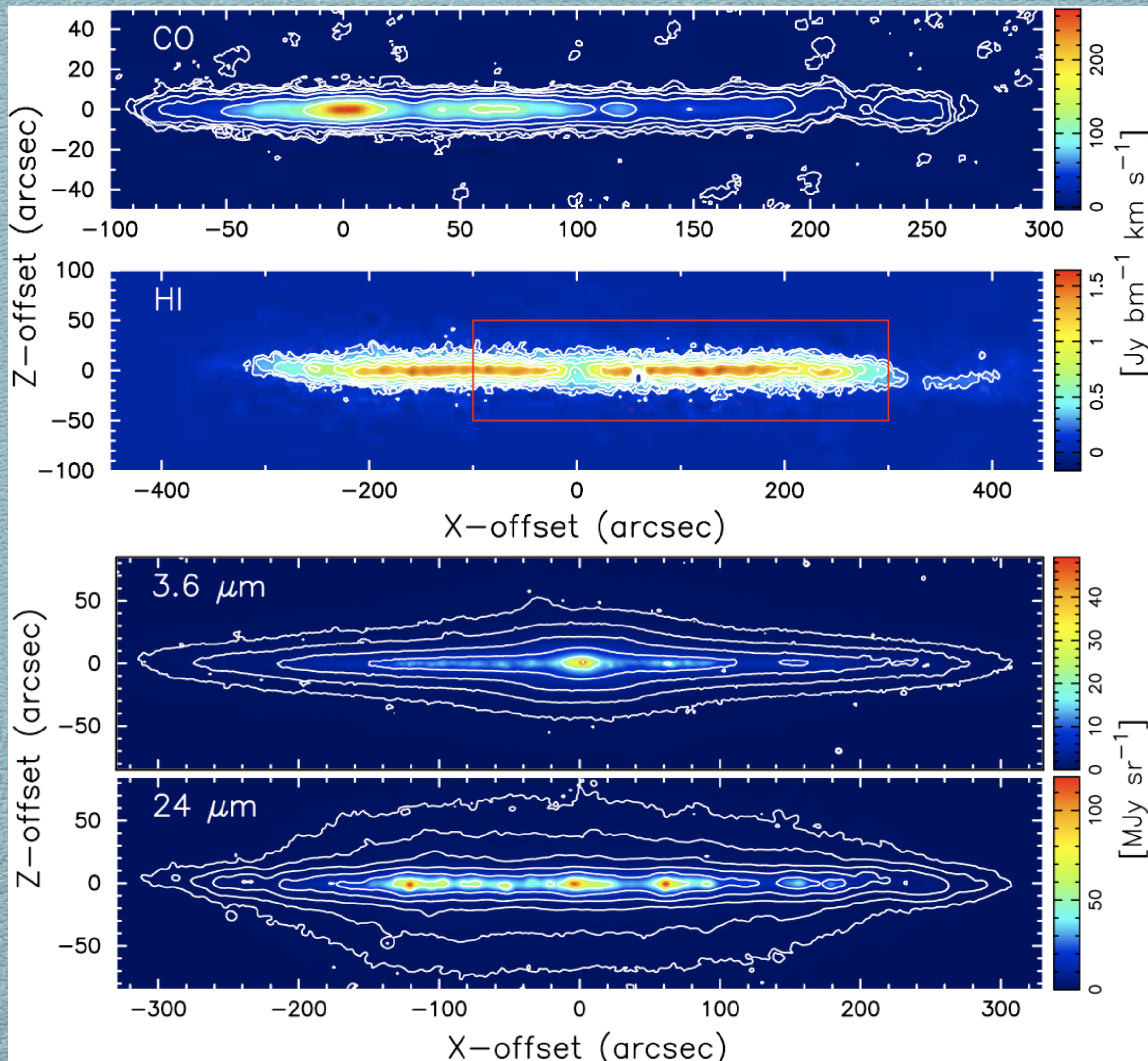
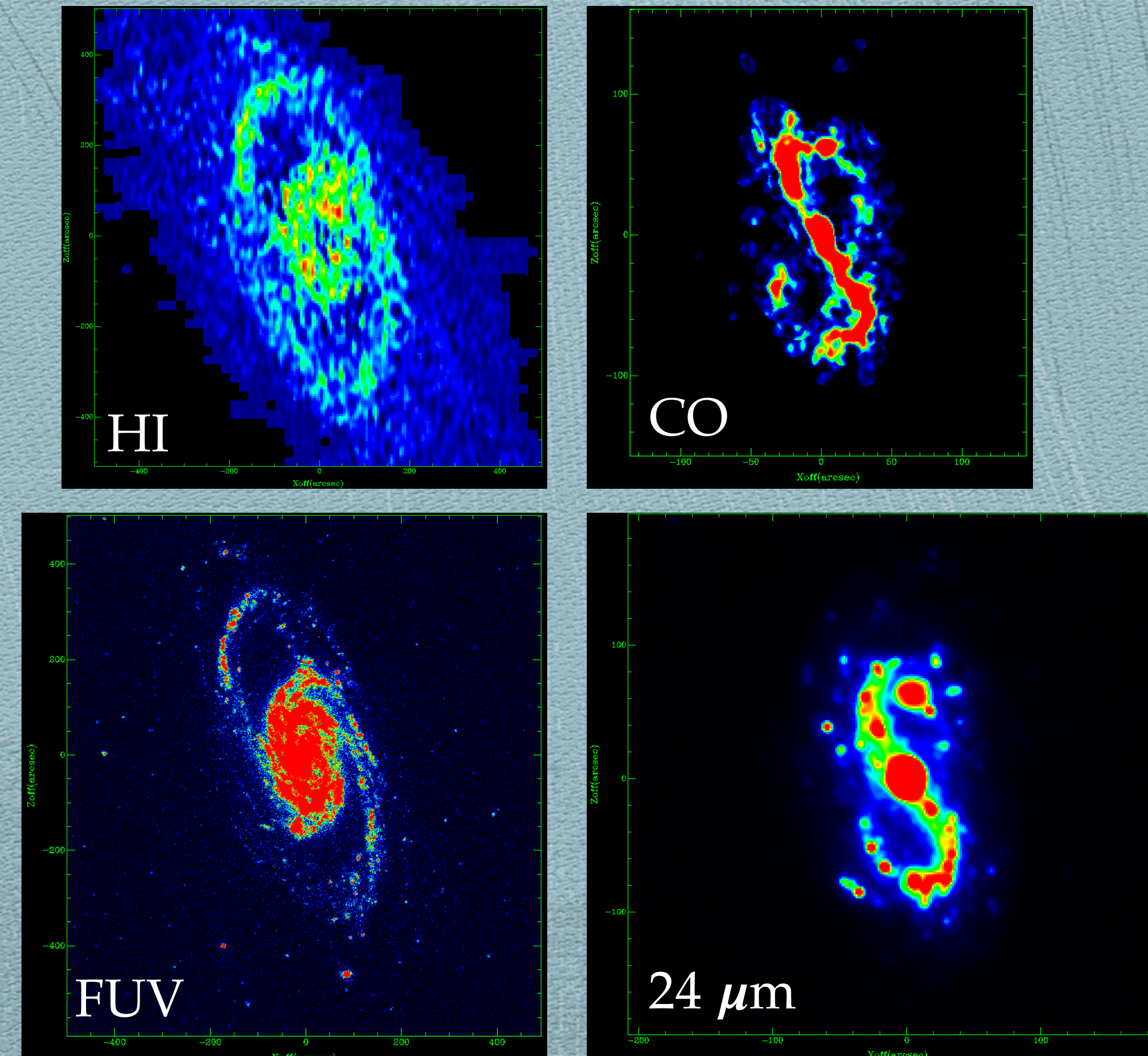
NGC 891



NGC 2903



The Interstellar Medium and Star Formation in Nearby Galaxies: Multi-Wavelength Analysis

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December 15, 2016

Introduction: what sets SFR?

Relationship between SFR and ISM properties

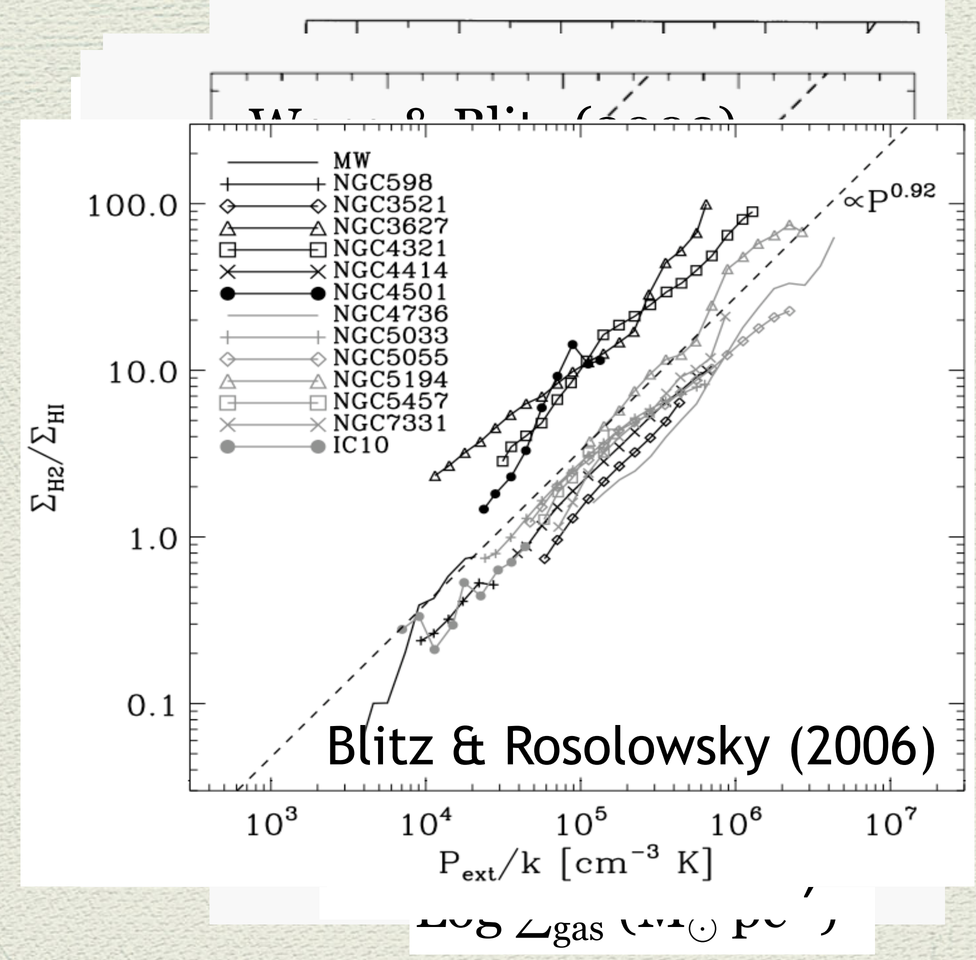
(1) star formation law (or Kennicutt-Schmidt law):

- Schmidt law (1959): SFR $\propto \rho_{gas}^{n}$
- Kennicutt (1998): $\Sigma_{SFR} \propto \Sigma_{gas}^{1.4}$
- Wong & Blitz (2002): $\Sigma_{SFR} \propto \Sigma_{H_2}^{0.78}$

(2) gravitational instability: Toomre $Q_{gas} \equiv \frac{\kappa \sigma_g}{\pi G \Sigma_{gas}} < 1$: unstable

(3) H_2/HI ratio vs. Pressure: $\Sigma_{H2}/\Sigma_{HI} \sim (P_o)^{\alpha}$

→ radial variation in scale height & velocity dispersion?



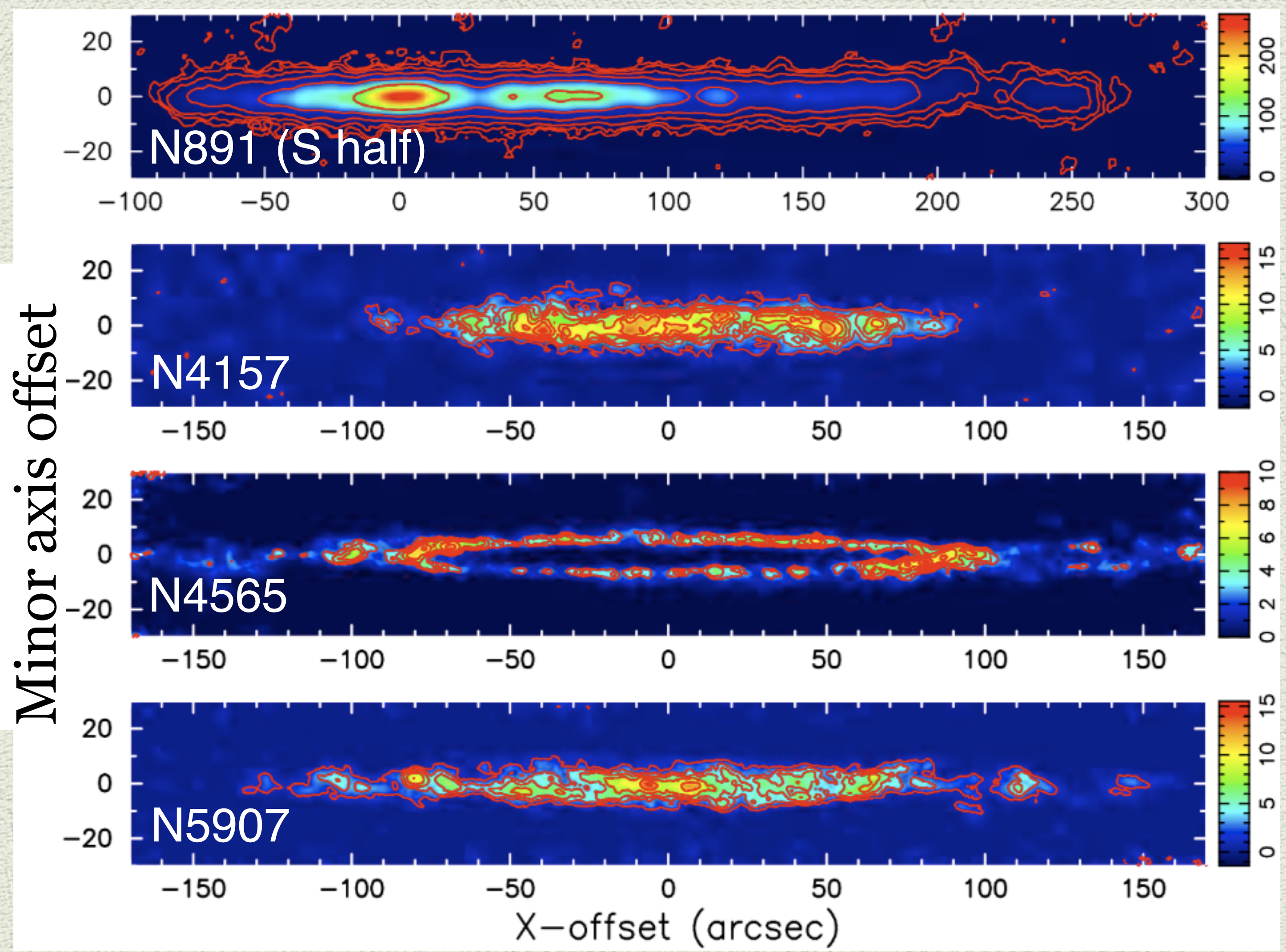
Vertical distribution

- scale heights as a function of radius for gas & stars
- vertical velocity dispersions with radius for gas & stars

Edge-on Galaxies

- disk thickness with radius →volume density & vertical velocity dispersion
- NGC 891, NGC 4157, NGC 4565 & NGC 5907

Observations: ^{12}CO (J=1→0) as a H_2 tracer



- N891:

  -BIMA, 7″ × 7″ & 10km/s

- N4157:

  -BIMA, 3.84″ × 3.30″ & 10km/s

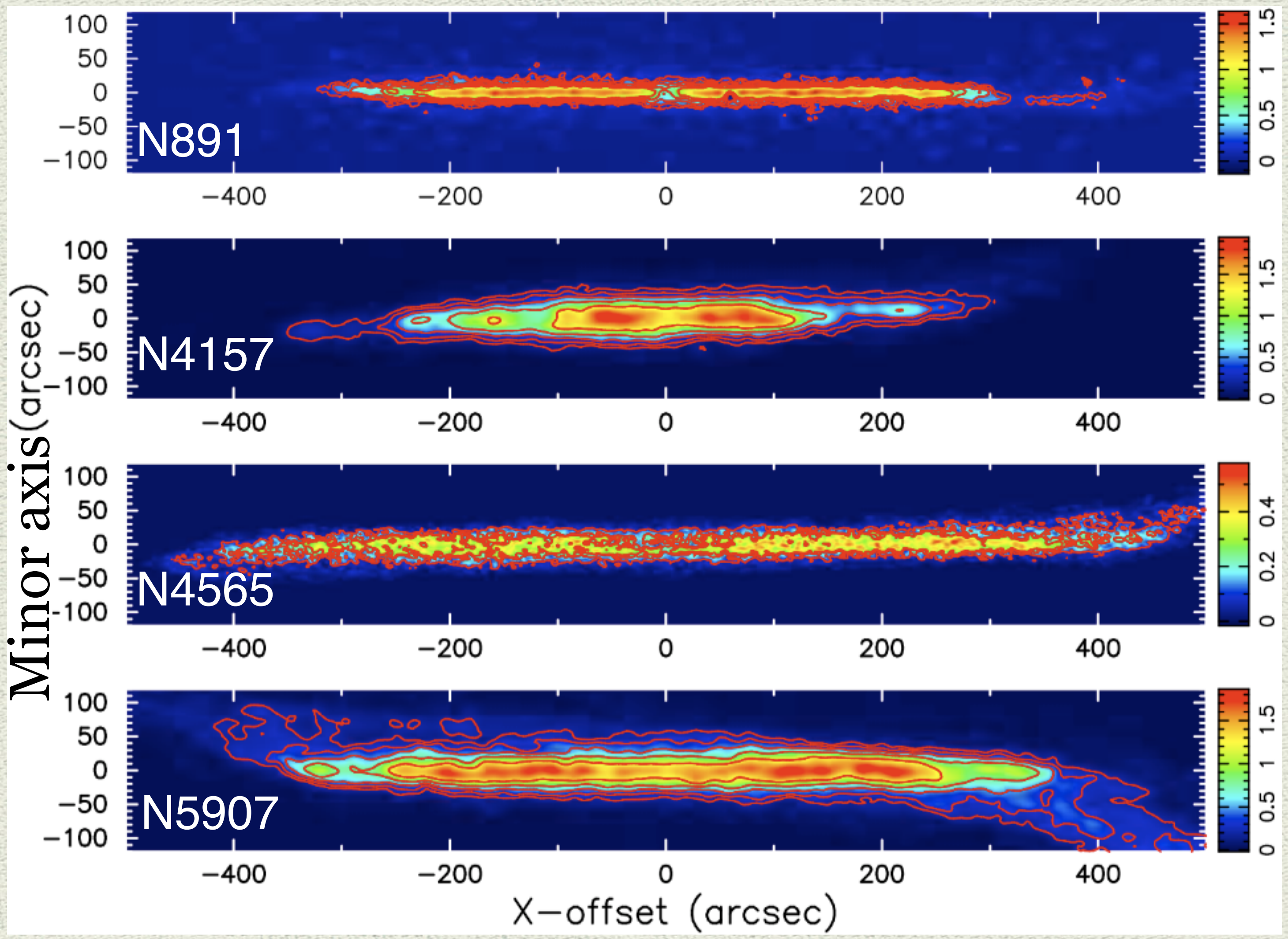
- N4565:

  -BIMA+CARMA, 3.60″ × 2.95″ & 10km/s

- N5907:

  -BIMA+CARMA, 3.48″ × 2.76″ & 10km/s

Observations: HI



- N891:

  -VLA, 11.56″ × 8.78″ & 20km/s

- N4157:

  -VLA, 15.69″ × 14.87″ & 20km/s

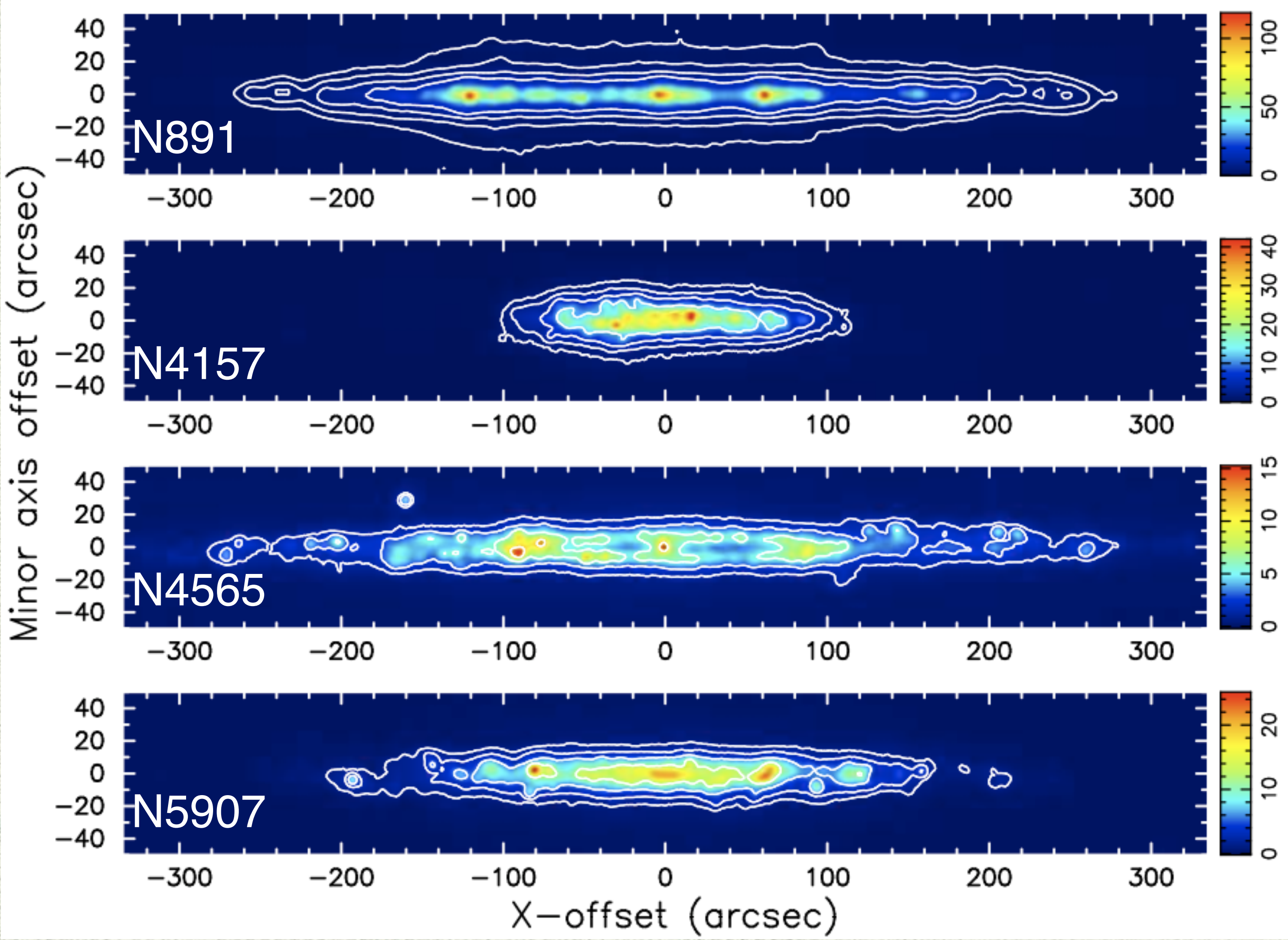
- N4565:

  -VLA, 6.26″ × 5.59″ & 20km/s

- N5907:

  -VLA, 15.43″ × 13.84″ & 20km/s

Observations: *Spitzer* IR data



- $\Sigma_{\rm stellar}$: Spitzer IRAC 3.6 μm as a stellar mass tracer

$$\Sigma_* \left[M_\odot \ {\rm pc}^{-2}\right] = 280 \ (\cos i) \ I_{3.6} \ [{\rm MJy \ sr}^{-1}]$$

Leroy et al. (2008)

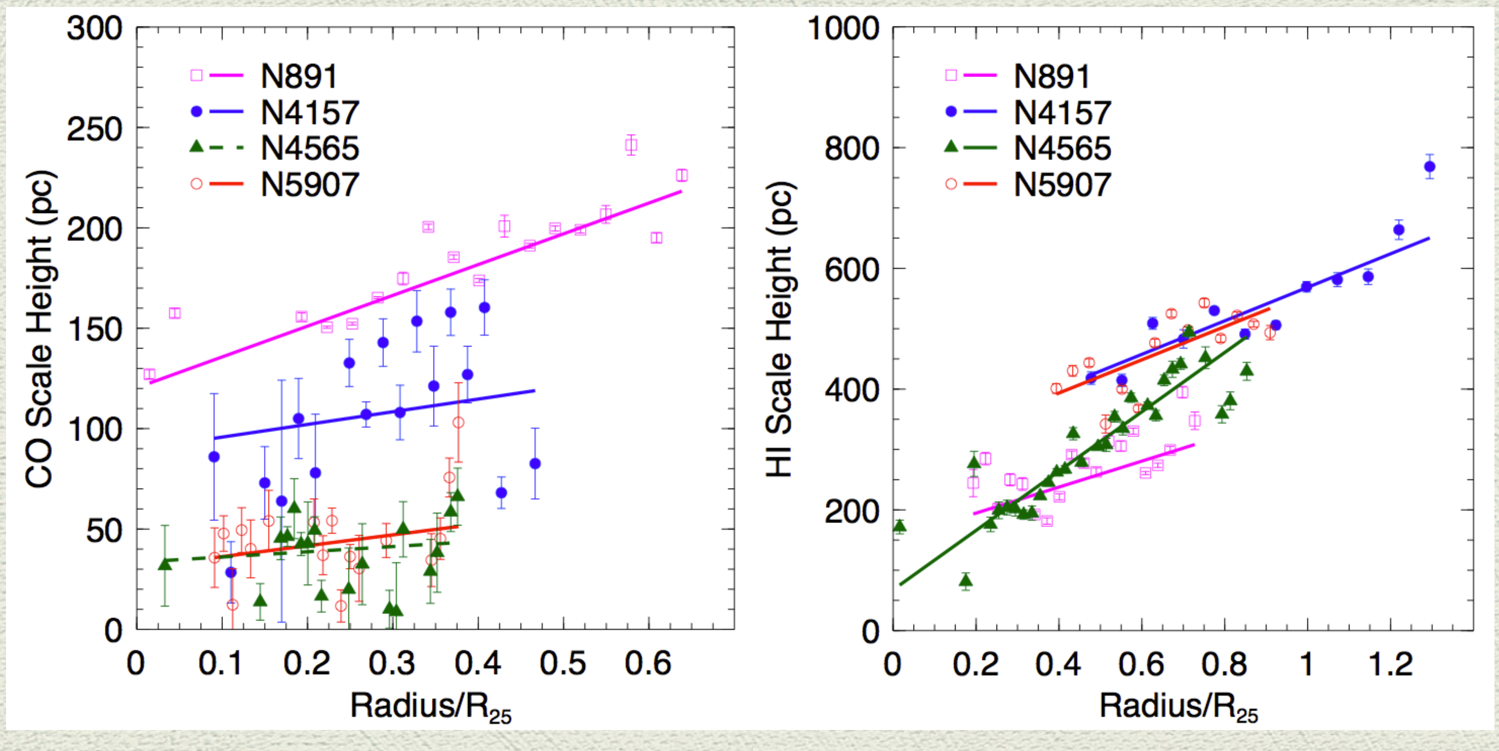
- $\Sigma_{\rm sfr}$: Spitzer MIPS 24 μm as a SFR tracer

$$\frac{\Sigma_{\rm SFR}}{M_\odot \ {\rm yr}^{-1} \, {\rm kpc}^{-2}} = 1.56 \times 10^{-35} \left(\frac{S_{24\,\mu{\rm m}}}{{\rm erg \ s}^{-1} \, {\rm kpc}^{-2}} \right)^{0.8104}$$

$$\frac{S_{24\,\mu{\rm m}}}{{\rm erg \ s}^{-1} \, {\rm kpc}^{-2}} = 1.5 \times 10^{40} \left(\frac{I_{24}}{{\rm MJy \ sr}^{-1}} \right)$$

Calzetti et al. (2007)

Vertical Structure: disk thickness

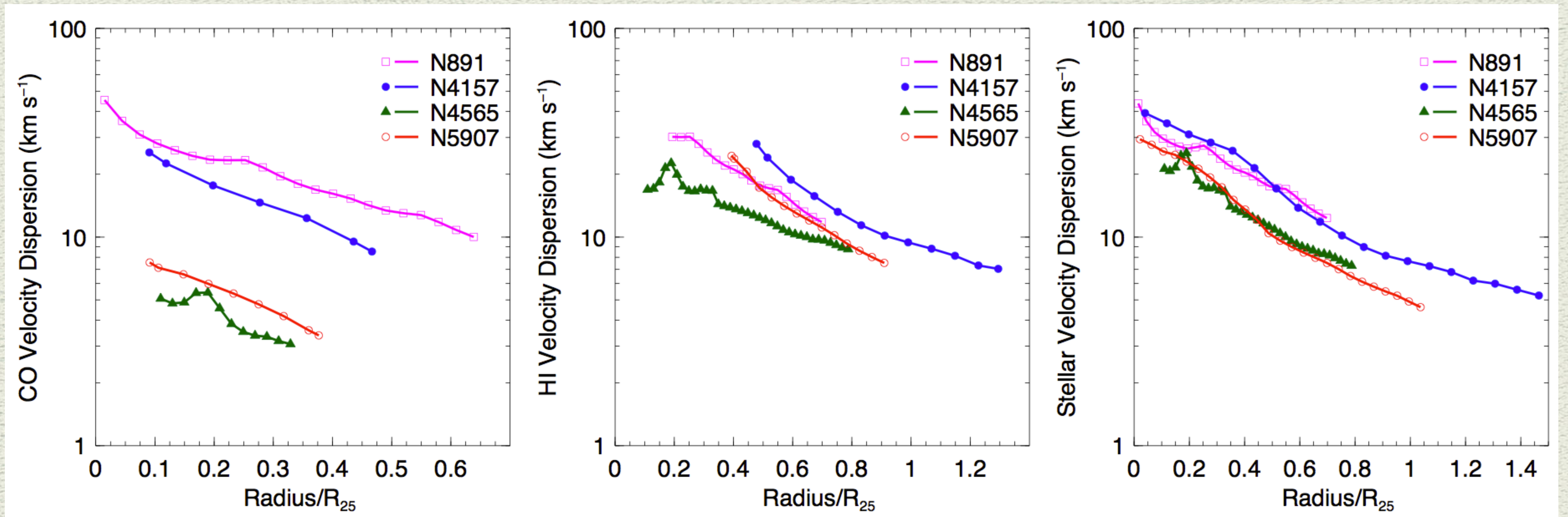


- Gaussian function fitting to the extreme velocity channels for almost edge-on galaxies
- Olling's method (1996) considering the projection effects for less edge-on galaxies

- Midplane volume density: using the derived surface density & the scale height assuming a Gaussian distribution for gas and a $\sec^2(z/h_*)$ function for stars

$$\rho_{0\mathrm{H}_2} = \frac{\Sigma_{\mathrm{H}_2}}{h_{\mathrm{H}_2}\sqrt{2\pi}} \qquad \rho_{0\mathrm{HI}} = \frac{\Sigma_{\mathrm{HI}}}{h_{\mathrm{HI}}\sqrt{2\pi}} \qquad \rho_{0*} = \frac{\Sigma_*}{2h_*}$$

Vertical Structure: vertical velocity dispersion

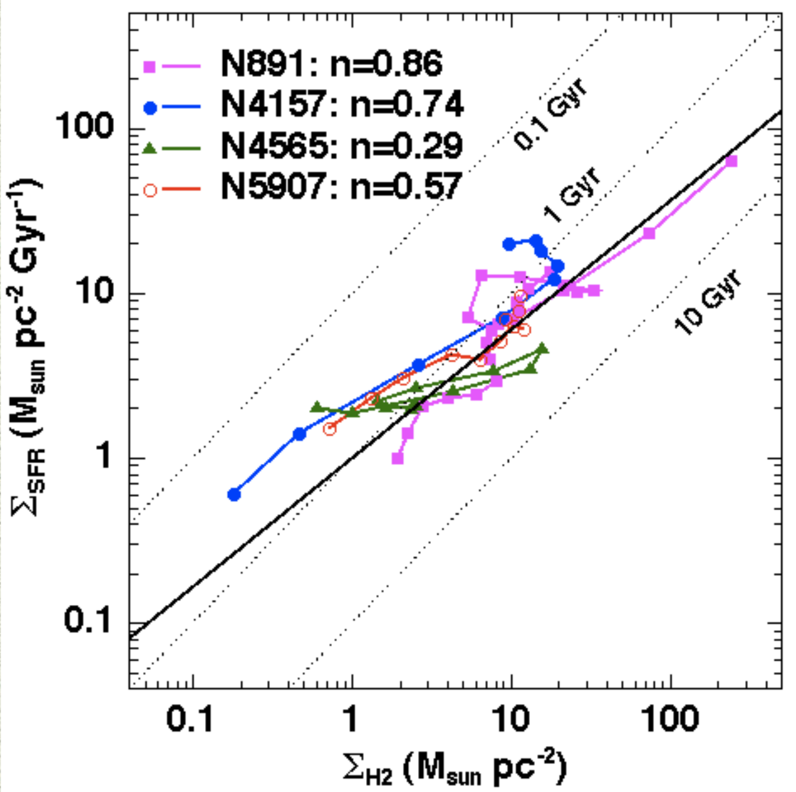


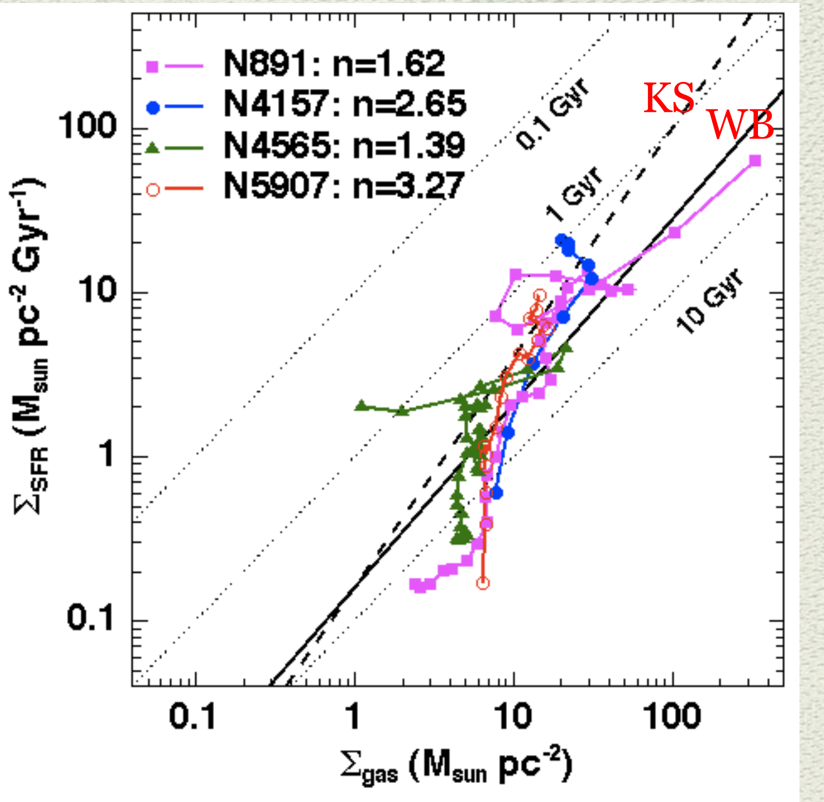
- Vertical velocity dispersions by solving the Poisson equation for a multi-component disk (Narayan & Jog 2002):

$$\sigma_i^2 = \frac{4\pi G \rho_{0,\mathrm{tot}} \rho_{0i}}{-\left(d^2\rho_i / dz^2\right)_{z=0}}$$

- Using the scale height (h) and the midplane volume density (ρ_0): $\sigma_g = (4\pi G h_g^2 \rho_{0,tot})^{0.5}$ & $\sigma_* = (2\pi G h_*^2 \rho_{0,tot})^{0.5}$

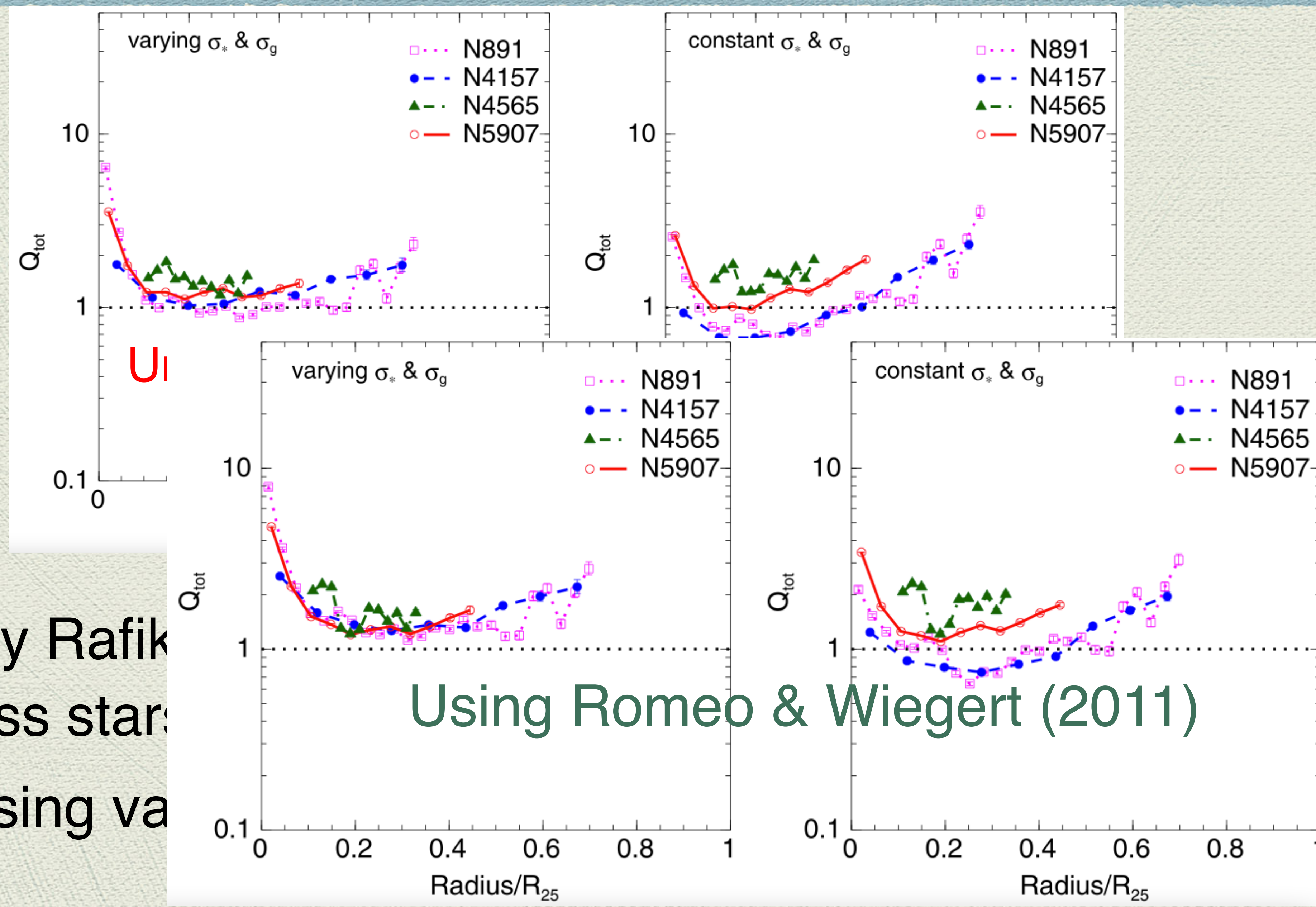
1. Star Formation Law (or Kennicutt-Schmidt Law)





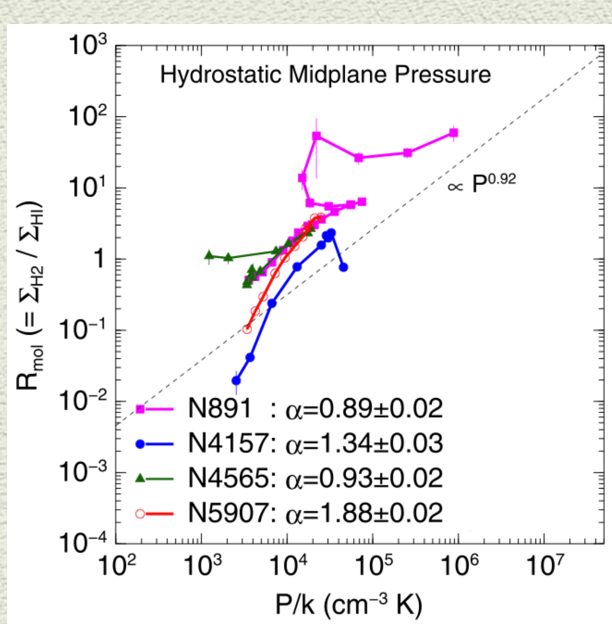
- $\Sigma_{SFR} \propto (\Sigma_{H_2})^{0.6}$ and $\Sigma_{SFR} \propto (\Sigma_{gas})^{2.2}$
- Kennicutt (1998): $\Sigma_{SFR} \propto (\Sigma_{gas})^{1.4}$
- Wong & Blitz (2002): $\Sigma_{SFR} \propto (\Sigma_{H_2})^{0.78}$ and $\Sigma_{SFR} \propto (\Sigma_{gas})^{1.12}$

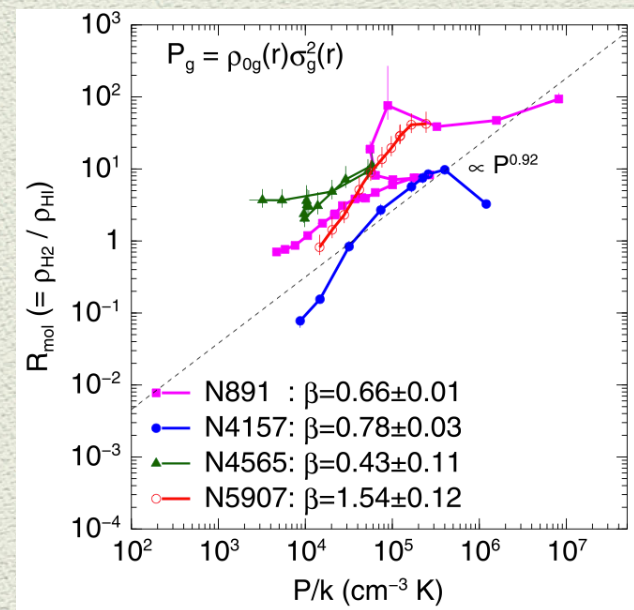
2. Gravitational Instability

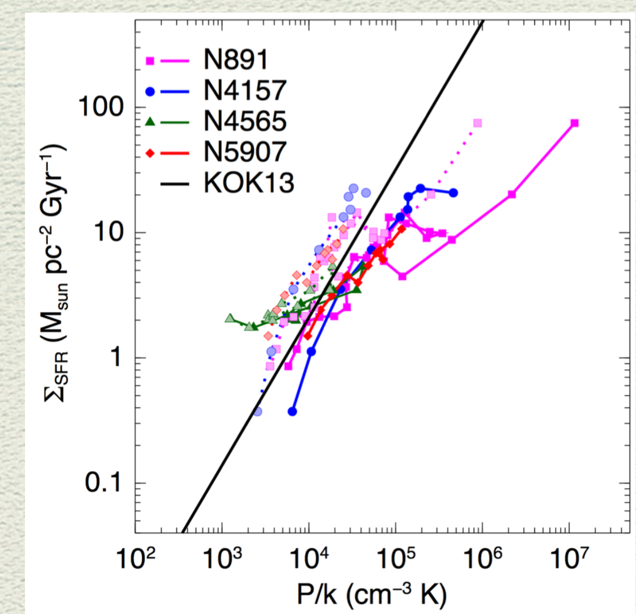


- $Q_{gas+star}$ by Rafik... and collisionless stars...
- $Q_{gas+Star}$ using va... formation
- $Q_{gas+Star}$ by Romeo and Wiegert (2011): considering realistically thick disks

3. Interstellar Gas Pressure







- Hydrostatic midplane pressure: $P_h = 0.89(G\Sigma_*)^{0.5}\Sigma_{gas}\sigma_{cg}/z_*^{0.5}$, where σ_{cg} = 8 km/s
- $\Sigma_{H_2}/\Sigma_{HI} \propto (P_h)^\alpha$, average $\boldsymbol{\alpha}$ = 1.26
- Interstellar Gas Pressure: $P_g \approx \rho_{oH_2}(r)\sigma^2_{H_2}(r) + \rho_{oHI}(r)\sigma^2_{HI}(r)$
- $\rho_{H_2}/\rho_{HI} \propto (P_g)^\beta$, average $\boldsymbol{\beta}$ = 0.85
- SFR vs. Pressure: $$\Sigma_{SFR} = 1.8 \times 10^{-3}\, M_\odot\, \mathrm{kpc}^{-2}\, \mathrm{yr}^{-1} \left(\frac{P_{tot,DE}/k_B}{10^4\, \mathrm{cm}^{-3}\, \mathrm{K}}\right)^{1.13}$$ (Kim, Ostriker & Kim 2013)

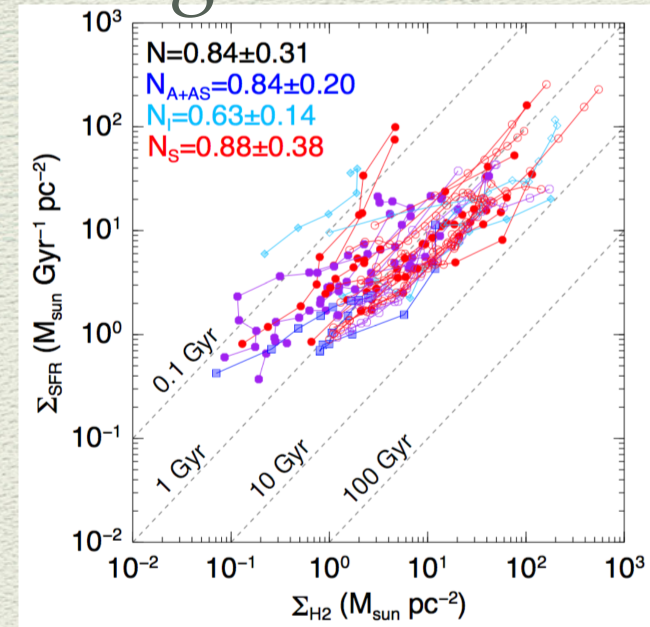
Star Formation vs. Gas Accretion

Galaxy sample: WSRT HI, CO, FUV, Spitzer 24μm

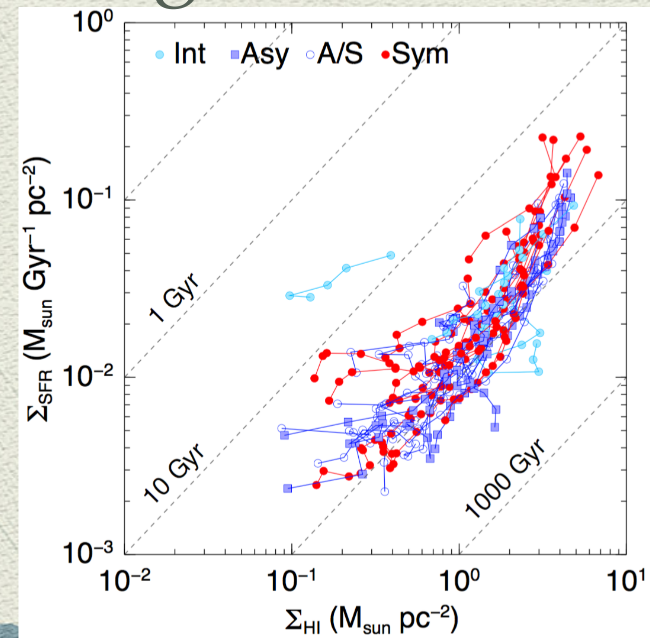
Galaxy (1)	Distance (Mpc) (2)	$\log\left(\frac{M_*}{M_\odot}\right)$ (3)	H I total flux (Jy km s^{-1}) (4)	r_{25} (arcsec) (5)	Inclination (°) (6)	V_{sys} (km s^{-1}) (7)	Galaxy Class (8)	CO Telescope (9)
UGC 1913 (NGC 925)	9.3	10.07	326	314	54^{V}	554	A/S	IRAM
UGC 2455 (NGC 1156)	6.5	9.28	64	99	52^{V}	375	S	
UGC 3334 (NGC 1961)	56.0	11.61	75	137	47^{L}	3934	I	IRAM
UGC 3851 (NGC 2366)	3.9	8.44	274	244	68^{V}	99	A	
UGC 4165 (NGC 2500)	9.8	9.35	36	87	28^{ES}	504	S	
UGC 4274 (NGC 2537)	8.1	9.32	20	52	33^{M}	452	S	
UGC 4305	5.0	8.76	253	238	40^{R}	142	A	
UGC 4862 (NGC 2782)	39.5	10.84	7	104	30^{W}	2543	I	
UGC 5079 (NGC 2903)	7.3	10.55	277	378	64^{V}	550	S	IRAM
UGC 5532 (NGC 3147)	43.0	11.57	32	117	35^{V}	2814	S	CARMA
UGC 5557 (NGC 3184)	10.1	10.28	123	222	21^{H}	592	A/S	BIMA
UGC 5789 (NGC 3319)	13.3	9.67	94	185	62^{V}	742	A/S	
UGC 5840 (NGC 3344)	6.9	9.91	186	212	18^{E}	588	S	
UGC 6537 (NGC 3726)	17.0	10.70	101	185	49^{V}	864	A/S	BIMA
UGC 6856 (NGC 3938)	15.5	10.44	86	161	24^{H}	808	S	BIMA
UGC 6869 (NGC 3949)	15.8	10.18	45	87	57^{L}	800	A/S	CARMA
UGC 7030 (NGC 4051)	12.9	10.21	44	157	41^{H}	704	S	BIMA
UGC 7166 (NGC 4151)	20.0	10.41	72	189	20^{N}	999	S	CARMA
UGC 7256 (NGC 4203)	22.4	10.89	49	102	51^{V}	1083	A	
UGC 7278 (NGC 4214)	3.8	9.10	260	255	44^{L}	292	S	IRAM
UGC 7323 (NGC 4242)	8.8	9.52	49	150	52^{V}	517	A/S	
UGC 7353 (NGC 4258)	8.0	10.64	509	559	66^{V}	454	S	BIMA
UGC 7524 (NGC 4395)	3.8	9.02	310	395	47^{V}	318	A	
UGC 7651 (NGC 4490)	9.2	10.17	252	189	60^{H}	565	I	BIMA
UGC 7766 (NGC 4559)	9.8	9.95	331	321	67^{V}	814	A/S	IRAM
UGC 7831 (NGC 4605)	4.4	9.37	54	173	56^{E}	146	A/S	CARMA
UGC 7853 (NGC 4618)	8.8	9.21	67	125	36^{O}	537	I	
UGC 7989 (NGC 4725)	26.8	11.46	145	321	44^{V}	1208	A	IRAM
UGC 12754 (NGC 7741)	12.5	9.73	53	131	49^{V}	752	S	

- No evidence for a positive correlation between gas accretion and star formation

Inner regions: SFR vs. H_2



Outer regions: SFR vs. HI



Future Work & Discussion

- Star Formation Law based on volume density
- More edge-on galaxies using ALMA to resolve the thickness of gas disks
- Star formation and gas accretion in distant galaxies

Summary & Conclusions

- Scale heights of gas and stars increase with radius and the vertical velocity dispersions of gas and stars decrease with radius
- Power-law correlation between Σ_{SFR} and Σ_{H_2}
- $Q_{gas+star}$ using varying σ_g & σ_* shows marginal instability
- Power-law correlation between the pressure and SFR