

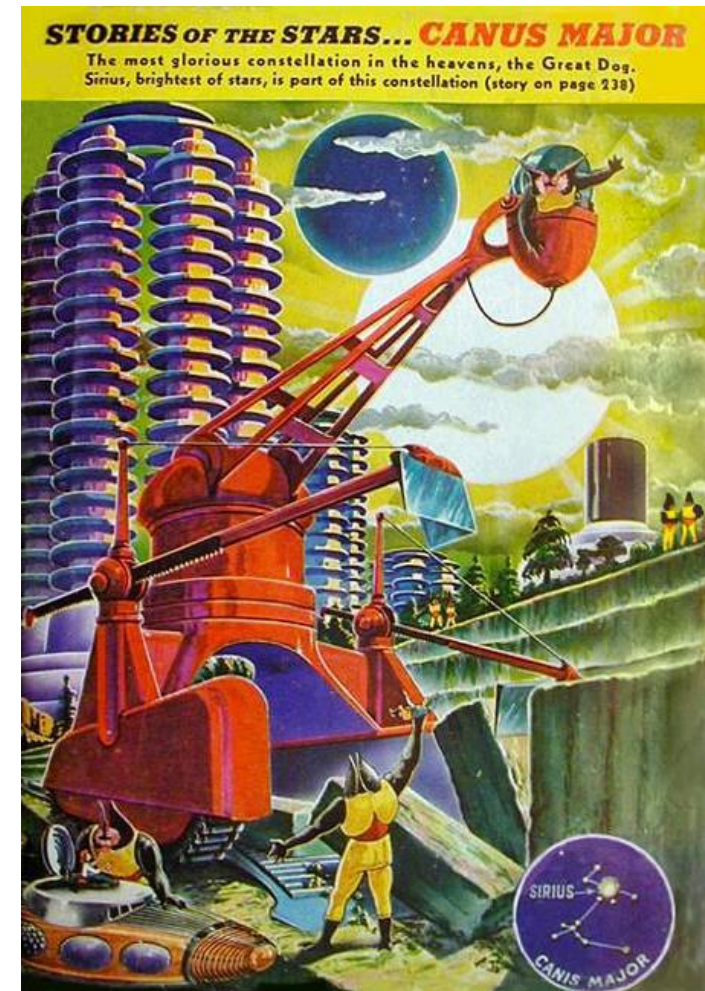
Predicting Sky Dome Appearance on Earth-like Extrasolar Worlds

Alexander Wilkie, Lukas Hošek

Outline

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- Analytical Models of Sky-Dome Radiance
- Adapting the Hošek Sky Model for Exoplanet Scenes
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- Conclusion

Exoplanet skies from Science Fiction Magazine covers



Studies of Exoplanet Appearance

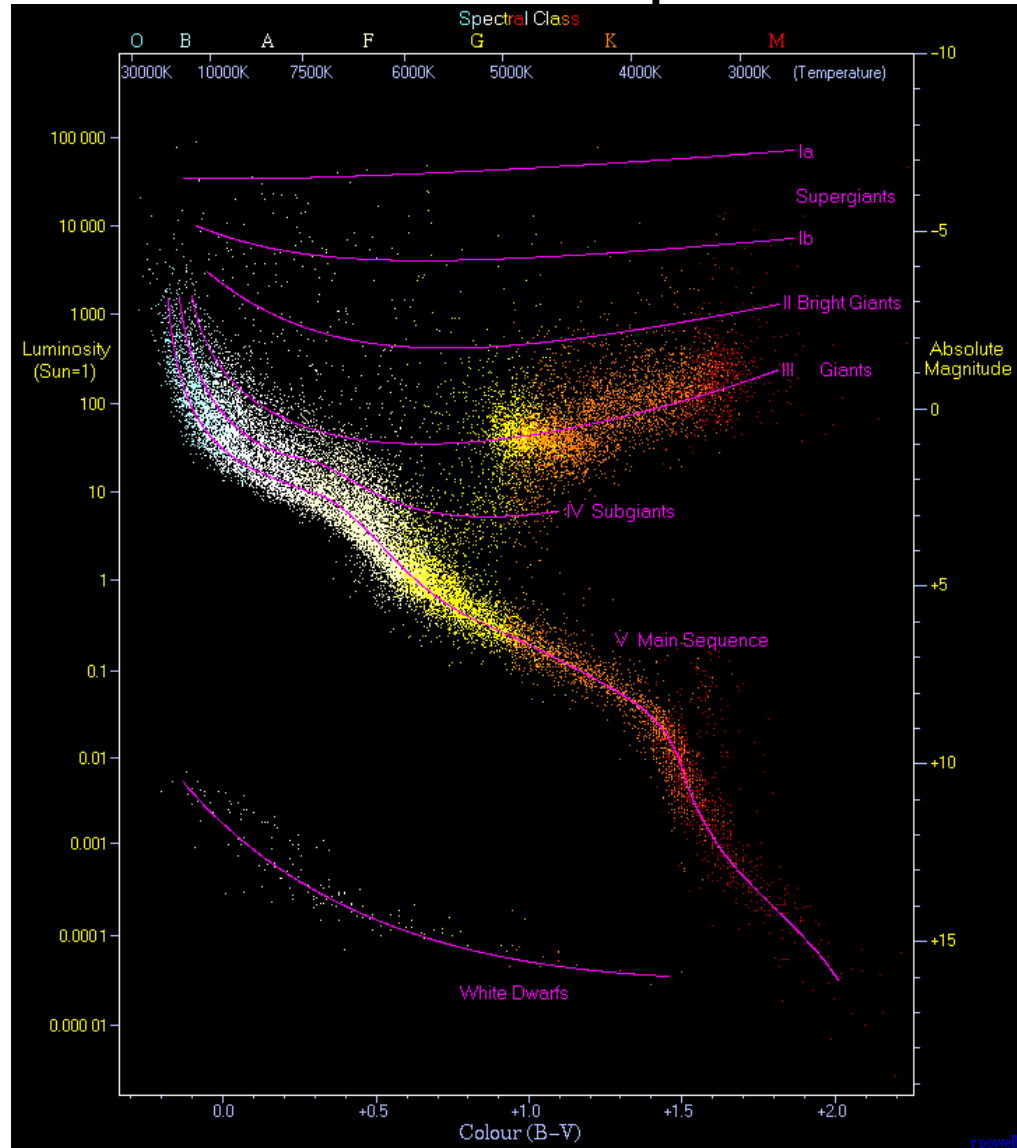


- Exoplanet Images from the 1977 movie Star Wars
- Tatooine orbits two stars
- Double shadows are missing



- Another source is the book „Xenology – An Introduction to the Scientific Study of Extraterrestrial Life, Intelligence, and Civilization“ – by R. Freitas

Star Emission Spectra



- Our Sun is class G
 - It has a temperature of 5.778 Kelvin
- Tatooine Stars are Class G and K
- Emission Spectra can, on a small-scale spectral level, differ considerably
- Largely irrelevant for the prediction of the appearance of objects for humans
- ⇒ Can be ignored

Analytical Models of Sky-Dome Radiance

- Explicit simulation of light transport in the atmosphere
 - Not used because of excessive computational requirements
- High dynamic range
 - Not suitable for prediction of exoplanet environments
- Analytic models of sky dome luminance
 - Is used, but also not generally useful for prediction of arbitrary exoplanet environments
 - It uses pre-computation of light scattering effects. But they are specific for terrestrial worlds \Rightarrow useless for intended purpose.

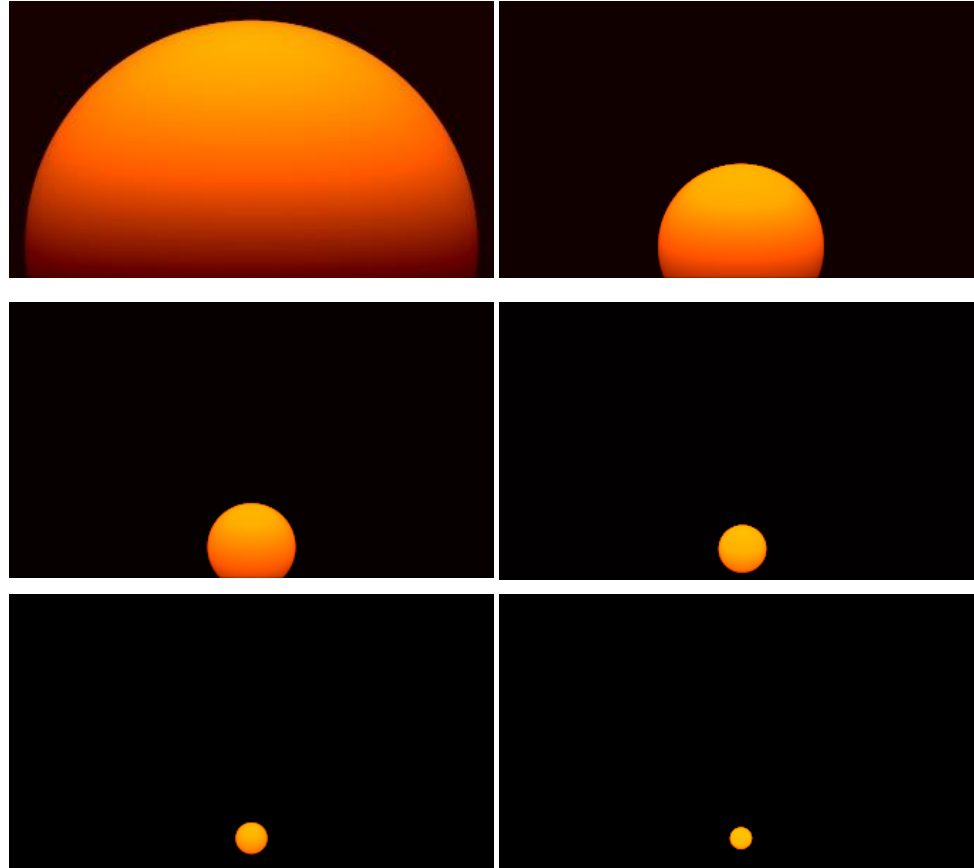
Adapting the Hošek Sky Model for Exoplanet Scenes

- Hošek Sky Model can be used, because it can compute sky dome luminance patterns and solar radiance independently for each waveband
 - Can be used to predict the appearance of the sky on Earth-like planets
- Includes the near UV range, which significantly affects the appearance of materials that include optical brighteners
- But some changes have to be made:
 - Sky dome luminance patterns
 - Direct solar radiance model

Adapting the Hošek Sky Model for Exoplanet Scenes

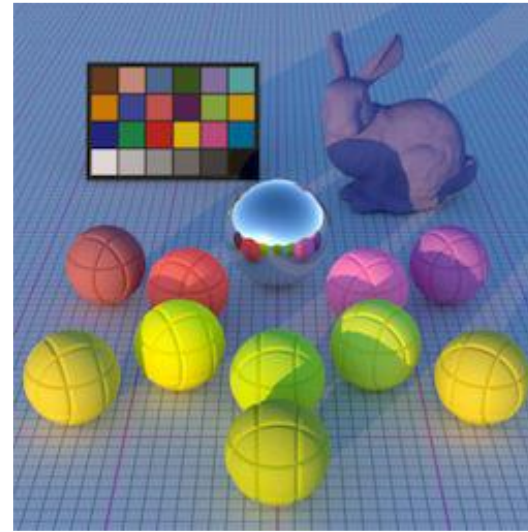
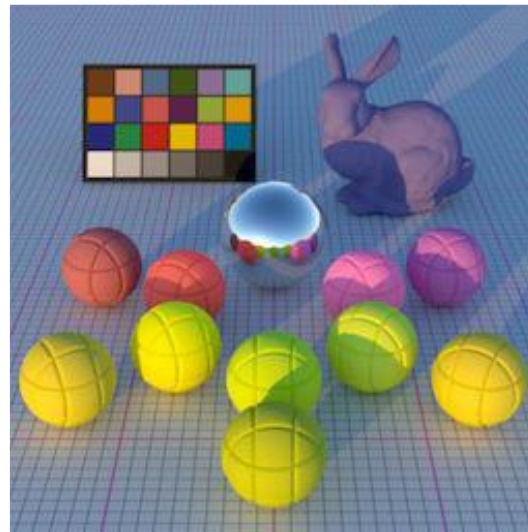
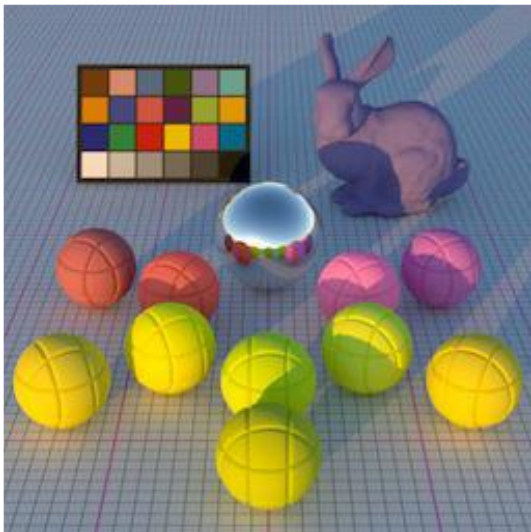
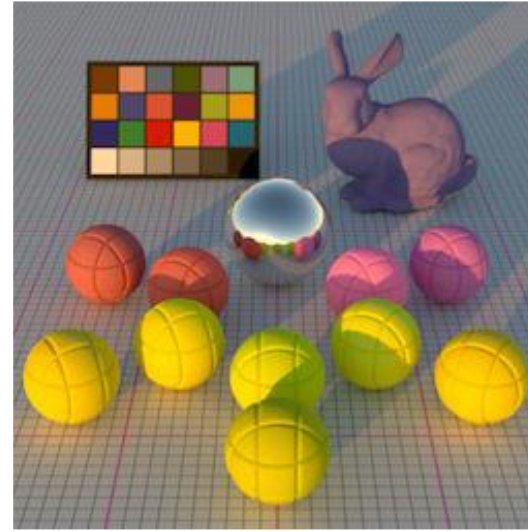
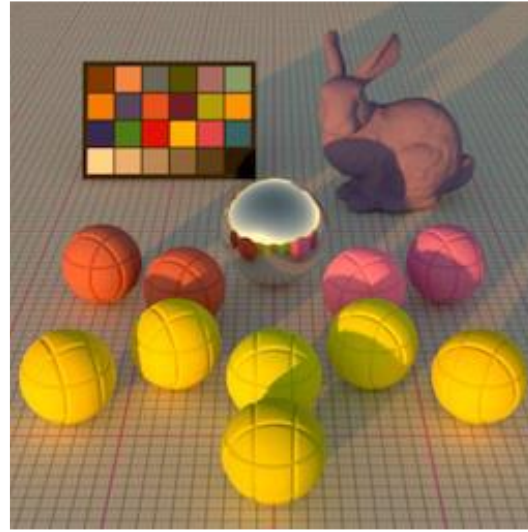
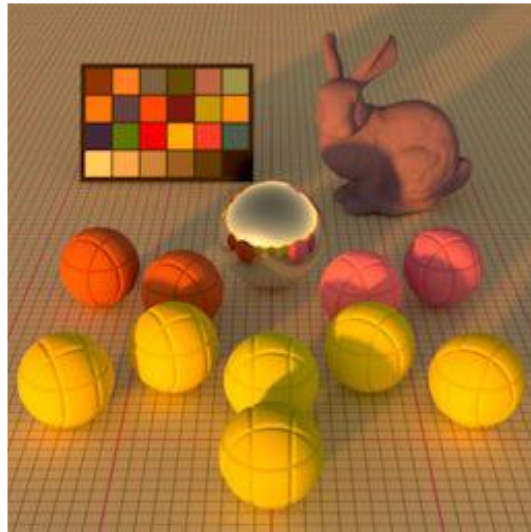
- Intensity of each waveband is solely dependent on the input radiance from the star
 - It is trivial to re-scale the wavebands to match a different star radiance
- Solar disc size on the dome and relative brightness scale of the sky dome have to be kept in mind

Sizes of the suns

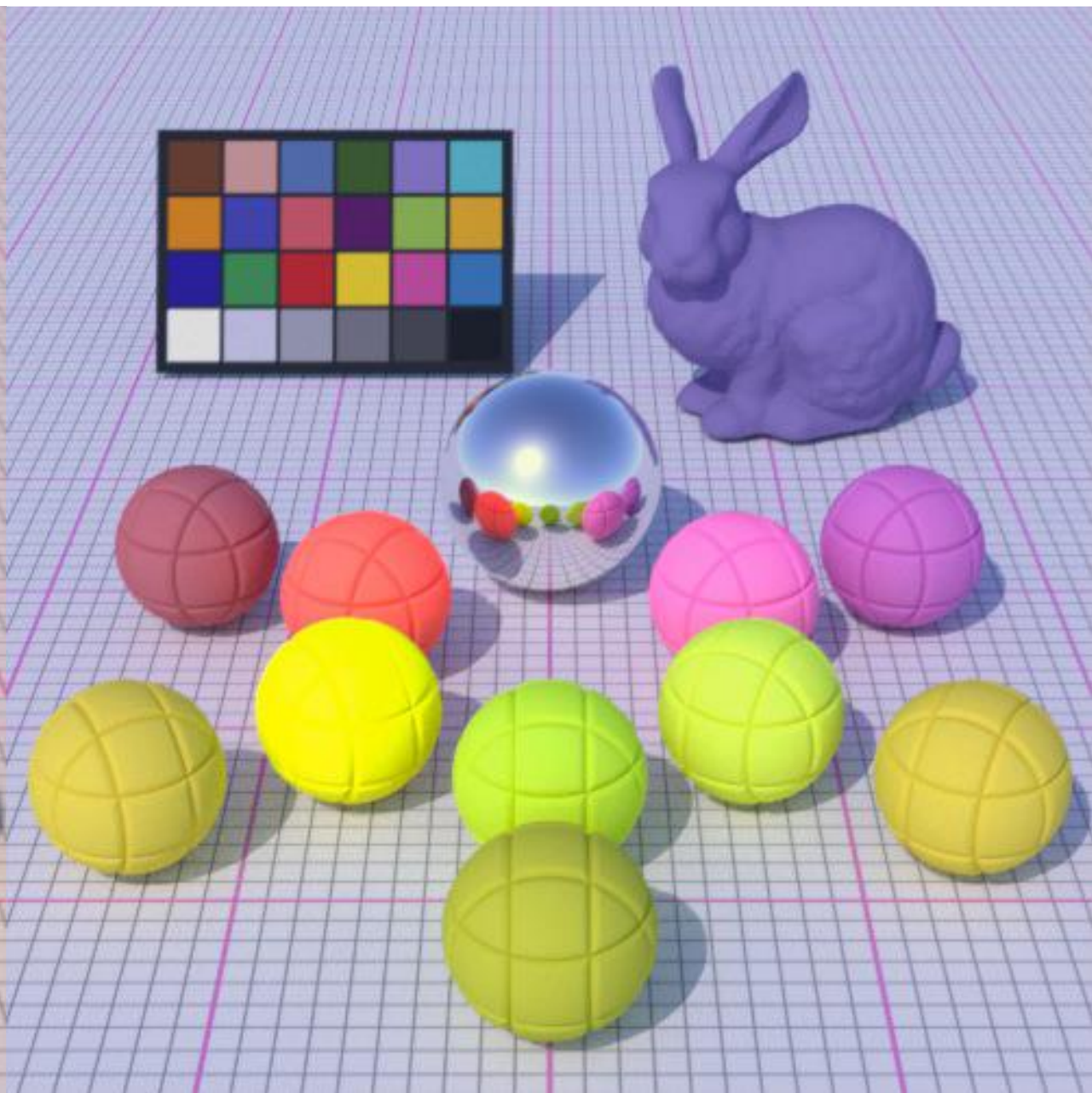


- Small range of absolute solar irradiance values for an earth-like planet to exist
- Therefore Red stars need to be much larger and white/blue stars have to be comparatively tiny
- In the model the solar disc gets shrunken or expanded
- \Rightarrow average energy over the visible range is roughly the same as for the terrestrial sun (wavebands get scaled aswell)
- Problem: The Model does not change the sky dome patterns for different sized sun
 - But luminance patterns don't change perceptibly

Results (Single Stars)



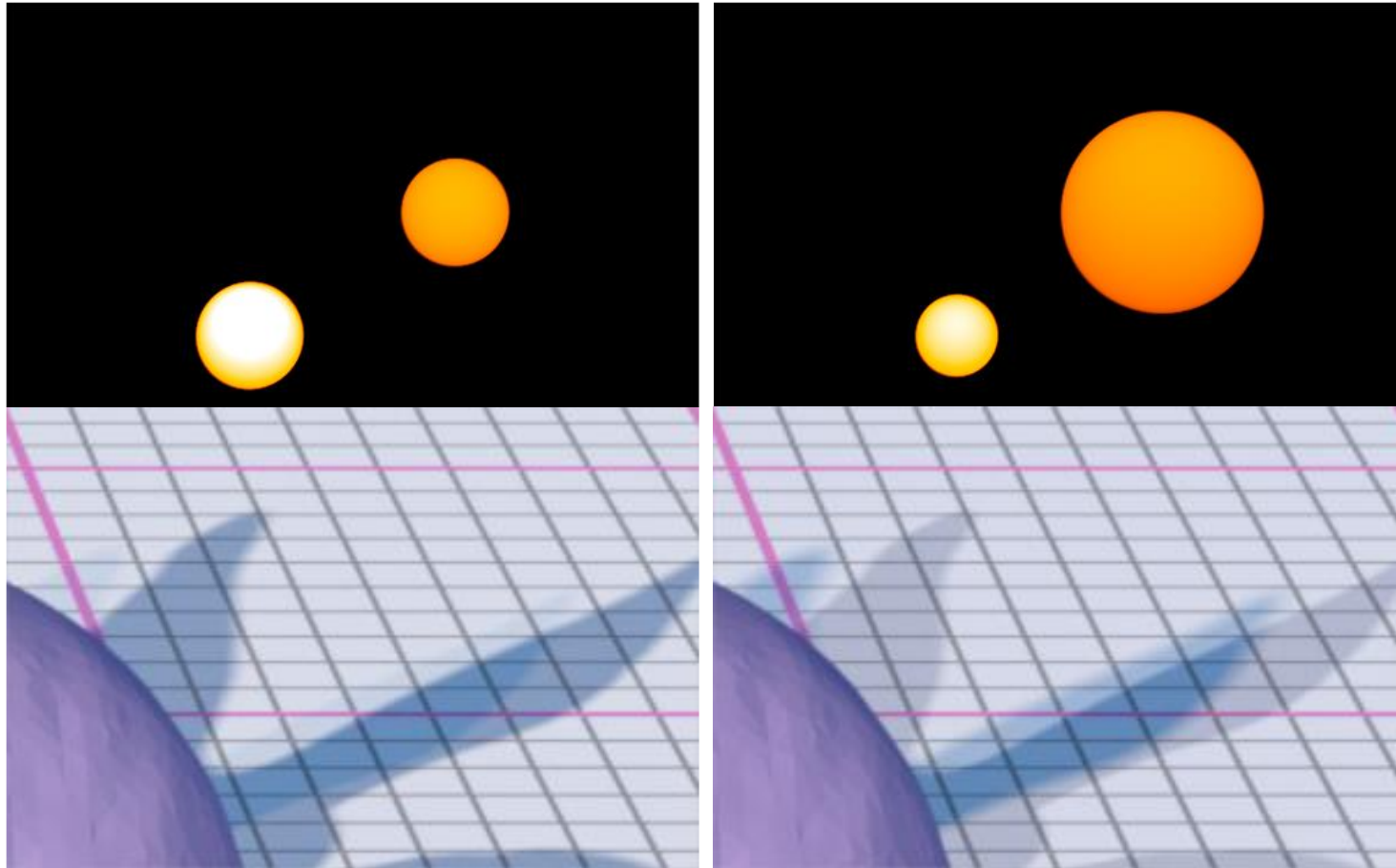
- Sunrise/sunset of an exoplanet illuminated by suns with 3k, 4k, 5k, 6.5k, 8k and 10k Kelvin surface temperature



Results (Binary Stars)

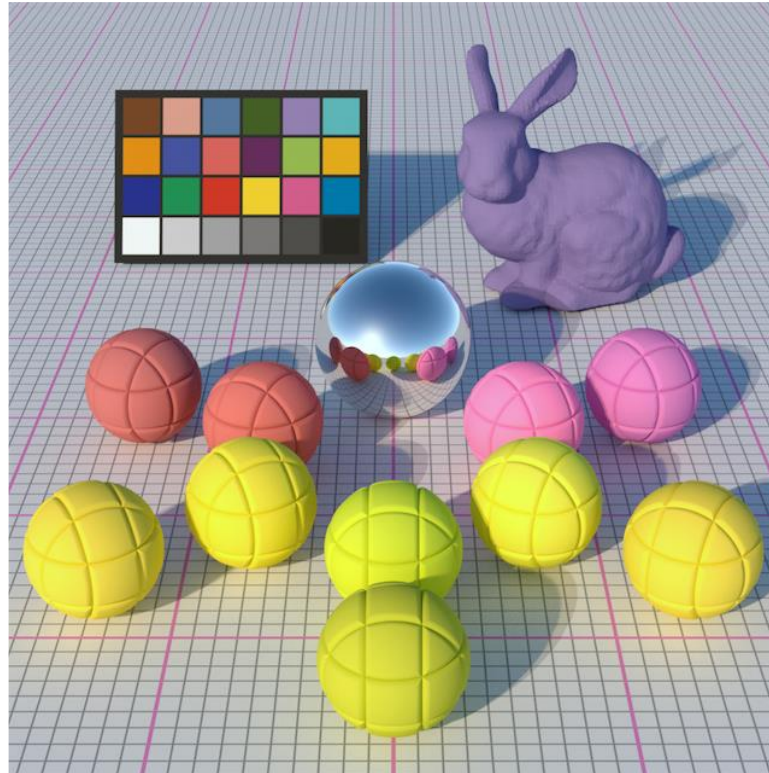
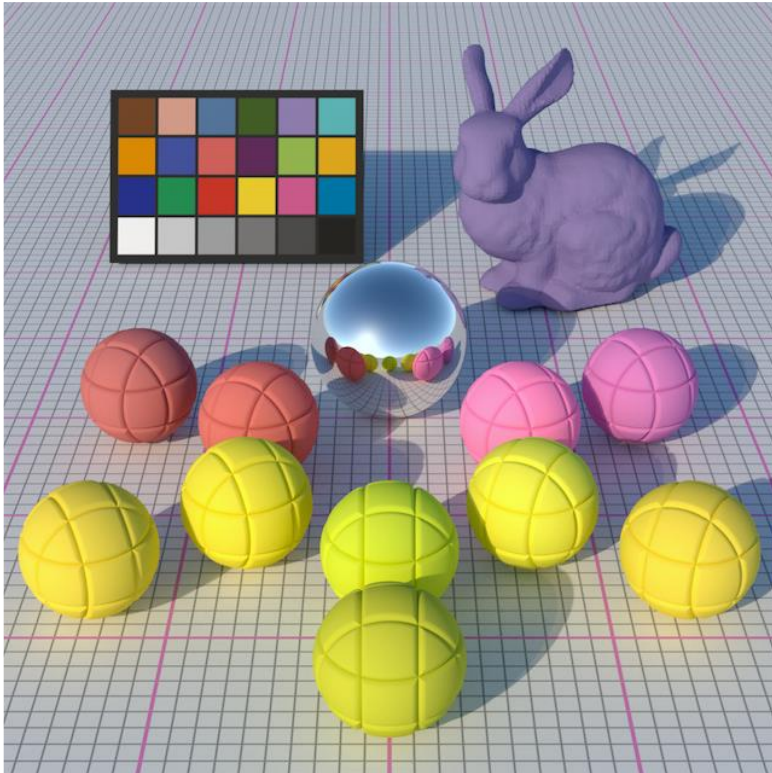
- For two stars, two models were taken and added together
- Care has to be taken to divide incoming radiation properly
 - E.g. every sun in a binary sky must only contribute 50% of the energy

Tatooine (Binary Stars)



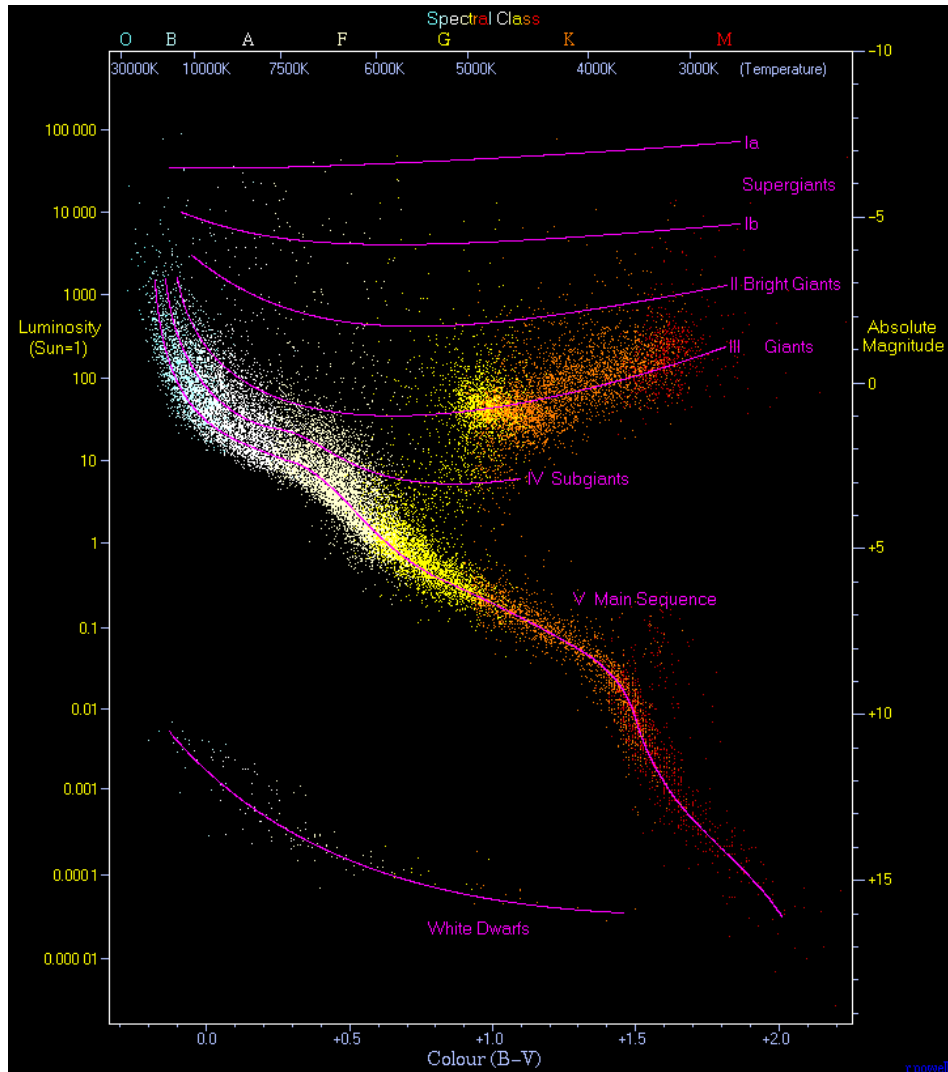
- Two class K and G stars, with 4k and 5.6k Kelvin surface temperature.
- Left: Both stars of equal size on the sky dome
- Right: Both stars with equal intensity

Tatooine (Binary Stars)



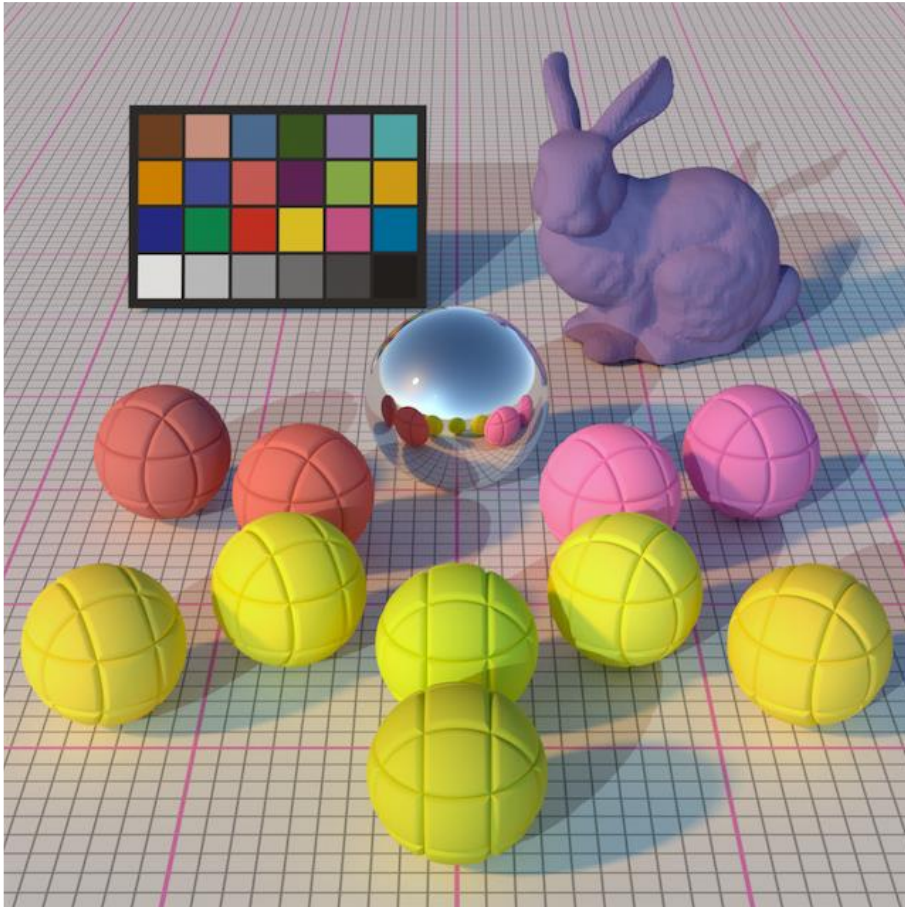
- Two class K and G stars, with 4k and 5.6k Kelvin surface temperature.
- Left: Both stars of equal size on the sky dome
- Right: Both stars with equal intensity

Solaris (Binary Stars)



- In the book „Solaris“ the planet orbits a red and a blue sun
- Two suns with equal brightness are chosen, with 9.8k and 2.6k Kelvin surface temperature

Solaris (Binary Stars)



- In the book „Solaris“ the planet orbits a red and a blue sun
- Two suns with equal brightness are chosen, with 9.8k and 2.6k Kelvin surface temperature
- Appearance of the scene still looks quite normal
- Noticeable are the shadows

Conclusion

- The appearance of outdoor scenes are very similar to that seen on Earth
- An important part of the appearance is the atmosphere itself
- Different star colours appear to play a less significant role than one would assume, especially if white balance is factored in