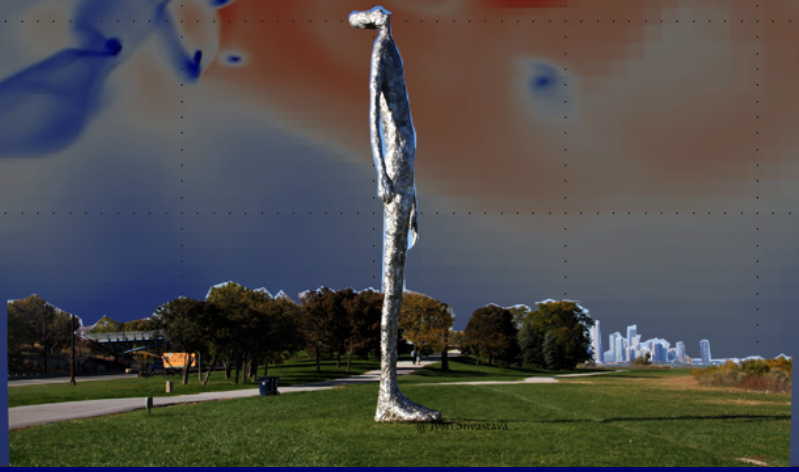
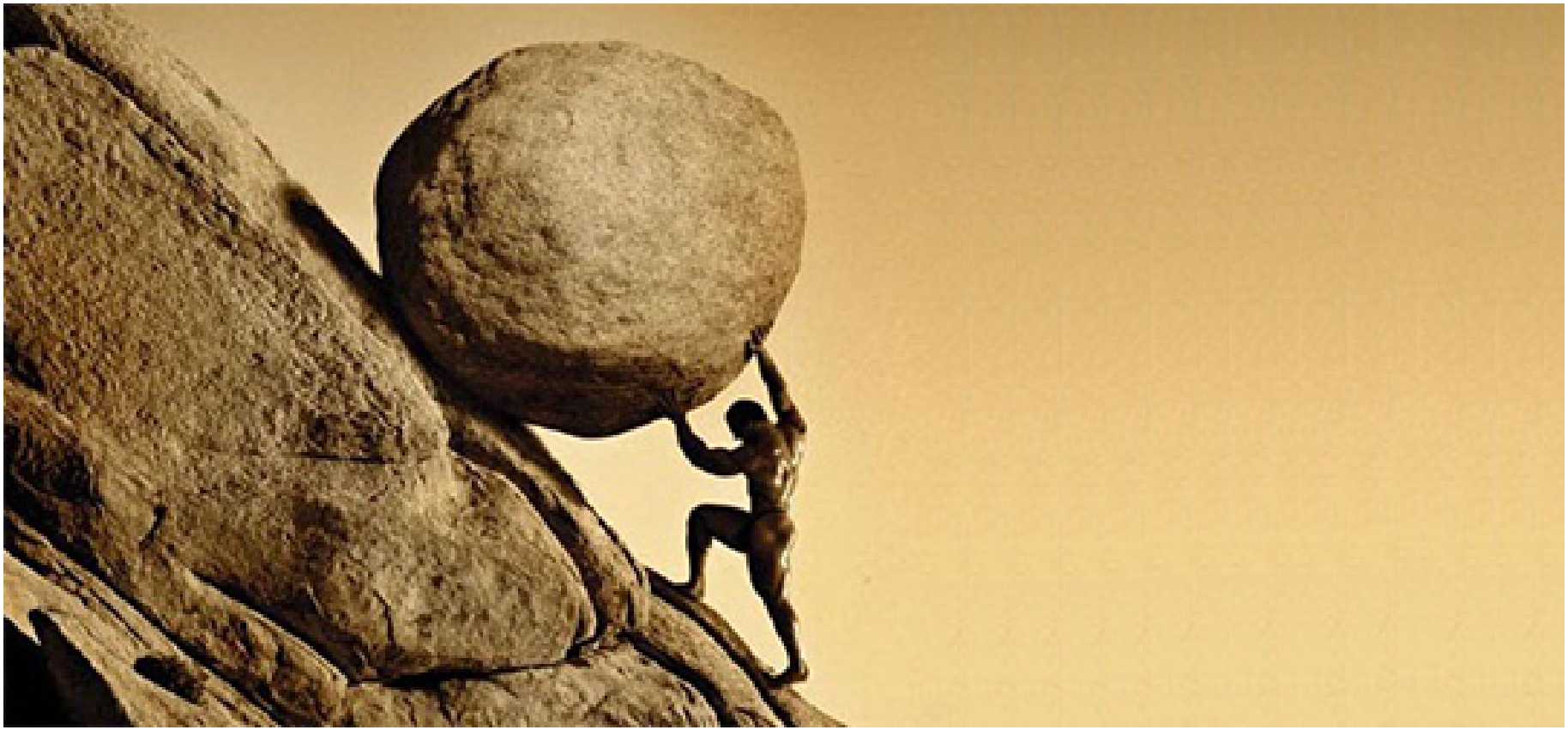
Interactive summary



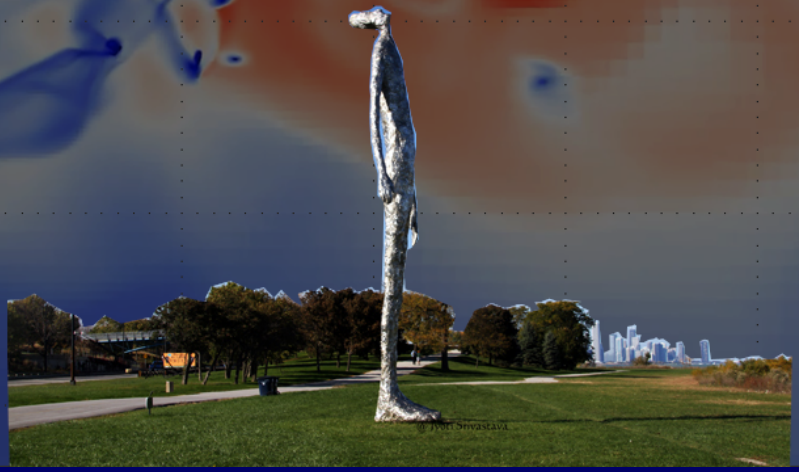
Tom Friedman, "Looking up", Lakeshore Drive, Chicago

7 September, 2018, 15th Potsdam Thinkshop



Interactive summary

first observations:
~20% of people ask ~80% of questions/comments



Tom Friedman, "Looking up", Lakeshore Drive, Chicago

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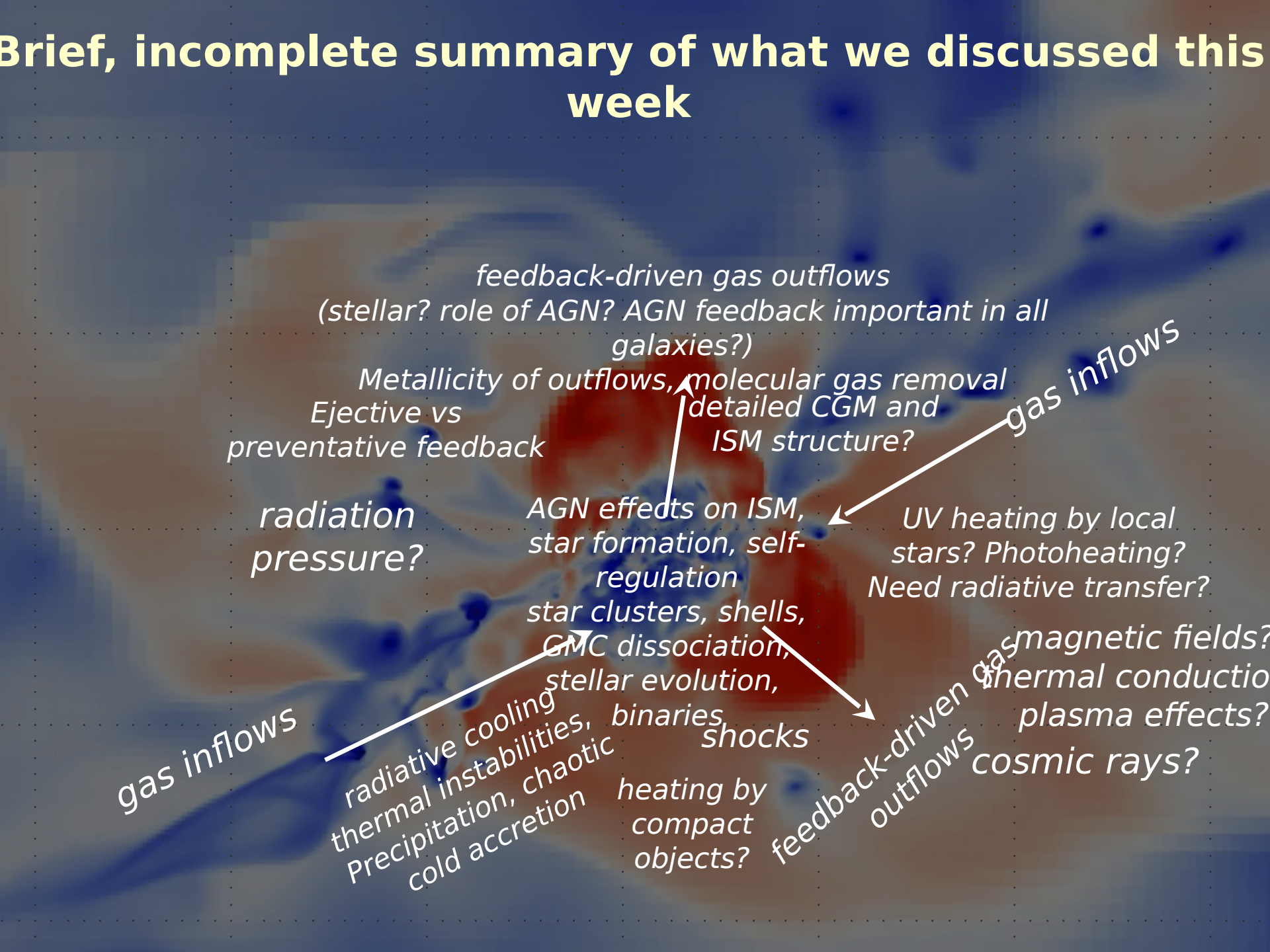
Interactive summary

Tom Friedman, "Looking up", Lakeshore Drive, Chicago

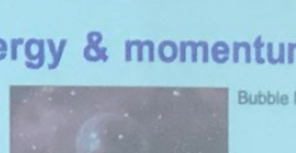
7 September, 2018, 15th Potsdam Thinkshop

Brief, incomplete summary of what we discussed this week

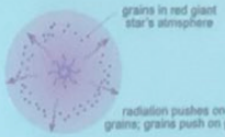


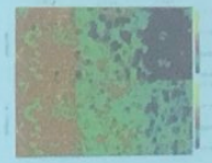
What physics is responsible for feedback in the first place?

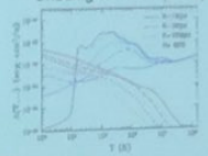
- Supernova explosions (energy & momentum input)
- Stellar winds
- AGN activity
- Radiation pressure on dust
- Photoionizing UV background and Reionization
- Modification of cooling through local UV/X-ray flux
- Photoelectric heating
- Cosmic ray pressure
- Magnetic pressure and MHD turbulence
- TeV-blazar heating of low density gas
- Exotic physics (decaying dark matter particles, etc.)

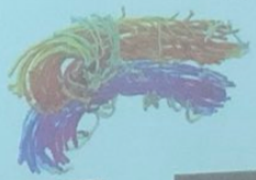

Bubble Nebula

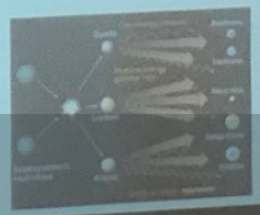

Kepler's Supernova




Ciardi al. (2003)


Gnedin & Hollon (2012)





Noam Libeskind @satellitegalaxy · Sep 3
#thinkshop2018

Feedback - a broad term! Credit: V Springel.

PHYSICS CHALLENGES

Feedback: resolving the cooling radius for supernovae, the Strömgren sphere for HII region, the photosphere (tau=1) for IR dominated regions. If not then subgrid models: decoupled wind, direct momentum injection: is it enough ? aren't we missing the multi-phase nature (temperature, density, velocity and mixing) of the gas, impact of core formation ?

MHD: small scale dynamos versus large scale field amplifications, LES generalised to MHD, star formation subgrid models with MHD

Cosmic rays: beyond a single average energy, multiple energy groups with multiple diffusion coefficients, results sensitive to parameters, predictability ?

Radiation (cooling and force) and chemistry: models for radiation transfer (beyond M1 and reduced speed of light), multiple energy band and multiple angular domains, self-shielding, reduction of cooling through soft X-rays, radiation force in UV and in IR, molecular and dust physics: from subgrid to background radiation to fully radiative molecular networks. BPT diagrams

Slide from discussion of feedback physics challenges led by Romain Teyssier on Tuesday

What physics is needed to model the ISM?

Dynamics
- Magneto-hydrodynamics (MHD)
- Self-gravity
- Radiation transport (both diffuse and point sources)
- Cosmic rays

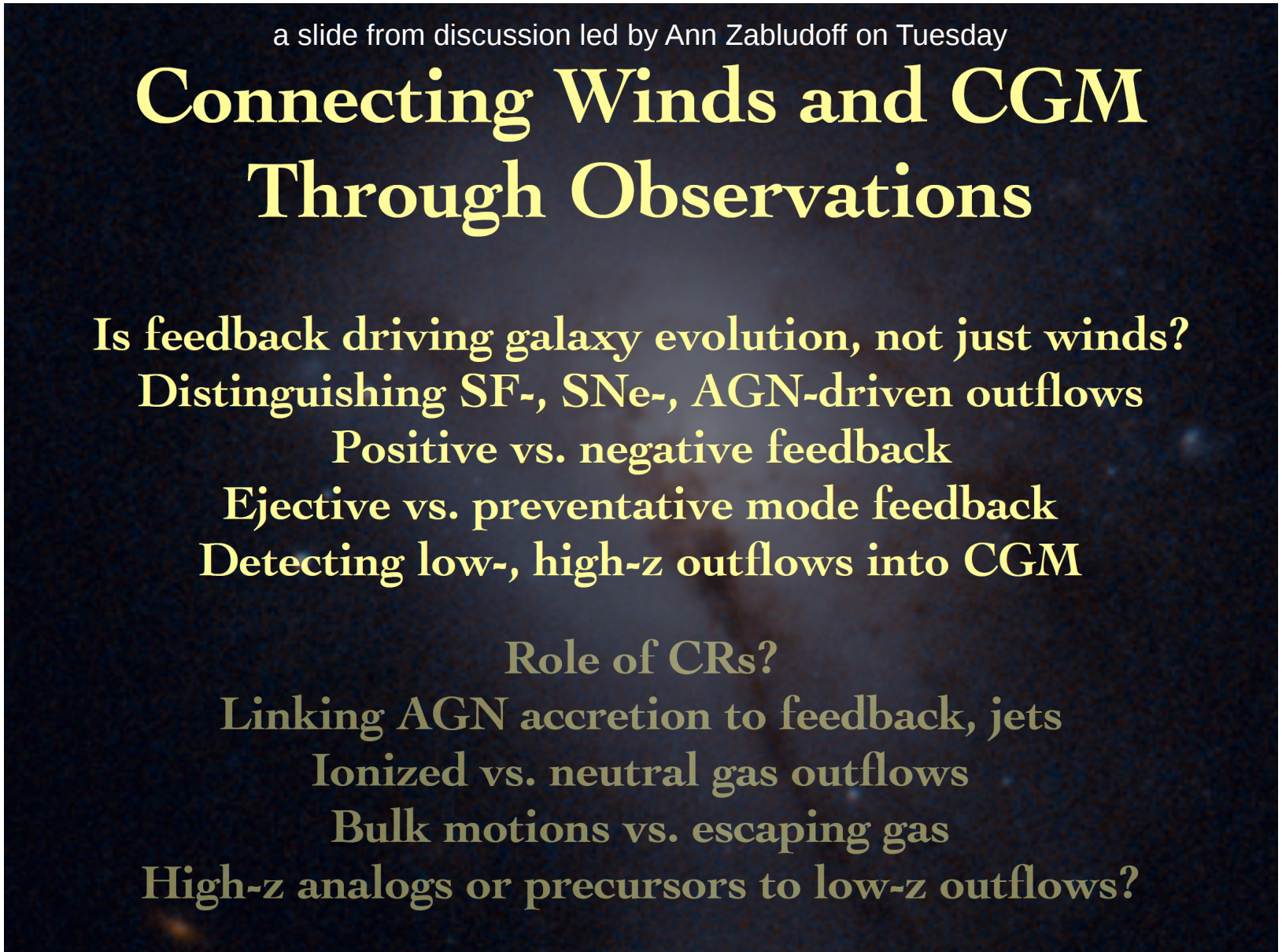
Microphysics
- Heating and cooling
- Chemistry
- Dust grains (dynamics and growth/destruction)

Diffusive processes
- Non-ideal MHD effects (resistivity and ambipolar diffusion)
- Thermal conduction

Sub-grid models
- Sink particles
- Supernovae and stellar winds

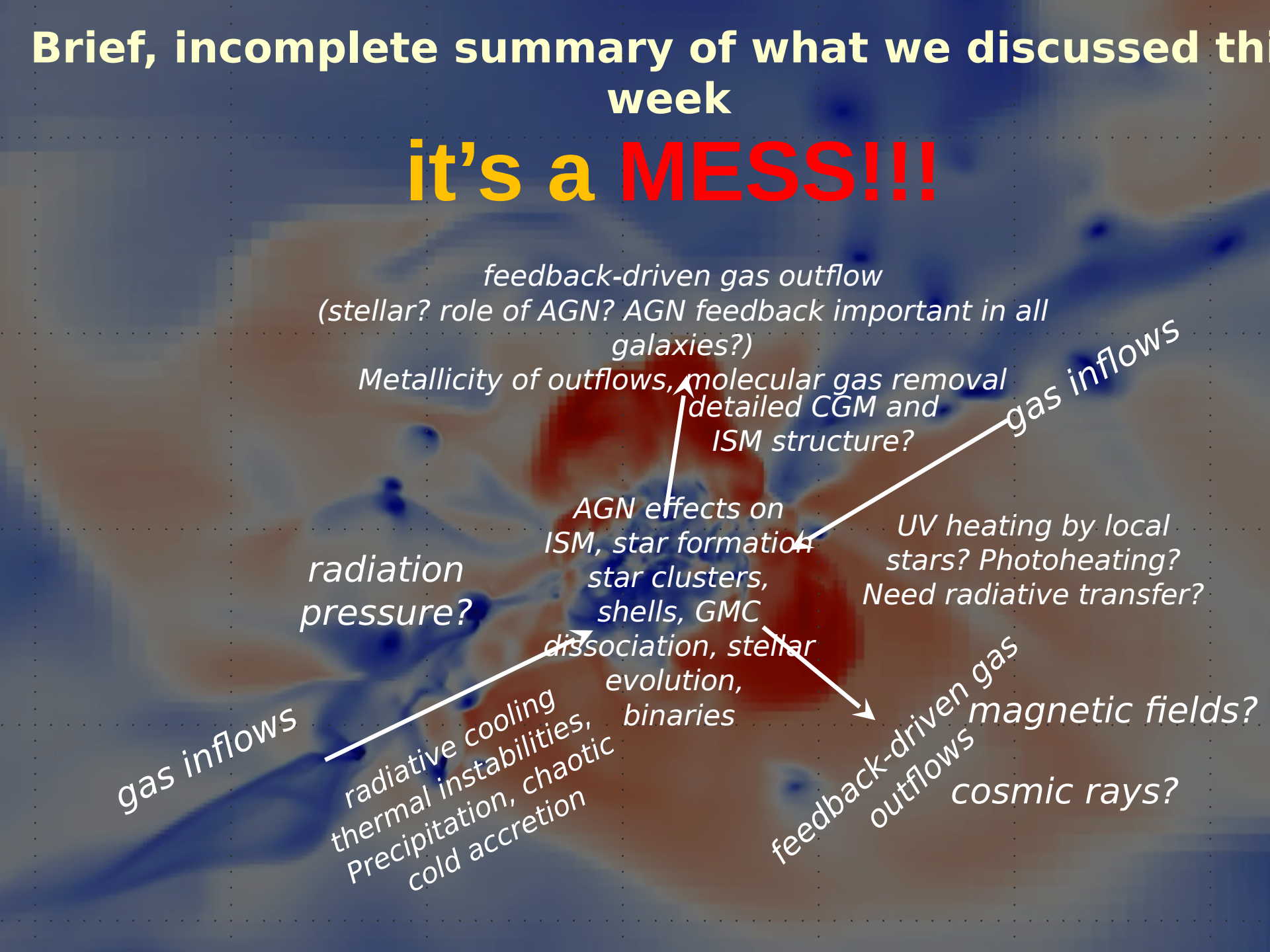
Slide from discussion on numerical challenges led by Jim Stone on Tuesday

this was not any different in observational parallel discussions, as far I can tell...



Brief, incomplete summary of what we discussed thi week

it's a MESS!!!



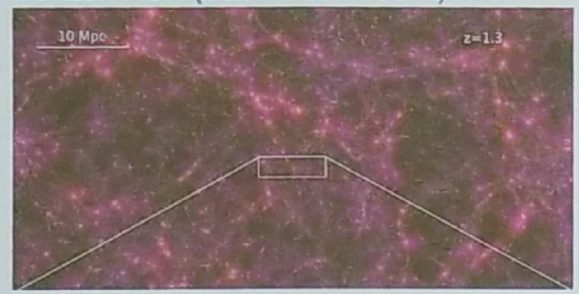

JCB

Hydrodynamical cosmological simulations of galaxy formation have made tremendous progress in recent years

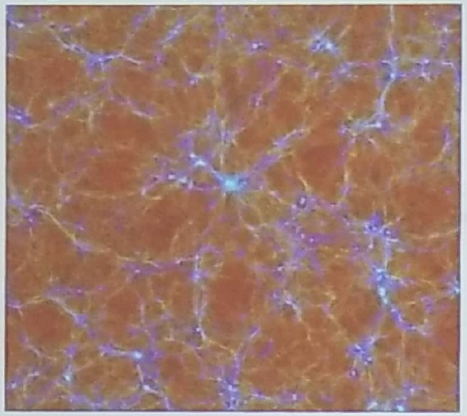
AN INCOMPLETE OVERVIEW OF SOME OF THE LARGER PROJECTS

Illustris (Vogelsberger et al. 2014)

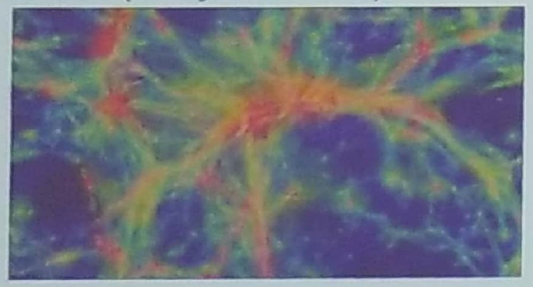
Horizon-AGN (Dubois et al. 2014)



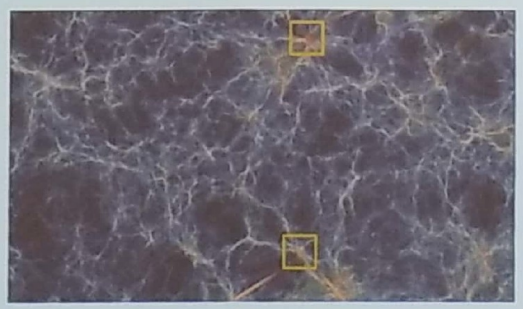
Magneticum (Dolag et al. 2014)



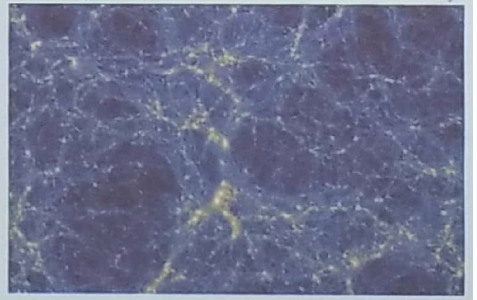
EAGLE (Schaye et al. 2015)



MassiveBlack II (Khandai et al. 2015)



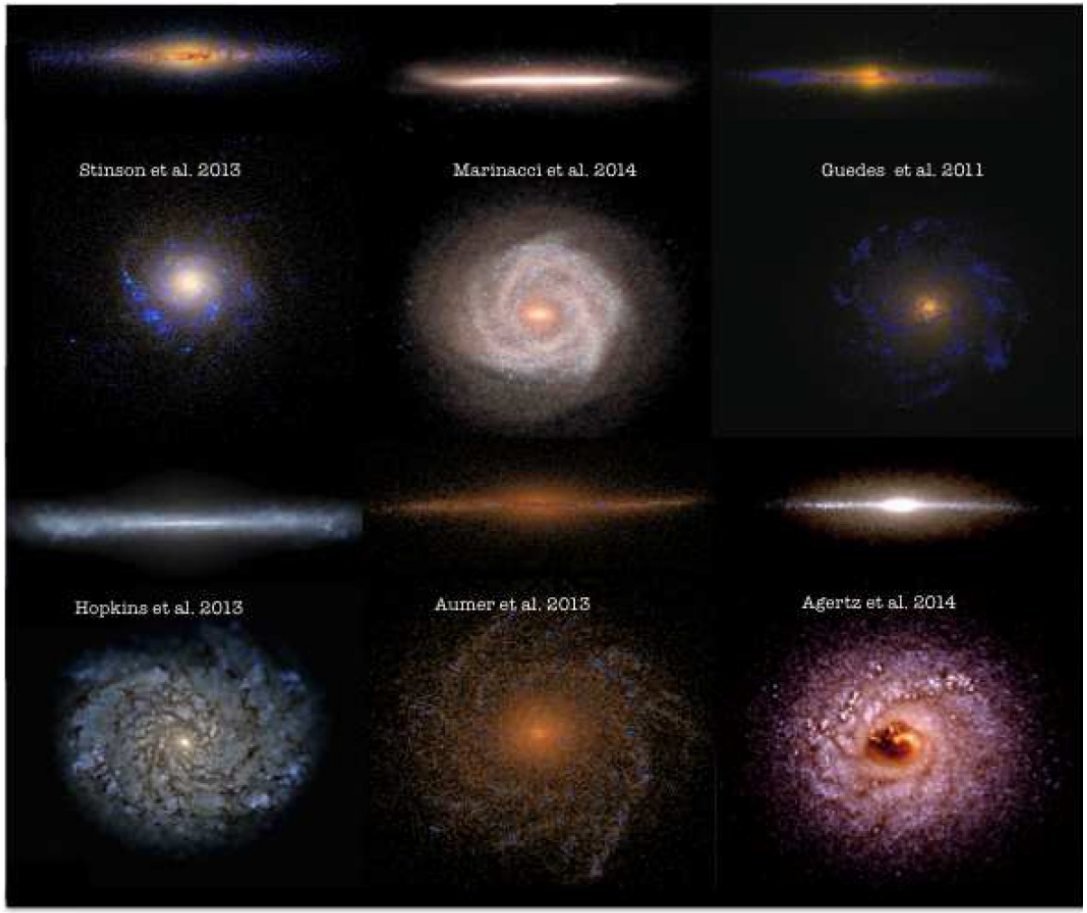
TNG (Illustris Collaboration 2017)



slide from V. Springel's talk on Monday

Modern simulations with efficient feedback produce galaxies with a mix of realistic morphologies and, importantly, late type disks

Feedback also helps to explain formation of ultra-diffuse galaxies (A. Di Cintio today),
but this is not the only factor (merger direction and alignment of baryons at different R play a role)

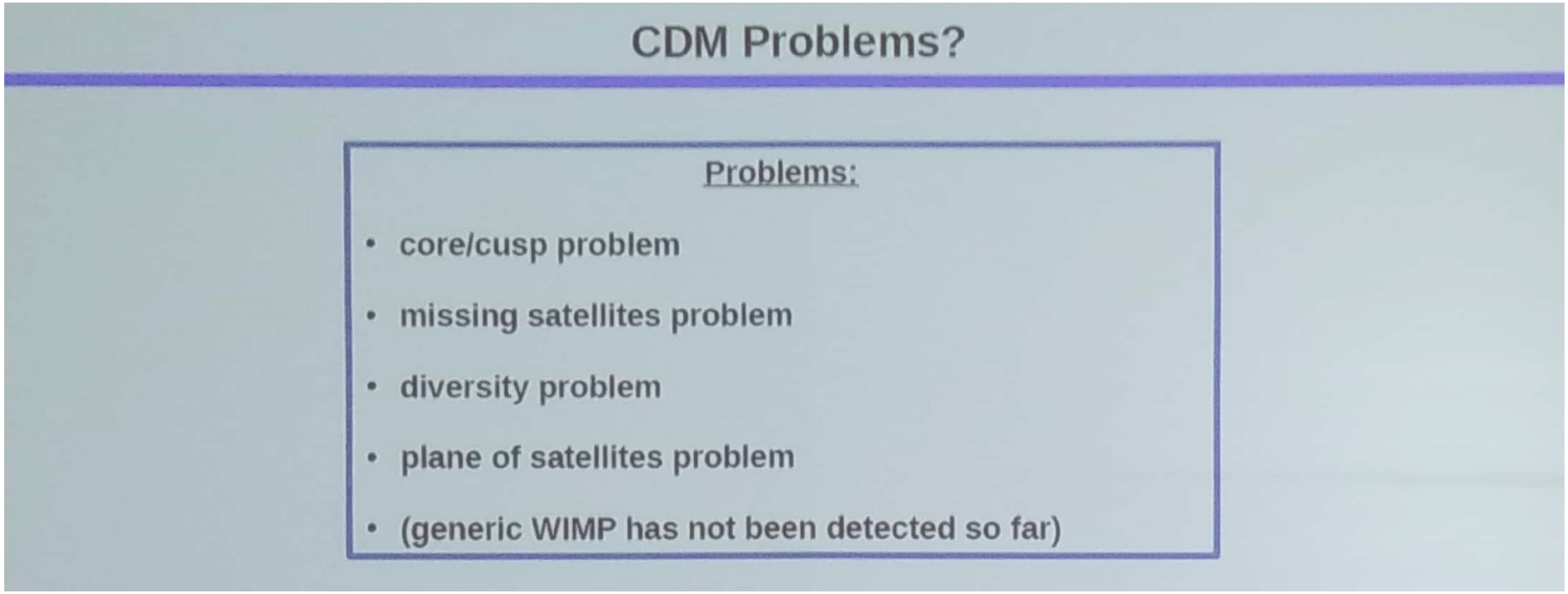


Naab & Ostriker 2017, ARAA review

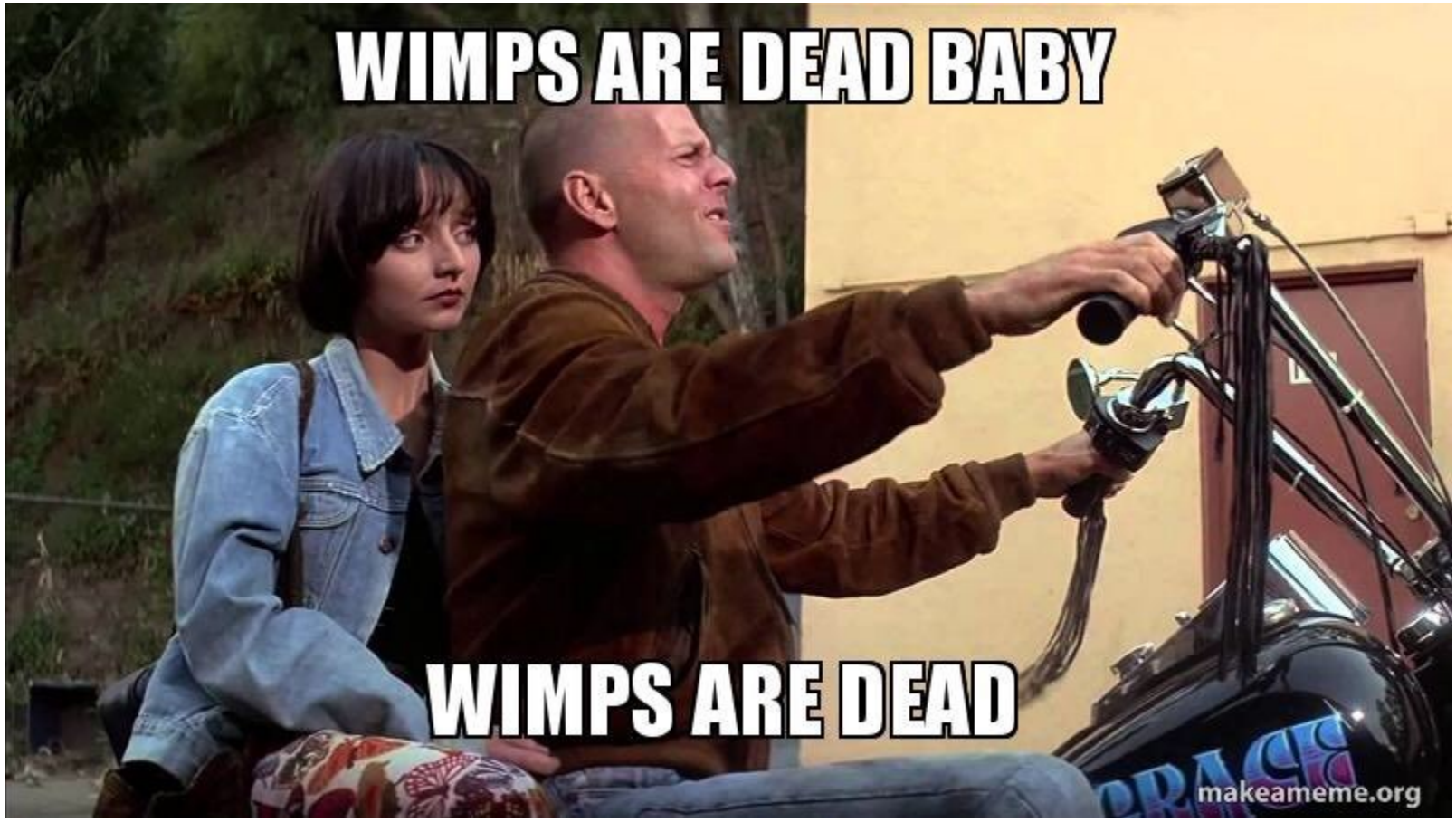
Hopkins et al. 2013, 2017
http://fire.northwestern.edu/about-fire/

CDM has challenges (M. Vogelsberger on Monday, J. Zavala Friday)

Solvable by feedback within CDM?



Slide from M. Vogelsberg's talk on Monday

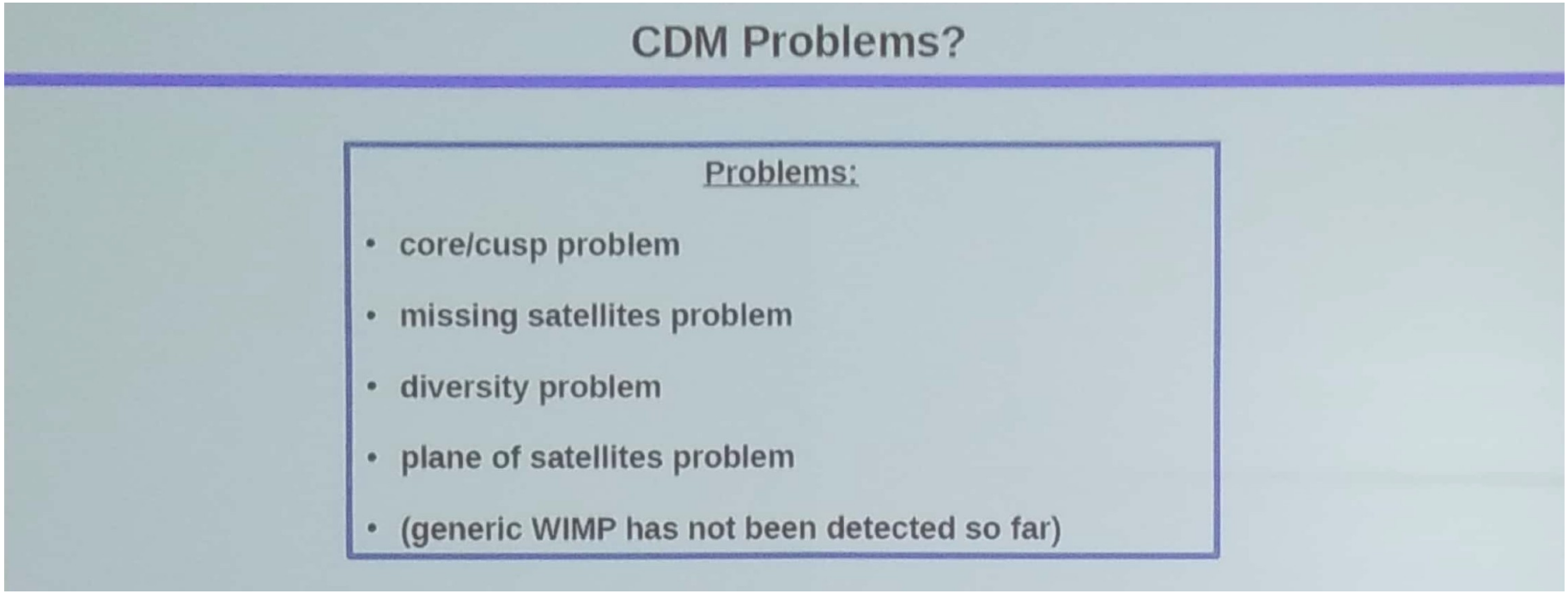


Noam Libeskind @satellitegalaxy · Sep 4

Teyssier: It's time for exotic Dark Matter, new physics #thinkshop2018

CDM has challenges (M. Vogelsberger on Monday, J. Zavala Friday)

Solvable by feedback within CDM?



Slide from M. Vogelsberg's talk on Monday

Massimo Gaspari @max_gasp · Sep 3

Buck on how to create dwarf galaxies — today im learning that all problems in galaxy formation have been solved... 🤯 #thinkshopIAP18 #thinkshop2018

Dizzy with success?

"I read a recent article about how we now understand the Universe and I am not very comfortable with that…" - Nicole Nesvadba

Quanta magazine

Physics Mathematics Biology Computer Science All Articles

COSMOLOGY

The Universe Is Not a Simulation, but We Can Now Simulate It

5

Computer simulations have become so accurate that cosmologists can now use them to study dark matter, supermassive black holes and other mysteries of the real evolving cosmos.

Natalie Wolchover

Senior Writer/Editor

June 12, 2018

“Dizzy with success” – Stalin, J.V., *Pravda 1930, No 60*

54 talks
50 posters
14 discussion sessions

Discussion!
(the interactive part)

Some recurring themes and questions

- Predictions are important! (but difficult)

  They are more difficult, but much more satisfying!

- Failures are successes. Observational non-detections or theoretical models that don't work are valuable for learning/understanding (we should publish more of them).

- Question: can we strive for or expect convergence in galaxy formation simulations?

- "We know what dark matter is doing", except when baryons are around and feedback is operating. And what about effects of merger history details on host halo and galaxy properties or "planes of satellites"?

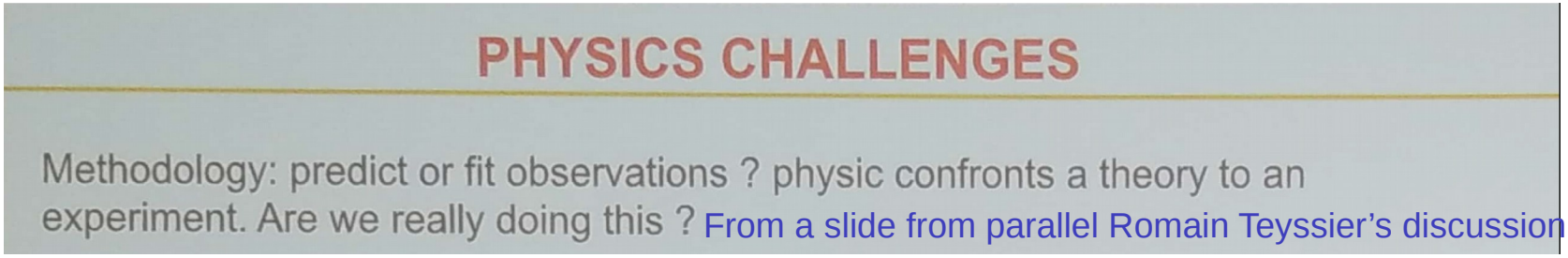
- It's not yet fully clear how to differentiate between "exotic" DM scenarios and feedback effects (but maybe we should pack the Occam's razor? Especially, as feedback effects have solid physics footing and are seen in several high-res simulations)

Predictions for observers?

May be controversial…

- Are theorists trying too hard to match observations?
- Were cold flows the last models theorists predicted for observers to prove/falsify?

Slide from Tanya Urrutia's discussion on Tuesday



From a slide from parallel Romain Teyssier's discussion

I’d add that insights are important too

“The purpose of computing
is insight, not numbers”

- Richard Hamming

Some recurring themes and questions

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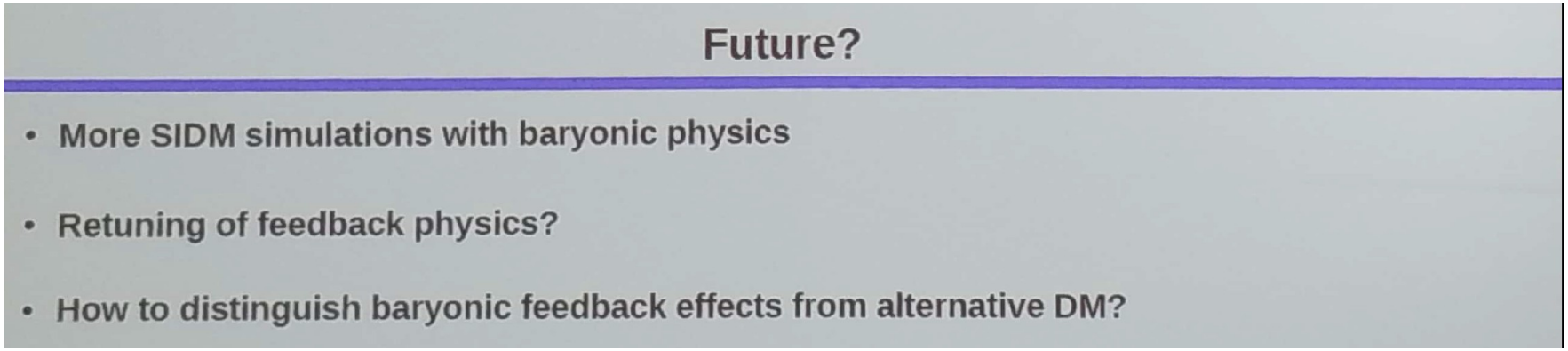
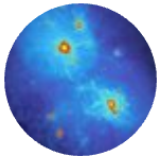
Can we distinguish between baryonic physics and “exotic” dark matter models? (A. Di Cintio, M. Vogelsberger on Monday, J. Zavala Friday)

Diversity on small scales (Santos-Santos, Zavala), but little on larger scale? (A. Pontzen)



from M. Vogelsberg’s slide on Tuesday



Noam Libeskind @satellitegalaxy · Sep 3

Arianna dicintio (session chair): How do we want to solve our small scales problems? With self interacting DM or with baryon physics? They both work! Vogelsberger: don’t have a consensus yet on the baryonic physics stuff. [Paging Dr **Occam**, please come with razor]. **#thinkshop2018**

➢ An ISM-dark matter connection?

An interesting/scary condition between our models for ISM physics, star formation and feedback and the ability of feedback to solve core/cusp and TBTF problems (A. Pontzen's discussion, A. Dutton's talk Friday)

There are specific requirements on star formation burstiness bursts on <~10 Myr time scales are needed (A. Pontzen Thurssday, A. Dutton, Friday). Maybe this is why no cores in APOSTLE and AURIGA (R. Grand, Friday)

➢ Dwarf galaxies as a testbed of star formation and feedback physics

Signatures of AGN-driven outflows in dwarfs? (G. Canalizo)

UV-heating post-reionization suppressing accretion (T. Buck), but star formation can be "re-ignited" (A. Wright)

Effective of UV heating, radiative transfer (A. Emerick's talk on Wednesday; modelling individual stars if only for ~100-200 Myrs…)

Some recurring themes and questions

- Cosmic rays are important! Radiation pressure is not so much (except inside massive, dense GMCs, and starbursts)
- Outflows are multiphase. Different phases give different results for wind properties (mass loading factors, etc.)
- Two modes of AGN feedback are important, but at different epochs each.
- AGN feedback is gentle? Does not remove ISM/molecular gas
- CGM is a critical testing ground for feedback models, but it's not clear yet how important thermal instabilities and processes on extremely small scales are. It exhibits many interesting properties (multiphase, warm gas is ubiquitous and evolves little)
- Magnetic fields "are in early stages of exploration" (in galaxy formation simulations), but it looks like their origin via feedback-aided galactic dynamo is a solved problem?

Voting with their feet

"Why are you interested in cosmic rays?…" - Peng Oh

"My main problem with including CR physics is that it's too sensitive to parameters…" - Romain Teyssier

Explosion of cosmic ray modelling in galaxy formation models (K. Yang's, C. Pfrommer, M. Ruszkowski, P. Grichidis talks on Wednesday, posters by. T.-K. Chan (FIRE), + work on local effects, implementation/transport Caprioli, Berlok, Ehler, Pais's posters)

Much evidence that cosmic ray physics is important in driving outflows and in interpreting observations in galaxies (R.-J. Dettmar) and clusters (C. Pfrommer)

Generic conclusion so far: CR-driven winds are cooler and smoother than SN-driven ones (Booth+ 13; Salem & Bryan '14; Liang+ 17), but do we know the relative importance and role of CR-feedback relative to other forms (A. Zabludoff's question)

Some recurring themes and questions

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a slide from discussion led by Tanya Urrutia on Tuesday

Galaxy Game of Thrones

- Many unpleasant ways for galaxies to be quenched…
  - Starvation (Winter is coming…)
  - Strangulation
  - Ram pressure stripping
  - Exploding dwarfs
  - Secular processes
  - Collisions/mergers
  - Shocks
  - DrAGoNs
- Which one sits on the Iron Throne?

M. Lacy – “Mapping the Pathways of Galaxy Transformation” conference

“AGN feedback is more of a Winnie-the-Pooh rather than a fire-breathing dragon…” - Michael Tremmel

Intermittent (chaotic) accretion of cold gas by AGN (A. Audibert, M. Gaspari)

Do we understand rapid depletion of gas in starbursts and their clumps (but yet the sizeable stellar masses of clumps)?

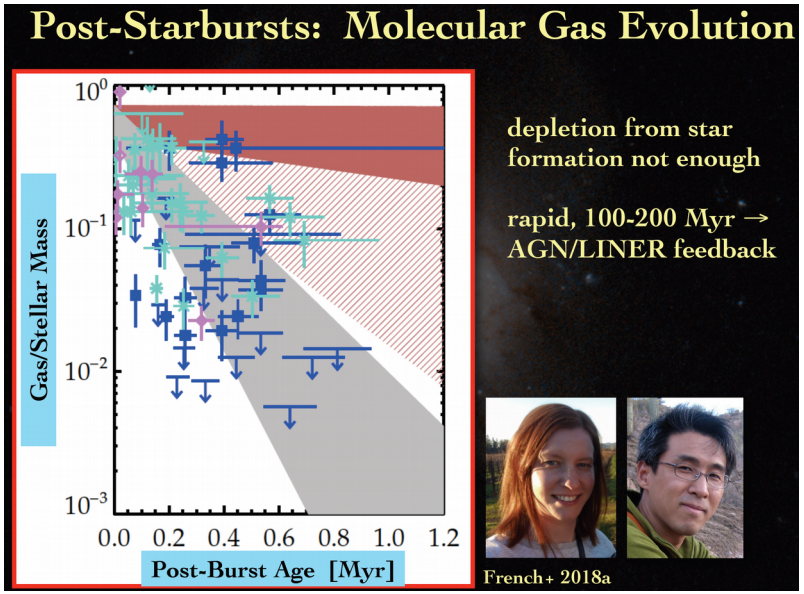
from Nicole Nesvadba's conclusions

+ **Little evidence for 'classical' gas depletion through winds**
  - little evidence of strong molecular outflows, in spite of extreme gas kinematics

... **where outflow components are seen, they are high mass, low velocity**
  → they can leave the clumps, but not the galaxy!
  → galactic fountains and cyclical fueling of starburst?
  → short gas depletion times of few Myr → are clumps transitory structures depending on balance between gas accretion and loss?

Evidence for the bottom-heavy IMF (N. Nesvadba)

from Ann Zabludoff's discussion



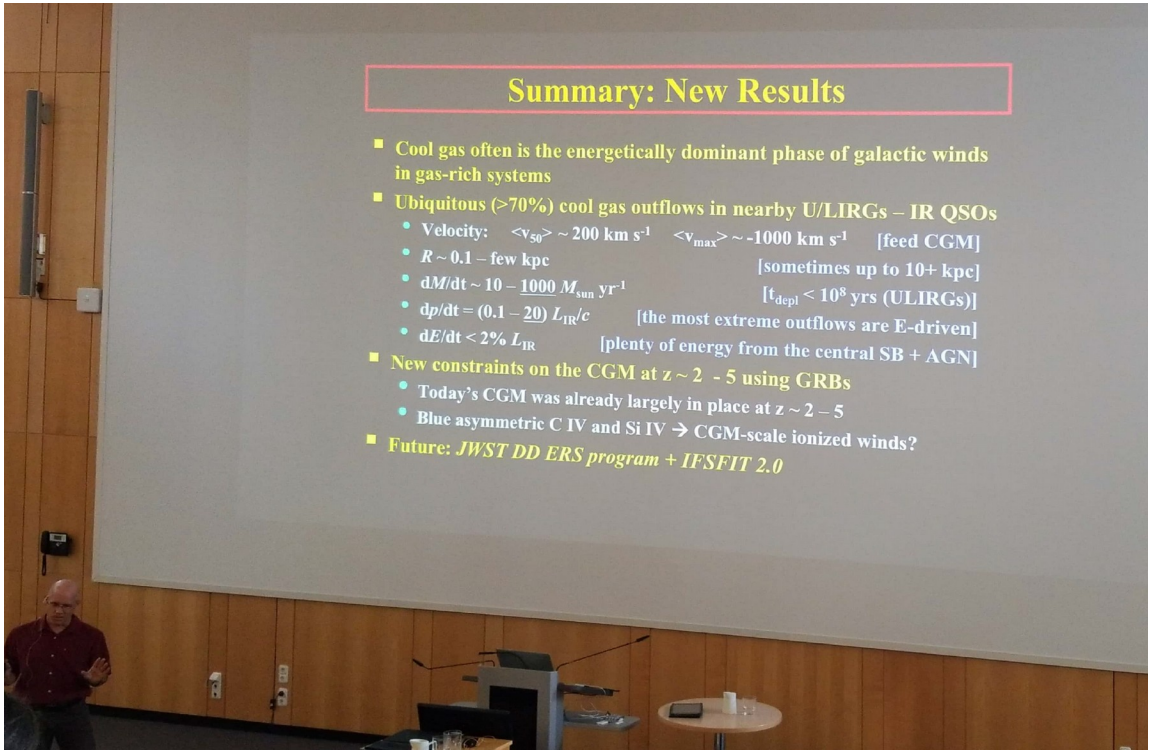
Cool, molecular gas is ubiquitous in starburst and QSO winds (S. Veilleux)

AGN do not destroy cold ISM and molecular gas (D. Rosario, A. Petric)

Modelling is challenging, but possible (C.-A. Faucher-Giguere's talk)

Molecular gas is also present in starburst-driven winds (R. Leaman's talk); results consistent with in situ cooling

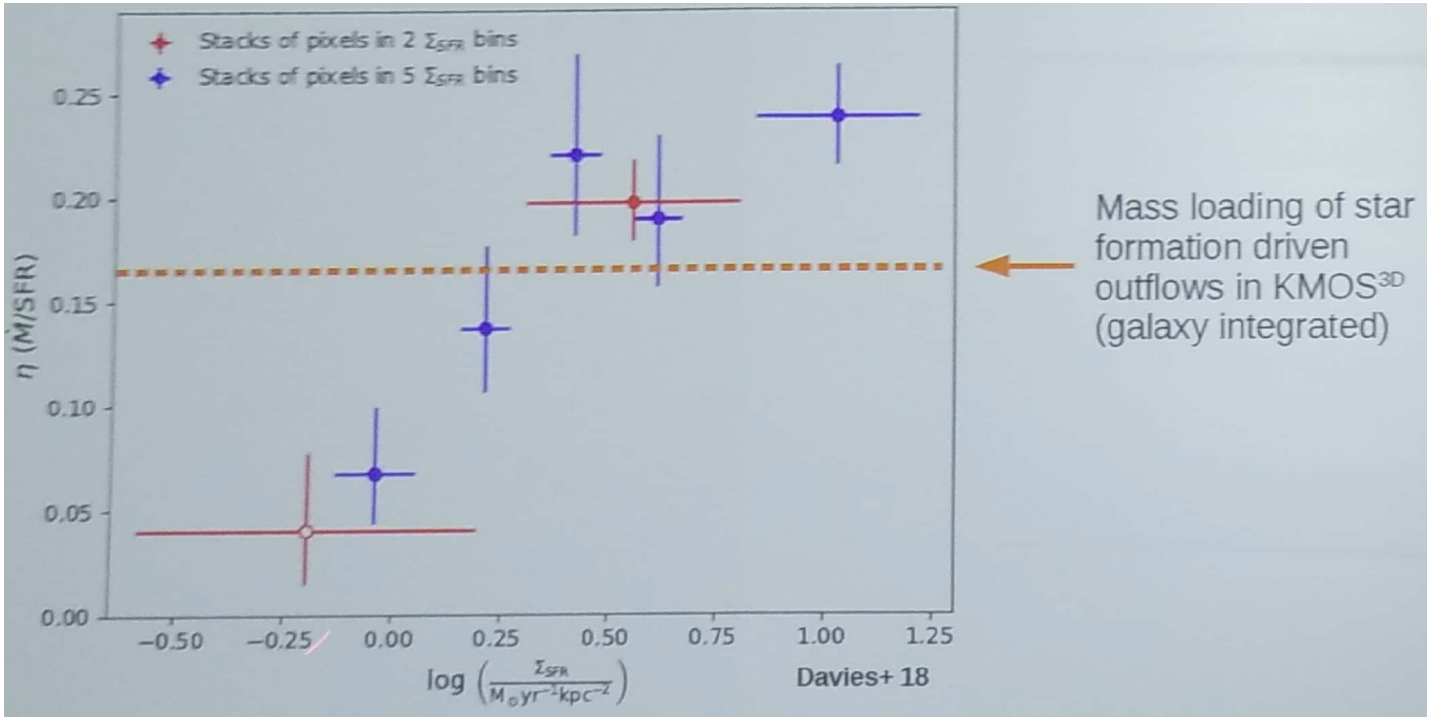
But mostly absent in z~3 GEMS starbursting galaxies (N. Nesvadba's talk), except for Emerald



Ionized gas outflows ubiquitous in z~0.6-2.6 galaxies (R. Davies), dwarf galaxies at z~0 (posters by J. Crisholm, A. Moiseev, O. Egorov)

Ionized outflows exhibit scalings close to those expected by momentum and energy-driven winds, but mass loading factors are very low (R. Davies). Little mass in the probed ionized gas? However, mass loading factors are estimated to be fairly large at high z (posters Y. Sugohara, G. Leung) and at z~0 at low masses (poster J. Chrisholm)

Ionized outflows are also ubiquitous in AGNs (B. Hausemann, R. Morganti)



Advances in radio-AGN mode observations/models

- Beautiful data from LOFAR sample of radio galaxies, revolutionalizing studies of radio AGN population (J. Croston).

  Estimates of energy carried by jets is difficult, but LOFAR LoTSS and WEAVE-LOFAR observations should improve estimates of radio AGN impact to z~1

- Advances in theory (C. Reynolds, E. Puchwein, R. Weinberger, M. Tremmel), but models still have a lot of uncertainties in cluster cores.

- Population constraints from radio-AGNs for models need to be considered! (most radio-loud AGNs don't live in clusters, J. Croston)
  + comparisons with high-resolution jet and bubble obs (R. Morganti)

- Questions:

  - How do we distinguish SF- , SNe-, AGN-driven, etc, outflows from one another? (A. Zabludoff)
  - Relative importance of different modes of AGN feedback?

Some recurring themes and questions

- Cosmic rays are important! Radiation pressure is not so much (except inside massive, dense GMCs, and starbursts)
- Outflows are multiphase. Different phases give different results for wind properties (mass loading factors, etc.)
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- Magnetic fields "are in early stages of exploration" (in galaxy formation simulations), but it looks like their origin via feedback-aided galactic dynamo is a solved problem?

Circumgalactic medium (CGM)

adapted from a Peng Oh's slide

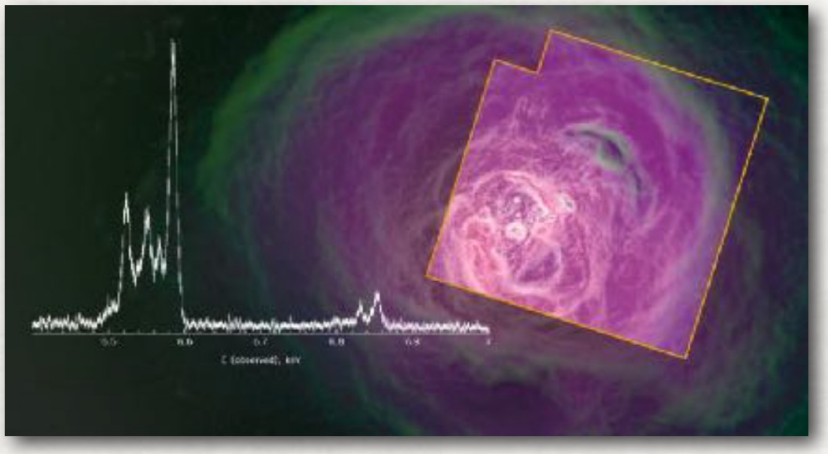
+ testing ground of feedback models?

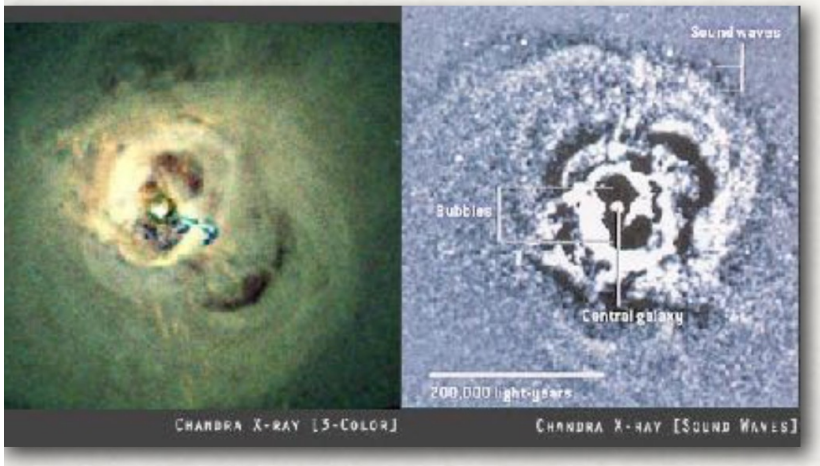
Different feedback models predict qualitatively different CGM, particularly in CR-driven winds (P. Girichidis' talk)

Warm gas in CGM barely evolves since z~2-3 (S. Veilleux, G. Rudie)
Challenge for models to reproduce this?

OBSERVATIONAL COMPARISONS

WHAT'S GOING TO DISTINGUISH BETWEEN DIFFERENT FEEDBACK MODELS?





A party pooper:

the ICM, the CGM's big brother

We see the hot gas, in X-ray and SZ

No need to guess from cold gas properties!

We see the energy source:
bubbles from radio mode feedback

But still no consensus solution:
thermal conduction, cosmic rays, turbulent dissipation & diffusion, weak shocks, sound waves, etc etc …

How to avoid this fate??

Peng Oh's slide

Some recurring themes and questions

- Star formation and depletion times are now studied on a wide range of scales and redshifts. They show some interesting trends. Very good models now exist explaining observations, but is the problem solved?

- Still lots to learn from stellar evolution models. Evolution in binaries changes budget of ionizing photons and, correspondingly, escape fractions significantly (talk by S. De Mink)

  Heating by compact sources in Es could be important (poster by D. L. Bakels)

- Deciding which form of feedback is important cannot be done from just at z~0 observations, feedback effects are critical at z>~1-2, so the relevant processes must work there.

  Questions (from A. Zabludoff): “At what epoch did each form of feedback reach its peak?”

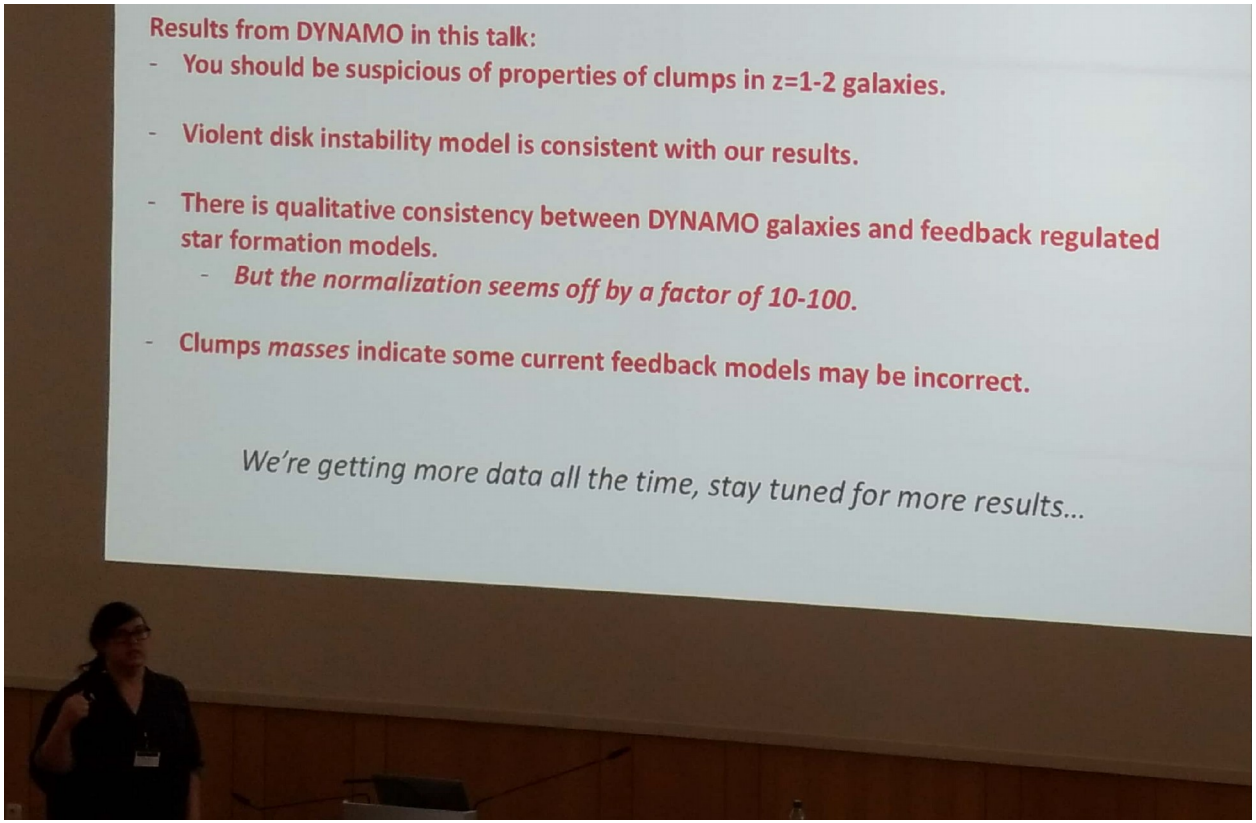
- At this conference the focus was almost completely on ejective feedback, but…

  “Do we know the relative importance of ejective vs preventative feedback?”

Starbursting galaxies at low and high z are qualitatively consistent with feedback/turbulence regulated model, but not qualitatively (D. Fisher, N. Nesvadba). *Alternative models?*

Universal “unboudedness”, universal star-formation “law”? (N. Nesvadba)

Clump masses are too high and inconsistent with efficient feedback, e.g. in FIRE simulations? (D. Fisher)

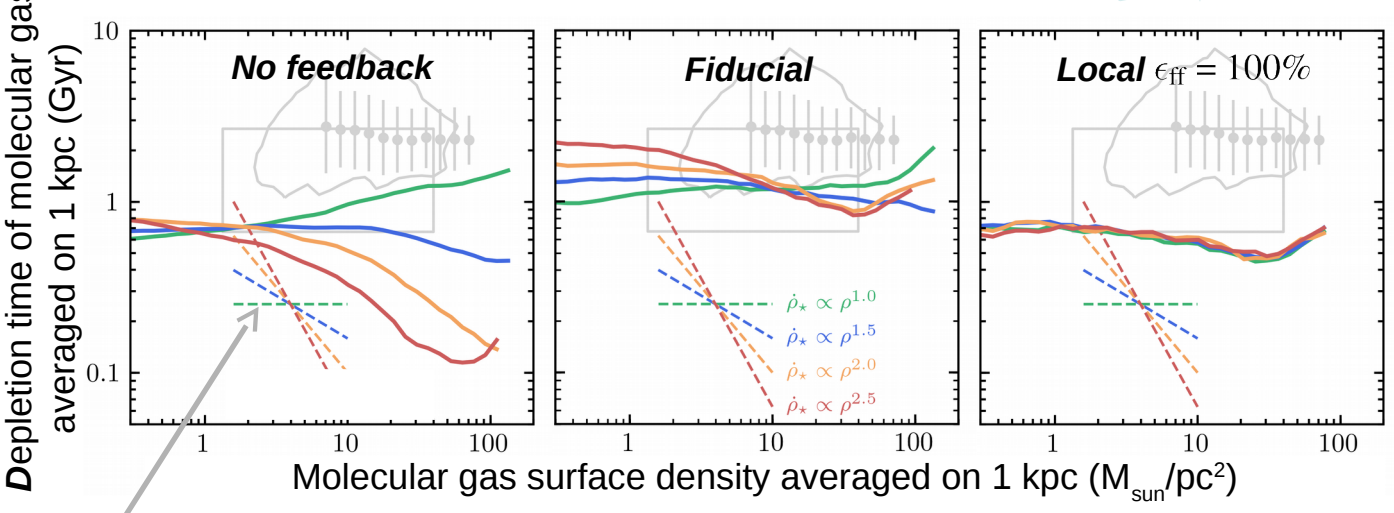


Self-regulation in high-resolution simulations, galaxy formation as an emergent phenomenon?

self-regulation of the slope of molecular KS relation
when feedback is efficient the KS slope on large scales is insensitive to the density slope of local star formation prescription on small scales

cf. Vadim Semenov's talk on Monday preparation

Feedback becomes more important



Slope of $\rho/\dot{\rho}_\star$ adopted on 40 pc scale

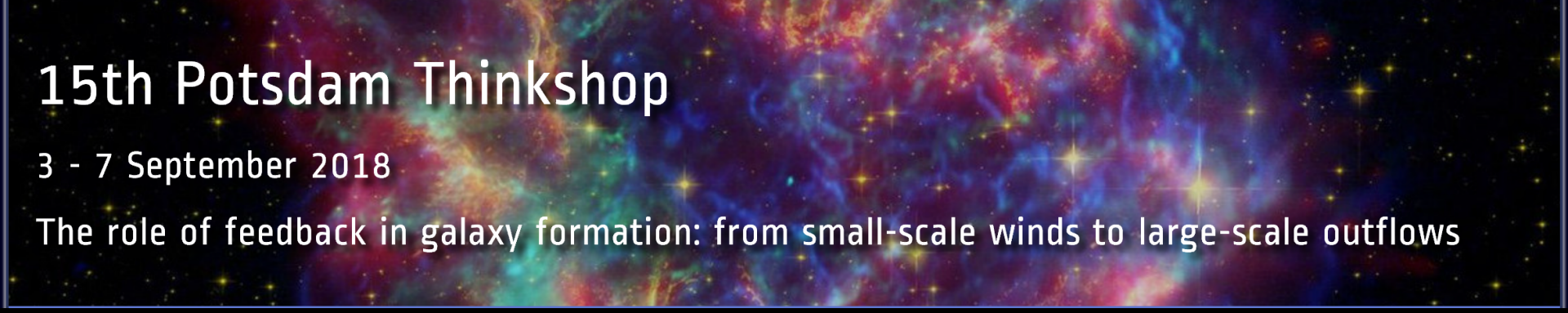
not to get lost we need to keep in mind the whole forest, while studying fascinating details of its trees and ecosystem

I will end with some statistics...

54 talks: 41 +- 8% female speakers

50 posters: 40 +- 9% female presenters

14 discussion sessions: 36 +- 16% female leads



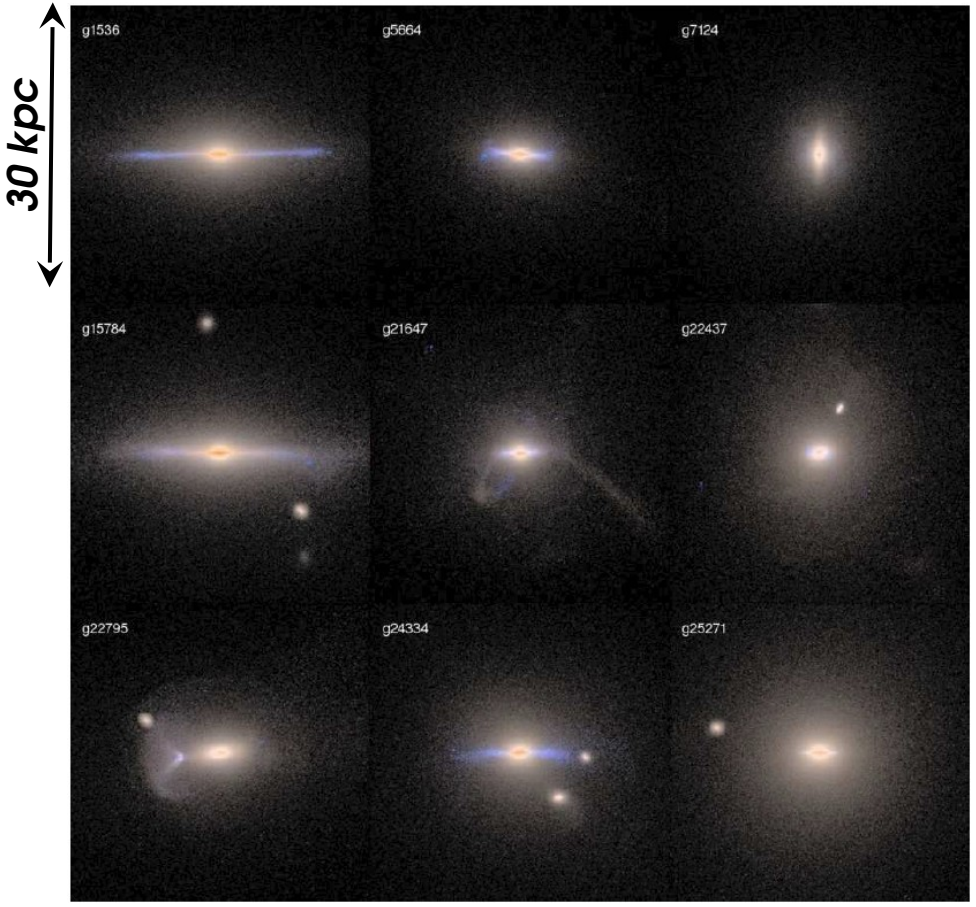
So let’s thank the organizers for a fun and stimulating week of feedback science!

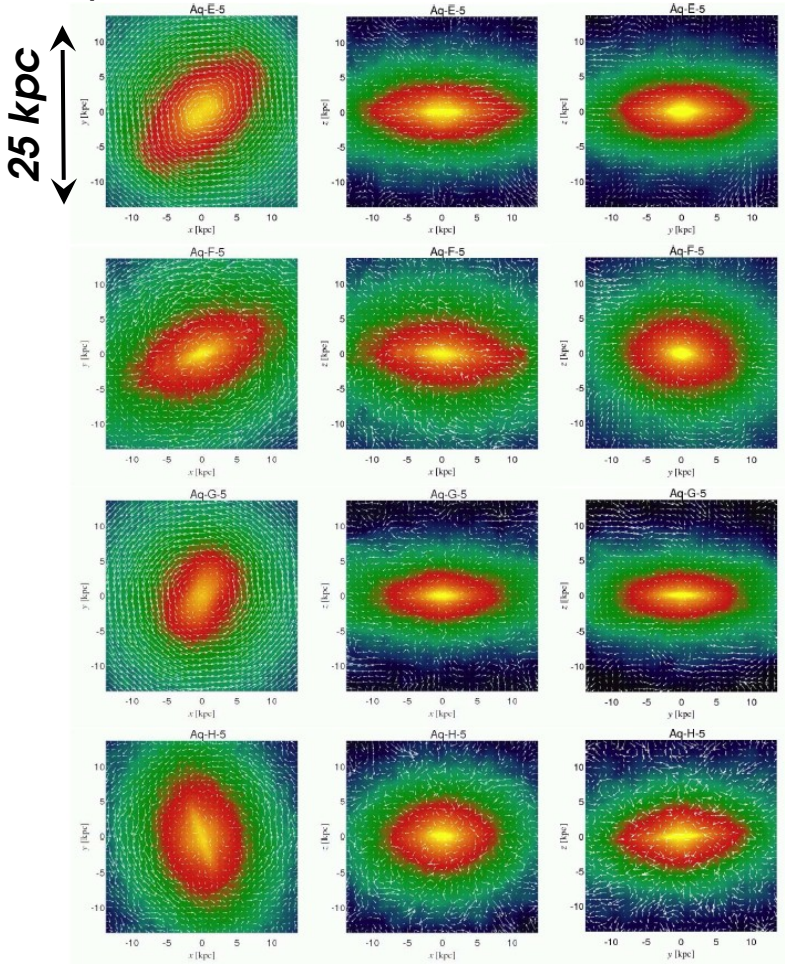
Safe travels everyone!

Undeniable theoretical progress in the last decade...

"*We should consider each failure as a success and we should make more errors.*"
- Andrew Pontzen

until ~2011 most simulations produced galaxies that were too massive, too compact, or dominated by spheroidal component





It's just a privilege to watch your mind at work...

“These papers are unintelligible, but I think they are basically correct…”

- Joop Schaye

“Certified organic, free-range, locally grown black holes.”

“Here we explore quenching in the wild.”

- Michael Tremmel

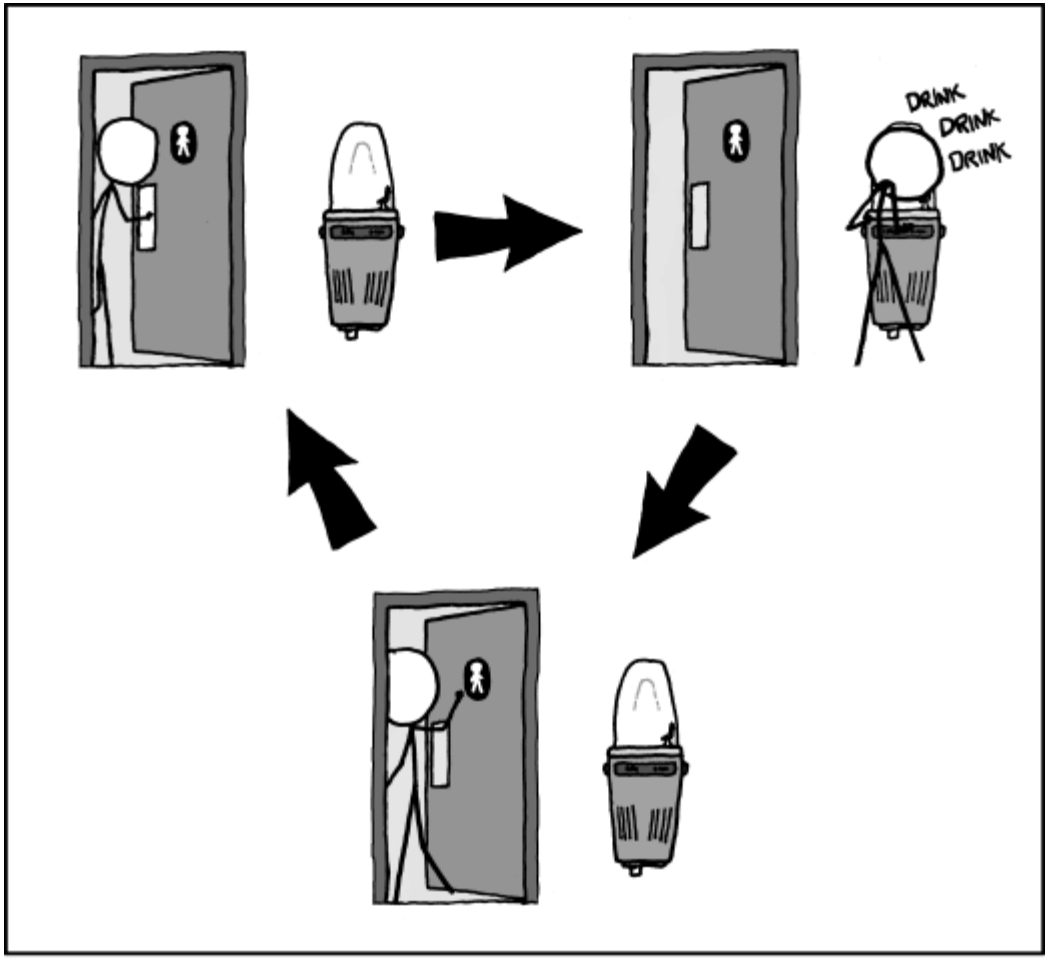
“I dedicate this slide to those targets that were never published...”

- Darshan Kakkad

“DRAMA simulations are really dramatic! It’s the first time I see radiation pressure doing anything.”

- Romain Teyssier

Star formation-feedback cycle



I AVOID DRINKING FOUNTAINS OUTSIDE BATHROOMS BECAUSE I'M AFRAID OF GETTING TRAPPED IN A LOOP.

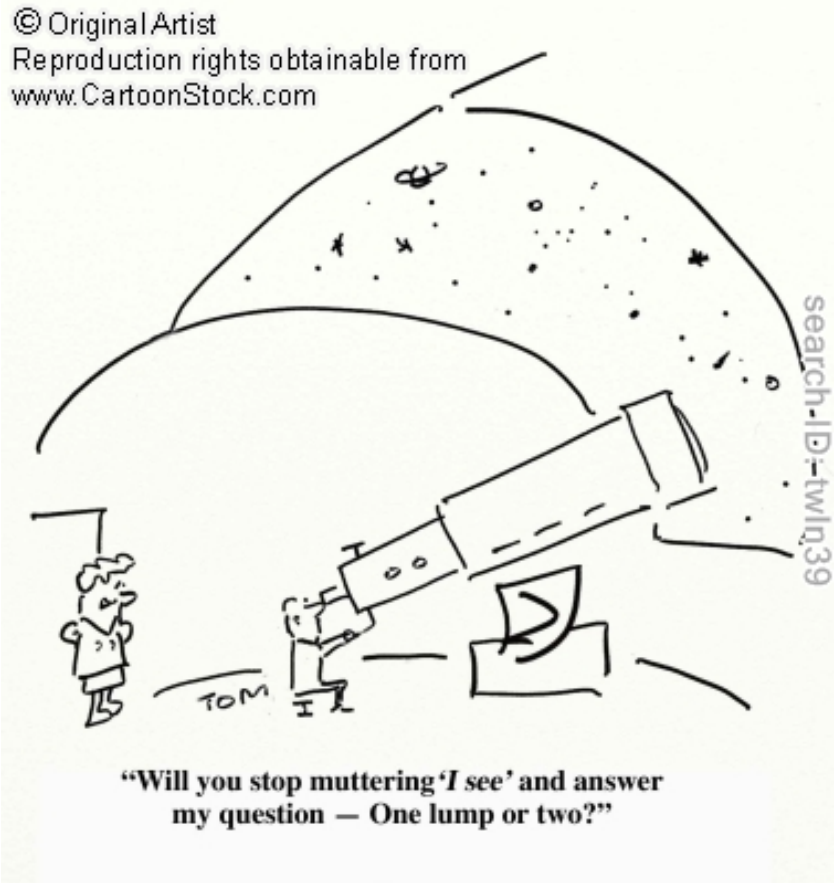
at this conference we heard a lot of exciting current results about stars and future possibilites

- Detailed assembly history of stellar halos of the Milky Way and other nearby galaxies (*Kathryn Johnston, Alis Deason, Emily Cunningham, Rachel Beaton, Elisa Toloba, David Sand, Aaron Romanowski, Ting Li, posters by Jeff Carlin, Mikito Tanaka, Ben Cook*)
- Detailed star formation histories of galaxies (*Dan Weisz, Carme Gallart, Alexia Lewis, Annette Ferguson*)
- Constraints on star cluster mode of star formation and element mixing (*Joss Bland-Hawthorn, Yan-Sen Ting, David Yong, posters Cliff Johnson, Hui Li*)
- Probing star formation in extreme environments in the early universe with metal poor stars and metallicity distributions in ultrafaint dwarfs (*Alis Deason, posters by Ani Chiti, Daniel Nagasawa, Andrew Pace*)
- Constraining masses with stellar kinematics (*Louis Strigari, Aaron Romanowski, poster by Robyn Sanderson*)

Question

How do we derive general conclusions about galaxy formation from very detailed information about a single or a handful of objects?

e.g., will detailed maps and kinematic measurements of stellar halo and Milky Way disk structure teach us about galaxies as a population? How?



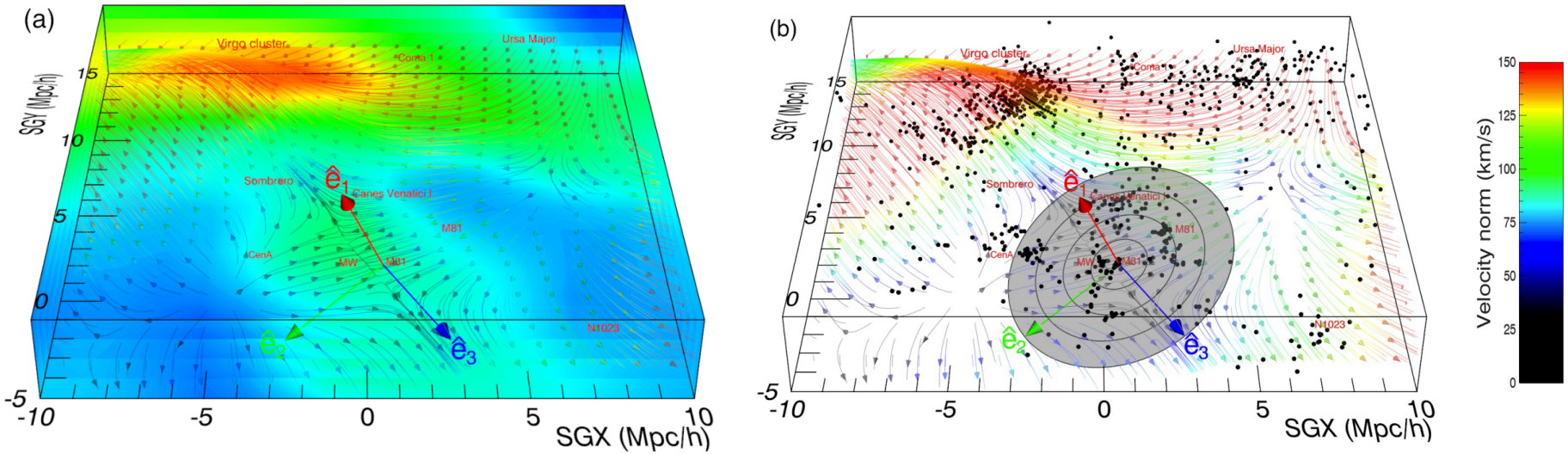
Having more systems should help [David Sand]

Need to develop theoretical framework for statistical properties of stellar halos [Brendan Giffen, poster by Ben Cook].

Question

Do we understand effects of environment in which Milky Way and the Local Group are located?

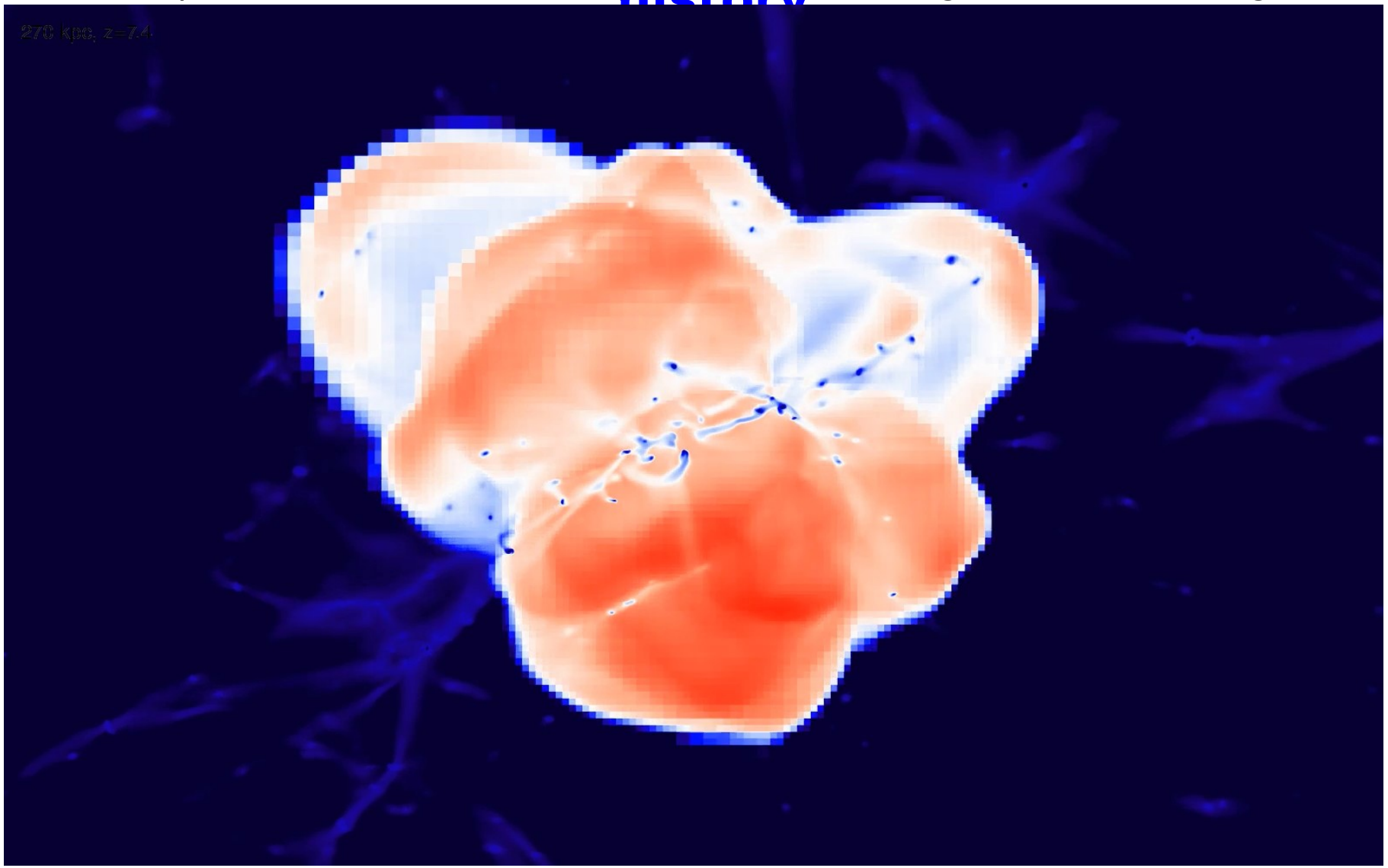
e.g., the Local Group is located in a very large sheet aligned with the Local Supercluster. MW and M31 satellite planes (+Cen A) are aligned quite well with this sheet [N. Libeskind's talk]. Understanding them is probably impossible without understanding effects of environment



Libeskind et al. 2015

Simulation of a Milky Way-sized progenitor with with strong feedback and realistic star formation history

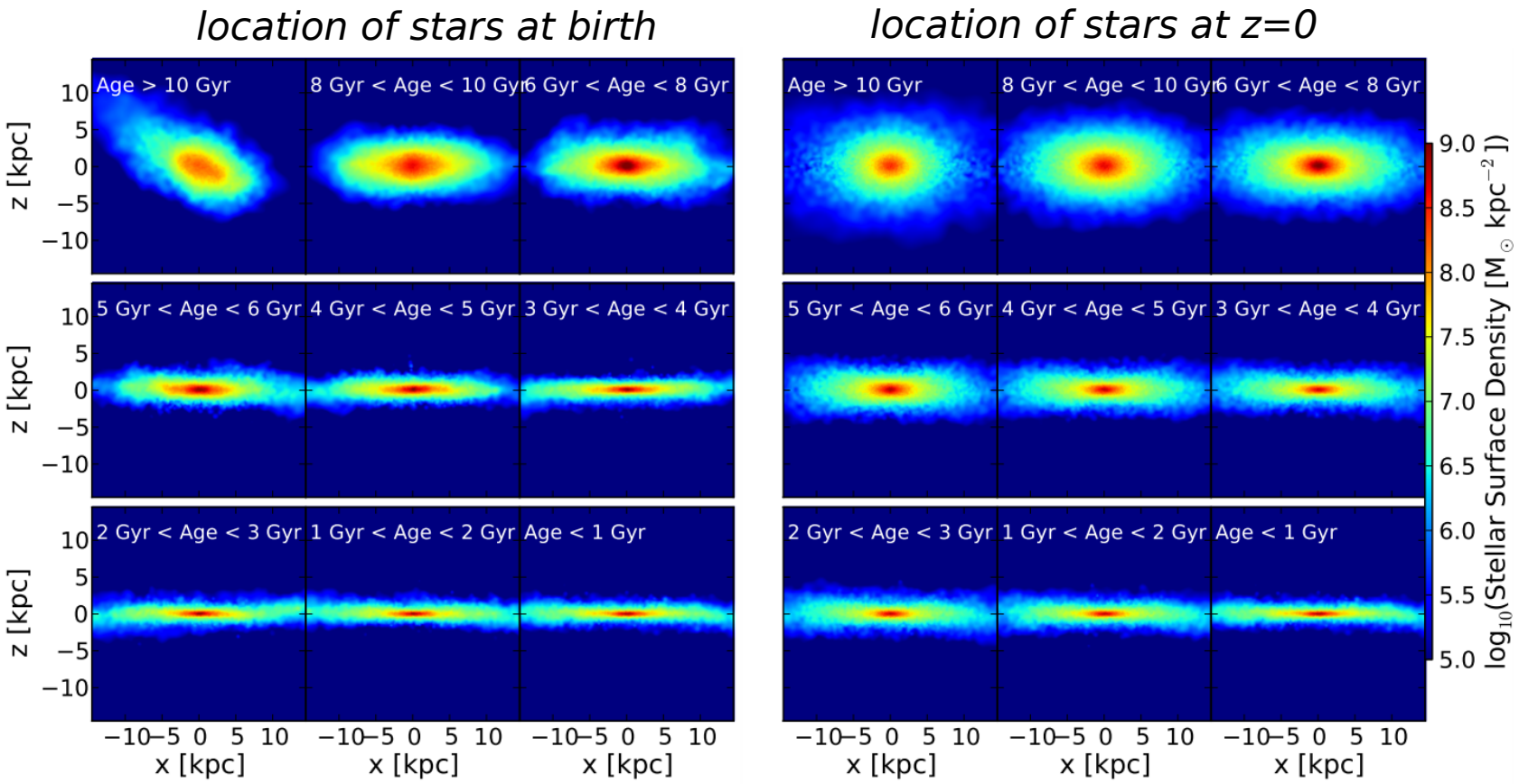
Temperature distribution of baryonic matter in a region around forming



Agertz & Kravtsov 2015, arxiv/1509.00853

Think of ways to challenge the models! (and of ways to improve them)

challenge what appears to be a generic prediction of current simulations: old stars are perturbed and hot and are concentrated towards the center? Is this consistent with the structure of nearby disks?



Stinson et al. 2013