White Dwarfs

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Jordan et al. 2008
Basic Physical Properties

Remnants of intermediate mass stars

Masses $\sim 0.3 - 1.3 \, M_\odot$

Luminosities $\sim 100 - 10^{-5} \, L_\odot$

$T_{eff} \sim 10^5 - 10^3 \, K$

Radii $\sim 6000 \, km$

Densities $\sim 1000 \, \frac{kg}{cm^3}$

Credit: University of Arizona
Formation

Stars with $\sim 0.5 - 8 M_\odot$

Evolve through giant branch stages

Shed outer layers, forming nebulae

Descends to WD patch of H-R diagram

Core contracts and becomes degenerate
Location on the H-R Diagram

Credit: Cornell Astronomy
White Dwarf Sub-Types

Varying core compositions

Helium WDs

Carbon/Oxygen WDs

Oxygen/Neon WDs

Dependent on progenitor mass
Classification Scheme

“D” for dwarf appended to designations

O, B, A – Decreasing He ionization

C – No metal lines

Z, Q – Increasing metal & carbon lines

~ 80% are classified as DA
Populations

Globular clusters and galactic disk

\sim 10\% \text{ of globular population}

Absolute mag found for WDs with parallax

Calculate distance, all at a similar distance

Color spread can be used to find age
Physics of the Stellar Interior: Degenerate Matter
Electron Degeneracy

Pauli Exclusion Principle

Increasing pressure $\rightarrow$ no longer ideal gas

Repulsion forces $e^-$ to occupy lower levels

Not free to move to higher levels $\rightarrow$ degenerate

Fermi-Dirac replaces Maxwell-Boltzmann
Equation of State

Nonrelativistic

\[ P_e = \left( \frac{3}{\pi} \right)^{2/3} \frac{h^2}{20 m_e m_p^{5/3}} \left( \frac{Z}{A} \right)^{5/3} \rho^{5/3} \]

Relativistic

\[ P_e = \left( \frac{3}{8\pi} \right)^{1/3} \frac{hc}{4 m_p^{4/3}} \left( \frac{Z}{A} \right)^{4/3} \rho^{4/3} \]
Chandrasekhar Mass Limit

\[ M_{max} = 5.87 \mu^{-2} \, M_{\odot} \]

Typical compositions \( \mu \approx 2 \)

Maximum mass \( \approx 1.44 \, - \, 1.47 \, M_{\odot} \)

Dependent on other factors

Confirmed through observations
Core Evolution

Newly formed core has $T \sim 10^8 K$

$T_{eff} \sim 10^5 K \rightarrow$ peaks in UV & X-Rays

Core begins conduction cooling

Regulated by opacity of upper layers

Constant size with cooling
Core Evolution Cont.

Nondegenerate upper layers insulate core

Core is $\sim$ isothermal

Cooling curve exponentially decays

At $T_{\text{eff}} \sim 6000 - 8000K \rightarrow$ Crystalization

Liquid core turns to solid
Cooling Curves

Camenzind 2007
Core Evolution Cont.

Crystallization releases latent heat

Extends cooling time

Eventually cool to ambient temperature

Black dwarf, none are seen yet?

The universe is not old enough!
Up Into the Atmosphere

Credit: Space Today
Atmospheres & Spectroscopy

H and He ionization lines

< 1% of total mass

Cooler WDs → only minor metal features

SED’s well fit by H only atmosphere

Due to gravitational stratification

$Log(g) \sim 8!$
WD Spectra

Hoard 2011
Circumstellar Environments
Nebulae

Planetary nebulae

Mostly around remnants of massive progenitors

Disperse quickly into ISM \sim{} million years

Elliptical and bipolar shapes

Quickly fade from highly ionized states
Planetary Nebula

Not isotropic
Disks of Material

Difficult to find around WDs?
Intrinsically faint, brightest in IR
Dust, gas, and “rocky” material
Detectable from IR excess
Contribute to atmospheric contamination

Hoard 2011
WD Disks

Origins:
- Remnant material
- Interstellar medium
- Disrupted comets
- Exoplanets

Hoard 2011
Binary Interactions

Credit: Kornmesser 2012
Accretion & Mass Transfer

Dense WD can accrete matter in binary

Normally from supergiant

Radiation seen in X-Rays, low efficiency

Mass transfer buildup on WD
Cataclysmic Variables

WD accreting matter from main sequence

Orbital period of a few hours

Low accretion rate

Hot spot in accretion disk

Reoccurring?
Type Ia Supernovae

C/O WD quickly accreting mass from partner
Mass buildup exceeds Chandrasekhar limit
Explosive fusion occurs, destroying WD
Up to $10^9 \, L_\odot$ for $\sim 80$ days

$M_{bol} \approx -18 \text{ to } -19$
Usefulness in Astronomy?

Credit: SmileQ8
Astrophysical Applications

Cosmochnronometry $\rightarrow$ probes for age

Missing mass in galaxies (TODD)

Test GR $\rightarrow$ redshift, gravitational waves

Type Ia Supernovae $\rightarrow$ “standard candles”

Cosmology $\rightarrow$ age and expansion of the universe
Testing General Relativity

Gravitational redshift & lensing

\( V_{esc} \approx 0.02c \)

Gravitational waves

Orbital decay

Indirect evidence

Kepler Light Curves for Lensing White Dwarf System

Credit: JPL
Gravitational Waves

Radiated orbital energy

Credit: National Geographic

Weisberg et al. 2010
Gravitational Waves

Hermes et al. 2012
Type Ia “Standard Candles”

Standard bolometric magnitudes

Small dispersion

Peak luminosity & decay relationship

1 SNe per 100-500 years in “typical” galaxy

Useful as cosmological probes
Accelerating Universe!

Reiss et al. 1998
Accelerating Universe!

Perlmutter et al. 1999
Type Ia “Standard Candles”???

Do we really know the progenitor?

- Mergers, unburnt cores, single star

Effects of metallicity, high redshift, dust?

Stellar composition in the early universe

Red outliers, other sources of error?
What Are WDs Worth to Astronomy?

\[ M_{\odot} \approx 1.98 \times 10^{36} \text{ mg} \rightarrow \$ 10^{38} \]
Review

Dense stellar remnants

Continuous cooling supported by degeneracy

Display simple atmospheres

Complicated circumstellar environments

Excellent tests of theory, when properly used


Refereed References


Questions?