AHEAD-2020 WP14

Tasks 14.6 & 14.8

- Blind-Line-Search and ID (14.6)
- Time-Evolving Photoionization (14.8)

F. Nicastro, A. Luminari, E. Piconcelli, L. Zppacosta

Blind Line Search Routine

- Fortran-90 Routine working in either HEASOFT or CIAO environments
- Extremely fast on 30,000 channel spectra (e.g. Athena-XIFU)
- Reads in:
  - RMF/RSP (FITS format)
  - Continuum-Normalized data in sigma (QDP|ASCII: e.g. from XSPEC or Sherpa)
  - Output Filenames prefix
  - (line statistical significance threshold in sigma + verbosity: default σ=4, v=0)
- Extracts LSF, computes LSF FWHM (i.e. spectral resolution)
- Scans the data searching for positive/negative unresolved, quasi-symmetric, line-like features, with integrated significance exceeding the threshold
- Reads in atomic-database (currently Verner et al., 2006) and looks for possible line-IDs (WiP)
- Writes out:
  - File containing list of 'detected' lines' energy, peak-significance, integrated-significance
  - File containing possible redshift IDs (WiP)

```
nicastro@Falcao.local% bls_v2 athena_xifu_1469_onaxis_pitch249um_v20160401.rsp LSF-convolved_Delchi_28_1.5e7.dat 4 0

 Response Filename: athena_xifu_1469_onaxis_pitch249um_v20160401.rsp
 Continuum-Normalized Filename: LSF-convolved_Delchi_28_1.5e7.dat
 Output Filename: 4
 Line Threshold Significance: 0
 Using default Verbosity: 0


  Number of Absorption Lines:           18
  Number of Emission Lines:            2
```

BLS Example: “Observation”

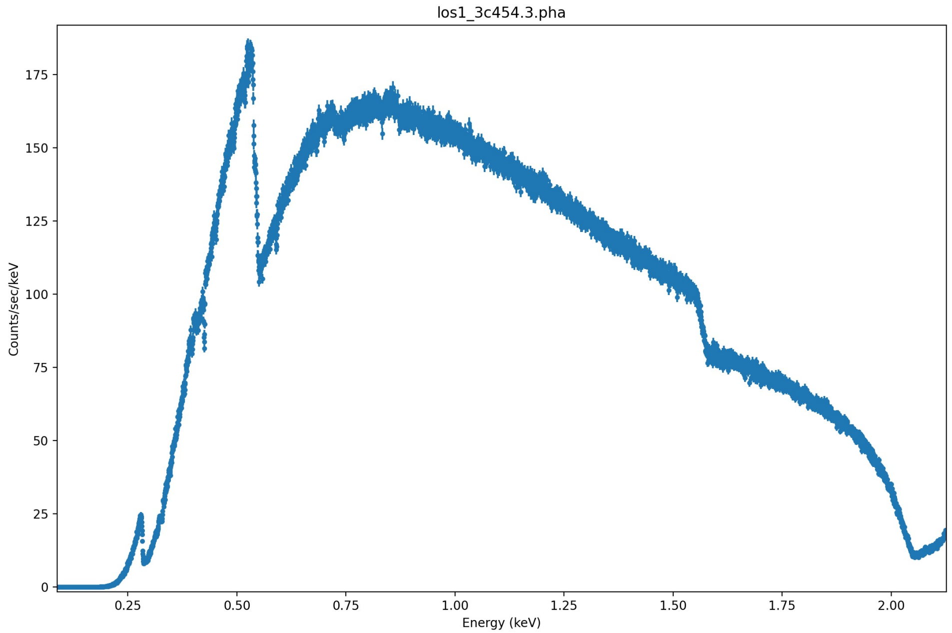
Line of Sight Extracted from Cen & Ostriker (2006) Hydro-Dynamical Simulations

Column Density | Redshift | Metallicity

```
nicastro@Falcao.local% more los_28_WoZ_WHIM.out
 No. of Filament, Last row of the Group in Original File; No of rows in Group; T(in K); NH(in cm-2);  Turbolence (in km/s); Redshift; log(U); Density (at t
he given z); Metallicity (compared to Solar)
```

1	3847	1	1379361.25	3.36197258E+18	261.441772	0.109475948	-1.93419802	1.08900003E-05	9.50078666E-02
2	4908	1	729345.250	3.23784322E+18	190.108902	0.140729979	-1.91785955	1.04900000E-05	0.201572582
3	4915	3	688116.562	3.43952801E+18	184.602371	0.140762627	-1.94454646	1.11622676E-05	0.506648600
4	4919	2	907217.188	3.20123498E+18	212.001709	0.140754178	-1.92046666	1.05629624E-05	0.220032334
5	9167	3	206526.281	3.33116976E+18	101.091904	0.273898929	-1.94133806	1.10789997E-05	1.66198611E-02
6	13305	6	214686.875	1.11909778E+19	103.111465	0.416768640	-2.30846786	3.37445308E-05	2.01087464E-02
7	13919	25	5417012.50	1.18929300E+20	515.280945	0.436983317	-2.99046493	7.81381386E-04	0.115085848
8	15462	1	115829.562	1.46608968E+19	75.7609711	0.495346159	-2.57376432	4.75099987E-05	1.01446602E-02
9	17371	7	451797.094	5.50937954E+18	149.567551	0.569676399	-2.06023479	1.45867716E-05	0.191525415
10	17940	4	143990.109	4.48879305E+18	84.4650497	0.590543449	-2.10365844	1.60944182E-05	1.46267880E-02
11	18372	4	398528.188	4.00824627E+18	140.527100	0.608431876	-2.02583265	1.34562370E-05	2.12974884E-02
12	18414	6	286541.844	1.97825693E+19	119.021568	0.609701395	-1.99990737	1.45019585E-05	0.195985019
13	18419	4	371265.344	1.66751582E+19	135.493530	0.610535920	-2.91440797	1.06934771E-04	0.309740871
14	19595	3	1126450.88	3.17020483E+18	236.260986	0.659921110	-1.91196179	1.03496823E-05	0.154758915
15	21110	5	148218.734	3.50232332E+18	85.6894989	0.724813461	-1.91181695	1.03493585E-05	7.48509616E-02

Athena-XIFU 100 ks mock spectrum of 3C454.3 (z=0.859)
@1 mCrab



BLS Example: output

Detected Line-list

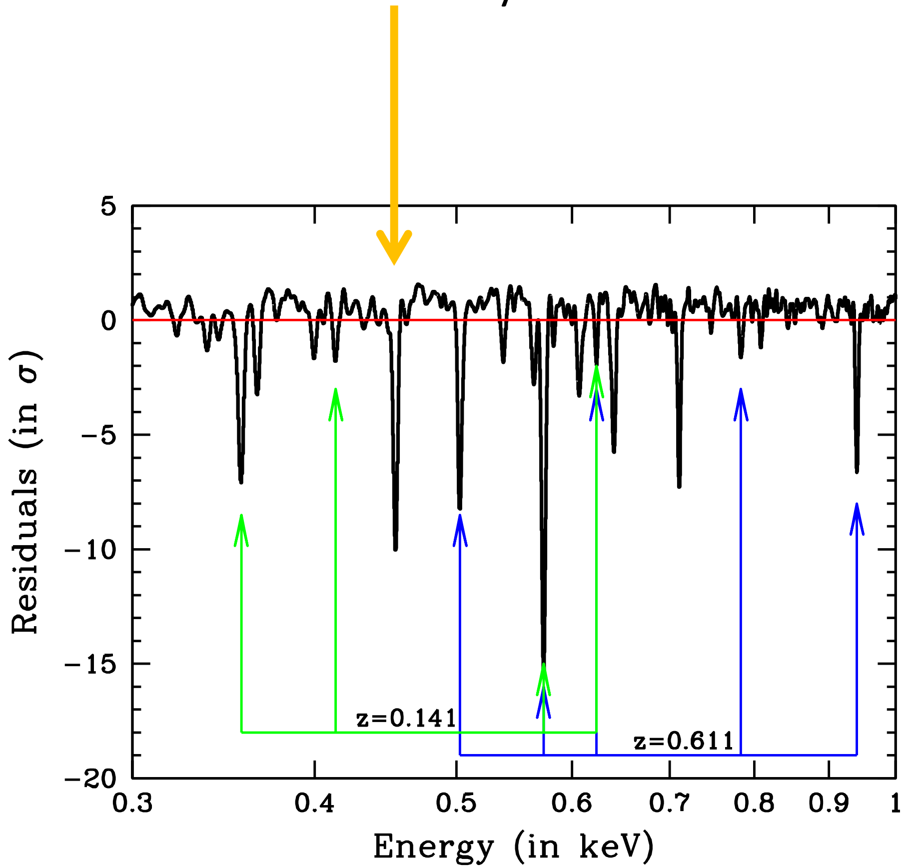
```
# Number of Absorption Lines:          17
# Number of Emission Lines:          2
# E (keV), Sigma-Peak, Sigma, Sigma-Threshold
# Negative Lines:
 0.267800003      1.59371269      4.03757238      4.00000000
 0.356200010      7.09524679      17.2754307      4.00000000
 0.413399994      1.77576268      4.03026819      4.00000000
 0.454200000      10.0198488      24.6709194      4.00000000
 0.503000021      8.24497032      20.4788818      4.00000000
 0.564999998      2.81150985      7.20422220      4.00000000
 0.573800027      15.4453526      39.6384010      4.00000000
 0.606999993      3.29755354      8.53451443      4.00000000
 0.623799980      1.95347917      4.41314697      4.00000000
 0.640600026      5.42002916      7.90693521      4.00000000
 0.641399980      5.75636578      14.7684107      4.00000000
 0.710600019      7.27873373      18.1650715      4.00000000
 0.711399972      6.76571894      9.38497066      4.00000000
 0.783399999      1.63223302      4.25715160      4.00000000
 0.940599978      6.63401318      17.7794666      4.00000000
  1.29740000     5.49634790     15.2450886     4.00000000
  1.71099997     1.81207728     4.86538553     4.00000000
# Positive Lines:
 0.470999986      1.57258713      4.53434849      4.00000000
 0.685000002      1.54889691      4.23500299      4.00000000
```

Tentative Redshift IDs

```
Possible Redshift: z =   0.611312509
=====================
1: Eobs =   0.356200010   ; E0 =   0.573949516   ; Ion: O7
      2 : Eobs =   0.413399994   ; E0 =   0.666116595   ; Ion: O7
      3 : Eobs =   0.573800027   ; E0 =   0.924571157   ; Ion: Ne9
      4 : Eobs =   0.623799980   ; E0 =    1.00513673   ; Ion: Fe21

Possible Redshift: z =   0.388363600
=====================
1: Eobs =   0.413399994   ; E0 =   0.573949516   ; Ion: O7
      2 : Eobs =   0.503000021   ; E0 =   0.698346913   ; Ion: O7
      3 : Eobs =   0.623799980   ; E0 =   0.866061211   ; Ion: Fe18
      5 : Eobs =   0.640600026   ; E0 =   0.889385760   ; Ion: Fe18
      6 : Eobs =   0.641399980   ; E0 =   0.890496373   ; Ion: Fe18
-----------------------------------------------------------------------------

Possible Redshift: z =   0.263649344
=====================
1: Eobs =   0.454200000   ; E0 =   0.573949516   ; Ion: O7
      2 : Eobs =   0.564999998   ; E0 =   0.713961899   ; Ion: O7
      3 : Eobs =   0.710600019   ; E0 =   0.897949219   ; Ion: Fe17
      4 : Eobs =   0.711399972   ; E0 =   0.898960114   ; Ion: Fe17
-----------------------------------------------------------------------------

Possible Redshift: z =   0.141052723
=====================
1: Eobs =   0.503000021   ; E0 =   0.573949516   ; Ion: O7
      2 : Eobs =   0.573800027   ; E0 =   0.654736102   ; Ion: O8
      4 : Eobs =   0.623799980   ; E0 =   0.711788654   ; Ion: O7
      5 : Eobs =   0.783399999   ; E0 =   0.893900692   ; Ion: Fe17
      6 : Eobs =   0.940599978   ; E0 =    1.07327414   ; Ion: Ne9
-----------------------------------------------------------------------------

Possible Redshift: z =    1.58398151E-02
=====================
1: Eobs =   0.564999998   ; E0 =   0.573949516   ; Ion: O7
      2 : Eobs =   0.640600026   ; E0 =   0.650747001   ; Ion: O8
      4 : Eobs =   0.641399980   ; E0 =   0.651559651   ; Ion: O8
      6 : Eobs =   0.710600019   ; E0 =   0.721855819   ; Ion: O7
      7 : Eobs =   0.711399972   ; E0 =   0.722668409   ; Ion: O7
-----------------------------------------------------------------------------

Possible Redshift: z =    2.60472298E-04
=====================
1: Eobs =   0.573800027   ; E0 =   0.573949516   ; Ion: O7
      2 : Eobs =   0.710600019   ; E0 =   0.710785091   ; Ion: O7
      3 : Eobs =   0.711399972   ; E0 =   0.711585283   ; Ion: O7
-----------------------------------------------------------------------------

Possible Redshift: z =   -5.44489026E-02
=====================
1: Eobs =   0.606999993   ; E0 =   0.573949516   ; Ion: O7
      2 : Eobs =   0.940599978   ; E0 =   0.889385343   ; Ion: Fe18
-----------------------------------------------------------------------------

Possible Redshift: z =   -7.99141526E-02
=====================
1: Eobs =   0.623799980   ; E0 =   0.573949516   ; Ion: O7
      2 : Eobs =   0.710600019   ; E0 =   0.653813004   ; Ion: O8
      4 : Eobs =   0.711399972   ; E0 =   0.654549062   ; Ion: O8
      6 : Eobs =   0.783399999   ; E0 =   0.720795274   ; Ion: O7
      7 : Eobs =   0.940599978   ; E0 =   0.865432739   ; Ion: Fe18
```

BLS Example: Line and Redshit IDs

Missed ID: OVIII Lyα z=0.437




```
Possible Redshift: z =   0.611312509
======================
1: Eobs =   0.356200010   ; E0 =   0.573949516   ; Ion: O7
       2 : Eobs =   0.413399994   ; E0 =   0.666116595   ; Ion: O7
       3 : Eobs =   0.573800027   ; E0 =   0.924571157   ; Ion: Ne9
       4 : Eobs =   0.623799980   ; E0 =   1.00513673   ; Ion: Fe21
```

```
Possible Redshift: z =   0.141052723
======================
1: Eobs =   0.503000021   ; E0 =   0.573949516   ; Ion: O7
       2 : Eobs =   0.573800027   ; E0 =   0.654736102   ; Ion: O8
       4 : Eobs =   0.623799980   ; E0 =   0.711788654   ; Ion: O7
       5 : Eobs =   0.783399999   ; E0 =   0.893900692   ; Ion: Fe17
       6 : Eobs =   0.940599978   ; E0 =   1.07327414   ; Ion: Ne9
```

BLS: To do (depending on funding, personnel, etc.)

- Update/Integrate (forbidden/intercombination, innershell resonant ground-state and metastable transitions) Atomic Database
- Improve Line/Redshift ID routine: needs to be smarter (AI training might help): e.g. starting from strongest and looking for right strength ratios (including saturation)
- Python interface to directly call BLS from within Sherpa|XSPEC
- GUI interface to locally iterate the procedure and plot results

14.8: Time-Evolving Photo-Ionization Device (TEPID: Luminari+22)

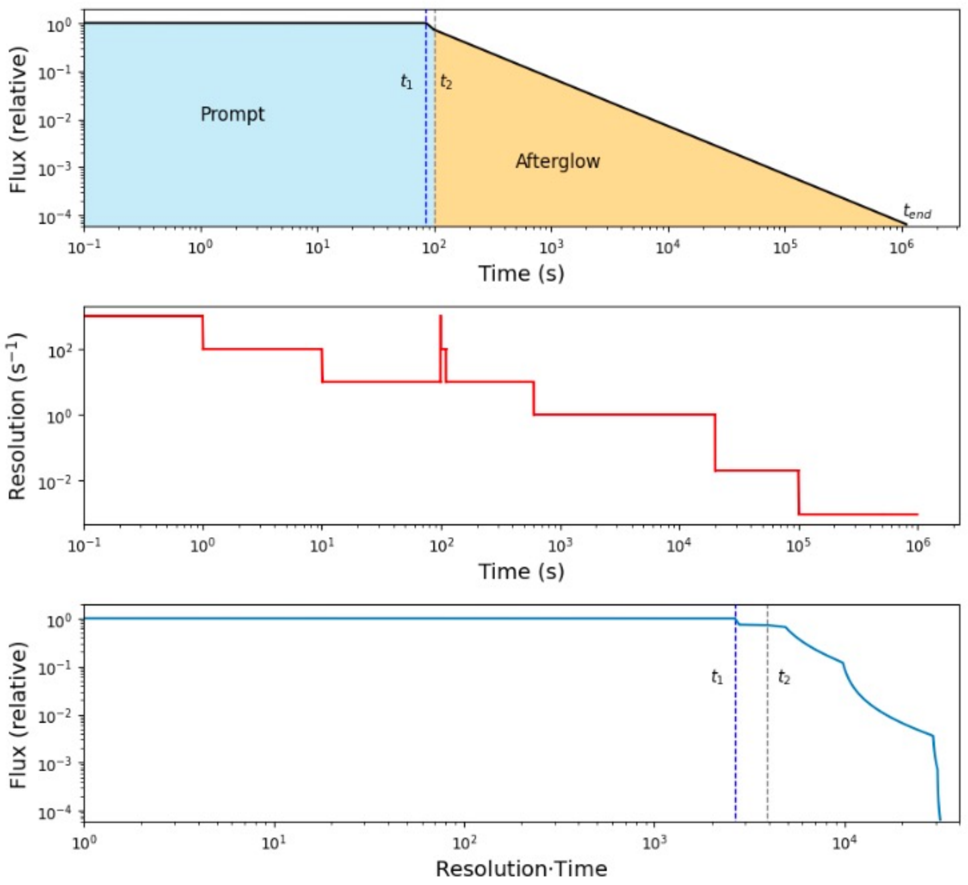
- Solves the system of 1st-order differential equations of time-evolving ionization balances following ionizing intensity variations with time
- Uses adaptive time-resolution algorithm to speed-up calculation
- Currently considers only photo-ionization and radiative recombinations and approximates on heating-cooling balance
- Includes radiative-transfer
- Applies to all variable ionizing sources: e.g. transients (GRBs) and AGNs
- Interfaces with Phase (Krongold+03), in XSPEC|Sherpa to produce mock spectra and fit data

$$\frac{dn_{X^i}}{dt} = -[F_{X^i} + \alpha_{\rm rec}(X^{i-1},\ T_e)n_e]n_{X^i} + F_{X^{i-1}}\,n_{X^{i-1}} + \alpha_{\rm rec}(X^i, T_e)n_e\,n_{X^{i+1}}\ . \quad (4)$$

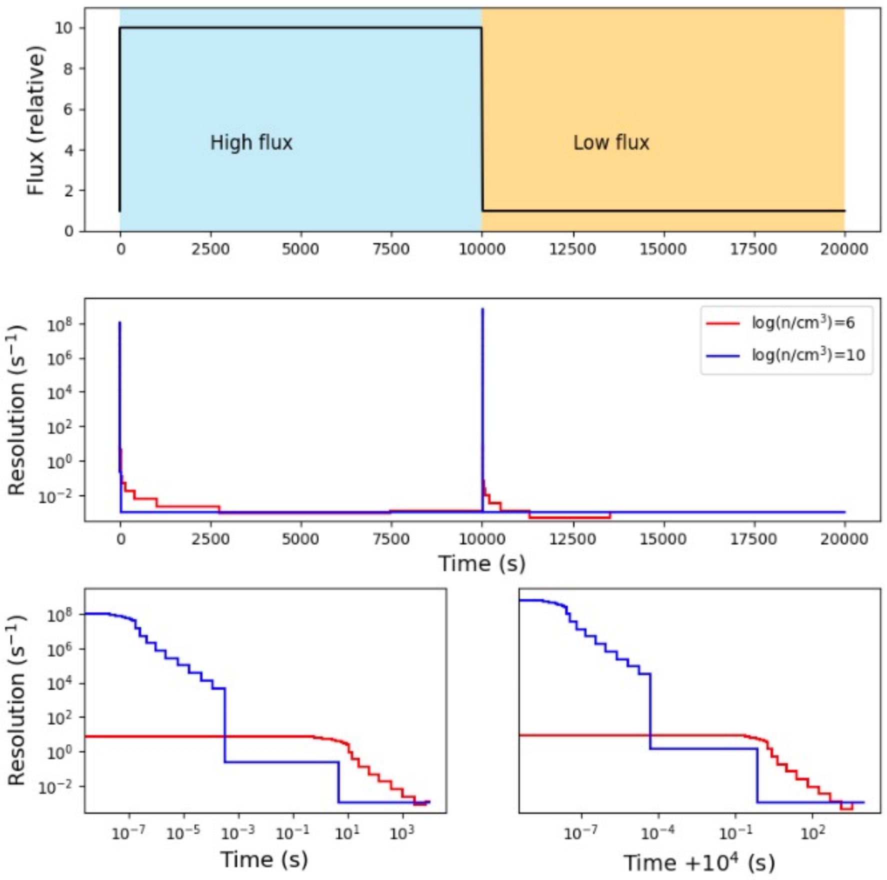
$$t_{eq} \approx \left\{(\alpha_{rr}(X^i, T_e)n_e)\cdot\left(\frac{\alpha_{rr}(X^{i-1}, T_e)}{\alpha_{rr}(X^i, T_e)} + \frac{n_{X^{i+1}}}{n_{X^i}}\right)\right\}^{-1}$$

TEPID: Adaptive-Resolution Algorithm

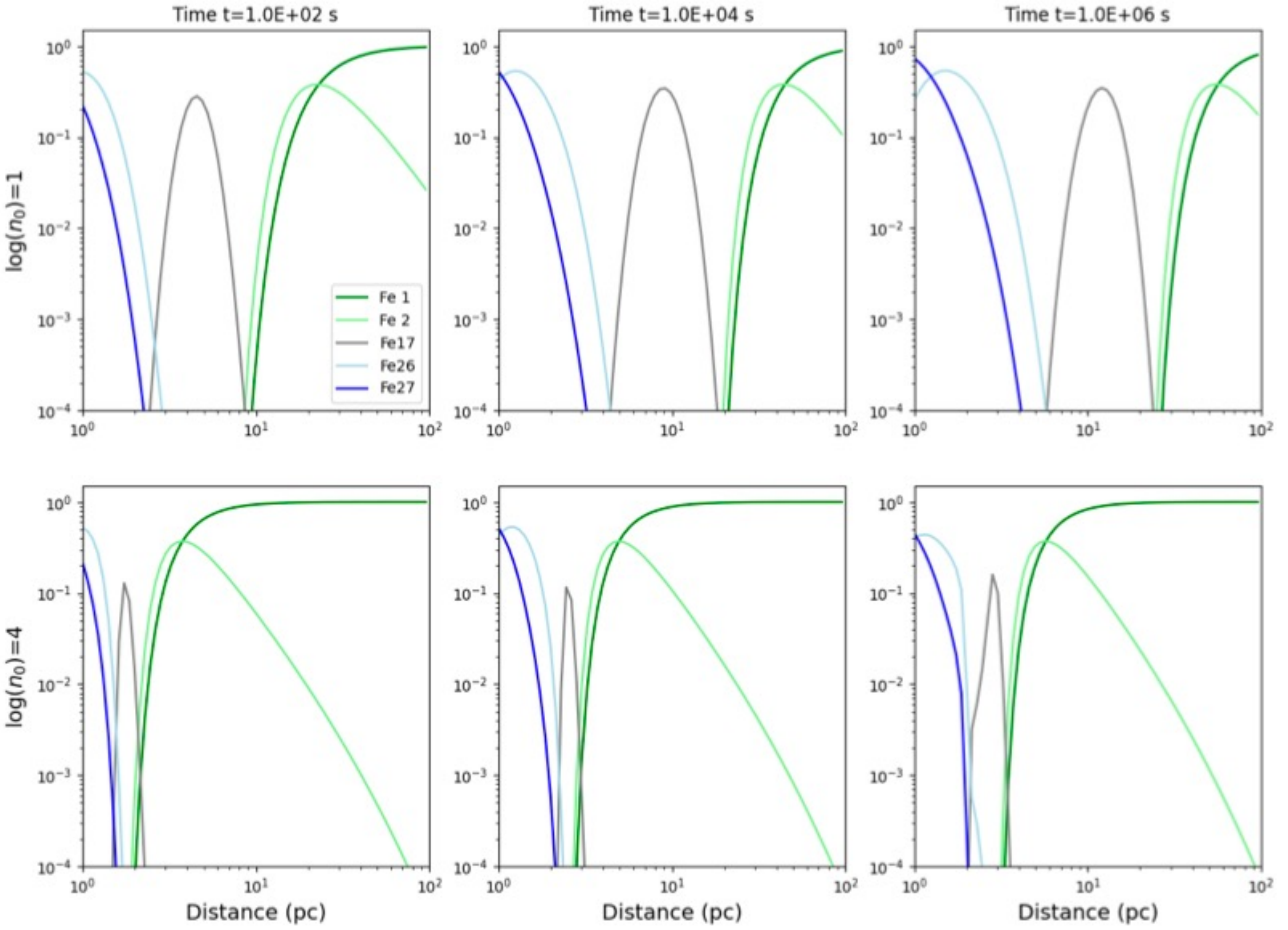
GRB case



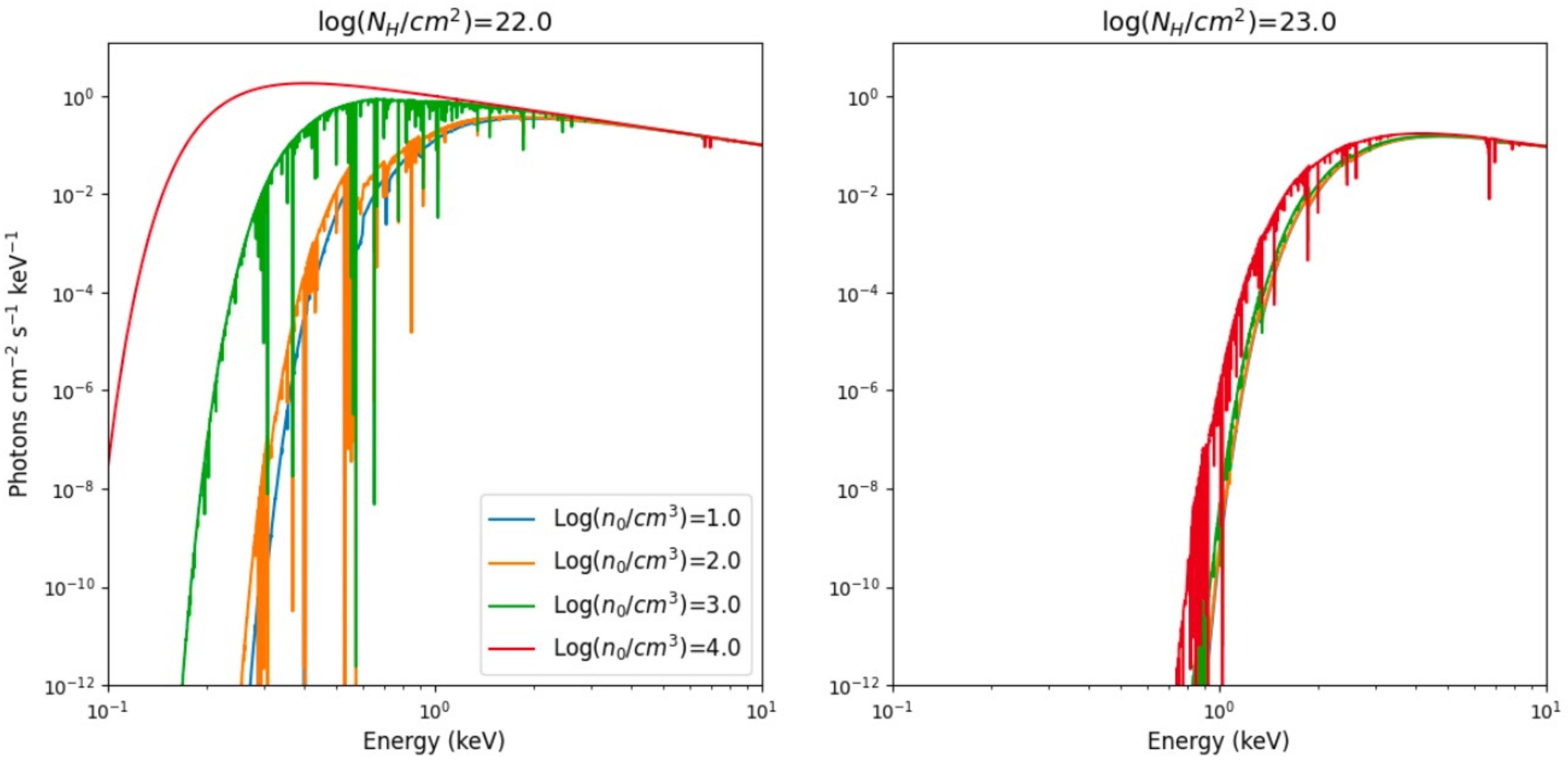
Up-and-Down case



TEPID: GRB-case: Stratified-Ionization



TEPID: GRB-case: Spectra vs Local Density



TEPID: AGN-case: Ionization Balance vs Time

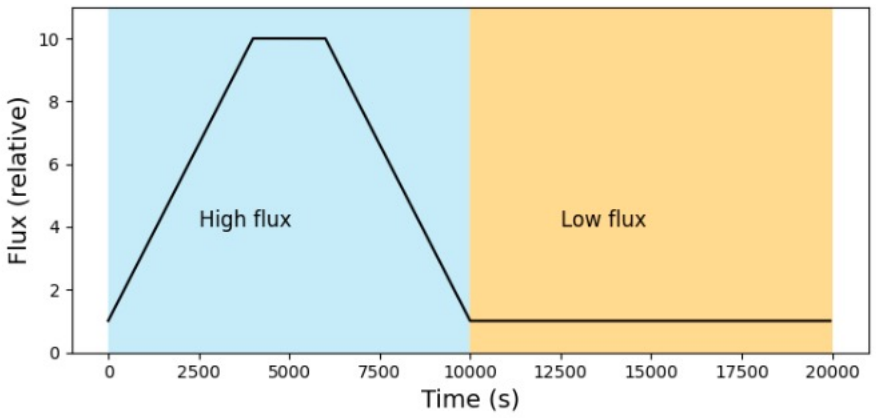
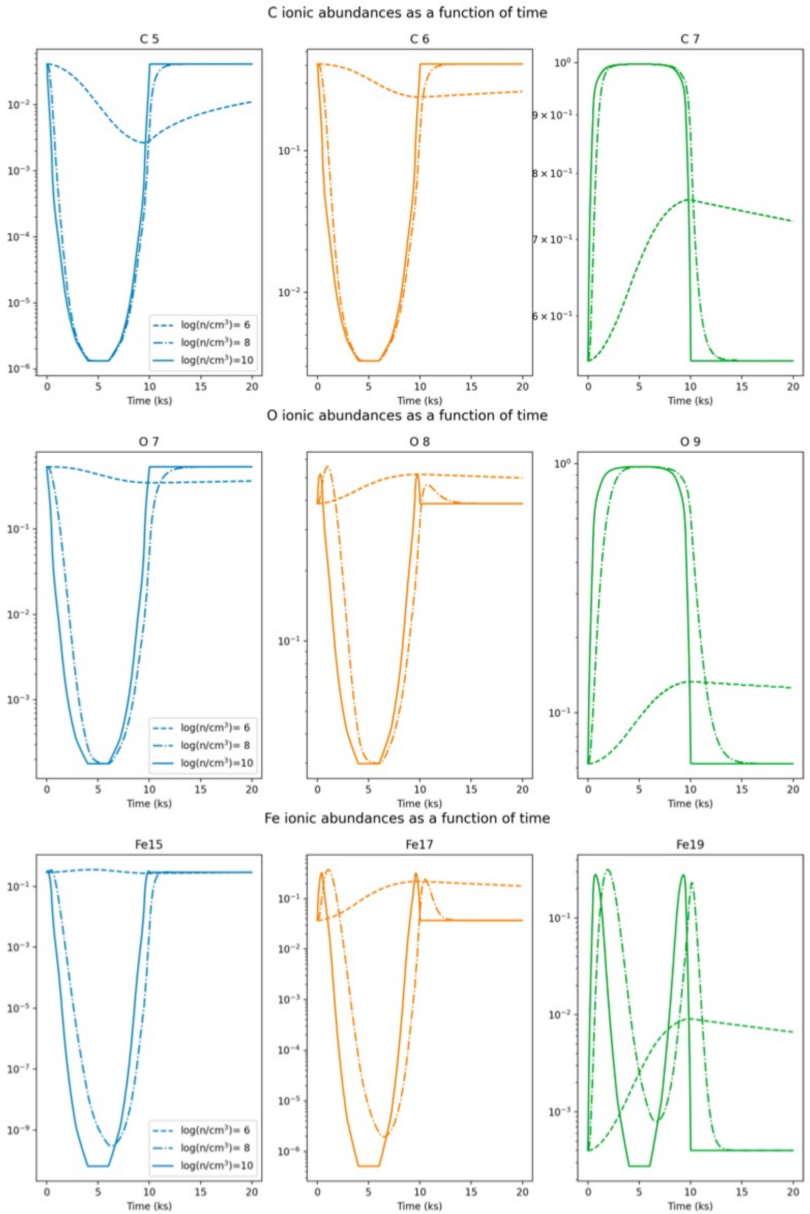
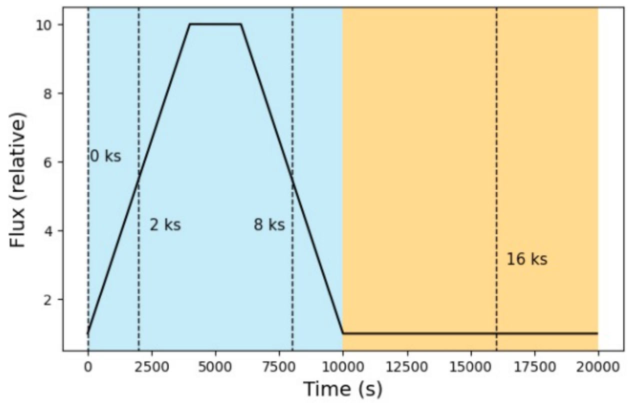
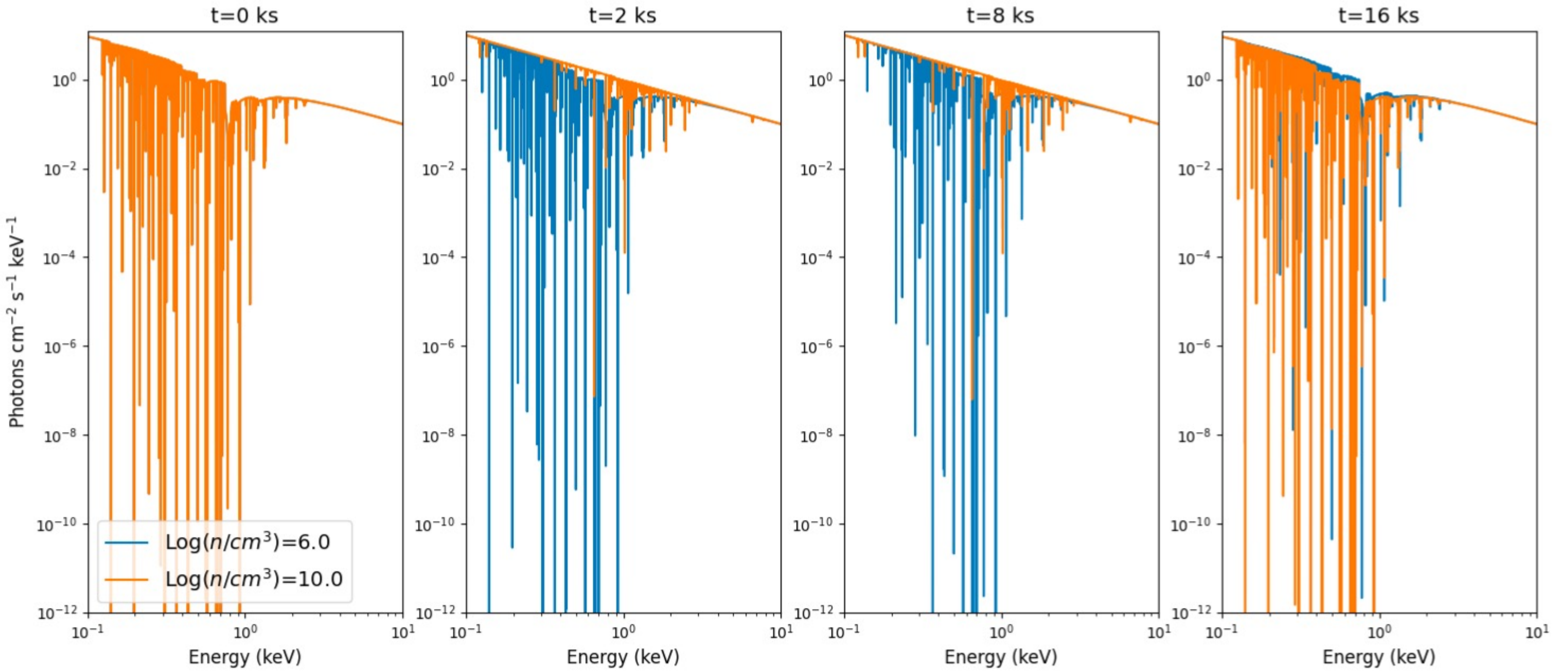


Fig. 9: AGN lightcurve



TEPID: AGN-case: Time-Resolved Spectra





TEPID: To do

- Include time-evolving population-level calculation and metastable transitions (to further constrain density)
- Include proper heating/cooling calculation
- Include additional ionization/recombination mechanisms (i.e. transition rates)
- Improve atomic-database
- Include proper pre-burst star-forming region ionization conditions based on simulations (Luminari, Graziani, in prep.)