Extended Schmidt Law
-- Existing Stars Control How Efficient New Stars Form

Yong Shi (IPAC/Caltech)

George Helou, Lin Yan, Lee Armus, Yanling Wu,
Casey Papovich, Sabrina Stierwalt

Schmidt Law: Relationships Between Gas and SFRs

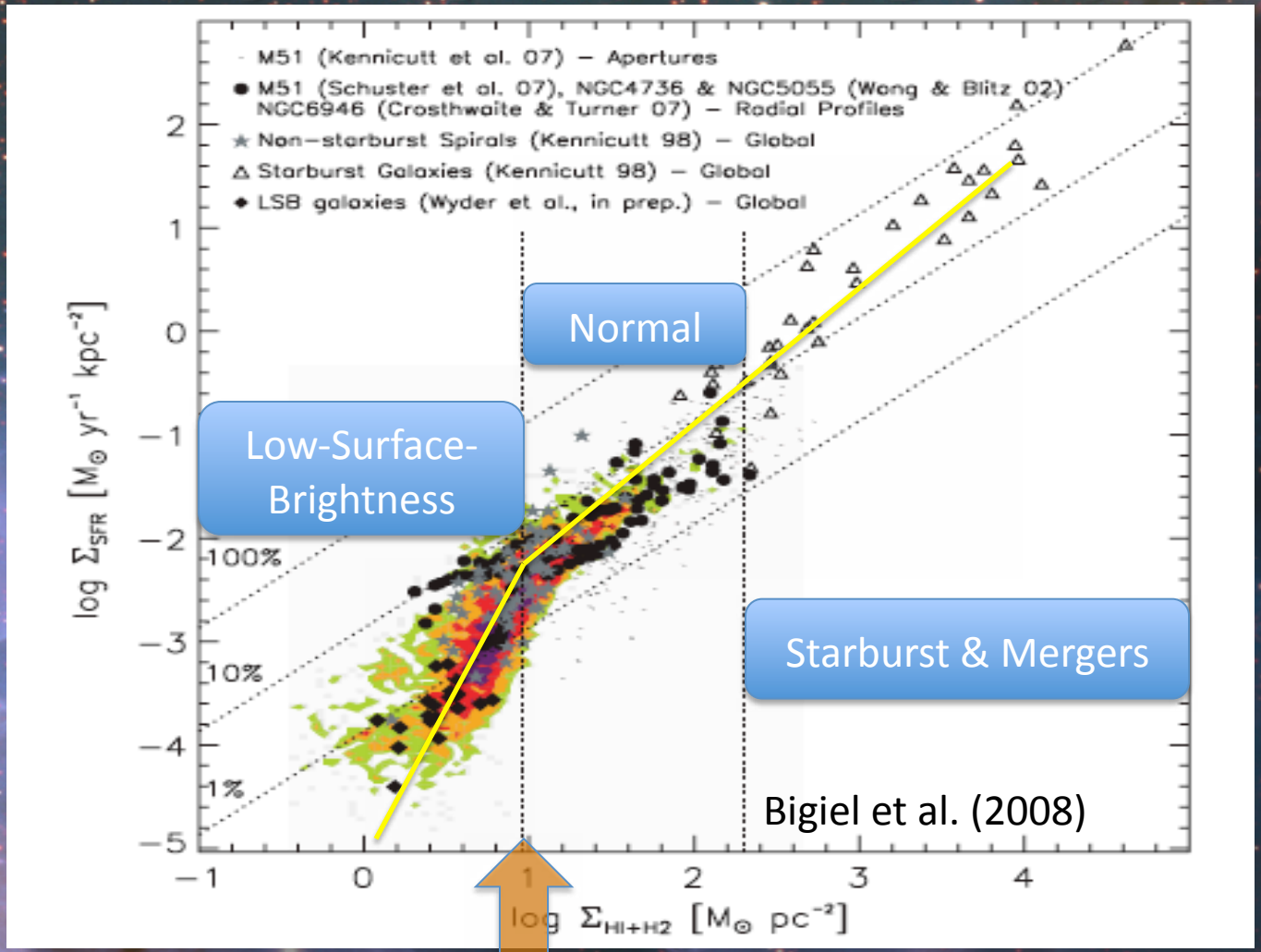
- Kennicutt-Schmidt Relation (Kennicutt et al. 1998):

$$\Sigma_{\mathrm{SFR}} \propto (\Sigma_{\mathrm{gas}})^{1.4 \pm 0.15}$$

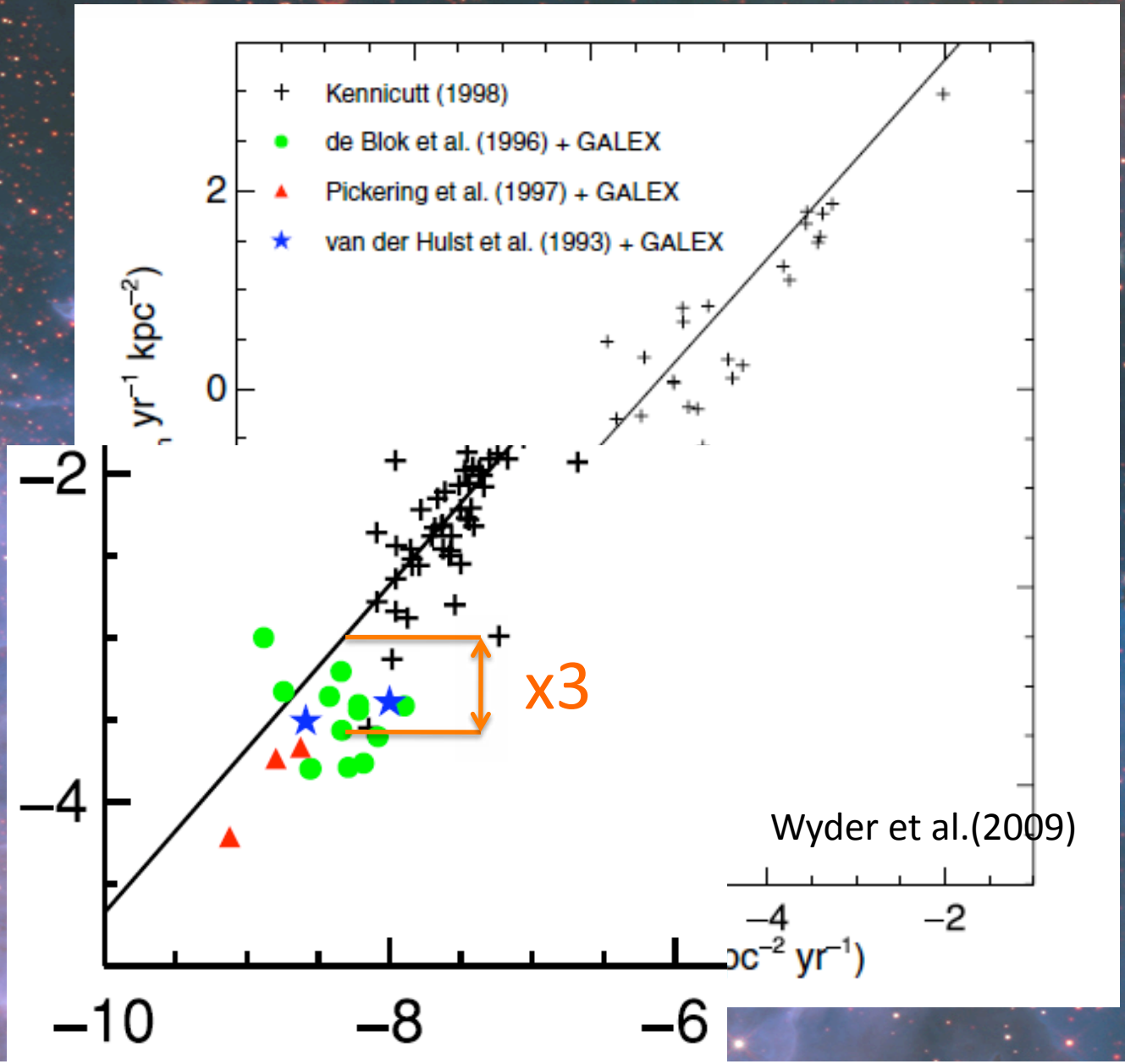
- Silk-Elmegreen Relation (Silk 1997; Elmegreen 1997):

$$\Sigma_{\mathrm{SFR}} \propto \frac{\Sigma_{\mathrm{gas}}}{\tau}; \tau = \text{orbital timescale}$$

KS Law For Individual Galaxies (Global) and Spatially-resolved Regions (1 Kpc)



SE Relationship:



Schmidt Law

- Kennicutt-Schmidt relation:

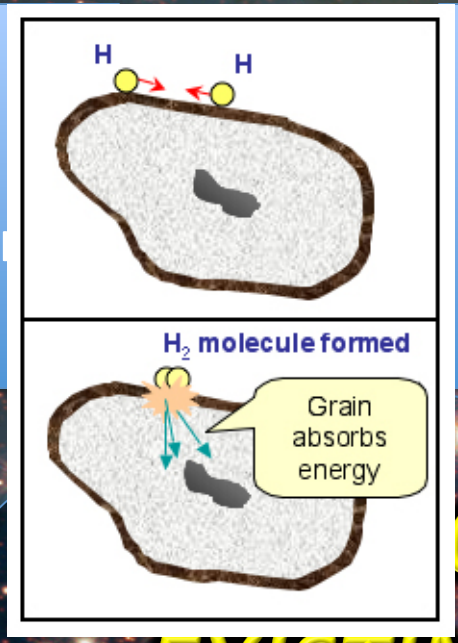
$$\Sigma_{SFR} \propto (\Sigma_{gas})^{1.4 \pm 0.15}$$

- Elmegreen-Silk relation:

$$\Sigma_{SFR} \propto \frac{\Sigma_{gas}}{\tau}; \tau = \text{orbital} - \text{timescale}$$

Stellar gravity:

- Help gas collapse
- Remove gas angular momentum



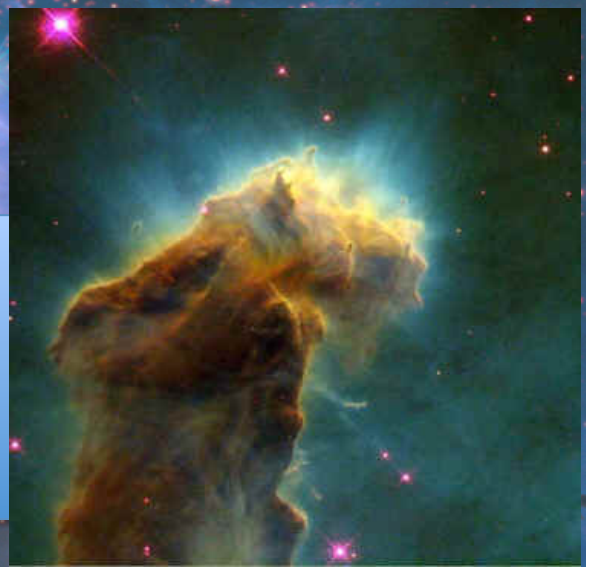
Metal Enrichment:

- ISM cooling
- Dust catalyzes H_2 formation
- Dust shields H_2 from radiation

OF EXISTING STARS

Stellar Radiation:

- Compress Gas to increase SFRs
- Heat gas to decrease SFRs



New approach:

Σ_{SFR} as a dependent variable

Σ_{gas} and Σ_{star} as independent variables

Diverse Galaxy Samples:

- Nearby Normal Galaxies (NNG)
- Low-Surface-Brightness (LSB) Galaxies
- Local LIRGs
- High-z BzK SFGs and SMGs

Σ_{SFR} as a function of Σ_{gas} and Σ_{star}

$$\Sigma_{\rm SFR} \propto \Sigma_{\rm gas}^{0.98\pm0.06} \Sigma_{\rm star}^{0.48\pm0.06}$$

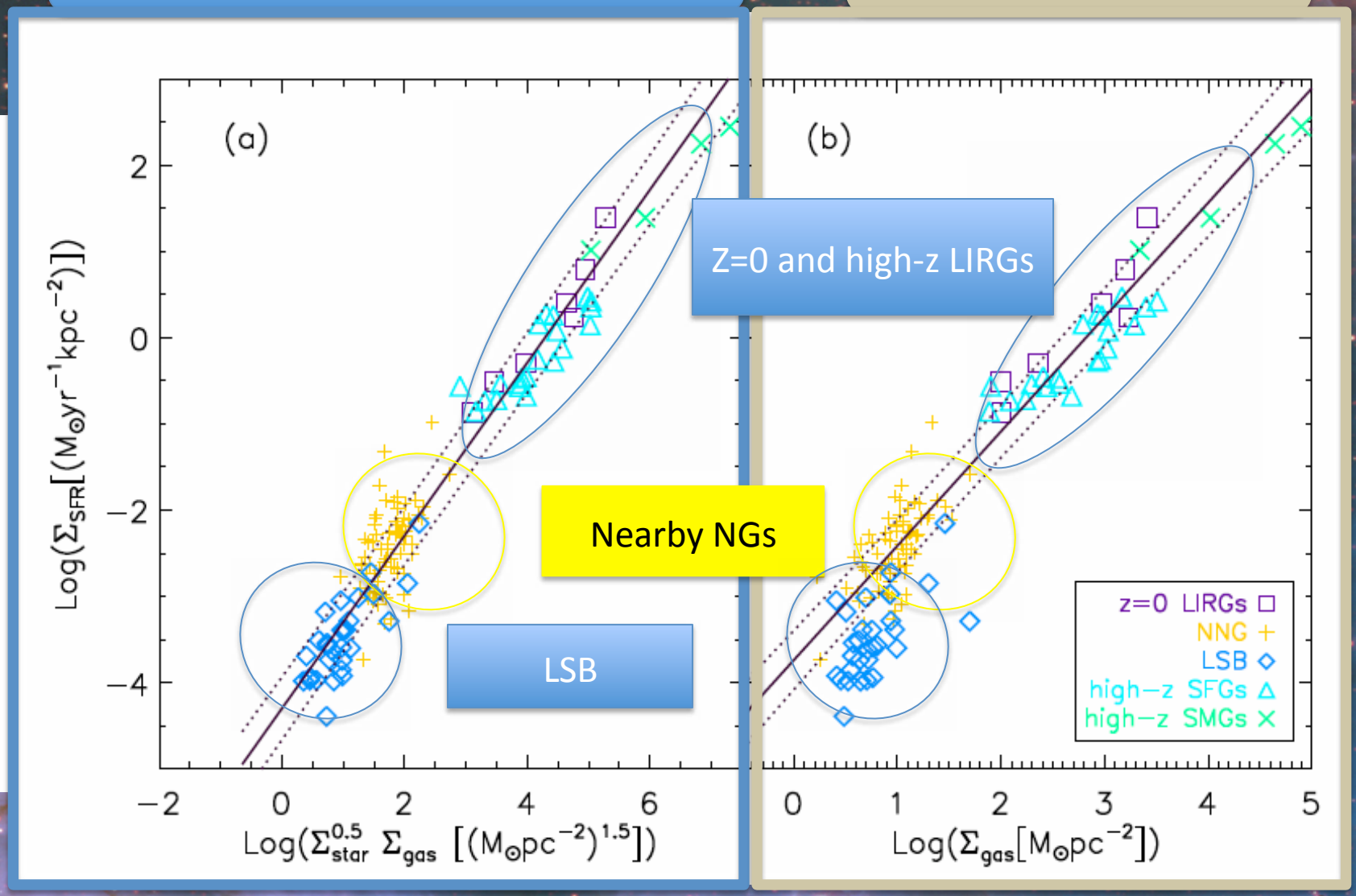
A *unity* index on Σ_{gas} gives a clear physical implication of the relation:

Star-Formation-Efficiency (SFE)=SFR/M_{gas} is a function of the stellar density. Or stellar density controls how efficient new stars form.

Extended Schmidt Law

KS Law

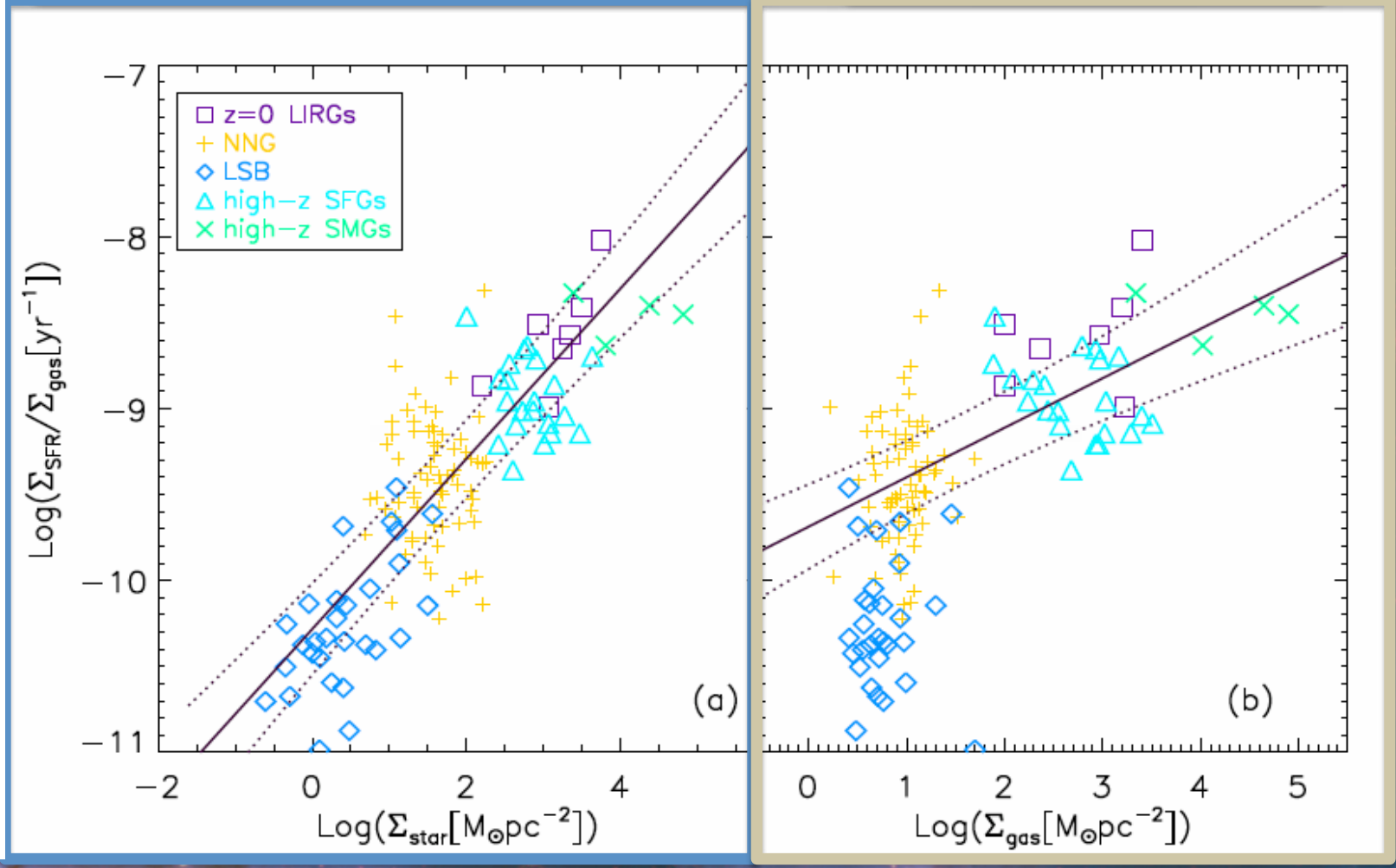
Star Formation Rate



Extended Schmidt Law

KS Law

Star Formation Efficiency



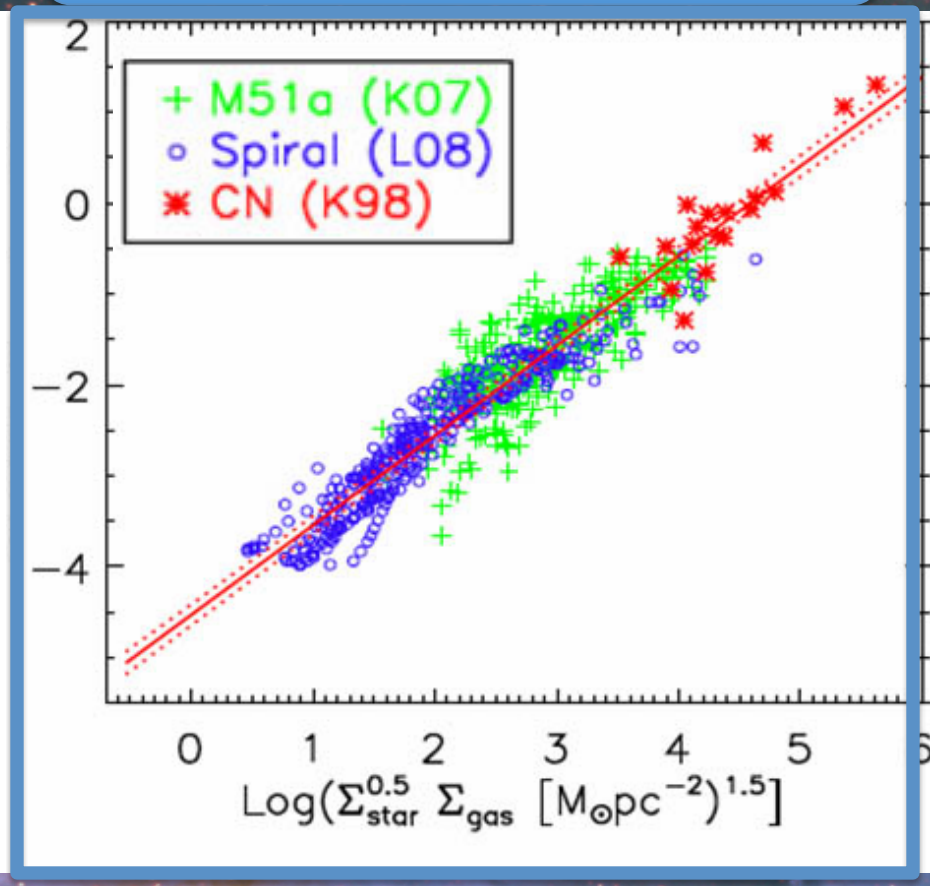
Extended Schmidt Law For Spatially-Resolved Regions

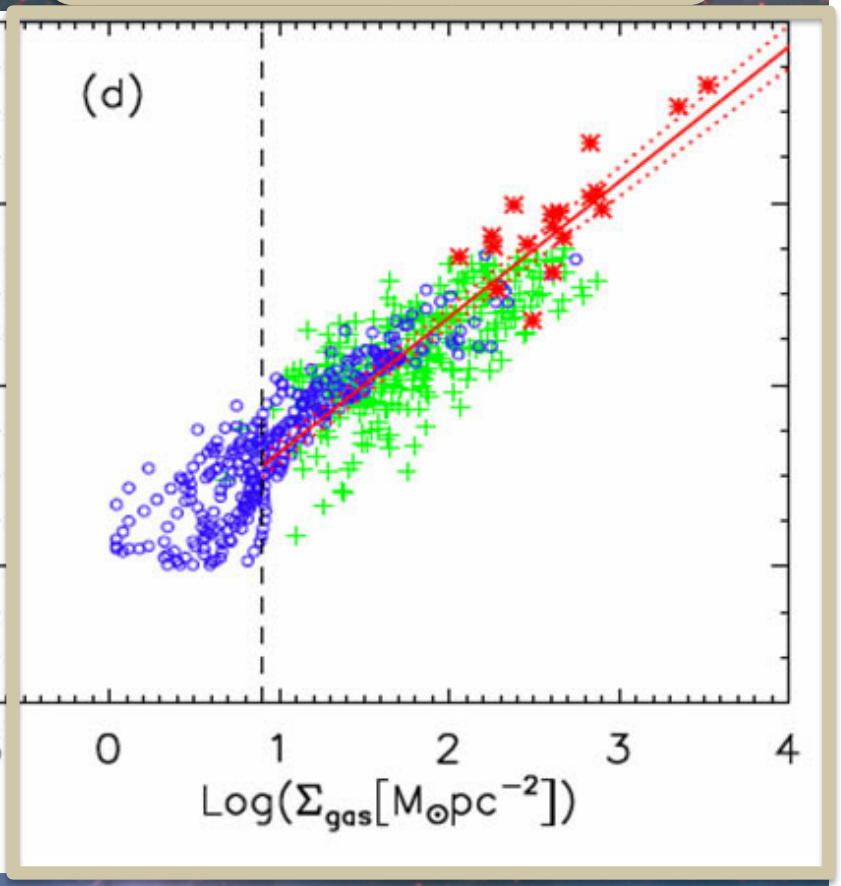
- Starburst Nuclei (Kennicutt et al. 1998).
- HII regions in M51a (Kennicutt et al. 2007).
- Radial Profiles Of Spiral Galaxies (Leroy et al. 2008).

Extended Schmidt Law

KS Law

Star Formation Rate





Physical Mechanism I:
Free-Fall In a Stellar-Dominated Gravitational Potential

Star formation as gas collapse per timescale:

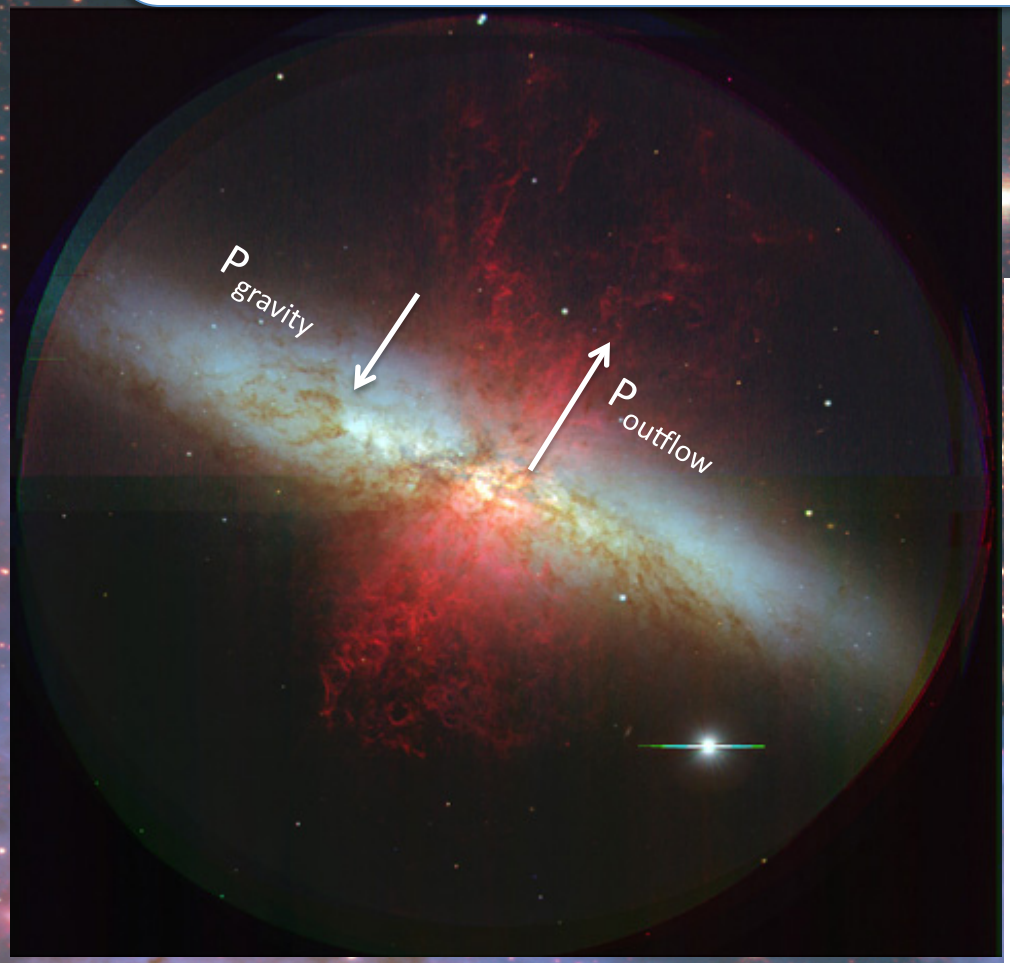
$$\Sigma_{SFR} \propto \frac{\Sigma_{gas}}{\tau}$$

A free-fall timescale in a stellar gravitational potential:

$$\tau = \tau_{ff} \propto \frac{1}{\rho^{0.5}} = \frac{h^{0.5}}{\Sigma_{star}^{0.5}}$$; if $\Sigma_{star} >> \Sigma_{gas}$

This explains the extended Schmidt law only if $\Sigma_{star} >> \Sigma_{gas}$

Physical Mechanism II:
Pressure-Supported Star Formation



$$P_{outflow} = P_{gravity}$$

$$P_{outflow} \approx P_{SN} + P_{RAD} \propto \Sigma_{SFR}$$

(Thompson et al. 2005)

$$P_{gravity} \propto \Sigma_{gas}(\rho_{star}^{0.5} + \frac{\pi}{4}\rho_{gas}^{0.5}) \approx \Sigma_{gas}\frac{\Sigma_{star}^{0.5}}{h^{0.5}}$$

(Blitz & Rosolowsky et al. 2004)

This explains the extended Schmidt law only if $\Sigma_{star} >> \Sigma_{gas}$

Summary

- An extended Schmidt law is proposed to relate the SFE (=SFR/gas-mass) to the stellar-mass surface density.
- Derived empirically from diverse galaxy samples.
- The exact physical mechanism needs further explorations.