1. Some Types of Deep Sky Objects

- Stars and star clusters
- Emission nebula
- Reflection nebula

2. Astronomical objects often have very simple, or at least well-known, spectra

3. Human Visual System Response

4. Typical Astronomical Imaging
5. Calibrated Astronomical Imaging

Object spectrum, $s(\lambda)$

$s(\lambda) = \sum F(\lambda)$

$f(\lambda)$ are basis functions, in this case:

$f(\lambda)$ is spd(3000K)

$f(\lambda)$ is spd(5000K)

Detector channel spectral sensitivity, $r(\lambda)$.

Detector response

$r = H f$

$r = \sum F(\lambda) F(\lambda) d\lambda$

$r = \sum F(\lambda) F(\lambda) d\lambda$

Colorimetric coupling between detector channels and display channels

$B = C^1 G H^1$

Display primaries

$p = Br$

Display colorimetry

$e = C p$

6. Why are the stars blue-green?

Stars are broadband emission sources. A typical star, say one with a temperature of 6500K, has a fairly uniform spectral power distribution (spd).

When measured by the three (narrow) passbands used in the emission nebula detector, stars will result in almost equal amplitudes in each channel.

In the illumination model of three line sources, equal amplitudes of each will result in a color that is strongly blue-green.

When there are equal-energy amounts of each primary, the result is a color that is outside of a typical RGB display gamut.

7. Calibrated Astronomical Imaging

Part 2: Blackbody radiators

Object spectrum, $s(\lambda)$

$s(\lambda) = \sum F(\lambda)$

Detector channel spectral sensitivity, $r(\lambda)$.

Detector response

$r = H f$

$r = \sum F(\lambda) F(\lambda) d\lambda$

$r = \sum F(\lambda) F(\lambda) d\lambda$

Colorimetric coupling between detector channels and display channels

$B = C^1 G H^1$

Display primaries

$p = Br$

Display colorimetry

$e = C p$
8. Simultaneous calibration of line and broadband emitters

Detector response

\[ r = H f \]

- \( r \) has 6 detectors.
- \( f \) now has 6 basis functions (lines plus blackbody bases).
- \( H \) is 6x6.

Display primaries

- Three RGB components result
- \( [3 \times 1] = [3 \times 6] \times [6 \times 1] \)

- \( B \) is now 3x6.
- \( G \), the cross products between color matching functions and the basis functions is also 3x6.

More work is needed to resolve the different signal-to-noise ratios of the various detector channels.

9. Combining individually calibrated images

Create median mask for use as spatial filter

- Weight each image by its mask and superpose them

The result is a correctly rendered emission nebula in a field of correctly colored stars!
1. **Colors of the Deep Sky**

### 10. Some Examples

#### N.A. Sharp, REU program, National Optical Astronomy Observatory/Association of Universities for Research in Astronomy/National Science Foundation

“This image was made by combining a number of exposures taken on the night of July 15th 1996, with a 2048x2048 CCD detector at the Burrell Schmidt telescope of the Warner and Swasey Observatory of Case Western Reserve University (CWRU), situated on Kitt Peak in southern Arizona.”

The color characteristics are typical of RGB exposures which have been color balanced for the stars.

---

#### Press release images

**Target:** NGC 6543

*This color picture, taken with the Wide Field Planetary Camera-2, is a composite of three images taken at different wavelengths. (red, hydrogen-alpha; blue, neutral oxygen, 6300 angstroms; green, ionized nitrogen, 6584 angstroms). NGC 6543 is also known as the Cat’s Eye Nebula. All three of these wavelengths are strongly red, but when assigned to different color channels, creates a pseudocolor image that helps astronomers visualize the chemistry and physical processes going on.*

---

#### Colormetric renderings

**Target:** The NASA Hubble Space Telescope has captured the sharpest view yet of the most famous of all planetary nebulae: the Ring Nebula (M57). In this October 1998 image, the telescope has looked down a barrel of gas cast off by a dying star thousands of years ago. This photo reveals elongated dark clumps of material embedded in the gas at the edge of the nebula; the dying central star floating in a blue haze of hot gas. The nebula is about a light-year in diameter and is located some 2,000 light-years from Earth in the direction of the constellation Lyra.

“The color image was assembled from three black-and-white photos taken through different color filters with the Hubble telescope’s Wide Field Planetary Camera 2. Blue isolates emission from very hot helium, which is located primarily close to the hot central star. Green represents ionized oxygen, which is located farther from the star. Red shows ionized nitrogen, which is radiated from the coolest gas, located farthest from the star. The gradations of color illustrate how the gas glows because it is bathed in ultraviolet radiation from the remnant central star, whose surface temperature is a white-hot 216,000 degrees Fahrenheit (120,000 degrees Celsius).”

---

**Target:** The same S-II (673nm), H-alpha (656nm), O-III (501nm) WFPC2 image channels for a region of this famous Hubble picture, colorimetrically combined. The area is bathed in the strong glow of hydrogen.

---

**Target:** A colormetric rendering of the same S-II (673nm), H-alpha (656nm), O-III (501nm) and He-II (469nm) images. The strength of the H-alpha line in the Ring Nebula is so strong that it contributes virtually nothing to the image, leaving the blue-green O-III to dominate until the very edge of the nebula. Not as pretty perhaps as the NASA promotional picture, but color-correct!”

---