Wave Propagation through Random Media

A “random medium” is one where the wave speed is a random function of position.

This usually means:

- Random in space and time.
- Internally rearranging
- Bulk flow (i.e. wind, advection)

But it may mean anything...

Many common assumptions and conditions might not be true.
For example: *Stationarity, Gaussian, Poisson, equilibrium, ergodic,* etc.

Just keep an open mind.

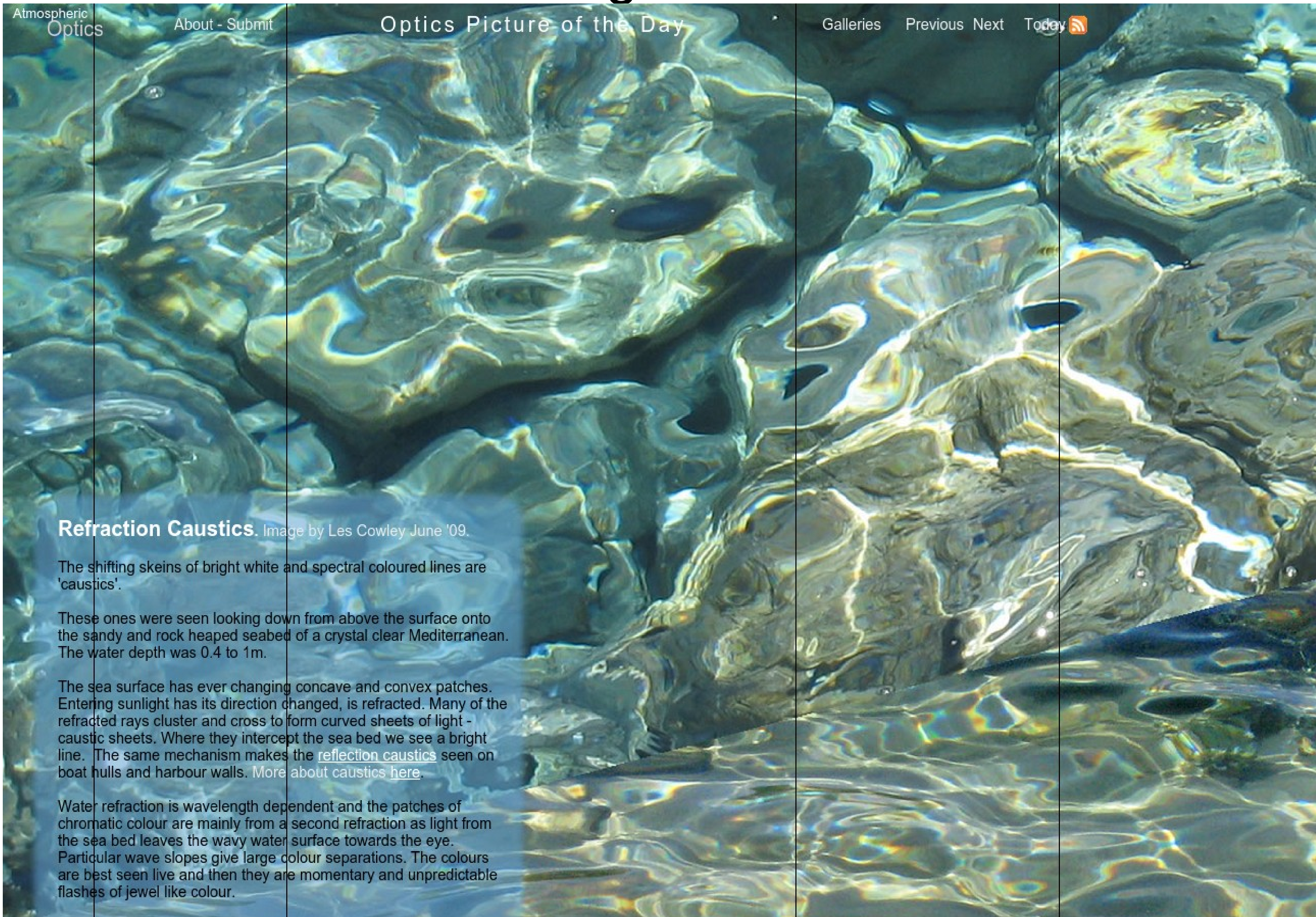
Wave Propagation through Random Media

The index of refraction, *n(x,y,z,t),* will usually be continuous and smooth in this course, but not always.

- Atmospheric turbulence (e.g. seeing and scintillation)
- Rain, fog, snow, hail, dust, etc. (Even large rocks as in distant starlight through a planetary ring system or a stellar debris disk.)
- Transmission or reflection through a fluctuating interface (swimming pool caustics, rough surface scattering)
- Non-isotropic media (ice crystals, magnetized plasma, phonons in crystals, etc.)
- Sound waves compressing optical fiber or other waveguide.
- Light or ultrasound through tissue and blood.
- Layered or structured media (e.g. mirages, fiber optics, ionosphere, ocean SOFAR channel, …)
- Distant quasars seen through the Universe of small gravitational lenses.

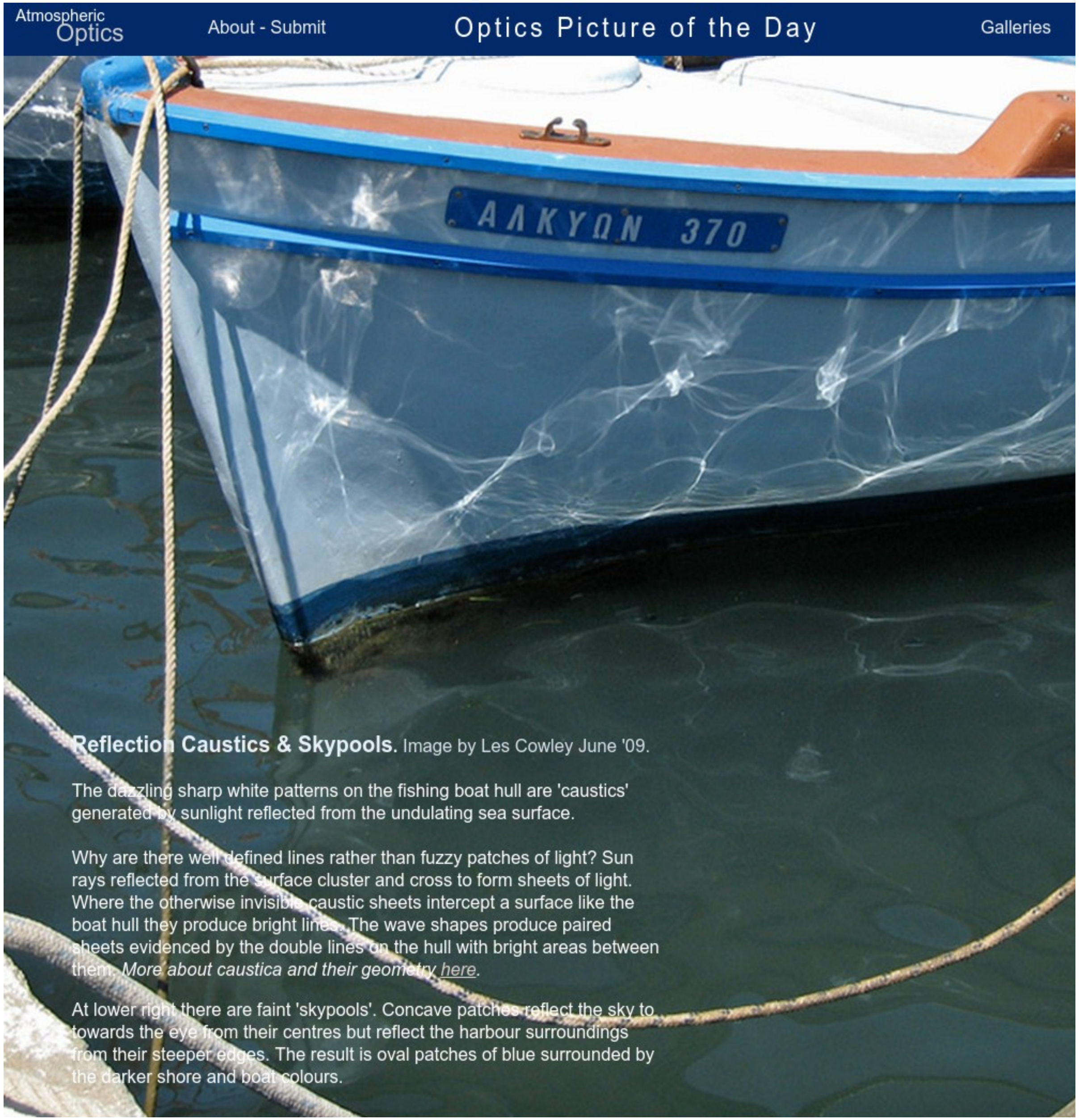
WPRM Phenomena

Random Surface Image Distortion and Caustics

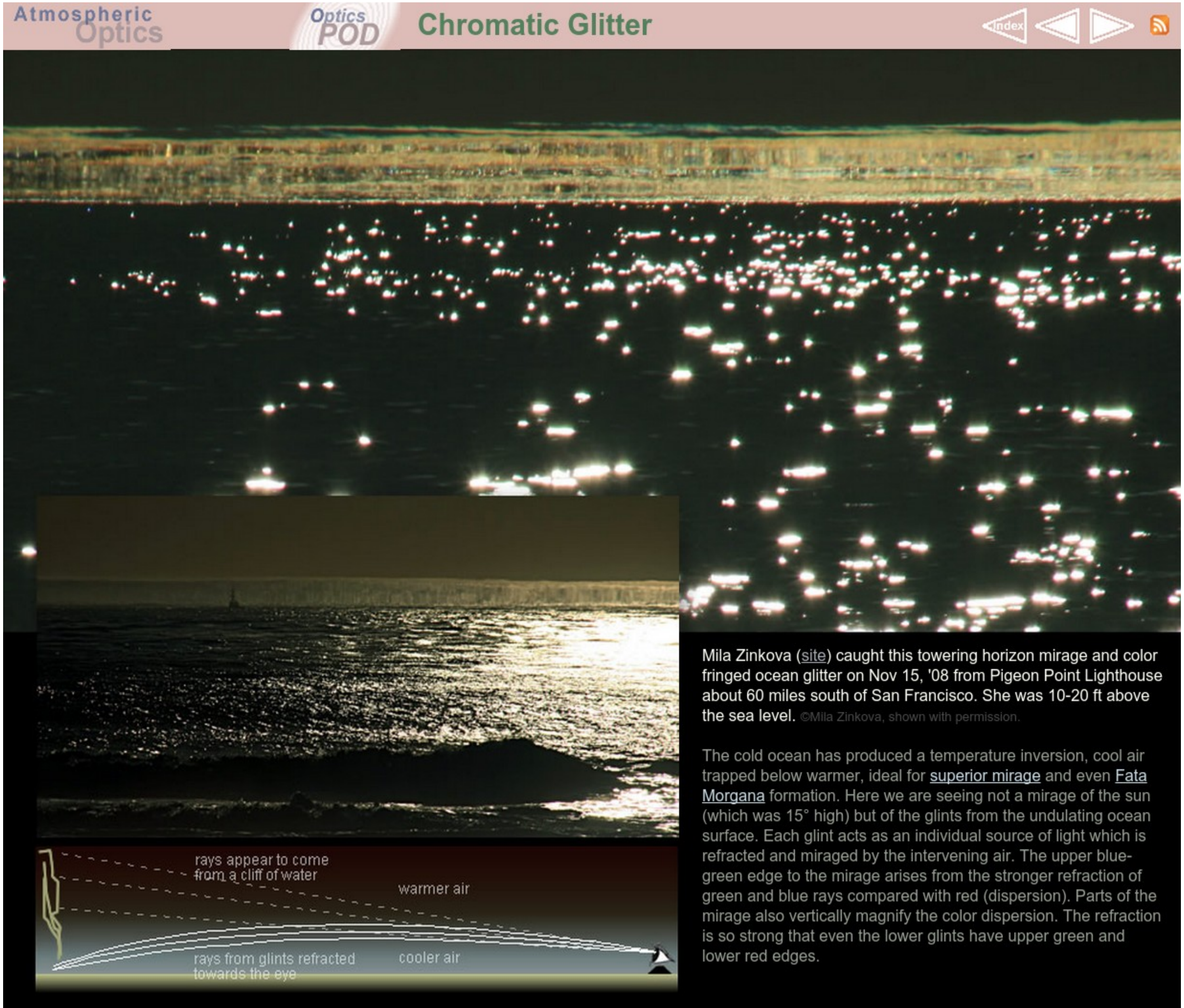


Refractive Image Distortion

Random Surface Reflection



Rough Surface Scattering



Scattering from Surface Waves

Optics Picture of the Day. http://atoptics.co.uk/opod.htm

High-angle backscatter

Glory on Pinnacle Ridge, Pen yr Ole Wen, Wales *photographed by John Hardwick in February 1993. It shows the classical appearance of a mountain glory as sunshine breaks through a mist. When the mist is nearby the glory is accompanied by your shadow. Larger image.*

Glories can be predicted by Mie scattering calculations as used in IRIS. The matching simulation at upper left shows that the droplets were small, only 10 micron diameter.

Glories are always directly opposite the sun, centered at the antisolar point and therefore below the horizon except at sunrise and sunset.

Look for them whenever mist or cloud is beneath you and the sun breaks through to shine on it.

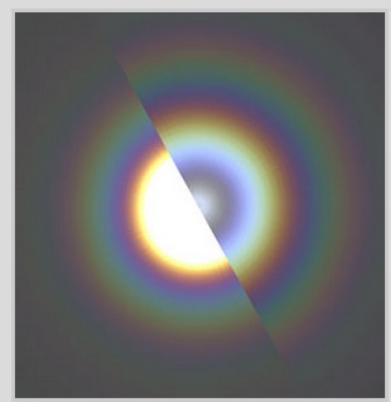
Glories can be seen on mountains and hillsides, from aircraft and in sea fog and even indoors.

They are formed when light is scattered backwards by individual water droplets.

They have a bright centre but not nearly as bright as the corona's aureole. Their rings are delicately coloured like those of the corona's, blue on the inside changing through greens to red and purple outside. The ring intensities fall off much more slowly than those of the corona and sometimes three or even four rings are visible.

Shadows converge on the antisolar point and so glories are nearly always accompanied by your shadow or that of the aircraft you are in. When the shadow is grotesquely distorted by perspective it is called a "Brocken spectre".

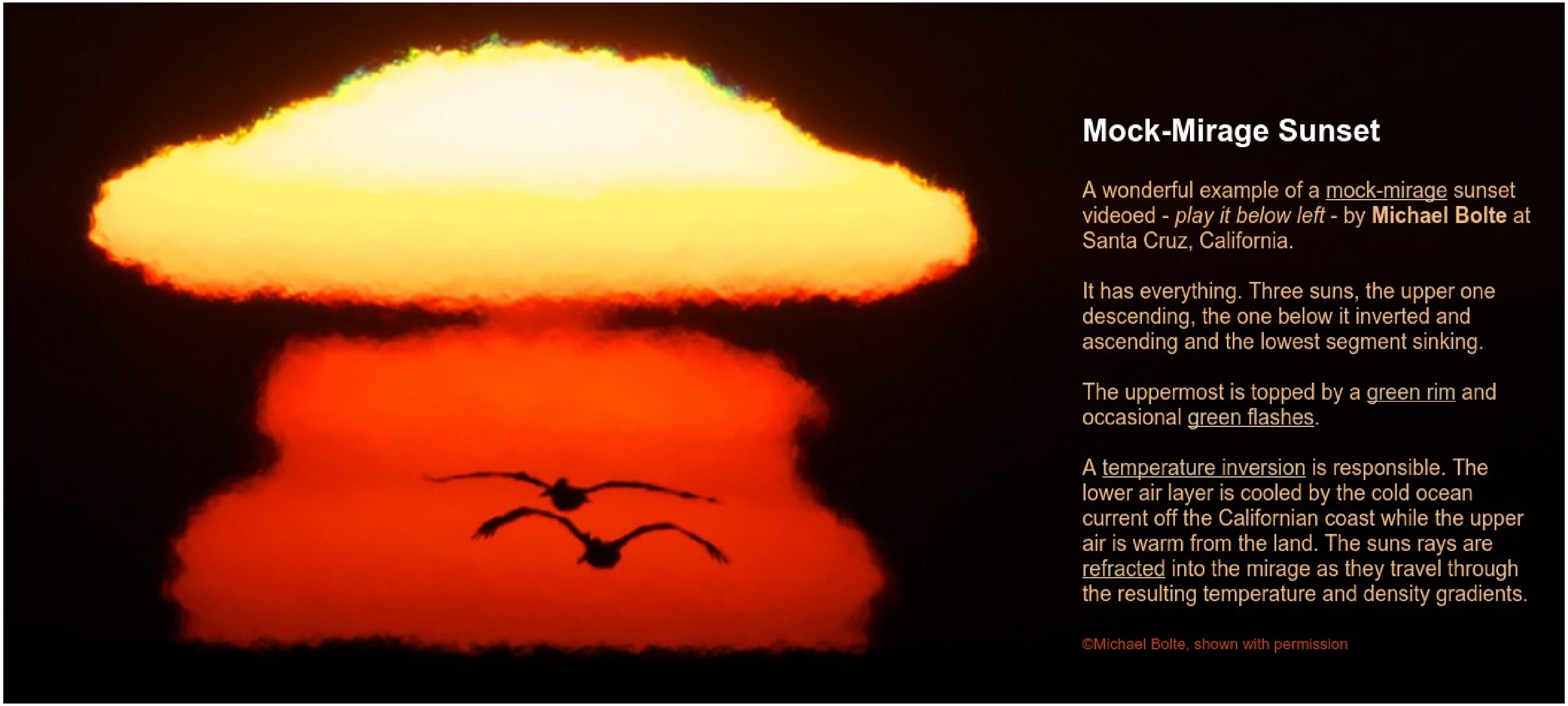
There are other glows at the antisolar point, the heiligenschein and the opposition effect but these do not have the glory's shimmering rings.



Glory (right) and corona (left) for 20µm dia. droplets - IRIS simulations.

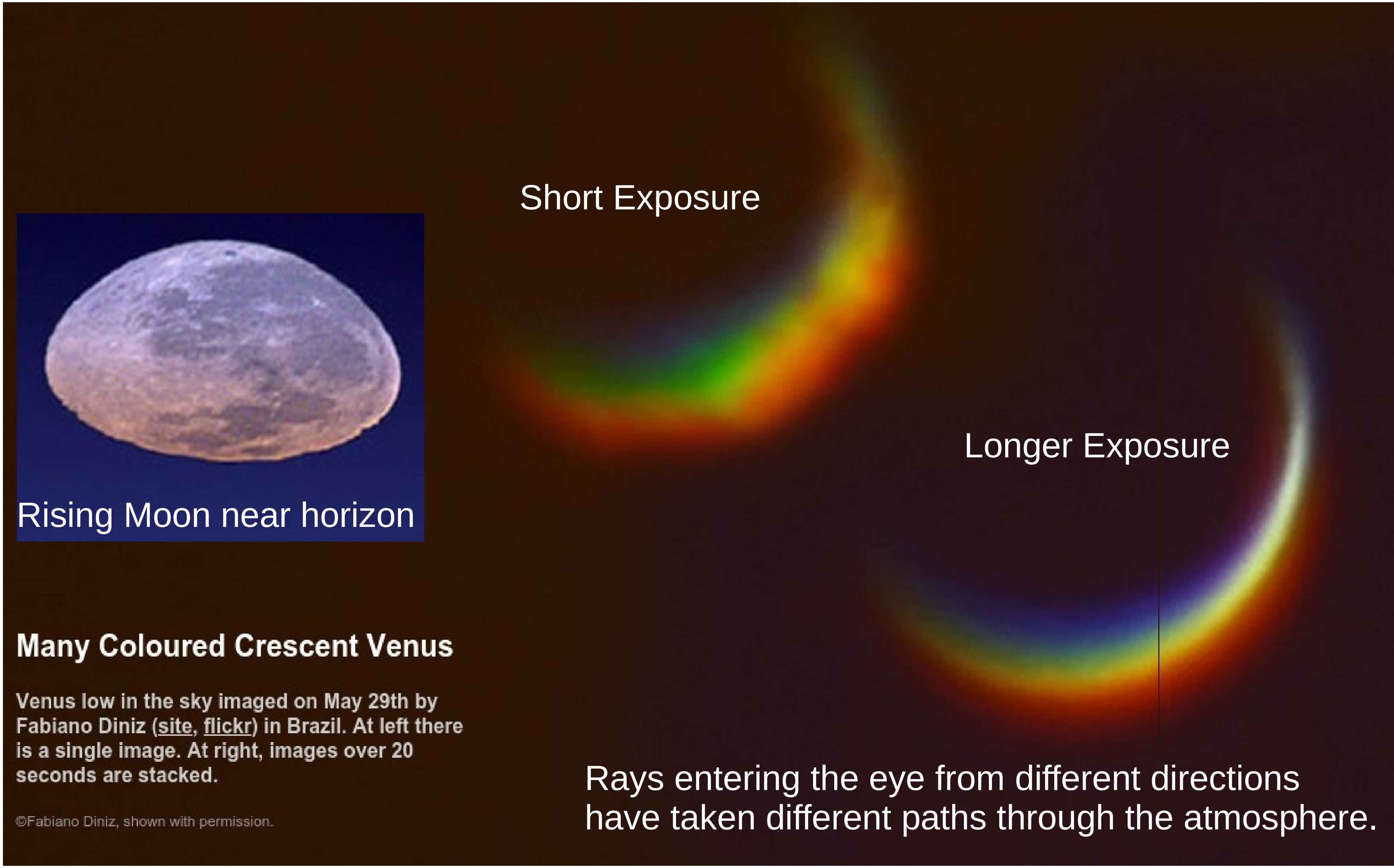
Optics Picture of the Day. http://atoptics.co.uk/opod.htm

Refraction and multipath propagation



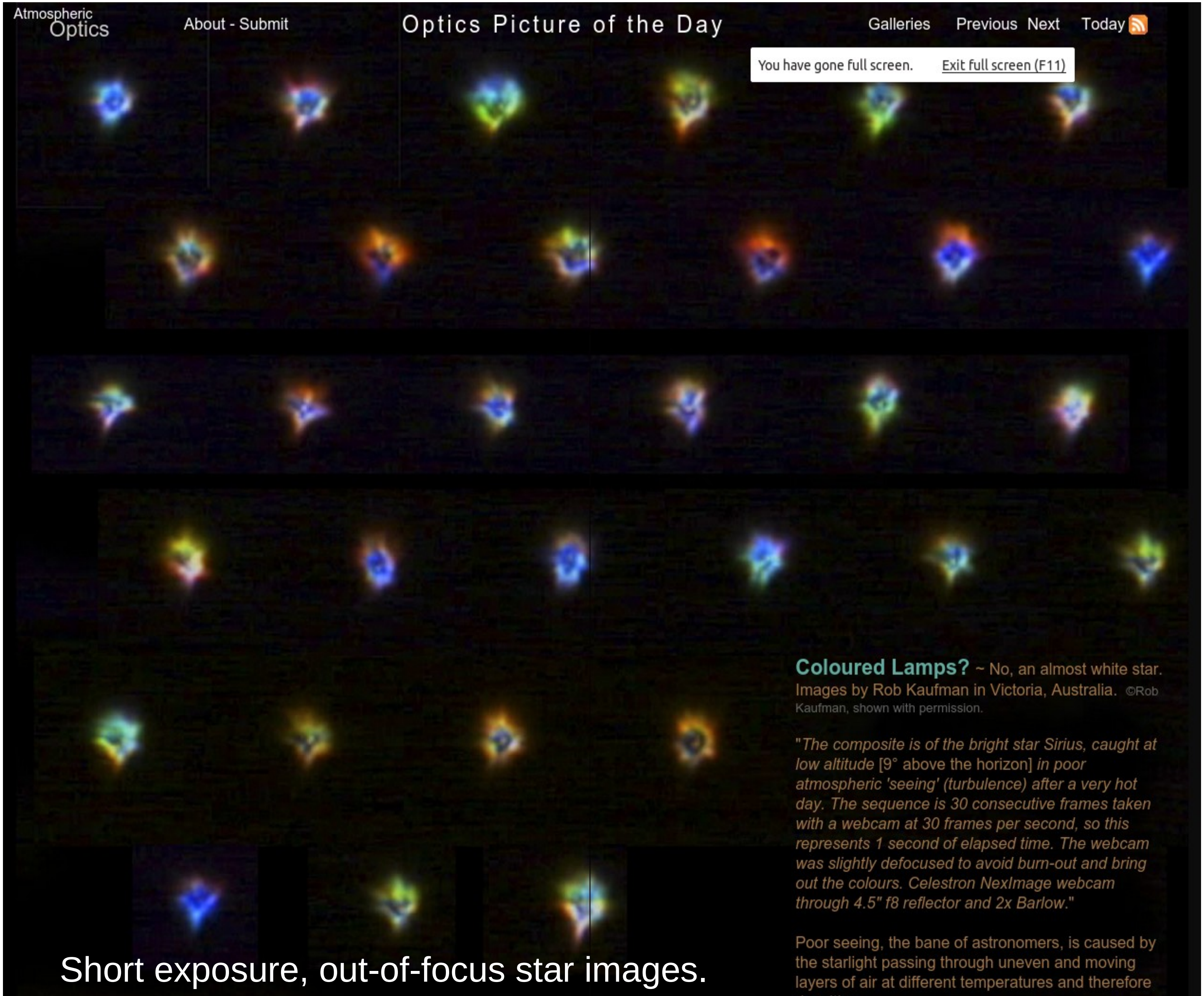
Optics Picture of the Day. http://atoptics.co.uk/opod.htm

Atmospheric Refraction and Dispersion



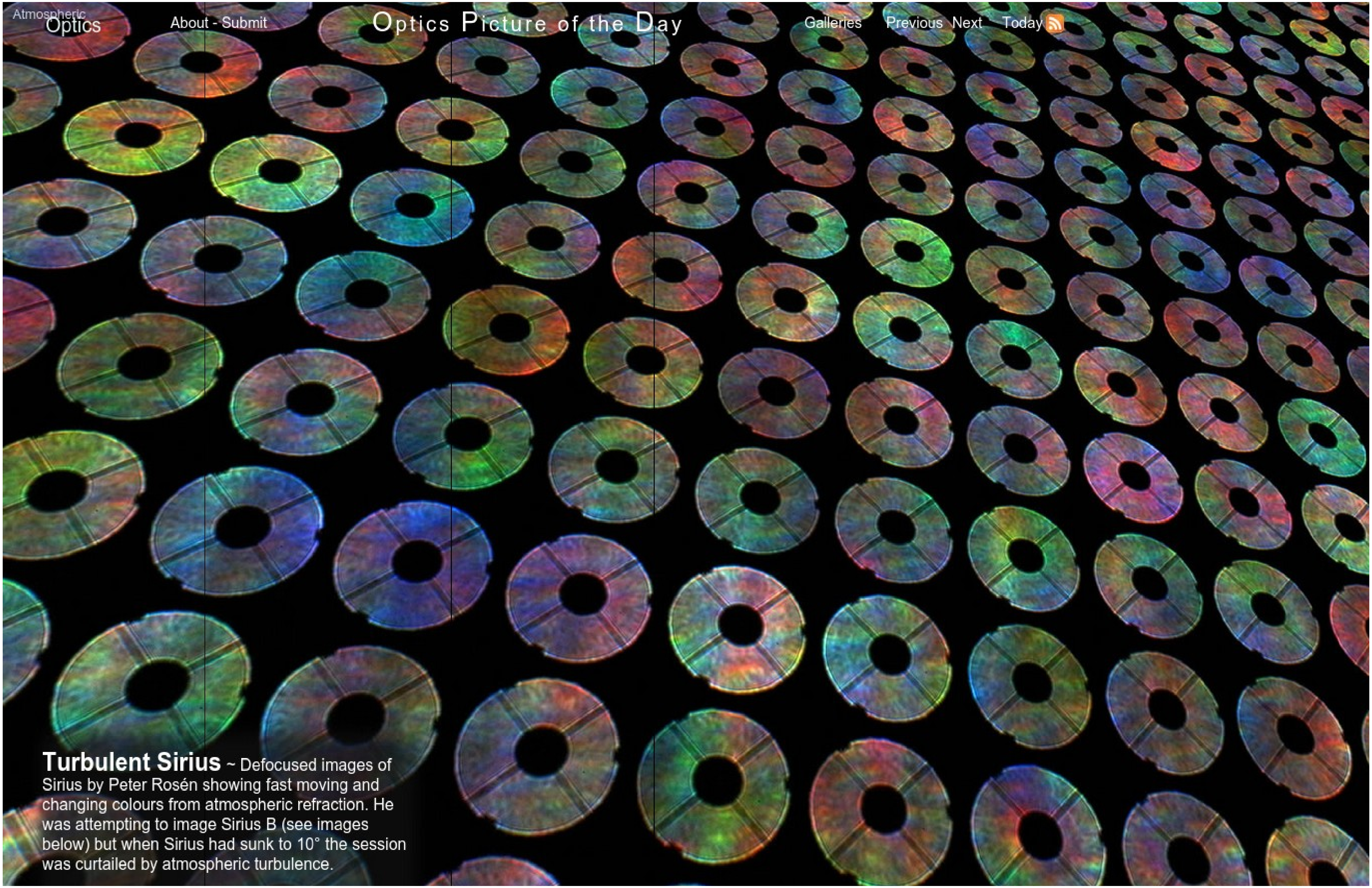
Optics Picture of the Day. http://atoptics.co.uk/opod.htm

Chromatic Scintillation



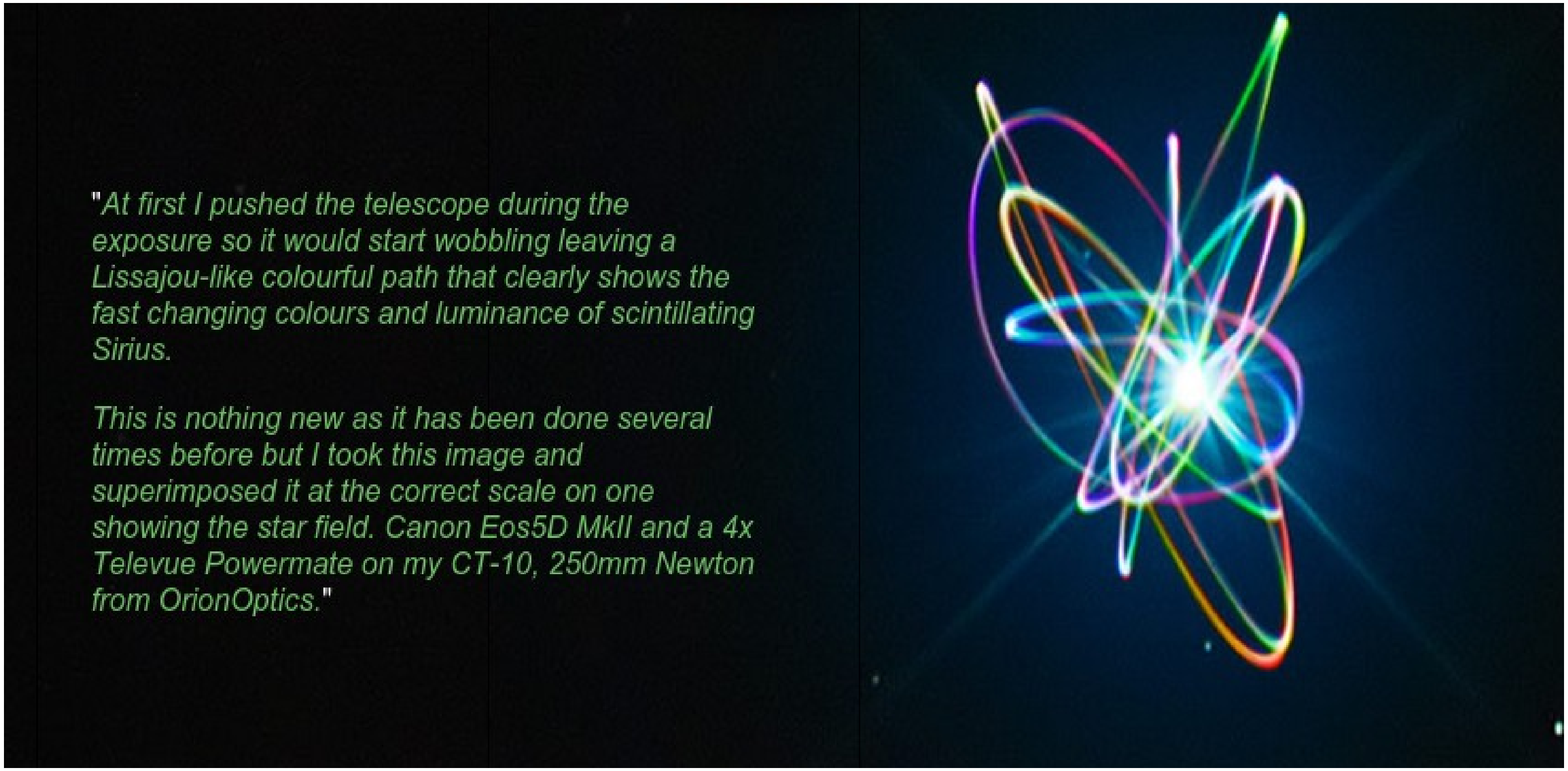
Short exposure, out-of-focus star images.

Chromatic Scintillation



Optics Picture of the Day. http://atoptics.co.uk/opod.htm

Evolution of Chromatic Scintillation



Optics Picture of the Day. http://atoptics.co.uk/opod.htm

Chromatic Radio Scintillation in the Interstellar Medium

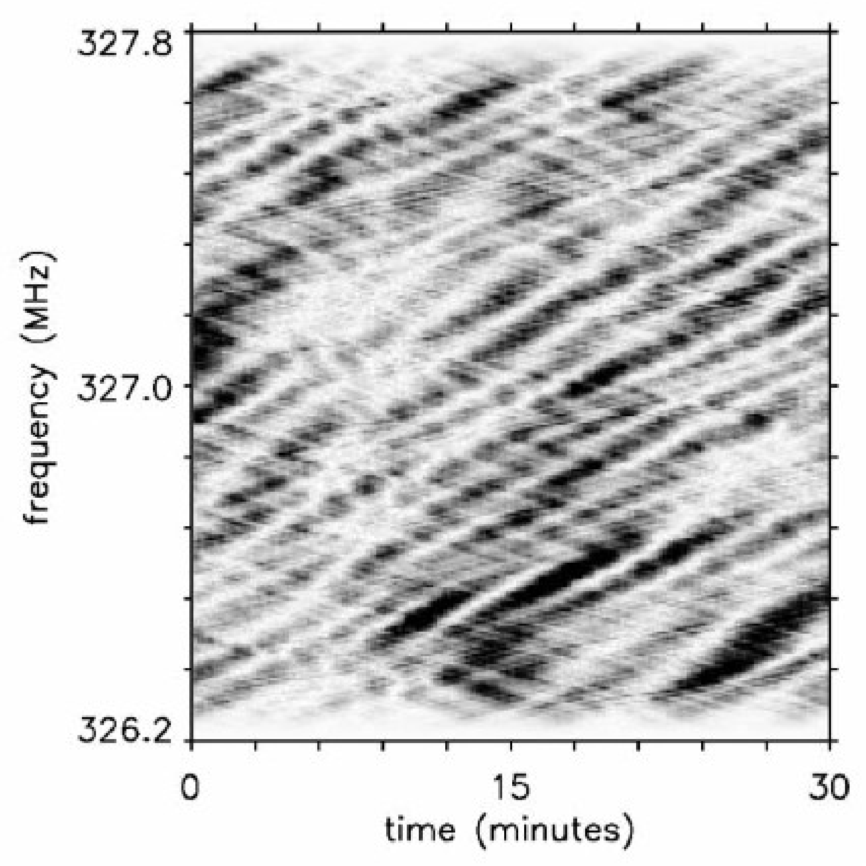


FIG. 1.—Dynamic spectrum of PSR B0834+06 observed on 2003 December 31. The flux density as a function of frequency and time is shown using a gray scale that is linear in power, with dark regions indicating high power. The criss-cross pattern is due to radio waves reaching the observer from a variety of angles (~10 mas away from the pulsar position), as detailed in the text.

Simulated ISS Dynamic Spectra

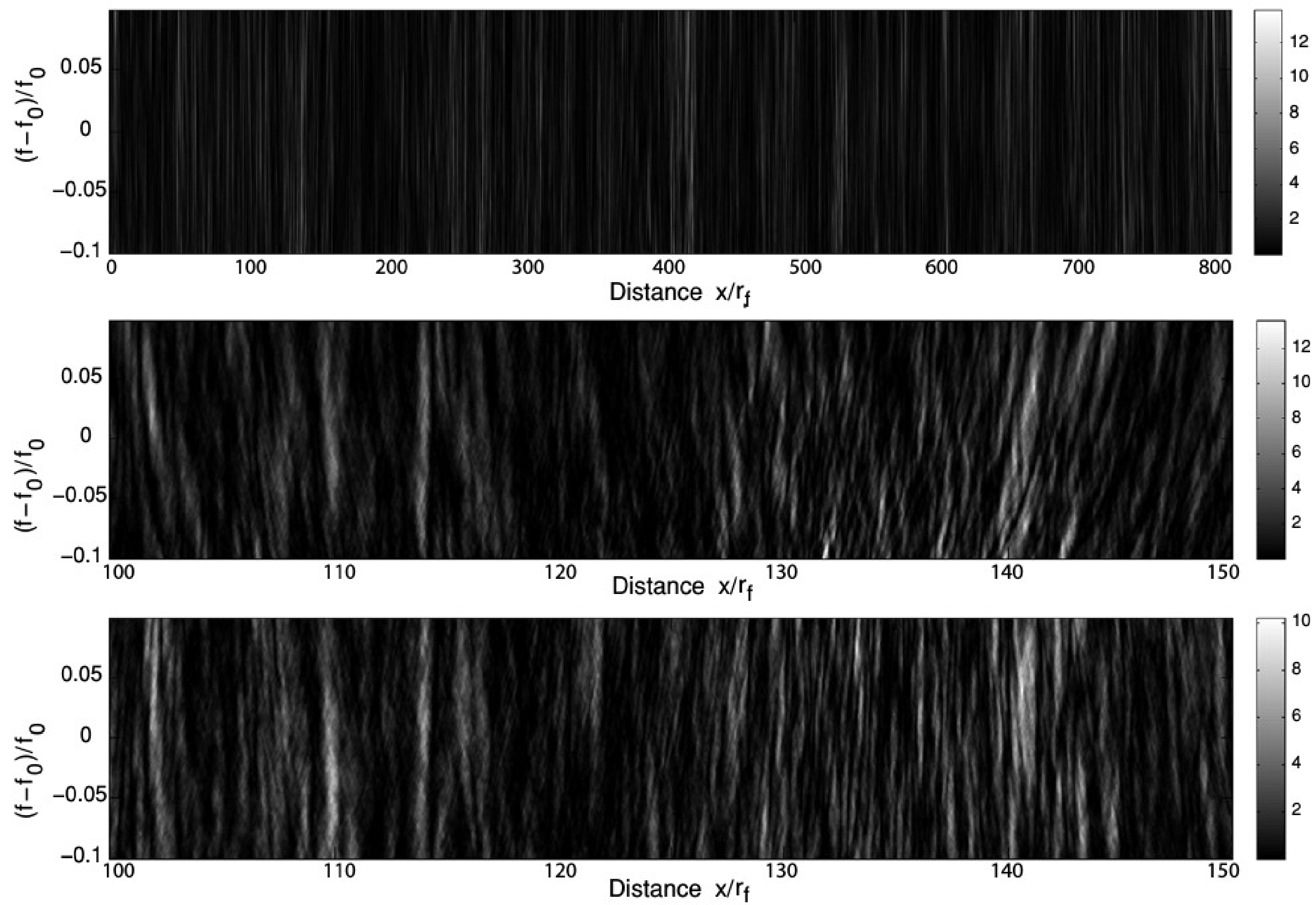
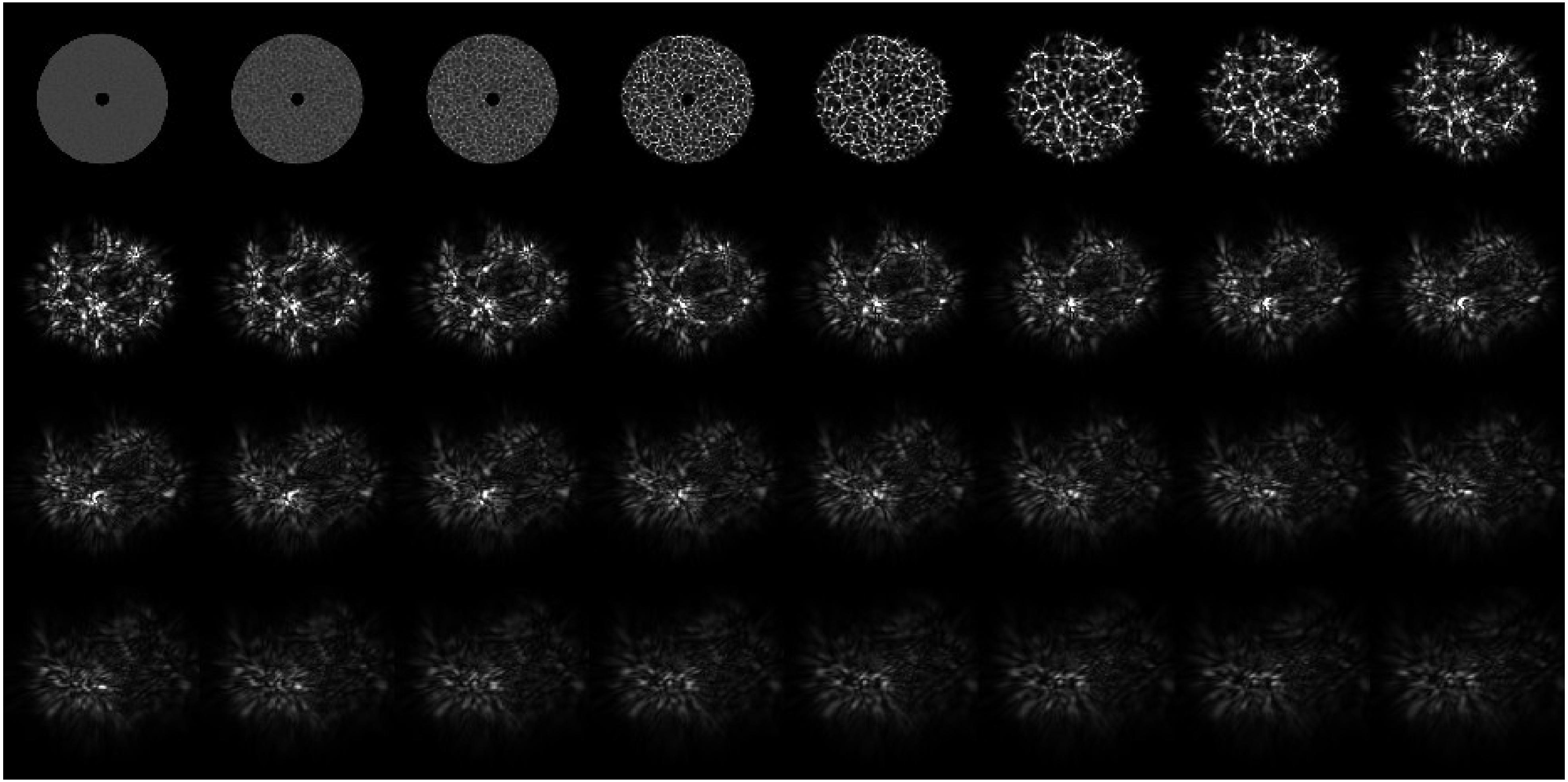
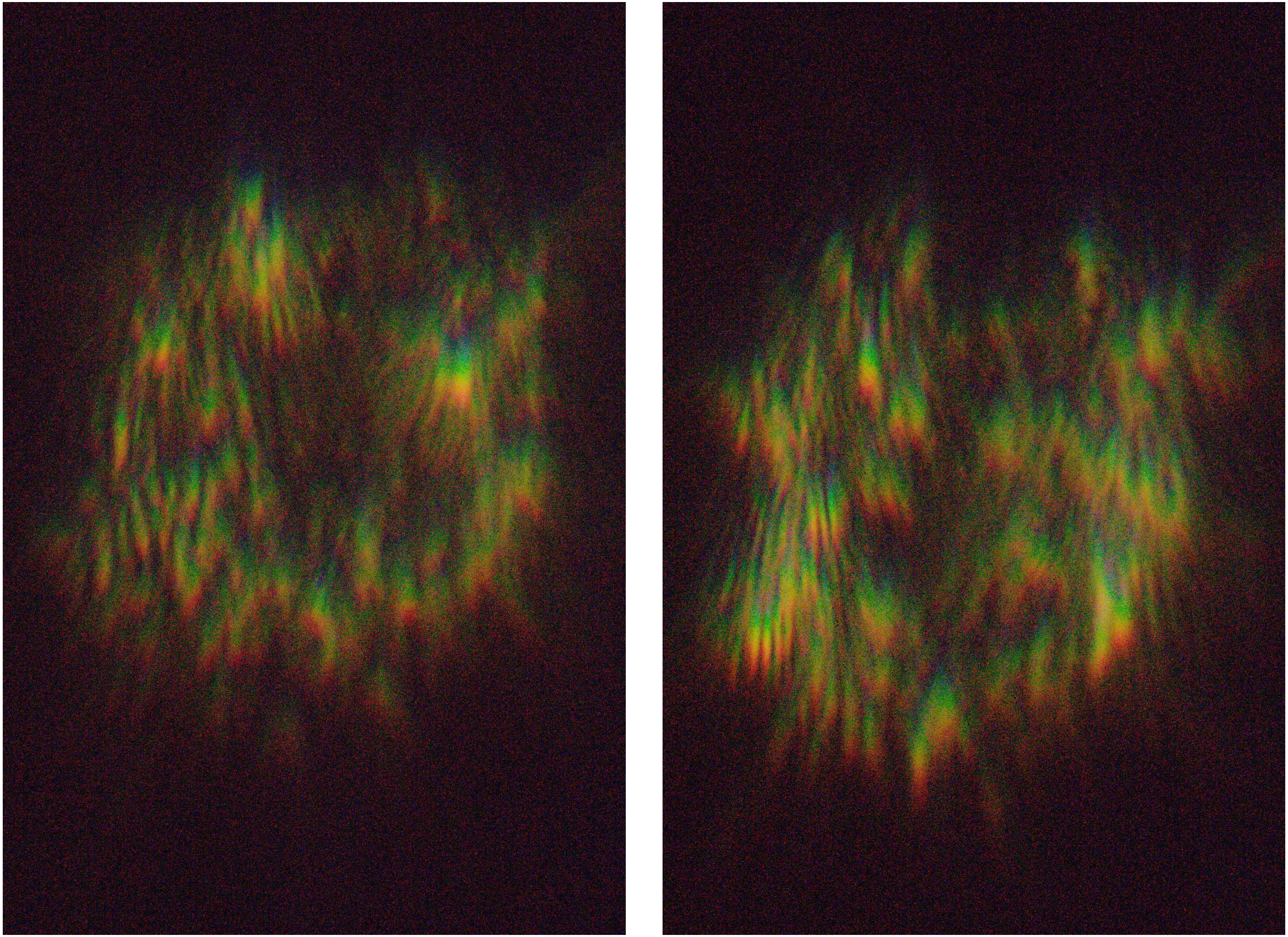


Figure 1. Dynamic spectra for $m_b^2 = 10$: (a) the top panel is the full dispersive simulation; (b) the middle panel is an expanded section of the top panel; (c) the bottom panel is the same as panel (b) except the simulation is run without dispersion. In each case, the abscissa is scaled with respect to the Fresnel scale r_f (about 3.2×10^5 km for a typical pulsar). If converted to a time axis using a velocity of 100 km s^{-1}, the full window corresponds to about a month of observation.

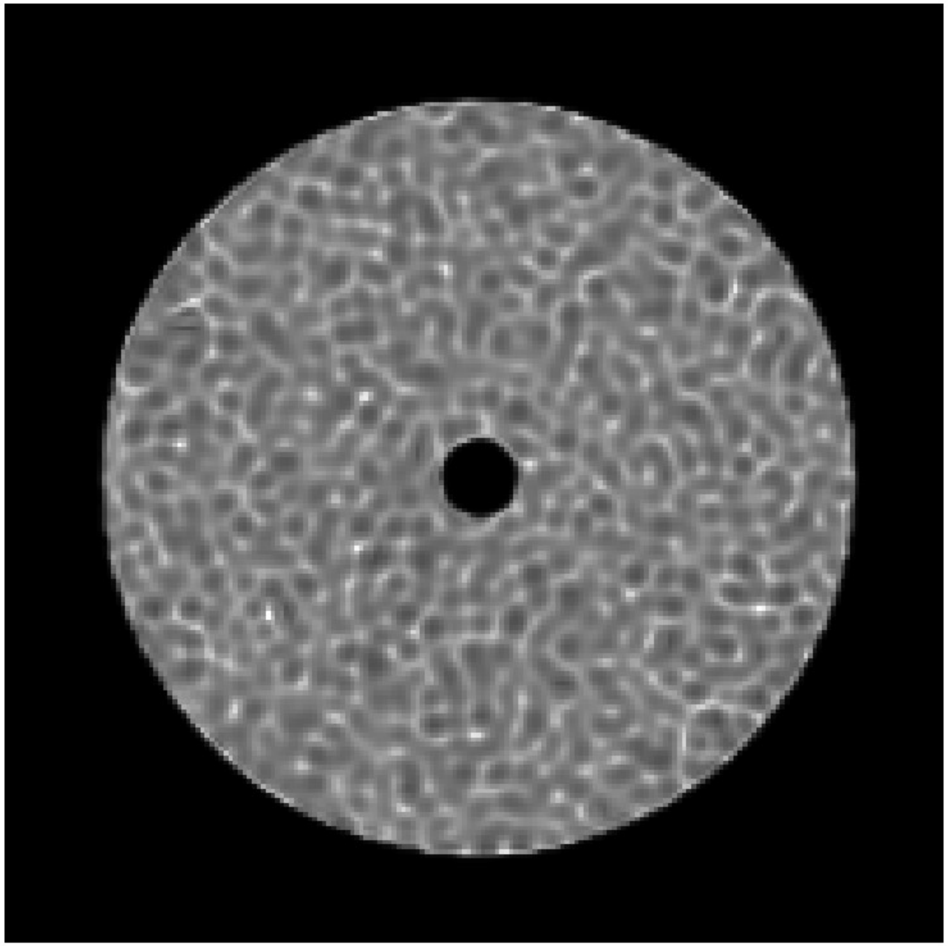
Evolution of Scintillation with Range



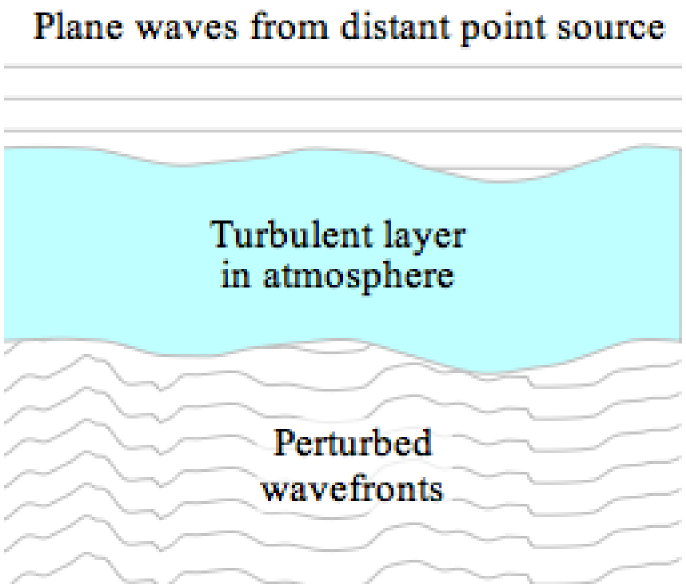
Defocused Star Images at the MMT

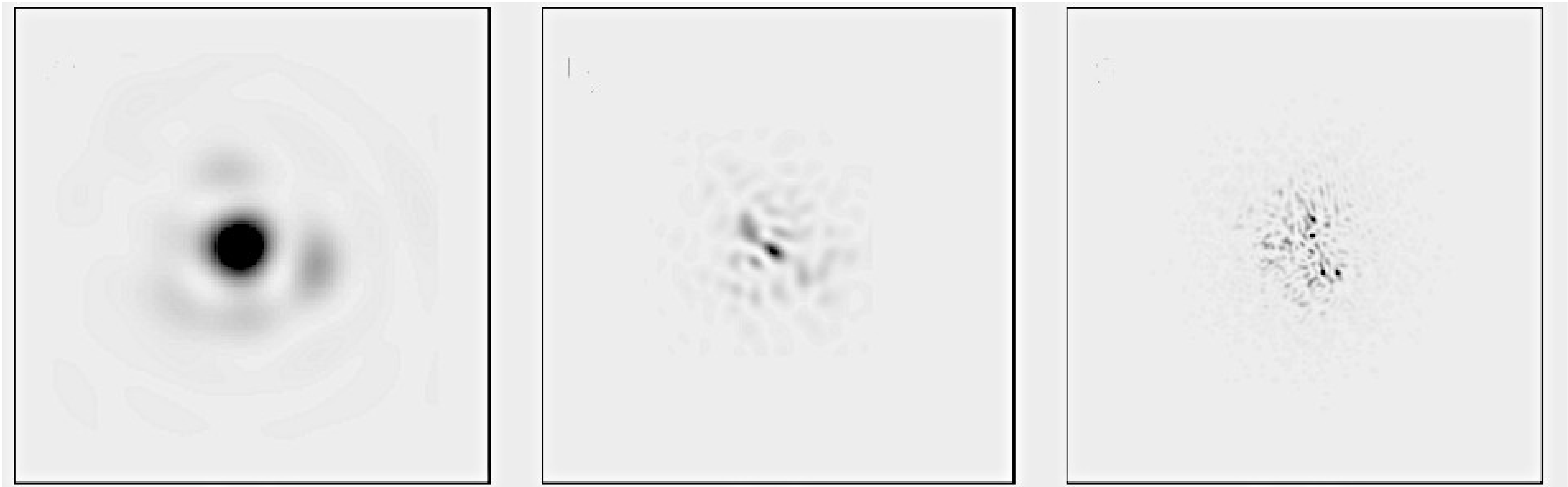


Weak Scintillation



Images with Increasing Aperture



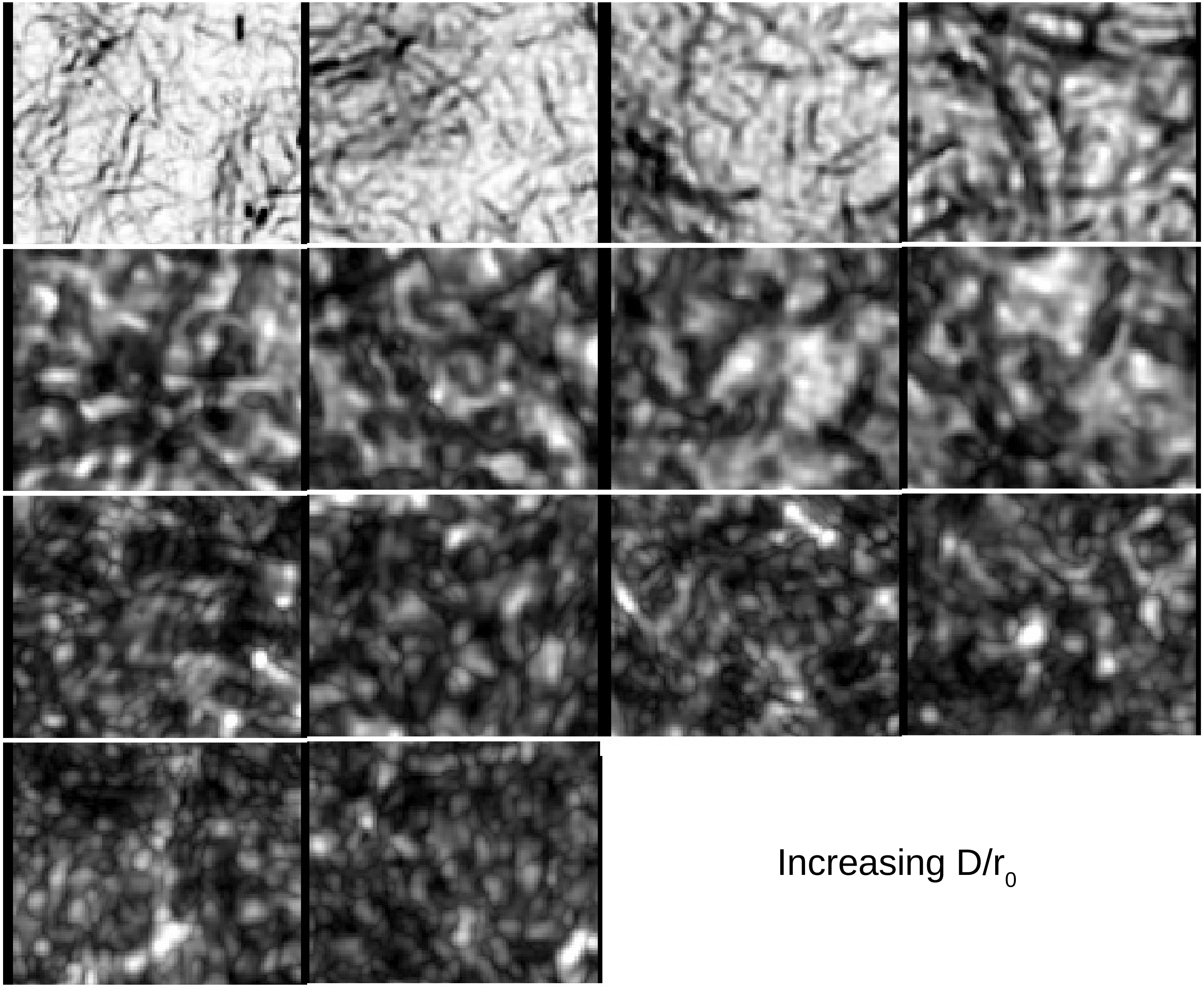


$D=2r_0$
(8in telescope @ V, r_0=10)

$D=7r_0$
(30in telescope @ V, r_0=10)

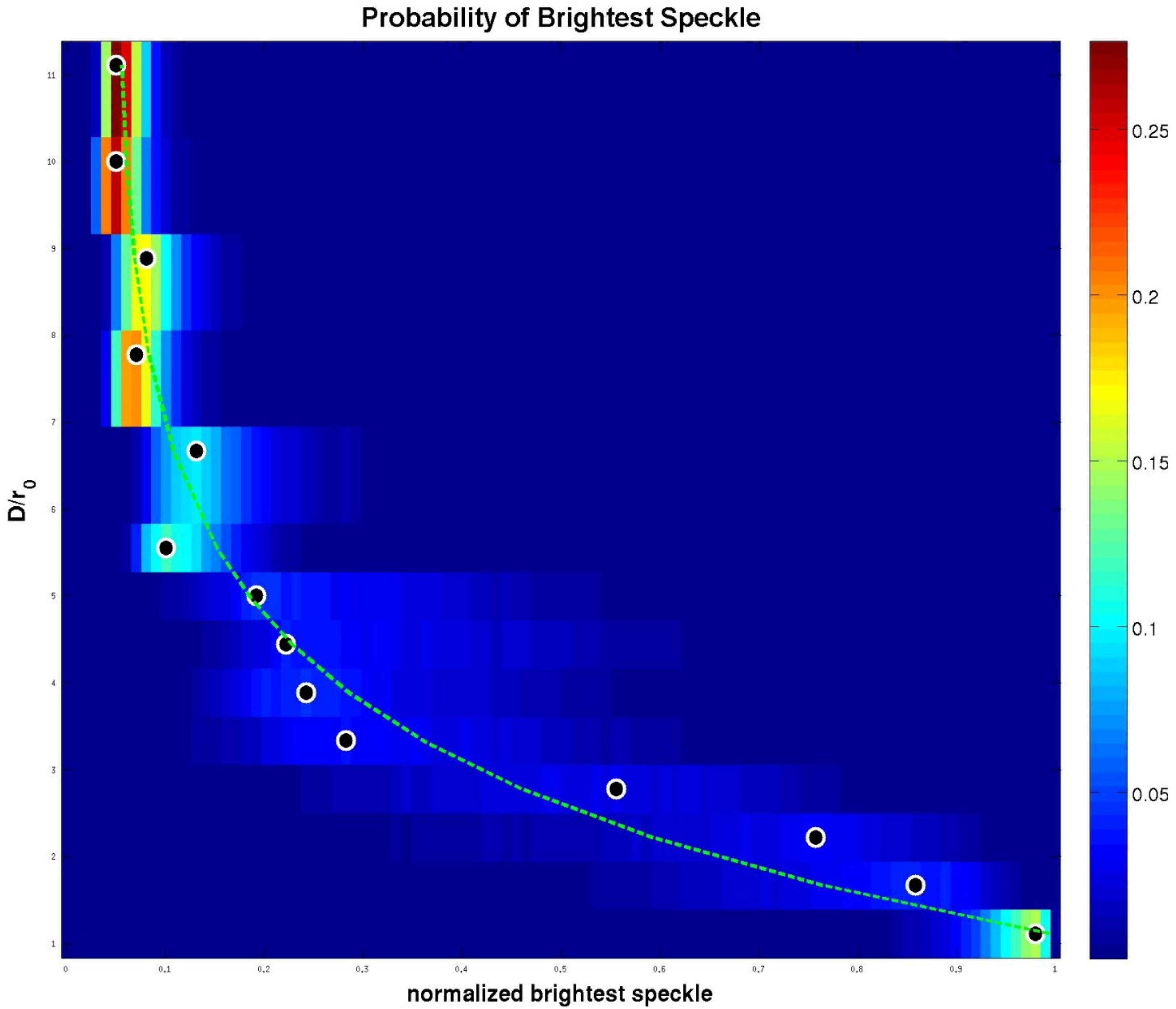
$D=20r_0$
(2m telescope @ V, r_0=10)

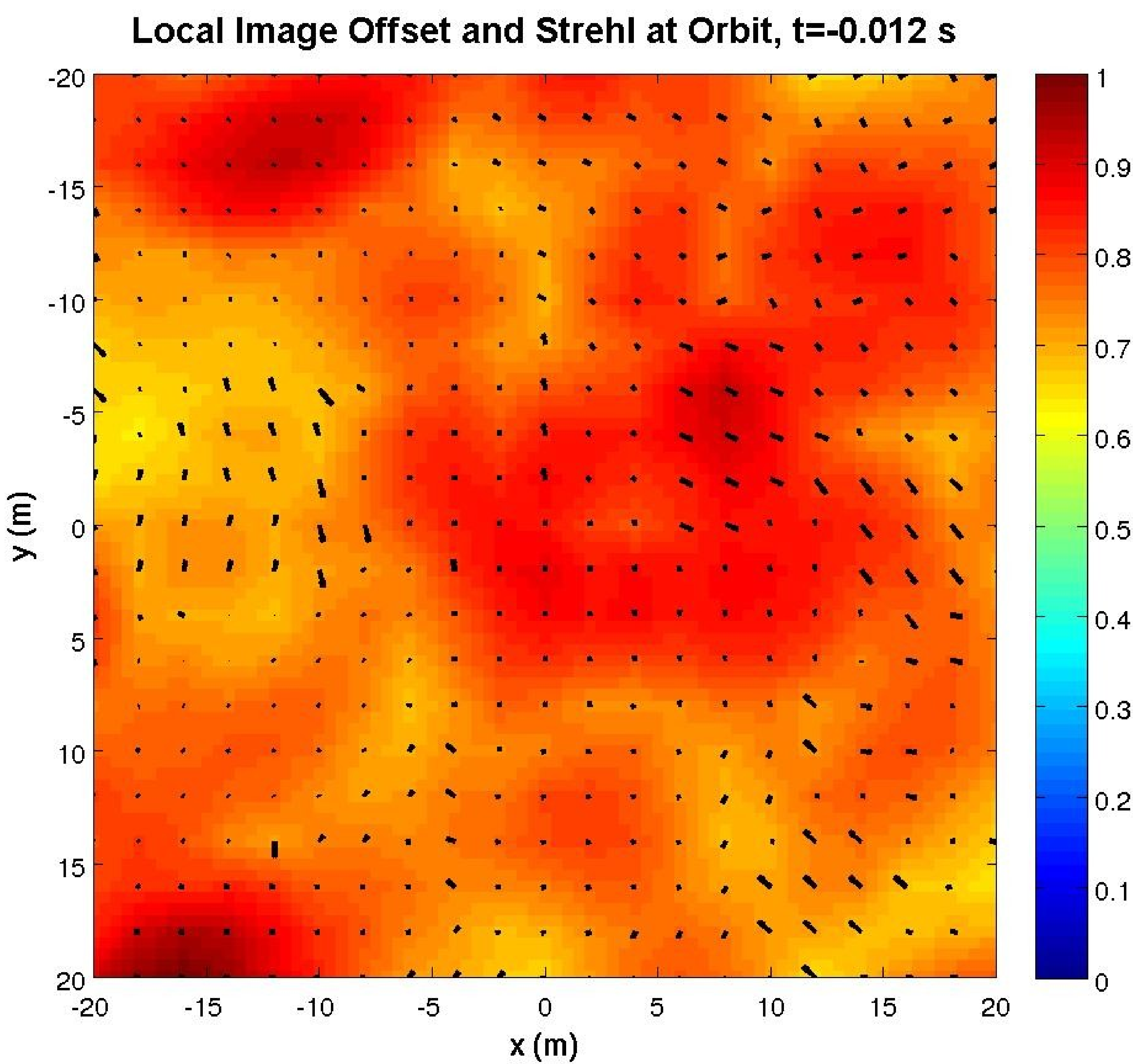
Brightest Speckle and Luckiness



Increasing D/r_0

Lucky Imaging vs Scattering Strength




Local Image Offset and Strehl at Orbit, t=-0.012 s
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x (m)
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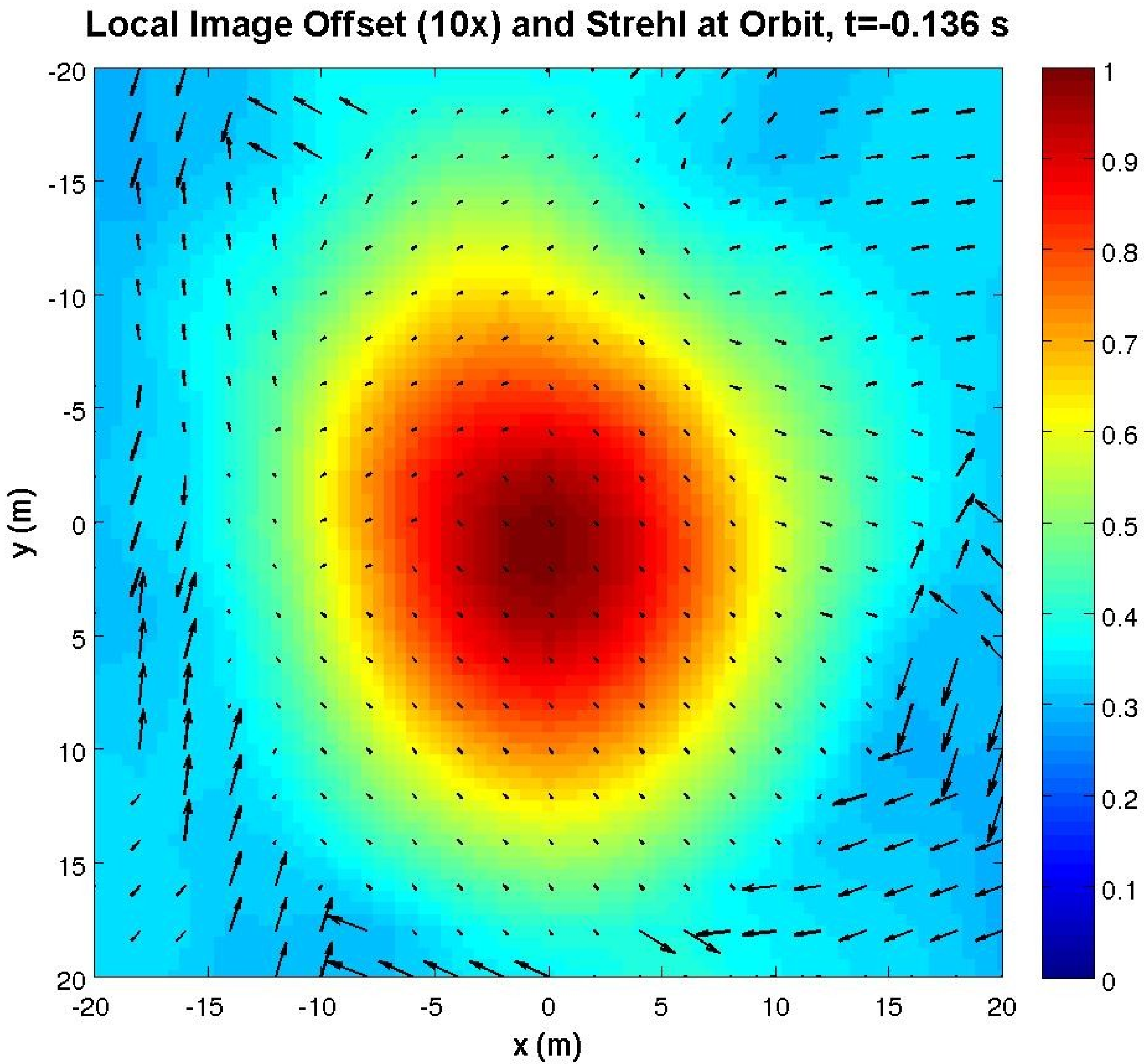
-15
-10
-5
0
5
10
15
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Local Image Offset (10x) and Strehl at Orbit, t=-0.136 s
y (m)
x (m)
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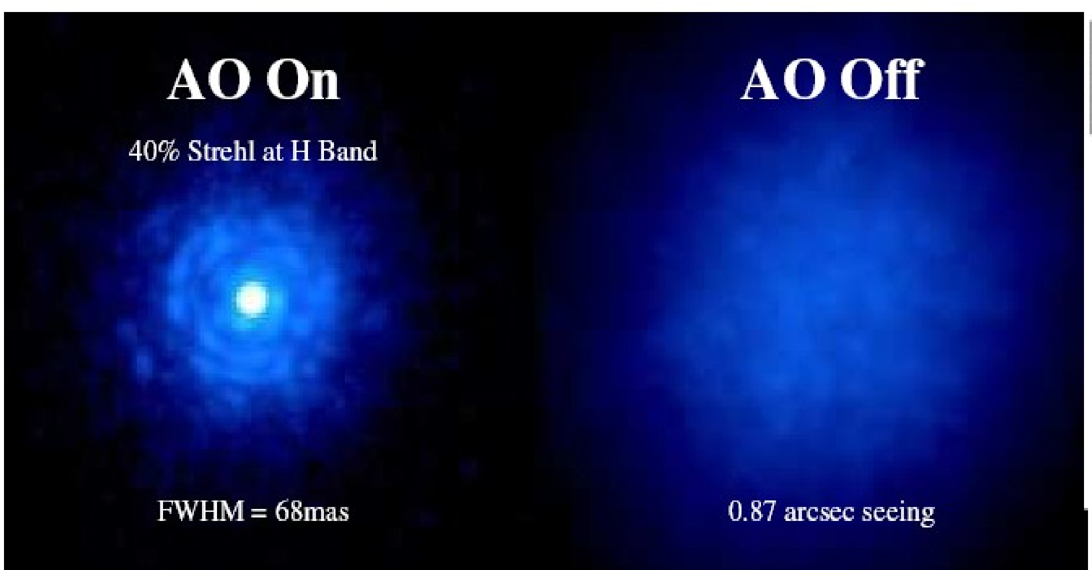
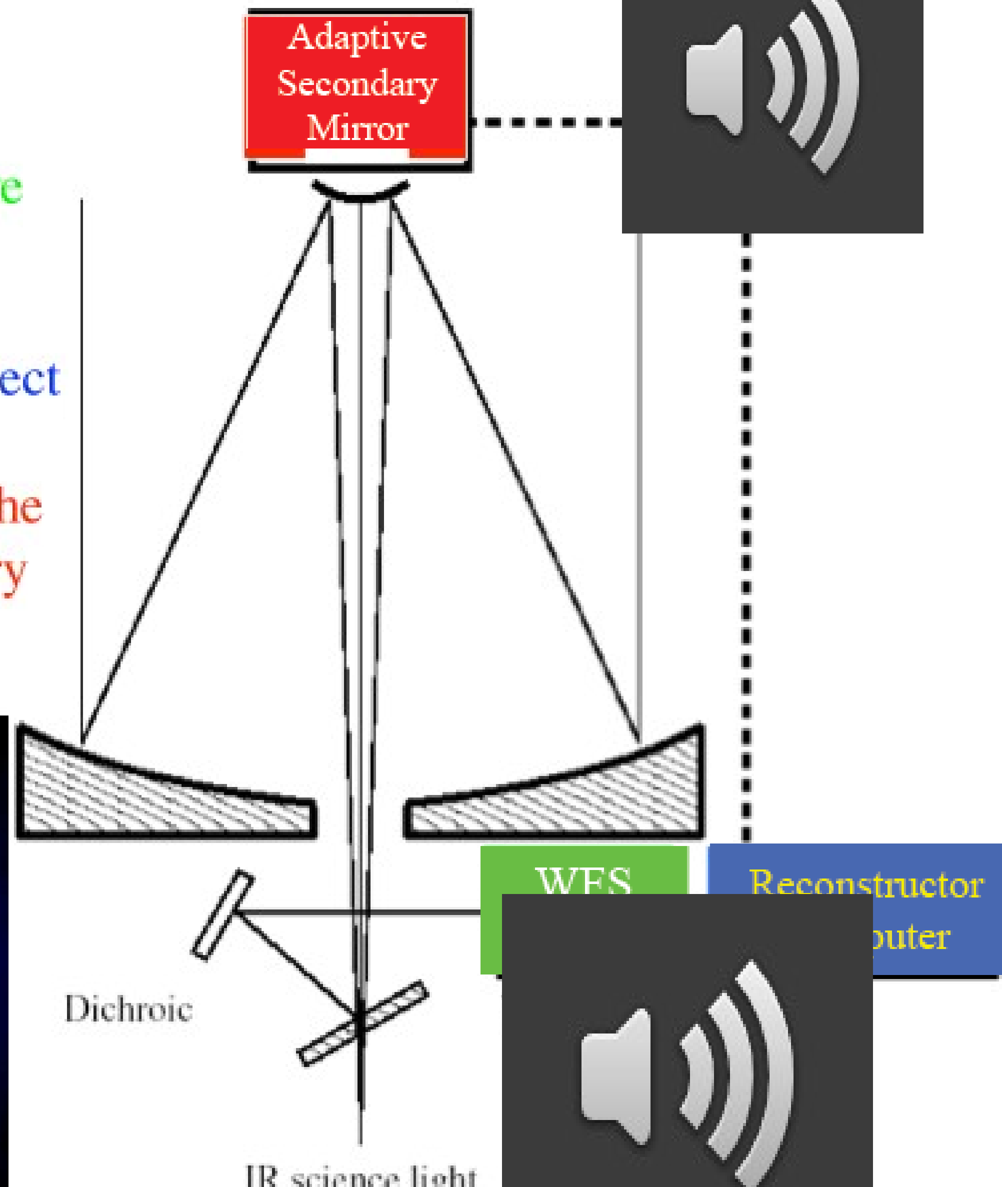
-15
-10
-5
0
5
10
15
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

The MMT AO System

This loop is performed at 550 Hz

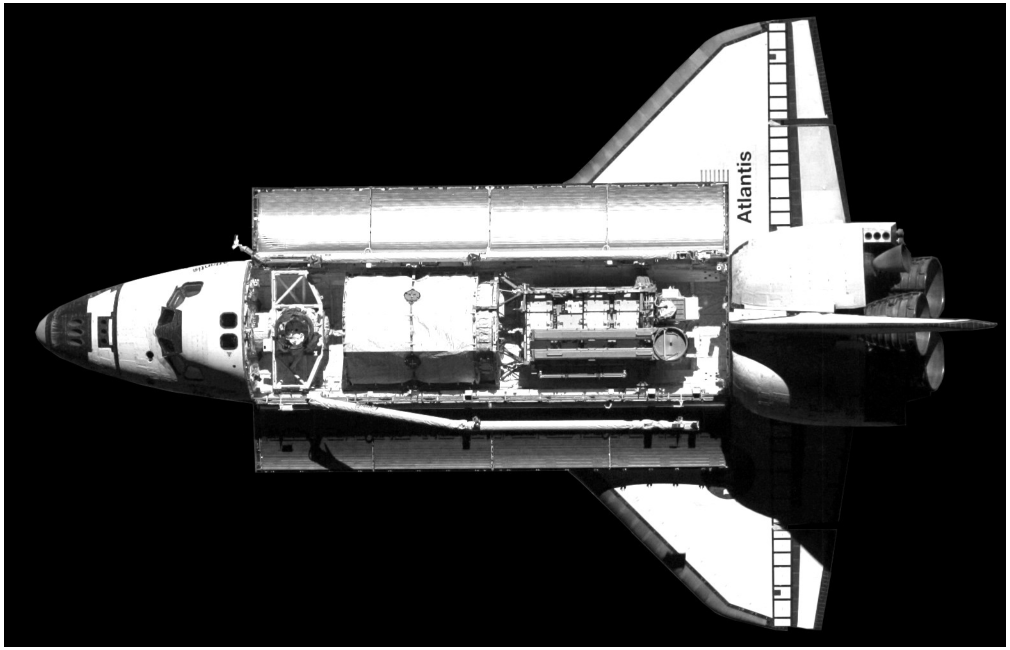
1. Measure aberrations due to the atmosphere with WFS Camera
2. Calculate secondary shape needed to correct measured aberration
3. Apply this shape to the deformable secondary

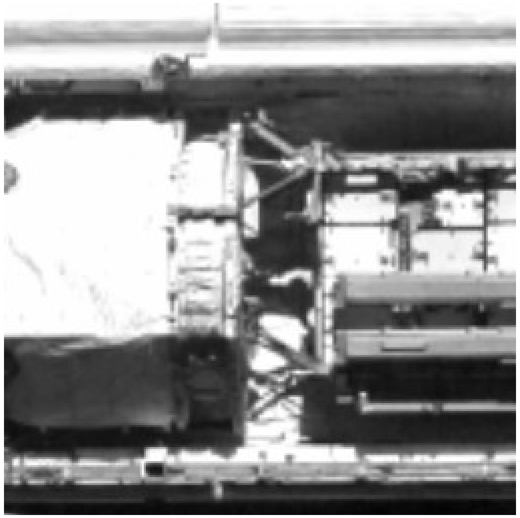


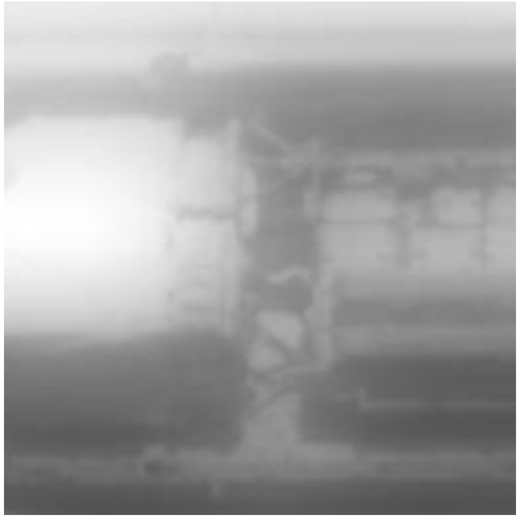


Imaging Sattelites from the ground

ISS 27th Oct 2006


Atlantis





Atmospheric Layers