Modeling Dark Star Atmospheres with PHOENIX

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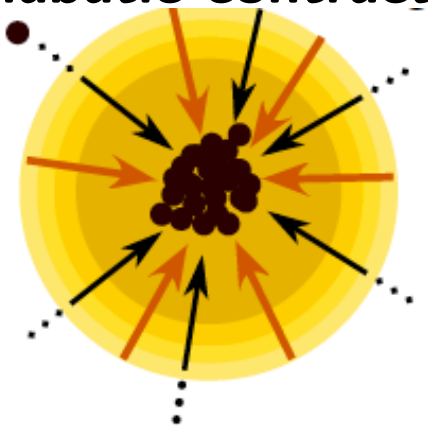
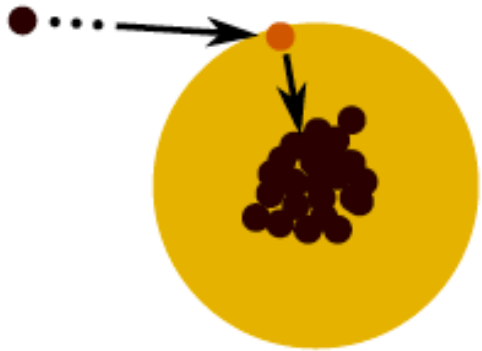
Dark Stars

- **DS**: A star whose structure and evolution have been affected by the annihilation of WIMPs.
- **Formation**: First stars formed in dark matter halos.
- **Burning Phase**: WIMP annihilation $\leftrightarrow$ additional energy source
- **Altered Properties**:
  - very bright but cold
  - puffy (large radius)
  - long lived

Adiabatic contraction



Scattering and capture



Source: Pat Scott, CRF 2010 Hamburg
http://www.physics.mcgill.ca/ patscott/darkstars/

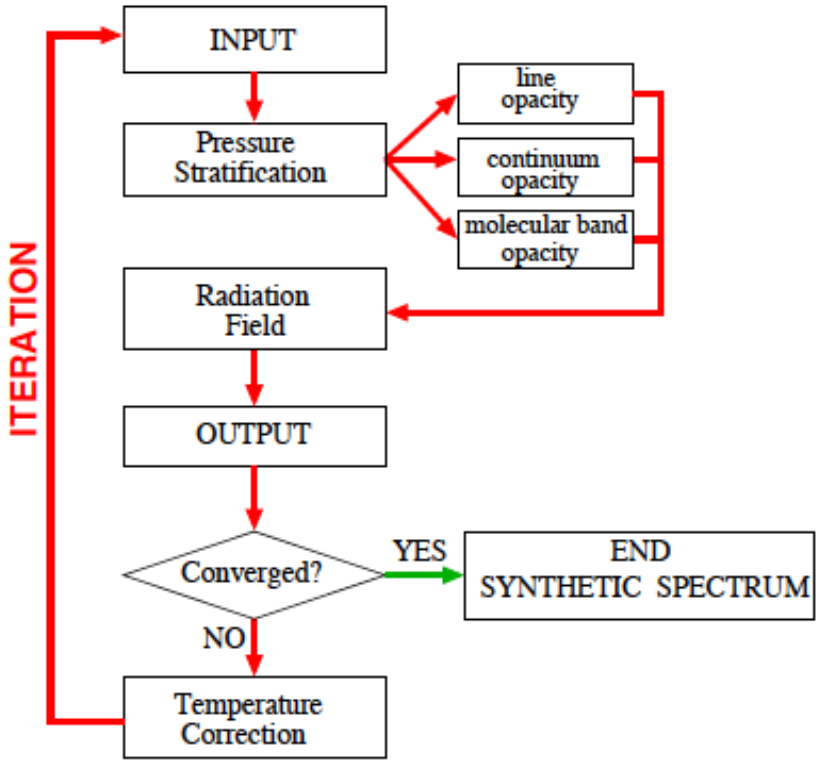
Modeling Dark Star Atmospheres with PHOENIX

- Observations detect light emitted from stars
  $\rightarrow$ How do DS spectra differ from normal star spectra?
  $\rightarrow$ Modeling of DS atmospheres
- PHOENIX: Very sophisticated code for the calculation of stellar and planetary atmospheres is being developed and maintained at the Hamburger Sternwarte.
  - Local thermal equilibrium (LTE)
  - Non local thermal equilibrium (NLTE)
  - Line broadening: Stark effekt and Van der Waals
  - Different metalicities
  - Just H, He, Li (primordial abundances)
  - Molecules
  - Much much more

Visit http://www.hs.uni-hamburg.de/EN/For/ThA/phoenix/

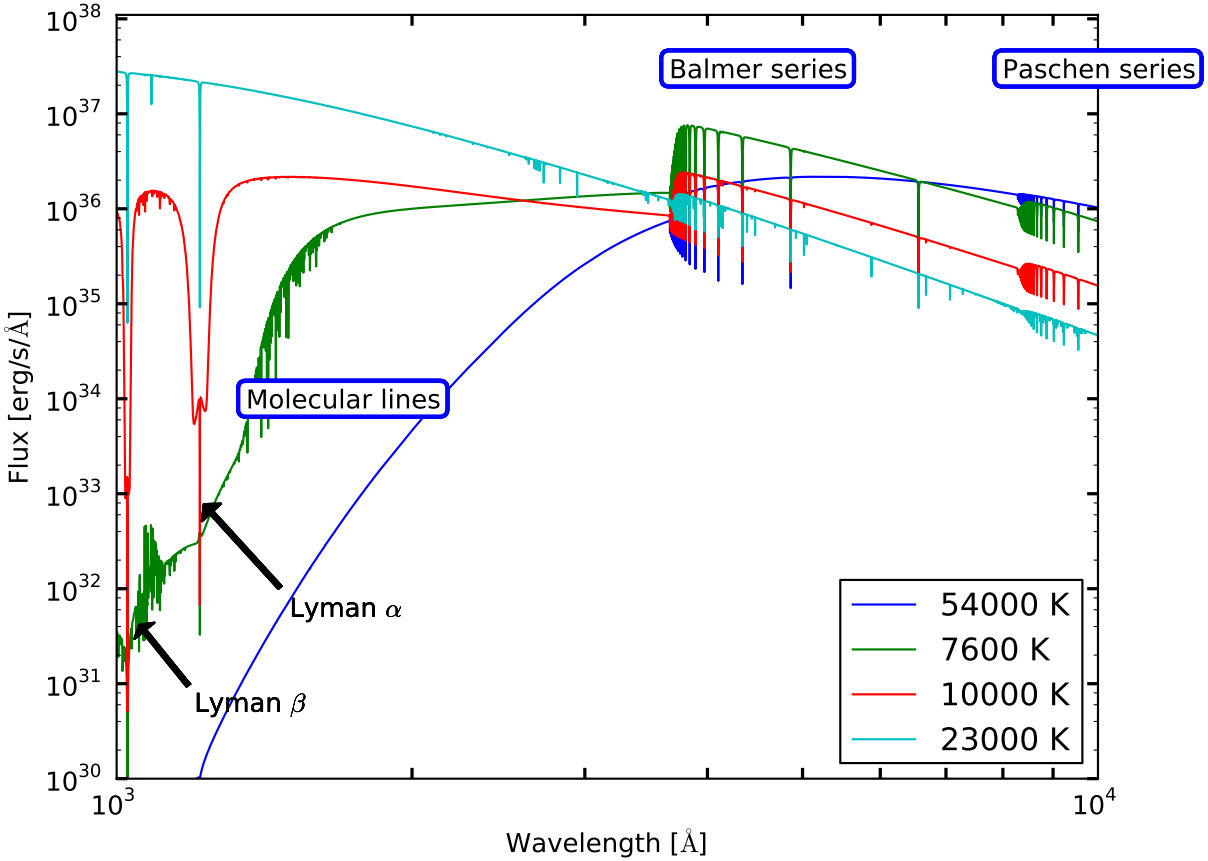
What does PHOENIX do?

- Solution in hydrostatic equilibrium
- The star is well-defined by giving the abundances and 3 of the following parameters :
  - Effective temperature (T_{eff})
  - Mass (M)
  - Radius (R)
  - Gravitational acceleration $g(R) = \frac{GM}{R^2}$
  - Luminosity ($L = 4\pi R^2 \sigma T_{eff}^4$)



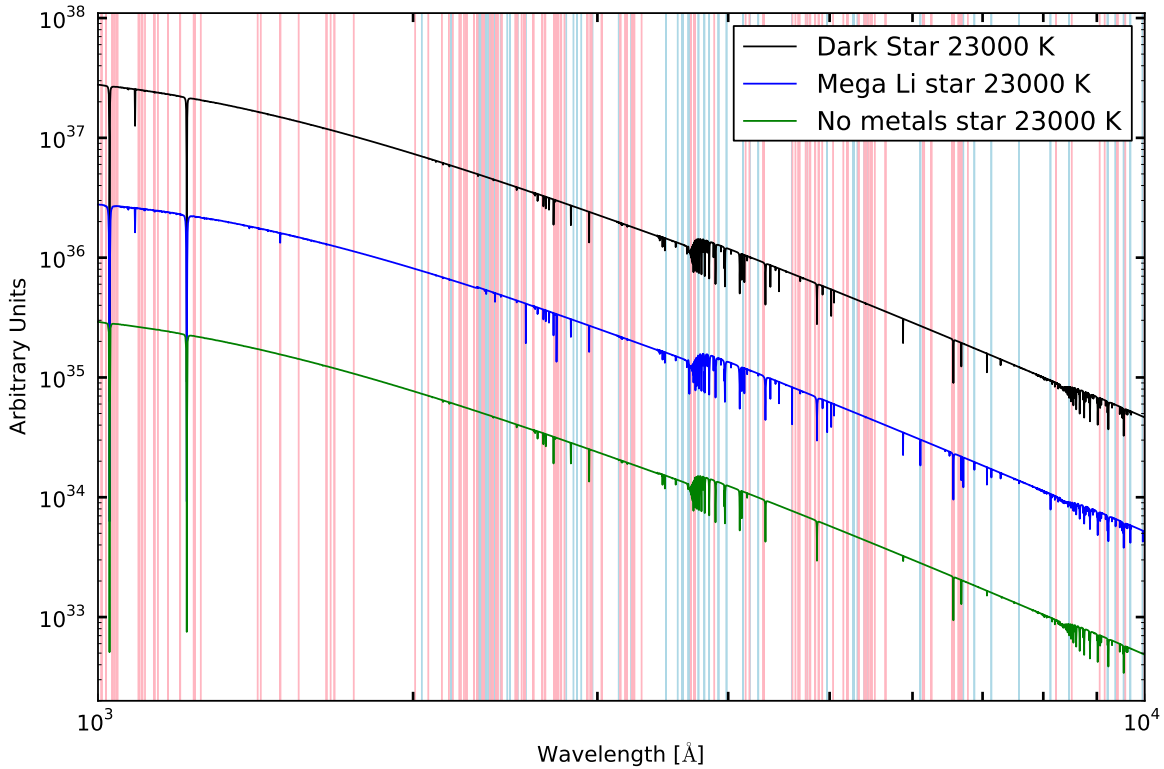
Source: Peter Hauschildt lectures

Example atmospheres: Molecular lines



- Molecular lines: Low temperatures → transitions between molecular states

Example atmospheres: Lithium



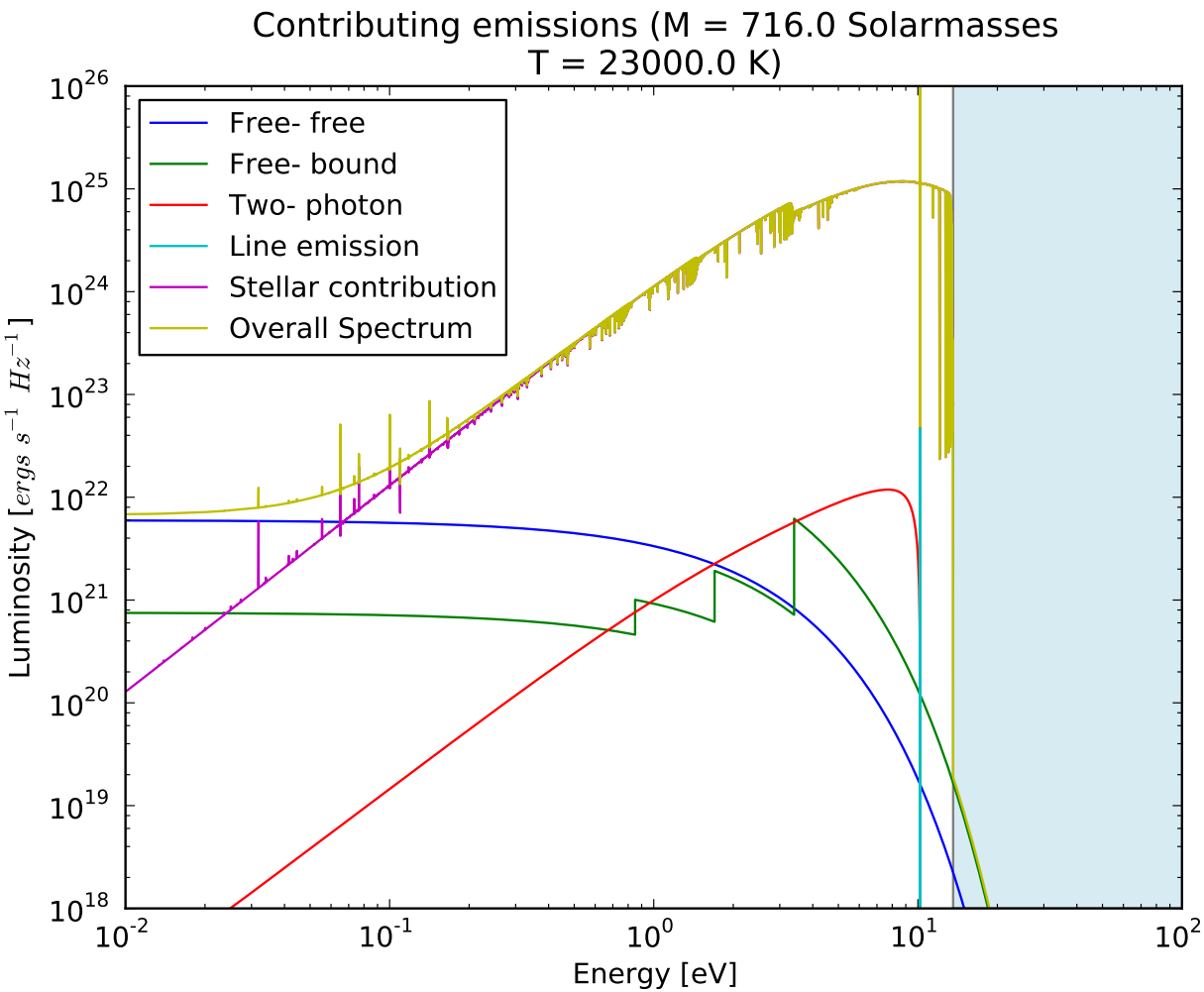
- No Li lines $\rightarrow$ cannot be used for identifying Dark Stars.

First Stars

Source: http://map.gsfc.nasa.gov/media/030651/030651_1_640.png

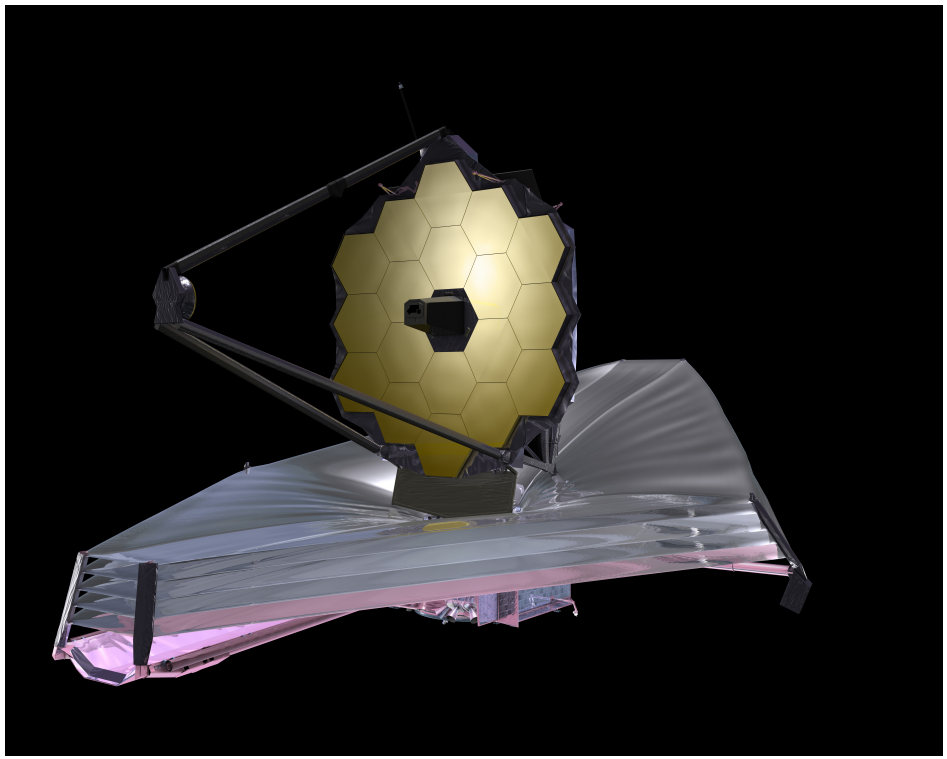
Nebular Emission

- Photons with energies above 13.6 eV ionize the gas.
- They are reemitted through different processes.
- No amplification or movement of the maximum due to nebula emission



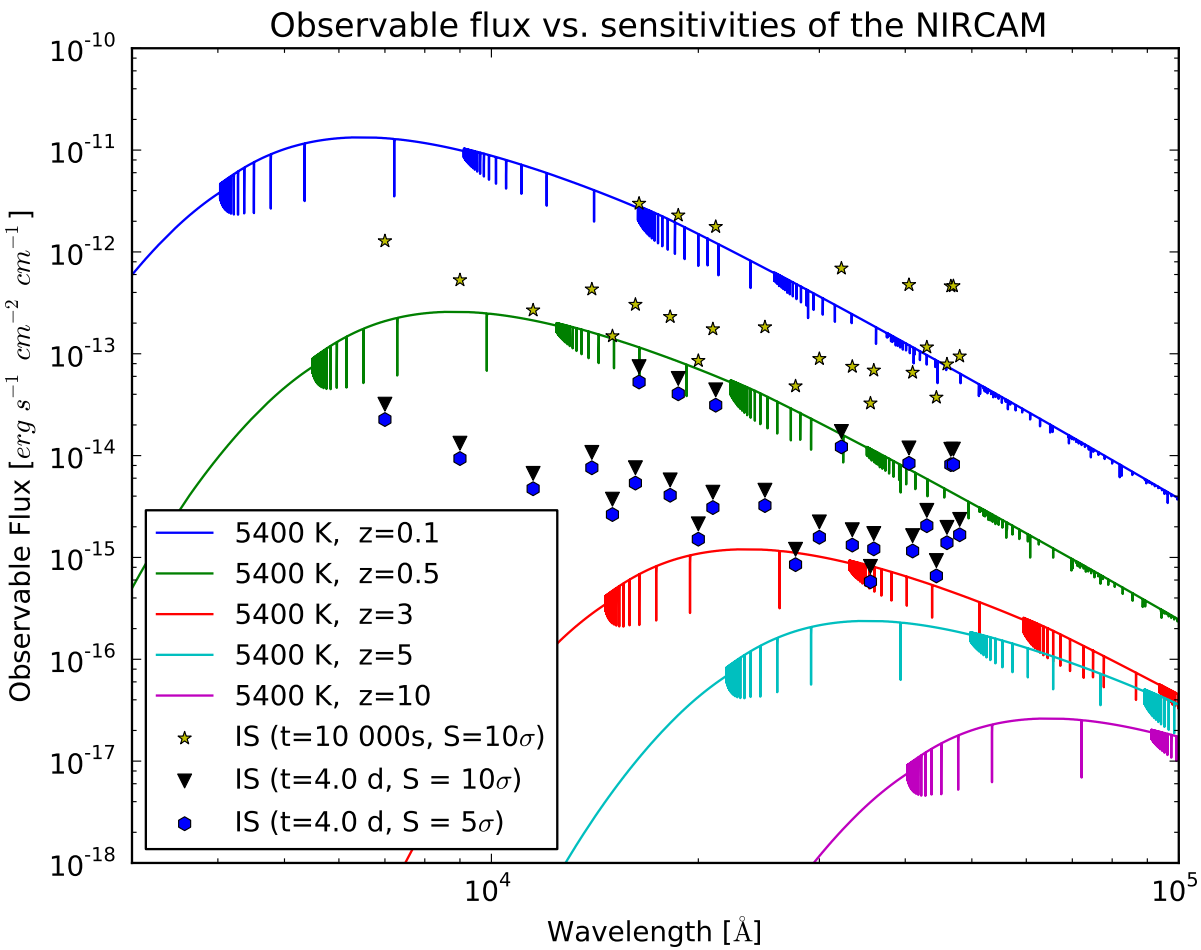
JWST: Could DS be detected?

- Observations in the infrared between 0.6 - 28 μm
- Goal: Observation of the most distant objects
  - First Stars
  - Star formation
  - Birth and evolution of galaxies
  - Epoch of re-ionization
- NIRCAM: 0.6-5 μm with high sensitivity



Source: http://www.jwst.nasa.gov/imagesartist13532

JWST: Could DS be detected?



- Case: No relevant background

Summary

- The atmospheres of DS are stable and can be calculated with PHOENIX
- Scanned temperature range: 5000 K - 25 000 K
- Spectra have interesting features:
  - Molecular lines
  - No Lithium lines
- Nebular emission is not important for temperatures below 40 000K.
- DS could possibly be detected by the JWST.

Outlook

- Calculations of the structure and evolution of DS using the code Dark Stars.
- Using the parameters favored recently by indirect detection experiments (small WIMP masses).
- Calculate the associated spectra.

References I