Star Forming Regions - bis: Embedding, morphology

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Part 1
The space distribution of stars in connection with the fragmented ISM

Segregation in young stellar populations : OB stars in Carina Herschel data (Gaczkowski et al. 2013)

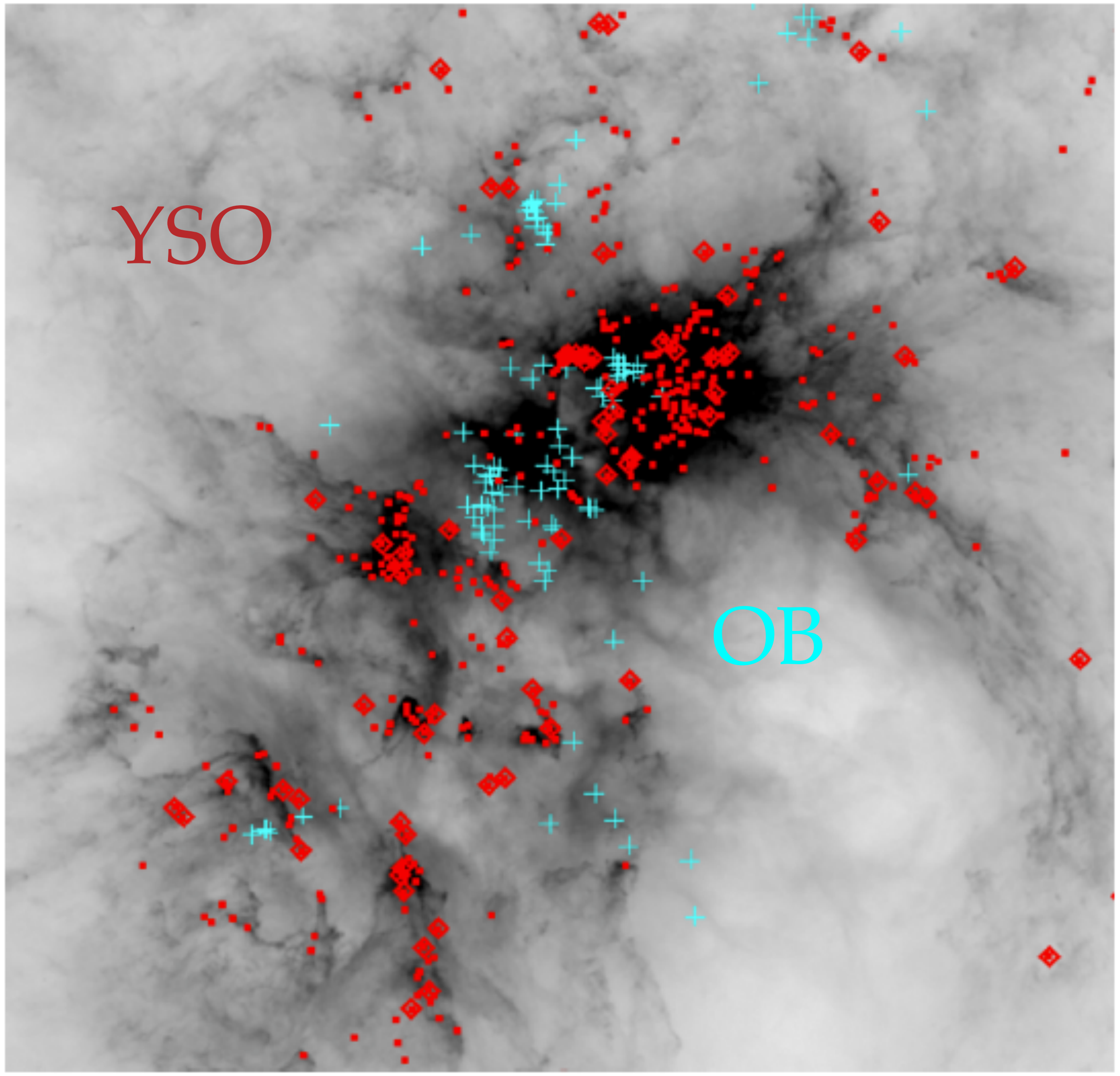


Figure 1.8: Herschel IR 70m observations of the Carina Nebula, with YSOs as red points and diamonds. Cyan crosses show OB stars. Both the gas and prestellar objects follow a substructured distribution. The figure was extracted from Gaczkowski et al. (2013).

"Cool baby, cool"

- 1d flows : recall basic relation to metal abundances, cooling rate and fragmentation (two-parameter law)

$$\epsilon = 4\sigma_s \rho \kappa(\alpha,\beta) T^4 \equiv k_\epsilon \rho^\alpha c_s^{2\beta+8}$$

emissivity

opacity

α = 1 (single) or 2 (two-body cooling)

- Scale-free hydrodynamics gives a relation of Jeans mass as function of time for collapse, t_c :

$$M_J(\alpha,\beta) = M_J^* m_o(t) \propto (t-t_c)^{\frac{1-2\omega}{\omega+1}}$$

$$\omega \equiv \frac{3/2-\alpha}{3/2+\alpha+\beta}$$

$-1/3 < \omega < 1/2$

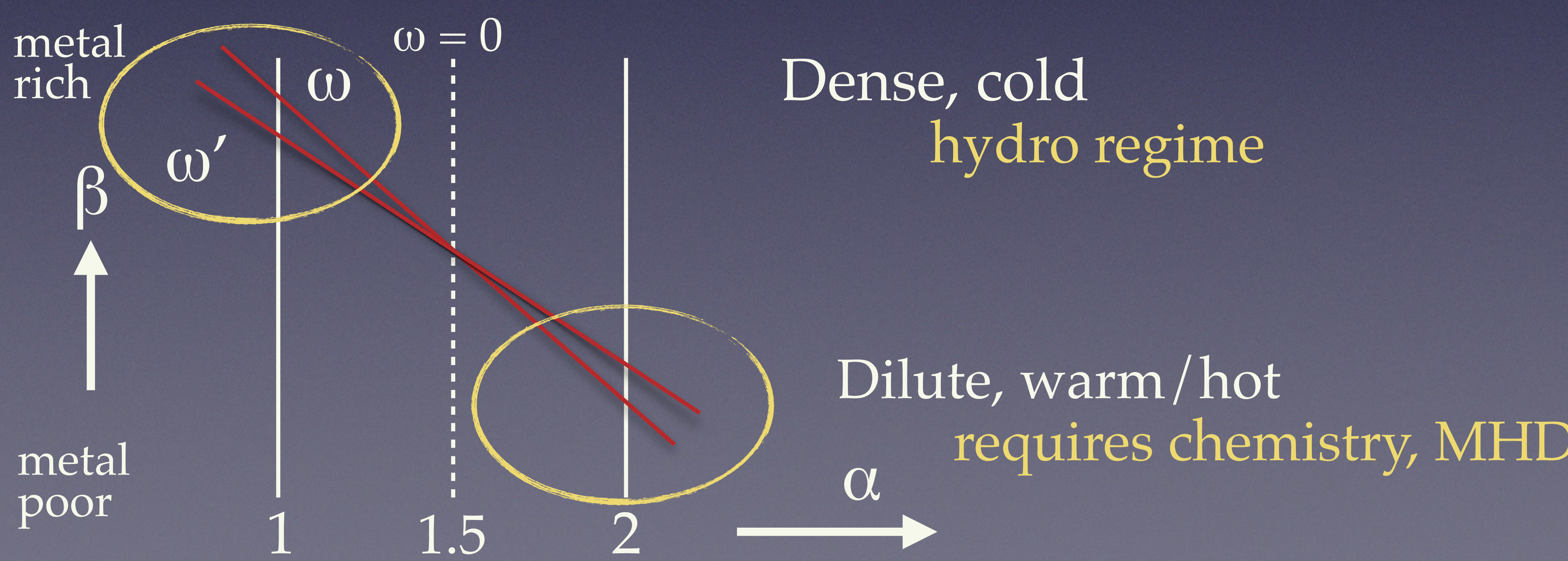
$\beta \approx [-5/2, -1]$ molecular

"Cool baby, cool" bis

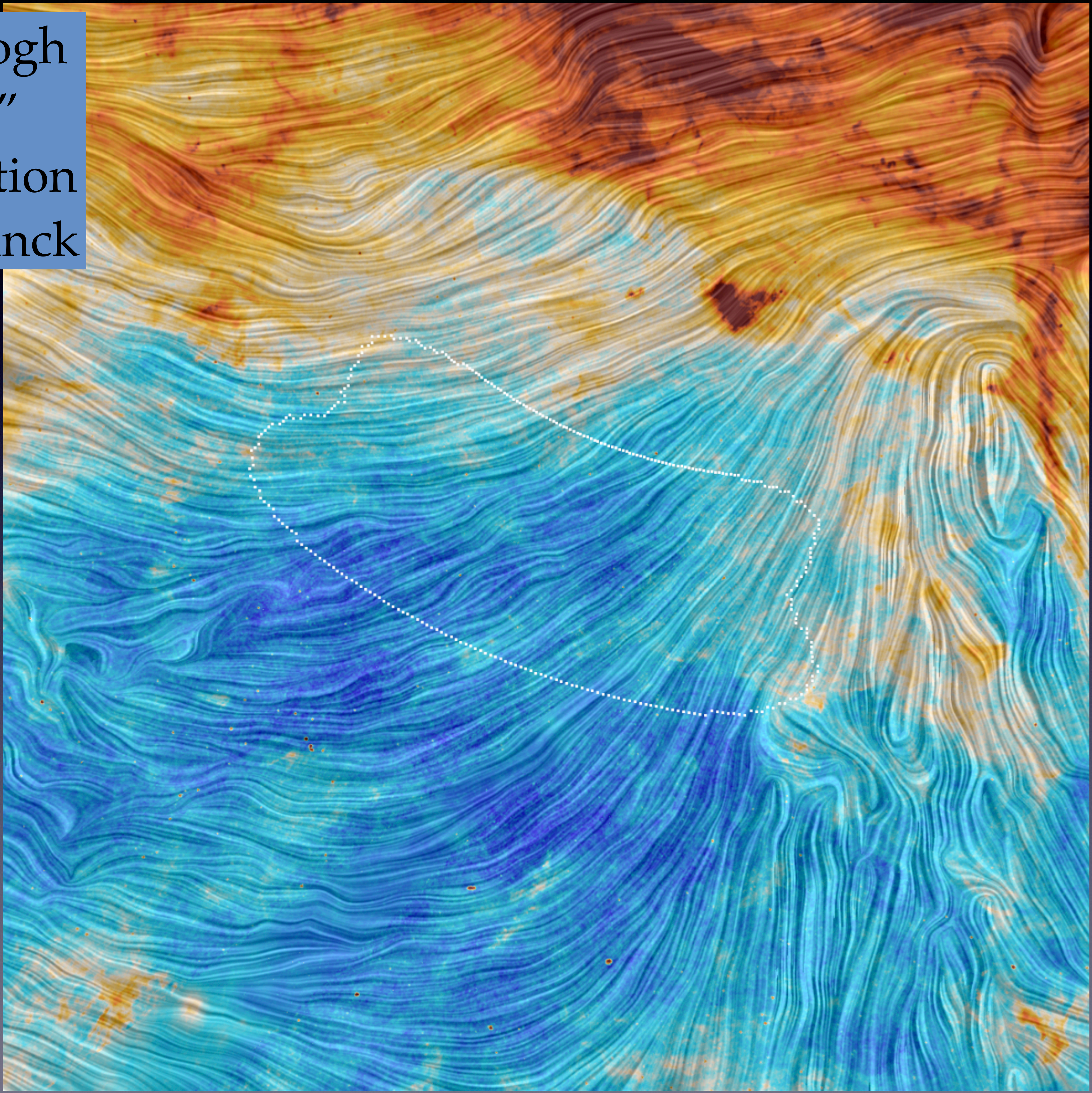
- fluctuations in metal abundances in fluid ➤ **variations in α,β and so ω. Then for two values ω' > ω :**

$$\lim_{t \to t_c} \frac{M_J(\omega')}{M_J(\omega)} \propto (t - t_c)^{3\frac{(\omega-\omega')}{(\omega+1)(\omega'+1)}} \to \infty$$

- In dense environments ε ~ ρ and so α = 1
- more metal rich environments (ω) have smaller M_J

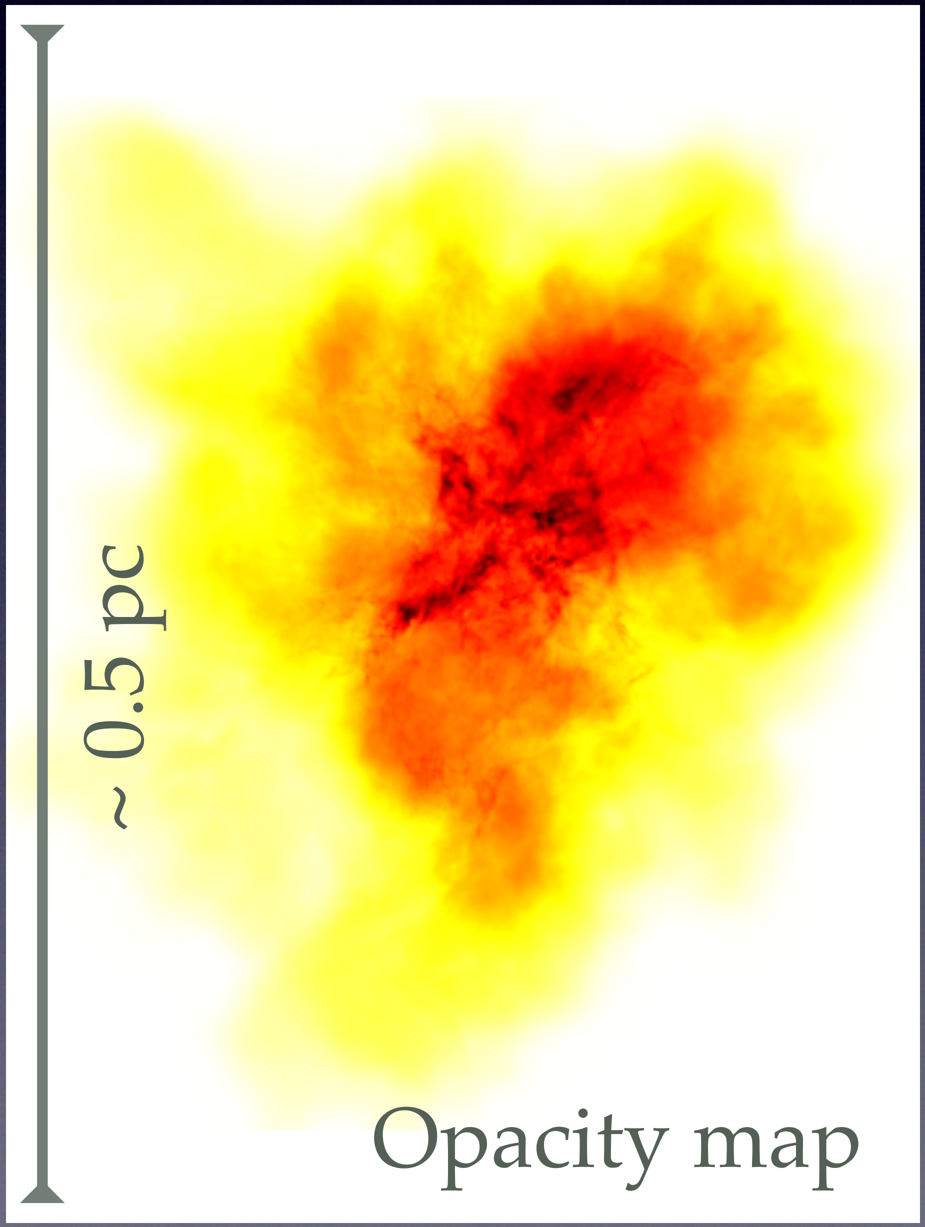


"van Gogh maps"
Polarisation from Planck

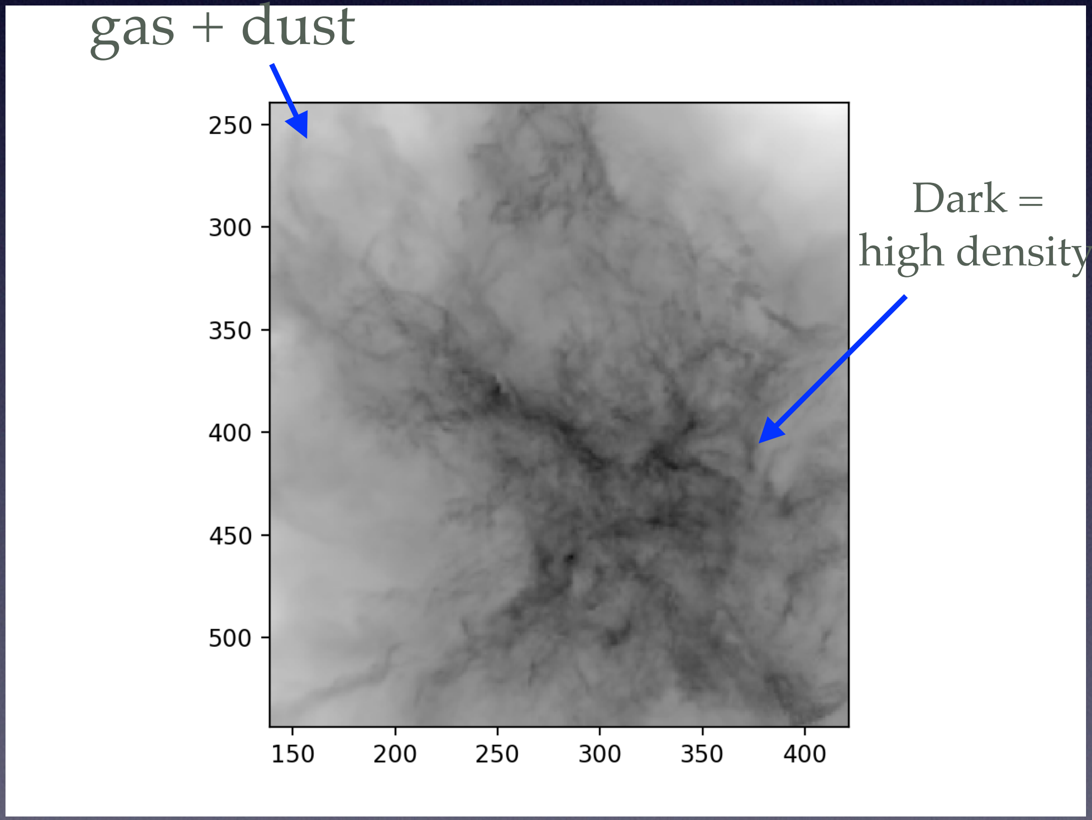


Dust grains alignment in B-field, anisotropic scatter

Expectations from hydro-calculations in high-density: single EoS, abundances

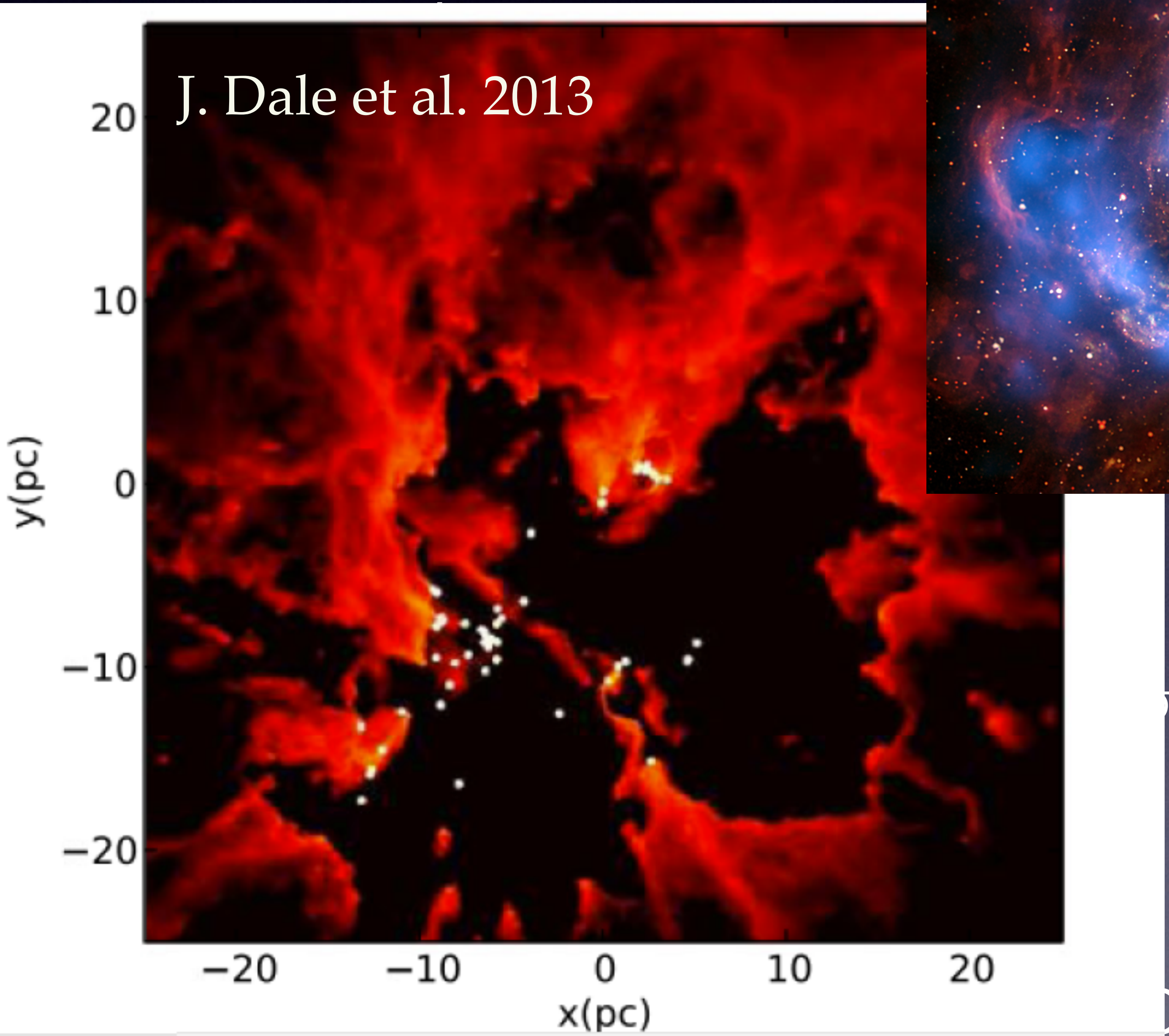


Hydro simulation of type SPH
from M. Bate 2012 MNRAS



Sample SPH calculation with opacity map
from SPLASH (D.Price)

Transition : embedded ▷ gas-free. Yes, but how .. ?



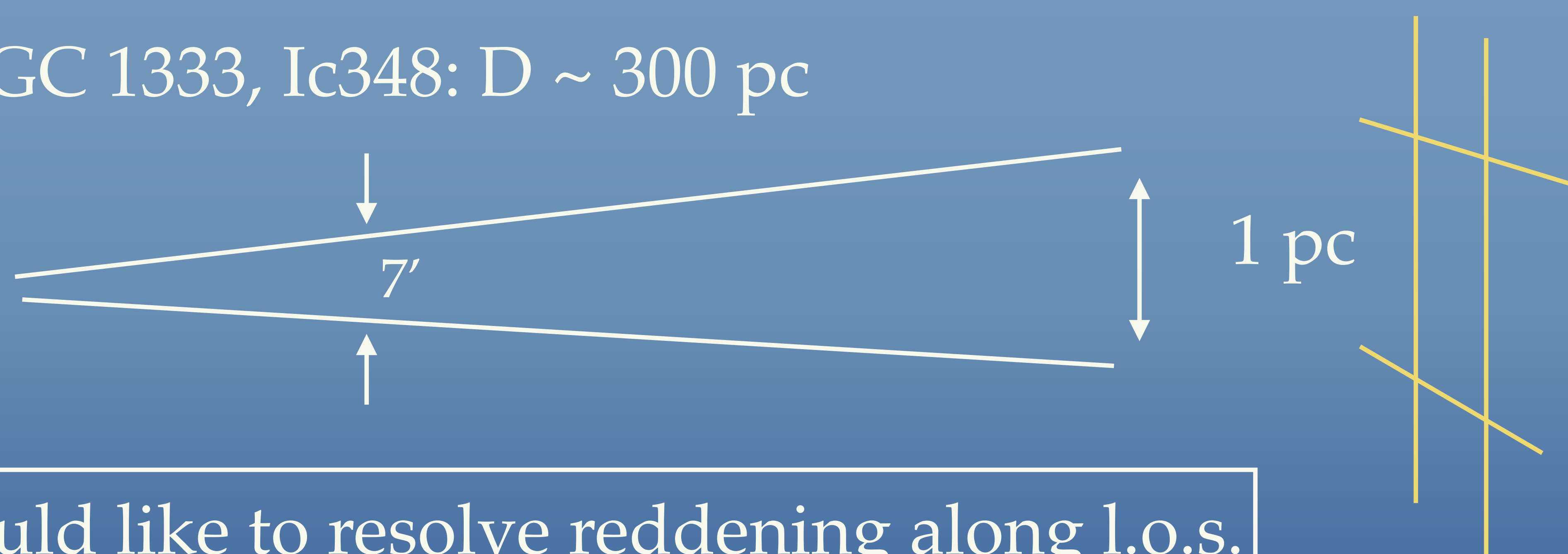
- embed … n.f.
- details … y argume … 10/2015 v … urvival rate
- active s … ave stellar kinema … r formation (*e.g.* ρ Oph … ~ 0.8 km/s [Foster et al. 2015, In-…
- *Global* … n a time-scale w … on time-scale

Completeness of sample
<u>using an extinction map (reddening)</u>

DM = Distance Modulus

- Use the Pan-Starrs 1 + 2mass E(B-V) map (see Green et al. 2015++)
- Set up maps at different distance scales (DM), same angular size
- slices of 0.5 magnitudes from data cube, use e.g. giant stars to go far into the MW disc
- Issue: physical size of ~ 1 pc fits in one map pixel ≈ 7′ at D ≈ 500 pc

NGC 1333, Ic348: D ~ 300 pc

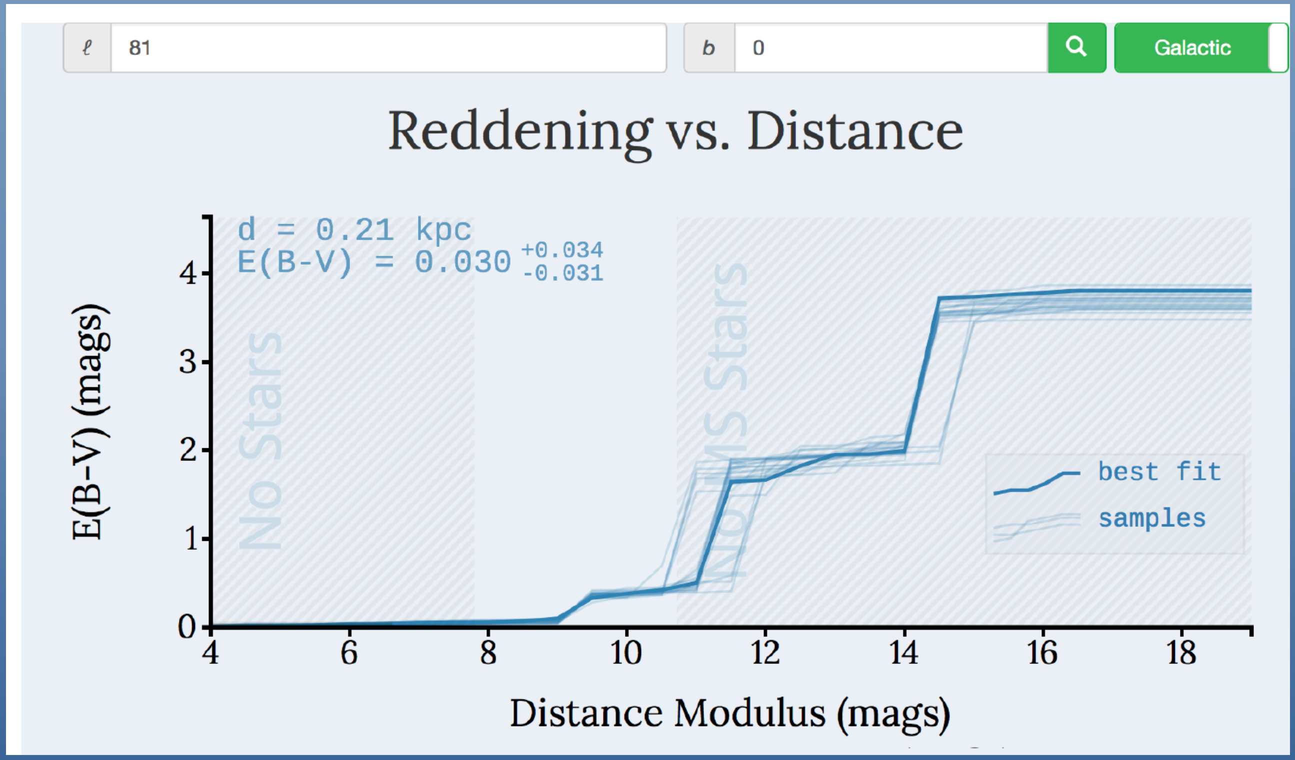


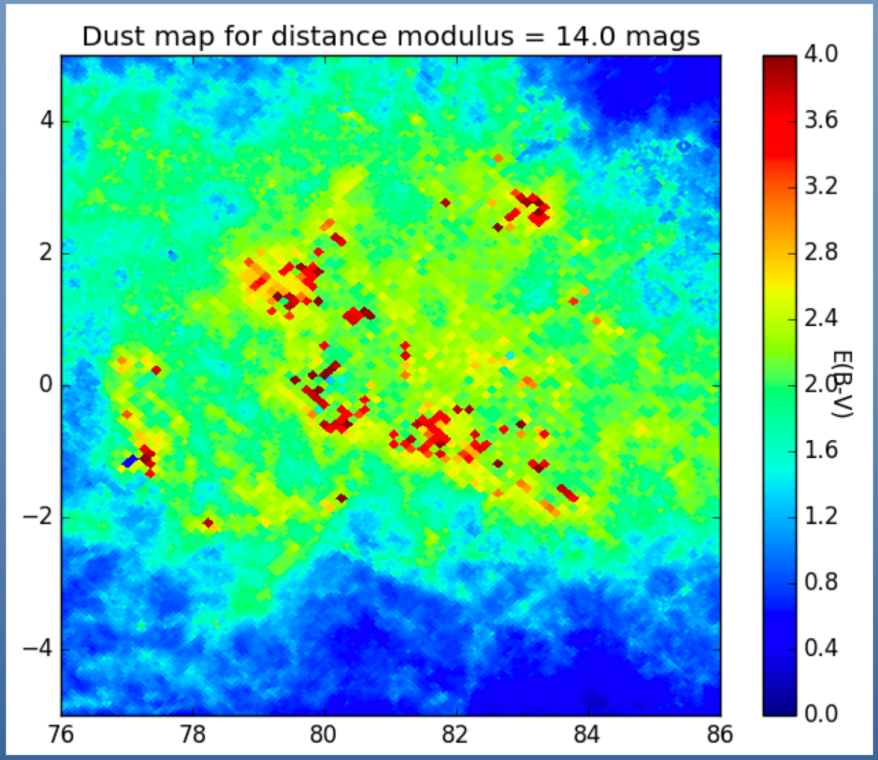
would like to resolve reddening along l.o.s.

Completeness of sample
using an extinction map (reddening)

DM = Distance Modulus

- On-line query map (see Green et al. 2015++)
- Precision of $v_{\perp} \sim 1$ km/s or better challenging for GAIA above $M_k \sim 21$
- Unresolved binary stars lead to shift in photometric centre
- Going deep (DM > 10 or ~ 1.3 .. kpc) becomes an issue, resolving the reddening along the l.o.s. vs *in situ* reddening (in the star-forming region).





Completeness of sample
using an extinction map (reddening)

DM = Distance Modulus

To be updated with v2 !!

- On-line query map (see Green et al. 2015++)
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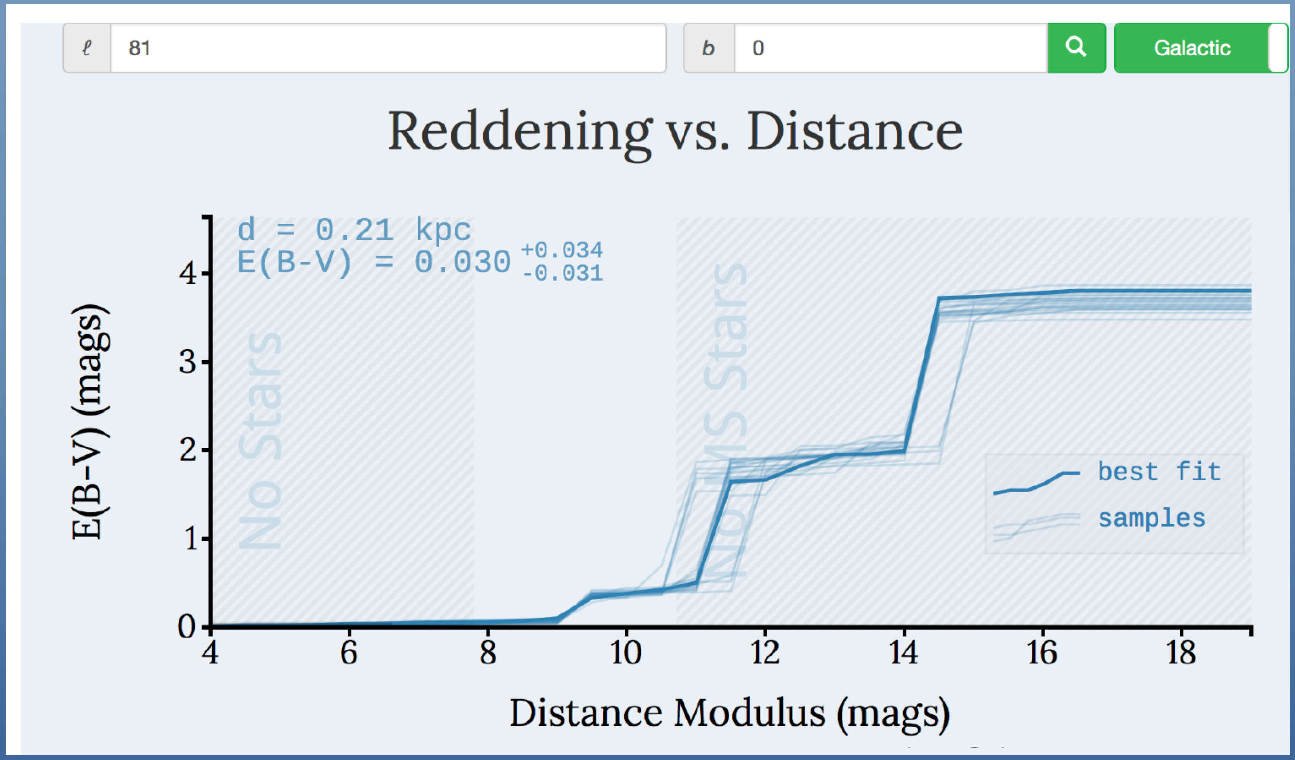
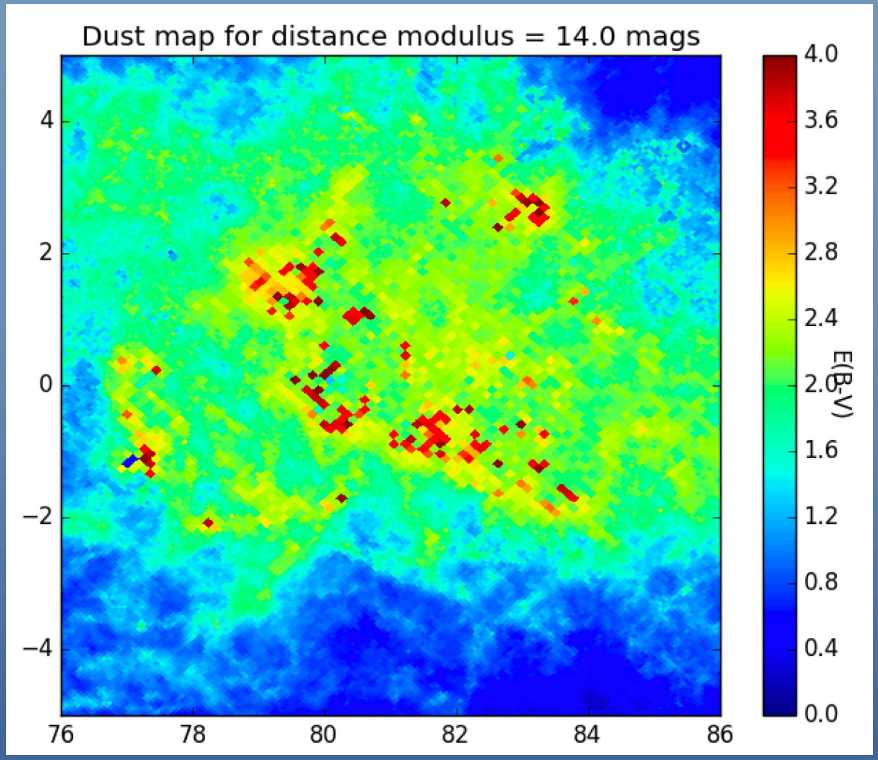
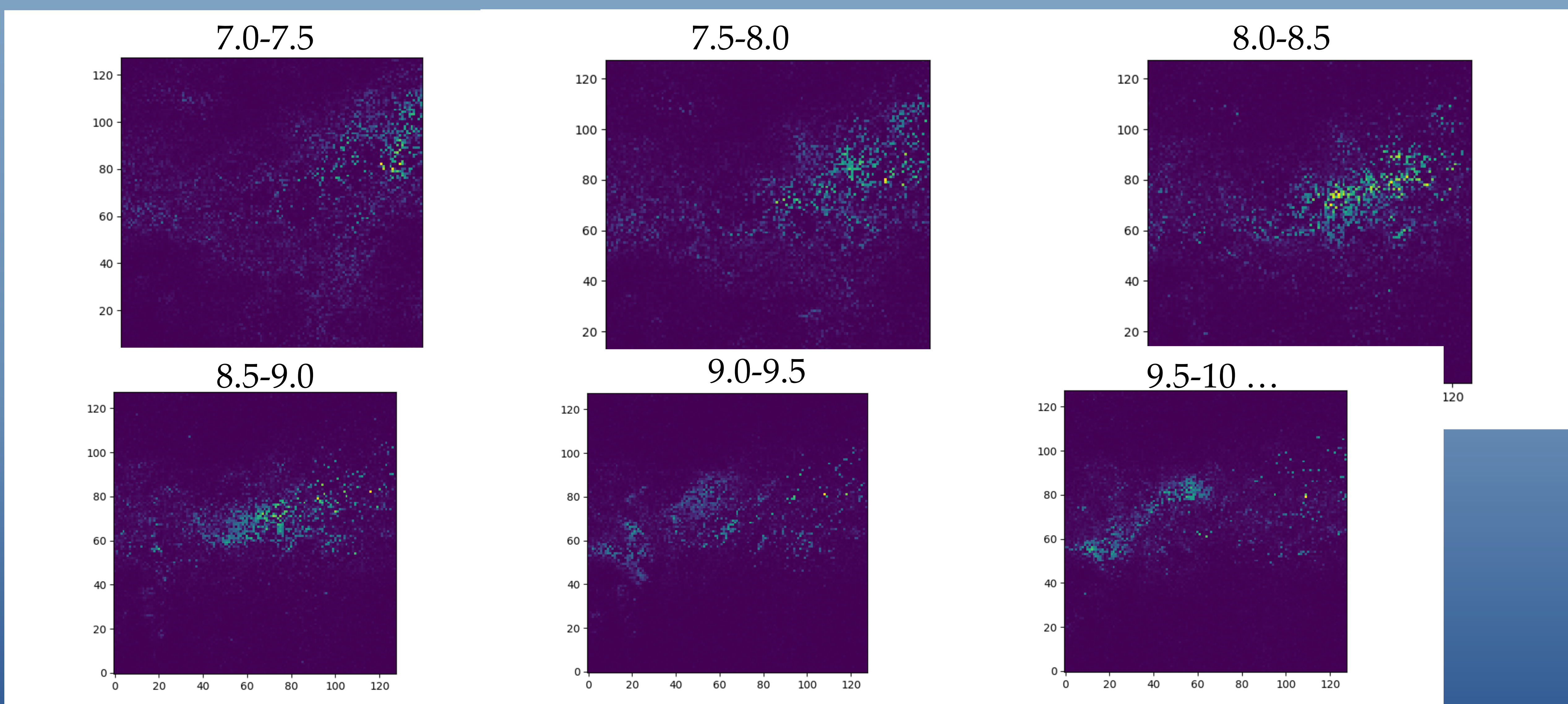




Completeness of sample
<u>using an extinction map (reddening)</u>

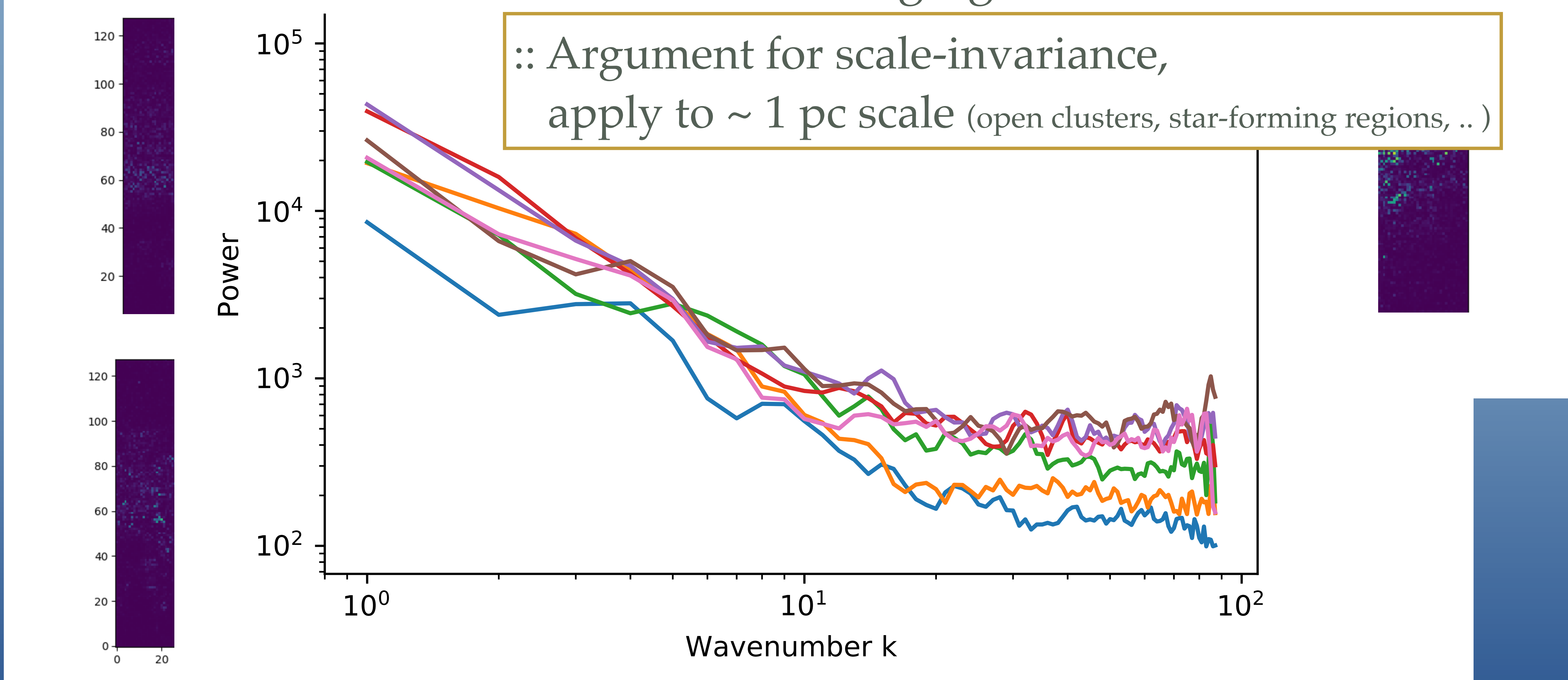
- Set up maps at different distance scales (DM), same angular size
- Get the FFT power-spectrum, compare different scales (<u>in</u> MW disc)



Completeness of sample
using an extinction map (reddening)

- Use the Pan-Starrs 1 extinction map (Green et al. 2015, ..)
- Set up maps at different distance scales (DM), same angular size

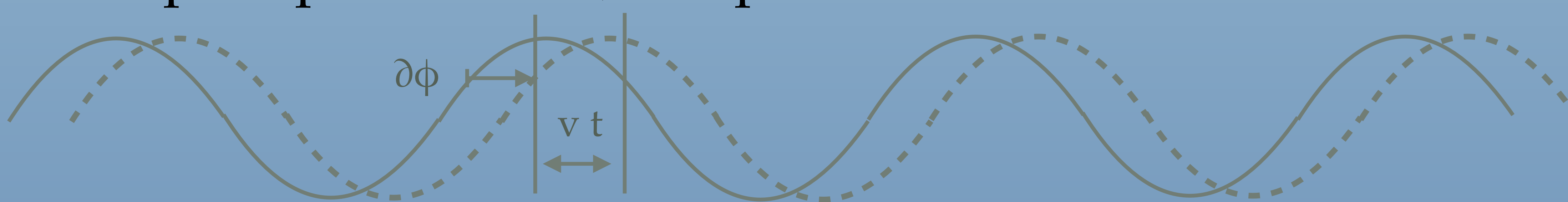
FFT power spectrum : fixed direction on the sky,
distance modulus ranging form 7 to 11

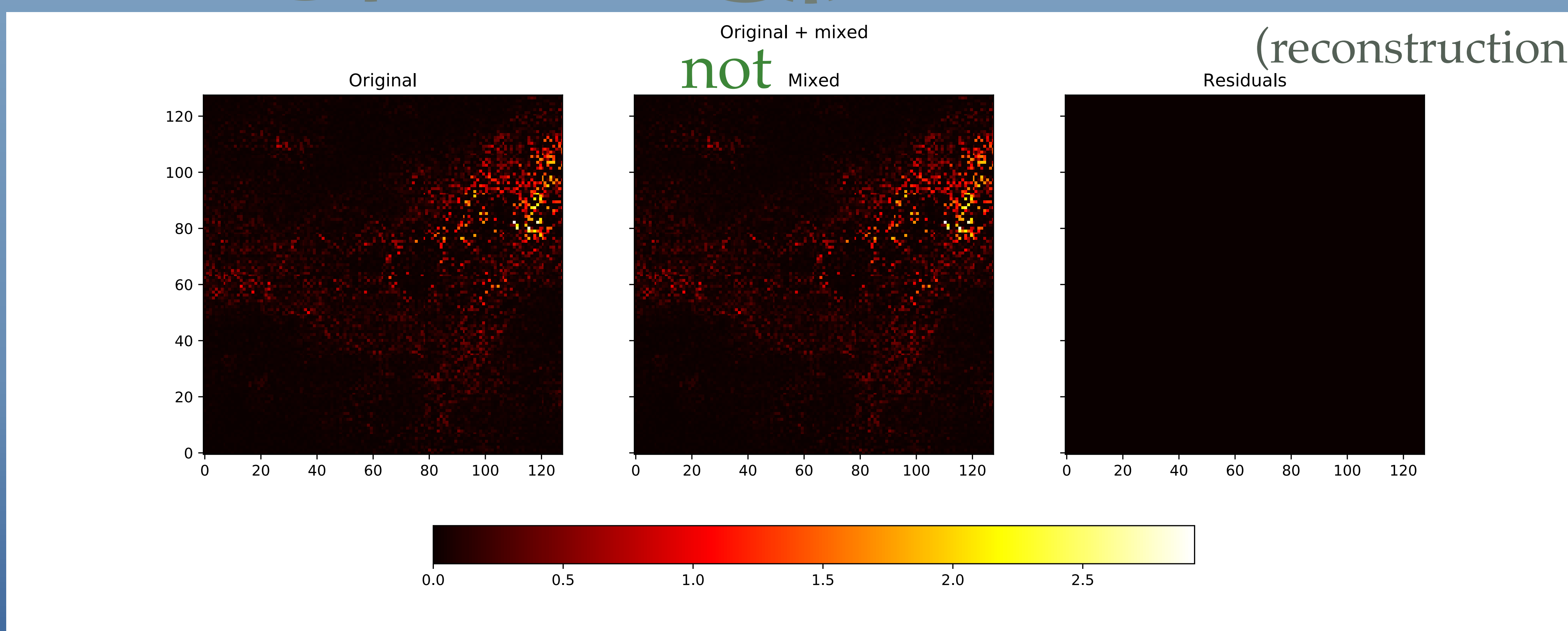


Application: embed the models in Milky Way disc

using an extinction map (reddening)

- Uncertainties in stellar ages = uncertainties in the phase of the Fourier modes (of sensible physical scale)
- Set up maps as before, but phase-mixed the Fourier modes





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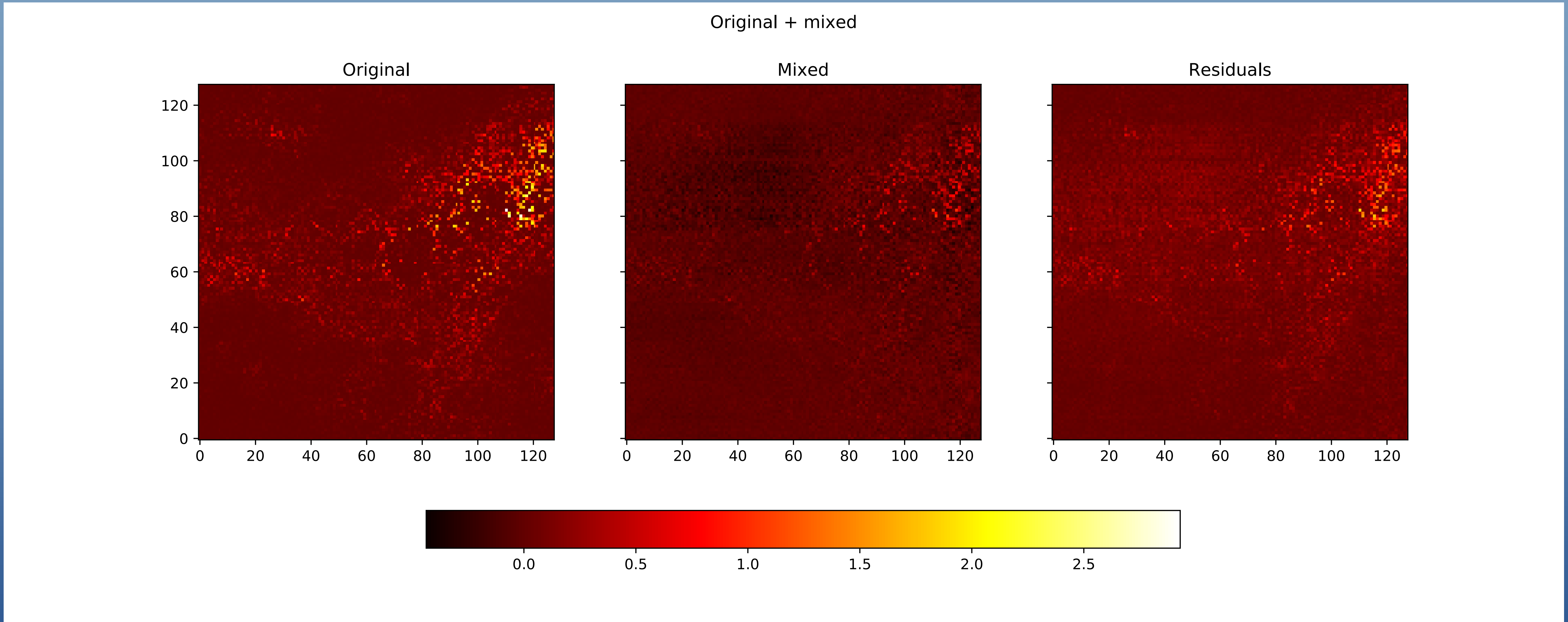
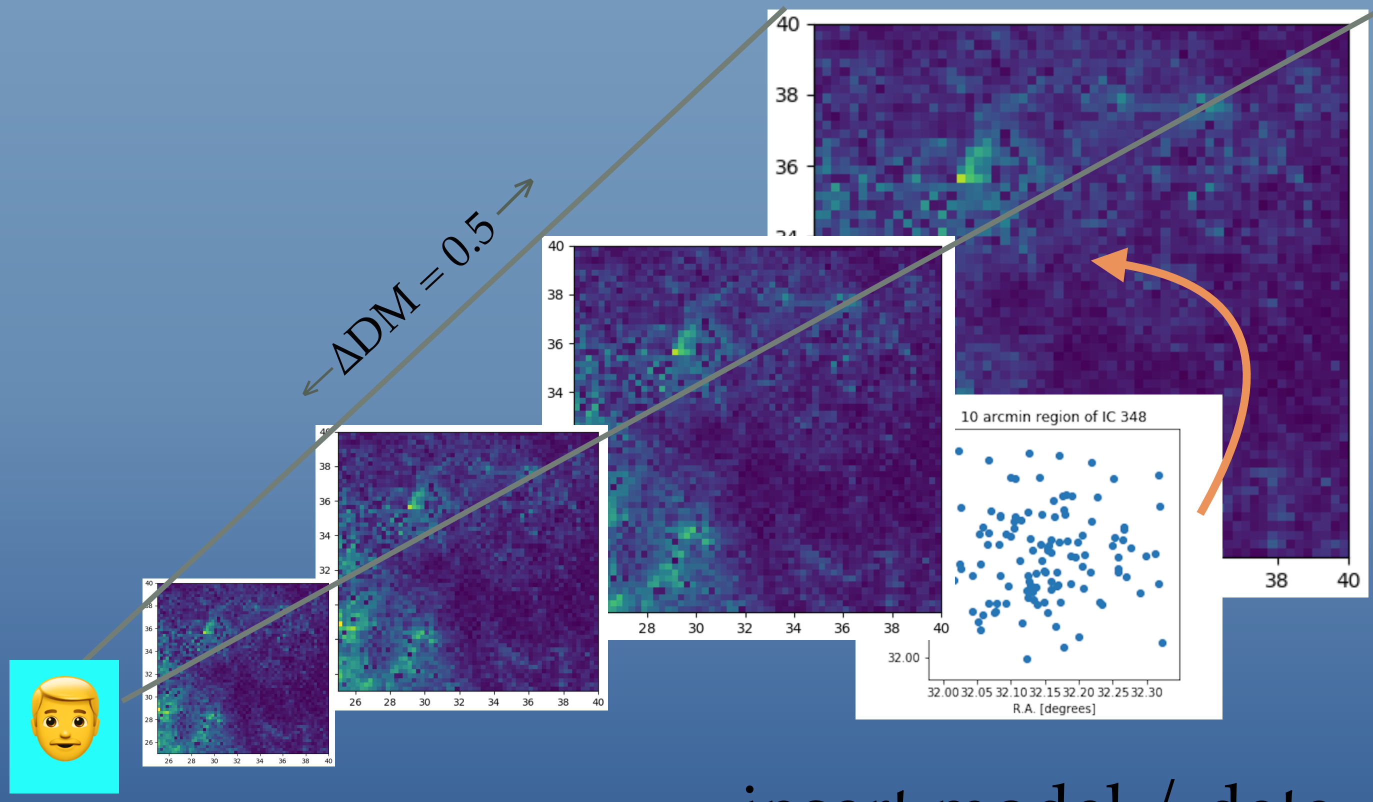
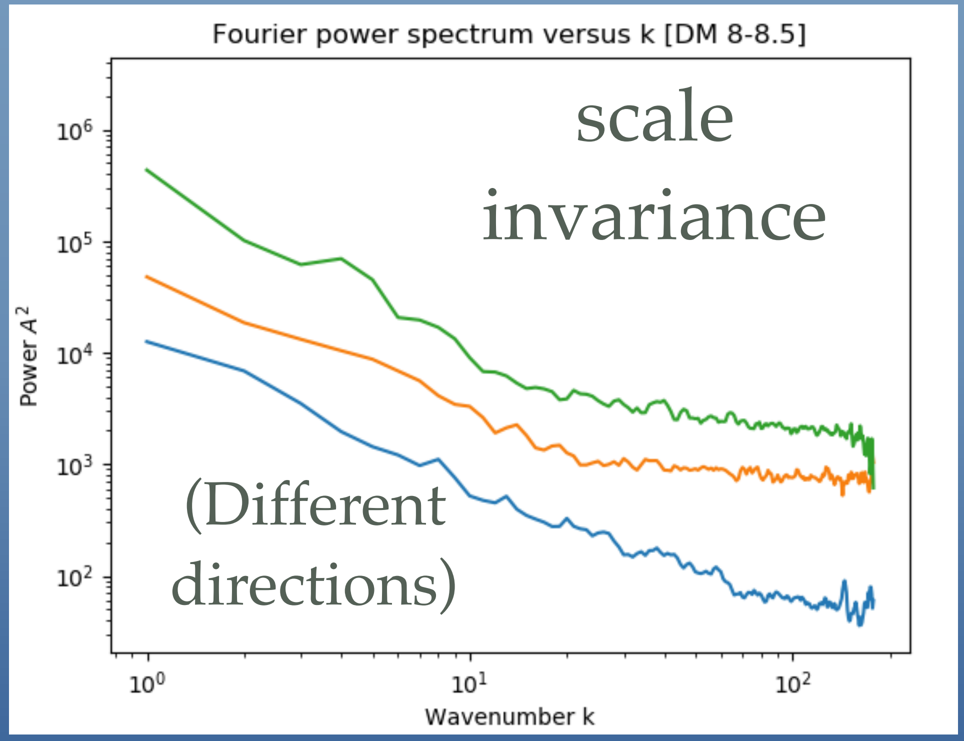


Exploring morphology using the <u>Minimum Spanning Tree approach</u>

- Morphology : apparent vs real .. selection, extinction
- Use the Pan-Starrs 1 extinction map (Green et al. 2015, ..)
- Fourier transform : phase mixing on ~ 1 pc scale in ~ 1 Myrs
- K-band extinction / bolometric correction : ± 20% completeness @ M_K = 21



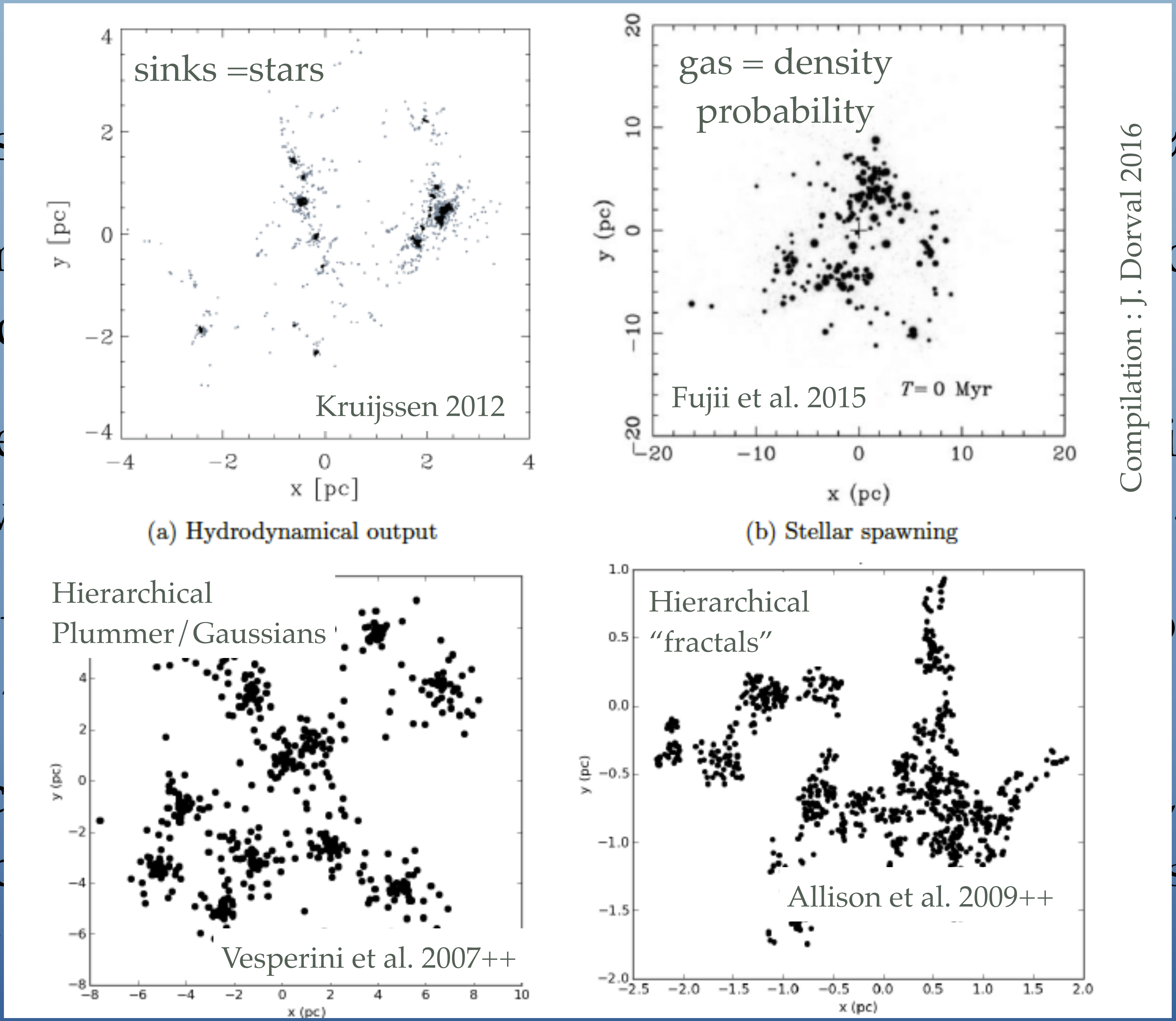
insert model / data



Part 2
The space distribution of stars viewed as a challenge to modelers

Initial conditions for stellar dynamics: different approaches

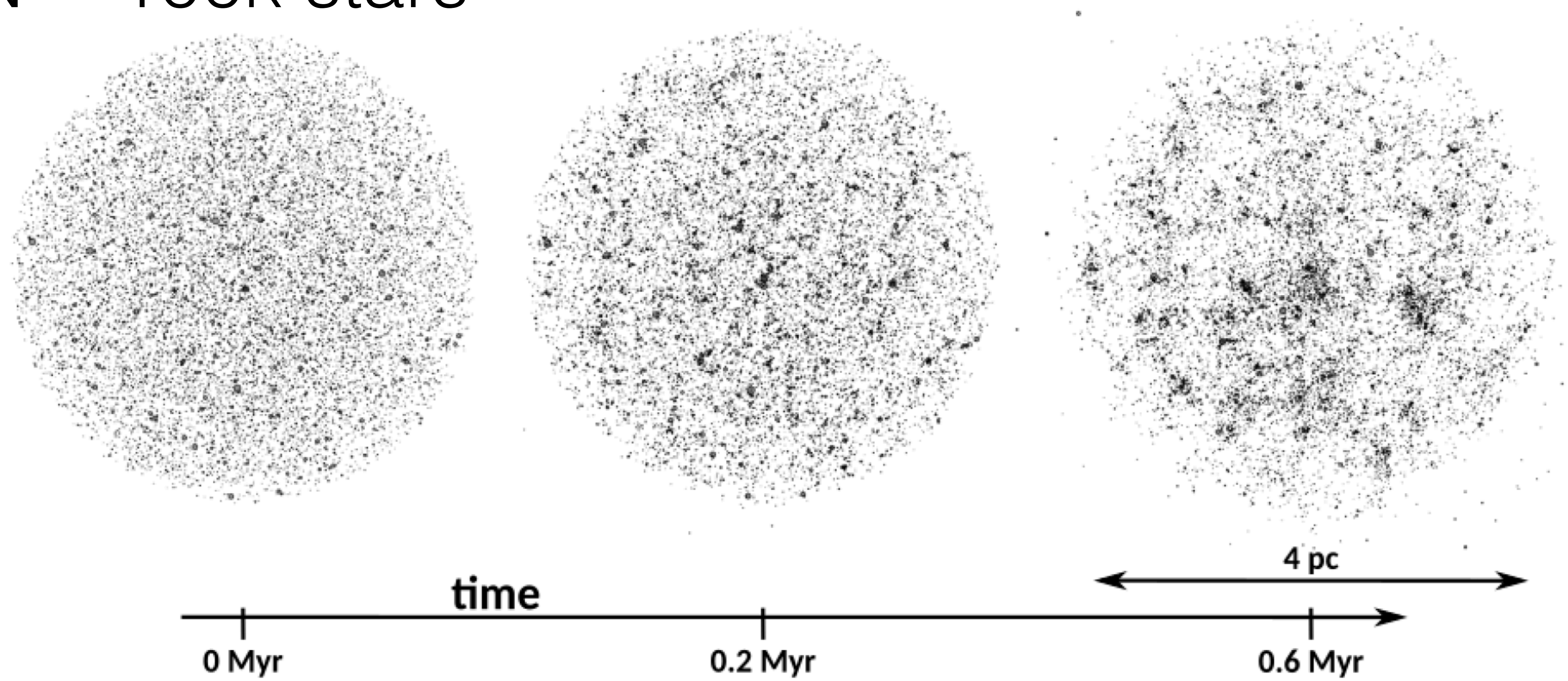
- Class … $k_\beta T$
- All m … ollap-se, n…
- Some … ies draw … 4, ..)
- Turb … ons (W43 … al. 2015)
- ’Frac … but veloc … son et al. 2009+



Fragmentation: non-linear dynamics

Dorval et al. 2016 MNRAS, 2017

N ~ 100k stars



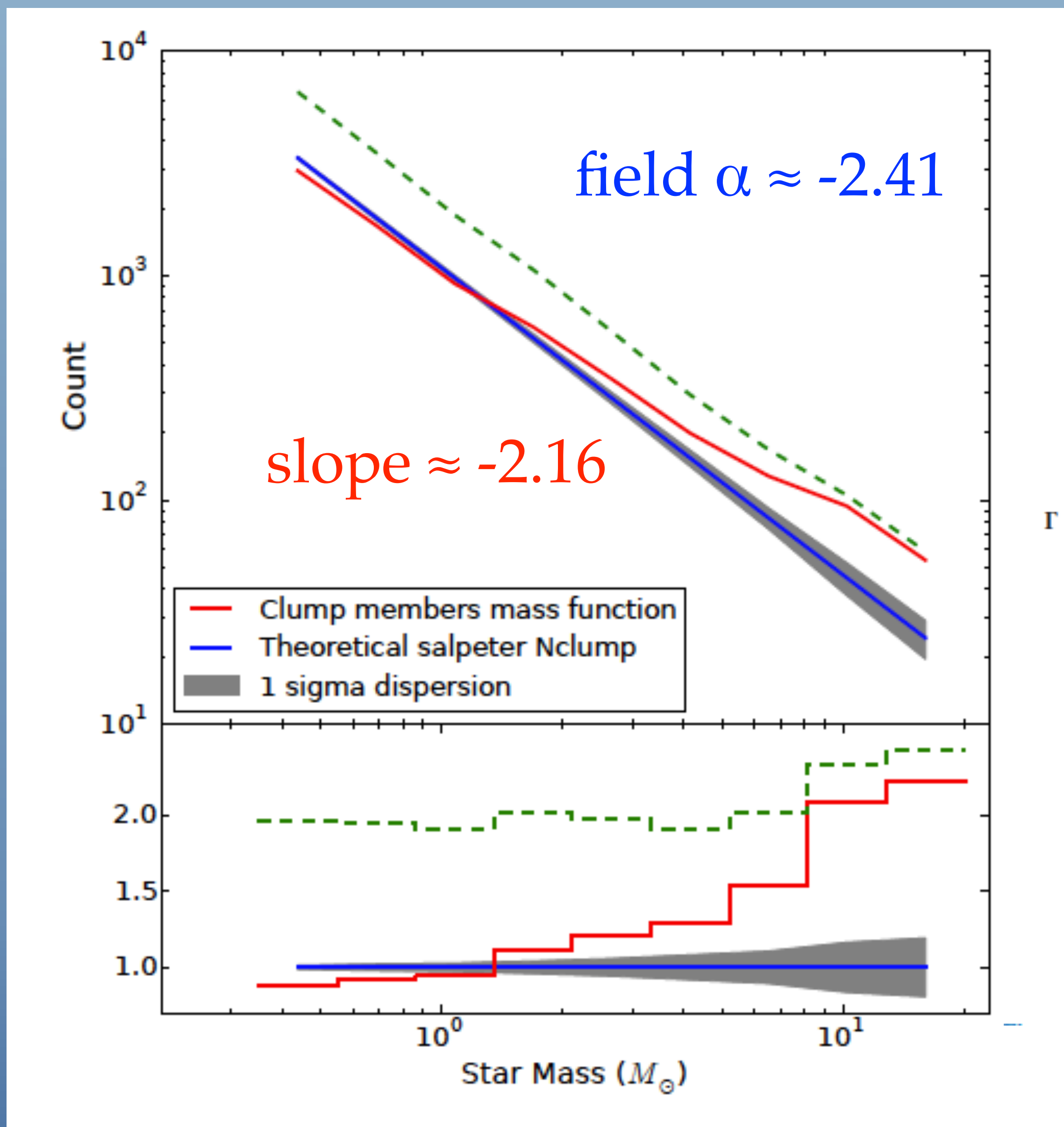
N: 100 ~ 1k (rich open cluster)

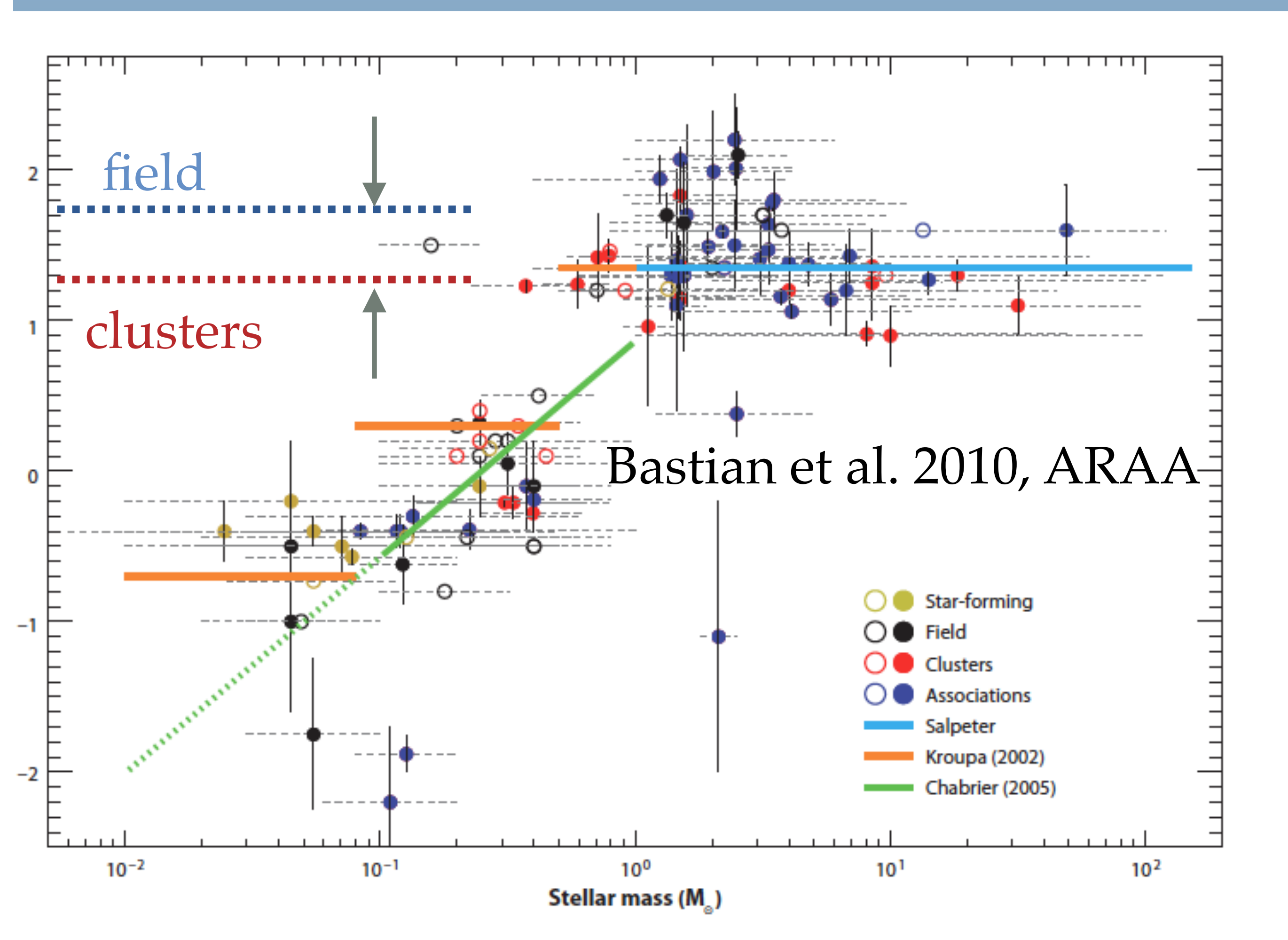
- Draw stars from IMF (canonical)
- Form binaries with primary-★ correlation

Extract subset of stellar clumps:

MST technique, HOP

Stellar clumps (2D): 50% of all stars
top-heavy, segregated ..



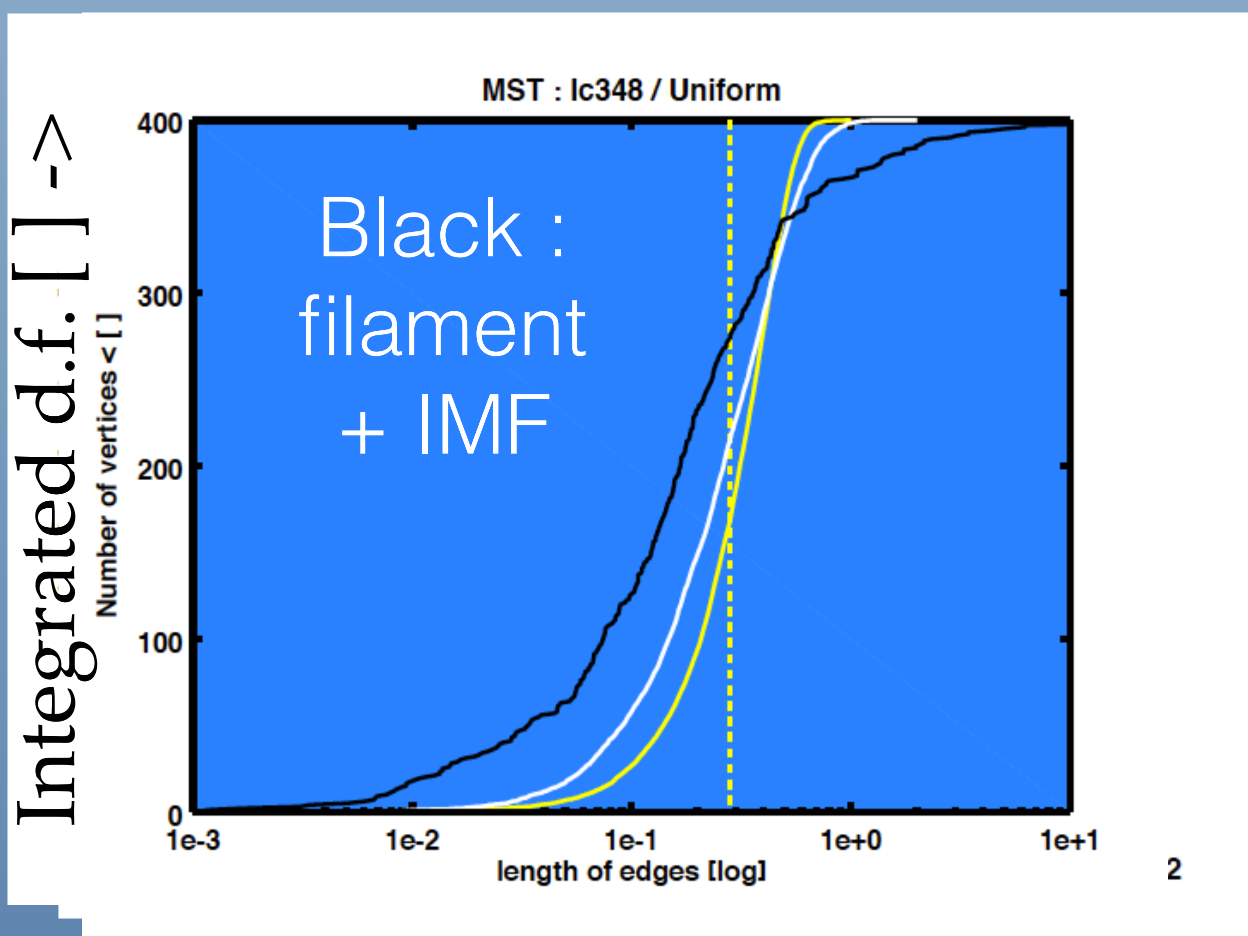


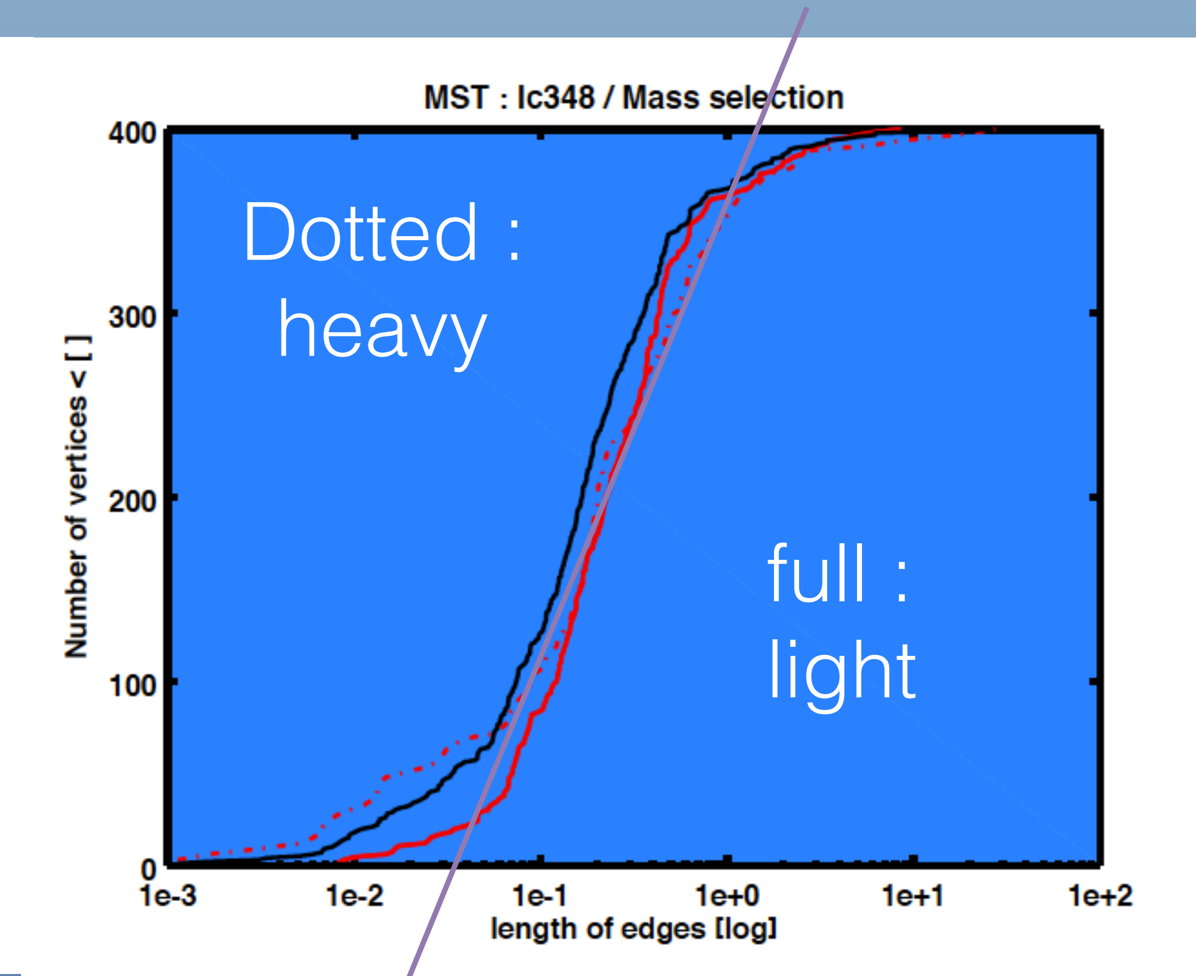
:: blue / grey : Salpeter (ensemble averaging)

Exploring morphology using the Minimum Spanning Tree, all member stars

Different projection angles

Selection by mass / renormalized



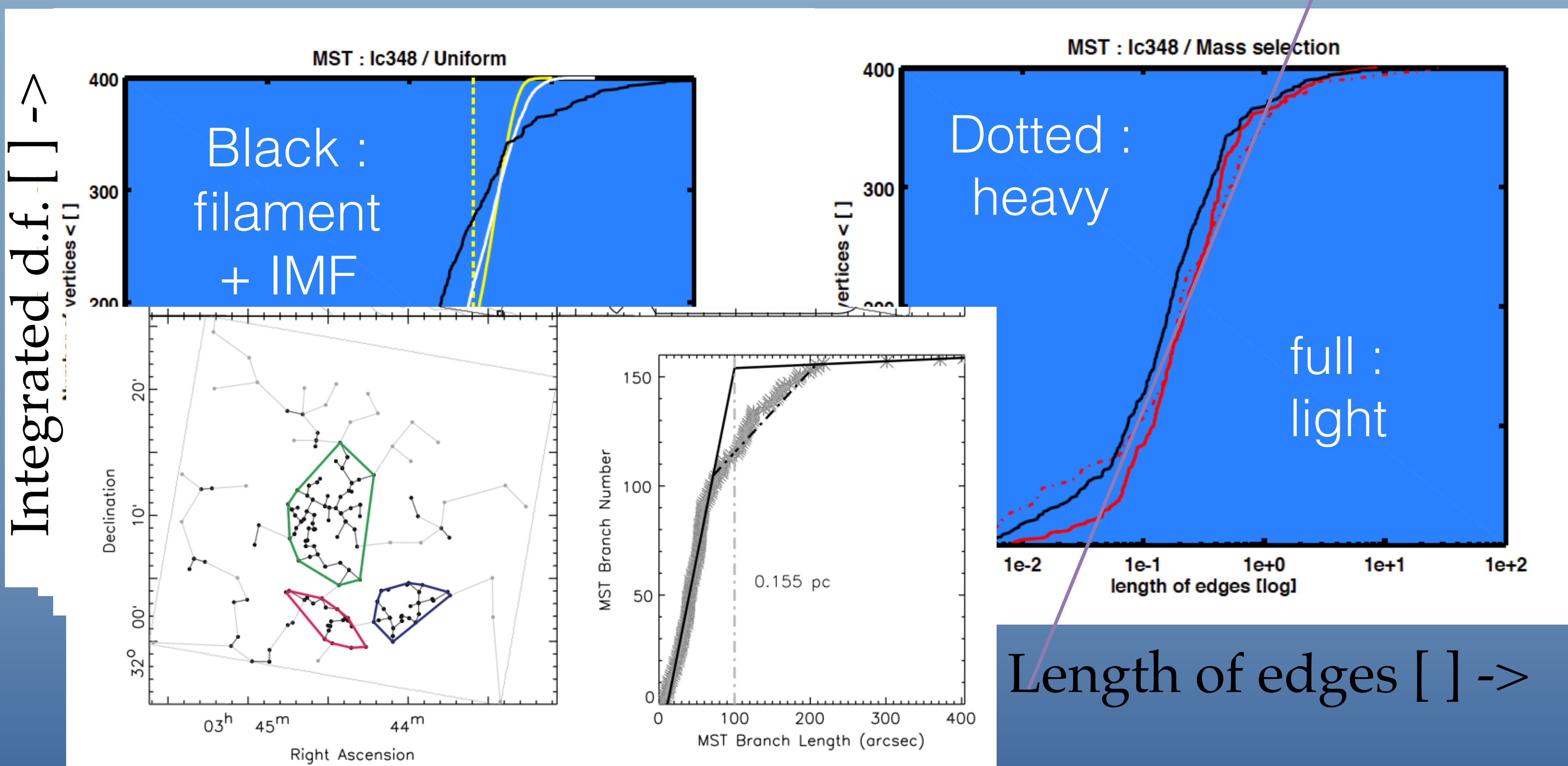


Length of edges [ ] ->

Exploring morphology using the <u>Minimum Spanning Tree, all member stars</u>

Different projection angles

Selection by mass / renormalized



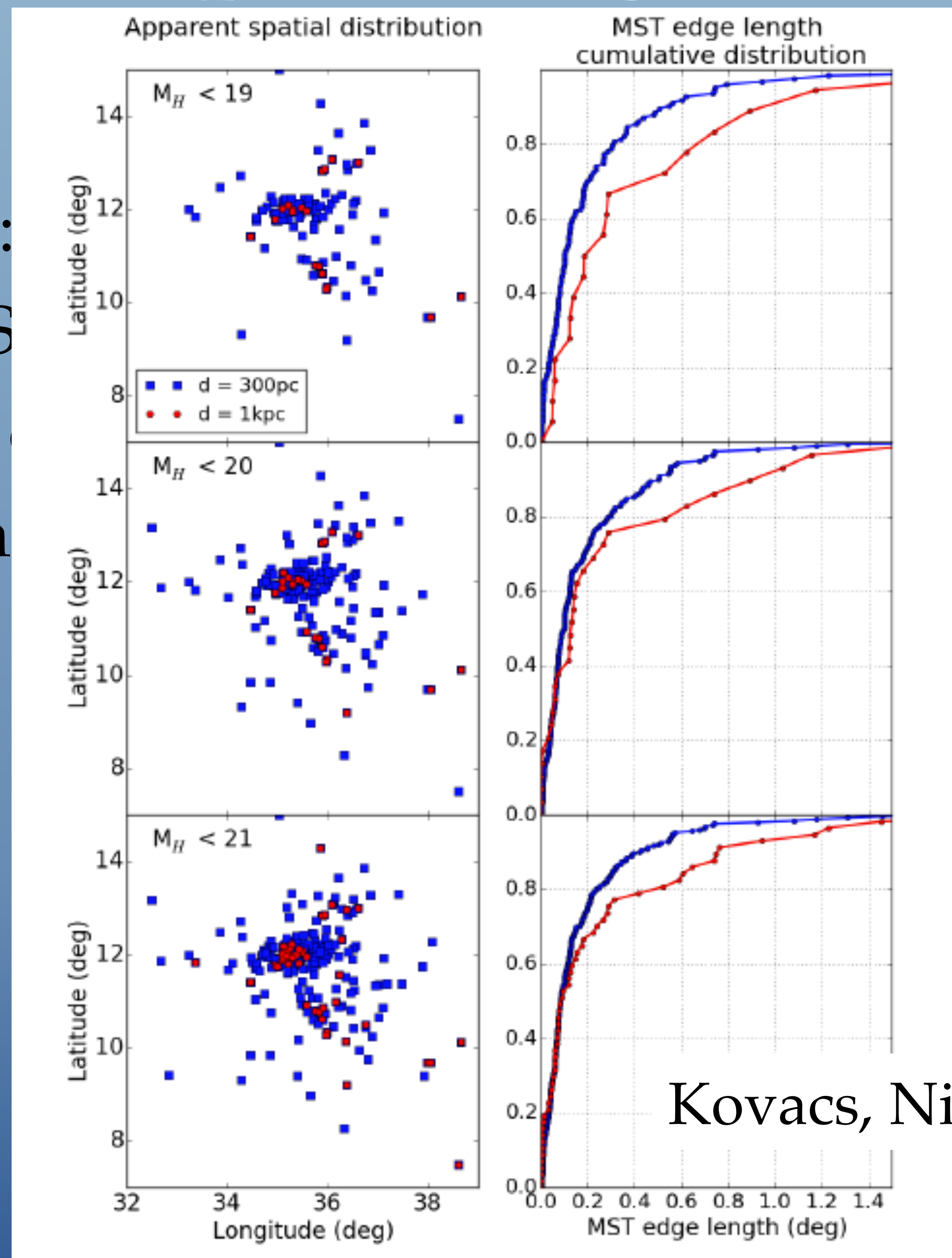
Guthermut et al. 2009, ApJS

Exploring morphology using the <u>Minimum Spanning Tree approach</u>

- Morphology : apparent vs real .. selection, extinction
- Use the Pan-Starrs 1 extinction map (Green et al. 2015, ..)
- Extinction (= distance effect) : shift on MST statistics
- Set up a clump with N ~ 400 stars (e.g. Ic348)

Exploring morphology using the Minimum Spanning Tree approach

- Morphology : tinction
- Use the Pan-S t al. 2015, ..)
- Extinction (= atistics
- Set up a clum

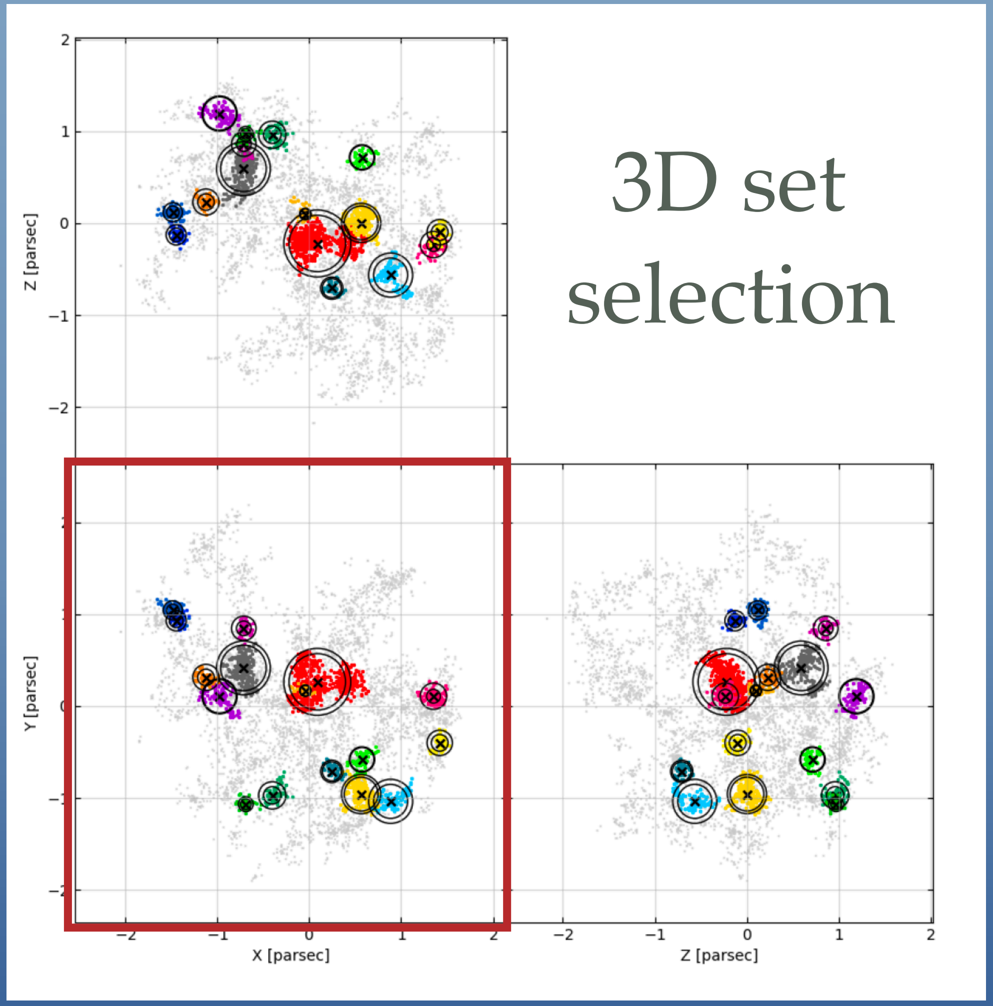


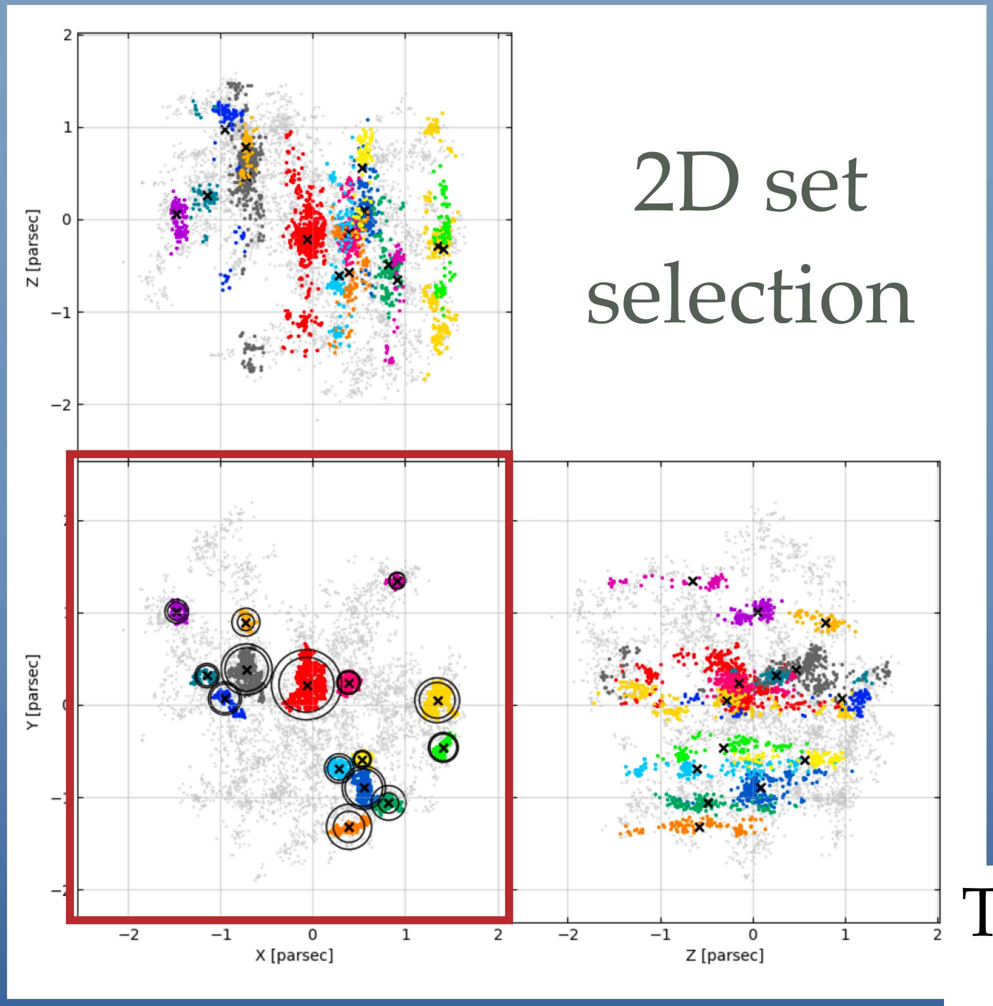
Kovacs, Niederkorn, Dorval, ..

Exploring morphology using the
Minimum Spanning Tree approach

Can we identify selection biases from projection?

- MST-selected stars: 2D vs 3D
- Apply the same selection criterion (l_{cut} = mean + $\sigma/2$)





T. Roland, in prep.

Exploring morphology using the Minimum Spanning Tree approach

Can we identify selection biases from projection?

- MST-selected stars: bound systems, 2D vs 3D
- Convert LOS velocity dispersion to mass: η-factor

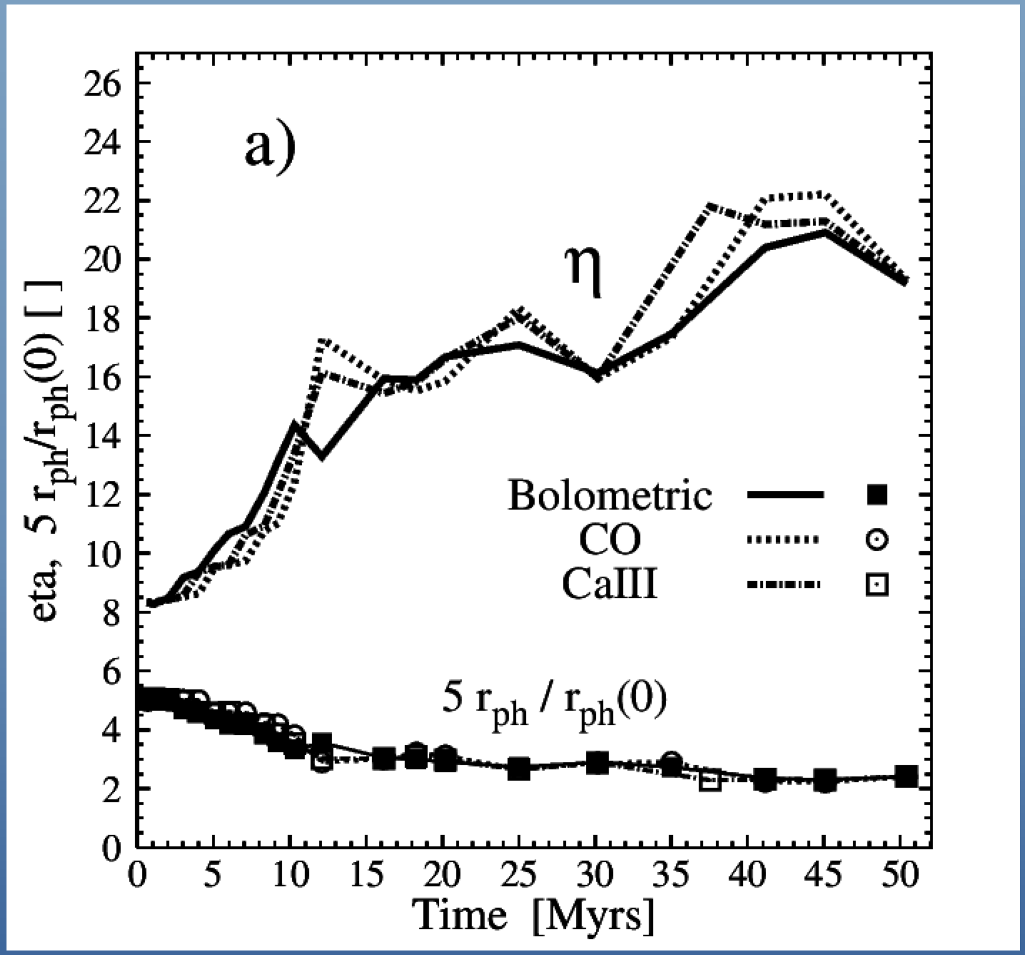
Virial Theorem:

theory / expectation

$$\frac{GM^2}{2r_g} = -\frac{1}{2} M \langle v^2 \rangle$$

Translates to observables:

$$M = \eta \frac{R_{ph}\,\sigma_{1d}^2}{G}$$

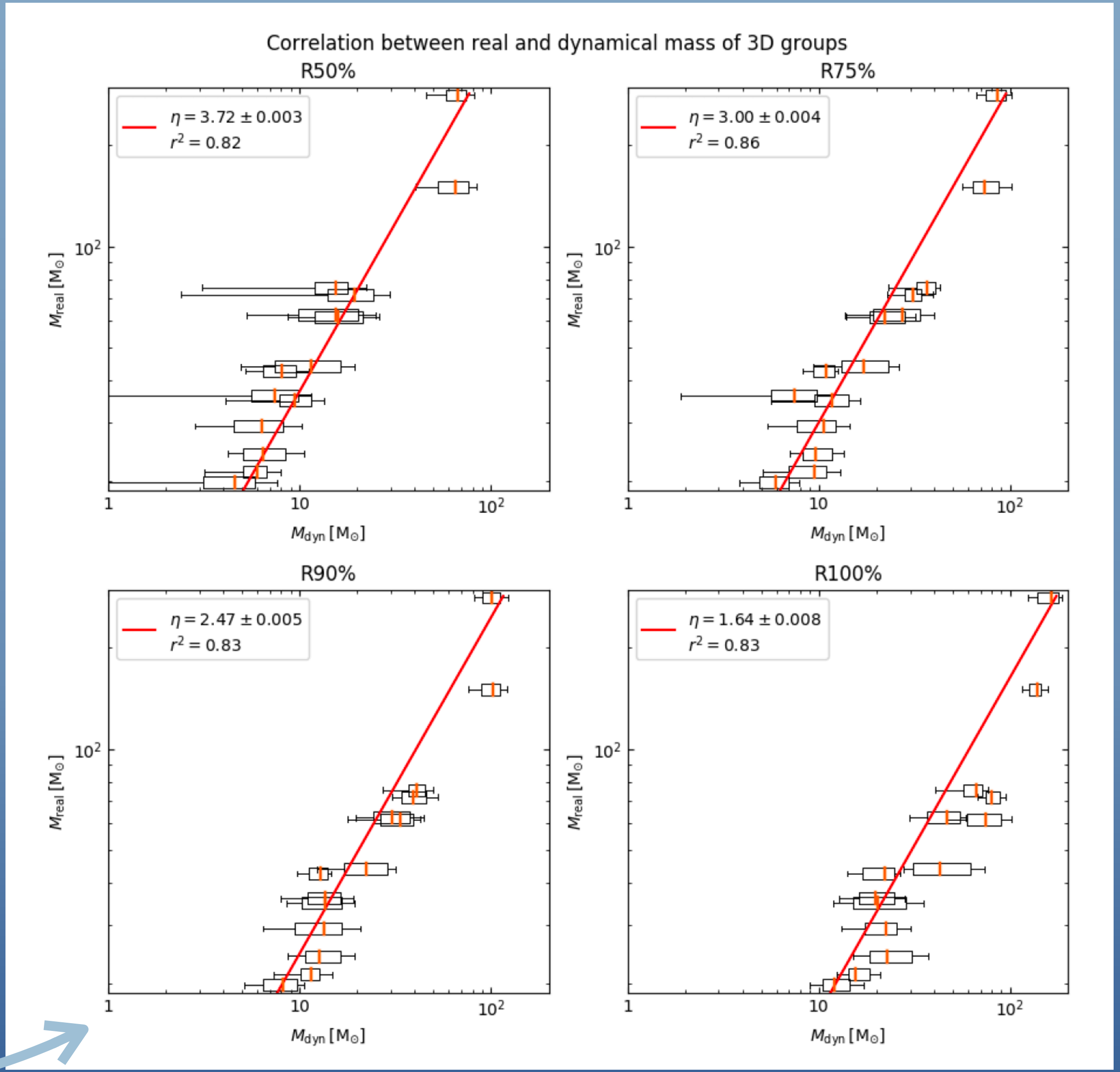


e.g., Boily et al. 2005

Exploring morphology using the Minimum Spanning Tree approach

- Compare (in 3D) expectations with selection
- Convert LOS velocity dispersion to mass: η-factor

Real mass M



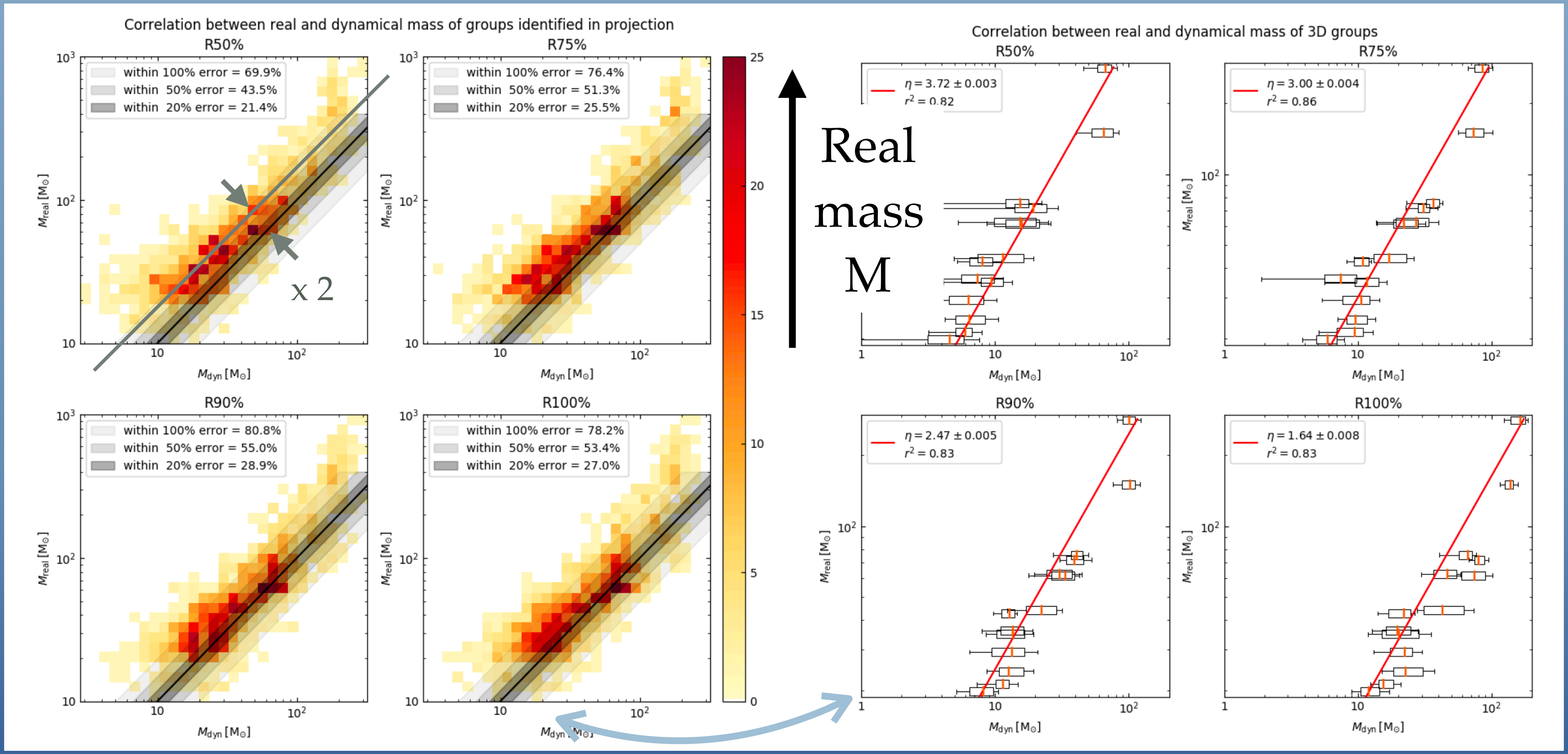
T. Roland, in prep.

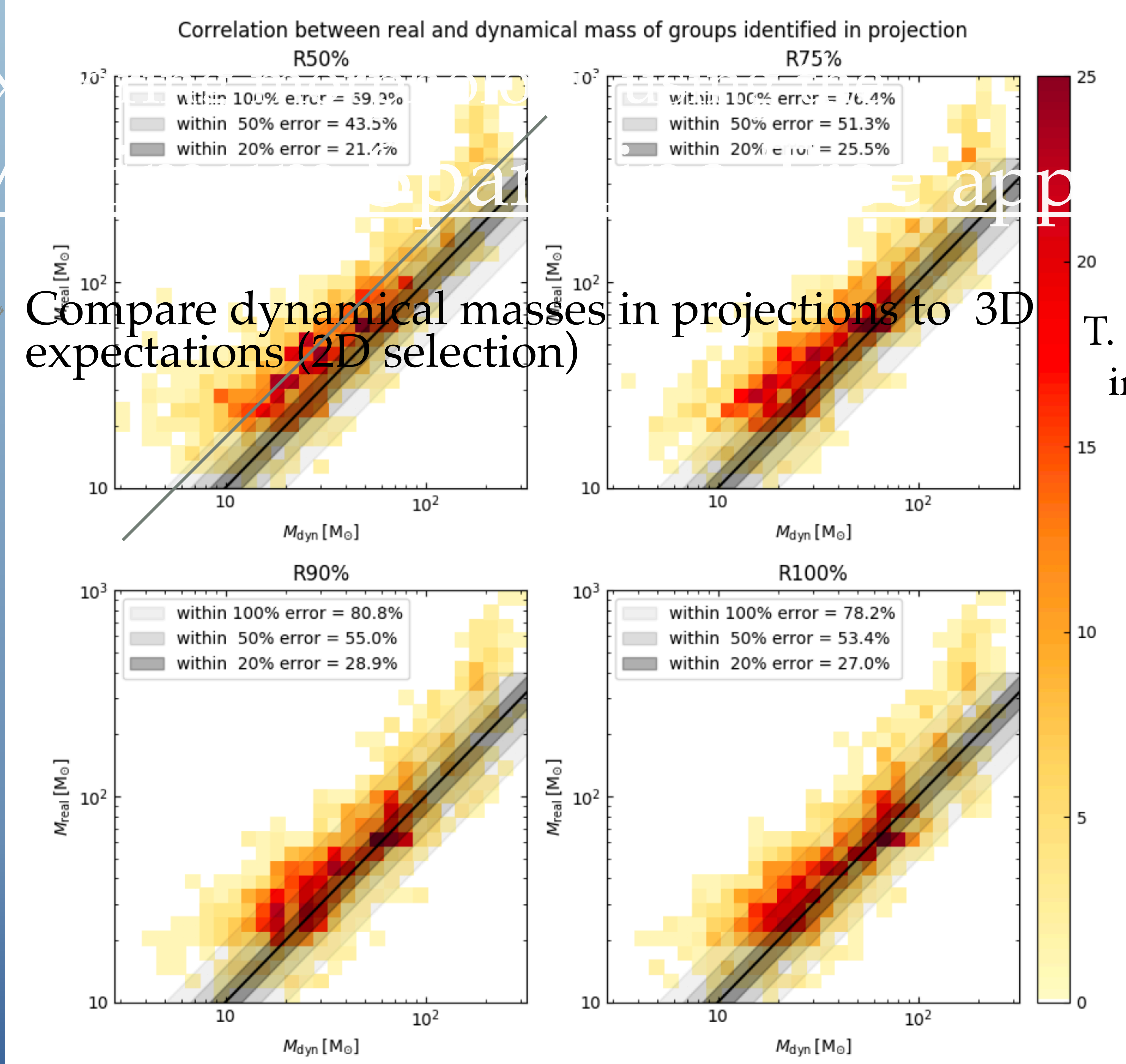
$$M = \eta \frac{R_{ph}\,\sigma_{1d}^2}{G}$$

Exploring morphology using the Minimum Spanning Tree approach

- Compare dynamical masses in projections to 3D expectations (2D selection)

T. Roland, in prep.





- Compare dynamical masses in projections to 3D expectations (2D selection)

T. Roland, in prep.

Part 3
Embedding models in the host galaxy becoming a necessity ..

(thank you Gaia DR2 ☹️)

Importance of embedding in the host galaxy: some challenges ..

Lengths

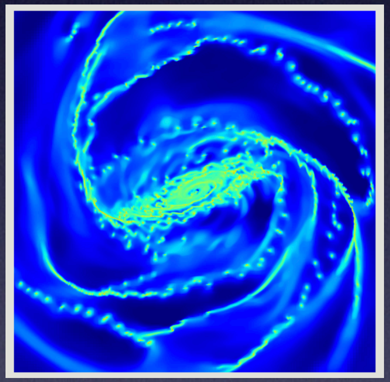
R$_\odot$ | AU | pc | kpc | 100 kpc | Mpc

times

< days | yr | Myr | 100 Myr | Gyr | > Gyr

0.5 pc

MHD (e.g. Hennebelle et al. 2018



10 kpc

see
He et al. 2019
AMR r ~ 20 pc
t ~ 3 Myr

SPH simulation SF Region
280 000 years
M. Bate (2008, 11, 13++)

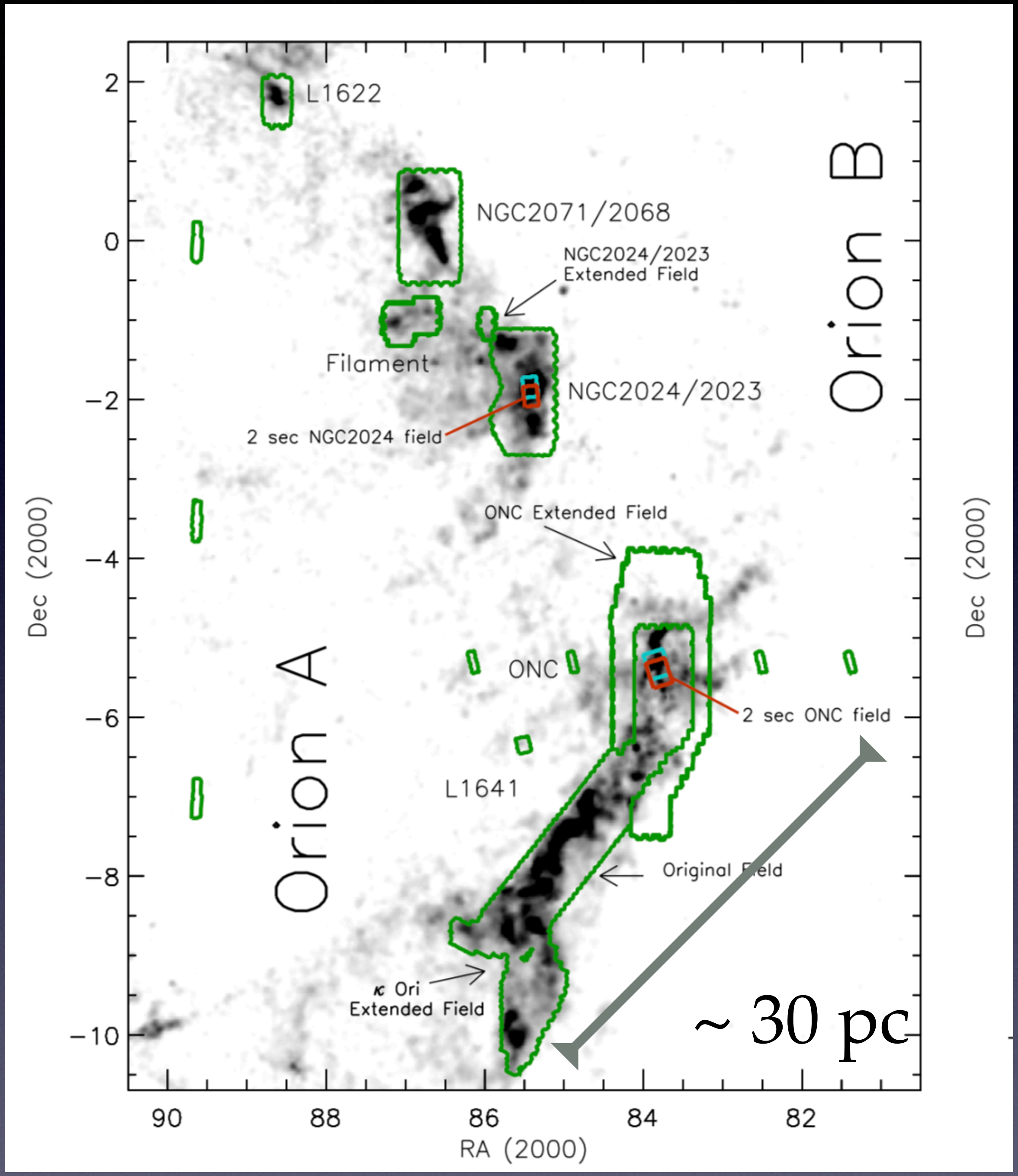
Ramses AMR simulation MW disc
300 Myrs
Florent Renaud (2013++)

Lack of communication between scales ~ pc ⇢ kpc

Both types of simulations have issues (time-stepping, memory size)

Combining many orders of magnitude in physical scales

Spitzer 3.6μm
+ 2mass xtcn



Milky Way disc
scale height h ~ 120 pc

Cases in point :
Star Forming Region: Orion A, Megeath et al. 2012

Combining many orders of magnitude in physical scales

A&A 619, A106 (2018)
https://doi.org/10.1051/0004-6361/201833901

Astronomy & Astrophysics

623 YSO Gaia-selected with L-excess
and σ_ω / ω < 0.1 parallax errors

3D shape of Orion A from *Gaia* DR2*

Josefa E. Großschedl[1], João Alves[1,2], Stefan Meingast[1], Christine Ackerl[1], Joana Ascenso[3], Hervé Bouy[4], Andreas Burkert[5,6], Jan Forbrich[7,8], Verena Fürnkranz[1], Alyssa Goodman[8], Álvaro Hacar[9], Gabor Herbst-Kiss[1], Charles J. Lada[8], Irati Larreina[1], Kieran Leschinski[1], Marco Lombardi[10], André Moitinho[11], Daniel Mortimer[12], and Eleonora Zari[9]

Table 1. Distances to sub-regions in Orion A from the lite

Reference	Method	Region	Distance (pc)
Genzel et al. (1981)	Proper motion and radial velocity of H_2O masers	Orion KL	480 ± 80
Hirota et al. (2007)	VERA/VLBI	Orion KL	437 ± 19
Menten et al. (2007)	VLBI	ONC	414 ± 7
Sandstrom et al. (2007)	VLBI	ONC	389^{+24}_{-21}
Kim et al. (2008)	VERA/VLBI	Orion KL	418 ± 6
Lombardi et al. (2011)	Density of foreground stars	Orion A	371 ± 10
Schlafly et al. (2014)[a]	PanSTARRS optical reddening (Green et al. 2014)	(l/b) at (208.4°, −19.6°) north of the ONC	418^{+43}_{-34}
		(l/b) at (209.1°, −19.9°) west of the ONC	478^{+84}_{-59}
		(l/b) at (209.0°, −20.1°) west of the ONC	416^{+42}_{-36}
		(l/b) at (209.8°, −19.5°) north to L1641-North	580^{+161}_{-107}
		(l/b) at (212.2°, −18.6°) east to L1641-South	490^{+27}_{-27}
		(l/b) at (212.4°, −19.9°) west to L1641-South	517^{+44}_{-38}
		(l/b) at (214.7°, −19.0°) south-east of L1647-South	497^{+42}_{-36}
Kounkel et al. (2017)[a]	VLBI	15 YSOs near the ONC	388 ± 5
		2 YSOs near L1641-South	428 ± 10
Kounkel et al. (2018)	*Gaia* DR2 of APOGEE-2 sources + HR-diagram selection	ONC	386 ± 3
		L1641-South	417 ± 4
		L1647	443 ± 5
Kuhn et al. (2018)	*Gaia* DR2 of *Chandra* X-ray sources	ONC	403^{+7}_{-6}
		North and south to ONC	~395

See also Fig. A.1.

Milky Way disc
scale height h ~ 120 pc

Cases in point :
Star Forming Regions: Orion A+ Gaia DR2

Combining many orders of magnitude in physical scales

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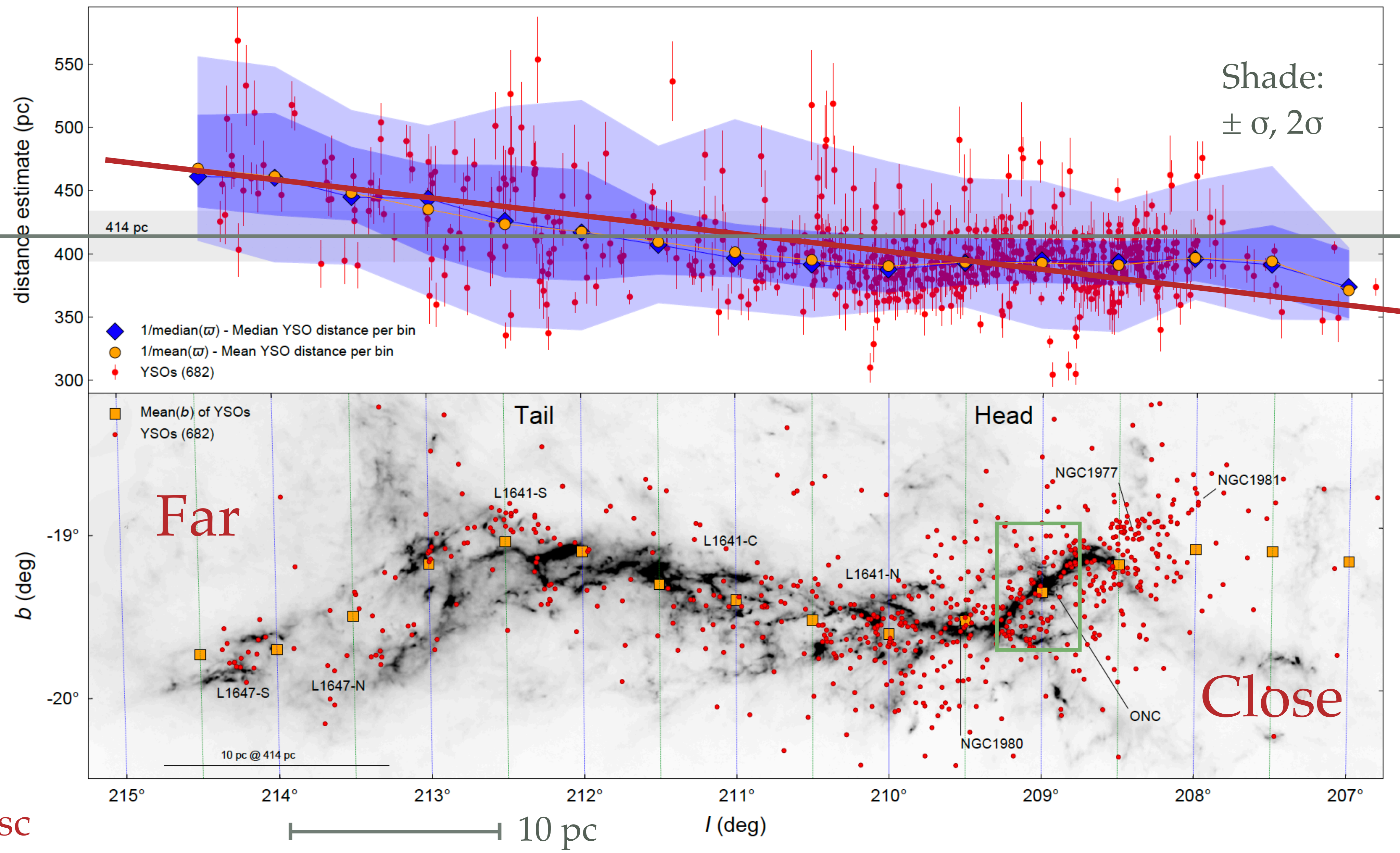

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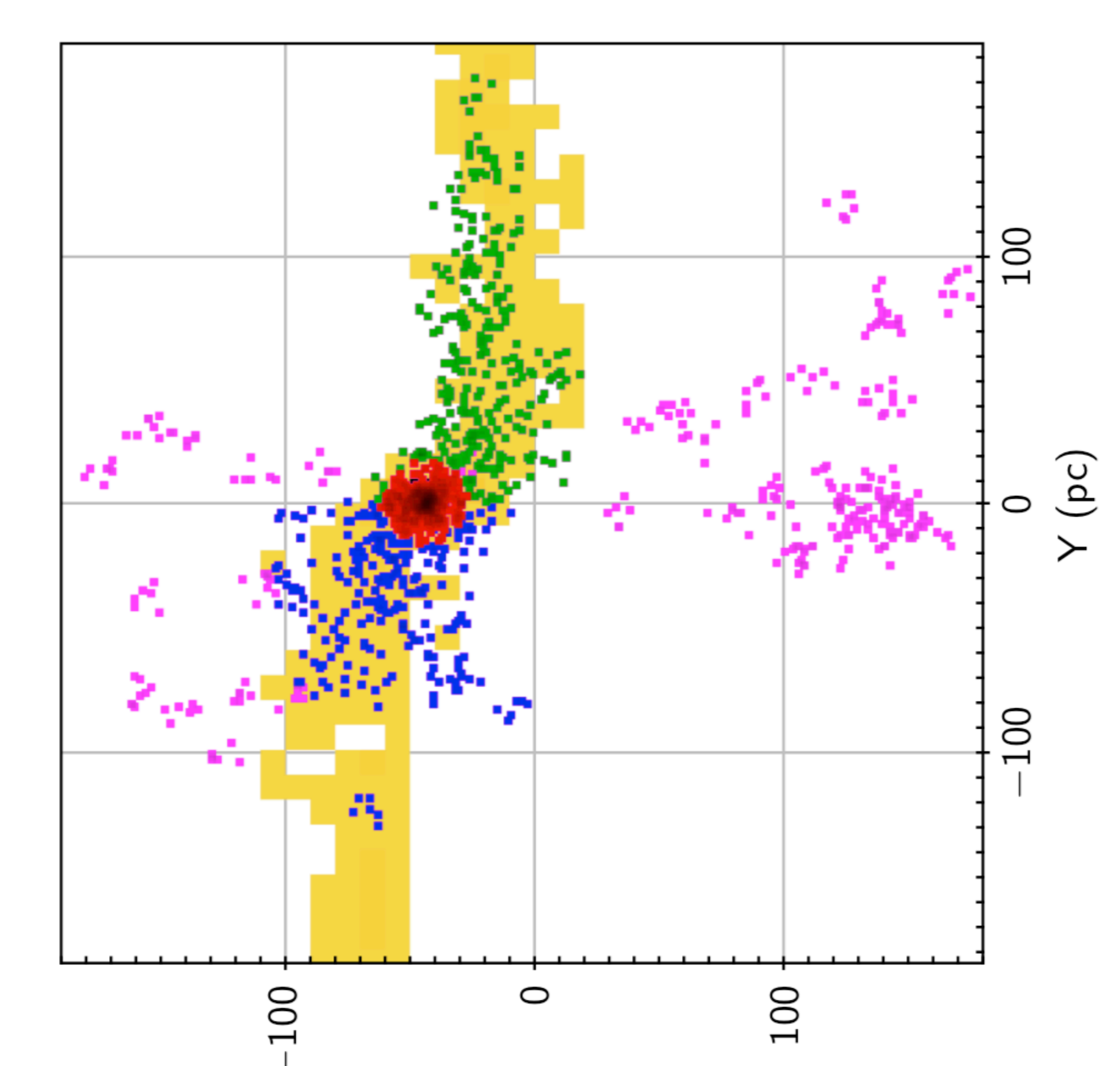
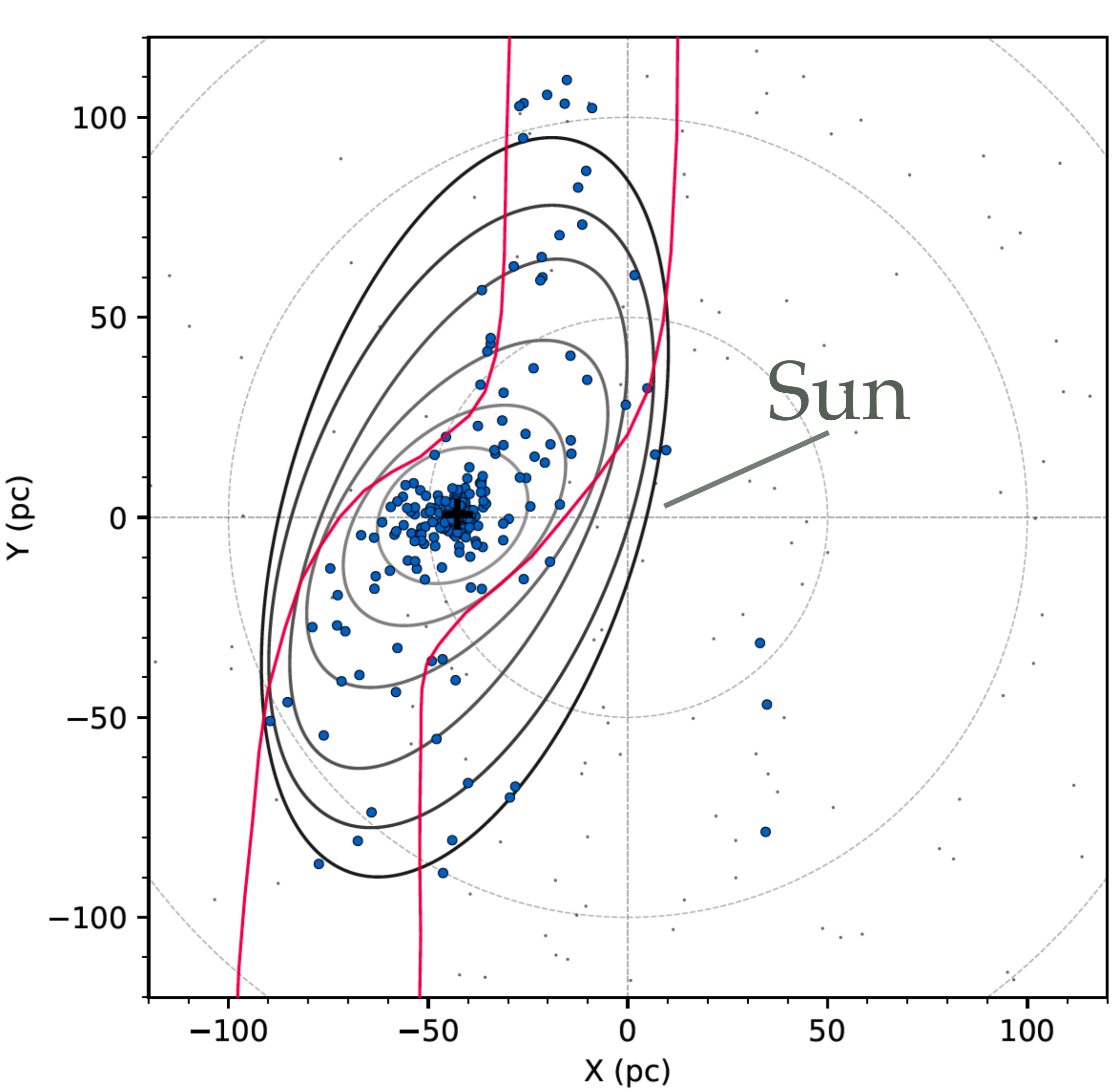
Combining many orders of magnitude in physical scales

S. Röser et al. 2019



Meingast & Alves 2019



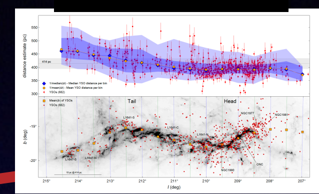
Anticipated by e.g. Chumak et al. 2005, Ernst et al 2011

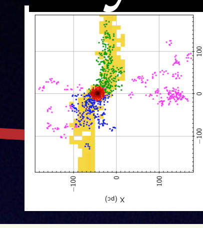
Cases in point :
The tidal tales of Hyades cluster from Gaia DR2

Importance of embedding in the host galaxy: some challenges ..

Lengths

R ⊙ | AU | Ori. A | Pleia. | Hya.) kpc | Mpc



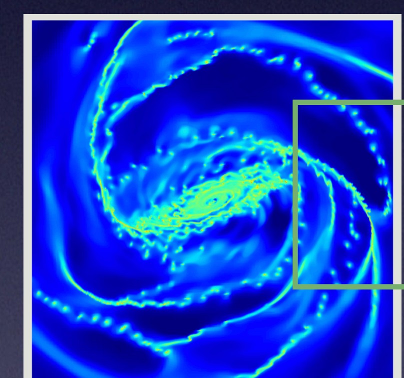


times

< days | yr | Myr | 100 Myr | Gyr | > Gyr

0.5 pc

MHD
(e.g.
Hennebelle
et al. 2018



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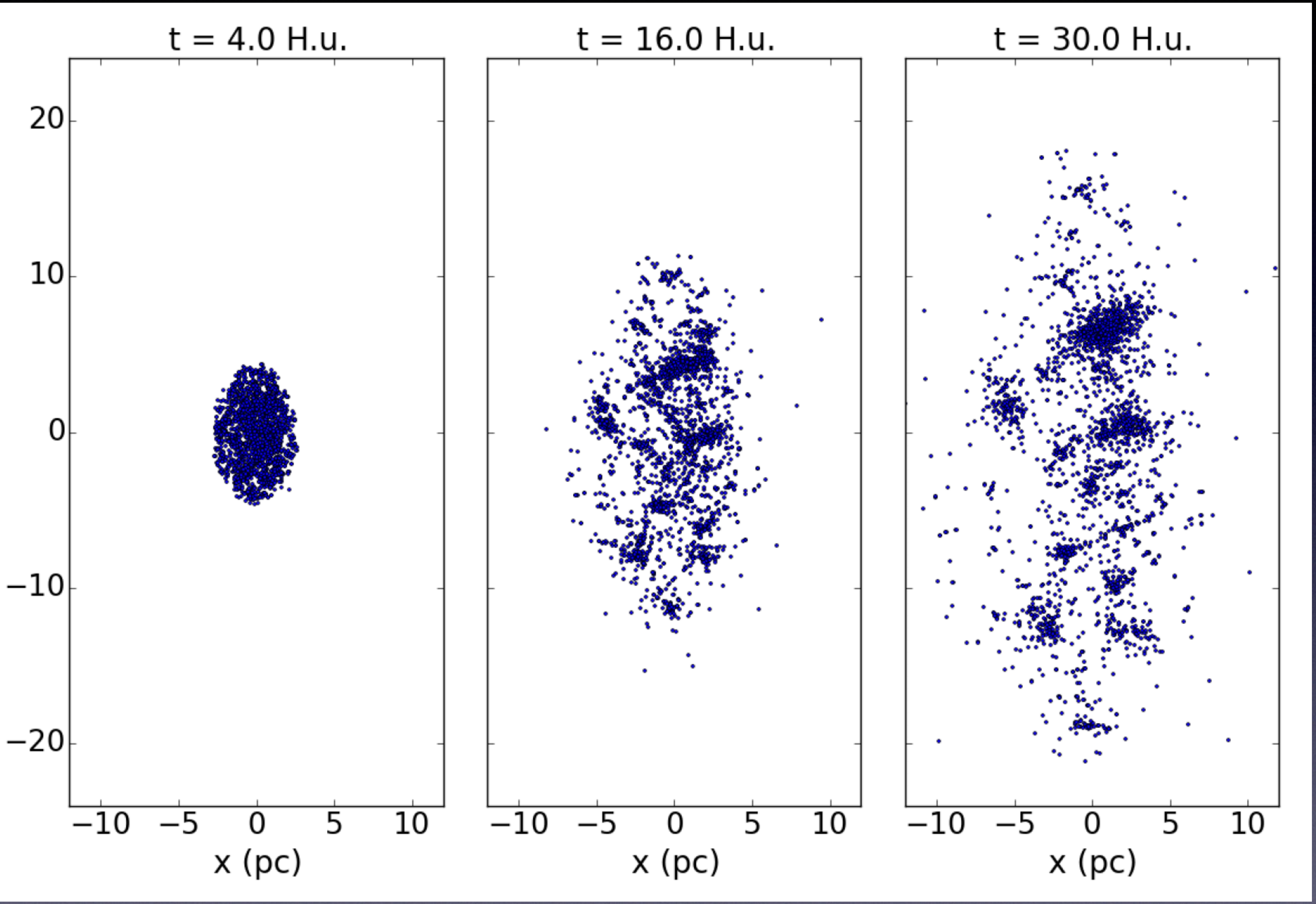
Both types of simulations have issues (time-stepping, memory size)

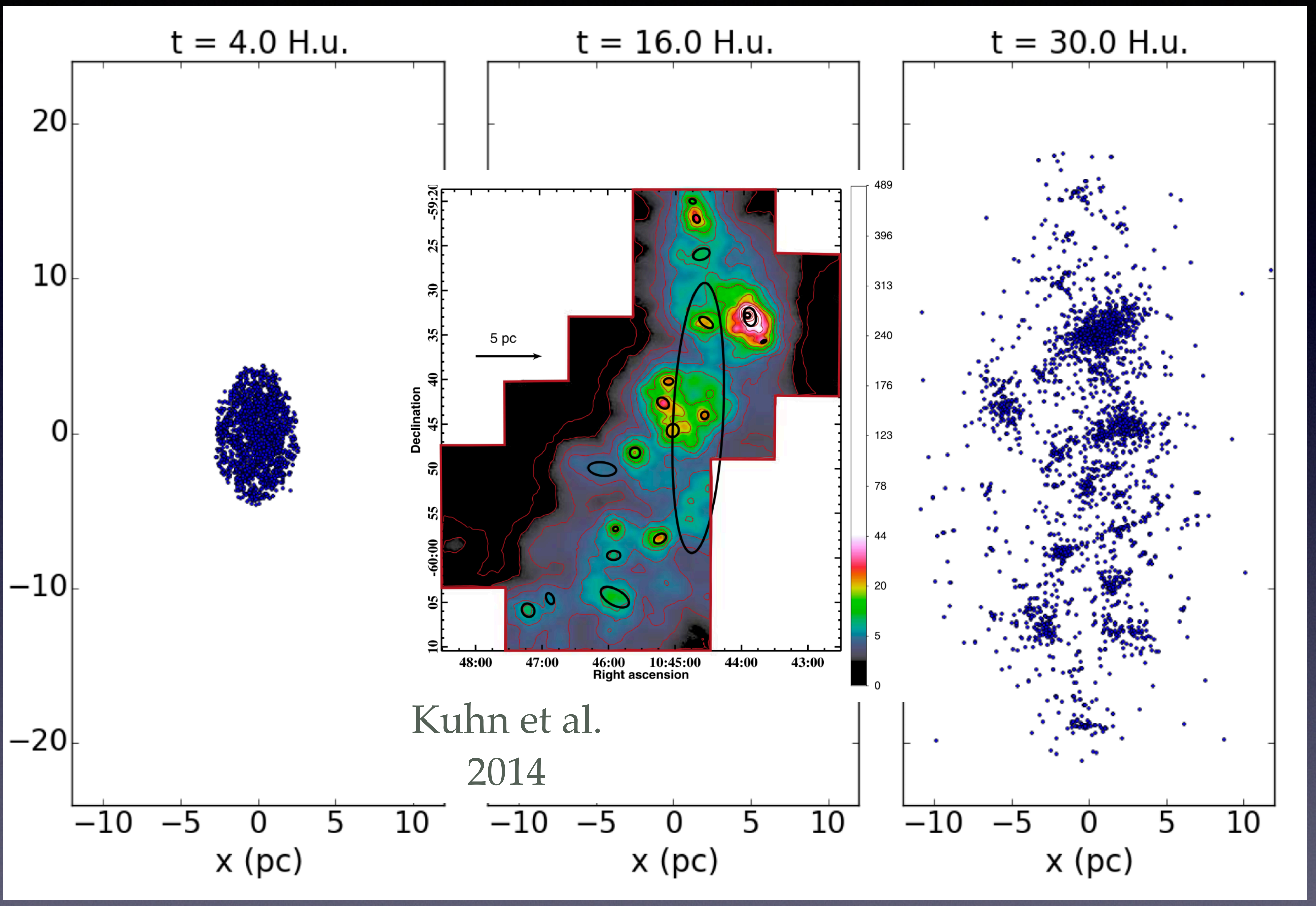
Combining many orders of magnitude in physical scales



Credits:
J. Dorval

Anchoring a filament to the background rotation pattern : tbc ..

Combining many orders of magnitude in physical scales



Credits:
J. Dorval

Anchoring a filament to the background rotation pattern : tbc ..

Summary / Thanks!

- Young clusters (open, rich) start out with odd geometry and sub-virial global velocities
- They should mix quickly yet have time to form stars first ..
- The stellar clumps are top-heavy with respect to field stars ;
- Strong biases in projection: up to factor 2 error in mass estimates
- Extinction maps scaled down to map out the low-mass stars, explore morphology, dynamics: tightening of B's ?

The predictive power of computational astrophysics *as a discovery tool*

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Topics

Strong gravity - Large-scale structure & galaxy formation - Star formation & interstellar medium - Stellar evolution, supernovae - Solar & exoplanetary systems - New computational tools & data mining

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