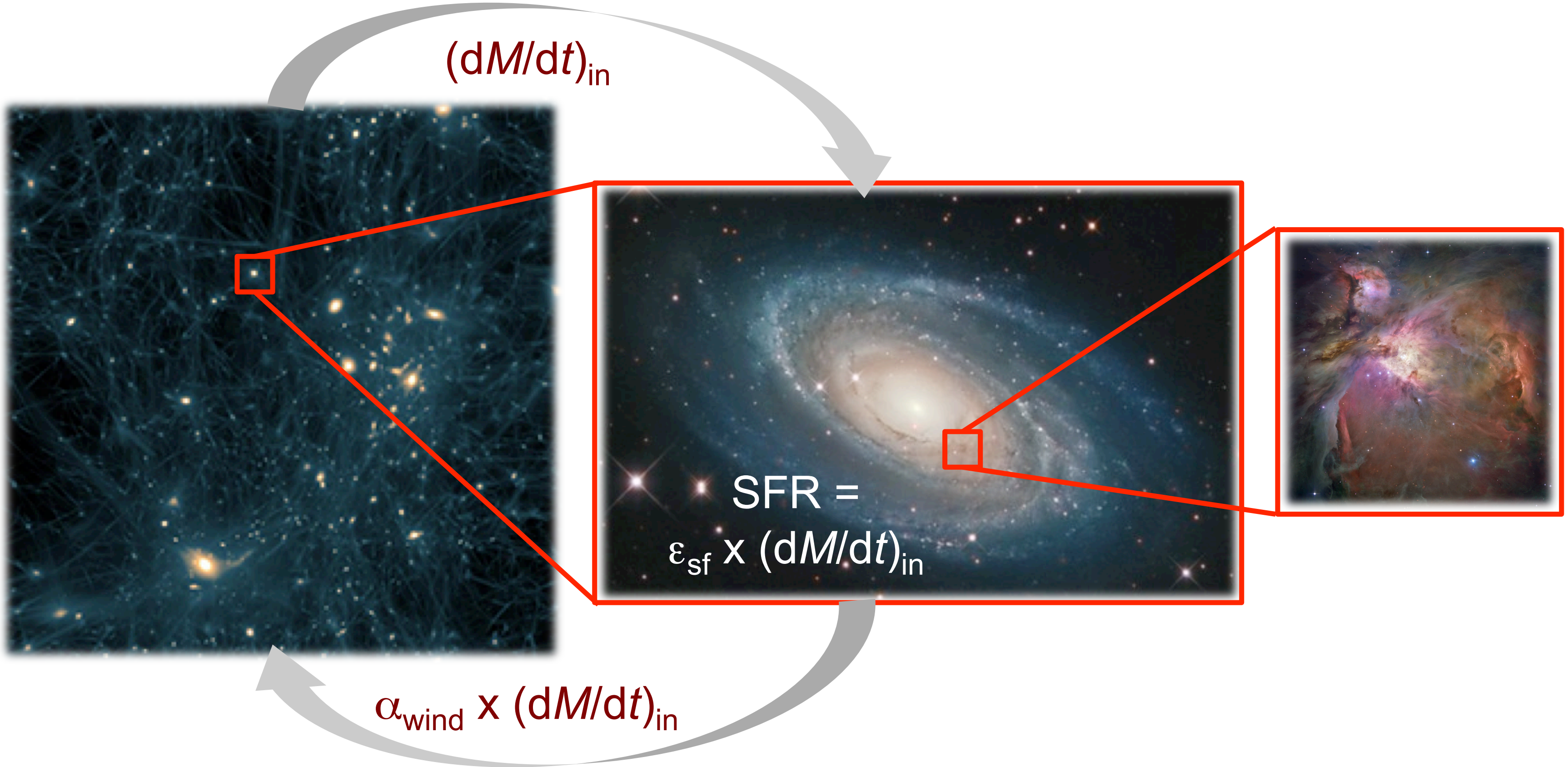
The multi-scale physics of galactic star formation across cosmic time

J. M. Diederik Kruijssen
MPA Garching

Is the IGM driving star formation?



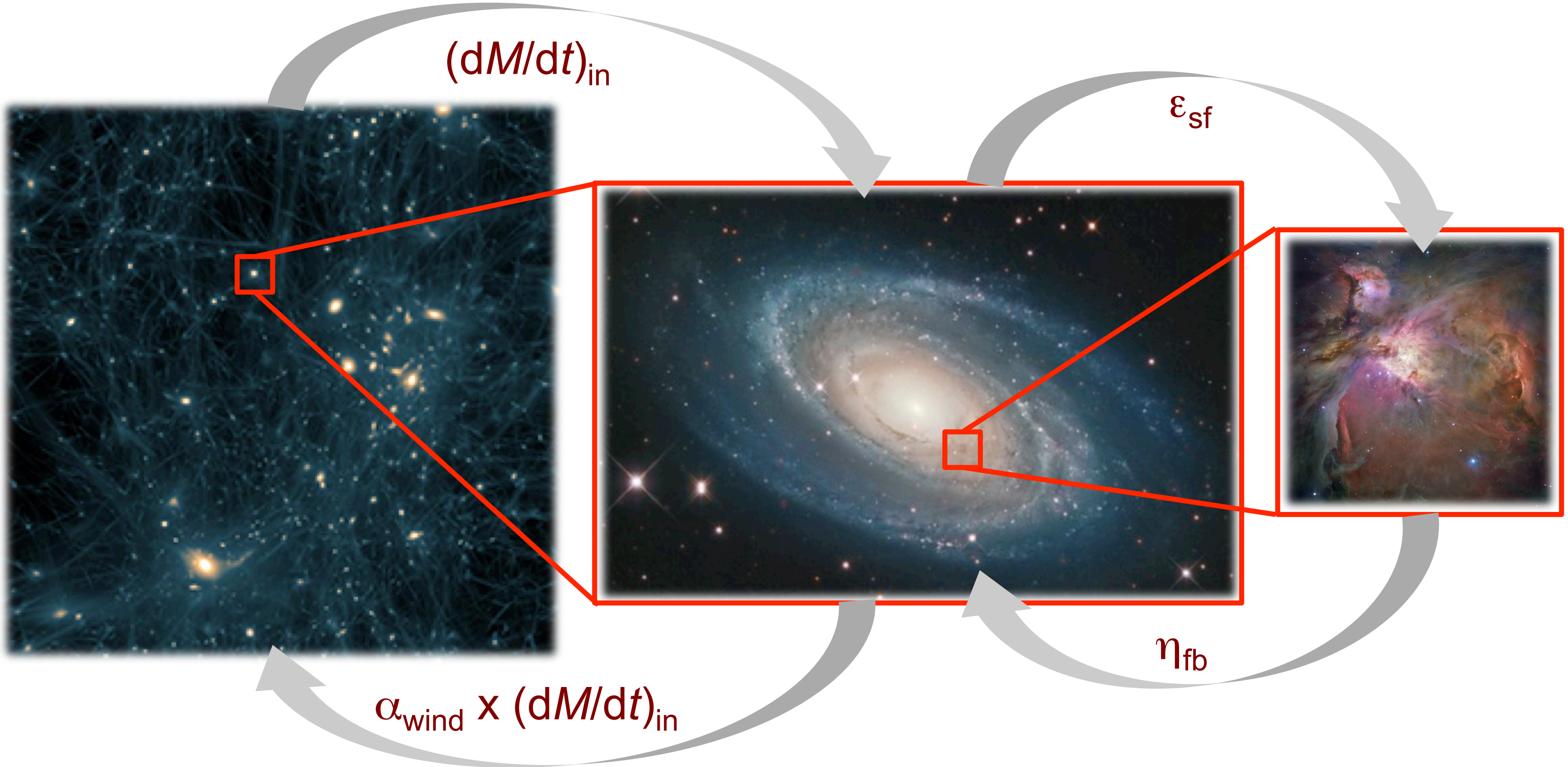
The constants contain most of the physics. As long as their origin is unknown, galaxy formation is unsolved – knowing the mass inflow rate is not enough.

Introduction
Principle
Simulations
Observations

Star formation occurs in localised events

NGC 300, GALEX

Is the IGM driving star formation?



The cloud-scale quantities set the galaxy properties (see e.g. FIRE) 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

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **439**, 3239–3252 (2014)
Advance Access publication 2014 February 24

doi:10.1093/mnras/stu098

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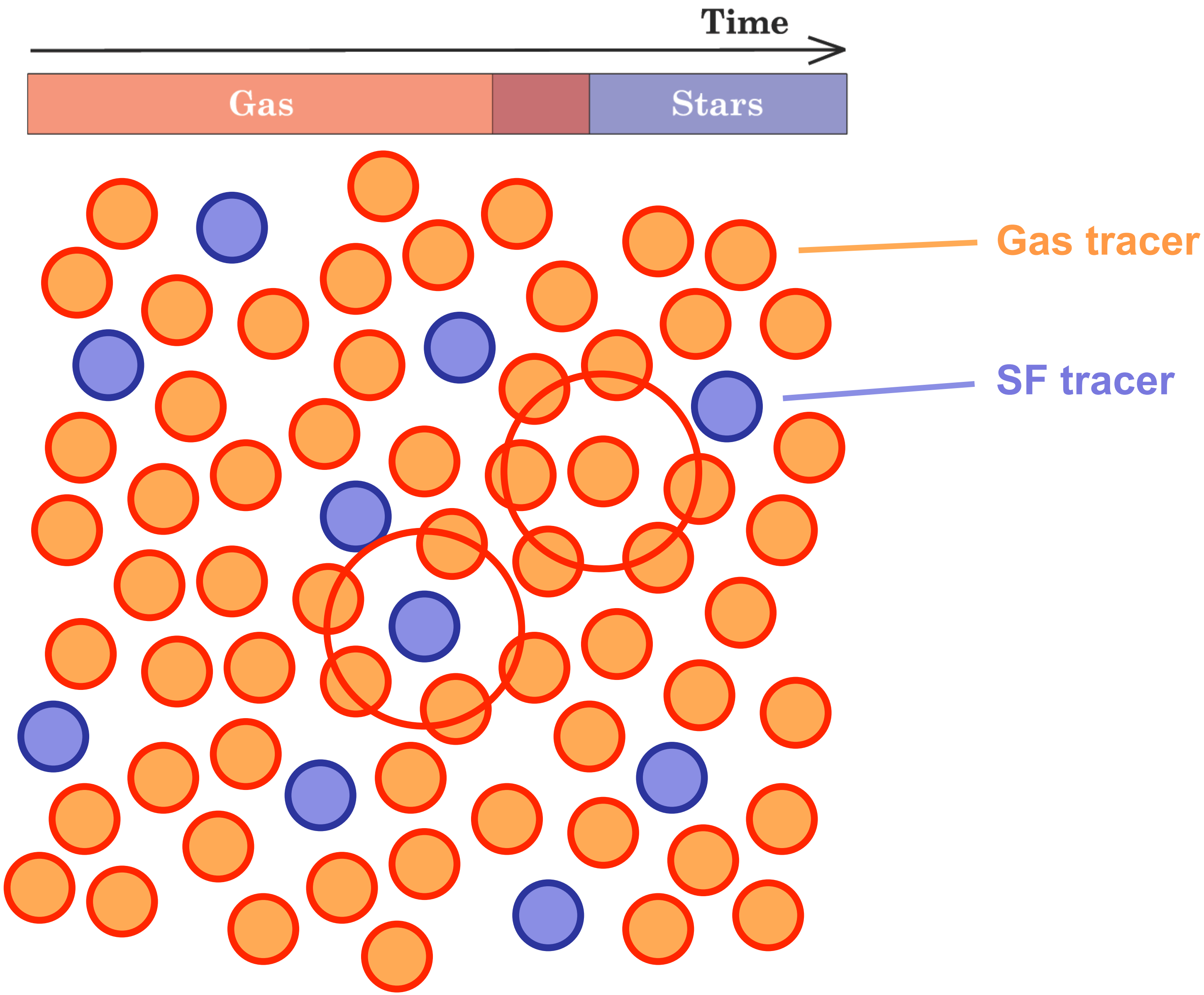
An uncertainty principle for star formation – I. Why galactic star formation relations break down below a certain spatial scale

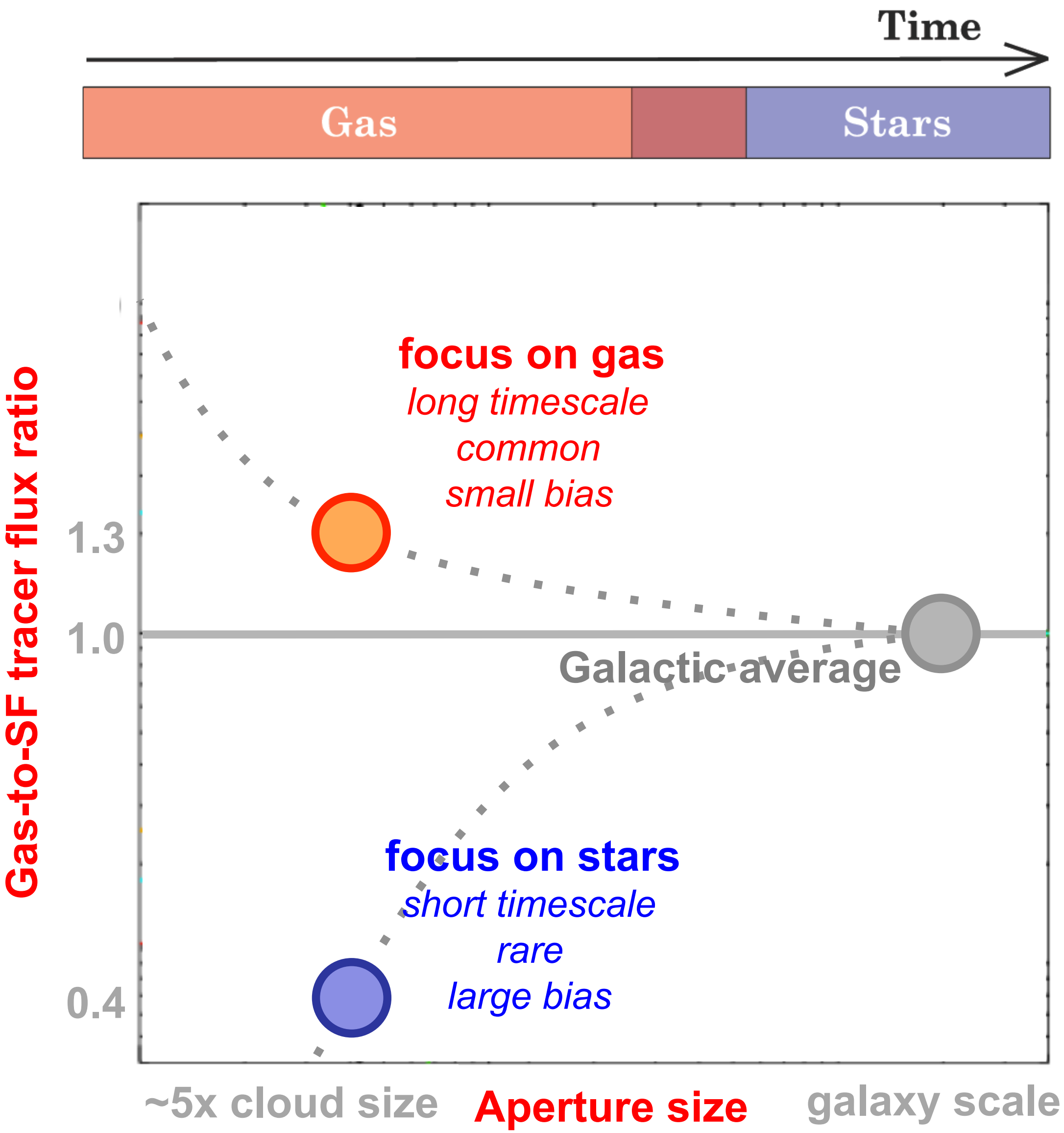
J. M. Diederik Kruijssen[1★] and Steven N. Longmore[2]

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

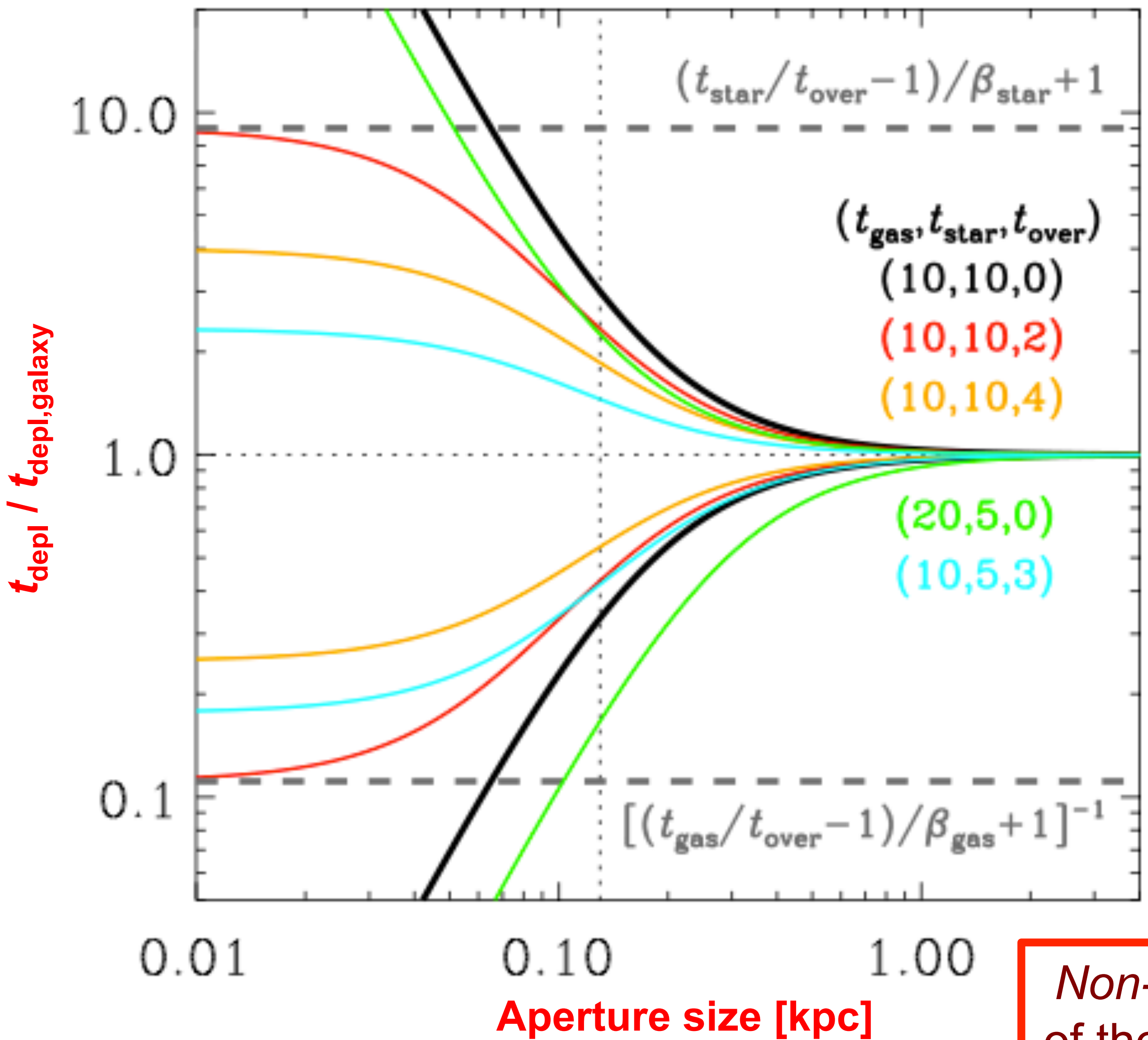


Gas-to-SF tracer ratio (== t_{depl}) as a function of spatial scale



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

Kruijssen & Longmore 2014, MNRAS 439, 3239



Centre on:

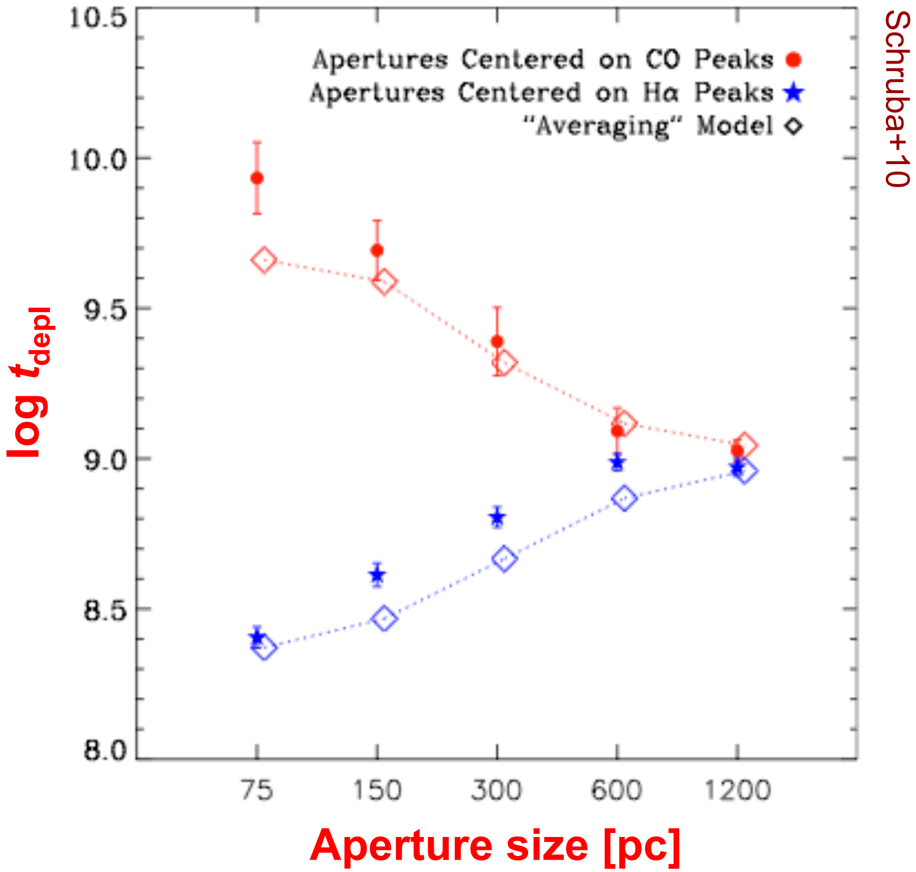
gas

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:

gas

stars

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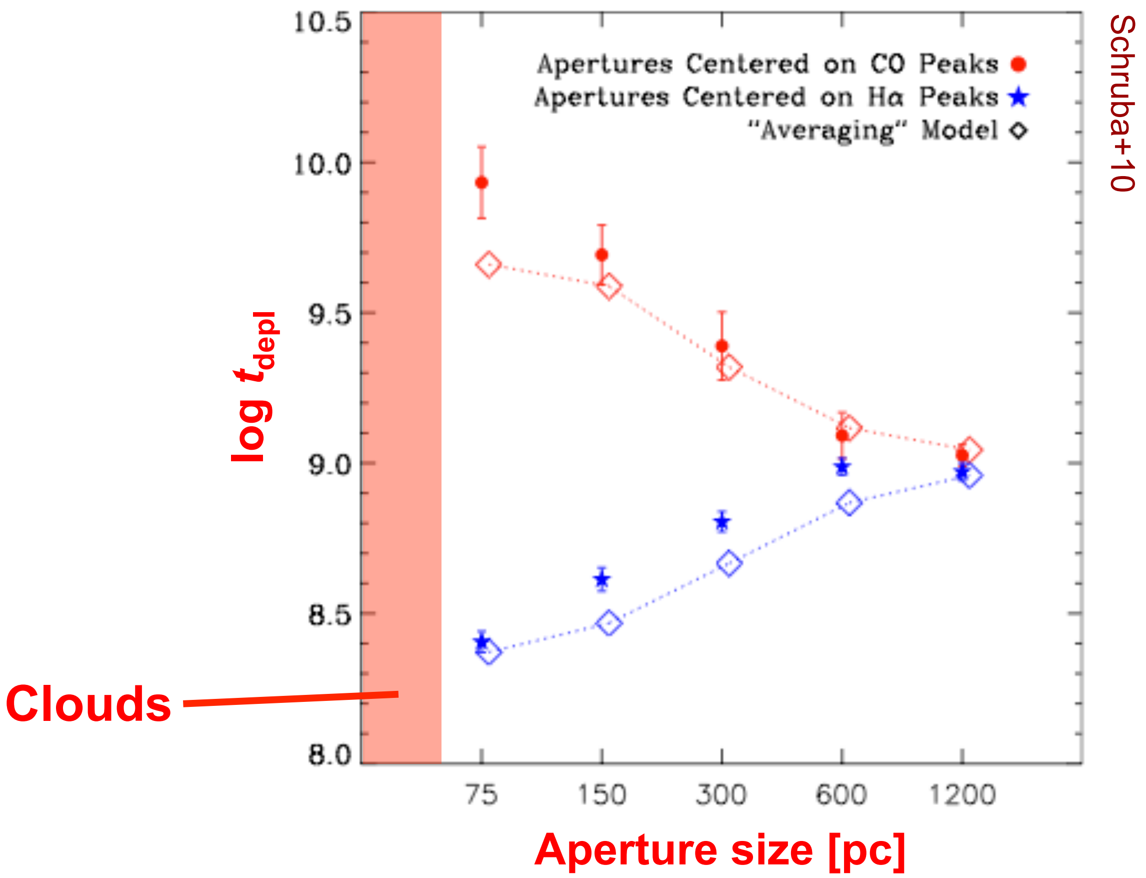
Gas-to-SFR ratio as a function of spatial scale

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



Centre on:

gas

stars

An uncertainty principle for star formation

Kruijssen & Longmore 2014, MNRAS 439, 3239

✧ Simple, but fundamental model describing multi-scale SF

✧ Potentially very powerful tool to obtain:
- time-scales involved in SF process (cloud/clump lifetimes, FB timescale, …)
- cloud/clump separation length
- star formation efficiency per cloud/clump
- feedback velocity, mass outflow rate, mass loading, ISM coupling efficiency

✧ 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 $z \sim 4$

An uncertainty principle for star formation

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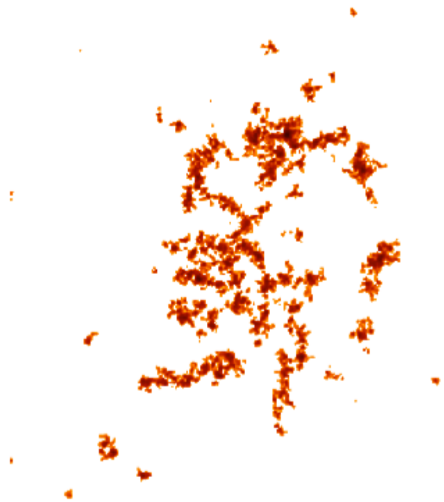
This is what ALMA, MUSE, etc. are made to do

2. practical application

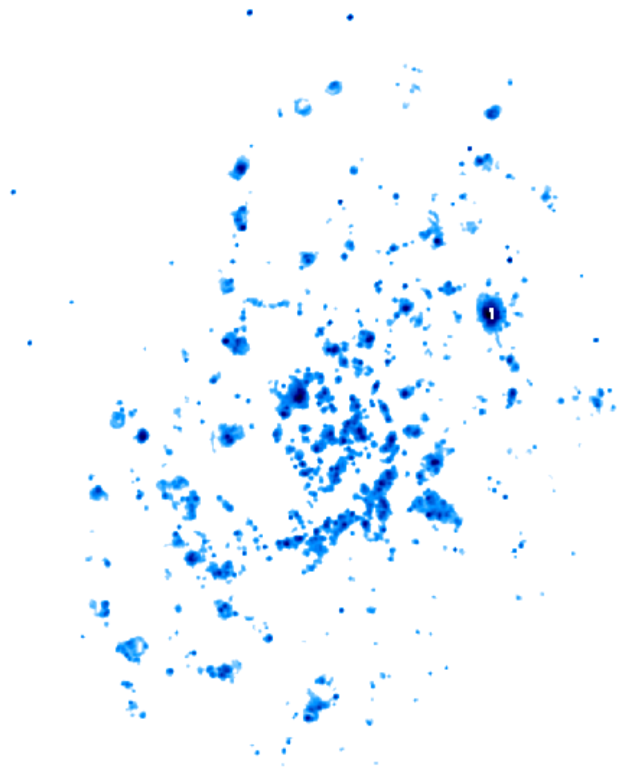
Practical application of characterising cloud-scale physics

✧ Step 1: select tracers

CO(1-0)



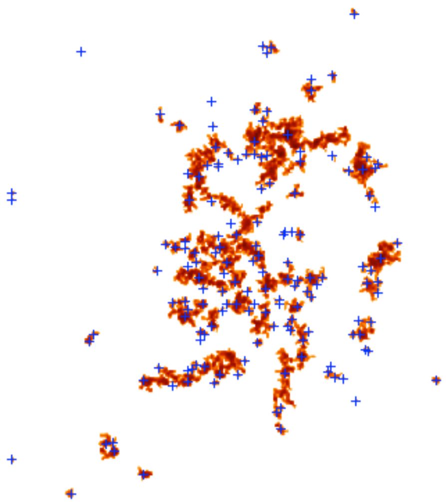
Hα → ~ 6 Myr



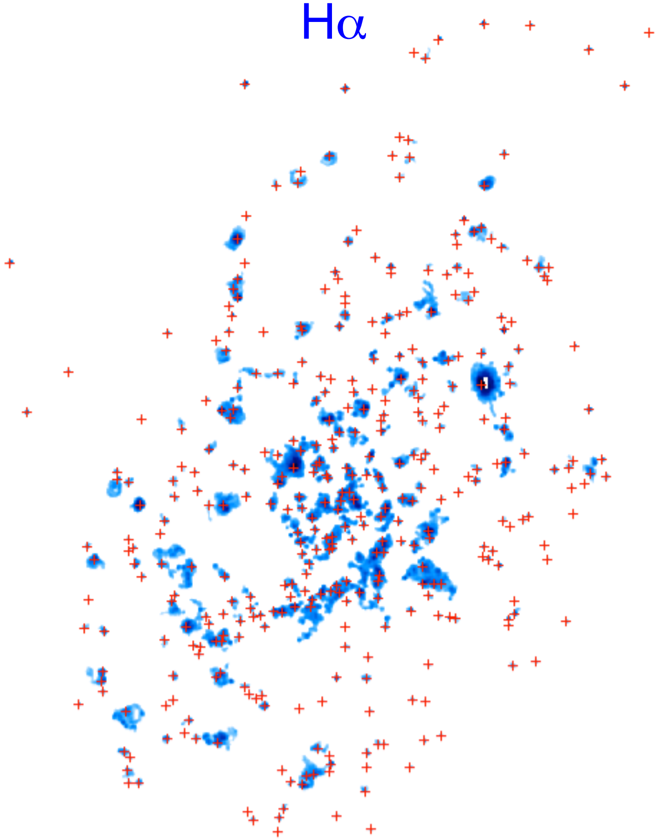
Practical application of characterising cloud-scale physics

✧ Step 2: select emission peaks

CO(1-0)

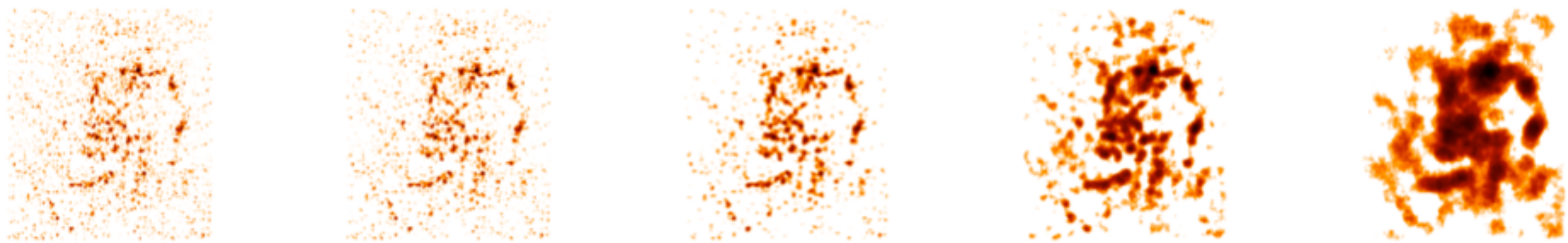


Hα

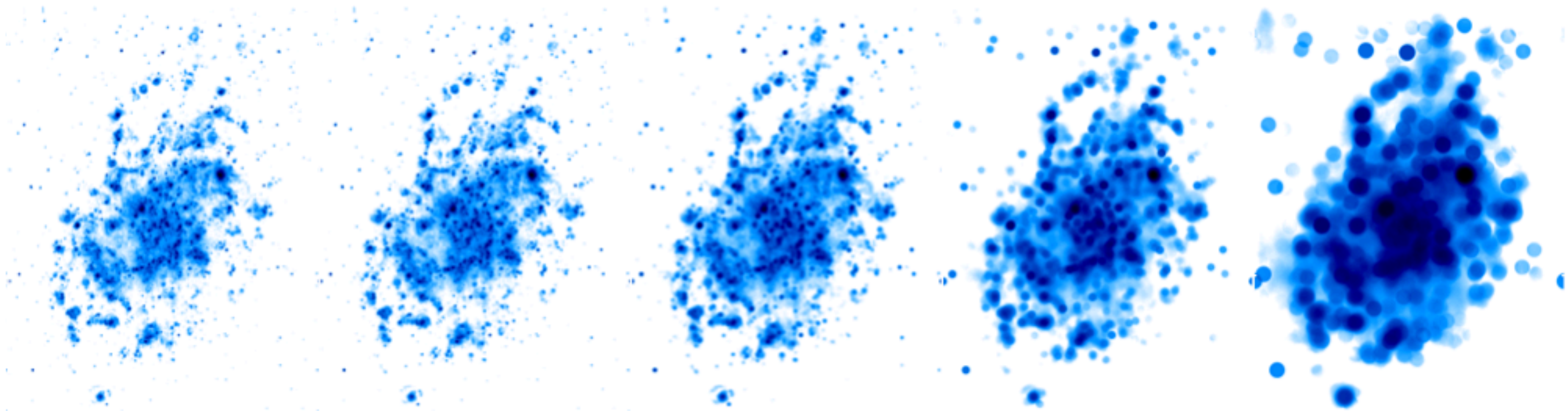


Practical application of characterising cloud-scale physics

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

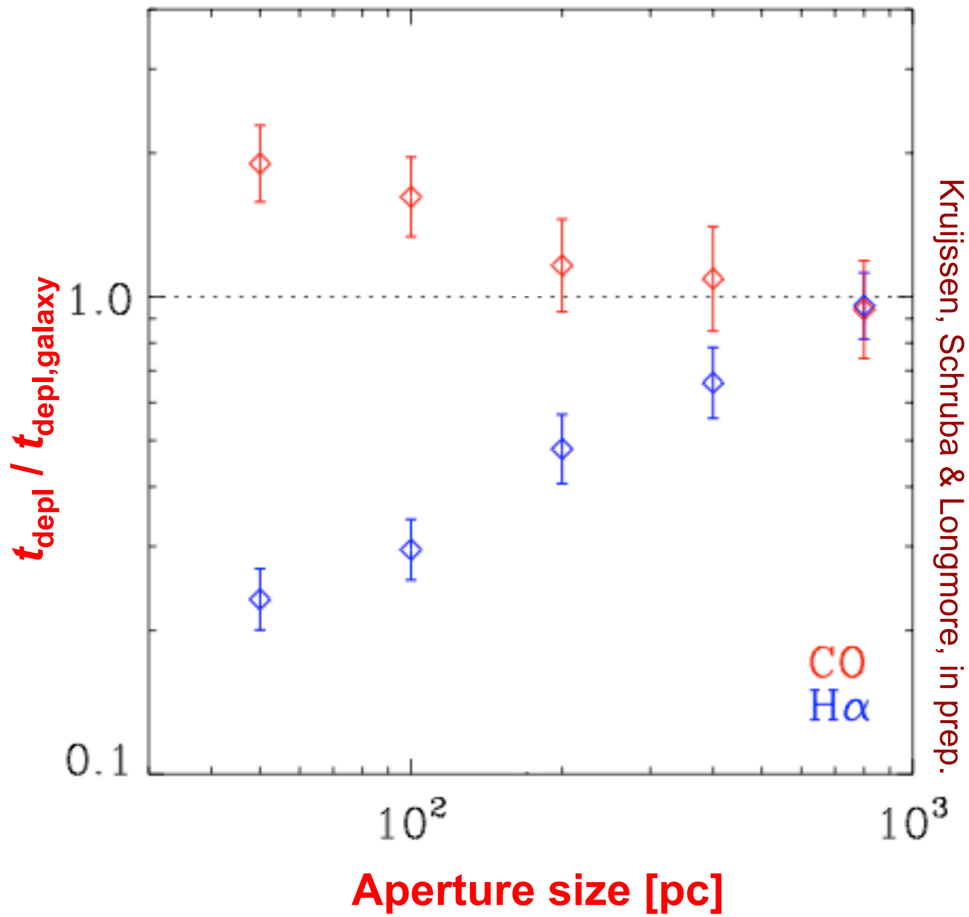


50 pc | 100 pc | 200 pc | 400 pc | 800 pc



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

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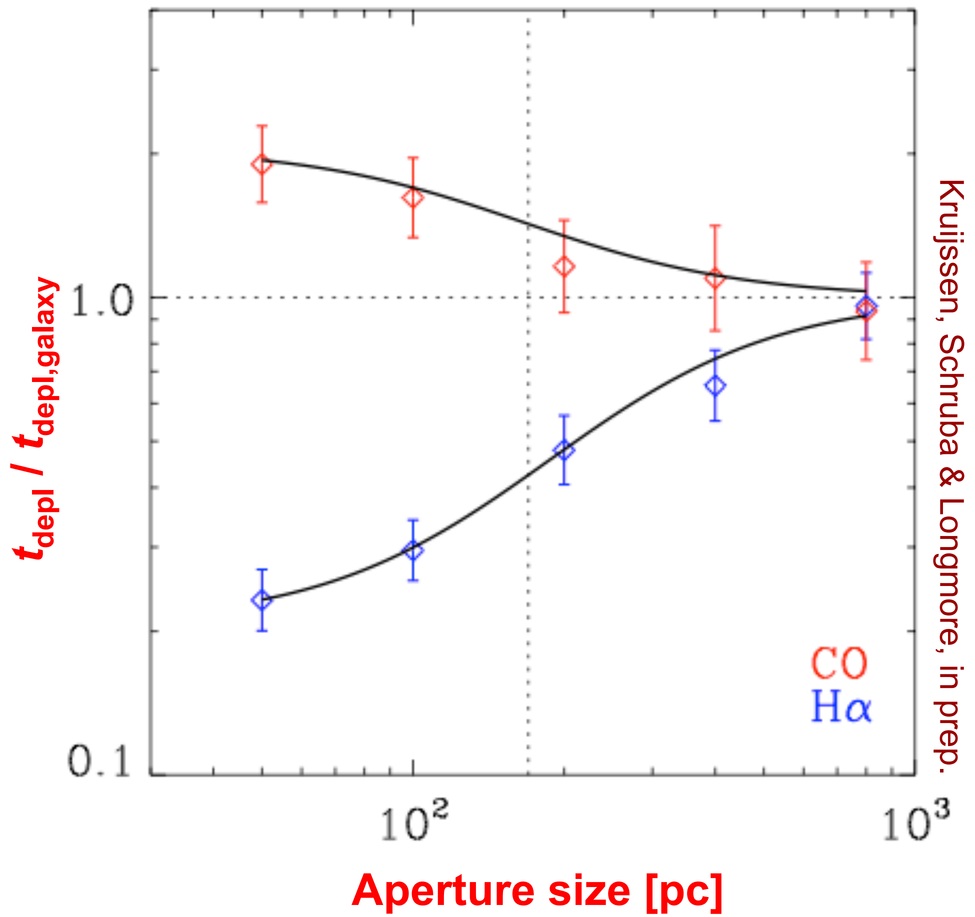
Practical application of characterising cloud-scale physics

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



Centre on:

gas

stars

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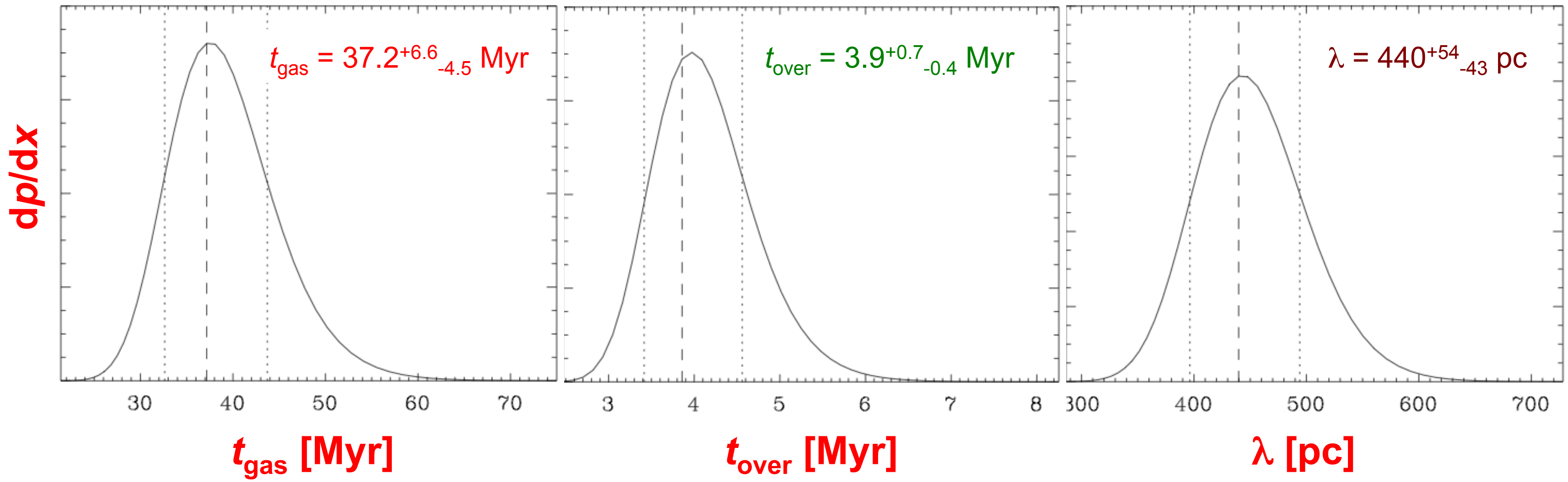
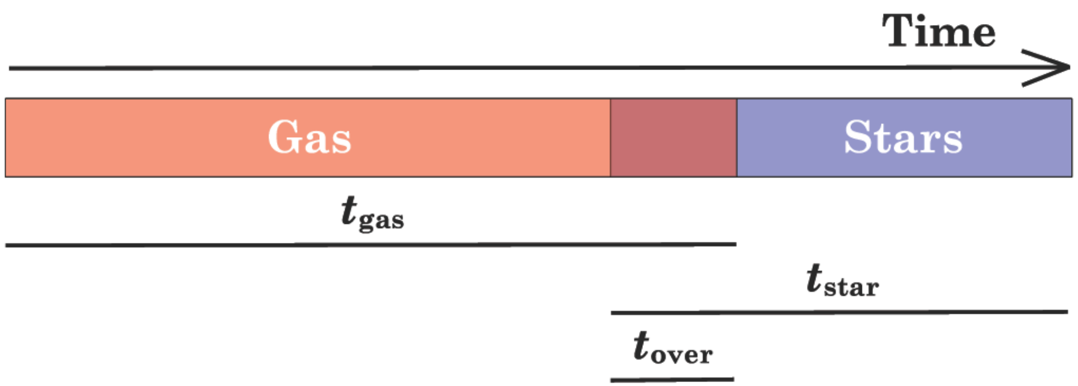
Practical application of characterising cloud-scale physics

✧ 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)

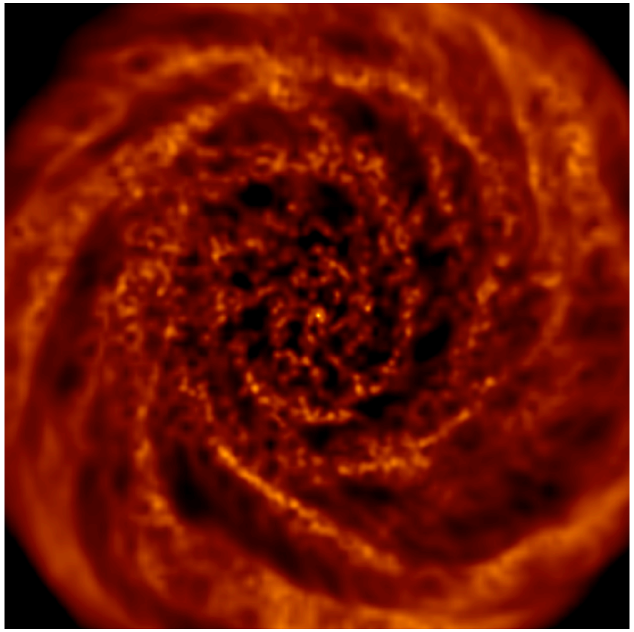
✧ Test using numerical simulations

✧ '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

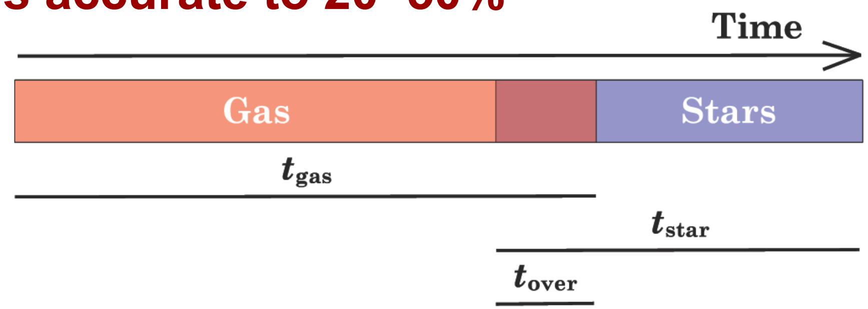
✧ M33-like disc, resolution in clouds is < 20 pc

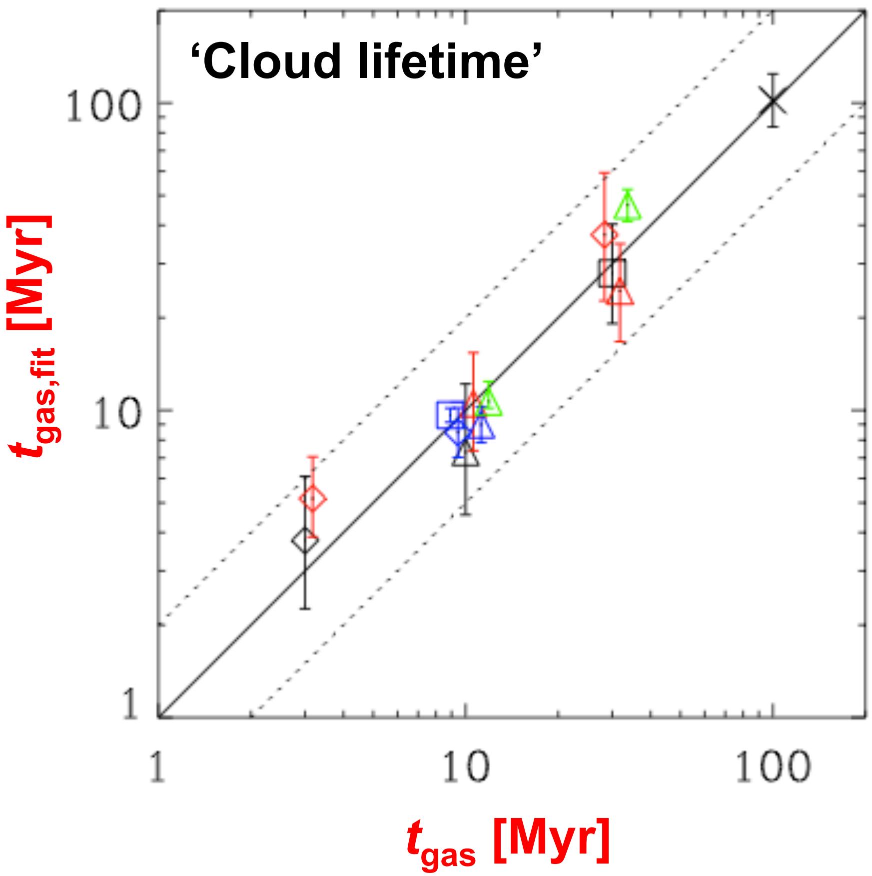
✧ Age-bin the stars and use maps for tests

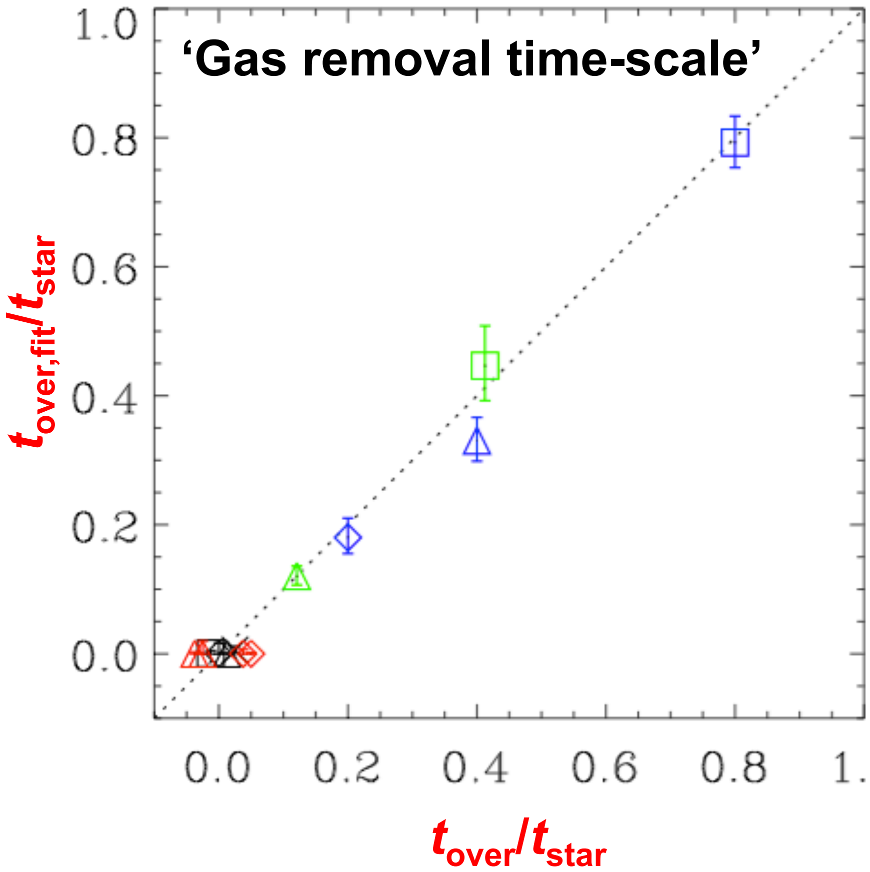
20 kpc



Current method is accurate to 20–50%







Kruijssen+, in prep.

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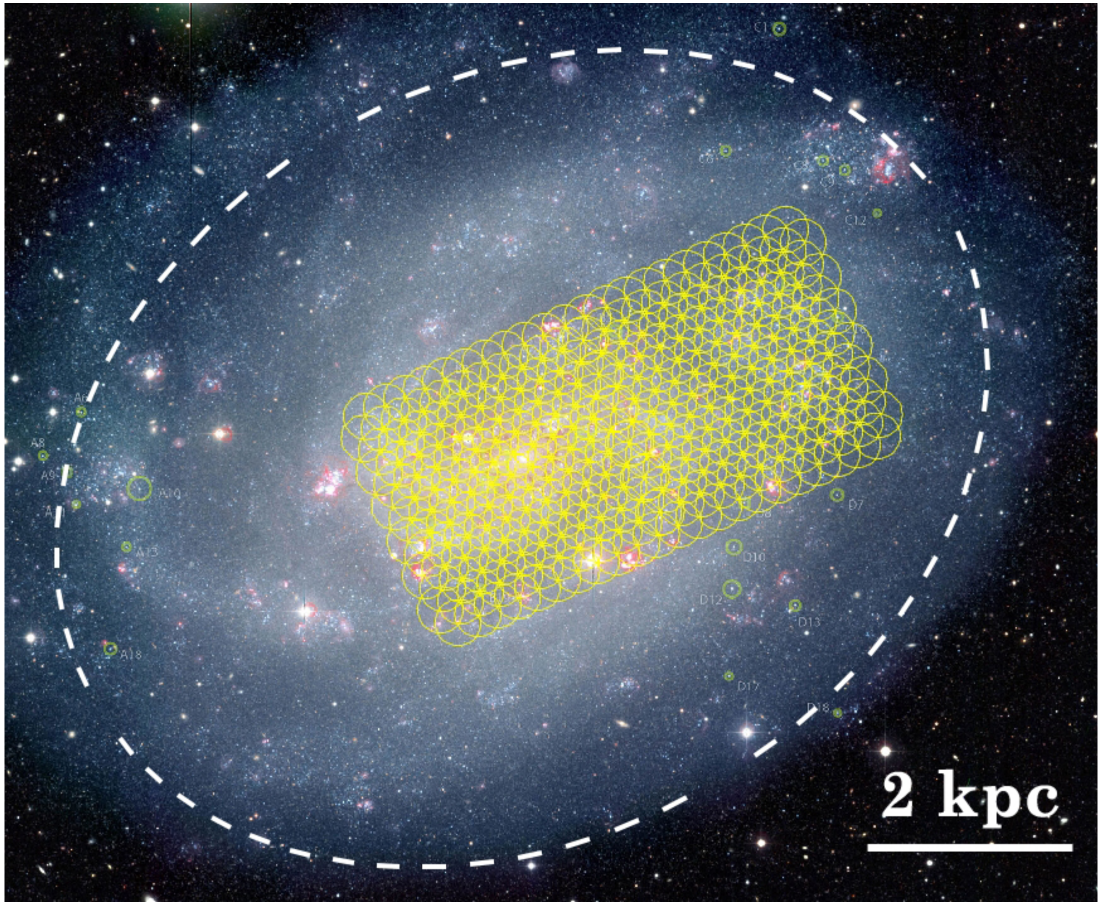
First test passed

Numerical simulations show that the method can be used to reliably measure tracer lifetimes – further tests are ongoing

4. application

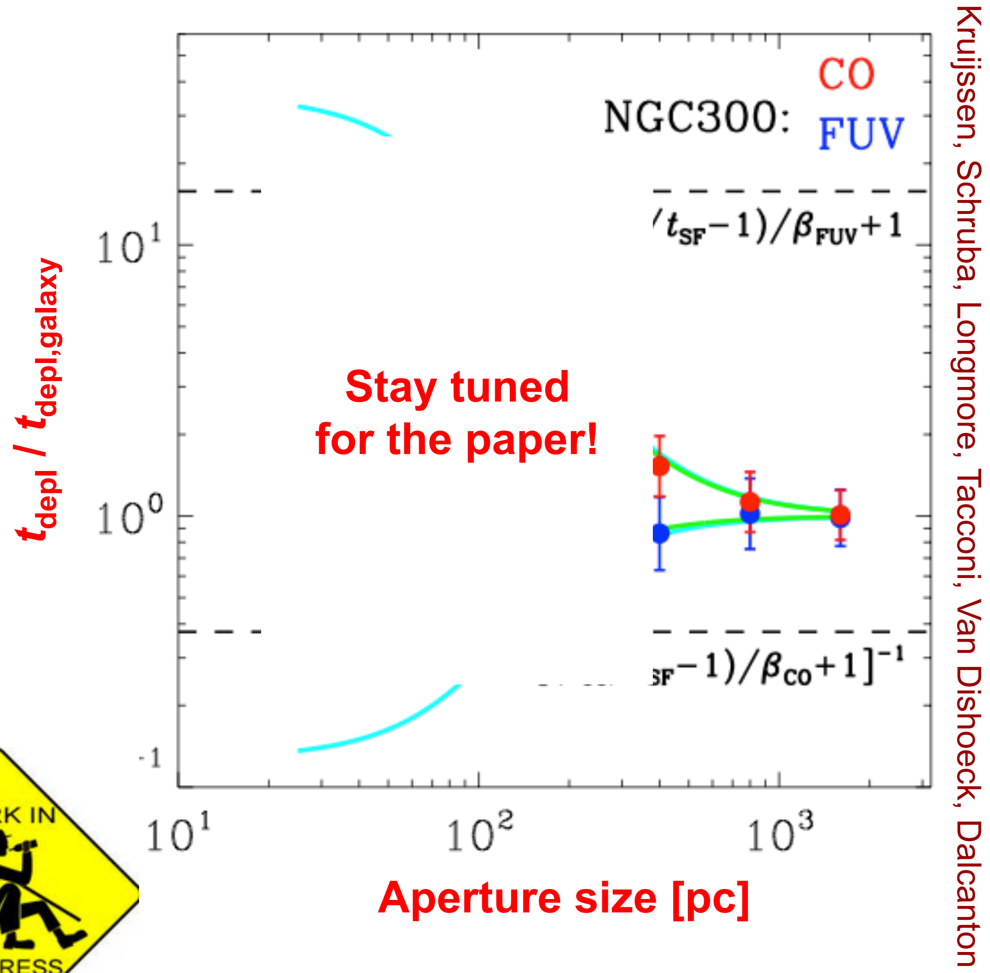
Application to NGC300

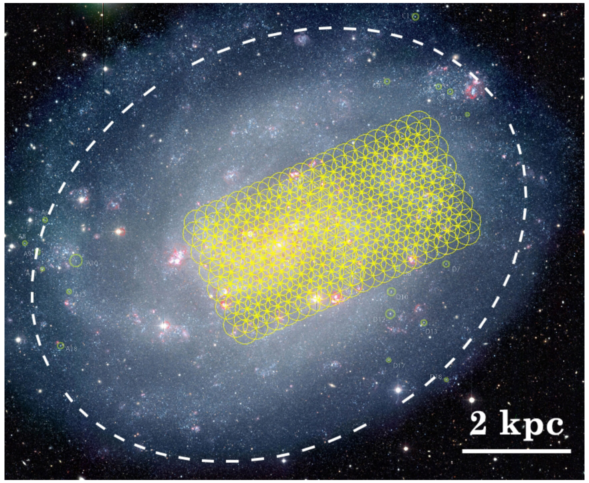


ALMA Cycle 2: Schruba, Kruijssen,
Longmore, Tacconi, Van Dishoeck, Dalcanton

Application to NGC300

✧ Using far-UV and CO(1-0)





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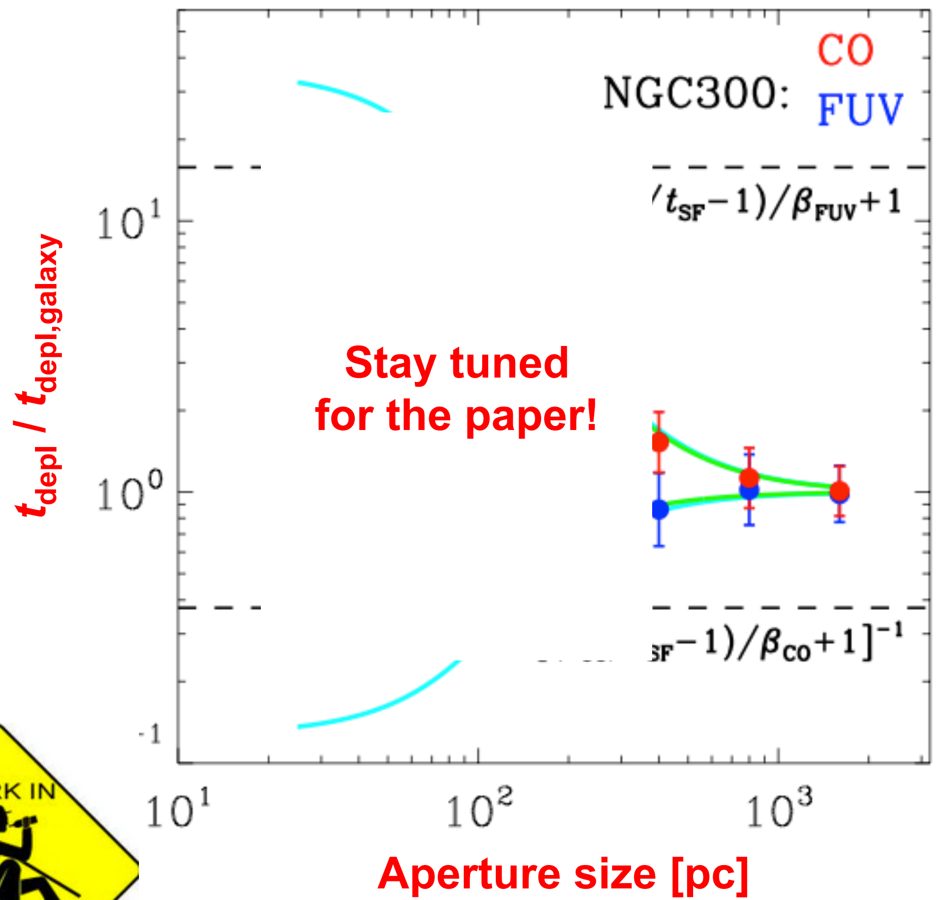
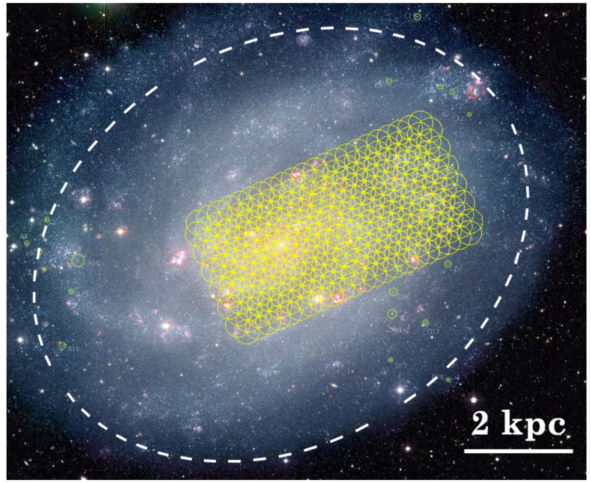


Kruijssen, Schruba, Longmore, Tacconi, Van Dishoeck, Dalcanton



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

t_{gas} =

t_{over} =

λ =

ε ~

v_{fb} =

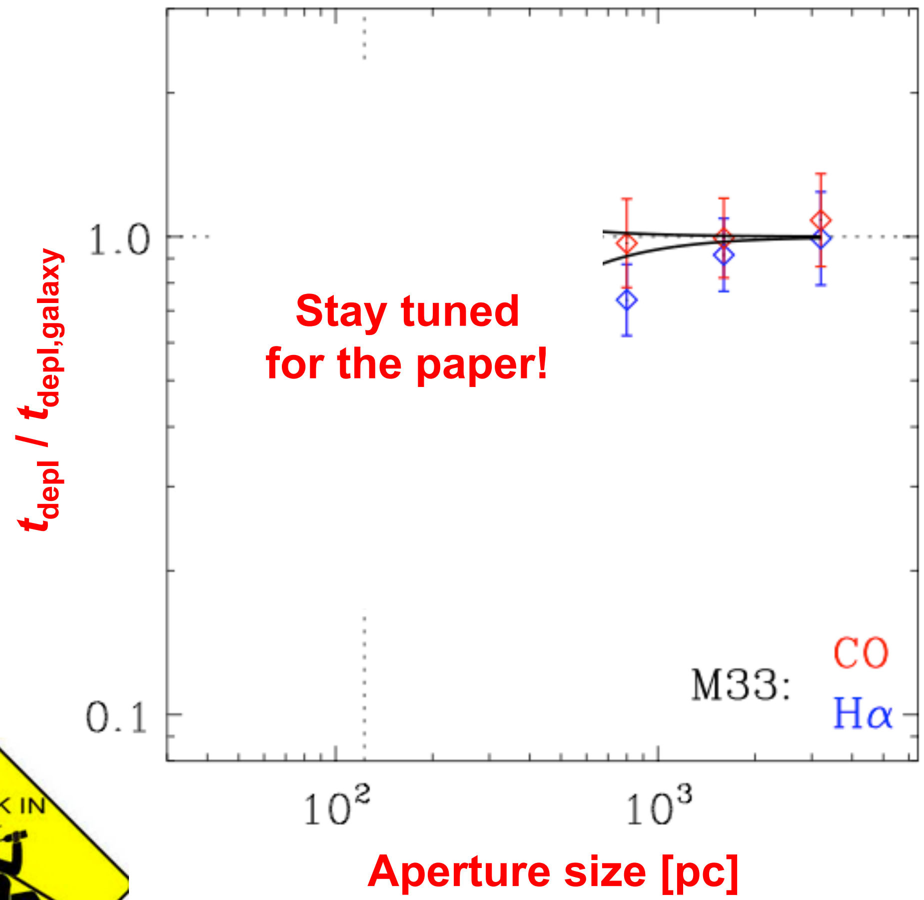
dM/dt ~

η_{fb} ~

Stay tuned for the paper!

Application to M33

✧ Using Hα and CO(1-0)



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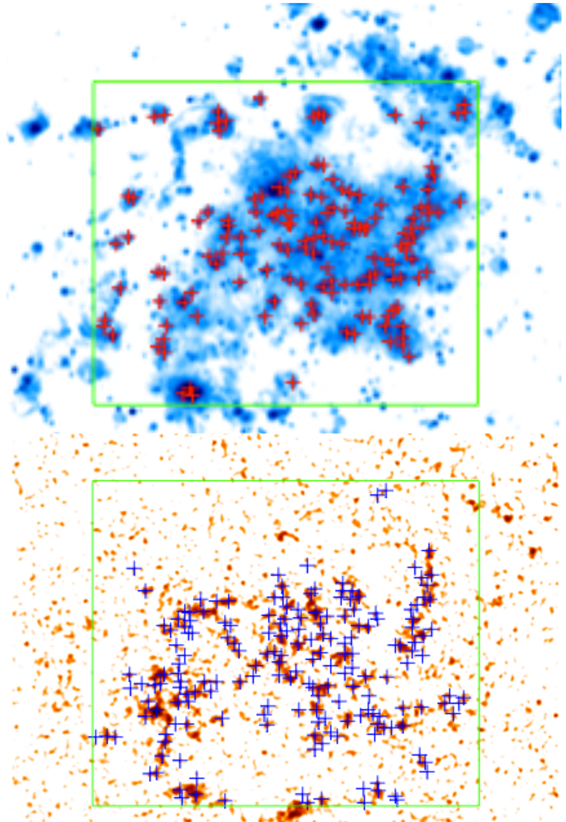
Kruijssen, Schruba & Longmore, in prep.



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

t_{gas} =

t_{over} =

λ =

ε ~

v_{fb} =

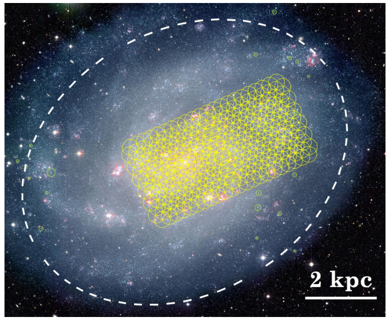
dM/dt ~

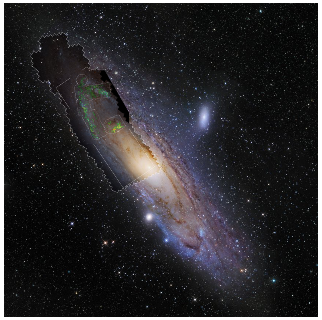
η_{fb} ~

Stay tuned for the paper!

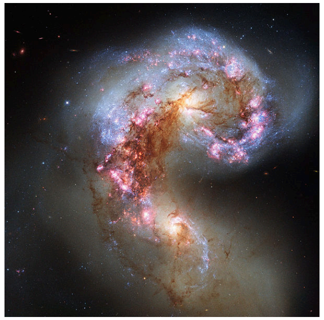
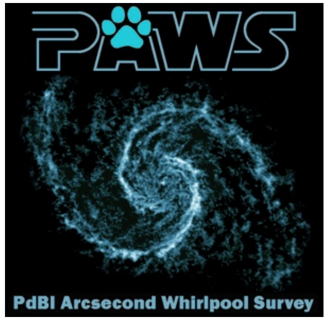
Representative number of nearby galaxies with in-hand data

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



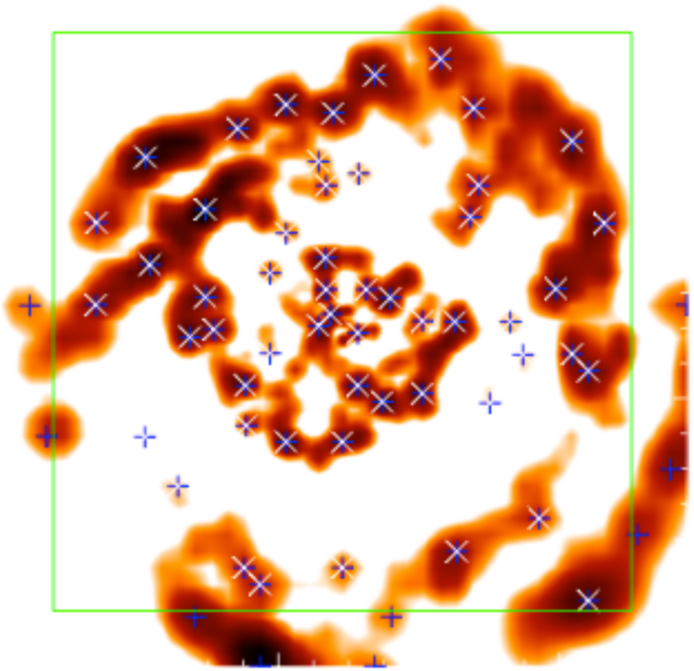




The number of galaxies will naturally explode during ALMA Cycles 3 ➔ *N*

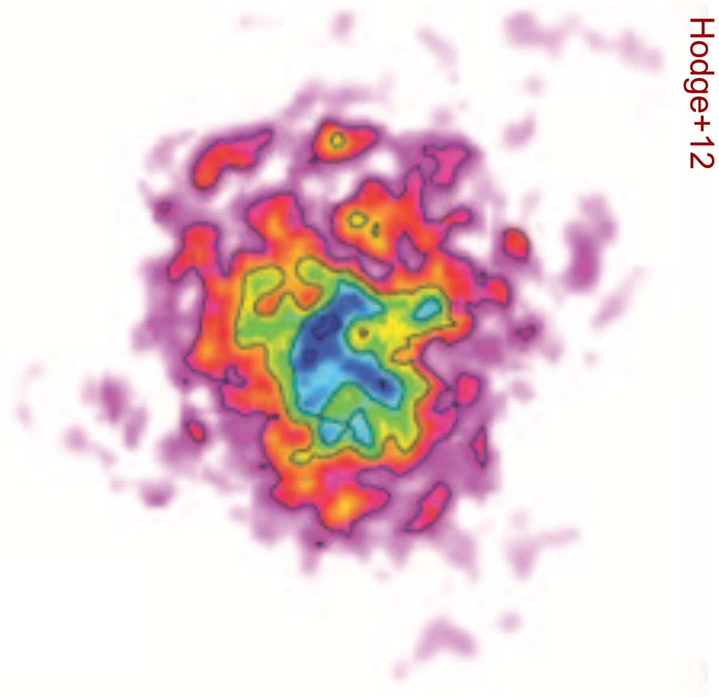
Method opens up entire observable Universe for cloud-scale SF studies



Low-resolution simulation

t_{gas} = 30 Myr

$t_{gas,fit} = 32^{+27}_{-12}$ Myr



Observed sub-mm galaxy CO(2–1)

$z = 4.05$

Conclusions

✧ 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 time-scales are accurate

✧ Quantities show environmental (in)variation: two galaxies already rule out universality of the cloud lifetime, SFE, feedback velocity, outflow rate

✧ Broad application only possible now with ALMA: systematically correlate cloud-scale quantities with host galaxy properties to constrain physics
➔ exciting future ahead

Is the IGM driving star formation?