The multi-scale physics of galactic star formation across cosmic time

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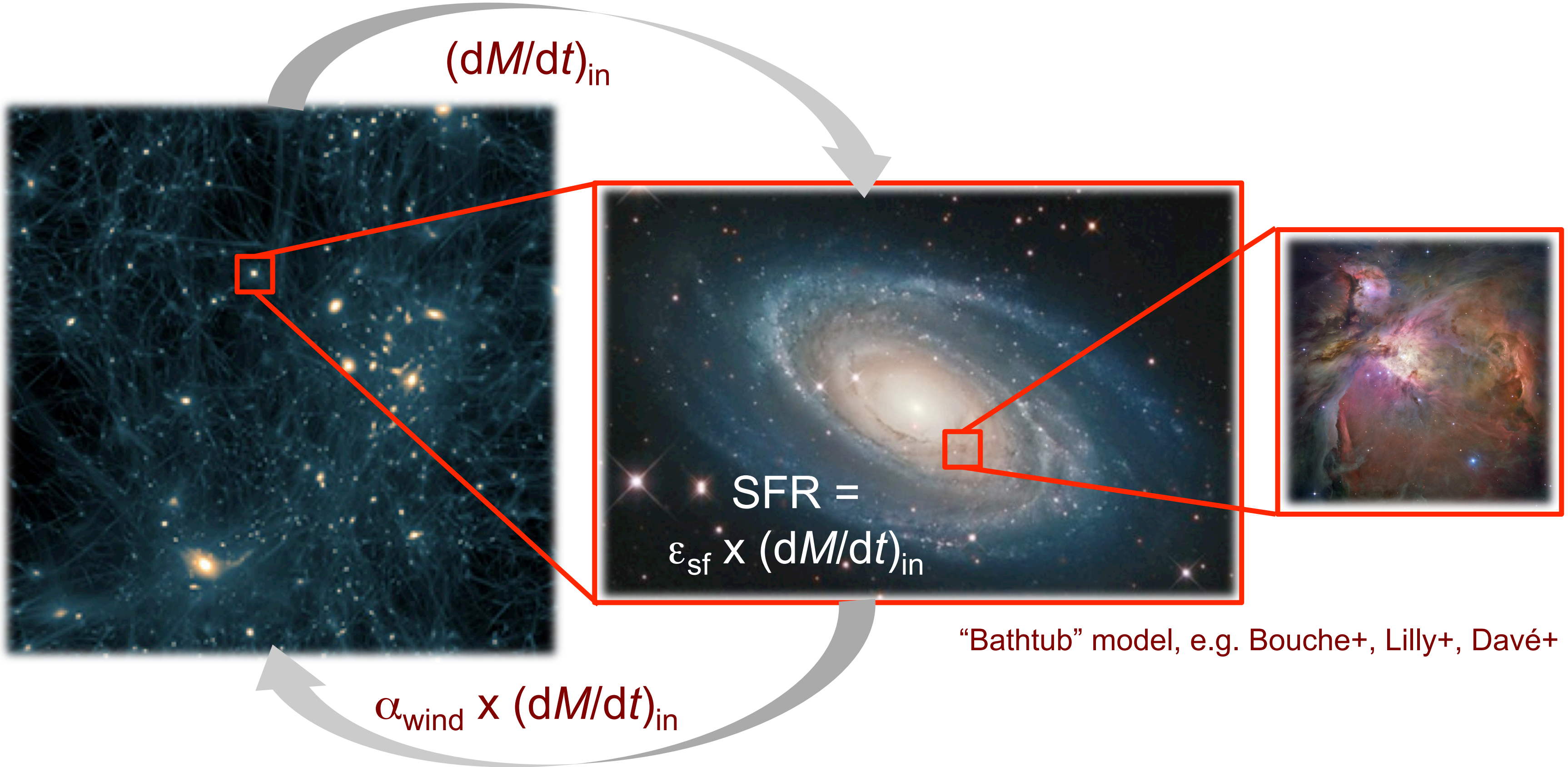
+ Andreas Schruba (MPE), Steve Longmore (Liverpool),
Daniel Haydon (Heidelberg), Alex Hygate (Heidelberg), and many others

Star formation during galaxy growth



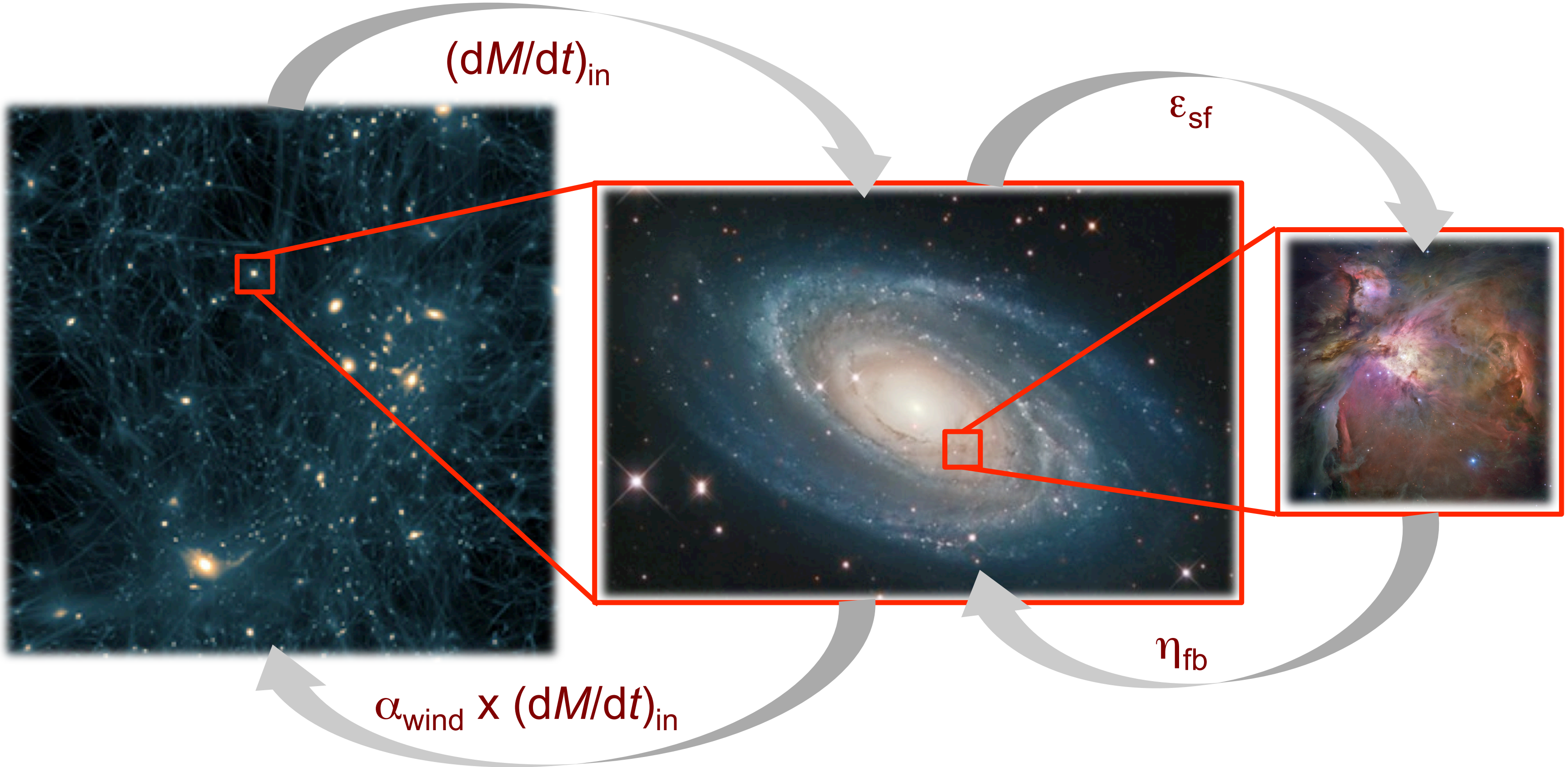
"Bathtub" model, e.g. Bouche+, Lilly+, Davé+

The constants contain most of the physics. As long as their origin is unknown, galaxy formation is unsolved – knowing the mass inflow rate is not enough.

Star formation occurs in localised events

NGC 300, GALEX

Star formation during galaxy growth



The cloud-scale quantities set the galaxy properties, but are unknown outside the Local Group. However, we have developed a new statistical method to systematically obtain them across cosmic time.

1. a toy model

Kruijssen & Longmore 2014, MNRAS 439, 3239

Introduction
Principle
Simulations
Observations

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **439**, 3239–3252 (2014) doi:10.1093/mnras/stu098
Advance Access publication 2014 February 24

An uncertainty principle for star formation – I. Why galactic star formation relations break down below a certain spatial scale

J. M. Diederik Kruijssen[1★] and Steven N. Longmore[2]

If a macroscopic correlation is caused by a time-evolution, then it *must* break down on small scales because the subsequent phases are resolved.

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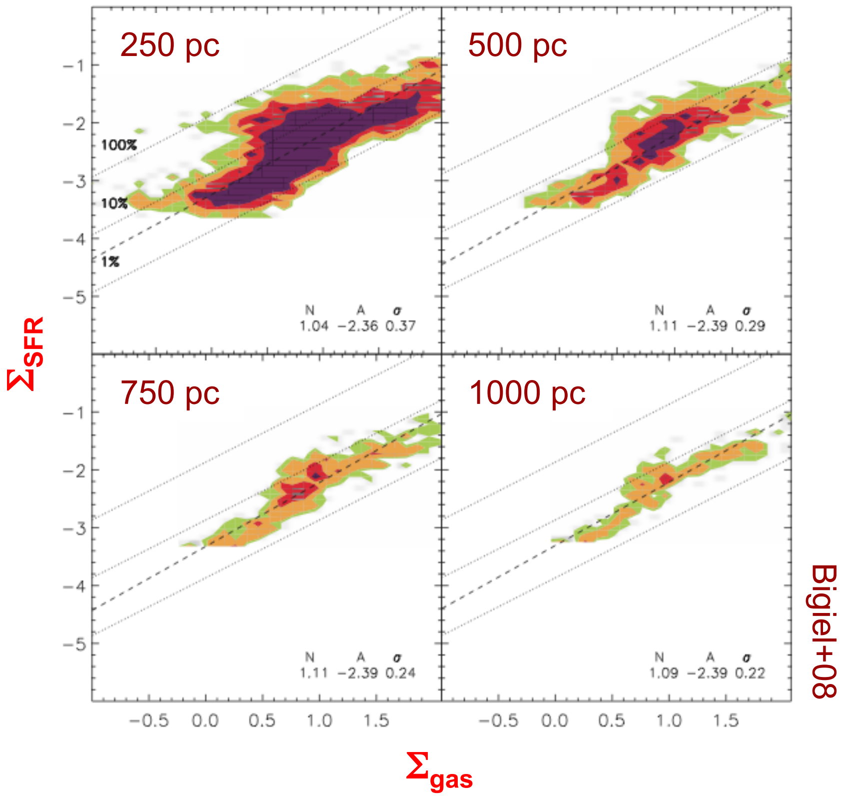

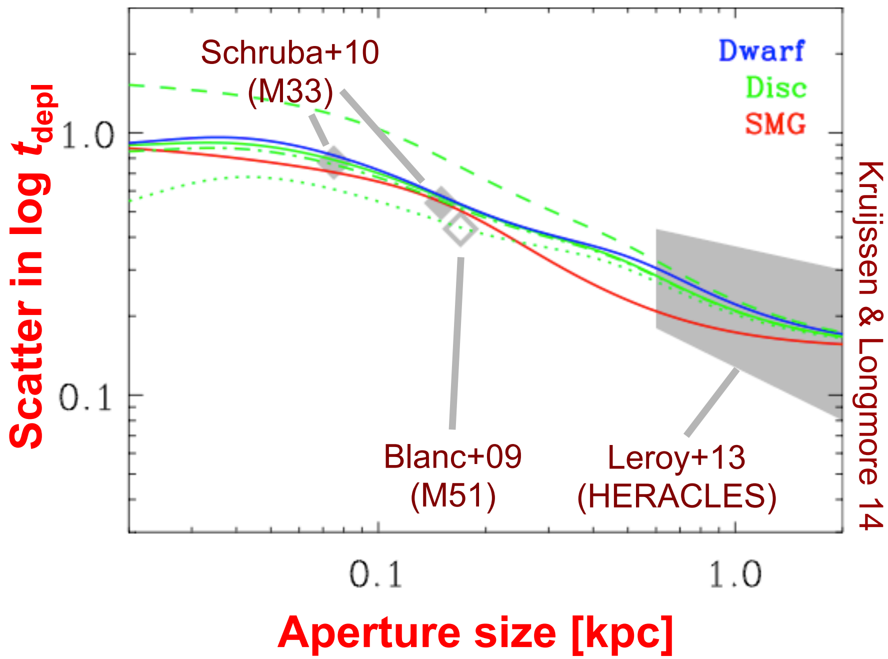

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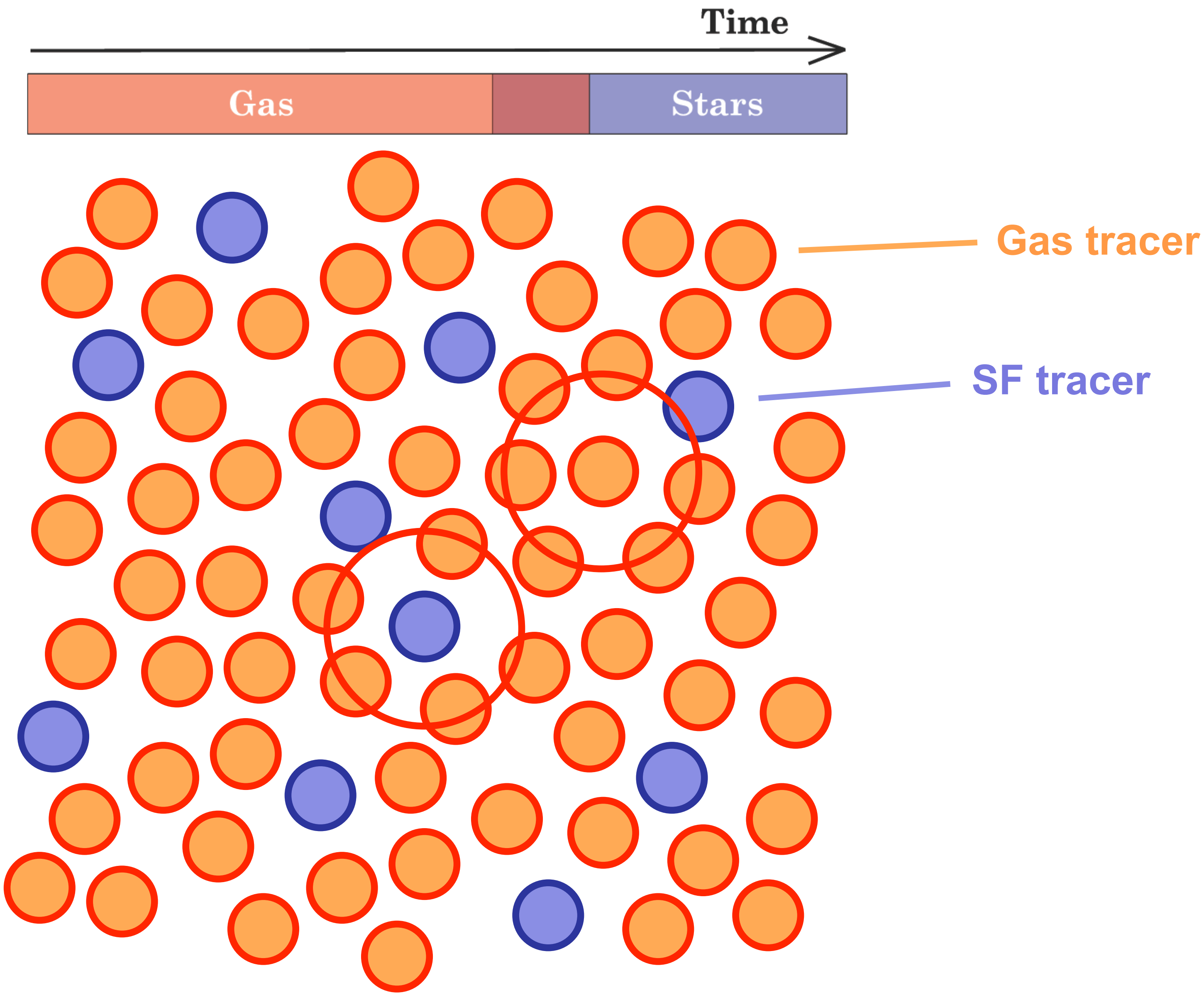
An uncertainty principle for star formation – I. Why galactic star formation relations break down below a certain spatial scale

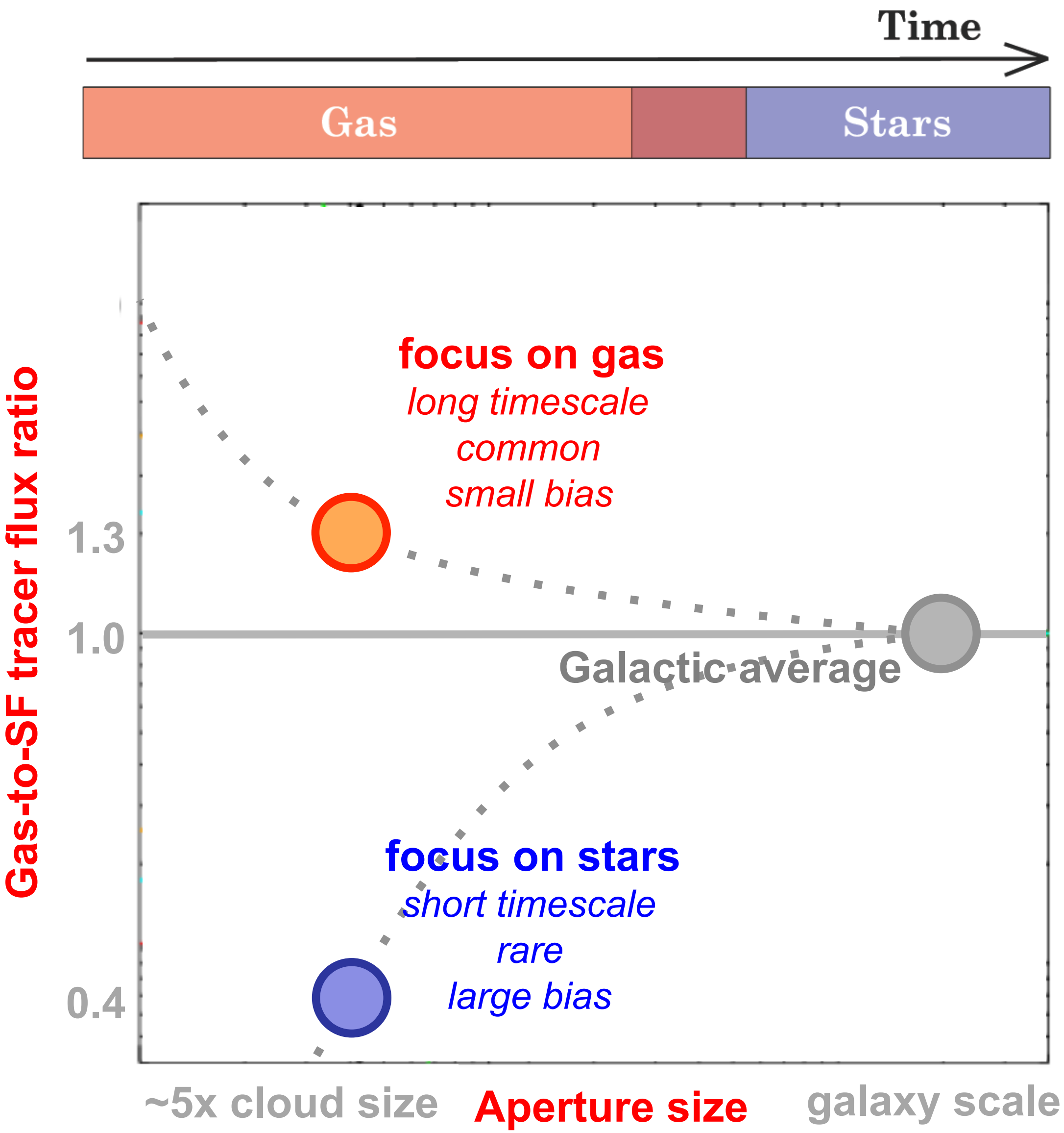
J. M. Diederik Kruijssen[1★] and Steven N. Longmore[2]

The *way in which* galactic star formation relations depend on the spatial scale is a direct probe of the physics of star formation on the cloud scale

Clouds & SF regions in a galaxy: evolution & spatial distribution

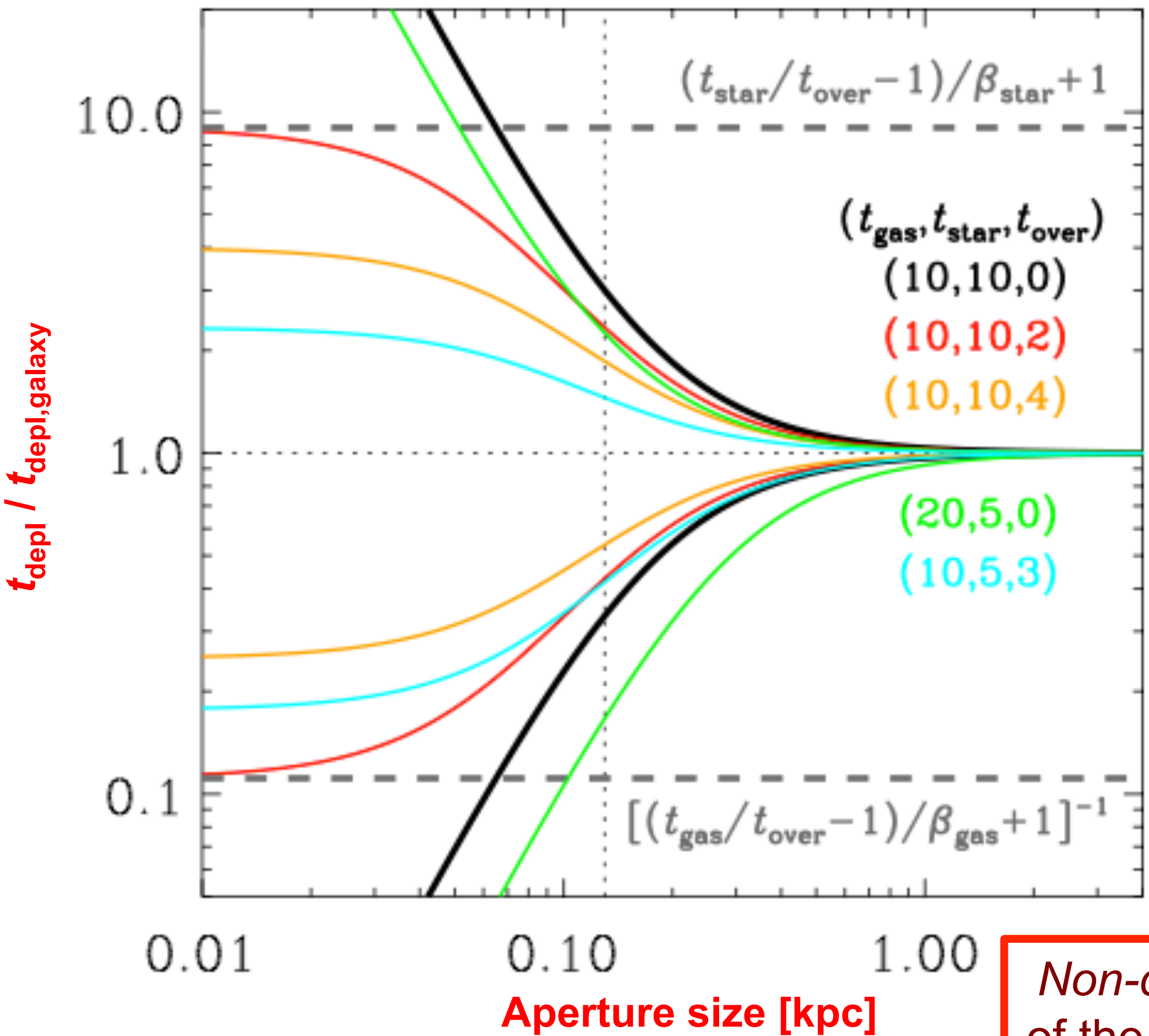


Gas-to-SF tracer ratio (== t_{depl}) as a function of spatial scale



Gas-to-SFR ratio as a function of spatial scale

Kruijssen & Longmore 2014, MNRAS 439, 3239



Centre on:

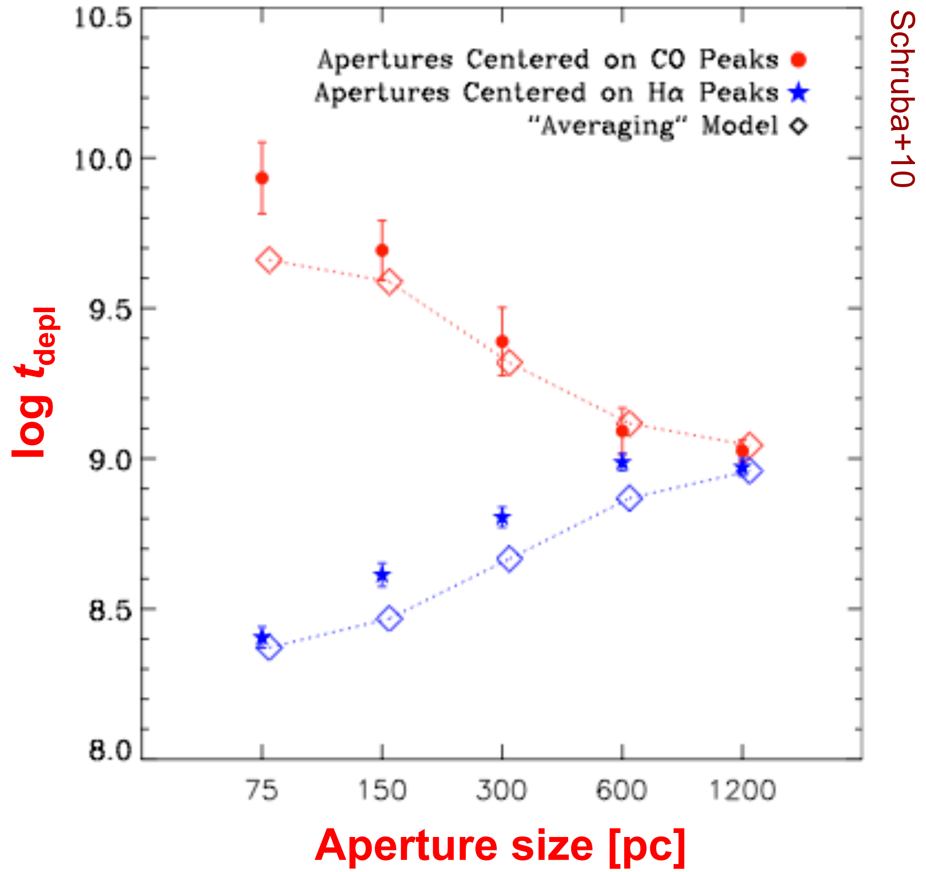
gas

stars

Non-degenerate measure of the cloud-scale time line

Gas-to-SFR ratio as a function of spatial scale

✧ Observations show the same behaviour



Centre on:

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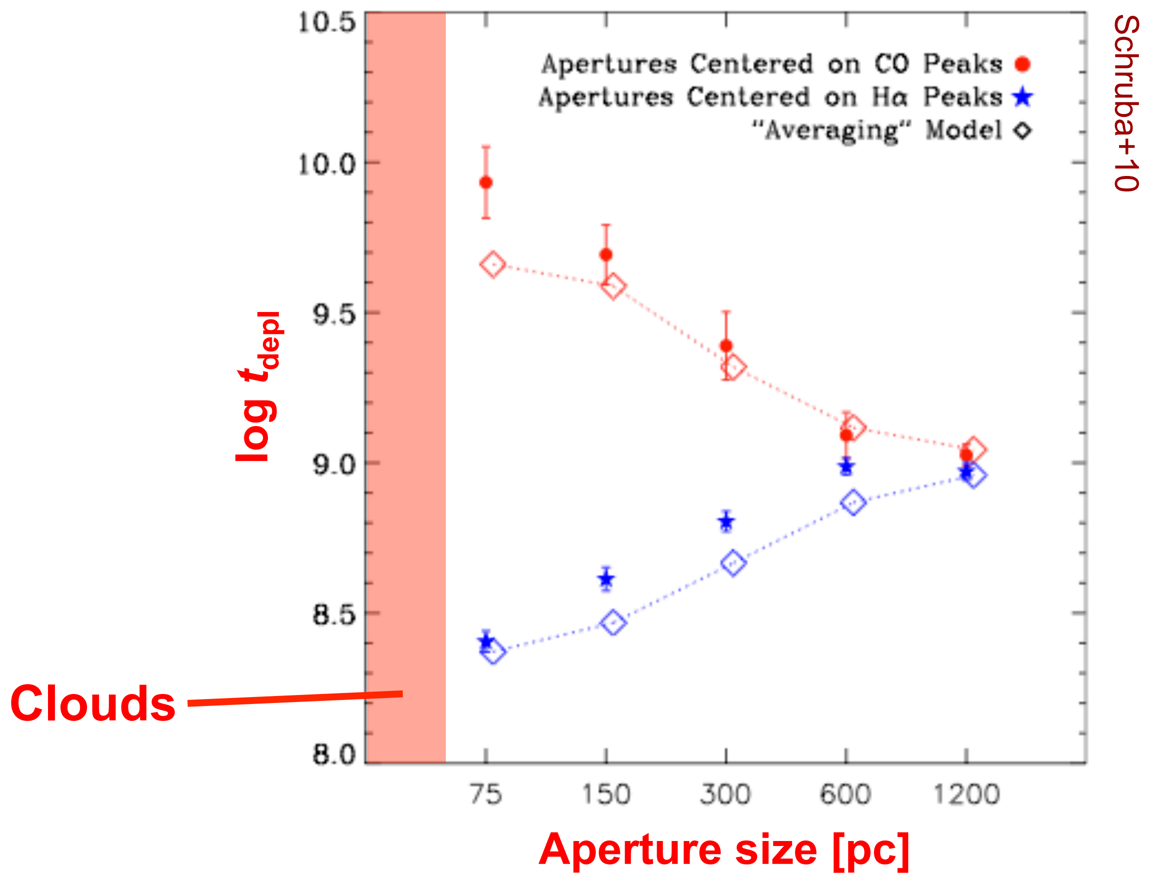
stars

Gas-to-SFR ratio as a function of spatial scale

✧ Imprint of condensations on size-scales ~5 times larger



Centre on:

gas

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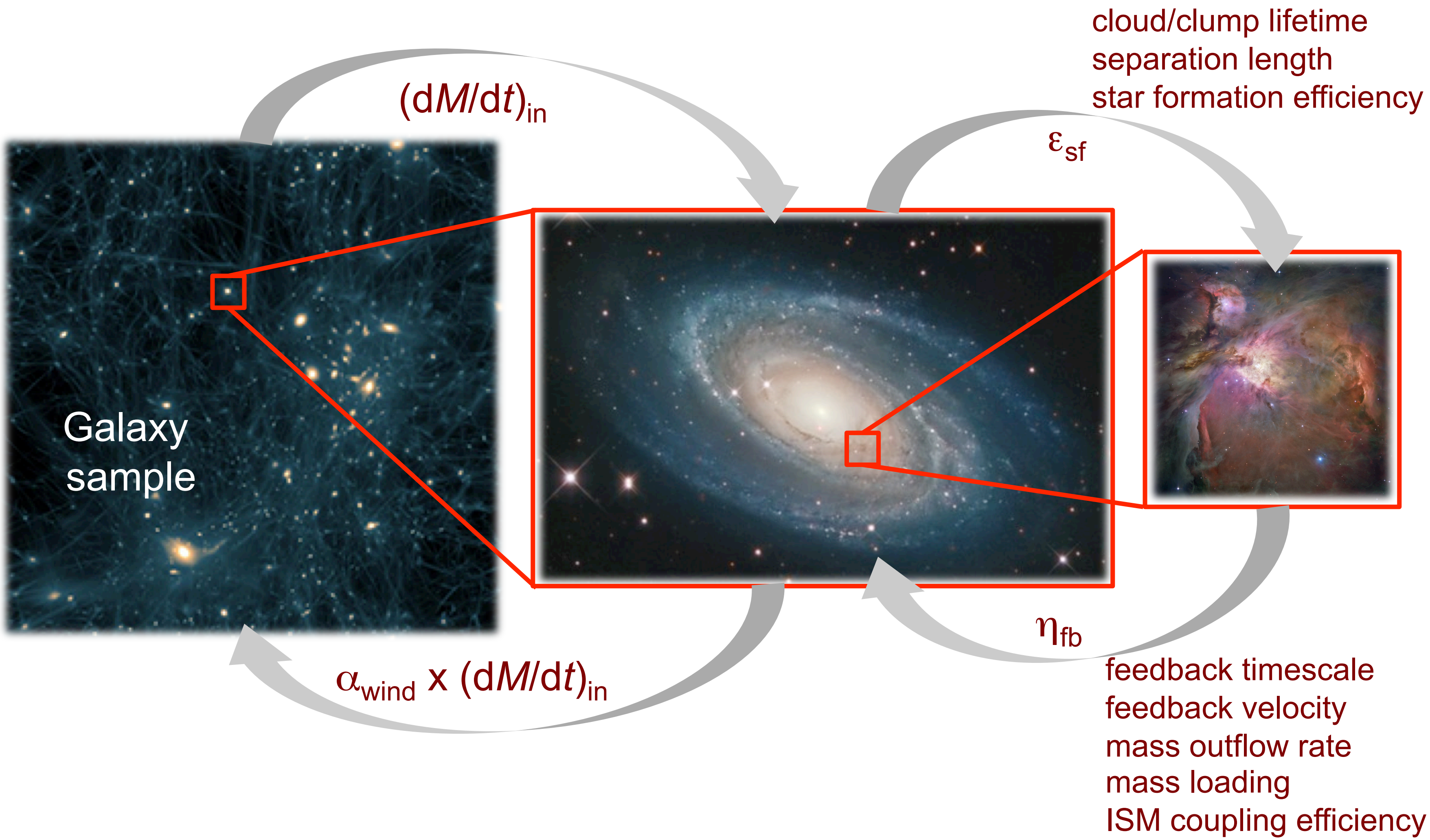
Simple, but fundamental model describing multi-scale SF

Kruijssen & Longmore 2014, MNRAS 439, 3239



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Simple, but fundamental model describing multi-scale SF

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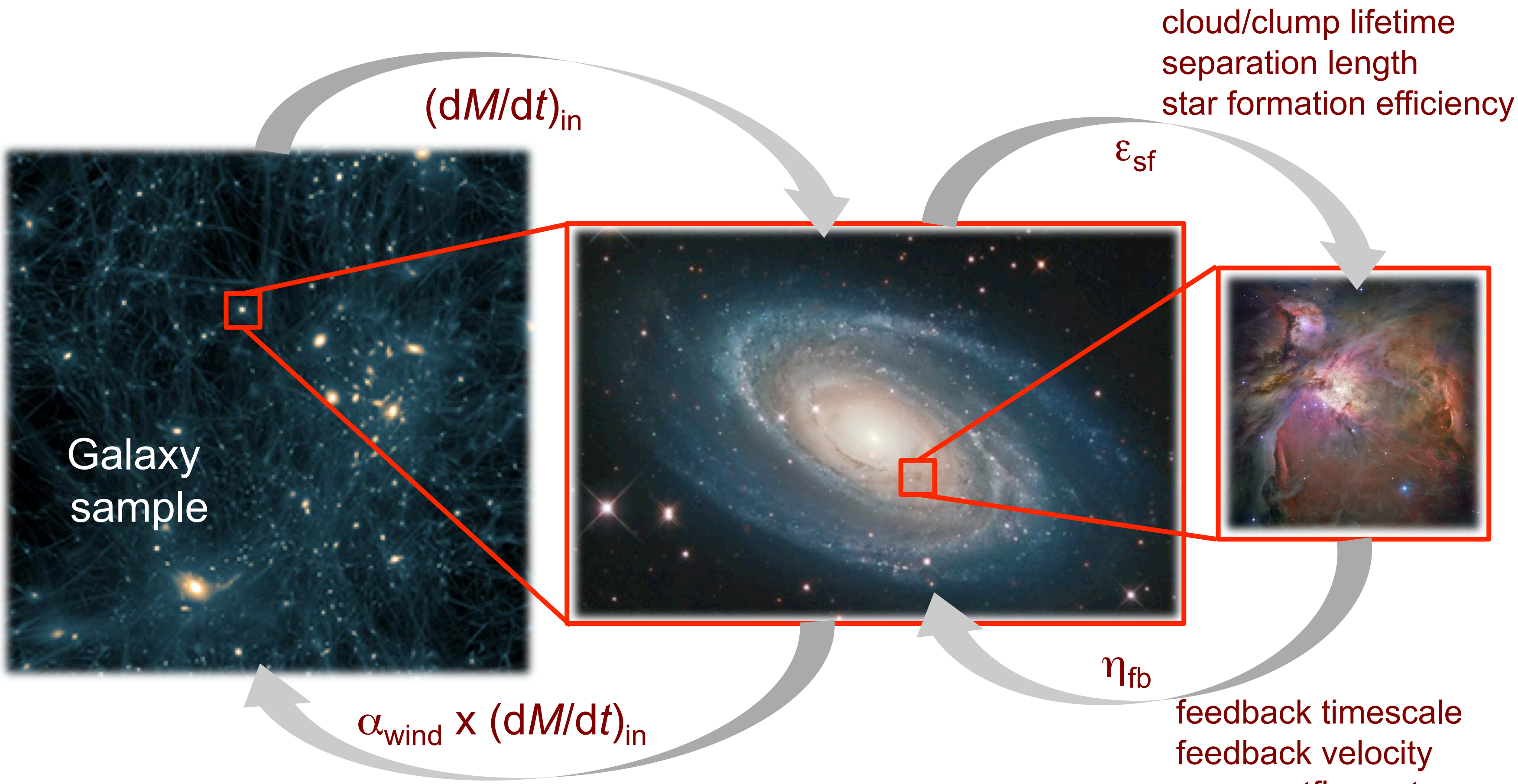

Improvements with respect to previous work:
- self-consistently accounts for statistics ➔ direct translation to time-scales
- no need to resolve individual clouds ➔ works out to $z \sim 4$

Multi-scale star formation across cosmic time

J. M. Diederik Kruijssen – Heidelberg University

Simple, but fundamental model describing multi-scale SF

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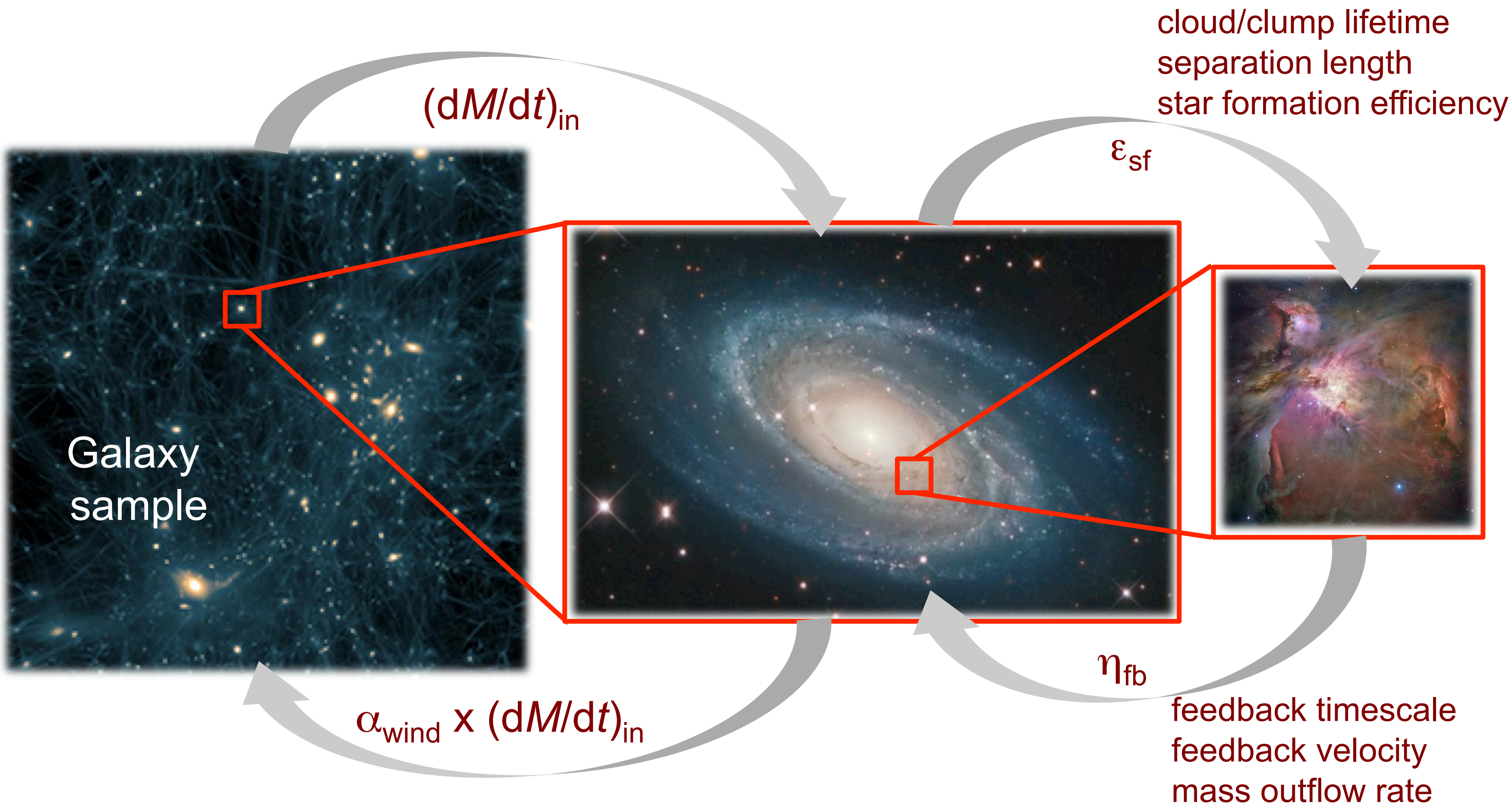


This is what ALMA, MUSE, etc. are made to do

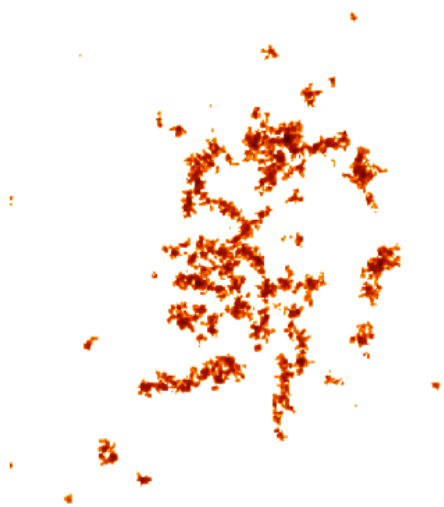
Improvements with respect to previous work:

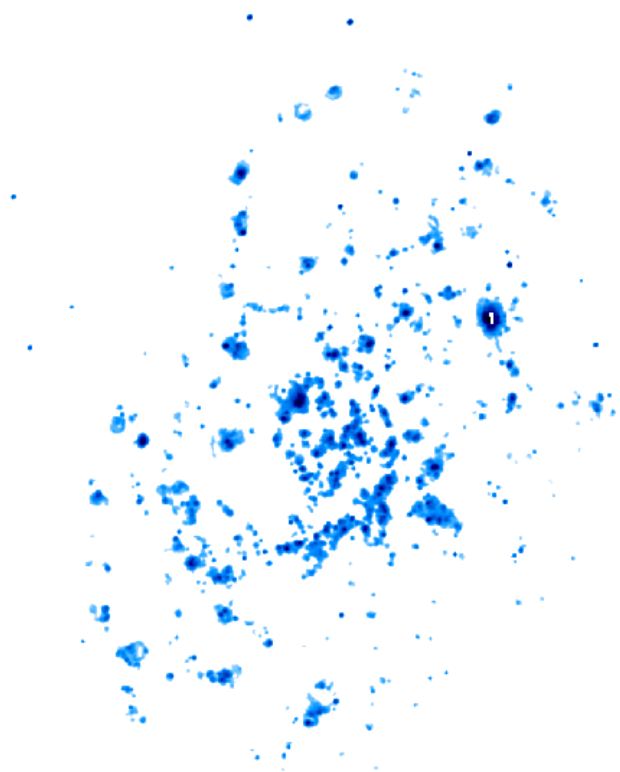
- self-consistently accounts for statistics ➔ direct transla
- no need to resolve individual clouds ➔ works out to $z \sim 4$

2. practical application

Practical application of characterising cloud-scale physics

✧ Step 1: select tracers

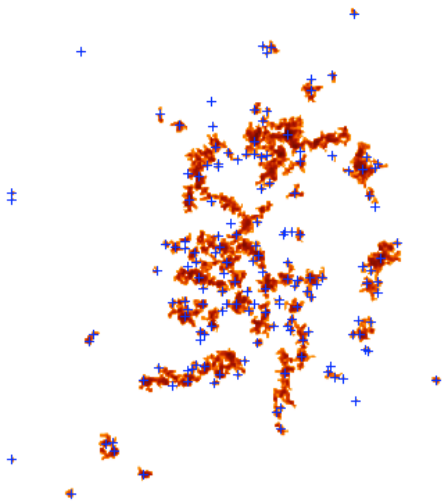




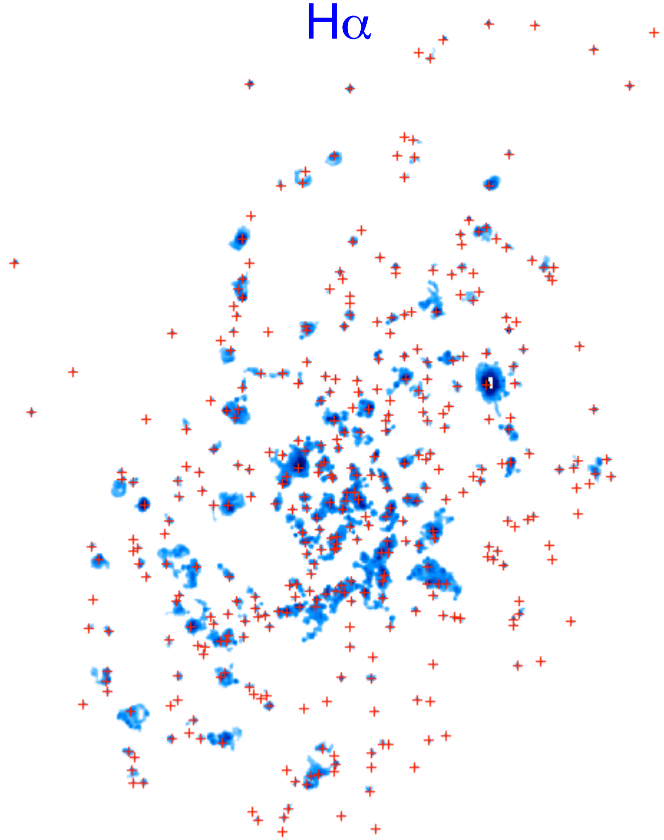
Practical application of characterising cloud-scale physics

✧ Step 2: select emission peaks

CO(1-0)

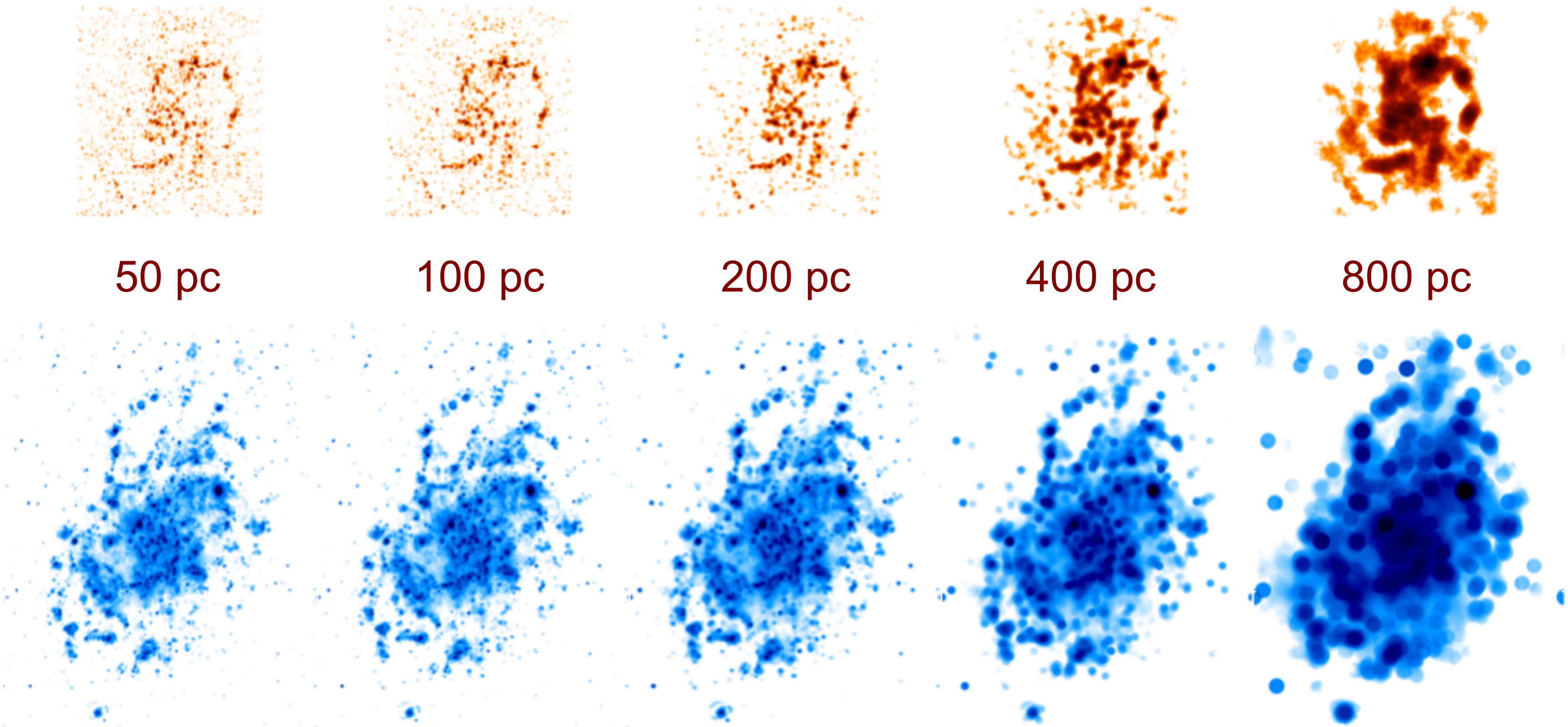


Hα



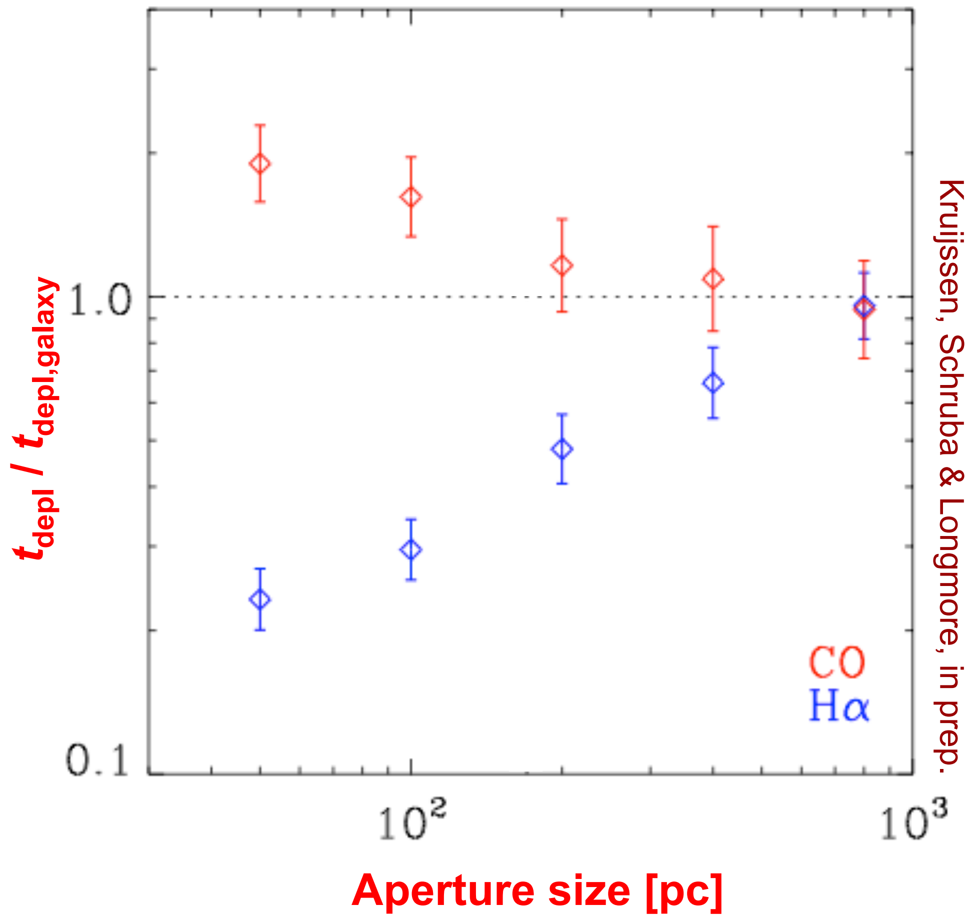
Practical application of characterising cloud-scale physics

✧ Step 3: convolve maps with top-hat kernels of varying size



Practical application of characterising cloud-scale physics

✧ Step 4: Gas-to-SFR ratio bias (= CO-to-Hα flux ratio w.r.t. galactic average)



Kruijssen, Schruba & Longmore, in prep.

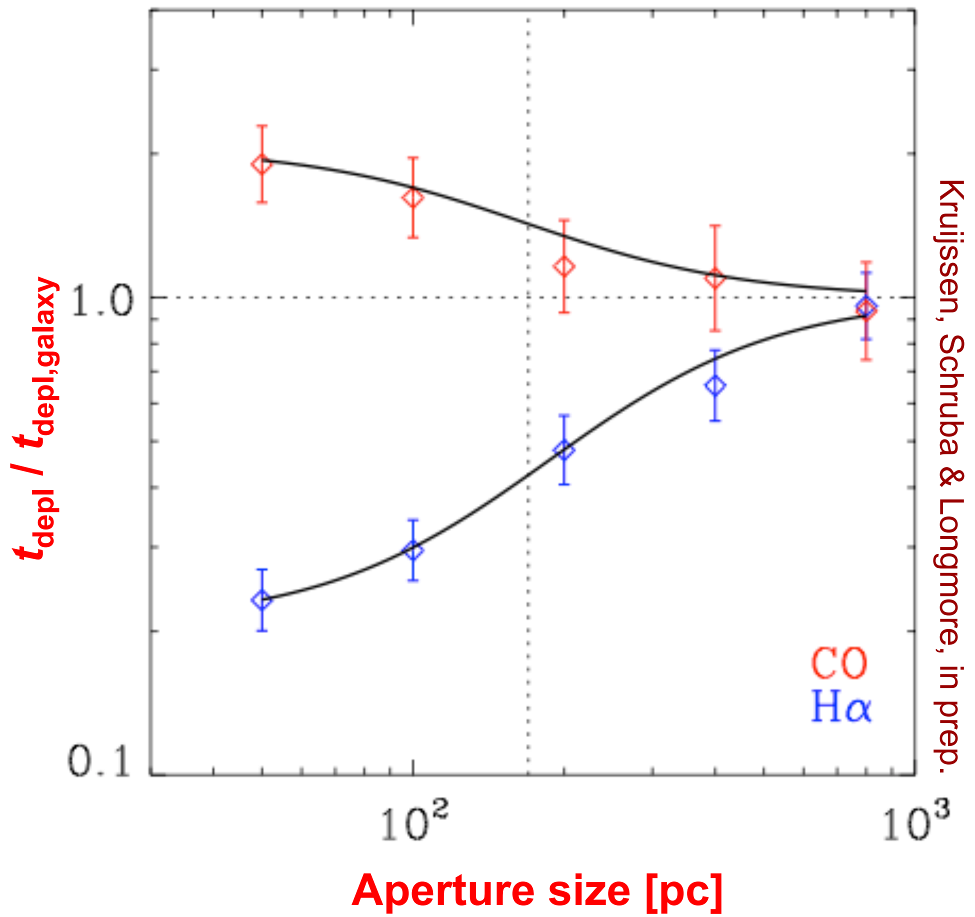
Centre on:

gas

stars

Practical application of characterising cloud-scale physics

✧ Step 5: fit gas-to-SFR bias ('tuning fork')



Centre on:

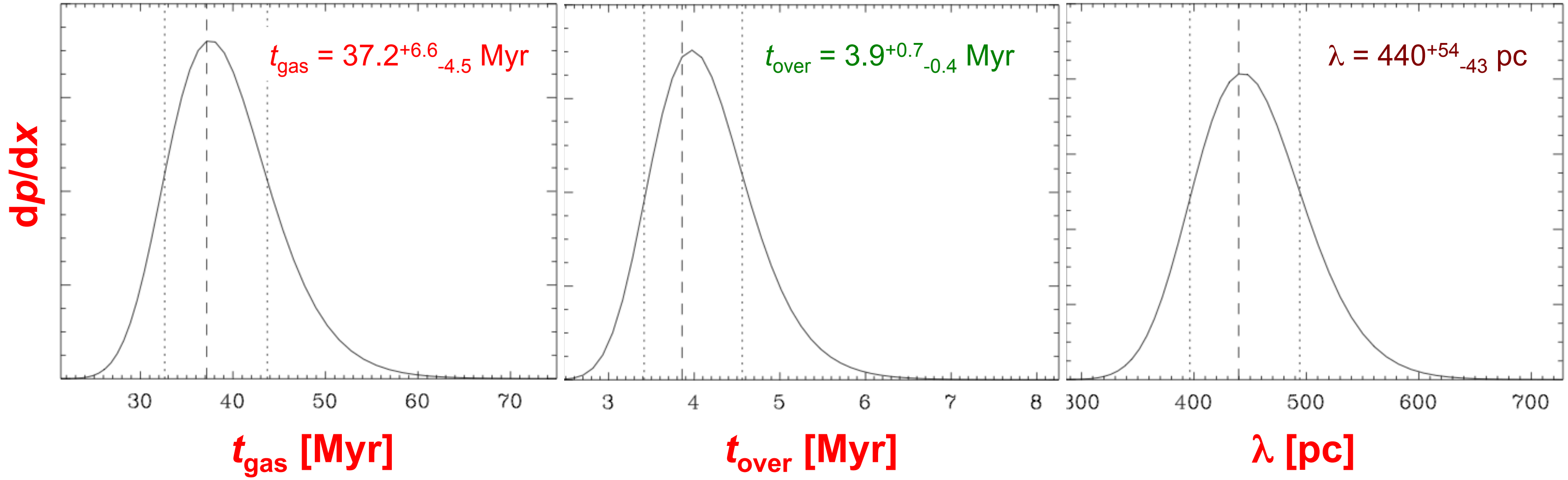
gas

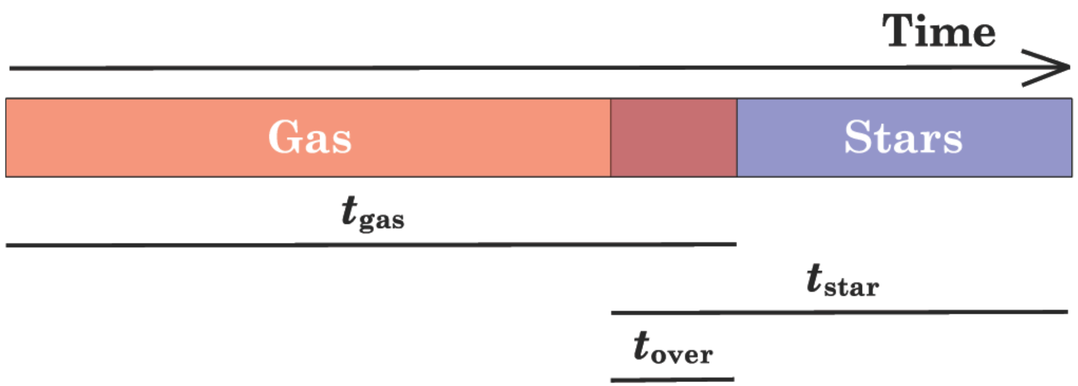
stars

Practical application of characterising cloud-scale physics

✧ Step 6: obtain t_{gas}, t_{over}, λ

Kruijssen, Schruba & Longmore, in prep.





3. numerical testing

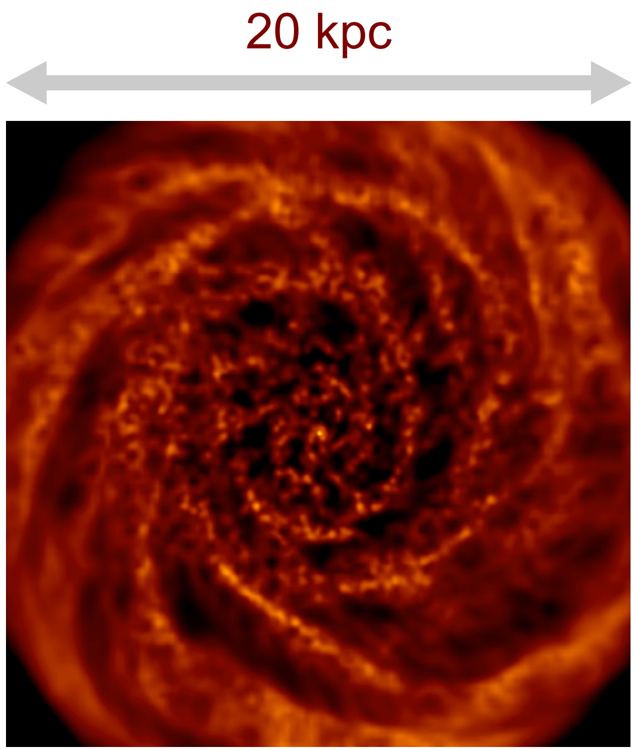
How well does it work?

(Kruijssen, White, Schruba, Hu, Longmore, Haydon, Hygate, Naab)

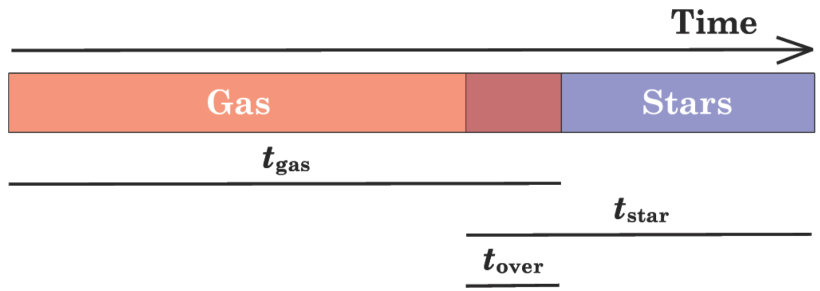
✧ Test using numerical simulations

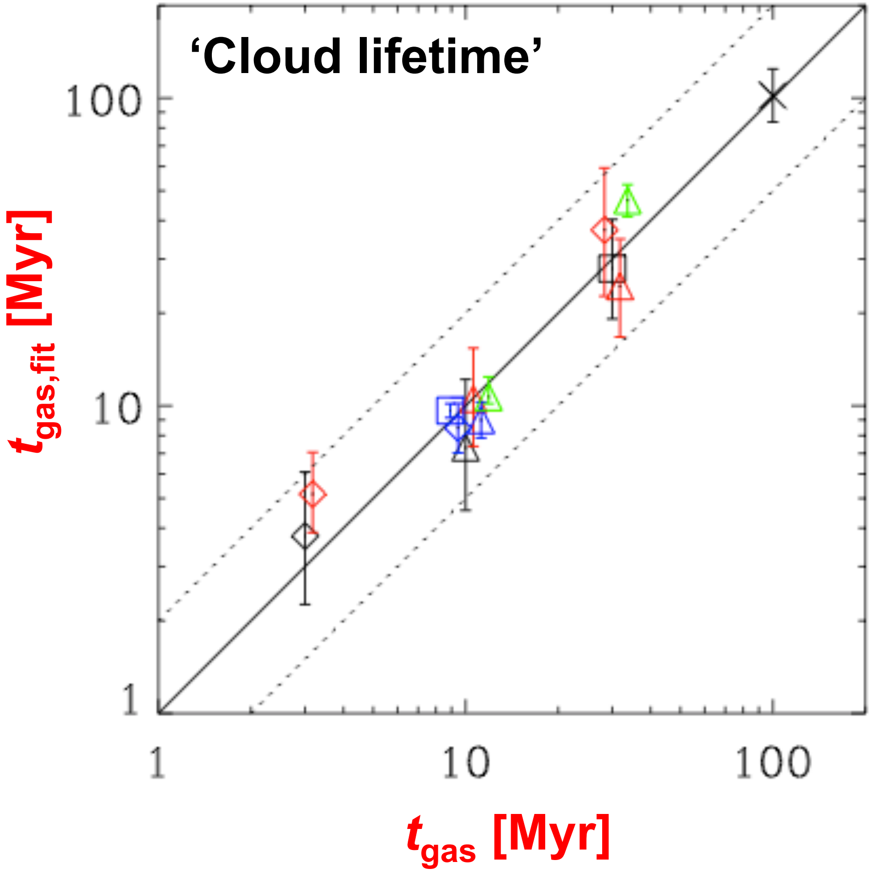
✧ ‘New SPH’ code P-Gadget – see Chia-Yu Hu et al. (2014)
- pressure-entropy SPH
- Wendland smoothing kernel
- improved artificial viscosity
- artificial thermal energy conduction

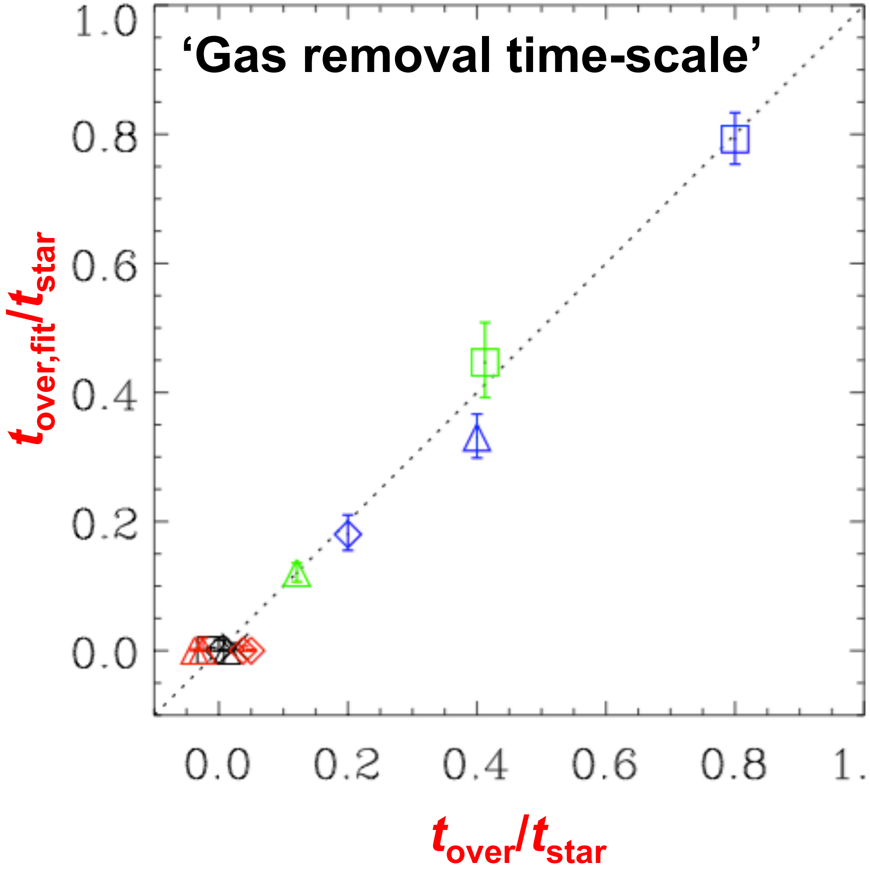
✧ M33-like disc, resolution in clouds is < 20 pc



Age-bin stars and use maps to test: current method is 20–50% accurate







Kruijssen+, in prep.

How do the observables/free parameters depend on the assumptions?

✧ No dependence on *reference time-scale of SF tracer* (< 0.3 dex)

✧ Physical dependence on *gas threshold density* ➔ trace density evolution $\rho(t)$

✧ No dependence on *inclination* if FWHM < $\lambda/2$ (< 0.1 dex for *i* < 70°)

✧ No dependence on *spatial resolution* if FWHM < $\lambda/2$ (< 0.3 dex)

✧ Error bars start blowing up if the *number of identified peaks* < 30

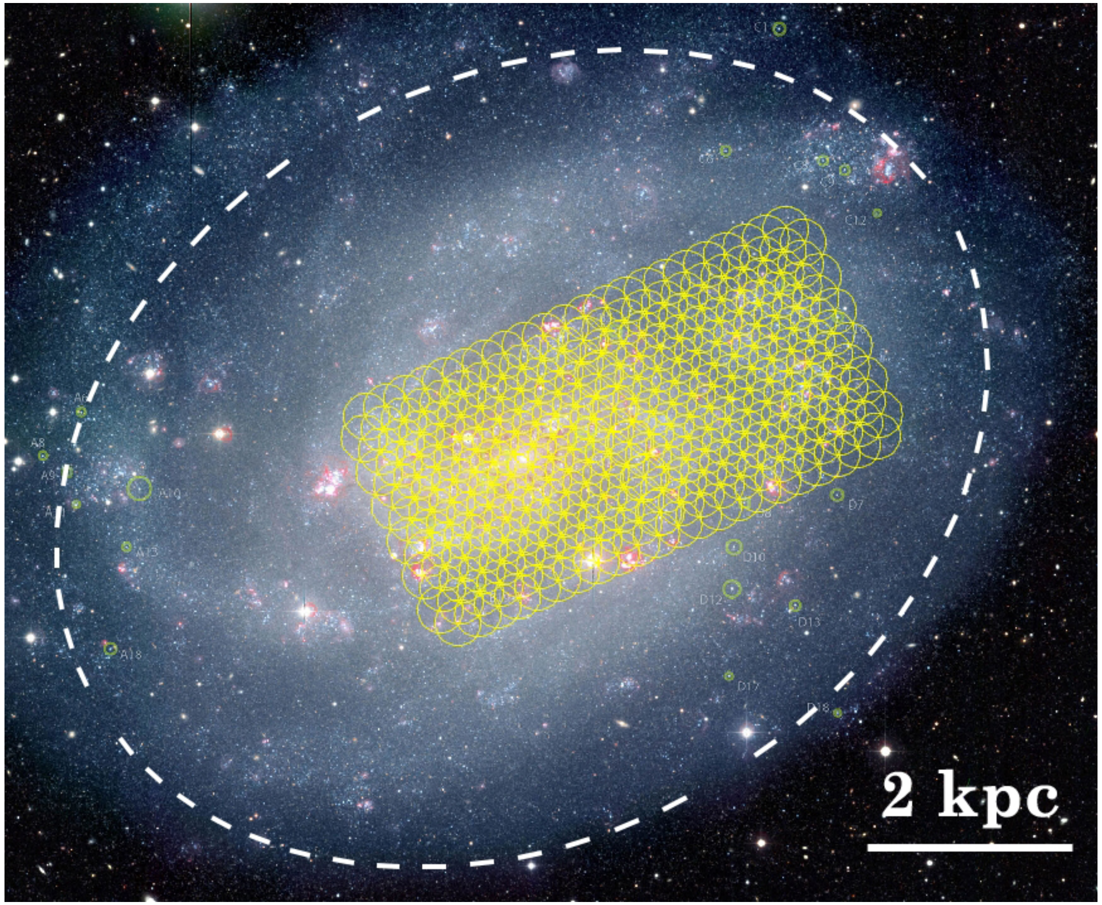
Requirement for best results: resolve $\lambda/2$ and identify at least 30 peaks

First test passed

Numerical simulations show that the method can be used to reliably measure tracer lifetimes

4. application

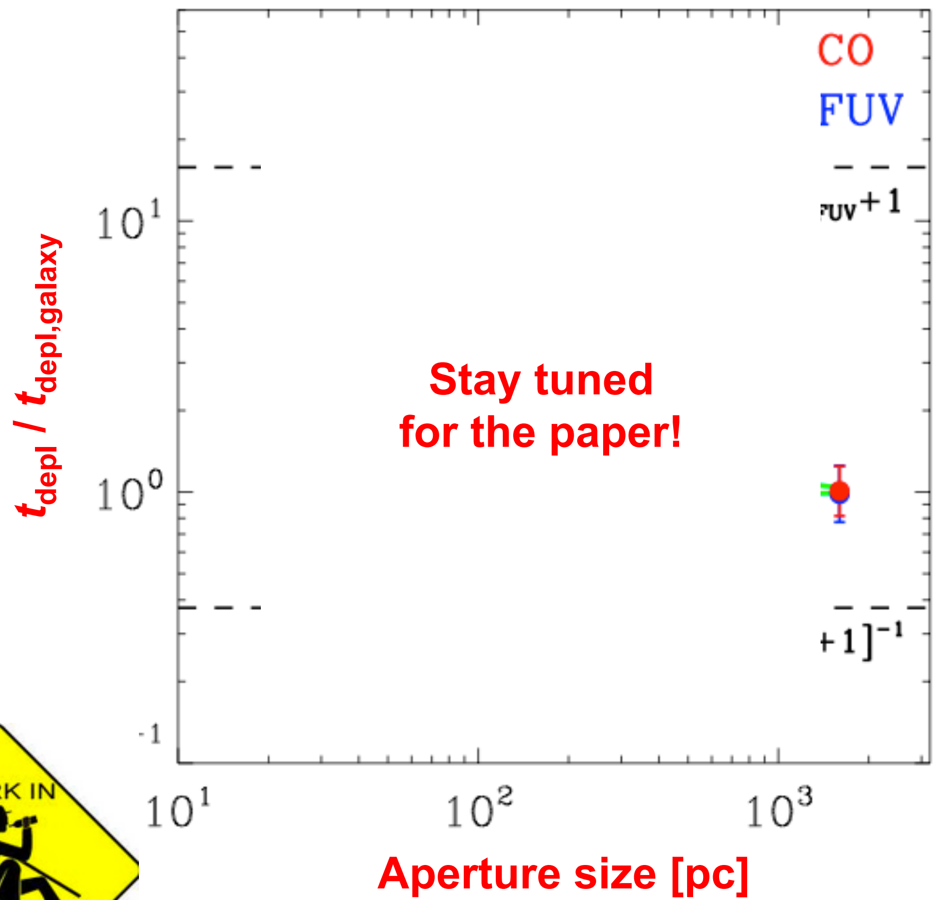
Application to NGC300



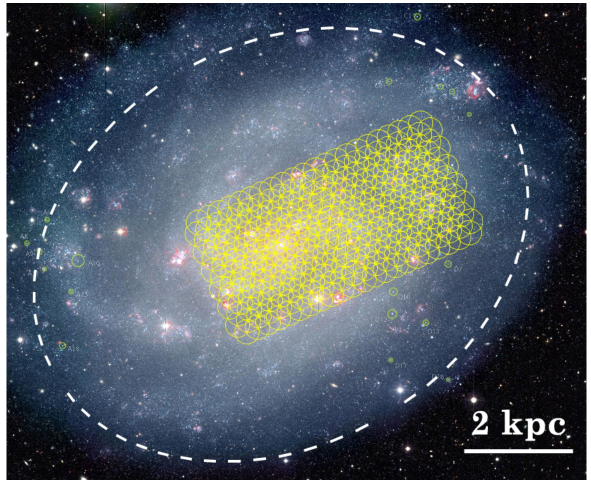
ALMA Cycle 2: Schruba, Kruijssen,
Longmore, Tacconi, Van Dishoeck, Dalcanton

Application to NGC300

✧ Using far-UV and CO(1-0)



Kruijssen, Schruba, Longmore, Tacconi, Van Dishoeck, Dalcanton



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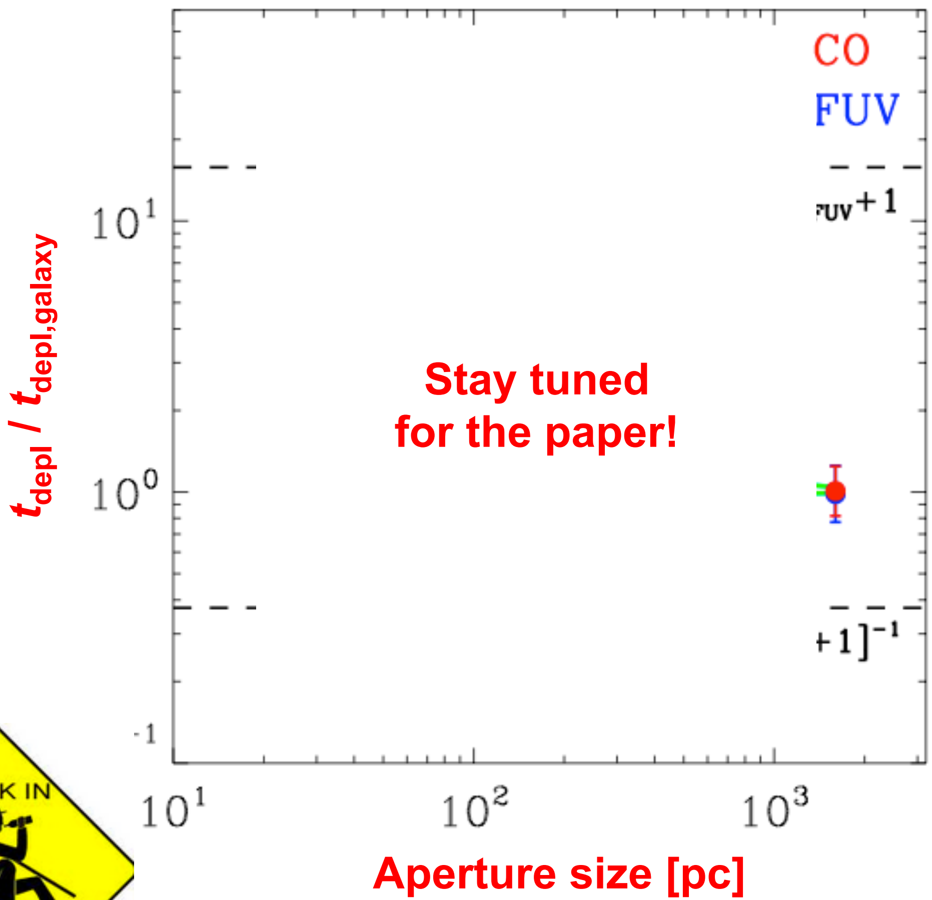
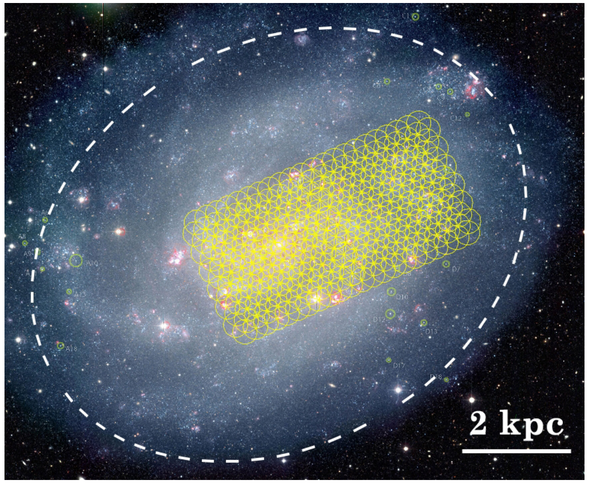


Kruijssen, Schruba, Longmore, Tacconi, Van Dishoeck, Dalcanton



For $t_{\rm star} - t_{\rm over}$ = 65 Myr:

$t_{\rm gas}$ =

$t_{\rm over}$ =

λ =

ε ~

$v_{\rm fb}$ =

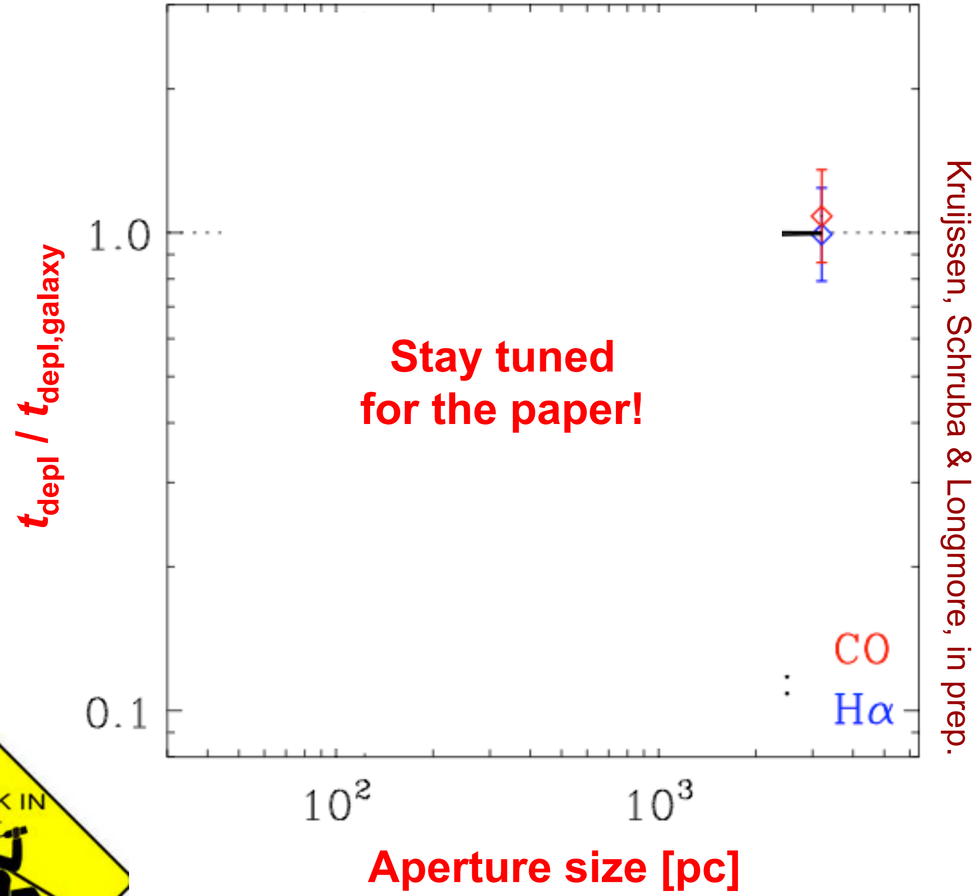
dM/dt ~

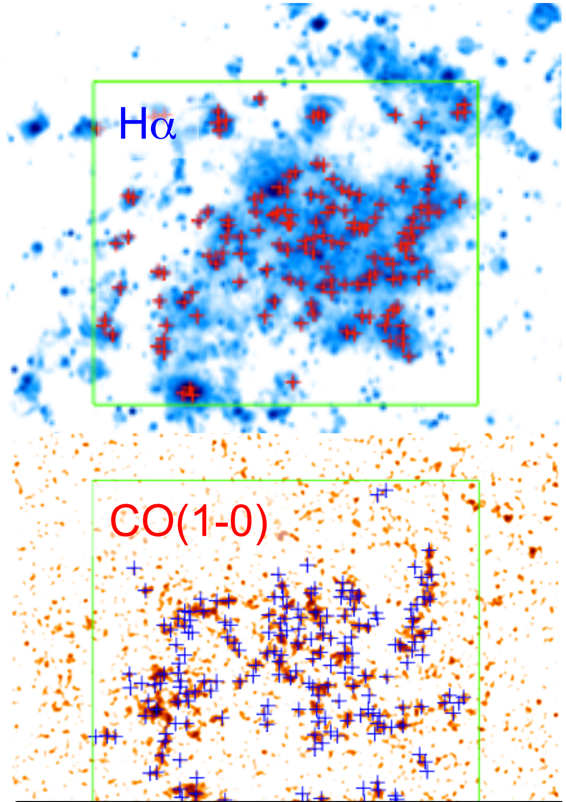
$\eta_{\rm fb}$ ~

Stay tuned for the paper!

M33: also differences between galaxies

✧ Using Hα and CO(1-0)





For $t_{\rm star} - t_{\rm over}$ = 6 Myr:

$t_{\rm gas}$ =

$t_{\rm over}$ =

λ =

ε ~

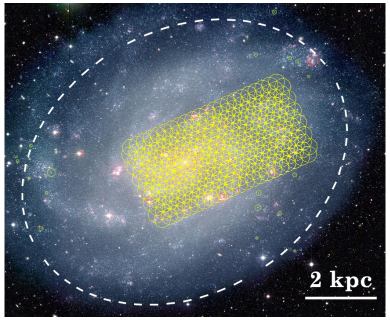
$v_{\rm fb}$ =

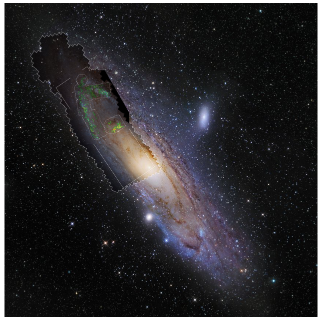
dM/dt ~

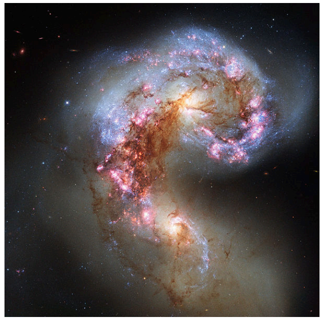
$\eta_{\rm fb}$ ~

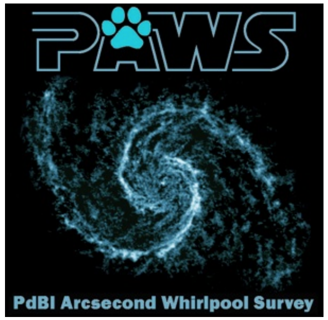
Representative number of nearby galaxies with in-hand data

✧ Enables *systematic* survey of cloud-scale star formation and feedback across a broad range of cosmic environments (rather than just Local Group)





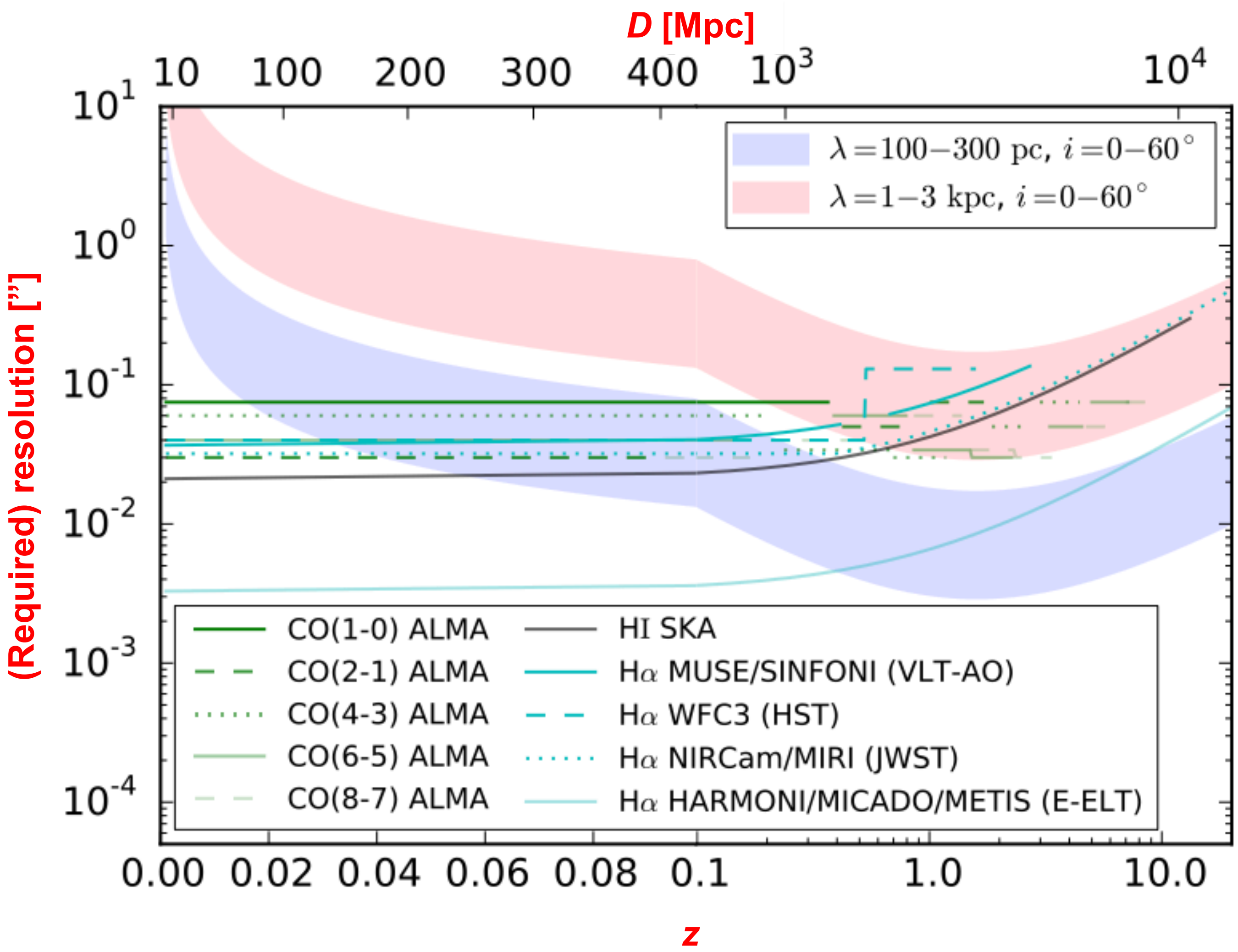




This number should/will* naturally explode during ALMA Cycles 4 ➔ *N*

*TAC: please circle which best applies

Method opens up entire observable Universe for cloud-scale SF studies



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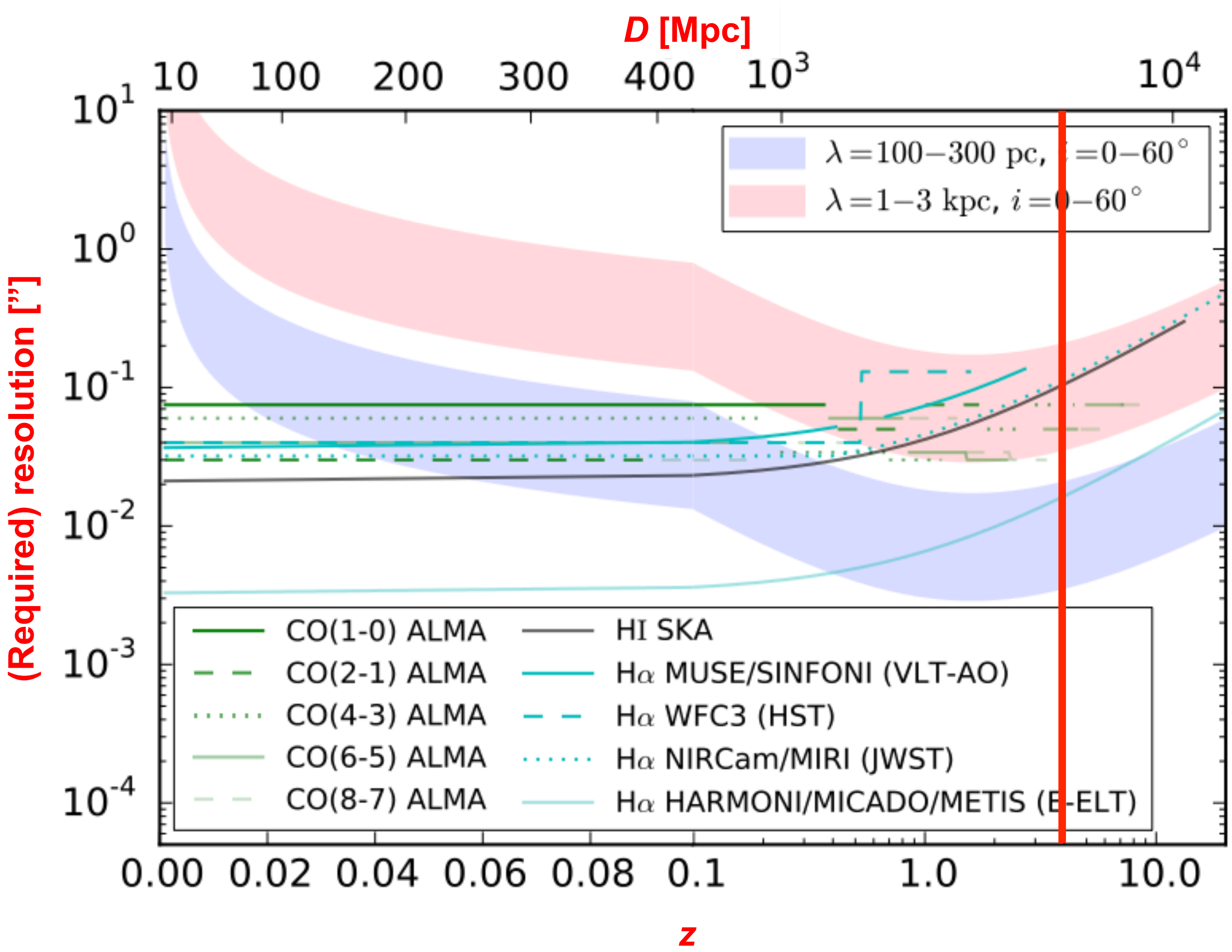
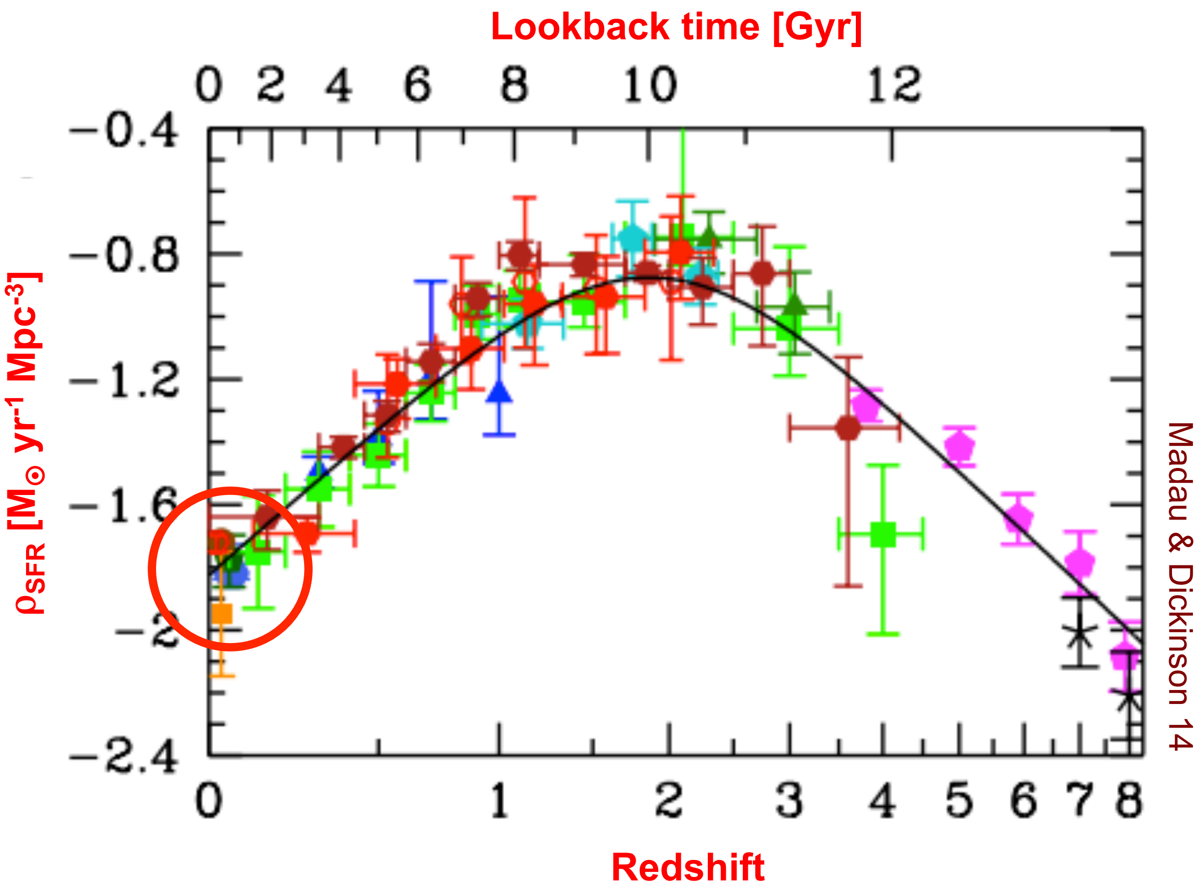


Probe SF & FB physics over cosmic epoch when most stars formed



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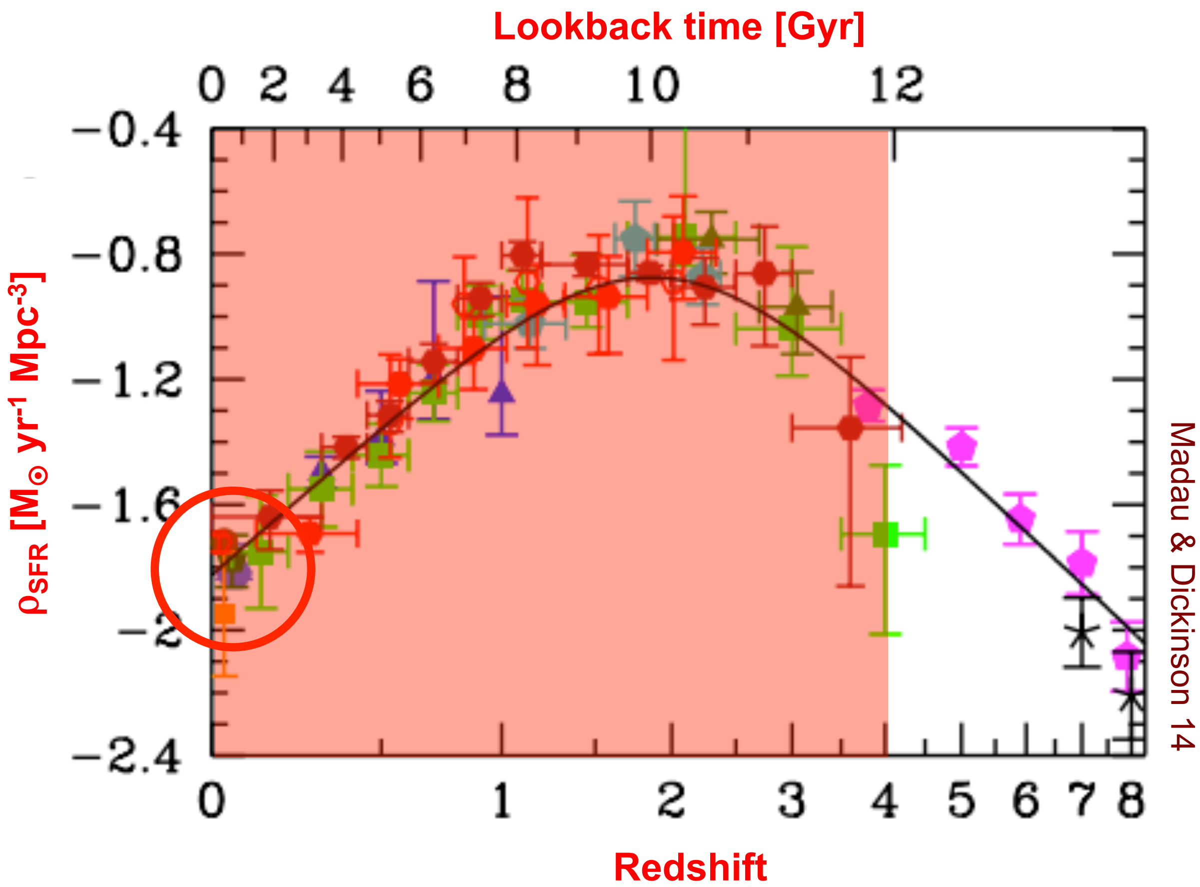

Summary

- ✧ New method to measure fundamental quantities characterising SF & FB
  Kruijssen & Longmore 2014, MNRAS 439, 3239
- ✧ Enables cloud-scale SF studies over cosmologically relevant distances
- ✧ Numerical simulations show measured quantities are accurate and robust
- ✧ Quantities show environmental (in)variation
- ✧ There is no universal cloud lifetime, SF efficiency or mass loading factor
- ✧ Broad application only possible now with ALMA
  ➔ exciting future ahead (if the TAC lets us ☺)