Exploring Your Depths

Astronomy Imaging in 3D

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Agenda

• Defining 3D Astronomical Imaging
• Fundamental Techniques
• 3D Multi-plane Rendering
• 3D Nebula Rendering (1)
• 3D Star Rendering Methods
• 3D Nebula Rendering (2)
• Recommended Tools
• Stereo Astronomical Imaging
Defining 3D Astronomical Imaging
Constrained versus Unconstrained!

(1) "Constrained"
- 3D environments extrapolated from 2D images
- True to the observed data
- Camera is constrained
- Artistic license minimized

(2) "Unconstrained"
- Fully 3D simulated objects visible from any angle
- Combines observed data with theoretical models
- Camera is unconstrained
- Artistic license maximized
But is it real?

- There is a distinction between reasonable visual extrapolation and pure imagination.
  - We do not really know what most objects look like from the side or behind.
  - However, reasonable assumptions can be made from theory and physical principles.

- Golden rule: Don’t go camera crazy!
  - Restraint is a visual virtue.
  - Constrained cameras still present enough motion to create striking 3D effects while remaining faithful to the original object image.
Movement Zones (RMZ, SMZ, IMZ)

Real Observer (You)

Virtual Observer

Observer position

Stars spaced along the line of sight

Too close to object

Target object

Realistic Movement Zone (RMZ)

Speculative Movement Zone (SMZ)

Imaginary Movement Zone (IMZ)

The camera can be moved to any vantage point without losing the visual fidelity of the original image.

Visual fidelity starts to break down but full data accuracy is still possible through physical models and reasoned assumption.

The camera moves too far beyond what can be observed from Earth so imagination must fill in the gaps.

Too close to object
"To create accurate 3D representations of astronomical objects and their environments that are spatially and geometrically accurate, visually faithful to the original image, and can be visualized from alternative viewpoints through still images, animation, and stereoscopy"
So.... Explore your depths

Stephan's Quintet: Hybrid rendered image. (Author: Wide field star-field, selected galaxies, Gemini 8 meter: NGC7320, other galaxies)
Fundamental Techniques
Analyzing astronomical depth cues

- Obvious Foreground Objects
- Occlusions: Foreground objects that block others
- Angle of observed object: Correct proportions can be derived from similar types
- Perceived Detail: Closer objects show more detail than distant ones
- Boundary crossing elements (Gas/Dust) that continue across multiple objects
- Central directional lighting: defines shape
Misleading astronomical depth cues

Non-Directional (emission nebula) lighting defines detail but not necessarily the true shape.

Shading provides clues to shape and form but is not comparable to a solid object.

Other missing cues:

Absence of binocular disparity (But can be simulated)

Absence of proper motion derived depth cues (Except for very close objects over years)
Separating the visual elements of an image

- **Photoshop Methods**
  - Selection Toolset (Color Range etc)
  - Repair with Color Replacement, Healing, Clone Brush etc
  - A lot of copy and paste!
- **Camera Filter Methods**
  - Narrow band filters reveal different levels of structural detail
  - Continuum filters to remove non-required data
- **Plate Solving methods**
- **3D Paint & Compositing Methods**
  - Z-depth layering of specific elements
  - Depth maps
Applying distance data to scene elements

- Sources of astronomical distance data
  - Ground or satellite based parallax measurements
  - Physical modeling from parameters such as size, mass, angular distance etc
  - Stellar photometry data
  - Standard Candles
  - Cosmological Red Shift data
  - Cepheids

Combining distance data with scene elements enables the simulation of a virtual 3D universe both along and off the line of sight
A 3D rendering primer

1 Modeling
Objects in the scene are created and positioned in space

2 Animation
The camera and the objects in the scene are animated

3 Rendering
Shaders and lights are applied and the scene is rendered frame by frame

4 Post-Production
The rendered frames are composited, recorded to video etc...

Creating Shaders

Textures are created from source images

Displacements (If needed) are created from source images

The shaders are test rendered before application and final rendering

Lights are created and positioned around the objects in scene
The Famous Teapot Nebula (Fake!)

Rendered with Aqsis to the RenderMan standard
4 methods for simulating 3D depth

2D Multi-Plane Rendering:
2D layered image planes scaled and panned to simulate 3D in a non-perspective environment

3D Multi-Plane Rendering:
2D image planes arranged or animated in a 3D environment with full perspective

3D Multi-Plane Displacement Mapping:
3D detail extracted from 2D image planes in a 3D perspective environment

3D Forced Perspective Rendering:
Simulating 3D by warping 2D image planes in 3D space to create the illusion of parallax
3D Multi-Plane Rendering

Source image:
Starfield and Quintet
Chris Ford (Author)
Other Quintet and NGC 7320
8 Meter Gemini
Stephan’s Quintet described

NGC7317
c. 347 MLY

NGC7318A
c. 349 MLY
(Tidally Disrupted)

NGC7318B
c. 304 MLY
(Passing Through)

Starfield
(In Milky Way)

NGC7319
356 MLY

NGC7320
c. 41 MLY

Tidal Tail ripped out by NGC7320C
(Off Image)

Source Image: GEMINI 8 Meter Telescope
Dissecting the image into separate elements

- Components separated into Texture Map layers in Photoshop
- Grayscale Opacity maps derived from Texture Maps
- Foreground star-field imaged by author (For sufficient camera motion space)
Spacing scene elements for depth

- Separated image elements texture mapped onto image planes
- Image planes spaced from camera (along Z-Axis) by red shift distance data
- (Spacing shown above is for illustration and not to scale)
A Journey to NGC 7320 (And Back)
3D Multi-Plane Displacement Mapping

Original image data:
Chris Ford (Author)
Displacing the Crab Nebula

- **Displaced surface**
  - Regular diffuse lighting avoids inaccurate shading artifacts

- **Color image is texture mapped onto the displaced surface**

- **Grayscale image drives vertical displacement of geometry normal to the surface orientation**
  - White = High
  - Black = Low

- **Crab Nebula Assumptions**
  - Cloud topography is illuminated from a central point light source
  - Obvious occlusions show depth order of image elements

Source images: Chris Ford (Author)
Squeezing 6500 light years in your computer

Starfield Multi-Planes

Camera Frustrum

Camera

Displacement Plane
• Wide field star-field imaged separately and combined and aligned in 3D
• Camera traverses a “constrained” baseline 8 Light years across
Integrating Hubble data...

- HST image displaced and combined with star field imaged by author
- Crab split into multiple displaced layers to illustrate interior luminosity
3D Nebula Rendering (1)
Analyzing a nebula image (M17)

Total: 2 star layers, 5 foreground nebula layers, 1 semi-transparent veil, 2 background nebula layers, 1 far background layer

Ultra violet radiation from hot young stars (off image) provides directional lighting for displacing gas and dust clouds

Semi-Transparent gaseous and dust veil (Streaming off the gas and dust) forms a translucent layer

Background nebula structure (1)

Foreground stars

Background nebula structure (2)

Occluded nebula layers sculpted by ultra-violet radiation from top left

Occluded nebula layer boundary closer to observer

Source: Hubble Gallery – M17
Reconstructing 3D depth

- Image width is 3 light years
- Camera traverses orbital path 1 light year in diameter

Displaced image layers are spaced along the Z-Axis

Side view of displaced multi-planes illustrating build up of depth
Nebula case study 1 - IC 1396

Existing images can be processed into 3D!
Nebula case study 1 - analyzing IC1399

- Ridiculous numbers of stars!
- Star density of 40 visible stars per 100 pixels square average
- Star density analysis reveals c. 25,000 stars in whole image

Narrow band Source image: Neil Fleming

“Hollowed” area receding from observer

Wispy dust tendrils

Multiple gas/dust occlusion layers

Ha Source image: Chris Ford

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Nebula case study 1 - element separation

Mask 1: Displays foreground nebula elements

Mask 2: Displays middle ground nebula elements

Mask 3: Displays back gas and dust elements

Original image

Background image with stars and upper layers removed

Grayscale for displacements (White = further away)
Total star count under-sampled (Smallest stars removed to reveal nebula detail)
The problem section!

- Scintillating stars as they pass over each other
- Bloated stars
  - Over exposed stars look horrible when you get too close
- Limitations on getting close due to low resolution
- Color bleeding from stars into background objects and vice versa
- Photoshop processing artifacts
- Noise in image obscuring faint background detail
- Lack of intuitive reference objects for proper depth perception
  - Intergalactic objects can be hard to orient yourself to
3D Star Rendering Techniques
3D star rendering - layer methods

Z-Axis Multi Plane Star Mapping

- Suitable for stars with known distances
- Suitable for foreground stars when target objects are very distant (i.e., galaxies)

The "Star Lens" Method

- Ideal for large clusters of stars where individual distances are unknown or approximately the same
- Need minimum 5 closely spaced planes to achieve realistic distribution

Individual stars can be mapped at correct distance along Z-Axis

Closely packed curved star planes with stars displaced into interior volume
3D star rendering - particle substitution

- A star-field texture can be used to emit particles
- Each white star emits one particle normal to the texture surface so that visual alignment with the original image is maintained
  - Each particle is sized according to the FWHM of the original star
  - Each particle is displaced a random distance along the normal for realistic depth spacing, OR assigned a real distance where known
  - Each particle inherits the color of the original star
- Particle stars are rendered with realistic glows
3D Star Rendering – growing globs

- The 3D form of globular clusters can be predicted
- Distribution of stars in this image of M13 determined by statistical analysis of color and visual density
- Globular “grown” from particle stars released and bound into a simulated gravity field

M13 Simulation

- 60% white stars
- 30% red stars
- 10% blue stars
3D Nebula Rendering (2)

IC 1396 (3D reconstruction from an original source image by Neil Fleming)
Nebula rendering with star substitution (1)

Soft star rendering – fully sampled original image
Nebula rendering with star substitution (2)

Added star glow
Case study 2 - Tarantula Nebula

Large numbers of foreground stars
Well defined nebula occlusions
Central illumination defines shape
Huge numbers of dim background stars

Source Image: NGC 2070 Tarantula Nebula, Courtesy of R Jay Gabany
Nebula case study 2 - element separation

- 5 Foreground Star Layers
- 1 Nebula Layer
- 3 Background star layers
- Animation Camera
- Camera orbital motion path

Original image

Image texture with stars extracted

Arrangement of image elements
Nebula case study 2 – orbiting the Tarantula
What tools do I need?

- **A Paint Application**
  - For separating image elements into layers
  - For creating stereoscopic still images
- **Recommendation: Photoshop**

- **A 3D Application**
  - For positioning scene elements in 3D space
  - For establishing alternate camera view points
  - For creating video and stereoscopic animation
- **Recommendation: Maya, 3ds max, XSI, Cinema4D, Hash, Blender etc**

- **A Editing and Compositing Application**
  - For editing, assembling, and outputting animation
  - For creating stereoscopic animation
- **Recommendation: After Effects**
Stereoscopic Astronomical Imaging
Stereoscopic viewing methods

- Cross your eyes!
- Anaglyph Glasses
- Shutter Glasses
- Shutter Glasses and Projector
- Polarized Projection
- Head Mounted Displays
- Lenticular/Barrier TFT

- All sorts of strange devices...!
Simple stereoscopic cinematography

- **Toe-in cameras**
  - Positive parallax
  - Objects appear behind the screen
  - Requires tweaking to avoid trapezoidal distortion
  - Not recommended for astronomical objects except extreme close ups, close fly bys, and zoom shots

- **Parallel cameras** *(Recommended)*
  - Negative parallax
  - Objects appear in viewer space or in front of screen
  - Easy to set up by simply displacing camera along X axis (It's how your eyes work)
  - Suitable for most astronomical objects
A sample stereoscopic anaglyph

- Inter-Ocular Distance = 120,000 Light Years!

3D is BACK TO FRONT!

Inter-Ocular rule of thumb:
- 30 to 1 rule
- Image offsets < 15%
Creating anaglyphs in Photoshop

- Open separately rendered Left and Right images
- "Select All" in left image
- "Copy" (left image) Red Channel and "Paste" into (right image) Red Channel
- Select RGB Channel and test with 3D effect with anaglyph glasses
- If 3D is "inside out" paste Right into Left or reverse the anaglyph glasses

Paste left Red Channel into Right Red Channel
Creating stereo animation in After Effects

- Separately render Left and Right animation frames of the object
- Use After Effects to merge Left and Right sequences and test the results

Use "3D Glasses" in Effects - > Perspective

Select Red Channel and Right Red Channel

Experiment with the image convergence wearing anaglyph glasses

Test at full resolution. Swap Left and Right if positive parallax results (Objects inside out)

Export in desired format
Put on your 3D glasses!

Left Eye = Red
Right Eye = Blue
The “Coming right at ya” shot!
Stereo rendering with displacement maps (1)
Stereo rendering with displacement maps (2)
Nebula rendering in stereo (IC1396)
Nebula rendering in stereo (IC1396)

All stars present via particle substitution
Summary

- 3D astronomical imaging is a synthesis of imaging, processing, current knowledge, real data, theory, interpretation, and creativity.
- The flood of data anticipated over the next decade requires a more sophisticated display format.
- The tools are accessible to anyone who has mastered Photoshop and other image processing applications.
- It is an ideal medium to interpret objects and vistas in a manner more intuitive to the human visual system.
- Parallels the ongoing evolution in display technologies that will be accessible to the consumer.
End

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