Dark Matter Particle Physics in Cosmological Simulations

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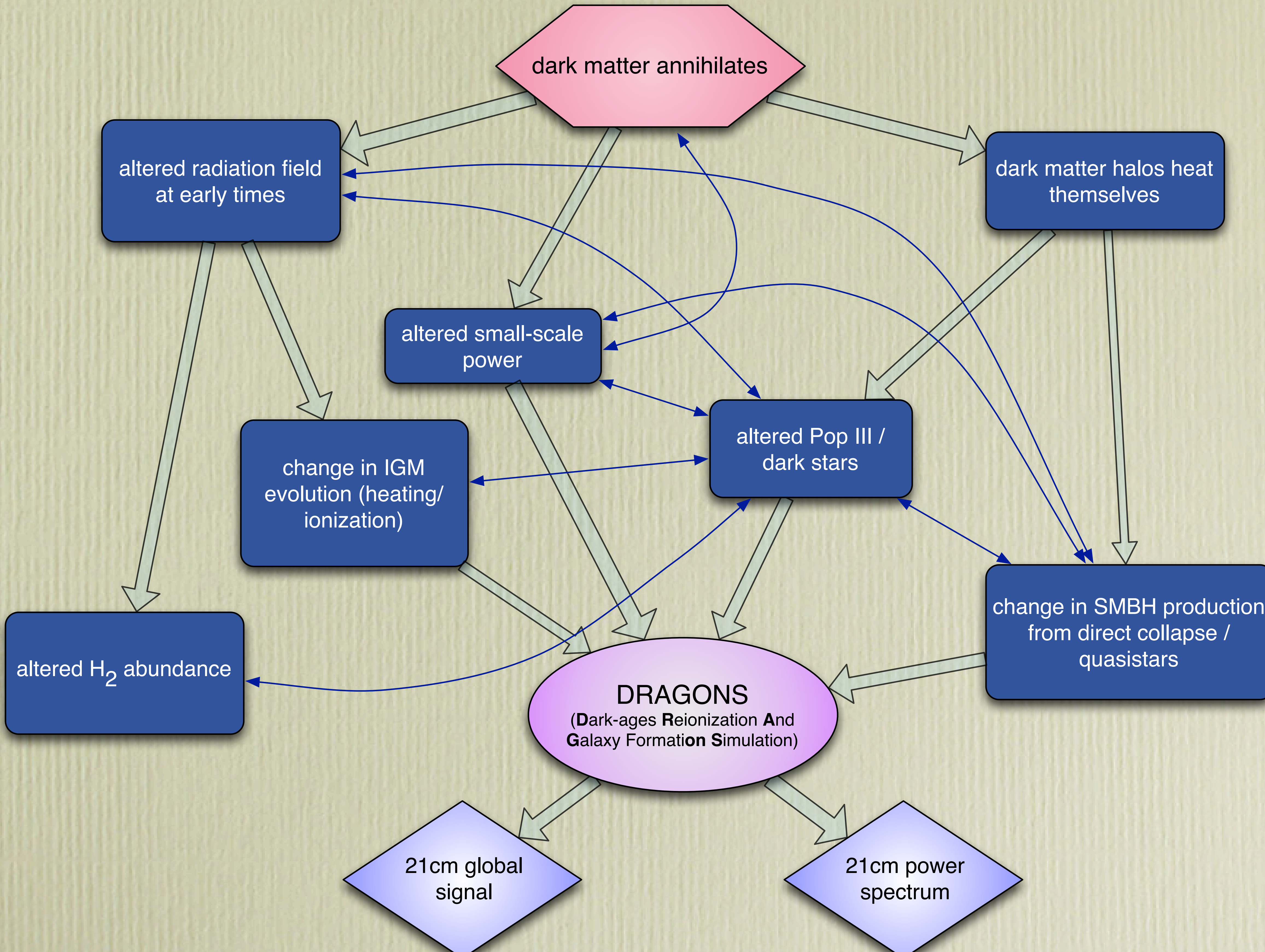
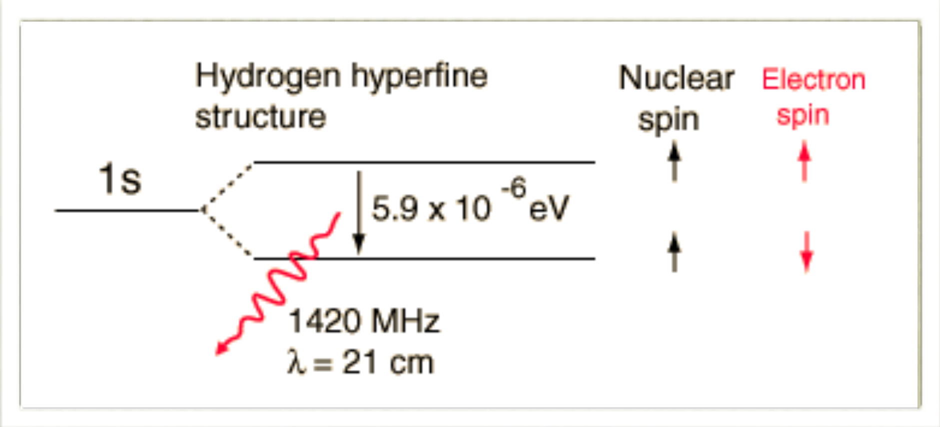
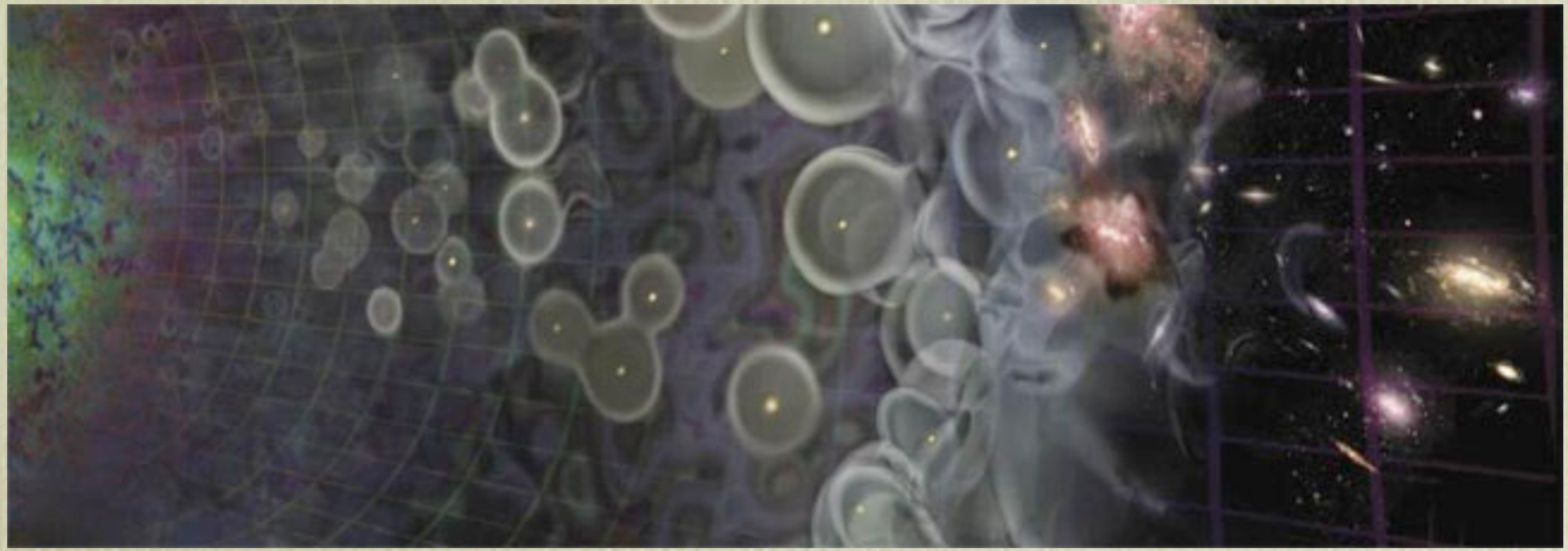

dark matter annihilates
altered radiation field at early times
dark matter halos heat themselves
altered small-scale power
change in IGM evolution (heating/ ionization)
altered Pop III / dark stars
altered H_2 abundance
change in SMBH production from direct collapse / quasistars
DRAGONS
(Dark-ages Reionization And Galaxy Formation Simulation)
21cm global signal
21cm power spectrum



The 21cm line

- Advantages for studying reionization / dark ages:
  - Unsaturated line => strong dependence on H properties, low attenuation
  - Can be seen in absorption or emission against CMB -- no bright source needed



z=50	z=20	z=13	z=6	z=0
ν=28 MHz	ν=70 MHz	ν=100 MHz	ν=200 MHz	ν=1420 MHz

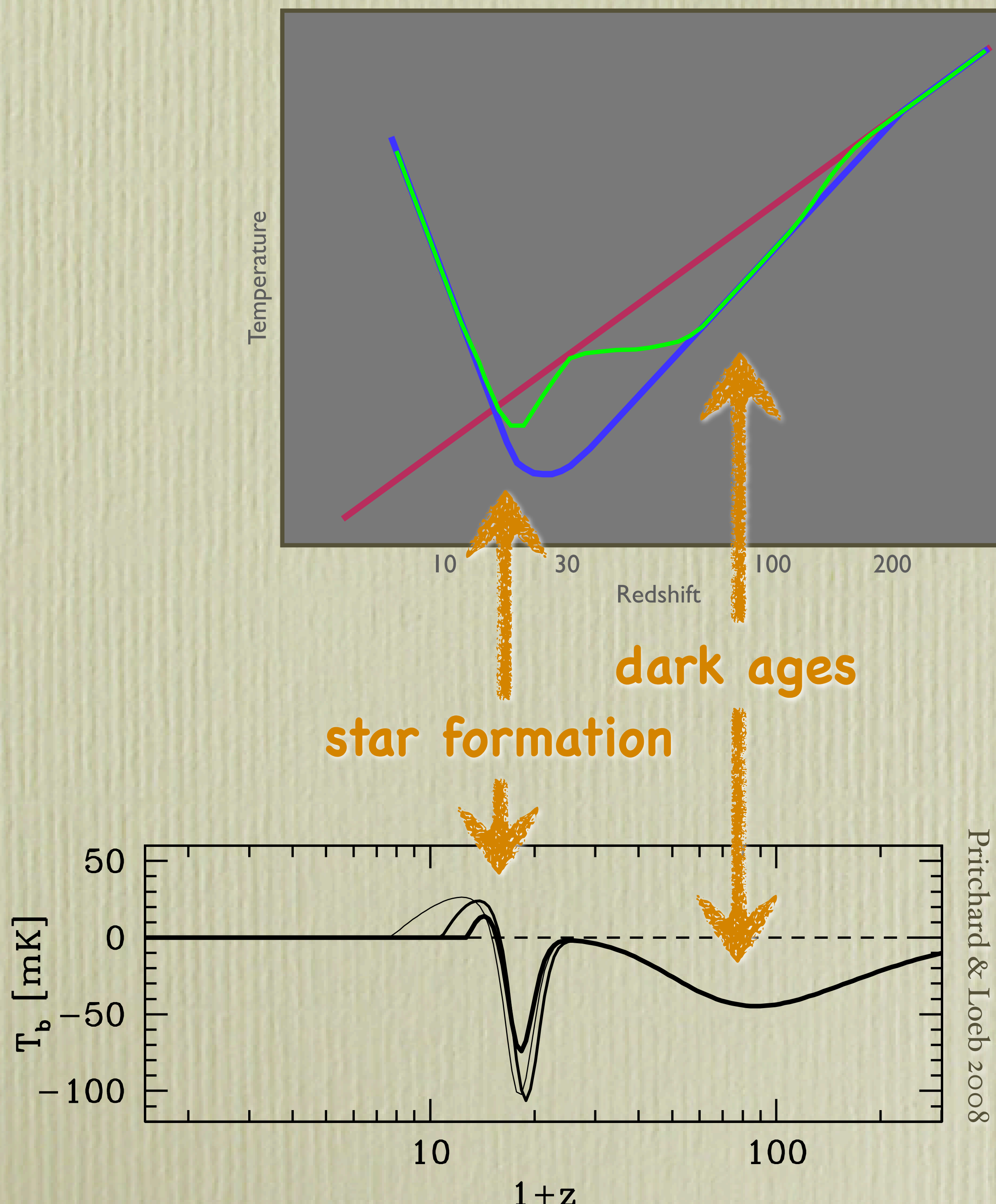
21cm & Fundamental Physics

- Two regimes:
  - Dark ages (z ~ 20-50) -- "clean" signal of exotic physics, if it can be measured (no astrophysics yet)
  - Epoch of Reionization (z ~ 6-10) -- very sensitive to source populations & IGM properties (but also messy)
- Dark ages harder observationally, but easier to interpret exotic physics

21cm & Fundamental Physics

- Major effects to look for:
  - Energy injection into the IGM (heating, ionization)
  - Alterations of small-scale power in matter distribution
  - Shape of matter power spectrum, non-gaussianities
  - Change in stellar or black hole populations

Global Signal in 21cm



- The spin temperature determines the relative occupancy of the hyperfine levels

- The brightness temperature measured by observations is determined by the spin temperature's coupling to the CMB temperature

Dark Matter Signals at High z

- Heating during the dark ages
  - CMB temperature and polarization
  - 21cm brightness temperature, power spectrum
- Altered stellar structure?
  - "Dark stars" (Freese, Dobler, Scott, Gondolo, others)
- Small-scale power spectrum (esp. hot DM)
- Chemistry (H_2 abundance)

Indirect Detection

- **Indirect detection** looks for the gamma-rays or particles that escape the halos -- but that's only a fraction of the energy
- Much of the annihilation energy goes to heating, ionization, photons that are absorbed locally

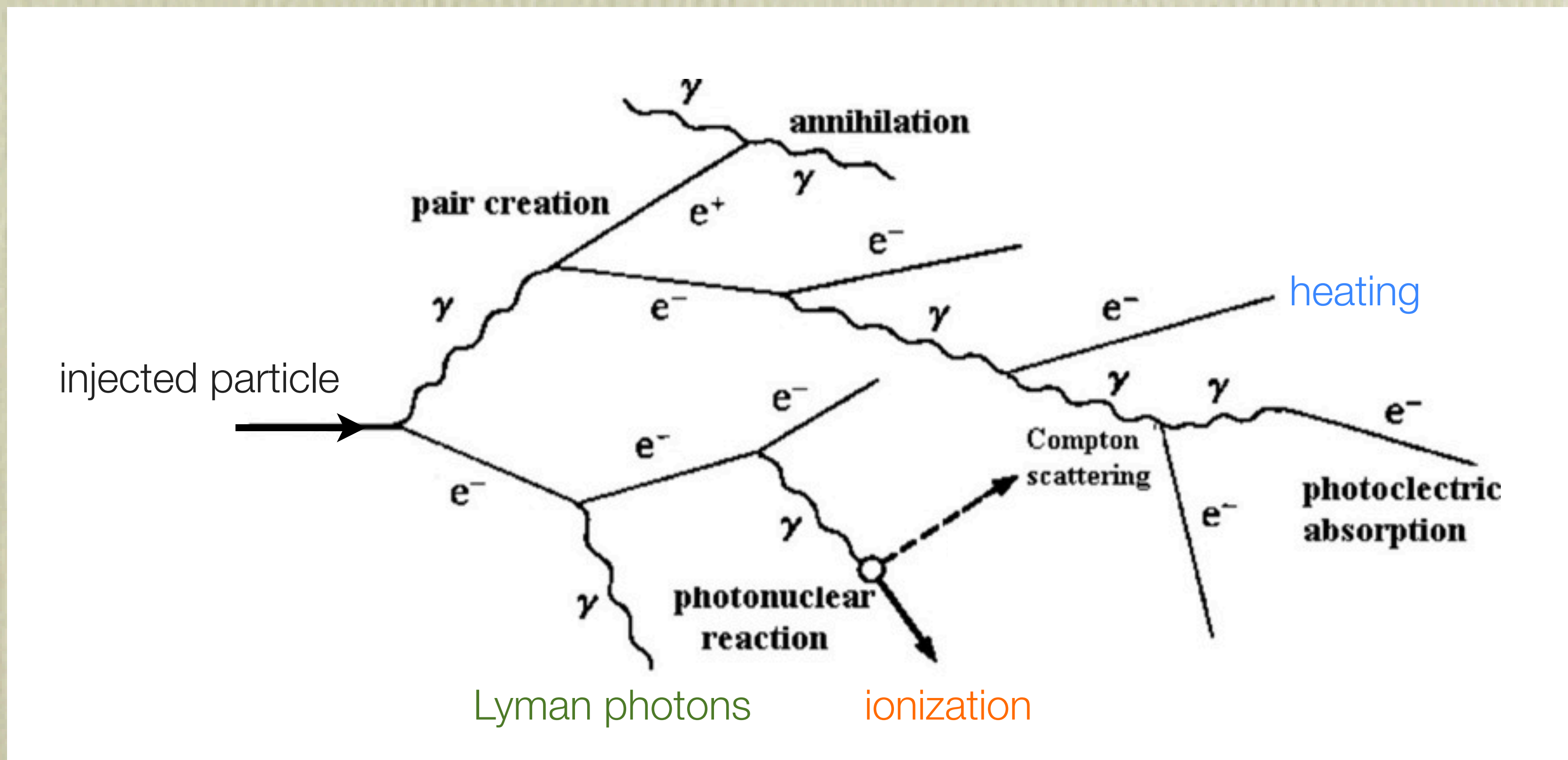
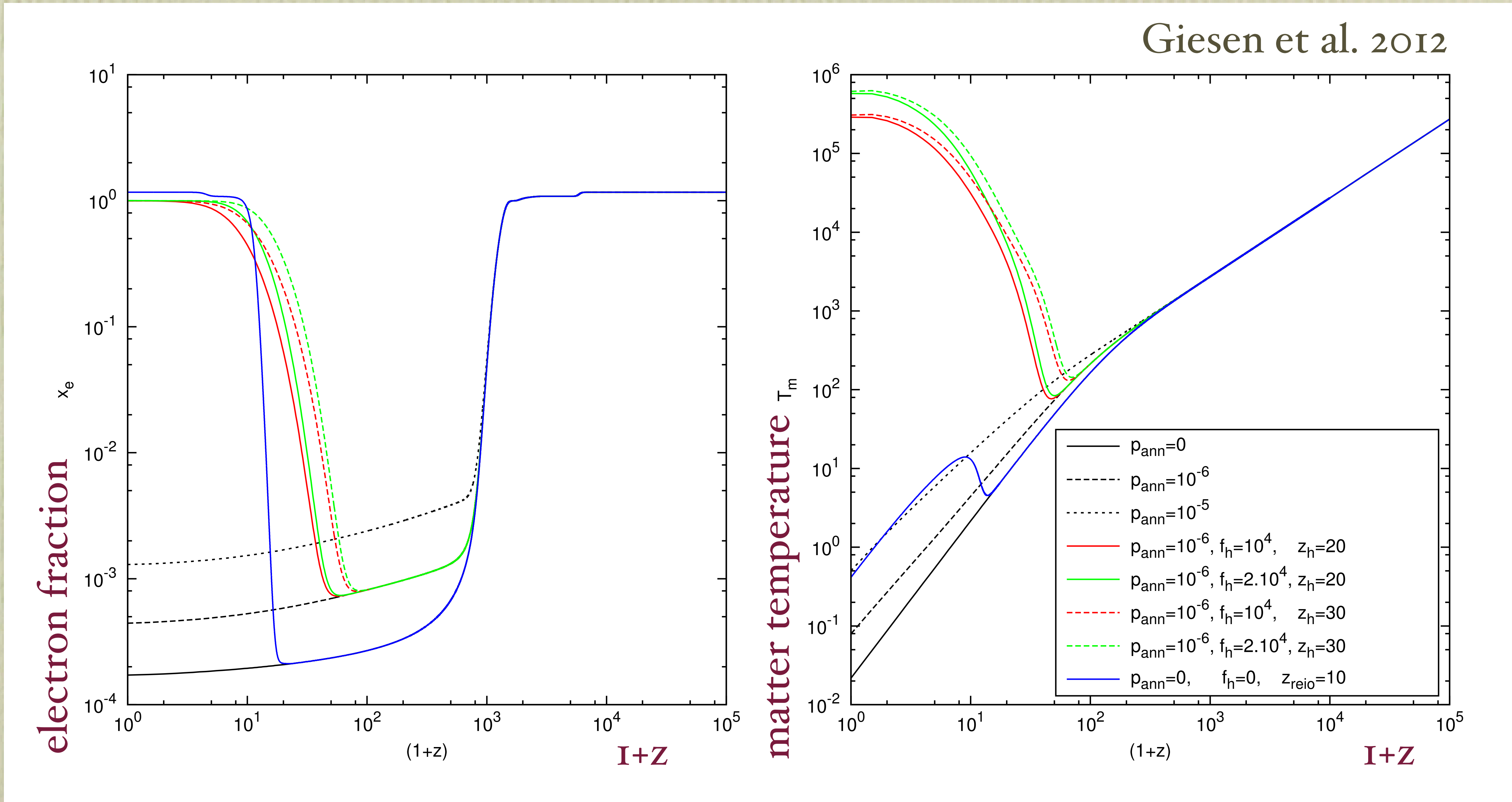


Image from talk by Carmelo Evoli

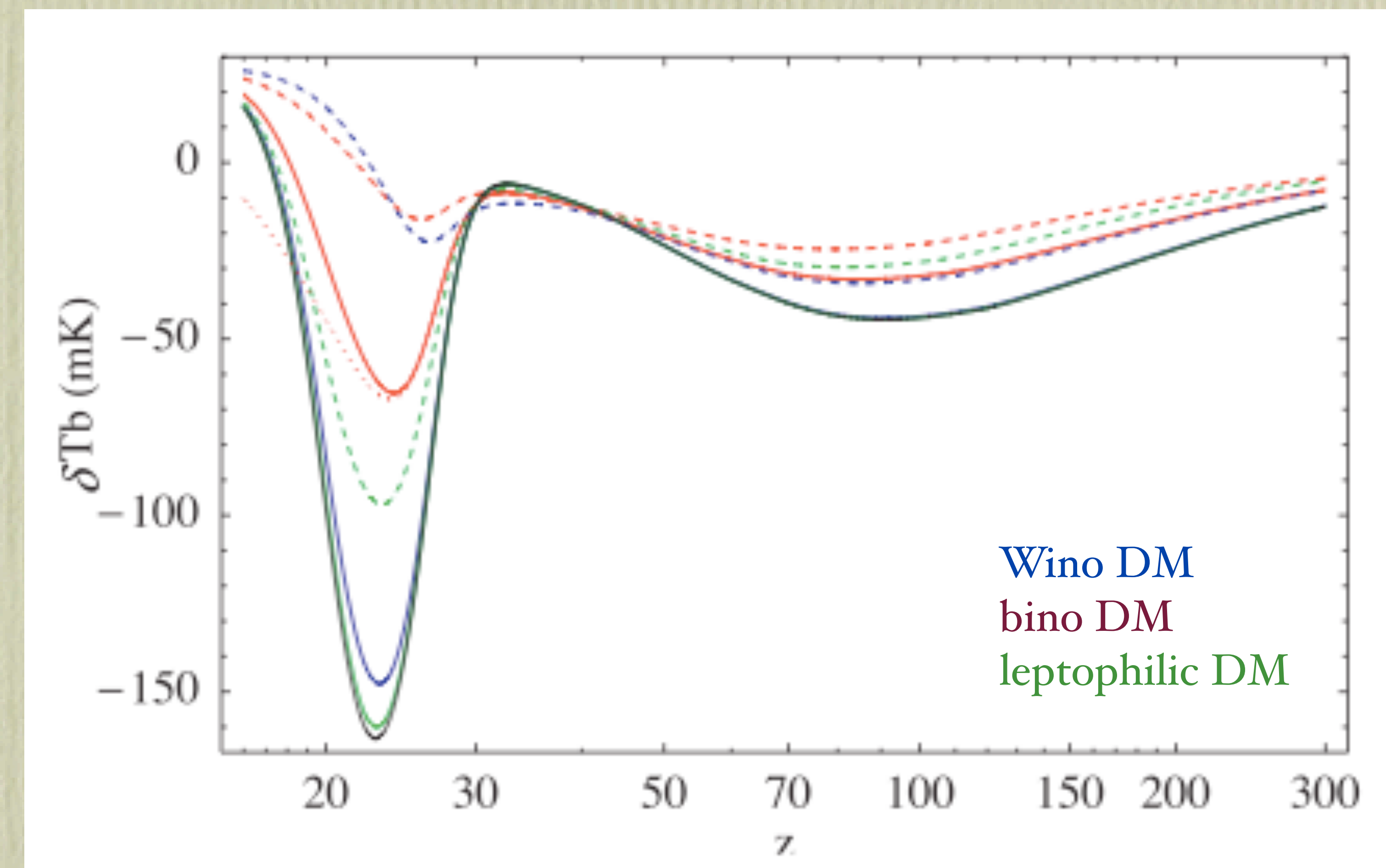
IGM Ionization & Temperature



p_{ann} = energy injection rate (normalized)

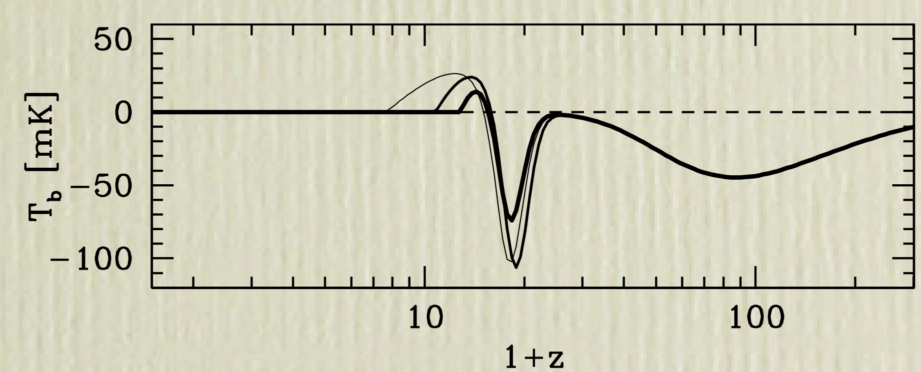
f_h related to halo formation redshift & concentration (higher f_h = higher formation redshift)

21cm Global Signal (IGM Heating/Ionization)

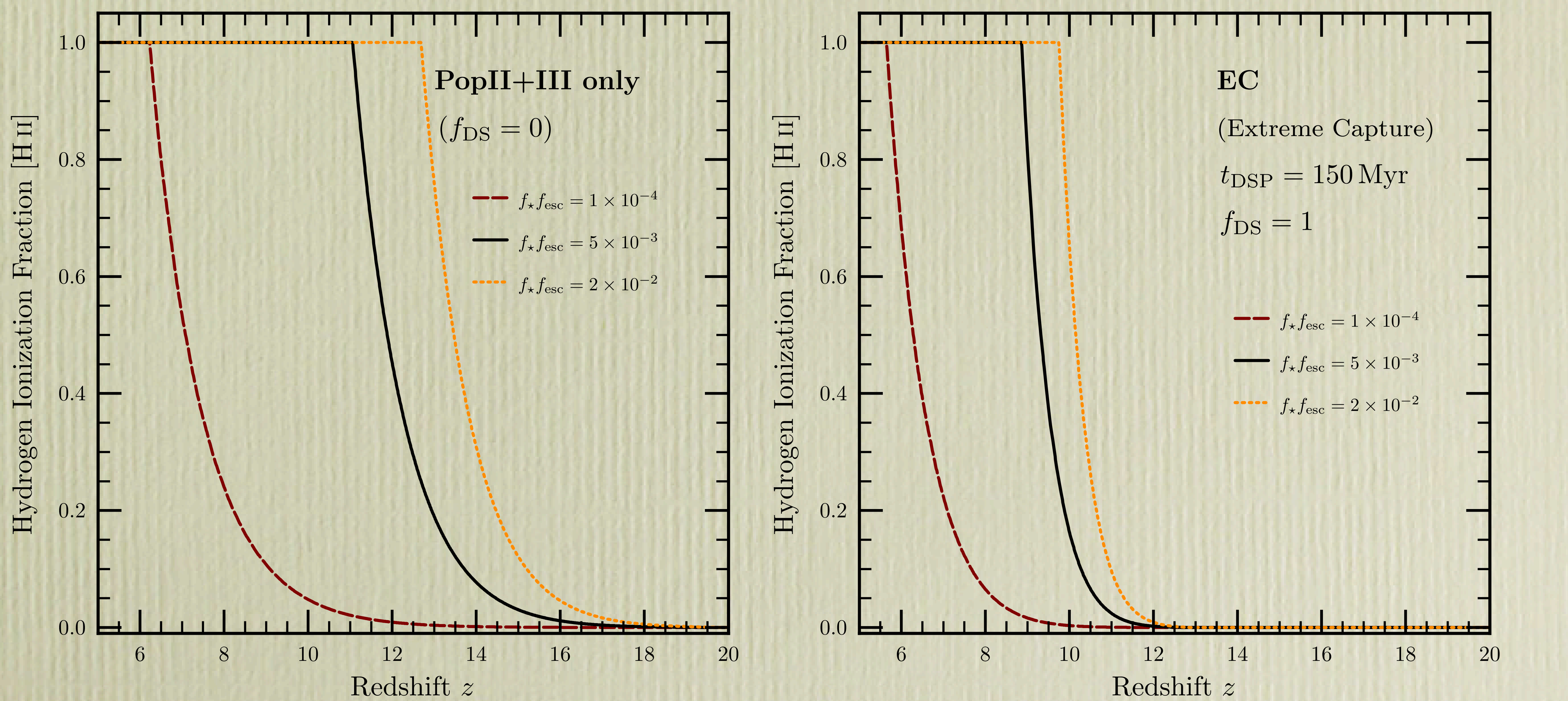


Valdes et al. 2012

DM model	Mass (GeV)	$\langle\sigma v\rangle$ ($cm^3\,s^{-1}$)	ϵ_0 ($eV\,s^{-1}$)	$\delta\tau_e$	Line style
W^+W^-	200	$\langle\sigma v\rangle_{th} = 3.0 \times 10^{-26}$	5.35×10^{-25}	1.53×10^{-3}	Blue solid
W^+W^-	200	$\langle\sigma v\rangle_{max} = 1.2 \times 10^{-24}$	2.14×10^{-23}	6.09×10^{-2}	Blue dashed
$b\bar{b}$	10	$\langle\sigma v\rangle_{th} = 3.0 \times 10^{-26}$	1.07×10^{-23}	1.80×10^{-2}	Red solid
$b\bar{b}$	10	$\langle\sigma v\rangle_{max} = 1.0 \times 10^{-25}$	3.57×10^{-23}	5.76×10^{-2}	Red dashed
$\mu^+\mu^-$	1000	$\langle\sigma v\rangle_{th} = 3.0 \times 10^{-26}$	1.07×10^{-25}	1.42×10^{-4}	Green solid
$\mu^+\mu^-$	1000	$\langle\sigma v\rangle_{max} = 1.4 \times 10^{-23}$	4.99×10^{-23}	6.18×10^{-2}	Green dashed



Dark Stars



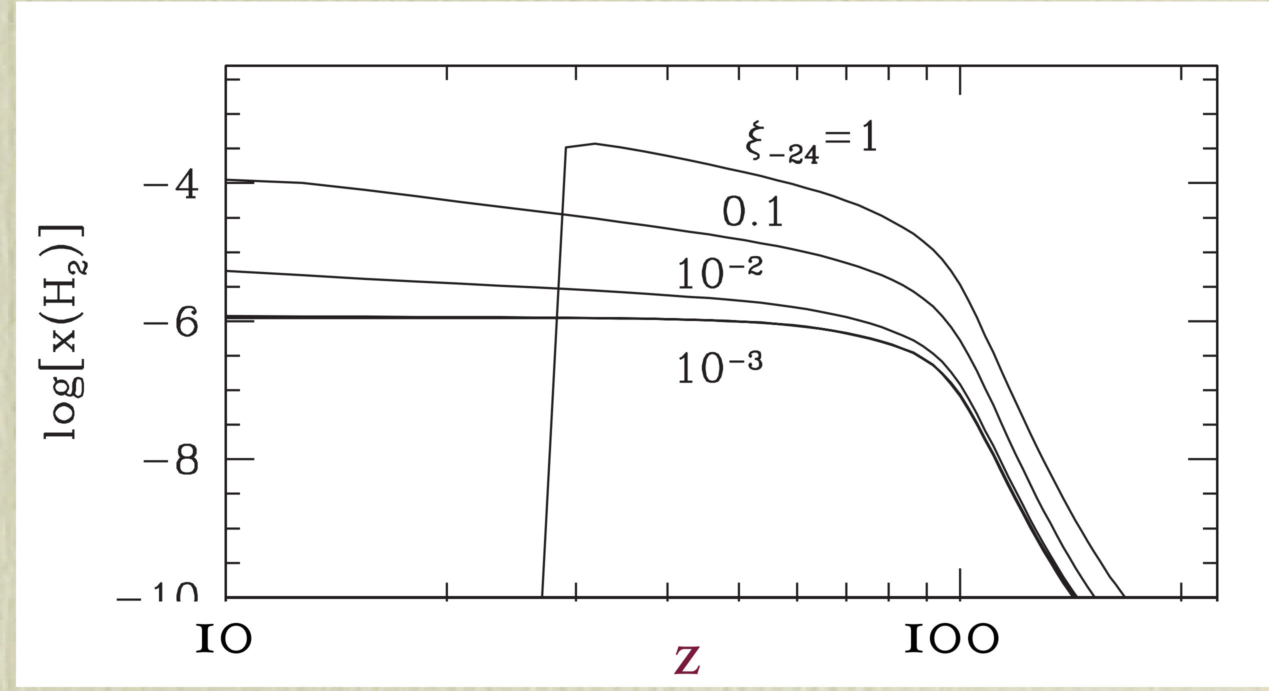
reionization **without** dark stars

reionization **with** dark stars

Molecular Hydrogen

- Free electrons are a catalyst for H_2 production:
  - $H + e^- \rightarrow H^- + \gamma$
  - $H^- + H \rightarrow H_2 + e^-$
- Sources of ionization (e.g., DM annihilation) can alter H_2 abundance via ionization

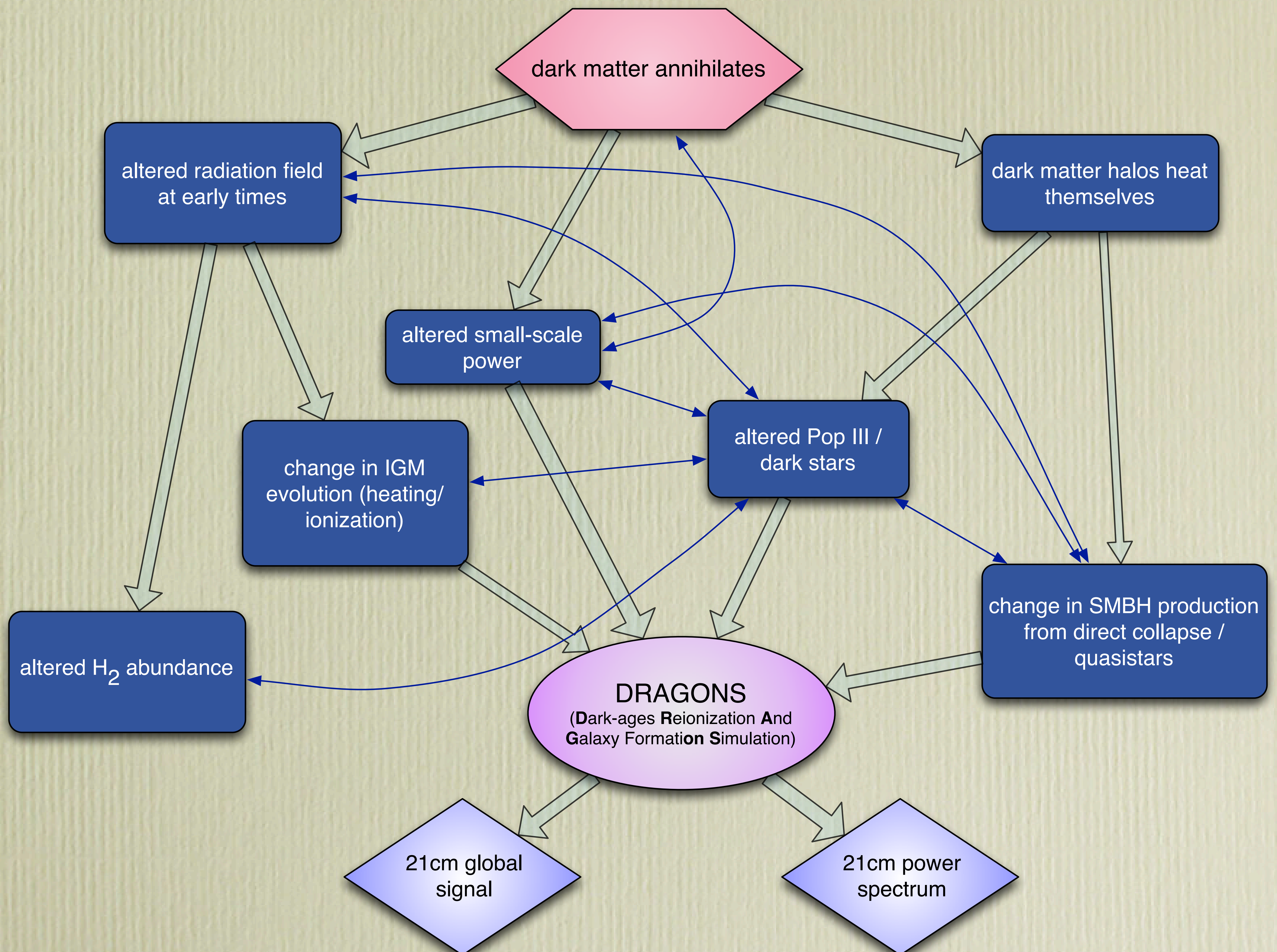
Furlanetto, Oh & Pierpaoli 2006



But UV can photo-dissociate H_2 => must consider full particle cascade

Putting it All Together

- Several ways DM can affect early structure formation and the high-z 21cm signal:
  - Internal heating of halos
    - Dark stars?
  - Overall evolution of IGM heating/ionization
    - New reionization models?
  - Radiation background
  - Small-scale power
    - Also feeds back into DM radiation, via power $\propto \rho^2$ term
  - H_2 abundance
    - Star formation
    - Direct collapse BHs?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DRAGONS
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21cm power spectrum

DRAGONS Code

- Suite of codes being developed for galaxy formation and reionization
- Melbourne Simulation Group
  Paul Angel, Camila Correa, Alan Duffy, Akila Jeeson Daniel, Antonios Katsianis, Hansik Kim, Simon Mutch, Jaehong Park, Bart Pindor, Greg Poole, Edoardo Tescari, Stuart Wyithe ...and new student: Sarah Schön
- Based on: 21cmFAST (Mesinger, Furlanetto & Cen), GADGET-2 (Springel), ROCKSTAR (Behroozi, Wechsler & Wu)
- This project: Add dark matter particle physics

Ongoing & Future Work

- Plan for the next few years: Incorporate all these effects into DRAGONS code suite
- End goal:
  - (A) New pathway to DM constraints/ detection and/or
  - (B) Estimate of uncertainties in reionization calculations due to uncertainty about DM

End