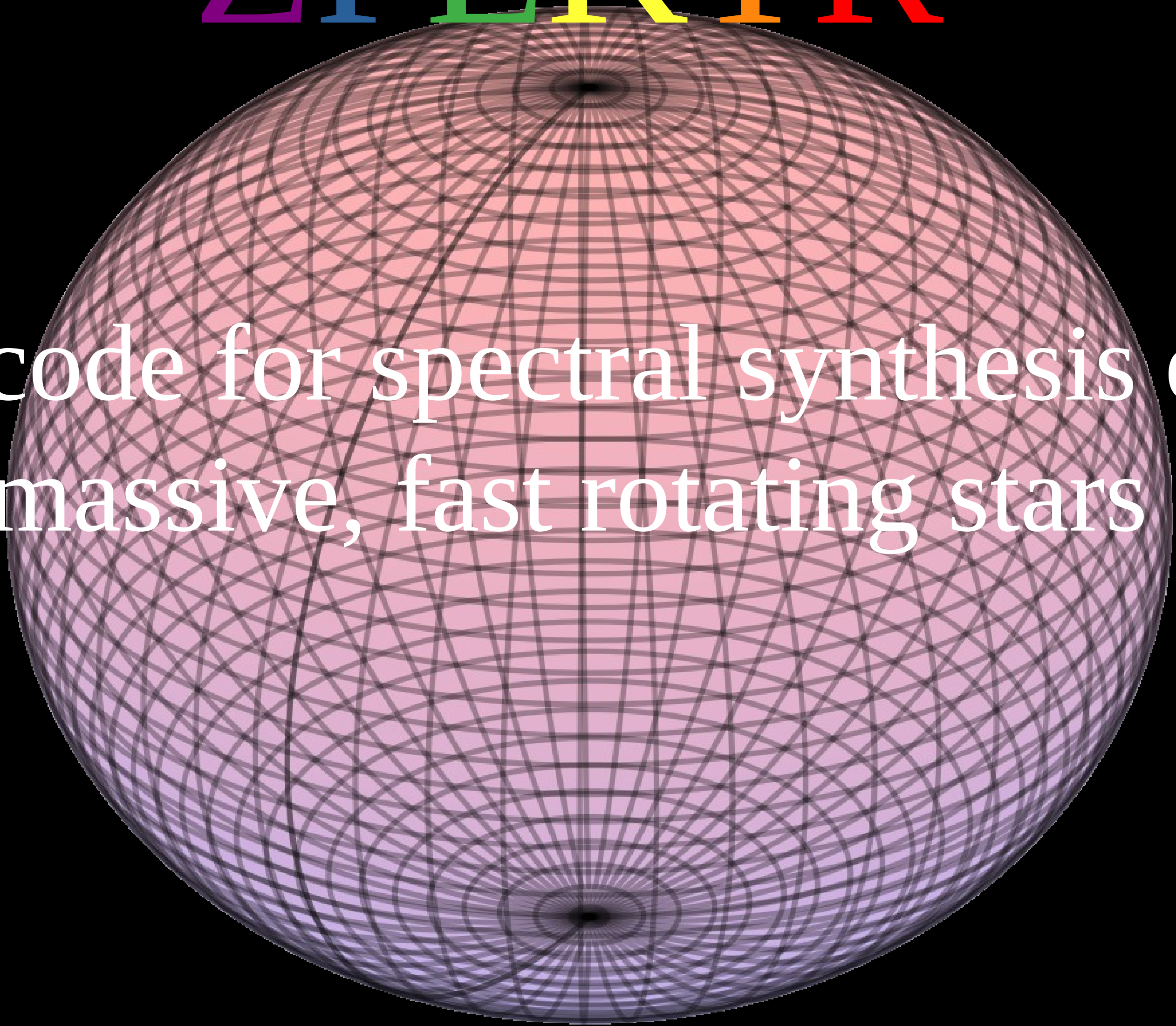
ZPEKTR



A code for spectral synthesis of massive, fast rotating stars

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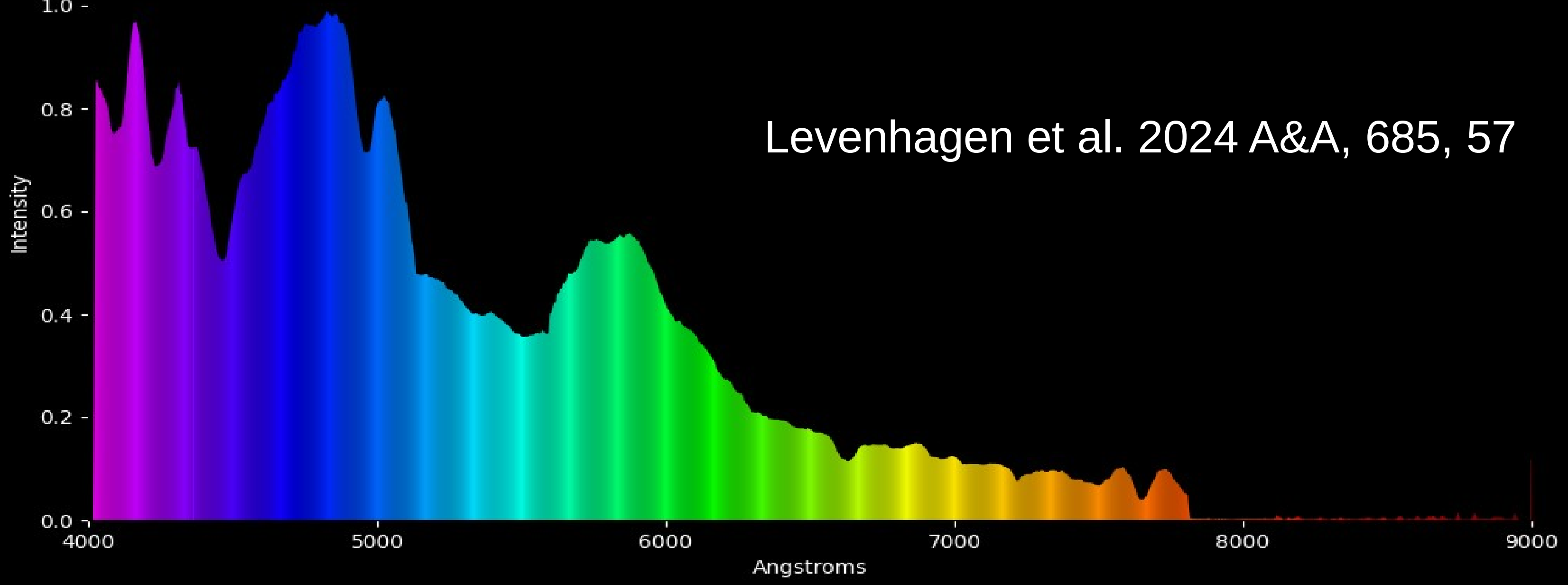
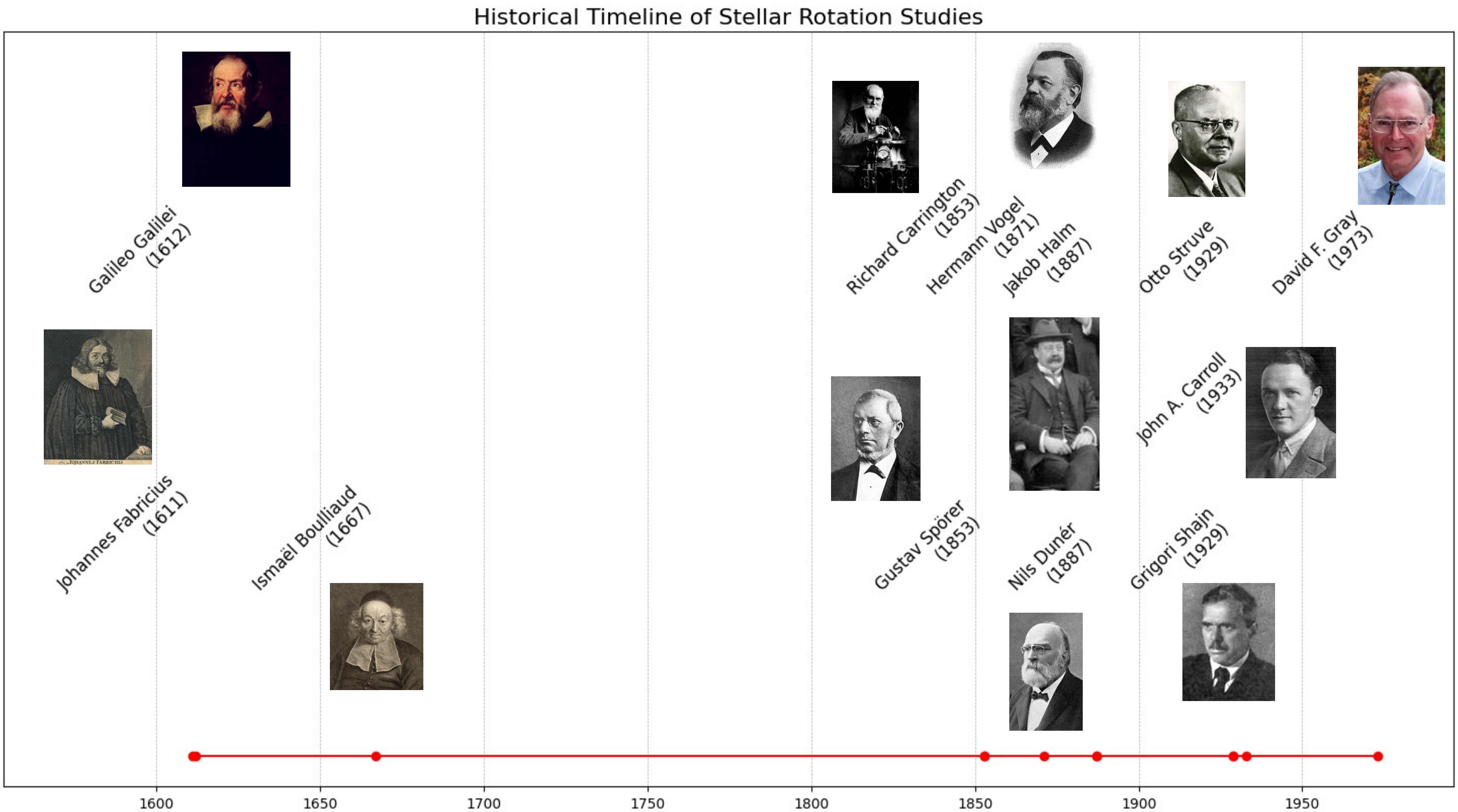
ZPEKTR - A code for spectral synthesis of massive, fast rotating stars

Ronaldo S. Levenhagen, Michel Curé, Catalina Arcos, Marcos P. Diaz, Ignacio Araya, Eduardo B. Amôres, Daniela Turis-Gallo, David Concha

Levenhagen et al. 2024 A&A, 685, 57



Short view of stellar rotation through time…



BUT…. what about the fast rotators?

Fast rotators are not spherical!

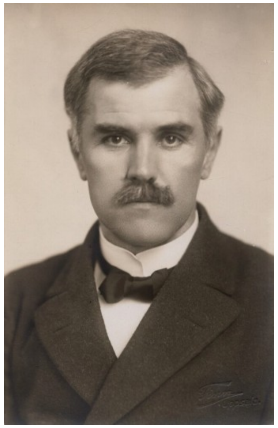
They are oblate, they suffer geometrical deformations induced by rotation

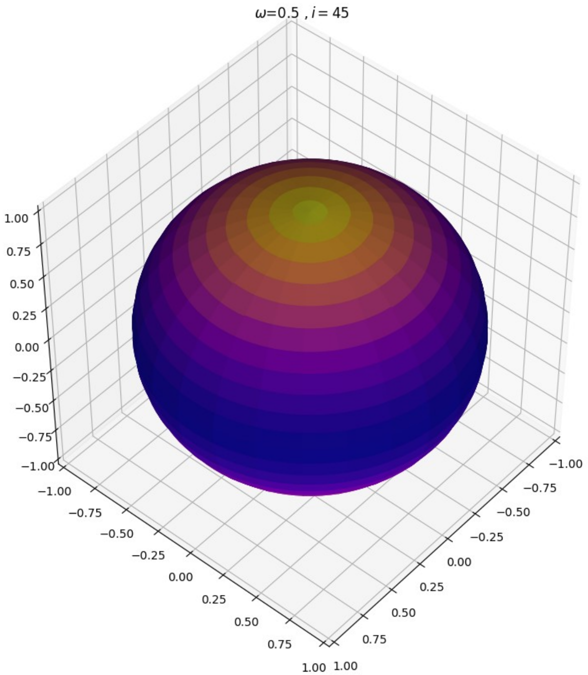
Radiative fluxes vary with the stellar latitude

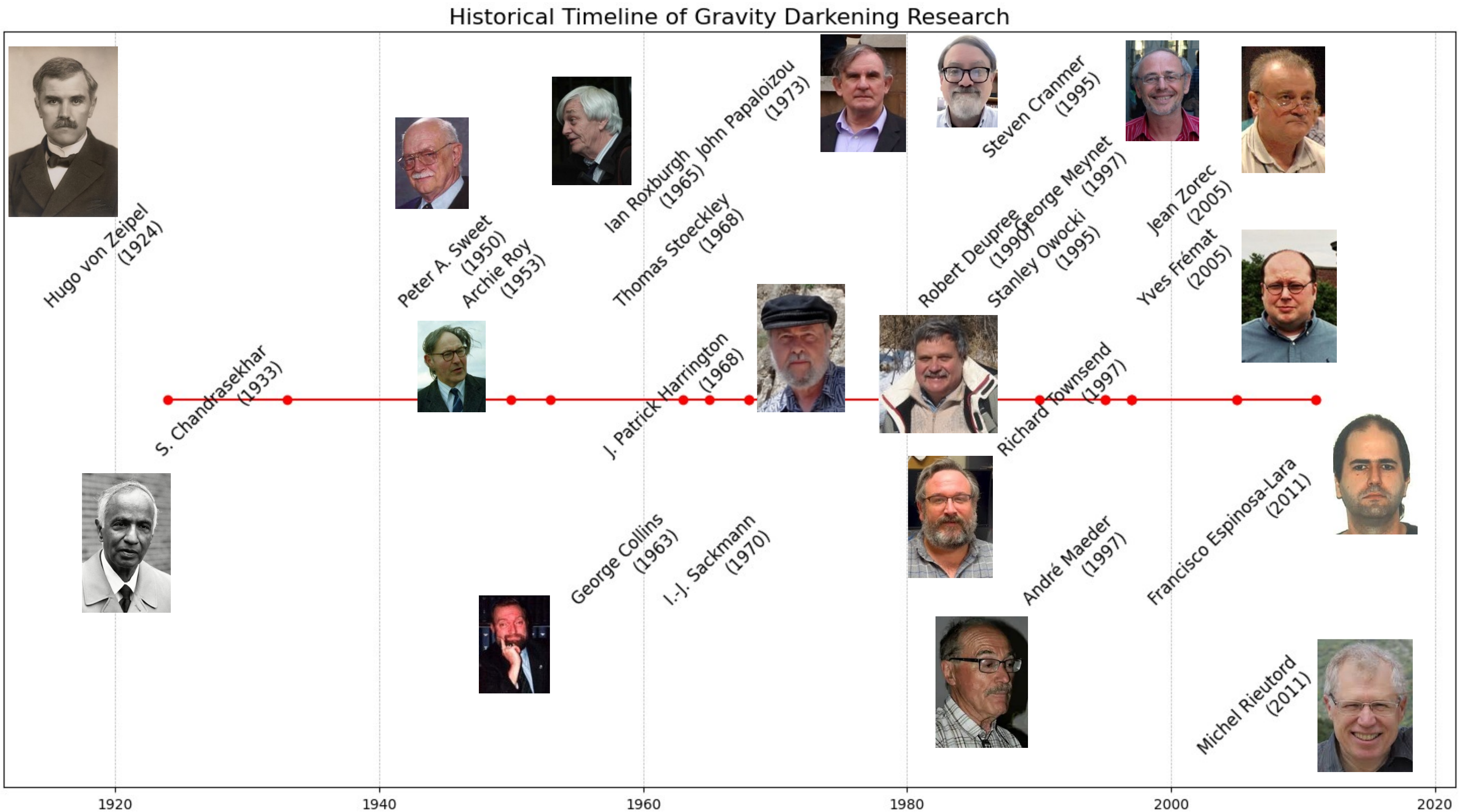
Gravity Darkening

Classical von Zeipel model (1924)

$$T_{\text{eff}}(\theta) = T_{\text{eff, pole}} \left(\frac{g(\theta)}{g_{\text{pole}}} \right)^{1/4}$$





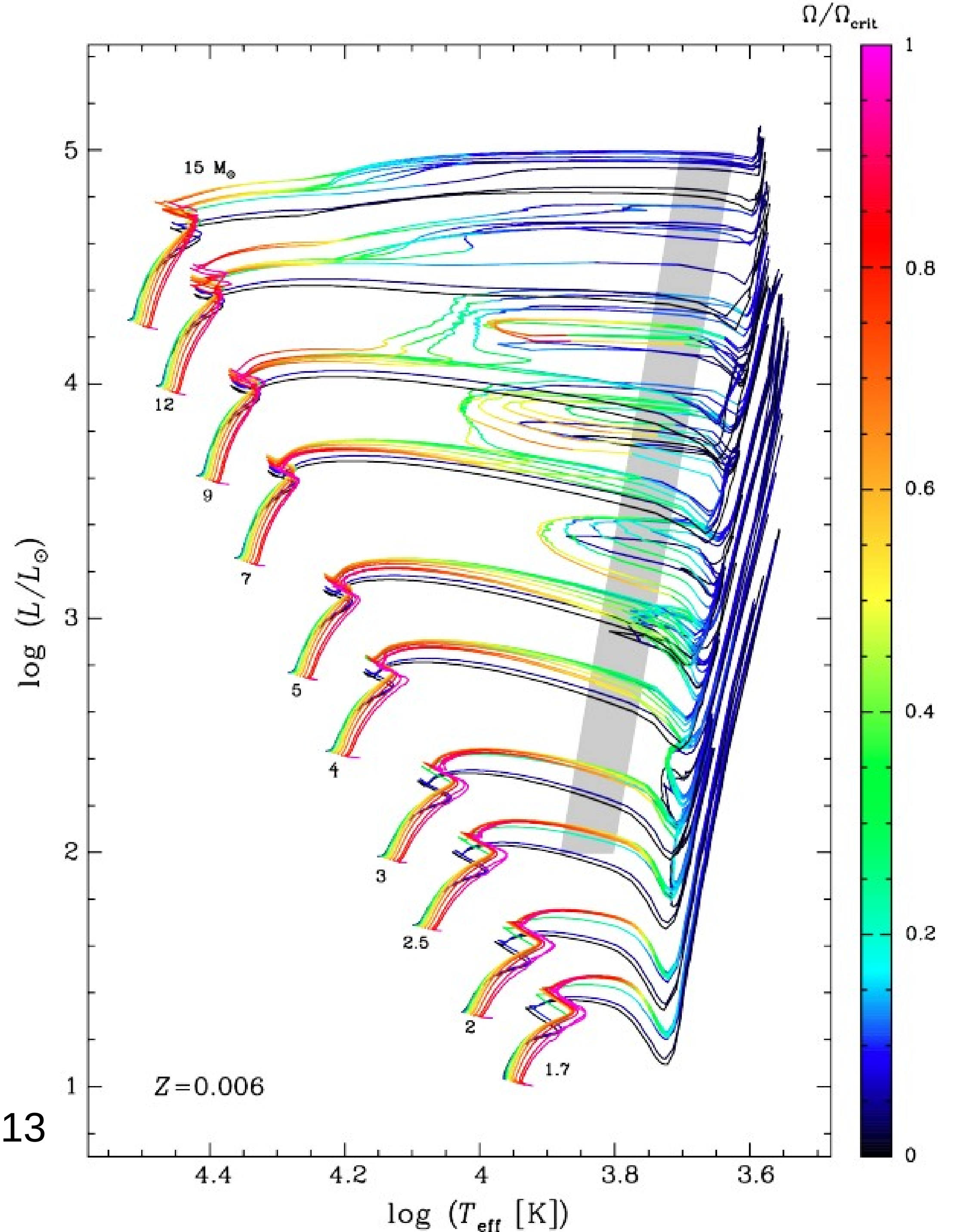


Historical Timeline of Gravity Darkening Research
Hugo von Zeipel (1924)
S. Chandrasekhar (1933)
Peter A. Sweet (1950)
Archie Roy (1953)
George Collins (1963)
Ian Roxburgh (1965)
Thomas Stoeckley (1968)
J. Patrick Harrington (1968)
I.-J. Sackmann (1970)
John Papaloizou (1973)
Robert Deupree (1990)
Steven Cranmer (1995)
Stanley Owocki (1995)
George Meynet (1997)
Richard Townsend (1997)
André Maeder (1997)
Jean Zorec (2005)
Yves Frémat (2005)
Francisco Espinosa-Lara (2011)
Michel Rieutord (2011)
1920
1940
1960
1980
2000
2020

Why should we care about fast rotation?

Striking Points:

Evolutionary tracks in the HR diagram change their positions



Georgy et al. 2013

Why should we care about fast rotation?

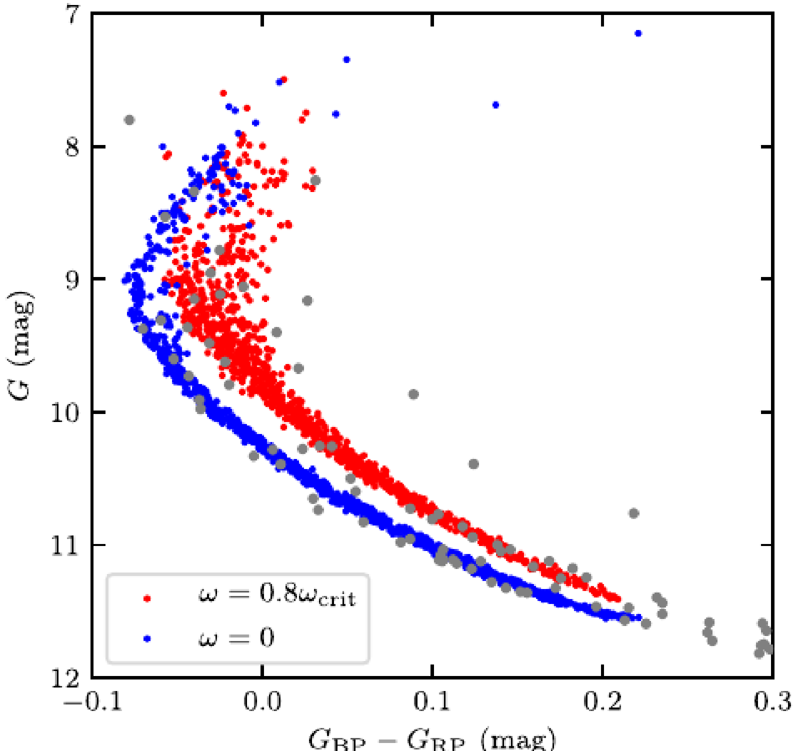
Striking Points:

Chemical mixing feeds the core with new fresh hydrogen, increasing stellar timelife and enriches the photosphere with core CNO products

Why should we care about fast rotation?

Striking Points:

Fast rotation increases the luminosities of massive stars, affecting the overall spectral energy distribution (SED) of stellar populations.



Weijia Sun et al. 2019

Why should we care about fast rotation?

Striking Points:

Stellar rotation significantly influences Stellar Population Synthesis models, particularly in enhancing the ultraviolet slopes up to 0.1 dex for up to ~400 Myr after a starburst.
(Weijia Sun 2024)

A&A, 685, A40 (2024)
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Astronomy & Astrophysics

Rotation in stellar evolution: Probing the influence on population synthesis in high-redshift galaxies

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ABSTRACT

Stellar population synthesis (SPS) is essential for understanding galaxy formation and evolution. However, the recent discovery of rotation-driven phenomena in star clusters warrants a review of uncertainties in SPS models caused by overlooked factors, including stellar rotation. In this study, we investigated the impact of rotation on SPS specifically using the PARSEC V2.0 rotation model and its implications for high-redshift galaxies with the JWST. Rotation enhances the ultraviolet (UV) flux for up to ~400 Myr after the starburst, with the slope of UV increasing as the population becomes faster rotating and metal-poorer. Using the `Prospector` tool, we constructed simulated galaxies and deduce their properties associated with dust and star formation. Our results suggest that rapid rotation models result in a gradual UV slope up to 0.1 dex higher and an approximately 50% increase in dust attenuation for identical wide-band spectral energy distributions. Furthermore, we investigated biases if the stellar population was characterized by rapid rotation and demonstrate that accurate estimation can be achieved for rotation rates up to $\omega_i = 0.6$. Accounting for the bias in the case of rapid rotation aligns specific star formation rates more closely with predictions from theoretical models. Notably, this also implies a slightly higher level of dust attenuation than previously anticipated, while still allowing for a "dust-free" interpretation of the galaxy. The impact of rapid rotation SPS models on the rest-UV luminosity function is found to be minimal. Overall, our findings have potentially important implications for comprehending dust attenuation and mass assembly history in the high-redshift Universe.

Key words. stars: early-type – stars: rotation – galaxies: high-redshift – ultraviolet: galaxies

There should have many unknown fast rotators around...

LAMOST (DR5) → 2,868 Early-Type stars

LAMOST (DR7) → 9,382 Early-Type stars

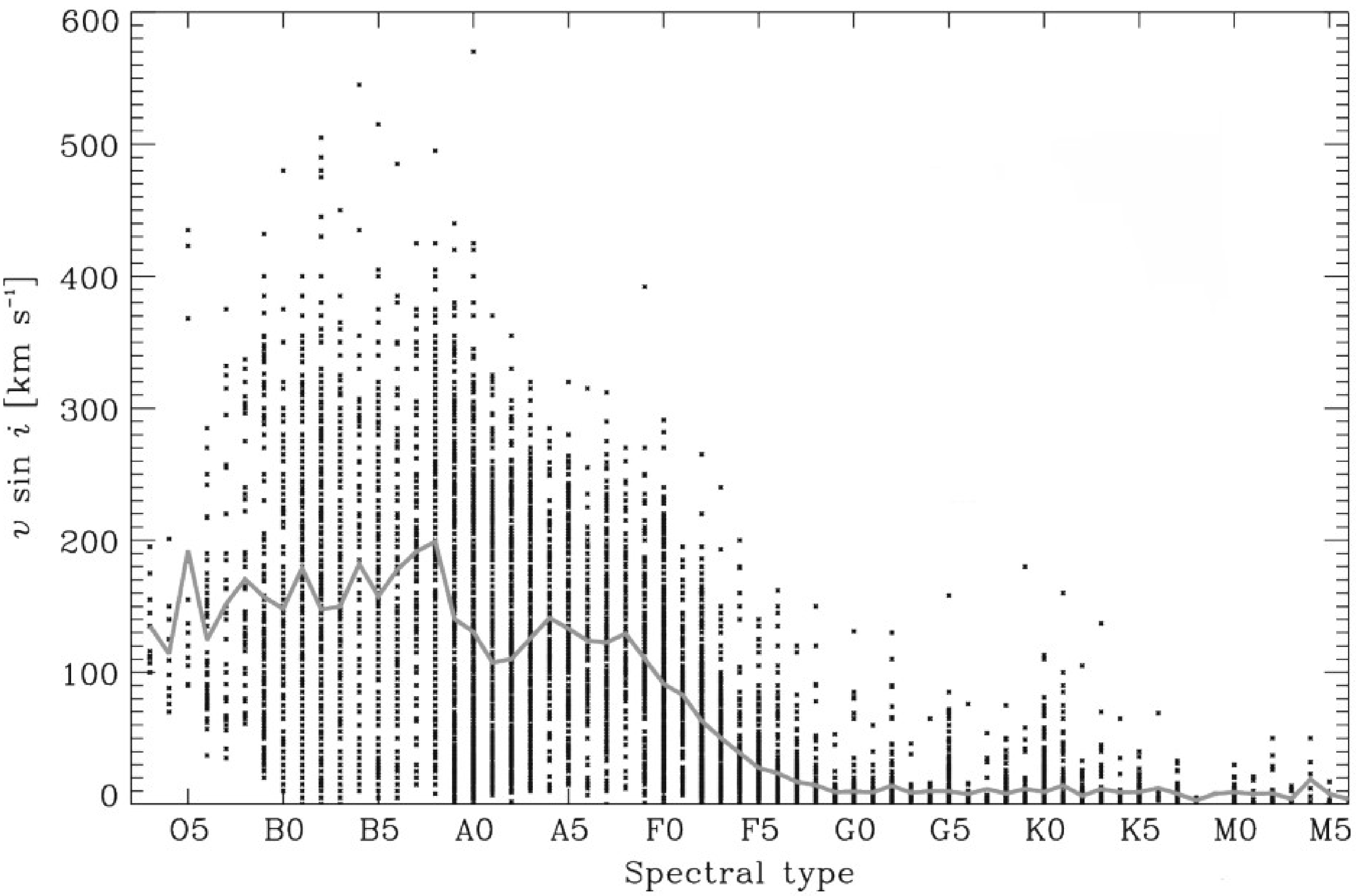
GAIA (DR2) → over 1.7 billion stars of all spectral types

~0.13% OB stars → ~ 2.2 million unknown OB-Type stars

~0.6% A stars → ~ 10.2 million unknown A-Type stars

~0.73% OBA stars → ~ 12.4 million unknown OBA-Type stars

Rotation velocities across the Main Sequence



Royer et al. 2009

ZPEKTR

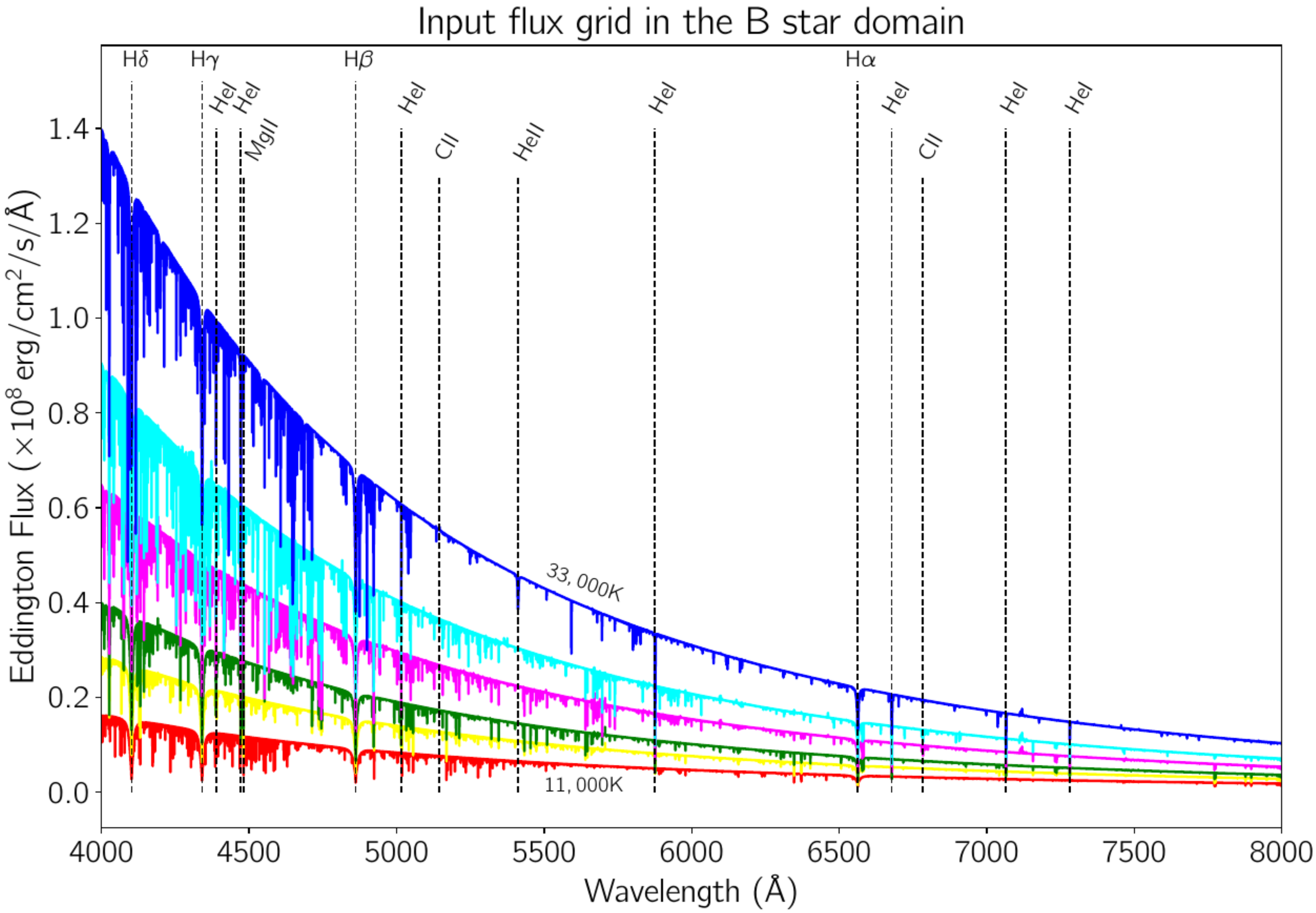
Acronym for:

"von ZeiPEl's code for gravity darKening specTRal synthesis"

Input models

TLUSTY/SYNSPEC CMFGEN ATLAS/SYNTH

MOOG MARCS



There are currently two main prescriptions…

Classical von Zeipel

$$T_{\text{eff}}(\theta) = T_{\text{eff, pole}} \left(\frac{g(\theta)}{g_{\text{pole}}} \right)^{1/4}$$

X

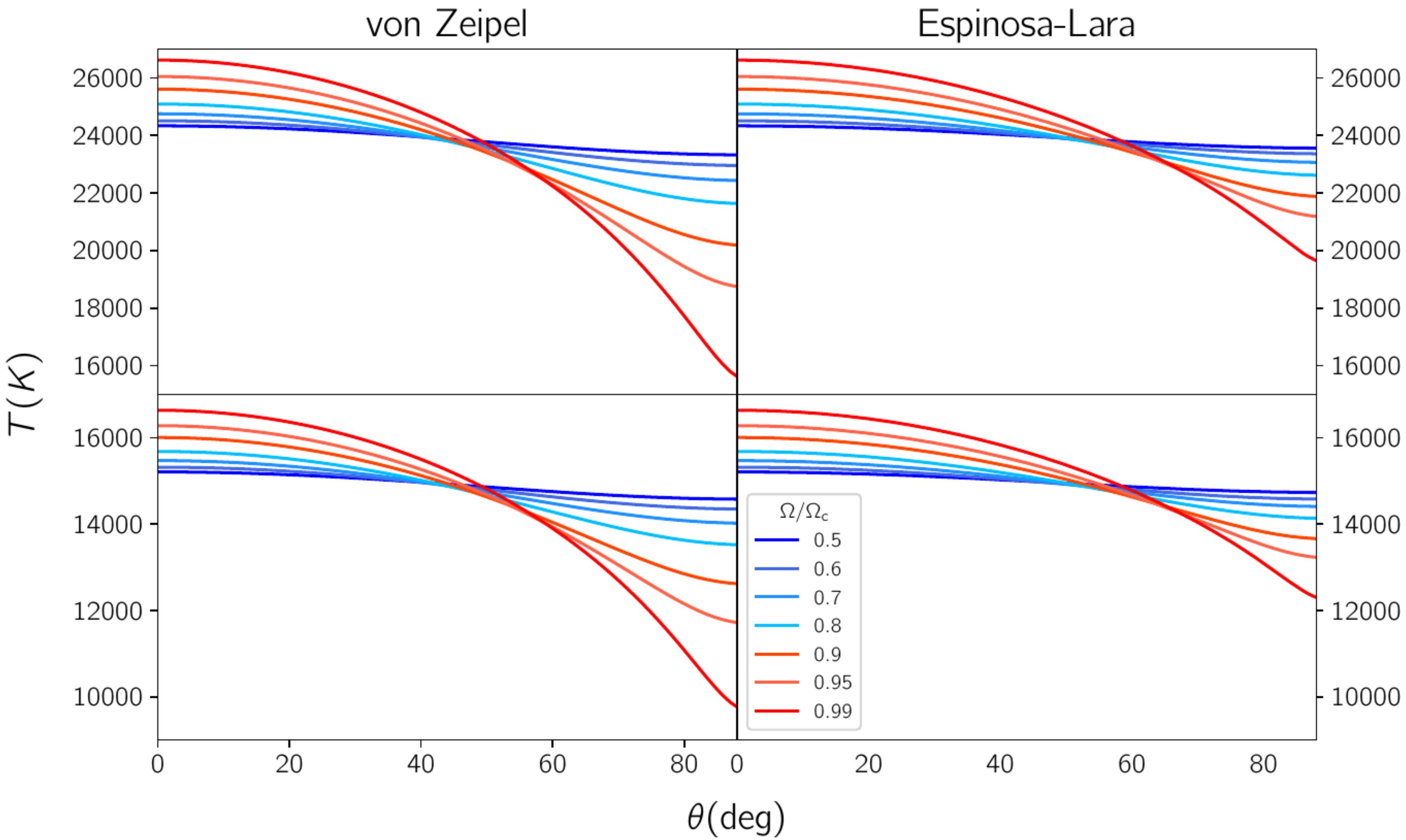
Espinosa-Lara

$$T_{\text{eff}}(\theta) = T_{\text{eff, pole}} \left(\frac{\tan^2 \Theta}{\tan^2 \theta} \cdot \frac{g(\theta)}{g_{\text{pole}}} \right)^{1/4}$$

$$\tau = \cos\Theta + \ln\tan\left(\frac{\Theta}{2}\right)$$

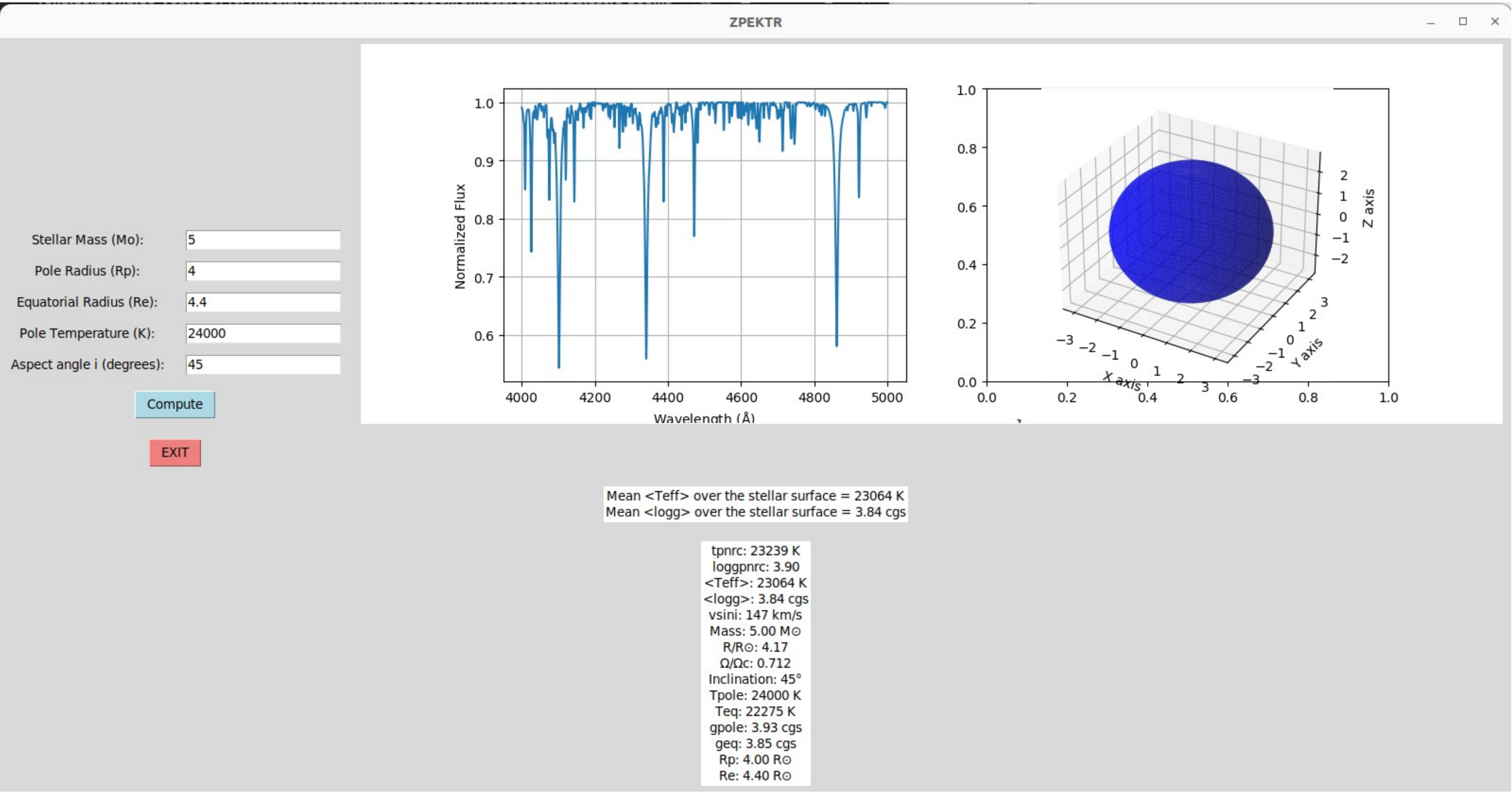
$$\tau = \frac{1}{3}\omega^2 \tilde{r}^3 \cos^3\theta + \cos\theta + \ln\tan\left(\frac{\theta}{2}\right)$$

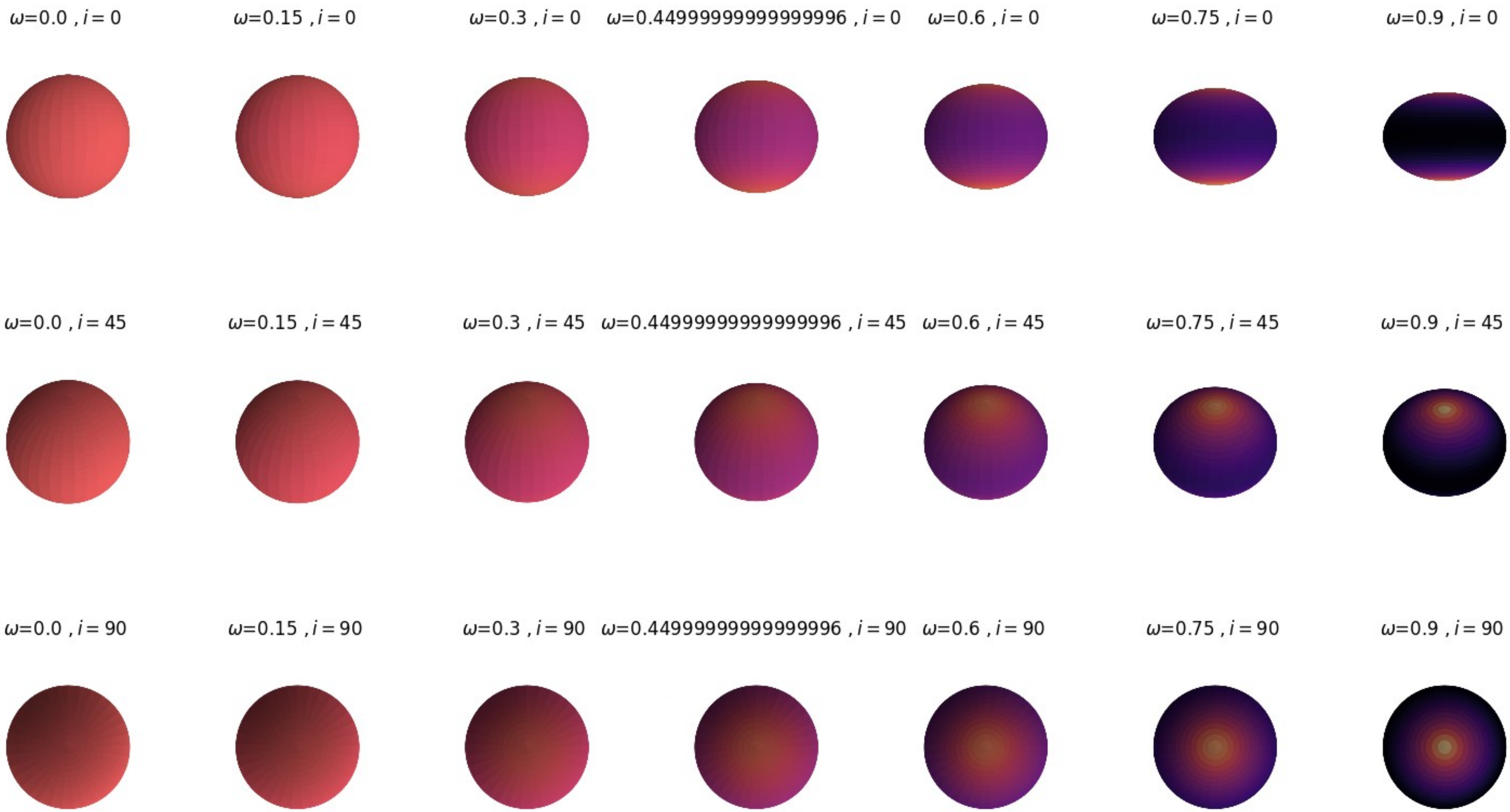
Temperature latitudinal profiles: PNRC Teff = 24,000 K



Levenhagen et al. 2024

New GUI interface of ZPEKTR (still under development):





ω=0.0 , i = 0
ω=0.15 , i = 0
ω=0.3 , i = 0
ω=0.44999999999999996 , i = 0
ω=0.6 , i = 0
ω=0.75 , i = 0
ω=0.9 , i = 0
ω=0.0 , i = 45
ω=0.15 , i = 45
ω=0.3 , i = 45
ω=0.44999999999999996 , i = 45
ω=0.6 , i = 45
ω=0.75 , i = 45
ω=0.9 , i = 45
ω=0.0 , i = 90
ω=0.15 , i = 90
ω=0.3 , i = 90
ω=0.44999999999999996 , i = 90
ω=0.6 , i = 90
ω=0.75 , i = 90
ω=0.9 , i = 90

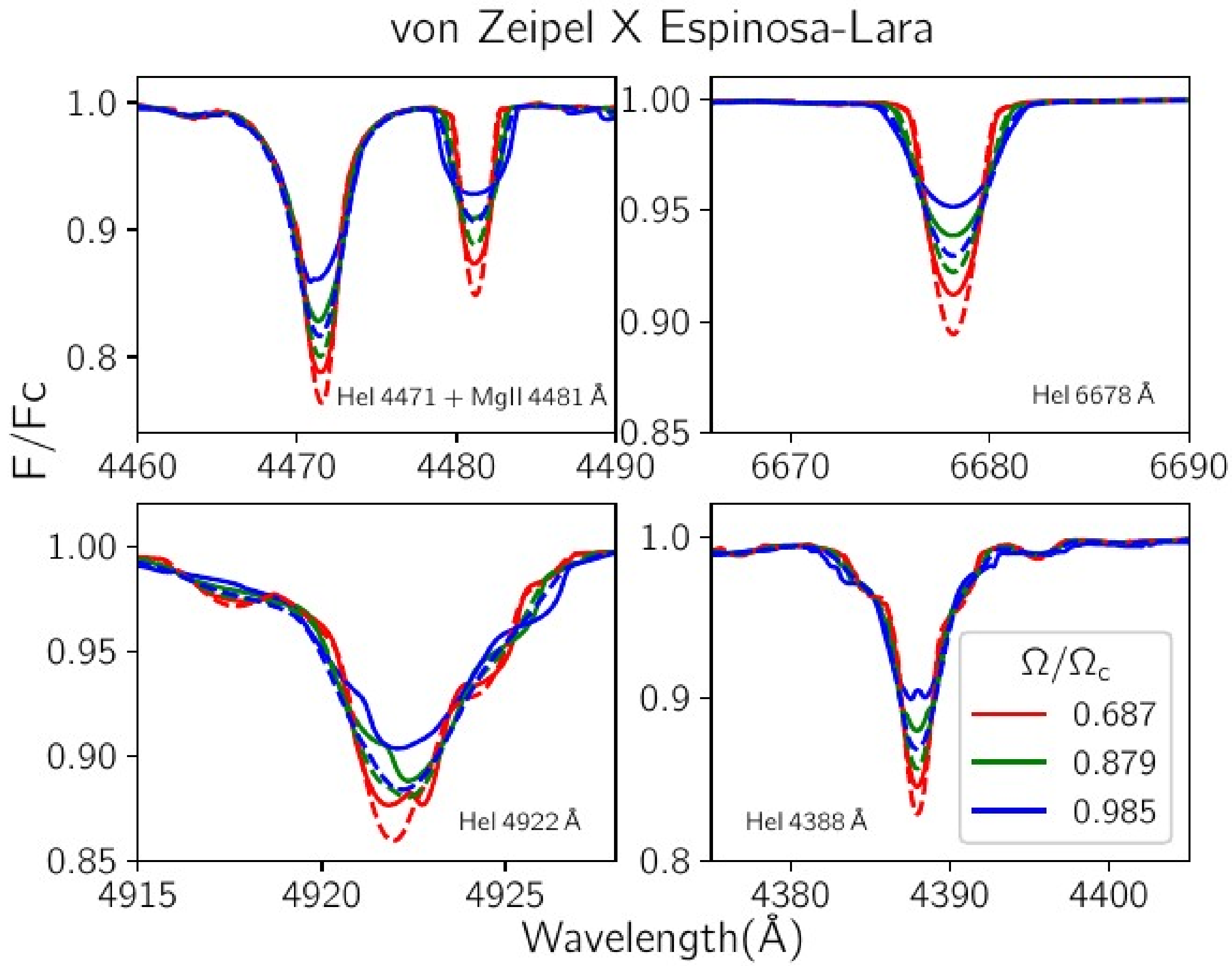
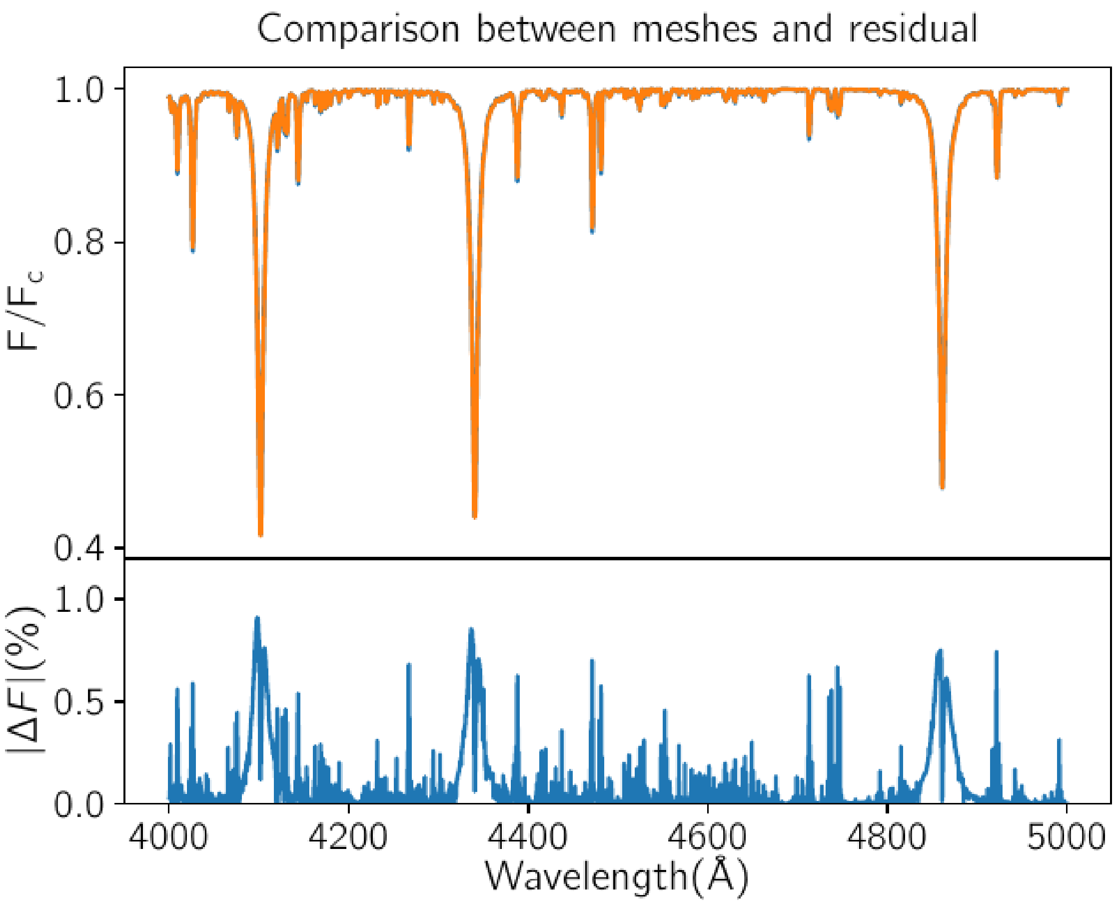
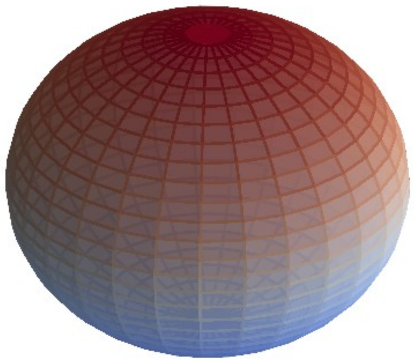
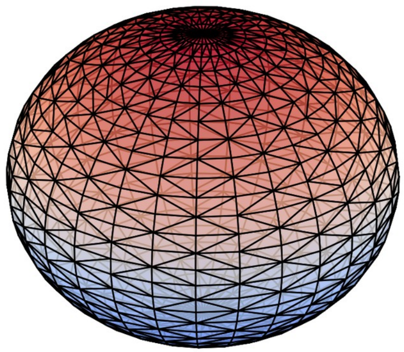


Fig. 3. Illustration of some classical von Zeipel (full lines) and Espinosa-Lara models (dashed lines) for He I 4471 + Mg II 4481, He I 4388, He I 4922, and He I 6678 Å. All models are built assuming a PNRC temperature of T = 15 000 K, M = 4.4 $M_{\odot}$, R = 6.17 $R_{\odot}$, and i = 35°, and showing the rotation rate $\omega = \Omega/\Omega_c$ for three values, ω = 0.687, 0.879, and 0.985.

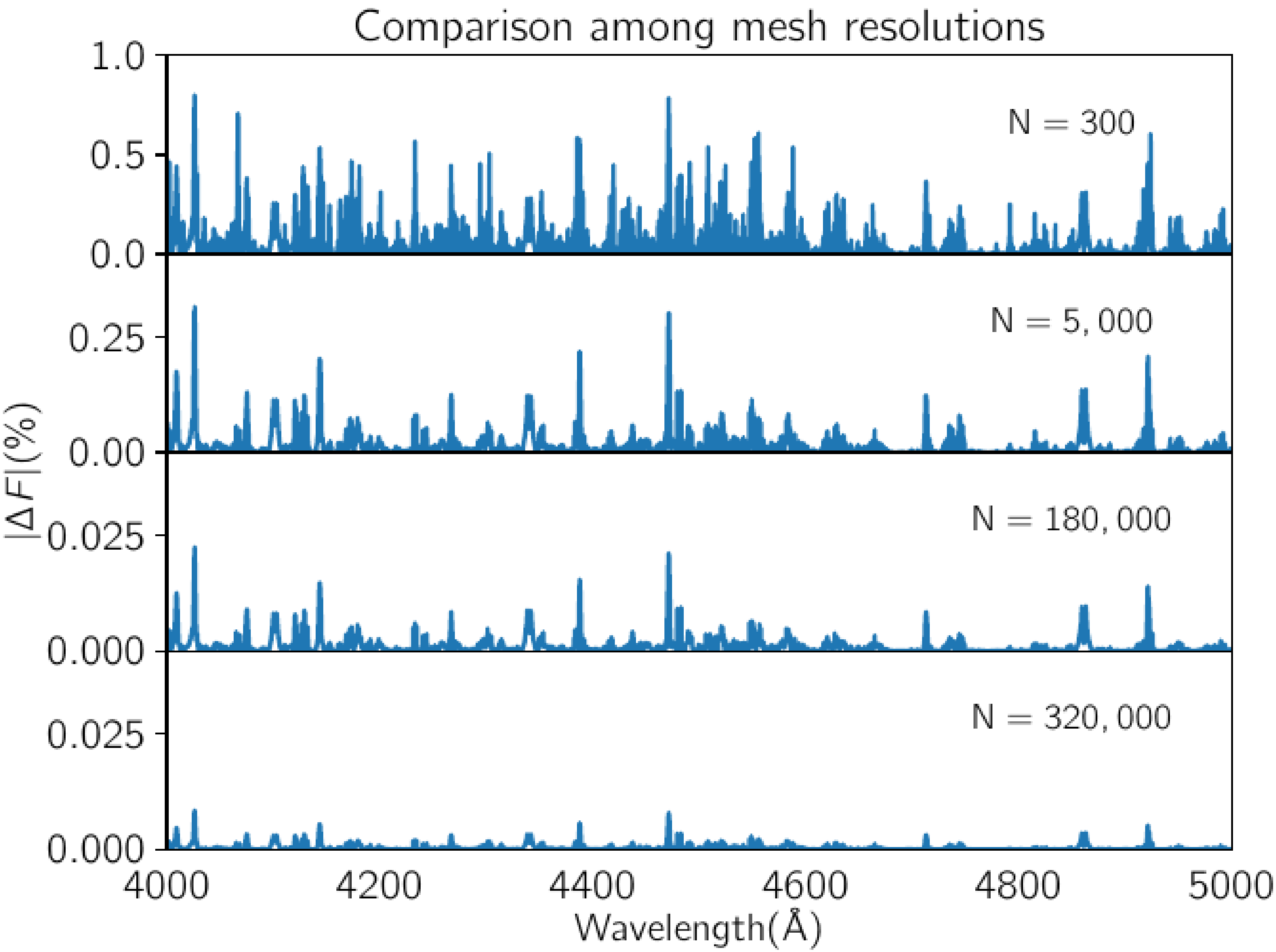
Levenhagen et al. 2024

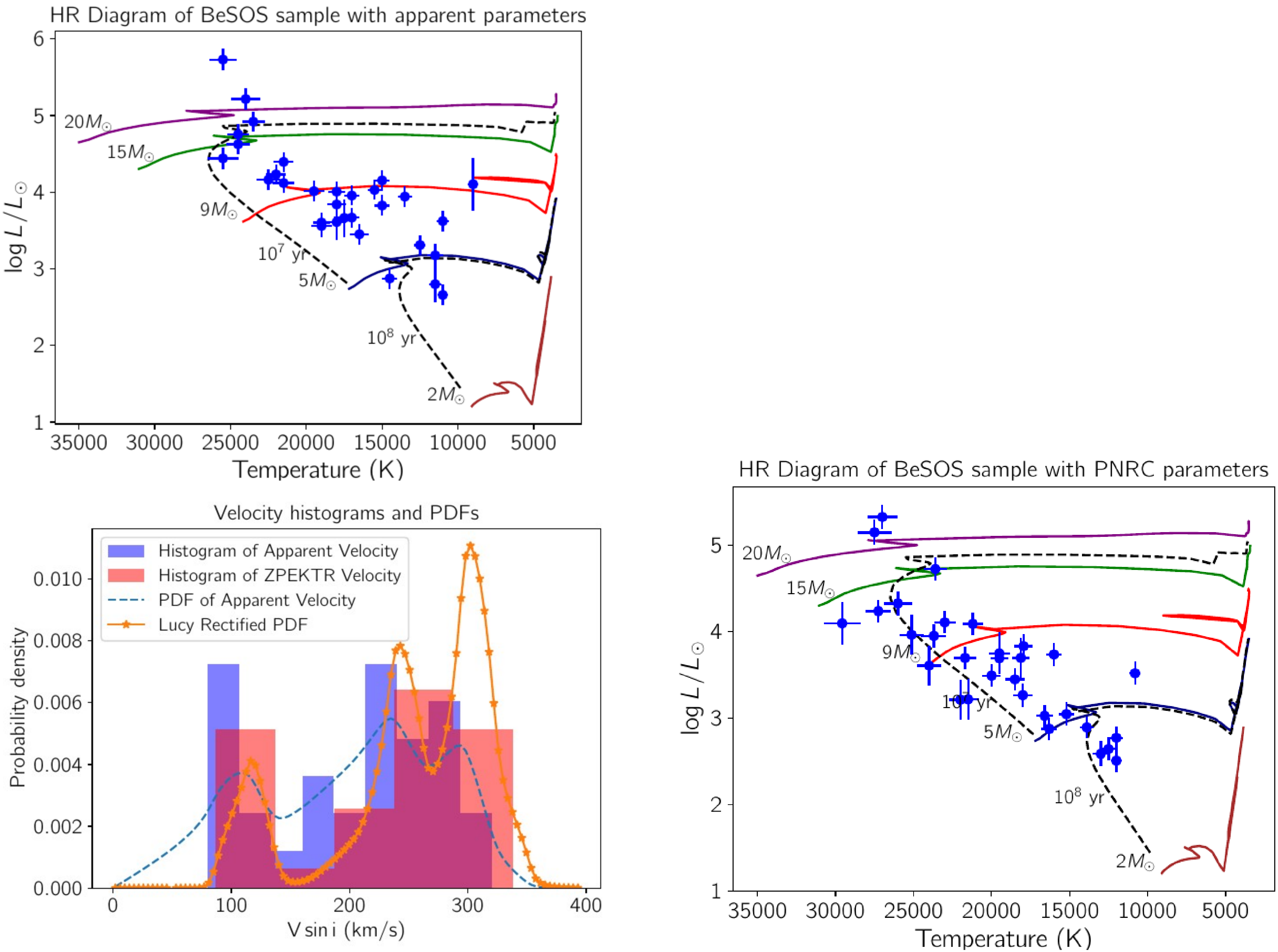




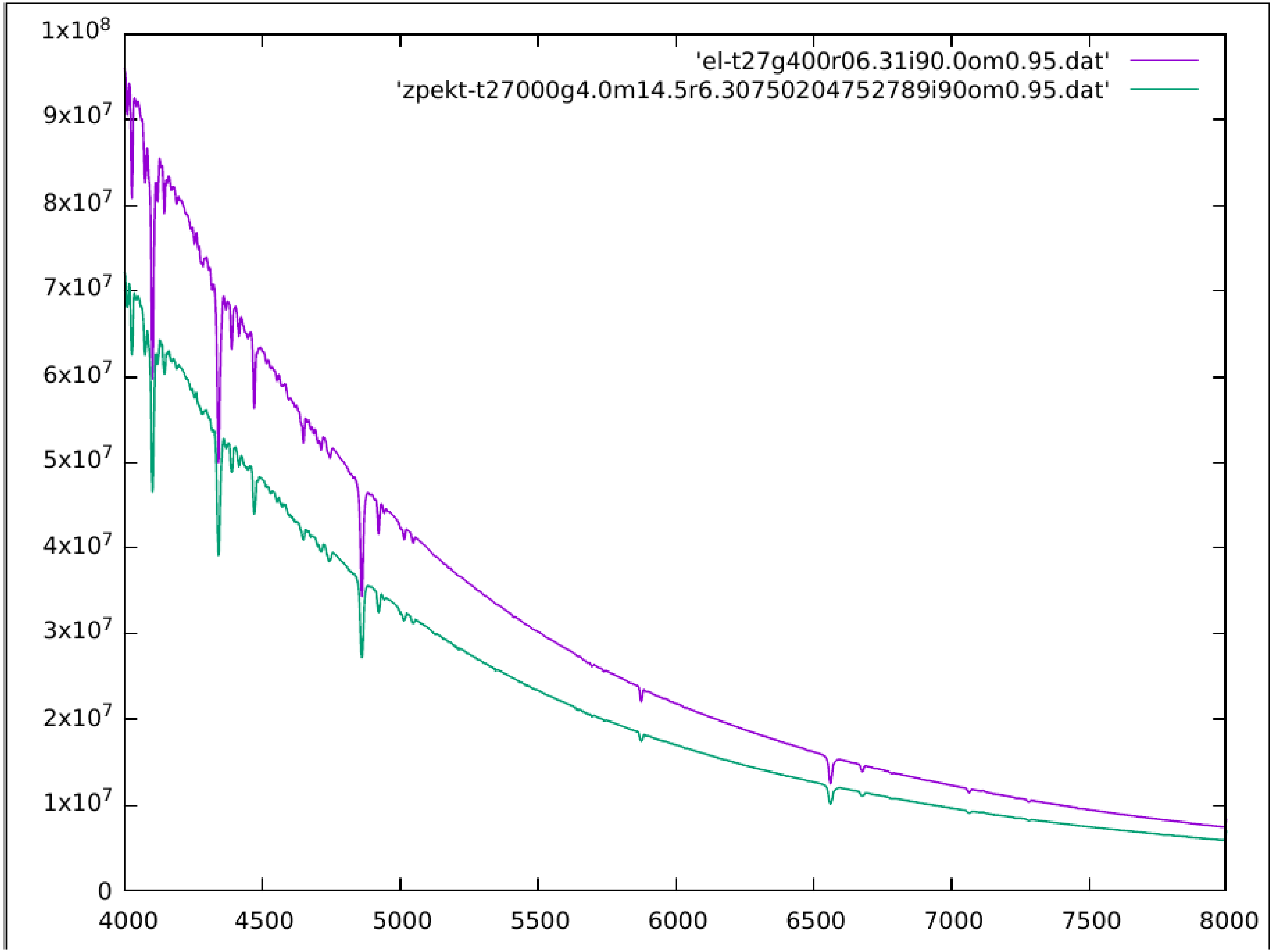


Levenhagen et al. 2024

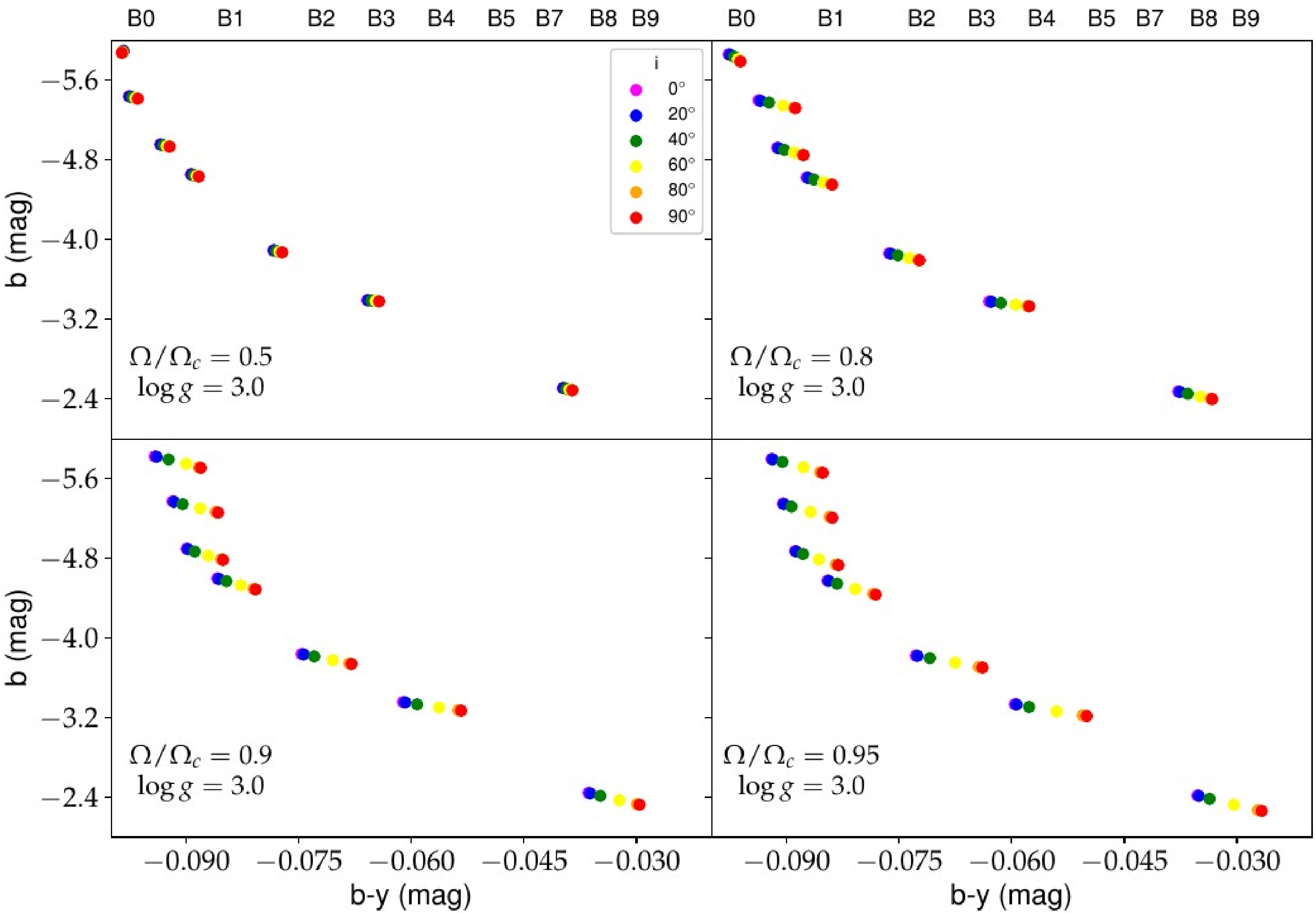

Comparison among mesh resolutions
N = 300
N = 5,000
N = 180,000
N = 320,000
1.0
0.5
0.0
0.25
0.00
0.025
0.000
0.025
0.000
|ΔF|(%)
4000
4200
4400
4600
4800
5000
Wavelength(Å)

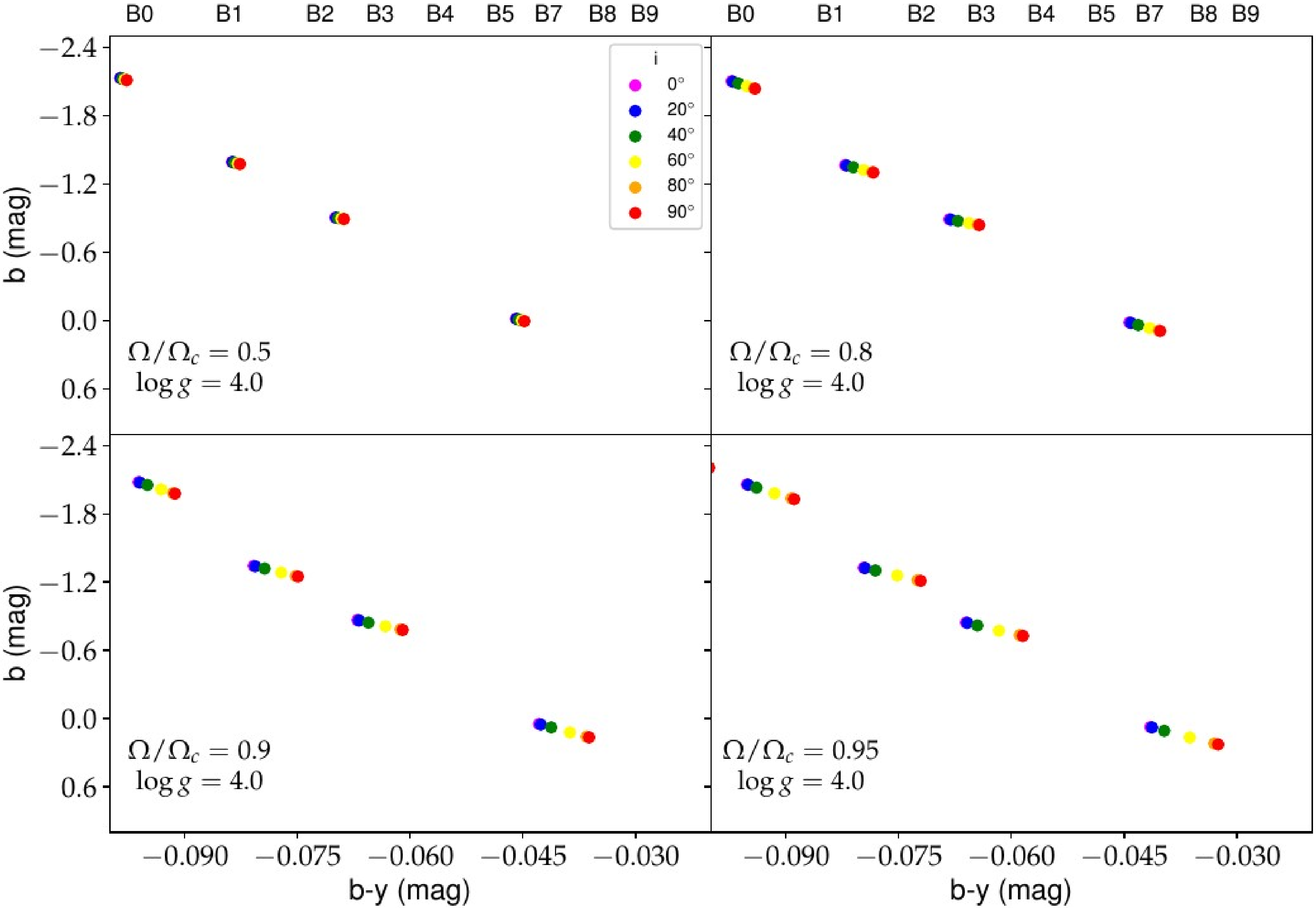

HR Diagram of BeSOS sample with apparent parameters
log $L/L_\odot$
Temperature (K)
$20M_\odot$
$15M_\odot$
$9M_\odot$
$5M_\odot$
$2M_\odot$
10^7 yr
10^8 yr
Velocity histograms and PDFs
Histogram of Apparent Velocity
Histogram of ZPEKTR Velocity
PDF of Apparent Velocity
Lucy Rectified PDF
Probability density
V sin i (km/s)
HR Diagram of BeSOS sample with PNRC parameters
log $L/L_\odot$
Temperature (K)
$20M_\odot$
$15M_\odot$
$9M_\odot$
$5M_\odot$
$2M_\odot$
10^7 yr
10^8 yr

Output fluxes



Synthetic Photometry





B0
B1
B2
B3
B4
B5
B7
B8
B9
i
0°
20°
40°
60°
80°
90°
b (mag)
b-y (mag)
−2.4
−1.8
−1.2
−0.6
0.0
0.6
−0.090
−0.075
−0.060
−0.045
−0.030
$\Omega/\Omega_c = 0.5$
$\log g = 4.0$
$\Omega/\Omega_c = 0.8$
$\log g = 4.0$
$\Omega/\Omega_c = 0.9$
$\log g = 4.0$
$\Omega/\Omega_c = 0.95$
$\log g = 4.0$

Further Improvements:

Adaptation to binary systems

Differential rotation

Thank you