Multiples: signal or noise?

Arthur B. Weglein

M-OSRP/Physics Dept./University of Houston

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Abstract

There has been considerable recent interest and activity (for example, published papers, international conference presentations and workshops) on the topic of using multiples as signal. Please see the reference section with a sample of papers on that subject. The purpose of this note is to provide an analysis and perspective with (in my view) some needed understanding, clarity and balance on this subject.

Background and the Claerbout imaging condition that we are adopting for our analysis and conclusion

To begin, "signal" within the context of exploration seismology refers to the useful parts of the seismic recorded data to be used for extracting subsurface information, for the migration and inversion of targets at depth. For the location of structure at depth, Claerbout (1971) pioneered and developed concepts and methods that merged one way wave propagation ideas with imaging conditions. Claerbout's three landmark imaging conditions are: (1)

the exploding reflector model, (2) the space and time coincidence of up and down waves, and (3) the predicted coincident source and receiver experiment at depth at time equals zero. The third imaging condition stands alone for clarity and definitiveness and in its potential to be extended for amplitude analysis at the target. Stolt and his colleagues (Clayton and Stolt, 1981; Stolt and Weglein, 1985; Stolt and Benson, 1986; Weglein and Stolt, 1999; Stolt and Weglein, 2012) then provided the extension, for one way waves, of the Claerbout source and receiver experiment imaging condition to allow for non coincident source and receiver at time equals zero, to realize structural and inversion objectives. The latter extension and generalization produced migration-inversion, or first determining where anything changed (migration) followed by what specifically changed (inversion) at the image location. Recently, several papers by Weglein and his colleagues (Weglein et al., 2011a,b; Liu and Weglein, 2014) provided the next step in the evolution of migration based on the Claerbout predicted source and receiver experiment imaging condition, extending the imaging concept and methodology for predicting an experiment in a volume with two way propagating waves. The latter method of imaging based on the Claerbout coincident source and receiver experiment at depth, in a medium with two way propagating waves, plays a central role in the analysis of this paper.

All current RTM methods, for two way waves, are extensions of the second of Claerbout's imaging conditions, and do not correspond to a source and receiver experiment at depth.

One doesn't have to look very far to find an example for two way propagating waves that calls for the latter predicted experiment at depth and imaging condition. Imaging from above or below a single horizontal reflector requires that two way wave propagation and Claerbout's predicted experiment imaging condition. Predicting a source and receiver experiment to locate and to determine the reflection coefficient from above, and, separately, from below, a single reflector requires two way wave migration, since the reflection data moves up to a source and receiver experiment located above the reflector and down to that experiment when the source and receiver are located below the reflector. Of course, the addition of, for example, multiples and/or diving waves also represent examples of two way wave propagation in the region where you want to predict the seismic experiment at depth.

For the purposes of this discussion we are going to adopt the Claerbout predicted coincident source and receiver experiment at time equals zero imaging condition for its peerless clarity, generality and quantitative information value. The example we present provides for the first time an analysis that starts with and follows how surface recorded data (with primaries and free surface and internal multiples) influences the subsequent experiment and imaging at each depth level, and specifically: (1) how each individual recorded event in the surface data is involved and contributes to the individual events of the predicted source and receiver experiment at each different depth, and then (2) what happens to that recorded surface event's contribution as the predicted experiment is at different depths, and at each depth how the surface recorded events contribute when applying the time equals zero imaging condition. Please see three cases we examine in the three videos (http://mosrp.uh.edu/events/event-news/multiples-signal-noise-a-clear-example-with-a-definitive-conclusion) and corresponding slide snapshots. In the three examples a unit amplitude plane wave is normal incident on a one-D earth. The first case (please see figures 1-3) is the example of a single reflector and a single primary, with no free surface or internal multiples. That single primary is the sole contributor to the events in the experiment above and below that single reflector. When the time equals zero condition is applied, the recorded primary is the only recorded event in the image, both below and above the reflector.

The second case has a single primary and a free surface multiple (please see figures 4-6). The predicted experiment above the reflector has two surface event contributions, from the primary and the free surface multiple. When the time equals zero imaging condition is applied then only the recorded primary contributes to the image. Below the reflector the predicted experiment has two events, a primary that has a downward reflection at the reflector, and a primary from the source to the free surface and then down to the predicted receiver. The original free surface multiple in the recorded data became a primary in the predicted experiment below the reflector. Hence, the primary and free surface multiple in the recorded data became two primaries for the experiment below the reflector. However, once the time equals zero imaging condition is applied to the predicted experiment, only the recorded primary contributes to the image and the recorded multiple does not.

In the third case (please see figures 7-11), we consider a subsurface with two reflectors and recorded primaries and internal multiples. As you follow the history that each event in the recorded data follows and then contributes to, first in the experiment at depth and then to the image at each depth, you reach the following conclusion. Recorded primaries and free surface multiples and internal multiples all contribute to events for the predicted experiment at depth. Sometimes multiples in the recorded data even become primaries in the predicated experiment at depth. However, only the recorded primaries contribute to the image at every depth. If you removed the multiples in the recorded data, the source and receiver experiment at depth would change, but not the image's location at the correct depth or its amplitude, the reflection coefficient.

Hence, for the purposes of imaging and inversion, primaries are signal and multiples are not. Multiples are not evil, or bad or irresponsible, they are simply not needed for locating and identifying targets.

The methods that seek to use multiples today as "signal" are really seeking to supply primaries that have not been recorded, due to limitations in acquisition, and to address the subsequent limited illumination that missing primaries can cause. They are not really using the multiple itself as an event to be followed into the subsurface for imaging purposes. The figure (12) illustrates the idea.

Assume a multiple is recorded, and a long offset primary that is a subevent is also recorded. The idea is to extract and predict the smaller offset, and not recorded primary from the recorded multiple and the recorded longer offset primary. All the various incarnations that are using multiples as "signal" are actually, and entirely after removing a recorded longer offset primary to have the output as a shorter offset unrecorded primary. It's primaries that the method is seeking to produce and to utilize.

There is another issue: in order to predict a free surface or internal multiple, the primary sub-events that constitute the multiple must be in the data, for the multiple prediction method to recognize an event as a multiple. If the short offset primary is not recorded, the multiple that is composed of the short and long offset multiple will not be predicted as a multiple. That issue and basic contradiction within the method is recognized by some who practice this method, and instead of predicting the multiple, they use all the events in the recoded data, primaries and multiples, and the multiples can be useful for predicting missing primaries but the primaries in the data will cause artifacts. There are other artifacts that also come along with this method that have been noted in the literature.

The reality of today's methods for using multiples to predict missing "primaries" are aimed at structural improvement, at best, and are relatively primitive, challenged, and questionable in terms of the amplitude and phase fidelity of the predicted primary. Those who go so far as to advocate using fewer sources and/or more widely separated cables because recorded multiples can produce "something like" a missing primary need to understand the deficits and costs including generating artifacts and less effectiveness with deeper primaries. Whether the tradeoff makes sense ought to depend, in part, on the depth of the target, the type of play, and whether a structural interpretation or amplitude analysis is planned within a drilling decision.

By the way, this entire wave equation migration analysis is ultimately based on the idea from Green (1828) that to predict a wave (an experiment) inside a volume you need to know the properties of the medium in the volume.

There is an alternative view: The inverse scattering series methods communicates that all processing objectives can be achieved directly and without subsurface information. The inverse scattering series treat multiples as a form of coherent noise, and provide distinct subseries to remove free surface and internal multiples before the distinct inverse scattering subseries for imaging and inversion achieve their goals using only primaries. If the inverse scattering series needed multiples to perform migration and inversion, it would not have provided subseries that remove those multiply reflected events. With a velocity model (wave equation migration) or without a velocity model (inverse scattering series imaging) only primaries are signal.

A key and essential point: conclusion

Hence, primaries are signal and multiples can be useful, at times, for predicting missing primaries. But it's primaries that are signal, that we use for structure and inversion.

Primaries are signal for all methods that seek to locate and identify targets.

The above three examples assumed you had an accurate **discontinuous** velocity and density model. Given an accurate discontinuous velocity and density model, and data with primaries and multiples, then we have convincingly and unambiguously demonstrated that only primaries contributed to the images at every depth. If you predicted the source and receiver experiment at depth with a **smooth** velocity, it is possible to correctly locate (but not invert) each recorded primary event—but with a smooth velocity model every free surface and internal multiple will then produce a false image/artifact/event. If you removed the multiples first you can correctly locate structure from recorded primaries using a smooth velocity model.

Hence, we conclude that the inability, in practice, to provide an accurate discontinuous velocity model is why multiples need to be removed before imaging. That reality has been the case, is the case, and will remain true for the foreseeable future. Thats why multiples need to be removed before imaging. Multiples can at times be useful for creating missing primaries, **but once the primary is provided,** we don't want the multiples themselves involved when we seek to locate and identify structure. As in the past, in this holistic, inclusive "multiples are signal" activity there is danger with over stating a new deliverance and cure-all, that undermines a measured and mature view that actually recognizes, appreciates and sees the value, but doesn't obfuscate or ignore fundamental and practical drawbacks and limitations.

Many things are useful for creating primaries: money, the seismic boat, the air-guns, the observer, the cable, computers, *etc.*, but we don't call all useful things signal.

Methods to provide a more complete set of primaries are to be supported and encouraged. Those methods include: (1) advances in and more complete acquisition, (2) interpolation and extrapolation methods, and (3) using multiples to predict missing primaries. However, a recorded primary is still the best and most accurate way to provide a primary, and the primary is the seismic signal.

Acknowledgements

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Figures

Figure 1:

Figure 2:

Figure 3:

Figure 4:

Figure 5:

Figure 6:

Figure 7:

Figure 8:

Figure 9:

Figure 10:

Figure 11:

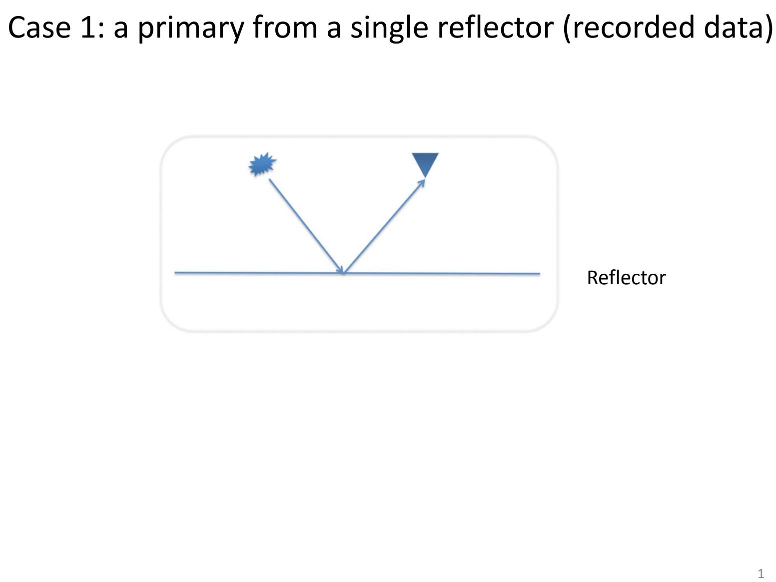

Case 1: a primary from a single reflector (recorded data)
Reflector
1

Figure 1:

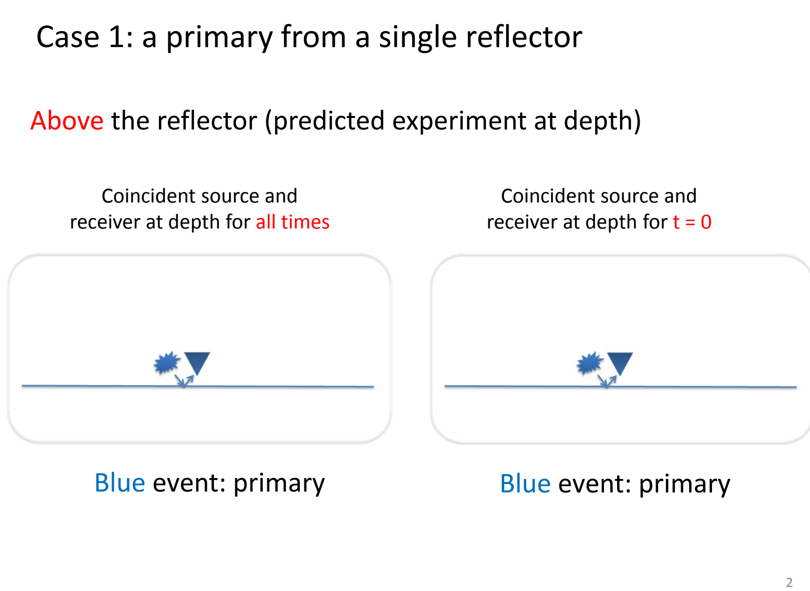

Case 1: a primary from a single reflector
Above the reflector (predicted experiment at depth)
Coincident source and
receiver at depth for all times
Coincident source and
receiver at depth for t = 0
Blue event: primary
Blue event: primary
2

Figure 2:

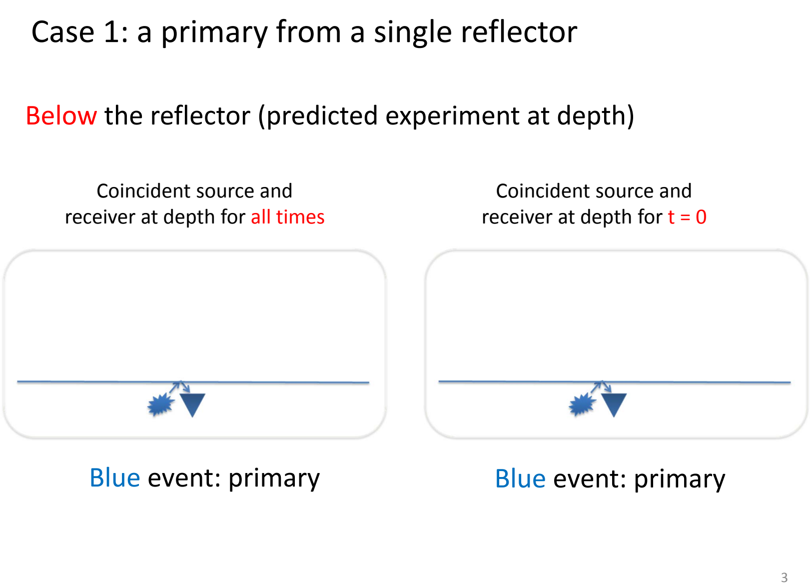
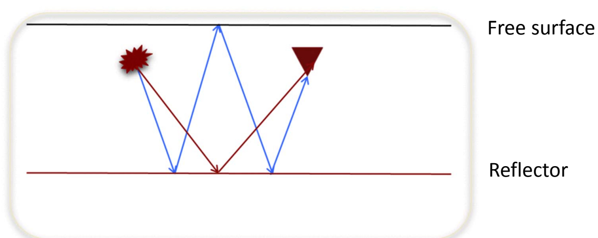

Case 1: a primary from a single reflector
Below the reflector (predicted experiment at depth)
Coincident source and
receiver at depth for all times
Coincident source and
receiver at depth for t = 0
Blue event: primary
Blue event: primary
3

Figure 3:

Case 2: a primary and a free-surface multiple (recorded data)



Red event: primary
Blue event: free-surface multiple

4

Figure 4:

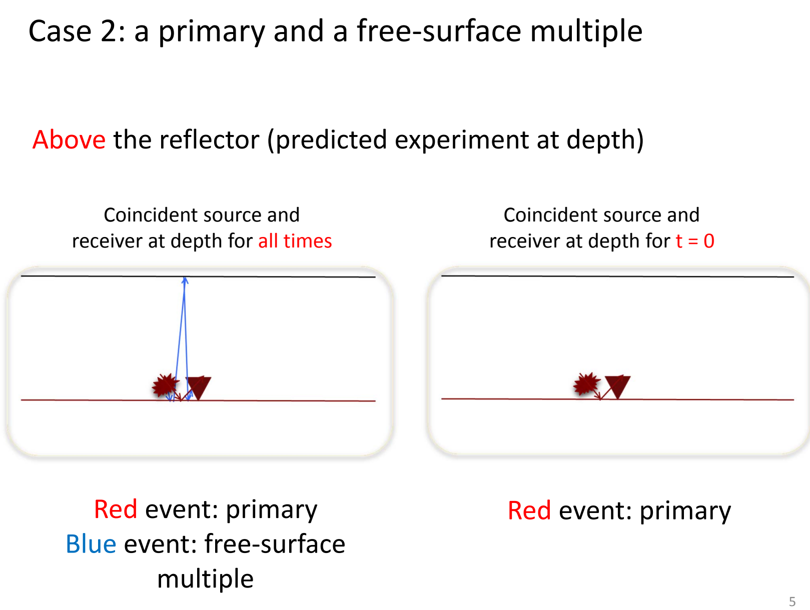

Case 2: a primary and a free-surface multiple
Above the reflector (predicted experiment at depth)
Coincident source and receiver at depth for all times
Coincident source and receiver at depth for t = 0
Red event: primary
Blue event: free-surface multiple
Red event: primary
5

Figure 5:

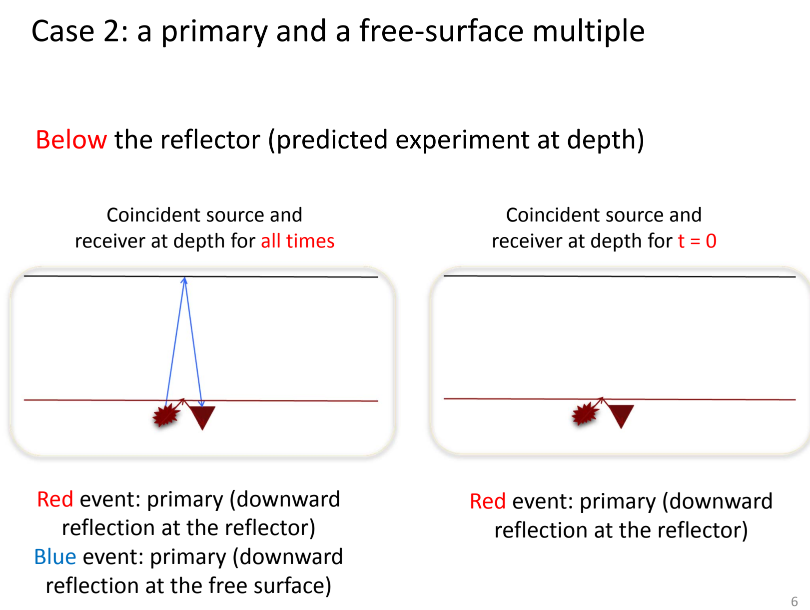
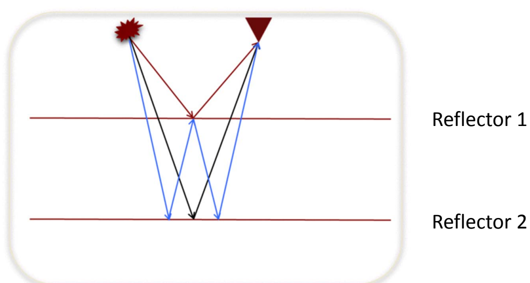

Case 2: a primary and a free-surface multiple
Below the reflector (predicted experiment at depth)
Coincident source and receiver at depth for all times
Coincident source and receiver at depth for t = 0
Red event: primary (downward reflection at the reflector)
Blue event: primary (downward reflection at the free surface)
Red event: primary (downward reflection at the reflector)
6

Figure 6:

Case 3: two primaries and an internal multiple
(recorded data)



Red event: primary from the first reflector
Black event: primary from the second reflector
Blue event: internal multiple

7

Figure 7:

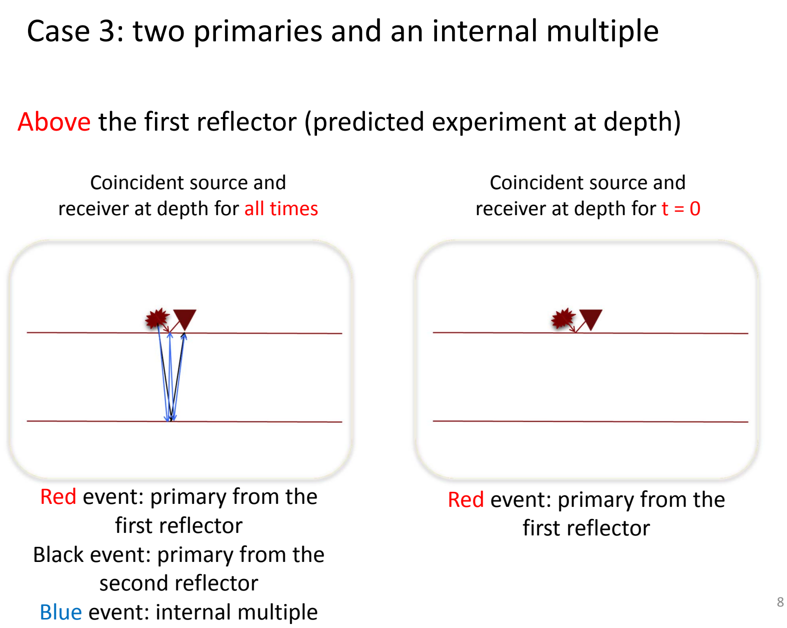

Case 3: two primaries and an internal multiple
Above the first reflector (predicted experiment at depth)
Coincident source and receiver at depth for all times
Coincident source and receiver at depth for t = 0
Red event: primary from the first reflector
Black event: primary from the second reflector
Blue event: internal multiple
Red event: primary from the first reflector
8

Figure 8:

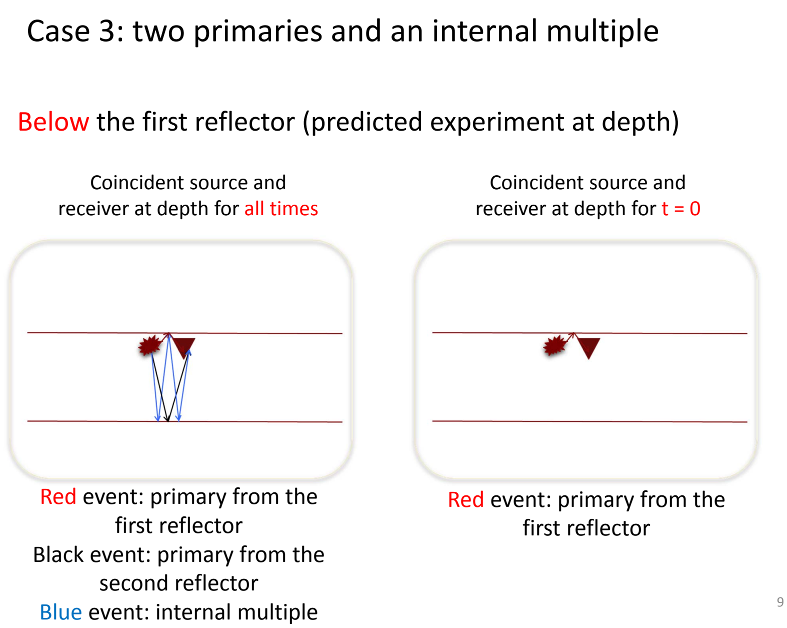

Case 3: two primaries and an internal multiple
Below the first reflector (predicted experiment at depth)
Coincident source and receiver at depth for all times
Coincident source and receiver at depth for t = 0
Red event: primary from the first reflector
Black event: primary from the second reflector
Blue event: internal multiple
Red event: primary from the first reflector
9

Figure 9:

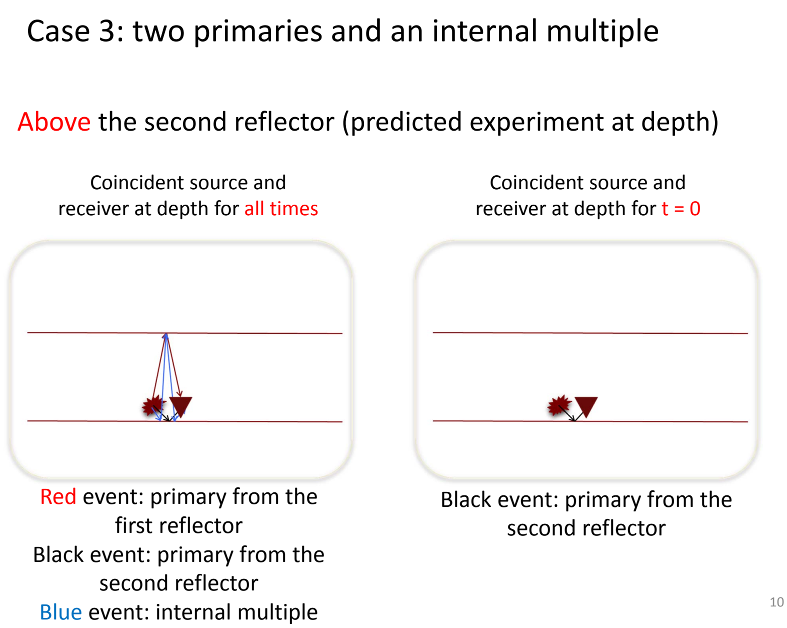

Case 3: two primaries and an internal multiple
Above the second reflector (predicted experiment at depth)
Coincident source and receiver at depth for all times
Coincident source and receiver at depth for t = 0
Red event: primary from the first reflector
Black event: primary from the second reflector
Blue event: internal multiple
Black event: primary from the second reflector
10

Figure 10:

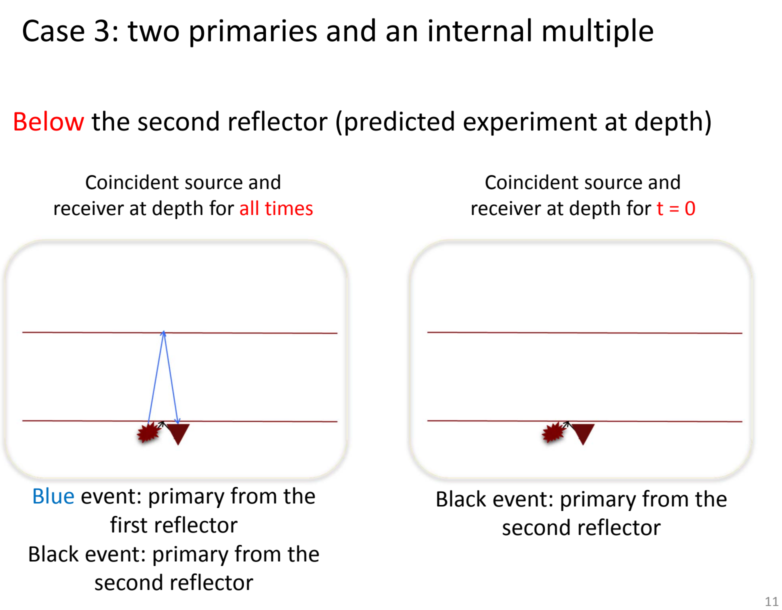
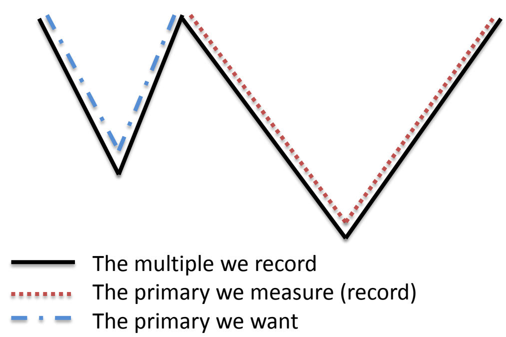

Case 3: two primaries and an internal multiple
Below the second reflector (predicted experiment at depth)
Coincident source and receiver at depth for all times
Coincident source and receiver at depth for t = 0
Blue event: primary from the first reflector
Black event: primary from the second reflector
Black event: primary from the second reflector
11

Figure 11:

Using Multiples for Imaging



- The multiple is used to find a missing primary.
- Primaries are what migration and inversion call for.

Figure 12: