The Light Amplifier Concept

Daniel Ferenc$^1$
Eckart Lorenz$^{1,2}$
Daniel Kranich$^1$
Alvin Laille$^1$

(1) Physics Department, University of California Davis
(2) Max Planck Institute, Munich

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Future particle astrophysics projects to study very rare phenomena

- Proton Decay
- Neutrino Physics
- Neutrino Astrophysics
- Gamma-ray Astronomy
  (low detection threshold & wide acceptance angle)
- Ultra-high energy cosmic rays (>10^{19} eV)
- Neutrinoless Double Beta Decay
- WIMP Searches
SEARCHING FOR RARE AND/OR WEAK RADIATION SOURCES

PARTICLE ASTROPHYSICS
(new generation of experiments)

NUCLEAR SECURITY
(nonproliferation)

MEDICAL IMAGING
WIDELY ACCESSIBLE MEDICAL DIAGNOSTICS
Industrial Mass-Production of Very-large-area cameras
small pixels, small area  

SCALE  

Larger pixels, huge area  

Small animal PET  

MEDICAL IMAGING  

‘Large animal’ (human) PET  

Luggage radiation monitoring  

NUCLEAR SECURITY  

~CONTAINER, TRUCK etc. monitoring  

MARKETS (STEADY, SUBSTANTIAL)  

SUPER-K  

PHYSICS  

UNO, HYPER-K MEMPHIS
A new Technology for Industrial Mass-Production of large photosensor areas, based on modified existing technologies (e.g. the assembly of modern, plasma and field-emission flat-panel TV screens; low production cost ~$1000 per sq. meter).

+ ‘REAL’ (non-physics) MARKETS,
Several Unconventional Photosensors

- Flat-Panel *ReFerence* Camera Concept (Patented)

- *Light Amplifier* - general concept
  - ReFerence panels $\rightarrow$ scintillator (fiber) readout
  - QUASAR or SMART PMT in a modified configuration
    + Geiger-mode APDs

- “SIMPLE” Space Imaging Camera Concept for EUSO, OWL, but also ground-based applications (Patented)
Cherenkov angle in water
\(\sim 40\) degrees

Full angular coverage

→ “Camera” surrounds the detector volume
Irreducibly Large Illuminated Area

strong **internal** signal concentration

Vacuum

( photon $\rightarrow$ photoelectron $\Rightarrow$ ‘no more Liouville’ )
Semiconductor Photosensors
→ developed very successfully
(but pixel sizes and areas - too small)

Vacuum Photosensors
(suitable for large-area applications, strong area reduction) did not develop significantly since mid-1960s

Why?
Because of the Vacuum?
Development of Other Vacuum Devices

~1960

~2000

Production Cost: < $1,000 per m²
7-pixel 5-inch ReFerence Flat-Panel Prototype

POSTER SESSION 1

UHV Transfer System:
- Photocathode deposition
- Indium/Au/Cr deposition
- Vacuum sealing
Ideal Light Concentrator
(takes the maximum of Liouville!)

Optimal Electron Lens

Photon

PIN, APD, or SCINTILLATOR

Photoelectrons

Photocathode

Optimal Electron Lens
Very Important: Hexagonal Packing
Flat-Panel Honeycomb Sandwich Camera Construction

Industrial Production (no glass blowing etc.)
Intrinsic Mechanical Stability, Low Buoyancy,..
Strong signal concentration, factor ~ 1500
(one of our goals)

Replaces the entire Dynode Column!
Provides ~100% Collection Efficiency!

- APD
- Scintillator + Fiber (both of small and comparable diameter \(\rightarrow\) good coupling efficiency)
Light Amplifier Concept

Scintillators + fiber optics

NO electronics in the vacuum

Resolution determined outside !!

READOUT ➔ APD array
Light Amplifier Concept

Scintillators + fiber optics

NO electronics in the vacuum

Resolution determined outside !!
SMART PMT, QUASAR
Hemispherical LIGHT AMPLIFIER

Scintillator
Y2SiO5(Ce)

Geiger-mode APD array

Al (100 nm)

Fiber Plate

1 photoelectron $\rightarrow$ >15 photons in APD

SMART PMT, QUASAR
CURRENT SETUP

SINGLE Geiger-mode APD, 1x1 mm²

No face-plate → low light
Collection Efficiency ~1:150

SMART PMT, QUASAR

Pulsed LED+fiber
Geiger-mode APD

ZS-2 from Sadygov, MICRON

EXTREMELY SIMPLE!
Very Simple Electronics

57.4 mV

20 kΩ

20 kΩ

1 kΩ

1 photo-electron → 200 mV

ZS-2 from Sadygov, MICRON

g = 25

1 pe → 200 mV
A Typical Single-Photon Signal in the Geiger-mode APD

1 photo-electron $\rightarrow$ 200 mV
Superposition of many light pulses in the Geiger-mode APD (signal integrated)

\[ \sim 5 \text{ photo-electrons} \rightarrow 1 \text{ V} \]
Superposition of many light pulses in the Geiger-mode APD (full bandwidth)

Note the individual photon structure and decay spectrum of the scintillator
Rotating Light Source (LED)

Image @ Scintillator

→ IMAGING (even without fiber coupling)
CONCLUSIONS

Light Amplifier:

*LIGHT IN-(VACUUM)-LIGHT OUT*

- CONCENTRATION (photoelectron focusing)
- AMPLIFICATION (photoelectron acceleration)

ADVANTAGES:

- No electronic components in the vacuum
- Extreme Simplicity & Robustness
  - Low cost, mass production

Tested - a QUASAR tube + a Geiger-mode APD
“Light Amplifier” Concept

Scintillators + fiber optics

NO electronics inside!!

Resolution determined outside!!

READOUT ➔ APD array
Spherical LIGHT AMPLIFIER

Fiber Plate

scintillator

Al (100 nm)

Geiger-mode APD array

1 photoelectron $\rightarrow$ >15 photons in APD

SMART PMT, QUASAR
Silicon photomultiplier (SiPM)

SiPM main features:
- Sensitive size $1\times1\text{mm}^2$ on chip $1.5\times1.5\text{ mm}^2$
- Gain $2\times10^6$
- $U_{\text{bias}} \approx 50\text{V}$
- Recovery time $\sim 100\text{ ns/pixel}$
- Number of pixels: 576
- Nuclear counter effect: negligible (due to Geiger mode)
- Insensitive to magnetic field
- Dynamic range $\sim 10^5\text{mm}^{-2}$

For further details see:
- "Advanced study of SiPM"

B. Dolgoshein  "SiPM possible applications"

Single photoelectron (single pixel) spectra

SiPM:
- excellent single photoelectron resolution
- low ENC expected

More about pixel signal resolution: tens of photoelectrons

$N_{ph} \approx 46$

- SiPM consists of a large number of pixel photoelectron counters with binary readout for each pixel, working as analogue device
- signal uniformity from pixel to pixel is quite good