ISE2A symposium

School of Science and Technology Physics Division

Liceo Scientifico e delle Scienze umane “Salvatore Cantone”

Università degli Studi di Napoli Federico II - Dipartimento di Fisica “Ettore Pancini”

Liceo Pluricomprensivo Renato Cartesio

A teaching-learning module on stellar structure and evolution

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Why Stars?

Stars are one of the most fascinating and charming topics.

Stars can be used as context to increase students' interest in scientific matters.

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Why Stars?

Stars as a big idea in its own right:

- Involve core concepts in classical and modern Physics
- Re-visit core concepts of classical physics: Newton's second law, hydrostatics, ideal gas law, waves
- Introduction of spectral analysis

Star Formation in the Tadpole Nebula
Image Credit: WISE, IRSA, NASA; Processing & Copyright: Francesco Antonucci

Why Stars?

- Introduction of advanced concept as matter-radiation interaction and quantum mechanics
- Inner stars' processes are connected with both Chemisty and Biology
- Connection with other big ideas in Astronomy (Lelliott & Rollnick, 2010): size and distances, galaxies, Universe

Students' understanding of stars

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- Stars are confused planet (Finegold & Pundak, 1990)
- Milky Way is composed by close stars (Finegold & Pundak, 1990)
- Distance between stars and Earth is difficult to estimate (Finegold & Pundak, 1990)
- Stars are motionless (Finegold & Pundak, 1990)
- Stars as "burning objects" (Agan, 2004)
- Stars emit monochromatic light (Agan, 2004)
- Role of gravity in star formation process is not recognized (Bailey, 2006)
- H-R diagram as a "real" trajectory (Agan, 2004)

Students’ understanding of stars

Students’ conceptions appear to be grouped in three distinct categories:

- Conceptions about the forces involved in stars’ formation and equilibrium
- Conceptions about stars’ emitted radiation
- Conceptions about stars’ inner processes

Key Ideas of the Teaching Learning Module (TLM)

Mechanical and thermal equilibrium

Spectral analysis

Energy and nuclear reactions

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Sample

Two intact classes of secondary school students (17-18 years old) for a total of 59 students

TLM's activities

4 phases

20 h

Evaluation of TLM

Pre and Post Test

Questionnaire adapted from Bardar et al (2007) and Bailey et al (2012)

Questionnaire

N	Question	Key Idea
1	What is a star?	Mechanical and thermal equilibrium
2	How do you think a star is formed?	Mechanical and thermal equilibrium
3	What are the main stellar inner processes?	Energy and nuclear reactions
4	What are the forces involved in the process of stellar formation?	Mechanical and thermal equilibrium
5	What influences the shape of a star?	Mechanical and thermal equilibrium
6	What factor does the temperature of a star depend on?	Energy and nuclear reactions
7	(Four drawings are shown) Which drawing represents the process by which an absorption line is formed?	Spectral analysis
8	Coolest stars emit most of their energy in…?	Spectral analysis
9	What happens during evolution of a star?	Energy and nuclear reactions
10	(Three spectral curves are shown) Which of the objects has the highest temperature?	Spectral analysis

Overview of TLM activities

Phase	Key Ideas	Time (h)	Driving questions	Intended objectives	Activities – what students do	Teaching materials and resources
1	Introduction to stars' parameters	2	'What is a star?'	To identify stellar quantities that can be measured	Discuss in small groups using sketches and words	Worksheet
			'Which physical quantities would you use to describe the stars' functioning?'		Determine Sun's mass through Newton's law	

Overview of TLM activities

Students are first guided to identify the stellar quantities that will be studied throughout the module:

1) radius
2) mass
3) temperature
4) matter composition

Misconceptions in Chemistry and Physics emerge

For the aims of the module, student's will focus on the Sun, because:

- it is a typical star in the main sequence of the H–R diagram;
- is the closest star to the Earth (1.5108 km)
- Is an easy example of star to study for students

Overview of TLM activities

Phase	Key Ideas	Time (h)	Driving questions	Intended objectives	Activities – what students do	Teaching materials and resources
2	Spectral analysis	8	'Which quantities can we measure using light emitted by stars?'	To infer information about stars' composition and processes from spectra	Estimate the fundamental frequency of Sun pressure waves	Software: Goldwave
				To distinguish different physical processes from spectral graphs	Estimate Sun's radius using the equation for the fundamental frequency of Sun pressure waves	Software: Spectralab
				To establish a relationships between emitted light and Sun surface temperature	Discuss the differences between spectra Of fluorescent And incandescent lamps	Software: Spectralab
					Analyse the Sunlight spectrum and discuss Planck's blackbody radiation function	
					Determine Sun's surface temperature through Wien's law	Software: Logger Pro

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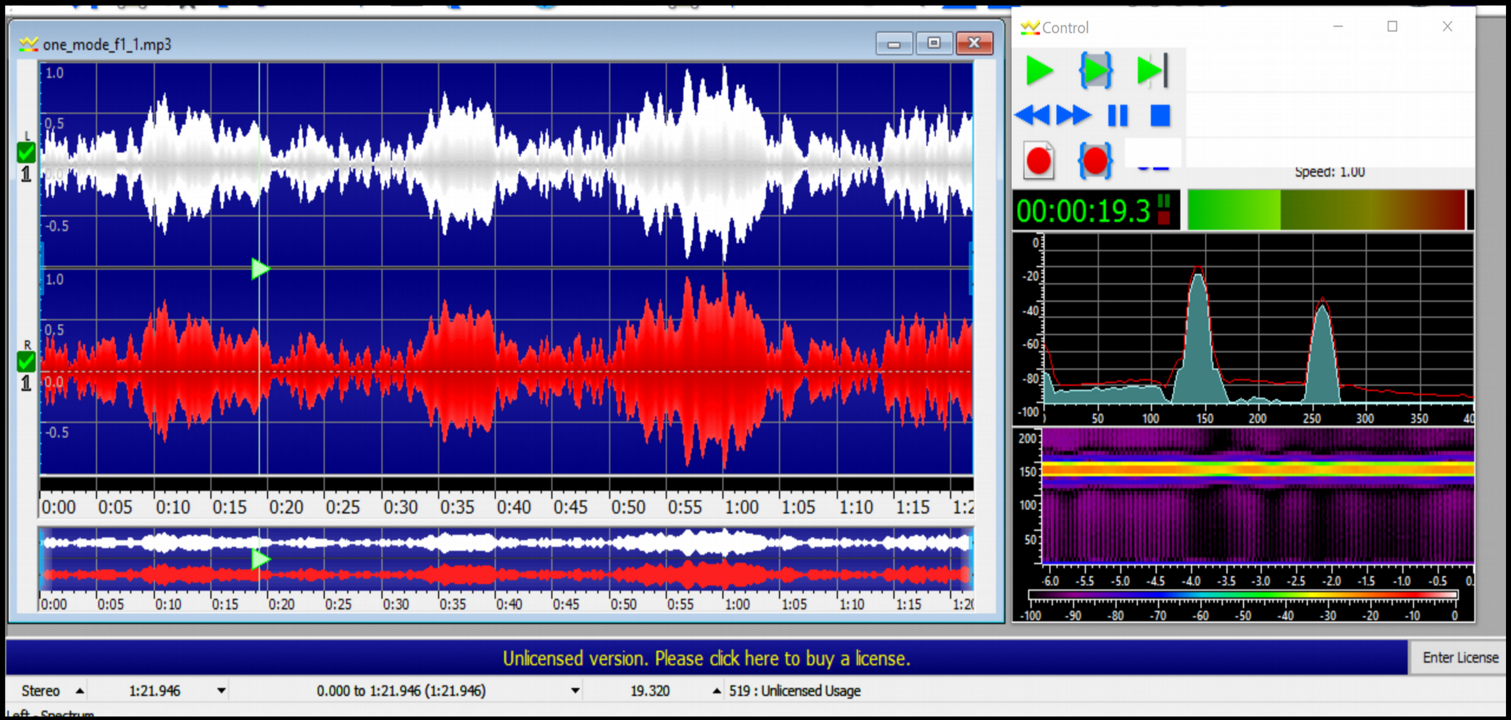
Students are guided to recognise that pressure waves are generated in inner shells of the Sun due to internal processes and that the fundamental frequency of such oscillations depends on geometrical factors (Leccia et al., 2015; Colantonio at al. 2016)

$$f \propto \frac{v_{sun}}{H_p} \propto \frac{M_S}{R_S^2 \sqrt{T}}$$



Solar mass has been calculated in the previous phase.
Attention is focused on the remaining two parameters, radius and temperature, one of which has to be determined with an independent measurement.

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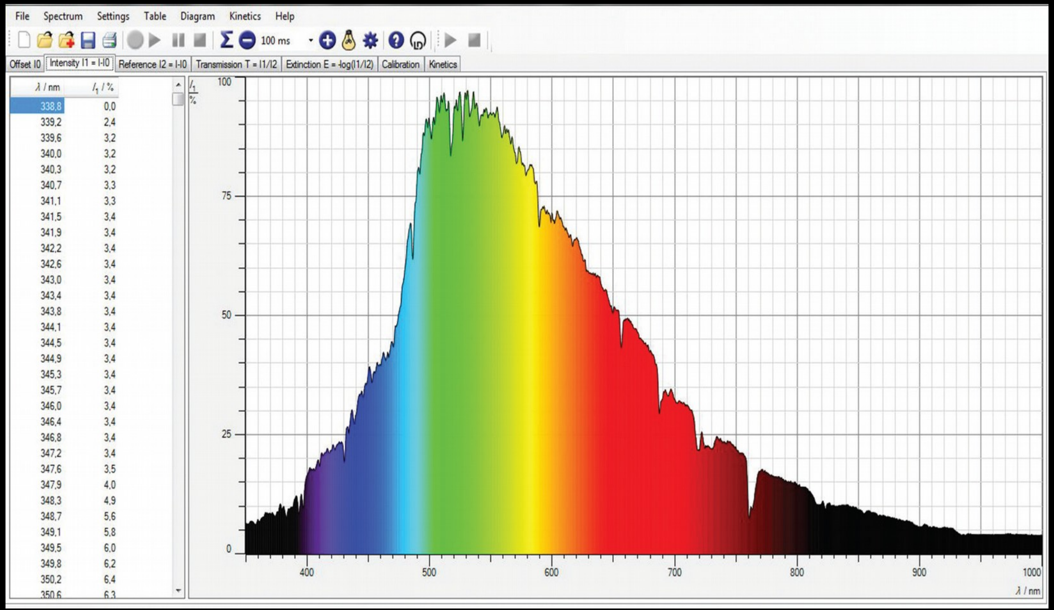

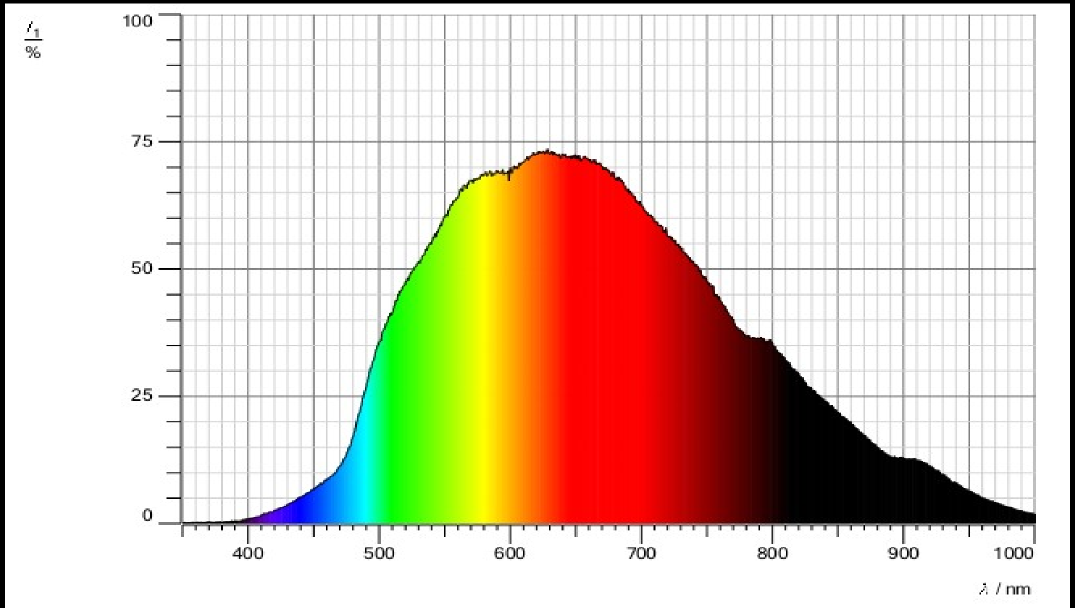

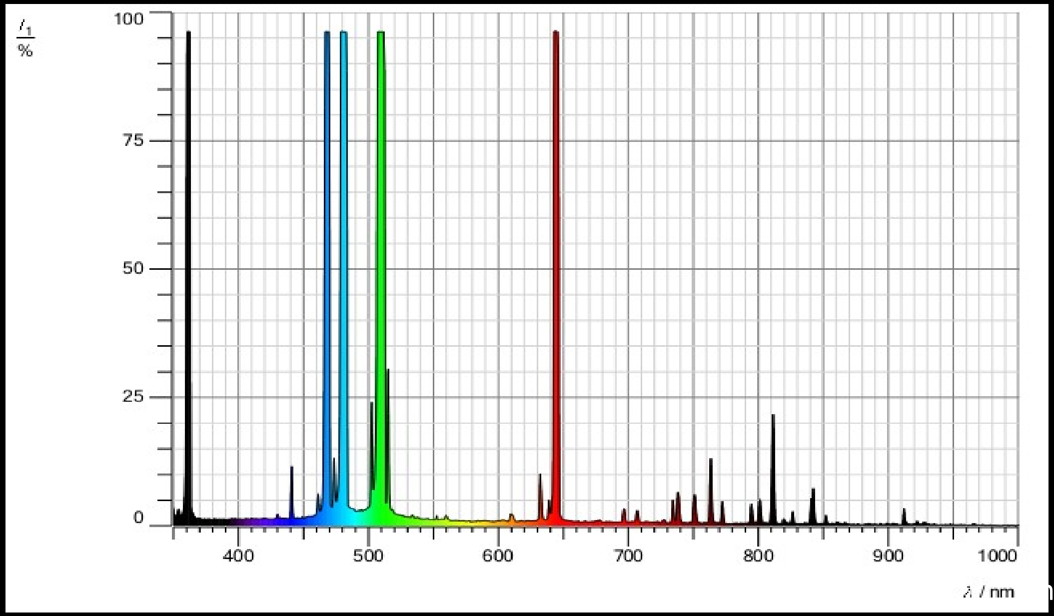

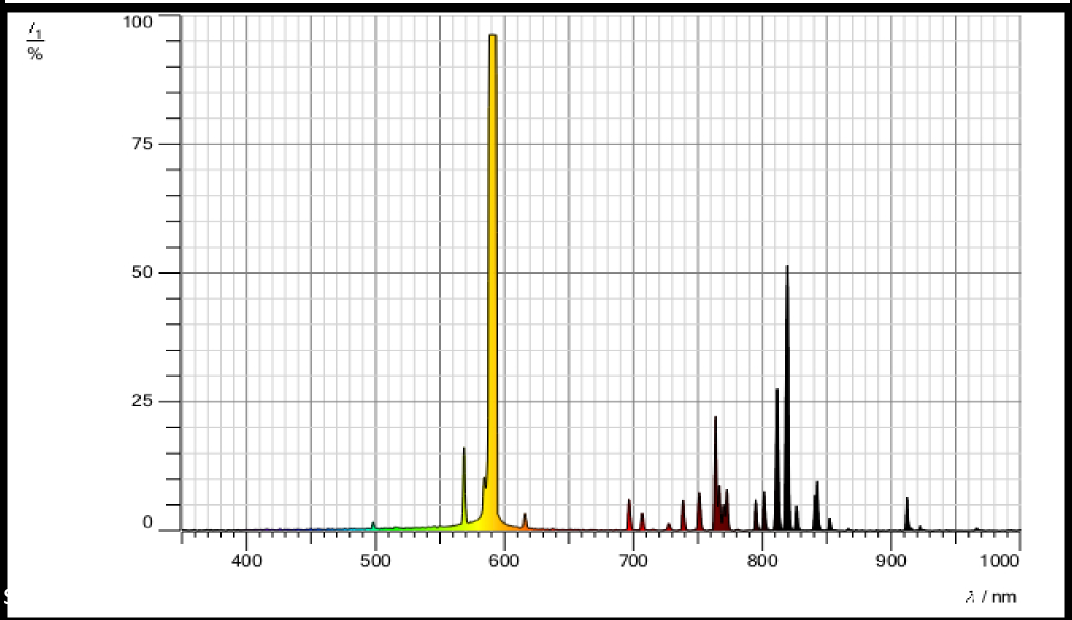

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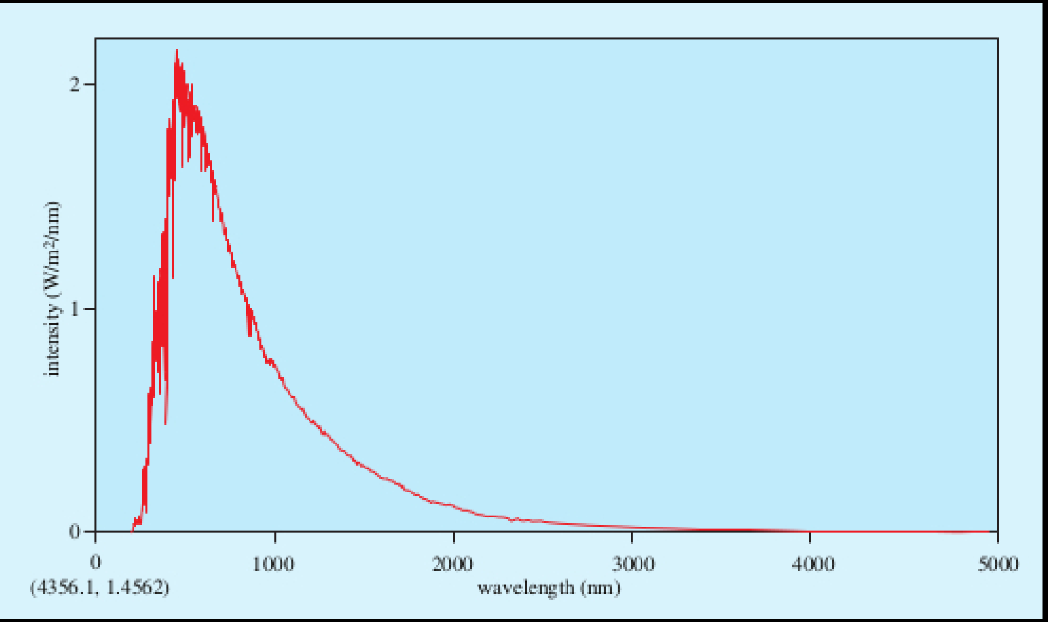

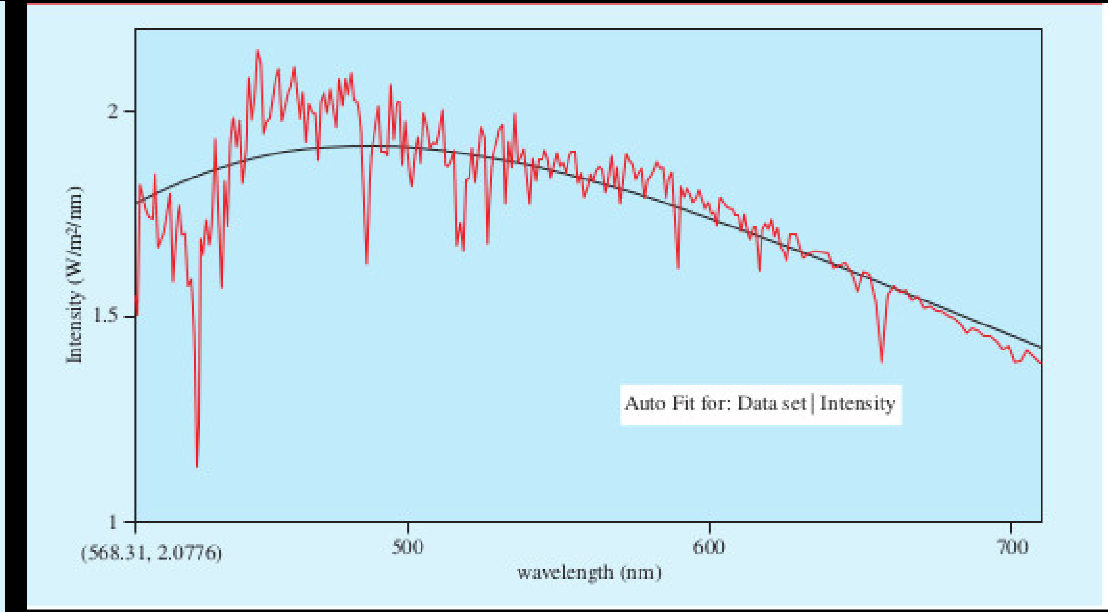

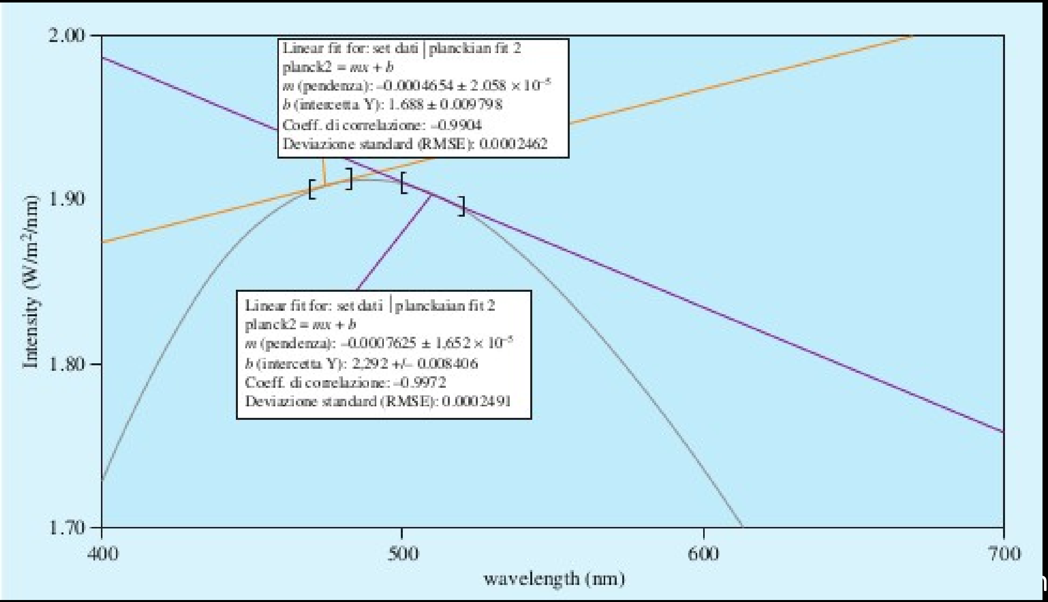

Linear fit procedure to estimate the wavelength corresponding to the maximum in the Sun's spectrum fitted by the Planckian function. Intersection is at λ_{max} = *(492 ± 15) nm*, which leads through Wien's law to an estimation of Sun surface temperature of $T = (5.9 \pm 0.2)\ 10^3$ *K*.

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Phase	Key Ideas	Time (h)	Driving questions	Intended objectives	Activities – what students do	Teaching materials and resources
3	Mechanical and thermal equilibrium	6	‘Which is the shape of a star and why?’	To introduce the role of gravitational force in the stars’ functioning mechanism	Estimate forces acting on a Sun’s volume element	Worksheet
			‘How can a star be in equilibrium?’	To justify the need for pressure forces	Estimate Sun’s rotational speed	Software: Tracker

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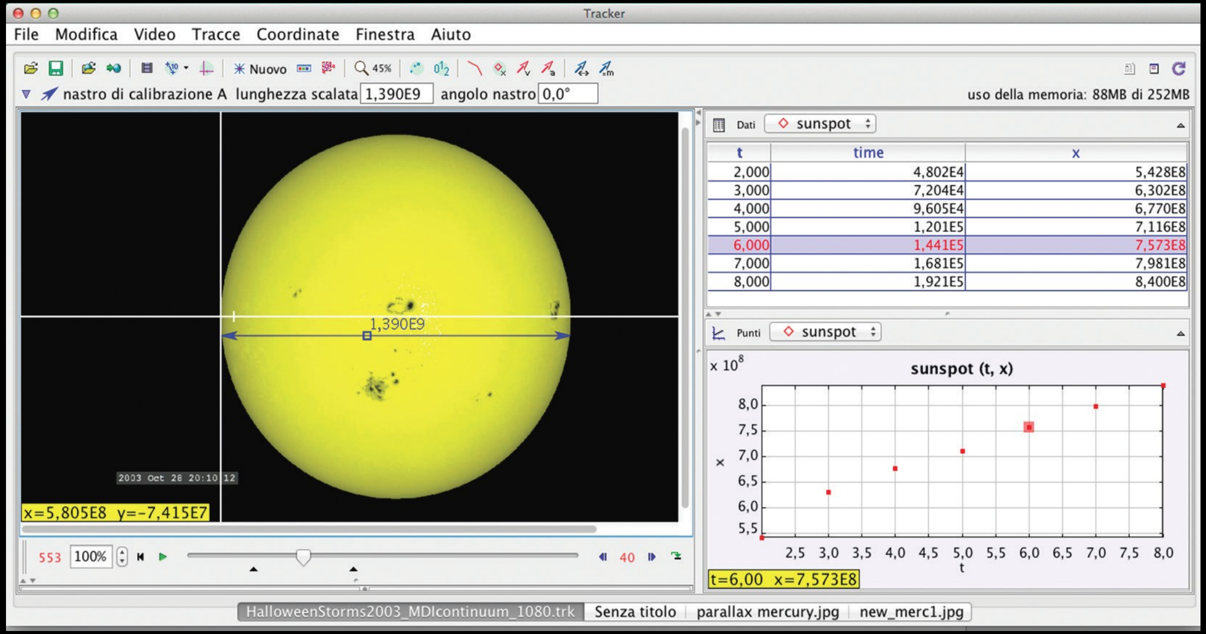

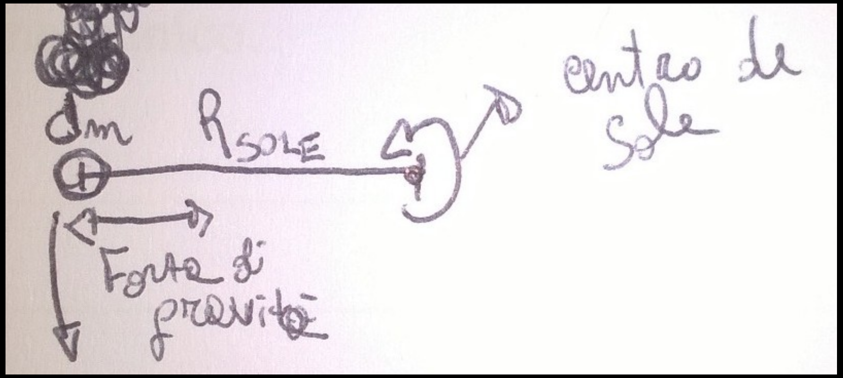

Tracker analysis of a video representing the motion of sunspots at equatorial latitude (https://svs.gsfc.nasa.gov/3502) during a 2-week period in October and November of 2003, obtained with Michelson Doppler interferometer (MDI). Left frame shows the tracking of the sunspot, right frame shows position versus time graph and table of the sunspot. A linear fit gives an estimate of the Sun rotational velocity v = (1.9 ± 0.1) 10^3 ms^{-1}.

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Phase	Key Ideas	Time (h)	Driving questions	Intended objectives	Activities – what students do	Teaching materials and resources
4	Energy and nuclear reactions	6	‘How you think a star is functioning?’	To justify stars’ functioning with increasing production of energy and of chemical elements To understand that evolution of a star depends only on its initial quantity of mass	Estimate energy delivered by the Sun Discuss basic nuclear reactions inside the Sun To distinguish between chemical and nuclear reactions	Worksheet

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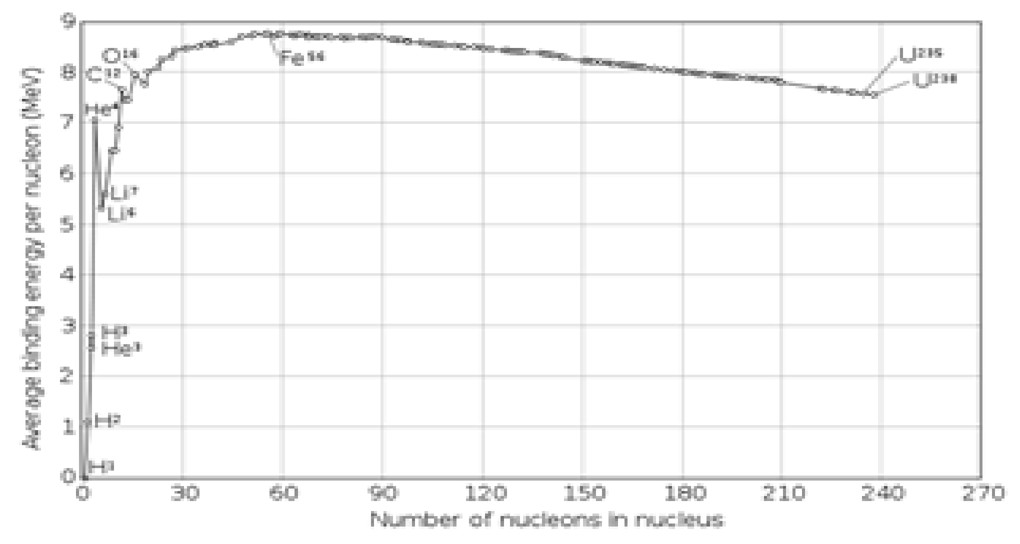
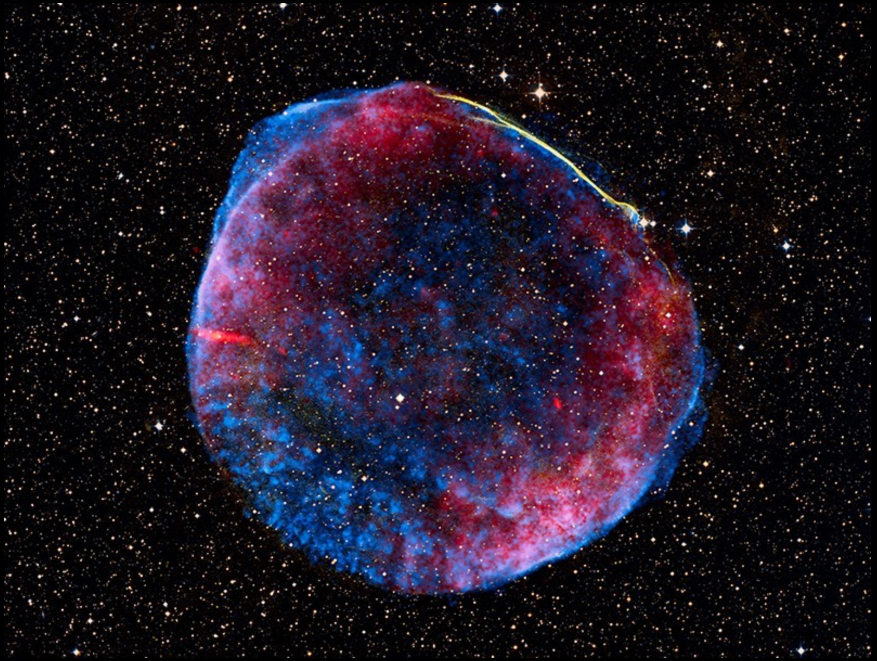
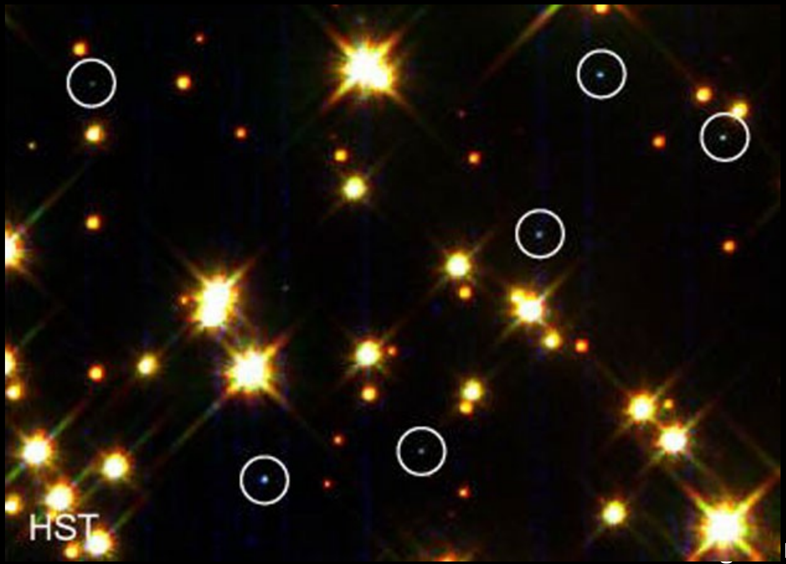




SN 1006 Supernova Remnant I
Credit: NASA, ESA, Zolt Levay (STScI)



White Dwarf Stars Cool
Credit: H. Richer (UBC) et al., WFPC2, HST, NASA

Assessing TLM efficacy

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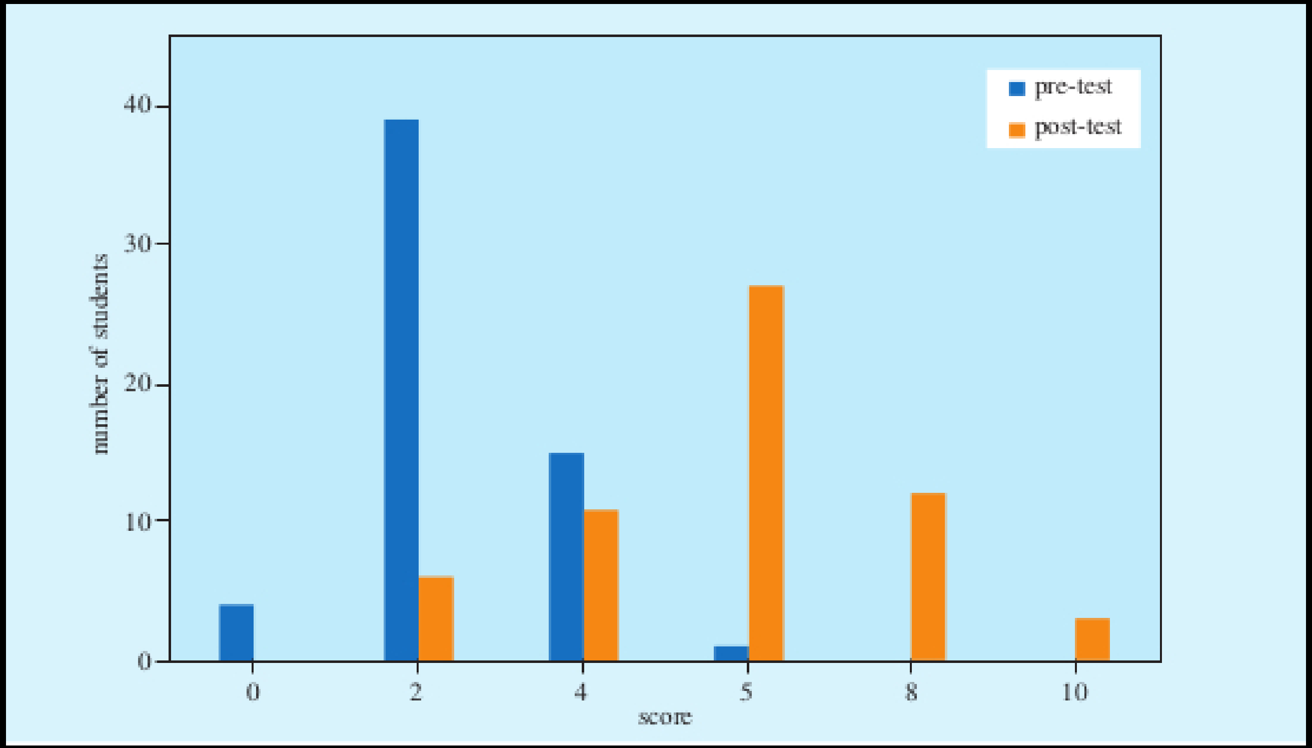
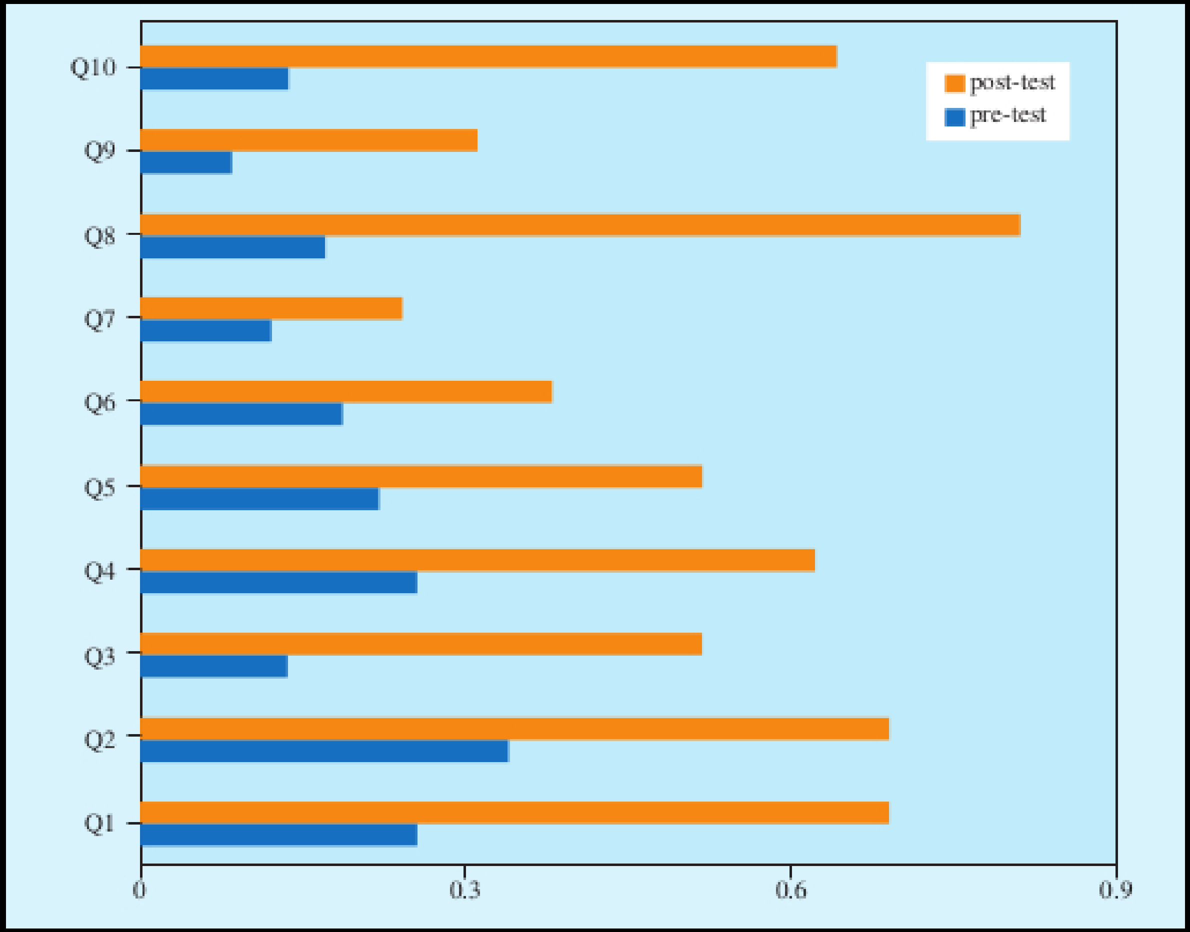


Correct answers were given 1 point.

Average pre-test score was 1.90 ± 0.14 (st.err.), while that of the post-test was 5.3 ± 0.3 (st.err.). Difference is statistically significant ($t = 11.420$, $df = 87.849$, $p < 10^{-4}$).

Students' score distribution in the pre- and post-activity questionnaire

Assessing TLM efficacy



Key Ideas	Pre (%)	Post (%)
Energy and nuclear reactions	14	40
Mechanical and thermal equilibrium	25	66
Spectral analysis	14	56

Frequency of students' correct answers in the pre- and post-activity questionnaire

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Conclusions

- Our study confirm previously studies: before the activities students have a scarse knowledge of nuclear fusion processes that undergo in stars’ core
- Our study supports the use of stars as rich context to help students achieve high level, ‘expert’, scientific reasoning skills.
- We plan to enrich our activities by including tasks about the birth, evolution, and death of stars by deepening the role of the star’s mass.
- We will use our TLM as a mean to test a Learning Progression focused on Stars.

Thank you for your attention

How to get a copy of the paper: mail to

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