# Development of InP detector and liquid scintillator containing metal complexes for pp/7Be solar neutrinos and neutrinoless double beta decay

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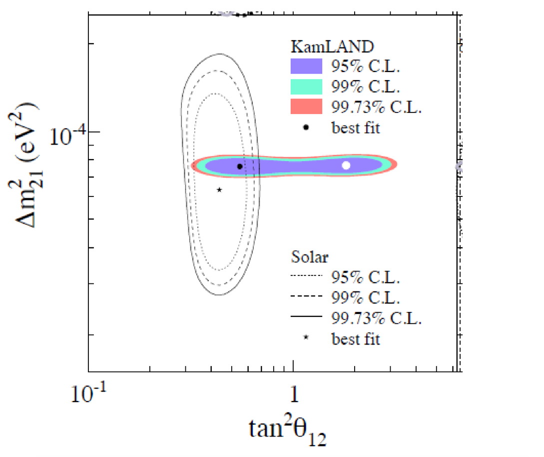
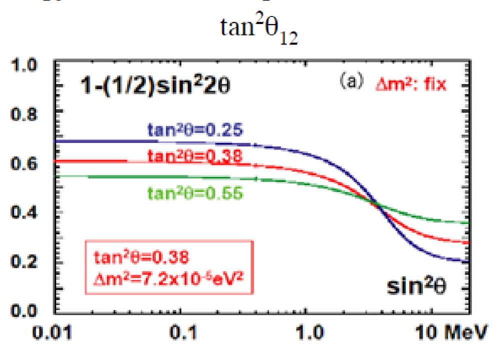
## 1. Measurement of pp/7Be solar ν

### ◆ Purpose : precise oscillation parameter $\theta_{12}$




- 96%C.L. allowed region obtained by global fit
  LMA solution (blue) : Cl + Ga + SK (D/N spectrum)
  KamLAND (green) → **confirm $\Delta m_{12}^2$**

$27° < \theta_{12} < 37°$

- mixing angle $\theta_{12}$ is not fixed compared with $\theta_{23}$ (obtained by Atm. ν)
- survival probability would increase at 5MeV or less in case of LMA solution, and the shape depends on the value of $\theta_{12}$.

**pp/$^7$Be solar neutrino spectrum could obtain precise $\theta_{12}$.**

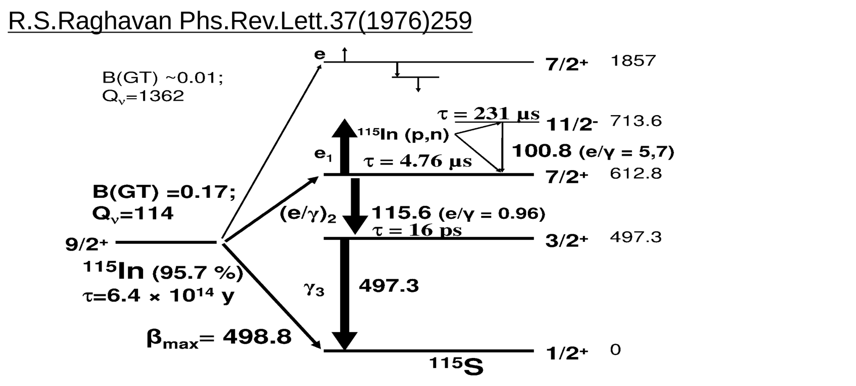
● **on-going solar 7Be experiment**
- KamLAND (Liquid scintillator, electron elastic scattering [ES])
- Borexino (Liquid scintillator, ES)

● **future solar pp/$^7$Be experiment**
- XMASS (LXe, ES, DARK MATTER)
- LENS (Liquid scintillator loaded In/Ye, charged current [CC])
- others

Y.Suzuki@Neutrino2004

### ◆ Technique of low energy solar neutrino detection

R.S.Raghavan Phys.Rev.Lett.37(1976)259




$^{115}In + \nu_e \rightarrow {}^{115}Sn^* + e_1^-$
$^{115}Sn^*(4.76\mu s) \rightarrow {}^{115}Sn + \gamma_2(115keV) + \gamma_3(497keV)$

● **Advantage**
- large cross section (~640SNU)
- direct counting for solar neutrinos
- sensitive to low energy region ($E_\nu \geqq 125$keV)
- energy measurement ($E_e = E_\nu - 125$keV)
- triple fold coincidence to extract neutrino signal from huge BG ($e_1 + \gamma_2 + \gamma_3$)

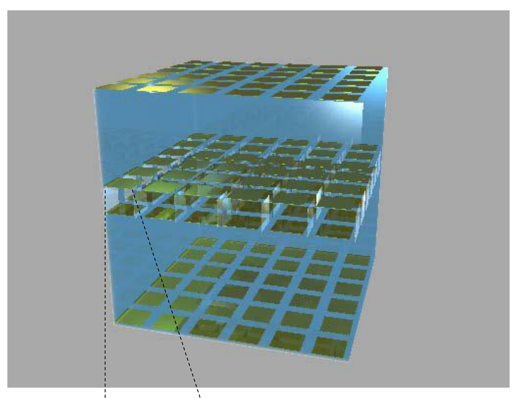
● **Disadvantage**
- natural β-decay of $^{115}$In ($\tau_{1/2} = 4.4 \times 10^{14}$ yr , Ee≧498keV)
- possible BG due to correlated accidental coincidence by radiative Bremsstrahlung

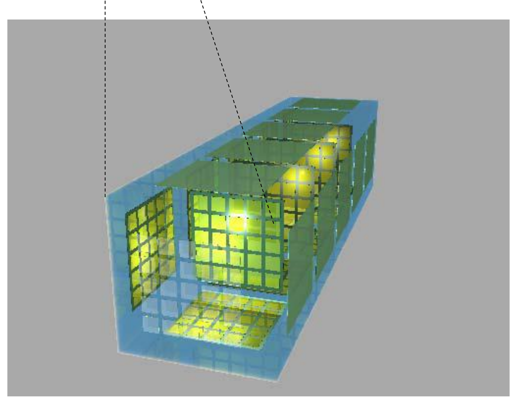
## 2. IPNOS phase-I experiment

### ◆ Indium Project on Neutrino Observation for Solar interior (IPNOS) experiment

●**Hybrid structure of InP and external scintillator**
- InP multi-pixel detector (10mmX10mmX0.2mm cell)
- external scintillator (Lxe) to detect $\gamma_1$ and $\gamma_2$

●**4tons of $^{115}$In detector for solar ν experiment**
- InP : 5.1tons ($2.0 \times 10^6$ modules with **ΔE/E~10%** )
- high Z material for external scintillator
- total size ~5m X ~5m X ~5m (depends on structure)





### ◆ IPNOS phase-I detecror

- 30cm cubic chamber (like XMASS 100kg prototype detector)
- InP multi-pixel detector inside of Liquid Xenon
- Chamber includes ~10kg InP detector
- Scintillation could be detected by InP itself

### ◆ Purpose

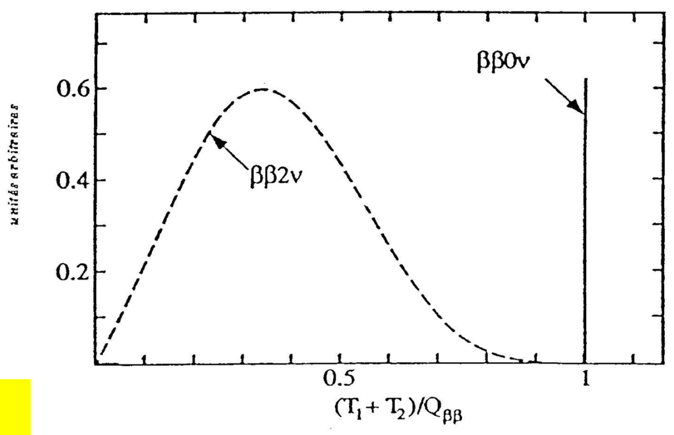
- demonstrate LowBG environment
- long stable operation (1 ppν event will be expected for half year)
- detect scintillation form $\gamma_3$ by InP detector

## 3. Neutrinoless Double Beta Decay

### ◆ Neutrinoless double beta decay

● Lifetime and neutrino mass
$[T_{1/2}^{0\nu}(0^+ \rightarrow 0^+)]^{-1} = G_{0\nu}(E_0,Z)|M_{0\nu}|^2 \langle m_\nu \rangle^2$

● Energy spectrum and lifetime measurement
- monochromatic energy = Q-value
- $T_{1/2} \sim a(Mt/\Delta EB)$ a: abundance M: mass t: meas.time ΔE: energy res. B: BG cnt. rate




**Requirement :**
**Low BG, Large target mass, High energy resolution**

### ◆ Double beta decay candidates

ββ emitters with $Q_{\beta\beta}$ >2 Mev

| Transition | $Q_{\beta\beta}$ (keV) | Abundance (%) ($^{232}Th$ = 100) |
|---|---|---|
| $^{110}Pd \rightarrow {}^{110}Cd$ | 2013 | 12 |
| $^{76}Ge \rightarrow {}^{76}Se$ | 2040 | 8 |
| $^{124}Sn \rightarrow {}^{124}Te$ | 2288 | 6 |
| $^{136}Xe \rightarrow {}^{136}Ba$ | 2479 | 9 |
| $^{130}Te \rightarrow {}^{130}Xe$ | 2533 | 34 |
| $^{116}Cd \rightarrow {}^{116}Sn$ | 2802 | 7 |
| $^{82}Se \rightarrow {}^{82}Kr$ | 2995 | 9 |
| $^{100}Mo \rightarrow {}^{100}Ru$ | 3034 | 10 |
| $^{96}Zr \rightarrow {}^{96}Mo$ | 3350 | 3 |
| $^{150}Nd \rightarrow {}^{150}Sm$ | 3667 | 6 |
| $^{48}Ca \rightarrow {}^{48}Ti$ | 4271 | 0.2 |

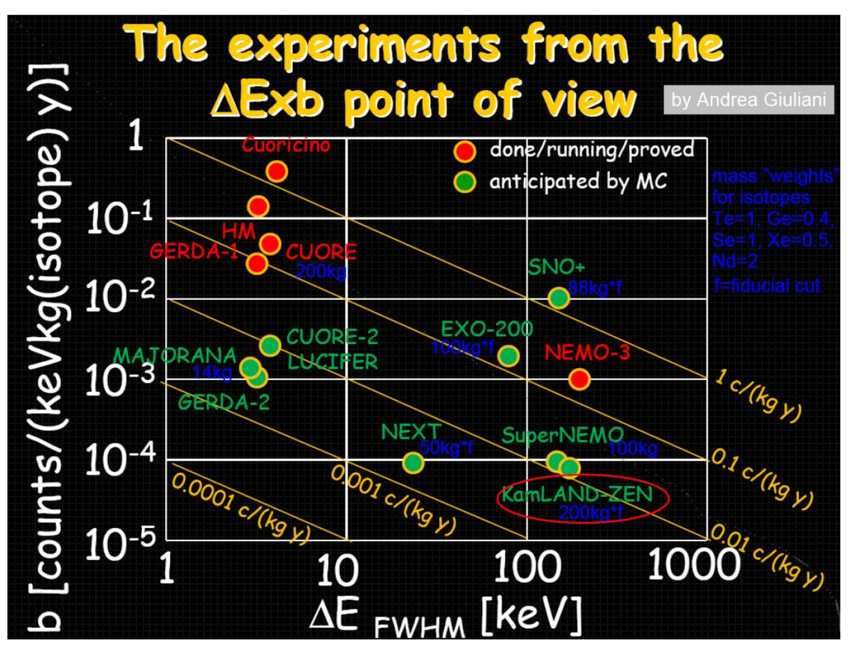
● above $^{208}$Tl γ line (2.614MeV)
$^{48}$Ca, $^{150}$Nd, $^{96}$Zr, $^{100}$Mo,$^{82}$Se…

● large abundance
$^{00}$Mo,$^{82}$Se, $^{150}$Nd, $^{96}$Zr

● solved in liquid scintillator formed metal complex

**Zirconium ($^{96}$Zr) is possible candidate**

### ◆ Experimental limits for neutrino mass




● high energy resolution
**4%@2.5MeV = 100keV**

● low background rate
**0.01count $kg^{-1}$ $y^{-1}$**

● large target mass
**~ ton scale**

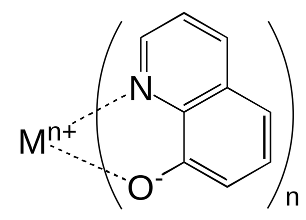
**Goal: $\langle m_\nu \rangle$~10meV**

## 4. Metal complex in liquid scintillator

### ◆ Development of liquid scintillator using metal complexes

● **goal : solubility : 10wt%, light yield : 60% of BC505**

● **8-quinolinolate metal complex (organic Electro Luminescence)**
- tris(8-quinolinolate) indium ($InQ_3$) **C27H18N3O3In (MW. 547.28)**
- tetrakis(8-quinolinolate)zirconium ($ZrQ_4$) **C36H24N4O4Zr (M.W. 667.84)**
- $InQ_3$ (for solar ν) and $ZrQ_4$ (for ββ-decay) have photo luminescence




M = In, n = 3; M = Zr, n = 4

● **Synthesis efficiency**

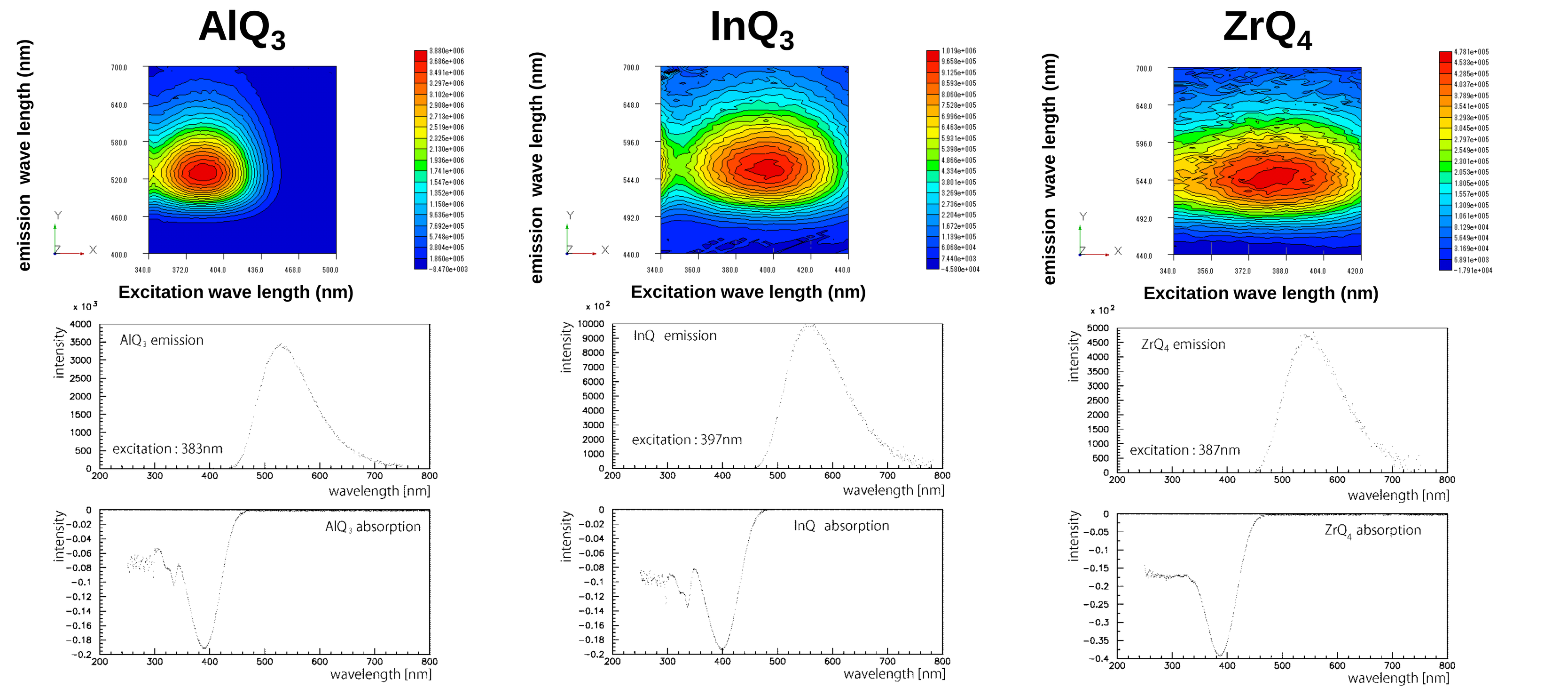
**$InQ_3$**
**primary yield 100%**
**sublimation 77%**

**$ZrQ_4$**
**primary yield 96%**
**sublimation 70%**

● **Solution of organic solvent**

Solvent : **Benzonitrile** (PhCN: $C_6H_5CN$)
density : 1.0g/mL flash point : 75°C
Photon emission : 291nm@maximum
Solubility of $InQ_3$ complex: **2wt%**
Attenuation length : 66cm (@0.5wt%)

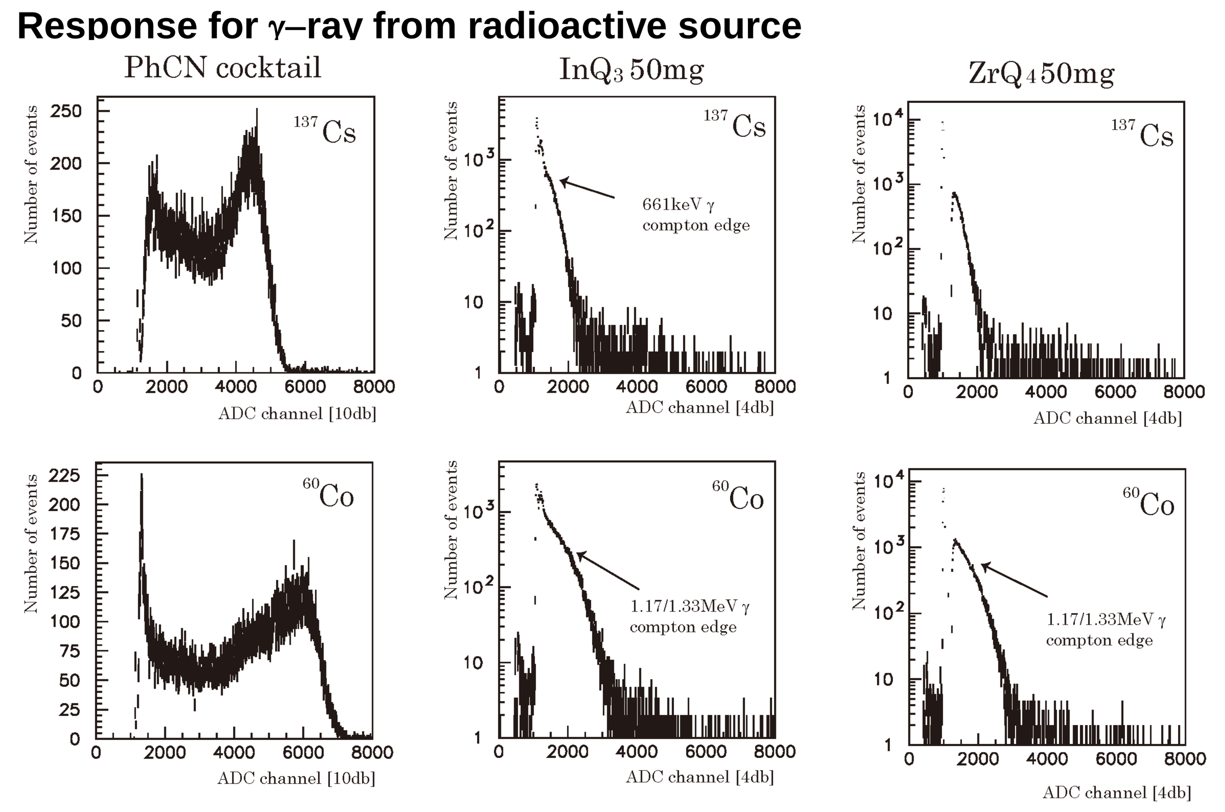
### ◆ Luminescence of 8-quinolinolate metal complex




### ◆ Performance of liquid scintillator

● **Setup**
- Hamamatsu H6410 2inch photomultiplier
- Fisherbrand 20mL Borosilicate Glass Scintilation Vials
- Acrylic light guide
- LeCroy 1182 charge sensitive VME ADC
- Cocktail : PhCN with PPO 100mg and POPOP 10mg

● **Response for γ–ray from radioactive source**



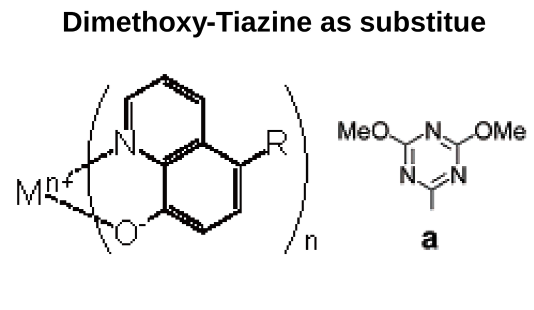

**$InQ_3$**
**Quantum Yield :**
**9.6%(PL : 5.0%)**
**QE: 0.09**

**$ZrQ_4$**
**Quantum Yield :**
**7.6%(PL: 1.1%)**
**QE:0.10**

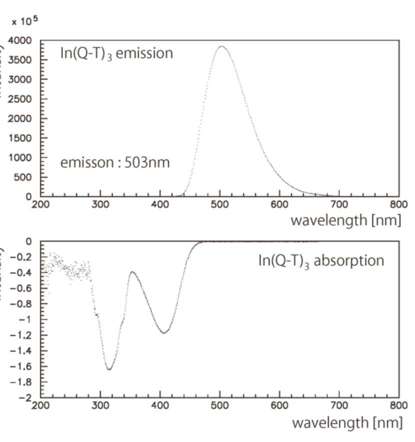
**Low light yeild due to small QY (order ~%)**

### ◆ Modify 8-quinolinolate ligand

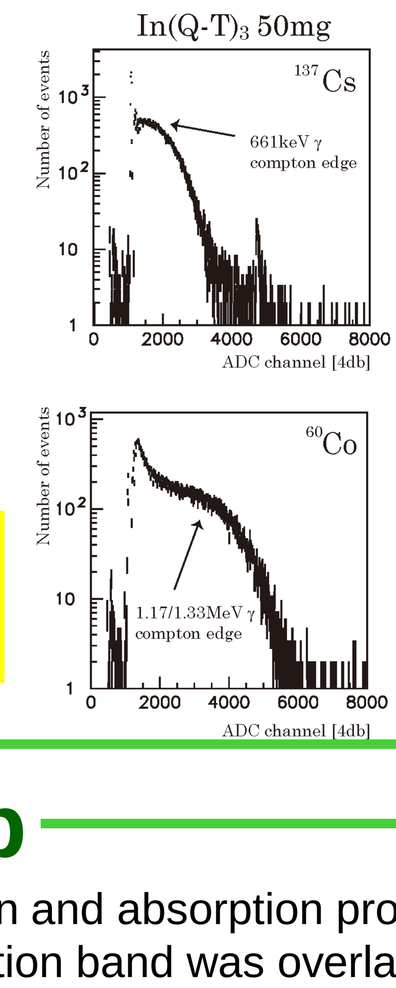
**Dimethoxy-Tiazine as substitue**




**Tris[5-(4,6-dimethoxy-1,3,5-triazine-2-yl)-8-quinolinolate]indium**
**$In(Q\text{-}T)_3$ M.W. = 964.62.**




**Confirm to shorten emission wavelength by substitue**



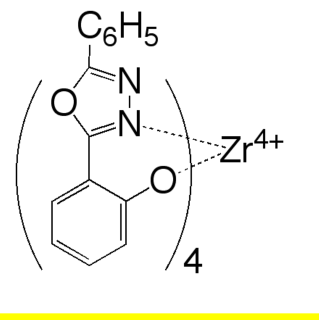

**$In(Q\text{-}T)_3$**
**Quantum Yield :**
**26.0%**
**(P.L.:20%)**
**~2 X $InQ_3$**
**QE: 0.19**
**~2 X $InQ_3$**

**L.Y. :**
**2.7 X $InQ_3$**

## 5. Next step

### ◆ Synthesize $Zr(Q\text{-}T)_4$ complex

### ◆ Synthesize Zr-ODZ complex




- **large Q.Y. ~0.8**

**expected large L.Y.**

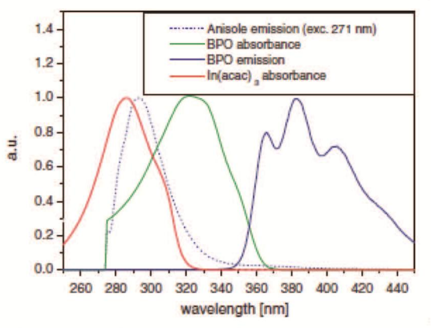
- **unknown solubility (solvent: PhCN ?)**

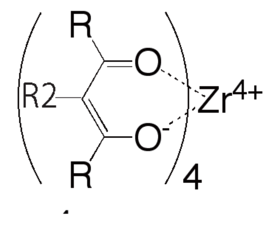
supported by **Grant-in-Aid for Scientific Research (C) 24540295**

### ◆ Synthesize diketon (acetyl acetone) complex with substitue

● beta diketon complex
good solubility (over 10wt.%) for anisole has been reported (**J. Radioanal. Nucl. Chem., 258(2003)255**)

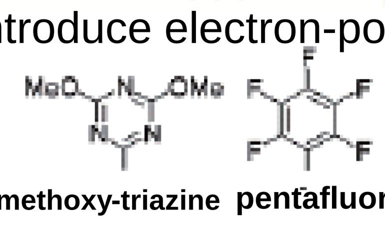
● emission and absorption problem
absorption band was overlapped with emission light from anisole (**Chem. Phys. Lett., 435(2007), 252**)




**R=$CH_3$ : acetylaceton**

● introduce electron-poor substitue




**Dimethoxy-triazine pentafluorophenyl**

**Move absorption band to shorter wavelength**

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