A Simple Model for the Relationship Between Star Formation and Surface Density

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Dobbs & Pringle 2009

Evaluating the Kennicutt/Schmidt law from simulations

- Galactic scale simulations cannot resolve star formation
  - require prescription for threshold density, efficiency, kinetic & thermal energy deposited

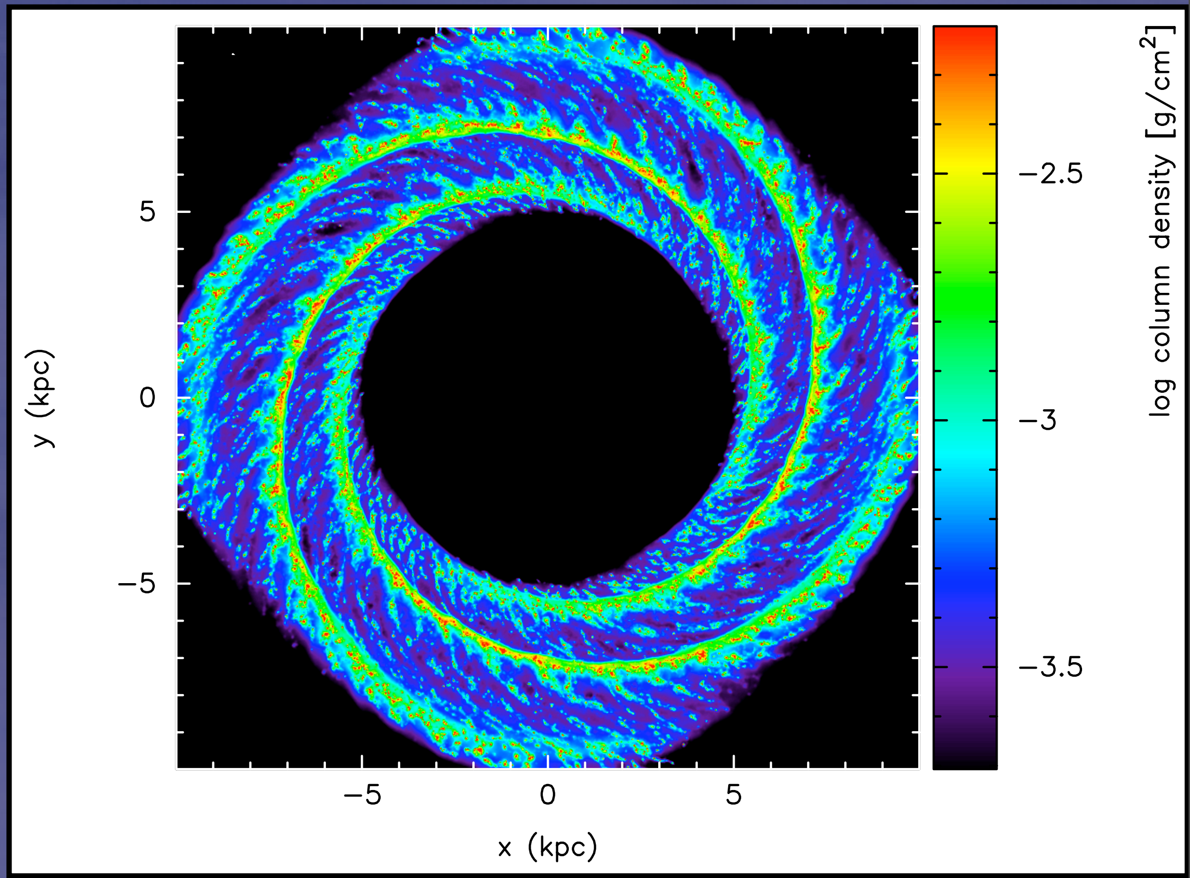
- How does star formation rate depend on the star formation implementation?

- Alternative approach
  - no implementation of star formation
  - calculate how much of the gas is gravitationally bound
  - but restricted to relatively low surface densities

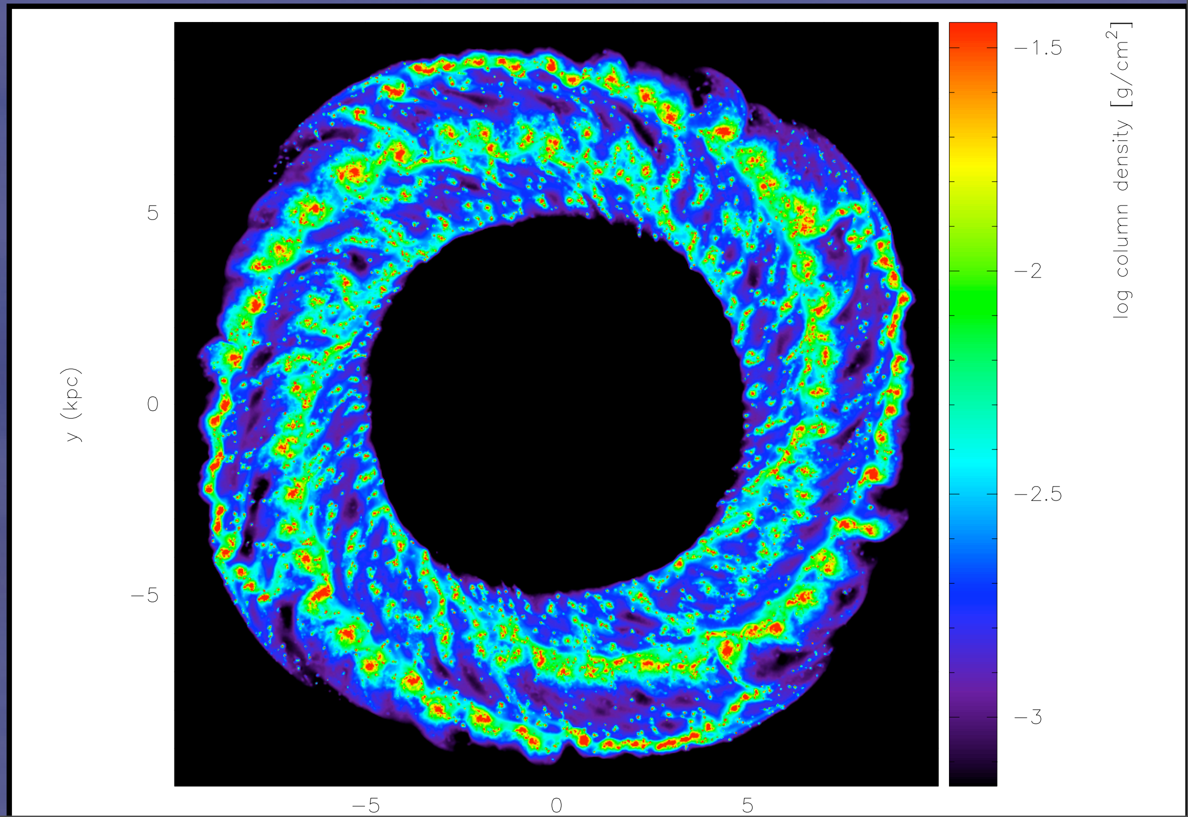
Details of simulations

- Described in Dobbs (2008)
- Use SPH (3D)
- Gas disc subject to a galactic spiral potential
- Simulations isothermal, adopting a two-phase medium
- Include self gravity and magnetic fields

$4\ M_{\odot}pc^{-2}$



$20\ M_{\odot}pc^{-2}$



Details of simulations

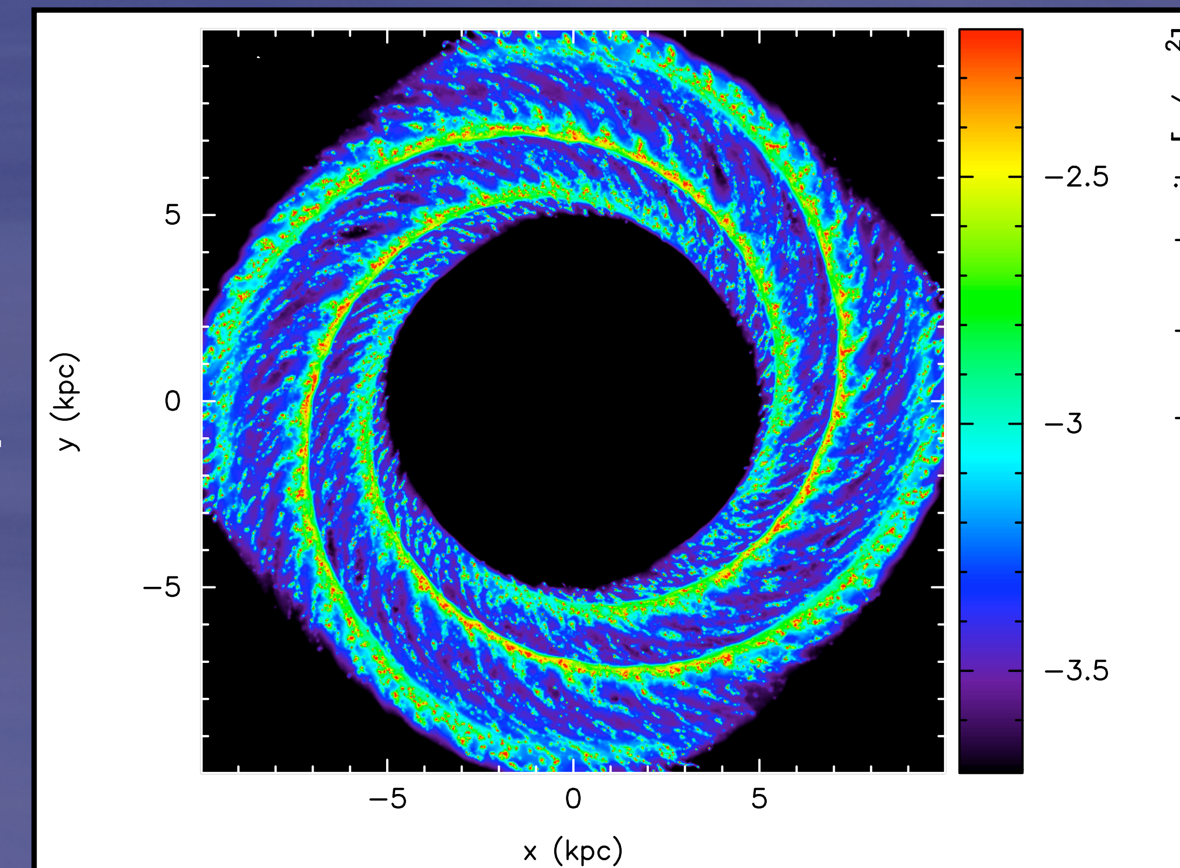
Low density regime

$\Sigma = 4, 8, 16, 20\ M_\odot pc^{-2}$

F = 4 %

$4\ M_\odot pc^{-2}$

250 Myr

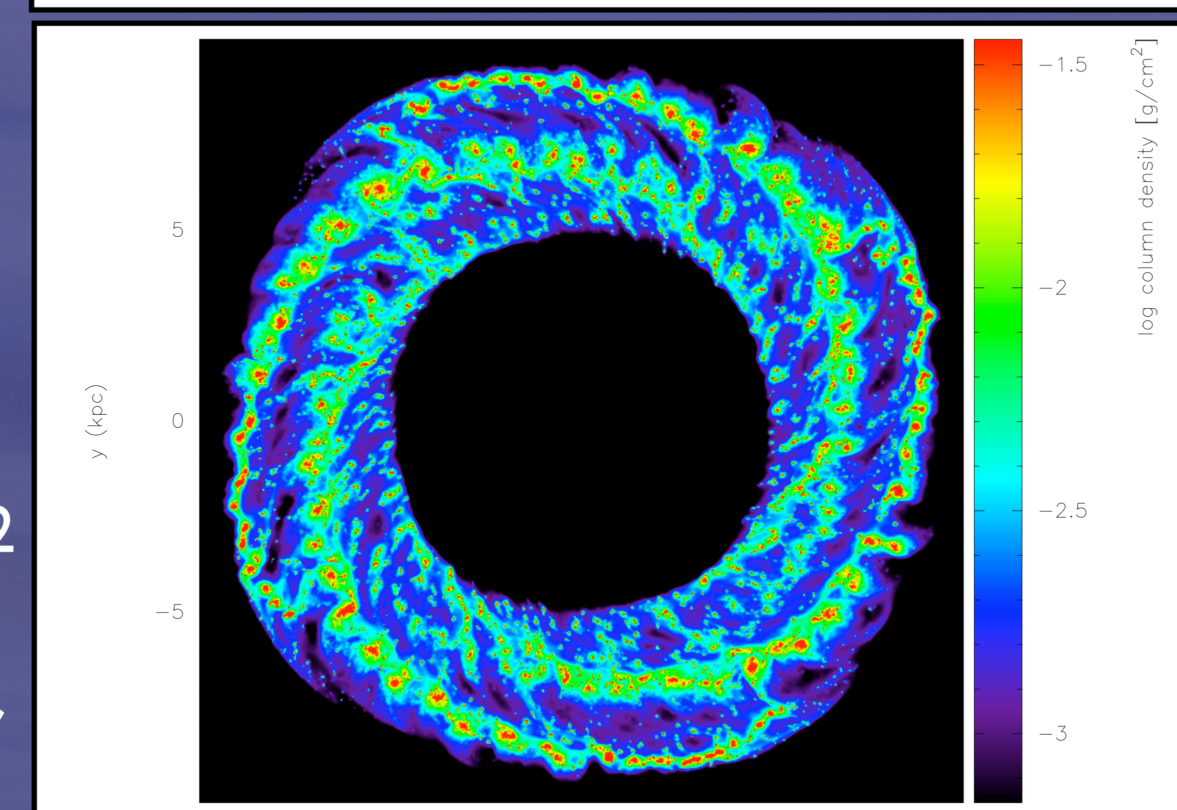


$\Sigma = 4\ M_\odot pc^{-2}$

F = 2, 4, 8 and 16 %

$20\ M_\odot pc^{-2}$

140 Myr



Estimating the (local) star formation rate

- S.F.R. estimated at snapshot of simulation
- Determine location of bound gas - increase radius of each bound 'clump' until $\alpha > 1$

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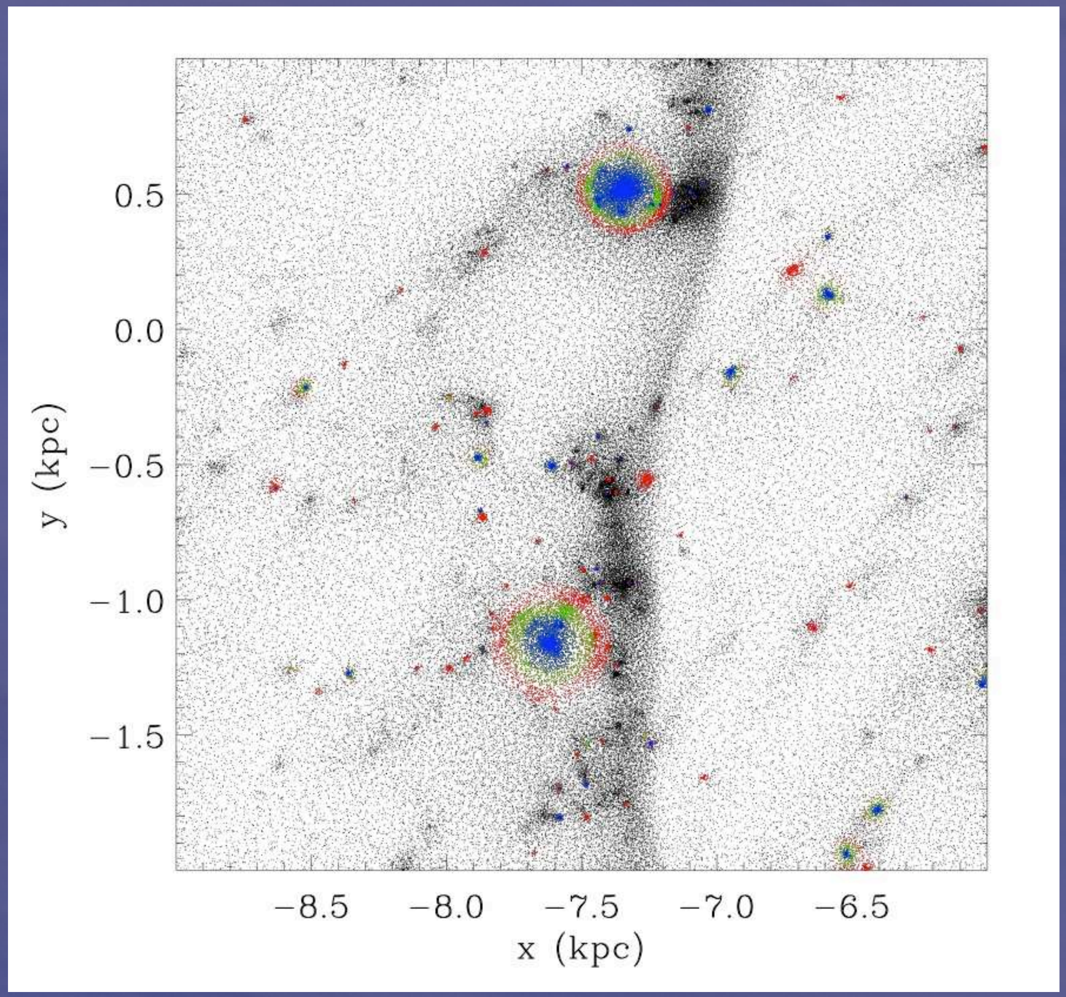
Section of spiral arm showing bound gas (Σ=8 $M_\odot pc^{-2}$):



Number of bound clumps

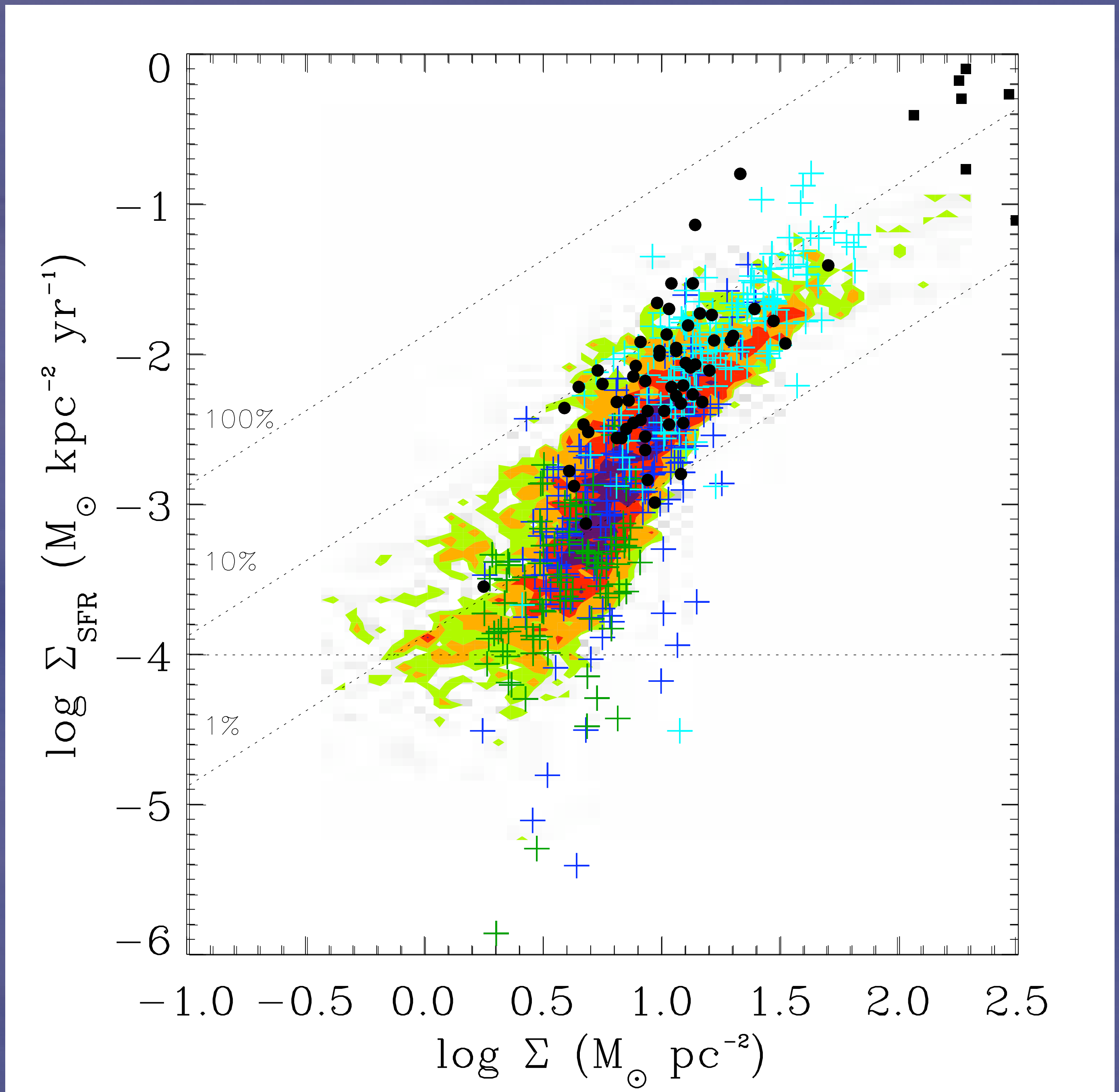
Mass of clump/ dynamical time

$$\Sigma_{\rm SFR} = \frac{\sum_{i=1}^{N} \epsilon \, \dot{M}_i}{A}$$

Area (500x500 pc)

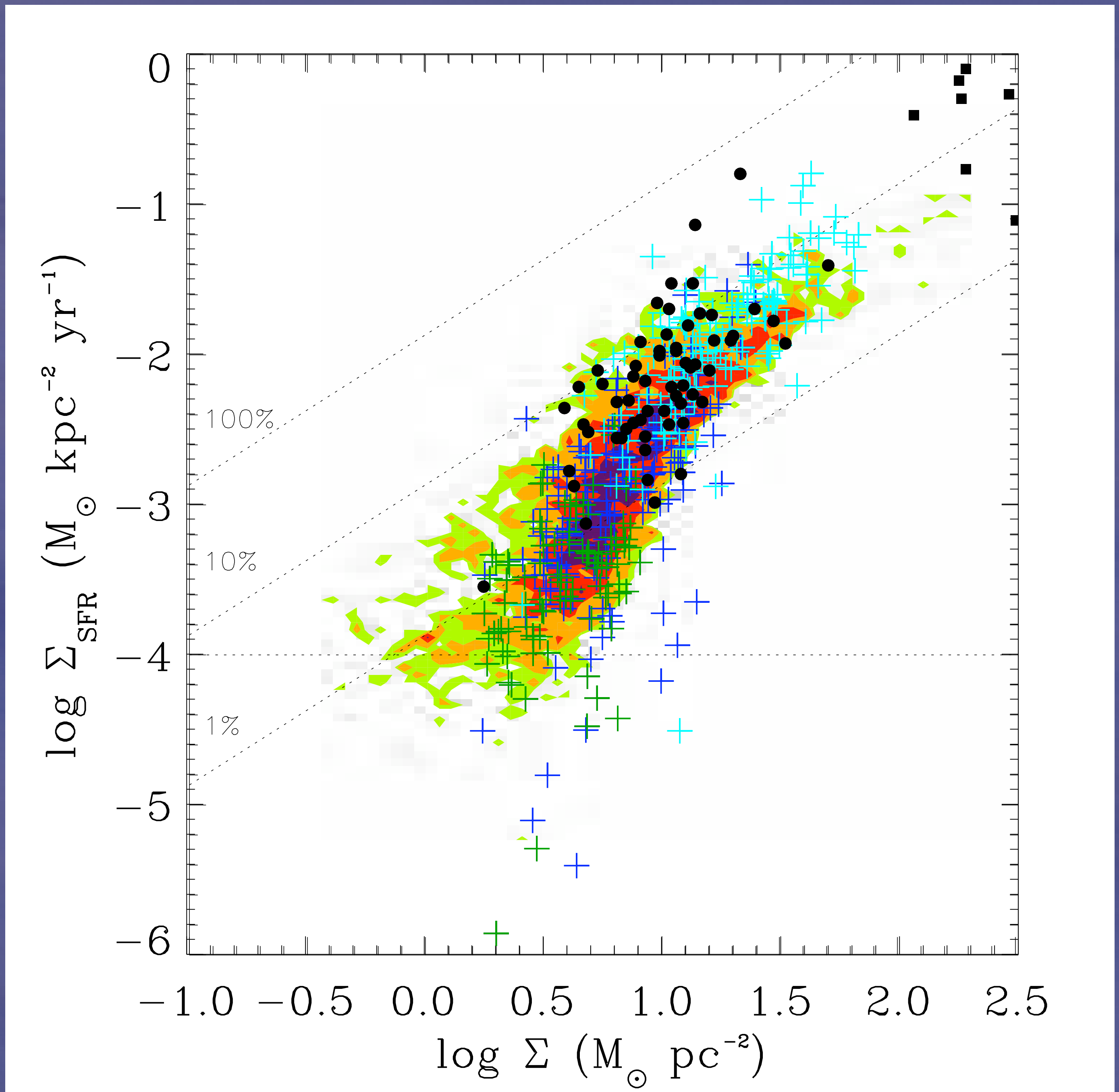
Efficiency

Comparison with observed Kennicutt-Schmidt law



- Estimate S.F.R. in 500 x 500 pc areas (each cross)
- Crosses - points from 4 (green), 8 (dark blue) and 20 $M_\odot pc^{-2}$ (cyan) calculations (i.e. 3 galaxies)
- Black points - Kennicutt 1998
- Contours - Bigiel et. al. 2008 (averaged over the galaxies in their sample)

Comparison with observed Kennicutt-Schmidt law

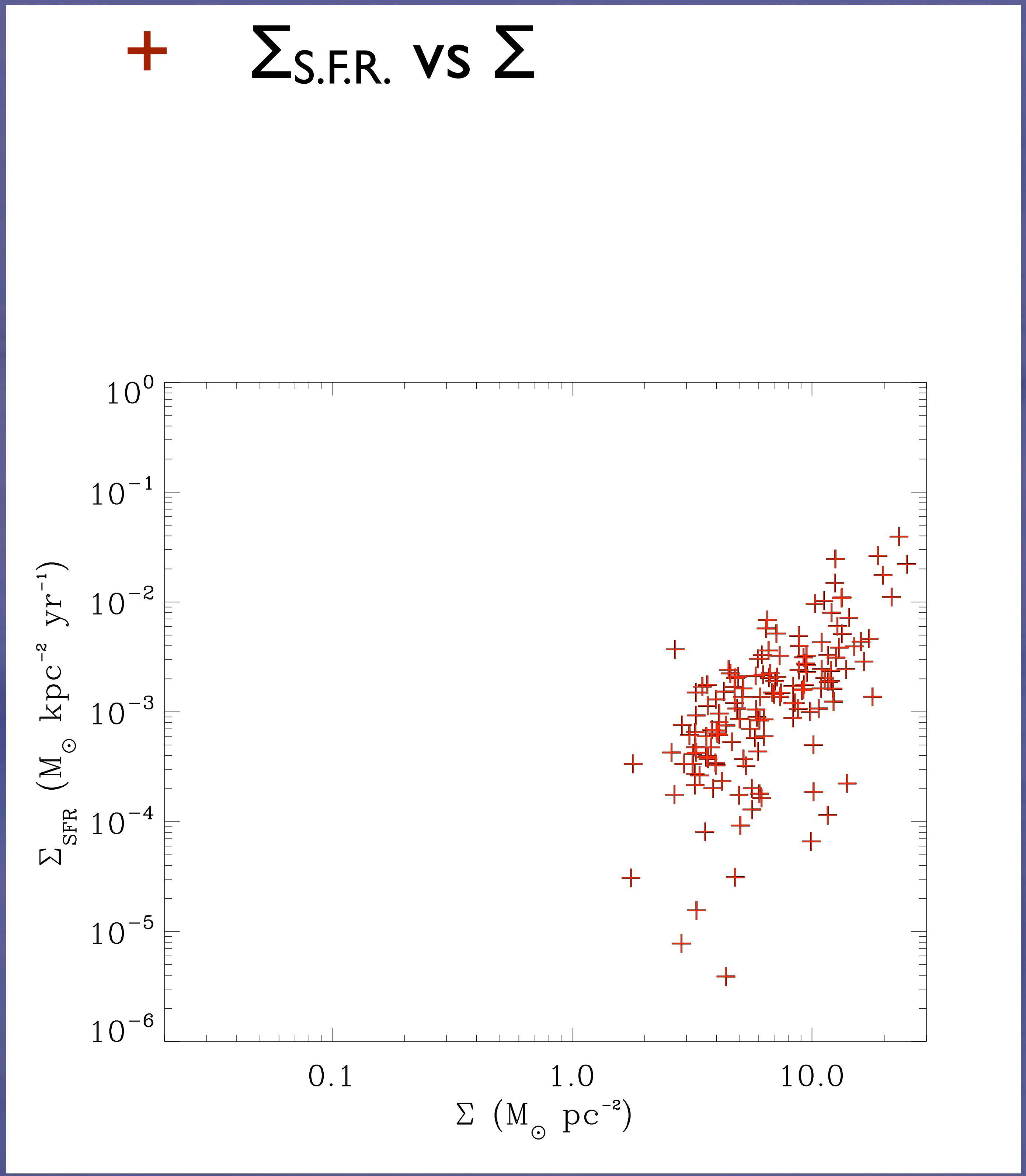


- Require ϵ=0.05 to match observations
- No linear relation - kink at 10 M⊙pc^{-2} for both simulations and observations
- Spread of points increases at lower Σ

What about different tracers?

- Observations indicate different star formation laws for different tracers
- Can we test this with simulations?

What about different tracers?



8 $M_\odot pc^{-2}$

- Gas within 500x500 pc region exhibits range of densities

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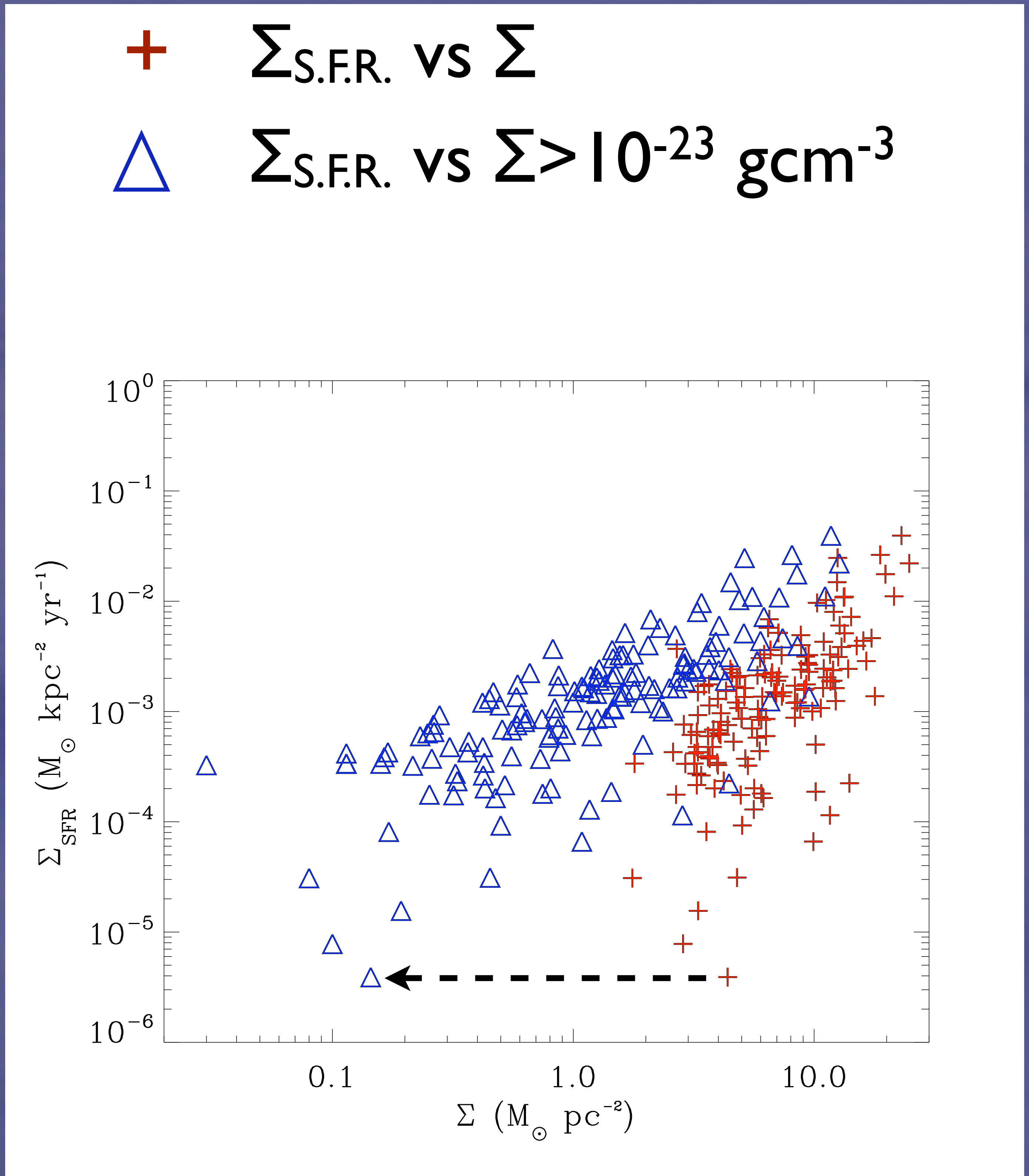

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- Gas within 500x500 pc region exhibits range of densities
- Only take gas with $\Sigma > 10^{-23}$ gcm^{-3}
  - low density points shifted left
  - linear relation

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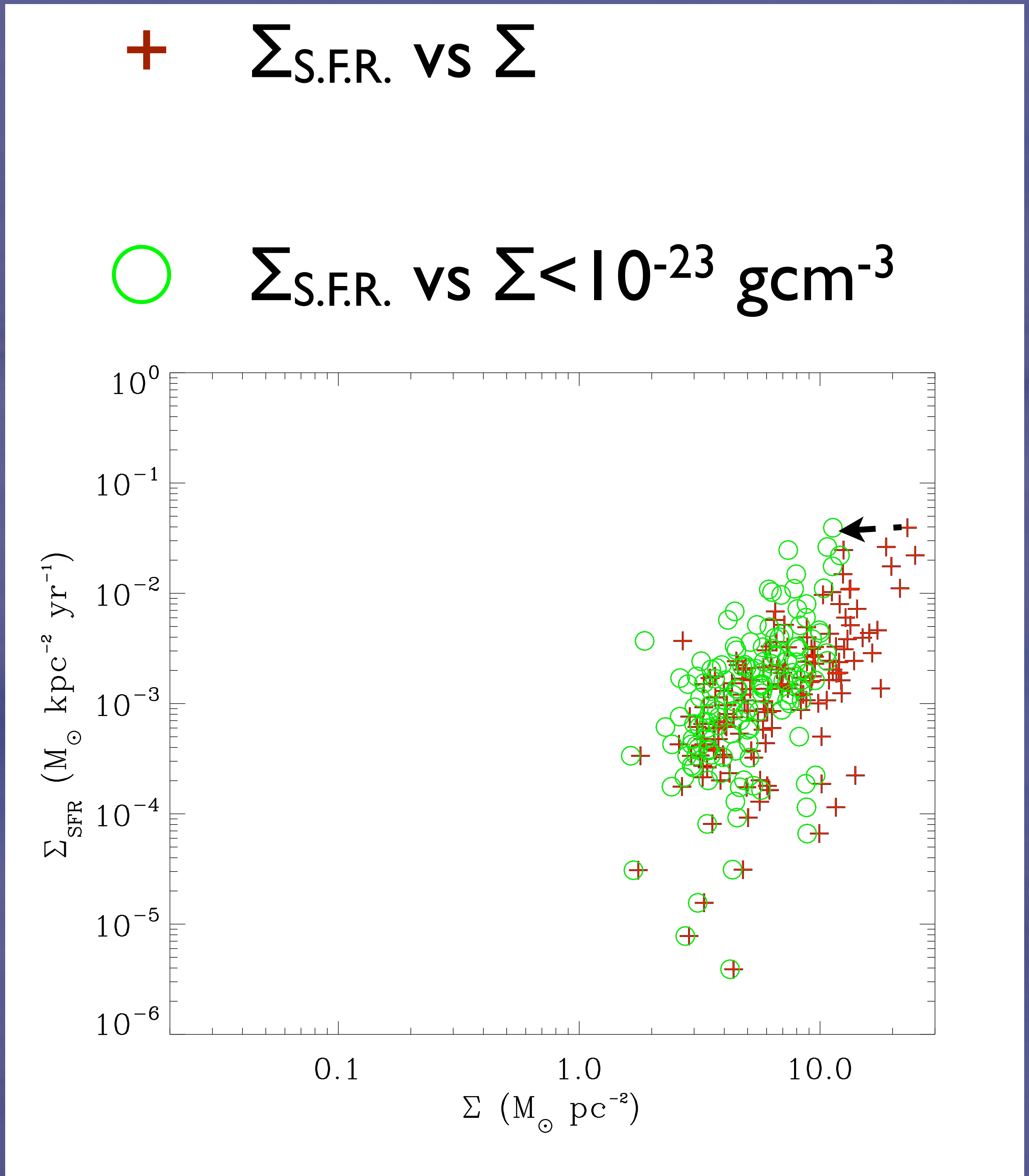

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- Take gas with Σ < 10^{-23} gcm^{-3}
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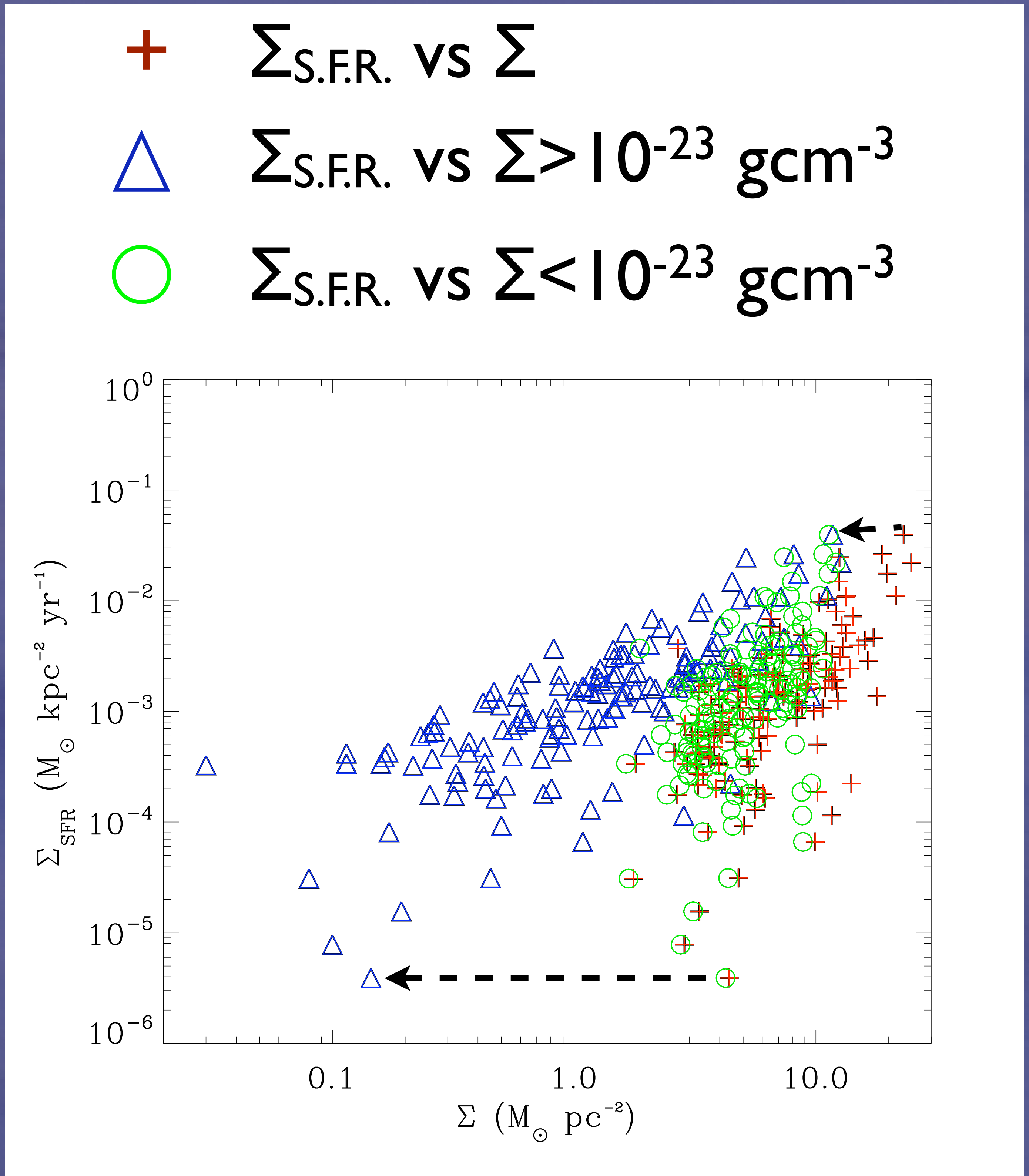

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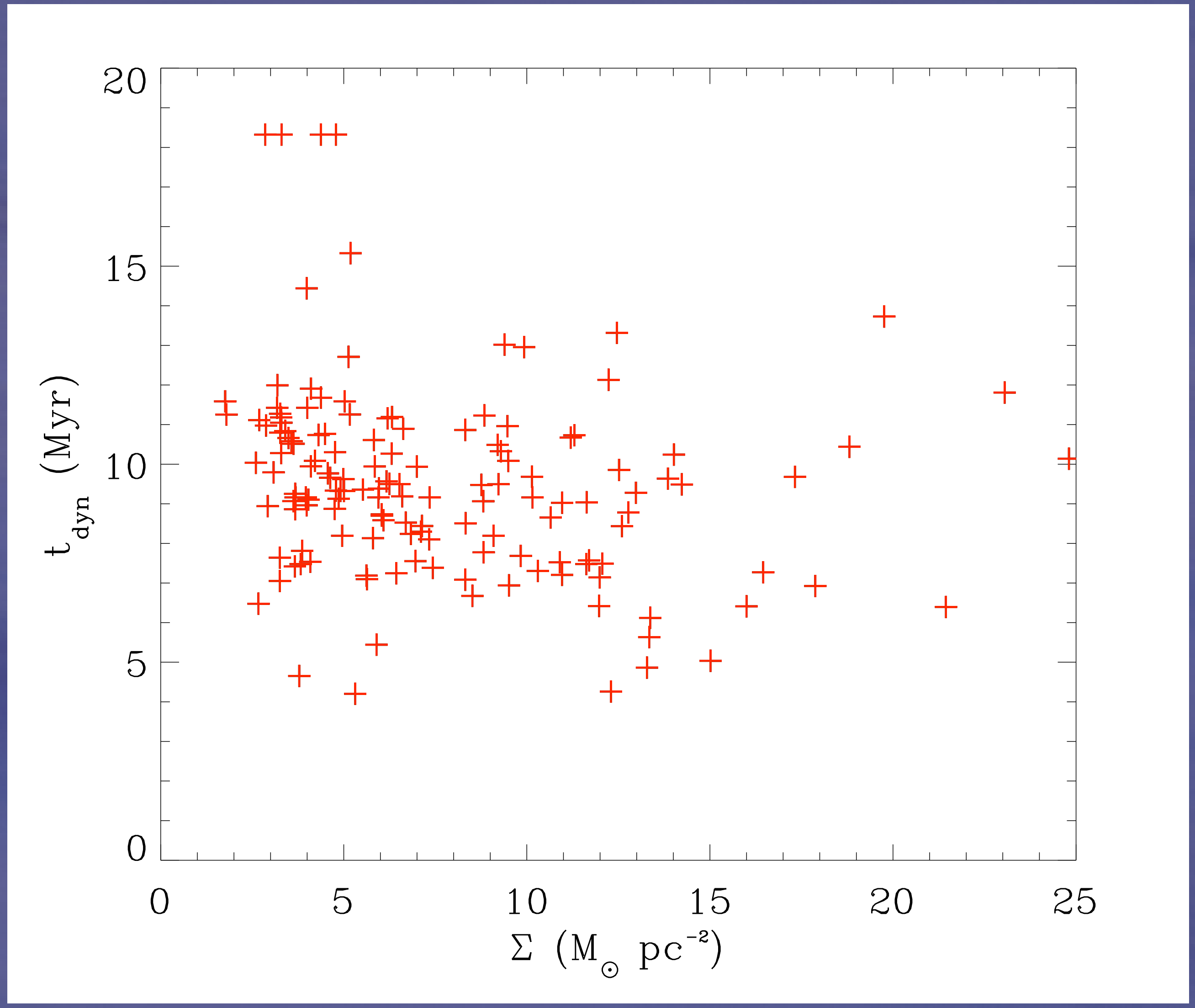
Why is the dependence linear for dense gas (H_2)?



- Free fall time not dependent on surface density
- S.F.R. just dependent on amount of gas (Σ)
- see also Krumholz & Thompson (2007)

Theoretical interpretation

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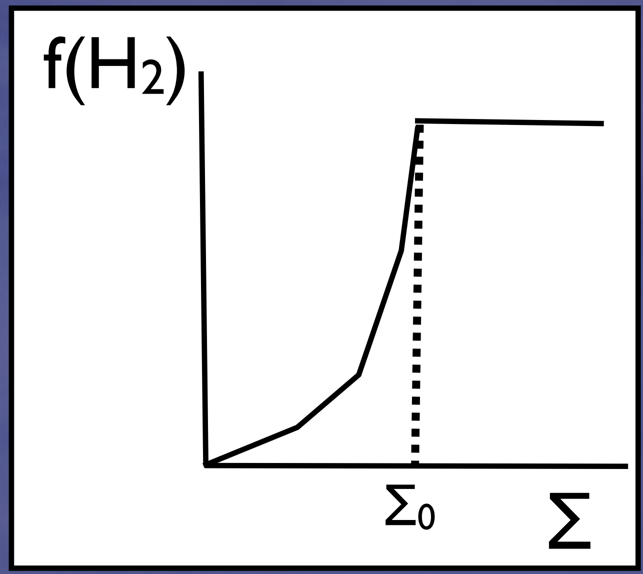
- Assume fraction of H_2 varies according to surface density: $f(H_2) = \left(\frac{\Sigma}{\Sigma_0}\right)^{\alpha} \quad \Sigma < \Sigma_0$

  $f(H_2) = 1$ otherwise



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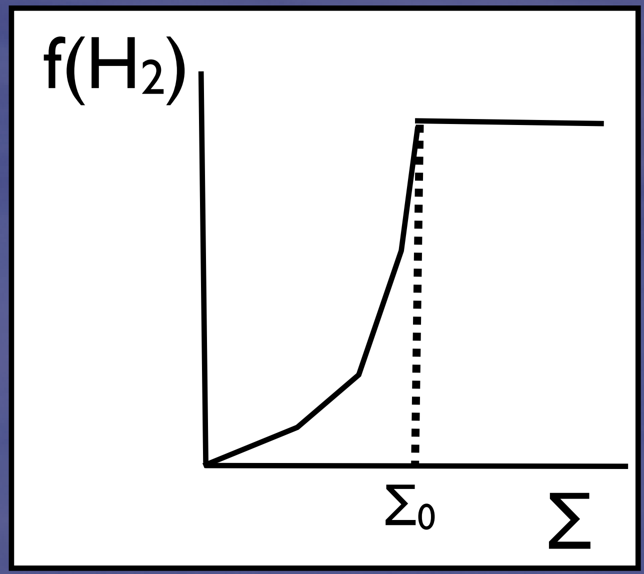

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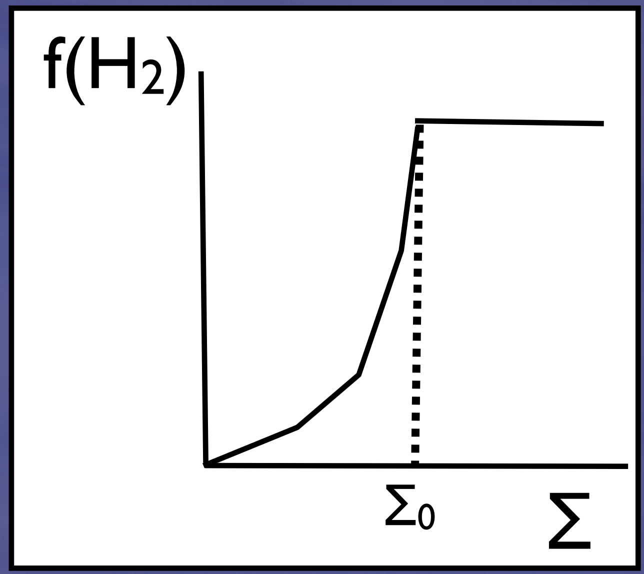

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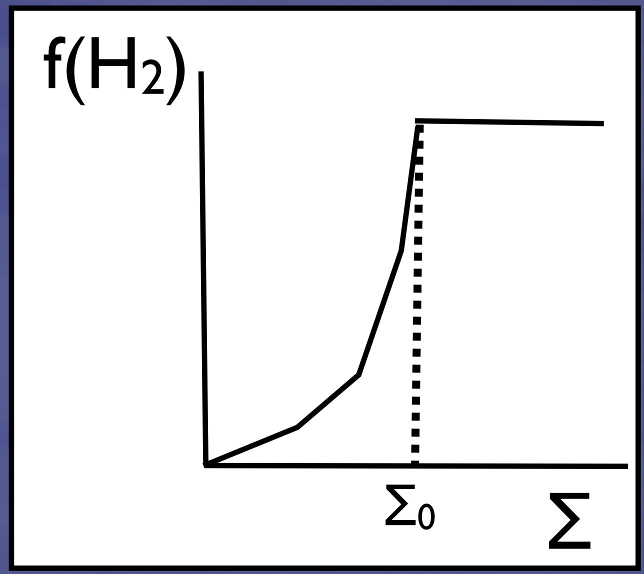

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- But for HI: $\quad \Sigma(HI) = \Sigma - \Sigma(H_2)$ $\qquad$ star formation rate multivalued!

e.g. $\Sigma(HI) = 0$ when $\Sigma_{SFR} = 0$ (i.e. $f(H_2)=0$), or $\Sigma_{SFR} > \Sigma_{SFR0}$ (i.e. $f(H_2)=1$)

Dependence for different tracers

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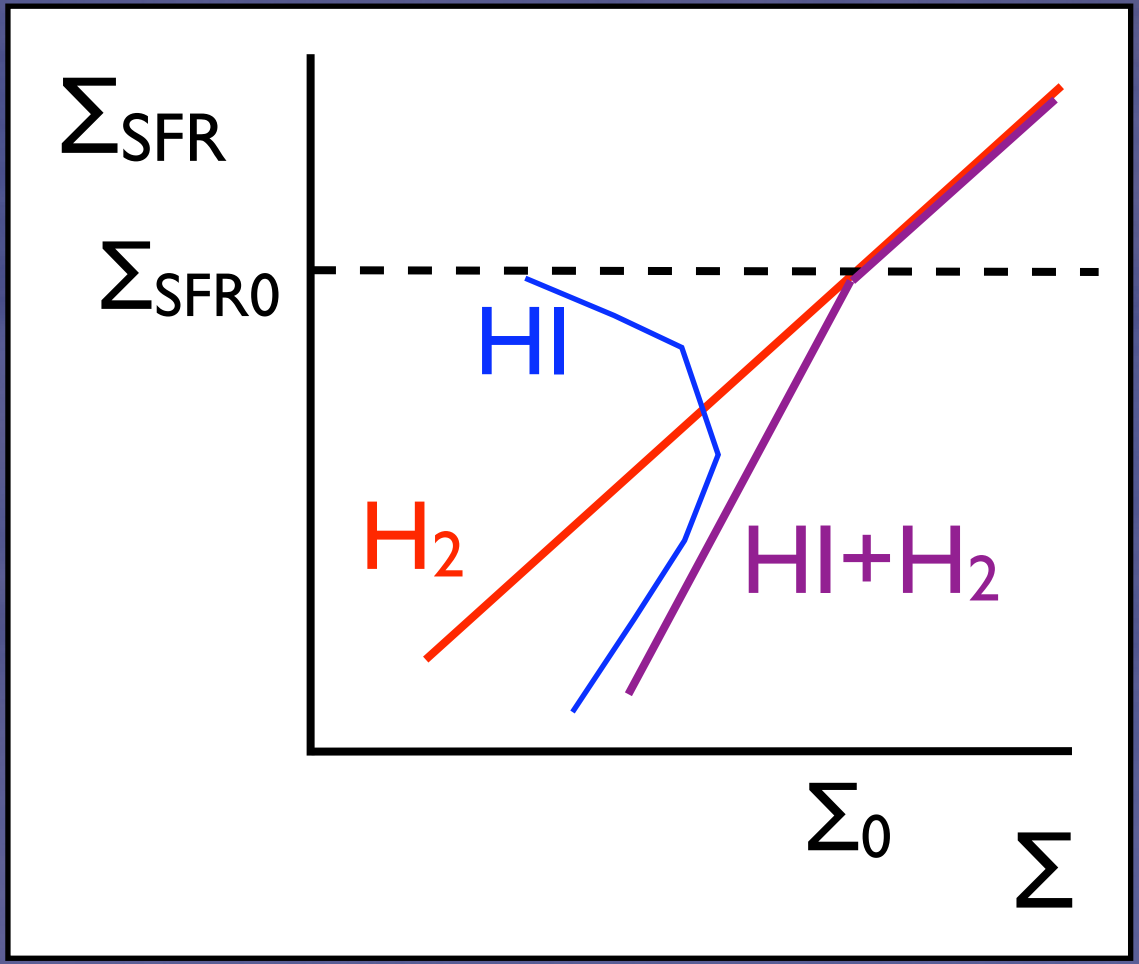

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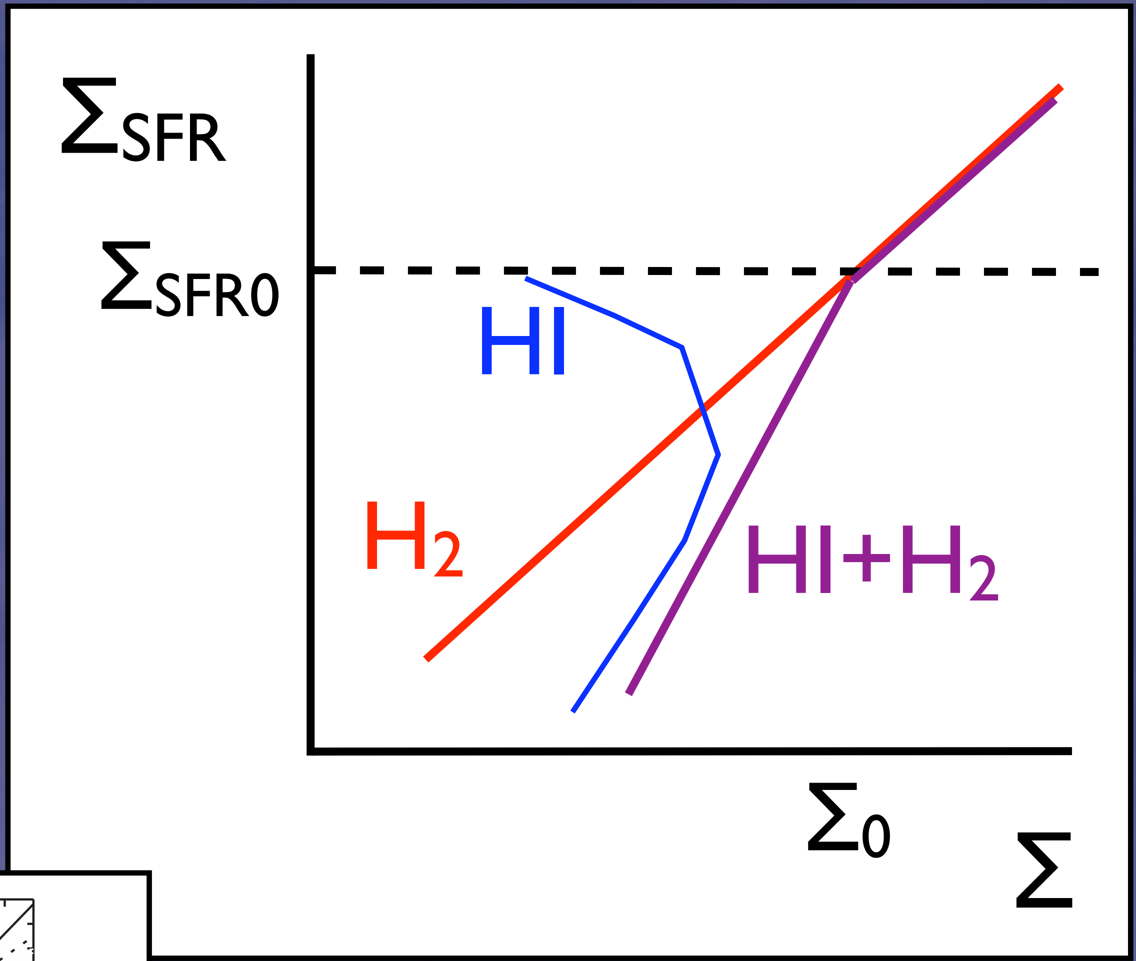
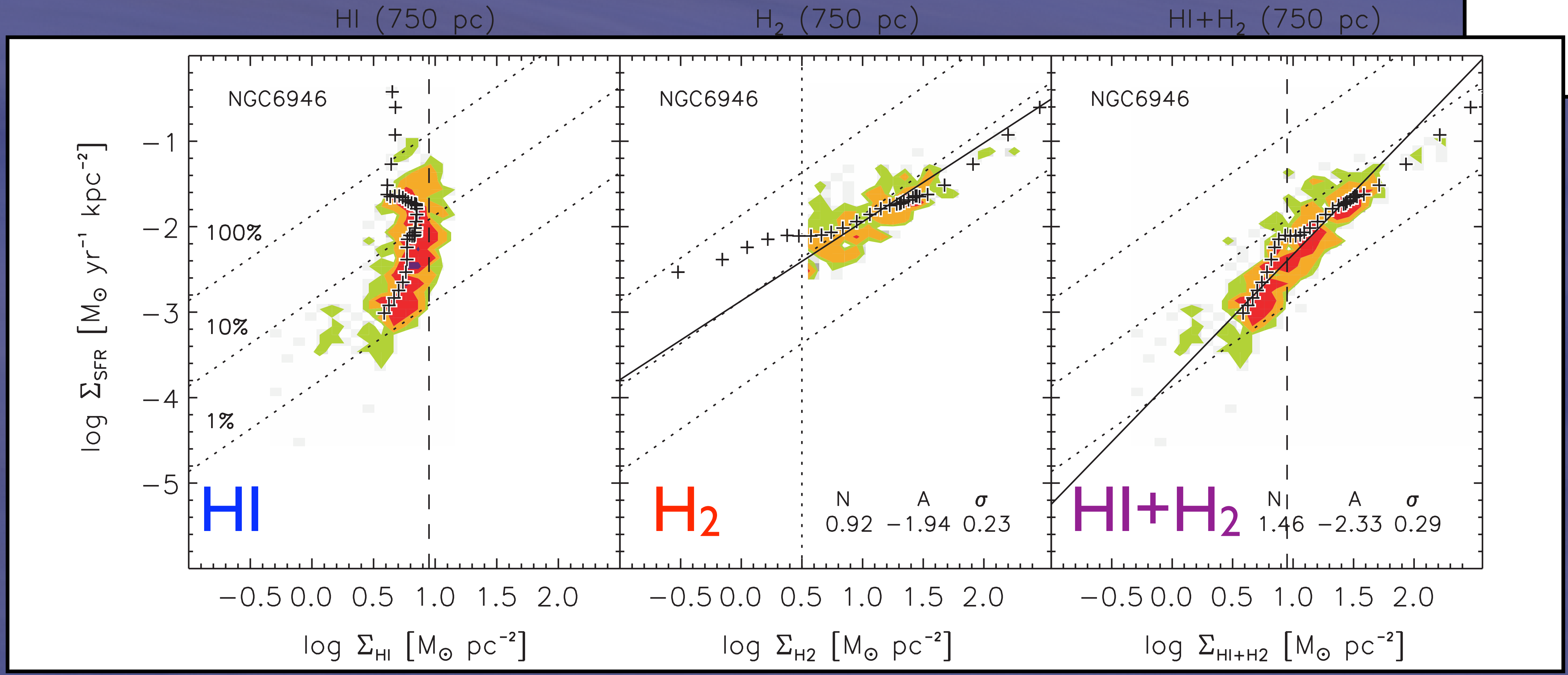
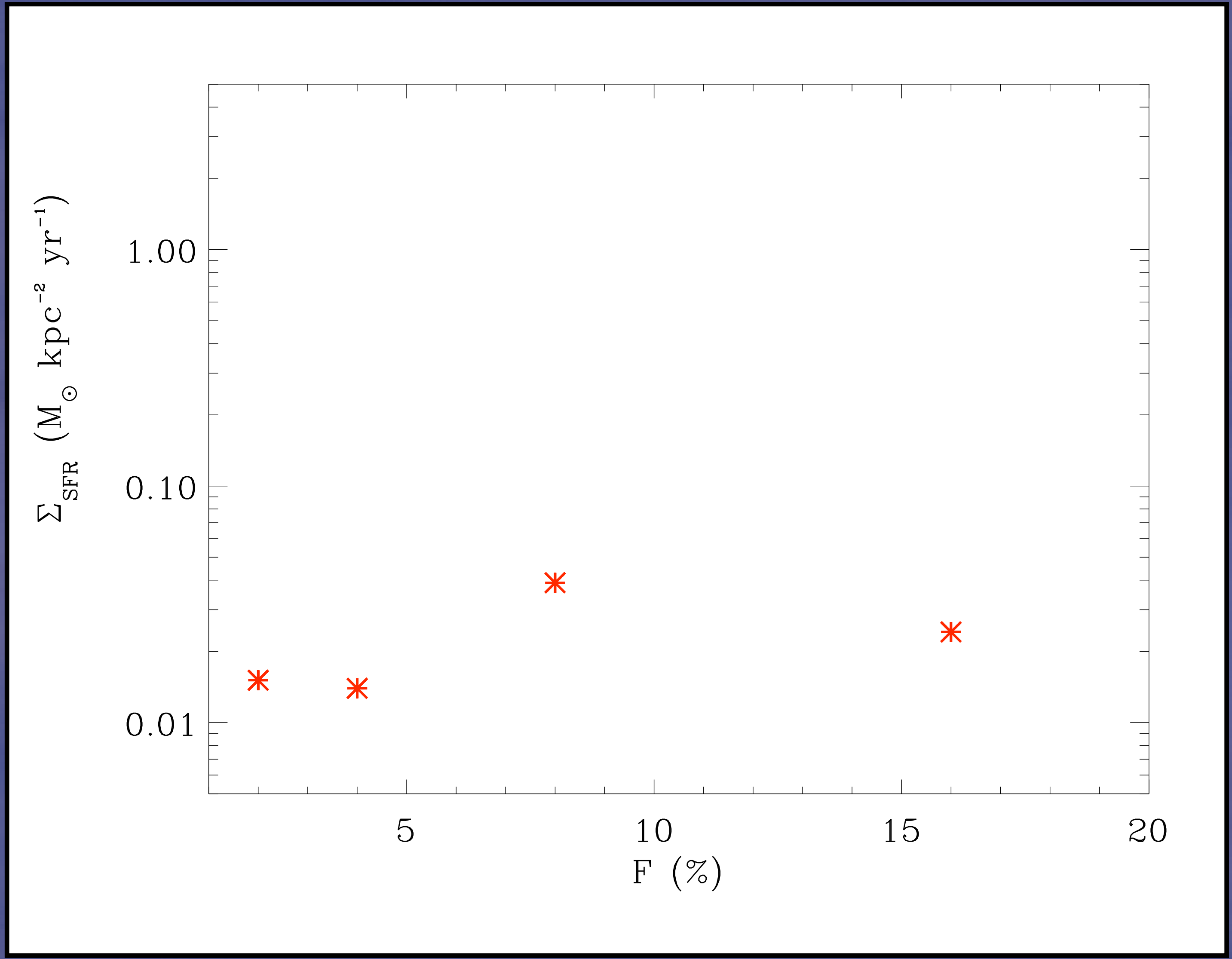




Example from Bigiel et. al. 2008

Dependence of (global) S.F.R. on shock strength

- Spiral shock triggering: produces higher star formation rate? (Elmegreen & Elmegreen 1986, Seigar & James 2002)
- Global star formation rate (over total area of disc)
- No dependence on shock strength in simulations



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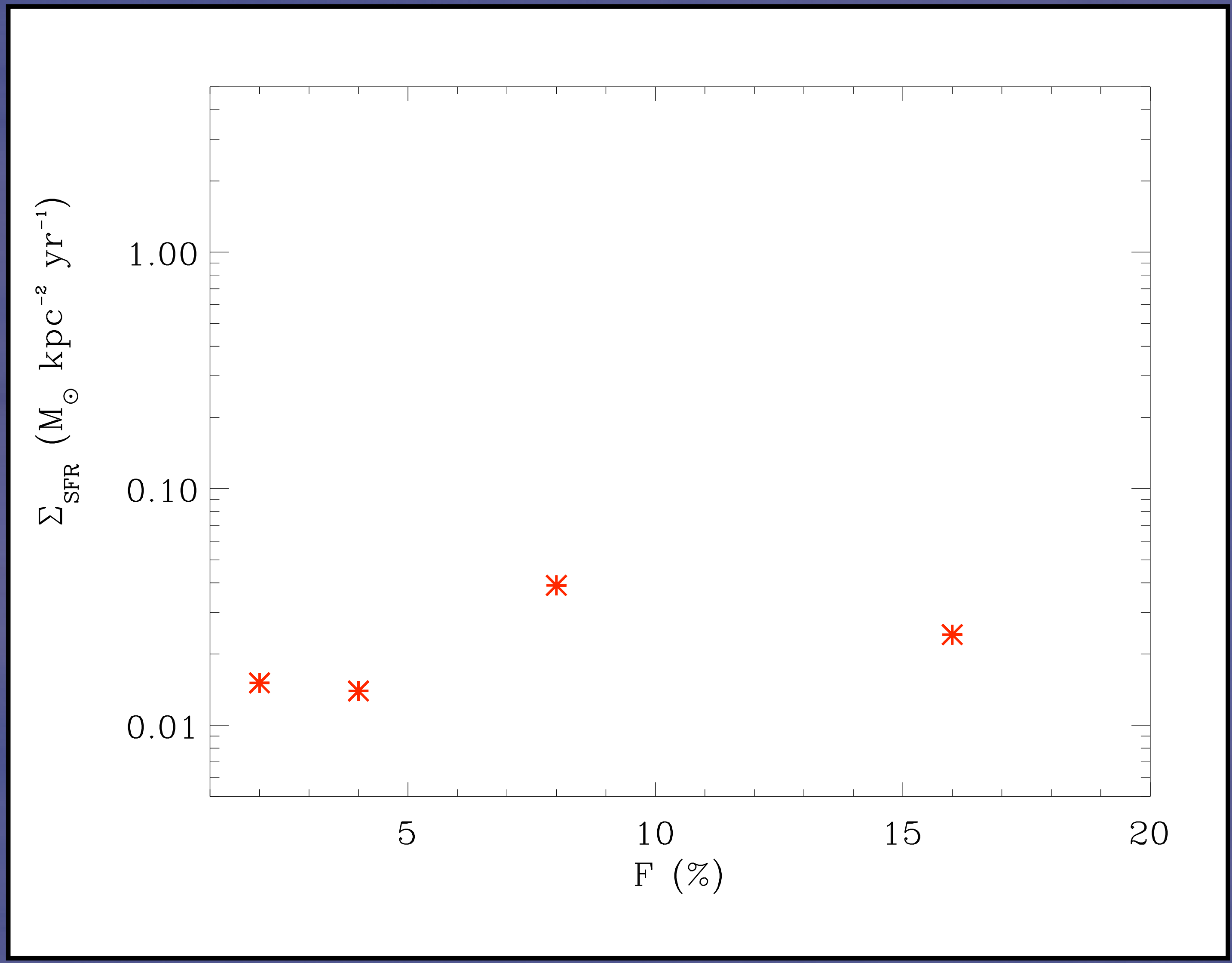
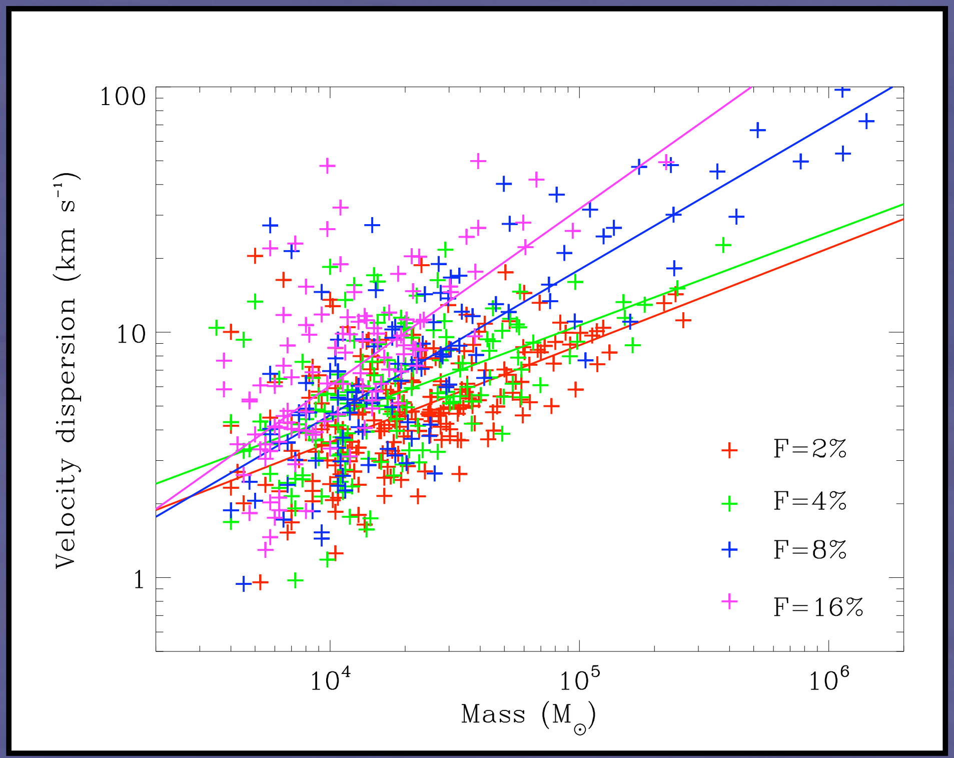
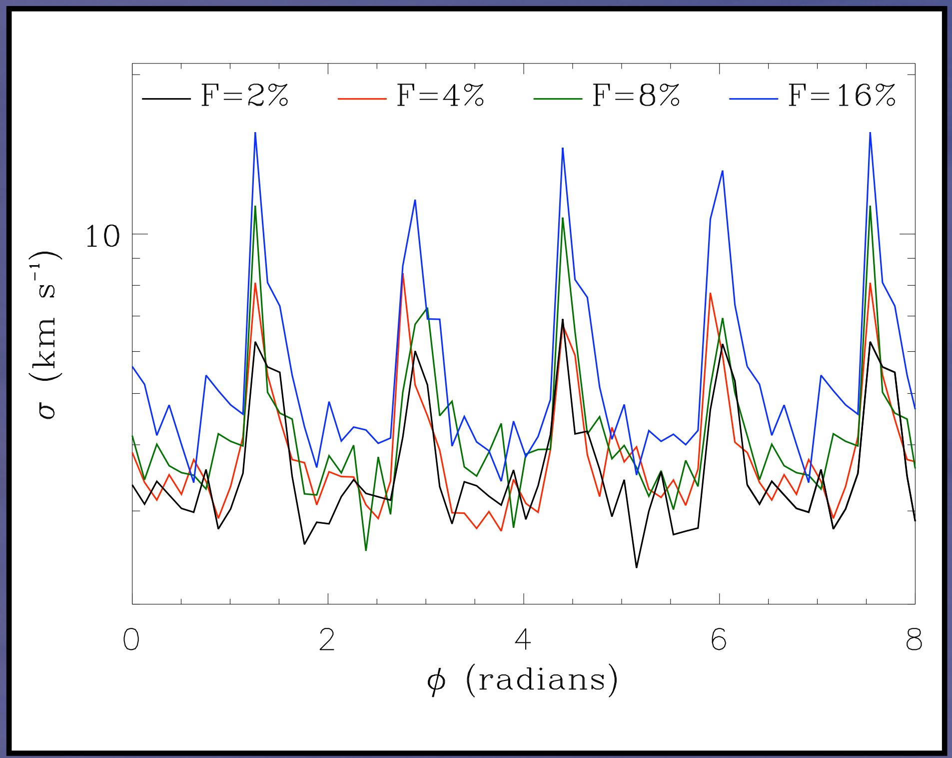
Why? α depends on σ - likely to increase in shock

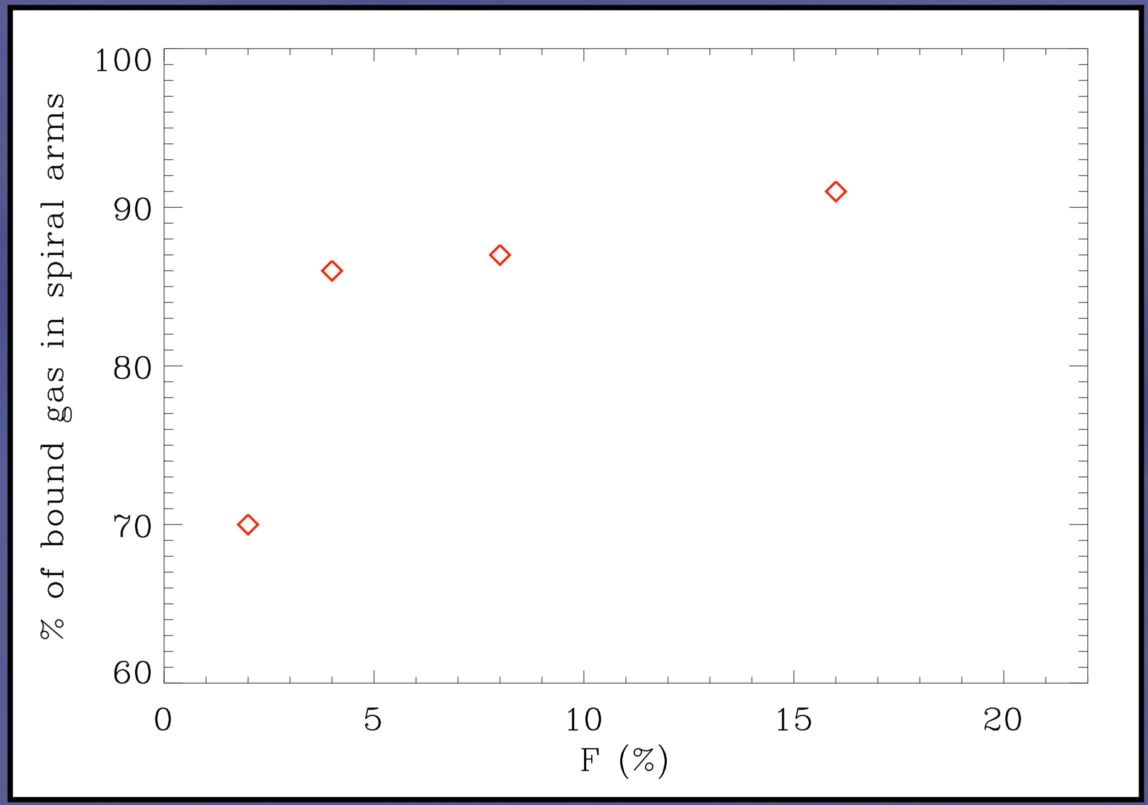


The star formation rate and spiral shocks





- Velocity dispersion versus mass of clump for different shock strengths (far left)
- Systematic increase in σ with shock strength
- Higher σ in spiral arms with stronger shocks (left)



- But more bound gas lies in the spiral arms at higher shock strengths

Conclusions

- Local S.F.R. calculated from bound gas reproduces observations, providing $\epsilon \sim 0.05$
  - S.F.R linearly proportional to Σ_{bound}
  - linear, since dynamical time-scales of bound clumps uncorrelated with Σ
- S.F.R. not well correlated with Σ_{total}
  - and no 1-1 relation with Σ_{HI}
- Global S.F.R does not depend on spiral shock strength
  - stronger shocks also produce a higher σ