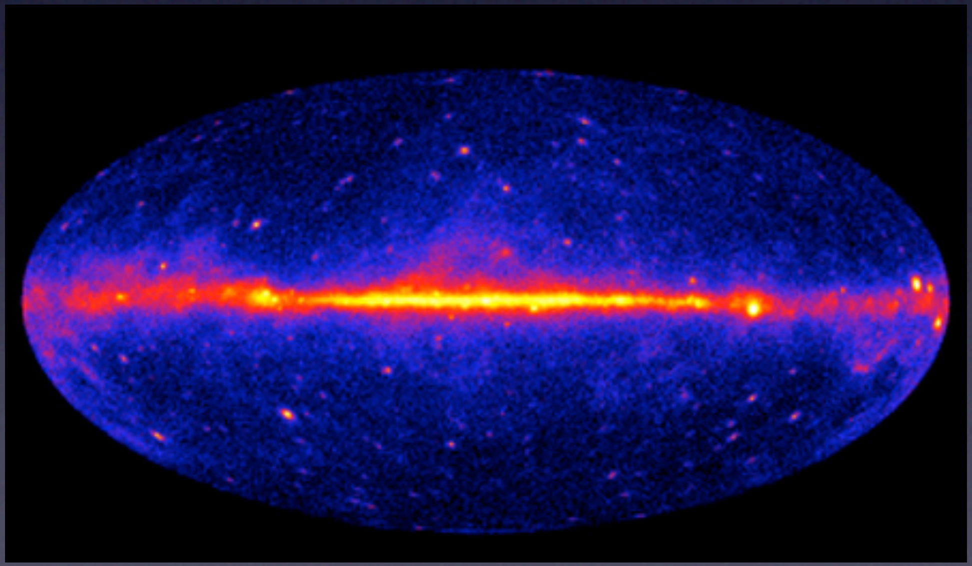
Fermi on DM Spikes

Douglas Spolyar
FermiLab & University of Chicago KICP

in collaboration with Pearl Sandick
K. Freese & J. Diemand

Text



arXiv:1008.3552; JCAP01(2011)018

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- The BH can generate a DM spike which is bound to the BH.
- The DM spike can still survive in the MilkyWay today.

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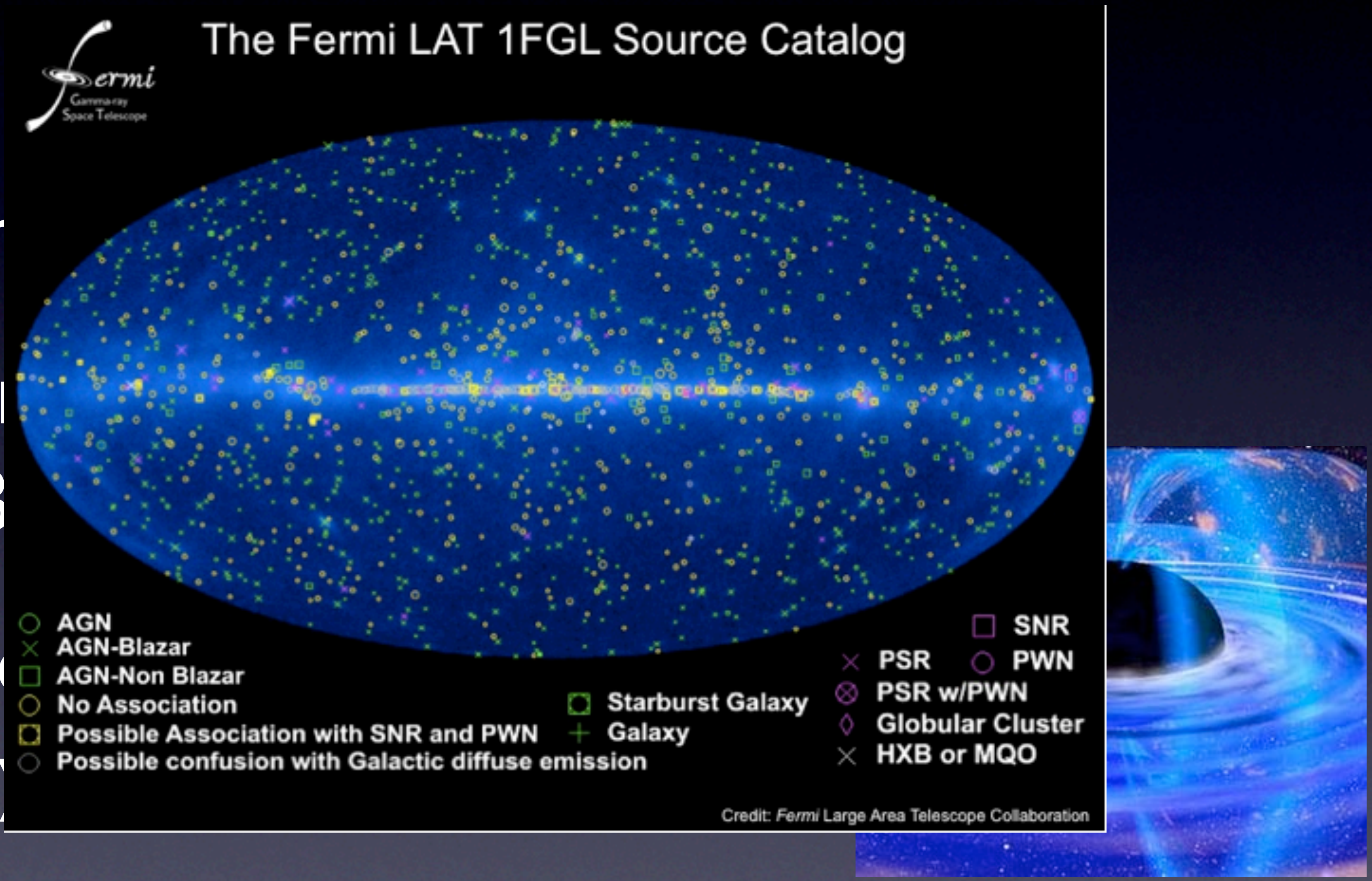
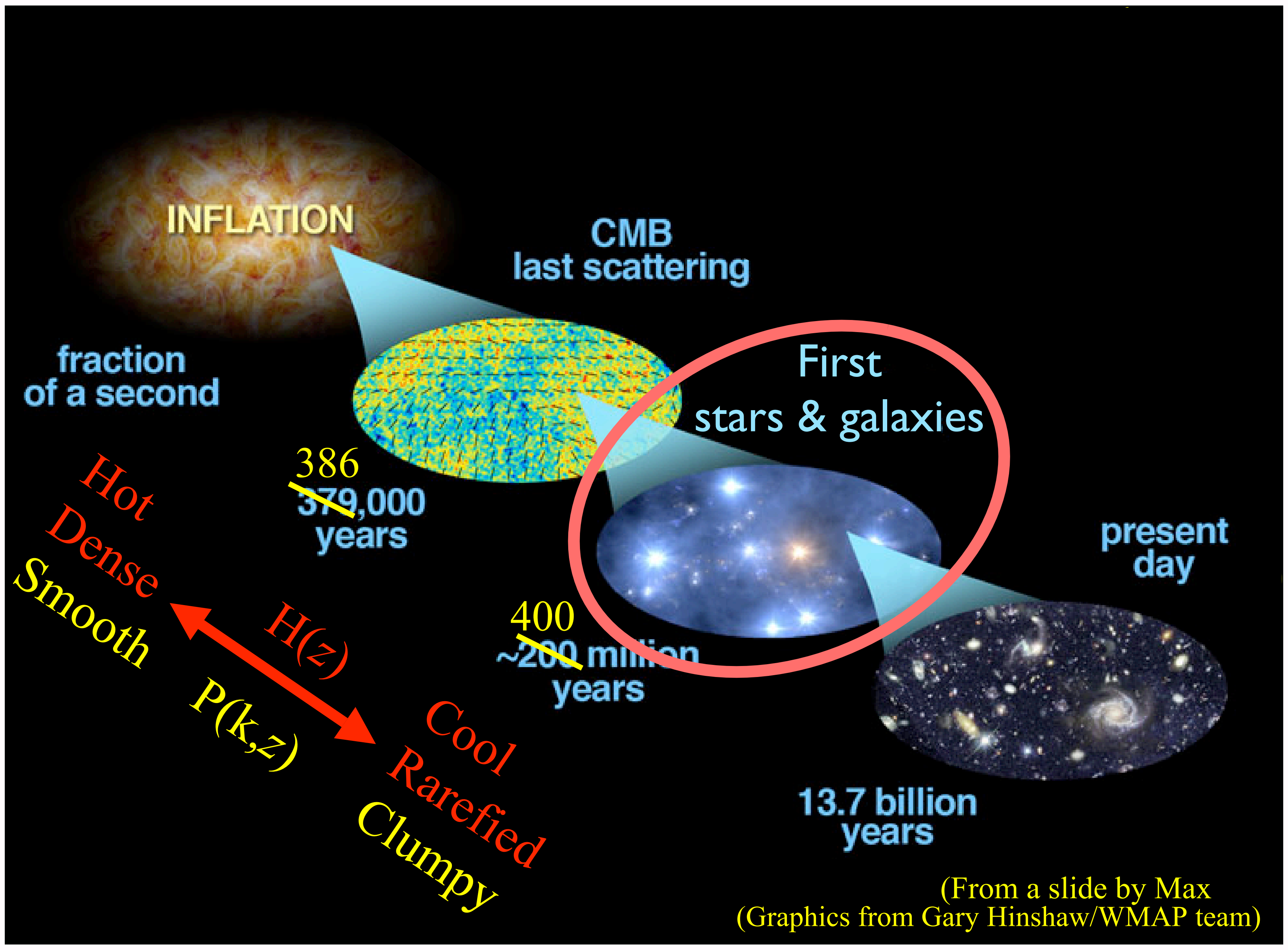


- If DM can annihilate, Fermi could detect the spike as an unidentified point source.

Outline

- BH formation
  - first stars/DarkStars
  - direct collapse
- DM spike formation and profile
- DM spikes in the MilkyWay
- Fermi Sky
- Limits on DM spikes
- Conclusion

The First Stars and first galaxies



(From a slide by Max
(Graphics from Gary Hinshaw/WMAP team)

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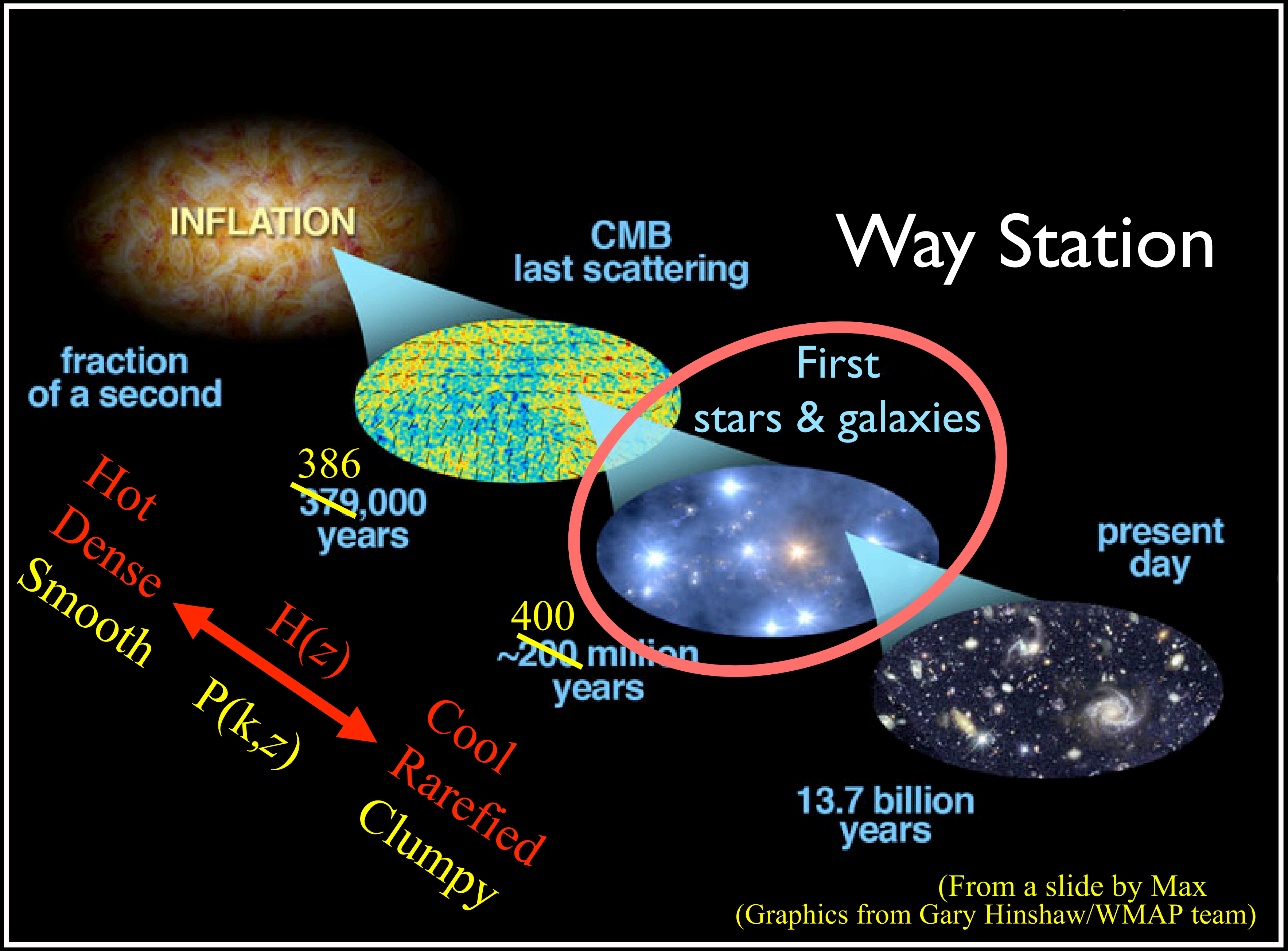

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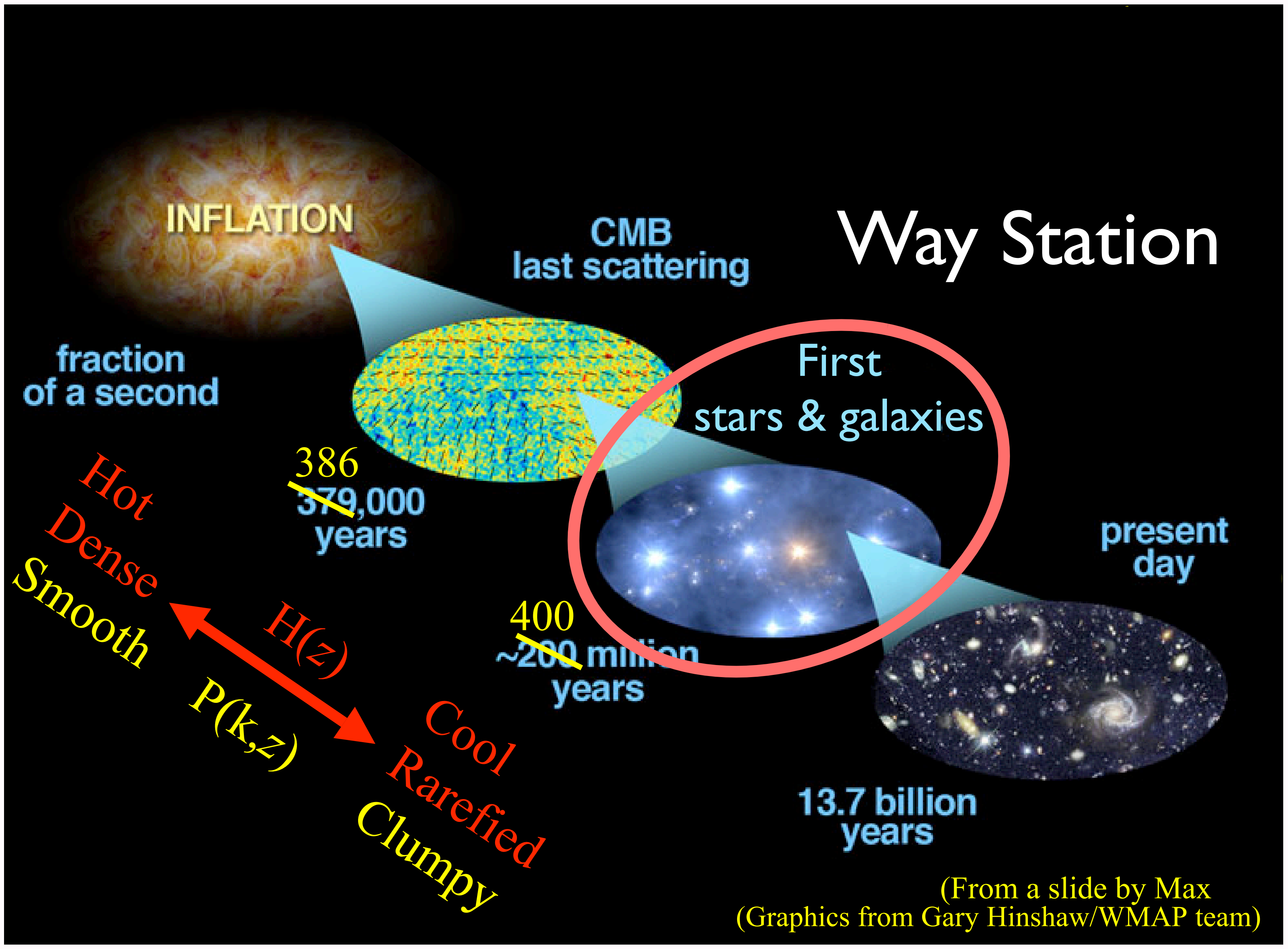

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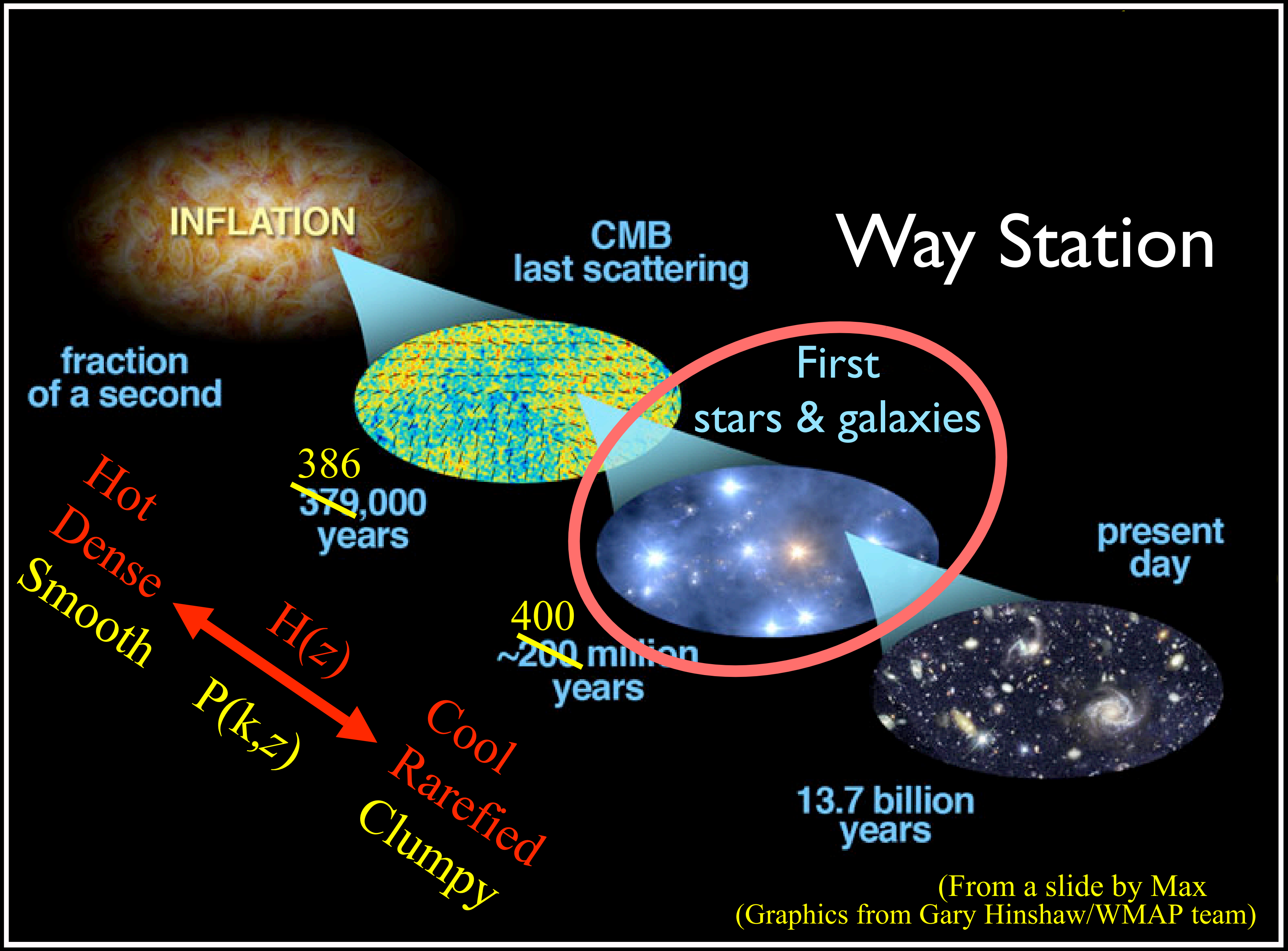
The First Stars and first galaxies

- Important for



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The First Stars and first galaxies

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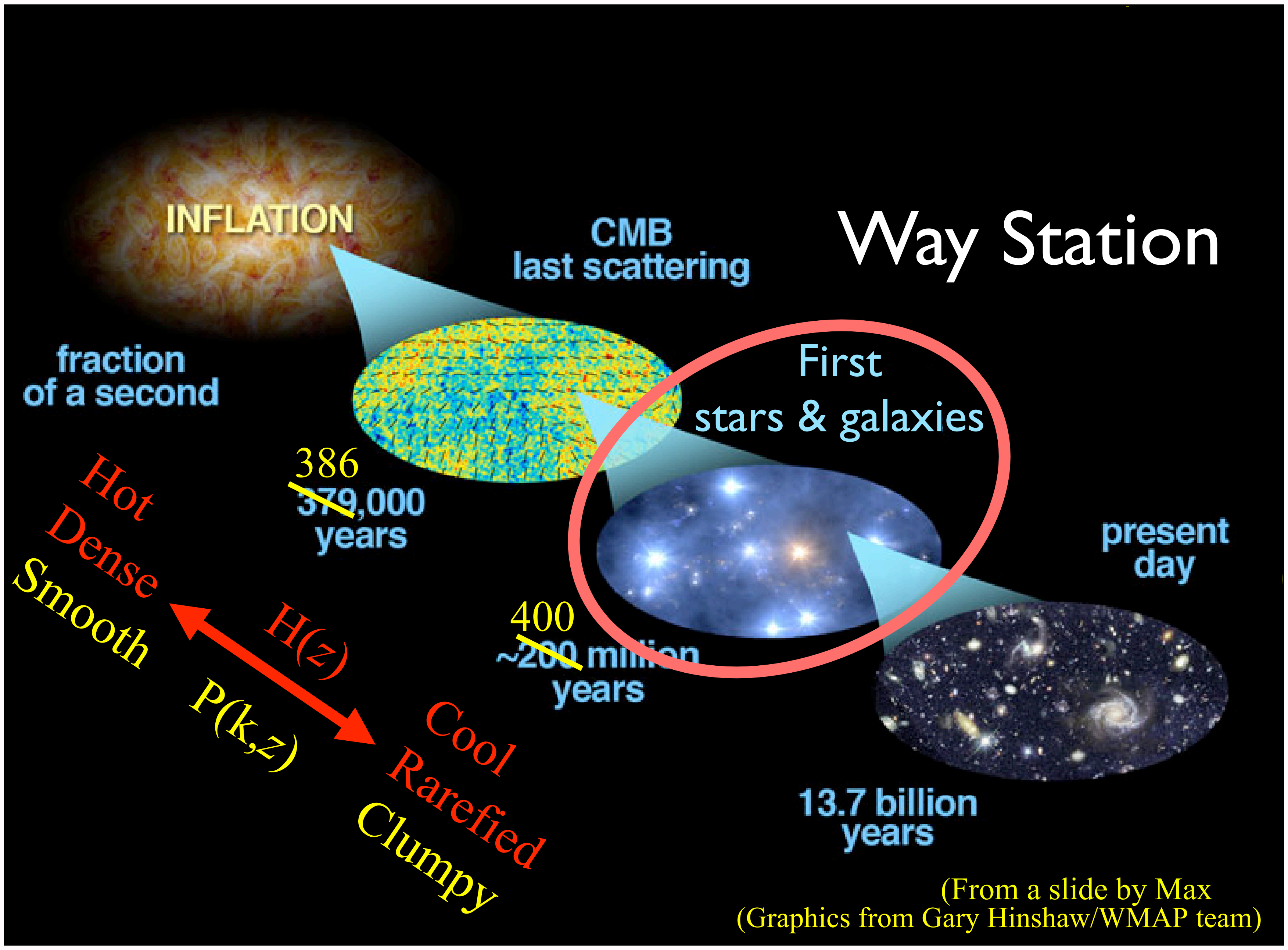

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The First Stars and first galaxies

- Important for
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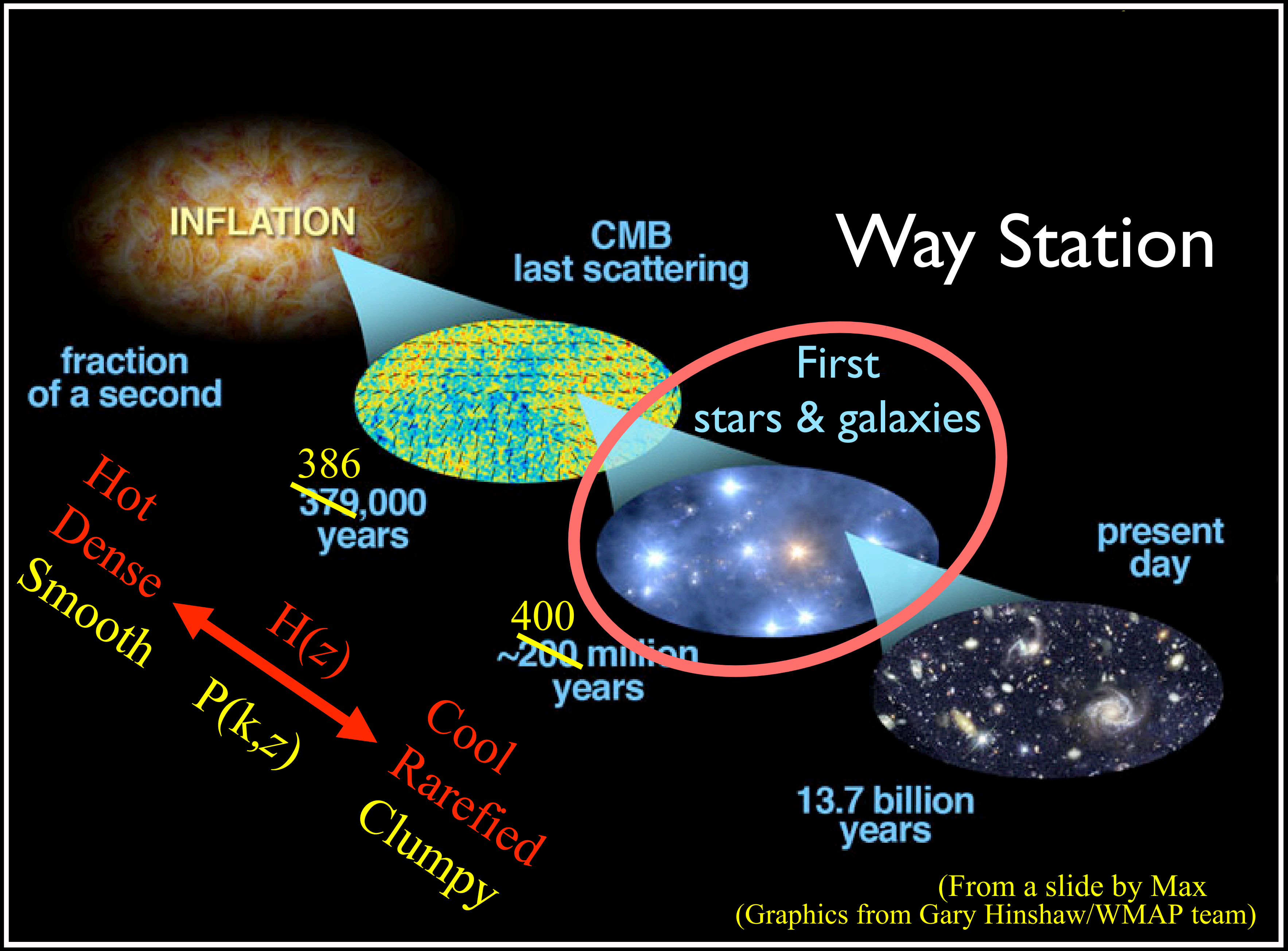
  - reionize the universe



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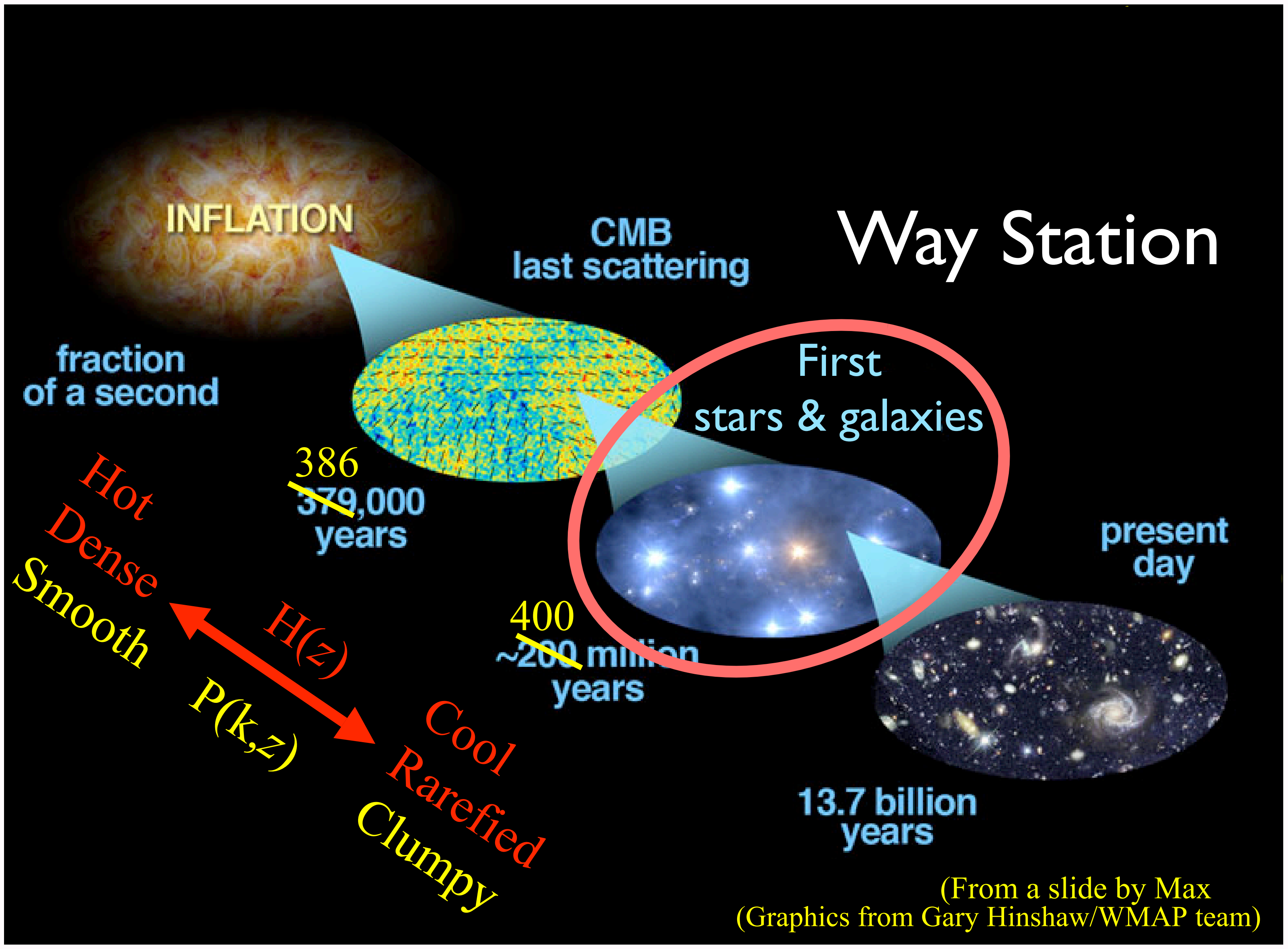

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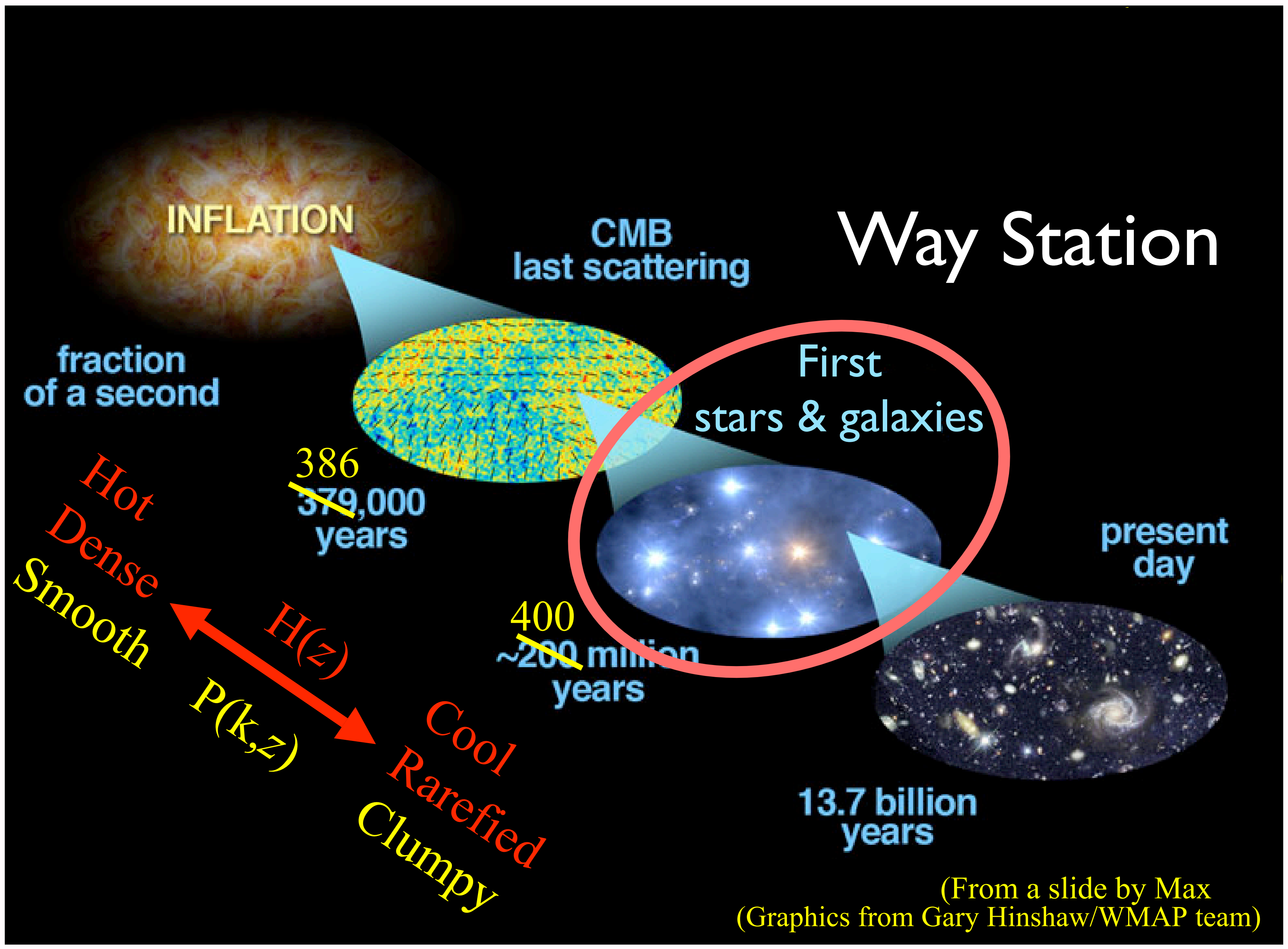

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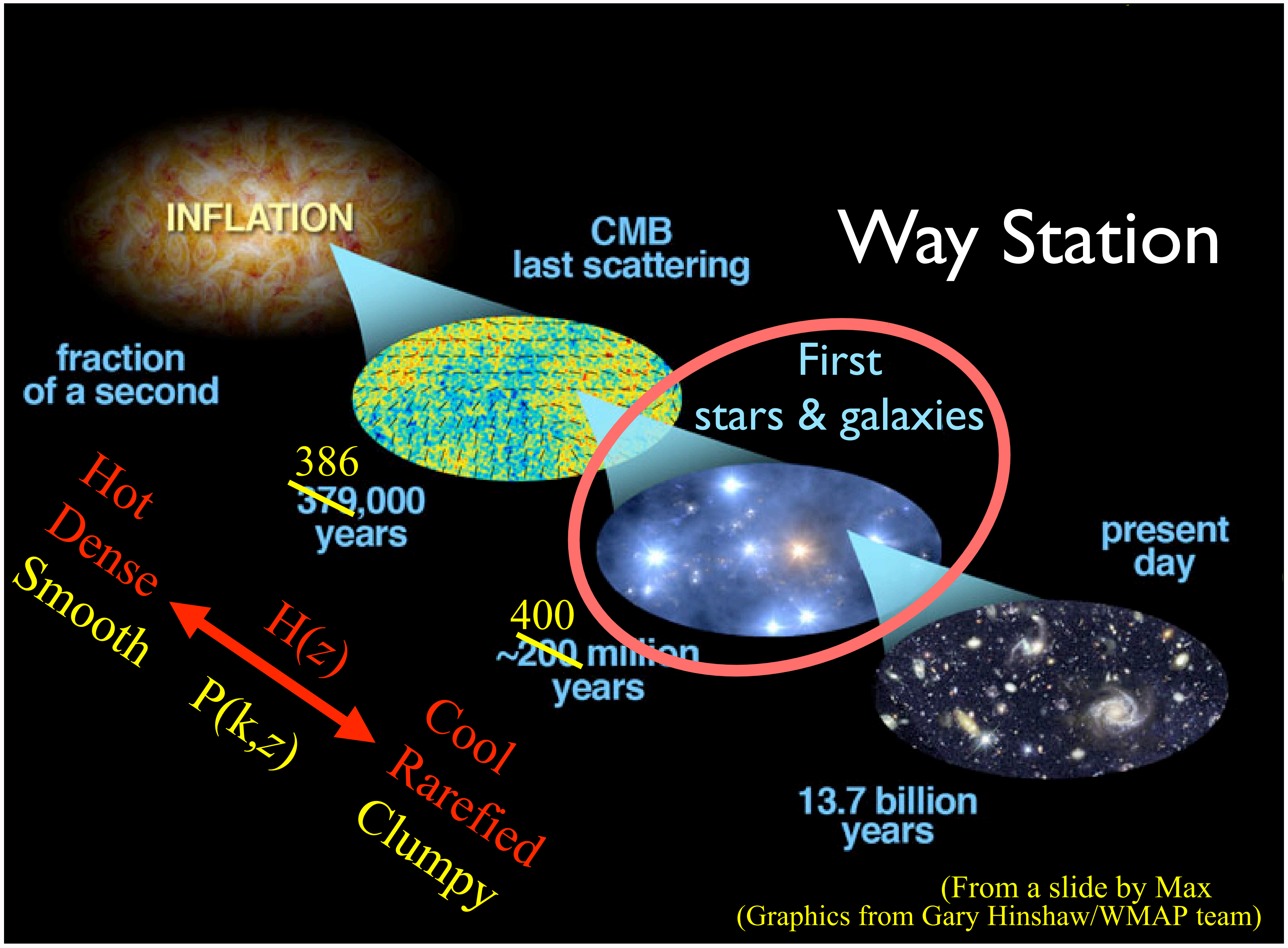

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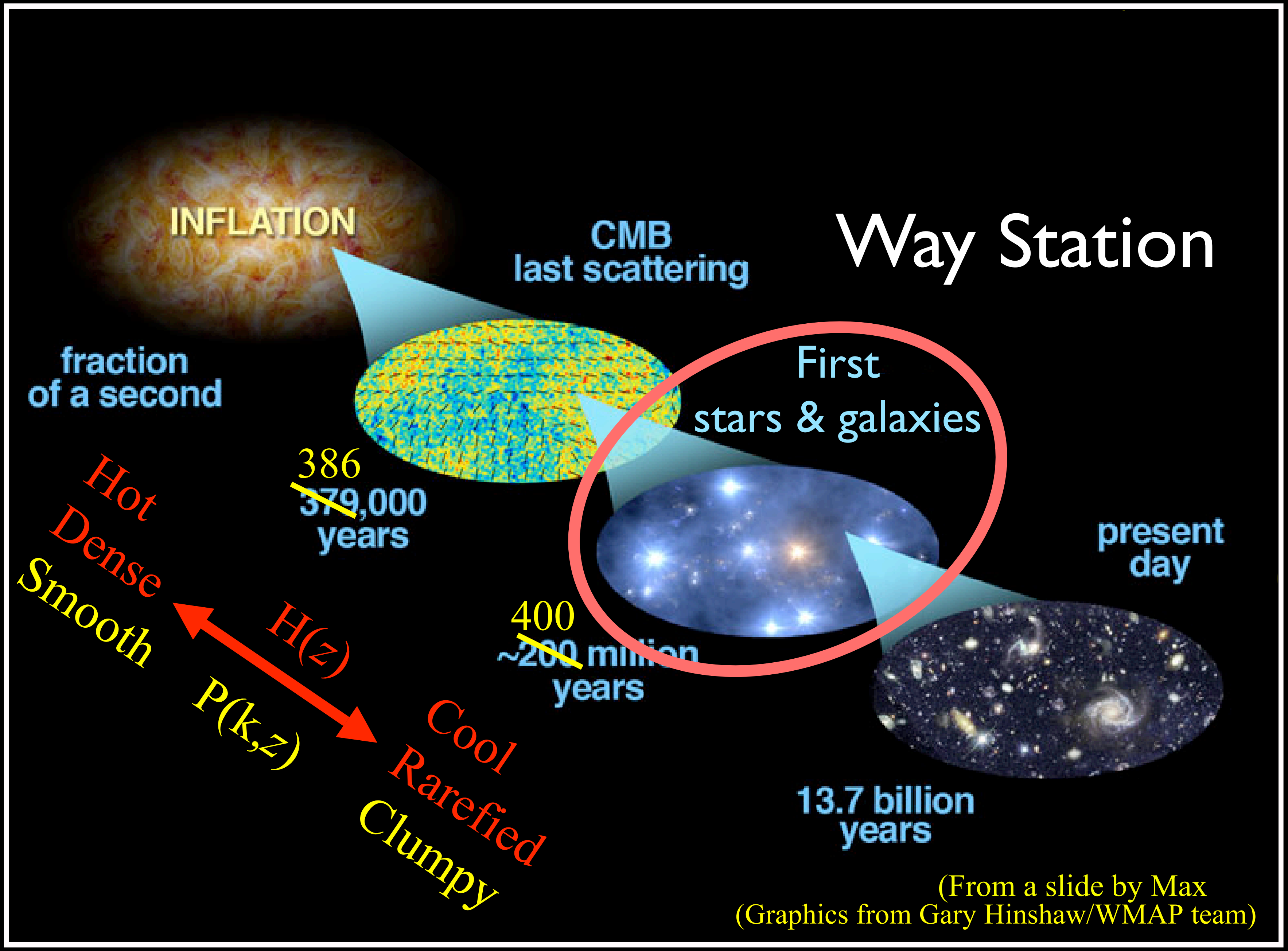

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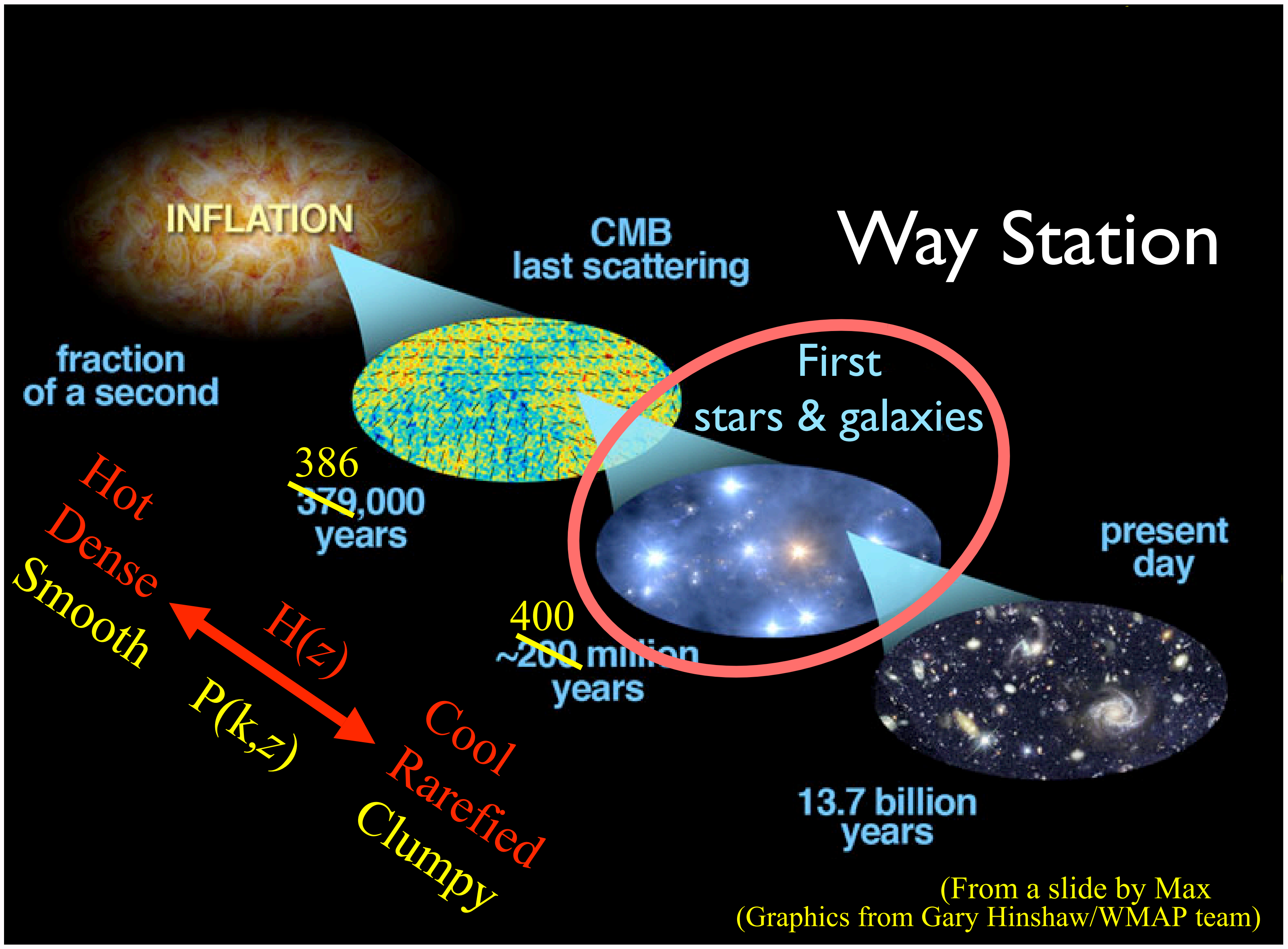
  - z = 50-5
  - Halos: 10^5 to 10^8 $(\mathrm{M}_\odot)$
  - Generate BHs



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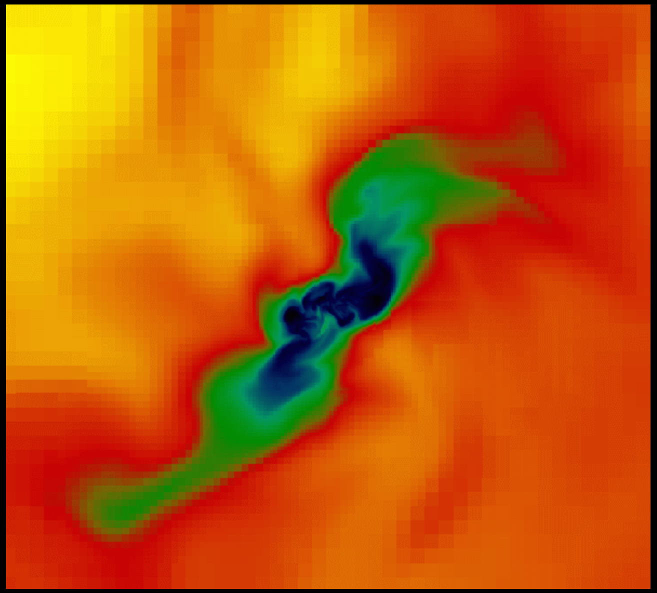
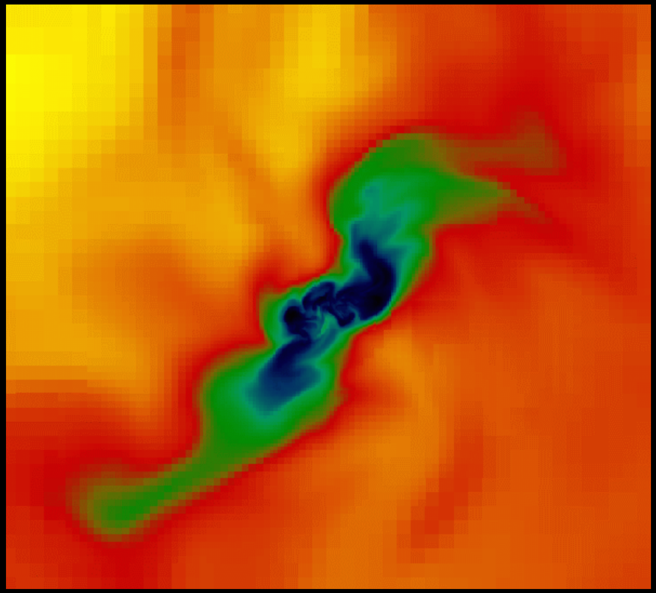
First Stars OverView



First Stars OverView

- Formation Basics



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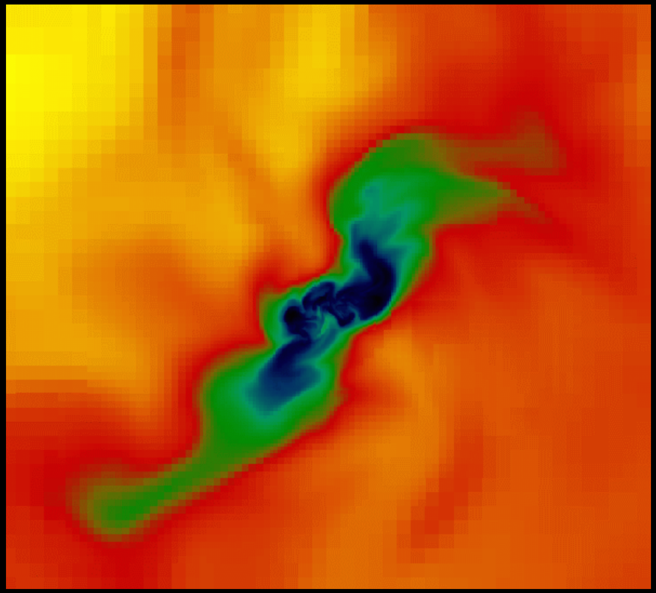

- Formation Basics
    - first luminous objects ever

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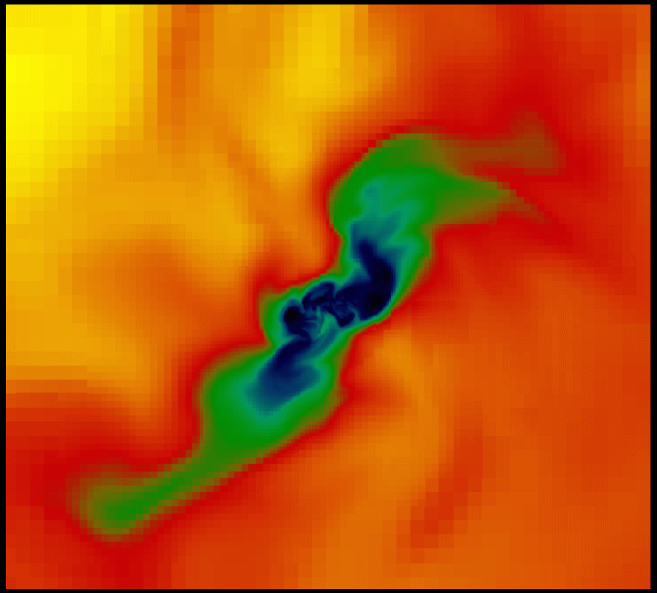

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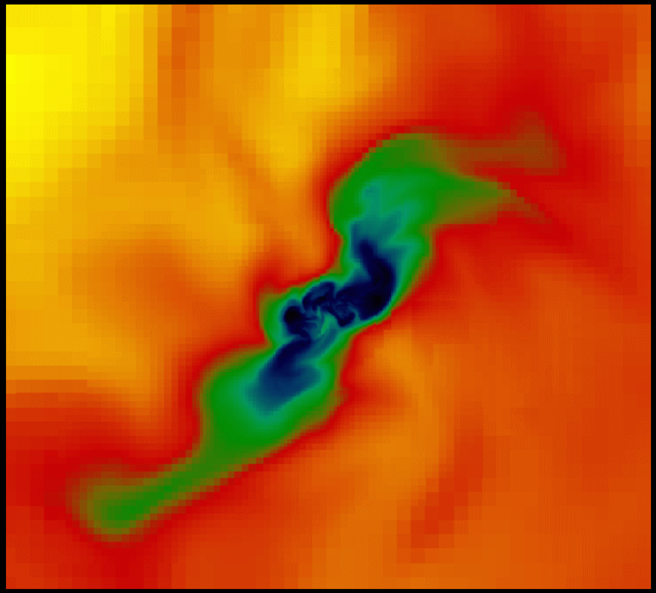

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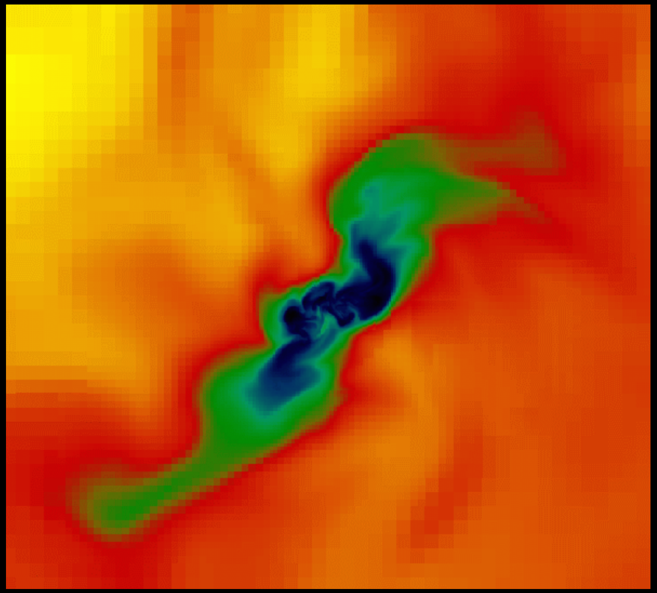

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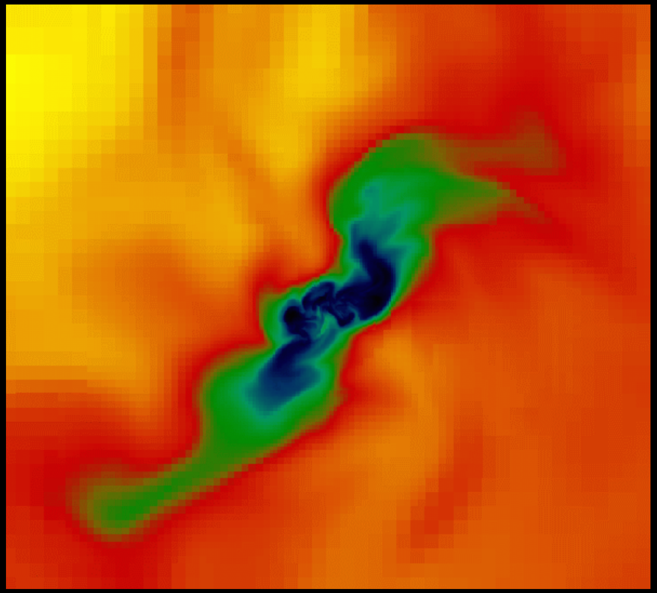

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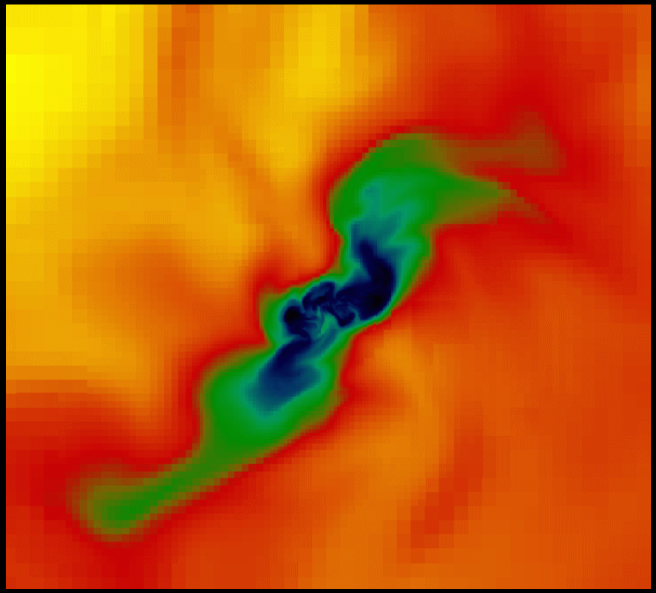

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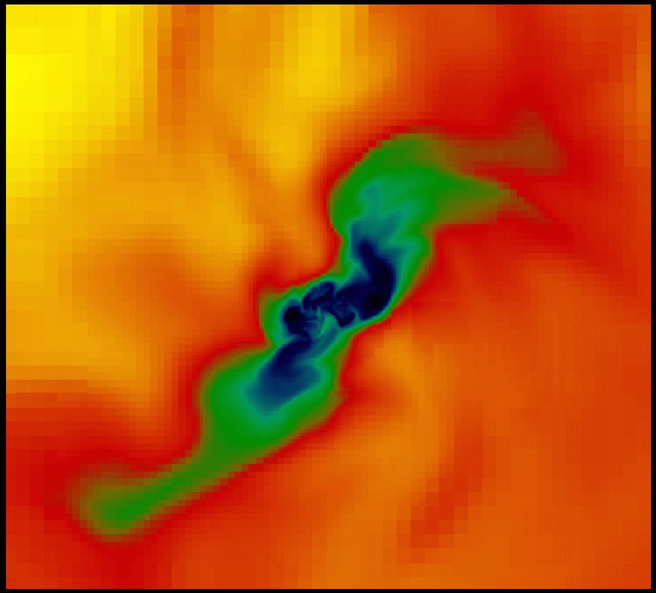

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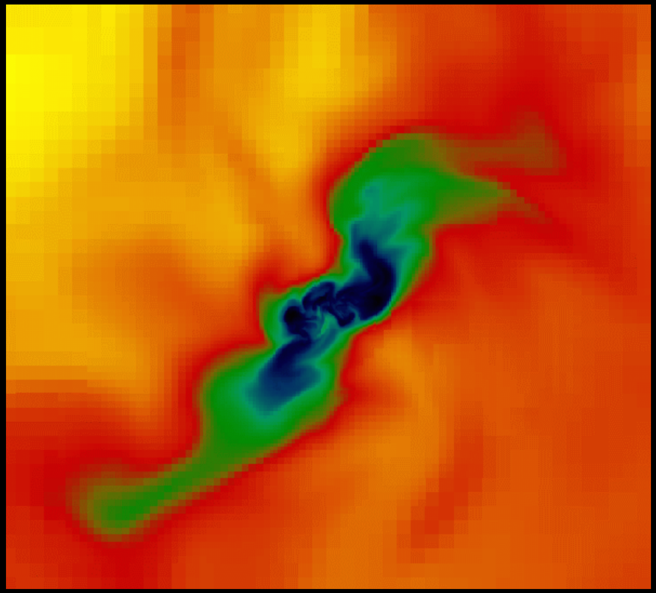

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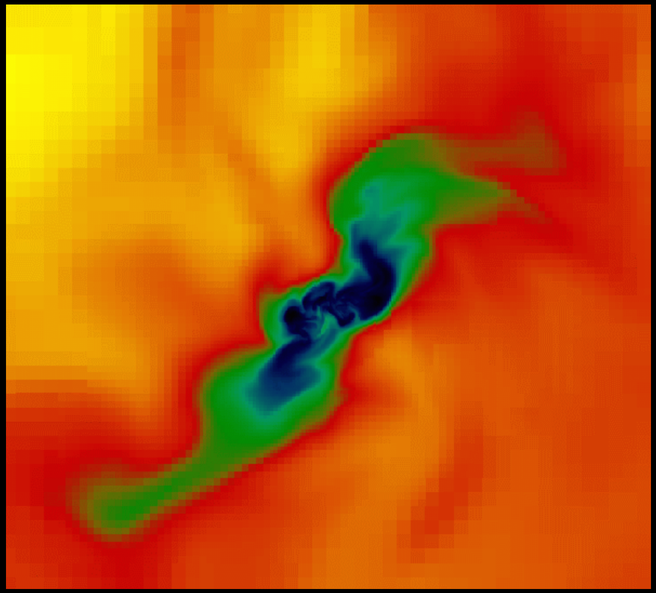

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      2. Form BH upon death.

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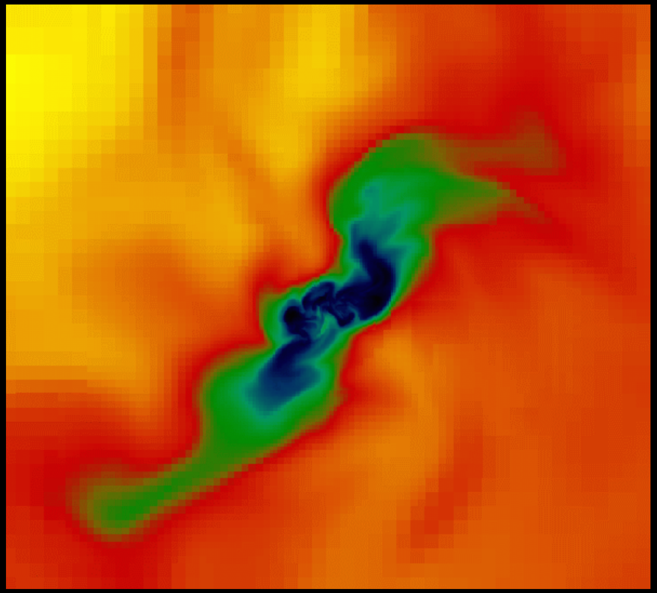

BH can also grow with accretion

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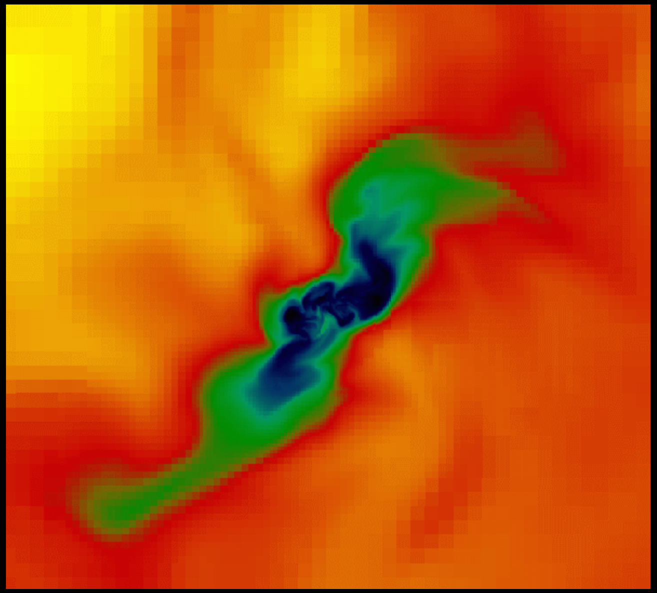


BH can also grow with accretion

Could first Stars be larger?
DarkStars

Dark-Star Spotter's Guide to the Universe

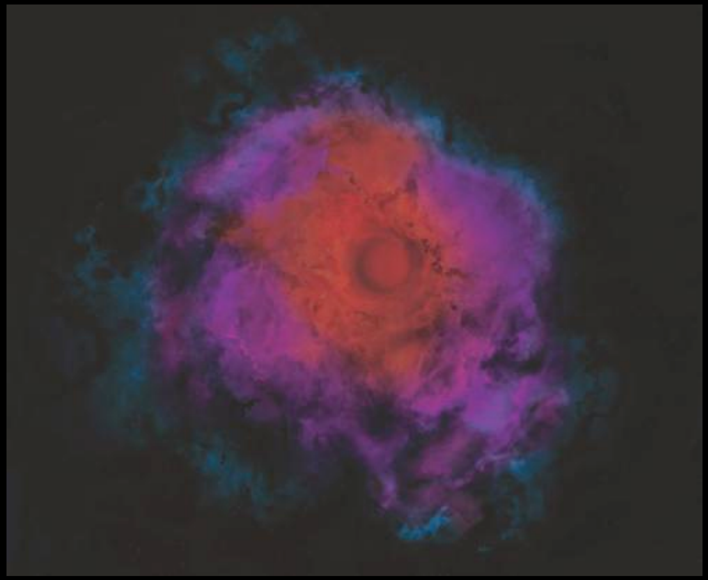
a definition of a 'Dark Star': any star whose structure or evolution has ben effected by DM annihilation

⟶ There are Many kinds of dark stars....

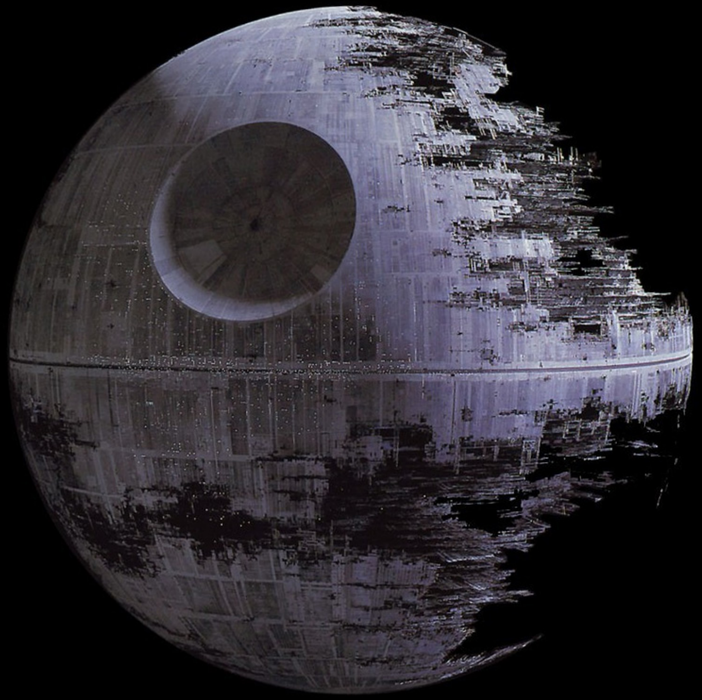
- **Main Sequence stars**- fed by scattering (salati, Spergel, Press, Scott, Fairbairn, iocco, Freese)
- **White dwarfs**- fed by scattering (Moskalenko, Wai, Fairbairn, etc.)
- Nuetron stars in the MIlky Way -fed by scattering (Fairbairn, Bertone)-considered any compact star
- The first stars in the early Universe - fed by scatter and by gravitational contraction (Spolyar, Freese, Iocco, Gondolo)

P. Scott

DarkStars in the Early Universe



- First Stars form Deep inside DM halo
  - Very high DM denisty
  - DM heating can drive the stellar structure
  - Star MUCH cooler than typical first stars
    - 10,000 K vs. 100,000 K
    - Hence can accrete More baryons
    - Live one the order of a million years
    - Mass can be much larger than first stars
      - 10^3 to 10^5 $\mathrm{M}_\odot$
      - Upon Collapse Form Massive BHs



Direct Collapse (DC) Star

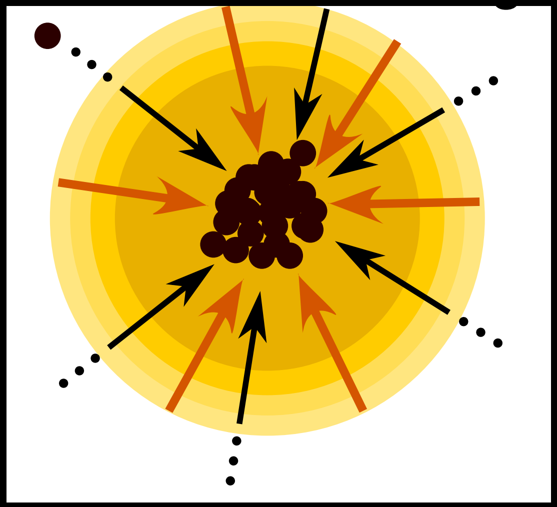
- In Halos with mass of $10^7 \text{ to } 10^9 \, \mathrm{M}_{\odot}$, gas rapidly cools due to Hydrogen cooling and neutrino cooling. The gas collapses to form a BH with a mass of $10^4 \text{ to } 10^6 \, \mathrm{M}_{\odot}$
- Haehnelt & Rees 1993; Umemera, Loeb & Turner; Loeb & Rasio 1994; Eisenstein & Loeb 1995; Bromm & Loeb 2003; Koushiappas, Bullock & Dekel 2004; Begelman, Volonteri & Rees 2006

Black Holes

Black Holes

Black Holes

- Many galaxies (if not all galaxies) have a Super Massive Black Hole at the center of the Galaxy.
  - Have observed high redshift quasars $z \gtrsim 6$
    - Presumably powered by accretion onto a massive central Black hole $\simeq 10^9 \mathrm{M}_\odot$
    - Believed to have grown from a seed BH which came from a DC Star, First Star, or Dark Star.
      - We will focus on BH which form around first star whether powered by DM or fusion. DC scenario will be qualitatively similar



DM spike

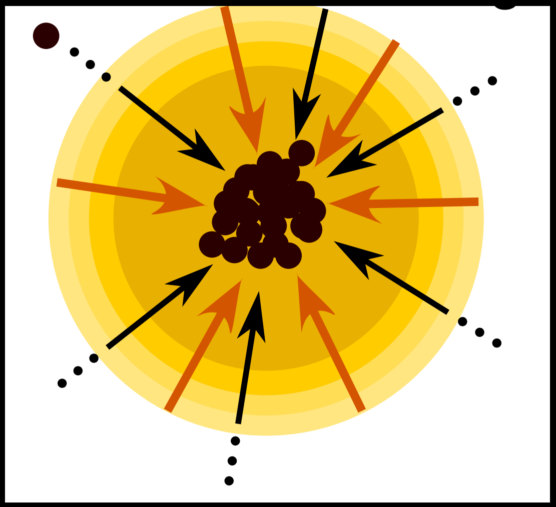
- Adiabatic contraction
  - as baryons fall in to form Dark star or accrete BHs (at center of halo), DM particles respond to potential well
  - using prescription from Blumenthal, Faber, Flores, & Primack 1986

$$r\,M(r) = \text{constant}$$

- We find a contracted profile

$$\rho_\chi(r) \sim r^{-1.9} \qquad\qquad \rho_\chi(r) \sim r^{-1}$$

DM spike



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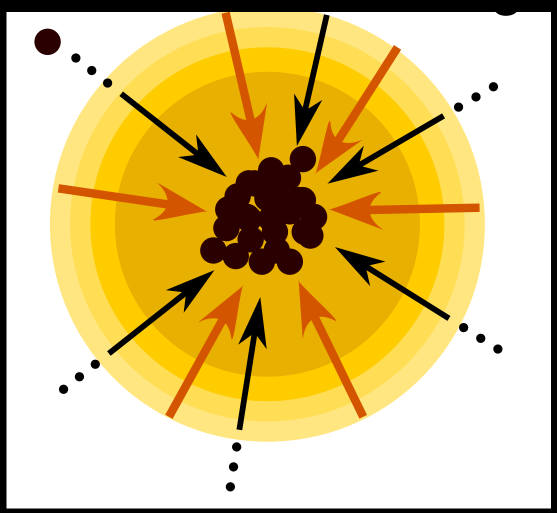

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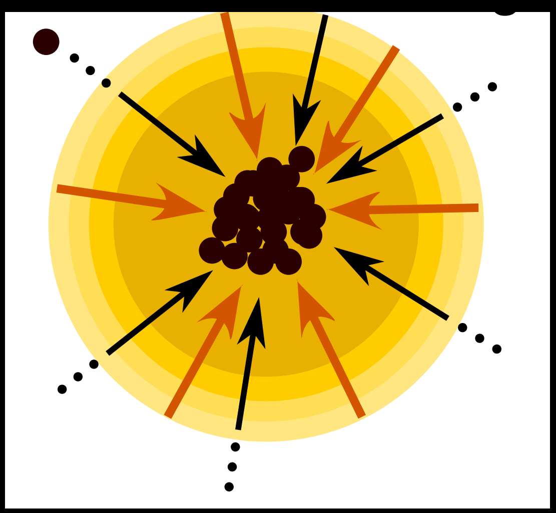
(NFW profile)



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(DM tracks the Baryons!)

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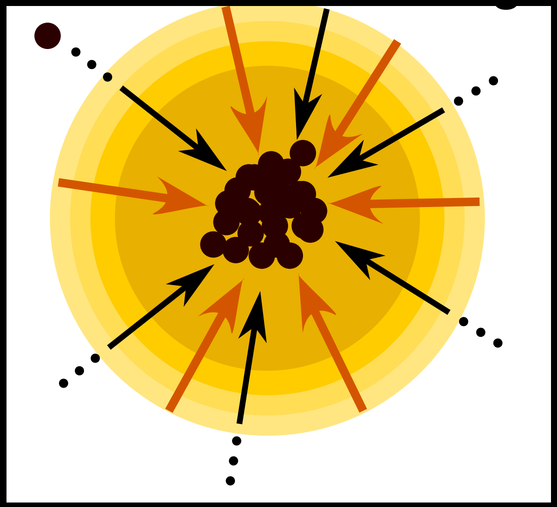

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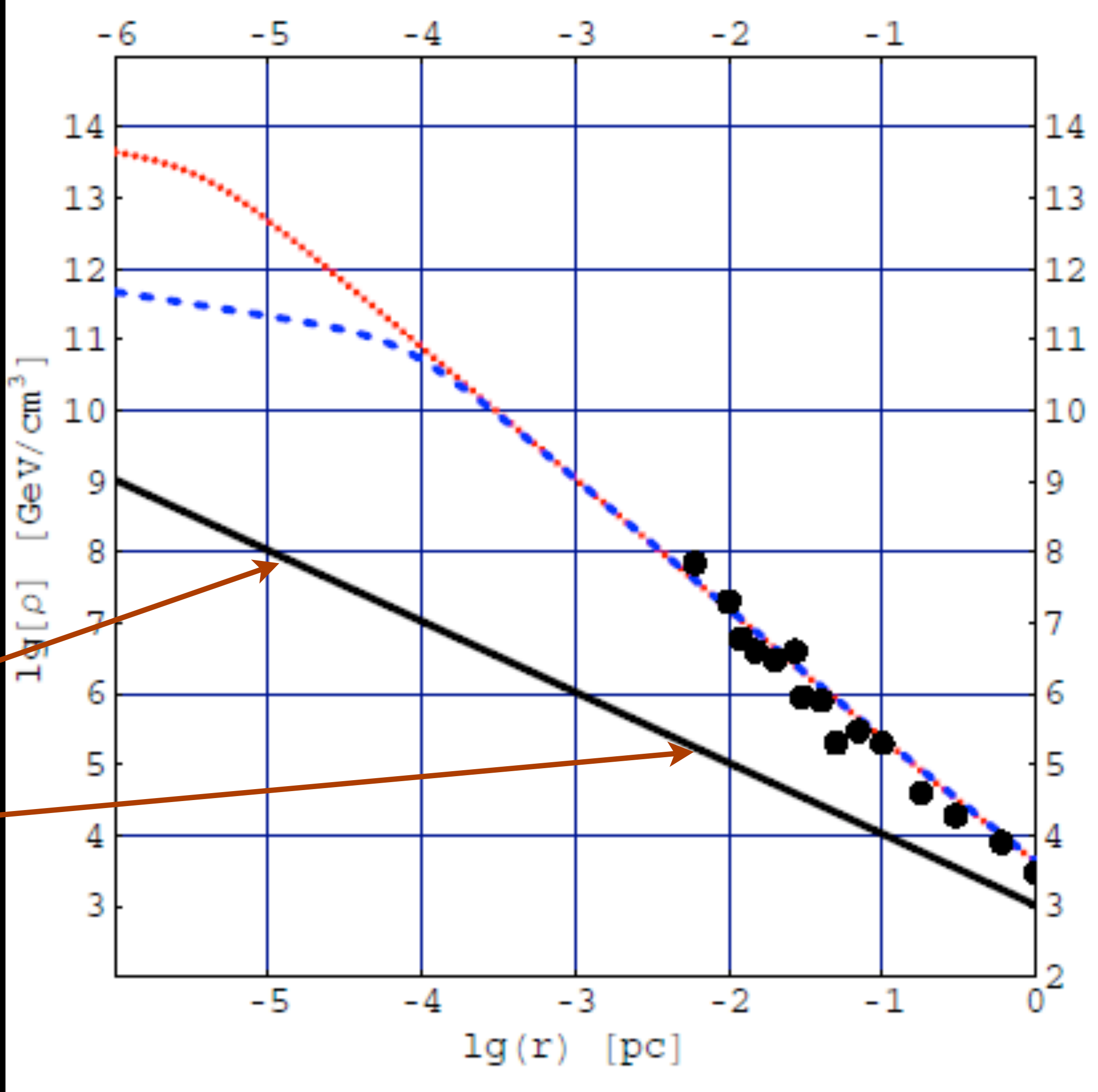
High Dark Matter densities!

Testing Adiabatic Contraction



Original
NFW Profile

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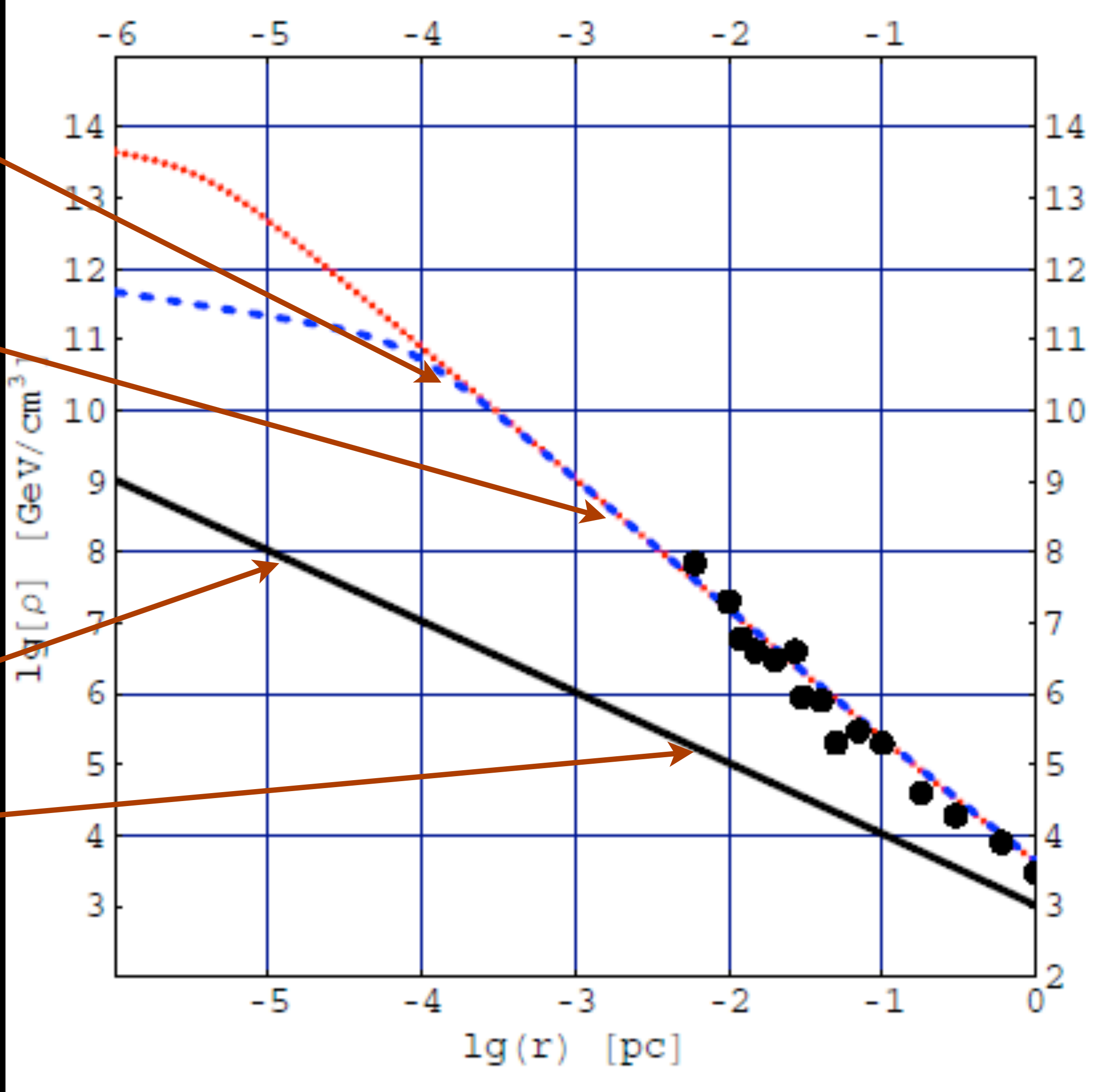

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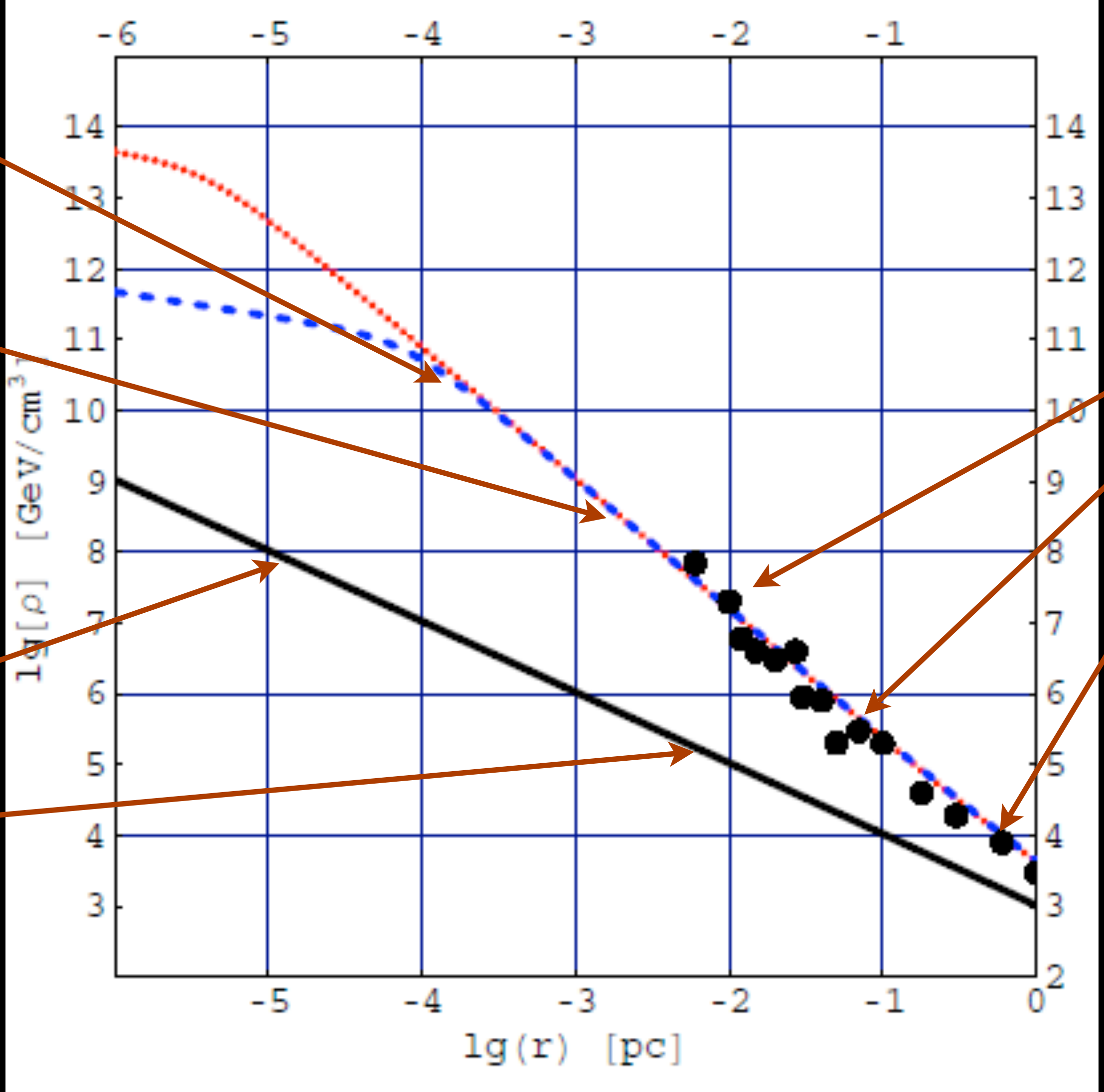
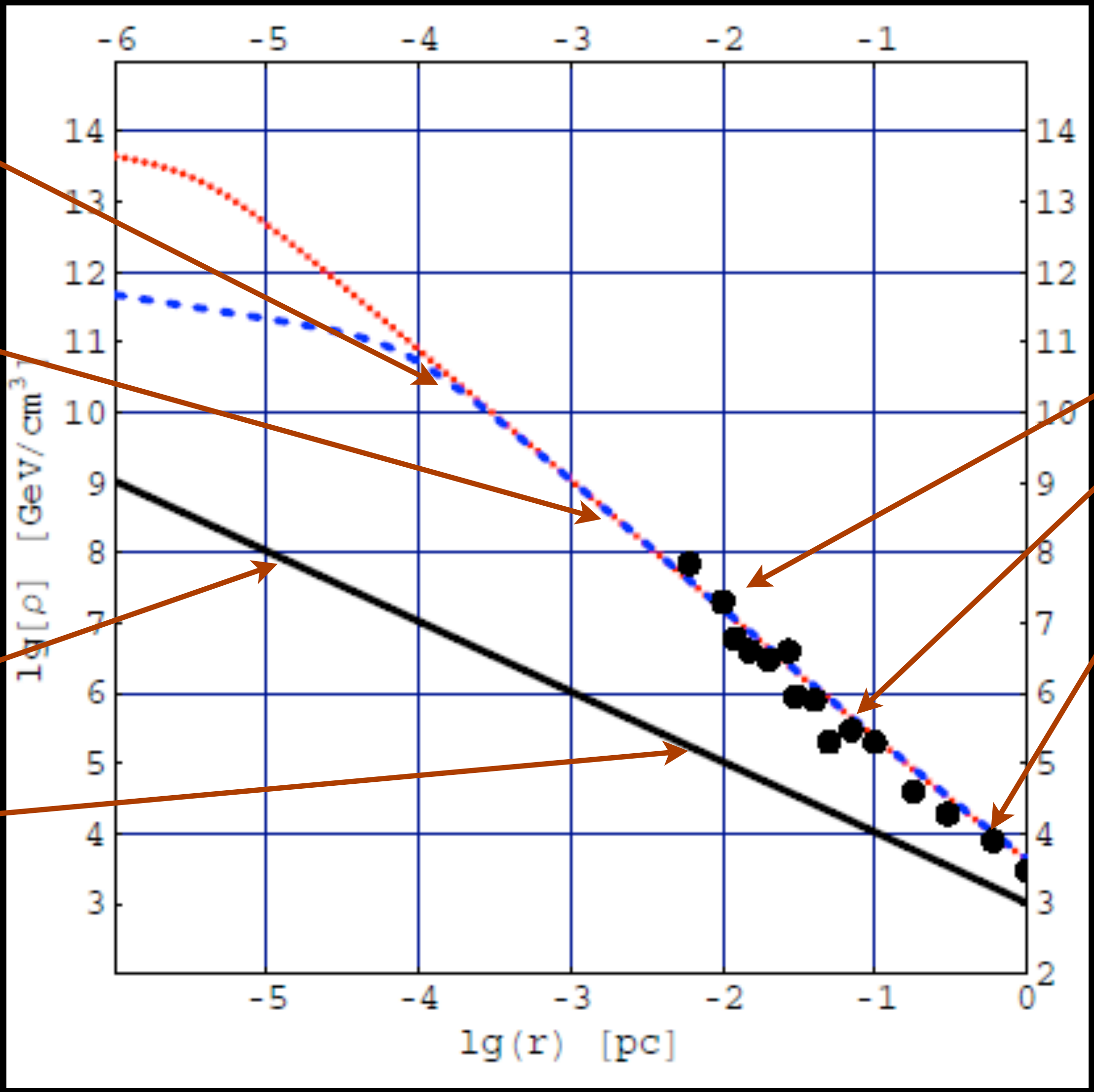


Adiabatically Contracted profile

Original NFW Profile

points from cosmological N-Body simulation

Testing Adiabatic Contraction



Adiabatically Contracted profile

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Original NFW Profile

Simple Prescription determine DM density within a factor of 2 !

What About DM spikes today?

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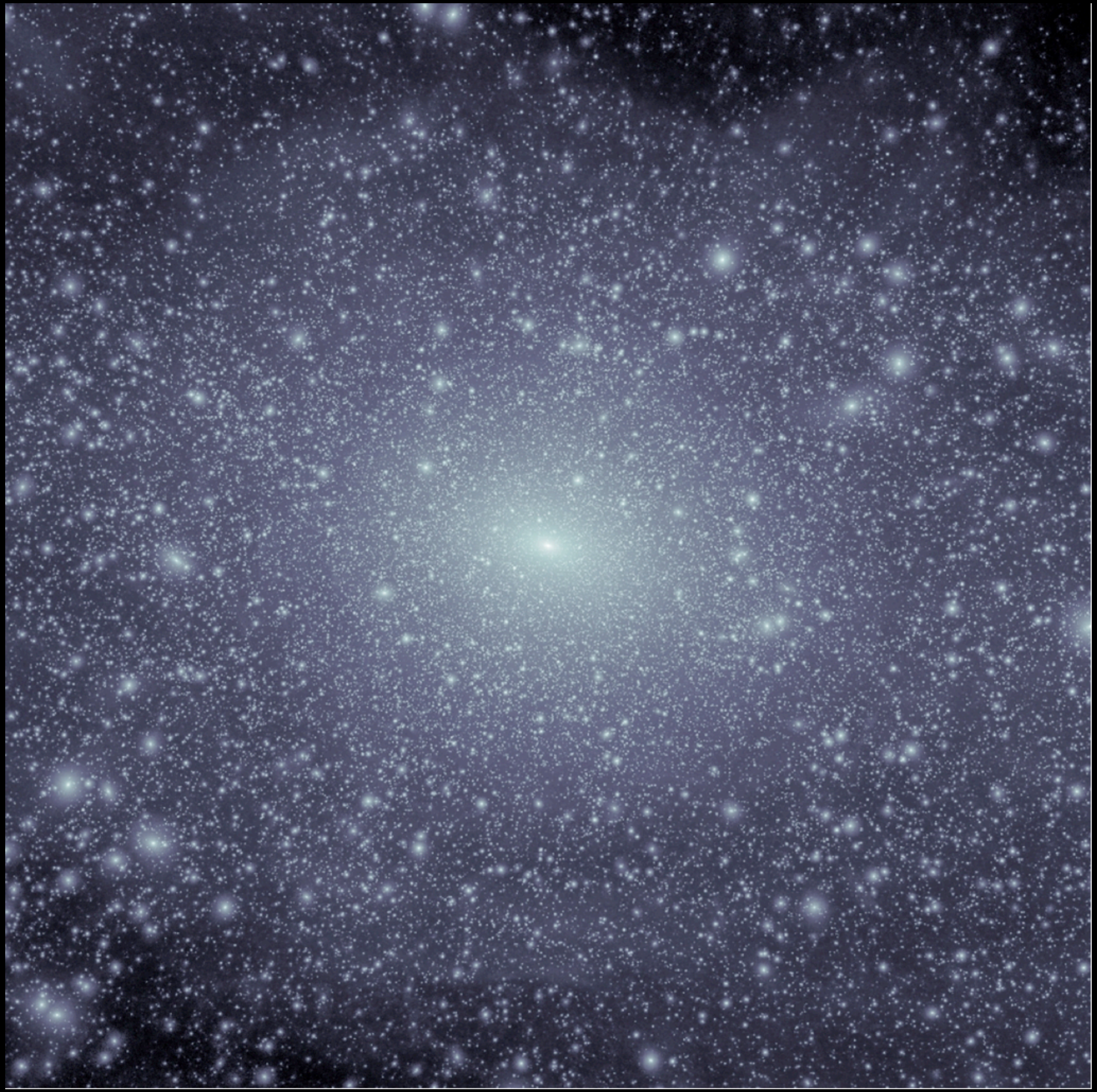
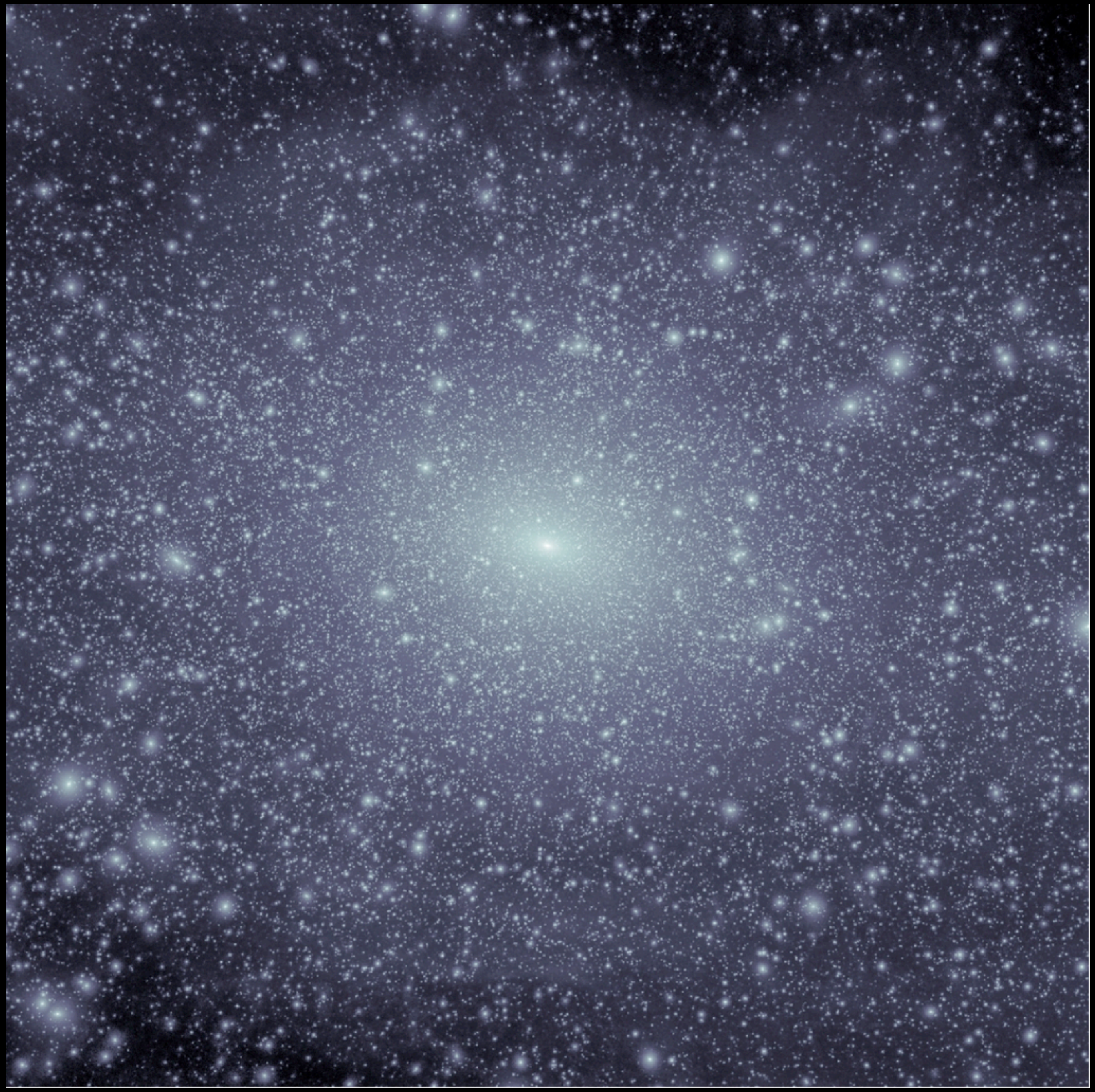
- Use Via Lactea II simulation



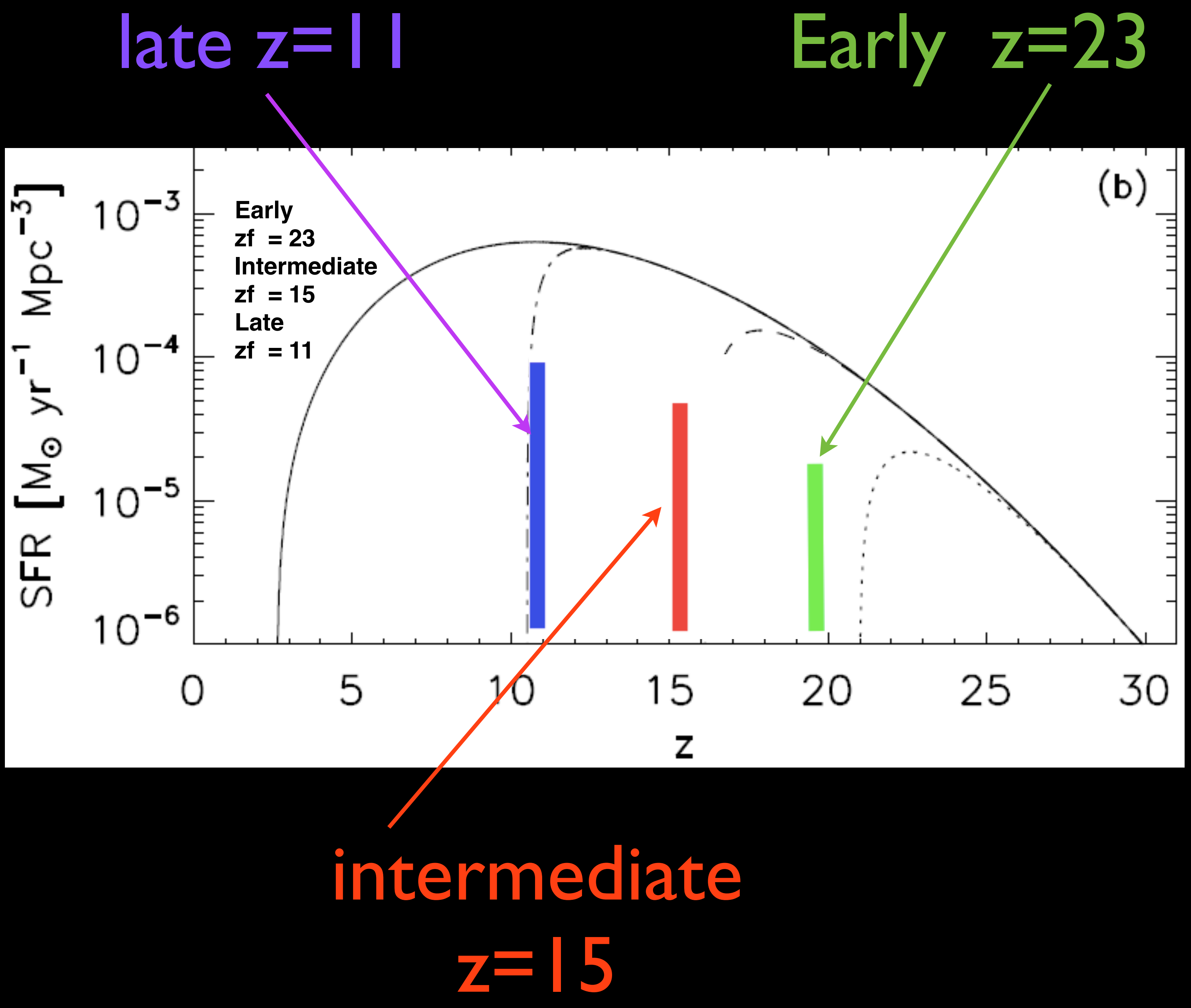
What About DM spikes today?

- Use Via Lactea II simulation
- to identify halos which could have hosted first stars and have survived until today

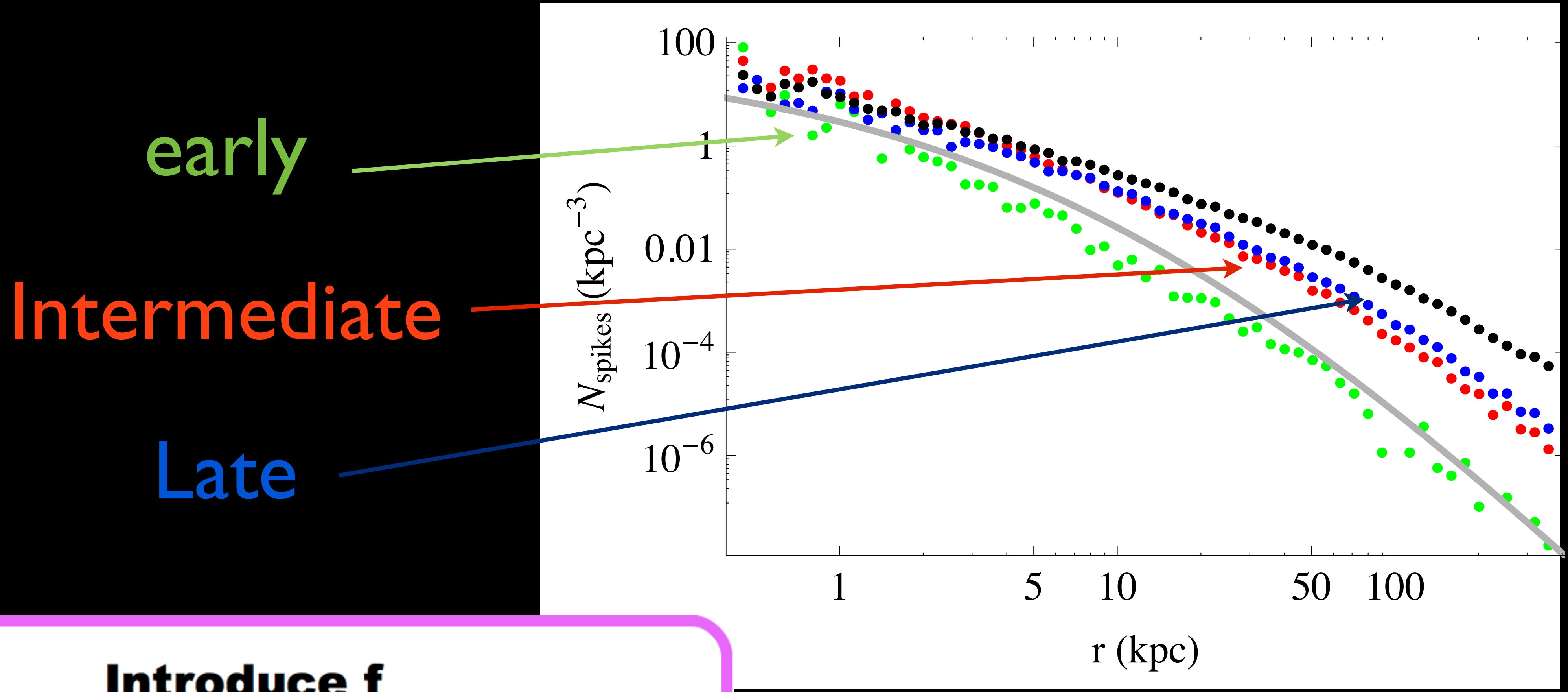


Identify halos hosting first stars

Parametrize end of Population III.1 star formation à la Greif & Bromm (2006):



Via Lactea II gives the distribution of the different host halos in MilkyWay Halo



Introduce f_{DS}

Actual N_{sp} = f_{DS} · Total Possible N_{sp}

Point Source vs. Diffuse Flux

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Two ways they could show up: (FSC and EGB both Abdo *et al.* 2010)

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Diffuse Flux

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Does the expected diffuse flux from all non-PS spikes overproduce the FGST-measured diffuse flux?

From a single Spike

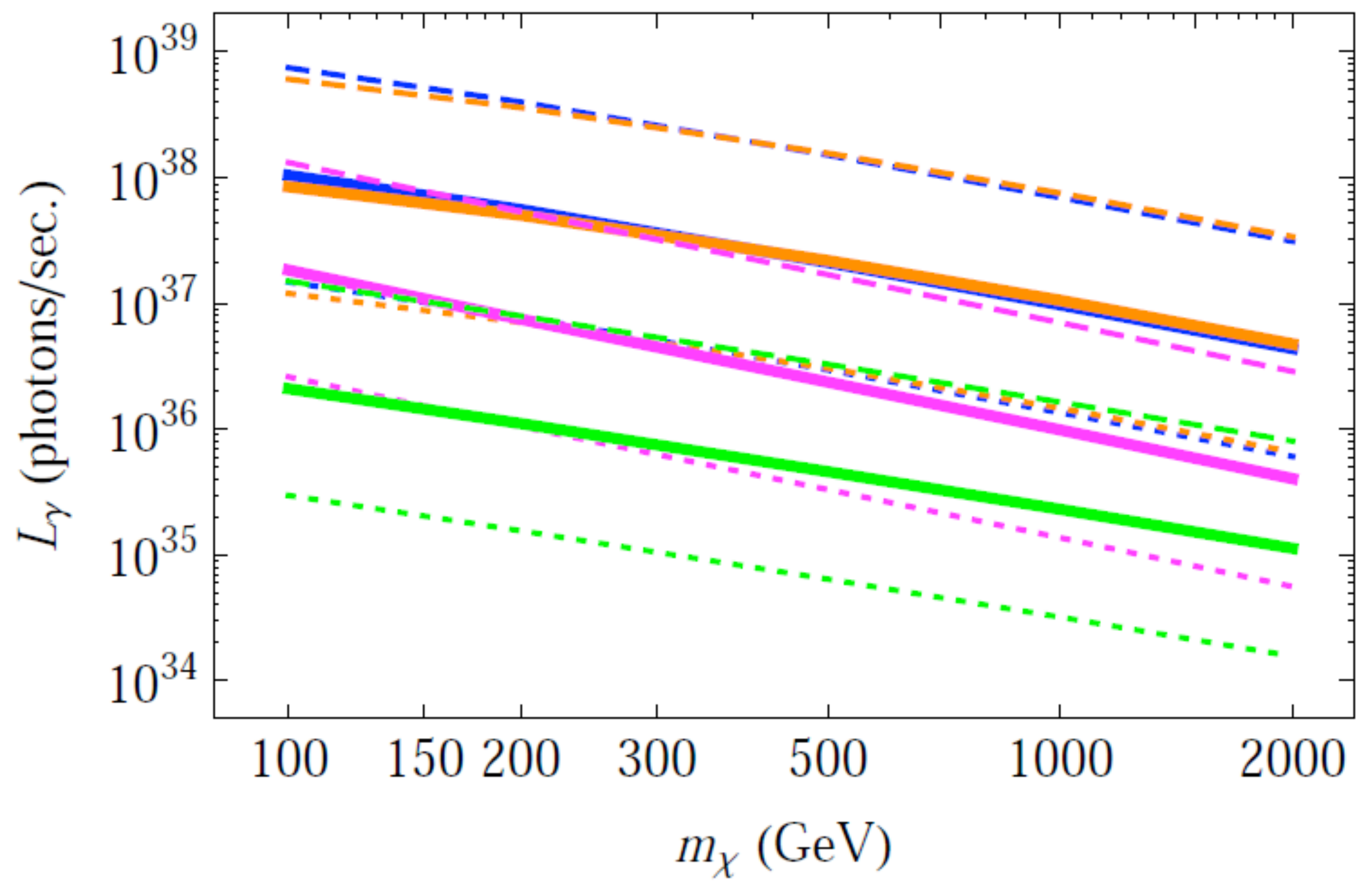
Annihilation Rate

$$\Gamma = \frac{\langle \sigma v \rangle}{2 m_\chi^2} \int_{r_{min}}^{r_{max}} dr\, 4\pi r^2\, \rho_{DM}^2$$

$$\langle \sigma v \rangle = 3 \times 10^{-26}\ \mathrm{cm}^3 \mathrm{s}^{-1}$$

Luminosity

$$\mathcal{L} = \int dE \sum_f \frac{dN_f}{dE} \Gamma_f$$



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Leptonic final states less luminous (especially muons – FSR only)

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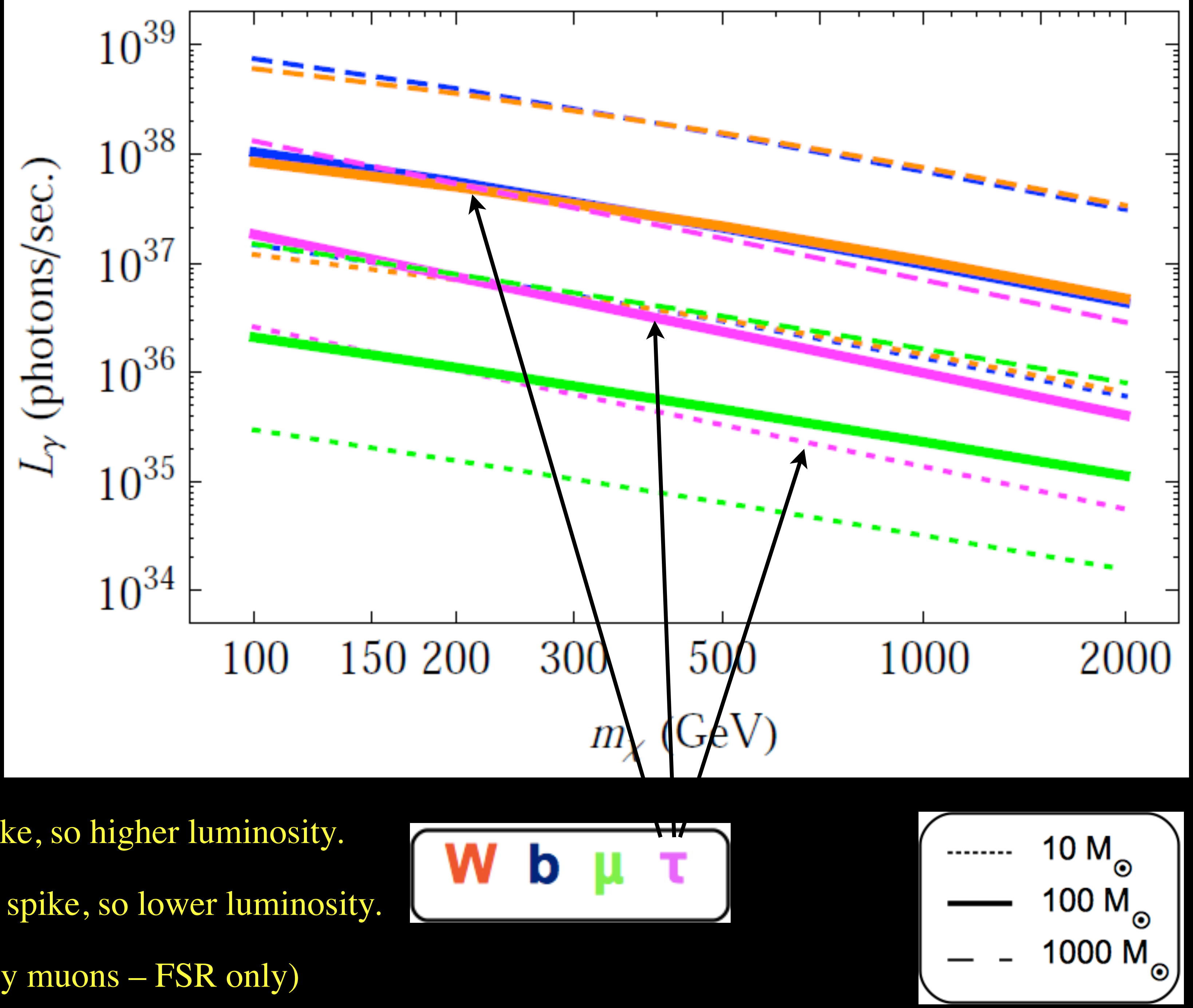

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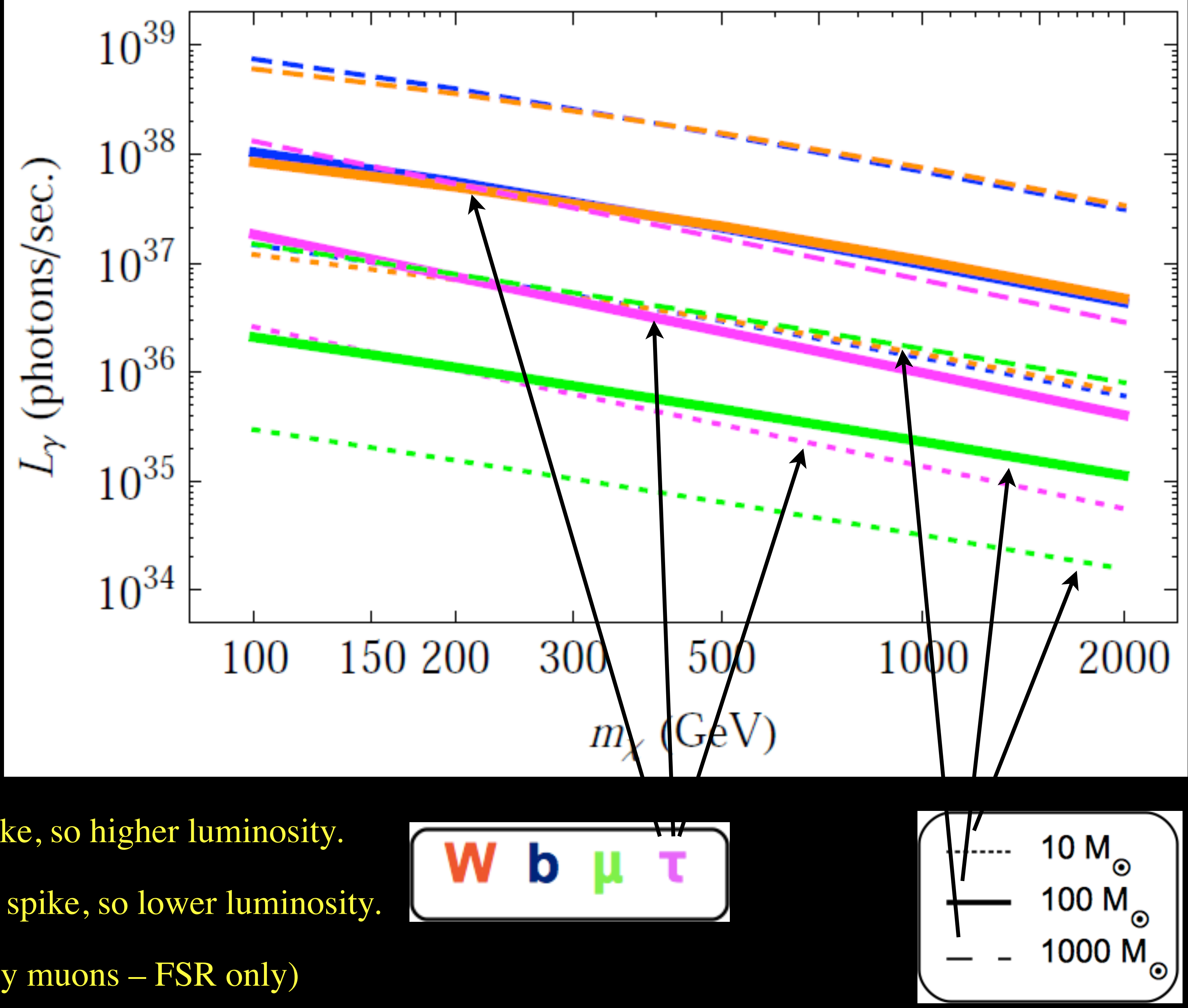

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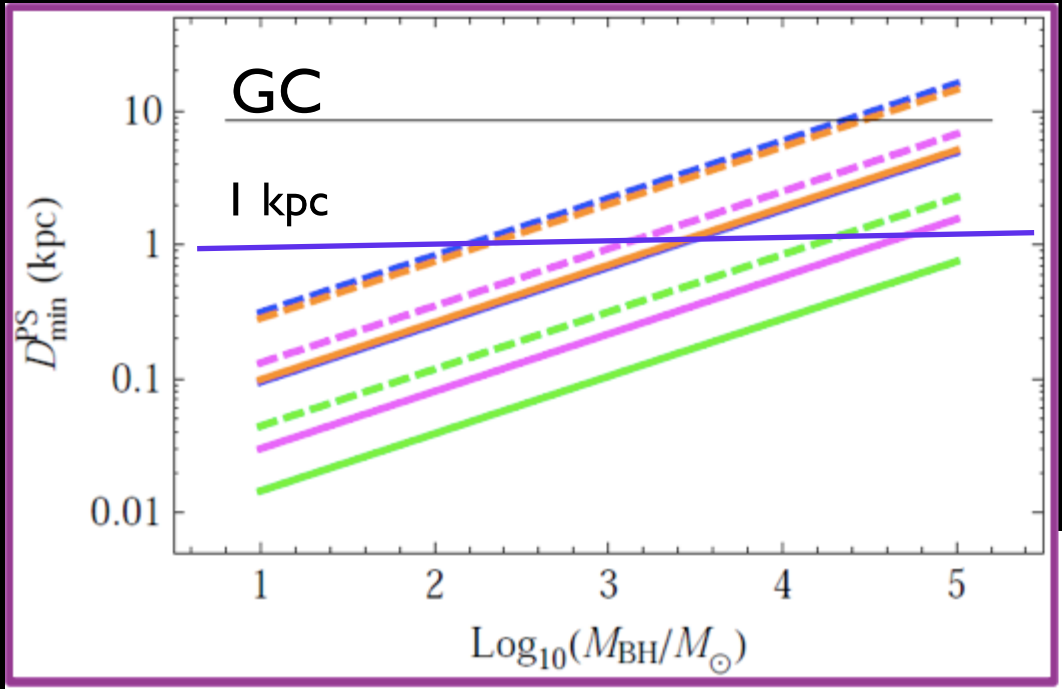
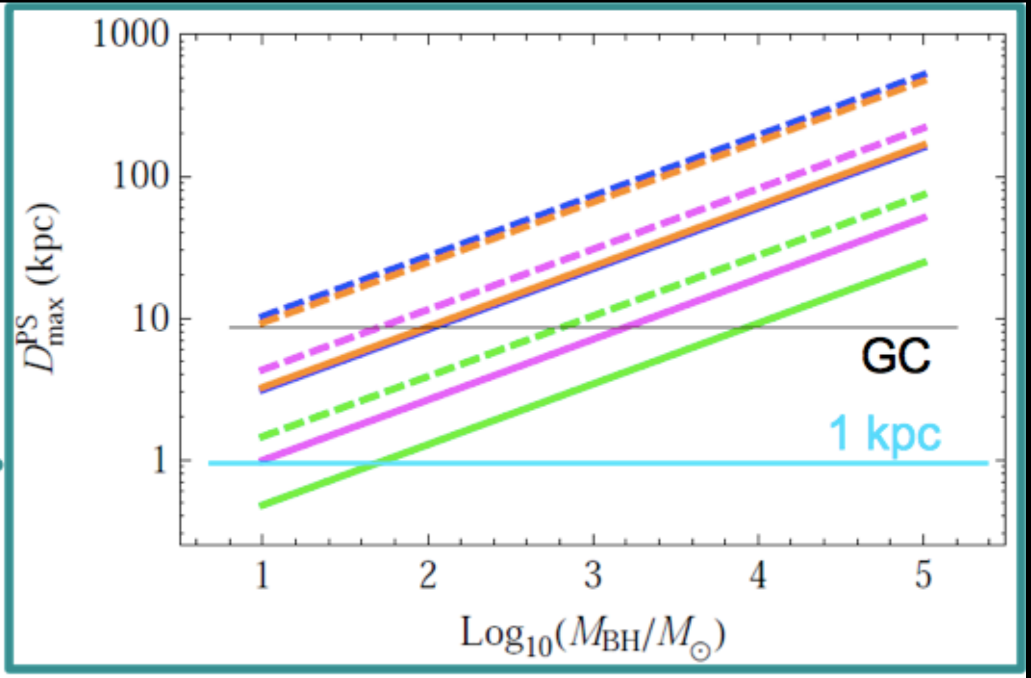
Point Sources



DminPS: minimum distance at which a PS can be located so that it's not brighter than the brightest FGST point source

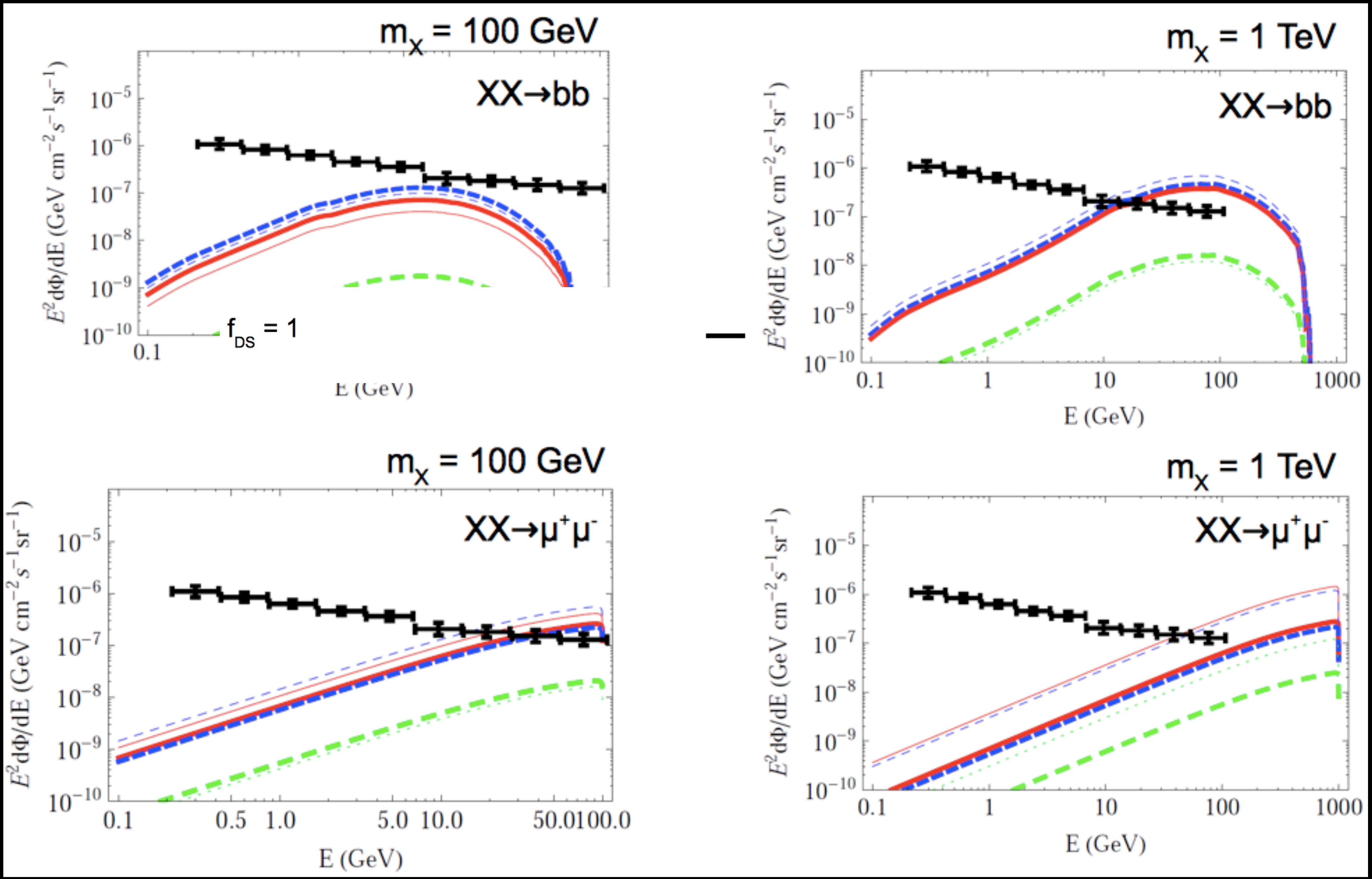
DmaxPS: maximal distance at which a PS would be bright enough to have been identified by FGST in the first year of operation



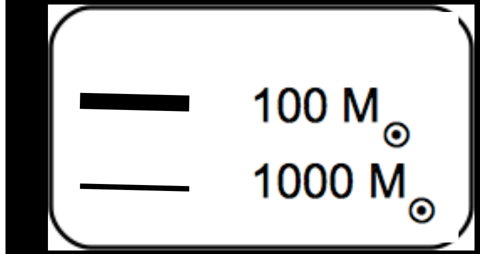
-------- 100 GeV

—— 1 TeV

Diffuse Flux



$$f_{\rm ds} = 1$$



Constraining f_{DS}

- With diffuse flux (“Diffuse Constraint”):

$$\Phi_i(f_{DS}) = f_{DS} \times \Phi_i(f_{DS} = 1)$$

Require that diffuse flux does not exceed the EGB by more than 3σ.

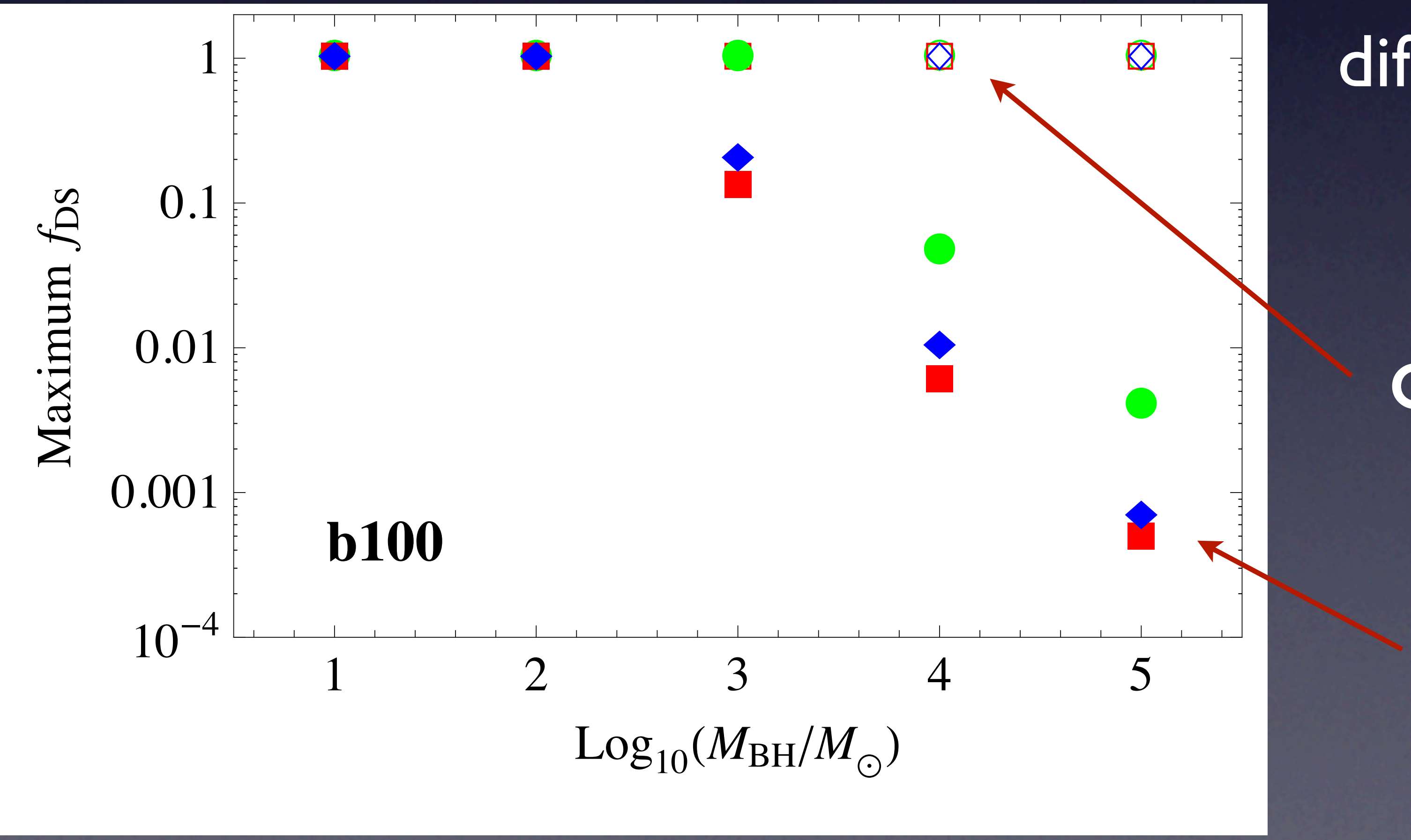
With point source population (“Point Source Constraint”):

$$\boxed{\begin{aligned} & N_{sp}(R, f_{DS}) = f_{DS} \times N_{sp}(R, f_{DS} = 1) \\ & \int_0^{D_{min}^{PS}} ds \int_{allsky} d\Omega \, N_{sp}(R, f_{DS}) \leq 1 \end{aligned}}$$

Require an expectation of < 1 spike within *DminPS* of our Solar System.

Fermi Constraints on Fraction of DM spikes

- DM =100 GeV
- Decays into b-mesons
- different colors correspond to different end of DS formation



open - diffuse background

closed - point sources

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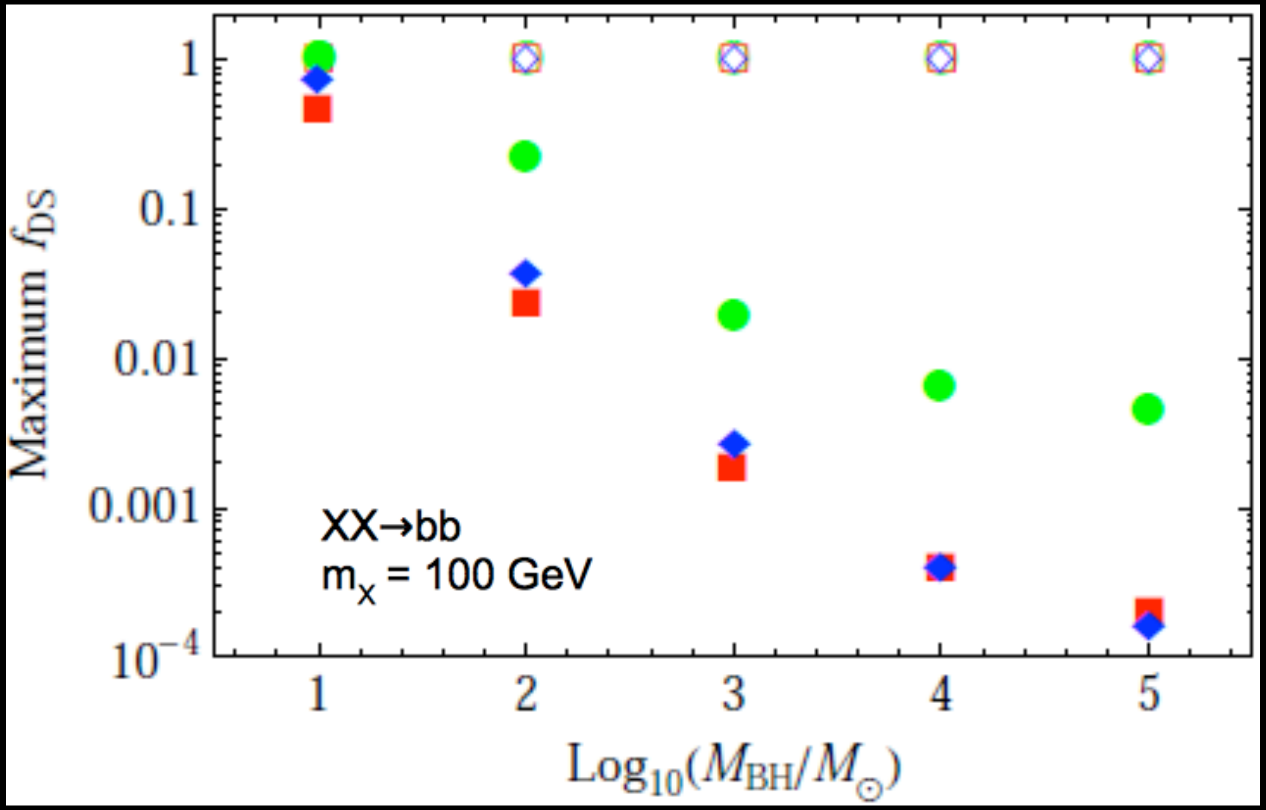
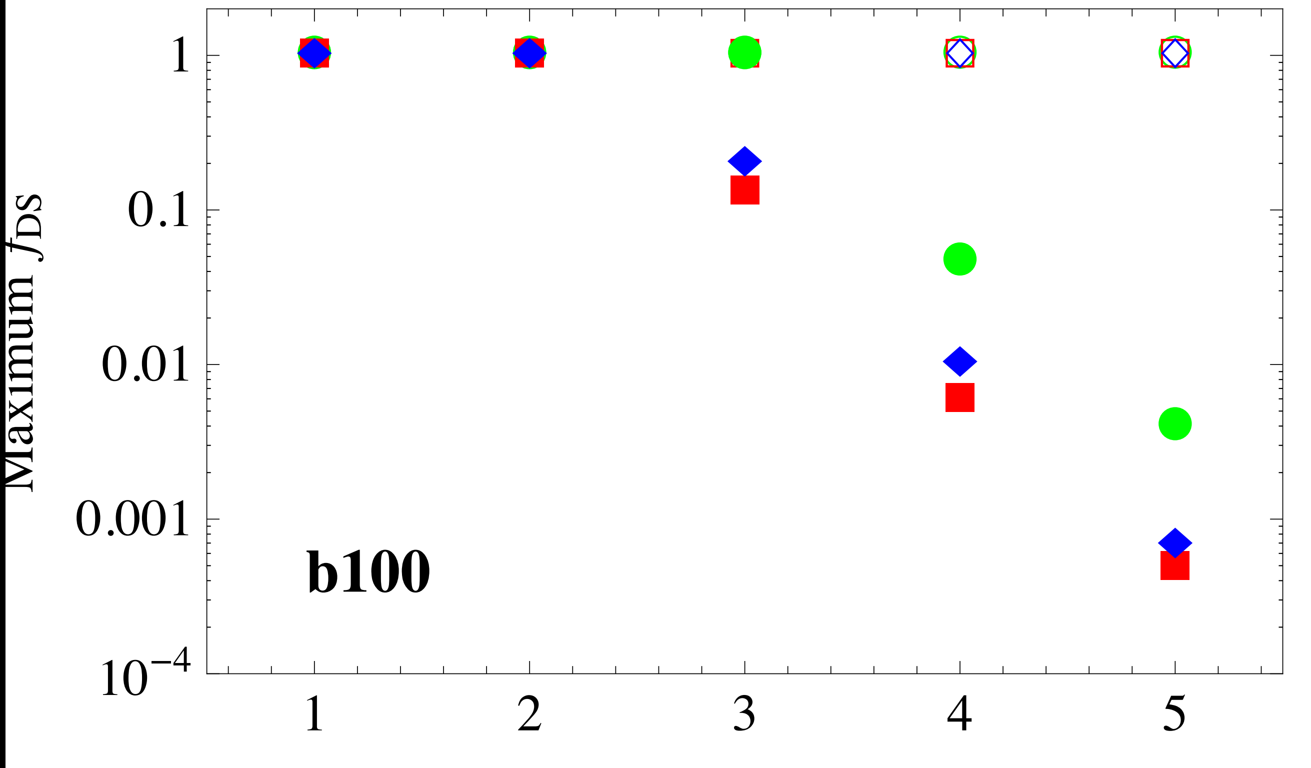
- What if we require that the brightest spike not be brighter than the brightest **unassociated** FGST point source?

Continue... Slightly less Conservative

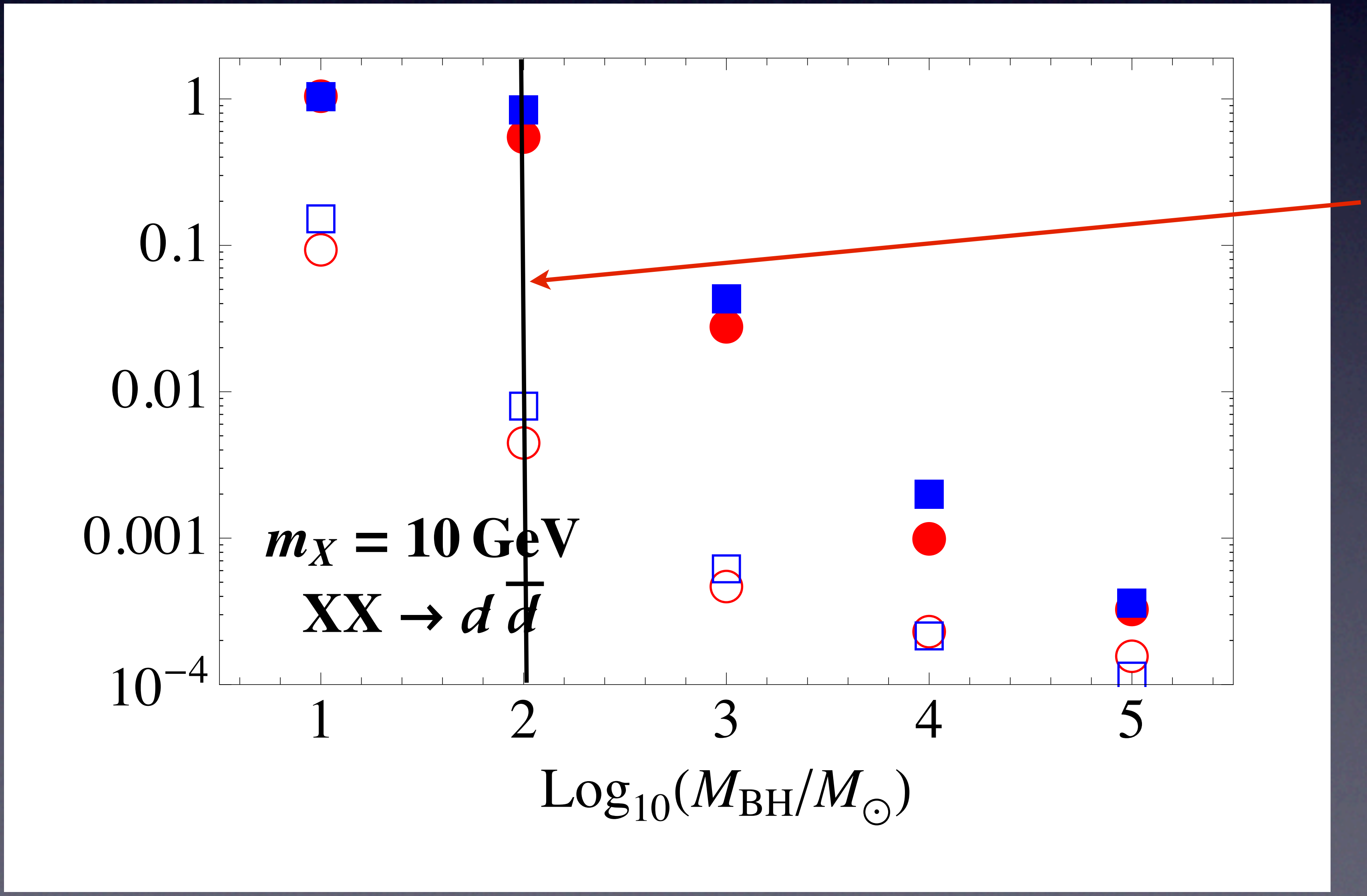




diffuse → open point source → filled

Strong Constraints on Low Mass WIMPs

- Motivated by DAMA, Cogent, CREST, Fermi GC excesses, etc.



Standard first star BH

Reversed!

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Fermi may have already seen some of these things! Buckley & Hooper (2010)

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