Subsea Detection During the Deepwater Horizon Spill

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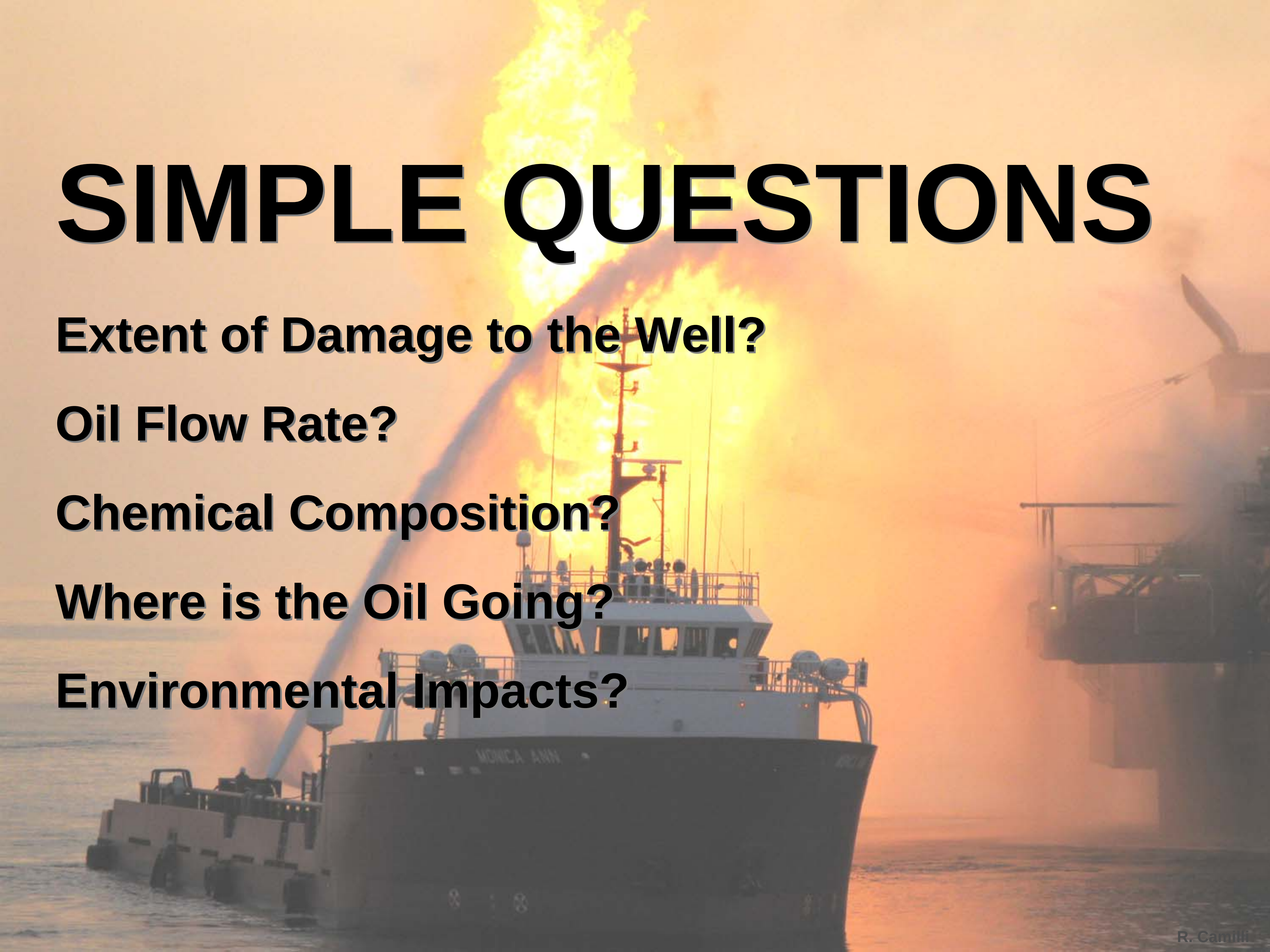
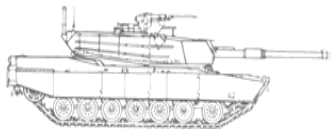
SIMPLE QUESTIONS

- Extent of Damage to the Well?
- Oil Flow Rate?
- Chemical Composition?
- Where is the Oil Going?
- Environmental Impacts?

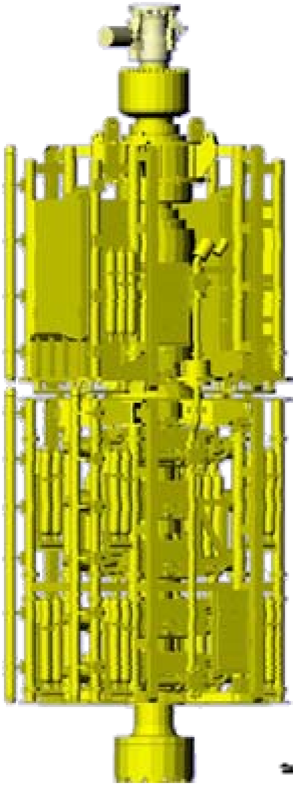


A Matter of Scale

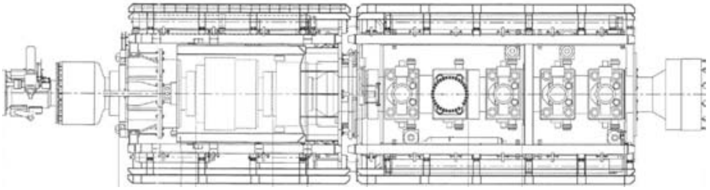
Tank M1 (9.8 m 61 tonnes)



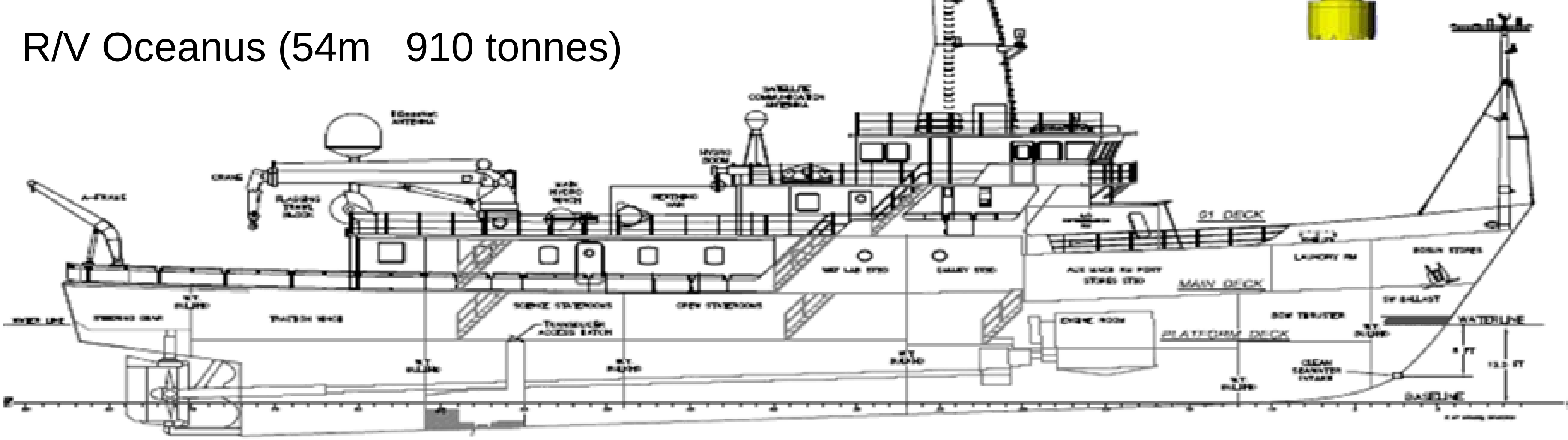
TL BOP
48 cm in diameter
1,000 bars of working pressure



BOP (16.5 m   280 tonnes)

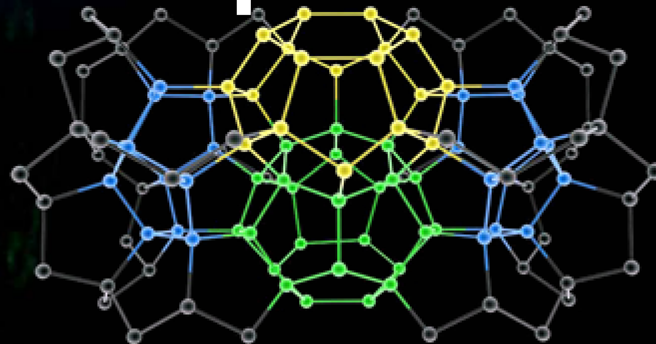


R/V Oceanus (54m   910 tonnes)

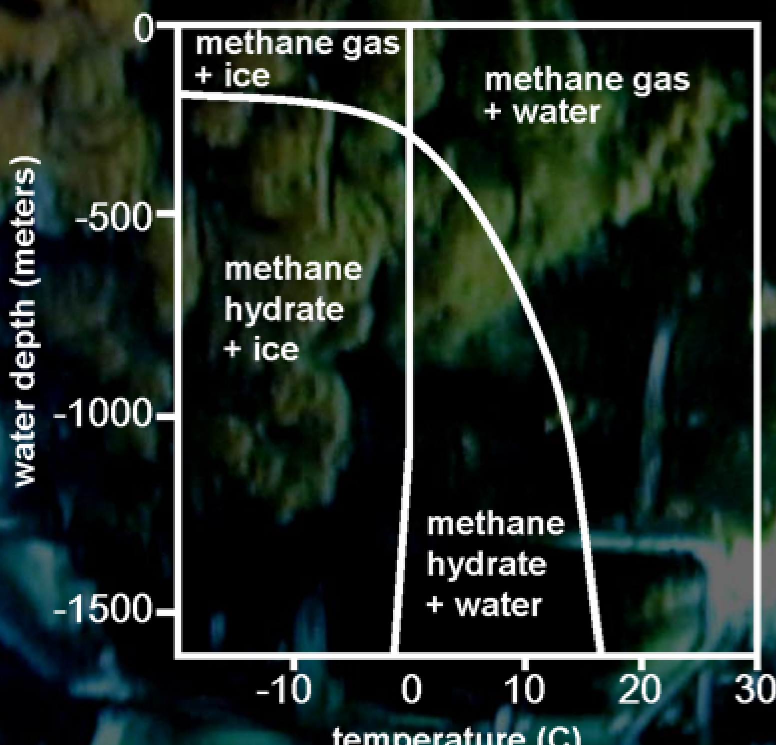


COMPOSITE PROFILE,

...and of Depth



from K. Jordan *Projects in Scientific Computing* 2005



R. Camilli

MEDICAL CHART

Patient: ***Gulf of Mexico***

Illness: severe internal bleeding

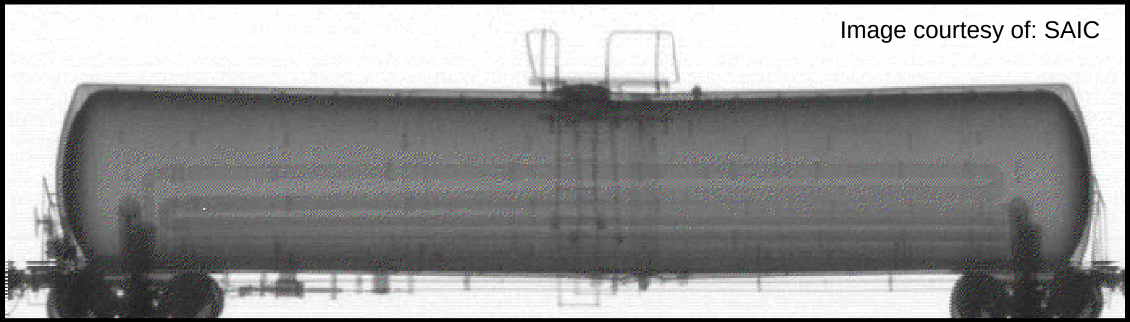
Details: explosion of Macondo well

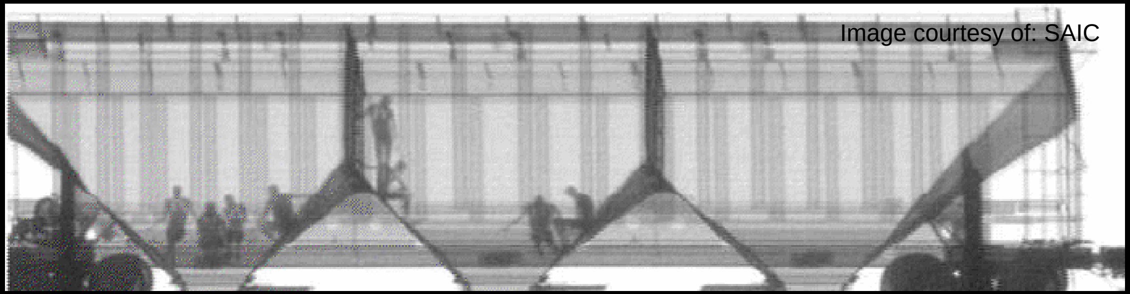
Doctor: Dr. Rov-Auv

	Procedure/Equipment	
✓	*Vital signs*	*Listen for audible flow restrictions with a hydrophone in direct contact*
✓	*Radiation*	*Cobalt-60 gamma imagery*
✓	*Ultrasound Doppler*	*Flow assessment with imagery & Doppler sonars*
✓	*Blood samples*	*Fluid sample taken from edge of BOP*
✓	*Angiography by tomodensitometry*	*Subsea plume analysis with in situ mass spectrometry (MS)*
✓	*Catheter*	*Geo-referenced sampling rosette*
✓	*Breathing & lung function test*	*Numerical Fluid Mechanical Modeling for microbial oxygen consumption*
✓	*Toxicology test*	*VOC analysis with P3 overflights and CRDS analysis on research vessel*
	Anticoagulant test	*Subsea dispersant sample and Fourier transform mass spectrometry*
	Vascular clamp	*Containment cap*
	Stitching	*"Bottom kill" cementing*
✓	*Post-op biopsy*	*Sediment core & coral sample analysis*

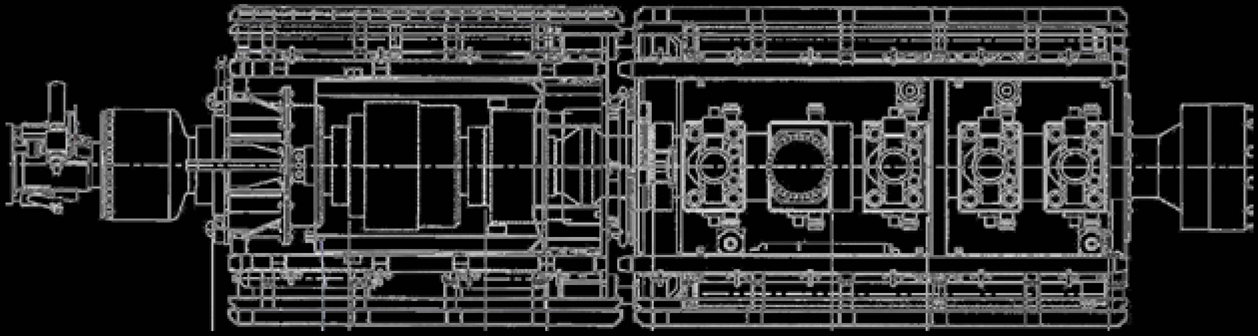
Cobalt-60 Gamma imaging

Internal structures and contents of rail carriages made visible by a gamma imaging system





CAD wireframe model of the Macondo well blowout preventer (BOP)

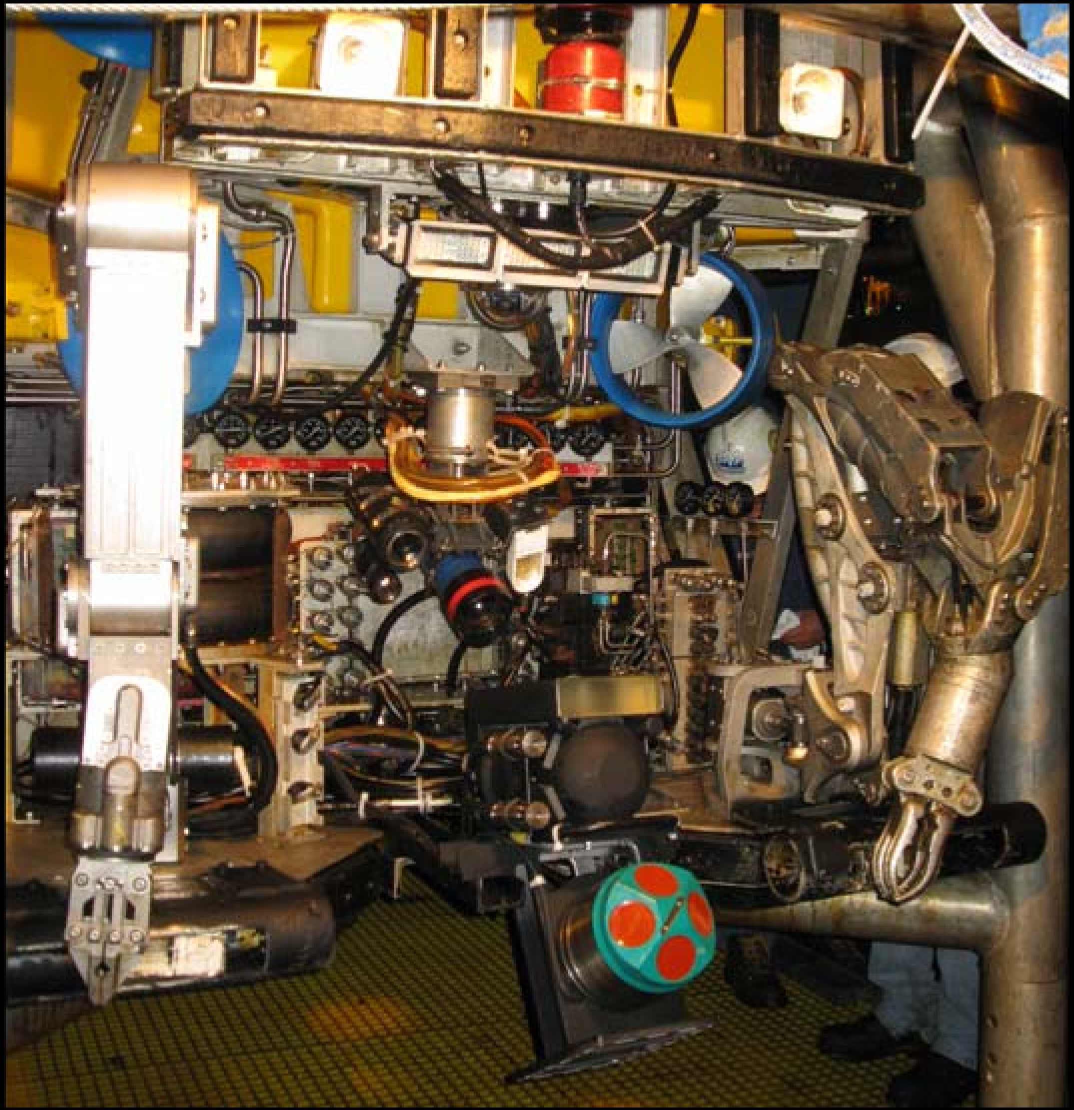


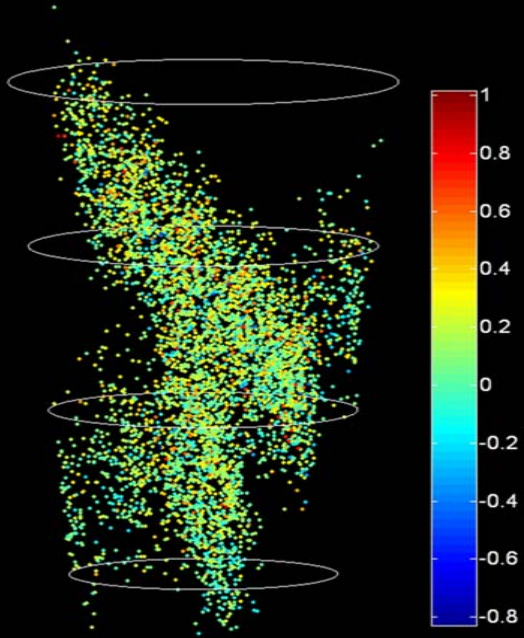
Doppler ultrasound

showing the rate and direction of blood flow in the umbilical cord of a fetus

(Nicolaides, et al., Placental and fetal Doppler, 2000)

Doppler acoustic velocity measurement system and multibeam sonar imaging

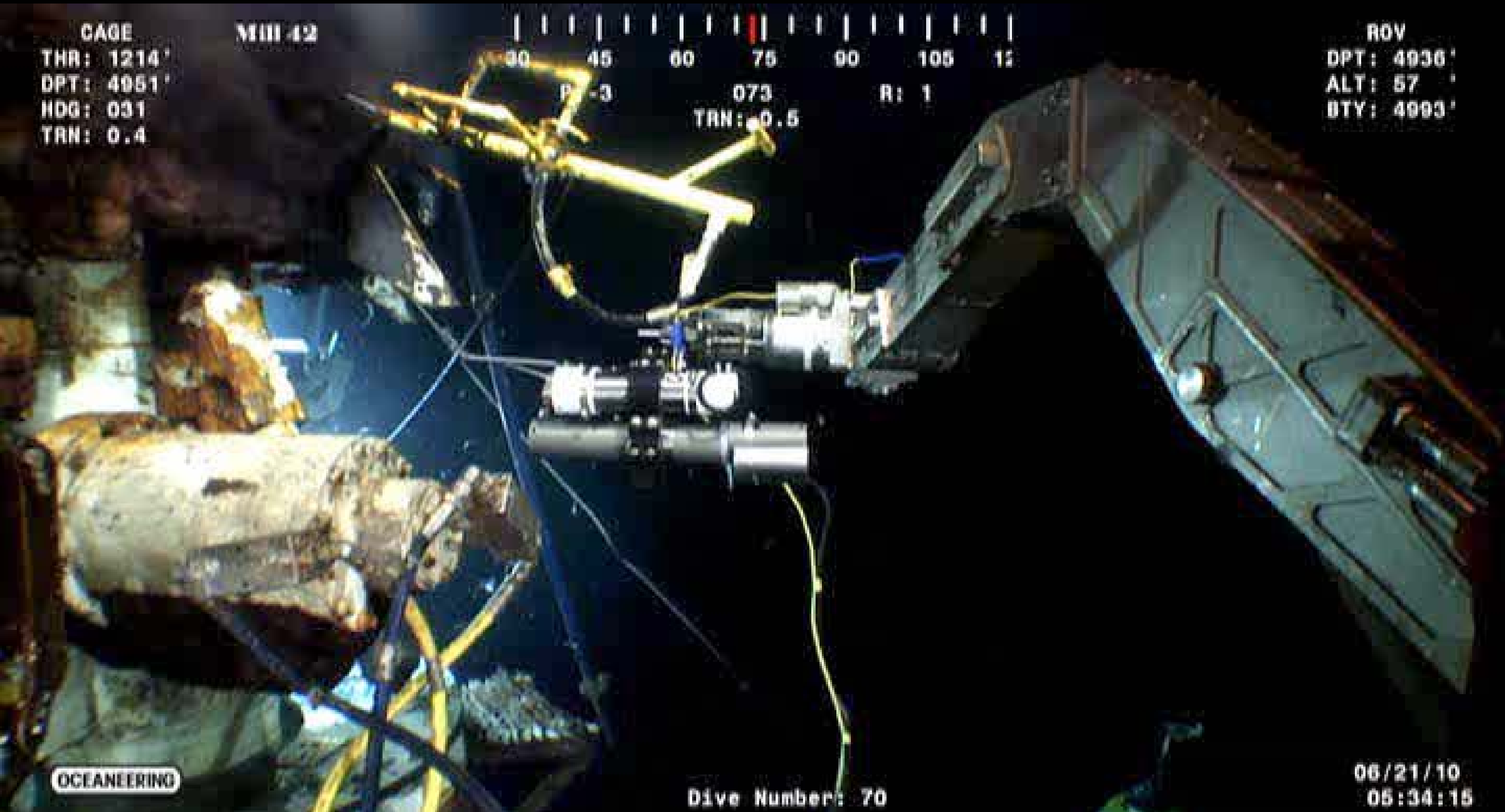




(Camilli , Di Iorio, et al., PNAS, 2011)

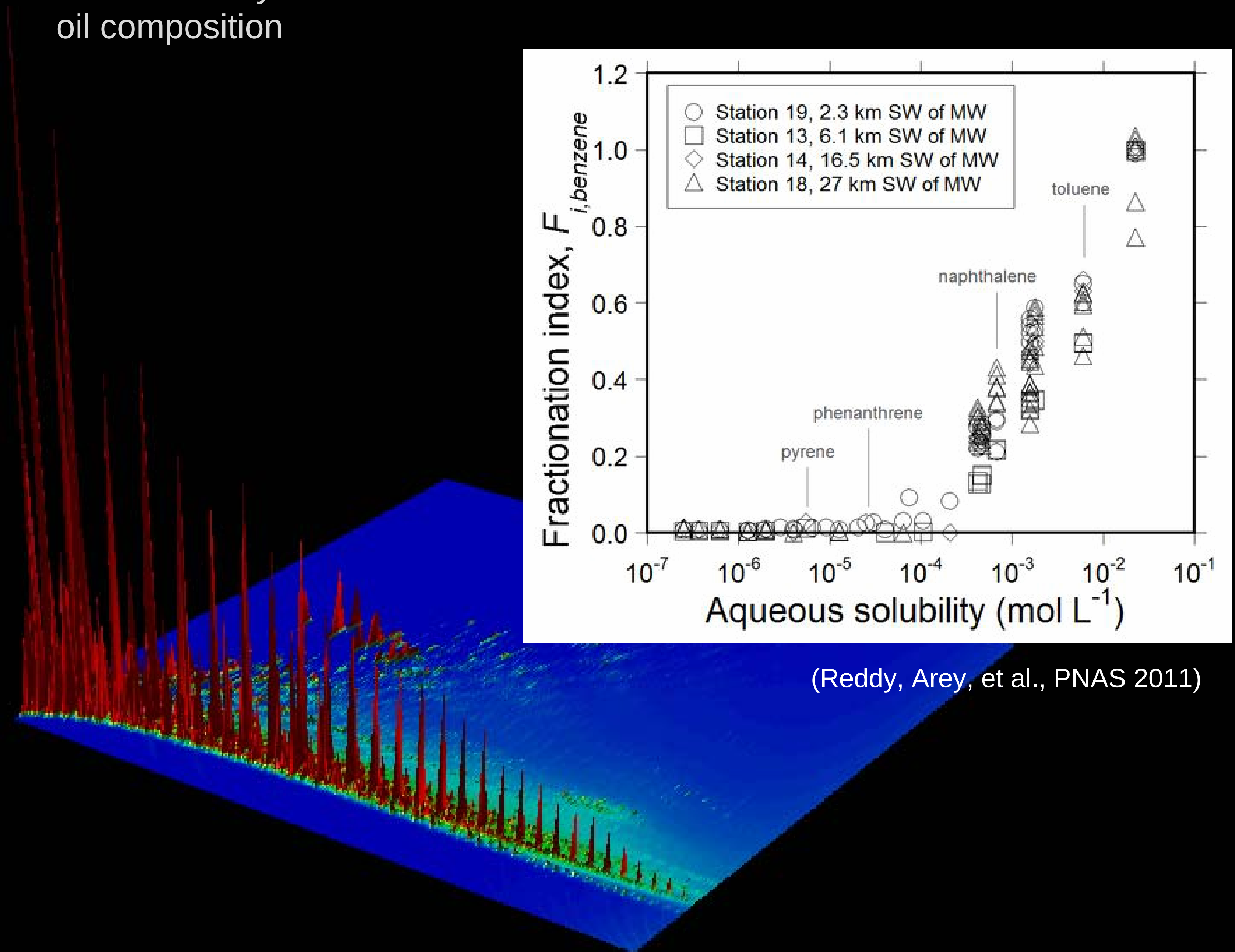
Acoustic flow rate analysis

- Sonar measurement of flow cross section
- Doppler sonar measurement of fluid velocity
- Analysis of fluid composition

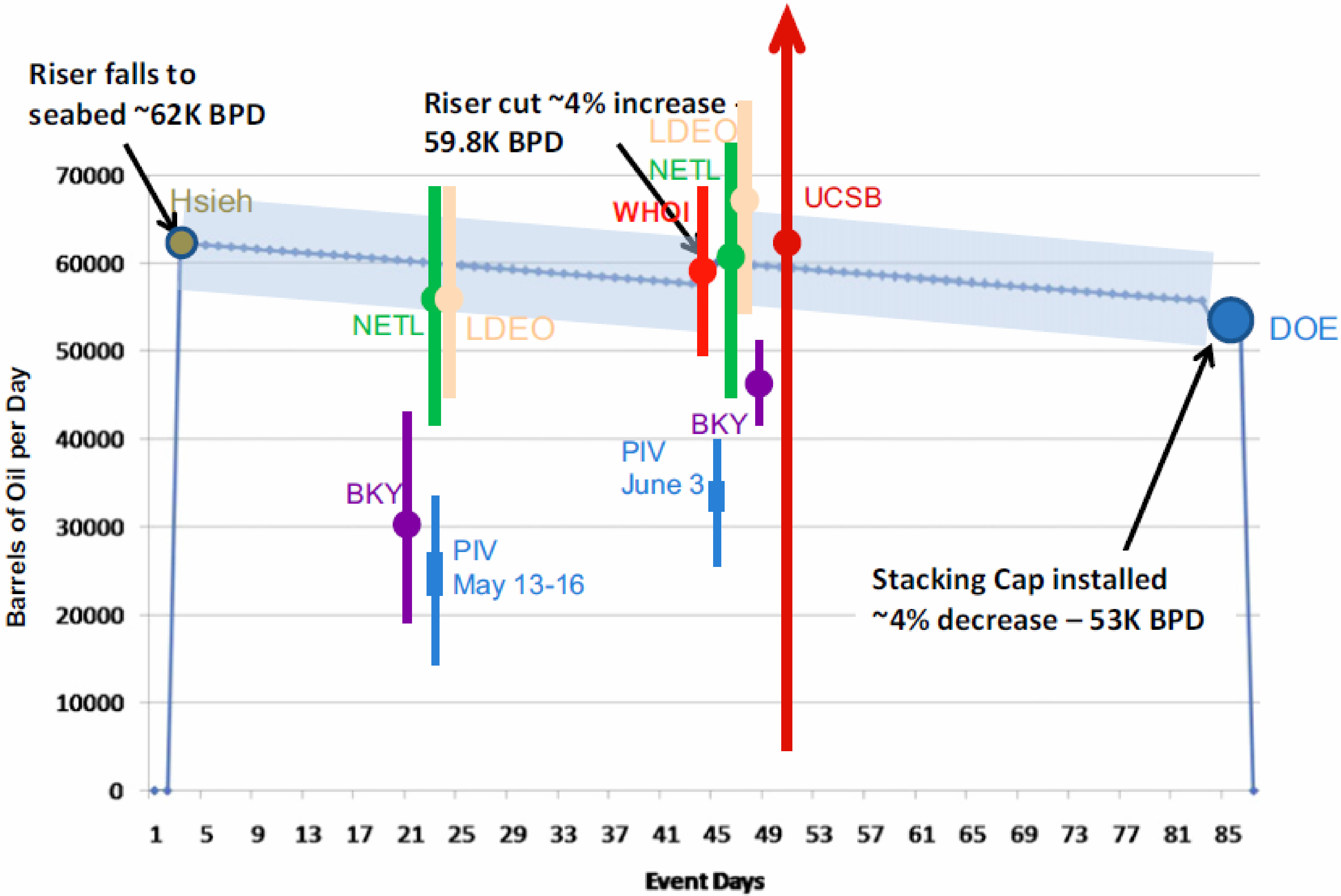


CAGE
THR: 1214'
DPT: 4951'
HDG: 031
TRN: 0.4
MHI 42
30 45 60 75 90 105
073
TRN: 0.5
R: 1
ROV
DPT: 4936'
ALT: 57
BTY: 4993'
OCEANEERING
Dive Number: 70
06/21/10
05:34:15

Detailed analysis of the Macondo well oil composition



(Reddy, Arey, et al., PNAS 2011)



(McNutt, Camilli, et al., PNAS, 2011)

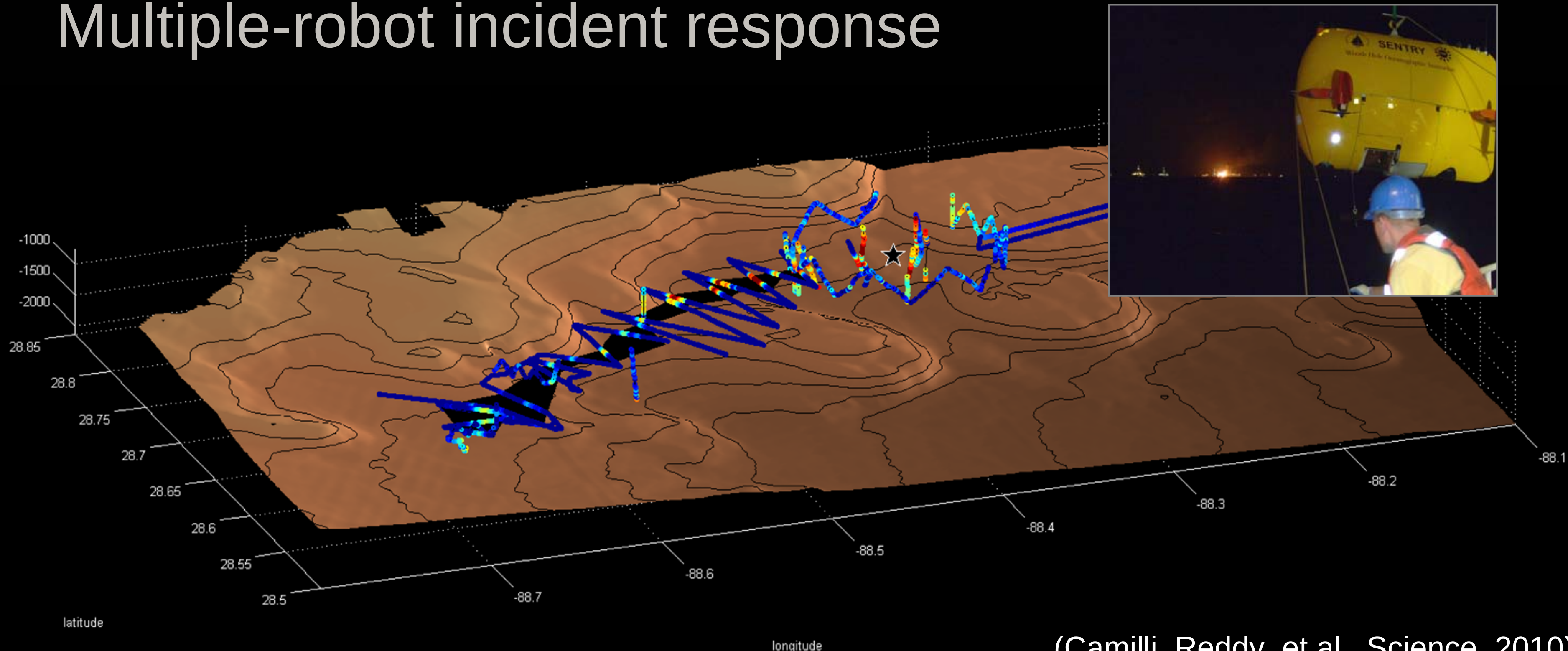
(Camilli, Reddy, et al., Science, 2010)

Angiography by tomodensitometry

Image showing the inferior vena cave, its structure of renal veins and the kidneys

(Yu et al., *BMJ Case Reports, 2010)*

Multiple-robot incident response



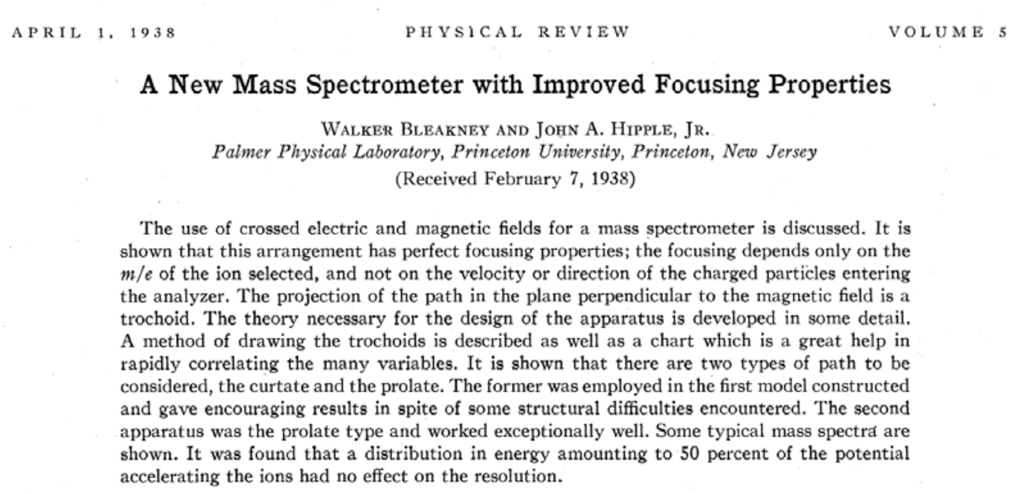
(Camilli, Reddy, et al., Science, 2010)


NRDA
GATHERER
SHIP ROSETTE
(Camilli, Reddy, et al., Science, 2010)

TETHYS in situ mass spectrometer

Atomic mass range	2-200 AMU
Power	25 Watts @ 24V
Maximum depth	5,000 metres
Endurance	~1 year operating continuously
Response time	~5 seconds
Sensitivity (Limit of Detection)	<1 µg/L
External dimensions (with 5,000 m housing)	23 cm diameter x 61cm length
Weight (with 5,000 m housing)	13 kg in water 35 kg in air
Moving parts	none

(Camilli and Duryea, ES&T, 2009)

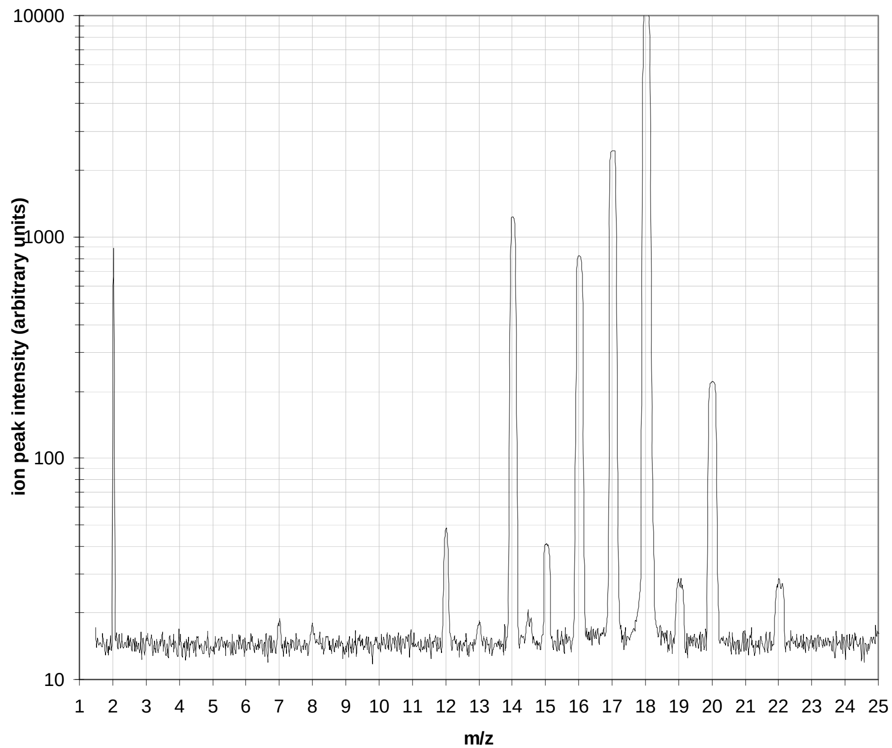


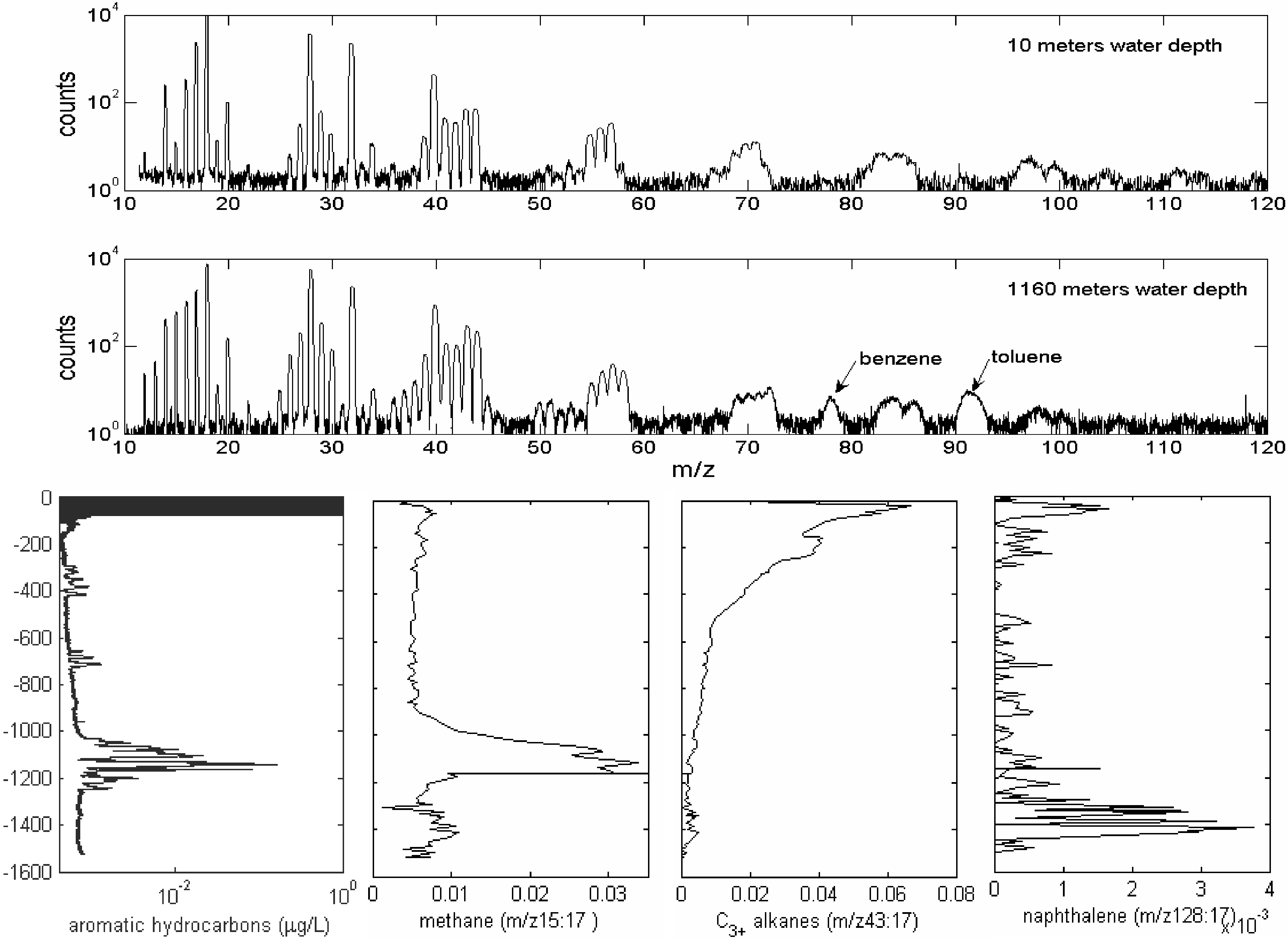
APRIL 1, 1938 PHYSICAL REVIEW VOLUME 53

A New Mass Spectrometer with Improved Focusing Properties

WALKER BLEAKNEY AND JOHN A. HIPPLE, JR.
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received February 7, 1938)

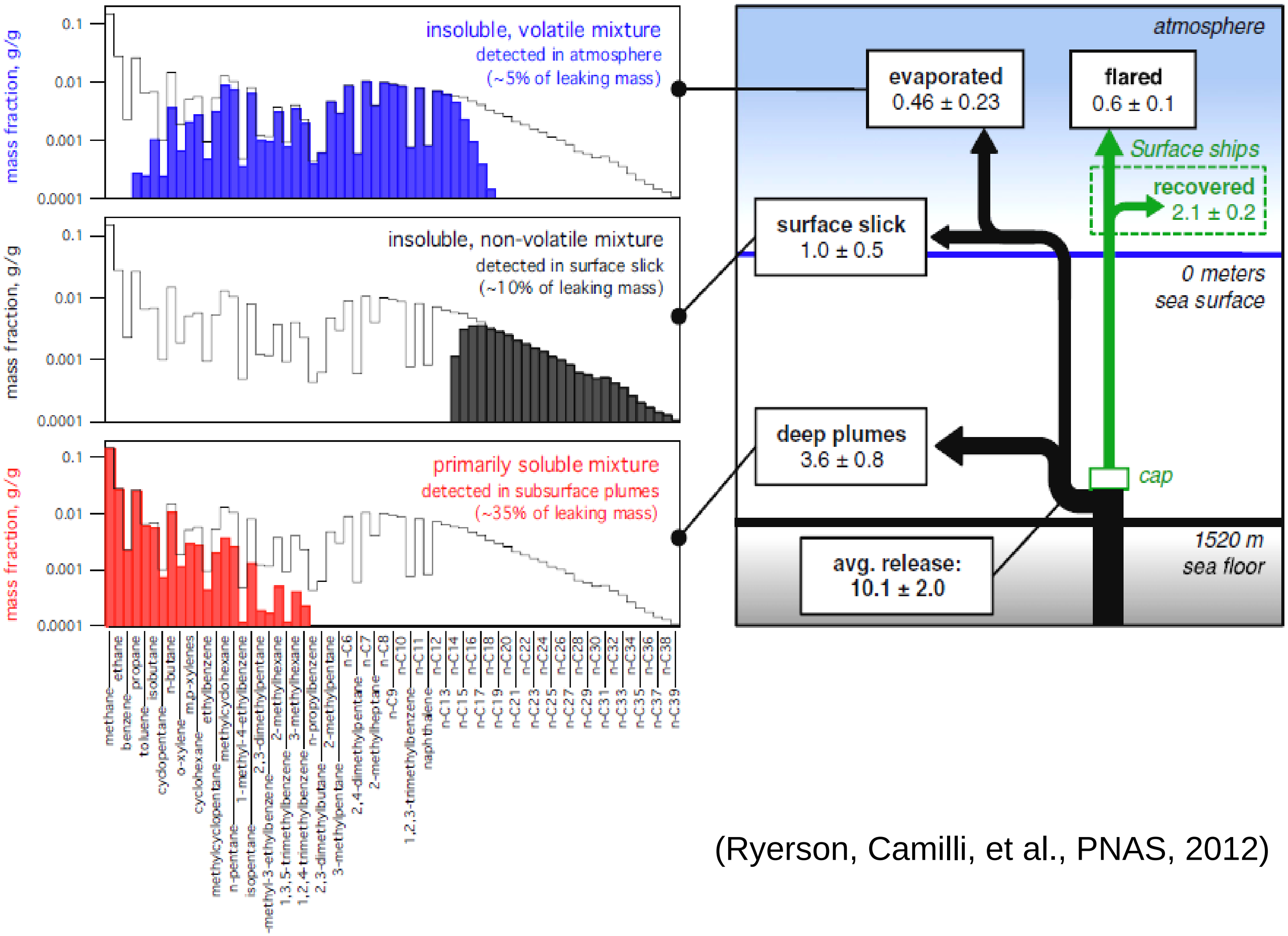
The use of crossed electric and magnetic fields for a mass spectrometer is discussed. It is shown that this arrangement has perfect focusing properties; the focusing depends only on the *m/e* of the ion selected, and not on the velocity or direction of the charged particles entering the analyzer. The projection of the path in the plane perpendicular to the magnetic field is a trochoid. The theory necessary for the design of the apparatus is developed in some detail. A method of drawing the trochoids is described as well as a chart which is a great help in rapidly correlating the many variables. It is shown that there are two types of path to be considered, the curtate and the prolate. The former was employed in the first model constructed and gave encouraging results in spite of some structural difficulties encountered. The second apparatus was the prolate type and worked exceptionally well. Some typical mass spectra are shown. It was found that a distribution in energy amounting to 50 percent of the potential accelerating the ions had no effect on the resolution.





(Camilli, Reddy, et al., Science, 2010)

Hydrocarbon composition and mass flows

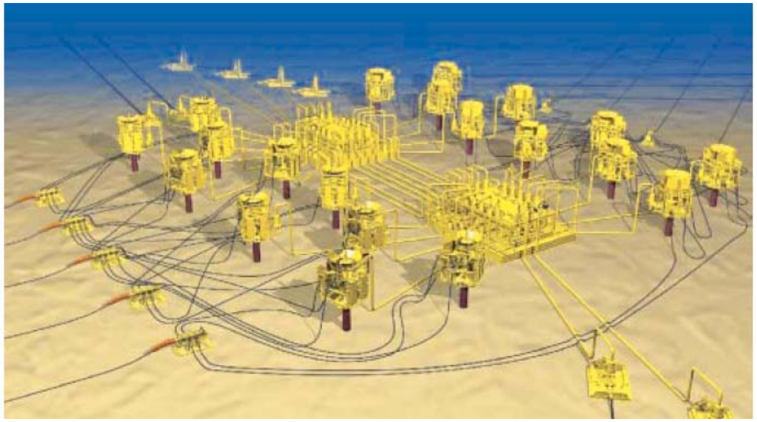


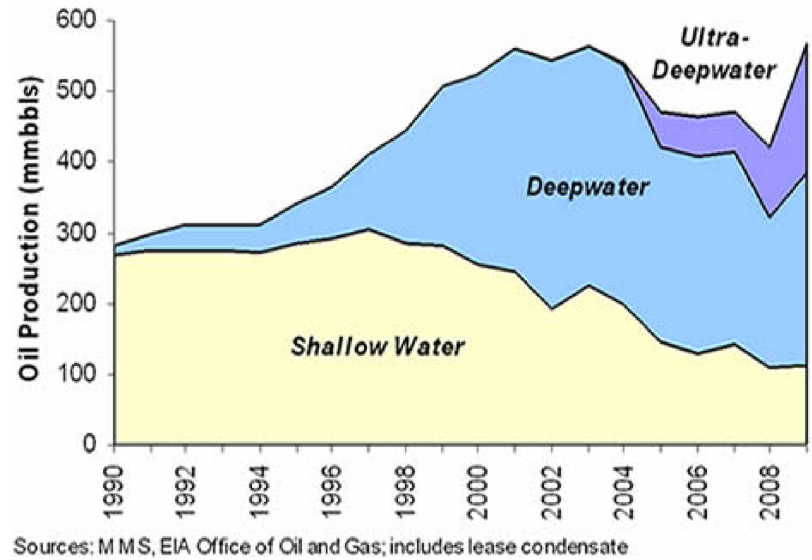
(Ryerson, Camilli, et al., PNAS, 2012)

(Valentine, Mezic, et al., PNAS, 2012)

Source: WHOI-MISO, NOAA/BOEMRE

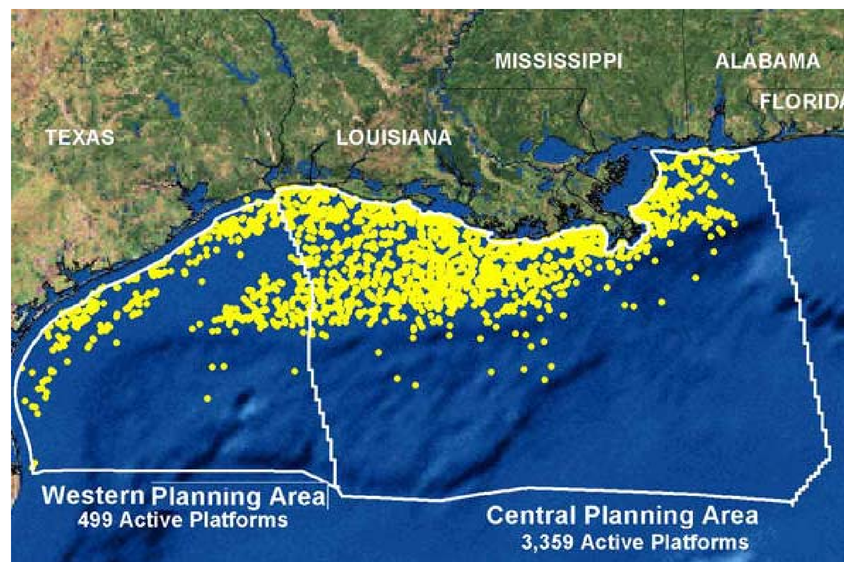
(White, Hsing, et al., PNAS, 2012)





<u>Constantly evolving technical challenges</u>

- Aging infrastructure
  - 3,800 platforms (1,000 inactive)
  - 27,000 abandoned wells
  - 45,000 km of pipeline
- Sedimentation and mass wasting
- Mapping and measurement errors
- Collisions, anchor drags, and impacts
- Hydrate formation
- Trapped subsurface plumes
- Increased well pressure/temperature
- Limited robotic capability/access
- Subsurface regulatory jurisdiction/enforcement



Probability of failure × consequence = risk magnitude

THANK YOU!

R. Camilli