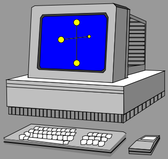
Stars, Dust and Megabytes: Astrophotography in the Southern Hemisphere



Axel Mellinger

Department of Physics
University of Potsdam, Germany

September 2006

Outline

Astro Imaging up to the 19th Century

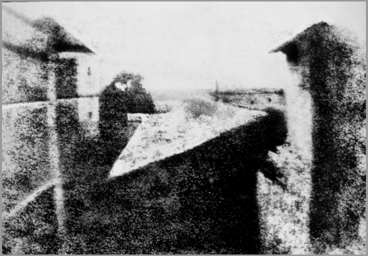
Vincent van Gogh

The Starry Night

Starry Night on the River Rhône

Start of the "Film Era"

1826...1838 First photographic images by JOSEPH N. NIÉPCE and LOUIS DAGUERRE. Exposure times in bright sunlight: **several minutes!**



1841 First *Daguerrotype* photo of the moon (JOHN W. DRAPER)

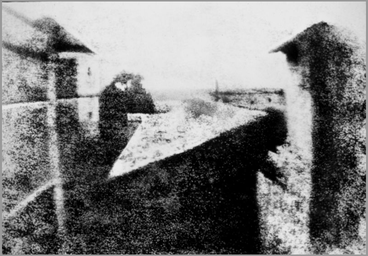
1841 *Calotype* process: first negative/positive images (WILLIAM F. TALBOT)

1871 Dry gelatin process (J. MADDOX)

1880 First photograph of the Orion Nebula (HENRY DRAPER)

Start of the “Film Era”

1826...1838 First photographic images by JOSEPH N. NIÉPCE and LOUIS DAGUERRE. Exposure times in bright sunlight: **several minutes!**



1841 First *Daguerrotype* photo of the moon (JOHN W. DRAPER)

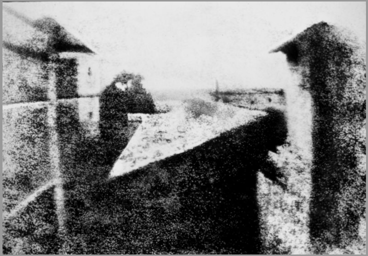
1841 *Calotype* process: first negative/positive images (WILLIAM F. TALBOT)

1871 Dry gelatin process (J. MADDOX)

1880 First photograph of the Orion Nebula (HENRY DRAPER)

Start of the "Film Era"

1826...1838 First photographic images by JOSEPH N. NIÉPCE and LOUIS DAGUERRE. Exposure times in bright sunlight: **several minutes!**



1841 First *Daguerrotype* photo of the moon (JOHN W. DRAPER)

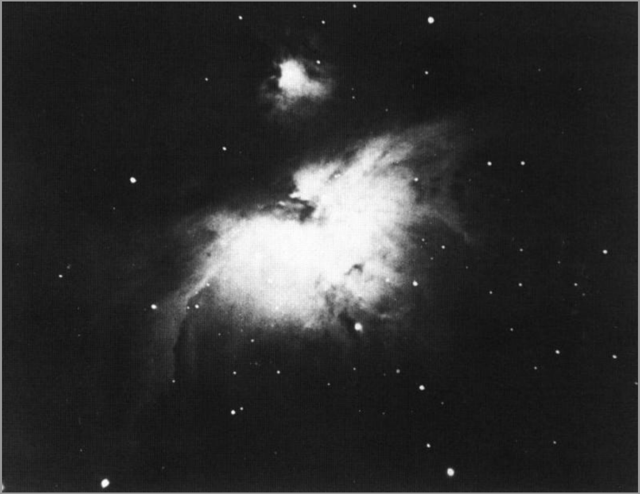
1841 *Calotype* process: first negative/positive images (WILLIAM F. TALBOT)

1871 Dry gelatin process (J. MADDOX)

1880 First photograph of the Orion Nebula (HENRY DRAPER)

Start of the "Film Era"

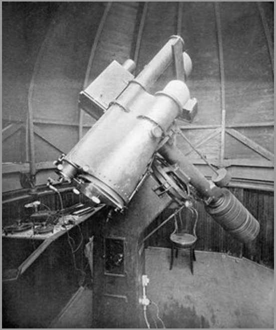
1883 Photographs show more detail than the human eye perceives

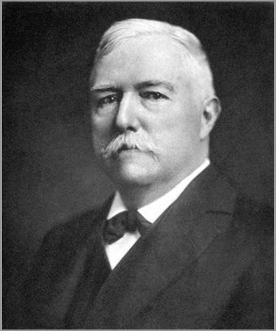


Orion Nebula (AINSLEE COMMON, England)

Start of the "Film Era"

1887…1923 EDWARD E. BARNARD, Lick Observatory:
Atlas of Selected Regions of the Milky Way
First wide-angle survey

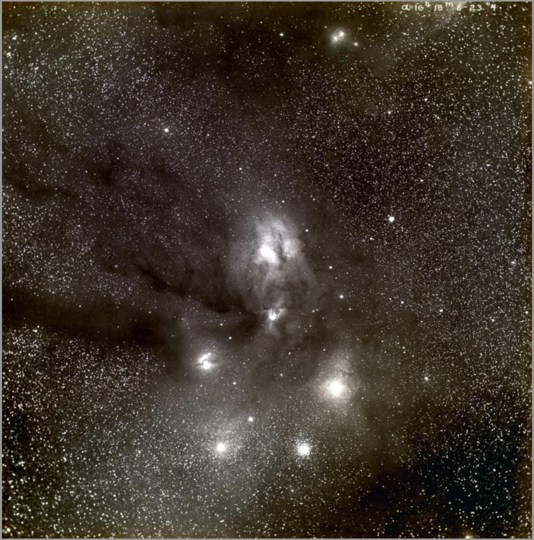




1950…1957 Palomar Observatory Sky Survey
894 plates in both red and blue light

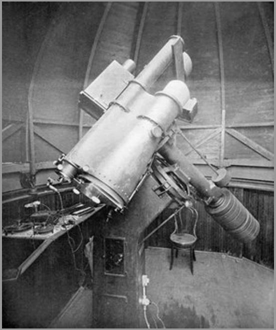
Start of the "Film Era"

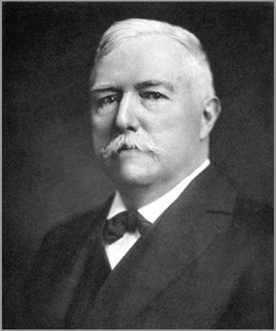
Antares/Rho Ophiuchi Region



Start of the “Film Era”

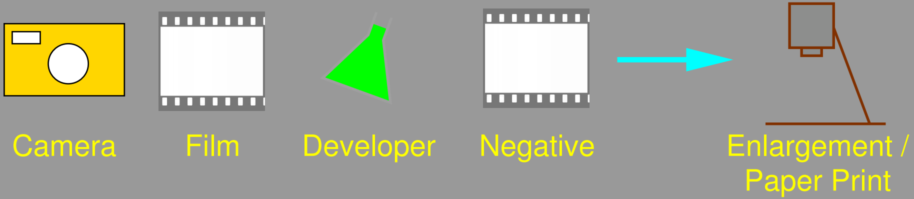
1887...1923 EDWARD E. BARNARD, Lick Observatory:
Atlas of Selected Regions of the Milky Way
First wide-angle survey



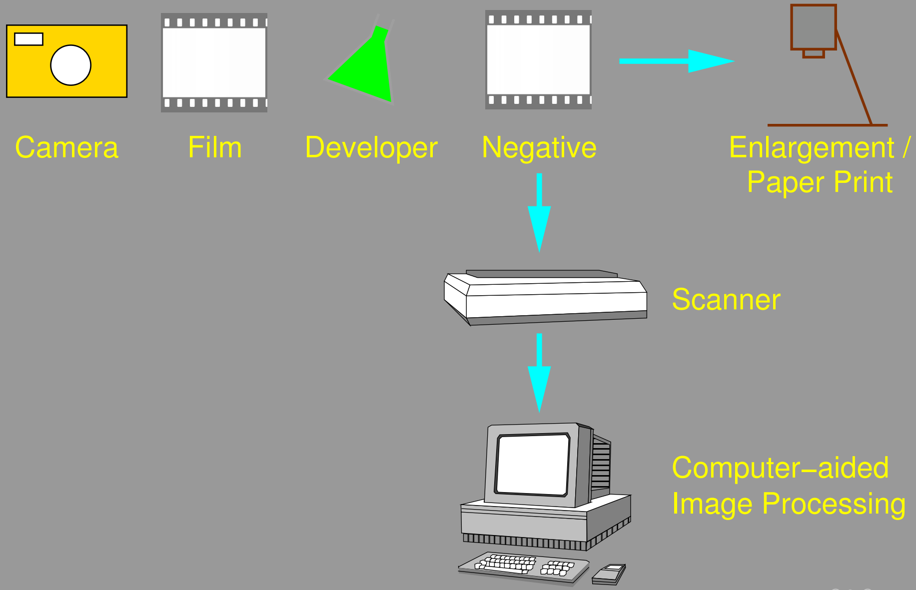


1950...1957 Palomar Observatory Sky Survey
894 plates in both red and blue light

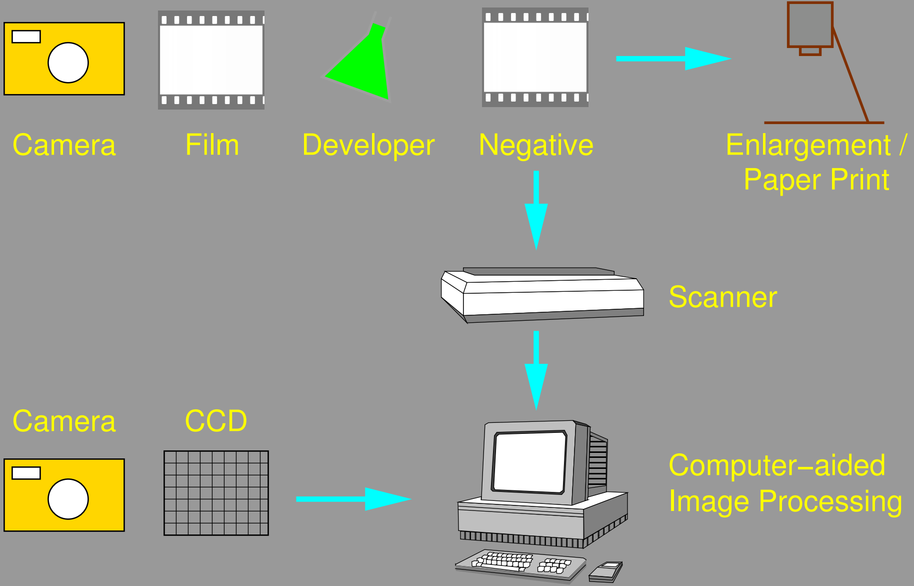
Astro Imaging in the 20th and 21st Century: Going Digital



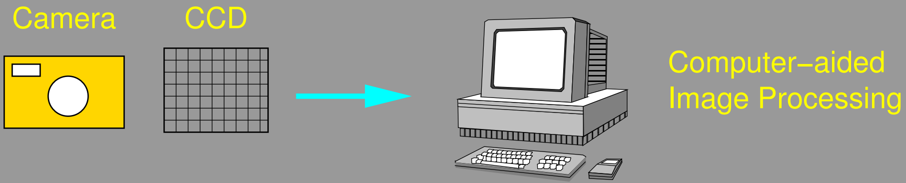
Astro Imaging in the 20th and 21st Century: Going Digital



Astro Imaging in the 20th and 21st Century: Going Digital



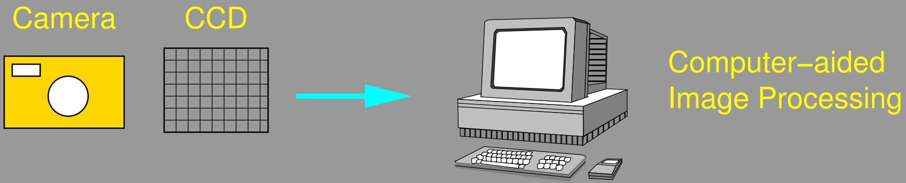
Astro Imaging in the 20th and 21st Century: Going Digital



Astro Imaging in the 20th and 21st Century: Going Digital

Advantages of digital photography

- declining availability of film
- high quantum yield (30 . . . 80 %; film: 1 %)
- linear detector
- virtually unlimited processing options for digital images



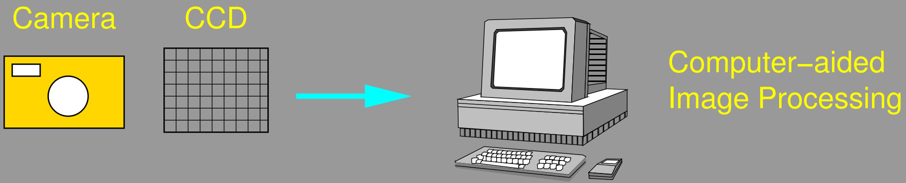
Astro Imaging in the 20th and 21st Century: Going Digital

Advantages of digital photography

- declining availability of film
- high quantum yield (30…80 %;   film: 1 %)
- linear detector
- virtually unlimited processing options for digital images

Disadvantages

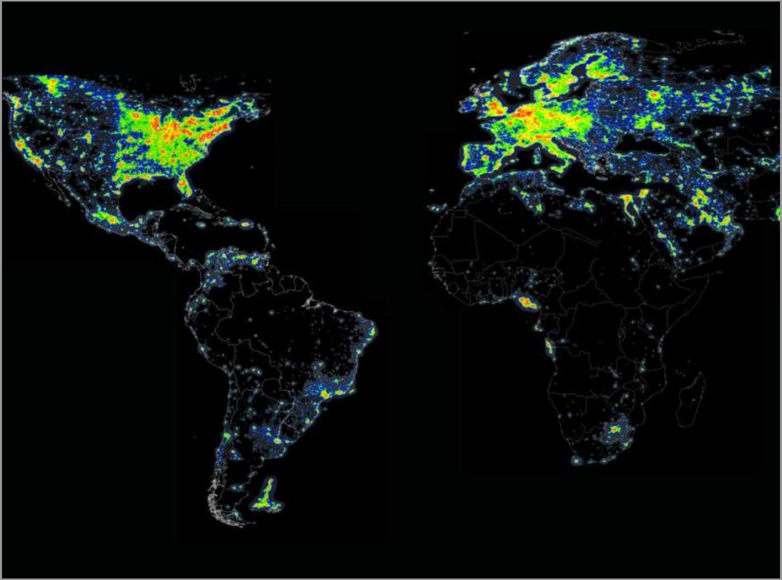
- high cost
- high electrical power requirements (Peltier cooler!)



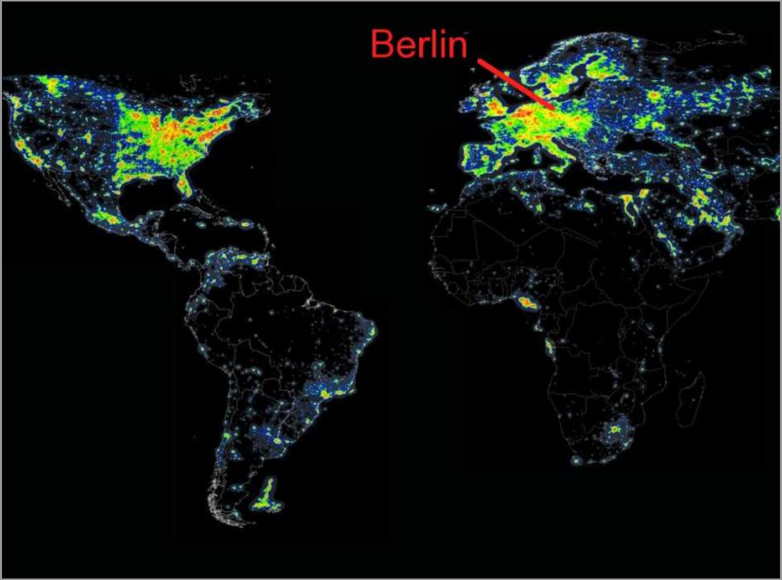
From Stars to Pixels: The Making of an Astro Photo

1. Dark-Sky Sites
2. Equipment: Telescope, Camera, . . .
3. Digital Image Processing

Dark Sky Locations?



Dark Sky Locations?

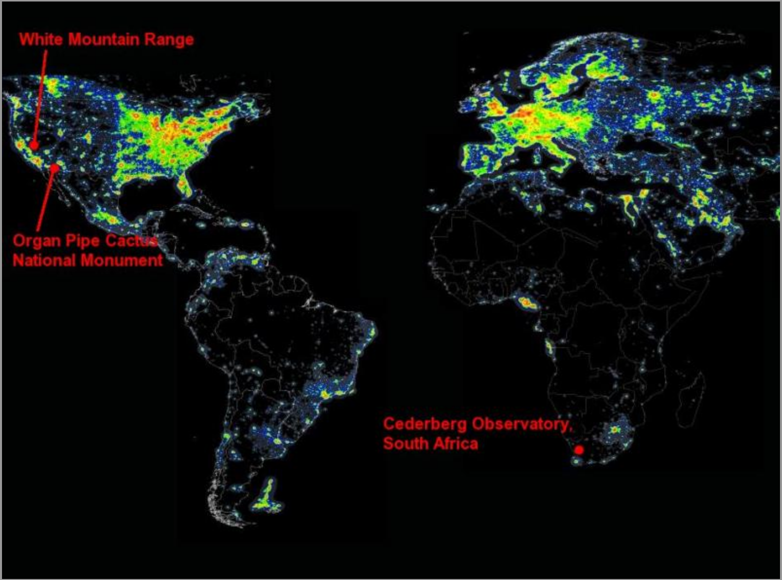


Berlin area: beautiful palaces, but . . .

Severe light pollution . . .

Severe light pollution . . . and nearly at sea level!

Dark Sky Locations



Eastern Sierra Nevada

Home of the Ancient Bristlecone Pines

White Mountain Research Station (Elevation 12,500 ft)

White Mountain Research Station (Elevation 12,500 ft)

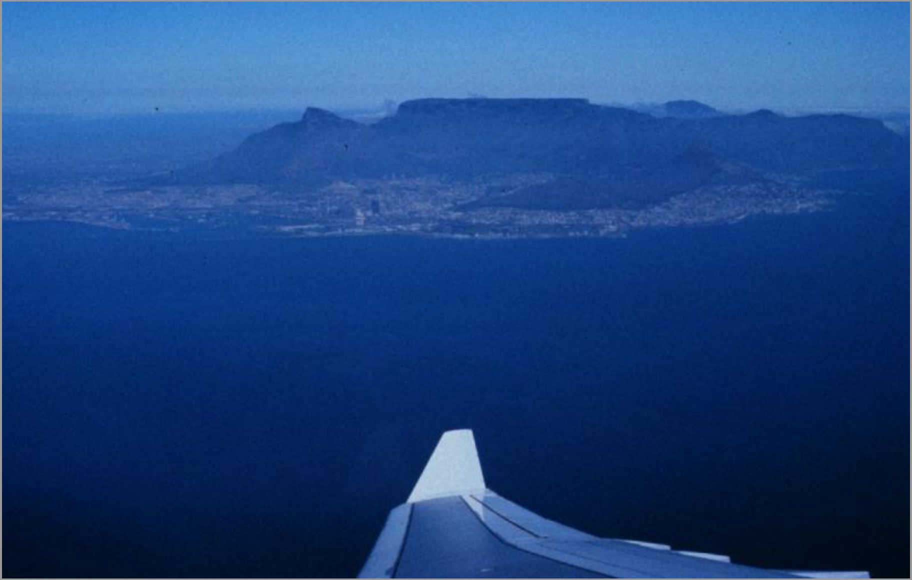
July 1997: Start of the Milky Way Panorama

The Sonora Desert: Organ Pipe Cactus National Monument

The Sonora Desert: Organ Pipe Cactus National Monument

South Africa

South Africa: Table Mountain/Cape Town



South Africa: Cape of Good Hope

Looking for Tourists . . .

Cederberg Mountains

Cederberg Observatory

Cederberg Star Trails

South African Large Telescope (SALT)

Koornlandskloof Guest Farm

Star Trails over Koornlandskloof

Koornlandskloof Guest Farm

From Stars to Pixels: The Making of an Astro Photo

1. Dark-Sky Sites
2. Equipment: Telescope, Camera, . . .
3. Digital Image Processing

Mobile Astrophotography Equipment

- Camera
  - Astro CCD
  - Consumer Digital
  - Film
- Camera lens (or telescope)
- Mount (for tracking)
- Guidescope (often with CCD autoguider)
- Laptop computer
- Battery (12 V, 2. . . 5 amps in the field)

Mobile Astrophotography Equipment

- Camera
  - Astro CCD
  - Consumer Digital
  - Film
- Camera lens (or telescope)
- Mount (for tracking)
- Guidescope
  (often with CCD autoguider)
- Laptop computer
- Battery
  (12 V, 2. . . 5 amps in the field)

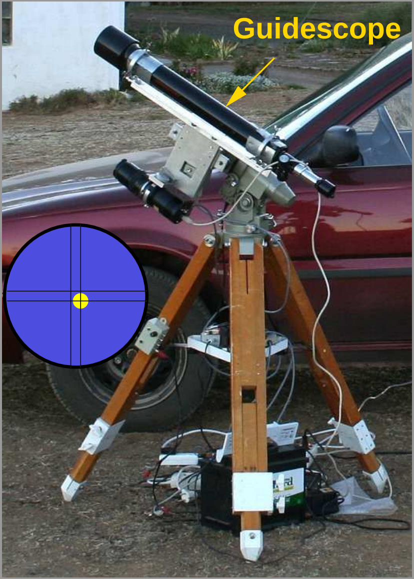
Mobile Astrophotography Equipment

- Camera
  - Astro CCD
  - Consumer Digital
  - Film
- Camera lens (or telescope)
- Mount (for tracking)
- Guidescope
  (often with CCD autoguider)
- Laptop computer
- Battery
  (12 V, 2...5 amps in the field)

Mobile Astrophotography Equipment

- Camera
  - Astro CCD
  - Consumer Digital
  - Film
- Camera lens (or telescope)
- Mount (for tracking)
- Guidescope
  (often with CCD autoguider)
- Laptop computer
- Battery
  (12 V, 2. . . 5 amps in the field)

Mobile Astrophotography Equipment



- Camera
  - Astro CCD
  - Consumer Digital
  - Film
- Camera lens (or telescope)
- Mount (for tracking)
- Guidescope
  (often with CCD autoguider)
- Laptop computer
- Battery
  (12 V, 2 . . . 5 amps in the field)

Mobile Astrophotography Equipment

- Camera
  - Astro CCD
  - Consumer Digital
  - Film
- Camera lens (or telescope)
- Mount (for tracking)
- Guidescope
  (often with CCD autoguider)
- Laptop computer
- Battery
  (12 V, 2. . . 5 amps in the field)

Mobile Astrophotography Equipment

- Camera
  - Astro CCD
  - Consumer Digital
  - Film
- Camera lens (or telescope)
- Mount (for tracking)
- Guidescope
  (often with CCD autoguider)
- Laptop computer
- Battery
  (12 V, 2. . . 5 amps in the field)

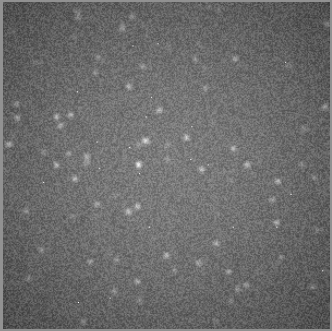
From Stars to Pixels: The Making of an Astro Photo

1. Dark-Sky Sites
2. Equipment: Telescope, Camera, . . .
3. Digital Image Processing

Digital Image Processing: Basic Steps

Removing artifacts

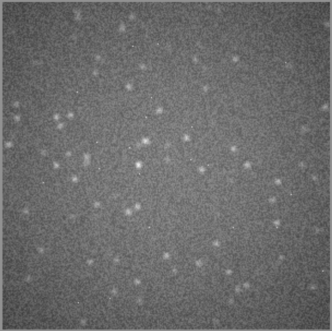
- Raw image shows
  - noise
  - “hot” pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting:
  divide by *flat frame*



Digital Image Processing: Basic Steps

Removing artifacts

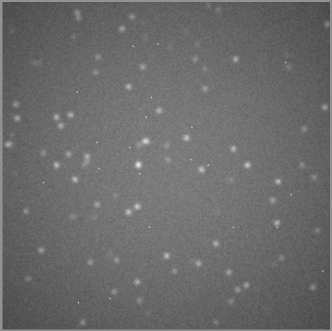
- Raw image shows
  - noise
  - “hot” pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting:
  divide by *flat frame*



Digital Image Processing: Basic Steps

Removing artifacts

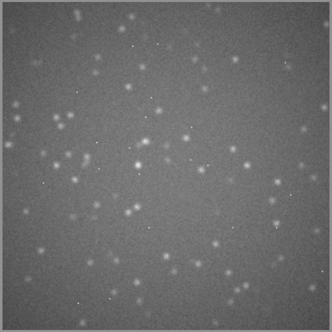
- Raw image shows
  - noise
  - “hot” pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting:
  divide by *flat frame*



Digital Image Processing: Basic Steps

Removing artifacts

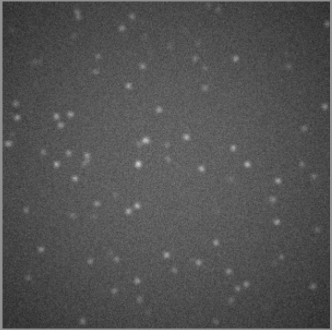
- Raw image shows
  - noise
  - “hot” pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting:
  divide by *flat frame*



Digital Image Processing: Basic Steps

Removing artifacts

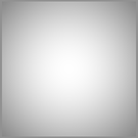
- Raw image shows
  - noise
  - “hot” pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting:
  divide by *flat frame*

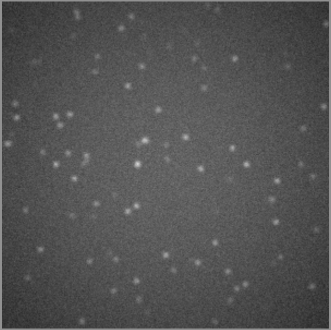


Digital Image Processing: Basic Steps

Removing artifacts

- Raw image shows
  - noise
  - “hot” pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting:
  divide by *flat frame*

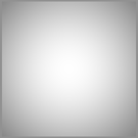


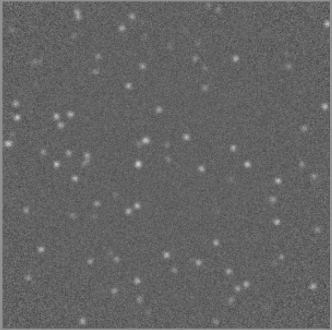


Digital Image Processing: Basic Steps

Removing artifacts

- Raw image shows
  - noise
  - "hot" pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting: divide by *flat frame*

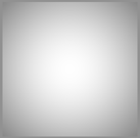


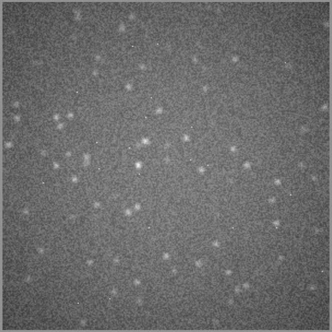


Digital Image Processing: Basic Steps

Removing artifacts

- Raw image shows
  - noise
  - “hot” pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting:
  divide by *flat frame*

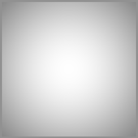


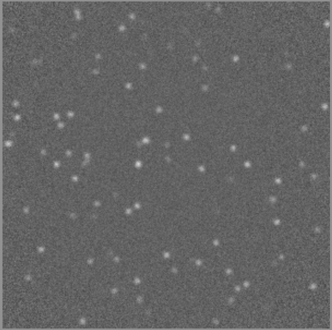


Digital Image Processing: Basic Steps

Removing artifacts

- Raw image shows
  - noise
  - “hot” pixels
  - vignetting (uneven illumination)
- Average images
- Remove dark current and hot pixels
- Remove vignetting:
  divide by *flat frame*





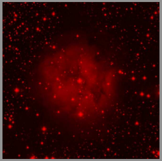
Digital Image Processing: Adding Color

Many astronomical CCD cameras have *monochrome* sensors!

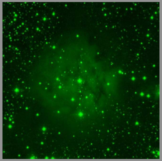
LRGB color composites of filtered images

L

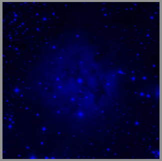
R



G



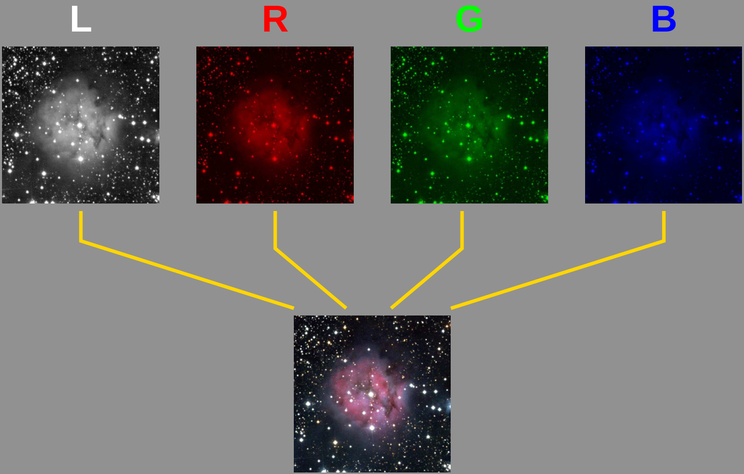
B



Digital Image Processing: Adding Color

Many astronomical CCD cameras have *monochrome* sensors!

LRGB color composites of filtered images

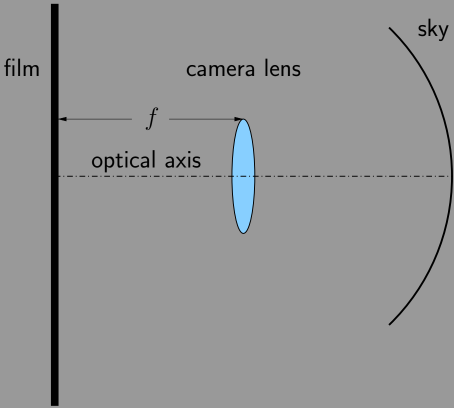


Mosaic Assembly

Why mosaics?

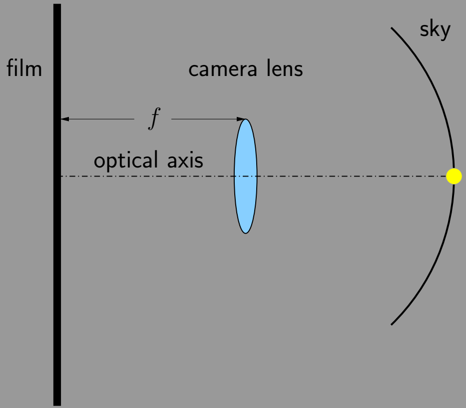
- Cover large field of view
- Create large, high-resolution images
  (e. g., for planetarium projection)
- Uses smaller, less expensive CCD cameras

Mosaics: geometric distortion



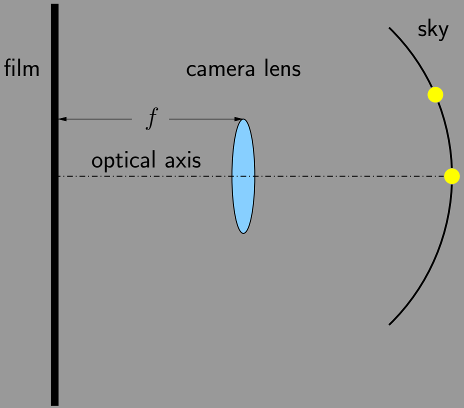
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



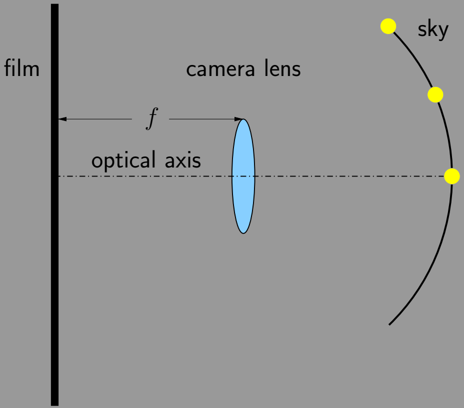
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



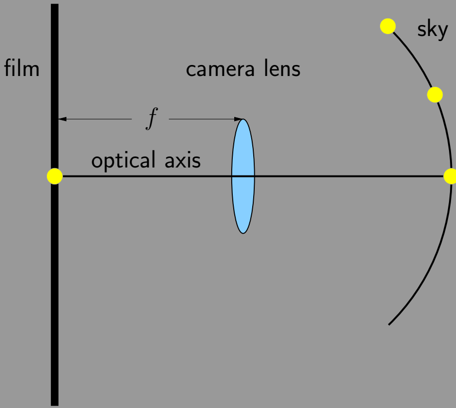
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



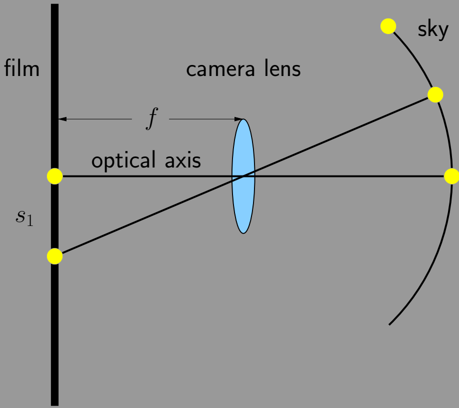
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



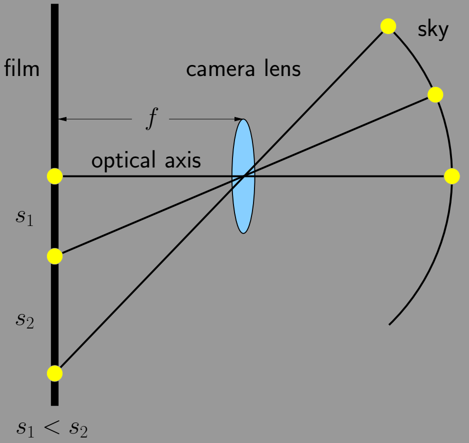
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



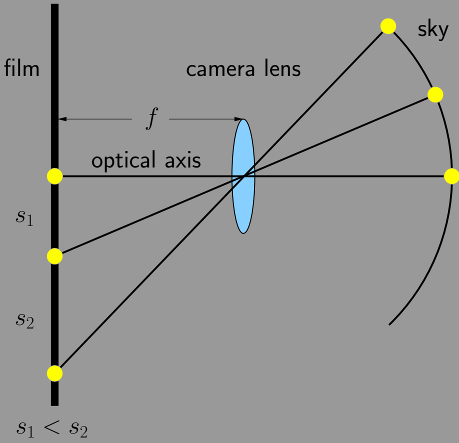
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



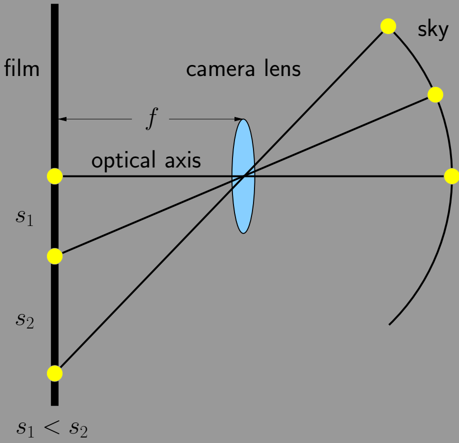
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



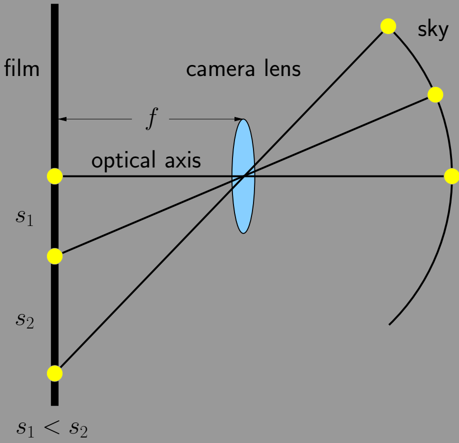
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



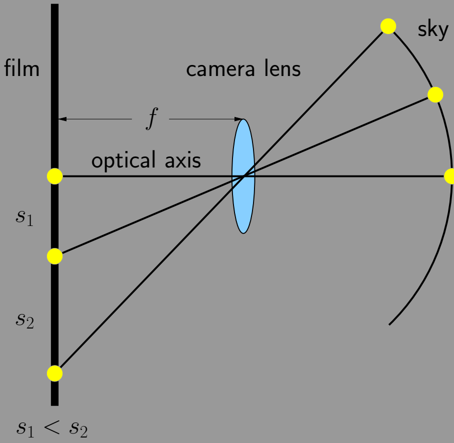
- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

Mosaics: geometric distortion



- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

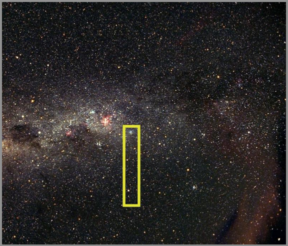
Mosaics: geometric distortion



- Spherical celestial sphere imaged onto planar film/CCD
- Distortion increases with increasing angle σ between star and optical axis
- Geometric effect – NOT an indication of a faulty camera lens
- Mathematical relation: $s = f \tan \sigma$
- can be corrected!

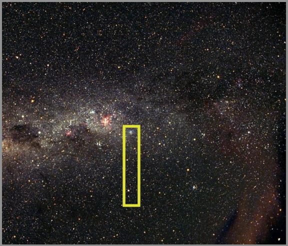
Mosaics: geometric distortion

Example: southern Milky Way around NGC 3114



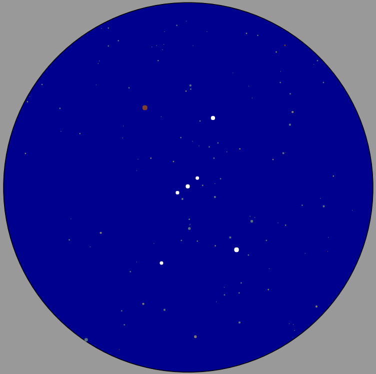
Mosaics: geometric distortion

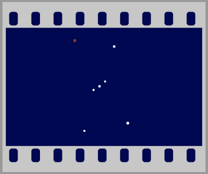
Example: southern Milky Way around NGC 3114



Astrometry: from Sky to CCD/Film

Conversion:
star coordinates $(\alpha, \delta) \rightarrow$
pixel coordinates (x, y)

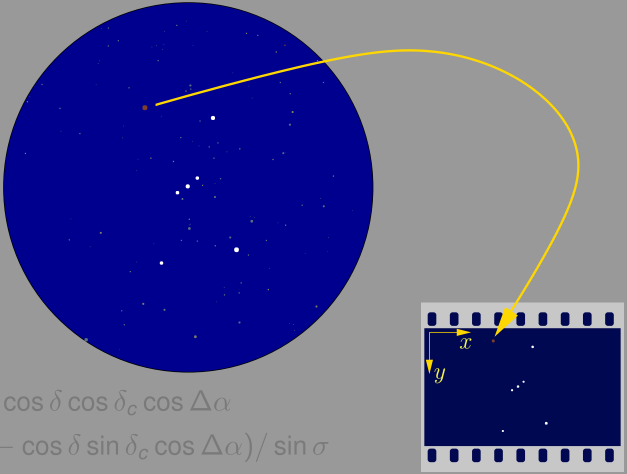




$$
\begin{aligned}
\cos\sigma &= \sin\delta\sin\delta_c + \cos\delta\cos\delta_c\cos\Delta\alpha \\
\cos\gamma &= (\sin\delta\cos\delta_c - \cos\delta\sin\delta_c\cos\Delta\alpha)/\sin\sigma \\
s &= f\tan\sigma \\
x &= x_c - s\sin(\gamma-\beta) \\
y &= y_c - s\cos(\gamma-\beta)
\end{aligned}
$$

Astrometry: from Sky to CCD/Film

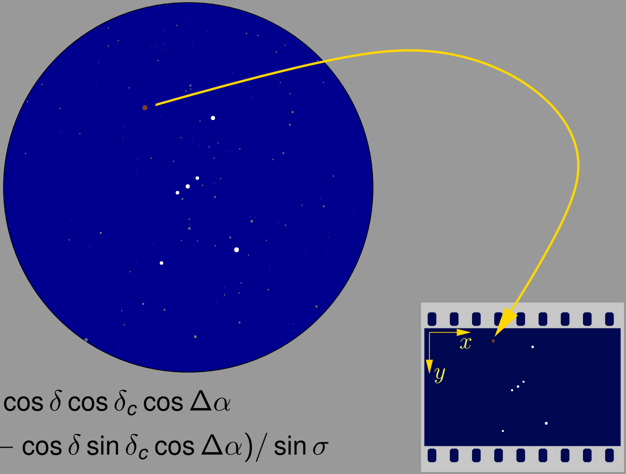
Conversion:
star coordinates $(\alpha, \delta) \rightarrow$
pixel coordinates (x, y)



$$
\begin{aligned}
\cos\sigma &= \sin\delta\sin\delta_c + \cos\delta\cos\delta_c\cos\Delta\alpha \\
\cos\gamma &= (\sin\delta\cos\delta_c - \cos\delta\sin\delta_c\cos\Delta\alpha)/\sin\sigma \\
s &= f\tan\sigma \\
x &= x_c - s\sin(\gamma - \beta) \\
y &= y_c - s\cos(\gamma - \beta)
\end{aligned}
$$

Astrometry: from Sky to CCD/Film

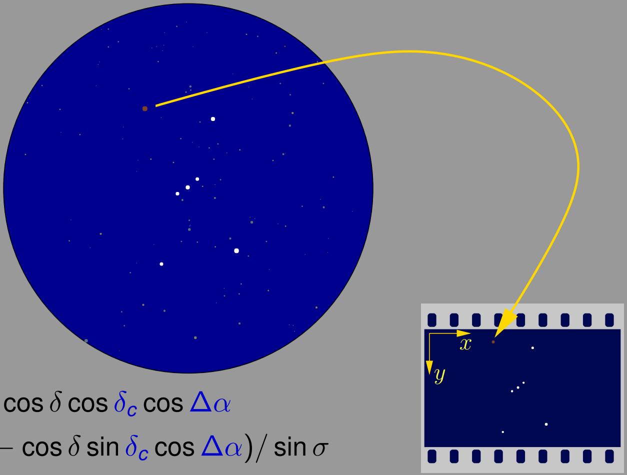
Conversion:
star coordinates $(\alpha, \delta) \rightarrow$
pixel coordinates (x, y)



$$
\begin{aligned}
\cos\sigma &= \sin\delta\sin\delta_c + \cos\delta\cos\delta_c\cos\Delta\alpha \\
\cos\gamma &= (\sin\delta\cos\delta_c - \cos\delta\sin\delta_c\cos\Delta\alpha)/\sin\sigma \\
s &= f\tan\sigma \\
x &= x_c - s\sin(\gamma-\beta) \\
y &= y_c - s\cos(\gamma-\beta)
\end{aligned}
$$

Astrometry: from Sky to CCD/Film

Conversion:
star coordinates $(\alpha, \delta) \rightarrow$
pixel coordinates (x, y)



$$
\begin{aligned}
\cos\sigma &= \sin\delta \sin\delta_c + \cos\delta\cos\delta_c\cos\Delta\alpha \\
\cos\gamma &= (\sin\delta\cos\delta_c - \cos\delta\sin\delta_c\cos\Delta\alpha)/\sin\sigma \\
s &= f\tan\sigma \\
x &= x_c - s\sin(\gamma - \beta) \\
y &= y_c - s\cos(\gamma - \beta)
\end{aligned}
$$

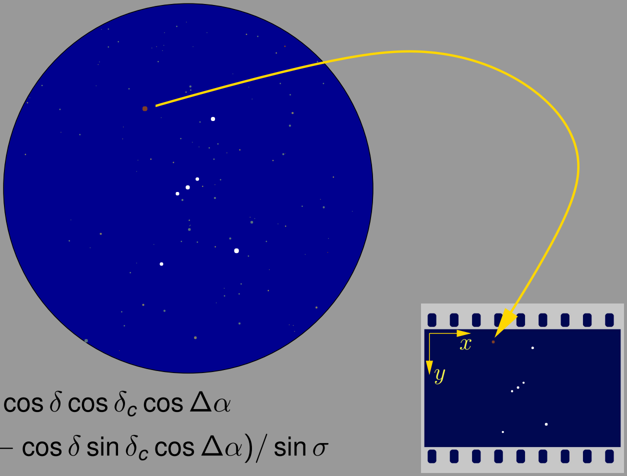
Unknown parameters

Astrometry: from Sky to CCD/Film

Conversion:

star coordinates $(\alpha, \delta) \rightarrow$

pixel coordinates (x, y)



$$
\begin{aligned}
\cos\sigma &= \sin\delta\sin\delta_c + \cos\delta\cos\delta_c\cos\Delta\alpha \\
\cos\gamma &= (\sin\delta\cos\delta_c - \cos\delta\sin\delta_c\cos\Delta\alpha)/\sin\sigma \\
s &= f\tan\sigma \\
x &= x_c - s\sin(\gamma - \beta) \\
y &= y_c - s\cos(\gamma - \beta)
\end{aligned}
$$

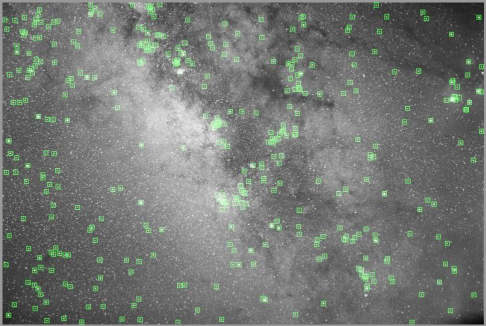
Unknown parameters
e. g. focal length f (0.03 % accuracy!)

Automatic Selection of Reference Stars

- Automatic star detection: Source Extractor
  E. Bertin, `http://terapix.iap.fr/soft/sextractor/`
- Extract reference stars from *Hubble Guide Star Catalog*
- Star matching: automatic pattern recognition
  M. Richmond, `http://spiff.rit.edu/match/`
- With reference stars: optimize projection parameters via a *least squares fit*

Automatic Selection of Reference Stars

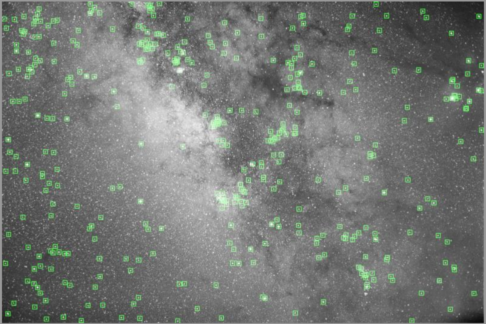
- Automatic star detection: Source Extractor
  E. Bertin, `http://terapix.iap.fr/soft/sextractor/`
- Extract reference stars from *Hubble Guide Star Catalog*
- Star matching: automatic pattern recognition
  M. Richmond, `http://spiff.rit.edu/match/`
- With reference stars: optimize projection parameters via a *least squares fit*



x	y
3291.8	906.3
3088.2	917.8
3662.2	115.4
3230.4	74.5

Automatic Selection of Reference Stars

- Automatic star detection: Source Extractor
  E. Bertin, `http://terapix.iap.fr/soft/sextractor/`
- Extract reference stars from *Hubble Guide Star Catalog*
- Star matching: automatic pattern recognition
  M. Richmond, `http://spiff.rit.edu/match/`
- With reference stars: optimize projection parameters via a *least squares fit*

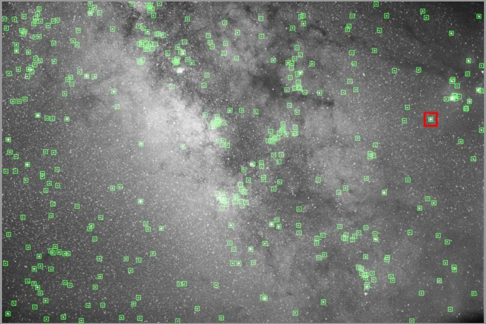


x	y
3291.8	906.3
3088.2	917.8
3662.2	115.4
3230.4	74.5

α	δ
16.4016	−20.0373
16.7501	−28.5095
16.5980	−28.2160
16.6982	−19.0912

Automatic Selection of Reference Stars

- Automatic star detection: Source Extractor
  E. Bertin, `http://terapix.iap.fr/soft/sextractor/`
- Extract reference stars from *Hubble Guide Star Catalog*
- Star matching: automatic pattern recognition
  M. Richmond, `http://spiff.rit.edu/match/`
- With reference stars: optimize projection parameters via a *least squares fit*

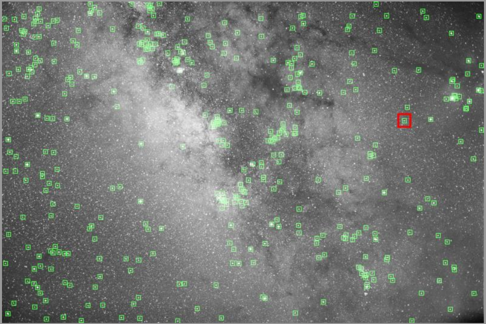


x	y
3291.8	906.3
3088.2	917.8
3662.2	115.4
3230.4	74.5

α	δ
16.4016	−20.0373
16.7501	−28.5095
16.5980	−28.2160
16.6982	−19.0912

Automatic Selection of Reference Stars

- Automatic star detection: Source Extractor
  E. Bertin, `http://terapix.iap.fr/soft/sextractor/`
- Extract reference stars from *Hubble Guide Star Catalog*
- Star matching: automatic pattern recognition
  M. Richmond, `http://spiff.rit.edu/match/`
- With reference stars: optimize projection parameters via a *least squares fit*

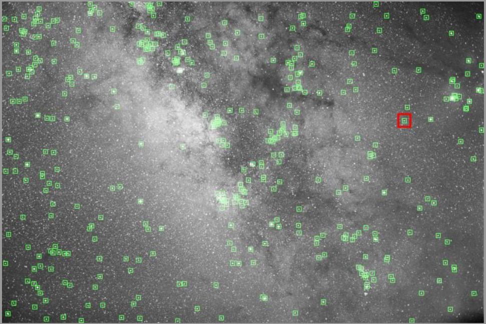


x	y
3291.8	906.3
3088.2	917.8
3662.2	115.4
3230.4	74.5

α	δ
16.4016	−20.0373
16.7501	−28.5095
16.5980	−28.2160
16.6982	−19.0912

Automatic Selection of Reference Stars

- Automatic star detection: Source Extractor
  E. Bertin, `http://terapix.iap.fr/soft/sextractor/`
- Extract reference stars from *Hubble Guide Star Catalog*
- Star matching: automatic pattern recognition
  M. Richmond, `http://spiff.rit.edu/match/`
- With reference stars: optimize projection parameters via a *least squares fit*



x	y
3291.8	906.3
3088.2	917.8
3662.2	115.4
3230.4	74.5

α	δ
16.4016	−20.0373
16.7501	−28.5095
16.5980	−28.2160
16.6982	−19.0912

Add projection parameters to FITS file

Flexible Image Transport System: standard image format in astronomy

```
CTYPE1   = 'RA---TAN'           / right ascension - gnomonic projection
CUNIT1   = 'deg     '
CRPIX1   =            659.2192 / reference point RA (pixel coordinate)
CRVAL1   =            138.5691 / right ascension (in deg.) at ref. point
CDELT1   =        -0.007175109 / degrees per pixel
CROTA1   =            12.66713

RADESYS = 'FK5     '
EQUINOX =                2000.
```

- World Coordinate System (WCS): Conversion from “pixel” to “world” coordinates (e. g. RA/Dec)

  E. W. Greisen, M. R. Calabretta, Astron. & Astrophys. **395**, 1061 (2002)
- Can be processed by WCS-aware software

Add projection parameters to FITS file

Flexible Image Transport System: standard image format in astronomy

```
CTYPE1  = 'RA---TAN'           / right ascension - gnomonic projection
CUNIT1  = 'deg     '
CRPIX1  =            659.2192 / reference point RA (pixel coordinate)
CRVAL1  =            138.5691 / right ascension (in deg.) at ref. point
CDELT1  =        -0.007175109 / degrees per pixel
CROTA1  =            12.66713

RADESYS = 'FK5     '
EQUINOX =               2000.
```

- World Coordinate System (WCS): Conversion from “pixel” to “world” coordinates (e. g. RA/Dec)

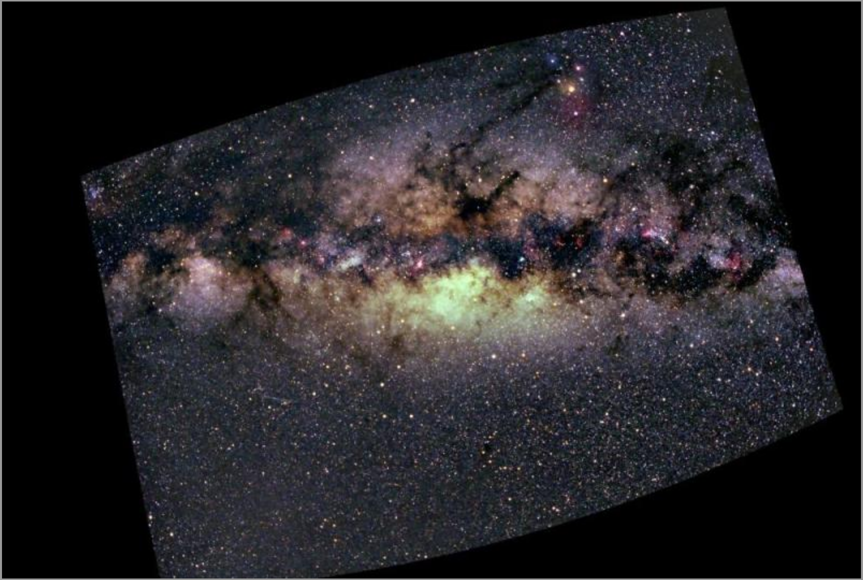
  E. W. Greisen, M. R. Calabretta, Astron. & Astrophys. **395**, 1061 (2002)
- Can be processed by WCS-aware software

Finally: Distortion Correction

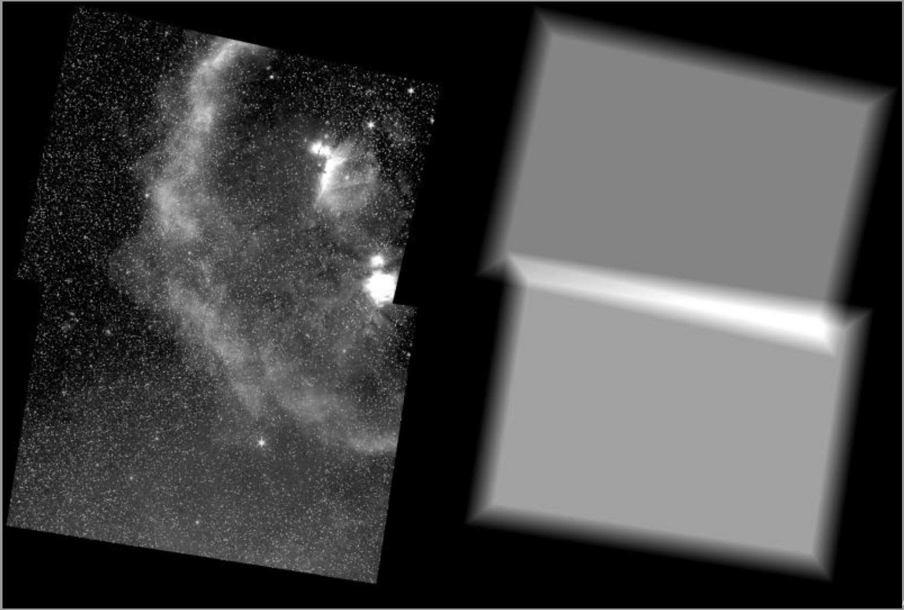
- Combine/transform FITS images: SWarp
  E. Bertin, `http://terapix.iap.fr`

Finally: Distortion Correction

Finally: Distortion Correction



Smooth Transitions via (*Weight Masks*

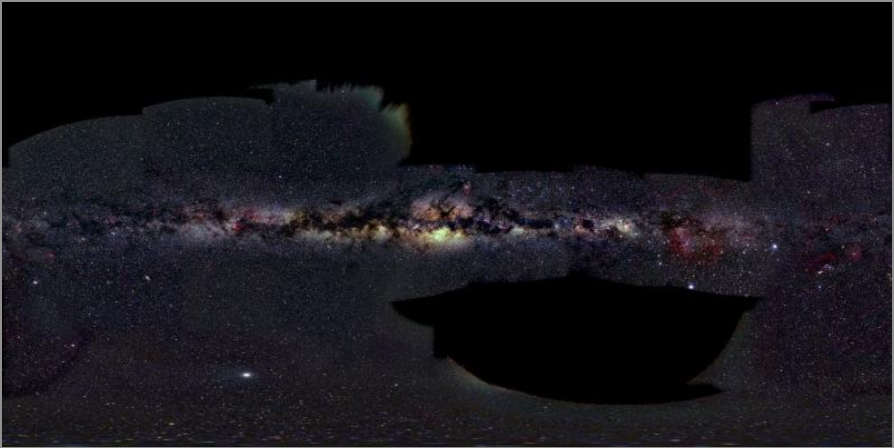


The All-Sky Panorama

May 1998

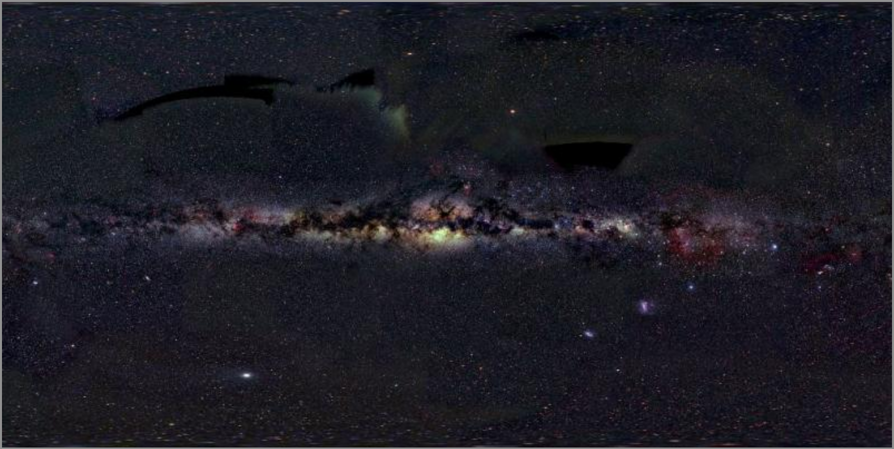
The All-Sky Panorama

February 1999



The All-Sky Panorama

October 1999

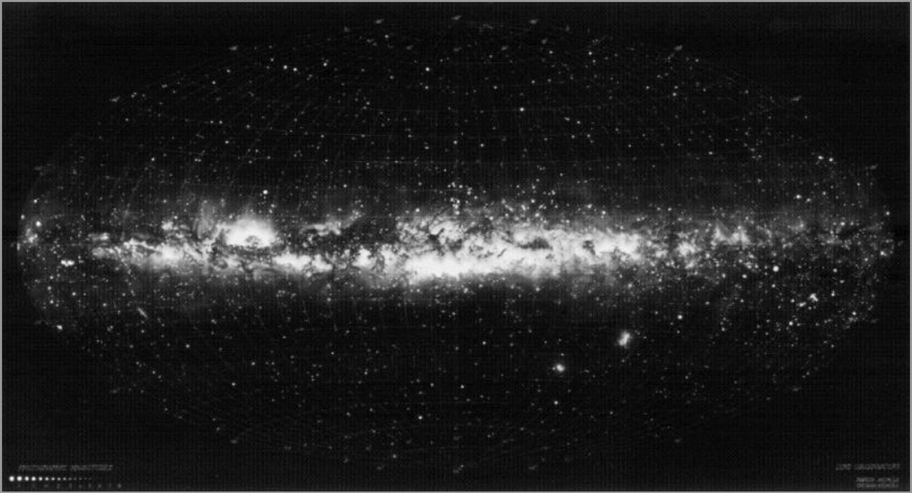


The All-Sky Panorama

May 2000: Ready!

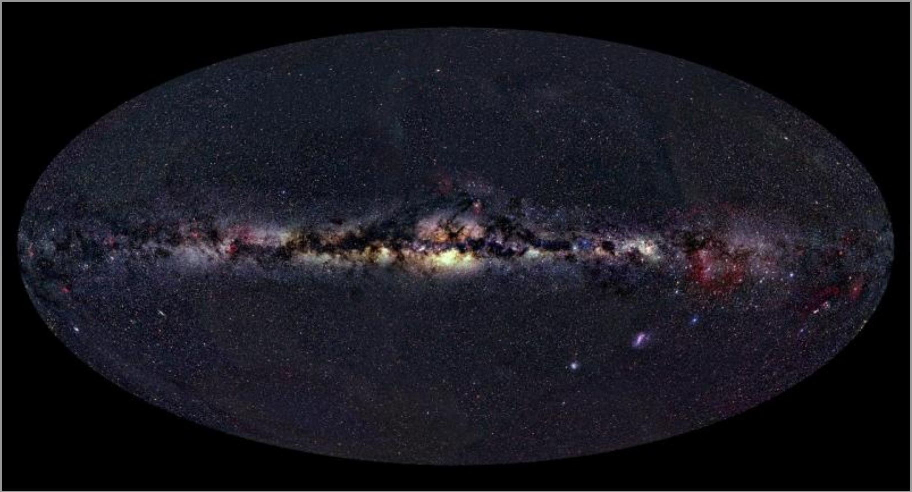
All-Sky Panoramas

1950s: All-sky panorama at Lund Observatory, Sweden



All-Sky Panoramas

Color panorama in Aitoff projection



Highlights of the Milky Way

Stars: Only up to a distance of 6000 light years!
(Diameter of our galaxy: more than 100,000 light years)

Dust: Limits our view at optical wavelengths!
Seeing through dust is possible:

- radio telescopes
- infra-red
- X-rays

Nebulae: Mostly hydrogen

- H_α: 656 nm = red
- H_β: 486 nm = blue
- [O III]: "forbidden" lines near 500 nm = blue-green

Highlights of the Milky Way

Stars: Only up to a distance of 6000 light years!
(Diameter of our galaxy: more than 100,000 light years)

Dust: Limits our view at optical wavelengths!
Seeing through dust is possible:

- radio telescopes
- infra-red
- X-rays

Nebulae: Mostly hydrogen

- H_α: 656 nm = red
- H_β: 486 nm = blue
- [O III]: "forbidden" lines near 500 nm = blue-green

Highlights of the Milky Way

Stars: Only up to a distance of 6000 light years!
(Diameter of our galaxy: more than 100,000 light years)

Dust: Limits our view at optical wavelengths!
Seeing through dust is possible:

- radio telescopes
- infra-red
- X-rays

Nebulae: Mostly hydrogen

- H_α: 656 nm = red
- H_β: 486 nm = blue
- [O III]: “forbidden” lines near 500 nm = blue-green

Highlights of the Milky Way

Stars: Only up to a distance of 6000 light years!
(Diameter of our galaxy: more than 100,000 light years)

Dust: Limits our view at optical wavelengths!
Seeing through dust is possible:

- radio telescopes
- infra-red
- X-rays

Nebulae: Mostly hydrogen

- H_α: 656 nm = red
- H_β: 486 nm = blue
- [O III]: “forbidden” lines near 500 nm = blue-green

Highlights of the Milky Way

Stars: Only up to a distance of 6000 light years!
(Diameter of our galaxy: more than 100,000 light years)

Dust: Limits our view at optical wavelengths!
Seeing through dust is possible:

- radio telescopes
- infra-red
- X-rays

Nebulae: Mostly hydrogen

- H_α: 656 nm = red
- H_β: 486 nm = blue
- [O III]: “forbidden” lines near 500 nm = blue-green

Highlights of the Milky Way

Stars: Only up to a distance of 6000 light years!
(Diameter of our galaxy: more than 100,000 light years)

Dust: Limits our view at optical wavelengths!
Seeing through dust is possible:

- radio telescopes
- infra-red
- X-rays

Nebulae: Mostly hydrogen

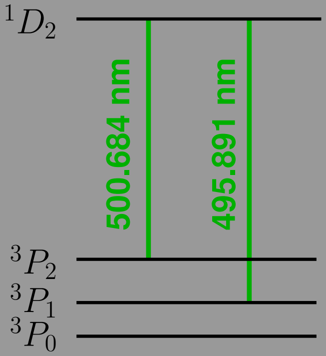
- H_α: 656 nm = red
- H_β: 486 nm = blue
- [O III]: “forbidden” lines near 500 nm = blue-green

"Forbidden" Lines

- metastable excited atomic states
- lifetime: seconds . . . minutes
- under lab conditions:
  de-excitation mostly via collisions
- O III (= O^{2+}): lines initially interpreted as new element "nebulium"
- Positive identification: I. Bowen, 1928

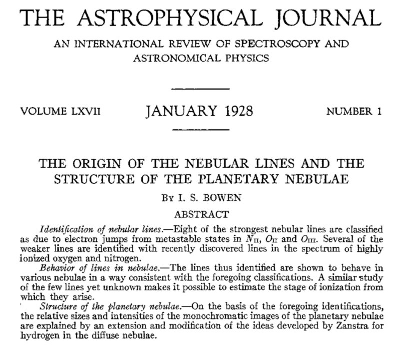
"Forbidden" Lines

- metastable excited atomic states
- lifetime: seconds ... minutes
- under lab conditions:
  de-excitation mostly via collisions
- O III (= O^{2+}): lines initially interpreted as new element "nebulium"
- Positive identification: I. Bowen, 1928



“Forbidden” Lines

- metastable excited atomic states
- lifetime: seconds … minutes
- under lab conditions: de-excitation mostly via collisions
- O III (= O^{2+}): lines initially interpreted as new element “nebulium”
- Positive identification: I. Bowen, 1928



THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME LXVII JANUARY 1928 NUMBER 1

THE ORIGIN OF THE NEBULAR LINES AND THE STRUCTURE OF THE PLANETARY NEBULAE

By I. S. BOWEN

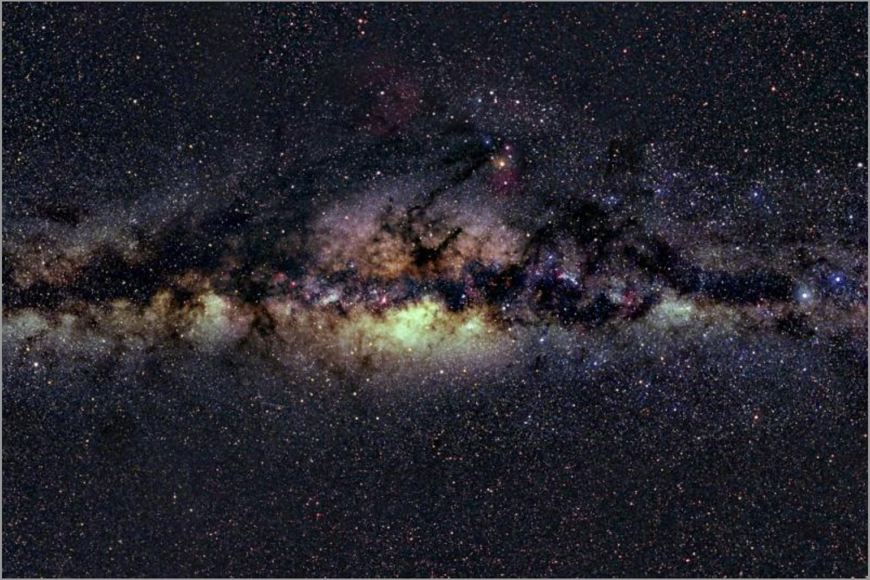
ABSTRACT

Identification of nebular lines.—Eight of the strongest nebular lines are classified as due to electron jumps from metastable states in N_{II}, O_{II} and O_{III}. Several of the weaker lines are identified with recently discovered lines in the spectrum of highly ionized oxygen and nitrogen.

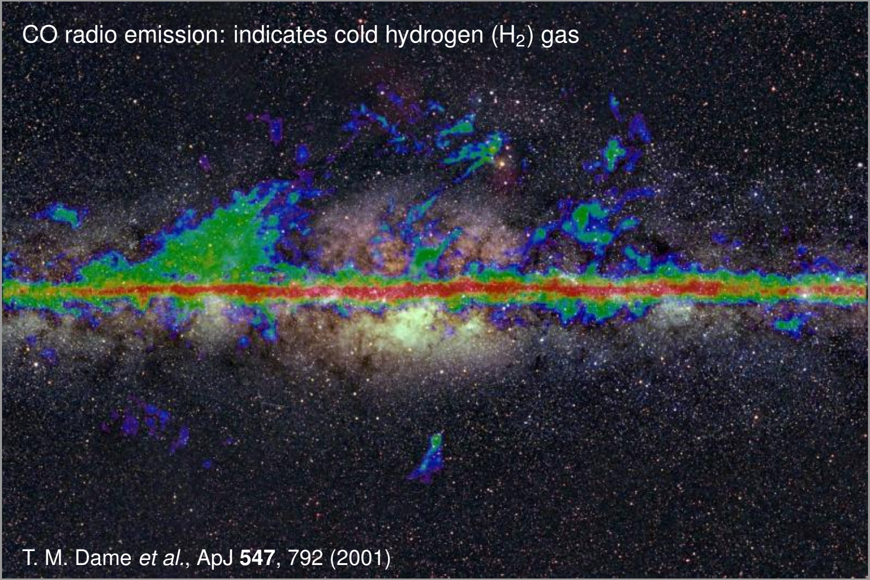
Behavior of lines in nebulae.—The lines thus identified are shown to behave in various nebulae in a way consistent with the foregoing classifications. A similar study of the few lines yet unknown makes it possible to estimate the stage of ionization from which they arise.

Structure of the planetary nebulae.—On the basis of the foregoing identifications, the relative sizes and intensities of the monochromatic images of the planetary nebulae are explained by an extension and modification of the ideas developed by Zanstra for hydrogen in the diffuse nebulae.

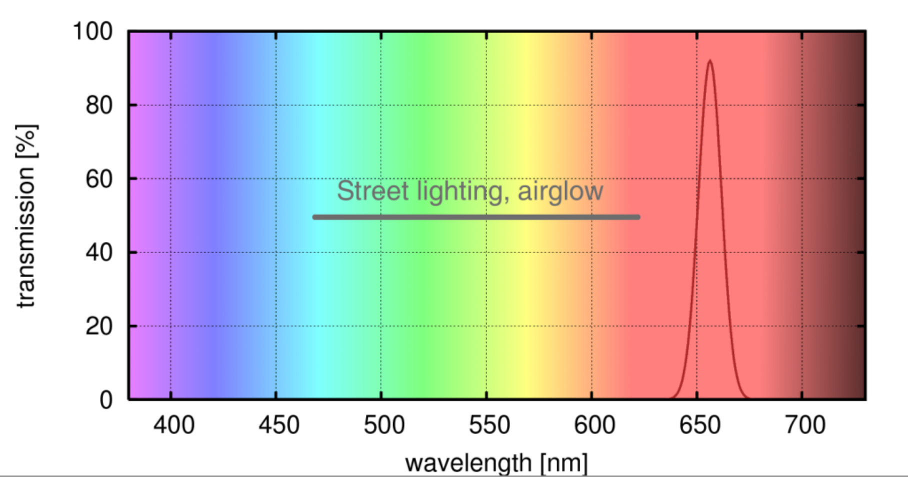
Dust and Gas in the Milky Way



Dust and Gas in the Milky Way



Narrow-band H_α Filter



- Recombination of ionized hydrogen gas $\longrightarrow H_\alpha$ (656.3 nm)
- Narrow-band filter blocks light pollution and airglow

Northern Cygnus in H_α light

- Emission nebulae: hydrogen gas, ionized by UV light of young, hot stars

The North America Nebula (NGC 7000)

- Emission nebulae: hydrogen gas, ionized by UV light of young, hot stars

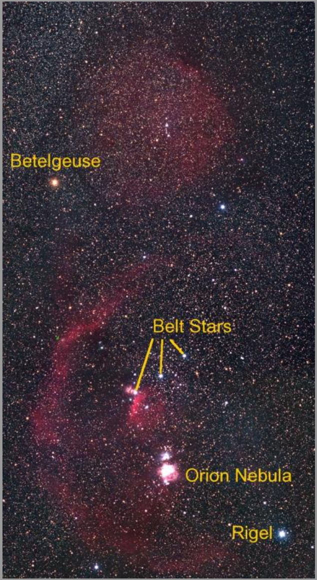
The North America Nebula (NGC 7000)

Gamma Cygni Nebula (IC 1318)

Orion/Barnard's Loop: Film image (6 frame mosaic)

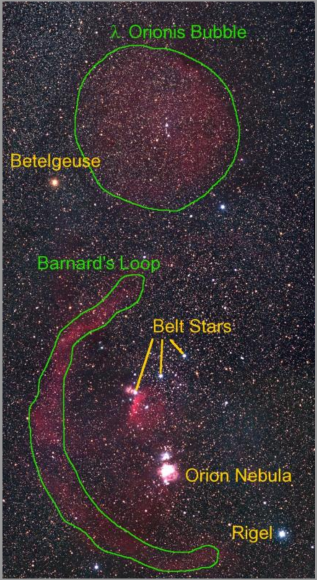
- Barnard's loop: discovered in 1895 on long exposure photographs with a portrait camera
- Distance: approx. 1600 light years
  diameter 300 light years
- Possibly the remnant of a Supernova explosion 2 million years ago
  (expansion speed approx. 20 km/s)

Orion/Barnard's Loop: Film image (6 frame mosaic)



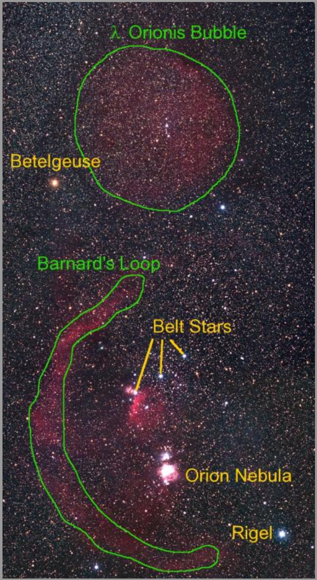
- Barnard's loop: discovered in 1895 on long exposure photographs with a portrait camera
- Distance: approx. 1600 light years
  diameter 300 light years
- Possibly the remnant of a Supernova explosion 2 million years ago
  (expansion speed approx. 20 km/s)

Orion/Barnard's Loop: Film image (6 frame mosaic)



- Barnard's loop: discovered in 1895 on long exposure photographs with a portrait camera
- Distance: approx. 1600 light years
  diameter 300 light years
- Possibly the remnant of a Supernova explosion 2 million years ago
  (expansion speed approx. 20 km/s)

Orion/Barnard's Loop: Film image (6 frame mosaic)



- Barnard's loop: discovered in 1895 on long exposure photographs with a portrait camera
- Distance: approx. 1600 light years
  diameter 300 light years
- Possibly the remnant of a Supernova explosion 2 million years ago
  (expansion speed approx. 20 km/s)

Orion/Barnard's Loop: Gemini 11 UV image

O'DELL *et al.* (*see* page 836)

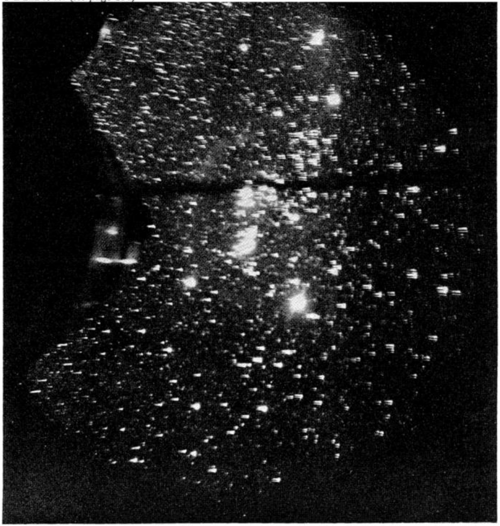


FIG. 1.—Objective-prism photograph of the constellation Orion made during E.V.A. by astronauts Charles Conrad and Richard Gordon from the Gemini 11 space vehicle. Astronomical north is at the top

- UV spectrogram taken by astronaut Richard Gordon during EVA in 1966
- UV-"Bubble" extends much further than visible structure

C. R. O'Dell, Donald G. York and Karl G. Henize, ApJ **150**, 835 (1967)

Orion/Barnard's Loop: H_α image (8 frame mosaic)

- Narrow-band H_α image at 656 nm

Orion/Barnard's Loop: H_αRGB image

- Red and luminance channel in film image replaced by H_α data

Orion/Barnard's Loop: H_αRGB image

“Witch Head” Nebula (IC 2118)

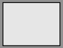
- Reflected light from Rigel (Orion)
- Rayleigh scattering → blue!

The Gum Nebula: a 1-million-year-old supernova remnant

Color imaging with two cameras

Astro CCD camera: H_α

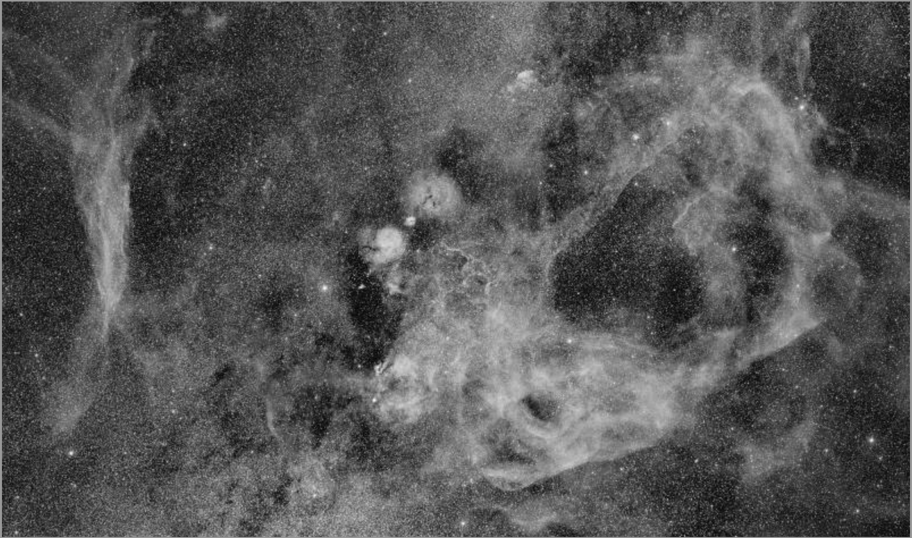
- monochrome
- chip size: 9.0×6.8 mm^2



Consumer DSLR camera: RGB

- color
- chip size: 22.2×14.8 mm^2

The Gum Nebula: H_α image



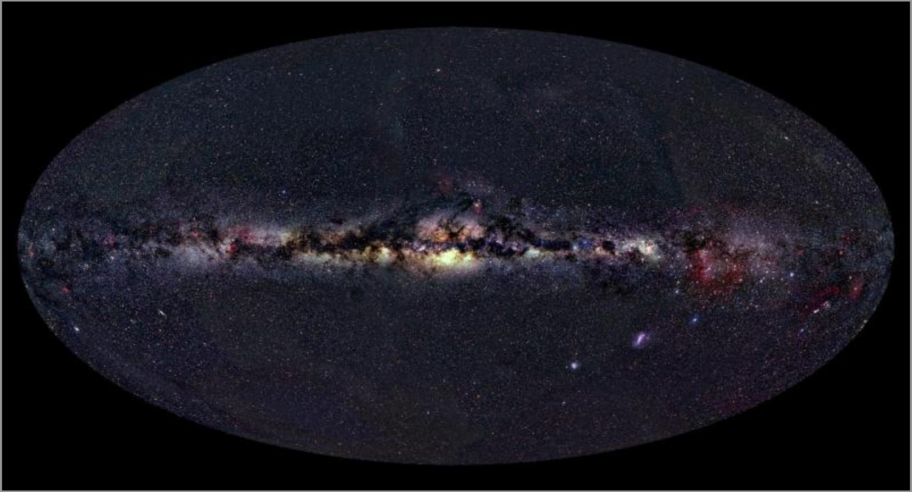
The Gum Nebula: RGB image

The Gum Nebula: “semi-false” color image

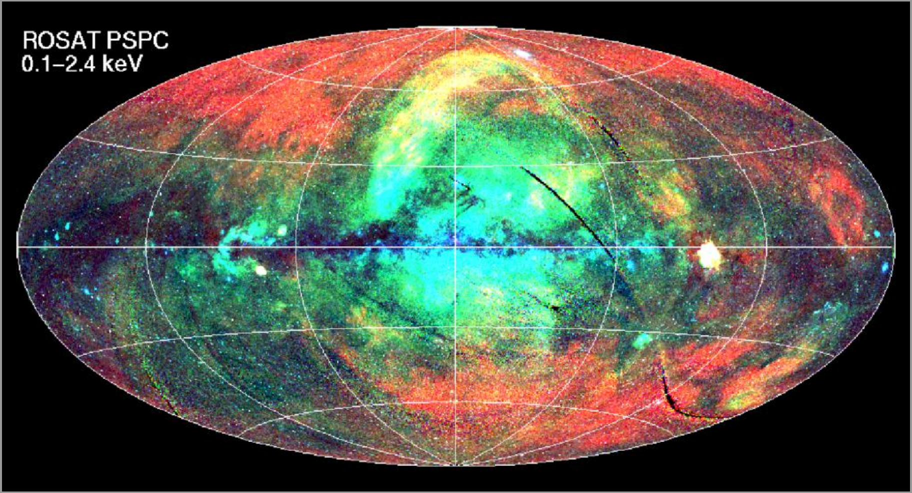
The Gum Nebula: “semi-false” color image

The Vela Supernova Remnant (≈ 11,000 years old)

Optical All-Sky

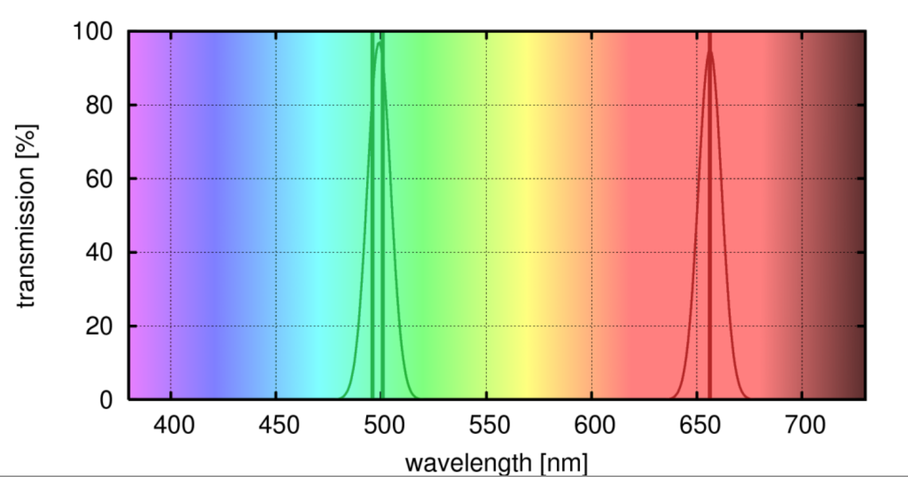


X-ray All-Sky (ROSAT Survey)



Vela SNR is the brightest X-ray source in the sky!

Another Emission Line: Doubly Ionized Oxygen [O III]



The Vela Supernova Remnant in H_α

The Vela Supernova Remnant in O-III

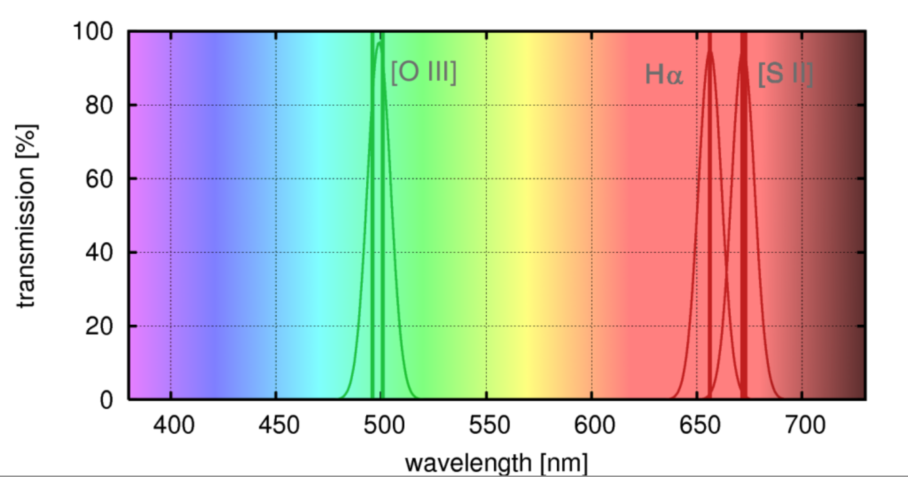
The Vela Supernova Remnant: Two-color image

The Vela Supernova Remnant: Two-color image

The Pencil Nebula: A Supernova Shockwave

The Pencil Nebula (Hubble Space Telescope)

Tri-Color Narrowband images: [S II], H_α, [O III]



The Eta Carinae Nebula:

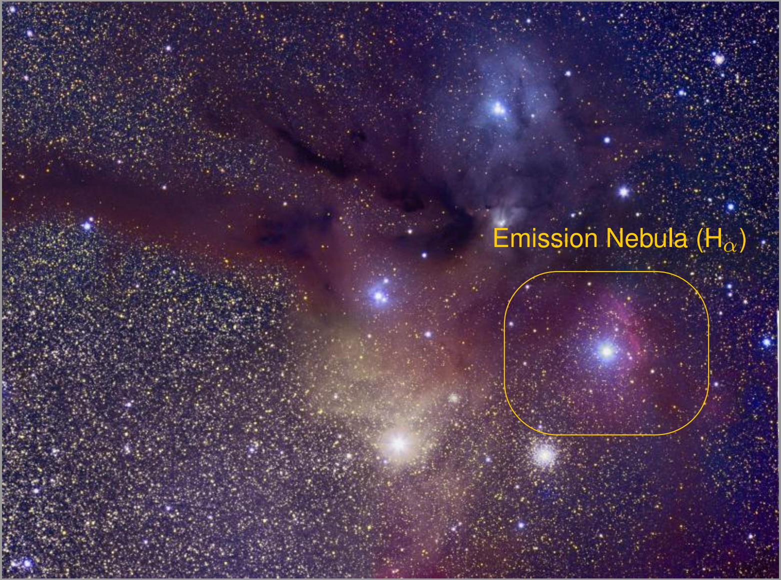
[S II] = red, H_α = green, [O III] = blue

The Eta Carinae Nebula:

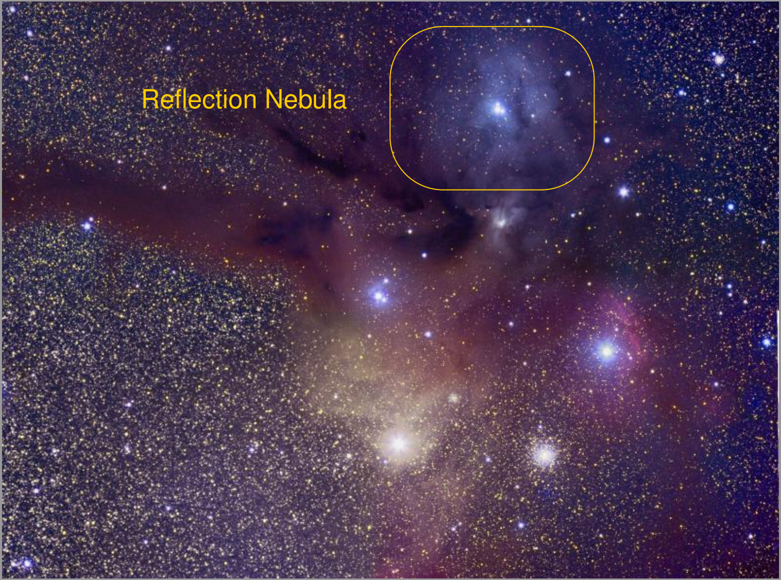
H_α = red, [O III] = green, [S II] = blue

In the Head of Scorpius

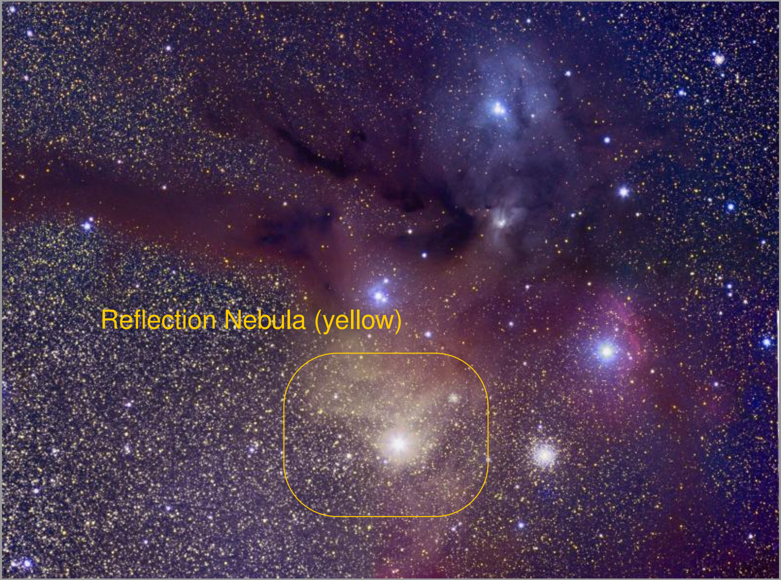
In the Head of Scorpius



In the Head of Scorpius



In the Head of Scorpius



In the Head of Scorpius

Reddening due to Interstellar Dust

Summary

- Tremendous progress in astrophotography over the past 150 years
- With some processing, the sky is colorful!

Summary

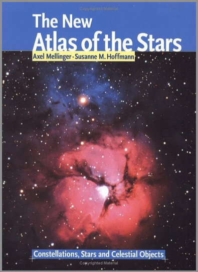
- Tremendous progress in astrophotography over the past 150 years
- With some processing, the sky is colorful!

Summary

- Tremendous progress in astrophotography over the past 150 years
- With some processing, the sky is colorful!

Further information

- Web site: `http://home.arcor-online.de/axel.mellinger/`
- Photographic Star Atlas:



A. Mellinger, S. Hoffmann:
The New Atlas of the Stars
Firefly Books Ltd.