Forging Connections: From Nuclei to the Cosmic Web
a JINA-CEE workshop

26-29 June 2017 *Kellogg Hotel and Conference Center, East Lansing, USA*
US/Eastern timezone

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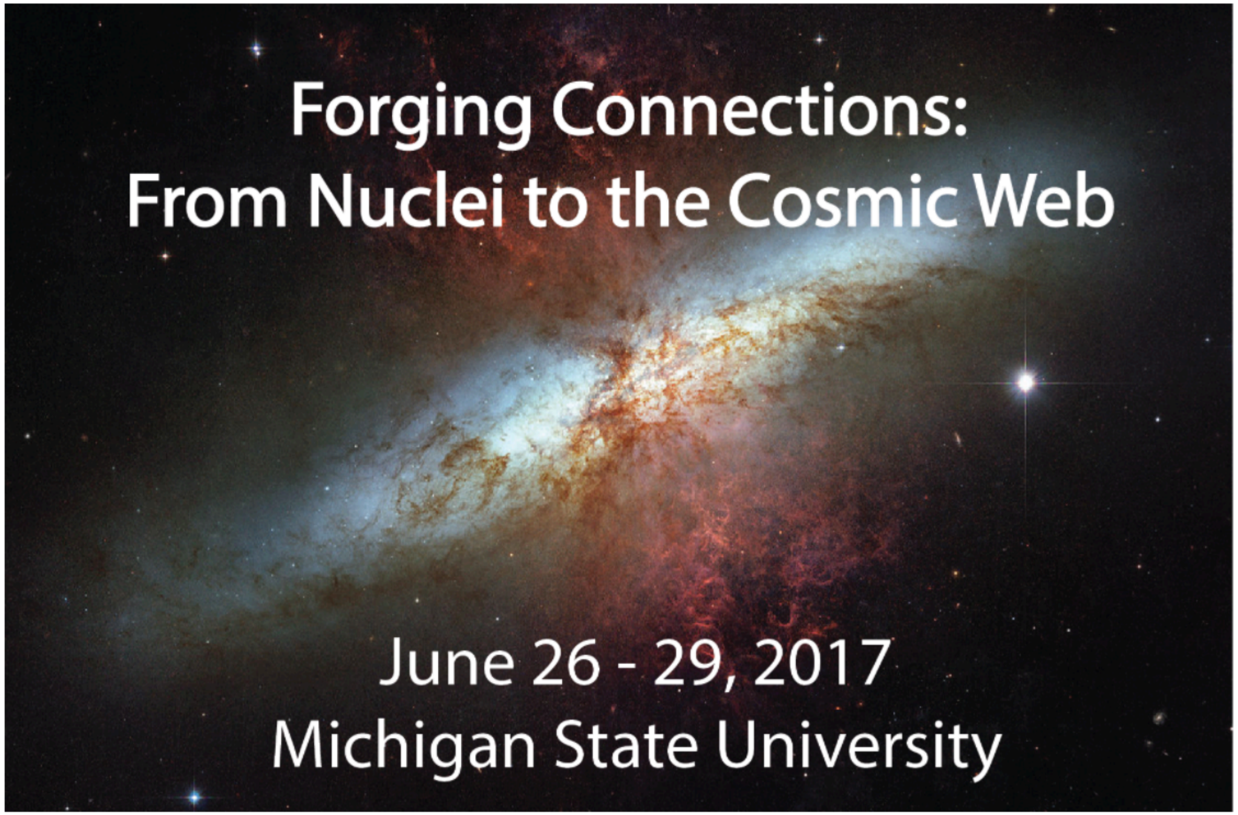


Vision

From Nuclei to the Cosmic Web strengthens interactions amongst the astrophysics and nuclear physics communities to facilitate scientific understanding of the formation and evolution of galaxies.

Conference summary

Joss Bland-Hawthorn

Congratulations to the SOC, especially Benoit & Brian, for such an inspired meeting.

How else does the broader community get to hear about the brilliant work at JINA-CEE, and related work elsewhere*. The fundamental work of reaction rates, line lists, atmospheric corrections etc. has been hidden from the broader community for too long, much the same way as the work of instrument and telescope builders goes unrecognized.*

This is one of the most interesting meetings I've attended in my career.

I trust there will be a vote of thanks for the LOC and ground staff that put all of this together. Very well done.

Vision

From Nuclei to the Cosmic Web strengthens interactions amongst the astrophysics and nuclear physics communities to facilitate scientific understanding of the formation and evolution of galaxies.

Motivation

Roughly half of the elements in the universe that are heavier than helium are in stars and the interstellar medium, and the rest is in the circumgalactic and intergalactic medium. All of these elements are produced in stars or their remnants, and they are critical to both structure formation (i.e., star and galaxy formation) and stellar evolution. The purpose of Forging Connections: From Nuclei to the Cosmic Web is to bring together observers, experimentalists, and theorists whose expertise spans the range of subjects necessary to understand the full life cycle of the baryonic content of the universe, and to forge connections to address the challenges relating to studying chemical enrichment in the era of large stellar and IGM surveys.

Rationale

The fundamental connections between chemical elements and the cosmos remain a rich site of fascinating challenges that include the interplay between stars, chemical evolution, galaxies, the intergalactic medium, and large scale structure. This bonanza of physical puzzles is closely linked with the generation of gravitational waves, the r-process from compact objects, and the diversity of exoplanet atmospheres.

Recent observational and experimental clues that challenge conventional wisdom coupled with the expectation of large quantities of data from upcoming surveys and experiments, coupled with new advances in modeling and simulations offer significant improvements in our quantitative understanding of the connections between nuclei and the cosmic web. An international and interdisciplinary meeting, Forging Connections: From Nuclei to the Cosmic Web is designed to promote collaboration to solve a range of open questions.

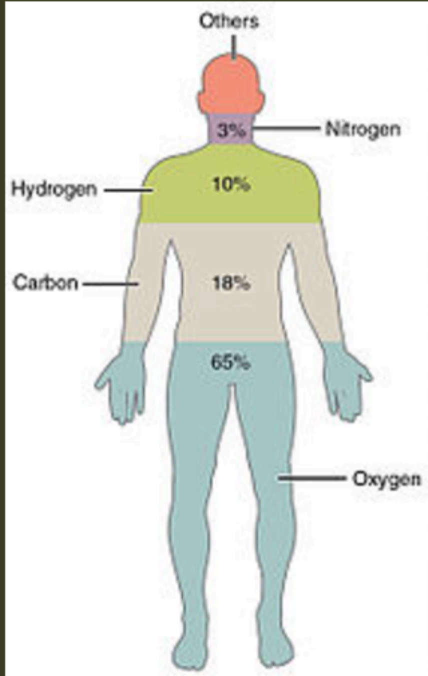
JINA: Joint Institute for Nuclear Astrophysics

The origin and fate of matter in our universe are the fundamental questions in nuclear astrophysics. The statement by Carl Sagan "we are made of star stuff" highlights and summarizes the fascination of this field. The desire and need for understanding the cosmos on the femto-scale while interpreting observations and events on the tera-scale created a momentum of intellectual fascination and challenge which has propelled the field to the forefront of physics.

The rapid growth of observational results, the tremendously expanding computational capabilities, and the new experimental and theoretical opportunities to probe and simulate the behavior of nuclei under extreme conditions now brings within reach the answers to many open questions. The rapid progress and expanding scope of the different disciplines constituting nuclear astrophysics also introduce an enormous level of complexity to the field.

The Physics Frontier Cente
of Notre Dame, Michigan S
Laboratory will provide an i
and stimulating collaboratio
point in a rapidly growing a

JINA will foster interdiscipli
educational initiatives at its
astrophysics at large. We i
physicists - theorists and e
in this endeavor and to hel
of nuclear astrophysics.



Element	Symbol	Percentage in Body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.1
Trace elements include boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).		less than 1.0

At Michigan State Universit
within the Department of P
Laboratory (NSCL) and has its own website at http://www.jinaweb.org/.

Snapshot of the meeting

Nuclear reactions, rates & fission
Wiescher, Dillman, Eichler

i-process
Herwig

s-process
Karakas, den Hartogh

Pre-SN, shell mergers
Peterman, Andrassy

CCSN/NSM, r-process, γ-process
Heger, Warren, Travaglio, Fröhlich, Fryer

XRB burst, rp-process, αp-process
Jacobs

Neutron star CM physics
Caplan

NLTE
Ezzedine

GCs, integrated light
Sakari, Conroy

SF/AGN bubbles/winds (γrays, RA decay)
Diehl, Bordoloi

UFDs
Frebel, Safarzadeh, Roederer, Lee, Ji

CGM
Tumlinson, Silvia, Som, Sorini

Surveys
Gilmore (GES, Gaia), Buder (Galah), Venn (Pristine), Presented: Apogee, SAGA, K2

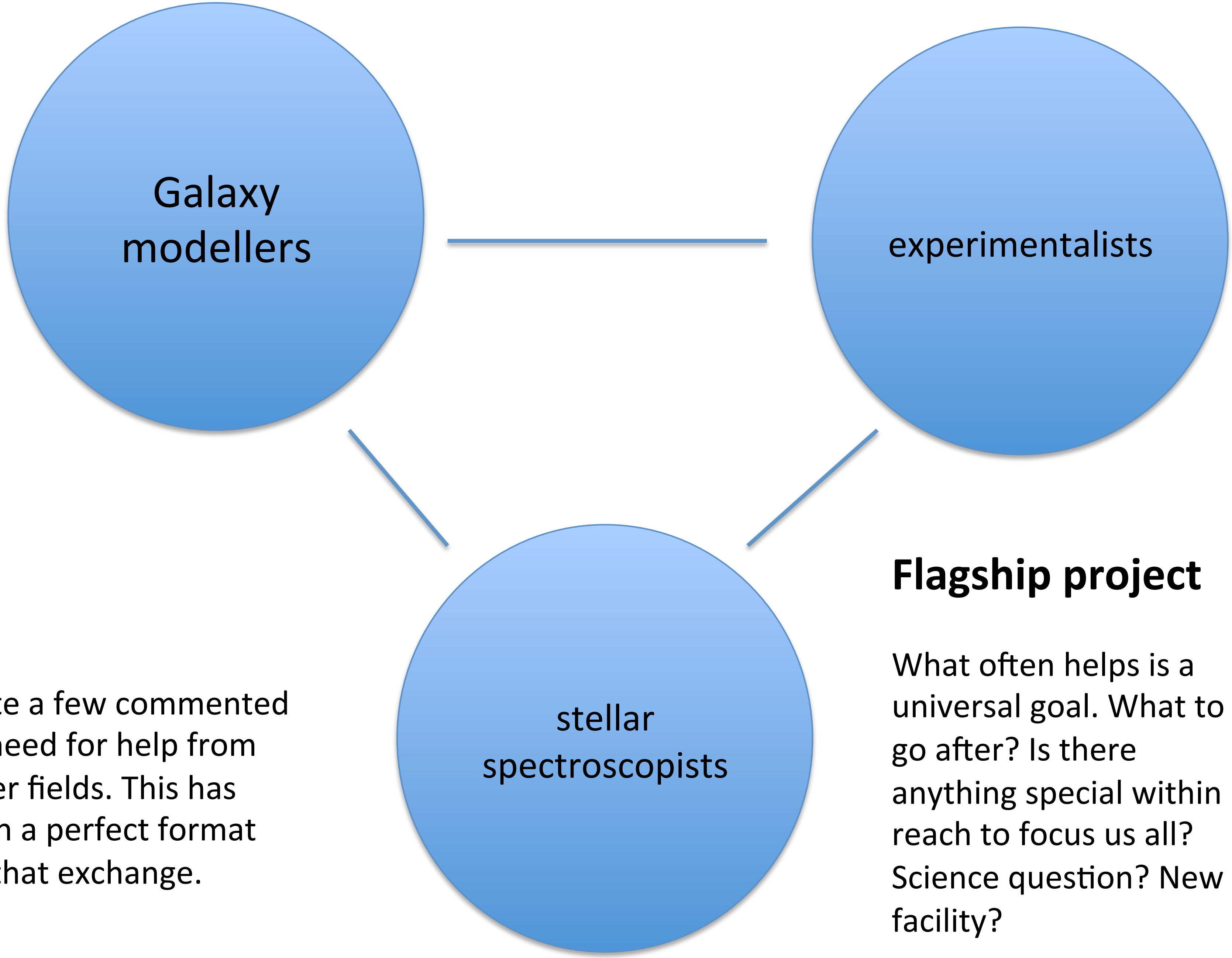
Big Picture - stellar evolution
Conroy, Gibson, JBH

Big Picture – ISM/dust/metals evolution
Mattsson, Pignatari, Berg

BBNS/neutrino cosmology
Grohs

Missing?

Exoplanetary science/meteoritic record, isotopes in stellar spec, BBNS/new physics, abundance pipeline experts



Quite a few commented on need for help from other fields. This has been a perfect format for that exchange.

Flagship project

What often helps is a universal goal. What to go after? Is there anything special within reach to focus us all? Science question? New facility?

Science of complexity

- Most fields start simply, increase in complexity, die or bifurcate (let's stay together!) – comment from Freeman Dyson (Nov 2016)

- Medical science says to deal with vast complexity and profound simple rules (new physics) can emerge eventually

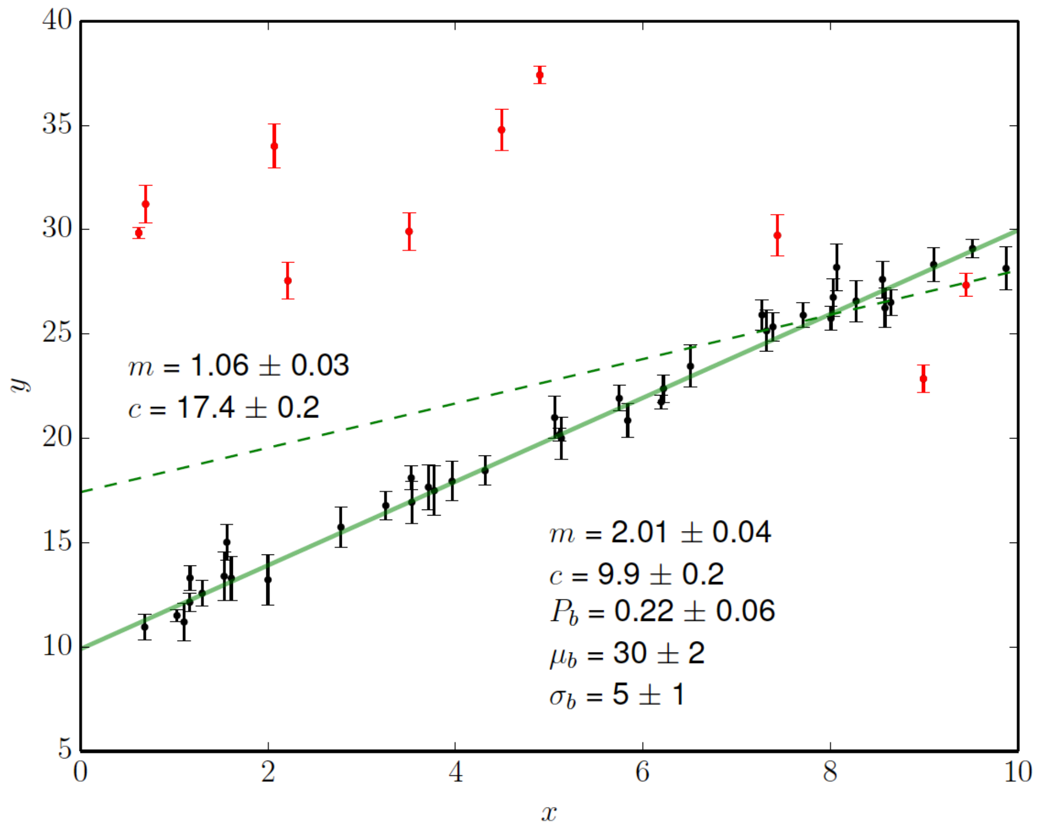
- We need controlled, differential measurement:
  Landau N-dimensional space, drive to extremes to reduce N

=> Outliers may be very important to insight, e.g. abundance anomalies.

To Joss Hawthorn

You ask a good question about subresolution models in galaxy formation. Sometimes it does seem hopeless to me, given the complexity and large range in scales that need to be accounted for. Perhaps one thing that gives me hope is the observational side, which tells us that galaxies exhibit a great deal of regularity in the properties. But, I am not sure if this is telling us that the outcome does not depend so much on details, or maybe it is so complicated that all the ingredients blend together in a way like the central limit theorem, which would be bad...

For private reflection: do you like data in toto, to force data to fit, or do you relish the outlier ?



S. Sharma, ARAA 2017 Astro-ph

Figure 3

Fitting a straight line to data with outliers. The outliers are shown as red points. The dashed line is the best fit line when an outlier model is not used. The solid line is the best fit line with an outlier model. The data was generated with model parameters $m = 2$ and $c = 10$. 20% of the points were set as outliers and sampled from $\mathcal{N}(30, 5^2)$.

Complexity exists all across the Galaxy:

e.g. we must remember galactic dynamics

Constructing a null hypothesis is still critical in a complex space, otherwise what are you learning ? How to set up a controlled experiment ?

A lot of information may be washed out by secular / violent effects which make a mess of "closed box" experiments:

- Blurring & churning (Sellwood & Binney) – transient spirality, accretion
- Bar formation (Pfenniger & Combes) – happened mostly after reionization
- Cusp/core (Pontzen & Governato) – happened after reionization

So what can we consider a clean localized volume?

Maybe GCs, OCs, UFDs, but not the Solar Neighbourhood, Gal Ctr ?

e.g. may need to rethink classic problems like the G dwarf problem ?

e.g. rise of the s-process for different components, treat in toto rather than radius ?

Let's play this all in reverse and learn about blurring processes over cosmic time.

FIRE / Latte

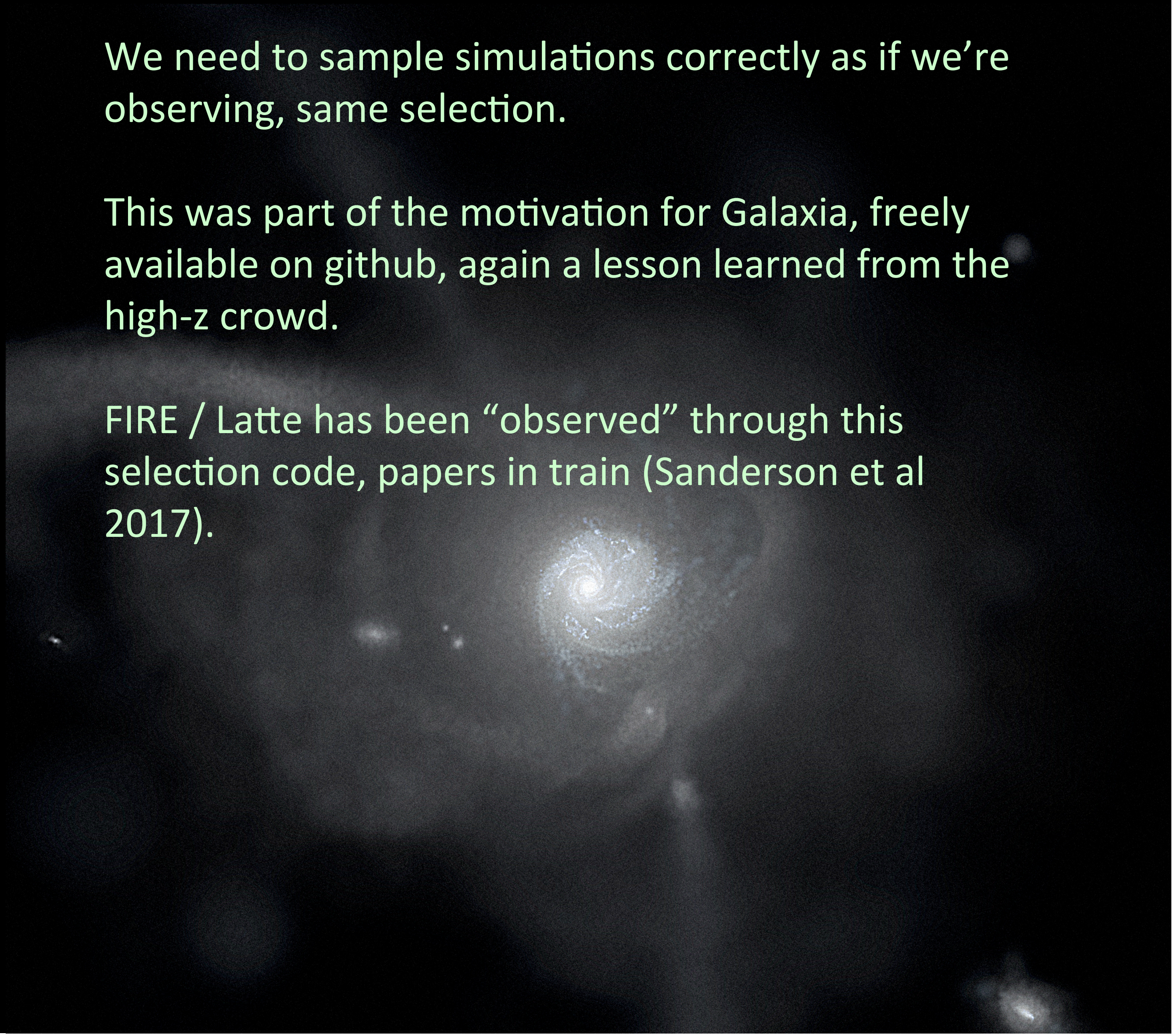
P. Hopkins, A. Wetzel
X. Ma, R. Sanderson

SELECTION FUNCTIONS

We need to sample simulations correctly as if we're observing, same selection.

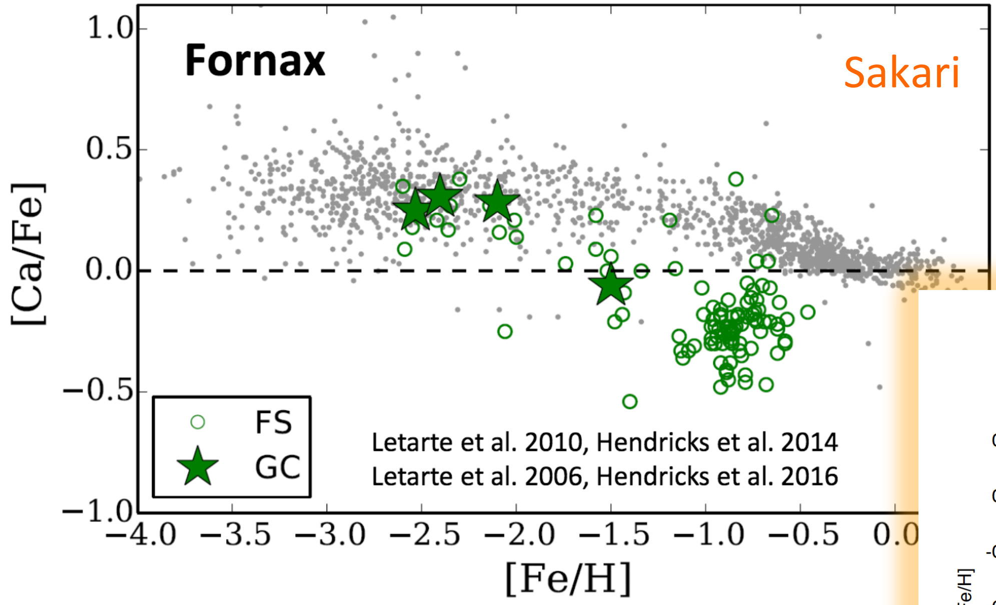
This was part of the motivation for Galaxia, freely available on github, again a lesson learned from the high-z crowd.

FIRE / Latte has been "observed" through this selection code, papers in train (Sanderson et al 2017).

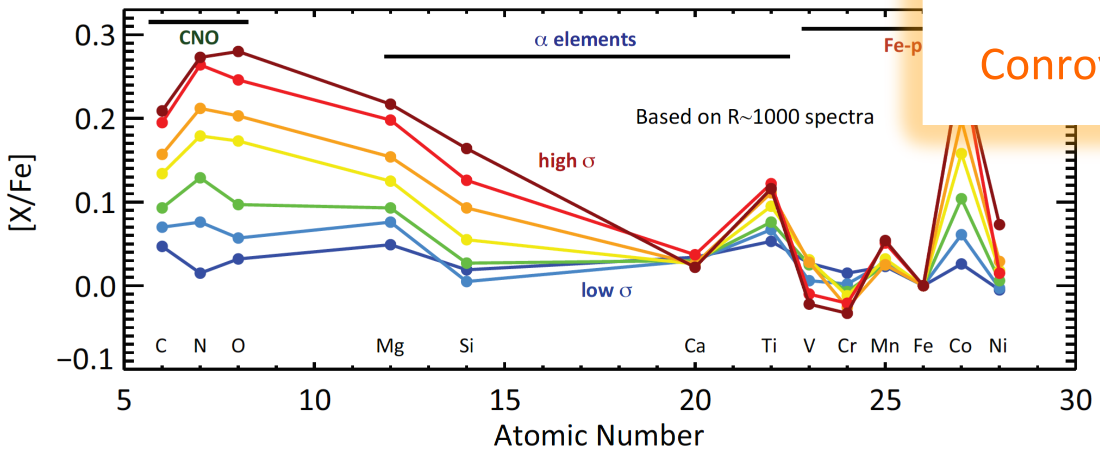


Integrated light spectroscopy

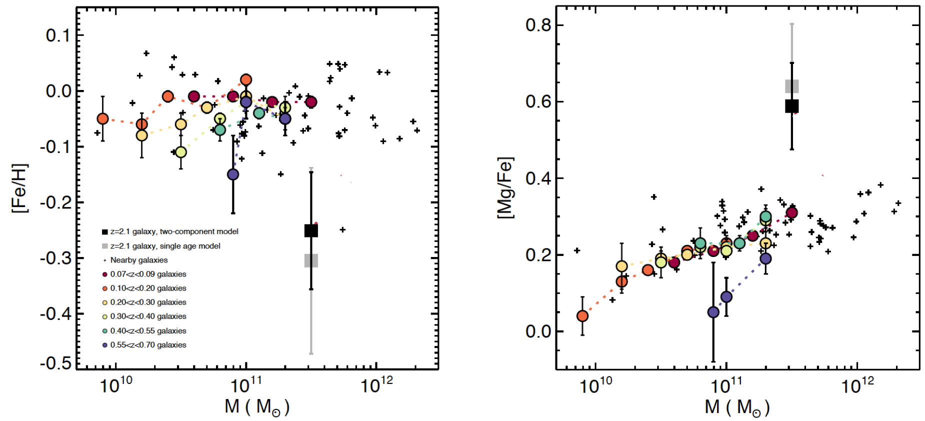
Impressive to see heavier metals emerge…



The abundance pattern of quiescent gala



A chemically-extreme stellar population



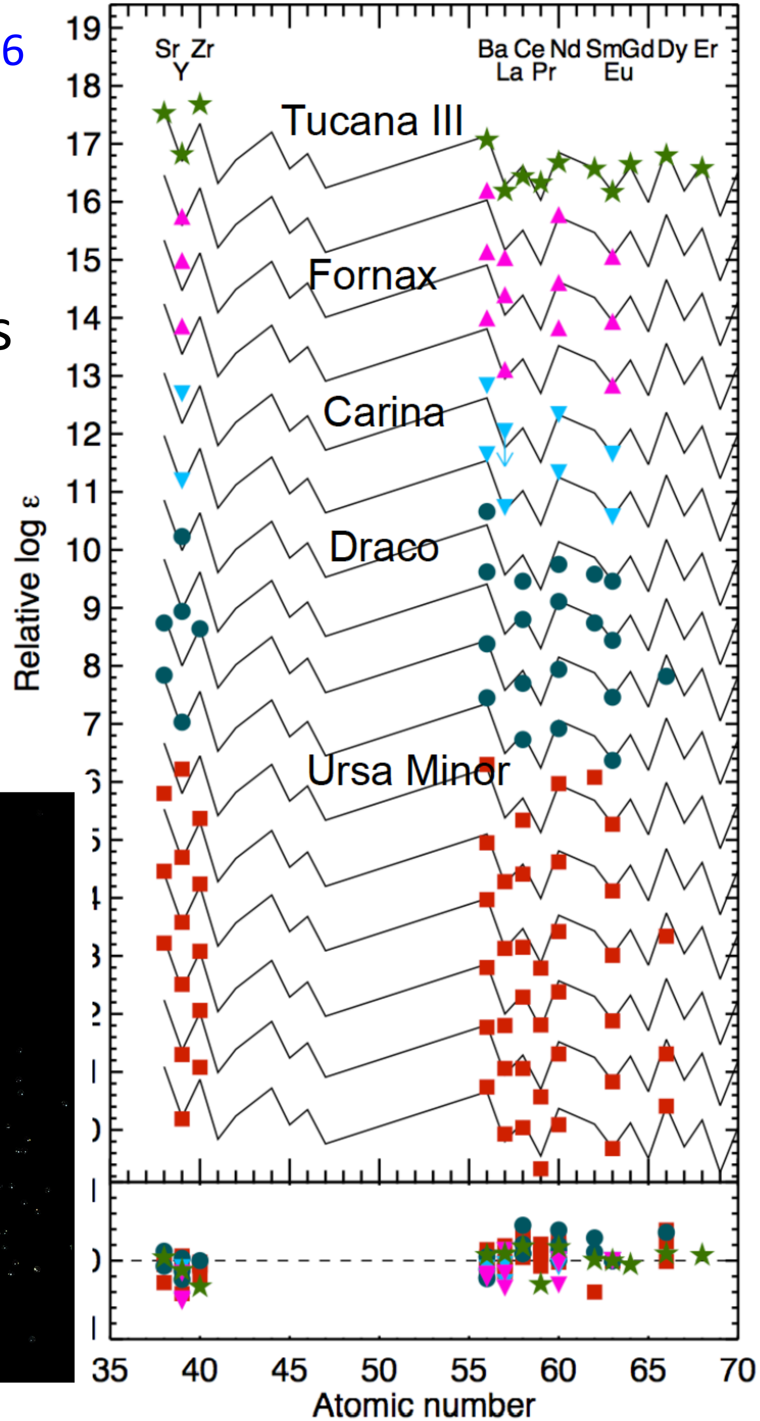
Conroy

The highest [Mg/Fe] ratio measured from the integrated light of a galaxy to date

Ji, Frebel, Simon, Chiti 2016

Ultra faint dwarfs are very exciting microcosms of early epochs, ancient chemistry, e.g. Ret II with unique r-process

Brown et al (2014) claim they predate reionization, and they've experienced few events.



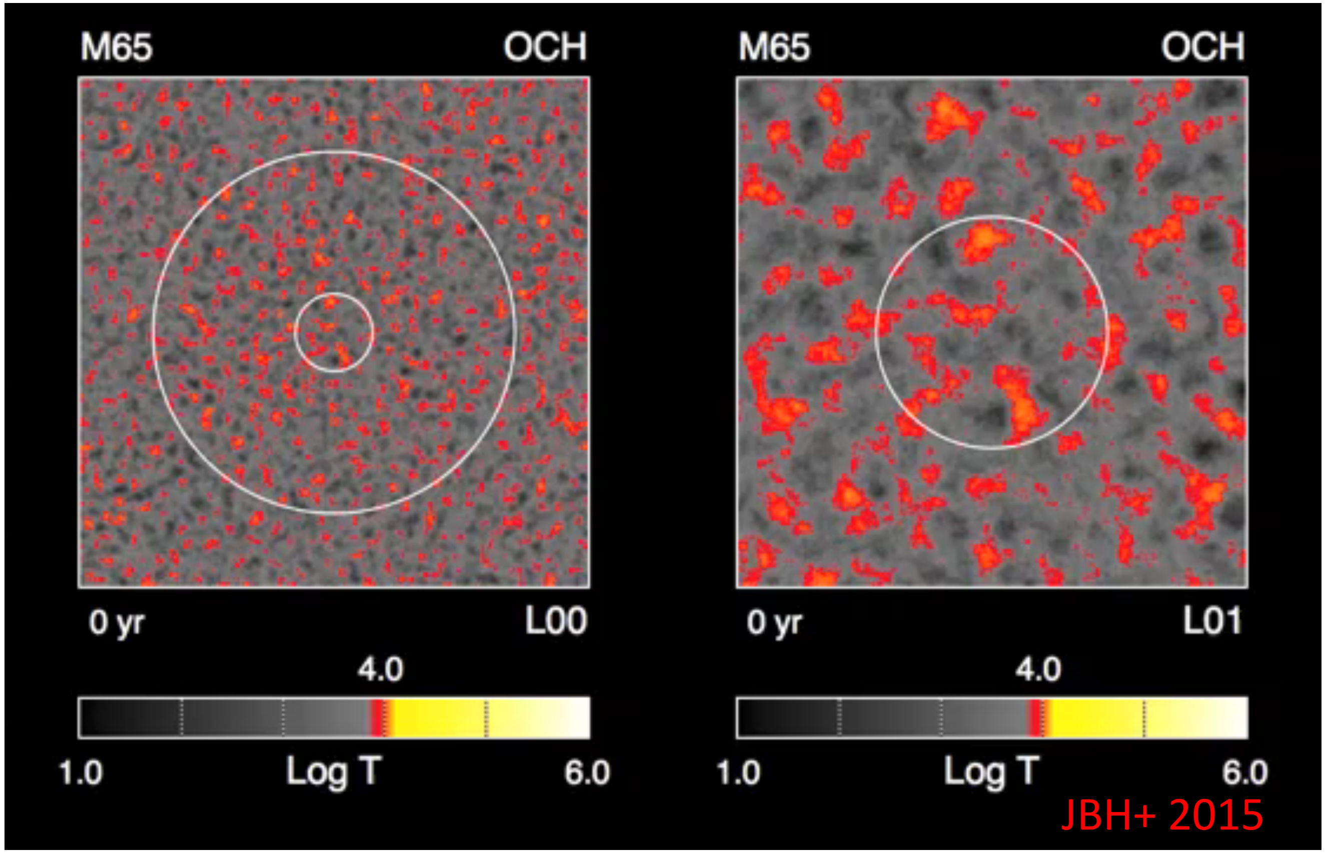
THE ASTROPHYSICAL JOURNAL

ULTRAFAINT DWARF GALAXIES—THE LOWEST-MASS RELICS FROM BEFORE REIONIZATION

Joss Bland-Hawthorn[1], Ralph Sutherland[2], and David Webster[3]

Published 2015 July 9 • • The Astrophysical Journal, Volume 807, Number 2

Gas in halos $M_{vir} \sim 10^7 M_\odot$ can survive pre-ionization & SN explosion of 25 $M_\odot$ star

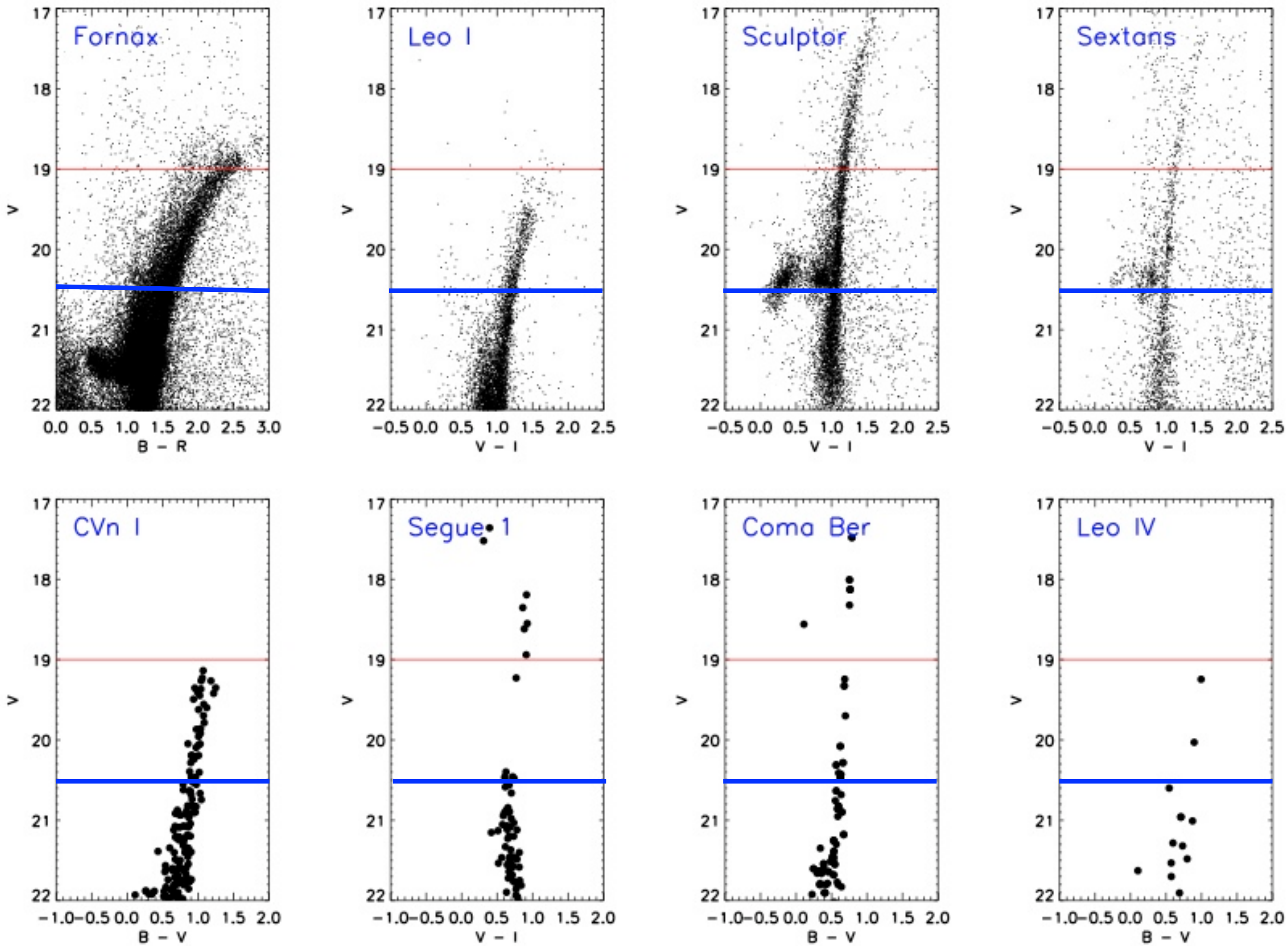


How:

1. off-centred star
2. fractal medium
3. resolved SN shock front
4. time dep. ionization
5. clustered SF through the **initial cluster mass function**

Results used in Webster+ 2014, 2015a,b,c

Really need MOS high res spectroscopy on ELTs

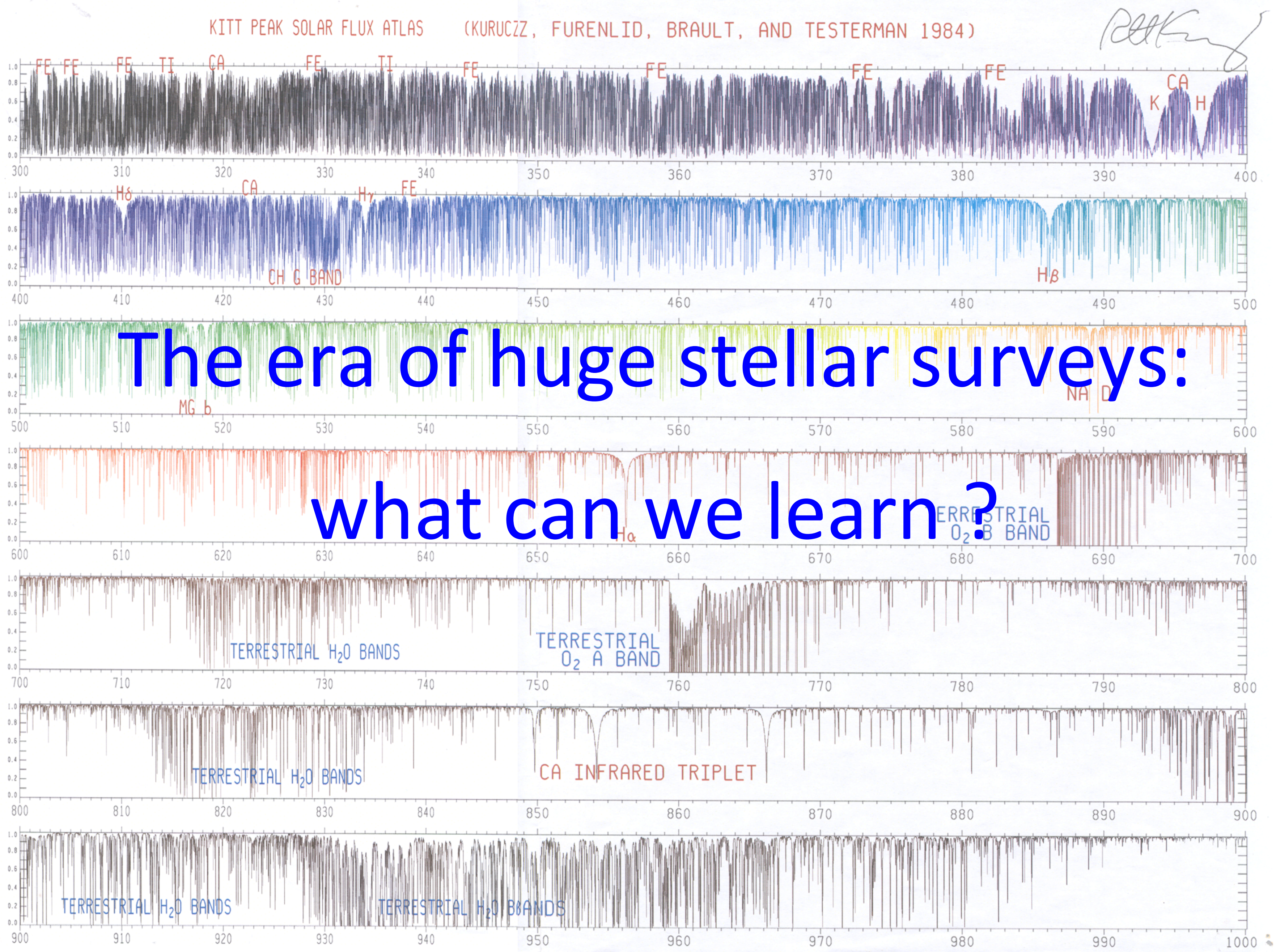


8m limit @ R=20K, V ~ 19, SNR ~ 30, 15 hours, **OPTICAL** (Frebel):
observe C, Na, Mg, Al, Si, Ca, Sc, Ti, Cr, Mn, Co, Ni, Zn, Ba, Sr

GMT/G-Clef (~10 objects in 20' field) limit @ R=20K should get us to V ~ 20.5

The era of huge stellar surveys:

what can we learn ?



More discussion needed

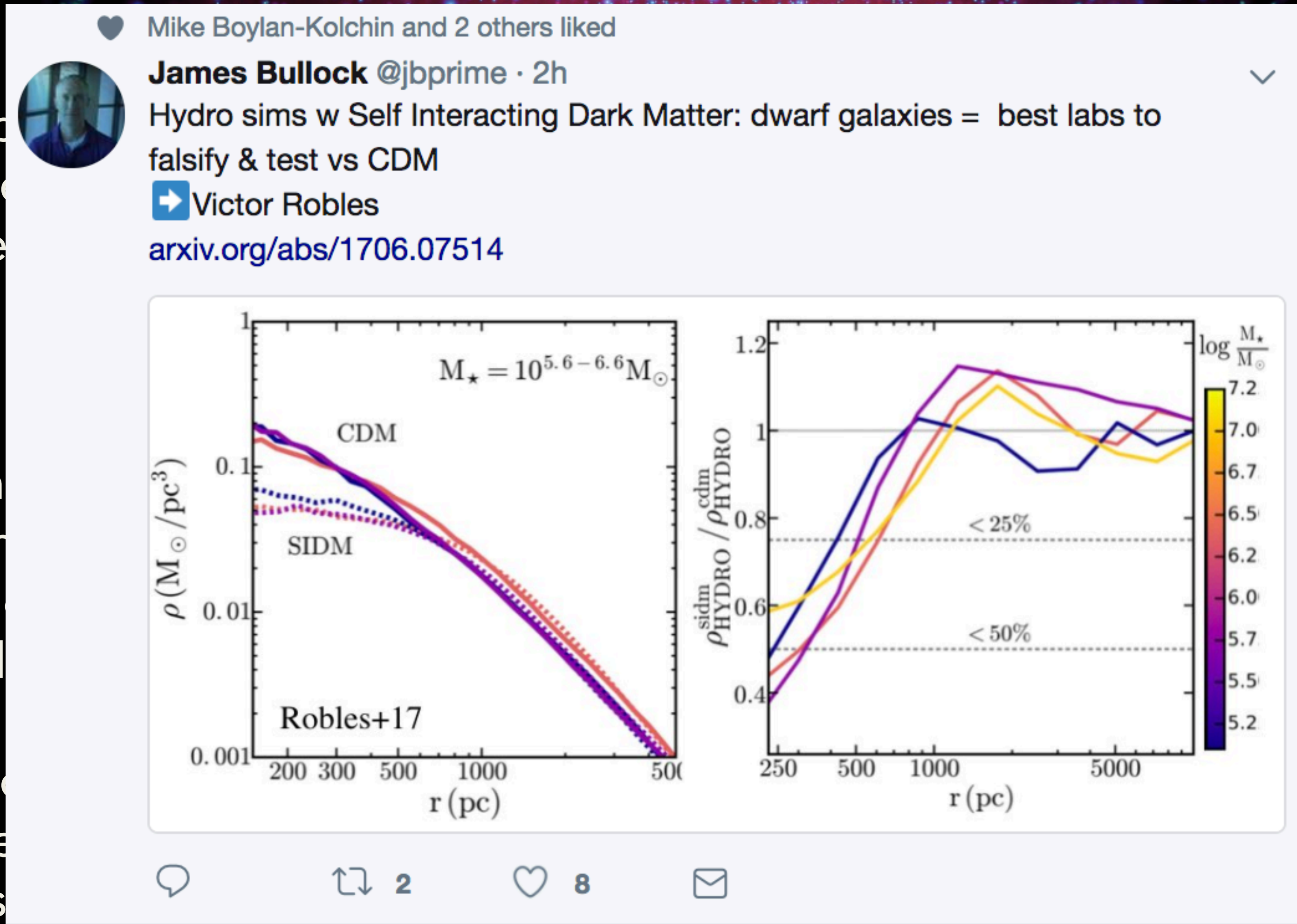
- GALAH/Gaia-ESO, note huge amount of work to get good abundances before big science statements. Incomplete line lists, 3D NLTE, systematics, etc. So when to start? E.g. When do we believe the scatter is real?
- Arnett: *isotopes keep theorists honest*, but can we measure many reliably in stellar spectra? What would it take to push for more?
- Spectra have far more info in them – dumb objective machine learning codes are better than clever codes !!
- Bringing together photometric, seismic, interferometric, spectroscopic data leads to first rate training sets. These are the fuel for the *Cannon* fire…
- One of the great unknowns or complexities is the impact of stellar rotation across all properties, models, observations... (this deserves its own review talk)
- **With awesome compute power easily accessible, you do need to rethink your strategy completely !! You can do new things in new ways.**

The big questions:
Are we really testing ΛCDM ?

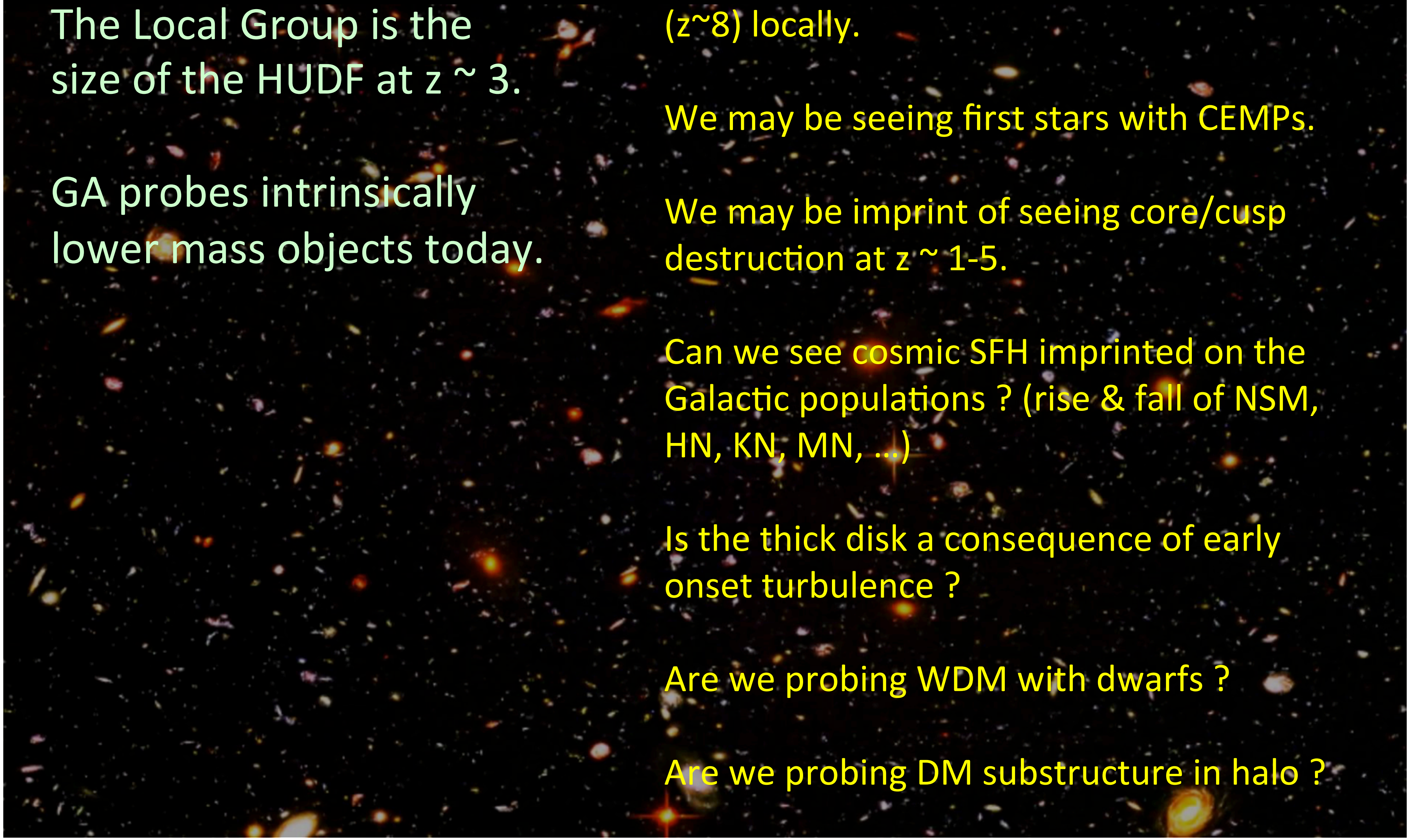
Let's not overdo
the pressure exe
field crowd to e
a survey. This is
Australia where

It is noble to un
complex system
of science. You
with well posed

You are closer t
science. In the e
under a single s
talk about "understanding galaxy formation
and evolution."



GA is the ultimate cold case



The Local Group is the size of the HUDF at z ~ 3.

GA probes intrinsically lower mass objects today.

We may be seeing imprint of reionization (z~8) locally.

We may be seeing first stars with CEMPs.

We may be imprint of seeing core/cusp destruction at z ~ 1-5.

Can we see cosmic SFH imprinted on the Galactic populations ? (rise & fall of NSM, HN, KN, MN, ...)

Is the thick disk a consequence of early onset turbulence ?

Are we probing WDM with dwarfs ?

Are we probing DM substructure in halo ?

GA is both evolutionary and environmental science.

Evolutionary: build up of components, metals, unravel past events
Environment: accretion, feedback, dynamical processes

Big GA questions:

1. Are we really testing ΛCDM, different CDM cosmologies ?

2. What is our relationship to M31, to the Local Group and beyond ?

3. How much of the past has been washed away ? How much of our narrative can we reconstruct ?

Beautiful physics in action

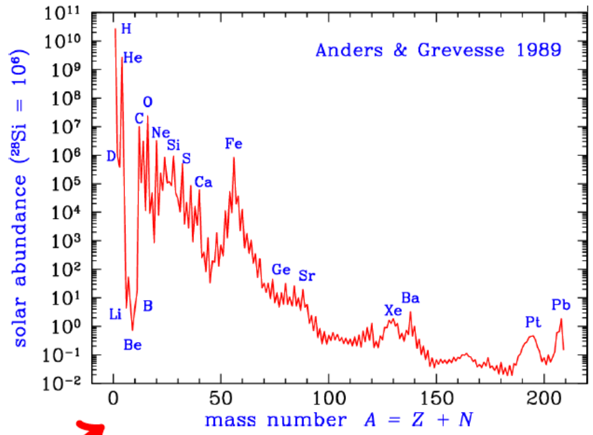
The solar abundances

s-process
AGB stars
massive stars

r-process
neutron star mergers?
MHD SNe?
ν-driven winds in CCSNe?

i-process?
AGB stars?

γ-process
CCSNe
type Ia SNe



explosive nucleosynthesis
CCSNe

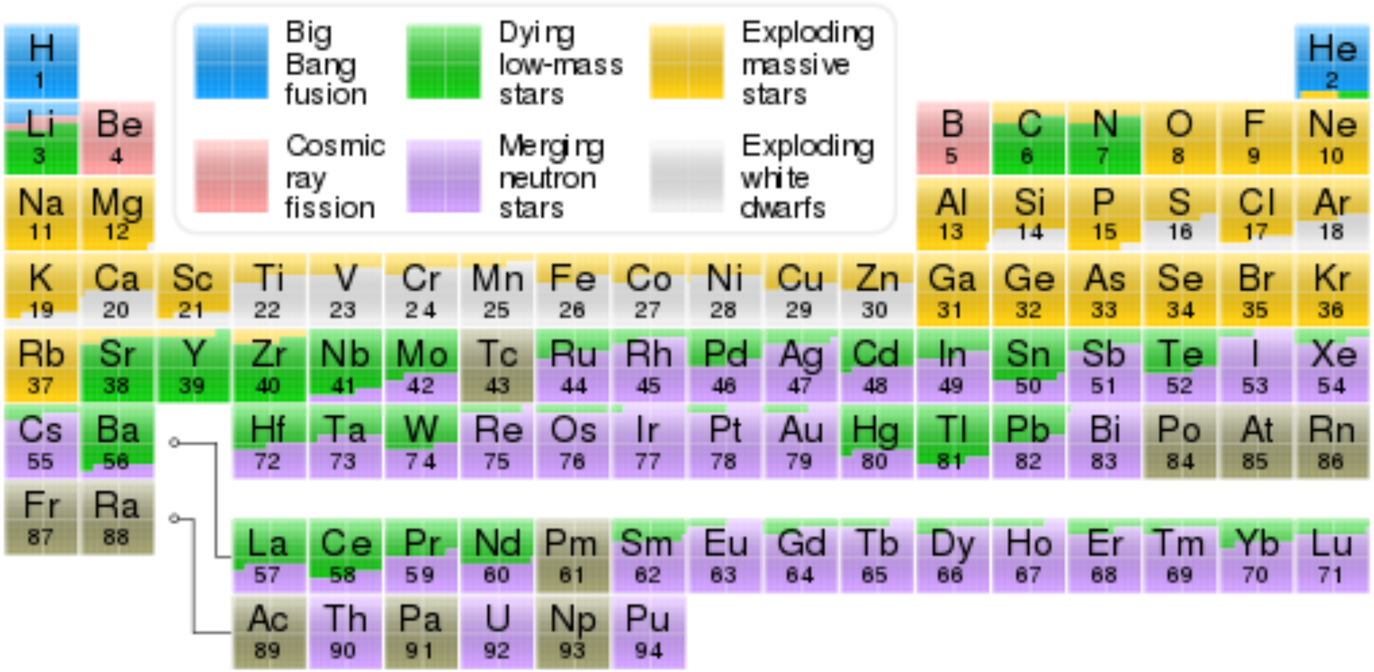
rp-process
X-ray (super-)bursts

νp-process
ν-driven winds in CCSNe

Rewriting the books:

NSM preferred over CCSN for the r-process?

It started almost as an afterthought at the end of Lattimer & Schramm 1974

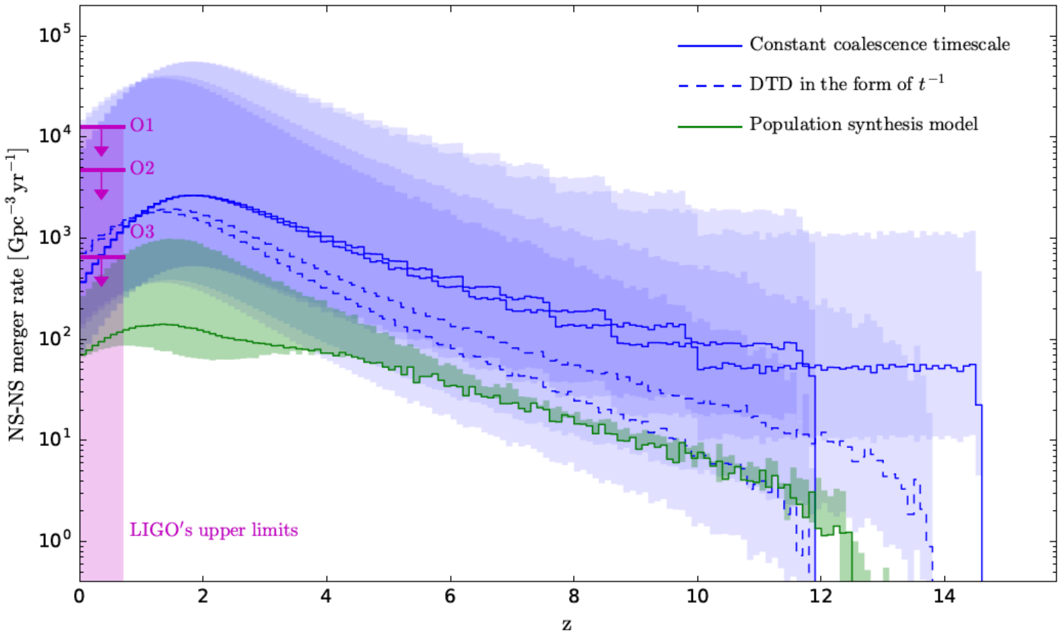


Is this any prospect of accretion disk nucleosynthesis ?

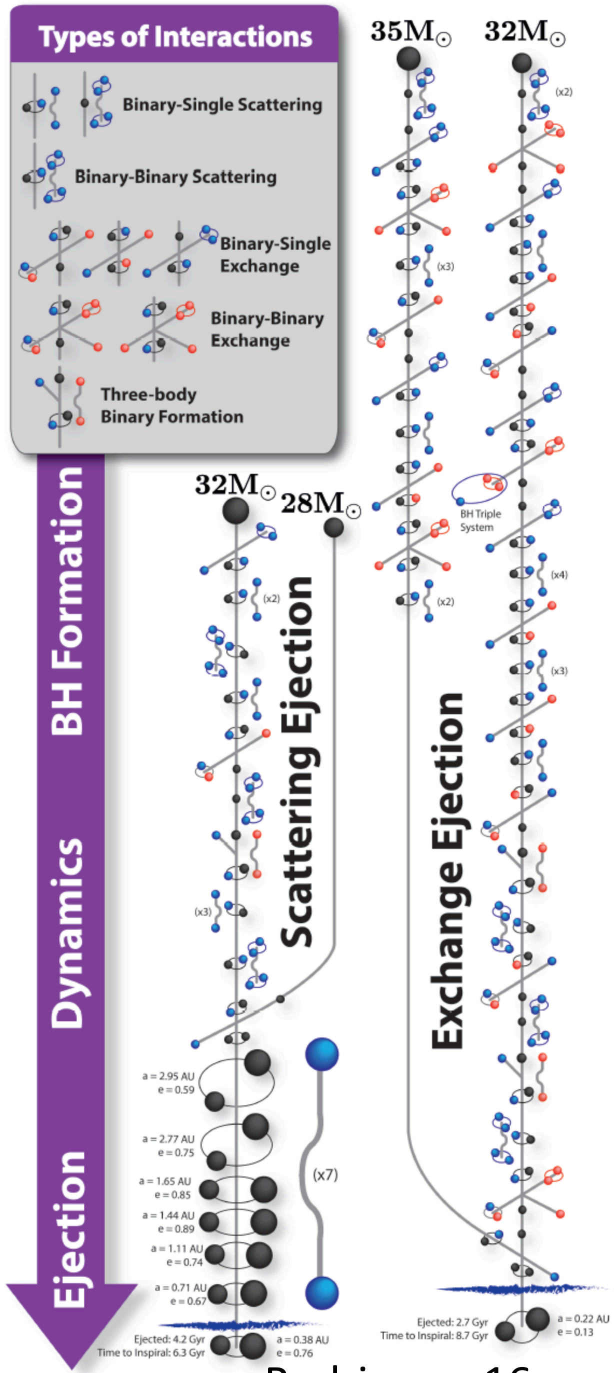
Going gaga over LIGO…

Nice constraints on r-process production via NSM and LIGO events to date. Yes, most LIGO events could trace back to ancient times.

But we need to see NSMs with LIGO to really nail this - surely a matter of time?



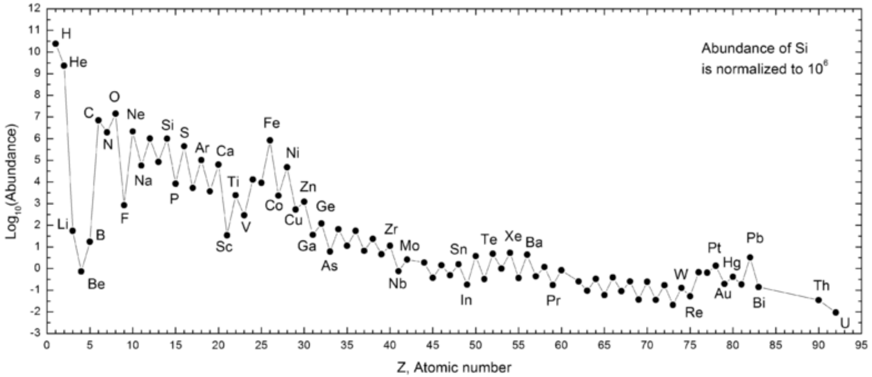
Coté + 2017

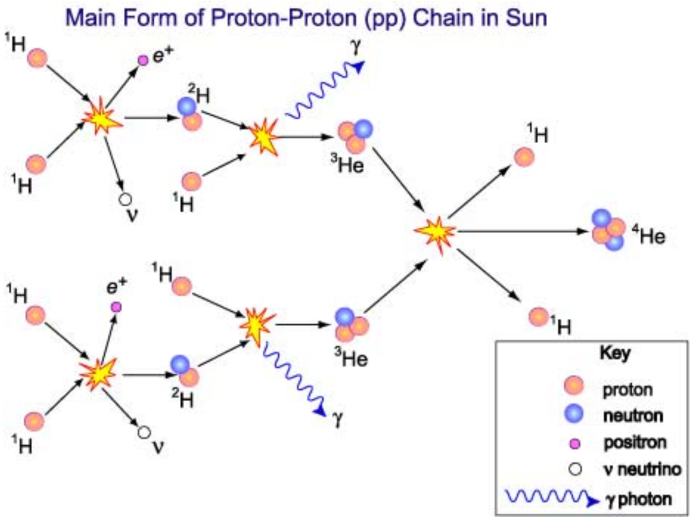


Rodriguez+16

Beautiful physics in action

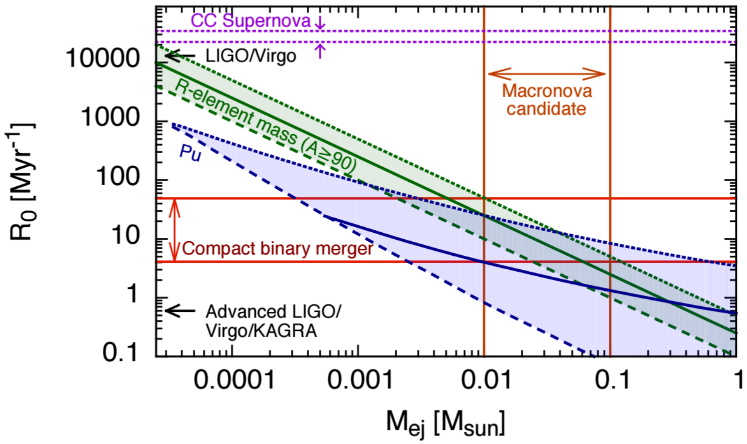
1. Amplitude of odd-even effect in observed stars smaller than simulations – why?

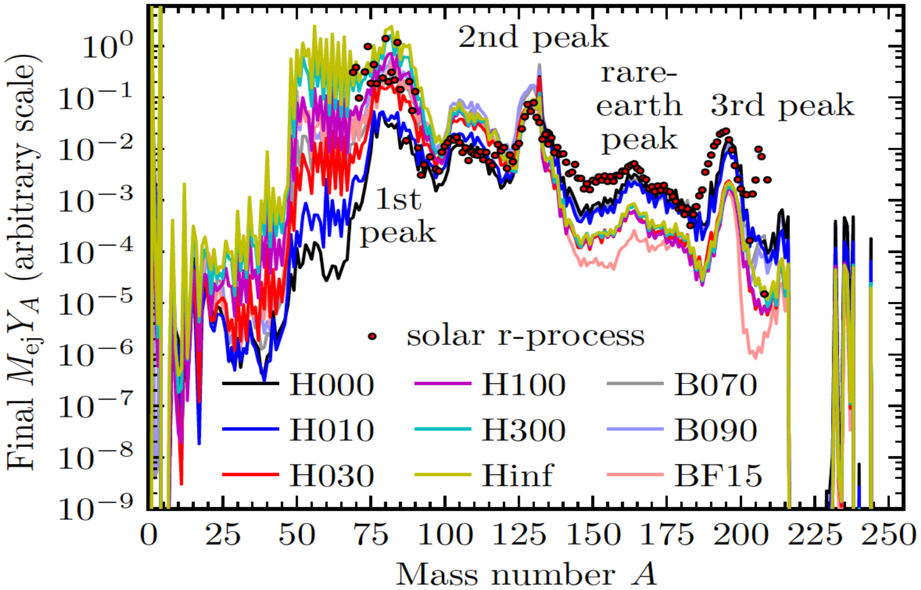




2. Too premature to talk about N distinct sites for *r* process ?

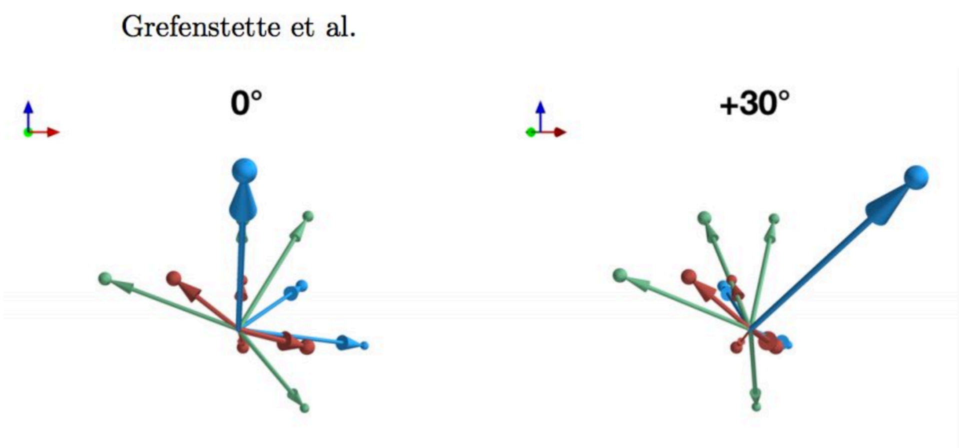
Lippuner+17

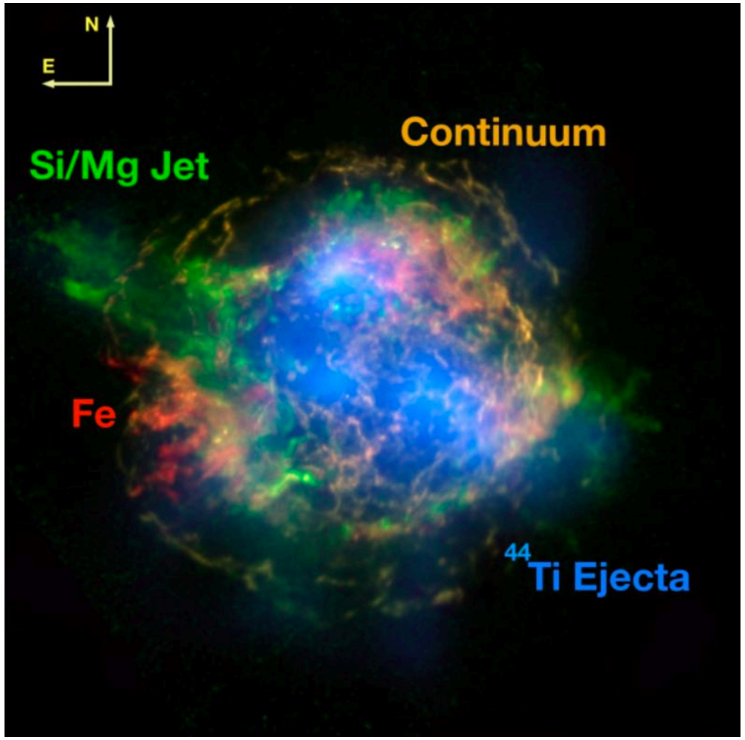




CCSN, SNIa, nova

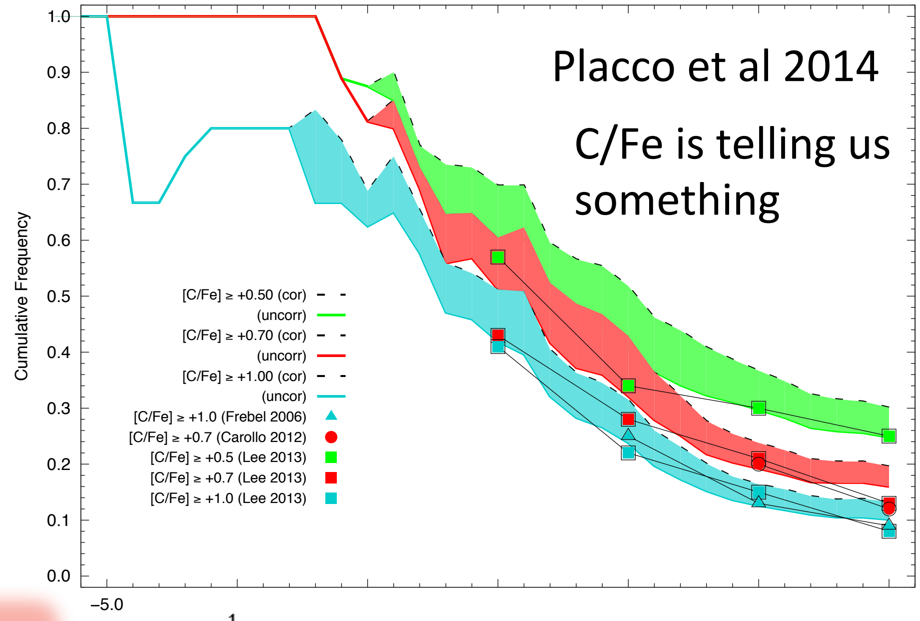
- Fantastic to see SNe, Novae modellers using light curve data (e.g. Co decay) to tie down precision models.
- SN 1987A (+neutrinos) continues to provide the strongest constraints ?
- Is there such a thing as a self consistent detonation and explosion ? *Not in 1D because can't do convection (Fröhlich).*

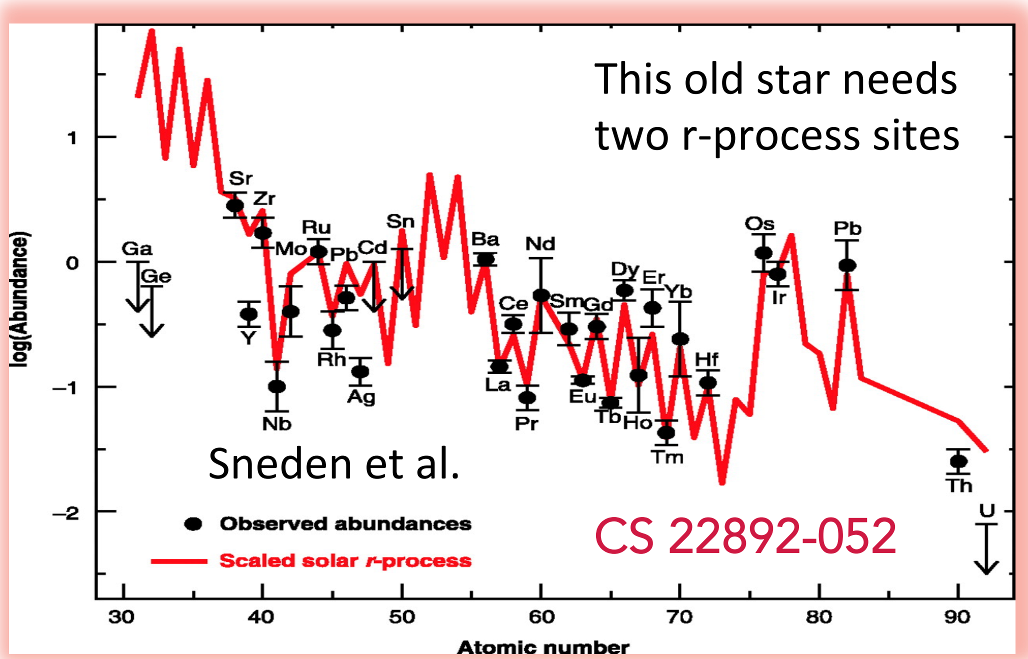


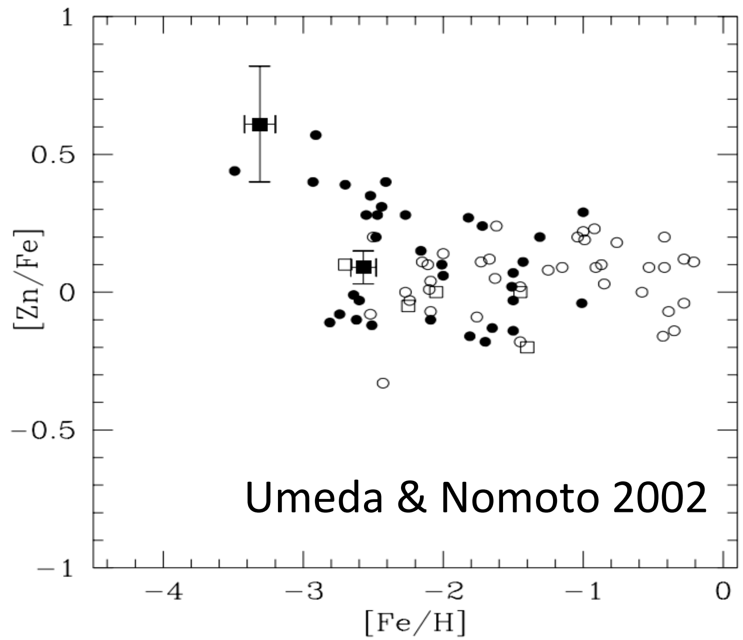


Signatures of the first stars ?

Others ?







Astroparticle physics

Why is this the domain of cosmologists testing BBNS, DM particles, and not inclusive of JINA style physics… ?

PHYSICAL REVIEW D **74,** 103509 (2006)

Big bang nucleosynthesis constraints on hadronically and electromagnetically decaying relic neutral particles

Karsten Jedamzik

Laboratoire de Physique Mathémathique et Théorique, Université de Montpellier II, 34095 Montpellier Cedex 5, France

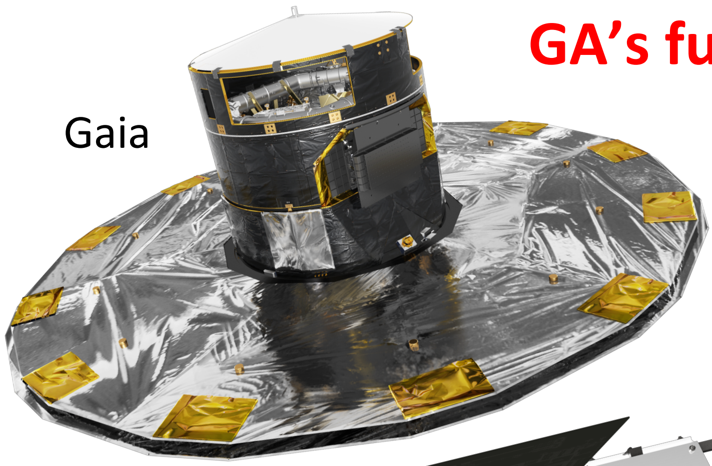
(Received 29 May 2006; published 8 November 2006)

Big bang nucleosynthesis in the presence of decaying relic neutral particles is examined in detail. All nonthermal processes important for the determination of light-element abundance yields of ^{2}H, ^{3}H, ^{3}He, ^{4}He, ^{6}Li, and ^{7}Li are coupled to the thermonuclear fusion reactions to obtain comparatively accurate results. Predicted light-element yields are compared to observationally inferred limits on primordial light-element abundances to infer constraints on the abundances and properties of relic decaying particles with decay times in the interval $0.01 \text{ sec} \lesssim \tau_X \lesssim 10^{12} \text{ sec}$. Decaying particles are typically constrained at early times by ^{4}He or ^{2}H, at intermediate times by ^{6}Li, and at large times by the ^{3}He/^{2}H ratio. Constraints are shown for a large number of hadronic branching ratios and decaying particle masses and may be applied to constrain the evolution of the early universe.

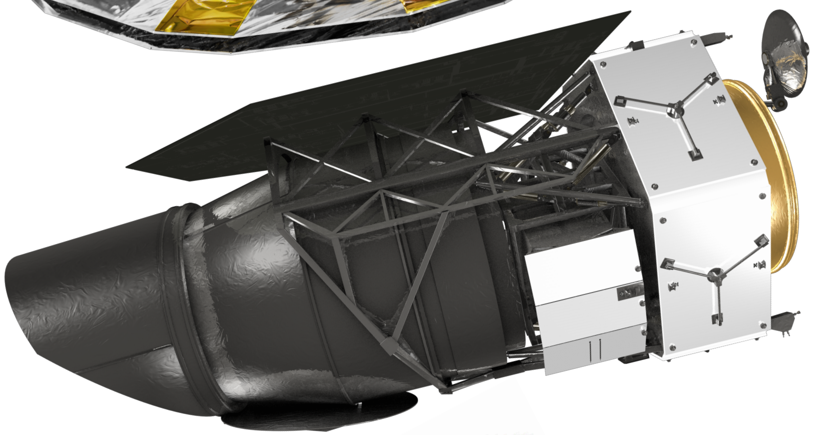
Future facilities

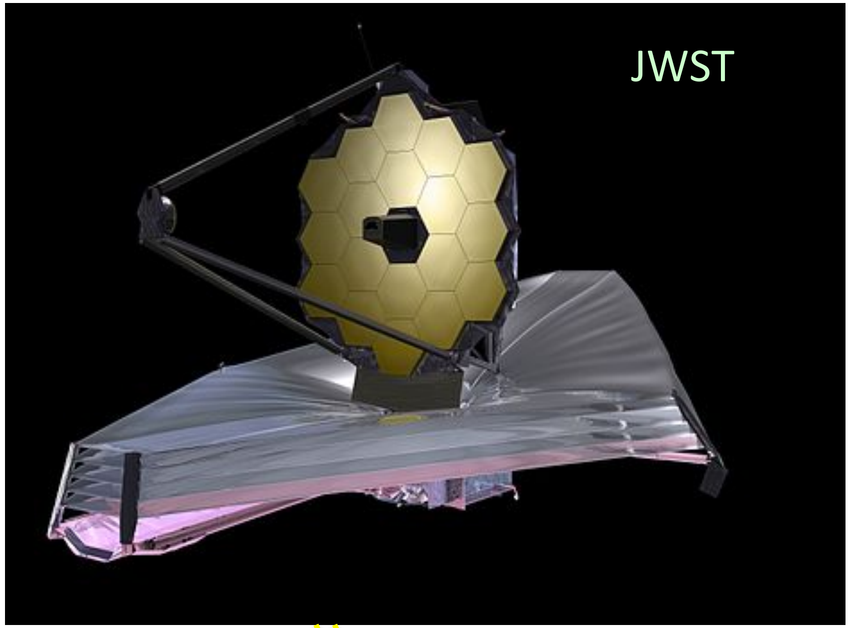
Experimental Techniques
Wiescher
Laboratory based nucleosynthesis

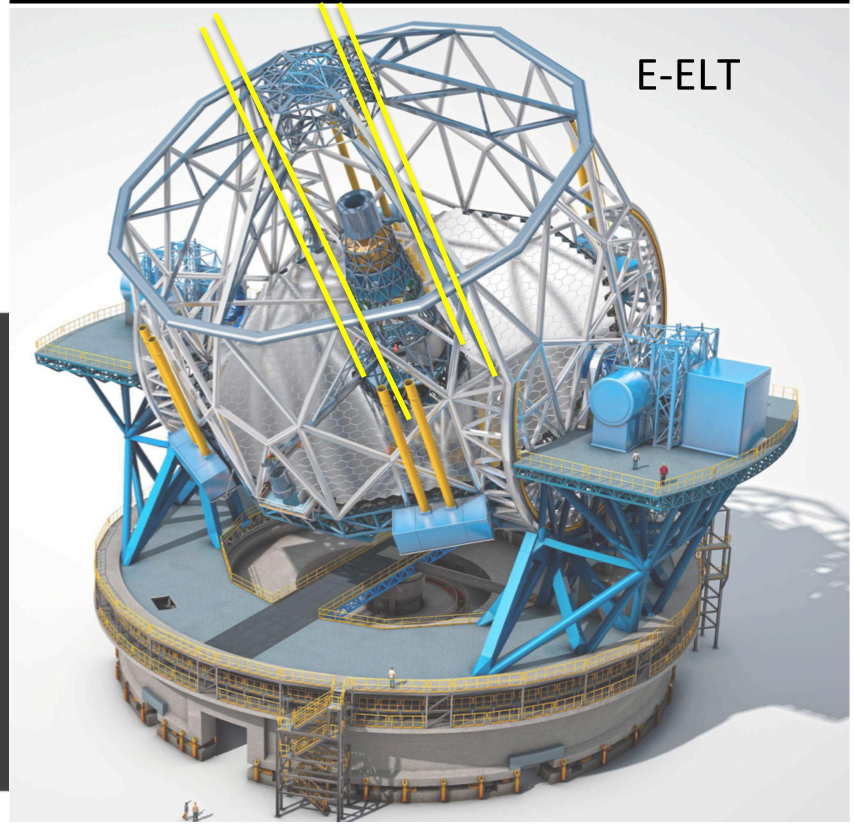
GA's future scopes

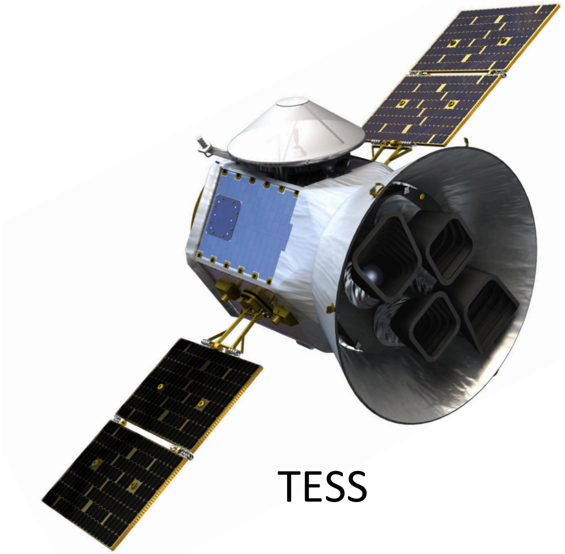


WFIRST

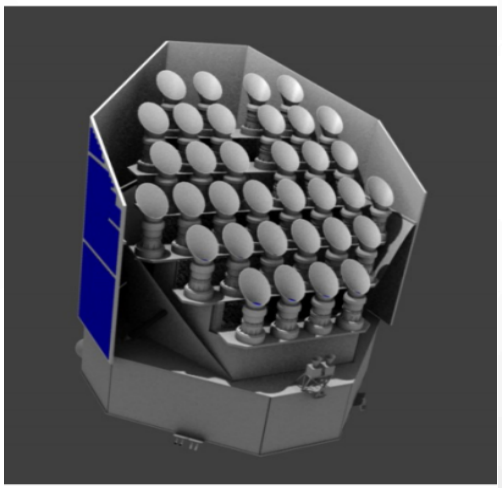




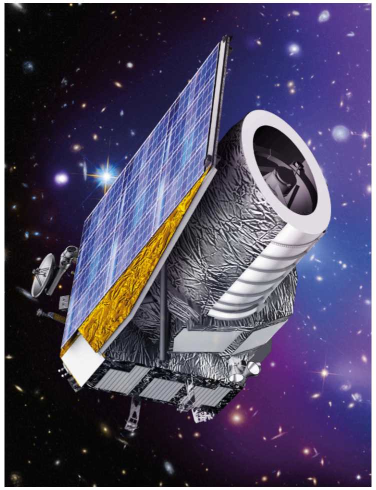




Plato



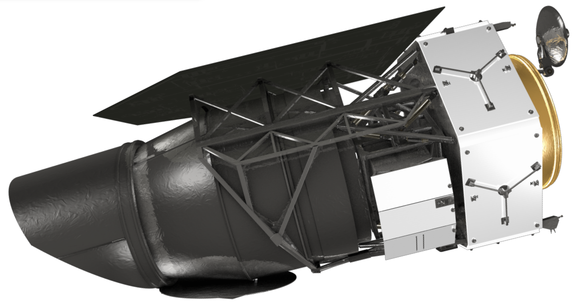
Highly complementary missions



EUCLID
2021-2027
15000 sq deg
$m_{5\sigma} \sim 25$
0.13”

LSST
2022-2032
18000 sq deg
$m_{5\sigma} \sim 27$
0.4”

WFIRST
2025-2031
2200 sq deg
$m_{5\sigma} \sim 27$
0.12”

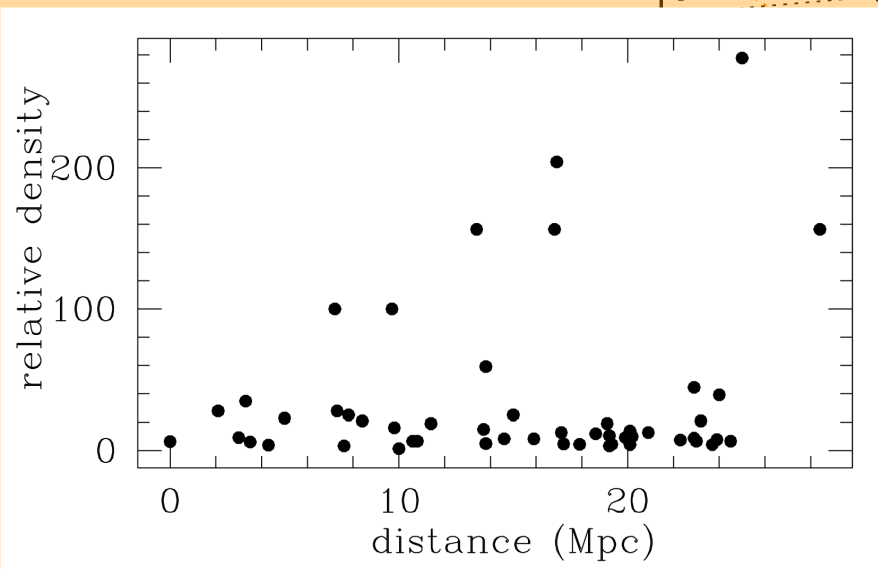


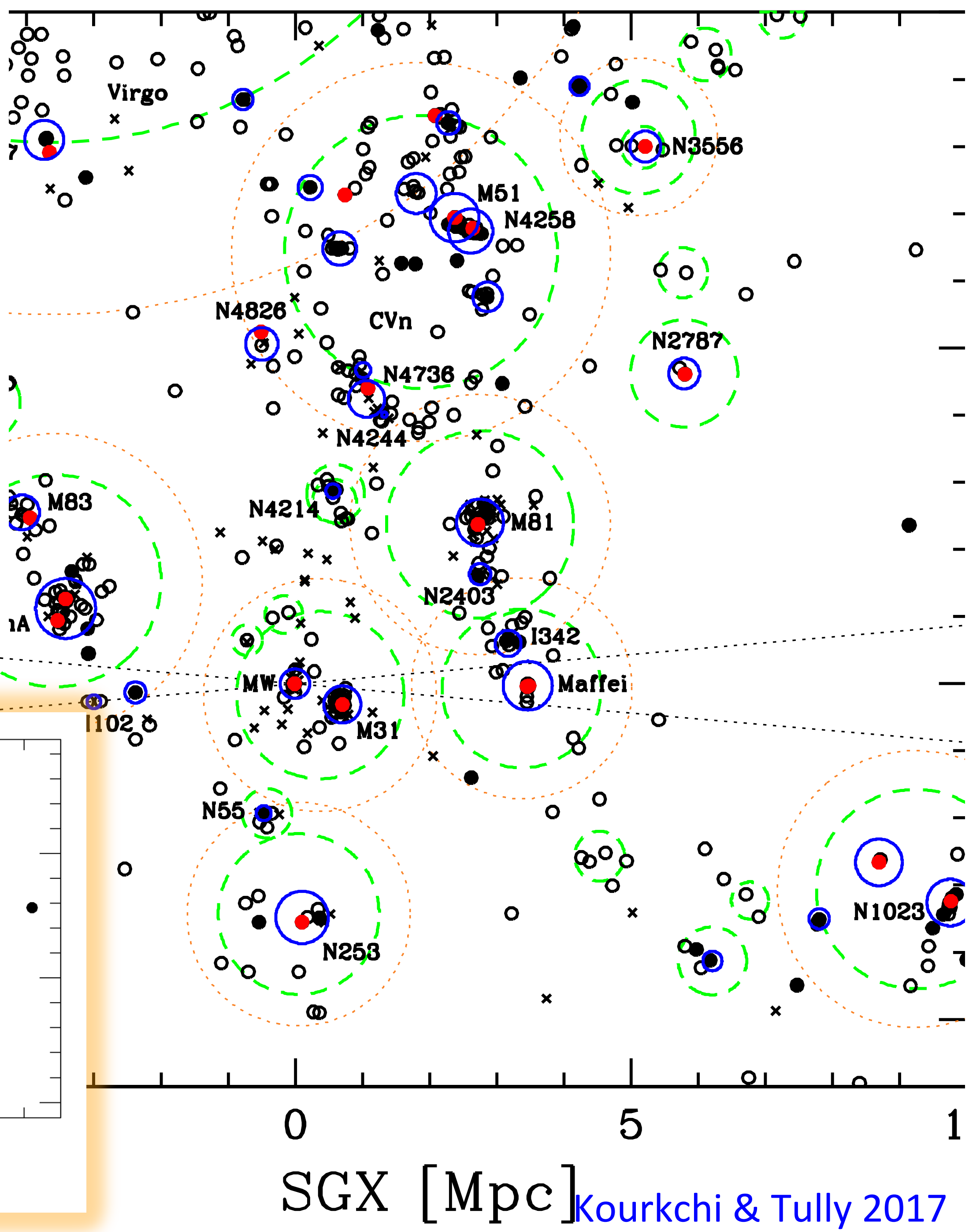
Deep multiband photometry leads spectroscopy for the initial selection, and is always needed in the holistic analysis.

NFC / GA is future proofed…

We will eventually need to push on to Virgo & beyond.

Tumlinson asked us to get behind LUVOIR 9-15m range telescope, essentially giant HST





Kourkchi & Tully 2017

Coming to a desktop near you… think outside the box on what you can do with computational power. It can change your thinking on all aspects of doing science, simulations, building instruments, reducing data! etc.

What does the inexorable rise of massive computational power really mean?

At a future time, consider GA simulations providing a holistic framework for our deliberations.

Imagine a workshop where we are all working towards the common goal of understanding data. (Airline and battle field simulators do something like this.)

We run all simulations in real time.

We request the latest reaction networks and stellar observations.
We re-run the abundance pipelines and spectroscopic measurements.
We request and match to catalogues (Gaia, photometric).

We “observe,” i.e. select, the simulation (e.g. using Galaxia).
We test the hypothesis.

We drill down and reveal where all the problems are, their inter-relations.
We might decide to re-run the GA simulator - with migration switched on, say - loop back.

This is one approach to confronting complexity.

Can we please do this all again?

From photometry/spectroscopy:

$$\delta T_{eff} \approx 100K \Rightarrow \frac{\delta T_{eff}}{T_{eff}} \approx 2\%$$

$$\frac{\delta L}{L} \approx 40\%$$

$L \propto R^2 T_{eff}^4$

$$\Rightarrow \frac{\delta R}{R} \approx 20\%$$

$$\Rightarrow \frac{\delta M}{M} \approx 10\%$$

Stellar models

From photometry/spectroscopy:

$$\frac{\delta L}{L} \approx 40\% \qquad \frac{\delta T_{eff}}{T_{eff}} \approx 2\% \quad \Longrightarrow \quad \frac{\delta L}{L} \approx 10\% \;\star$$

$$\frac{\delta R}{R} \approx 20\% \qquad \frac{\delta M}{M} \approx 10\%$$

From seismology:

Large separation

$$\Delta\nu \propto \bar{\rho}^{1/2}$$

$$\frac{\delta \Delta\nu}{\Delta\nu} \approx 0.5\% \quad \Longrightarrow \quad \frac{\delta \bar{\rho}}{\bar{\rho}} \approx 1\%$$

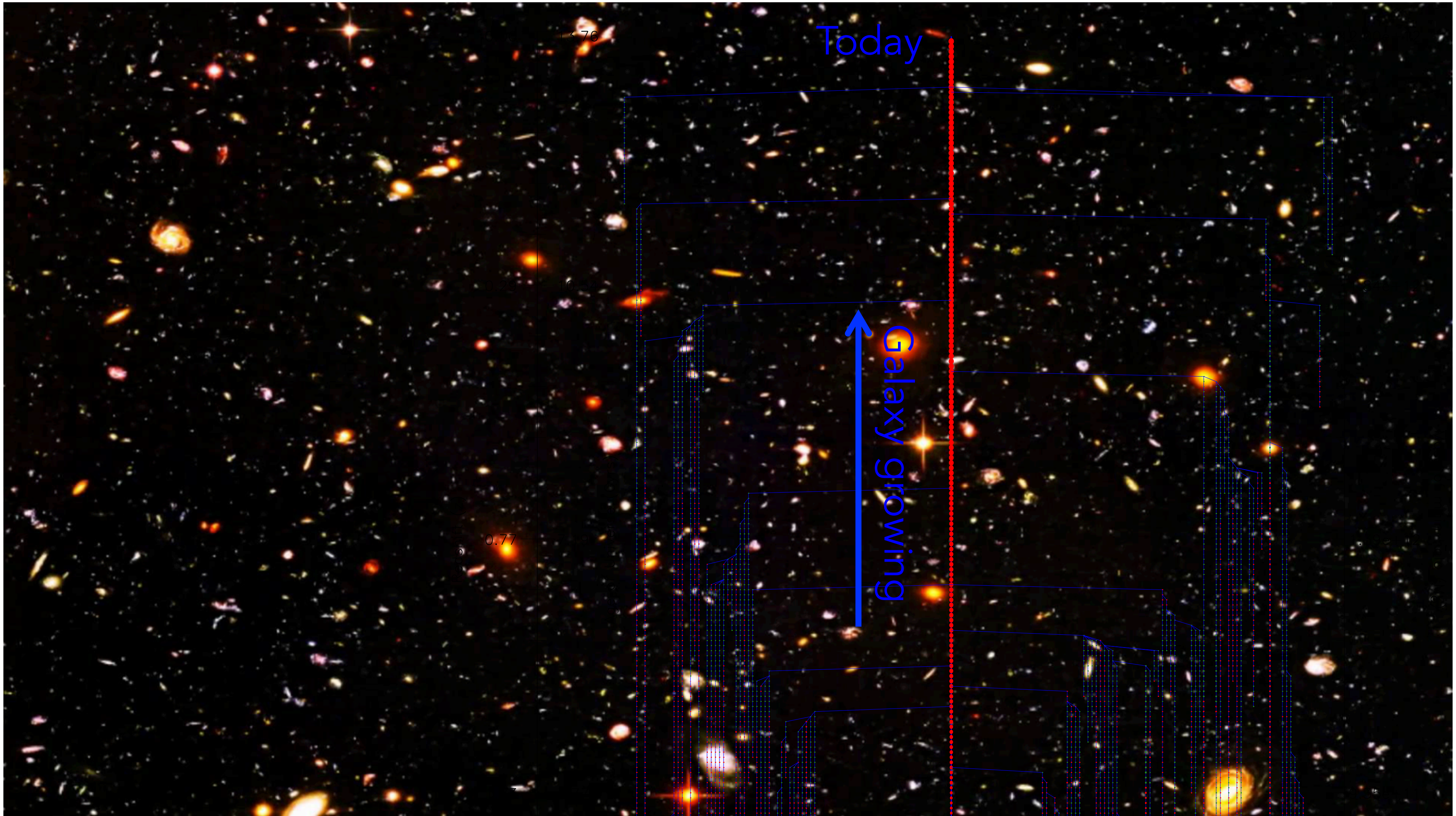
$$\bar{\rho} \propto \frac{M}{R^3}$$

$$\Longrightarrow \quad \frac{\delta R}{R} \approx 3\% \;\star$$

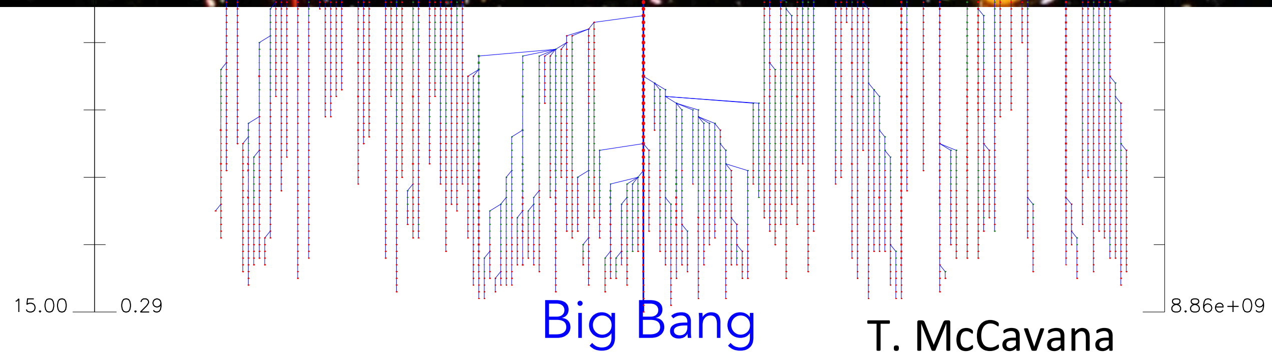
Small separation

$$\frac{\delta \nu_0}{\nu_0} \approx 10\% \quad \Longrightarrow \quad \delta\,\text{age} \approx 10\% \cdot t_{MS} \approx 1Gyr \;\star$$

For a one solar mass star



Nice complementarity
HUDF is size of LG at z~3



T. McCavana