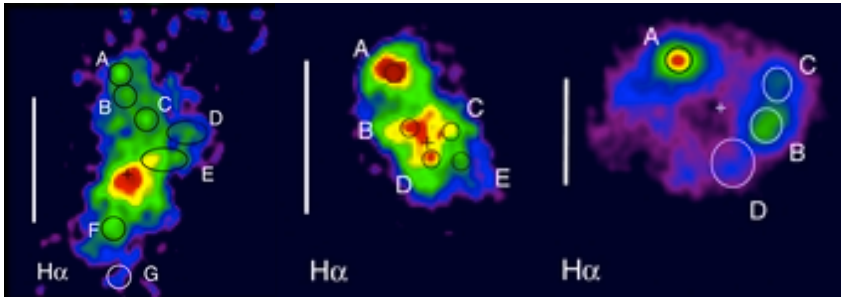
DYNAMO Galaxies Look Like High-z Clumpy Galaxies

DYNAMO Blurred to z=2

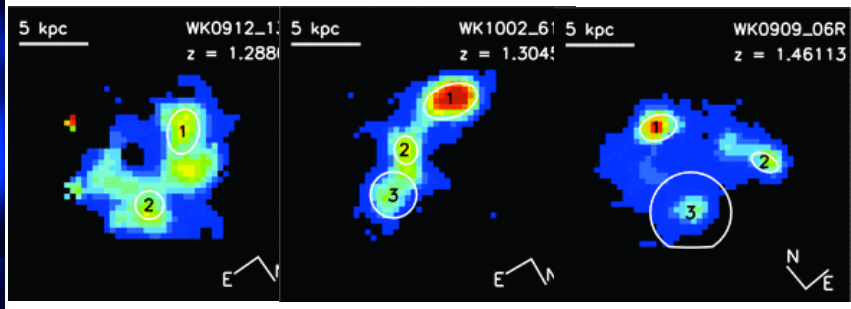


Fisher et al (*2017 MNRAS*)

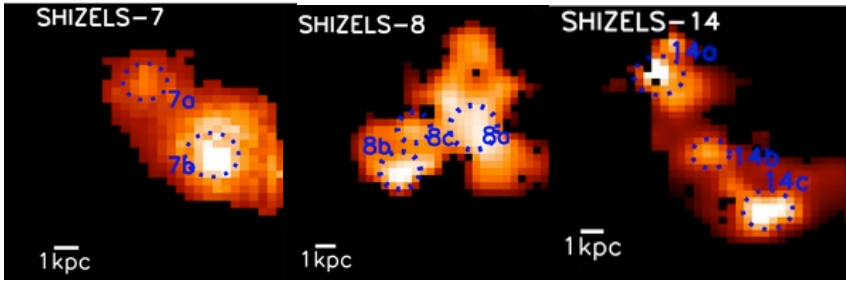
Genzel et al. (2011)

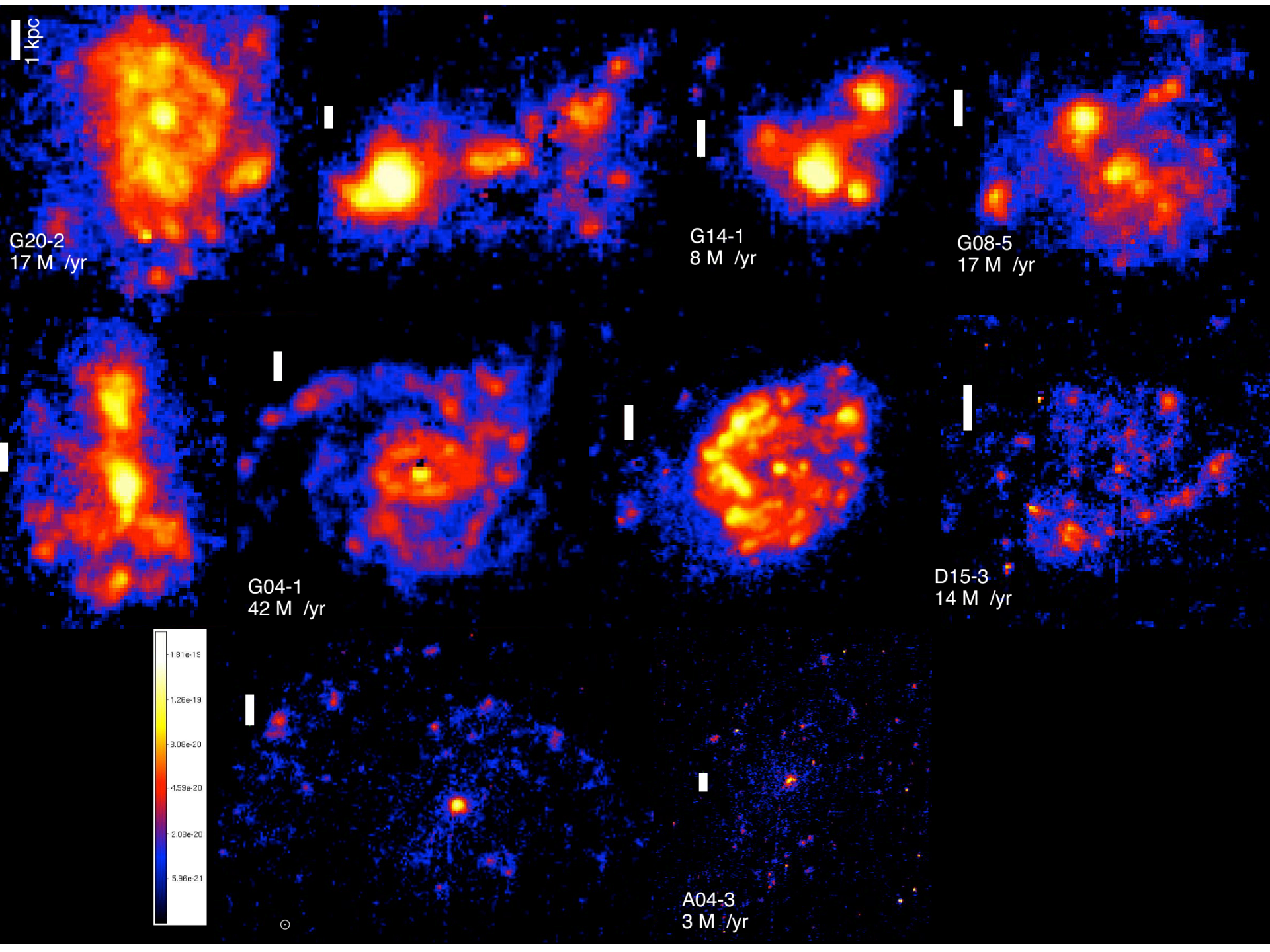


Wisnioski et al. (2012)

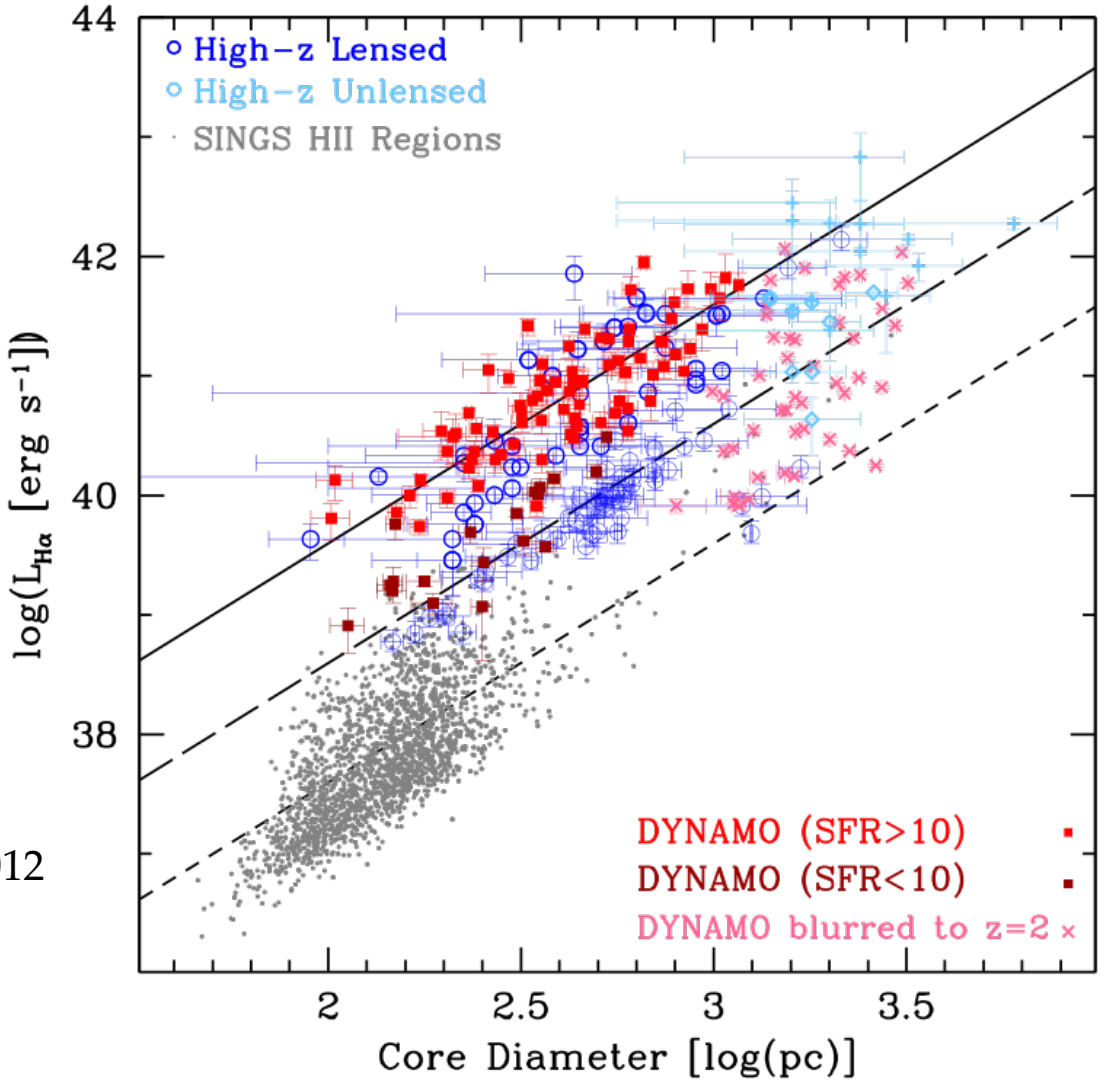


Swinbank et al. (2012)




1 kpc
G20-2
17 M /yr
G14-1
8 M /yr
G08-5
17 M /yr
G04-1
42 M /yr
D15-3
14 M /yr
A04-3
3 M /yr
1.81e-19
1.26e-19
8.08e-20
4.59e-20
2.08e-20
5.96e-21

DYNAMO clumps are big and bright, consistent with high-z clumps.

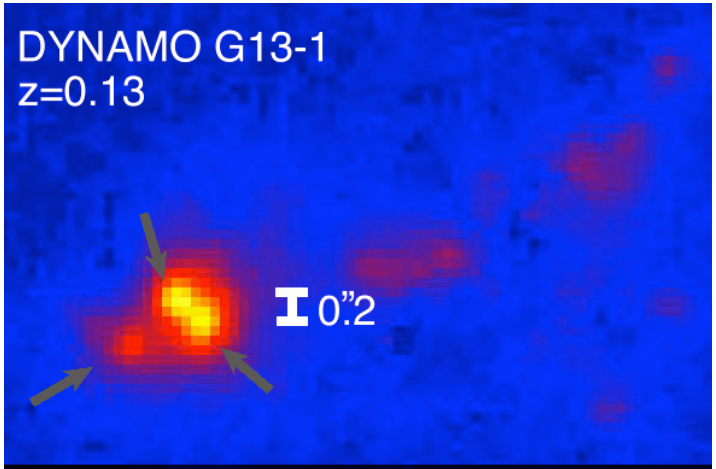


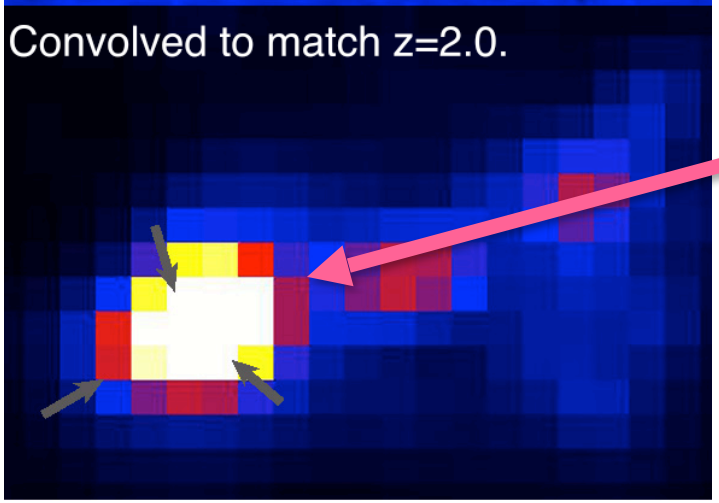
DYNAMO:
Fisher et al (2017)

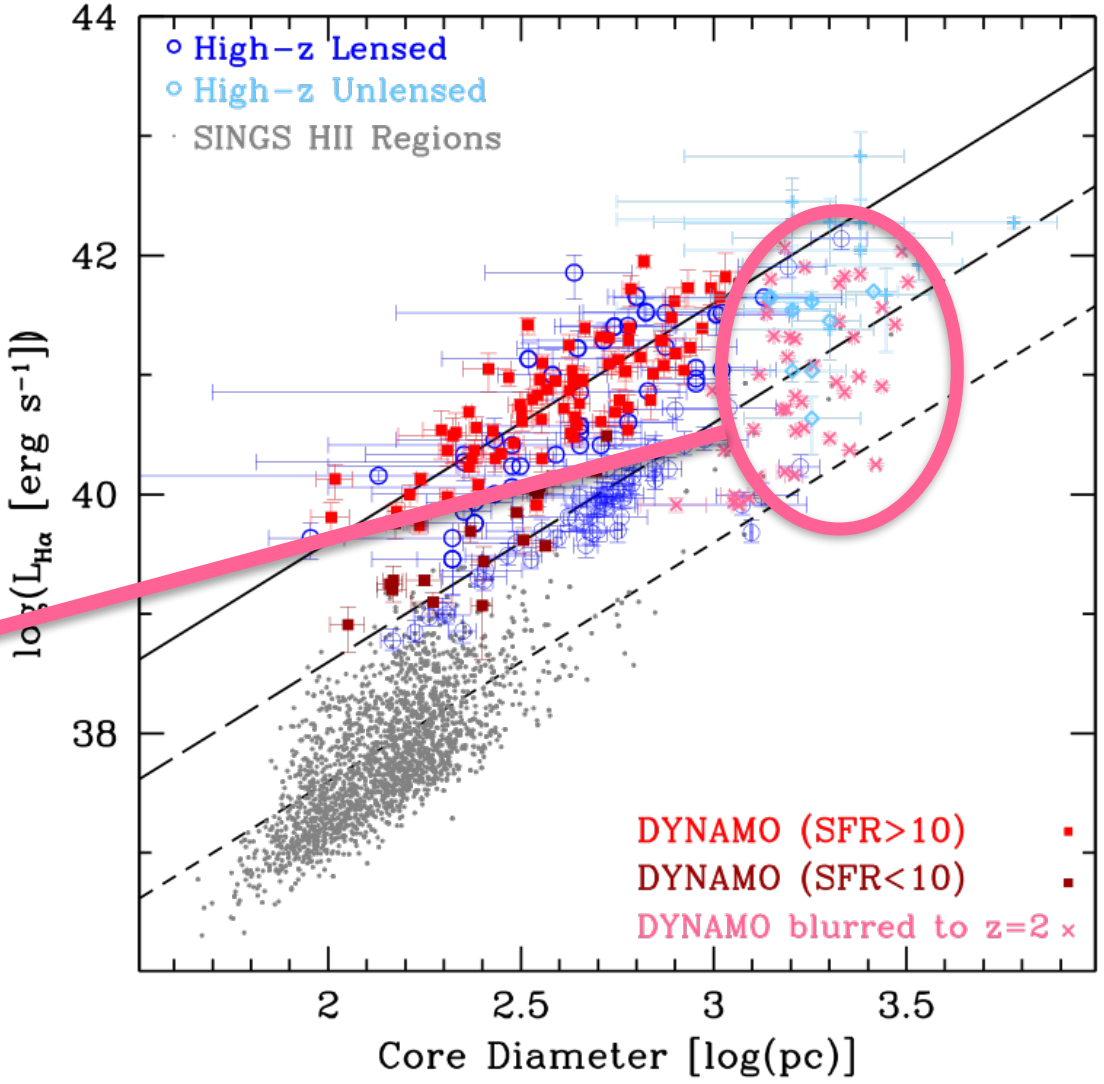
Unlensed high-z:
Genzel et al. 2011 Wisnioski et al. 2012
Swinbank et al. 2012

Lensed high-z:
Livermore et al. 2012,2015

The largest clumps at z=2 resolution are associated with sets of clumps.

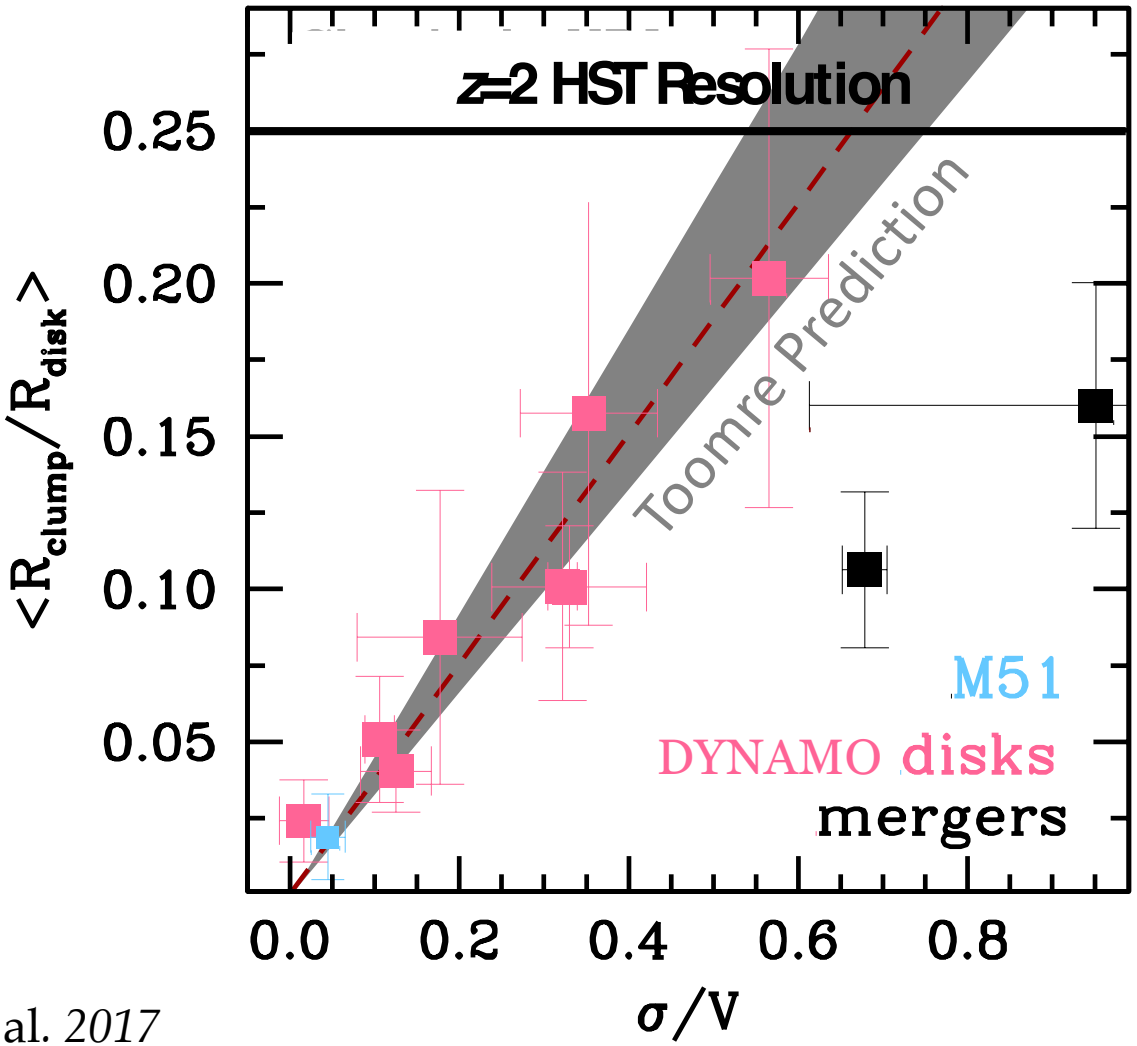






DYNAMO clumps agree with direct predictions from unstable disk model.

Strong, linear correlations of clump size with σ/V (and not shown



Also White et al 2017 find correlation of f_{gas}- σ/V

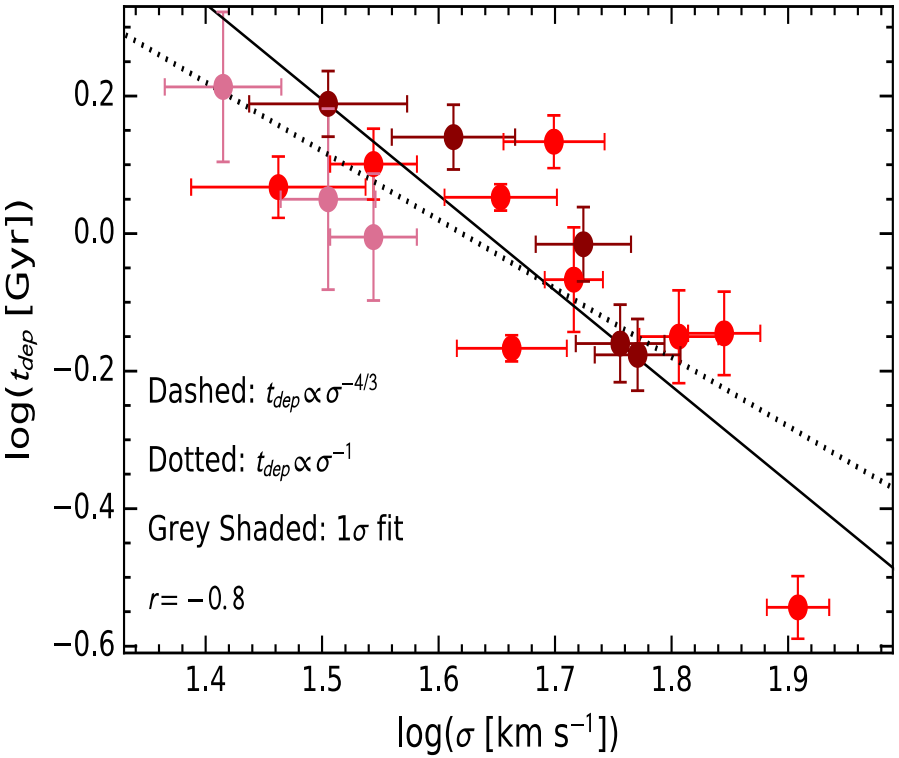
Fisher et al. *2017*

Qualitative consistency with Star Formation Feedback Theory

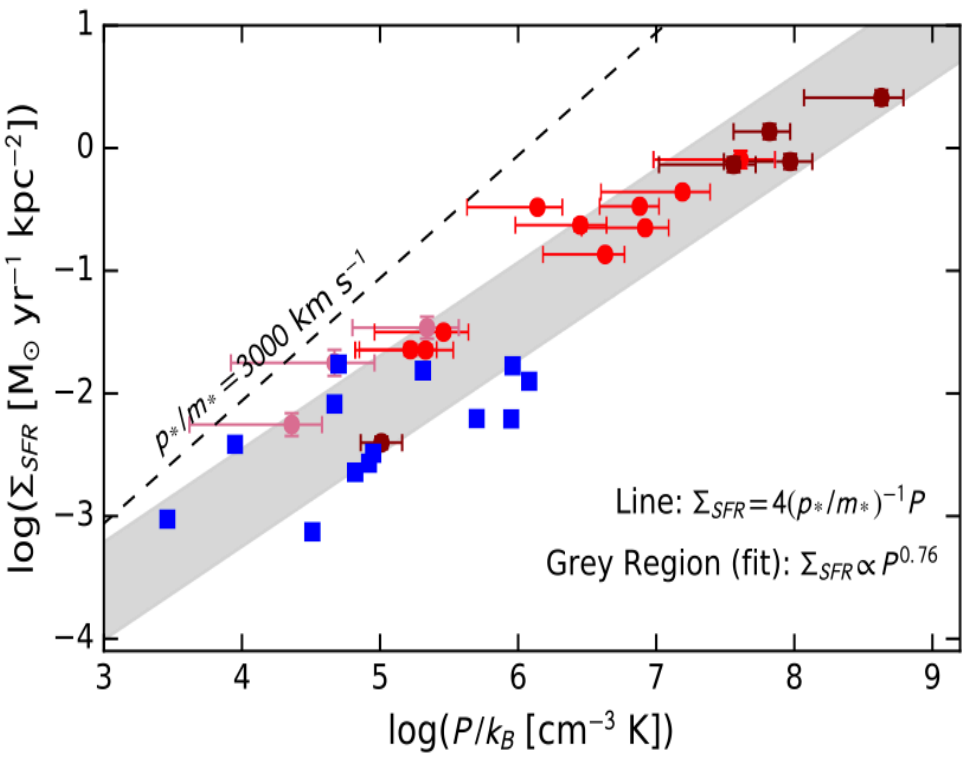
Predicted scaling relations of SF Regulated Feedback Theory

(Ostriker et al 2011, Shetty & Ostriker 2012, Faucher-Gigere et al. 2013, …):

$t_{dep} \propto \sigma^{-1}$



$\Sigma_{SFR} \propto P$



… but not fully a *quantitative* success

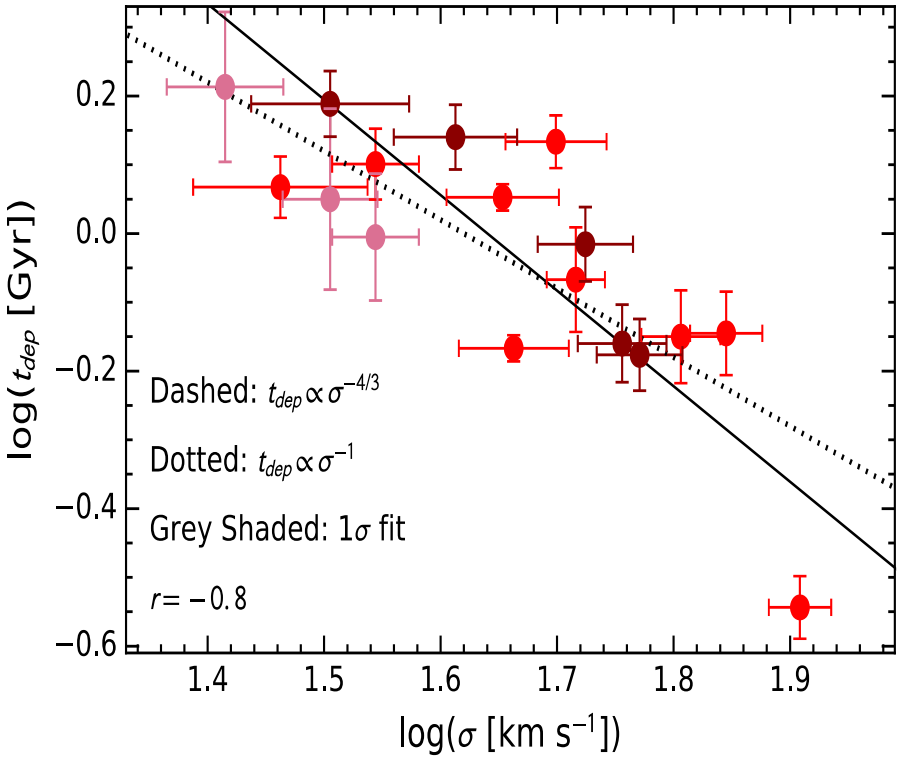
$p_* / m_* \sim 2.7\ (t_{dep}/ t_{ff})\ \sigma$

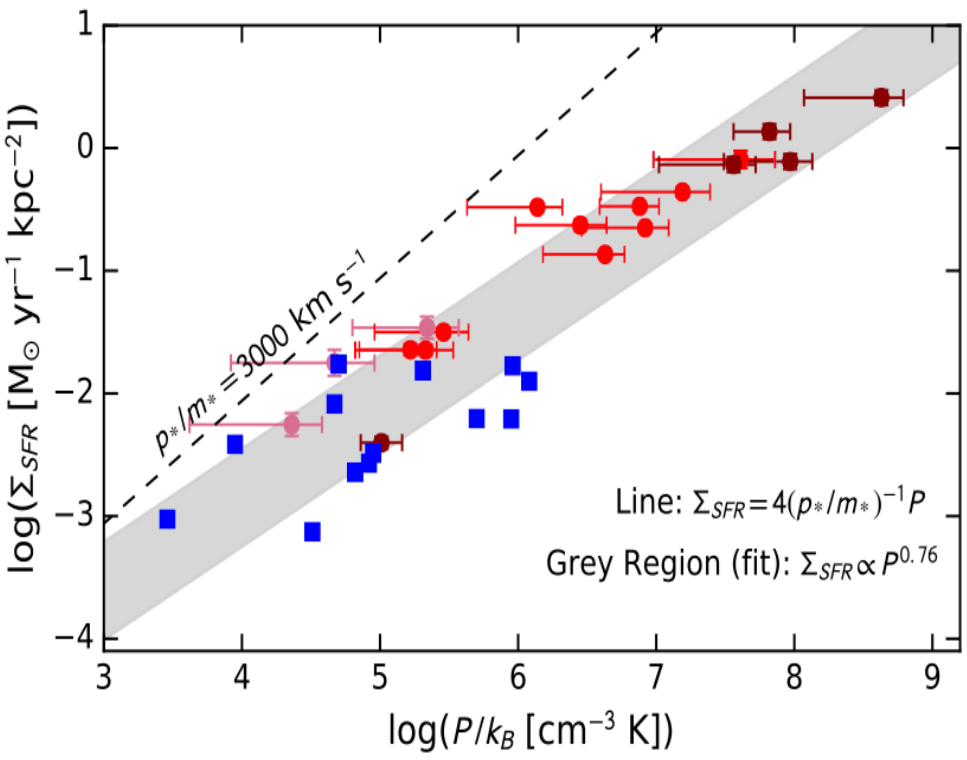
$p_* / m_* \sim 4\ P / \Sigma_{SFR}$

Simulations & Models: 3000 km s^{-1}

Low Pressure Disks (local spirals): 3000 - 10^4 km s^{-1}

High Pressure Disks (z ~ 1 main sequence): 10^4 - 10^5 km s^{-1}

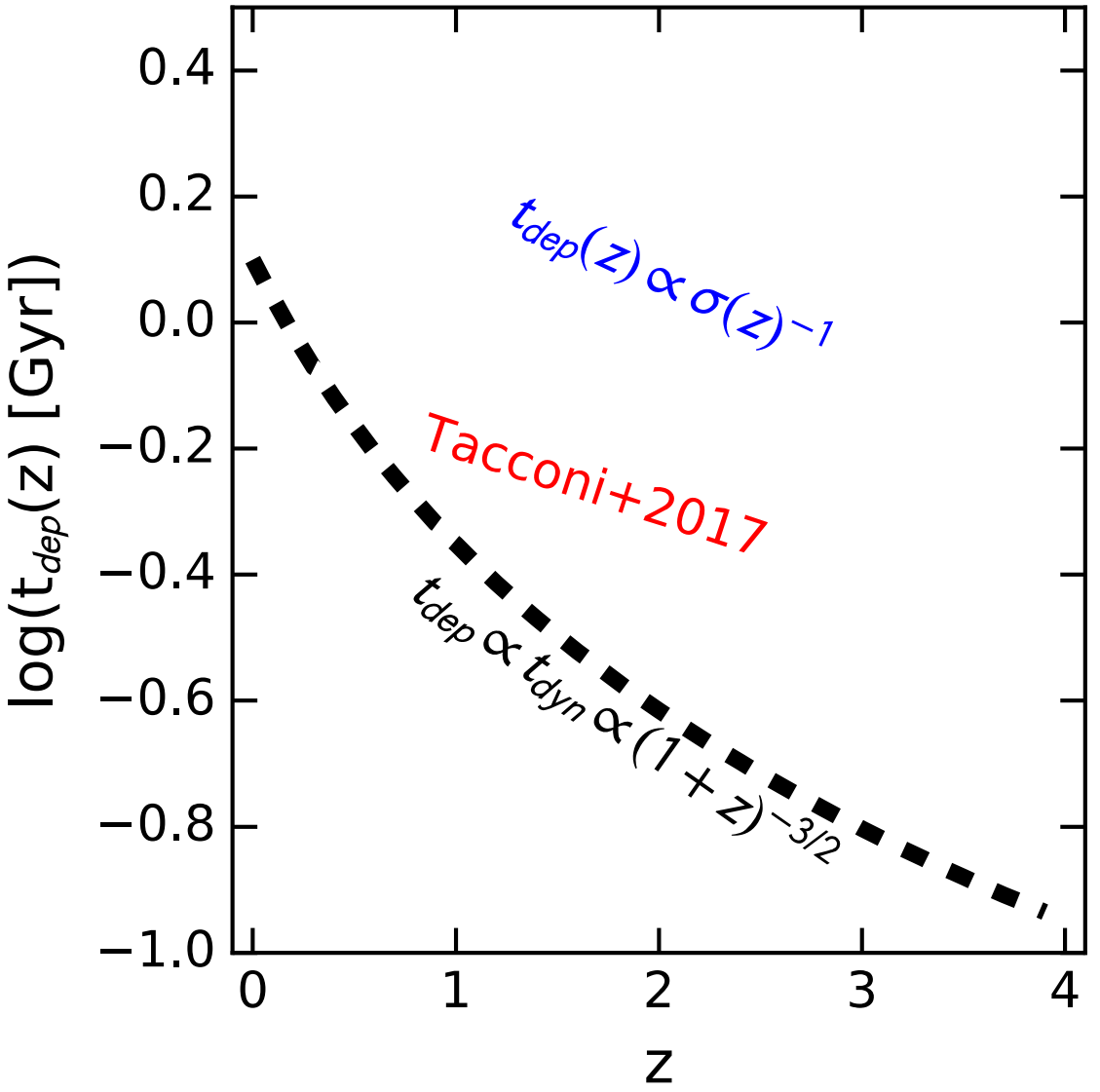




Feedback regulation could* explain redshift evolution of t_{dep}

*If we assume empirical relations from DYNAMO galaxies.

σ(z) : Wisnioski et al. 2015
t_{dep}(z) : Tacconi et al. (2017)



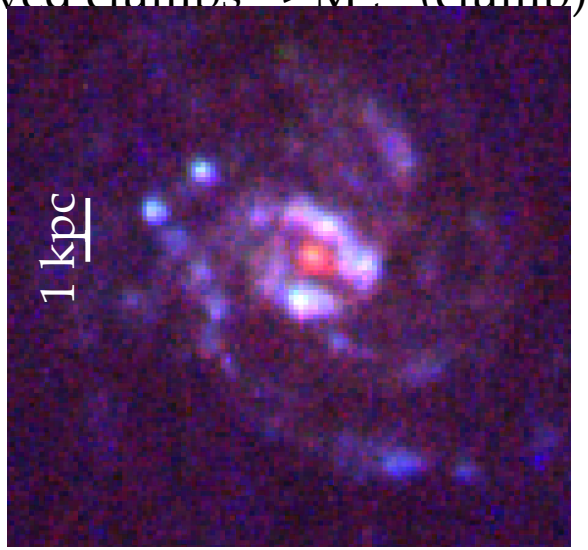
Fisher et al. *submitted*

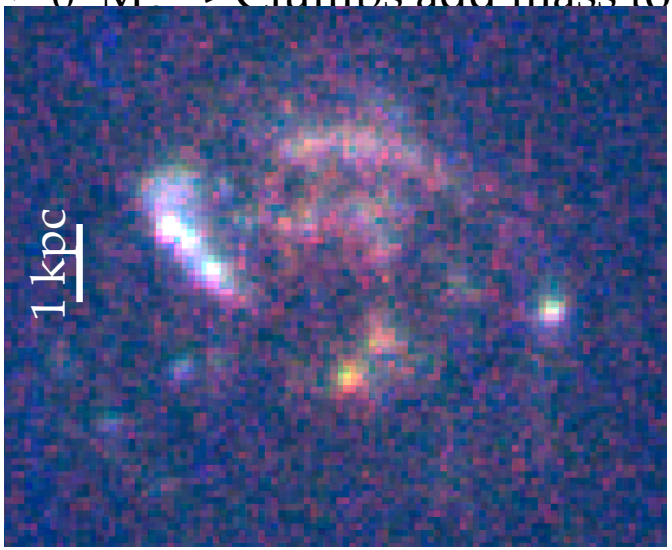
Measuring ages & stellar mass of clumps is ideally suited for DYNAMO.

Simulation is pretty well divided into 2 camps:

Long-lived clumps → M_{star} (clump) ~ $5x10^8$ $M_\odot$ → Clumps build bulges

Short-lived clumps → M_{star} (clump) ~ 0 $M_\odot$ → Clumps add mass to (thick?) disks





- Hα Equivalent Widths as age proxy: Isabella Lamperti et al *submitted*
- Keck/AO K-band measurement of clump masses: Heidi White et al (near submission) **M_*=0.5-5 x 10^8 $M_\odot$ Not consistent with high radiation pressure (e.g. FIRE)**

Postdoc on DYNAMO galaxies.

I am looking for a postdoc to work on ALMA and/or Hubble data on DYNAMO galaxies.

If you are interested (or know someone) please contact me.



DYNAMO: Turbulent, Clumpy disks in the nearby Universe

DYNAMO galaxies are…

gas rich, clumpy, turbulent galaxies in local Universe.

Results from DYNAMO in this talk:

- **You should be suspicious of properties of clumps in z=1-2 galaxies.**

- **Violent disk instability model is consistent with our results.**

- **There is qualitative consistency between DYNAMO galaxies and feedback regulated star formation models.**
  - ***But the normalization seems off by a factor of 10-100.***

- **Clumps *masses* indicate some current feedback models may be incorrect.**

We're getting more data all the time, stay tuned for more results…

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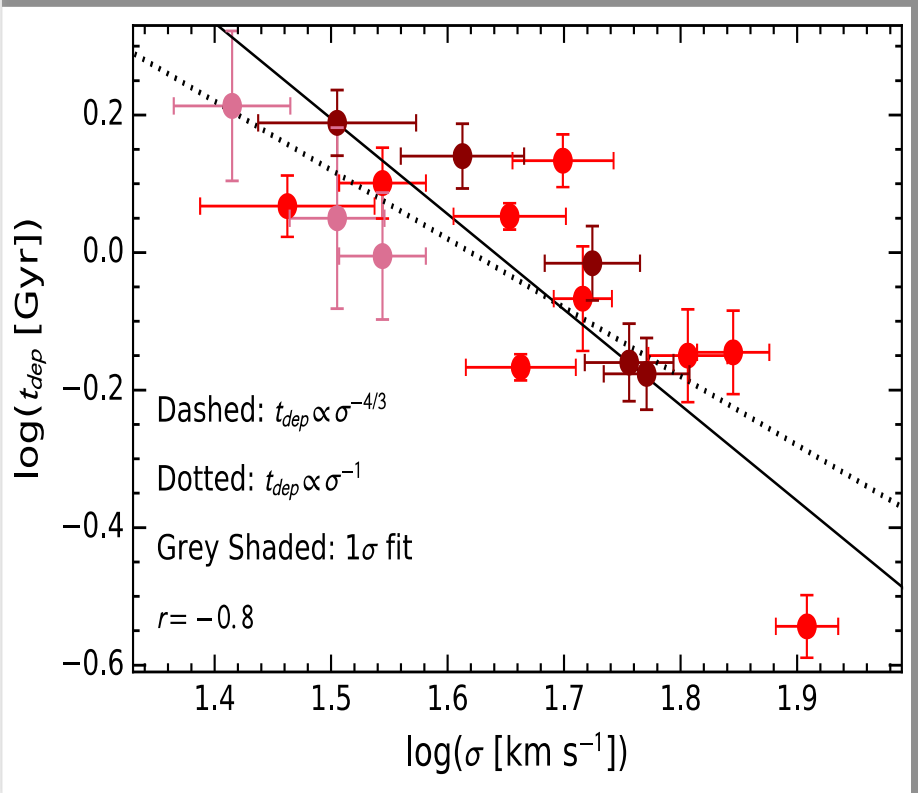

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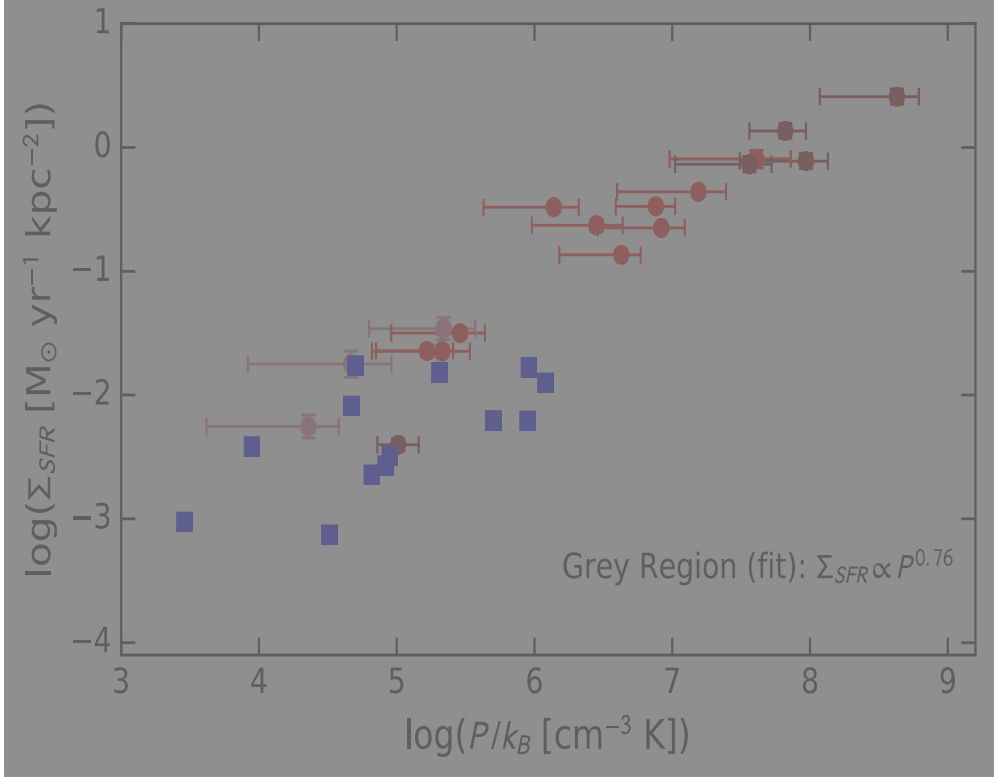

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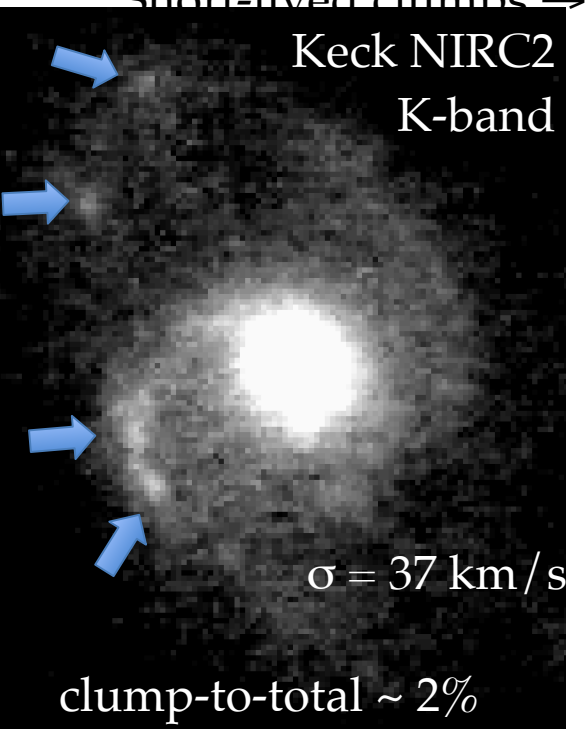
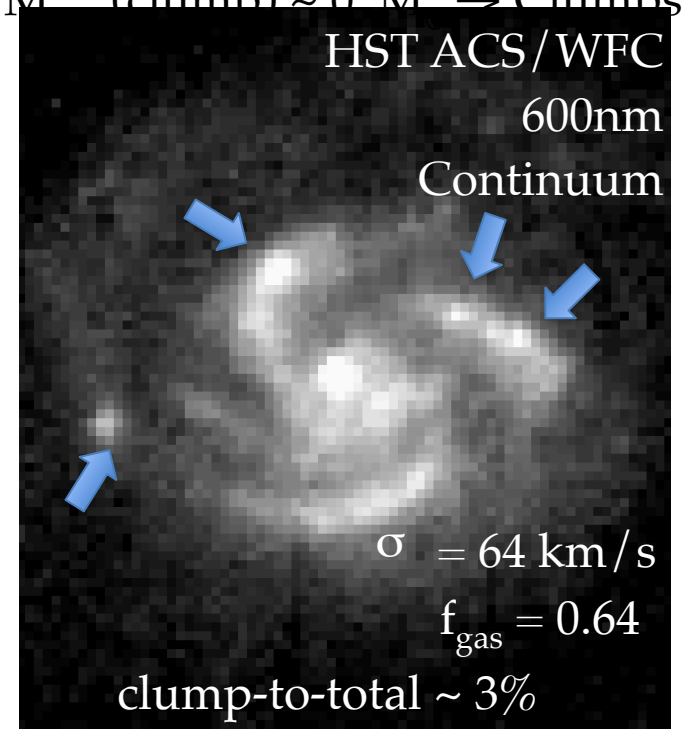
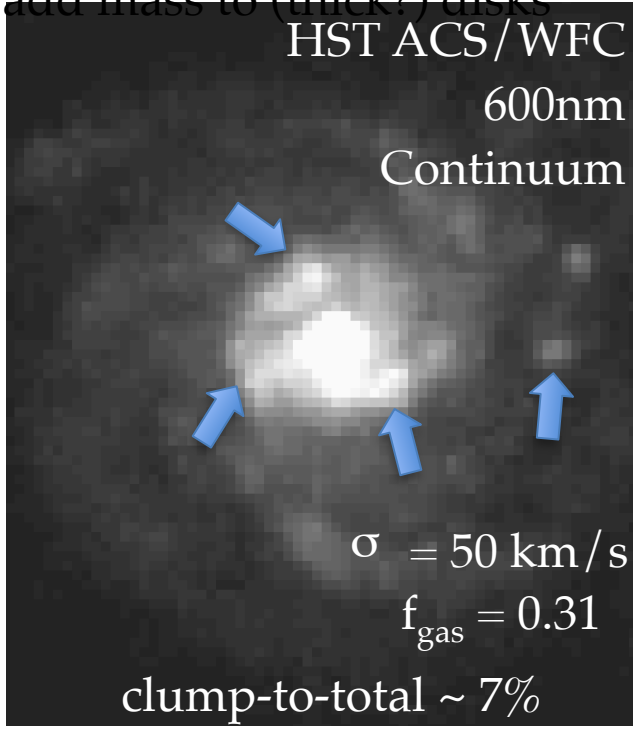
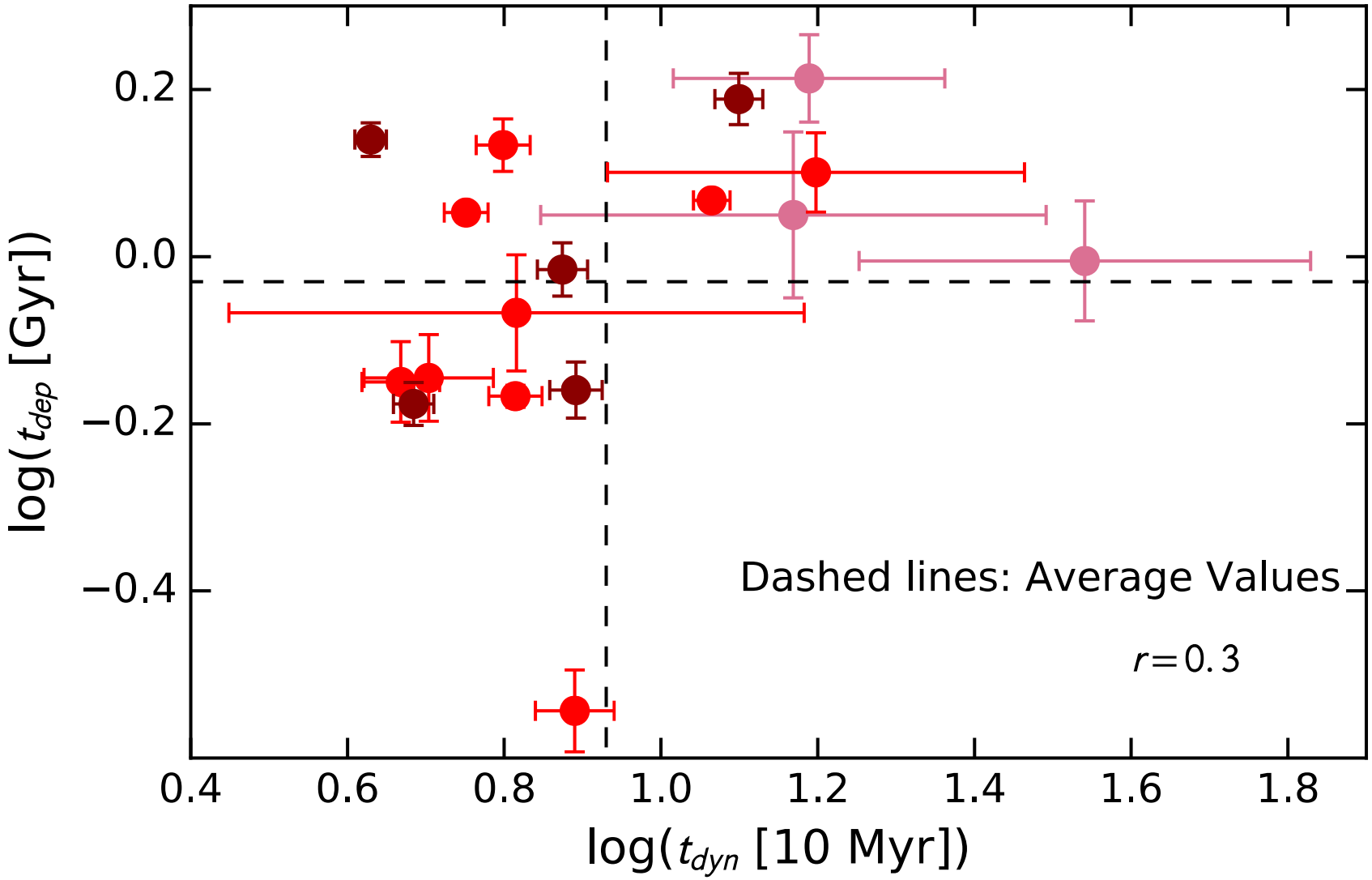


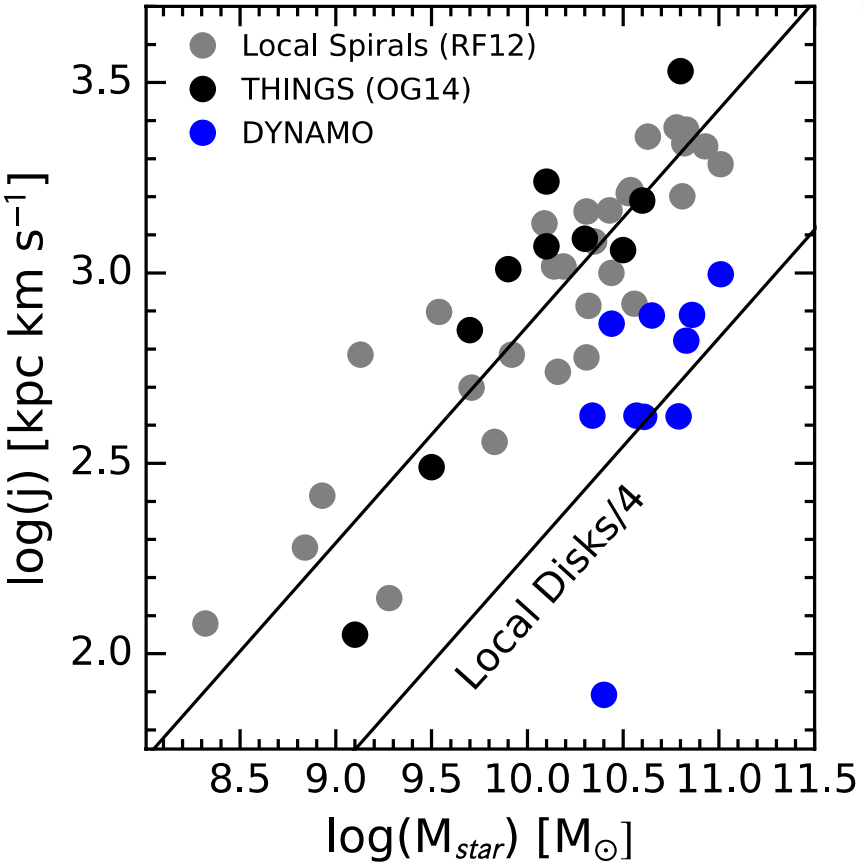




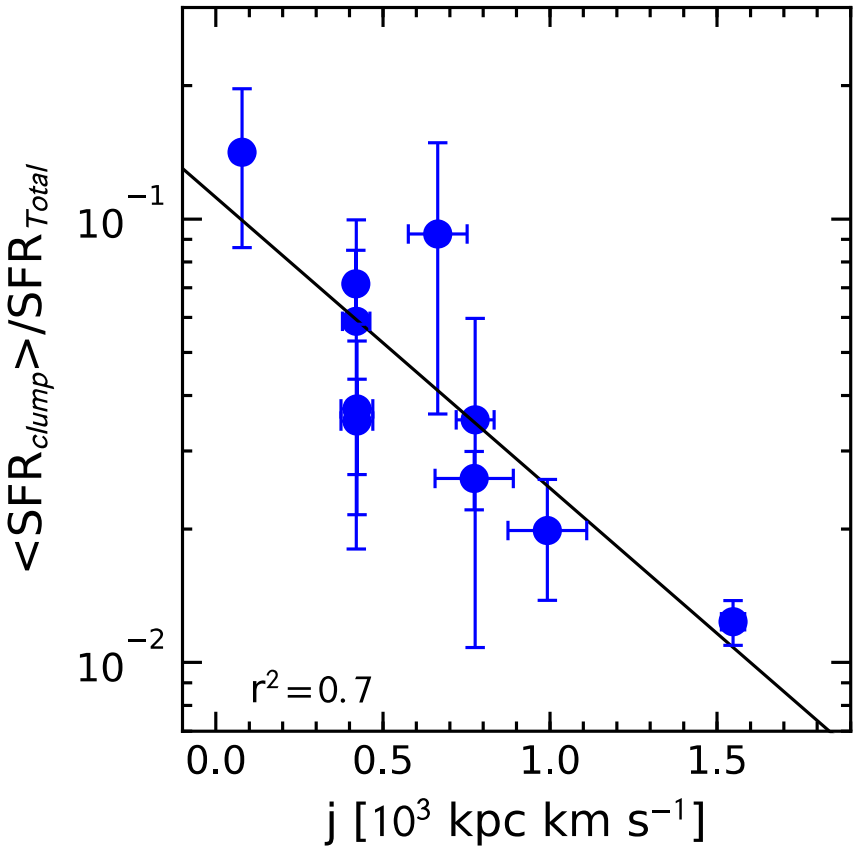
Little-to-no correlation with dynamical time



Angular Momentum plays an important role in turbulent, clumpy disks.



Clumpy disks are deficient in angular momentum



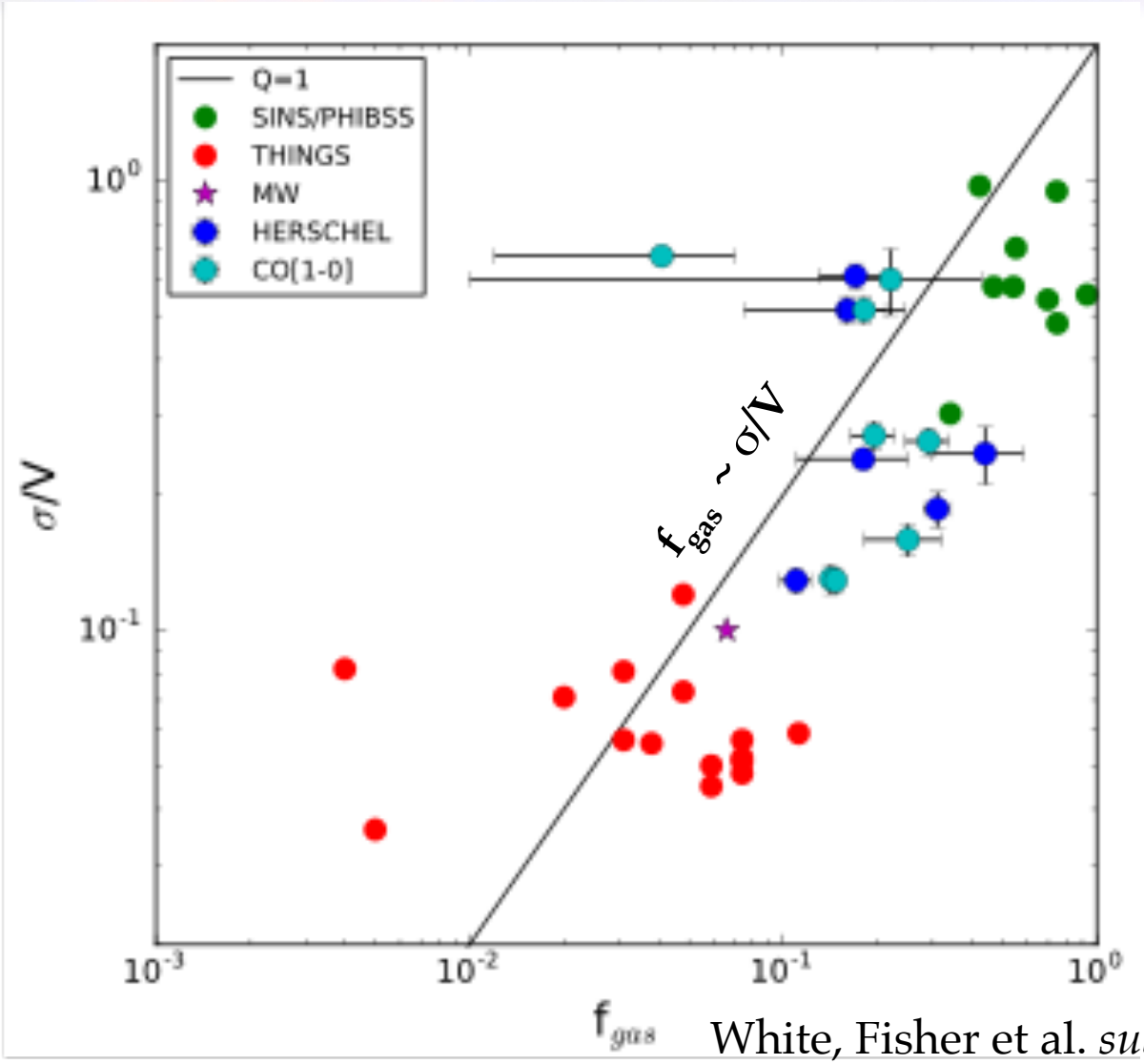
Bigger clumps are in disks with lower angular momentum.

Obreschkow et al. *2015*, Sweet et al *in prep*, Fisher et al. *in prep*

DYNAMO clumps agree with direct predictions from unstable disk model.

It is widely assumed that clumpy, disks satisfy $\mathbf{Q_{gas}}$~1

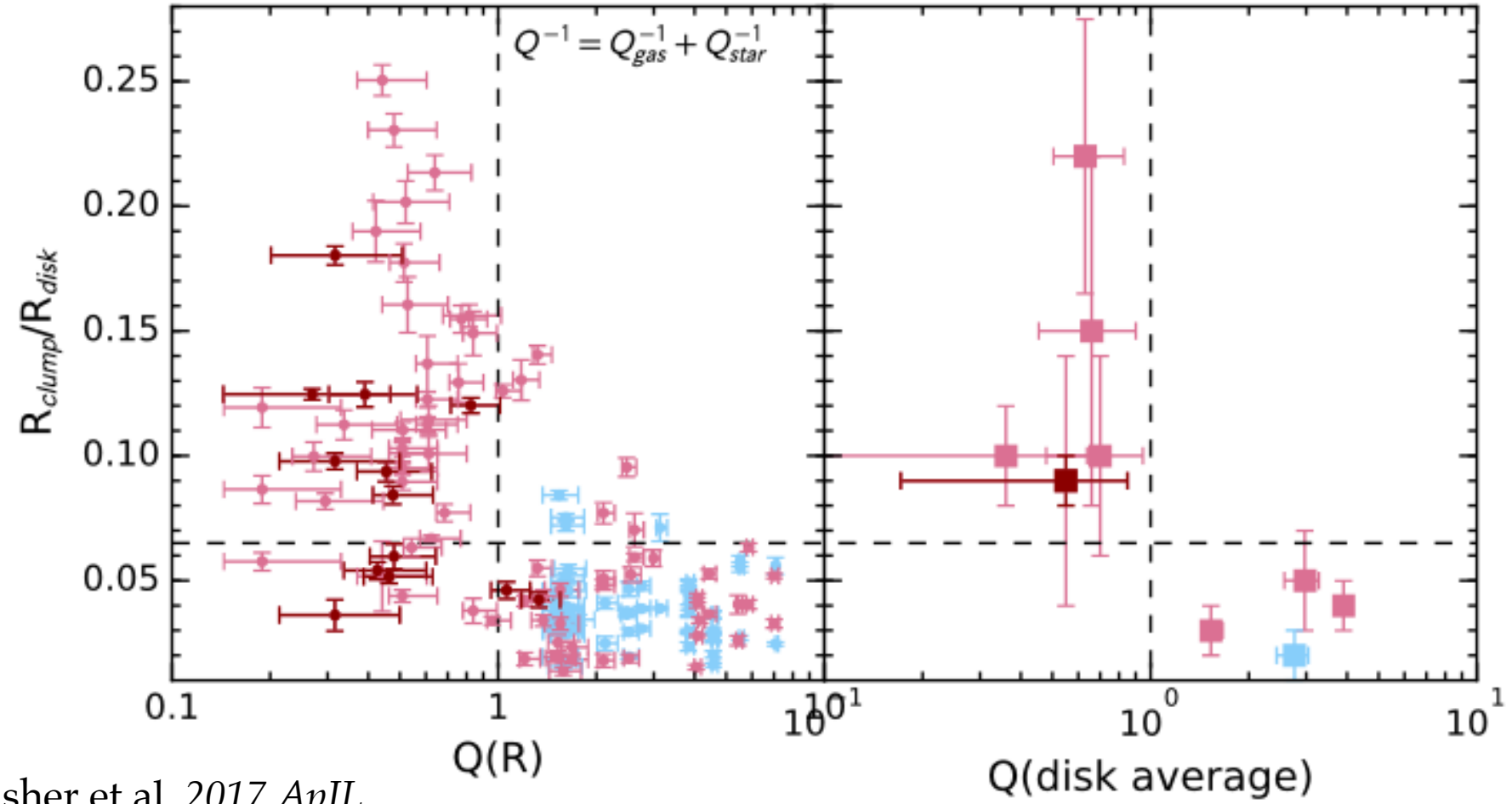
which implies f_{gas}~σ/*V*.



White, Fisher et al. *submitted*

Larger clumps are only located in regions of disk with Q_{tot}<1.

Note: Q is radially averaged two-fluid combination of stars & disks.

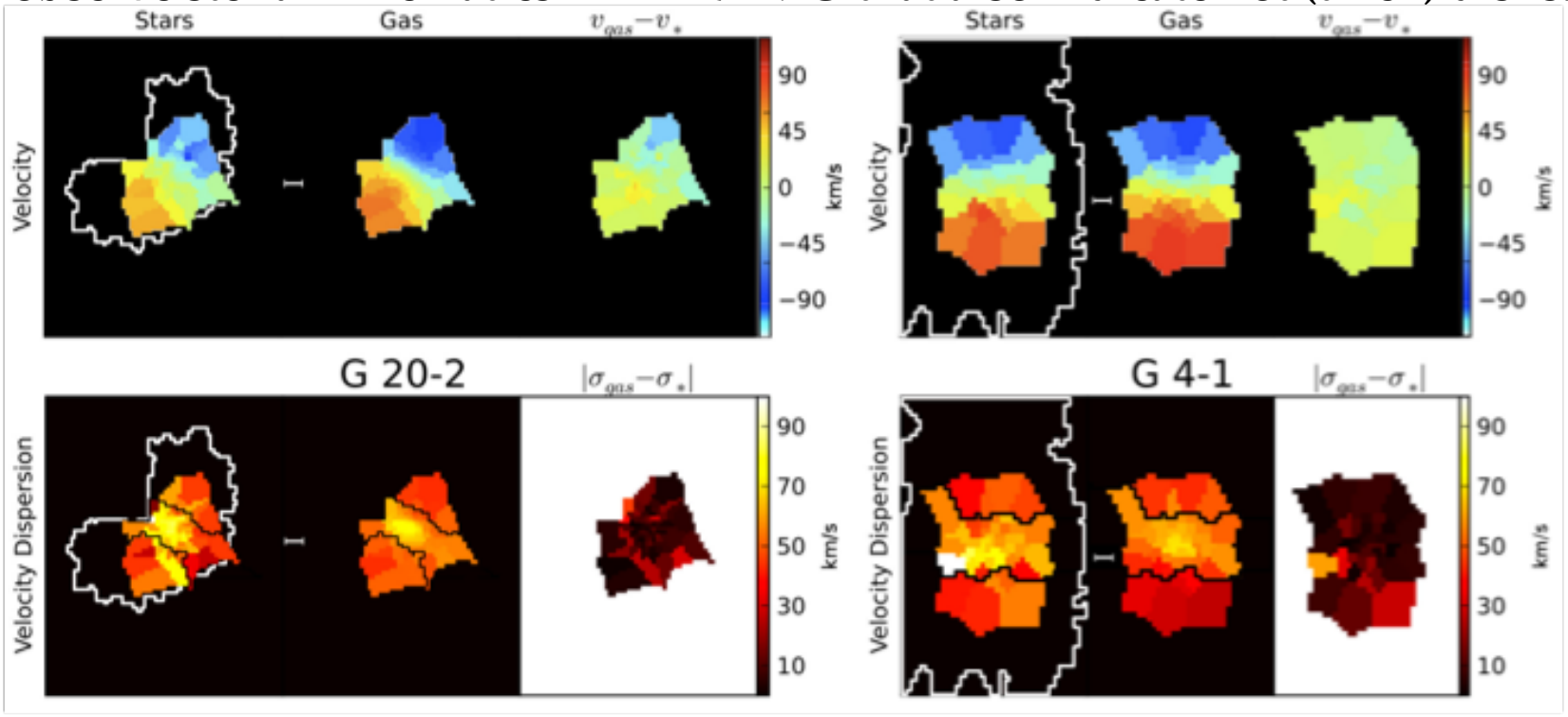


Fisher et al. *2017 ApJL*

In DYNAMO gas rich galaxies may be building thick disks

Assuming a marginally stable disk and hydrostatic equilibrium, one can derive…

We observe stellar kinematics in DYNAMO that also indicate hot (thick) disks.



Bassett, Glazebrook et al 2014