

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1

```
0001 ! Recombination module for CAM
0002
0003 !cccccccccccccccccccccccccccc
0004 !C Integrator for Cosmic Reco
0005 !C developed by Douglas Scott
0006 !C based on calculations in t
0007 !C (ApJ, 523, L1, 1999).
0008 !and "fudge" updates in Wong,
0009 !C
0010 !C Permission to use, copy, m
0011 !C any tier, this software an
0012 !C fee or royalty is hereby g
0013 !C the following copyright no
0014 !C and that the same appear o
0015 !C including modifications th
0016 !C
0017 !C Copyright 1999–2010 by Uni
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0019 !C THIS SOFTWARE IS PROVIDED
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0022 !C U.B.C. MAKES NO REPRESENTA
0023 !C MERCHANTABILITY OR FITNESS
0024 !C THE USE OF THE LICENSED SO
0025 !C ANY THIRD PARTY PATENTS, C
0026 !C
0027 !cccccccccccccccccccccccccccc
0028 !
0029 !CN      Name:          RECFAST
0030 !CV      Version: 1.5.2
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1

```
0001 ! Recombination module for
0002
0003 !cccccccccccccccccccccccccccc
0004 !C Integrator for Cosmic
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0007 !C (ApJ, 523, L1, 1999).
0008 !and "fudge" updates in W
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0012 !C fee or royalty is here
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0014 !C and that the same appe
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0026 !C
0027 !cccccccccccccccccccccccccccc
0028 !
0029 !CN      Name:          RECF
0030 !CV      Version: 1.5.2
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 31

```
0031 !C
0032 !CP Purpose: Calculate i
0033 !CP Solves for H a
0034 !CP H "fudge factor
0035 !CP HeI fudge facto
0036 !C
0037 !CD Description: Solves f
0038 !CD using the equations i
0039 !CD The Cosmological mode
0040 !CD The matter temperatu
0041 !CD Scott & Scott (2009)
0042 !CD The values for \alph
0043 !CD The singlet HeI coef
0044 !CD Additional He "fudge
0045 !CD and Scott (2008).
0046 !CD Extra fitting functi
0047 !CD for extra H physics
0048 !CD Care is taken to use
0049 !C
0050 !CA Arguments:
0051 !CA Name, Description
0052 !CA real(dl) throughout
0053 !CA
0054 !CA z is redshift - w is
0055 !CA x is total ionised fr
0056 !CA x_H is ionized fracti
0057 !CA x_He is ionized fract
0058 !CA (note that x_He=n_H
0059 !CA Tmat is matter temper
0060 !CA f's are the derivativ
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 31

```
0031 !C
0032 !CP Purpose: Calcula
0033 !CP Solves for
0034 !CP H "fudge fa
0035 !CP HeI fudge f
0036 !C
0037 !CD Description: Solv
0038 !CD using the equatio
0039 !CD The Cosmological
0040 !CD The matter temperatu
0041 !CD Scott & Scott (2009)
0042 !CD The values for \alph
0043 !CD The singlet HeI coef
0044 !CD Additional He "fudge
0045 !CD and Scott (2008).
0046 !CD Extra fitting functi
0047 !CD for extra H physics
0048 !CD Care is taken to use
0049 !C
0050 !CA Arguments:
0051 !CA Name, Description
0052 !CA real(dl) througho
0053 !CA
0054 !CA z is redshift - w is
0055 !CA x is total ionise
0056 !CA x_H is ionized fr
0057 !CA x_He is ionized f
0058 !CA (note that x_He=n_H
0059 !CA Tmat is matter te
0060 !CA f's are the deriv
```

/Users/lp1opa/Compare/camb_simdata/recfast.f90, Top line: 61

0061 !CA alphaB is case B reco
0062 !CA alpHe is the singlet
0063 !CA a_PPB is Pequignot, P
0064 !CA b_PPB is Pequignot, P
0065 !CA c_PPB is Pequignot, P
0066 !CA d_PPB is Pequignot, P
0067 !CA a_VF is Verner and Fe
0068 !CA b_VF is Verner and Fe
0069 !CA T_0 is Verner and Fer
0070 !CA T_1 is Verner and Fer
0071 !CA Tnow is the observed
0072 !CA Yp is the primordial
0073 !CA fHe is He/H number ra
0074 !CA Trad and Tmat are rad
0075 !CA epsilon is the ap
0076 !CA OmegaB is Omega in ba
0077 !CA H is Hubble constant
0078 !CA HO is Hubble constant
0079 !CA bigH is 100 km/s/Mpc
0080 !CA Hz is the value o
0081 !CA G is grvitational con
0082 !CA n is number density o
0083 !CA Nnow is number densit
0084 !CA x0 is initial ionized
0085 !CA x_H0 is initial ioniz
0086 !CA x_He0 is initial ioni
0087 !CA rhs is dummy for calc
0088 !CA zinitial and zfinal a
0089 !CA zeq is the redshift o
0090 !CA zstart and zend are f

/Users/lp1opa/Compare/camb_des/recfast.f90, Top line: 61

0061 !CA alphaB is case B
0062 !CA alpHe is the sing
0063 !CA a_PPB is Pequigno
0064 !CA b_PPB is Pequigno
0065 !CA c_PPB is Pequigno
0066 !CA d_PPB is Pequigno
0067 !CA a_VF is Verner an
0068 !CA b_VF is Verner an
0069 !CA T_0 is Verner and
0070 !CA T_1 is Verner and
0071 !CA Tnow is the obser
0072 !CA Yp is the primord
0073 !CA fHe is He/H numbe
0074 !CA Trad and Tmat are
0075 !CA epsilon is the ap
0076 !CA OmegaB is Omega i
0077 !CA H is Hubble const
0078 !CA HO is Hubble cons
0079 !CA bigH is 100 km/s/
0080 !CA Hz is the value o
0081 !CA G is grvitational
0082 !CA n is number densi
0083 !CA Nnow is number de
0084 !CA x0 is initial ion
0085 !CA x_H0 is initial i
0086 !CA x_He0 is initial
0087 !CA rhs is dummy for
0088 !CA zinitial and zfin
0089 !CA zeq is the redshi
0090 !CA zstart and zend a

/Users/lp1opa/Compare/camb_simdata/recfast.f90, Top line: 91

```
0091 !CA      C,k_B,h_P: speed of 1
0092 !CA      m_e,m_H: electron mas
0093 !CA      not4: ratio of 4He at
0094 !CA      sigma: Thomson cross-
0095 !CA      a_rad: radiation cons
0096 !CA      Lambda: 2s-1s two pho
0097 !CA      Lambda_He: 2s-1s two
0098 !CA      DeltaB: energy of fir
0099 !CA      DeltaB_He: energy of
0100 !CA      L_H_ion: level for H
0101 !CA      L_H_alpha: level for
0102 !CA      L_He1_ion: level for
0103 !CA      L_He2_ion: level for
0104 !CA      L_He_2s: level for He
0105 !CA      L_He_2p: level for He
0106 !CA      Lalpha: Ly alpha wave
0107 !CA      Lalpha_He: Helium I 2
0108 !CA      mu_H,mu_T: mass per H
0109 !CA      H_frac: follow Tmat w
0110 !CA      CDB=DeltaB/k_B
0111 !CA      CDB_He=DeltaB_He/k_B
0112 !CA      CB1=CDB*4.          La
0113 !CA      CB1_He1: CB1 for HeI
0114 !CA      CB1_He2: CB1 for HeII
0115 !CA      CR=2*Pi*(m_e/h_P)*(k_
0116 !CA      CK=Lalpha**3/(8.*Pi)
0117 !CA      CK_He=Lalpha_He**3/(8
0118 !CA      CL=C*h_P/(k_B*Lalpha)
0119 !CA      CL_He=C*h_P/(k_B*Lalp
0120 !CA      CT=(8./3.)*(sigma/(m_
```

/Users/lp1opa/Compare/camb_des/recfast.f90, Top line: 91

```
0091 !CA      C,k_B,h_P: speed
0092 !CA      m_e,m_H: electron
0093 !CA      not4: ratio of 4H
0094 !CA      sigma: Thomson cr
0095 !CA      a_rad: radiation
0096 !CA      Lambda: 2s-1s two
0097 !CA      Lambda_He: 2s-1s
0098 !CA      DeltaB: energy of
0099 !CA      DeltaB_He: energy
0100 !CA      L_H_ion: level fo
0101 !CA      L_H_alpha: level
0102 !CA      L_He1_ion: level
0103 !CA      L_He2_ion: level
0104 !CA      L_He_2s: level fo
0105 !CA      L_He_2p: level fo
0106 !CA      Lalpha: Ly alpha
0107 !CA      Lalpha_He: Helium
0108 !CA      mu_H,mu_T: mass p
0109 !CA      H_frac: follow Tm
0110 !CA      CDB=DeltaB/k_B
0111 !CA      CDB_He=DeltaB_He/
0112 !CA      CB1=CDB*4.
0113 !CA      CB1_He1: CB1 for
0114 !CA      CB1_He2: CB1 for
0115 !CA      CR=2*Pi*(m_e/h_P)
0116 !CA      CK=Lalpha**3/(8.*
0117 !CA      CK_He=Lalpha_He**
0118 !CA      CL=C*h_P/(k_B*Lal
0119 !CA      CL_He=C*h_P/(k_B*
0120 !CA      CT=(8./3.)*(sigma/
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 121

```
0121 !CA      Bfact=exp((E_2p-E_2s)
0122 !CA b_He= "fudge factor" for
0123 !CA Heswitch=integer for modi
0124 !CA Parameters and quantities
0125 !CA and also the continuum o
0126 !CA suggested by KIV, astro-
0127 !CA a_trip: used to fit HeI t
0128 !CA b_trip: used to fit HeI t
0129 !CA L_He_2Pt: level for 23P01
0130 !CA L_He_2St: level for 23S1-
0131 !CA L_He2St_ion: level for 23
0132 !CA A2P_s: Einstein A coeffic
0133 !CA A2P_t: Einstein A coeffic
0134 !CA sigma_He_2Ps: H ionizatio
0135 !CA sigma_He_2Pt: H ionizatio
0136 !CA CL_PSt = h_P*C*(L_He_2Pt
0137 !CA CfHe_t: triplet statistic
0138 !CA      Hswitch is an boolean
0139 !CA      AGauss1 is the amplit
0140 !CA      AGauss2 is the amplit
0141 !CA      zGauss1 is the ln(1+z
0142 !CA      zGauss2 is the ln(1+z
0143 !CA      wGauss1 is the width
0144 !CA      wGauss2 is the width
0145
0146
0147 !CA      tol: tolerance for th
0148 !CA      cw(24),w(3,9): work s
0149 !CA      Ndim: number of d.e.'
0150 !CA      Nz: number of output
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 121

```
0121 !CA      Bfact=exp((E_2p-E
0122 !CA b_He= "fudge factor"
0123 !CA Heswitch=integer for
0124 !CA Parameters and quanti
0125 !CA and also the continuu
0126 !CA suggested by KIV, as
0127 !CA a_trip: used to fit H
0128 !CA b_trip: used to fit H
0129 !CA L_He_2Pt: level for 2
0130 !CA L_He_2St: level for 2
0131 !CA L_He2St_ion: level fo
0132 !CA A2P_s: Einstein A coe
0133 !CA A2P_t: Einstein A coe
0134 !CA sigma_He_2Ps: H ioniz
0135 !CA sigma_He_2Pt: H ioniz
0136 !CA CL_PSt = h_P*C*(L_He_
0137 !CA CfHe_t: triplet stati
0138 !CA      Hswitch is an boolean
0139 !CA      AGauss1 is the amplit
0140 !CA      AGauss2 is the amplit
0141 !CA      zGauss1 is the ln(1+z
0142 !CA      zGauss2 is the ln(1+z
0143 !CA      wGauss1 is the width
0144 !CA      wGauss2 is the width
0145
0146
0147 !CA      tol: tolerance fo
0148 !CA      cw(24),w(3,9): wo
0149 !CA      Ndim: number of d
0150 !CA      Nz: number of out
```

/Users/lp1opa/Compare/camb_simdata/recfast.f90, Top line: 151

```
0151 !CA I: loop index (integer  
0152 !CA ind,nw: work-space fo  
0153 !C  
0154 !CF File & device access:  
0155 !CF Unit /I,IO,O /Name (  
0156 !C  
0157 !CM Modules called:  
0158 !CM DVERK (numerical inte  
0159 !CM GET_INIT (initial val  
0160 !CM ION (ionization and T  
0161 !C  
0162 !CC Comments:  
0163 !CC none  
0164 !C  
0165 !CH History:  
0166 !CH CREATED (s  
0167 !CH RECREATED 11th Jan 0167  
0168 !CH includes va 0168  
0169 !CH uses DVERK 0169  
0170 !CH initial con 0170  
0171 !CH TESTED a 0171  
0172 !CH MODIFIED January 0172  
0173 !CH January 199 0173  
0174 !CH January 199 0174  
0175 !CH March 1995 0175  
0176 !CH August 1997 0176  
0177 !CH July 1998 ( 0177  
0178 !CH Nov 1998 (c 0178  
0179 !CH Jan 1999 (t 0179  
0180 !CH Sept 1999 ( 0180
```

/Users/lp1opa/Compare/camb_des/recfast.f90, Top line: 151

```
0151 !CA I: loop index (in  
0152 !CA ind,nw: work-spac  
0153 !C  
0154 !CF File & device acc  
0155 !CF Unit /I,IO,O /Na  
0156 !C  
0157 !CM Modules called:  
0158 !CM DVERK (numerical  
0159 !CM GET_INIT (initial  
0160 !CM ION (ionization a  
0161 !C  
0162 !CC Comments:  
0163 !CC none  
0164 !C  
0165 !CH History:  
0166 !CH CREATED  
0167 !CH RECREATED 11th 0167  
0168 !CH include 0168  
0169 !CH uses DV 0169  
0170 !CH initial 0170  
0171 !CH TESTED  
0172 !CH MODIFIED Janu 0172  
0173 !CH January 0173  
0174 !CH January 0174  
0175 !CH March 1 0175  
0176 !CH August 0176  
0177 !CH July 19 0177  
0178 !CH Nov 199 0178  
0179 !CH Jan 199 0179  
0180 !CH Sept 19 0180
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 181

0181	!CH	Sept 199
0182	!CH	Nov 1
0183	!CH	Aug 2
0184	!CH	Feb 2
0185	!CH	Oct 2
0186	!	March
0187	!	March
0188	!	
0189	!	June
0190	!	Octob
0191	!	Octob
0192	!	Octob
0193	!CH	January 2008
0194	!CH	inc
0195	!	Feb 2008 R
0196	!	r
0197	!CH	Sept
0198	!	Sept 2008 Re
0199	!	Ge
0200	!CH	Jan 2010 (ad)
0201	!CH	
0202	!AL	June 2012 upd
0203	!AL	Sept 2012 cha
0204	!!	=====
0205	!!	=====
0206		
0207		module RECDATA
0208		use constants
0209		implicit none
0210		

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 181

0181	!CH	Sept
0182	!CH	N
0183	!CH	A
0184	!CH	F
0185	!CH	O
0186	!	M
0187	!	M
0188	!	
0189	!	J
0190	!	O
0191	!	O
0192	!	O
0193	!CH	January
0194	!CH	
0195	!	Feb 2008
0196	!	
0197	!CH	
0198	!	
0199	!	
0200	!CH	Jan 2010 (ad)
0201	!CH	
0202	!AL	June 2012
0203	!AL	Sept 2012
0204	!!	=====
0205	!!	=====
0206		
0207		module RECDATA
0208		use constants
0209		implicit none
0210		

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 211

```
0211  
0212      real(dl) Lambda,Delta  
0213      real(dl) Lambda_He,La  
0214      real(dl) L_H_ion,L_H_  
0215      real(dl) CB1,CDB,CR,C  
0216      real(dl) A2P_s,A2P_t,  
0217      real(dl) L_He_2Pt,L_  
0218  
0219  
0220      real(dl), parameter :  
0221      real(dl), parameter :  
0222      real(dl), parameter :  
0223  
0224      real(dl) Tnow,HO  
0225      integer :: n_eq = 3  
0226  
0227 !The following only used for  
0228      real(dl) OmegaK, Omega  
0229  
0230  
0231 !Fundamental constants in SI  
0232 ! ("not4" pointed out by  
0233  
0234      data    Lambda      / 0234  
0235      data    Lambda_He   / 0235  
0236      data    L_H_ion    / 0236  
0237      data    L_H_alpha   / 0237  
0238      data    L_He1_ion  / 0238  
0239      data    L_He2_ion  / 0239  
0240      data    L_He_2s    / 0240
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 211

```
0211  
0212      real(dl) Lambda,DeltaB,De  
0213      real(dl) Lambda_He,Lalpha  
0214      real(dl) L_H_ion,L_H_alpha  
0215      real(dl) CB1,CDB,CR,CK,CL  
0216      real(dl) A2P_s,A2P_t,sigm  
0217      real(dl) L_He_2Pt,L_He_2  
0218  
0219  
0220      real(dl), parameter :: bi  
0221      real(dl), parameter :: si  
0222      real(dl), parameter :: no  
0223  
0224      real(dl) Tnow,HO  
0225      integer :: n_eq = 3  
0226  
0227 !The following only used  
0228      real(dl) OmegaK, OmegaT,  
0229  
0230  
0231 !Fundamental constants in SI  
0232 ! ("not4" pointed out by  
0233  
0234      data    Lambda      / 0234  
0235      data    Lambda_He   / 0235  
0236      data    L_H_ion    / 0236  
0237      data    L_H_alpha   / 0237  
0238      data    L_He1_ion  / 0238  
0239      data    L_He2_ion  / 0239  
0240      data    L_He_2s    / 0240
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 241

```
0241      data L_He_2p /  
0242 ! 2 photon rates and atomic  
0243  
0244      data A2P_s /  
0245      data A2P_t /  
0246      data L_He_2Pt /  
0247      data L_He_2St /  
0248      data L_He2St_ion /  
0249      data sigma_He_2Ps /  
0250      data sigma_He_2Pt /  
0251 ! Atomic data for HeI
```

```
0252  
0253  
0254 end module RECDATA
```

```
0255  
0256  
0257 module Recombination  
0258 use constants  
0259 use AMLUtils  
0260 implicit none  
0261 private
```

```
0262  
0263 real(dl), parameter : 0263  
0264 real(dl), parameter : 0264  
0265 integer, parameter : 0265  
0266 real(dl), parameter : 0266  
0267  
0268 integer, parameter :: 0268  
0269 real(dl), parameter : 0269  
0270 logical, parameter : 0270
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 241

```
0241      data L_He_2p / 1.71  
0242 ! 2 photon rates and at  
0243  
0244      data A2P_s / 1.79  
0245      data A2P_t / 177.  
0246      data L_He_2Pt / 1.69  
0247      data L_He_2St / 1.59  
0248      data L_He2St_ion / 3.84  
0249      data sigma_He_2Ps /  
0250      data sigma_He_2Pt /  
0251 ! Atomic data for HeI
```

```
0252  
0253  
0254 end module RECDATA
```

```
0255  
0256  
0257 module Recombination  
0258 use constants  
0259 use AMLUtils  
0260 implicit none  
0261 private
```

```
0262  
0263 real(dl), parameter :: z  
0264 real(dl), parameter :: z  
0265 integer, parameter :: Nz  
0266 real(dl), parameter :: de  
0267  
0268 integer, parameter :: RE  
0269 real(dl), parameter :: RE  
0270 logical, parameter :: RE
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 271

```
0271      real(dl), parameter :  
0272      real(dl), parameter :  
0273          !fudge parameter  
0274  
0275      real(dl) :: AGauss1 =  
0276      real(dl) :: AGauss2 =  
0277      real(dl) :: zGauss1 =  
0278      real(dl) :: zGauss2 =  
0279      real(dl) :: wGauss1 =  
0280      real(dl) :: wGauss2 =  
0281          !Gaussian fits for extra  
0282  
0283 type RecombinationPar  
0284  
0285      real(dl) :: RECFAST_f  
0286      real(dl) :: RECFAST_h  
0287      integer :: RECFAST_n  
0288      logical :: RECFAST_l  
0289      !0) no change from ol  
0290      !1) full expression  
0291      !'    1P-1S transition  
0292      !2) also including e  
0293      !'    singlet (based on  
0294      !'    Kholupenko, Ivan  
0295      !3) only including r  
0296      !4) including 3 and t  
0297      !'    (although this is  
0298      !5) including only 1  
0299      !6) including all of them  
0300
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 271

```
0271      real(dl), parameter :: RECFAST_f  
0272      real(dl), parameter :: RECFAST_h  
0273          !fudge parameter if RECFA  
0274  
0275      real(dl) :: AGauss1 =  
0276      real(dl) :: AGauss2 =  
0277      real(dl) :: zGauss1 =  
0278      real(dl) :: zGauss2 =  
0279      real(dl) :: wGauss1 =  
0280      real(dl) :: wGauss2 =  
0281          !Gaussian fits for extra  
0282  
0283 type RecombinationParams  
0284  
0285      real(dl) :: RECFAST_f  
0286      real(dl) :: RECFAST_h  
0287      integer :: RECFAST_n  
0288      logical :: RECFAST_l  
0289      !0) no change from ol  
0290      !1) full expression f  
0291      !'    1P-1S transition  
0292      !2) also including ef  
0293      !'    singlet (based on  
0294      !'    Kholupenko, Ivan  
0295      !3) only including re  
0296      !4) including 3 and t  
0297      !'    (although this is  
0298      !5) including only 1  
0299      !6) including all of them  
0300
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 301

```
0301      end type Recombinati  
0302  
0303      character(LEN=*), par  
0304  
0305      real(dl) zrec(Nz),xre  
0306  
0307      real(dl), parameter ::  
0308      logical, parameter ::  
0309      real(dl), parameter ::  
0310  
0311  
0312      real(dl), parameter ::  
0313      real(dl) :: NNow, fHe  
0314  
0315  
0316      logical :: Do21cm = .  
0317      logical :: doTmatTspi  
0318  
0319      real(dl) :: recombina  
0320      real(dl) :: recombina  
0321  
0322  
0323      public RecombinationP  
0324          Recombination_  
0325          kappa_HH_21cm,  
0326          Do21cm, doTmat  
0327          recombination_  
0328  
0329      contains  
0330
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 301

```
0301      end type RecombinationPa  
0302  
0303      character(LEN=*), paramet  
0304  
0305      real(dl) zrec(Nz),xrec(Nz  
0306  
0307      real(dl), parameter :: Do  
0308      logical, parameter :: evo  
0309      real(dl), parameter :: Do  
0310  
0311  
0312      real(dl), parameter :: B0  
0313      real(dl) :: NNow, fHe  
0314  
0315  
0316      logical :: Do21cm = .fals  
0317      logical :: doTmatTspin =  
0318  
0319      real(dl) :: recombination  
0320      real(dl) :: recombination  
0321  
0322  
0323      public RecombinationParam  
0324          Recombination_ReadPar  
0325          kappa_HH_21cm,kappa_e  
0326          Do21cm, doTmatTspin,  
0327          recombination_saha_ta  
0328  
0329      contains  
0330
```

/Users/lp1opa/Compare/camb_simdata/recfast.f90, Top line: 331

```
0331  
0332  
0333 subroutine Recombina  
0334 use IniFile  
0335 Type(RecombinationP  
0336 Type(TIniFile) :: I  
0337  
0338  
0339 R%RECFAST_fudge_  
0340 R%RECFAST_Heswit  
0341 R%RECFAST_Hswitc  
0342 R%RECFAST_fudge_  
0343 AGauss1 = Ini_RE  
0344 AGauss2 = Ini_RE  
0345 zGauss1 = Ini_RE  
0346 zGauss2 = Ini_RE  
0347 wGauss1 = Ini_RE  
0348 wGauss2 = Ini_RE  
0349 if (R%RECFAST_Hs  
0350 R%RECFAST_fud  
0351 end if  
0352 end subroutine Recom  
0353  
0354 subroutine Recombinat  
0355 type (RecombinationP  
0356  
0357  
0358 R%RECFAST_fudge = R  
0359 R%RECFAST_fudge_He  
0360 R%RECFAST_Heswitch
```

/Users/lp1opa/Compare/camb_des/recfast.f90, Top line: 331

```
0331  
0332  
0333 subroutine Recombination_  
0334 use IniFile  
0335 Type(RecombinationParams)  
0336 Type(TIniFile) :: Ini  
0337  
0338  
0339 R%RECFAST_fudge_He = Ini_  
0340 R%RECFAST_Heswitch = Ini_  
0341 R%RECFAST_Hswitch = Ini_R  
0342 R%RECFAST_fudge = Ini_Rea  
0343 AGauss1 = Ini_Read_Double  
0344 AGauss2 = Ini_Read_Double  
0345 zGauss1 = Ini_Read_Double  
0346 zGauss2 = Ini_Read_Double  
0347 wGauss1 = Ini_Read_Double  
0348 wGauss2 = Ini_Read_Double  
0349 if (R%RECFAST_Hswitch) th  
0350 R%RECFAST_fudge = R%R  
0351 end if  
0352 end subroutine Recombinat  
0353  
0354 subroutine Recombination_  
0355 type (RecombinationParams  
0356  
0357  
0358 R%RECFAST_fudge = RECFAST  
0359 R%RECFAST_fudge_He = RECF  
0360 R%RECFAST_Heswitch = RECF
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 361

```
0361      R%RECFAST_Hswitch =  
0362      if (R%RECFAST_Hswitch)  
0363          R%RECFAST_fudge = REC  
0364      end if  
0365  
0366  end subroutine Recomb  
0367  
0368  
0369  subroutine Recombinat  
0370      Type(RecombinationP  
0371      logical, intent(ino  
0372  
0373      if (R%RECFAST_H  
0374          OK = .fa  
0375          write(*, *'  
0376      end if  
0377  
0378  end subroutine Recom  
0379  
0380  
0381  function Recombinatio  
0382  use RECDATA, only : T  
0383  real(dl) zst,a,z,az,b  
0384  integer ilo,ihi  
0385  
0386  if (.not. doTmatTspin  
0387  z=1/a-1  
0388  if (z >= zrec(1)) the  
0389      Recombination_tm=  
0390  else
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 361

```
0361      R%RECFAST_Hswitch = RECF  
0362      if (R%RECFAST_Hswitch) th  
0363          R%RECFAST_fudge = REC  
0364      end if  
0365  
0366  end subroutine Recombinat  
0367  
0368  
0369  subroutine Recombination_  
0370      Type(RecombinationParams)  
0371      logical, intent(inout) ::  
0372  
0373      if (R%RECFAST_Heswitch<0  
0374          OK = .false.  
0375          write(*, *) 'RECFAST_H  
0376      end if  
0377  
0378  end subroutine Recombinat  
0379  
0380  
0381  function Recombination_tm  
0382  use RECDATA, only : Tnow  
0383  real(dl) zst,a,z,az,bz,Re  
0384  integer ilo,ihi  
0385  
0386  if (.not. doTmatTspin) ca  
0387  z=1/a-1  
0388  if (z >= zrec(1)) then  
0389      Recombination_tm=Tnow  
0390  else
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 391

```
0391      if (z <=zrec(nz)) th  
0392          Recombination_tm=Tm  
0393      else  
0394          zst=(zinitial-z)/de  
0395          ihi= int(zst)  
0396          ilo = ihi+1  
0397          az=zst - int(zst)  
0398          bz=1-az  
0399          Recombination_tm=az  
0400          ((az**3-az)*dTmrec  
0401      endif  
0402      endif  
0403  
0404 end function Recombin  
0405  
0406  
0407 function Recombinatio  
0408 !zrec(1) is zinitial-  
0409 real(dl), intent(in)  
0410 real(dl) zst,z,az,bz,  
0411 integer ilo,ihi  
0412  
0413 z=1/a-1  
0414 if (z.ge.zrec(1)) the  
0415     Recombination_ts=ts  
0416 else  
0417     if (z.le.zrec(nz)) t  
0418         Recombination_ts=ts  
0419     else  
0420         zst=(zinitial-z)/de
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 391

```
0391      if (z <=zrec(nz)) the  
0392          Recombination_tm=  
0393      else  
0394          zst=(zinitial-z)/  
0395          ihi= int(zst)  
0396          ilo = ihi+1  
0397          az=zst - int(zst)  
0398          bz=1-az  
0399          Recombination_tm=  
0400          ((az**3-az)*d  
0401      endif  
0402      endif  
0403  
0404 end function Recombinatio  
0405  
0406  
0407 function Recombination_ts  
0408 !zrec(1) is zinitial-delt  
0409 real(dl), intent(in) :: a  
0410 real(dl) zst,z,az,bz,Reco  
0411 integer ilo,ihi  
0412  
0413 z=1/a-1  
0414 if (z.ge.zrec(1)) then  
0415     Recombination_ts=tsre  
0416 else  
0417     if (z.le.zrec(nz)) th  
0418         Recombination_ts=  
0419     else  
0420         zst=(zinitial-z)/
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 421

```
0421 ihi= int(zst)
0422 ilo = ihi+1
0423 az=zst - int(zst)
0424 bz=1-az
0425
0426 Recombination_ts=az
0427 ((az**3-az)*dtsrec
0428 endif
0429 endif
0430
0431 end function Recombin
0432
0433
0434 function Recombinatio
0435 real(dl), intent(in)
0436 real(dl) zst,z,az,bz,
0437 integer ilo,ihi
0438
0439 z=1/a-1
0440 if (z.ge.zrec(1)) the
0441   Recombination_xe=xr
0442 else
0443   if (z.le.zrec(nz)) t
0444     Recombination_xe=xr
0445 else
0446   zst=(zinitial-z)/de
0447   ihi= int(zst)
0448   ilo = ihi+1
0449   az=zst - int(zst)
0450   bz=1-az
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 421

```
0421 ihi= int(zst)
0422 ilo = ihi+1
0423 az=zst - int(zst)
0424 bz=1-az
0425
0426 Recombination_ts=
0427 ((az**3-az)*d
0428 endif
0429 endif
0430
0431 end function Recombinatio
0432
0433
0434 function Recombination_xe
0435 real(dl), intent(in) :: a
0436 real(dl) zst,z,az,bz,Reco
0437 integer ilo,ihi
0438
0439 z=1/a-1
0440 if (z.ge.zrec(1)) then
0441   Recombination_xe=xrec
0442 else
0443   if (z.le.zrec(nz)) th
0444     Recombination_xe=
0445 else
0446   zst=(zinitial-z)/
0447   ihi= int(zst)
0448   ilo = ihi+1
0449   az=zst - int(zst)
0450   bz=1-az
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 451

```
0451      Recombination_xe=az  
0452          ((az**3-az)*dxrec(  
0453              endif  
0454          endif  
0455  
0456      end function Recombin  
0457  
0458  
0459  
0460 subroutine Recombinat  
0461 !Would love to pass s  
0462 !hence mess passing p  
0463 !Note recfast only us  
0464 !nnu currently not us  
0465 use RECDATA  
0466 use AMLUtils  
0467 implicit none  
0468 Type (RecombinationPa  
0469  
0470     real(dl), save :: las  
0471  
0472     real(dl) Trad,Tmat,Ts  
0473     integer I  
0474  
0475     real(dl), intent(in)  
0476     real(dl), intent(in),  
0477     real(dl) z,n,x,x0,rhs  
0478     real(dl) zstart,zend,  
0479     real(dl) cw(24)  
0480     real(dl), dimension(:
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 451

```
0451      Recombination_xe=  
0452          ((az**3-az)*d  
0453              endif  
0454          endif  
0455  
0456      end function Recombinatio  
0457  
0458  
0459  
0460 subroutine Recombination_  
0461 !Would love to pass struc  
0462 !hence mess passing param  
0463 !Note recfast only uses O  
0464 !nnu currently not used h  
0465 use RECDATA  
0466 use AMLUtils  
0467 implicit none  
0468 Type (RecombinationParams  
0469  
0470     real(dl), save :: last_Om  
0471  
0472     real(dl) Trad,Tmat,Tspin,  
0473     integer I  
0474  
0475     real(dl), intent(in) :: O  
0476     real(dl), intent(in), opt  
0477     real(dl) z,n,x,x0,rhs,x_H  
0478     real(dl) zstart,zend,tcmb  
0479     real(dl) cw(24)  
0480     real(dl), dimension(:, :, :),
```

/Users/lplopa/Compare/camb_simdata/recfast.f90, Top line: 481

```
0481      real(dl) y(4)
0482      real(dl) C10, tau_21T
0483      real(dl) fnu
0484      integer ind,nw
0485
0486      !
0487      --- Parameter statement
0488      real(dl), parameter ::
0489      real(dl) dtauda
0490      external dtauda, dverk
0491
0492      !
0493      =====
0494      if (Last_OmB==OmegaB
0495          dtauda(0.2352375
0496          .and. last_fudg
0497          !This takes up mos
0498          !For example if ca
0499
0500          Last_dtauda = dtauda
0501          Last_OmB = OmegaB
0502          Last_H0 = h0inp
0503          Last_YHe=yp
0504          last_fudge = Recomb%R
0505          last_fudgeHe = Recomb
0506
0507          if (Do21cm) doTmatTsp
0508
0509
0510      !      write(*,*) 'recfast ve
```

/Users/lplopa/Compare/camb_des/recfast.f90, Top line: 481

```
0481      real(dl) y(4)
0482      real(dl) C10, tau_21Ts
0483      real(dl) fnu
0484      integer ind,nw
0485
0486      !
0487      --- Parameter statement
0488      real(dl), parameter :: to
0489      real(dl) dtauda
0490      external dtauda, dverk
0491
0492      !
0493      =====
0494      if (Last_OmB==OmegaB .and.
0495          dtauda(0.2352375823_d
0496          .and. last_fudgeHe==R
0497          !This takes up most of th
0498          !For example if called wi
0499
0500          Last_dtauda = dtauda(0.2
0501          Last_OmB = OmegaB
0502          Last_H0 = h0inp
0503          Last_YHe=yp
0504          last_fudge = Recomb%RECFA
0505          last_fudgeHe = Recomb%REC
0506
0507          if (Do21cm) doTmatTspin =
0508
0509
0510      !      write(*,*) 'recfas
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 511

```
0511 !           write(*,*)'Using Humm
0512 !           write(*,*)' with fudg
0513 !           write(*,*)'and tabula
0514 !           write(*,*)  
0515
0516 !           n_eq = 3
0517 if (Evolve_Ts) n_eq=4
0518 allocate(w(n_eq,9))
0519
0520 !           recombination_saha_z=
0521
0522 !           Tnow=tcmb
0523 !           These are easy to inq
0524 z = zinitial
0525 !           will output every 1 i
0526
0527 !Not general, but only for a
0528 OmegaT=OmegaC+OmegaB
0529 OmegaK=1.d0-OmegaT-Om
0530
0531 !
0532 !           convert the Hubble co
0533 H = H0inp/100._dl
0534 HO = H*bigH
0535
0536
0537 !
0538 !           sort out the helium a
0539 mu_H = 1.d0/(1.d0-Yp)
0540 mu_T = not4/(not4-(no
fHe = Yp/(not4*(1.d0-
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 511

```
0511 !           write(*,*)'Using
0512 !           write(*,*)' with
0513 !           write(*,*)'and ta
0514 !           write(*,*)  
0515
0516 !           n_eq = 3
0517 if (Evolve_Ts) n_eq=4
0518 allocate(w(n_eq,9))
0519
0520 !           recombination_saha_z=0.d0
0521
0522 !           Tnow=tcmb
0523 !           These are easy to
0524 z = zinitial
0525 !           will output every
0526
0527 !Not general, but only fo
0528 OmegaT=OmegaC+OmegaB
0529 OmegaK=1.d0-OmegaT-OmegaV
0530
0531 !
0532 !           convert the Hubb
0533 H = H0inp/100._dl
0534 HO = H*bigH
0535
0536
0537 !
0538 !           sort out the heli
0539 mu_H = 1.d0/(1.d0-Yp)
0540 mu_T = not4/(not4-(not4-1
fHe = Yp/(not4*(1.d0-
```

/Users/lp1opa/Compare/camb_simdata/recfast.f90, Top line: 541

```
0541  
0542  
0543 Nnow = 3._dl*HO*HO*Om  
0544  
0545 n = Nnow * (1._dl+z)*  
0546 fnu = (21.d0/8.d0)*(4.  
0547 ! (this is explicitly fo  
0548 z_eq = (3.d0*(HO*C)**  
0549 z_eq = z_eq - 1.d0  
0550  
0551 !  
0552 Set up some constants  
0553 Lalpha = 1.d0/L_H_alp  
0554 Lalpha_He = 1.d0/L_He  
0555 DeltaB = h_P*C*(L_H_i  
0556 CDB = DeltaB/k_B  
0557 DeltaB_He = h_P*C*(L_  
0558 CDB_He = DeltaB_He/k_  
0559 CB1 = h_P*C*L_H_ion/k  
0560 CB1_He1 = h_P*C*L_He1  
0561 CB1_He2 = h_P*C*L_He2  
0562 CR = 2.d0*Pi*(m_e/h_P)  
0563 CK = Lalpha**3/(8.d0*  
0564 CK_He = Lalpha_He**3/  
0565 CL = C*h_P/(k_B*Lalph  
0566 CL_He = C*h_P/(k_B/L_  
0567 CT = Compton_CT / MPC  
0568  
0569 Bfact = h_P*C*(L_He_2  
0570
```

/Users/lp1opa/Compare/camb_des/recfast.f90, Top line: 541

```
0541  
0542  
0543 Nnow = 3._dl*HO*HO*OmegaB  
0544  
0545 n = Nnow * (1._dl+z)**3  
0546 fnu = (21.d0/8.d0)*(4.d0/  
0547 ! (this is explicitly fo  
0548 z_eq = (3.d0*(HO*C)**2/(8  
0549 z_eq = z_eq - 1.d0  
0550  
0551 ! Set up some const  
0552 Lalpha = 1.d0/L_H_alpha  
0553 Lalpha_He = 1.d0/L_He_2p  
0554 DeltaB = h_P*C*(L_H_ion-L  
0555 CDB = DeltaB/k_B  
0556 DeltaB_He = h_P*C*(L_He1_  
0557 CDB_He = DeltaB_He/k_B  
0558 CB1 = h_P*C*L_H_ion/k_B  
0559 CB1_He1 = h_P*C*L_He1_ion  
0560 CB1_He2 = h_P*C*L_He2_ion  
0561 CR = 2.d0*Pi*(m_e/h_P)*(k  
0562 CK = Lalpha**3/(8.d0*Pi)  
0563 CK_He = Lalpha_He**3/(8.d  
0564 CL = C*h_P/(k_B*Lalph)  
0565 CL_He = C*h_P/(k_B/L_He_2  
0566 CT = Compton_CT / MPC_in_  
0567  
0568  
0569 Bfact = h_P*C*(L_He_2p-L_  
0570
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 571

```
0571 ! Matter departs from r  
0572 ! choose some safely sm  
0573 H_frac = 1D-3  
0574  
0575 !  
0576 Fudge factor to appro  
0577 fu=Recomb%RECFAST_fud  
0578  
0579 ! Set initial matter te  
0580 y(3) = Tnow*(1._dl+z)  
0581 Tmat = y(3)  
0582 y(4) = Tmat  
0583 Tspin = Tmat  
0584  
0585 call get_init(z,x_H0,  
0586  
0587 y(1) = x_H0  
0588 y(2) = x_He0  
0589  
0590 ! OK that's the initial  
0591  
0592  
0593 ! Set up work-space stu  
0594 ind = 1  
0595 nw = n_eq  
0596 do i = 1,24  
0597 cw(i) = 0._dl  
0598 end do  
0599  
0600 do i = 1,Nz
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 571

```
0571 ! Matter departs fr  
0572 ! choose some safel  
0573 H_frac = 1D-3  
0574  
0575 !  
0576 ! Fudge factor to a  
0577 fu=Recomb%RECFAST_fudge  
0578  
0579 ! Set initial matte  
0580 y(3) = Tnow*(1._dl+z)  
0581 Tmat = y(3)  
0582 y(4) = Tmat  
0583 Tspin = Tmat  
0584  
0585 call get_init(z,x_H0,x_He  
0586  
0587 y(1) = x_H0  
0588 y(2) = x_He0  
0589  
0590 ! OK that's the ini  
0591  
0592  
0593 ! Set up work-space  
0594 ind = 1  
0595 nw = n_eq  
0596 do i = 1,24  
0597 cw(i) = 0._dl  
0598 end do  
0599  
0600 do i = 1,Nz
```

/Users/lplopa/Compare/camb_simdata/recfast.f90, Top line: 601

```
0601 ! calculate the start a  
0602 ! or just at each z  
0603 zstart = zinitial  
0604 zend = zinitial  
0605  
0606 ! Use Saha to get x_e, using  
0607 ! and for neutral helium.  
0608 ! Everything ionized above z=  
0609 ! Assume He all singly ionize  
0610 ! He is 99% singly ionized, a  
0611  
0612 z = zend  
0613  
0614 if (zend > 8000._dl)  
0615  
0616 x_H0 = 1._dl  
0617 x_He0 = 1._dl  
0618 x0 = 1._dl+2._dl*  
0619 y(1) = x_H0  
0620 y(2) = x_He0  
0621 y(3) = Tnow*(1._d  
0622 y(4) = y(3)  
0623  
0624 else if(z > 5000._d  
0625  
0626 x_H0 = 1._dl  
0627 x_He0 = 1._dl  
0628 rhs = exp(-CB1_He2/(Tn  
0629 - CB1_He2/(Tn  
0630 rhs = rhs*1._dl
```

/Users/lplopa/Compare/camb_des/recfast.f90, Top line: 601

```
0601 ! calculate the  
0602 ! or just at ea  
0603 zstart = zinitial -  
0604 zend = zinitial -  
0605  
0606 ! Use Saha to get x_e  
0607 ! and for neutral hel  
0608 ! Everything ionized  
0609 ! Assume He all singl  
0610 ! He is 99% singly io  
0611  
0612 z = zend  
0613  
0614 if (zend > 8000._dl)  
0615  
0616 x_H0 = 1._dl  
0617 x_He0 = 1._dl  
0618 x0 = 1._dl+2._dl*  
0619 y(1) = x_H0  
0620 y(2) = x_He0  
0621 y(3) = Tnow*(1._d  
0622 y(4) = y(3)  
0623  
0624 else if(z > 5000._dl)  
0625  
0626 x_H0 = 1._dl  
0627 x_He0 = 1._dl  
0628 rhs = exp(-CB1_He2/(Tn  
0629 - CB1_He2/(Tn  
0630 rhs = rhs*1._dl
```

/Users/lp1opa/Compare/camb_simdata/recfast.f90, Top line: 631

```
0631          x0 = 0.5d0 * ( sq
0632                  + 4._dl*(1._d
0633          y(1) = x_H0
0634          y(2) = x_He0
0635          y(3) = Tnow*(1._d
0636          y(4) = y(3)
0637
0638      else if(z > 3500._d
0639
0640          x_H0 = 1._dl
0641          x_He0 = 1._dl
0642          x0 = x_H0 + fHe*x
0643          y(1) = x_H0
0644          y(2) = x_He0
0645          y(3) = Tnow*(1._d
0646          y(4) = y(3)
0647
0648      else if(y(2) > 0.99
0649
0650          x_H0 = 1._dl
0651          rhs = exp( 1.5d0
0652                  - CB1_He1/(Tn
0653          rhs = rhs*4._dl
0654          x_He0 = 0.5d0 * (
0655                  + 4._dl*(1._d
0656          x0 = x_He0
0657          x_He0 = (x0 - 1._
0658          y(1) = x_H0
0659          y(2) = x_He0
0660          y(3) = Tnow*(1._d
```

/Users/lp1opa/Compare/camb_des/recfast.f90, Top line: 631

```
0631          x0 = 0.5d0 * ( sq
0632                  + 4._dl*(1._d
0633          y(1) = x_H0
0634          y(2) = x_He0
0635          y(3) = Tnow*(1._d
0636          y(4) = y(3)
0637
0638      else if(z > 3500._dl)
0639
0640          x_H0 = 1._dl
0641          x_He0 = 1._dl
0642          x0 = x_H0 + fHe*x
0643          y(1) = x_H0
0644          y(2) = x_He0
0645          y(3) = Tnow*(1._d
0646          y(4) = y(3)
0647
0648      else if(y(2) > 0.99)
0649
0650          x_H0 = 1._dl
0651          rhs = exp( 1.5d0
0652                  - CB1_He1/(Tn
0653          rhs = rhs*4._dl
0654          x_He0 = 0.5d0 * (
0655                  + 4._dl*(1._d
0656          x0 = x_He0
0657          x_He0 = (x0 - 1._
0658          y(1) = x_H0
0659          y(2) = x_He0
0660          y(3) = Tnow*(1._d
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 661

```
0661          y(4) = y(3)
0662
0663      else if (y(1) > 0.9
0664
0665          rhs = exp( 1.5d0
0666              - CB1/(Tnow*( 
0667          x_H0 = 0.5d0 * (s
0668
0669          call DVERK(Recomb
0670          y(1) = x_H0
0671          x0 = y(1) + fHe*y
0672          y(4)=y(3)
0673      else
0674
0675          call DVERK(Recomb
0676
0677          x0 = y(1) + fHe*y
0678
0679      end if
0680
0681      Trad = Tnow * (1._d
0682      Tmat = y(3)
0683      x_H = y(1)
0684      x_He = y(2)
0685      x = x0
0686
0687      zrec(i)=zend
0688      xrec(i)=x
0689
0690
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 661

```
0661          y(4) = y(3)
0662
0663      else if (y(1) > 0.99d
0664
0665          rhs = exp( 1.5d0
0666              - CB1/(Tnow*( 
0667          x_H0 = 0.5d0 * (s
0668
0669          call DVERK(Recomb
0670          y(1) = x_H0
0671          x0 = y(1) + fHe*y
0672          y(4)=y(3)
0673      else
0674
0675          call DVERK(Recomb
0676
0677          x0 = y(1) + fHe*y
0678
0679      end if
0680
0681      Trad = Tnow * (1._d1+
0682      Tmat = y(3)
0683      x_H = y(1)
0684      x_He = y(2)
0685      x = x0
0686
0687      zrec(i)=zend
0688      xrec(i)=x
0689
0690
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 691

```
0691      if (doTmatTspin) th
0692          if (Evolve_Ts . .
0693              Tspin = y(4)
0694          else
0695              C10 = Nnow * (
0696                  tau_21Ts = lin
0697
0698                  Tspin = Trad*((
0699                      tau_21Ts/
0700
0701                  y(4) = Tspin
0702          end if
0703
0704          tsrec(i) = Tspi
0705          tmrec(i) = Tmat
0706
0707      end if
0708
0709      !           write (*, '(5E15.5)
0710
0711      end do
0712
0713      d0hi=1.0d40
0714      d0lo=1.0d40
0715      call spline(zrec,xrec
0716      if (doTmatTspin) then
0717          call spline(zrec,tsr
0718          call spline(zrec,tmr
0719      end if
0720      deallocate(w)
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 691

```
0691      if (doTmatTspin) then
0692          if (Evolve_Ts .an
0693              Tspin = y(4)
0694          else
0695              C10 = Nnow *
0696              tau_21Ts = li
0697
0698              Tspin = Trad*
0699              tau_21Ts/
0700
0701              y(4) = Tspin
0702      end if
0703
0704      tsrec(i) = Tspin
0705      tmrec(i) = Tmat
0706
0707  end if
0708
0709      !
0710      write (*, '
0711  end do
0712
0713  d0hi=1.0d40
0714  d0lo=1.0d40
0715  call spline(zrec,xrec,nz,
0716  if (doTmatTspin) then
0717      call spline(zrec,tsre
0718      call spline(zrec,tmre
0719  end if
0720  deallocate(w)
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 721

```
0721
0722      end subroutine Recomb
0723
0724      !
0725      subroutine GET_INIT(z
0726
0727      !      Set up the initial co
0728      !      but not pathological
0729      !      Initial ionization fr
0730      use RECDATA
0731      implicit none
0732
0733
0734      real(dl) z,x0,rhs,x_H
0735
0736
0737      if(z > 8000._dl)then
0738
0739          x_H0 = 1._dl
0740          x_He0 = 1._dl
0741          x0 = 1._dl+2._dl*fHe
0742
0743      else if(z > 3500._dl)
0744
0745          x_H0 = 1._dl
0746          x_He0 = 1._dl
0747          rhs = exp( 1.5d0
0748              - CB1_He2/(Tn
0749          rhs = rhs*1._dl      !r
0750          x0 = 0.5d0 * ( sqrt(
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 721

```
0721
0722      end subroutine Recombinat
0723
0724      !
0725      subroutine GET_INIT(z,x_H
0726
0727      !      Set up the initia
0728      !      but not pathologi
0729      !      Initial ionizatio
0730      use RECDATA
0731      implicit none
0732
0733
0734      real(dl) z,x0,rhs,x_H0,x_
0735
0736
0737      if(z > 8000._dl)then
0738
0739          x_H0 = 1._dl
0740          x_He0 = 1._dl
0741          x0 = 1._dl+2._dl*fHe
0742
0743      else if(z > 3500._dl)
0744
0745          x_H0 = 1._dl
0746          x_He0 = 1._dl
0747          rhs = exp( 1.5d0 * lo
0748              - CB1_He2/(Tnow*
0749          rhs = rhs*1._dl      !r
0750          x0 = 0.5d0 * ( sqrt(
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 751

```
0751      + 4._dl*(1._d
0752
0753      else if(z > 2000._dl)
0754
0755      x_H0 = 1._dl
0756      rhs = exp( 1.5d0
0757          - CB1_He1/(Tn
0758      rhs = rhs*4._dl !r
0759      x_He0 = 0.5d0 * 
0760      x0 = x_He0
0761      x_He0 = (x0 - 1._
0762
0763      else
0764
0765      rhs = exp( 1.5d0
0766          - CB1/(Tnow*(1.
0767      x_H0 = 0.5d0 * (s
0768      x_He0 = 0._dl
0769      x0 = x_H0
0770
0771      end if
0772
0773      end subroutine GET_IN
0774
0775
0776
0777
0778      subroutine ION(Recomb
0779      use RECDATA
0780      implicit none
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 751

```
0751      + 4._dl*(1._dl+2.
0752
0753      else if(z > 2000._dl)then
0754
0755      x_H0 = 1._dl
0756      rhs = exp( 1.5d0 * lo
0757          - CB1_He1/(Tnow*(1.
0758      rhs = rhs*4._dl !r
0759      x_He0 = 0.5d0 * ( sq
0760      x0 = x_He0
0761      x_He0 = (x0 - 1._dl)/
0762
0763      else
0764
0765      rhs = exp( 1.5d0 * lo
0766          - CB1/(Tnow*(1._d
0767      x_H0 = 0.5d0 * (sqrt(
0768      x_He0 = 0._dl
0769      x0 = x_H0
0770
0771      end if
0772
0773
0774
0775
0776
0777
0778      subroutine ION(Recomb,Ndi
0779      use RECDATA
0780      implicit none
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 781

```
0781  
0782      integer Ndim  
0783      Type (RecombinationPa  
0784  
0785      real(dl) z,x,n,n_He,T  
0786      real(dl) y(Ndim),f(Nd  
0787      real(dl) Rup,Rdown,K,  
0788      real(dl) timeTh,timeH  
0789      real(dl) a_VF,b_VF,T_  
0790      real(dl) tauHe_s,pHe_  
0791      real(dl) a_trip,b_tri  
0792      real(dl) Doppler,gamm  
0793      real(dl) tauHe_t,pHe_  
0794      real(dl) epsilon  
0795      integer Heflag  
0796      real(dl) dtauda  
0797      real(dl) C10, dHdz  
0798      external dtauda  
0799  
0800      !  
0801      the Pequignot, Petitj  
0802      a_PPB = 4.309d0  
0803      b_PPB = -0.6166d0  
0804      c_PPB = 0.6703d0  
0805      d_PPB = 0.5300d0  
0806      the Verner and Ferlan  
0807      fixed to match those  
0808      a_VF = 10.d0**(-16.74  
0809      b_VF = 0.711d0  
0810      T_0 = 10.d0** (0.47712  
0811      T_1 = 10.d0** (5.114d0
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 781

```
0781  
0782      integer Ndim  
0783      Type (RecombinationParams  
0784  
0785      real(dl) z,x,n,n_He,Trad,  
0786      real(dl) y(Ndim),f(Ndim)  
0787      real(dl) Rup,Rdown,K,K_He  
0788      real(dl) timeTh,timeH  
0789      real(dl) a_VF,b_VF,T_0,T_  
0790      real(dl) tauHe_s,pHe_s  
0791      real(dl) a_trip,b_trip,Rd  
0792      real(dl) Doppler,gamma_2P  
0793      real(dl) tauHe_t,pHe_t,CL  
0794      real(dl) epsilon  
0795      integer Heflag  
0796      real(dl) dtauda  
0797      real(dl) C10, dHdz  
0798      external dtauda  
0799  
0800      !  
0801      the Pequignot, Pe  
0802      a_PPB = 4.309d0  
0803      b_PPB = -0.6166d0  
0804      c_PPB = 0.6703d0  
0805      d_PPB = 0.5300d0  
0806      !  
0807      the Verner and Fe  
0808      !  
0809      fixed to match th  
0810      a_VF = 10.d0**(-16.744d0)  
0811      b_VF = 0.711d0  
0812      T_0 = 10.d0** (0.477121d0)  
0813      T_1 = 10.d0** (5.114d0)
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 811

```
0811 ! fitting parameters for  
0812 ! (matches Hummer's tabl  
0813  
0814 a_trip = 10.d0**(-16.  
0815 b_trip = 0.761D0  
0816  
0817  
0818 x_H = y(1)  
0819 x_He = y(2)  
0820 x = x_H + fHe * x_He  
0821 Tmat = y(3)  
0822 ! Tspin = y(4)  
0823  
0824 n = Nnow * (1._dl+z)*  
0825 n_He = fHe * Nnow * (  
0826 Trad = Tnow * (1._dl+  
0827  
0828 Hz = 1/dtauda(1/(1._d  
0829  
0830  
0831 ! Get the radiative rat  
0832  
0833 Rdown=1.d-19*a_PPB*(T  
0834 / (1._dl+c_PPB  
0835 Rup = Rdown * (CR*Tma  
0836  
0837 ! calculate He using a  
0838 sq_0 = sqrt(Tmat/T_0)  
0839 sq_1 = sqrt(Tmat/T_1)  
0840 ! typo here corrected b
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 811

```
0811 ! fitting parameters  
0812 ! (matches Hummer's  
0813  
0814 a_trip = 10.d0**(-16.306d  
0815 b_trip = 0.761D0  
0816  
0817  
0818 x_H = y(1)  
0819 x_He = y(2)  
0820 x = x_H + fHe * x_He  
0821 Tmat = y(3)  
0822 ! Tspin = y(4)  
0823  
0824 n = Nnow * (1._dl+z)**3  
0825 n_He = fHe * Nnow * (1._d  
0826 Trad = Tnow * (1._dl+z)  
0827  
0828 Hz = 1/dtauda(1/(1._d  
0829  
0830  
0831 ! Get the radiative  
0832  
0833 Rdown=1.d-19*a_PPB*(Tmat/  
0834 / (1._dl+c_PPB*(Tmat/1  
0835 Rup = Rdown * (CR*Tmat)**  
0836  
0837 ! calculate He usin  
0838 sq_0 = sqrt(Tmat/T_0)  
0839 sq_1 = sqrt(Tmat/T_1)  
0840 ! typo here correct
```

/Users/lp1opa/Compare/camb_simdata/recfast.f90, Top line: 841

```
0841      Rdown_He = a_VF/(sq_0
0842      Rdown_He = Rdown_He/( 
0843      Rup_He = Rdown_He*(CR
0844      Rup_He = 4.d0*Rup_He
0845      !          Avoid overflow (point
0846      if((Bfact/Tmat) > 680
0847          He_Boltz = exp(680.
0848      else
0849          He_Boltz = exp(Bfac
0850      end if
0851      !          now deal with H and i
0852      if (.not. Recomb%RECFAST
0853          K = CK/Hz !Peebles coef
0854      else
0855      !c          fit a double Gaussian
0856          K = CK/Hz*(1.0d0 &
0857              +AGauss1*exp(-((log(1
0858              +AGauss2*exp(-((log(1
0859      end if
0860
0861
0862      ! add the HeI part, using s
0863      Rdown_trip = a_trip/(sq_0
0864      Rdown_trip = Rdown_trip/( 
0865      Rup_trip = Rdown_trip*dex
0866      Rup_trip = Rup_trip*((CR*
0867      !          last factor here is the s
0868
0869      !          try to avoid "NaN" wh
0870      if ((x_He.lt.5.d-9) .or.
```

/Users/lp1opa/Compare/camb_des/recfast.f90, Top line: 841

```
0841      Rdown_He = a_VF/(sq_0*(1.
0842      Rdown_He = Rdown_He/(1.d0
0843      Rup_He = Rdown_He*(CR*Tma
0844      Rup_He = 4.d0*Rup_He
0845      !          Avoid overflow (p
0846      if((Bfact/Tmat) > 680.d0)
0847          He_Boltz = exp(680.d0
0848      else
0849          He_Boltz = exp(Bfact/
0850      end if
0851      !          now deal with H and i
0852      if (.not. Recomb%RECFAST
0853          K = CK/Hz !Peebles co
0854      else
0855      !c          fit a double
0856          K = CK/Hz*(1.0d0 &
0857              +AGauss1*exp(-((1
0858              +AGauss2*exp(-((1
0859      end if
0860
0861
0862      ! add the HeI part, usin
0863      Rdown_trip = a_trip/(sq_0
0864      Rdown_trip = Rdown_trip/( 
0865      Rup_trip = Rdown_trip*dex
0866      Rup_trip = Rup_trip*((CR*
0867      !          last factor here is t
0868
0869      !          try to avoid "NaN"
0870      if ((x_He.lt.5.d-9) .or.
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 871

```
0871      Heflag = 0
0872      else
0873      Heflag = Recomb%RECFAST
0874      end if
0875      if (Heflag.eq.0)then
0876      K_He = CK_He/Hz
0877      else !for Heflag>0
0878      tauHe_s = A2P_s*CK_He*3
0879      pHe_s = (1.d0 - dexp(-t
0880      K_He = 1.d0/(A2P_s*pHe_
0881      if (((Heflag.eq.2) .or.
0882      if (((Heflag.eq.2) .or.
0883      !AL changed July 08 to
0884
0885      ! use fitting formula for c
0886      ! first get the Doppler wid
0887      Doppler = 2.D0*k_B*Tm
0888      Doppler = C*L_He_2p*d
0889      gamma_2Ps = 3.d0*A2P_
0890      /(dsqrt(Pi)*sigma
0891      /((C*L_He_2p)**2.
0892      pb = 0.36d0 !value f
0893      qb = Recomb%RECFAST_f
0894      ! calculate AHcon, the valu
0895      AHcon = A2P_s/(1.d0+p
0896      K_He=1.d0/((A2P_s*pHe
0897      end if
0898      if (Heflag.ge.3) then
0899      tauHe_t = A2P_t*n_He*
0900      tauHe_t = tauHe_t /(8
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 871

```
0871      Heflag = 0
0872      else
0873      Heflag = Recomb%RECFA
0874      end if
0875      if (Heflag.eq.0)then
0876      K_He = CK_He/Hz
0877      else !for Heflag>0
0878      tauHe_s = A2P_s*CK_He
0879      pHe_s = (1.d0 - dexp(
0880      K_He = 1.d0/(A2P_s*pH
0881      ! if (((Heflag.e
0882      if (((Heflag.eq.2) .o
0883      !AL changed July
0884
0885      ! use fitting f
0886      ! first get the
0887      Doppler = 2.D0*k_
0888      Doppler = C*L_He_
0889      gamma_2Ps = 3.d0*
0890      /(dsqrt(Pi)*s
0891      /((C*L_He_2p)
0892      pb = 0.36d0 !val
0893      qb = Recomb%RECFA
0894      ! calculate AHc
0895      AHcon = A2P_s/(1.
0896      K_He=1.d0/((A2P_s
0897      end if
0898      if (Heflag.ge.3) then
0899      tauHe_t = A2P_t*n_
0900      tauHe_t = tauHe_t
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 901

```
0901      pHe_t = (1.d0 - dexp(0902      CL_PSt = h_P*C*(L_He_0903      if ((Heflag.eq.3) .or0904      !           if ((Heflag.eq.3) .o0905      CfHe_t = A2P_t*pH0906      CfHe_t = CfHe_t/(0907      else0908      Doppler = 2.d0*k_0909      Doppler = C*L_He_0910      gamma_2Pt = 3.d0*0911      /(dsqrt(Pi)*sigma0912      /((C*L_He_2Pt)**20913      ! use the fitting param0914      pb = 0.66d00915      qb = 0.9d00916      AHcon = A2P_t/(1.0917      CfHe_t = (A2P_t*p0918      CfHe_t = CfHe_t/(0919      end if0920      end if0921      end if0922      !0923      Estimates of Thomson0924      timeTh=(1._dl/(CT*Trad0925      timeH=2./ (3.*HO*(1._d0926      0927      ! calculate the derivat0928      0929      ! turn on H only for x_0930      (clunky, but seems to
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 901

```
0901      pHe_t = (1.d0 - d0902      CL_PSt = h_P*C*(L_He_0903      if ((Heflag.eq.3)0904      !           if (0905      CfHe_t = A2P_0906      CfHe_t = CfHe0907      else0908      Doppler = 2.d0909      Doppler = C*L_He_0910      gamma_2Pt = 3.0911      /(dsqrt(Pi)*sigma0912      /((C*L_He_2Pt)**20913      ! use the f0914      pb = 0.66d00915      qb = 0.9d00916      AHcon = A2P_t0917      CfHe_t = (A2P_t0918      CfHe_t = CfHe0919      end if0920      end if0921      end if0922      !0923      Estimates of Thom0924      timeTh=(1._dl/(CT*Trad**40925      timeH=2./ (3.*HO*(1._dl+z)0926      0927      ! calculate the der0928      0929      ! turn on H only fo0930      (clunky, but seem
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 931

```
0931      if (x_H > 0.99) then  
0932          f(1) = 0._d1  
0933      !!  
0934      else if (x_H > 0.98  
0935      else if (x_H.gt.0.985d0  
0936          f(1) = (x*x_H*n*R  
0937          recombination_sah  
0938      !AL: following commented as n  
0939      !    for interest, calculate t  
0940      !    (without the fudge)  
0941      !    factor=(1.d0 + K*Lamb  
0942      !    /(Hz*(1.d0+z)*(1.d0+K  
0943      !    +K*Rup*n*(1.d0-x)))  
0944      else !use full rate for H  
0945          f(1) = ((x*x_H*n*Rdow  
0946          *(1.d0 + K*La  
0947          /(Hz*(1.d0+z)  
0948          +K*Rup*n*(1.d  
0949  
0950      end if  
0951  
0952      !    turn off the He once  
0953      if (x_He < 1.e-15) then  
0954          f(2)=0.d0  
0955      else  
0956  
0957          f(2) = ((x*x_He*n*Rdo  
0958          - Rup_He*(1-x_He)  
0959          *(1 + K_He*La  
0960          /(Hz*(1+z) &
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 931

```
0931      if (x_H > 0.99) then    !d  
0932          f(1) = 0._d1  
0933      !!  
0934      else if (x_H > 0.98  
0935      else if (x_H.gt.0.985d0)  
0936          f(1) = (x*x_H*n*Rdown  
0937          recombination_saha_z  
0938      !AL: following commen  
0939      !    for interest, cal  
0940      !    (without the fudg  
0941      !    factor=(1.d0  
0942      !    /(Hz*(1.d0+z)  
0943      !    +K*Rup*n*(1.d  
0944  
0945          f(1) = ((x*x_H*n*Rdow  
0946          *(1.d0 + K*Lambda  
0947          /(Hz*(1.d0+z)*(1.  
0948          +K*Rup*n*(1.d0-x_<br>  
0949  
0950      end if  
0951  
0952      !    turn off the He o  
0953      if (x_He < 1.e-15) then  
0954          f(2)=0.d0  
0955      else  
0956  
0957          f(2) = ((x*x_He*n*Rdo  
0958          - Rup_He*(1-x_He)  
0959          *(1 + K_He*Lambda  
0960          /(Hz*(1+z) &
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 961

```
0961           * (1 + K_He)*(  
0962 !     Modification to HeI recom  
0963         if (Heflag.ge.3) th  
0964             f(2) = f(2)+ (x*x  
0965               - (1.d0-x_He)*3.  
0966               *CfHe_t/(Hz*(1.d  
0967             end if  
0968  
0969  
0970         end if  
0971  
0972         if (timeTh < H_frac*t  
0973           f(3)=Tmat/(1  
0974           additional term to sm  
0975           (suggested by Adam Mo  
0976             dHdz = (HO**2/2.d0/H  
0977               + 3.d0*OmegaT*(1.d0+  
0978  
0979             epsilon = Hz*(1.d0+x+  
0980             f(3) = Tnow &  
0981               + epsilon*((1.d0+fHe)  
0982               - epsilon* dHdz/Hz +  
0983  
0984         else  
0985             f(3)= CT * (T  
0986               * (Tm  
0987         end if  
0988  
0989         ! print *, z, f(3)*(  
0990
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 961

```
0961           * (1 + K_He)*(Lamb  
0962 !     Modification to H  
0963         if (Heflag.ge.3) then  
0964             f(2) = f(2)+ (x*x  
0965               - (1.d0-x_He)  
0966               *CfHe_t/(Hz*(  
0967             end if  
0968  
0969  
0970         end if  
0971  
0972         if (timeTh < H_frac*timeH  
0973           !  
0974           f(3)  
0975           !     additional te  
0976           !     (suggested by  
0977             dHdz = (HO**2/2.d0/Hz  
0978               + 3.d0*OmegaT*(1.  
0979  
0980             epsilon = Hz*(1.d0+x+  
0981             f(3) = Tnow &  
0982               + epsilon*((1.d0+  
0983               - epsilon* dHdz/H  
0984  
0985         else  
0986             f(3)= CT * (Trad**4)  
0987               * (Tmat-Trad) / (  
0988         end if  
0989  
0990         ! print *, z, f(3)*(1+z)/
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 991

```
0991      if (Do21cm .and. evol
0992
0993      !           follow the matter
0994      if (timeTh < H_fr
0995          f(4) = Tnow !
0996      else
0997          if (z< 1/Do21
0998
0999          Tspin = y(4)
1000          C10 = n*(kap
1001
1002          f(4) = 4*Tsp
1003          else
1004          f(4)=f(3)
1005          end if
1006      end if
1007
1008      end if
1009
1010     end subroutine ION
1011
1012
1013
1014     function dDeltaxe_dta
1015     !d x_e/d tau assuming
1016     !it is not accurate f
1017     use RECDATA
1018     implicit none
1019     real(dl) dDeltaxe_dta
1020     real(dl), intent(in):
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 991

```
0991      if (Do21cm .and. evolve_T
0992
0993      !           follow the ma
0994      if (timeTh < H_frac*t
0995          f(4) = Tnow !spin
0996      else
0997          if (z< 1/Do21cm_m
0998
0999          Tspin = y(4)
1000          C10 = n*(kapp
1001
1002          f(4) = 4*Tspi
1003          else
1004          f(4)=f(3)
1005          end if
1006      end if
1007
1008      end if
1009
1010     end subroutine ION
1011
1012
1013
1014     function dDeltaxe_dtau(a,
1015     !d x_e/d tau assuming Hel
1016     !it is not accurate for x
1017     use RECDATA
1018     implicit none
1019     real(dl) dDeltaxe_dtau
1020     real(dl), intent(in):: a,
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1021

```
1021      real(dl) Delta_Tg  
1022      real(dl) xedot,z,x,n,  
1023      real(dl) Rup,Rdown,K  
1024      real(dl) a_PPB,b_PPB,  
1025      real(dl) delta_alpha,  
1026      real(dl) dtauda  
1027      external dtauda  
1028  
1029  
1030      Delta_tg =Delta_Tm  
1031      x_H = min(1._dl,Recom  
1032  
1033      !  
1034      the Pequignot, Petitj  
1035      a_PPB = 4.309d0  
1036      b_PPB = -0.6166d0  
1037      c_PPB = 0.6703d0  
1038      d_PPB = 0.5300d0  
1039      z=1/a-1  
1040  
1041      x = x_H  
1042  
1043      n = Nnow /a**3  
1044      n_He = fHe * n  
1045      Trad = Tnow /a  
1046      clh = 1/dtauda(a)/a !  
1047      Hz = clh/a/MPC_in_sec !no  
1048  
1049      Tmat = Recombination_  
1050
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1021

```
1021      real(dl) Delta_Tg  
1022      real(dl) xedot,z,x,n,n_He  
1023      real(dl) Rup,Rdown,K  
1024      real(dl) a_PPB,b_PPB,c_PP  
1025      real(dl) delta_alpha, del  
1026      real(dl) dtauda  
1027      external dtauda  
1028  
1029  
1030      Delta_tg =Delta_Tm  
1031      x_H = min(1._dl,Recombina  
1032  
1033      !  
1034      the Pequignot, Pe  
1035      a_PPB = 4.309d0  
1036      b_PPB = -0.6166d0  
1037      c_PPB = 0.6703d0  
1038      d_PPB = 0.5300d0  
1039      z=1/a-1  
1040  
1041      x = x_H  
1042  
1043      n = Nnow /a**3  
1044      n_He = fHe * n  
1045      Trad = Tnow /a  
1046      clh = 1/dtauda(a)/a !conf  
1047      Hz = clh/a/MPC_in_sec !no  
1048  
1049      Tmat = Recombination_tm(a  
1050
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1051

```
1051 !      Get the radiative rat
1052
1053     Rdown=1.d-19*a_PPB*(T
1054             /(1._dl+c_PPB
1055     Rup = Rdown * (CR*Tma
1056
1057     K = CK/Hz
1058
1059
1060     Rdown = Rdown*fu
1061     Rup = Rup*fu
1062     C_r = a*(1.d0 + K*La
1063
1064     xedot = -(x*x_H*n*Rdo
1065
1066     delta_alpha = (b_PPB
1067     delta_beta = delta_alpha
1068     delta_K = - hdot/clh
1069
1070
1071     dlnC_r = -Rup*K*n*( (
1072             / ( 1.d0+K*(Lambda+
1073
1074     dDeltaxe_dtau= xedot/
1075             - C_r*( (2*Delta_xe
1076
1077
1078 !Approximate form valid at la
1079 !     dDeltaxe_dtau= xedot
1080
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1051

```
1051 !      Get the radiative
1052
1053     Rdown=1.d-19*a_PPB*(Tmat/
1054             /(1._dl+c_PPB*(Tmat/1
1055     Rup = Rdown * (CR*Tmat)**
1056
1057     K = CK/Hz
1058
1059
1060     Rdown = Rdown*fu
1061     Rup = Rup*fu
1062     C_r = a*(1.d0 + K*Lambda
1063
1064     xedot = -(x*x_H*n*Rdown -
1065
1066     delta_alpha = (b_PPB + c_
1067     delta_beta = delta_alpha
1068     delta_K = - hdot/clh - kv
1069
1070
1071     dlnC_r = -Rup*K*n*( (Delta_
1072             / ( 1.d0+K*(Lambda+Rup
1073
1074     dDeltaxe_dtau= xedot/x_H*
1075             - C_r*( (2*Delta_xe +
1076
1077
1078 !Approximate form valid at la
1079 !     dDeltaxe_dtau= x
1080
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1081

```
1081  
1082      end function dDeltaxe  
1083  
1084 ! =====  
1085  
1086  
1087      function polevl(x,c)  
1088      implicit none  
1089      integer N  
1090      real(dl) polevl  
1091      real(dl) x,ans  
1092      real(dl) coef(N+1)  
1093  
1094      integer i  
1095  
1096      ans=coef(1)  
1097      do i=2,N+1  
1098          ans=ans*x+coef(i)  
1099      end do  
1100      polevl=ans  
1101  
1102      end function polevl  
1103  
1104  
1105      function derivpolev  
1106      implicit none  
1107      integer N  
1108      real(dl) derivpolev  
1109      real(dl) x,ans  
1110      real(dl) coef(N+1)
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1081

```
1081  
1082      end function dDeltaxe_dta  
1083  
1084 ! =====  
1085  
1086  
1087      function polevl(x,coef,N)  
1088      implicit none  
1089      integer N  
1090      real(dl) polevl  
1091      real(dl) x,ans  
1092      real(dl) coef(N+1)  
1093  
1094      integer i  
1095  
1096      ans=coef(1)  
1097      do i=2,N+1  
1098          ans=ans*x+coef(i)  
1099      end do  
1100      polevl=ans  
1101  
1102      end function polevl  
1103  
1104  
1105      function derivpolevl(x,co  
1106      implicit none  
1107      integer N  
1108      real(dl) derivpolevl  
1109      real(dl) x,ans  
1110      real(dl) coef(N+1)
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1111

```
1111      integer i
1112
1113      ans=coef(1)*N
1114      do i=2,N
1115          ans=ans*x+coef(i)
1116      end do
1117      derivpolevl=ans
1118
1119      end function derivp
1120
1121
1122      function kappa_HH_21c
1123      !Polynomial fit to Hy
1124      !if deriv return d lo
1125      real(dl), intent(in)
1126      logical, intent(in)
1127      real(dl), dimension
1128          (/ 0.00120402_dl,
1129      integer, parameter :: n_t
1130      integer, dimension(n_t
1131          (/ 1, 2, 4, 6, 8, 10,
1132      real, dimension(n_table
1133          (/ 1.38e-13, 1.43e-
1134              3.67e-11, 5.38e-11,
1135              1.02e-10, 1.11e-10,
1136              4.97e-10, 6.03e-10,
1137
1138      real(dl) kappa_HH_21
1139      real(dl), save, dimension
1140      integer xlo, xhi
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1111

```
1111      integer i
1112
1113      ans=coef(1)*N
1114      do i=2,N
1115          ans=ans*x+coef(i)*(N-
1116      end do
1117      derivpolevl=ans
1118
1119      end function derivpolevl
1120
1121
1122      function kappa_HH_21cm(T,
1123      !Polynomial fit to Hydrog
1124      !if deriv return d log ka
1125      real(dl), intent(in) :: T
1126      logical, intent(in) :: de
1127      !           real(dl), dimens
1128          (/ 0.00120402_d
1129      integer, parameter :: n_t
1130      integer, dimension(n_table
1131          (/ 1, 2, 4, 6, 8, 10, 15
1132      real, dimension(n_table),
1133          (/ 1.38e-13, 1.43e-13
1134              3.67e-11, 5.38e-11, 6.8
1135              1.02e-10, 1.11e-10, 1.1
1136              4.97e-10, 6.03e-10, 6.8
1137
1138      real(dl) kappa_HH_21cm, 1
1139      real(dl), save, dimension
1140      integer xlo, xhi
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1141

```
1141      real(dl) :: a0, b0,  
1142  
1143      if (.not. allocated(  
1144  
1145          allocate(logRate  
1146          logRates = log(r  
1147          logTemps = log(r  
1148          call spline(logT  
1149      end if  
1150  
1151      if (T<=Temps(1)) then  
1152          if (deriv) then  
1153              kappa_HH_21cm =  
1154          else  
1155              kappa_HH_21cm =  
1156          end if  
1157          return  
1158      elseif (T >=Temps(n_  
1159          if (deriv) then  
1160              kappa_HH_21cm =  
1161          else  
1162              kappa_HH_21cm =  
1163          end if  
1164          return  
1165      end if  
1166  
1167      logT = log(T)  
1168      xlo=0  
1169      do xhi=2, n_table  
1170          if (logT < logTemps(x
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1141

```
1141      real(dl) :: a0, b0, ho  
1142  
1143      if (.not. allocated(logRa  
1144  
1145      allocate(logRates(n_t  
1146      logRates = log(real(r  
1147      logTemps = log(real(T  
1148      call spline(logTemps,  
1149  end if  
1150  
1151  if (T<=Temps(1)) then  
1152      if (deriv) then  
1153          kappa_HH_21cm = 0  
1154      else  
1155          kappa_HH_21cm = r  
1156      end if  
1157      return  
1158  elseif (T >=Temps(n_table  
1159      if (deriv) then  
1160          kappa_HH_21cm = 0  
1161      else  
1162          kappa_HH_21cm = r  
1163      end if  
1164      return  
1165  end if  
1166  
1167  logT = log(T)  
1168  xlo=0  
1169  do xhi=2, n_table  
1170      if (logT < logTemps(x
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1171

```
1171          xlo = xhi-1
1172          exit
1173      end if
1174  end do
1175  xhi = xlo+1

1177  ho=logTemps(xhi)-log
1178  a0=(logTemps(xhi)-lo
1179  b0=1-a0

1181  if (deriv) then
1182    kappa_HH_21cm = (1
1183      ( ddlogRates(xh
1184      kappa_HH_21cm = de
1185  else
1186    logRate = a0*logRat
1187    kappa_HH_21cm = exp
1188    kappa_HH_21cm = ex

1190  end if

1192 end function kappa_HH

1195 function kappa_eH_21c
1196 !Polynomial fit to el
1197 !if deriv return d lo
1198 ! from astro-ph/06080
1199 !     1 2.39e-10
1200 !     2 3.37e-10
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1171

```
1171          xlo = xhi-1
1172          exit
1173      end if
1174  end do
1175  xhi = xlo+1

1177  ho=logTemps(xhi)-logTemps
1178  a0=(logTemps(xhi)-logT)/h
1179  b0=1-a0

1181  if (deriv) then
1182    kappa_HH_21cm = (log
1183      ( ddlogRates(xhi)
1184      !
1185  else
1186    logRate = a0*logRates
1187    kappa_HH_21cm = exp(1
1188      !
1189
1190  end if

1192 end function kappa_HH_21c

1195 function kappa_eH_21cm(T,
1196 !Polynomial fit to electr
1197 !if deriv return d log ka
1198 ! from astro-ph/0608032
1199 !     1 2.39e-10
1200 !     2 3.37e-10
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1201

```
1201      !      5 5.3e-10
1202      !      10 7.46e-10
1203      !      20 1.05e-9
1204      !      50 1.63e-9
1205      !      100 2.26e-9
1206      !      200 3.11e-9
1207      !      500 4.59e-9
1208      !      1000 5.92e-9
1209      !      2000 7.15e-9
1210      !      5000 8.17e-9
1211      !      10000 8.37e-9
1212      !      15000 8.29e-9
1213      !      20000 8.11e-9
1214      real(dl), intent(in)
1215      logical, intent(in)
1216      real(dl), dimension(
1217          (/5.86236d-005, -0
1218
1219      real(dl) kappa_eH_21
1220
1221      logT = log(T)
1222      if (deriv) then
1223          kappa_eH_21cm = deriv
1224      else
1225          kappa_eH_21cm = exp(p)
1226      end if
1227
1228      end function kappa_eH
1229
1230
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1201

```
1201      !      5 5.3e-10
1202      !      10 7.46e-10
1203      !      20 1.05e-9
1204      !      50 1.63e-9
1205      !      100 2.26e-9
1206      !      200 3.11e-9
1207      !      500 4.59e-9
1208      !      1000 5.92e-9
1209      !      2000 7.15e-9
1210      !      5000 8.17e-9
1211      !      10000 8.37e-9
1212      !      15000 8.29e-9
1213      !      20000 8.11e-9
1214      real(dl), intent(in) :: T
1215      logical, intent(in) :: deriv
1216      real(dl), dimension(6), p
1217          (/5.86236d-005, -0.0
1218
1219      real(dl) kappa_eH_21cm, 1
1220
1221      logT = log(T)
1222      if (deriv) then
1223          kappa_eH_21cm = deriv
1224      else
1225          kappa_eH_21cm = exp(p)
1226      end if
1227
1228      end function kappa_eH_21cm
1229
1230
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1231

```
1231  
1232  
1233     function kappa_pH_21c  
1234     !Not actually used  
1235     !Polynomial fit to pr  
1236     !if deriv return d lo  
1237     real(dl), intent(in)  
1238     logical, intent(in)  
1239     integer, parameter ::  
1240     integer, dimension(n  
1241     (/ 1, 2, 5, 10, 20, 5  
1242     real, dimension(n_ta  
1243     (/ 0.4028, 0.4517, 0  
1244     1.301, 1.48, 1.6  
1245  
1246     real(dl) kappa_pH_21  
1247     real(dl), save, dime  
1248     integer xlo, xhi  
1249     real(dl) :: a0, b0,  
1250     real(dl):: factor =  
1251  
1252     if (.not. allocated(  
1253  
1254         allocate(logRate  
1255         logRates = log(r  
1256         logTemps = log(r  
1257         call spline(logT  
1258     end if  
1259  
1260     if (T<=Temps(1)) the
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1231

```
1231  
1232  
1233     function kappa_pH_21cm(T,  
1234     !Not actually used  
1235     !Polynomial fit to proton  
1236     !if deriv return d log ka  
1237     real(dl), intent(in) :: T  
1238     logical, intent(in) :: de  
1239     integer, parameter :: n_t  
1240     integer, dimension(n_tabl  
1241     (/ 1, 2, 5, 10, 20, 50,  
1242     real, dimension(n_table),  
1243     (/ 0.4028, 0.4517, 0.4  
1244     1.301, 1.48, 1.695, 1.9  
1245  
1246     real(dl) kappa_pH_21cm, 1  
1247     real(dl), save, dimension  
1248     integer xlo, xhi  
1249     real(dl) :: a0, b0, ho  
1250     real(dl):: factor = 0.01*  
1251  
1252     if (.not. allocated(logRa  
1253  
1254         allocate(logRates(n_t  
1255         logRates = log(real(r  
1256         logTemps = log(real(T  
1257         call spline(logTemps,  
1258     end if  
1259  
1260     if (T<=Temps(1)) then
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1261

```
1261      if (deriv) then  
1262          kappa_pH_21cm =  
1263      else  
1264          kappa_pH_21cm =  
1265      end if  
1266      return  
1267  elseif (T >=Temps(n_  
1268      if (deriv) then  
1269          kappa_pH_21cm =  
1270      else  
1271          kappa_pH_21cm =  
1272      end if  
1273      return  
1274  end if  
1275  
1276      logT = log(T)  
1277      xlo=0  
1278      do xhi=2, n_table  
1279          if (logT < logTemps  
1280              xlo = xhi-1  
1281              exit  
1282          end if  
1283      end do  
1284      xhi = xlo+1  
1285  
1286      ho=logTemps(xhi)-log  
1287      a0=(logTemps(xhi)-lo  
1288      b0=1-a0  
1289  
1290      if (deriv) then
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1261

```
1261      if (deriv) then  
1262          kappa_pH_21cm = 0  
1263      else  
1264          kappa_pH_21cm = r  
1265      end if  
1266      return  
1267  elseif (T >=Temps(n_table  
1268      if (deriv) then  
1269          kappa_pH_21cm = 0  
1270      else  
1271          kappa_pH_21cm = r  
1272      end if  
1273      return  
1274  end if  
1275  
1276      logT = log(T)  
1277      xlo=0  
1278      do xhi=2, n_table  
1279          if (logT < logTemps(x  
1280              xlo = xhi-1  
1281              exit  
1282          end if  
1283      end do  
1284      xhi = xlo+1  
1285  
1286      ho=logTemps(xhi)-logTemps  
1287      a0=(logTemps(xhi)-logT)/h  
1288      b0=1-a0  
1289  
1290      if (deriv) then
```

/Users/lp1lopa/Compare/camb_simdata/recfast.f90, Top line: 1291

```
1291      kappa_pH_21cm = (1  
1292          ( ddlogRates(xhi)*  
1293      else  
1294          logRate = a0*logRat  
1295          kappa_pH_21cm = exp  
1296      end if  
1297  
1298      end function kappa_pH  
1299  
1300  
1301      end module Recombinat  
1302  
1303
```

/Users/lp1lopa/Compare/camb_des/recfast.f90, Top line: 1291

```
1291      kappa_pH_21cm = (log  
1292          ( ddlogRates(xhi)  
1293      else  
1294          logRate = a0*logRates  
1295          kappa_pH_21cm = exp(1  
1296      end if  
1297  
1298      end function kappa_pH_21c  
1299  
1300  
1301      end module Recombination  
1302  
1303
```