Deviation from Larson and Schmidt-Kennicutt relations in Galactic Molecular Cloud Complex

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THE SCALING RELATIONS AND STAR FORMATION LAWS OF MINI-STARBURST COMPLEXES

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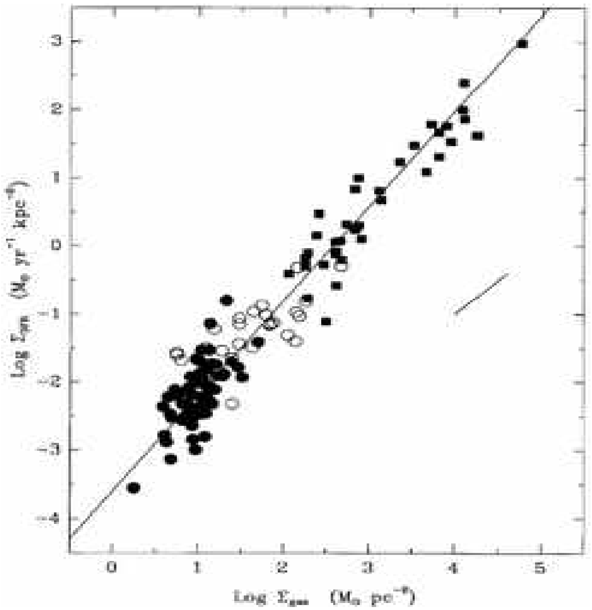
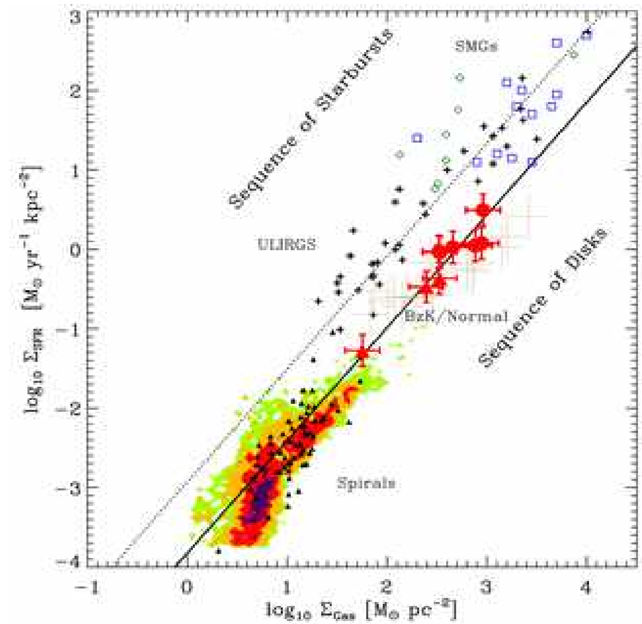
Nguyen Luong et al. 2016, arXiv:1605.01104
http://adsabs.harvard.edu/abs/2016ApJ...833...23N

Motivation

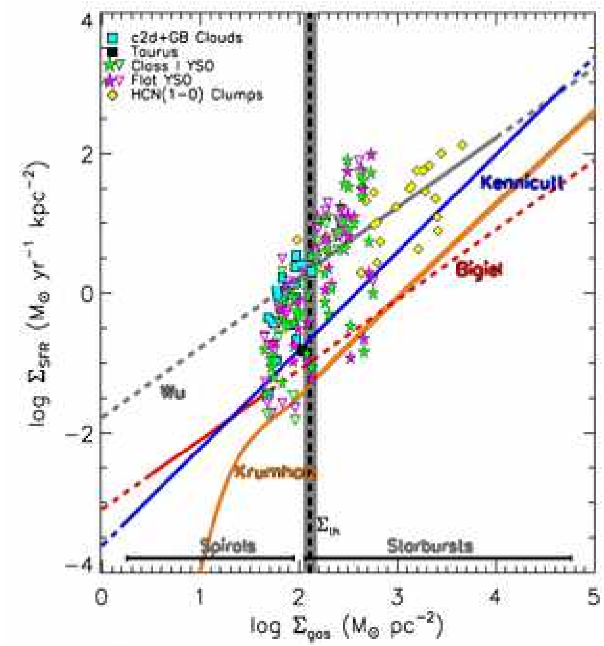
Deviation from Schmidt-Kennicutt relation



Kennicutt 1998



Daddi et al. 2010



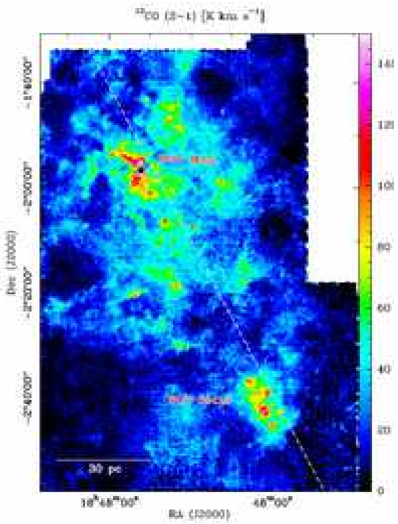
Heiderman et al. 2010

Questions:

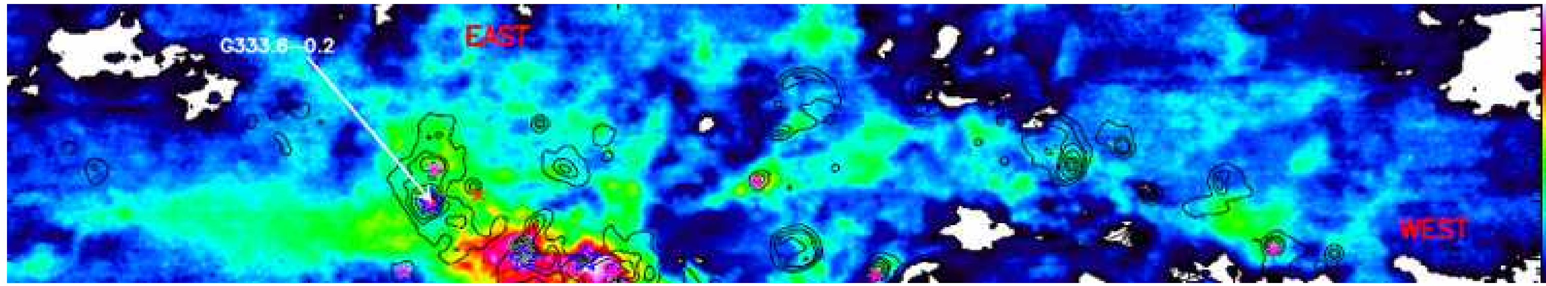
Schmidt-Kennicutt relation in molecular cloud complex (MCC,50-100 pc)

Do Larson relations also deviate from the original universal relations?

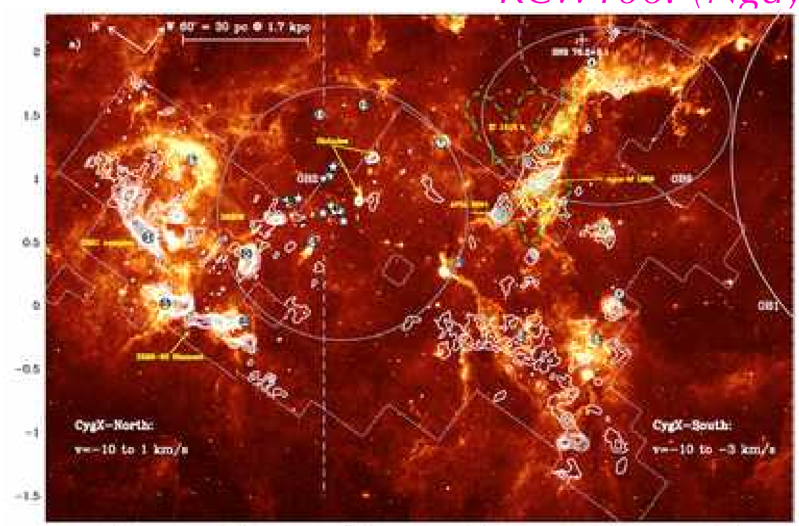
Molecular cloud complex



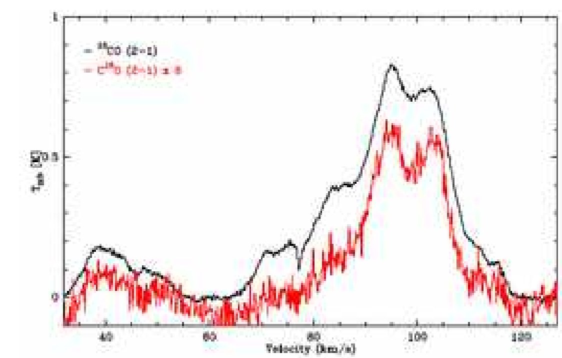
W43: (NLQ11, Carlhoff et al. 13)



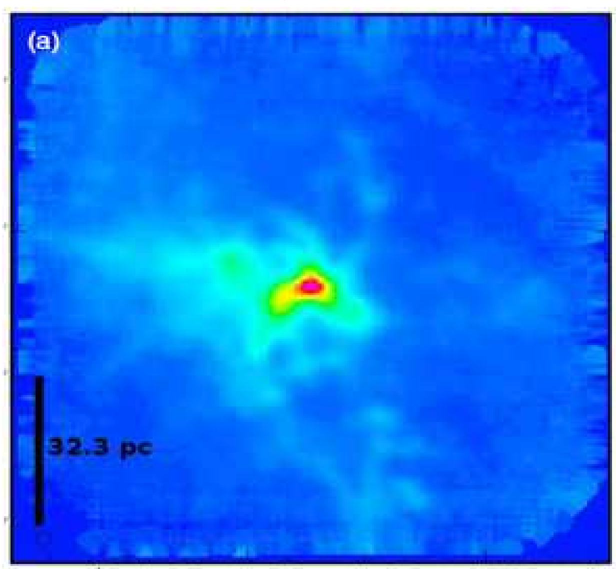
RCW106: (Nguyen et al. 14, Lowe et al. 14)



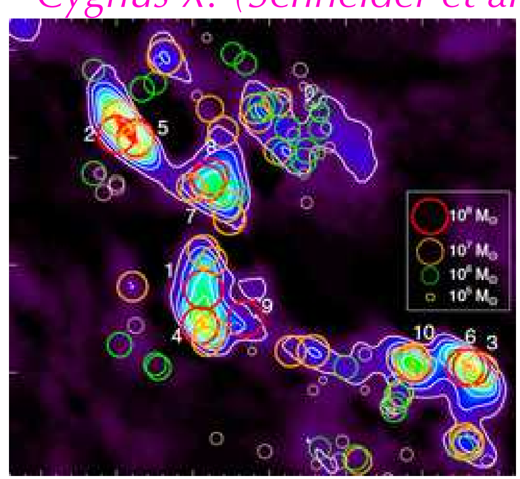
Cygnus X: (Schneider et al. 06, Motte et al.



W43: (NLQ11, Carlhoff et al. 13)



(Galvan-Madrid et al. 13)



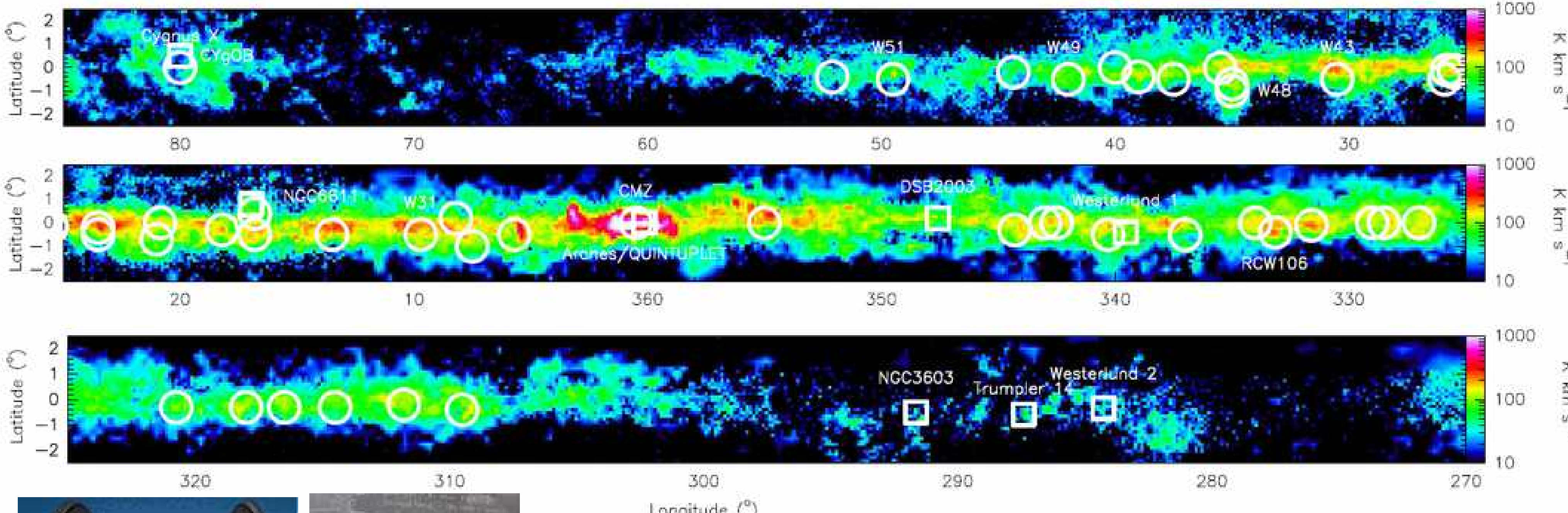
(Wei,Keto,Ho12)

Properties:

Mass ~10^6 Msun

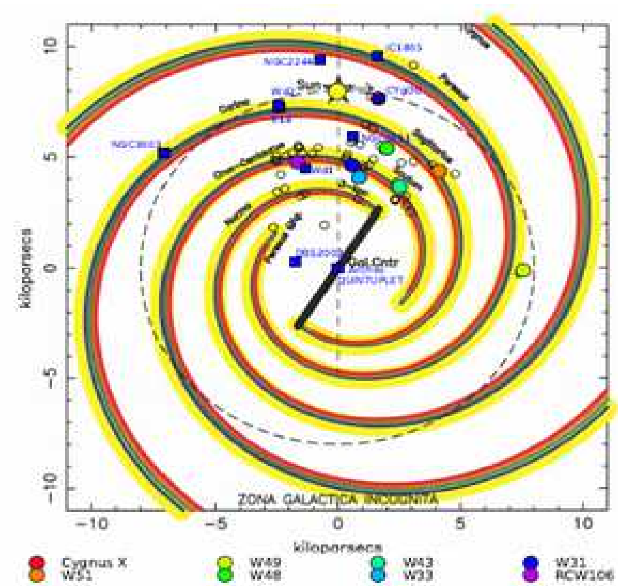
Velocity dispersion > 8 km/s

MCC sample in the Milky Way



Nguyen-Luong et al 2016

Patrick Thaddeus (1932-2017), Dame et al. 2001



Data from CfA 1.2m telescopes CO survey:

Friend-of-friend algorithm Duchamp source extraction

Selection by eyes

$M_{LTE} > 10^6$ Msun

MCC sample in the Milky Way

Table 1
Cloud and SFR Characteristics of the Massive MCCs in the Milky Way

Complex name	l (°)	b (°)	V_{LSR} (km s^{-1})	σ (km s^{-1})	d (kpc)	A $\times 10^{-2}$ (kpc^2)	R (pc)	L_{CO} $\times 10^5$ ($L_\odot$)	M_{gas} $\times 10^6$ ($M_\odot$)	Σ_{gas} ($M_\odot$ pc^{-2})	$S_{21 cm}^{int}$ (Jy)	SFR ($M_\odot$ yr^{-1})	Σ_{SFR} ($M_\odot$ yr^{-1}kpc^{-2})	α_{vir}
G111	111.0	−1.0	−49	7.9	3.34	5.7	134	7.2	2.2	38.7	1860	0.014	0.25	4.4
G80-CygnusX	80.0	0.0	2	6.6	1.5	3.7	108	40.7	2.2	59.9	45759	0.062	1.68	2.5
G52......	52.1	−0.4	55	6.9	6.9	2.0	79	1.8	1.9	95.6	2818	0.0725	3.6	2.3
G49-W51....	49.5	−0.5	57	9.8	5.41	1.8	76	3.6	2.5	139.9	10237	0.184	10.2 2	3.4
G44.4......	44.4	−0.2	61	7.2	9.3	1.8	75	2.7	1.5	82.7	5272	0.070	3.89	3.1
G42-W49....	42.0	−0.5	63	9.5	11.1	2.8	93	1.5	4.9	179.2	6069	0.51	17.86	2.0
G40........	40.0	0.0	32	6.1	2.2	3.4	104	13.0	1.8	52.1	7783	0.026	0.77	2.5
G39........	39.0	−0.4	65	27.3	12.1	13.1	204	33.1	15.7	120.2	6447	0.079	0.60	11.3
G35-W48....	35.0	−1.0	46	14.0	3.27	3.3	101	15.3	4.5	138.0	8379	0.075	2.27	5.2
G30-W43....	30.5	−0.5	93	16.3	5.5	2.8	94	11.1	9.3	329.5	15282	0.320	11.40	3.1
G25.9......	25.9	−0.5	100	10.0	5.4	2.5	88	4.5	3.7	148.5	12688	0.255	10.24	2.8
G25.5 + 52 km s^{-1}	25.5	−0.2	52	11.1	3.4	1.1	58	5.2	1.7	154.0	15012	0.120	10.91	5.0
G25.5 + 102 km s^{-1}	25.5	−0.1	102	11.8	5.5	2.7	93	5.6	4.6	169.8	15164	0.317	11.75	3.2
G23.7 + 60 km s^{-1}	23.7	−0.5	60	9.9	6.21	2.0	80	4.4	4.7	230.9	15342	0.407	20.40	2.0
G24 + 100 km s^{-1}	23.5	−0.2	93	21.1	5.9	3.2	101	13.9	13.2	411.9	17171	0.413	12.91	4.0
G21........	21.0	−0.7	51	13.2	3.6	1.2	61	7.3	2.6	216.8	11690	0.1048	6.10	4.8
G20.9......	20.9	0.0	32	14.7	2.6	0.6	44	5.1	1.0	151.3	12909	0.060	10.0 0	11.8
G18.2......	18.2	−0.3	47	10.3	3.6	1.2	61	7.3	2.6	217.7	5044	0.045	3.75	3.0
G16.8-M16/M17....	16.8	0.4	23	5.9	1.98	0.5	39	4.7	0.7	140.7	8560	0.031	6.20	2.3
G13.5-W33..	13.5	−0.5	24	36.1	2.92	1.2	61	29.8	4.7	393.2	439	0.00175	0.149	19.8
G10-W31....	9.7	−0.5	22	15.7	4.95	2.3	85	14.0	9.5	416.2	-	-	1.0	2.6
G8.2.......	8.2	0.2	17	8.4	2.9	0.8	49	6.3	1.5	188.4	-	-	1.0	2.8
G7.5.......	7.5	−1.0	17	8.7	3.0	0.8	51	7.9	2.0	234.4	-	-	1.0	2.3
G3.5.......	5.7	−0.5	13	8.6	3.1	2.8	93	19.0	5.0	179.7	-	-	0.9	1.6
G0-CMZ.....	0.5	0.0	−6	23.1	7.9	51.6	405	74.8	128.5	249.1	-	-	0.9	2.0
G355.......	355.0	0.0	95	20.0	6.1	0.8	50	2.7	2.8	344.2	824	0.0212	2.50	8.4
G344.......	344.3	−0.3	−71	8.1	4.8	2.6	91	3.3	2.1	80.4	703	0.0112	0.423	3.3
G343.......	343.0	0.0	−28	8.0	2.7	2.6	91	17.5	3.4	129.7	426	0.00214	0.077	2.0
G342-127 km s^{-1}	342.5	0.0	−127	8.1	8.10	3.5	105	2.2	2.5	71.3	245	0.007	0.17	3.2
G342-79 km s^{-1}	342.5	0.0	−79	7.8	4.74	2.3	85	3.4	2.4	102.8	245	0.004	0.173	2.5
G340.......	340.3	−0.5	−37	14.1	3.41	0.8	51	10.4	2.6	309.4	684	0.00426	0.50	4.6
G337.......	337.0	−0.5	−118	8.9	7.85	3.8	109	2.3	2.9	76.5	2385	0.074	1.95	3.5
G334.......	334.0	0.0	−87	9.4	4.9	2.2	84	4.1	2.7	122.4	2312	0.0384	1.77	3.2
G330-RCW106	333.1	−0.4	−46	13.9	3.5	0.9	53	11.7	3.2	348.4	3111	0.0278	3.22	3.8
G331-90 km s^{-1}	331.6	−0.1	−93	10.4	7.44	2.5	88	5.5	4.0	162.0	1863	0.0348	1.40	2.8
G329-75 km s^{-1}..	328.5	0.0	−75	30.2	4.4	4.1	114	28.0	15.1	369.5	714	0.0095	0.244	8.0
G329-25 km s^{-1}..	329.0	0.0	−45	7.7	3.0	3.3	103	14.3	3.5	104.6	917	0.00571	0.18	2.0
G327.......	327.0	0.0	−45	7.8	2.9	1.8	75	11.3	2.7 4	149.4	2563	0.0149	0.83	2.0
G320.......	320.8	−0.3	−62	12.3	4.0	1.5	69	4.2	1.9	124.1	811	0.00897	0.67	6.5
G318.......	318.0	−0.3	−44	8.1	3.0	0.8	51	5.5	1.4	163.6	833	0.00518	0.625	2.9
G316.5.....	316.5	−0.3	−48	9.1	3.3	1.0	57	6.1	1.9	180.0	1224	0.0092	0.1	3.0
G314.......	314.5	−0.3	−49	8.9	3.6	1.2	61	7.4	2.6	219.3	280	0.0025	0.25	2.1
G311.......	311.8	−0.2	−49	8.9	4.0	2.4	86	11.7	5.1	214.4	1099	0.0121	0.5	1.6
G309.......	309.5	−0.4	−44	11.2	3.8	1.8	75	9.0	3.7	205.9	528	0.0053	0.28	3.0

Nguyen-Luong et al 2016

MCC's Mass and Star Formation Rate measurement

Gas cloud properties from CfA CO survey (Dame et al. 2001):

Mass
Gas surface density
Velocity dispersion

SFR from 21 cm radio continuum form VGPS, CGPS and SGPS:

VLA Galactic Plane Survey (VGPS, Stil et al. 2006): 18°– 67°
Canadian Galactic Plane Survey (CGPS, Taylor et al. 2003): 63°– 175°
Southern Galactic Plane Survey (SGPS, Haverkorn et al. 2006):253°– 358°

Complement data

Cores/ clumps/ GMCs: 0.01-50 pc

Maruta et al. (2010) , Onishi et al. (2002), Shimajiri et al. (2015), Heyer et al. (2009), Roman-Duval et al. (2010), Evans et al. (2014), Heiderman et al. (2010), Lada et al. (2010), Evans et al. (2014)

MCCs: 50-100 pc

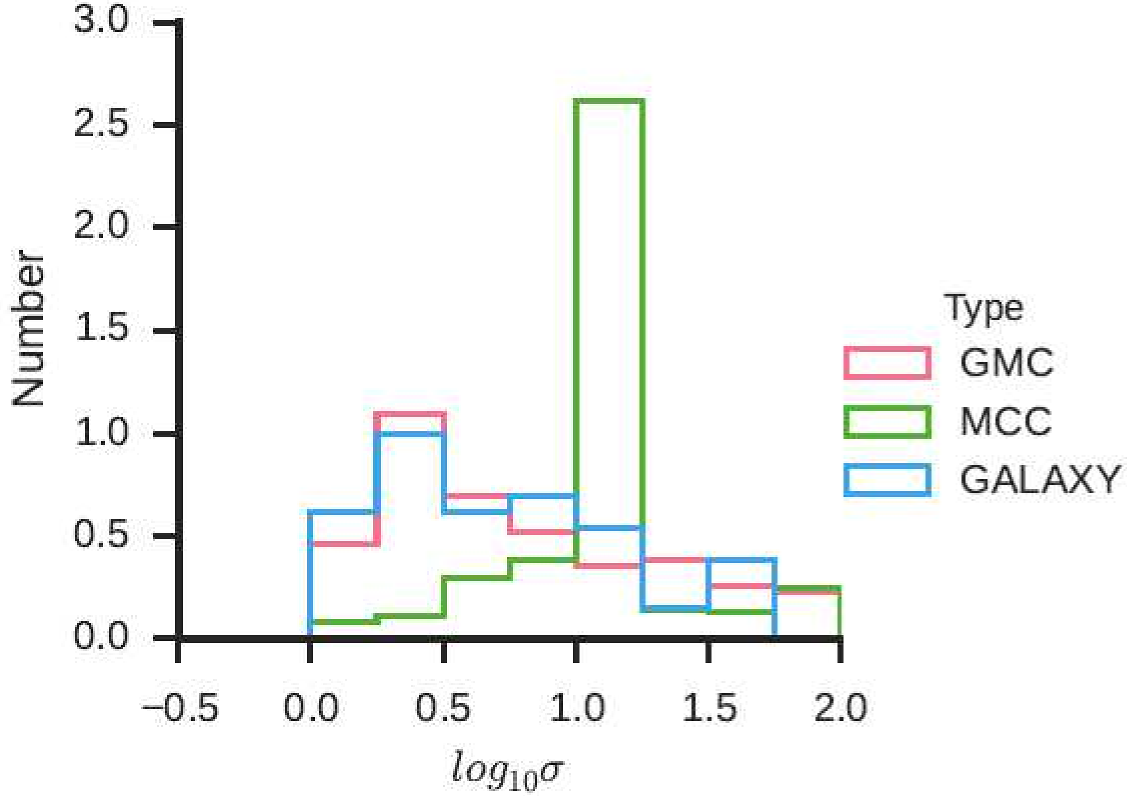
García et al. (2014), Murray (2011), Donovan-Meyer et al. (2013), Rosolowsky (2007), Miura et al. (2012, 2014) , Wei et al. (2012), García et al. (2014), Bolatto et al. (2008) , Murray (2011)

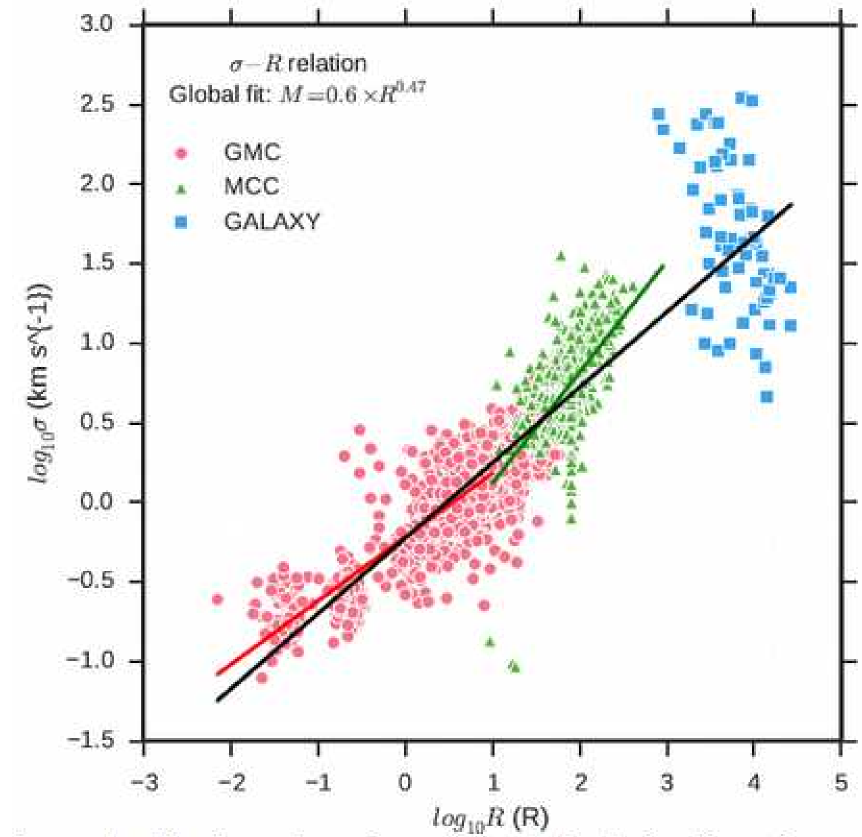
Galaxies:

Leroy et al. (2013) , Tacconi et al. (2013) , Genzel et al. (2010)

8 order of magnitudes in Size
13 order of magnitudes in Mass
Mass are measured by CO but SFR tracers are differents

Virial parameter and sigma-radius relation

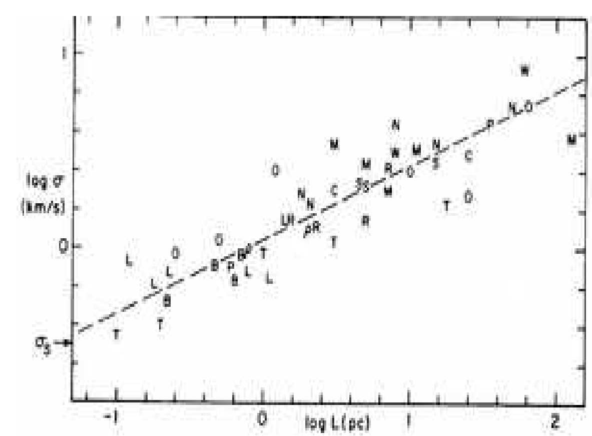




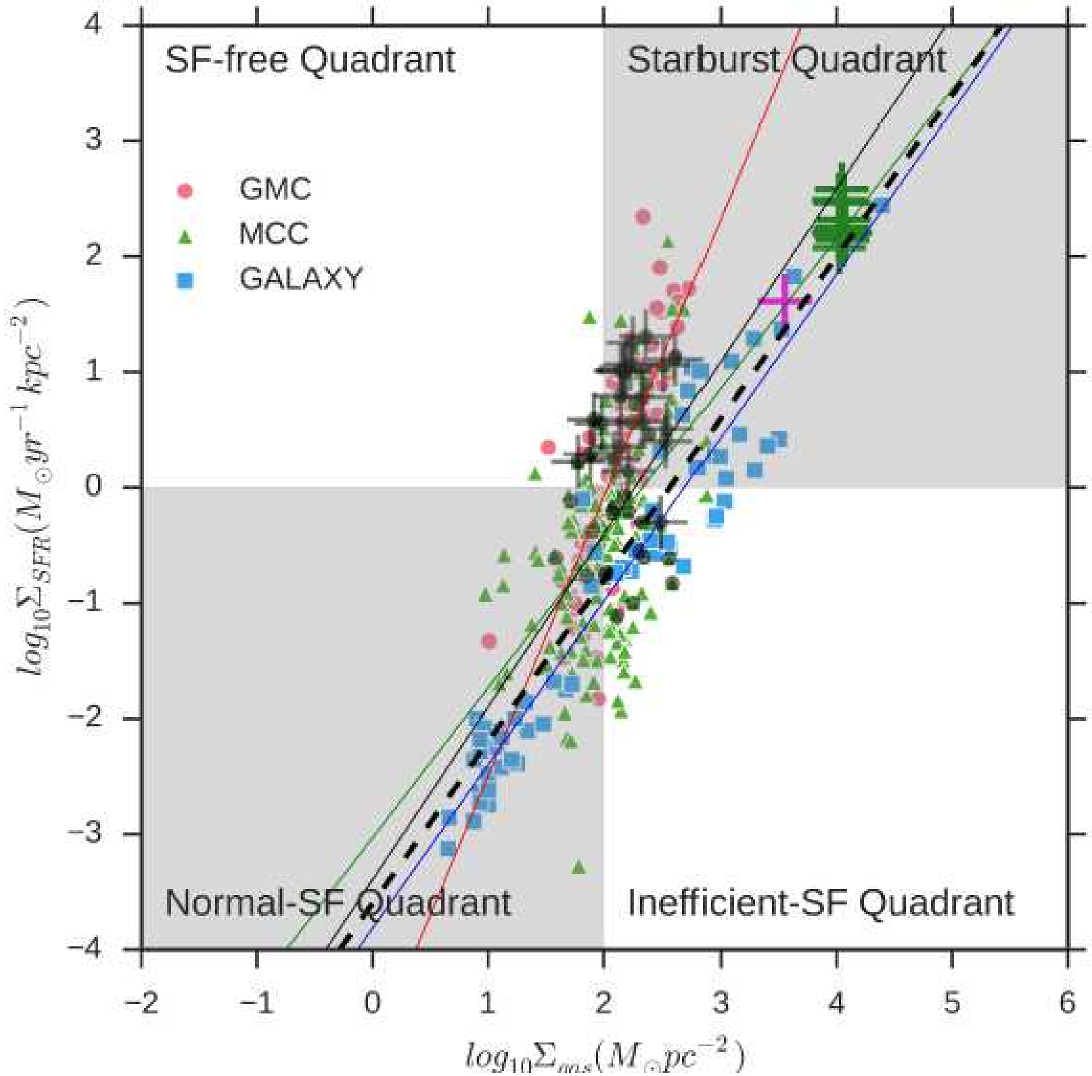
MCC:
- dominated by kinetic energy
- gravitationally unbound
- MCC is more dynamically evolving

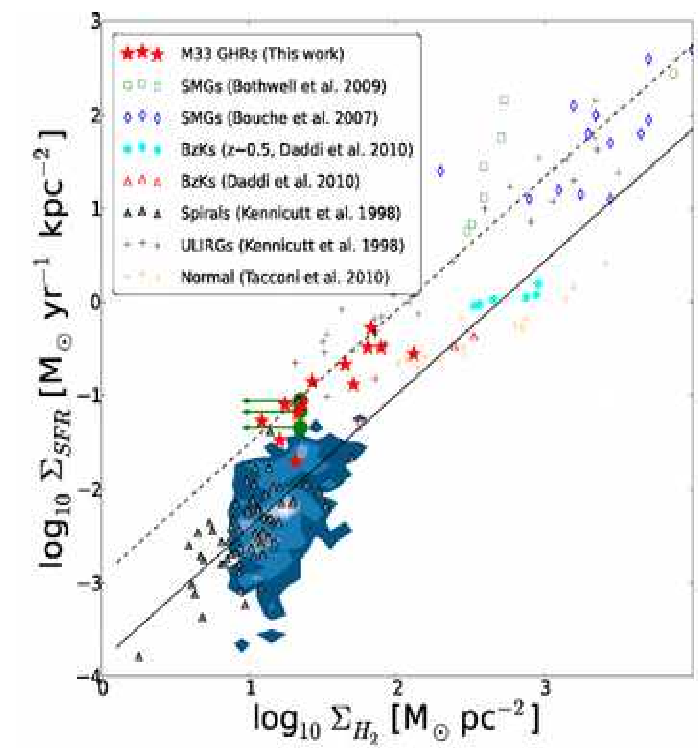
(Howard, Pudritz, Harris16,17)

Slope:
- global 0.47
- MCC: 0.7



SFR density – Gas density relation

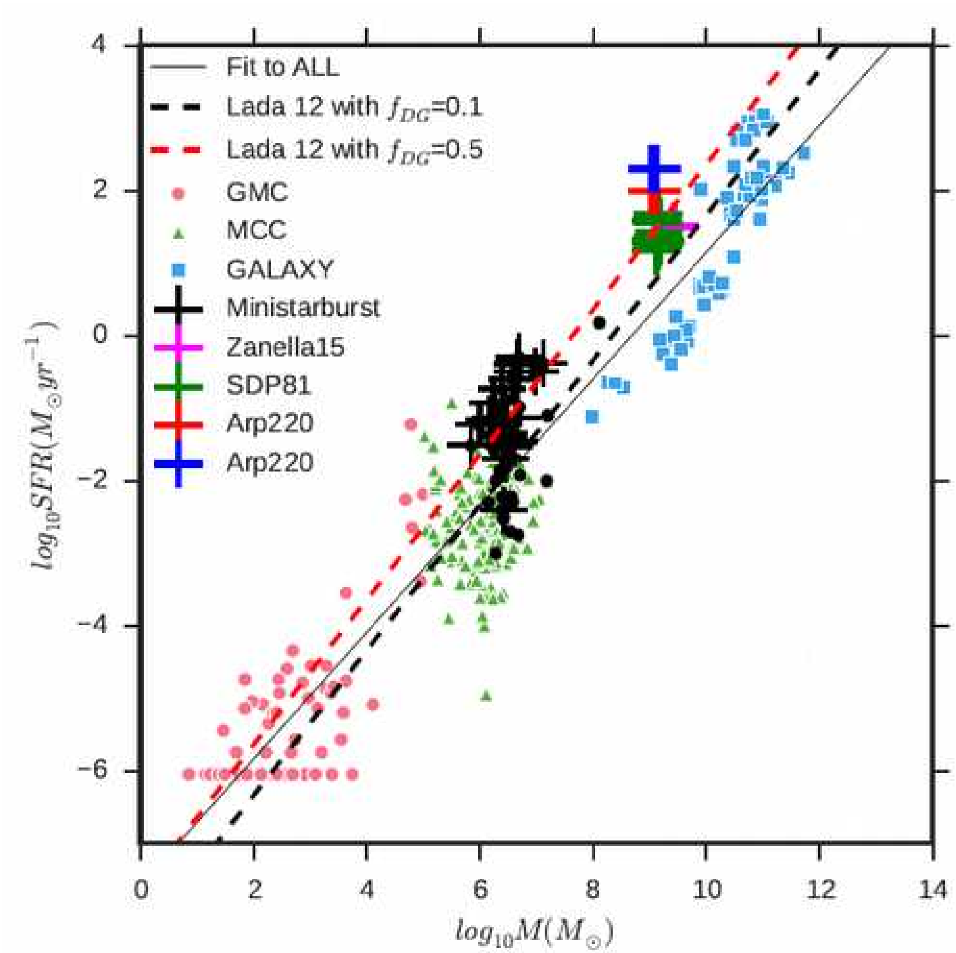


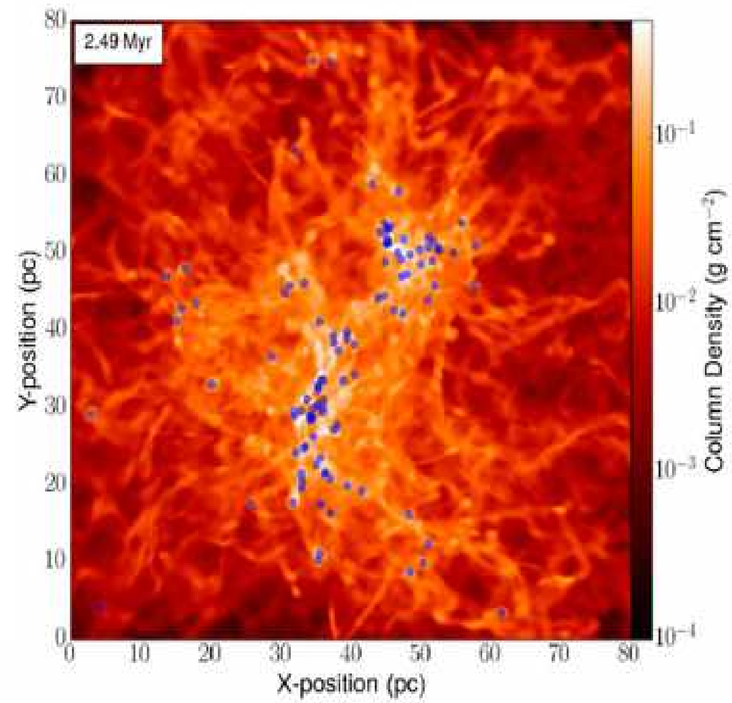


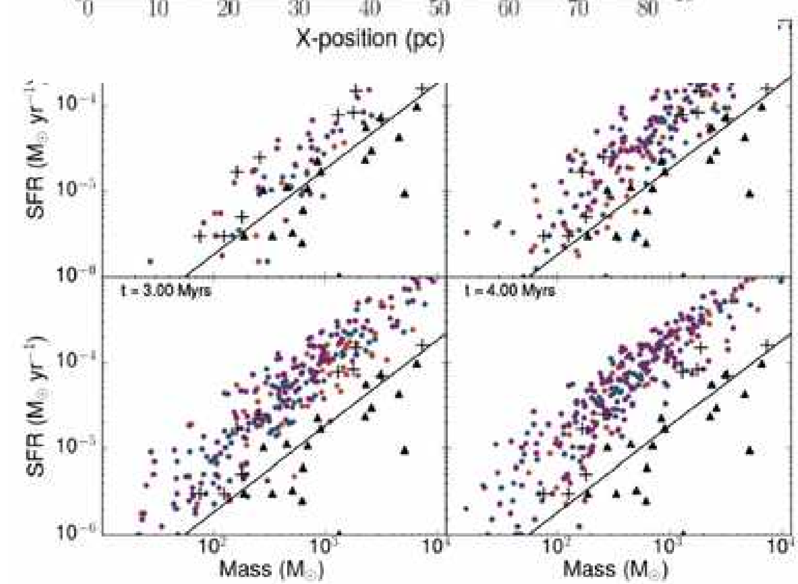
MCC:
- offset from the global Schmidt-Kennicut law
- Different mode of SF: ministarburst mode
- SK diagram is divided into four quadrants

(NLQ+16)

SFR –Total Gas Mass Relation



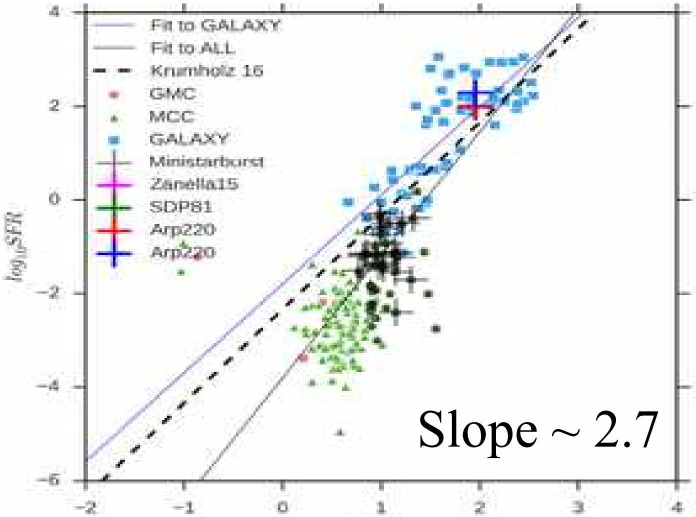


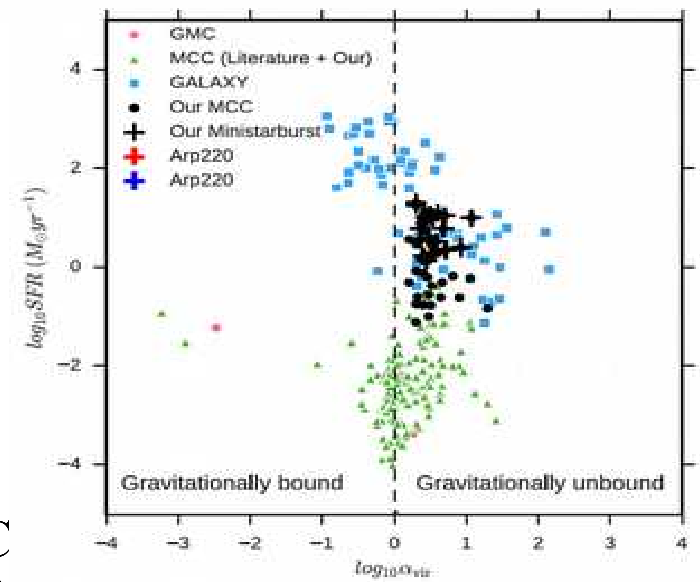


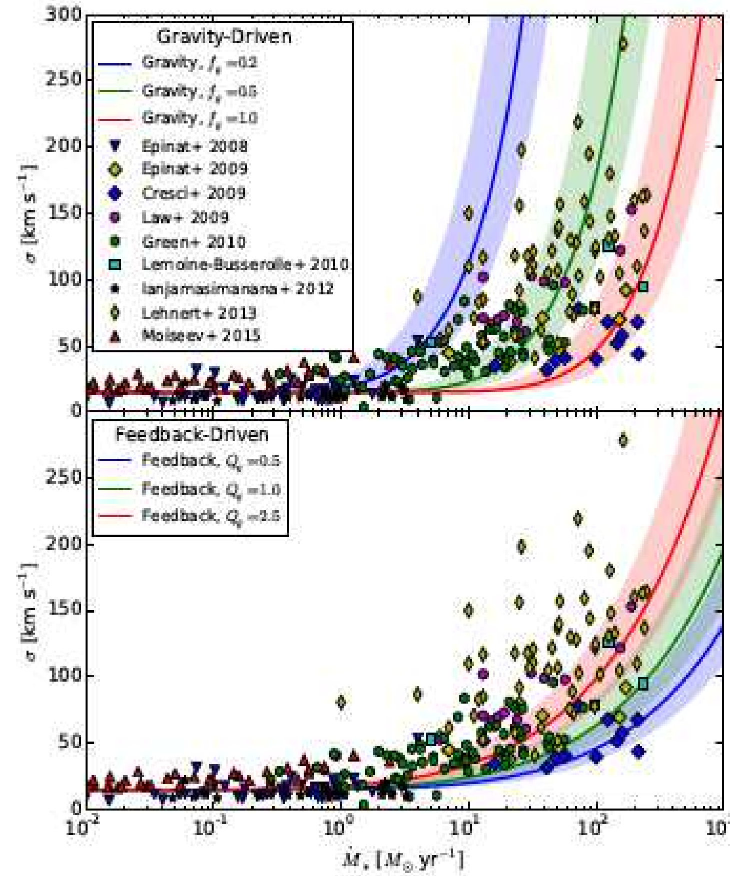
MCC:
- Fill the Lada 2010 plot
- Connect local to global SFR-Mass relation
- Probably can also divided into difrerent SF tracks

(Howard, Pudritz, Harris16,17)

SFR –velocity dispersion Relation





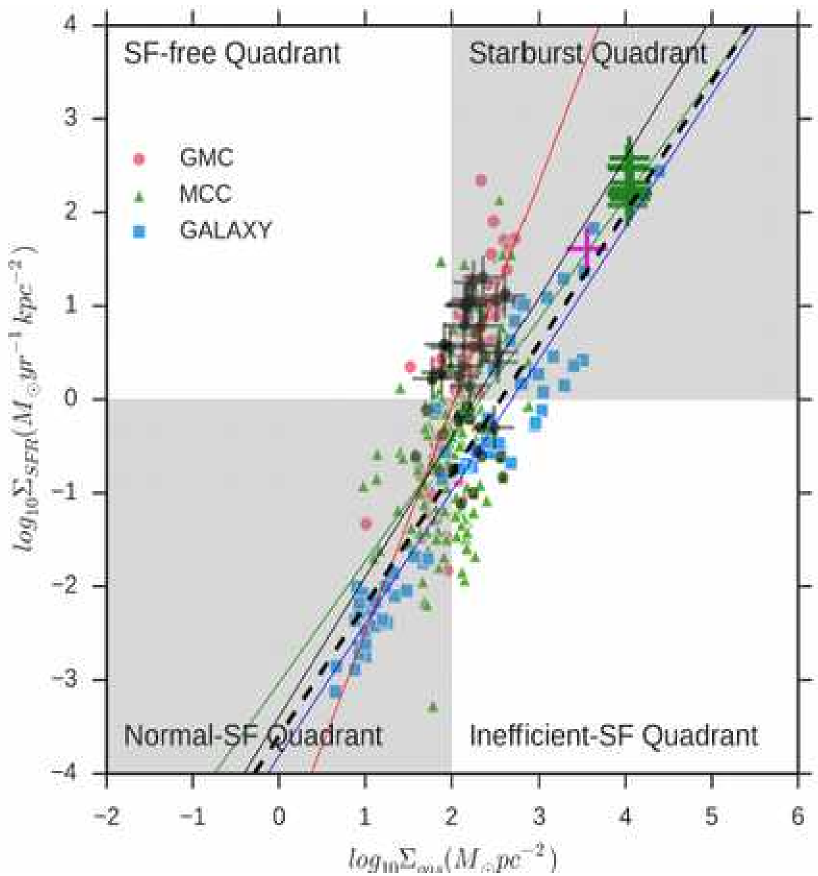


(Krumholz+16)

MC

- If all other scaling laws hold, slope = 3-8
- Our slope (2.6) is shallower than prediction and slower than Krumholz et al. (2016): turbulence is driven by star formation feedback (steeper slope~2) and/or that it is produced by gravitational instability (shallower slope)
- Dynamics are different in different population

Massive star forming complex (Ministarburst)



Mass ~ 106 Msun
Radius ~ 30-70 pc
Large velocity dispersion
High fraction of dense gas
Multiple gas clouds along the line of sights
and on plane
Large scale atomic gas flows fuel the central molecular cloud complex
Form high mass stars or massive cluster

(Motte+03,NLQ+11,NLQ+13,Louvet+16,NLQ16)

CONCLUSION

MCCs are mostly gravitationally unbound, massive, large

Universal KS, Larson relations is not applicable across all scales

Two modes of star formation: massive SF (ministarburst) vs normal cluster SF