Simulating IGM/CGM line absorption from cosmological simulations

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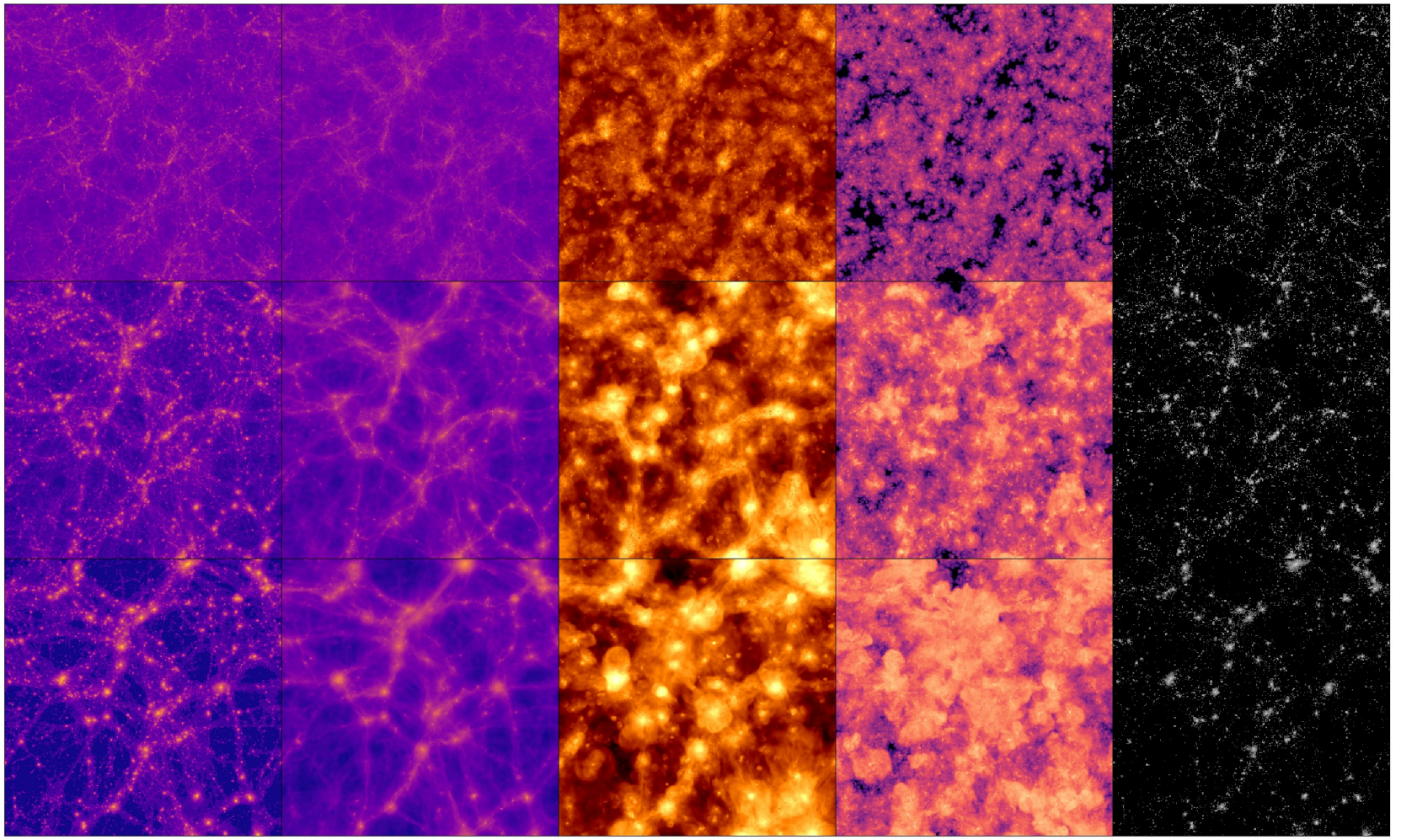
Simulations: examples

cosmological hydrodynamical simulations: (review: https://arxiv.org/pdf/1909.07976.pdf)

- **EAGLE**: gas mass resolution 1.81×10^6 $M_\odot$, volume 100^3 $cMpc^3$ (Ref-L100N1504)
  public data release: http://icc.dur.ac.uk/Eagle/database.php
  papers: Schaye et al. (2015, description), Crain et al. (2015, feedback calibration) McAlpine et al. (2016, galaxy and halo catalogues), The EAGLE Team (2017, full data release)
- **IllustrisTNG**: gas mass resolution 1.4×10^6 $M_\odot$, volume 110.7^3 $cMpc^3$ (TNG100-1)
  public data release: https://www.tng-project.org/data/
- **Magneticum**: gas mass resolution up to 7.3×10^6 $M_\odot$, volumes 18^3 – 2688^3 $(cMpc/h)^3$
  website: http://www.magneticum.org/index.html (some data available)
- **HorizonAGN**: resolution ~1 pkpc (maximum refinement), volume 100^3 $(cMpc/h)^3$
  website: https://www.horizon-simulation.org/data.html (some data available)
- **Mufasa**: gas mass resolution 1.82×10^7 $M_\odot$ (50^3 $(cMpc/h)^3$), volumes 12.5^3 – 50^3 $(cMpc/h)^3$
  presentation paper: https://ui.adsabs.harvard.edu/abs/2016MNRAS.462.3265D/abstract
- **Romulus25:** gas mass resolution 2.12×10^5 $M_\odot$, volume 25^3 $cMpc^3$,
  more information: https://mtremmel.github.io/research.html
- **MassiveBlack-II**: gas mass resolution ~ 10^6 $M_\odot$, volume 1003 cMpc3
  website: http://mbii.phys.cmu.edu, presentation paper: https://arxiv.org/pdf/1402.0888.pdf

EAGLE (25 cMpc)



Simulations: physics

- gravity, hydrodynamics
- radiative cooling
- star formation, stellar feedback
- black hole seeding, AGN feedback
- sometimes: magnetic fields, thermal conduction, dust, …

Things to look out for:

- ISM model: single-phase, pressure floor
- directly probing the feedback model (calibrated to galaxy statistics): e.g. temperature for stochastic heating

Specwizard: inputs

Simulation (SPH)
Snapshots with:
- redshift
- cosmological parameters
- simulated volume

Gas particles with:
- location
- peculiar velocity
- mass
- size
- temperature
- density
- abundances
- star formation rate

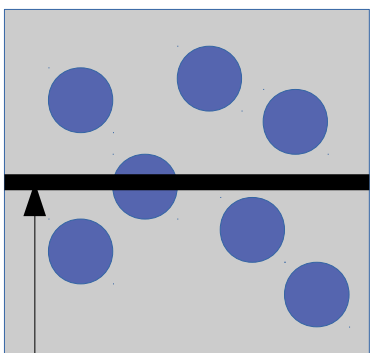
Ionization tables
ion fractions as a function of n(H), T, redshift
Assume:
- ionization equilibrium
- optically thin gas
- uniform, redshift-dependent UV/X-ray background (Haardt & Madau, 2001)
- Cloudy 7.02 model

Atomic data
wavelength and oscillator strength of each line of each ion
part of the specwizard code

Code and documentation:
https://github.com/nastasha-w/specwizard_versions
branch: nastasha
Paper: e.g. Tepper-Garcia et al. (2011, §3.1)

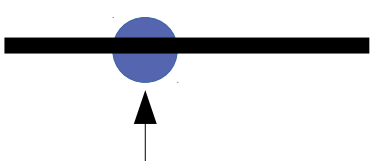
Specwizard: calculations

Simulated volume



Sightline (periodic)

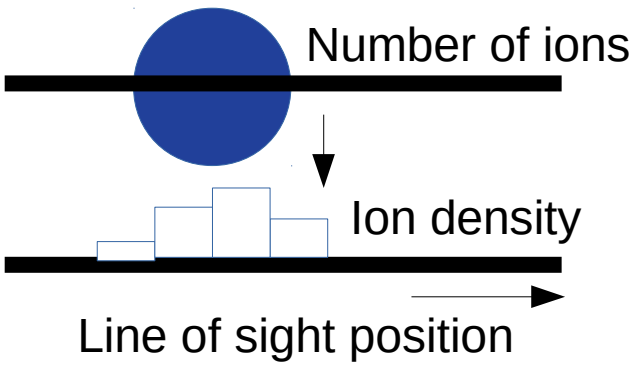
1. Select a sightline, and the particles that intersect it



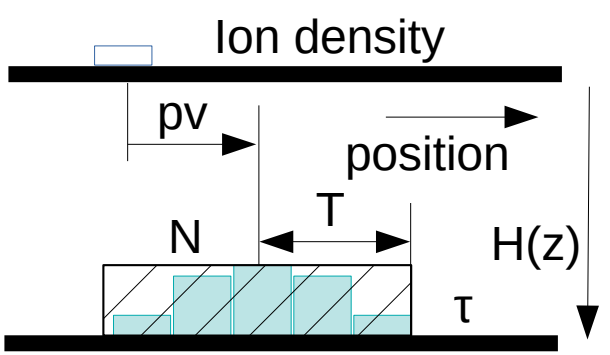
ρ, T, Z, Mass
+ z, ion tables

2. Calculate the number of ions in each particle along the sightline

3. calculate the ion density along the sightline

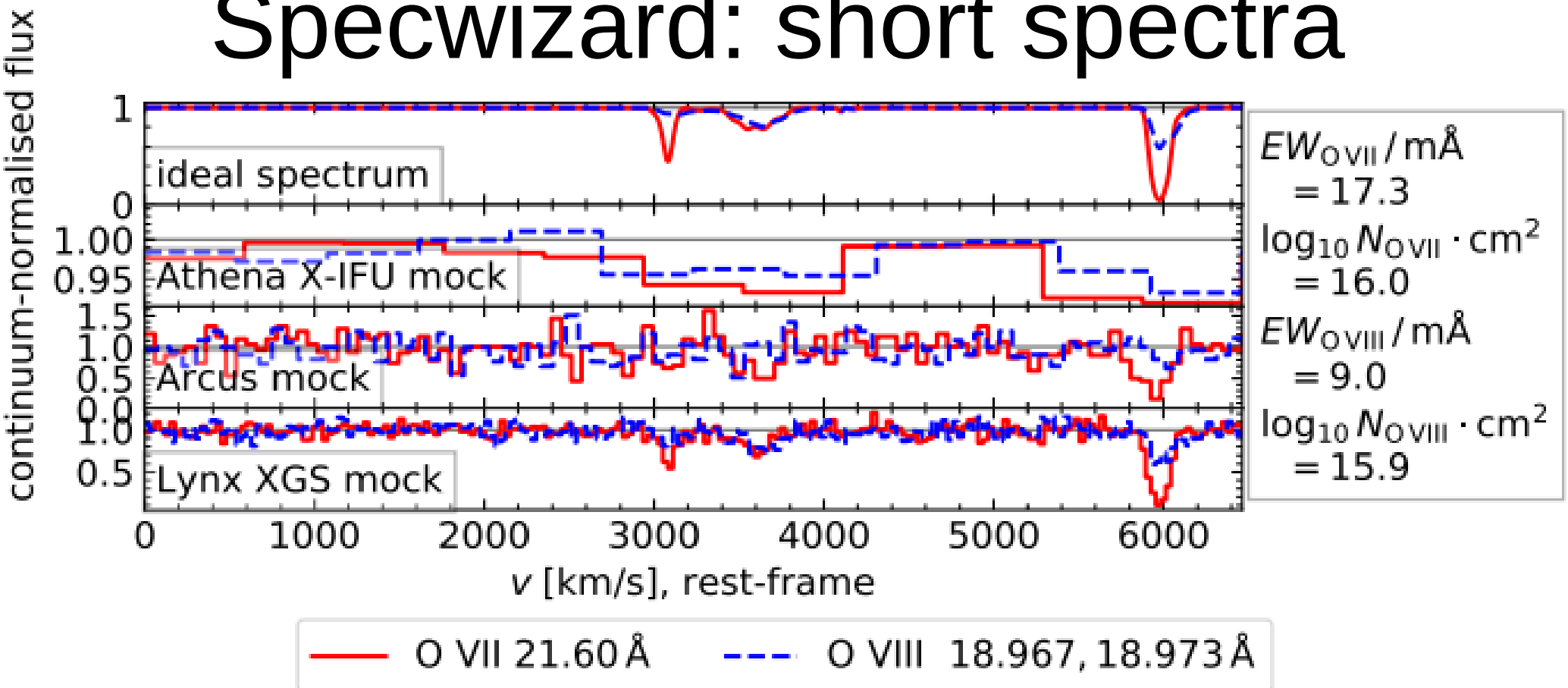


4. Calculate the optical depth in redshift space



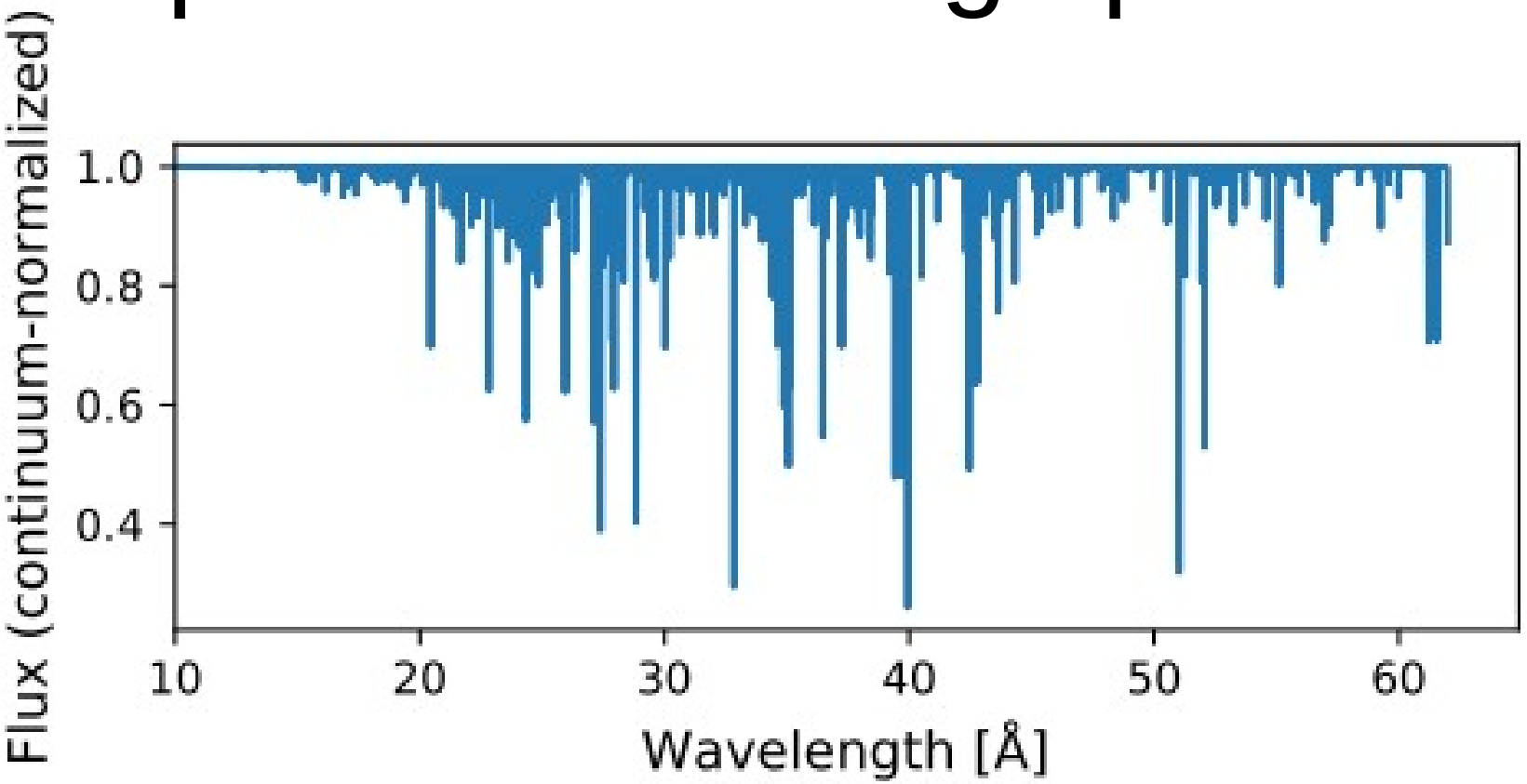
pv = peculiar velocity
N = ion density × cell size

Specwizard: short spectra



Using a 2-10 keV flux of 10^{-11} erg/cm^2/s, photon spectral index Γ=1.8, 100 ks exposure
Athena data: Barret *et al.* 2018, Lumb *et al.* 2017; Arcus data: Smith *et al.* 2016; Lynx data: The Lynx Team 2018
Figure from: Wijers et al. (2019) – https://arxiv.org/abs/1904.01057

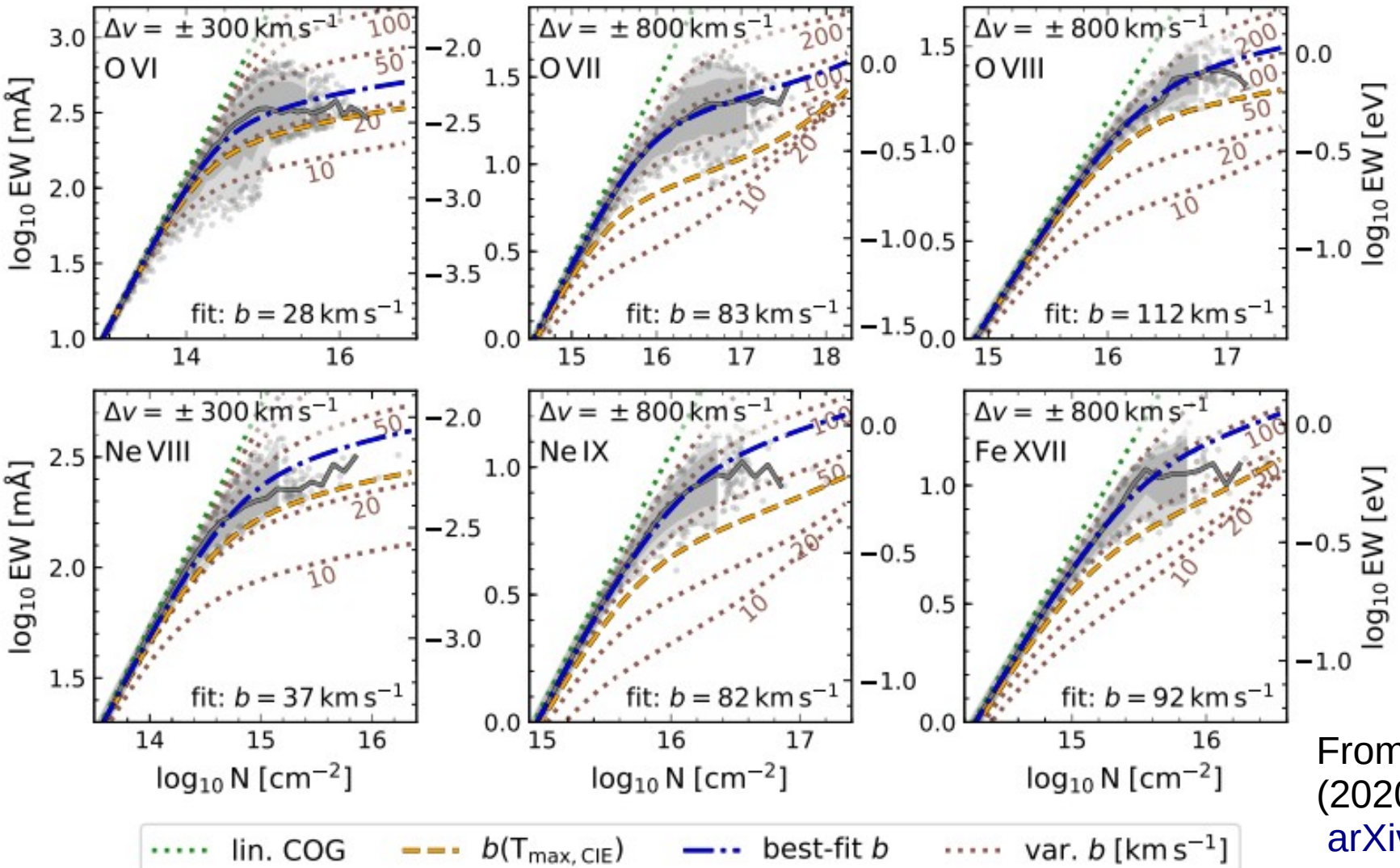
Specwizard: long spectra



Preliminary, using a number of transitions of C V, C VI, O VII, O VIII, Fe XVII, and Ne IX

Redshifts 0.0002 – 1.0, resolution: 0.5 km/s short spectrum, 0.3 mA long spectrum

Specwizard: curve of growth



From: Wijers et al. (2020, preprint): arXiv:2004.05171

Summary

- Cosmological, hydrodynamical simulations: provide lots of data on galaxies, CGM, IGrM, ICM (to some extent), IGM; beware of ‘artifacts’ and model limitations
- Eagle: cosmological, hydrodynamical simulation, data is publicly release
- Specwizard: package for virtual spectra from Eagle data, available on github, but no structured release so far