XSEDE Andrew Emerick

- Alex's outline
    - https://www.discovermagazine.com/the-sciences/unsolicited-advice-x-how-to-frame-a-winning-proposal
    - X is important and interesting
        - Dwarf galaxy formation, including/especially the early universe, is important and interesting. [brainstorm things that are important and interesting; this is a UFD-biased set of things]
            - Extreme end of galaxy formation: faint, metal-poor, dark matter dominated. Relics from the beginning of the universe.
            - Formation history
                - These galaxies build up metal-poor Galactic halo (Lambda CDM/hierarchical galaxy formation) (e.g. Frebel & Norris 2015)
                - All galaxies pass through this phase in early universe(?)
                - No true z=0 star-forming counterparts (not the same gas pressures as early intense merging time) [cite?]
            - Differing stellar populations and nucleosynthesis
                - They are relatively simple galaxies, often used to study nucleosynthesis (e.g. r-process Ji+16, SN1a explosion mechanism Kirby+19)
                - Hosts of the first stars, preserve their signatures (e.g. Ji+15)
                - Might have different IMF (Geha+13)
            - Cosmology
                - Reionization: important/necessary sources of early ionizing photons (Wise+14, Robertson+15), but their formation is also affected by reionization (Weisz+14, Brown+14)
                - Smallest galaxies are key for dark matter models, but we don't know how to populate them (e.g. Jethwa et al., Nadler+19)
        - Stellar abundances are the key to understand dwarf galaxies
            - Abundances are a convolution of stellar evolution and galaxy formation timescales
            - Examples: [alpha/Fe], [s/Fe].
                - Figure here?

        - Abundances can probe very short timescale: massive star bursts, earliest star formation
        - Abundances can probe the first stellar pops
        - For some galaxies (e.g. UFDs, relic first galaxies) this is the *only* way to get their history. We'll never see these directly.
- But
    - Observations have outpaced models for almost a decade
        - Reaching dozens to hundreds of abundances in dwarf galaxies
        - Abundance *scatter* is the new thing we've measured
            - [Is it the case that including mixing breaks one-zone models? I think yes, the median vs mean thing] [AE: I agree... can cite my Emerick+2018b paper for hints of this and Corlies+2019 paper (particularly relevant since it uses John's sims)]
        - Figure: showing data with abundance scatter.
            - Kirby+09-11, Hill+19, Ji+prep for Ret II
    - We can model the trends, but not the scatter: almost all current models just do the mean.
        - Usual models: instantaneous recyling, instantaneous full mixing, one-zone
        - sometimes put in mixing by hand (Cescutti et al.)
        - Almost always vastly oversimplified treatment of galaxy formation
    - Modeling dwarf galaxies is hard and requires simulations
        - It is stochastic and bursty: need a large sample to get the full distribution
        - individual stars make a big difference on feedback: need detailed physics AE: and accounts for stochasticity explicitly
- This is how we address "But"
    - It's actually computationally feasible, because dwarf galaxies are small and a lot of the action happens early so we don't have to simulate that far! AE: Explicitly, just need to do z ~8-9 to get all / most of SFH for low mass dwarfs, and really even to z ~10 is still valuable and interesting (past PopIII to PopII transition...). Less than 1 Gyr of evolution.
    - We will do high-res simulations of early universe with new model (AE: Minor point, this is not a zoom simulation of individual halo but a small box of multiple low mass halos...)

        - We have done now with idealized simulations, but not on this scale in cosmological timescale
        - [Why do we have to do cosmological now?]
        - AE: Downside of idealized is that evolution is highly subject to the effects of the ICs which are realistic, but still constructed ad hoc. ICs were constructed at z = 0, and not representative of galaxy evolution at high-z. Plus, impossible to rfully replicate cosmological accretion, CGM / IGM interactions, and halo-halo pollution. In short, idealized simulations are cheap(er) ways to lay foundational understanding of physics but cosmological is real test for proper comparison to real galaxies.
    - No one has done this yet.
        - Closest is Jeon, focusing mostly on Pop III vs Pop II
        - Wise+ did not track multiple species, used star cluster approx
        - AE: Can also cite Oscar Agertz's recent EDGE sims (https://ui.adsabs.harvard.edu/abs/2020MNRAS.491.1656A/abstract) with zooms of UFDs to z = 0 (but still SSP and only Fe and O). Maybe also FIRE-2 stuff from Coral or Ivana Escala's paper, but again still SSPs and while do track multiple species, have simple chem E model (C and N are only AGB metals, no Ba or other post-Fe s-process elements).
    - [The reason we can do this now but not before is...]
        - AE: Its become clear that computational resources are now sufficient to be able to attempt something like this. Individual stars is really the "new frontier" in galaxy evolution simulations, and major intertia in transitioning from SSPs to this model. So, partly because only recently (i.e. last 2-3 years) have these models been developed.
    - Key requirements of the simulation:
        - High-resolution: individual stars
        - [Other key physics?]
        - Track abundances individually, and as multiple fields
        - Run to z~10 (or 6)?
- Key questions and goals
    - What physics determines abundance scatter in dwarf galaxies?
        - star formation history/burstiness, metal mixing, stochastic enrichment, other?

            - (how) does this evolve with galaxy mass?
            - [another way to say this: what do we learn from measuring abundance scatter?] AE: I like phrasing it this way... what can we extract about galaxy evolution physics from observed stellar abundances... can use these sims to test that concept
        - We need to do this ^ for many different elements. AE: emphasize distinctions with SN, SNIa, AGB (s-process) tracers... need all...
        - Can we recover the formation histories of early galaxies using abundances, in the presence of stochasticity and metal mixing?
        - Is there a galaxy mass [or age] where stochasticity damps down?
        - A base model for chemical evolution in the first galaxies
- Current outline on overleaf
    - Stellar abundances trace galactic evolution.
        - Lots of surveys getting data in the MW and dwarf galaxies.
        - Probe information-rich scatter in stellar abundance patterns.
        - Scatter is more important at low metallicity.
        - Abundances are convolution of galaxy formation and stellar evolution.
        - [Last sentence.]
    - Observation quality > simulation quality.
        - Stellar feedback
        - Metal mixing
    - Motivate high-z galaxy formation, UFDs + low-mass dwarfs
    - Abundance ratios vs metallicity trace enrichment timescales
        - Usually: alpha-knee
        - s-process also works.
        - scatter in abundance ratios makes interpreting the evolution nearly imposible.
    - Need high-resolution simulations resolving lots of physics. This is not done yet. We will do it.
    - Key Questions and goals